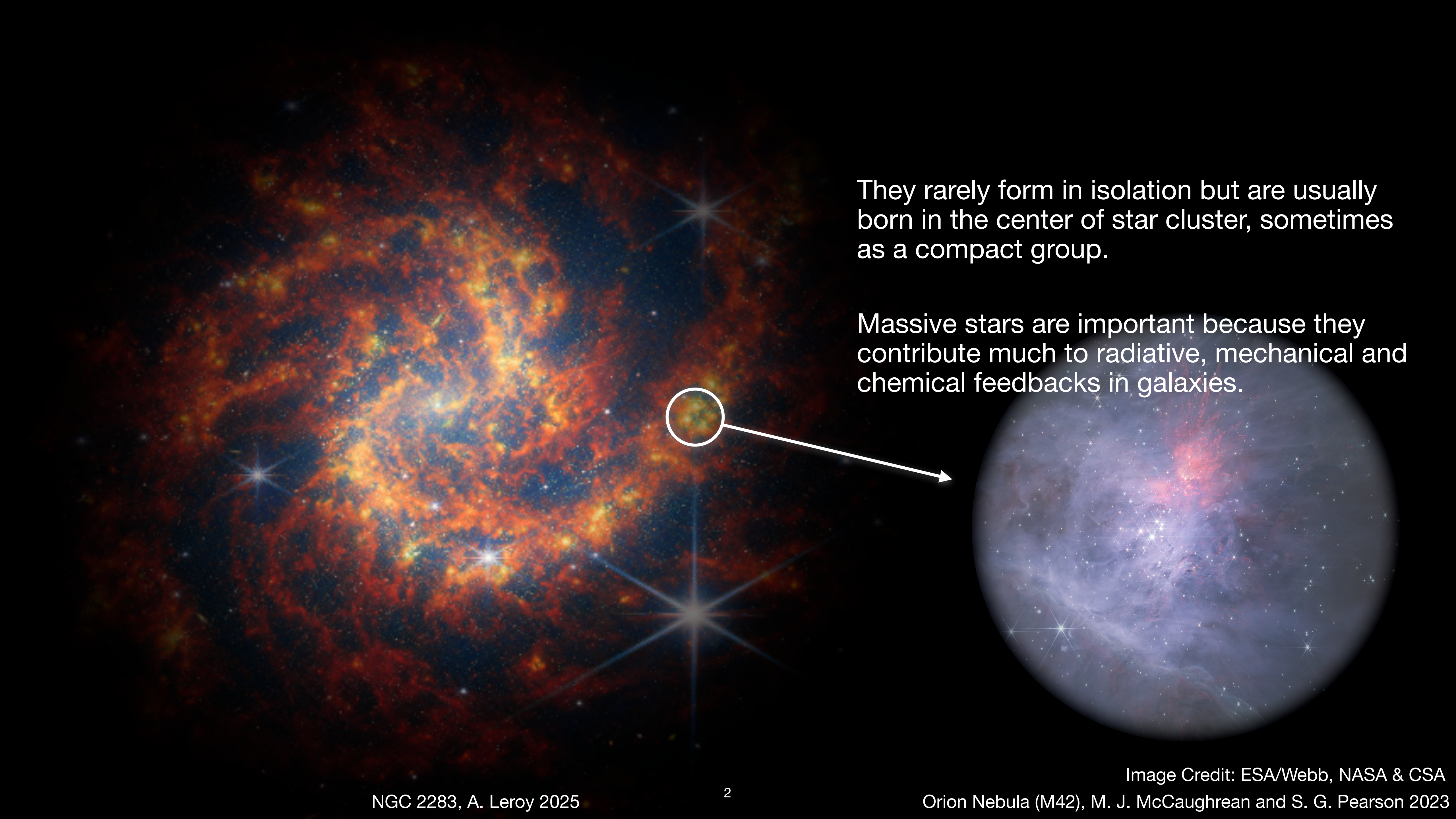


A Forming Quadruple Massive Stellar System

We capture a key snapshot of a compact OB quadruple stellar system, likely the progenitor of Orion Trapezium, but much further away and more embedded...

Presenter: Fengwei Xu 🍁 (PFE postdoc at MPIA, fengwei@mpia.de)

Collaborators: Henrik Beuther, Mark McCaughrean, Tie Liu, Yichen Zhang, Paul F. Goldsmith, Hauyu Baobab Liu, Guido Garay, Keping Qiu, Shanghuo Li, Qizhou Zhang, Di Li, Jingwen Wu, Kee-Tae Kim, Ken'ichi Tatematsu, Siju Zhang, Dezhao Meng, Zhihao Fu, Xiaofeng Mai, Sihan Jiao, Wenyu Jiao, André Oliva, Dongting Yang, and Ke Wang



They rarely form in isolation but are usually born in the center of star cluster, sometimes as a compact group.

Massive stars are important because they contribute much to radiative, mechanical and chemical feedbacks in galaxies.





Orion Trapezium
Main members



Orion Trapezium - a compact OB quadruple system

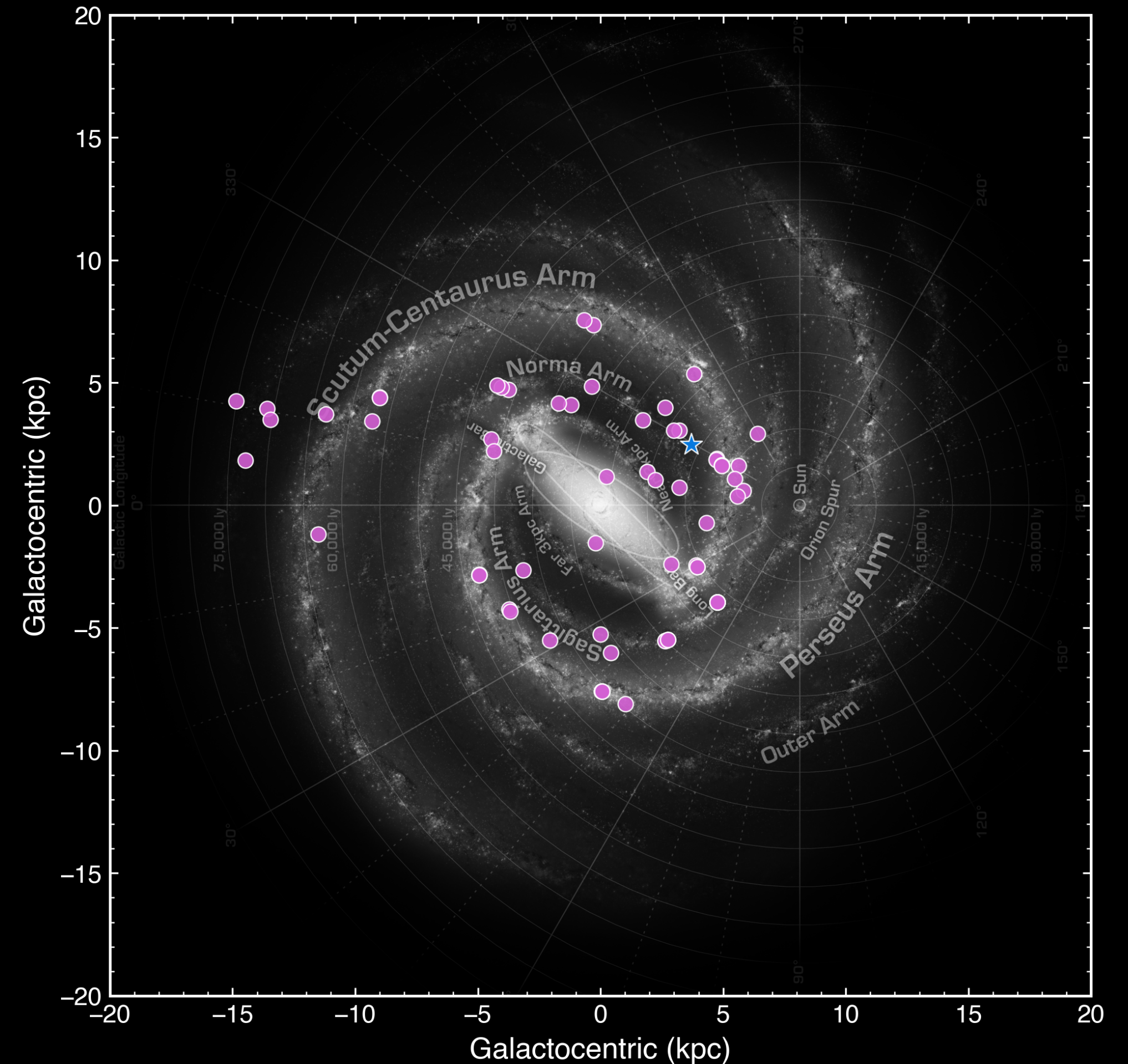
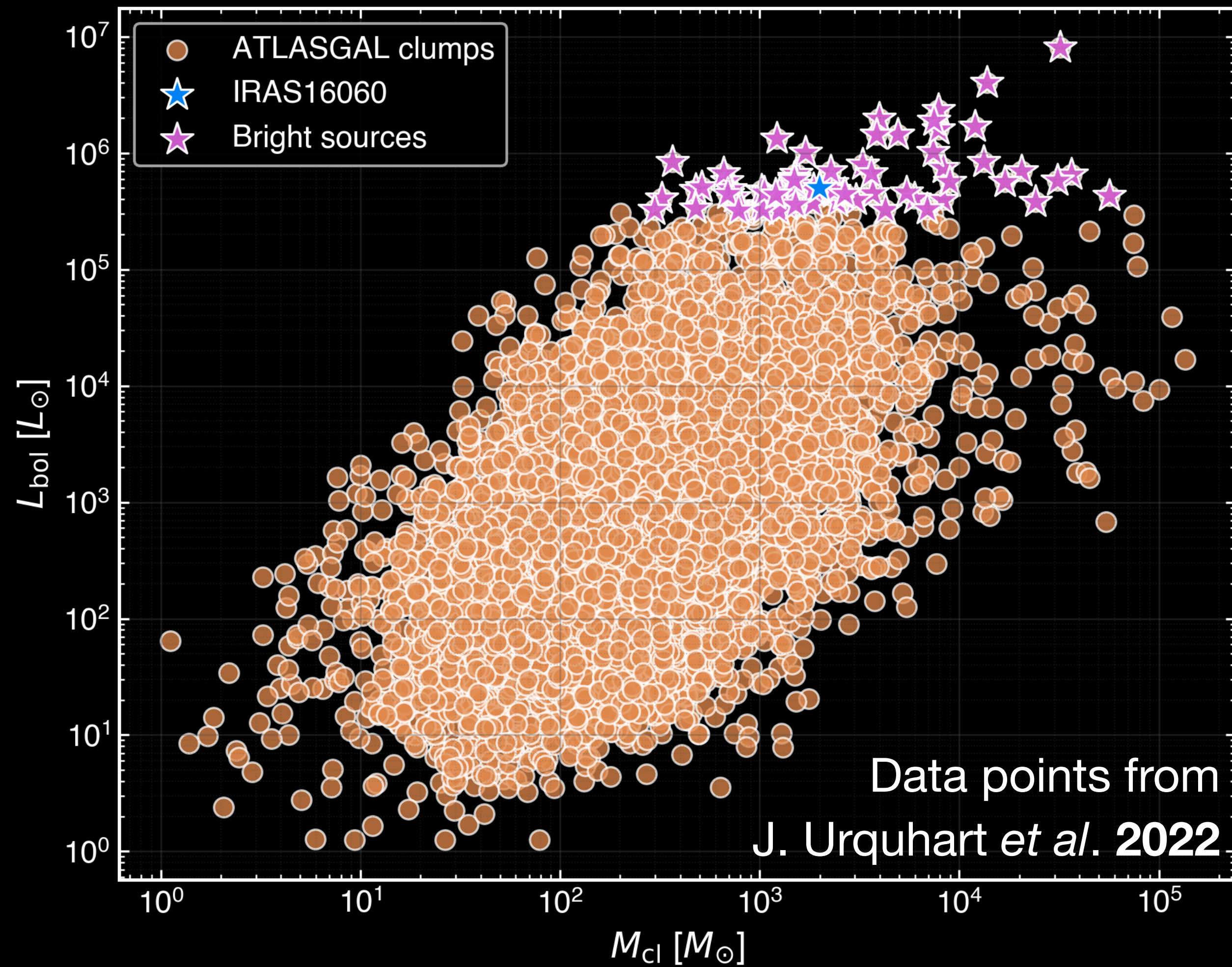
Primordial formation by converging gas flows?
(E. Vázquez-Semadeni et al. 2019)

Embedded star clusters have the record of their formation
How does such compact OB system form?
(e.g., C. Lada & E. Lada 2003)

Dynamical relaxation from subclusters?
(R. Allison et al. 2007)

