# THE 12/13 CARBON RATIO IN THE CHA I MOLECULAR CLOUD COMPLEX

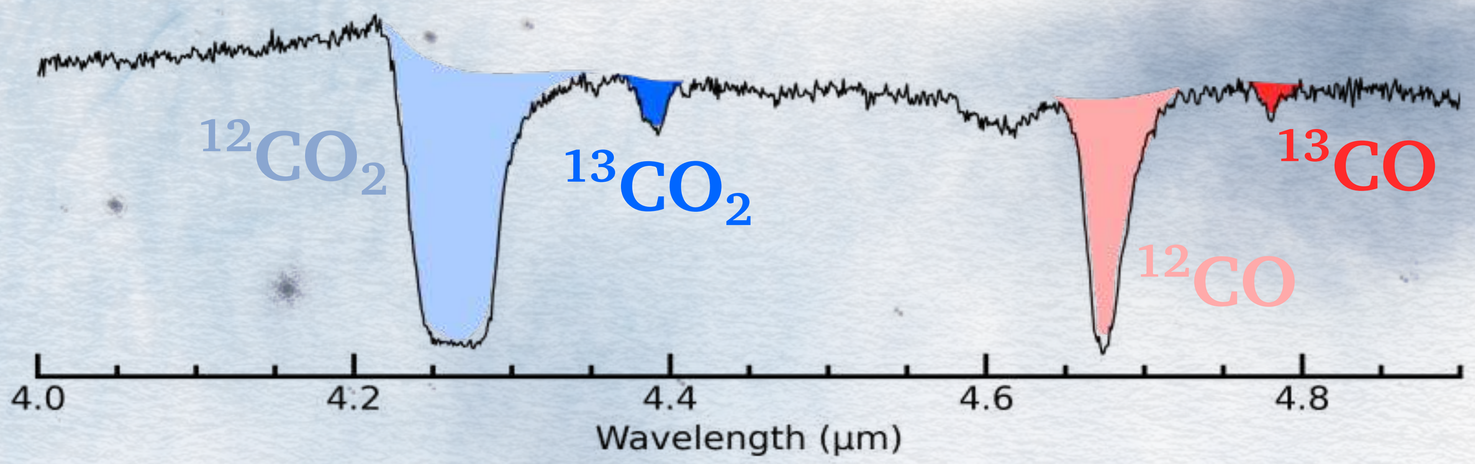

M.F. Rashman[1], H. Dickinson[1], Z..L. Smith[2], H.J. Fraser[1], M. McClure[2], E. Tsiakaliari[1], L. Demaria[1] + the IceAge Team (in prep)

[1] *School of Physical Sciences, The Open University, Milton Keynes, UK*
[2] *Leiden Observatory, Leiden University, Leiden, the Netherlands*


Science and Technology Facilities Council
The Open University

## Carbon isotopes in ice

- **Does the $^{12}C/^{13}C$ ratio vary between ice species?**
- **Is there spatial variability in $^{12}C/^{13}C$ ratio across a molecular cloud?**
- **Is the origin of the 12C/13C ratio consistent with later evolutionary stages in star and planet formation**



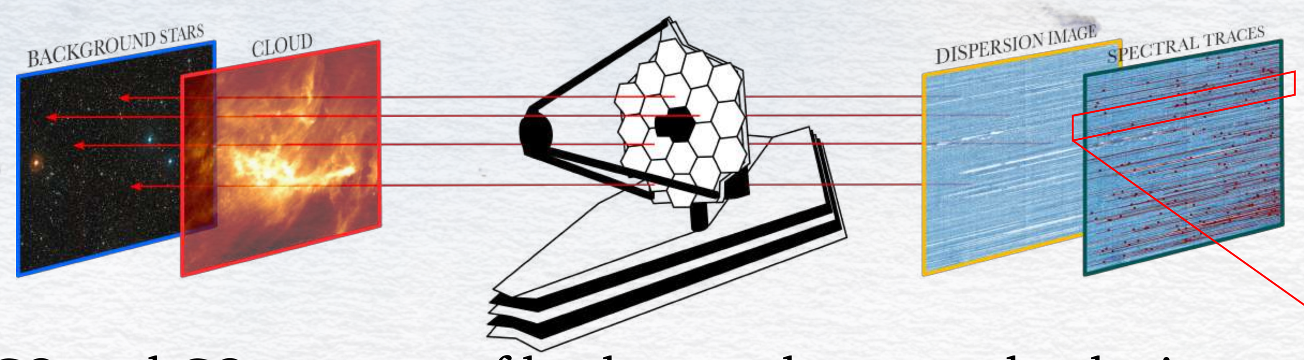

*$^{12}C$ & $^{13}C$ are detected in $CO_2$ and CO ice observed towards molecular clouds and dense core environments [e.g. 1-4].*

