Multifrequency VLBI observations of masers in evolved stars

Interest and need of systematic astrometric observations

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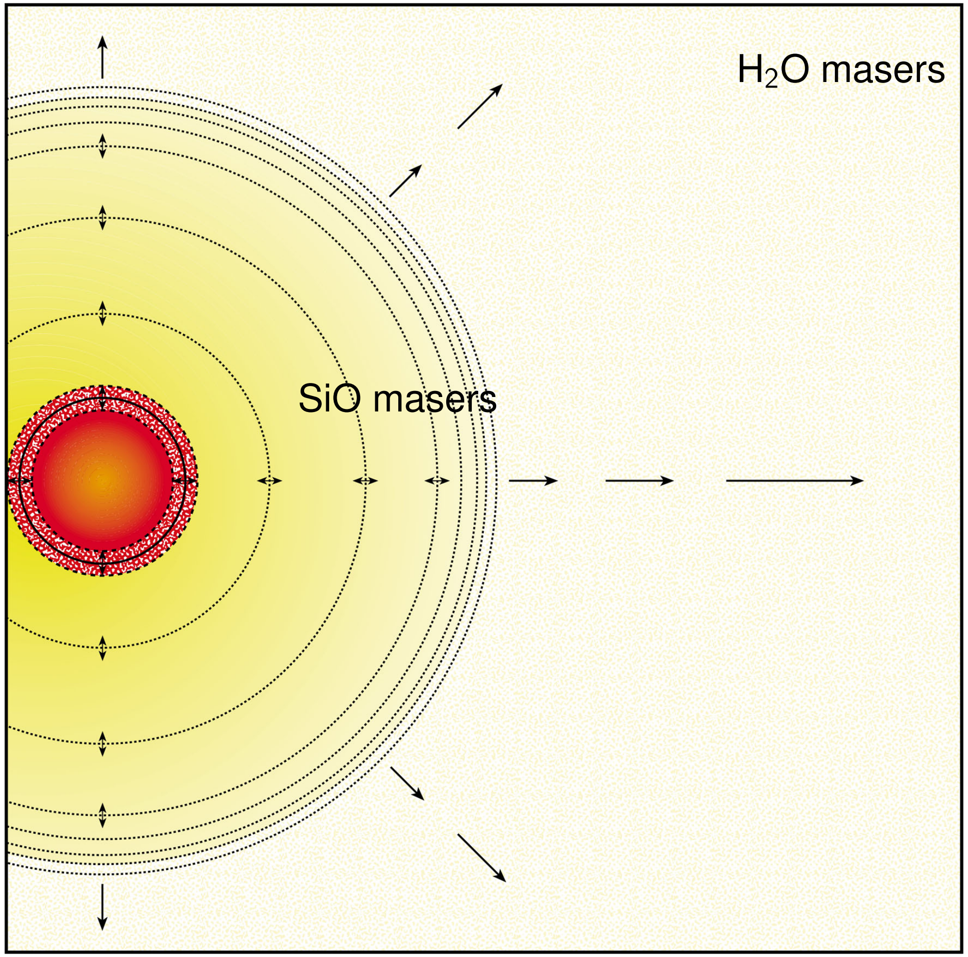
Evolved stars (AGBs and RSGs) lose material

Dynamics only active in inner circumstellar regions



SiO and H_2O masers from inner shells

crucial for dust formation and mass ejection

– extended atmosphere, due to shocks

– dust formation

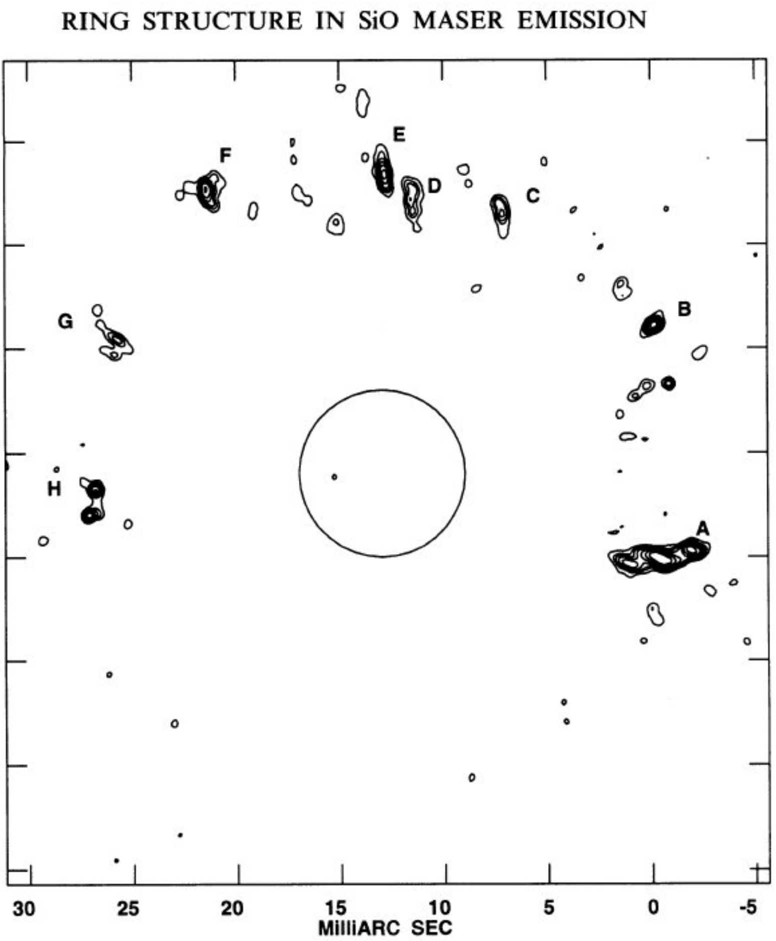
– dust and gas acceleration

but masers are difficult to interpret

emission of OH and CO (+ HCN, CS, etc)

come from outer shells at constant velocity

VLBI (VLBA) maps of SiO masers: TX CAM

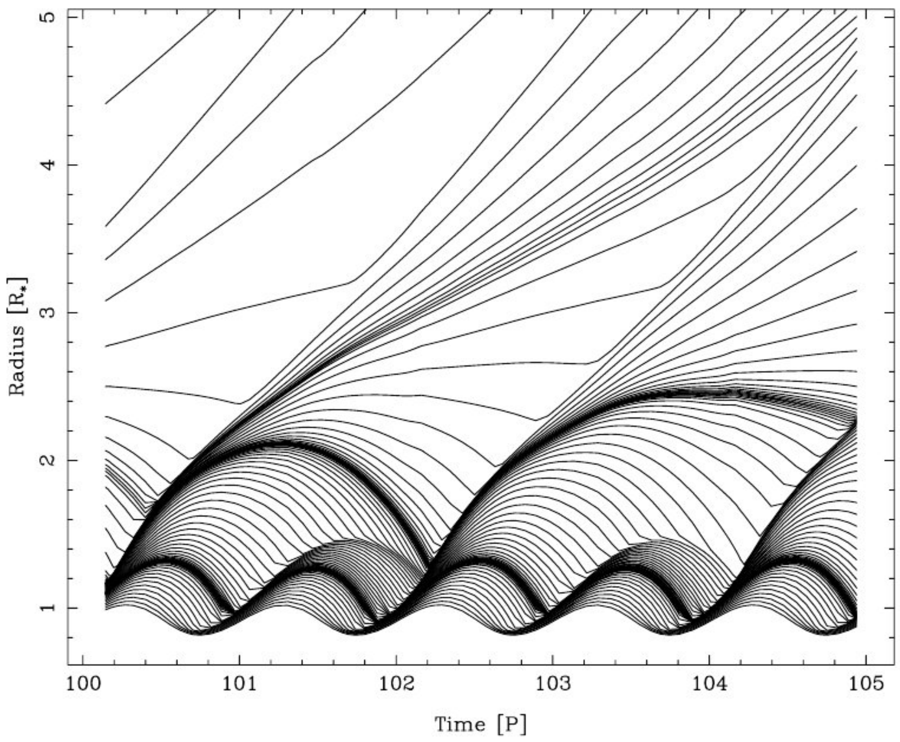


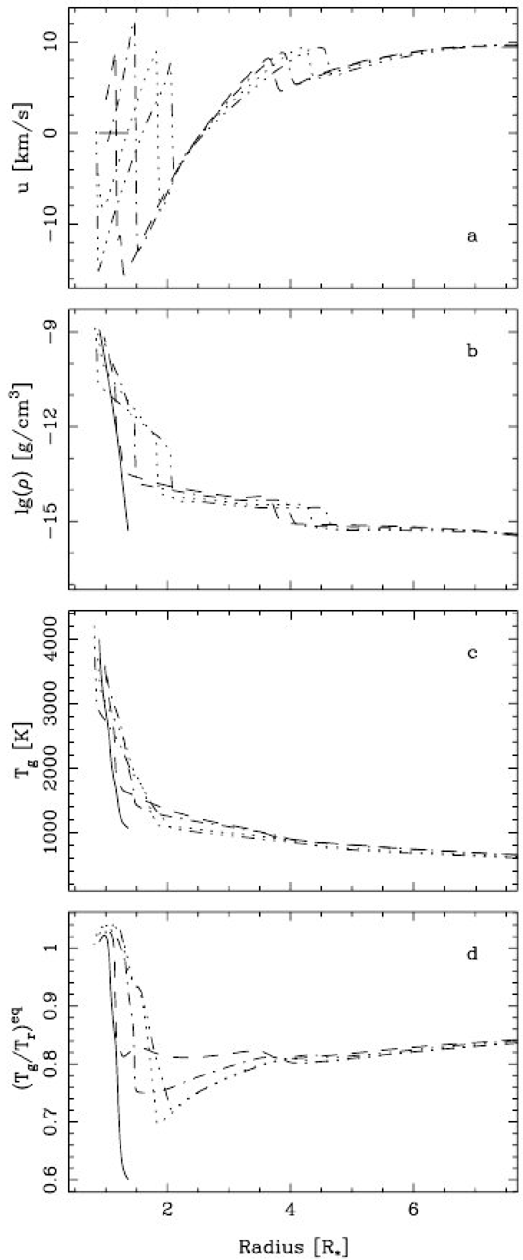
Ring structure at a few stellar radii
due to tangential amplification

Masers probe inner regions in pulsation-expansion

Diamond et al. (1994, ApJ 430, L61)

Pulsation, grain formation, and expansion in AGB stars





Detailed calculations of grain formation and dynamics

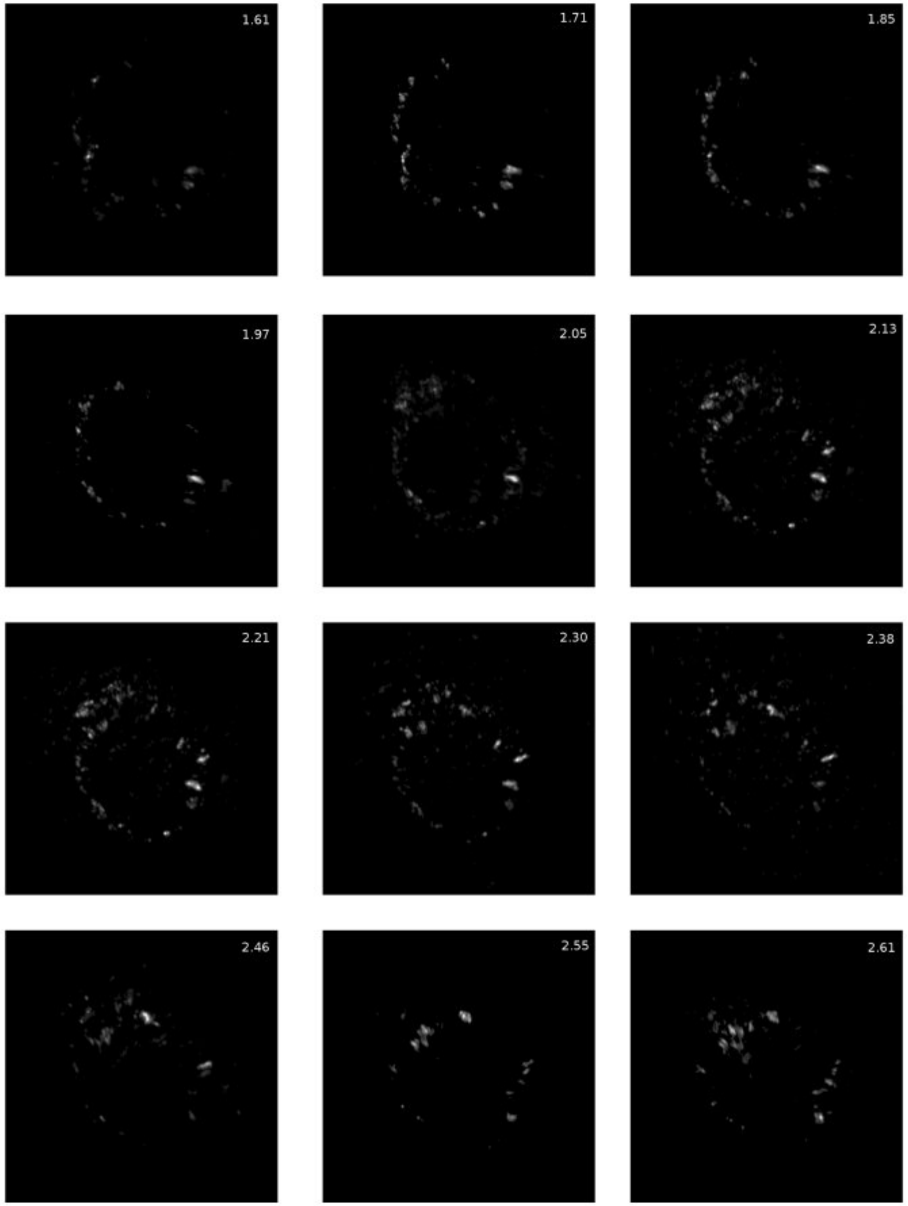
Pulsations keep material 'in levitation'

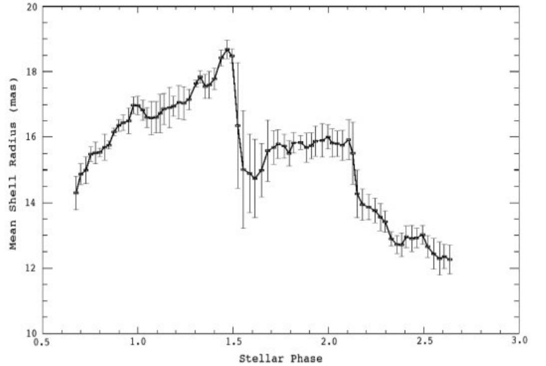
at some point, temperature drops and grains form

