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Asteroid Observations at the Wise Observatory

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Abstract. The Wise Observatory was established in 1971 to serve the needs of astrophysical research in Israel. Since its inauguration, the main research instrument was a 1.0-m telescope that was heavily modified during the years and modern equipment was added to enhance its performance. In the first decade of the 21^{st} century a second telescope with an 0.46-m primary was added, primarily to allow intensive studies of asteroids. These two instruments are heavily used for photometric studies of asteroids, mainly in a semi-automatic observing mode.

Photometry is an effective tool to study the properties of asteroids since rotation periods and shapes are easily derived from the measured lightcurves. Other properties such as size, surface chemical composition and structure can also be derived. Binarity can be revealed by eclipses or by the detection of two or more periods in the lightcurve.

Our research is focused on Near-Earth asteroids (NEAs), objects that approach Earth significantly. We use intensively the 0.46-m telescope equipped with a wide field (40.5' x 27.3') CCD camera at its prime focus to derive lightcurves in a "clear" band, and the 1.0-m telescope to measure the asteroid colors as a function of lightcurve phase. The observations and image reduction are done semi-automatically using off-the-shelf software and specially tailored programs.

By now more than fifty asteroids have been observed as main targets and ~100 other asteroids were photometrically measured while appearing in the main target fields. From this data set some binary asteroids were discovered, objects that can reveal the asteroid's density. The collected data are used to investigate correlations between the asteroid spins and other parameters such as their locations and sizes.

In the spirit of the MEARIM meeting, the Wise Observatory and the Tel Aviv University are ready to collaborate with astronomers of other countries in the region to achieve high-quality astronomy and to promote Space Research and Space Research education throughout the Middle East and Africa.

Keywords. telescopes, minor planets, asteroids, techniques: photometric

1. Introduction

Tel Aviv University (TAU) was founded in stages, starting from 1956 with the university receiving full accreditation from Israel's Council for Higher Education in 1969 under its first President, Dr. George S. Wise. With slightly more than 100 students in its early days, Tel Aviv University grew to about 30,000 students of all faculties and degrees at present. With the addition of new research tracks, it became obvious that there was a need to develop experimental astrophysics within the Physics Department, founded in 1969. The second President of Tel Aviv University, Professor Yuval Ne'eman, decided at

Figure 1. The Wise Observatory observing facilities. From left to right: the dome of the T40 and main building, the dome of the C18, and the box enclosure of the WHAT.

that time to establish an academic astronomical observatory as a research unit of TAU, despite the fact that no astronomers were yet among the TAU staff.

The establishing of the observatory started with a site survey that quickly converged on the small town of Mizpe Ramon in the Negev desert, some 220-km south of Tel Aviv (longitude 34°45' 48" E, latitude 30°35'45" N, altitude 875 m), and at a time zone that is -2 hours relative to Universal Time. The observatory site is about 5 km west of Mizpe Ramon and 86 km south of the large town of Beer Sheva.

At present, the WO hosts four observing instruments; the CONCAM (a fisheye CCD camera imaging the night sky every 180 seconds; see Pereira 2003), the Wise Hungarian Automatic Telescope (WHAT, a $\sim 7^{\circ}.8 \times 7^{\circ}.8$ field of view CCD telescope for photometric monitoring of relatively bright stars), the 0.46-m telescope (C18) and the 1.0-m telescope (T40). Figure 1 shows a view of the various domes now in operation, The CONCAM is mounted on the WO roof.

2. The 1.0-m Telescope

The construction of the building started at the same time as the telescope was constructed in the US, at the Boller & Chivens plant, where a duplicate of the Swope 40-inch telescope intended for Las Campanas was ordered. The optics are a Mount Wilson/Palomar Observatories design, consisting of a 40-inch diameter clear aperture f/4 primary mirror, a 20.1-inch diameter f/7 Ritchey-Chrétien secondary mirror, and a quartz corrector lens located 4 inches below the surface of the primary mirror, providing a flat focal field of up to 2.5 degrees in diameter with a plate scale of 30 arcsec mm^{-1}. An f/13.5 Cassegrain secondary mirror is also available, but is hardly used nowadays.

