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The Synchronous Network of small Robotic Telescopes (Ukrainian RoboNet. Avant-project)

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1 Introduction

The primary systems of automated telescopes were designed to search for simultaneous optical activity associated with gamma ray bursts in response to real-time burst notifications provided by the networks like BATSE/BACODINE. One of the first such system GROCSE II as far back as 1995 consisted of 4 cameras on a single mount and had a 4 second slewing time and could reach $V \sim 14$ with a 5 sec exposure to obtain the first images of a gamma ray burst. However, many of these systems failed to identify any positive optical counterparts. First "triggered" telescopes were needed to diversify their operations and design specifications so that to provide observations in other areas of astronomy, astrophysics and space science. We may point out such programs as: to find Supernovae and other optical transients in galaxy clusters; the "temporal spectroscopy" of variable stars (the Whole Earth Telescope), which provides observational data on the internal structure of stars; monitoring of lensed quasars, in order to detect the time-delay between the images (Lensed Quasars Monitoring project); the closely spaced monitoring of microlensing events provided by the network of telescopes to reveal the presence of planets near the lens or the source (CMAN project); time-resolved photometry of flare stars in the frame of international multi-observatory campaigns, and so on. The opportunities of small robotic telescopes are demonstrated by the some following examples.

TAROT (Boer, 2003) is an automatic, autonomous observatory whose first objective is the real-time detection of optical transient counterparts of cosmic gamma ray bursts (GRBs). TAROT is linked to space experiments devoted to the detection and localization of GRBs, as HETE-2, an experiment with a participation of the CESR, and also CGRO/BATSE, SAX, and SWIFT (http://tarot4.obs-azur.fr/). Telescope: D = 250 mm , F = 800 mm. Camera: Andor Tech. equipped by a CCD Marconi 4240. The limiting magnitude is of $V \sim 17$ with a 10 sec and $V \sim 19$ with a 1 min exposure. For example, TAROT began observations of GRB detected by HETE on 09 Feb 2005, 03:55:21 UT, 26 seconds after the GCN notice. 84 unfiltered images of 30 sec taken 03:56 to 05:04 UT were co added. The associated optical transient (OT) is not detected at the limiting magnitude of $R = 19.2$.

Full automated Internet-telescope MASTER (Mobile Astronomical System of the TElescope-Robots), Russia, Near Moscow, Alexander Krylov Observatory, Sternberg Astronomical Institute. MASTER is the first Russian robotic telescope for observations gamma-ray bursts (http://observ.pereplet.ru/resurs_e.shtml). Modified Richter-Slefogt Camera, D = 355 mm, D/f – 1:2.4, Flat FOV – $5 \times 5°$. CCD-camera AP16E (4000x4000). MASTER Sky Survey was started in January 2004. On optical observations of GRB: GRB030418 (GCN 2158) – 11 hours after the GRB, first observation, OT limit 16.5; GRB040308 (GCN 2543) – 48 h after trigger time, OT limit 21.2 mag .

Make also examples of the small-sized automatic telescopes employing for collaborations. The WHAT (Wise Hungarian Automated Telescope) is a small robotic telescope located at the Wise observatory, near the city of Mizpe-Ramon, Israel (http://wise-obs.tau.ac.il/). The telescope is designed to be fully automated and be controlled remotely via a web-interface. The WHAT consists of a Canon 200 mm f/1.8 lens and an Apogee 2048x2048 pixel CCD, yielding a 6x6 degree field of view. The project is a collaboration between the Wise observatory of the Tel-Aviv University and Konkoly observatory of the Hungarian Academy of Sciences. Among first images is comet NEAT on May 11, 2004.

Micro Observatory (Harvard-Smithsonian Center for Astrophysics, New Jersey): a Network of five automated telescopes controlled over the Internet; for students and teachers, nation wide; PIs: O. Gingerich and Ph. Sadler (Querci, 1999).

Tenagra Observatory, Sonoita, Arizona; robotic telescope, D = 350 mm, remote observing; Supernova patrol; minor planet discovery; time series studies of variable stars; also dedicated to education; PI – Dr. M. Schwartz (Querci, 1999).

