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Physical properties of asteroids using the WFCAM Transit Survey and the Virtual Observatory

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Abstract

We describe here a methodology to identify asteroids serendipitously observed in large-area astronomical surveys using Virtual Observatory tools such as SkyBoT, TOPCAT, and STILTS. The application of this method on the WFCAM Transit Survey is demonstrated.

We provide almost 15,000 accurate positions (mean RMS 0.15 arcsec) and J-band magnitudes (typical accuracy of 0.11 mag) for over 1600 asteroids. From the repeated observations we build light curves and use them to determine the asteroid fundamental physical parameters, such as their rotational period or their multiplicity.

1. Introduction

Most of the ∼750,000 solar system small bodies known today are asteroids. Their study is motivated by their intrinsic importance as remnants of the early stages of the solar system formation and by practical reasons concerning space exploration and their frequent impacts with the Earth.

Wide imaging surveys, in particular those located not far from the ecliptic, offer the opportunity to discover and characterize asteroids serendipitously observed (e.g. [6]). Among them, exoplanets surveys are excellent resources to get dense lightcurves of asteroids as both types of targets share similar observing requirements: large field of views (FOV), long sequences, and short cadence. Lightcurves can be then used to determine fundamental physical parameters of asteroids. Indeed, the asteroid's shape, rotational period and the scattering properties of the surface can be determined from the analysis of the changes on the asteroid's brightness due to changes in its geometry.

In this study we have made use of the WFCAM Transit Survey (WTS), with 200 nights over five years at the 3.8-m United Kingdom Infrared Telescope (UKIRT). The purpose of WTS was to perform the first ever systematic near-infrared search for transiting exo-planets around cool dwarfs. It ran as a backup programme when observing conditions were not good enough. As a consequence, the observations were not uniformly distributed over time. WTS targeted four fields, each 1.6 square degrees in size, in J-band and observed them once in the $ZYHK_s$ filters. The four detectors of WFCAM cover 13.65 arcmin × 13.65 arcmin each and have a plate scale of 0.4 arcsec.

2 Methodology

Our workflow makes use of SExtractor ([1]), Aladin Sky Atlas ([3] and [2]), the STILTS package ([7], as well as the IDL and Python programming languages.

2.1 Pre-processing and source extraction

We gathered 30 877 bias and flat corrected and astrometrically calibrated WTS images from the WFCAM Science Archive[1]. We helped us with Aladin to extract the subimage taken by each of the four detectors and manage them independently. After discarding images observed in other filters than J and defective images, we searched for asteroids in 121 462 subimages, all in the J band.

Sources were detected by running SExtractor on every subimage. Using the Gaia DR1 ([4] and [5]) catalogue as a reference we estimated an average astrometric error for the SExtractor sources of 0.15 arcsec ($\sigma_{SExtractor}$).

To distinguish between moving asteroids and any other source in the field, we built a catalog composed by all SExtractor sources detected at the same position

[1] http://wsa.roe.ac.uk/

in different images within an error of 0.4 arcsec. This catalog covers the four regions observed in the WTS and contains 1 049 284 unique sources, mainly celestial sources but also bad pixels and artifacts. From now on, we will refer to this catalogue as the *Non-moving Source Catalog*.

2.2 Asteroid identification

We identified the asteroids lying in our images at the epoch of observation making use of the Virtual Observatory-compliant service SkyBoT (Sky Body Tracker, Berthier et al. 2006). SkyBoT provides a fast and simple cone-search method to list all known asteroids within a given FOV at a given epoch.

For each subimage, we obtained the list of asteroid counterpart candidates by cross-matching the SExtractor catalog with the SkyBoT positions of the asteroids lying in the image within a 3σ radius, where σ is given by:

$$\sigma = sqrt({\sigma_{SExtractor}}^2 + {\sigma_{SkyBoT}}^2), \qquad (1)$$

According to Skybot, there were 41 804 asteroid positions lying inside the field of view of the images in the J-band. For 14 685 of them, we obtained one asteroid counterpart candidate per asteroid position after removing the false counterparts using the *Non-moving Source Catalog* and applying five additional quality control tests:

- Nearly constant separations between the SExtractor position and the one provided by SkyBot.
- For each night, less than 20% difference in right ascention and declination proper motions between those computed from SExtractor counterparts and those provided by SkyBoT. If true, we flagged them with *A* and with *B* otherwise.
- Linear regression test within the same night. If $|r| \geq 0.9$ we assumed linearity and flagged them with *A* flag and with *B* otherwise.
- $(V-J)$ colors between 0.6 mag and 2.3 mag are flagged with *A*, assuming $(V-J)$ = 1.2–1.7 for asteroids and a maximum light curve amplitude of 0.6 mag. *B* flag otherwise.

Almost 98% of the remaining 25589 positions of asteroids for which we do not have candidate counterparts correspond either to asteroids with magnitudes close or beyond the magnitude limit of the images or asteroids that are being obscured by a bright field star.

Table 1: Number of asteroids and detections.

Class	# asteroids (fraction)	# asteroid detections
Main Belt	1492 (93.0)	13608
Hungaria	53 (3.3)	370
Trojan	42 (2.6)	490
Mars-Crosser	26 (1.6)	196
Near-Earth Asteroid	7 (0.4)	21

2.3 Asteroid characterization

The 14 685 confirmed asteroid positions correspond to 1 620 asteroids, for which we provide α and δ coordinates, $\mu_\alpha \cos(\delta)$ and μ_δ proper motions, epoch, J band magnitude and test flags. The number of asteroid and asteroid detections in the survey is summarized in Table 1 for each class of object.

Light curve building requires the comparison of asteroid magnitudes obtained at different nights. The photometric calibration of each subimage was done using the 2MASS catalogue. The distribution of magnitudes of the **14 585** asteroid counterparts identified in this work peaks at around 18.3 mag, which reflects the limiting magnitude of the survey although asteroids up to 20.6 mag have been detected.

The analysis of the light curves and the determination of the associated physical parameters is currently on-going.

3. Summary and Conclusions

We have developed a robust methodology to identify asteroids in large area surveys using Virtual Observatory tools. We proved this method to be efficient making use of the WFCAM Transit Survey. We were able to identify over 1 600 asteroids in near 15 000 different epochs for which we provide positions, proper motions and J band magnitudes, as well as physical parameters for a subset of them. Asteroid positions have been reported to the Minor Planet Center[2] to improve their associated orbital parameters.

[2]http://minorplanetcenter.net

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