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Near IR lunar occultation observations and results from Gurushikhar Observatory

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Abstract. Lunar occultation in the near infrared is an elegant and effective technique of achieving high angular resolution in the range of milliarcseconds. Apart from determining with good accuracy the angular diameter and effective temperature of many late type giants and supergiants, the method has also been used to probe the circumstellar regions of many of these stars. A program of high angular resolution studies by the method of lunar occultations in the infrared is being pursued at the 1.2m Gurushikhar telescope. Here the method is outlined and highlighted with interesting results from the Gurushikhar telescope.

Key words : lunar occultation, infrared, late type stars.

1. Introduction

At the Physical Research Laboratory, Ahmedabad, studies on high angular resolution in the near infrared by the method of lunar occulations are being pursued for several years now. The prime motivation for developing the technique in the near infrared region was the desire to do something different from conventional photometry and spectrophotometry with the new 1.2m Gurushikhar telescope. The potential of the lunar occultation technique to reach milli-arc second levels of angular resolution was very attractive from this point of view. Such high angular resolutions are unachievable with filled aperture techniques like Speckle or Adaptive optics even at the largest telescopes. Long baseline optical interferometry is the only real alternative but it is an immensely complicated method requiring a large level of investment in terms of technical manpower, money and time. The price to pay in lunar occultations is that it is a one dimensional event-based technique, limited to objects occulted by the moon. Even so, there are several hundreds of bright ($m_k < 3$) unresolved sources in the original 2 micron sky survey (TMSS) which can be well studied by lunar occultation methods.

One of the primary objectives of the Lunar occultation program is to measure angular diameters (ϕ) accurately and hence deduce the effective temperature of stars from the relation which is independent of distance to the star.

$$F_{bol} = (\phi/2)^2 \, \sigma T^4 \quad (1)$$

where F_{bol} is the bolometric flux from the star and σ the Stefan-Boltzmann constant. If the signal to noise ratio on the occultation fringes in good (S/N>50) then it is possible to achieve an accuracy of better than 5 per cent in angular diameter. When good bolometric fluxes are available the effective temperatures can be determined to better than 3 percent in accuracy. Such direct measurements of a fundamental quantity like effective temperature are important to constrain theoretical models of stellar atmospheres, especially for late type stars of spectral types later than M5.

The near infrared region around 2 micron where these stars emit most of their flux is therefore an ideal spectral region for these measurements. Further in this region the noise in the occultation light curves, dominated by the scattered light of the moon, is also minimised compared to the optical regions leading to more accurate angular diameters.

In recent years with the availability of accurate parallaxes for many stars from Hipparcos satellite data, it has become possible to convert accurate angular diameters to accurate linear diameters which can be directly compared with theoretical models.

Other objectives of the lunar occultation program include direct detection of circumstellar shells around late type stars, direct evidence for pulsational activity in Mira type variables from a detection of variation of angular diameter during a period, inference of the presence of star spots on the disks of large angular size stars from high quality occultation light curves and serendipitous discoveries of close binaries.

2. Methodology

The intensity of light curve obtained in a lunar occultation is of the form

$$I(t) = \int_{-\infty}^{+\infty} \int_{-A/2}^{+A/2} \int_{\lambda 1}^{\lambda 2} \int_{-\delta\tau}^{0} S(\phi)F(\omega)O(\alpha)\Delta(\lambda)T(\tau)d\phi d\alpha d\lambda d\tau + \beta(t) \quad (2)$$

where S(ϕ) is the one dimensional source function in the direction of occultation which has to be extracted. F(ω) is the Fresnel diffraction pattern of a point source and ω, the Fresnel number which is given by

$$\omega = \left(\frac{2}{\lambda d}\right)^{1/2} [V(t-t_o)+d\tan\phi+\alpha] \quad (3)$$

where d is the distance to the moon, λ is the wavelength of observation, and α is the linear displacement term to account for telescope averaging effect. V refers to the velocity component on the earth's surface in the direction of occultation and t_o is the instant of occultation when the star's signal falls to 25 percent of its unocculted value. O(α), $\Delta(\lambda)$ and T(τ) are functions which take into account respectively smearing effects of telescope aperture, finite optical bandwidth and finite time response of the system. For a typical event with V = 0.5 Km/s four Fresnel maxima are covered in a time span of ~ 130 millisec at 2.2 micron. The entire event can be considered to be over in ~ 200 milliseconds. Millisecond sampling of the data during this time is required.

