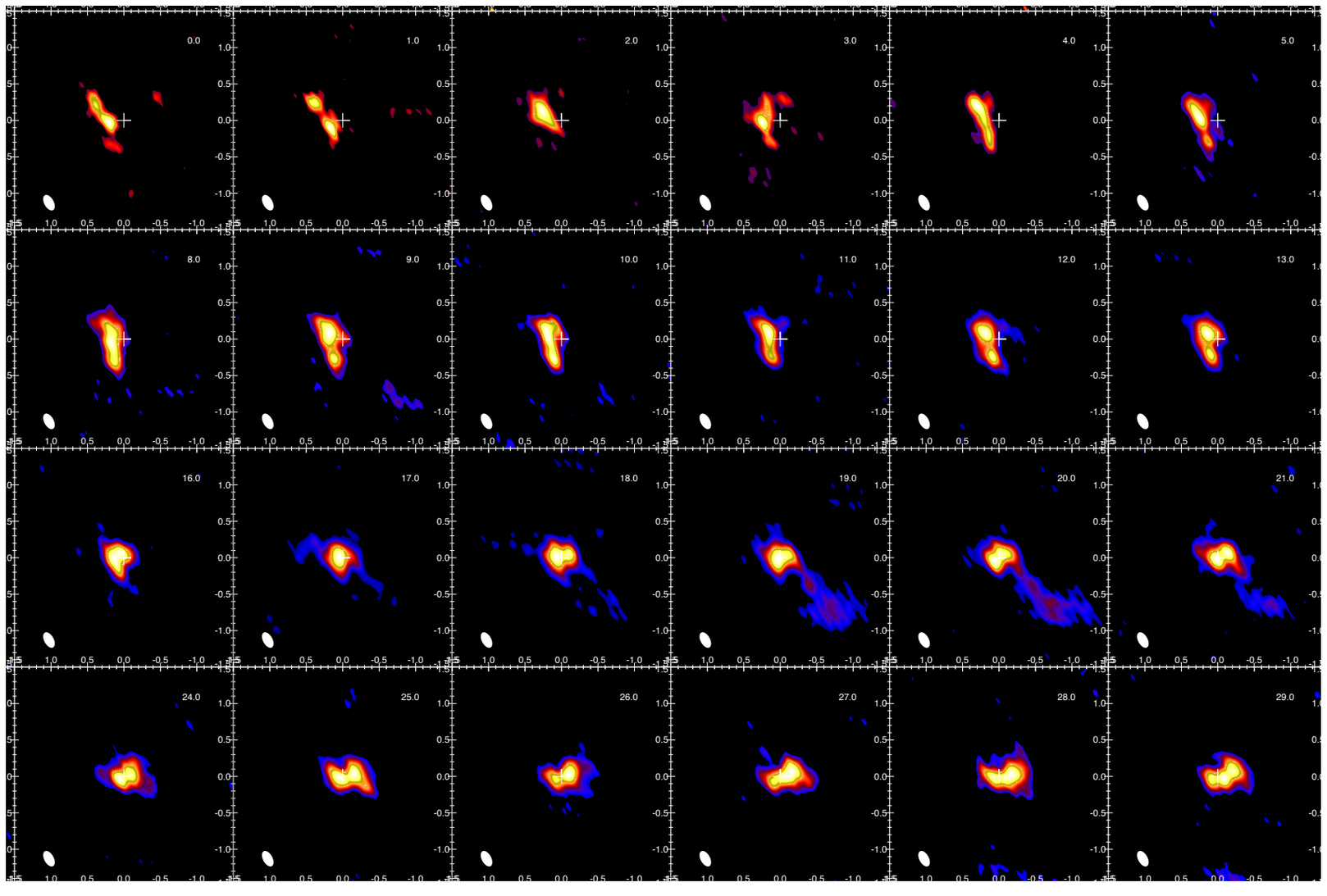
**ELVIRE DE BECK - ONSALA SPACE OBSERVATORY, SWEDEN**

# TITANIUM DIOXIDE AROUND THE RED SUPERGIANT VY CMA



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# EVOLVED STARS

## THEIR WINDS

- Gas & dust

- Driving mechanism?
    - Shocks
    - Radiation pressure / scattering on dust
    - Convection
    - Magnetic fields
    - … ?

