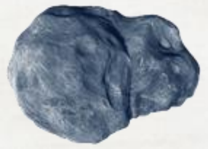
Observatório Nacional

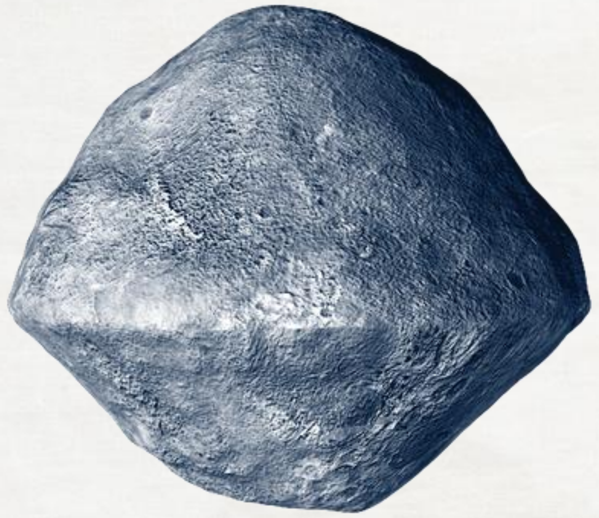
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO



Propriedades físicas e dinâmicas de pequenos corpos do Sistema Solar

Dr. Filipe Monteiro

Observatório Nacional



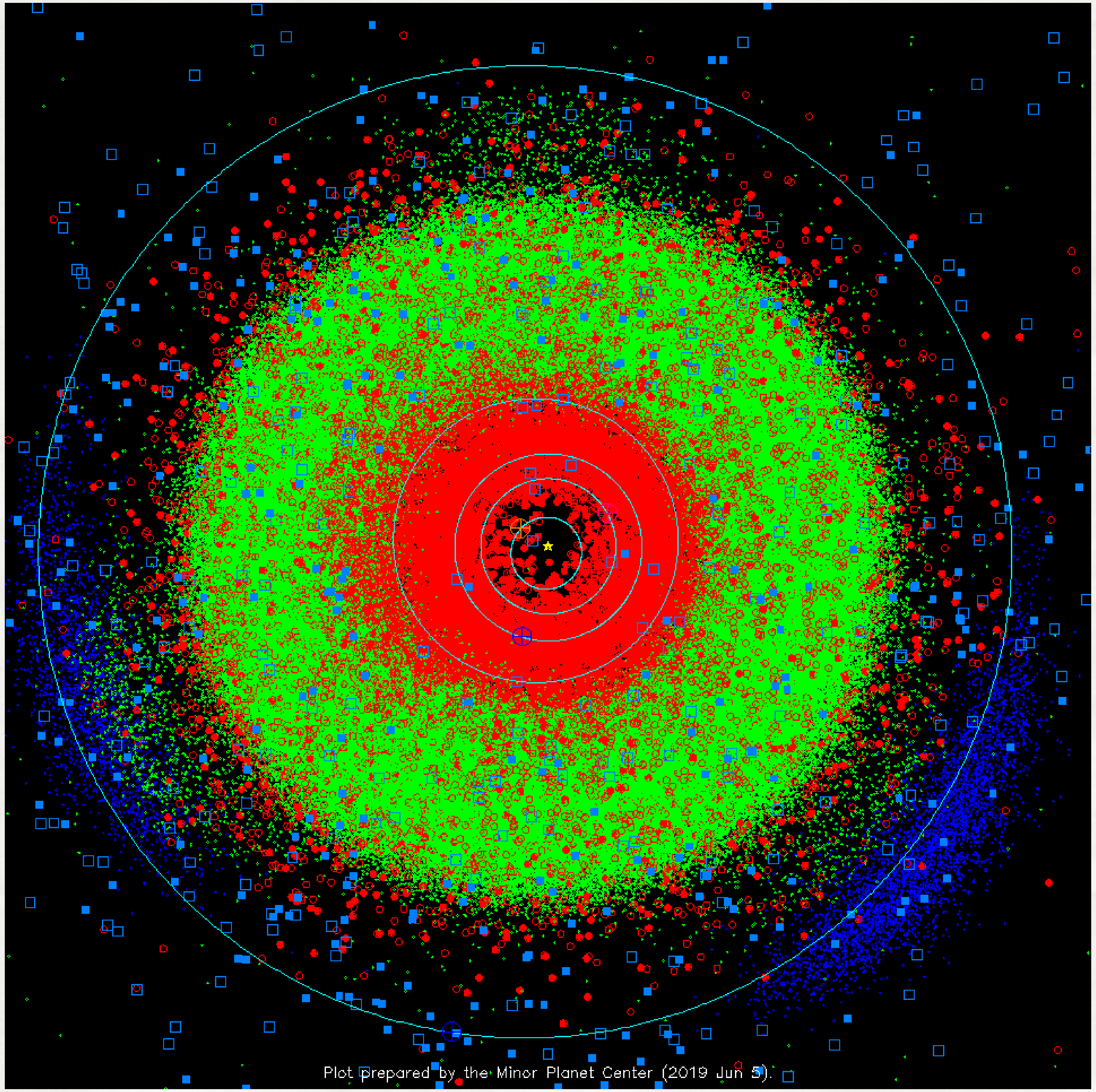
Escola de Inverno em Astrofísica 2026
20-24 de julho de 2026, Observatório Nacional

IMPACTON

Conteúdo/objetivos – parte 2

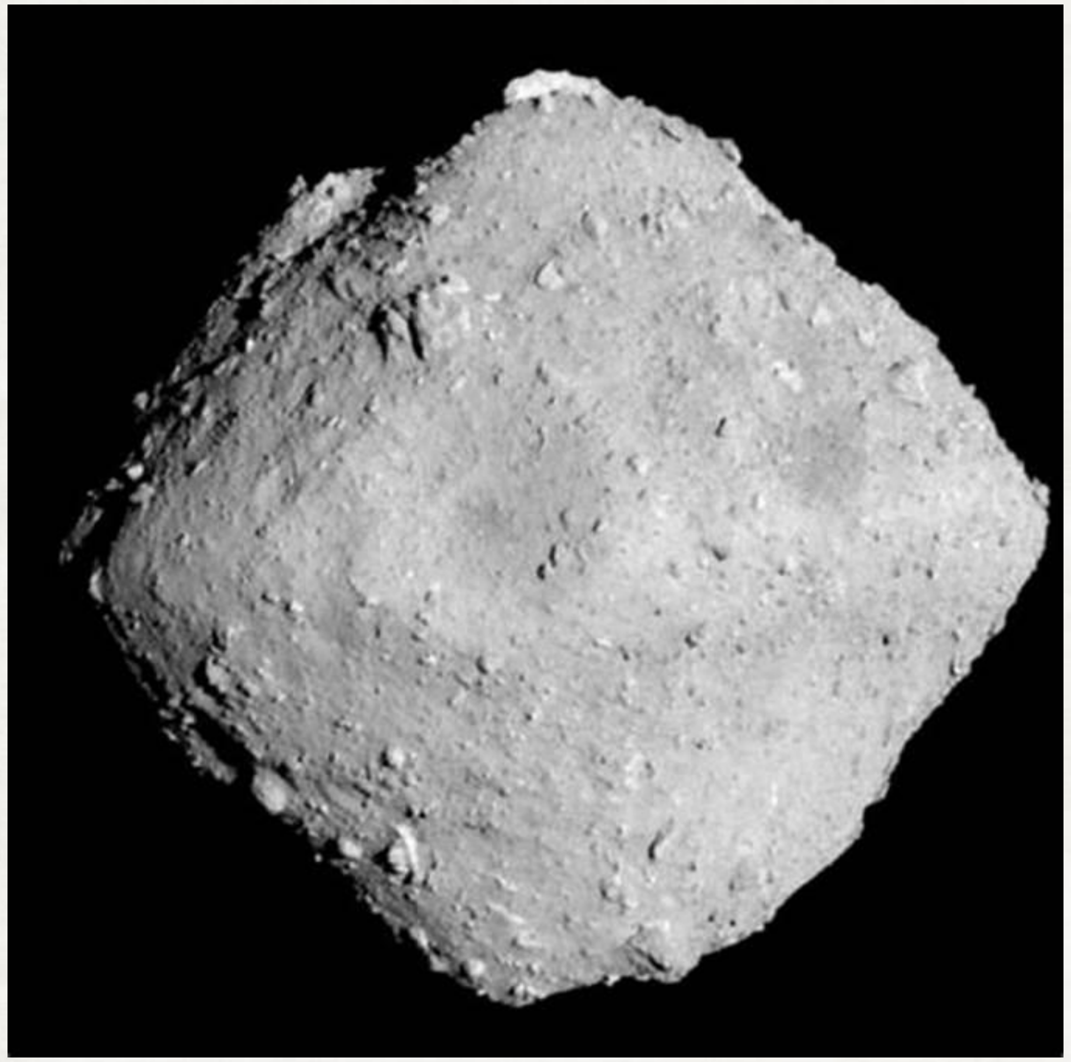
- Detecção e caracterização de sistemas binários de asteroides.
- Técnicas de observação de pequenos corpos, incluindo as infraestruturas que o Brasil tem acesso.
- Propriedades físicas de asteroides (tamanho, forma, período de rotação, composição, estrutura interna, etc).
- Conclusões

Pequenos corpos do Sistema Solar

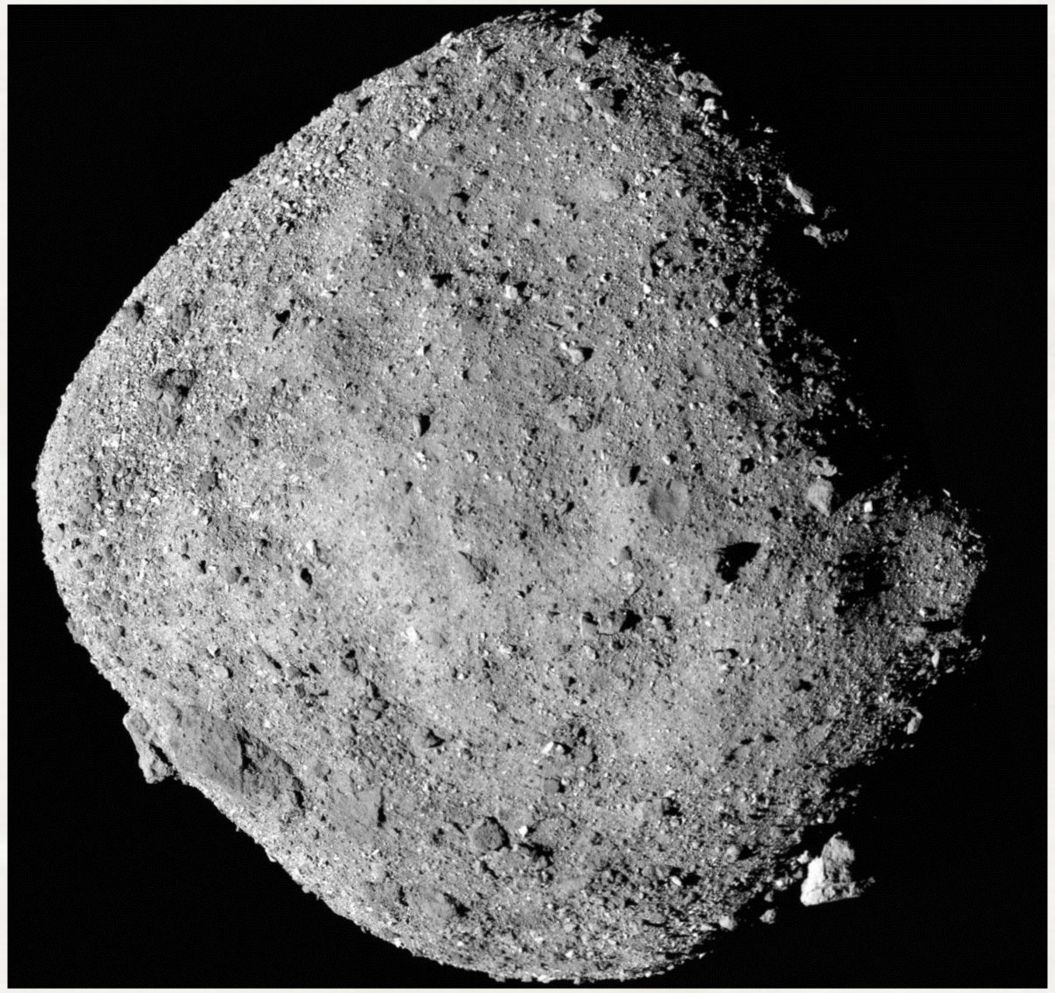


- Asteroides do Cinturão Principal
- Asteroides próximos da Terra
- Asteroides troianos de Júpiter

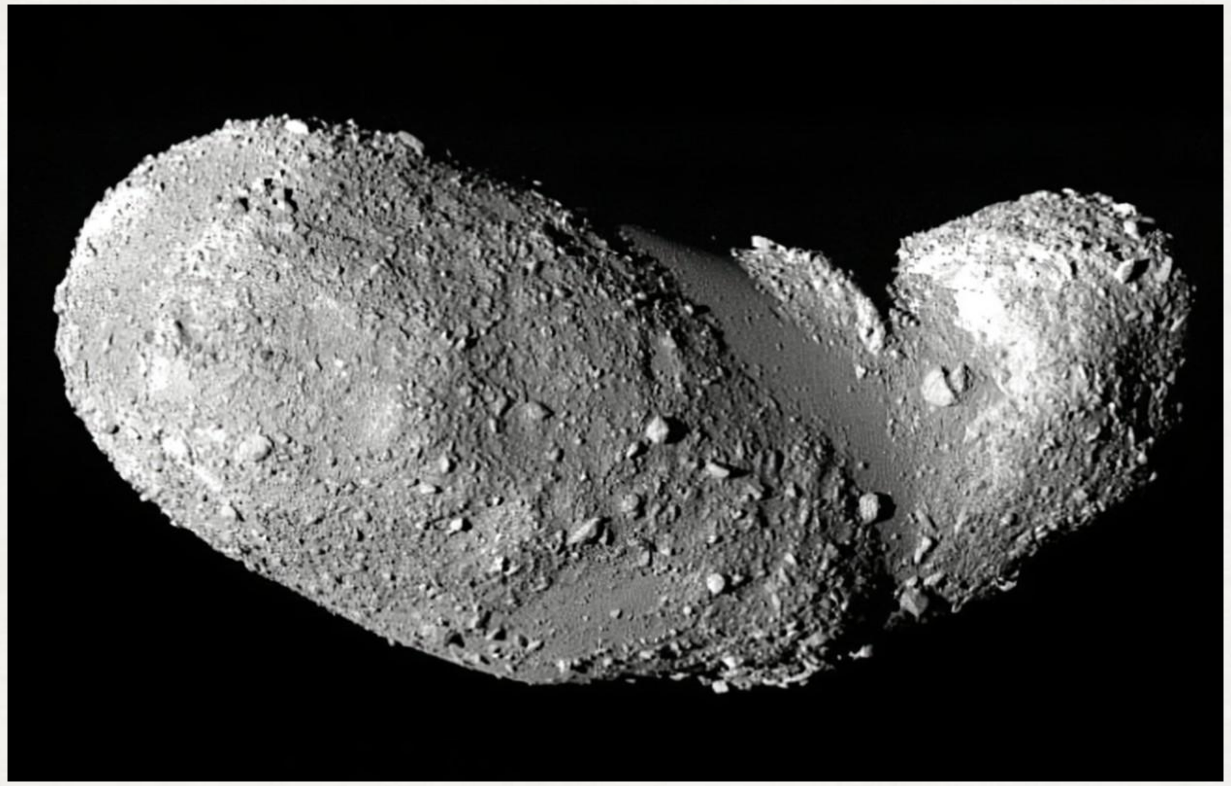
Asteroides visitados por sondas



Ryugu, Hayabusa 2 da JAXA



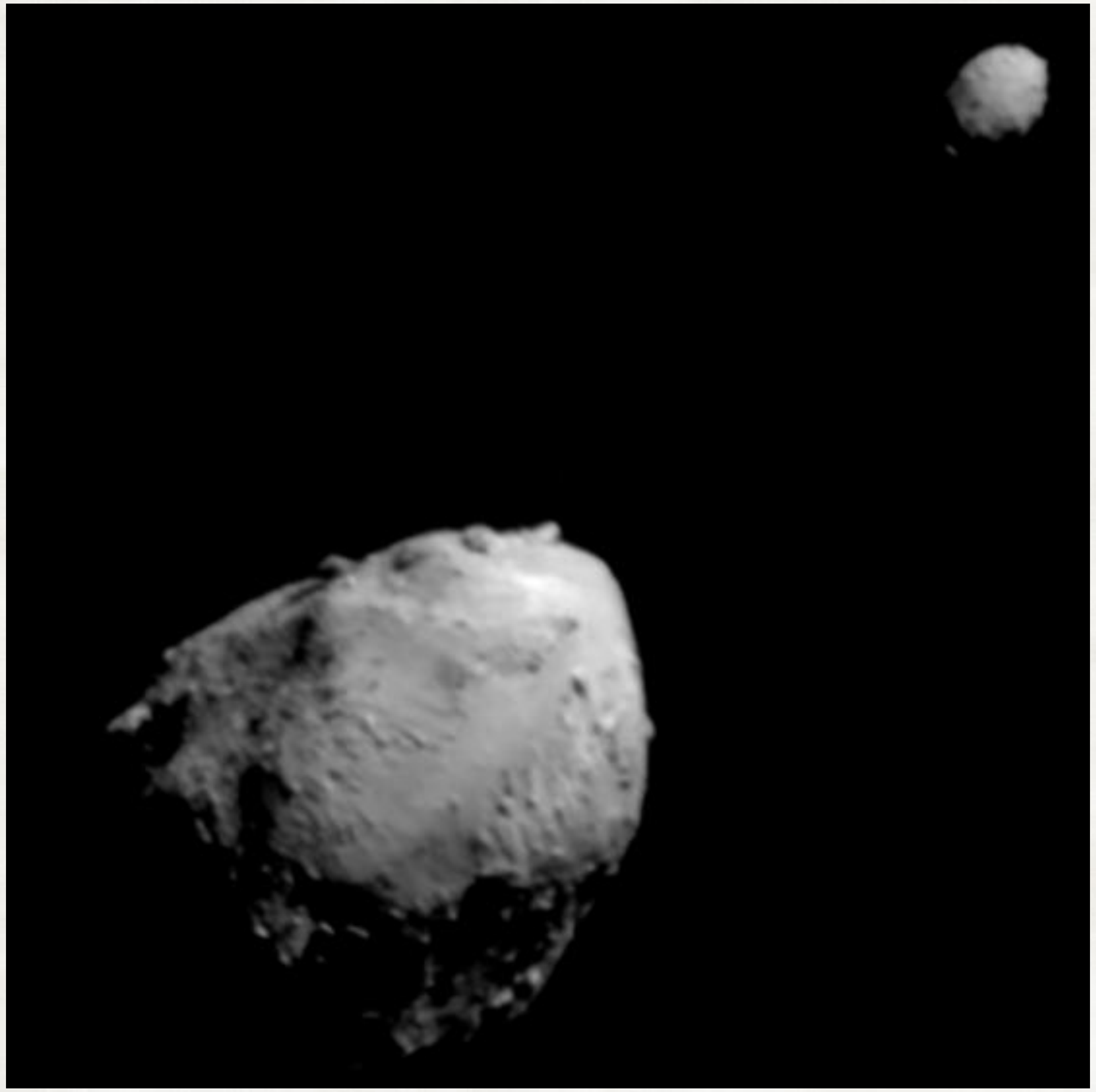
Bennu, OSIRIS-Rex/NASA



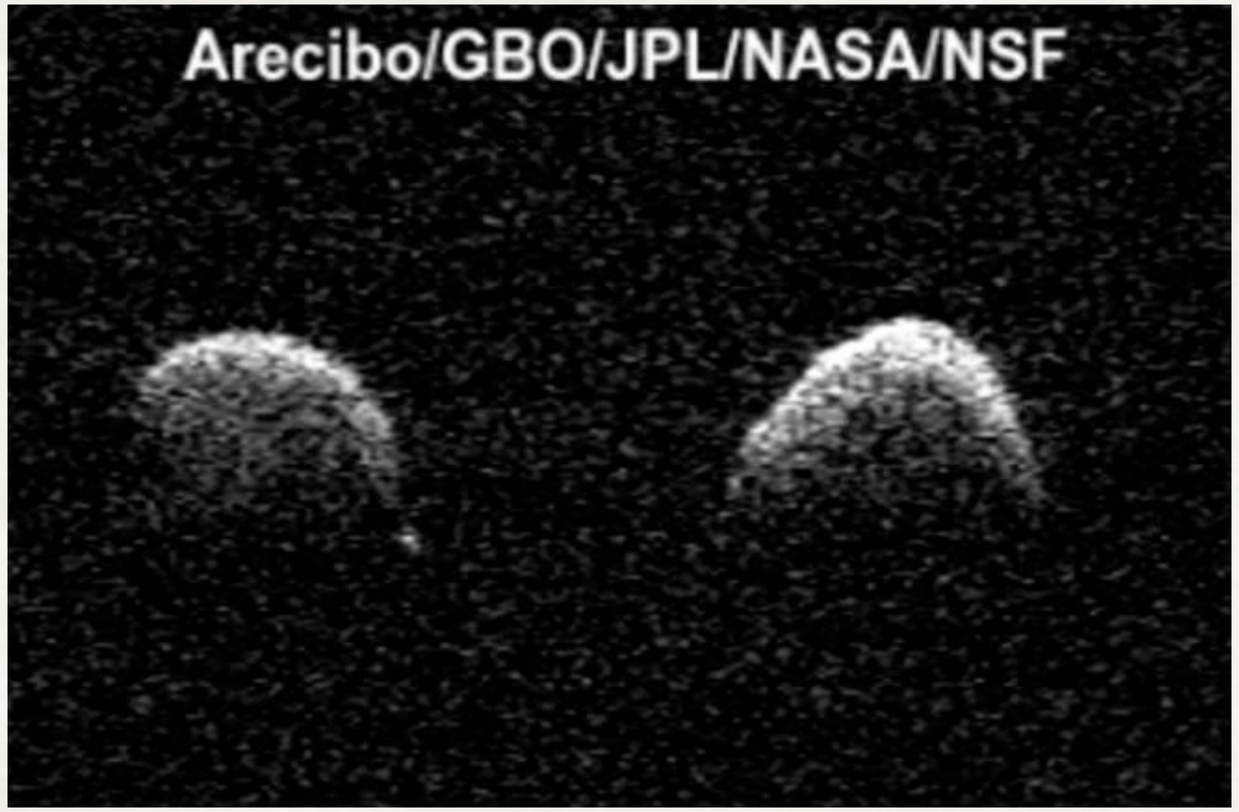
Itokawa, Hayabusa 1 - JAXA

Eros, Shoemaker/NASA

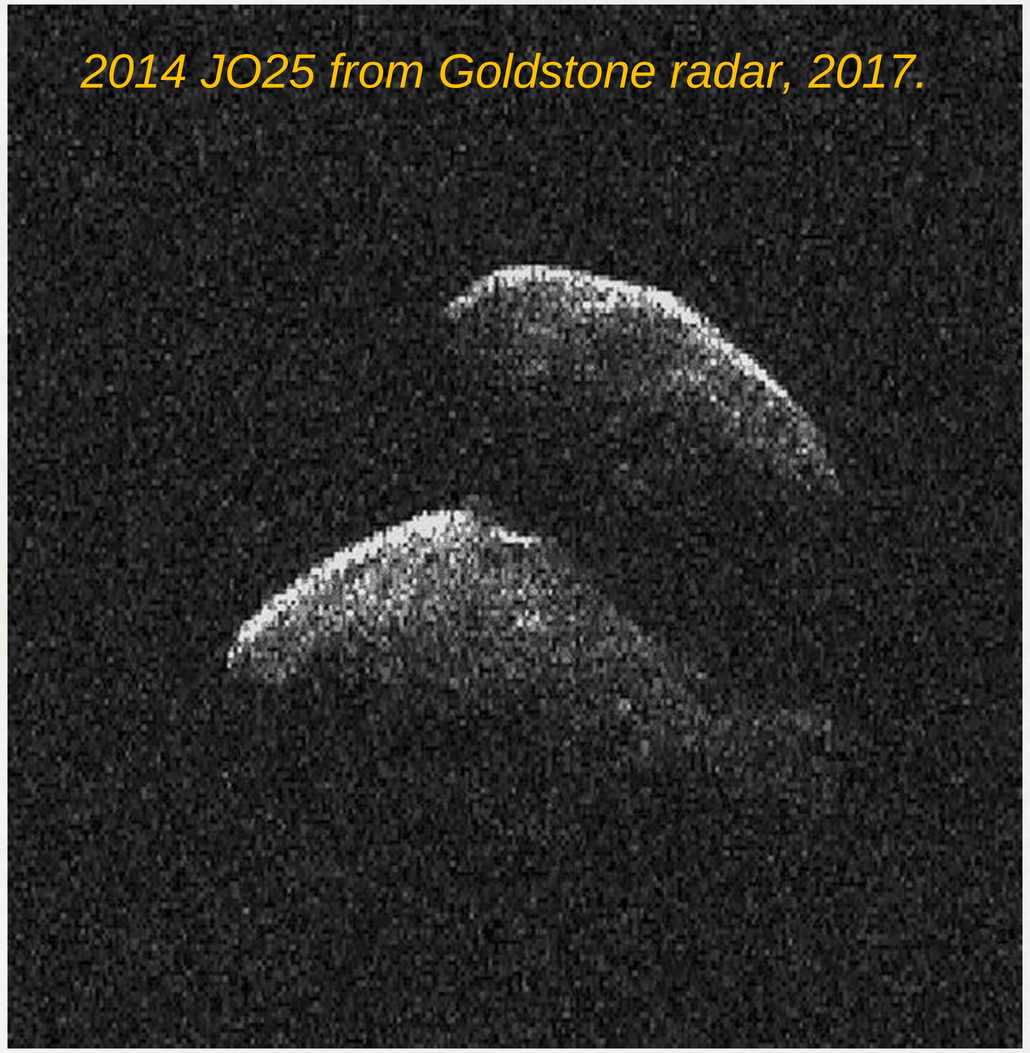
Binary asteroids



Didymos System from NASA's DART spacecraft.

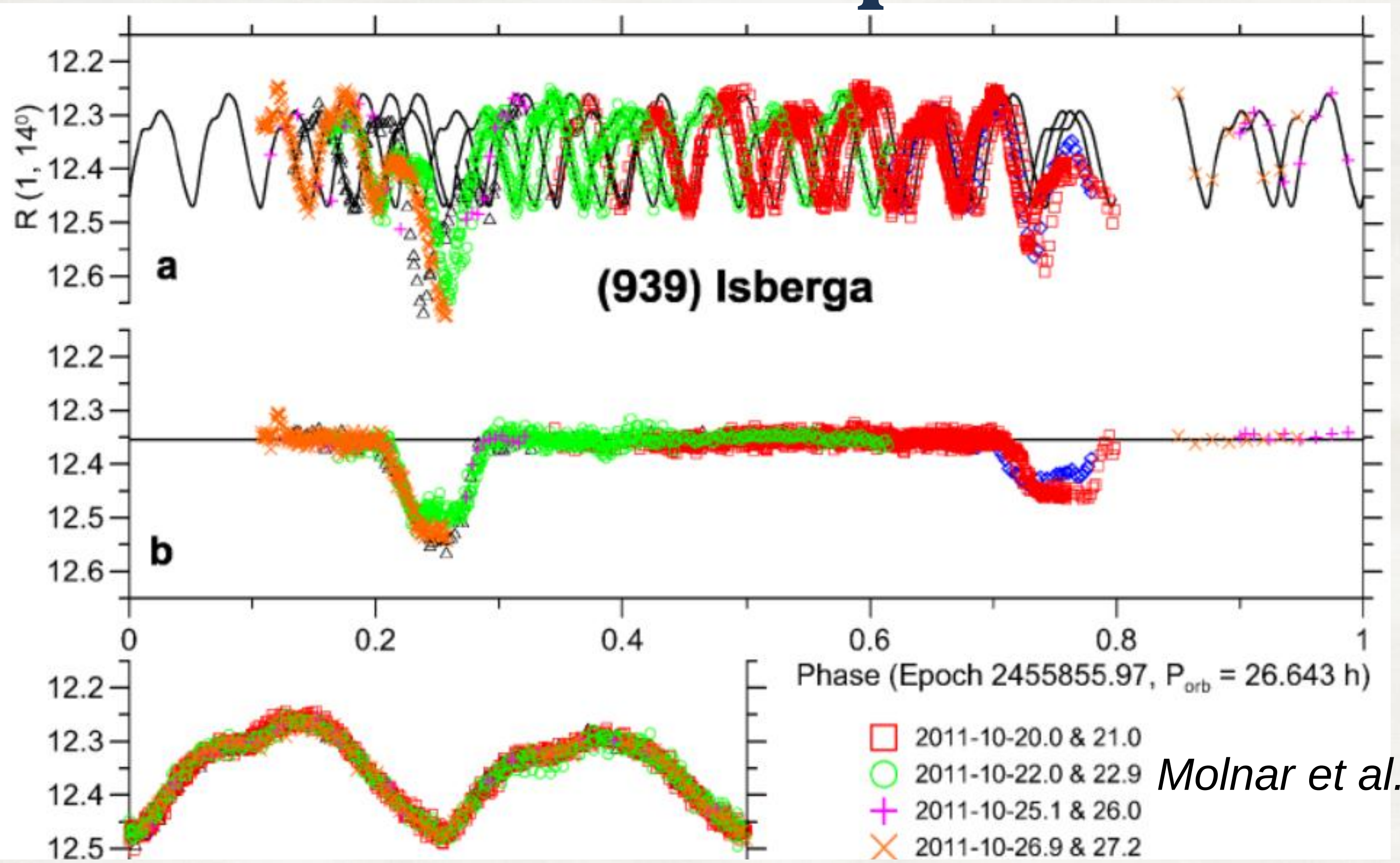


Binary NEO 2017 YE5.
Model credit: NASA/JPL-Caltech.

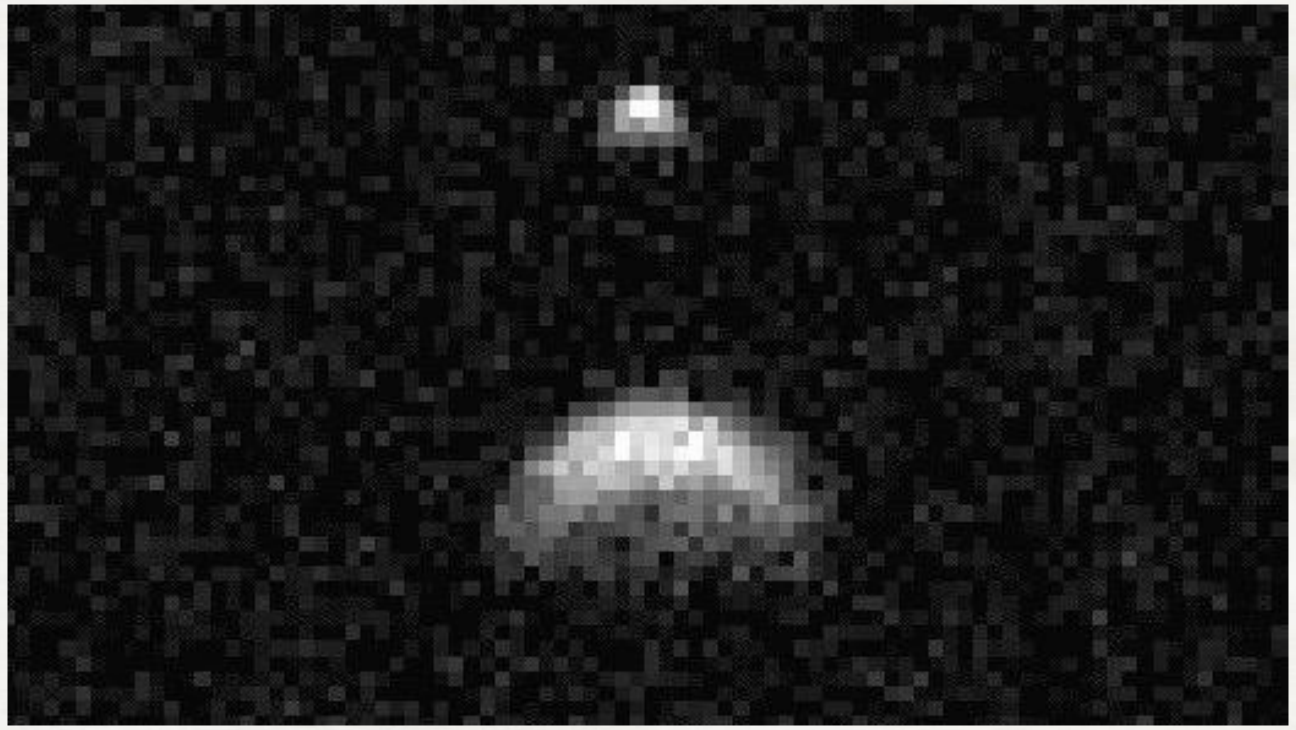


Arrokoth from NASA's New Horizons, 2014

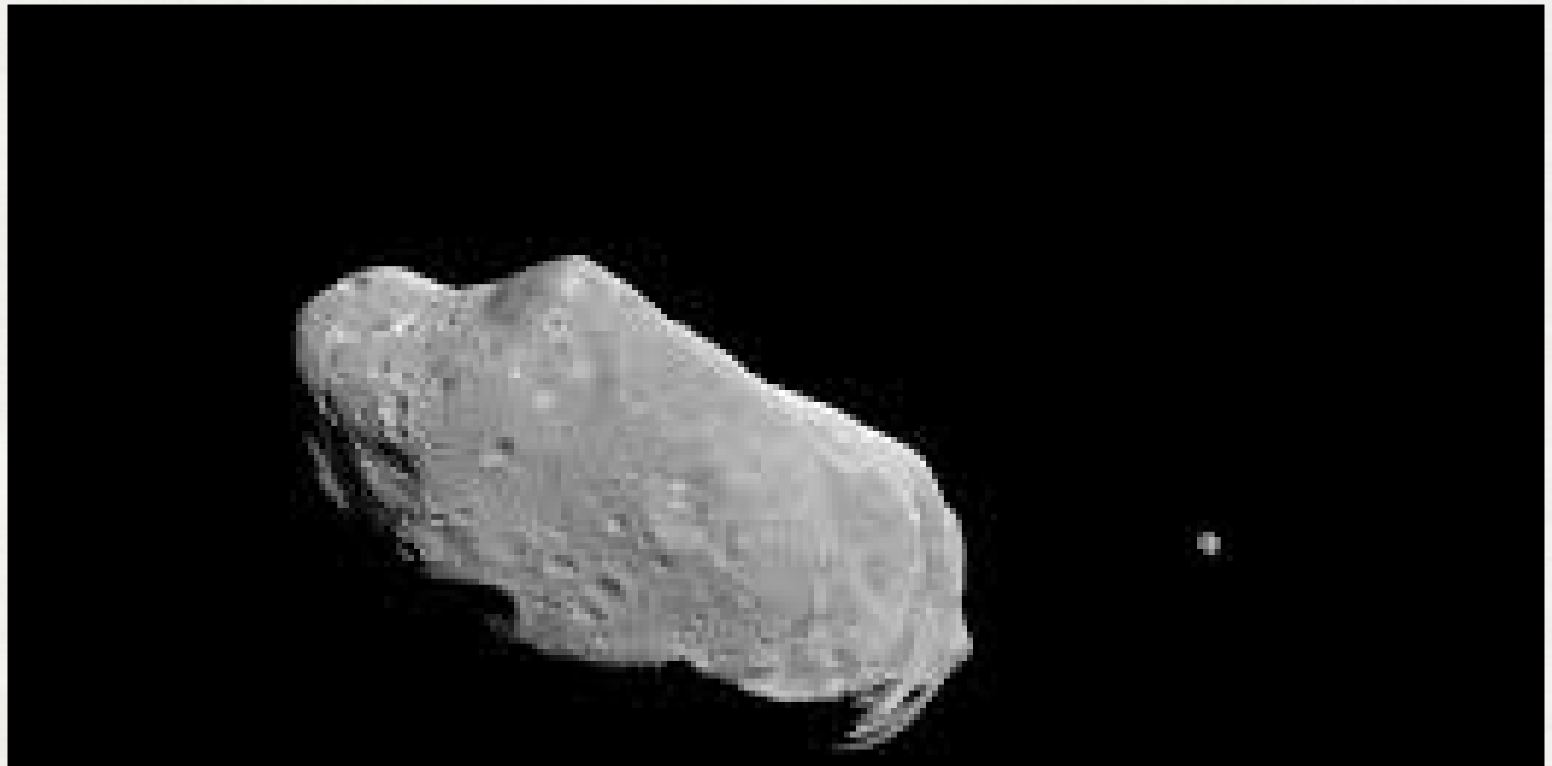
Detection techniques



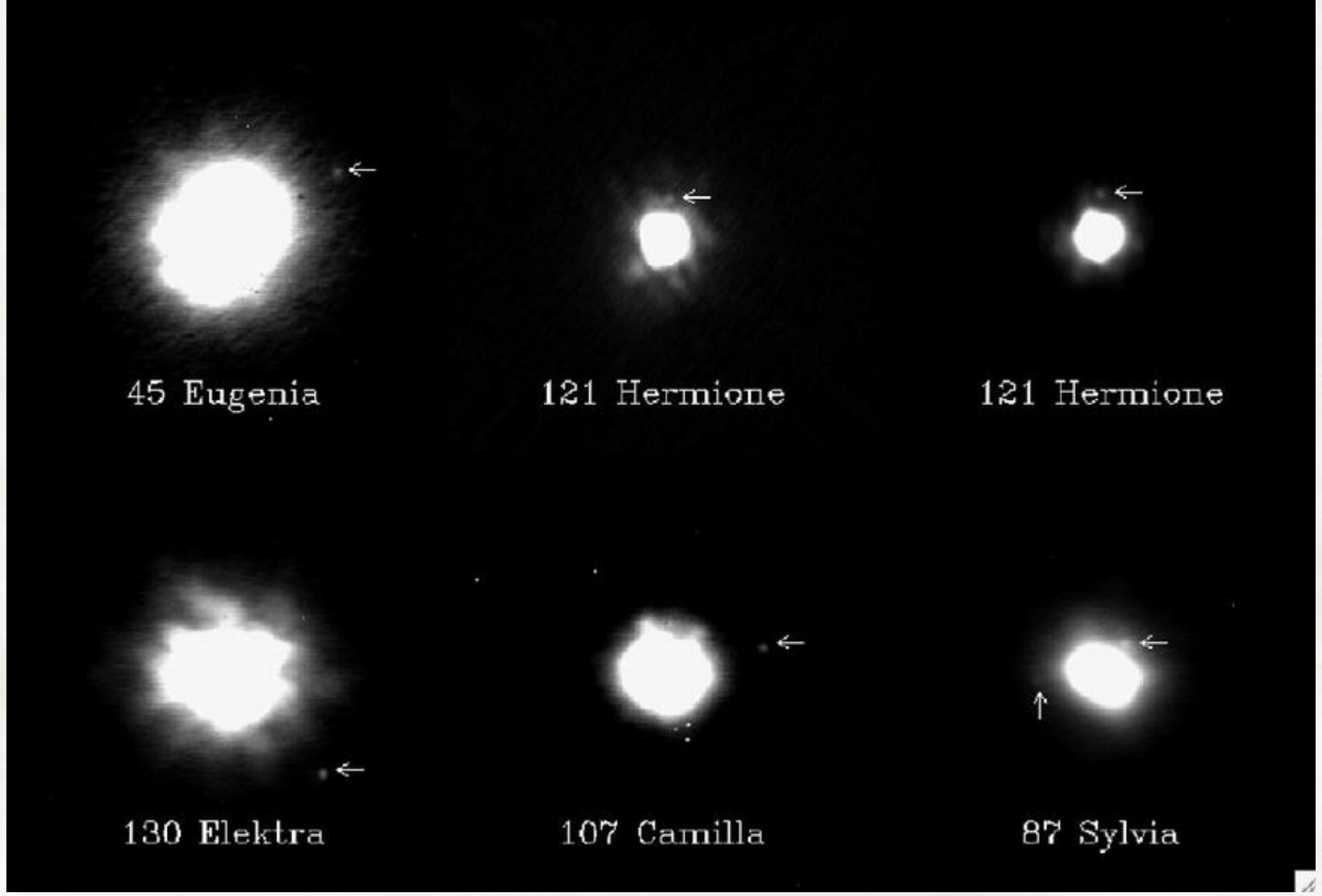
Molnar et al. (2008)



NEO 2018 EB (Arecibo radar)

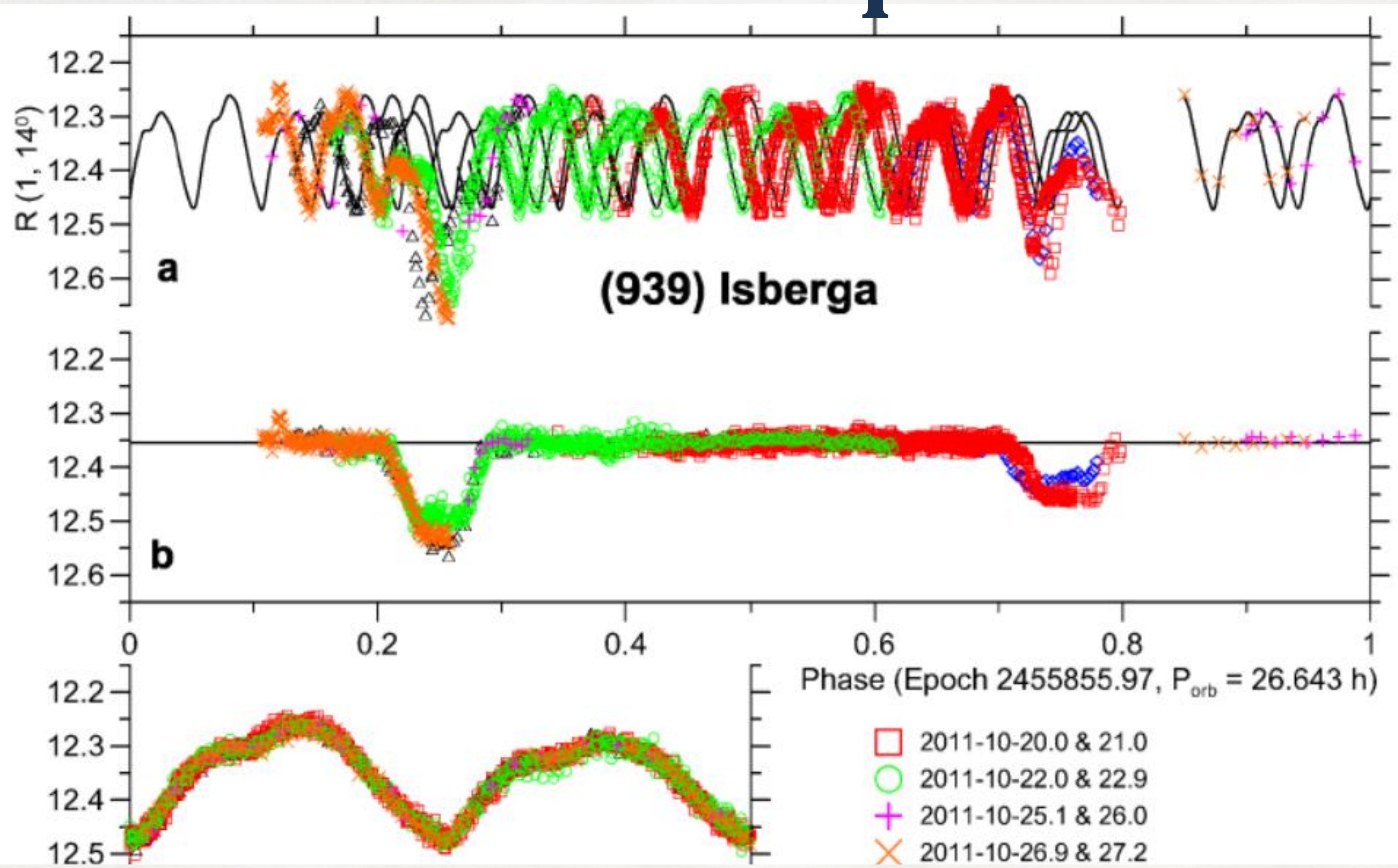


Galileu Mission, 1993, NASA, JPL

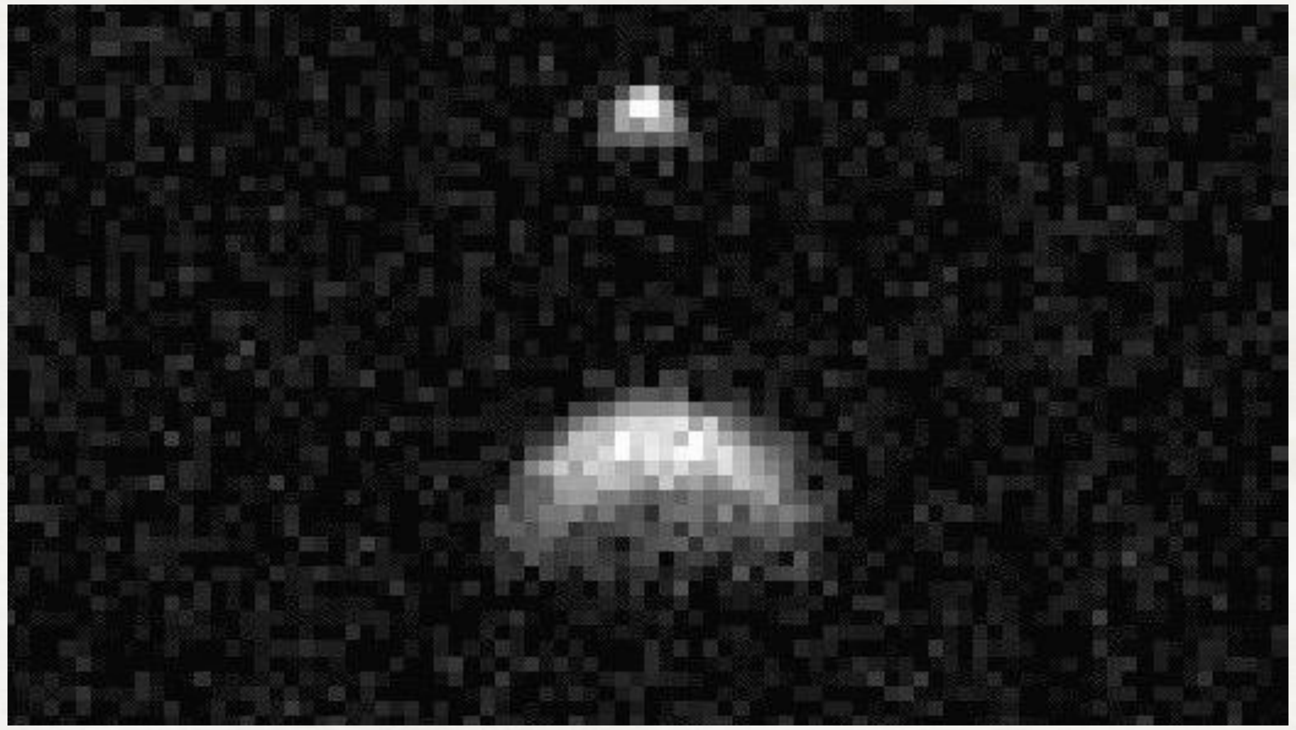


Marchis et al. (2006)

