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Wide–Field Sky Monitoring - Optical and X-rays

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Abstract. We report on selected projects in wide-field sky imaging. This includes the recent efforts to digitize the astronomical sky plate archives and to apply these data for various scientific projects. We also address and discuss the status of the development of related algorithms and software programs. These data may easily provide very long term monitoring over very extended time intervals (up to more than 100 years) with limiting magnitudes between 12 and 23. The further experiments include CCD sky monitors, OMC camera onboard the ESA Integral satellite, robotic telescopes, and innovative wide-field X-ray telescopes.

Key words. Stars: imaging – Surveys – X-rays: telescopes

1. Introduction

The wide–field sky monitoring and imaging is valuable in numerous regions of astrophysics including multispectral analyses of high–energy sources. The recent and future activities in the wide–field sky imaging and sky monitoring of the High Energy Astrophysics Group at the Astronomical Institute of the Academy of Sciences of the Czech Republic includes the following programs. (1) Optical monitoring and analyses of selected targets with robotic telescopes – BART, BOOTES, SUPER–BART, BOOTES–IR (2) Analyses of archival sky patrol plates (3) Satellite experiments: INTEGRAL OMC, LOBSTER (4) CCD sky monitoring – long term analyses (in collaboration)

2. Robotic telescopes

2.1. BART

The Burst Alert Robotic Telescope BART is a 25 cm aperture Meade CCD telescope with customized software and attached 64 mm aperture wide-field camera. The primary goal is the rapid follow-up observation of positions of Gamma Ray Bursts (GRBs) provided by satellites (HETE, INTEGRAL, Swift, ...) but the secondary scientific program includes selected sources such as blazars, AGNs, and Cataclysmic Variables, mostly linked to the ESA INTEGRAL project. For the wide–field sky imaging is especially important the wide–field camera (identical with the Integral OMC Test Device) pro-

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viding FOV of nearly 6 x 7 degrees and achieving a limiting magnitude of 15.5. The database of images taken by this device can be accessed via a www form interface at http://lascaux.asu.cas.cz. We also develop a larger CCD telescope with the aperture of 50 cm and we expect to operate it from mid of 2003. Considerations have also started on a high speed SUPERBART telescope of a Richter-Slevogt type with aperture of 70 cm.

2.2. BOOTES

The BOOTES system is a result of Spanish–Czech collaboration and has 2 stations in Spain with 3 robotized Meade 30 cm telescopes with SBIG ST–8 CCD cameras and wide-field CCD cameras attached (Castro–Tirado et al., 1999). The telescopes are fully automated. One telescope includes a wide–field prisma spectrograph developed by Ondřejov Observatory mechanical workshop, specially designed for the BOOTES robotic telescope. The spectrograph achieves a limiting magnitude 13.5 over 0.5 deg FOV and the spectrum can be taken within 1 min after receiving an alert message. More recently there are efforts to develop and to operate a larger (aperture of 60 cm) BOOTES-IR robotic telescope in excellent climatic conditions of the Sierra Nevada Observatory in Spain.

2.3. Scientific goals of the robotic systems

The scientific goals of the BART and BOOTES systems can be briefly outlined as follows.

- GRB follow–up observations - within 30 seconds, automated response
- Rapid response to alerts from Čerenkov telescopes (new)
- Secondary science - monitoring and photometry of selected triggers (mostly blazars, QSOs, AGNs, and selected binary galactic sources) with focus on objects linked to the INTEGRAL satellite programme.
- Tests of newly developed software etc.
- Wide involvement of astronomy and informatics students

3. Integral OMC Camera

OMC (Optical Monitoring Camera) is one of four onboard experiments on the ESA INTEGRAL satellite. The OMC test camera (Test Device) is in routine operation at the Ondřejov Observatory. Our contributions focus mainly on software and on science. The OMC camera is expected to provide valuable data for blazar/AGN analyses especially for objects located inside galactic scans, which will be provided every 3 days, covering the range between + and - 13 degrees from the galactic equator. The instrument will provide V filter photometry down to mag 18. Due to limited onboard memory, only 100 objects per pointing will be evaluated. The objects will be selected from the OMC catalogue as objects located in the OMC FOV, taking into account the allocated priority.