- Dust around oxygen-rich stars
    - size
    - chemical composition

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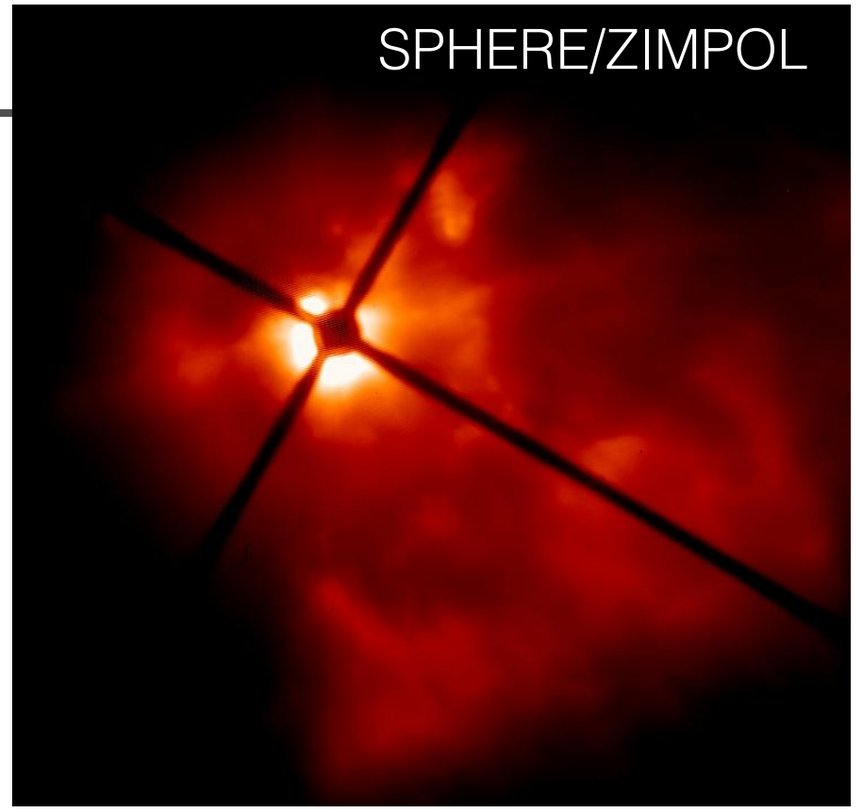
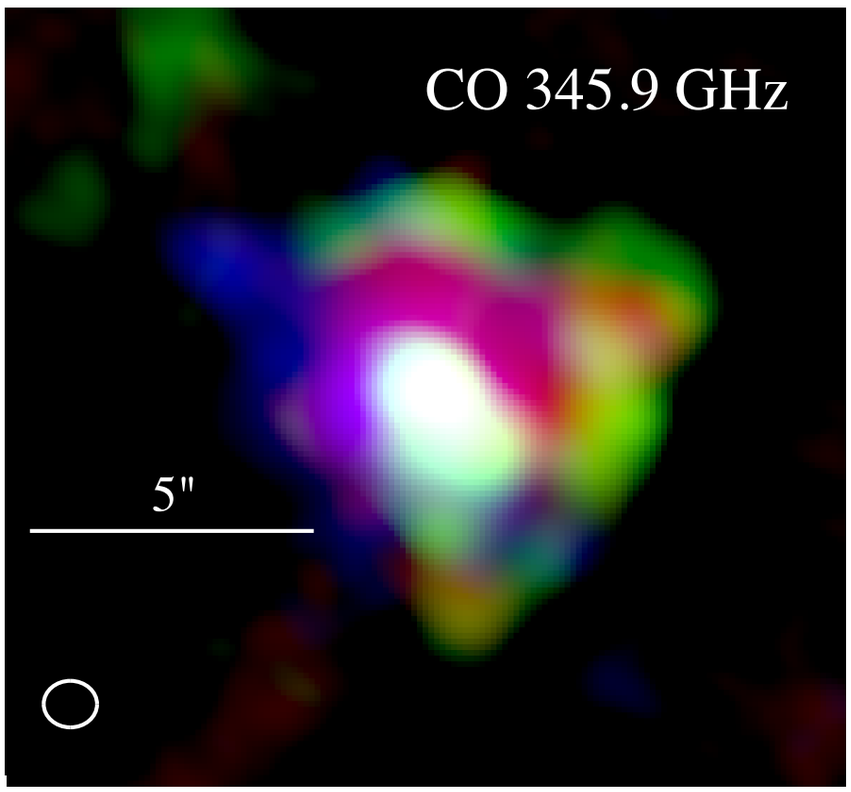
# VY CANIS MAJORIS

