Wind shaping and other observational tracers of binary companions to AGB stars

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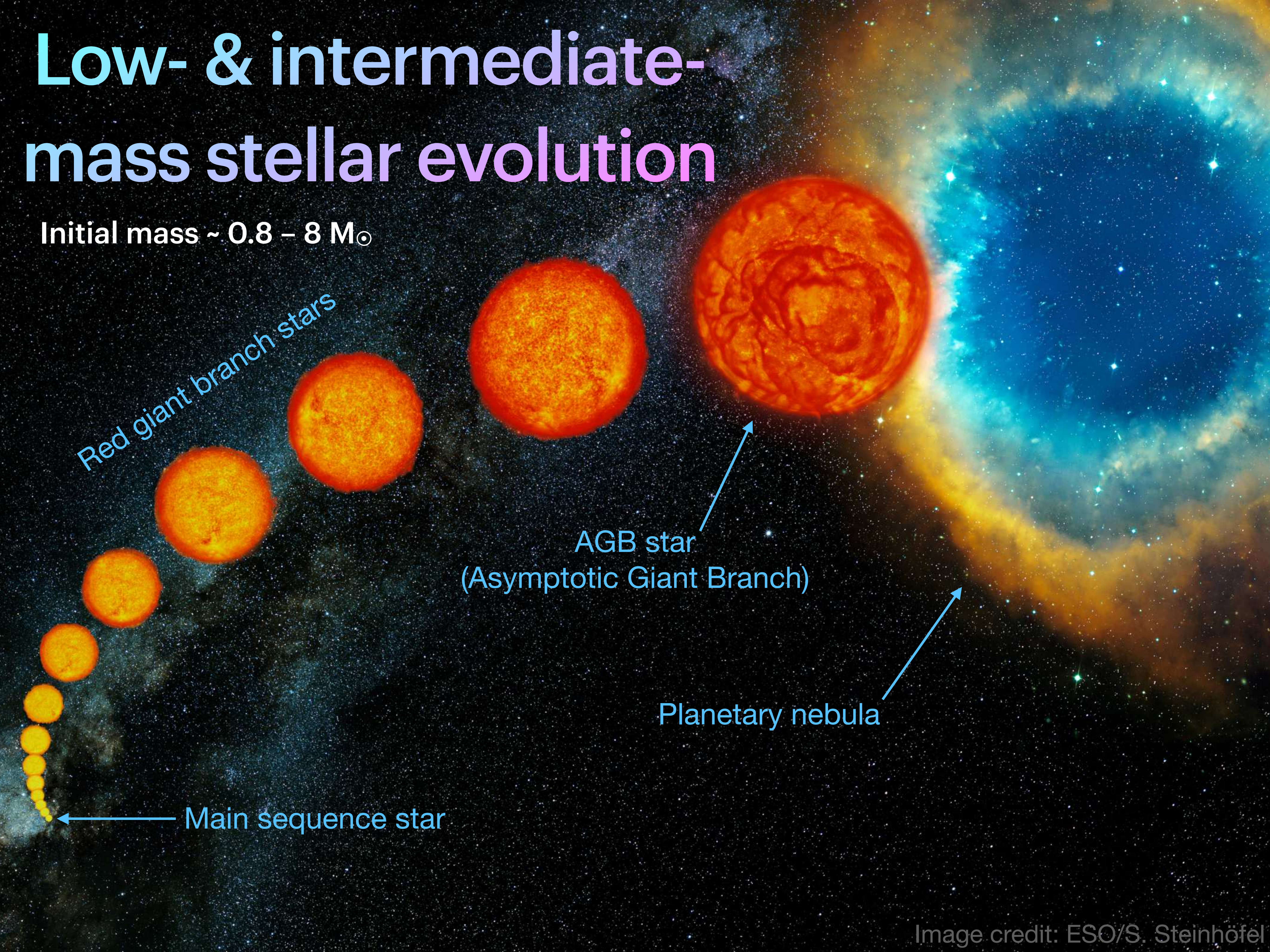
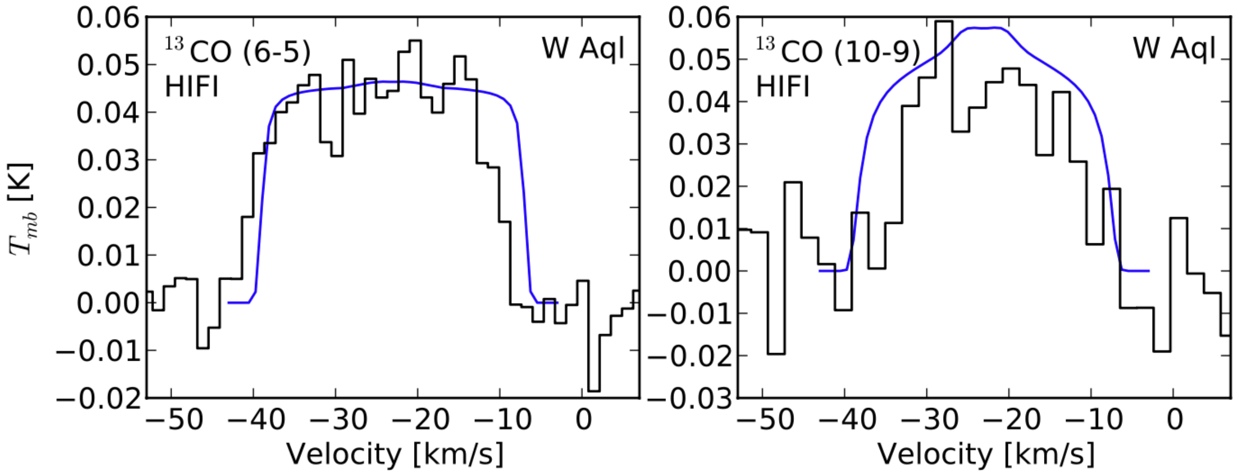

Low- & intermediate-mass stellar evolution
Initial mass ~ 0.8 – 8 M☉
Red giant branch stars
AGB star
(Asymptotic Giant Branch)
Planetary nebula
Main sequence star
Image credit: ESO/S. Steinhöfel

Studies of AGB stars (before ALMA)

- Single-dish observations
- Assume almost everything is an isolated/single star
- Spherically symmetric models for calculating mass-loss rates
- And molecular abundances

(Example from Danilovich et al, 2014)



