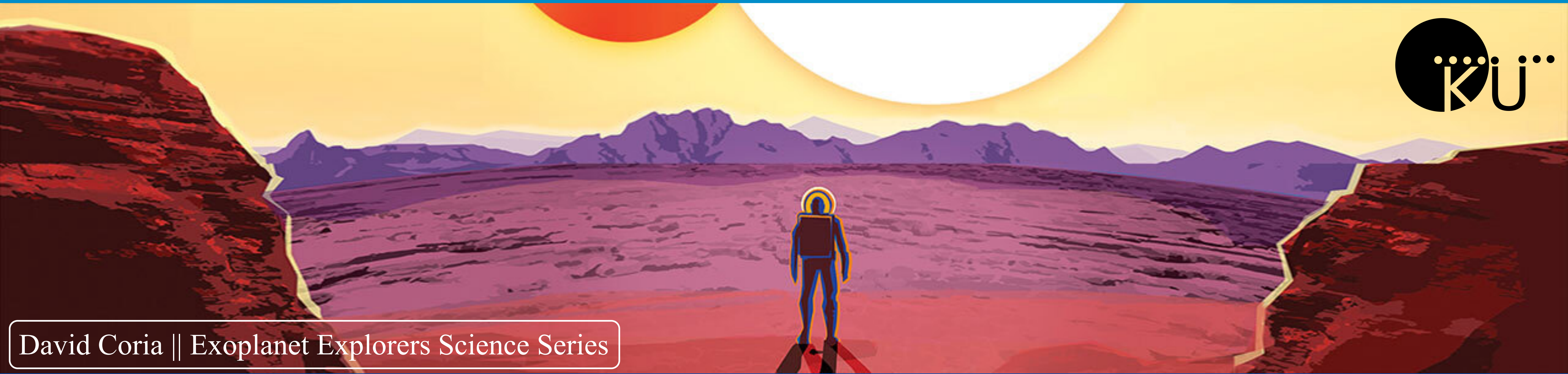
The Missing Link: Connecting Exoplanets and Galactic Chemical Evolution via Stellar Abundances

David Coria[1], Ian Crossfield[1], Joshua Lothringer[2]

[1]Department of Physics & Astronomy, University of Kansas, Lawrence, KS, USA

[2]Department of Physics & Astronomy, Johns Hopkins University, Baltimore, MD, USA



Overview

1. Discuss the significance of stellar abundances

2. Data Processing + Isotopic Abundance calculations

3. Next Steps

Overview

1. Discuss the significance of stellar abundances

2. Data Processing + Isotopic Abundance calculations

3. Next Steps

Overview

1. Discuss the significance of stellar abundances

2. Data Processing + Isotopic Abundance calculations

3. Next Steps

Why study abundances?

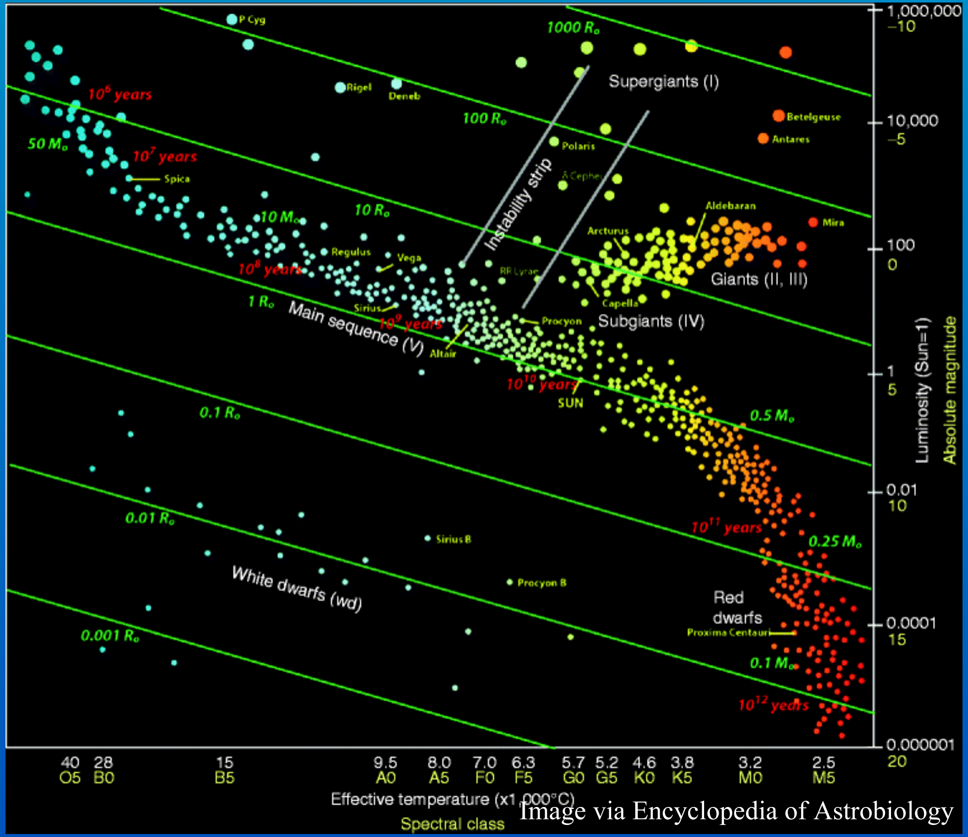


Image via Encyclopedia of Astrobiology

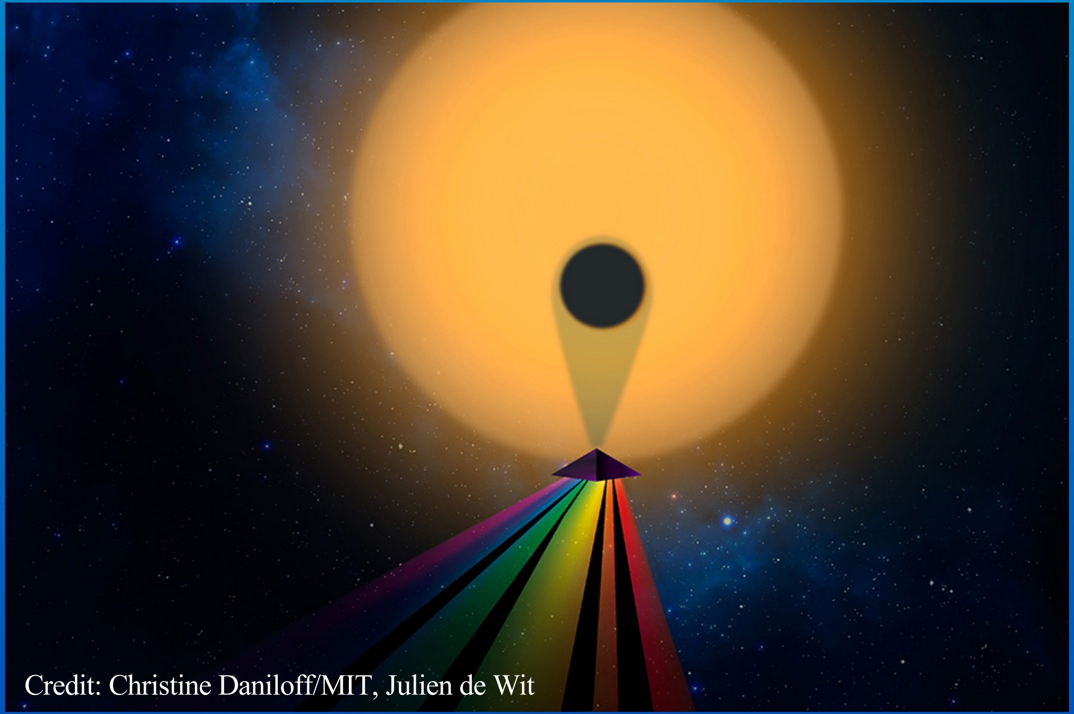
Stellar chemical properties carry an ABUNDANCE of info!

1) Elemental enrichment helps us study: star formation, age constraints, interior modeling, planetary system formation, planet habitability
2) Can compare stellar abundances to: local ISM, YSOs, and GCE models

Elemental Abundances: C & O

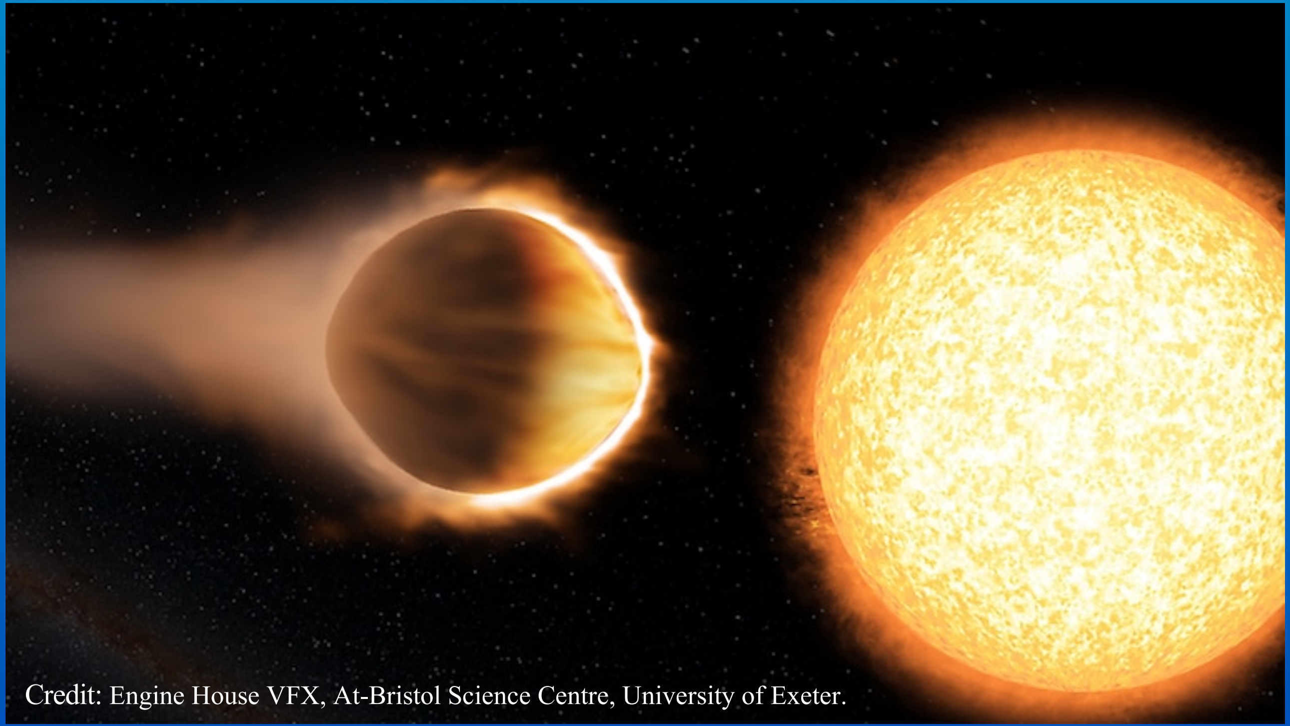
C/O Ratio: volatile elements; ice + gas + rock chemistry; exoplanet atmospheres

Volatile Analysis via Transmission Spectroscopy



Credit: Christine Daniloff/MIT, Julien de Wit

WASP-121b: Stratosphere Detection



Credit: Engine House VFX, At-Bristol Science Centre, University of Exeter.

