FLUOR
Data modeling and interpretation

Michelson Summer School

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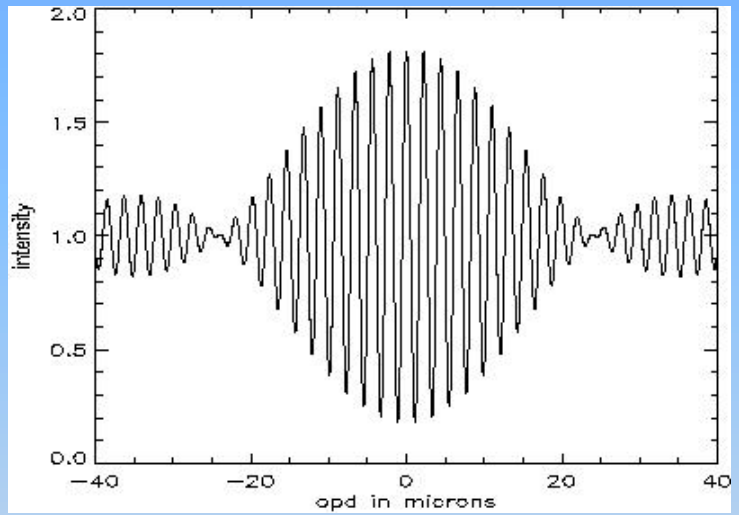
DATA MODELING & INTERPRETATION

- INTERFEROMETRIC OBSERVABLES
- SIMPLE MODELS
- MORE ELABORATED MODELS
- QUALITY CONTROL
- LAB PART: RX Boo and R Leo examples
- CONCLUSIONS on R Leo

Interferometric observables

- ZVC theorem:



$$\Rightarrow \quad V(\vec{B}_p/\lambda) = \frac{\tilde{I}(\vec{\delta} = \vec{B}_p/\lambda)}{\tilde{I}(\vec{\delta} = \vec{0})}$$

- In practice: visibility modulus, phase closure, astrometric signature...

- FLUOR: V squared modulus integrated over the bandpass

An inversion & minimization problem

Choose model with physical parameters P

Simulation ↓

Brightness distribution (P)

Fourier transform ↓

$$V_{th}(\vec{\omega}_1, P), V_{th}(\vec{\omega}_2, P), \ldots, V_{th}(\vec{\omega}_n, P)$$

Data set:

