

Continuum and Line Polarisation @ ALMA band 5: the supergiant VY CMa

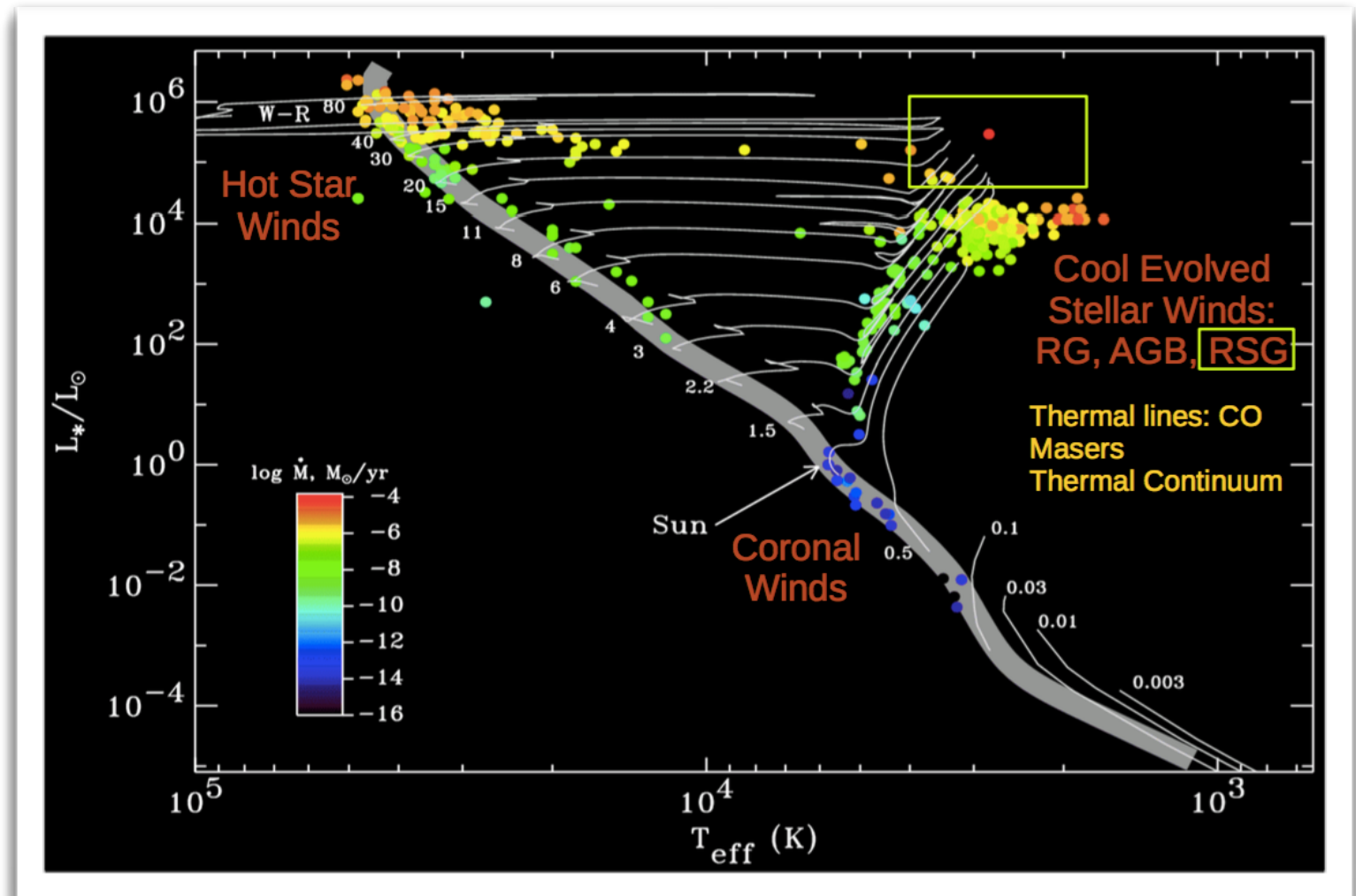
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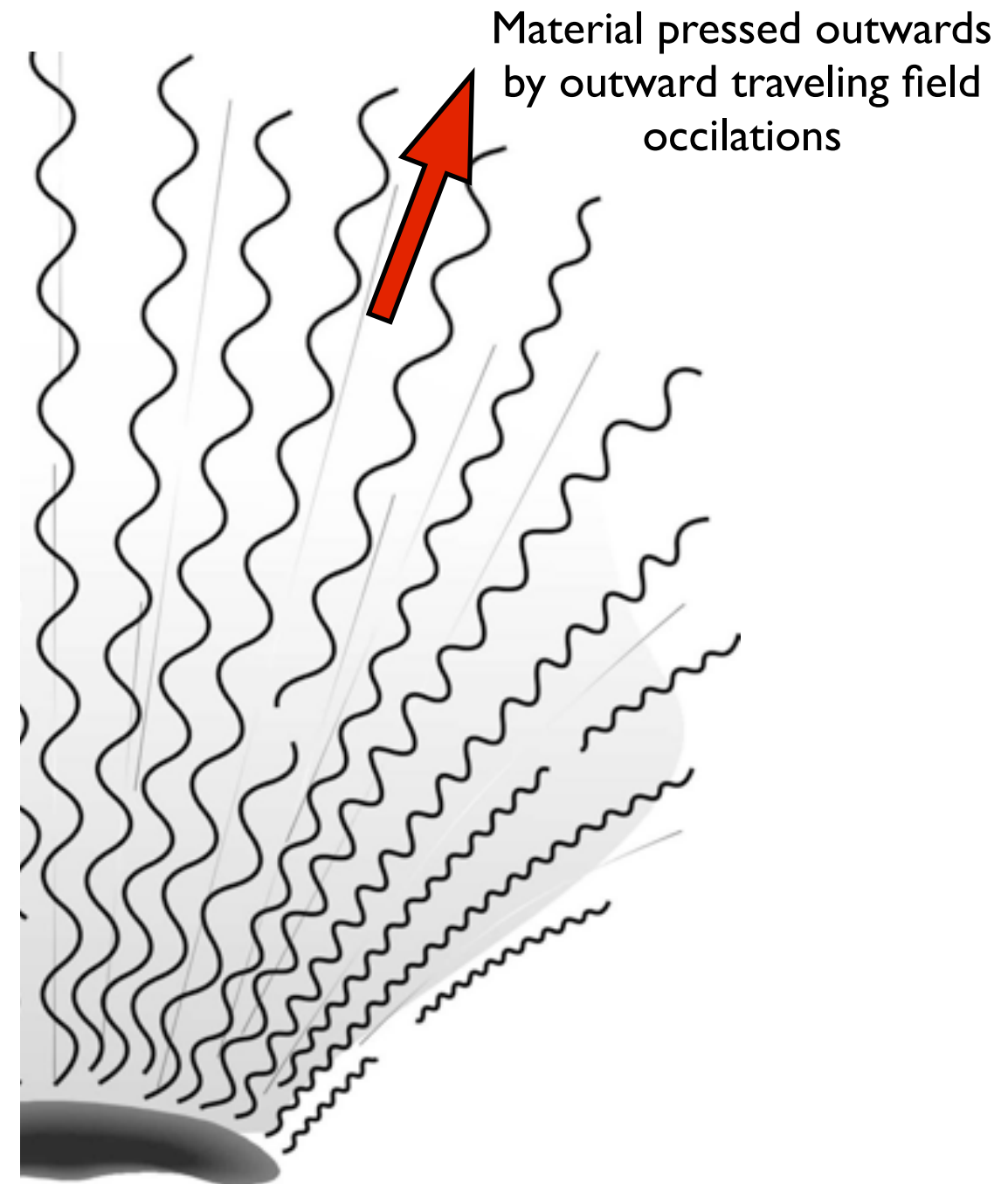
Supergiant winds

- Puzzle of RSG mass loss
 - $dM/dt = 10^{-4}-10^{-6} M_{\odot}/\text{yr}$
- AGB stars:
 - (generally) pulsations + radiation pressure
- RSG problems:
 - small amplitude pulsations (e.g. Smith et al. 1989)
 - dust too far away? (many R_* , e.g. Danchi et al. 1994)
- RSG solutions?
 - Convection? Radiation pressure on line? *Magnetic fields?*



