Small Bodies of the Solar System in the Data of the ASAS Project

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Abstract

The data collected during the three stages of the All Sky Automated Survey (ASAS) project are reviewed from the point of view of searching for traces of small Solar System bodies. There are over 150 000 frames collected during the first five years of the project. There are many traces of meteors, asteroids and comets in these images. They are a potential source of valuable information about meteor showers of the southern hemisphere and orbital elements of newly discovered asteroids and comets. We point out on the possibility of discovering new comets and Near-Earth asteroids by analyzing the ASAS data using a newly developed image subtraction method.

1 The ASAS Project

As was suggested by Paczyński (1997), many interesting scientific programs can be done even with surveys covering only the brightest observable objects. The main topics include variable stars, comets, asteroids, meteors, near-Earth objects (NEOs), supernovae, AGNs and optical afterglows of gamma ray bursts.

One such project is the All Sky Automated Survey (ASAS). Its final goal is the photometric monitoring of $\approx 10^7$ stars brighter than 14 magnitude all over the sky. The initial idea for the project is due to Prof. Bohdan Paczyński of Princeton University. The prototype instrument, located at the Las Campanas Observatory (operated by the Carnegie Institution of Washington), and the data pipeline were developed by Dr. Grzegorz Pojmański of the Warsaw University Observatory (Pojmański 1997).

A low cost prototype instrument (ASAS-1, ASAS-2), equipped with a 768×512 Kodak CCD and 135/1.8 Sigmatel telephoto lens, mounted on the robotic mount developed at the Warsaw University Astronomical Observatory , operated at the Las Campanas Observatory, Chile from 1997 April 7 to 2000 June 6. It took over 120 3-minute exposures per night, continuously monitoring about 300 sq. degs of the sky.

The instrument had a scale of 14.2 arcsec/pixel and a 3×2 deg field of view. An I-band Cousins (Schott RG-9, 3mm) filter was used giving a limiting magnitude around 13 mag.