$$V_m(\vec{\omega}_1), V_m(\vec{\omega}_2), \ldots, V_m(\vec{\omega}_n)$$

$$(\sigma_1, \sigma_2, \ldots, \sigma_n)$$

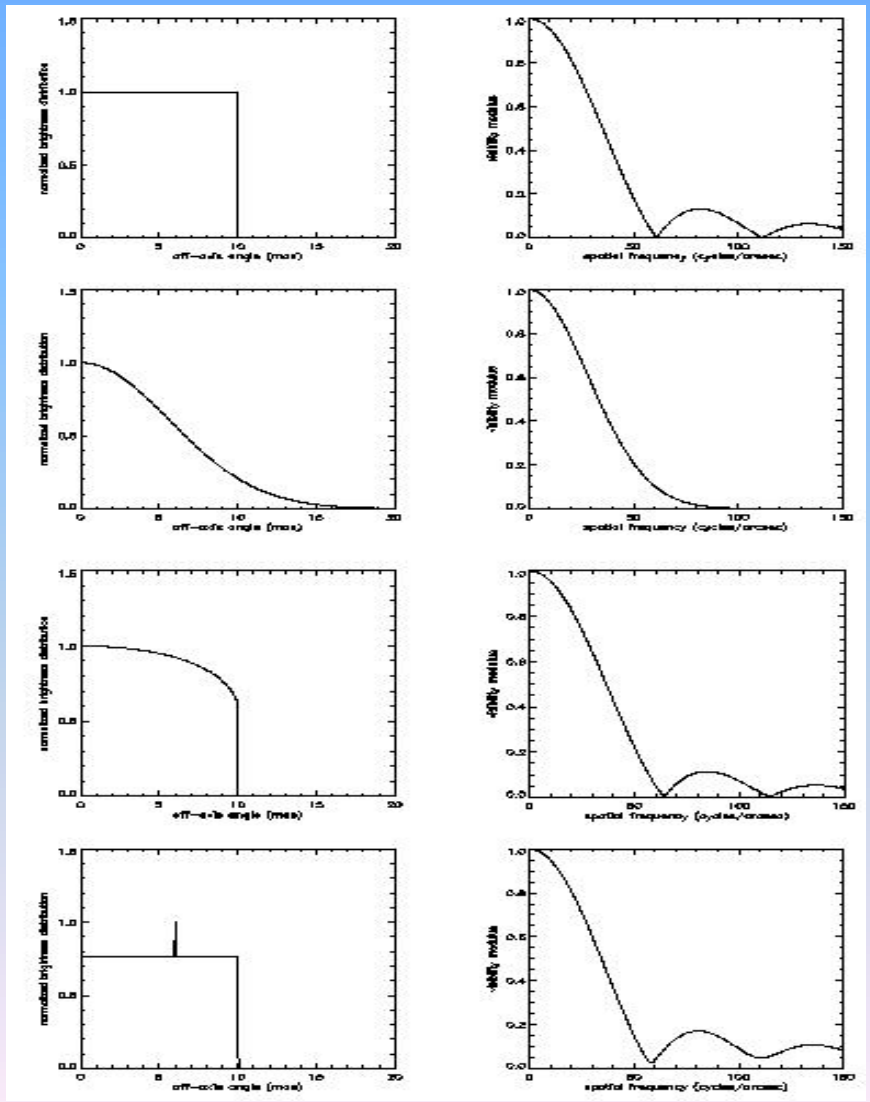
Minimization
of merit function

$$P = \phi, T_{int}, \tau, r_{int}, r_{ext}, \ldots$$

Best fit parameters P, error bars,
merit function value

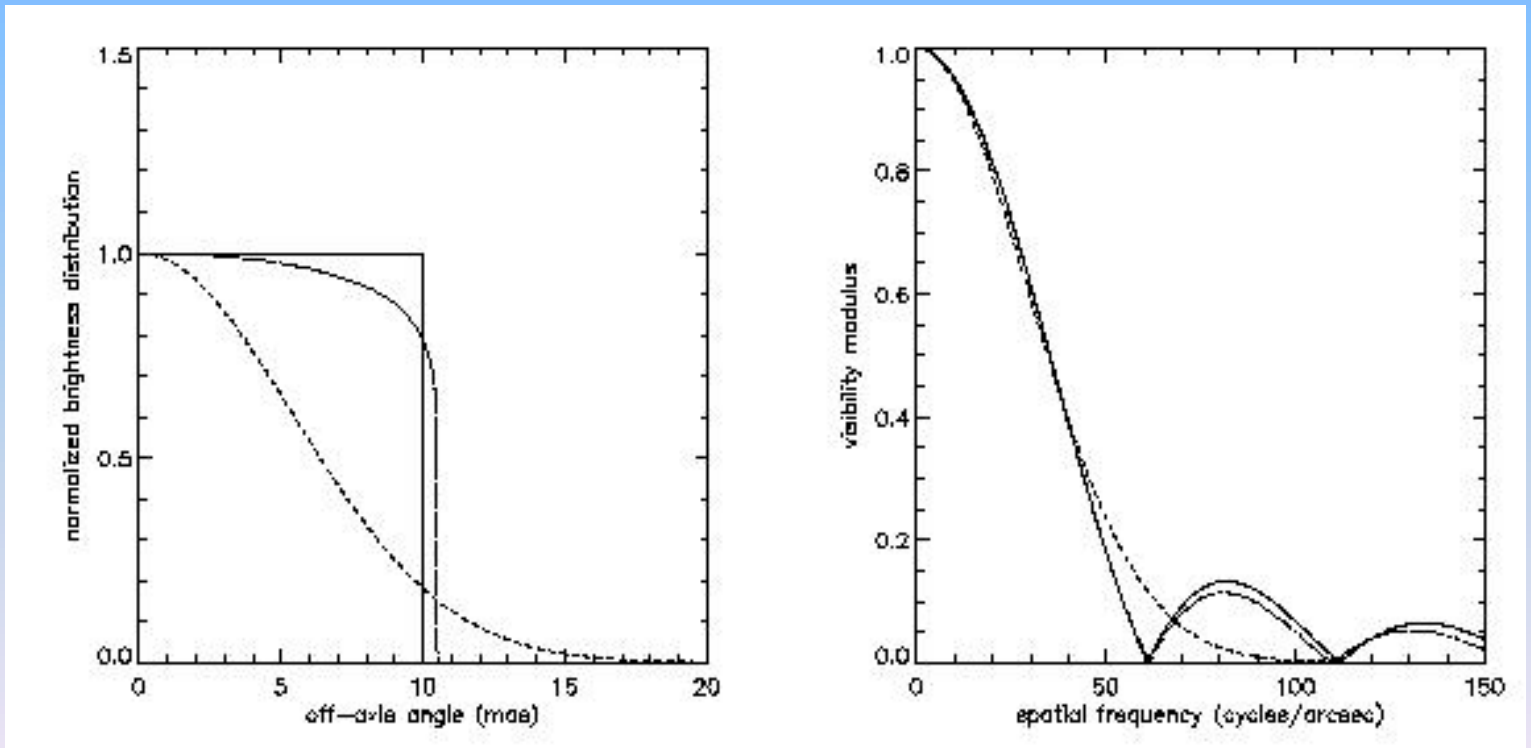
Simple models: 1 to 4 parameters fit

- Uniform disk fit
- Gaussian distribution(s)
- Limb darkened disk fit
- UD + Stellar spot



