

Large program **PRODIGE**: the first results

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PROtostars to Disks: Global Evolution (PRODIGE)

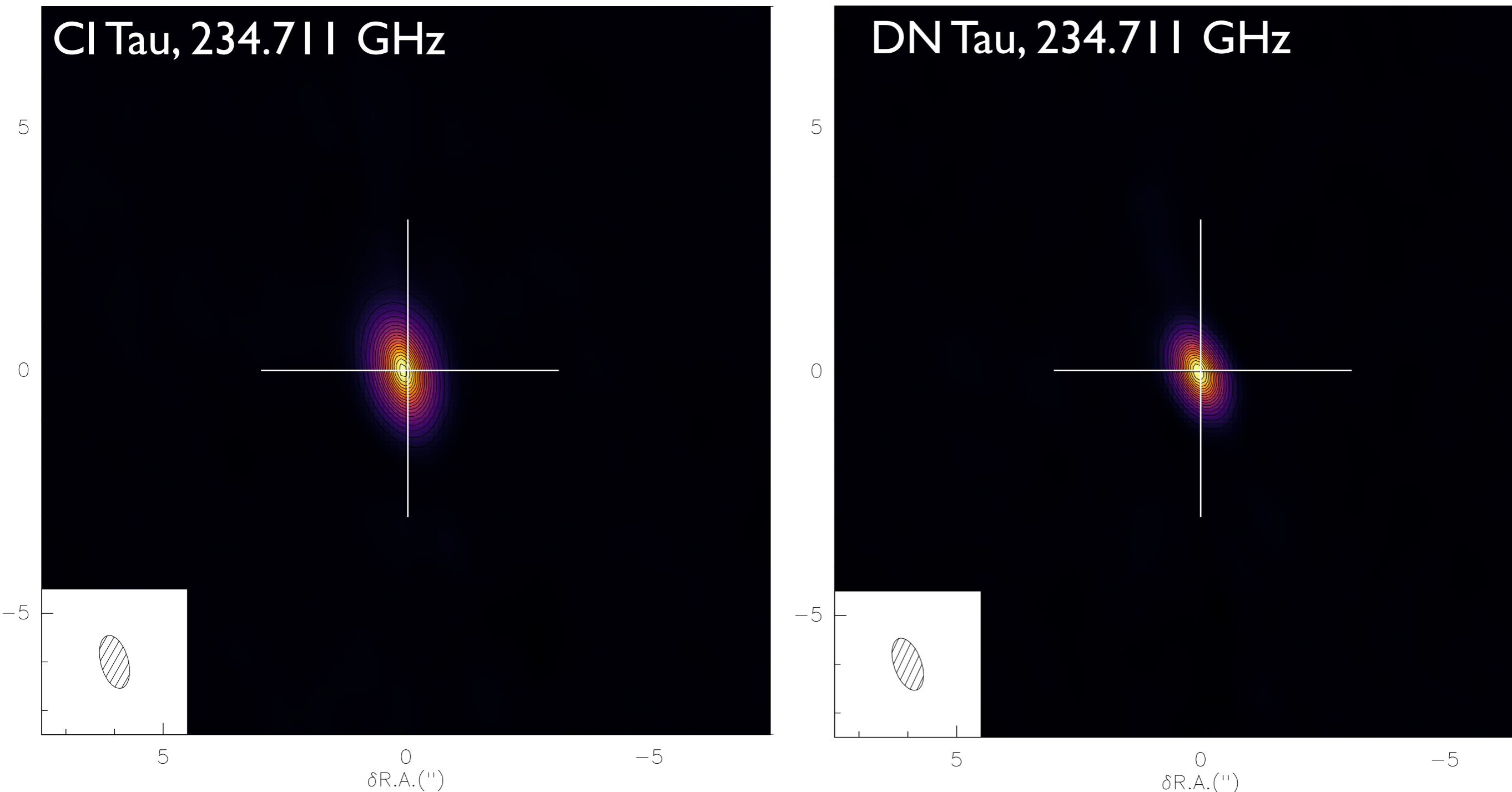
- MPG-IRAM Observing Program at NOEMA (~600 h)
- **Goal:** structure and composition of protostellar envelopes and disks
- **Class 0/I part (PI: P. Caselli):** 30 protostars in Perseus
- **Class II part (PI: Th. Henning):** 8 T Tauri disks in Taurus
 - Resolutions $\sim 0.9''$ & 0.3 km/s, noise ~ 0.1 K
 - Line survey at 201–280 GHz
 - Physics & Chemistry



