Cross validation of albedo determination for 1627 Ivar from three different techniques

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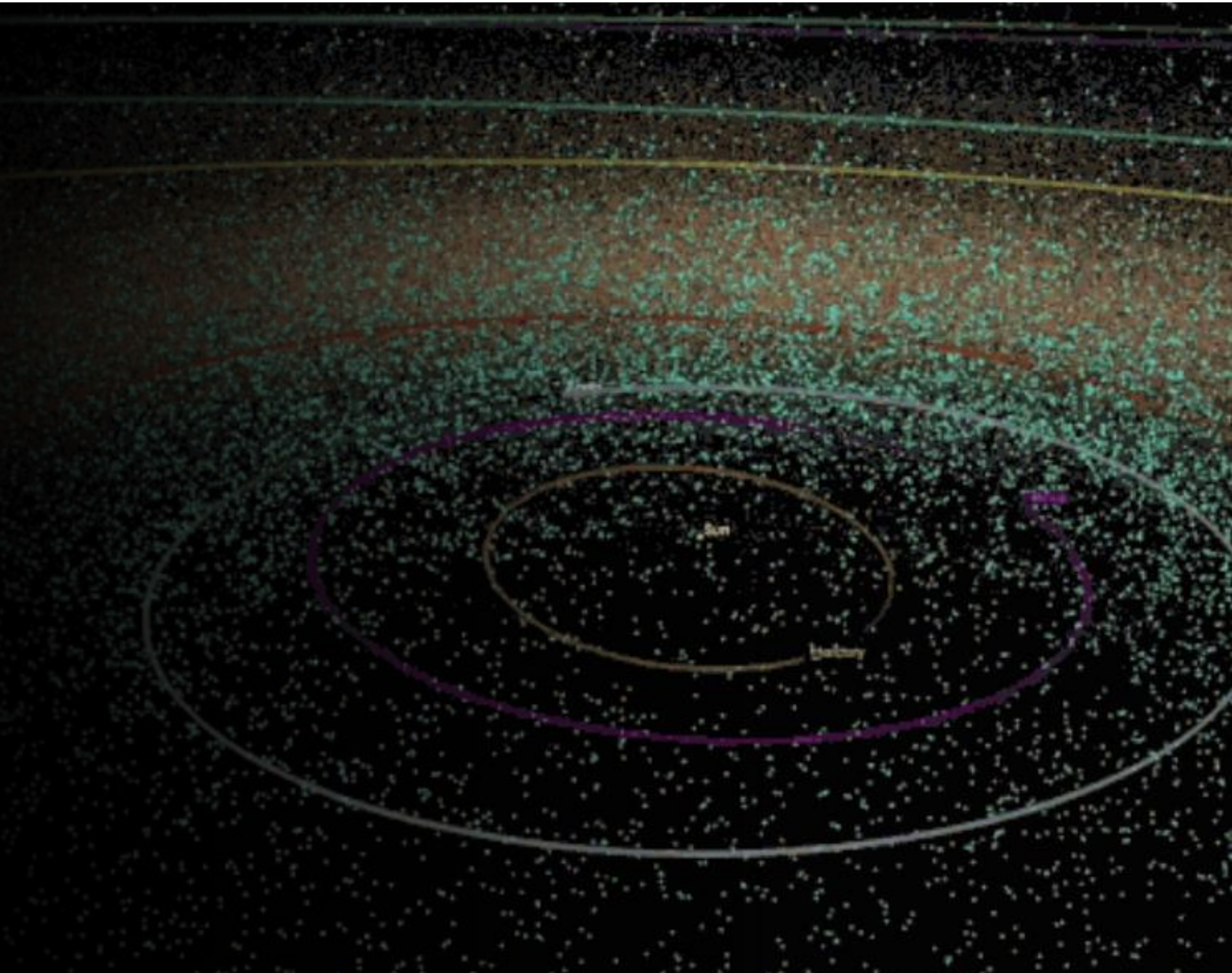
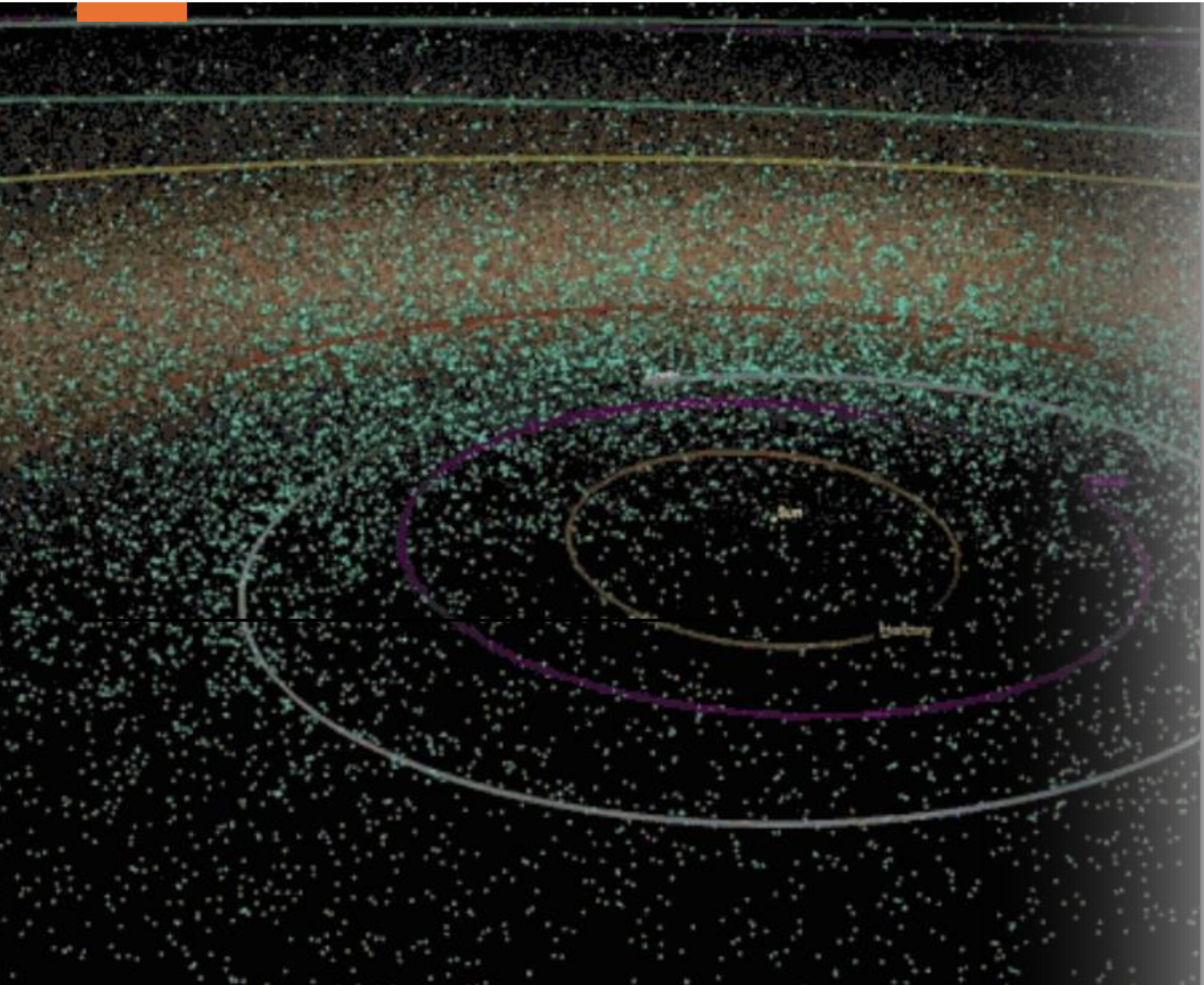