Bradford Robotic Telescope Observatory on Oxenhope moor; robotic and remote observing; D = 460 mm, a web-based interface; automated pointing system; for authorized users, schools and amateurs (Querci, 1999).

Thus, at present not only large telescopes of the 10-m class can do a lot of astrophysics but also small-sized ones from 25-cm to 1-m diameters can lead off new fields of research, too. Robotic telescopes, as well as networks of them can make a powerful tool for the multi-wavelength observations of all the types of variable stars during a long time, comets, near-earth objects, minor planets, as well as a valuable tool for education.

2 Practical aspects of SNRT

Exclusive aspect of SNRT consists of synchronous operation of several far remote telescopes based on the robotic instrumentation and software. This allows studying wider class of problems at other viewing angle as compared with single telescopes. So, SNRT uses GPS technology to take the pointing, guidance and observations in the synchronous operating mode. Remote telescopes can be synchronized to UTC within better than 1 μs. This opens a unique opportunity for studying ultrashort-period variability. The telescopes are supplied with a low resolution optical fiber spectrograph for time-resolved spectrography. This permits studying short-time variations both in a continuous spectrum and spectral lines simultaneously. SNRT is designed to be controlled remotely via a web-based interface. This allows both remote observations and obtaining of results on line for users continent wide. The Joint Engineering and Operation Center provides a development of the robotic instrumentation, software and oversees day-to-day operations.

3 SNRT system perfomance

SNRT is completed with the NexStar GPS telescopes (Fig 1). The NexStar GPS users are in the next generation of computer automated telescopes. The NexStar with its on-board GPS and digital compass system pinpoints its exact location and points automatically to the specified star.

3.1 Specifications

Telescope motion and operations of the CCD, photometer and spectrograph have been placed under computer control, allowing automated observations for long-term survey and monitoring projects. The NexStar GPS has 280 mm f/10/6.3/2 optics. Imaging can be done either unfiltered or through U, B, V, R and I broad-band filters. The NexStar GPS has a designated auto guiding serial port for use with a CCD autoguider. The auxiliary RS-232 port allows to control the NexStar remotely.

Fig. 1. The NexStar GPS

- Optical design................................Schmidt-Cassegrain optical system
- Clear aperture................................280 mm
- Focal ratio.....................................f/10/6.3/2
- Filters..U, B, V, R, I, Clear
- CCD ....the Alta E Series camera, E2V Back-illuminated
- Pixel format..................................2048 columns x 2048 rows, 27.6 x 27.6 mm
- Pixel size.......................................13.5 microns square
- Field of view covered by CCD.......34 / 54 / 164 arc min for f / 10 / 6.3 / 2 focal ratios
- The mid band 3600 – 9400 Angstrom (Absolute Quantum Efficiency > 30%, Peak QE > 90%)
- Programmable, intelligent cooling to 60C below
- Precision Time Delayed Integration readout
- Dual 16-bit and12-bit digitization to 24 Mbytes camera memory
- 100 bT Ethernet interface: up to 300 kHz throughput TCP / IP or UDP protocols
- Drift scanning may be programmed from 5.12 microsecond to 336 milliseconds per row, with up to 65535 rows per image
- Binning up to 10 Horizontal x 4096 Vertical
- Multiple images (up to 65535) can be acquired and transferred to camera memory automatically.

The Alta E Series Cameras represent new paradigms. The Alta family also includes a full line of cameras with USB 2.0 interface, with speeds up to 10 MHz. Two LEDs are provided for user display functions. Users may program each LED for one of the following status displays: Expose: Image Active; Image Done; Flushing; Ext. Trigger; Ext. Shutter Input; Ext. Start Readout; or other miscellaneous diagnostic functions. Two camera's serial ports are included for control of other devices such as mounts, focusers, filter wheels and spectrographs, enabling the camera to act as host to most / all peripheral equipment without the need for a local computer in remote control settings. Serial port control is also accessible / programmable through the ActiveX camera driver. All these enable the NexStar GPS to act as peripheral equipment of user's computer in the remote control mode.