Data Reduction, Imaging, Analysis

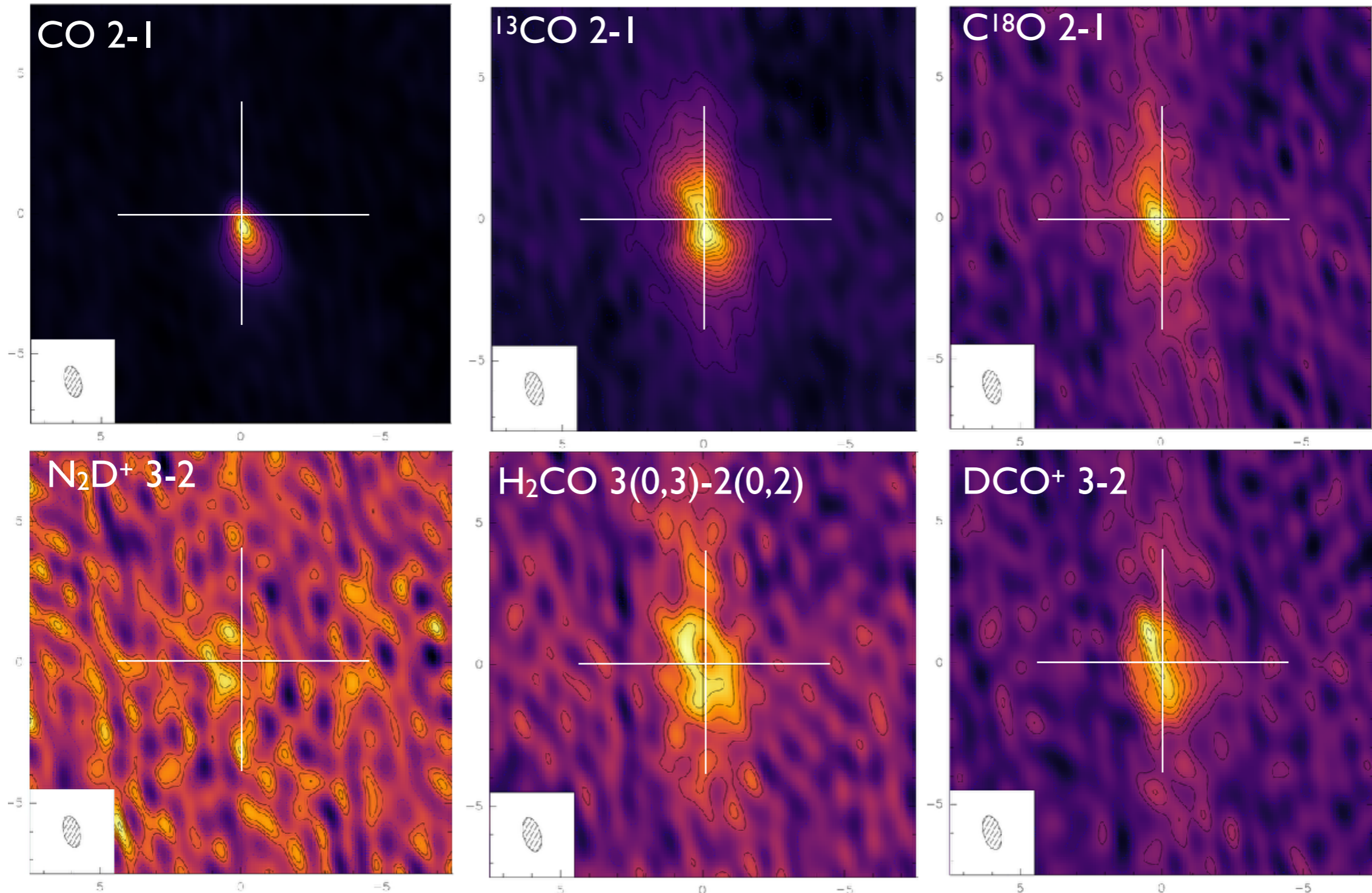
- Reduction and calibration at IRAM
- Automatic pipeline (Gildas/IMAGER):
 - Proper motion correction
 - Custom line catalog
 - Self-calibration & Imaging
 - S/N boost (Kepler deprojection, matched filter, ...)
- **Results:** datacubes, channel maps, moment maps, etc.

Dust continuum at 1.3 mm



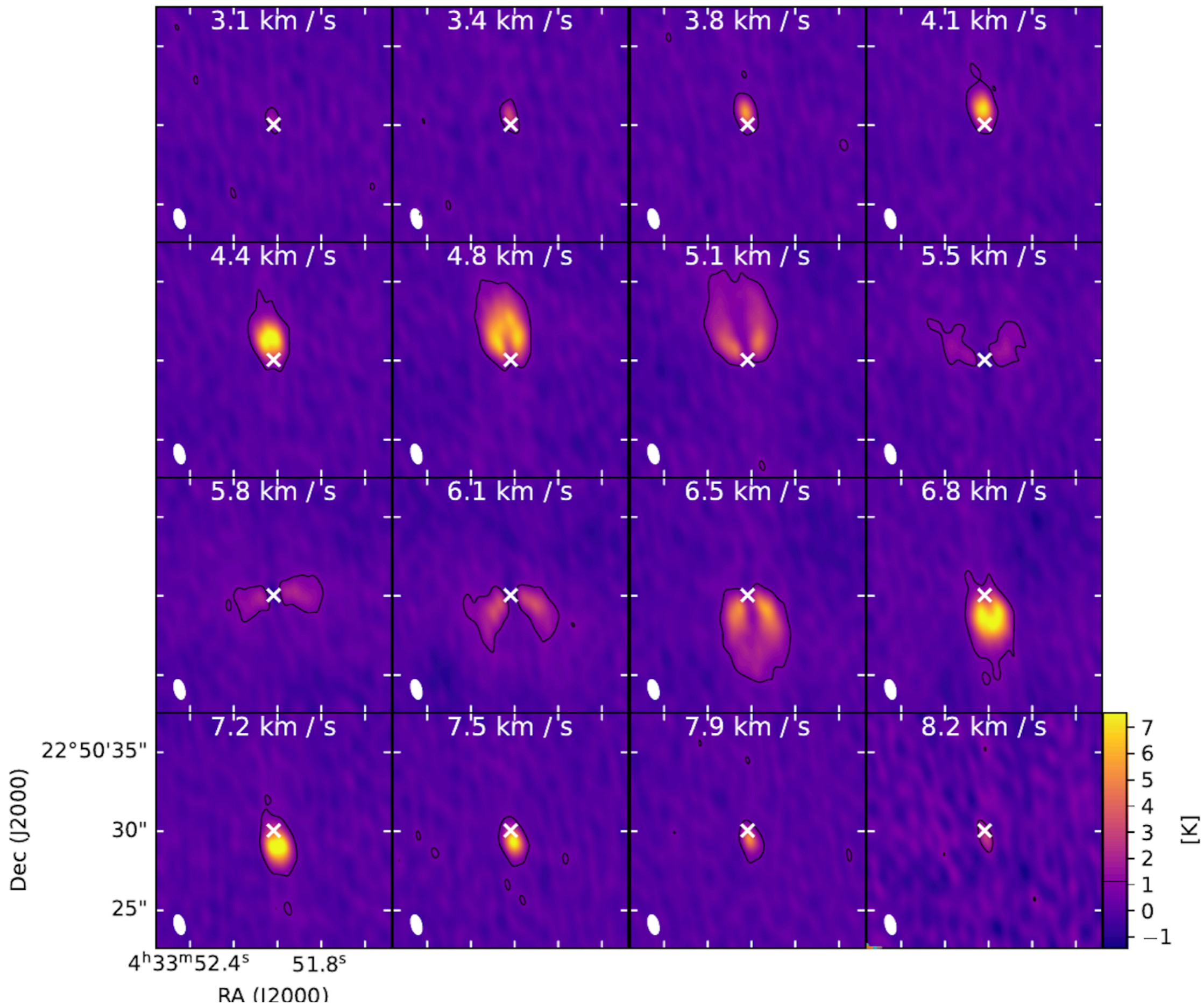
- Gaia DR2 proper motion correction works
- Elliptical beams $\sim 1.2'' \times 0.6''$ (or $0.8 - 0.9''$ effectively)
- Wide PolyFiX bandwidth \Rightarrow spectral indices

