

SHAPE AND SIZE MEASUREMENTS OF ASTEROIDS BY THE HST FINE GUIDANCE SENSORS

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ABSTRACT

For the first time an observing program based upon the use of the Fine Guidance Sensor (FGS) of the Hubble Space Telescope (HST) has successfully provided precise measurements of asteroid diameters and shapes. Six objects, suspected to be binary bodies, have been observed. We will give a short overview of the FGS interferometer and of the results obtained. Some bodies are generally close in shape to three axis ellipsoid; others, such as (216) Kleopatra, clearly show the hints of complex structures. The suspected duplicity of Hektor cannot be ruled out or confirmed due to the low S/N ratio.

Key words: asteroids, Hubble Space Telescope.

1. INTRODUCTION

The FGS is an interferometer built around a Koester prism, in which interference is produced between the two beams coming from the defocalised semi-pupils of the telescope. The flux associated to the two beams is then collected at the exit of the prism, and then measured by two phototubes. The difference between the two fluxes is a function of the wavefront inclination at the prism surface of entrance. The FGS is capable to scan the focal plane on short distances (typically 2 arcsec) along two perpendicular directions (FGS-X, FGS-Y), associated to two Koester devices. During the scan, the wavefront associated to source placed inside the scan area changes its inclination. As a consequence, the difference between the fluxes at the exit of the prism changes. The exact value of this difference is related the position on the focal plane, along the scan direction. The resulting function, normalised to the total flux, is called "S-curve" due to its overall shape. The high value of its derivative around the central zero determines its sensitivity to small displacements of the source, thus yielding the required characteristic for guiding purposes.

HST has three such instruments on its focal plane. One of them (the FGS "astrometer") is available for astrometric observations. A detailed description can be found in the FGS Instrument Handbook on the STScI site

(<http://www.stsci.edu>).

In our case, we are mainly interested to the changes of shape in the S-curve that are produced when an extended source of complex shape is observed. In fact, the response function depends upon the light distribution of the observed body, thus allowing to resolve narrow binary stars or to measure their diameter (see e.g. Lattanzi et al. 1997).

The FGS nominal performance on binary stars separation gives a maximal resolving power around 7-10 mas (milliarcsec) down to $V=14.5$. The one-orbit photometry error is of ~ 0.001 magnitudes, while apparent diameters can be determined with a sensitivity around 2 mas.

2. FGS AND ASTEROIDS

The observing program #7488 was devoted to the observation by HST/FGS of 6 asteroids, all suspected (mainly from lightcurves) to have strongly elongated shapes or to be binary objects. The capabilities of HST/FGS in the case of extended objects or close binaries can be simulated by computing the convolution of the signal corresponding to a point-like source, such as a star, to the light distribution of the target.

As we will show on real observations, the S-curve amplitude is smaller for large diameter objects, and contains features that are related to the brightness distribution of the target. As a consequence, in principle, several FGS scans obtained along different directions could allow the signal inversion and the reconstruction of a high resolution synthetic image. However, this is not possible for several reasons: the observing time required, the limitations on the change of orientation of the FGS (i.e. of the whole HST system), etc. It is therefore necessary to rely upon some *a priori model* of the target, in order to retrieve the essential informations from a limited number of scans. We decided to maximize the number of targets, and the six asteroids were observed each during a different orbit. An *orbit* is, in fact, the time allocation unit of HST, corresponding in our case to about 45-50 minutes of observation.

Several problems are related to the particular case of FGS observations of asteroids, namely:

(63) Ausonia, 2 Apr. 1998 15h50 UTC

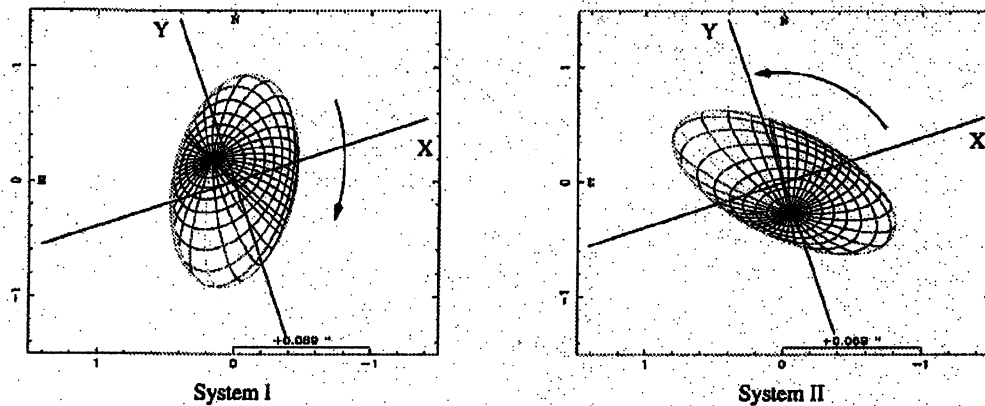


Figure 1. The orientation of the ellipsoid representing (63) Ausonia at the beginning of the observation (at left). The other available pole is ruled out by the FGS observations, being not compatible.

