Isotope Ratios in L1521E

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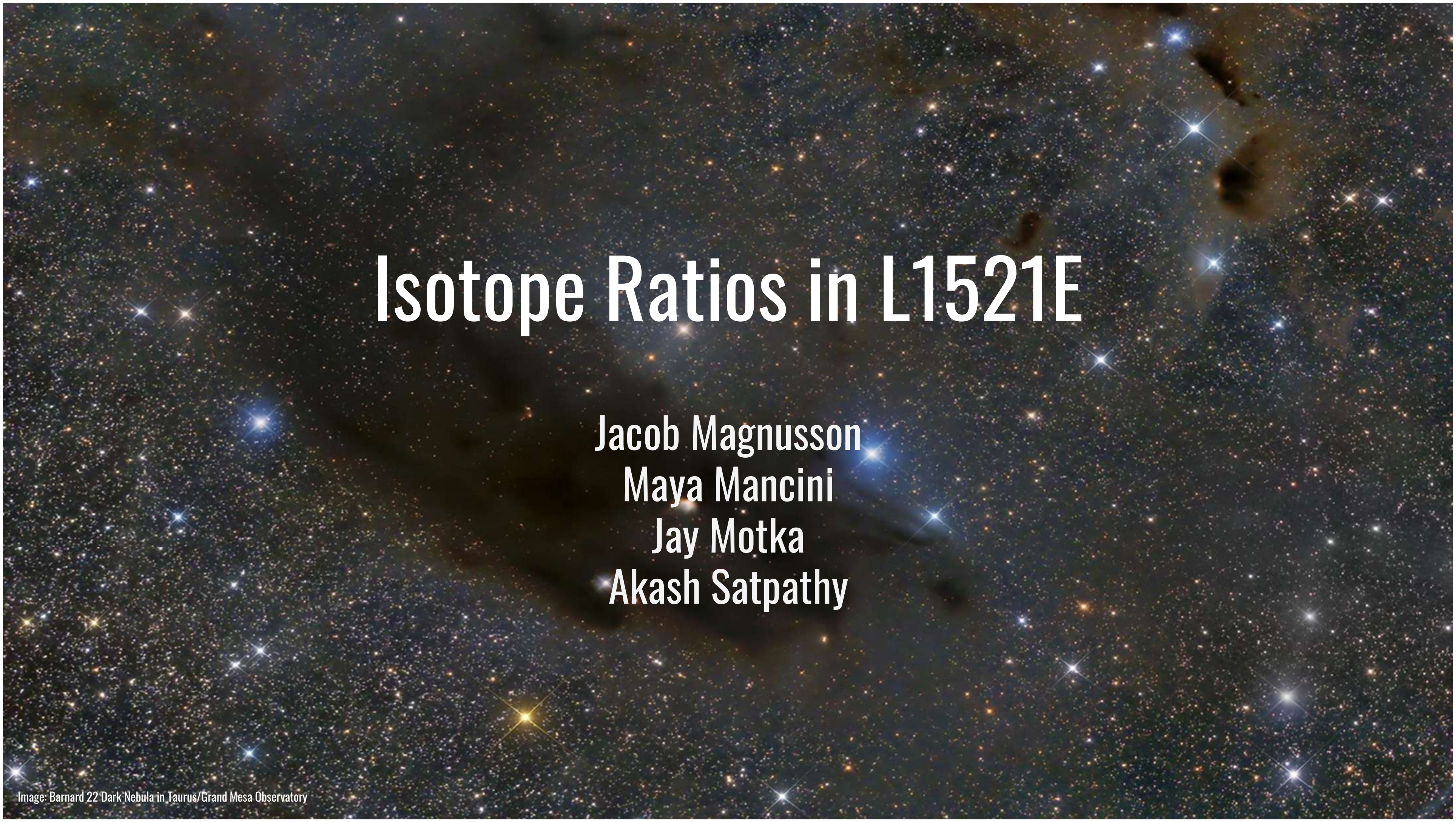


Image: Barnard 22 Dark Nebula in Taurus/Grand Mesa Observatory

Scientific Motivation

- Isotopic abundance ratios gives information about galactic chemical structure and evolution in addition to planet formation and the synthesis of heavy elements.
- C and O are created during stellar nucleosynthesis.
- Thus, their isotopic ratio gives information on star formation (Langer & Penzias 1993).
- It is interesting to look at carbon and oxygen based molecules like CO and its isotopic species.
- Gravitationally bound, starless (dark) pre-stellar cores gives us information about initial conditions of star formation.