Phot credit: EarthSky.org

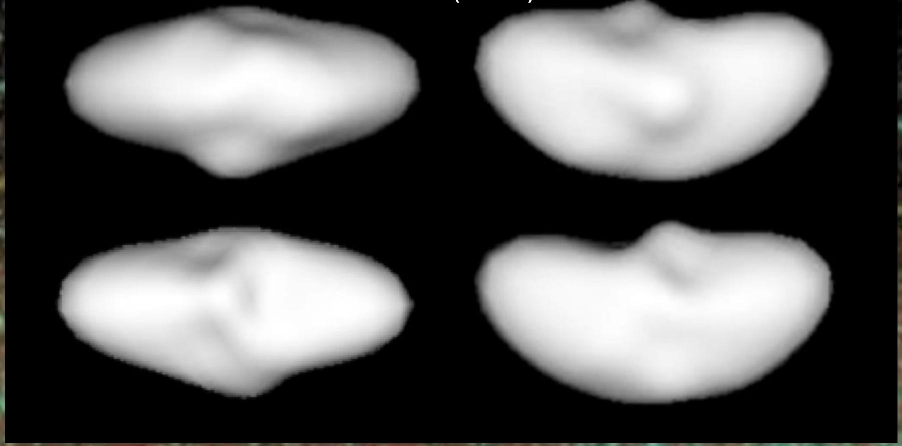


1627 Ivar

- Amor class: q>1.017 au but <1.3 au
- Taxonomy class: Sq
- Sydereal period: 4.795 h

1627 Ivar: size

Phot credit: Kaasalainen et al. (2004)



Radar echos:

- about twice as long as it is wide, maximum axis ~ 12 ± 2.4 km (Ostro et al. 1990)

Approximating to spherical shape:

- 8.845 km (Mainzer et al. 2014)
- 7.7 ± 0.6 km (Hanuš et al. 2015)

Radar and lightcurved based-model (Crowell 2017):

- three-body fixed coordinates: 15.15 × 6.25 × 5.66 km) ± 10%
- volume spherical equivalent = 8.12 ± 0.47 km)

1627 Ivar: albedo

Small - Body Database Lookup:

- 0.15

Mainzer et al. (2011):

- 0.151

Mainzer et al. (2014):

