# MINOR PLANET OBSERVING TOOLS AND STRATEGIES AT CRNI VRH OBSERVATORY

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**Abstract**

A small amateur observatory is often faced with several restrictions in terms of observing opportunities due to lack of equipment and time of the observing crew. Especially, small field of view and small telescopes limit probability both for new discoveries and reliable follow-up of asteroids. It is therefore necessary to direct efforts
of limited amateur astronomers' time to the most efficient activities which will enhance the success of observations.

Experiences of the Crni Vrh Observatory (106) are presented. To utilize the existing equipment, we have developed robotic telescope and several software packages which are used for telescope and CCD camera control, automatic observation scheduling, astrometric and photometric reduction, automatic detection of moving objects, object identification, and data archiving. The level of automatization achieved is such that we can have two telescopes running with schedule for the whole night in thirty minutes after the arrival to the observatory. Telescopes run unattended until the nautical dawn when they are automatically parked. After the last image is taken we need no more than one hour to check observations of unidentified objects and send them to MPC, while the automatically identified objects with well-known orbits do not even need to be inspected visually.

Observing strategy has been chosen so that it maximizes production of useful observations, yet it does not diminish the probability for new discoveries. In spite of a rather small field of view we received 67 principal designations in the period from January 1999 to February 2000, and contributed more than 8000 observations to the MPC. Statistics of observations shows not only good efficiency but also good astrometric accuracy when compared to other observatories.

A very important factor in the successful development of our observing program is that we develop the majority of our software and hardware by ourselves. This helps us better understand any problems that may arise during the operations and lets us remove them quickly. Limited funds proved to be a lesser problem if a lot of personal work and invention are invested into such project.

## 1. Introduction

Asteroid and comet observing program called PIKA started in early 1998. It is based on experiences in comet observations, telescope construction and data analysis. During last two and half years we invested significant efforts in development of equipment, software and observing strategies. In this paper we present basic information about the observatory in section 2. Section 3 contains details about the equipment used at the observatory while section 4 is dedicated to a brief description of the software related with the observating program.. Developing an efficient observing strategy is critical for efficient use of observing time. This is described in section 5. Quantitative results of the project are presented in section 6. Finally, som e thoughts about the future work conclude this paper in section 7.

## 2. Basic information

Crni Vrh Observatory is located in Slovenia at longitude E14.5 and latitude N46. It is some 45 minute drive from the Slovenian capital of Ljubljana. The observatory gets on average between 100 and 120 cloudless nights yearly. Naked eye limiting magnitude is between 6.0 and 6.5. Light polution is relatively modest, mostly from two nearby small cities and, under certain conditions, from two major cities, Ljubljana and Trst (Trieste, Italy). Currently, the observatory is equipped with two automated telescopes (19 cm, f/4 and 36 cm, f 6.7) with CCD cameras and is in operation on almost each suitable night. Major activities are astrometric observations and photometry of bright stars while in past most of the time was dedicated to comet observations and imaging.

Observatory crew consists of four people, three of them are regular observers. All team members contribute to constant new developments at the observatory, either of software and hardware or by maintenance.

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Observatory is privately owned by one of the authors (H. M.), but is closely connected to the Faculty of Mathematics and Physics (FMF) which owns part of equipment and performs some of educational and scientific programs at this observatory.

A decision for establishment of asteroid and comet search and follow-up program was made in late 1997 after team members met and introuced to each their existing knowledge and experiences. A substantial background in comet observing, construction of telescope mounts and data analysis procedures already existed and this knowledge was afterwards directed into an establishment of the search program, named PIKA (Slovenian acronim for Comet and Asteroid Search Program). By 1998 a completely automated custom designed telescope mount was built, as well as software for telescope and camera control and for automatic astrometry and moving object detection.
These efforts resulted in discovery of first asteroid (now 9674 Slovenija) during the follow-up of NEO in 1998 and of a number of new discoveries in 1999, using 19 cm ACIT telescope. In 1999, another telescope and CCD camera, previously partly manually controlled, were completely automated. what caused a significant increase of the number of observations.