And then came ALMA

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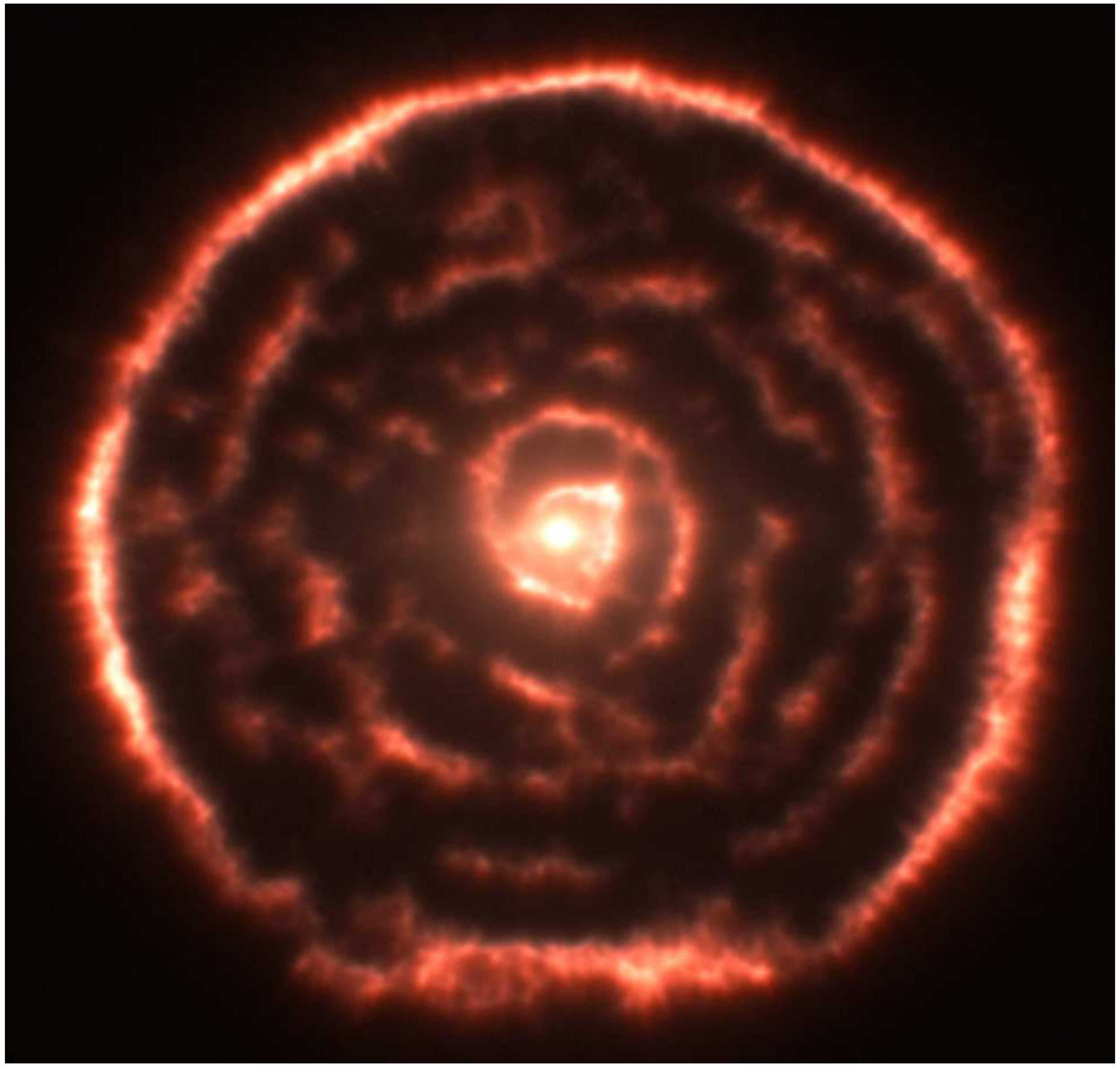
- CO in R Scl revealed an unexpected spiral shape
- (Outer circle is previously-known detached shell)
- Such a pattern can only be explained by a companion
- (Still haven't directly detected the companion)



ALMA (ESO/NAOJ/NRAO)/M. Maercker et al. (2012)

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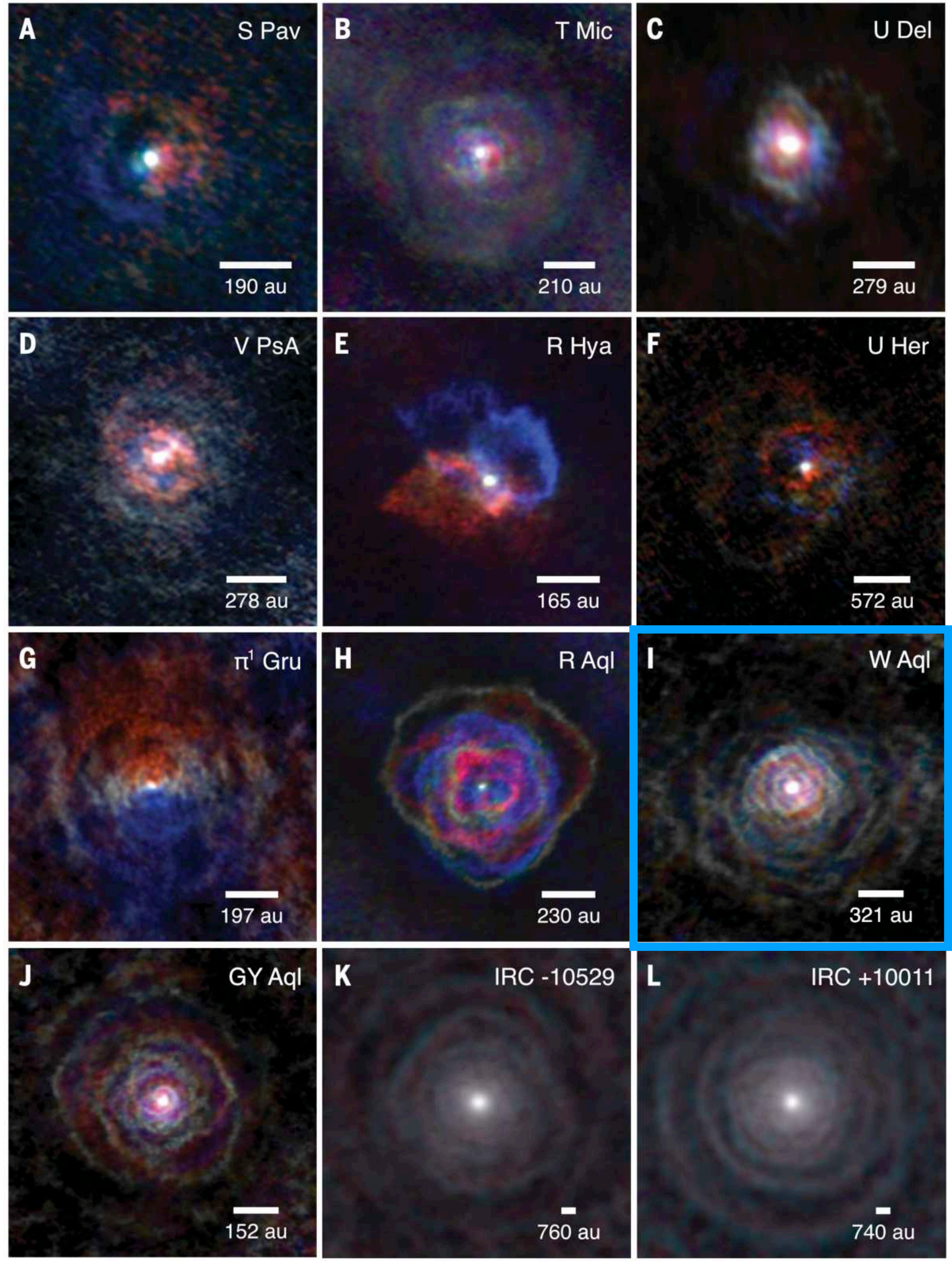
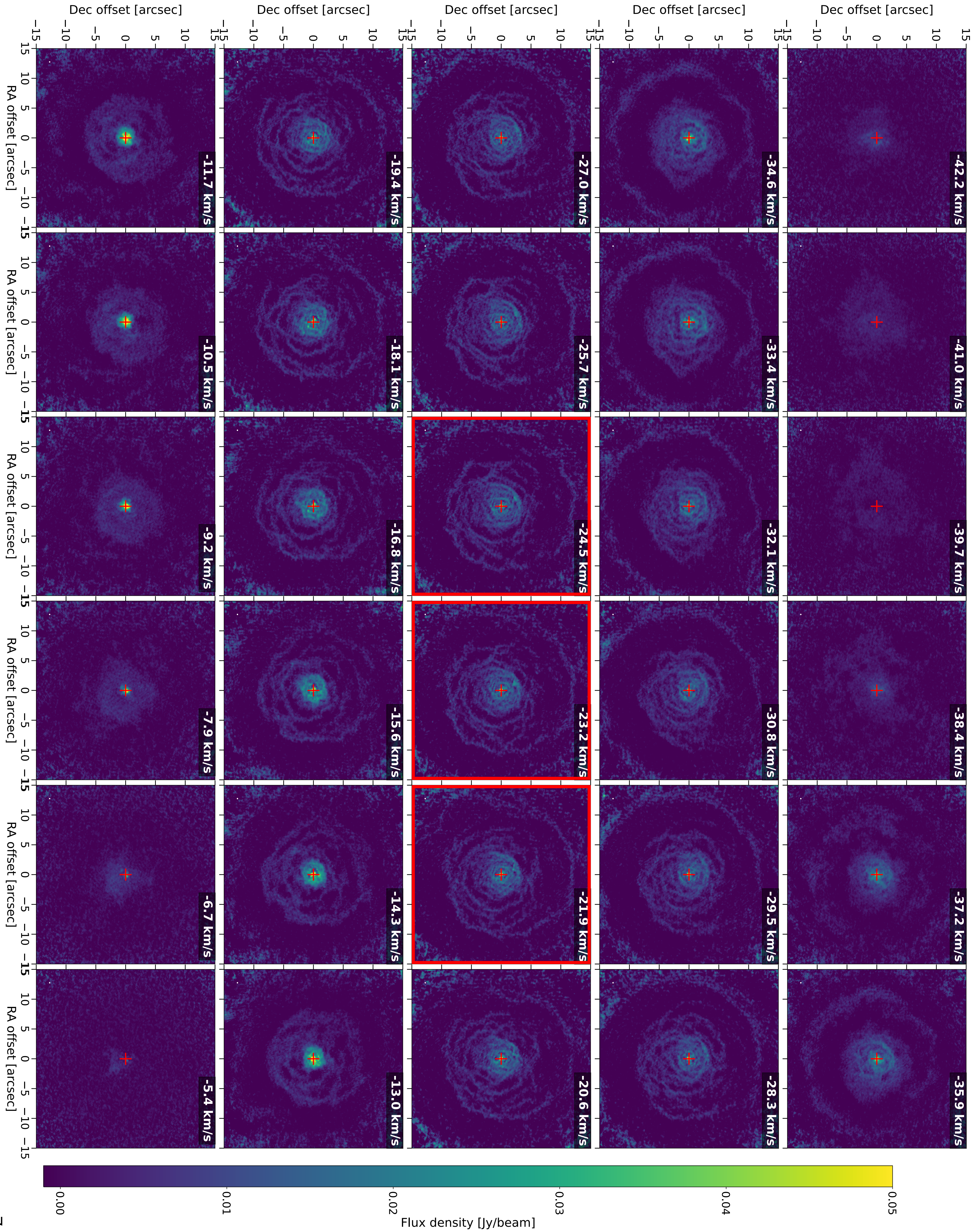
Decin et al, *Science* 369, 1497–1500 (2020)