Cl Tau (0th moment maps)

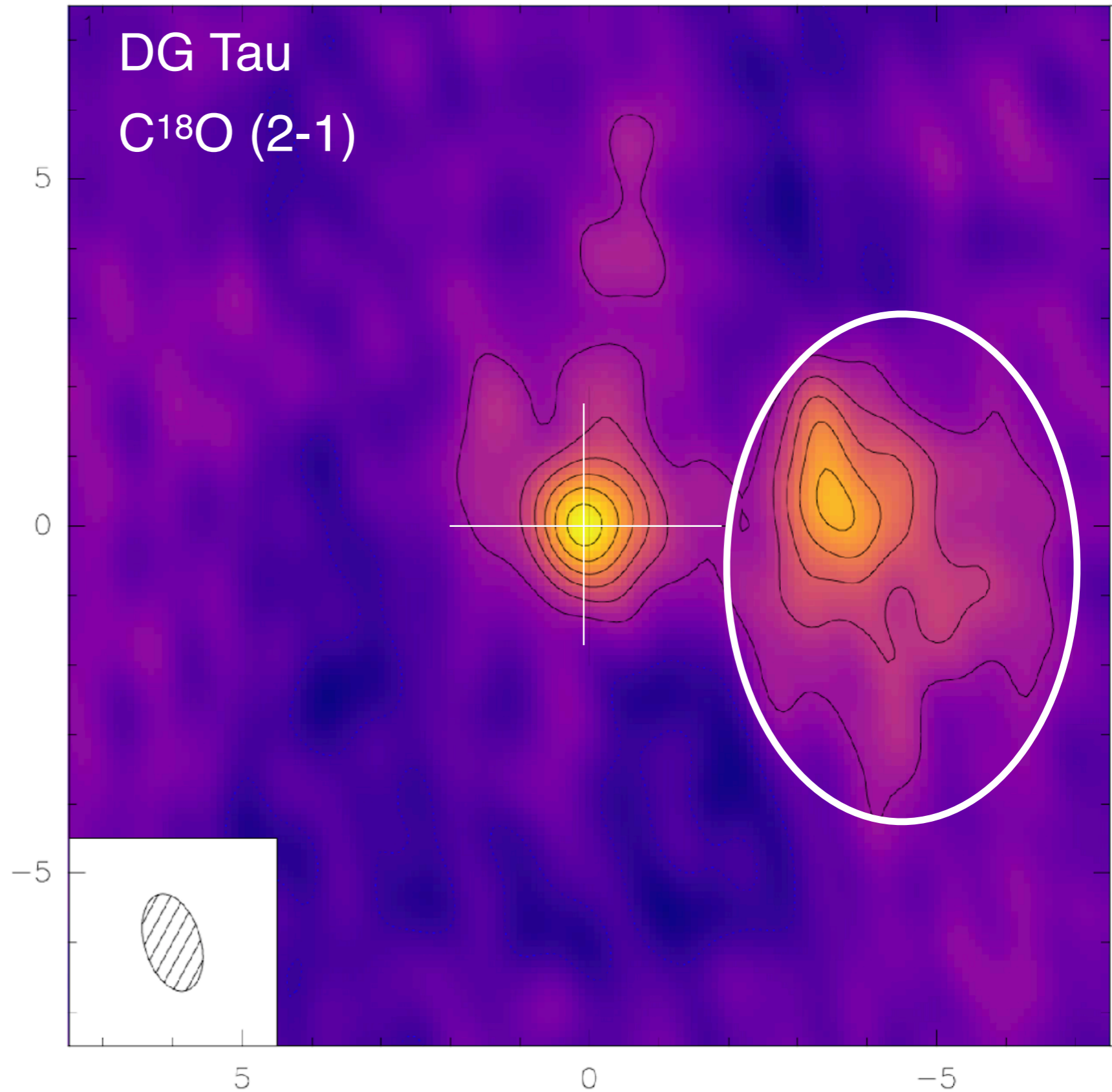
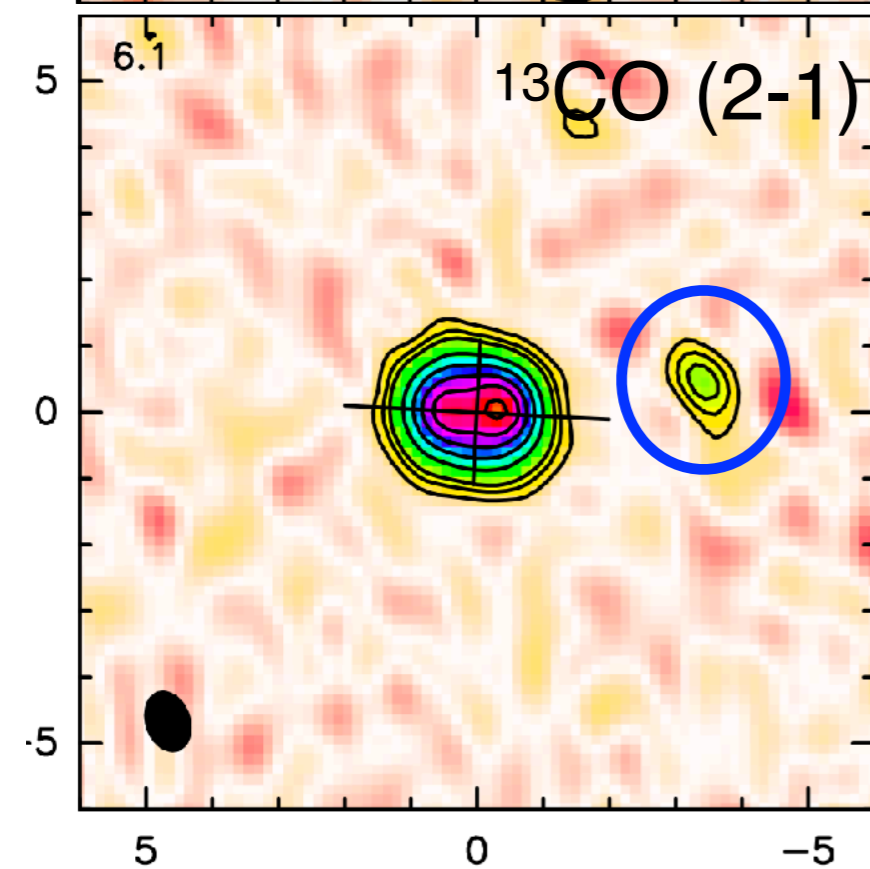
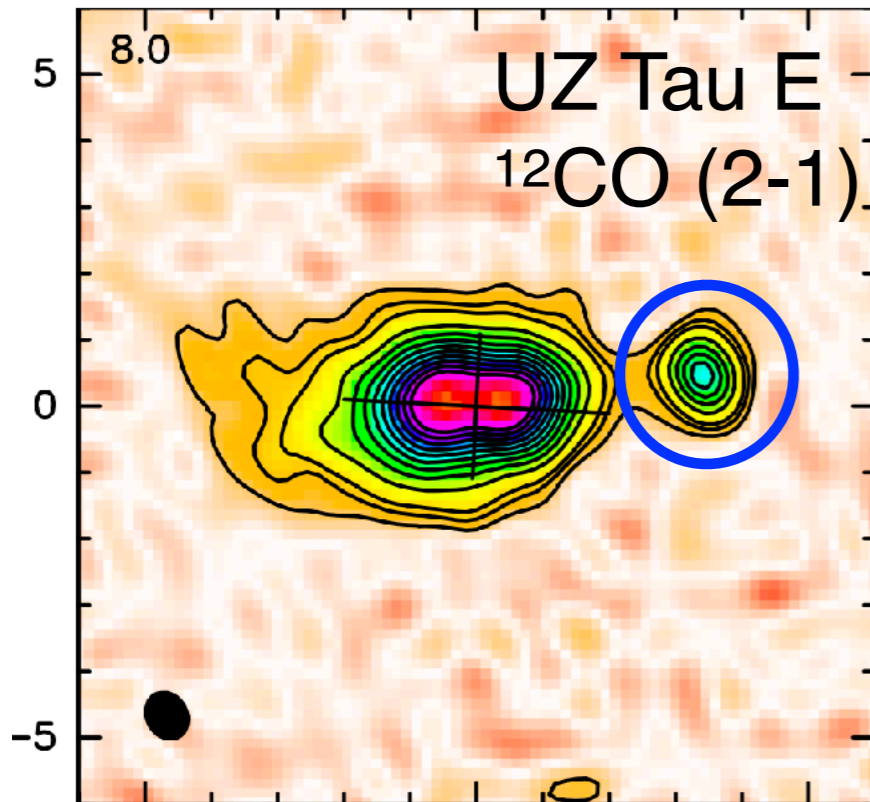


- CO isotopologues plus weaker lines
- **Challenge #1:** foreground absorption for opt. thick lines
- **Challenge #2:** emission rings or holes