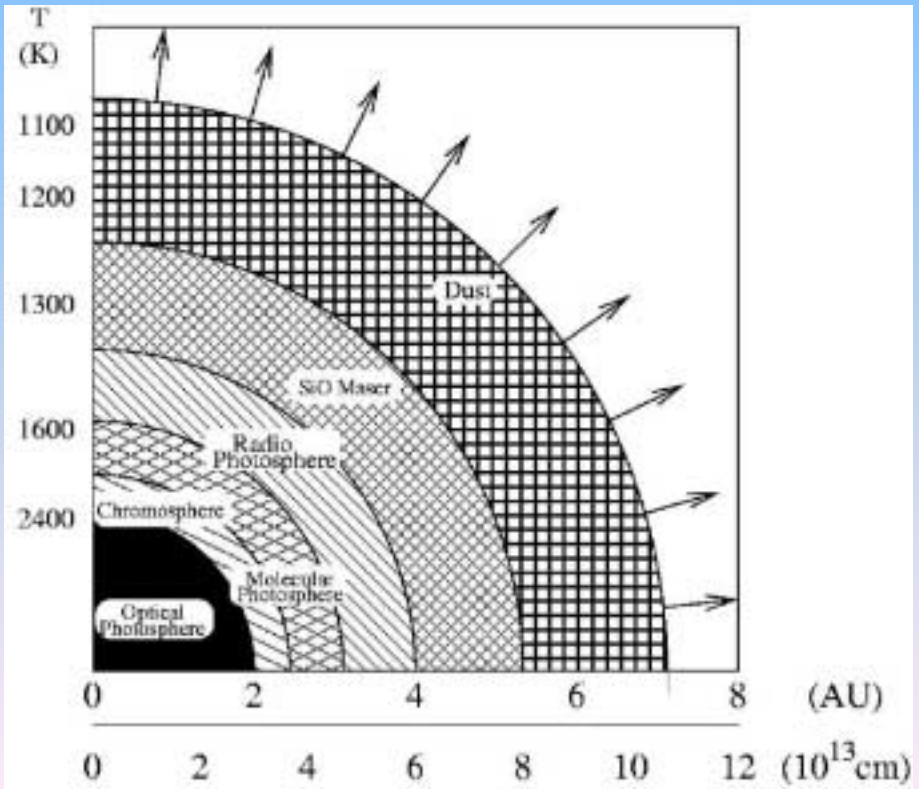
Uniqueness and Accuracy

Few observables… many models...



More elaborated Mira models

- Limb darkening (Scholz and Takeda 1987, Bessel et al. 1996, Hoffman et al. 1998)
- Dust shells: 3-D radiative transfer (Lopez et al. 1997)
- Semi-empirical 1-D radiative transfer: star + envelope



“Quality control”

- Is the fitted model physically viable?

  Check robustness by adding constraints: spectra, multi-λ (J,H,K, L, radio), multi-resolution data, stars of same type...

- Estimate the quality and uniqueness of the fit

ex: $$\chi^2(P_1 \ldots P_M) = \sum_{i=1}^{N} \left(V_{th}(S_i, P) - V_m(S_i)\right)^2 / \sigma_i^2$$

- Make sure error bars are significant (use low spatial fr. V)
- Better well constrain few parameters of a simple model
- Predictability and simplicity

LAB PART III

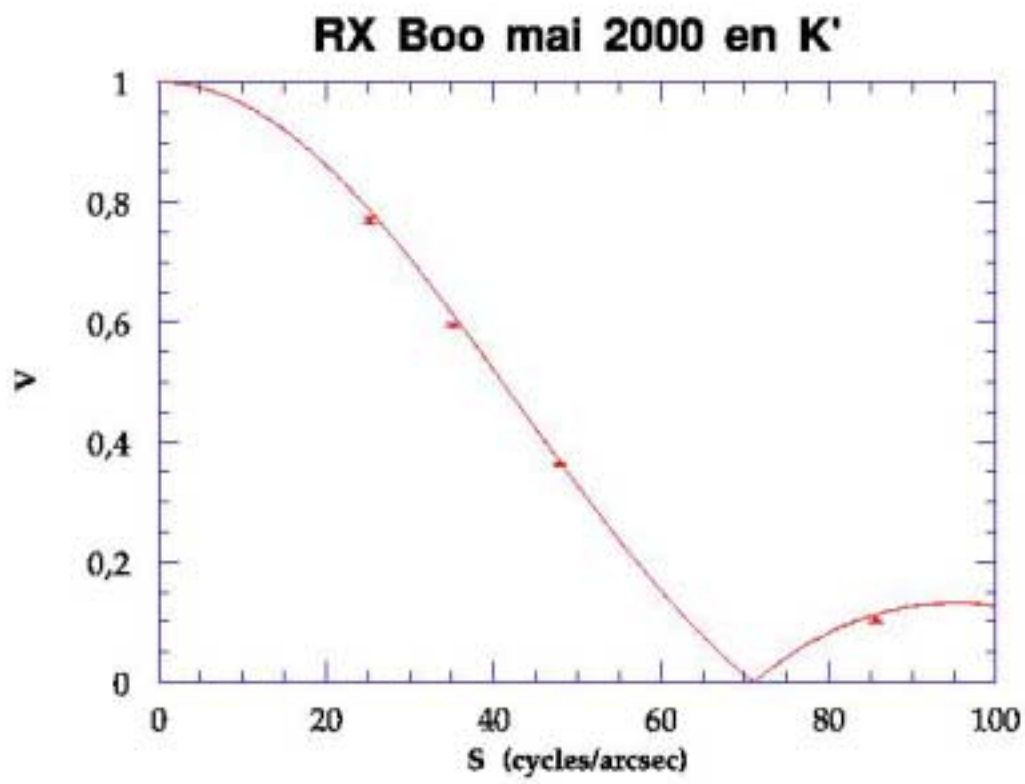
- Modeling of RX Boo (M8 III SR) 2000 data: UD and LD fits
- go to:

Code Fluor/Astronomy/Data modelling/

select all files option, open Find LD diameter LabVIEW vi

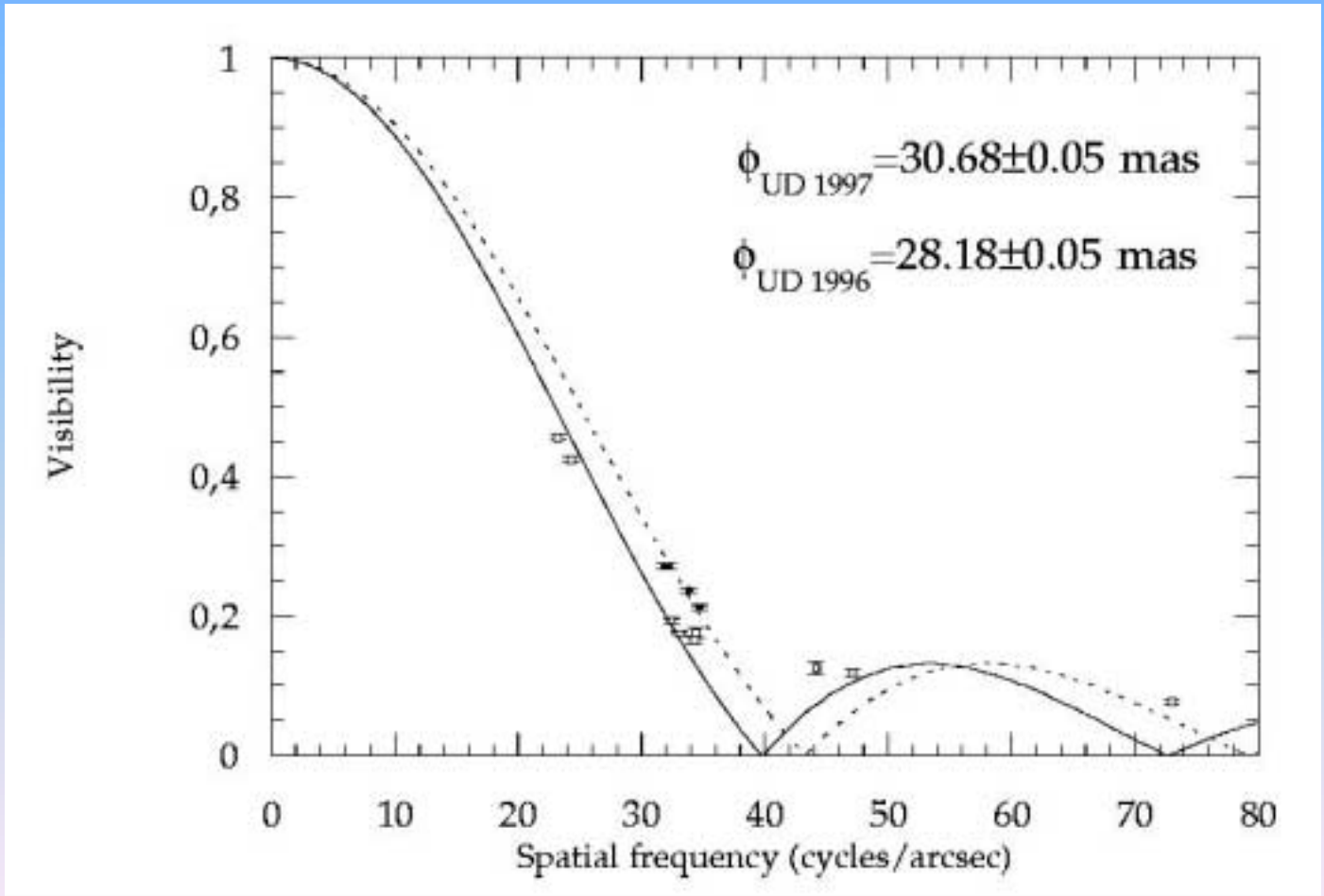
relevant parameters: n points, A,B LD coefficients, error bars...