Scientific Motivation and Goals

- Lynds 1521E shows low chemical depletion of star material tracers.
- Thus, it is still in the very early stages of star formation (Nagy et al. 2019).
- Frequencies of (2-1) rotational transitions of CO and its isotopes are not far apart.
- Pairs of these lines can be observed simultaneously! (It’s convenient.)
- Thus, we present to look at (2-1) transition lines of CO and its isotopes from L1521E, situated in Taurus.

- Goal: To calculate isotopic abundance ratios of C and O.

Observations

- The SMT 1.3 mm Receiver was used for observations:
  - ALMA Band 6 (205 – 280 GHz)
  - Dual polarization, SBS
  - Typical $T_{sys@230GHz}$ = 200-275 K
  - Best $T_{sys@230GHz}$ = 130-160 K
- Well suited to observe CO isotopes as they vary in the range 209 - 231 Hz.

Line (2-1)	Scans	Total Integration Time (Seconds)
$^{12}C^{16}O$	18	6480
$^{13}C^{16}O$	18	6480
$^{12}C^{17}O$	24	8640
$^{13}C^{17}O$	24	8640
$^{12}C^{18}O$	24	8640
$^{13}C^{18}O$	24	8640
$^{12}C^{16}O^{1}$	4	1440
$^{13}C^{16}O^{1}$	4	1440

Image 1: Total integration time for each of the lines

Observer: Group 2
Observer Initials: dpm
Obs_ID: Marrone2020B2_02
Catalog: group2.cat
Class File: class_002.smt
Observing mode: beam switching
Beam throw: +/- 2 arcmin
Switch rate: 2.5 Hz
Integration time : 3600s
Front end: 1.2mm RX
Back end: Mode: 4 IF; Bandwidth: 128 MHz

