HST/FGS INTERFEROMETRIC OBSERVATIONS OF ASTEROIDS

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ABSTRACT. Six asteroids - suspected to be (nearly) contact-binaries - were successfully observed with the HST/FGS interferometer. The observations generally provide size and shape parameters and rule out wrong pole solutions. Only (216) Kleopatra shows a double-lobed shape. All other are closer to a single tri-axial ellipsoid, in particular the shape of the S-type asteroid (63) Ausonia is close to the one of a Jacobi ellipsoid. The data for (15) Eunomia suggest departure from ellipsoidal shape and non-uniform albedo.

1. Introduction

The existence of satellites of asteroids is now well established thanks to adaptive optics observations. Among such systems, a class of particular interest is the one formed by binaries of similarly sized components like (90) Antiope. Such systems of nearly contact binaries were already suspected on the basis of theoretical work on collisional process in the main belt (e.g. Farinella et al., 1982) or on analysis of light-curves (Tedesco, 1979). Observations with the HST Fine Guidance Sensor astrometer (FGS#3) have been proposed to detect such binary asteroids. The targets selected for this observing program (7488, P.I. V. Zappalà) are relatively bright, show large magnitude amplitude and small rotation period, and have light-curves that are compatible with a binary structure (Cellino et al., 1985).

In Sect. 2 we present the observing strategy. In Sect. 3 we present the data reduction and analysis, followed by the preliminary application to the observations of the asteroids (216) Kleopatra, (63) Ausonia and (15) Eunomia in Sect. 4.

2. The observations

The FGS astrometer is well adapted to resolve binary and extended stars (Lattanzi, 1997). After the pioneering of program 4669, this program is the first successful attempt to resolve solar system objects with this instrument. Observations are carried out in TRANS mode through the clear PUPIL filter and cover approximately 10 visits. Since no tracking is possible the target should preferably have a low angular velocity with respect to the stars; thus observations are carried out near the quadratures. However, due to their finite distance and the displacement of the HST platform during the observation run, the asteroids have a non negligible parallax. This must be taken into account in the data reduction. In order to increase the efficiency of a binary system detection, the observations cover approximately ½ hour near the asteroid's predicted light-curve maximum. The FGS provides the interferogram (also called S-curve) on two perpendicular axis (Nelan & Makidon, 1999). The covering of the spatial-frequency domain is thus limited to these two directions. The highest and lowest frequencies are related to the sampling step-size (1-1.5 mas) and the scan-length (2 arcsec) respectively. In order to increase the SNR, the data from successive scans (typically 4) are merged following the procedure applied by Lattanzi et al. (1997), yielding two mean S-curves (one for each FGS axis) per visit.

A synthetic S-curve is constructed from the convolution of a transfer function (available for a star) with the target's image. The targets are modelled in this work by tri-axial ellipsoids. The change in the S-curve for single and binary asteroids is shown in Fig. 1, in agreement with previous results obtained for stellar disks. Interesting to note is the apparition of a secondary extremum at the S-curve's zero point in the case of a binary system.

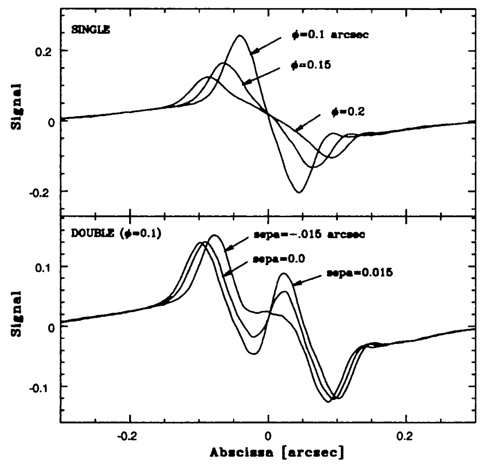

Figure 1. Interferogram on one FGS-axis for resolved single and binary asteroids. Graphs are given for different apparent diameters ϕ and separations in arcseconds.

3. Data analysis

Each S-curve provides information on the size of the target's apparent shape projected on the FGS-axis. Moreover the combined analysis of the data acquired during the asteroid rotation allows to constrain its 3-dimensional shape. We process a non-linear least-squares fit to the data according to a model that takes into account the pole orientation and the ellipsoid's shape. Initial values for the spin-axis direction and the semiaxis ratio come from published pole solutions. Such a fit enables to resolve the usual ambiguity in the pole direction, and provides the ellipsoid's sizes ($a \geq b \geq c$), the rotational phase angle, and possibly the components separation in case of a binary system. Since limb-darkening on the surface cannot be retrieved from the HST data alone, only uniform brightness is considered although other light-scattering laws are implemented in the model.