Detection techniques

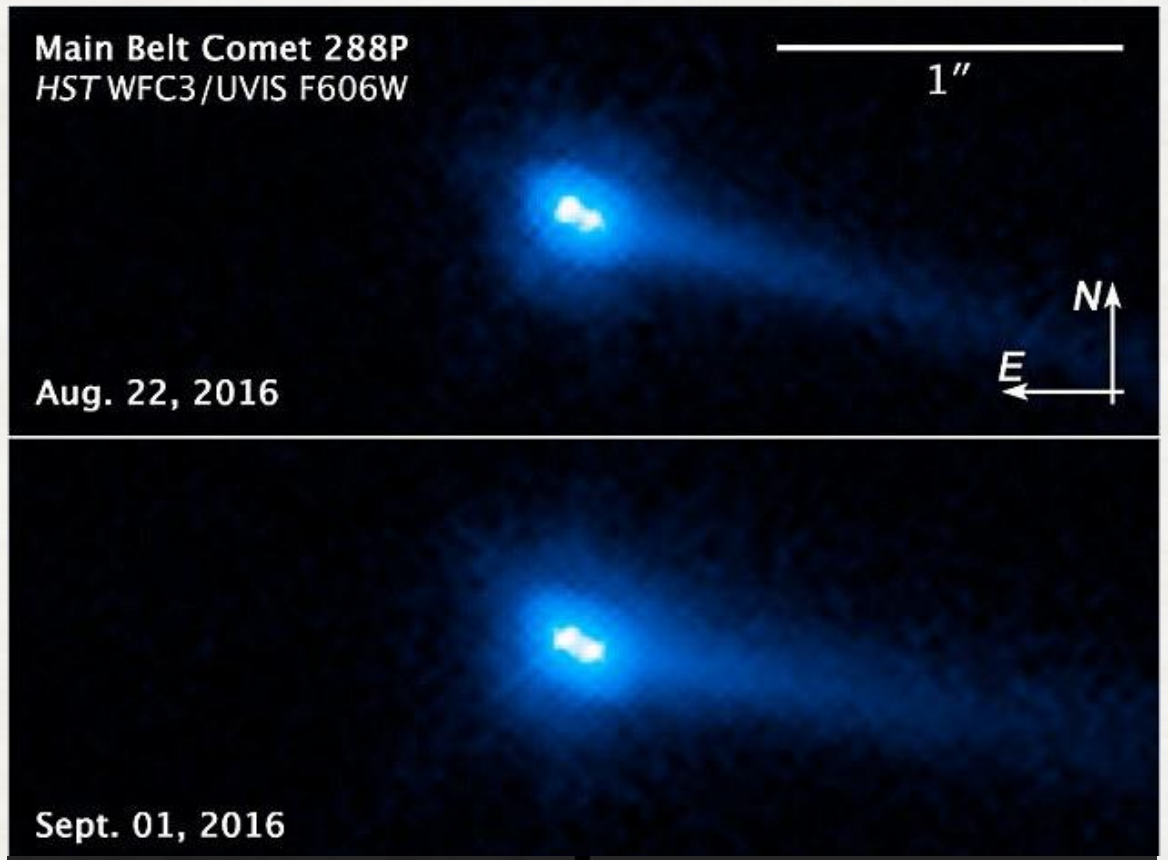


Molnar et al. (2008)



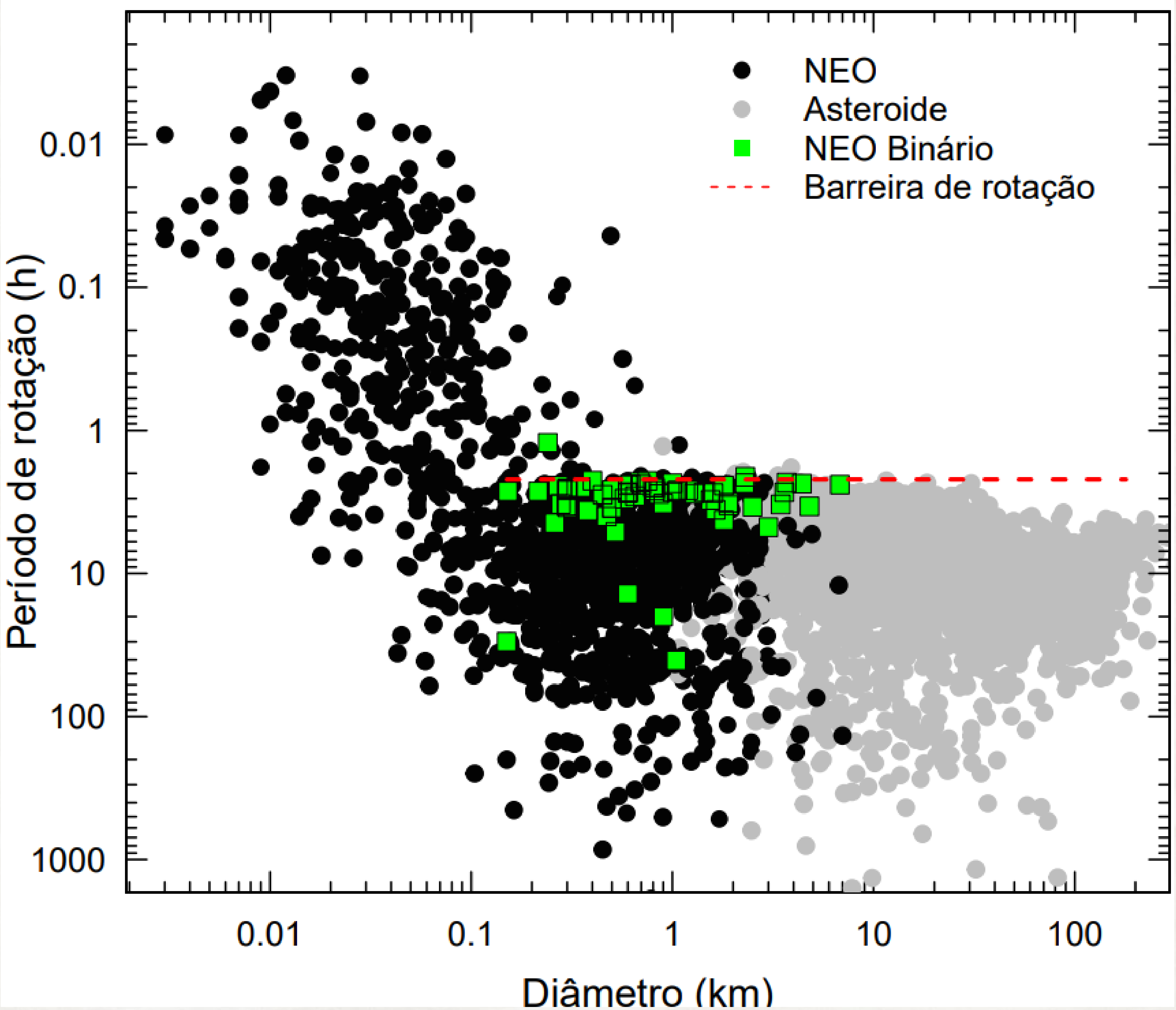
NEO 2018 EB (Arecibo radar)

Agarwal et al. (2017)



High Resolution Camera on HST.
Noll et al. (2008)

Diameter vs. Rotational Period

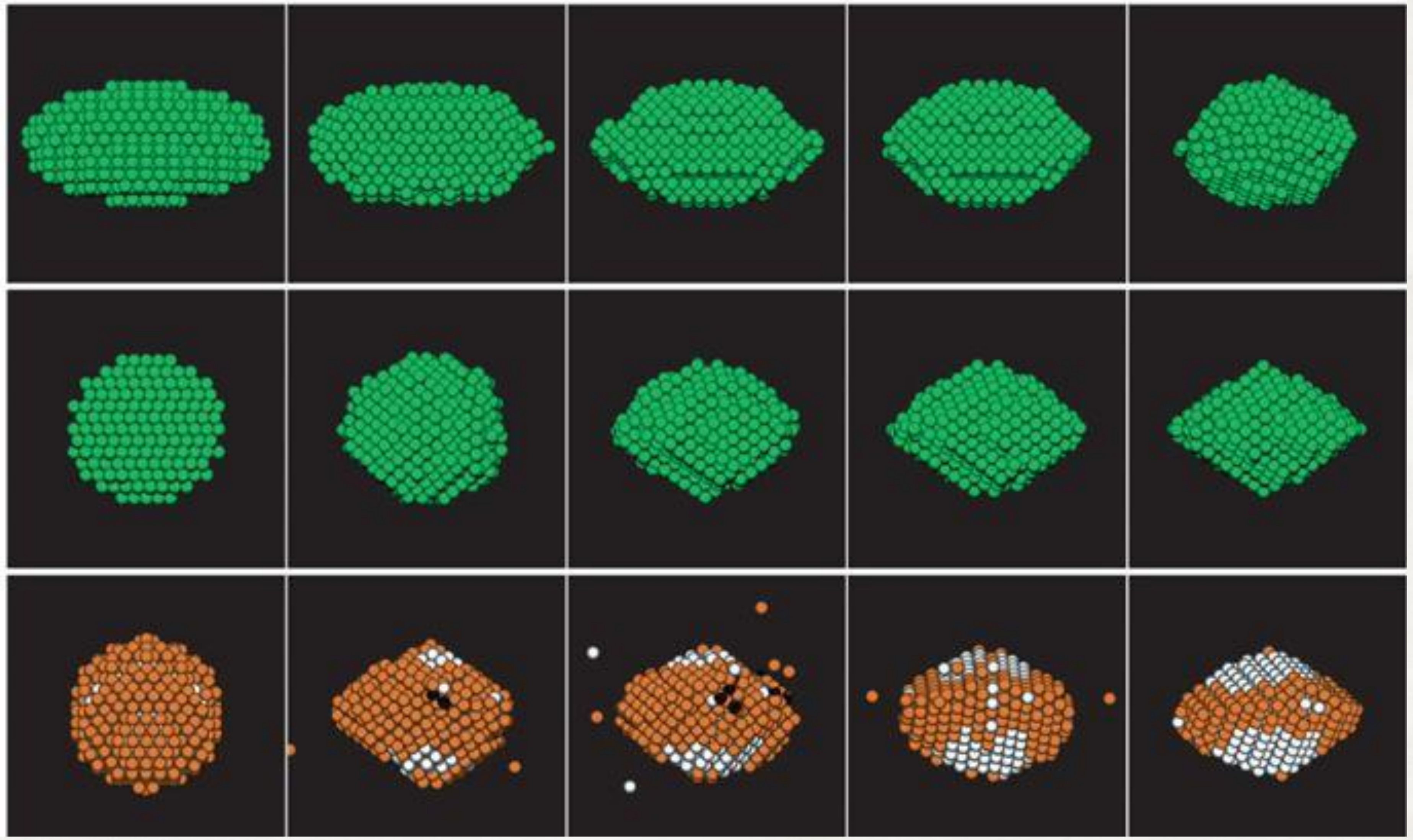


- ❑ Binary asteroids are frequent among NEAs (and MBAs) larger than about 200 m: The fraction of binaries estimated 15 ± 4% (Pravec et al. 2006).

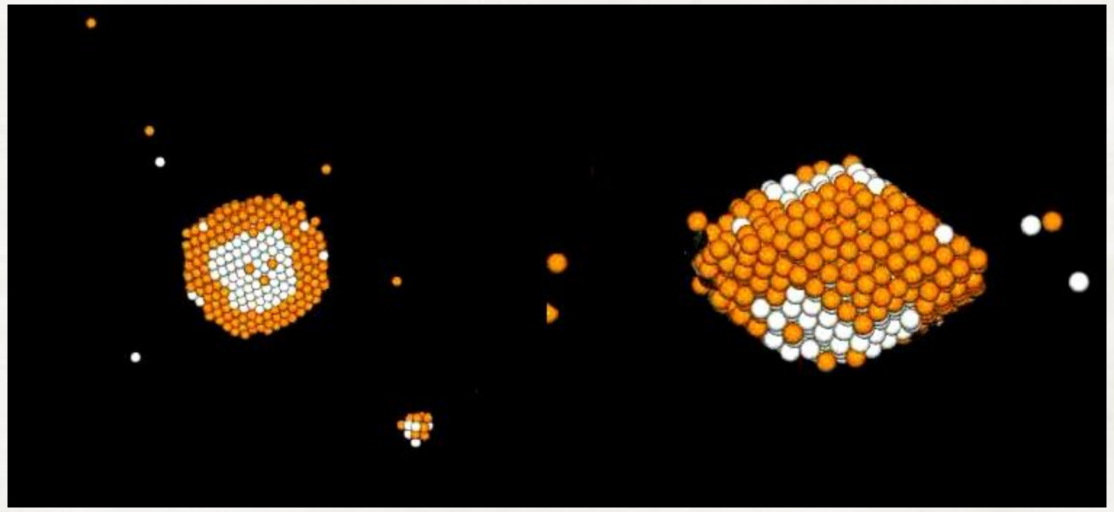
- ❑ Some properties of binary NEAs (Margot et al., 2015):
  - P_1 = 2.2 – 5 hours
  - Δm <0,3 mag
  - D1 = 120 m to 10 km (to 20km for MBAs)
  - **Most of them are S-complex asteroids and differentied bodies (Minker et al. 2023)**

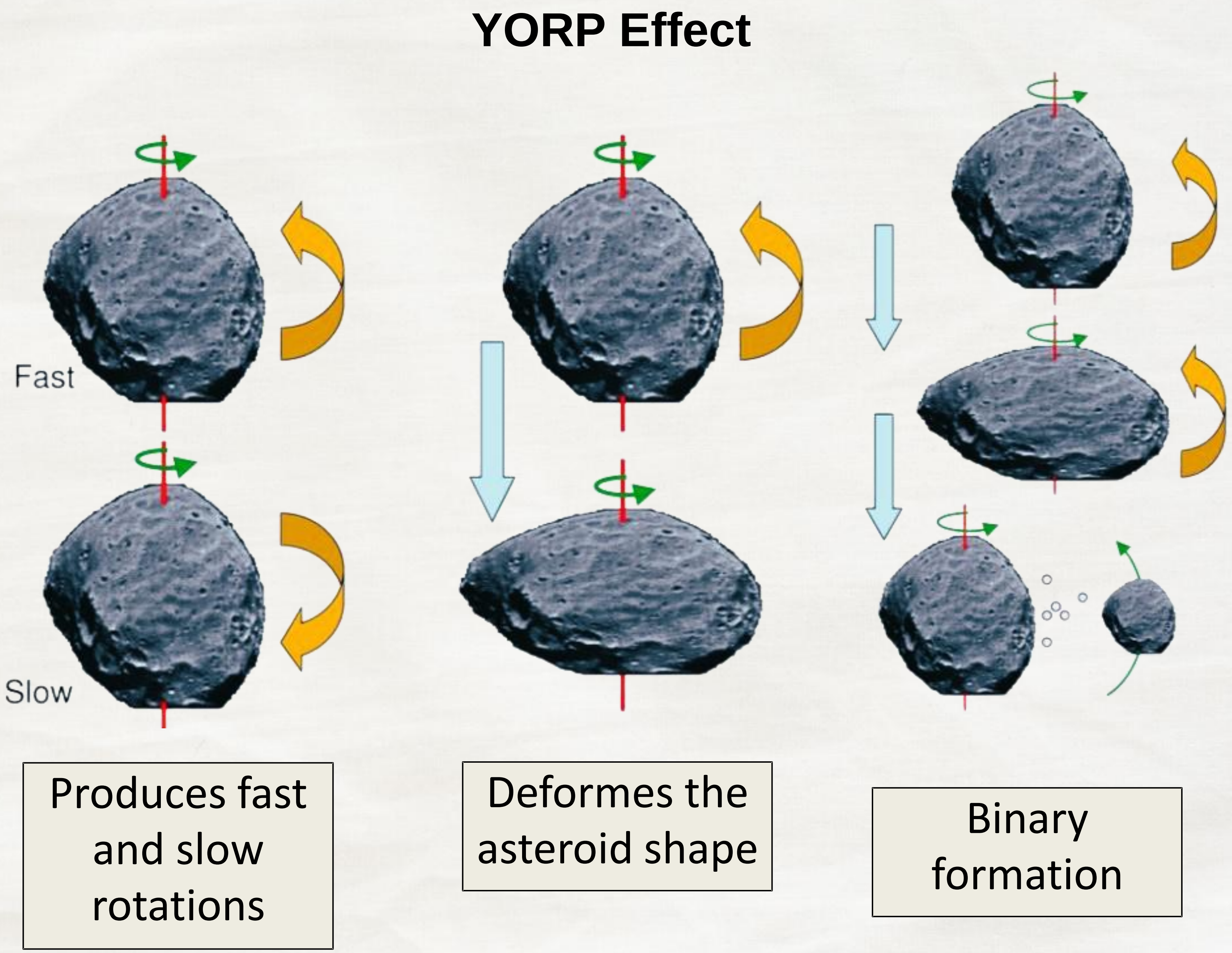
- ❑ Many observational biases contribute to the small number of detections (even when using different techniques).

Binary formation

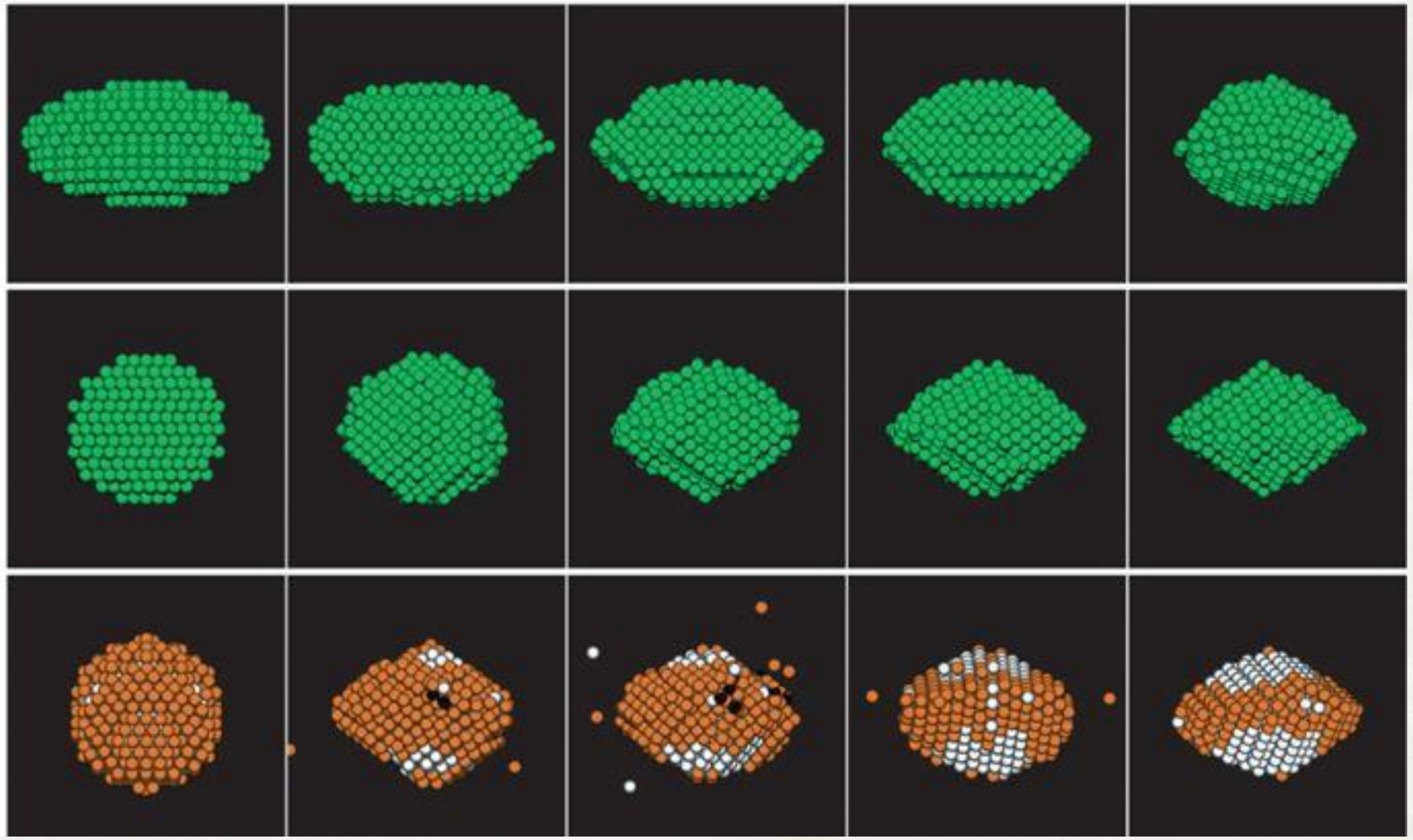


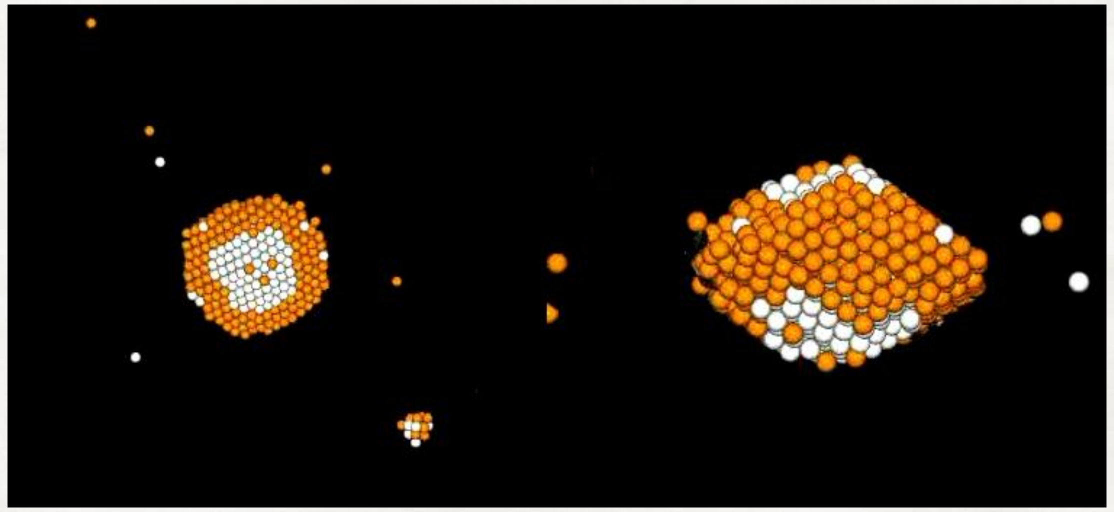
Walsh et al. (2008)



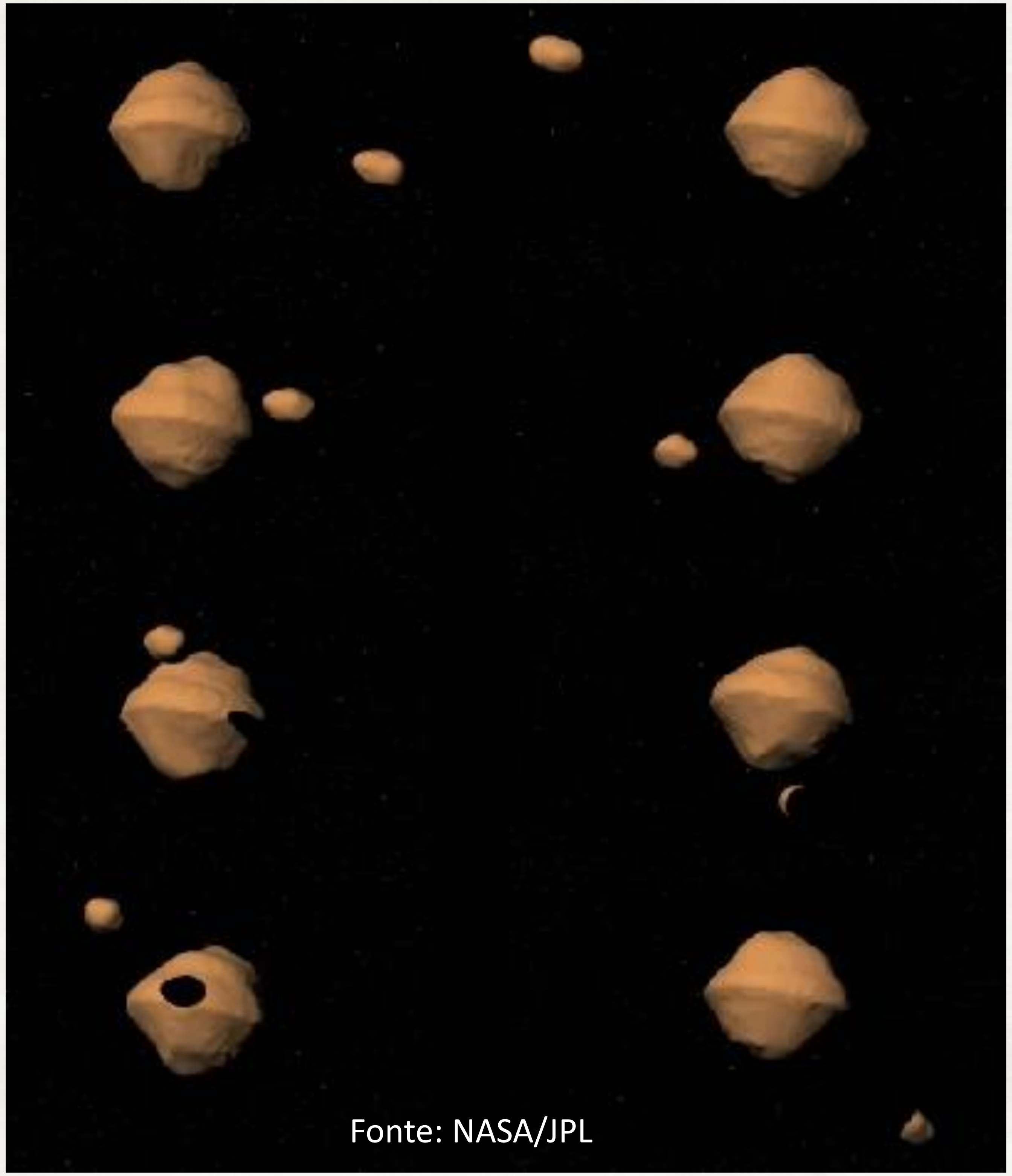


Binary formation



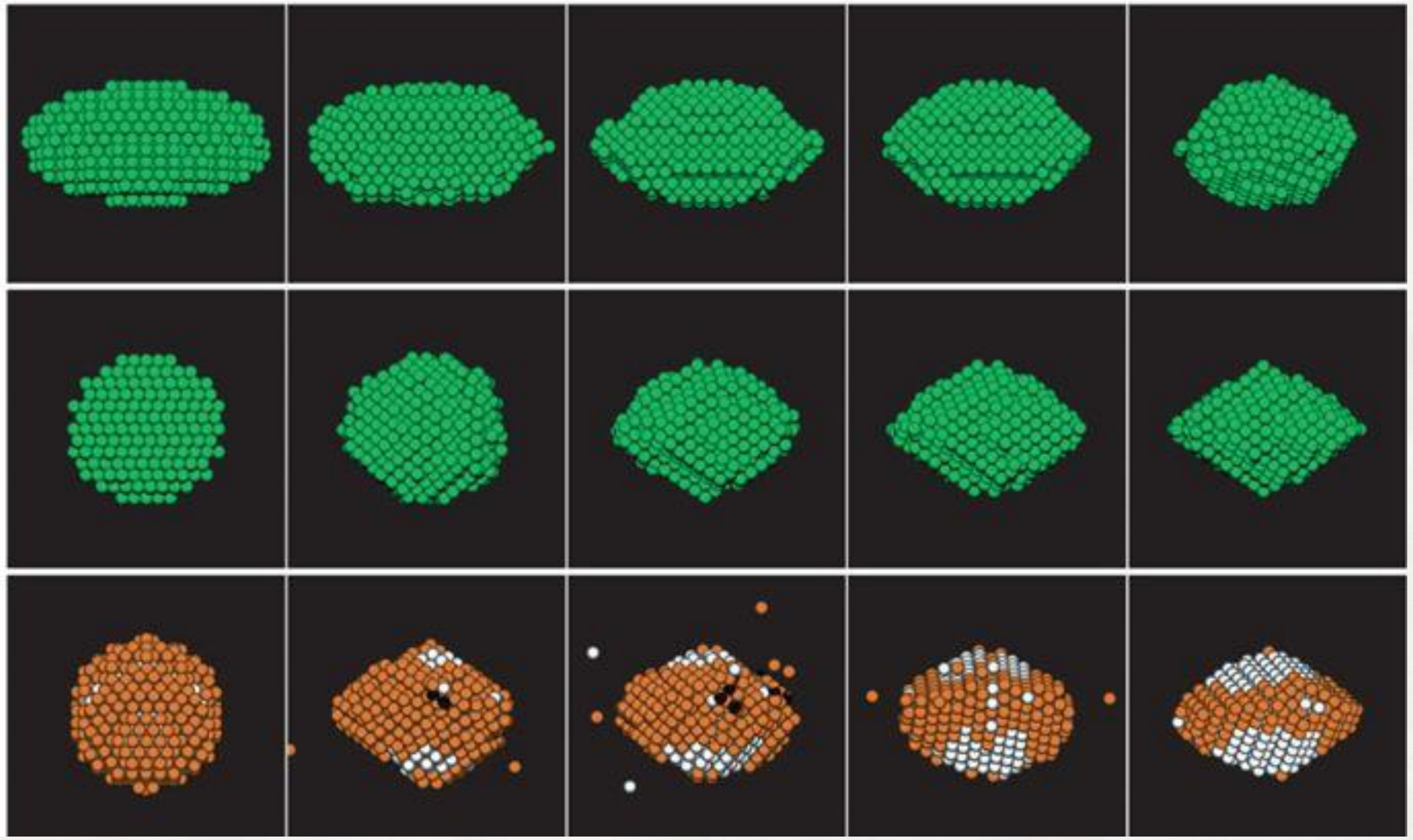


Walsh et al. (2008)

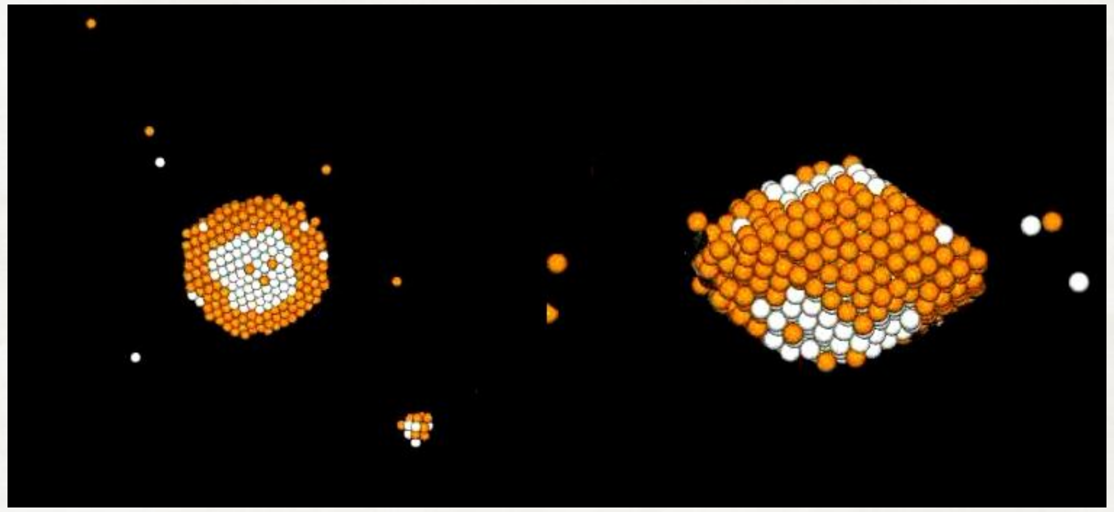


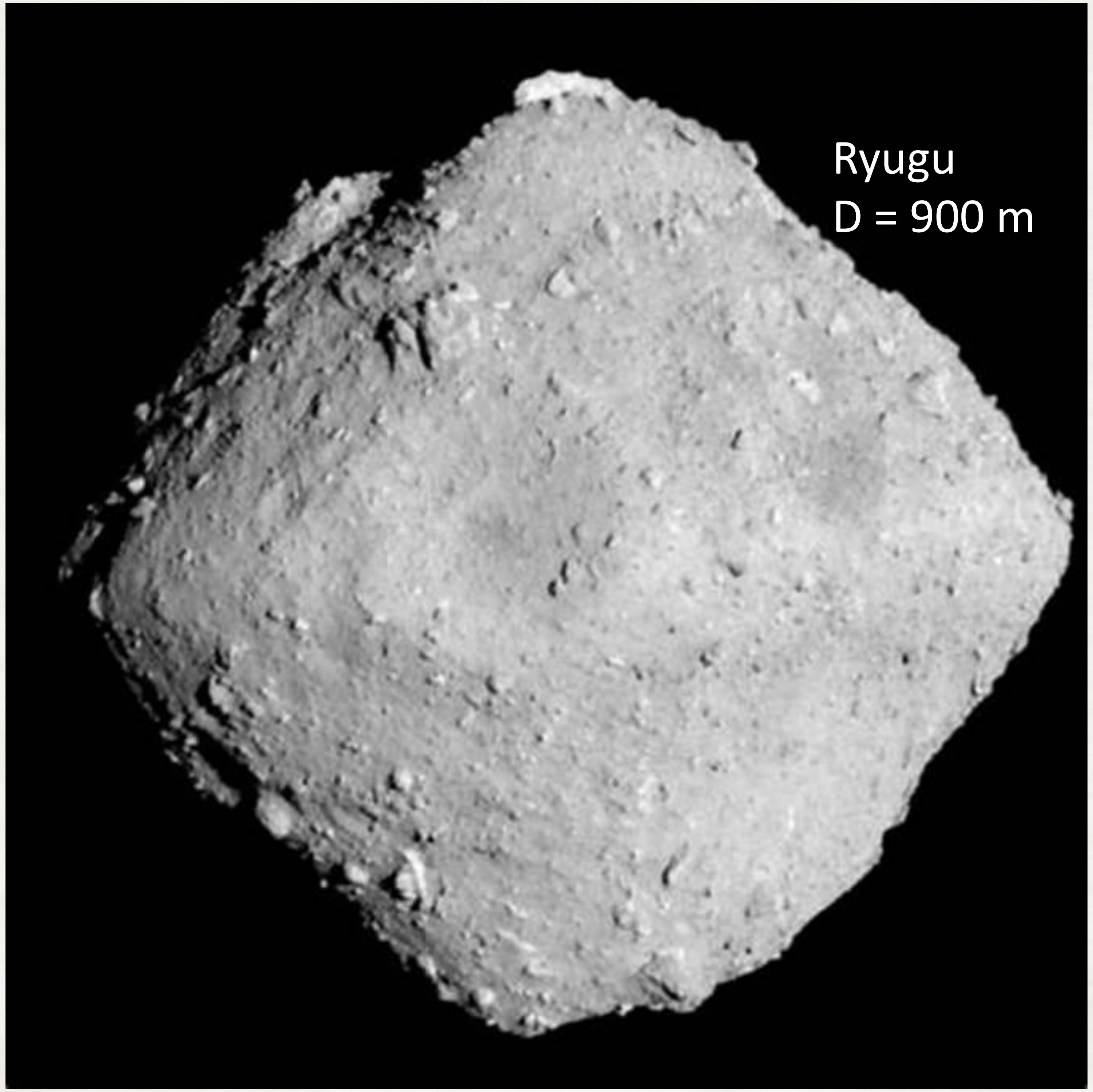
NEO 1999 KW4 (P=2,76 h)
Ostro et al. (2006); Pravec et al. (2006)

Binary formation



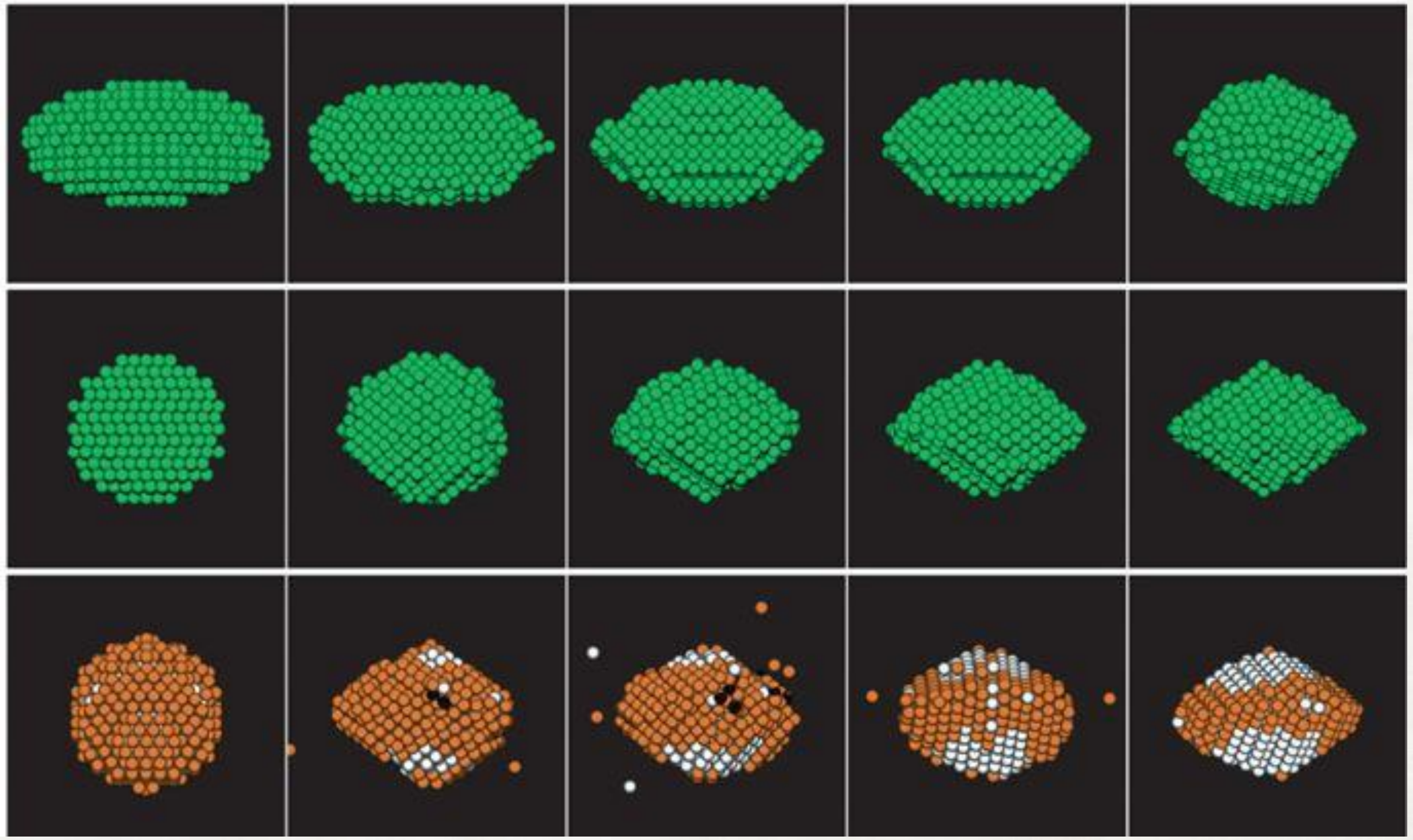
Walsh et al. (2008)



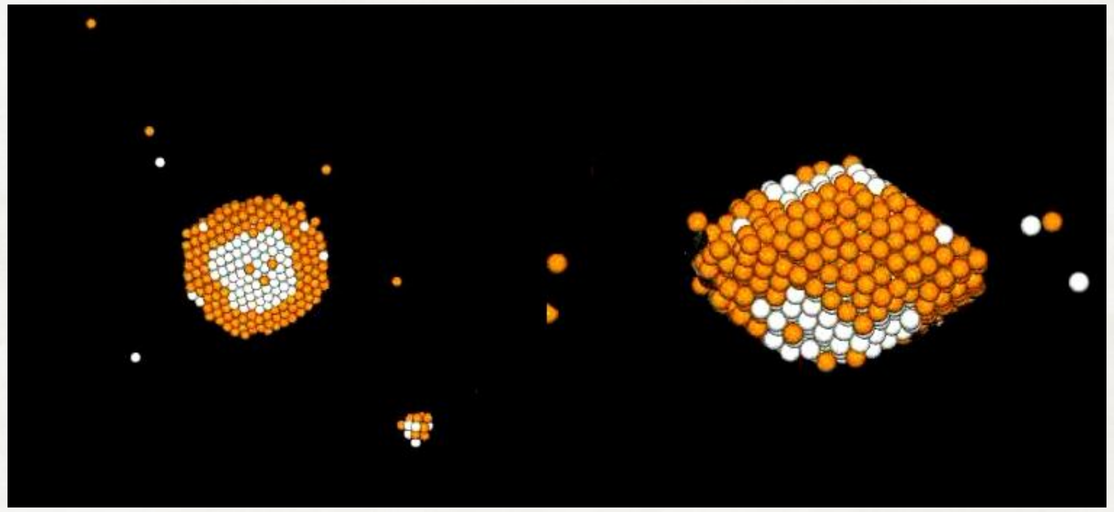


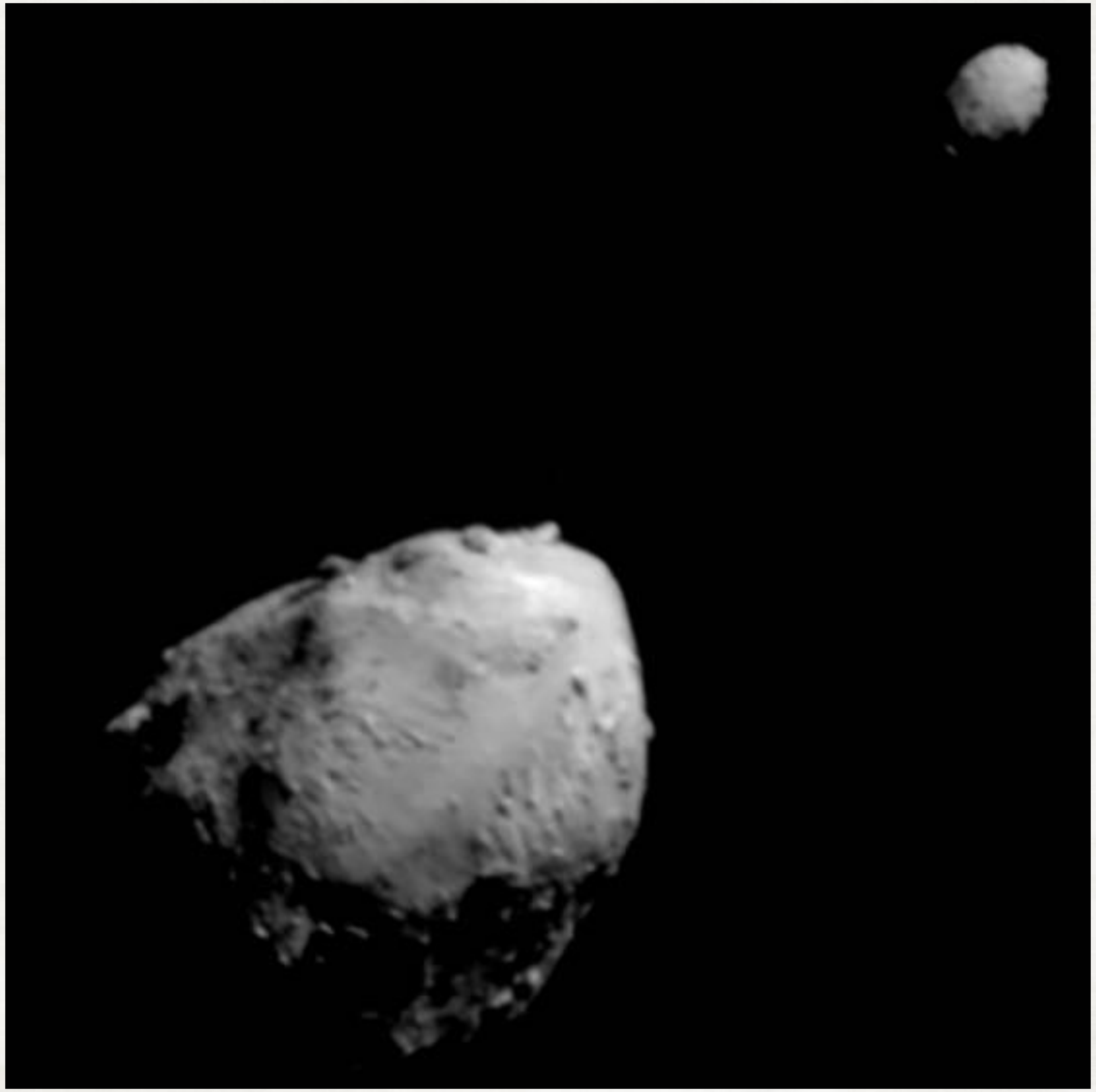
Sonda Hayabusa-2 (JAXA)
2014 - 2020

Binary formation



Walsh et al. (2008)

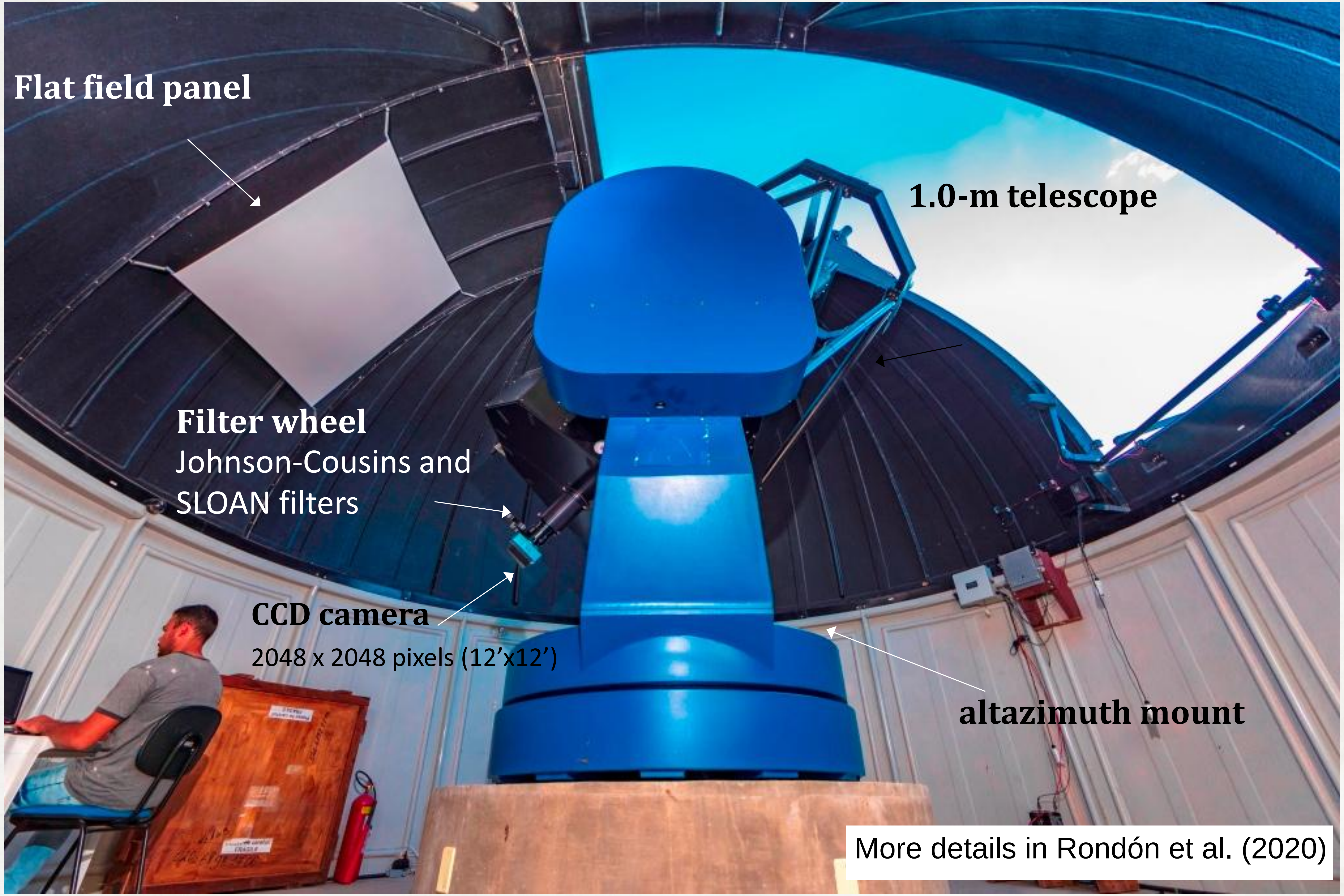


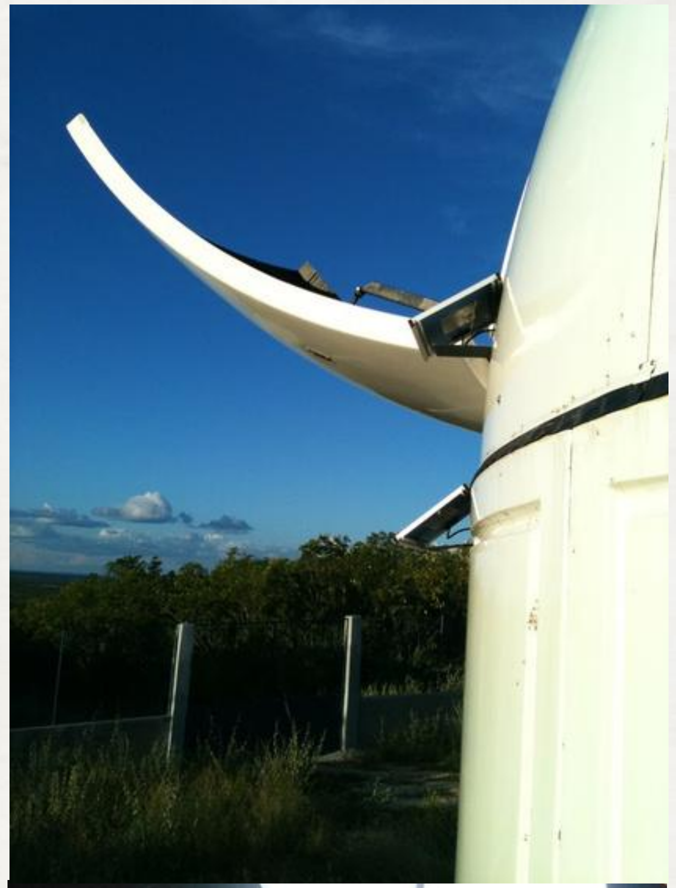


Didymos (Left) and Dimorphos (right), from DART.
Crédito NASA/Johns Hopkins APL
Madeira et al. (2023, 2024)

Onde observar asteroides do Brasil?