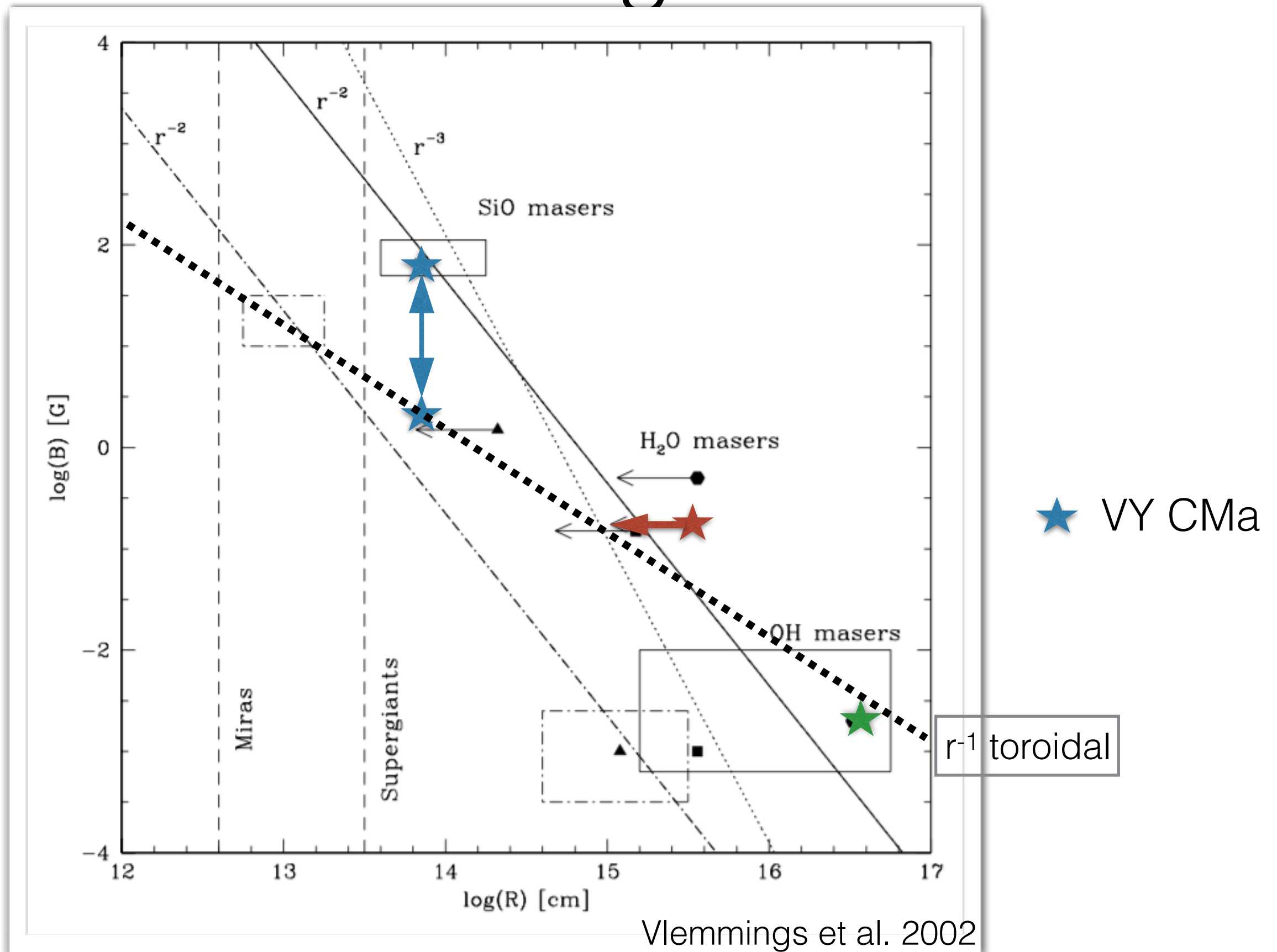
Magnetic Fields I

- *Alfvén-wave driven mass loss:*
Low-frequency oscillations of the magnetic field and coupled ions
 - injecting energy in the wind
- General Alfvén wind reaches too high velocity
 - Cool giant stars would naturally provide dissipation:
 - neutral gas interaction at lower temperatures
 - widening magnetic flux tubes
 - reflected waves
 - mode conversion for non-straight fields
- Potentially needed for supergiants, though hybrid models work for AGBs



e.g. Hartmann & MacGregor 1980, Falceta-Gonçalves et al. 2006,
(Hybrid models) Thirumalai & Heyl 2010

Magnetic fields II

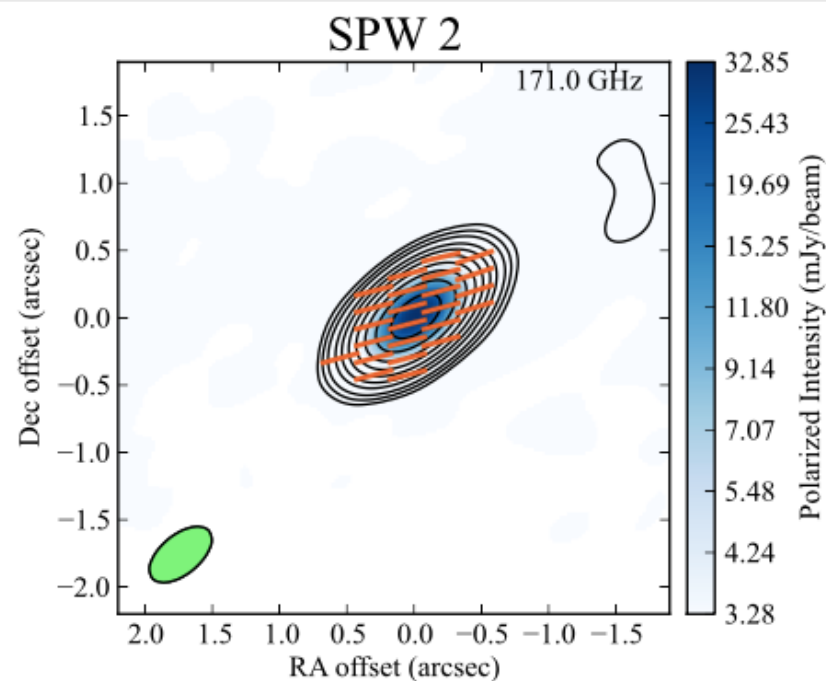
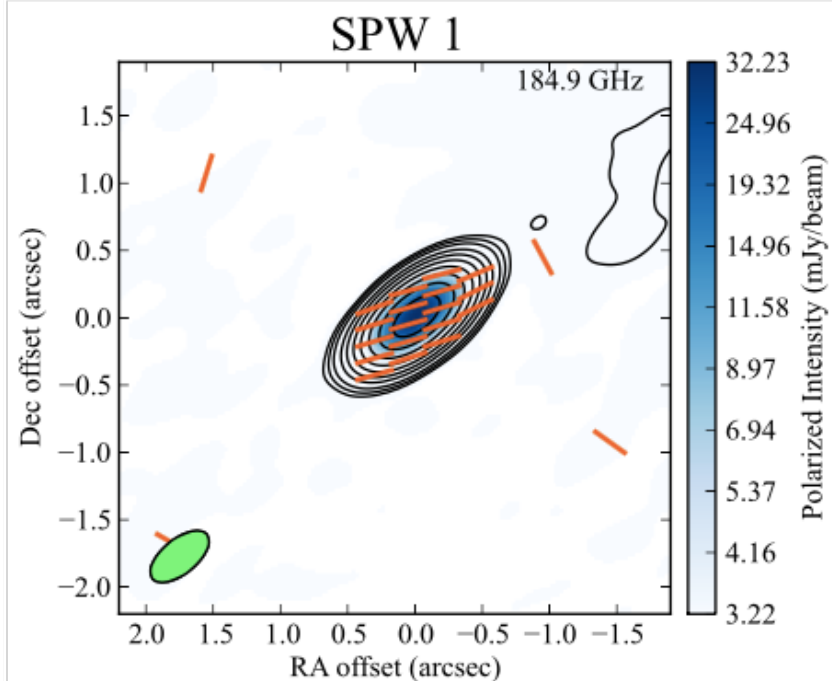


ALMA Band 5 observations

- VY CMa SiO(4-3) and H₂O masers
 - observed Oct 16, 2016 with 15 antennas
 - full polarisation
 - data reduction described in memo (Marti-Vidal et al. 2016)

SPW	Chan 0 (GHz)	Chan. Width (MHz)	Num. Chan	Total BW (GHz)
0	183.1817	0.244	960	0.2344
1	183.9461	1.953	960	1.8750
2	171.9360	-1.953	960	1.8750
3	172.5291	-0.244	480	0.1172
4	173.7360	-0.244	480	0.1172