4. Archival sky patrol plates

4.1. Introduction

The photographic sky patrol archives can easily provide thousands of exposures for any celestial position, reaching monitoring intervals of up to few years of continuous monitoring - i.e. tens of thousands of hours. The recent efforts to digitize the plates and the corresponding software development significantly facilitate the extraction of unique scientific data from archival records and related reductions and analyses.

The photographic sky monitoring is available for more than 100 years. However, only the recent development of photographic scanners and powerful computers allows an efficient extraction of scientific data. Some of the archives have very high quality plates achieving limiting magnitudes of up to 20 ... 23 (direct imaging) and /or 17....19 (spectral with objective prism).

There are more than 3 millions of archival astronomical photographic plates located in dozens of observatories around the world (Hudec, 1999). Only a fraction of the archives have devices for digitization of plates. Some of the archives have started projects to develop high quality scanners to convert all plates into files/CD ROMs (e.g. The Royal Observatory Brussels). There are efforts to use these data for automated evaluation of objects on the plates and creating their light curves (Hudec et al., 1999).

4.2. The photographic sky patrols still in operation

Two of the photographic sky patrols are still in operation, regularly taking photographic patrol images every clear night. The Ondrejov all sky patrol operated for monitoring of bright meteors has a sensitivity of mag 12 in the best case and a very large sky coverage (full visible sky hemisphere). The Sonneberg sky patrol is operated for variable stars simultaneously in two colors with limits 14 ... 15 but a less extended (one plate covers 30 x 30 deg) sky coverage. Both programs exhibit suitable scanners to digitize and to evaluate the patrol images.

4.3. The UDAPAC project

The recent UDAPAC Project represents the first effort to create an European Plate Centre with related facilities, staff, software and expertise to extract scientific information from archival astronomical plates. The UDAPAC plate center is located at the Royal Observatory in Brussels, Belgium, with many other scientists involved (http://midasf.oma.be/ fido/ovid.html).

Archival and sky patrol plates represent a valuable tool in investigations of various types of high energy sources such as blazars/quasars, X–ray binaries, X–ray and gamma–ray transients, etc. It is obvious that the automated evaluation of sky patrol plates has large potential in:

- providing extended monitoring intervals with good sampling,
- allowing long-term evolution and changes to be studied
- searching for optically variable AGNs-QSOs-blazars and other objects
- providing their light curves with good sampling
- searching for their flares
- providing simultaneous and quasisimultaneous optical data for satellite campaigns, even back in time
- monitoring of objects as base for proposals for ToO (Target of Opportunity) for satellite high energy observations
- providing extended database for identification and classification of sources

The detection and investigation of very large amplitude flares from AGNs may serve as an example. There is increasing evidence that some AGNs may exhibit very large amplitude flares exceeding magnitude 10 (Hudec et al. , 1996). These large flares are however rare so very large fractions of monitoring times (of order of thousands hrs or more) are required to detect them. This can accessed easily on plates but hardly by other methods.

Some collections (Hamburg, Sonneberg, Edinburgh,...) include also spectral plates taken by objective prism. This can also provide important tool for object identification and classification. Some of the X-ray objects detected by recent analyses can be very easily rediscovered and further studied - even back in the history - on high quality direct and spectral archival plates.

4.4. Suggestions for the future

- Rapid evaluation of the plates obtained in still running patrol systems (within one day or so) - monitoring of activity of high-energy sources and providing inputs for satellites - ToO.
- Extended digitization of plates - automated searches for HE counterparts

as well as their classification and detailed study and automated generation of densely populated long-term light curves of all objects on the plates.
– Innovative methods and procedures to complete these tasks.

4.5. *The software development*

So far, the data recorded on archival plates were accessible only by special procedures. The recent wide digitization of plate collections offers significantly easier access by computers. However, there is still a gap between the digitized archive and the scientific use. Special software is required to fill this gap.

We have developed new algorithms to access data on digitized plates and have tested these techniques in trial sets of digitized plates from the Sonneberg Observatory sky patrol archive. The new algorithm is based on the flood method. This method, applied to the digitized photographic plates, is able to reveal the star images for further analyses. This method has been tested on a set of digitized Sonneberg Sky Patrol plates with very promising results if compared with other methods. The flood method is based on a similar idea as the watershed method and is reasonably simple and quick.

