Surveys Are Your Friends

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Abstract. Over the past decade, several all-sky photometric surveys have taken place or are underway. The typical amateur astronomer might think that these surveys have found everything there is to discover in the sky in the magnitude ranges of their telescopes, and that there is no reason to consider a photometric program. Similar surveys have been performed for asteroids, for example, and it is very hard for an amateur to now discover new, bright asteroids. In fact, the optical photometric surveys have quite the opposite effect for variability studies. While the surveys have been very proficient at finding variable objects, they are not well suited for detailed studies of the objects they find. This talk will highlight the most current surveys and what kind of objects and limitations are present in each.

References

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1. Introduction

Creating surveys is a direct follow-on to the research of many astronomers: studying a specific class of objects. What better way to study that class than to find all of its possible members? Surveys have been performed in various passbands, covering the entire sky only once or a small portion of the sky multiple times, and with different instrumentation from direct imaging to spectroscopy. Many of these surveys have little interest for the typical variable-star observer, but many of the recent ones have direct relevance. What will be covered in this paper will be some of the photometric surveys that can be useful to the observer. This paper covers much of the material presented in Henden (2003), but from a different perspective.

One of the main concerns from both amateurs and professionals alike is whether existing surveys are general enough that they encroach on the possible observational research projects that can be done by individuals. This has happened in the asteroid community, for example. About a decade ago, it was easy for small telescope users to find new asteroids, spend a few nights obtaining astrometry and becoming the discoverer of those asteroids. The incentive for many amateurs is that the discoverer of an asteroid has the privilege of naming that asteroid. However, several professional sites obtained funding to implement asteroid searches, primarily to locate near-earth objects that had the potential to impact the earth and cause significant damage. These sites, such as LINEAR, NEAT, Spacewatch and LONEOS, soon developed instrumentation and software sufficiently complex to pretty much discover any asteroid brighter than about 20th magnitude. Since this is the limiting magnitude for many small telescopes, the number of individual discoveries has dropped dramatically. There are certainly other asteroid-related projects that small telescopes can do effectively, but discovering new asteroids is not one of them anymore.

Will the same thing happen for variable-star enthusiasts? This depends on the details of the current ongoing and future surveys. In most cases, the surveys help rather than hinder, and this paper is designed to show how one can use the surveys to further their own variable-star and other photometric research.

2. Astrometric Surveys

There have been astrometric surveys for centuries. The recent ones have built upon the massive photographic surveys carried out by the meter-class Schmidt telescopes during the last half of the twentieth century. These large photographic plates were digitized by groups at the Space Telescope Science Institute (STScI), CalTech, U.S. Naval Observatory (USNO), Royal Greenwich Observatory, and others. The most frequently used products from these digitization efforts is the USNO-A2.0 and USNO-B1.0 catalogs. These provide all-sky coverage, astrometric accuracy in the 0.25arcsec range, and with a limiting magnitude of around 21st. Their main deficiency is the inability to deblend the crowded Milky Way fields. However, for most variable-star and asteroid work, the USNO-B catalog provides a reference frame for determining the object positions, and by going to the pixel servers such as
http://www.nofs.navy.mil/data/FchPix/
you can download small extractions of the digitized plates that cover specific areas.
We have used these extractions when determining which of a close pair of stars was variable (since there are often 5 or more plates that cover a specific region, and those plates were taken many decades apart), the progenitor of novae, approximate colors of objects, etc.

Some variability studies have been performed using the Sky Survey plates. Drissen et al. (1994) used the SRC-J plate overlap regions (one square degree corners of each plate) to look for variable objects. Since the plate corners have the most photometric problems, only high amplitude variability can be studied in this manner. However, the digitized plate material has not been datamined beyond Drissen's study.

There are other astrometric surveys, of course. The Hipparcos satellite carried an experiment called Tycho that surveyed all stars brighter than about 11th magnitude, determining quality photometry in two colors as well as astrometric positions that have typically a few tens of milliarcsec accuracy. An ongoing astrometric survey is UCAC, involving CCD imaging of the entire sky down to 16th magnitude and with similar accuracy as Tycho. There are a couple of other smaller astrometric surveys, such as the CAMC, that have good accuracy but do not cover the entire sky.

The main use of the astrometric surveys/catalogs is for astrometry. They rarely have good photometry since their primary goal is the positions of objects.

3. Photometric Surveys

There have been many photometric surveys in various passbands. These surveys try to cover the entire sky to some limiting magnitude, typically only acquiring one observation per object. The primary use of these surveys (as far as the variable star enthusiast is concerned) is for providing a photometric reference frame for observations.

Tycho2 is the catalog produced by the Tycho team for the Hipparcos satellite. This instrument surveyed the entire sky with a photoelectric photometer in two passbands that are very similar to Johnson B and V. The limiting magnitude is about 11, with photometric errors increasing dramatically beyond about 10th magnitude. You can download the entire 2-million star catalog from
http://www.astro.ku.dk/~erik/Tycho-2
(and a CD is available), but most users just access the catalog from the VizieR site:
http://vizier.cfa.harvard.edu/viz-bin/VizieR

(plus several mirror sites around the world). In fact, many of the catalogs mentioned in this paper can be searched from VizieR, and it should be the first place anyone looks.
VizieR, for example, provides columns of converted Bt/Vt magnitudes into Johnson B/V magnitudes. We will discuss Tycho2 in more detail in the next section.