A High Speed Infrared Photometer specially developed for occultation work is shown in Fig. 1. System details are discussed in Ashok et al. (1994). The IR signal is recorded without chopping at 1 ms intervals typically for a period of 30 seconds centred on the predicted time of occultation. The relatively large time span of data accumulation is required to take into account the uncertainties in the predicted time arising due to errors in stellar co-ordinates and also to properly correct for any gradients produced in the signal due to lunar background. While slow scintillation and seeing effects do not affect the actual data, fast scintillation effects (~ 100 Hz) can distort the fringes and need to be carefully corrected for in the analysis.

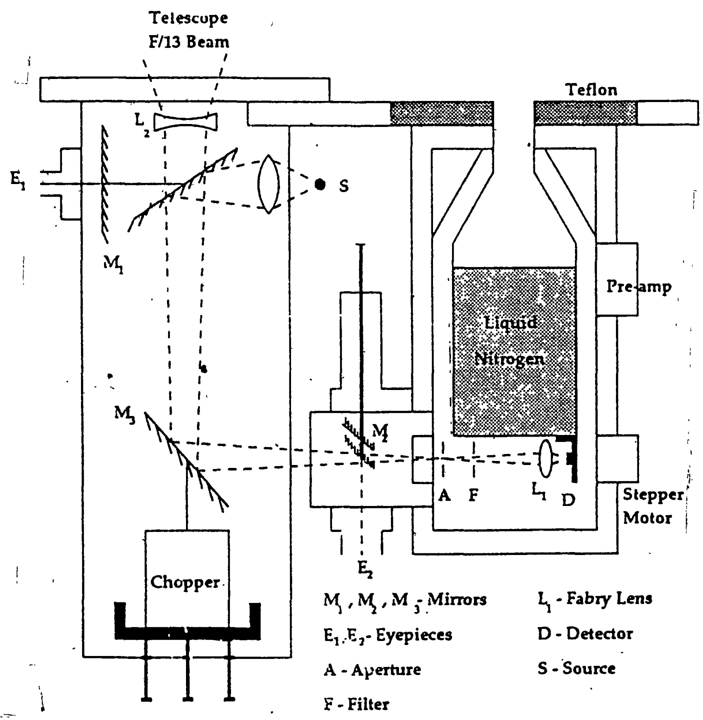

Figure 1. Near infrared fast photometer.

The basic analysis is to fit the least square solution to the data involving time of occultation (t_o), velocity component (V), signal and background level and the uniform disk angular size. The effect of finite angular size is taken into account by dividing the stellar disk into a number of vertical zones each of which can be treated as a seperate point source with relative intensity weighted according to the area of the zone. There is provision to include effects of gradients in the sky background in the analysis. When the S/N on the fringes is very good (S/N > 100) it is possible to use a model independent method to deduce stellar disk diameter and also detect the existence, if any, of a circumstellar shell around the star.

3. Observations

The first successful observations in the K band were made in November 1990 at the 1.2 m telescope at Gurushikhar. (Chandrasekhar et al., 1994) Since then occultation observations have been carried out successfully with the same instrumental system at the 1 m and 0.75m telescopes of Vainu Bappu observatory, Kavalur and in recent years (1994-97) extensively at the Gurushikhar telescope. The statistics of the events is given in Fig. 2a and Fig. 2b. Many of the events are reappearance events which require the telescope to be pointed exactly in the direction where the star will reappear from behind the moon. Most of the occultation objects are late type giants and supergiants.

