The Lunar Occultation of CW Leo – a Great Finale for TIMMI

B. STECKLUM, Thüringer Landessternwarte, Tautenburg, Germany
H.-U. KÄUFL, ESO, Garching, Germany
A. RICHICHI, Arcetri Observatory, Firenze, Italy

Although TIMMI (Käufl et al. 1992), ESO's thermal infrared multi-mode instrument, had been decommissioned after Period 61, it got its very last chance on November 11th, 1998. The measurement was a special one, recording the lunar occultation of the well-known carbon star CW Leo[1], and the present contribution summarises these observations.

When TIMMI was under construction, perhaps none of its builders anticipated that the burst read-out mode implemented for technical reasons would ever yield scientific results. This mode offered the possibility to acquire an image sequence of 509 frames at rates up to 125 Hz. Thus, it was well suited to record fast transient phenomena such as occultations. When the authors discussed this capability a few years ago, it turned out that measurements of lunar occultations may yield an angular resolution of about 30 milliseconds of arc (mas) at the wavelength of about 10 µm, similar to that expected for the VLTI. This would enable detailed studies of the distribution of circumstellar dust around evolved stars. Consequently, proposals were submitted which aimed at the derivation of the angular diameter of asymptotic-giant-branch (AGB) stars. Despite some difficulties that led to the loss of a few events, several light curves were acquired for infrared sources with 12 µm fluxes in the range of 5 . . . 50 Jy. Since the required time resolution is in the order of 20 . . . 40 ms, the measurements had to be performed in staring mode, i.e. without applying the chopping/nodding technique commonly used to eliminate the overwhelming thermal background. Furthermore, as a consequence of the limited number of frames, the predictions had to be accurate to within typically 15 . . . 20 seconds to catch the event, a condition that was not always met (primarily due to the positional errors for infrared sources, which went undetected in optical surveys). Moreover, the comparatively small FOV of TIMMI (18″ × 18″) in combination with the poor tracking of the telescope (close to the Moon or during daytime the auto-guider does not work!) always provided for sufficient challenges for the observing team.

These measurements allowed the derivation of a few angular diameters and were crucial to assess the dependence of the attainable angular resolution on the signal-to-noise ratio. First results were presented at the ESO workshop Science

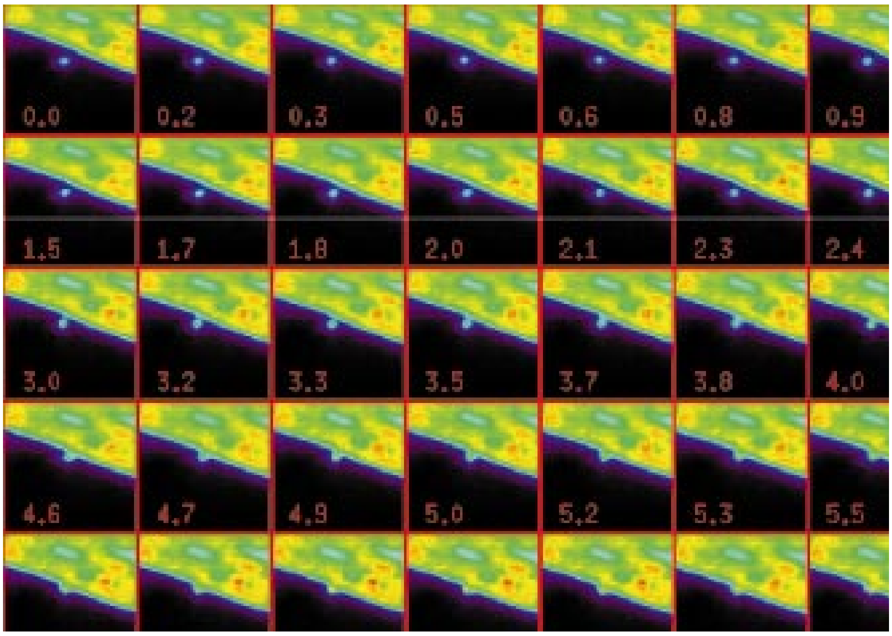

Figure 1: Sequence of the disappearance of CW Leo using linear intensity scale. Each frame is the average of three individual images.