- 0.174 ± 0.02

Delbo et al. (2003):

- 0.15 (NEATM result)

Delbo et al. (2003):

- 0.20 (STM)

Fornasier et al. (2006):

- 0.3 (polarimetry)

Hanuš et al. (2015):

- 0.255 +0.02 −0.014 (VS-TPM)

$$D = \frac{1329}{\sqrt{p}} \times 10^{-H/5}$$

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Photometry for H-magnitude

Thermophysical Modeling (TPM)

Polarimetry

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Phot credit: EarthSky.org

Photometric measurements

- We extracted observations of Ivar from the version 2 of the Asteroid Terrestrial-impact Last Alert System (ATLAS) Solar System Catalog (SSCAT).
- We fitted these observations using the H, G1, G2 model of the asteroid phase function (Muinonen et al., 2010) using a Markov Chain Monte Carlo (MCMC) routine.
- The MCMC is run using prior information on the expected G1 and G2 parameters based on the results from Mahlke et al. (2021).

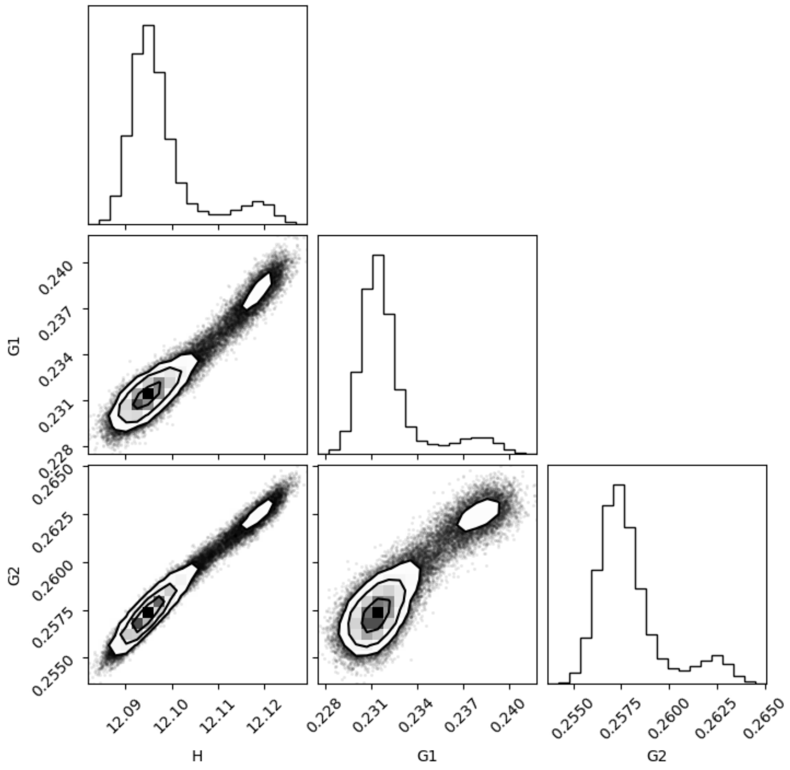


Figure 1: Corner plots and progression of the MCMC routine fitting for H, G1 and G2.

Photometric measurements

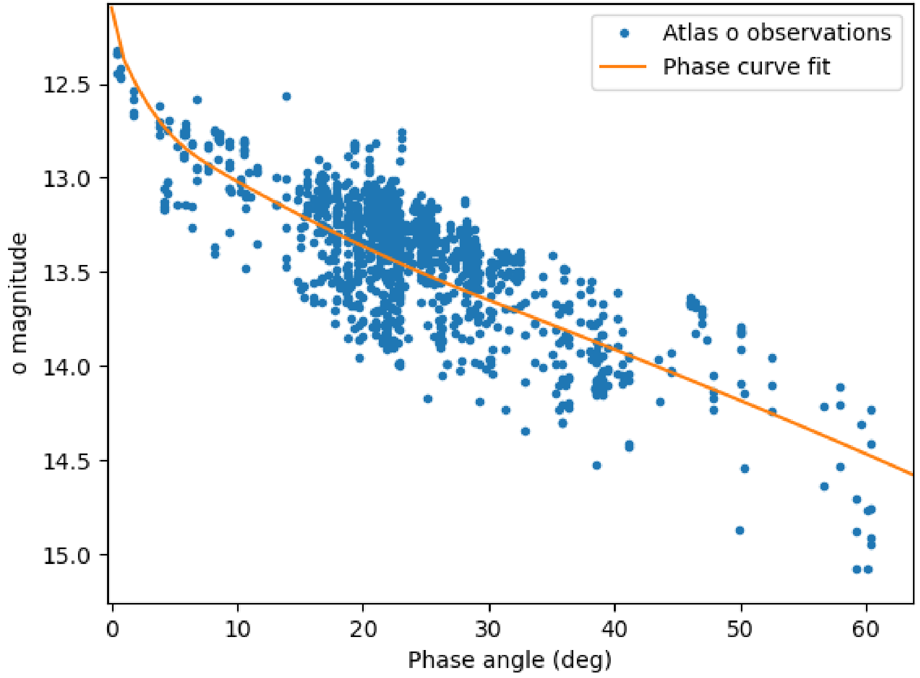


Figure 2: fitted phase curve of Ivar, with the data extracted from the SSCAT.