Elemental Abundances: Mg & Si

Mg/Si Ratio: rock chemistry, geology; exoplanet interiors

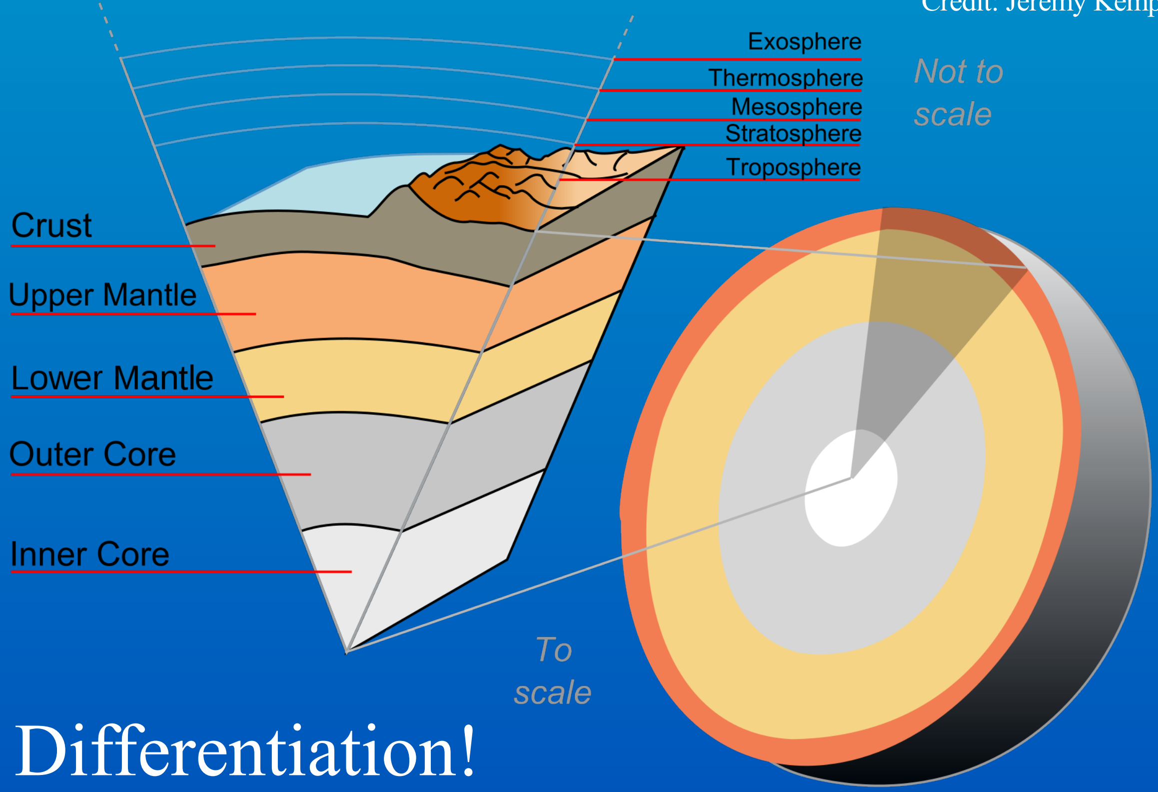
Olivine:
$(Mg_2, Fe_2)SiO_4$

Pyroxene: $XY(Si,Al)_2O_6$

X = Ca, Na, Fe, Mg

Y = Cr, Al, Fe. Mg, Co …

Credit: Jeremy Kemp

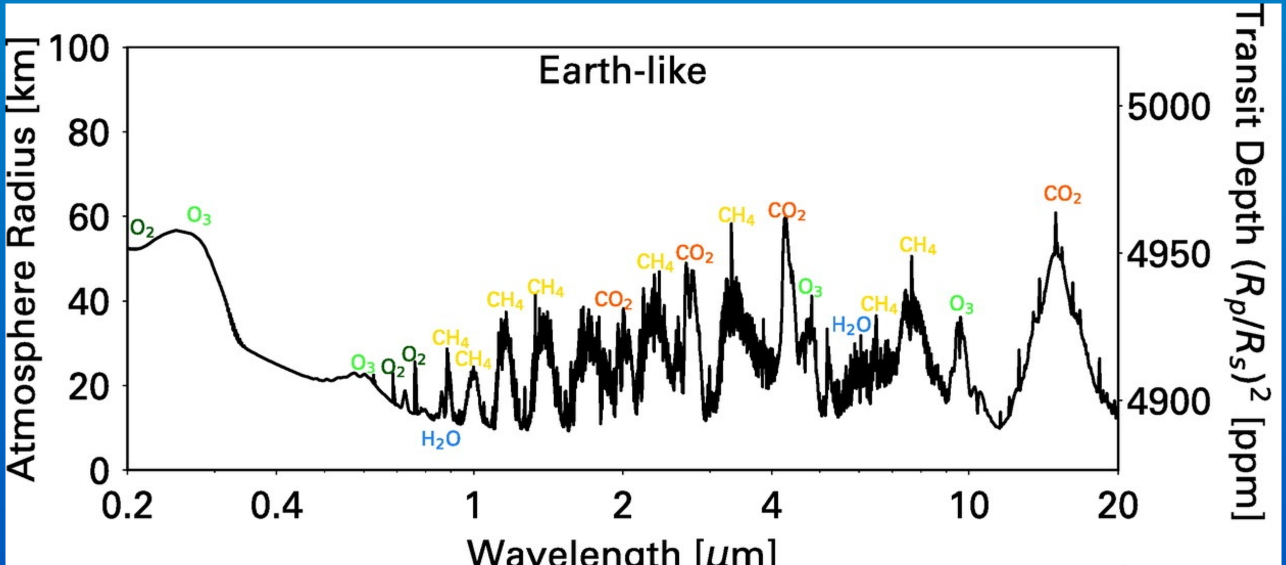


Differentiation!

Elemental Abundances: C & O, Mg & Si

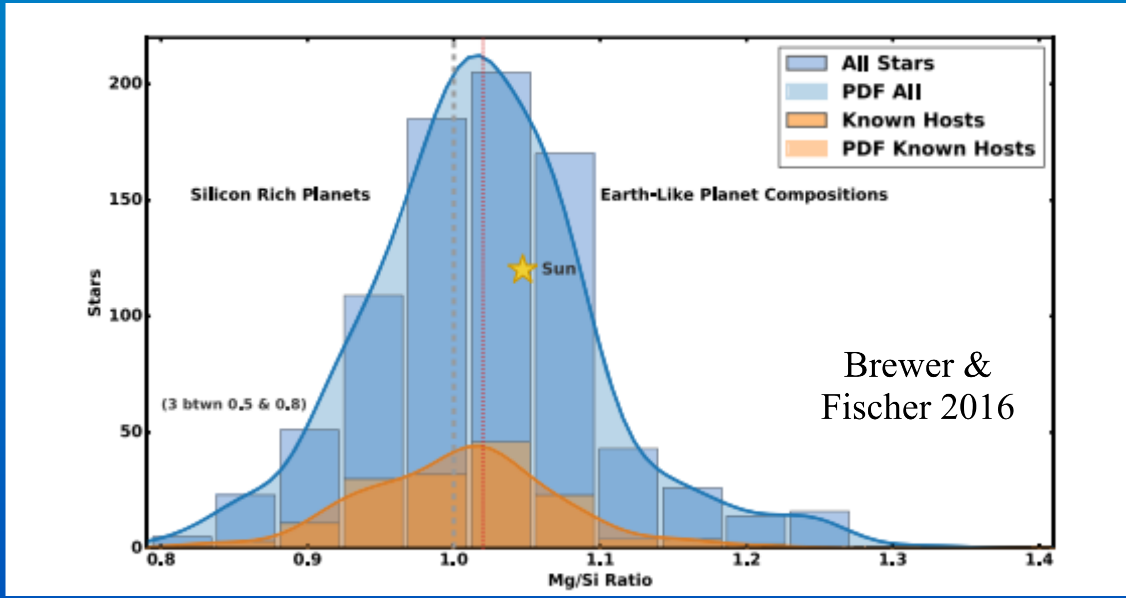
It's important to look for C/O and Mg/Si ratios significantly different from what we know!!!

C & O in a model transit spectrum:



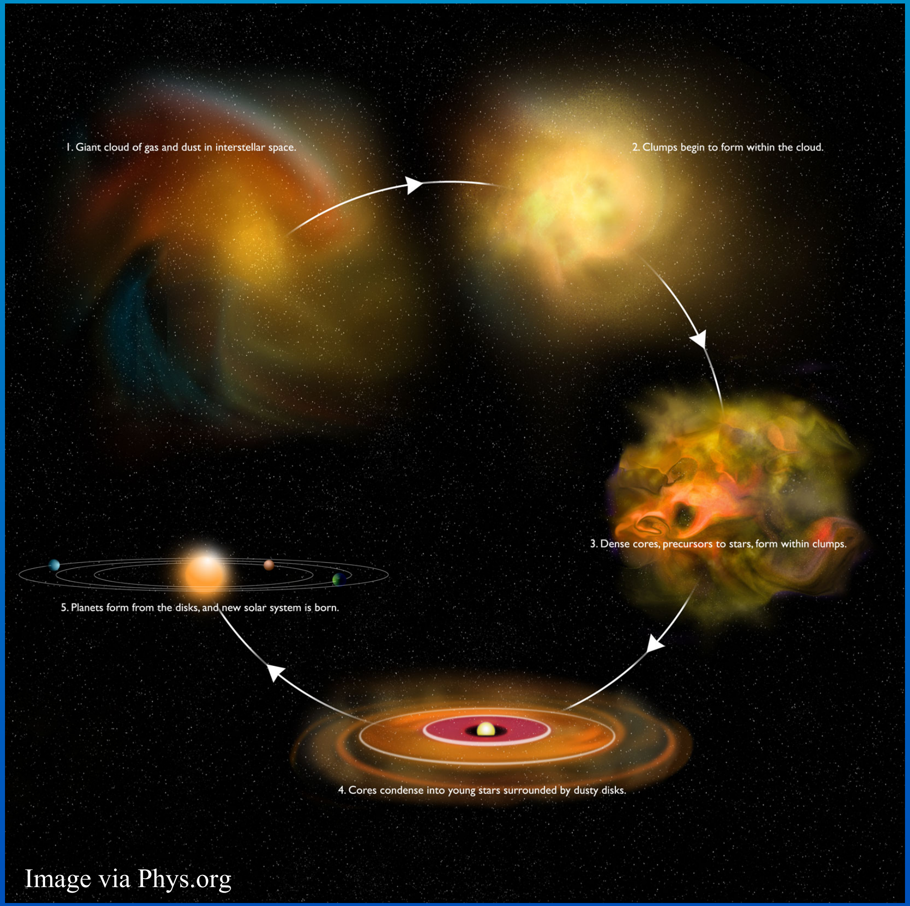
Meadows+ 2018

Distribution of Mg/Si Ratios:



Brewer & Fischer 2016

Why study abundances?



Stellar chemical properties carry an ABUNDANCE of info!

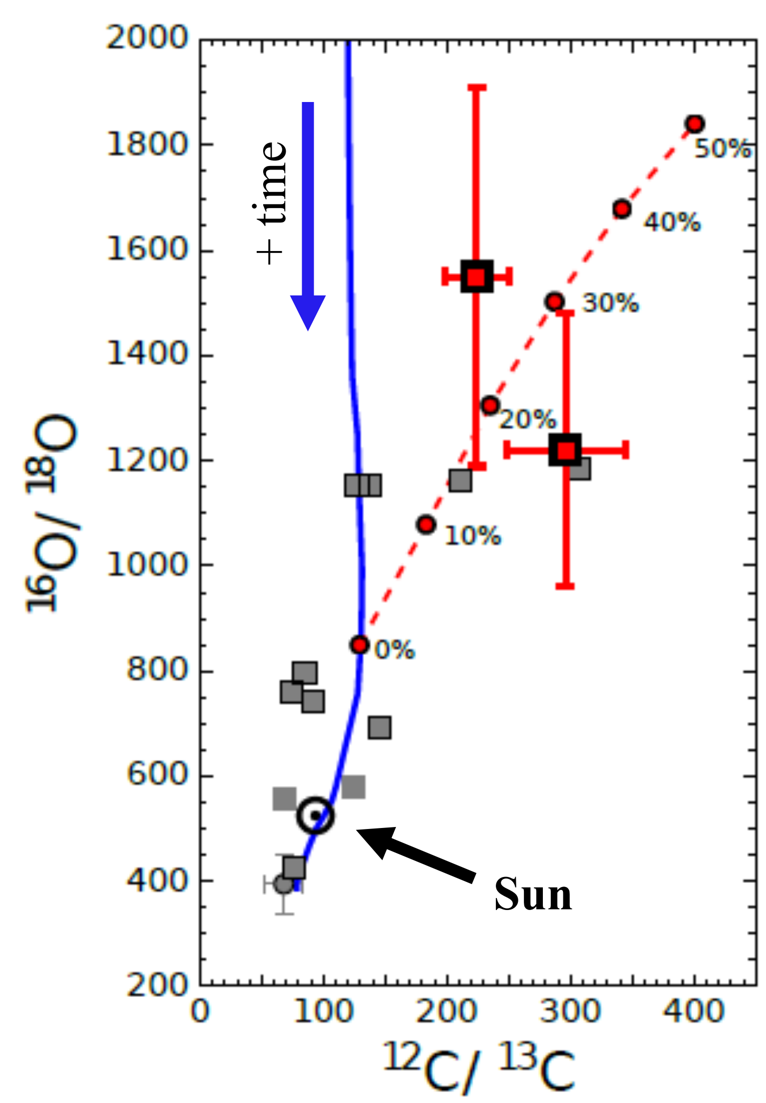
1) Elemental enrichment helps us study: star formation, age constraints, interior modeling, planetary system formation, planet habitability
2) Can compare stellar abundances to: local Interstellar Medium (ISM), Young Stellar Objects (YSOs), and Galactic Chemical Evolution (GCE) models