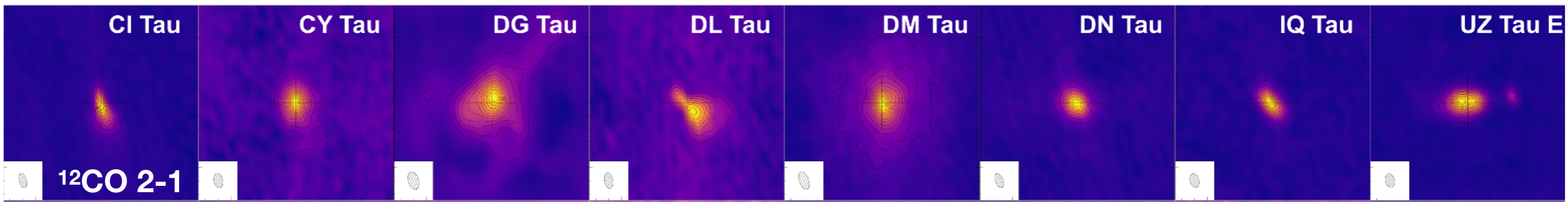
Cl Tau, channel maps of ^{13}CO 2-1



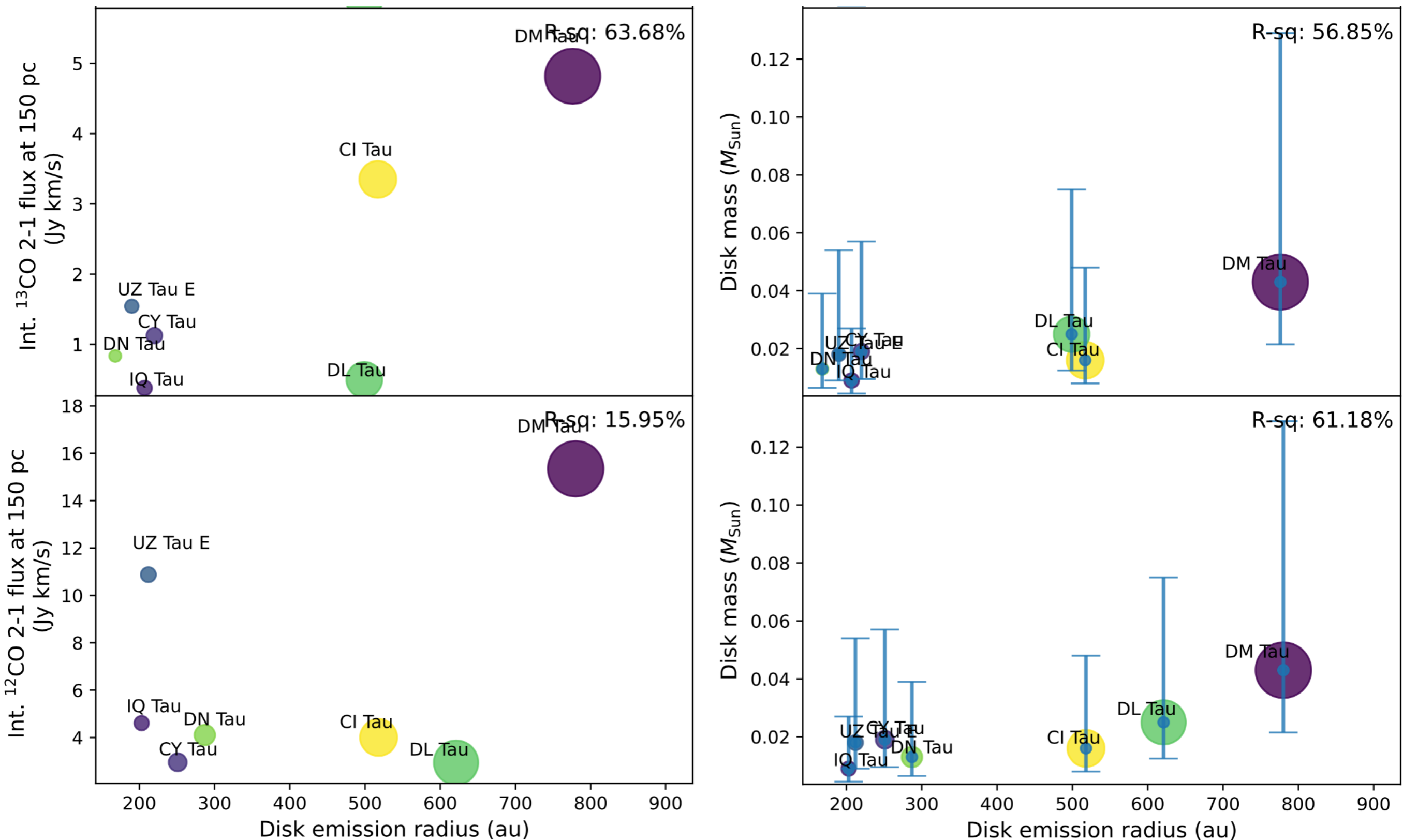
Multiplicity, outflow, ...



- **Challenge #3:** Multiplicity of UZ Tau E, outflow & envelope in DG Tau



radius



- Strong CO depletion by x160 in DL Tau (Sturm et al. 2022)
- DL Tau could be $\sim 7 - 9$ Myr old (others are $\sim 2 - 3$ Myr old)

