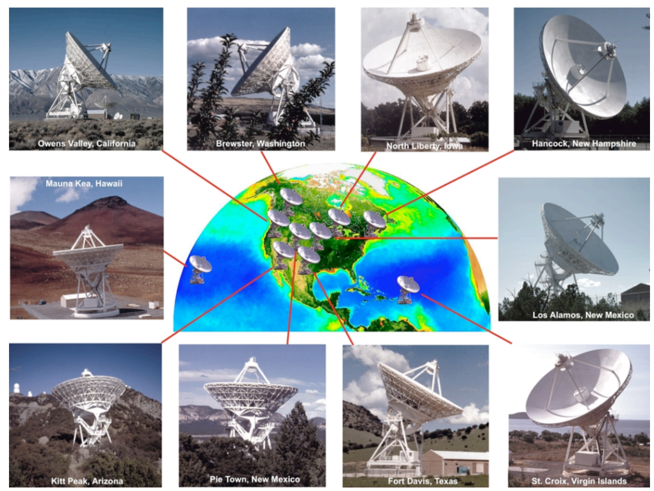
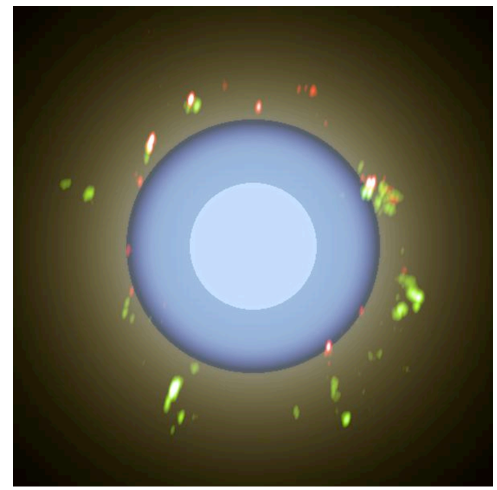
The Mira variable S Ori: SiO maser shells related to the photosphere and dust shell at 3 epochs

Program of coordinated interferometry of oxygen-rich evolved stars at near-infrared, mid-infrared, and radio wavelengths using the VLTI in conjunction with the VLBA. Concentrated on the Mira variables S Ori, GX Mon, RR Aql, and the supergiant AH Sco.