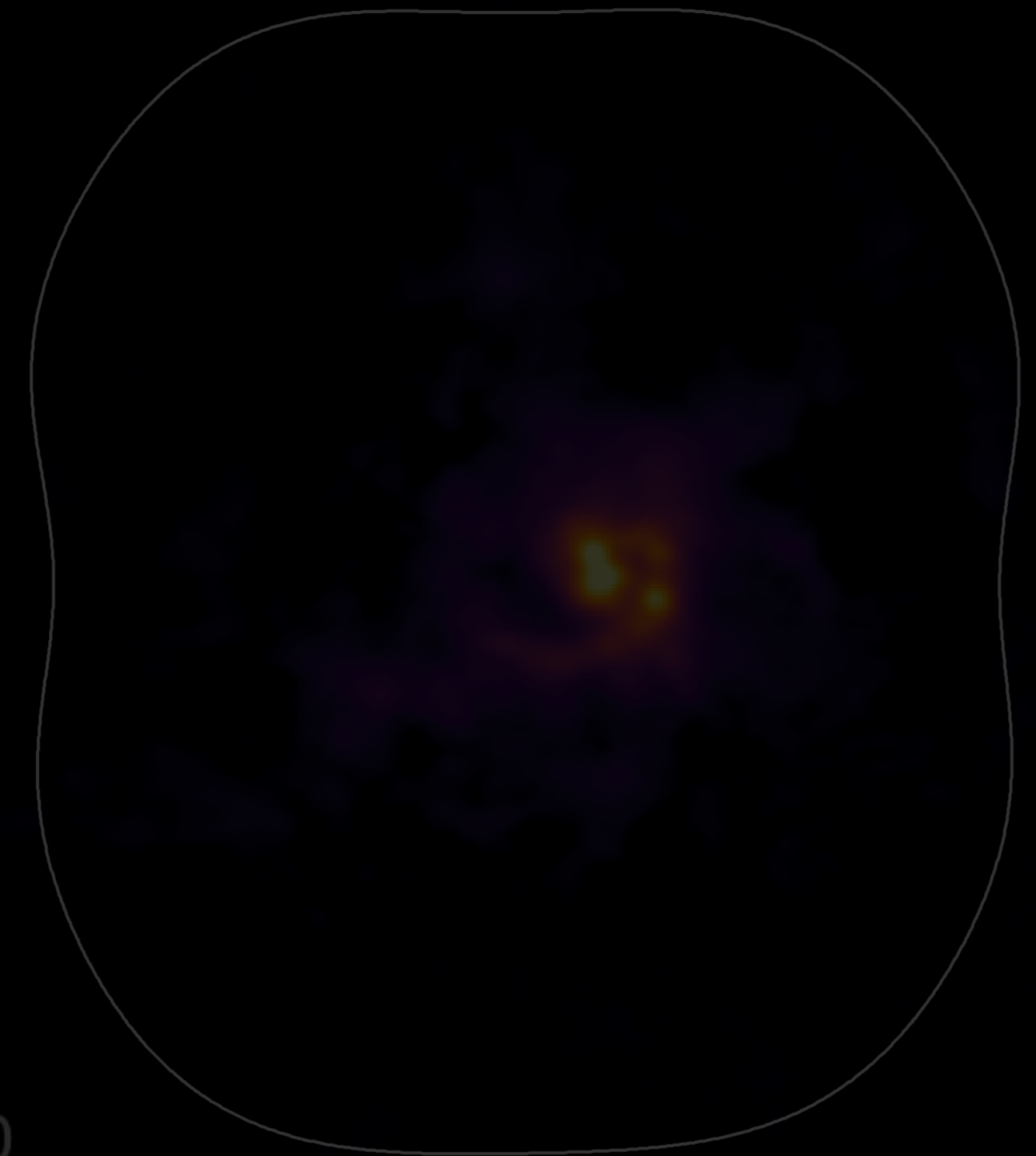
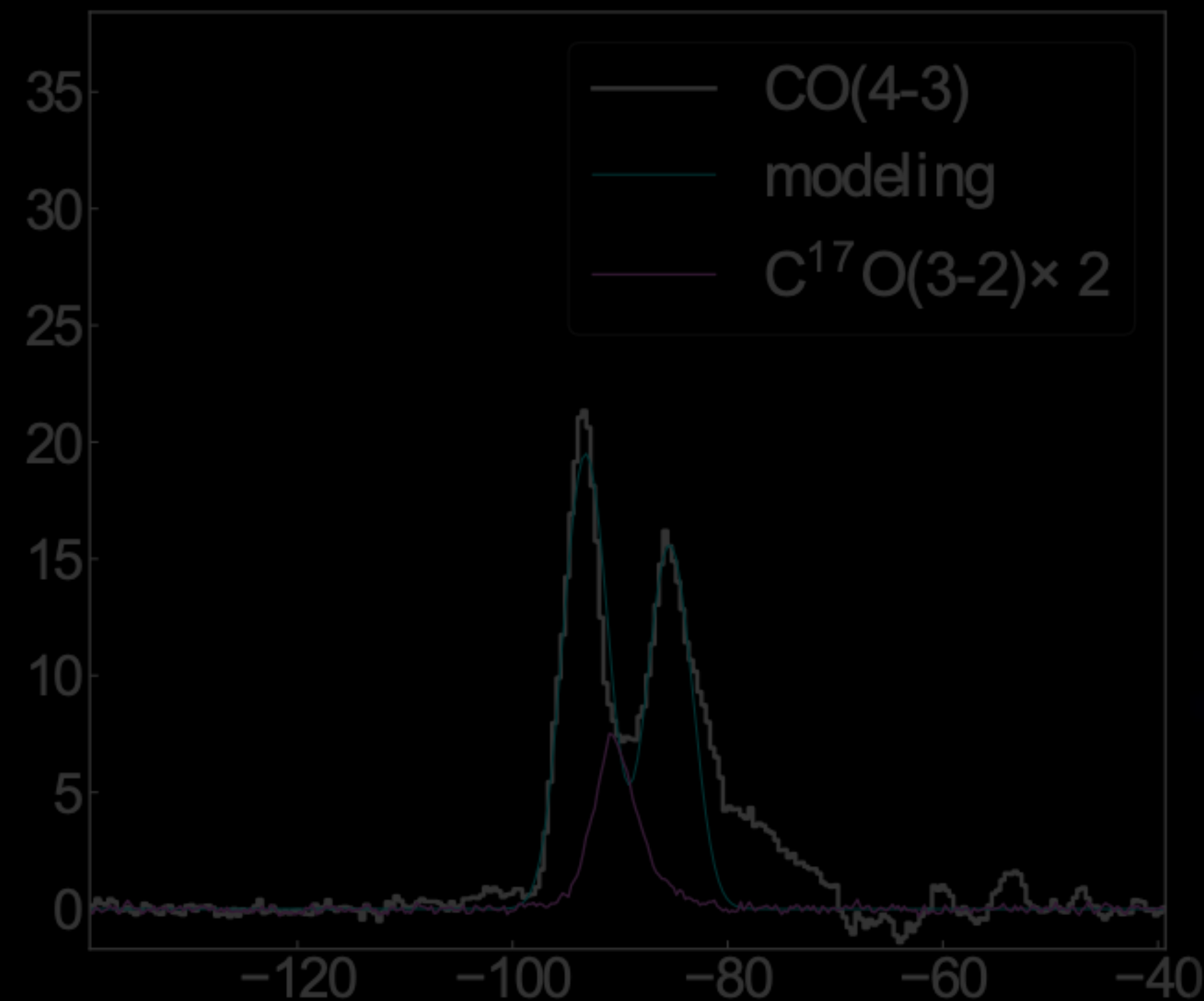
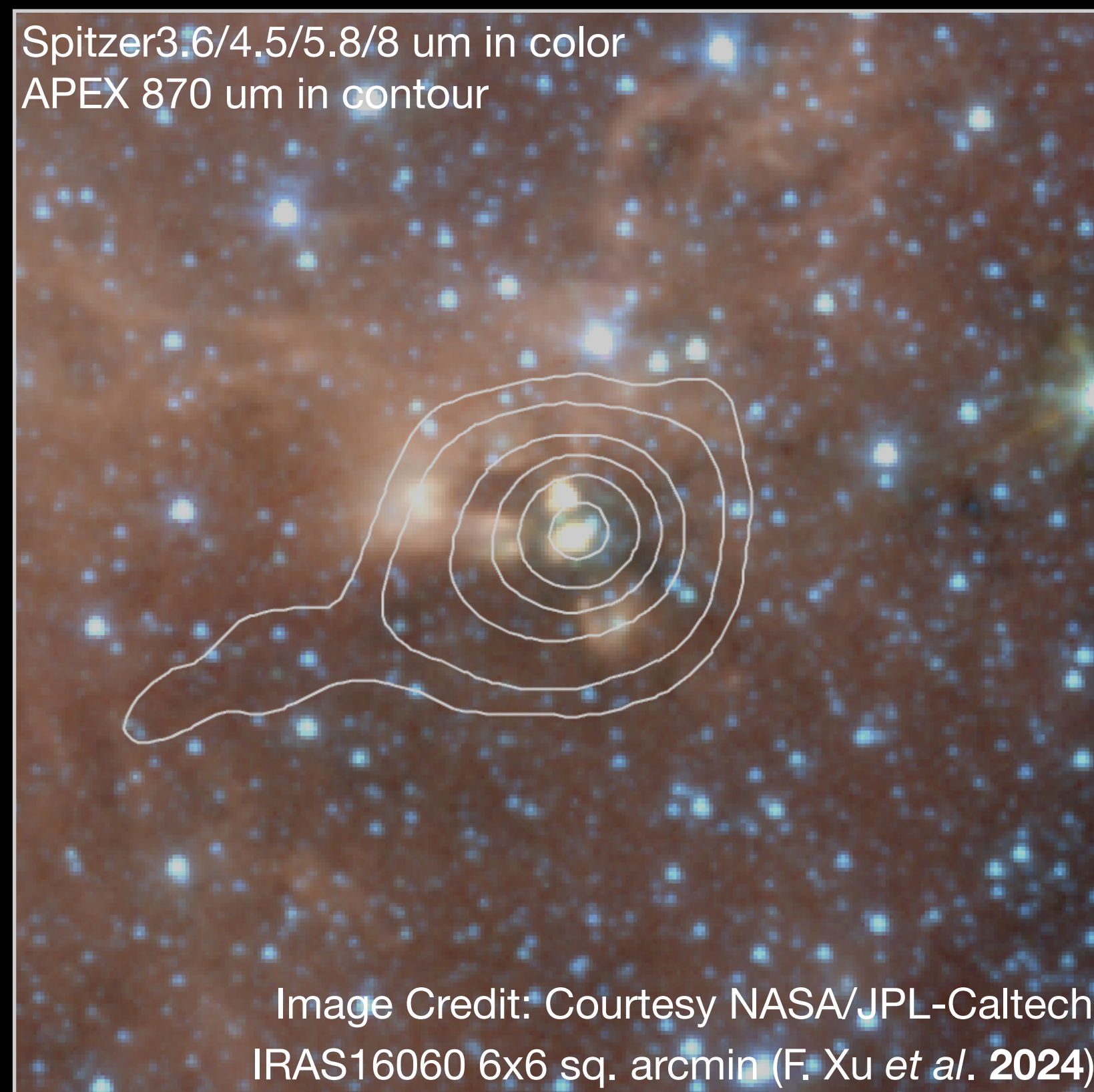
Serendipitous discovery of an OB quadruple

Most luminous star-forming regions throughout the Milky Way



Serendipitous discovery of an OB quadruple

IRAS16060: a promising candidate of a proto-OB cluster



High extinction $A_v \sim 1,000$
Large mass reservoir $M_{\text{enc}} \sim 2,140 M_{\odot}$

Atacama Large Millimeter/submillimeter Array (ALMA)

