Combining MIDI Measurements and Lunar Occultation Observations with TIMMI2

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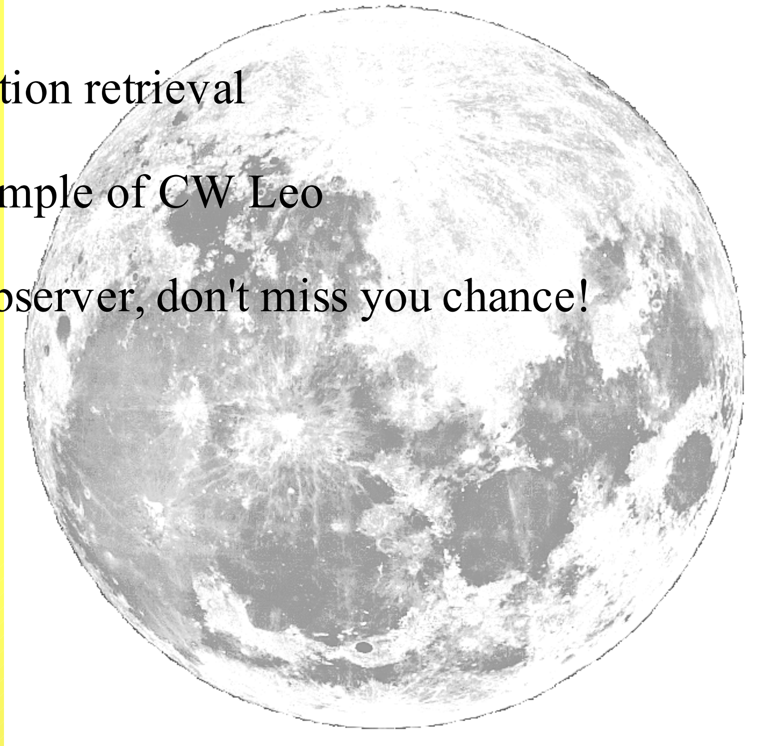
Outline:

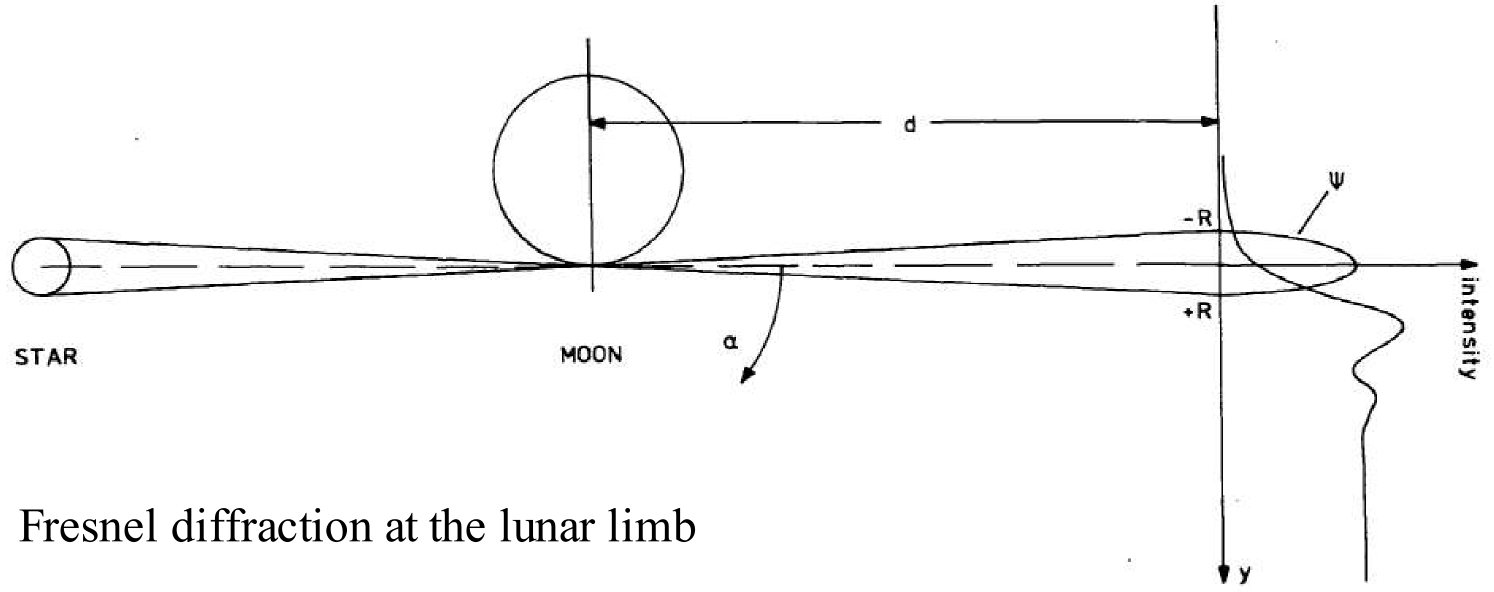
- Basic principle of lunar occultations (LO)
- Observational requirements and sensitivity
- Target selection
- Information retrieval
- The example of CW Leo
- MIDI observer, don't miss you chance!



