Quantifying the C/O ratio in the planet-forming environments around very low-mass stars

Javiera K. Díaz-Berríos (pyjkd@leeds.ac.uk)

UKI discs meeting, Coventry, September 2024

UNIVERSITY OF LEEDS

Adapted from Miotello+2023

PROTOPLANETARY DISKS

CHEMISTRY IN PLANET-FORMING REGIONS

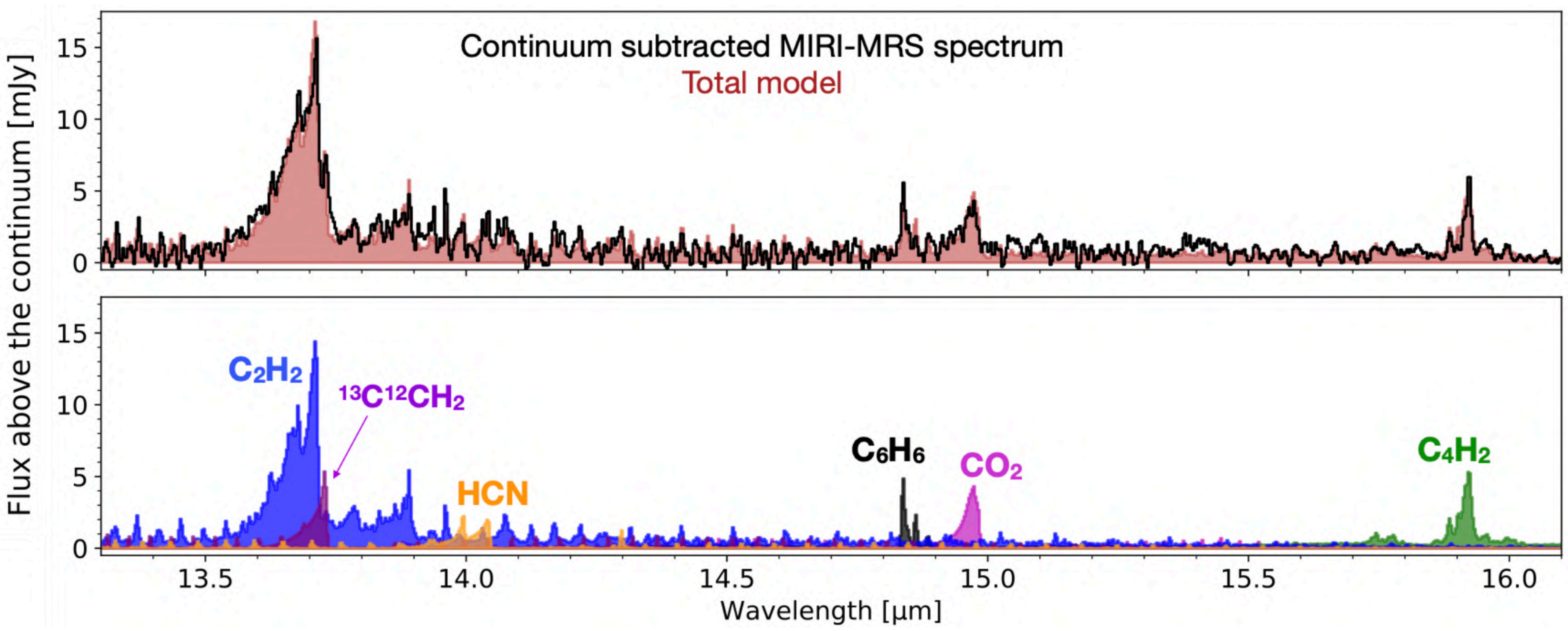
Why very low-mass stars ($M<0.6M_\odot$)?

Most common hosts of exoplanetary systems!