4. Preliminary results

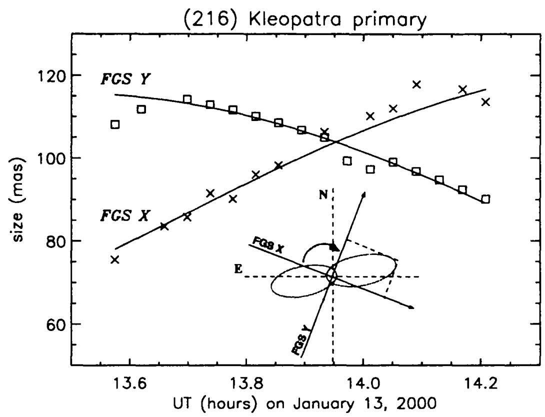

Figure 2. Along-scan sizes and shape-model for (216) Kleopatra.

The M-type asteroid (216) Kleopatra has a non-convex, bi-lobated shape (see Fig. 2). None of the grid-model with nearly-in-contact or separated components does provide a completely satisfactory fit to the data. The best-fit model consists of two overlapping tri-axial ellipsoids. Such a simple model only gives some indication on the overall shape of the asteroid since the residuals clearly show non-modelled effects. It is however coherent with adaptive optics or radar observations (Ostro et al., 2000). Since the sub-Earth point latitude was relatively large during the observation run, the shortest principal axis is only marginally determined (Table 1). On the other hand the longest axis are given with a formal precision of the order of 1 mas.

Table 1. Ellipsoids model for (216) Kleopatra, (15) Eunomia and (63) Ausonia. Values in parenthesis are not well constrained by the observations.

	Primary			Secondary			Separation
	a	b	c	a'	b'	c'	d
Kleopatra	75.9	37.4	(17.6)	71.5	35.2	(25.3)	125.4
Eunomia	181	(103)	102				
Ausonia	75.5	33	(33)				

The shape of the S-type asteroid (63) Ausonia is close to a prolate spheroid. The size of the shortest axis *c* is not well constrained by the available data. Assuming this asteroid to be a rubble-pile made of uncompressible homogeneous fluid in hydrostatic equilibrium, its shape must follow that of a Jacobi ellipsoid (Farinella et al., 1981). This in turn provides a bulk density of 0.6 g/cm^3, or a 80% porosity. Since this seems unrealistic, some hypothesis must be relaxed (e.g. compressible fluid, internal cohesion, non homogeneity, friction,...).

The S-type asteroid (15) Eunomia is not a binary. The size of the axis b is not well constrained by the available data. Moreover the fit with an ellipsoidal figure of uniform brightness is not completely satisfactory. Introducing a dark spot in the model-grid improves the goodness of fit (see Fig. 3), but the spot is unrealistically large and the model strongly disagrees with observed light-curves for this object. The data thus also reflects significant departure from the ellipsoidal shape.

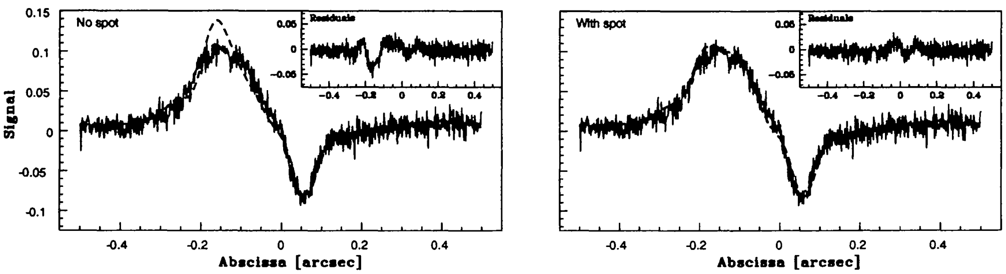

Figure 3. Best-fit solution for (15) Eunomia with and without a spot.

5. Conclusion

The HST/FGS astrometer is a powerful instrument for resolving asteroids. Although the spatial-frequency coverage is limited, it provides a resolution of the order of the mas. Ellipsoidal shapes generally fit the data of this program inside the noise level. The data for Ausonia are well modelled by a prolate spheroid; the data for Eunomia show a departure from an ideal prolate spheroid that can not be completely explained by the presence of a dark spot; the data for Kleopatra shows that this asteroid has a non-convex bi-lobated shape. The best-fit tri-axial ellipsoid models are given with a precision of the order of 1 km.

Considering the limited observing time and since the observations were optimised for detection of binary systems, they only cover a fraction of the rotation period close to a light-curve maximum. Thus the tri-axial ellipsoid shape-model is constrained on a small part of the body and it cannot reflect known asymmetries in observed light-curves. Observations over a larger time span and at different epochs are needed to fully constrain the ellipsoid shape as well as albedo markings or departure from the ideal tri-axial ellipsoid. The HST/FGS astrometer also provides an excellent laboratory to test 3-dimensional shapes of asteroids determined by other means (e.g. radar or light-curve inversion). These asteroids should however preferably be brighter than V<14 to get sufficient sensitivity.

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