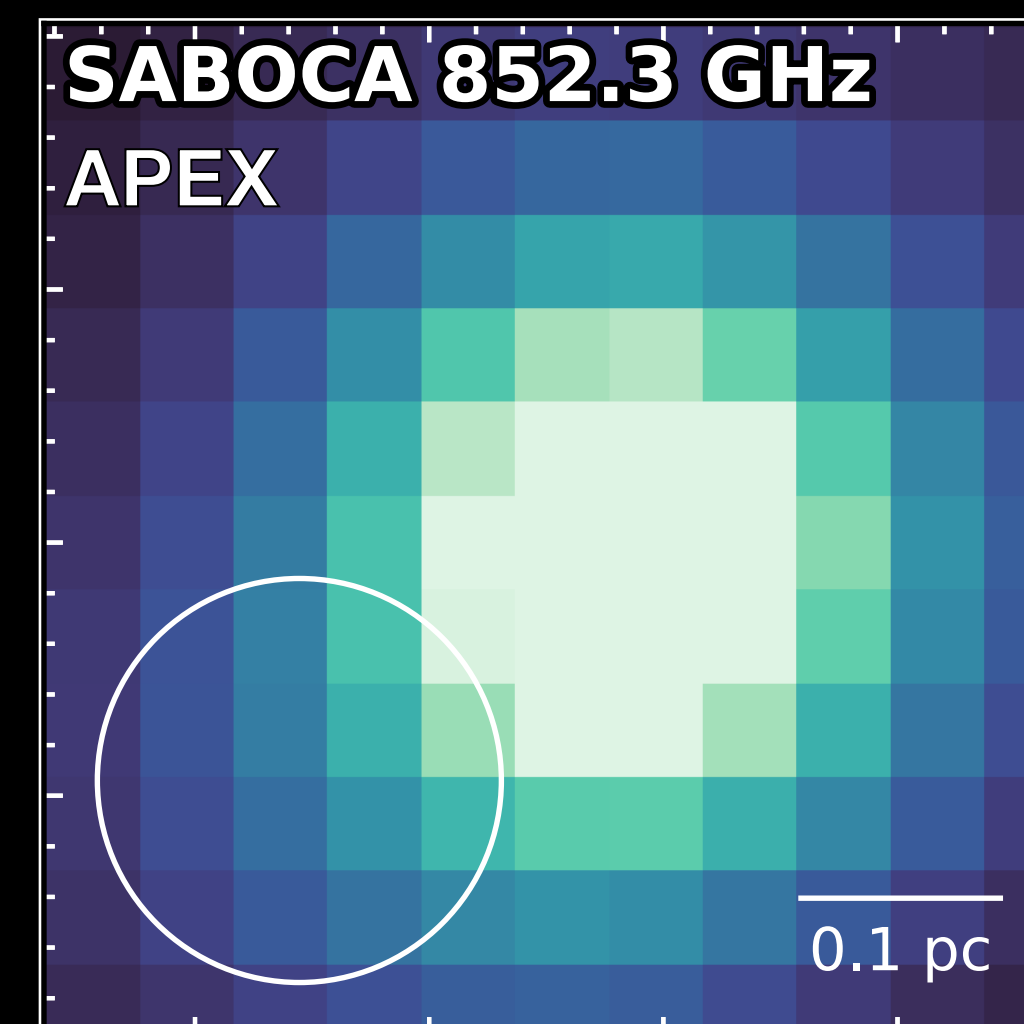
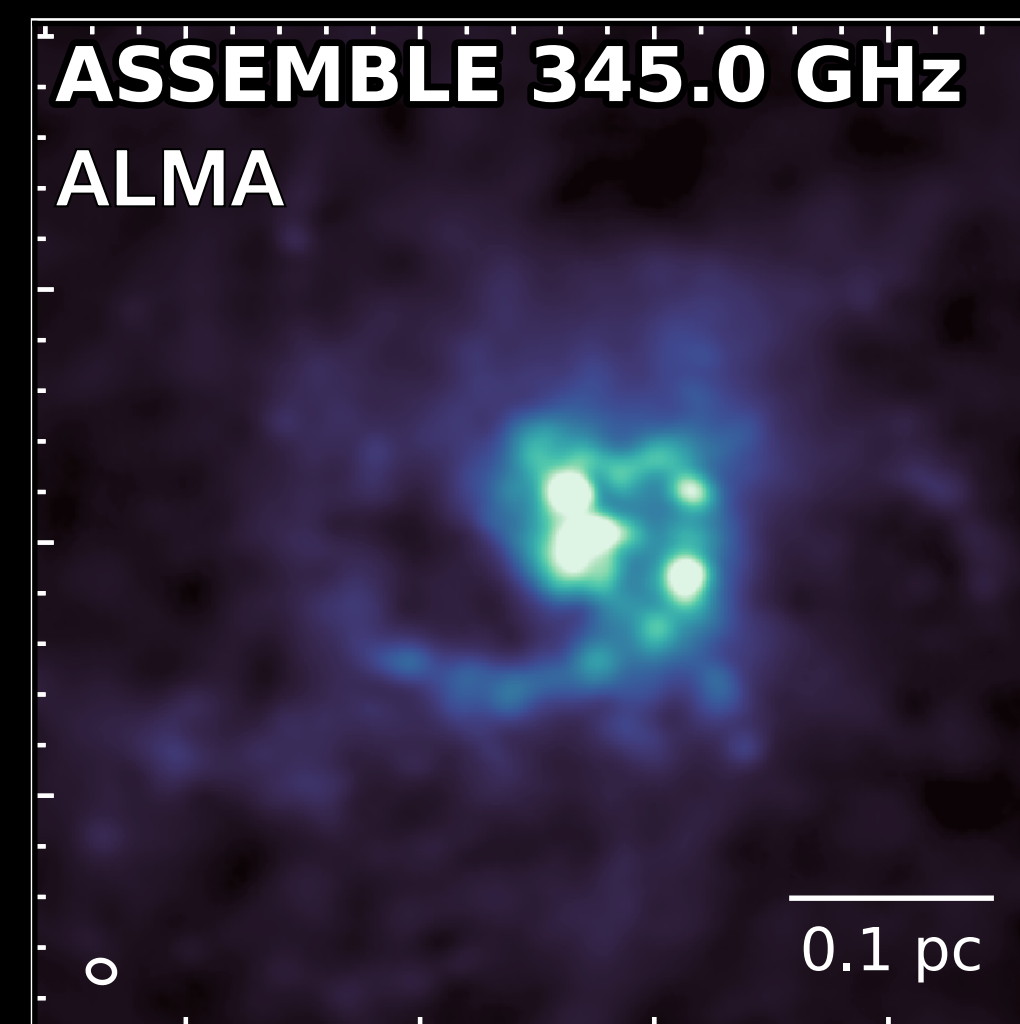
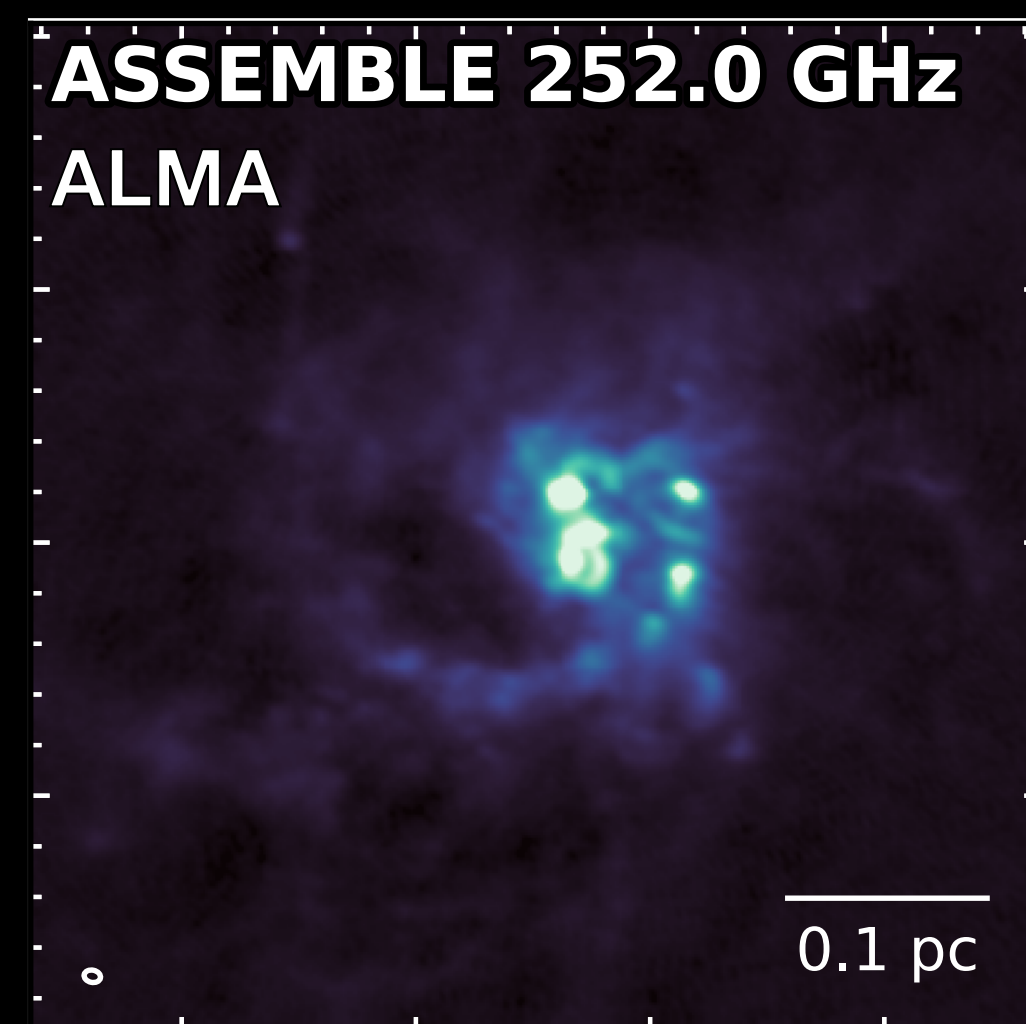
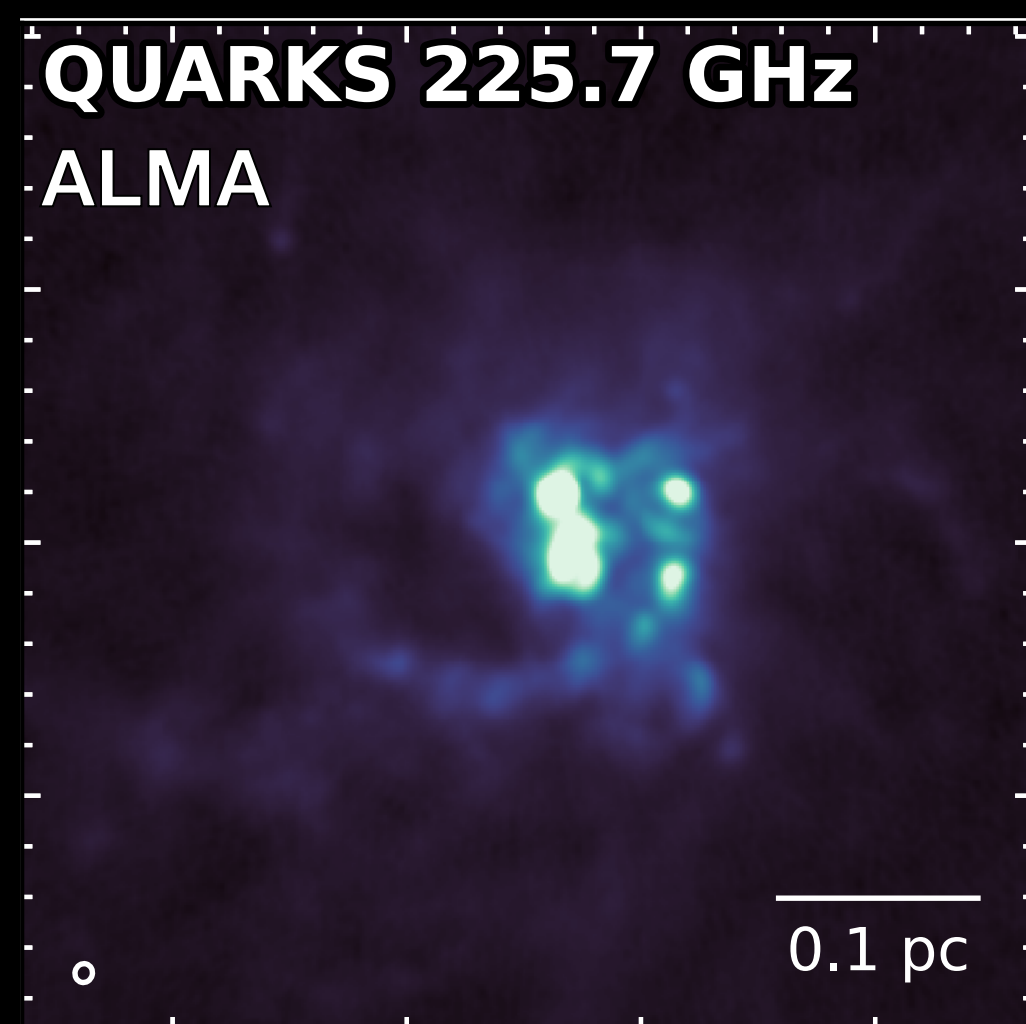
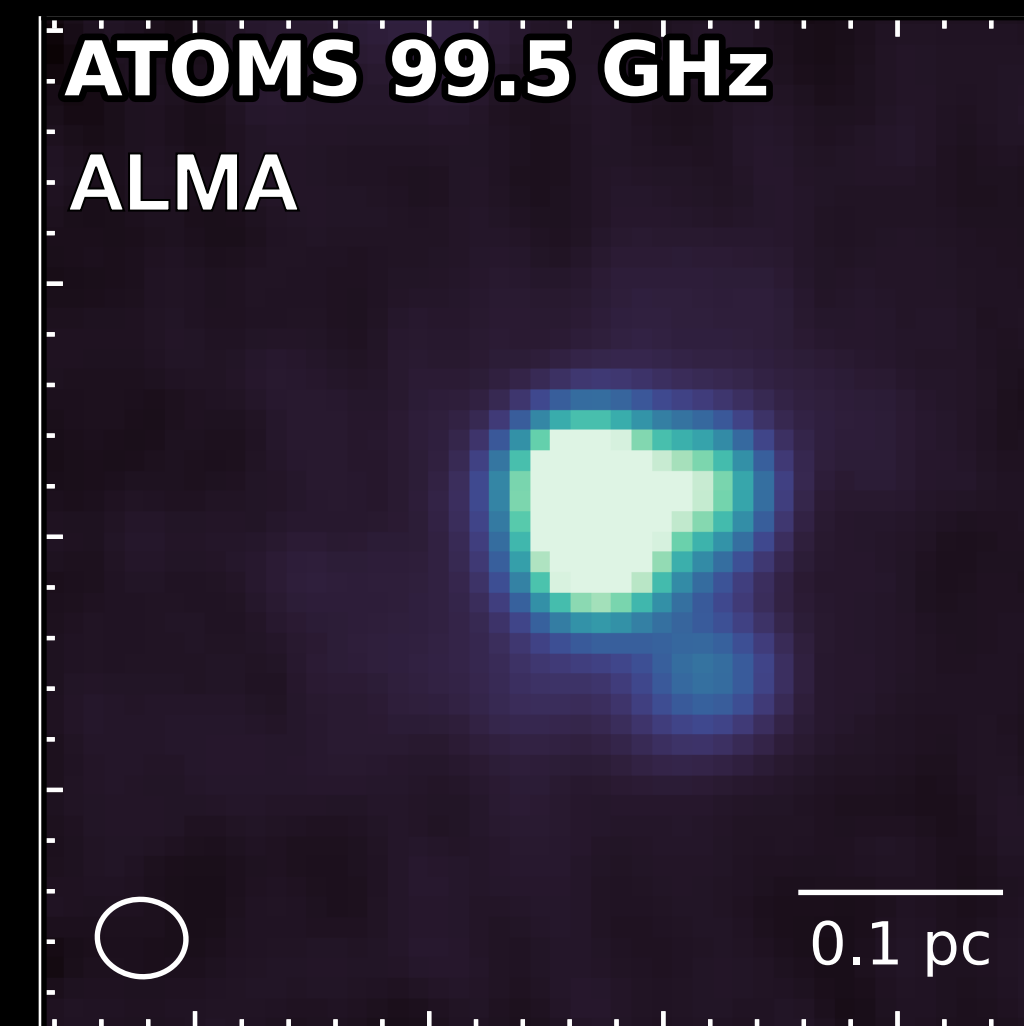
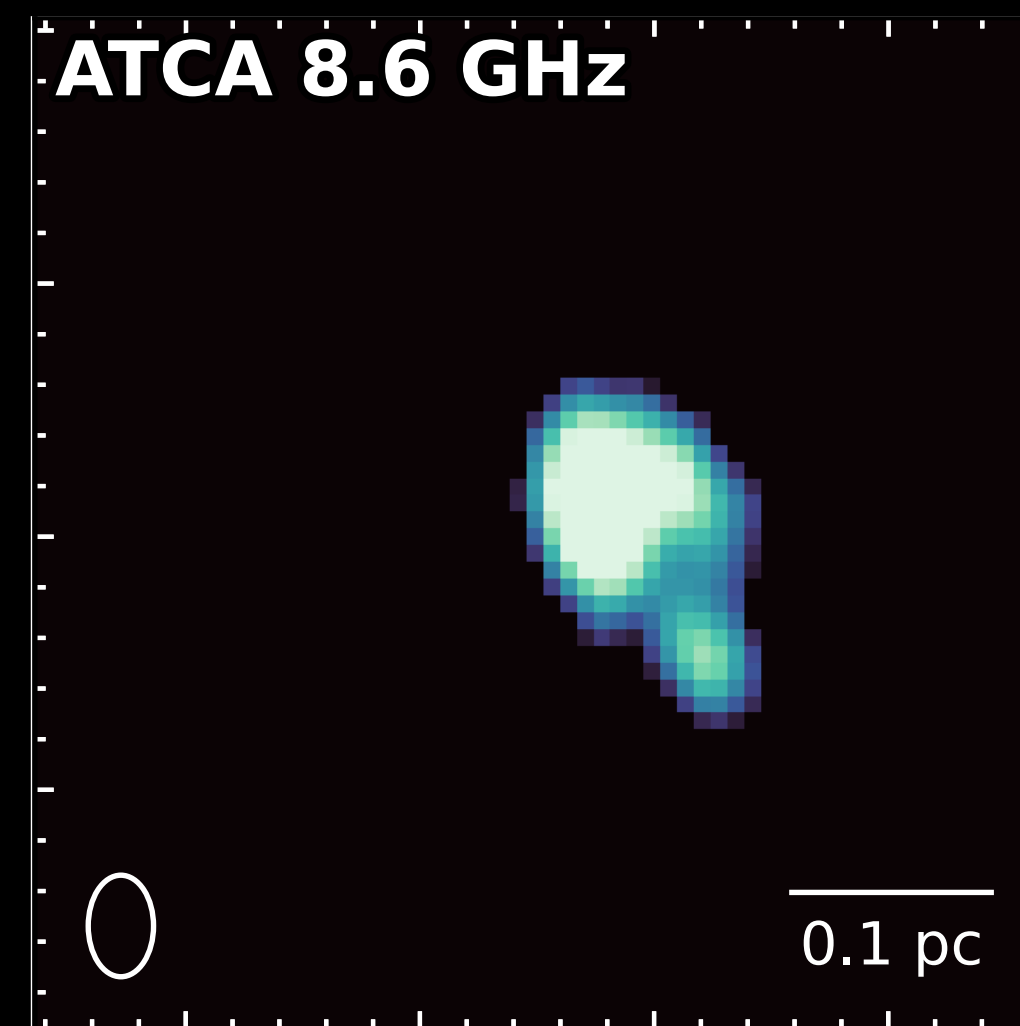