Table 2: Observed spectral windows

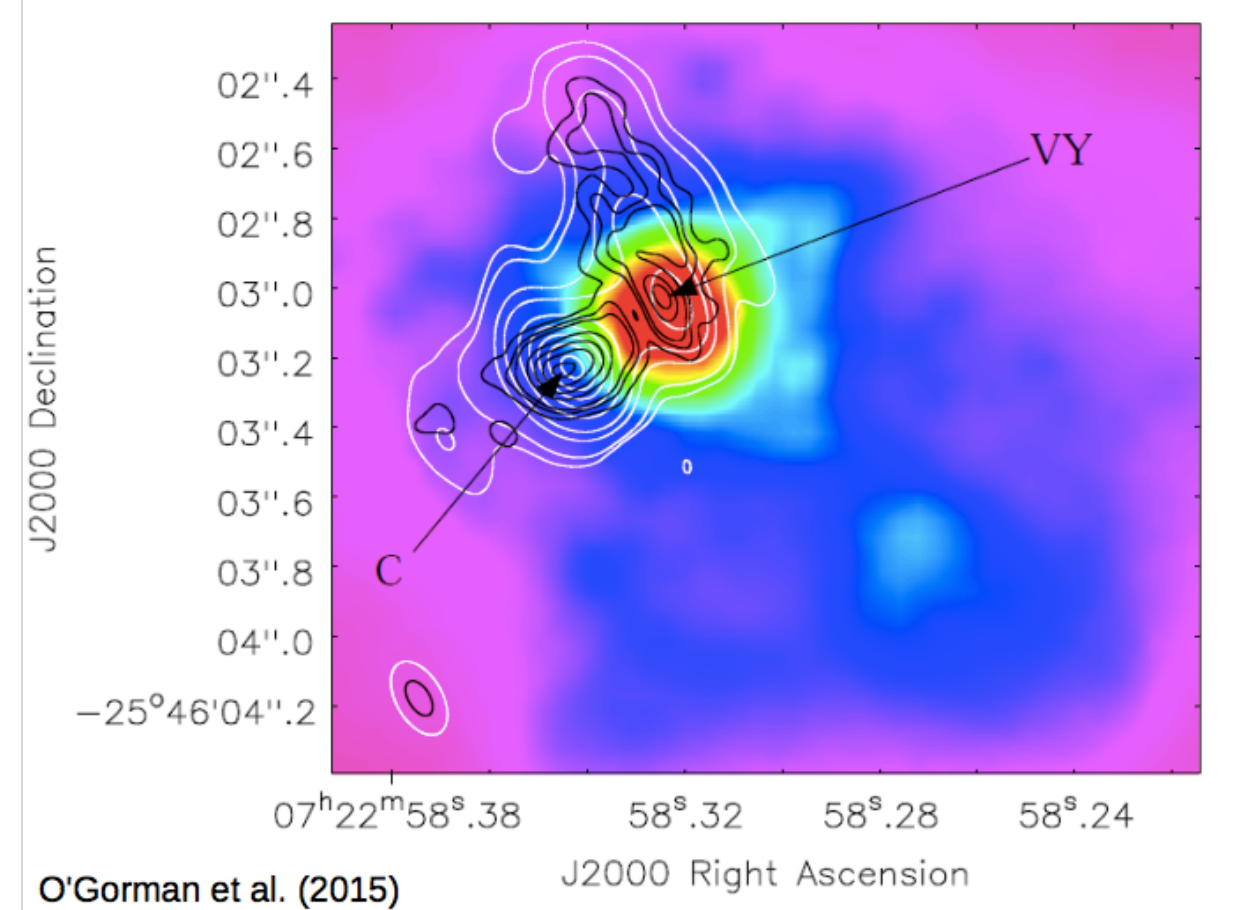
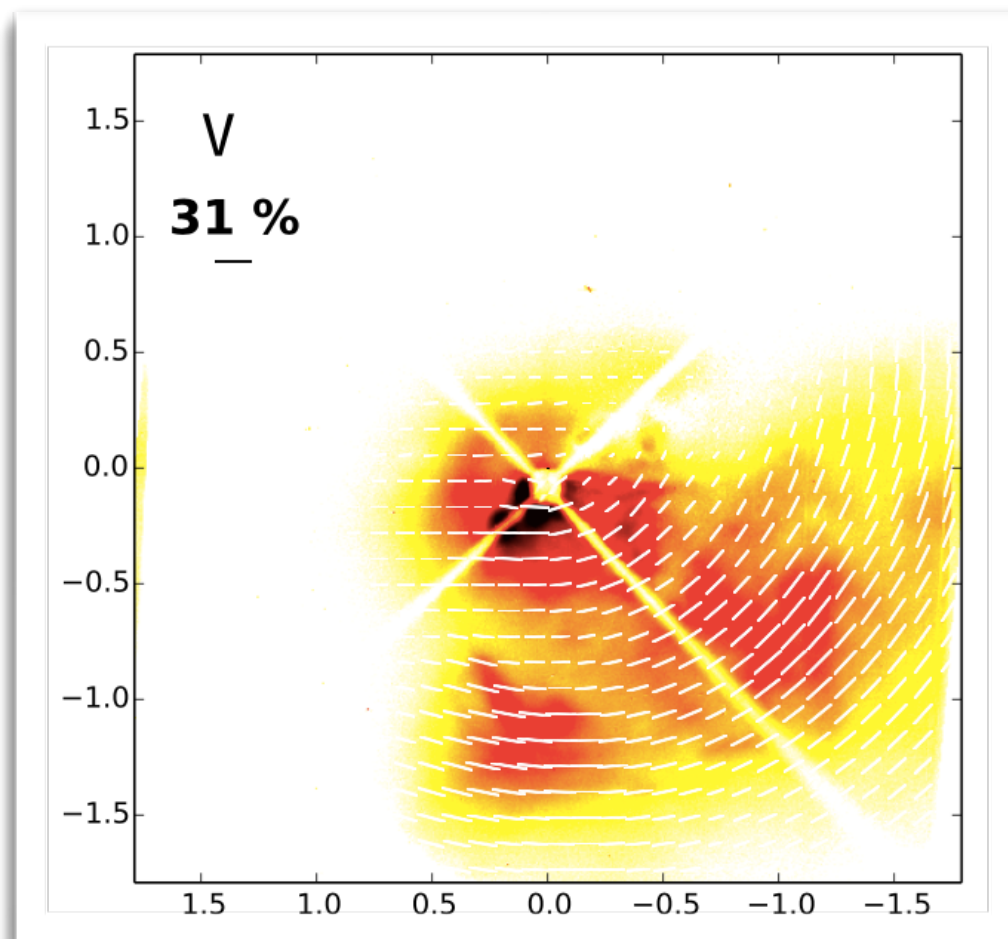
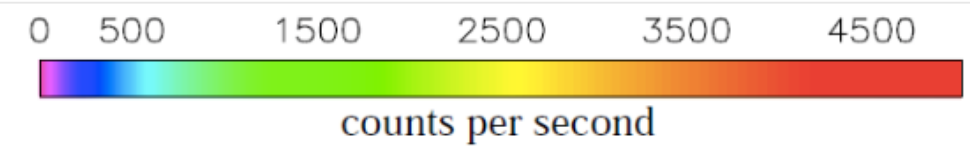


Polarisation calibrator J0522-3627

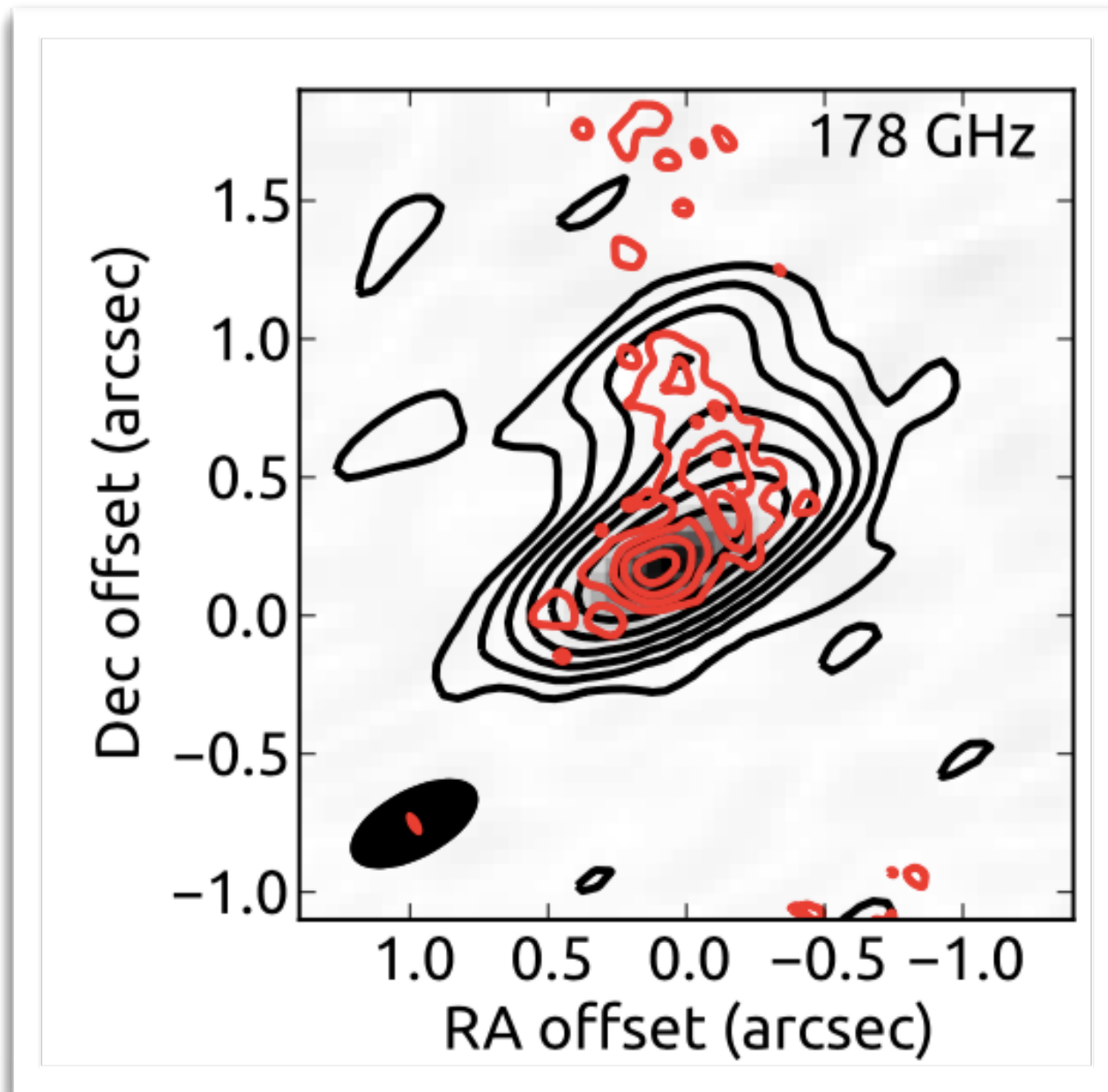
VY CMa

L_* (L_\odot)	$2\text{-}5 \times 10^5$
T_{eff} (K)	2800
Spectral type	M5e Ia
M_* (M_\odot)	25
d (pc)	1200 ± 100
Angular diameter (mas)	11
dM/dt ($M_\odot \text{ yr}^{-1}$)	$3 \times 10^{-3}\text{-}10^{-4}$