Stecklum, Käufl, & Richichi (1997), in:
Science with the VLTI, ed. F. Paresce

Käufl, Stecklum, & Richichi (1998)
Proc. SPIE 3350

Basic Principle of Lunar Occultations

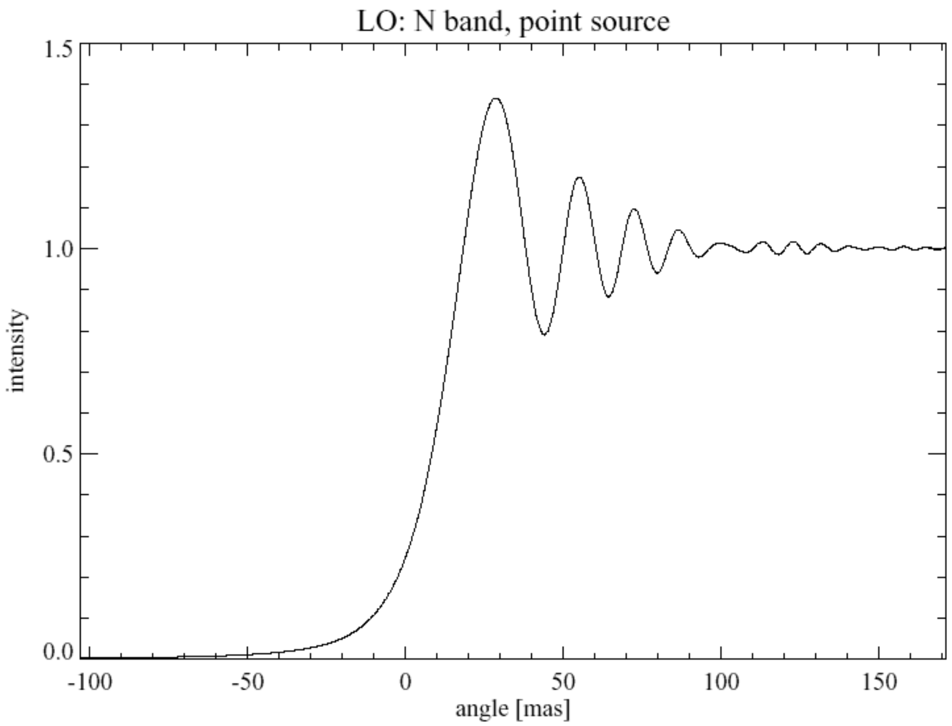


Fresnel diffraction at the lunar limb

Fresnel scale: $\Theta_F = (\lambda/2d)^{½}$

Angular size: $\Theta_F(10\mu m) \approx 25$ mas

Time scale: $\Delta T(\Theta_F) \approx 50$ ms



Object points at the same distance from the lunar limb will cause identical diffraction patterns → net integration of the intensity distribution over one dimension

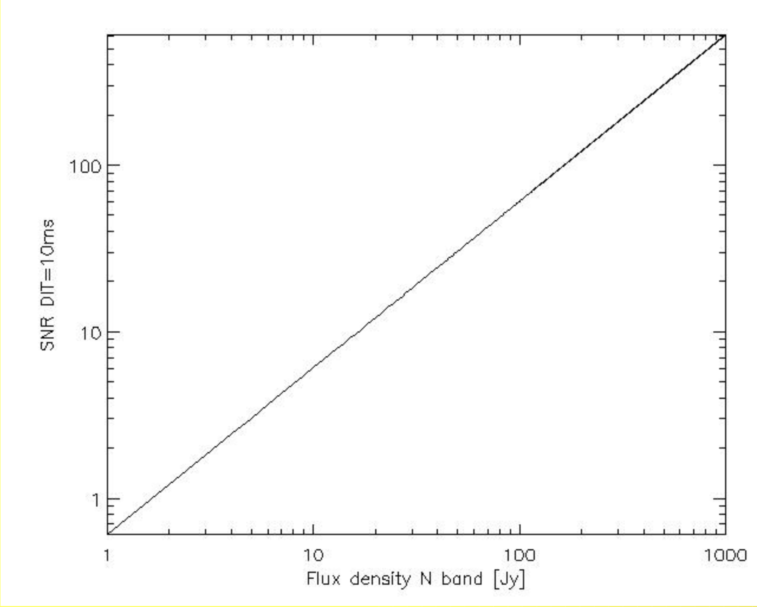
The observed fringe pattern is the convolution of the strip brightness distribution with the fringe pattern of a point source.

Observational Requirements and Sensitivity

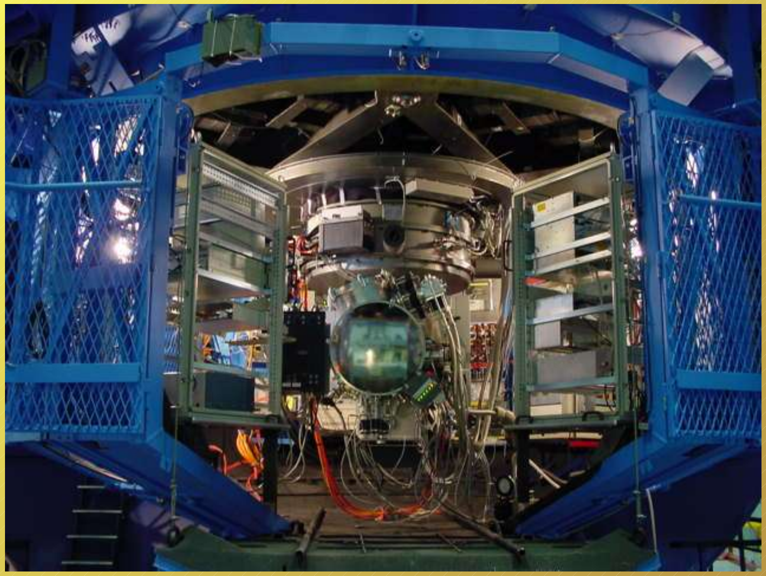
Thermal background in the Airy disk for *N* band: ~10^{10} photons/s
Full well capacity of the detector pixels: ~10^7 e^-
→ short detector read-out times (~10ms) to avoid of saturation from the background in the thermal infrared (IR)

Each thermal IR camera/low-res spectrometer has the potential for recording LOs!