Source 1: L15221E

Line: 13C18O(2-1)
Frequency: 209.41909830 GHz

Line:13C17O(2-1)
Frequency: 214.57387300

Line:12C17O(2-1)
Frequency: 224.71418700 GHz

Line:13C16O(2-1)
Frequency: 220.39861950 GHz

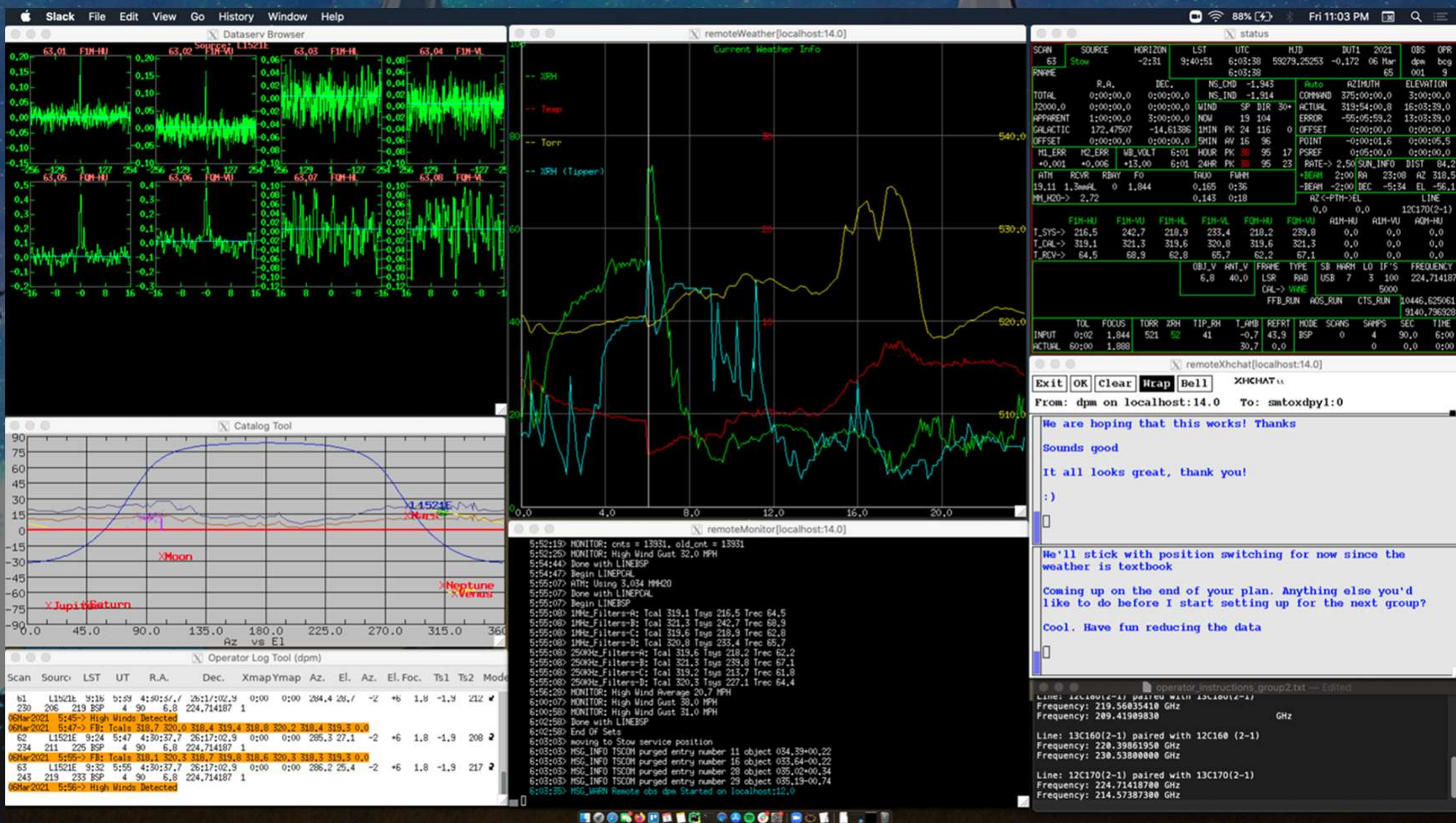
Line:12C18O(2-1)
Frequency: 219.56035410 GHz