Galactic Chemical Evolution (GCE) Models

M-Dwarfs (Crossfield+ 2019):

Young Stellar Objects:

Kobayashi (2011) GCE Model:
Proposed GCE Correction:



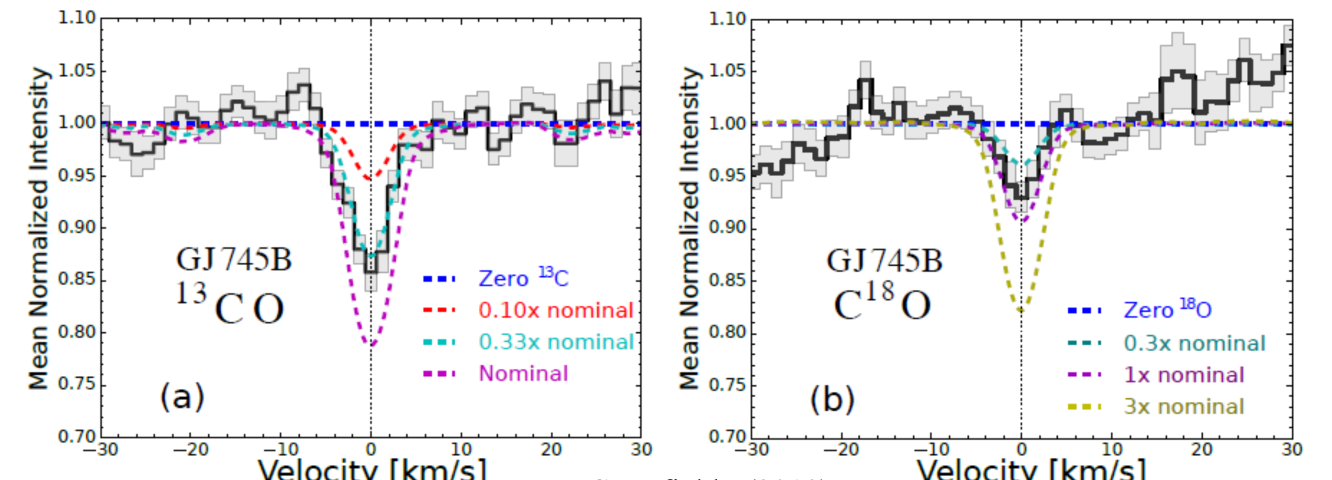
Kobayashi (2011); Crossfield et al. (2019)

Short-Term Goal: Isotopic Abundances

High-resolution spectroscopy allows for isotopic abundance analysis; even in M-dwarfs with low S/N spectra + molecular line contamination!!!

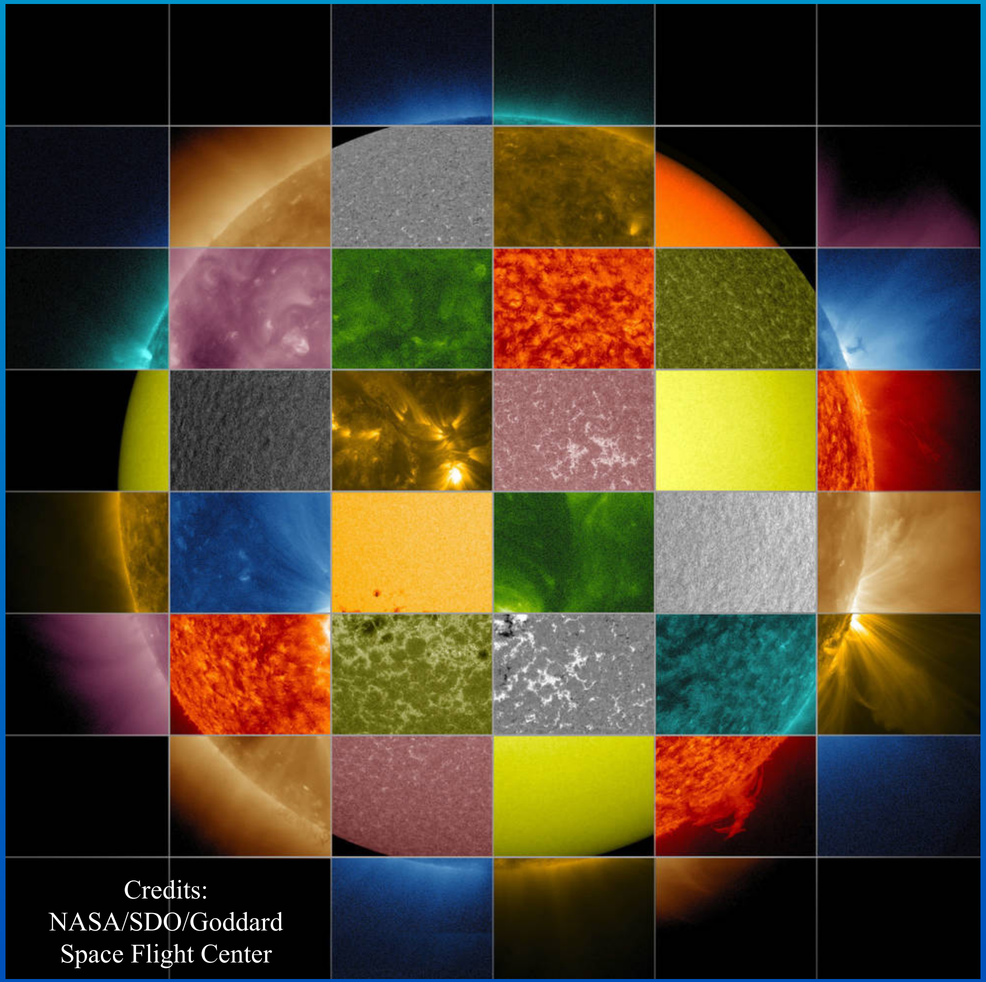
Task: Calculate CO isotopic abundances in 6 solar twin stars AND:

moving group stars, cool binaries, field M-dwarfs, JWST-targeted exoplanet host stars



Crossfield+ (2019)

Why Solar Twins?



What star do we know the BEST???
Hint: Name rhymes with “Fun”

Generating model spectra is far easier for solar twins than for other stars!

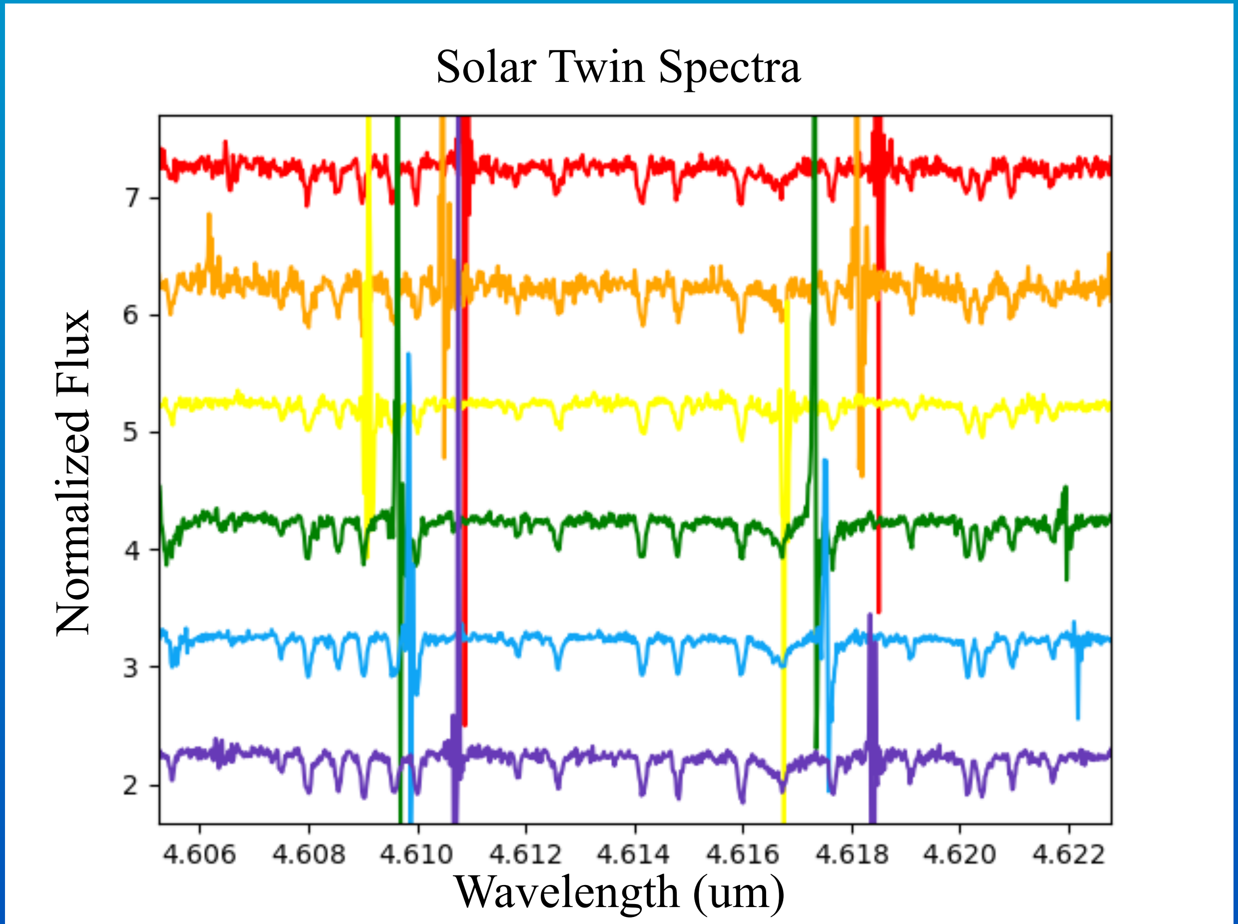
Solar twins are hot enough that we don’t see the molecular absorption present in cooler KM dwarfs

Solar Twin Sample

O0(hot) B A F G K M9(cool)

Star	Spectral Type	T_eff (K)	Radius (xSol)	Age (Gyr)
ST #1	G5V	5838	0.96	2.42
ST #2	G4V	5758	0.95	5.51
ST #3	G8V	5848	1.0	1.01
ST #4	G2V	5683	0.96	3.67
ST #5	G2V	5814	1.03	3.09
ST #6	G3V	5694	1.04	6.66
Sun	G2V	5780	1.0	4.603