- Plots show selected red- and blue- shifted channels, relative to the stellar velocities (white)
- We see spirals, bipolar jets, hourglass shapes, a rose…



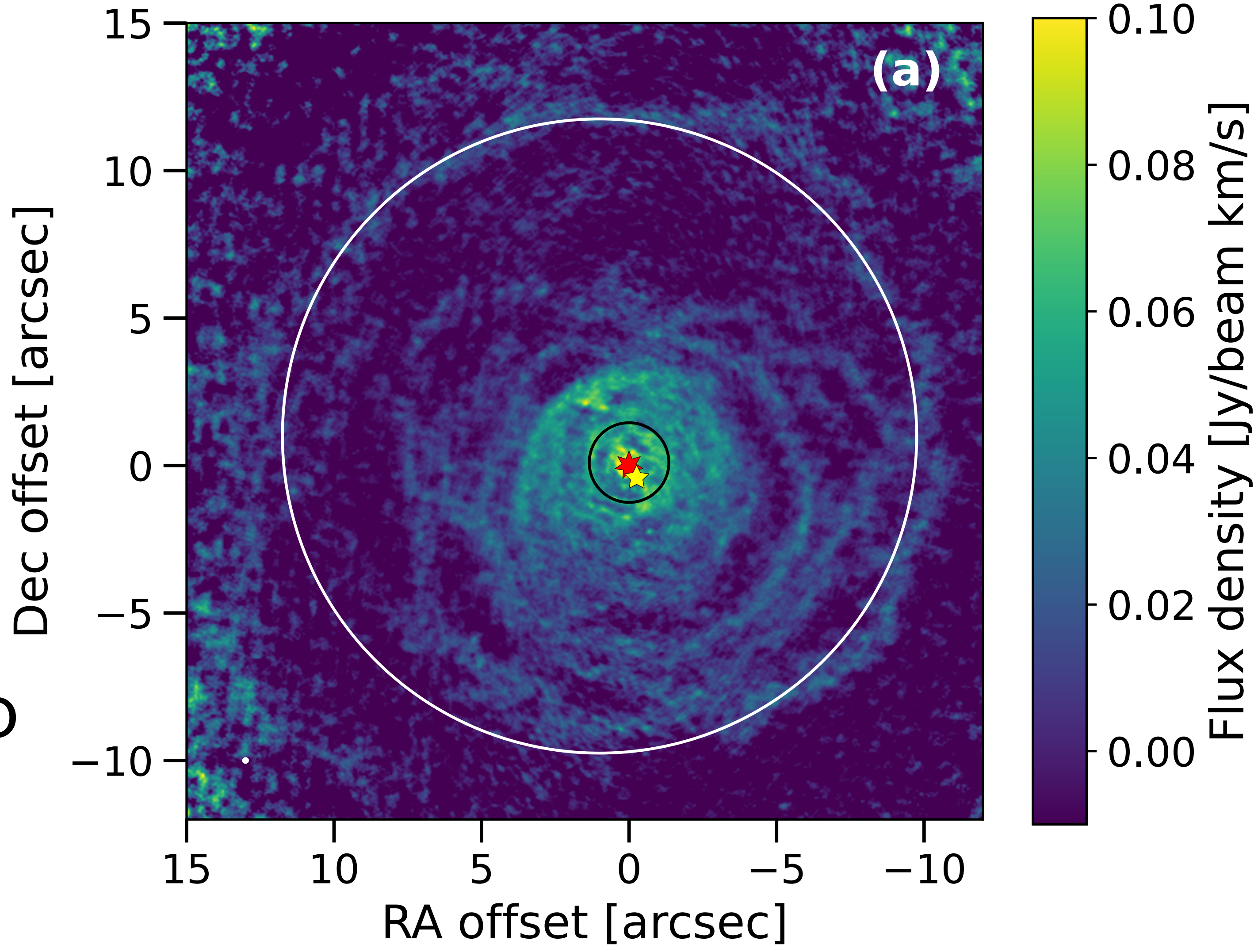
W Aql CO channels



W Aquilae – CO

Central channels

- Observational limitations such as:
  - lost flux,
  - noise,
  - resolution
- make comparing with hydro models tricky
- Even with a know binary companion



