INFRARED VARIABLE STAR OBSERVING FROM THE ROTHNEY
ASTROPHYSICAL OBSERVATORY

E. F. MILONE, F. M. BABOTT, T. A. CLARK, S. M. DOUGHERTY,
D. J. I. FRY, J. T. HIMER, D. A. LEAHEY, A. R. TAYLOR, and
A. G. ANANTH
Rothney Astrophysical Observatory
University of Calgary, Calgary, AB, Canada T2N 1N4

ABSTRACT The infrared telescope of the Rothney
Astrophysical Observatory is now used on a routine basis to
monitor variable stars as well as to carry out absolute
photometry programs, exceptional difficulties with aurorae and
cloud conditions for the past two years notwithstanding.
Illustrations of recent photometry and plans for future
improvements are given.

I. INTRODUCTION

The Rothney Astrophysical Observatory (RAO) and the development,
construction, and general operation of its telescopes and instrumenta-
tion have been amply described elsewhere (Milone et al. 1982; Clark
and Milone 1990; Milone et al. 1990 and citations contained therein).
Here we review the properties that make it suitable for variable star
photometry, provide preliminary results, and discuss future plans.

II. EFFICIENCY OF THE IRT

The IRT is an efficient variable star telescope despite its bulk, its alt-alt
mounting which causes field rotation and requires driving on both axes,
and the intrinsic slowness of IR detection techniques. It is efficient for
several reasons. First, the driving motion of the IRT is designed to
minimize travel time across the sky, achieving a maximum rate of 2°/sec
at the mid point of the travel arc.

Second, it uses a computer cache of stored positions which it can
access and apply quickly, minimizing travel time between variable and
comparison stars.

Third, it uses an algorithm to centroid automatically upon the
infrared signal, a process we refer to as peaking. Although this process is
not efficient for marginally detectable signals, and requires ~30 s for
adequate centroiding in both coordinates (and more if the algorithm is
unsuccessful in the first pass due to noise), it can be disabled for these
weaker signals, permitting manual peaking on the signal.

Finally, during detection, an optical tracker keeps the star

1 Publications of the RAO Series B No. 18
within a prescribed aperture. Tracking precision is currently at ±2.5 arc-sec, not within the median FWHP seeing, which is ~2 arc-sec at our site, but adequate for single-detector photometry with apertures ≥15 arc-sec. The tracking is maintained by fast feedback loops connected to star trackers mounted at three locations, any one of which can be used at any given time. One intensified CCD camera (ICC) is mounted at the Cassegrain focus. A gold-coated diagonal mirror acts as a beamsplitter by sending the infrared flux into one of two dewar side ports. At this port, tracking is accomplished on the rotating, chopped image, close to, but due to the wavelength dependence of refraction not identical to, the detected signal. The other ICCs are located on two auxiliary telescopes on opposite sides of the same mounting. One of these is on a 14-in Celestron, the other on an 8-inch Celestron. Focusing is accomplished at the console. During the 'nodding' operation, when the telescope is shifted a distance equal to the chopping throw so that signals from star and sky are shifted 180 degrees, the tracker 'walks' the star across to its new position on the screen. No observer intervention is required, and the nodding operation requires ~10 s. The telescope is then moved automatically to repeat on the new infrared signal, this signal providing the new locking position for the optical tracker. Thus the principal disadvantage of the alt-alt mounting - its field rotation - is overcome thanks to the digital control of movement in both axes.

III. RECENT PHOTOMETRY

The current faint star limit of the star trackers is V ~13, and the telescope is able to obtain good S/N in the IR right down to the tracking limit because the tracker itself does not require high S/N to work. Objects of current study include Be stars, Cyg X-1, several eclipsing and pulsating variable stars, and a nova. Examples of photometry carried out with the IRT in the past two years are shown in Figs. 1-3.

Long-term infrared variability has been identified in Be stars by SMD, who has carried out a systematic study of 101 of these objects at the RAO (Dougherty et al. 1991). In total, forty three IR variables were identified by comparison with earlier IR surveys made at other sites. Fig. 1 shows an example of the variations identified in one of the stars, ω Ori.

D. Leahy and A. G. Ananth have been collaborating on a multi-wavelength campaign on Cyg X-1. They have found evidence of night-to-night variation in JHK. The K variation is shown in Fig. 2 plotted against phase, assuming Kemp's (1977) ephemeris.

More recently, the RAO participated in an international multiwavelength campaign on ER Vul, a 0.6d detached eclipsing binary system suspected of extensive and migrating spot regions.

In Fig. 3 systemic JHK data from 1991 Sept 27 UT are shown plotted against fractional JDN (Julian Day Number) for ER Vul and comparison and check stars. The variable star data represent a portion of the light curve between 0.3-0.4p, according to the elements: E0 = 40182.2621, P = 0.69809409 (GCVS, 3rd. ed.). The comparison and check stars were SAO 89378 and SAO 89398, respectively. The data were corrected for extinction via Bouguer coefficients: k'J = 0.163 ± 0.022, k'H = 0.133 ± 0.035, and k'K = 0.151 ± 0.027; the mean systemic comparison star magnitudes were determined to be: j0 = 6.827 ± 0.007, h0 = 5.531 ± 0.015, and k0 = 6.529 ± 0.010; differenced and transformed by means of

© Astronomical Society of the Pacific • Provided by the NASA Astrophysics Data System
Fig. 1. The light variation in JHK and L passbands of the Be star ω Ori.

observations of three IR standards, the standardized values for SAO 89378 are found to be: K = 6.537, J-K = 0.206, and H-K = 0.051. The averaged differential K, J-K, and H-K values in the sense V-C are plotted in Fig. 4. It is instructive that the telescope log for the night indicates 'low grade aurorae', followed by 'luminous auroral arcs', and 'dimmer but flaming and pulsating aurorae'. The aurora provides a limit to the precision attainable under such circumstances, as we note later; however, to this degree of precision it is possible to work, at least some of the time, thanks to the phase-sensitive detection of the lock-in amplification process.

