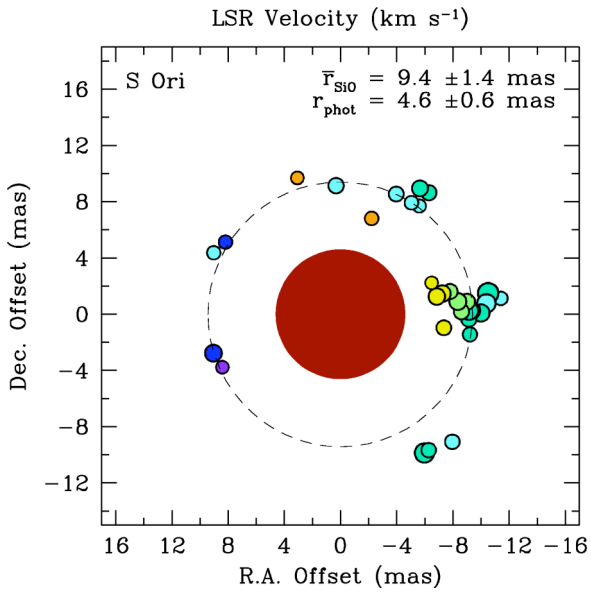
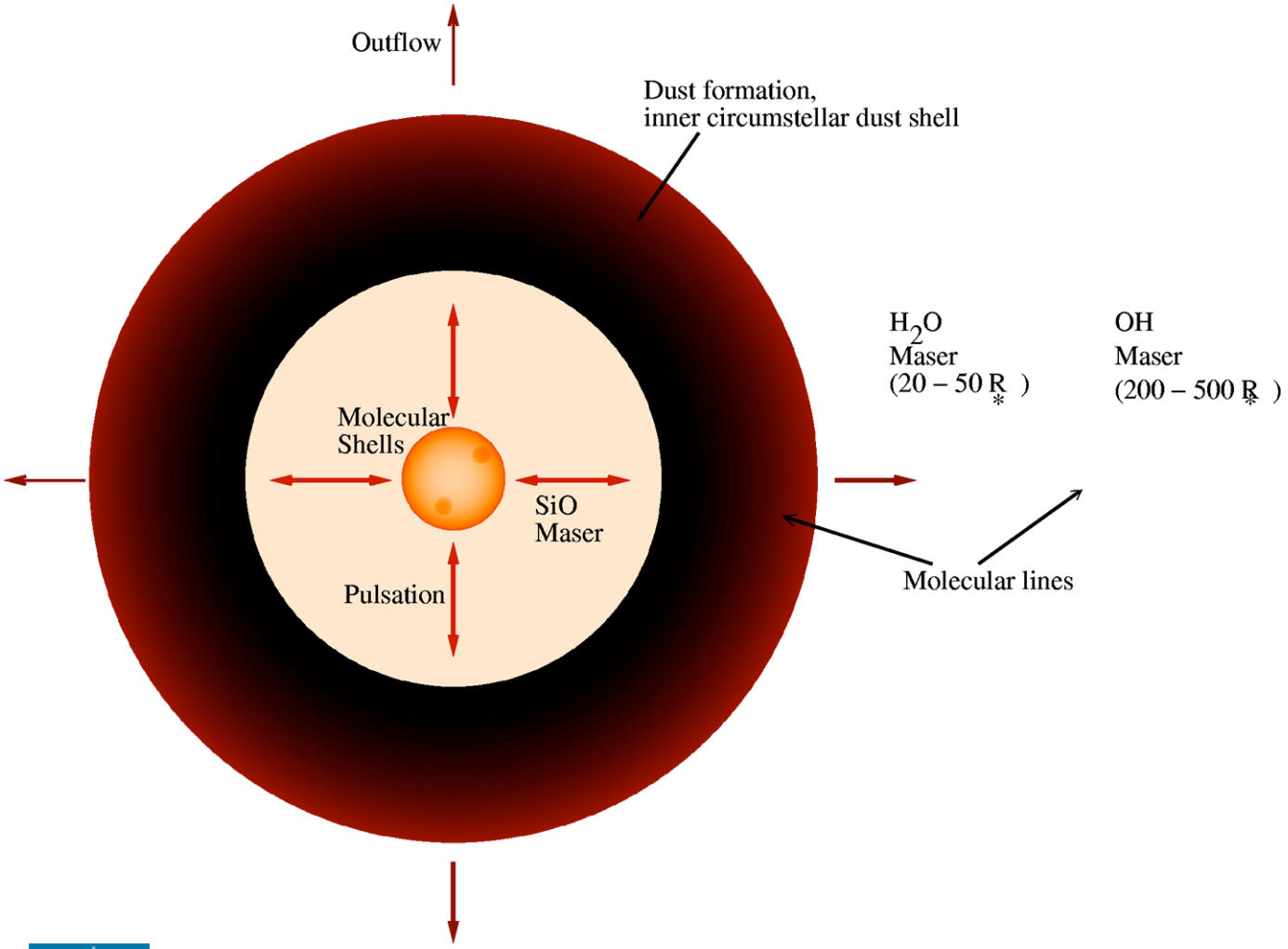
Multi-wavelength interferometry of evolved stars



Markus Wittkowski (ESO),
David A. Boboltz (USNO), Thomas Driebe, Keiichi Ohnaka (MPIfR)

The power of optical/IR interferometry: Recent scientific results and second generation VLTI instrumentation.
An ESO Workshop.
Garching, April 4-8, 2005

Schematic View of a Mira star



VLTI (AMBER & MIDI):

- Size and shape of IR and MIR photosphere.
- CLV, effects by molecular layers, inhomogeneities.
- Size, chemistry, shape of the warm dust shell.

VLBA:

- SiO maser zone: size, shape, kinematics.
- Radio photosphere.
- Water and OH maser at larger distances.

