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# Lunar occultations in the infrared: Evolution from single element detectors to sub-arrays

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**Abstract.** Lunar Occultations is an elegant high angular resolution technique capable of reaching one dimensional resolutions of a few milliarc seconds on a large number of sources in the celestial path of the moon. At PRL we have been pursuing this method for nearly two decades at the 1.2m telescope of Mt Abu Observatory mainly in the near IR K band with a few excursions into the L band. Many of the resolved sources are late type M Giants, AGB variables (SRVs and Miras) and carbon stars. Apart from effective temperatures, the presence, extent and sometimes the structure of the circumstellar material could be inferred from high S/N occultation light curves. The IR instrumentation for observing lunar occultations has progressed from single element InSb based fast photometers to using area of interest sub-arrays of the NICMOS camera at Mt Abu. Details of sub-array mode and some recent science highlights are presented.

*Keywords* : lunar occultation – infrared – subarray – dust shells

## 1. Introduction

In this era of big telescopes,optical interferometers with base lines of hundreds of meters, huge budgets and manpower, I would still like to think that small projects at modest sized telescope have a niche of their own to make valuable scientific contributions. The lunar occultation(LO) program at Mt Abu Observatory is one such program which has survived the the major shift from one pixel to multi pixel 2D array detectors in the near infrared. The program has been pursued diligently at Mt Abu for nearly two decades mostly in the K band at 2.2 μm with very occasional forays into the difficult L band at 3.6 μm for a few bright sources. With the single pixel InSb detectors resolution of uniform disk (UD) angular diameters have lead to determination

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of effective temperatures of these sources which include a number of late type stars including several AGB stars and carbon stars. Complex shell structures have been resolved in diverse sources like the carbon star IRC +10216 (CW Leo) and rotational structures in WR 104. These earlier efforts and results are well documented in a earlier review (Chandrasekhar 2005). In this review we focus on the efforts made with a sub-array of the NICMOS IR camera and some recent results.

## 2. Instrumentation

The single element InSb detectors had a limiting K magnitude of 3.0 and were well suited for sources in the first Two Micron sky survey (TMSS). The advent of the 2 Micron All Sky Survey (2MASS) catalogue provides many sources much fainter than K =3 with well defined positions so that precise LO predictions could be made for the observatory site. Apart from increased sensitivity the array detector- in this case a HgCdTe 256×256 pixel device, had a smaller pixel size of 40 μm compared to the 500 μm detector size of InSb. This resulted in a decreased background per pixel from the scattered moonlit sky. Using a area-of- interest (AOI) subarray of 10×10 pixels it was possible to obtain S/N in excess of 40 with an integration time of only 3 millisec for sources upto a K magnitude of 5.0. The major drawback of using IR arrays for LO lies in the poor sampling time of the light curve compared to single InSb detectors. Even with a small 10×10 pixel subarray due to inherent delays in reset, readout and processing electronics a 3 millisec integration time translates to 8.952 millisec sampling time. The best sampling time achieved by our efforts was 7.5 millisec with a 2 millisec integration time on the NICMOS HdCdTe chip. As NICMOS camera operates only in the old MS-DOS environment it has been found difficult to reduce the electronics deadtime to less than 2 millisec per sample. Our initial attempts to use the NICMOS array are detailed in a earlier paper (Chandrasekhar et al. 2003).

## 3. Observations

Inside the full NICMOS array the 10×10 pixel sub-array is positioned in the first quadrant usually centred at (40,40). The position of the sub-array can be chosen anywhere within the first quadrant but not outside it. Regions of bad pixels are avoided while choosing the sub-array region. The star to be occulted is acquired in the K filter and positioned inside sub-array about two minutes before event time. The AOI program is loaded and data acquisition is initiated about 20 sec before predicted time. A total of 4800 subframes are acquired during data acquisition time of 43 sec. When the frame count which is displayed reaches 4500, the telescope is rapidly switched to nearby sky to acquire a few skyframes for later sky subtraction. Fig. 1 shows a sky subtracted frame of the sub-array and its contour map. The star occupies about 6×4 pixels (3×2 arcsec) consistent with seeing. The occultation light curve is derived from the sky subtracted subframes either as total counts or as average counts/pixel. No other extraction mask has been used to derive the light curve.

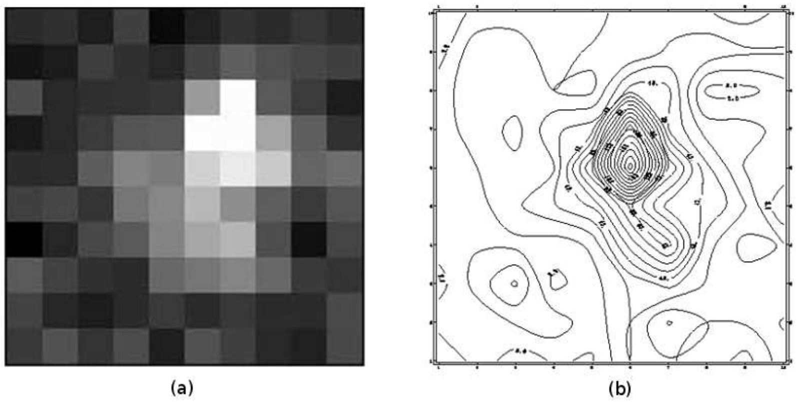


**Figure 1.** A sky subtracted subframe image and its contour plot. Each side of 10×10 pixel sub-array is 5 arcsec. The seeing limited star image occupies 3×2 arcsec in the subarray.