5. CCD Sky Monitors

The ROTSE CCD sky monitor is operated and directed by the University of Michigan, USA. It is an automated telescope for GRB follow–up optical analyses, but provides also daily CCD sky monitoring down to -30 degrees declination with a limiting magnitude of 15. Three year database is available so far and data are available via collaboration/proposal submission Our ROTSE proposal/collaboration focus on evaluation of two fields (with Cyg X–2 and with OJ287, both fields exhibit a large number of other variable objects), the main goal being to develop and to test method for searches for new variable stars and objects and their classification including generating light curves for selected objects. The problem related with this type of experiment is how to transfer and to manage Terabytes of raw data, as well as the reliable pipeline for automated data analyses.

6. Wide–field imaging in X–rays

Wide field X-ray optics (with FOV of up to 180 deg) has been suggested in 70ies by Schmidt (Schmidt, 1975, orthogonal stacks of reflectors) and by Angel (Angel, 1979, array of square cells) but has not been constructed until recently. The **Schmidt** device consists of a set of flat reflecting surfaces. The plane reflectors are arranged in an uniform radial pattern around the perimeter of a cylinder of radius R. X-rays from a given direction are focussed to a line on the surface of a cylinder of radius R/2. The 1D dimensional focusing device offers a wide field of view, up to maximum of 2π with the coded aperture. Two such systems in sequence, with orthogonal stacks of reflectors, form a double-focusing device. The full lobster-eye optical grazing incidence X-ray objective in the **Angel** arrangement consists of numerous tiny square cells located on the sphere and is similar to the reflective eyes of macruran crustaceans such as lobsters. The field of view can be made as large as desired. It is possible to achieve good efficiency for photon energies up to 10 keV and/or even more if additional coatings are applied. Spatial resolution of a few seconds of arc over the full field is possible, in principle, if very small reflecting cells can be fabricated.
The recent efforts have lead to the design and development of prototypes of LE X-ray telescopes (Inneman et al., 2000, Hudec et al., 2000). The medium prototype of the Schmidt geometry represents one module and consists of two perpendicular arrays of double-sided X-ray reflecting flats (36 and 42 double-sided flats 100 x 80 mm each). The flats are 0.3 mm thick and gold-coated. The focal distance is 400 mm from the midplane. The FOV of one module is about

6.5 degrees. More such modules may create an array with substantially larger FOV. The optical and X-ray tests indicate performance close to those calculated and expected (e.g. by ray tracing). The advanced mini-Schmidt prototypes are based on 0.1 mm thick glass plates 23 x 23 mm, gold coated, spaced at 0.3 mm. 60 such plates are used for one module, the double focusing device is created by two such modules. The aperture/length ratio is 80, the reflecting surface microroughness amounts to 0.2 - 0.5 nm. The FOV of the module is 2.5 deg. More recently, both the micro and macro Schmidt LE arrays have been designed, assembled and tested in optical and partially in X-rays. The micro module is based on very thin gold-coated glass foils only 50 microns thick spaced at 70 microns, the size of the full module being 3 x 6 mm. The macro module consists of 300 x 300 mm large gold-coated glass foils 0.75 mm thick spaced at 12 mm, the full module size represents 300 x 600 mm.

The use of imaging optics resulting in sensitive X-ray sky monitoring will be advantageous for many scientific areas. The science of LE X-ray telescopes will include supernova explosions , X–ray afterglows of GRBs, high–energy binary sources, AGNs, blazars, X-ray novae, X-ray flares on stars, X-ray transients, cataclysmic variables etc. The use of LE telescopes will allow these objects to be detected and studied by sky patrol monitoring. The high sensitivity and wide–field coverage of Lobster telescopes will provide the unique opportunity to detect Supernovae in X-rays. So far, only few such detections exist, mostly due to insufficient sensitivity and poor angular resolution of recent X-ray sky monitors.

7. Conclusions

The recent analyses confirm the valuable and unique scientific information recorded in archival astronomical plates. For more recent time intervals (starting 1998 or so), archival monitoring data for various objects can be also retrieved from CCD sky monitoring provided by CCD sky monitors such as ROTSE, BART and BOOTES. The various prototypes of both Schmidt as well as Angel arrangements have been produced and tested successfully for the first time, demonstrating the possibility to construct these lenses by innovative but feasible technologies. This makes the proposals for space projects with very wide field lobster eye optics possible. The long-term analyses of X-ray emission of blazars as well as their flaring activity will represent an important part of the related scientific program.

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