ALMA (B7,B9) + Hubble

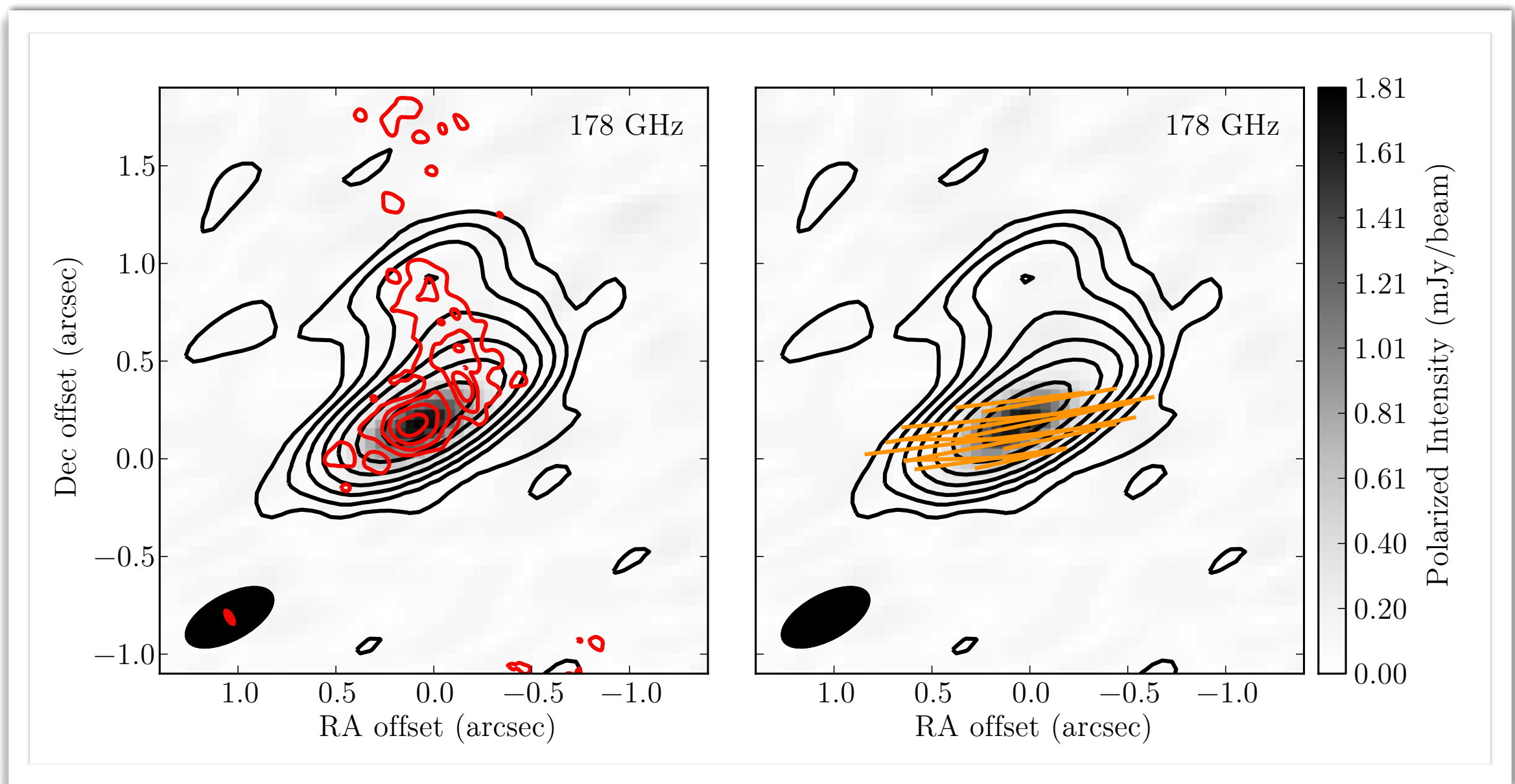


VY CMa B5 continuum



- Still dominated by Clump C
 - spectral index (~ -2) consistent with O’Gorman et al. (2015)
 - still optically thick?
 - VLA detection (O’Gorman et al, in prep.) indicates turnover ~ 150 GHz
 - dust mass 10x higher: $\sim 3 \times 10^{-3} M_{\odot}$!
 - or large grains?