### 3. Equipment

Two telescopes are currently used. The smaller one (ACIT - Automatic Comet Imaging Telescope) uses 19 cm, f/4 Lictenknecker flat field Schmidt-Cassegrain optics. The limiting magnitude in 1 minute exposures is between 16.5 to 17.0, while under optimal conditions we see up to magnitude 17.5. A very important characteristic of this optical tube is its construction with invar elements which hold the secondary mirror at the fixed distance from the primary. No focusing is ever needed unless we remove the camera.

| | *ACIT* | *C-14* |
|---|---|---|
| Optics | 19 cm, f/4 flat field (Lichtenknecker) | 36 cm, f/11 + f/6.7 reducer (Celestron) |
| Mount | Fork type, friction drive, stepping motors, step 0.11" (home made) | Fork type, friction drive, stepping motors, step ????? (home made) |
| CCD | HiSIS 44, 1536x1024 pixel Kodak | FLI + TK1024 1024x1024 thinned |
| Limit. magnitude in 1 min. | 16.5-17 unfiltered | 18.5 unfiltered |
| Field of view | 1 degree x 0.7 degree | 0.28 degree x 0.18 degree*<br>0.6 degree x 0.6 degree** |

*The FOV before April 2000 with Wright camera. Almost all observations below are made with this camera
**FOV with the recently installed FLI camera
Table 1. Telescopes used at Crni Vrh observatory

The larger telescope uses 36 cm, f/11 optical tube of Celestron 14, equipped with f/6.7 focal reducer. The limiting magnitude of this telescope with back-illuminated CCD camera and no filter is between 18.5 and 19 magnitude.

Telescope mounts are completely designed by ourselves, together with electronics for stepping motor control. They use a friction drive concept (fig. 1), which removes periodic errors almost entirely. We can make unguided exposures of up to 10 minutes. During our survey program we never use more than 2 minute exposures and practically all images have no guiding problems at all. Analysis of the pointing accuracy for the C14 telescope is presented in fig. 2.

teleskopi, pointing accuracy, limiting magnitude.

The observatory has an ISDN connection with the Internet. This is very convenient for the connection to time servers. Every hour one of the computers connects to the Internet, adjust the time and transmits data from the locally installes weather station to our home page.

Two Pentium computers with large RAM and hard disks are in control each of its own telescope. Every image that we take is written to a CD-ROM

### 4. Software

On both computers that we use we have the Linux operating system. This allows us access to freely available development tools such as compilers and GUI builders. Probably most important aspect of using Linux is its exceptional stability, allowing us to never switch the computers off except for hardware upgrades.

Almost all of the software that we use for observations is developed by ourselves, except for routines for image correction which use IRAF functions.

Telescopes and CCD cameras are controlled by custom written device drivers. A server program *tserver* acts as a mediator between the high level commands issued by the user or application programs and between the drivers which access the hardware directly.

In the data processing pipeline one of the major programs is *fitsblink*, which is used for object detection, matching with catalogs, astrometry and generation of MPC observation reports. It also allows display and comparison of FITS images on a computer screeen. More about this program is available at [1].

For the identification of known asteroids we developed *asteroid_server* [2], which uses Lowell asteroid database [3].

Additional, stand-alone programs take care for the alignment of images and detection of moving objects. To achieve specific tasks, we connect major programs by using scripting languages such as Python [4] and Perl [5]. This lets us a flexible adjustment requirements imposed by changes of strategies.

All images that we take and all observations that we make are also archived in the database. As a database server we use PostgreSQL [6] to which we connect with a set of small client programs which insert and retrieve information. There is also limited public WWW acccess to these databases: it is possible ta get a list of images which contain certain coordinates [7], to see sky coverage by our telescopes [8] and to view statistics of our observations [9].