Finally, an observation of Nova Herculis 1991 was obtained in April. The optical star tracker had difficulty tracking this V = 12.7 source in mediocre seeing, but the infrared detector did not. The
Fig. 2. Preliminary results showing instrumental K-band night-to-night variations in Cyg X-1. Phases are computed with respect to the elements: $E_0 = 2443638.63$ and $P = 5.60^d$.

detection yielded the following preliminary values: $J = 3.986 \pm 0.008$; $H = 1.215 \pm 0.005$; and $K = 0.694 \pm 0.003$, where the errors represent internal precision only.

Even though some variable star data have been secured over the past two years, the process has not been easy. As already noted, one particular difficulty in recent years at this high geomagnetic latitude site has been bright and rapid sky variation because of auroral activity. During part of 1990 and the first half of 1991, few clear nights were without some level of visible aurora. The effect showed up in various ways, on one night afflicting one broadband IR bandpass and on the next night another; presumably this has to do with the atmospheric height of the excited molecular species, most likely the hydroxyl radical. The most severe effects on the signal waveform seem to occur when flaming and pulsating aurorae - resembling bomb bursts - are seen. We have found no particular defense from this form of aurora, but fortunately this form does not predominate. On many occasions, more quiescent arcs or curtains, provided they are not directly in the field of view, may permit modest precision (2-3%) photometry to be achieved. In the presence of rapid variation, $S/N > 20$ is possible, as Fig. 3 demonstrates.

IV. PLANNED IMPROVEMENTS

The major limitations to direct imaging with the IRT are the large images provided by our 1.5-m metal mirror and the limiting precision of the current star tracker. The latter is scheduled to undergo an order of
Fig. 3. Observations of the eclipsing binary ER Vul (x), comparison star (o) and check star (+) transformed to the Johnson K passband.

magnitude improvement within the next year, as we begin planning for a new mirror cell to house the 1.8-m honeycomb mirror now in use at the Apache Point Observatory in New Mexico. Thanks to a cooperative agreement with the Astrophysical Research Consortium, and a grant from Dr. A. R. Cross, the RAO's benefactor, the new mirror has been satisfactorily polished to provide images with ~1 arc-sec FWHM images. The mirror is scheduled to be returned to the RAO by mid-1992. These improvements will make it possible to carry out direct imaging with infrared arrays as they become accessible to us.

In an age of sharp competition for funding, it may be asked if infrared astronomy should be attempted at other than prime sites such as those in Chile or Hawaii. In addition to fundamental difficulties in transforming infrared magnitudes to outside the atmosphere, at a moderate-altitude site such as ours, the effects of variable atmospheric extinction in the infrared can be doubly worrisome. However, the situation is far from hopeless, especially for differential variable star photometry.

For single channel detectors, a useful option for efficient differential photometry is a RADS - a rapid, alternate detection - type system, where program, comparison, and sky can be repeatedly sampled in rapid succession. Unfortunately, the operation of such a system is considerably more complex in the infrared than in the optical. The sky gradient must be carefully determined, and a single sampling of the sky

© Astronomical Society of the Pacific • Provided by the NASA Astrophysics Data System
in the vicinity of each of the two stars, as is carried out in RADS, is insufficient. Moreover, the motion of the secondary mirror is severely limited by the condition that the warm environment around the primary mirror should not be imaged - at least if the thermal IR is to be observed. It is also the case that sky brightness and transparency effects occurring at the chopping frequency cannot be defeated in this way. For that remedy, an option is an IR array to provide direct imaging. While great strides have been made in such detectors, at the moment they are still relatively expensive, suffer from relatively large pixel sizes, and relatively few pixels. Nevertheless, these limitations are certain to improve, and they have already become the detectors of choice for the near IR. They provide a golden opportunity for differential variable star photometry in the infrared.

More generally, in accordance with suggestions made at a meeting of IAU Commissions 25 and 9 at the 1988 General Assembly in Baltimore (Milone 1989), a Working Group of Commission 25 is examining the infrared atmospheric window transmissions and infrared flux distributions with the intention of redefining the JHKLM passbands to minimize their susceptibility to terrestrial atmospheric extinction effects. At this writing, in Calgary, A. T. Young (on leave from SDSU), Milone, and C. R. Stagg are currently at work on the project, which also entails real-time modeling of the atmosphere and improvement of the algorithms for determining extinction. If this work is successful, it should be possible to carry out routine, standardized infrared photometry from most observatory sites, with the added benefit of partial daytime operation for some sources. At the best sites it should considerably improve determinations of extra-atmosphere magnitudes.
and colors and the transformability of such data. Indeed, work at Mauna Kea has indicated that the spread in extinction decreases sharply when narrower passbands, better centered in the atmospheric windows, are employed.

REFERENCES

Kemp, J. C. 1977, IAU Circ., No. 3149

DISCUSSION

K. Kissell: Who will inherit the former Mt. Lemmon 1.2 meter mirror when it is replaced by the glass Rodger Angel mirror?

E. Milone: Yet to be decided. Possibly to be sold at cost.