The Future of Visual Observations in Variable Star Research

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Abstract This paper discusses several questions: Is the age of visual observations in variable star research coming to an end? What are the benefits and limitations of current and future surveys and CCD observations, and how do such surveys impact the visual observer interested in contributing to variable star research in a meaningful way?

1. Questions

The author is currently a visual observer monitoring cataclysmic variables for outbursts and following the behavior of many long period variables with faint minima. So this subject is of specific relevance personally, and perhaps it is interesting to a number of other variable star observers.

Up until late in the 20th century the monitoring of variable stars was primarily the province of dedicated visual observers. Organizations including the American Association of Variable Star Observers (AAVSO), Association Française des Observateurs d'Étoiles Variables (AFOEV), and The British Astronomical Association Variable Star Section (BAAVSS) have amassed millions of visual observations. These data have been used by astronomers and researchers to analyze and predict the behavior of variable stars.

Technological advances and the availability of CCDs have radically changed the landscape of variable star research. The tools and equipment available to amateur and professional astronomers has improved dramatically, and this raises the question: Has the potential precision of the measurements made by more sophisticated equipment rendered the visual observer obsolete?

Several satellite and ground-based surveys have covered the entire sky. All-sky surveys are currently in progress in many band-passes, and more are coming online in the future. For this discussion photometric and variability surveys will be the main focus. How does the current status and foreseeable future of photometric and variability surveys impact individuals monitoring variable stars visually?

If the ultimate goal is to make a contribution to science, what is the perception and acceptance of visual observations by the scientific community?

For this paper, the relative strengths and weaknesses of visual observations, CCD observations, and surveys will be compared. Photoelectric photometry is not discussed in any detail because it has not been perceived as a "threat" to the future viability of visual observations.

2. Visual observations

Visual observation's main advantage is the ease with which it can be done. With minimal equipment and some basic training anyone can make observations. There are plenty of bright variables that can be monitored with the unaided eye or an easily transportable, inexpensive pair of binoculars. Telescopic observations do not require tracking, so less expensive alt/azimuth telescopes and Dobsonians can be used. This ease of operation opens the door to variable star observing to the greatest number of observers.

Another advantage is the immediate notification of results and reporting observations. The Internet has made it possible to report observations, unusual activity, or discoveries in near real time to organizations and other observers around the world. There is no need for often time-consuming tasks such as reduction of data or examining plates or photos.

The sheer number and distribution over the globe of observers willing to make and report visual observations has resulted in excellent coverage of the behavior of hundreds of stars, with timelines extending back decades. These observations, when stored in a central repository, have proven to be a valuable, scientifically useful set of data.

A comparison between visual and CCD observations of the limiting magnitude per inch of aperture is no contest. With the same telescope a CCD will be able to detect and measure much fainter stars than a visual observer. The ability to detect faint stars visually is also affected by factors such as dark adaptation, light pollution, age of the observer, fatigue, experience, and so on.

Comparison of the potential precision of the observation and the amplitude of change detectable is also not contested. It is generally agreed that the precision of visual observations is 0.1 magnitude or greater at best. When the observations of many observers are combined the scatter in the data can be as large as 1.5–2.0 magnitudes. There are extremely talented observers who can attain precision better than 0.1 magnitude, but this is not the norm.

Observations by visual observers may at times be affected by bias from preconceived notions, expectations, or foreknowledge of the behavior or activity of variable stars.

Observations reported by visual observers are sometimes difficult, if not impossible, to verify. There is no permanent record, such as a photo or image, of the observer's visual impression other than the reported estimate. For this reason a single, unconfirmed observation of a unique event may be viewed with some suspicion or flagged as discrepant even if quite real.

Visual observations are, by definition, limited to visual wavelengths, a narrow band of the electro-magnetic spectrum. Observations of stars in other band passes yield valuable information that will never be recorded visually.

Due to this lack of precision, and inability to archive or verify individual visual observations, scientists are less likely to use an individual's observations or combine them with CCD observations taken with a standard set of filters in data analysis or preparation of scientific papers.

3. CCD observations

Some of the strengths of CCD observations have been touched upon in the previous section.

Precision to 0.02 magnitude or better is attainable with training, experience, and diligence. This opens the door to many kinds of variable stars or behaviors that are beyond the detection of visual observers, such as fluctuations in brightness less than 0.1 magnitude.

CCDs are able to detect and measure much fainter stars per inch of aperture than visual observers. Thus thousands of faint variables and the minima of brighter variables can be covered more extensively and accurately with CCDs.

CCD observations can be automated. The telescope can be programmed in advance to monitor hundreds of targets and the CCD will not suffer the human effects of fatigue, bias from preconceived notions, or from "shivering your lips off."

The use of standardized filters with CCDs adds another important tool to the toolbox of observers. Observations from different observers using standard filters can be combined for even greater accuracy. Information about stars in wavelengths other than visual yields important information about the nature and behavior of variable stars.

CCD observations can be archived digitally for future refinement, recalibration, and verification.

For all these reasons CCD observations are more readily accepted, in fact preferred, by scientific publications.

Some drawbacks of CCD observing relate to the complexity and expense of the equipment. Although the price of CCDs is gradually coming down, it is still a far more expensive endeavor than visual observing. The CCD itself is only one of many components the observer must obtain to observe variables. There is also the expense of filters and filter wheels, computers, hardware and software. The demand on the drive system of the telescope means a beefier, more expensive type of mount is required than for visual work.

Learning to operate the camera, hardware and software, and locating and tracking targets presents challenges and a steep learning curve for the observer. Before accurate measurements can be made observers must master dark, bias, and flat fielding as well as transformation coefficients and data reduction.

These factors exclude many observers limited by financial means or technical expertise.