Credits background: NASA/JPL-Caltech

DISKS AROUND VERY LOW-MASS STARS

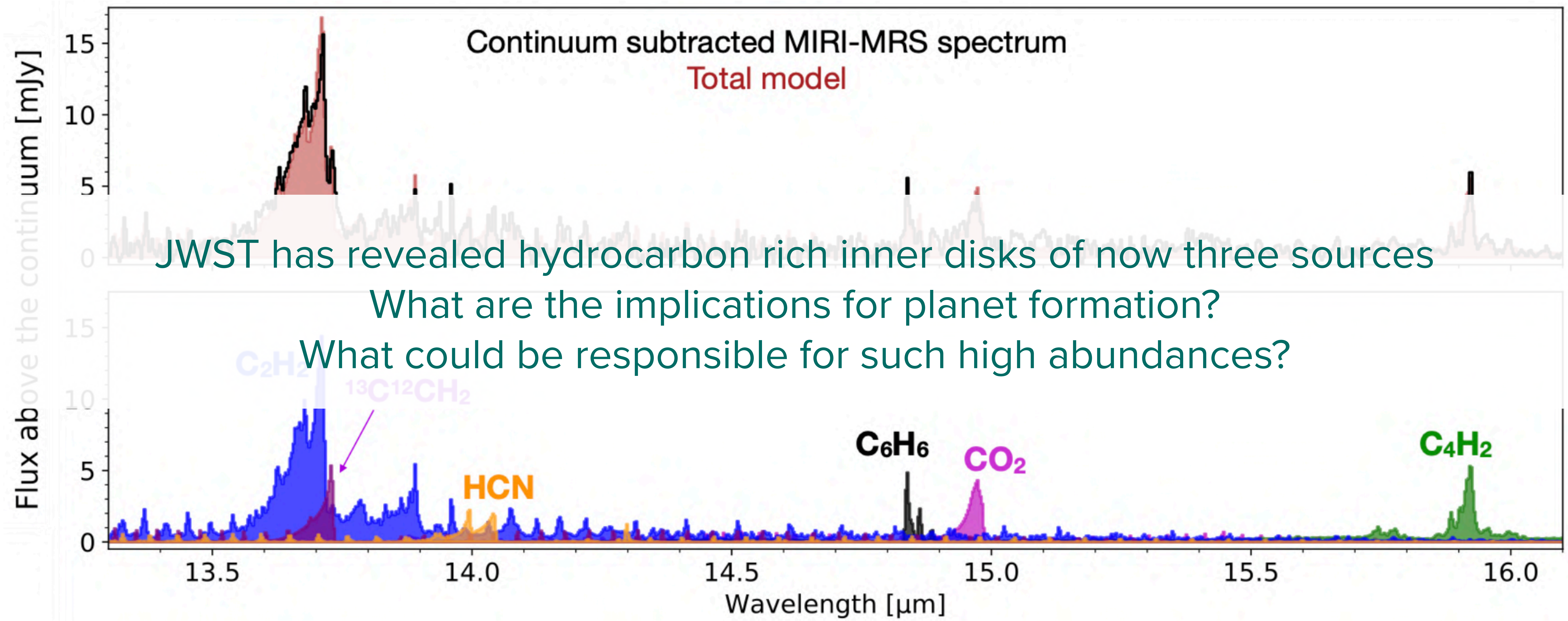
THE CASE OF J160532' JWST OBSERVATIONS



Tabone+2023, van Dishoeck+2023

DISKS AROUND VERY LOW-MASS STARS

THE CASE OF J160532' JWST OBSERVATIONS



JWST has revealed hydrocarbon rich inner disks of now three sources

What are the implications for planet formation?

What could be responsible for such high abundances?

Tabone+2023, van Dishoeck+2023, Arabhavi+2024, Kanwar+2024, Kaeufer+2024

van Dishoeck+2023, Tabone+2023, **Díaz-Berríos, J. K.**, Walsh, C., and van Dishoeck, E. F. (in prep.)

HOW TO EXPLAIN THE HIGH ABUNDANCES?

Hydrocarbon chemistry is sensitive to C/O ratios

What mechanisms could be occurring in the disk to affect the C/O ratio?