The telescope (T40) was delivered in 1970 and regular observations started from 1971 using primarily photographic plates for imaging and spectroscopy. The observatory was officially inaugurated in October 1971 and was named after Dr. Wise and his lady "The Florence and George Wise Observatory". A two-channel fast photometer patterned after the Oke design was added in 1972, and a two-star photoelectric photometer of the Nather design was constructed in 1975. Image tubes were introduced in the late 1970s for viewing and for photometry, and an electronographic camera from RGO was added at about the same time. The first CCD camera, based on an RCA chip with 320×512 pixels was introduced in 1985.

The phasing out of photographic techniques was initiated at the WO simultaneously with the introduction of CCD cameras. The current work-horse is a Princeton Instruments CCD with a thinned and back-illuminated VersArray 1300B chip with 1340×1300 pixels, each subtending 0.6 arcsec. The camera is equipped with different filters mounted in a computer-controlled filter wheel and the entire operation can be conducted remotely. The same for the operation of the telescope and the dome, so that imaging operations can be conducted from the Tel Aviv campus or even from the home of the observer using fast internet connections.

One research aspect that developed into a major WO activity branch is of time-series studies of astronomical phenomena. A project to monitor photometrically and spectroscopically Active Galactic Nuclei (AGNs) is still running, following about 30 years of data collection. This project yielded a large number of ground-breaking measurements, such as the broad line region size relation with the luminosity of the AGN (Kaspi et al. 2005), or results from a 30+ year monitoring of some high-lumnosity AGNs (Kaspi et al. 2007).

Other major projects include searches for supernovae or for extrasolar planets (using transits or lensing events), observations of novae and cataclysmic variables, studies of star-forming galaxies in a variety of environments, and studies of Near Earth Objects (NEOs) and other asteroids. These studies, mainly part of PhD projects, are observation-intensive and require guaranteed telescope access for a large number of nights and for a number of years. The oversubscription of the available nights on the T40, the need to follow-up possible discoveries of relatively bright objects with smaller telescopes but with long observing runs, and a desire to provide a fallback capability in case of major technical problems with the T40, required therefore the expansion of the WO observational capabilities.

3. The 0.46-m Telescope

The second telescope of the Wise Observatory, a 0.46-m Centurion 18 (C18) was installed in 2005 and an extended description of it and its ancillary systems, including a description of its performance, was recently published (Brosch et al. 2008). Its operation enhances significantly the observing possibilities at the WO. The telescope operates from a small dome and is equipped with a large-format CCD camera. The C18 uses a prime-focus design with an 18-inch (0.46-m) hyperbolic primary mirror figured to provide an f/2.8 focus. The light-weighted mirror reflects the incoming light to the focal plane through a doublet corrector lens. The telescope is designed to image on detectors as wide as regular (35-mm) camera film though with significant edge-of-field vignetting, but we now use a much smaller detector, and the images are very reasonable indeed (FWHM=∼2".9 at the edge of the CCD, only 13% worse than at field center, with most image size attributable to local seeing).

The telescope was equipped from the outset with a Santa Barbara Instrument Group (SBIG) ST-10 XME USB CCD camera custom-fitted to our specific telescope by AstroWorks and delivered together with the telescope. This thermoelectrically-cooled chip has 2184×1472 pixels each subtending 1.1 arcsec at the f/2.8 focus of the telescope. The imaged field of view is therefore 40'.5×27'.3. A second, smaller CCD, mounted next to the science CCD, allows guiding on a nearby star using exactly the same optical assembly.