*Dos Santos+ 2016



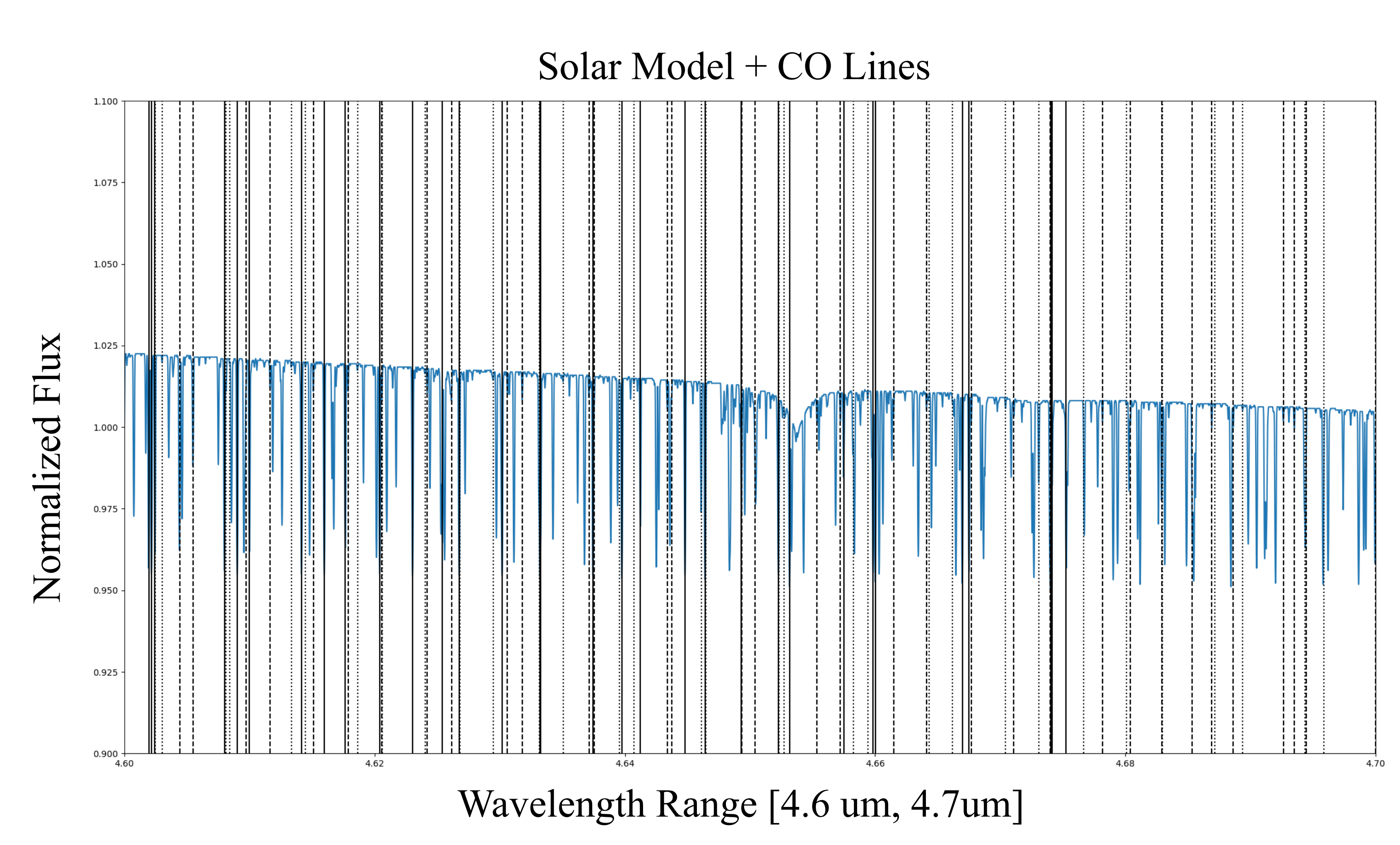
Calculating Isotopic Abundances: Step 1

Goal: Measure isotopologue abundances ($^{12}C^{16}O$, $^{13}C^{16}O$, $^{12}C^{18}O$) to determine isotopic abundance ratios ($^{12}C/^{13}C$, $^{18}O/^{16}O$)

Note: Isotopologue is to *Molecule* what Isotope is to *Atom*
*Different mass numbers

Step 1: Identify CO absorption lines!!!

^{12}CO, ^{13}CO, and $C^{18}O$ lines from HITRAN

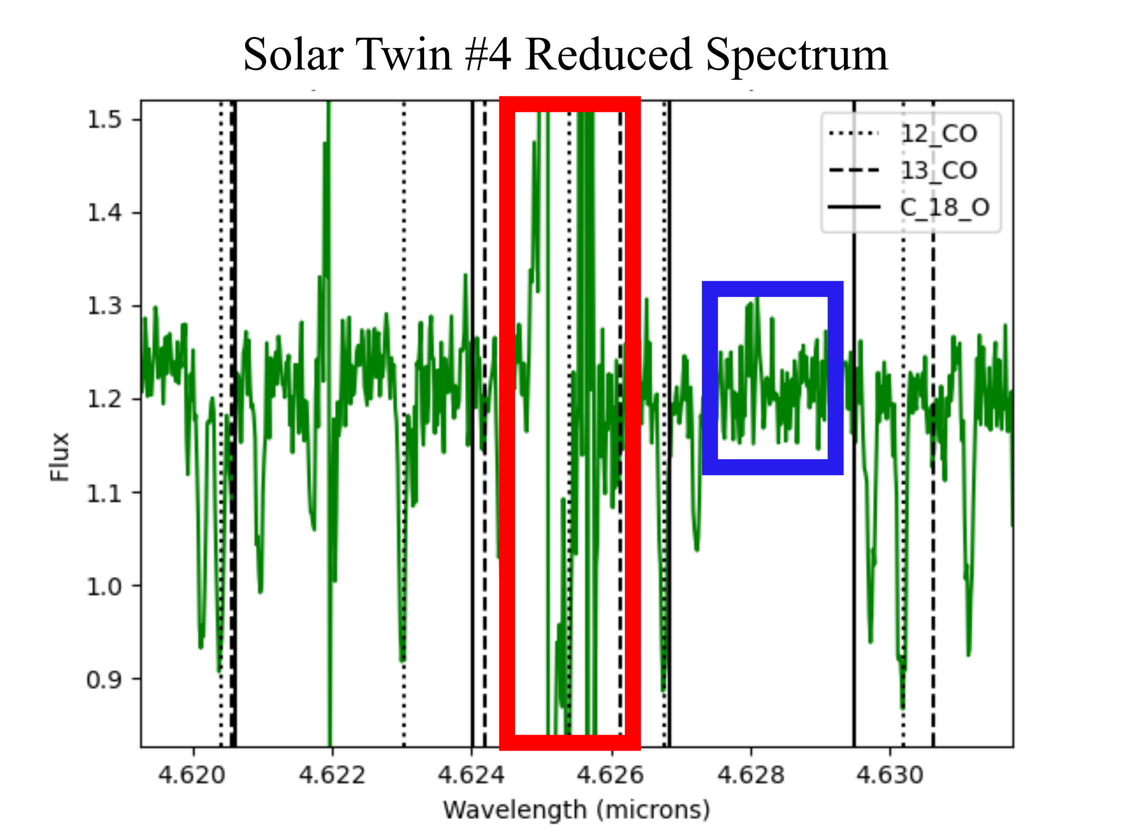


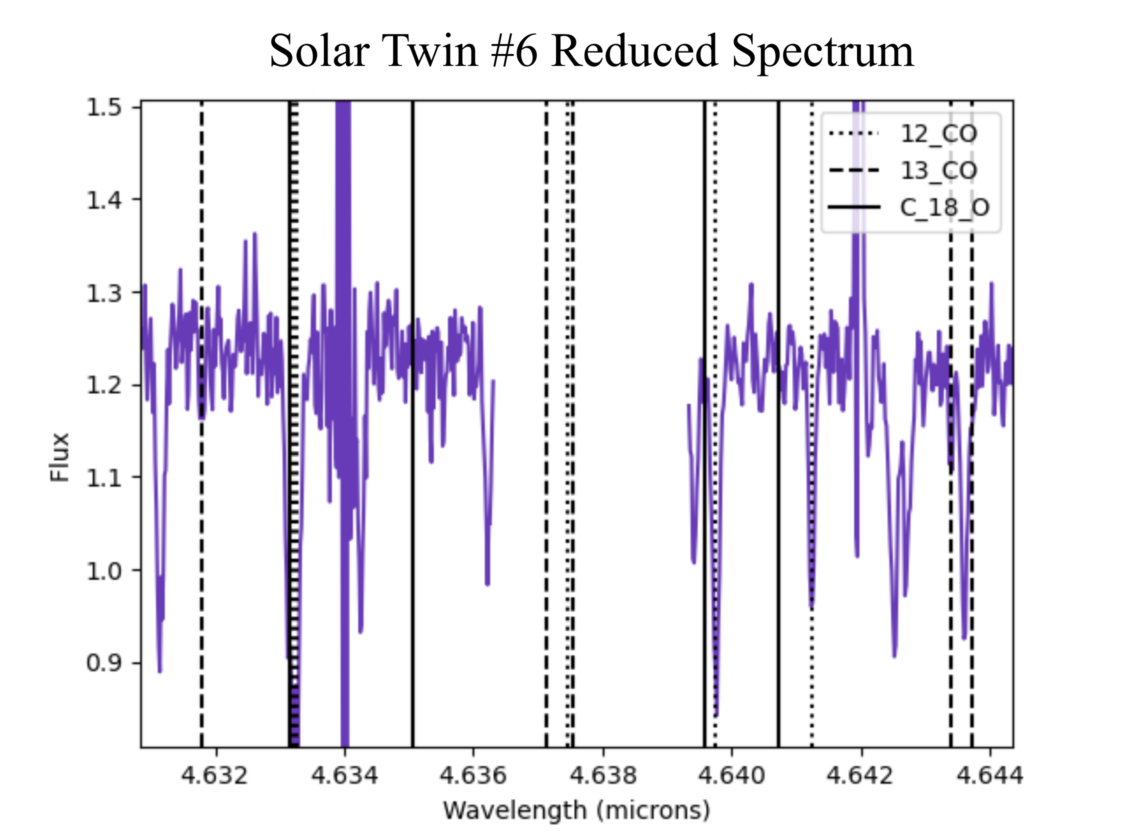
107 different CO lines in this MIR region!!!

41 ^{12}CO lines
34 ^{13}CO lines
32 $C^{18}O$ lines

Identify Useable Lines

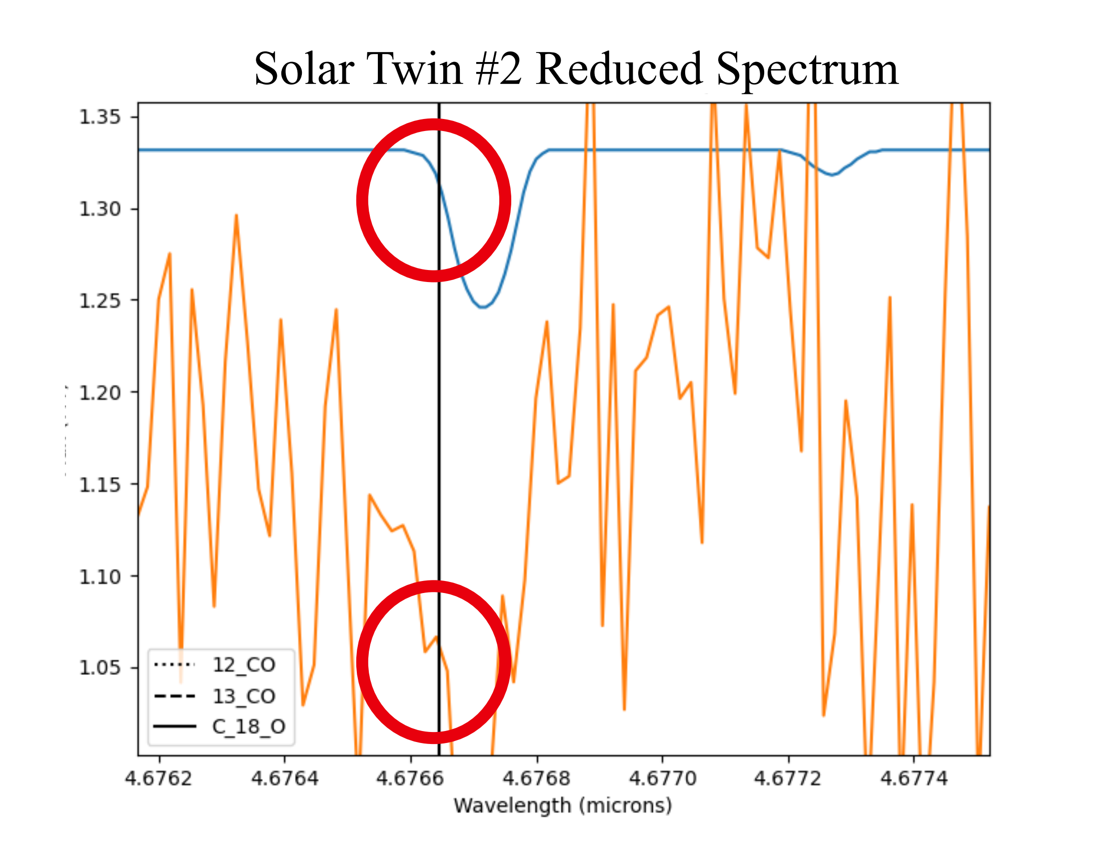
Remove lines obscured by tellurics and lines that are out of our instrument's range.