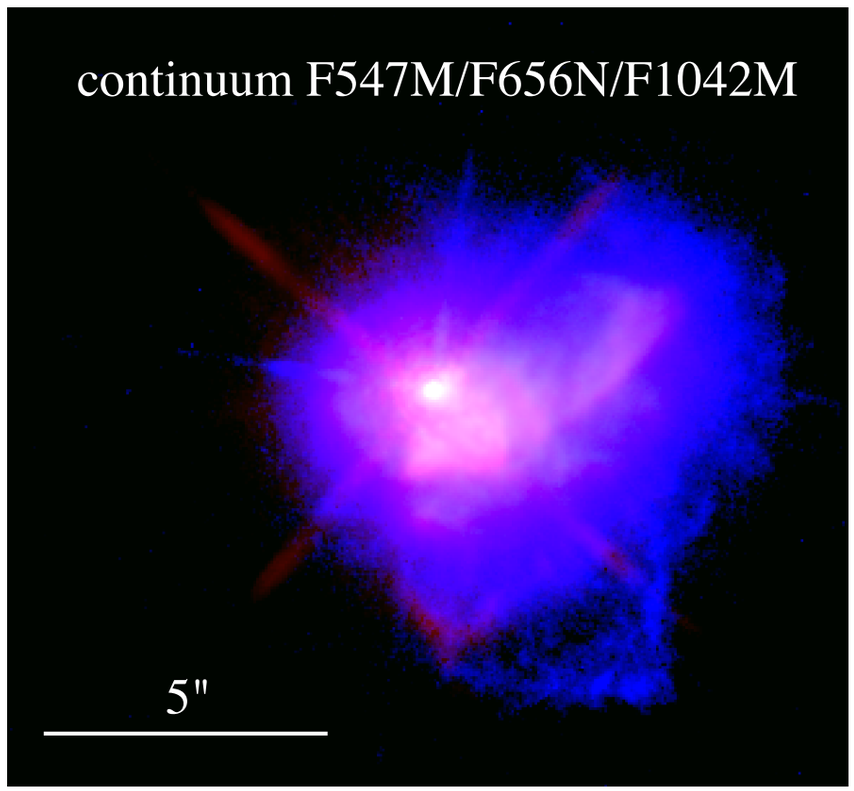
## INTRO

- 25 $M_{sun}$
- 300,000 $L_{sun}$
- 1420 $R_{sun}$
- Mass-loss rate ~ 2 x $10^{-4}$ $M_{sun}$/yr
- Outflows, arcs, knots … VERY complex!

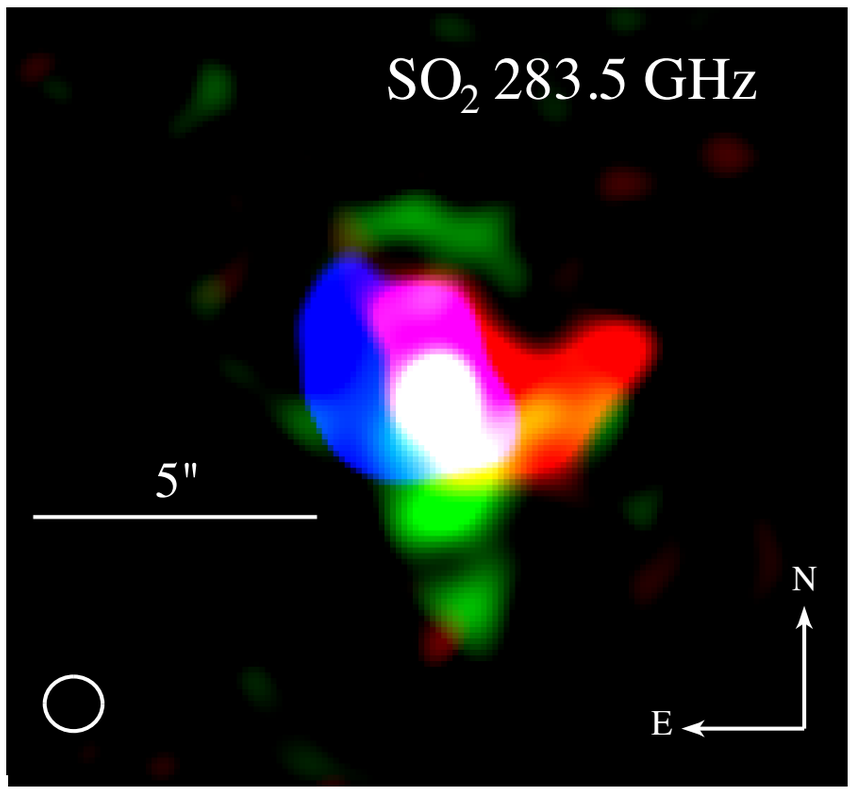



SMA




HST




Kaminski et al. (2013) SMA

# VY CANIS MAJORIS

## THE ALMA OBSERVATIONS

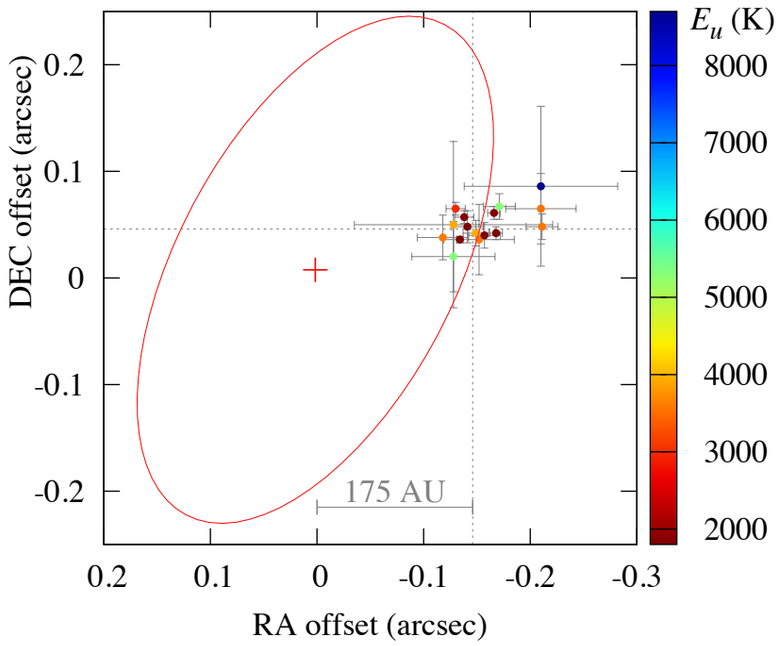
- ALMA = Atacama Large Millimetre/sub-millimetre Array