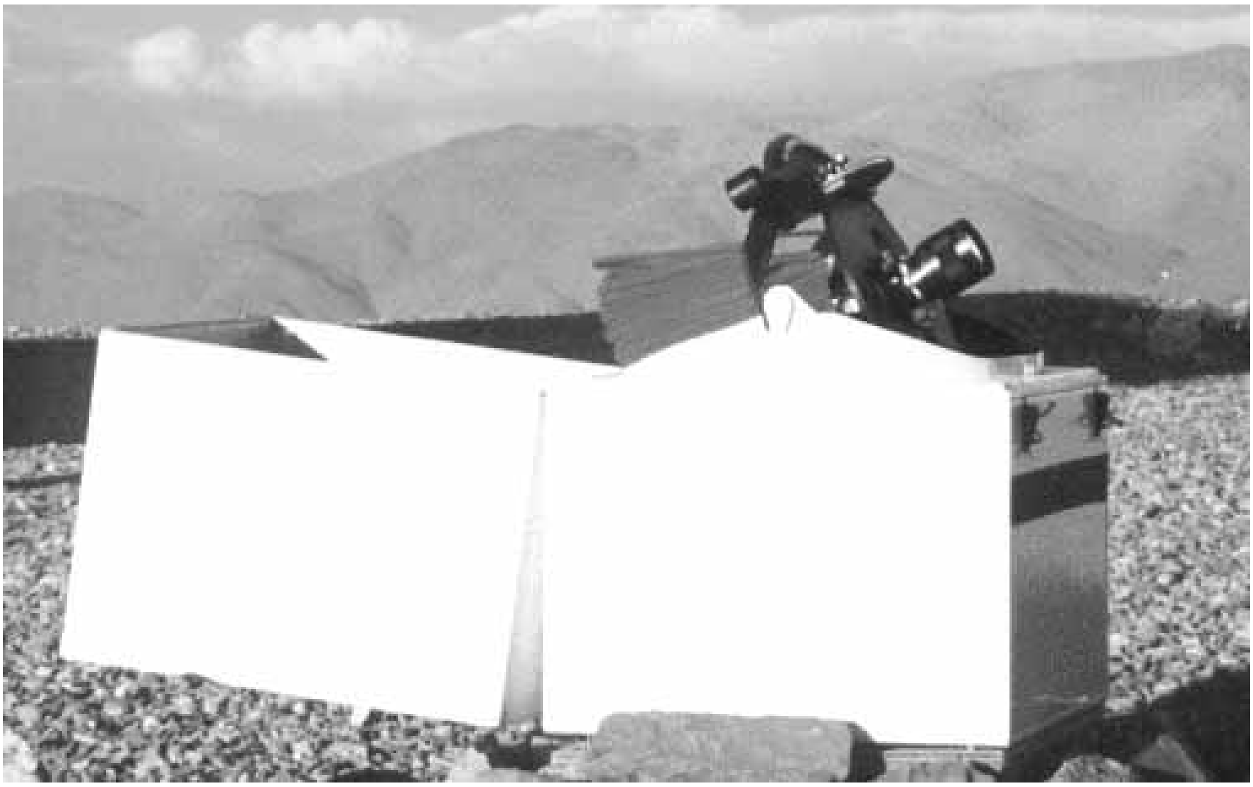

Figure 1: *The ASAS prototype instrument in Las Campanas Observatory, Chile*

The mount, camera and electronics box were housed in the 0.6-m × 0.6-m × 0.8-m waterproof plywood box (Fig. 1). During the second stage of the project (ASAS-2), the instrument was moved to the 10-inch astrograph dome of the Las Campanas Observatory.

During over three years of operation (1997 April 7 – 2000 June 6) ASAS-1 and ASAS-2 collected over 80 000 frames.

2 Current Status of the ASAS

In August 2000 the ASAS project started its third phase. Since that time it has consisted of four instruments: two twin wide-field telescopes each equipped with a 200/2.8 Minolta telephoto lens and a 2048 × 2048 Apogee AP-10 CCD camera covering 8.8 × 8.8 deg of the sky through the Johnson V and Cousins I filters, the narrow-field telescope which is a $F = 750$ mm, $D = 250$ mm, $F/3.3$ Cassegrain-like instrument with not F/3.3. a 3-element Wyne corrector. It has the same 2048 × 2048 Apogee AP-10 CCD camera and I filter. The field of view is 2.2 × 2.2 deg, but the optimum PSF ($FWHM < 2.5$ pixels) is currently available only inside a circular field of ≈ 1 deg radius. Additionally, the sky is monitored using a very-wide-field scope equipped with a Minolta 50/4 lens and 2048 × 2048 Apogee AP-10 CCD camera giving a field of view as large as 36 × 26 deg. The technical informations of all ASAS-3 instruments are summarized in Table 1.

In 2000 August, the ASAS-3 system was installed in the 10-inch astrograph dome of the Las Campanas Observatory. In 2002 April, the ASAS-3 moved to a separate, custom-made enclosure housing all four instruments placed in front of the 1.3-meter Polish telescope (Fig.

2).

Table 1: *Table 1. Technical information about ASAS-3 instruments*

	wide-field instruments	**narrow-field telescope**	**very-wide-field scope**
Optics	Minolta 200/2.8 lens	25-cm Cassegrain 250/3.3	Minolta 50/4 lens
FOV	$8.8° \times 8.8°$	$2.2° \times 2.2°$	$36° \times 26°$
LM	13 mag.	16 mag.	10 mag.
Filter	V, I	I	I

More information, pictures and scientific data can be found on the ASAS Home Page at `http://www.astrouw.edu.pl/~gp/asas/asas.html`.

