COMPARISON OF TOPOGRAPHIC MODELS FOR ASTEROIDS TO THE HST/FGS DATA

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ABSTRACT/RESUME

Knowledge of the size and shape of asteroids is of high importance to better understand their collisional evolution and internal structure. Presently, most of the largest asteroids (exception made of the few largest) are supposed to be rubble-piles of cohesionless aggregates, some having possibly equilibrium figures [1,2]. Topographic models for asteroids can be derived from analysis of radar Doppler-imaging data [3] or inversion of lightcurve data [4]. Such models can be confronted to other independent observations such as stellar occultations, lightcurves, and mostly high resolution interferometric data from the Hubble Space Telescope (HST) Fine Guidance Sensor (FGS). We present the results obtained from the comparison to the HST/FGS data of (15) Eunomia, (44) Nysa, (216) Kleopatra, and (624) Hektor.
We show that the HST/FGS data can provide valuable constraints on the topographic models of Kleopatra. Moreover, this procedure enables us to determine accurate and direct measurements of the linear size of the asteroids which cannot be retrieved from disk-integrated photometry alone.

1. INTRODUCTION

Six asteroids (five main-belt and one Trojan of Jupiter) were observed so far with the HST/FGS [5]. In addition to the usual data inversion problem [6], such high-resolution observational data can be used to test or refine existing shape models obtained by other techniques (e.g. radar imaging or photometric light-curves). In this work we present the results obtained for the comparison of the models obtained by radar-imaging for Kleopatra [7], and those obtained by photometric lightcurve inversion [8] for Eunomia, Nysa and Hektor.

The calculation of a synthetic HST/FGS interferogram (or S-curve) is performed by the convolution of an observed point-like source transfer function *TF* along one of the FGS axis (obtained from the HST calibration data-base) with the body's image *O* [6]:

$$S(x) = O \otimes TF = \left\langle \iint_{Target} I(u,v)\, TF(x-u)\, du\, dv \right\rangle \qquad (1)$$

where $I(u,v)$ is the brightness distribution, and the integral limits are given by the target's shape. Once the physical ephemeris and the light-scattering properties of the asteroid are set, these interferograms can be computed in a straightforward manner by numerical integration for any shape modelled by polygons and vertices given in topographic coordinates.

2. MODELS FROM RADAR–IMAGING DATA

A topographic model for Kleopatra was obtained by radar Doppler-imaging [7]. Due to limited SNR the uncertainty is ~15 km for the shape and additionally 25% for the absolute size. The pole coordinates and rotation period are given by the model. The zero rotational phase, which is not in the model, can easily be obtained from the timing of lightcurve. Since the light-scattering properties in the visible domain cannot be constrained by the radar observations, these were modelled in this work by a Minnaert law that reproduces the lightcurve amplitudes observed at small or moderate aspect angle.
The radar model is in global agreement with the HST/FGS data. However, comparison to lightcurves observed at large aspect angles showed that the radar-derived nominal model's flattening seems to be underestimated. Moreover, the comparison to the HST/FGS data given in Fig.1 shows that there are medium scale inadequateness of the nominal model.

Proceedings of Asteroids, Comets, Meteors (ACM 2002), 29 July – 2 August 2002, Technical University Berlin, Berlin, Germany (ESA-SP-500, November 2002)

