

ESO Garching 1-3 February 2017

EVOLVED STARS

WITH BAND 5

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CHALMERS



Evolved stars with band 5 — outline

Evolved stars

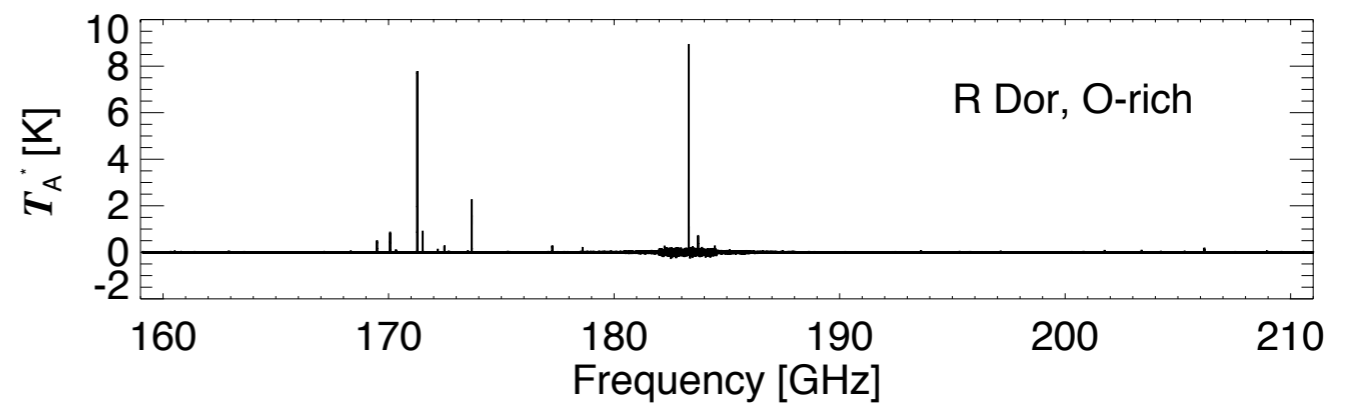
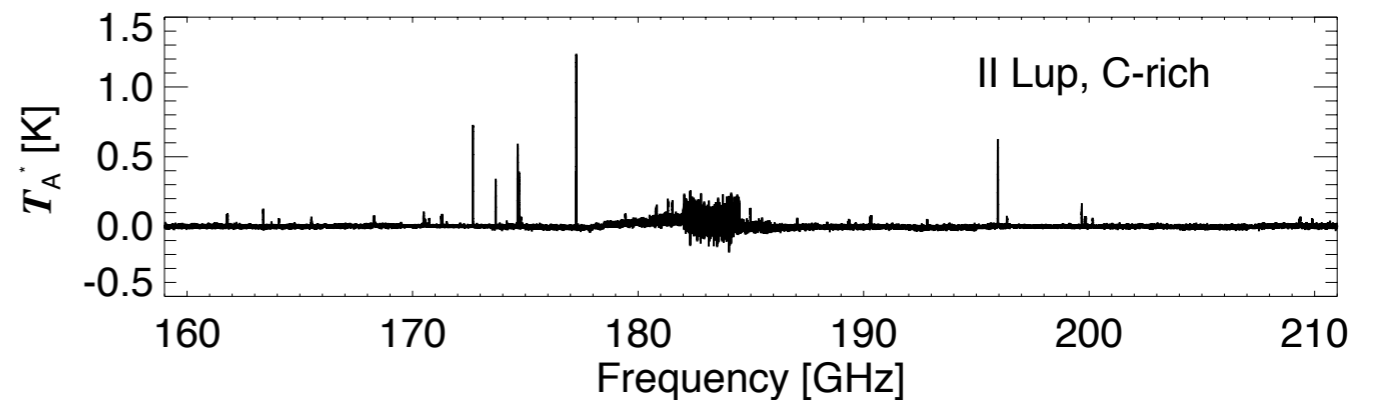
- which?
- what?

... with SEPIA/band 5

- spectral lines
- spectral surveys
- line polarisation

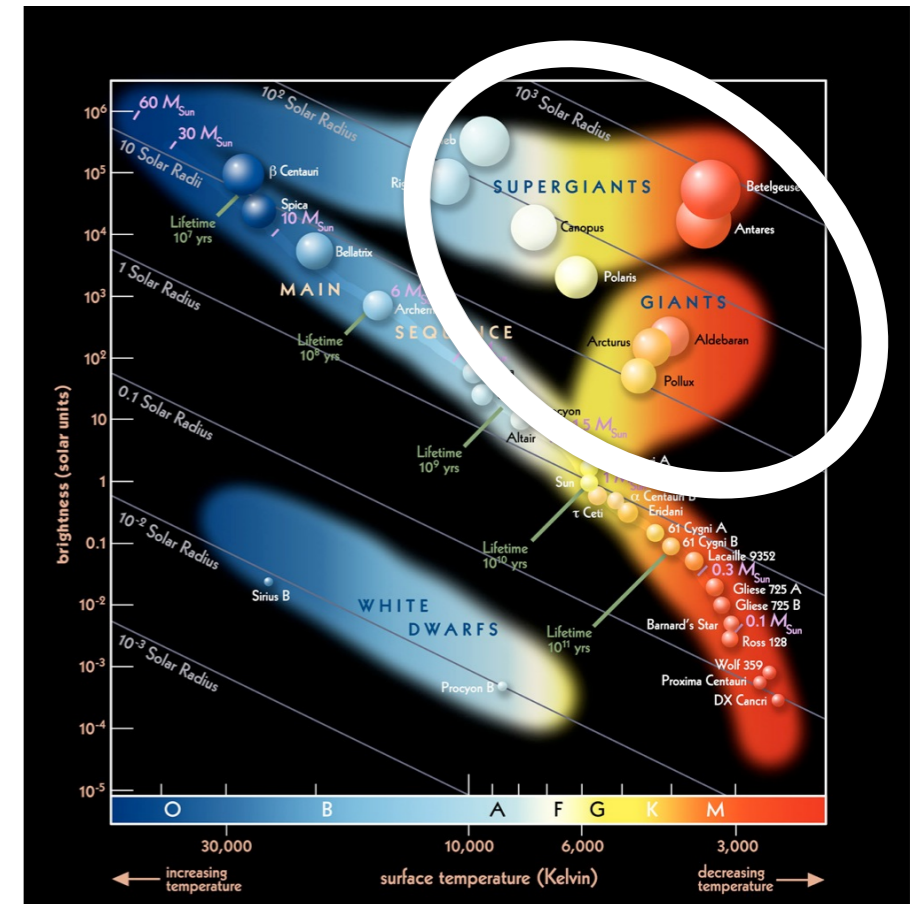
... with ALMA/band 5

- size scales
- dust polarisation



Evolved stars at long wavelengths

- Low-/intermediate mass
 - Red giant stars
 - Asymptotic giant branch (AGB) stars
 - Post-AGB stars
 - Planetary nebulae (PNe)
- High mass
 - Red supergiant stars
 - Yellow hypergiant stars
 - Wolf Rayet stars
 - SN remnants



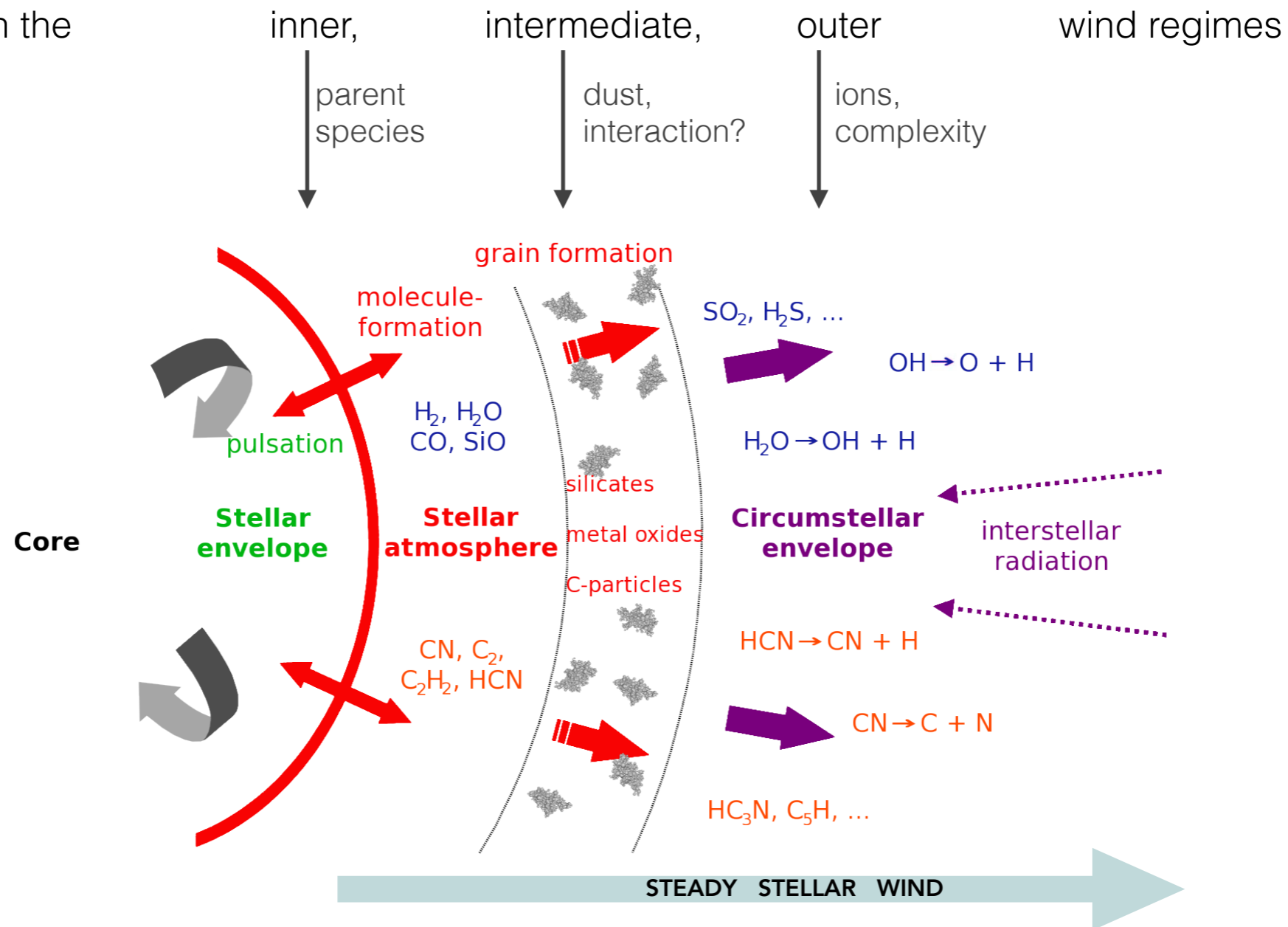
- Gas
 - **enrichment** in e.g. *s*-process/*r*-process elements → chemical evolution of galaxies
 - CO, HCN, C, SiO, H₂O
carbon chains, ions, metals, isotopes
- Dust
 - key role in the **formation of dust**