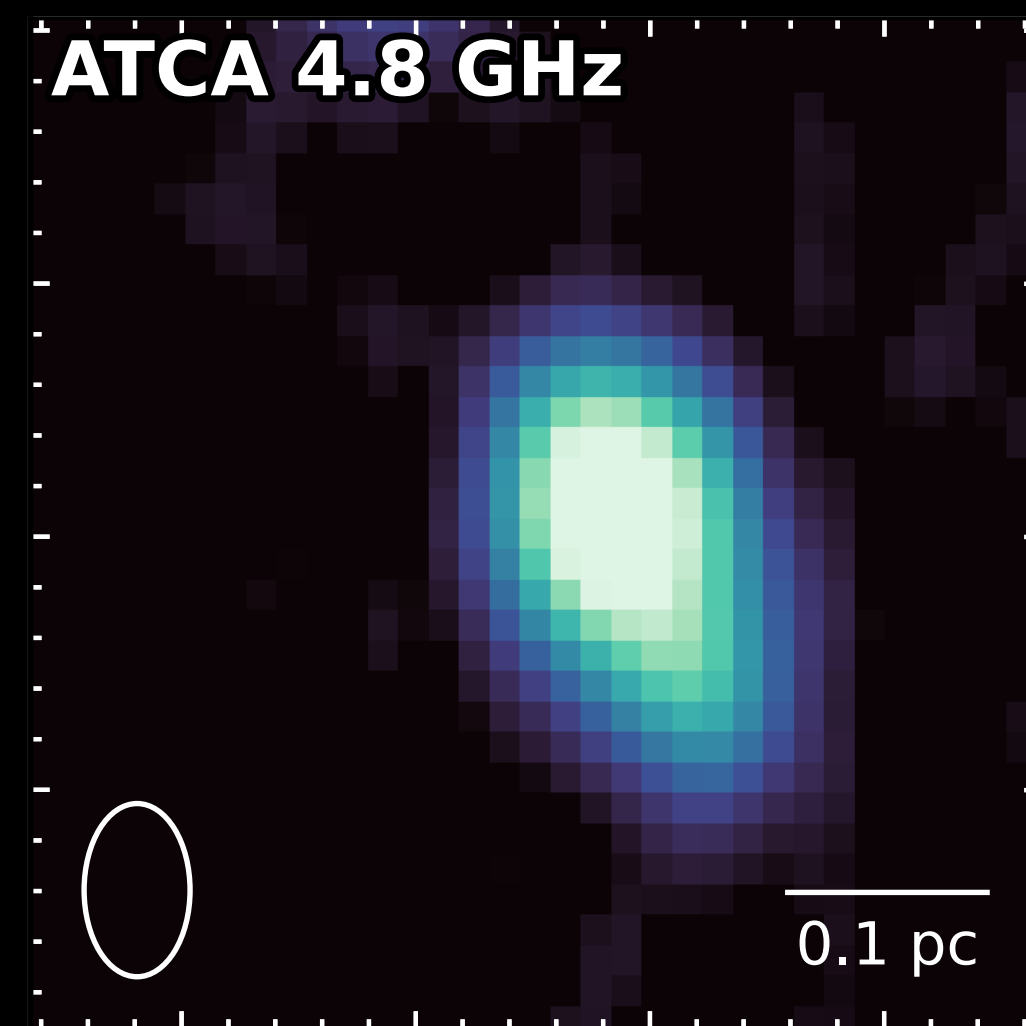
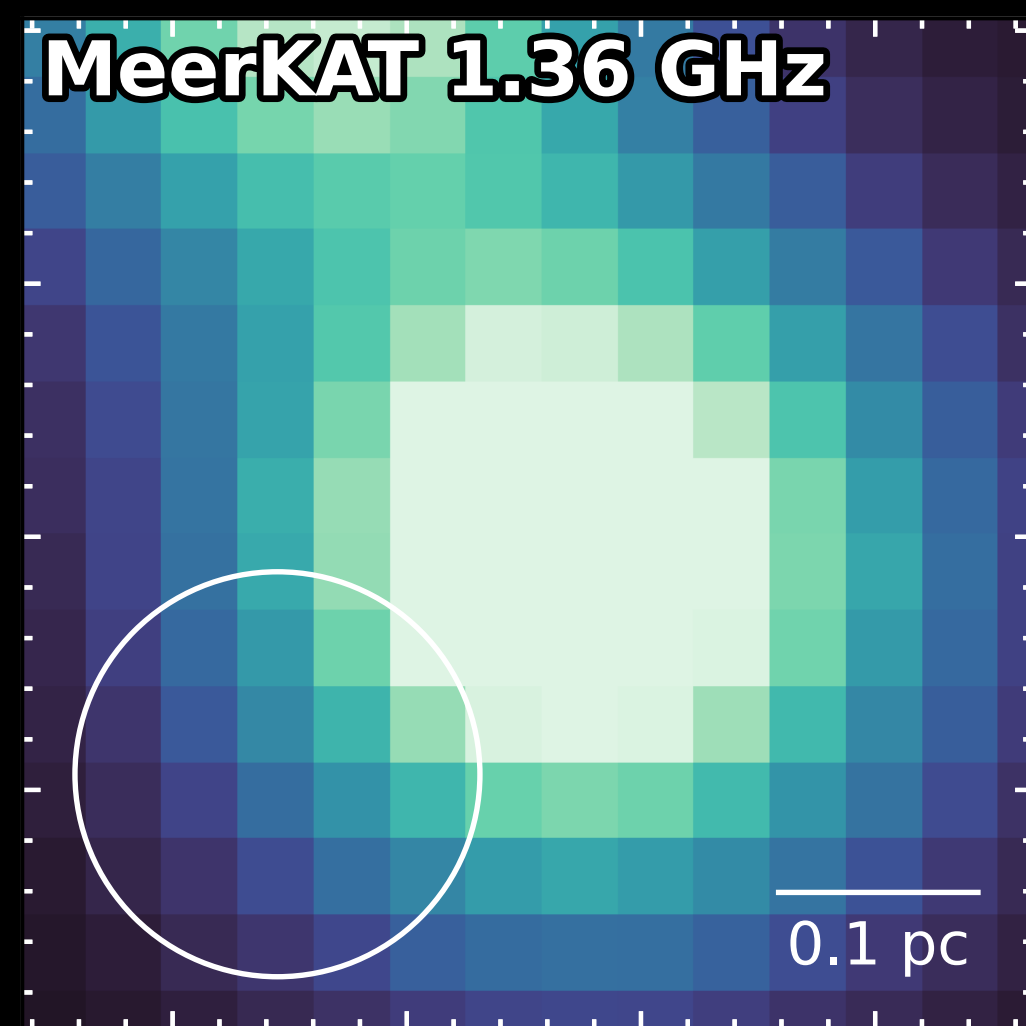
Wavelengths (mm)	3.0	1.3	1.2	0.9
Observing Dates	Nov. 2019	Mar. 2024	Jun. 2024	May. 2025
Baselines (meters)	9—500	9—400	15-1400	15-1400
Angular resolution (")	1.6	0.30	0.28	0.40