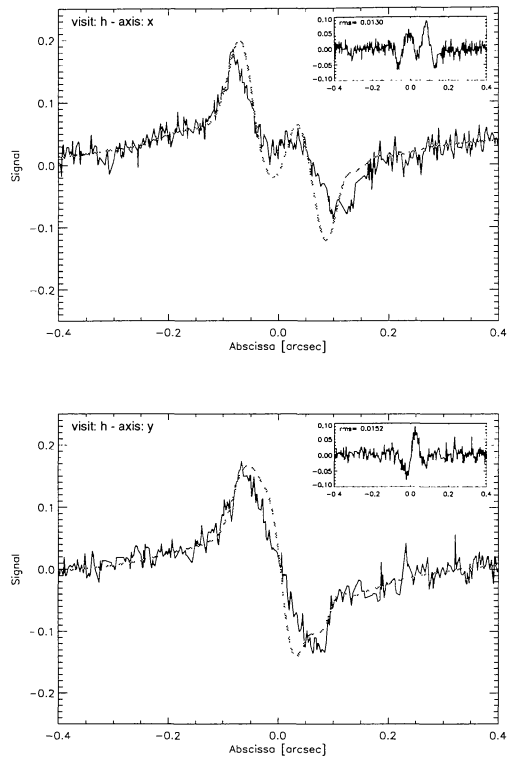

Fig. 1. Computed (from the radar model) and observed S-curves for (216) Kleopatra on last visit. Residuals are given in the inset

Interesting to note, the HST/FGS data can be relatively well modelled by a profile composed of two 'overlapping' ellipsoids [9], while the radar data do not rule out the presence of an empty gap in the middle of the asteroid [7]. Such model, which shall have major consequences on the asteroid bulk density and formation theory, might provide better results. The HST/FGS observations seems to support a formation made from a coalescence of the components of separated binary pair. They should provide valuable additional constraints to the radar data inversion.

3. MODELS FROM PHOTOMETRIC DATA

The pole coordinates, rotation period, zero rotational phase, as well as the light-scattering parameters are given by the model. On the other hand the linear size of the object cannot be determined from integrated photometric data. Thus the only free parameter for comparison to the HST/FGS data, is a scaling factor that is determined by minimising the residuals for all available visits and on both FGS-X and -Y axes. The resulting scaled dimensions along the principal axes are given in Table 1. The mean diameter is the diameter of the *sphere* that would have the same volume. It appears that the spin pole of the photometric model is close, within a few degrees, to the principal axis of largest moment of inertia. All photometric models retained in this work have convex profiles.

Table. 1. Scaled sizes for the photometric models

Name	Largest dimensions	Mean diameter
	km x km x km	km
(15) Eunomia	331.4 x 321.7 x 220.6	285.2
(44) Nysa	114.9 x 105.0 x 67.8	86.8
(624) Hektor	423.1 x 232.1 x 174.8	248.1

Fig. 2 to 7 give an example of the physical ephemeris and the comparison to arbitrarily selected HST/FGS visits for Eunomia, Nysa and Hektor.

4.1 (15) Eunomia

The particular asymmetric feature observed on the S-curves for the FGS-X axis is well reproduced by the photometric model. Such particular S-curve could also be explained by an ovoid or octants shape model. Combining the photometric and FGS data set should provide a much more refined shape model.
With the presently determined value for the volume (39% larger than the IRAS V4.0 derived volume) the bulk density of Eunomia can be estimated, from a mass of $(1.26\pm0.3)\times10^{-11}$ M_{sol} derived by [10], to 2.1±0.5 g/cm^3. Further, assuming S-type asteroids to be space-weathered H or L ordinary chondrites (which link has not yet been established) with an average bulk density of 3.4 g/cm^3, would result in a macro-porosity for Eunomia of 40±15%. The shape and bulk densities found are also compatible with an equilibrium configuration of a cohesionless body and small friction angle [2]. A better knowledge of the possible friction angle in asteroids materials, in connection to their macroporisity, is now needed.

4.2 (44) Nysa

The asymmetric cone structure of the photometric model for Nysa is in general agreement with the HST/FGS data. A single ellipsoid model would provide an acceptable fit to our FGS data, but, on the other hand, it would not adequately reproduce observed light-curves. The goodness of fit to the HST/FGS data is also acceptable when considering two slightly overlapping ellipsoids with a diameter ratio of the order of 0.6. The HST/FGS observations seems to support a concave feature arising probably from a contact-binary structure [11]. A refined shape-model shall be obtained when combining the FGS data to the photometric lightcurve inversion.

4.3 (624) Hektor

Hektor is the faintest asteroid of this observing program, and maybe at the limit of acceptable SNR with the FGS#3 astrometer. The photometric model is in global agreement with the HST/FGS data, but experience – in the inversion of the photometric data – showed that the large planar stretches on the convex solution usually indicates non convexities in the profile. Observations with the FGSR1 – of higher SNR – should help to reveal or constrain possible concavities in the body's shape.