Evolved stars at long wavelengths

Winds

AGB / RSG circumstellar envelope (also YHG?)

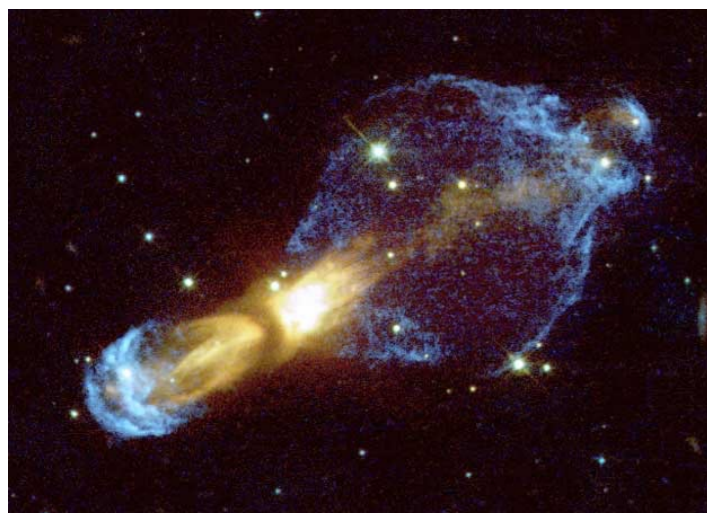
- dust budget
- CO [not band 5]
 - mass-loss rate
 - $T(r)$
 - $\rho(r)$
- chemistry in the



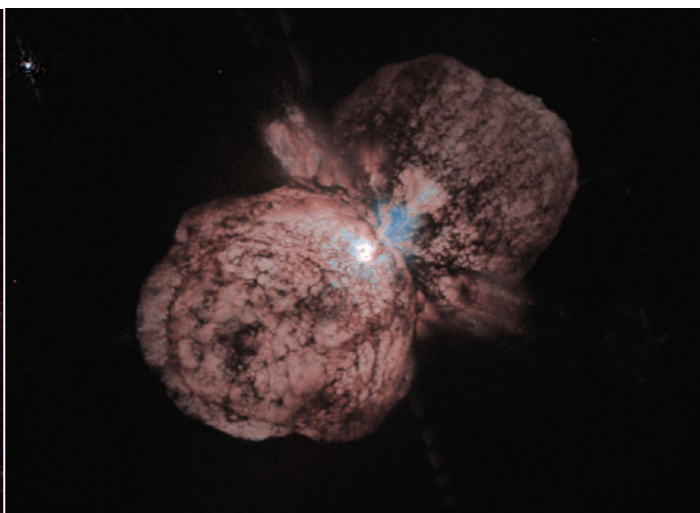
Evolved stars at long wavelengths

Winds

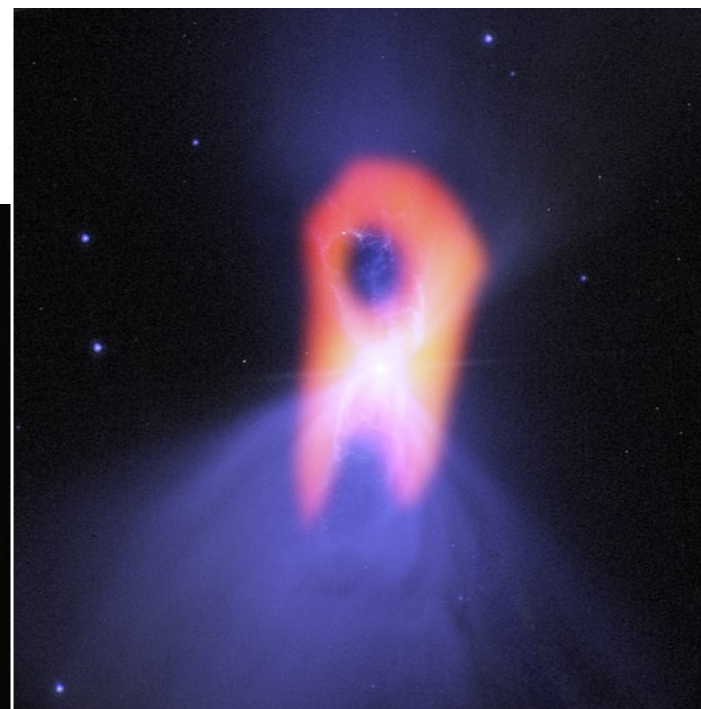
- Post-AGB/PNe circumstellar environment
 - dust budget
 - gas chemistry
 - deviations from spherical symmetry
 - binarity
 - AGB stage: spirals (R Scl, LL Peg, ...), bubbles (Mira), ...
 - post-common envelope: jets (HD101584), ...
 - magnetic fields
- SN remnant
 - dust formation/destruction
 - gas chemistry (—> [talk I. De Looze](#))