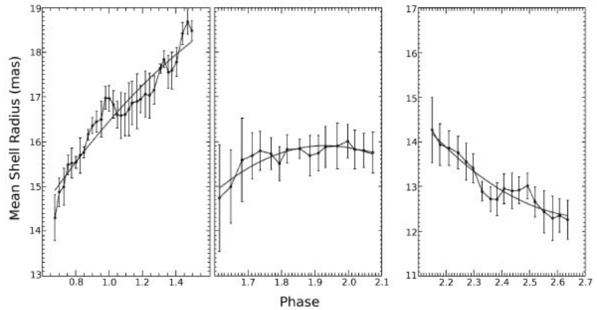
=> fast expansion dominates

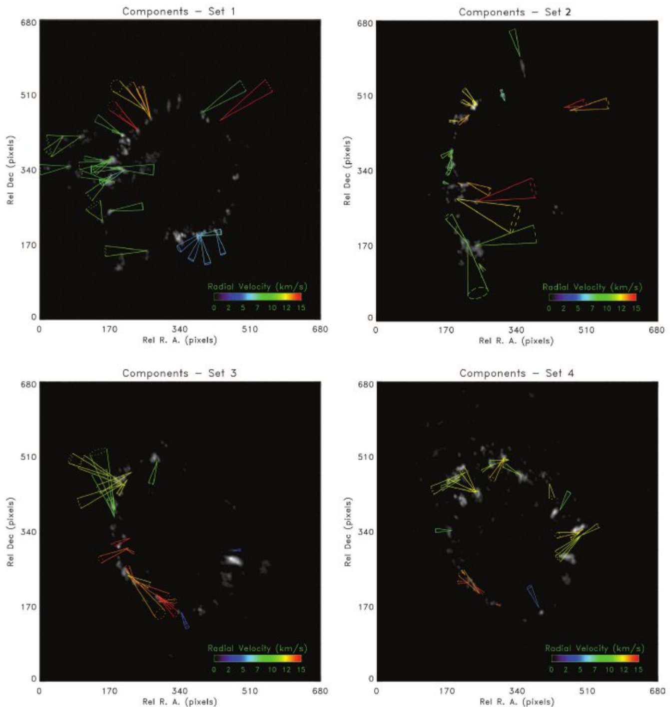
Höfner et al. (2003, AA 399, 589)

Pulsation can be observed with SiO masers



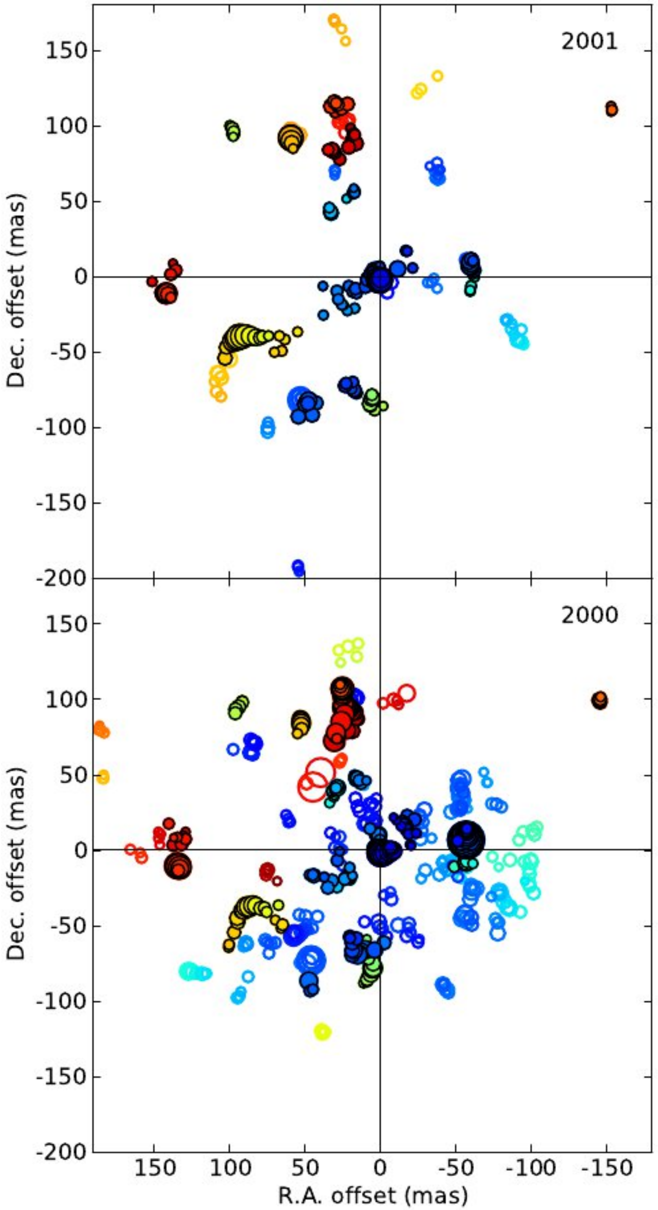




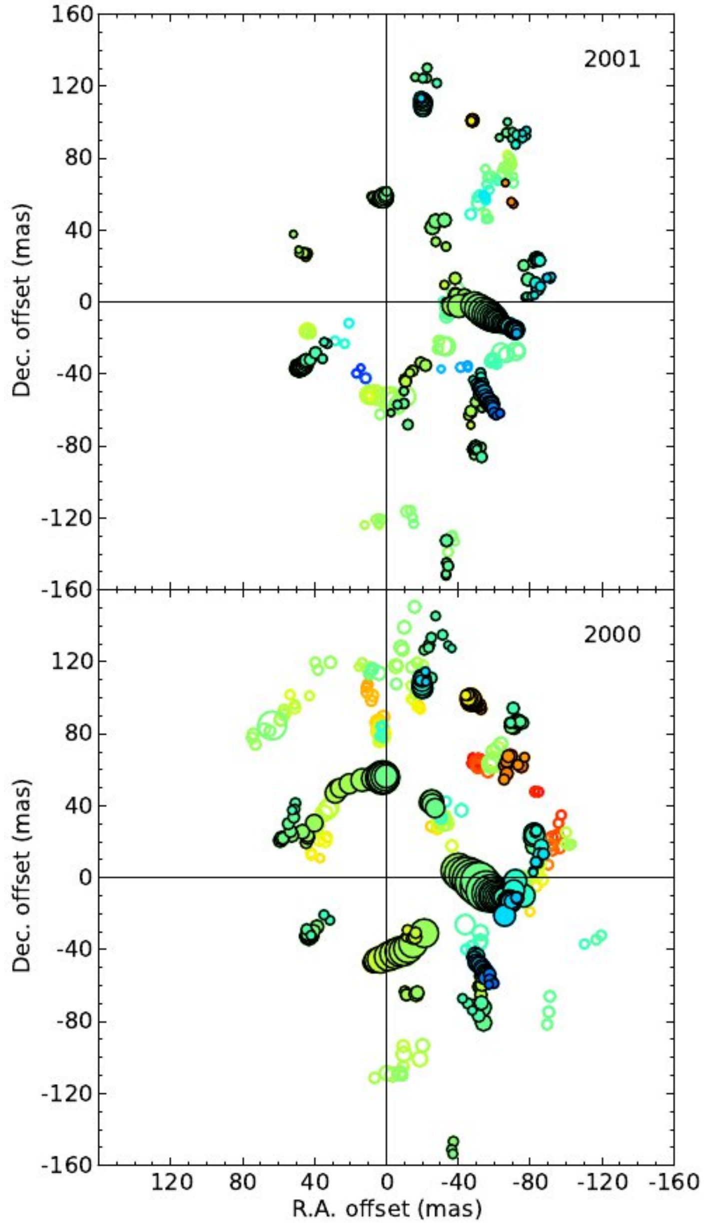


Gonidakis et al. (2010 , ApJ 406, 395)

Water masers appear in outer shells



IK Tau



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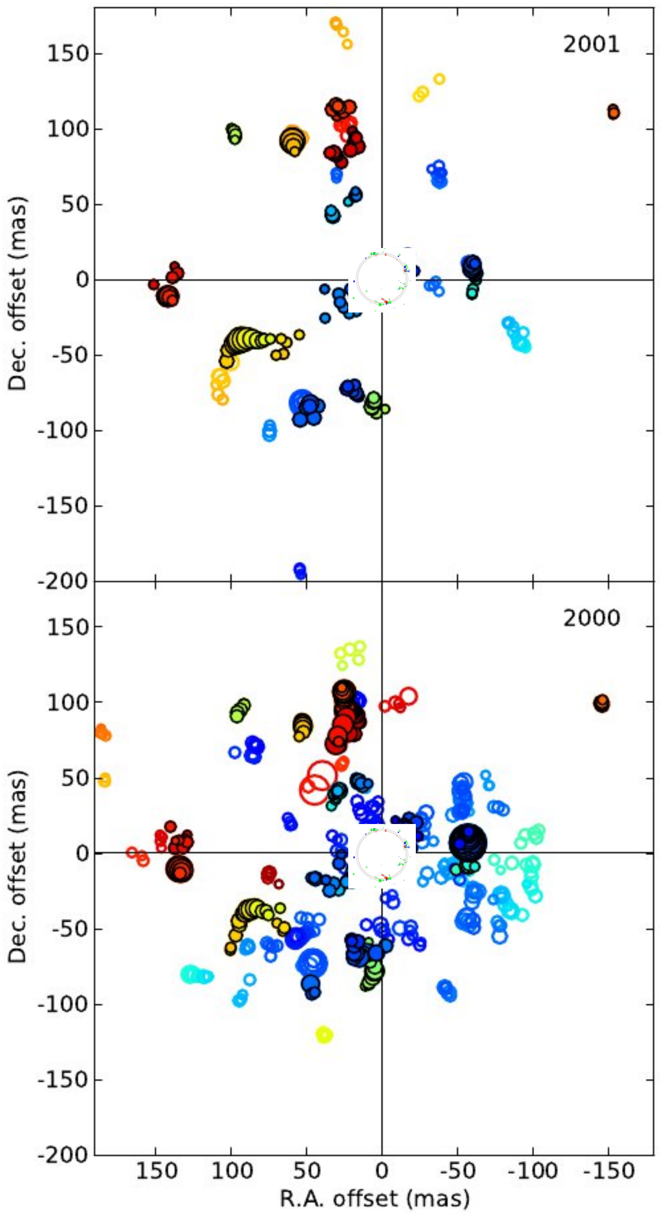
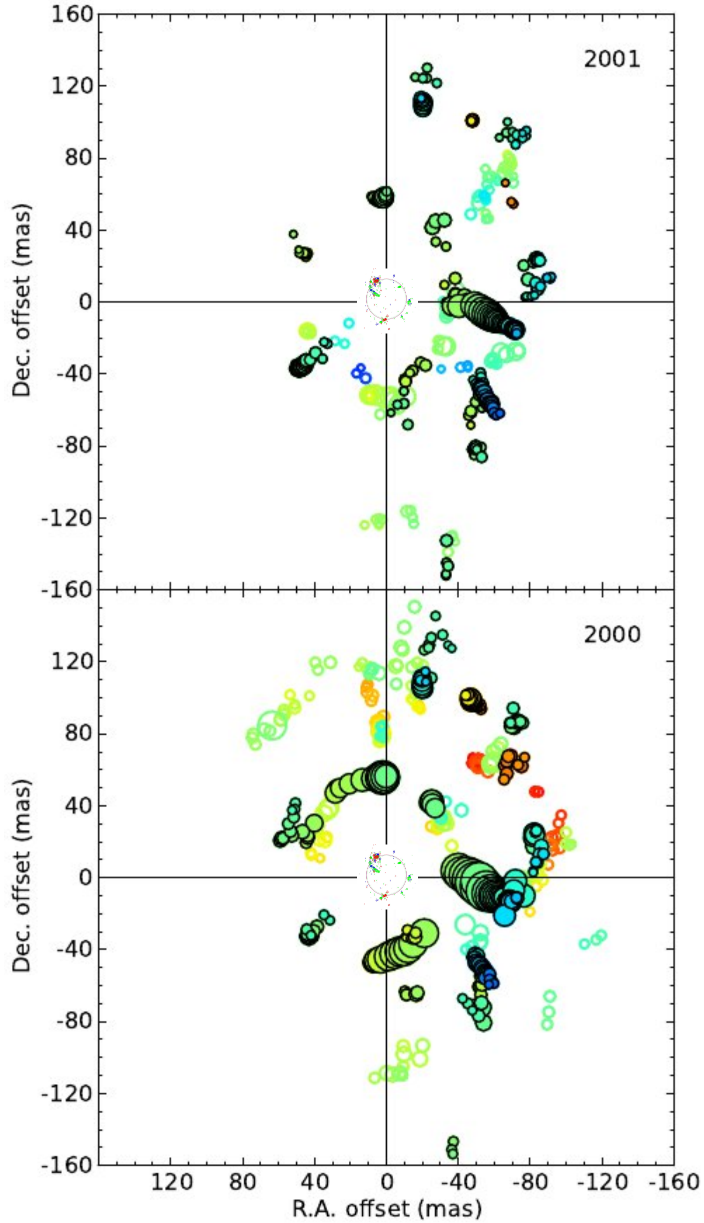
Richards et al. (2012, AA 546, 16)

Water masers appear in outer shells, comparison with SiO?



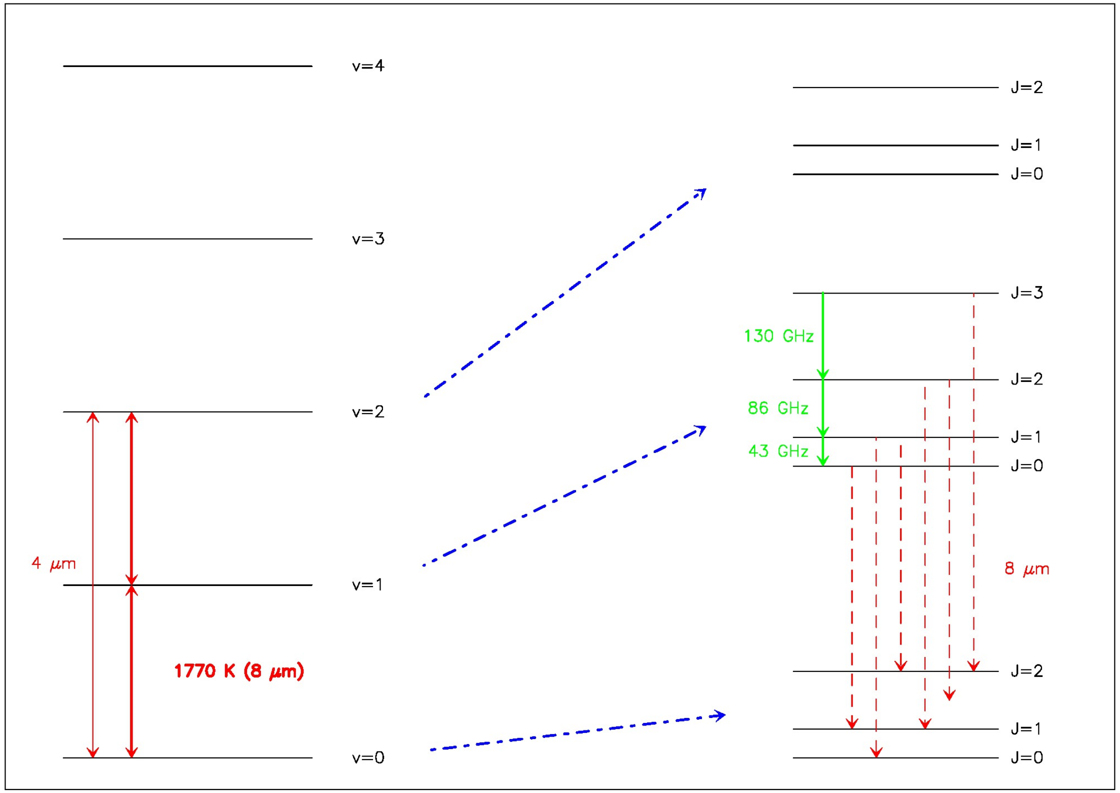


Richards et al. (2012, AA 546, 16), Desmurs et al. (2014, AA 565, 127)

Further study of physical conditions in very inner shells require maser models!!