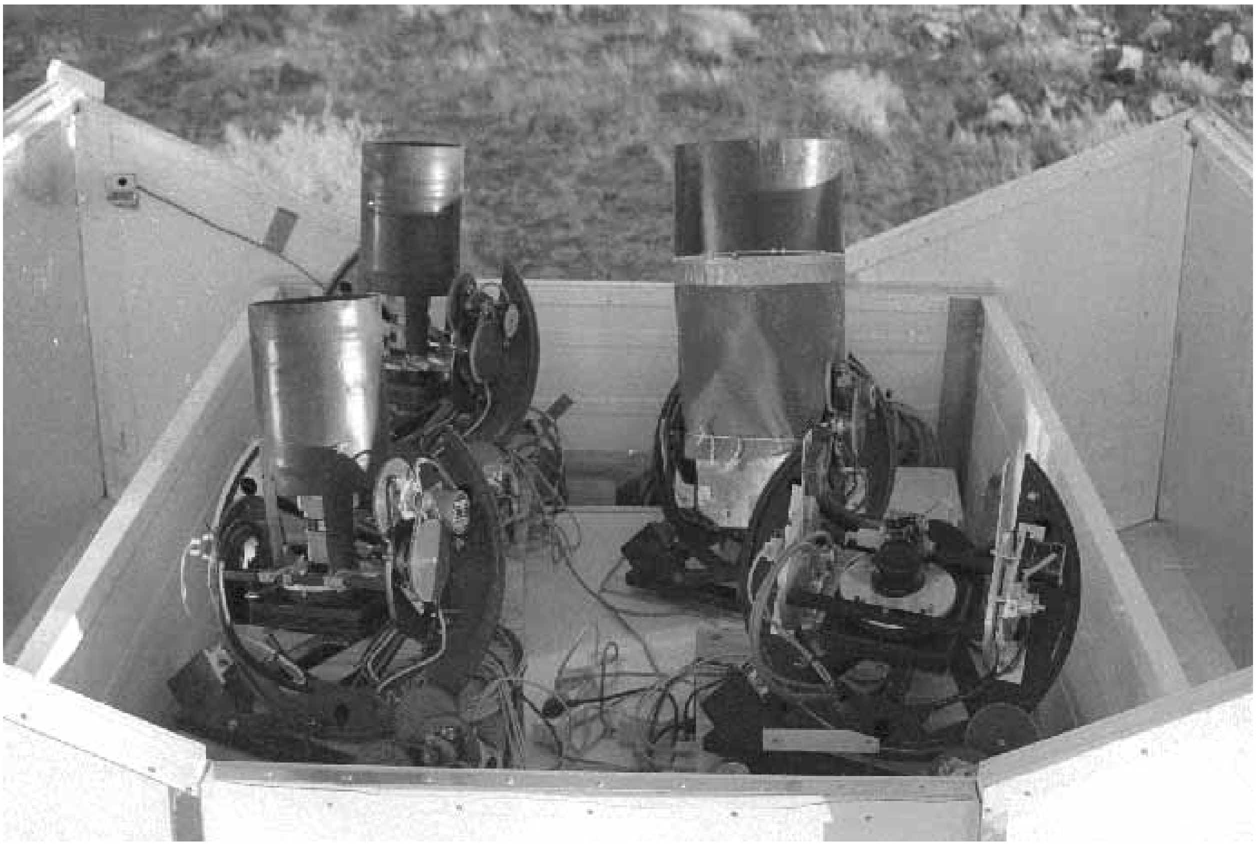

Figure 2: *The ASAS-3 instruments in the custom-made automated enclosure*

3 Scientific Results of the ASAS

The main results of the ASAS projects were presented by Pojmanski (1998, 2000). The first of these papers describes results of the first two months of observations when 45 000 stars in 24 fields covering 140 square degrees were monitored. A period search revealed 126 variable stars brighter than 13 mag of which only 30 were previously known. The other objects were newly discovered variables - mainly eclipsing binaries (75%) and pulsating stars (17%).

Pojmański (1998), using the ASAS data, also estimated that the completeness of the current variable stars catalogs is smaller than 50% for stars brighter than 9 mag.

The results of the first stage of the ASAS project were given by Pojmański (2000). More than 140 000 stars in 50 fields covering 300 square degrees were monitored, resulting in the ASAS Photometric I-band Catalog containing over 5×10^7 individual measurements. The Catalog is available on-line at the ASAS Home Page.

A search for variable stars revealed over 350 periodic and 3500 miscellaneous variables brighter than 13 mag. Only 630 of them were known or suspected variables included in the *General Catalogue of Variable Stars.*

Additionally, six stars included in the list of Landolt (1992) standard stars were found to be variables in the ASAS data.

The first results of the third stage of the ASAS project were recently published by Pojmański (2002). In this paper over 1.3 million stars brighter than $V = 15$ mag detected on 40 000 frames were analyzed and 3126 objects were found to be variable.

Up to now the ASAS project has collected over 150 000 frames.

4 Small bodies of the Solar System in the ASAS data

4.1 Asteroids

The limiting magnitude of the main ASAS instruments, ranging from 13 to 16 mag, is too low to allow the discovery of new asteroids from the main belt. However, it is sufficient to detect and make follow-up observations of Near-Earth Objects.

According to the currently operating searches for minor bodies of the Solar System such as Spacewatch, LINEAR, NEAT, LONEOS, there are a few dozen NEOs brighter than 16 mag discovered per year. The large database of the ASAS containing over 150 000 frames is a potential source of many pre-discovery observations of these objects. The pre-discovery observations give the possibility of better determination of the orbital parameters of these bodies which is crucial information allowing one to estimate the potential impact risks.