LO observations have to be done in staring mode



SNR for LO observations in the *N* band with DIT=10ms



TIMMI2 in the cage of the ESO 3.6-m telescope

First LO observations with TIMMI (Käufl et al. 1992, 64x64 pixels, ~500 frames) in 1996

TIMMI2 (Reimann et al. 1998, 320x240 Raytheon detector) is capable of measuring LOs after the replacement of the initial read-out electronics by ESO's IRACE system; no on-sky tests yet but observing time in P72 granted, most promising mode: (slitless) low-res spectroscopy (R~160)

Target Selection

“Unbiased” sample of occultation targets due to lunar orbit (sky coverage ~10%), mean time between occultation cycles ~9 yrs

There are several sky regions harboring numerous and/or interesting targets, e.g., Galactic Bulge (incl. GC, AGB stars, massive YSOs), Taurus, Ophiuchus, Orion, CW Leo.

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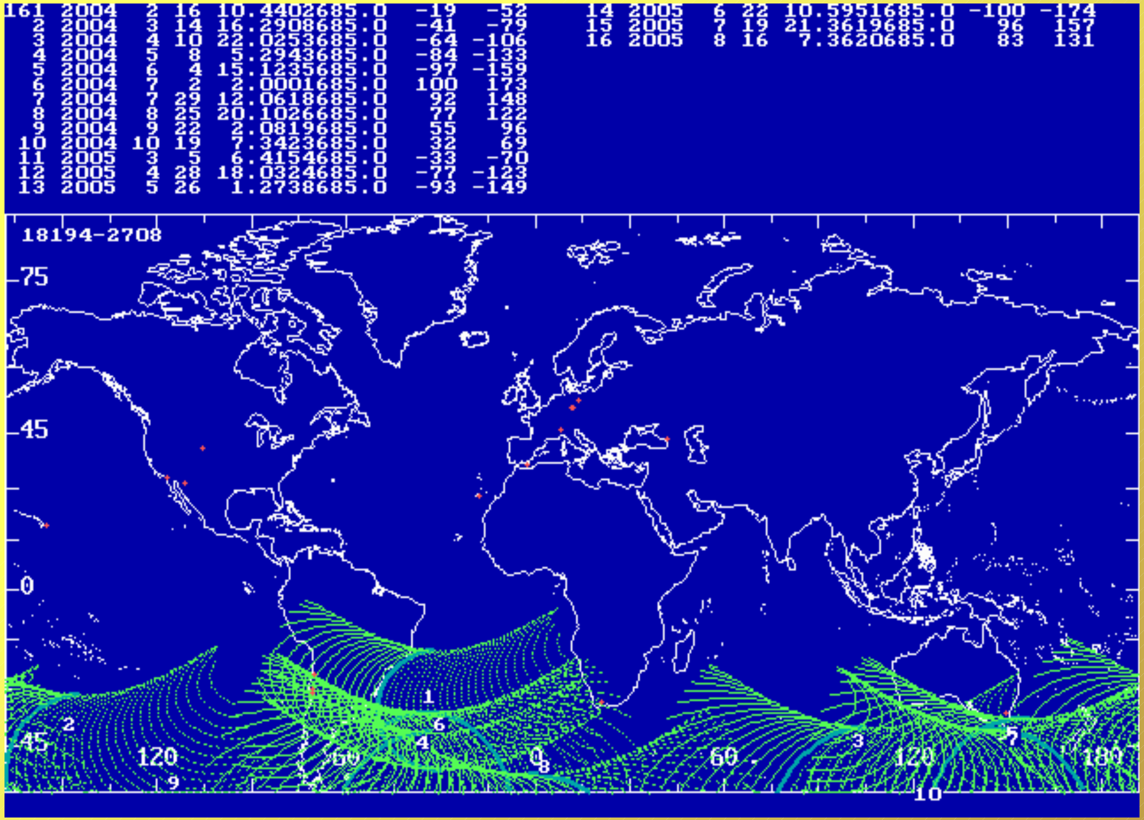
Occultation forecast for La Silla for IRAS sources
with F(12)>25Jy
yyyy mm dd  IRAS          F(12)    F(25)    F(60)
2004  2  9  11432+0648   42.920   10.850    1.762
2004  2 16  18194-2708  685.000  264.600   70.060
2004  4  6  13389-0827   27.150    6.676    1.039
2004  4 10  17450-2724   55.650   41.240   34.690