SiO pumping still debated: collisional?, radiative?

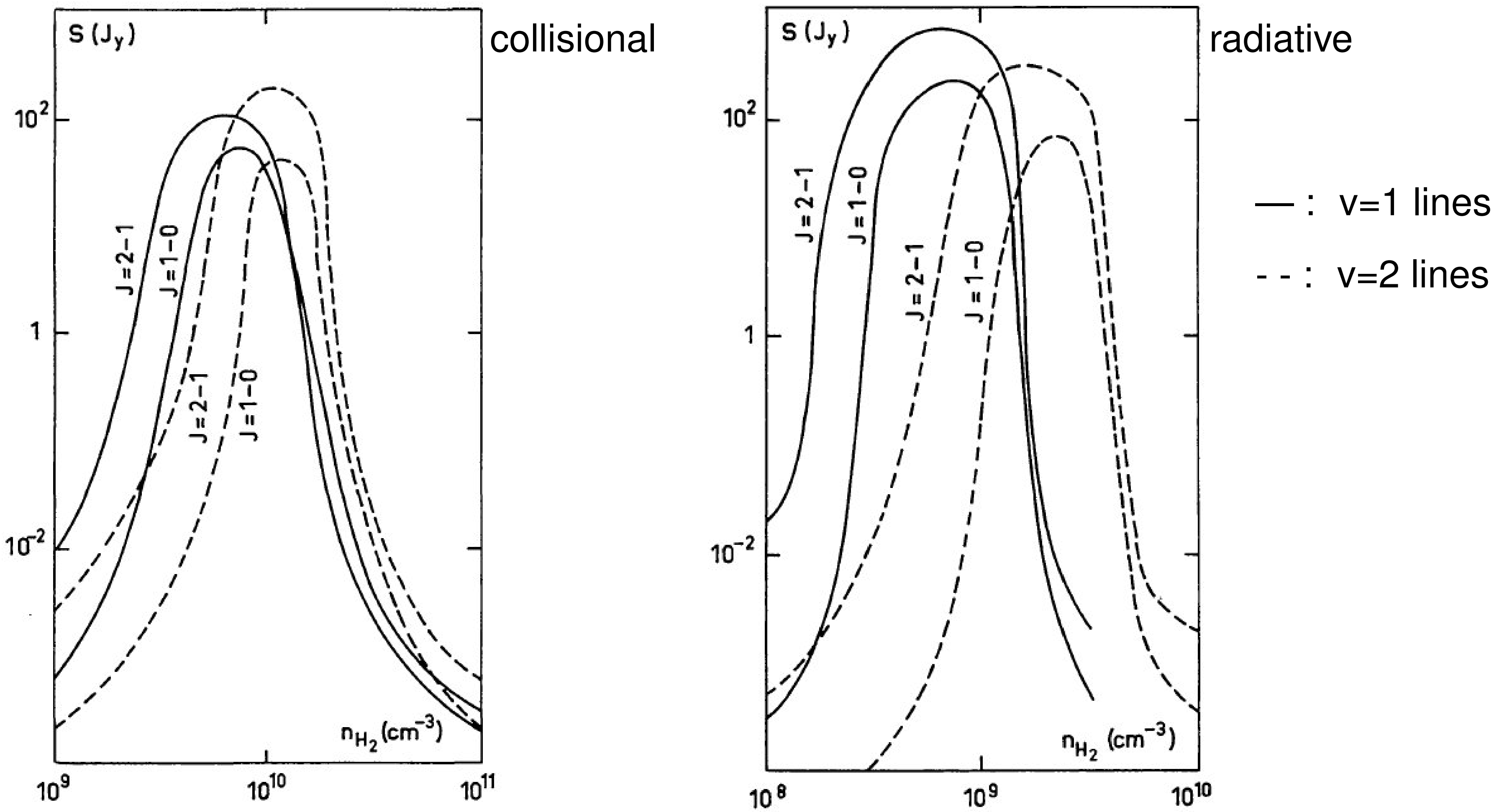
SiO: LEVELS AND TRANSITIONS



v $\geq$ 1 rotational line masers due to opacity in v –> v–1 transitions

How v (v>0) levels are populated?

Collisional vs. radiative pumping – coincident spots for v=1,2 J=1-0 (λ=7mm)?

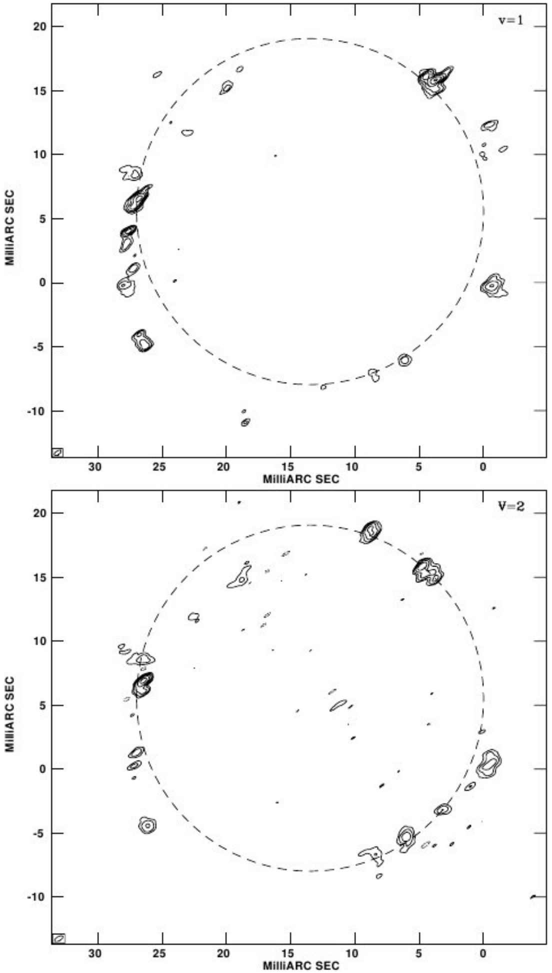


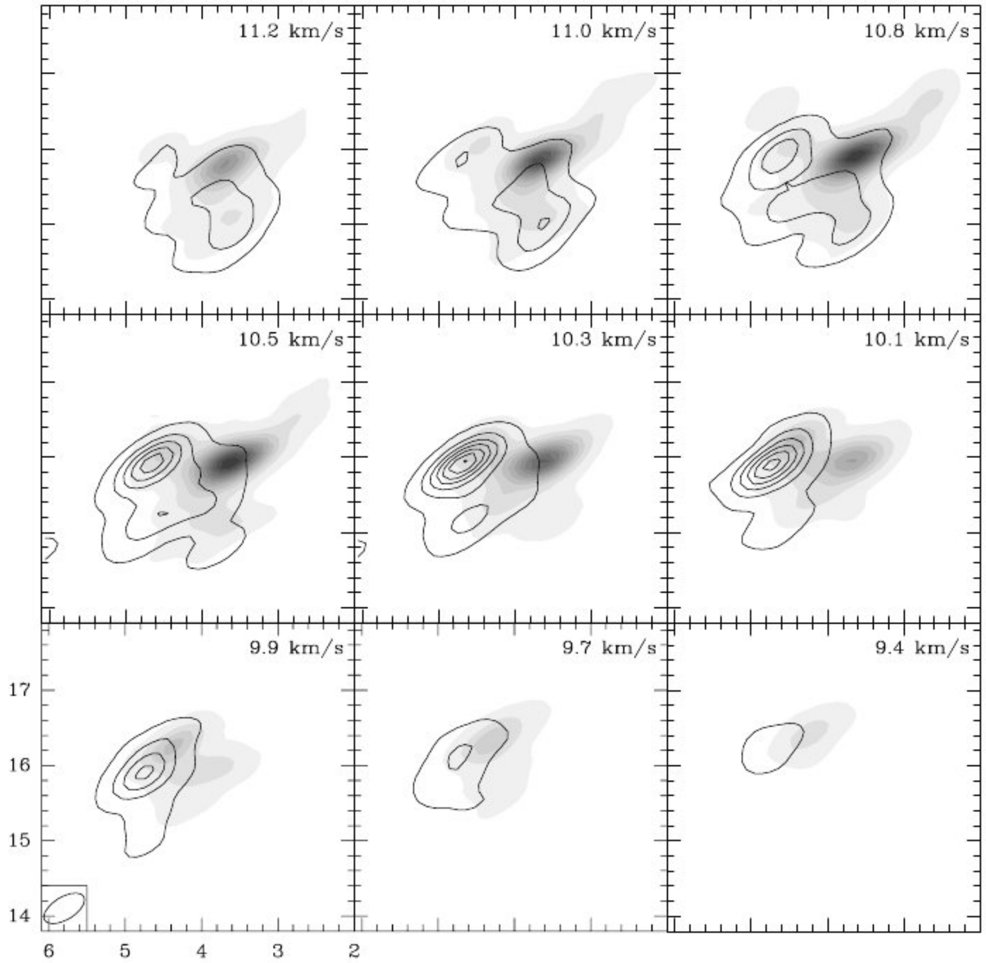
Collisional masers require much higher densities

Radiative pumping discriminates v=1 and v=2 masers: come from different regions

Bujarrabal & Nguyen-Q-Rieu (1981, A&A 102, 65), Lockett & Elitzur (1992, ApJ 399, 704); see new calc. in Gray et al. (2009, MNRAS 394, 51)

Collisional vs. radiative pumping – coincident spots for v=1,2 J=1-0 (λ=7mm)?





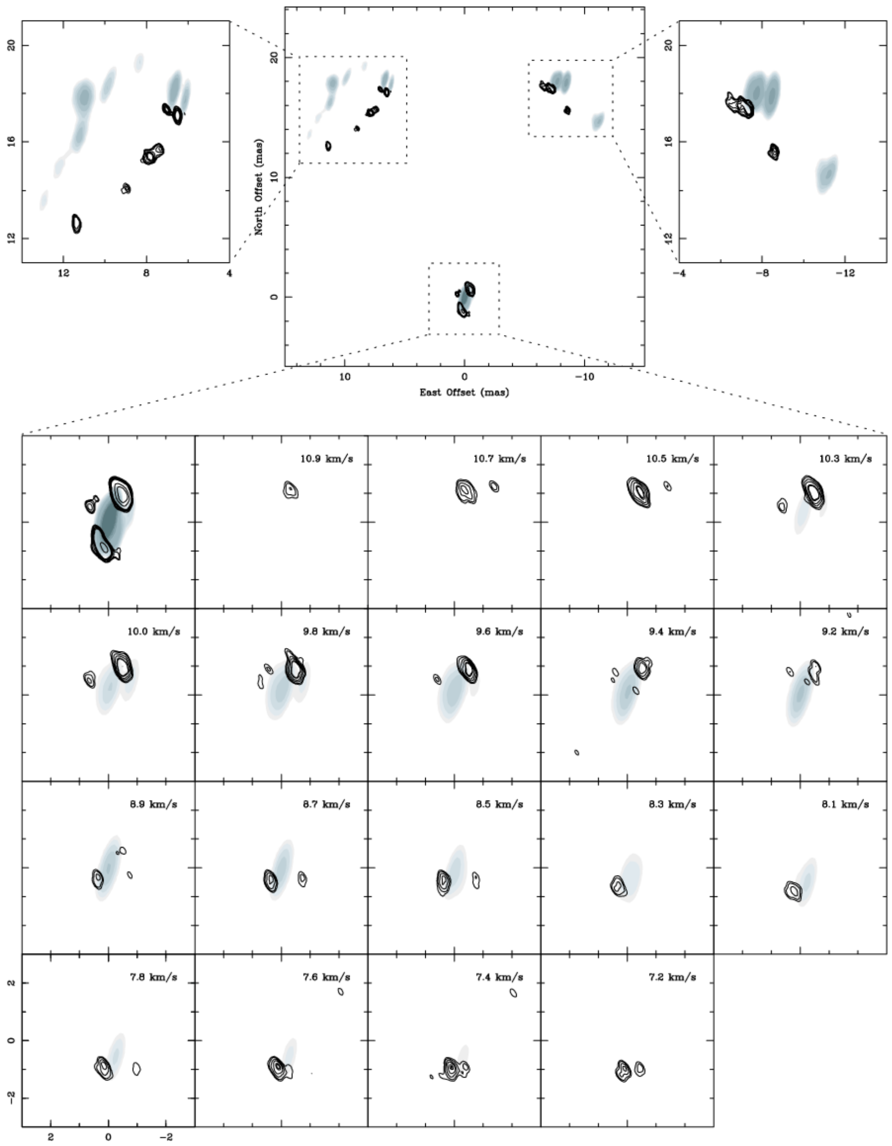
TX Cam

Apparently similar distributions

but v=2 ring is slightly smaller and peaks very rarely appear in the same position

Desmurs et al. (2000, AA 360, 189), Soria-Ruiz et al. (2004, AA426, 131), Kamohara et al. (2010, AA 510, 69); etc

Collisional vs. radiative pumping – coincident spots for v=1,2 J=1-0 (λ=7mm)?