RX Boo UD fit


RX Boo mai 2000 en K'
1
0,8
0,6
0,4
0,2
0
V
0
20
40
60
80
100
S (cycles/arcsec)

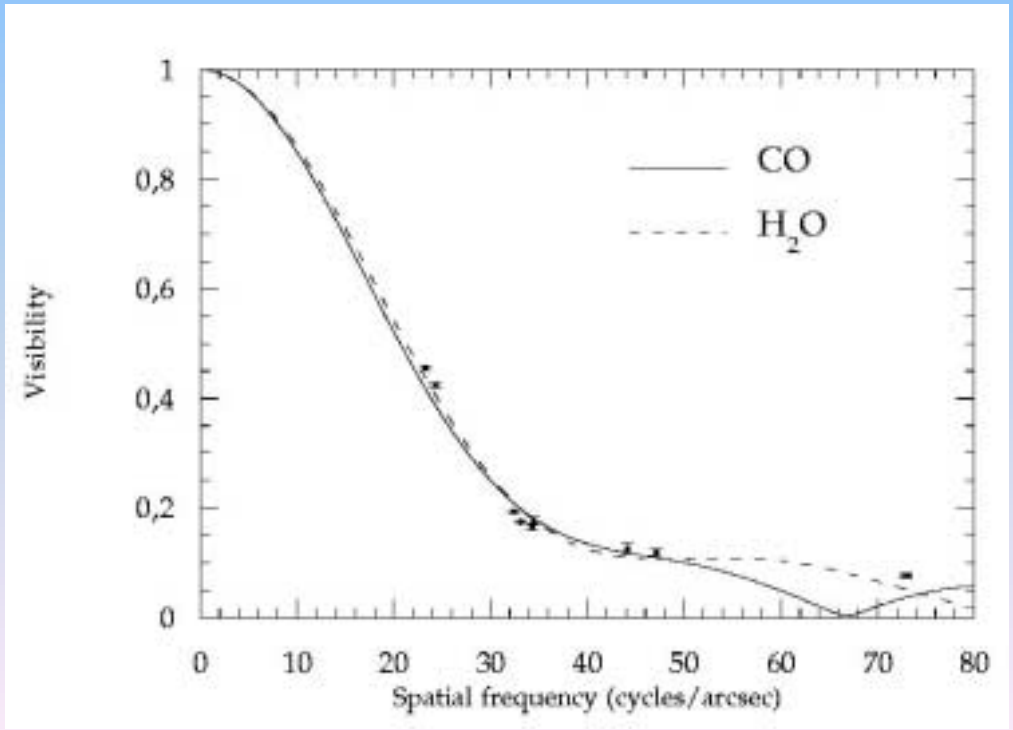
R Leo 1996-97 K data

ϕ_{96}=0.24 ϕ_{97}=0.28



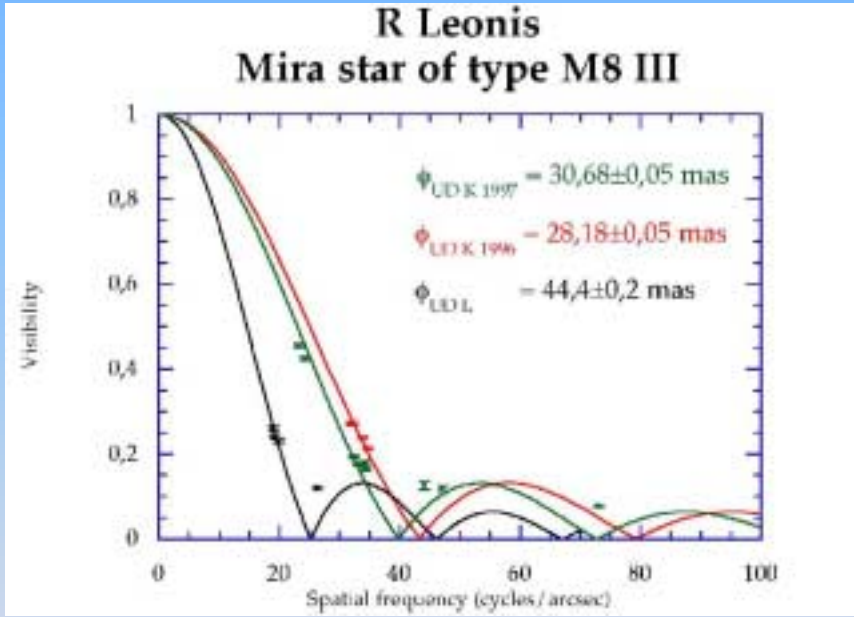
Fitting R Leo K band high frequency data
(Perrin et al. 1999)

- Limb darkening, limb brightening, spots...
- Diffusion by CO and H_2O:



R Leo at other wavelengths

- L band [3.4, 4.1 μm]
  (FLUOR, IOTA)