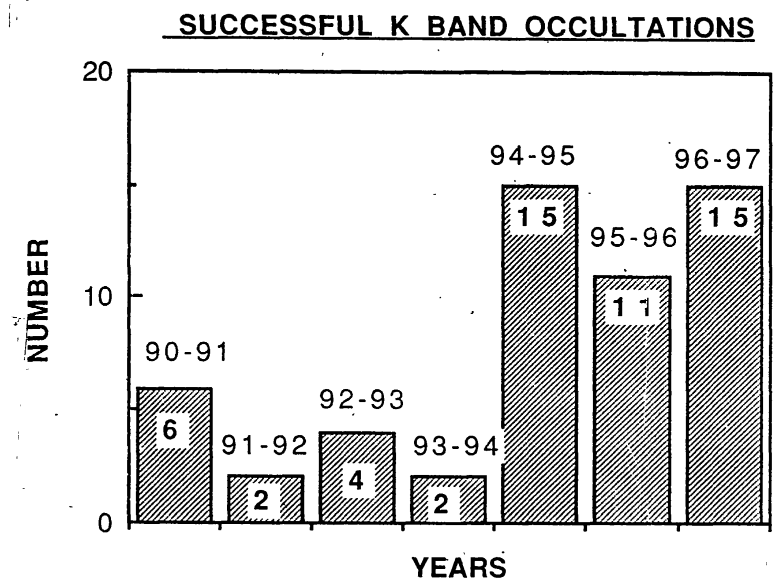

Figure 2a. Yearly statistics of infrared occultation observed successfully.

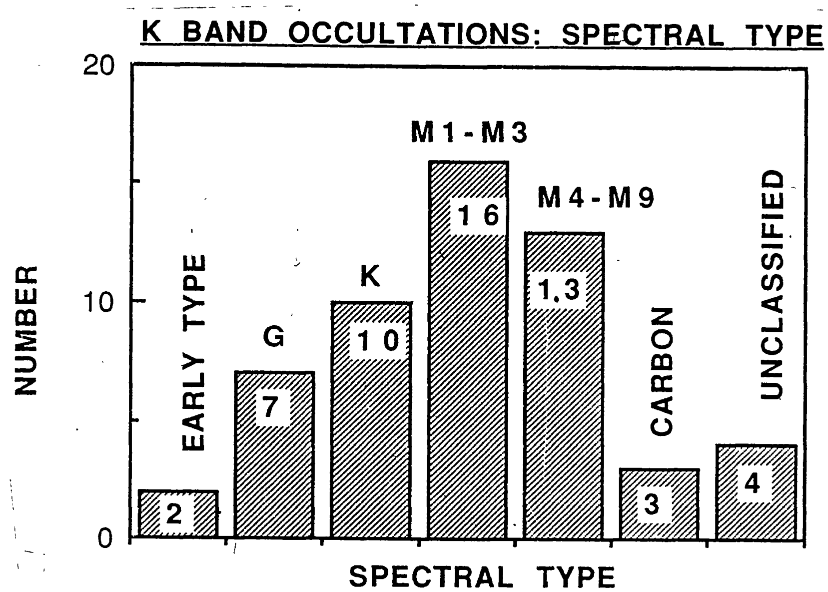

Figure 2b. Spectral type distribution of the occulted stars.

The occultation observations have been followed up by J, H, K photometry with the same experimental system. In a few cases low and medium resolution spectroscopy has also been carried out. The limit of angular resolution experimentally achieved is depicted in Fig. 3. The star IRC 20169 (Zeta Gem) is at the limit of our resolving capability at 2 milliarcseconds.