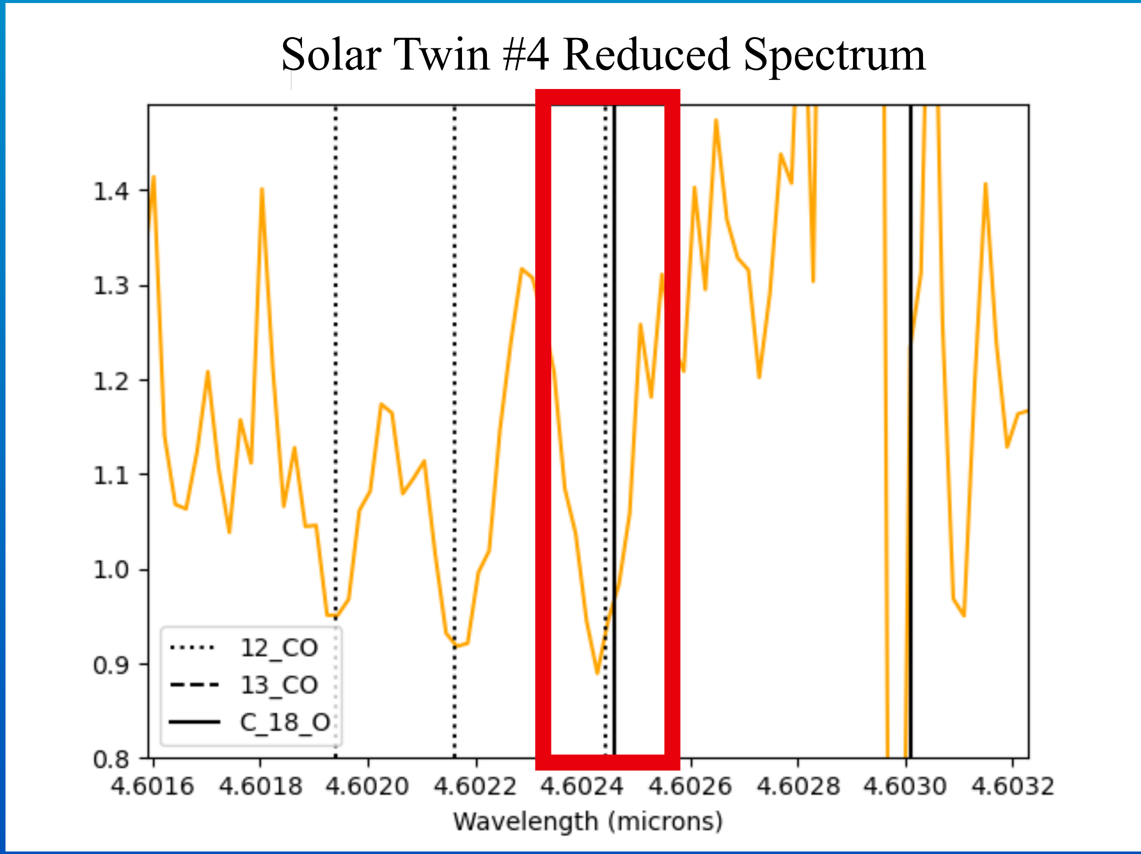




Identify Useable Lines

Remove lines that are dominated by stronger spectral features!





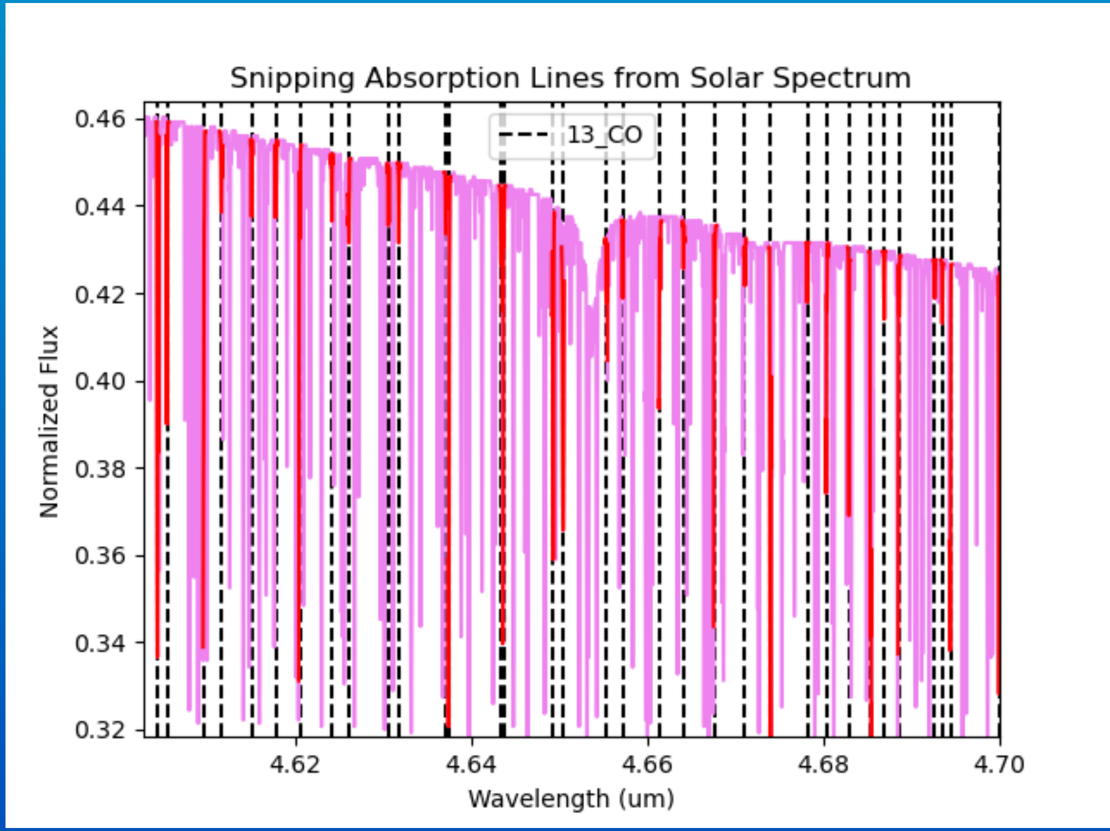
Calculating Isotopic Abundances: Step 2

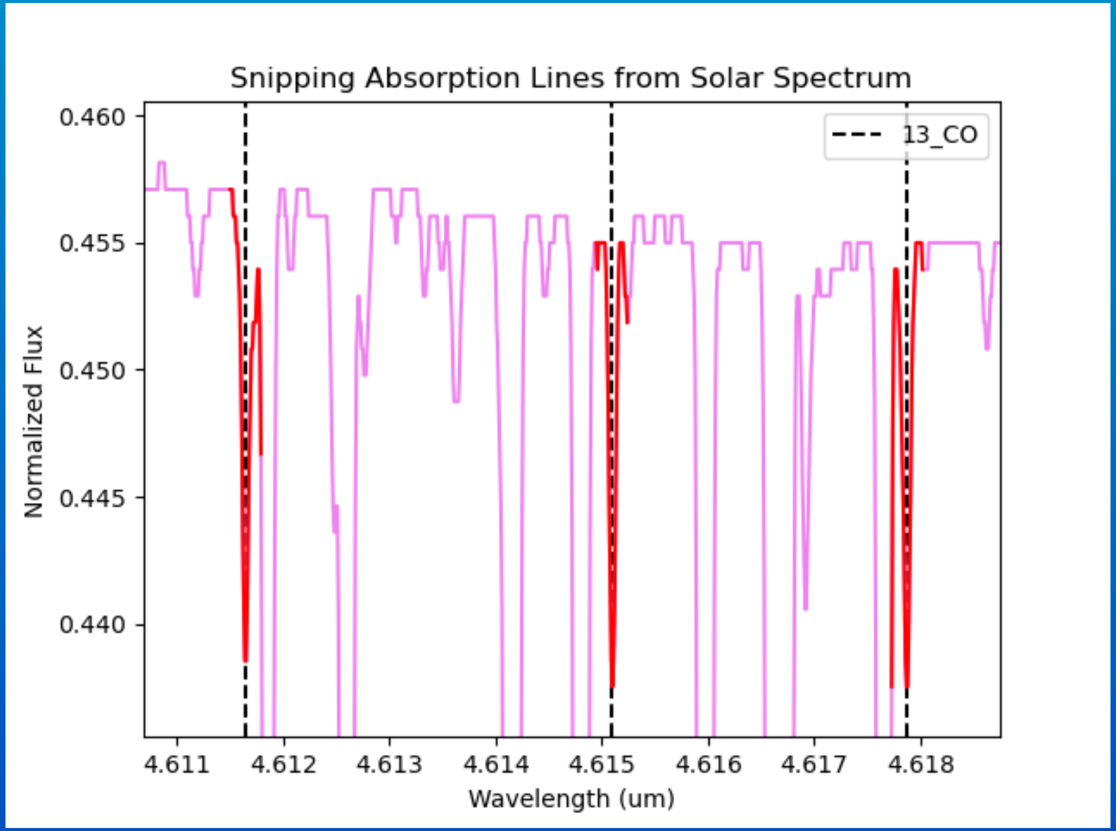
Step 2: Snip the CO absorption features out of the solar twin spectrum and stack to create a single line profile

