National Aeronautics and
Space Administration
Jet Propulsion Laboratory
NASA Management Office
FOIA Public Liaison Office
4800 Oak Grove Dr., M/S 180-200K
Pasadena, CA 91109-8001

Reply to Attn of: RA000/NMO

April 3, 2018

Arnold & Porter, LLP
Attn: Mr. Ronald D. Lee, Esq.
601 Massachusetts Ave. NW
Washington, DC 20001-3743

FOIA Request 18-JPL-F-00247

Dear Mr. Lee:

This is the second interim response to your Freedom of Information Act (FOIA) dated January 5, 2018 and received at the NASA Jet Propulsion Laboratory FOIA Public Liaison Office on January 8, 2018. Your request was assigned Case File Number 18-JPL-F-00247. Your request submitted on behalf of Dr. Nathan Myhrvold, enumerated 9 items related to the NEOWISE (Near-Earth Object Wide-field Infrared Survey Explorer) mission managed and operated by JPL for NASA's Science Mission Directorate, and its efforts to estimate diameters and albedos of near-Earth objects, particularly asteroids. Specifically your request sought the following:

> **1) All specification documents for NEOWISE concerning the Near-Earth Asteroid Thermal Model (NEATM), its variants, and all other thermal models used by NEOWISE to generate the estimates of asteroid diameters, visible albedos, or infrared albedos uploaded to the Planetary Data System (PDS) and published in NEOWISE's scientific publications. By way of example, such documents may include, but are not limited to, any System Requirements Documents, Project Requirements Documents, Interface Requirements Documents, and Concept of Operations documents, as discussed in Sections 2.3 and 4.2.1.3 of NASA's Systems Engineering Handbook (available at https://www.acq.osd.mil/se/docsINASA-SP-2007-61 05-Rev-1-Final-3lDec2007.pdf).**
>
> **2) All documents measuring the accuracy of the Near-Earth Asteroid Thermal Model (NEATM), its variants, or all other thermal models used by NEOWISE to generate the asteroid diameter estimates uploaded to the Planetary Data System and published in NEOWISE's scientific publications. By way of example, such documents may include, but are not limited to, Measures of Effectiveness documents, Measures of Performance documents, Technical Performance Measure documents, and Verification Documents, as discussed in Sections 5.4.1.3 and 6.7.2.2 of NASA's Systems Engineering Handbook (available at https:/ Iwww.acq.osd.mil/se/docsINASA-SP-2007 -61 OS-Rev-l-Final-31 Dec2007 .pdf).**

3) All computer code and other data files for the Near-Earth Asteroid Thermal Model (NEATM) or other thermal models used by NEOWISE to generate the asteroid diameter estimates uploaded to the Planetary Data System and published in NEOWISE's scientific publications.

4) All NF-1676 Document Availability Authorization forms produced for the computer code and other data files requested in request 3. We understand that NF-1676 Document Availability Authorization forms are generated when Scientific and Technical Information is released outside of NASA, as set forth in Section I (c) of NASA Policy Directive 2200.1 C (available at https:llnodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=2200&s=I C), **and Section 6.4 of** NASA Policy Directive 2200.2D (available at https:llnodis3.gsfc.nasa.gov/displayDir.cfm?Internal ID=N PR 2200 002D &page name=Chapter6).

5) All Technical Review documents produced for the computer code and other data files requested in request 3. We understand that Technical Review documents are generated before NF-1676 Document Availability Authorization forms are approved, as set forth in Section 6.4 of NASA Policy Directive 2200.2D (available at https:llnodis3.gsfc.nasa.gov/displayDir.cfm?Internal ID=N PR 2200 002D &page name=Chapter6).

6) All email and other correspondence concerning the design of, limits of, and revisions to the Near-Earth Asteroid Thermal Model (NEATM) or other thermal models (including email or other correspondence concerning drafts of journal articles, conference presentations or posters, or media releases involving NEOWISE methods, models, or results, or mentioning radar, occultation, or spacecraft estimates of diameter), between any NASA/JPL members of the NEOWISE team and external astronomers, including but not limited to:

- **i.** **Victor Ali-Lagoa;**
- **ii.** **Alan Harris;**
- **iii.** **Josef Hanus;**
- **iv.** **Marco Delbo;**
- **v.** **Josef Durech;**
- **vi.** **Robert McMillan;**
- **vii.** **Michael Skrutskie;**
- **viii.** **David Tholen;**
- **ix.** **Russell Walker;**
- **x.** **Carrie Nugent;**
- **xi.** **Vishnu Reddy;**
- **xii.** **Jean-Luc Margot; or**
- **xiii.** **Thomas Statler**

7) All reports of NEOWISE asteroid results for which the "FIT_CODE" is listed as "-VB-." We understand based on the documentation for the Planetary Data System (attached as Exhibit A[1]) that the "FIT_CODE" is a four-character code indicating parameters allowed to vary in thermal fit, the parameters being D=diameter,

V=visible geometric albedo, B=NEATM beaming parameter, I=infrared geometric albedo, and - = parameter held fixed for fit, such that "-VB-" means visible geometric albedo and NEATM beaming parameter were allowed to vary, but diameter and infrared geometric albedo were not. An example of a result with FIT_CODE "-VB-" is attached as Exhibit B[2].

8) All documents relating to requests by individuals inside or outside NASA for NEOWISE code, specifications, or output; NASA's or JPL's responses to such requests; and NASA's or JPL's policies or procedures for handling such requests, including but not limited to any requests made by Thomas Statler in 2016 for NEOWISE code. An example of a document relating to one such request is attached as Exhibit C.

9) All (a) drafts and revisions of; (b) comments to and from authors, reviewers, and collaborators regarding, (c) associated email messages attaching or linking, and (d) NF-1676 Document Availability Authorization forms or Technical Review documents produced for, each of the following papers:

i. Mainzer, A., Bauer, J.M., Grav, T., Masiero, J.R., Cutri, R.M., Wright, E., Nugent, C.R., Stevenson, R., Clyne, E., Cukrov, G., Masci, F., 2014. The Population of Tiny Near-Earth Objects Observed by NEOWISE. Astrophys.J.784,110. doi:10.1088/0004-637X178412/ 110.

ii. Grav, T., Mainzer, A.K., Bauer, J., Masiero, J., Spahr, T., McMillan, R.S., Walker, R., Cutri, R., Wright, E., Eisenhardt, P.R.M., Blauvelt, E., DeBaun, E., Elsbury, D., Gautier, T., Gomillion, S., Hand, E., Wilkins, A., 20 II. WISE/NEOWISE Observations of the Jovian Trojans: Preliminary Results. Astrophys.1. 742,40. doi:10.1088/0004-637X1742/1/40.

iii. Grav, T., Mainzer, A., Bauer, J.M., Masiero, J., Spahr, T., McMillan, R.S., Walker, R., Cutri, R., Wright, E.L., Eisenhardt, P.R.M., Blauvelt, E., DeBaun, E., Elsbury, D., Gautier, T., Gomillion, S., Hand, E., Wilkins, A., 2011. WISE/Neowise Observations of the Hilda Population: Preliminary Results. Astrophys. J. 744, 197. doi:l0.1088/0004-637X1744/2/197.

iv Masiero, J.R., Grav, T., Mainzer, A., Nugent, C.R., Bauer, J.M., Stevenson, R., Sonnett, S., 2014. Main Belt Asteroids with WISE/NEOWISE: NearInfrared Albedos. Astrophys. J. 791, 121. doi:10.1088/0004-637X1791/2/121.

v. Mainzer, A., Grav, T., Masiero, J., Bauer, J.M., Cutri, R.M., Mcmillan, R.S., Nugent, C.R., Tholen, D., Walker, R., Wright, E.L., 2012. Physical Parameters of Asteroids Estimated from the WISE 3 Band Data and NEOWISE Post-Cryogenic Survey. Astrophys. J. Lett. 760, L12. doi: 10.1 088/2041-8205/760/11L12.

vi. **Masiero, J.R., Mainzer, A., Grav, T., Bauer, J.M., Cutri, R.M., Nugent, C., Cabrera, M.S., 2012. Preliminary analysis of WISE/NEOWISE 3-band cryogenic and post-cryogenic observations of main belt asteroids. Astrophys. 1. 759, L8. doi: I 0.1 088/2041-8205/759/11L8.**

vii. **Nugent, C.R., Mainzer, A., Masiero, J., Bauer, J., Cutri, R.M., Grav, T., Kramer, E., Sonnett, S., Stevenson, R., Wright, E.L., 2015. NEOWISE Reactivation Mission Year One: Preliminary Asteroid Diameters and Albedos. Astrophys. J. 814, 117. doi:10.1088/0004-637X/814/2/117.**

viii. **Nugent, C.R., Mainzer, A., Masiero, J., Wright, E.L., Bauer, J., Grav, T., Kramer, E.A., Sonnett, S., 2016. Observed asteroid surface area in the thermal infrared. Astron. 1. 153, 90. doi:10.3847/1538-38811153/2/90.**

ix. **Tedesco, E.F., Noah, P.V., Noah, M., Price, S.D., 2002. The Supplemental IRAS Minor Planet Survey. Astron. J. 123, 1056-1085. doi:10.1086/338320. (With respect to this paper only, please apply a time frame of 2000 to 2002 for the search.)**

x. **Ryan, E.L., Woodward, C.E., 2010. Rectified asteroid albedos and diameters from IRAS and MSX Photometry Catalogs. Astron. J. 140, 933. doi: I 0.1 088/0004-6256/140/4/933.**

For all requests above, except where otherwise noted, we request responsive documents from January 1, 2010 to the present. NASA should perform "a reasonable search" for the requested documents. 14 C.F.R. § 1206.401(b). A reasonable search should include, but not be limited to, the files of JPL scientists Drs. Amy Mainzer, James Bauer, Joseph Masiero, Carolyn (Carrie) R. Nugent, Rachel Stevenson, Peter Eisenhardt, Thomas Gautier IV, Sarah Sonnett, and Emily Kramer.

In accordance with NASA's FOIA regulations (14 CFR §1206.305), a search was conducted by JPL (Caltech) for the records you requested. We notified you on February 21, 2018 that we completed processing items 2-5 and 7 of your request in our first interim response. Records are now being released for this second interim response as the result of searches to produce responsive records to items 1, 8 and 9 of your request, completing these portions of your request.

1) All specification documents for NEOWISE concerning the Near-Earth Asteroid Thermal Model (NEATM), its variants, and all other thermal models used by NEOWISE to generate the estimates of asteroid diameters, visible albedos, or infrared albedos uploaded to the Planetary Data System (PDS) and published in NEOWISE's scientific publications. By way of example, such documents may include, but are not limited to, any System Requirements Documents, Project Requirements Documents, Interface Requirements Documents, and Concept of Operations documents, as discussed in Sections 2.3 and 4.2.1.3 of NASA's

Systems Engineering Handbook (available at https://www.acq.osd.mil/se/docsINASA-SP-2007-61 05-Rev-1-Final-3lDec2007.pdf).

• The specifications for NEATM and other thermal models used by NEOWISE in relation to the findings in PDS are included as part of the archive submitted to the PDS. The PDS record is, by requirement of the archive, complete and self-contained. All government records are publically available in the PDS archive, here: https://pds.jpl.nasa.gov/ds-view/pds/viewDataset.jsp?dsid=EAR-A-COMPIL-5-NEOWISEDIAM-V1.0 and in publically available NEOWISE published papers (see Attachment A).

8) All documents relating to requests by individuals inside or outside NASA for NEOWISE code, specifications, or output; NASA's or JPL's responses to such requests; and NASA's or JPL's policies or procedures for handling such requests, including but not limited to any requests made by Thomas Statler in 2016 for NEOWISE code.

• There are no responsive government records for requests for NEOWISE code. Requests for this material would be referred to the third party owners of the code.

9) All (a) drafts and revisions of; (b) comments to and from authors, reviewers, and collaborators regarding, (c) associated email messages attaching or linking, and (d) NF-1676 Document Availability Authorization forms or Technical Review documents produced for, each of the following papers [Items i-x]

• Drafts (a), comments (b), and email communications (c) relating to papers prior to publication are considered contractor records pursuant to provision H-16 (b) of NASA Prime Contract NNN12AA01C and therefore are not subject to release under the FOIA. There are no responsive records to the request in subsection (d) because JPL does not utilize NF-1676 forms.

With this letter we are also informing you that additional time is necessary to enable us to complete our search. Thank you for your patience as we continue our search and review process for item 6 in your request. Please be advised we have begun searching for records and determined that the agency may have records responsive to this item. We plan to make interim rolling releases as records are processed. Accordingly, we look forward to and hope to conclude issuing our final response within the next several weeks.

Although a review has not been initiated for the additional records at this time and because of the nature of record you have requested, we anticipate some information within the additional records *may* be exempt from disclosure either in full or in part pursuant to FOIA Exemption 5 U.S.C. § 552 (b)(4), "...trade secrets and commercial or financial information obtained from a person and privileged or confidential," FOIA Exemption 5 U.S.C. § 552 (b)(5), "...inter-agency or intra-agency memorandums or letters which would not be available by law to a party other than an agency in litigation with the agency," and FOIA Exemption 5 U.S.C. § 552 (b)(6), "...information about individuals in personnel and medical files and similar files the disclosure of which would constitute a clearly unwarranted invasion of personal privacy."

You have the right to appeal this delay for item 6 and this interim response. Under 14 CFR § 1206.700, you may appeal this denial within 90 calendar days from the date of this letter by writing to:

Administrator
NASA Headquarters
Executive Secretariat
MS 9R17
300 E Street, SW
Washington, DC 20546
ATTN: FOIA Appeals

The appeal should be marked "Appeal under the Freedom of Information Act" both on the envelope and the face of the letter. A copy of your initial request must be enclosed along with a copy of this adverse determination and any other correspondence with the FOIA office. In order to expedite the appellate process and ensure full consideration of your appeal, your appeal should contain a brief statement of the reasons you believe this initial decision to be in error. However, as explained above, we are continuing to process your request and ask that you wait if you wait to file an appeal once a final response has been issued.

For your information, the Office of Government Information Services (OGIS) offers mediation services to resolve disputes between FOIA requesters and Federal agencies. The contact information for OGIS is as follows: Office of Government Information Services, National Archives and Records Administration, Room 2510, 8601 Adelphi Road, College Park, Maryland 20740-6001 or ogis@nara.gov.

Please feel free to contact me for further assistance in writing to this center at the address shown on the letterhead. You may also e-mail correspondence to jpl-foia@nasa.gov or reach me by telephone at 818-393-6779 and fax at 818-393-3160. Also, you may contact Ms. Nikki Gramian Principal Agency FOIA Officer and Chief Public Liaison at 202-358-0625.

Thank you very much.

Sincerely,

Dennis B. Mahon
Freedom of Information Act
Public Liaison Officer

Sign on

SAO/NASA ADS Astronomy Abstract Service

Title: NEOWISE Reactivation Mission Year Three: Asteroid Diameters and Albedos

Authors: Masiero, Joseph R.; Nugent, C.; Mainzer, A. K.; Wright, E. L.; Bauer, J. M.; Cutri, R. M.; Grav, T.; Kramer, E.; Sonnett, S.

Affiliation: AA(Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, MS 183-301, Pasadena, CA 91109, USA Joseph.Masiero@jpl.nasa.gov 0000-0003-2638-720X), AB(California Institute of Technology, Infrared Processing and Analysis Center, 1200 California Boulevard, Pasadena, CA 91125, USA), AC(Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, MS 183-301, Pasadena, CA 91109, USA), AD(University of California, Los Angeles, CA 90095, USA 0000-0001-5058-1593), AE(University of Maryland, College Park, MD 20742, USA), AF(California Institute of Technology, Infrared Processing and Analysis Center, 1200 California Boulevard, Pasadena, CA 91125, USA 0000-0002-0077-2305), AG(Planetary Science Institute, 1700 E Fort Lowell Road #106, Tucson, AZ 85719, USA 0000-0002-3379-0534), AH(Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, MS 183-301, Pasadena, CA 91109, USA 0000-0003-0457-2519), AI(Planetary Science Institute, 1700 E Fort Lowell Road #106, Tucson, AZ 85719, USA 0000-0003-2762-8909)

Publication: The Astronomical Journal, Volume 154, Issue 4, article id. 168, 10 pp. (2017). (AJ Homepage)

Publication Date: 10/2017

Origin: IOP

Astronomy Keywords: minor planets, asteroids: general

DOI: 10.3847/1538-3881/aa89ec

Bibliographic Code: 2017AJ....154..168M

Abstract

The Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) reactivation mission has completed its third year of surveying the sky in the thermal infrared for near-Earth asteroids and comets. NEOWISE collects simultaneous observations at 3.4 and 4.6 μm of solar system objects passing through its field of regard. These data allow for the determination of total thermal emission from bodies in the inner solar system, and thus the sizes of these objects. In this paper, we present thermal model fits of asteroid diameters for 170 NEOs and 6110 Main Belt asteroids (MBAs) detected during the third year of the survey, as well as the associated optical geometric albedos. We compare our results with previous thermal model results from NEOWISE for overlapping sample sets, as well as diameters determined through other independent methods, and find that our diameter measurements for NEOs agree to within 26% (1σ) of previously measured values. Diameters for the MBAs are within 17% (1σ). This brings the total number of unique near-Earth objects characterized by the NEOWISE survey to 541, surpassing the

number observed during the fully cryogenic mission in 2010.

Title: Observed Asteroid Surface Area in the Thermal Infrared

Authors: Nugent, C. R.; Mainzer, A.; Masiero, J.; Wright, E. L.; Bauer, J.; Grav, T.; Kramer, E.; Sonnett, S.

Affiliation: AA(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA), AB(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AC(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-2638-720X), AD(Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA 0000-0001-5058-1593), AE(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AF(Planetary Science Institute, Tucson, AZ, USA 0000-0002-3379-0534), AG(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-0457-2519), AH(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-2762-8909)

Publication: The Astronomical Journal, Volume 153, Issue 2, article id. 90, 5 pp. (2017). (AJ Homepage)

Publication Date: 02/2017

Origin: IOP

Astronomy Keywords: minor planets, asteroids: general, radiation mechanisms: thermal

DOI: 10.3847/1538-3881/153/2/90

Bibliographic Code: 2017AJ....153...90N

Abstract

The rapid accumulation of thermal infrared observations and shape models of asteroids has led to increased interest in thermophysical modeling. Most of these infrared observations are unresolved. We consider what fraction of an asteroid's surface area contributes the bulk of the emitted thermal flux for two model asteroids of different shapes over a range of thermal parameters. The resulting observed surface in the infrared is generally more fragmented than the area observed in visible wavelengths, indicating high sensitivity to shape. For objects with low values of the thermal parameter, small fractions of the surface contribute the majority of thermally emitted flux. Calculating observed areas could enable the production of spatially resolved thermal inertia maps from non-resolved observations of asteroids.

Title: The Albedo Distribution of Near Earth Asteroids

Authors: Wright, Edward L.; Mainzer, Amy; Masiero, Joseph; Grav, Tommy; Bauer, James

Affiliation: AA(UCLA Astronomy, P.O. Box 951547, Los Angeles, CA 90095-1547, USA wright@astro.ucla.edu 0000-0001-5058-1593), AB(Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive Pasadena, CA, 91109-8001, USA), AC(Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive Pasadena, CA, 91109-8001, USA 0000-0003-2638-720X), AD(Planetary Sciences Institute, 1700 E Fort Lowell Road #106, Tucson, AZ 85719, USA 0000-0002-3379-0534), AE(Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive Pasadena, CA, 91109-8001, USA; Infrared Processing and Analysis Center, 770 South Wilson Avenue Pasadena, CA 91125, USA)

Publication: The Astronomical Journal, Volume 152, Issue 4, article id. 79, 4 pp. (2016). (AJ Homepage)

Publication Date: 10/2016

Origin: IOP

Astronomy Keywords: minor planets, asteroids: general

DOI: 10.3847/0004-6256/152/4/79

Bibliographic Code: 2016AJ....152...79W

Abstract

The cryogenic Wide-field Infrared Survey Explorer (WISE) mission in 2010 was extremely sensitive to asteroids and not biased against detecting dark objects. The albedos of 428 near Earth asteroids (NEAs) observed by WISE during its fully cryogenic mission can be fit quite well by a three parameter function that is the sum of two Rayleigh distributions. The Rayleigh distribution is zero for negative values, and follows f(x) =x\exp [-{x}^{2}/(2{σ }^{2})]/{σ }^{2} for positive x. The peak value is at x = σ, so the position and width are tied together. The three parameters are the fraction of the objects in the dark population, the position of the dark peak, and the position of the brighter peak. We find that 25.3% of the NEAs observed by WISE are in a very dark population peaking at $p_V = 0.030$, while the other 74.7% of the NEAs seen by WISE are in a moderately dark population peaking at $p_V = 0.168$. A consequence of this bimodal distribution is that the congressional mandate to find 90% of all NEAs larger than 140 m diameter cannot be satisfied by surveying to H = 22 mag, since a 140 m diameter asteroid at the very dark peak has H = 23.7 mag, and more than 10% of NEAs are darker than $p_V = 0.03$.

Title: NEOWISE Reactivation Mission Year Two: Asteroid Diameters and Albedos

Authors: Nugent, C. R.; Mainzer, A.; Bauer, J.; Cutri, R. M.; Kramer, E. A.; Grav, T.; Masiero, J.; Sonnett, S.; Wright, E. L.

Affiliation: AA(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA cnugent@ipac.caltech.edu), AB(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AC(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AD(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA 0000-0002-0077-2305), AE(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-0457-2519), AF(Planetary Science Institute, Tucson, AZ, USA 0000-0002-3379-0534), AG(Jet

Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-2638-720X), AH(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-2762-8909), AI(Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA 0000-0001-5058-1593)

Publication: The Astronomical Journal, Volume 152, Issue 3, article id. 63, 12 pp. (2016). (AJ Homepage)

Publication Date: 09/2016

Origin: IOP

Astronomy Keywords: minor planets, asteroids: general, surveys

DOI: 10.3847/0004-6256/152/3/63

Bibliographic Code: 2016AJ....152...63N

Abstract

The Near-Earth Object Wide-Field Infrared Survey Explorer (NEOWISE) mission continues to detect, track, and characterize minor planets. We present diameters and albedos calculated from observations taken during the second year since the spacecraft was reactivated in late 2013. These include 207 near-Earth asteroids (NEAs) and 8885 other asteroids. Of the NEAs, 84% NEAs did not have previously measured diameters and albedos by the NEOWISE mission. Comparison of sizes and albedos calculated from NEOWISE measurements with those measured by occultations, spacecraft, and radar-derived shapes shows accuracy consistent with previous NEOWISE publications. Diameters and albedos fall within ±˜20% and ±˜40%, 1-sigma, respectively, of those measured by these alternate techniques. NEOWISE continues to preferentially discover near-Earth objects which are large (>100 m), and have low albedos.

Title: NEOWISE Diameters and Albedos V1.0

Authors: Mainzer, A. K.; Bauer, J. M.; Cutri, R. M.; Grav, T.; Kramer, E. A.; Masiero, J. R.; Nugent, C. R.; Sonnett, S. M.; Stevenson, R. A.; Wright, E. L.

Publication: NASA Planetary Data System, id. EAR-A-COMPIL-5-NEOWISEDIAM-V1.0

Publication Date: 06/2016

Origin: PDS

Bibliographic Code: 2016PDSS..247.....M

Abstract

This PDS data set represents a compilation of published diameters, optical albedos, near-infrared albedos, and beaming parameters for minor planets detected by NEOWISE during the fully cryogenic, 3-band cryo, post-cryo and NEOWISE-Reactivation Year 1 operations. It contains data covering

near-Earth asteroids, Main Belt asteroids, active Main Belt objects, Hildas, Jupiter Trojans, Centaurs, and Jovian and Saturnian irregular satellites. Methodology for physical property determination is described in the referenced articles.

Title:	NEOWISE Reactivation Mission Year One: Preliminary Asteroid Diameters and Albedos
Authors:	Nugent, C. R.; Mainzer, A.; Masiero, J.; Bauer, J.; Cutri, R. M.; Grav, T.; Kramer, E.; Sonnett, S.; Stevenson, R.; Wright, E. L.
Affiliation:	AA(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA cnugent@ipac.caltech.edu), AB(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AC(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AD(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AE(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA 0000-0002-0077-2305), AF(Planetary Science Institute, Tucson, AZ, USA), AG(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-0457-2519), AH(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA 0000-0003-2762-8909), AI(Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA), AJ(Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA 0000-0001-5058-1593)
Publication:	The Astrophysical Journal, Volume 814, Issue 2, article id. 117, 13 pp. (2015). (ApJ Homepage)
Publication Date:	12/2015
Origin:	IOP
Astronomy Keywords:	minor planets, asteroids: general
DOI:	10.1088/0004-637X/814/2/117
Bibliographic Code:	2015ApJ...814..117N

Abstract

We present preliminary diameters and albedos for 7956 asteroids detected in the first year of the NEOWISE Reactivation mission. Of those, 201 are near-Earth asteroids and 7755 are Main Belt or Mars-crossing asteroids. 17% of these objects have not been previously characterized using the Near-Earth Object Wide-field Infrared Survey Explorer, or "NEOWISE" thermal measurements. Diameters are determined to an accuracy of ~20% or better. If good-quality H magnitudes are available, albedos can be determined to within ~40% or better.

Title:	Characterizing asteroids multiply-observed at infrared wavelengths
Authors:	Koren, Seth C.; Wright, Edward L.; Mainzer, A.

Affiliation:	AA(Department of Physics & Astronomy, University of Pennsylvania, Philadelphia, PA 19104, USA), AB(UCLA Astronomy, PO Box 951547, Los Angeles, CA 90095-1547, USA), AC(Jet Propulsion Laboratory, Pasadena, CA 91109, USA)
Publication:	Icarus, Volume 258, p. 82-91. (Icarus Homepage)
Publication Date:	09/2015
Origin:	ELSEVIER
Keywords:	Asteroids, Infrared observations, rotation
Abstract Copyright:	(c) 2015 Elsevier Inc.
DOI:	10.1016/j.icarus.2015.06.014
Bibliographic Code:	2015Icar..258...82K

Abstract

We report Markov chain Monte Carlo fits of the thermophysical model of Wright (Wright, E.L. [2007]. Astrophysics e-prints arXiv:astro-ph/0703058) to the fluxes of 10 asteroids which have been observed by both WISE and NEOWISE. This model is especially useful when one has observations of an asteroid at multiple epochs, as it takes advantage of the views of different local times and latitudes to determine the spin axis and the thermal parameter. Many of the asteroids NEOWISE observes will have already been imaged by WISE, so this proof of concept shows there is an opportunity to use a rotating cratered thermophysical model to determine surface thermal properties of a large number of asteroids.

Title:	Space-Based Thermal Infrared Studies of Asteroids
Authors:	Mainzer, A.; Usui, F.; Trilling, D. E.
Publication:	Asteroids IV, Patrick Michel, Francesca E. DeMeo, and William F. Bottke (eds.), University of Arizona Press, Tucson, 895 pp. ISBN: 978-0-816-53213-1, 2015., p.89-106
Publication Date:	00/2015
Origin:	LPI
DOI:	10.2458/azu_uapress_9780816532131-ch005
Bibliographic Code:	2015aste.book...89M

Abstract

Large-area surveys operating at mid-infrared wavelengths have proven to be a valuable means of discovering and characterizing minor planets. Through the use of radiometric models, it is possible to derive physical properties such as diameters, albedos, and thermal inertia for large numbers of objects. Modern detector array technology has resulted in a significant improvement in spatial resolution and sensitivity compared with previous generations of spacebased infrared telescopes, giving rise to a commensurate increase in the number of objects that have been observed at these wavelengths.

Spacebased infrared surveys of asteroids therefore offer an effective method of rapidly gathering information about the orbital and physical properties of small-body populations. The AKARI, Wide-field Infrared Survey Explorer (WISE)/ Near- Earth Object Wide-field Infrared Survey Explorer (NEOWISE), Spitzer Space Telescope, and Herschel Space Observatory missions have significantly increased the number of minor planets with well-determined diameters and albedos.

Title: Initial Performance of the NEOWISE Reactivation Mission

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Origin: IOP

Astronomy Keywords: comets: general, infrared: general, minor planets, asteroids: general, space vehicles, surveys

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Bibliographic Code: 2014ApJ...792...30M

Abstract

NASA's Wide-field Infrared Survey Explorer (WISE) spacecraft has been brought out of hibernation and has resumed surveying the sky at 3.4 and 4.6 μm. The scientific objectives of the NEOWISE reactivation mission are to detect, track, and characterize near-Earth asteroids and comets. The search for minor planets resumed on 2013 December 23, and the first new near-Earth object (NEO) was discovered 6 days later. As an infrared survey, NEOWISE detects asteroids based on their thermal emission and is equally sensitive to high and low albedo objects; consequently, NEOWISE-discovered NEOs tend to be large and dark. Over the course of its three-year mission, NEOWISE will determine radiometrically derived diameters and albedos for ~2000 NEOs and tens of thousands of Main Belt asteroids. The 32 months of hibernation have had no significant effect on the mission's performance. Image quality, sensitivity, photometric and astrometric accuracy, completeness, and the rate of minor planet detections are all essentially unchanged from the prime mission's post-cryogenic phase.

Title: Main-belt Asteroids with WISE/NEOWISE: Near-infrared Albedos

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Publication: The Astrophysical Journal, Volume 791, Issue 2, article id. 121, 11 pp. (2014). (ApJ Homepage)

Publication Date: 08/2014

Origin: IOP

Astronomy Keywords: minor planets, asteroids: general

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Abstract

We present revised near-infrared albedo fits of 2835 main-belt asteroids observed by WISE/NEOWISE over the course of its fully cryogenic survey in 2010. These fits are derived from reflected-light near-infrared images taken simultaneously with thermal emission measurements, allowing for more accurate measurements of the near-infrared albedos than is possible for visible albedo measurements. Because our sample requires reflected light measurements, it undersamples small, low-albedo asteroids, as well as those with blue spectral slopes across the wavelengths investigated. We find that the main belt separates into three distinct groups of 6%, 16%, and 40% reflectance at 3.4 μm. Conversely, the 4.6 μm albedo distribution spans the full range of possible values with no clear grouping. Asteroid families show a narrow distribution of 3.4 μm albedos within each family that map to one of the three observed groupings, with the (221) Eos family being the sole family associated with the 16% reflectance 3.4 μm albedo group. We show that near-infrared albedos derived from simultaneous thermal emission and reflected light measurements are important indicators of asteroid taxonomy and can identify interesting targets for spectroscopic follow-up.

Title: The Population of Tiny Near-Earth Objects Observed by NEOWISE

Authors: Mainzer, A.; Bauer, J.; Grav, T.; Masiero, J.; Cutri, R. M.; Wright, E.; Nugent, C. R.; Stevenson, R.; Clyne, E.; Cukrov, G.; Masci, F.

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Publication: The Astrophysical Journal, Volume 784, Issue 2, article id. 110, 7 pp. (2014). (ApJ Homepage)

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Origin: IOP

Astronomy Keywords: atlases, catalogs, infrared: general, minor planets, asteroids: general, surveys

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Abstract

Only a very small fraction of the asteroid population at size scales comparable to the object that exploded over Chelyabinsk, Russia has been discovered to date, and physical properties are poorly characterized. We present previously unreported detections of 105 close approaching near-Earth objects (NEOs) by the Wide-field Infrared Survey Explorer (WISE) mission's NEOWISE project. These infrared observations constrain physical properties such as diameter and albedo for these objects, many of which are found to be smaller than 100 m. Because these objects are intrinsically faint, they were detected by WISE during very close approaches to the Earth, often at large apparent on-sky velocities. We observe a trend of increasing albedo with decreasing size, but as this sample of NEOs was discovered by visible light surveys, it is likely that selection biases against finding small, dark NEOs influence this finding.

Title: Physical Parameters of Asteroids Estimated from the WISE 3-Band Data and NEOWISE Post-Cryogenic Survey

Authors: Mainzer, A.; Grav, T.; Masiero, J.; Bauer, J.; Cutri, R. M.; McMillan, R. S.; Nugent, C. R.; Tholen, D.; Walker, R.; Wright, E. L.

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Publication:	The Astrophysical Journal Letters, Volume 760, Issue 1, article id. L12, 6 pp. (2012). (ApJL Homepage)
Publication Date:	11/2012
Origin:	IOP
Astronomy Keywords:	atlases, catalogs, minor planets, asteroids: general, surveys
DOI:	10.1088/2041-8205/760/1/L12
Bibliographic Code:	2012ApJ...760L..12M

Abstract

Enhancements to the science data processing pipeline of NASA's Wide-field Infrared Survey Explorer (WISE) mission, collectively known as NEOWISE, resulted in the detection of >158,000 minor planets in four infrared wavelengths during the fully cryogenic portion of the mission. Following the depletion of its cryogen, NASA's Planetary Science Directorate funded a four-month extension to complete the survey of the inner edge of the Main Asteroid Belt and to detect and discover near-Earth objects (NEOs). This extended survey phase, known as the NEOWISE Post-Cryogenic Survey, resulted in the detection of ~6500 large Main Belt asteroids and 86 NEOs in its 3.4 and 4.6 μm channels. During the Post-Cryogenic Survey, NEOWISE discovered and detected a number of asteroids co-orbital with the Earth and Mars, including the first known Earth Trojan. We present preliminary thermal fits for these and other NEOs detected during the 3-Band Cryogenic and Post-Cryogenic Surveys.