**5. Observing strategies**

With any existing equipment and software, very different observing strategies are possible. We have set as a goal to maximize the number of observations and to keep probability for new discoveries as high as possible. With the C-14 telescope which, until recently, only had 17'x11' field of view, the scanning of sky fields placed next to each other did not produce a satisfactory number of observations. We hence decided to target some asteroid with each exposure. The method how to choose the asteroids is a matter of constant revision, depending on efficiency of major sky survey programs and the state of our own software We take three images of each field of view and find the moving objects automatically. As a constant method of verification of our efficiency, the predicted positions of asteroids are shown together with the detected objects so that we can always see whether some asteroid was missed. Usual causes of failure to detect asteroids are blending with stars and changes of seeing which may cause disappearance of the object on one of the images.

**6. Results**

**Observations**

The number of observations that we submit to MPC has dramatically increased after the commisioning C-14 telescope fro automatic operation and the decision to target asteroids with each exposure. Although the FOV and aperture were rather modest, we became one of the most productive observatories in the world, although still two orders of magnitude less than LINEAR. Table 1 actually reveals that we became 2nd biggest contributor of all amateur observatories and many professional in years 1999 and by April 2000, being only overtaken by Visnjan Observatory (120).

| | ***1998*** | | ***1999*** | | ***2000**** | |
|---|---|---|---|---|---|---|
| | ***Code*** | ***No. of obs.*** | ***Code*** | ***No. of obs.*** | ***Code*** | ***No. of obs.*** |
| 1 | 704 | 343905 | 704 | 621557 | 704 | 412299 |
| 2 | 699 | 71807 | 699 | 95615 | 699 | 42934 |
| 3 | 566 | 21807 | 703 | 89378 | 703 | 33149 |
| 4 | 691 | 18501 | 691 | 28052 | 691 | 20002 |
| 5 | 809 | 12442 | 120 | 13168 | 608 | 9995 |
| 6 | 910 | 10725 | 689h | 7356 | 120 | 5037 |
| 7 | 327 | 10706 | 106 | 6529 | 106 | 3258 |

Table 1. Ten leading suppliers of observations by the number of observations in last three years. In 1998, 106 was in the 72 place with 231 observations. Note that the number of observations does not reflect the actual number of submitted observations - only those for object of sufficiently well determined orbits.

*Observations up to mid-April 2000

| | *1998* | | *1999* | | *2000** | |
|---|---|---|---|---|---|---|
| 8 | 120 | 6655 | 046 | 5325 | 046 | 1910 |
| 9 | 046 | 5110 | 557 | 4438 | 049 | 1544 |
| 10 | 689h | 4698 | 610 | 3647 | 411 | 1209 |

Although all measurements are peformed completely in batch mode and only decisions about the acceptance of measurements of new objects are done interactively, the astrometric accuracy still seems to be satisfactory. Table 2 shows accuracy of major contributors (defined as those which contributed at least 400 observations in 2000, according to [10].

| Code | Obs. | <1" | s |
|---|---|---|---|
| 360 | 501 | 98.2 | 0.46 |
| 858 | 415 | 94.2 | 0.53 |
| 691 | 20002 | 92.7 | 0.57 |
| 888 | 757 | 89.6 | 0.62 |
| 046 | 1910 | 90.9 | 0.64 |
| 413 | 594 | 94.3 | 0.65 |
| 557 | 922 | 89.2 | 0.67 |
| 118 | 643 | 88.3 | 0.67 |
| 699 | 42934 | 85.9 | 0.68 |
| 106 | 3258 | 88.1 | 0.69 |
| 684 | 603 | 85.1 | 0.69 |
| 012 | 564 | 81.0 | 0.83 |
| 704 | 412299 | 80.9 | 0.83 |
| 703 | 33149 | 82.0 | 0.85 |
| 608 | 9995 | 69.9 | 0.94 |
| 732 | 950 | 72.3 | 1.00 |
| 610 | 955 | 71.6 | 1.05 |
| 151 | 571 | 67.8 | 1.13 |
| 104 | 810 | 66.1 | 1.16 |
| 049 | 1544 | 52.1 | 1.17 |
| 120 | 5037 | 61.0 | 1.19 |
| 411 | 1209 | 50.0 | 1.38 |
| 739 | 447 | 64.2 | 1.43 |

