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Preliminary Results From The AAVSO Infrared Photometry Group

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Abstract

The *American Association of Variable Star Observers* (AAVSO) established a near-infrared observers group in 2003. There are 27 variable stars currently in the AAVSO IR Photometry program, including eclipsing binaries, Cepheid variables, and semiregular, Mira, and irregular variables; there are hundreds more bright variables that can be observed. Observations of variable stars as faint as 4th magnitude are possible using the *Optec SSP-4* IR photoelectric photometer with telescopes smaller than 0.3 meters in diameter. Over 600 *J*- and *H*-band observations are currently available on-line from the *AAVSO International Database* (www.aavso.org), and observations are continuing. We highlight the contributions that the AAVSO observer community are making to this important research area, and present current results for five variable stars in the AAVSO PEP IR program: Mira, R Leo, W Ori, eta Aql, and Algol.

Introduction

Infrared astronomy has opened a valuable new window on the universe, and the technology for observing in the infrared has become both more sophisticated and more commonplace. High-quality, calibrated IR data can be obtained with relatively inexpensive technology. In 2001, the AAVSO proposed to support and pursue the field of near-infrared amateur photometry, to observe often-neglected, bright variable stars in standard near-infrared pass-bands useful for multi-wavelength studies. Henden (2002) established a set of 52 primary IR standard stars, and in 2003 the AAVSO formally initiated the *Infrared Photoelectric Photometry Program*.

This program fills a neglected niche in infrared astronomy -- the photometry of bright variables. There is still an enormous amount of astrophysics that can be learned from the study of bright stars in the near-infrared, but photometry of bright variables can be unfeasible with modern detectors on larger telescopes where the amount of telescope time is very limited. With simple and relatively inexpensive photometric equipment, the amateur and professional small-telescope communities can now perform photometry in this astrophysically important wavelength regime.

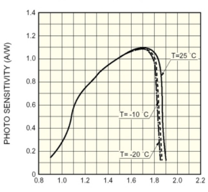

Figure 1: spectral response of the Optec SSP-4 photoelectric photometer. The photometer utilizes an InGaAs pin diode photometer, with a peak spectral response around 1.6 microns. The response of this device drops off rapidly redwards of 1.8 microns, making K-band photometry unfeasible.

Observing with the SSP-4 IR Photoelectric Photometer

The single-channel SSP-4 photometer uses a Hamamatsu G5851-203 InGaAS PIN photodiode detector and commercially-available J- and H-band filters. The response of the detector (Figure 1) peaks in the H-band with good sensitivity in the J-band. The photometer, targeting eyepiece, and filter assembly are housed in a unit that fits a standard 1.25-inch eyepiece port. Thus, the instrument can be attached to nearly any commercially available small telescope (Figure 2). It is easily interfaced with a personal computer for data acquisition.

Calibrated photometry is performed using standard, single-channel PEP methods (see Henden 2002 for details) and the resulting data are submitted to AAVSO by the observers. These data are then entered into the AAVSO database where they may be freely downloaded via our usual web interface (http://www.aavso.org/data/download/). Over 600 *J*- and *H*-band photometric measurements have been obtained by AAVSO PEP-IR observers.

Figure 2: An example PEP-IR setup: the *SSP-4* mounted on a 10" *Meade LX200*. The photometer unit fits into the standard 1.25-inch port at the Cassegrain focus.

Table 1: Selected program stars

Star	Type	Period (d)	m_{vis}	m_J	m_H
o Cet	Mira	331.96	2.0	-1.8	-2.6
R Leo	Mira	309.95	4.4	-1.6	-2.4
W Ori	SRb	212	5.5	1.0	0.0
η Aql	δ Cep	7.176641	3.48	2.2	1.9
β Per	Algol	2.8673043	2.12	2.0	1.9

IR observations of Mira stars

Mira stars are among the most well-observed objects in the AAVSO International Database. Because they are IR-bright, they are excellent targets for the IR photoelectric photometry program as well. Figure 3 shows the visual and IR light curves of omi Cet (Mira) and R Leo. The sinusoidal infrared light variations are almost entirely due to temperature variations during the pulsation cycle, as opposed to the strongly peaked visual light variations, which depend upon both temperature and opacity changes. There is a phase lag between the optical and IR peaks of a few tenths of a cycle, in agreement with an analysis of COBE-DIRBE photometry (Smith et al. 2005).

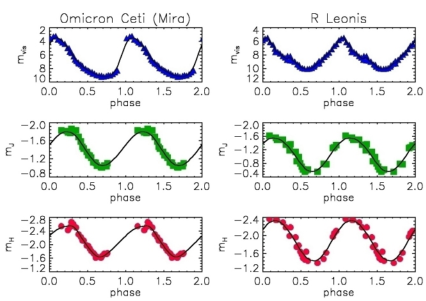

Figure 3: visual, *J*-, and *H*-band light curves of omi Cet (Mira) and R Leo. The data points are phase-averaged, using the periods in Table 1 for the folding period, and the time-of-maximum estimates from Bulletin 66 of the AAVSO (Mattei 2003). The IR light curves are much more sinusoidal than the visual light curves, and lag the visual peak by 0.1-0.2 period. (Note: the solid line is simply a smooth curve through the data, meant to guide the eye.)