Image 2: Observing plan PDF

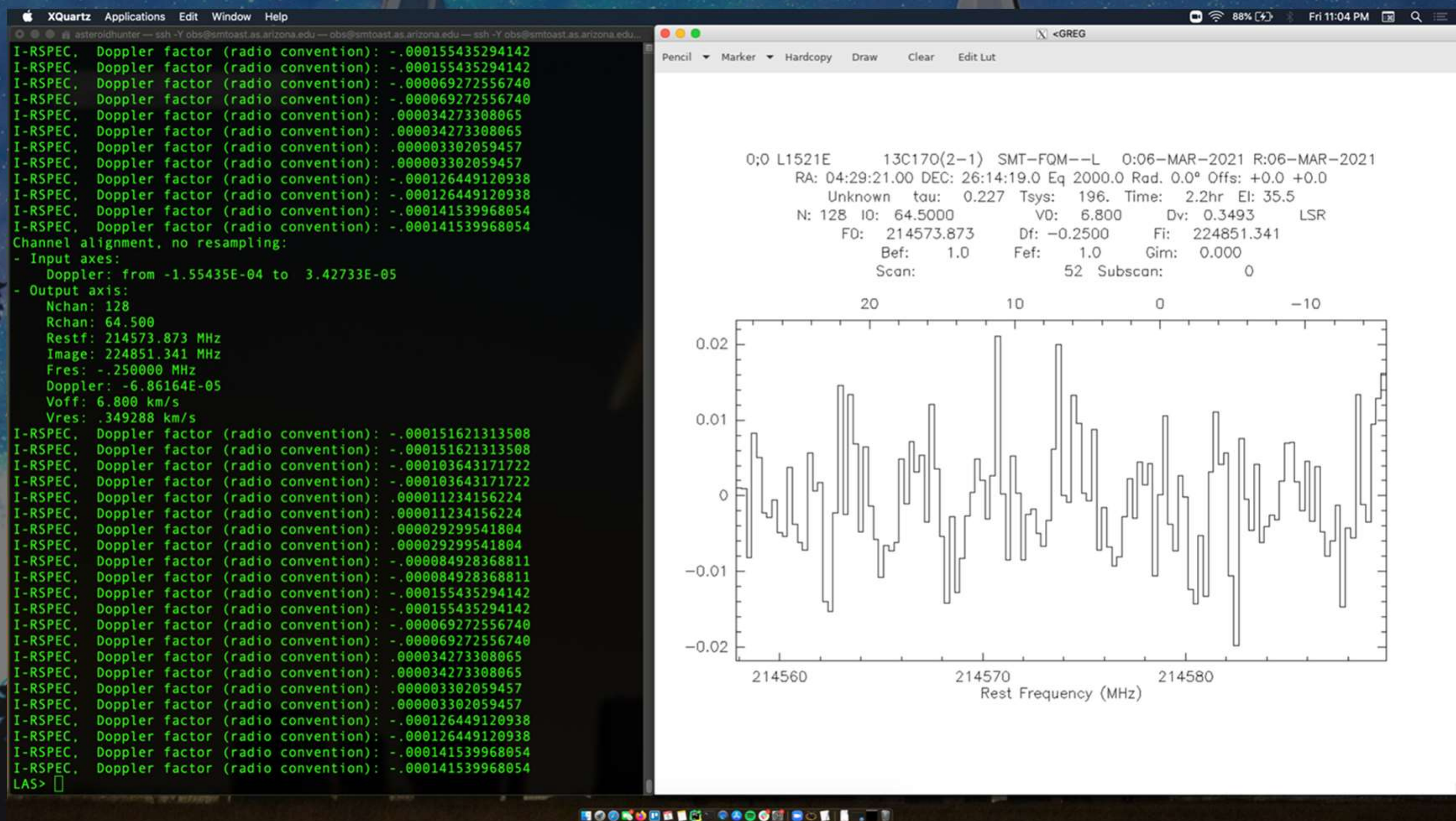
- CO lines were chosen using Splatalogue, and coordinate information was found using SIMBAD.
- Observing time span: 3 LST to 9 LST on the 6th of March, 2021
- Mars was used as the bright continuum source for calibration
- Most of the observations were done using *beam switching* method
- Ryan Keenan provided some additional observations using the *position switching* method (on the 7th of March, 2021)