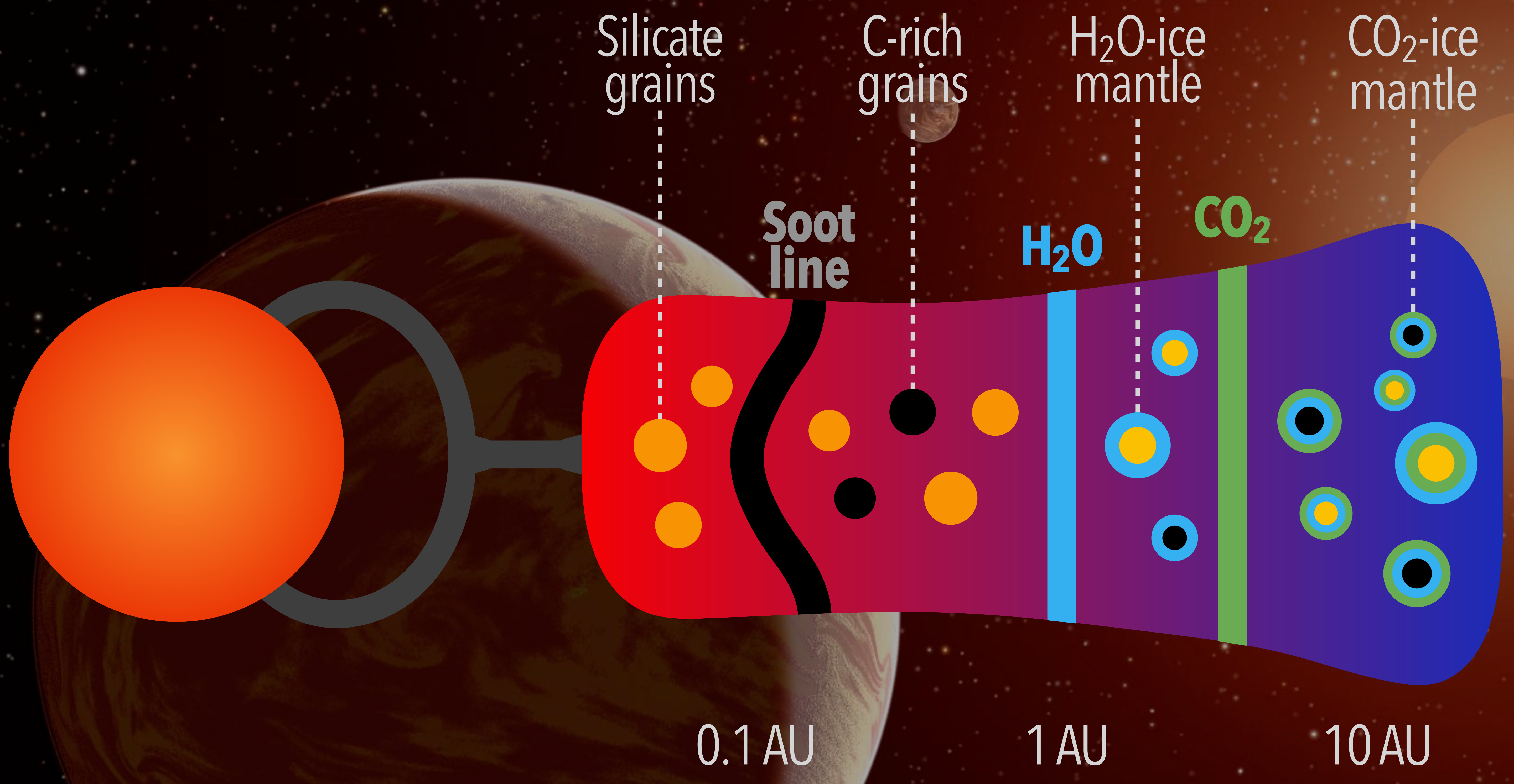
Credits background: NASA/JPL-Caltech

van Dishoeck+2023, Tabone+2023, **Díaz-Berríos, J. K.**, Walsh, C., and van Dishoeck, E. F. (in prep.)

HOW TO EXPLAIN THE HIGH ABUNDANCES?

Hydrocarbon chemistry
is sensitive to C/O ratios

What mechanisms could be occurring
in the disk to affect the C/O ratio?