- CSV observations
    - 20 antennas
    - 14m … 2.7 km baselines
    - Angular resolution ~0.13″ at 320 GHz, ~0.06″ at 658 GHz
      (0.13″ ~ 25 stellar radii)

- Primary goal: $H_2O$ masers
- Other results:
    - continuum structure
    - > 80 emission features: $H_2O$, $TiO_2$, NaCl, $SO_2$, MgCl, SiS, SiO, … ( + vibrational states & isotopologues)

# VY CANIS MAJORIS

## THE CONTINUUM




***Before ALMA***

*offset between continuum and molecular emission*
*e.g. Muller et al. (2007), Kaminski et al. (2013)*

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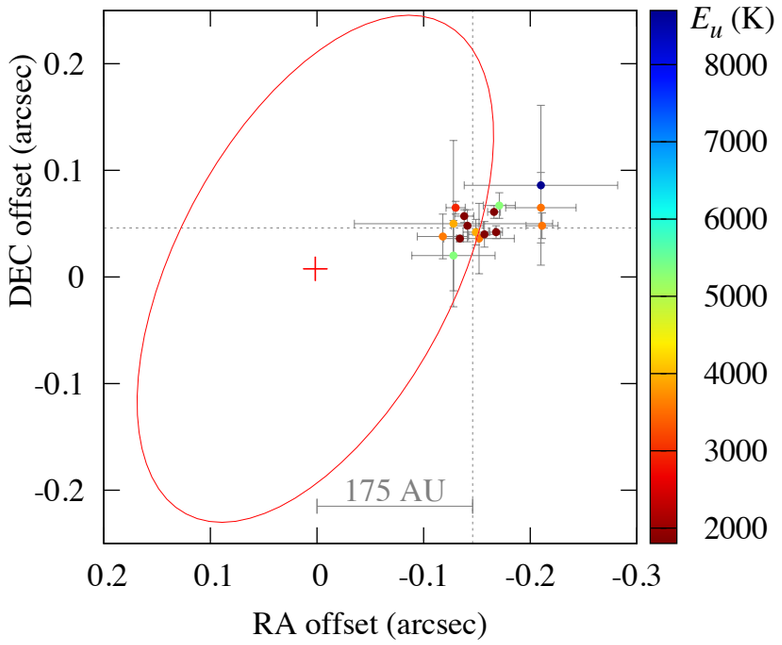