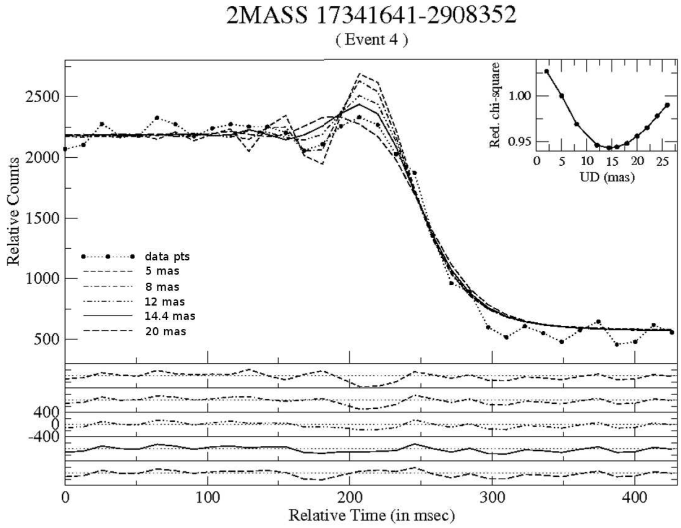


**Figure 2.** Galactic centre LO events: Event 4 data and model fits with various UD angular sizes. Best fit is at UD of 14.4 milli-arcsec as shown by minimum of inset error plot. Residuals (Data-Model) are shown at the bottom for angular sizes from 5 to 20 milliarcsec.

## 4. Analysis and results

The method of analysis, once the light curve has been generated from the sky-subtracted sky frames, is similar to that for a single element fast photometer. A non-linear least square fit involving five parameters - signal and background level, event time, velocity component of the moon in the direction of the occultation and the uniform

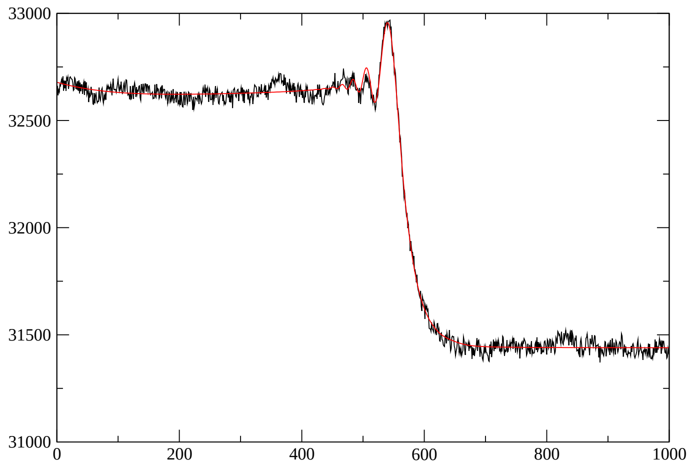


**Figure 3.** Observed and model fitted Occultation light curve of Mira variable BS Aur. The derived UD angular diameter is 5.00±0.70 milliarcsec.

disk angular diameter is carried out. Finite filter bandwidth, telescope aperture over which fringes are averaged is also considered in the analysis. The details are discussed in earlier papers (Chandrasekhar & Mondal 2001 and Chandrasekhar & Baug 2010).

### 4.1 Galactic centre region events

Lunar Occultation of stars in the direction of the galactic centre, which are rare events, was observed from Mt Abu Observatory in September 2007. Out of a total of 17 predicted events upto K magnitude of 5.0, 12 events were successfully observed in the K band. A detailed analysis showed that while most of the sources remained unresolved with UD diameter < 3 milliarcsec, 3 sources were clearly above the resolution limit. Two of these sources are late type M giants and the third is a carbon star. One of the sources (Event 4, M6.5III) exhibits a particularly large angular size of about 14 milliarcsec suggesting a large circumstellar envelope (Fig. 2). Another source (Event 5) is clearly a binary with a brightness ratio of 4:1 and a projected separation of 30±5 milliarcseconds (Chandrasekhar & Baug 2010).

### 4.2 AGB variables

UD angular diameters of two oxygen rich Miras (AW Aur and BS Aur) and three Semi Regular Variables (GP Tau,RS Cap and RT Cap) were measured. The measurements for the two Miras and one SRV (GP Tau) are first time measurements of angular diameters for these stars. Using an IR color index (K-[12]) and angular measurements it was possible to infer that one Mira (BS Aur) has an apparent enhanced angular diameter because of a circumstellar shell formed due to mass loss effects. Fig. 3 shows the occultaion light curve and best model fit for this Mira variable. The derived UD angular diameter of the source is 5.00±0.70 milliarcsec (Baug & Chandrasekhar 2012).

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