$^{12}C/^{13}C$ ratios that differ from the local ISM reflect chemical complexity in the local environment [5-7].

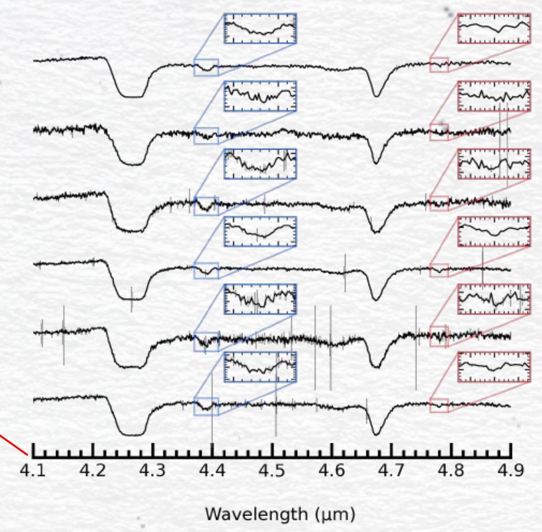
Spatial- or species-dependent variation provides insight into the formation pathway and chemical evolution of C-bearing ices in pre- and proto-stellar environments.

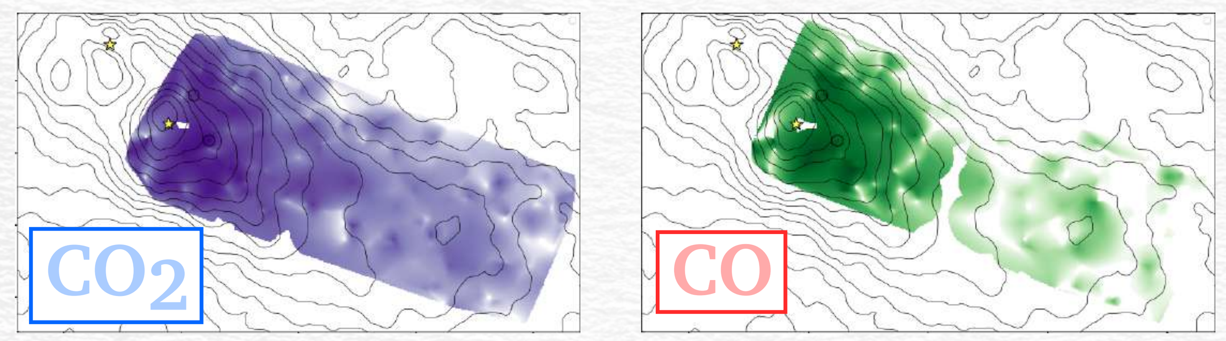
## JWST probing the ice environment at high spatial and spectral resolution

- JWST NIRCam wide field slitless spectroscopy (WFSS) towards Cha I molecular cloud.
- Detections of $CO_2$ & CO ice along ~400 lines of sight.
- Mapping on spatial scales of ~1000 AU.