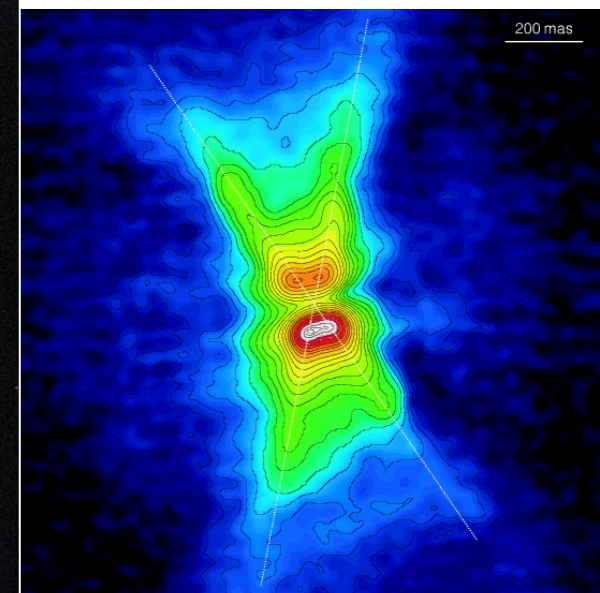
OH 231.8 +4.2 [AGB?], HST



η Carinae, HST



Boomerang Nebula, HST + ALMA



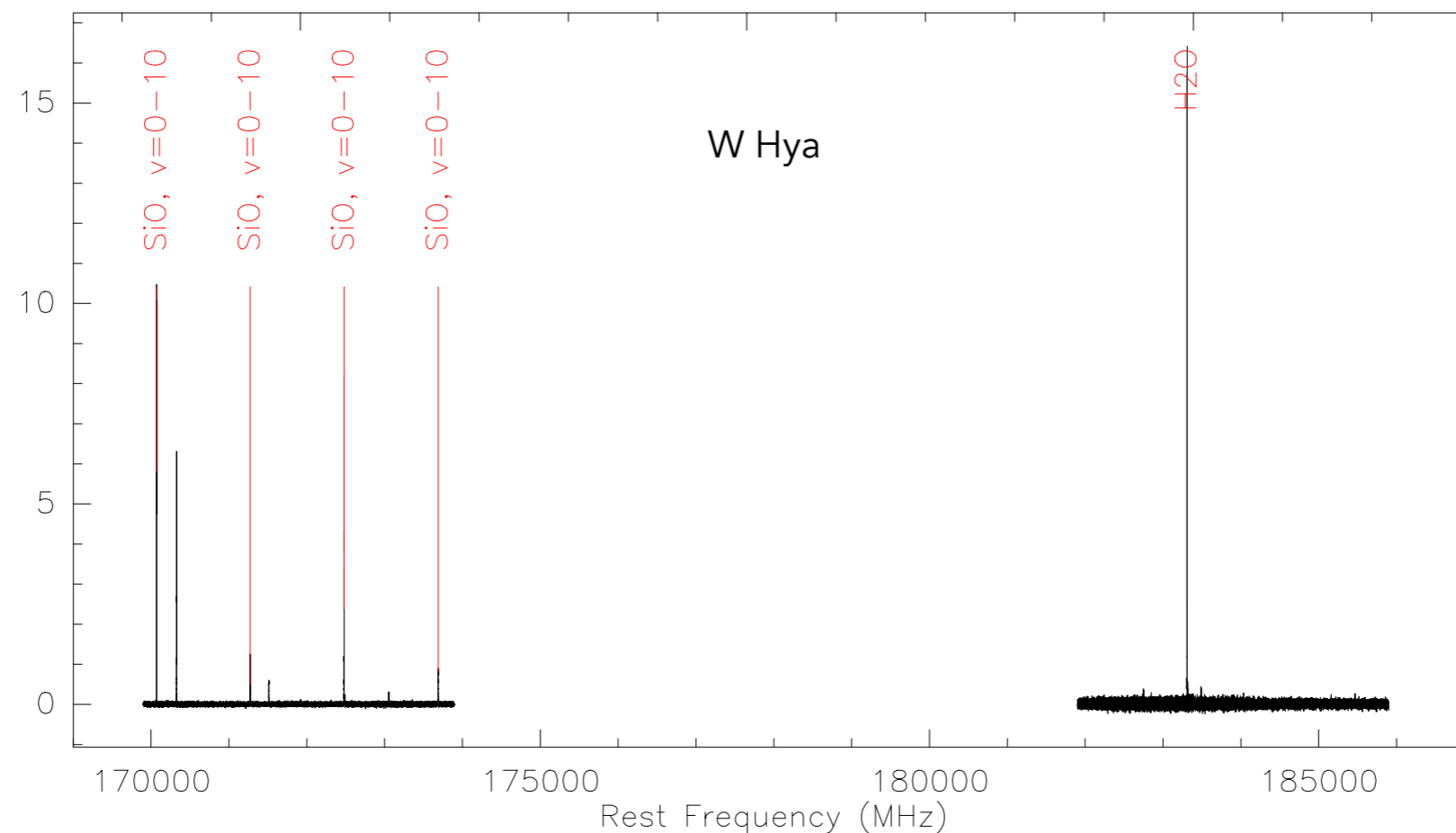
Red Rectangle, Keck

Evolved stars with SEPIA/band 5

Lines

- H₂O maser at 183.3 GHz
—> *talks E. Humphreys, A. Richards*
- SiO ($J=4-3$)
 - multiple v states
 - multiple isotopologues
 - maser in $v > 0$
—> *talk E. Humphreys*

>> simultaneous observations of H₂O and SiO masers!!

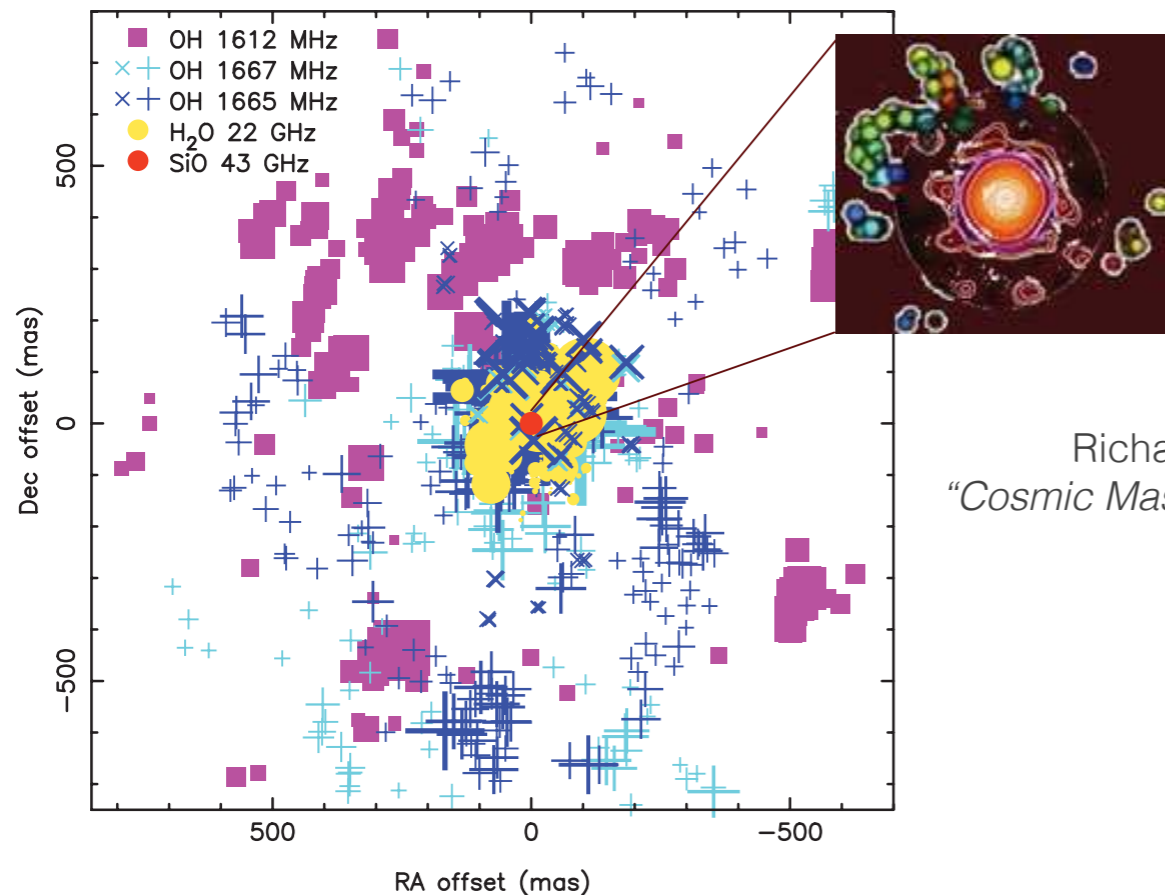


Evolved stars with SEPIA/band 5

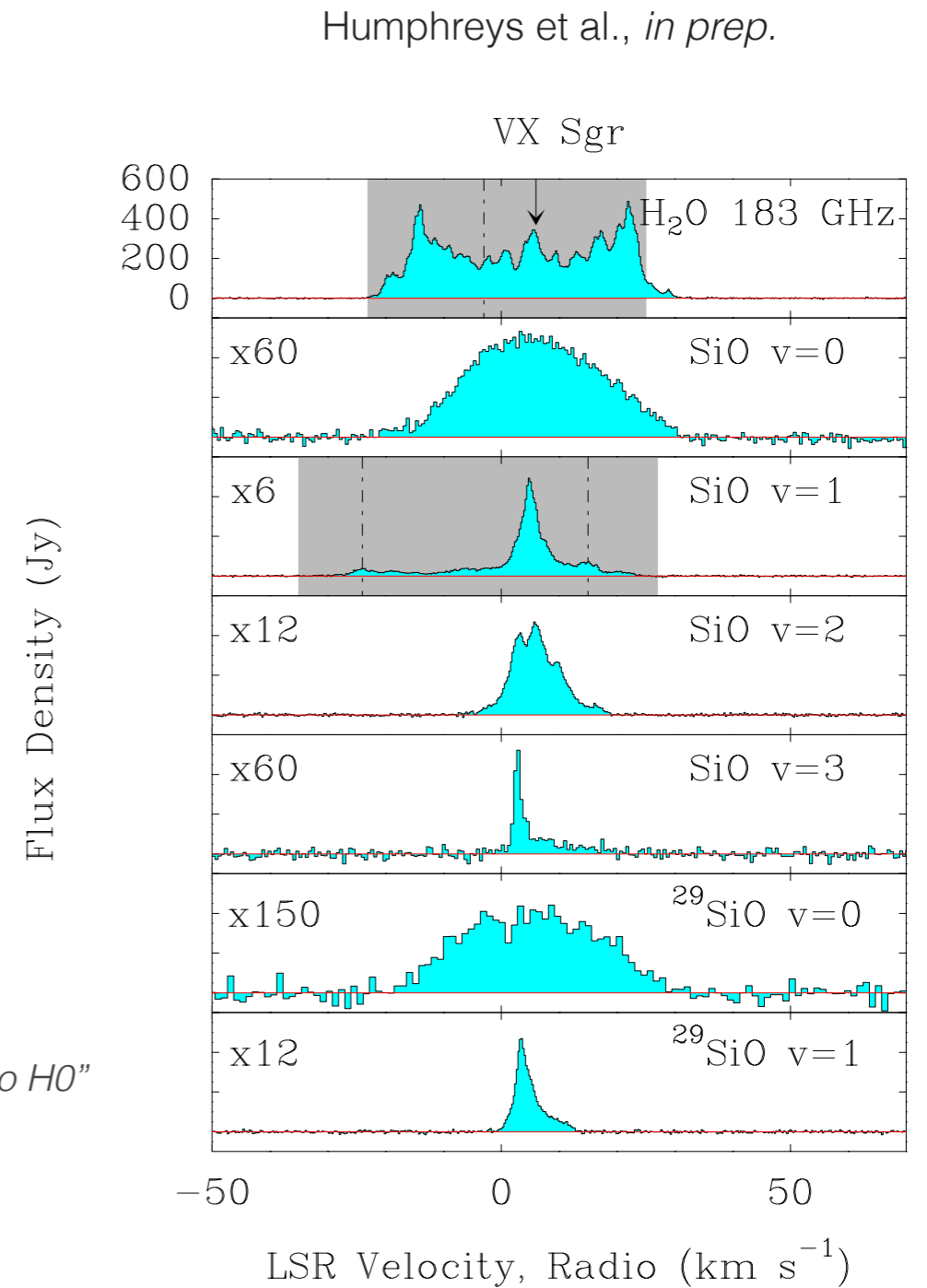
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—> *talk E. Humphreys*

➤ simultaneous observations of H₂O and SiO masers!!



