Astrometry and Light Curves of Asteroids with the SUBARU Telecope

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Abstract

We present the reductions of observations of a single ecliptic field, carried out over one night in September 2, 2002, at the focus of the SUBARU 8.2 m telescope. The frames necessary for the reduction were retrieved through the database SMOKA (Subaru Mitaka Okayama Kiso Archive System) High frequency multi shots imaging of the fields enable to detect sub-kilometric asteroids and to perform astrometric and photometric reduction, leading in some cases to the extraction of light curves.

1 Introduction

After developing wide field imaging reduction techniques at the laboratory SYRTE (Paris Observatory), we decided to proceed to a data mining of wide fields images taken at the focus of large telescopes, to test our software on very deep fields. Our choice was made on the SMOKA database (Subaru Mitaka Okayama Kiso Archive system). In particular we were attracted by a series of images performed over two consecutive nights, on September 2 and 3, 2002, that is to say roughly 10 years ago. These images were taken with the Suprime-Cam, which is a 80-mega pixel (10240 $\times$ 8192) mosaic camera, covering a wide field of 34' $\times$ 27', and is composed of ten 2k $\times$ 4k CCD chips, with a resolution of 0".202 per pixel. The images were taken by F.Yoshida and T. Nakamura in the frame of an observational program called SMBAS (Sub km Main Belt Asteroid Survey).

Two different fields, close to the ecliptic plane, were observed during the two consecutive night sessions mentioned above, called respectively FIELDA and FIELDB. This observational two nights session was called SMBAS-III, as a third campaign following SMBAS-I (February 22 and 25, 2001) and SMBASII (October 21, 2001) The second field was chosen at the east side of the first one, to avoid common objects. Both FIELDA and FIELDB were surveyed with the R band and the B band. The exposure time was set at 120 seconds. This choice comes from the fact that outer edge MBA's (Main Belt Asteroids) move with an apparent angular rate of roughly 0.5"/mn, whereas the seeing at Mauna Kea has an average value of 0.9". Therefore a longer exposure time would result in non pointlike objects, not appropriate for detection and measurements.

Data reduction was performed using the SDFRED1 software provided by SMOKA (Yagi et al.,2002; Ouchi et al.,2004) and also using the standard IRAF procedures as it was done previously by two co-authors of this paper (Yoshida et al., 2003; Yoshida et al., 2007). First, chip by chip master flat and bias images are generated, then averaged.

Filter	Start Obs. time	End Obs. time	Airmass at Start	Airmass at End
B	06:24:11.342	20:29:08.011	2.228	2.179
R	06:37:37.639	07:48:35.000	2.024	1.438
B	07:56:13.436	08:01:10.017	1.391	1.378
R	08:07:42.159	09:53:03.000	1.343	1.134
B	09:58:54.506	10:03:51.014	1.130	1.129
R	10:09:32.756	13:59:56.005	1.127	2.069
B	14:07:22.773	14:17:21.015	2.216	2.361
R	14:25:18.557	14:53:57.017	2.576	3.449

Table 1: Start and end observational time, and corresponding airmass for FIELDA centered at (22:41:38.179,-07:37:35.32), and for each series of B- and R-band images:

2 Two methods of detection

Two methods were used for the detection of objects : the eye-detection method and an automatic one based on numerical algorithms, developed by one of the authors (JA).

2.1 The eye detection technique

The eye detection technique consists of creating a combined image for detecting objects in the R-band. 5 images were used, Denoting the image x in the R-band by R_x, the combined R image was obtained by the following R_1-R_2+R_3-R_4+R_5, Thus for each moving object we end up with three bright and two dark dots that mark the position of the object.

In the B-band, we use a combination of R and B bands successive images to detect the objects, as the observations in the B-band were not continuous in time. Thus we used two R-images, one R_{-B} taken just before the B image and one R_{+B} taken after. We thus obtain a combined image $c_1 R_{-B}$ -B+$c_2.R_{+B}$; c_1 and c_2 being two coefficient required to adjust the sky level of each image. The position of the objects (2 bright spots and one dark, in pixel count are then reported.

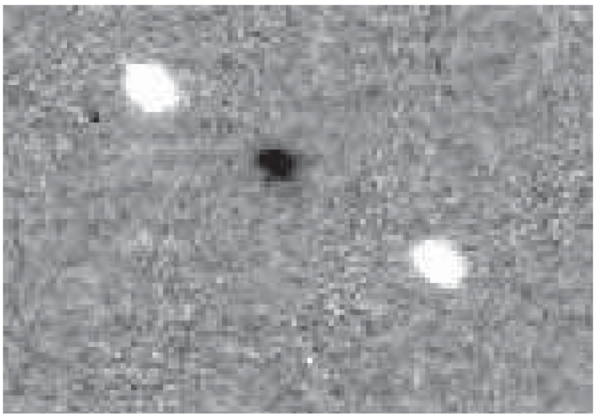

Figure 1: Detection of a moving object through the R-B-R combined method

2.2 The automatic detection method

The second method is automatic. The routine begins by subtracting the bias and taking into acount the flatfield for each exposure. It then goes through each exposure, pixel by pixel, and identifies the reasonably bright, unsaturated stars. A position and flux are measured for each star in each exposure. The positions are used to make the link of the coordinate system from each exposure to that of the first exposure. We also construct a PSF (point-spread function) model for each exposure based on the 2-D profiles of the observed stars.