- We extracted the G1 and G2 distributions for all the S-type asteroids in Mahlke et al. (2021) and used it as a prior information for the expected G1 and G2 for Ivar (Vega and Devogèle method).
- We obtained H magnitude (in the o band) of 12.10±0.02, G1 = 0.23±0.01, and G2 = 0.26 ± 0.01
- Correcting for the v band, we obtained

$$\mathbf{H_V = 12.43 \pm 0.01}$$

- Using d = 8.12 ± 0.47 km (Crowell 2017), we get

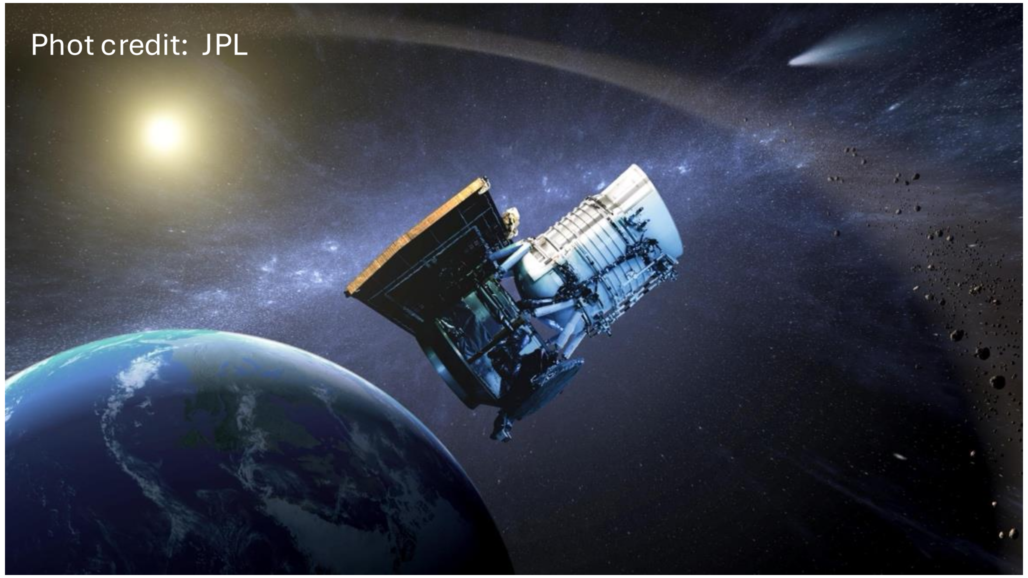
Thermophysical Modeling (TPM)

- We use the rotating, cratered thermophysical model introduced by Wright (2007), which uses synthetic hemispherical unresolved craters to represent the surface roughness.
- Employing an affine-invariant MCMC simulation we can produce best fits for up to 10 different free parameters.

Diameter Albedo

NEOWISE

- Wide-field Infrared Survey Explorer: 2009 to 2024
- 2009 to 2011: four effective wavelength bands (3.4, 4.6, 12 and 22 µm)
- 2011 to 2013: hibernation period
- 2013: NEOWISE, only W1 and W2
- It has completed 1.6 million measurements of 44,00 different solar system objects, including 1,598 NEOs

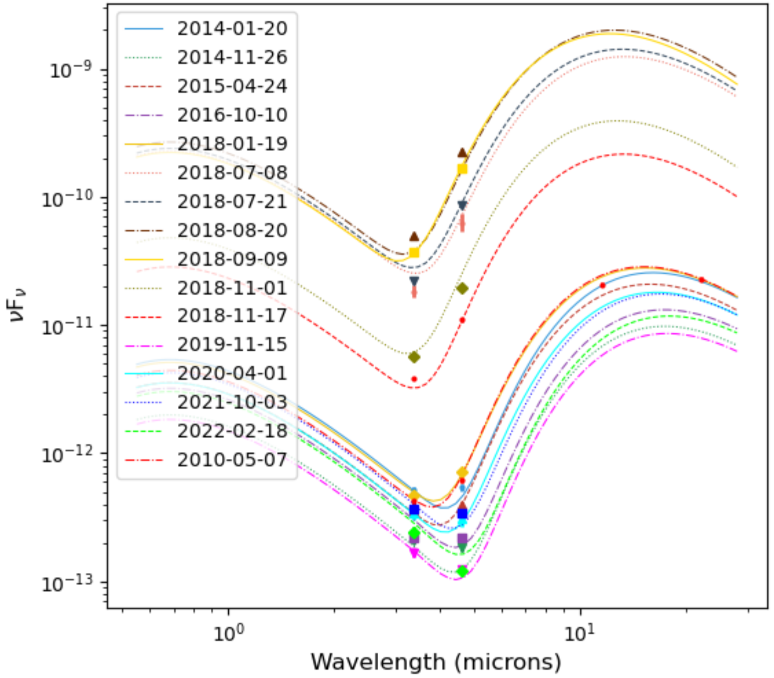


Thermophysical Modeling (TPM)

- We queried the Infrared Science Archive to find all data available from all phases of the NEOWISE mission.
- The Image Search tool was used to check every detection returned by the Catalog and filter the data.
- 16 epochs of observation were deemed acceptable and were then downloaded and prepared to be input into the thermophysical model.
- The TPM also uses knowledge of the **object's rotation period**, as well as the **updated absolute magnitude** determined with the Photometric Measurements.