VX Sgr
Richards et al., 2012
"Cosmic Masers — from OH to H0"



Evolved stars with SEPIA/band 5

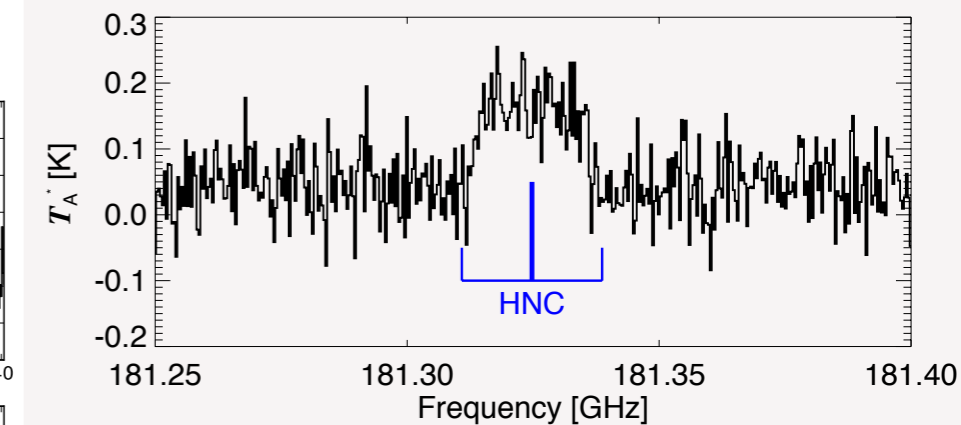
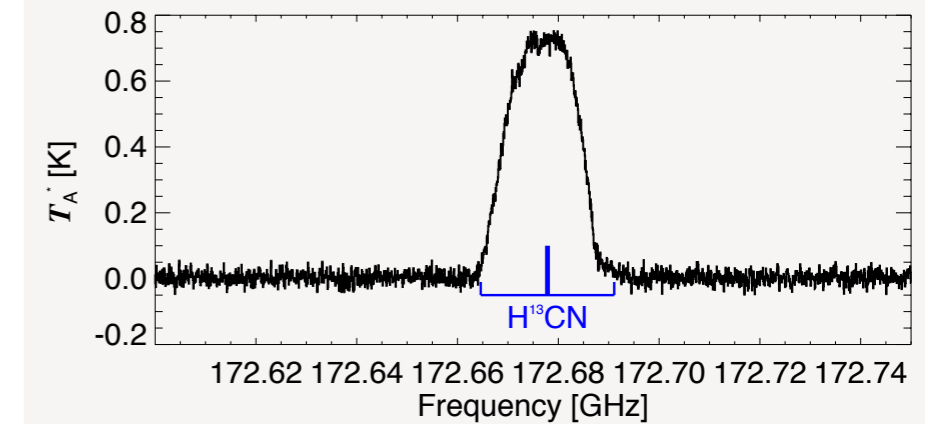
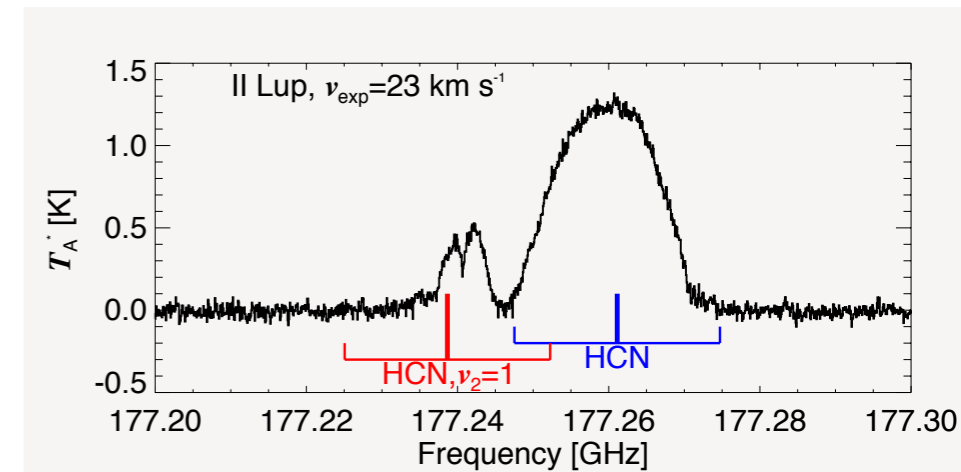
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- SiO ($J=4-3$)
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 - maser in $v > 0$
—> *talk E. Humphreys*
- >> **simultaneous observations of H₂O and SiO masers!!**
 - traced throughout outflow
 - physical conditions
 - dynamics
 - magnetic field: strength and morphology
 - ALMA needed for imaging at high angular resolution
- Oxygen isotopes: $^{17}\text{O}/^{18}\text{O}$ gives **initial mass** for AGB stars (Karakas & Lugaro, 2016; Cristallo et al., 2015)
 - R Dor: 1.3 - 1.4 M_{sun} (De Beck et al., *in prep.*; $J = 4-3, \dots, 8-7$)

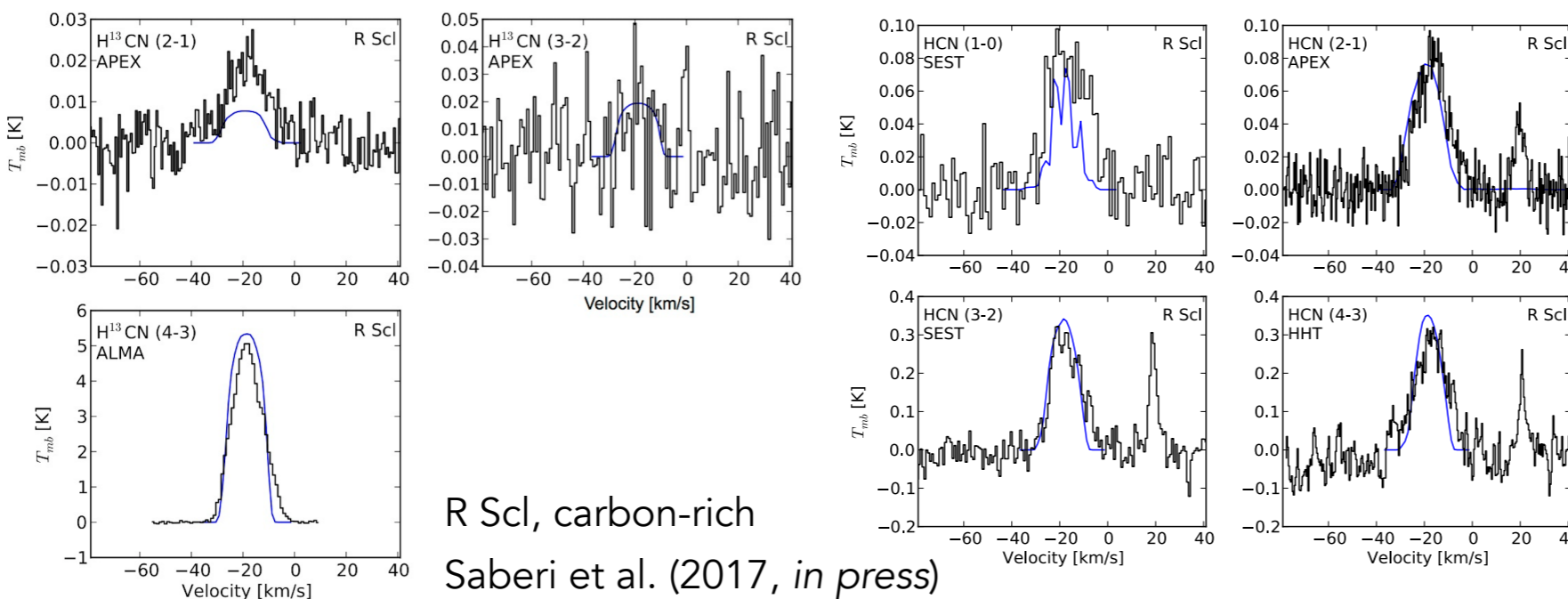
Evolved stars with SEPIA/band 5

Lines

- HCN (J=2-1; $v=0,1$)
 - HCN around all chemical type AGB stars
brightest for C-type
→ *talk K. Menten*
- individual stars:
adding low-excitation constraints for RT models, e.g. R Scl
(Saber et al., 2017, A&A, *in press*)
- CN/HCN constrains stellar UV field strength → age of PNe
- HNC at 181.3 GHz



II Lup, high mass-loss rate, carbon-rich
De Beck et al. (*in prep.*)



Evolved stars with SEPIA/band 5

Lines

- ions, e.g. HCO⁺
- carbon chains, e.g. HC₃N, C₂H
- CS

H₂S → *talk T. Danilovich*

> parent species, i.e. close to AGB star

> high mass-loss rate ($>10^{-6} M_{\text{sun}}/\text{yr}$)