Step 2b: Repeat for solar models w/ 0x, 1/3x, 1x, and 3x solar CO

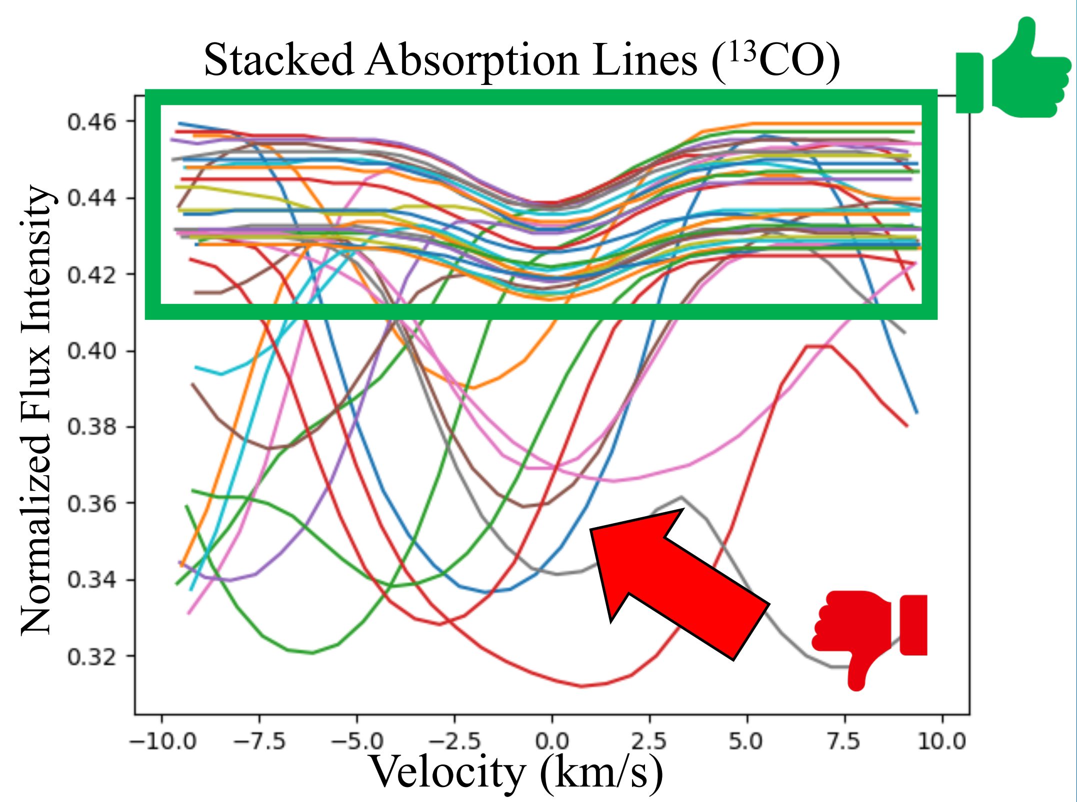
Snipping Out the Absorption Features

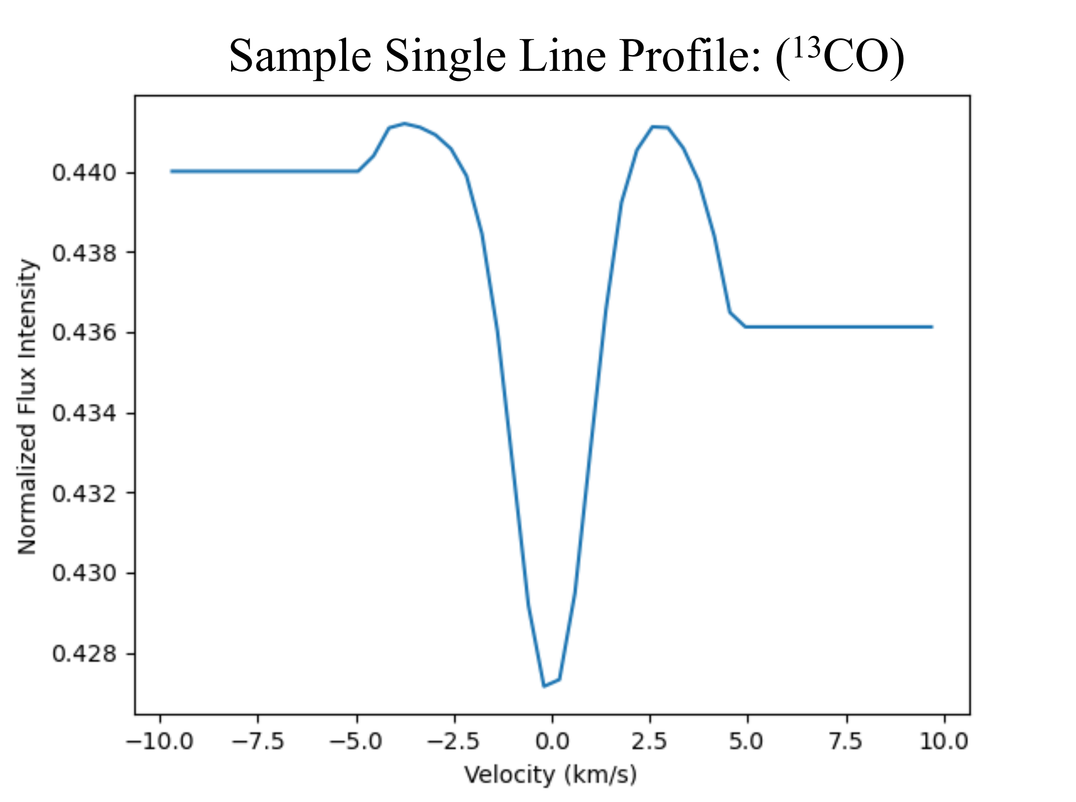
Full Spectrum:
Snip:





Creating a Single Line Profile



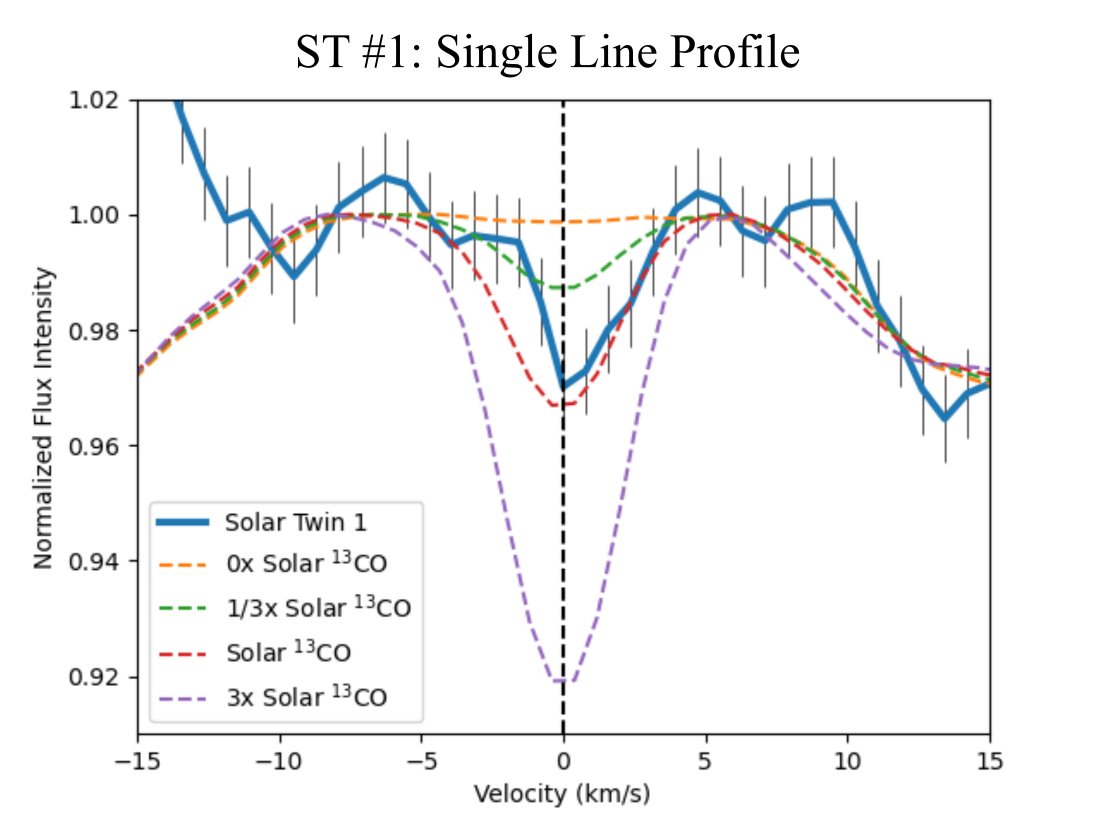


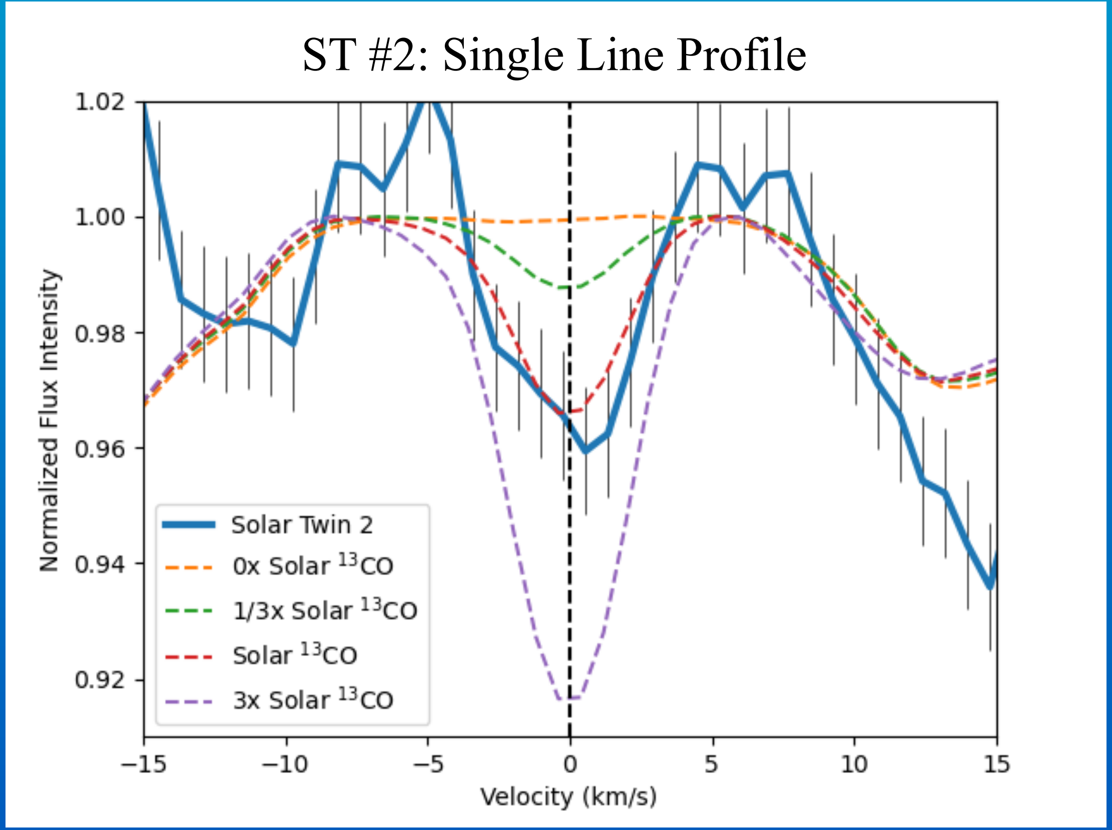
Wavelength to Velocity: $$v = \frac{\lambda - \lambda_0}{\lambda_0} c$$

Calculating Isotopic Abundances: Step 3

Step 3: Compare single line profiles (Solar Twin vs. Models)

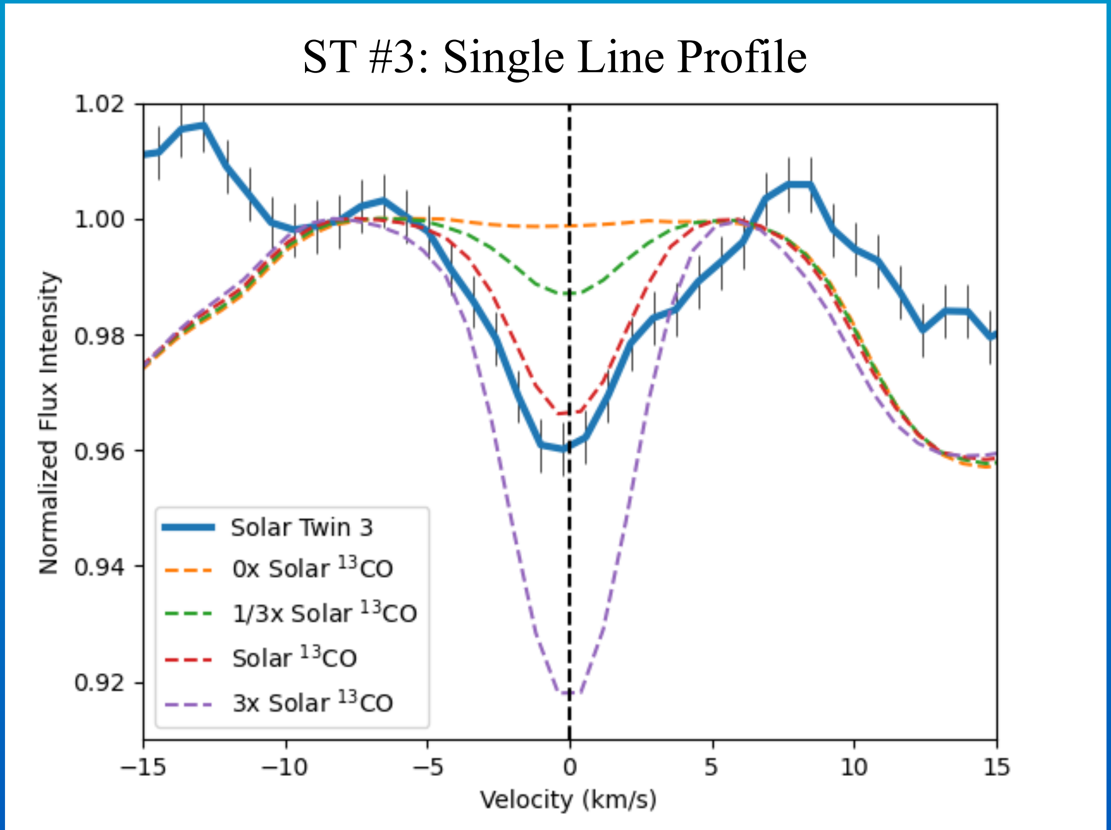
^{13}CO Abundance Plots!!!