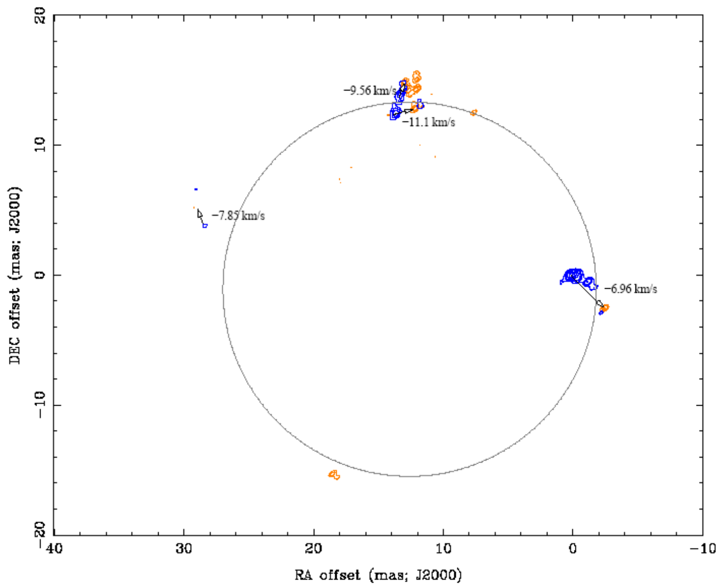
IRC +10011

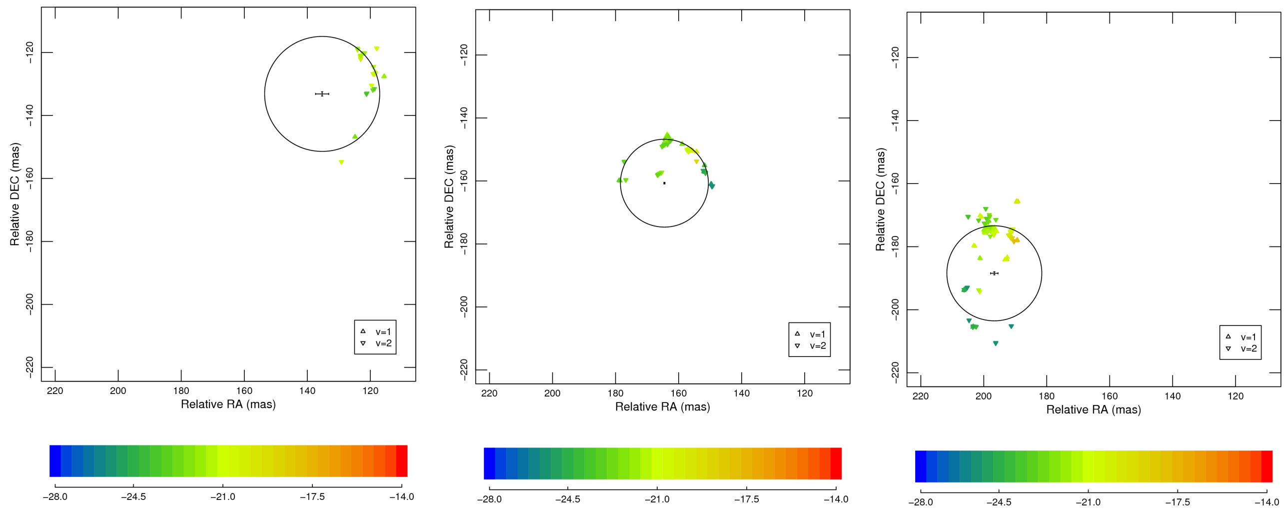
v=2 J=1-0 (contours) surrounds v=1 J=1-0 avoiding it !

- should we conclude that pumping is radiative?
- can n vary by a factor 10 in 1 mas? ($\sim$1/10 R_*)?
- v=2 J=1-0 is not in the center!

very good maps with sub-mas resolution, but are relative positions of v=1 and 2 accurate?

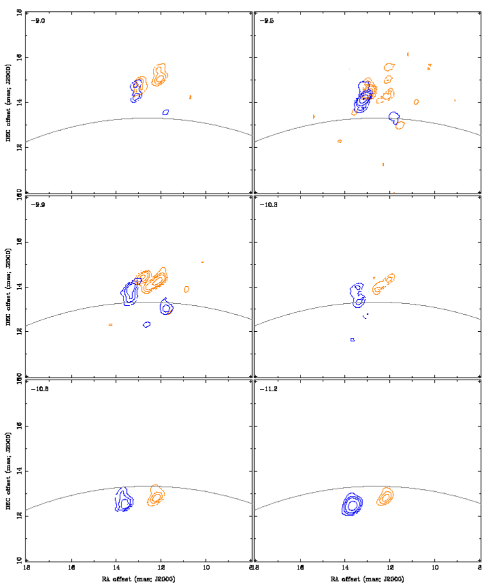
Coincident spots for v=1,2 (λ=7mm)? Some accurate astrometry: VERA





R Aqr observed 11 epochs (to measure parallax)

$\lesssim$ 10% of identified spots are coincident



R LMi

v=1 J=1-0

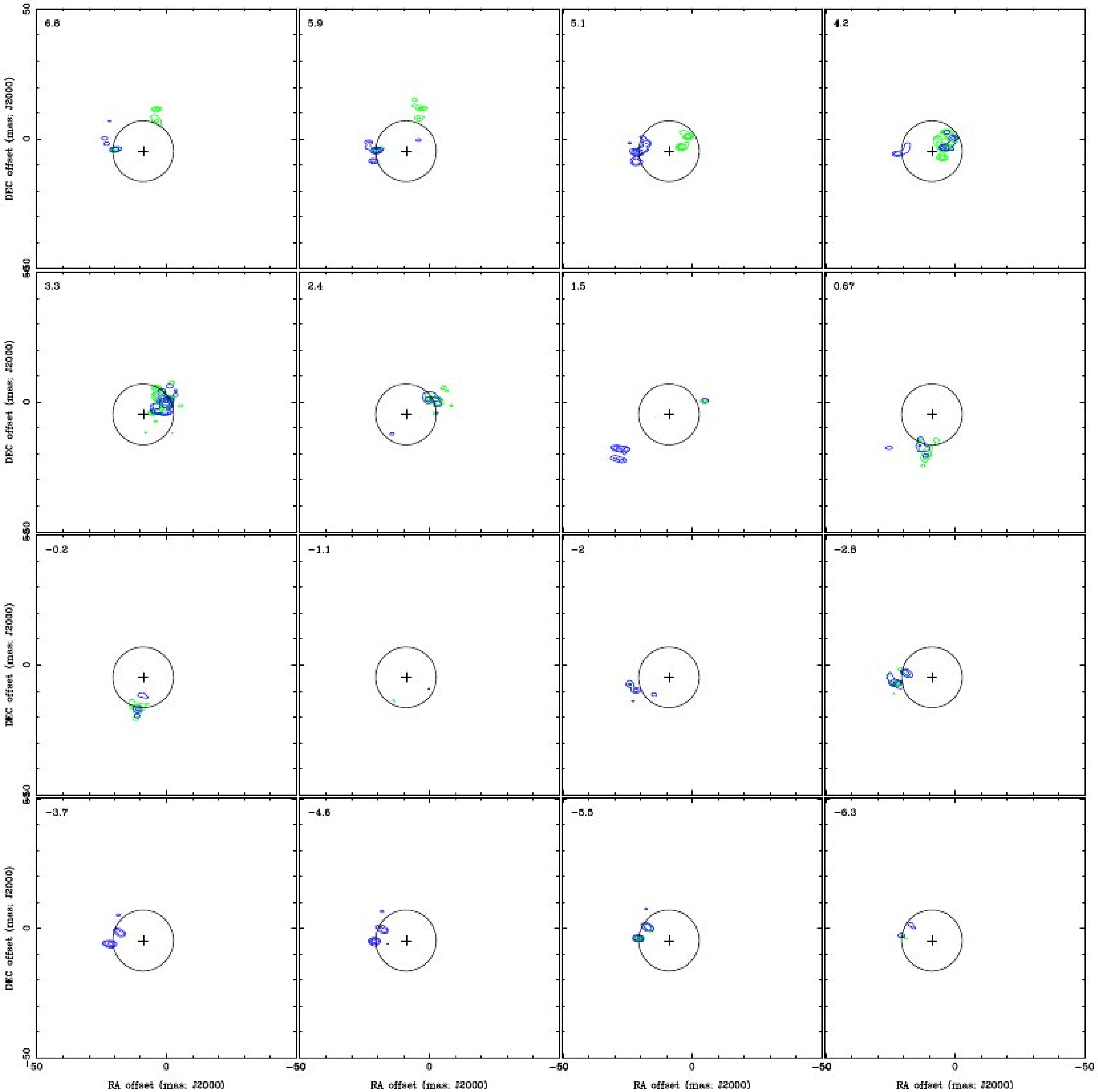
v=2 J=1-0

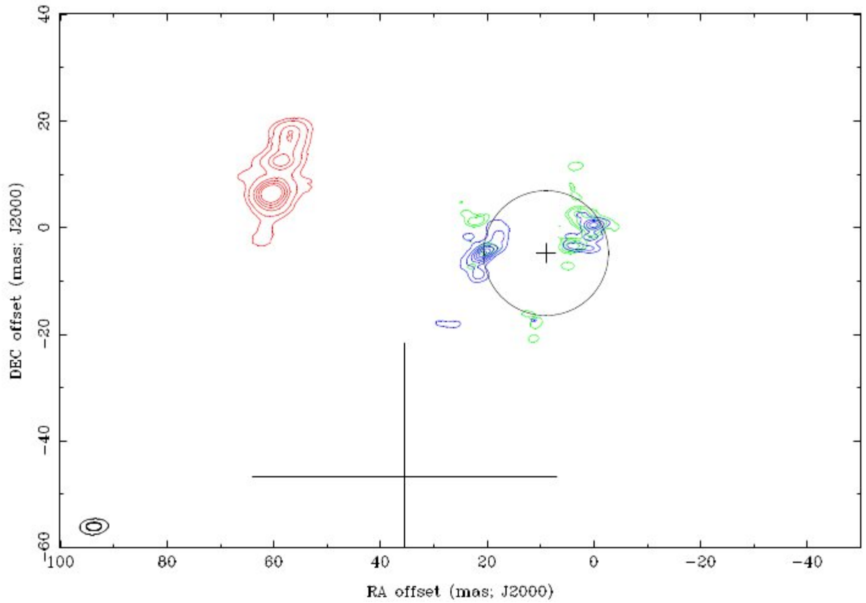
v=1,2 J=1-0 are nearby, almost no coincidence

but difficult observation

Rioja et al. (2008, PASJ, 60, 1031), Kamohara et al. (2010, AA 510, 69); see also Imai et al. (2010, PASJ 62, 431), Yi et al. (2005, AA 432, 531)

Coincident spots for v=1,2 (λ=7mm)? Some accurate astrometry: KVN





v=1 J=1-0

v=2 J=1-0

H_2O 22 GHz

phase transfer from 22 GHz

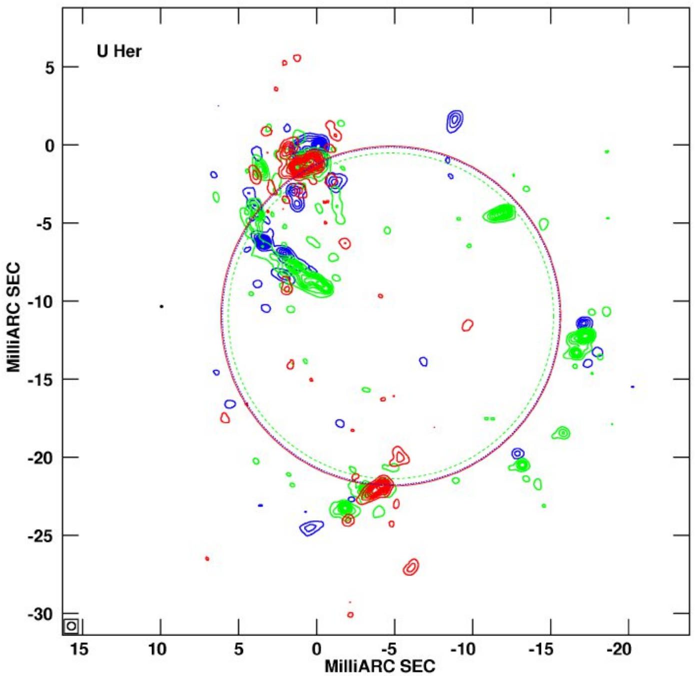
KVN multi-ν obs. program going on

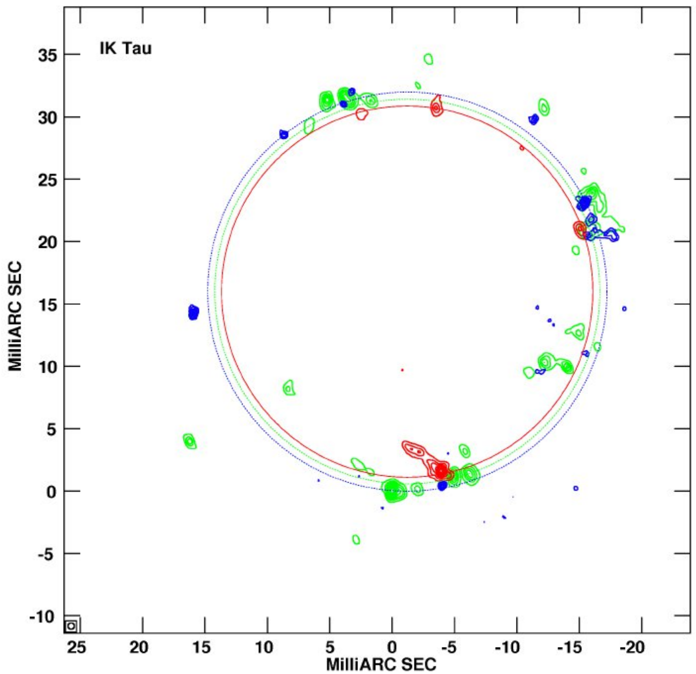
Dodson et al. (2014, AJ 148, 97), Rioja et al. (2014, AJ 148, 84); see also talks by M. Rioja and Do-young Byun

Other SiO lines: v=3 J=1-0 (λ=7mm)

One would expect v=3 (high excitation) lines to be closer to the star

BUT





·····: v=1 J=1-0

·····: v=2 J=1-0

·····: v=3, J=1-0

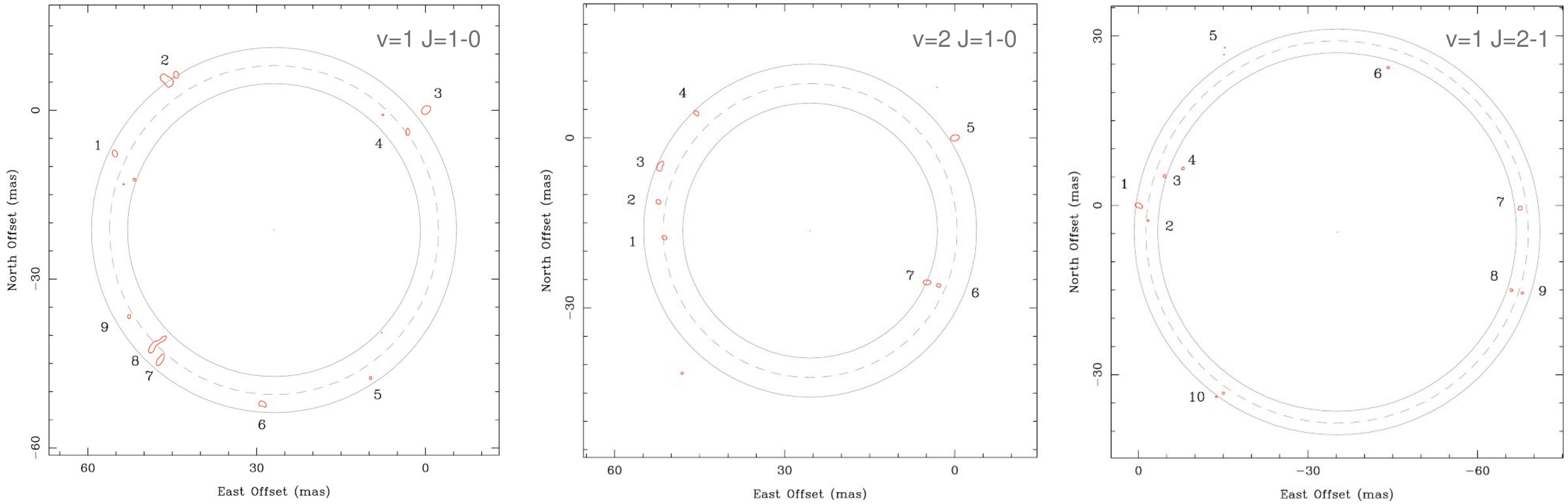
All three lines occupy surprisingly similar regions   always with rare coincidences