Title:	Preliminary Analysis of WISE/NEOWISE 3-Band Cryogenic and Post-cryogenic Observations of Main Belt Asteroids
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Publication:	The Astrophysical Journal Letters, Volume 759, Issue 1, article id. L8, 5 pp. (2012). (ApJL Homepage)

Publication Date: 11/2012

Origin: IOP

Astronomy Keywords: minor planets, asteroids: general

DOI: 10.1088/2041-8205/759/1/L8

Bibliographic Code: 2012ApJ...759L...8M

Abstract

We present preliminary diameters and albedos for 13511 Main Belt asteroids (MBAs) that were observed during the 3-Band Cryo phase of the Wide-field Infrared Survey Explorer (WISE; after the outer cryogen tank was exhausted) and as part of the NEOWISE Post-Cryo Survey (after the inner cryogen tank was exhausted). With a reduced or complete loss of sensitivity in the two long wavelength channels of WISE, the uncertainty in our fitted diameters and albedos is increased to ~20% for diameter and ~40% for albedo. Diameter fits using only the 3.4 and 4.6 μm channels are shown to be dependent on the literature optical H absolute magnitudes. These data allow us to increase the number of size estimates for large MBAs which have been identified as members of dynamical families. We present thermal fits for 14 asteroids previously identified as the parents of a dynamical family that were not observed during the fully cryogenic mission.

Title: WISE/NEOWISE Observations of the Jovian Trojan Population: Taxonomy

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Publication: The Astrophysical Journal, Volume 759, Issue 1, article id. 49, 10 pp. (2012). (ApJ Homepage)

Publication Date: 11/2012

Origin: IOP

Astronomy Keywords: infrared: planetary systems, minor planets, asteroids: general

DOI: 10.1088/0004-637X/759/1/49

Bibliographic Code: 2012ApJ...759...49G

Abstract

We present updated/new thermal model fits for 478 Jovian Trojan asteroids observed with the Wide-field Infrared Survey Explorer (WISE). Using the fact that the two shortest bands used by WISE, centered on 3.4 and 4.6 μm, are dominated by reflected light, we derive albedos of a significant fraction of these objects in these bands. While the visible albedos of both the C-, P-, and D-type asteroids are strikingly similar, the WISE data reveal that the albedo at 3.4 μm is different between C-/P- and D-types. The albedo at 3.4 μm can thus be used to classify the objects, with C-/P-types having values less than 10% and D-types have values larger than 10%. Classifying all objects larger than 50 km shows that the D-type objects dominate both the leading cloud (L_4), with a fraction of 84%, and trailing cloud (L_5), with a fraction of 71%-80%. The two clouds thus have very similar taxonomic distribution for these large objects, but the leading cloud has a larger number of these large objects, $L_4/L_5 = 1.34$. The taxonomic distribution of the Jovian Trojans is found to be different from that of the large Hildas, which is dominated by C- and P-type objects. At smaller sizes, the fraction of D-type Hildas starts increasing, showing more similarities with the Jovian Trojans. If this similarity is confirmed through deeper surveys, it could hold important clues to the formation and evolution of the two populations. The Jovian Trojans does have similar taxonomic distribution to that of the Jovian irregular satellites, but lacks the ultra red surfaces found among the Saturnian irregular satellites and Centaur population.

Title: WISE/NEOWISE Observations of the Hilda Population: Preliminary Results

Authors: Grav, T.; Mainzer, A. K.; Bauer, J.; Masiero, J.; Spahr, T.; McMillan, R. S.; Walker, R.; Cutri, R.; Wright, E.; Eisenhardt, P. R.; Blauvelt, E.; DeBaun, E.; Elsbury, D.; Gautier, T.; Gomillion, S.; Hand, E.; Wilkins, A.

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Publication: The Astrophysical Journal, Volume 744, Issue 2, article id. 197, 15 pp. (2012). (ApJ Homepage)

Publication Date: 01/2012

Origin: IOP

Astronomy Keywords: infrared: planetary systems, minor planets, asteroids: general, surveys

DOI: 10.1088/0004-637X/744/2/197

Bibliographic Code: 2012ApJ...744..197G

Abstract

We present the preliminary analysis of 1023 known asteroids in the Hilda region of the solar system observed by the NEOWISE component of the Wide-field Infrared Survey Explorer (WISE). The sizes of the Hildas observed range from ~3 to 200 km. We find no size-albedo dependency as reported by other projects. The albedos of our sample are low, with a weighted mean value of $p_V = 0.055 \pm 0.018$, for all sizes sampled by the NEOWISE survey. We observed a significant fraction of the objects in the two known collisional families in the Hilda population. It is found that the Hilda collisional family is brighter, with a weighted mean albedo of $p_V = 0.061 \pm 0.011$, than the general population and dominated by D-type asteroids, while the Schubart collisional family is darker, with a weighted mean albedo of $p_V = 0.039 \pm 0.013$. Using the reflected sunlight in the two shortest WISE bandpasses, we are able to derive a method for taxonomic classification of ~10% of the Hildas detected in the NEOWISE survey. For the Hildas with diameter larger than 30 km, there are 67^{+7}_{-15}% D-type asteroids and 26^{+17}_{-5}% C-/P-type asteroids (with the majority of these being P-types).

Title: NEOWISE Observations of Near-Earth Objects: Preliminary Results

Authors: Mainzer, A.; Grav, T.; Bauer, J.; Masiero, J.; McMillan, R. S.; Cutri, R. M.; Walker, R.; Wright, E.; Eisenhardt, P.; Tholen, D. J.; Spahr, T.; Jedicke, R.; Denneau, L.; DeBaun, E.; Elsbury, D.; Gautier, T.; Gomillion, S.; Hand, E.; Mo, W.; Watkins, J.; Wilkins, A.; Bryngelson, G. L.; Del Pino Molina, A.; Desai, S.; Gómez Camus, M.; Hidalgo, S. L.; Konstantopoulos, I.; Larsen, J. A.; Maleszewski, C.; Malkan, M. A.; Mauduit, J.-C.; Mullan, B. L.; Olszewski, E. W.; Pforr, J.; Saro, A.; Scotti, J. V.; Wasserman, L. H.

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Abstract

With the NEOWISE portion of the Wide-field Infrared Survey Explorer (WISE) project, we have carried out a highly uniform survey of the near-Earth object (NEO) population at thermal infrared wavelengths ranging from 3 to 22 μm, allowing us to refine estimates of their numbers, sizes, and albedos. The NEOWISE survey detected NEOs the same way whether they were previously known or not, subject to the availability of ground-based follow-up observations, resulting in the discovery of more than 130 new NEOs. The survey's uniform sensitivity, observing cadence, and image quality have permitted extrapolation of the 428 near-Earth asteroids (NEAs) detected by NEOWISE during the fully cryogenic portion of the WISE mission to the larger population. We find that there are 981 ± 19 NEAs larger than 1 km and 20,500 ± 3000 NEAs larger than 100 m. We show that the Spaceguard goal of detecting 90% of all 1 km NEAs has been met, and that the cumulative size distribution is best represented by a broken power law with a slope of 1.32 ± 0.14 below 1.5 km. This power-law slope produces ~13, 200 ± 1900 NEAs with D > 140 m. Although previous studies predict another break in the cumulative size distribution below D ~ 50-100 m, resulting in an increase in the number of NEOs in this size range and smaller, we did not detect enough objects to comment on this increase. The overall number for the NEA population between 100 and 1000 m is lower than previous estimates. The numbers of near-Earth comets and potentially hazardous NEOs will be the subject of future work.

Title: WISE/NEOWISE Observations of the Jovian Trojans: Preliminary Results

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Abstract

We present the preliminary analysis of over 1739 known and 349 candidate Jovian Trojans observed by the NEOWISE component of the Wide-field Infrared Survey Explorer (WISE). With this survey the available diameters, albedos, and beaming parameters for the Jovian Trojans have been increased by more than an order of magnitude compared to previous surveys. We find that the Jovian Trojan population is very homogenous for sizes larger than ~10 km (close to the detection limit of WISE for these objects). The observed sample consists almost exclusively of low albedo objects, having a mean albedo value of 0.07 ± 0.03. The beaming parameter was also derived for a large fraction of the observed sample, and it is also very homogenous with an observed mean value of 0.88 ± 0.13. Preliminary debiasing of the survey shows that our observed sample is consistent with the leading cloud containing more objects than the trailing cloud. We estimate the fraction to be N(leading)/N(trailing) ~ 1.4 ± 0.2, lower than the 1.6 ± 0.1 value derived by Szabó et al.

Title: Main Belt Asteroids with WISE/NEOWISE. I. Preliminary Albedos and Diameters

Authors: Masiero, Joseph R.; Mainzer, A. K.; Grav, T.; Bauer, J. M.; Cutri, R. M.; Dailey, J.; Eisenhardt, P. R. M.; McMillan, R. S.; Spahr, T. B.; Skrutskie, M. F.; Tholen, D.; Walker, R. G.; Wright, E. L.; DeBaun, E.; Elsbury, D.; Gautier, T., IV; Gomillion, S.; Wilkins, A.

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Abstract

We present initial results from the Wide-field Infrared Survey Explorer (WISE), a four-band all-sky thermal infrared survey that produces data well suited for measuring the physical properties of asteroids, and the NEOWISE enhancement to the WISE mission allowing for detailed study of solar system objects. Using a NEATM thermal model fitting routine, we compute diameters for over 100,000 Main Belt asteroids from their IR thermal flux, with errors better than 10%. We then incorporate literature values of visible measurements (in the form of the H absolute magnitude) to determine albedos. Using these data we investigate the albedo and diameter distributions of the Main Belt. As observed previously, we find a change in the average albedo when comparing the inner, middle, and outer portions of the Main Belt. We also confirm that the albedo distribution of each region is strongly bimodal. We observe groupings of objects with similar albedos in regions of the Main Belt associated with dynamical breakup families. Asteroid families typically show a characteristic albedo for all members, but there are notable

exceptions to this. This paper is the first look at the Main Belt asteroids in the WISE data, and only represents the preliminary, observed raw size, and albedo distributions for the populations considered. These distributions are subject to survey biases inherent to the NEOWISE data set and cannot yet be interpreted as describing the true populations; the debiased size and albedo distributions will be the subject of the next paper in this series.

Title:	Thermal Model Calibration for Minor Planets Observed with WISE/NEOWISE: Comparison with Infrared Astronomical Satellite
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Abstract

With thermal infrared observations detected by the NEOWISE project, we have measured diameters for 1742 minor planets that were also observed by the Infrared Astronomical Satellite (IRAS). We have compared the diameters and albedo derived by applying a spherical thermal model to the objects detected by NEOWISE and find that they are generally in good agreement with the IRAS values. We have shown that diameters computed from NEOWISE data are often less systematically biased than those found with IRAS. This demonstrates that the NEOWISE data set can provide accurate physical parameters for the >157,000 minor planets that were detected by NEOWISE.

Title: Thermal Model Calibration for Minor Planets Observed with Wide-field Infrared

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Abstract

With the Wide-field Infrared Survey Explorer (WISE), we have observed over 157,000 minor planets. Included in these are a number of near-Earth objects, main-belt asteroids, and irregular satellites which have well measured physical properties (via radar studies and in situ imaging) such as diameters. We have used these objects to validate models of thermal emission and reflected sunlight using the WISE measurements, as well as the color corrections derived in Wright et al. for the four WISE bandpasses as a function of effective temperature. We have used 50 objects with diameters measured by radar or in situ imaging to characterize the systematic errors implicit in using the WISE data with a faceted spherical near-Earth asteroid thermal model (NEATM) to compute diameters and albedos. By using the previously measured diameters and H magnitudes with a spherical NEATM model, we compute the predicted fluxes (after applying the color corrections given in Wright et al.) in each of the four WISE bands and compare them to the measured magnitudes. We find minimum systematic flux errors of 5%-10%, and hence minimum relative diameter and albedo errors of ~10% and ~20%, respectively. Additionally, visible albedos for the objects are computed and compared to the albedos at 3.4 μm and 4.6 μm, which contain a combination of reflected sunlight and thermal emission for most minor planets observed by WISE. Finally, we derive a linear relationship between subsolar temperature and effective temperature, which

allows the color corrections given in Wright et al. to be used for minor planets by computing only subsolar temperature instead of a faceted thermophysical model. The thermal models derived in this paper are not intended to supplant previous measurements made using radar or spacecraft imaging; rather, we have used them to characterize the errors that should be expected when computing diameters and albedos of minor planets observed by WISE using a spherical NEATM model.

Title: Preliminary Results from NEOWISE: An Enhancement to the Wide-field Infrared Survey Explorer for Solar System Science

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Abstract

The Wide-field Infrared Survey Explorer (WISE) has surveyed the entire sky at four infrared wavelengths with greatly improved sensitivity and spatial resolution compared to its predecessors, the Infrared Astronomical Satellite and the Cosmic Background Explorer. NASA's Planetary Science Division has funded an enhancement to the WISE data processing system called "NEOWISE" that allows detection and archiving of moving objects found in the WISE data. NEOWISE has mined the WISE images for a wide array of small bodies in our solar system, including near-Earth objects (NEOs), Main Belt asteroids, comets, Trojans, and Centaurs. By the end of survey operations in 2011 February, NEOWISE identified over 157,000 asteroids, including more than 500 NEOs and ~120 comets. The NEOWISE data set will enable a panoply of new scientific investigations.

Title: The Wide-field Infrared Survey Explorer (WISE): Mission Description and Initial On-orbit Performance

Authors: Wright, Edward L.; Eisenhardt, Peter R. M.; Mainzer, Amy K.; Ressler, Michael E.; Cutri, Roc M.; Jarrett, Thomas; Kirkpatrick, J. Davy; Padgett, Deborah; McMillan, Robert S.; Skrutskie, Michael; Stanford, S. A.; Cohen, Martin; Walker, Russell G.; Mather, John C.; Leisawitz, David; Gautier, Thomas N., III; McLean, Ian; Benford, Dominic; Lonsdale, Carol J.; Blain, Andrew; Mendez, Bryan; Irace, William R.; Duval, Valerie; Liu, Fengchuan; Royer, Don; Heinrichsen, Ingolf; Howard, Joan; Shannon, Mark; Kendall, Martha; Walsh, Amy L.; Larsen, Mark;

Cardon, Joel G.; Schick, Scott; Schwalm, Mark; Abid, Mohamed; Fabinsky, Beth; Naes, Larry; Tsai, Chao-Wei

Affiliation: AA(UCLA Astronomy, P.O. Box 951547, Los Angeles, CA 90095-1547, USA wright@astro.ucla.edu), AB(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AC(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AD(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AE(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA), AF(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA), AG(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA), AH(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA), AI(University of Arizona, 1629 East University Boulevard, Tucson, AZ 85721, USA), AJ(Department of Astronomy, University of Virginia, Charlottesville, VA 22903, USA), AK(Physics Department, University of California, Davis, CA 95616, USA ; Institute of Geophysics and Planetary Physics, LLNL, Livermore, CA 94551, USA), AL(Monterey Institute for Research in Astronomy, 200 8th Street, Marina, CA 93933, USA), AM(Monterey Institute for Research in Astronomy, 200 8th Street, Marina, CA 93933, USA), AN(NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA), AO(NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA), AP(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AQ(UCLA Astronomy, P.O. Box 951547, Los Angeles, CA 90095-1547, USA), AR(NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA), AS(National Radio Astronomy Observatory, Charlottesville, VA 22903, USA), AT(California Institute of Technology, Pasadena, CA 91125, USA), AU(Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA), AV(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AW(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AX(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AY(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), AZ(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), BA(Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, CO 80301, USA), BB(Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, CO 80301, USA), BC(Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, CO 80301, USA), BD(Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, CO 80301, USA), BE(Space Dynamics Laboratory, 1695 North Research Park Way, North Logan, UT 84341, USA), BF(Space Dynamics Laboratory, 1695 North Research Park Way, North Logan, UT 84341, USA), BG(Practical Technology Solutions, Inc., P.O. Box 6336, North Logan, UT 8434, USA), BH(L-3 Communications SSG-Tinsley, Wilmington, MA 01887, USA), BI(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), BJ(Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA), BK(Lockheed Martin Advanced Technology Center, Palo Alto, CA 94304, USA ; Retired.), BL(Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125, USA)

Publication: The Astronomical Journal, Volume 140, Issue 6, article id. 1868-1881 (2010). (AJ Homepage)

Publication Date: 12/2010

Origin: IOP

Astronomy Keywords: infrared: general, space vehicles, surveys

DOI: 10.1088/0004-6256/140/6/1868

Bibliographic Code: 2010AJ....140.1868W

Abstract

The all sky surveys done by the Palomar Observatory Schmidt, the European Southern Observatory Schmidt, and the United Kingdom Schmidt, the InfraRed Astronomical Satellite, and the Two Micron All Sky Survey have proven to be extremely useful tools for astronomy with value that lasts for decades. The Wide-field Infrared Survey Explorer (WISE) is mapping the whole sky following its launch on 2009 December 14. WISE began surveying the sky on 2010 January 14 and completed its first full coverage of the sky on July 17. The survey will continue to cover the sky a second time until the cryogen is exhausted (anticipated in 2010 November). WISE is achieving 5σ point source sensitivities better than 0.08, 0.11, 1, and 6 mJy in unconfused regions on the ecliptic in bands centered at wavelengths of 3.4, 4.6, 12, and 22 μm. Sensitivity improves toward the ecliptic poles due to denser coverage and lower zodiacal background. The angular resolution is 6farcs1, 6farcs4, 6farcs5, and 12farcs0 at 3.4, 4.6, 12, and 22 μm, and the astrometric precision for high signal-to-noise sources is better than 0farcs15.

National Aeronautics and
Space Administration
Jet Propulsion Laboratory
NASA Management Office
FOIA Public Liaison Office
4800 Oak Grove Dr., M/S 180-200K
Pasadena, CA 91109-8001

Reply to Attn of: RA000/NMO

May 11, 2018

Arnold & Porter, LLP
Attn: Mr. Ronald D. Lee, Esq.
601 Massachusetts Ave. NW
Washington, DC 20001-3743

FOIA Request 18-JPL-F-00247

Dear Mr. Lee:

This is the final response to your Freedom of Information Act (FOIA) dated January 5, 2018 and received at the NASA Jet Propulsion Laboratory FOIA Public Liaison Office on January 8, 2018. Your request was assigned Case File Number 18-JPL-F-00247. Your request submitted on behalf of Dr. Nathan Myhrvold, enumerated 9 items related to the NEOWISE (Near-Earth Object Wide-field Infrared Survey Explorer) mission managed and operated by JPL for NASA's Science Mission Directorate, and its efforts to estimate diameters and albedos of near-Earth objects, particularly asteroids. Specifically your request sought the following:

> **1) All specification documents for NEOWISE concerning the Near-Earth Asteroid Thermal Model (NEATM), its variants, and all other thermal models used by NEOWISE to generate the estimates of asteroid diameters, visible albedos, or infrared albedos uploaded to the Planetary Data System (PDS) and published in NEOWISE's scientific publications. By way of example, such documents may include, but are not limited to, any System Requirements Documents, Project Requirements Documents, Interface Requirements Documents, and Concept of Operations documents, as discussed in Sections 2.3 and 4.2.1.3 of NASA's Systems Engineering Handbook (available at https://www.acq.osd.mil/se/docsINASA-SP-2007-61 05-Rev-1-Final-3lDec2007.pdf).**
>
> **2) All documents measuring the accuracy of the Near-Earth Asteroid Thermal Model (NEATM), its variants, or all other thermal models used by NEOWISE to generate the asteroid diameter estimates uploaded to the Planetary Data System and published in NEOWISE's scientific publications. By way of example, such documents may include, but are not limited to, Measures of Effectiveness documents, Measures of Performance documents, Technical Performance Measure documents, and Verification Documents, as discussed in Sections 5.4.1.3 and 6.7.2.2 of NASA's Systems Engineering Handbook (available at https:/ Iwww.acq.osd.mil/se/docsINASA-SP-2007 -61 OS-Rev-l-Final-31 Dec2007 .pdf).**
>
> **3) All computer code and other data files for the Near-Earth Asteroid Thermal Model (NEATM) or other thermal models used by NEOWISE to generate the**

asteroid diameter estimates uploaded to the Planetary Data System and published in NEOWISE's scientific publications.

4) All NF-1676 Document Availability Authorization forms produced for the computer code and other data files requested in request 3. We understand that NF-1676 Document Availability Authorization forms are generated when Scientific and Technical Information is released outside of NASA, as set forth in Section I (c) of NASA Policy Directive 2200.1 C (available at https:llnodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=2200&s=I C), and Section 6.4 of NASA Policy Directive 2200.2D (available at https:llnodis3.gsfc.nasa.gov/displayDir.cfm?Internal ID=N PR 2200 002D &page name=Chapter6).

5) All Technical Review documents produced for the computer code and other data files requested in request 3. We understand that Technical Review documents are generated before NF-1676 Document Availability Authorization forms are approved, as set forth in Section 6.4 of NASA Policy Directive 2200.2D (available at https:llnodis3.gsfc.nasa.gov/displayDir.cfm?Internal ID=N PR 2200 002D &page name=Chapter6).

6) All email and other correspondence concerning the design of, limits of, and revisions to the Near-Earth Asteroid Thermal Model (NEATM) or other thermal models (including email or other correspondence concerning drafts of journal articles, conference presentations or posters, or media releases involving NEOWISE methods, models, or results, or mentioning radar, occultation, or spacecraft estimates of diameter), between any NASA/JPL members of the NEOWISE team and external astronomers, including but not limited to:

- **i. Victor Ali-Lagoa;**
- **ii. Alan Harris;**
- **iii. Josef Hanus;**
- **iv. Marco Delbo;**
- **v. Josef Durech;**
- **vi. Robert McMillan;**
- **vii. Michael Skrutskie;**
- **viii. David Tholen;**
- **ix. Russell Walker;**
- **x. Carrie Nugent;**
- **xi. Vishnu Reddy;**
- **xii. Jean-Luc Margot; or**
- **xiii. Thomas Statler**

7) All reports of NEOWISE asteroid results for which the "FIT_CODE" is listed as "-VB-." We understand based on the documentation for the Planetary Data System (attached as Exhibit A[1]) that the "FIT_CODE" is a four-character code indicating parameters allowed to vary in thermal fit, the parameters being D=diameter, V=visible geometric albedo, B=NEATM beaming parameter, I=infrared geometric albedo, and - = parameter held fixed for fit, such that "-VB-" means visible

geometric albedo and NEATM beaming parameter were allowed to vary, but diameter and infrared geometric albedo were not. An example of a result with FIT_CODE "-VB-" is attached as Exhibit B[2].

8) All documents relating to requests by individuals inside or outside NASA for NEOWISE code, specifications, or output; NASA's or JPL's responses to such requests; and NASA's or JPL's policies or procedures for handling such requests, including but not limited to any requests made by Thomas Statler in 2016 for NEOWISE code. An example of a document relating to one such request is attached as Exhibit C.

9) All (a) drafts and revisions of; (b) comments to and from authors, reviewers, and collaborators regarding, (c) associated email messages attaching or linking, and (d) NF-1676 Document Availability Authorization forms or Technical Review documents produced for, each of the following papers:

i. Mainzer, A., Bauer, J.M., Grav, T., Masiero, J.R., Cutri, R.M., Wright, E., Nugent, C.R., Stevenson, R., Clyne, E., Cukrov, G., Masci, F., 2014. The Population of Tiny Near-Earth Objects Observed by NEOWISE. Astrophys.J.784,110. doi:10.1088/0004-637X178412/ 110.

ii. Grav, T., Mainzer, A.K., Bauer, J., Masiero, J., Spahr, T., McMillan, R.S., Walker, R., Cutri, R., Wright, E., Eisenhardt, P.R.M., Blauvelt, E., DeBaun, E., Elsbury, D., Gautier, T., Gomillion, S., Hand, E., Wilkins, A., 20 II. WISE/NEOWISE Observations of the Jovian Trojans: Preliminary Results. Astrophys.1. 742,40. doi:10.1088/0004-637X1742/1/40.

iii. Grav, T., Mainzer, A., Bauer, J.M., Masiero, J., Spahr, T., McMillan, R.S., Walker, R., Cutri, R., Wright, E.L., Eisenhardt, P.R.M., Blauvelt, E., DeBaun, E., Elsbury, D., Gautier, T., Gomillion, S., Hand, E., Wilkins, A., 2011. WISE/Neowise Observations of the Hilda Population: Preliminary Results. Astrophys. J. 744, 197. doi:l0.1088/0004-637X1744/2/197.

iv Masiero, J.R., Grav, T., Mainzer, A., Nugent, C.R., Bauer, J.M., Stevenson, R., Sonnett, S., 2014. Main Belt Asteroids with WISE/NEOWISE: NearInfrared Albedos. Astrophys. J. 791, 121. doi:10.1088/0004-637X1791/2/121.

v. Mainzer, A., Grav, T., Masiero, J., Bauer, J.M., Cutri, R.M., Mcmillan, R.S., Nugent, C.R., Tholen, D., Walker, R, Wright, E.L., 2012. Physical Parameters of Asteroids Estimated from the WISE 3 Band Data and NEOWISE Post-Cryogenic Survey. Astrophys. J. Lett. 760, L12. doi: 10.1 088/2041-8205/760/11L12.

vi. Masiero, J.R., Mainzer, A., Grav, T., Bauer, J.M., Cutri, R.M., Nugent, C., Cabrera, M.S., 2012. Preliminary analysis of

WISE/NEOWISE 3-band cryogenic and post-cryogenic observations of main belt asteroids. Astrophys. 1. 759, L8. doi: I 0.1 088/2041-8205/759/11L8.

vii. Nugent, C.R., Mainzer, A., Masiero, J., Bauer, J., Cutri, R.M., Grav, T., Kramer, E., Sonnett, S., Stevenson, R., Wright, E.L., 2015. NEOWISE Reactivation Mission Year One: Preliminary Asteroid Diameters and Albedos. Astrophys. J. 814, 117. doi:10.1088/0004-637X/814/2/117.

viii. Nugent, C.R., Mainzer, A., Masiero, J., Wright, E.L., Bauer, J., Grav, T., Kramer, E.A., Sonnett, S., 2016. Observed asteroid surface area in the thermal infrared. Astron. 1. 153, 90. doi:10.3847/1538-38811153/2/90.

ix. Tedesco, E.F., Noah, P.V., Noah, M., Price, S.D., 2002. The Supplemental IRAS Minor Planet Survey. Astron. J. 123, 1056-1085. doi:10.1086/338320. (With respect to this paper only, please apply a time frame of 2000 to 2002 for the search.)

x. Ryan, E.L., Woodward, C.E., 2010. Rectified asteroid albedos and diameters from IRAS and MSX Photometry Catalogs. Astron. J. 140, 933. doi: I 0.1 088/0004-6256/140/4/933.

For all requests above, except where otherwise noted, we request responsive documents from January 1, 2010 to the present. NASA should perform "a reasonable search" for the requested documents. 14 C.F.R. § 1206.401(b). A reasonable search should include, but not be limited to, the files of JPL scientists Drs. Amy Mainzer, James Bauer, Joseph Masiero, Carolyn (Carrie) R. Nugent, Rachel Stevenson, Peter Eisenhardt, Thomas Gautier IV, Sarah Sonnett, and Emily Kramer.

In accordance with NASA's FOIA regulations (14 CFR §1206.305), a search was conducted by JPL (Caltech) and HQ for the records you requested. We notified you on February 21, 2018 that we completed processing items 2-5 and 7 of your request in our first interim response. We notified you on April 3, 2018 that we completed processing items 1, 8 and 9 of your request in our second interim response. Records are now being released for this final response as the result of searches to produce responsive records to item 6 of your request, completing all portions of your request.

6) All email and other correspondence concerning the design of, limits of, and revisions to the Near-Earth Asteroid Thermal Model (NEATM) or other thermal models (including email or other correspondence concerning drafts of journal articles, conference presentations or posters, or media releases involving NEOWISE methods, models, or results, or mentioning radar, occultation, or spacecraft estimates of diameter), between any NASA/JPL members of the NEOWISE team and external astronomers, including but not limited to:

i. **Victor Ali-Lagoa;**
ii. **Alan Harris;**
iii. **Josef Hanus;**
iv. **Marco Delbo;**
v. **Josef Durech;**
vi. **Robert McMillan;**
vii. **Michael Skrutskie;**
viii. **David Tholen;**
ix. **Russell Walker;**
x. **Carrie Nugent;**
xi. **Vishnu Reddy;**
xii. **Jean-Luc Margot; or**
xiii. **Thomas Statler**

Our office located 60 pages in response to item 6 of your request. We have reviewed these responsive records under the FOIA to determine whether they may be accessed under the FOIA's provisions. Based on that review, this office is providing the following:

46 page(s) are being released in full (RIF);
4 page(s) are being released in part (RIP);
6 page(s) are withheld in full (WIF);
4 page(s) are duplicate copies of material already processed.

NASA redacted from the enclosed documents information that fell within FOIA Exemptions 3, 4, 5, and 6; 5 U.S.C. § 552 (b)(3), (b)(4), (b)(5), and (b)(6).

FOIA Exemption 3, 5 U.S.C. § 552 (b)(3) protects information "...specifically exempted from disclosure by statute (other than Section 552b of this title) provided that such statute (A) requires that the matters be withheld from the public in such a manner as to leave no discretion on the issue, or (B) establishes particular criteria for withholding or refers to particular types of matters to be withheld. Under 10 U.S.C. 2305(g), competitive proposals [*specifically e-mails identified as "mail2016jan4*," and "*mail2016jan9*" *and attachment* "*shape_effects_tss*" *which relate to a pending proposal*] are specifically excluded from disclosure unless they are incorporated by reference in the final contract, a sole-source proposal or an unsolicited proposal, and may not be released by the agency,"

FOIA Exemption 4, 5 U.S.C. § 552 (b)(4) protects "...trade secrets and commercial or financial information obtained from a person and privileged or confidential,"

FOIA Exemption 5, 5 U.S.C. § 552 (b)(5) protects "...inter-agency or intra-agency memorandums or letters which would not be available by law to a party other than an agency in litigation with the agency." and

FOIA Exemption 6, 5 U.S.C. § 552 (b)(6), allows withholding of "...information about individuals in personnel and medical files and similar files the disclosure of which would constitute a clearly unwarranted invasion of personal privacy."

This concludes NASA's search and response to item 6 of your FOIA request. These records were within the control and possession of NASA employees. Should there be other internal communications created by the prime contractor and not in NASA's control, they are considered contractor records pursuant to the NASA Prime Contract NNN12AA01C, Section H-16 (b)(1) and not subject to the FOIA.

You have the right under 14 CFR §1206.700 to appeal this determination within 90 days of the date of this letter. Your appeal must be in writing and should be addressed to:

Administrator
NASA Headquarters
Executive Secretariat
MS 9R17
300 E Street, SW
Washington, DC 20546
ATTN: FOIA Appeals

The appeal should be marked "Appeal under the Freedom of Information Act" both on the envelope and the face of the letter. A copy of your initial request must be enclosed along with a copy of this adverse determination and any other correspondence with the FOIA office. In order to expedite the appellate process and ensure full consideration of your appeal, your appeal should contain a brief statement of the reasons you believe this initial decision to be in error. However, as explained above, we are continuing to process your request and ask that you wait if you wait to file an appeal once a final response has been issued.

For your information, the Office of Government Information Services (OGIS) offers mediation services to resolve disputes between FOIA requesters and Federal agencies. The contact information for OGIS is as follows: Office of Government Information Services, National Archives and Records Administration, Room 2510, 8601 Adelphi Road, College Park, Maryland 20740-6001 or ogis@nara.gov.

Please feel free to contact me for further assistance in writing to this center at the address shown on the letterhead. You may also e-mail correspondence to jpl-foia@nasa.gov or reach me by telephone at 818-393-6779 and fax at 818-393-3160. Also, before filing an appeal, you may wish to contact Ms. Nikki Gramian, Principal Agency FOIA Officer and Chief Public Liaison at 202-358-0625 to assist with any questions or concerns you may have regarding this response.

Thank you very much.