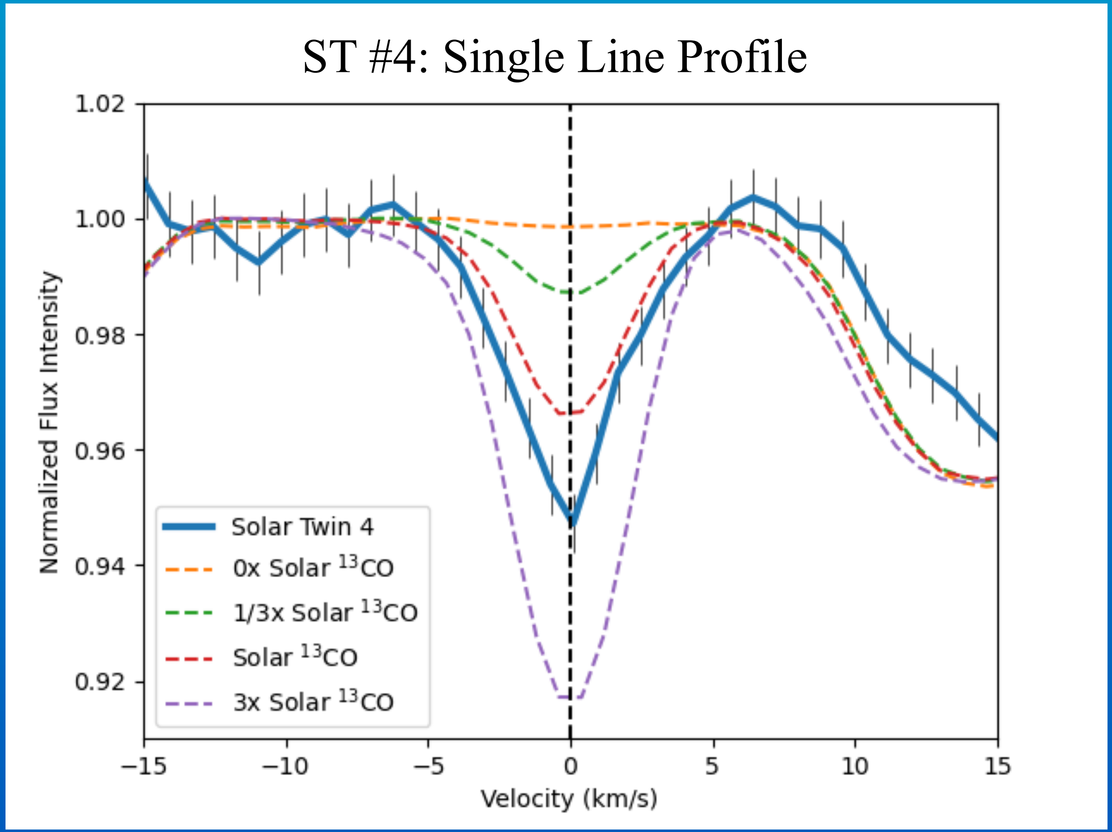




Coria+ in prep.

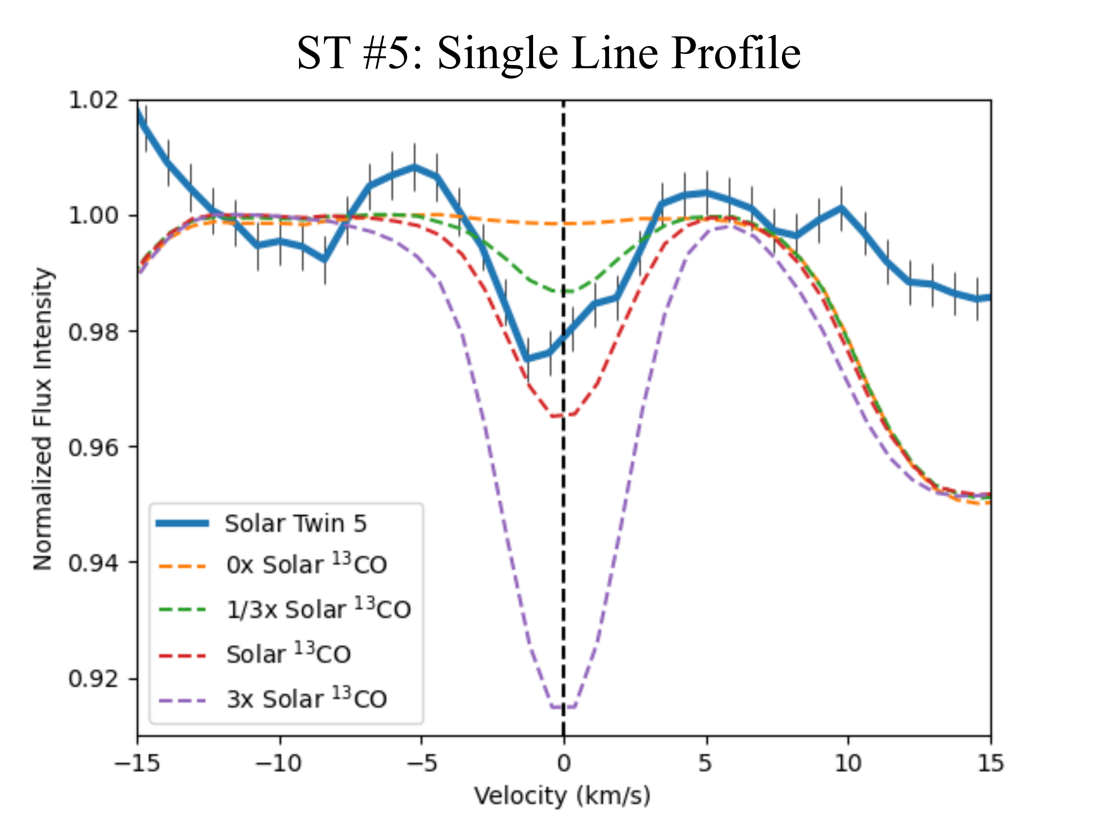
^{13}CO Abundance Plots!!!

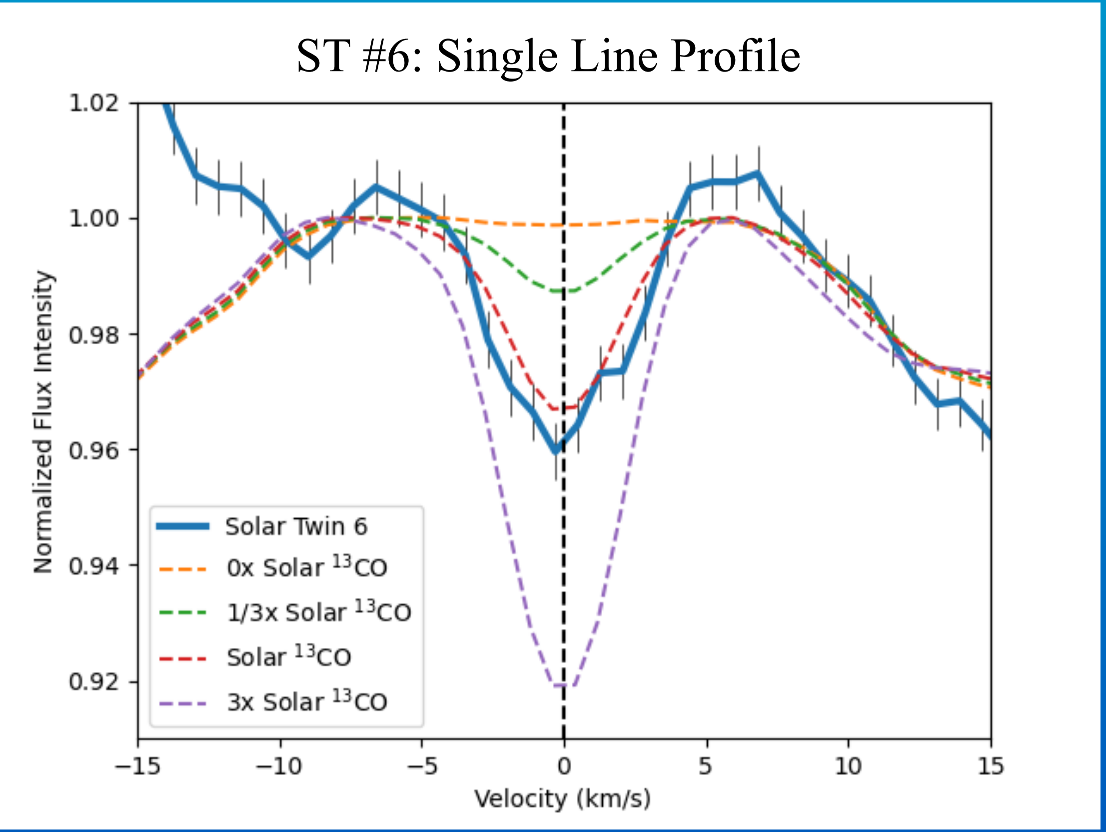




Coria+ in prep.

^{13}CO Abundance Plots!!!