Outline

- Ion-neutral gas decomposition
- Gravitational potential
- Gas kinematics
- Energetics

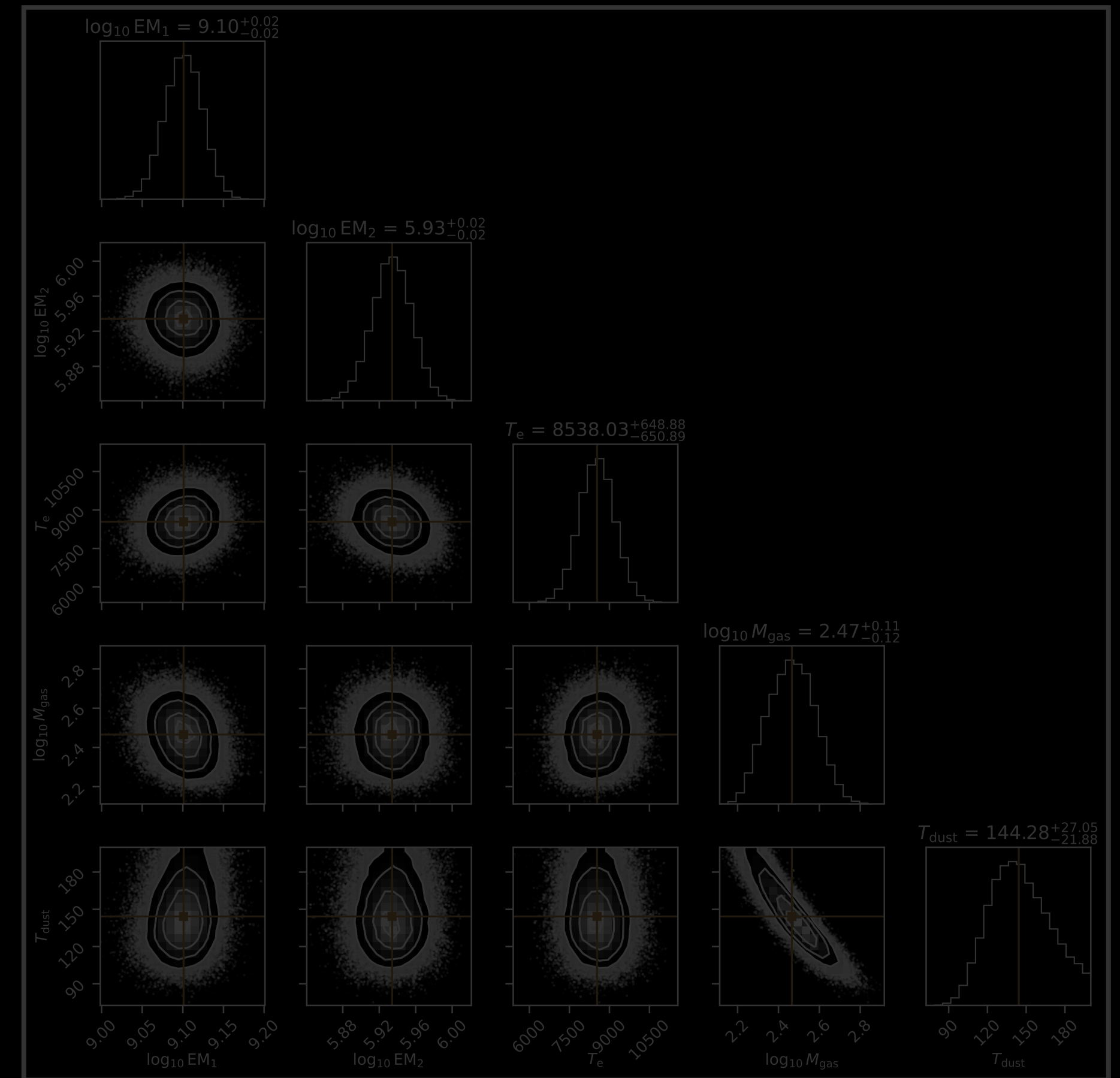
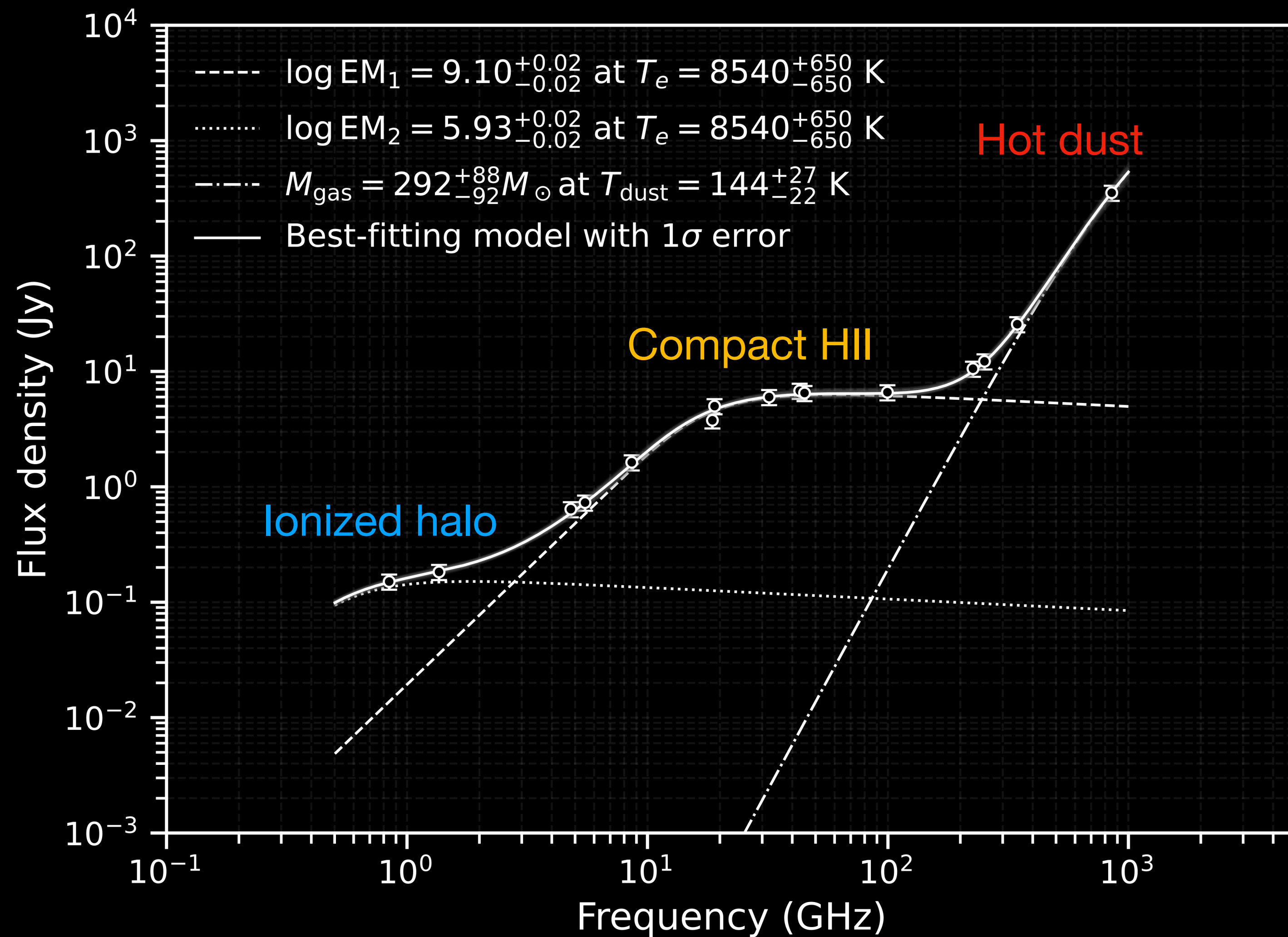
Ion-neutral gas decomposition

Broadband photometry of 0.84 – 850 GHz



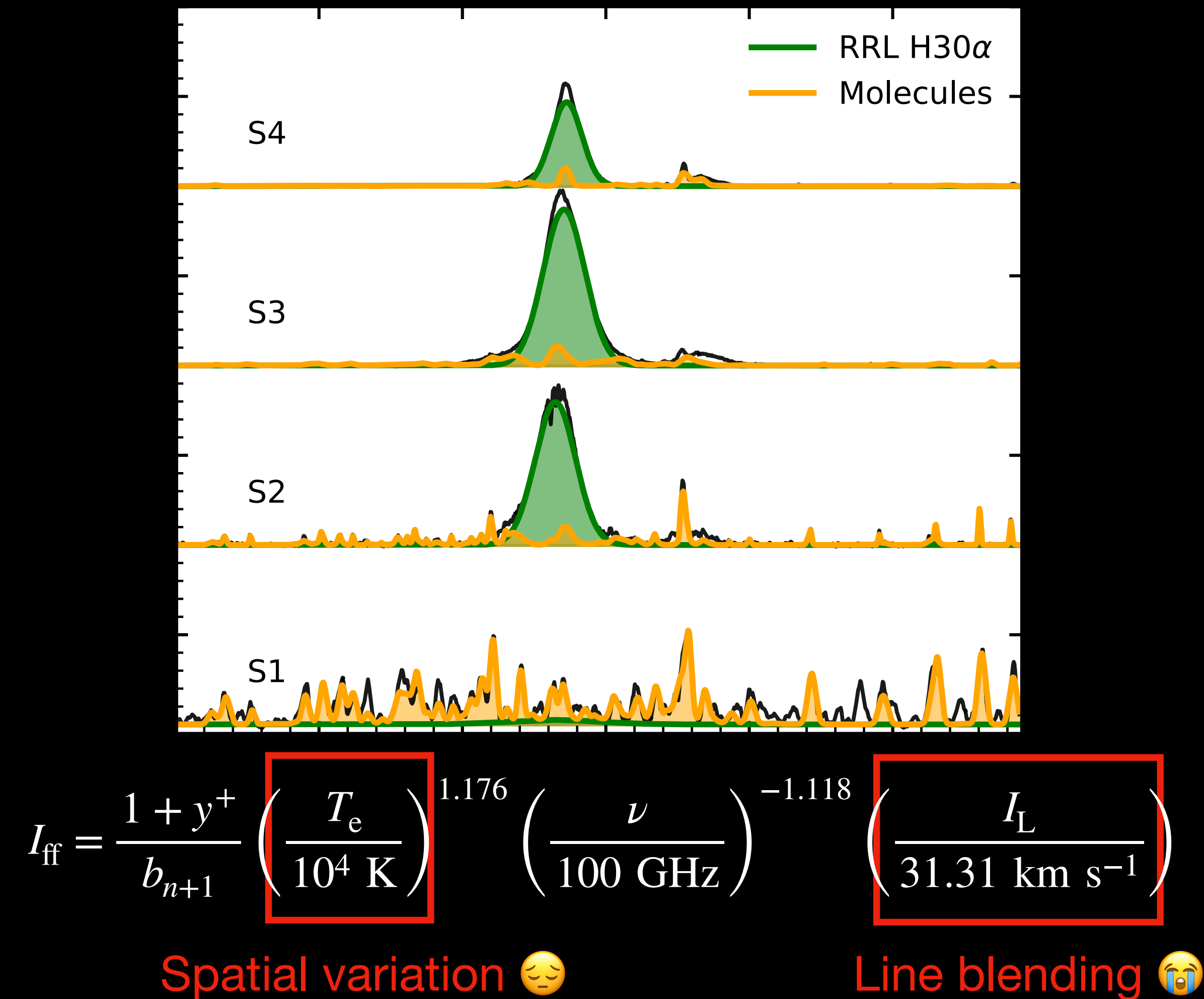
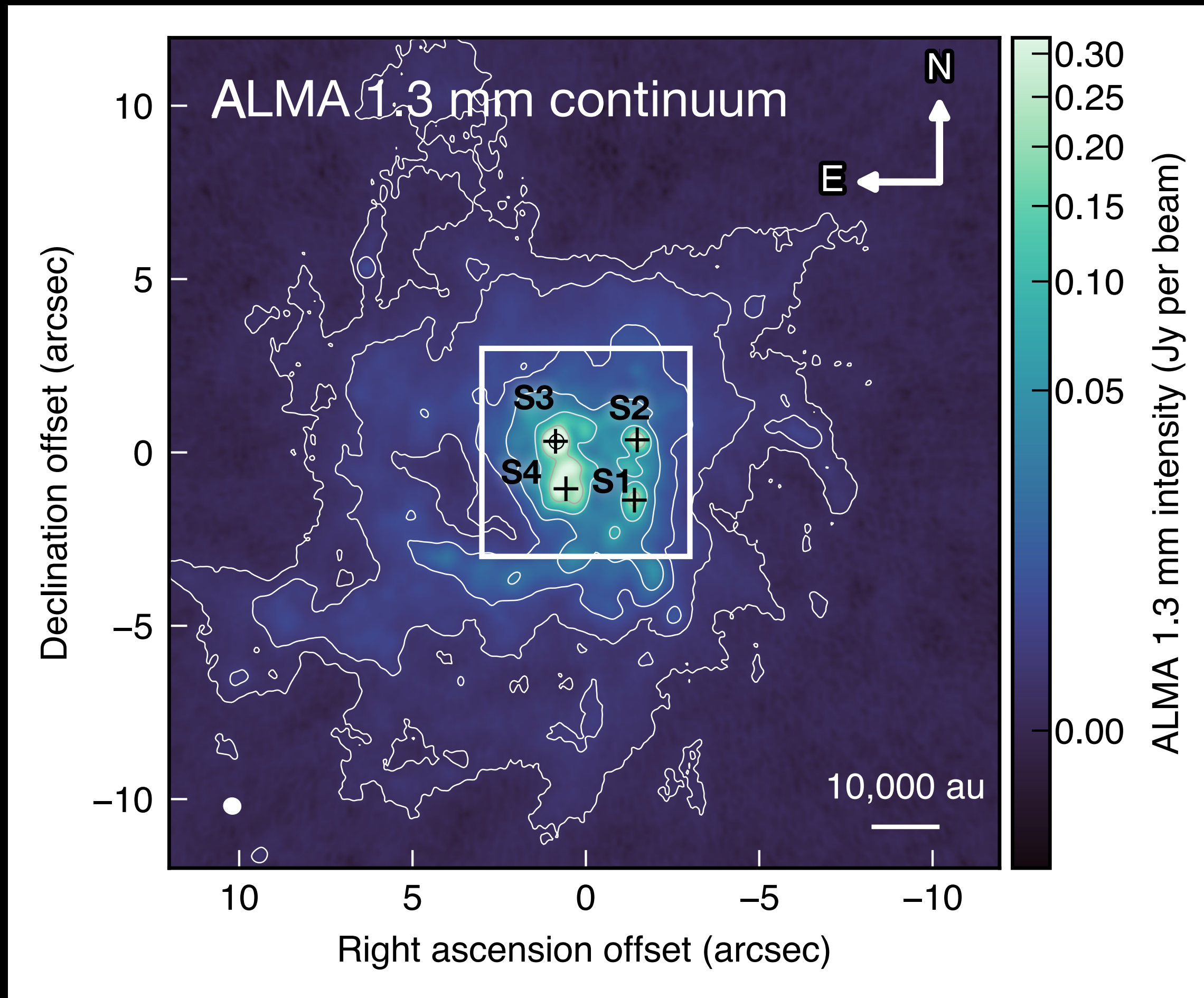
Integrated spectral energy distribution fitting