The CCD is used in "white light" without filters to allow the highest possible sensitivity. The chip response reaches 87% quantum efficiency near 630 nm, implying an overall response similar to a "wide-R" band. On a dark night with photometric conditions the sky background is 10–15 counts per pixel per second. Comparing with the R-band magnitude of standard stars (Landolt 1992) the sky as measured on the C18 images in the "wide-R" band is about 20.4 mag arcsec^{-1} and stars of 19.5 magnitudes are detectable with S/N≃25.

Given the small size of the telescope and the high degree of automation desired, we chose a small dome that would not allow routine operation with a human inside, but would allow unrestricted access to the sky for the C18. From among the off-the-shelf domes we chose a Prodome 10-foot dome from Technical Innovations USA (http://www.homedome.com/), equipped with two wall rings to provide sufficient height for the C18 in all directions.

The fiberglass dome was equipped by Technical Innovations with an electrical shutter and with the necessary sensors to operate the *Digital Dome Works (DDW)* software bundled with the dome; this allows control of all the dome functions from a computer. We equipped the dome with a weather station mounted on a nearby mast, a video camera with a commandable light source that allows remote viewing of the telescope and of part of the dome to derive indications about its position, and a "Robo reboot" device for *DDW*. The latter was installed to allow the remote initialization of the dome functions in case of a power failure.

We decided that all the software would be tailored into a suite of operating programs that would conform to the *ASCOM* standards (AStronomy Common Object Model, http://ascom-standards.org/). The *ACP* (Astronomer's Control Program) software is a product of DC-3 Dreams (http://acp.dc3.com/). *ACP* controls the telescope motion and pointing, and can change automatically between different sky fields according to a nightly observing plan. *ACP* also solves astrometricaly the images collected by the CCD, and improves automatically the pointing of the telescopes using these solutions. The *ACP* software is a gateway to the *MaximDL* (http://www.cyanogen.com/products/maxim_main.htm) program that operates the CCD. Different types of exposures, guiding and cooling of the CCD can be commanded manually using *MaximDL*, but in most cases we use the *ACP* code envelope (the *AcquireImages* script) to operate the entire system. The focusing is also done automatically using the freeware *FocusMax* (http://users.bsdwebsolutions.com/ larryweber/), a software package that operates the Robo-focus and searches automatically for the best FWHM of a selected star.

The C18 is used by different researchers at the Tel-Aviv University for various goals such as studies of physical parameters of asteroids, the investigation of extrasolar planets, and the monitoring of variable AGNs.

4. Photometric Studies of Asteroids and Other Solar System Bodies

Planetary studies at the Wise Observatory started with imaging and spectroscopic observations of comets (Wehinger & Wyckoff 1974, Wehinger et al. 1974), with photometric monitoring of the comet-asteroid Chiron (Prialnik et al. 1995), and with studies of the rotational properties of comets with photoelectric photometry (Leibowitz & Brosch 1986a, b, c) or of Kuiper Belt objects (KBOs) using CCD photometry (Choi et al. 2003). Since 2000, we decided to concentrate on Near-Earth objects following our selection by the Israel Space Agency to establish a National NEO Knowledge at the WO.

At the WO we focus on photometry, which allows the derivation of valuable data on asteroid properties: periodicity in light curves of asteroids coincides with their spins; shape is determined by examining the light curve amplitude; axis orientation is derived by studying changes in the light curve amplitude; special features in the light curves, such as eclipses, may suggest binarity and can shed light on the object structure and density. Such studies are important since knowledge of the nature of a possible impactor asteroid is essential to devise plans for its demise or deflection. For instance, most existing proposals would be defeated if the body is a "rubble pile" of gravel held together by the mutual gravity of its components, or if it is a binary orbiting the center of mass.