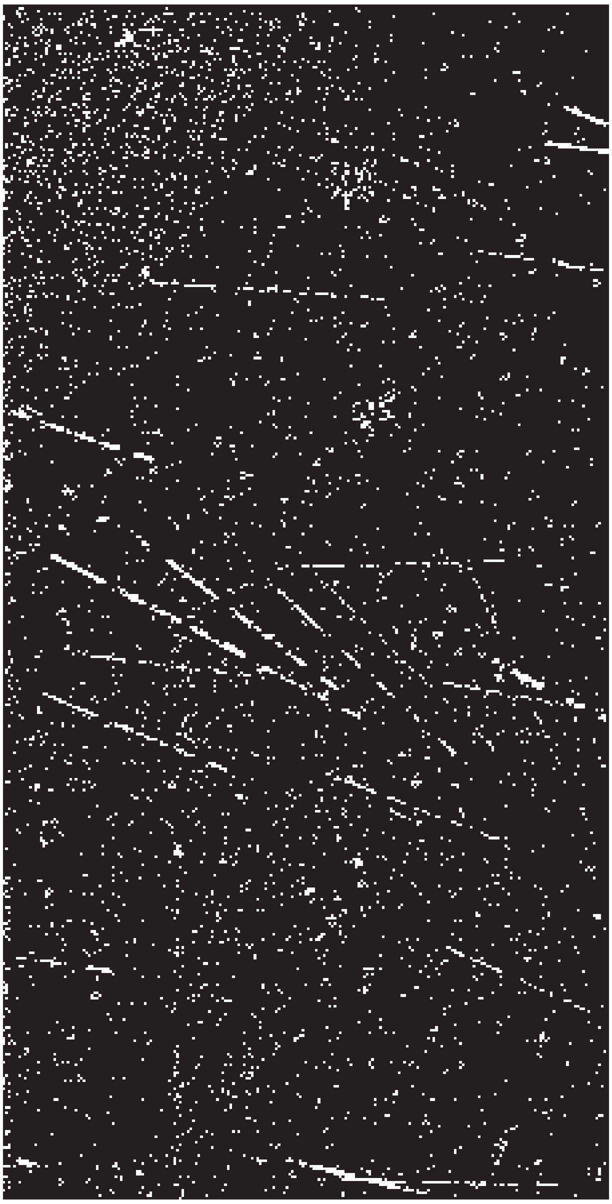

Figure 2: Image stacked within a 70 min total integration time, obtained with the automated method.

To detect the asteroids, we take into account each exposure and subtract the known stars using the PSF model. . We also subtract a smooth model of the background. Then we convolve the exposure with the expected size of an asteroid (3x5 pixels), in order to highlight detections that have the anticipated shape. We make a list of detections that are a minimum distance from known stars and are more significant than a given threshold The observed trails described by the moving object are measured and the positions of the moving object in pixels are reported.

As a second step, we measure the trails. This task is far from being easy, just because the fact that we see the trails does not mean that the computer can identify them. This task is realized through a statistical analysis of the residual stack image (stack image realized at the previous stage). We are now able to measure the trails, and measure the velocities in pixels/s in both x and y directions.

3 Astrometric calibration

Once the objects have been identified and their positions have been measured in pixel count, we proceed to the astrometric calibration. For that purpose we use the GAIA-GBOT (**G**round **B**ased **O**ptical **T**racking)