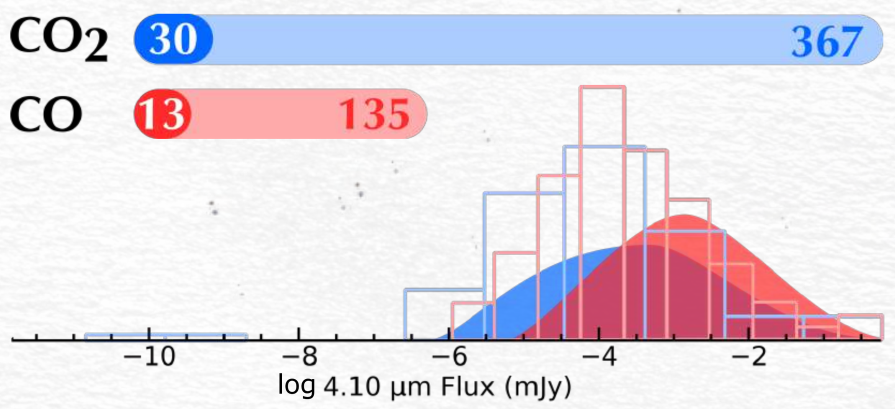

CO and $CO_2$ spectra of background stars and galaxies are extracted from spectral traces in F444W grism images using the OU NIRCam WFSS extraction code[8].



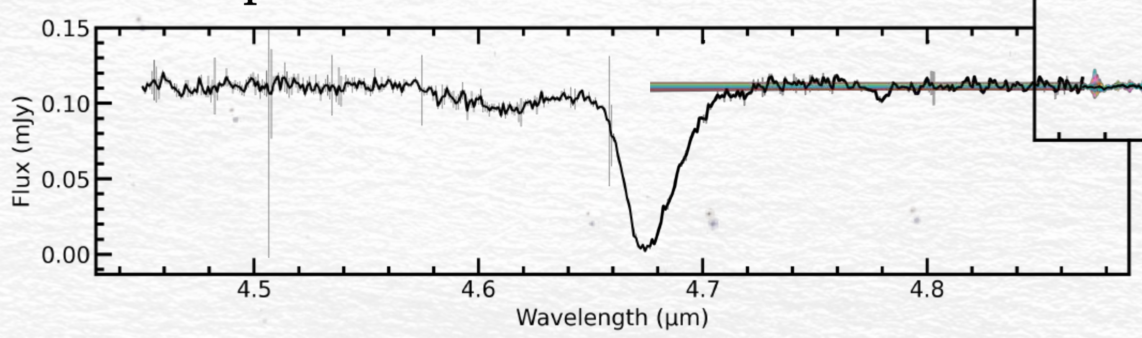

*The large volume of spectra provides the ability to spatially analyse ice column density and composition across Cha I using ice mapping techniques [e.g. 9].*

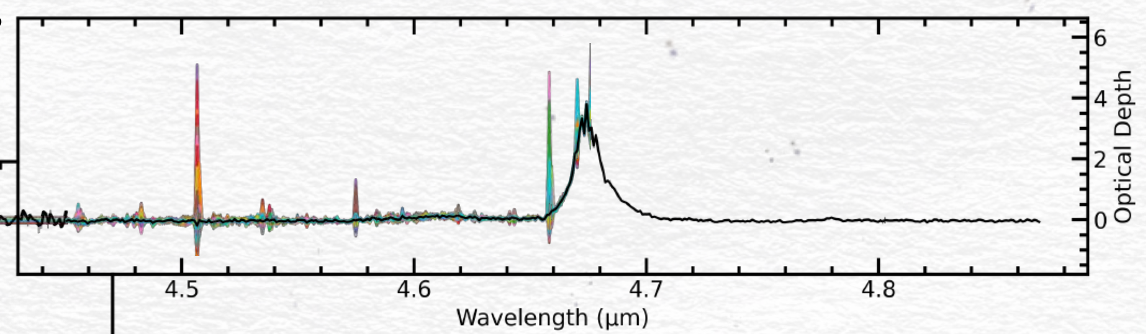
## Semi-autonomous spectral analysis




*$^{13}C$ isotope detected in ~10% of CO & $CO_2$. Detections not limited to brightest background stars*