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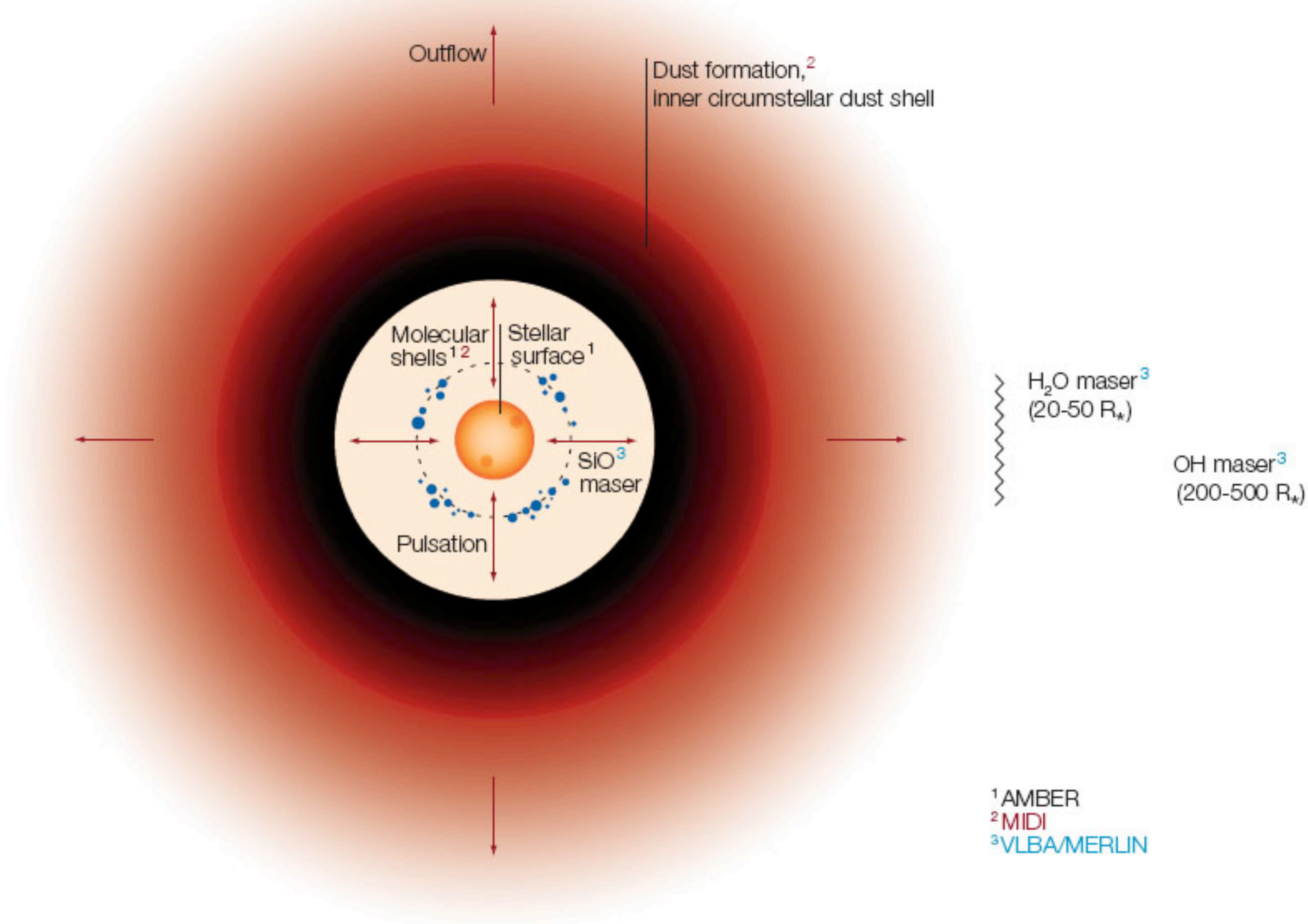
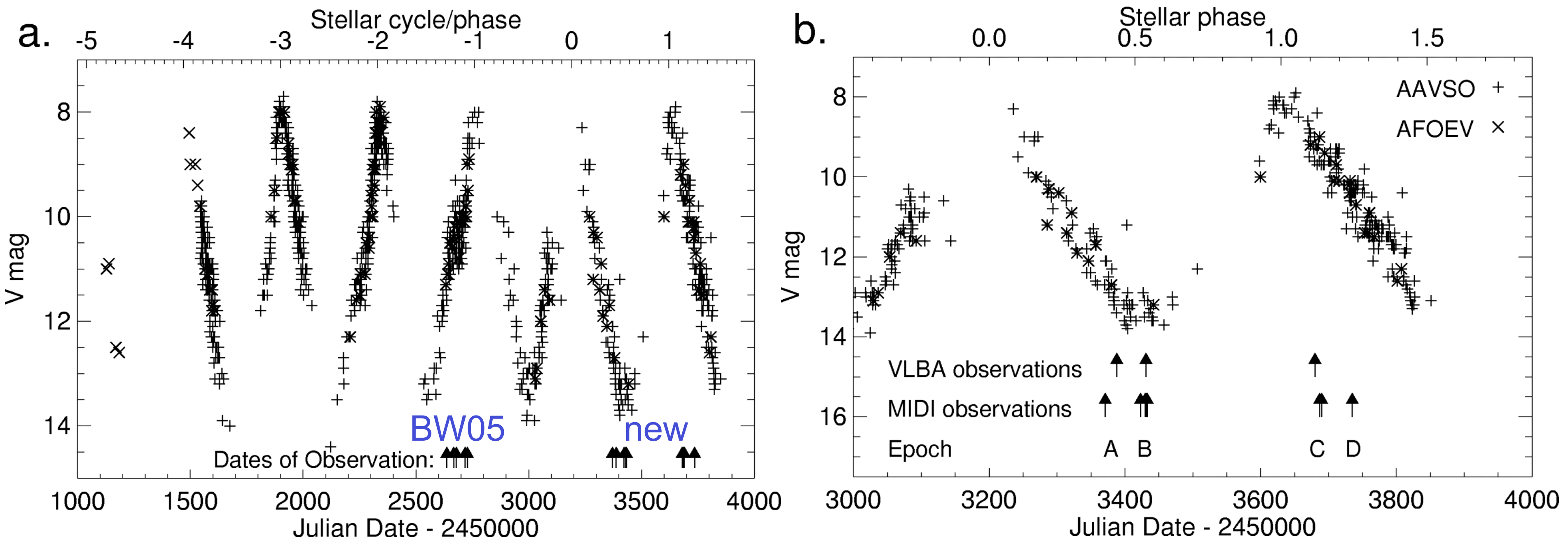
David A. Boboltz (U.S. Naval Observatory),
Keiichi Ohnaka, Thomas Driebe (MPIfR Bonn)
Michael Scholz (Univ. Heidelberg/ Univ. Sydney)

Sketch of an oxygen-rich Mira star



Concurrent VLTI and VLBA observations of S Ori

S Ori : M6.5e-M9.5e; V=7.2-14.0; P~430d; d~480 pc; SiO and OH maser



First coordinated VLTI/VLBA observations:
VINCI: 25 Jan – 31 Mar 2003, phases 0.80 - 0.95.
VLBA : 29 Dec 2002, phase 0.73

Boboltz & Wittkowski 2005

New VLTI/MIDI and VLBA observations:
3 contemporaneous (differences < 0.04 *P*) epochs
between Dec 2004 and Nov. 2005 at phases 0.44, 0.56, 1.15, (1.27).