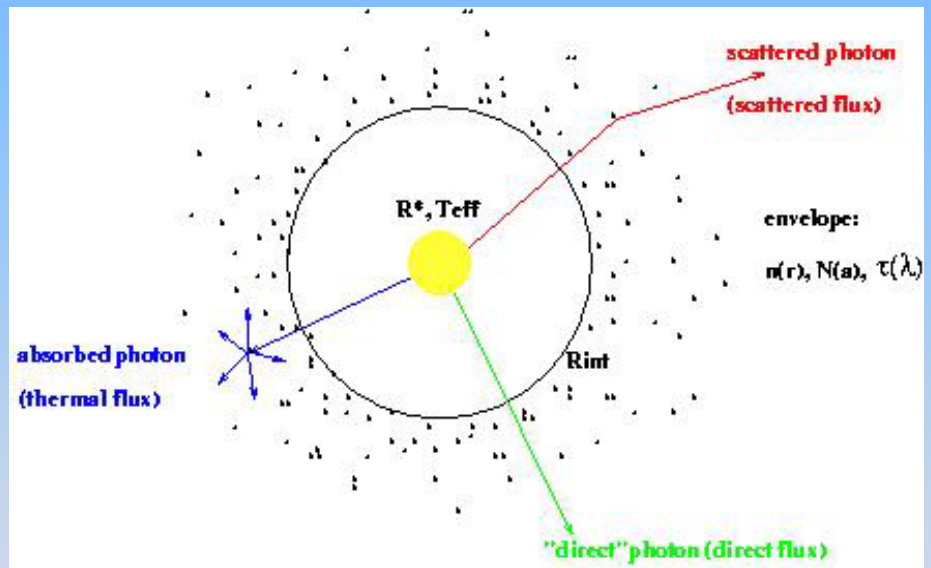
- 11.15 μm (ISI,Berkeley):

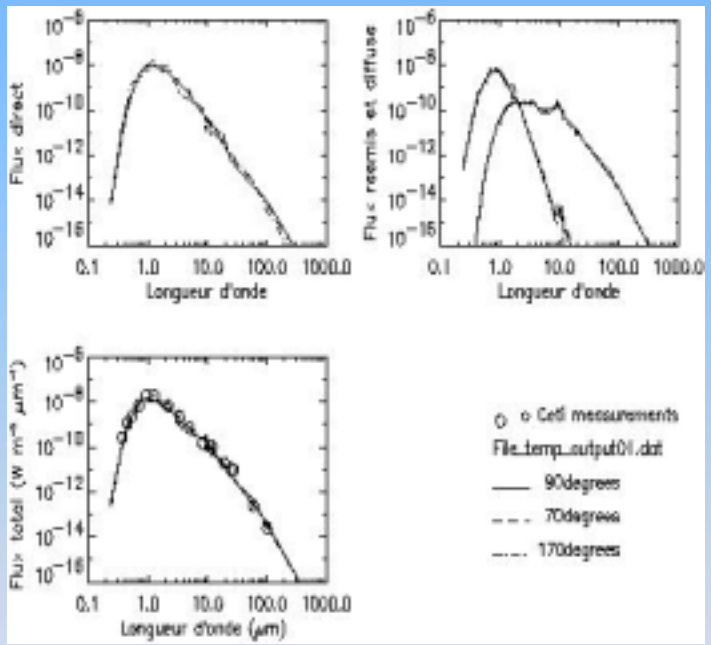
Detection of dust shell with R_{int}=70mas, T_{int}=800K,

τ(11.15 μm)=0.1

Radiative transfer through dust

Monte Carlo 3-D simulation
(Lopez et al. 1998)





ISI derived dust shell parameters do not explain K/L discrepancy (too thin shell)

o Ceti: back to molecules !

Yamamura et al. 1999 (ISO spectrum):