Ionized halo + **Compact HII** + **Hot dust envelope**



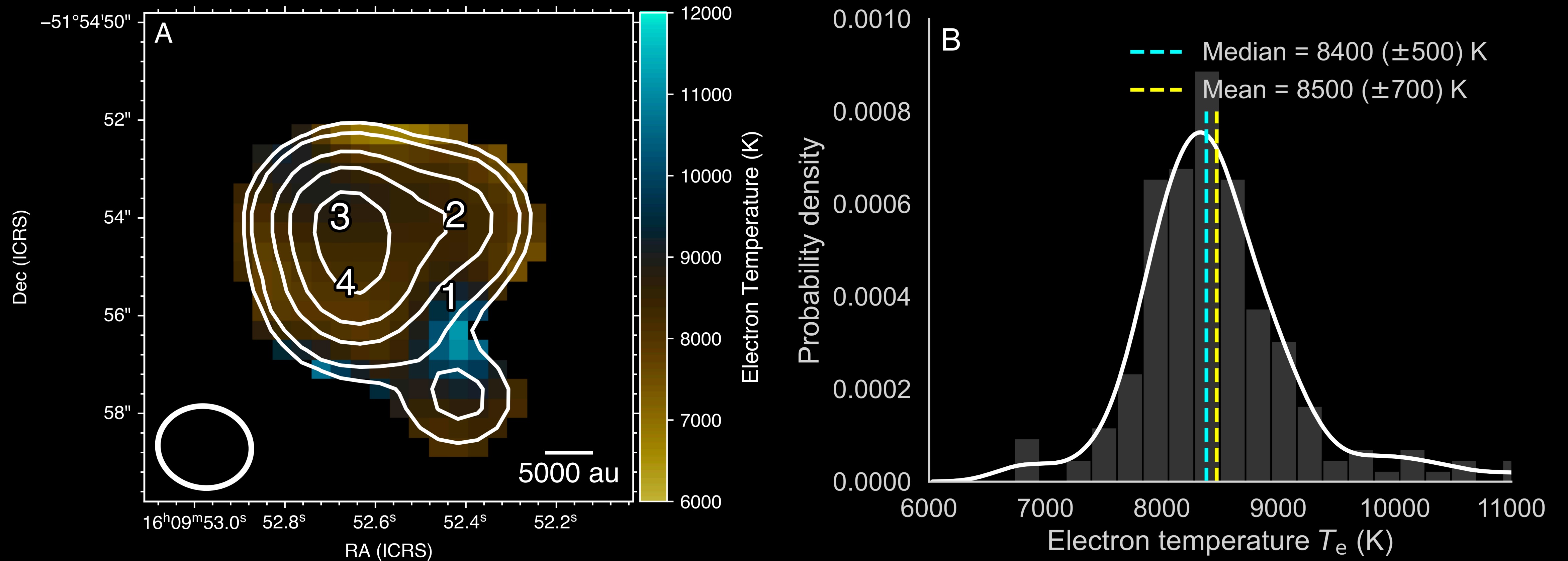
Mixture of free-free and dust emission

About 40% dust emission and 60% free-free emission at 1.3 mm



Electron temperature map

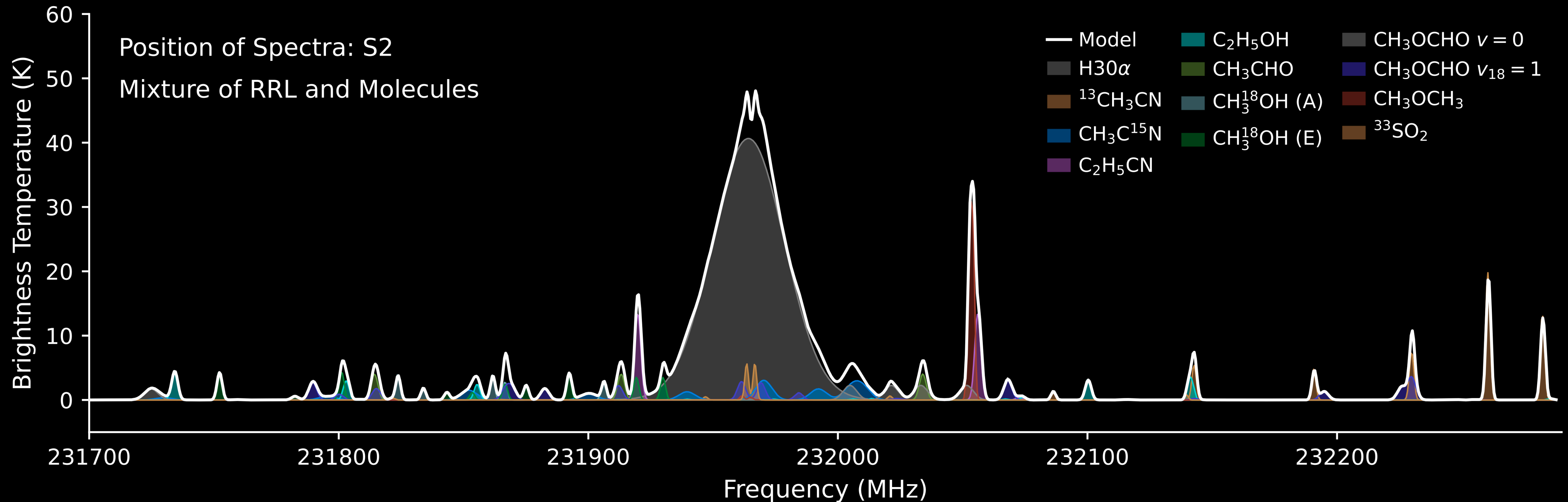
Measured from line-to-continuum ratio at 3 mm



Numerically consistent with our SED result of 8540 K

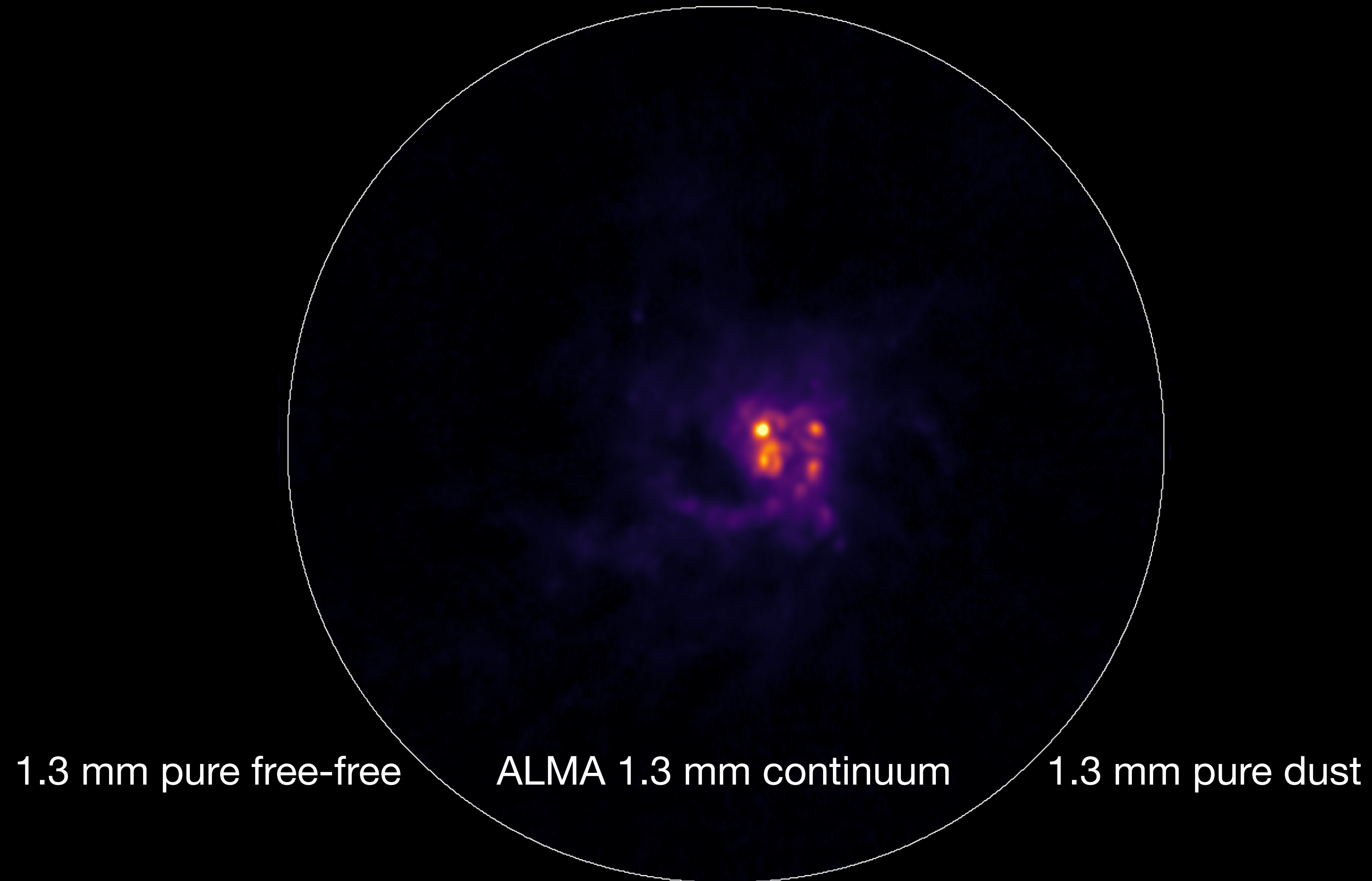
Isolate H30 α radio recombination line (RRL)

Simultaneous fitting mol. and RRL with physical models

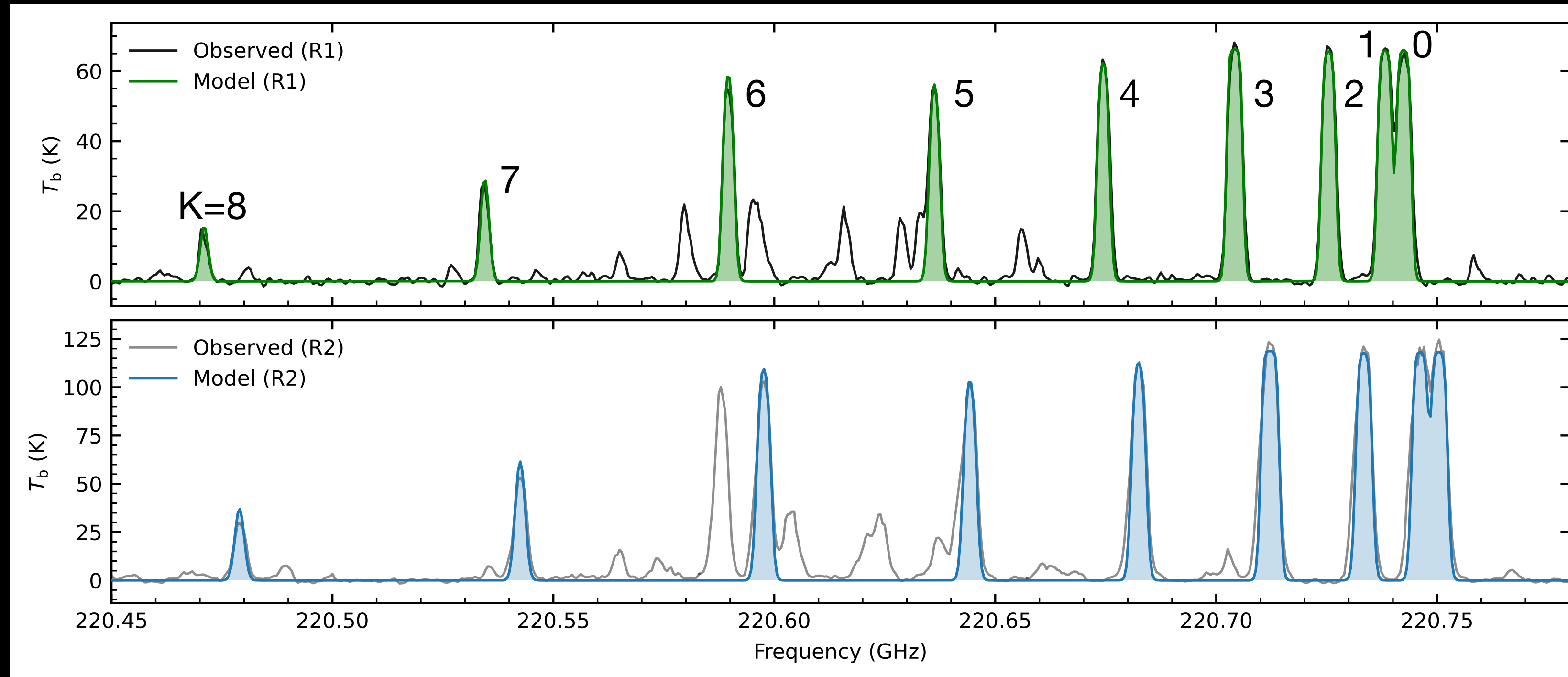


Spectral model fitting is done under the XCLASS context (T. Möller *et al.* **2017**)

Ionised and molecular gas decomposition

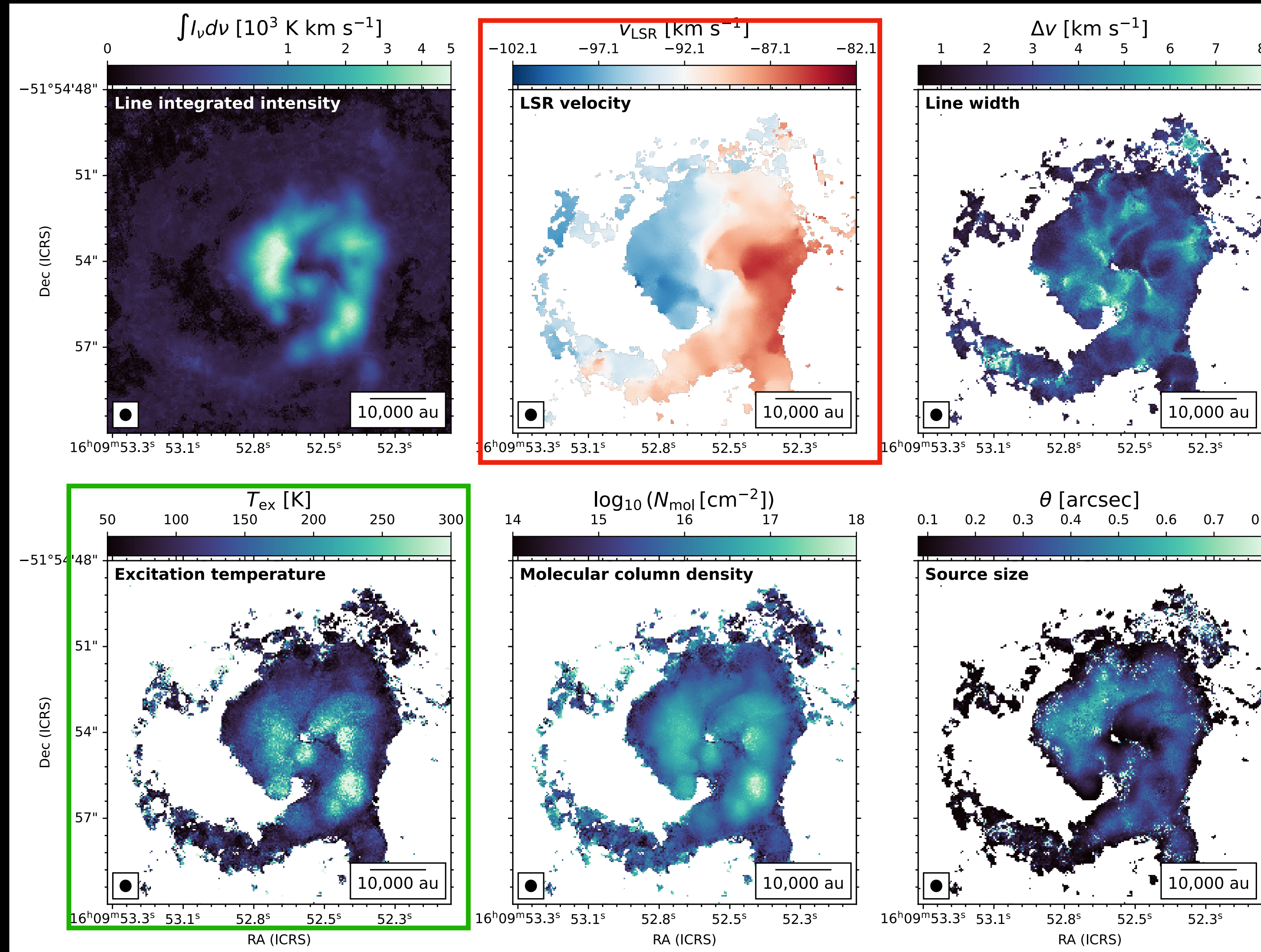


Methyl cyanid: velo. and temp. diagnoses



- Methyl cyanid (CH₃CN) as a **rotor molecule**, have a series of K-ladders (with wide range of upper energy levels, from 60 up to 900 K) within a narrow frequency range.
- K-ladders can be **only (de)-excited by collision** rather than spontaneous emission. So it is sensitive to the local thermalized temperature, i.e., the temperature of H₂/dust molecules.
- CH₃CN forms in dust grains, which **is released to gas phase** when it is at the warm-up phase. So its abundance and therefore line intensity is higher as closer to protostars.