Image: Submillimeter Telescope/Arizona Radio Observatory

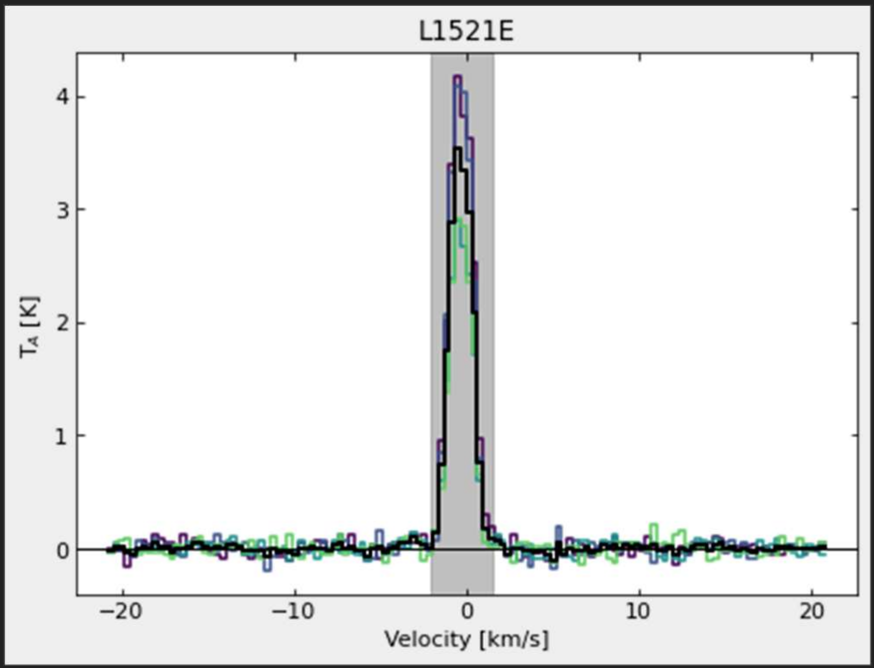
Observations



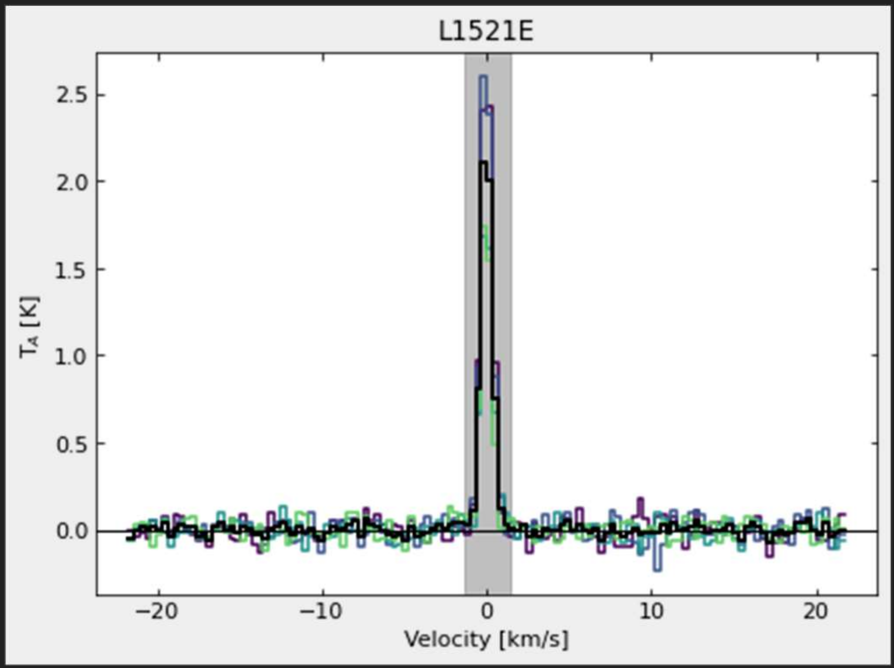
Observations



Measurements

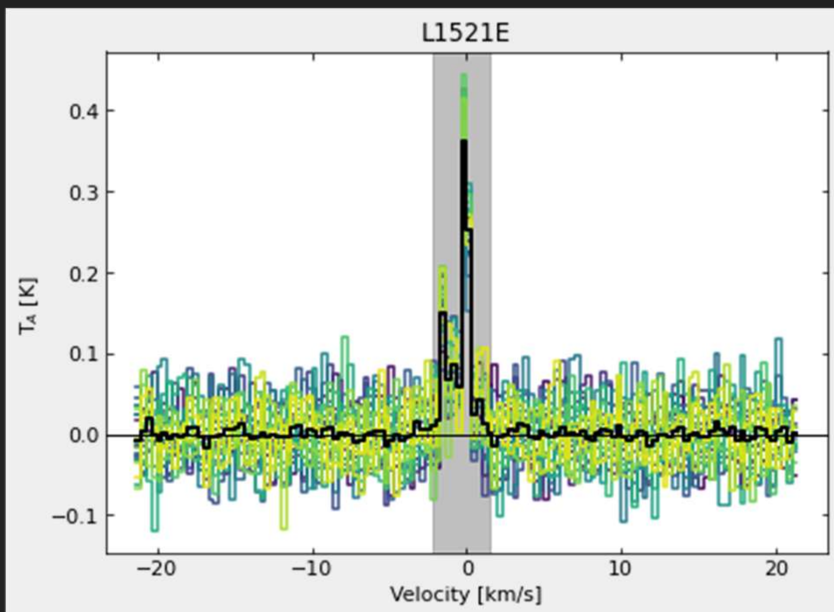


$^{12}C^{16}O$

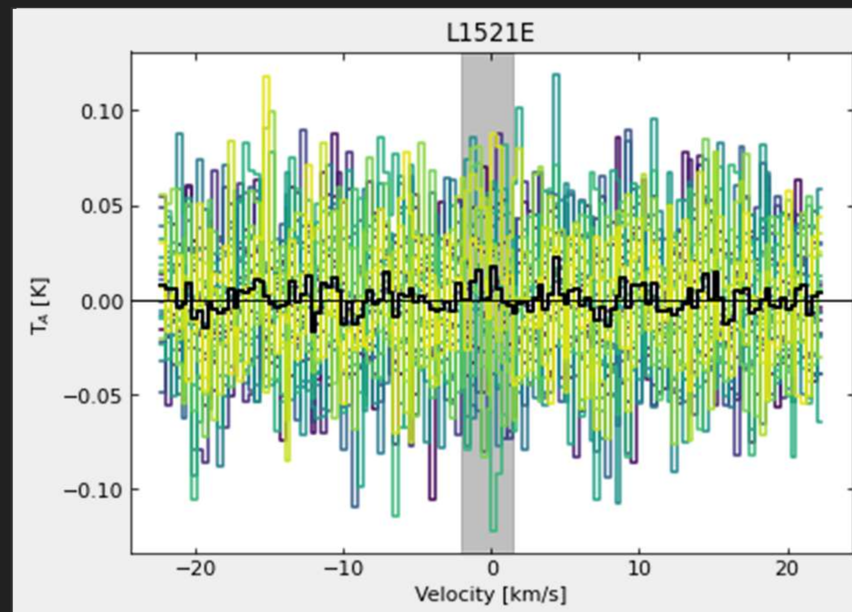


$^{13}C^{16}O$

Measurements

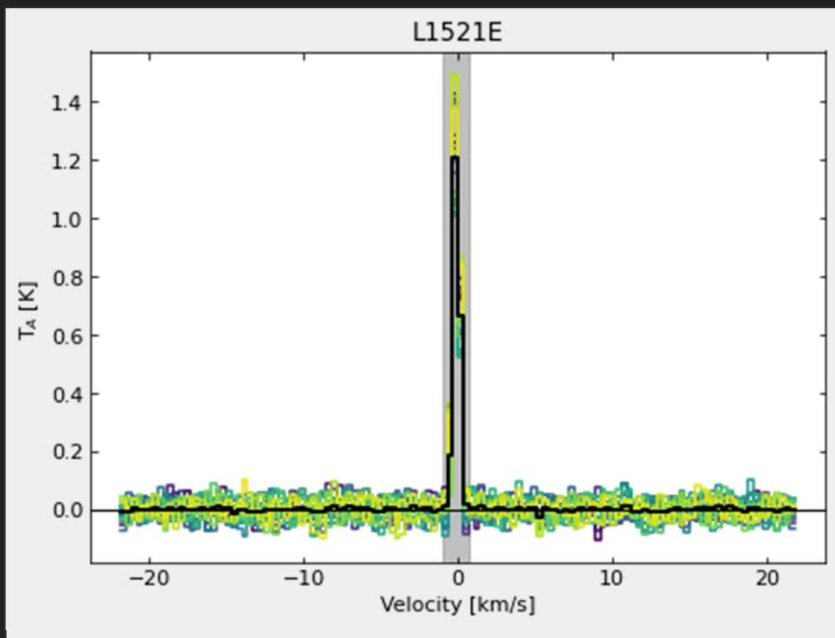


$^{12}C^{17}O$

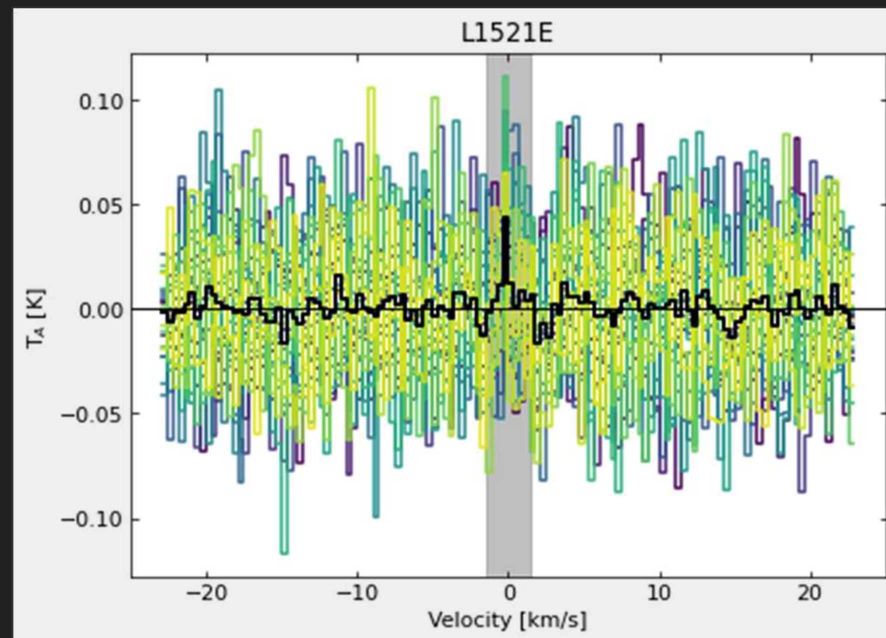


$^{13}C^{17}O$

Measurements



$^{12}C^{18}O$



$^{13}C^{18}O$

Theory

- Going from integrated temperatures to abundance ratios is a complicated exercise in radiative transfer calculation.