Due to the fact that the majority of projects searching for NEOs work under the northern sky we hope that the ASAS data collected continuously over five years will allow us to discover some previously unknown NEOs in the southern sky.

4.2 Comets

In recent years the number of comets appearing in our sky has varied from 20 to 40 per year. We reviewed the *IAU Circulars* from 1999 to 2002 looking for notes describing comet discoveries. We found 137 such notes, not including those made by the SOHO mission. The comets detected by SOHO are always discovered very close to the Sun and therefore are out of range of other projects and amateur astronomers searching for comets.

Fig. 3 shows the distribution of comet brightnesses at discovery. The vertical solid line

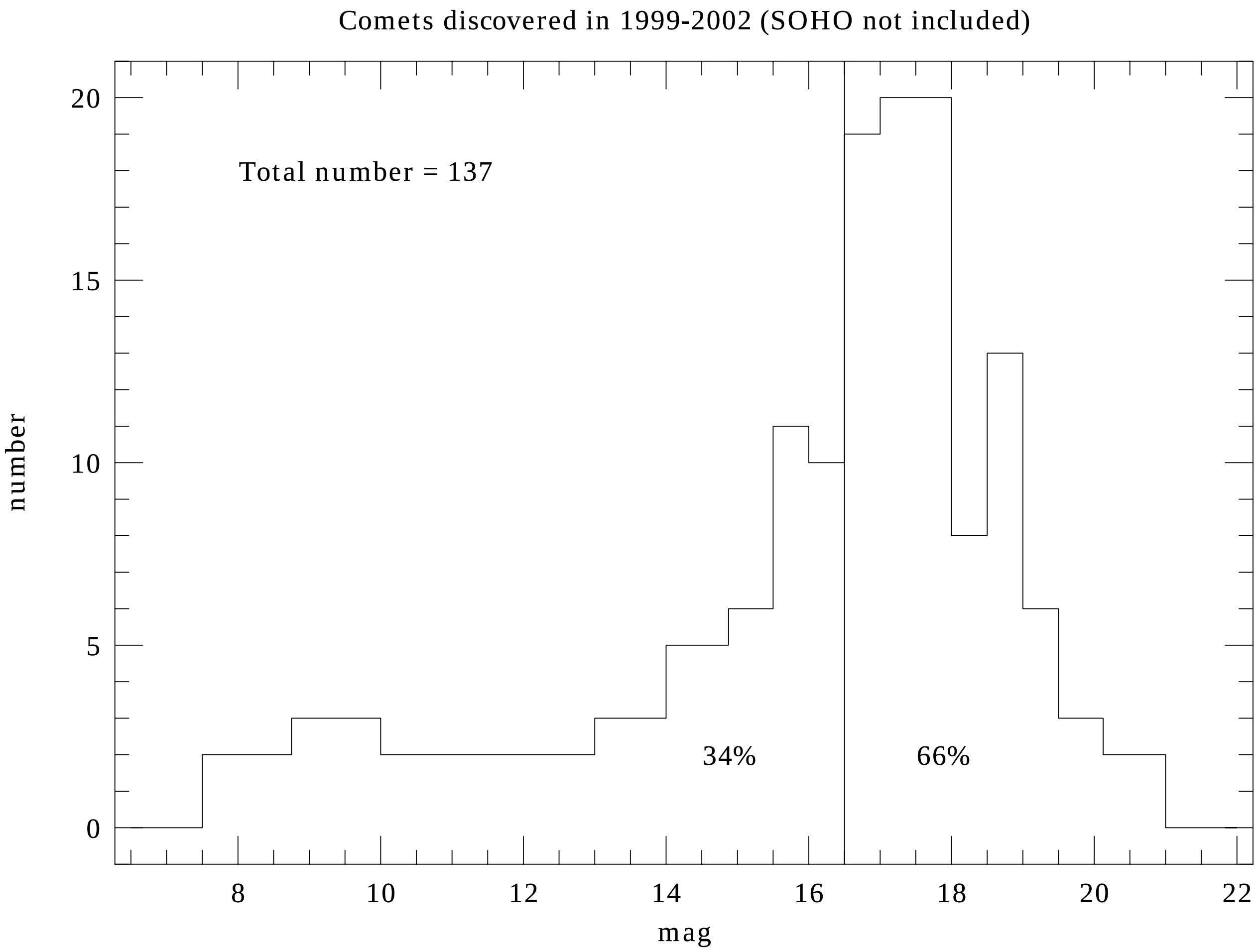

Figure 3: *The distribution of the comet brightnesses at discovery based on the data published in IAU Circulars*