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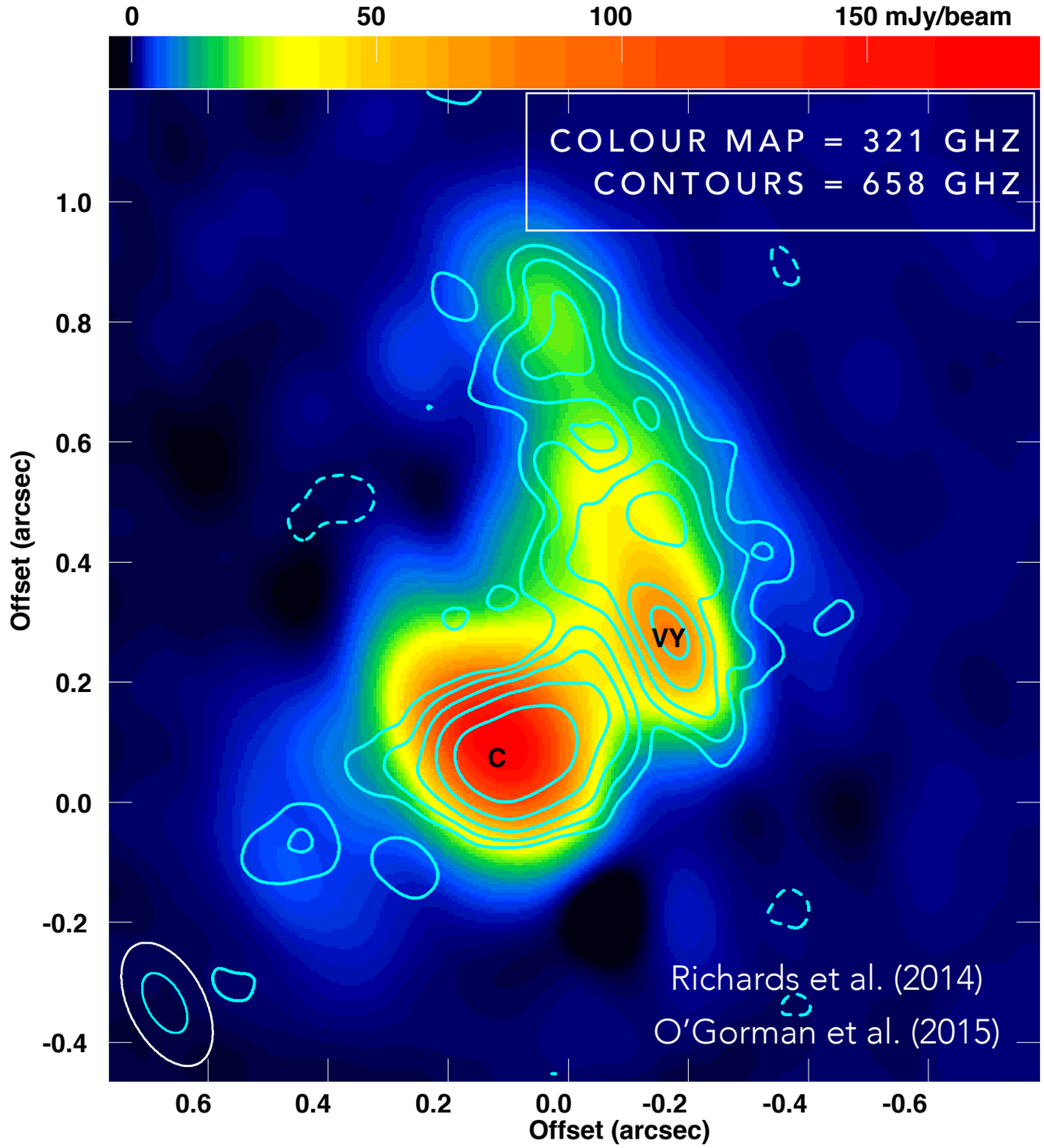