Observatório Astronômico do Sertão de Itaparica – OASI



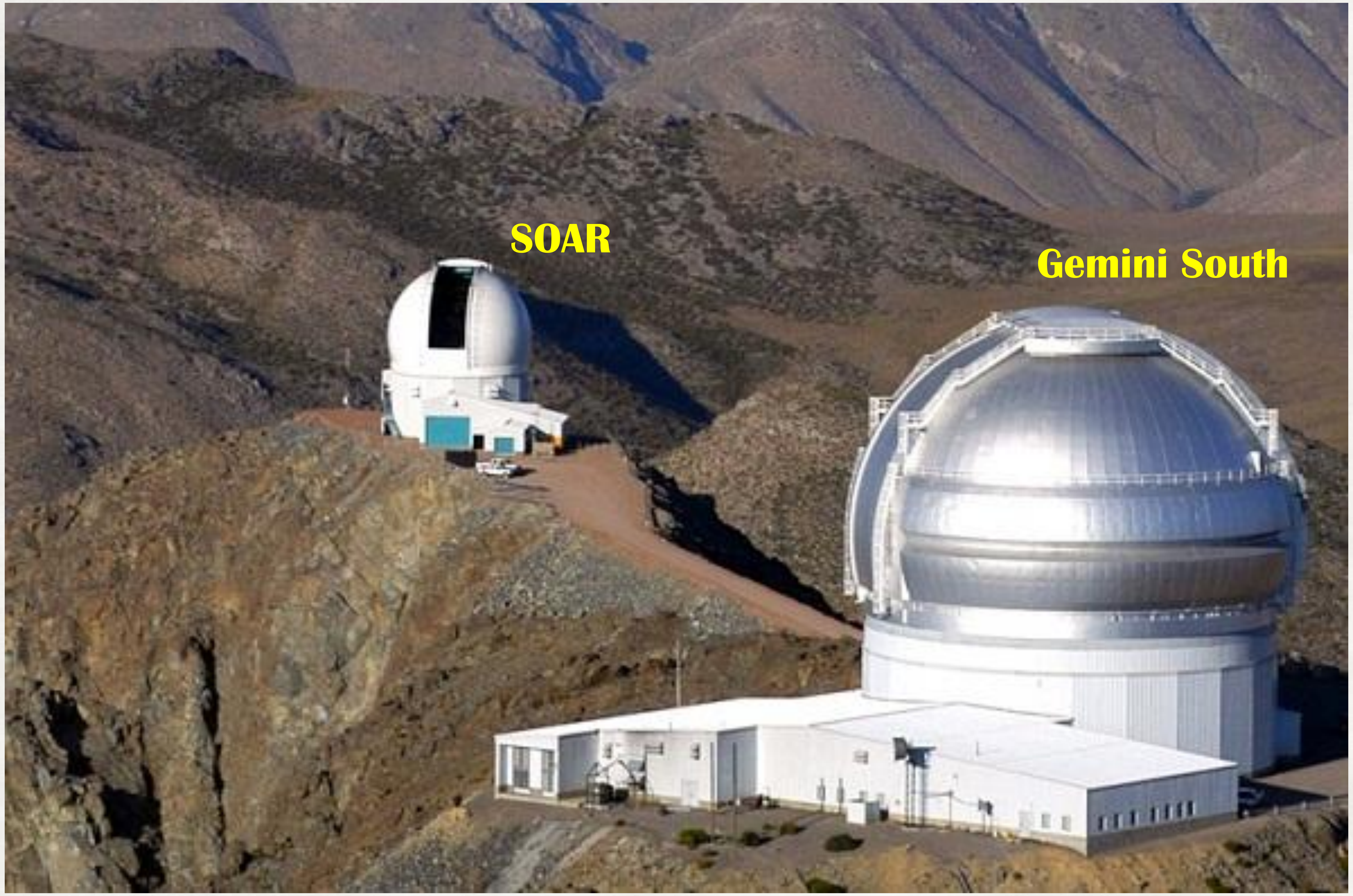


Observatório Pico dos Dias (OPD-LNA/MCTI)

1.6-m Telescope – SPARC4 (SDSS filters system)

0.6-m Telescope
Filter R (Johnson)

Telescopes in Chile



SOAR Telescope

- Location: Cerro Pachón, Chile, at an altitude of 2,700 meters.
- International consortium and partners (Brazil, NOAO, UNC, MSU).
- **4.2-meter aperture.**
- Spectroscopy to analyze chemical composition.
- Photometry to measure luminosity variations.
- Polarimetry to study light scattering properties

Gemini Telescope

- Location: Cerro Pachón, Chile, at an altitude of 2,737 meters.
- Operated by a consortium including the United States, Canada, Brazil, Chile, Argentina, and South Korea.
- Part of the International Gemini Observatory, which includes the Gemini North in Hawaii and Gemini South in Chile.
- **8.1-meter aperture.**
- Spectroscopy/Photometry.

Other Observatories

0.61-m Telescope
Johnson filters system (BVRI)

0.35-m Telescope
(Clear)

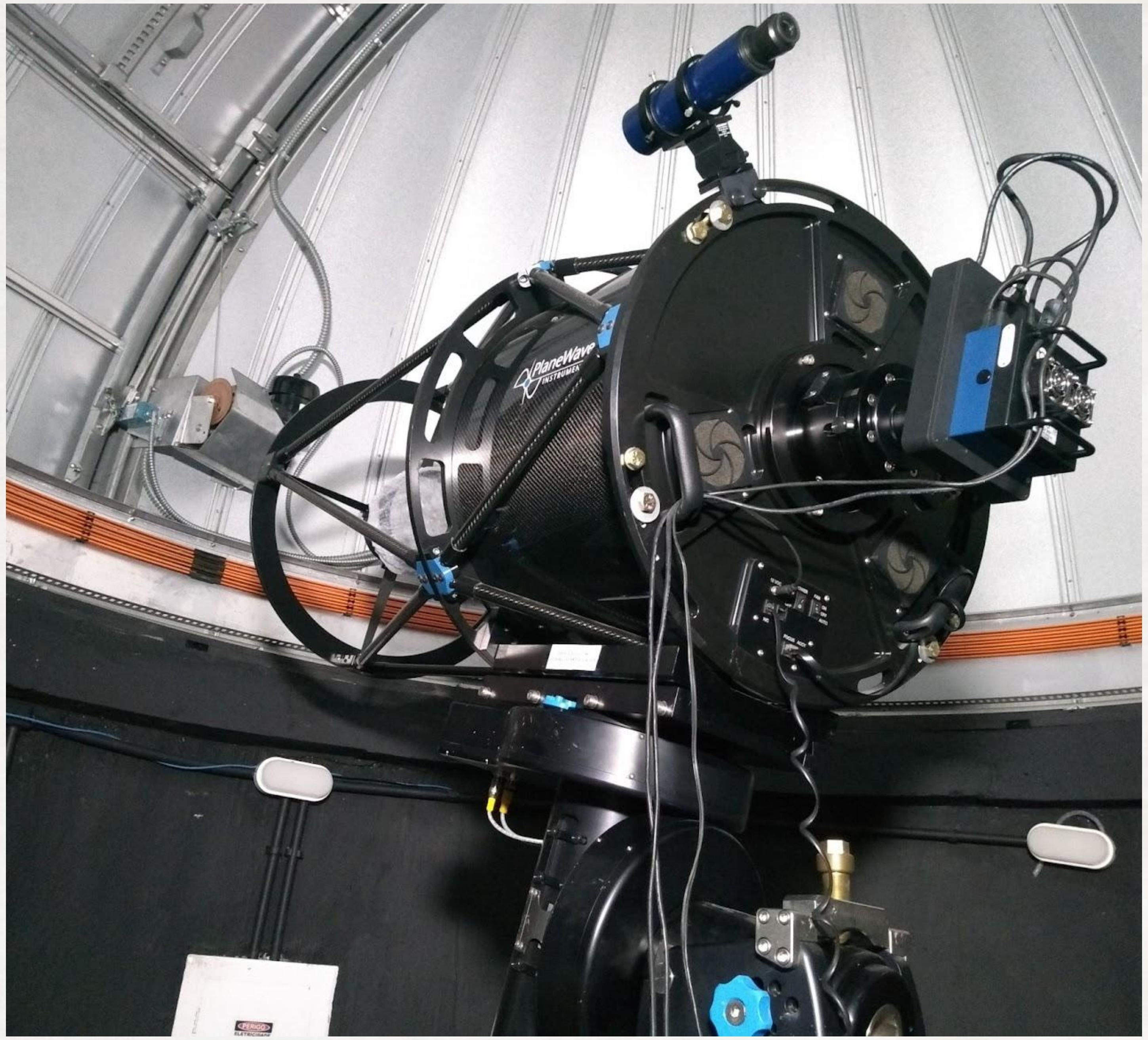
Blue Mountain Observatory – BMO, Australia

2.2-m Telescope
Johnson filters system (BVRI)

0.84-m Telescope
Filter R (Johnson)

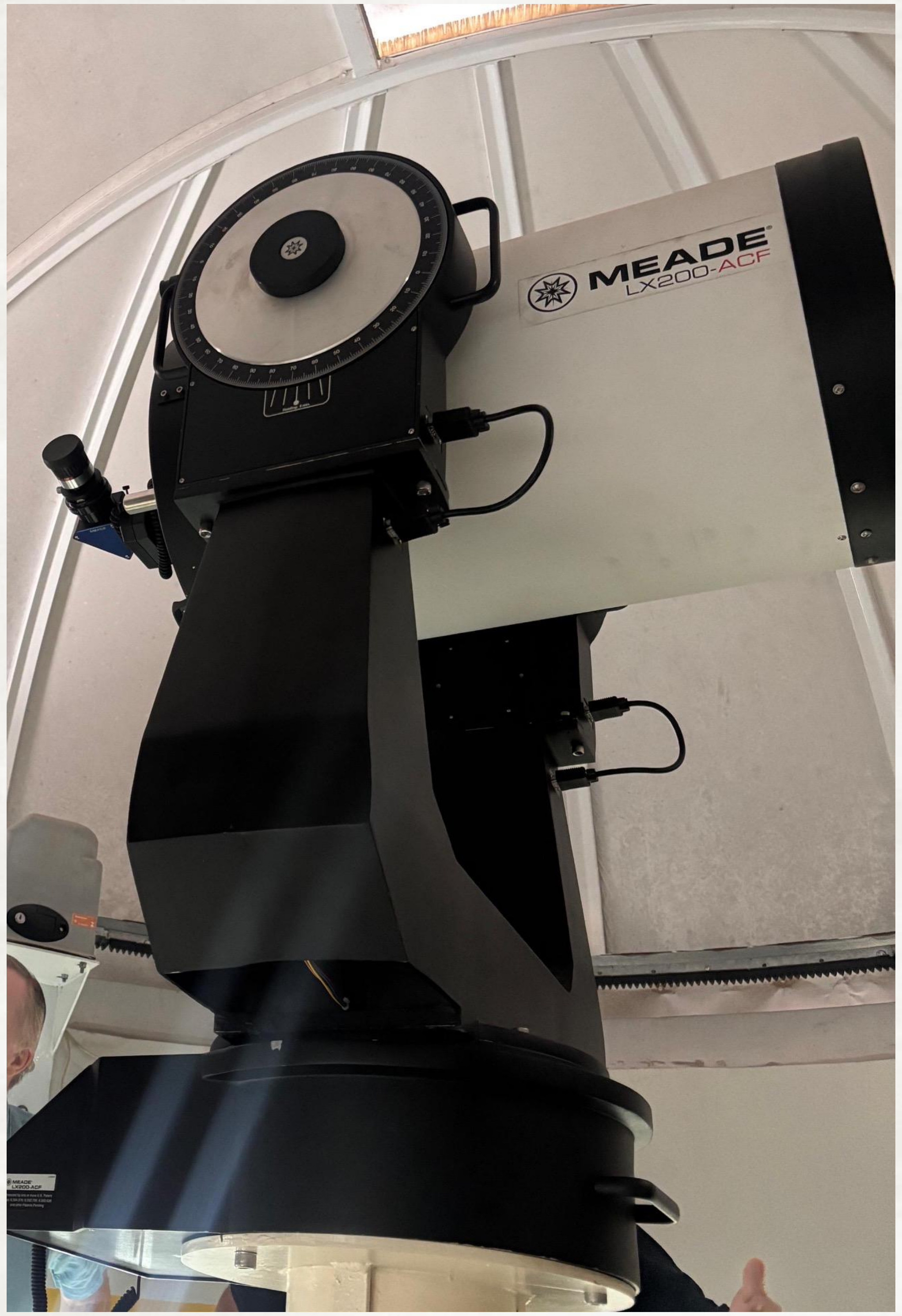
Observatorio Astronomico San Pedro Mártir – SPM, Mexico

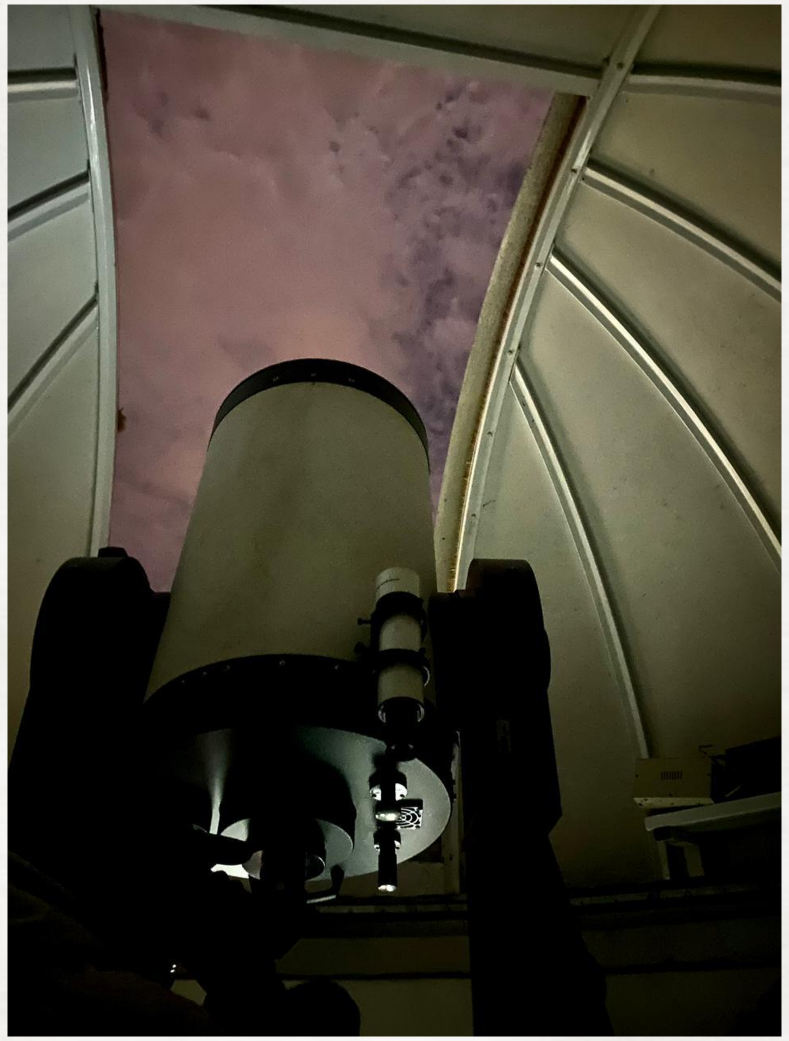
Other Observatories



0.51-m Telescope
filters system (BVRI – g,r,i,z)

Observatório Astronômico Antares – Feira de Santana, Bahia



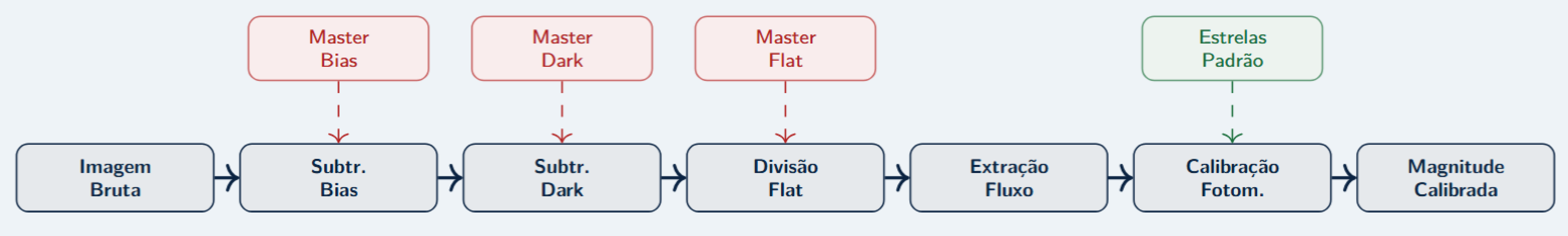


0.40-m Telescope

Observatório do GPDO – UNESP, Guaratinguetá

Fotometria — Processo de Redução

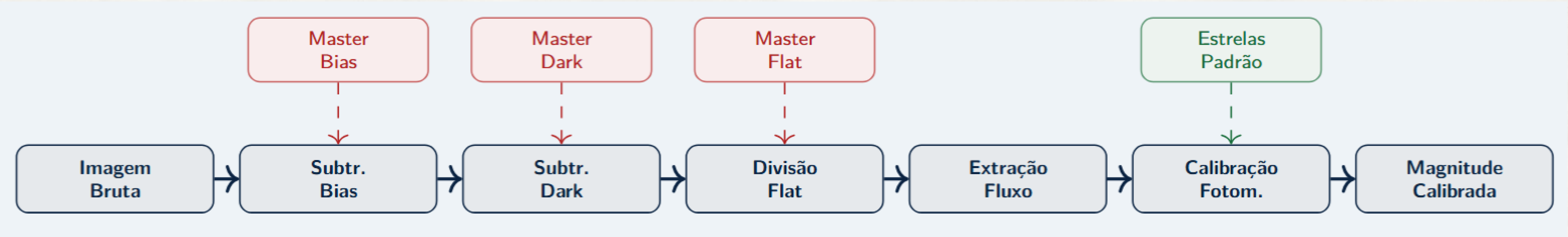
Do CCD bruto à magnitude calibrada



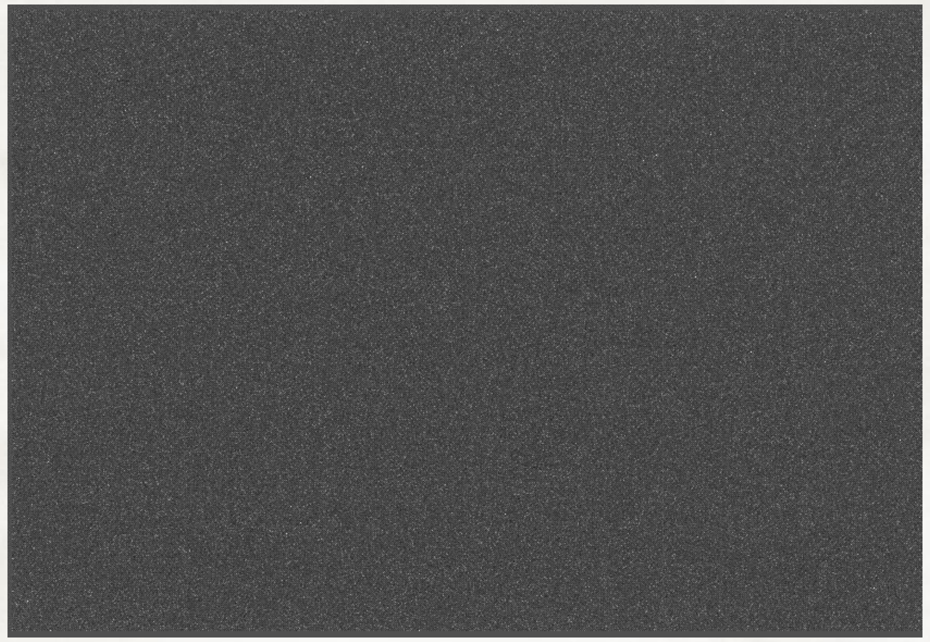
$$\text{Imagem Corrigida} = (\text{Light} - \text{MasterDark}) \times \frac{\text{Média}(\text{MasterFlat} - \text{MasterBias})}{\text{MasterFlat} - \text{MasterBias}}$$

Fotometria — Processo de Redução

Do CCD bruto à magnitude calibrada








Fotometria — Processo de Redução

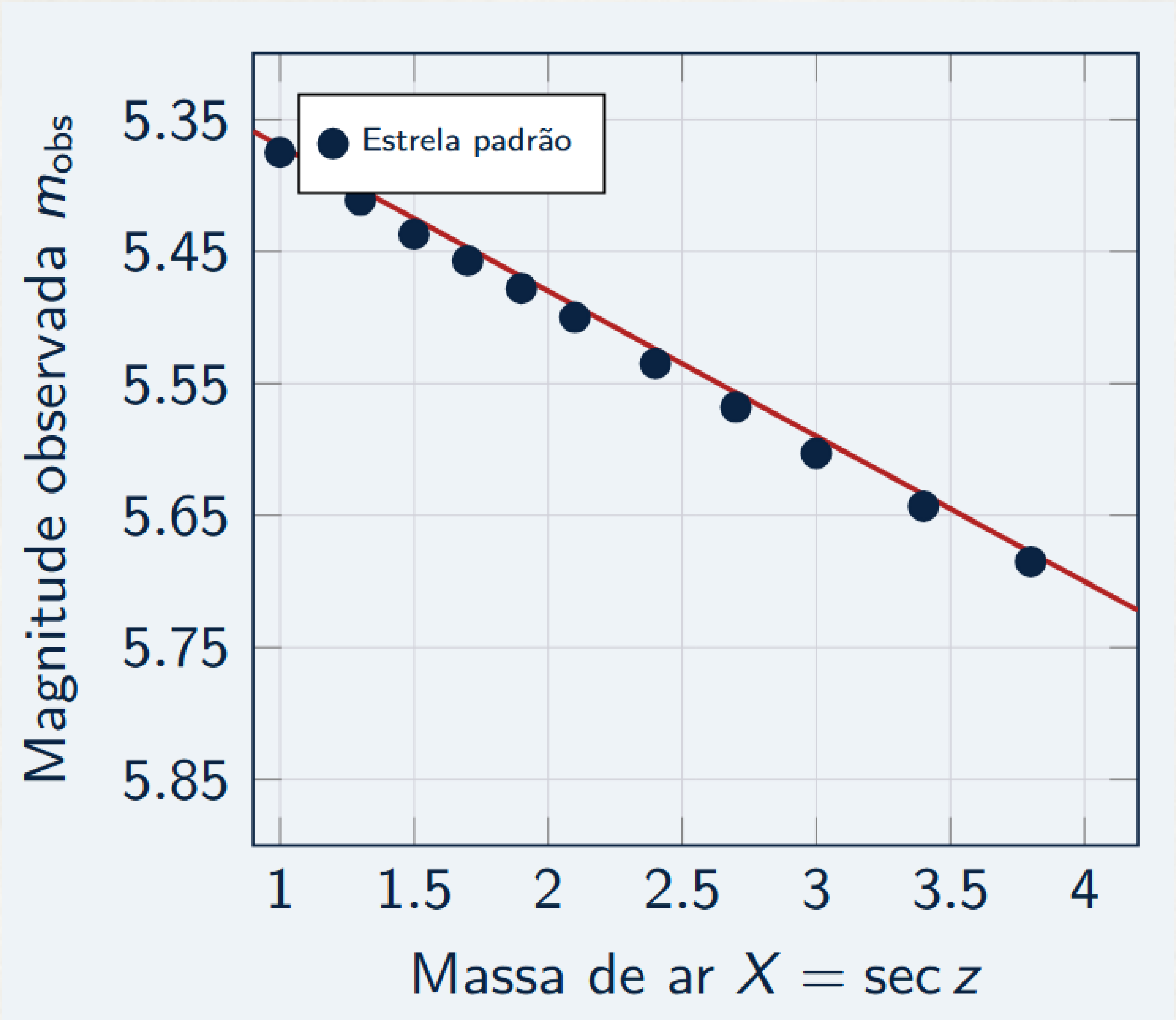
Do CCD bruto à magnitude calibrada

O que é fotometria?

Técnica que mede a **quantidade de energia** (fluxo) recebida de um objeto, geralmente filtrando por bandas espectrais definidas.

O que é extinção atmosférica?

A atmosfera absorve e espalha a luz estelar. A atenuação depende da **massa de ar** X percorrida pelo feixe luminoso.



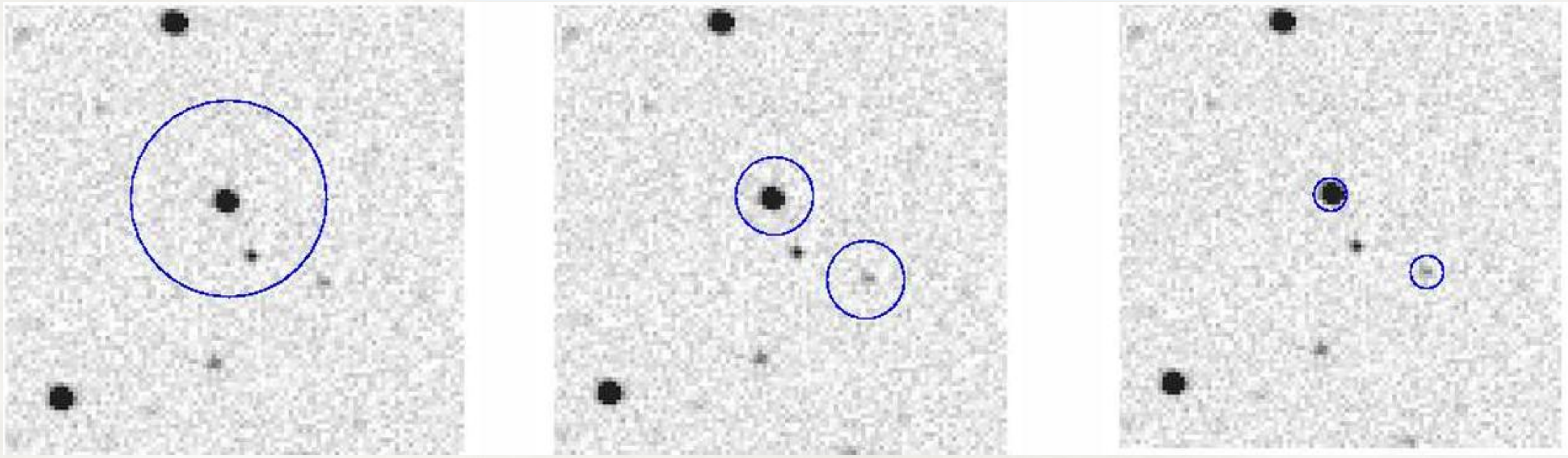
Lei de Bouguer–Lambert–Beer

$$m_{obs}(\lambda) = m_0(\lambda) + k(\lambda) \cdot X$$

m_{obs}: magnitude observada m_0: magnitude fora da atmosfera

k: coef. de extinção (mag/massa de ar)

$X = \sec z \approx 1/\sin(\text{alt})$: massa de ar



Fotometria — Equações Fundamentais

Magnitude instrumental e calibrada

$$m_{\text{inst}} = -2.5\log_{10}(F_{\text{ADU}}/t_{\text{exp}})$$

$$m_{\text{cal}} = m_{\text{inst}} + Z - k\,X$$

Z=ponto zero k=coef. extinção $X = \sec z$=massa de ar

Fotometria diferencial

$$\Delta m = m_{\text{alvo}} - m_{\text{ref}} = -2.5\log_{10}\left(\frac{F_{\text{alvo}}}{F_{\text{ref}}}\right)$$

Ideal para curvas de luz!

Magnitude absoluta H (fase zero)

$$H = V - 5\log_{10}(r\,\Delta) + f(\alpha)$$

r, Δ: distâncias heliocêntrica e geocêntrica (UA)

$f(\alpha)$: função de fase HG (Bowell et al. 1989)

Índices de cor

$$B-V = m_B - m_V \qquad V-R = m_V - m_R$$

Azul quente: $B-V<0$ Vermelho frio: $B-V>1$

Módulo de distância

$$m - M = 5\log_{10}\left(\frac{d}{10\text{ pc}}\right)$$

Razão sinal-ruído (SNR)

$$\text{SNR} = \frac{N_\star}{\sqrt{N_\star + n_p(N_{\text{céu}} + N_D + \sigma_R^2)}}$$

$N_\star$: fótons da estrela n_p: pixels na abertura

N_D: dark σ_R: ruído de leitura

Photometry and physical characterization of asteroids

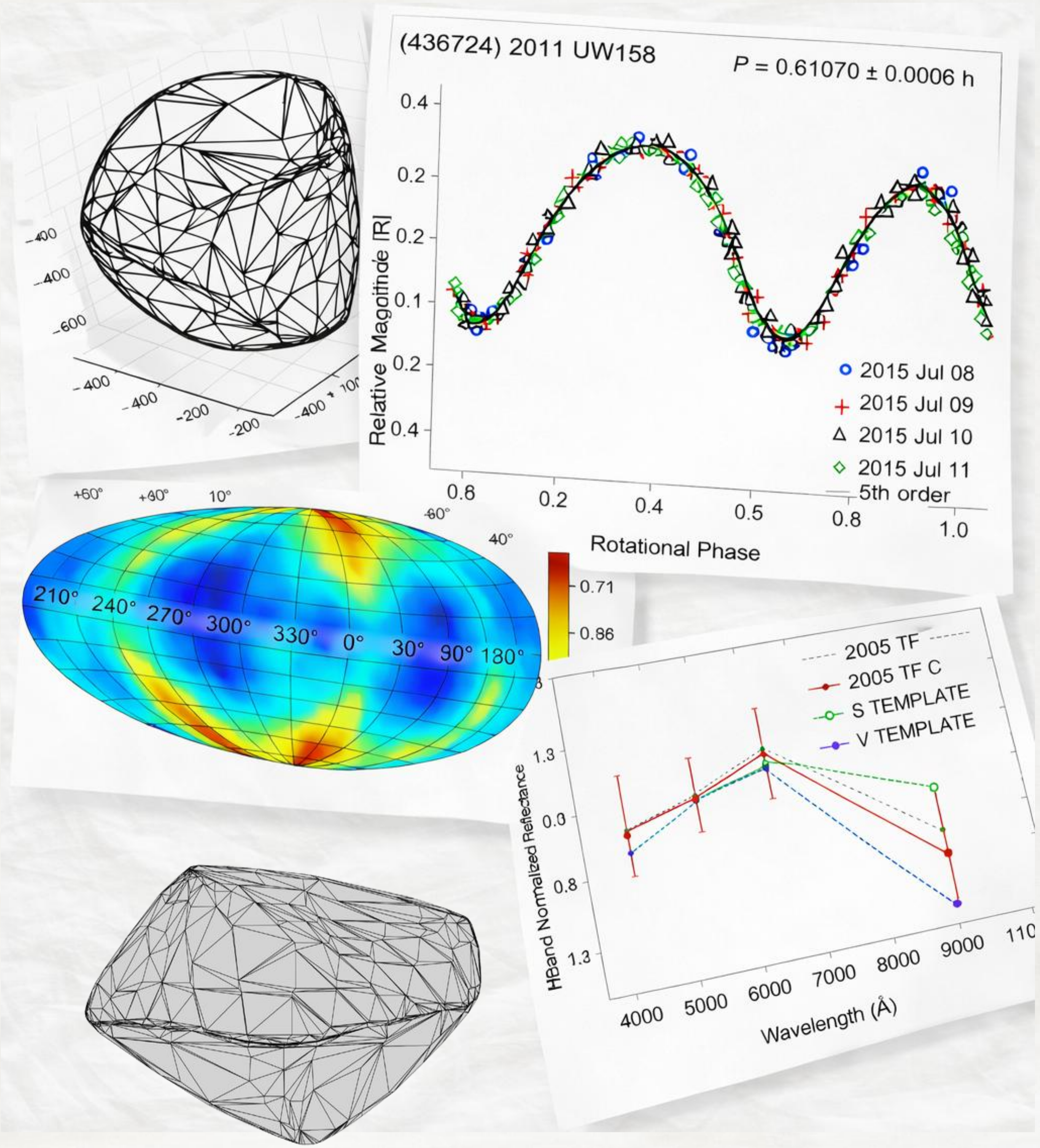
Photometric data

Orbit

Rotational Properties (multiply periods, spin orientation) and Shape model

Surface Properties (Absolute magnitude and diameter, surface parameters)

Color indices (photometric spectra, taxonomical classification)



Lightcurves analysis

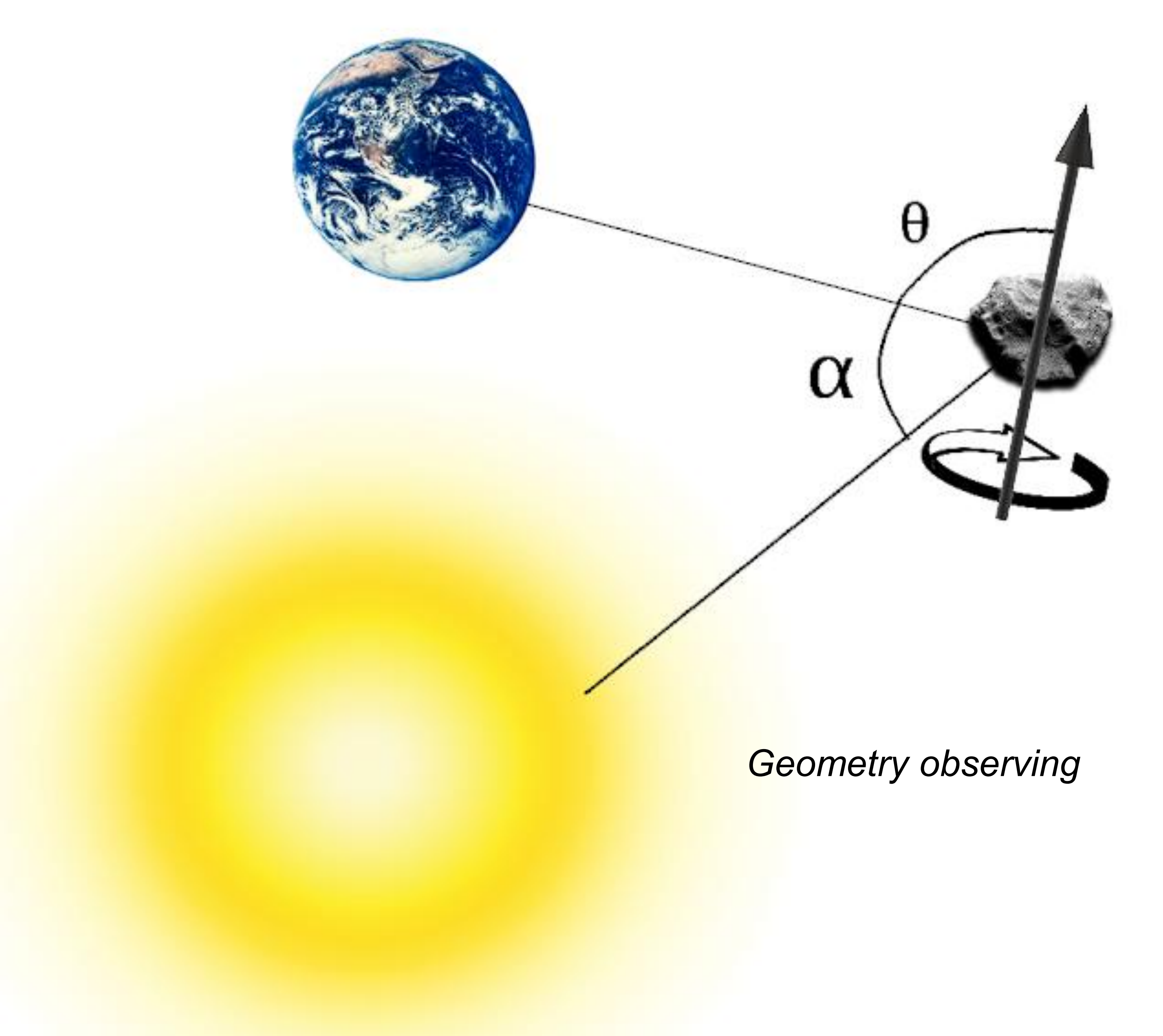
Brightness change over time caused by rotation - Lightcurve.

- The apparent brightness depends on:

  1. the distance from the Earth and the Sun (known)
  2. Geometry Sun-asteroid-Earth (known)

- Unknown parameters:

  1. Shape
  2. rotation state (spin axis direction, period of rotation)
  3. surface properties (albedo, light-scattering behaviour)



Geometry observing

Lightcurves analysis

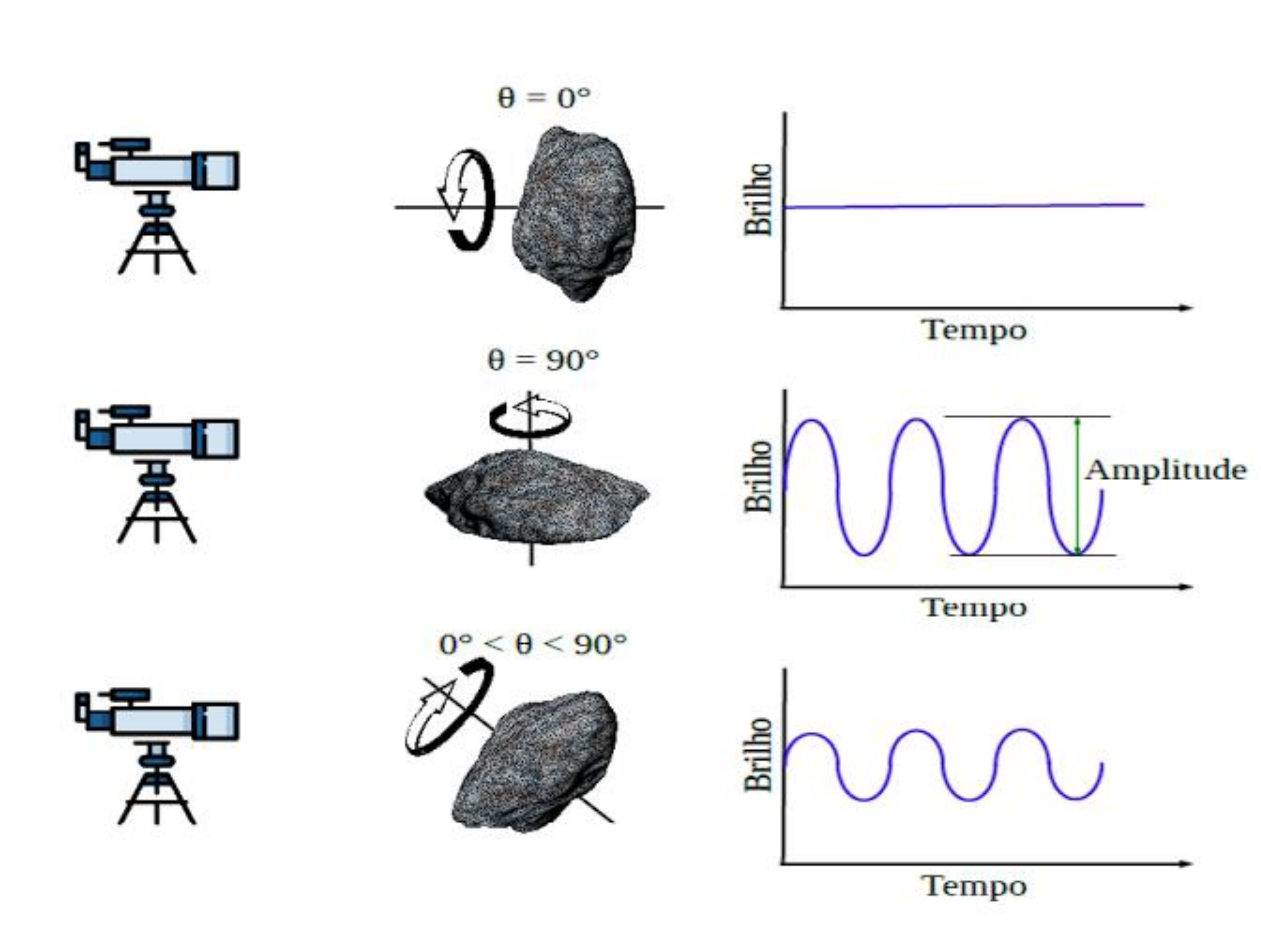
Brightness change over time caused by rotation - Lightcurve.