Thermophysical Modeling (TPM)

Model	Diameter (km)	Albedo	Theta ($Jm^{-2}s^{-1/2}K^{-1}$)	Crater Fraction	p_{IR}/p_V
Spherical	7.914 ± 0.418	0.28 ± 0.10	4.594 ± 2.407	$0.182^{+0.604}_{-0.144}$	$1.715^{+0.304}_{-0.266}$
Triaxial	6.700 ± 0.935	0.36 ± 0.15	3.743 ± 2.785	$0.473^{+0.354}_{-0.322}$	$1.424^{+0.389}_{-0.289}$



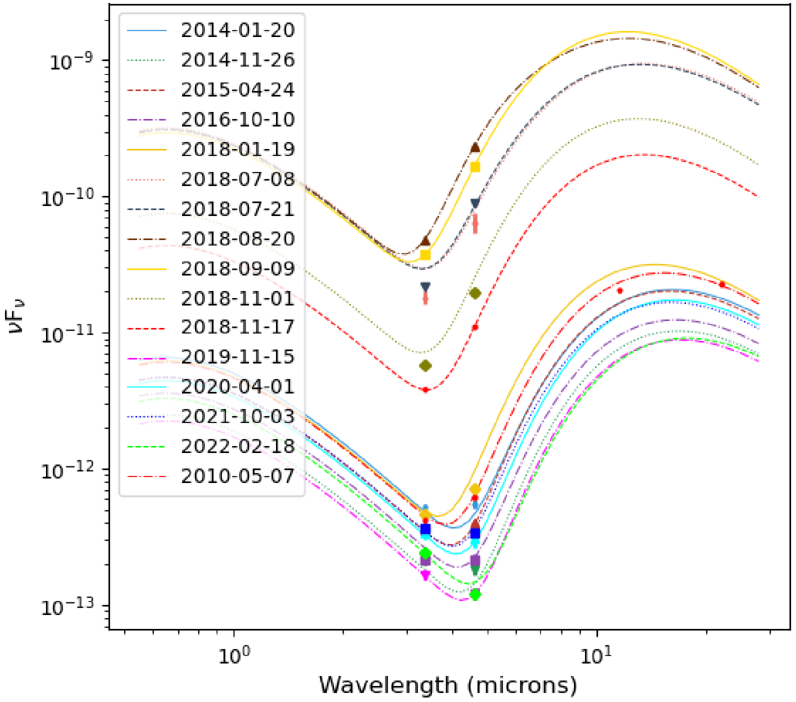
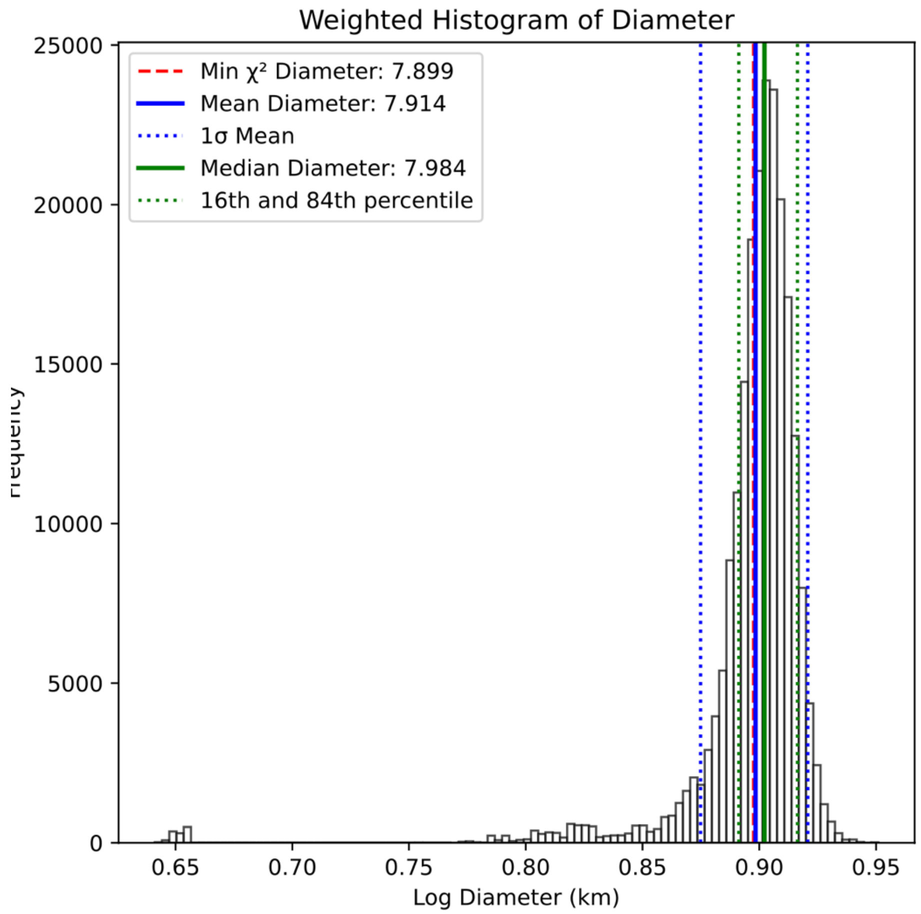