> 168.8 GHz line best tracer

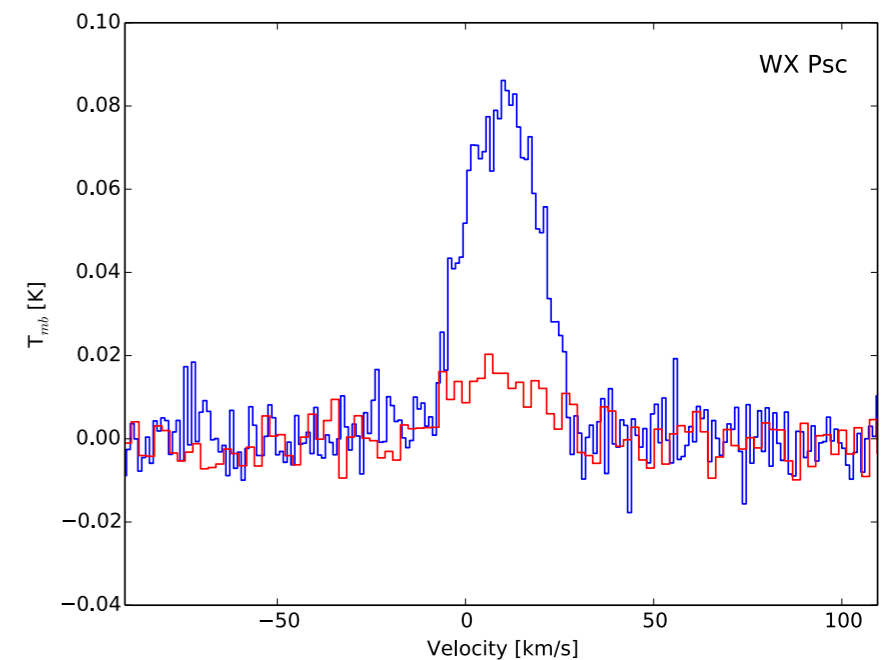
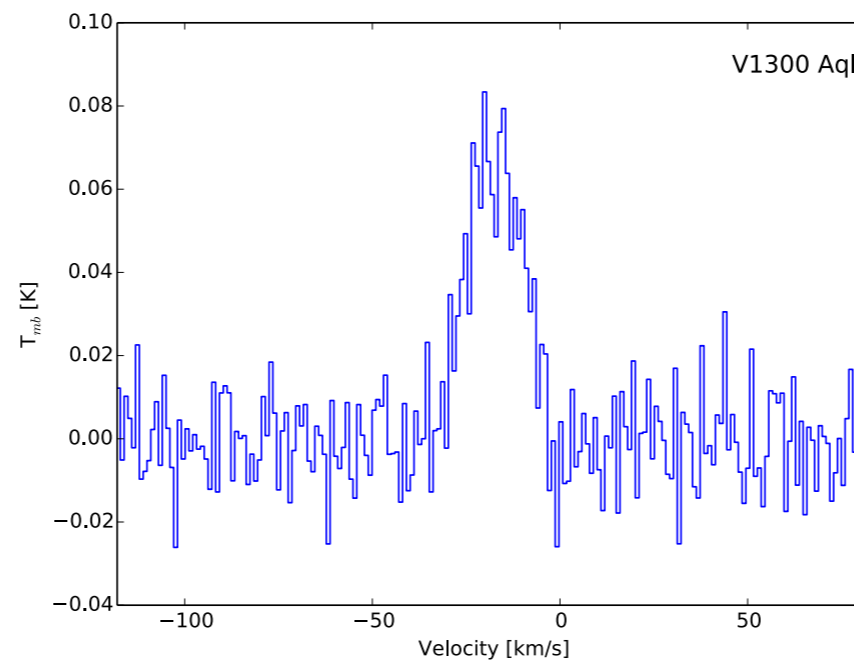
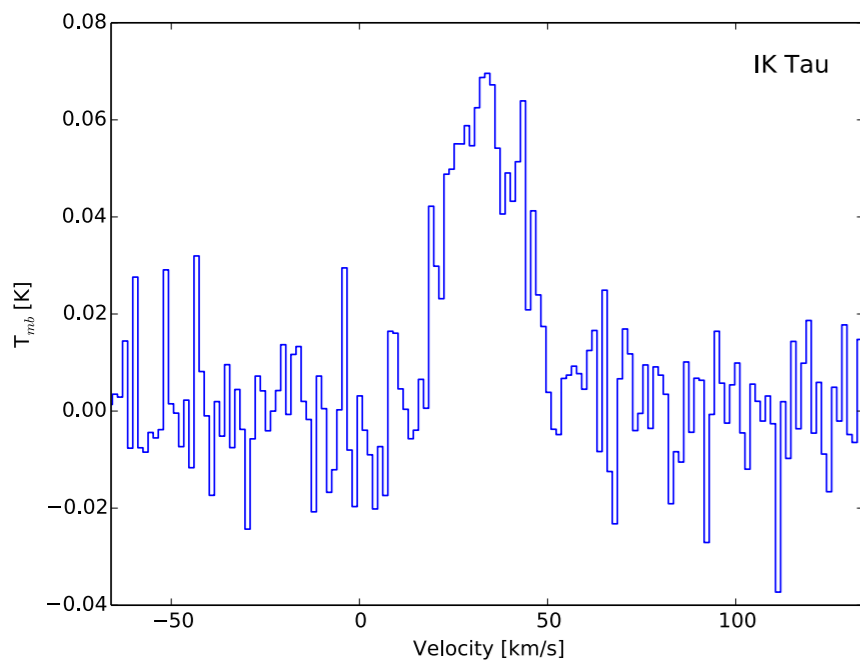
> chemistry?