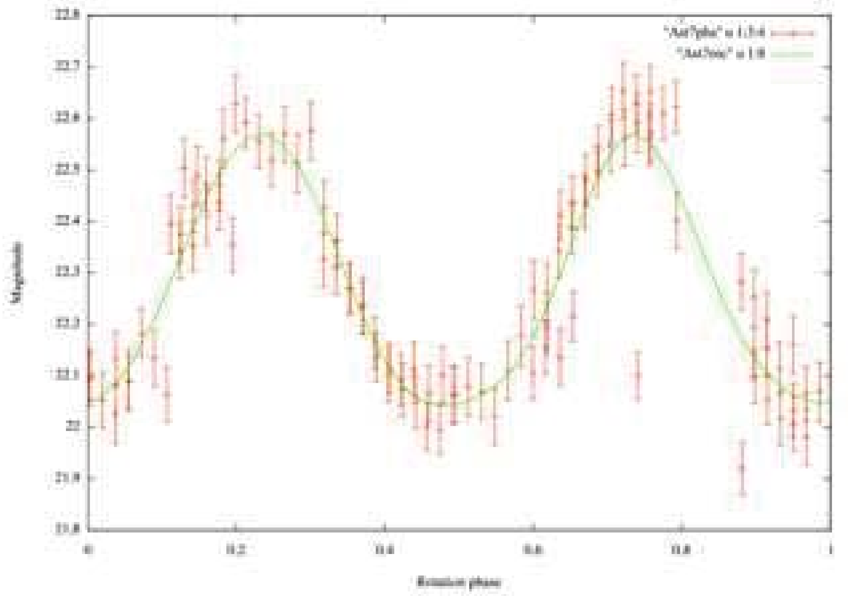

Figure 3: Asteroid light-curve obtained during the SMBAS-III session

PIPELINE (Bouquillon et al.,2012). It is devoted to the optical tracking of the GAIA mission in order to fully attain its goal in terms of astrometric precision. The expected astrometric accuracy is of 20 mas with respect to the stars in the background field, which corresponds to 150 m for the position on the orbit of GAIA.

The pipeline uses the PPMXL star catalog (Roeser et al.,2010) as reference. The astrometric calibration consits at first to go through all the exposure images, one by one, and to detect the sources brighter than a defined threshold. Then, once the sources have been identified, we extract the positions of the centroids in pixels, as well as the corresponding fluxes. When this step has been completed, we download, from the PPMXL astrometric catalog, the stars corresponding to the field of view of the observation (this information is retrieved through the header of the fits files). Then we connect the sources found in the field to those given by the catalogue. Therefore it is possible to redetermines the scale and the parameters of transformation matrices for astrometric reduction. Once applied to our data, the scale was found to be 201.996 $mas/pixel$ which is really close to the theoretical value of 202 mas (Miyazaki et al.,2002).

4 Photometric-analysis using the GBOT-pipeline

One of our interests in analyzing the SMBAS-III data, is to study the size and taxonomic distributions of the identified populations (MBO's, NEA's and TNO's) as well as to investigate the spin period distributions of each of S-type and C-type groups by retrieving their light curves. For this purpose we use the GAIA-GBOT pipeline (Bouquillon et al.,2012), that was not initially destined for it. We proceed as follows : First we input the ephemeris of the asteroid (identified previously), by giving its initial position at the first epoch of detection in the field as well as its proper motion vector. This information is then updated into the .fits files headers.Second, as was done for the astrometric calibration (see the previous section), the stars in the field are identified and their positions and fluxes measured. The photometric calibration is done by cross-identifying stars with the GSC2.3 photometric star catalog (Lasker et al.,2008) Then we go through all the exposures, one by one, and follow the target (the asteroid) reporting its position and measuring its flux, from which the magnitude can be computed.

5 Results and conclusion

The reductions of SMBAS-III have not been achieved so far, but we have detected at all 184 asteroids in FIELDA corresponding to the first night of observation. In the sample several NEA's and TNO's have clearly been identified. We could get an estimation of the orbital parameters (and in partticular the

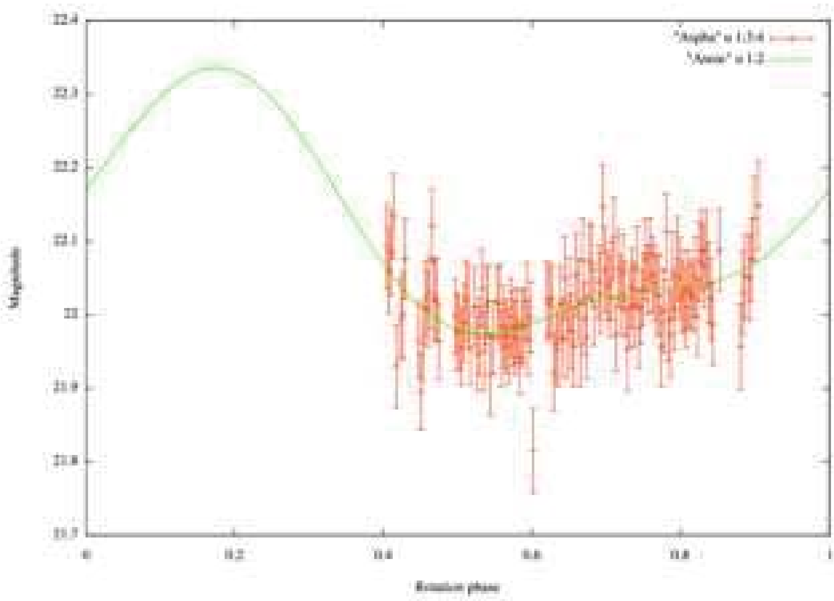

Figure 4: Asteroid light-curve obtained during the SMBAS-III session

heliocentric distance and the inclination with respect to the ecliptic) for each asteroid. We could deduce also significant light curves for very faint objects, as can be seen in Figs. X and Y. This work constitutes a part of D. Souami PhD thesis and the results will be gathered in papers with one related to the ACM meeting (Niigata, 2012) to come soon (Souami et al.,2012).

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