Sincerely,

Dennis B. Mahon
Freedom of Information Act
Public Liaison Officer

Johnson, Lindley (HQ-DG000)

From:	Mainzer, Amy (3266) <Amy.Mainzer@jpl.nasa.gov>
Sent:	Wednesday, November 22, 2017 1:14 PM
To:	Johnson, Lindley (HQ-DG000); Kelley, Michael S. (HQ-DG000); Fast, Kelly E. (HQ-DG000)
Cc:	Fabinsky, Beth E (JPL-7240)[Jet Propulsion Laboratory]; Masiero, Joseph R (JPL-3224)[Jet Propulsion Laboratory]
Subject:	NEOWISE status

-NEOWISE discovery N00c79x has received followup and was designated in an MPEC as 2017 VT14. This object is a high-eccentricity NEO with Earth MOID=0.004 AU. This NEO has a close pass with Earth (d=0.009 AU = 3.5 LD) on 17 Dec 2017. Preliminary thermal fit gives D~200m, pV~4%. We have notified the JPL radar group in case this is a good
target for radar observations.

-Candidate object N00c7sk has been posted to the NEOCP and awaits followup.

-A recent paper by Durech et al. (arXiv:1711.05987) uses cryogenic NEOWISE data combined with optical light curves to constrain the sizes and thermal inertias of near-Earth asteroids, allowing them to measure YORP acceleration rates for (161989) Cacus and (tentatively) for (1685) Toro, as well as confirm the previously published YORP rate for (3103) Eger and the measured Yarkovsky acceleration for (2100) Ra-Shalom.

-A recent paper by Marciniak et al. (arXiv:1711.01893) performs detailed thermophysical modeling of 5 large, slow-rotating MBAs using WISE, IRAS, AKARI, lightcurve inversion, and occultations to derive precise sizes and thermal inertias. The authors find that these objects have unusually large inertias for their size, and find sizes that are within 10% of the NEATM-derived values published by the NEOWISE team for 4 objects, and 15% for the last.

[redacted]

[redacted]

Subject: NEOCam: Shape effects on mean radius
Date: Monday, January 4, 2016 at 4:20:22 PM Mountain Standard Time
From: [redacted]
To:
CC:
Attachments: shape_effects_tss.pdf

Dear [redacted]

I've done some [redacted] (b)(5) previous [redacted] point. I attach [redacted] the [redacted] I offer this as a start to the discussion [redacted]

Best,
(b)(3) (10USC 2[redacted]4) (b)(5), (b)(6)

Deletion Page

Requester: Ronald Lee (Arnold & Porter Kay Scholer LLP)
Request #: 18-JPL-F-00247

5 Page(s) is/are being withheld in full and the following marked exemption(s) is/are being claimed.

EXEMPTIONS CLAIMED:

FOIA: 5 U.S.C. § 552

- [ ] b(1)
- [ ] b(2)
- [x] b(3): 10 U.S.C. 2305(g)
- [x] b(4)
- [x] b(5)
- [x] b(6)
- [ ] b(7)(A)
- [ ] b(7)(C)
- [ ] b(7)(D)
- [ ] b(7)(E)
- [ ] b(7)(F)

PRIVACY ACT: 5 U.S.C. § 552a

- [ ] d(5)
- [ ] j(1)
- [ ] j(2)
- [ ] k(1)
- [ ] k(2)
- [ ] k(3)
- [ ] k(4)
- [ ] k(5)
- [ ] k(6)
- [ ] k(7)

Description of Document withheld: Draft report for NEOCam team entitled "shape_effects_tss.pdf."

Subject: Re: NEOCam: Shape effects on mean radius
Date: Saturday, January 9, 2016 at 3:13:19 PM Mountain Standard Time
From: [redacted]
To:
CC:

(b)(3) 10USC [redacted] 4) (b)(5), (b)(6)

Let's do that. If you can [redacted] (in the .det format [redacted], I can run the models.

(b)(3) 10USC 2 [redacted] 4) (b)(5), (b)(6)

On Jan 8, 2016, at 10:01 PM, [redacted] wrote:

(b)(3) 10USC Hi [redacted] everyone,

This is really interesting. I'm curious [redacted] then that would be confirmation we are on the right track.

Also, I'm sending [redacted] with a larger sample size, especially), please chime in.

Have a good weekend,

(b)(3) 10USC [redacted] (b)(5), (b)(6)

On Mon, Jan 4, 2016 at 3:20 PM, [redacted] wrote:

Dear [redacted],

I've done some [redacted] previous [redacted] point. I attach [redacted] I offer this as a start to the discussion [redacted]

Best,

(b)(3) 10USC 2 [redacted] (4) (b)(5), (b)(6)

--

[redacted]

Astronomy & Astrophysics manuscript no. 31479_corr
November 7, 2017

Photometric survey, modelling, and scaling of long-period and low-amplitude asteroids

A. Marciniak[1], P. Bartczak[1], T. Müller[2], J. J. Sanabria[3], V. Alí-Lagoa[2], P. Antonini[4], R. Behrend[5], L. Bernasconi[6], M. Bronikowska[7], M. Butkiewicz - Bąk[1], A. Cikota[8], R. Crippa[9], R. Ditteon[10], G. Dudziński[1], R. Duffard[11], K. Dziadura[1], S. Fauvaud[12], S. Geier[3,13], R. Hirsch[1], J. Horbowicz[1], M. Hren[8], L. Jerosimic[8], K. Kamiński[1], P. Kankiewicz[14], I. Konstanciak[1], P. Korlevic[8], E. Kosturkiewicz[1], V. Kudak[15,16], F. Manzini[9], N. Morales[11], M. Murawiecka[17], W. Ogłoza[18], D. Oszkiewicz[1], F. Pilcher[19], T. Polakis[20], R. Poncy[21], T. Santana-Ros[1], M. Siwak[18], B. Skiff[22], K. Sobkowiak[1], R. Stoss[8], M. Żejmo[23], and K. Żukowski[1]

[1] Astronomical Observatory Institute, Faculty of Physics, A. Mickiewicz University, Słoneczna 36, 60-286 Poznań, Poland. E-mail: am@amu.edu.pl
[2] Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstrasse 1, 85748 Garching, Germany
[3] Instituto de Astrofísica de Canarias, C/ Vía Lactea, s/n, 38205 La Laguna, Tenerife, Spain
[4] Observatoire des Hauts Patys, F-84410 Bédoin, France
[5] Geneva Observatory, CH-1290 Sauverny, Switzerland
[6] Les Engarouines Observatory, F-84570 Mallemort-du-Comtat, France
[7] Institute of Geology, A. Mickiewicz University, Krygowskiego 12, 61-606 Poznań
[8] OAM - Mallorca, Camí de l'Observatori s/n 07144 Costitx Mallorca, Illes Balears, Spain
[9] Stazione Astronomica di Sozzago, I-28060 Sozzago, Italy
[10] Rose-Hulman Institute of Technology, CM 171 5500 Wabash Ave., Terre Haute, IN 47803, USA
[11] Departamento de Sistema Solar, Instituto de Astrofísica de Andalucía (CSIC), Glorieta de la Astronomía s/n, 18008 Granada, Spain
[12] Observatoíre du Bois de Bardon, 16110 Taponnat, France
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ABSTRACT

Context. The available set of spin and shape modelled asteroids is strongly biased against slowly rotating targets and those with low lightcurve amplitudes. This is due to the observing selection effects. As a consequence, the current picture of asteroid spin axis distribution, rotation rates, radiometric properties, or aspects related to the object's internal structure might be affected too.
Aims. To counteract these selection effects, we are running a photometric campaign of a large sample of main belt asteroids omitted in most previous studies. Using least chi-squared fitting we determined synodic rotation periods and verified previous determinations. When a dataset for a given target was sufficiently large and varied, we performed spin and shape modelling with two different methods to compare their performance.
Methods. We used the convex inversion method and the non-convex SAGE algorithm, applied on the same datasets of dense lightcurves. Both methods search for the lowest deviations between observed and modelled lightcurves, though using different approaches. Unlike convex inversion, the SAGE method allows for the existence of valleys and indentations on the shapes based only on lightcurves.
Results. We obtain detailed spin and shape models for the first five targets of our sample: (159) Aemilia, (227) Philosophia, (329) Svea, (478) Tergeste, and (487) Venetia. When compared to stellar occultation chords, our models obtained an absolute size scale and major topographic features of the shape models were also confirmed. When applied to thermophysical modelling, they provided a very good fit to the infrared data and allowed their size, albedo, and thermal inertia to be determined.
Conclusions. Convex and non-convex shape models provide comparable fits to lightcurves. However, some non-convex models fit notably better to stellar occultation chords and to infrared data in sophisticated thermophysical modelling (TPM). In some cases TPM showed strong preference for one of the spin and shape solutions. Also, we confirmed that slowly rotating asteroids tend to have higher-than-average values of thermal inertia, which might be caused by properties of the surface layers underlying the skin depth.

Key words. techniques: photometric – minor planets: asteroids

1. Introduction

Physical parameters of asteroids such as the period of rotation and orientation of the spin axis are related to various processes that these bodies undergo. The rotation of large asteroids probably reflects the primordial spin acquired during the accretion phase in the protoplanetary disc (Johansen & Lacerda 2010), which for smaller objects was later modified by impacts, collisions, and thermal forces, which are strongest for small asteroids (Bottke et al. 2006). Asteroid rotations can reveal both their internal cohesion and the degree of fragmentation (Holsapple 2007). Numerical simulations by Takeda & Ohtsuki (2009) suggest that bodies of a rubble-pile structure usually spin down as a result of impacting events. Also, the long-term evolution under the thermal reradiation force (YORP effect) can both spin up and spin down asteroids (Rubincam 2000). However, so far only the spin-up of the rotation period has been directly detected (e.g. Lowry et al. 2007, 2014; Kaasalainen et al. 2007; Ďurech et al. 2008)

The spatial distribution of asteroid spin axes suggests that the largest bodies generally preserved their primordial, prograde spin, while smaller ones, with diameters less than 30 km, seem to be strongly affected by the YORP effect that pushes these axes towards extreme values of obliquities (Hanuš et al. 2013). The spins of prograde rotators under the YORP effect influence can be captured into spin-orbit resonances, sometimes even forming spin clusters (Slivan 2002; Kryszczyńska et al. 2012).

However, what is now known about these physical properties of asteroids is based on statistically non-representative samples. Most of the well-studied asteroids (those with the spin and shape model) are targets of relatively fast spin and substantial elongation of shape, possibly also coupled with extreme spin axis obliquity, which results in fast and large brightness variations (Fig. 1). The reason for this state are the observing selection effects discussed in our first paper on this subject (Marciniak et al. 2015, hereafter M2015), and summarised in the next section.

Asteroid shape models created by lightcurve inversion methods are naturally most detailed when created basing on rich datasets of dense lightcurves. High-quality lightcurves from at least five apparitions gained over a wide range of aspect and phase angles are a necessary prerequisite to obtain unique spin and shape solutions with main topographic features (usually coming in pairs of two indistinguishable mirror solutions for the pole). The obtained models can be convex representations of real shapes (in the convex inversion method by Kaasalainen & Torppa 2001; Kaasalainen et al. 2001), but can also be non-convex, more closely reproducing real asteroid shapes when supported by auxiliary data (in KOALA and ADAM algorithms, Carry et al. 2012; Viikinkoski et al. 2015), but also based on lightcurves alone (in the SAGE algorithm, Bartczak et al. 2014, Bartczak & Dudziński, MNRAS, accepted).

Even after the Gaia Solar System catalogue is released, which is expected at the beginning of the next decade, the most reliable way to study spins (sidereal periods and spin axis positions) of a number of new bodies of low amplitudes and long periods is the traditional dense photometry performed on a network of small and medium-sized ground-based telescopes. The precise shape modelling technique is, and will most probably remain, the only tool allowing a substantial number of such challenging targets to be studied in detail because Gaia and most of the other sky surveys will deliver only a few tens of sparse datapoints for each observed asteroid, only providing ellipsoidal approximations of the real shapes. However, the number of targets with precise shape models cannot be as large as when modelling on sparse data because of the high demand of observing time, which reaches hundreds of hours for each long-period target (see Table 8 in Appendix A).

Detailed asteroid shape models with concavities are in high demand for precise density determinations (Carry 2012), modelling the thermal YORP and Yarkovsky effects (Vokrouhlický et al. 2015) – including self-heating – and accurate thermophysical modelling (Delbo et al. 2015) from which one can infer their sizes, albedos, surface roughness, and thermal inertia values, allowing further studies of their composition and surface and subsurface properties. Apart from studying asteroid parameters for themselves, such research has other very practical applications. Large asteroids are very good calibration standards for infrared observatories like Herschel, APEX, and ALMA, perfectly filling the gap in the flux levels of stellar and planetary calibration sources (Müller & Lagerros 2002; Müller et al. 2014a). However, their flux changes have to be clearly predictable, and should not vary much over short timescales. Slowly rotating asteroids of low lightcurve amplitudes are best for such applications.

In this work we perform spin and shape modelling using two lightcure inversion methods: the convex inversion method (Kaasalainen & Torppa 2001; Kaasalainen et al. 2001) and the non-convex SAGE algorithm (Bartczak et al. 2014, Bartczak & Dudziński, MNRAS, accepted). Later we validate and at the same time compare the resulting shapes by fitting them to data from other techniques: multi-chord stellar occultations, and all available thermal infrared data. This way our shape models also get absolute size scale, both radiometric and non-radiometric.

The next section discusses the selection effects in asteroid studies, and briefly describes our observing campaign to counteract them. Section 3 describes spin and shape modelling methods, and brings a description of thermophysical modelling and occultation fitting procedures used primarily to scale our models. Section 4 contains the observing campaign intermediate results, another set of targets with corrected period determinations. In Section 5 we present models for five targets of our sample that have enough data for full spin and shape modelling, scale them by thermophysical modelling, and where possible also by occultations. The last section describes the conclusions and planned future work. Appendix A contains observation details and new lightcurves.

2. Selection effects and the observing campaign

2.1. Observing and modelling biases in asteroid studies

Statistical considerations in this section are based on the Minor Planer Center Lightcurve Database (LCDB, Warner et al. 2009, updated 2016 September 5) using a sample of the ~1200 brightest main belt asteroids (those with absolute magnitudes H≤11 mag, Fig. 1),[1] which translates to diameters down to 12-37 km, depending on albedo (after MPC conversion table[2]). The rationale behind such a choice is that in this sample 97% the main belt bodies have rotation period determined and available information on the lightcurve amplitude from at least one apparition. Among the fainter targets (H between 11 and 13 mag) there are many bodies with no information on the rotation parameters, so

[1] The exact number of asteroids with certain H magnitude varies over time, due to updates in magnitude and albedo determinations gathered in LCDB.

[2] `http://www.minorplanetcenter.net/iau/lists/Sizes.html`

one cannot draw firm conclusions on the median period or amplitude. However, the selection effects discussed here are even more profound in the group of these fainter targets (equivalent diameters from 37 to 5 km, Fig. 2).

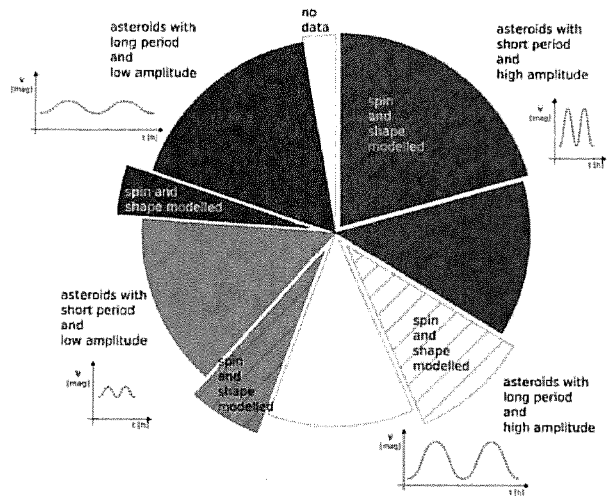

Fig. 1. Current distribution of known periods and maximum amplitudes among the ~1200 brightest main belt asteroids (based on LCDB, Warner et al. 2009, updated 2016 September 5). Division values are P=12 hours and a_{max}=0.25 mag. The amount of spin and shape modelled targets is marked within each group. Asteroids with specific features are over-represented, while others are largely omitted.

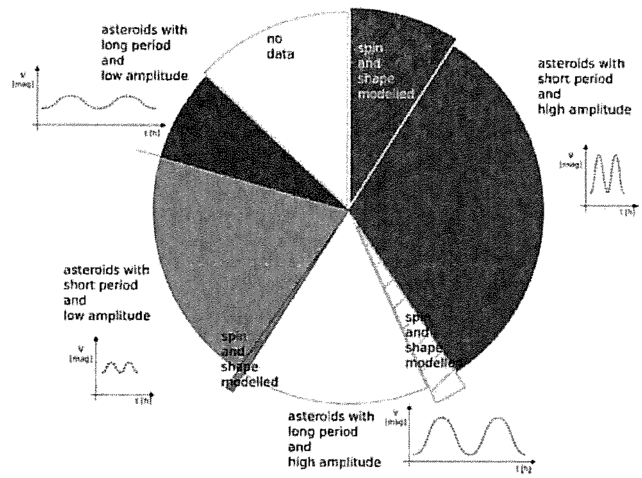

Fig. 2. Same as Fig. 1, but for the ~2270 fainter MB targets, with H between 11 and 13 mag (source: LCDB). There are ~270 large-amplitude targets (from those on the right side of the chart) with available spin and shape model, while only a few low-amplitude targets with a model (left side). Judging from the sample of only those small asteroids that have available shape models, and not taking into consideration the distribution of the amplitudes of all asteroids, can create a false impression that almost all small asteroids are strongly elongated.

Because asteroid modelling using lightcurve inversion requires data from a wide variety of observing geometries, it is far more observationally demanding to gather a sufficient number of dense lightcurves over multiple apparitions for long-period targets (here those with P>12 hours) than for those with quicker rotation. However, not including them in spin and shape studies means omitting around half of the whole asteroid population in question (see the upper left and lower right part of Fig. 1). Moreover, recent results from Kepler-K2 continuous observations spanning weeks show that there are substantially more slow-rotators among faint main belt asteroids and Jupiter Trojans than ground-based studies have shown (Szabó et al. 2016, 2017; Molnár et al. 2017). Observations from the ground are naturally burdened with selection bias, absent when observing for long time spans from space.

Another problematic group of asteroids are those with low amplitudes of their brightness variations (here those with a_{max} ≤0.25 mag). They are almost as numerous as those with large amplitudes (greater than 0.25 mag); even so, they are spin and shape modelled very rarely (see the left part of Fig. 1) because their study requires photometric data of very good accuracy, while data most often used for modelling asteroids nowadays come as a byproduct of large astrometric surveys. As such, these data are characterised by very low photometric accuracy (0.1 - 0.2 mag on average, Hanuš et al. 2011), so the modelling is missing most of the low-amplitude population (Ďurech et al. 2016).

As a result there is a large 'white spot' in the parameter space, where very little is known about large groups of asteroids (upper left part of Fig. 1). We do not know their spin axis distribution, their shapes, or internal structure. Some of them may be tumbling, can be tidally despun by a large companion, or slowed down by the YORP effect. Also, their thermal inertia might be different than those rotating faster, as it seems to increase with the rotation period (Harris & Drube 2016) due to sampling of different depths that have different thermal properties. However, for now only 10% of the asteroids observed in the infrared by IRAS and WISE space observatories have thermal inertia determined. It has been stressed that efforts should be made to carry out sophisticated thermophysical modelling of slowly rotating asteroids. Thermophysical modelling (TPM) techniques work best for objects with reliable shape and spin information. The existing multi-epoch, multi-wavelength thermal measurements can then be used to determine radiometric properties (effective size, geometric albedo, thermal inertia, surface roughness, emissivity) and to study if a given shape and spin solution can explain all measurements simultaneously (see e.g. Müller et al. 2014b).

2.2. Observing campaign

In order to counteract the above-mentioned selection effects, we are conducting an extensive and long-term observing campaign targeting around a hundred bright (H≤11mag) main belt asteroids that display both a long period of rotation (P>12 h) and a low lightcurve amplitude (a_{max} ≤0.25 mag), which are the objects that have been largely omitted in most of the previous spin and shape studies. We coordinate the multi-site campaign with about 20 observing stations placed around the world, from Europe through western US, to Korea and Japan. The detailed description of the campaign can be found in M2015. Table 1 gives the information on the observing sites participating in this project. It also includes chosen sites of the group led by R.

Behrend as we use some of the archival data gathered by this group, so far published only on the Observatoire de Geneve website[3].

We perform unfiltered, or R-filter photometric observations of a given target until we get full rotation coverage and possibly also register notable phase angle effects. After that, the observations within one apparition are folded together in a composite lightcurve (Figs. 26 - 49) for synodic period determination. When the period is found to be in disagreement with the value in the MPC Lightcurve Database (LCDB), the observations concentrate on this target to confirm the new period value. The observations are repeated in each apparition until data of good quality and quantity from at least five well-spaced apparitions are gathered, including those already available in the literature. In the course of the campaign the maximum amplitudes of some targets appeared to be larger than 0.25 mag, while periods of some others were shorter than 12 hours, violating our initial selection criteria, nonetheless they remained on our target list.

Table 8 in Appendix A summarises new observations for 11 targets studied in this paper (6 targets with corrected periods, and 5 with new models), presenting values important for spin and shape studies: mid-date of given lightcurve, sky ecliptic longitude of the target (λ), phase angle (α), observing run duration, photometric error, and the observer's name with the observing site.

The best way to present the trustability of period determinations and the reliability of the obtained spin and shape models is to present the quality and quantity of supporting lightcurves and the model fit. Our data are presented in Appendix A in the form of composite lightcurves. Alongside lightcurves of modelled targets, we present the orientation on the zero phase of the best shape model, generated using the ISAM service[4], described in Marciniak et al. (2012). In Figs. 13, 16, 18, 22, and 24 we also present model example fits to lightcurves.

3. Spin and shape modelling; scaling the models

3.1. Lightcurve inversion methods

The Shaping Asteroids with Genetic Evolution (SAGE) modelling algorithm was developed at the Astronomical Observatory Institute of AMU Poznań (Bartczak et al. 2014, Bartczak & Dudziński, MNRAS, accepted). Thus, we utilise the local cluster with the SAGE code for the spin and shape modelling in parallel with the now classical convex inversion method by Kaasalainen & Torppa (2001); Kaasalainen et al. (2001).

SAGE is a genetic algorithm that mutates the shape models to find the specimens that are best suited to lightcurve data. Although main belt asteroids can only be observed at relatively small phase angles (up to 30°at most), it has been shown that their lightcurves contain signatures of non-convex topographic features, so that these features can be successfully reproduced in the shape models (Bartczak & Dudziński, MNRAS, accepted). When modelling on lightcurves is a priori complemented by auxiliary data like adaptive optics or occultation contours in one multi-data inversion process, such non-concavities gain more support (as in models created using ADAM algorithm, Viikinkoski et al. 2015; Hanuš et al. 2017). However, when SAGE non-convex models based exclusively on lightcurves are a posteriori compared to multi-chord occultations, their topographic features are confirmed, as has been shown in the case of binary asteroid (90) Antiope (Bartczak et al. 2014), but also in simulations and real-case studies performed recently by Bartczak & Dudziński (MNRAS, accepted).

The modelling here was performed independently using the convex inversion and SAGE methods, on the same datasets, taking as a starting value only the synodic period estimates from a set of composite lightcurves. The solutions for the poles and the shapes were searched over the whole possible range. From each method a set of internally consistent spin and shape solutions was obtained, and the uncertainty on the spin parameters was evaluated from the scatter of the best solutions for the pole (taking all the solutions with the best root mean square deviation (RMSD) enlarged by up to 10%). The lightcurves produced by models from both methods fit the data around the noise level without big differences in the overall quality of the fit (measured by RMSD) between the two methods, so it might seem that the models fit the lightcurves in the same way. However, the overall sum of deviations does not reflect the subtle differences of the lightcurve fits between the two methods, like sometimes visible better fitting of the SAGE models to critical features (e.g. deep minima or abrupt dimmings), where non-convex features most clearly manifest themselves. Such features, due to their short duration, usually contain far fewer datapoints than other lightcurve fragments, so their influence on the RMSD value is very small. However during the SAGE optimisation process the biggest weight is given to the worst fitting lightcurves, so in further iterations these fragments have a bigger influence on the shape model and are fitted better. Still, the final (unweighted) RMSD value might be the same, when other lightcurves have a slightly worse fit, and the large number of points in them makes the small change more significant for RMSD. So, using only the RMSD of the fit, we have no means to tell which model best represents the real shape. Here we present one of possible solutions for the shape chosen from a family of very similar shape models; however, without a method to estimate shape uncertainties, it is hard to compare the performance of the two methods.

The shape models from the two methods were often similar to each other, clearly indicating that convex models are the convex hulls of more complex shapes, successfully reproduced by the SAGE algorithm. However, in some cases the shapes looked distinctively different, and only the pole-on projections were similar. The orientation of the two models in pairs of figures like 3 and 4 is the same, so these shape projections can be directly compared. Different positions of the x- and y-axes are caused by their different definitions: in SAGE models the rotation axis is the axis of biggest inertia, and the x-axis of the smallest inertia. In convex models, the z-axis should also correspond to the biggest inertia, but the x-axis is connected with the epoch of the first observation, so its orientation does not correspond to any specific feature of the shape model[5]

3.2. Thermophysical modelling

This radiometric technique consists in the exploitation of thermal data in the mid- to far-infrared and data in the visible. Thermophysical models allow the derivation of size, albedo, and thermal properties for small bodies (see Delbo et al. 2015, and references therein). There are different model implementations

[3] http://obswww.unige.ch/~behrend/page_cou.html

[4] http://isam.astro.amu.edu.pl

[5] There is a different sequence of rotations in the reference frame definitions of the convex and non-convex models, so if both models were to be placed in the plane of sky, the rotation of -270° around the z-axis would be necessary for the SAGE models to match the orientations of the convex models.

Site name	Abbreviation	IAU code	Location	Telescope
Borowiec Observatory (Poland)	Bor.	187	52 N, 17 E	0.4m
Montsec Observatory (Catalonia, Spain)	OAdM	C65	42 N, 01 E	0.8m
Organ Mesa Observatory (NM, USA)	Organ M.	G50	32 N, 107 W	0.35m
Winer Observatory (AZ, USA)	Winer	648	32 N, 111 W	0.70m
Bisei Spaceguard Center (Okayama, Japan)	Bisei	300	35 N, 134 E	0.5m and 1m
Mt. Suhora Astronomical Observatory (Poland)	Suh.		50 N, 20 E	0.25m and 0.60m
Le Bois de Bardon Observatory (France)	Bardon		45 N, 0 E	0.28m
Adiyaman Observatory (Turkey)	Adi.		38 N, 38 E	0.6m
Derenivka Observatory (Ukraine)	Der.	K99	48 N, 22 E	0.4m
JKU Astronomical Observatory, Kielce (Poland)	Kie.	B02	51 N, 21 E	0.35m
Pic du Midi Observatory (France)	Pic.	586	43 N, 0 E	0.6m
Teide Observatory (Tenerife, Spain)	Teide	954	28 N, 16 W	0.8m
Roque de los Muchachos (La Palma, Spain)	ORM	950	29 N, 18 W	1m and 1.2m
Kitt Peak National Observatory (AZ, USA)	KPNO	G82	32 N, 112 W	1m
Lowell Observatory (AZ, USA)	Lowell	688	35 N, 112 W	0.78m
Command Module Observatory, Tempe (AZ, USA)	Tempe	V02	33 N, 112 W	0.32 m
Cerro Tololo Interamerican Observatory (Chile)	CTIO	807	30 S, 71 W	0.6m
La Sagra Observatory (Spain)	La Sagra		38 N, 3 W	0.35m
Piszkesteto Mountain Station (Hungary)	Pisz.	461	48 N, 20 E	1m
Sobaeksan Optical Astronomy Obs. (Korea)	Sobaek	345	37 N, 128 E	0.61m
Flarestar Observatory (Malta)	Flare.	171	36 N, 14 E	0.25m
Astronomy Observatory of Sertao de Itaparica (Brasil)	OASI	Y28	9 S, 39 W	1 m
Observatoire des Engarouines (France)	Engar.	A14	44 N, 5 E	0.21m
Le Crès (France)	Le Cres	177	44 N, 4 E	0.4m
Observatoire des Hauts Patys, Bédoin (France)	Hauts Patys	132	44 N, 5 E	0.30m
OAM - Mallorca (Spain)	OAM	620	40 N, 3 E	0.3m
Stazione Astronomica di Sozzago (Italy)	Sozzago	A12	45 N, 9 E	0.40m

Table 1. Observing sites participating in this project

available, ranging from simple thermal models assuming spherical shapes at opposition without heat conduction into the surface to more sophisticated thermophysical model implementations which take complex shapes and rotational properties into account; at the same time heat conduction, shadowing effects, and self-heating effects are calculated for a given illumination and observing geometry. Here, we are interested in assigning reliable scales to the obtained spin-shape solutions, deriving high-quality geometric albedos, estimating the surface's thermal inertia, and finding indications for the levels of surface roughness. For our analysis, we therefore used a TPM code developed by Lagerros (1996, 1997, 1998) and extensively tested and validated (e.g. by Müller & Lagerros 1998, 2002). The TPM allows the use of all kind of shape solutions (convex and non-convex). It considers the true observing and illumination geometry to calculate the surface temperature distribution for any given epoch. The 1D heat conduction into the surface, shadowing, and self-heating effects are calculated. Good examples for TPM applications to main belt asteroids can be found in Müller et al. (2014a) for Ceres, Pallas,Vesta, and Lutetia, or in Marsset et al. (2017) for Hebe.

We applied the following procedure:

- We use a given convex or non-convex shape-spin solution (see previous section);
- The small-scale surface roughness is approximated by hemi-spherical segment craters covering a smooth surface. We consider different levels of roughness ranging from 0.1 to 0.9 for the rms of the surface slopes;
- The thermal inertia is considered as a free parameter, with values between zero (i.e. no heat conductivity, surface is in instantaneous equilibrium with the insolation) and 2000 $\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$ (bare rock surface with very high heat conductivity);
- The characterisation of the reflected light is given by the H-G (or H-G1-G2) solutions;
- For each observed and calibrated infrared measurement we determine all possible size and albedo solutions for the full range of thermal inertias and roughness levels;
- We search for the lowest χ^2 solution in size, albedo, and thermal inertia/roughness for all thermal IR measurements combined;
- We calculate the 3-σ solutions for the available set of thermal measurements: We consider 1/(N-ν) where N is the number of (thermal) measurements and ν is the number of free parameters, here $\nu = 2$ because we fit for diameter and thermal inertia. We also fit for albedo, but here we make use of another measurement (the H magnitude). We define the n-σ confidence interval by accepting all solutions that have

$$\chi^2 < \chi^2_{min} + n^2, \quad (1)$$

where χ^2 is the actual

$$\chi^2 = \sum \left(\frac{obs - mod}{err} \right)^2; \quad (2)$$

- Solutions are only accepted if the reduced χ^2 values are reasonably close to 1.0. In this case the 'unreduced' χ^2 will have a minimum equal to N-2, and the 3-σ limit for N observations is at N-2 + 3^2 = N - 7;
- The minima for the reduced χ^2 for each shape and spin solution are given in Table 6.

The results of this procedure are the following:

- We find the best radiometric size which corresponds to the size of an equal-volume sphere and can be used to scale the given shape-spin solution;

- We determine the geometric albedo (closely connected to the given H magnitude);
- We estimate the possible range of thermal inertias (higher or lower values would introduce problems when comparing pre- and post-opposition IR data);
- Assuming low roughness gives lower values for the thermal inertia, higher levels of roughness lead to slightly higher thermal inertias. Our IR data are usually not good enough to break the degeneracy between thermal inertia and roughness, but we consider this aspect in the solutions in Table 7;
- In some cases the minimum χ^2 values for the different shape-spin solutions for a given target are very different: in these cases we favour the solution with the best χ^2 fit.

The radiometric technique is not very sensitive to the exact shape, and provides sizes and albedos with around 5% accuracy in the most favourable cases. It is the most productive way of determining sizes and albedos for large samples of asteroid IR measurements (as coming from IRAS, AKARI, WISE surveys), but it also allows spin properties to be constrained and wide ranges of shape-spin solutions to be discarded. The radiometric analysis uses thermal data from different epochs, phase angles, wavelengths, and rotational phases. The resulting radiometric size is therefore closely related to the full 3D body, while occultations are only representative of the 2D cross section of the body.

3.3. Stellar occultation fitting

Stellar occultations by main belt asteroids are being observed by a few active groups (like Noth American[6], European[7], or East Asian observers[8]), and published in the Planetary Data System[9] (PDS, see Dunham et al. 2016), providing great complementary data for asteroid physical studies. Occultation timing measurements of such events enable scaling of the otherwise scale-free shape models, and also confirm their major and intermediate-size topographic features. Very often they can also break the mirror-pole symmetry intrinsic to the lightcurve inversion models.

When the occultation observation is successful and at least three well-spaced chords are obtained with good accuracy, it is possible to overlay the occultation shadow chords and the photometric asteroid model (as in e.g. Timerson et al. 2009; Ďurech et al. 2011) with relatively small uncertainty regarding the exact position of the model contour.