1. The apparent motion of the target, due to two components: the orbital motion of the Earth and of the asteroid, and the HST motion along its orbit. FGS is NOT capable of tracking a moving object, as a consequence the object can be lost if re-centering is not performed when required. Furthermore, the S-curve is built over several seconds, thus resulting in a distorted signal.
2. The rotational phase of the target. In order to detect duplicity or strong flattening, the object should be observed, in principle, when appears with a maximum extension on the sky.
3. The limited S/N ratio, especially for faint objects.

For these reasons, the targets have been observed close to a stationary point. A correction, derived from the telemetry files of the HST, is then applied to the data, in order to remove the residual effect of the apparent motion on the S-curve. Furthermore, the objects selected had a known rotational pole, and a set of 4-6 consecutive observations was acquired in a short time (2-3 minutes) in order to dispose of equivalent scans to be averaged, thus improving the S/N ratio. After the averaging, we thus had at our disposal a serie of ~ 10 scans, homogeneously distributed in time, on both axis, for each object.

3. RESULTS: SOME RELEVANT EXAMPLE

The data reduction process is divided in two steps. The first step concerns the derivation of the approximate size of the object, at all the observing epochs, as projected along the FGS axis. In fact, due to rotation, the variation in size during the observation is well detectable, despite the observation last a small fraction of the rotation period. In the second step, an unique 3D shape, consistent with all the observations is searched for. If necessary, this new model is used to improve the results obtained in the first step. The whole procedure is repeated until the fit

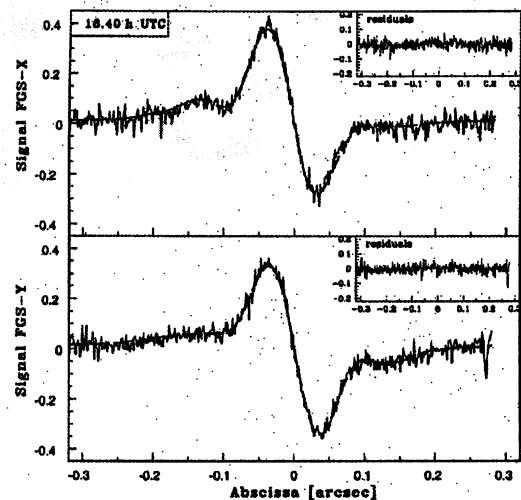


Figure 2. The Ausonia S-curves at the beginning of the observation, fitted by using the three axis ellipsoid given in Table 1. No significant departure from the ellipsoidal shape is detectable.

converges to a satisfying solution. In the following, we present some examples of the results obtained by this procedure. The whole set of mesures and detailed conclusions are discussed in Tanga et al. (2002).

3.1. (63) Ausonia

Figure 2 shows the S-curves of (63) Ausonia for a selected epoch. The residuals of the fit with a three axis ellipsoid are shown in the inset and are very small in this case, showing that a 3D ellipsoid is completely consistent with the available FGS data. The resulting sizes are given in Table 1. It must be noted that the value of the c axis is affected by a high uncertainty (around 5 mas or more) while a and b are constrained to a 1 mas level. The reason for the difficulty in estimating c is due to the geometry of

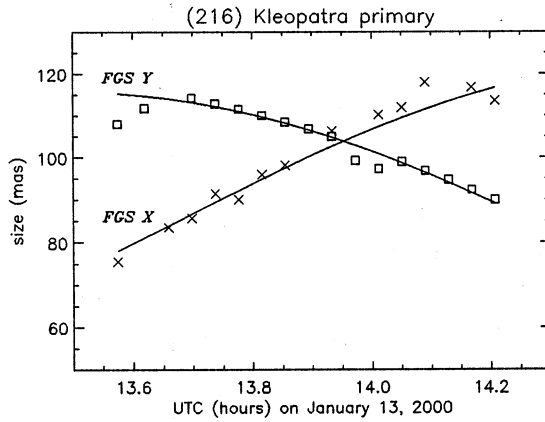


Figure 3. The variation of the sizes projected on FGS-X and FGS-Y for the main component of the double-lobed asteroid (216) Kleopatra, during the observation. The shape of the object and its orientation relatively to the FGS axis are represented by the two ellipsoids below the curves.

the target (Figure 1), and to the fact that the orientation of c does not change during the observation.