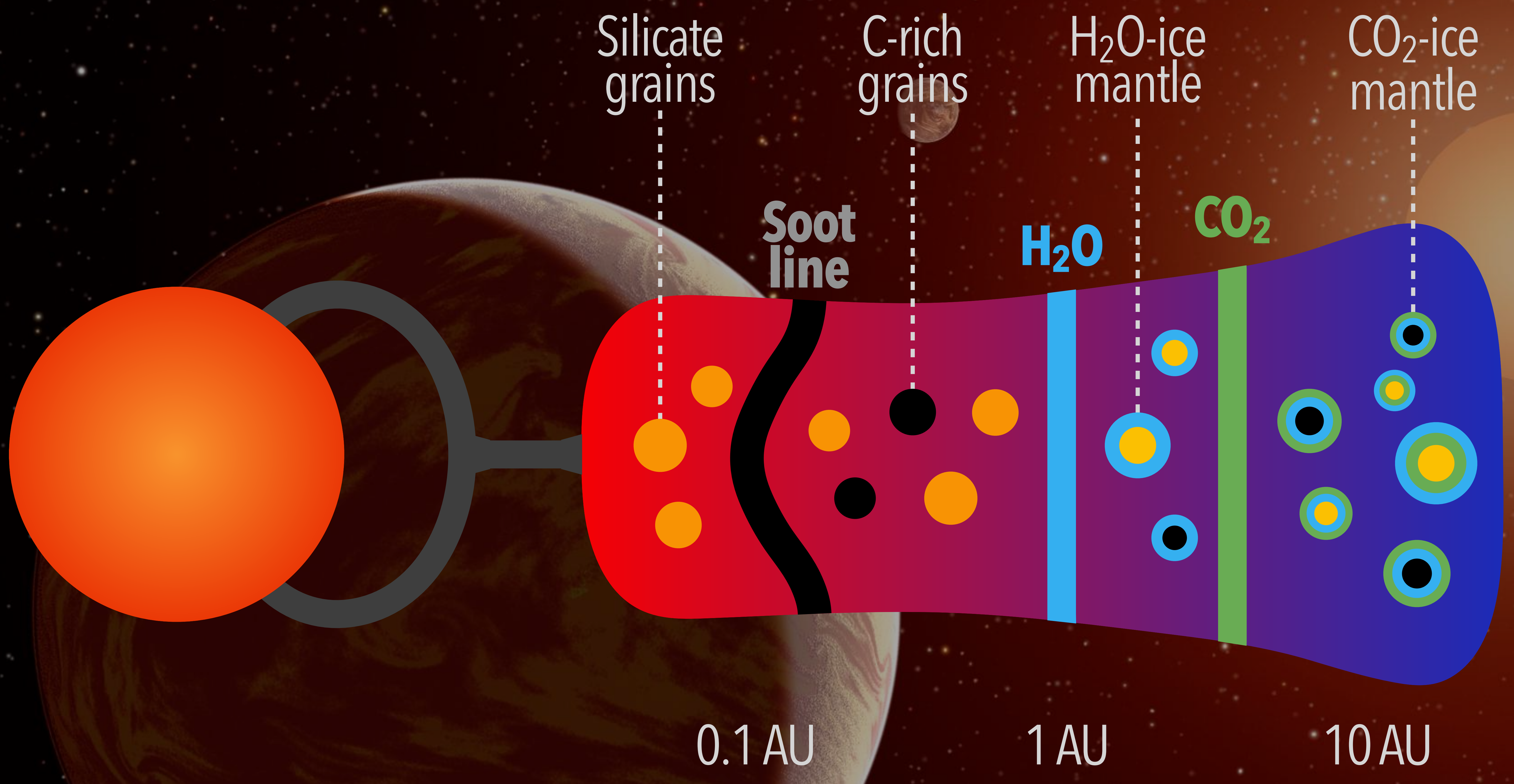
Credits background: NASA/JPL-Caltech

van Dishoeck+2023, Tabone+2023, **Díaz-Berríos, J. K.**, Walsh, C., and van Dishoeck, E. F. (in prep.)

HOW TO EXPLAIN THE HIGH ABUNDANCES?

Hydrocarbon chemistry is sensitive to C/O ratios

What mechanisms could be occurring in the disk to affect the C/O ratio?