Looking beyond CO

For AGB stars we usually detect several molecules

- Some molecules follow the same density structures as CO
  - e.g. HC_3N for carbon stars (Kim et al. 2017)
- Some molecules form when a stellar companion brings its UV photons to the party
  - e.g. SiN (and a few others) seen for W Aql

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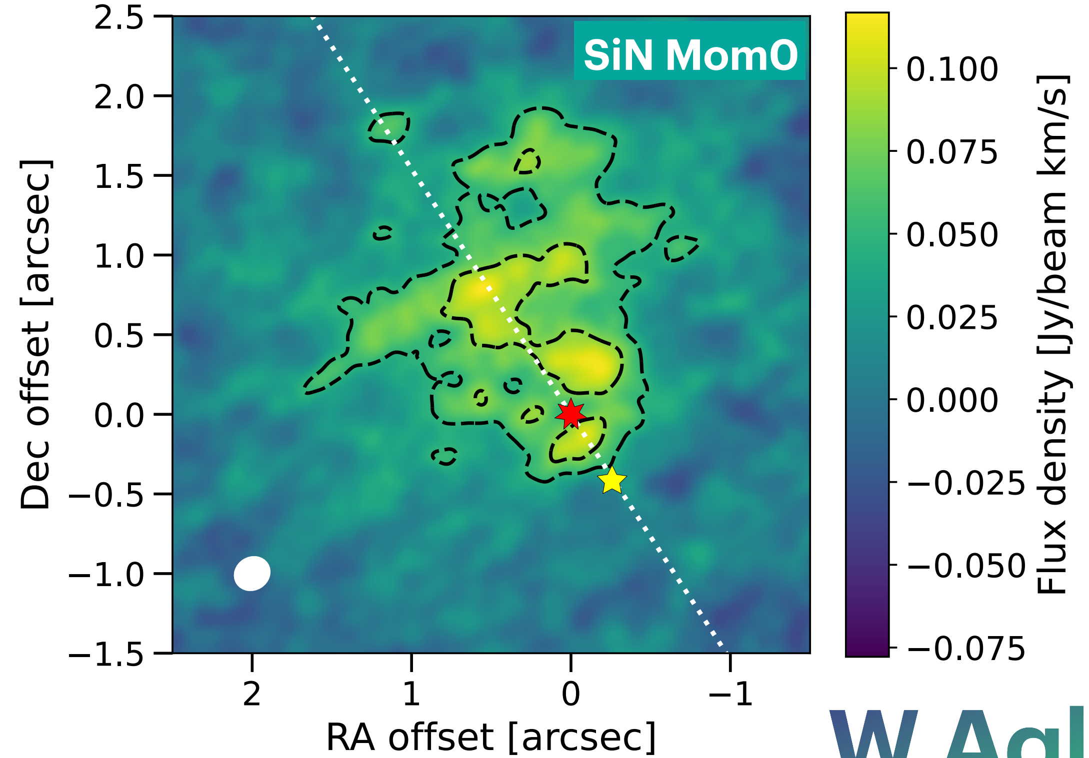
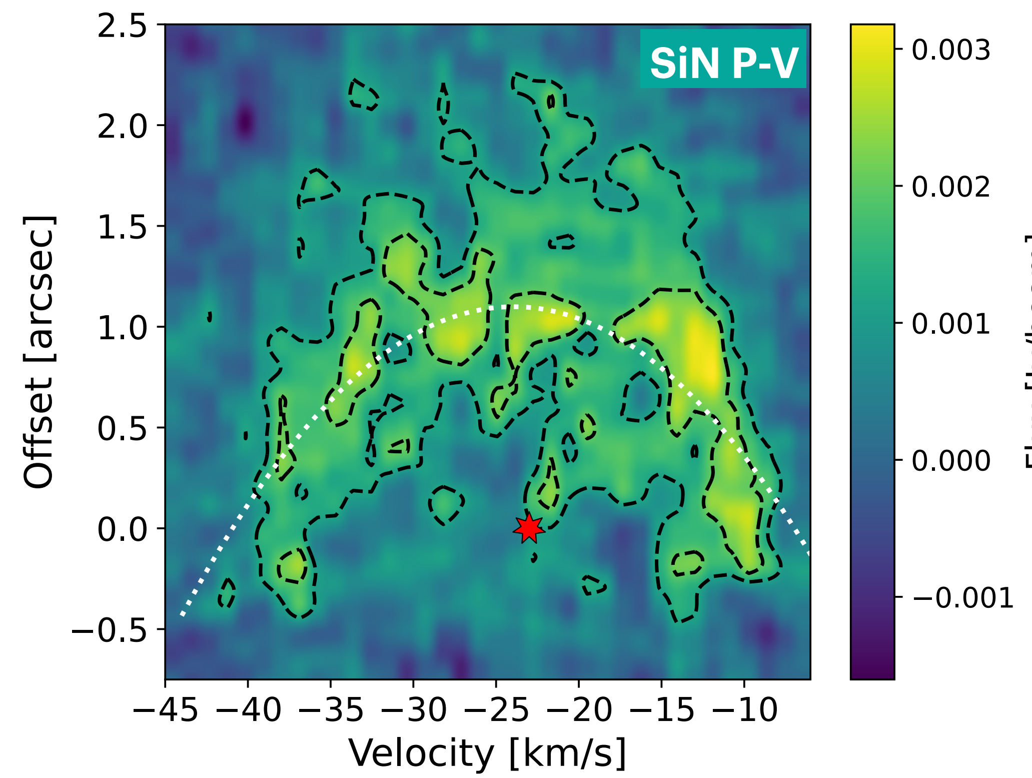
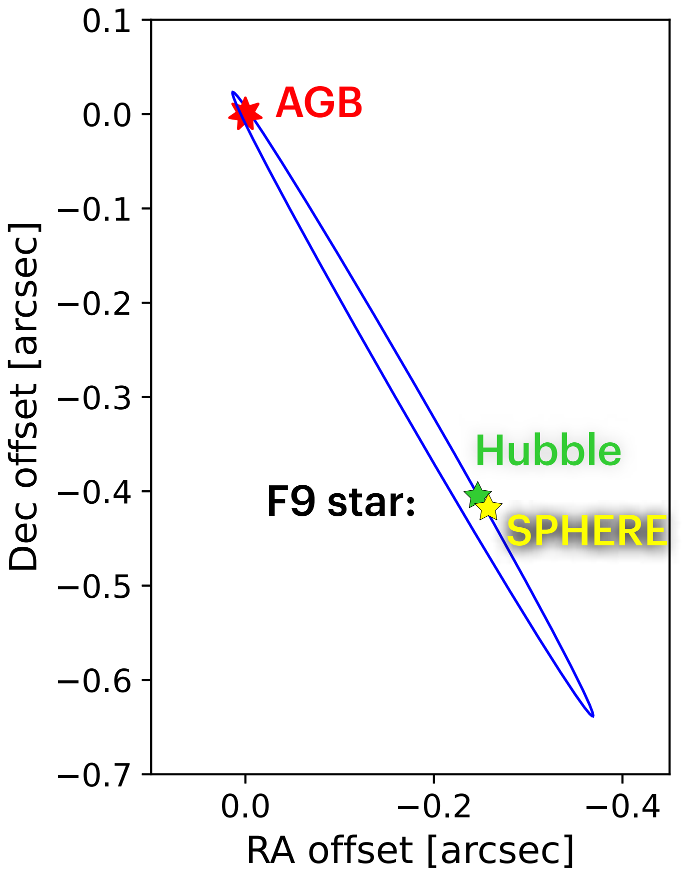