ALMA (band 5) essential for spatial information

$J_{K_a, K_c} = 1_{1,0} - 1_{0,1}$

--- H₂³²S --- H₂³⁴S

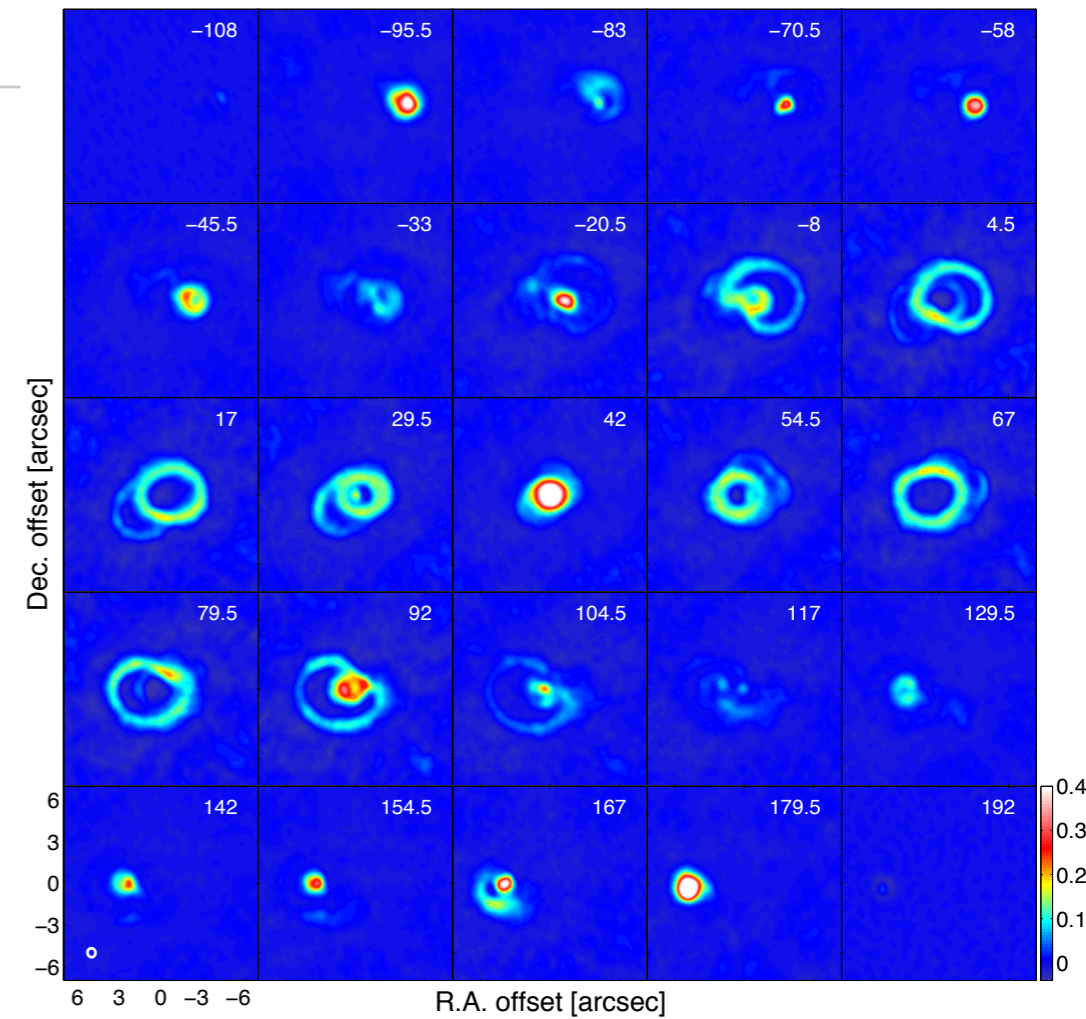
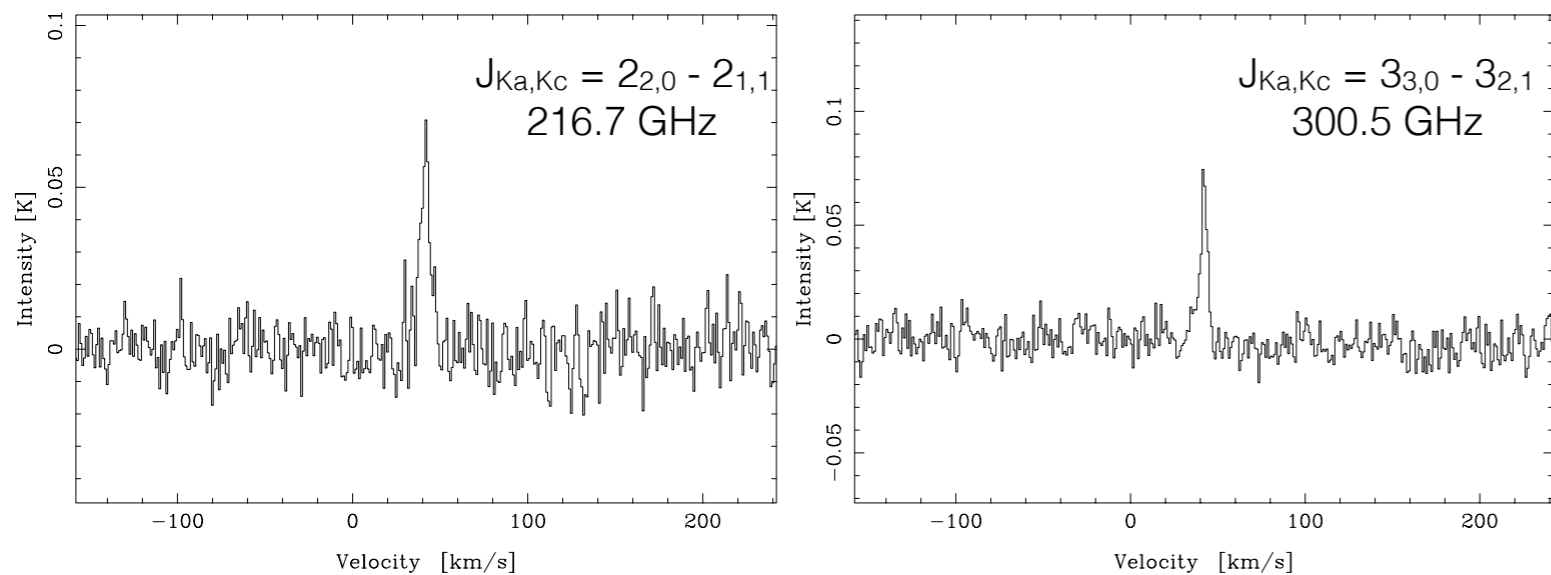
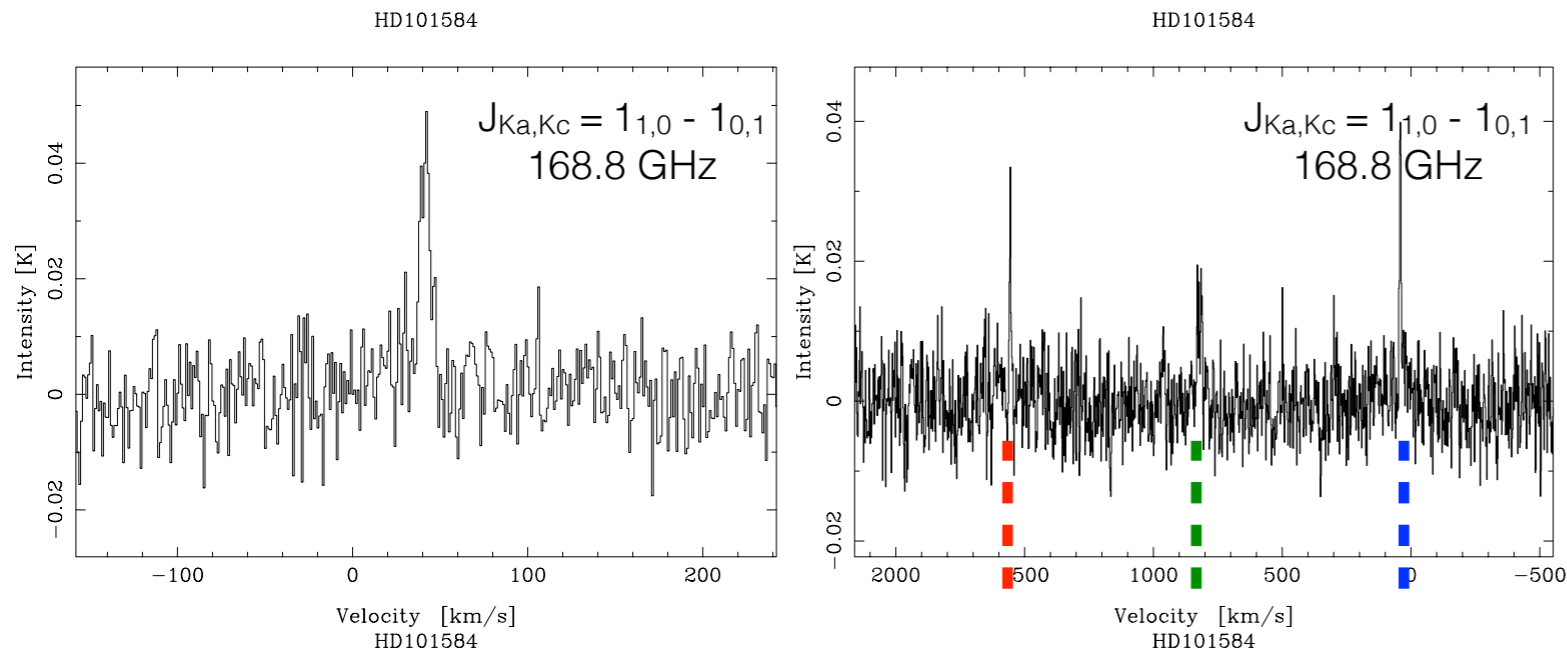
Danilovich et al., *in prep.*



Evolved stars with SEPIA/band 5

Lines

- H_2S
 - > ... AGB ...
 - > HD 101584, post-AGB, post-common envelope
 - ALMA \rightarrow ^{12}CO , ^{13}CO , H_2^{32}S , H_2^{33}S , H_2^{34}S



$^{12}\text{CO}(J=2-1)$, ALMA, resolution $\sim 0.5''$
Olofsson et al., 2015, A&A, 576, L15

--- H_2^{32}S --- H_2^{33}S --- H_2^{34}S

Olofsson et al., *in prep.*

Evolved stars with SEPIA/band 5

Lines

Pointing sources in HCN ($J=2-1$) and/or SiO ($\nu=0,1,2; J=4-3$)
—> 2.5" accuracy

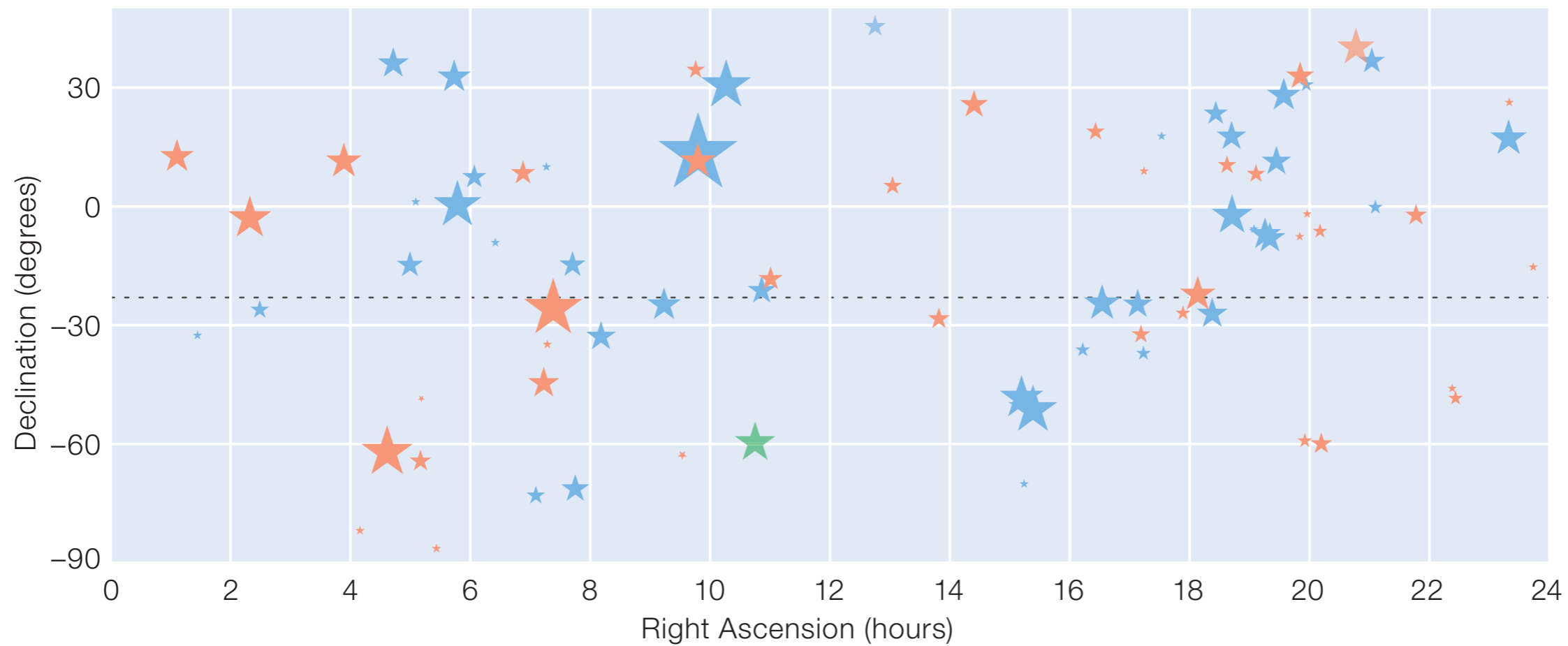


Figure 4. Local Siderial Time (LST) distribution of Band 5 pointing sources (HCN [blue], SiO [red] and continuum [green]). The size of each symbol is proportional to the logarithm of the integrated flux (K km/s). The dotted line indicates the latitude of the APEX telescope.