Data modeling

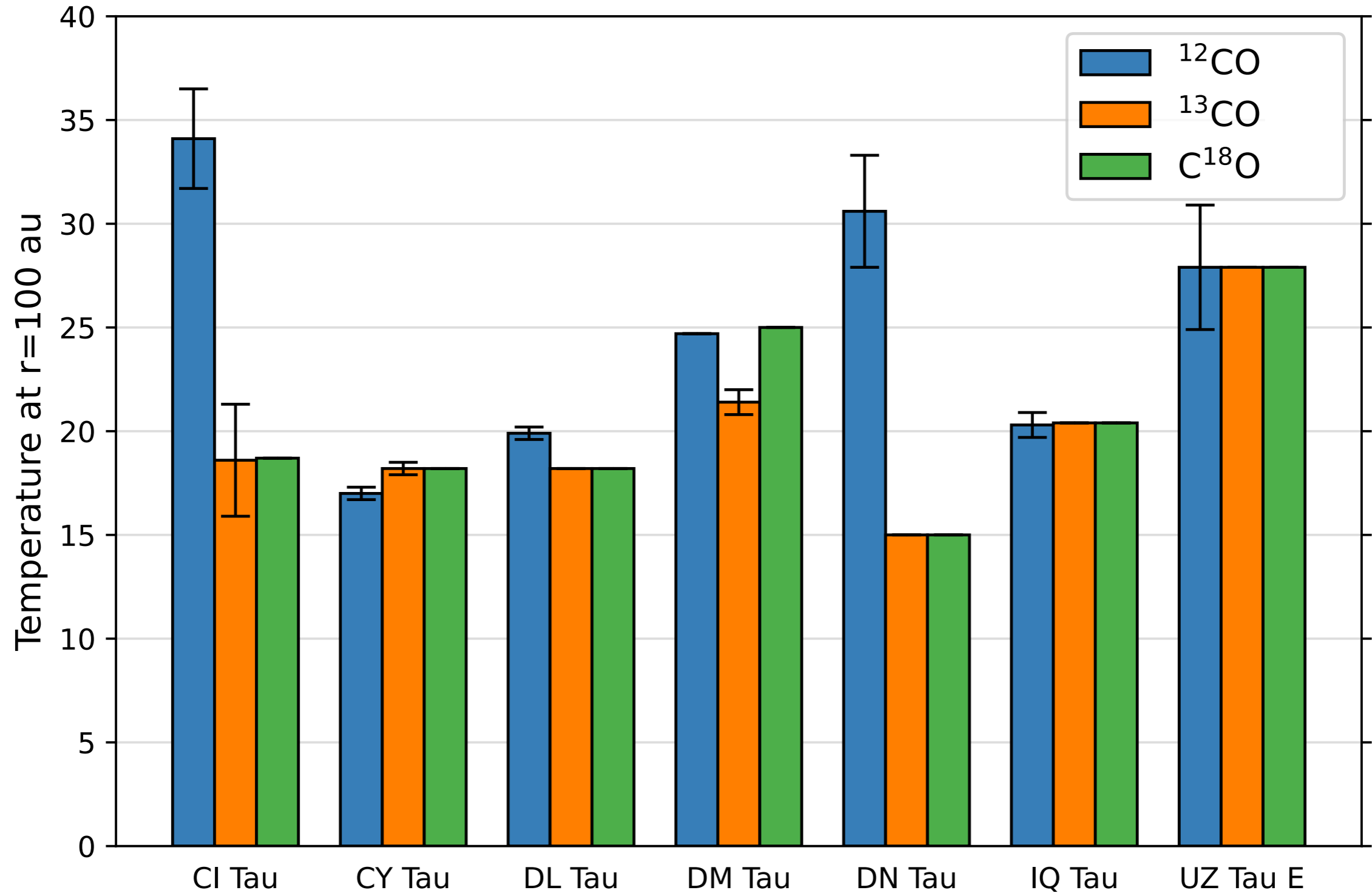
- **Fitting data with DiskFit:**

- 1D physics and chemistry (power laws)
- Gaussian vertical density distribution
- LTE or LVG radiative transfer
- MCMC minimization of uv visibilities