Of the five targets modelled here, these multichord events were available for two of them and it allowed us to independently scale, compare, and verify their spin and shape models. The translation of the timings from PDS to chords on the Earth fundamental plane (ξ, η) has been done using the method described in Ďurech et al. (2011). Both convex and non-convex 3D shape models obtained here have been translated into scalable 2D contours, according to sky-plane shape orientation for a given moment, and then overlaid on the timing chords so as to minimise the overall rms deviations between the contour and the chords, taking into account the timing uncertainties. As a result, the models were scaled in kilometres with good accuracy; the maximum size of a given shape model was later translated into the diameter of the equivalent volume sphere. Results are described and plotted in Section 4. The list of all the observers of asteroid occultations that were utilised in this work can be found in Appendix B (Dunham et al. 2016).

4. Corrected period determinations

The first and rather unexpected result of our observing campaign was that as much as 25% of the numerous bright main belt asteroids with both long period and small amplitude had a previously incorrectly determined synodic period of rotation (M2015). Their period quality codes in LCDB were 3, 2+, and 2. Although periods with code 2 and lower should be considered unreliable; usually, all period values with codes higher than 1+ are taken into account in the majority of spin state studies of asteroids. The wrong period determination in the cases that we studied was due to previous incomplete or noisy lightcurve coverage, which often led the alias period to be incorrectly identified as the true rotation period.

As an example, in Figs. 26 - 30 we present a few more cases where we found rotation periods substantially different from the values accepted in LCDB (Warner et al. 2009). Below, we briefly review previous works on these targets and describe our findings. Their previous and new period values are presented in Table 2. Together with targets for which we already had corrected period values (M2015, and Marciniak et al. 2016), their overall number (16) compared to the number of our targets for which we found secure period determinations (65) confirms our previous findings that around a quarter of bright long-period asteroids with low amplitudes had incorrectly determined rotation periods. More precisely, out of 16 targets with incorrect periods, four targets had period quality code 3, two had code 2+, and ten had code 2. So if only the reliable periods (code 3 and 2+) were considered, the percentage of incorrect values in the group of bright long-period, low-amplitude targets would be around 10%.

4.1. (551) Ortrud

The first report on lightcurve and period of (551) Ortrud was made by Robinson (2002), who determined a 13.05 h period based on an asymmetric, bimodal lightcurve from the year 2001. Although three consecutive works on this target, Behrend et al. (www) in 2003 and 2006, and Buchheim (2007) in 2006 reported a different period (17.59, 17.401, and 17.416 hours, respectively), the adopted value in LCDB remained unchanged due to the low quality code assigned to these determinations.

During our observations, we found that only the period of 17.420 ± 0.001 hours can fit the data we gathered in 2016 (Fig. 26), confirming the findings from the three latter works. So it turned out that the correct period has already been identified, but our data put it on firmer ground. The amplitude was at the level of 0.19 ± 0.01 mag. The lightcurve, as in each observed apparition, is characterised by narrow minima and wide complex maxima.

4.2. (581) Tauntonia

Previously observed by group led by R. Behrend in 2005 and 2006, Tauntonia displayed very low amplitude lightcurves that seemed to fit a period of around 16.5 - 16.2 hours (Behrend et al., www). Stephens (2010) found instead that the period was 24.90

[6] http://www.asteroidoccultation.com/observationResults/
[7] http://www.euraster.net/results/index.html
[8] http://sendaiuchukan.jp/data/occult-e/occult-e.html
[9] http://sbn.psi.edu/pds/resource/occ.html

asteroid name	amplitude (LCDB and *this work*) [mag]	Period (LCDB) [h]	Period quality code	Period (this work) [h]
Targets with new periods:				
(551) Ortrud	0.14 - *0.19*	13.05	2	**17.416** ± 0.001
(581) Tauntonia	0.07 - 0.20	16.54	2	**24.987** ± 0.007
(830) Petropolitana	0.15 - *0.42*	39.0	2	**169.52** ± 0.06
(923) Herluga	0.16 - *0.28*	19.746	2	**29.71** ± 0.04
(932) Hooveria	0.20 - *0.24*	39.1	2+	**78.44** ± 0.01
(995) Sternberga	0.06 - 0.20	14.612	2+	**11.198** ± 0.002
Targets with models:				
(159) Aemilia	0.17 - 0.26	24.476	3	24.486 ± 0.002
(227) Philosophia	0.06 - 0.20	52.98	2 A	**26.468** ± 0.003
(329) Svea	0.09 - *0.24*	22.778	2+	22.777 ± 0.005
(478) Tergeste	0.15 - 0.30	16.104	2+	16.105 ± 0.002
(487) Venetia	0.03 - 0.30	13.34	3	13.342 ± 0.002

Table 2. Synodic periods and amplitude values found within this project compared to literature data gathered previously in LCDB. Boldface indicates period determinations substantially differing from previously accepted values.

hours, based on an asymmetric 0.20 mag amplitude lightcurve from the year 2010.

Our data from 2016 can be best folded with period 24.987 ± 0.007 hours, creating an unusual though consistent composite lightcurve (Fig. 27), and 0.18 ± 0.02 mag amplitude, confirming the determination by Stephens (2010).

4.3. (830) Petropolitana

The only lightcurve observations of Petropolitana were reported by Behrend et al. (www), with a period estimated to 39.0 hours, based only on three separate fragments. In Hanuš et al. (2016), there is a model of this target based exclusively on sparse data from astrometric sky surveys, where the sidereal period is 37.347 hours, found by scanning a standard period span of up to 100 hours.

Our observations suggest a much longer period: 169.52 ± 0.06 hours, based on calibrated data with nightly zero point adjustments (Fig. 28). The lightcurve behaviour is bimodal with a large amplitude (0.42 ± 0.02 mag). So this is a very long-period target, but not low-amplitude.

4.4. (923) Herluga

The only previous work on the lightcurve of (923) Herluga was published by Brinsfield (2009). The period determined at that time, 19.746 h, was based on an imperfect composite lightcurve with some clearly misfitting fragments.

Our observations of this target did not allow us to find a satisfactory fit to any period until 2016, when we gathered 11 long lightcurve fragments. The only period that fits the new data (and data from all the previous observations) is 29.71 ± 0.04 hours, which applied to the data from the year 2016 reveals a complex, trimodal lightcurve where one of the minima is deeper than the others (Fig. 29). The amplitude was unusually large for this target: 0.28 ± 0.02 mag.

4.5. (932) Hooveria

The first period determinations for Hooveria, 29.947 or 30.370 hours, were made by Sada (2004) from a bimodal folded lightcurve behaviour. Another set of data was obtained by Warner et al. (2010) and a period of 39.15 hours was found, producing a monomodal lightcurve of rather large amplitude for this type (0.22 mag). In the same work, Warner et al. (2010) reanalysed the data obtained by Sada (2004) and was also able to fit them with a 39.15-hour period, now making it monomodal.

Our extensive observations of Hooveria in late 2016 and careful nightly zero point adjustments using CMC15, APASS, and GAIA catalogue stars have shown that the rotation period of Hooveria must be twice as long, being 78.44 ± 0.01 hours and producing a bimodal lightcurve with clearly asymmetric extrema and 0.24 ± 0.01 mag amplitude (Fig. 30). Fitting these data with a 39-hour period would require large shifts in reduced magnitudes of steps bigger than 0.05 mag, much larger than the absolutisation errors.

4.6. (995) Sternberga

All of the previous reports on the period of (995) Sternberga claimed different values: Barucci et al. (1992) give 16.406 hours; Behrend et al. (www) estimated P > 12 h; Stephens (2005) found 15.26 h, later corrected to 14.612 h in Stephens (2013) based on new data of larger amplitude.

Our analysis of this target since the beginning suggests that none of the previous values can be confirmed, and instead the period is either 22.404 hours or 11.202 hours (Marciniak et al. 2014). Finally, data from the apparition in 2016 confirmed the lower value providing a good fit to 11.198 ± 0.002 hours; this period was unambiguously found in spite of a very small amplitude of 0.06 ± 0.01 mag (Fig. 31). Also, it fits all the previously obtained data.

In summary, the substantial number of periods that needed a revision was found among the brightest main belt targets ($H \leq 11$) available to most small telescopes. Among the fainter targets these effects can be expected to an even greater extent, due to more noise in the photometric data. So one has to be careful when interpreting, for example a frequency-diameter plot, especially in the regions where fainter targets reside (diameters less than $\sim$ 30 km). Many such targets might have incorrect period values, but a huge number of them are simply not present in the plot because their periods are unknown. Those that are present in the small diameter range of the frequency–diameter plot are strongly influenced by observing biases, favouring large amplitudes and short periods.

From our campaign, since the beginning of the project in 2013, we have gathered around 8000 hours of photometric data, resulting in a few tens of full composite lightcurves of our long-period, low-amplitude targets each year. This dataset enables spin and shape modelling of the first representatives of our sample.

5. Individual models

In the following we provide the description of previous works on given target and the new data obtained within this work, presented as composite lightcurves in Figures 32 - 49 in Appendix A. Next we describe the modelling process and the results of the spin and shape solutions presented in Table 3 and pairs of figures (see Figs. 3 and 4). Table 3 gives the spin solutions from both methods with uncertainty and RMSD (root mean square deviation) values. The first column gives the sidereal period value, the next four columns give two pairs of solutions for the north pole of the spin axis (J2000 ecliptic coordinates), all with uncertainty values. In the fifth column there is the observing span in years, number of apparitions (N_{app}), and individual lightcurves (N_{lc}) used to create the models. The last column provides the code of the modelling method. Tables 4 and 5 give the values for the diameters from the occultation fitting, and Table 7 the diameters from thermophysical modelling, both techniques described in the following sections. Additionally, Table 7 gives the best fitting albedo and thermal inertia values. For reference, the effective diameters from IRAS (Tedesco et al. 2004), AKARI (Usui et al. 2011), and WISE (Mainzer et al. 2011; Masiero et al. 2011) surveys are given.

A model example fit to the lightcurves is presented in Fig. 13, 16, and others. Additionally, to visualise what combination of aspect and shape can produce the given lightcurves, next to the composite lightcurves in Appendix A we present shape models oriented at zero epoch using the ISAM service[10]. On the web page these plots can be set in motion, together with the rotating shape model.

5.1. (159) Aemilia

Lightcurves of (159) Aemilia have been previously obtained by Harris & Young (1989), Behrend et al. (www), Ditteon & Hawkins (2007), and Pilcher (2013). Initially there was controversy over whether the rotation period is close to 16 or 24 hours; this issue was resolved by Pilcher (2013) based on multiple coverage from the year 2012 folded with a period of 24.476 hours. The lightcurve amplitudes varied from 0.17 to 0.26 mag.

We observed Aemilia in two other apparitions, in 2014 and 2015. Additionally, we present here unpublished lightcurves from 2005 obtained by the group led by Raoul Behrend and based on incomplete coverage. The morphology of the new lightcurves was similar to previously observed ones; there were characteristic "shelves" after the maxima, one of which had a tendency to evolve to a third maximum when observed at a larger phase angle (Figs. 32 - 34 in Appendix A). The synodic periods of the composite lightcurves were around 24.49 hours, with amplitudes from 0.24 mag to 0.18 mag.

The dataset for the lightcurve inversions consisted of 45 individual lightcurve fragments from six apparitions (1981, 2005, 2006, 2012-2013, 2014, and 2015), well spread over the asteroid orbit and a range of phase angles (see Table 8). We did not use the short and noisy fragment from 2008; all the other available data were used in the modelling process. The dataset consisted of around 200 hours of dense lightcurve observations.

[10] http://isam.astro.amu.edu.pl

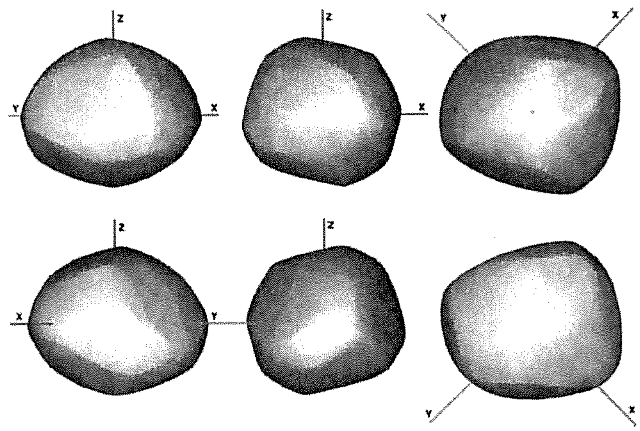

Fig. 3. Convex shape model of (159) Aemilia from the lightcurve inversion method shown in six projections. The z-axis is the axis of rotation. Compare with Fig.4.

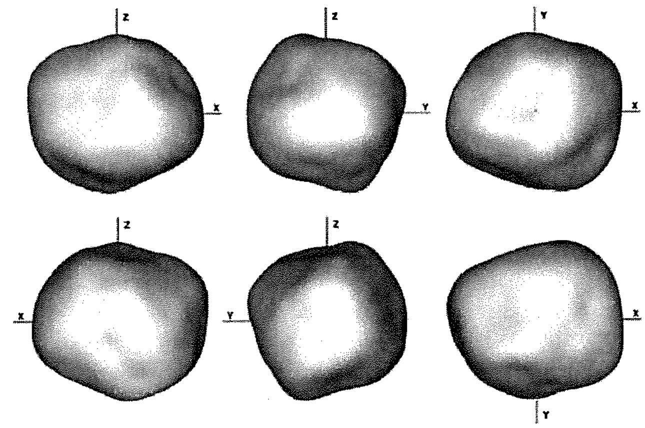

Fig. 4. Non-convex shape model of (159) Aemilia from the SAGE algorithm shown in six projections. The z-axis is the axis of rotation, while the x-axis is the longest axis of the shape model.

In the convex inversion, the spherical harmonics expansion and convexity regularisation weight had to be increased in order to produce realistic physical shape models (Fig. 3). The sidereal period value and both solutions for the spin axis (Table 3) clearly stood out in the parameter space in terms of lowest RMSD (0.014 mag). The example fit to the lightcurves is shown in Fig. 13. The last lightcurve from the apparition in 2014, and the first one from 2015, both obtained at large phase angles, had the worst fit to the model lightcurves. All the resulting shape solutions were roughly similar to each other. Some shapes resembled a deltoid, while others were more ellipsoidal; there were small differences in the vertical dimensions. Here we present only one of the possible shapes for pole 1, which has been the standard practice in presenting lightcurve inversion solutions.

The non-convex model obtained with the SAGE algorithm fits the lightcurves similarly well (RMSD=0.014 mag, Fig. 13) and similar spin solutions were found (Table 3), but the shape is more compact, with slight indentations and some large bulges (Fig. 4). The genetic evolution runs all led to the final shapes that were very similar to each other, and the only differences were in the depth of the largest 'basins', which were still present

Sidereal period [hours]	Pole 1 λ_p	Pole 1 β_p	Pole 2 λ_p	Pole 2 β_p	RMSD [mag]	Observing span (years)	N_{app}	N_{lc}	Method
(159) Aemilia									
24.4787	139°	+68°	348°	+59°	0.014	1981–2015	6	45	convex LI
±0.0001	±18°	±8°	±18°	±6°					
24.4787	139°	+66°	349°	+63°	0.014	"	"	"	SAGE
±0.0001	±7°	±5°	±7°	±6°					
(227) Philosophia									
26.4614	95°	+19°	272°	−1°	0.011	2006–2016	5	97	convex LI
±0.0001	±5°	±4°	±6°	±2°					
26.4612	97°	+16°	271°	0°	0.009	"	"	"	SAGE
±0.0003	±5°	±5°	±5°	±5°					
(329) Svea									
22.7670	33°	+51°	-	-	0.010	1986–2016	6	60	convex LI
±0.0001	±15°	±10°	-	-					
22.7671	**21°**	**+47°**	-	-	0.011	"	"	"	SAGE
±0.0002	±7°	±5°	-	-					
(478) Tergeste									
16.10308	2°	−42°	216°	−56°	0.011	1980–2016	6	48	convex LI
±0.00003	±2°	±3°	±6°	±4°					
16.10312	4°	−43°	**218°**	**-56°**	0.011	"	"	"	SAGE
±0.00003	±6°	±5°	±9°	±7°					
(487) Venetia									
13.34133	78°	+3°	252°	+3°	0.012	1984–2015	8	34	convex LI
±0.00001	±7°	±10°	±8°	±12°					
13.34133	70°	+8°	**255°**	**+8°**	0.011	"	"	"	SAGE
±0.00002	±6°	±11°	±5°	±10°					

Table 3. Parameters of the spin models of the five targets studied here, and the uncertainty values. Column 1 gives the sidereal period of rotation; Cols. 2 -5 give two sets of pole J2000.0 longitude and latitude; Col. 6 gives the rms deviations of the model lightcurves from the data; Cols. 7 - 9 give the photometric dataset parameters (observing span, number of apparitions, and individual lightcurve fragments). The last column contains the name of the lightcurve inversion (LI) method. The preferred pole solutions are shown in bold. The second pole solution of (329) Svea, though possible in the lightcurve inversion, was clearly rejected by occultation fitting.

on each final shape. The final solution had spin axis parameters close to the average of all the obtained solutions and had the lowest RMSD.

	Pole 1	Pole 2
CONVEX	130 ± 7 km	130 ± 8 km
SAGE	135 ± 7 km	138 ± 7 km

Table 4. Equivalent volume sphere diameters of (159) Aemilia models fitted to the occultation from 2 May 2009. Compare with radiometric diameter from TPM in Table 7.

The fitting to all four solutions (two mirror poles from the convex inversion and two from the SAGE algorithm) to the four-chord occultation from 2 May 2009 (Dunham et al. 2016) does not provide a preferred solution for the pole or shape, but allows us to scale the model (see Fig. 14). The size of both convex and non-convex models fitted to this occultation yields equivalent volume sphere diameters from 130 to 138 km; the SAGE solutions are a few kilometres larger than the convex models (see Table 4). In Table 7, we present the radiometric size for the model solution that best fits in thermophysical modelling, i.e. 137 km, in very good agreement with the size from occultations.

The application of inversion models of (159) Aemilia in thermophysical modelling is a rare example of a remarkably good fit with no trend in the O-C plots (see Figs. 15). These O-C plots show nicely if a given model solution (size, shape, thermal properties) can explain all the thermal measurements simultaneously. Ratios close to 1.0 (solid line) indicate an excellent match between observation and the corresponding model prediction; ratios in the range 0.9 and 1.1 (dashed lines) reflect typical calibration uncertainties of thermal measurements. As a rule of thumb, a 10% flux error roughly translates into a 5% error in the object's radiometric size solution. Finding many data points outside the +/-10% lines usually indicates that the shape/spin solution has some problems. Therefore, systematic offsets in the O-C plots indicate a problem with the radiometric size solution. Strong trends in the Obs/TPM ratio with wavelength point towards problems with the thermal surface properties (thermal inertia and roughness), an asymmetry in the pre- and post-opposition ratios are connected to an incorrect thermal inertia, while outliers in the rotational-phase plot point to shape-related issues. We used H=8.100 mag and G=0.09, after Pravec et al. (2012), and infrared data from IRAS (6 x 4 band detections), AKARI (5 datapoints), and WISE W3/W4 bands (20 datapoints). Both convex and non-convex models with both pole solutions fit the data similarly well, and substantially better than a spherical model (see Table 6).

The first model solution from the SAGE method (λ = 139°, β = 66°) seems to be the overall best solution (the reduced χ^2 of 0.44) and intermediate level of surface roughness, optimum thermal inertia around 50 SI units (higher for higher roughness, lower for lower roughness), effective size of around 137.0 km (around 10 km larger than in previous determinations), and geometric V-band albedo of 0.054. Uncertainty values can be found in Table 7. The radiometric size is in agreement with lower values for the size from occultation fitting, but is still slightly higher than in all previous determinations that used a spherical model for the shape, also partly due to lower albedo than in previous works (see Table 7).

5.2. (227) Philosophia

(227) Philosophia has been observed by many authors, e.g. Bembrick et al. (2006), Ditteon & Hawkins (2007), Behrend et al. (www), Alkema (2013), Pilcher & Alkema (2014a,b), but the controversy regarding its rotation period remains (see our discussion on this target in M2015). In our previous work we considered a period of 26.46 hours as the most probable, based on our monomodal lightcurve from the apparition on the verge of 2013 and 2014. Still, the currently accepted value in LCDB is twice as long, 52.98 hours; however, it is annotated as not fully certain and ambiguous (code 2, and label A). The reported amplitudes ranged from 0.06 to 0.20 mag, but these values can be influenced by incorrect periods used for folding the lightcurves.

During the observing campaign within this work, we obtained extensive datasets from two more apparitions of Philosophia, in 2015 and 2016, in addition to the one from 2013-2014. In both of them a clearly bimodal behaviour over the shorter period timescale has been recorded, which resolves the problem of uncertain period, confirming our value of 26.46 hours (see Figs. 36 and 37 in Appendix A). This period fits all the available data from previous apparitions. In additional, we present here the data from apparition in 2006 from Behrend et al. (www) and Ditteon & Hawkins (2007) folded together (Fig. 37). Overall, the behaviour of the lightcurve variations changes from monomodal to bimodal with minima of unequal depth, and other irregularities. Curiously, monomodal lightcurves of this target do not display smaller amplitudes than bimodal ones, contrary to what is usually the case; instead, the amplitude remains on a stable level of around 0.15 mag in all apparitions.

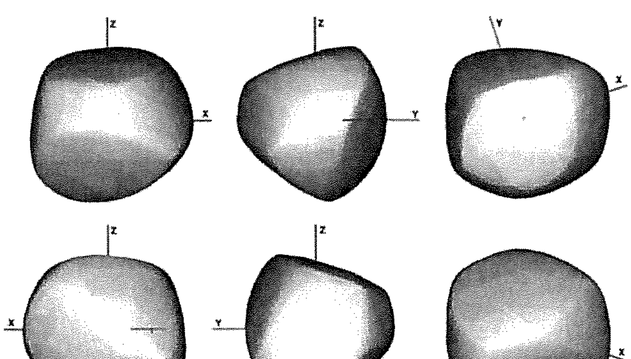

Fig. 5. Convex shape model of (227) Philosophia from the lightcurve inversion method shown in six projections

Unfortunately, the data from the years 2004 and 2005 were not available. For the modelling, we used all the other data from five distinct apparitions (2006, 2012-2013, 2013-2014, 2015, and 2016); there are as many as 97 separate lightcurve fragments, covering a total of around 500 hours. The modelling with the convex inversion method clearly pointed to two strong solutions for the spin axis, which appeared to have low inclination to the ecliptic (Table 3), as was expected from the lightcurve morphology changes. The shape model is quite atypical, with a triangular appearance when viewed from the equator (Fig. 5). This shape actually caused the most problems in the convex inversion as almost all the resulting shapes had an axis of greatest inertia tensor not coincident with the spin axis, regardless of the starting parameters. We present here two solutions where the difference between the rotation axis and the axis of greatest inertia were smallest. The fit to the lightcurves is satisfactory (RMSD = 0.011 mag, Fig. 16) with the exception of the first two lightcurves from the year 2015.

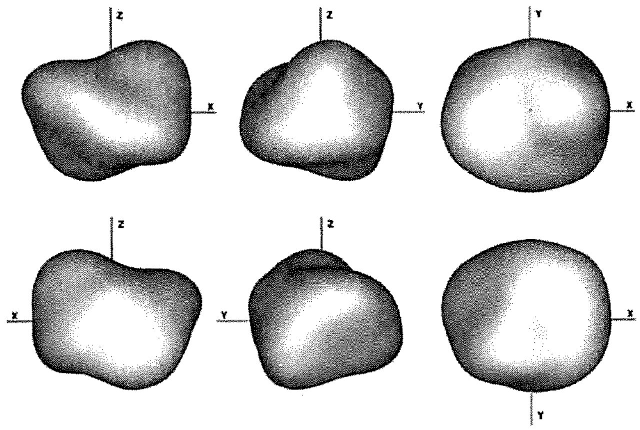

Fig. 6. Non-convex shape model of (227) Philosophia from the SAGE algorithm shown in six projections

The SAGE algorithm also had problems with modelling this target. Some evolutionary paths were stuck in a blind track and finding a unique solution took much more CPU time than usual (one week compared to two days on the cluster consisting of ten 6-core 3GHz AMD processors and 2 GB RAM). Finally, two sets of solutions for the pole and shape were found (Table 3, Fig. 6); however, when starting the evolution around the expected mirror solution, the process often ended up near the other pole. Most probably, the mirror solution had the incorrect inertia tensor, thus was often rejected by the algorithm. Still, as the results from the convex inversion suggest, both pole solutions can fit the data on a similar level, so we consider the mirror pole solution equally possible. Here, the two above-mentioned lightcurves also fit worse than all the other fragments, and the overall RMSD value is 0.009 mag. The non-convex shape model of Philosophia is even more specific: one lobe is substantially larger than the other, and there are many strongly non-convex features. However, its pole-on outline largely coincides with the corresponding solution from the convex inversion.

In thermophysical modelling, Philosophia turned out to be the worst constrained case of the five targets studied here. Actually, the convex and SAGE models fit to thermal data was only slightly better than the corresponding spherical shape solution with the same spin parameters, indicating that inversion shape solutions are not yet perfect. We used an H value equal to 9.1 mag and a G value equal to 0.15,[11] and thermal data from

[11] after: https://mp3c.oca.eu

IRAS (16 measurements), AKARI (6), and WISE W3/W4 (17). It seems that high-roughness solutions are favoured (Table 6).

The overall best fit in TPM is found for the first convex solution (λ=95°, β=+19°) with a χ^2 of 1.2. The model fits best for a high level of surface roughness, optimum thermal inertia around 100-150 SI units, effective size in the range of 91-105 km (in agreement with previous determinations), and geometric V-band albedo of 0.038-0.044 (Table 7).

One explanation for this behaviour of the models is that the data are not well balanced with respect to phase angles: there is only one data point at a negative phase angle (i.e. before the opposition). There is no clear trend with wavelength or with rotational phase (Fig. 17), but the data quality is not optimal. Also, the low pole of Philosophia might be the source of the problems; in pole-on geometries for many months one of the hemispheres is heated constantly and that heat can penetrate to much deeper layers which have different thermal properties from the surface regolith. For a change, in geometries closer to equator-on, there are normal diurnal variations in the heat wave. Unfortunately, there is no multi-chord stellar occultation by Philosophia for comparison with the radiometric parameters or topographic features of the models obtained here.

5.3. (329) Svea

Svea is one of the first targets from our survey for which we found substantially different period than that accepted in LCDB (see M2015). Observed previously by Weidenschilling et al. (1990), Pray (2006), Menke et al. (2008), and Behrend et al. (www), Svea displayed the ambiguous periods 15.201 hours or 22.778 hours. In M2015, we confirmed a 22.78-hour period based on data from the year 2013, and since that time we have gathered data from two more apparitions, in 2014, and 2016. The lightcurve morphology of Svea is interesting and strongly variable; from clearly trimodal, through almost flat, to the more usual bimodal lightcurve of larger amplitude (see Figs. 39 and 40). Available data from all apparitions fit the 22.78-hour period, and display amplitudes from 0.09 to 0.24 mag.

For the modelling, we were able to use our data from three apparitions coupled with data from 2005 provided by Menke et al. (2008), from 2006 by Behrend et al. (www), and only one of the four lightcurves from 1986 saved as a composit by Weidenschillig (1990). In total, there are 60 lightcurve fragments from six apparitions.

In the modelling by the convex lightcurve inversion method, two resulting pole solutions were closer together than in the usual miror-pole symmetry, differing by only 124° in ecliptic longitude, with a similar values for pole latitude (Table 3). The shape model vertical dimensions were not well constrained, but the other features were stable (Fig. 7), providing a good fit to lightcurves at 0.010 mag level for both pole solutions (Fig. 18).

The SAGE spin solutions were 145° apart (Table 3) and the corresponding shape models showed some large indentations near the equator and one of the poles (Fig. 8). The fit to the lightcurves shows 0.011 RMSD and is very similar to the fit by the convex models (Fig. 18).

In the case of Svea, there are two very good multi-chord occultations available (Dunham et al. 2016) observed from Japan in 2011 (7 chords), and from Florida, USA, in 2013 (6 chords), giving a rare opportunity to test the shape models down to the medium-scale details. Additionally, in these events, a few negative results were recorded, allowing for better size constraints. Appendix B lists occultation observers and site names. Fitting our models of Svea to these occultations gave remarkably good results, clearly allowing us to reject one of the mirror pole solutions (pole 2, shown in Fig. 20), and confirming the first pole solution with indentations and other shape features of the SAGE model (Fig. 19). The convex model for pole 1 also fits both occultations well, but the non-convex model fits markedly better. This way the model gets unique validation and it shows that major topographic features present in the non-convex models made with SAGE are confirmed when auxiliary data are available. The fitting to two occultation events was done independently, but the results are internally consistent. Obtained size estimates range from 70 to 74 km for the effective diameter (see Table 5), which agrees with the radiometric size (77.5 km in Table 7) within the error bars.

Curiously, in thermophysical modelling it is the convex model (but also pole 1) that is slightly preferred. However, all

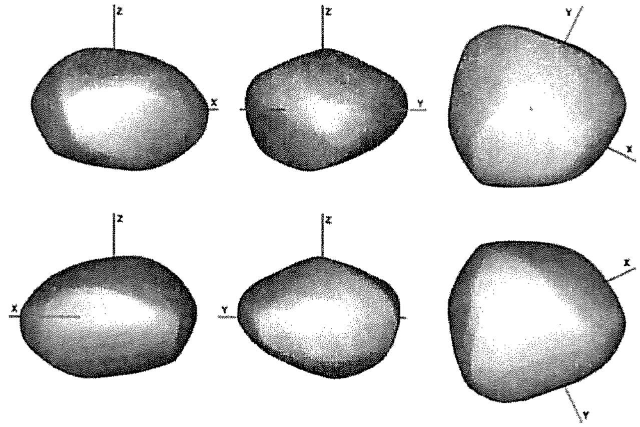

Fig. 7. Convex shape model of (329) Svea from the lightcurve inversion method shown in six projections

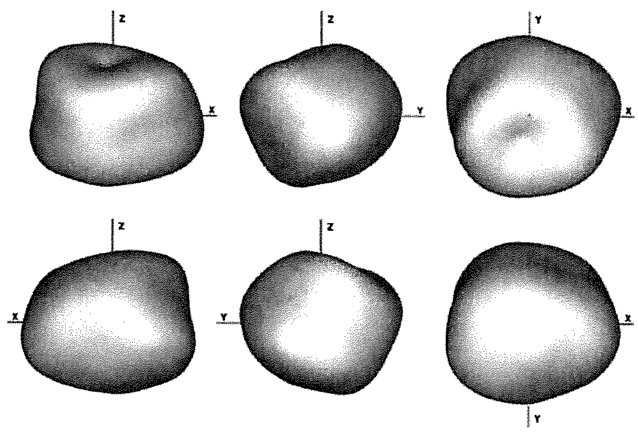

Fig. 8. Non-convex shape model of (329) Svea from the SAGE algorithm shown in six projections

	2011	2013
CONVEX	72 ± 4 km	74 ± 5 km
SAGE	70 ± 4 km	72 ± 3 km

Table 5. Equivalent volume sphere diameters of the (329) Svea models pole 1, fitted to two occultations: from 28 December 2011 and 7 March 2013. Compare with radiometric diameter from TPM in Table 7.

the inversion solutions clearly fit better to the thermal data than does the corresponding spherical shape solution with the same spin properties. In TPM the preference of pole 1 over pole 2 is stronger than the preference of the best fitting convex model over the non-convex solution; however, all the fits are at an acceptable level (see Table 6). Overall, the thermal data seem to point towards a spin axis close to $\lambda = 33^{\circ}$ and $\beta = +51^{\circ}$. The convex inversion solution for this pole provides an excellent fit to all thermal data (reduced χ^2 below 1.0) with an intermediate level of surface roughness, optimum thermal inertia around 75 SI units, effective size of around 77.5 km (confirming the value from occultations), and geometric V-band albedo of 0.055. The O-C plots for the best solution are shown in Fig. 21, and the uncertainties on the derived values are given in Table 7. The infrared data that were used came from IRAS (20 measurements), AKARI (9), Wise W3/W4 (28), and MSX (8), and the adopted absolute magnitude and slope were 9.34 and 0.04, respectively.