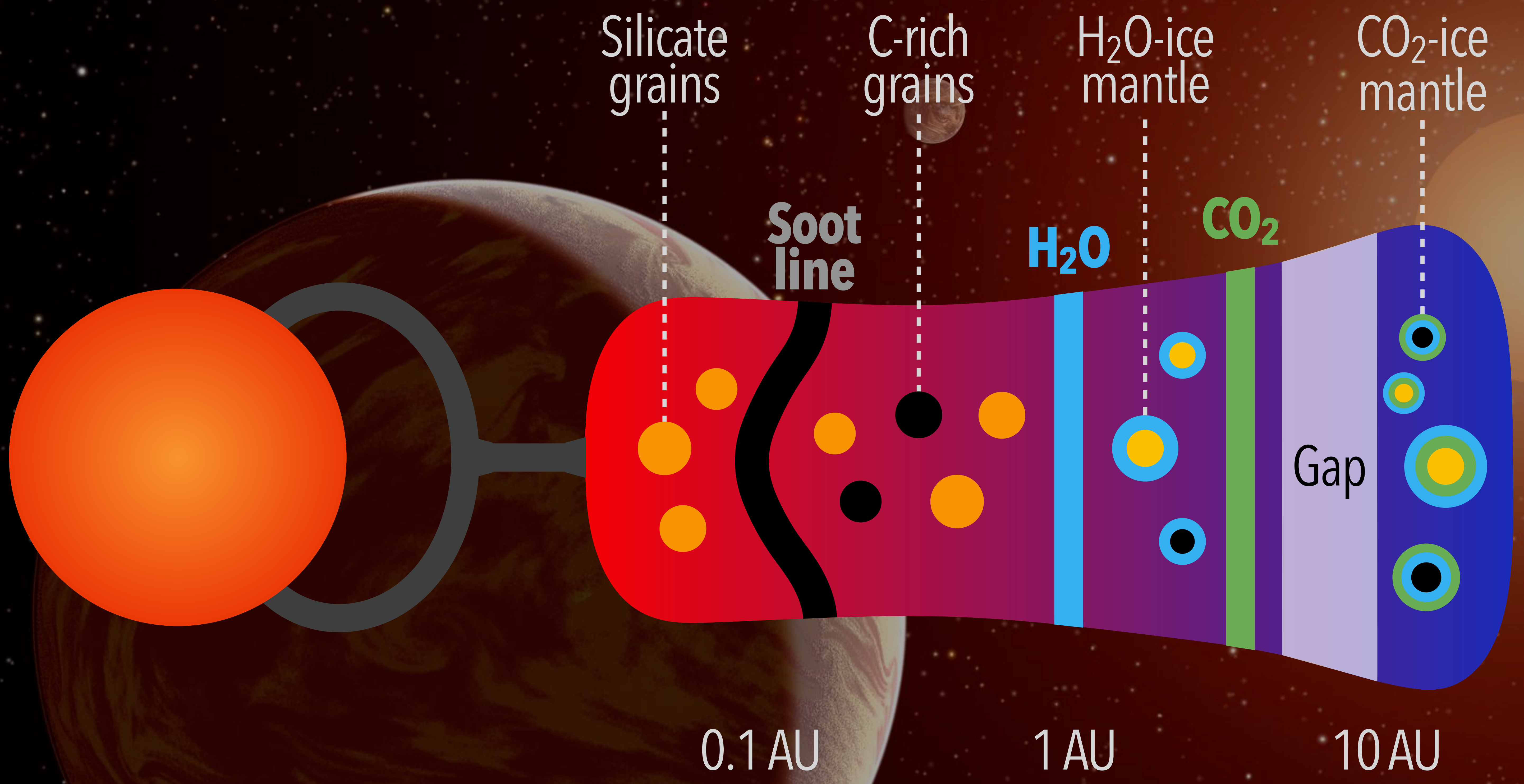


CARBON GRAIN DESTRUCTION RELEASING CARBON INTO THE GAS PHASE

HOW TO EXPLAIN THE HIGH ABUNDANCES?

Hydrocarbon chemistry is sensitive to C/O ratios

What mechanisms could be occurring in the disk to affect the C/O ratio?