Desmurs et al. (2014, AA 565, 127)

Other SiO lines: v=1 J=2-1, λ=3mm => difficult observation

One would expect the v=1 J=2-1 line to be very similar to v=1 J=1-0

BUT larger ring and no coincidence at all



R Leo

Soria-Ruiz et al. (2007, AA 468, L1)

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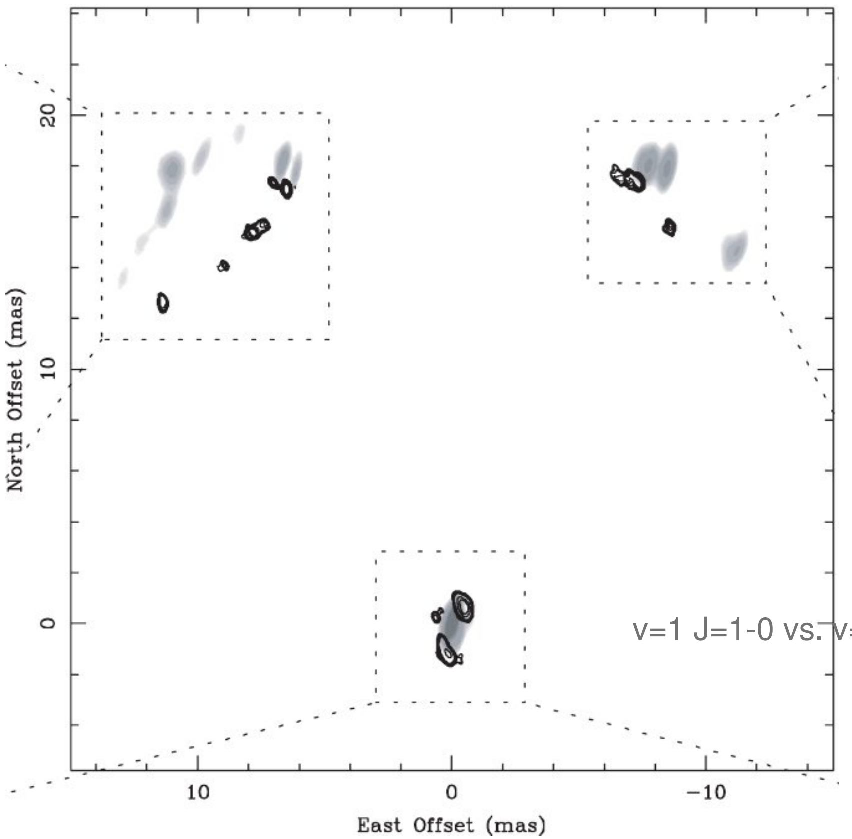

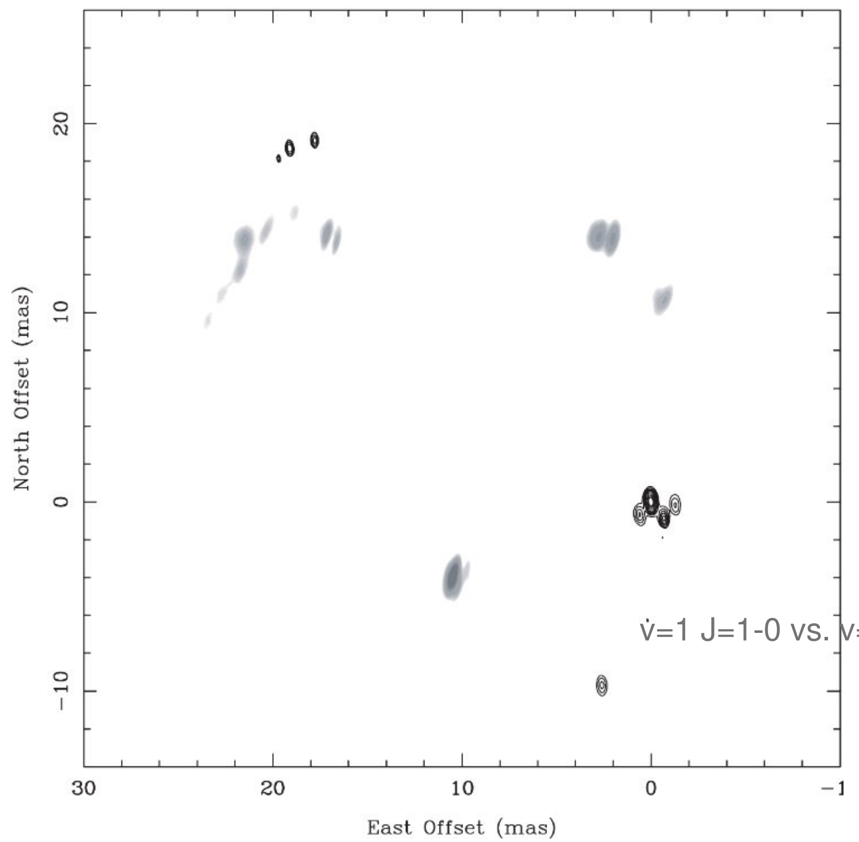

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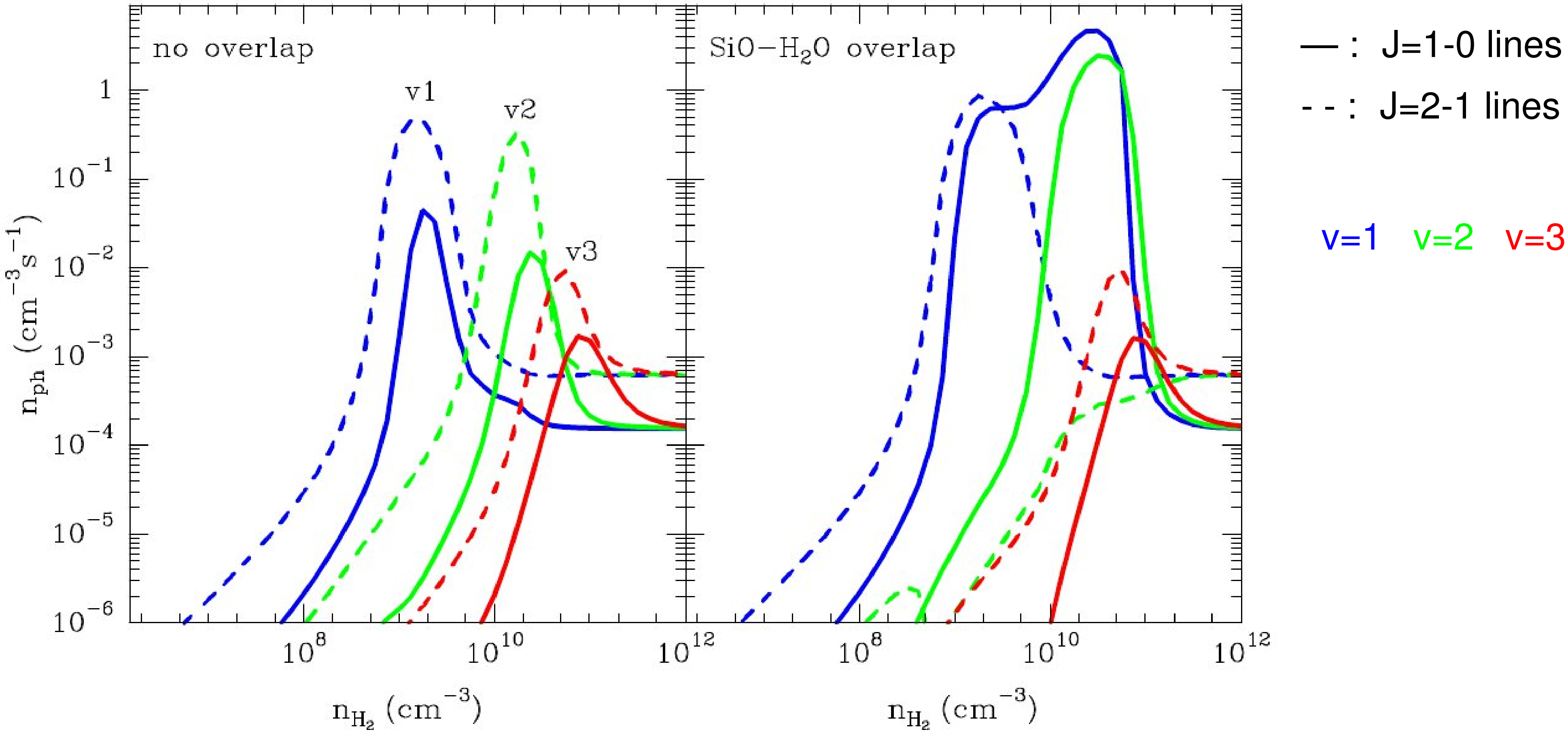
Soria-Ruiz et al. (2004, AA 426, 131)

A possible explanation: overlap between SiO and H_2O vibrational lines

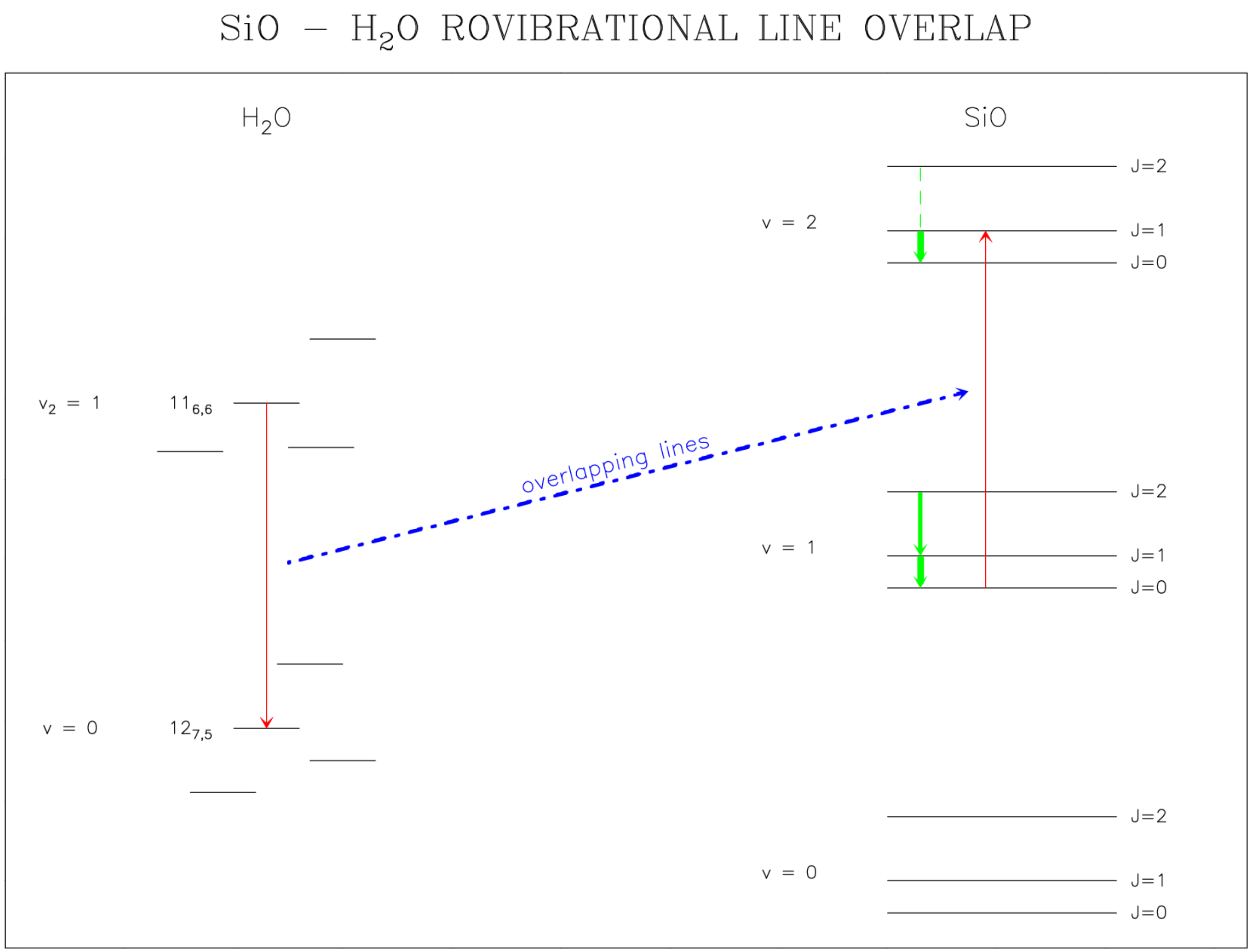
Simple excitation models have serious problems to explain spatial distributions



BUT line overlap could help

Desmurs et al. (2014, AA 565, 127)

A possible explanation: overlap between SiO and H_2O vibrational lines

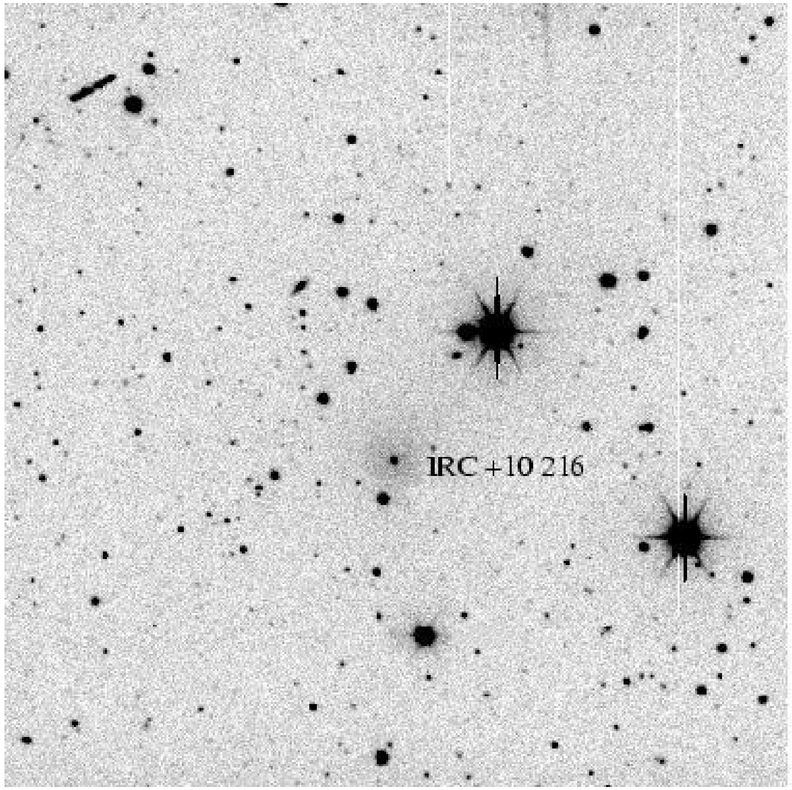


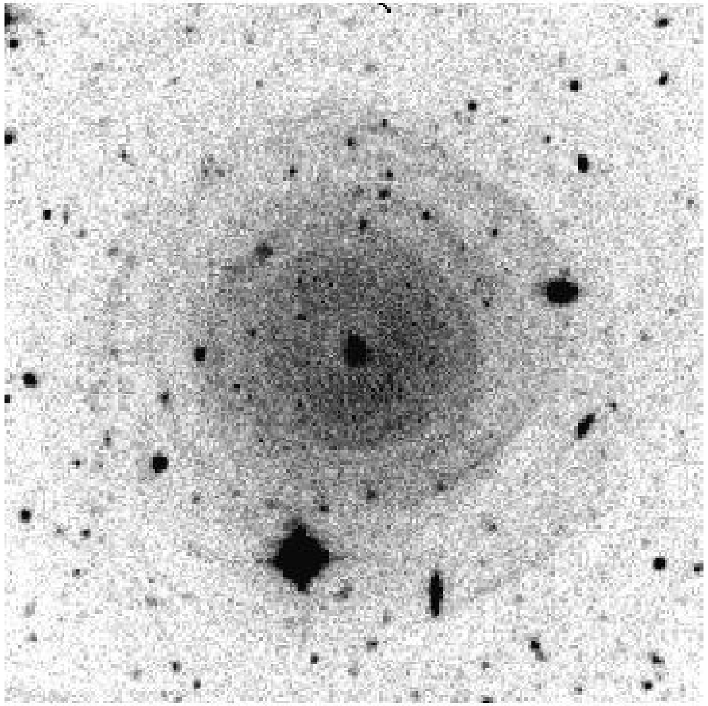
explains the underexcited v=2 J=2-1 line and the distributions of the strong masers