denotes the limiting magnitude of the ASAS narrow-field telescope. It is clear that as many as 34% of comets could be discovered by analyzing the ASAS images. The probability of detection of a new bright comet in ASAS data is quite high taking into account two facts: first, the field of view of the ASAS instrument is significantly larger than fields of view of the telescopes used by NEAT, LONEOS, Spacewatch, LINEAR and others; and secondly the ASAS operates under the southern sky while the majority of the aforementioned surveys cover only the northern sky. Also the number of astronomy amateurs looking for comets is significantly higher in the northern hemisphere than in the southern one.

4.3 Meteors

The large field of view of the ASAS instruments and their reasonable limiting magnitudes ensure that we will be able to detect a large number of meteor trails. The data collected by the ASAS have several advantages in comparison with ordinary photographic observations. First of all, the whole set of images is already in digital form not needing film purchase, development and picture scanning. Additionally, the very-wide-field scope has a field of view comparable to a typical photographic equipment but significantly higher limiting magnitude. The wide-field and narrow-field telescopes have fields of view of the same size as in telescopic meteor observations but, in the case of ASAS, the detector is not a human eye but a CCD chip giving significantly higher limiting magnitude and good precision in determining meteor paths coordinates.

The only serious disadvantage of the ASAS instruments is the lack of a rotating shutter, making impossible the determination of meteor angular velocities. In spite of this we will still be able to detect and analyze meteors from showers with medium and high geocentric velocities. For example, in the RADIANT software (Arlt 1992) we can assume all angular velocities to be of type D (i.e. fast). The typical error of angular velocity estimate made by a visual observer is around 5-8 deg/second (i.e. one class of velocity on five or six steps scale - see Koschack 1991 for a detailed discussion). Thus our assumption includes within the error limits the meteors from C, D and E classes, i.e. with angular velocities from around 10 to 25 deg/second. The number of meteors with angular velocities from that range is significantly higher than the number of meteors with 0-10 deg/second velocities, giving us hope that we can detect and analyze all meteor showers with geocentric velocities higher than 30 km/s. According to the *IMO Working List of Meteor Showers* given by McBeath (2002), as many as 70% of meteor showers have geocentric velocities of at least 30 km/s.

To summarize, ASAS data are of the same quality as telescopic meteor observations taking into account only angular velocity estimates. On the other hand, the precision of determining the beginnings and ends of meteor paths and their magnitudes is significantly higher using the ASAS data. Additionally, the sample of meteors captured on the ASAS images is free from the biases and errors typical of telescopic work, such as errors in plotting and missing some fraction of the events.

One of the meteors captured during the first stage of the ASAS project is shown in Fig. 4.