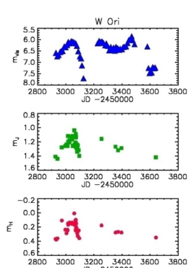

Figure 4: Visual and IR light curves of the semiregular variable W Ori. The infrared light curves track the visual light variations well, although annual solar interference prevented IR observations during the deep decline around JD 2453150. W Ori is the best-observed semiregular variable in the PEP-IR program. Other semiregulars include eta Gem, SW Vir, R Lyr, and rho Cas.

W Ori

W Ori is a bright ($m_{v,max}$~5.5), well-observed semiregular carbon star. Like other semiregulars of type SRb, it exhibits low-amplitude, less-regular pulsations than SRa and Mira stars, and its carbon spectral type makes it a challenge for visual observers. The irregularity of the SRb stars is not fully understood, although large-scale convection may play a role (Lebzelter, Griffin, & Hinkle 2005). The PEP-IR light curves of W Ori track the visual observations well (see Figure 4). Although this star has yet to be extensively covered, IR observations of this and other carbon stars may provide an excellent measure of the underlying bolometric variations, and would complement both visual and optical photoelectric photometry. Continued multiwavelength monitoring may provide further clues on the pulsation physics of W Ori and the other semiregular stars.

Eta Aquilae & the Cepheid variables

Eta Aql is a naked-eye Cepheid with a well-defined period of 7.176641 days. Figure 5 shows the visual and IR light curves, and phased radial velocities (from Storm et al. 2004) of eta Aql. Infrared photometry of Cepheids can be used both for multiwavelength modeling of the atmospheric and photospheric physics of pulsation, and for calibrating the galactic Cepheid infrared period-luminosity relation. Although eta Aql is currently the only Cepheid in the PEP-IR program, other Cepheids including delta Cephei, Polaris, and X and W Sgr are easily bright enough for observing with the SSP-4.

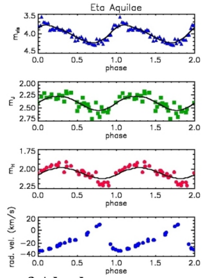

Figure 5: Visual, *J*- and *H*-band light curves and (archival) radial velocity curve of eta Aql. The IR light curves clearly phase with the visually-defined period, and show a slight phase lag of about 0.2 behind the visual light curve. They are also slightly asymmetrical and weakly show a bump on the descending branch as does the visual curve.

IR observations of Algol

Algol is the prototype of a class of evolved close binaries where mass transfer has occurred on a large scale, reversing the initial mass ratio of the system. The B8 primary is a main sequence star while the secondary is an evolved late G or early K subgiant. Because the secondary is much cooler than the primary, the secondary eclipse is very shallow in the visible but in the infrared the eclipse is much deeper and can be more accurately modeled, leading to improved estimates of the system parameters.

Here, the primary minimum is well-defined in the visual, *J*- and *H*-bands. The secondary minimum (phase ~ 0.5) is less so, although it is more pronounced at longer wavelengths as expected for cool secondaries. Although the time-resolution of the AAVSO data are not as high, the overall features of the J- and H-band light curves match those of previous IR photometry of Algol (e.g. Zeilik, Bayliss, & Heckert 1980).

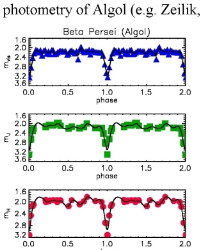

Figure 6: Visual, *J*- and *H*-band light curves of Algol (beta Persei). The primary eclipse (phase 1.0) is well defined in all three bandpasses, but the secondary eclipse at phase 0.5 is only pronounced in the *H*-band. Future observations will be made to improve photometric accuracy, providing better data for eclipse modeling.

Conclusions

The AAVSO PEP-IR program has produced high-quality light curves for several bright stars of astrophysical interest. It has also shown that the amateur and small-telescope professional communities can provide useful IR data that supplements and expands upon the photometric work done at larger facilities (e.g. 2MASS, and the continuing IR photometric monitoring of LPVs by P. Whitelock et al). By using a relatively simple, inexpensive, commercially-available photometer, this important field is now within reach of many observers professional and amateur alike.

The AAVSO welcomes suggestions and collaborations from the astronomical community and invites participation in the PEP-IR program. Possible projects for the AAVSO PEP-IR program include expanding the number and variety of variables observed, observing fainter stars with larger-aperture telescopes, and support for targeted multiwavelength campaigns. For further information, please contact aavso@aavso.org, or subscribe to our discussion group (http://groups.yahoo.com/group/ssp-4).

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