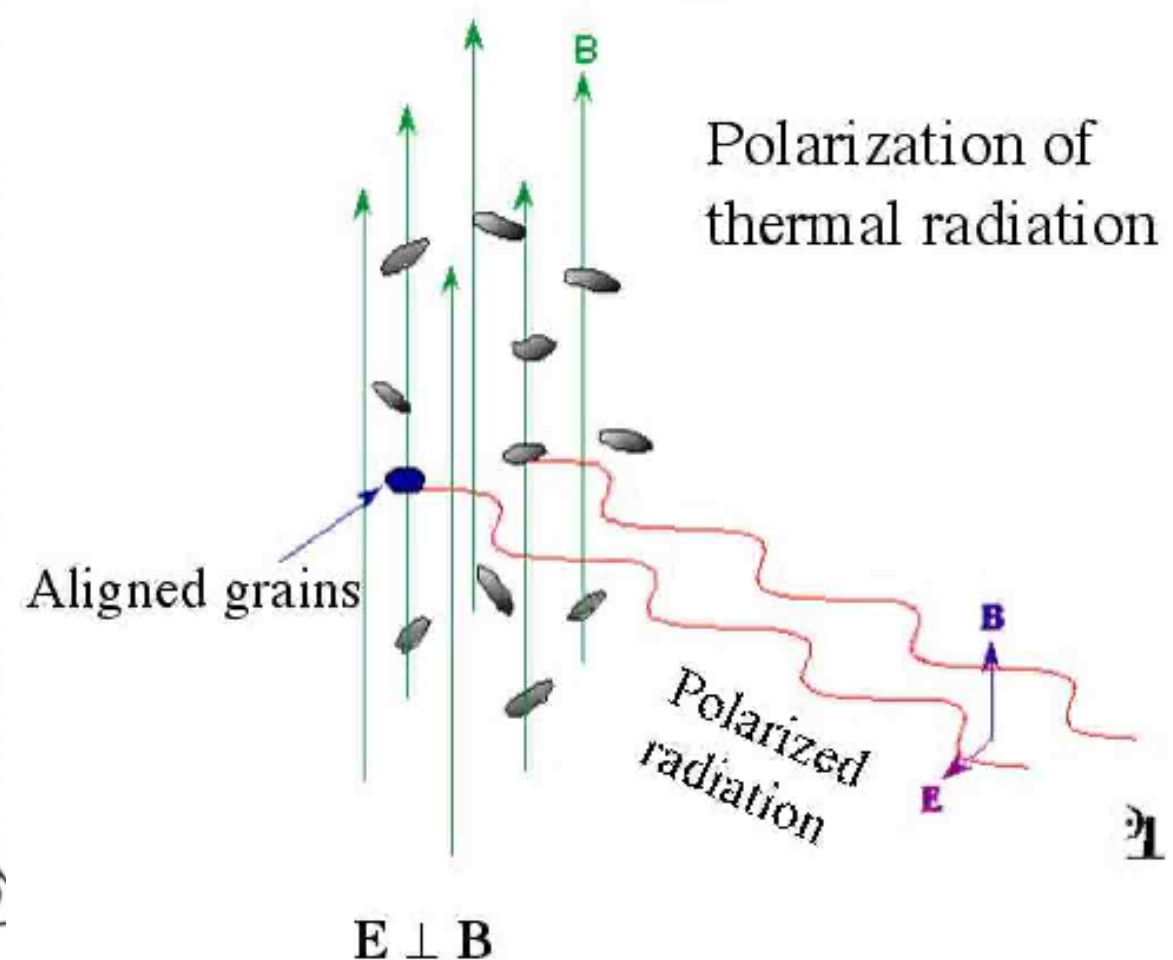
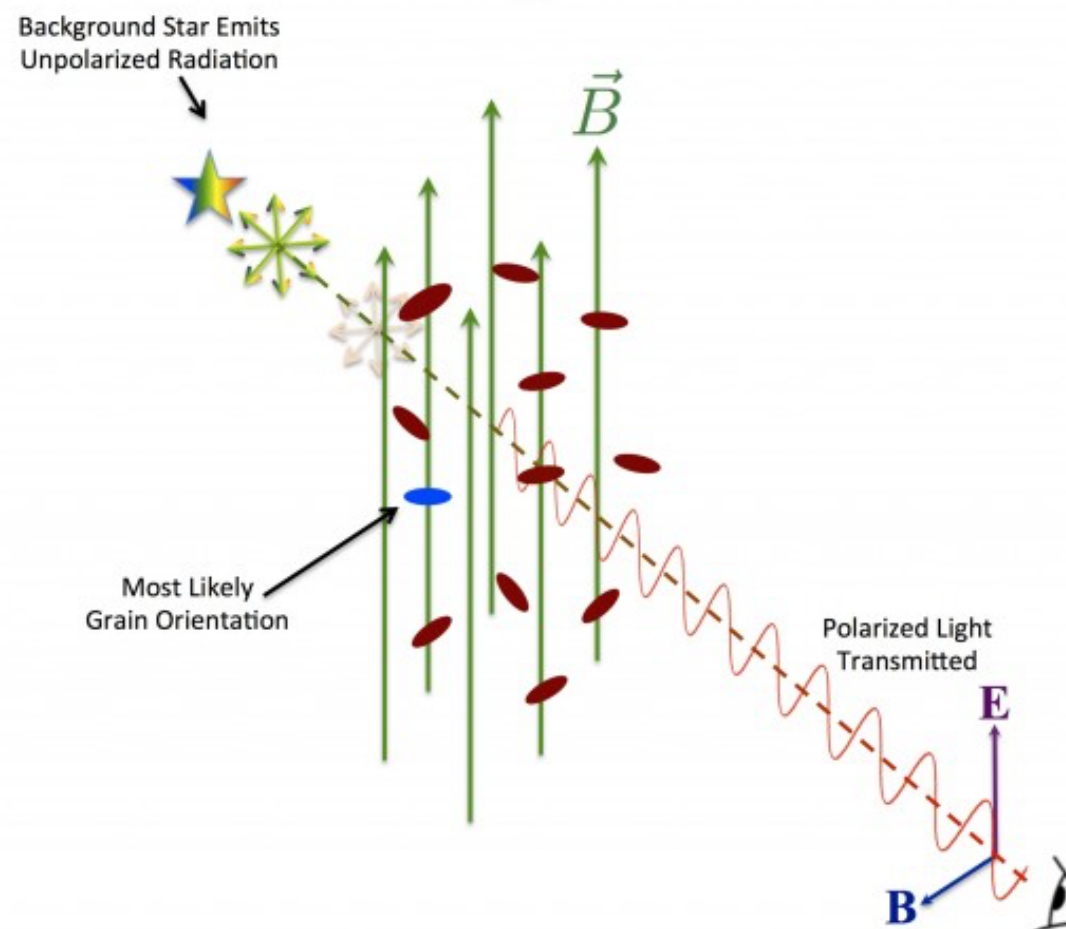
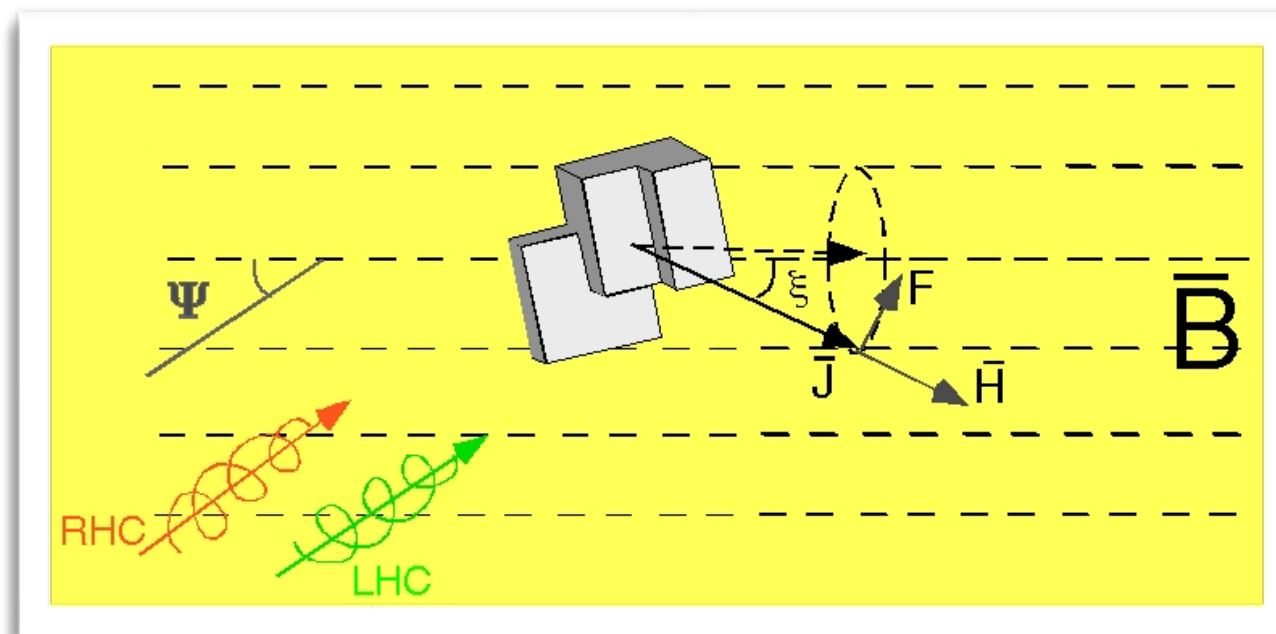
Continuum polarisation



First detection of (sub)mm dust
polarisation around an evolved star

90 degree rotated
(magnetic field) vectors

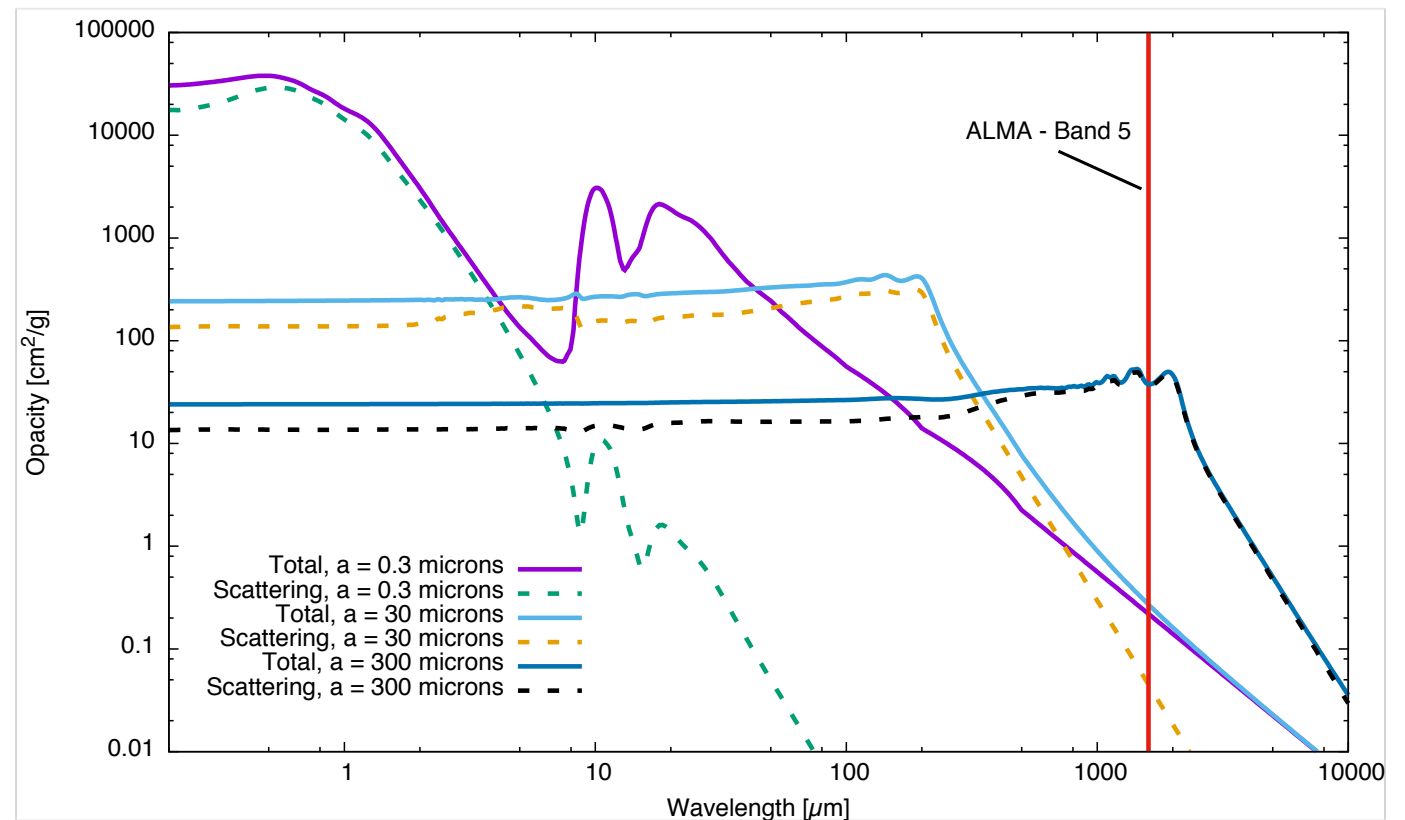
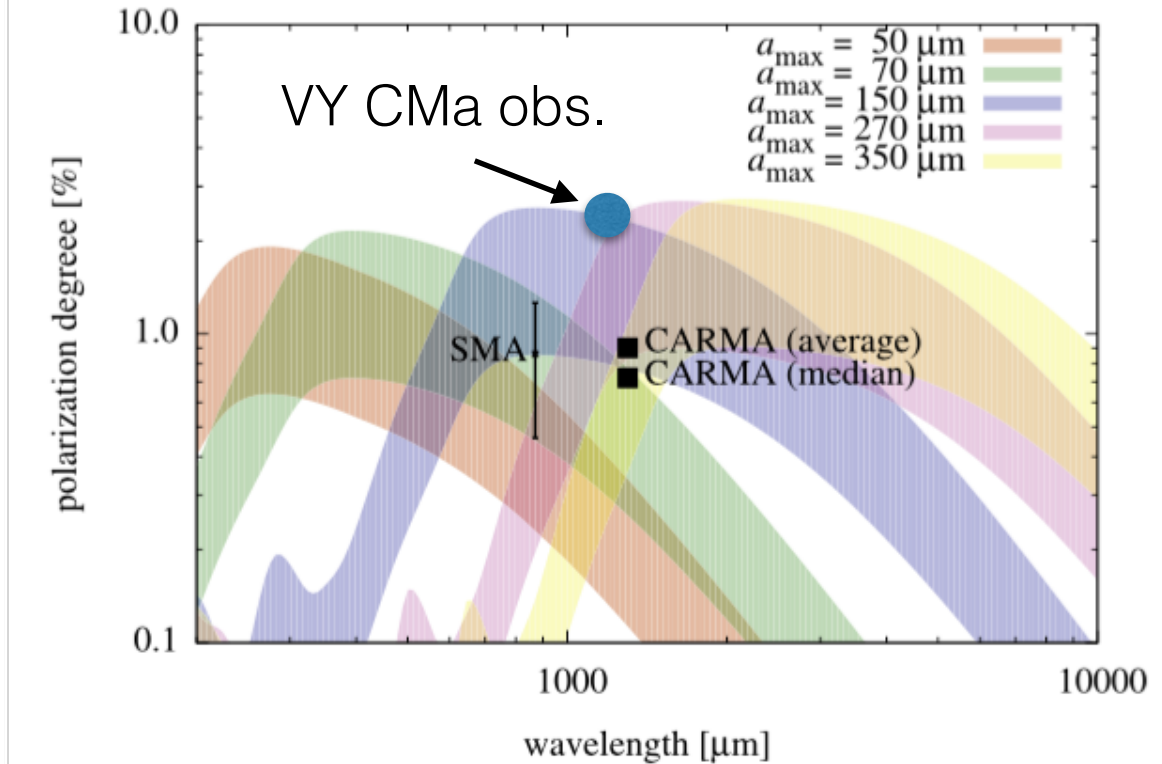
Origins of the dust polarisation: radiative alignment