Figure 3: Spectral Energy Density fits for the spherical (left) and triaxial (right) model of Ivar.

Thermophysical Modeling (TPM) - diameter



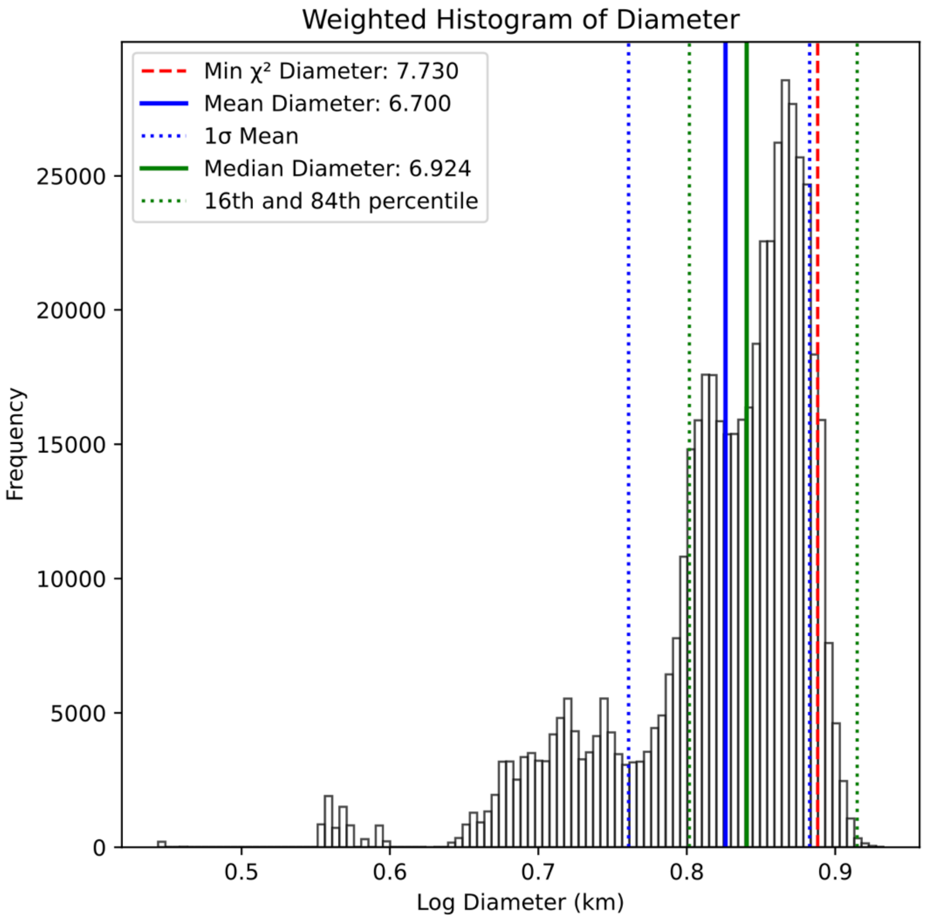


Figure 4: Diameter fits for the spherical (left) and triaxial (right) model.