- The apparent brightness depends on:

  1. the distance from the Earth and the Sun (known)
  2. Geometry Sun-asteroid-Earth (known)

- Unknown parameters:

  1. Shape
  2. rotation state (spin axis direction, period of rotation)
  3. surface properties (albedo, light-scattering behaviour)



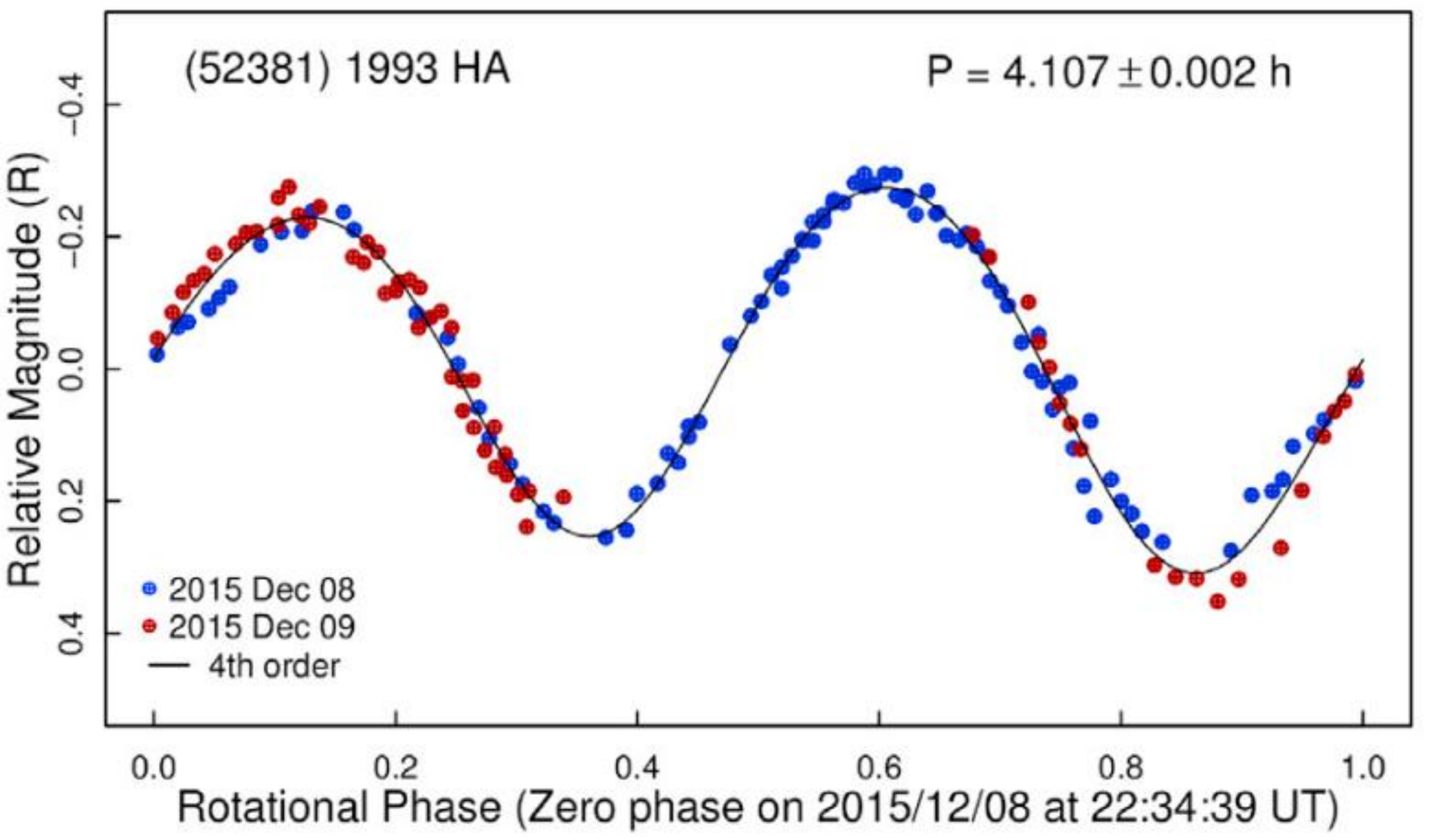
Lightcurves analysis

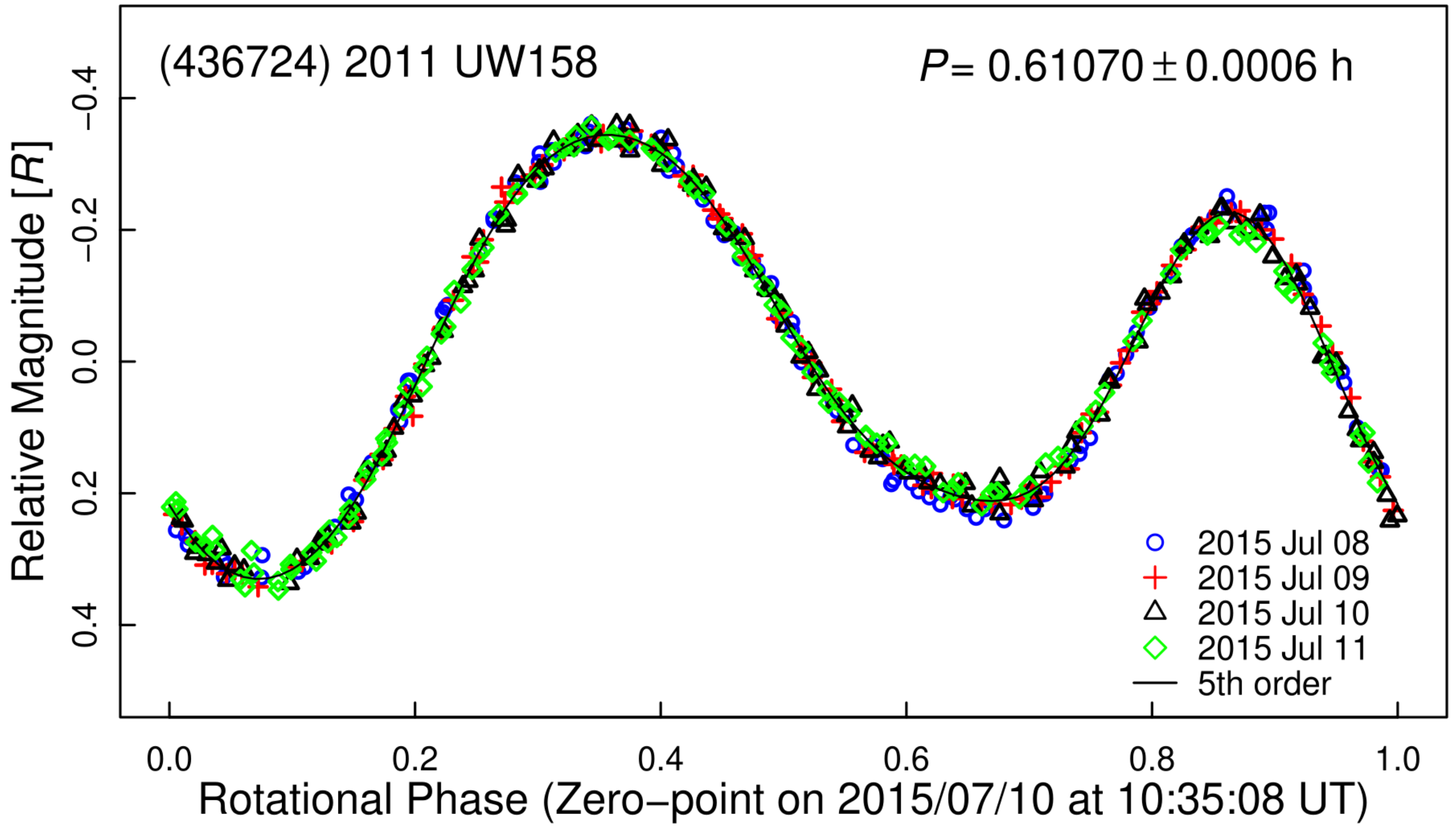
Fourier Analysis of Light Curves (Harris et al., 1989):

$$V(\alpha, t) = V(\alpha) + \sum_{l=1}^{n} [A_l \sin \frac{2\pi l}{P}(t - t_0) + B_l \cos \frac{2\pi l}{P}(t - t_0)]$$

- $V(\alpha,t)$ is the magnitude at a phase angle (α) at a given instant t;
- $V(\alpha)$ is the average magnitude at a phase angle α;
- Al and Bl are the Fourier coefficients;
- P is the rotation period;
- T_0 is the midpoint of the observation interval;
- N is the degree of the polynomial.

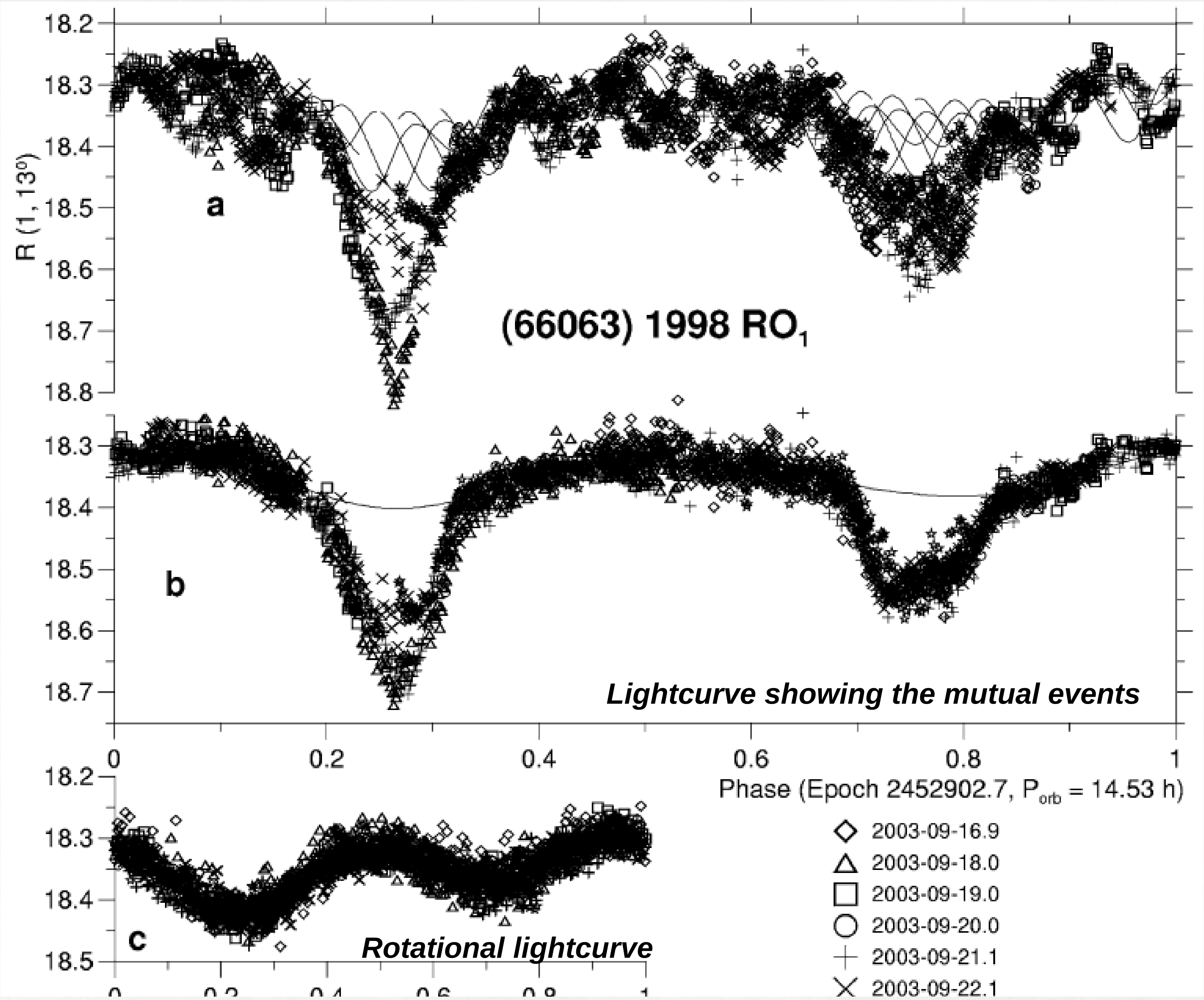
Monteiro et al. (2020)





Complex lightcurves analysis

A simple sum of two Fourier series (Pravec et al. 2006)



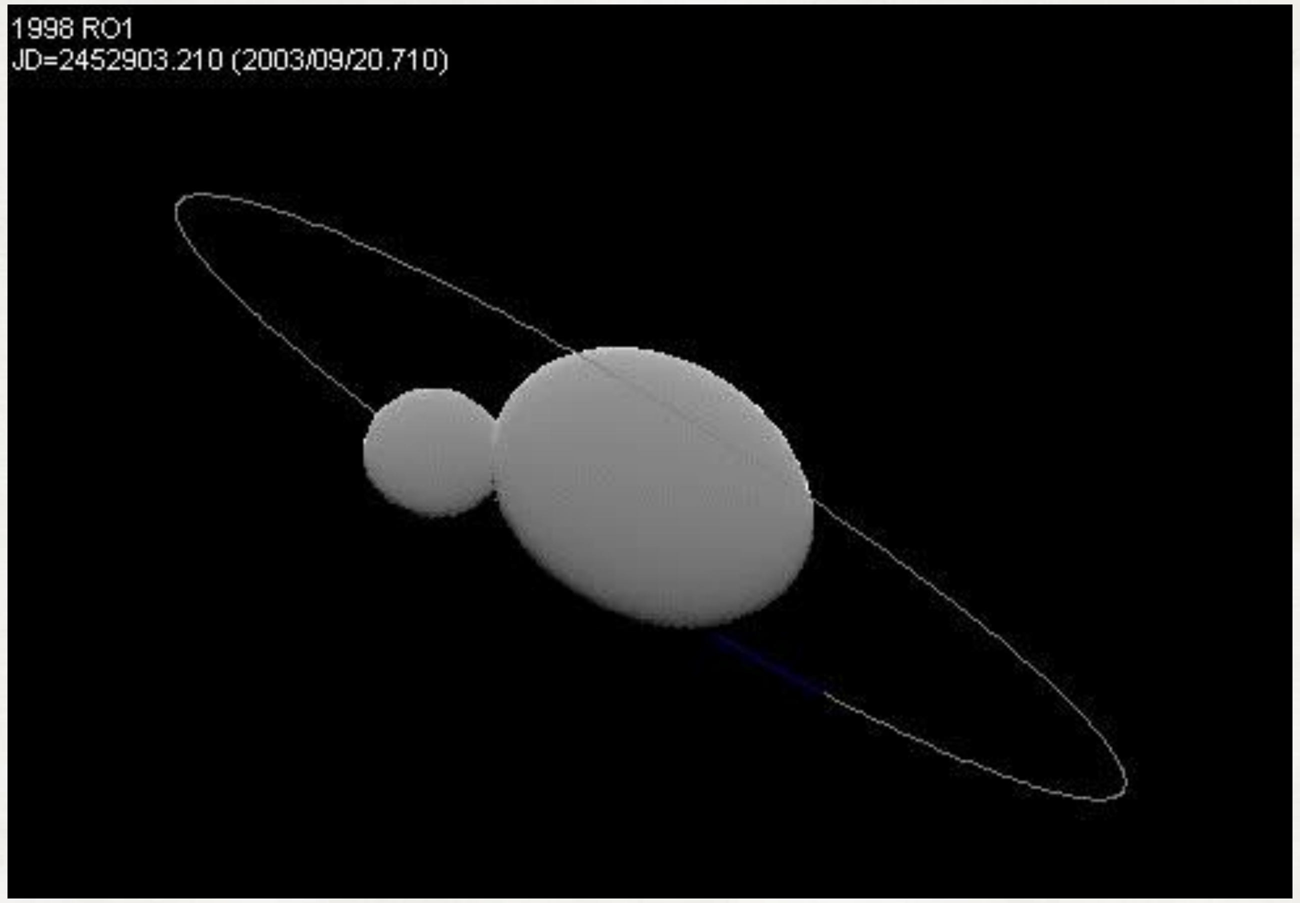
$$F(t) = F_1(t) + F_2(t) \tag{1}$$

$$F_1(t) = C_1 + \sum_{k=1}^{m_1} \left[S_{1k} \sin \frac{2\pi k}{P_1}(t - t_0) + C_{1k} \cos \frac{2\pi k}{P_1}(t - t_0) \right] \tag{2}$$

$$F_2(t) = C_2 + \sum_{k=1}^{m_2} \left[S_{2k} \sin \frac{2\pi k}{P_2}(t - t_0) + C_{2k} \cos \frac{2\pi k}{P_2}(t - t_0) \right], \tag{3}$$

In the dual-period search process, the primary period is derived from the composite lightcurve, which is subtracted from the original data, leaving only the variations due to the secondary component and mutual events.

Complex lightcurves analysis



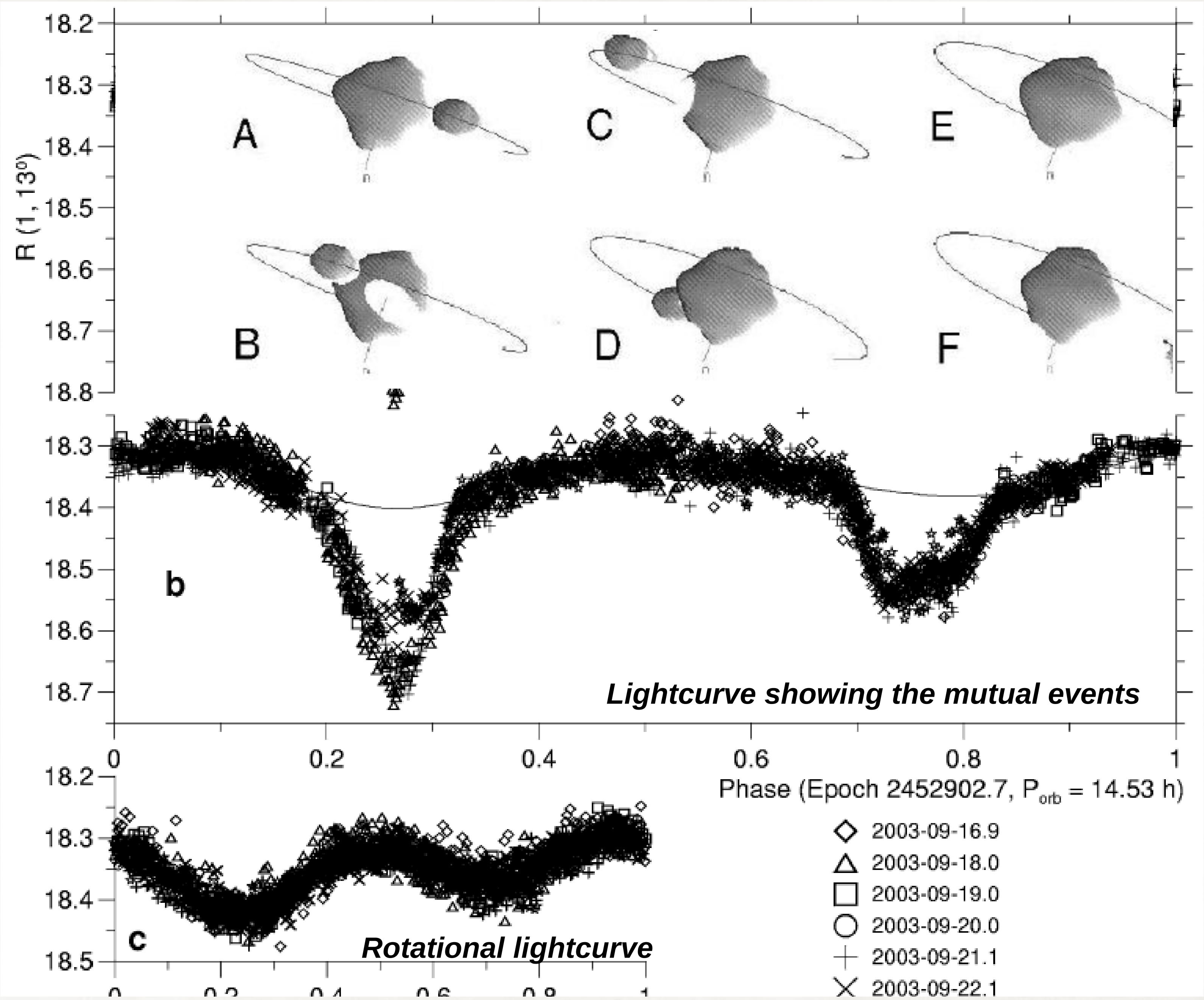
Scheirich and Pravec (2009)

$$F(t) = F_1(t) + F_2(t) \quad (1)$$

$$F_1(t) = C_1 + \sum_{k=1}^{m_1} \left[S_{1k} \sin \frac{2\pi k}{P_1}(t - t_0) + C_{1k} \cos \frac{2\pi k}{P_1}(t - t_0) \right] \quad (2)$$

$$F_2(t) = C_2 + \sum_{k=1}^{m_2} \left[S_{2k} \sin \frac{2\pi k}{P_2}(t - t_0) + C_{2k} \cos \frac{2\pi k}{P_2}(t - t_0) \right], \quad (3)$$

A simple sum of two Fourier series (Pravec et al. 2006)



In the dual-period search process, the primary period is derived from the composite lightcurve, which is subtracted from the original data, leaving only the variations due to the secondary component and mutual events.

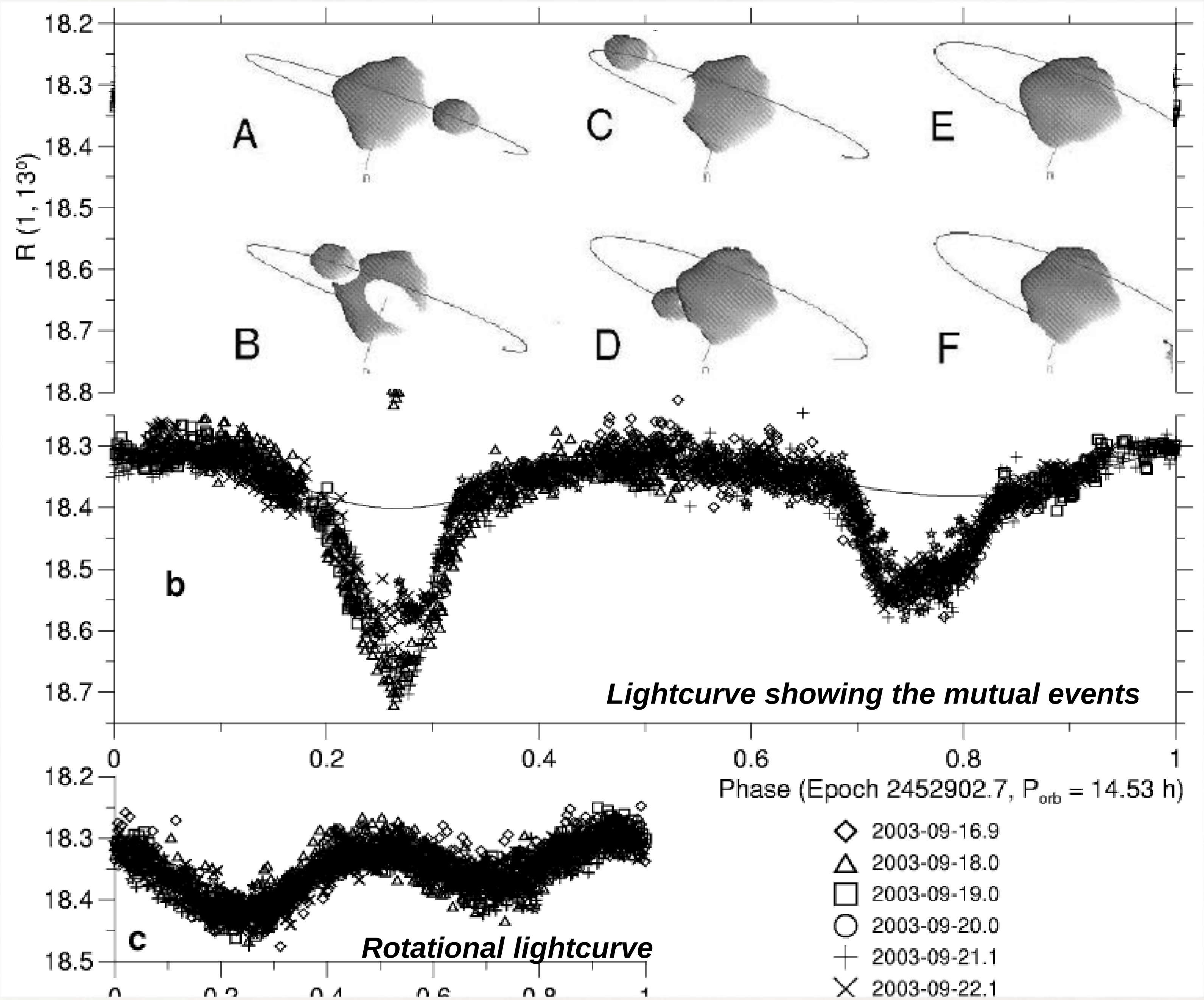
Physical parameters from lightcurves

(1) $$\frac{D_s}{D_p} \geq [1 - 10^{-0.4\Delta m}]^{1/2}$$

(2) $$\frac{a}{D_p} = \frac{(1 + \frac{D_s}{D_p})}{(2\pi \frac{\Delta t}{P_{orb}}) - \alpha}$$

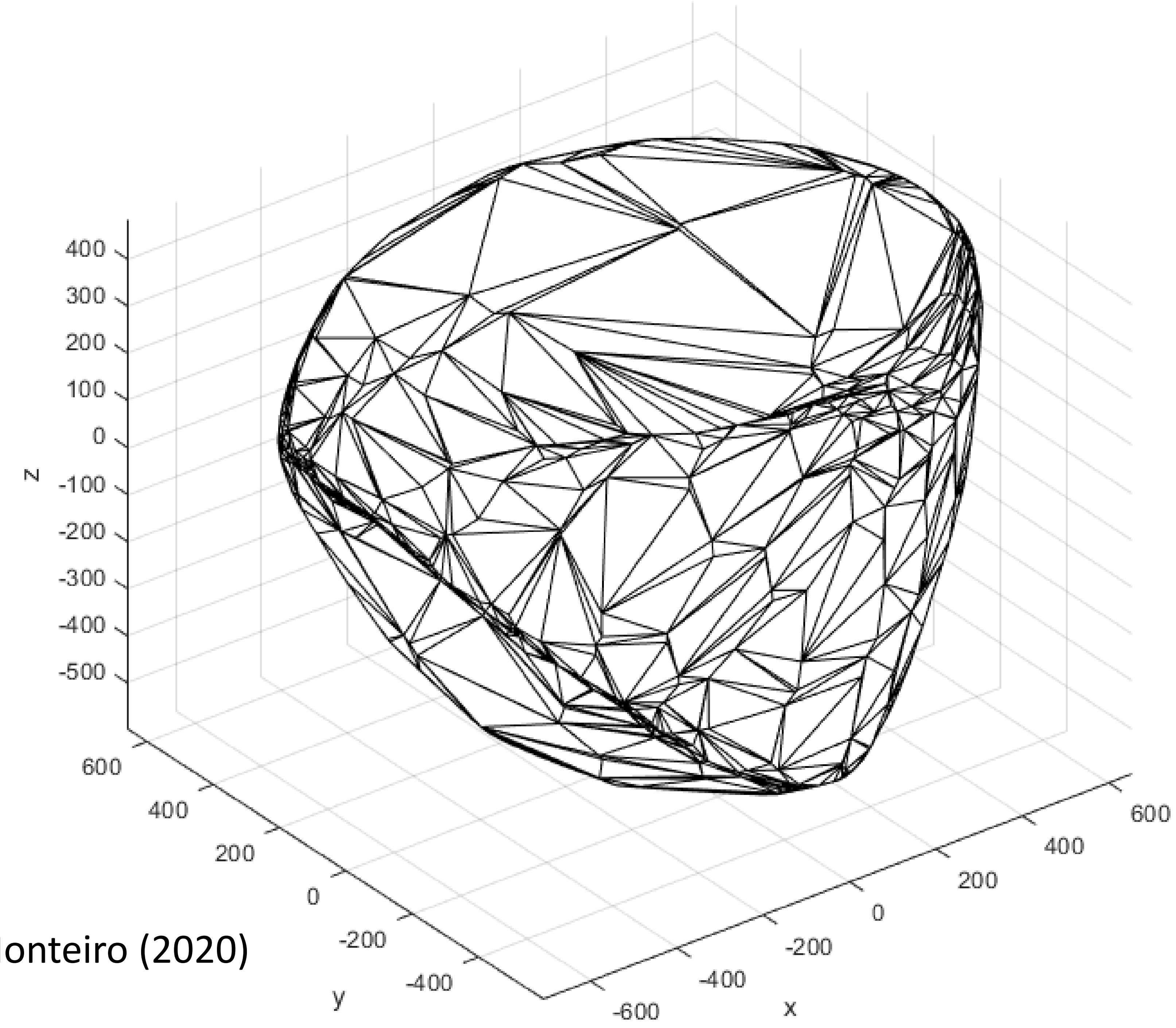
(3) $$\rho_p = \frac{24\pi}{GP_{orb}^2} (\frac{a}{D_p})^3 \frac{1}{1 + (\frac{D_s}{D_p})^3}$$

A simple sum of two Fourier series (Pravec et al. 2006)



In the dual-period search process, the primary period is derived from the composite lightcurve, which is subtracted from the original data, leaving only the variations due to the secondary component and mutual events.

Shape model and Spin parameters



Monteiro (2020)

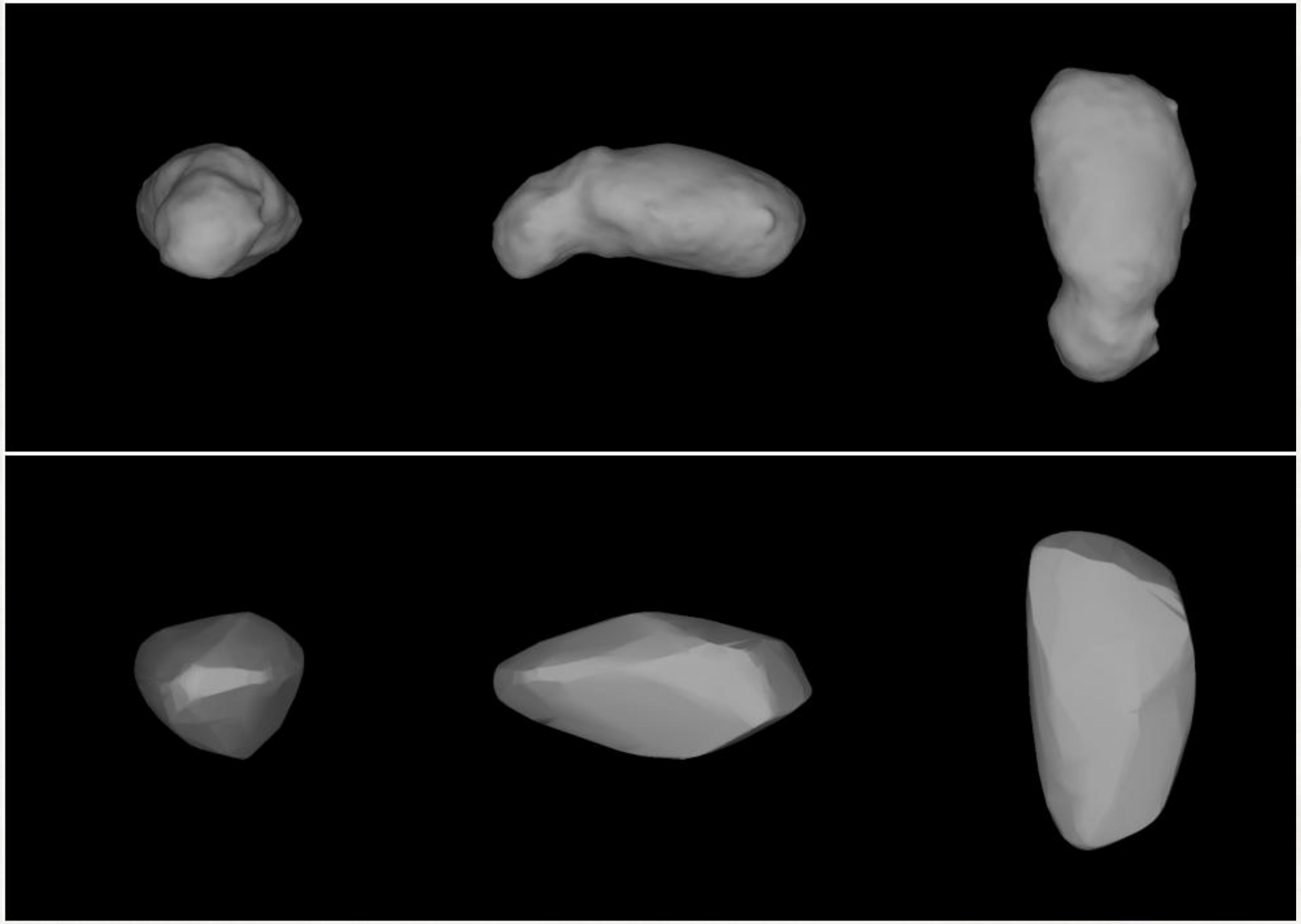
- Spin direction and shape model are determined using the **Lightcurve Inversion Method** (Kaasalainen & Torppa, 2001; Kaasalainen et al. 2001).

- The method assumes a combination of **Lambert and Lommel-Seeliger scattering laws** as the physical model for the asteroid surface reflectance (S), according to the equation:

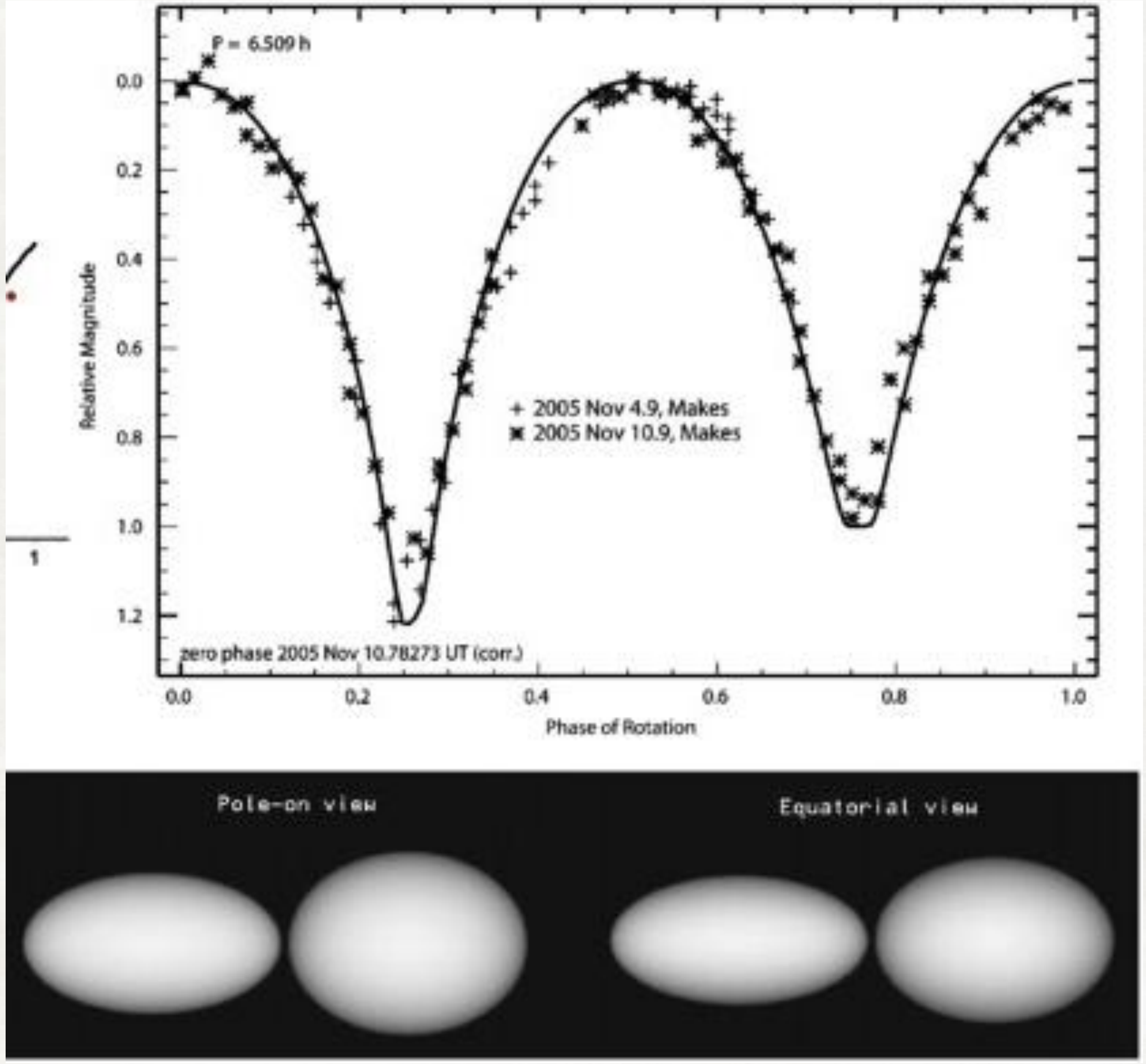
$$S(\mu, \mu_0, \alpha) = f(\alpha)[S_{LS}(\mu, \mu_0) + cS_L(\mu, \mu_0)]$$

- The inversion program also solves the coordinates and vertices of the model surface polygons by applying **Minkowski minimization** method as well as converts these polygons into triangles using the **octant triangulation**.

Shape model and Spin parameters



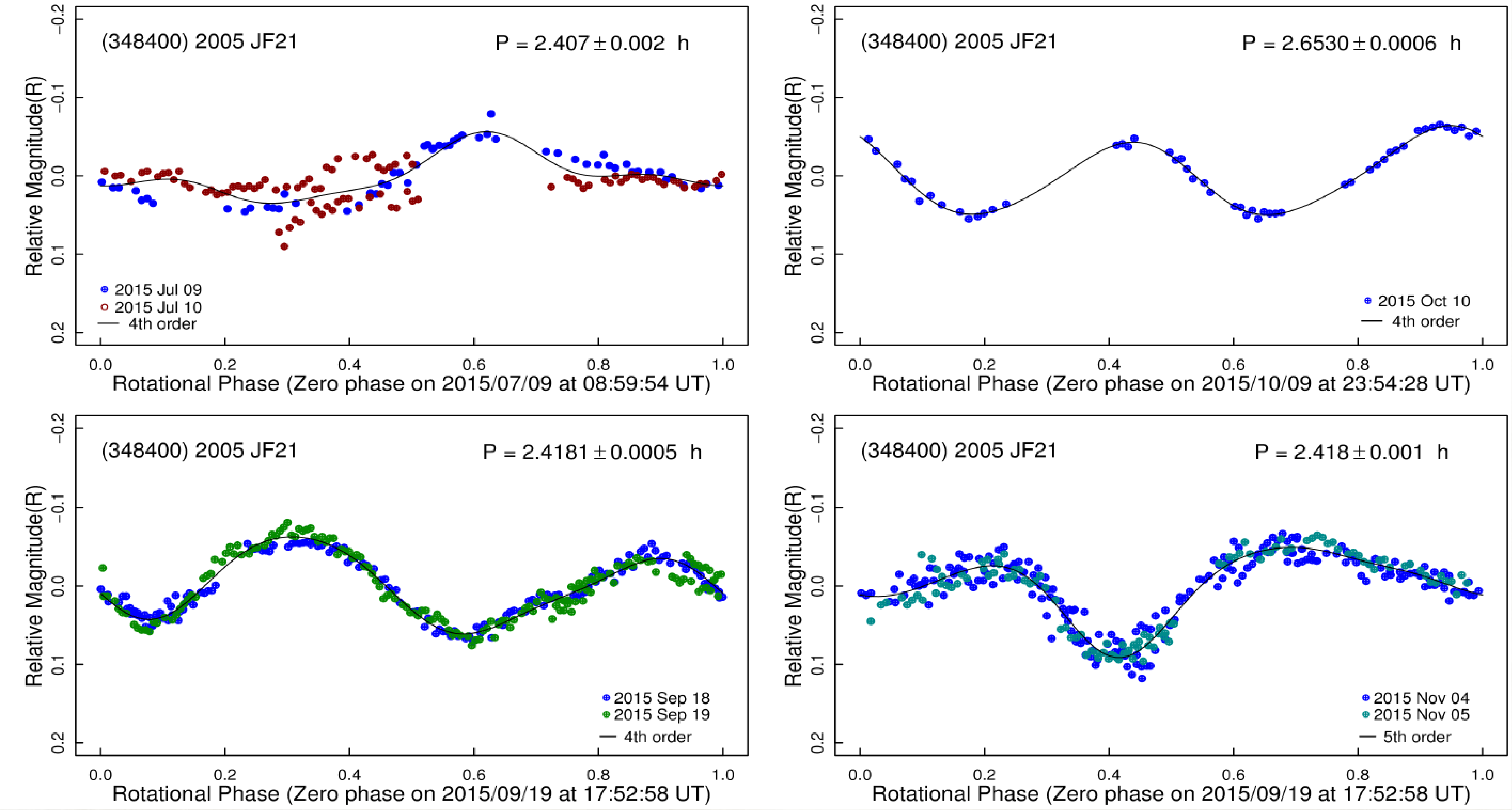
Comparison of the real shape with the model of (25143) Itokawa



(Descamps et al., 2007)

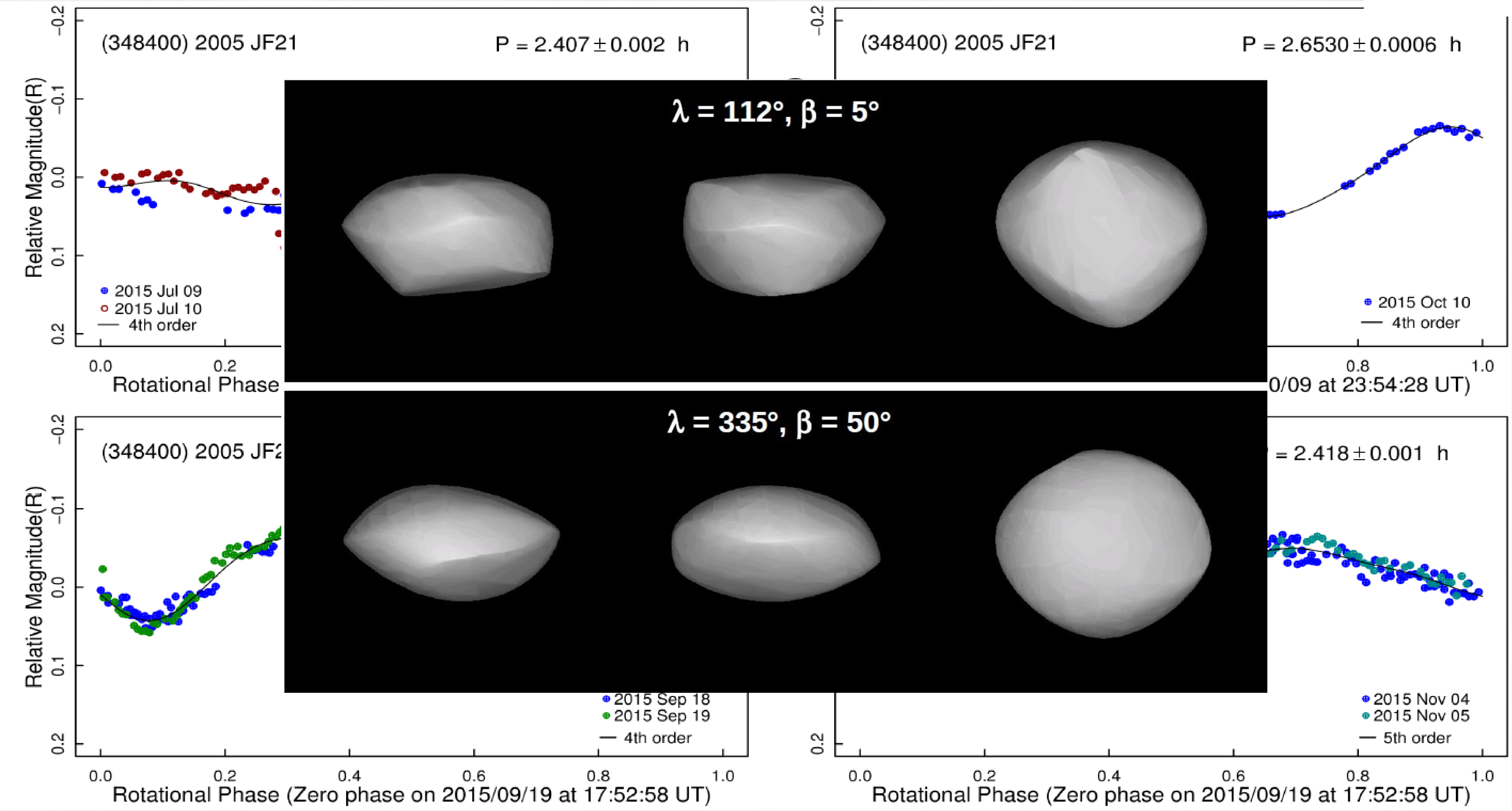
Shape model and Spin parameters

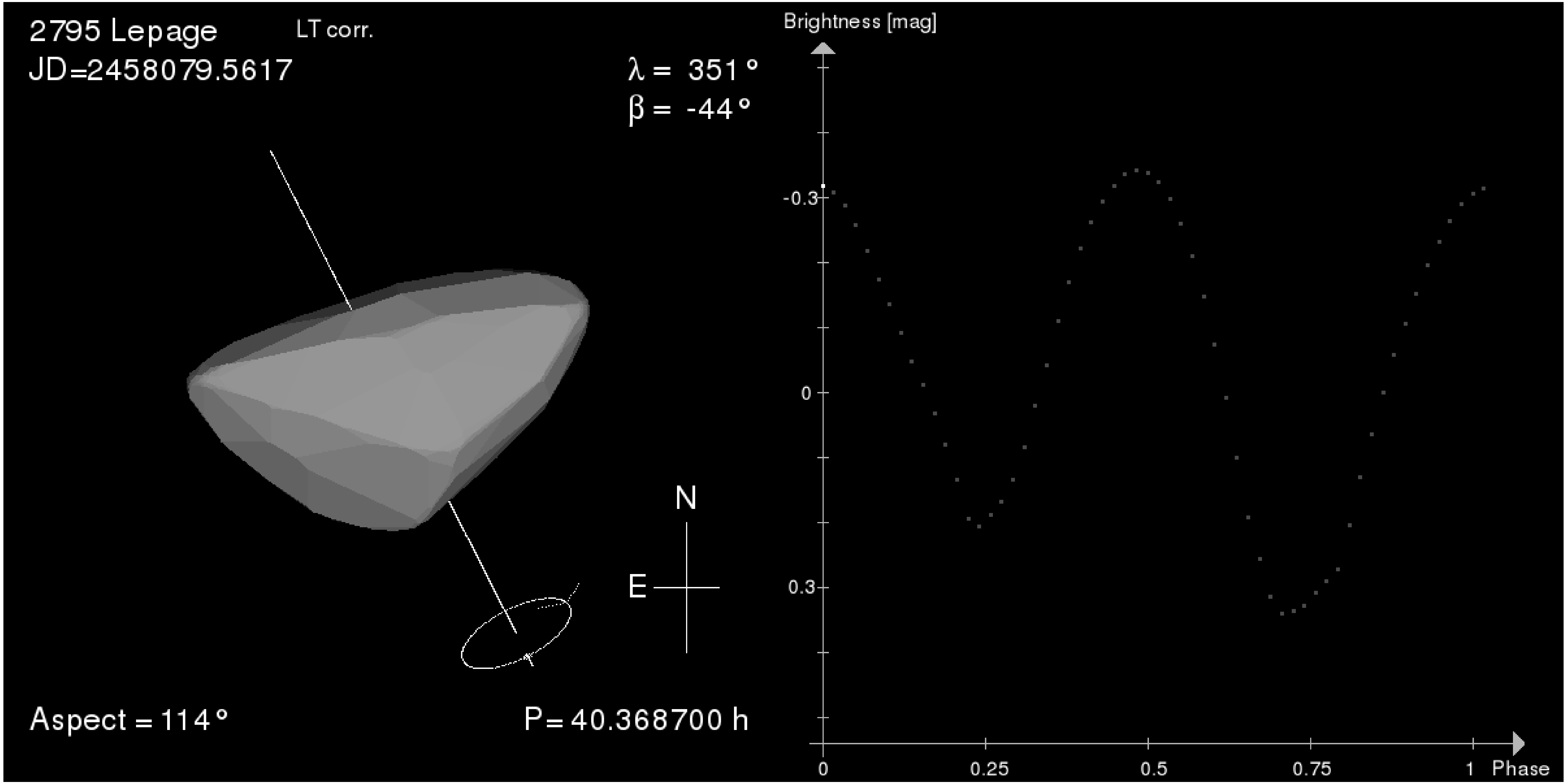
Monteiro et al. (2020)