2004  5  2  12226+0102   91.640   28.690    5.756
2004  5 31  13389-0827   27.150    6.676    1.039
2004  6  4  17501-2656  243.600  195.500   61.120
2004  6  4  17517-2731   27.000   22.220   21.930
2004  7  2  18194-2708  685.000  264.600   70.060
2004  7  2  18194-2708  685.000  264.600   70.060
2004  7 29  17517-2731   27.000   22.220   21.930
2004  8 24  16235-2416   35.120  265.000 2196.000
2004  8 24  16240-2430   39.440   74.020  197.300
2004  9 19  16052-2339   50.200   24.860    3.332
2004 10  5  06011+2829   67.900   34.610    6.103
2004 10 20  19038-2744   26.050    6.019    1.052
2005  2  5  17450-2724   55.650   41.240   34.690
2005  2 26  12020+0254   30.450   18.300    3.077
2005  4  1  18100-2808   28.210   22.890    3.192
2005  4 28  17455-2800   82.840  468.600 2543.000
2005  4 28  17473-2751  144.000  112.300   20.880
2005  4 28  17488-2800  250.100  148.300   18.390
2005  4 28  17495-2813   37.530   31.450   12.210
2005  6 22  18018-2802  139.700   80.650   14.580
2005  6 22  18018-2802  139.700   80.650   14.580
2005  6 23  19038-2744   26.050    6.019    1.052
2005  6 27  23142-0759   64.640   16.910    2.682
2005  8 16  18100-2808   28.210   22.890    3.192
2005  9 11  17361-2807   26.400   24.170    5.972