Thermophysical Modeling (TPM) - albedo

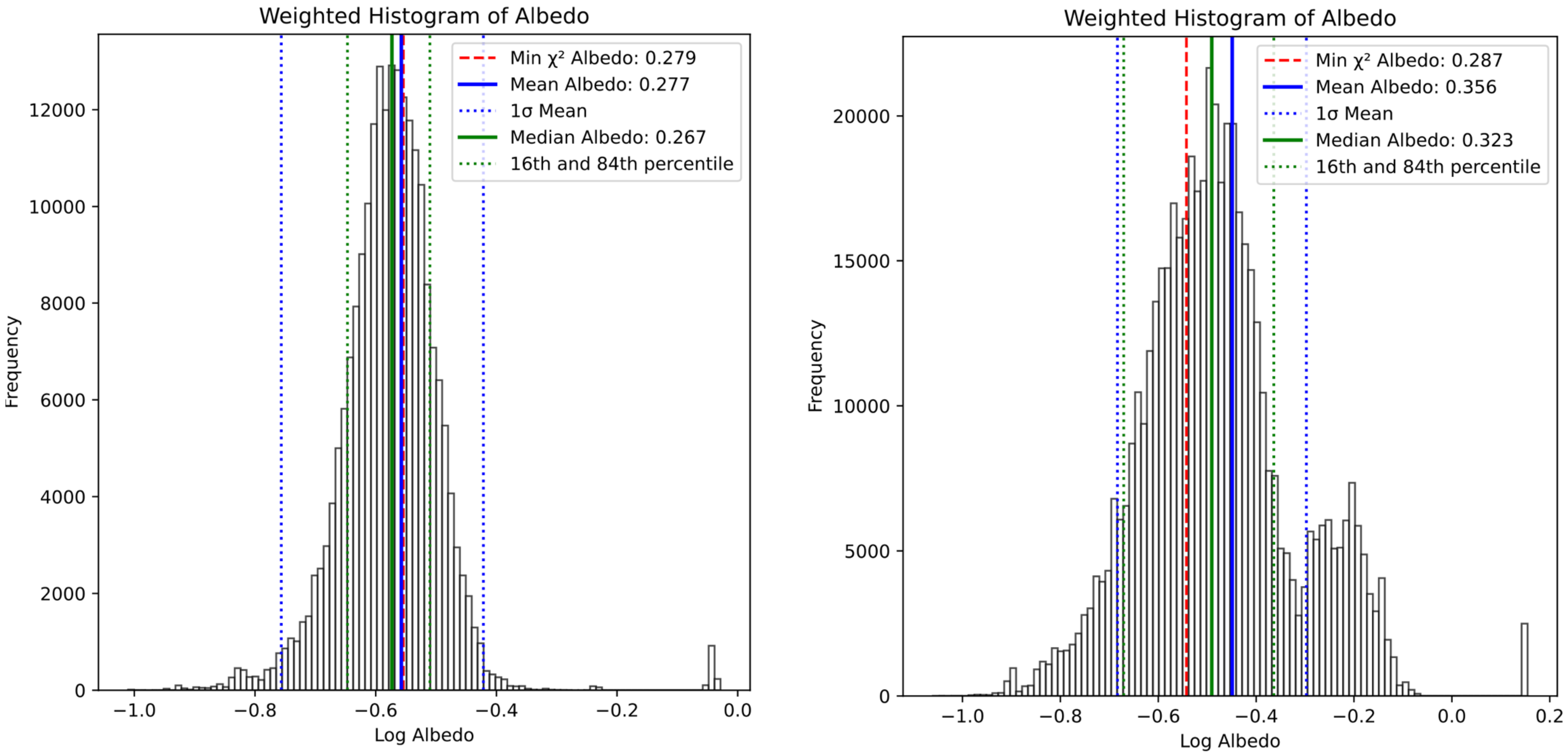


Figure 5: Albedo fits for the spherical (left) and triaxial (right) model.

Polarimetry

- We define the linear degree of polarization (P_R) as

$$P_{\mathrm{r}} = \frac{I_{\perp} - I_{\parallel}}{I_{\perp} + I_{\parallel}},$$

- For all asteroids, P_R is displaying variation as a function of the phase angle, α (angle between the Sun, the object, and the observer).
- First the polarization is null at opposition (α = 0 °), then P_R will be displaying negative values (polarization in the scattering plane up to an inversion angle usually found around α = 20 °.

Polarimetry

- We observed Ivar in polarimetry with the Torino Polarimeter (ToPol) and the polarimetric mode of the two-channel focal reducer FoReRo2.
- With ToPol we obtained 14 observations with phase angles ranging from 4.24° to 29.4°, to sample both the negative polarization branch (when P_R is negative) and the positive polarization branch (when P_R is positive) allowing to determine the slope at inversion angle.
- With FoReRo we obtained one polarimetric observations at a phase angle of $\alpha = 34.29°$.

Polarimetry

- We modelled the phase-polarization curve of Ivar using the exponential-linear Cellino et al. (2015) relationship:

$$P_r(\alpha) = A\left(\exp\left(-\alpha/B\right) - 1\right) + C\alpha$$

- Using the slope-albedo relation from (Cellino et al. 2015), we obtain an albedo of $\mathbf{p_V = 0.24\ {+0.04}\ {-0.02}}$.