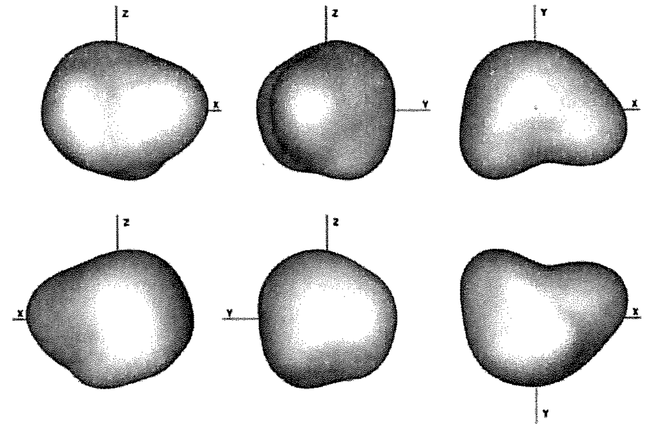

Fig. 10. Non-convex shape model of (478) Tergeste from the SAGE algorithm shown in six projections

5.4. (478) Tergeste

Asteroid (478) Tergeste was observed previously for lightcurves in only two apparitions, by Harris & Young (1989) and Behrend et al. (www). In the latter, it displayed a 0.22 mag amplitude lightcurve of 16.104 hours period. We observed it in our project since 2013 through four consecutive apparitions, confirming the period around 16.104 hours and registering lightcurves of 0.15 up to 0.30 mag amplitudes. Those with larger amplitudes showed sharp minima and wide asymmetric maxima, while others were smoother and more regular (see Figs. 41 to 45).

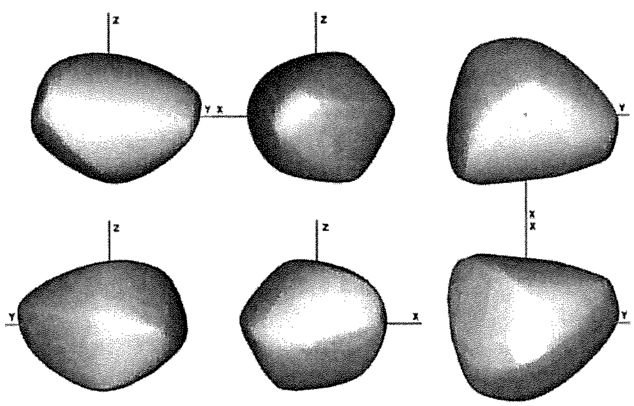

Fig. 9. Convex shape model of (478) Tergeste from the lightcurve inversion method shown in six projections

For the modelling, we used a dataset consisting of 48 lightcurves from six apparitions (in 1980, 2005, 2013, 2014, 2015, and 2016). In the convex inversion, a convexity regularisation weight had to be slightly increased in order to make some shape models physical (rotating around the axis of greatest inertia tensor). There are two narrow solutions for the pole in the parameter space (Table 3), and the shape models are trapezoidal (Fig. 9). The fit to the lightcurves is on a 0.011 magnitude level (see Fig. 22).

The non-convex SAGE models confirm these pole solutions within the small error bars (Table 3), but here the shapes are more complex, e.g. with a large valley visible from the pole-on view (Fig. 10) in a place where the convex models showed a straight, planar area. Both spin solution models provide a similar fit to lightcurves (0.011 mag) 22. However, the Tergeste model fit (see Section 3.1) shows the tendency of non-convex models to better fit deep and sharp lightcurve minima (see middle plot of Fig. 22). These local features, with only a few datapoints, cannot notably influence the overall RMSD value, but they clearly need some shadowing to be correctly reproduced (see the shape model projection in Fig. 42).

There is no multi-chord stellar occultation to discriminate between two equally possible pole solutions from lightcurve inversion for Tergeste, but surprisingly the thermophysical modelling shows a strong preference for one of the spin and shape solutions (Table 6). non-convex model 2 (at $\lambda = 218^{\circ}$, $\beta = -56^{\circ}$) provides a very good fit to the thermal data (χ^2 around 1.0), while the other inversion spin and shape solutions give fits that are at least 1.5 times worse (at the edge of being acceptable), and the spherical model gives a fit that is 2.5 times worse. The preferred solution provides a very good fit to the thermal data (28 datapoints from IRAS, 8 from AKARI, and 18 from WISE W3/W4 bands, adopting H=7.96 and G=0.15; Fig. 23) with an intermediate level of surface roughness, optimum thermal inertia around 75 SI units, effective size around 87.3 km, and geometric V-band albedo of 0.15 (the last two values are closest to AKARI determinations, see Table 7).

5.5. (487) Venetia

Observed previously in as many as six apparitions, (487) Venetia displayed lightcurves of varying shape and amplitude. However, some of the observations only partially covered its 13.34-hour lightcurve (Weidenschilling et al. 1990; Shevchenko et al. 1992; Neely 1992; Schober et al. 1994; Ferrero 2014, Behrend et al., www).

Erikson et al. (2000), and Tungalag et al. (2002) published spin and shape solution for Venetia with similar spin axis coordinates, but a notable difference in sidereal period:
Erikson et al. (2000) $\lambda_p = 268^{\circ}$, $\beta_p = -24^{\circ}$, $P = 13.34153$ h
Tungalag et al. (2002) $\lambda_p = 259^{\circ}$, $\beta_p = -30^{\circ}$, $P = 13.33170$ h.
We observed Venetia over three consecutive apparitions, registering full lightcurves that were often almost featureless, while in other apparitions it showed a substantial amplitude of 0.23

mag (Figs. 47 - 49). This behaviour is a strong indication of an elongated object with low inclination of the spin axis.

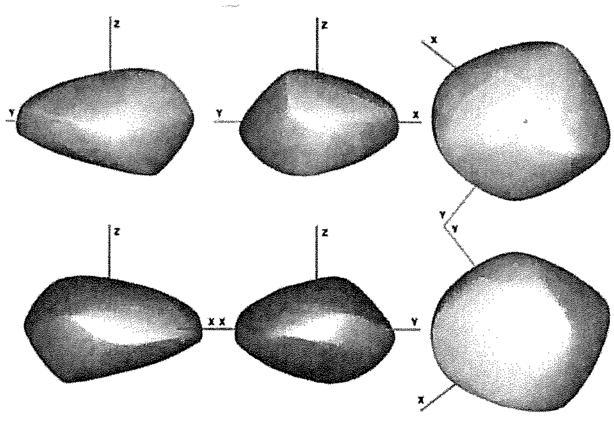

Fig. 11. Convex shape model of (487) Venetia from the lightcurve inversion method shown in six projections

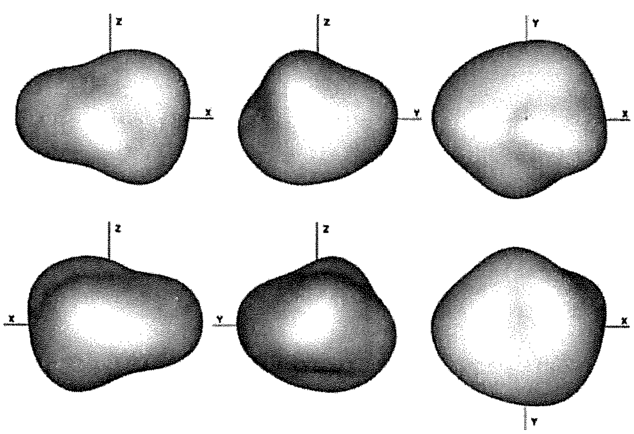

Fig. 12. Non-convex shape model of (487) Venetia from the SAGE algorithm shown in six projections

The lightcurve inversion indeed resulted in very small pole latitudes (see Table 3). The convex inversion model displays a somewhat angular flattened shape (Fig. 11), while the SAGE model has a smoother and more complex appearance (Fig. 12). Both model types failed to reproduce tiny but complex brightness variations from pole-on geometries (Fig. 24) at the level of a few 0.01 mag, revealing the limits of lightcurve inversion. However, generally the fit was very good at the level of 0.011 mag RMSD in both methods. Our models are close in sidereal period to the value determined by Erikson et al. (2000), and in pole longitude to both pole solutions published by Erikson et al. (2000) and Tungalag et al. (2002); however, they disagree in pole latitude. Our slightly positive values are far from both of the previous determinations (Table 3).

Here too there are no available stellar occultations to verify or confirm one of the spin and shape solutions. However, thermophysical modelling shows a similarly strong preference for one of the spin and shape solutions, as in the previous case of (478) Tergeste. Best χ^2=1.04 is as much as two times better for the (487) Venetia non-convex model at λ = 255°, β = +8° than for any of its convex models, and 25% better than its mirror non-convex counterpart (see Table 6). The thermal data came from IRAS (32 measurements), AKARI (7), and WISE W3/W4 (46), with adopted H and G values of 8.14, and 0.15, respectively. The best fitting thermophysical parameters are an intermediate level of surface roughness, optimum thermal inertia of around 100 SI units, effective size ~69.5 km, and geometric V-band albedo of 0.21 (see Table 7). The thermal data used here were well-balanced with pre- and post-opposition geometries, also in the WISE data. One small issue is the small sinusoidal trend with rotational phase visible in the WISE data (squares in Fig. 25). It might indicate some imperfections in the shape model or alternatively the increased infrared flux contribution of surface layers underneath the skin depth from pole-on geometries. Some discrepancy can also be found for one WISE dataset compared to the model of (478) Tergeste (Fig. 23), also a possible indicator of some missing shape features. Unfortunately, the WISE W1 data are too few and sparse to change the shape models when used as purely reflected light in parallel with all the lightcurve data.

shape model (λ, β)	low roughness	high roughness
(159) Aemilia		
sphere (139°, +68°)	1.16	1.21
sphere (348°, +59°)	1.15	1.21
convex (139°, +68°)	0.61	0.53
convex (348°, +59°)	0.44	0.56
SAGE (139°, +66°)	0.44	0.47
SAGE (349°, +63°)	0.53	0.52
(227) Philosophia		
sphere (95°, +19°)	2.67	1.34
sphere (272°, -1°)	2.67	1.45
convex (95°, +19°)	2.37	1.22
convex (272°, -1°)	2.49	1.34
SAGE (97°, +16°)	1.93	1.28
SAGE (271°, 0°)	1.93	1.40
(329) Svea		
sphere (33°, +51°)	1.63	1.61
sphere (157°, +47°)	1.67	1.60
convex (33°, +51°)	0.98	0.97
convex (157°, +47°)	1.38	1.17
SAGE (21°, +47°)	1.21	1.09
SAGE (166°, +39°)	1.39	1.55
(478) Tergeste		
sphere (2°, -42°)	2.86	2.24
sphere (216°, -56°)	2.41	1.98
convex (2°, -42°)	2.18	2.59
convex (216°, -56°)	1.53	1.81
SAGE (4°, -43°)	1.44	1.68
SAGE (218°, -56°)	1.03	1.08
(487) Venetia		
sphere (78°, +3°)	2.39	1.62
sphere (252°, +3°)	1.38	1.09
convex (78°, +3°)	2.01	2.69
convex (252°, +3°)	1.82	2.88
SAGE (70°, +8°)	1.30	1.79
SAGE (255°, +8°)	1.04	1.23

Table 6. Reduced χ^2 minimum values of various models fit to infrared data in thermophysical modelling. The first column gives the shape model type and spin axis position.

Target	D_{AKARI} [km]	D_{IRAS} [km]	D_{WISE} [km]	Radiometric solution for combined data Diameter [km]	Albedo	Thermal inertia $[\mathrm{Jm^{-2}s^{-0.5}K^{-1}}]$
159 Aemilia	130.0	125.0	127.4	137 ±8	0.054 ±0.015	50 ±50
227 Philosophia	95.6	87.3	105.3	101 ±5	0.041 ±0.005	125 ±90
329 Svea	70.4	77.8	69.2	78 ±4	0.055 ±0.015	75 ±50
478 Tergeste	85.6	79.5	77.2	87 ±6	0.15 ±0.02	75 ±45
487 Venetia	66.1	63.1	65.6	70 ±4	0.21 ±0.02	100 ±75

Table 7. Asteroid diameters from AKARI, IRAS, and WISE compared to values obtained here on combined data for the preferred pole solution (Col. 5) using TPM. The last two columns contain the derived albedo and thermal inertia values. Errors are full 3-σ range.

6. Summary and future work

This work is a first step towards actual debiasing the available set of spin and shape models for asteroids to include real targets of abundant group with long rotation periods and low amplitude lightcurves. We determined here spin and scaled shape solutions with albedo and thermal inertia values for the first five asteroids from our sample. The diameters are in most cases in good agreement with previous determinations from the IRAS, AKARI, and WISE surveys, though our values are usually a few kilometres larger. The reason for this small discrepancy might be that the cited sizes are usually based on single-epoch measurements, i.e. corresponding more to the apparent cross-section, and on a simple thermal model. The radiometric results obtained here are based on multiple wavelength, epoch, phase-angle, and rotational-phase data, and refer to the scaling size for a given 3D shape solution.

Spin and shape models, and thermal inertia values for these targets are determined here for the first time (except for (487) Venetia). When most of our sample is modelled and applied this way, the existing bias in these parameters will be largely diminished, at least for bright targets (i.e. for most of large and medium-sized main belt asteroids). We predict that we will complete the task over the course of the next three years.

Our results based on five test cases have shown that asteroid models obtained with both convex and non-convex lightcurve inversion are largely comparable. In some applications (ocultation fitting and thermophysical modelling); however, non-convex models often do somewhat better, sometimes even allowing a choice between two mirror pole solutions. Thanks to the large amount and the high quality of the data used, both model types are smooth and fit the data close to noise level. The differences between the shape models do not manifest themselves in the RMSD value, but they do in the subtle details of the lightcurve fit.

On the contrary, models based on sparse data are usually characterised by low-resolution angular shapes that tend to be problematic in further applications like the above. Nonetheless, sparse data models are good for general statistical studies of spin properties, provided that the data are properly debiased, which is not a trivial task (see e.g. Cibulková et al. 2016). As the Gaia mission is expected to provide absolute photometric data of much better accuracy than previously used sky surveys, some of the biases described in this work are expected to decrease, like those against long-period targets with large amplitudes. Still, to a large extent, low-amplitude targets are going to be problematic for the Gaia mission algorithm for asteroid modelling, as has been shown by Santana-Ros et al. (2015). A substantial amount of low-amplitude asteroids (even up to 80% of targets with equivalent ellipsoid dimensions a/b≤1.25, especially those with poles of low inclination to the ecliptic) will be either rejected or wrongly inverted by this algorithm. Thus, it is essential to focus ground-based photometric studies on these more demanding targets to make the well-studied population as complete and varied as possible, and also to start to alleviate biases expected in the future.

Some of our targets that should soon be modellable coincide with asteroids for which the Gaia mission is expected to provide reliable mass estimates, so after scaling them, e.g. by thermophysical modelling, it will be possible to calculate their densities. Practically all of our targets are characterised by complex lightcurves, i.e. a certain signature of asymmetric, complex shapes. Approximating these shapes with simple ellipsoids (as in the Gaia algorithm for asteroids, Cellino et al. 2009) can lead to large errors in derived volumes, which would consequently propagate to large errors in densities (e.g. Carry 2012). Our modelling is going to provide precise shape models that can be further validated and scaled using stellar occultations, adaptive optics imaging, or thermophysical modelling. This way the derived volumes and densities should be possibly closest to real values.

Since most of our targets are bright, both in the visible and the infrared range, many of them have thermal data of good quality, and some even have continuous thermal lightcurves, which – coupled with reliable shape models – are a good input for thermophysical modelling and further studies on their physical parameters (e.g. thermal inertias, albedoes, and sizes) and also on the development of the TPM method itself. Some of them may prove to be good candidates for secondary calibrators for infrared observatories like ALMA, APEX, or IRAM (Müller & Lagerros 2002) as their infrared flux is only weakly and slowly variable (although in a predictable way), which are desirable features of calibrator asteroids.

Cases like 227, 478, and 487 add support to the suggestion of Harris & Drube (2016) that slowly rotating asteroids have higher thermal inertia values, but a larger sample is still needed. Our modelled targets applied in careful thermophysical modelling show best fitting values from 50 to 125 SI units, which seems to fit the trend to higher values of thermal inertia for rotation periods longer than 10 hours (see fig. 5 in Harris & Drube 2016). With slower rotation, the heat penetrates deeper to more compact subregolith layers with substantially higher density and thermal conductivity, which both seem to rapidly grow with depth.

Thermal inertia appears to grow by a factor of 10 (main belt asteroids) and 20 (near-Earth objects) with a depth of just 10 cm (Harris & Drube 2016). Alternatively, the growth observed here might also be related to the objects' sizes: a low thermal inertia of 15 has been found for large (fine-grained regolith covered) asteroids with sizes much larger than 100 km, but we are looking here at objects below or close to 100 km. They might have less low-conductivity material on the surface, due to reduced gravity. Our future works are going to provide thermal inertia values for a larger sample of slow-rotators, a highly needed input for further studies of subsurface layers of asteroids.

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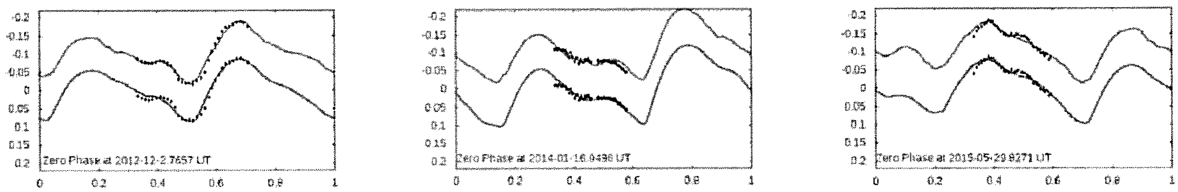

Fig. 13. Convex (upper curve) and non-convex (lower curve) model lightcurves of (159) Aemilia fitted to data from various apparitions (black points)

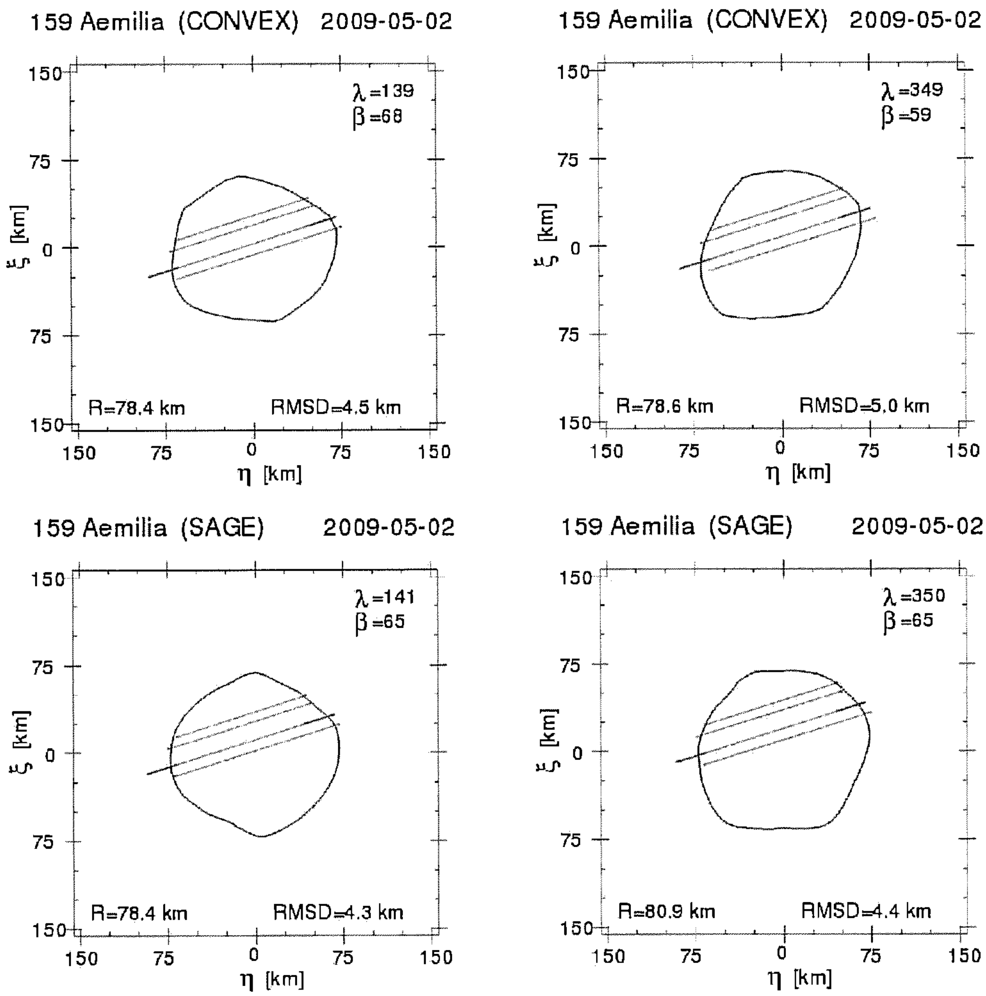

Fig. 14. Stellar occultation fits of convex (top) and non-convex (bottom) models of (159) Aemilia. At the end of each chord a timing uncertainty is marked. R is the radius of the largest model dimension. For equivalent volume sphere diameters see Table 4.

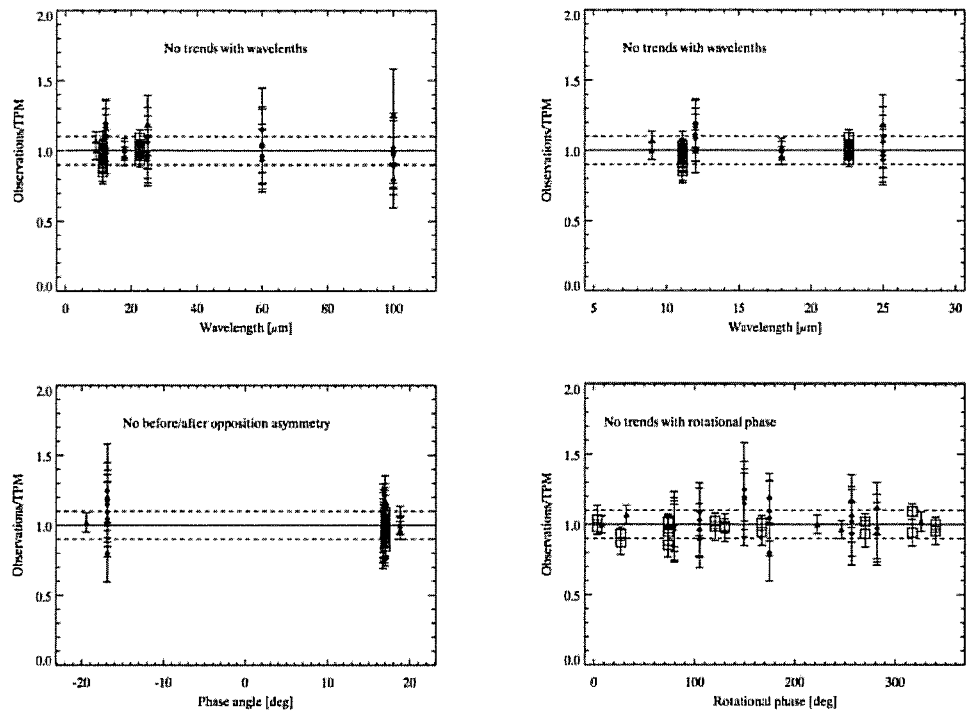

Fig. 15. O-C diagrams for the thermophysical model of (159) Aemilia using SAGE model 1. They illustrate how well the spin/shape model works against thermal infrared data. The dashed lines indicate +/-10% in the observation-to-model ratio, which corresponds to typical flux errors of thermal measurements. There are no trends with wavelength, rotation, or pre- and post-opposition asymmetry. For the best fitting thermal parameters see Table 7. Triangles: data from AKARI, squares: WISE W3/W4, small diamonds: IRAS.

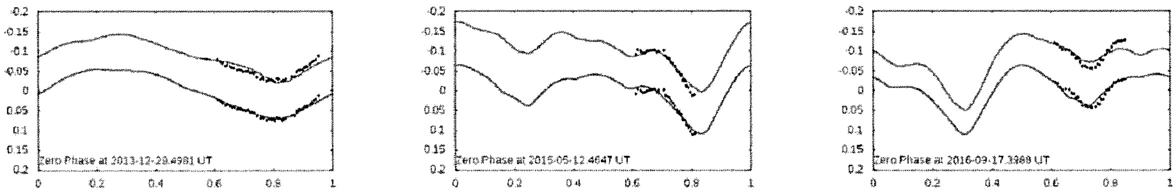

Fig. 16. Convex (upper curve) and non-convex (lower curve) model lightcurves of (227) Philosophia fitted to data from various apparitions (black points)

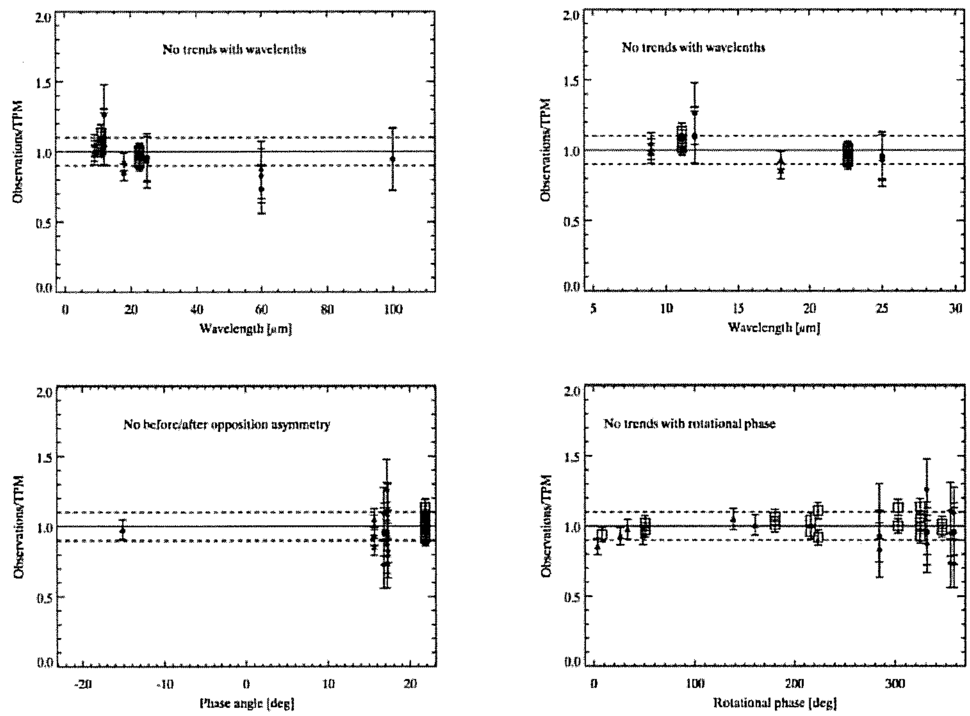

Fig. 17. O-C diagrams for the thermophysical model of (227) Philosphia, using convex model 1, illustrating that the spin/shape model works quite well against the thermal infrared data. There are no clear trends with wavelength, rotation, or pre- and post-opposition asymmetry. For best fitting thermal parameters see Table 7.

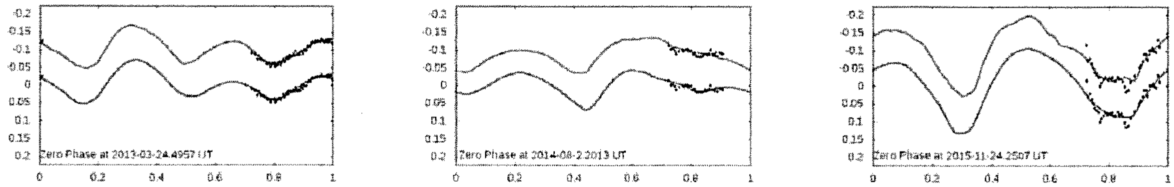

Fig. 18. Convex (upper curve) and non-convex (lower curve) model lightcurves of (329) Svea fitted to data from various apparitions (black points)

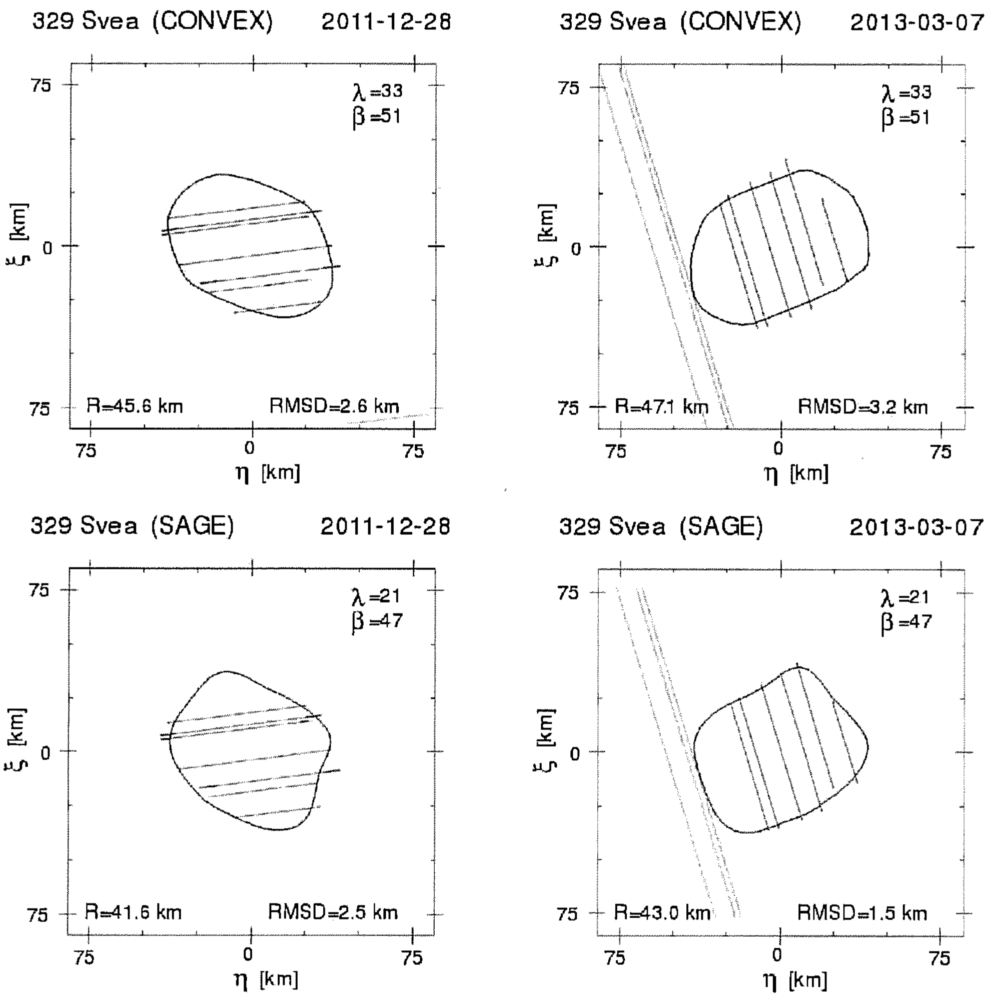

Fig. 19. Two stellar occultation fits of convex (top) and non-convex (bottom) models of (329) Svea, pole 1. At the end of each chord a timing uncertainty is marked. R is the radius of the largest model dimension.

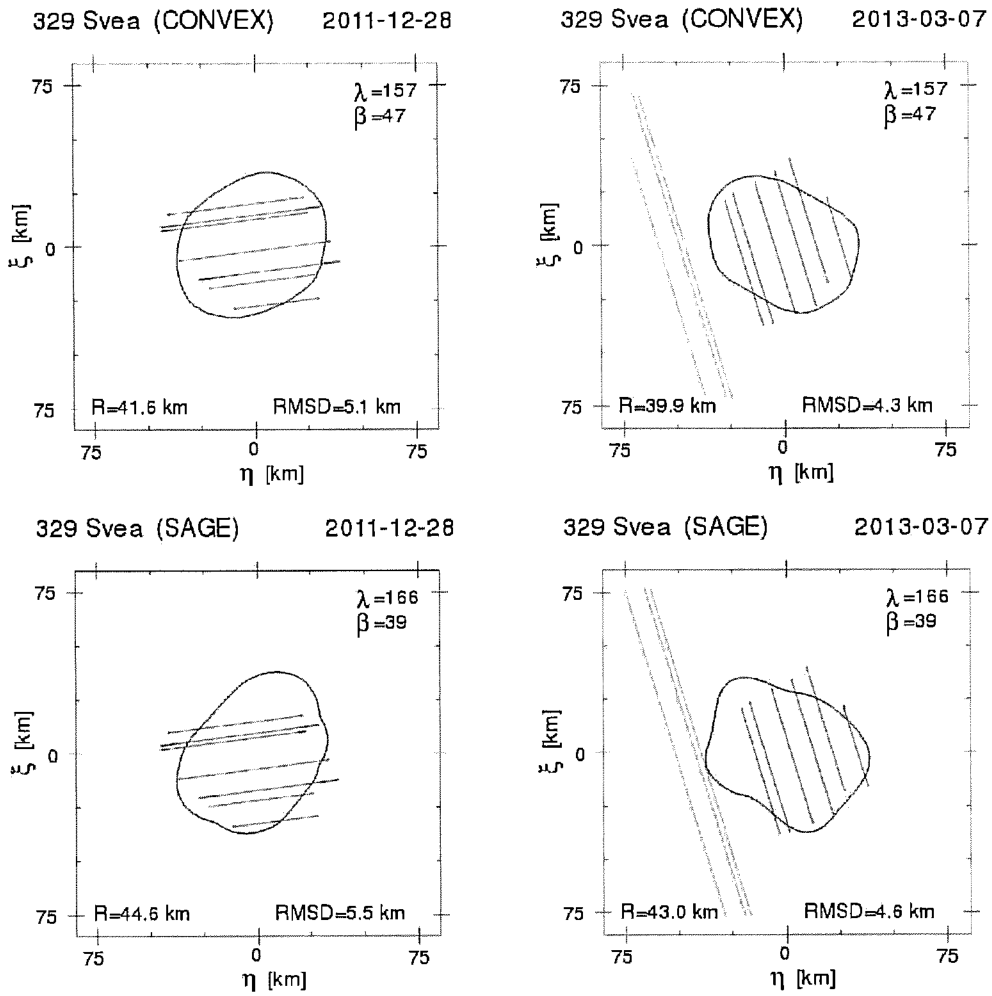

Fig. 20. Svea occultation fits for mirror pole solution (pole 2 from Table 3). The clear misfit of this pole solution allows it to be safely rejected in favour of the pole 1 solution (compare Fig. 19).