2005 11  6  18100-2808   28.210   22.890    3.192
```



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161 2004  2 16 10.4402685.0  -19  -52         14 2005  6 22 10.5951685.0 -100 -174
  2 2004  3 14 16.2908685.0  -41  -79         15 2005  7 19 21.3619685.0   96  157
  3 2004  4 10 22.0253685.0  -64 -106         16 2005  8 16  7.3620685.0   83  131
  4 2004  5  8  5.2943685.0  -84 -133
  5 2004  6  4 15.1235685.0  -97 -159
  6 2004  7  2  2.0001685.0  100  173
  7 2004  7 29 12.0618685.0   92  148
  8 2004  8 25 20.1026685.0   77  122
  9 2004  9 22  2.0819685.0   55   96
 10 2004 10 19  7.3423685.0   32   69
 11 2005  3  5  6.4154685.0  -33  -70
 12 2005  4 28 18.0324685.0  -77 -123
 13 2005  5 26  1.2738685.0  -93 -149
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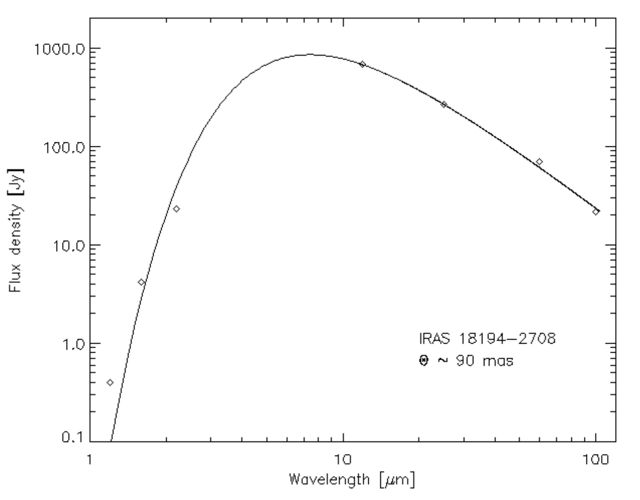
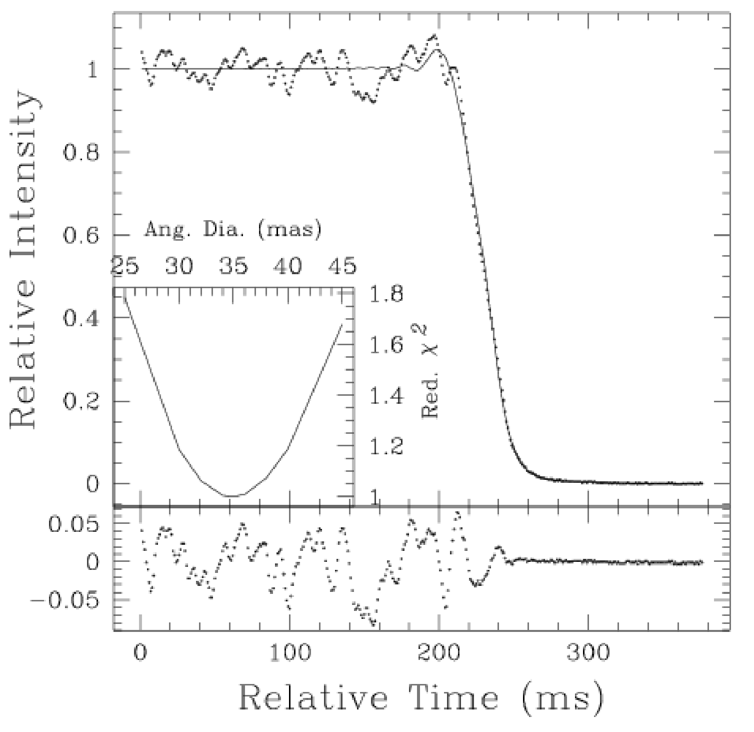


Global LO prediction for the carbon star V5104 Sgr (top) and crude BB fit of its SED (left, $T_{eff} \approx 230K$, $\Theta \approx 90mas$)

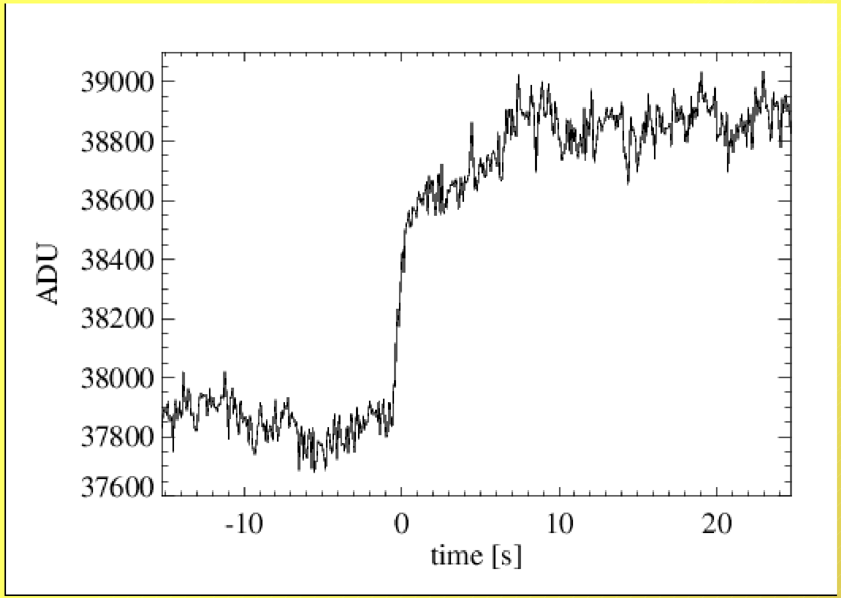
Information Retrieval

I) Fit of the observed fringe pattern using a model (binary star, uniform disk, output of radiative transfer calculations)

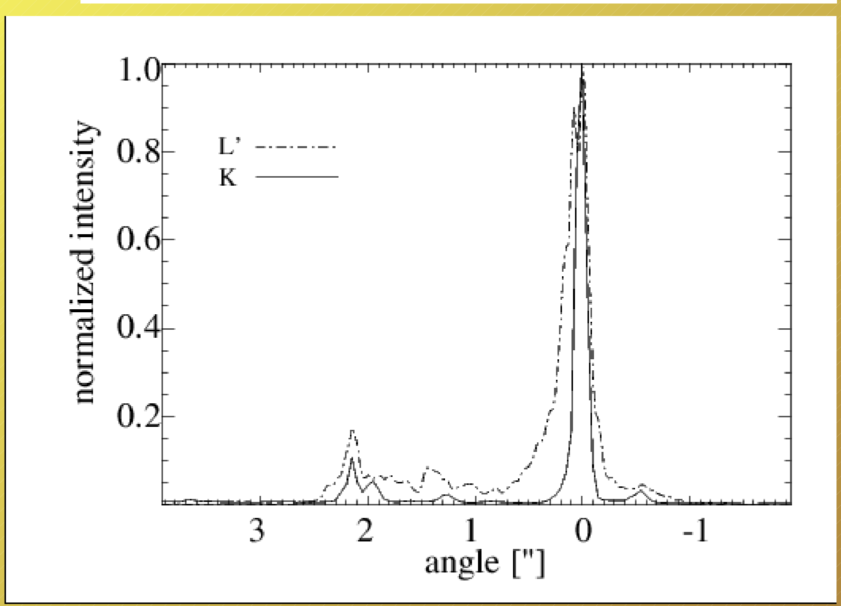