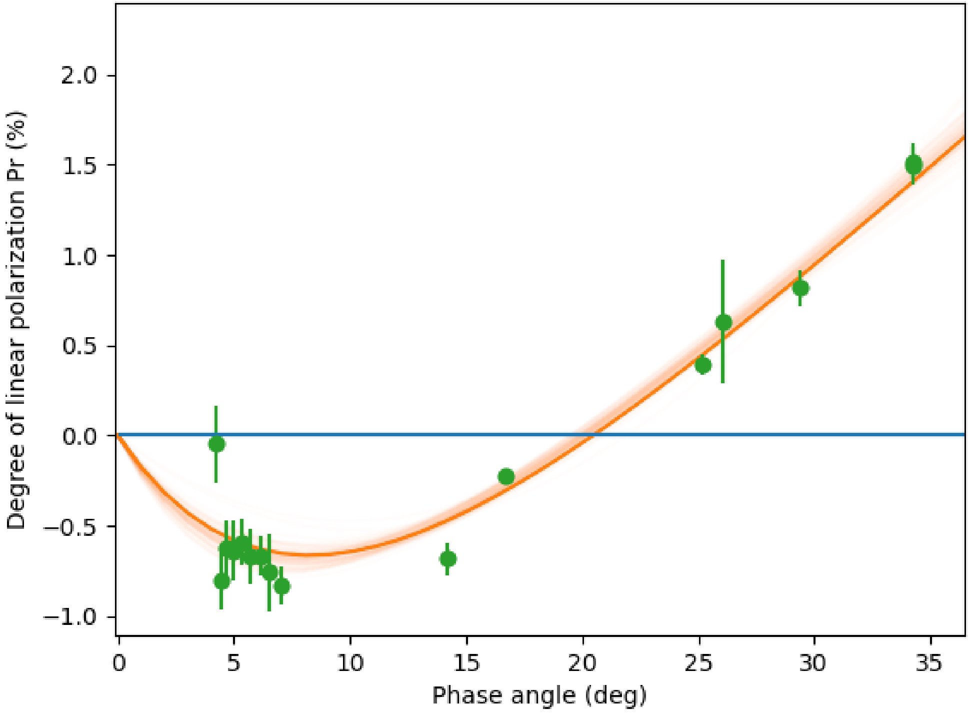


Figure 6: Phase polarization curve of Ivar. The fainter orange lines correspond to the fits explored by the MCMC before finding the best one.

Polarimetry

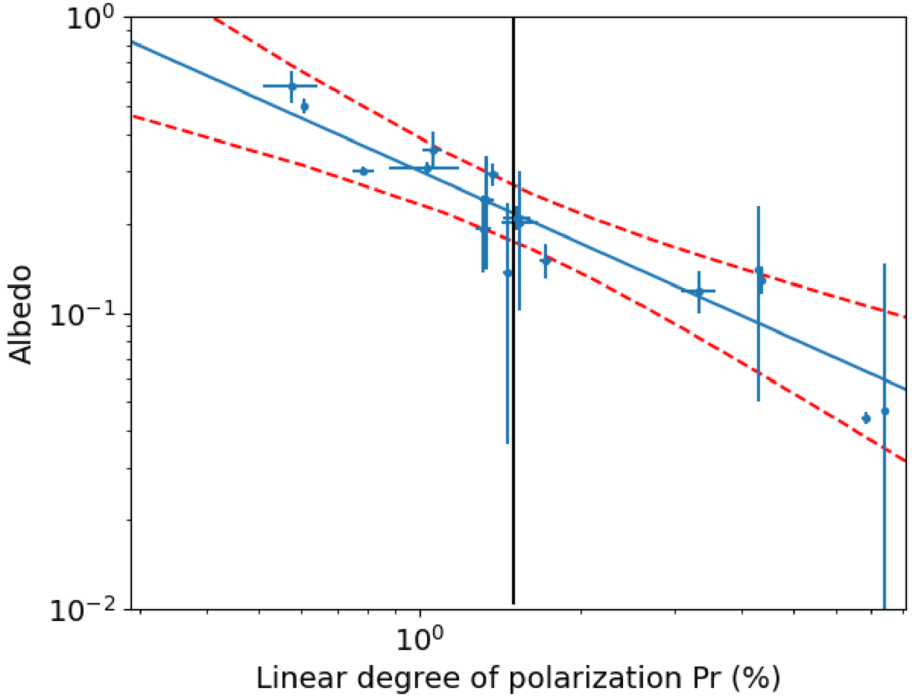


Figure 7 : Resulting calibration at angle α = 34.29°.

- We also calibrated the albedo-polarization relation at the highest phase angle measurements at α = 34.29° with a linear degree of polarization P_R = 1.5%
- This calibration is obtained by comparing with other asteroids for which polarization measurements at the same phase angle are available and for which albedo has been obtained through methods independent of polarimetry.
- We obtain a similar albedo value of **p_V = 0.21 ± 0.05**

Comparison

Technique	Albedo
Photometric measurements	0.29 ± 0.03
Spherical TPM	0.28 ± 0.1
Triaxial TPM	0.36 ± 0.15
Polarimetry - fitted slope at inversion angle	$0.24^{+0.04}_{-0.02}$
Polarimetry - highest phase angle measurement	0.21 ± 0.05

The weighted average gives **$p_V = 0.26 \pm 0.02$**

Conclusions

- Photometry-based measurements of absolute magnitude vary based on the apparition.
- TPM provides constraints on several parameters, including **size**, but requires lots of data.
- Polarimetry is the fastest method to obtain results, independent of other parameters.
- We found a new value for Ivar's albedo of $\mathbf{p_V = 0.26 \pm 0.02}$**,** in agreement with all our methods.

Future work

- We aim to expand the catalogue of objects studied with the presented cross-reference approach
- This will further validate the polarimetry method and establish it as a streamlined tool to quickly derive Near Earth Asteroids' albedos and therefore their taxonomy classification.

Acknowledgments

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(I'm also looking for graduate programs! ☺)