The Carlsberg Meridian Telescope (CAMC) is a converted transit telescope that uses a CCD to map the southern sky, primarily for precise astrometry. However, they do use the SDSS r' filter, similar to Cousins R, and provide magnitude information in their catalog. You can access the catalog from
http://www.ast.cam.ac.uk/~dwe/SRF/camc.html

The USNO CCD Astrometric Catalog (UCAC) is again primarily an astrometric catalog. They used a 20cm telescope with CCD and a non-standard filter that is halfway between Johnson V and Cousins R. The photometry is relatively good, and is quite good differentially (stars within the same small field). You can access the catalog at
http://ad.usno.mavy.mil/ucac/

The Two-Micron All Sky Survey (2MASS) was an all-sky survey in the JHK passbands. The photometry is good, and can often be used in conjunction with a single optical passband (such as V) to provide color information necessary for selecting comparison stars in a field or doing transformations. The main site is
http://www.ipac.caltech.edu/2mass/
but again you can access it through VizieR.

The Deep Near-Infrared Survey (DENIS) was a competitor to 2MASS, covering only the southern sky in SDSS I' and near-IR JK passbands. This single-epoch catalog has reasonable quality photometry, gives an optical passband, and can be used in conjunction with 2MASS to look for variability. You can access the catalog at
http://www-denis.iap.fr/denis.html

The Roentgen Satellite (ROSAT) point source catalog contains some 95K sources over about 15percent of the entire sky, covering from about 0.1 to 2.0 kev energies. You can access the catalog through VizieR, or go to the home page:
http://wave.xray.mpe.mpg.de/rosat/rra/

The Faint Images of the Radio Sky at Twenty Centimeters (FIRST) survey begain in 1993 using the VLA at a frequency of 1.5GHz. It is slated to cover 10K square degrees of the North and South Galactic Caps and is essentially complete. You can access the catalog through VizieR or at the FIRST hompage:
http://sundog.stsci.edu/

The Midcourse Space Experiment (MSX) used a 35cm space telescope to survey the entire sky in 6 bands from 4.3 to 21 microns. The catalog contains 529724 point sources and is more complete and with higher spatial resolution than IRAS, but without the long wavelength bands. The MSX mission is described on its project page:
http://www.ipac.caltech.edu/ipac/msx/msx.html

The InfraRed Astronomical Satellite (IRAS) was a mission that covered the entire sky in the 12, 25, 60 and 100 micron regions. The point source catalog, containing some 250K sources, can be obtained through VizieR.

The Sloan Digital Sky Survey (SDSS) is an ambitious ground-based project that is covering about 10K square degrees of the sky in 5 wavelengths (ugriz) down to 22nd magnitude. About a million objects will also have spectra; most of these are galaxies, but a fair number are stars. You can access the current data release at:

http://www.sdss.org
The photometry is very good, saturating at about 14th magnitude. Conversions from the SDSS ugriz system into the Johnson-Cousins system are available.

Note that very few of these all-sky catalogs cover the visual wavelengths, and those that do typically have non-standard filters. Their primary use is in determining colors of objects in your fields, for finding objects with peculiar colors, and studying objects at wide wavelengths.

4. Variability Surveys

There have been a few surveys designed either specifically for finding variable objects, or with survey attributes that permit variability searches.

The Robotic Transient Search Experiment (ROTSE) operated a very wide-field unfiltered camera system in New Mexico for many years. One year's worth of data was processed and searched for variable objects. That database can be interrogated at:
http://skydot.lanl.gov
Called the Northern Sky Variability Study, it contains information on millions of stars down to about 14th magnitude.

The All-Sky Automated Survey (ASAS) is an ongoing survey using small automated telescopes at Las Campanas Observatory. It provides V-band photometry over the entire southern sky. The web page:
http://www.astrouw.edu/pl/~gp/asas/asas.html
has a user interface to obtain both photometric and time series information for any star or region of the southern sky. A northern hemisphere version of this survey (HAT) is underway at KPNO.

The Amateur Sky Survey (TASS) uses pairs of 10cm telescopes to image 4x4 square degrees in the sky simultaneously at V and Ic. They have covered the entire northern sky at least once, and intend to revisit all fields as often as possible for several more years. They have a photometric catalog available at
http://www.tass-survey.org
The catalog is relatively complete from about 7th to about 13th magnitudes, with crowding problems in the Milky Way.

The Lowell Near-Earth Object Survey (LONEOS) uses a 0.5m Schmidt telescope plus CCD array to image large regions of the sky every night. Their photometric data has been archived and is being searched for variable objects. You may be able to access specific objects by checking with the LONEOS team:
http://asteroid.lowell.edu/asteroid/loneos/loneos.html
Note, however, that LONEOS observes unfiltered. Similar datasets are potentially available from NEAT, LINEAR, SPACEWATCH and other NEO surveys.