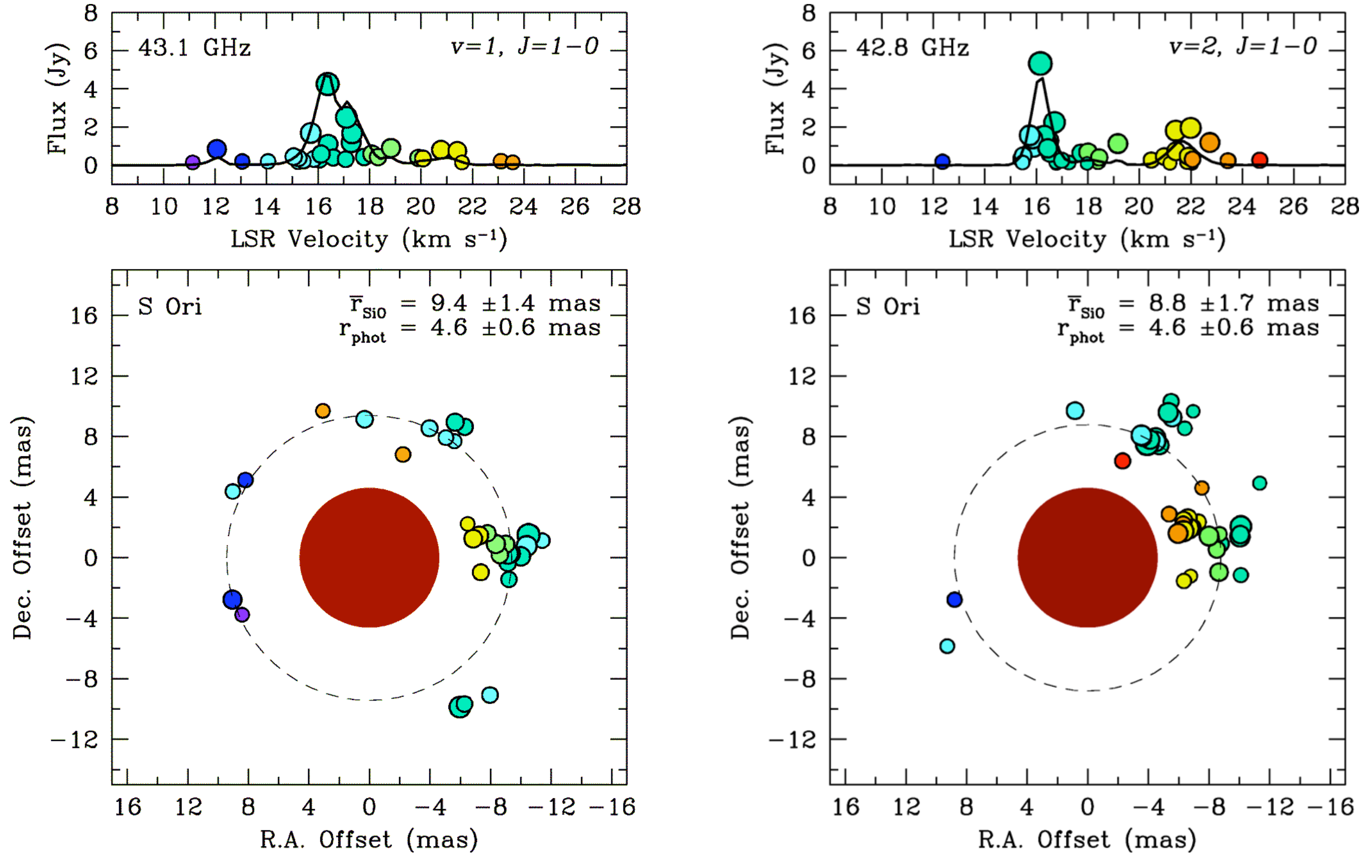
Wittkowski, Boboltz, et al., submitted

Modeling of the infrared interferometric data

- We model the stellar atmosphere using Scholz & Wood models: P and M series (Ireland et al. 2004a/b). These are complete self-excited dynamic model atmospheres of Mira stars that include the effects from molecular layers lying above the continuum-forming layers.
- We model the dust shell using the radiative transfer code mcsim_mpi (Ohnaka et al. 2006). Dust chemistry follows the work by Lorenz-Martins & Pompeia (2000): Dust shells of AGB stars consist of Al_2O_3 grains, silicate grains, or a mix thereof.

  S Ori: Al_2O_3 grains alone, confirmed by our study.
- Model parameters: Model phase; R_{in}, τ_V, density gradient p; Θ_{phot} fitted.

VINCI and VLBA observations of S Ori (BW05)