$$I_\nu = I_\nu(0)e^{-\tau_\nu} + S_\nu(1 - e^{-\tau_\nu}),$$

$$T_R = (J_\nu(T_{ex}) - J_\nu(T_{cmb}))(1 - e^{-\tau_\nu}).$$

- Mangum and Shirley arrive at the solution to the radiative transfer equation in temperature units with a negligible background. We assume optically thin.

Theory

- Difficult to motivate this now, but imagine taking the ratio of the integrated temperature of two different lines (The different isotopes)

$$\frac{\int T_{R,12C}dv}{\int T_{R,13C}dv} = \frac{\int (J_{12C}(T_{ex}) - J_{12C}(T_{cmb}))\tau_{12C}dv}{\int (J_{13C}(T_{ex}) - J_{13C}(T_{cmb}))\tau_{13C}dv}.$$

- Exponential from the previous slide was expanded in the optically thin limit, reducing it to a term linear on optical depth

Theory

- The optical depth will look like some column density times a cross section

$$\frac{\int T_{R,12C}\,dv}{\int T_{R,13C}\,dv} = \frac{\tau_{12C}\Delta v_{12C}}{\tau_{13C}\Delta v_{13C}}$$

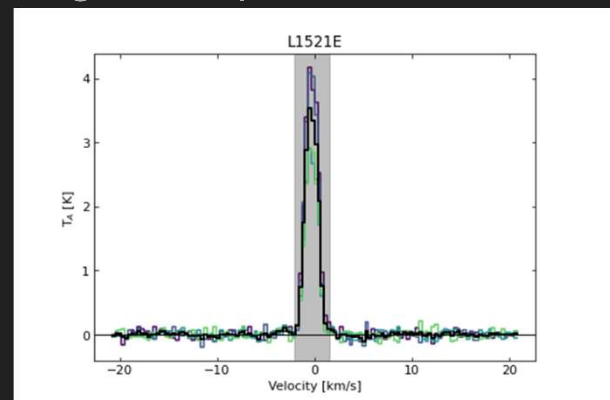
$$\frac{\tau_{12C}}{\tau_{13C}} = \frac{\sigma N_{12C}}{\sigma N_{13C}} = \frac{N_{12C}}{N_{13C}}$$

- The cross sections at their respective frequencies are approximated to be the same.