Shape model and Spin parameters

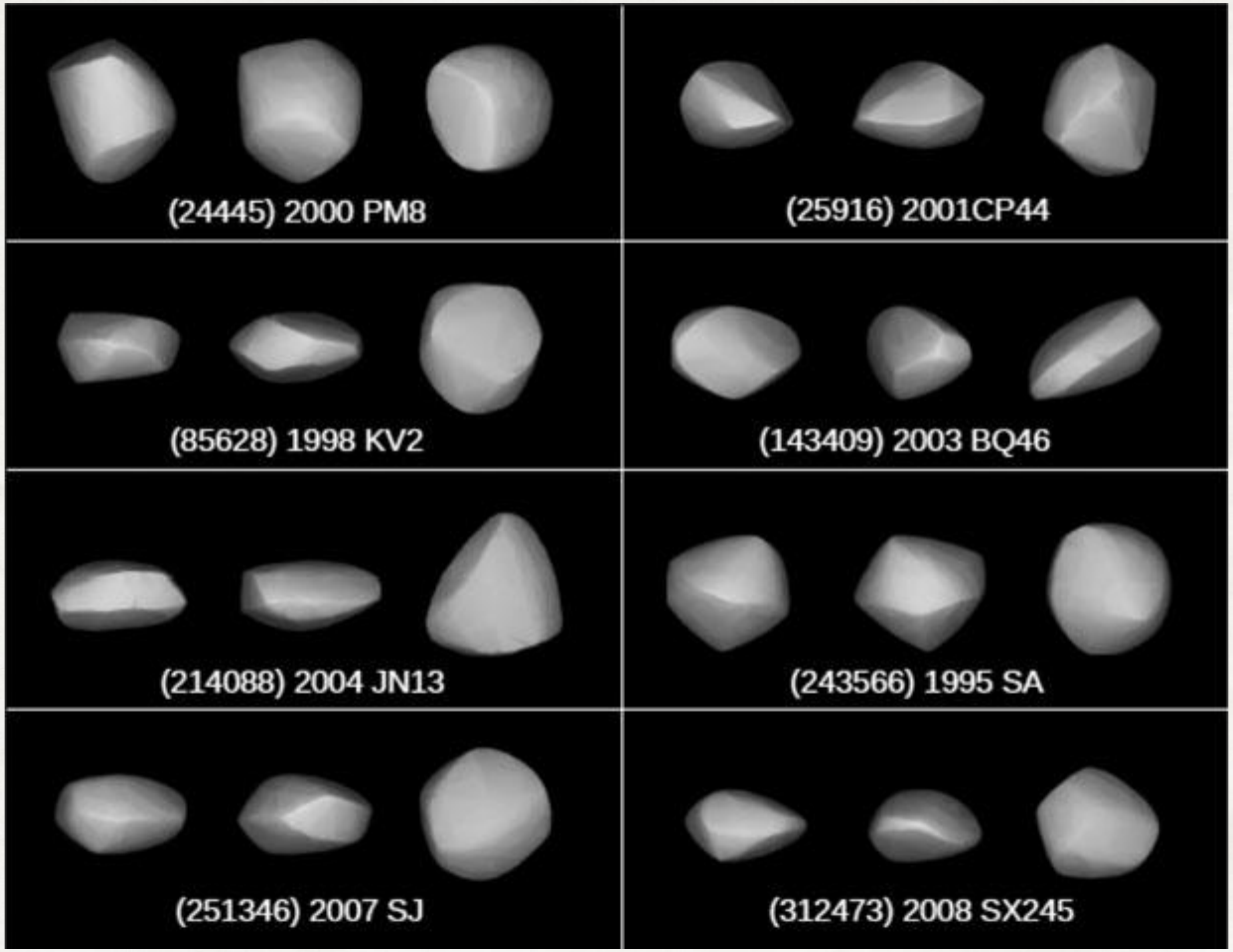
Monteiro et al. (2020)

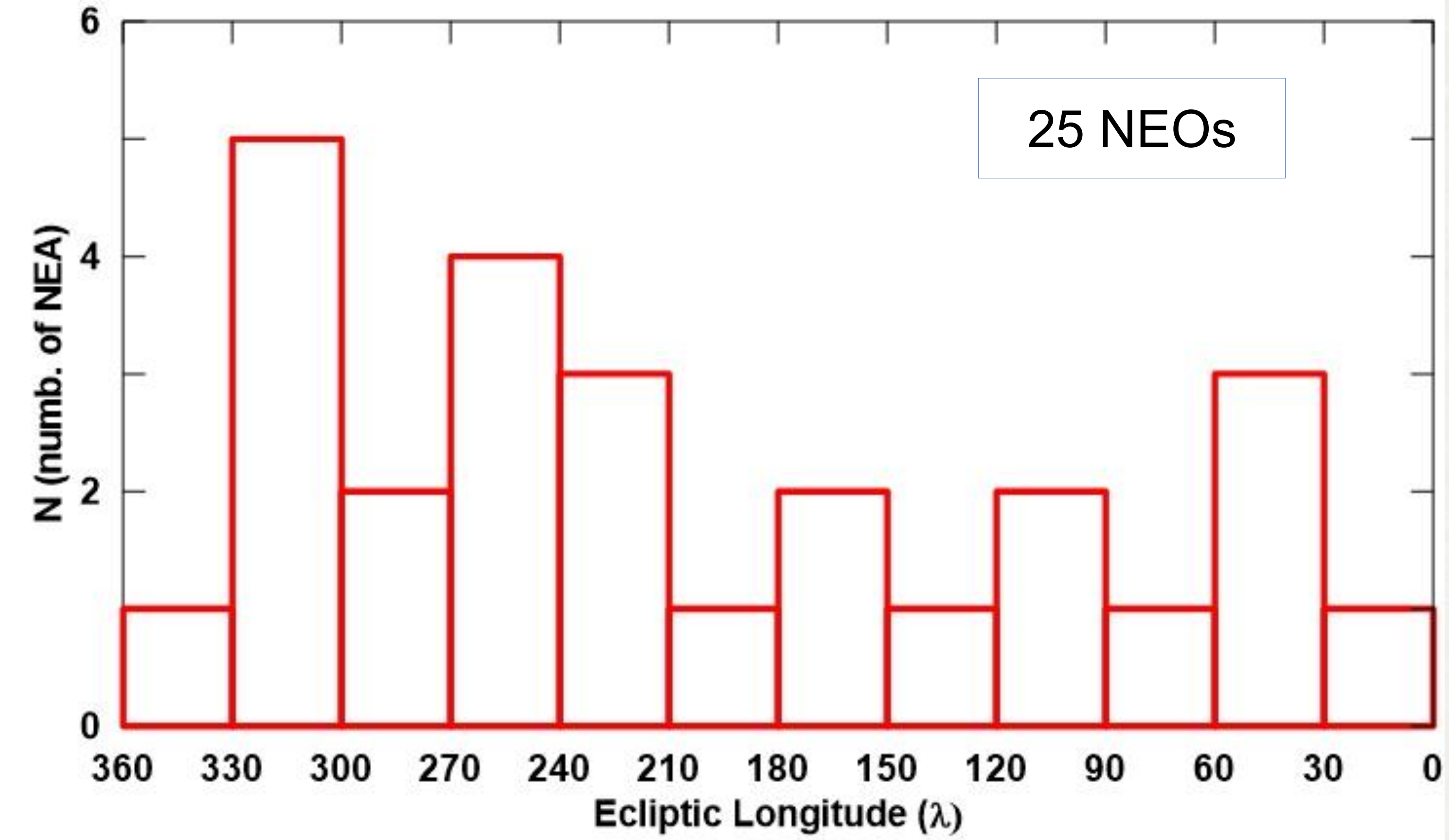


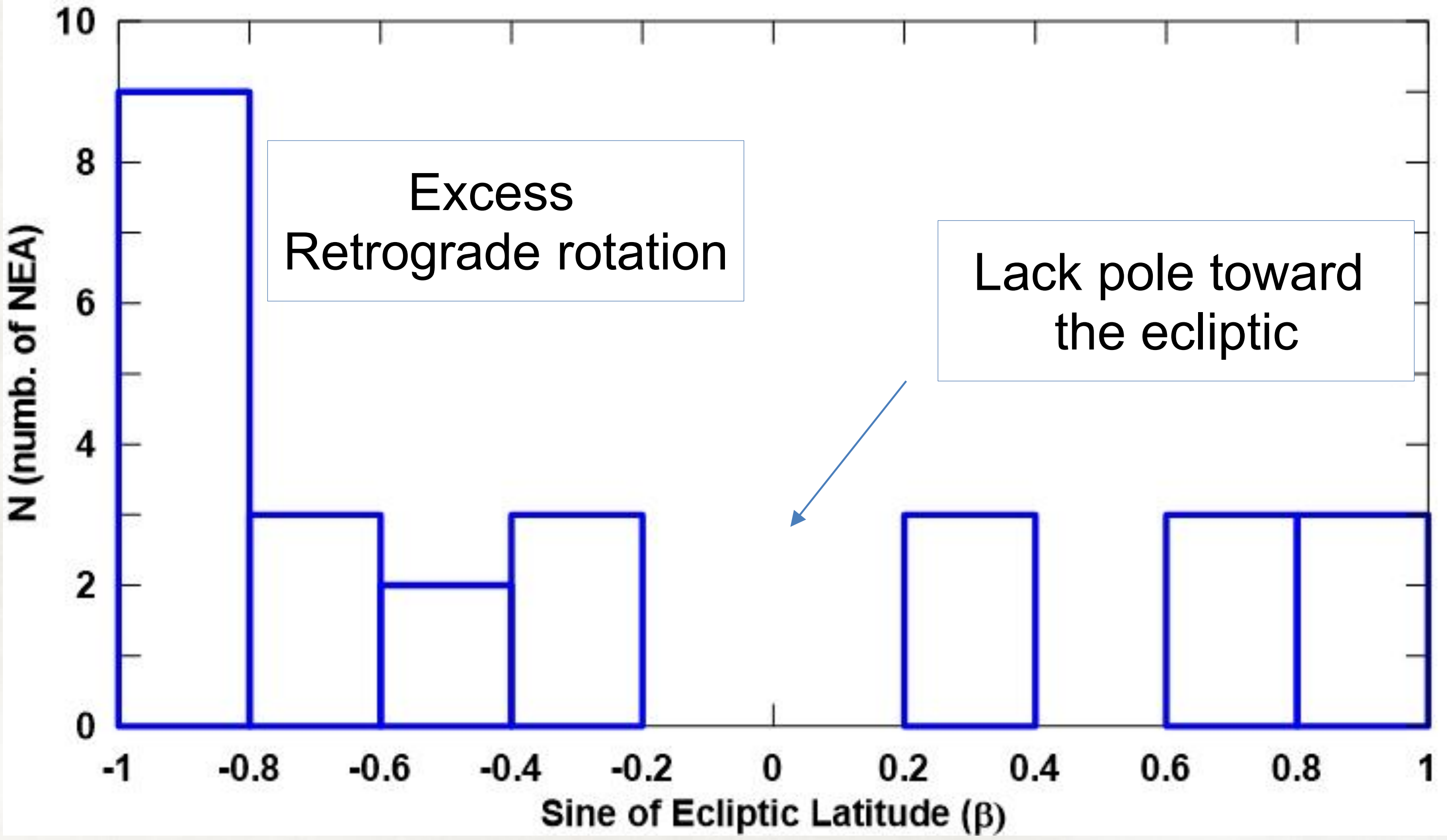


2795 Lepage
LT corr.
JD=2458079.5617
λ = 351°
β = -44°
N
E
Aspect = 114°
P= 40.368700 h
Brightness [mag]
-0.3
0
0.3
0
0.25
0.5
0.75
1
Phase

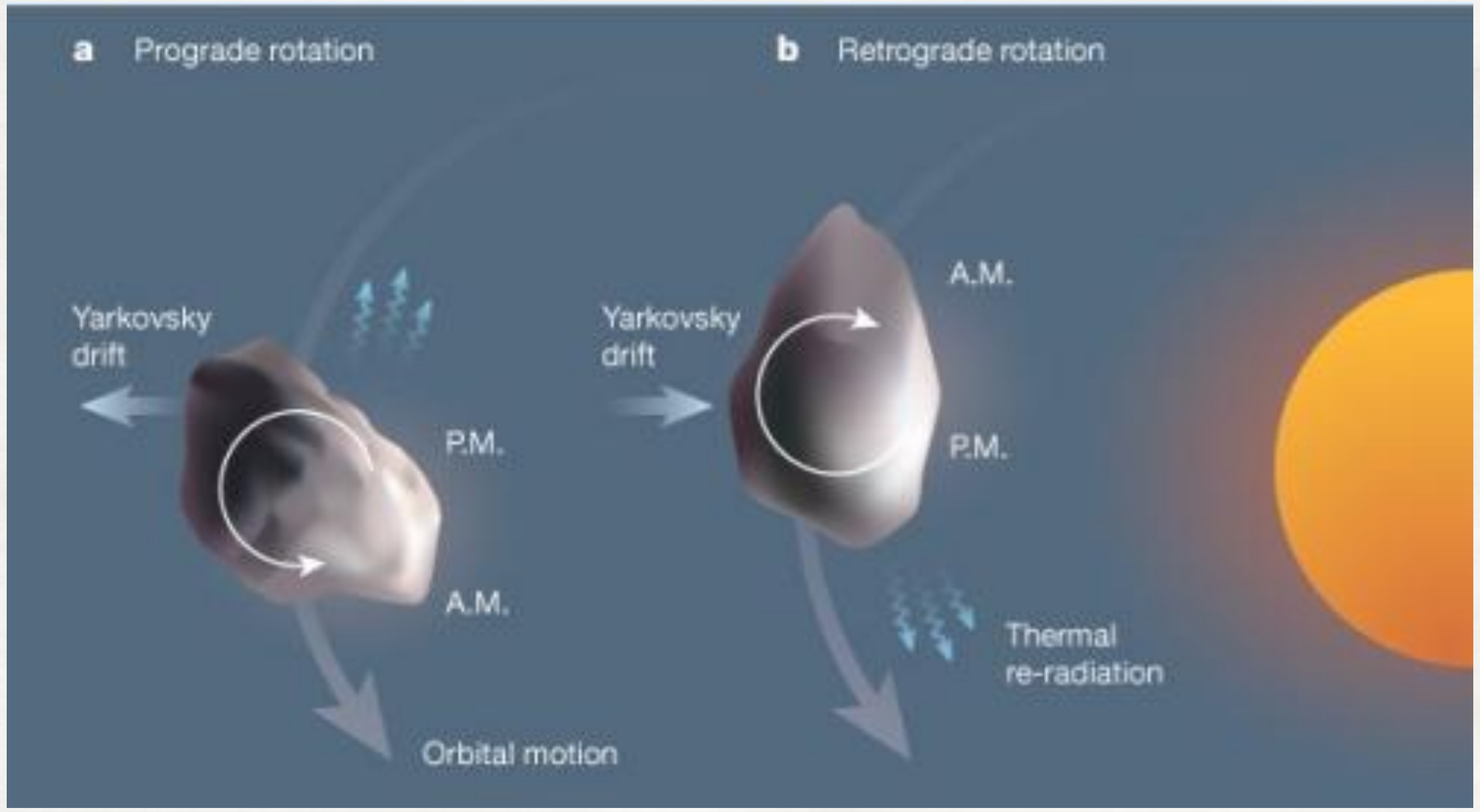
Shape model and Spin parameters



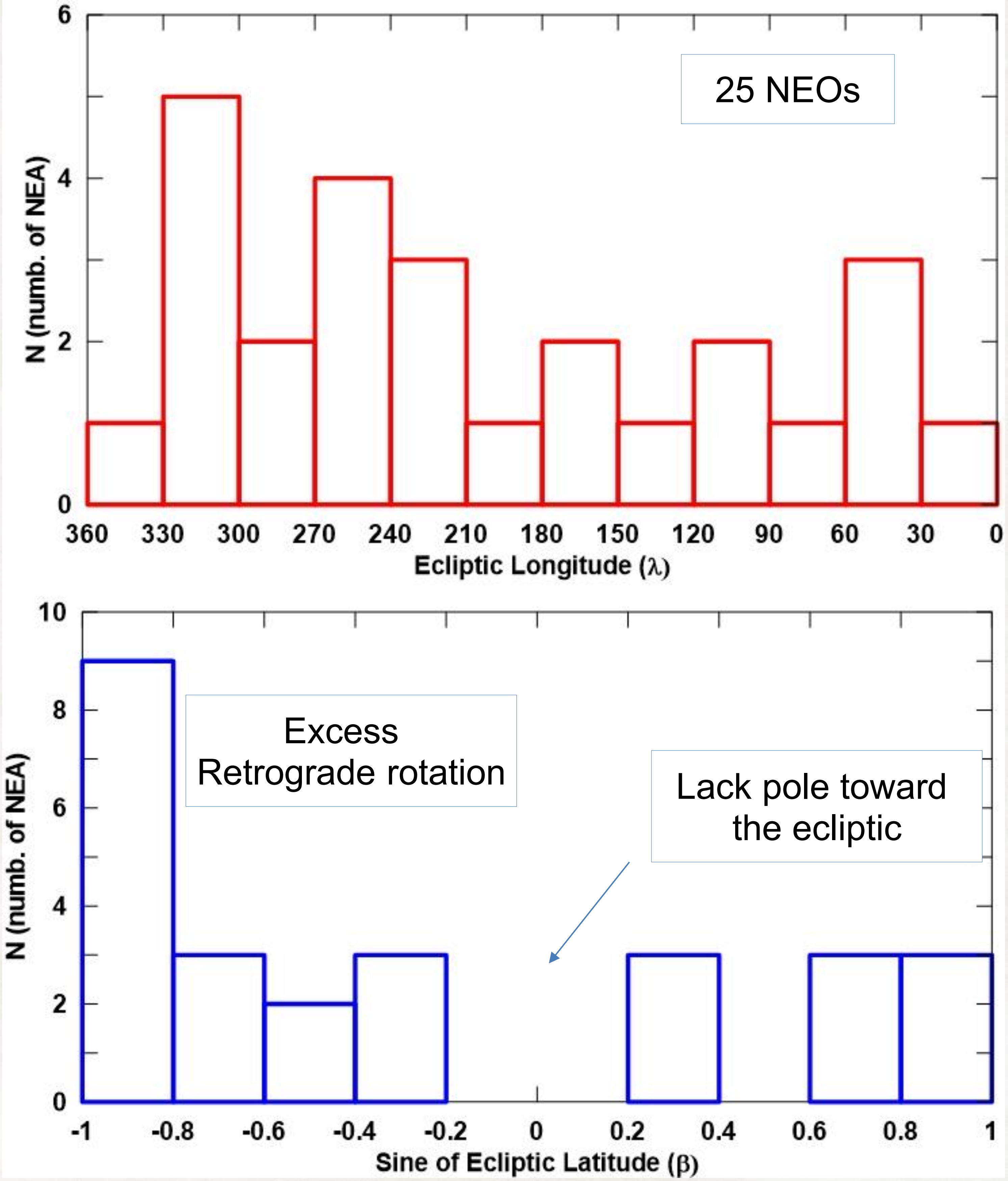




Shape model and Spin parameters



$$\frac{da}{dt} = \frac{8}{3}\frac{(1-A)\Phi}{\rho D n}\cdot\left[\frac{\kappa\Theta}{1+2\kappa\Theta+2\kappa^2\Theta^2}\right]\cdot\cos\gamma$$

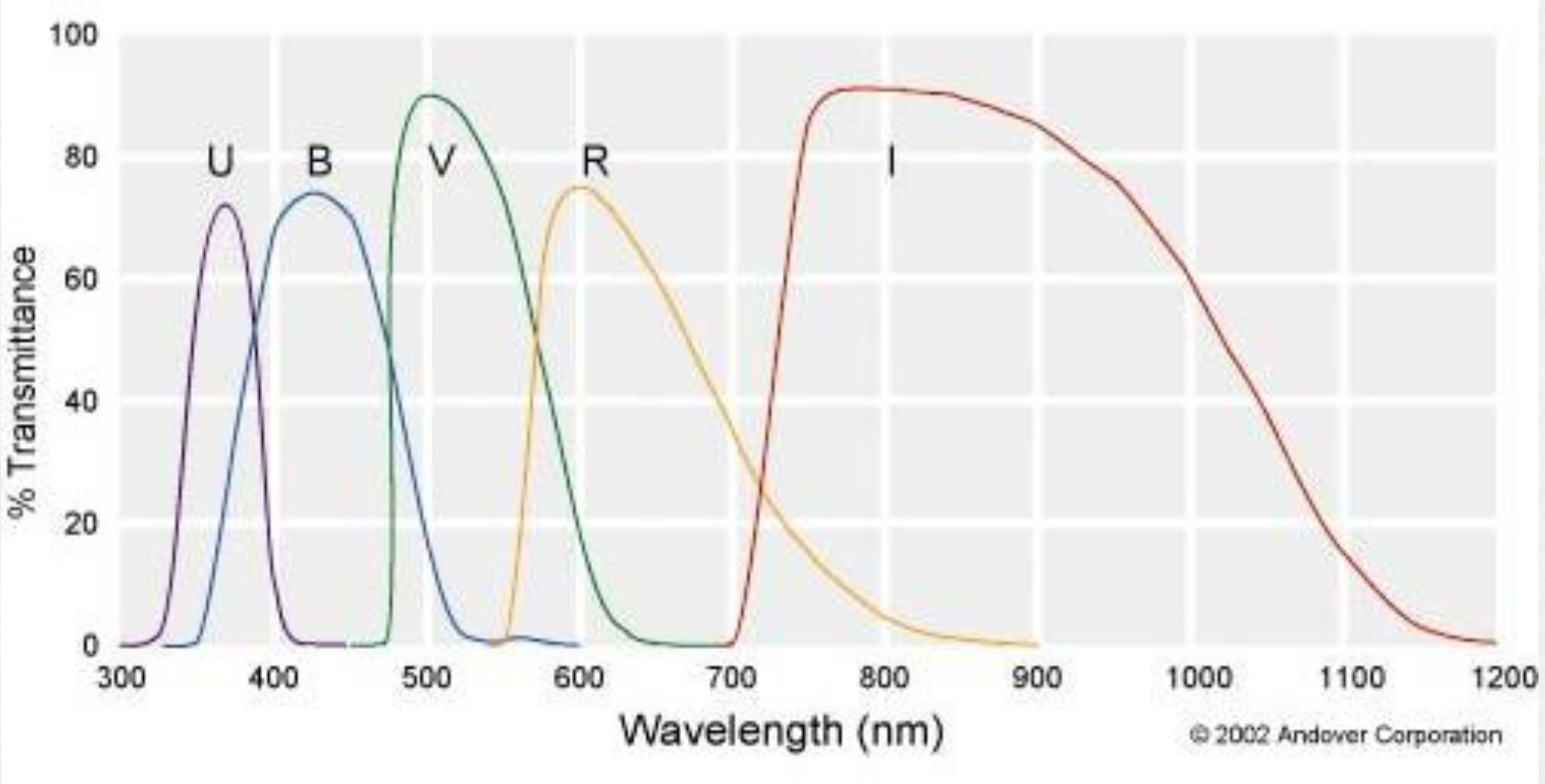


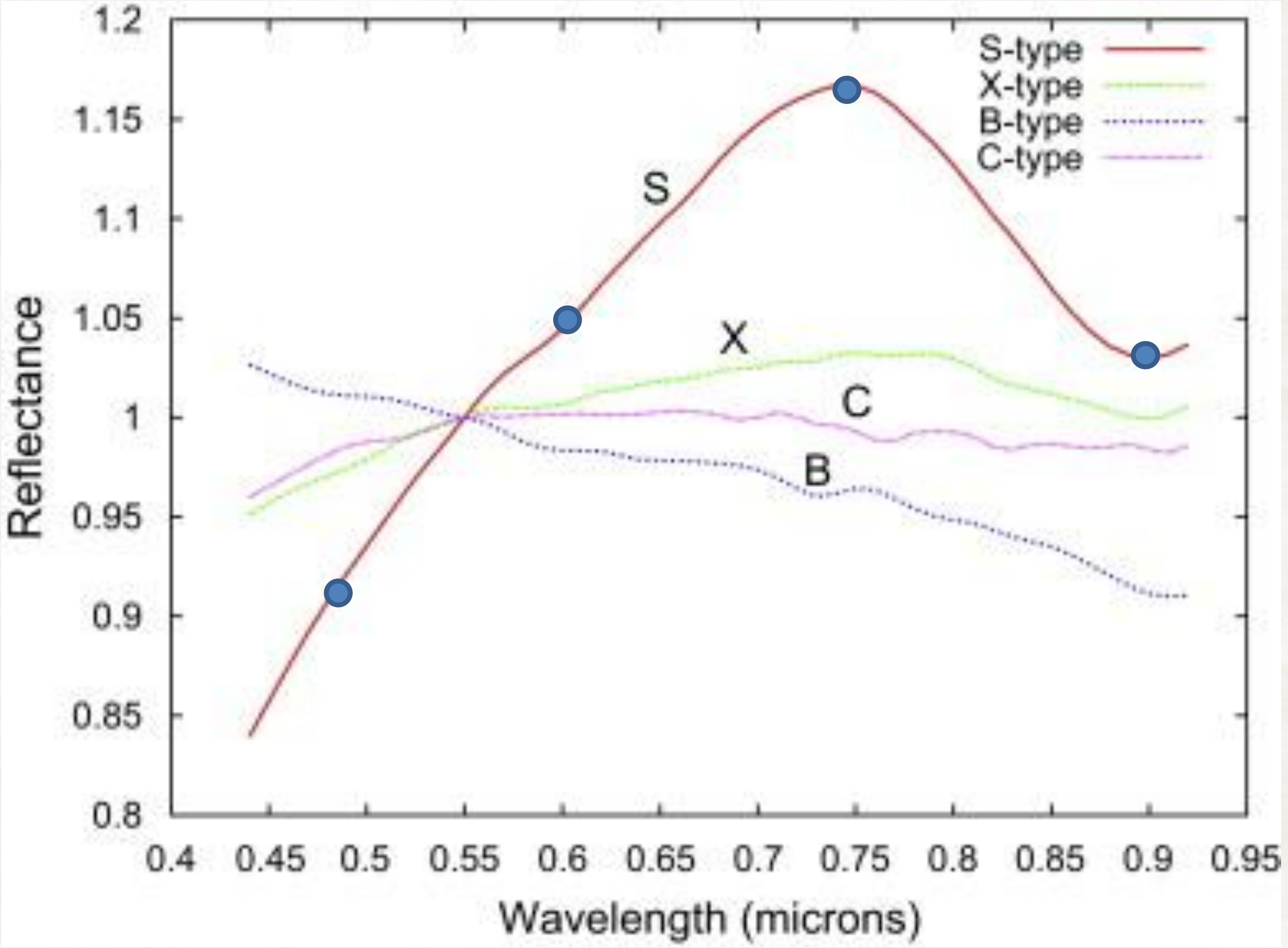
Photometric Spectrum

Colors are traditionaly written as:

U-B, B-V, V-R, R- I (Johnson system)

u-g, g-r, r-i , i-z (Sloan system)





$$(m_B - m_V)_A,\ (m_R - m_V)_A, \text{ and } (m_I - m_V)_A$$

$$(m_B - m_V)_\odot,\ (m_R - m_V)_\odot, \text{ and } (m_I - m_V)_\odot$$

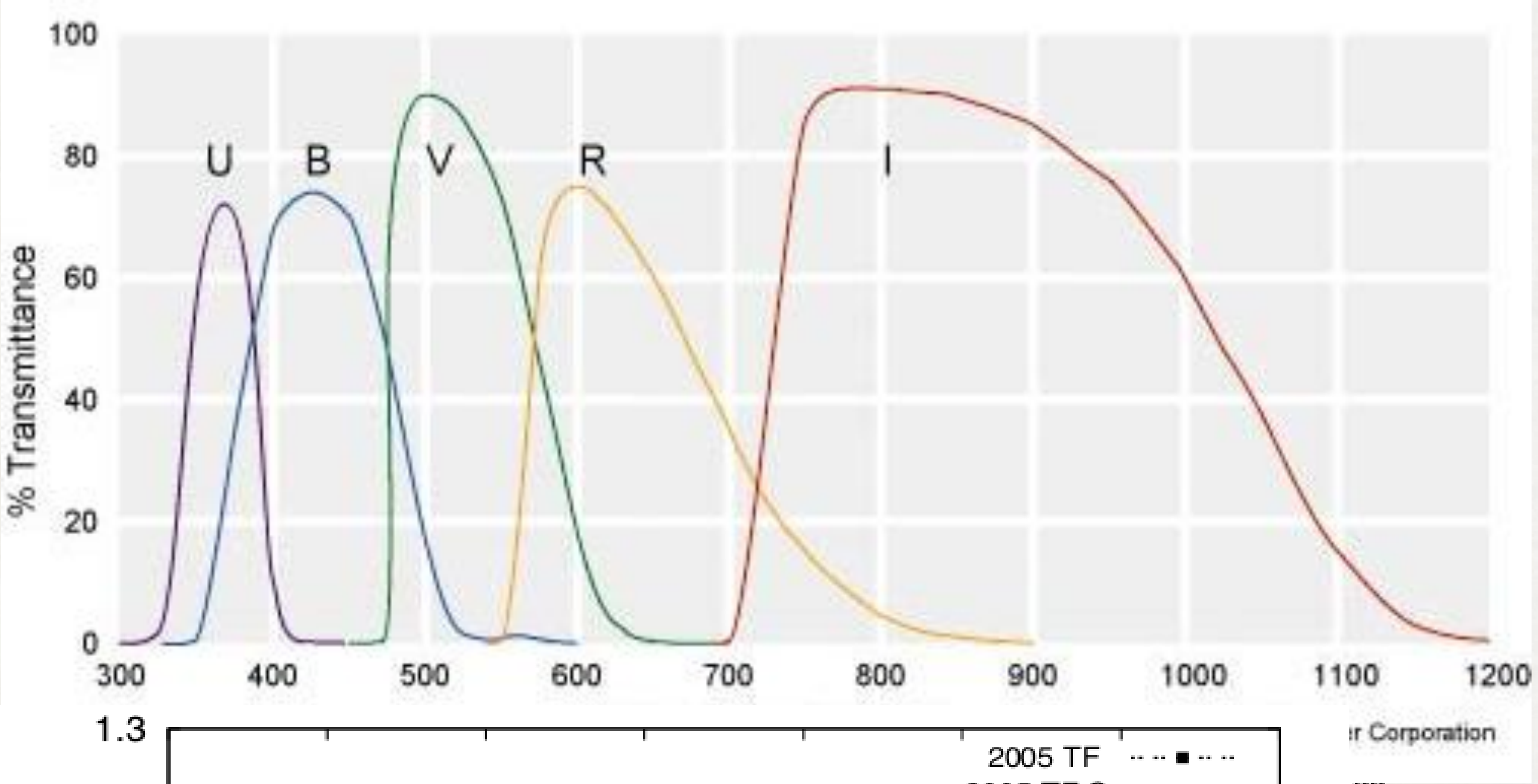
$$R_\lambda = 10^{-0.4[(M_\lambda - M_v)-(M_\lambda - M_v)_\odot]}$$

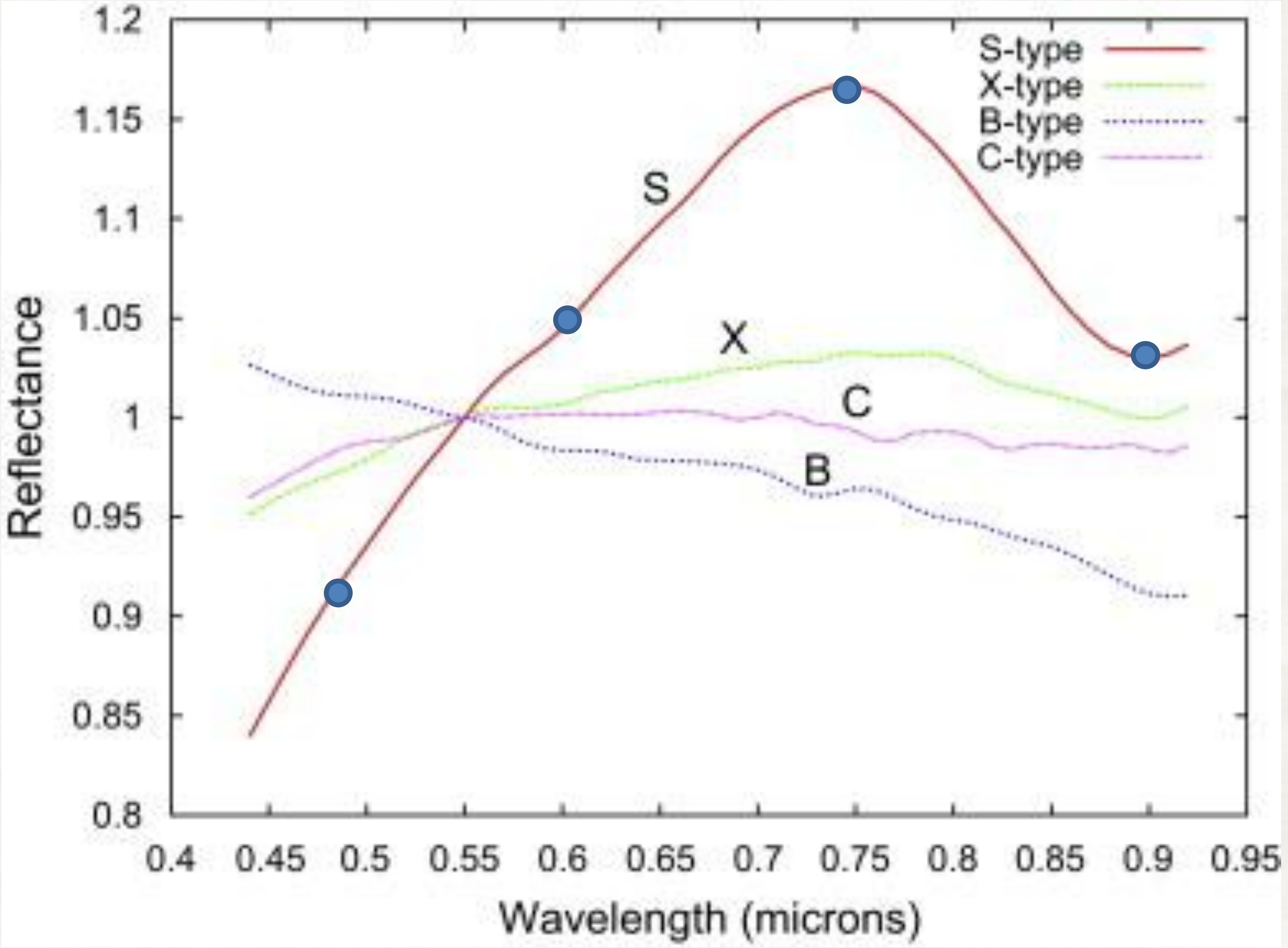
Photometric Spectrum

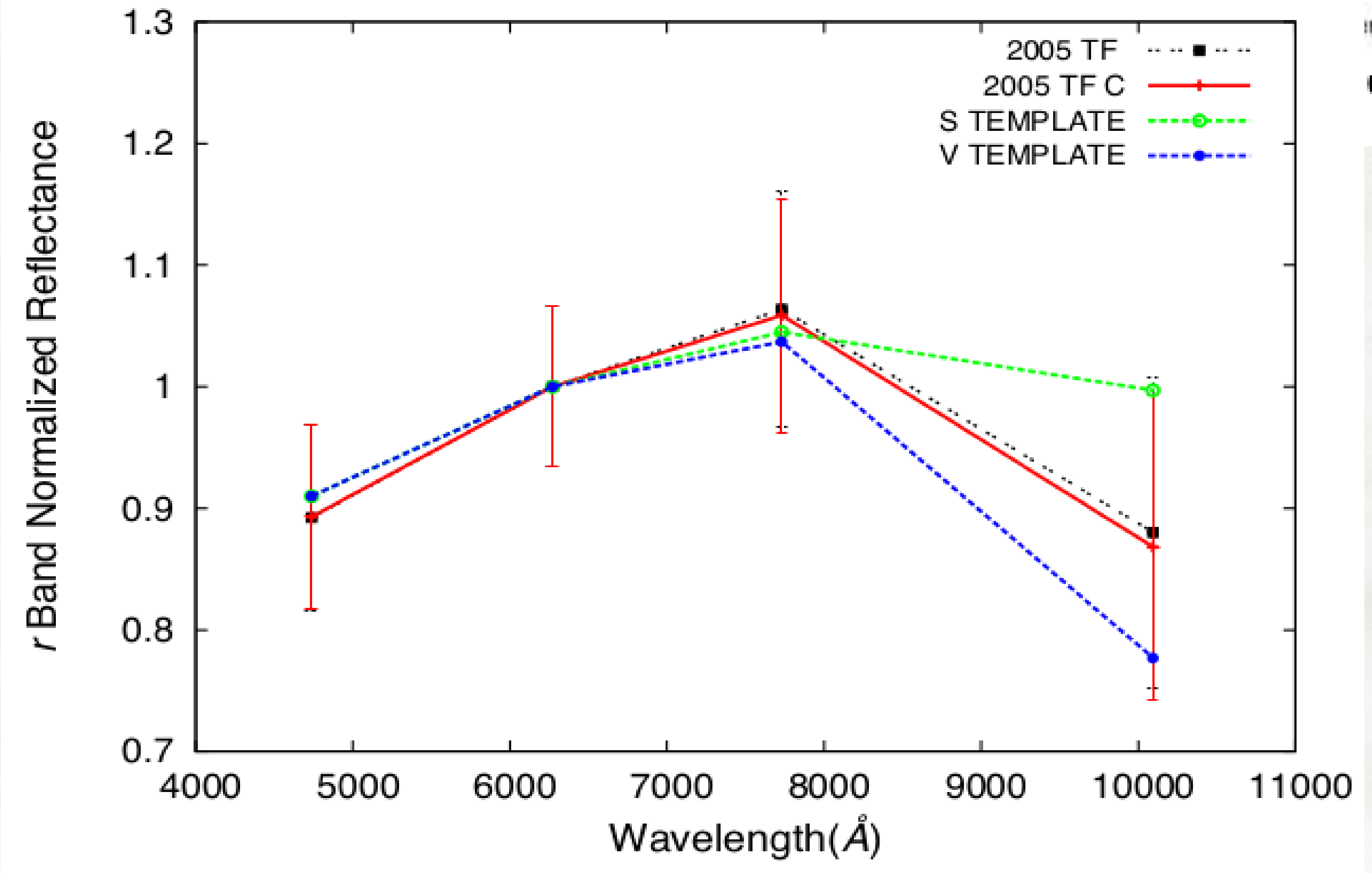
Colors are traditionaly written as:

U-B, B-V, V-R, R- I (Johnson system)

u-g, g-r, r-i , i-z (Sloan system)







Phase curves – Absolute magnitude and Diameter

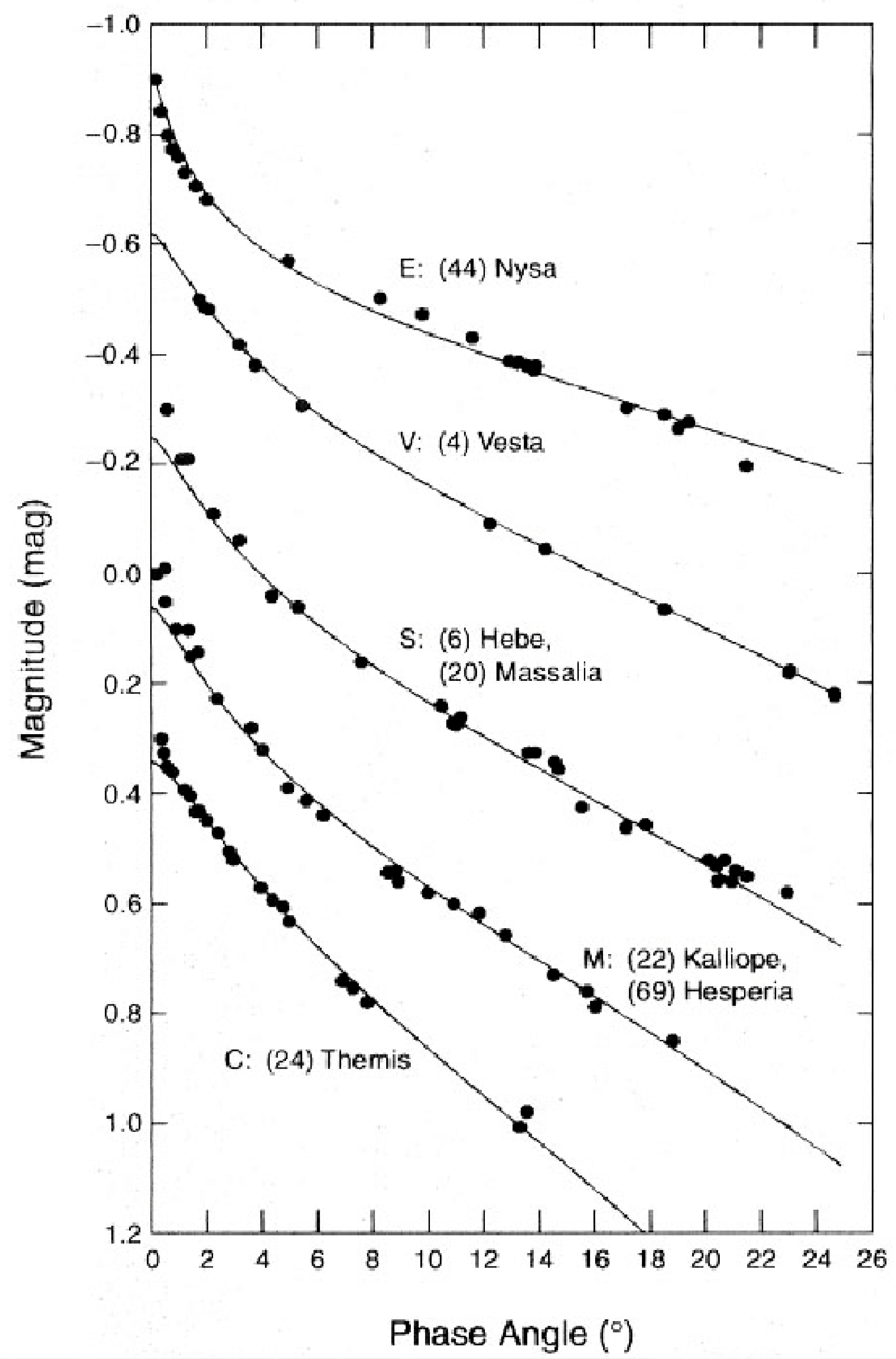
- Three-parameter H- G_1-G_2 nonlinear model (Penttilä et al., 2016)

$$H(\alpha) = H_0 - 2.5\log_{10}[(G_1\Phi_1(\alpha) + G_2\Phi_2(\alpha) + (1 - G_1 - G_2)\Phi 3(\alpha)],$$

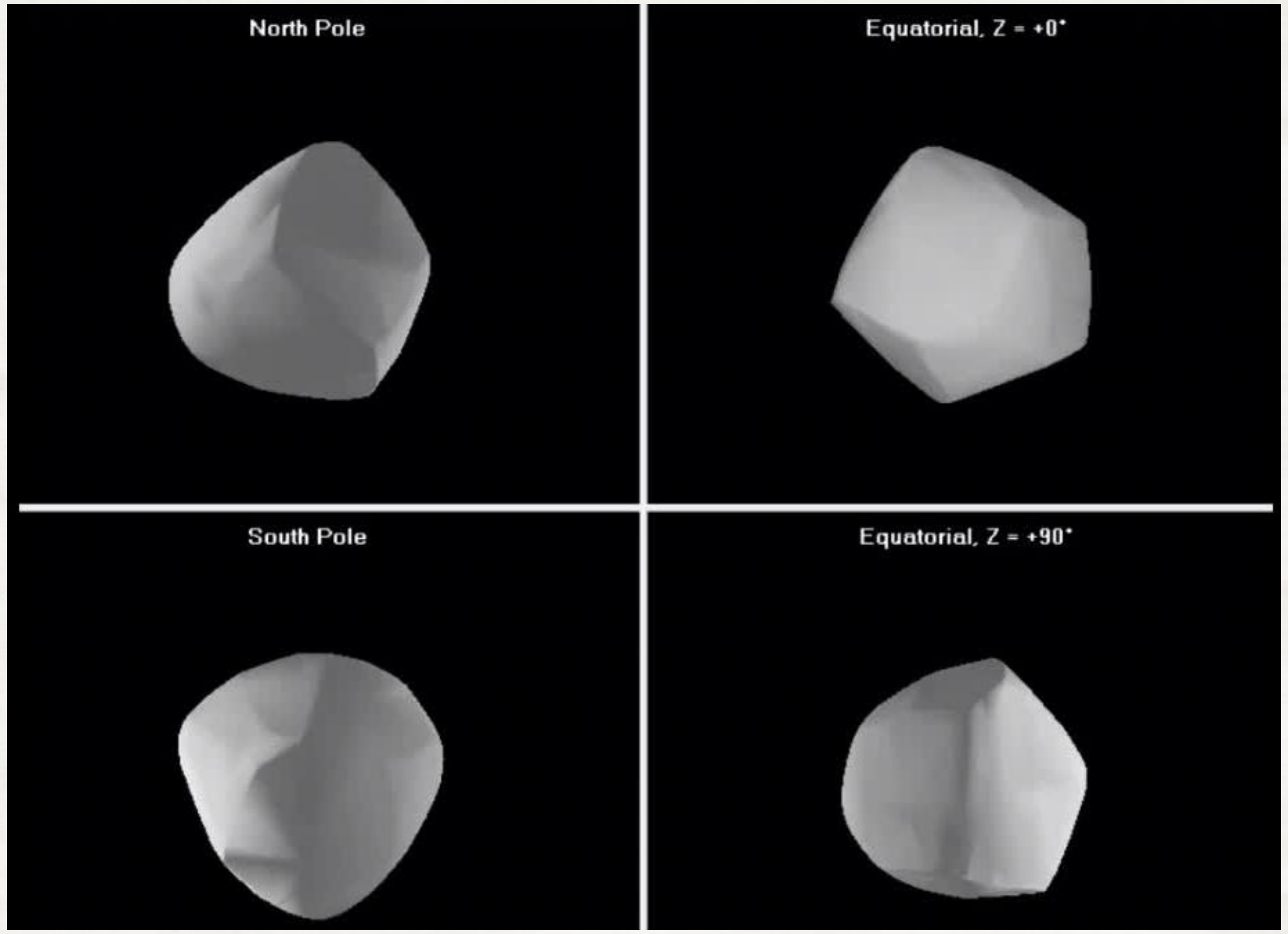
- H → Absolute magnitude

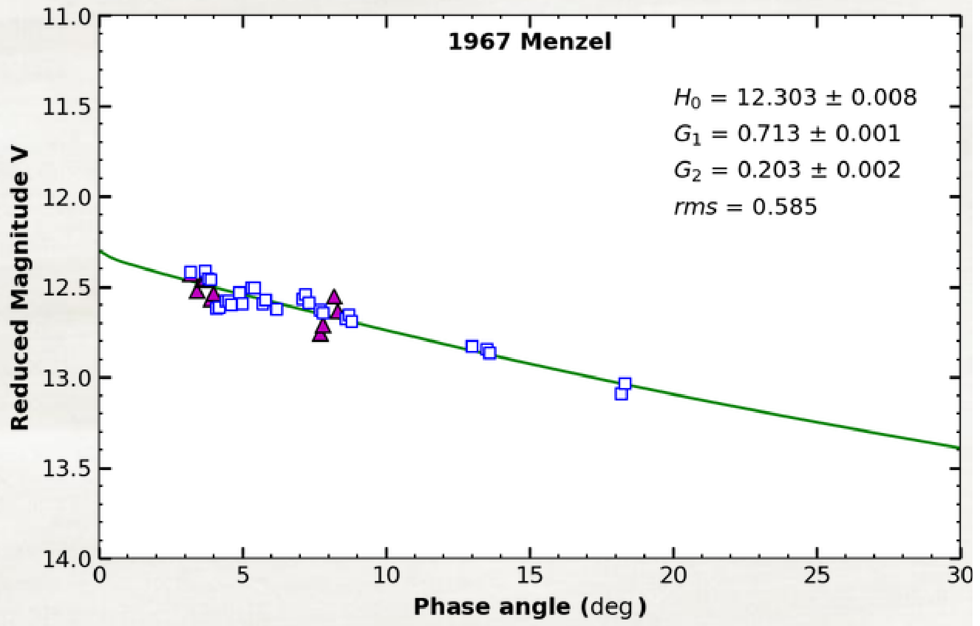
$$D = \frac{1329}{\sqrt{p_v}} 10^{-0.2H} \text{ km.}$$

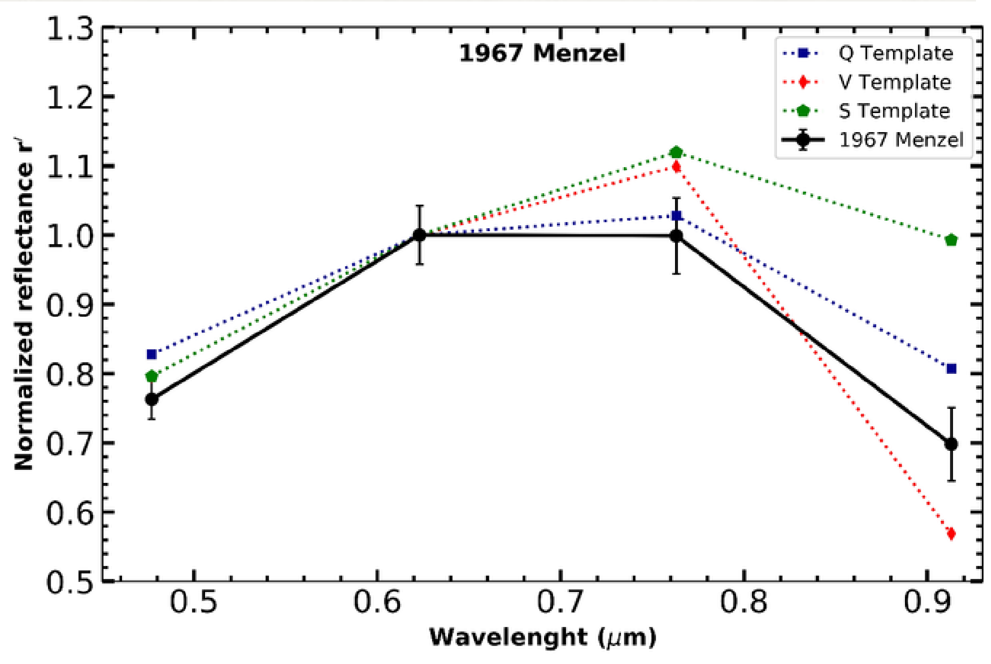
- G_1-G_2 → Slope parameters – associated to superficial composition of asteroids.