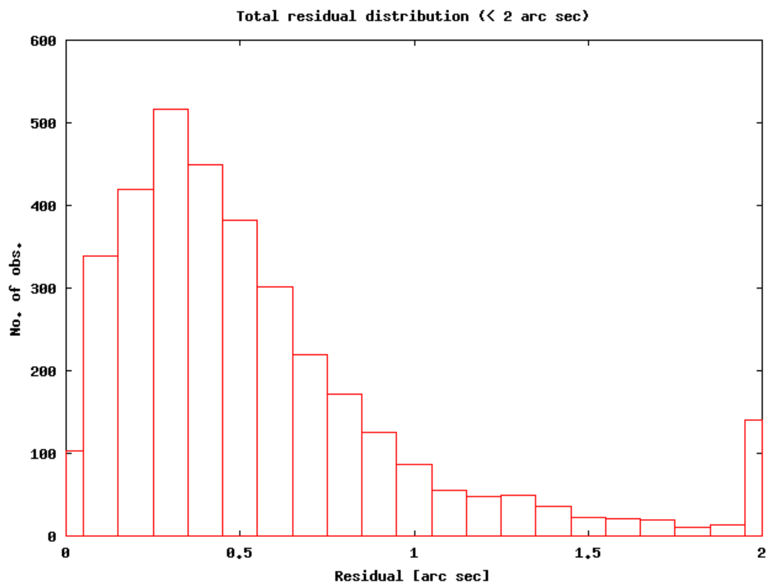


Fig. 1 Distribution of total residuals submitted by 106 by April 2000. Graph is produced by the WWW based residual engine [11]. 50 % percent of observations have residuals better than 0.5 arcseconds.

Table 2. Residuals of observatories which submitted at least observation in year 2000. Columns from left to right are: observatory code, number of submitted observations, percentage of observations with residuals better than 1", and average residual. The table is sorted by the last column.

**Discoveries**

While targeting of asteroids does increase the overall efficiency of observing time, it does not influence the number of discoveries. The number of discoveries varies largely in dependence of activity of major asteroid survey programs. While our first discoveries in 1999 were made with a 19-cm telescope, later development of events and analysis of results of other observers led us to think that only going to fainter magnitudes than major surveys (currently 18.5 to 19) can leave place for a reasonable of new discoveries. Table 3 shows statistics of Crni Vrh asteroid discoveries supplied by MPC in the DISCSTATUS report of April 22 2000.

| | *1997* | *1998* | *1999* | *2000* |
|---|---|---|---|---|
| Primary designation | 4 | 1 | 21 | 2 |
| Single opposition | 2 | 0 | 27 | 3 |
| No orbit | 4 | 0 | 5 | 1 |
| Linked to other | 1 | 0 | 9 | 0 |
| TOTALS | 11 | 1 | 62 | 6 |

Table 3. Summary of asteroid discoveries at Crni Vrh Observatory in the period 1997-April 2000. First row lists numbers of asteroids which were linked to previous observations but retained our designation, second row refers to asteroid s observed at single opposition only, third row to asteroids with unsufficient follow-up to get an orbit and the fourth row refers to asteroids which were linked to other observations and the other designation was primary.

1997 asteroids were discovered "manually" before the establishment of the PIKA project by H. M. Two asteroids from 1997 on the one from 1998 are numbered, while seven others are observed at 4 or more oppositions. All together 80 our designations are in the MPC database. This is the result of 200 objects which we could not immediatelly identify after observations. Most of remaining 120 suspect objects were identified with current discoveries which did not make it to the Lowell asteroid database at the time we made our observations.

**Acknowledment**

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**References**

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