- **Output:**

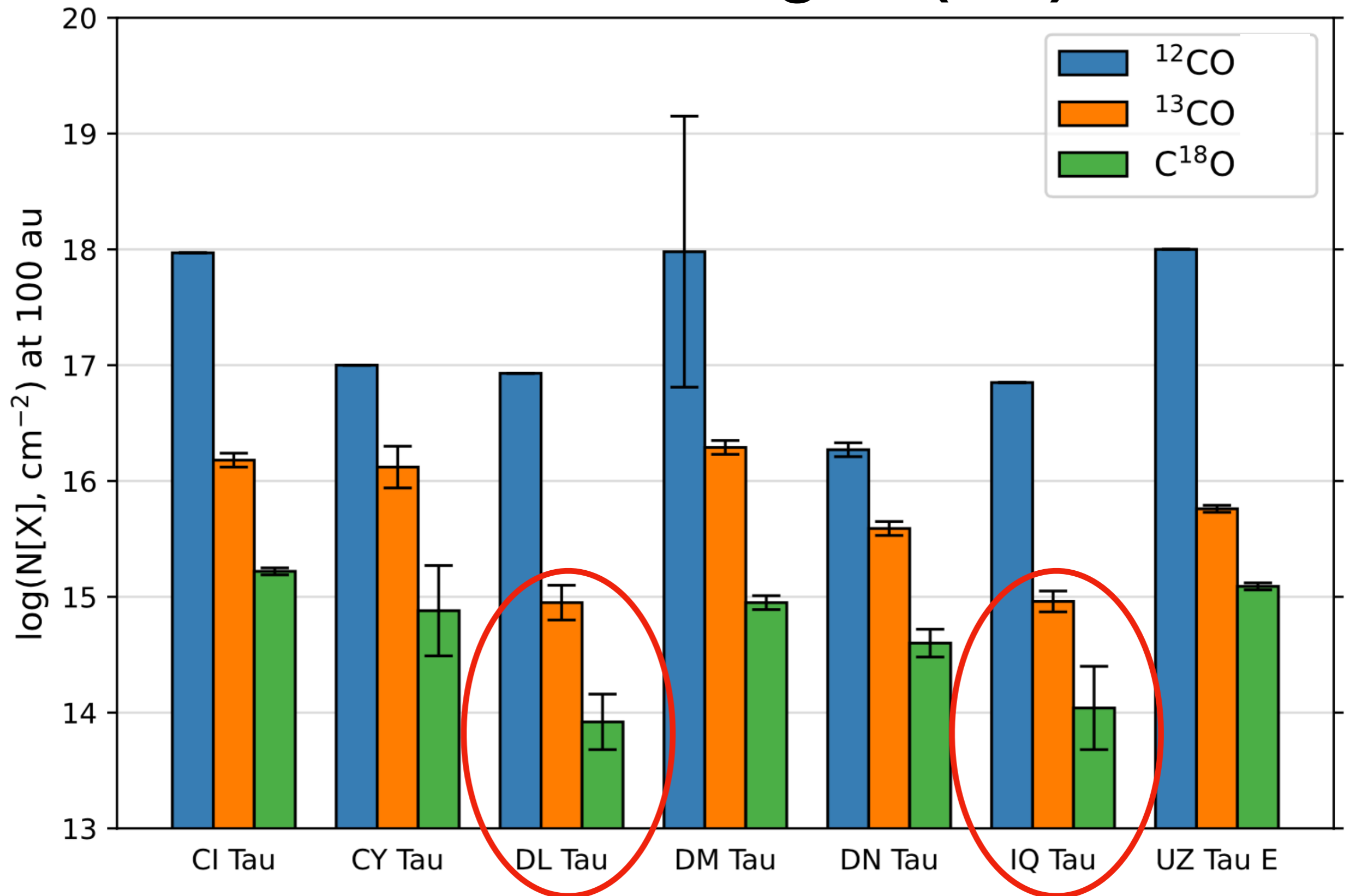
- Disk geometry, kinematics, M_{star} , V_{sys} , ...
- Radial profiles of T , surface density, column densities
- 17 parameters total