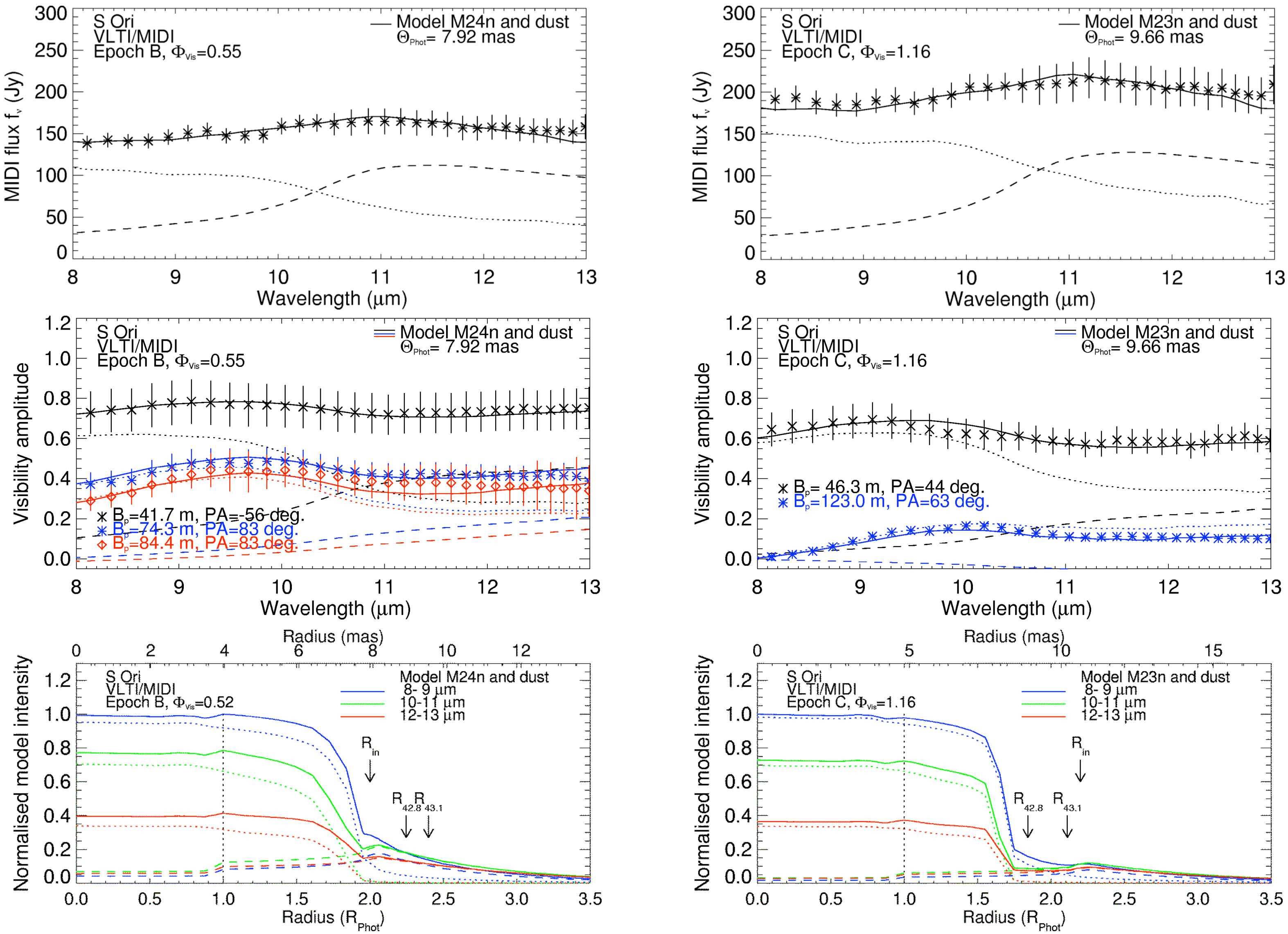


VLTI/VINCI data: K-band UD diameter 10.5 mas (phase 0.80) - 10.2 mas (0.95).
Extrapolation to phase 0.73 and correction $\Theta_{UD/cont}$ => Θ_{cont}=9.2 mas

SiO maser ring radius: 2.0 R_* (43.1 GHz) and 1.9 R_* (42.8 GHz) at stellar phase 0.73, free of the usual uncertainty inherent in comparing observations widely spaced in phase.

Boboltz & Wittkowski 2005

MIDI observations of S Ori (Dec. 2004 - Dec. 2005)