The C18 is mainly used for differential photometry of known asteroids as a primary target, but also enables the detection of new asteroids. The large field of the CCD allows the asteroids to cross one CCD field or less per night, even for the fast-moving Near-Earth Objects (NEOs) that can traverse at angular velocities of 0.1" sec^{-1} or slower. This ensures that the same comparison stars are used while calibrating the differential photometry. Exposure times between 30 to 180 sec are fixed for every night, depending on the object's expected magnitude and angular velocity, the nightly seeing, and the sky background. The lower limit for the signal to noise ratio of acceptable images is ∼10, thus asteroids that move too fast (⩾0.1"/sec) or are too faint (⩾18.5 mag) are de-selected for observation. Objects brighter than 12 mag are also avoided, to prevent CCD saturation. The images are reduced using bias, dark and normalized flat field images. Time is fixed at mid-exposure for each image. The IRAF *phot* function is used for the photometric measurements. Apertures of four pixel (∼4.5 arcsec) radius are usually chosen. The mean sky value is measured in an annulus with an inner radius of 10 pixels and a width of 10 pixels around the asteroid. The photometric values are calibrated to a differential magnitude level using 100-500 local comparison stars that are also measured on every image of a specific field. For each image a magnitude shift is calculated, compared to a good reference image. This massive comparison solves the question of transient opacity changes, and results in a photometric error of ∼0.01 mag.

Most of the observed asteroids are followed-up on different nights; this changes the background star field. Some asteroids are also observed at different phase angles and their brightness can change dramatically from one session to another. To allow comparisons and light curve folding to determine the asteroid spin, the instrumental differential photometric values are calibrated to standard R-band magnitudes using ∼20 stars from the Landolt equatorial standards (Landolt 1992). These are observed at air masses between 1.1 to 2.5, while simultaneously observing the asteroid fields that include the same local comparison stars used for the relative calibration. Such observations are done only on photometric nights. The extinction coefficients and the zero point are obtained using the Landolt standards after measuring them as described above. From these, the absolute magnitudes of the local comparison stars of each field are derived, followed by a calculation of the magnitude shift between the daily weighted-mean magnitudes and the catalog magnitudes of the comparison stars. This magnitude shift is added to the photometric results of the relevant field and asteroid. The procedure introduces an additional photometric error of 0.02-0.03 mag.

Since the images are obtained in white light, they are calibrated by the Landolt standards assuming the measurements are in the Cousins R system. In addition, the asteroid magnitudes are corrected for light travel time and are reduced to a Solar System absolute magnitude scale at a 1 a.u. geocentric and heliocentric distances, to yield $H(1,\alpha^0)$ values (Bowell et al. 1989).

To retrieve the light curve period and amplitude, the data analysis includes folding all the calibrated magnitudes to one rotation phase, at zero phase angle, using two basic techniques: a Fourier decomposition to determine the variability period(s) (Harris & Lupishko 1989) and the H-G system for calibrating the phase angle influence on the magnitude (Bowel et al. 1989). An example is shown on Figure **??** were a simple model was fitted to the observed data points of the Apollo asteroid (40267) 1999 GJ_4. The figure displays the folded light curve from which the rotation period P is deduced (here P=4.50±0.01 hours).

While the main advantage of the wide field of view of the C18 is the ability to observe even a fast-moving NEO in the same field during one night (Polishook & Brosch 2007), the instrument allows also the simultaneous monitoring of the light variations from several asteroids in the same field of view. Looking at Main Belt asteroids, many objects can be seen sharing the same field (our recent record is 11 objects in one field with 180 second exposures and is shown in Figure 3.

5. Interesting Results Concerning Asteroids

5.1. *Near-Earth Objects*

Photometric observations were conducted on eight Aten near-Earth asteroids, with the goal of building physical models for the objects (85989) 1999 JD_6, (86450) 2000 CK_{33}, (86667) 2000 FO_{10}, (137170) 1999 HF_1, 1999 MN, 2000 PJ_5, 2002 JC and 2003 NZ_6 (Polishook & Brosch 2008a). Atens form a subgroup of the near-Earth asteroids with semi-major axes smaller than one a.u. Such objects are difficult to observe for a major part of their orbits.