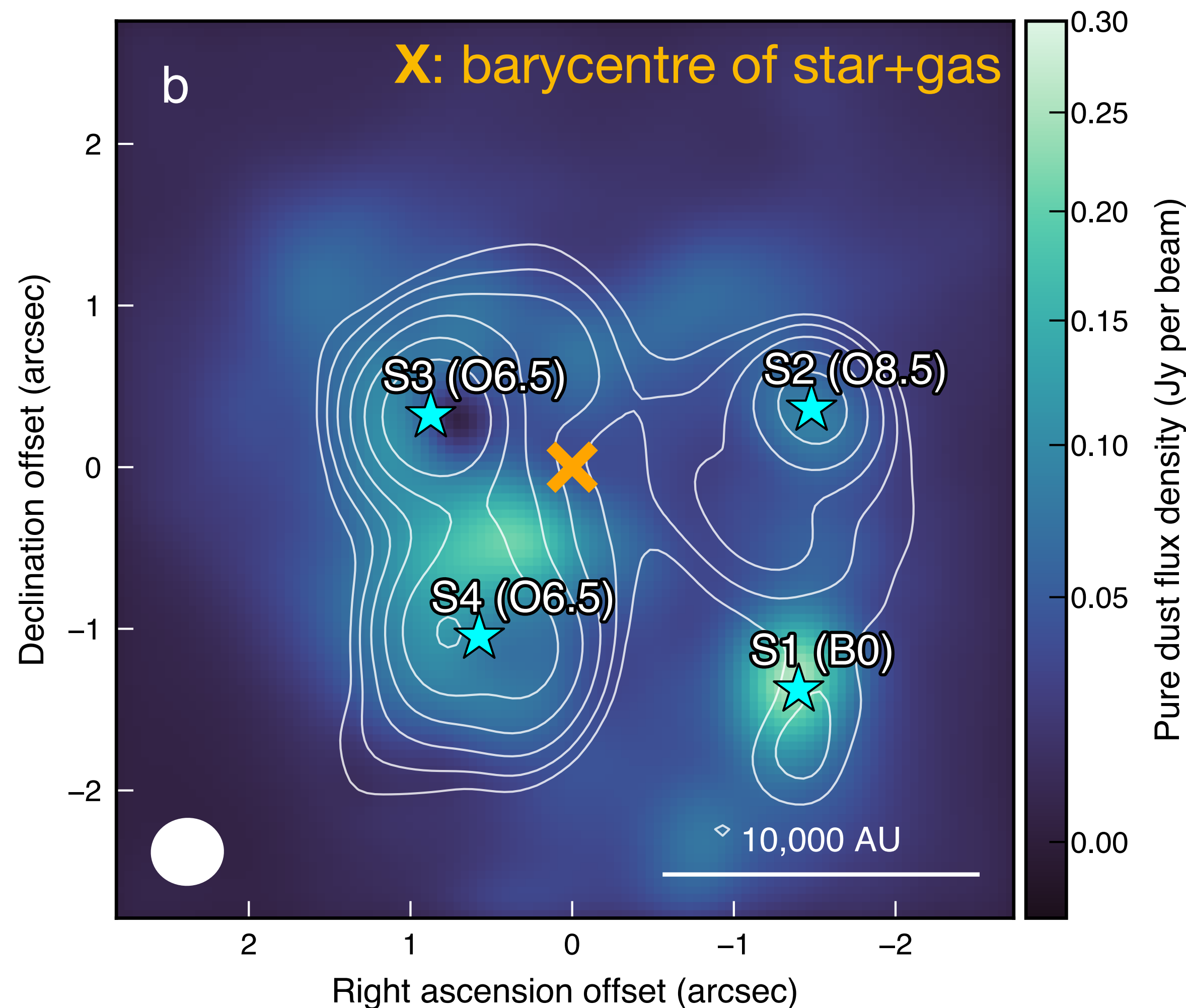
Methyl cyanid: **velo.** and **temp.** diagnoses



Spectral map fitting is done under the spectuner context (Y. Qiu *et al.* 2025)

Gravitational potential

Molecular gas $300 M_{\odot}$ and stellar mass $100 M_{\odot}$

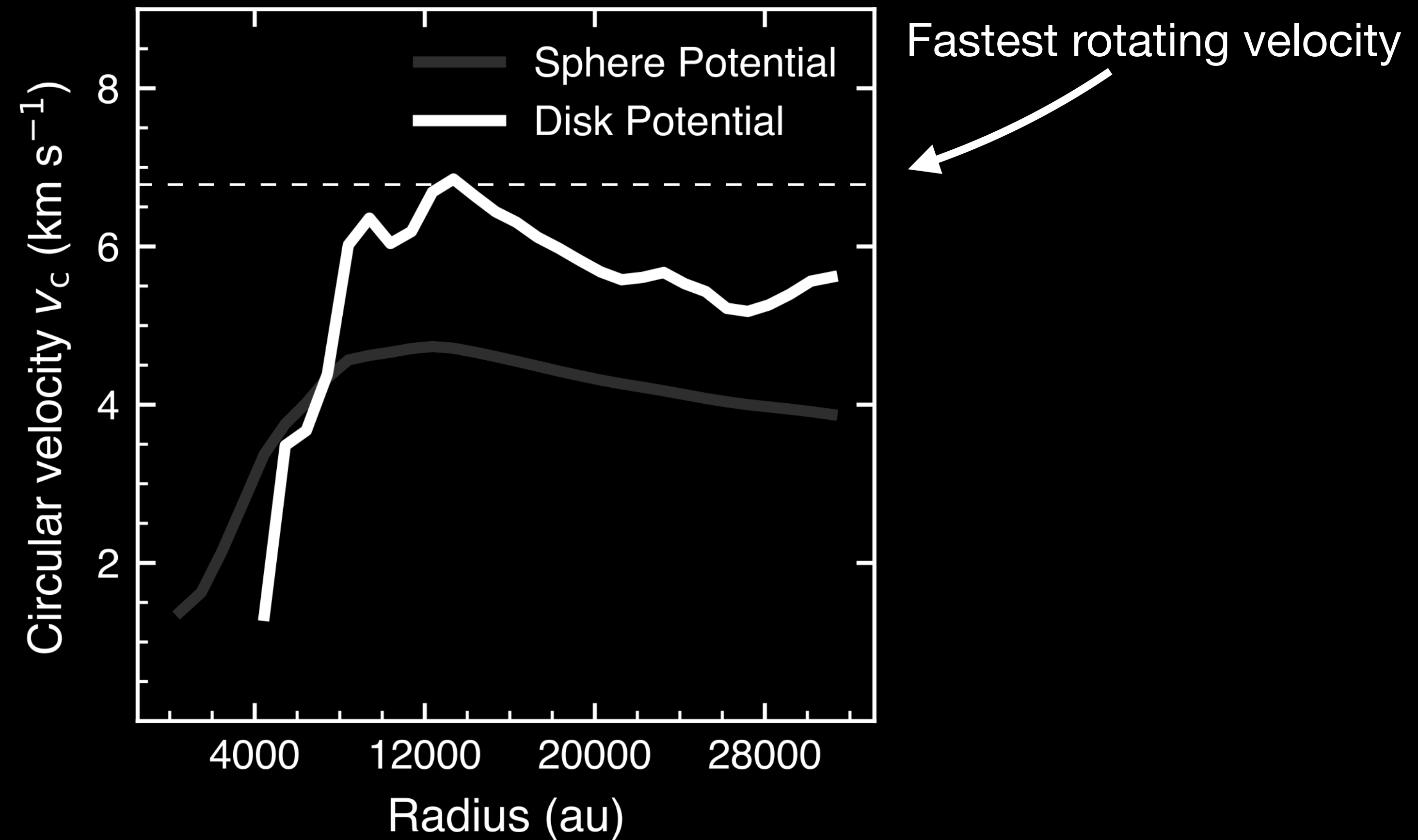


Based on the Lyman continuum photon rates, the system contains one B0 star, one O8.5 star, and two O6.5 stars.

From dust and (gas) temperature, we obtain a molecular gas column density map via gray-body radiation law.

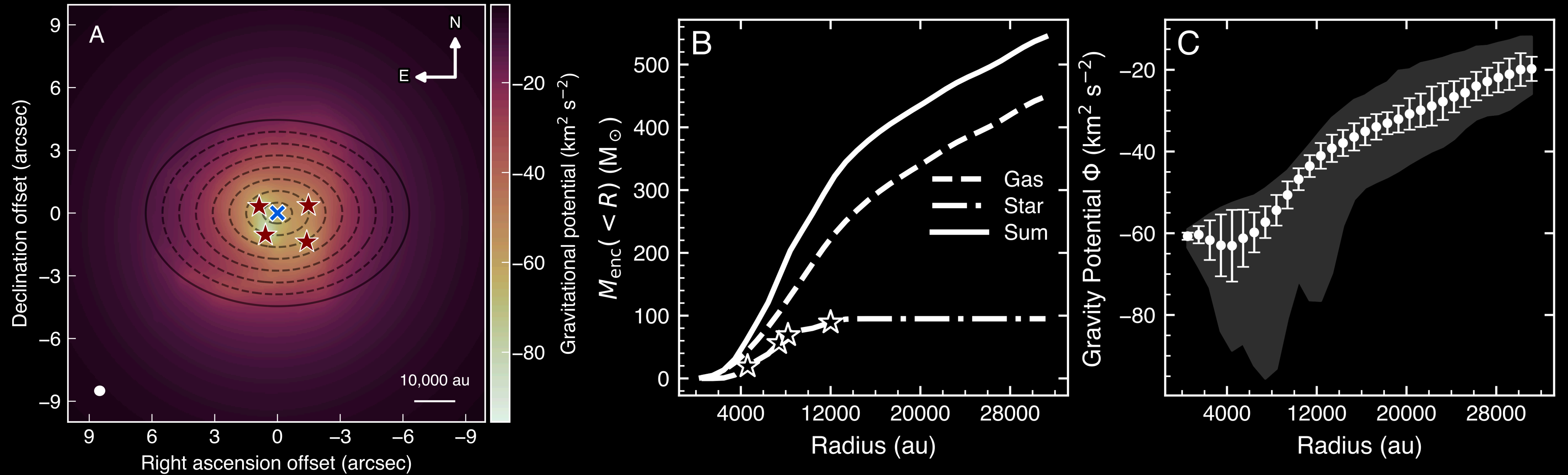
From the stellar and gas surface density, IRAS16060 is an **off-centre** system.

It must be a rotation-flattened envelope



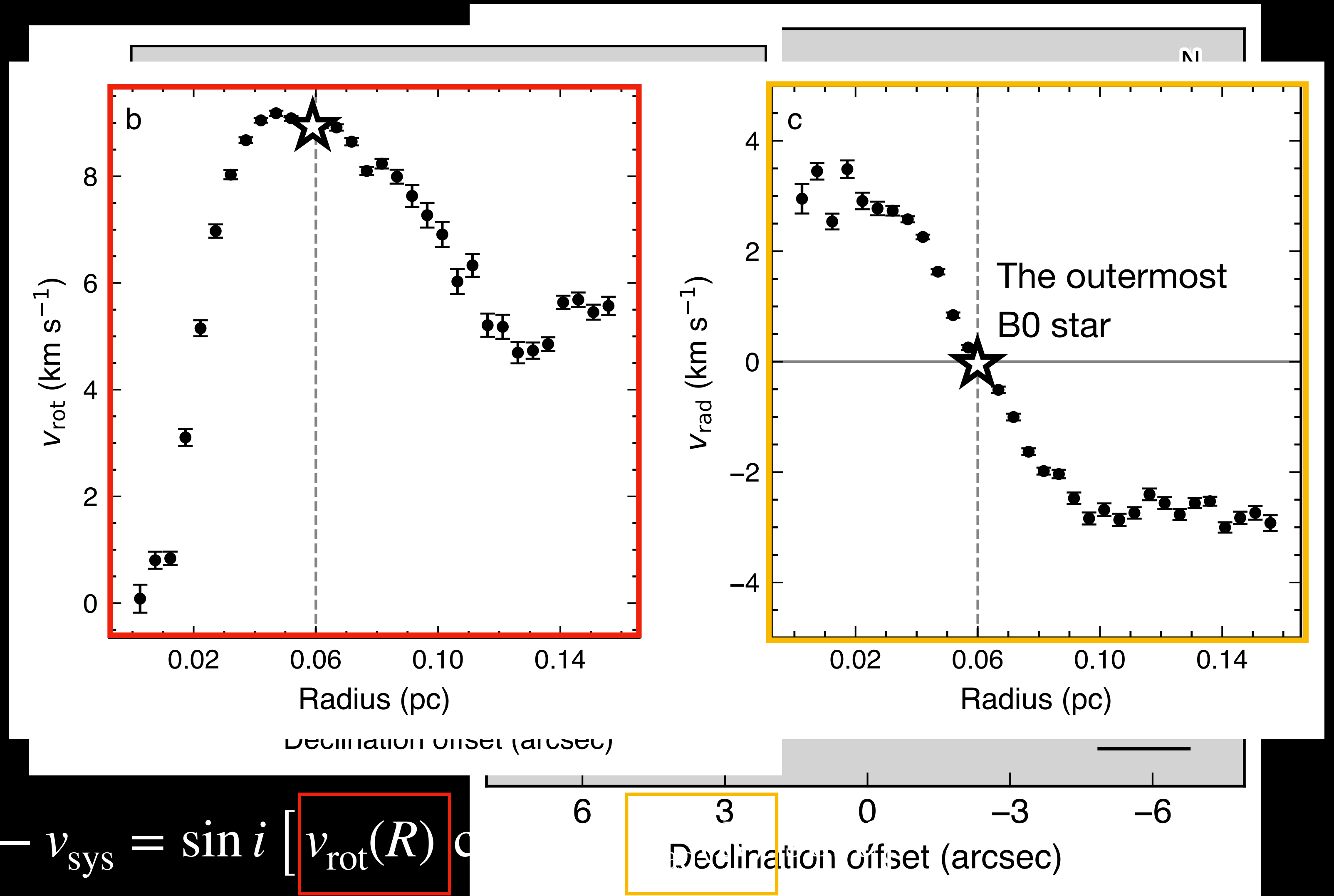
Disk-like morphology produces a more realistic rotation curve.