Theory

- Approximating a rectangular line profile, the integral simplifies to the velocity width of our line.

$$\frac{\int T_{R,12C}\,dv}{\int T_{R,13C}\,dv} = \frac{N_{12C}\Delta v_{12C}}{N_{13C}\Delta v_{13C}} = \frac{^{12}C\Delta v_{12C}}{^{13}C\Delta v_{13C}}$$
$$\implies \frac{^{12}C}{^{13}C} = \frac{\Delta v_{13C}\int T_{R,12C}\,dv}{\Delta v_{12C}\int T_{R,13C}\,dv}$$



(a) $^{12}C^{16}O$

- Everything on the right hand side can be measured, so we can arrive at an abundance ratio.*

* No chemical fractionation (preferential reaction of lighter isotopes)

Data Analysis

- Masking
- Baseline Removal
  - Degree 5 Polynomial
- Averaging
  - Weighted using System Temp
- Integration

Line	$\int T_R dv$
$^{12}C^{16}O$ (J = 2-1)	6.0332 ± 0.346
$^{13}C^{16}O$ (J = 2-1)	2.0895 ± 0.0288
$^{12}C^{17}O$ (J = 2-1)	0.3632 ± 0.0071
$^{13}C^{17}O$ (J = 2-1)	0.0148 ± 0.0078
$^{12}C^{18}O$ (J = 2-1)	0.7058 ± 0.0045
$^{13}C^{18}O$ (J = 2-1)	0.0312 ± 0.0062

Data Analysis

- We used the CHAOS pipeline to process our scans
- In doing so, we produced the following integrated antenna temperatures for each line of the CO species we observed
- These values were then used to directly calculate the ratios 12C/13C, 16O/17O, and 16O/18O

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Results

- For calculation, we utilized our working equation derived in the theory section

- We made sure to use the combination of isotopologues that minimized the standard deviation

- In doing so, we ended up not combining CO species with ^{12}C to find our Oxygen ratios, nor did we use $^{12}C^{16}0$ for any calculation because it was not assumed to be optically thin

$^{12}C/^{13}C$	$^{16}O/^{17}O$	$^{16}O/^{18}O$
39.95 ± 7.89	176.57 ± 92.57	71.81 ± 14.22

Results

- We compared our ratios to known values in the local ISM (Langer & Penzias 1993).
- We also compared our $^{12}C/^{13}C$ ratio to one already observed in L1521E which was $^{12}C/^{13}C = 58.8 \pm 3.7$ (Ikeda et al. 2002).
- Our values were in the expected range for the ISM.
- Our measured value of $^{12}C/^{13}C$ is lesser than the observed value in Ikeda et al. (2002) by about 31%.
- Might be due to poor SNR (about 5.1) of $^{13}C^{18}O$ line and along with very generous theoretical assumptions.
- Very large error in the measurement of $^{16}O/^{17}O$ is due to extremely poor SNR of 1.9 for $^{13}C^{17}O$.

Conclusion and Discussion

- While our calculated values were within the expected range, there were deviations that were not insignificant by any means.

- This relative error can be attributed to a number of factors:
  - Our many theoretical assumptions
  - Limited time
  - Limitations of the SMT 1.3mm receiver at frequencies near 200 GHz
  - Poor SNR

Future Prospects

- More precise data is needed the most.
- Thus, more integration time would give us precise measurements.
- Rectangular line profile that we took in the theoretical calculations can be further modified to fit the Gaussian velocity profile.
- CHAOS is being actively developed, and doesn’t have all needed features implemented yet. We believe line profile fitting would be incredibly useful to either implement into CHAOS or pair with CHAOS.
- Weighted temperature integrations to better standardize a reference column density.

References

Ikeda M., Hirota T., Yamamoto S., 2002, ApJ, 575, 250

Langer W. D., Penzias A. A., 1993, ApJ, 408, 539

Mangum J. G., Shirley Y. L., 2015, PASP, 127, 266

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