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Search for Trojans of Saturn, Uranus and Neptune with ASTROVIRTEL *

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Abstract. This report describes the current status of an on-going work, performed in the frame of an approved ASTROVIRTEL program, having the aim to detect bodies orbiting around the Lagrangian points of the outer planets, analogous to the Jupiter Trojans. Till now, a large number of images taken with the WFI of the 2.2m telescope of ESO at La Silla has been examined. Although still unsuccessful in respect to outer Trojans, the search (given the designation I03 by the Minor Planet Center, in the following MPC) has already produced many new asteroids, some with interesting orbits.

1. Introduction

In year 2001 we proposed to ASTROVIRTEL a program aimed to find minor bodies orbiting in the Lagrangian points of the outer planets, founding our expectation on the theoretical and observational scenario expounded in the present paragraph. Indeed, the possibility of the existence of bodies in L4 and L5 of the three outer planets has been debated in the literature by several authors, who put forward different considerations regarding the stability of their orbits. In the following, we will call generically 'Trojans' these bodies. The recent discovery of the first Neptune Trojan (2001 QR322) has triggered additional observational surveys aimed to search Trojans of the outer planets. The stages envisioned for the growth of Jupiter were presumably reproduced during the formation of Saturn and, as a consequence, the planet should have trapped local planetesimals as Trojans as well. On the other hand, a critical aspect of the Trojan-type orbits of Saturn is that they are easily unstable (De La Barre et al. (1996), Marzari, F. et al. (2002), Nesvorny, D., & Dones, L. (2002)).
More controversial is the theory of Uranus and Neptune Trojan capture, because the formation process of the two smaller ice giant planets is not well known. For these planets, a possible capture of local planetesimals as Trojans may have occurred

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in the final phase of growth of the two planets.

As shown by the above short summary, it is clear that the discovery of Trojans of the outer planets would have a strong impact on the understanding of process of planetary formation, in particular for Uranus and Neptune. Based on these considerations, we have been granted access to the Astrovirtel data base in order to examine images taken with a variety of telescopes, including the Hubble Space Telescope.

Up to now, we have analyzed, by using dedicated codes, almost all the ESO 2.2m telescope WFI images received from the Astrovirtel archive, extracting about 2000 positions of known and new objects, mostly many Main Belt asteroids. We detected in particular three Jupiter Trojans candidates and a TNO.

2. The WFI images

From the Astrovirtel archive, we extracted WFI images taking into account our special requirements about positions, dates, filters, and exposure times, that is almost 3 images of the same sky field, taken in the same night, possibly with the same filter, and with the same exposure time (more than 180 sec.).

In June 2002, we received 14 DLTs containing the images satisfying those criteria. There are in total about 3500 images, the oldest dating back to 1999, but only 30% of them are scientific images. As is well known, the WFI images consist of a mosaic of 8 chips; the scale is 0.238 arcsec/px, the total field of view (with gaps) is $34' \times 33'$ (8250×8196 pixels), so that a preliminary heavy work of image composition and flat fielding was absolutely mandatory. In the following paragraph we give some details of the overall procedure.

In Fig. 1, the sky coverage corresponding to all the material we have (both images from the archive and also the images taken in our accepted proposal of 2002) is shown.

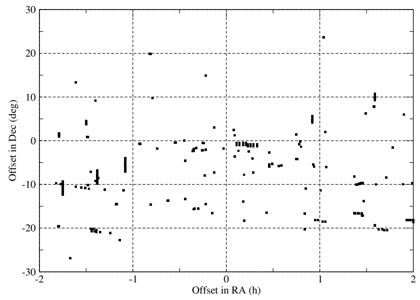

Fig. 1. Sky coverage. The figure exhibits the offset of the frames with respect to the position of L4 and L5 of each planet. The offset has been calculated considering the position of the Lagrangian points at the date of which each image has been taken.

3. Reduction of the Mosaic frames

After the necessary correction by flat field and bias using the *mscred* package, the images have been assembled in a unique frame; we need to do this, because the software packages used in the following steps can't handle mosaic images. This part of the work is done by using the *wfpdred* package (Rizzi L. (2003)). After this step, we filter the images, if needed, with a median filter, in order to remove bad pixels and cosmic rays, as much as possible. A special procedure had to be implemented for the many I-band images, which shows conspicuous fringing.

The search for moving bodies is performed by using *fitsblink*, a software written by a group of researchers from Ljubljana (Škvarč, J., (2002)). It detects possible candidates as asteroids, because of their movements with respect to stars field. It also gives the possibility to recognize known asteroids by using a database containing all of them (this database is continuously updated via the MPC). The already known asteroids are marked on the display in a different way for easy visual recognition.