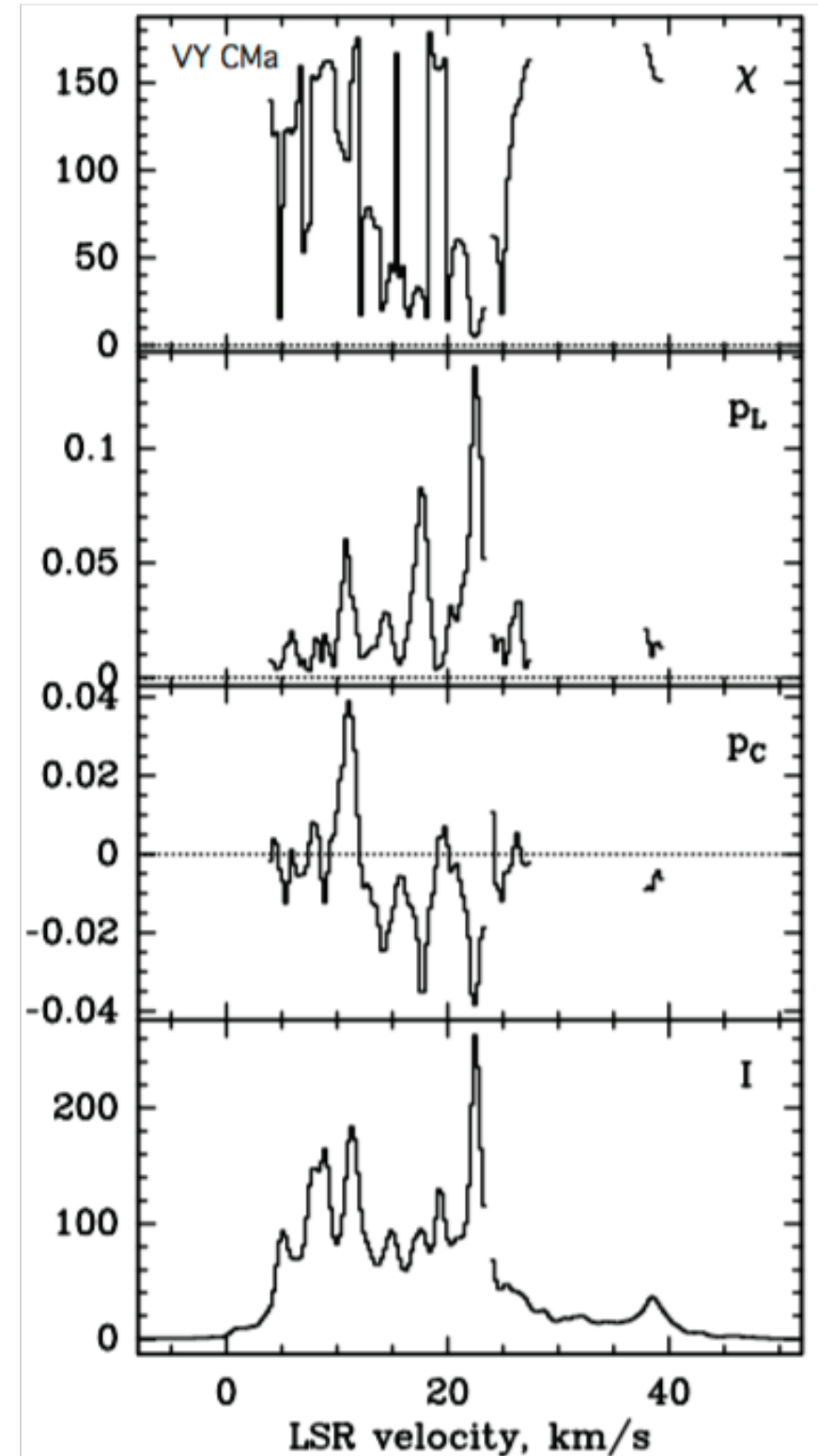
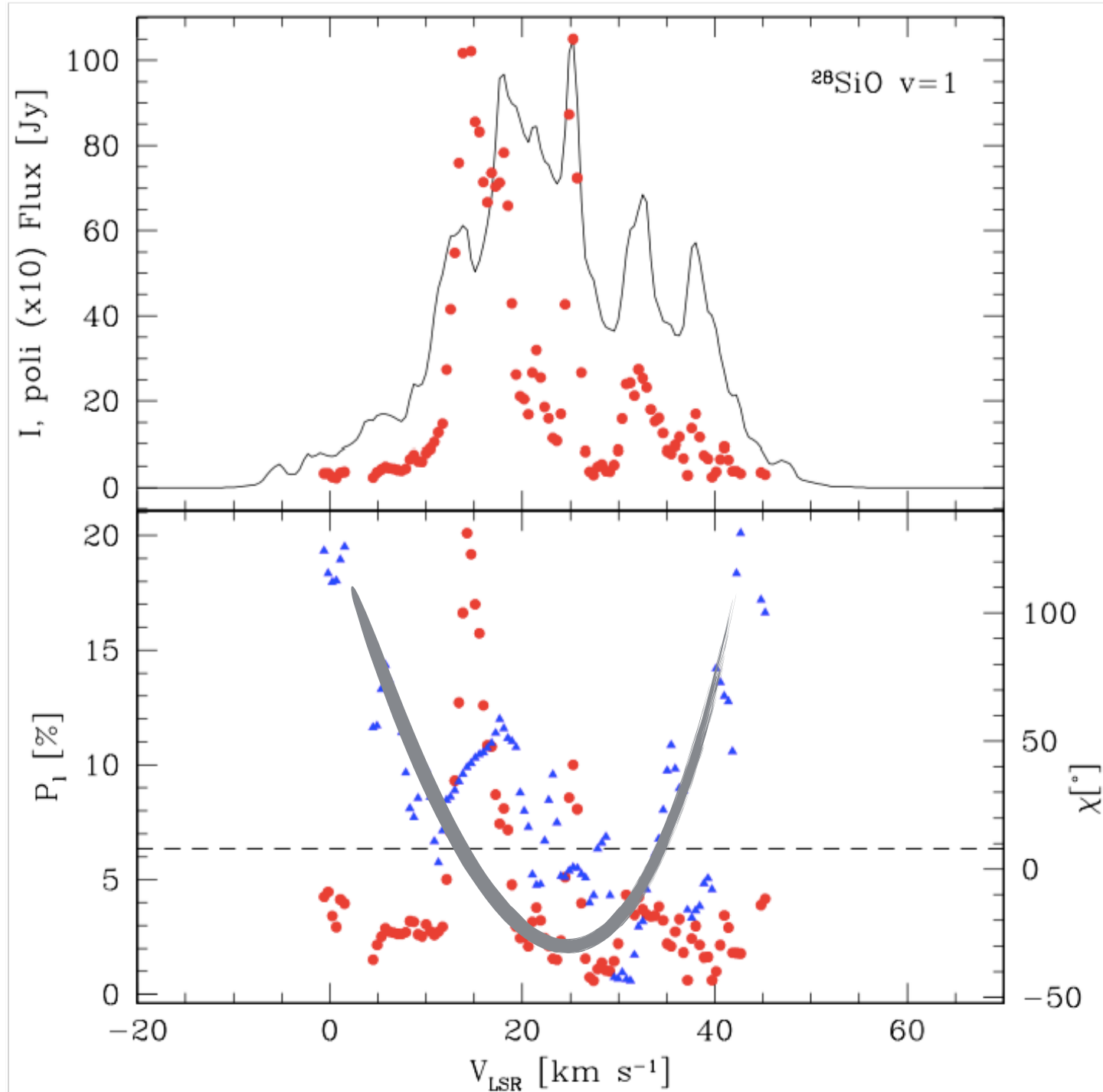
Origins of the dust polarisation