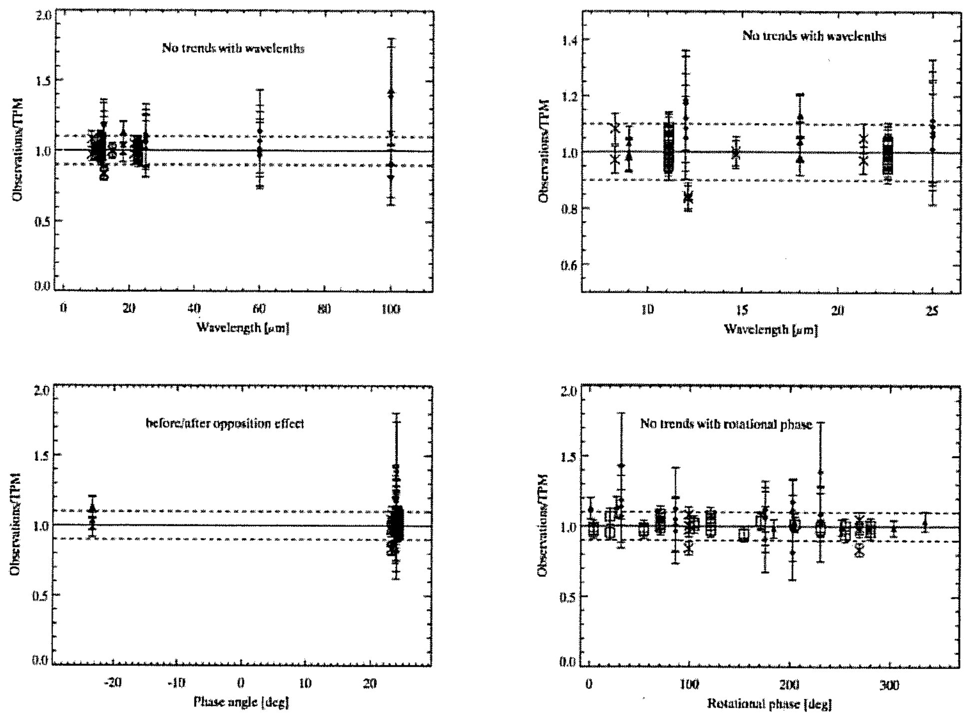

Fig. 21. O-C diagrams for the thermophysical model of (329) Svea using convex model 1. There are no trends with wavelength, rotation, or pre- and post-opposition asymmetry. For the best fitting thermal parameters see Table 7. Triangles: data from AKARI, squares: WISE W3/W4, small diamonds: IRAS, X-symbols: MSX.

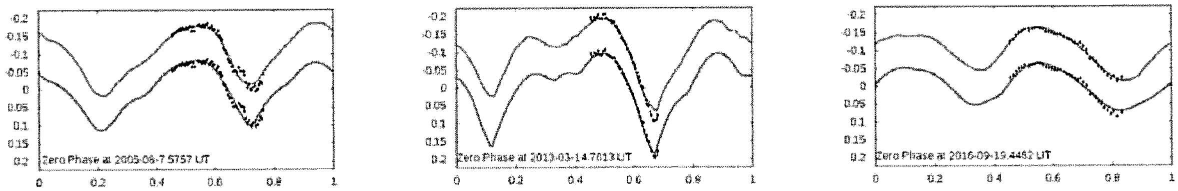

Fig. 22. Convex (upper curve) and non-convex (lower curve) model lightcurves of (478) Tergeste fitted to the data from various apparitions (black points)

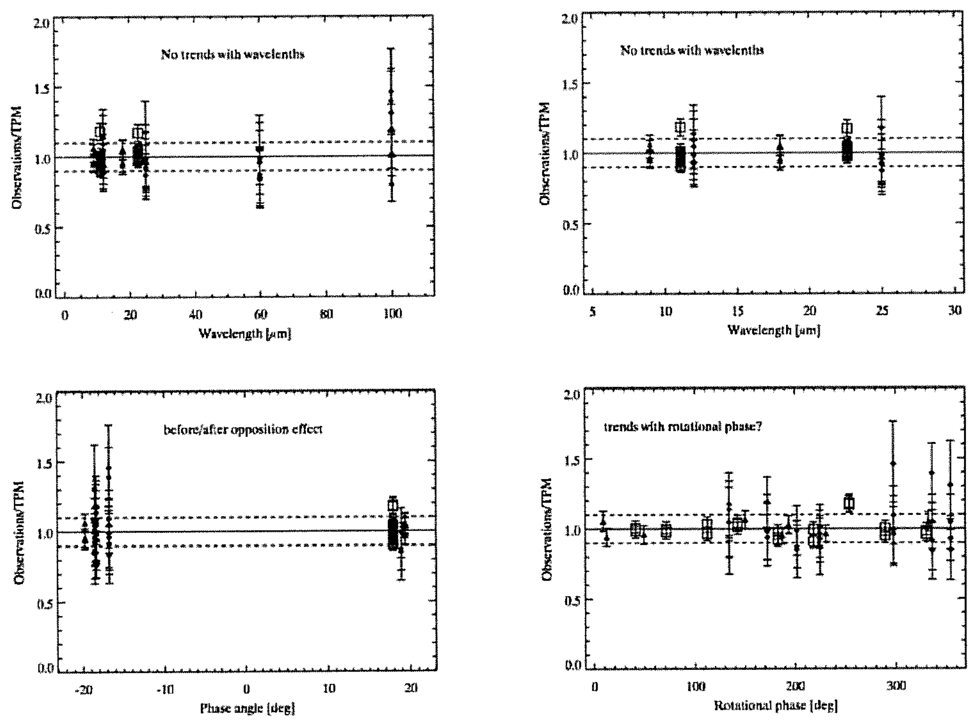

Fig. 23. O-C diagrams for thermophysical model of (478) Tergeste, using SAGE model 2. There are no trends with wavelength or pre- and post-opposition asymmetry. The two outliers at rotational phase 250 deg might be an indication for a small-scale shape problem, but could also be connected to a wrong flux (single WISE W3/W4 epoch where a bright background source might have influenced the photometry). For best fitting thermal parameters see Table 7.

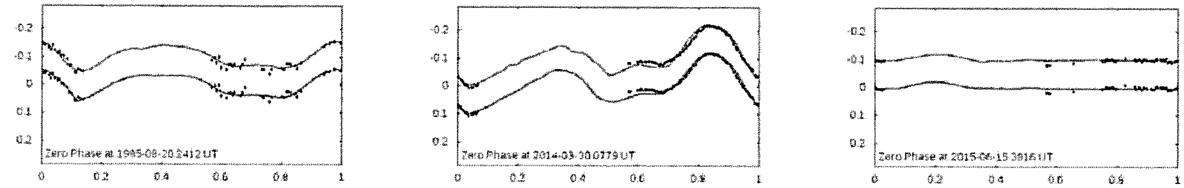

Fig. 24. Convex (upper curve) and non-convex (lower curve) model lightcurves of (487) Venetia fitted to the data from various apparitions (black points)

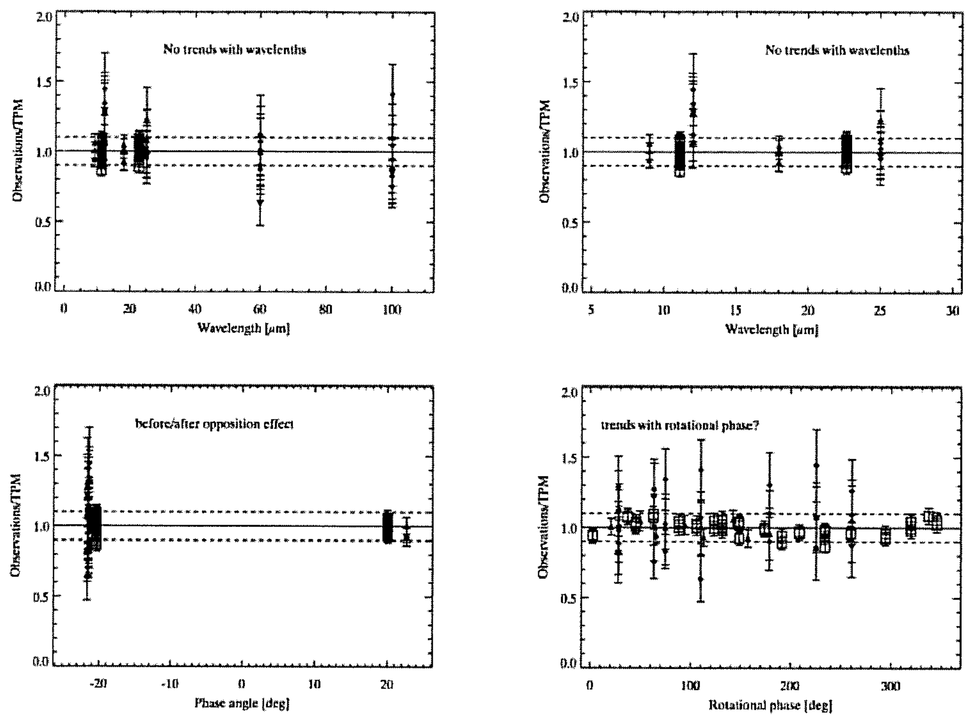

Fig. 25. O-C diagrams for the thermophysical model of (487) Venetia using SAGE model 2. There are no trends with wavelength or pre- and post-opposition asymmetry, but some trends with rotation can be noticed in the WISE data (box symbol). These data cover the object's full rotation during two separate epochs in January and July 2010, and residual trends can only be explained by shape effects. For the best fitting thermal parameters see Table 7.

Appendix A

Observing runs details (Table 8) and composite lightcurves of asteroids with new period determinations (Figures 26 - 30) and asteroids with spin and shape models presented here (Figures 32 - 49).

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site
(551) Ortrud						
2016 Aug 31.0	32.9	17.5	4.7	0.005	K. Żukowski	Borowiec
2016 Sep 02.0	33.0	17.1	4.8	0.008	A. Marciniak	Borowiec
2016 Sep 03.0	33.0	16.8	3.7	0.008	R. Hirsch	Borowiec
2016 Sep 05.4	32.9	16.3	3.6	0.011	F. Pilcher	Organ Mesa Obs.
2016 Sep 09.0	32.8	15.4	4.8	0.014	M. Butkiewicz Bąk	Borowiec
2016 Sep 13.4	32.6	14.1	5.3	0.006	F. Pilcher	Organ Mesa Obs.
2016 Sep 14.4	32.5	13.8	7.2	0.007	F. Pilcher	Organ Mesa Obs.
2016 Sep 15.3	32.4	13.6	2.8	0.013	F. Pilcher	Organ Mesa Obs.
2016 Oct 01.3	30.4	7.8	8.4	0.005	F. Pilcher	Organ Mesa Obs.
2016 Nov 18.2	21.4	12.2	5.7	0.016	T. Polakis	Tempe
2016 Nov 19.2	21.3	12.5	5.7	0.016	T. Polakis	Tempe
2016 Nov 22.2	21.0	13.5	5.9	0.017	T. Polakis	Tempe
2016 Nov 23.2	20.9	13.8	5.2	0.016	T. Polakis	Tempe
2016 Nov 24.2	20.9	14.1	6.0	0.018	T. Polakis	Tempe
2016 Nov 25.2	20.8	14.4	4.1	0.016	T. Polakis	Tempe
			77.9 total			
(581) Tauntonia						
2016 Jan 28.3	120.2	4.2	1.7	0.002	K. Kamiński	Winer Obs.
2016 Jan 29.4	119.9	4.5	7.2	0.006	K. Kamiński	Winer Obs.
2016 Feb 22.4	115.6	11.6	6.0	0.011	K. Kamiński	Winer Obs.
2016 Feb 24.2	115.4	12.1	5.7	0.012	K. Kamiński	Winer Obs.
2016 Feb 26.3	115.2	12.6	7.6	0.006	K. Kamiński	Winer Obs.
2016 Mar 23.9	114.5	17.5	5.8	0.007	-	Montsec Obs.
2016 Mar 24.9	114.5	17.6	5.8	0.007	-	Montsec Obs.
2016 Mar 27.9	114.7	17.9	5.8	0.005	-	Montsec Obs.
2016 Mar 31.9	115.1	18.2	3.4	0.006	-	Montsec Obs.
			49.0 total			
(830) Petropolitana						
2017 Mar 01.4	178.0	5.1	7.6	0.012	T. Polakis	Tempe
2017 Mar 02.4	177.8	4.8	7.5	0.013	T. Polakis	Tempe
2017 Mar 04.4	177.5	4.1	7.6	0.011	T. Polakis	Tempe
2017 Mar 06.4	177.1	3.3	7.5	0.010	T. Polakis	Tempe
2017 Mar 07.4	176.9	3.0	7.5	0.009	T. Polakis	Tempe
2017 Mar 08.4	176.7	2.6	7.2	0.010	T. Polakis	Tempe
2017 Mar 09.4	176.5	2.3	6.9	0.014	T. Polakis	Tempe
2017 Mar 10.4	176.3	1.9	6.9	0.011	T. Polakis	Tempe
2017 Apr 14.2	170.2	9.9	6.8	0.013	T. Polakis	Tempe
2017 Apr 15.2	170.1	10.2	6.6	0.011	T. Polakis	Tempe
2017 Apr 18.3	169.8	11.0	3.0	0.017	T. Polakis	Tempe
2017 Apr 19.2	169.7	11.2	6.1	0.017	T. Polakis	Tempe
2017 Apr 20.2	169.6	11.5	6.1	0.019	T. Polakis	Tempe
2017 Apr 21.2	169.5	11.7	5.7	0.019	T. Polakis	Tempe
2017 Apr 22.2	169.4	12.0	5.9	0.016	T. Polakis	Tempe
2017 Apr 23.3	169.3	12.2	4.1	0.017	T. Polakis	Tempe
2017 Apr 24.2	169.2	12.5	5.2	0.023	T. Polakis	Tempe
			108.2 total			

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site
(923) Herluga						
2016 Jul 26.0	330.2	13.1	4.2	0.007	-	Montsec Obs.
2016 Jul 27.0	330.0	12.8	3.2	0.006	-	Montsec Obs.
2016 Jul 28.0	329.8	12.6	3.2	0.005	-	Montsec Obs.
2016 Aug 03.0	328.7	10.8	3.8	0.003	-	Montsec Obs.
2016 Aug 04.0	328.5	10.6	3.6	0.019	-	Montsec Obs.
2016 Aug 08.0	327.6	9.6	4.4	0.003	-	Montsec Obs.
2016 Aug 11.0	326.9	9.0	7.3	0.006	-	Montsec Obs.
2016 Aug 15.1	326.0	8.4	7.6	0.002	S. Geier	JKT, ORM
2016 Aug 19.9	324.8	8.3	6.7	0.022	R. Hirsch	Borowiec
2016 Aug 22.9	324.0	8.5	7.0	0.014	K. Żukowski	Borowiec
2016 Sep 06.9	320.7	12.2	5.7	0.008	A. Marciniak	Borowiec
2016 Sep 10.9	320.0	13.6	5.3	0.013	A. Marciniak	Borowiec
			62.0 total			
(932) Hooveria						
2016 Nov 18.3	58.8	4.6	10.2	0.007	T. Polakis	Tempe
2016 Nov 19.3	58.6	4.5	10.2	0.006	T. Polakis	Tempe
2016 Nov 22.3	57.8	4.7	10.2	0.005	T. Polakis	Tempe
2016 Nov 23.3	57.5	4.9	11.9	0.007	T. Polakis	Tempe
2016 Nov 24.2	57.3	5.1	7.5	0.007	T. Polakis	Tempe
2016 Nov 25.3	57.0	5.4	10.1	0.006	T. Polakis	Tempe
2016 Nov 26.4	56.8	5.7	2.1	0.010	T. Polakis	Tempe
2016 Nov 30.2	55.8	7.2	8.7	0.007	T. Polakis	Tempe
2016 Dec 01.3	55.6	7.7	6.9	0.007	T. Polakis	Tempe
2016 Dec 03.3	55.1	8.5	6.3	0.008	T. Polakis	Tempe
2016 Dec 04.3	54.9	9.0	9.2	0.007	T. Polakis	Tempe
2016 Dec 05.3	54.7	9.4	9.2	0.007	T. Polakis	Tempe
2016 Dec 09.2	53.9	11.2	9.0	0.008	T. Polakis	Tempe
2016 Dec 18.2	52.5	15.0	7.4	0.009	T. Polakis	Tempe
2016 Dec 19.2	52.4	15.4	7.4	0.009	T. Polakis	Tempe
2016 Dec 20.1	52.3	15.8	3.3	0.015	T. Polakis	Tempe
			129.6 total			
(995) Sternberga						
2016 May 04.4	265.0	15.1	3.9	0.006	B. Skiff	Lowell Obs.
2016 May 11.2	264.3	13.0	2.0	0.003	S. Geier	Teide
2016 May 24.0	262.4	8.7	2.1	0.028	V. Kudak	Derenivka
2016 Jun 02.2	260.4	6.0	0.8	0.006	B. Skiff	Lowell Obs.
2016 Jun 03.3	260.1	5.8	7.0	0.004	B. Skiff	Lowell Obs.
2016 Jun 04.3	259.9	5.6	7.1	0.004	B. Skiff	Lowell Obs.
2016 Jun 05.3	259.7	5.5	7.0	0.005	B. Skiff	Lowell Obs.
2016 Jun 06.3	259.4	5.4	7.0	0.006	B. Skiff	Lowell Obs.
2016 Jun 07.3	259.2	5.3	4.0	0.007	T. Polakis	Tempe
2016 Jun 08.1	259.0	5.3	4.1	0.020	R. Duffard	La Sagra
2016 Jun 08.4	259.0	5.3	4.2	0.008	T. Polakis	Tempe
2016 Jun 09.1	258.8	5.3	3.4	0.016	R. Duffard	La Sagra
2016 Jun 10.1	258.5	5.4	3.7	0.014	R. Duffard	La Sagra
2016 Jun 12.1	258.0	5.6	2.8	0.018	R. Duffard	La Sagra
2016 Jun 13.1	258.0	5.8	3.2	0.021	R. Duffard	La Sagra
2016 Jun 13.3	257.7	5.8	6.7	0.005	B. Skiff	Lowell Obs.
2016 Jun 30.9	253.8	11.6	3.3	0.004	-	Montsec Obs.
2016 Jul 06.0	253.0	13.5	3.0	0.008	-	Montsec Obs.
2016 Jul 06.9	252.8	13.8	2.4	0.004	S. Fauvaud	Bardon Obs.
2016 Jul 07.0	252.8	13.8	3.0	0.008	-	Montsec Obs.
2016 Jul 08.0	252.6	14.2	1.9	0.005	S. Fauvaud	Bardon Obs.
2016 Jul 08.9	252.5	14.5	2.8	0.005	S. Fauvaud	Bardon Obs.
2016 Jul 09.0	252.5	14.5	3.2	0.006	-	Montsec Obs.
2016 Jul 10.0	252.4	14.9	3.9	0.005	S. Fauvaud	Bardon Obs.
			92.5 total			

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site	
(159) Aemilia							
2005 Jul 03.1	317.6	10.2	2.6	0.013	L. Bernasconi	Obs. des Engarouines	
2005 Jul 09.0	316.9	8.5	3.5	0.011	L. Bernasconi	Obs. des Engarouines	
2005 Jul 11.0	316.6	8.0	4.3	0.018	L. Bernasconi	Obs. des Engarouines	
2005 Aug 07.0	311.8	0.8	5.6	0.014	L. Bernasconi	Obs. des Engarouines	
2005 Aug 09.0	311.4	1.5	5.9	0.015	L. Bernasconi	Obs. des Engarouines	
2013 Dec 28.2	180.3	19.9	3.5	0.004	R. Hirsch	Borowiec	
2014 Jan 17.4	182.6	18.0	6.0	0.006	F. Pilcher	Organ Mesa Obs.	
2014 Jan 25.1	182.9	16.7	5.5	0.006	K. Sobkowiak	Borowiec	
2014 Jan 28.4	182.9	16.1	6.9	0.003	F. Pilcher	Organ Mesa Obs.	
2014 Feb 04.1	182.7	14.5	6.5	0.005	A. Marciniak	Borowiec	
2014 Feb 09.4	182.4	13.1	7.5	0.006	F. Pilcher	Organ Mesa Obs.	
2014 Feb 13.1	182.0	12.0	7.5	0.005	A. Marciniak	Borowiec	
2014 Feb 21.1	181.0	9.5	6.2	0.005	I. Konstanciak	Borowiec	
2014 Mar 29.9	173.9	5.5	7.0	0.004	A. Marciniak	Borowiec	
2015 Apr 29.4	259.0	11.4	5.0	0.007	K. Kamiński	Winer Obs.	
2015 May 19.9	256.1	5.6	2.9	0.005	M. Żejmo	Adiyaman Obs.	
2015 May 30.3	254.1	2.8	7.6	0.010	K. Kamiński	Winer Obs.	
2015 May 30.4	254.1	2.8	6.4	0.008	F. Pilcher	Organ Mesa Obs.	
2015 Jun 12.9	251.5	3.8	4.2	0.007	M. Żejmo	Adiyaman Obs.	
2015 Jun 18.0	250.6	5.2	4.9	0.005	-	Montsec Obs.	
2015 Jun 20.3	250.2	5.9	4.3	0.004	F. Pilcher	Organ Mesa Obs.	
2015 Jun 22.2	249.8	6.4	5.7	0.005	F. Pilcher	Organ Mesa Obs.	
2015 Jun 25.0	249.4	7.2	4.4	0.003	-	Montsec Obs.	
2015 Jul 02.2	248.3	9.3	5.1	0.010	F. Pilcher	Organ Mesa Obs.	
2015 Jul 07.2	247.8	10.6	4.7	0.006	F. Pilcher	Organ Mesa Obs.	
			133.7 total				

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site	
(227) Philosophia							
2006 Nov 09.1	43.6	3.2	4.2	0.030	R. Ditteon	Oakley Obs.	
2006 Nov 09.3	43.6	3.2	4.3	0.035	R. Ditteon	Oakley Obs.	
2006 Nov 10.1	43.4	3.3	5.1	0.028	R. Ditteon	Oakley Obs.	
2006 Nov 10.3	43.4	3.3	3.3	0.038	R. Ditteon	Oakley Obs.	
2006 Nov 15.0	42.5	4.0	9.6	0.011	P. Antonini	Obs. Hauts Patys	
2006 Nov 29.9	39.9	7.5	7.2	0.020	P. Antonini	Obs. Hauts Patys	
2006 Dec 27.9	37.3	12.9	8.4	0.026	P. Antonini	Obs. Hauts Patys	
2015 Apr 15.4	223.0	8.5	6.0	0.004	K. Kamiński	Winer Obs.	
2015 Apr 17.4	222.7	7.9	6.0	0.003	K. Kamiński	Winer Obs.	
2015 Apr 19.4	222.3	7.4	6.0	0.003	K. Kamiński	Winer Obs.	
2015 Apr 30.3	220.2	5.6	5.0	0.004	K. Kamiński	Winer Obs.	
2015 May 06.3	219.0	6.1	5.3	0.009	K. Kamiński	Winer Obs.	
2015 May 10.3	218.2	7.0	5.8	0.003	K. Kamiński	Winer Obs.	
2015 May 12.3	217.8	7.6	3.3	0.008	K. Kamiński	Winer Obs.	
2015 May 13.3	217.6	7.9	5.3	0.004	K. Kamiński	Winer Obs.	
2015 May 14.3	217.5	8.2	5.0	0.007	K. Kamiński	Winer Obs.	
2015 May 28.2	215.4	12.8	4.1	0.003	K. Kamiński	Winer Obs.	
2015 Jun 29.9	215.1	20.8	2.5	0.005	A. Marciniak	Teide Obs.	
2016 Jul 07.4	337.6	15.3	3.1	0.003	D. Oszkiewicz, B. Skiff	Lowell Obs.	
2016 Jul 14.4	337.2	13.6	4.7	0.004	D. Oszkiewicz, B. Skiff	Lowell Obs.	
2016 Jul 17.4	337.0	12.8	5.1	0.007	D. Oszkiewicz, B. Skiff	Lowell Obs.	
2016 Jul 21.3	336.6	11.7	4.7	0.015	D. Oszkiewicz	Cerro Tololo	
2016 Jul 25.1	336.1	10.5	5.7	0.004	A. Marciniak	Teide Obs.	
2016 Jul 28.4	335.6	9.5	4.7	0.005	D. Oszkiewicz, B. Skiff	Lowell Obs.	
2016 Aug 12.3	333.0	4.2	7.2	0.004	B. Skiff	Lowell Obs.	
2016 Aug 14.3	332.6	3.5	7.7	0.006	B. Skiff	Lowell Obs.	
2016 Aug 15.3	332.4	3.1	7.7	0.008	F. Pilcher	Organ Mesa Obs.	
2016 Aug 15.3	332.4	3.1	7.0	0.005	B. Skiff	Lowell Obs.	
2016 Aug 16.3	332.2	2.7	7.3	0.008	F. Pilcher	Organ Mesa Obs.	
2016 Aug 21.0	331.3	1.0	4.3	0.009	-	Montsec Obs.	
2016 Aug 23.3	330.8	0.3	6.4	0.011	F. Pilcher	Organ Mesa Obs.	
2016 Aug 26.9	330.1	1.3	4.2	0.007	R. Hirsch	Borowiec	
2016 Aug 29.3	329.6	2.2	5.8	0.004	B. Skiff	Lowell Obs.	
2016 Sep 04.4	328.4	4.4	7.4	0.004	B. Skiff	Lowell Obs.	
2016 Sep 08.0	327.8	5.7	5.2	0.006	-	Montsec Obs.	
2016 Sep 09.2	327.6	6.1	7.0	0.005	F. Pilcher	Organ Mesa Obs.	
2016 Sep 09.2	327.6	6.1	7.3	0.004	B. Skiff	Lowell Obs.	
2016 Sep 10.2	327.4	6.4	6.9	0.006	F. Pilcher	Organ Mesa Obs.	
2016 Sep 11.2	327.2	6.8	6.9	0.006	F. Pilcher	Organ Mesa Obs.	
2016 Sep 11.2	327.2	6.8	7.4	0.005	B. Skiff	Lowell Obs.	
2016 Sep 17.2	326.3	8.7	6.6	0.008	B. Skiff	Lowell Obs.	
2016 Sep 17.2	326.3	8.7	5.0	0.013	F. Pilcher	Organ Mesa Obs.	
2016 Sep 18.2	326.2	9.0	6.5	0.009	F. Pilcher	Organ Mesa Obs.	
2016 Sep 18.2	326.2	9.0	6.5	0.008	B. Skiff	Lowell Obs.	
2016 Sep 19.2	326.1	9.3	6.5	0.009	F. Pilcher	Organ Mesa Obs.	
2016 Sep 19.2	326.1	9.3	6.5	0.008	B. Skiff	Lowell Obs.	
2016 Sep 24.3	325.5	10.7	2.8	0.007	B. Skiff	Lowell Obs.	
2016 Sep 25.2	325.4	11.0	5.6	0.006	B. Skiff	Lowell Obs.	
2016 Sep 26.1	325.3	11.2	2.0	0.005	B. Skiff	Lowell Obs.	
2016 Oct 02.1	324.8	12.7	6.2	0.006	B. Skiff	Lowell Obs.	
			284.3 total				

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site	
(329) Svea							
2006 Jul 24.0	325.6	11.9	4.3	0.022	L. Bernasconi	Obs. des Engarouines	
2006 Jul 26.0	325.2	11.2	6.2	0.028	L. Bernasconi	Obs. des Engarouines	
2006 Jul 29.0	324.5	10.2	5.1	0.022	L. Bernasconi	Obs. des Engarouines	
2006 Jul 30.0	324.3	9.9	5.8	0.023	L. Bernasconi	Obs. des Engarouines	
2006 Aug 21.0	318.9	7.3	6.4	0.009	R. Poncy	Le Crès	
2006 Aug 22.0	318.7	7.5	6.2	0.010	R. Poncy	Le Crès	
2006 Aug 27.9	317.3	9.0	6.2	0.012	R. Poncy	Le Crès	
2014 Jul 30.0	352.9	17.3	3.2	0.004	A. Marciniak	Borowiec	
2014 Aug 03.0	352.6	16.1	4.5	0.007	A. Marciniak	Borowiec	
2014 Aug 09.0	351.9	14.0	5.0	0.010	A. Marciniak	Borowiec	
2014 Aug 28.0	348.2	6.2	6.5	0.007	A. Marciniak	Borowiec	
2014 Sep 04.0	346.5	3.4	6.5	0.009	A. Marciniak	Borowiec	
2014 Sep 19.0	342.7	5.6	5.0	0.011	A. Marciniak	Borowiec	
2014 Sep 28.8	340.6	9.8	3.0	0.017	A. Marciniak	Borowiec	
2014 Oct 03.8	339.7	11.8	5.7	0.025	K. Sobkowiak	Borowiec	
2014 Oct 09.8	338.9	14.0	2.4	0.006	J. Horbowicz	Borowiec	
2014 Oct 10.2	338.9	14.2	4.7	0.007	F. Pilcher	Organ Mesa Obs.	
2014 Nov 26.2	341.3	22.9	3.7	0.007	K. Kamiński	Winer Obs.	
2015 Nov 25.1	110.0	17.8	6.2	0.009	R. Hirsch	Borowiec	
2015 Dec 14.0	107.5	12.9	5.9	0.002	-	Montsec Obs.	
2015 Dec 16.0	107.1	12.4	7.4	0.010	-	Montsec Obs.	
2015 Dec 17.0	107.0	12.2	8.3	0.008	-	Montsec Obs.	
2015 Dec 18.0	106.7	11.9	7.4	0.005	-	Montsec Obs.	
2015 Dec 19.0	106.5	11.7	7.5	0.009	-	Montsec Obs.	
2015 Dec 22.0	105.8	11.0	7.6	0.004	-	Montsec Obs.	
2015 Dec 23.0	105.5	10.8	7.5	0.006	-	Montsec Obs.	
2015 Dec 28.0	104.3	9.9	7.4	0.025	-	Montsec Obs.	
2015 Dec 29.9	103.8	9.7	3.8	0.004	-	Montsec Obs.	
2015 Dec 30.9	103.5	9.6	4.3	0.002	-	Montsec Obs.	
2016 Jan 24.9	97.4	13.0	7.4	0.006	-	Montsec Obs.	
2016 Feb 01.9	96.0	15.2	7.6	0.005	-	Montsec Obs.	
2016 Mar 02.2	95.4	21.5	3.0	0.004	K. Kamiński	Winer Obs.	
			181.7 total				