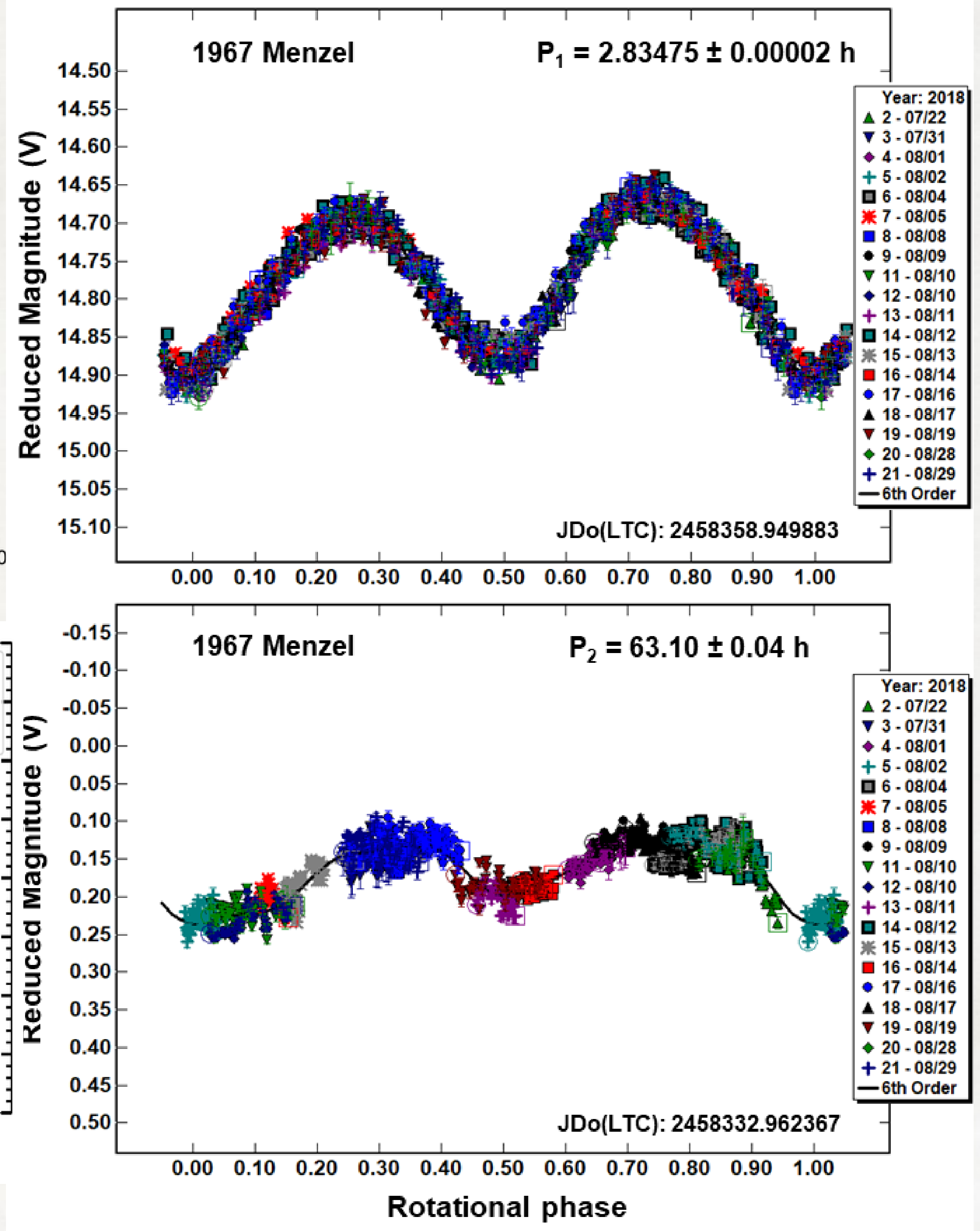


Exemplo: Caracterização de 1967 Menzel





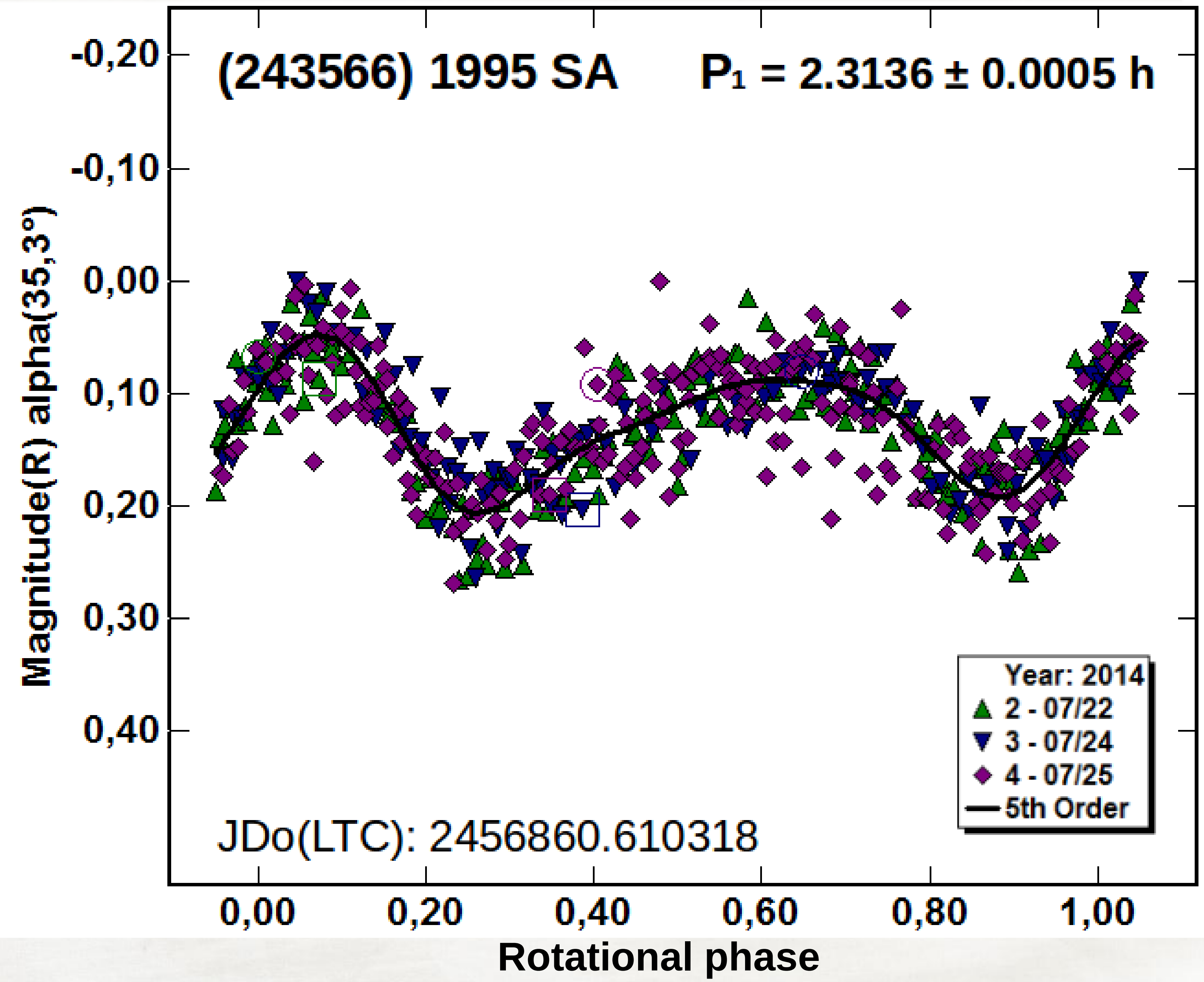


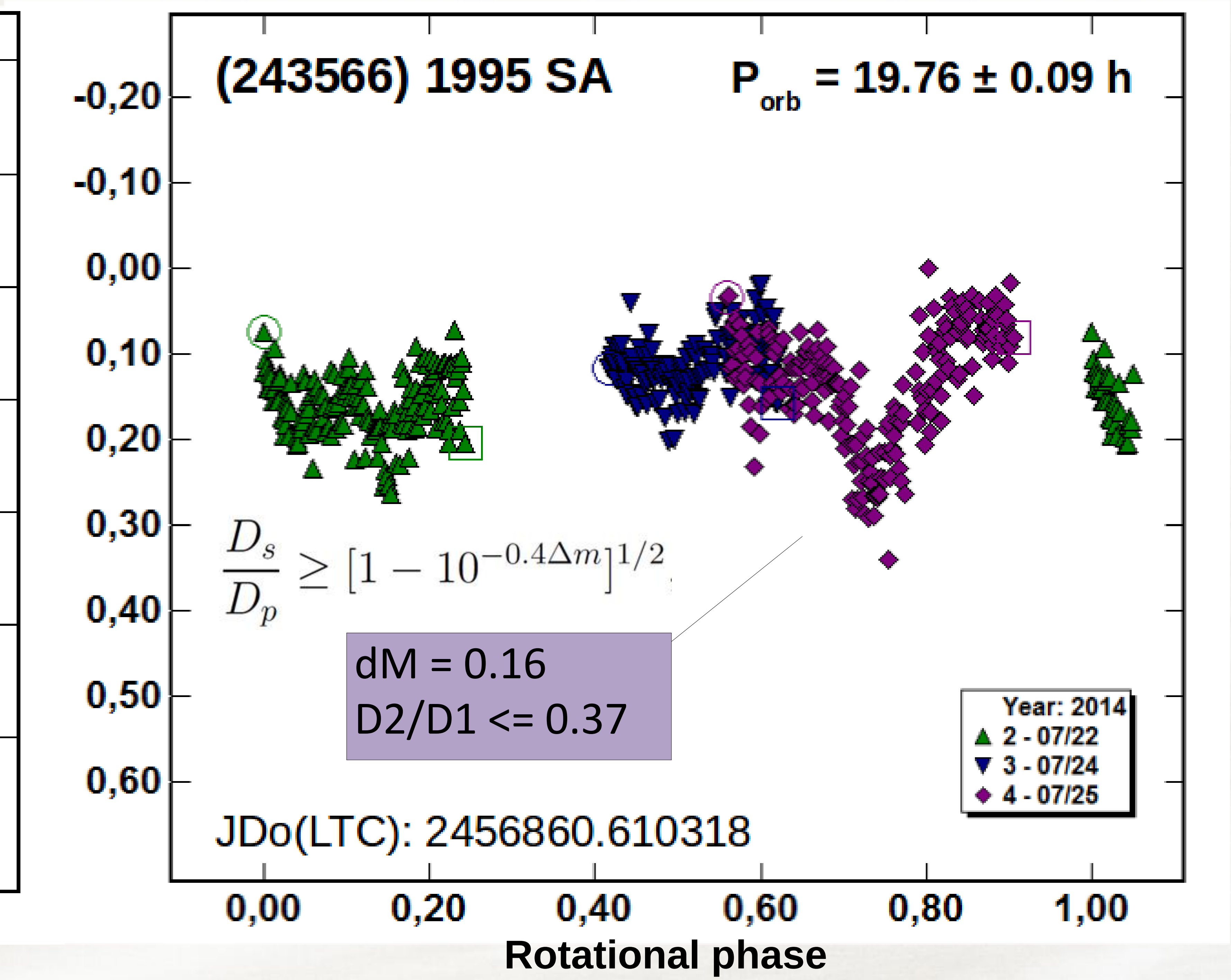


Monteiro et al. (2026)

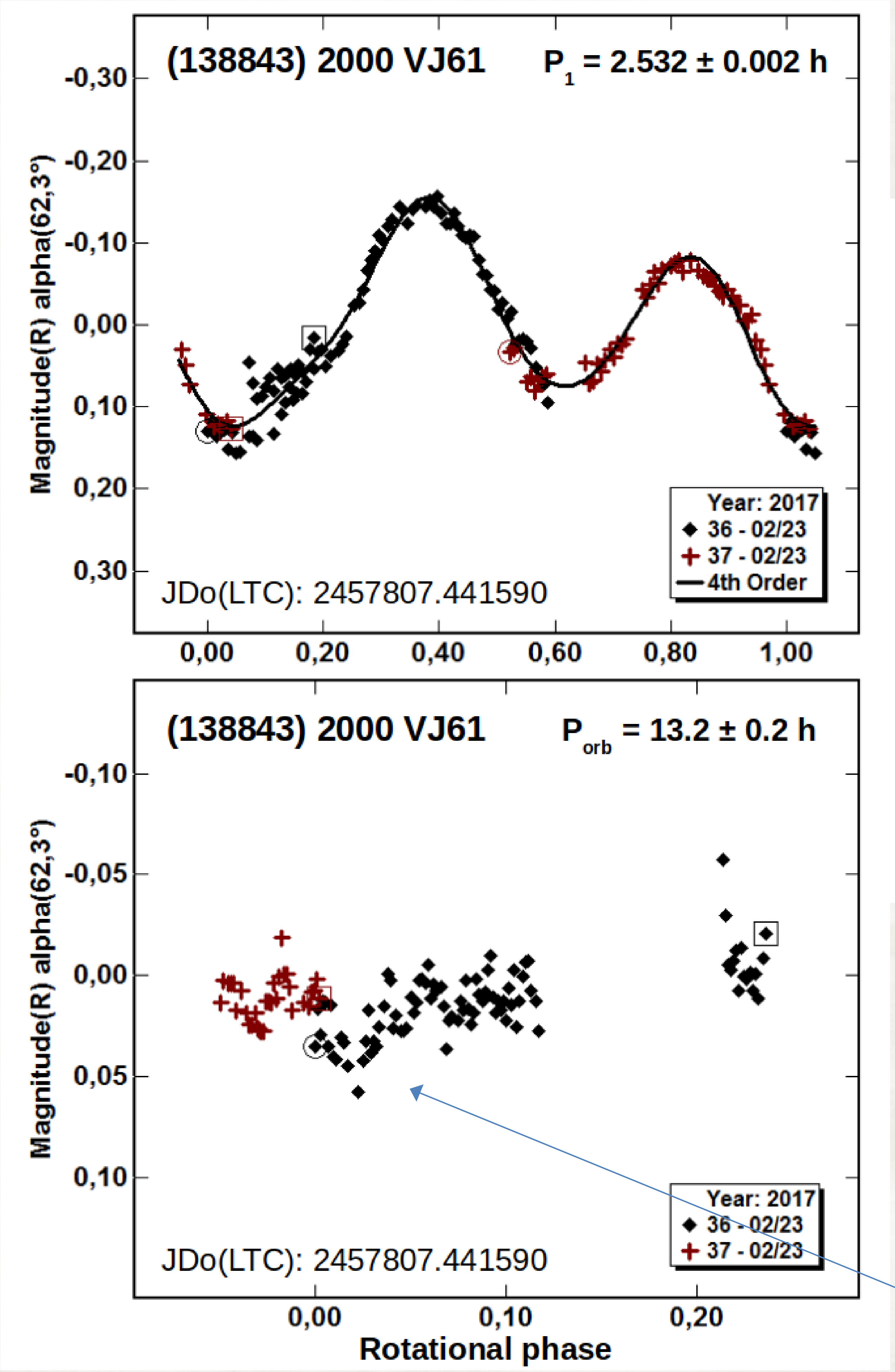
Exemplo: Caracterização de (243566) 1995 SA

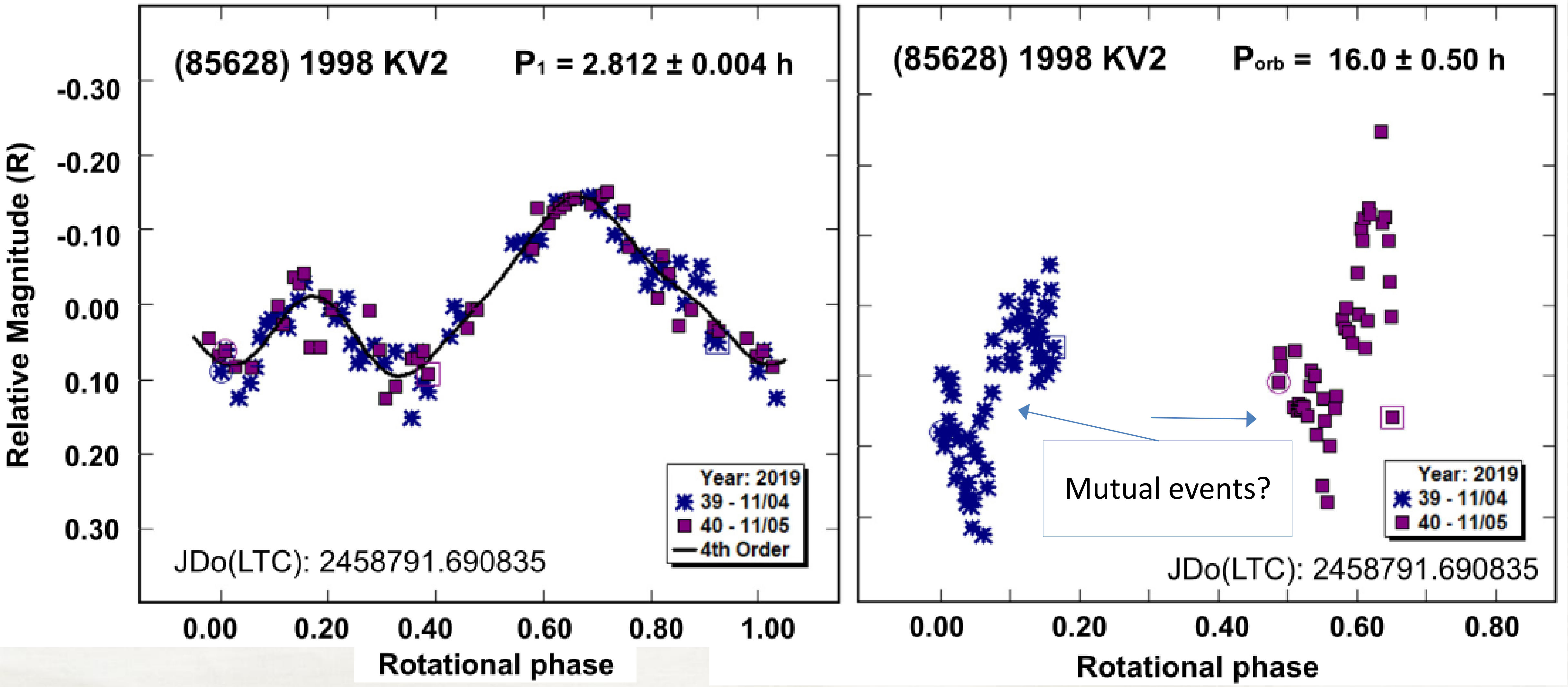
Monteiro et al. in preparing





Binários suspeitos



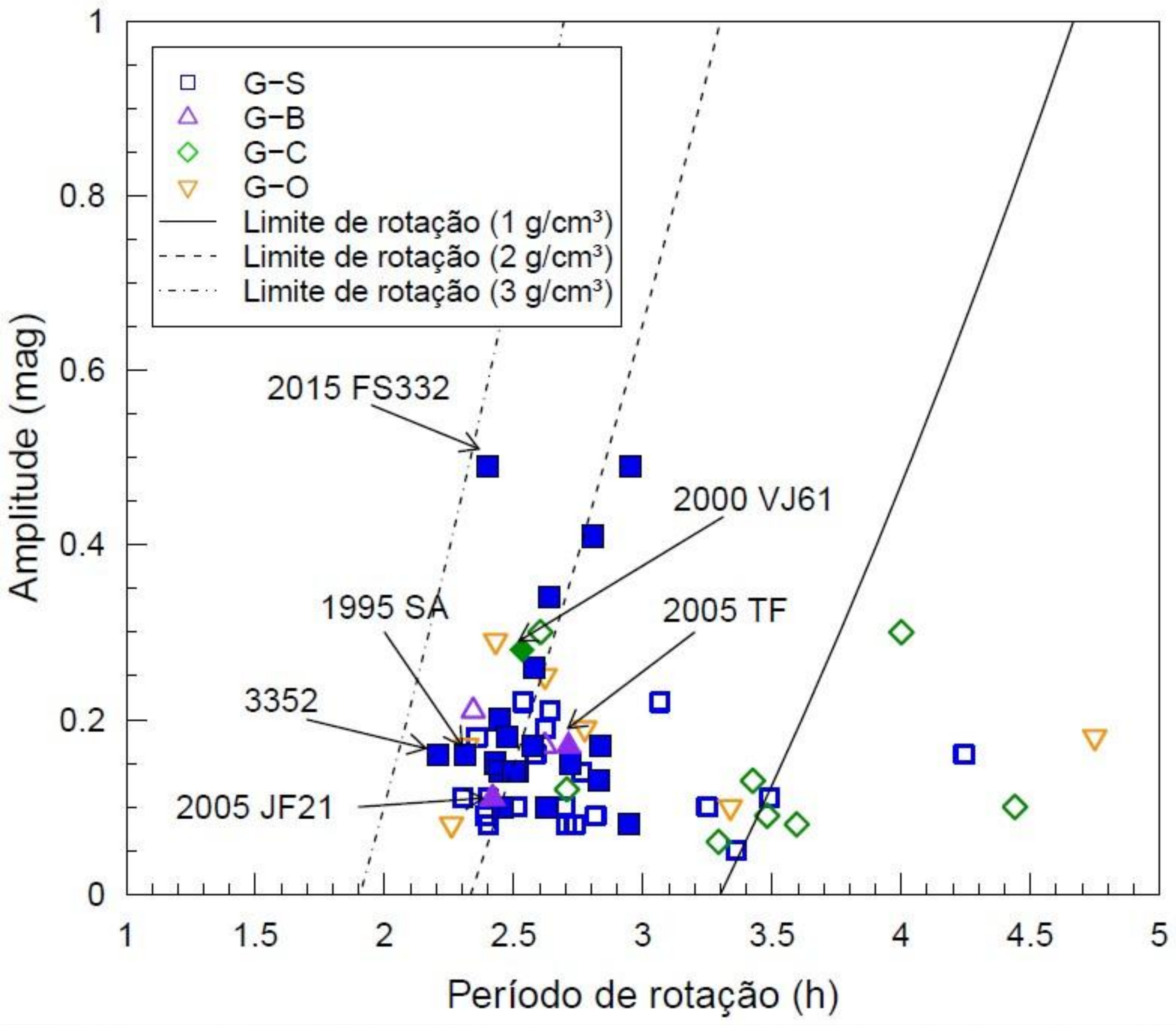


Monteiro et al. (2023)

Mutual event

In this study, we found 8 suspected binary NEOs, whose lightcurves showed signals of a possible satellite.

Análise da força de coesão



Drucker-Prager Failure Criterion

$$\frac{1}{6}[(\overline{\sigma}_x - \overline{\sigma}_y)^2 + (\overline{\sigma}_y - \overline{\sigma}_z)^2 + (\overline{\sigma}_z - \overline{\sigma}_x)^2] \leq [k - s(\overline{\sigma}_x + \overline{\sigma}_y + \overline{\sigma}_z)]^2, \qquad (9)$$

where $\overline{\sigma}_x$, $\overline{\sigma}_y$, and $\overline{\sigma}_z$ are the three average stresses, k is the internal cohesion and s is a slope constant. The slope constant is determined from the angle of friction ϕ, assumed here to be an angle of friction typical for lunar regolith of 40° (Sánchez & Scheeres 2014), using the following expression:

$$s = \frac{2\sin\phi}{\sqrt{3}(3 - \sin\phi)}. \qquad (10)$$

The average normal stress components ($\overline{\sigma}_x$, $\overline{\sigma}_y$, and $\overline{\sigma}_z$) can be calculated by

$$\overline{\sigma}_x = (\rho\omega^2 - 2\pi\rho^2 G A_x)\frac{a^2}{5}, \qquad (11)$$

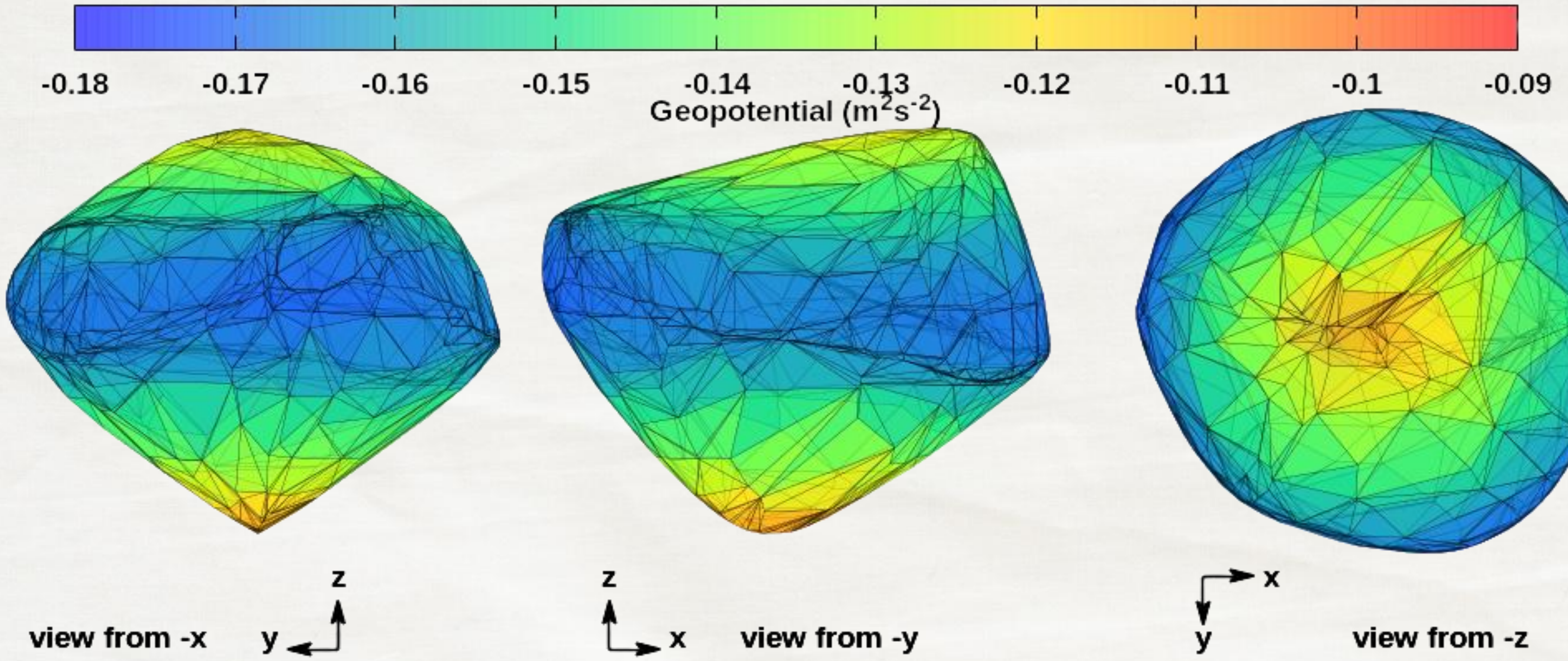
$$\overline{\sigma}_y = (\rho\omega^2 - 2\pi\rho^2 G A_y)\frac{b^2}{5}, \qquad (12)$$

$$\overline{\sigma}_z = (-2\pi\rho^2 G A_z)\frac{c^2}{5}, \qquad (13)$$

where ρ is the bulk density, ω is the spin rate, G is the gravitational

Exemplo: Dinâmica da superfície de (243566) 1995 SA

Surface dynamics - Geopotential



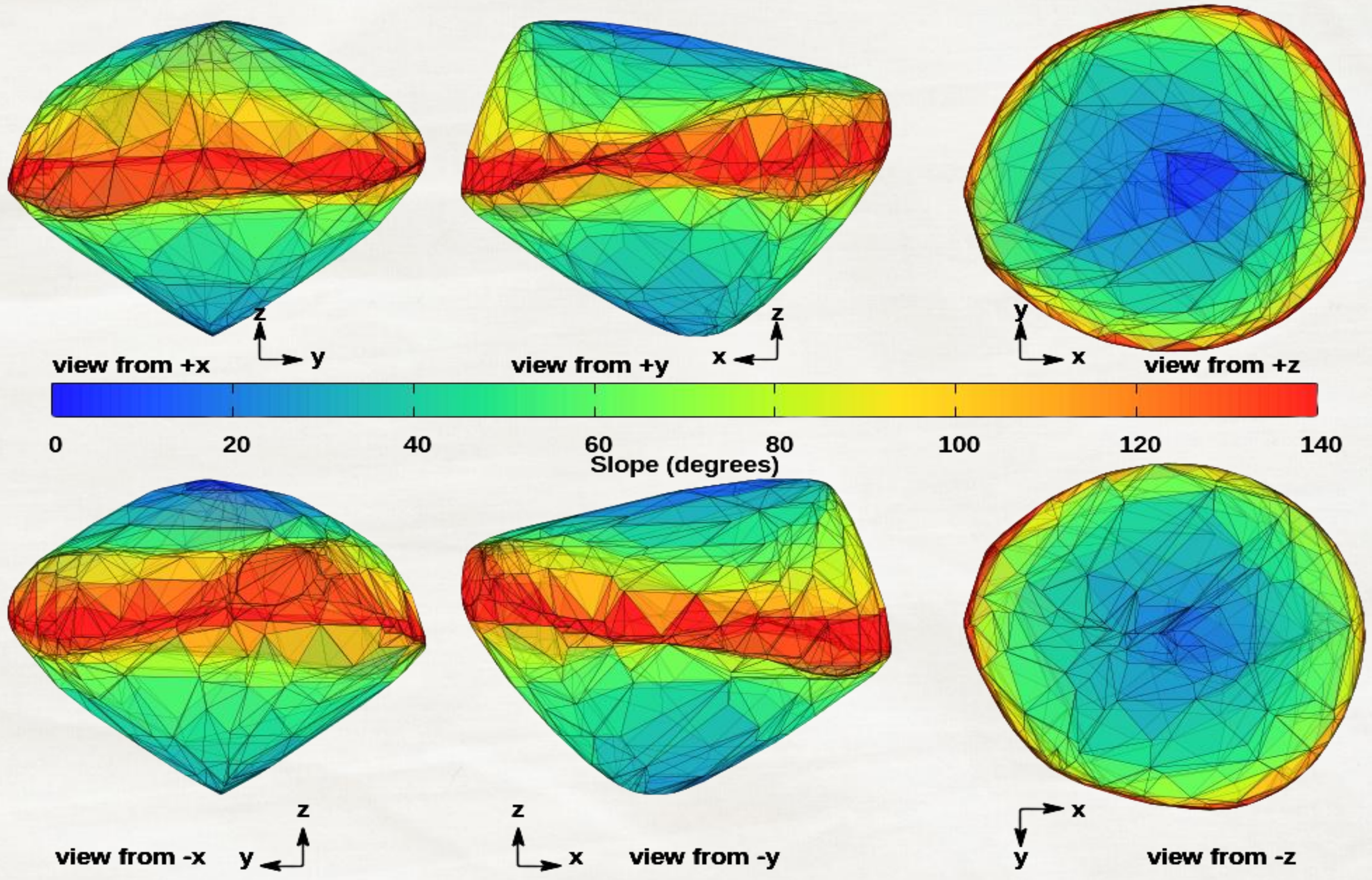
O mapa geopotencial mostra como a gravidade e a rotação, juntas, controlam a estabilidade da superfície e a acumulação de material na superfície irregular do asteroide.

Geopotential across the surface of NEO 1995 SA computed for a density of 2.2 g/cm³

Exemplo: Dinâmica da superfície de (243566) 1995 SA

Surface dynamics - Slopes

O mapa de Slopes mostra regiões de potencial instabilidade da superfície e movimento do regolito, impulsionados pela forma local e pela gravidade efetiva.

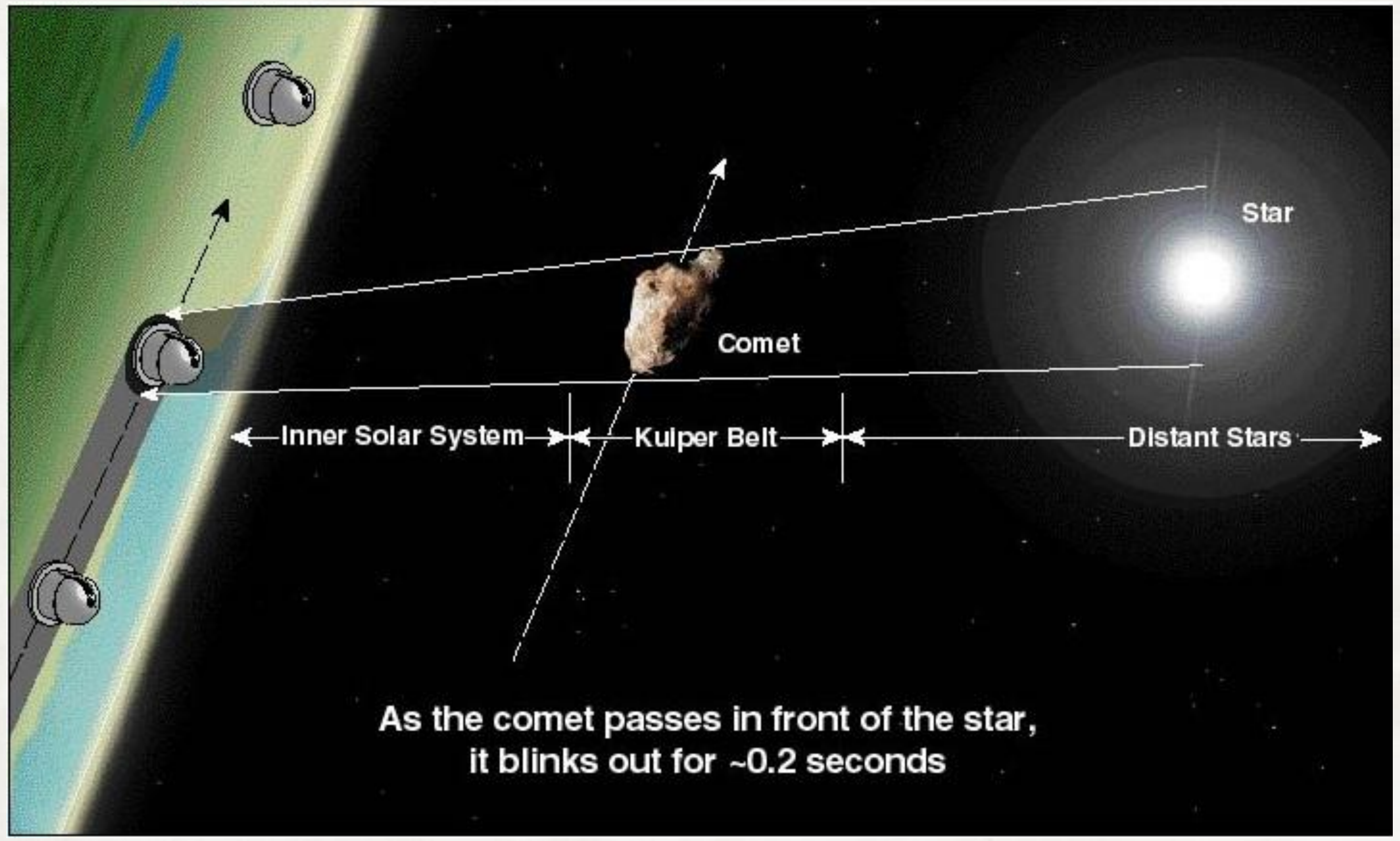


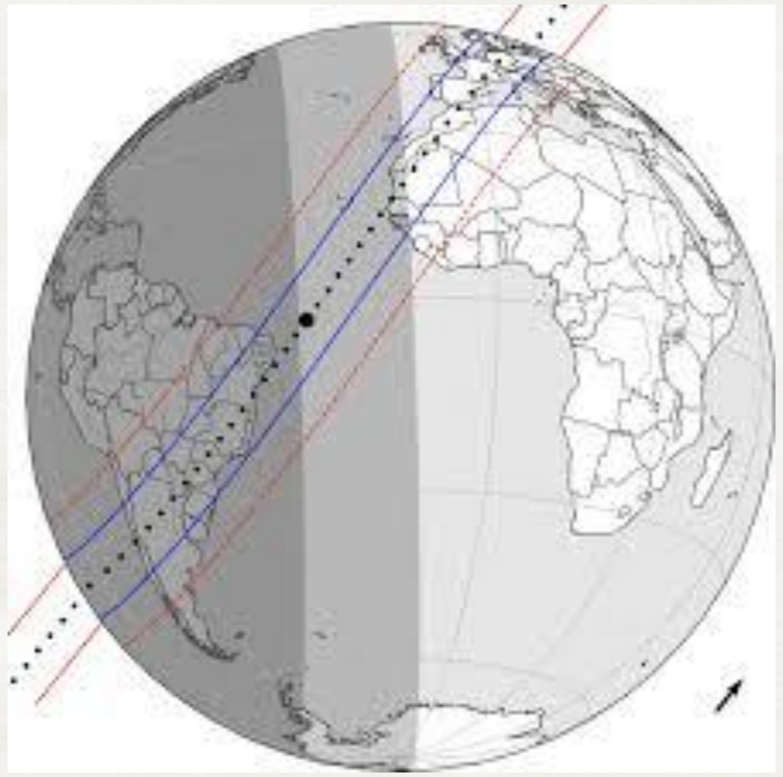
Slopes computed across the surface of NEO 1995 SA computed for a bulk density of 2.0 g/cm³

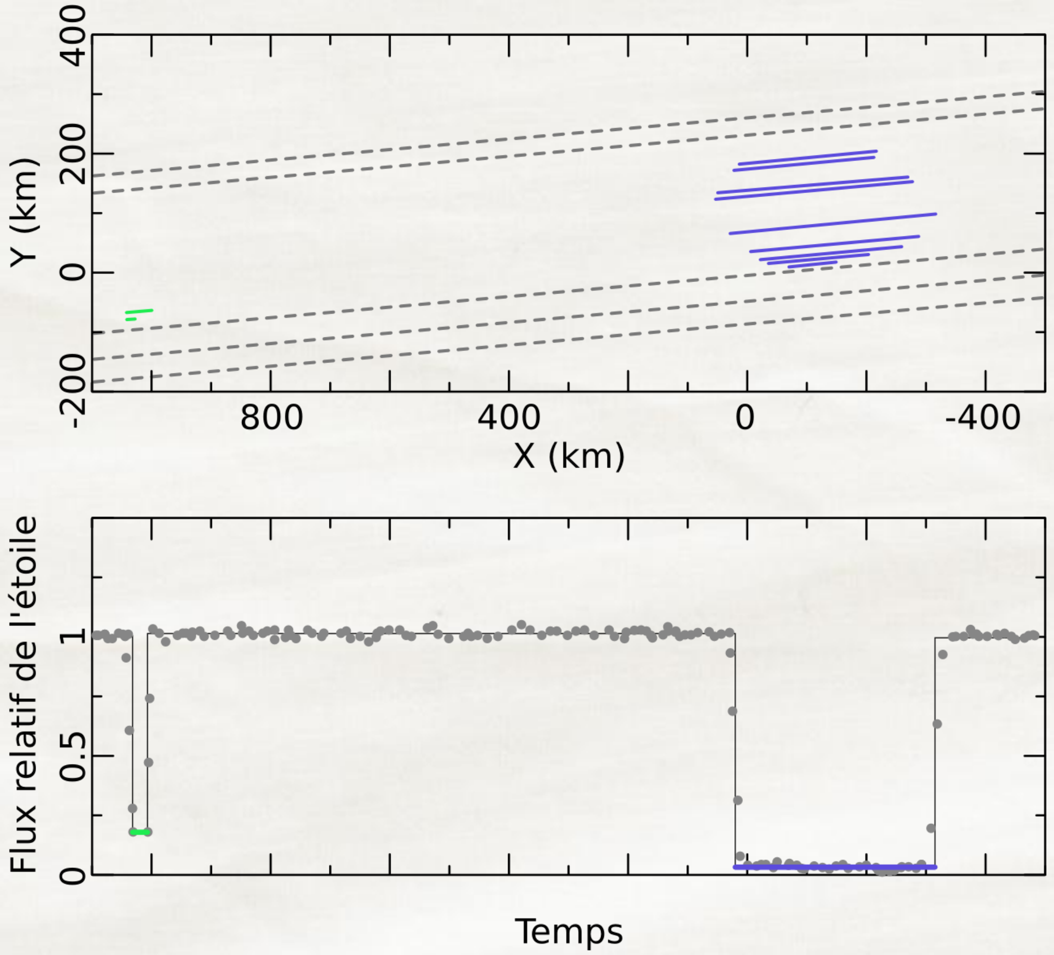
Ocultação estelar

- Ocorre quando um astro (como planeta, lua ou asteroide) passa na frente de uma estrela distante, bloqueando sua luz temporariamente para quem observa da Terra.