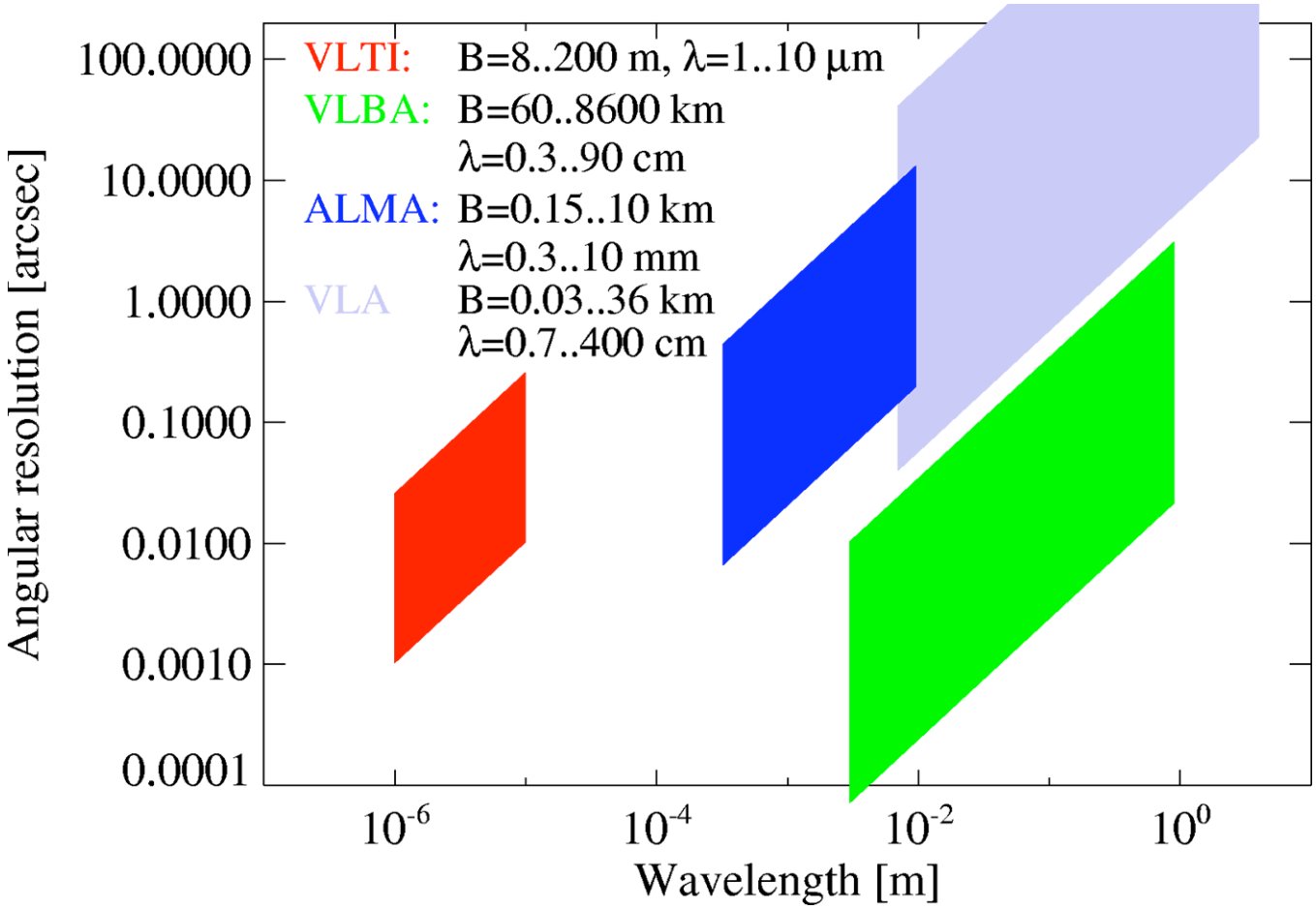
ALMA:

- mm Photosphere.
- Cool dust.
- High-fidelity images.
- Molecular bands

Other facilities:

- Parallaxes.
- Bolometric fluxes.
- High-resolution spectra.
- Outer envelope (AO).

Comparison of VLTI, VLBA, and ALMA



- VLTI, VLBA, and ALMA can observe the same targets in terms of angular resolution and sensitivity.
- They provide complementary information on different components.

Telescopes:

VLTI : 4 x 8m + 4 x 1.8 m

VLBA : 10 x 25 m

ALMA : 64 x 12 m

VLA : 27 x 25 m

Project overview

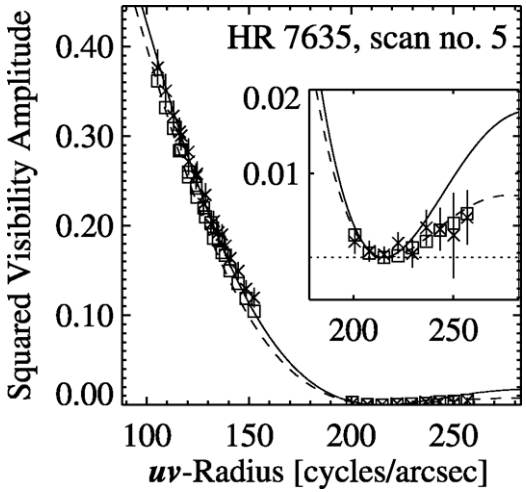
Comparisons of the different regions of the CSE and the star itself using different facility often suffer from **uncertainties inherent in comparing variable stars widely spaces in time** and stellar phase (discussion in Boboltz & Wittkowski 2005).

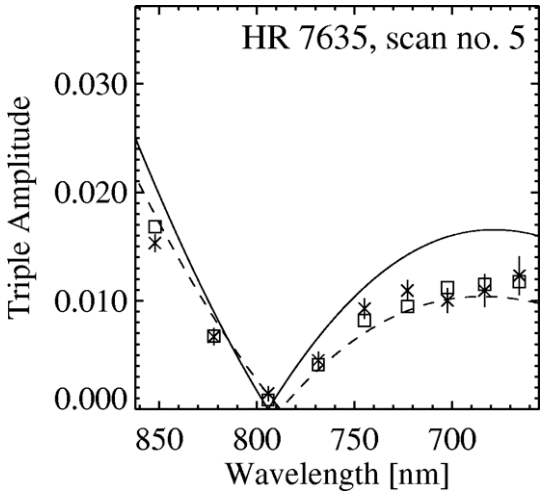
We have established a program of **coordinated multi-wavelength interferometry** (VLTI & VLBA) aiming at a better understanding of the structure of the stellar atmosphere and CSE, the mass-loss process, and the evolution of spherical stars toward axisymmetric planetary nebulae.