W Aql



Determining the orbit

- Can estimate orbital period from **CO**,
- Time since last periastron from **SiN** and **photometry**,
- Inclination of orbit from **SiN**.
- Feedback between Phantom model and observations to understand origin of structures



Phantom model

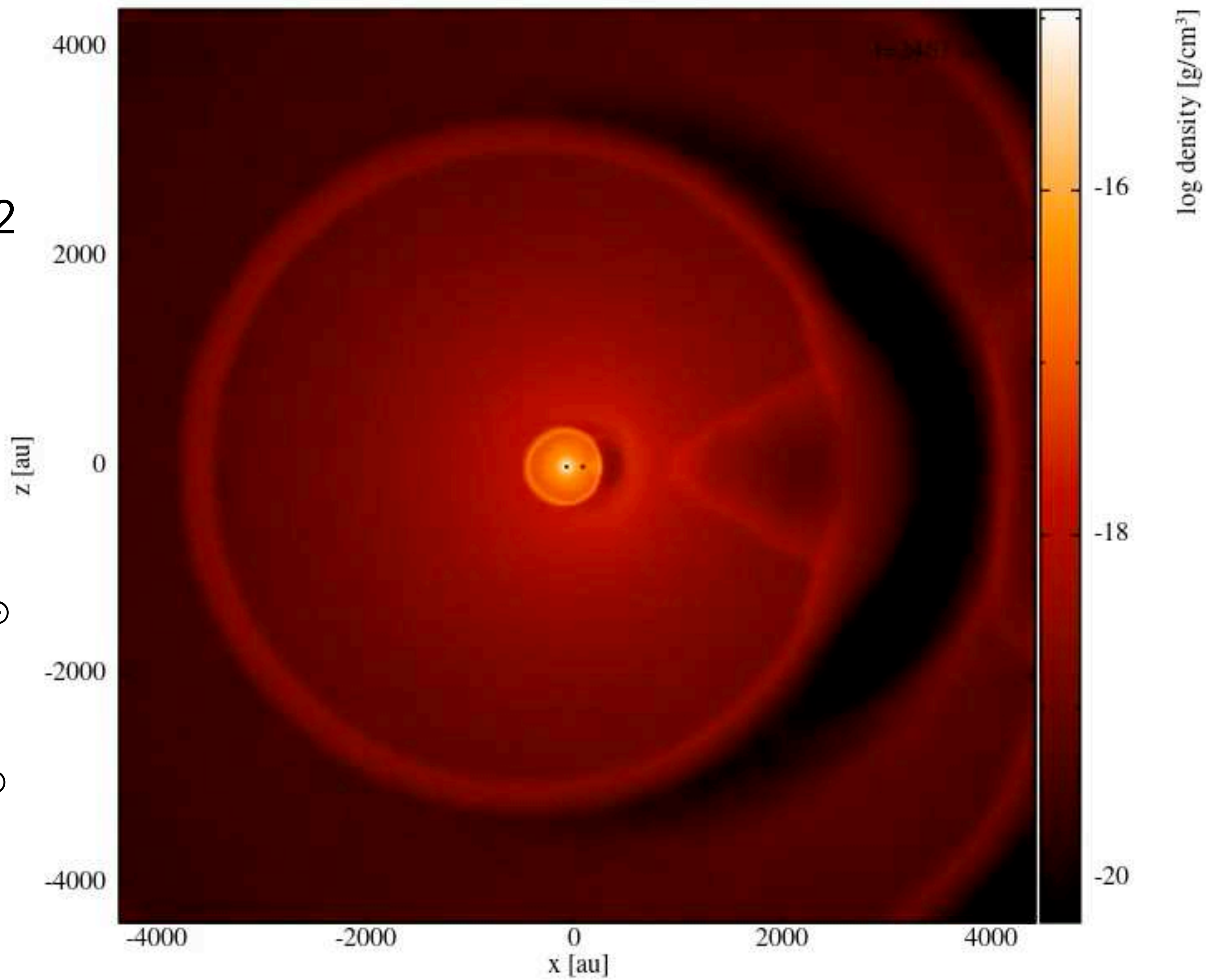