MIDI total flux

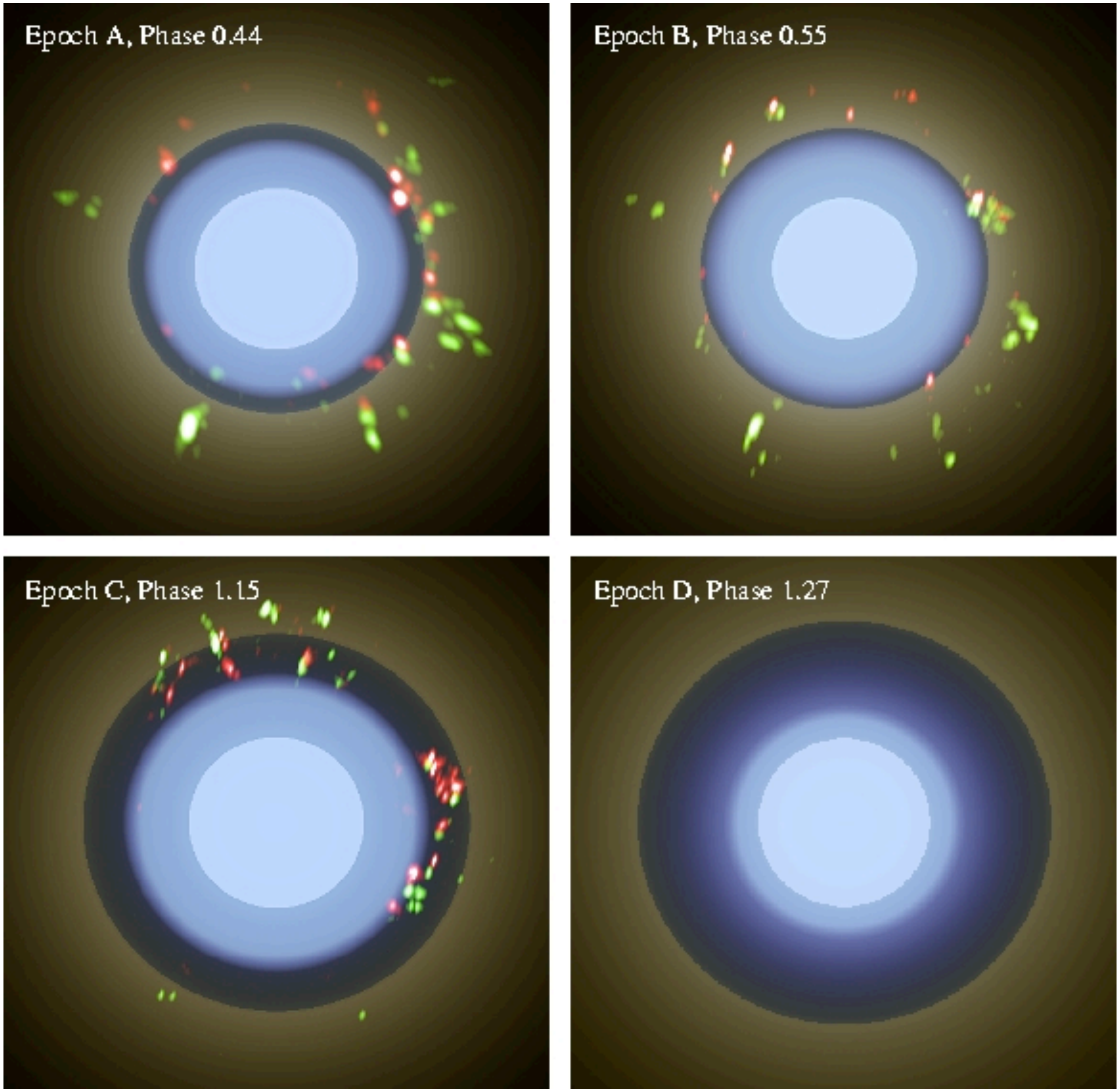
MIDI visibility

Model intensity

M22
Al_2O_3 grains
τ_V=2.5
R_{in}=1.8 R_*
p=3.5

Θ_*=9.0 mas

$R_{43.1}$=2.2 R_*
$R_{42.8}$=2.1 R_*



M24n
Al_2O_3 grains
τ_V=2.5
R_{in}=2.0 R_*
p=3.5

Θ_*=7.9 mas

$R_{43.1}$=2.4 R_*
$R_{42.8}$=2.3 R_*

M23n
Al_2O_3 grains
τ_V=1.5
R_{in}=2.2 R_*
p=3.0

Θ_*=9.7 mas

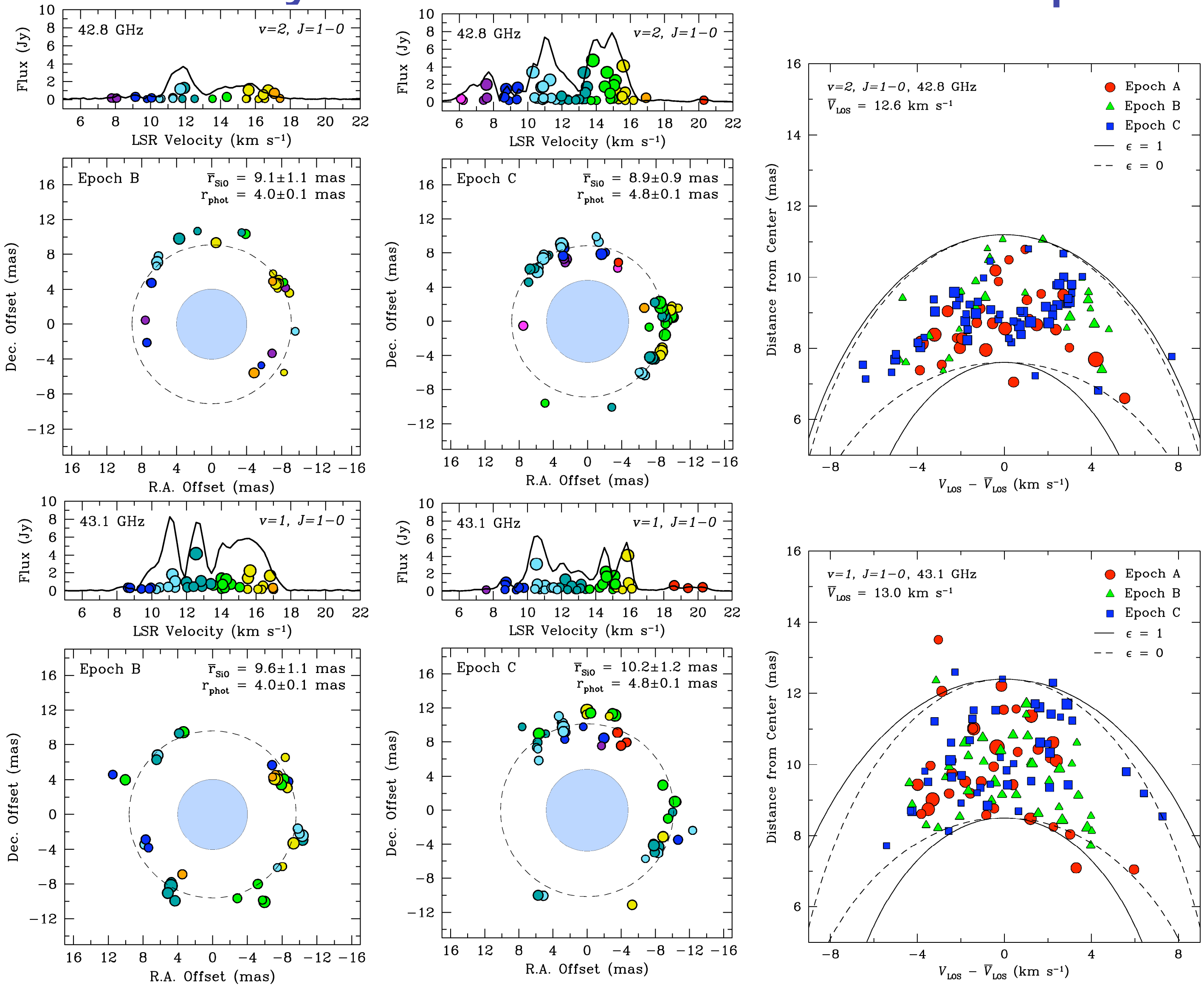
$R_{43.1}$=2.1 R_*
$R_{42.8}$=1.9 R_*

M21n
Al_2O_3 grains
τ_V=1.5
R_{in}=2.4 R_*
p=2.5

Θ_*=9.5 mas

(red) v=2, J=1-0, 42.8 GHz and (green) v=1, J=1-0, 43.1 GHz maser images on MIDI model