The Quasar Equatorial Survey Team (QUEST) used the CIDA Schmidt telescope in Venezuela to survey the equatorial zone between -6 and 6 degrees declination in BVR, along with obtaining objective prism spectra of many of the objects. A complete catalog has not been posted on-line, but you might try the web site:
http://www.astro.yale.edu/bailyn/quest.html
to get more information.

SDSS. As mentioned above, SDSS provides 5-filter photometry of a large region of the northern sky. It also covers a southern strip multiple times to search for variable objects, and intends to expand its program to perform more galactic structure projects in the near future. In addition, there are overlap regions on most of the scans that can provide variability information, albeit with only a few visits. The variability information is not yet available, but you can check at the web site for updates.

The Massive Compact Halo Object (MACHO) experiment used the Mt. Stromlo 50-inch telescope and a twin-beam CCD camera to obtain simultaneous V and R photometry for many millions of objects in the Galactic Bulge, LMC and SMC. The data is on-line at:
http://wwwmacho.anu.edu/au/Data/MachoData.html
While the spatial coverage is not large, this database is great if your stars happen to fall within one of their fields.

The Optical Gravitational Lensing Experiment (OGLE) uses a 1.3m telescope with V and I filters at Las Campanas to image dense star regions such as the Galactic Bulge, SMC and LMC to look for MACHO events. Their data is also useful to look for any kind of variability. You can find results at:
http://www.astrouw.edu.pl/~ftp/ogle/index.html
However, their full catalog is not available on-line. Note that there are many other surveys for MACHO-like events, again covering only small regions of the sky.

There are several ongoing experiments to look for planetary transits (such as STARE) that cover small regions of sky, much like the MACHO experiments. If your objects happen to fall in those regions, then considerable photometry will be available.

5. Future Surveys

The Galaxy Explorer (GALEX) will survey the entire sky in two UV wavelength bands. It has started to release data. See the web page:
http://www.srl.caltech.edu/galex/
for more details.

The Panoramic Survey Telescope and Rapid Response System (PanSTARRS) is an innovative design for wide-field imaging. Using 4 2-meter telescopes, each with a 3 degree field of view, it is planned to cover the entire sky several times each month. The first telescope is planned to be on-line in 2006. What filters (if any) that will be used is still to be decided; however, since it is funded by the federal government, all data will be publically accessible. See the web page:
http://pan-starrs.ifa.hawaii.edu/public/index.html
for more details.

The Global Astrometric Interferometer for Astrophysics (GAIA) spacecraft is expected to obtain precise positions (and parallaxes) for all objects brighter than 18th magnitude. It will also obtain photometry in several passbands and spectra of most objects brighter than about 15th magnitude. The launch date is still uncertain, but probably not before 2012. The web page is
http://astro.esa.int/gaia

QUEST2, like its predecessor QUEST, was conceived as a quasar survey experiment. The camera is already in use at the Palomar 1.2m Schmidt telescope. This experiment is now envisoned as a stellar survey as well, with multiple visits per field to obtain variability information. See the web site:
http://hepwww.physics.yale.edu/quest/palomar.html
for more information. The camera is being shared with the NEAT team.

The Large-aperture Synoptic Survey Telescope (LSST) is a proposed 8-meter telescope with a very large field of view. It is designed to do repeated observations of about 20K square degrees of sky very rapidly, perhaps every few days depending on the final science goals. This telescope is unlikely to go on-line until 2010-2020 timeframe. See the main web page at
http://www.dmtelescope.org

SWIFT (no acronym) is a multi-wavelength space mission designed to study gamma-ray bursts in detail. At the same time, it will be performing a sensitive survey of the sky in a hard x-ray band. Launch is expected in the Fall of 2004. See its web page:
http://swift.gsfc.nasa.gov/
for more detail.

6. Using the Surveys

Even the existing variability surveys do not usurp the role of the small telescope. There is just too much sky to cover, especially when multiple wavelength coverage or high time resolution are needed. What most of the variability surveys provide is knowledge as to whether a star is variable or not. The constant stars are then usable as comparison stars for performing differential photometry in a field. The variable stars may have crude light curves from the surveys that can be improved by detailed observing of each object. For example, eclipsing binaries can use time-series data in multiple passbands to provide input for analytical models of the systems. Long period variables like Miras and RV Tauri variables may have good light curves in the variability surveys, but usually only in one wavelength band and often only for a few years. The long-term light curves such as provided by the AAVSO may contain far more useful scientific information on long period variables than any short-term survey. So the main role of the variability surveys is to provide a long list of targets for which detailed studies are desired.

Summary

This paper has primarily given a long list of existing and future survey projects. Web links for most of these surveys are provided. While links have a habit of disappearing in short timescales, most of these projects have been adequately funded to provide a home for their databases for many years to come. Archival sites like VizieR and the upcoming Virtual Observatory program will be another means of keeping these datasets on-line. When you are studying variable objects, investigate some of these datasets and see if additional photometric information might be available. Sometimes it can help you decide whether an object is worth further study, or to choose a set of objects that are convenient to study with the equipment in hand. There are thousands of variable objects in need of photometry, so enjoy the process!