The observations were performed at the WO with the T40 and with a cryogenically-cooled SITe CCD. At the f/7 focus of the telescope this CCD covers a field of view of 34'×17' with 4096 2048 pixels allowing observations of Atens in the same imaged field during a complete night, permitting the use of the same local reference stars for calibration of the differential photometry. The results show rotation periods from 2.3 to almost 26 h.

The lightcurve of 2000 PJ_5 exhibits a binary character with a probable highly eccentric orbital rotation of the secondary component. The different periods of the known binary 1999 HF_1 are easily detected. Other Atens have lightcurves that can be interpreted as produced in a binary system with a synchronous rotation; these are features such as an amplitude higher than one magnitide, V-shaped minima and U-shaped maxima (2003 NZ_6, 2000 CK_{33} and perhaps also 1999 JD_6).

Color variations during rotation and phase angle change were searched for and demonstrate the wide variety among Atens. The very red colors of 2000 CK_{33} suggest a unique surface composition for this near-Earth object. This asteroid does not match the known taxonomic classifications.

The high percentage of binaries and possible binaries reported here, suggests that binarity is a very common phenomenon for Atens, perhaps even more than for other NEA groups among which 15% are assumed to be binaries (Bottke and Melosh, 1996).

5.2. *Main Belt Asteroids*

Photometry results of 32 asteroids are reported from only seven observing nights on only seven fields, consisting of 34.11 cumulative hours of observations (Polishook & Brosch 2008b). The data were obtained with a wide-field CCD imaging at the prime focus of the C18 at the Wise Observatory. The fields are located within 1°.50 from the ecliptic plane and include a region within the main asteroid belt. The observed fields show a projected density of 23.7 asteroids per square degree to the limit of our observations. 13 of the lightcurves show a well defined modulation and were successfully analyzed to derive the asteroids' spins. 11 of these objects have diameters in order of two km and less, enlarging significantly the database of small main belt asteroids with known spin. Five other asteroids were not observed sufficiently to derive a rotation period and we present only some boundary values for them. 14 lightcurves did not show clear variability due to high observational error, low light amplitude or long periodicity not covered well by the seven-night run.

The observations took place on October 4, 5, 6 and 31, and on November 2, 3 and 5, all in 2007. On six of the seven nights the telescope was aimed at the Near-Earth asteroid (NEA) (2212) Hephaistos for an average of 5.5 hours per night, while it was crossing the main belt at a heliocentric distance of 2.74 to 2.88 AU. As a result, 7.2

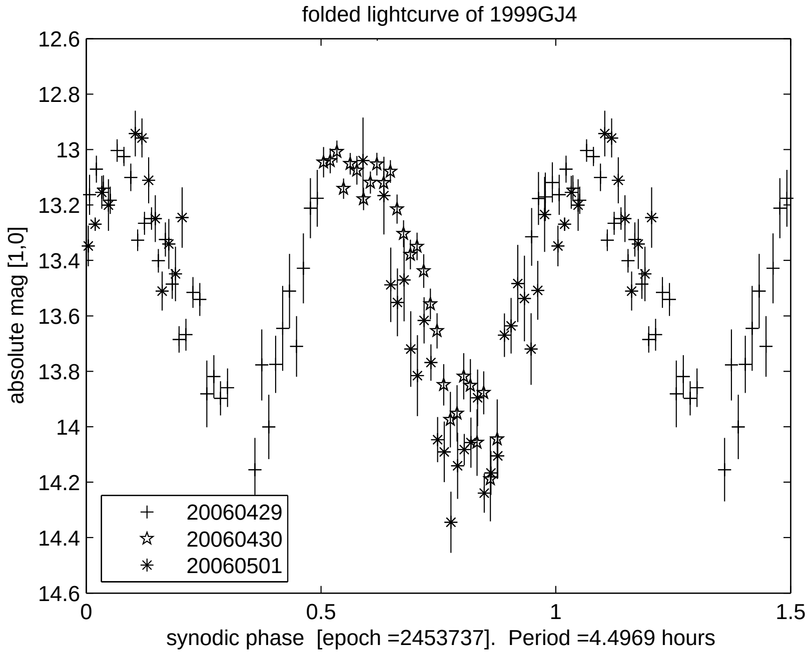

Figure 2. Light curve of the Apollo NEO (40267) 1999 GJ_4 obtained at the Wise Observatory. The measured light points were folded with a period of 4.50 hours and show an amplitude of 1.1 mag.