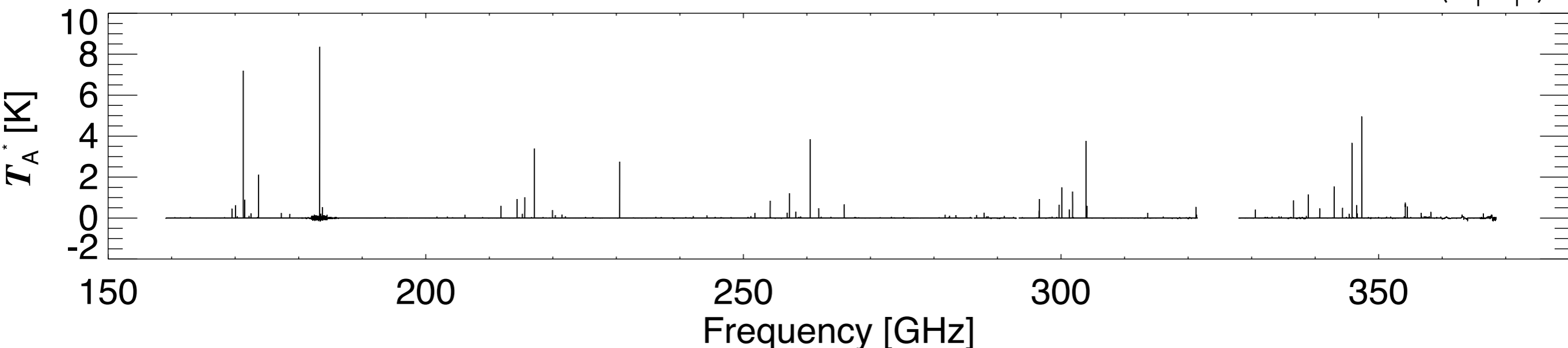
Evolved stars with SEPIA/band 5

Spectral surveys

- unbiased coverage —> towards full inventory of circumstellar gas
- cover gap between IRAM/EMIR receivers E1 and E2 (184 - 202 GHz)
e.g. SO₂, SiO isotopologues, PN, PO, C₄H, CS, SiS
- AGB stars
 - R Dor [OSO; P.I. H. Olofsson; P95; 9hrs] — ~70 lines (~300 in full range)
 - II Lup [OSO; P.I. E. De Beck; P98; 5hrs]
 - *upcoming*: sample covering different
 - chemical types (3M, 1S, 3C-type)
 - density regimes
 - P.I. T. Danilovich [ESO; P99; 36hrs]
 - P.I. E. De Beck [OSO; P99; 41hrs]

R Dor, low mass-loss rate, oxygen-rich

De Beck et al. (in prep.)



Evolved stars with SEPIA/band 5

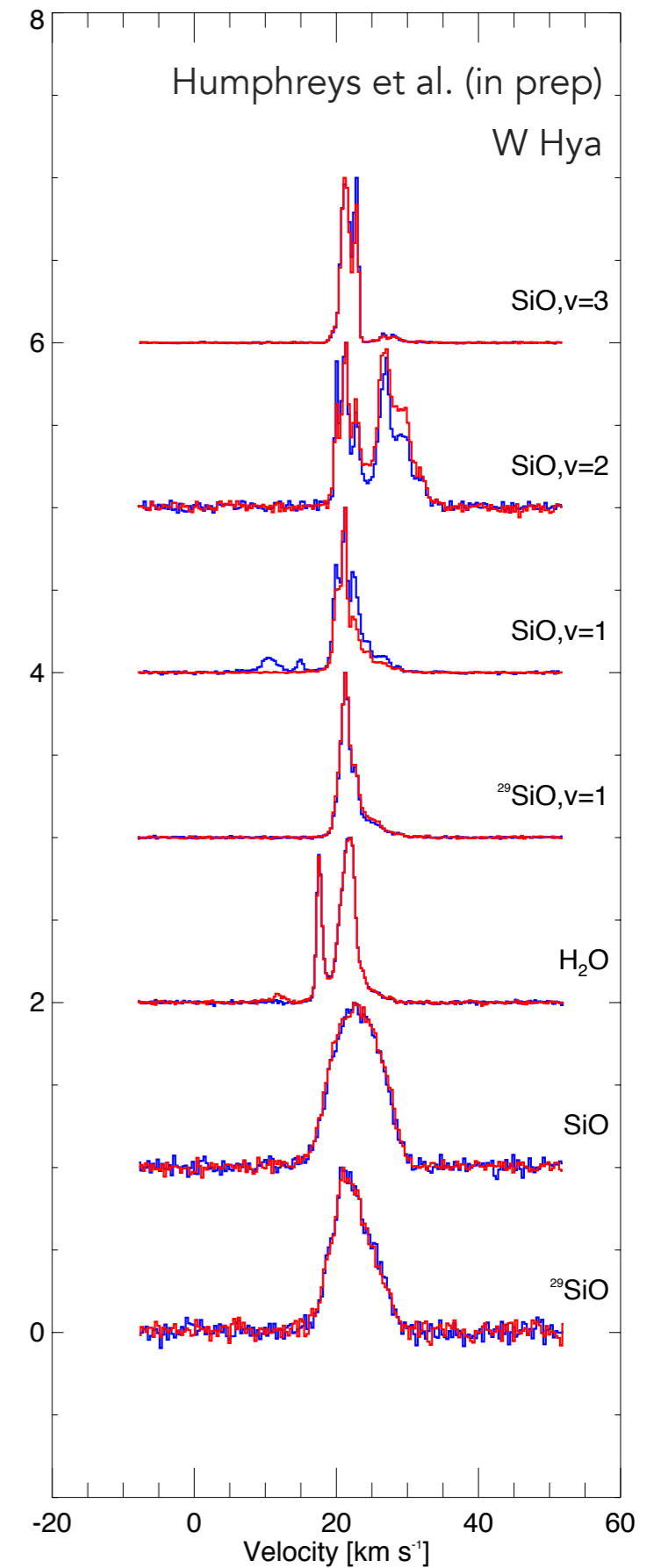
Polarisation

... of molecular line emission

- pumping mechanism of masers
- magnetic field strength

... of dust emission

>>> ALMA

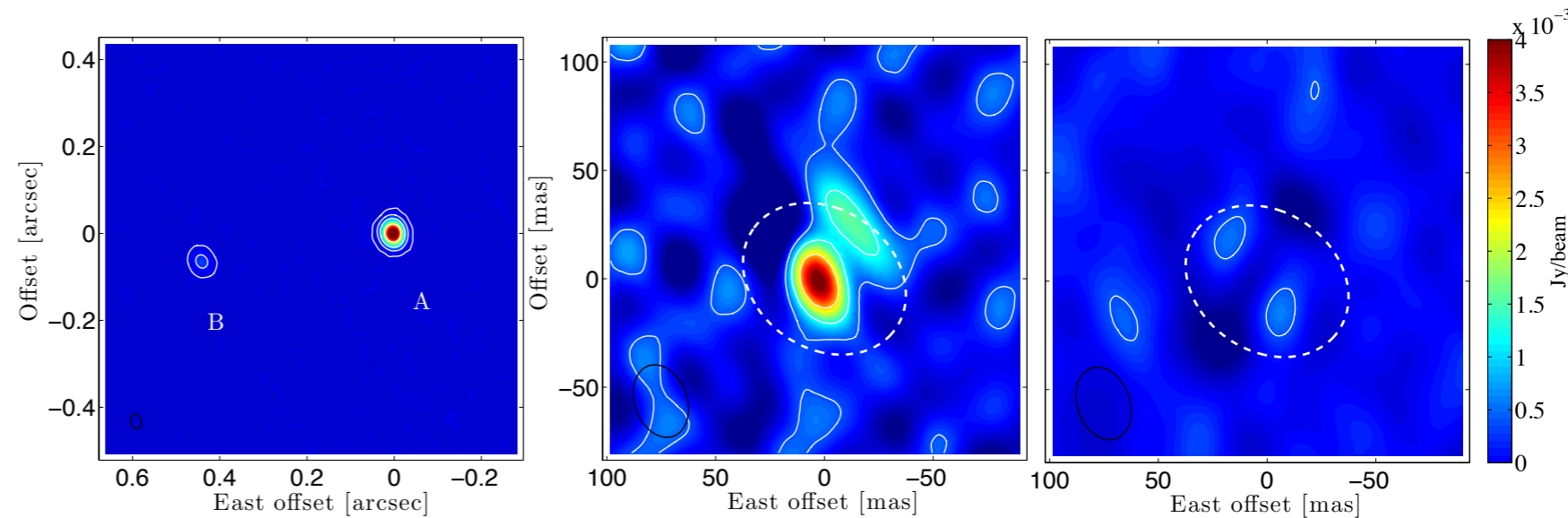


Evolved stars with ALMA/band 5

Size scales

1" = 300 AU at 300 pc
~ 100-300 R_{*}

ALMA has previously resolved the stellar surface of the AGB star Mira
Vlemmings et al., 2015, A&A, 577, L4
Matthews et al., 2015, ApJ, 808