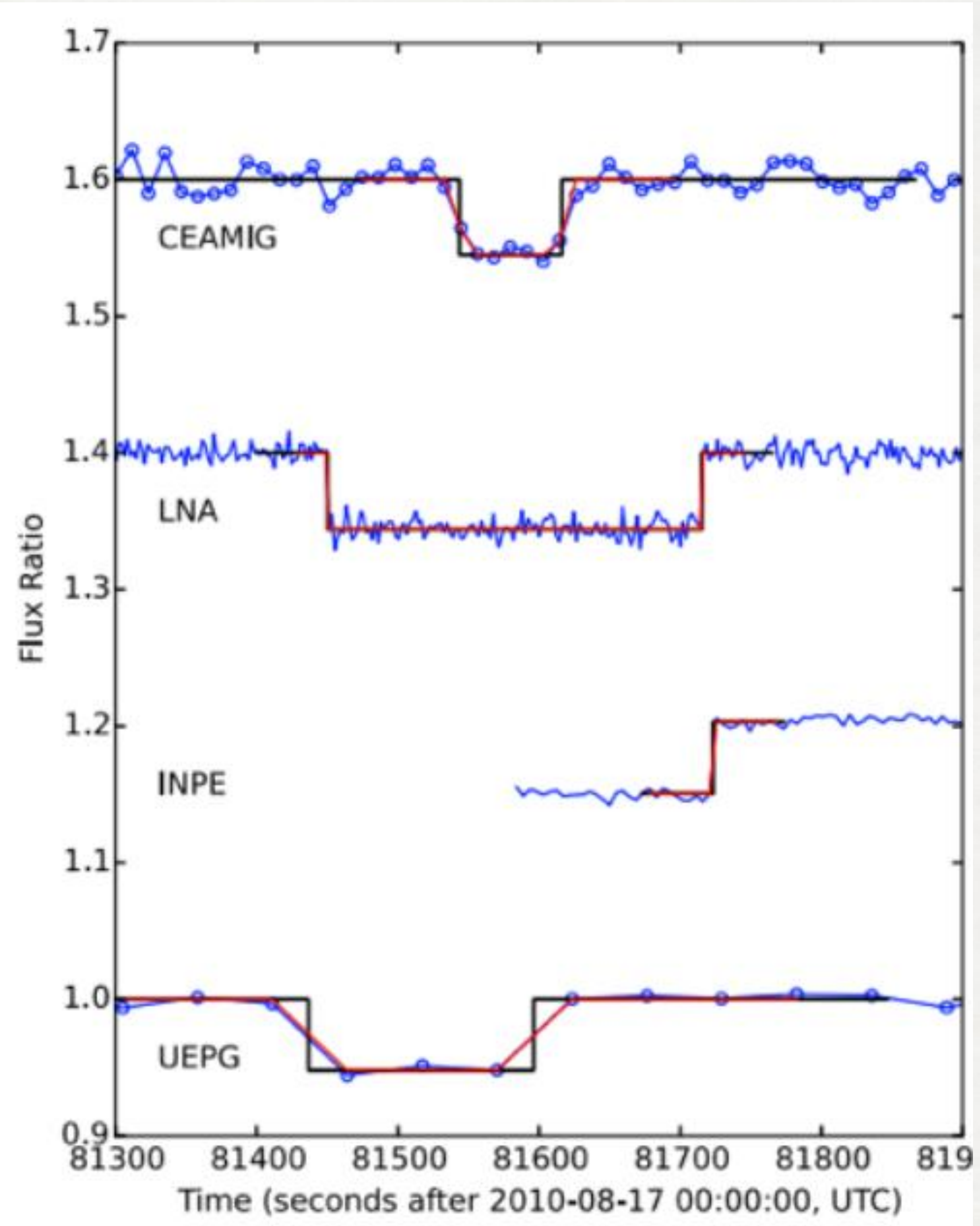
- Medir o tempo exato desse bloqueio permite descobrir o tamanho do astro, se ele possui atmosfera ou se tem anéis ao seu redor.







Carry et al. 2010



Tamanho de Ceres, Gomes-Junior et al. (2015)

Polarimetria – Albedo

Grau de polarização

$$P(\alpha) = \frac{F_\perp - F_\parallel}{F_\perp + F_\parallel} \times 100\%$$

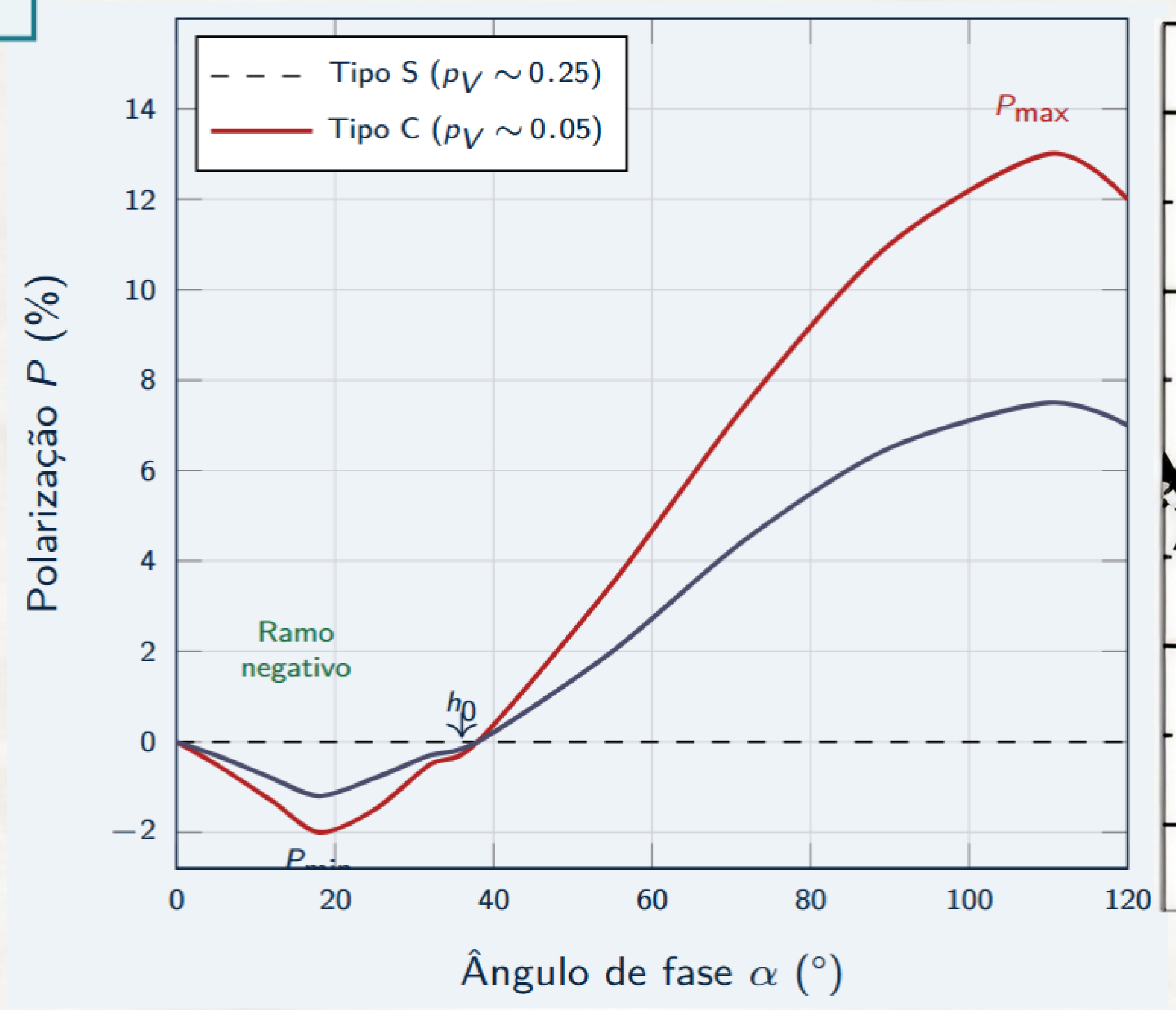
$F_\perp, F_\parallel$: fluxos $\perp$ e $\parallel$ ao plano de espalhamento

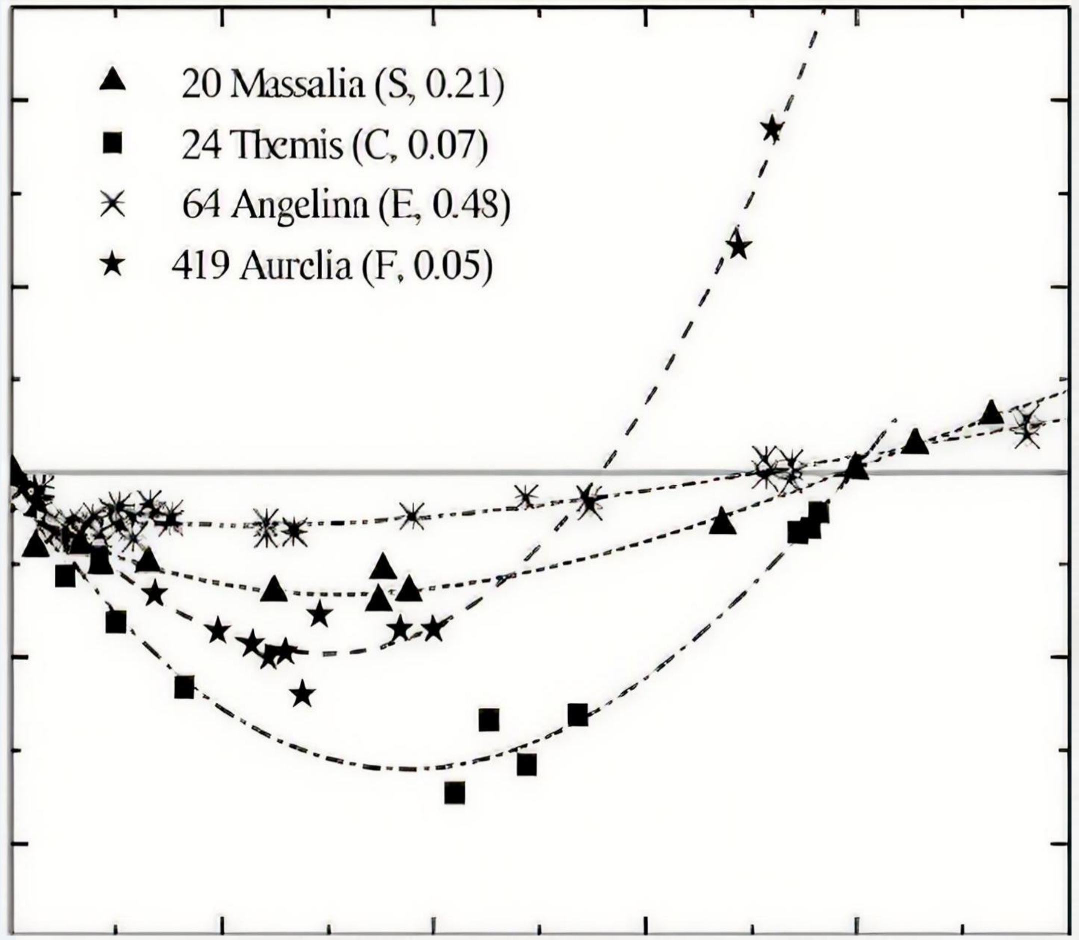
α = ângulo de fase (Sol–objeto–observador)

O que a curva revela

- **Ramo negativo** ($\alpha < 20°$): $P < 0$ — retroespalhamento coerente pelo regolito
- h_0: inversão de polarização ($P = 0$) — diagnóstico de textura
- P_{min}: mínimo da curva — correlaciona com albedo:
  $\log p_V = C_1 \log P_{max} + C_2$
  $C_1 \approx -1.118, \quad C_2 \approx -1.779$
  Determina albedo independentemente do tamanho!
- P_{max}: máximo ($\alpha \sim 100°$) — principal indicador de albedo

- A luz refletida por superfícies fica parcialmente polarizada linearmente. O grau e ângulo de-pendem do ângulo de fase, albedo e textura.





Polarimetria – SPARC4 no OPD/LNA

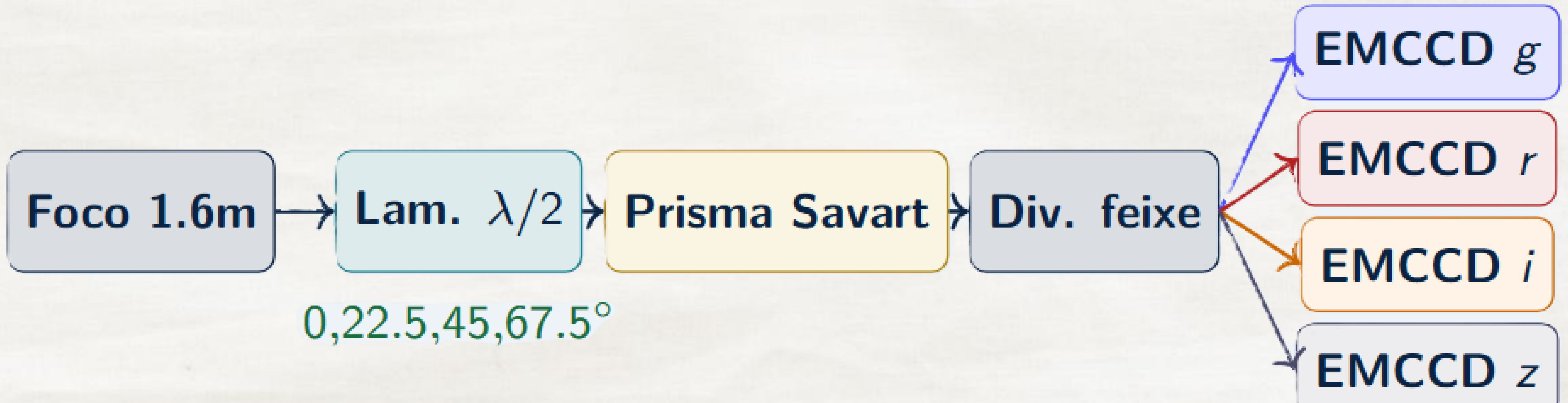
Simultaneous Polarimeter and Rapid Camera in 4 bands

O instrumento SPARC4

Câmera de imageamento simultâneo em **4 bandas fotométricas** (g, r, i, z SDSS), instalada no telescópio de 1.6 m do **OPD/LNA (Pico dos Dias)**. Possui modo **fotométrico** e modo **polarimétrico**.

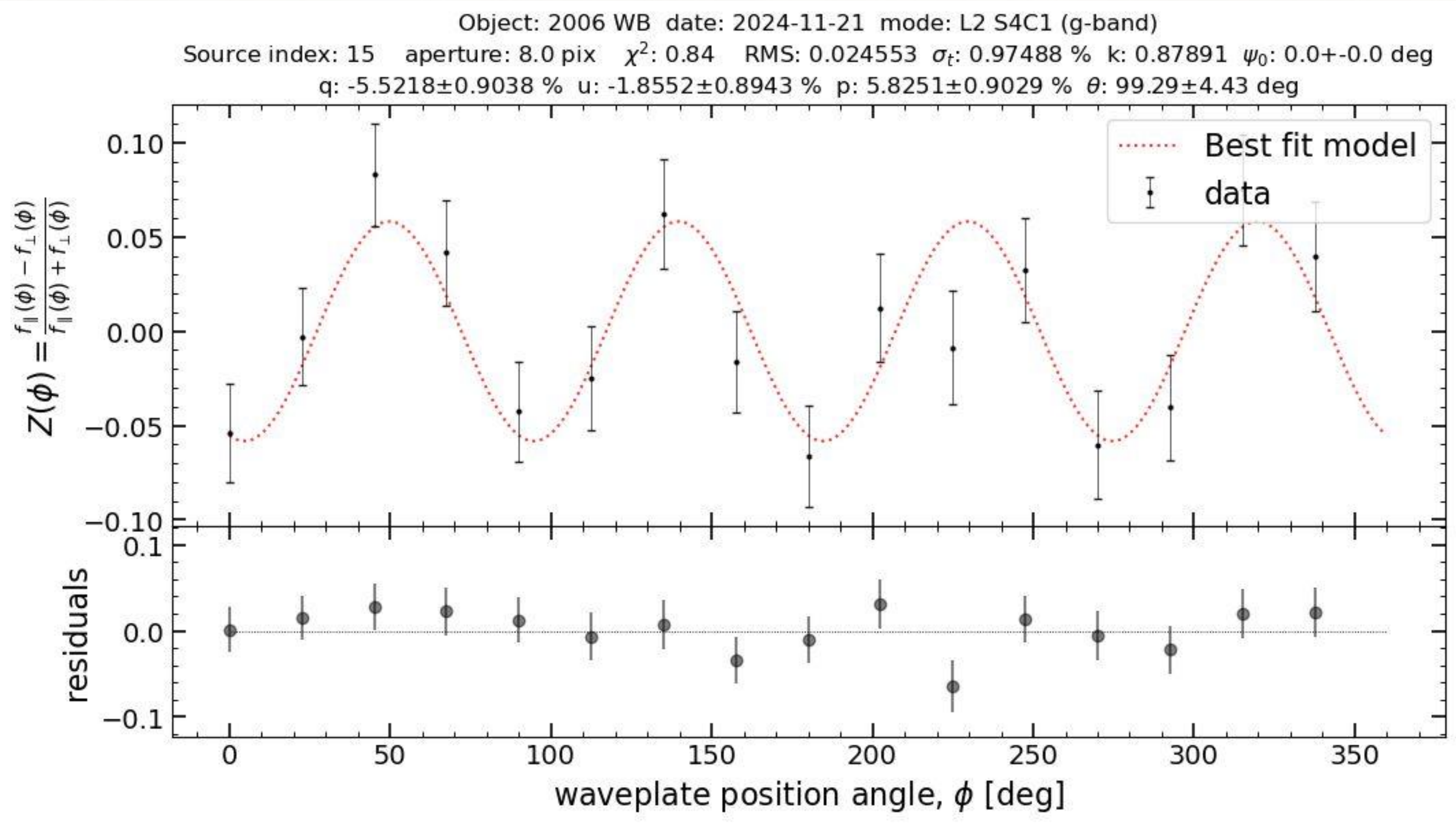
- 4 câmeras EMCCD simultâneas (bandas g, r , i, z)
- Roda de lâminas retardadoras λ/2 e λ/4. O módulo possui 16 posições de rotação, separadas por 22.5° → Stokes Q e U.
- Prisma de Savart para análise de polarização. Funciona como um divisor de feixe de duplo feixe (dual-beam), dividindo em dois feixes ortogonais, criando duas imagens de cada fonte no detector.
- Simultâneo em 4 bandas → índices de cor +pol. em uma única exposição

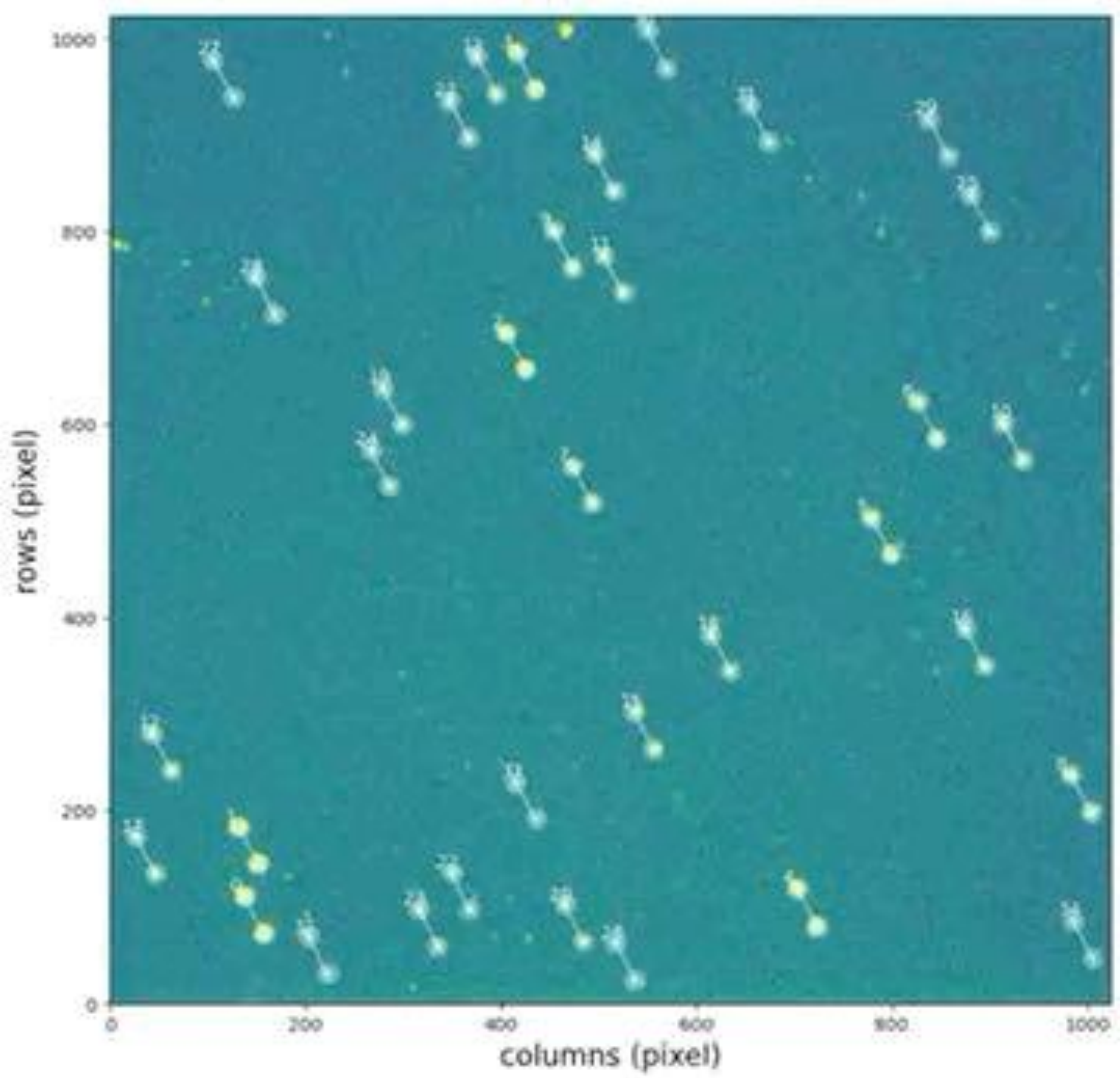
Esquema óptico — SPARC4



g: 400–550 nm r: 550–700 nm i: 700–820 nm z: 820–1000 nm

Polarimetria – SPARC4 no OPD/LNA





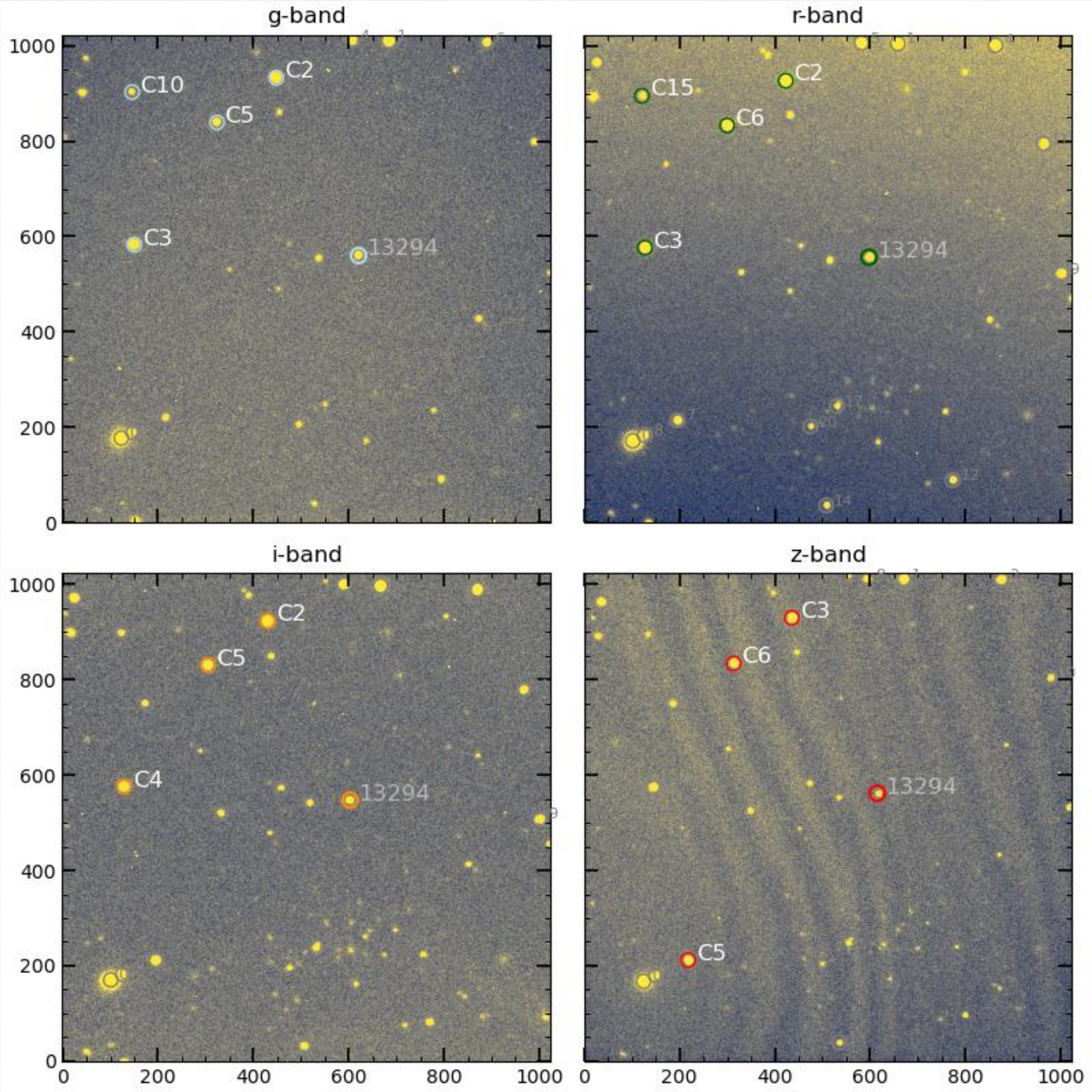
Mede apenas os parâmetros Q (polarização vertical/horizontal) e U (polarização a ±45°). A curva de assimetria segue uma modulação em **4θ**:

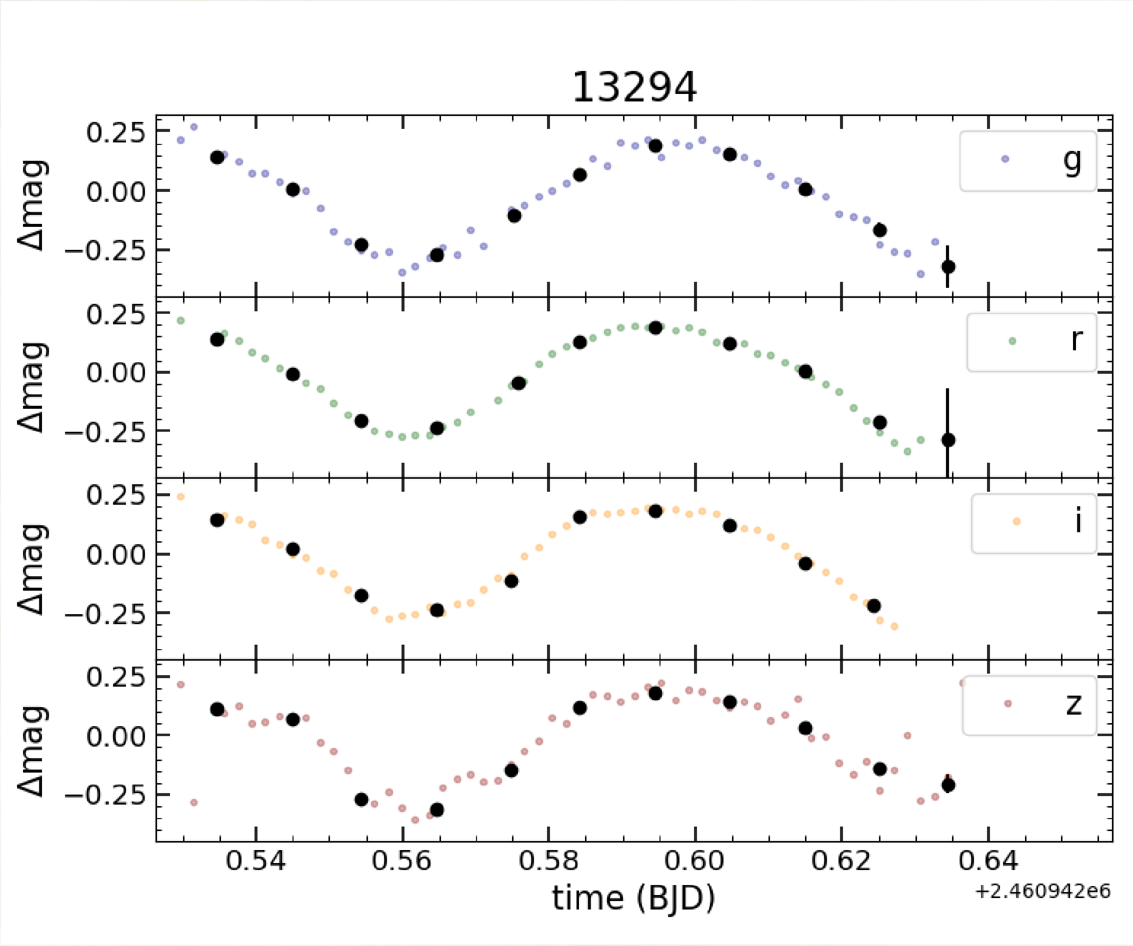
$$A(\theta) = q \cdot \cos(4\theta) + u \cdot \sin(4\theta)$$

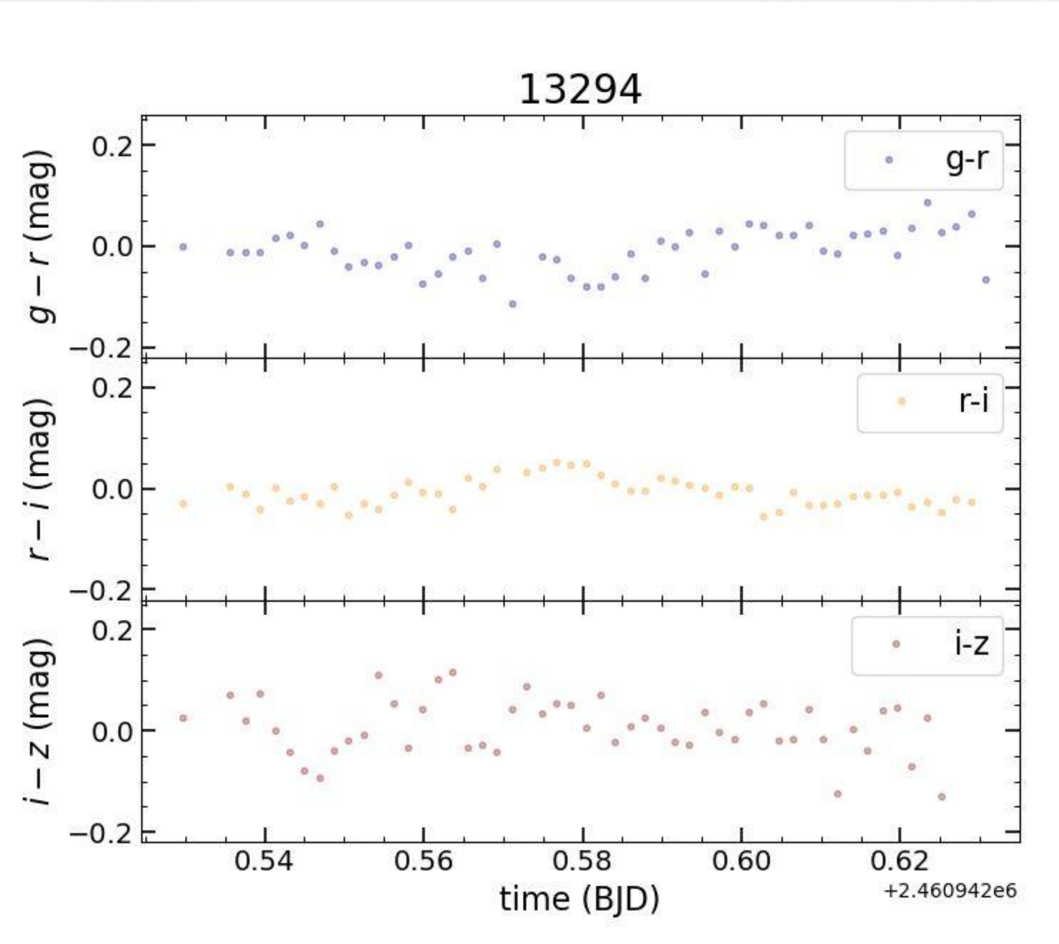
Onde q = Q/I e u = U/I são os parâmetros de Stokes normalizados. Na SPARC4, como a lâmina gira em 16 posições fixas de 22,5°, um ajuste de mínimos quadrados (fitting) ou uma Transformada de Fourier discreta isola as amplitudes de q e u.

- **Grau de Polarização Linear (P):** $P = \sqrt{q^2 + u^2}$
- **Ângulo de Posição da Polarização (Θ):** $\Theta = \frac{1}{2}\arctan\left(\frac{u}{q}\right)$

Fotometria – SPARC4 no OPD/LNA

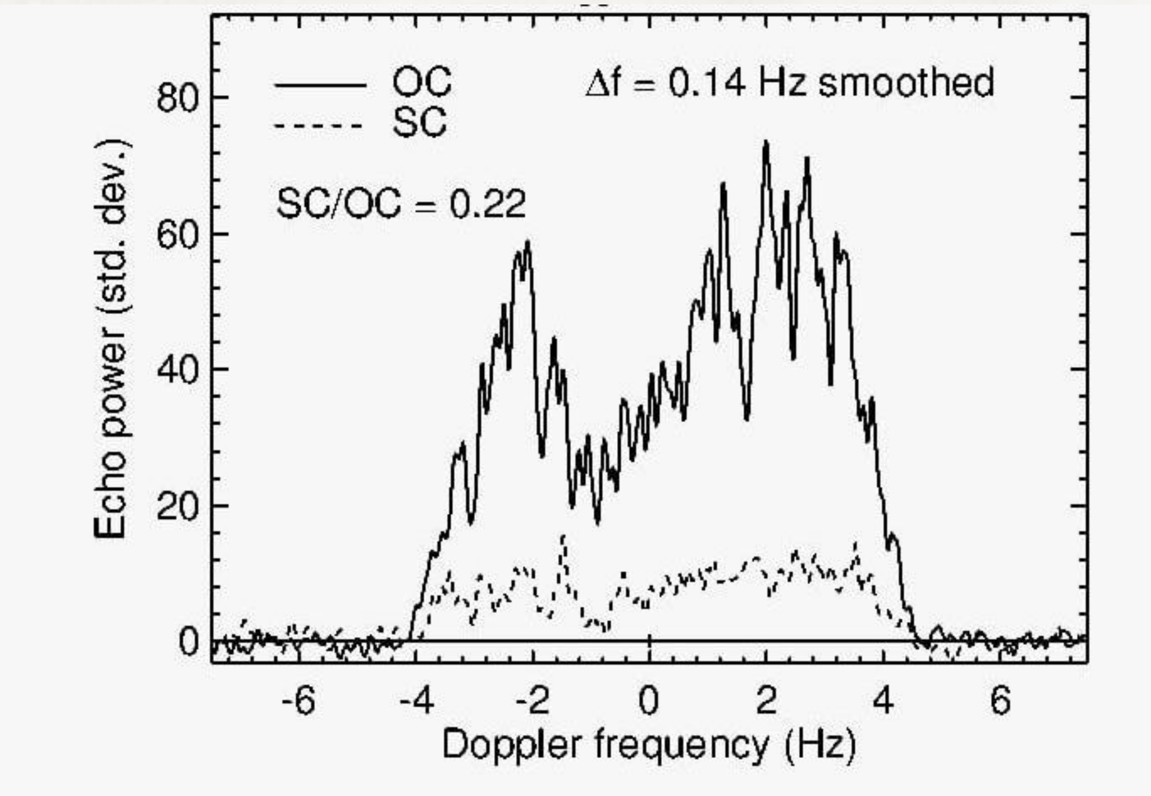


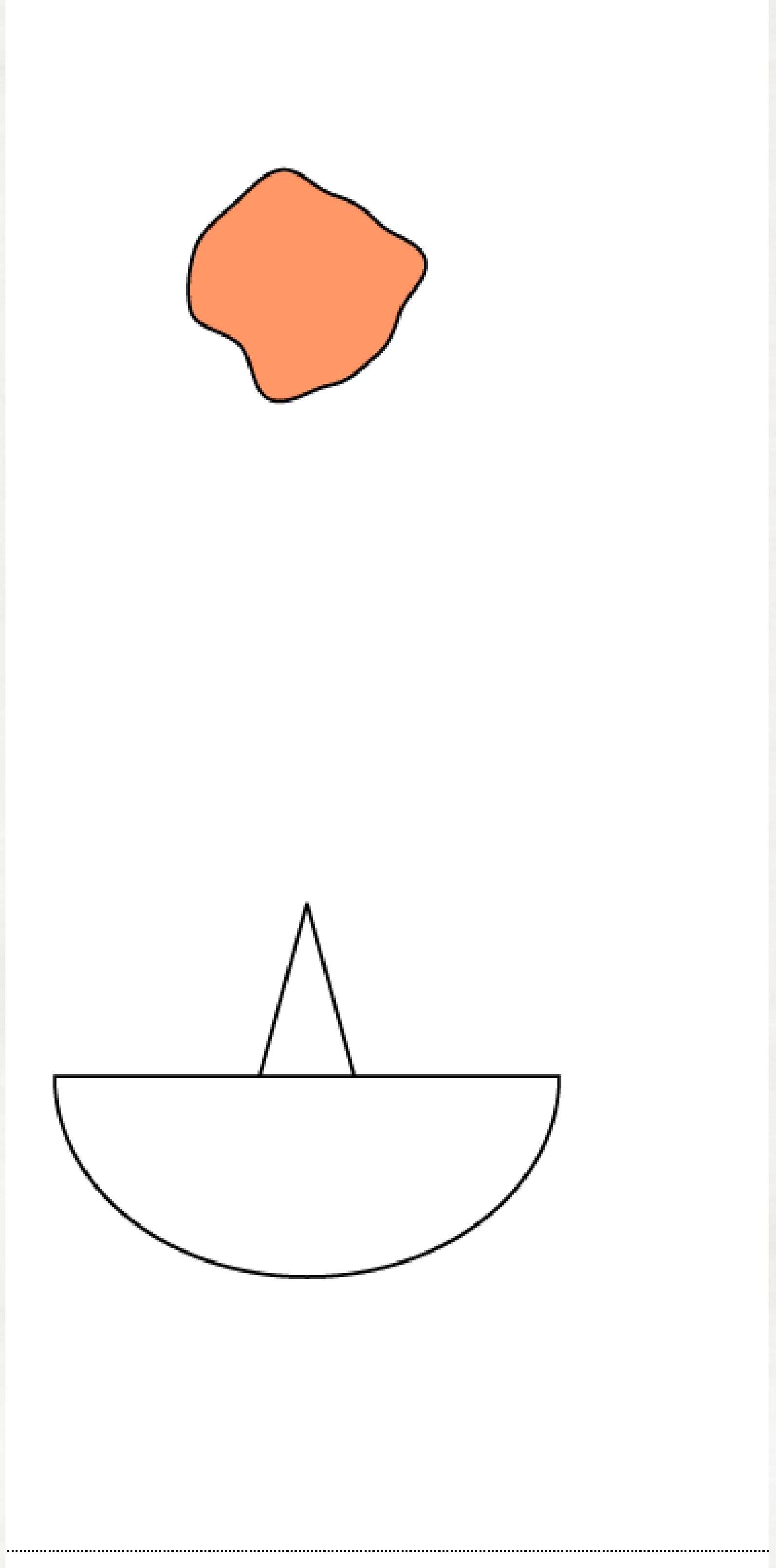




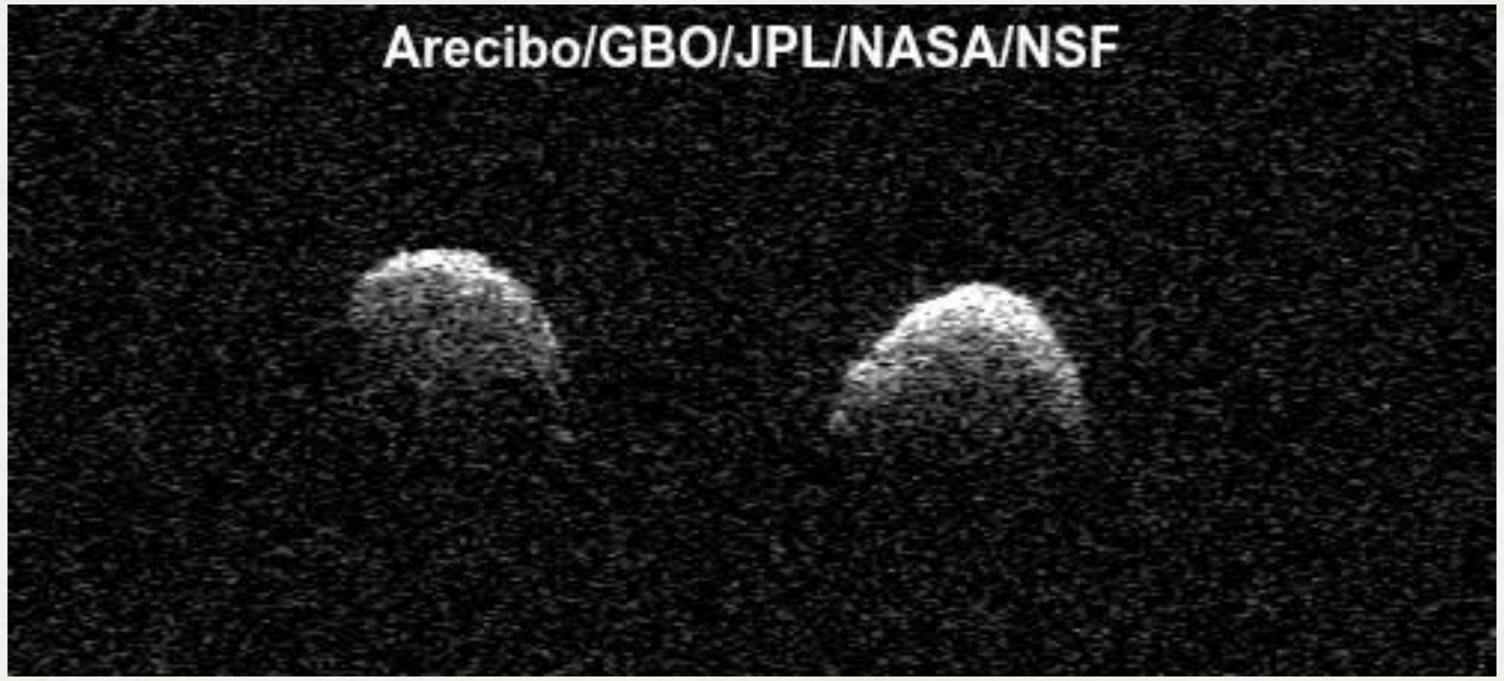
Radar Planetário (Ativo)

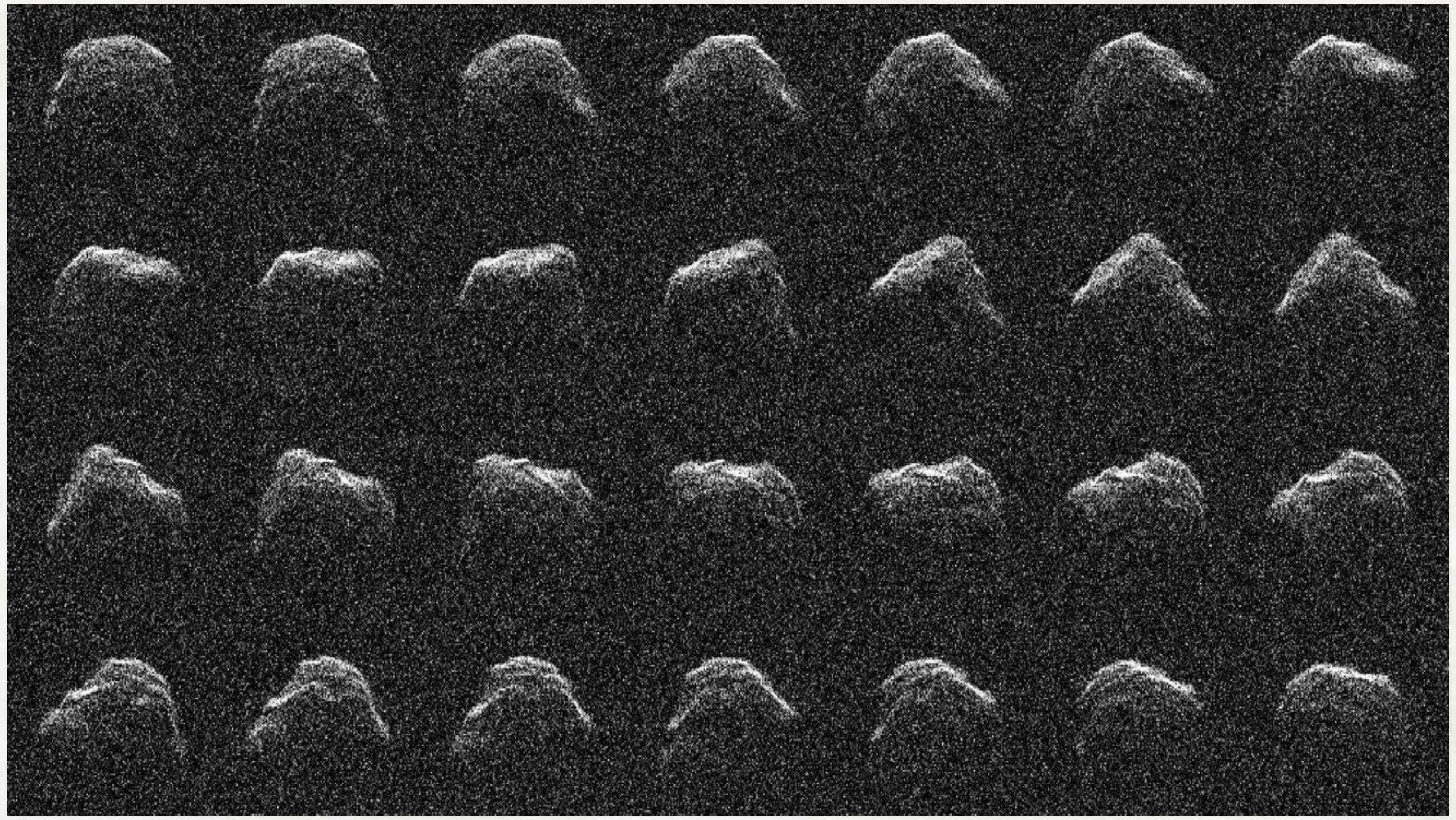
- O radiotelescópio é modificado para funcionar como um transmissor e receptor simultaneamente (ou em dupla com outra antena).
- Envia-se um sinal de rádio para o asteroide e analisa-se o eco refletido. Ao medir o tempo que o sinal de rádio leva para ir e voltar (Δ t), os astrônomos calculam a distância exata até o asteroide, sendo possível mapear o asteroide e determinar suas dimensões exatas.
- O espectro Doppler desse eco revela a rotação do asteroide, além de propriedades da superfície do asteroide.
- As imagens detalhadas de asteroides feitas por radar não são fotografias ópticas, mas sim mapas matemáticos gerados a partir da decodificação do espectro Doppler e do atraso de tempo do sinal (chamadas de imagens Delay-Doppler).