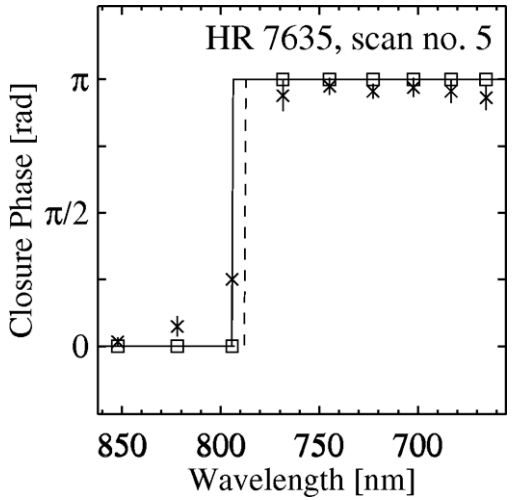
We concentrate on a few stars. First results of VINCI+VLBA/SiO observations of S Ori are published by Boboltz & Wittkowski (2005). We are in the process of analyzing VLTI/MIDI and concurrent VLBA data of **RR Aql, AH Sco, and S Ori** at different epochs.

Optical

Intensity profiles: NPOI observations of Gam Sge(M0III)







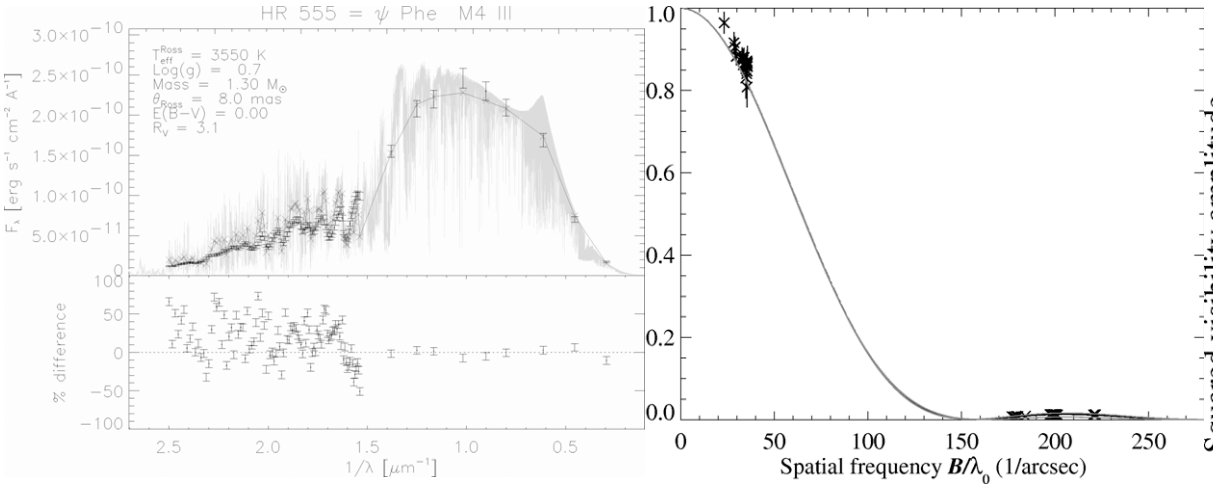
- Multi-wavelengths in the optical
- Limb-darkening probed by monochromatic intensity profiles *and* wavelength dependence (similar to AMBER's potential)
- Constraints of model atmosphere parameters succeeded !

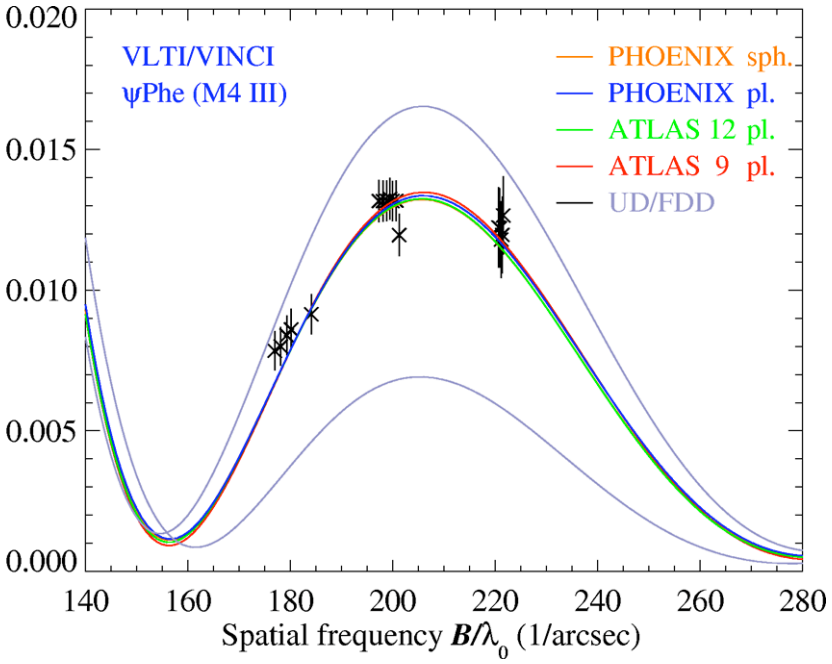
log g /$T_{\rm eff}$	0.0	0.5	1.0	1.5	2.0	2.5
3500	1.50	1.40	1.35	1.38	1.47	1.58
3750	1.29	1.29	1.29	1.29	1.27	1.26
4000	1.18	1.17	1.17	1.17	1.18	1.18
4250	1.20	1.20	1.19	1.19	1.19	1.19
4500	1.26	1.25	1.24	1.23	1.23	1.23

Wittkowski et al. 2001, A&A, 377, 981

NIR

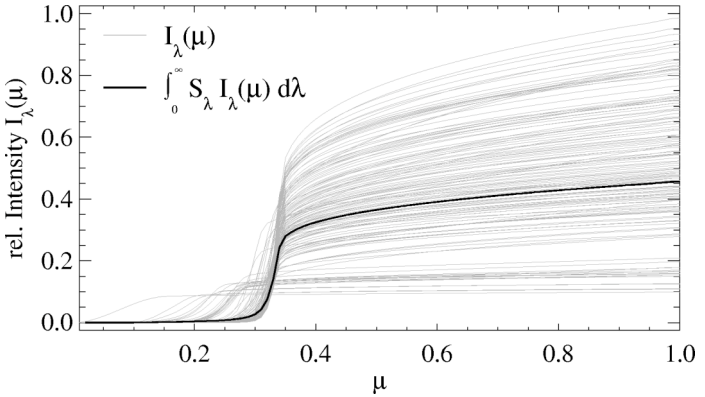
Intensity profiles: VLTI observations of Psi Phe (M4III)





Broad-band VLTI/VINCI observations of the limb-darkening of Psi Phe succeeded in 2001.