Data reduction of observations can be time consuming, and reporting of observations is rarely done in real time, as can be the case with visual observations. The time invested in preparation, taking flats, and obtaining images in several bandpasses may also limit the number of targets the CCD observer can measure in a night.

On the other side of the limiting magnitude discussion are the bright stars that saturate in CCD images. The dynamic range of the CCD is limited. If fainter stars are being recorded with longer exposure times, data can become less reliable for bright stars in the field as they become saturated on the chip.

4. Surveys

Astrometric surveys such as USNO A2.0 or USNO B1.0 rarely deliver reliable photometric results because the emphasis is on positions, not photometry. Therefore, they will not be considered in this paper.

Photometric or variability surveys that have run their course can not be considered as replacements or even encroaching on the observing programs of individuals or groups. These would include all-sky surveys resulting in catalogs or data such as Tycho 2, 2MASS, or NSVS. Tycho and 2MASS may yield good photometric results in their respective ranges and bandpasses, but they are not ongoing efforts. The Northern Sky Variability Survey (NSVS) is only one year's worth of the data collected by the Robotic Optical Transient Search Experiment (ROTSE). It contains information on millions of stars down to 14th magnitude, but it too is an experiment that has been discontinued.

The surveys having the most direct impact on the viability or usefulness of visual observations are those that are accurately measuring great numbers of stars on an ongoing basis. The existence of these surveys has been touted as the death knell to the age of visual observation in some circles.

The All Sky Automated Survey (ASAS) is an ongoing survey supplying *V* band photometry for the entire southern sky. It accurately measures stars in the 7th to 13th magnitude range. There are problems with crowded fields in the Milky Way, making the photometry less reliable there.

The Amateur Sky Survey (TASS) is an ongoing survey that simultaneously measures stars in *V* and *Ic*. It has covered the northern sky at least once and should continue for several more years. It too covers stars in the 7th to 13th magnitude range, and has problems with photometry in crowded regions of the Milky Way.

While all these surveys supply useful information on the variability or constancy of millions of stars, each has its limits in the magnitude range covered, wavelengths observed, cadence of observations, and duration of the experiment.

5. Conclusions

The most surprising conclusion after looking at the current state of affairs in variable star research is that monitoring of naked eye and bright binocular variable stars seems to be essentially a wide open field for the visual observer. There are Photoelectric Photometry observers plugging away at their program stars, but most of the surveys do not include stars brighter than 7th magnitude in their studies. These stars do not appear to be favored targets of observers with telescopes employing CCDs either, due to the brightness of the stars.

Surveys and variability studies can be data-mined to detect variability or confirm constancy, but they do not produce the long-term light curves needed to provide useful scientific information on long period variables like Miras and RV Tauri type stars. Nor can they be used to keep track of stars whose most interesting behavior may occur on timescales of many years or decades, such as recurrent novae, WZ Sge or R CrB type stars. It is precisely the continuity of long term data that makes visual observations of these stars so valuable.

Ongoing surveys may be used to confirm or discover many more eclipsing variables, but light curves produced from the data often require additional observations at higher cadence to determine the period or magnitude range more accurately. Visual and CCD observers have been working in concert to obtain this kind of information on EBs and RR Lyrae stars for years.

On the faint end of the magnitude scale, none of the current all sky surveys go much deeper than 13th magnitude. A great number of long period variables have ranges whose minima far exceed this limit. An even greater proportion of cataclysmic variables never gets this bright at maximum. Monitoring long period variables' minima (fainter than 13th magnitude) and most cataclysmic variables for outbursts is still beyond the reach of these surveys.

Coordinated efforts to monitor stars with extreme magnitude ranges can better utilize the resources and strengths of visual and CCD observers. Visual observers can concentrate on the brighter range of the variables and hand off the data collection once the star falls below the threshold of visual detection.

There is no doubt that CCDs can deliver data with more precision than visual observations. The sensitivity of CCDs also enables them to detect small amplitude changes like superhumps in CVs, eclipses less than 0.2 magnitude in depth, or the minute pulsations of some Cepheids or Delta Scuti type variables. But these areas have never been the province of visual observers.

Discoveries are still being made and scientific papers written based on information obtained through visual observations. The discovery of the variability of δ Scorpii by Sebastian Otero is an example of a naked eye star that has been observed and measured for hundreds of years suddenly being found to be a variable star by a visual observer. On the other end of the scale, a previously unknown RR Lyrae star was recently discovered in the field of HX Pegasi. Michael Linnolt made this 14th magnitude find while visually observing HX Peg, even though the field had been observed and calibrated on several nights by one of the world's leading CCD photometrists in the process of determining a comparison sequence for HX Peg.

The main arguments for making visual estimates hold true now as they have in the past. There are still too many stars and too much sky to monitor for any survey or group or individual to claim they have covered it all. New variable stars are being discovered all the time, and these will require years of study in some cases to determine their properties and behavior.

The instrument you employ depends largely on what kind of research or observing you plan to do. There is room for everyone to enjoy the sky and contribute to science.

The list of visual targets that will not be usurped or supplanted by CCDs or surveys any time soon is still quite long:

- Naked eye and bright binocular variables with amplitudes greater than 0.2V,
- Long-term monitoring of long period variables such as Miras and RV Tau types,
- Monitoring outbursts of cataclysmic variables,
- Follow up observations of newly discovered variables to determine long term behavior,
- Follow up observations of EBs to determine approximate times of minima, to be followed on by precise CCD time-series observations,
- Visual observations specifically requested as part of coordinated observing runs with satellites.

Lastly, there is something about looking through the eyepiece of a fine telescope on a cool, crisp night that cannot be compared to sitting in front of a computer monitor or watching television while the CCD does all the work. That feeling will never die. There will always be visual observers.