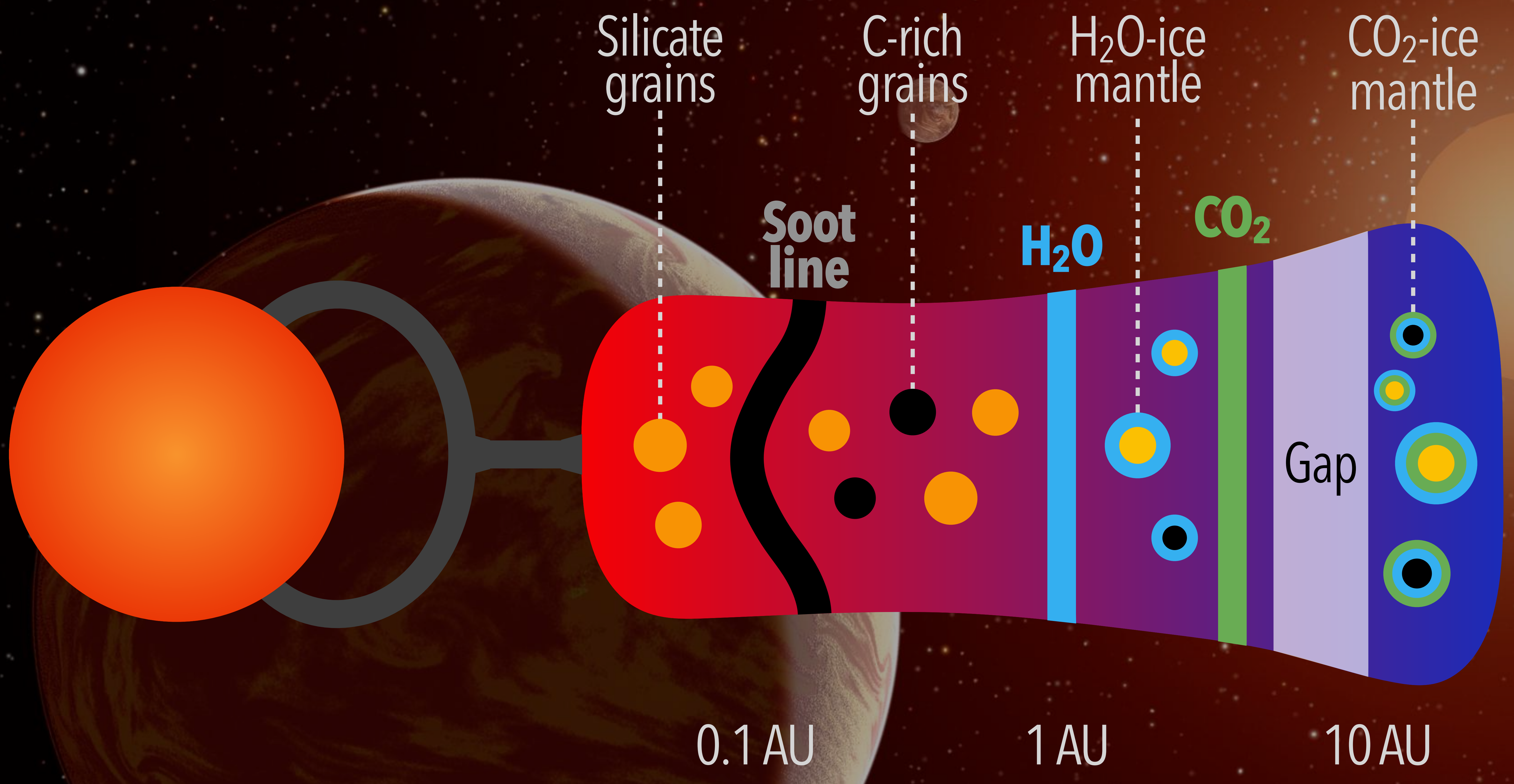


CARBON GRAIN DESTRUCTION RELEASING CARBON INTO THE GAS PHASE

OXYGEN DEPLETION DUE TO ICY PEBBLE TRAPPING IN THE OUTER DISK

van Dishoeck+2023, Tabone+2023, **Díaz-Berríos, J. K.**, Walsh, C., and van Dishoeck, E. F. (in prep.)

HOW TO EXPLAIN THE HIGH ABUNDANCES?



Hydrocarbon chemistry is sensitive to C/O ratios

What mechanisms could be occurring in the disk to affect the C/O ratio?