We choose three images corresponding to the same sky field and with (almost) the same exposure time. The images do not need to be taken in the same night, because fitsblink can handle images taken in different days, for example about 24 hours apart. Such a choice is useful for the detection of very slow moving objects, such as the sought-for Uranus' and Neptune's Trojans. In its first passage, for each of the 3 images *fitsblink* creates a catalog of bright sources. These catalogs are compared with the appropriate section of the USNO catalog, in order to recognize real stars, to make a good astrometry and to estimate the calibrated magnitude of all extracted objects. The stars are then cut off from these 3 lists of sources; the remaining objects are stored in new files (one per image), and they represent all possible asteroid candidates. From these 3 lists the software extracts objects that are moving along a linear path, namely that describe an arc of orbit of a possible real object. As the last step, we check by eye if the candidate objects are real or if they are false detections. During this phase we are automatically advised if the detected objects are new or already in the MPC data base, because the software marks them with a different symbol. Once we decide they are real, we record their positions and estimated magnitudes on a file written according to the MPC format. These files are then sent to the MPC for the calculation of the orbit.

Three positions are in principle sufficient to derive a preliminary orbit, but more are needed to calculate a well defined one. So we look for other images taken in the same field, during the same days or a few days later, in the available database.

At this point, we calculate projected velocities (in RA and DEC) of all moving targets in order to have some immediate information about their nature. We also generate a plot for the expected distribution of velocities in that field at that date, using the AMIGO code. This is a fortran code (Marchi 2002), which produces a distribution of asteroid's velocities as projected on the sky (namely velocity in RA and Dec) for any given direction of the line of sight at any date. In this way, we are able to distinguish, at least in favorable cases, between interesting objects and non interesting ones (normal Main Belt). Indeed, for some dates and fields, different groups of asteroids are well separated in the RA-Dec velocity plane. For these cases, if we superimpose the detected objects to the RA-Dec velocity plane, we immediately see which group they could belong to, but of course we cannot be sure if they are real members of a particular group. In effect, some groups of asteroids, such as NEOs, can be more or less everywhere in this plot. In other words, with the help of such plots we can be sure that if an object lies outside of the regions corresponding to Trojans, it will not be a Trojan; but if an object belongs to the region of Trojans we cannot conclude that it is surely a Trojan. A proper orbit will always be needed. This method works well essentially at opposition and in quadratures, at intermediate angles all classes more or less overlap. Notice that for a given direction of view, not all the Lagrangian regions are simultaneously visible and hence they are not included in the plots.

4. First Results

As already said, from the Astrovirtel archive we selected 1066 scientific WFI images. Up to now, about 830 of these images have been corrected by flat field and bias, processed with the *wfpdred* package, and stored on DVDs. More than 300 of them have been analyzed till the end of the process (including the visual check).

As a result we have already submitted to the MPC about 60 reports, containing approximately 2000 positions of 700 distinct asteroids, mainly belonging to the Main Belt. The faintest objects are around R = 24.0; there are also several fairly bright but not numbered objects (e.g. one has R = 15.9). The MPC has already awarded I03 about sixty preliminary designations.

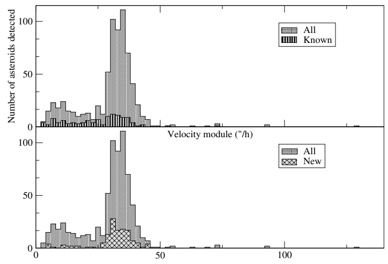

Fig. 2. The number of the detected objects vs. their velocity

In Fig.2, the number of the detected objects vs. their velocities is shown, distinguishing the already known objects and the new designations. At this stage, a statistical analysis of the material is fairly difficult, because we are using images taken with a variety of filters, exposure times and positions.

A few weeks ago, we received and analyzed the new set of proprietary images taken with WFI in February 2003 as result of an accepted proposal submitted to ESO for the cycle P70. The scientific images of this new set are about 70, and they are all around L4 of Saturn. No Saturn Trojan candidates have been found on these images.

5. Future work

The correction of the 830 images till the *wfpdred* procedure took about 5 months (one person full time). In December 2002 we installed the *fitsblink* software, which became almost immediately ready for regular production work.
So we estimate that at the present pace and with the present human resources (one person full time), 9 more months of work will be needed to UPd to complete their share of work on the WFI images.

In the early future, we have to complete the analisis of the material received from the Astrovirtel Archive, which is still stored in DLTs.

Finally we have to test the dependence of the velocity distributions on the solar elongation and the Earth's position, the preliminary results of maximum efficiency at opposition and quadratures of Amigo being subjected to closer scrutiny. A new proposal has also been submitted for P72.

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