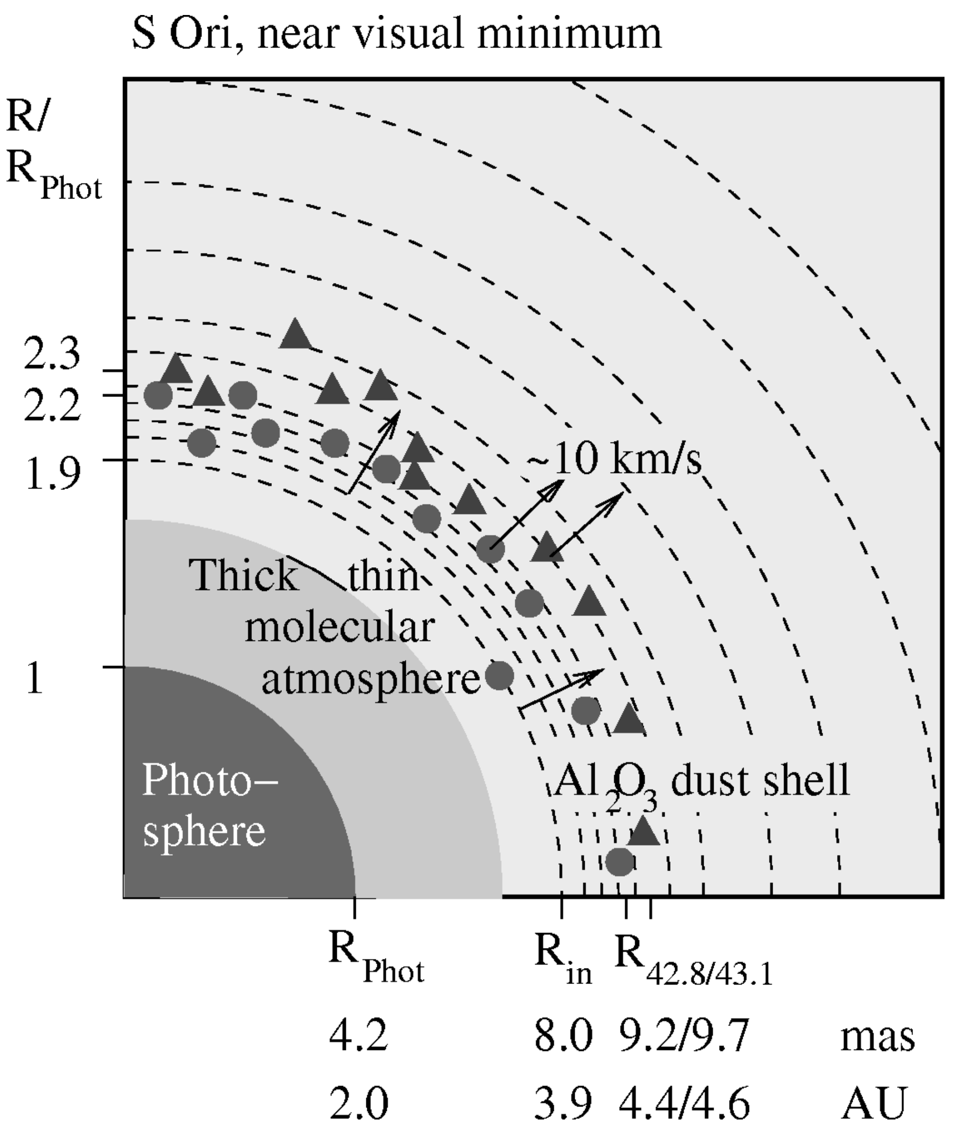
Velocity structure of the maser spots

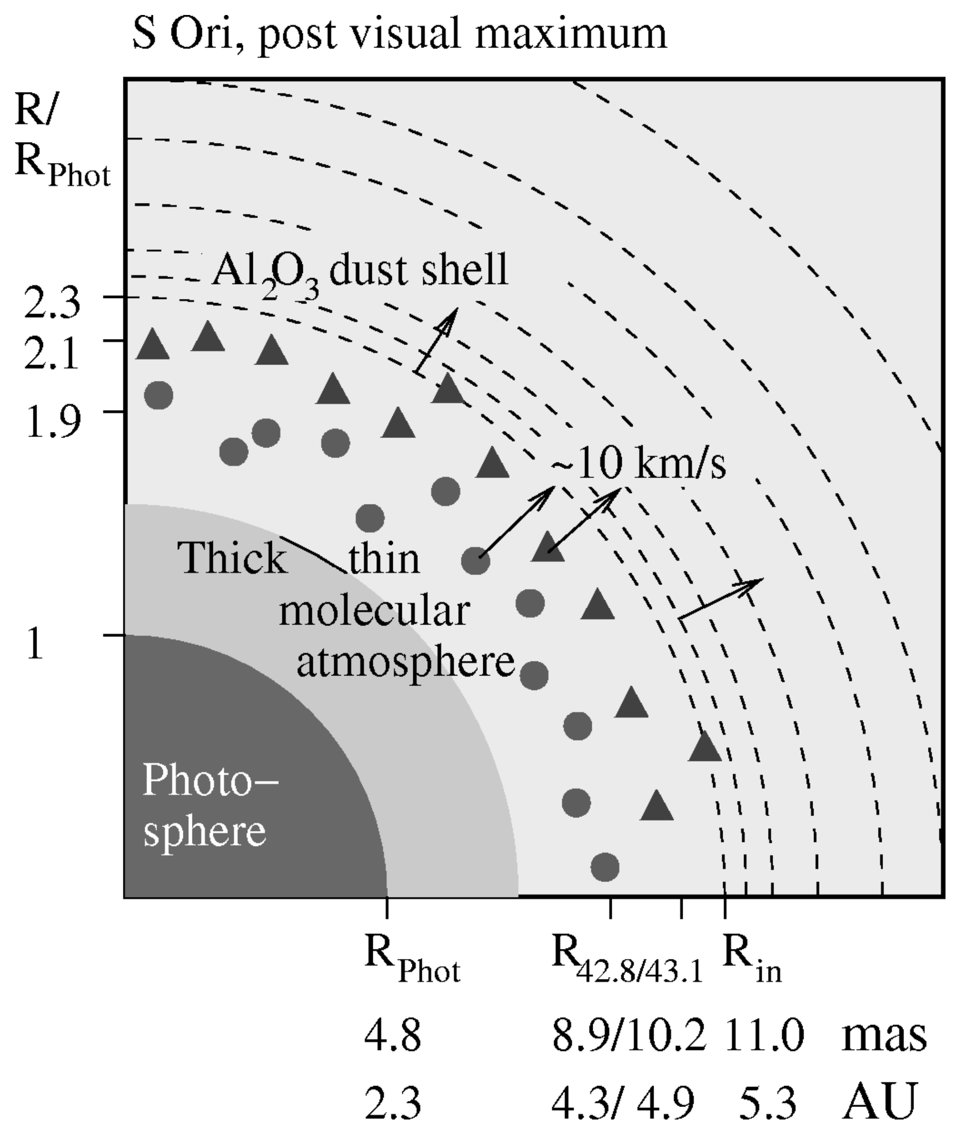


Best scenario:
Expanding spherical shell with a velocity between 7 km/sec and 10.5 km/sec.

