The aim of this paper is to present an outline of the idea which I expect will lead to

Introduction

ABSTRACT

Montroming AI Sky for Variability

For the follow-up observations with the largest telescopes

Astronomers have already discovered thousands of new variable stars, a

A few percent of all stars are variable, yet over 90% of variables brighter
image all sky visible from a particular site every clear night, and archive the data, for example ROTSE and LOTIS. There are several other projects under development, and in various stages of implementation, like ASAS, STARE and TAROT. A lot of information about these and many other projects is available on the World Wide Web. The links can be found on my home page\(^1\). This paper has been influenced by my experience with the OGLE (Udalski et al. 1997\(^2\)) and ASAS (Pojmański 2000\(^3\)), and to a large extent it presents my plans for the future.

The existing catalogs of variable stars are very incomplete. Pojmański (2000) discovered almost 4,000 variable stars brighter than \( I = 13 \) mag in a small area of the sky, just 300 square degrees. Only 4% of these are listed in any catalog of variable stars, while 96% are new discoveries. Using archive ROTSE data Akerlof et al. (2000) found 1781 periodic variable stars brighter than 14 mag in 2,000 square degrees, 90% of these were new discoveries. All these observations were made with very small, automated instruments, with an aperture of only 4". There may be about one million variable stars in the whole sky accessible to ROTSE and ASAS, waiting to be discovered.

Why should we bother? The simplest answer is: because those variables are out there. For those who would like to know more specific reasons I shall list some in the next section, also see Paczynski (1997).

How should the searches be done? There are many approaches. Some are very focused, like ROTSE and LOTIS, concentrating on a single goal: to detect optical flashes associated with gamma-ray bursts. In addition to a large number of upper limits there was one spectacular discovery of an optical flash associated with the GRB 990123, which peaked at 9 mag (Akerlof et al. 1999), with the source being at a large redshift, \( z = 1.6 \). By design ROTSE archives the data, but a broad search of variability is not high on the priority list, though it has generated an interesting paper (Akerlof et al. 2000). Other projects, like VSNET, monitor variability of a large number of preselected stars. Still other projects, like ASAS, are not focused on any particular type of variability or any specific objects, with a broad goal to monitor everything that varies in brightness (stars, AGNs, etc.) or position (asteroids). Preliminary results were presented by Pojmański (1997, 1998, 2000). In this paper I am making a case for such broad searches.

How should the projects evolve? I think it makes sense to start small and to expand

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\(^1\)http://www.astro.princeton.edu/faculty/bp.html
\(^2\)http://www.astro.princeton.edu/~ogle/
\(^3\)http://archive.princeton.edu/~asas/
gradually. There are several reasons. A small projects costs less than a big one, it is easier to develop, and a relatively small data rate is easier to handle. Software, which is the most difficult and expensive part of any survey, can be developed gradually. Once a small system works, all the way from photons entering the aperture to the first paper(s) with the early results, it is relatively easy to expand, having learnt what are the difficult elements. This is the pattern followed by the OGLE and ASAS.

There are several important aspects of data handling: real time data processing, calibration, developing public domain archives and alerts. Problems in these areas are as much technological as sociological or psychological. To take full advantage of the all sky monitoring an easy public access to the data is very important.

2. The Goals

The many goals of all sky variability searches were listed and discussed in the past (Paczyński 1997). The following is a brief summary.

A well calibrated survey with well described search method will provide large complete samples of eclipsing binaries, pulsating stars, exploding stars, stars with large proper motions, quasars, asteroids, comets, and other types of objects. Complete samples are important for statistical studies of the galactic structure, the stellar evolution, the history of our planetary system, etc.

A large number of variables of any specific type will allow future selection of the ‘cleanest’, simplest objects. A physicist in his or her laboratory may create conditions which allow a study of a specific phenomenon with a minimum of disturbances. An astronomer cannot influence the universe, various objects can be only observed. However, given a large number of objects an astronomer may select one (or several) which are the simplest, the ‘cleanest’ from some particular point of view, and analyze them in great details with follow-up observations, which will provide a better understanding and/or a better calibration of the particular type of objects and/or processes.

In a large sample some very rare objects or events will be detected. A spectacular example from the past is FG Sagittæ, a nucleus of a planetary nebula undergoing a helium shell flash in front of our telescopes (Woodward et al. 1993, and references therein). Some may provide spectacles which bring astronomy to the general public. Some recent examples are the supernova 1987A in the Large Magellanic Cloud, and a collision of the comet Shoemaker-Levy with Jupiter in the summer of 1994.
Fully automated real time data processing will provide instant alerts for a variety of unique targets of opportunity: optical flashes from gamma-ray bursts, novae, dwarf novae, supernovae, gravitational microlensing events, small asteroids that collide with earth every year, etc. Such alerts will provide indispensable information for the largest and most expensive space and ground based telescopes, which have tremendous light collecting power and/or resolution but have small fields of view.