LO of R Leo (*K* band) together with best fit (solid line), residuals (bottom) and reduced χ^2 (insert)
Tej et al. (1999)

II) Recovery of the strip brightness distribution by deconvolution using a model PSF



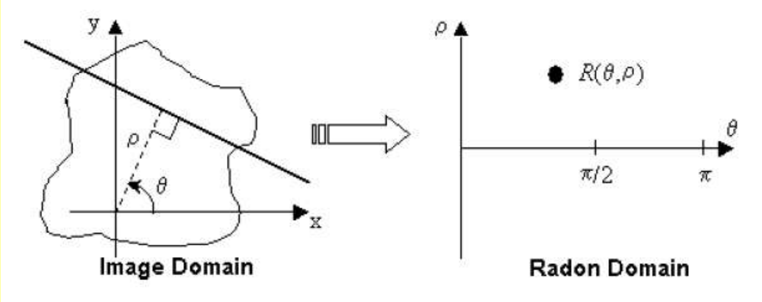
LO of the O7 star Herschel 36 (*L'* band)
Stecklum et al. (1995)



Deconvolved strip brightness distribution (dashed-dotted line) and synthetic strip brightness distribution based on adaptive optics imaging in the *K* band (full line)

Information Retrieval

III) In case of multiple occultation observations, the application of a tomographic technique (back-projection based on the Radon transform) allows to recover the image (at least in principle, with some inherent smoothing):

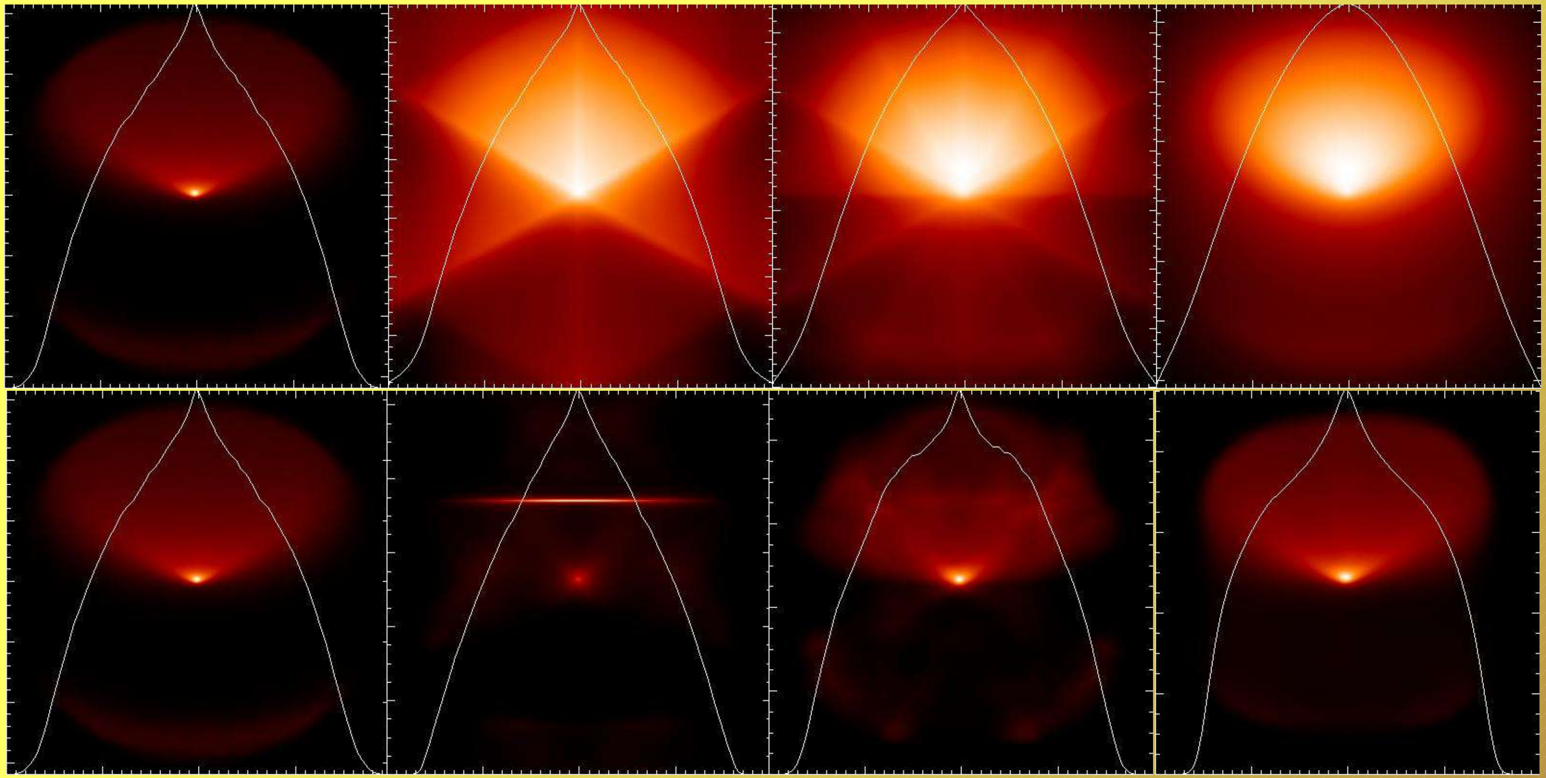


$$R(\theta, \rho) = \int_{-\infty}^{\infty} A(\rho\cos\theta - s\sin\theta,\ \rho\sin\theta + s\cos\theta)\,ds$$

Radon transform

$$B(x, y) = \int_{0}^{\pi} R(\theta,\ x\cos\theta + y\sin\theta)\,d\theta$$

Back-projection

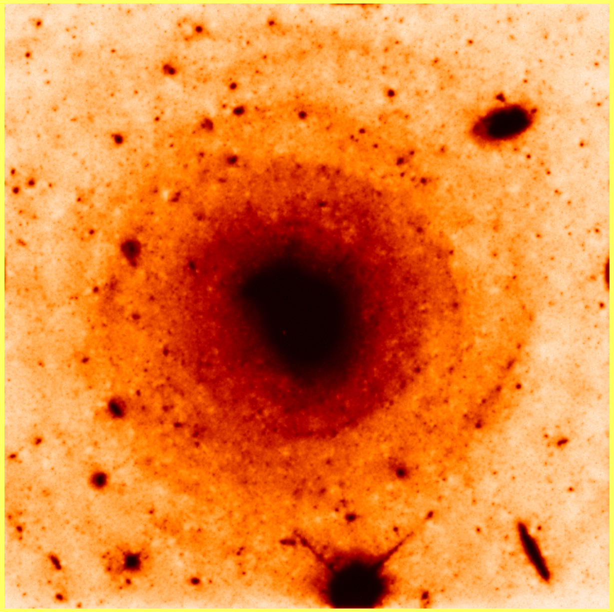


From left to right: Intensity distribution of a circumstellar disk computed with MC3D (Wolf, Henning, & Stecklum 2002) with superimposed strip brightness distribution; reconstructed images with 3, 6, and 1257 projections and corresponding strip brightness distributions without (top) and with Lucy deconvolution (bottom)