DiskFit modeling: $T_{\text{ex}}(\text{CO})$



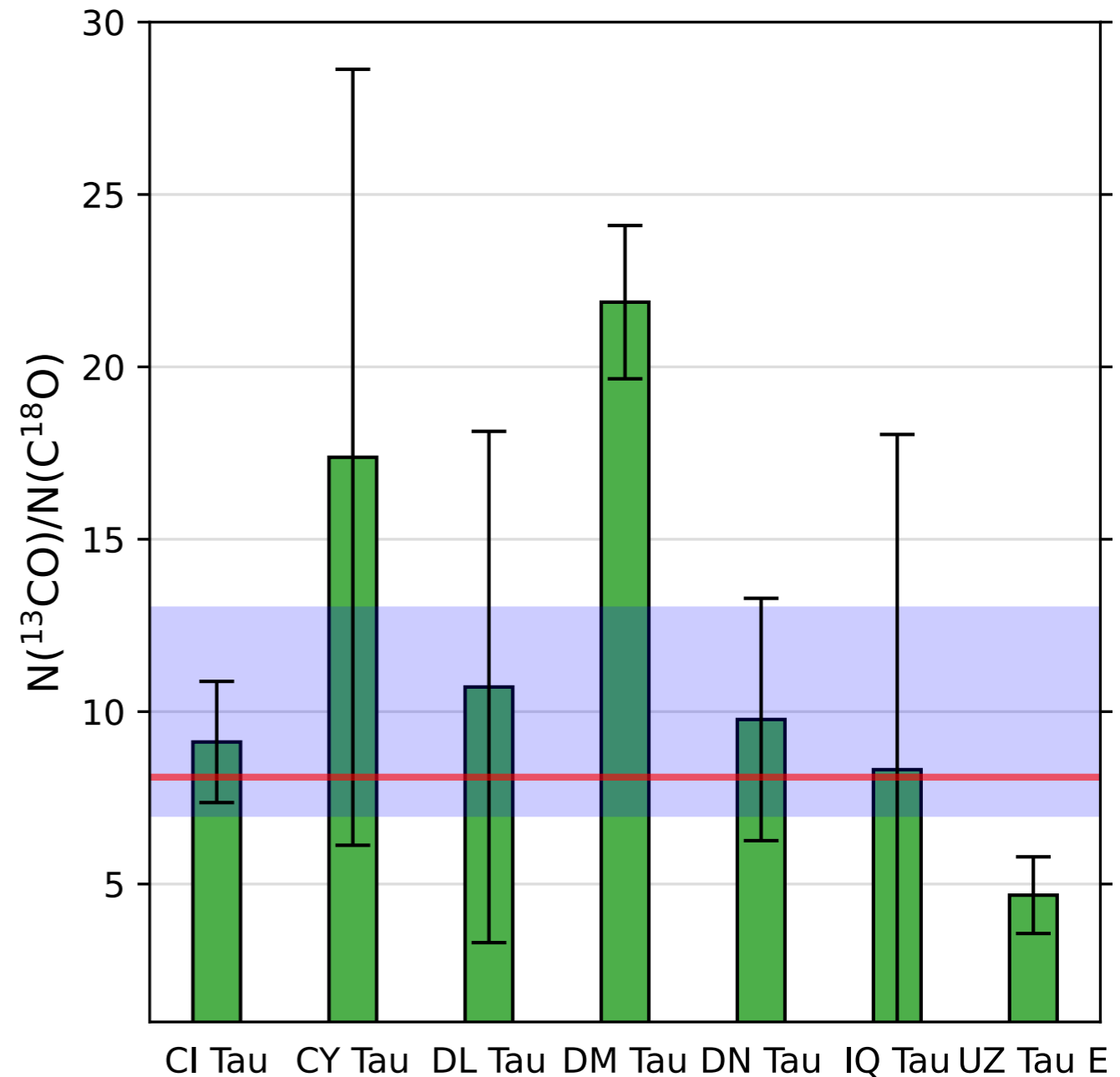
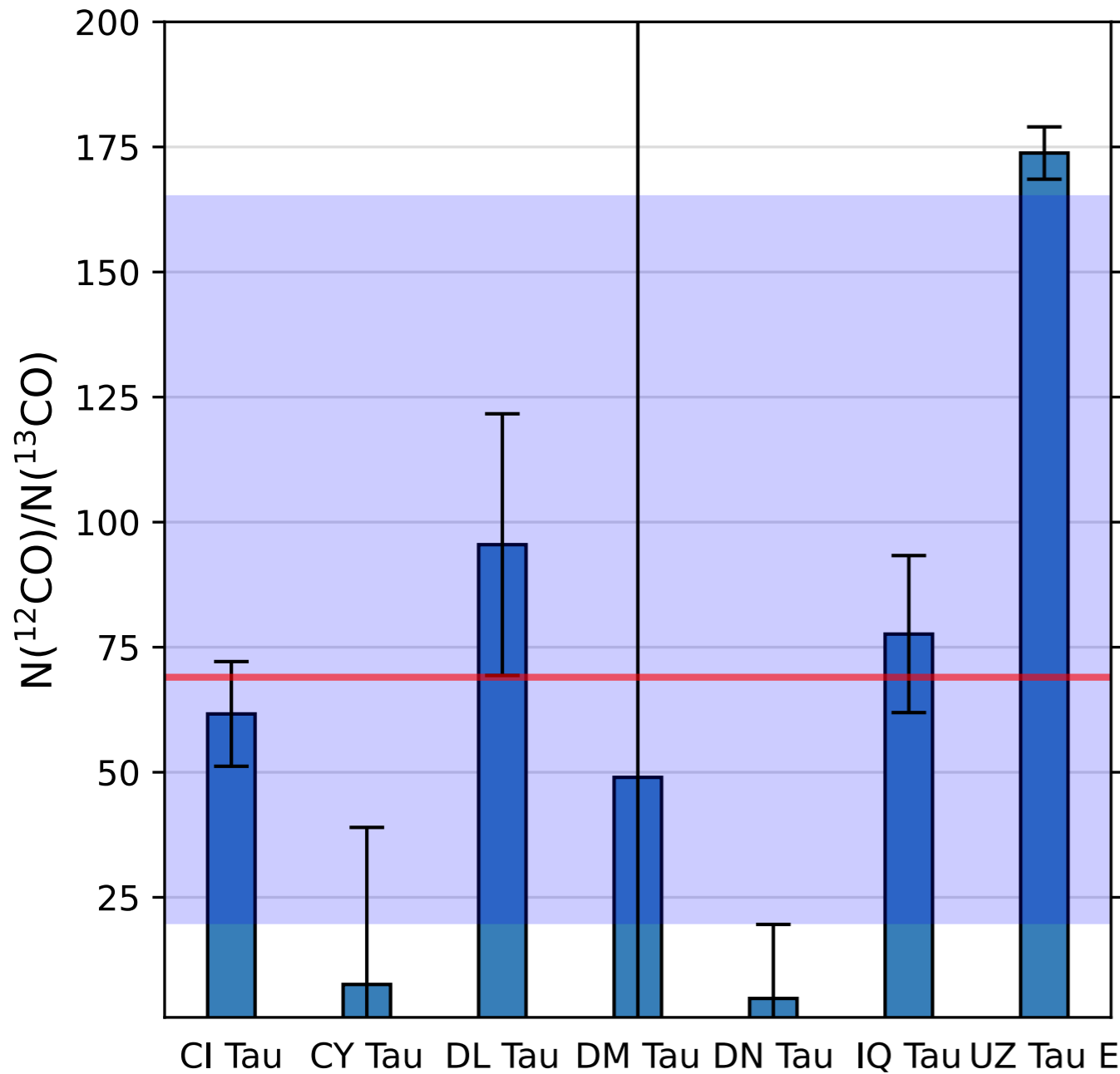
- CO gas: $T \sim 15 - 35$ K
- CI Tau & DN Tau have highest L^* \Rightarrow warmest ^{12}CO gas?
- UZ Tau E has highest M_{acc} and smallest disk \Rightarrow warmer

DiskFit modeling: N(CO)



- $N(^{12}\text{CO})$ is ill-constrained: $\sim 5 \times 10^{16} - 10^{18} \text{ cm}^{-2}$
- $N(^{13}\text{CO}, \text{C}^{18}\text{O})$: low in DL Tau (CO depletion) and IQ Tau (low

DiskFit modeling: Isotopic ratios



- $^{12}\text{CO}/^{13}\text{CO}$: vary within observed range of $\sim 20 - 165$
- $^{13}\text{CO}/\text{C}^{18}\text{O}$: vary close to observed range of $\sim 8 - 12$
- UZ Tau E is an outlier

Conclusions

- Diverse disk data (intensity, distribution)
- CO gas has $T \sim 15 - 35$ K
- Evidence for CO depletion in DL Tau
- Isotopic ratios are mostly consistent with ISM/disk values
- CO fluxes and disk masses scale with emission sizes (?)