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site	
(478) Tergeste							
2005 Jul 16.0	315.2	8.3	4.7	0.006	L. Bernasconi	Obs. des Engarouines	
2005 Jul 17.0	315.0	8.1	5.2	0.021	L. Bernasconi	Obs. des Engarouines	
2005 Aug 06.0	311.1	5.7	5.0	0.007	L. Bernasconi	Obs. des Engarouines	
2005 Aug 08.0	310.7	5.6	5.8	0.010	L. Bernasconi	Obs. des Engarouines	
2005 Aug 08.0	310.7	5.8	4.9	0.010	R. Crippa, F. Manzini	Stazione Astro. di Sozzago	
2005 Aug 09.9	310.3	6.0	2.4	0.010	R. Crippa, F. Manzini	Stazione Astro. di Sozzago	
2005 Aug 12.0	309.8	6.3	5.0	0.010	L. Bernasconi	Obs. des Engarouines	
2005 Aug 12.9	309.7	6.5	4.2	0.006	R. Stoss, P. Korlevic, M. Hren, A. Cikota, L. Jerosimic	OAM-Mallorca	
2005 Aug 13.0	309.6	6.5	4.2	0.006	R. Crippa, F. Manzini	Stazione Astro. di Sozzago	
2005 Aug 13.0	309.6	6.5	5.8	0.013	L. Bernasconi	Obs. des Engarouines	
2005 Aug 15.0	309.2	6.8	3.2	0.007	R. Crippa, F. Manzini	Stazione Astro. di Sozzago	
2005 Aug 16.0	309.0	7.0	3.2	0.007	R. Crippa, F. Manzini	Stazione Astro. di Sozzago	
2012 Nov 26.2	108.5	14.7	1.5	0.006	M. Murawiecka	Borowiec	
2013 Feb 15.1	95.7	16.5	2.8	0.003	F. Pilcher	Organ Mesa Obs.	
2013 Feb 16.1	95.6	16.7	4.1	0.003	F. Pilcher	Organ Mesa Obs.	
2013 Feb 22.1	95.6	17.9	4.3	0.008	F. Pilcher	Organ Mesa Obs.	
2013 Feb 24.1	95.7	18.3	4.2	0.005	F. Pilcher	Organ Mesa Obs.	
2013 Mar 12.1	97.0	20.3	2.7	0.003	F. Pilcher	Organ Mesa Obs.	
2013 Mar 15.1	97.4	20.6	3.7	0.004	F. Pilcher	Organ Mesa Obs.	
2013 Mar 17.2	97.7	20.7	3.9	0.005	F. Pilcher	Organ Mesa Obs.	
2013 Mar 26.2	99.3	21.1	3.8	0.006	F. Pilcher	Organ Mesa Obs.	
2013 Mar 26.8	99.5	21.1	2.5	0.009	R. Hirsch	Borowiec	
2014 Apr 18.0	201.3	4.0	4.5	0.008	-	Montsec Obs.	
2014 Apr 19.0	201.1	4.2	4.6	0.011	-	Montsec Obs.	
2014 Apr 24.0	200.1	5.5	4.2	0.012	-	Montsec Obs.	
2014 May 15.2	196.8	12.0	4.5	0.005	F. Pilcher	Organ Mesa Obs.	
2014 May 16.2	196.6	12.3	4.6	0.005	F. Pilcher	Organ Mesa Obs.	
2014 May 23.9	196.0	14.2	2.0	0.005	-	Montsec Obs.	
2014 May 27.0	195.9	14.9	2.0	0.007	-	Montsec Obs.	
2015 Jun 18.0	279.8	5.6	4.7	0.005	-	Montsec Obs.	
2015 Jun 19.0	279.6	5.4	5.5	0.006	-	Montsec Obs.	
2015 Jun 21.0	279.3	5.0	5.2	0.011	-	Montsec Obs.	
2015 Jun 27.1	278.0	4.2	6.8	0.003	A. Marciniak	Obs. del Teide	
2015 Jun 28.9	277.6	4.1	1.5	0.003	A. Marciniak	Obs. del Teide	
2015 Jul 18.0	273.9	7.6	4.5	0.010	-	Montsec Obs.	
2015 Jul 26.9	272.5	9.9	1.5	0.006	A. Marciniak	Borowiec	
2015 Aug 03.7	271.6	11.9	4.2	0.003	M. Żejmo	Adiyaman Obs.	
2015 Aug 08.8	271.6	13.0	2.2	0.004	M. Żejmo	Adiyaman Obs.	
2016 Aug 02.0	357.6	14.1	3.4	0.008	K. Żukowski	Borowiec	
2016 Aug 07.9	357.1	12.9	3.0	0.008	A. Marciniak	Borowiec	
2016 Aug 08.9	357.0	12.6	3.0	0.005	K. Żukowski	Borowiec	
2016 Aug 25.0	354.8	8.7	4.9	0.006	K. Żukowski	Borowiec	
2016 Aug 26.0	354.6	8.5	7.2	0.003	A. Marciniak	Borowiec	
2016 Aug 28.8	354.1	7.8	2.5	0.002	R. Hirsch	Borowiec	
2016 Sep 19.9	349.6	5.9	6.5	0.008	R. Hirsch	Borowiec	
			180.1 total				

Date	λ [deg]	Phase angle [deg]	Duration [hours]	σ [mag]	Observer	Site	
(487) Venetia							
2006 Apr 29.1	236.4	7.6	2.5	0.013	L. Bernasconi	Obs. des Engarouines	
2006 May 10.0	234.0	5.1	5.9	0.015	L. Bernasconi	Obs. des Engarouines	
2006 May 11.0	233.8	5.0	5.8	0.009	L. Bernasconi	Obs. des Engarouines	
2012 Oct 29.0	62.3	11.7	7.5	0.012	M. Bronikowska	Borowiec	
2012 Nov 10.2	59.8	7.5	1.0	0.009	W. Ogłoza, E. Kosturkiewicz	Suhora	
2012 Nov 11.1	59.6	7.2	4.5	0.007	W. Ogłoza, E. Kosturkiewicz	Suhora	
2012 Dec 28.8	51.2	17.1	7.5	0.008	K. Sobkowiak	Borowiec	
2013 Mar 02.8	61.7	22.9	3.2	0.006	R. Hirsch	Borowiec	
2013 Mar 03.8	62.0	22.9	2.7	0.005	M. Bronikowska	Borowiec	
2014 Feb 05.1	174.6	13.0	7.8	0.006	R. Hirsch	Borowiec	
2014 Feb 06.1	174.5	12.7	2.7	0.006	A. Marciniak	Borowiec	
2014 Feb 23.1	171.5	7.2	3.8	0.008	K. Sobkowiak	Borowiec	
2014 Feb 23.8	171.4	7.0	5.5	0.014	P. Kankiewicz	Kielce	
2014 Mar 09.1	168.3	4.4	5.1	0.007	R. Hirsch	Borowiec	
2014 Mar 10.1	168.1	4.5	2.1	0.016	J. Horbowicz	Borowiec	
2014 Mar 30.0	163.8	9.6	6.6	0.004	W. Ogłoza, E. Kosturkiewicz	Suhora	
2014 Apr 11.9	161.9	13.6	5.5	0.003	M. Siwak, E. Kosturkiewicz	Suhora	
2014 Apr 12.9	161.8	13.8	4.8	0.006	M. Siwak, E. Kosturkiewicz	Suhora	
2014 May 21.9	162.6	20.2	3.2	0.006	R. Hirsch	Borowiec	
2015 May 08.0	263.6	12.5	3.2	0.005	W. Ogłoza	Suhora	
2015 May 10.4	263.3	11.8	2.3	0.004	K. Kamiński	Winer	
2015 May 19.0	262.0	9.0	2.4	0.002	M. Żejmo	Adiyaman	
2015 May 31.0	259.6	5.1	4.7	0.004	-	Montsec	
2015 Jun 13.9	256.4	4.0	4.0	0.004	M. Żejmo	Adiyaman	
2015 Jun 15.3	256.1	4.3	6.2	0.003	F. Pilcher	Organ Mesa Obs.	
2015 Jun 17.3	255.7	4.9	3.5	0.003	F. Pilcher	Organ Mesa Obs.	
2015 Jun 18.0	255.5	5.1	5.3	0.005	-	Montsec	
			119.3 total				

Table 8. Observation details: mid-time observing date, ecliptic longitude of the target, sun-target-observer phase angle, duration of the observing run, brightness scatter, observer, and site name. See Table 1 for telescope and site details.

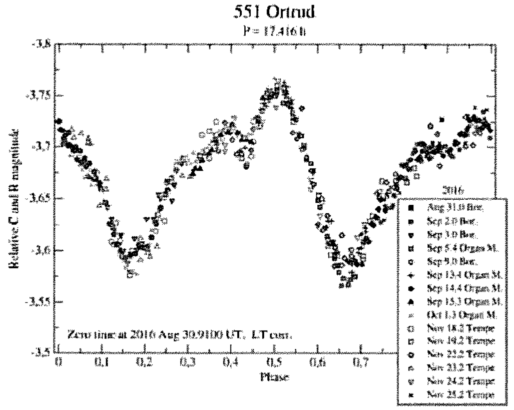

Fig. 26. Composite lightcurve of (551) Ortrud in the year 2016

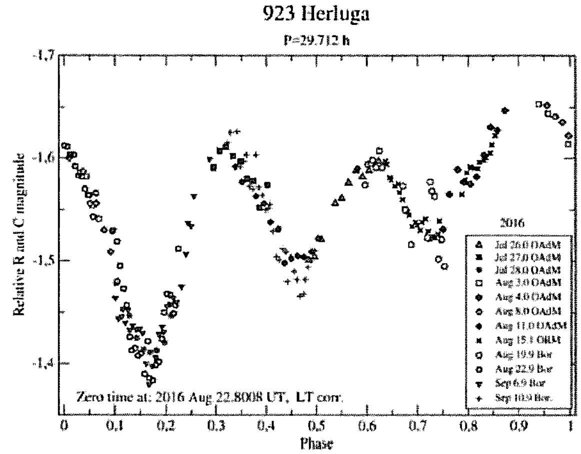

Fig. 29. Composite lightcurve of (923) Herluga in 2016

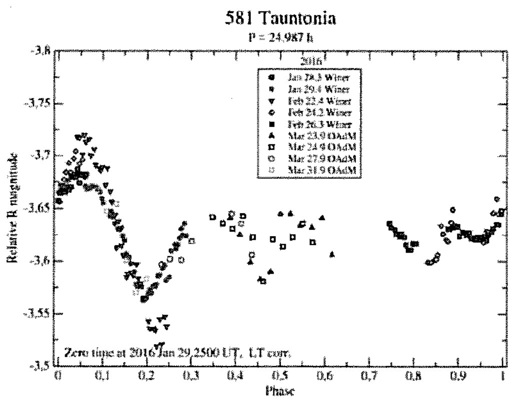

Fig. 27. Composite lightcurve of (581) Tauntonia in 2016

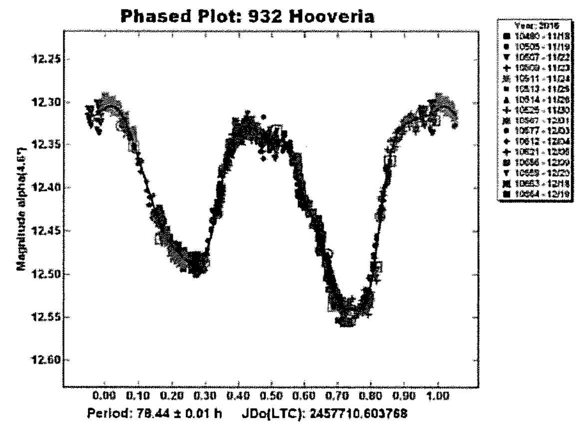

Fig. 30. Calibrated composite lightcurve of (932) Hooveria in 2016

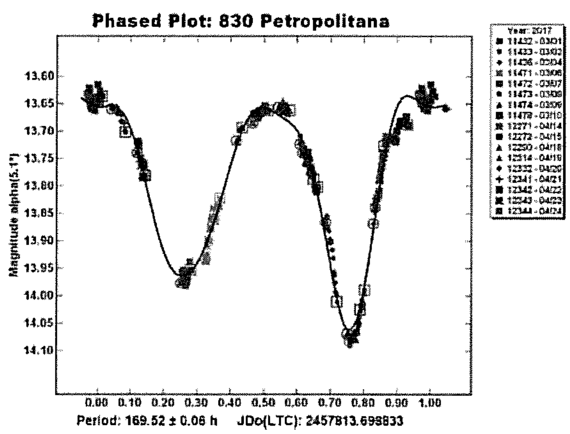

Fig. 28. Calibrated composite lightcurve of (830) Petropolitana in 2017

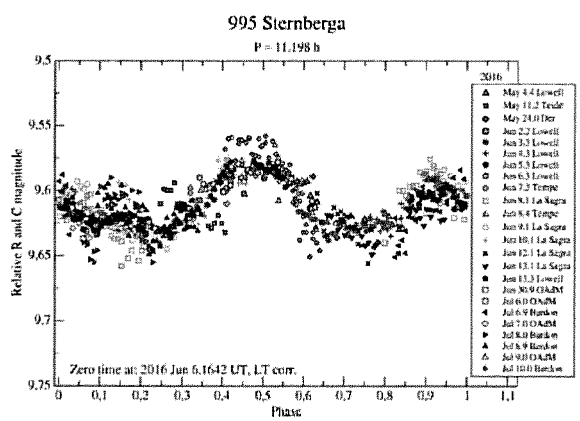

Fig. 31. Composite lightcurve of (995) Sternberga in 2016

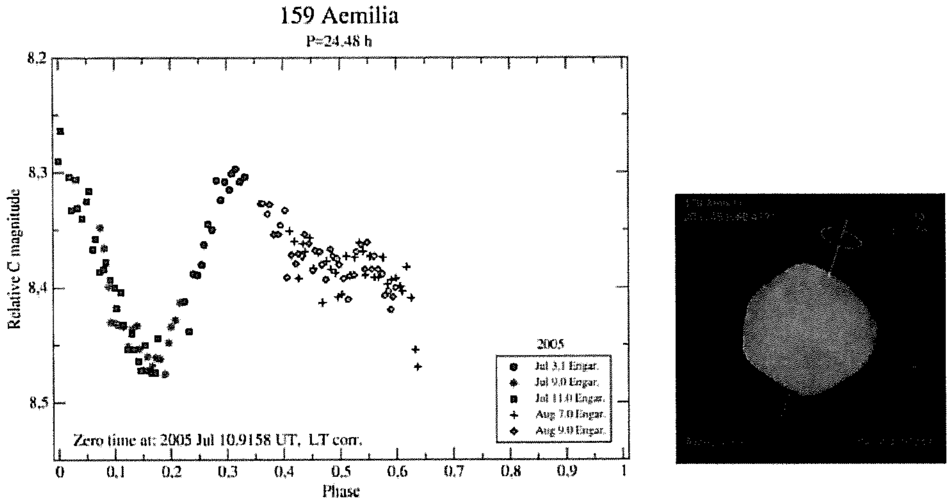

Fig. 32. Composite lightcurve of (159) Aemilia in the year 2005 with the orientation of SAGE model 1 for the zero phase

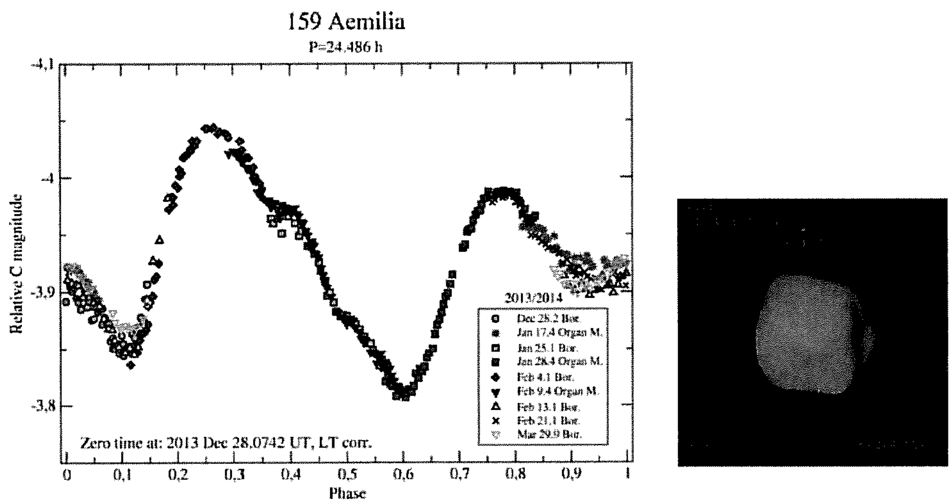

Fig. 33. Composite lightcurve of (159) Aemilia in the years 2013-2014 with the orientation of SAGE model 1 for the zero phase

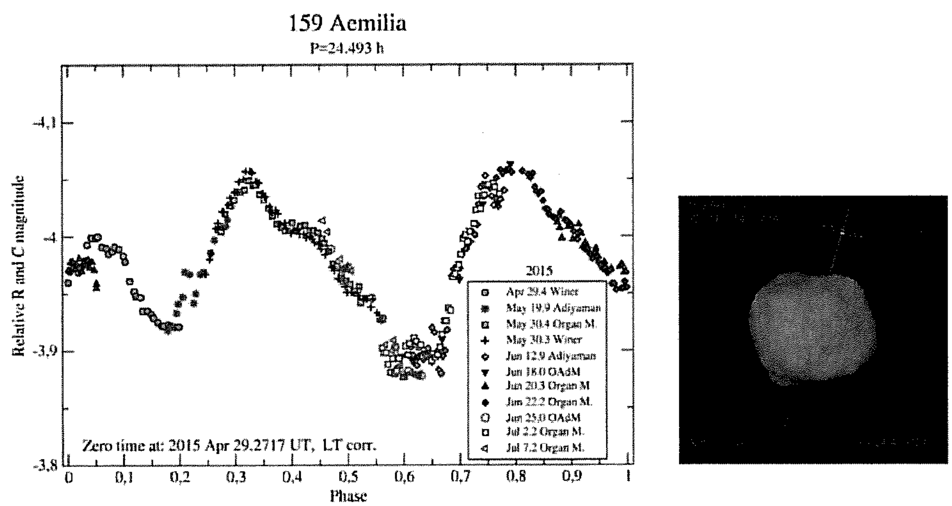

Fig. 34. Composite lightcurve of (159) Aemilia in the year 2015 with the orientation of SAGE model 1 for the zero phase

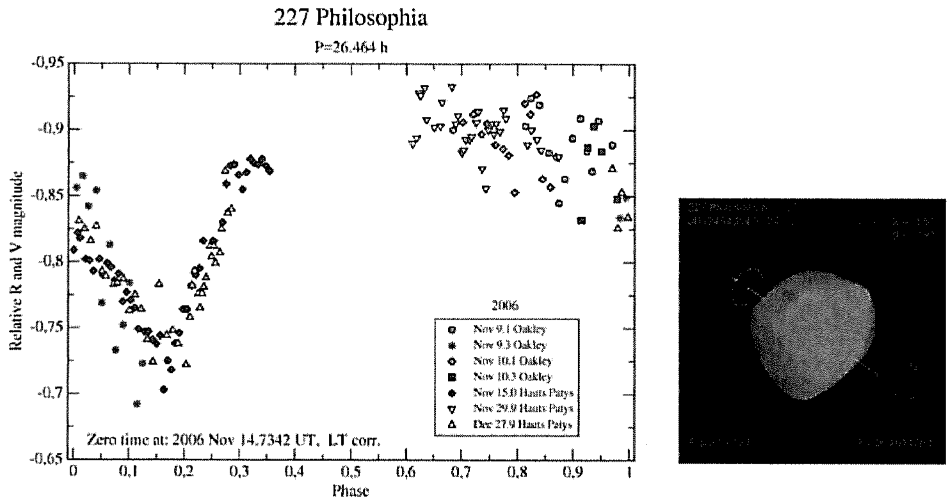

Fig. 35. Composite lightcurve of (227) Philosophia in the year 2006 with the orientation of convex model 1 for the zero phase

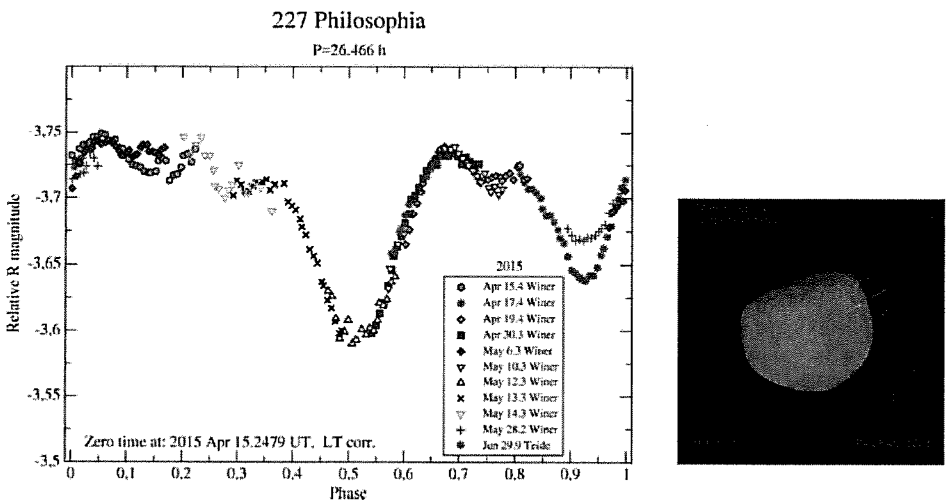

Fig. 36. Composite lightcurve of (227) Philosophia in the year 2015 with the orientation of convex model 1 for the zero phase

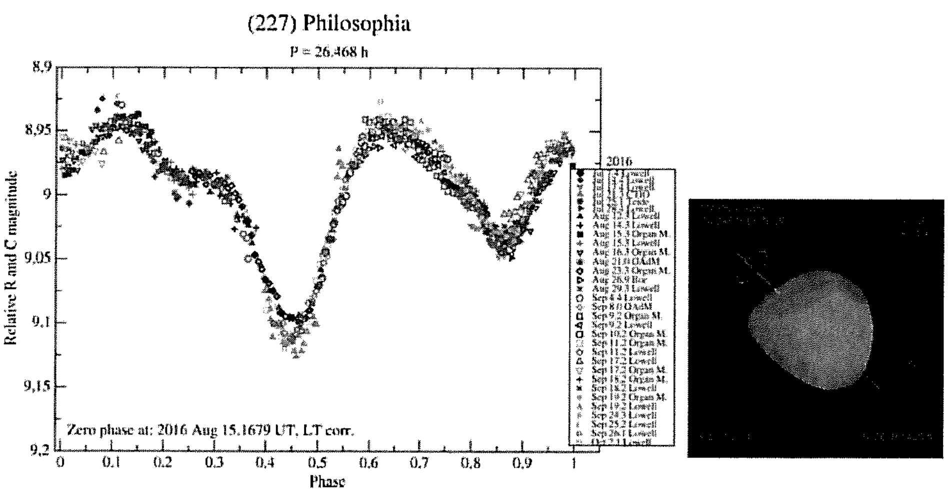

Fig. 37. Composite lightcurve of (227) Philosophia in the year 2016 with the orientation of convex model 1 for the zero phase

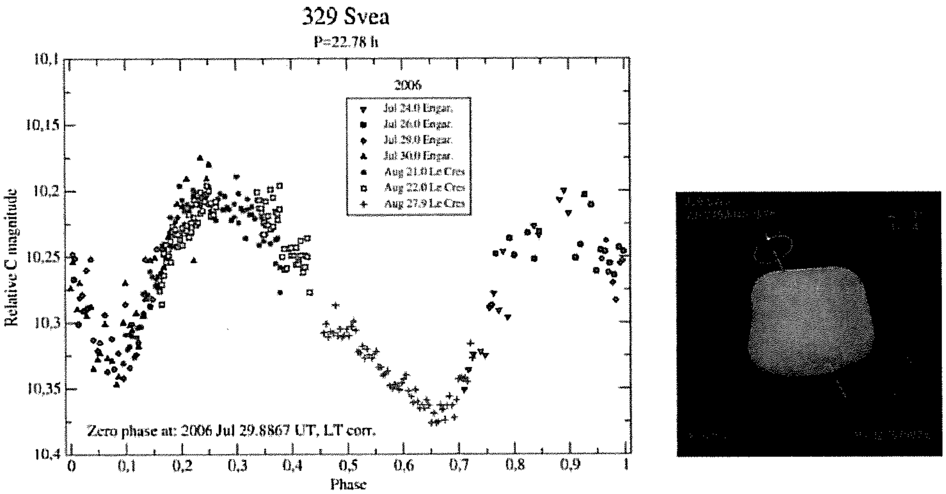

Fig. 38. Composite lightcurve of (329) Svea in the year 2006 with the orientation of SAGE model 1 for the zero phase

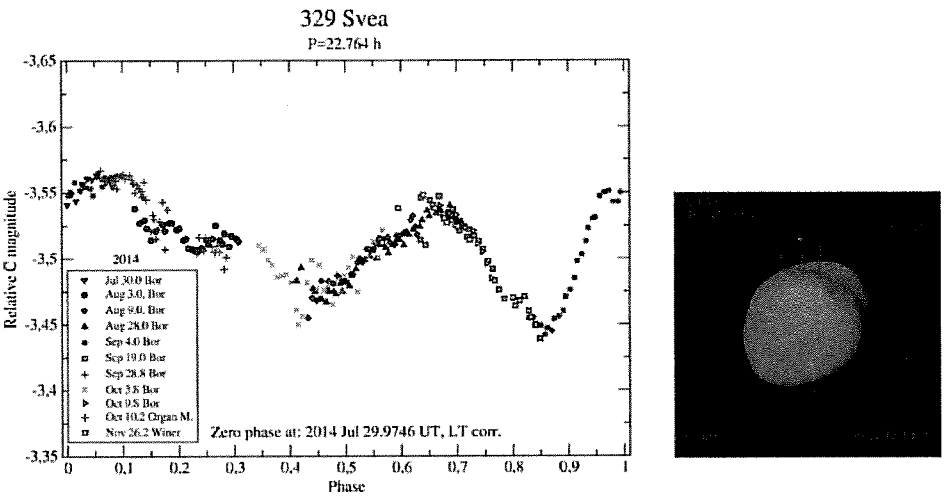

Fig. 39. Composite lightcurve of (329) Svea in the year 2014 with the orientation of SAGE model 1 for the zero phase

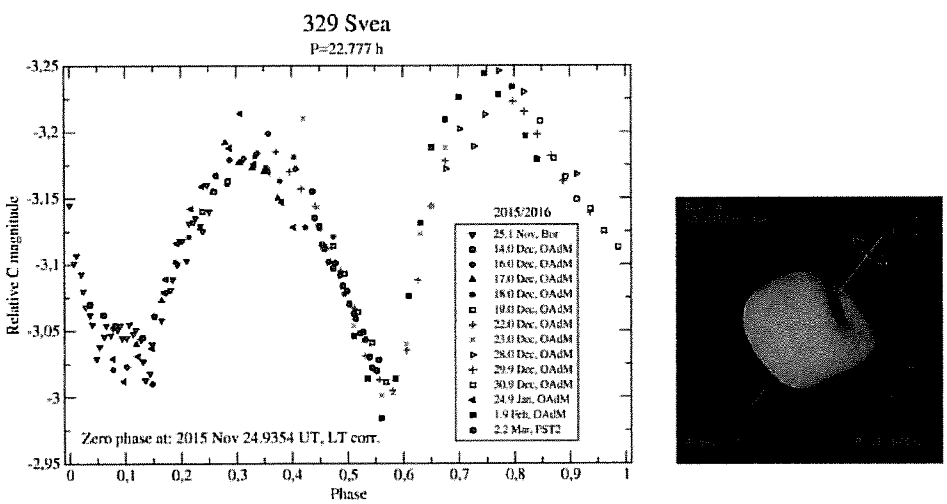

Fig. 40. Composite lightcurve of (329) Svea in the years 2015-2016 with the orientation of SAGE model 1 for the zero phase

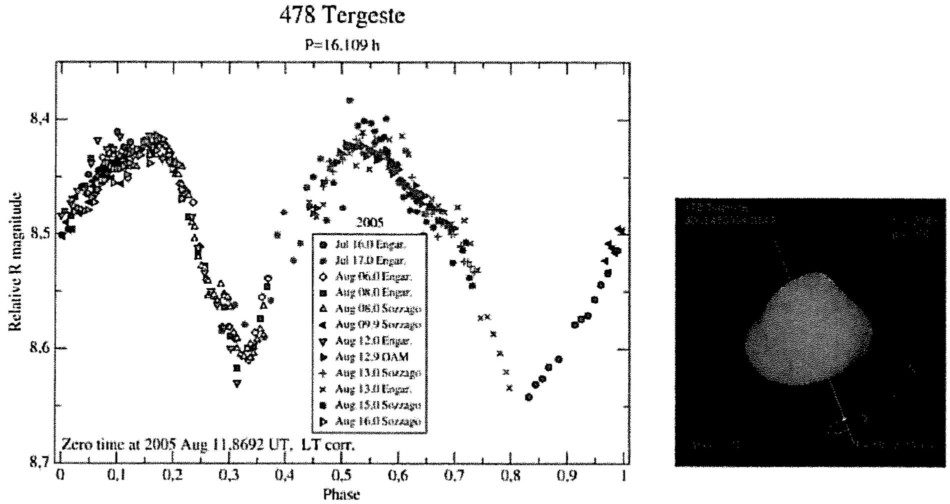

Fig. 41. Composite lightcurve of (478) Tergeste in the year 2005 with the orientation of SAGE model 2 for the zero phase

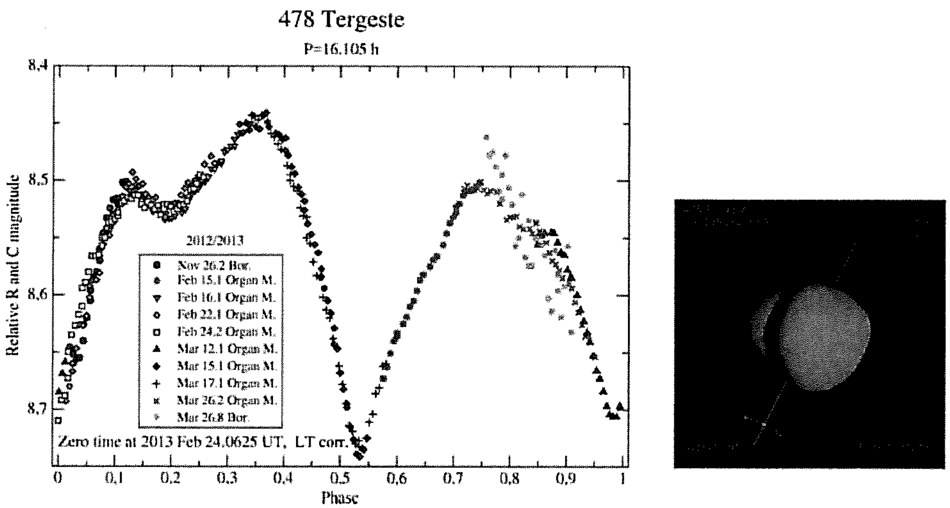

Fig. 42. Composite lightcurve of (478) Tergeste in the years 2012-2013 with the orientation of SAGE model 2 for the zero phase

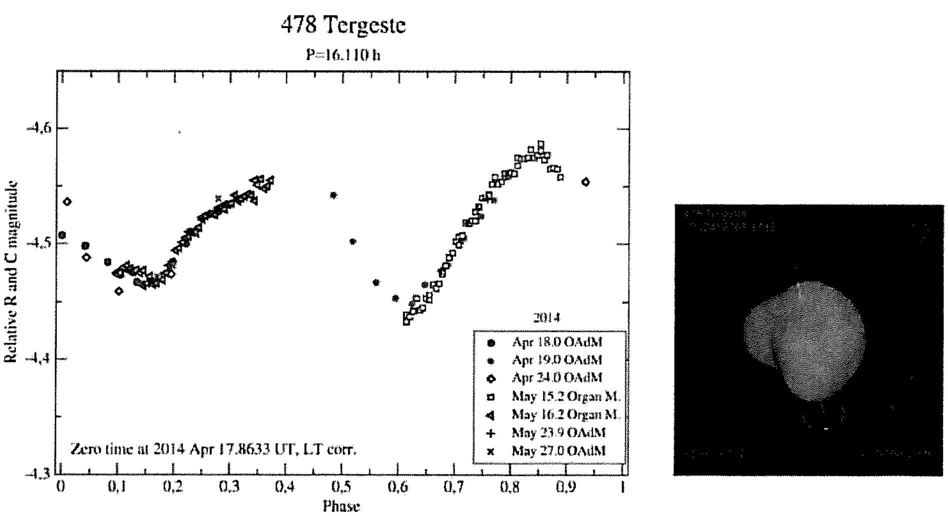

Fig. 43. Composite lightcurve of (478) Tergeste in the year 2014 with the orientation of SAGE model 2 for the zero phase

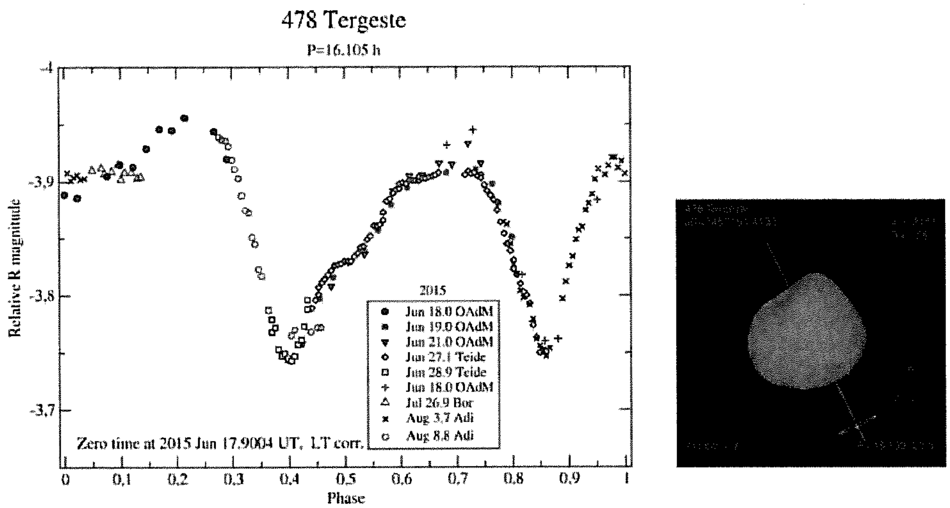

Fig. 44. Composite lightcurve of (478) Tergeste in the year 2015 with the orientation of SAGE model 2 for the zero phase