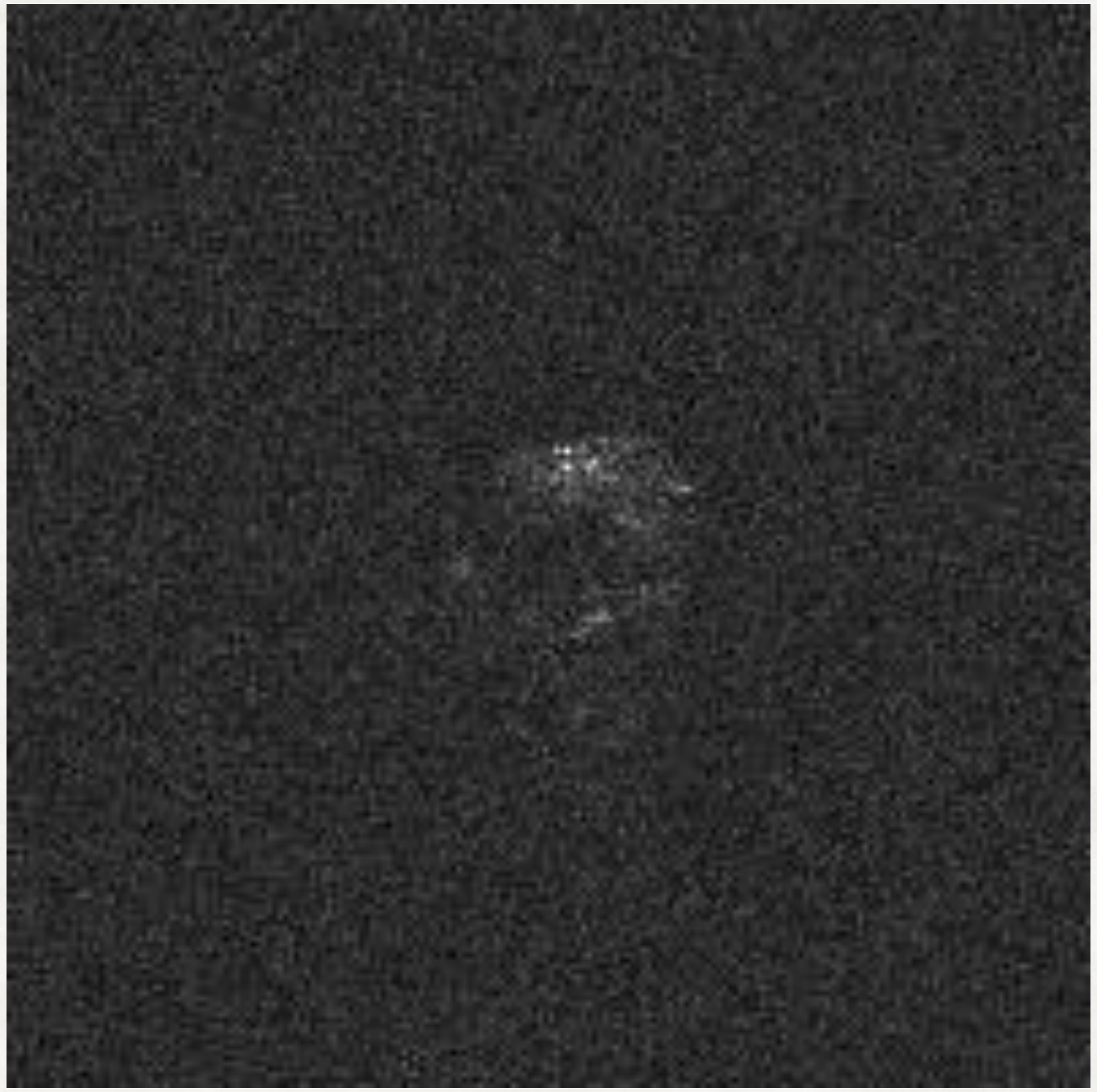




Radar Planetário (Ativo)



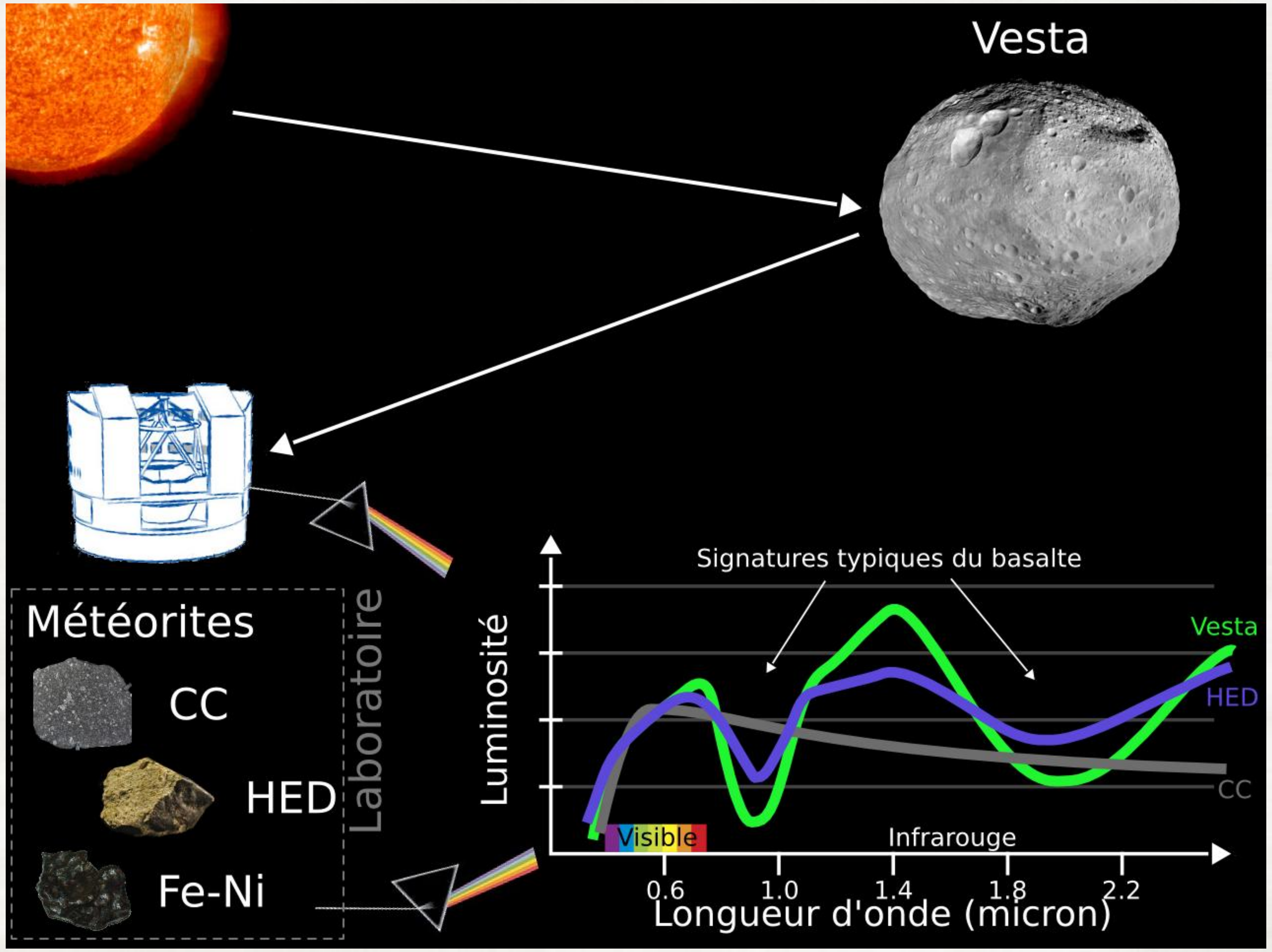




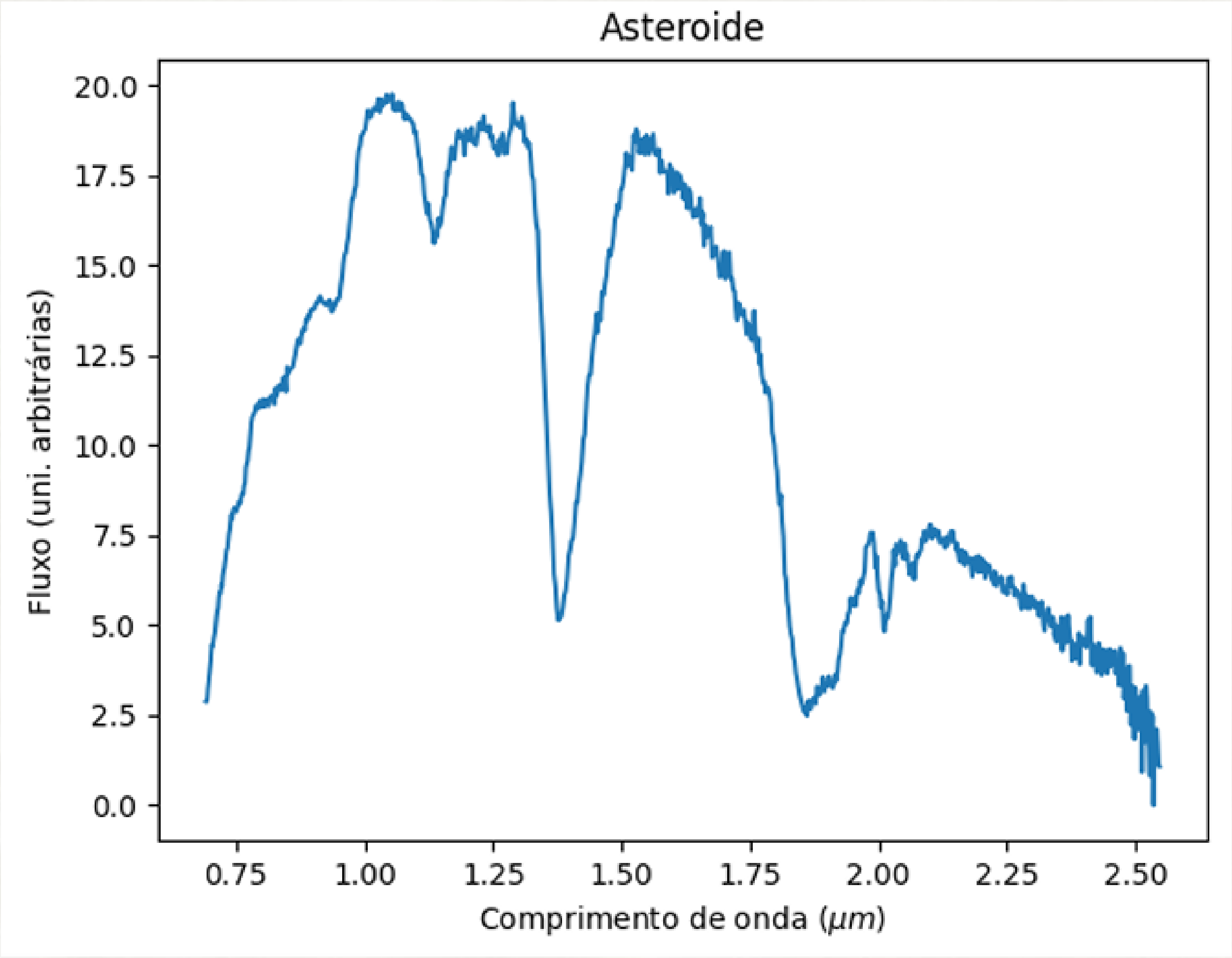
Fonte: Arecibo website

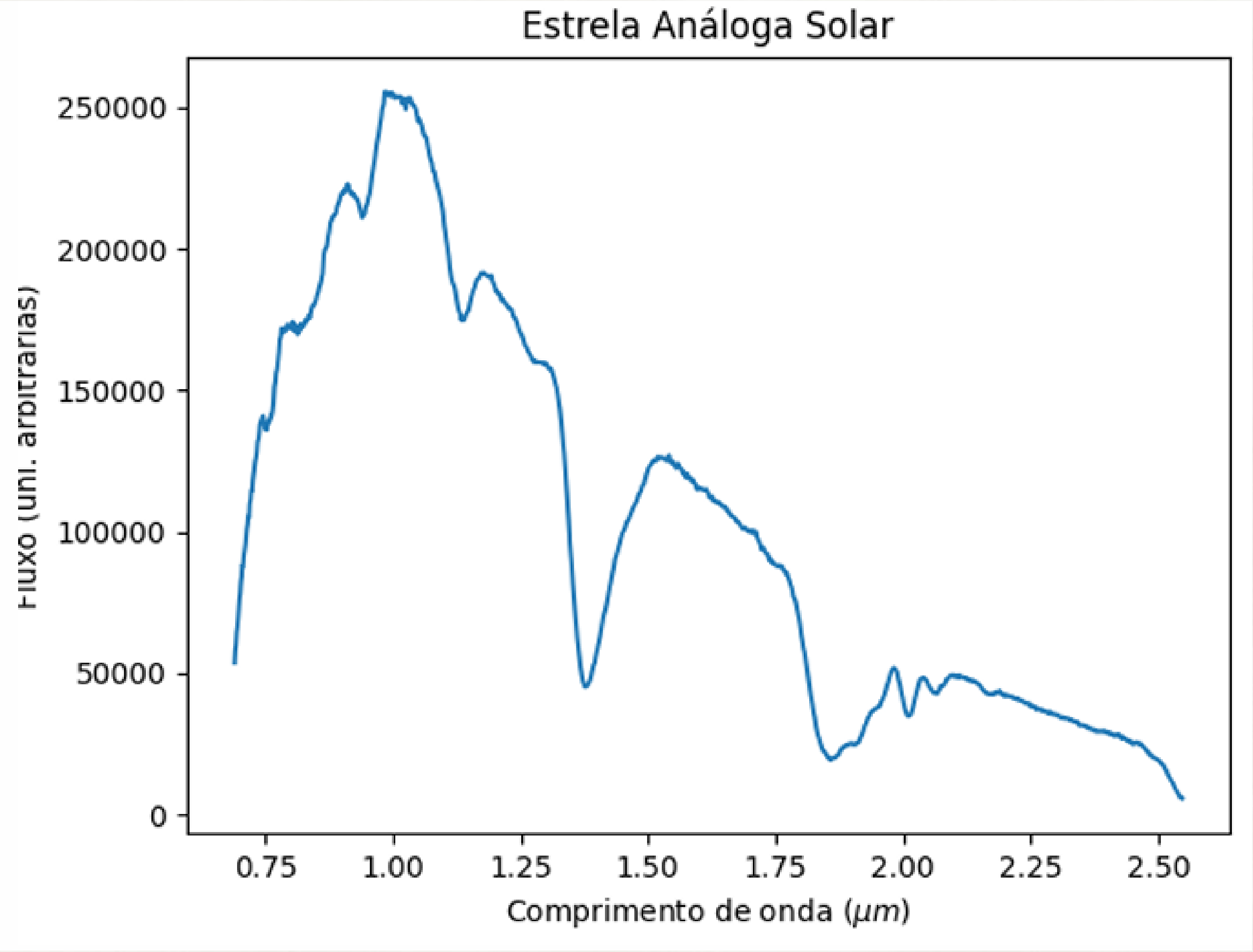
Espectroscopia

1. Coleta de Luz: Um telescópio capta a luz fraca refletida pelo asteroide.
2. Dispersão: A luz passa por um espectrógrafo (equipamento com redes de difração ou prismas), que separa a luz em suas cores e comprimentos de onda constituintes.
3. Registro: Um sensor capta essa imagem e gera o chamado espectro de reflectância.
4. Análise de Dados: O gráfico resultante é cruzado com bases de dados de laboratório de rochas e meteoritos para determinar a classificação taxonômica (como os tipos C, S ou M)



Espectroscopia





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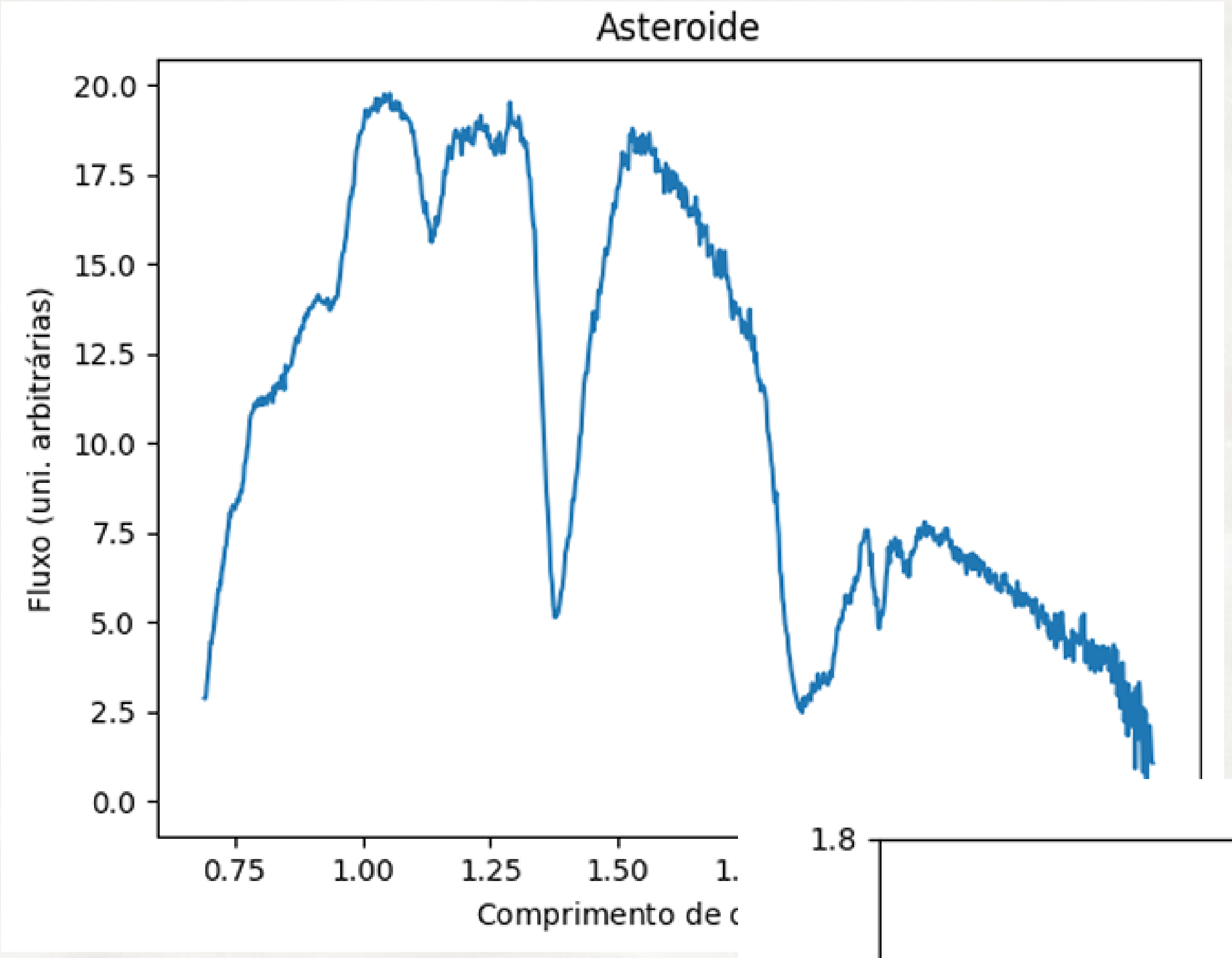
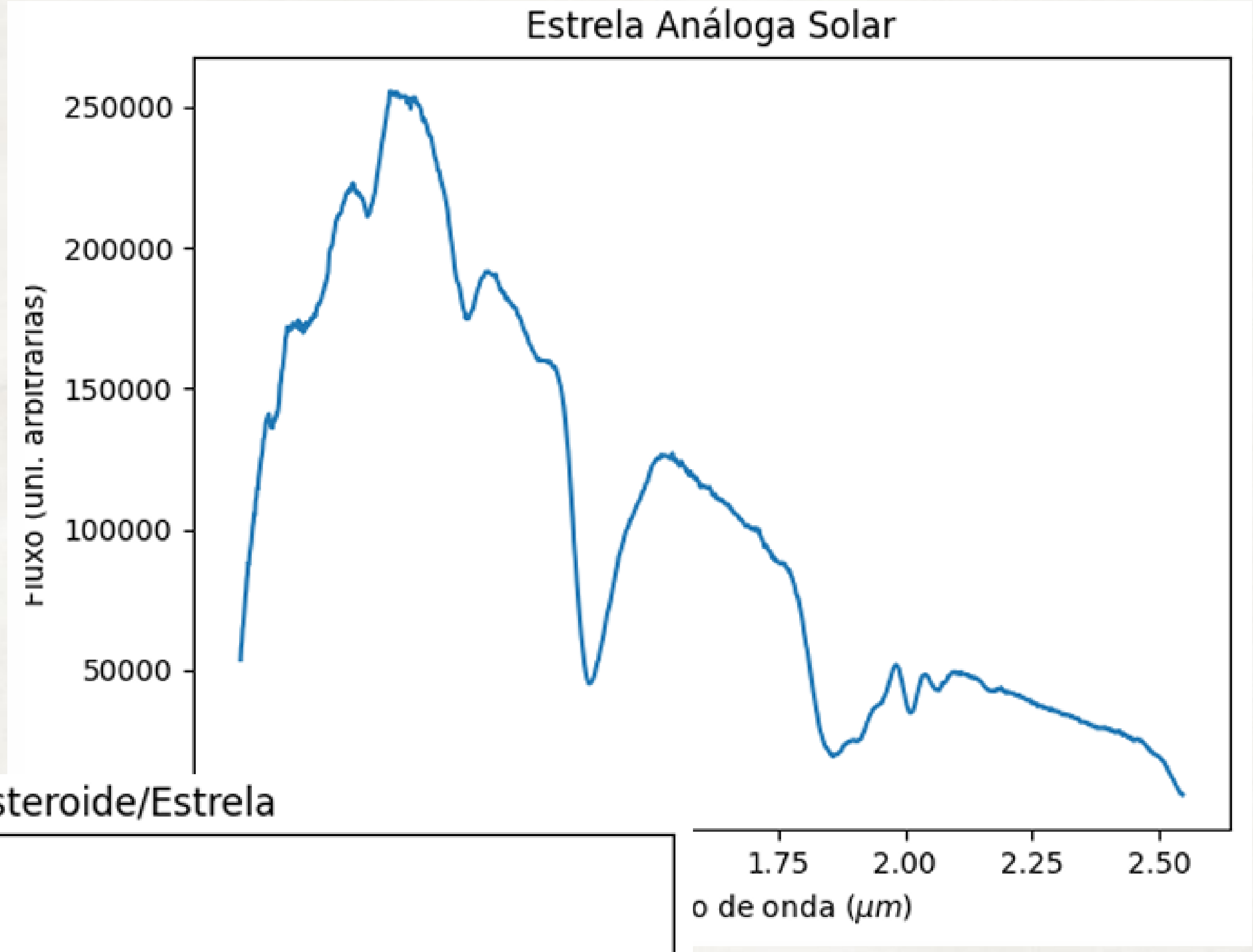
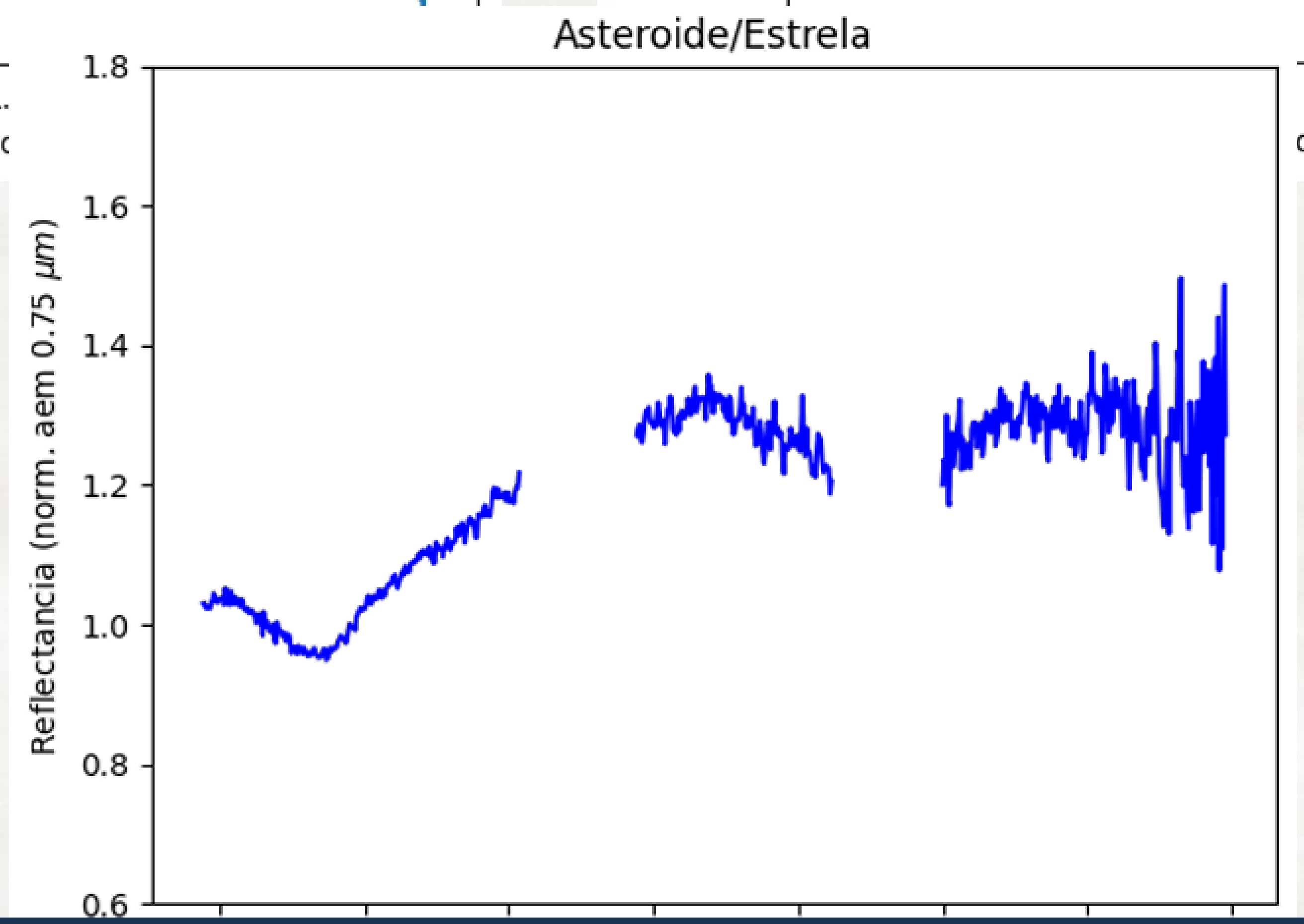


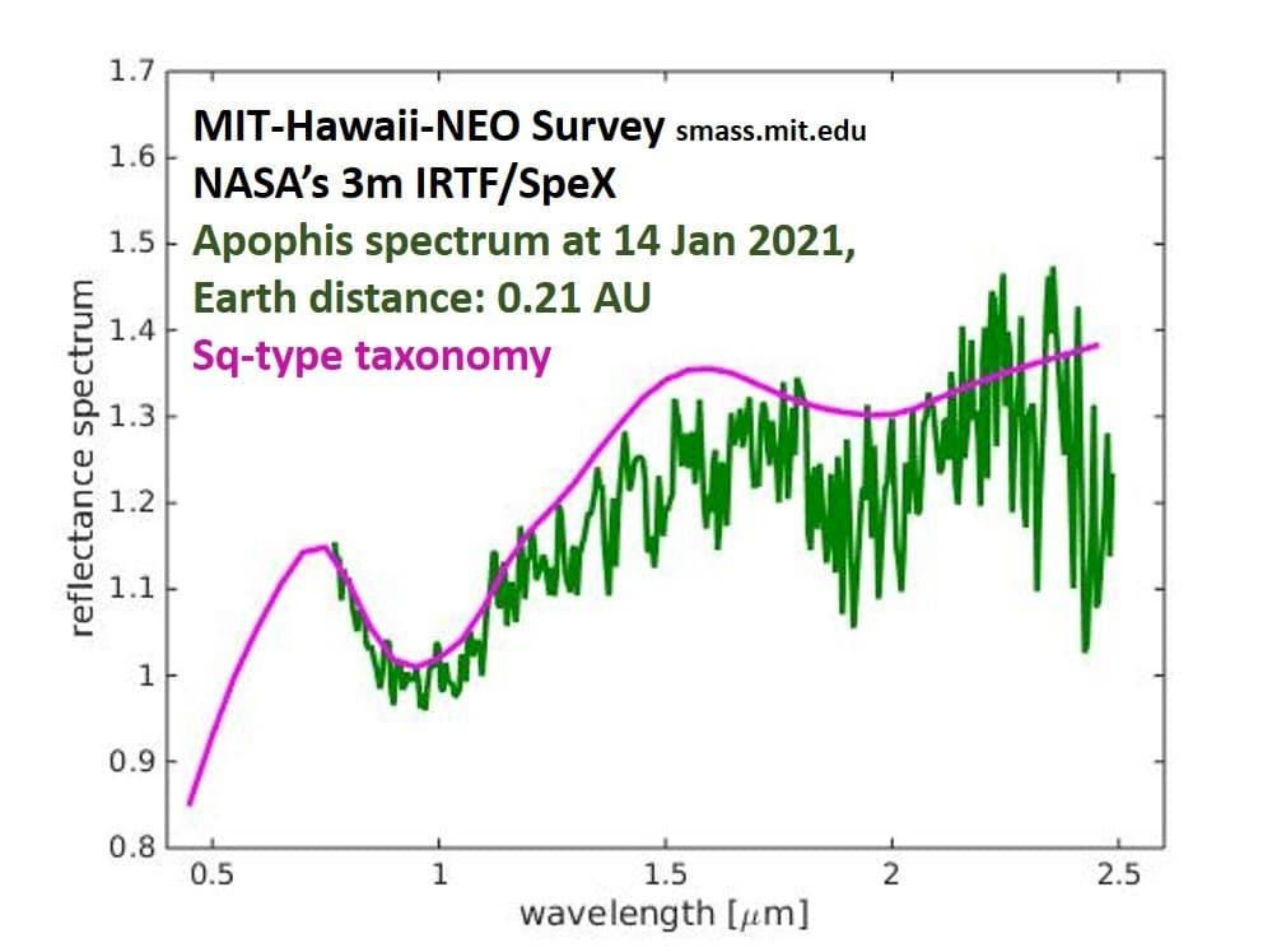


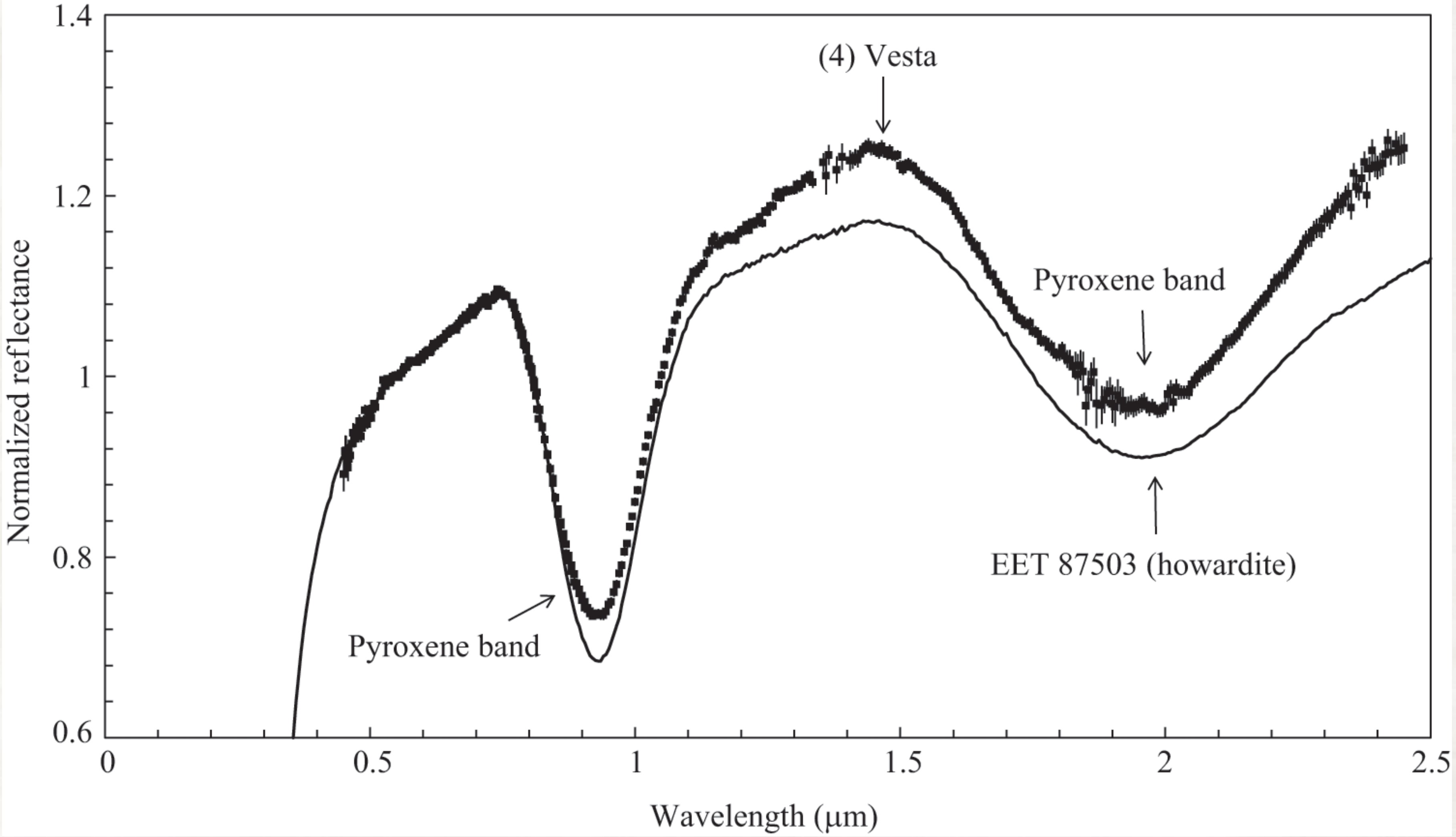


No caso do espectro de um asteroide, você **divide** o espectro do asteroide pelo espectro da estrela calibradora (chamada de análoga solar).

A operação matemática é a divisão porque o objetivo é obter a **reflectância** da superfície do asteroide

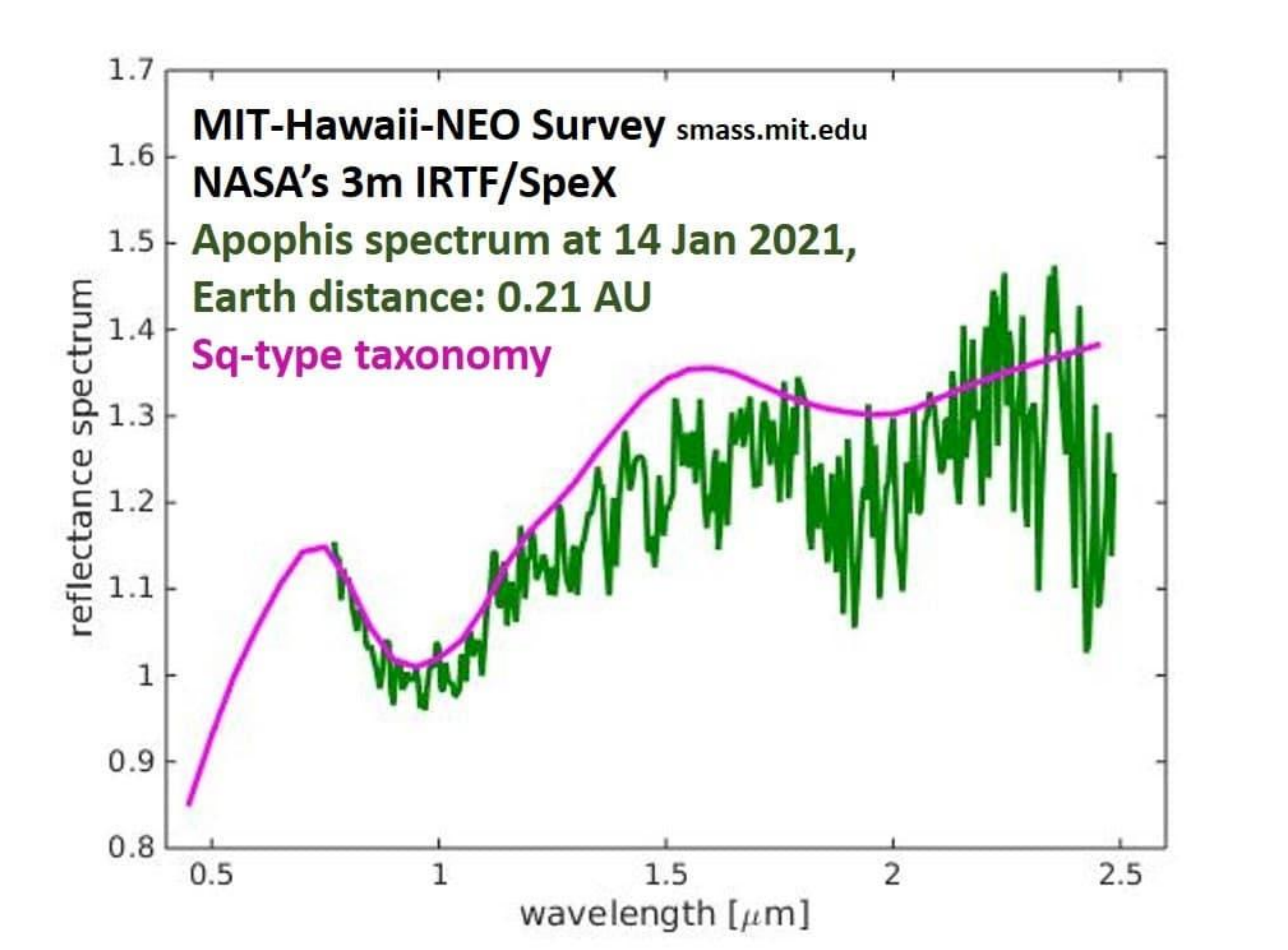
Espectroscopia - Exemplos





Reddy et al. 2018

Espectroscopia - Exemplos

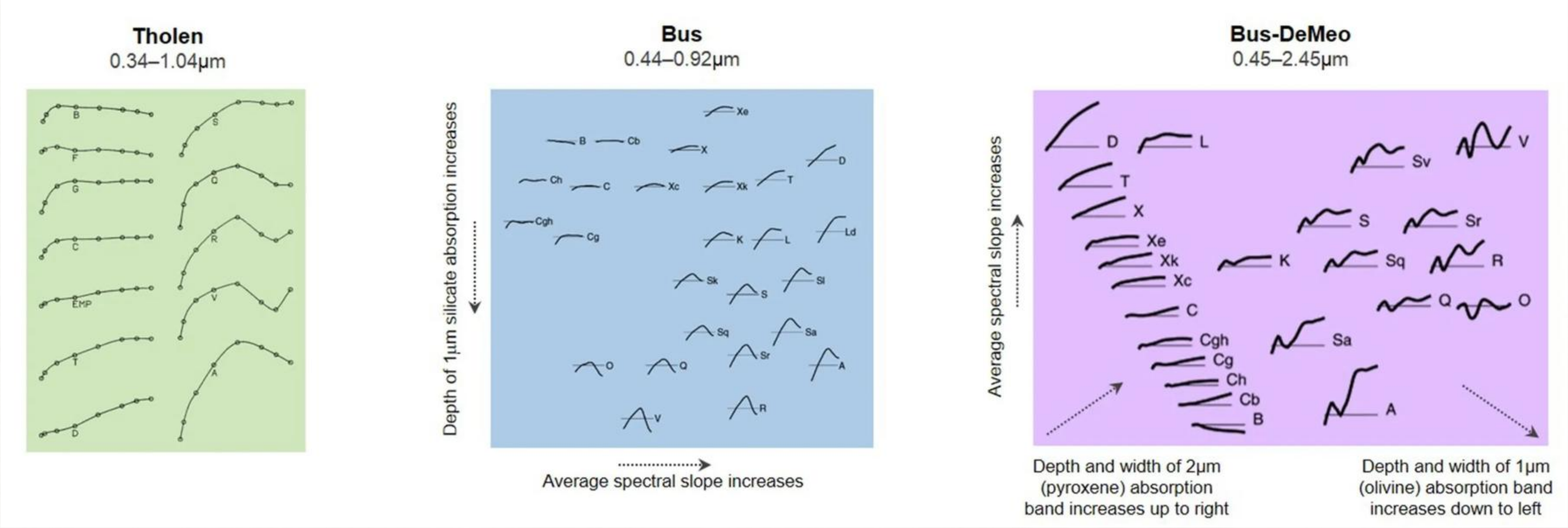


Reddy et al. 2018

Table 2. Spectral Band Parameters and Composition for Apophis

Parameter	This Work	Binzel et al. (2009)	MITHNEOS
Band I Center (μm)	0.99 ± 0.01	1.01 ± 0.01	0.99 ± 0.01
Band II Center (μm)	1.87 ± 0.04	1.84 ± 0.11	2.03 ± 0.08
Band I Depth (%)	17.0 ± 0.1	15.3 ± 0.3	17.2 ± 0.2
Band II Depth (%)	6.8 ± 0.1	3.3 ± 0.3	5.2 ± 0.2
Band Area Ratio (BAR)	0.42 ± 0.03	0.56 ± 0.07	0.30 ± 0.03
Temp. corrected BAR	0.39 ± 0.03	0.54 ± 0.07	0.27 ± 0.03
Olivine composition (mol %)	Fa (28.6 ± 1.3)	Fa (30.1 ± 1.3)	Fa (28.4 ± 1.3)
Pyroxene composition (mol %)	Fs (23.6 ± 1.4)	Fs (24.8 ± 1.4)	Fs (23.4 ± 1.4)
ol/(ol+px)	0.63 ± 0.03	0.59 ± 0.03	0.65 ± 0.03
Temp. corrected ol/(ol+px)	0.63 ± 0.03	0.60 ± 0.03	0.66 ± 0.03

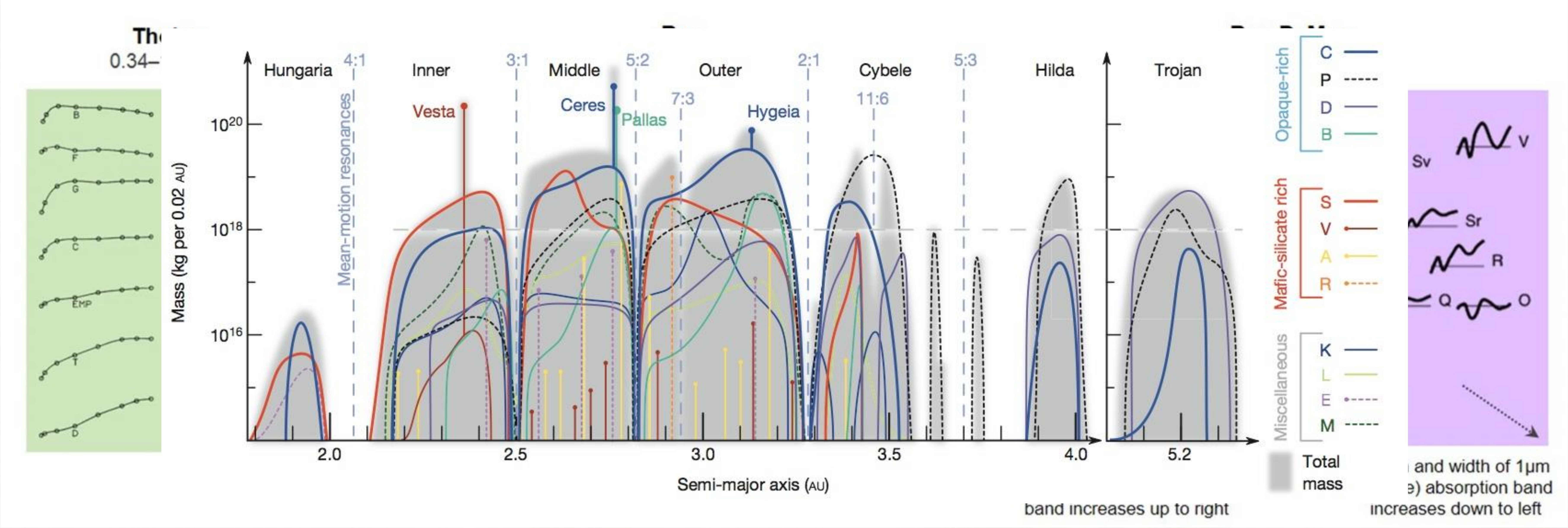
Espectroscopia



***Segregação de asteroides em grupos a partir de propriedades observacionais; * Inferência de composição; * Distribuição orbital - famílias de asteroides**

Espectroscopia

F. E. DeMeo and B. Carry , 2014



*Segregação de asteroides em grupos a partir de propriedades observacionais; * Inferência de composição; * Distribuição orbital - famílias de asteroides

Conclusões

- ❖ Conhecer as características dos asteroides permite identificar de onde vêm os asteroides próximos da Terra e mapear a distribuição de materiais no Sistema Solar, em participar , da água.

- ❖ Contribuir para a restrição dos modelos de formação.

- ❖ Defesa Planetária: Determinar a densidade e coesão, o que irá definir a melhor estratégia de prevenção de impacto. Ex. Asteroides Tipo S são mais densos e coesos; Tipo C podem ser "pilhas de entulho"(rubble piles).

- ❖ É preciso um esforço global mais intenso para caracterização desses pequenos corpos.

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Resultado integrado

Tamanho ▪ forma ▪ rotação ▪ composição mineral ▪ albedo geométrico ▪ órbita precisa ▪ risco de impacto ▪ densidade bulk ▪ estrutura interna

IMPACTON

Obrigado!

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