CARBON GRAIN DESTRUCTION RELEASING CARBON INTO THE GAS PHASE

OXYGEN DEPLETION DUE TO ICY PEBBLE TRAPPING IN THE OUTER DISK

CARBON ENRICHMENT AND OXYGEN DEPLETION

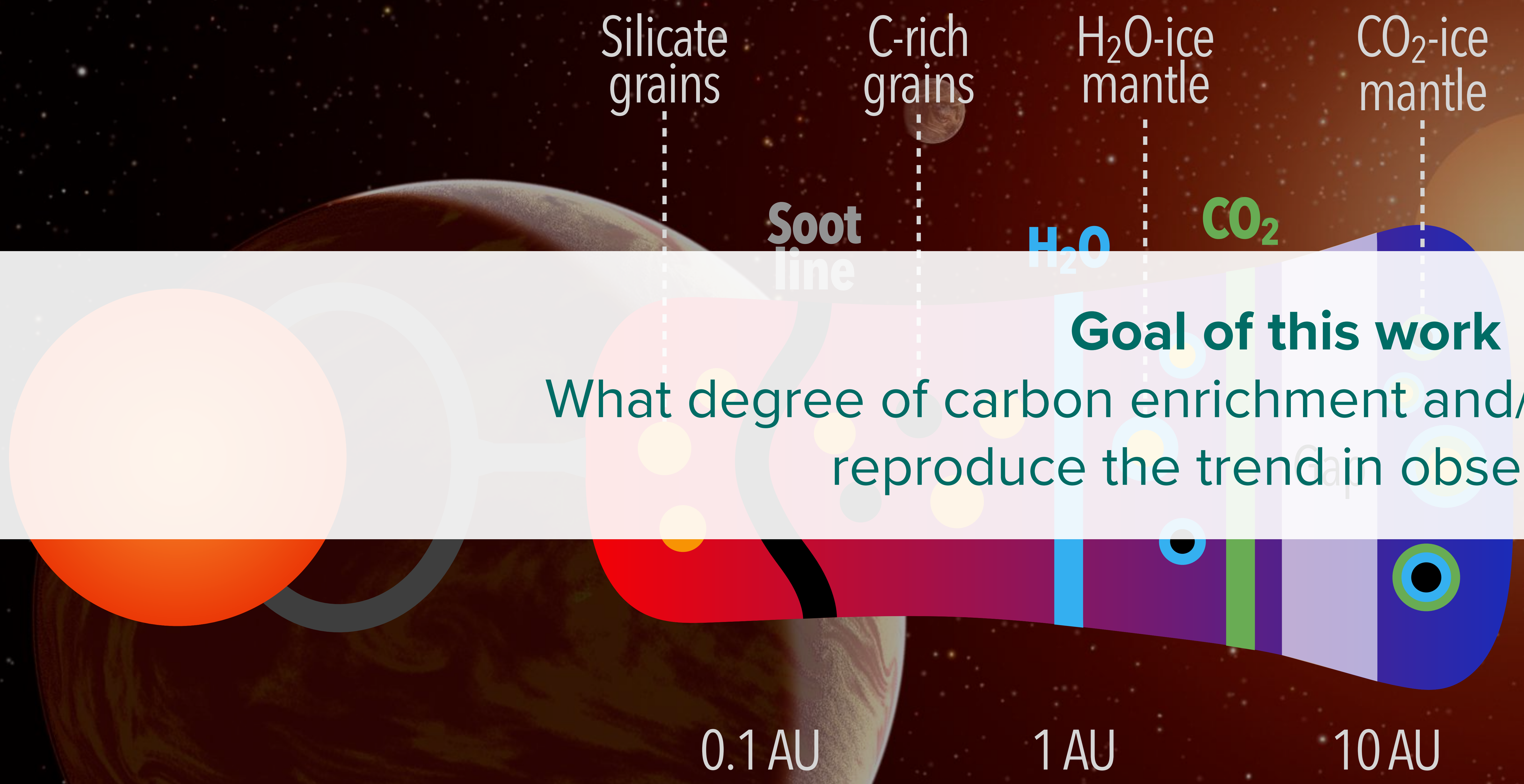
Credits background: NASA/JPL-Caltech

van Dishoeck+2023, Tabone+2023, **Díaz-Berríos, J. K.**, Walsh, C., and van Dishoeck, E. F. (in prep.)