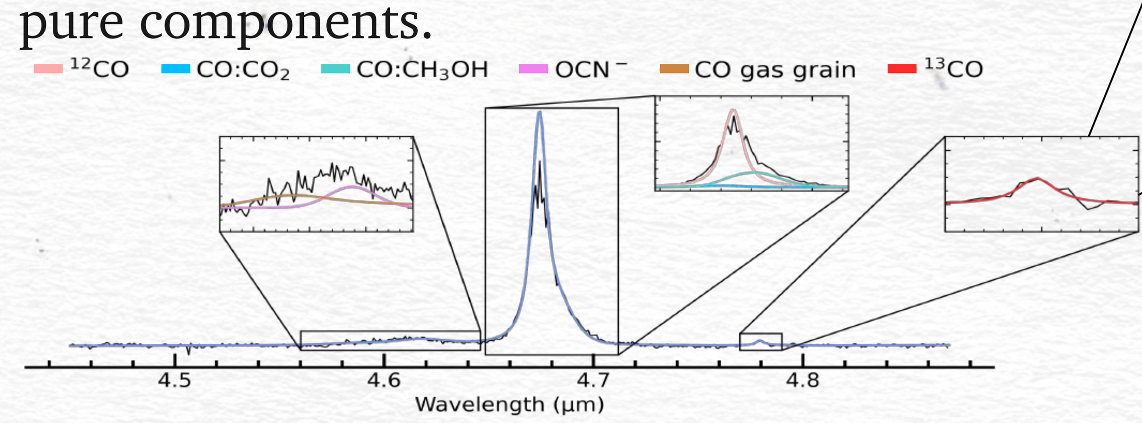
1000 local baselines are estimated using Gaussian process regression. Photospheric models are subtracted.

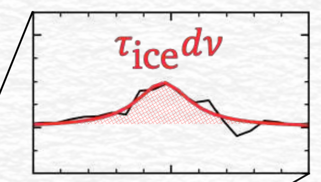



1000 optical depth spectra are calculated to generate a median. The 0.16 & 0.84 quantiles are taken as the upper and lower bounds respectively.

A multi-component fit is made to the ice functional band using grain shape corrected lab data for ice mixtures and analytical functions for pure components.