4. DISCUSSION AND FUTURE WORK

Due to time allocation limitation, our data cover 5 to 10% of an asteroid rotation period only, and at a single aspect angle. It is also limited to two axes in the spatial frequency domain coverage. Thus the whole object's surface is not tested in these comparisons. Of course, the shape of an S-curve and its sensitivity to macroscopic structure depends on the apparent size of the target. On the other hand the photometric data does not provide strong constraints for the determination of non-convex profiles.

This work enables to derive the size of the object with a precision of the order of 2 km (depending on the goodness of fit to the data). Moreover it shows that the HST/FGS observations can valuably constrain shape models, and hopefully reveal suspected profile concavities. In a future work those should be added in the lightcurve inversion procedure, in particular for Kleopatra and Hektor. Additional data at different aspects and scanning geometry, and with higher SNR from the FGSR#1 would be valuable.

Moreover the combination of such HST/FGS and photometric data (providing accurate size and volume determinations) to the asteroids mass determination (expected with the GAIA mission [12]) shall provide a huge step in our knowledge of the internal structure of a large sample of asteroids.

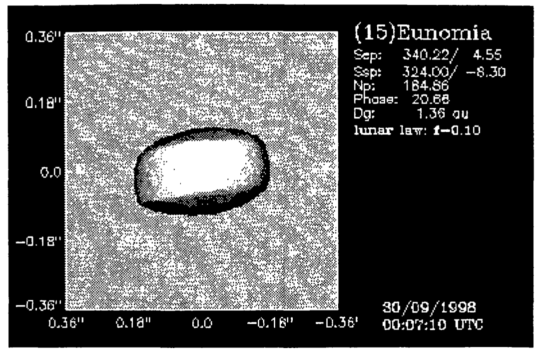

Fig. 2. Physical ephemeris of (15) Eunomia on last visit

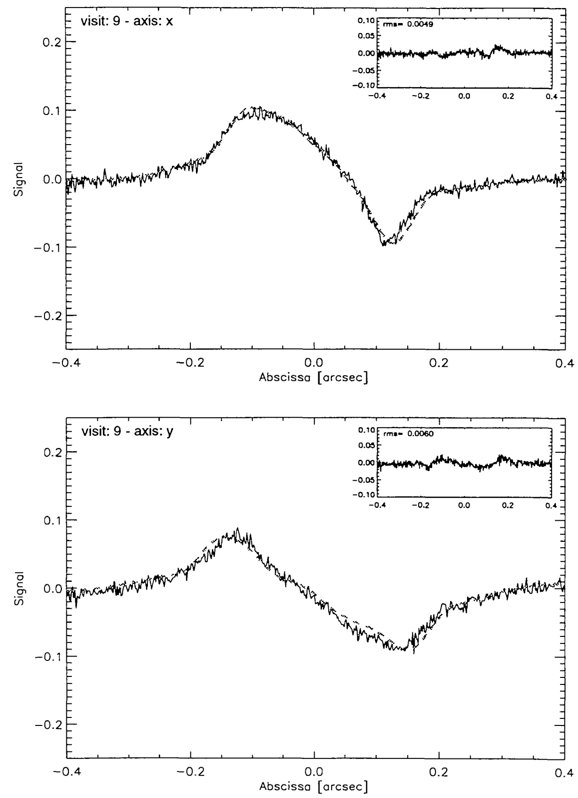

Fig. 3. Computed (from the photometric model) and observed S-curves for (15) Eunomia on last visit. Residuals are given in the inset

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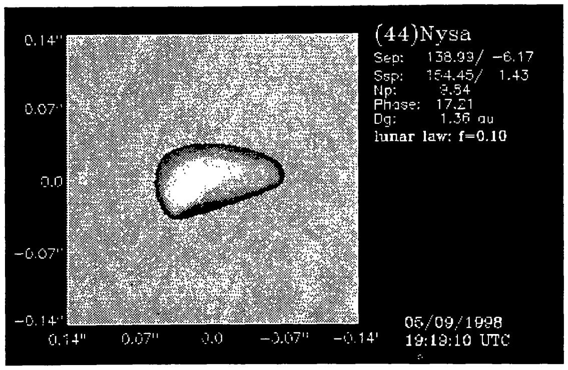