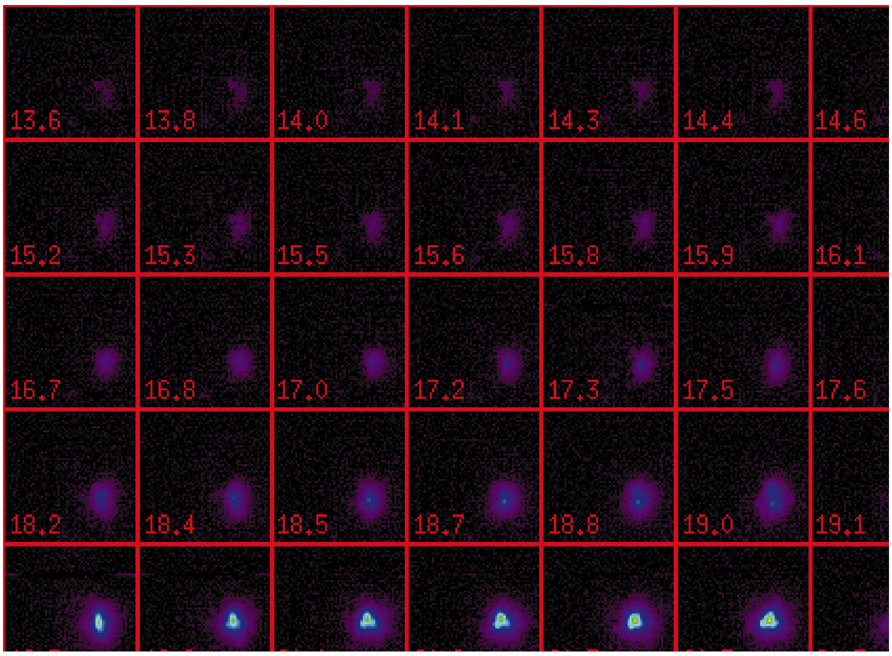

Figure 2: Sequence of the reappearance of CW Leo using a square-root intensity scale. Each frame is the average of three individual images. The elongation of the source is due to the uncovering of the western halo while the central peak is still occulted.

[1] In the Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Acker et al., 1992), CW Leo is listed as a possible planetary nebula).

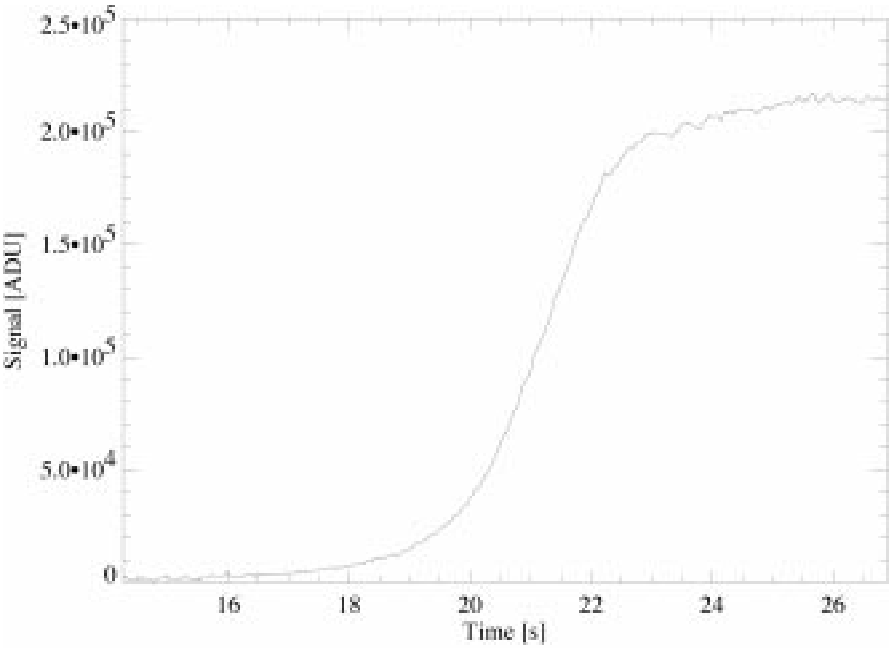

Figure 3: Light curve of the reappearance of CW Leo. Some disturbances at almost full signal level are due to scintillation.

with the VLTI (Stecklum et al. 1997). The prospects of this observing technique that intrinsically yields one-dimensional information in combination with the VLTI has been discussed recently (Käufl et al. 1998).