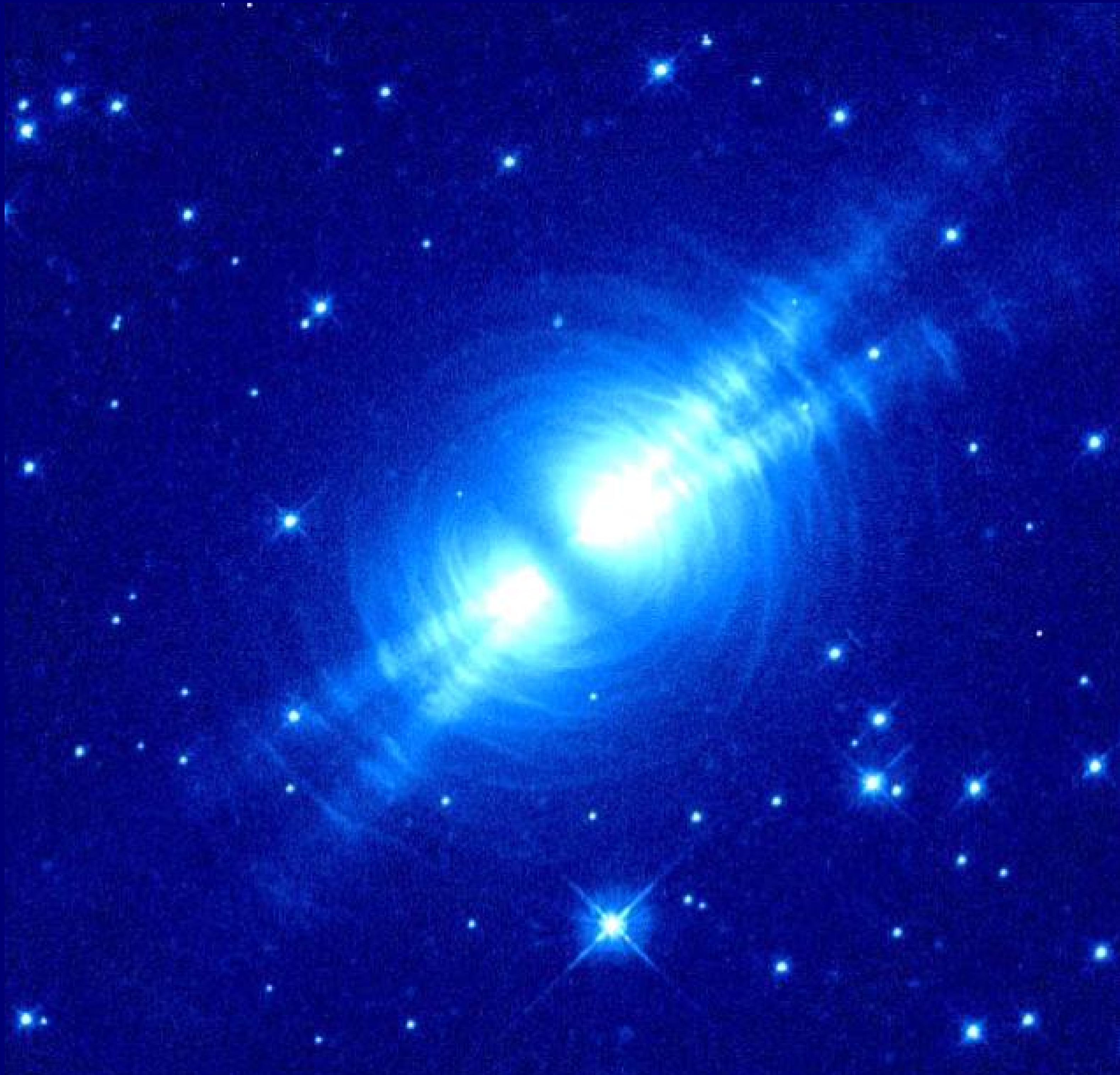
at least qualitatively and keeping in mind the observational (and theoretical) problems

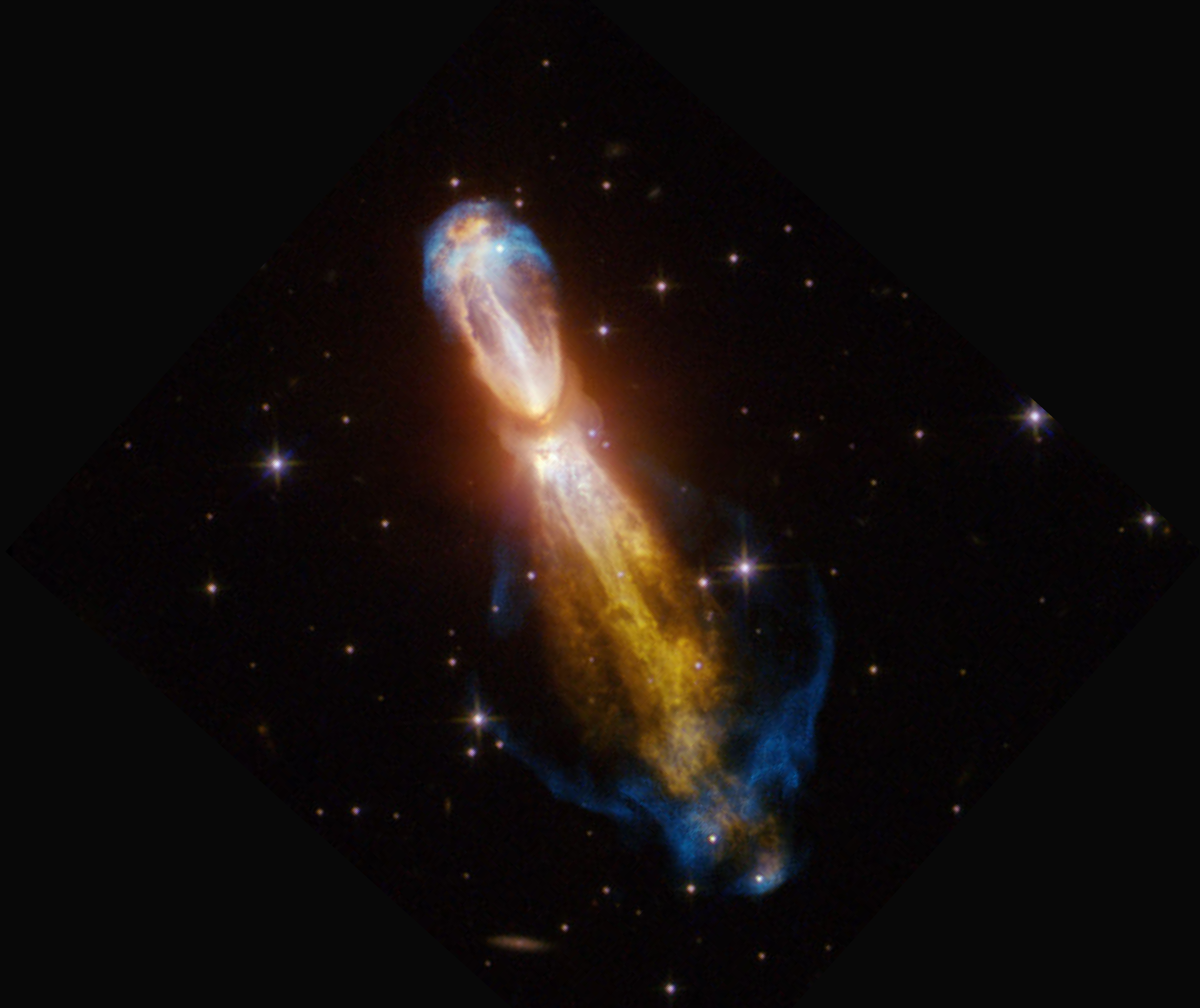
Olofsson et al. (1985, AA 150, 169), Desmurs et al. (2014, AA 565, 127)

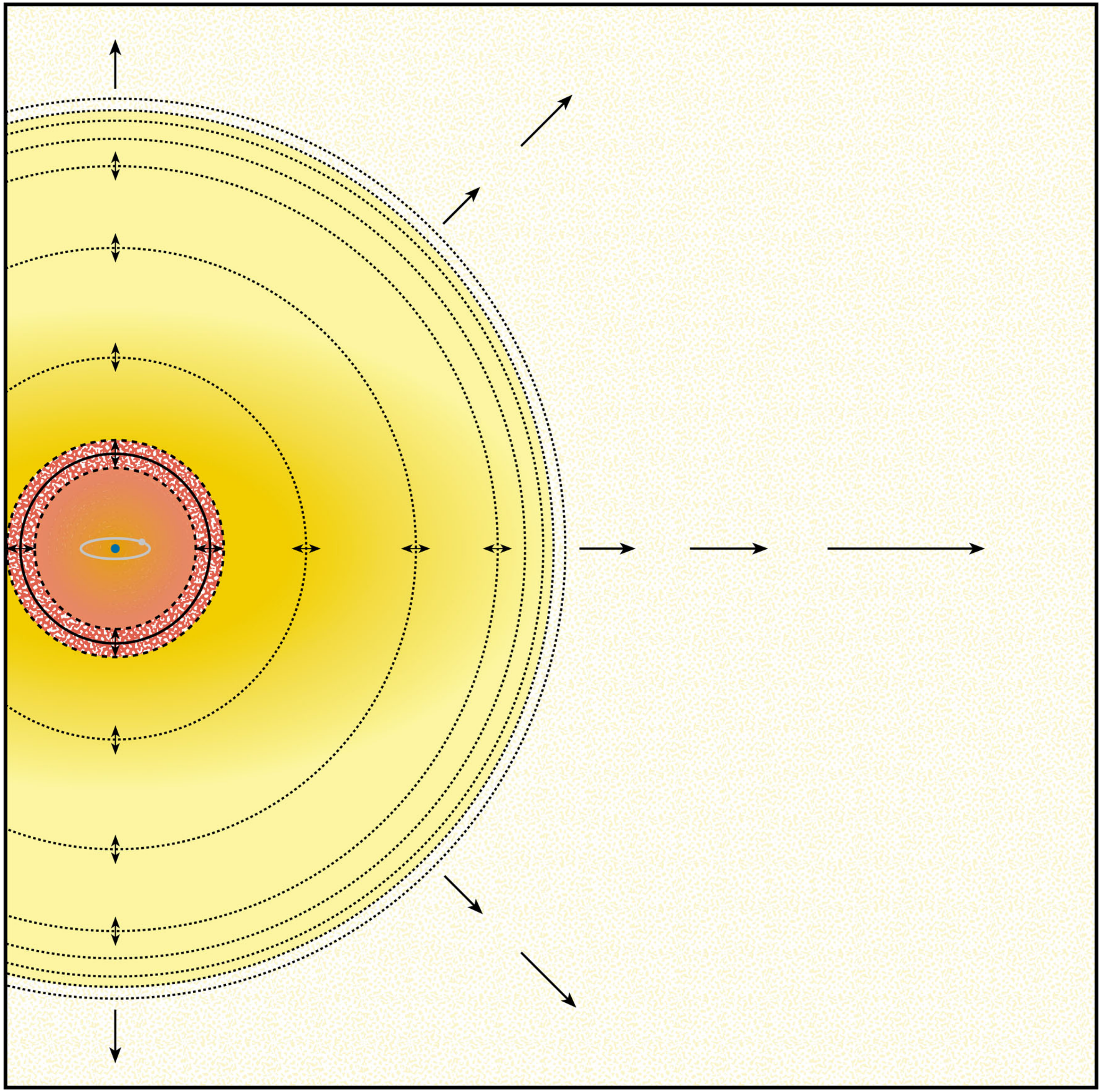
post-AGB evolution: the spectacular birth of planetary nebulae (PNe)