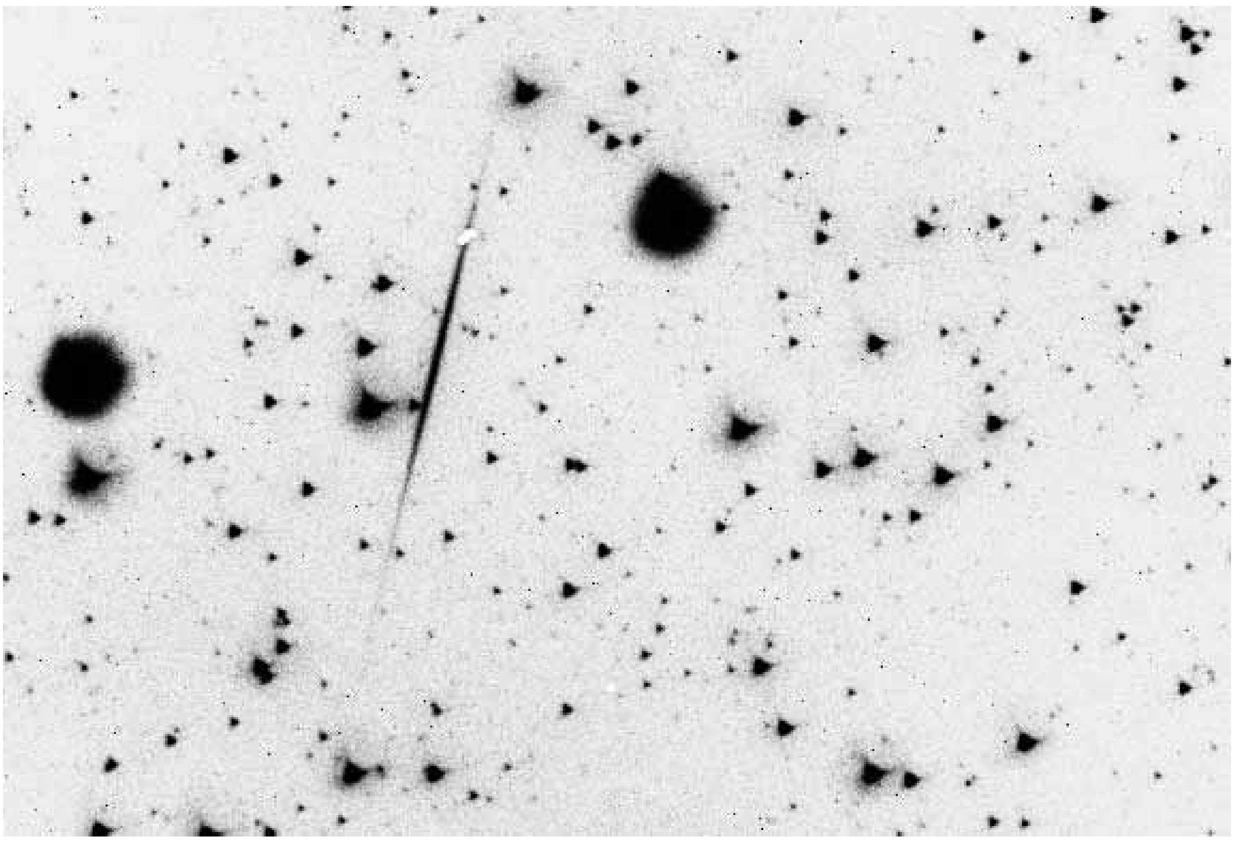

Figure 4: *One of the meteors captured during the first stage of the ASAS project*

5 Data reduction

The initial reduction of the CCD frames (subtracting BIAS, DARK images and dividing by FLAT-FIELD images) will be done using the standard routines in the IRAF CCDPROC package. [1]

A further reduction will be done using a newly developed image subtraction method ISIS (Alard and Lupton 1998, Alard 2000). ISIS is based on the fast optimal image subtraction algorithm. Subtraction is done between the reference image (obtained by stacking several best seeing and low background images) and each image from the data set transformed to the coordinate grid of the reference image. Before subtraction, the reference image is modified to exactly match the seeing of each image from the data set. This is done by finding the convolution kernel and difference in background levels between the reference and subtracted image. There are more details in the papers of Alard and Lupton (1998) and Alard (2000).

It was shown by Alard (1999) and Olech et al. (1999) that ISIS works very well even in very dense regions of the Galactic bulge and in the cores of the globular clusters. In the first applications, ISIS produced light curves with a quality significantly better than obtained by traditional methods such as DAOPHOT and DOPHOT.