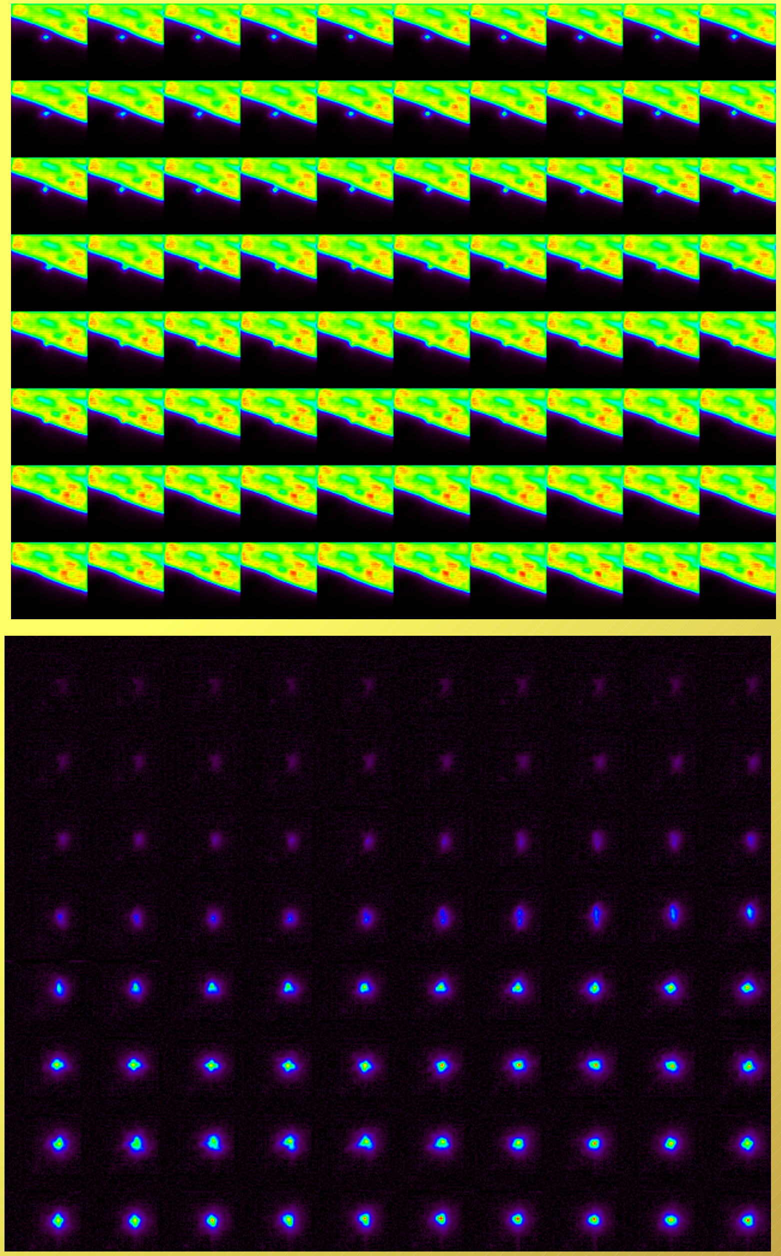
The Example of CW Leo

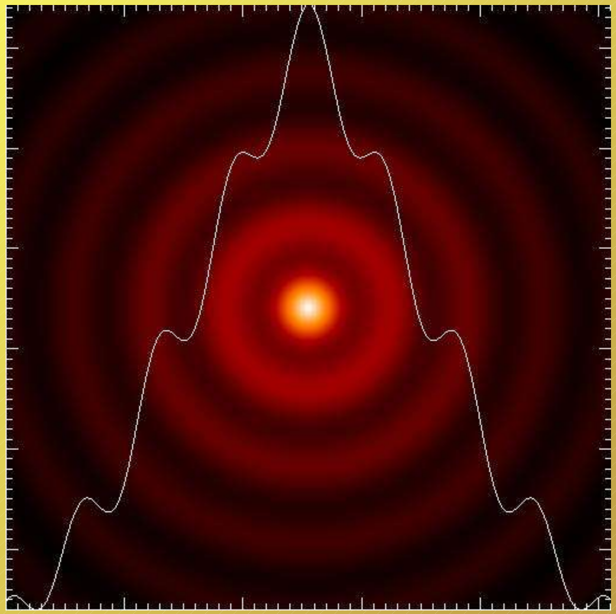
CW Leo (IRC+10216)
Daytime observation with TIMMI (1998 Nov. 11th, 11.6µm)

Stecklum, Käufl, & Richichi (1999)



HST WFPC *V* image
Mauron & Huggins (2000)

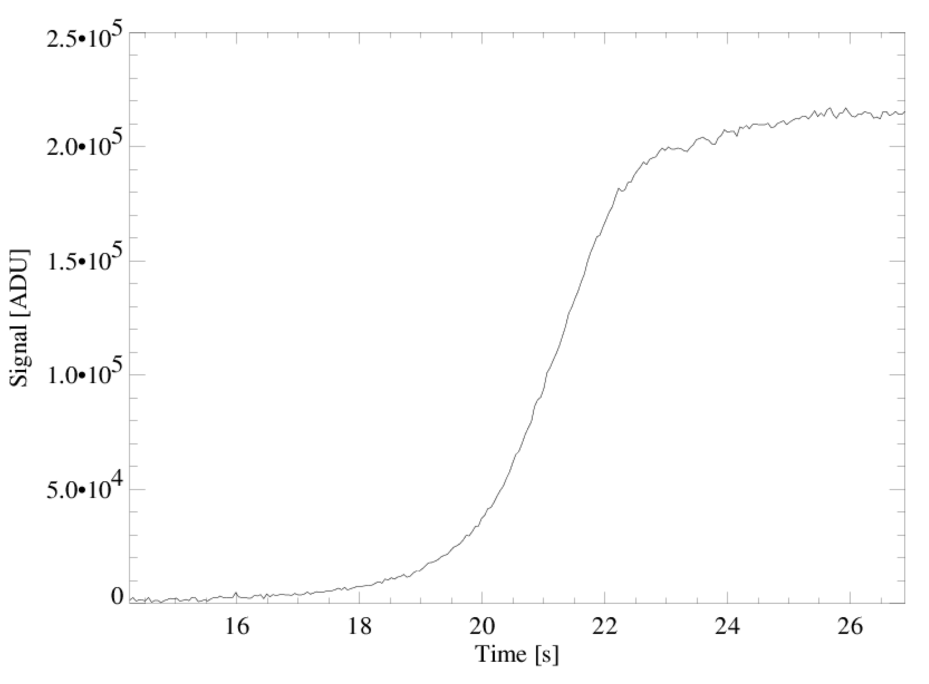




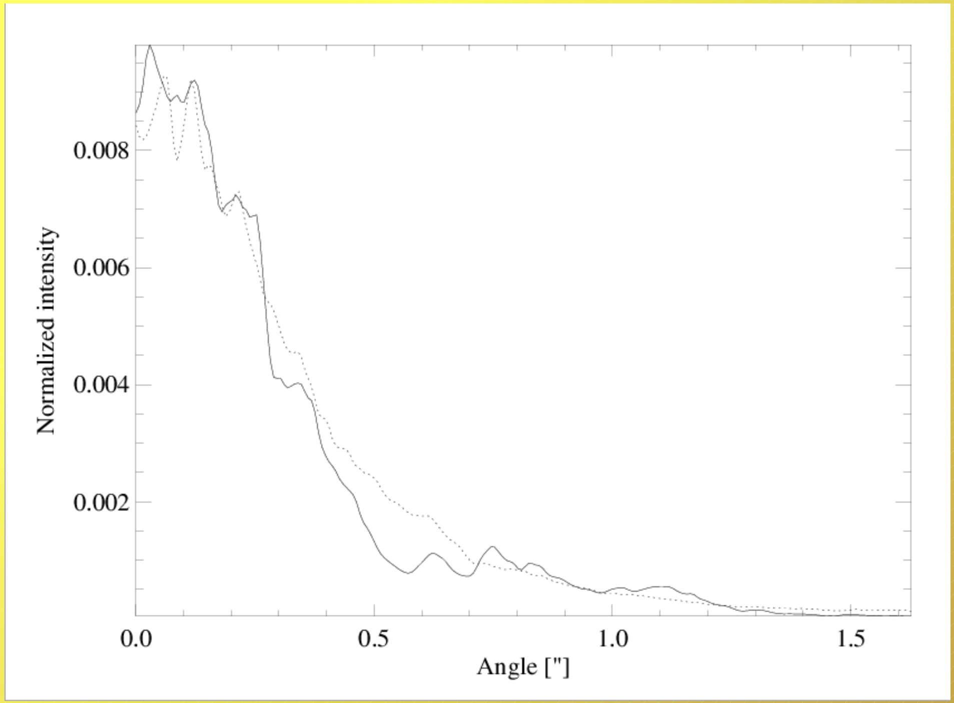
Strip brightness distribution for optical thick concentric dust shells

Time series of the disappearance (top) and reappearance (bottom) of CW Leo (each image is the average of three frames taken in staring mode with 50ms detector integration time)

The Example of CW Leo



Light curve of the reappearance (SNR ≈ 540)



Deconvolved strip brightness distribution, folded around the "center of light"

Major results:

- No detection of the central star → optically thick dust configuration
- Up to four coherent wiggle features indicate the presence of onionlike dust shells close to the star
- The separation of these shells suggests dust formation with sub-harmonic frequencies of the Mira-pulsation, in accordance with models (Schröder et al. 1998)

MIDI observer, don't miss your chance!

LO observations provide angular resolution similar to MIDI with a very small demand on observing time. LOs of targets appropriate for OT proposals in P73 (F (*N*) ≥ 5 Jy) can be detected with TIMMI2 at SNR ≥ 3. Due to the integration over one spatial coordinate, strip brightness distributions derived from LOs cannot be easily used to fill the *uv*-plane.

Immediate rewards:

- Binary stars: intensity ratio and projected separation from LO; one visibility point is enough to fix the position angle of the system
- Angular diameters: LOs will generally sample a different “projected baseline” than MIDI, thus allow conclusions on deviations from spherical symmetry
- Extended sources: additional constraints on models will shrink acceptable parameter space; almost simultaneous LO/MIDI observations should be attempted for variable sources
- The strip brightness distribution provides information on the object symmetry, i.e., a coarse phase which can be helpful as initial guess for iterative phase reconstruction (e.g., Fienup 1978)

Historic perspective:

The situation concerning LOs in the IR is getting similar to that in radio astronomy about 40 years ago. Radio astronomers abondoned the use of LOs when their interferometric arrays became available.