Mass distribution and gravitational potential



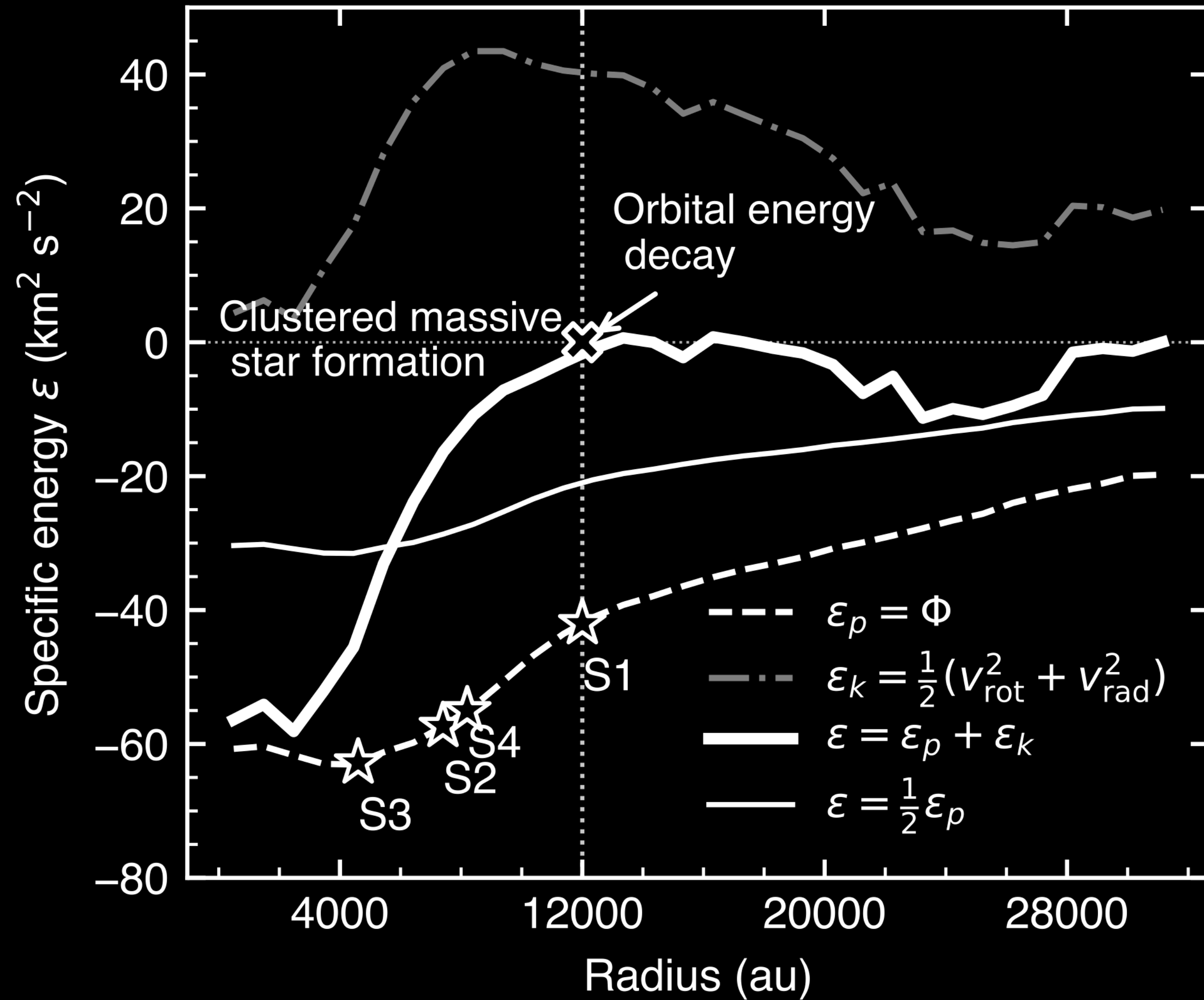
Gas kinematics

Velocity decomposition at each annulus

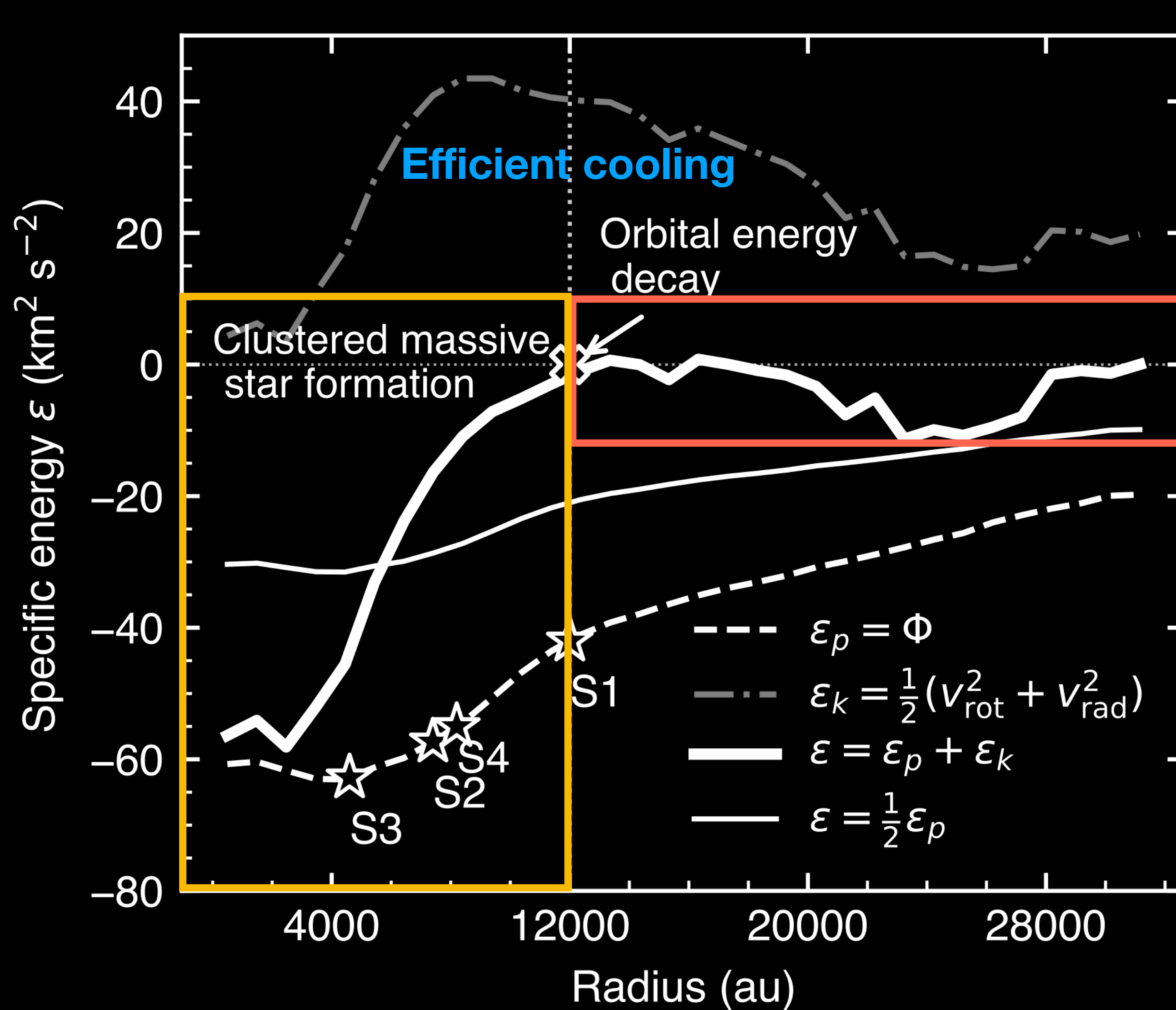


Energetics

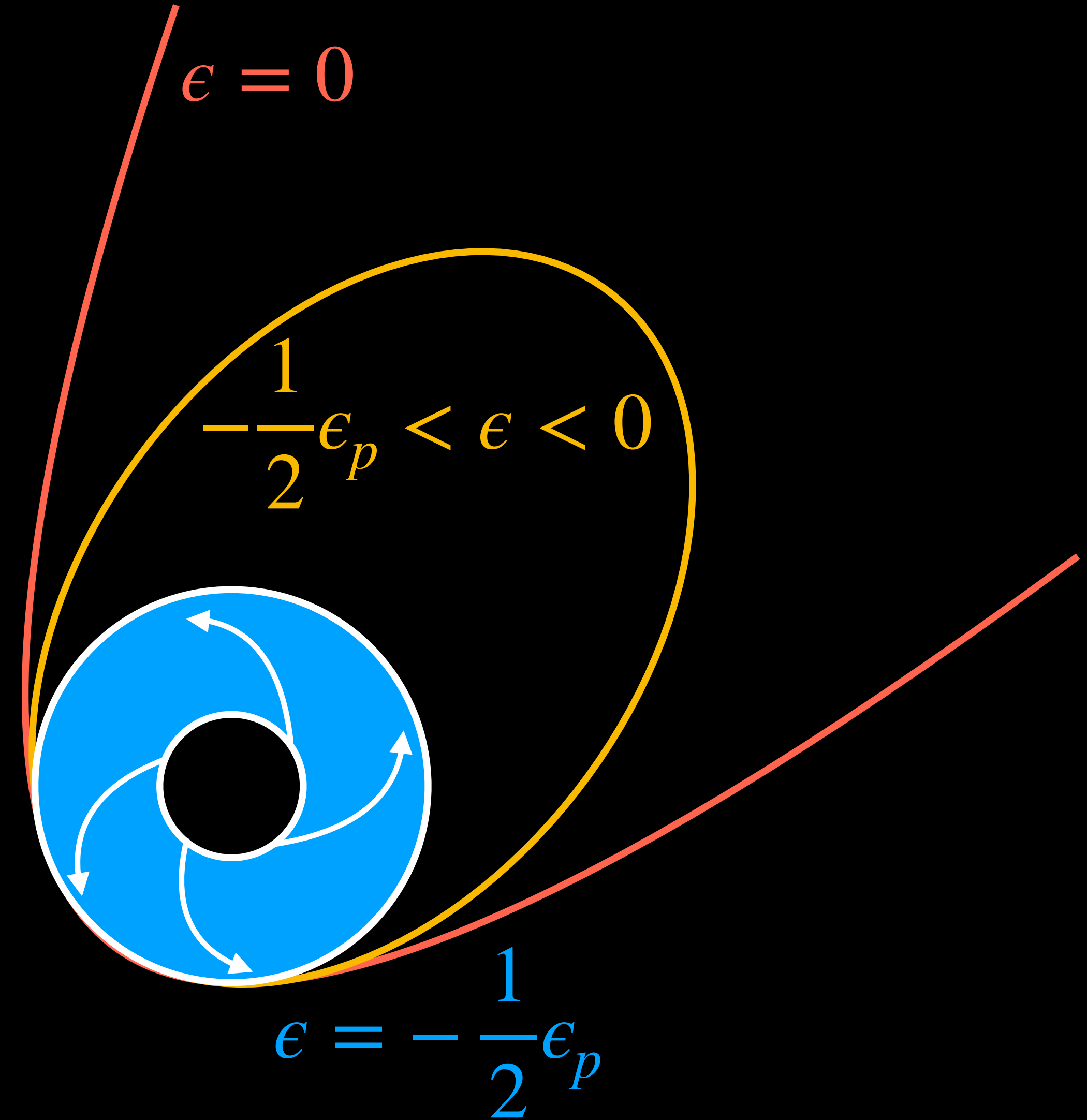
Orbital specific energy distribution



Orbital specific energy distribution



Newtonian mechanics in 1687



Conclusion

I. A Trapezium-like OB quadruple forms in a massive rotating env.

II. Star and flattened envelope produce an off-centre potential.

III. Gas inflows and reaches max. rotation at 12,000 au.

IV. Orbital energy decays at 12,000 au, which is defined as a grav captured radius.

Imaginary scenario (Procreate & ChatGPT)