Approximate angular scales in band 5

- ACA
 - resolution: 6 - 8"
 - MRS: 30" - 45" [most of the CSE]
- 12m array
 - 16 km max baseline with angular resolution: 0.020 - 0.035" [(sub-)stellar scales for $d < 300$ pc]

Evolved stars with ALMA/band 5

Lines

- H₂O maser at 183.3 GHz → [*talk A. Richards*](#)
- SiO $J=4-3$
- HCN $J=2-1, v=0,1$
- H₂S
- ...
- e.g. cherrypicking from spectral scans

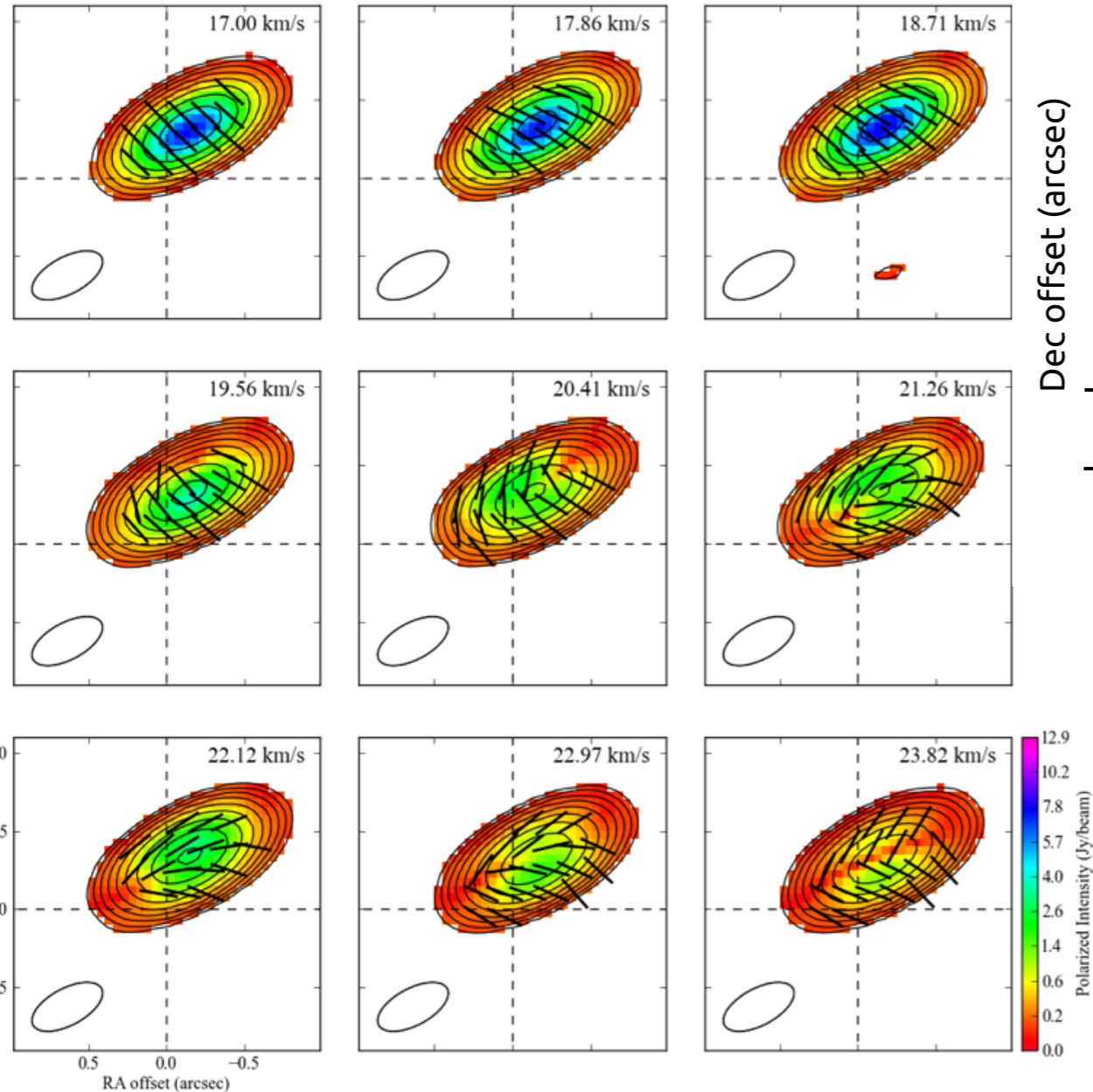
Resolvable at high angular resolution

- dynamics, kinematics
- morphology
- constrain $T(r)$, $\rho(r)$, $v(r)$, radiation field
- variability
- abundances on AU scales → chemical networks

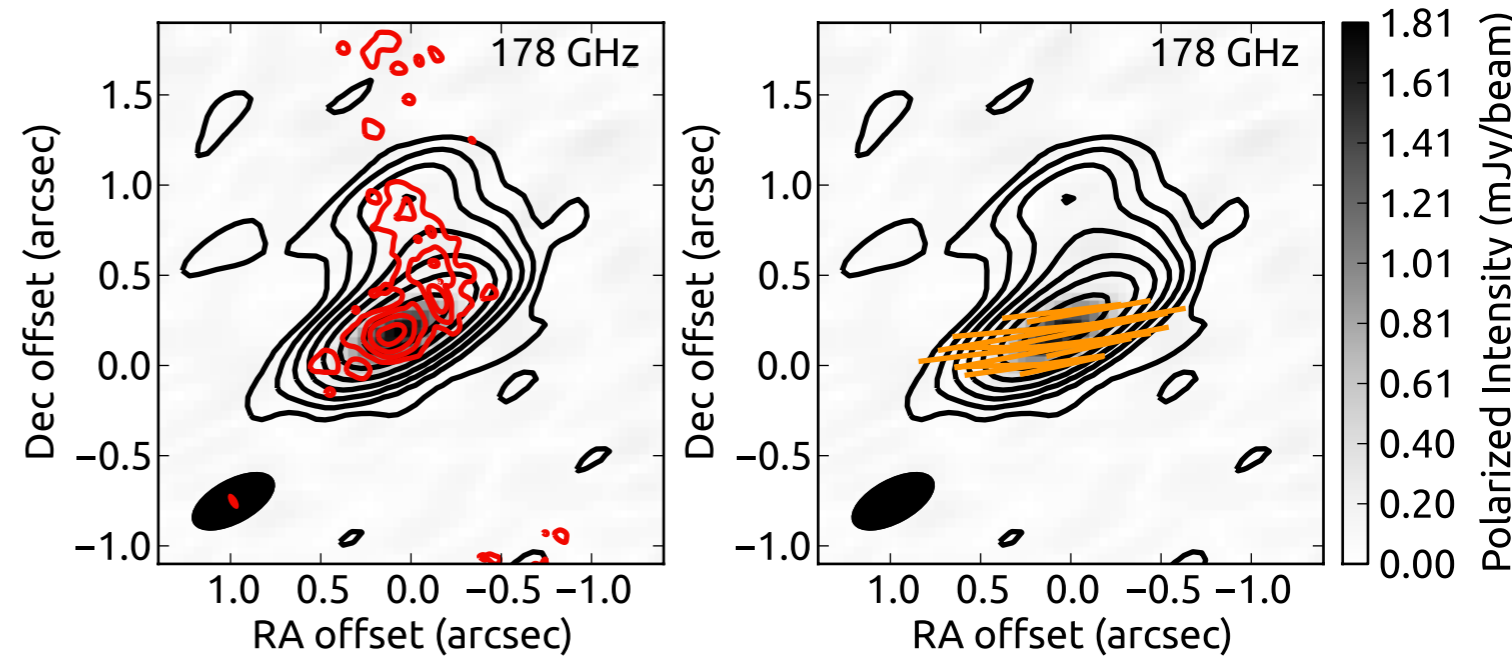
Evolved stars with ALMA/band 5

Polarisation

... of line emission



... of dust emission



Band 5 SV data

VY CMa, red supergiant

ALMA: SiO (J=4-3) & continuum

~ 0.25" x 0.5" resolution

Vlemmings et al., *in prep.*

Constraints on

—> [talk W. Vlemmings](#)

- Magnetic fields
- Dust grain properties

Evolved stars with band 5 — summary

- Gas — APEX & ALMA
 - efficient full-band scans (8 settings, 0.5GHz overlap)
 - simultaneous coverage of H₂O, SiO masers
 - HCN, H₂S, carbon chains, ...
 - down to (sub-)stellar scales for nearby objects
 - abundance structure at high resolution —> chemical networks
 - magnetic field strength & structure
- Dust — ALMA
- Polarisation
 - magnetic field
 - strength & morphology
 - role in wind acceleration and shaping (also PNe!)
 - dust grain properties