Atmosphere models, as constrained by comparison to spectrophotometry, predict a limb-darkening curve that is consistent with the VINCI data. Significant differences between similar models can not be seen.

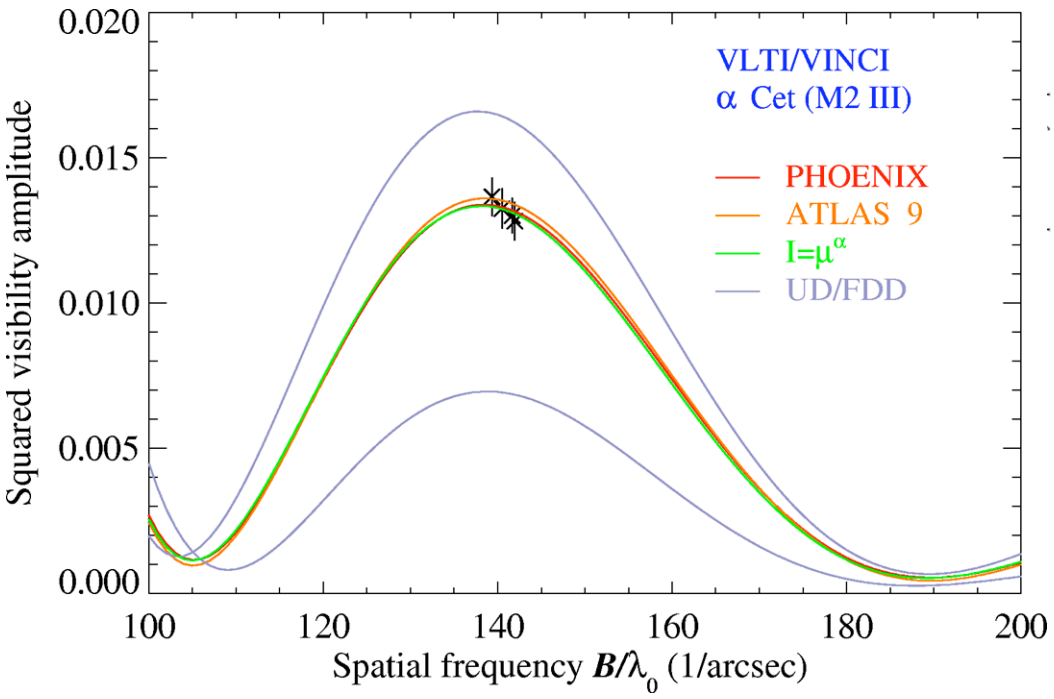


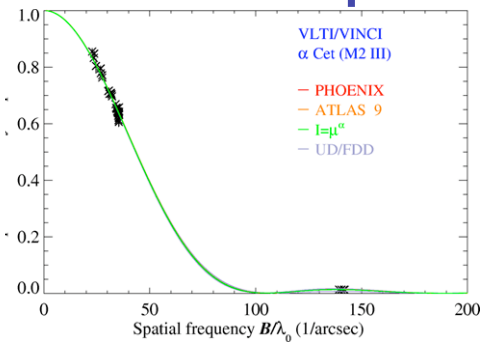
=> spectro-interferometry with AMBER

Wittkowski et al. 2004, A&A, 413, 711

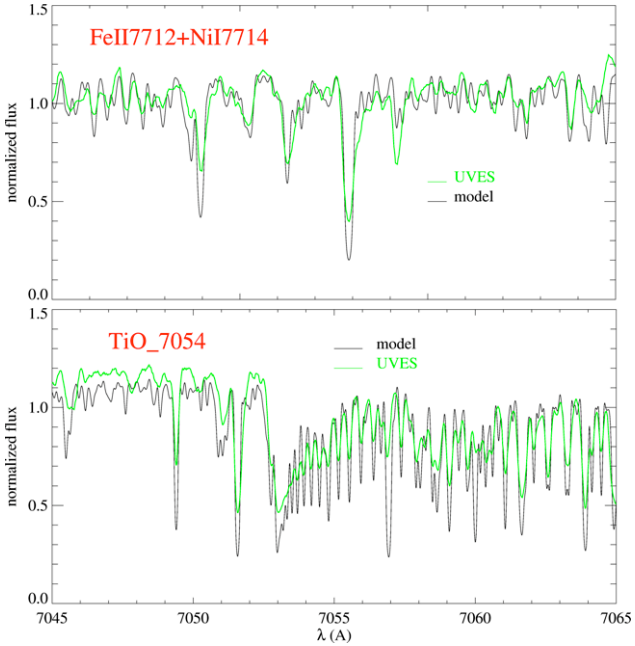
UV/optical (spectroscopy), NIR K (interferometry)

UVES and VINCI observations of Alpha Ceti (M2 III)





UVES:



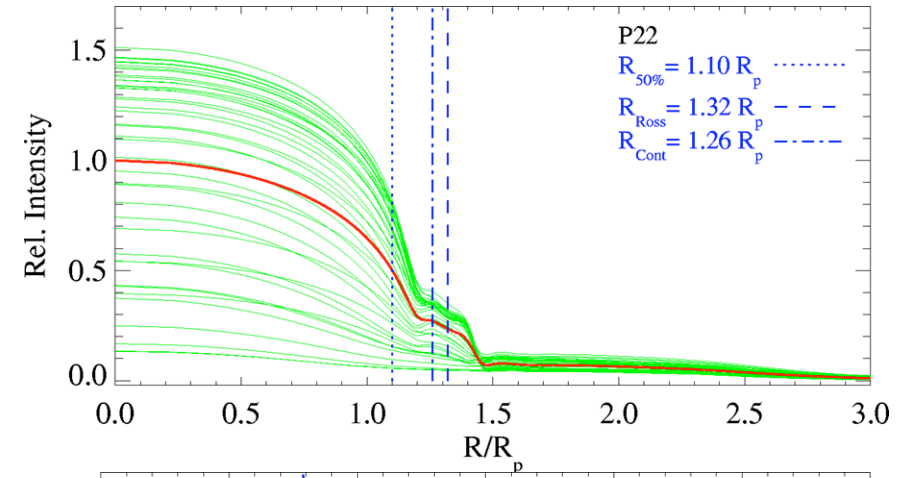
Simultaneous comparison to spectrophotometry, high-resolution spectra, and interferometry provides strong tests of model atmospheres.

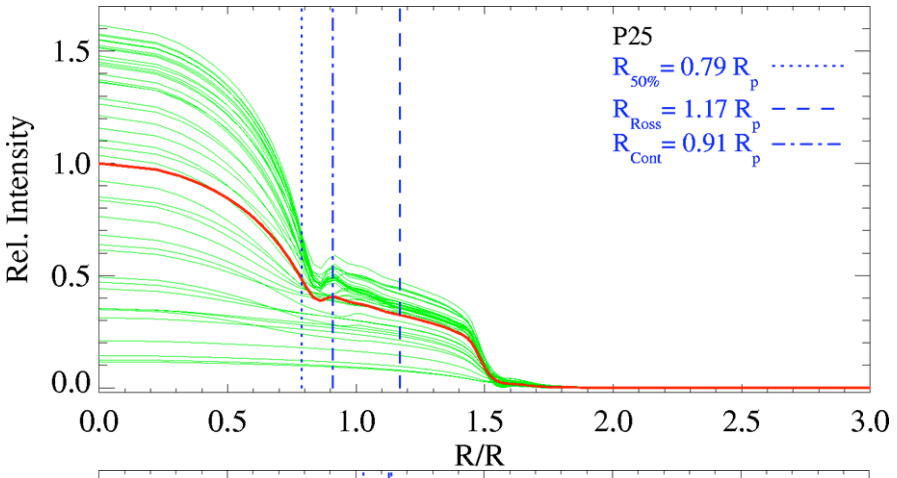
Roccatagliata, Wittkowski, Aufdenberg, Wolff, et al., in preparation

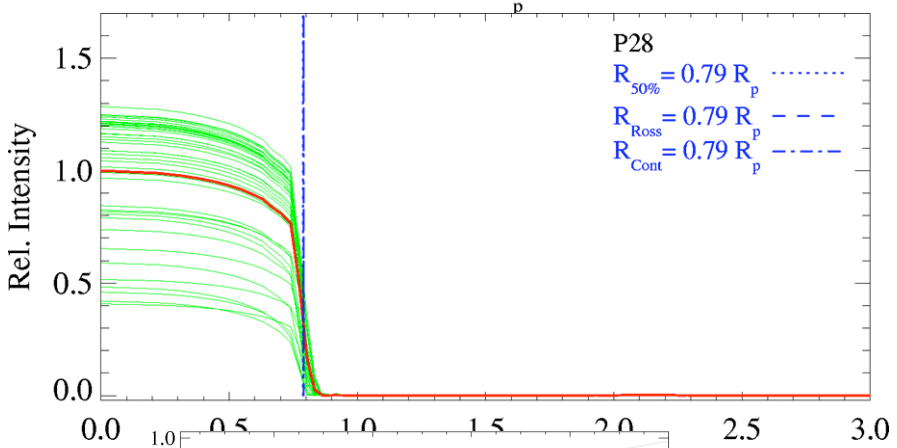
Poster 1-19 (V. Roccatagliata)

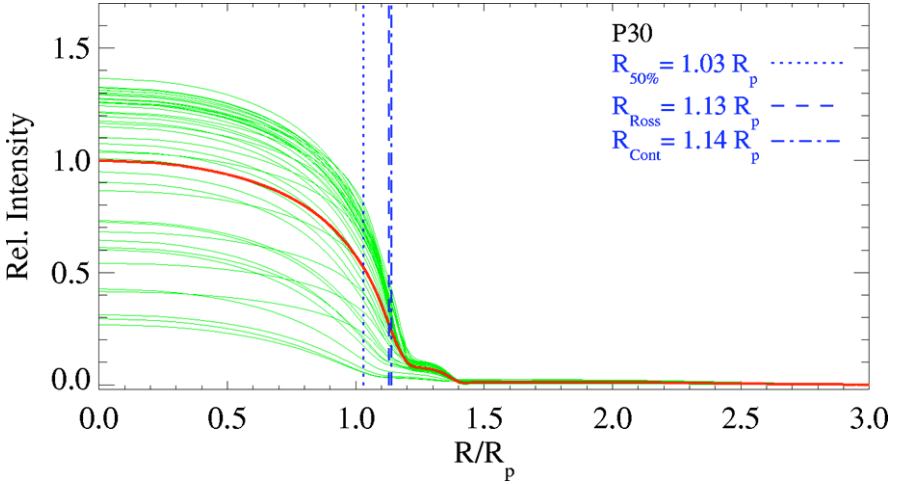
M. Scholz & P. Wood (2004), private communication :

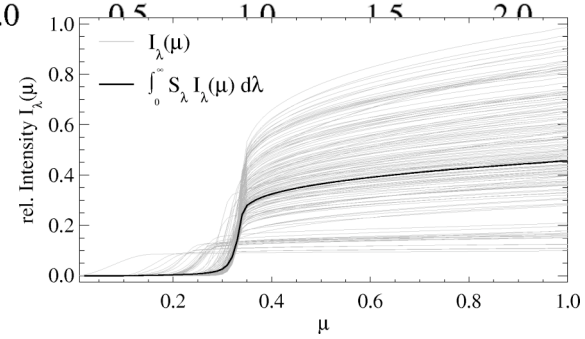
Dynamic model atmospheres and Mira CLVs (K)