Main Belt asteroids on average were included in each field and were photometrically measured, in addition to the primary target (2212) Hephaistos. On the last night of this run (November 5, 2007) we performed a follow-up observation on one of the asteroids, (36405) 2000 OB_{48}, which was observed during a previous night. Altogether, we observed 32 different asteroids excluding (2212) Hephaistos. To achieve a point-like FWHM given the prevailing observation conditions (average angular velocity of 0".01 per sec, seeing FWHM of 2.5 pixels) an exposure time of 150 seconds was chosen (120 seconds on November 5).

6. Conclusions

We described here the capabilities of the Wise Observatory, with special emphasis on observations of Solar System bodies. We presented published results regarding NEAs and results being prepared for publication about MBAs. We stressed to facility with which one can obtain world-class observations; these do not require the active presence of an observer at the telescope since the data acquisition is performed remotely.

The Wise Observatory and the Tel Aviv University are ready to collaborate on a regional basis with astronomers of other countries in achieving high-quality astronomy and in promoting Space Research and Space Research education throughout the Middle East and Africa.

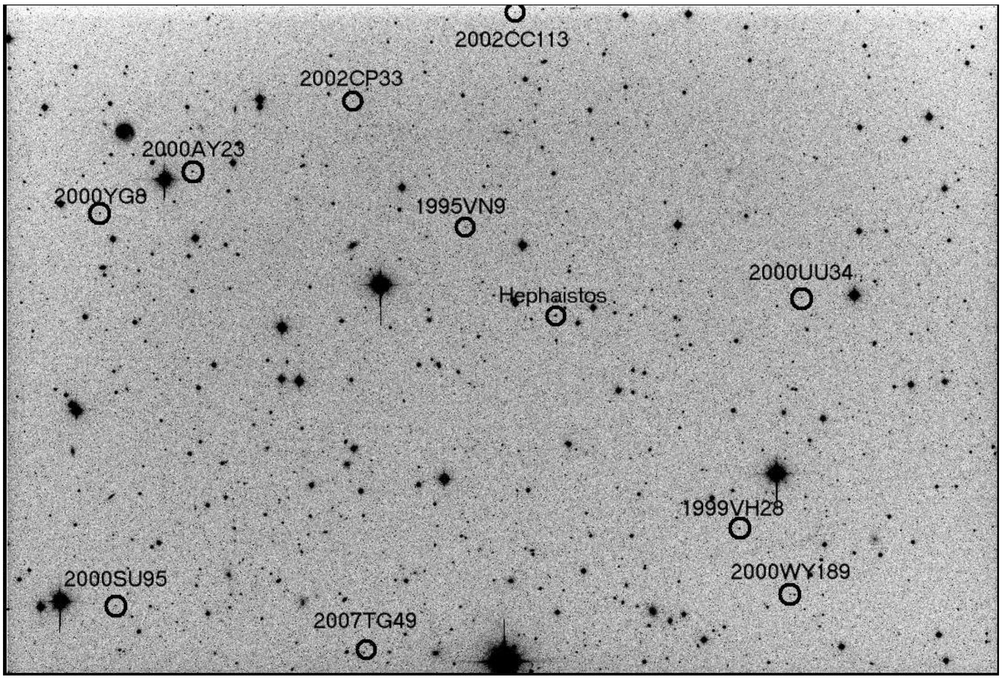

Figure 3. Eleven asteroids appear on this wide field (40.5'x27.3') image obtained with the C18 (displayed here as negative). Each asteroid is labeled with its name and is marked by a circle. The field was followed for 7.75 hours and the light curve of each asteroid was measured.

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