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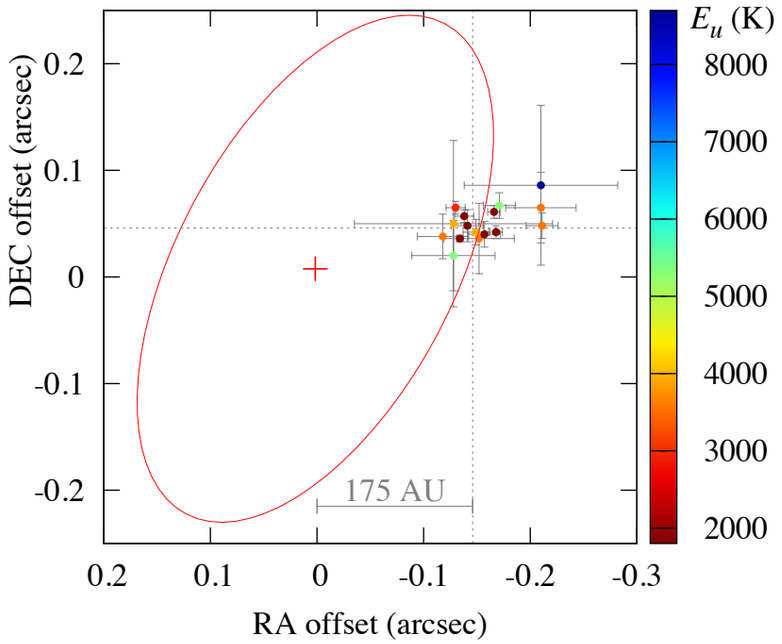
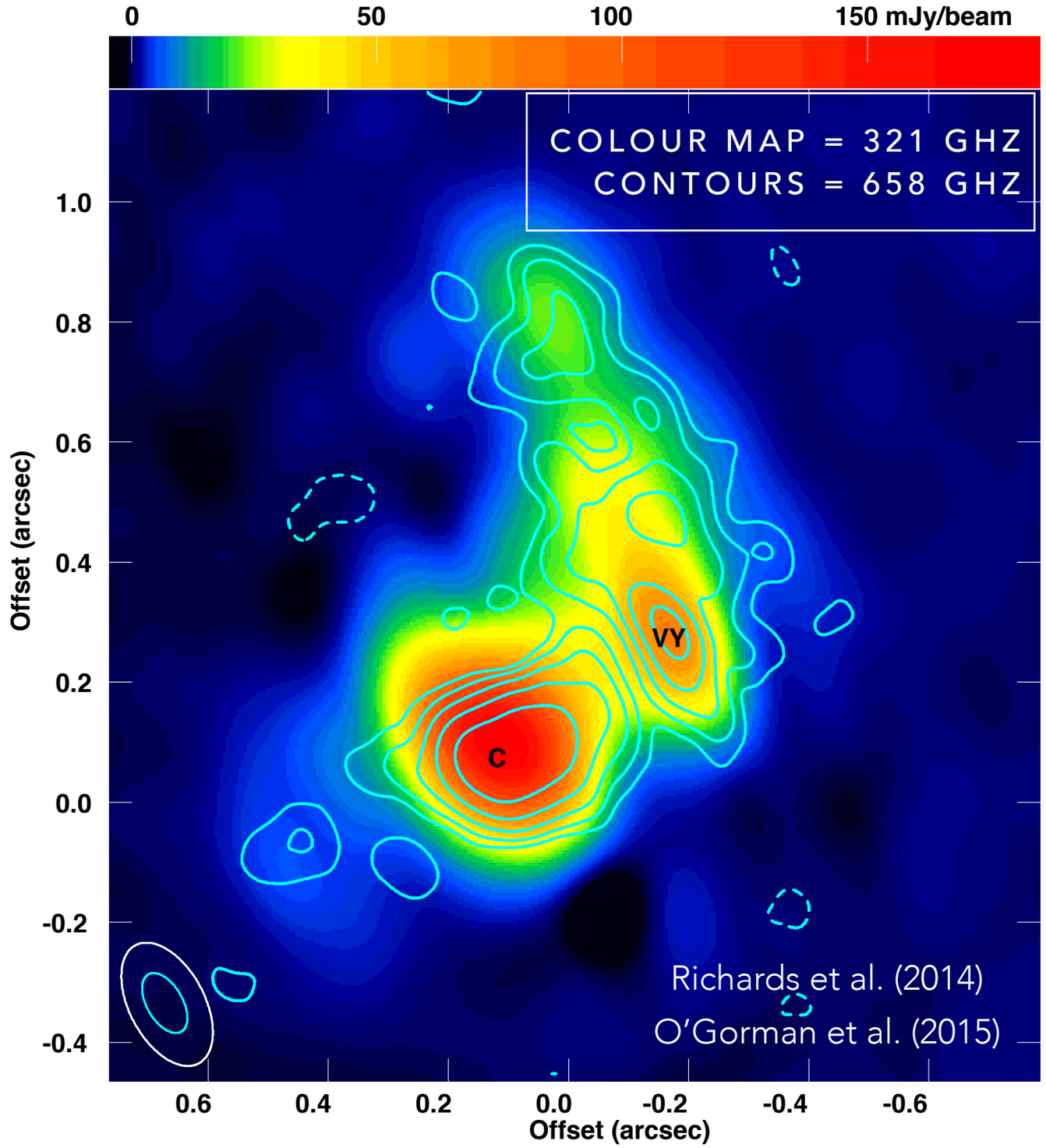



- $H_2O$ masers at 321, 325, 658 GHz
  - centre of expansion = star (VY)
- Peak of continuum = "blob" C
  - 2.5 x $10^{-4}$ $M_{sun}$ (= 1/2 $M_{Jupiter}$)
  - < 100 K
  - no molecular emission