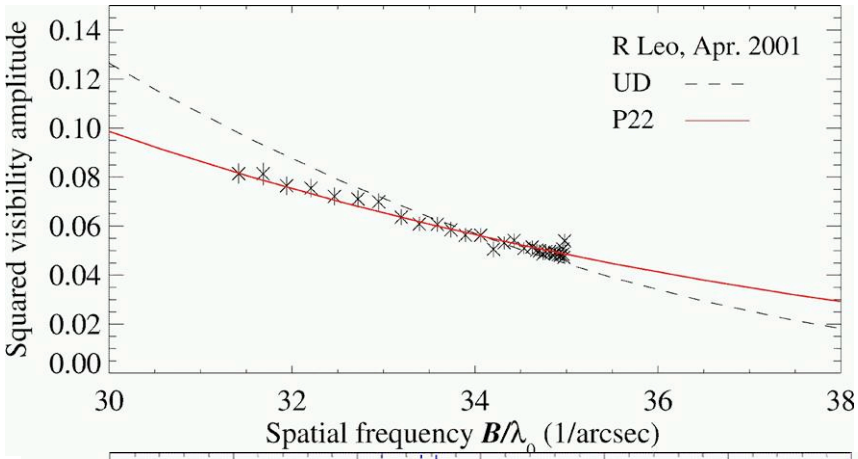


CLVs are strongly affected by molecular shells.
Strong phase (and cycle) dependence.
Difficult definition of the stellar radius.

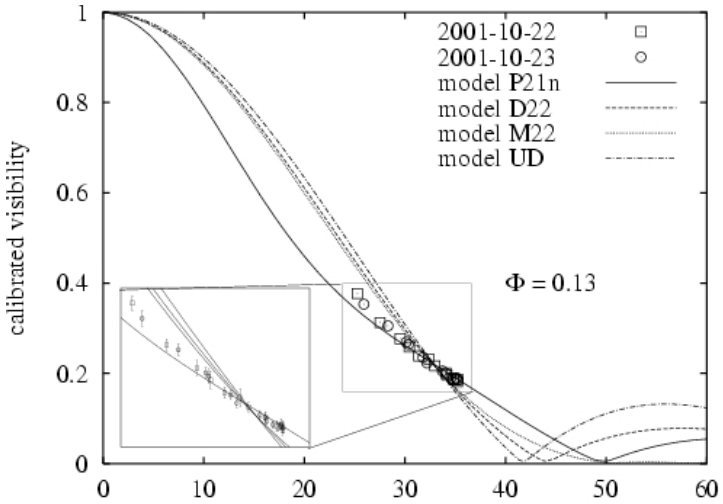
NIR

VINCI observations of the Miras o Cet and R Leo

R Leo:



o Cet

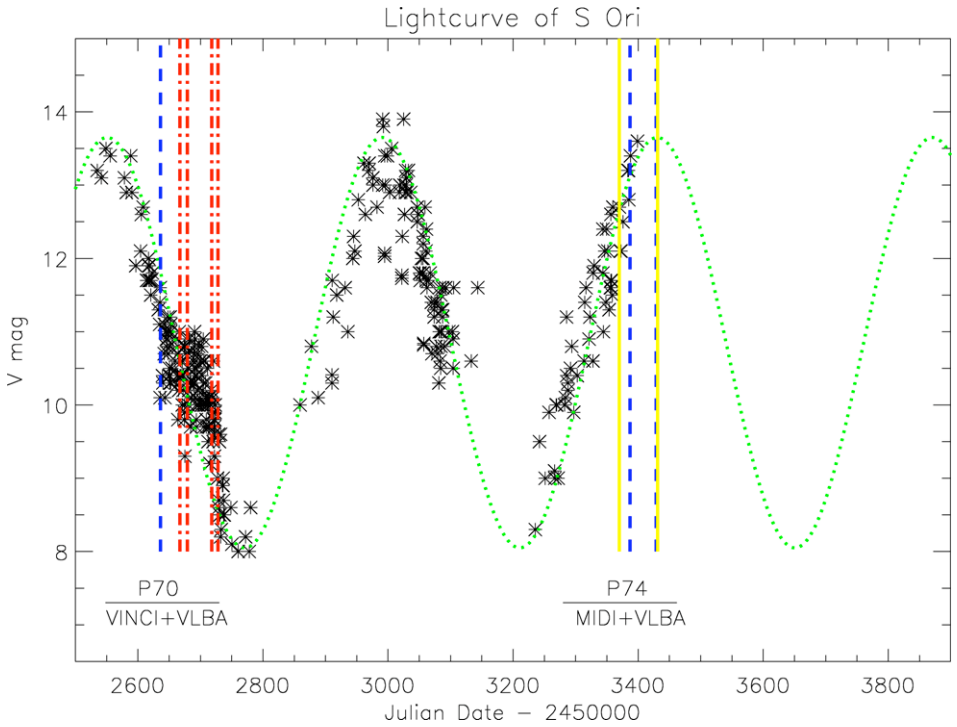


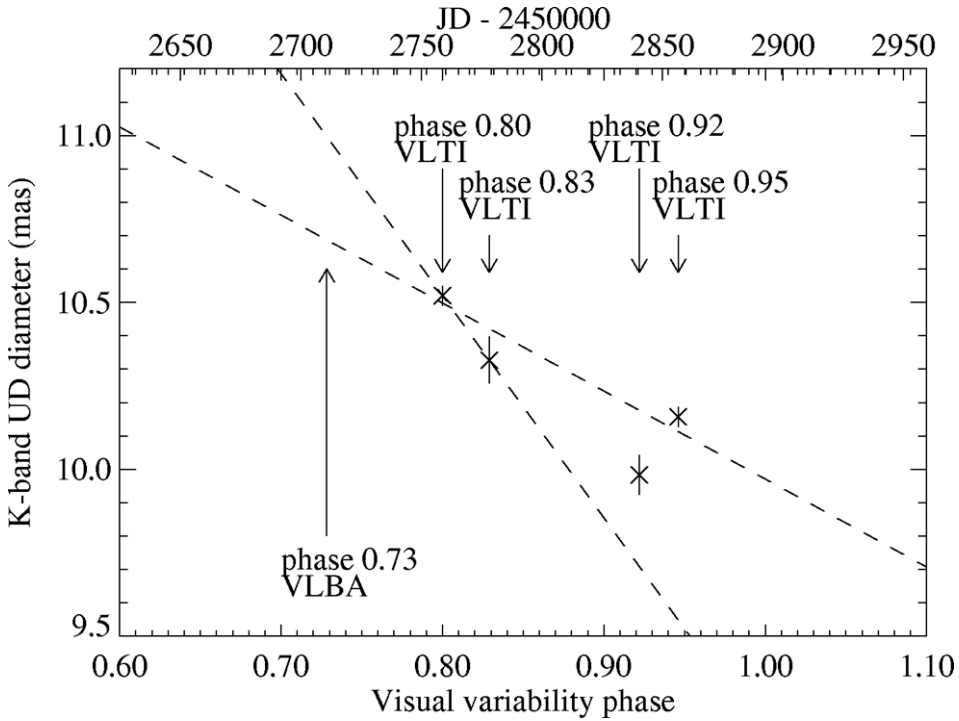
The CLVs are different from a UD already in the first lobe, and consistent with predictions by dynamic atmosphere models.

Woodruff et al. 2004, A&A, 421, 703
Fedele et al. 2005, A&A, 431, 1019
Talk 1-9 (R Leo, D. Fedele)
Poster 2-18 (o Cet, T. Driebe)

Radio, NIR, & MIR

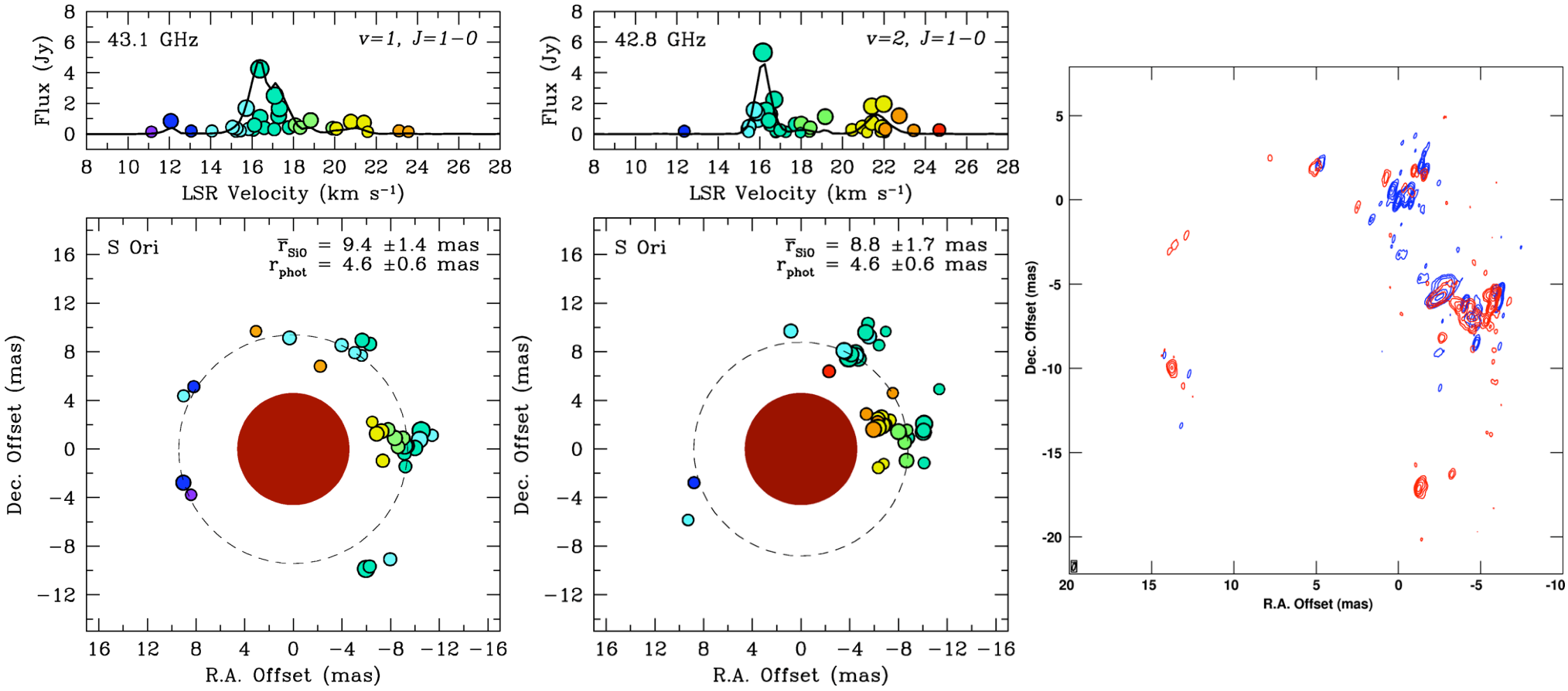
Observations of the Mira variable S Ori :
Joint VLBA (SiO maser)/VLTI (VINCI) obs.;
Joint VLBA (SiO maser)/VLTI (MIDI) obs.





Boboltz & Wittkowski 2005, ApJ, 618, 953
Boboltz, Driebe, Ohnaka, Wittkowski, in prep.