The archive of photometric measurements will provide a documentation of the history for millions of objects, some of which may turn out to be very interesting in the future. The Harvard patrol plates and the Palomar Sky Survey atlas provide an excellent example of how valuable an astronomical archive can be.

New objects and phenomena will be discovered; this is virtually guaranteed whenever the volume of data increases by several orders of magnitude.

A specific example of targets for calibration to be provided by the all sky searches are the detached eclipsing binaries. The distance to the Magellanic Clouds is the important step towards the determination of the Hubble constant, and its uncertainty is the largest contributor to the error in the $H_0$ obtained by the HST Key Project (see Mould et al. 2000, and references therein). The most direct and accurate distance to the LMC and SMC obtainable with current technology is a century old method based on detached eclipsing binaries. An excellent outline of the method with a complete list of historical references and the up-to-date status is provided by Kruszewski & Semeniuk (1999). For the method to be fully trusted it has to be calibrated with relatively nearby, and hence bright eclipsing binaries, towards which purely geometric distances can be measured by means of parallaxes or a combination of astrometry and radial velocity amplitudes. To select the best object for the task a complete list of such systems is needed, yet the existing catalogs are very incomplete (see Paczyński 1997, Pojmański 2000).

3. Alerts and Archives

It is somewhat surprising that while there are several examples of various alert systems that work well (e.g. microlensing alerts by MACHO in the past, OGLE, and to some extent EROS in the past as well as now), large archives of variability are not so easy to find. There are technical as well as sociological or psychological problems. While my experience is mostly based on microlensing searches, similar patterns can be found elsewhere.

Some projects, like OGLE, try to release as much data as possible. The reason: there is far too much data for a small team to fully analyze, and the more citations there are to
the OGLE, the better it is for the project. Still, only a small fraction of the total has been released as quality control, calibration etc. are very labor intensive and time consuming. Microlensing photometry is placed on the Web in near real time, but catalogs of pulsating and eclipsing stars take at least a year to prepare, while there has been no general release of $\sim 10^7$ photometric measurements of $\sim 10^5$ variables of many kinds. VSNET provides data for many interesting variable stars at their Web site 4. Another example of almost immediate release of data is provided by the All Sky Monitor team on the Rossi X-ray Timing Explorer though the volume is relatively modest and hence easy to handle.

I expect that before too long robust enough software will be developed to allow virtually all data from projects like OGLE and ASAS to be put on the Web in near real time. The question remains: how many teams will be willing to follow this policy? I think it depends on the way the community evaluates the performance of a project, and on the policy according to which tenure positions are filled. It will be difficult to persuade many to make their data instantly available to the public if the intellectual effort and ingenuity needed for developing a fully functional system (hardware and software) will be considered to be less valuable than the ‘science’ of plotting quantity ‘Y’ versus quantity ‘X’ and discovering a correlation in somebody’s well calibrated data.

A related issue is: should a survey project be broken down into the well defined elements, each done by a single person or a small group? Or should the whole effort be combined in a very large team, with all papers having several dozen authors listed alphabetically, and no way to find out whom to credit and whom to blame for different parts of the project? It is rare that more than a few people do the real work on which a particular paper is based. Is it more sensible to put all the names together, or to cite as separate papers the well defined parts of the whole project? Note that the OGLE has only 6 or 8 members on its team, while ASAS is a single person operation. A very successful DUO project (Alard 1996a,1996b) was mostly a work of a single graduate student. Variability monitoring can also be done by amateur astronomers, as demonstrated by AAVSO, and recently by TASS (Richmond et al. 2000). There is nothing intrinsic to all sky variability searches that requires huge teams and a near anonymity of the real doers. Can the division of labor, with a proper recognition of the diverse contributions, be implemented in astrophysics? It works in economy: ‘The greatest improvement in the productive powers of labour, and the greater part of the skill, dexterity, and judgment with which it is anywhere directed, or applied, seem to have been the effect of the division of labour’ (Smith 1776).

I think that in a matter of just a few years it will be possible to have an unrestricted

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4http://www.kusastro.kyoto-u.ac.jp/vsnet/
access over the Internet to the up-to-date information about the status of any bright variable star, as well as its past variability, with the due credit being automatically given to those who will have provided the data. It is likely that only some people and some teams will follow this open policy, but this may be sufficient to make it practical and to see what impact will it have on astronomy in general. I expect, or at least I hope, that major contributors to the data archives and the alerts will be respected enough to be offered tenure jobs at the major universities.

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