Angle between maser plane and LOS:
90 deg. +/- 25 deg.

Sketch of the radial structure of S Ori's CSE

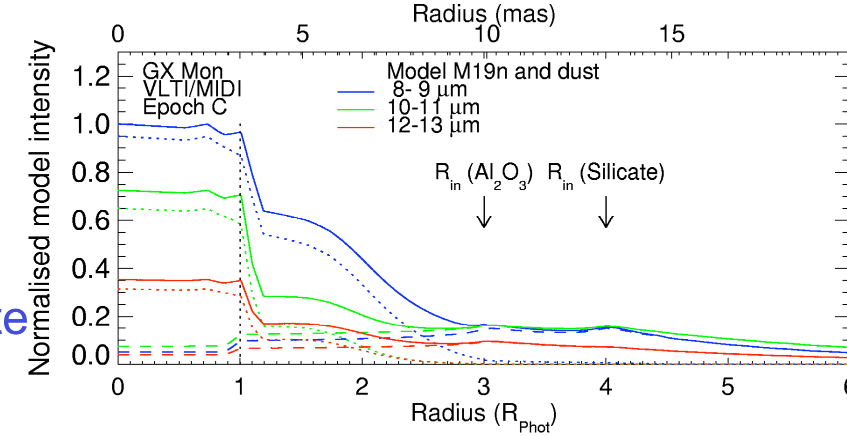


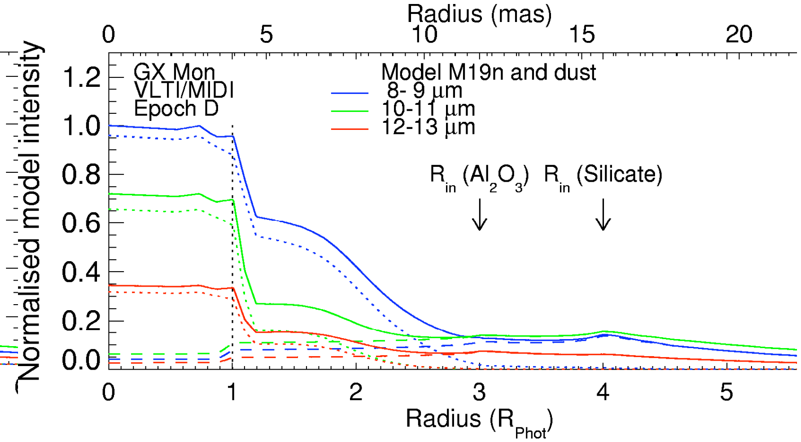


-> Poster by D. Boboltz et al.