Thanks to Jolien Malfait

Eccentricity = 0.92

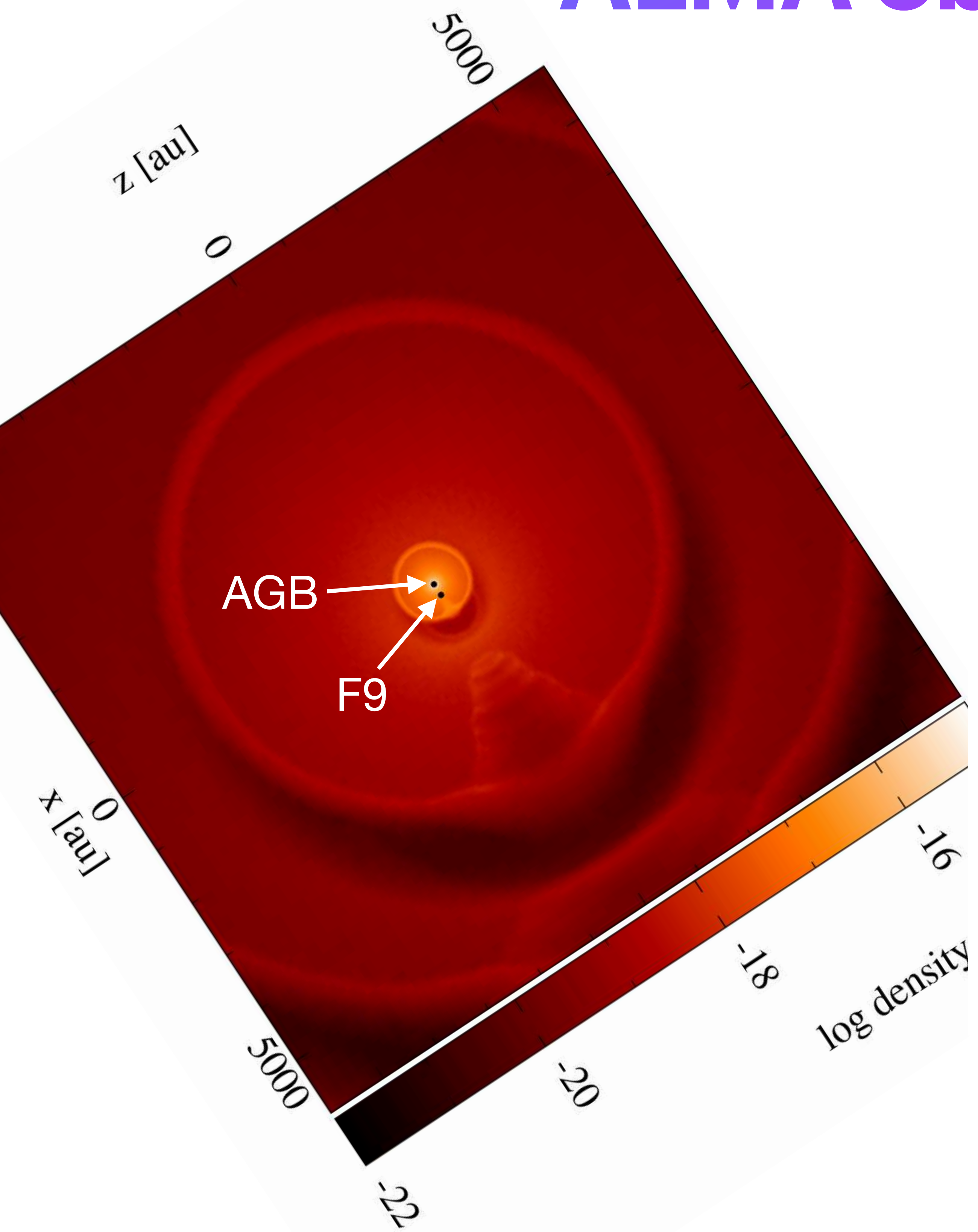
Semimajor axis = 125 AU

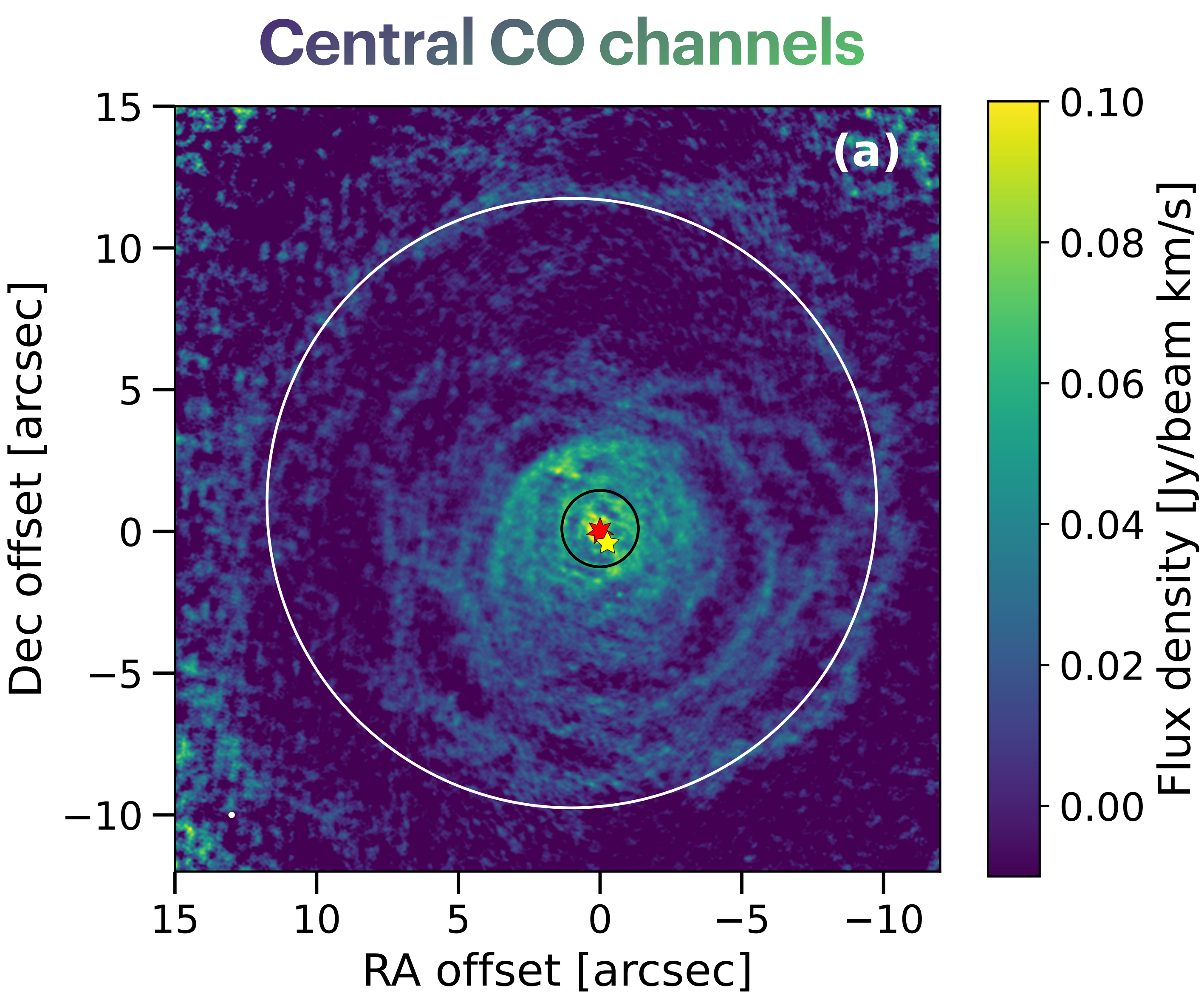
AGB mass = 1.6 $M_\odot$

F9 mass = 1.06 $M_\odot$



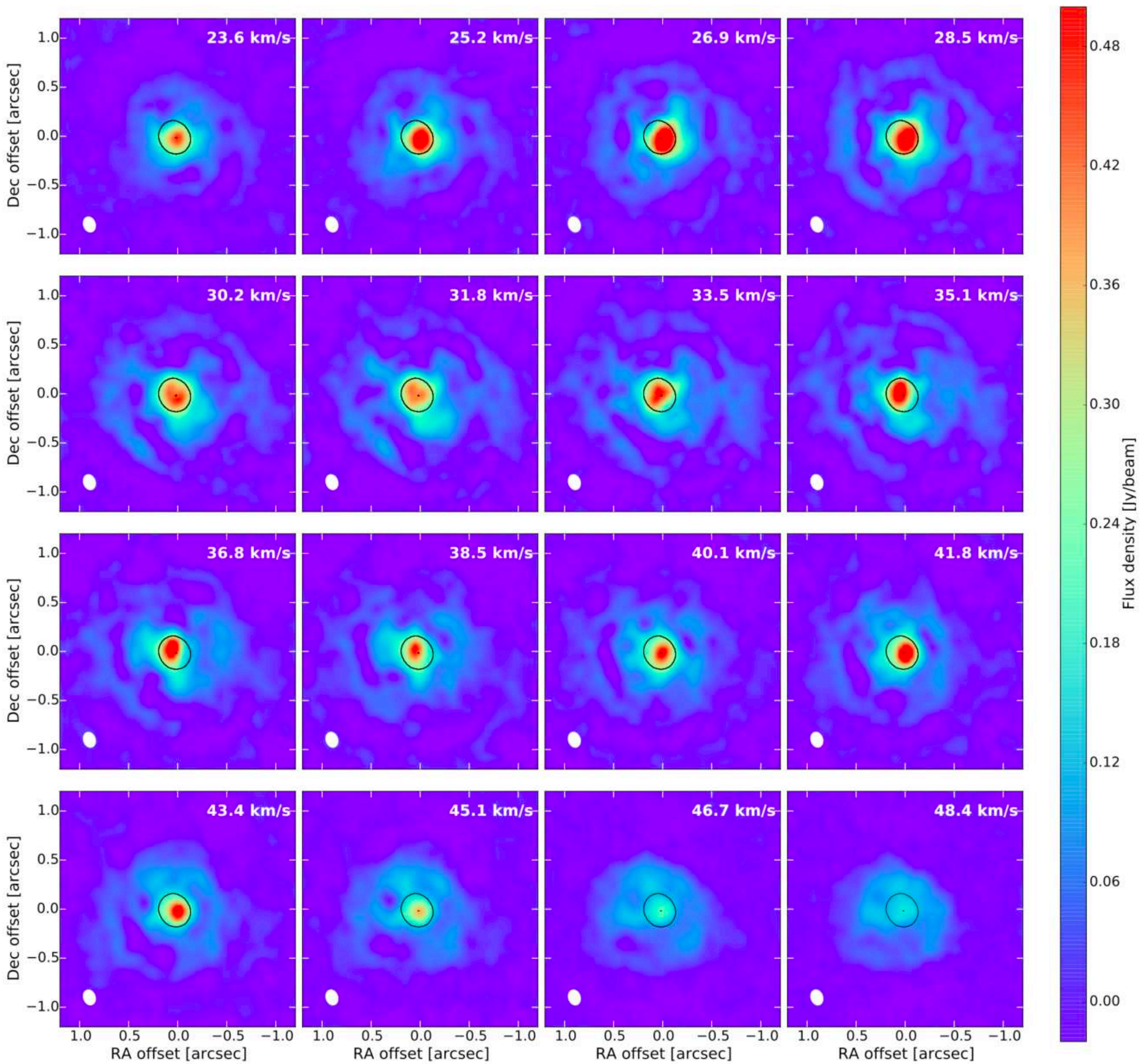
Comparison between Phantom and ALMA observations





IK Tau