4 The search for short-lived flare events

Detection of both the fine scale and short-term variability with several synchronously operated telescopes represents a novel approach in astrophysics. A considerable gain can be achieved in point of detection of

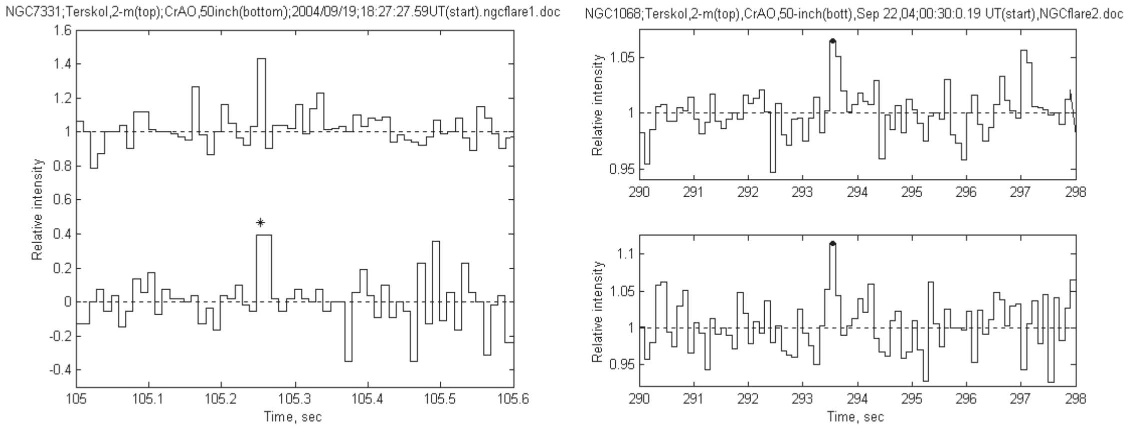

Fig. 2. Left side: The light curves of NGC7331 taken synchronously at intervals of 10 ms with the Terskol 2-m (upper) and the Crimean 50-inch (lower) telescopes separated by a distance of about thousand kilometers from each other on Sept 19, 2004, 18:27:27.59 UT (start time) in the B band. Both curves are in relative units, the lower is shifted for convenience. The joint confidence probability of a burst is of 99.999880 percent. Right side: The same for the Seyfert galaxy NGC1068 on Sept 22, 2004, 00:30:00.19 UT (start time). The light curves are taken synchronously at intervals of 10 ms and rebinned to 0.5 s with the Terskol 2-m (upper) and the Crimean 50-inch (lower) telescopes, the B band. The flare event is defined by the joint confidence probability of 99.999917 percent.

short-lived bursts utilizing the coincidence technique. Employment of the long-term Flare Monitor with two far remote telescopes had revealed short burst events in some galaxies. For example, the light curves taken synchronously from the core of NGC7331 with the Terskol 2-m and the Crimean 50-inch telescopes on Sept 19, 2004, 18:27:28 UT show coincident burst with duration of some hundredths of a second and amplitude of about 0.4 mag in the B band (Fig 2, left side). Applications of the coincidence technique to the Seyfert galaxy NGC1068 also revealed a short burst (Fig 2, right side). The burst consists of a fast ($\sim 0.1\,s$) rise time pulse with decay time about 1 s. Short-lived bursts are the most directly linked to accretion processes in the vicinity of compact objects, and discovery of such events can provide unique information on black holes in centers of galaxies and dense globular clusters. The long-term Flare Monitor within the frame of the SNRT project may lead to substantial possibilities in detecting of both extreme small scale and short-lived stellar variability in the various types of variable stars.