Joint VLBA/VLTI observations of S Ori (P70)



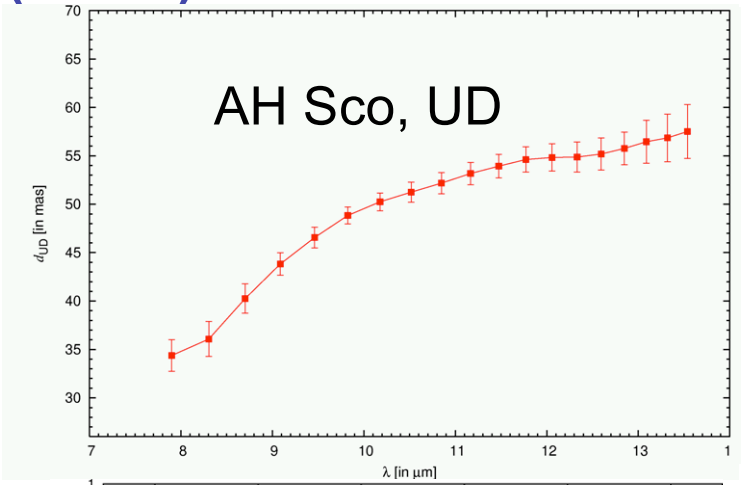
Boboltz & Wittkowski 2005, ApJ, 618, 953

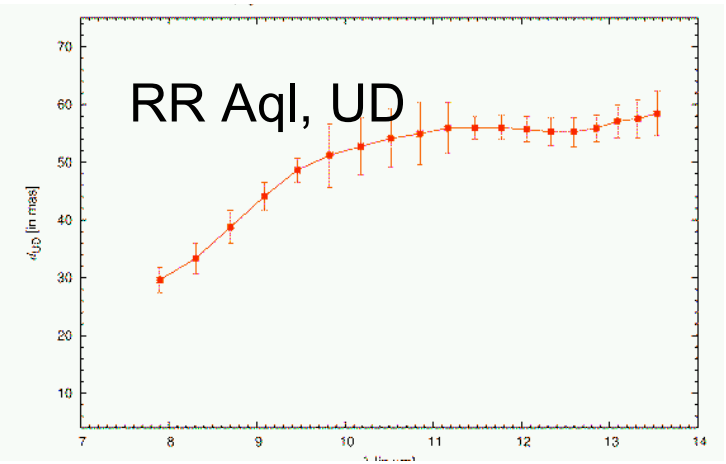
Joint VLBA/VLTI observations of S Ori (P70)

- First coordinated VLBA and VLTI observations
- Simultaneous VLBA observations of the 43.1 GHz and 42.8 GHz SiO maser emission toward S Ori (phase 0.73).
- Coordinated K-band VINCI observations (phase 0.8-0.95).
- Average distance of the masers from the center of the distribution is 9.4 mas and 8.8 mas for the two transitions. No significant inidication of global infall, expansion, or rotation.
- K-band UD diameter decreases from ~10.5 mas to ~10.2 mas
- UD diameter extrapolated to 0.73 and corrected to a Rosseland /continuum diameter using model atmospheres: 9.2 mas (at pre-maximum phases: small corrrection, intensity profile relatively close to a UD).
- Average distance of the maser spots from the stellar surface: 2.0/1.9 R_*
- This result is virtually free of the usual uncertainty inherent in combining observations widely separated in time/stellar phase.

Boboltz & Wittkowski 2005, ApJ, 618, 953

Joint VLBA/MIDI observations of RR Aql and AH Sco (P73)





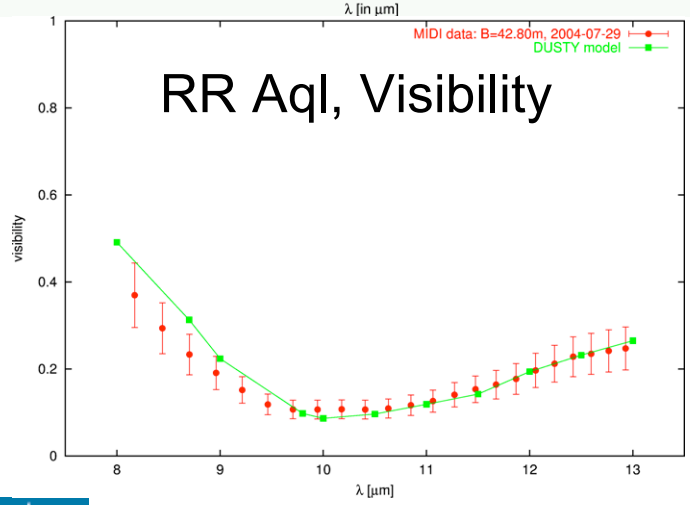
Stellar UD:

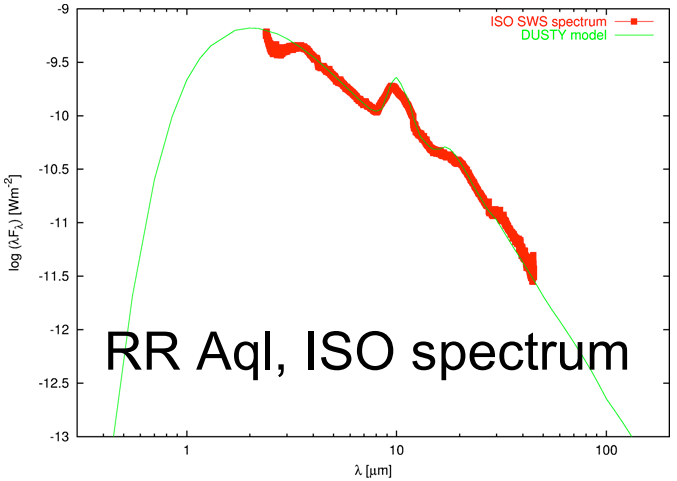
7-10 mas

Equiv. UD across N:

AH Sco: 35-58 mas

RR Aql: 30-60 mas





RR Aql model:
Stellar radius 6.8 mas
Inner dust radius 22 mas
Temperature at inner
Edge of the dust shell:
1000K.

Boboltz, Driebe, Ohnaka, Wittkowski, in prep.

Wishlist for 2nd generation instrumentation :

- Multi-way beam combiners in the NIR (6-8 beams) and MIR (4 beams) to map stellar structure, in particular to trace inhomogeneities from the stellar surface outward.
- Longer baselines to study the stellar surface structure in more detail, and the better match the ang. resolution of the VLBA.
- Extension to the Optical, to have a higher resolution, and because stellar atmospheric structure can better be probed in the optical (e.g. stronger LD, see NPOI results).
- Higher spectral resolution, comparable to UVES, e.g. to detect temperature inhomogeneities across the stellar disk by atomic and molecular band strengths?