Fig. 4. Physical ephemeris of (44) Nysa on last visit

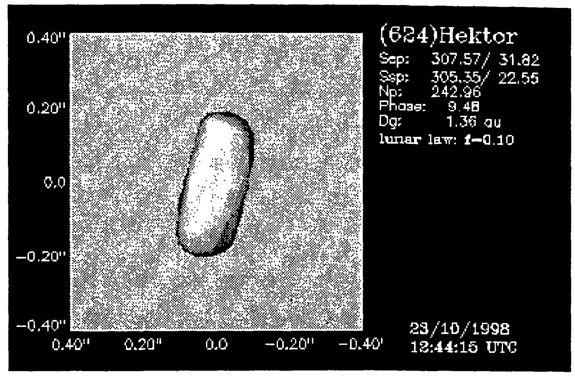

Fig. 6. Physical ephemeris of (624) Hektor on last visit

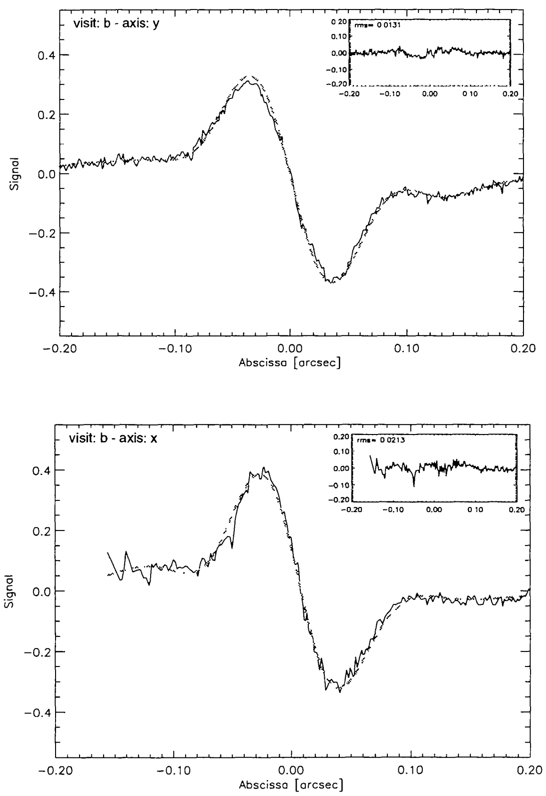

Fig. 5. Same as Fig.3 for (44) Nysa

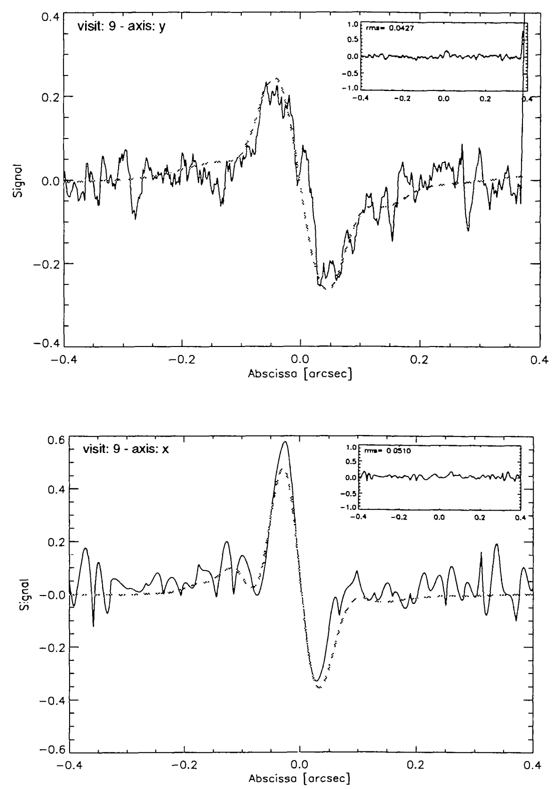

Fig. 7. Same as Fig.3 for (624) Hektor

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