A very surveyed oxygen-rich AGB star



- Channel maps of HCN show spiral-like structure (Decin et al 2018)
- Similar structure is seen in CO but with more resolved-out flux

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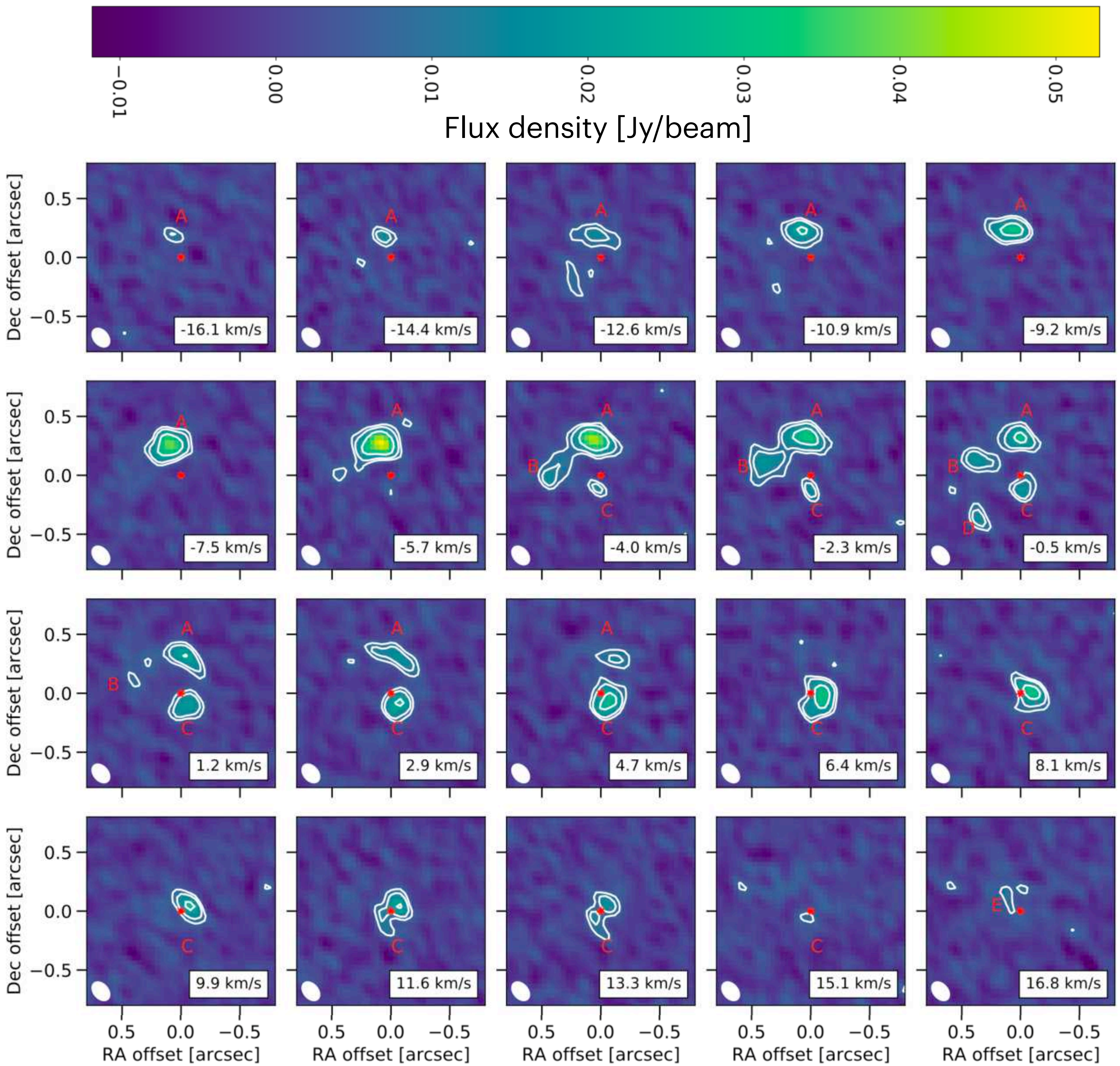
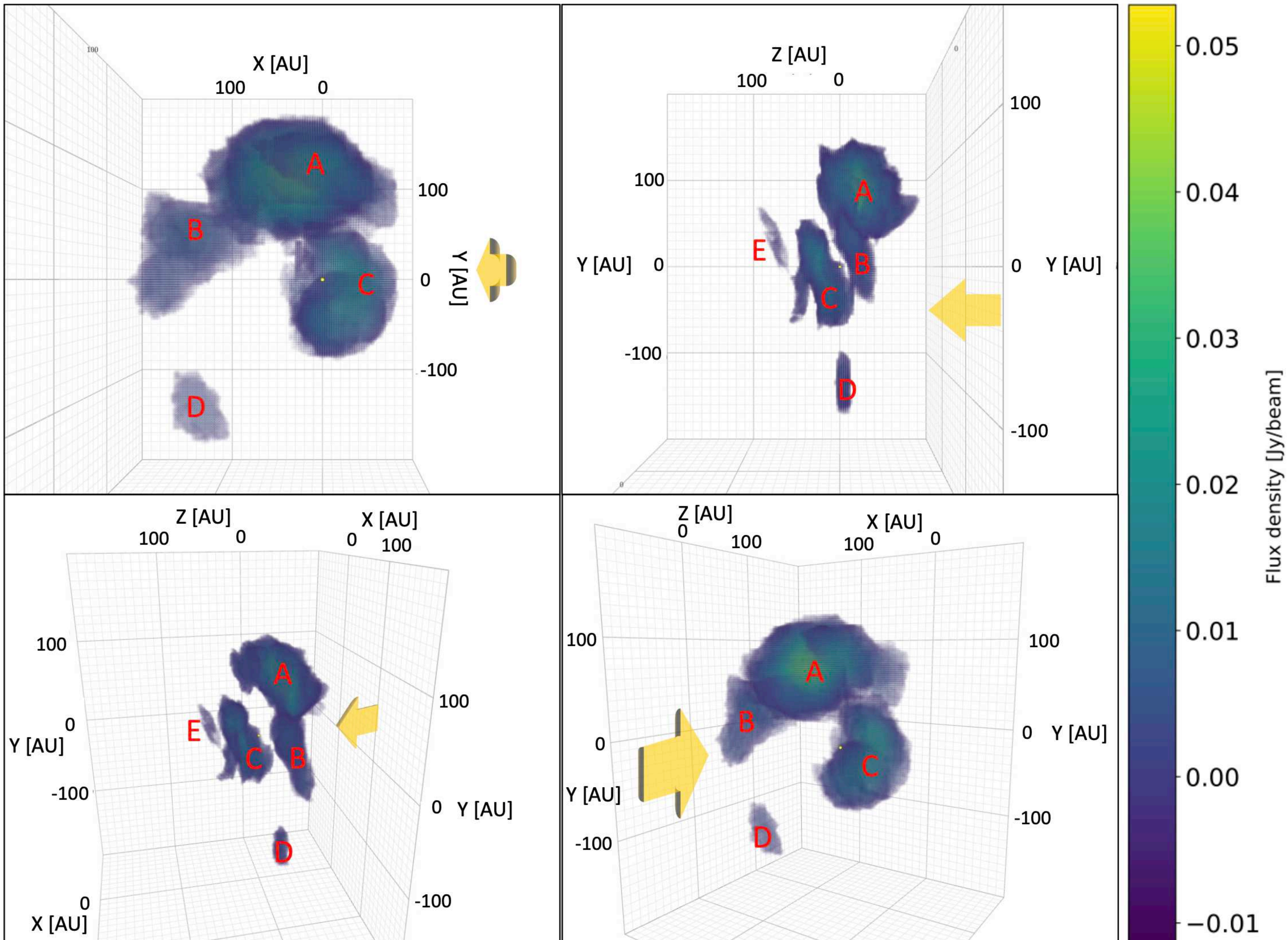