- Scattering (e.g. Kataoka et al. 2016)
 - Needs grains $> 100 \mu\text{m}$
 - Clump C optically thin with $\sim \text{few} \times 10^{-5} M_{\odot}$ very large dust?
 - Requires very complex scattering morphology
- Emission
 - Magnetically aligned dust grains
 - Silicate dust
 - Magnetic field $\sim 0.1\text{-}1$ Gauss (for sufficiently short alignment timescale)?
 - observed in the H_2O masers (~ 0.2 G, Vlemmings et al. 2002)

HL Tau disk model from Kataoka et al.

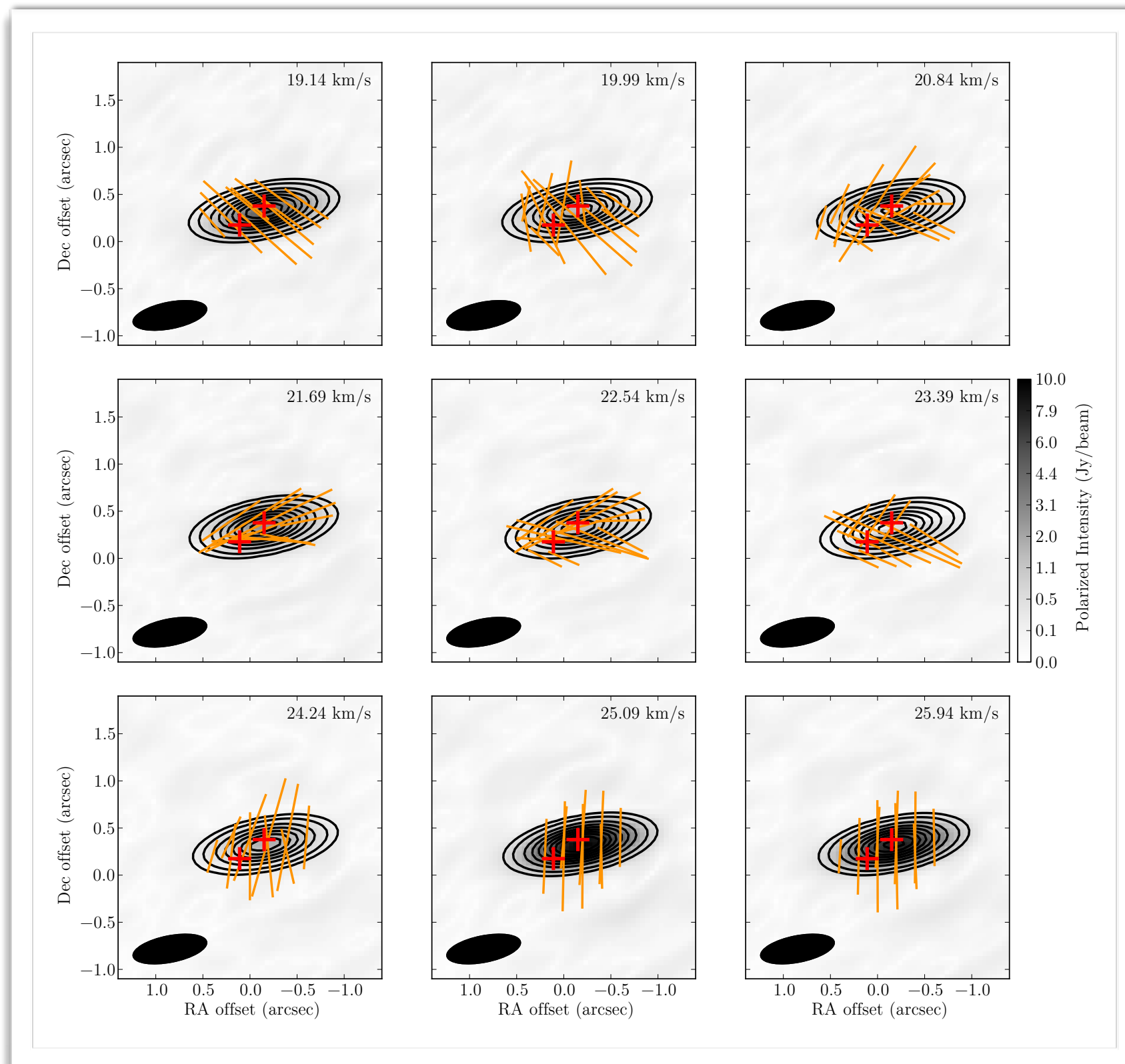


SiO maser polarisation: linear

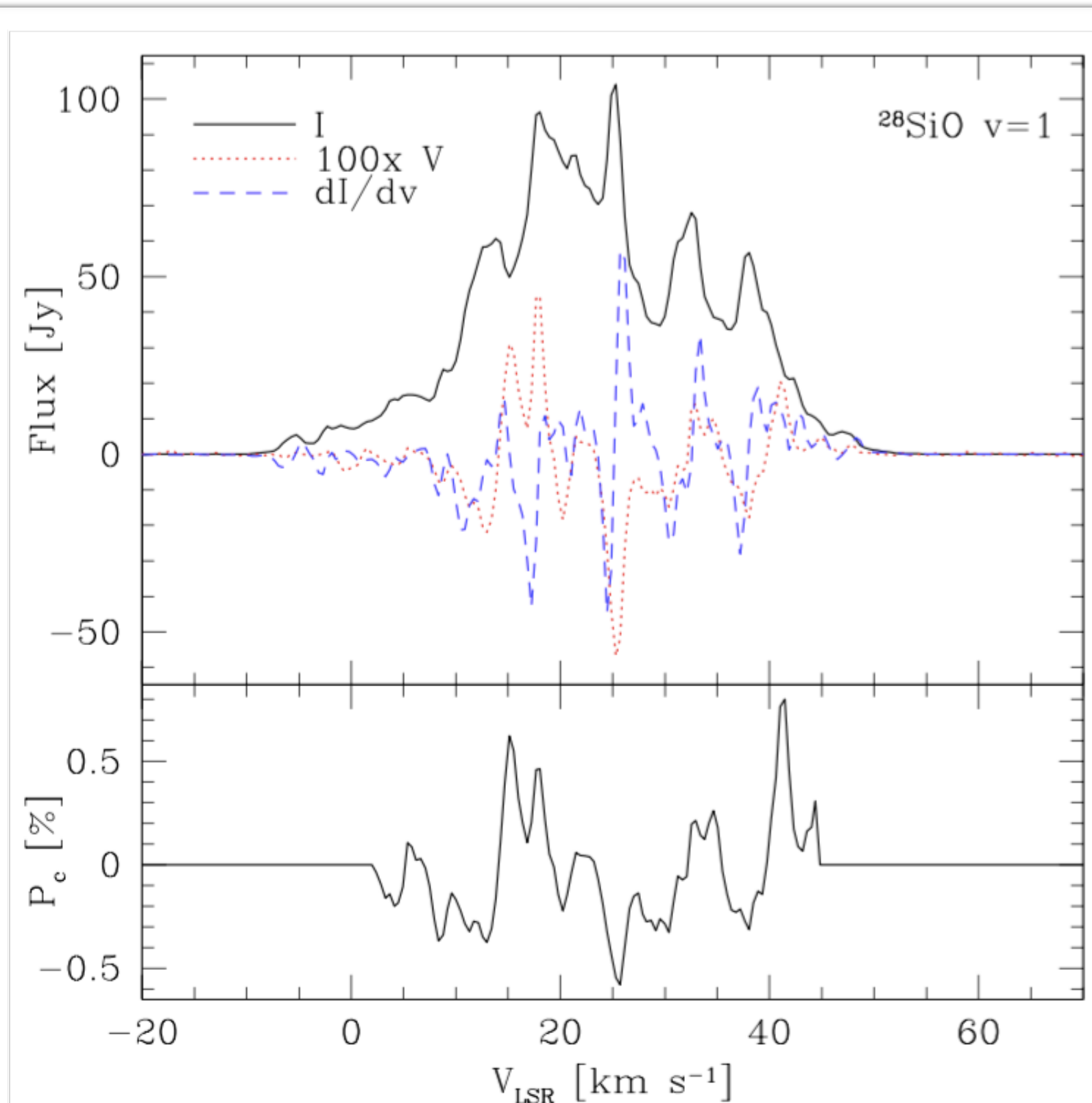


Herpin et al. 2006

SiO maser polarisation: linear

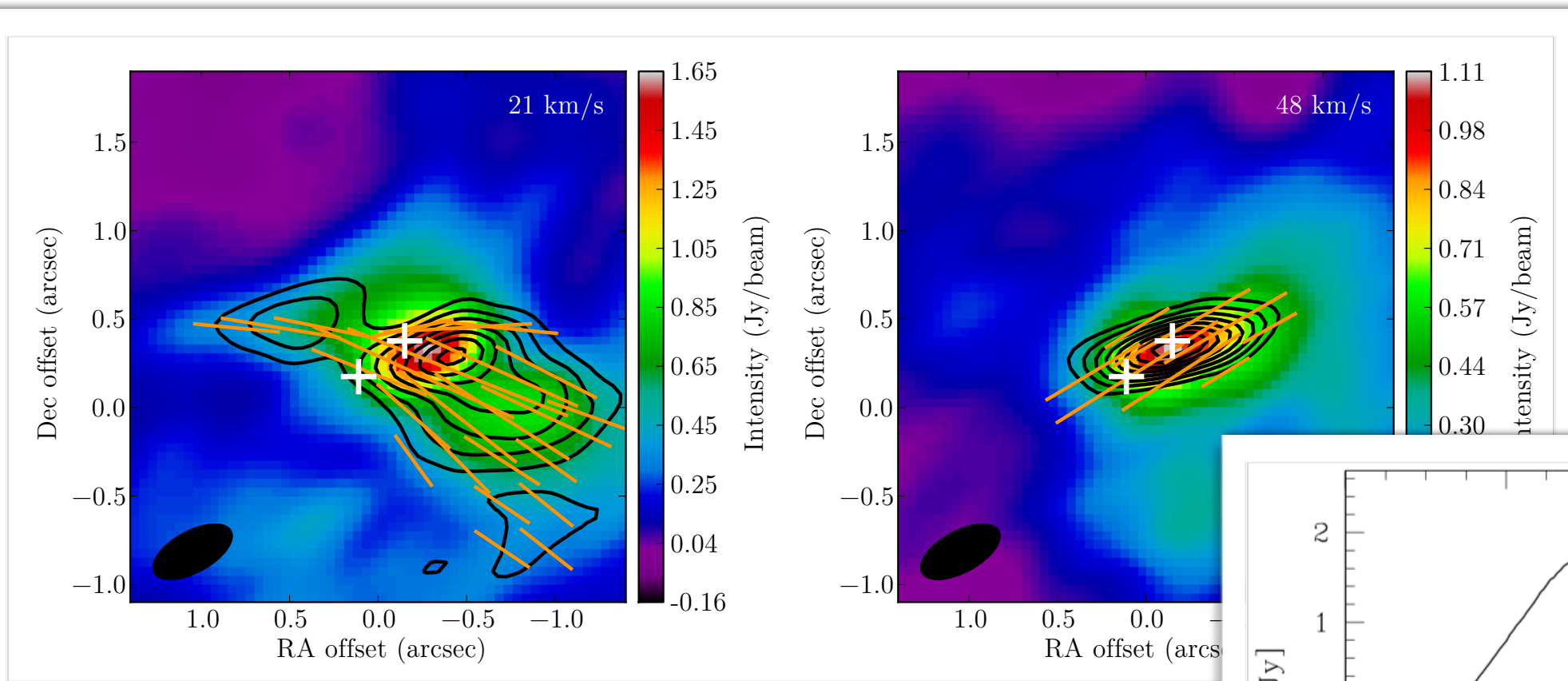


SiO maser polarisation: circular

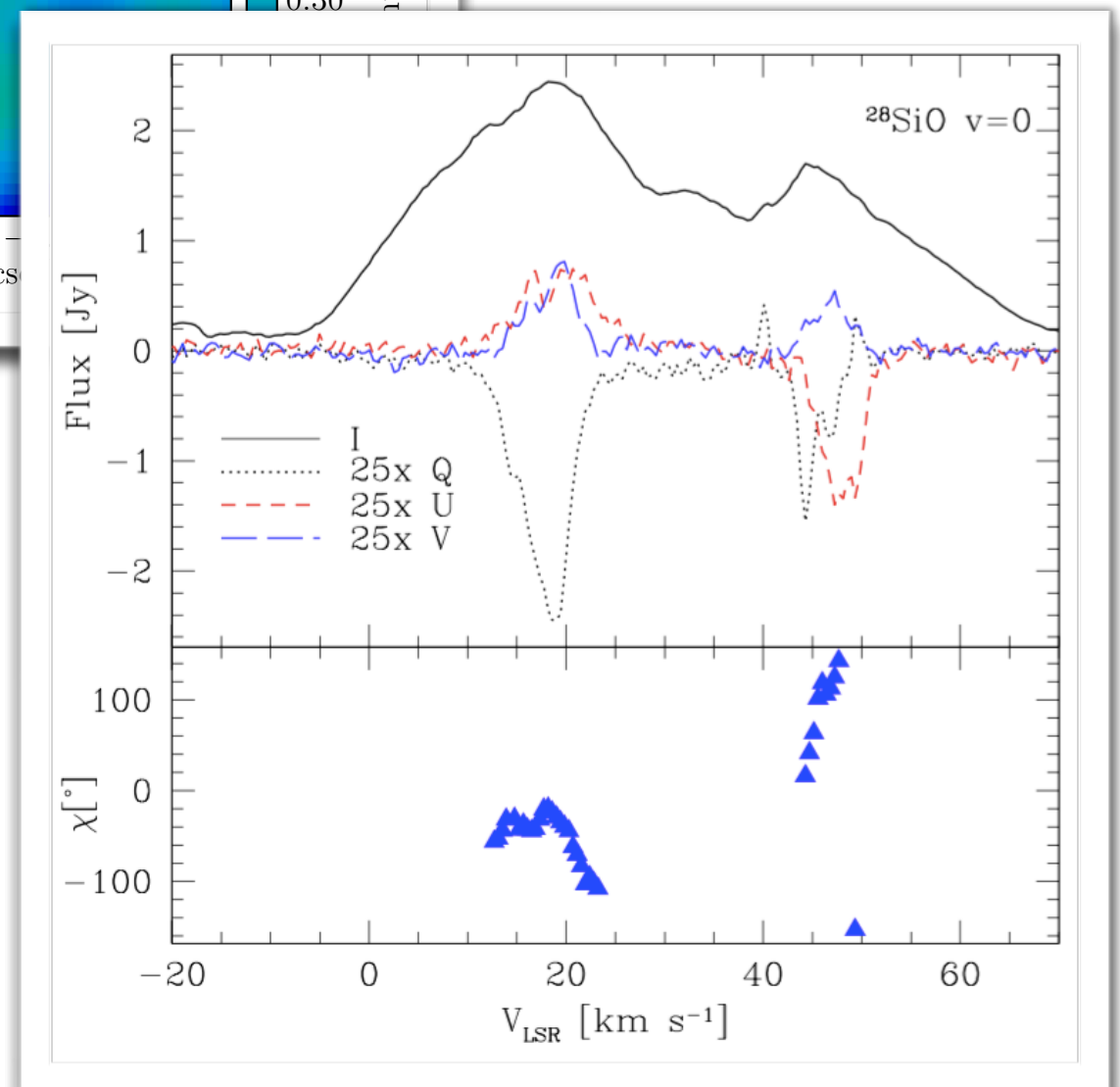


- Zeeman interpretation:
 - $B \cos(\theta) \approx 0.65 P_c$ [G] for 173 GHz SiO maser
 - 0.5-1.0 Gauss
 - consistent with previous SiO and H_2O maser results

Non-maser SiO polarisation



- Goldreich-Kylafis effect
 - magnetic field or radiatively aligned molecules
 - obs. display signature of both
 - likely non-Zeeman circular polarisation



Summary and conclusions

- The first (sub)mm dust polarisation detection around an evolved star
 - scattering unlikely
 - magnetically aligned grains in VY CMa Clump C
 - 0.1-1 G field, non-carbonaceous grains
 - magnetic ejection?
- SiO and thermal line polarisation
 - indicates complex magnetic field
 - 0.5-1 G
- Further evidence of importance of magnetic field for RSG winds
- Highlights the power of ALMA for similar studies of (maybe slightly less complex) evolved stars