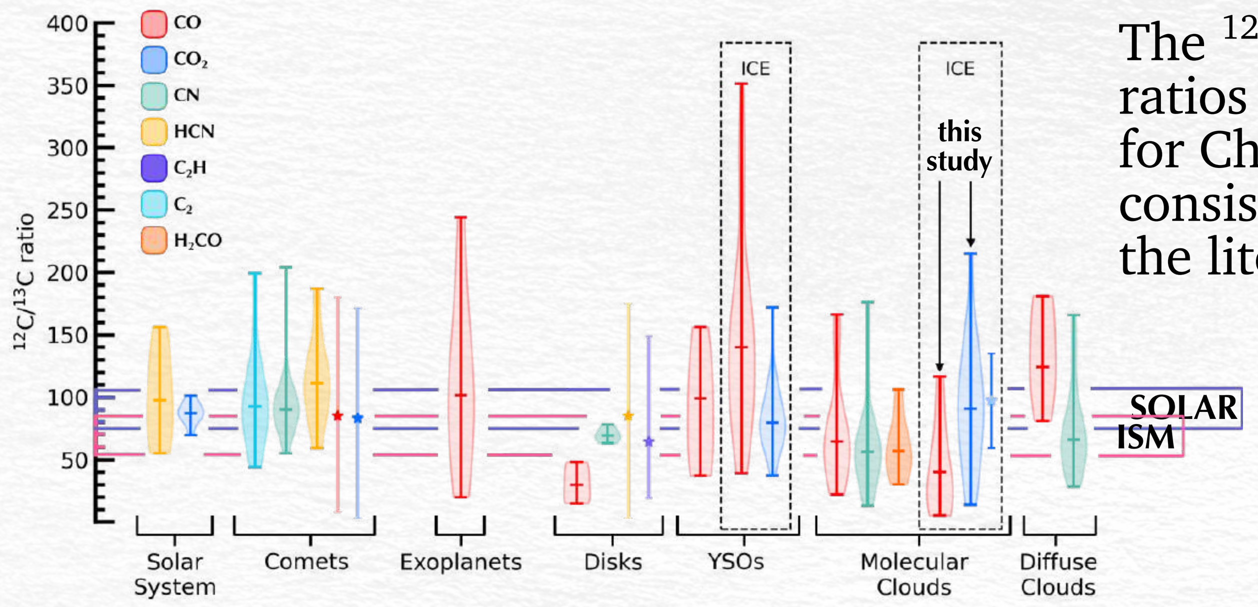


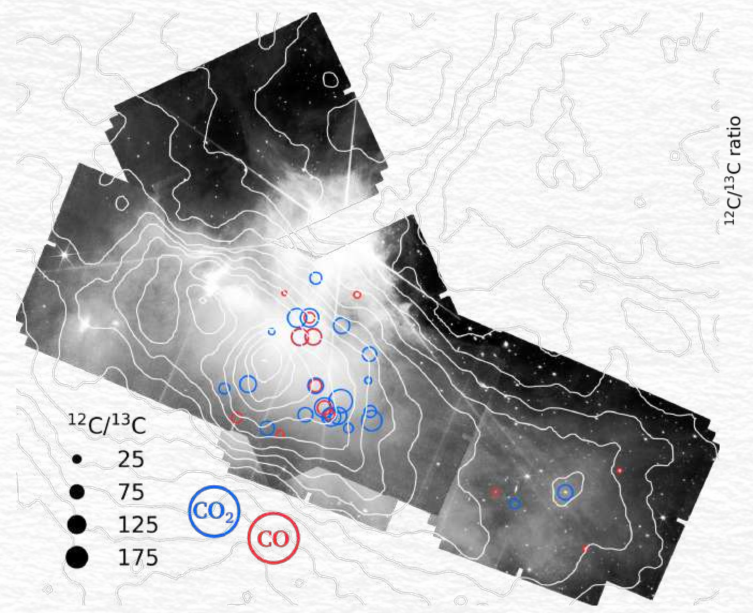

$$N_{ice} = \int \frac{\tau_{ice}dv}{A}$$

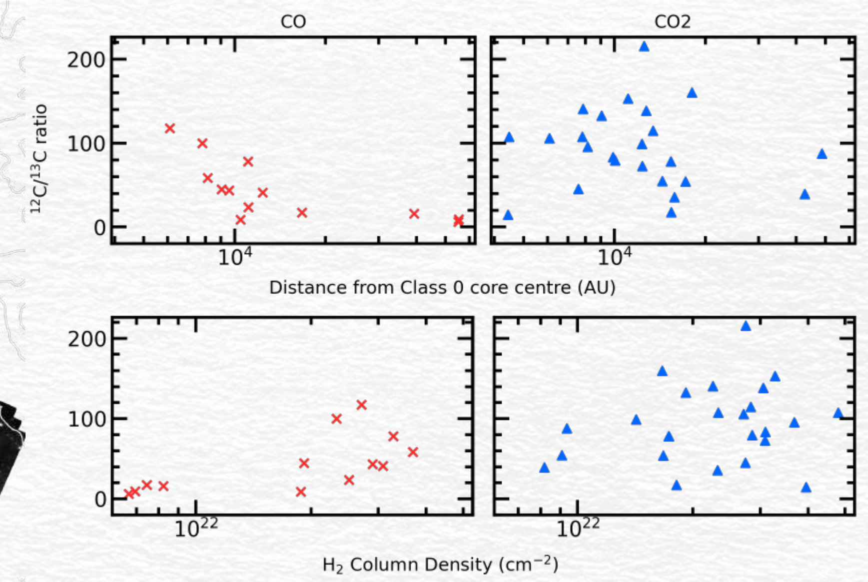
The column density of $^{12}C$ and $^{13}C$ are derived from the component fits and the band strength.

## 12/13C ratios across the outer regions of Cha I




The $^{12}C/^{13}C$ ratios derived for Cha I are consistent with the literature.




- **When measured along the same sightline, the $^{12}C/^{13}C$ ratios of CO and $CO_2$ ice are not consistent.**
- **The amount of $^{13}CO$ respective to $^{12}CO$ decreases with increasing dust density.**
- **Discrepancy between ice species possibly arising due to different formation mechanisms (i.e. freeze out from gas phase vs grain surface reactions) favouring different $^{13}C$ enrichment?**

*Image Credit: NASA/ESA/M. McClure/F. Sun/Z. L. Smith*


**References:** *1. Boogert et al. (2000); 2. Pontoppidan (2006); 3. McClure et al. (2023); 4. Brunken et al. (2024); 5. Roueff et al. (2015); 6. Brown et al. (1989); 7. Yurimoto et al. (2004); 8. Smith et al. (in prep); 9. Smith et al. (2025)*



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