Monthly lunar occultations of a certain celestial object that is close enough to the ecliptic occur during a cycle that lasts up to 1.5 years when the Moon sweeps through that area in the sky. The forecast showed that an occultation of CW Leo, aka IRC+10216, the brightest celestial object at $\lambda \approx 10$ µm in the northern hemisphere, would occur for a visibility area including La Silla in fall 1998. Notably, the visibility regions for the current cycle of CW Leo do not include many major observing sites. Moreover, the next event visible from ESO observing facilities will be in 2008. Thus, it was our definite goal to observe the 1998 event in order to reveal the fine structure of the thermal emission from the dense dust envelope. A pioneering mid-infrared measurement also employing the lunar occultation technique by Toombs et al. (1972) revealed the presence of a core with a diameter of about 0.4″, which is surrounded by a 2″ halo. More recent observations by Sloan and Egan (1995) applying the deconvolution of slit-scanned profiles yielded evidence for two shells at the resolution of 0.7″. In the near-infrared, speckle interferometry revealed the presence of bright blobs in the dust shell located within 0.4″ (Haniff & Buscher 1998, Weigelt et al. 1998). The large net polarisation observed at 1 µm (Shawl & Zellner 1970) implies that these features are due to scattering rather than thermal emission. Thus, it is hard to assess the overall structure of the envelope from the morphology of these regions. From dynamical models of dust formation (Winters et al. 1995), an onion-like structure of the dust shell is predicted. Such a morphology has been observed already in Planetary Nebulae (e.g. in the Cygnus Egg nebula aka CRL 2688) and it has been suggested that CW Leo is already in the transition phase to such an object (e.g. Skinner et al. 1998). The shells around CW Leo are also a good test case for the thermonuclear evolution models for AGB stars, work that has been pioneered by Iben & Renzini (1983). Although the presence of circumstellar matter at angular distances up to $\sim 1'$ has been established by CCD imaging (Crabtree et al. 1987) and interferometric radio observations (Groenewegen et al. 1998), the large dust column density precludes the detection of the innermost shells at optical and near-infrared wavelengths. It was the main objective of the authors to trace the thermal emission from these discrete dust layers in order to prove that the model of Winters et al. (1995) for the prescription of dust formation on the AGB is basically correct.

The fact that the observations could be scheduled was not certain though the science case was tempting. Finally, all we would need was two times 30 seconds of observing time to measure both dis- and reappearance. Thus, we are happy to acknowledge that TIMMI was made available to us for this special event and appreciate the support of the 3.6-m telescope team. The occultations occurred on daytime (about 1.5 hours before local noon) after a long set-up night. About two hours before the main events, a chance to check everything was given by the occultation of HD 84194 which went fine. This star is offset by about 1.3° from CW Leo, and we wanted to use it as "parking star" when CW Leo would be hidden by the Moon. Since the huge brightness of CW Leo rendered it possible to record the disappearance at the bright (i.e. hot) limb of the Moon as well, two different settings of the detector electronics were prepared. The successful observation of the disappearance became clear when the initial images appeared on the screen showing the Moon steadily approaching CW Leo and finally occulting it. The major part of this image sequence is displayed in Figure 1. However, some nervousness arose when we were unable to find the offset star after the storage of the data was finished. After all, it was approximately 9:30 local time in the morning and the re-acquisition of a suitable