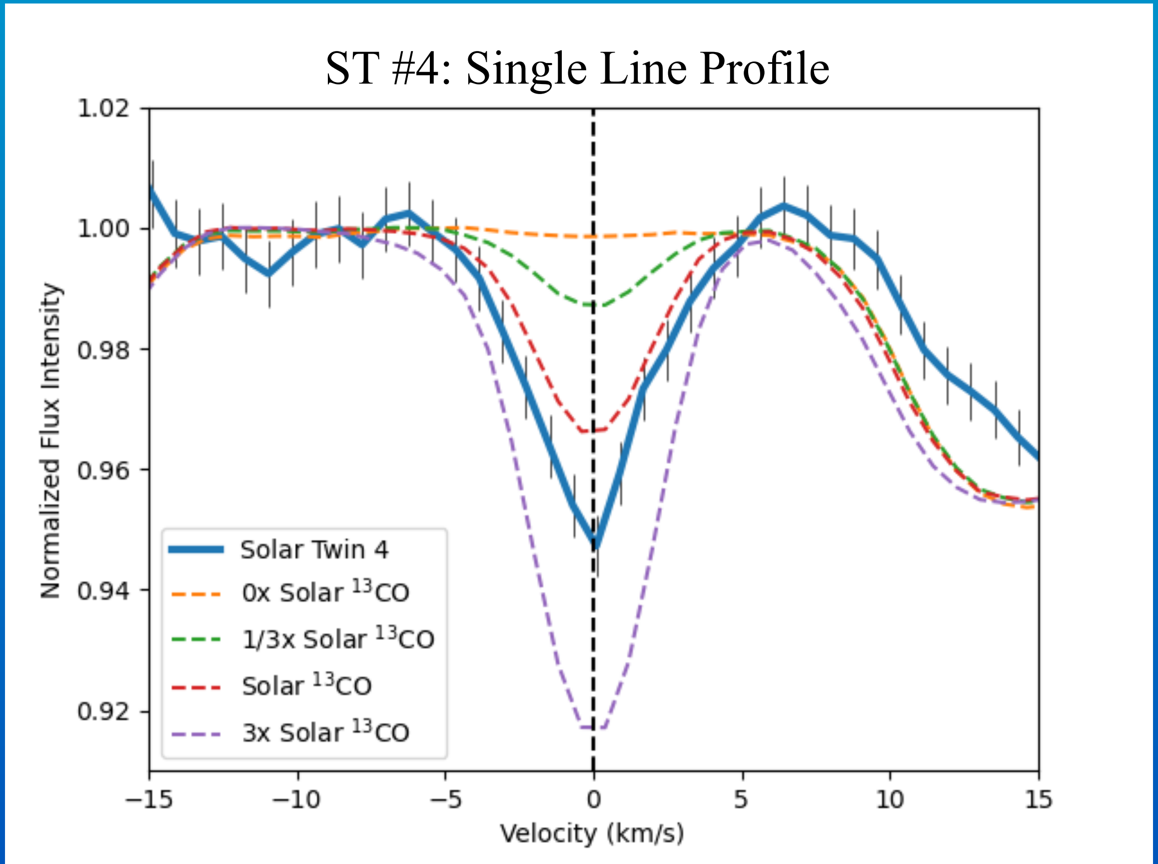


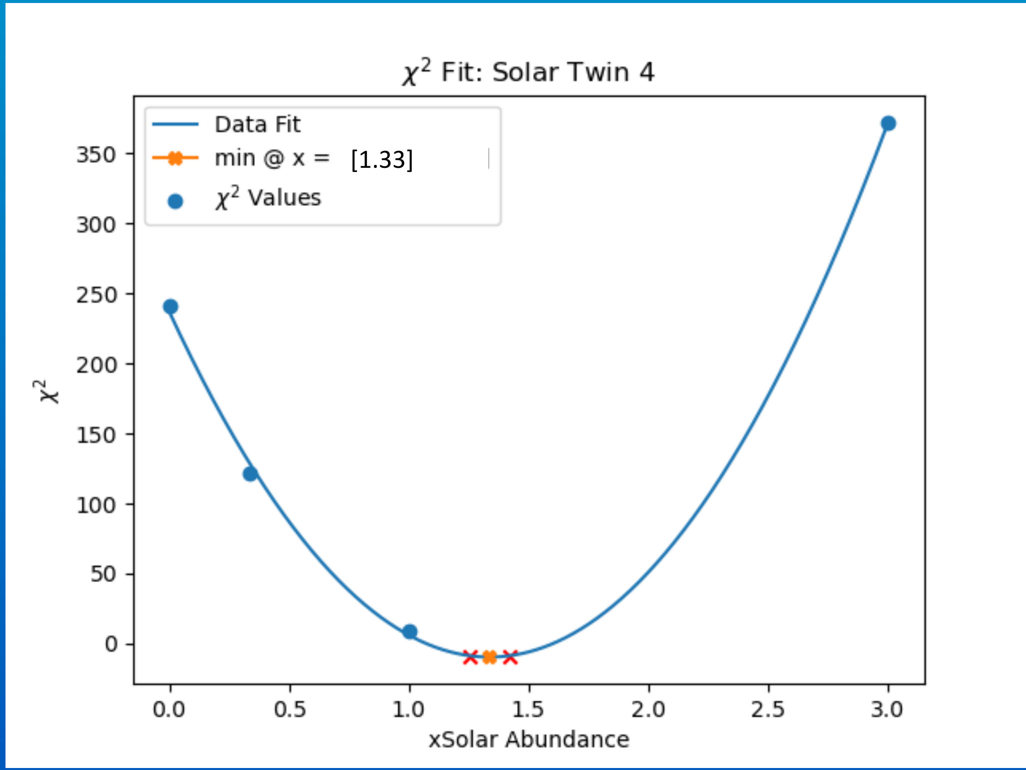
Coria+ in prep.

Calculating Isotopic Abundances: Step 4

Step 4: Derive final abundance values using chi-squared fit tests

Using Chi-Squared Fit Tests for a Final Value





Final Abundances + Additional Parameters

***Table from Earlier

Star	Spectral Type	T_eff (K)	Radius (xSol)	Age (Gyr)
ST #1	G5V	5838	0.96	2.42
ST #2	G4V	5758	0.95	5.51
ST #3	G8V	5848	1.0	1.01
ST #4	G2V	5683	0.96	3.67
ST #5	G2V	5814	1.03	3.09
ST #6	G3V	5694	1.04	6.66
Sun	G2V	5780	1.0	4.603

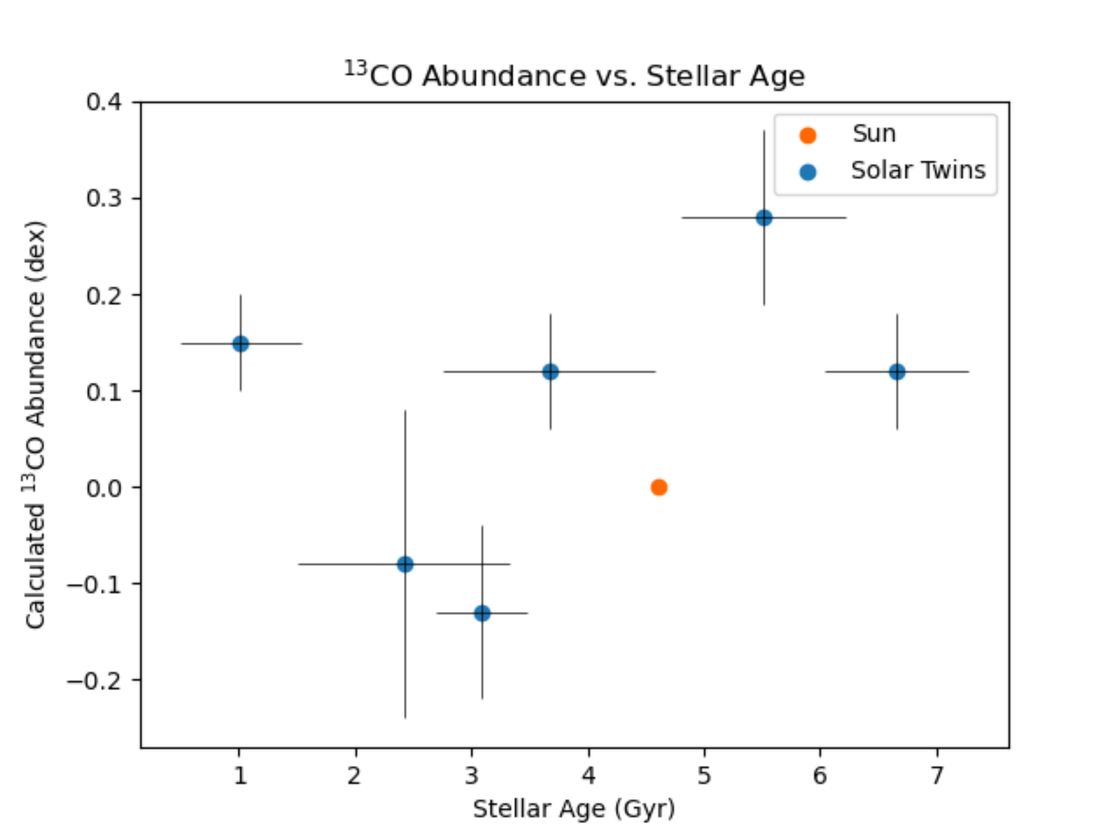
*Dos Santos+ 2016

+

Metallicity log(Fe/H)	Elemental Carbon log(C/H)	Elemental Oxygen log(O/H)	New! ^{13}CO (dex)	TBD! $C^{18}O$ (dex)	TBD! ^{13}CO (dex)
-0.093	-0.05	-0.01	-0.08	?	?
-0.096	-0.11	-0.05	0.28	?	?
0.138	?	?	0.15	?	?
0.036	-0.02	-0.02	0.12	?	?
0.056	0.02	0.03	-0.13	?	?
0.015	0.03	-0.03	0.12	?	?
-0.477?	-0.358?	-0.326?	0.0	0.0	0.0

*Dos Santos+ 2016, Brewer & Fischer 2016

Next Steps: Test Correlation



Compare ^{12}CO, ^{13}CO, C^{18}O Abundances with:

- Stellar Age
- Metallicity (Fe/H)
- Elemental Carbon (C/H)
- Elemental Oxygen (O/H)

Coria+ in prep.

Next Steps: Test GCE Models

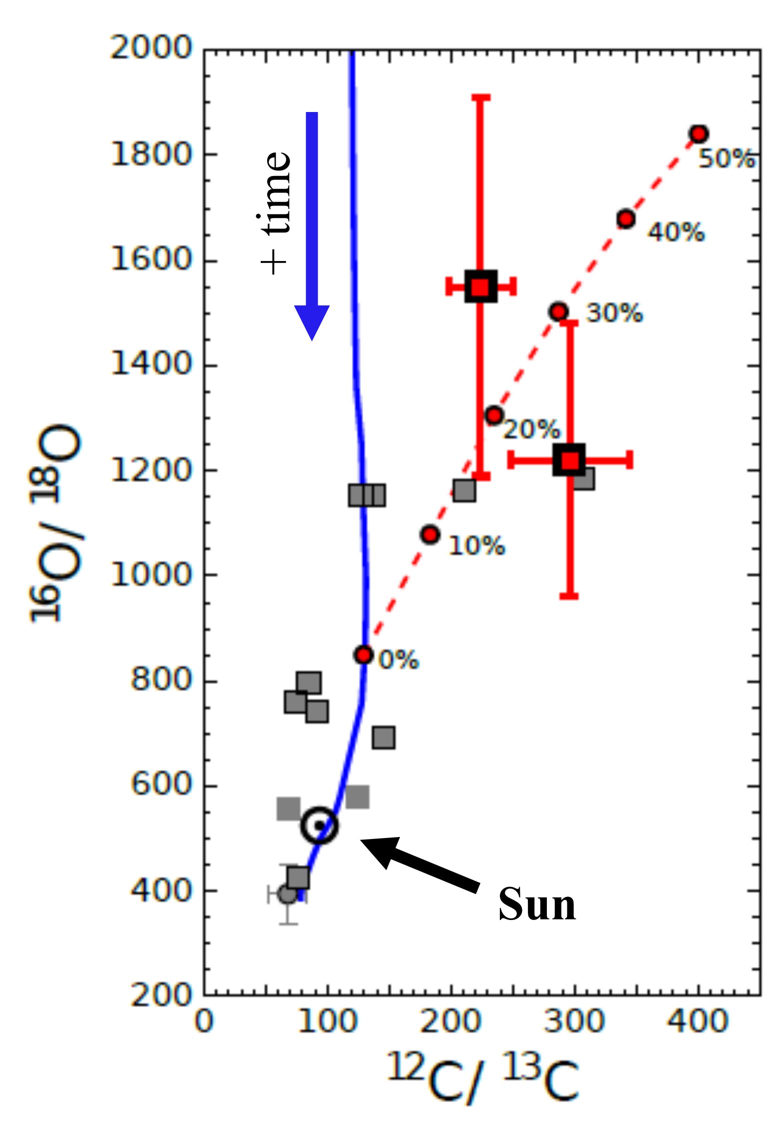
M-Dwarfs (Crossfield+ 2019):

Young Stellar Objects:

Kobayashi (2011) GCE Model:
Proposed GCE Correction:

Compare measurements to GCE models, find/explore any discrepancies

Determine causes for these inconsistencies!

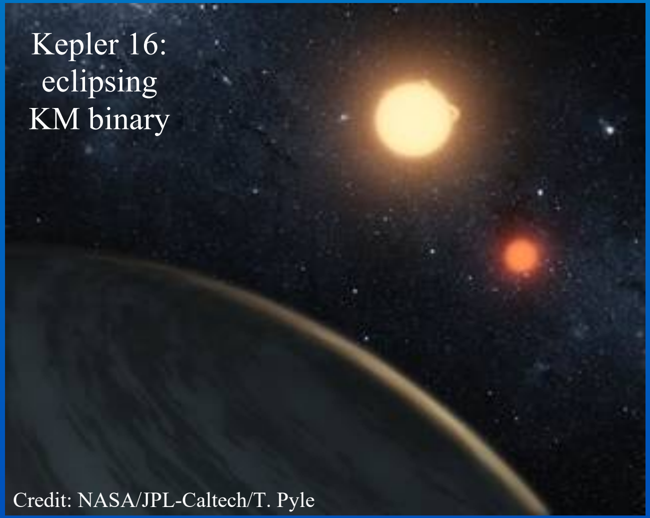


Kobayashi (2011); Crossfield et al. (2019)

Next Steps: Isotopic Analysis for Other Stars

1) Repeat abundance analysis for different stars: FGK(+M) binaries, moving group stars, field M-dwarfs, and JWST-targeted exoplanet host stars

2) Continue to test abundances for age correlation, GCE model discrepancies, etc…



Conclusion

- Isotopic Abundances are useful in the study of exoplanet atmospheres/composition AND in the calibration of GCE models.
- Stacked absorption lines allow for us to turn a set of relatively low S/N CO lines into a single CO profile with much higher S/N.
- Next Steps: Continue isotopic abundance analysis for different stars; test correlations and GCE models

Questions? Contact Me!

Thanks for listening!!! Any questions???

Email: drcoria@ku.edu