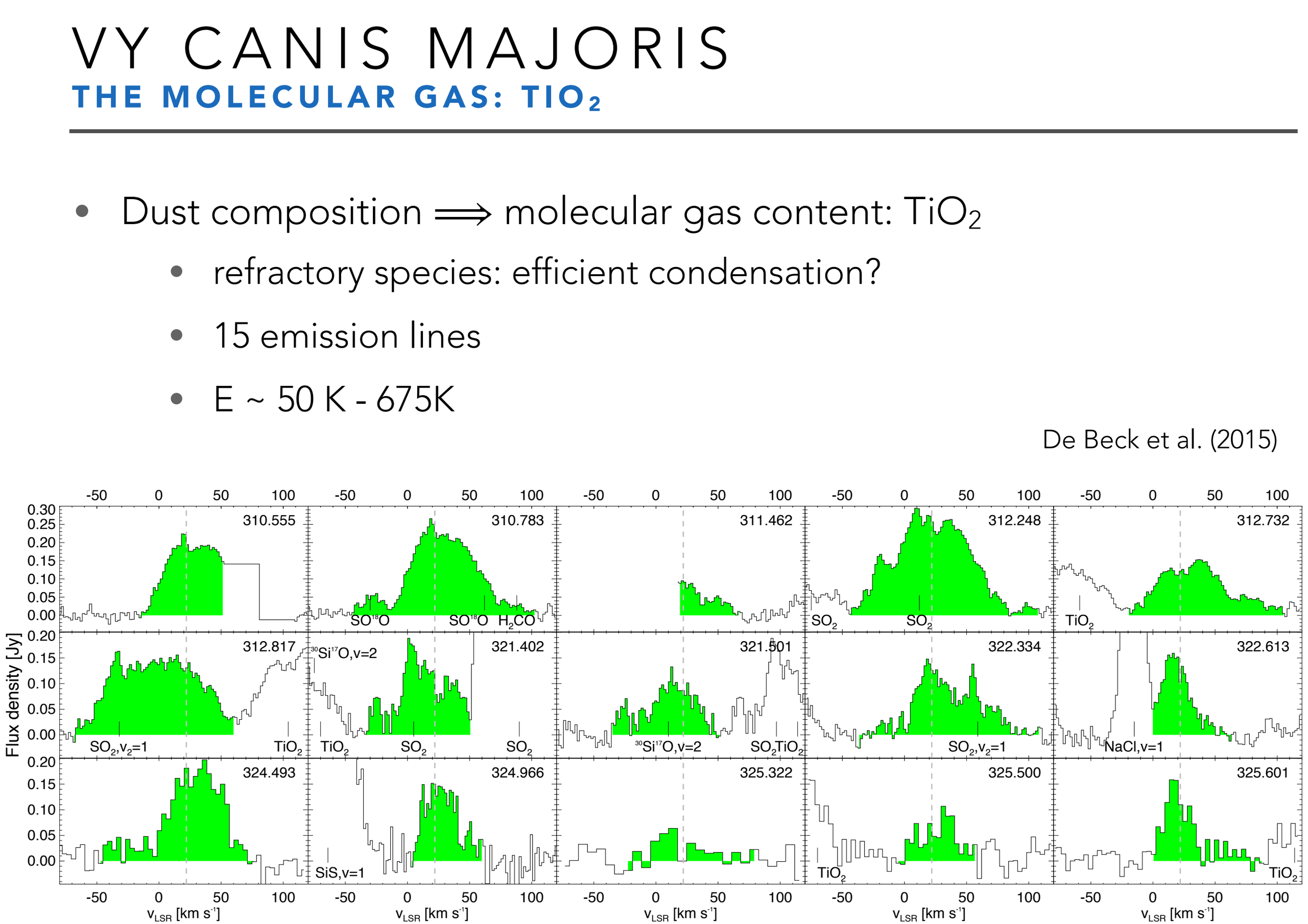


# VY CANIS MAJORIS

## THE MOLECULAR GAS: $TiO_2$

- Dust composition $\Longrightarrow$ molecular gas content: $TiO_2$
  - refractory species: efficient condensation?
  - 15 emission lines
  - E ~ 50 K - 675K

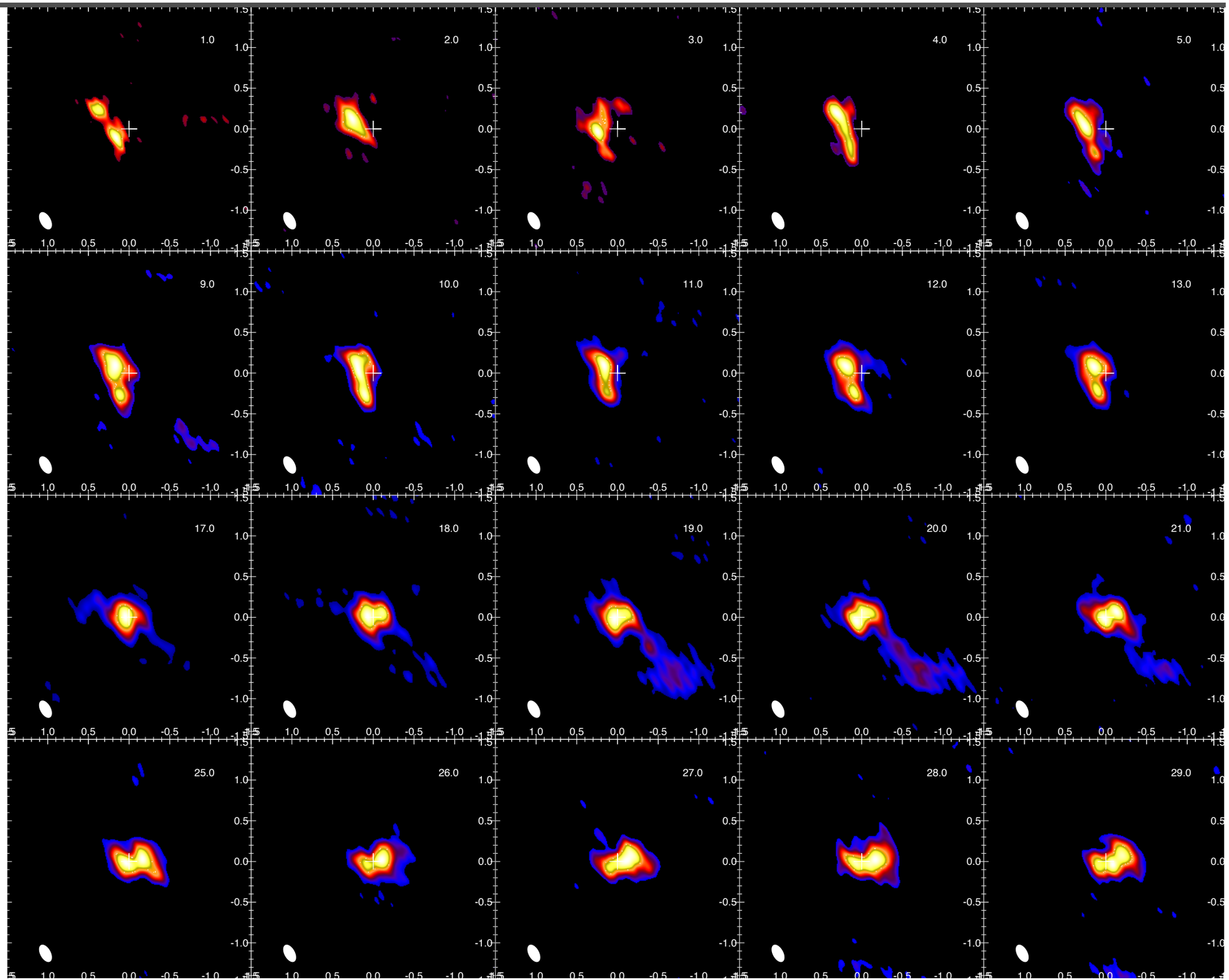
De Beck et al. (2015)