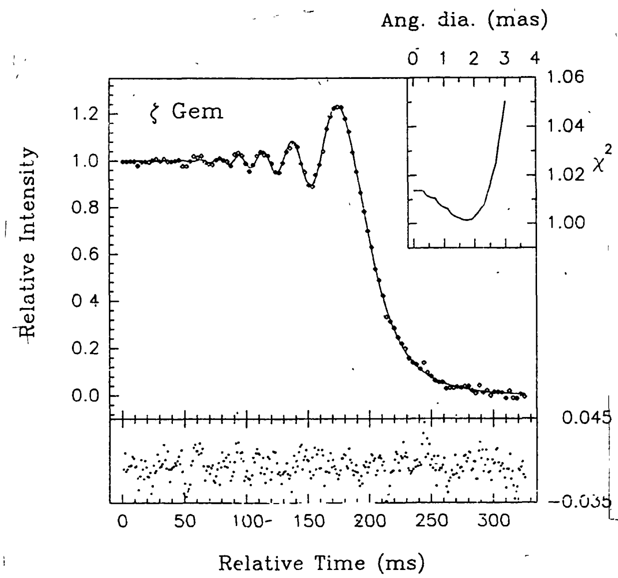

Figure 3. Limit of achievable resolution in the K band (IRC 20169) at 2 milliarcseconds. Inset shows error curve which has a minimum near this value.

4. Results

1. TX Psc : TX Psc is a bright carbon star (m_k = –0.76). Carbon stars are characterised by their red colours, low temperatures and presence of IR excess indicative of circumstellar matter. High angular resolution observations of carbon stars are very limited. In 1993-94 we observed two occultations of TX Psc, one at Gurushikhar and the other at Kavalur as part of an international campaign of lunar occultation observations on this star. The recovered brightness profiles from the campaign indicate a clear departure from circular symmetry. The observed profiles can be satisfactorily explained by a model of the source consisting of the central star and an asymmetric circumstellar shell with an inner radius, close to the photosphere at < 2 R_*. The dust temperature in the shell is constrained to ~ 1300 K. The detection of asymmetric structures so close to the star indicate that existing models of carbon stars which predict shell formation only around cooler carbon stars require substantial revision (Richichi et al. 1995).

2. TV Gem : TV Gem is a distant (d = 1200 pc) oxygen rich supergiant classified as M1 Iab. From IRAS observations it is known to have a strong silicate feature at 9.7 µm. A careful analysis of our occultation data on TV Gem has shown that in addition to the stellar disk, for best fit to the data, a circumstellar shell at a distance of 20±5 R_* is needed. The shell contribution to the K band flux is ~ 3%. The presence of such a shell is consistent with the 9.7 mm silicate signature which occurs in the same region. The star itself is well resolved with a uniform disk angular size diameter of 4.9±0.3 milliarcseconds. The recovered one dimensional profile of the extended component is shown in Fig. 4. Fig. 5 shows the observed spectrum of TV Gem along with various components contributing to it. It can be seen that 60 μm and 100 μm IRAS data require an additional shell at ~ 500 R_* due to older dust. The picture that energes is that of a supergiant star which has undergone sporadic mass loss resulting in dust condensation in two shells in a time scale of a few decades. Since the well known supergiant α Ori also has two detected shells at 25 R_* and 50 R_*, a sporadic mass loss phenomenon could well be a general property of early M Supergiants (Sam Ragland et al. 1997).