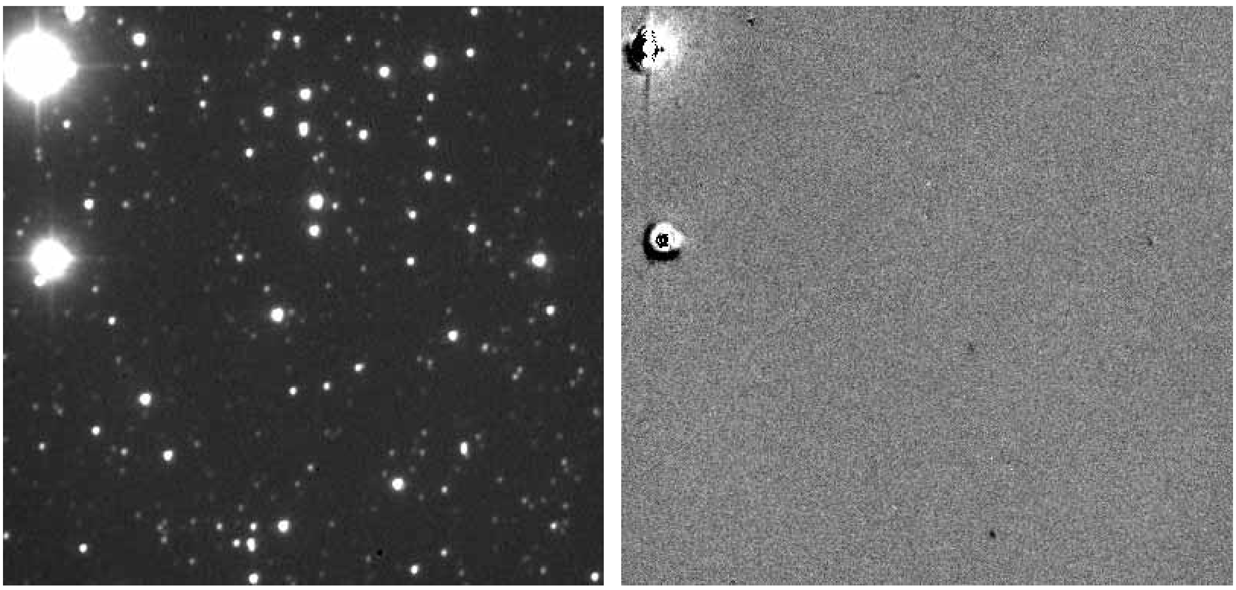

Figure 5: *Left panel: Raw image of the field placed in the Galactic plane. Right panel: Image obtained after the subtraction of the reference frame from the raw one*

A simple example of the ISIS results is shown in Fig. 5. There is a raw image of the Galactic field quite rich in stars on the left panel. On the right panel one can see the image obtained after the subtraction of the reference frame from the raw one. It is clearly visible that we can detect only residuals left after subtraction of saturated stars and few black dots which are in fact the variable star candidates.

In case of the ASAS data, the images produced by the ISIS software should contain almost no

[1]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

traces of constant stars and only black and white dots corresponding to variable stars, comets and asteroids, and straight lines with traces of meteors and satellites. The subtracted images always contain a small number of easily detectable objects and thus are ideal for looking for traces of small Solar System bodies. The point-like objects such as asteroids and comets could be easy traced using for example the `find` algorithm of the DAOPHOT software (Stetson 1987) and straight lines we could detect using the Hough transform (Trayner et al. 1998).

Additionally, it is also easy to determine the equatorial coordinates of all detected objects because whole set of images is transformed onto the common coordinate grid and we need only find the conversion from the (x, y) to the (α, δ) plane once.

6 Expected results

We will publish the orbital elements of newly discovered comets and Near-Earth asteroids and also submit our observations of minor Solar System bodies to the *Minor Planet Center* allowing the better determination of their orbits.

We would also like to publish the catalogue of recorded meteor paths and magnitudes and analyze the activity and radiant distribution of the meteor showers from the southern hemisphere.

The automated software for detection of the comets, asteroids and meteors paths will be made available to other projects such as ASAS and Optical Gravitational Lensing Experiment (OGLE).

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References

Alard C., and Lupton R.H., (1998), *ApJ*, **503**, 325

Alard C., (1999), *Astron. Astrophys.*, **343**, 10

Alard C., (2000), *Astron. Astrophys. Suppl. Ser.*, **144**, 363

Arlt R., (1992) *WGN*, **20**, 62

Koschack R., (1991), *WGN*, **19**, 225

Landolt A.U., (1992), *Astronomical Journal*, **104**, 340

McBeath A., (2002), *"2003 Meteor Shower Calendar"*, IMO_INFO (2-03)

Olech A., Woźniak P., Alard C., Kałużny J., and Thompson I.B., (1999), *MNRAS*, **310**, 759

Paczyński B., (1997), *"The Future of Massive Variablity Searches"*, in *Proceedings of 12th*

IAP Colloquium: "Variable Stars and the Astrophysical Returns of Microlensing Searches", Paris, ed. R. Ferlet, p. 357

Pojmański G., (1997), *Acta Astronomica*, **47**, 467

Pojmański G., (1998), *Acta Astronomica*, **48**, 35

Pojmański G., (2000), *Acta Astronomica*, **50**, 177

Pojmański G., (2002), *Acta Astronomica*, **52**, 397

Stetson P.B., (1987), *PASP*, **99**, 191

Trayner C., Bailey N.J., and Haynes B.R., (1998), in *Proceedings of the IMC 1997*, Petnica, Yugoslavia, eds. A. Knöfel and A. McBeath, p. 65

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