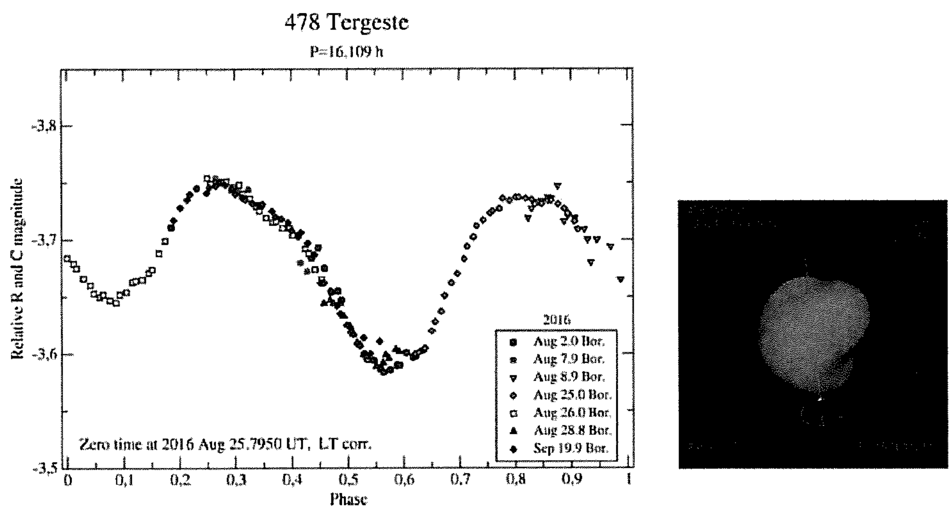

Fig. 45. Composite lightcurve of (478) Tergeste in the year 2016 with the orientation of SAGE model 2 for the zero phase

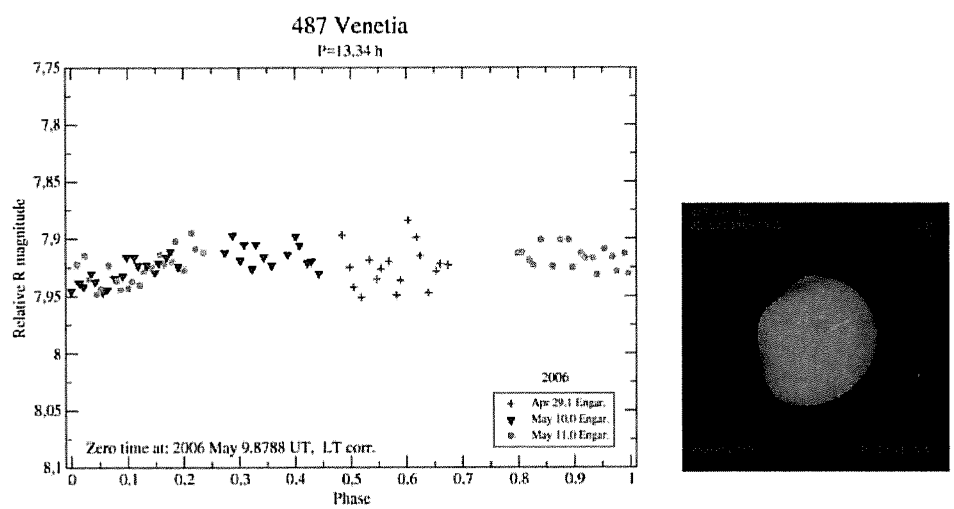

Fig. 46. Composite lightcurve of (487) Venetia in the year 2006 with the orientation of SAGE model 2 for the zero phase

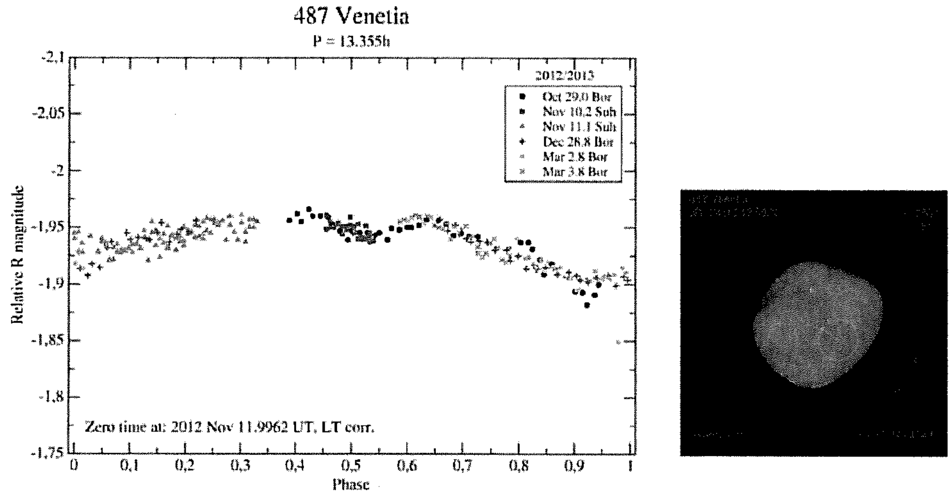

Fig. 47. Composite lightcurve of (487) Venetia in the years 2012-2013 with the orientation of SAGE model 2 for the zero phase

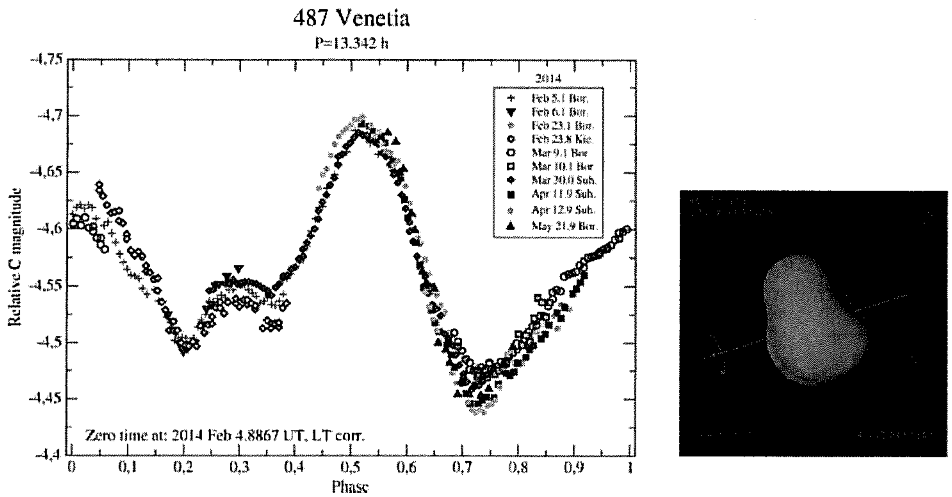

Fig. 48. Composite lightcurve of (487) Venetia in the year 2014 with the orientation of SAGE model 2 for the zero phase

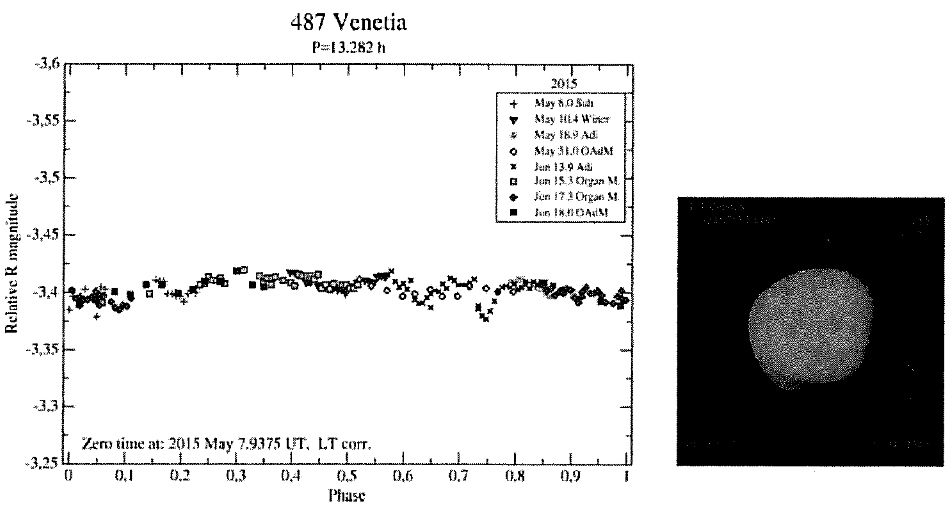

Fig. 49. Composite lightcurve of (487) Venetia in the year 2015 with the orientation of SAGE model 2 for the zero phase

Appendix B

List of stellar occultation observers.

(159) Aemilia (2009-05-02), USA

S. Meesner (Northfield, Minnesota)
S. Conard (Gamber, Maryland)
B. Koch (Faribault, Minnesota)
A. Scheck (Laurel, Maryland)

(329) Svea (2011-12-28), Japan

H. Tomioka (Hitachi city, Ibaraki Prefecture)
H. Takashima (Kashiwa, Chiba)
K. Kitazato (Musashino, Tokyo)
Y. Watanabe (Inabe, Mie)
S. Ida (Higashiomi, Shiga)
M. Ishida (Moriyama, Shiga)
M. Owada (Hamamatsu, Shizuoka)
K. Kasazumi (Takatsuki, Osaka)
S. Okamoto (Tsuyama, Okayama)
N. Tatsumi (Akaiwa, Okayama)
Hironaka and Miyamaoto (Hiroshima University Observatory, Hiroshima)

(329) Svea (2013-03-07), USA

P. Maley (5 sites, Forida)
D. Liles (Florida)
A. Cruz (Glen St. Mary, Florida)
E. Gray (Macclenny, Florida)
J. Brueggemann (Florida)
C. McDougal (Tampa, Florida)
T. Campbel (3 sites, Florida)

From: Johnson, Lindley (HQ-DG000) <lindley.johnson@nasa.gov>
Sent: Thursday, July 23, 2015 09:53
To: Mainzer, Amy (3266); Tommy Grav; Tim Spahr
Subject: RE: new version

Oh, joy.

From: Mainzer, Amy (3266) [mailto:Amy.Mainzer@jpl.nasa.gov]
Sent: Thursday, July 23, 2015 12:40 PM
To: Tommy Grav; Tim Spahr; Johnson, Lindley (HQ-DG000)
Subject: FW: new version

FYI

From: Nathan Myhrvold <nathanm@intven.com>
Date: Wednesday, July 22, 2015 8:01 PM
To: JPL <amy.mainzer@jpl.nasa.gov>
Subject: new version

I have submitted the paper, but also have had several extended email dialogs with Alan Harris (both of them!) and with Bruce Hapke. They agree with my derivation of NEATM model and my interpretation of Kirchhoff's law. However, Hapke suggested I change the notation for the albedo calculations so I have done so.

I am working further on that issue and should have something to show you soon.

Nathan

From: Johnson, Lindley (HQ-DG000) <lindley.johnson@nasa.gov>
Sent: Wednesday, April 25, 2012 09:40
To: Clavin, Whitney B (1871)
Cc: Mainzer, Amy (3266)
Subject: RE: NEOWise Summary of paper

Hi, Whitney.

I think you've identified good points for the story, but I'm thinking of a different path through them. I think you start with 3, then talk about 4 & 5, which are really two aspects of the same element, and then 1 and end with 2.

This is the story line as I see it. NEOWISE has given us the best population sample of the PHAs to date. They are smaller and brighter, probably indicating their origin as relatively recent breakups from the Main Belt. Because they have a MBA origin, that puts them in lower inclination orbits, which is confirmed by the NEOWISE sample. (But please don't call them "flat" orbits! All orbits are "flat". PHA orbits seem to be more "aligned with the plane of the solar system" – due to their MBA origin, probably.) And conveniently, this also makes them more easily accessible for human spaceflight.

Lindley

Lindley N. Johnson
NEO Observations Program Executive
Planetary Science Division
Science Mission Directorate
HQ NASA

202 358-2314
Lindley.Johnson-1@nasa.gov

From: Clavin, Whitney B (1871) [mailto:whitney.b.clavin@jpl.nasa.gov]
Sent: Tuesday, April 24, 2012 9:42 PM
To: Johnson, Lindley (HQ-DG000)
Cc: Mainzer, Amy
Subject: Re: NEOWise Summary of paper

Hi Lindley,

I'll probably start writing this release text up soon since Amy's paper was accepted. Can you look at my message points below and let me know if you have any comments about them before I start writing? I've got 5 message points below, which may not all make into the NASA release (as you know it has to be really simple and 2 pages or under). Which message points do you think are most important to include? I would think #1,3 and then 2.

Thanks!
-Whitney

From: "Mainzer, Amy (3266)" <Amy.Mainzer@jpl.nasa.gov>
Date: Mon, 9 Apr 2012 09:25:36 -0700
To: "Johnson, Lindley (HQ-DG000)" <lindley.johnson@nasa.gov>, JD Harrington <jharring@nasa.gov>

Cc: "Brown, Dwayne C. (HQ-NB070)" <dwayne.c.brown@nasa.gov>, Whitney Clavin <Whitney.B.Clavin@jpl.nasa.gov>
Subject: Re: NEOWise Summary of paper

The paper is almost through the review process; I have been through the first round and have responded, and the referee has asked for a few minor changes. I'm hoping to resubmit the manuscript today as they are small. Lindley, I'll send you a separate email with the technical details summarizing the reviewer's comments and the response in a little while. The referee was Al Harris of Pasadena.

From: "Johnson, Lindley (HQ-DG000)" <lindley.johnson@nasa.gov>
Date: Mon, 9 Apr 2012 03:48:03 -0700
To: "HARRINGTON, J D (HQ-NG000)" <jharring@nasa.gov>
Cc: "Brown, Dwayne C. (HQ-NG000)" <dwayne.c.brown@nasa.gov>, "Mainzer, Amy (3266)" <Amy.Mainzer@jpl.nasa.gov>, "Clavin, Whitney B (1871)" <whitney.b.clavin@jpl.nasa.gov>
Subject: RE: NEOWise Summary of paper

I'll stay in touch with Amy on this paper as it goes through review. If this all survives the peer review of the paper, it could warrant some kind of press event, but not necessarily a full up press conference.

Lindley

Lindley N. Johnson
NEO Observations Program Executive
Planetary Science Division
Science Mission Directorate
HQ NASA

202 358-2314
Lindley.Johnson-1@nasa.gov

From: HARRINGTON, J D (HQ-NG000)
Sent: Friday, April 06, 2012 9:10 AM
To: Johnson, Lindley (HQ-DG000)
Cc: Brown, Dwayne C. (HQ-NG000)
Subject: NEOWise Summary of paper

Lindley,

Can you take a look at this science summary that JPL sent me a few weeks ago (it was just a heads up). They thought you might think it warrants a news conference. What say you?

J.D.

J.D. HARRINGTON
Public Affairs Officer
National Aeronautics and Space Administration
Office of Communications
Science Mission Directorate / Astrophysics Division
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Suite 7N24
Washington, D.C. 20546-0001
Email: j.d.harrington@nasa.gov

Voice: (202) 358-5241
Cell: (202) 262-7048
Fax: (202) 358-3530

Creativity is all in your mind!

From: Clavin, Whitney B (1871) [mailto:whitney.b.clavin@jpl.nasa.gov]
Sent: Monday, March 19, 2012 4:50 PM
To: Brown, Dwayne C. (HQ-NG000); HARRINGTON, J D (HQ-NG000)
Cc: PERROTTO, TRENT J. (HQ-NG000); Agle, David C
Subject: Re: summary of paper

Hi there,

Wanted to put an upcoming NEOWISE paper on your radar (pun highly intended). The paper is not yet accepted but should be within weeks, after which time we could do press. The paper probably wouldn't be published for a month or two after it's accepted. A summary is below, with the major news points in bold. And then if you look further below, there's a summary from Amy with a bit more science. Amy has already spoken to Lindley about this research. Our office is thinking this should be a news release, but we are interested in getting your feedback. Amy thought that perhaps Lindley would want a news conference.

-Whitney

1. **A statistical survey based on data from NASA's NEOWISE mission has revealed that potentially hazardous asteroids, or PHAs, may have less inclined orbits relative to Earth's, or more "flat" orbits, than previous believed.** PHAs are those asteroids that come within 4.6 million miles of Earth. They are the more hazardous subset of near-Earth asteroids, which are those that come within 120 million miles of the sun. **The results indicate that the PHA population may be more hazardous than previous thought, since low-inclination orbits are more likely to encounter Earth**. (A future paper will explicitly calculate this increase in hazard based on population models.)

2. **The lower-inclination PHAs may offer more accessible targets for human exploration**, because they would be easier to get to (you don't need as much energy to get to an orbit similar to Earth's).

3. **The NEOWISE observations also allow for the best, and perhaps first, good estimation of the total PHA population**. The results suggest there are roughly 4,700 PHAs larger than 100 meters in size. Of these, about 20 to 30 percent have been discovered so far, which loosely matches prior estimates of the numbers of PHAs left to find. (Team is checking literature to determine what other estimates may have been reported before.)

4. **The results also show that the PHAs as a whole are smaller and brighter, which may mean they have a different composition on average than the rest of the NEOs.**

5. The data also reveal that many of the PHAs with lower-inclination orbits are also smaller and brighter than the rest of the bunch. **This indicates that this particular subset of PHAs may have originated from a break-up event between larger asteroids in the Main Belt between Mars and Jupiter**. More data are needed to support this theory.

From: "Mainzer, Amy (3266)" <Amy.Mainzer@jpl.nasa.gov>
Date: Mon, 12 Mar 2012 19:18:31 -0700
To: Whitney Clavin <Whitney.B.Clavin@jpl.nasa.gov>
Subject: summary of paper

Hi, Whit-

Here is the summary of the NEO subpopulations paper.

Amy

Summary of paper "Characterizing Subpopulations within the Near Earth Objects with NEOWISE: Preliminary Results" by A. Mainzer et al.

Submitted to Astrophysical Journal
Referee's report received

This paper takes the near-Earth object (NEO) sample detected by NEOWISE using the WISE Moving Object Processing System (WMOPS) and considers sub-groups within the NEOs. In particular, the paper focuses on potentially hazardous asteroids (PHAs), which are NEOs that have orbits that get within 0.05 AU of the Earth's orbit. PHAs are a population of interest because they have some change of evolving into impactors over the next 100 years or so. We are taking advantage of the uniformity and thermal wavelengths offered by the NEOWISE survey to make an estimate of the number of PHAs larger than 100 m, to study the physical properties of the PHAs, and to learn about their orbits. We found that there are about 4700+/-1450 PHAs larger than 100m; this is the first time, to my knowledge, that a firm prediction has been made of their numbers. Of these, only about 20-30% have been discovered to date, so many more remain to be found.

We have also studied three additional classes of NEOs, the Atens, Apollos, and Amors. Broadly speaking, these represent Earth-crossing (Atens and Apollos) and non-Earth crossing asteroids (Amors). Within the Amors, we find that those with perihelia less than 1.1 AU are smaller and brighter than those with perihelia larger than 1.1 AU. This result suggests that the two groups of Amors have different origins: the high perihelion Amors are more likely to be dead or dormant comets tossed inward by Jupiter, while the low perihelion Amors are more likely to originate within the Main Belt.

We have also found that the PHAs tend to be somewhat smaller and brighter than the average NEO. Furthermore, our result suggests that there are more PHAs with low orbital inclinations that are predicted by the current model, and these lowinclination PHAs tend to be smaller and brighter than the rest of the PHAs. This result suggests that a) the hazard to Earth may be somewhat greater than expected from their numbers alone, since low inclination PHAs will tend to have greater chances of impact; b) the low inclination PHAs may have a different origin than the rest of the PHAs, and the rest of the NEOs; c) there may be more accessible targets for human exploration. We show with a back-of-the-envelope calculation that a breakup of a relatively small low inclination family member in the Main Belt could be responsible for the overabundance of small, bright, low inclination PHAs that we see. We caution, however, that our sample size is somewhat small and would be improved by finding more PHAs. This result will inform future calculations of impact hazard, as well as the best ways to search for hazardous asteroids.

Subject: Re: NY Times
Date: Tuesday, April 12, 2016 at 10:26:05 AM Eastern Daylight Time
From: Statler, Thomas S. (HQ-DG000)[NASA IPA]
To: Mainzer, Amy (JPL-3266)[Jet Propulsion Laboratory]
CC: Billings, Linda (HQ-DG000)[NATIONAL INSTITUTE OF AEROSPACE], Johnson, Lindley (HQ-DG000)

I read Nathan's previous draft and gave him some pointed suggestions without trying to referee the paper. He is doing some things correctly and other things incorrectly. In the end I see his basic results as largely confirming earlier results in broad brush, but with some modifications. I think that his calculations on the error distributions deserve to be examined carefully. Unfortunately he feels it's his duty to explain to the community in great detail every single thing that he thinks the NEOWISE team did wrong. I did my best to coach him not to go that route. But I can only do so much. He sent me a new draft over the weekend that I haven't looked at yet; he says that I will think it is still too harsh.

Tom

On Apr 12, 2016, at 10:16 AM, Mainzer, Amy (3266) <Amy.Mainzer@jpl.nasa.gov> wrote:

> Yes, all too well. Nathan has made some basic mathematical errors in his calculations; he does not understand how we handle the absolute magnitudes of the asteroids in the thermal modeling. If I make the same erroneous assumptions, I can reproduce his results.
>
> ---
>
> **From:** Linda Billings < (b) (6)
> **Date:** Tuesday, April 12, 2016 6:59 AM
> **To:** JPL <amy.mainzer@jpl.nasa.gov>
> **Cc:** "Johnson, Lindley (HQ-DG000)" <lindley.johnson@nasa.gov>, "Statler, Thomas S. (HQ-DG000)[NASA IPA]" <thomas.s.statler@nasa.gov>

Subject: Re: NY Times

This is Nathan Myhrvold's paper - remember him?

I'm CCing Lindley and Tom Statler, who are aware of this paper and may have some advice. Nathan attended the last SBAG meeting, in CA. He's rich and famous (and, IMHO, quite eccentric), so reporters will always listen to him.

Sigh...

Linda

Linda Billings, Ph.D.
Consultant to NASA's Astrobiology Program and Planetary Defense Coordination Office
National Institute of Aerospace
ph. 703-528-2334, 703-635-9799 (mobile)
@lbillin
http://doctorlinda.wordpress.com

On Tue, Apr 12, 2016 at 9:42 AM, Mainzer, Amy (3266) <Amy.Mainzer@jpl.nasa.gov> wrote:

> FYI - could use some help with this.
>
> Begin forwarded message:
>
> > **From:** "Agle, David C (1871)" <david.c.agle@jpl.nasa.gov>
> > **Date:** April 12, 2016 at 6:47:55 AM MDT
> > **To:** "Mainzer, Amy (3266)" <Amy.Mainzer@jpl.nasa.gov>
> > **Subject: NY Times**
> >
> > Hi Amy,
> > Got a call from the NY Times (Ken Chang) regarding a paper a 'Nathan Marigold' (not sure on name – it was a garbled phone message) is putting out/has put out about 'NEOWISE data being a lot less reliable than thought.'
> > Can you call me at your earliest convenience?
> > DC

Subject: Meet today re: NEOCam TPM

Date: Thursday, January 28, 2016 at 10:03:12 AM Mountain Standard Time

From: Statler, Thomas S. (HQ-DG000)[NASA IPA]

To: Carrie Nugent, Brozovic, Marina (JPL-392R)[Jet Propulsion Laboratory], tgrav@psi.edu

CC: Mainzer, Amy (JPL-3266)[Jet Propulsion Laboratory], Chesley, Steven R (JPL-392R)[Jet Propulsion Laboratory]

Dear Marina, Carrie, Tommy,

If at all possible I'd like to meet with you some time today or early tomorrow morning to talk about thermophysical modeling and rotational variability. Can do this individually or together, but I'm booked at noon as well as 3:30 to 5:00, and have to leave tomorrow before 11. Please let me know when you'd like to meet up.

Steve, not sure if you are still attending SBAG but if so you're included too.

Cheers,
Tom

Thomas S. Statler, Ph.D.
Discipline Scientist
Planetary Science Division
NASA Headquarters
Washington DC 20546-0001
+1-202-358-0272

Subject: Re: Meet today re: NEOCam TPM
Date: Thursday, January 28, 2016 at 12:08:16 PM Mountain Standard Time
From: Statler, Thomas S. (HQ-DG000)[NASA IPA]
To: Carrie Nugent
CC: Brozovic, Marina (JPL-392R)[Jet Propulsion Laboratory], tgrav@psi.edu, Chesley, Steven R (JPL-392R)[Jet Propulsion Laboratory]

Ok, let's aim for as close to 5 pm as possible, modulo blender emergencies.

Thomas S. Statler, Ph.D.
Discipline Scientist
Planetary Science Division
NASA Headquarters

On Jan 28, 2016, at 9:46 AM, Carrie Nugent <cnugent@ipac.caltech.edu> wrote:

> I've got meetings this morning, will be there at noon. Busy right after lunch for about a half hour and want to attend Amy's talk. Not coming in tomorrow. Could meet before 6 but need to get blender to Rob.
>
> On Thu, Jan 28, 2016 at 9:43 AM, Brozovic, Marina (392R) <Marina.Brozovic@jpl.nasa.gov> wrote:
>
>> I'm here all day today, but I will not be coming in tomorrow.
>> I am available until about 6-ish pm today.
>>
>> Marina
>>
>> ---
>>
>> **From:** "Statler, Thomas S. (HQ-DG000)[NASA IPA]" <thomas.s.statler@nasa.gov>
>> **Date:** Thursday, January 28, 2016 at 9:03 AM
>> **To:** Carrie Nugent <cnugent@ipac.caltech.edu>, "Brozovic, Marina (392R)" <Marina.Brozovic@jpl.nasa.gov>, "tgrav@psi.edu" <tgrav@psi.edu>
>> **Cc:** "Mainzer, Amy (3266)" <Amy.Mainzer@jpl.nasa.gov>, "Chesley, Steven R (392R)" <Steve.Chesley@jpl.nasa.gov>
>> **Subject:** Meet today re: NEOCam TPM
>>
>> Dear Marina, Carrie, Tommy,
>>
>> If at all possible I'd like to meet with you some time today or early tomorrow morning to talk about thermophysical modeling and rotational variability. Can do this individually or together, but I'm booked at noon as well as 3:30 to 5:00, and have to leave tomorrow before 11. Please let me know when you'd like to meet up.

Steve, not sure if you are still attending SBAG but if so you're included too.

Cheers,
Tom

Thomas S. Statler, Ph.D.
Discipline Scientist
Planetary Science Division
NASA Headquarters
Washington DC 20546-0001
+1-202-358-0272

--

Dr. Carrie Nugent

Scientist
NEOWISE Team
www.crnugent.com

Subject: Re: Myhrvold on NYT
Date: Tuesday, May 24, 2016 at 9:30:51 AM Eastern Daylight Time
From: Statler, Thomas S. (HQ-DG000)[NASA IPA]
To: Mainzer, Amy (JPL-3266)[Jet Propulsion Laboratory]
CC: Billings, Linda (HQ-DG000)[NATIONAL INSTITUTE OF AEROSPACE], Johnson, Lindley (HQ-DG000), Brown, Dwayne C. (HQ-NG000), Cantillo, Laurie (HQ-NG000)[INNOVATIVE TECHNOLOGIES INCORPORATED]

Amy,

Then I guess I misunderstood you on the phone. I thought you were reading from a draft document but maybe you were just talking and I hadn't heard the close-quote marks. My mistake.

Thomas S. Statler, Ph.D.
Discipline Scientist
Planetary Science Division
NASA Headquarters

On May 24, 2016, at 9:17 AM, Mainzer, Amy (3266) <Amy.Mainzer@jpl.nasa.gov> wrote:

> Tom, the JPL draft we worked up says nothing about the writer. We stuck to the technical issues and pointed out a few of the most obvious errors.
>
> The only time I mentioned Ken is during the interview with Lee Billings. He asked where Nathan got the idea that we misused radar data as our own. I answered truthfully that this misunderstanding originally came from Ken, since this was what was in the correspondence with him.
>
> I am happy to have HQ and PAO handle this and am confident in your approach. I appreciate this since I need to focus on other things.
>
> On May 24, 2016, at 5:42 AM, Linda Billings (b) (6) wrote:
>
>> Speaking as a scholar of journalism -
>>
>> There is no point in criticizing the NY Times or Ken Chang in any way or form or channel - it's considered the news outlet of record. In the world of mass media, the NY Times is a bigger deal than NASA is.

Chang's story is prototypical - overall, "fair and balanced," but leading with the sensational stuff - to get people to read it. The story is framed as a "spat" - conflict is the #1 news value, as it has been for a century (or more). Of course I don't like this story - but it's prototypical, standard, "newsy" in journalistic terms.

My five cents worth: everybody take a deep breath......

And, yes, let peer review do its thing,

LB

Linda Billings, Ph.D.
Consultant to NASA's Astrobiology Program and Planetary Defense Coordination Office
National Institute of Aerospace
ph. (b) (6)
@lbillin
http://doctorlinda.wordpress.com

On Mon, May 23, 2016 at 6:36 PM, Statler, Thomas S. (HQ-DG000)[NASA IPA] <thomas.s.statler@nasa.gov> wrote:

> Just got off the weekly telecon for NEOCam, and as you might expect there is substantial heat under many collars. I understand that multiple statements are being drafted. I'm going to go ahead and offer my opinions, in the interest of time, even though they haven't been asked for.
>
> 1. NYT deserves criticism for publishing an article that has a clear bias in tone based on a non-peer-reviewed paper.
> 2. My understanding is that the JPL PAO statement being drafted is overtly and personally critical of the NYT writer. Regardless of whether the contentions are true, I think that NASA and JPL shouldn't go that route because it will inevitably look bad.
> 3. Myhrvold has a lot of errors in his paper. Some are substantial, and affect his calculations and results. Others are sloppy but incidental. The temptation to point out EVERY error should be resisted – if the flaws in his paper need to be publicly aired, any such statement should stick to the most important points.
> 4. Everyone has the right to write a paper, submit it for publication, and post it to arXiv before review. That's not at issue.
> 5. The peer review process is SUPPOSED to weed out egregious errors and we should hope that it does in this case.
>
> I hope some of this is helpful.
>
> Tom
>
> From: "Statler, Thomas S. (HQ-DG000)[NASA IPA]" <thomas.s.statler@nasa.gov<mailto:thomas.s.statler@nasa.gov>>
> Date: Monday, May 23, 2016 at 6:01 PM
> To: "Johnson, Lindley (HQ-DG000)" <lindley.johnson@nasa.gov<mailto:lindley.johnson@nasa.gov>>, "Brown, Dwayne C. (HQ-NG000)" <dwayne.c.brown@nasa.gov<mailto:dwayne.c.brown@nasa.gov>>
> Subject: Myhrvold on NYT

In case you hadn't seen it:

http://www.nytimes.com/2016/05/24/science/asteroids-nathan-myhrvold-nasa.html

Subject: Re: Chang paper is out
Date: Monday, May 23, 2016 at 11:07:15 PM Eastern Daylight Time
From: Statler, Thomas S. (HQ-DG000)[NASA IPA]
To: Johnson, Lindley (HQ-DG000)

Will do.

On May 23, 2016, at 9:47 PM, Johnson, Lindley (HQ-DG000) <lindley.johnson@nasa.gov> wrote:

Please take a look at this draft response from JPL.

Can you verify that Myhrvoid made all these mistakes in his paper?

Need your take before noon tomorrow.

Lindley

Sent via the Samsung GALAXY S® 5, an AT&T 4G LTE smartphone

-------- Original message --------
From: "Cantillo, Laurie (HQ-NG000)[INNOVATIVE TECHNOLOGIES INCORPORATED]" <laura.l.cantillo@nasa.gov>
Date: 5/23/2016 17:23 (GMT-06:00)
To: "Johnson, Lindley (HQ-DG000)" <lindley.johnson@nasa.gov>
Cc: "Brown, Dwayne C. (HQ-NG000)" <dwayne.c.brown@nasa.gov>
Subject: Fwd: Chang paper is out

My initial reaction is that we would only add fuel to the fire by publishing a response. Thoughts?

Sent from my iPhone

Begin forwarded message:

From: "McGregor, Veronica (1870)" <veronica.c.mcgregor@jpl.nasa.gov>