# VY CANIS MAJORIS

## THE MOLECULAR GAS: $TiO_2$

- spatially resolved for the first time
- complex




De Beck et al. (2015)

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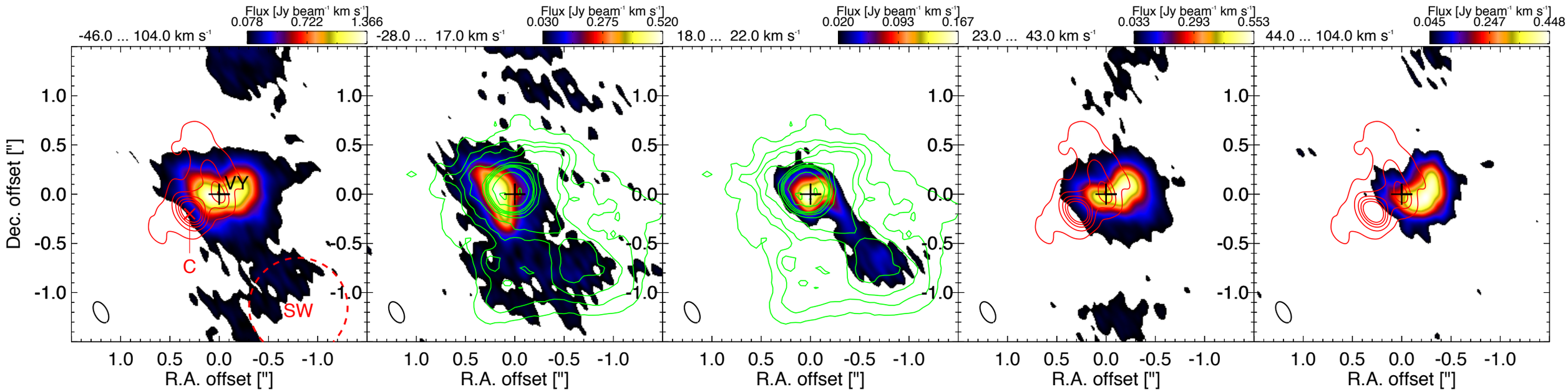


~0.9″ emission region

Wind runs into C, breaks up.

Peak around the star.

South-west tail and clump.

Peak around the star.

Extension west of star.

Doubly peaked, highly variable with v: clumpy?

Mainly west of star.

North-west curvature?

De Beck et al. (2015)

# VY CANIS MAJORIS

## THE MOLECULAR GAS: $TiO_2$

- Radiative excitation of $TiO_2$
  - very high dipole moment
  - collisional versus radiative transition rates
  - correspondence with scattered light observations: stellar radiation field less attenuated

- Derived abundance $TiO_2/H_2 \sim 4 \times 10^{-8}$
  - small role in dust formation
  - freed up from dust, e.g. through shocks?
  - inefficient depletion of $TiO_2$
    supported by Gobrecht et al. (2015)
  - implications for dust around AGB stars?

De Beck et al. (2015)

# VY CANIS MAJORIS

## CONCLUSIONS

- 15 emission lines of $TiO_2$ in ALMA observations
- spatially resolved for the first time

- clumpy, anisotropic outflow
- accelerating bipolar-like structure, runs into “blob” C
- south-west
    - tail towards observer
    - clump in $TiO_2$, NaCl
      & previously $H_2S$, CS, SiS, NS
- radiative excitation

- significant amount of $TiO_2$ beyond dust-formation zone
- inefficiently depleted from gas phase

$\Longrightarrow$ <u>minor role in dust formation</u>