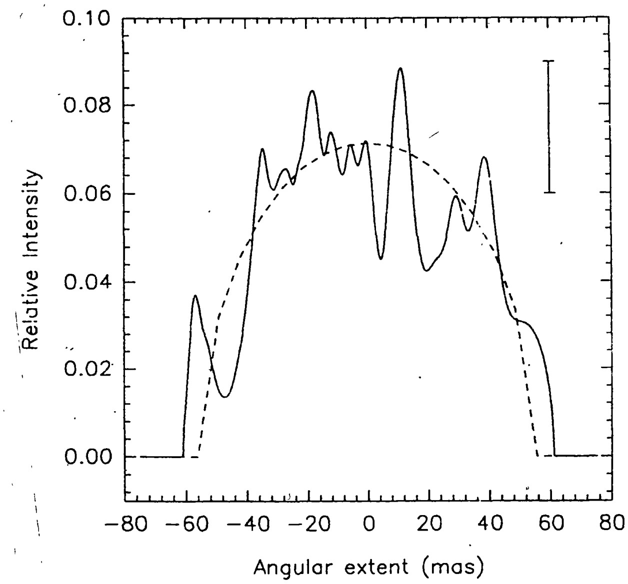

Figure 4. The shell around TV Gem.

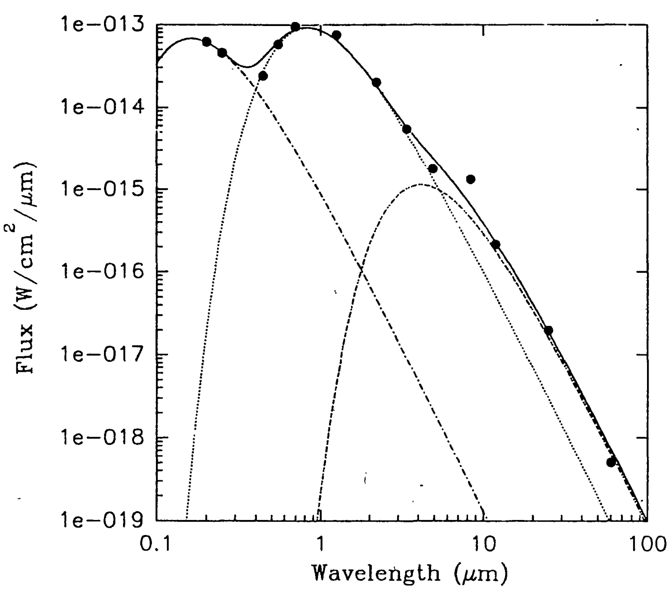

Figure 5. Spectrum of TV Gem and the contributions of different components.

M giants : Our K band occultation observations on six M giants namely IRC 20190, NSV 1529, IRC 00198, BQ Ori, IRC 10194 and IRC 10024 falling in the spectral range M2-M7 have been analysed. Four out of six stars are found to be resolved. Angular diameters and deduced effective temperatures for these stars are listed in Table 1. Source details and detailed discussions can be found in Sam Ragland et al. (1997).

Table 1. Lunar occultations of M giants.

Source	Sp.Class	ϕ(mas)	Teff
IRC 20190	M2III	≤ 2	-
NSV 1529	M2-M7	3.3±0.3	3380±160
IRC +00198	M2III	≤ 2	-
BQ Ori	M5III	4.2±0.2	3460±100
IRC 10194	M3.3III	4.2±0.5	2760±170
IRC 10024	M2III	3.2±0.2	3650±100

Among the sources which have been observed recently is the interesting source IRC-20563, a suspected Mira type variable. Two good quality occultations have been observed on this star and data analysis is in progress to establish angular size variation if any in this star (Tej et al. 1998). More recently the Mira variable R Leo has been successfully observed by us with a smaller bandwidth (λ/60) at ~ 3.2 μm. Recognizing the importance of L band (3.6 μm) observations for emphasising circumstellar features in the occultation light curve, a two channel fast photometer for simultaneous K and L band observations has been built and is undergoing tests at the Gurushikhar telescope (Mondal et al., 1998). In conclusion, the lunar occultation technique in near infrared, has been demonstrated at PRL to be a very effective method of reaching milliarcseconds of angular resolution even with modest telescope apertures of 1m class. With the growing number of long baseline optical interferometers, the time is fast approaching for a close comparison of the values of angular diameters derived from both methods.

Acknowledgements

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