- Channel maps of HCN and CO show spiral-like structure (Decin et al 2018)
- NaCl shows clumpy structure not centred on the star (Coenegrachts et al, *submitted*)

NaCl in clumps around IK Tau

Coenegrachts et al, submitted to A&A



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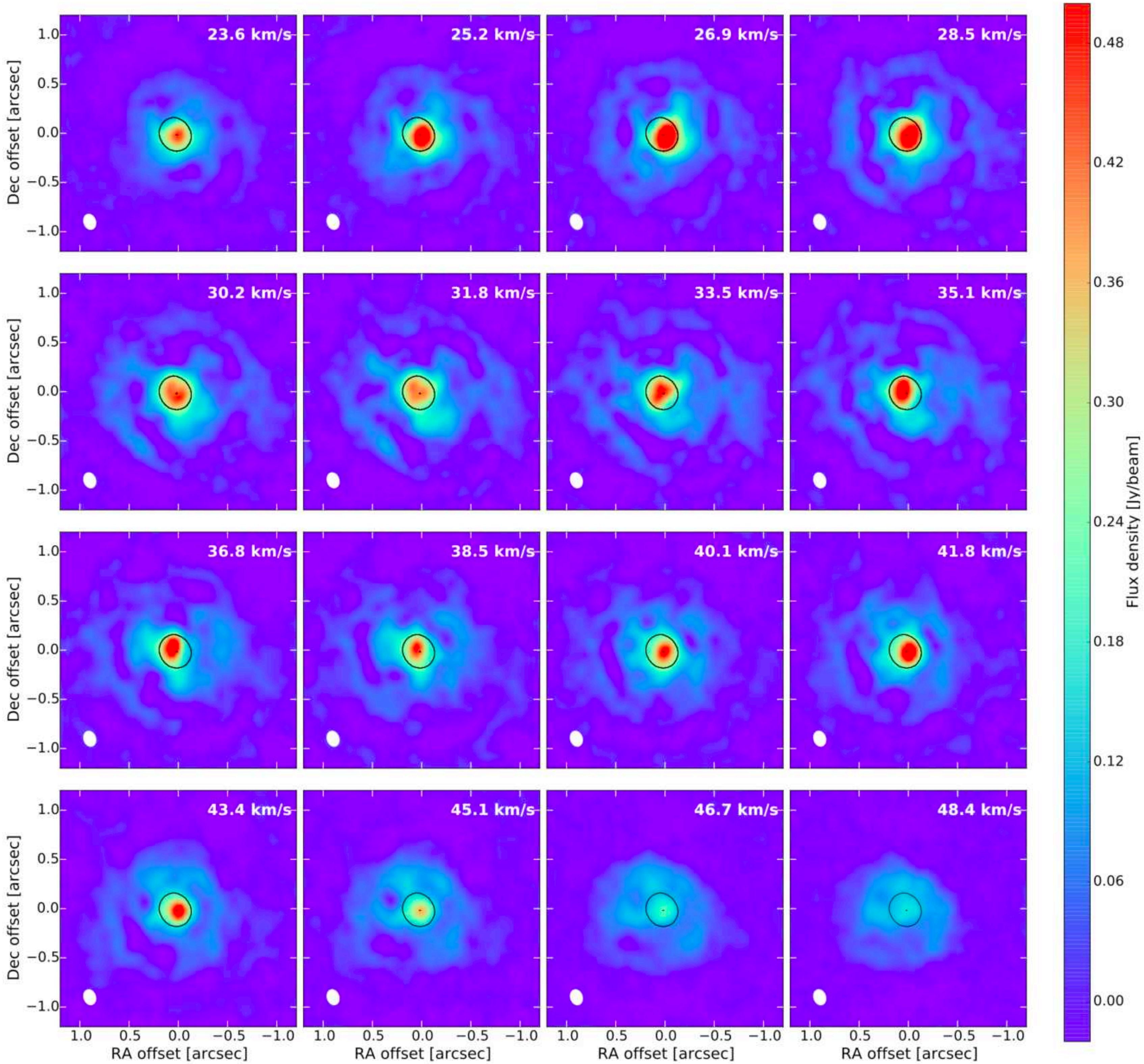

- Understanding NaCl structure could help us understand the more complicated structures seen in HCN and CO etc emission.

Conclusions

And take-home message

- CO is a good tracer of structure and density…
- But it's not the only molecule we have at our disposal.
- Examining other molecular tracers can give valuable insights into the dynamics and interactions of binary systems.
- Once the chemical details are understood for AGB stars, can apply them to more complicated environments.