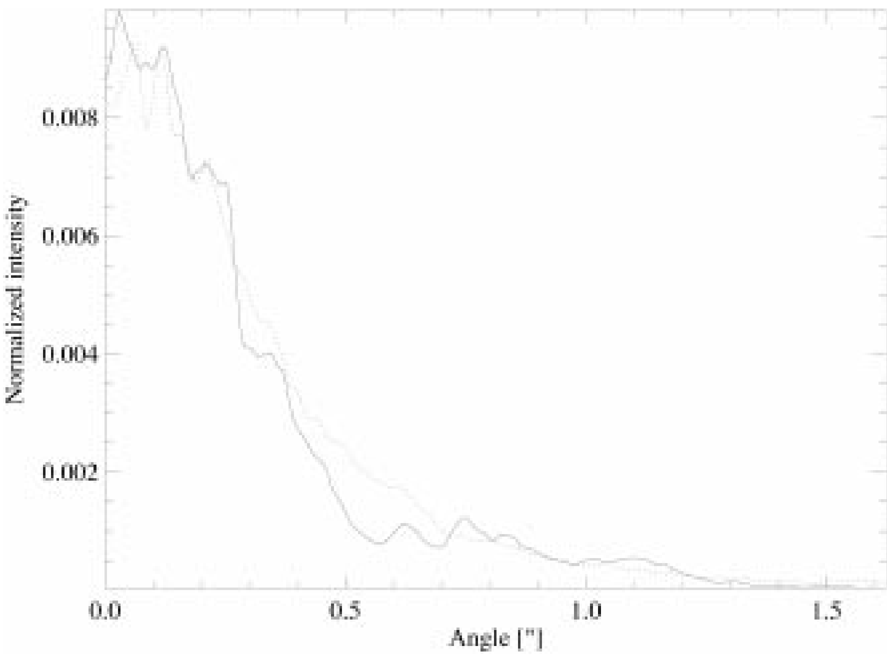

Figure 4: Reconstructed intensity profile splitted into eastern (dotted line) and western part (solid line). Four coinciding local peaks can be recognised, which presumably trace individual dust shells.

guidestar had to rely entirely on infrared imaging with TIMMI. Luckily, the nearby bright variable R Leo could be acquired and, after correcting the telescope co-ordinates on this source, the “parking star” could also be acquired. The detector setting was then changed for the reappearance for which the lunar background should be negligible. The final keystroke to start the burstmode for the reappearance was entered on $14^h 10^m 09^s$ UT. The data acquisition was active for 25 seconds and soon after, the individual images of the sequence were displayed. Excitation was rising when after 300 frames the screen still showed pure background. But then the intensity scaling of the display changed, indicating an increasing signal that soon overwhelmed the background level. With great joy we realised that the reappearance was caught late but not too late. Figure 2 shows the corresponding stack of frames. A more realistic impression can be obtained by watching the MPEG movies available at these URLs:

http://www.ls.eso.org/lasilla/Telescopes/360cat/timmi
http://www.tls-tautenburg.de/research/cw_leo.html and
http://www.arcetri.astro.it/~luna/irc10216.html

The first result presented here is based on the preliminary light curve of the reappearance shown in Figure 3. The one-dimensional brightness profile of CW Leo was derived by deconvolving this light curve with a point-source model according to the Fresnel prescription of diffraction at the lunar limb, taking into account all observational circumstances (spectral and temporal bandwidth, etc.). The deconvolution procedure utilises a maximum-entropy algorithm, which is the same as in Stecklum et al. (1995). The resulting brightness distribution has a FWHM of 0.6″, which confirms previous estimates. The eastern part is more wiggly, presumably due to scintillation, which influenced the last part of the light curve. Figure 4 provides a superposition of the eastern and western parts of the brightness profile. It can be recognised that there are step-like features in the profile, which occur almost symmetrically on either side. At least four such steps can be distinguished. Although the reduction of the data just started, we are confident that these features are not spurious but represent imprints of the innermost dust shells. Furthermore, the profile looks rather flat-topped and is much broader at its peak than the often-adopted angular diameter of the star of 40 mas. This indicates that either the photosphere is much more extended than previously believed or even hidden from direct view at mid-infrared wavelengths.

More in-depth conclusions will be drawn by comparing the final brightness profiles to model calculations. For us observers, the measurement was a breathtaking experience, and for TIMMI, it was a great finale. We’ll miss you.