3.2. (216) Kleopatra

This was most irregular body observed, composed by two lobes as detected by radar (Ostro et al., 2000). The HST/FGS signal suggest an elongated shape, well approximated by two - not detached - ellipsoids, whose signature is well visible in the S-curve. The overall shape appears to be more elongated and flattened in comparison to radar data. Details are given in Tanga et al., 2001.

3.3. (624) Hektor

This trojan is the faintest asteroid observed by HST/FGS during the program ($V=15.0$ at the epoch of the observation). The response functions is best fitted by a very elongated shape, but due to the low S/N ratio it is not possible to clarify if (624) Hektor can really be considered a contact binary as supposed in the past (Weidenschilling 1980). Figure 4 shows the best-fit shape obtained by HST observations.

The S/N noise was at the limit of the performance of FGS.

3.4. (15) Eunomia

(15) Eunomia is the object having the largest apparent size, as shown by the low amplitude of the S-curve. The shape of the signal is consistent with a shape more complex than a simple ellipsoid, as shown in Figure 4.

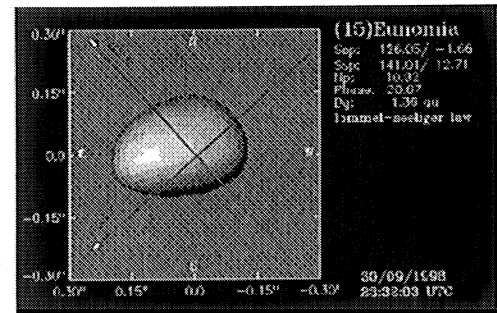
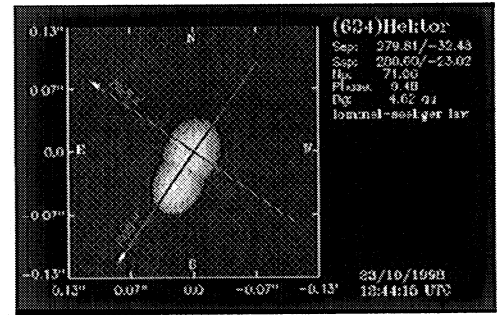


Figure 4. Upper panel: the indicative shape of Hektor obtained by a best-fit of the FGS observations. The noisy data set does not allow to draw definitive conclusions. Lower panel: the suggested shape of (15) Eunomia is consistent with the strongly asymmetric S-curve obtained for this object. Other possible solutions require the use of other constraints, such as those coming from photometry. See Hestroffer et al. (this volume) for a further discussion.

4. CONCLUSIONS

Table 1 shows the relevant parameters measured. We remark that:

1. The FGS is demonstrated here to be capable of obtaining precise measurements of asteroid sizes (uncertainty ~ 2 mas). The procedure is greatly favoured by a knowledge of the rotation pole. The possibility of deriving a 3D shape is due to the rotation of the object during the observation (40-50 minutes).
2. For a single-orbit observation, the axes being not favorably oriented are affected by much larger errors ($\sim 5-10$ mas).
3. Our measures are consistent with IRAS diameters, however the average radius of each object (computed as the radius of the sphere equivalent in volume) can differ by about 15% from the IRAS data (Tanga et al. 2002). HST/FGS size measurements could then be used to refine the calibration of thermal models.
4. The model reconstruction is based on some simple assumptions, in particular that the albedo is essentially uniform and that simple shapes account for the

Table 1. A summary of FGS size measurements, under the hypothesis of ellipsoidal bodies. (216) Kleopatra, having a complex shape, is not shown here. The last column gives the ratio of the axis; the parentheses indicate that either b or c are not well constrained.

Name	a, b, c (km)	a/b, a/c
(15) Eunomia	181, 103, 102	(1.76), 1.78
(43) Ariadne	45, 26, 26	1.71, (1.71)
(44) Nysa	59, 35, 35	(1.72), 1.72
(63) Ausonia	75, 33, 33	2.28, (2.28)
(624) Hektor	62, 28, 28	2.21, 2.21

main features detected on the S-curve. Significant departures from the ellipsoidal model are however present.

5. The combination of FGS data with photometry, and/or observations at several aspect angles could allow to retrieve a complete 3D shape. For an example see the presentation by Hestroffer et al. (this volume).

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