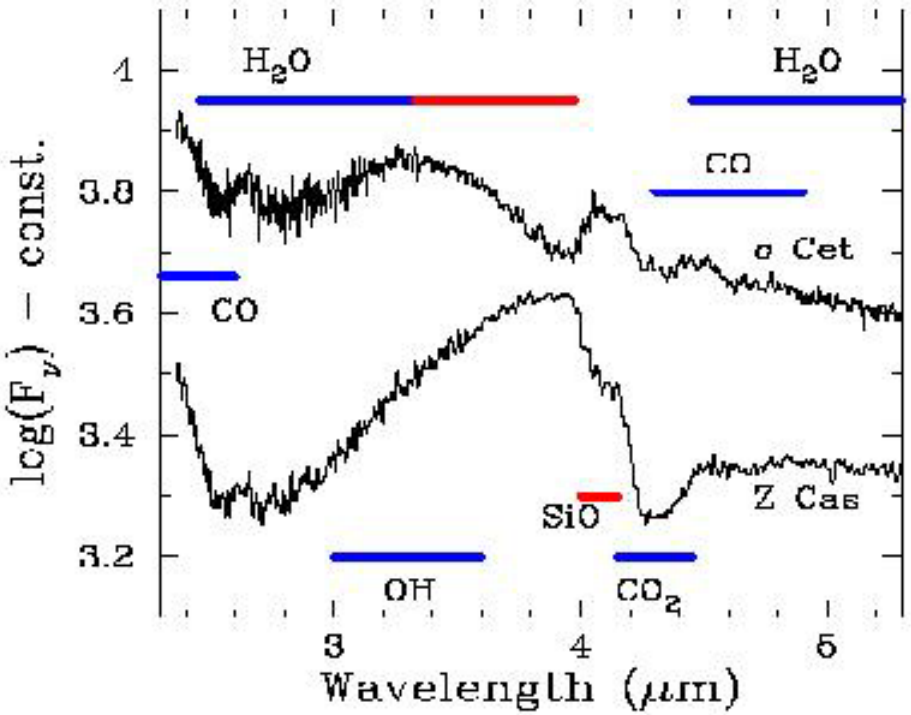
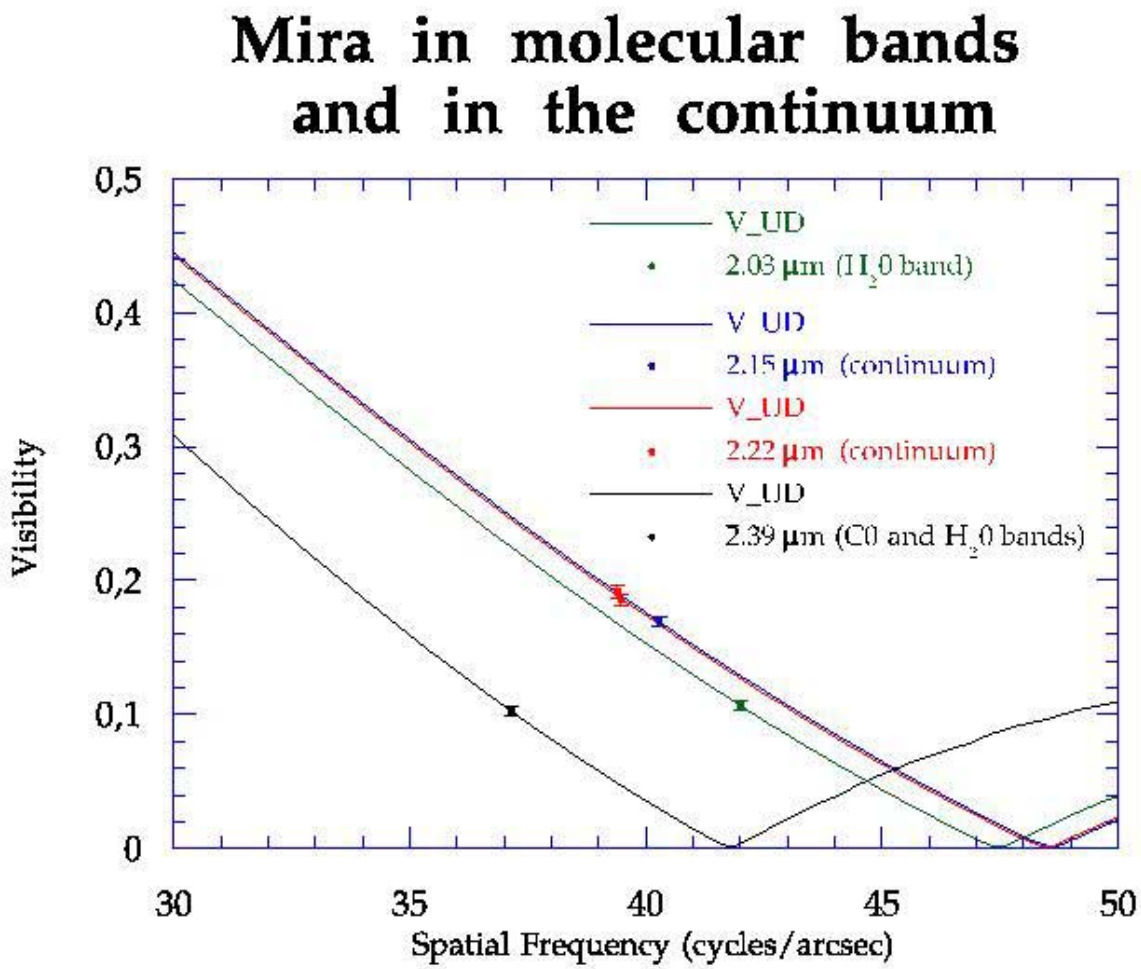


Fig. 1. ISO/SWS spectra of two oxygen-rich Miras between 2.4–5.3 μm. The spectral resolution is about 600 for o Cet and 300 for Z Cas. Identifications for the major spectral features are indicated.

Table 1. Properties of the stars and results of modeling.

Object		o Cet	
Sp. Type[1]		M5e–M9e	
Period[1]		331.96d	
	N(cm^{-2})	T(K)	R(R$_*$)
H_2O (hot)	$3.0\,10^{21}$	2000	2.0
SiO	$1.0\,10^{21}$	2000†	2.0†
H_2O (cool)	$3.0\,10^{20}$	1400	2.3
CO_2	$2.0\,10^{17}$	800	2.3†
$\mathcal{N}_{H_2O}$ (hot)		$2.7\,10^{49}$	
$\mathcal{N}_{H_2O}$ (cool)		$3.6\,10^{48}$	
n_{H_2O} (hot)		$4.8\,10^{7}$ cm^{-3}	
n_{H_2O} (cool)		$1.1\,10^{7}$ cm^{-3}	
Phase[2]		0.99	