5 A note on microlensing

Microlensing appears as a single object of increased apparent brightness because of the passage of the gravitational lens across the Earth-source line. For the details one needs general relativity. A microlensing event may be caused by objects such as normal stars, neutron stars, black holes or planets. Lensing of stars in the Milky Way and its environs by foreground stellar-sized masses is now routinely observed; this requires very large surveys because of order 1 in 10^6 stars is being strongly lensed (Sutherland, 1999). The nature of the objects giving rise to the lensing towards the Magellanic Clouds are a significant puzzle at present; the inferred lens masses are well above 0.1 solar mass, which means that they cannot be ordinary hydrogen-burning stars, as these would be visible in large numbers in deep images, e.g. the Hubble Deep Field. Sutherland (1999) noted an extraordinary solution of the problem, e.g. possibly primordial black holes (PBH). This is a very important result, as these objects would have been virtually impossible to detect directly. Towards the globular clusters microlensing events may be observable because of lensing of stars by PBH / BH concentrated in the clusters or in the foreground of them (timescales from hours to days). Miller et al. (2002) suggest that in some tens of per cent of globular clusters a very massive black hole is formed. This black hole sinks in $\leq 10^6$ yr to the center of the cluster, where in the $\sim 10^{10}$ yr lifetime of the cluster it accretes $\sim 10^3$ $M_\odot$, primarily in the form of lighter black holes.

Another active area is the search for microlensing towards the galaxies like M31. Two groups called AGAPE and MEGA have done pilot studies towards M31 (Sutherland, 2001). The detection of four microlensing events towards M31 is now established. The events detected are all compatible with stellar lenses (Novati, 2003).

6 Some questions on time-resolved spectrography

Time-resolved spectra are proposed to be obtained by means of a fibre-fed spectrograph with the effective resolution of about 15 Angstrom. Such observables as spectral energy distribution of the continuous spectra, the Balmer jump, the slope of continuum emission redward of the Balmer jump, the Balmer decrement, the members of the Balmer series with quantum number up to 10. . . 11, the Ca II K-line and the like appears to be available for constant and variable stars up to $V \sim 11$ in sampling cycles of about a few minutes duration. These observables allow to calculate spectroscopic models for stellar flares and other transients, to study the non-LTE effects without profile information. This mode of operation seems greatly desirable in addition to the broad-band photometry (Kunkel, 1970).

7 SNRT and the ultrahigh variability

We want to point out that the study of fast varying sources can be put into practice with SNRT. We may talk of superfast photometry when we searching for time varying phenomena whose characteristic time scale are much less than the mean time between two photons. Emission variations on timescales down to microseconds might be encountered (1) in objects far from thermodynamic equilibrium, (2) in the X and gamma-ray sources (3) in accretion discs around compact objects, etc. (Dravins, 1994). For sparse quantum fluxes light curves are of little use. However, according to the Fourier theorem, there are not any restrictions on the absolute values of the mean intensity, frequency of sampling, etc. Thus, the Fourier transform is an efficient tool for detection and estimation the signals in superfast photometry. In particular, the minimum detectable amplitude of a signal depends only on the total number of photons, which have arrived. The data network synchronization of the SNRT is based on GPS receiver to discipline local photometer timing systems relative to UTC. Tracking the source with two or more distant telescopes synchronized to UTC and utilizing the cross-correlation technique we can detect and estimate ultrashort-lived temporal variations.

8 SNRT's attitude towards SETI

The SETI project (Search for ExtraTerrestrial Intelligence) is based on scanning a large part of the sky with radio-telescopes. The incoming data is recorded in real-time, giving an enormous amount of noisy data The successful outcome of this matter is in doubt for many years. The innovative philosophy stands on three fundamental pillars: (1) the optics, (2) the minimalism of a problem solver and (3) the simplicity of a conclusion. The natural sources of radiation (the Poisson and Gaussian streams of quanta) are characterized by the minimal information capacity (the first and second moments only) and, hence, maximal entropy. Any information message reduces entropy of a light quantum stream. Entropy is a common concept in many fields, mainly in signal processing. Different entropy criteria are available and can be easily integrated with the Shannon/energy/threshold or the user defined entropy functions. Classical entropy-based criteria describe information-related properties for an accurate representation of a supposed stationary random or a periodic signal. The threshold statistical detector measures entropy of a light stream and gives out the message on suspicious objects. The detailed statistical analysis of quanta follows in a range of frequencies up to 1 MHz. We must cover all the frequency range of hypothetical communications.

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