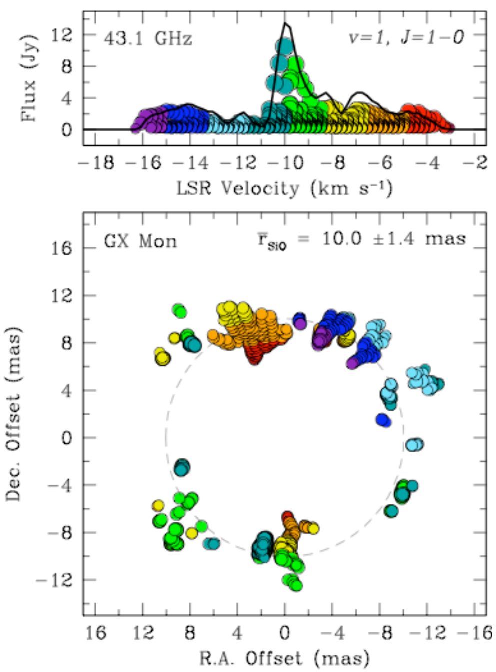
The Mira variable GX Mon (work in progress)

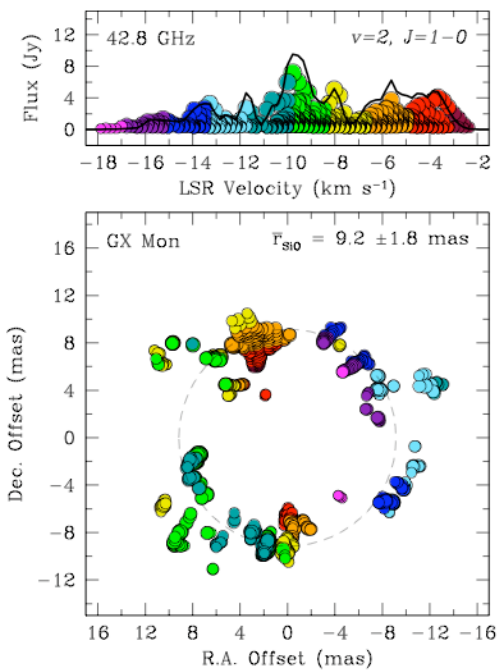
2 MIDI epochs:
15 Nov. 2005 &
27 Dec. 2005
Dust shell of
Al_2O_3 *and* Silicate

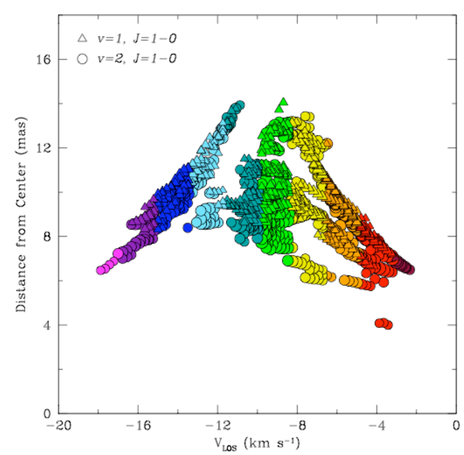




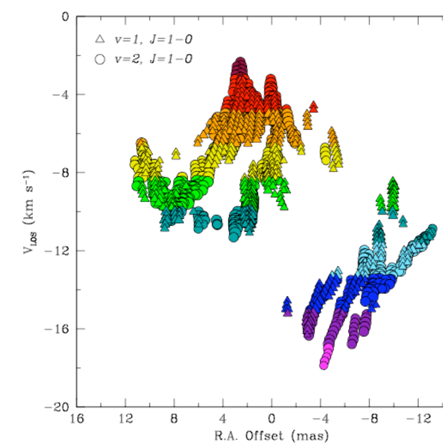
Single VLBA epoch: 8 April 2006







-> expansion



-> rotation ?

Summary

- S Ori shows significant phase dependences of photospheric radii and dust shell parameters.
- SiO masers and Al_2O_3 dust grains form at relatively small radii of ~1.8-2.4 photospheric radii, and are colocated near visual minimum.
- Our results of S Ori suggest increased mass-loss and dust formation close to the surface near visual minimum and an expanded dust shell after visual maximum.
- In the case of S Ori, silicon is not bound in silicates.
- In the case of GX Mon, Al_2O_3 grains at relatively small radii -again colocated with the SiO masers- *and* silicate grains at larger radii can be seen. Clearly higher optical depth than in the case of S Ori.
- Velocity structure of the maser spots indicate radial gas expansion.

- To come: Finer monitoring using MIDI/ATs; addition of NIR monitoring using AMBER/ATs; monitoring over more than one period; extension to H_20 and OH maser (wind region); comparison to new modern models of pulsation and dust formation.