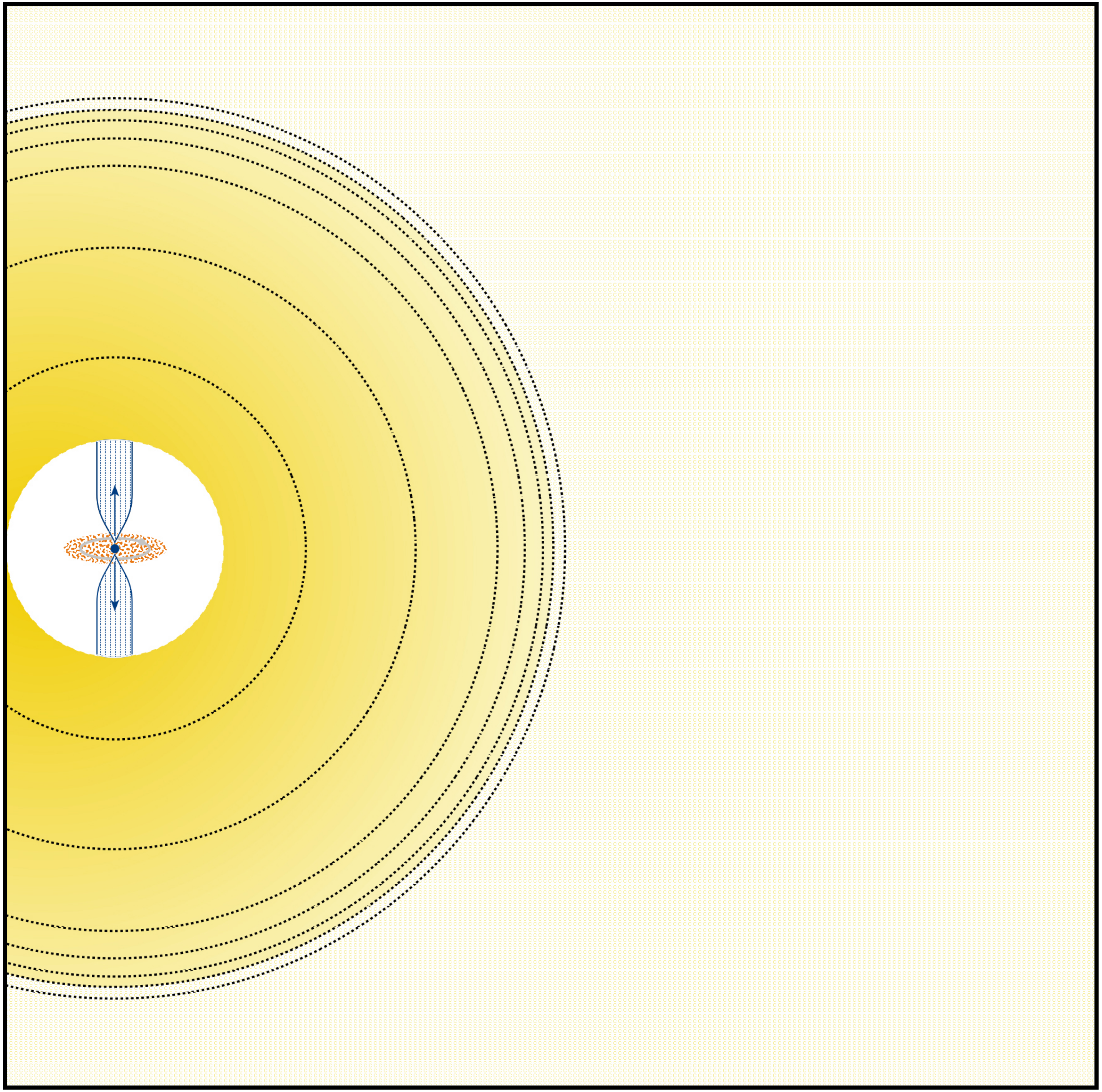


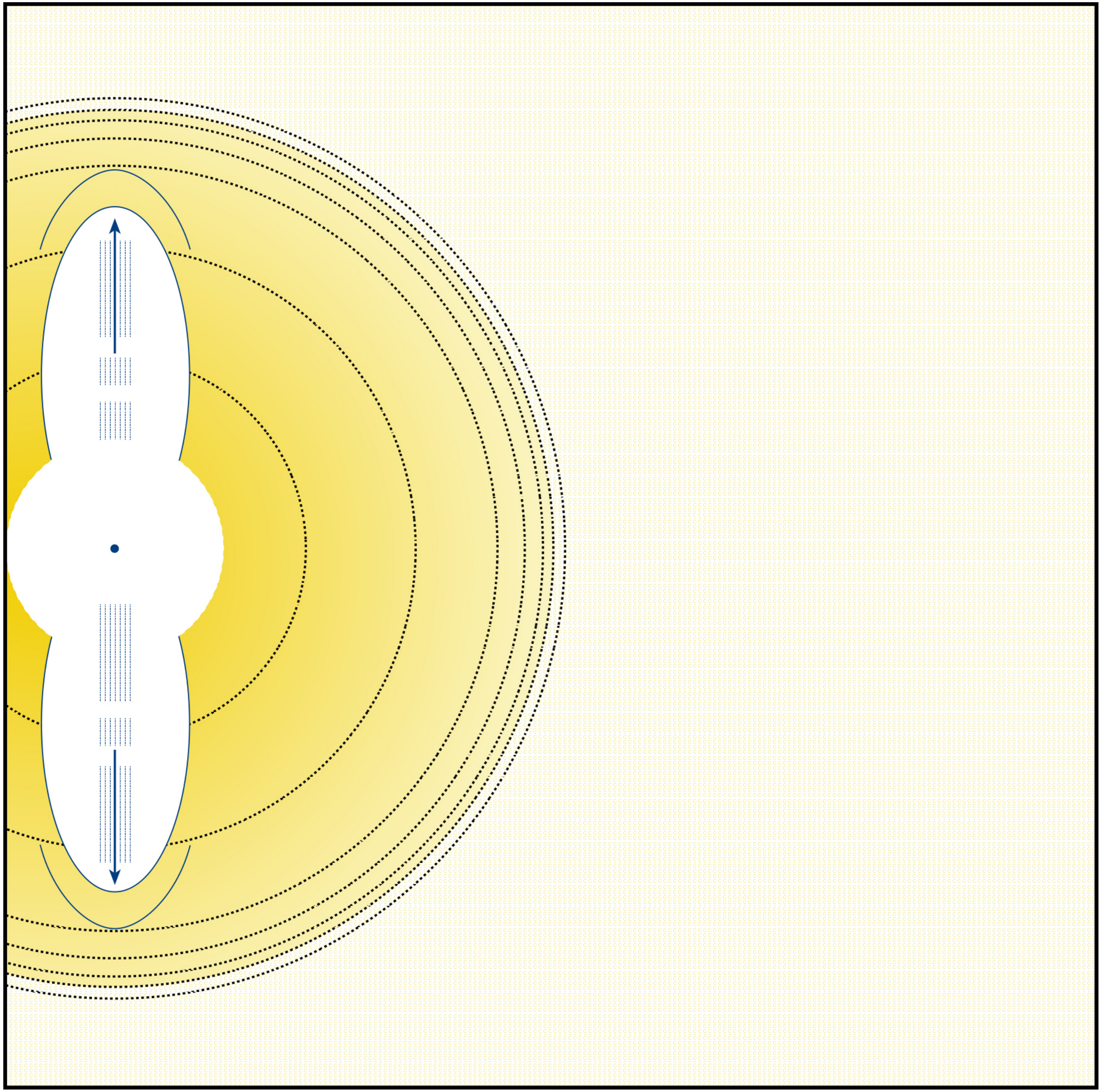


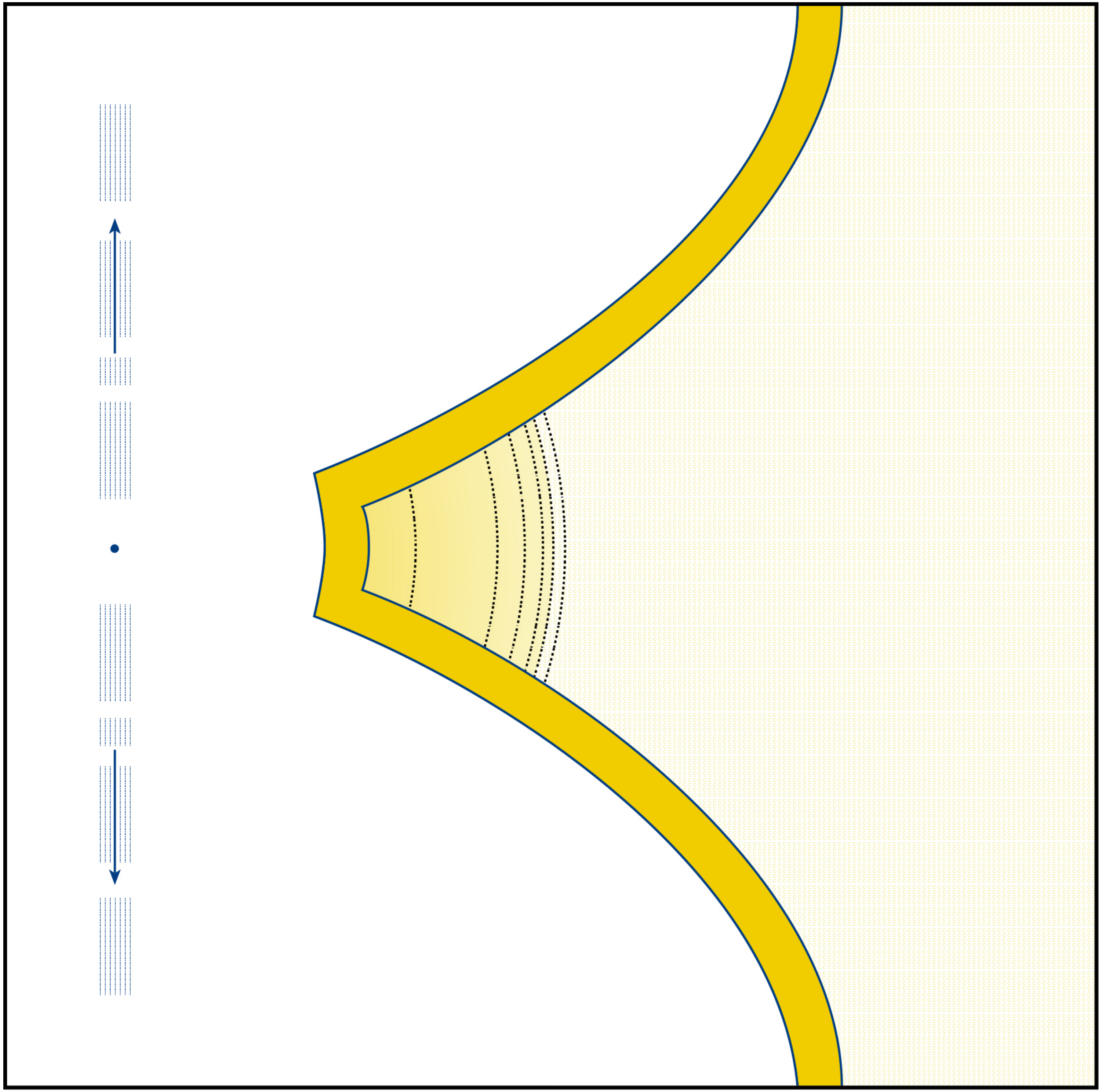


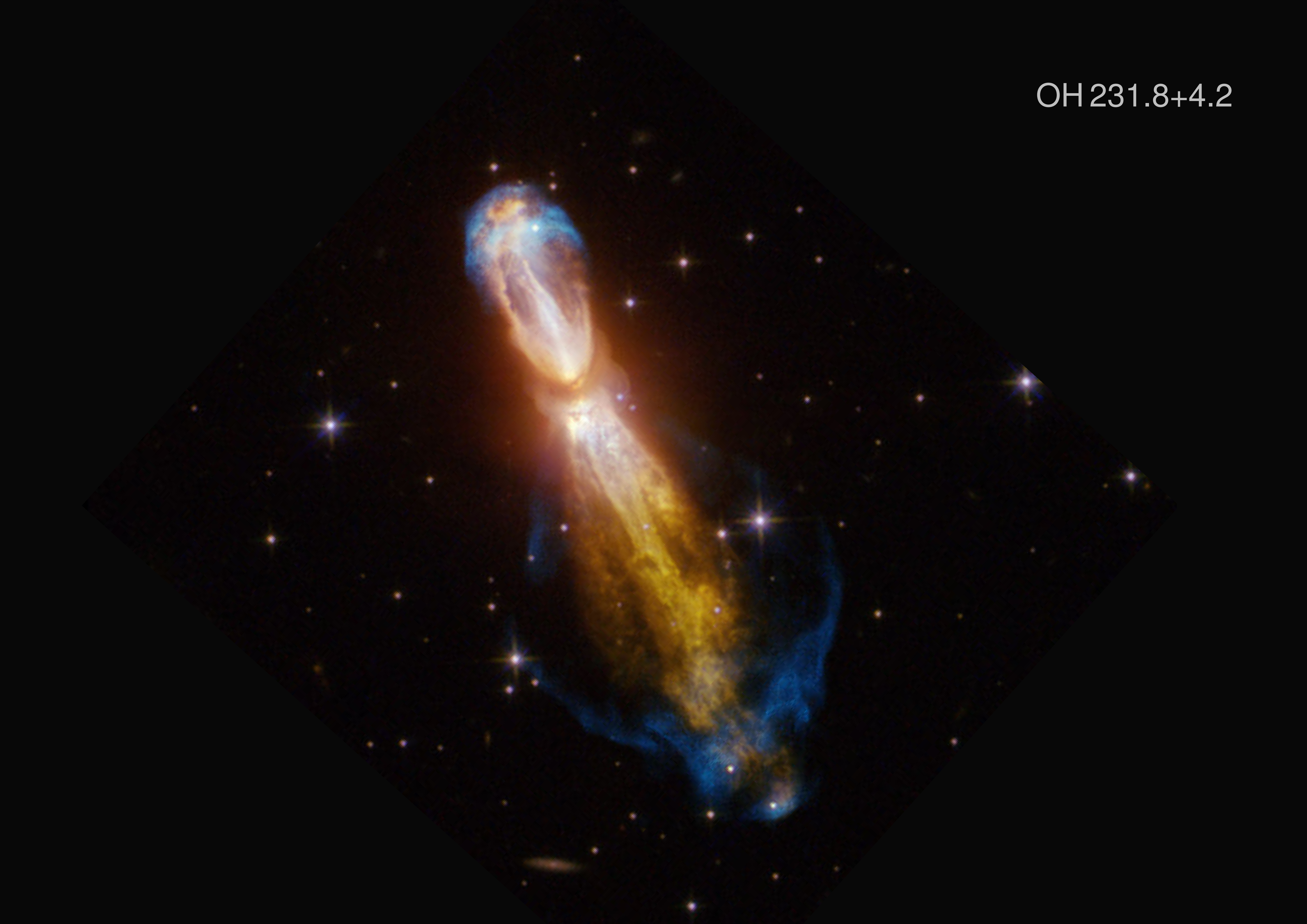




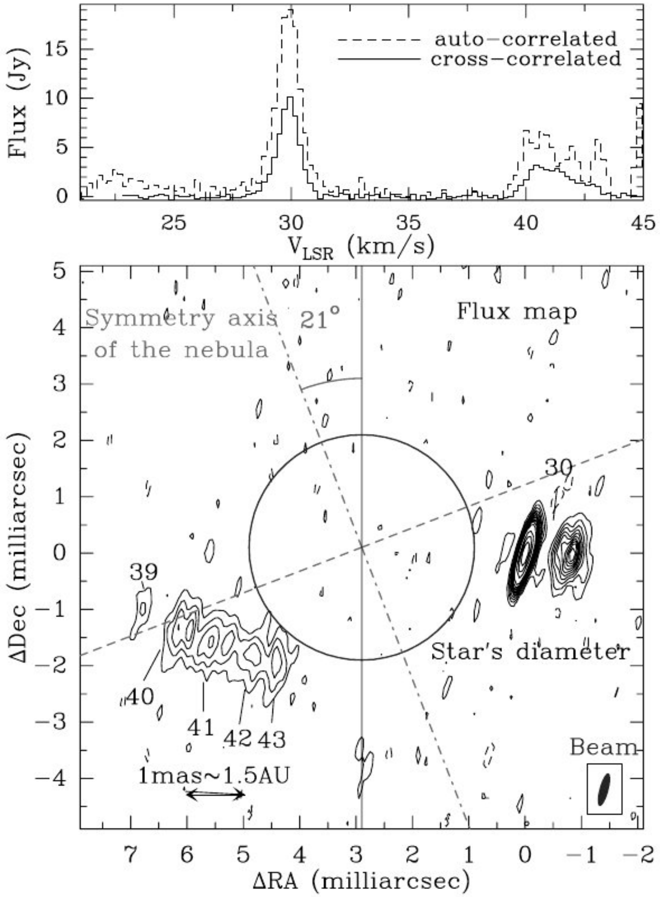


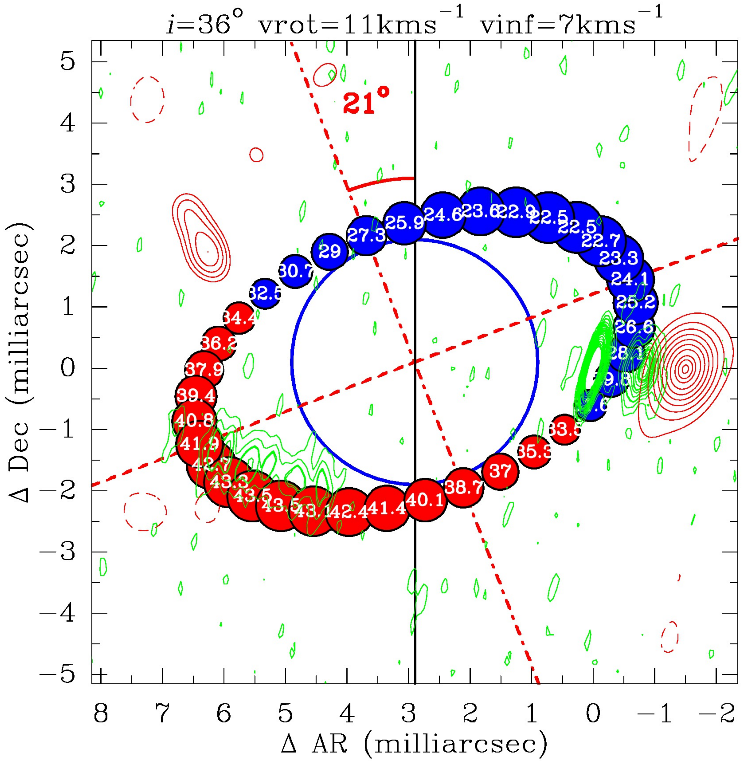





OH 231.8+4.2

SiO masers can be observed in OH 231.8+4.2





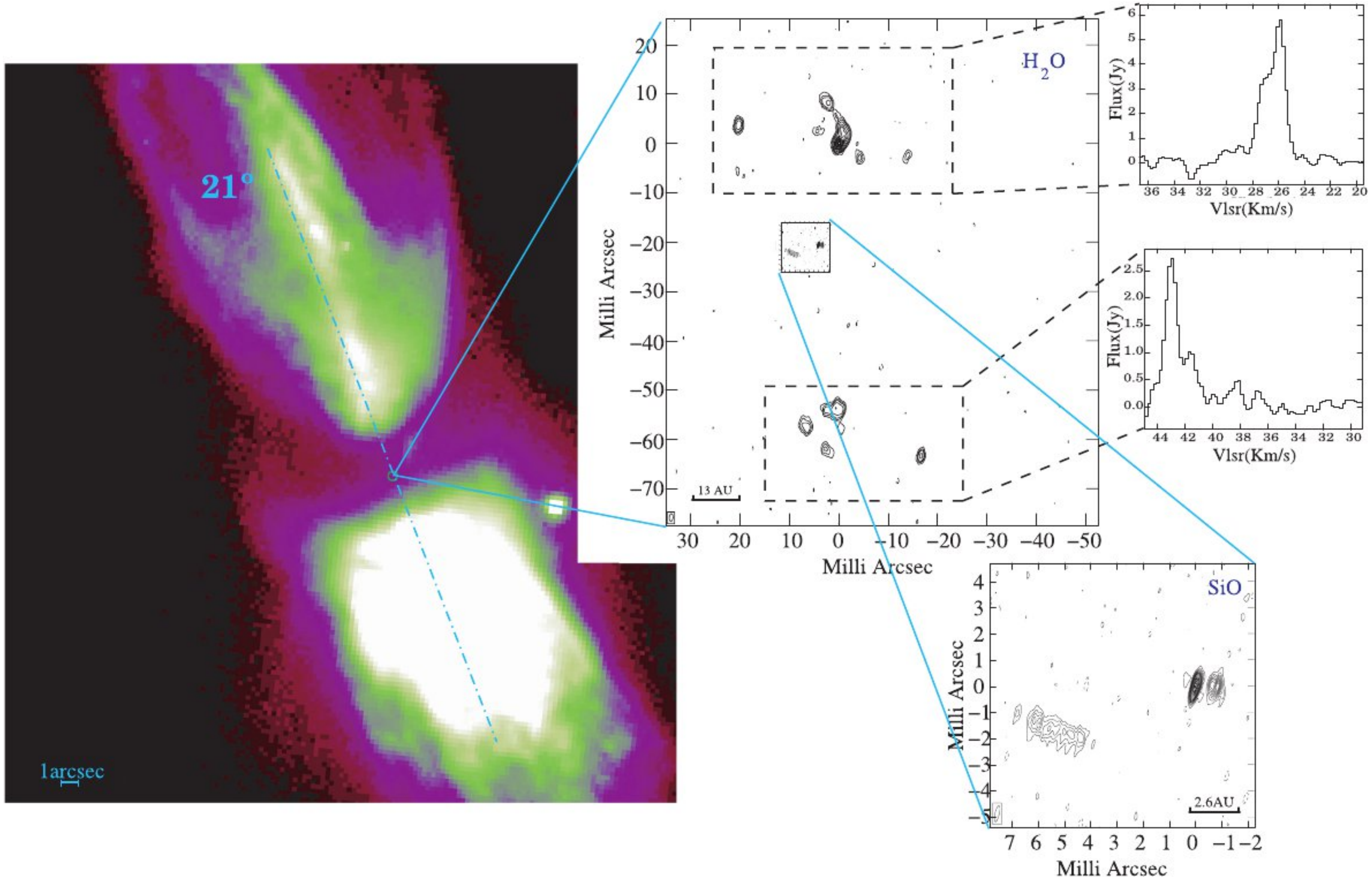
SiO masers come from a disk (around the star)

whose velocity field is compatible with rotation (+ some accretion)

first detection (at that time) of a Keplerian disk in a post-AGB object?

Sánchez Contreas et al. (2002, AA 385, L1)

Also H_2O masers mapped in OH 231.8+4.2



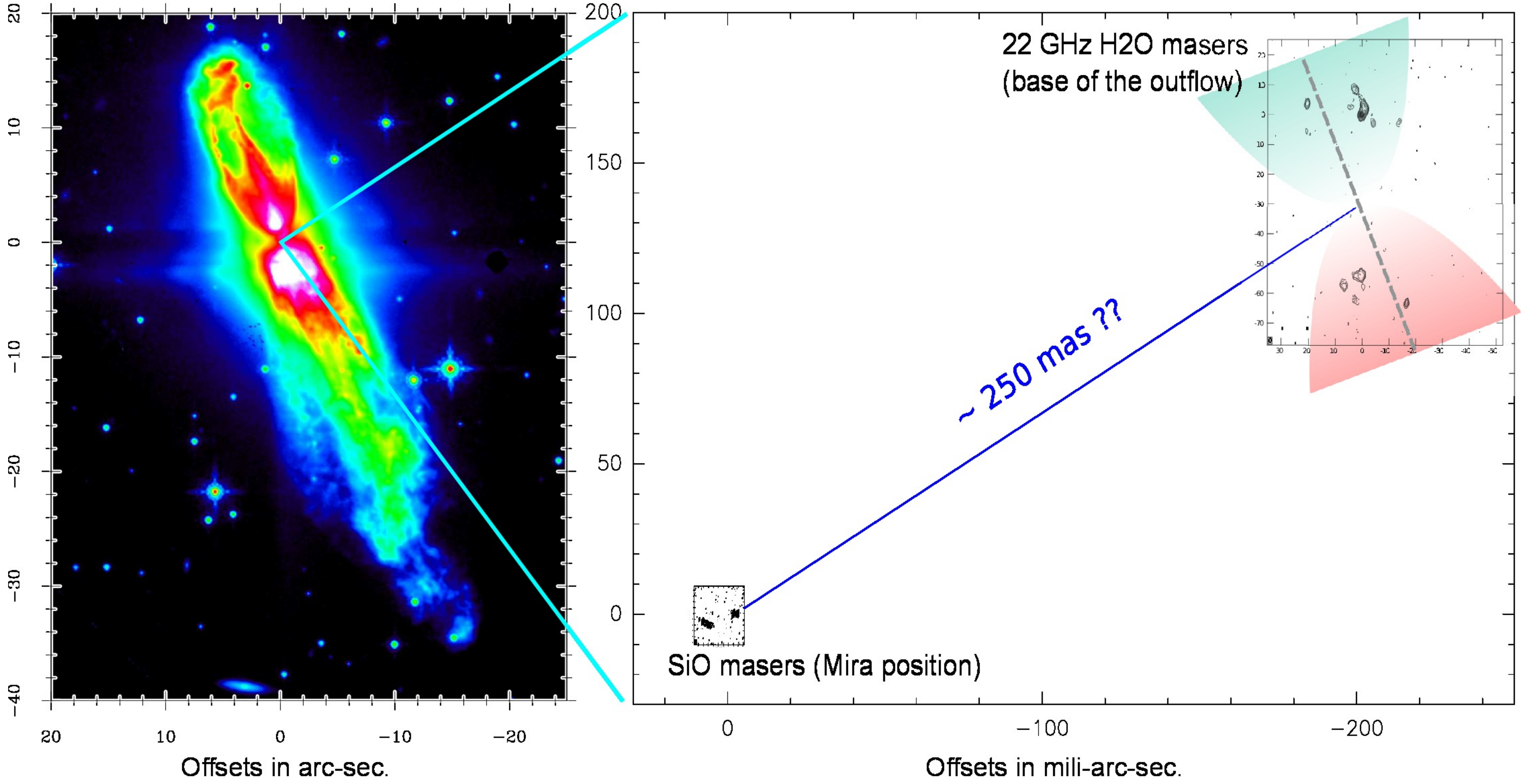
Water masers seem to be in the base of the bipolar outflow and share its velocity field

SiO would trace the disk in the center

But relative positions are poorly known !! particularly due to the SiO data

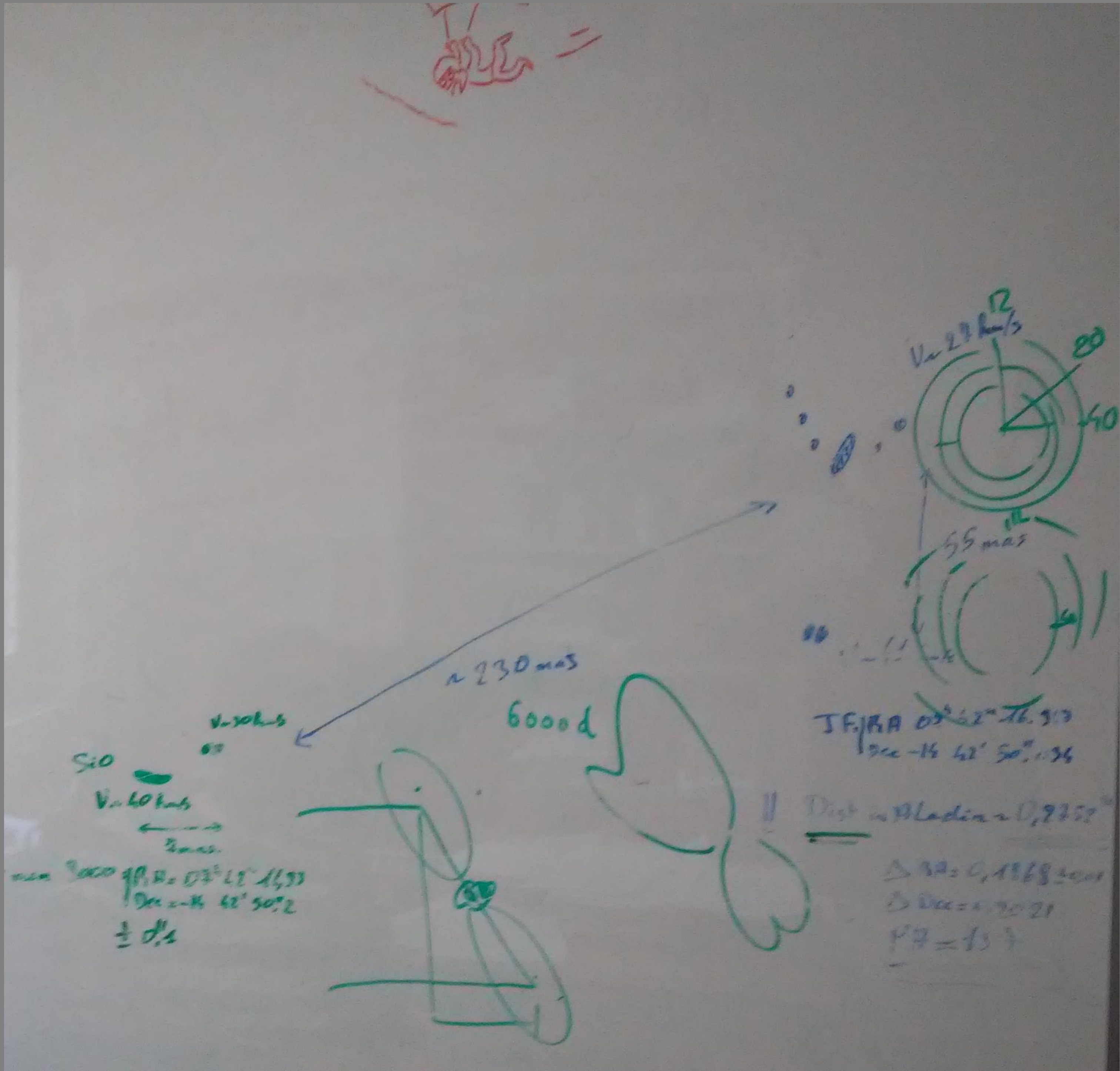
Desmurs et al. (2007, AA 468, 189)

Attempts to accurately place H_2O and SiO masers in OH 231.8+4.2



More recent (accurate?) information place them quite far away

First observations performed more than ten years ago, results are not yet concluding



... just a few days ago

CONCLUSIONS: absolute astrometry and systematic multifreq. observations

Multi-ν VLBI can be done at present, sometimes with absolute astrometry

BUT

difficult astrometry still at 7mm, not many results published

hard observations at higher frequencies, almost impossible astrometry

HOWEVER such observations would be basic to study

- inner layers around red giants –> grain formation and mass loss
- the SiO pumping mechanisms, still under (polite) debate
- the inner regions of post-AGB nebulae –> end of the AGB and birth of PNe

Systematic and accurate multifrequency observations will strongly help

- to systematically map several lines, particularly at high ν (43, 86, 130, 215, ... GHz)
- to obtain a good astrometry, particularly thanks to phase transfer from 22 GHz