References

Acker, A., Ochsenbein, R., Stenholm, B., Tylenda, R., Marcout, J., & Schon, C., 1992, *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae*, ESO.
Crabtree, D.R., McLaren, R.A., & Christian, C.A., 1987, in: *Late Stages of Stellar Evolution*, eds. S. Kwok & S.R. Pottasch, Kluwer Academic Publ., 145.
Groenewegen, M.A.T., van der Veen, W.E.C.J., Lefloch, B., & Omont, A., 1998, *A&A*, **322**, L21.
Haniff, Ch. & Buscher, 1998, *A&A*, **334**, L5.
Iben, I., & Renzini, A., 1983, *ARA&A*, **21**, 271.
Käufl, H.-U., Jouan, R., Lagage, P.O., Masse, P., Mestreau, P., Tarrius, A., 1992, *The Messenger* **70**, 67.
Käufl, H.-U., Stecklum, B., & Richichi, A., 1998, Proc. SPIE, 3350, p. 267.
Shawl, S.J. & Zellner, B., 1970, ApJ, 162, L19.
Skinner, C.J., Meixner, M., & Bobrowski, M., 1998, *MNRAS*, **300**, L29
Sloan, G.C. & Egan, M.P., 1995, ApJ, 444, 452
Stecklum, B., Henning, T., Eckart, A., Howell, R.R., & Hoare, M., 1995, *ApJ*, **445**, L153.
Stecklum, B., Käufl, H.-U., Richichi, A., 1997, in: Science with the VLTI, ed. F. Paresce, Springer-Verlag, 153.
Toombs, R.L., Becklin, E.E., Frogel, J.A., Law, S.K., Porter, F.C., & Westphal, J.A., 1972, *ApJ*, **173**, L71.
Weigelt, G., Balega, Y., Blöcker, T., Fleischer, A.J., Osterbart, R., & Winters, J.M., 1998, *A&A*, **333**, L51.
Winters, J.M., Fleischer, A.J., Gauger, A., & Sedlmayr, E., 1995, *A&A* **302**, 483.

Stecklum@methusalix.tls-tautenburg.de
(Bringfried Stecklum)
hukaufl@eso.org

The Reflex Cluster Survey: Observing Strategy and First Results on Large-Scale Structure

L. GUZZO [1], H. BÖHRINGER [2], P. SCHUECKER [2], C.A. COLLINS [3], S. SCHINDLER [3], D.M. NEUMANN [4], S. DE GRANDI [1], R. CRUDDACE [5], G. CHINCARINI [1,6], A.C. EDGE [7], P.A. SHAVER [8], W. VOGES [2]

[1]*Osservatorio Astronomico di Brera, Milano/Merate, Italy*
[2]*Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany*
[3]*Liverpool John Moores University, Liverpool, U.K.*
[4]*CEA Saclay, Service d’Astrophysique, Gif-sur-Yvette, France*
[5]*Naval Research Laboratory, Washington D.C., U.S.A.*
[6]*Dipartimento di Fisica, Università degli Studi di Milano, Italy*
[7]*Physics Department, University of Durham, U.K.*
[8]*European Southern Observatory, Garching, Germany*

1. Introduction

As a modern version of ancient cartographers, during the last 20 years cosmologists have been able to construct more and more detailed maps of the large-scale structure of the Universe, as delineated by the distribution of galaxies in space. This has been possible through the development of redshift surveys, whose efficiency in covering ever larger volumes has increased exponentially thanks to the parallel evolution in the performances of spectrographs and detectors (see e.g. Da Costa 1998 and Chincarini & Guzzo 1998, for recent reviews of the historical development of this field).

While the most recent projects, as the Las Campanas Redshift Survey (LCRS, Shectman et al. 1996) and the ESO Slice Project (ESP, Vettolani et al. 1997) have considerably enlarged our view by collecting several thousands of redshifts out to a depth of $\sim 500\ h^{-1}$ Mpc[1], the quest for mapping a “fair sample” of the Universe is not yet fully over. These modern galaxy redshift surveys have indeed been able to show for the first time that large-scale structures such as superclusters and voids keep sizes that are smaller than those of the surveys themselves (i.e. $\sim$ 100–200 h^{-1} Mpc). This is

[1]Here h is the Hubble constant in units of 100 km s^{-1} Mpc^{-1}.