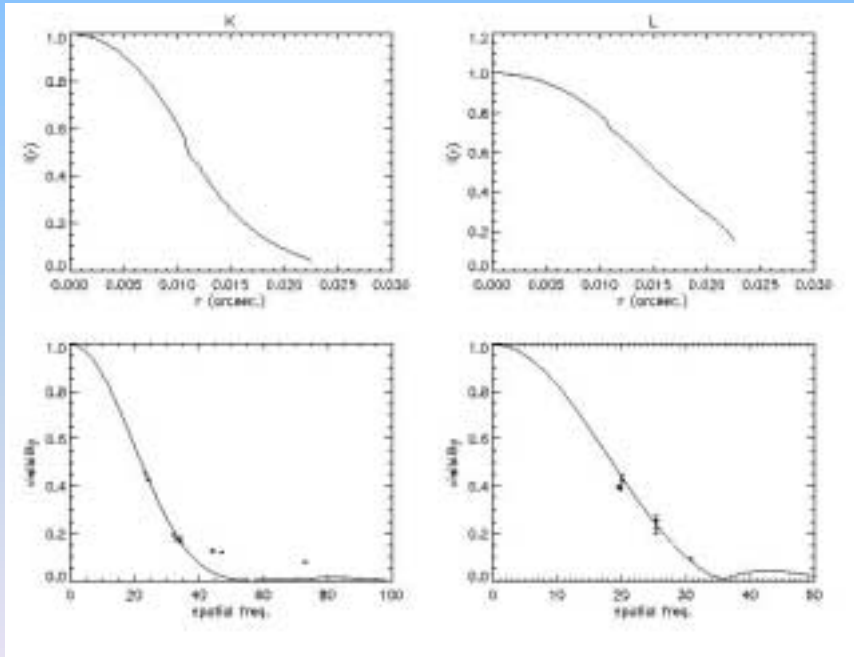
O Ceti narrow band data



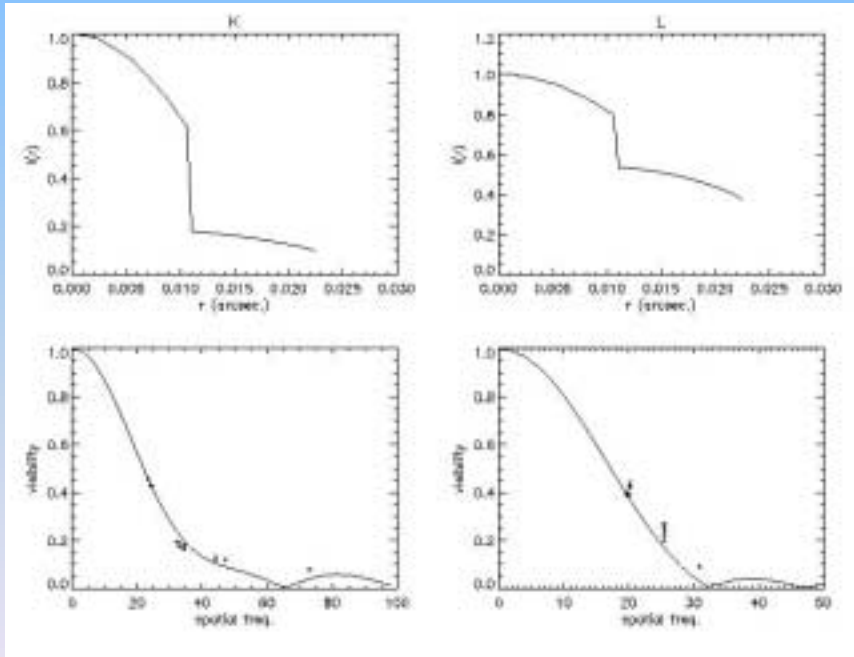
Semi empirical 1-D radiative transfer

Star + shell: $T(R) \alpha 1/R^{0.5}$, $n(R) \alpha R^2$,
Best fits to R Leo K/L data: T*=2700K,
R*=11mas,R_{int}=12mas or R_{int}=18mas ,R_{ext}=23mas,
$\tau(K)=3.5$, $\tau(L)=3$

Continuous distribution (no gap)



Gap between photosphere and shell



K/L discrepancy would be solely due to a temperature effect (shell Planck-like emission, on-going work by A. Merand and S. Ridgway)

Conclusions on R Leo

- High frequency 2.2 μm V data: best fit = molecular diffusion models
- 3.7 μm V data: much larger structure compatible with thermal emission (2000K) of extended (2-3 R*) layers
- 3.7 μm V data not fitted by ISI dust shell models
- Evidence for extended hot (2000 K) molecular gas layers (CO, H_2O, OH, SiO..) around o Ceti optically thick in the [2.5 -5 μm] region
- R Leo: dust close to star and/or hot (2000 K) extended (2-3 R*) optically thick (τ=1-3 @ 2 to 5 μm) molecular gas layers ? Impact on stellar core size / pulsation mode
- Better λ and t coverage needed and on-going: collaborations!