HOW TO EXPLAIN THE HIGH ABUNDANCES?

Hydrocarbon chemistry is sensitive to C/O ratios

What mechanisms could be occurring in the disk to affect the C/O ratio?



CARBON GRAIN DESTRUCTION RELEASING CARBON INTO THE GAS PHASE

OXYGEN DEPLETION DUE TO ICY PEBBLE TRAPPING IN THE OUTER DISK

CARBON ENRICHMENT AND OXYGEN DEPLETION

Goal of this work

What degree of carbon enrichment and/or oxygen depletion reproduce the trend in observations?

Credits background: NASA/JPL-Caltech

CHEMICAL MODELS

PHYSICAL STRUCTURE OF A DISK AROUND A VERY LOW MASS STAR

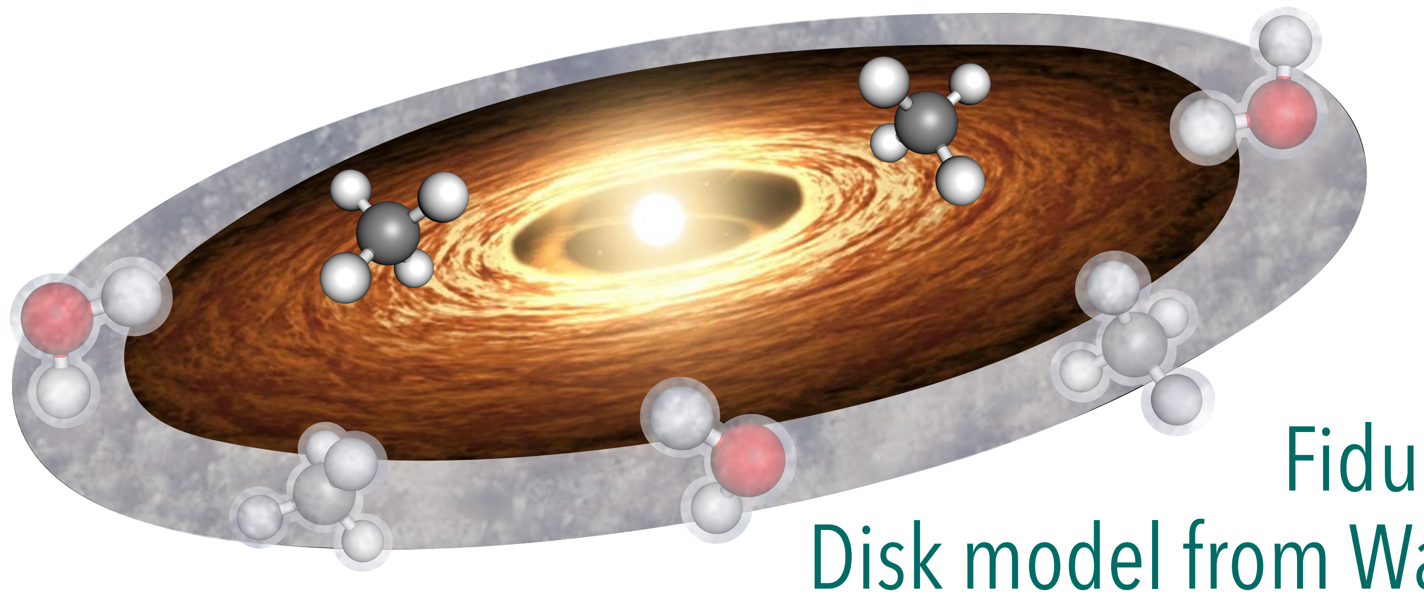
PHYSICAL PARAMETERS FOR THE DISK MODEL

Parameter	Value
Stellar mass ($M_\star$)	$0.1\ M_\odot$
Stellar radius ($R_\star$)	$0.7\ R_\odot$
Effective temperature ($T_\star$)	3000 K
Accretion mass rate ($\dot{M}$)	$10^{-9}\ M_\odot\ yr^{-1}$
Surf. density inner disk (Σ_{10AU})	$1.0\ g\ cm^{-2}$

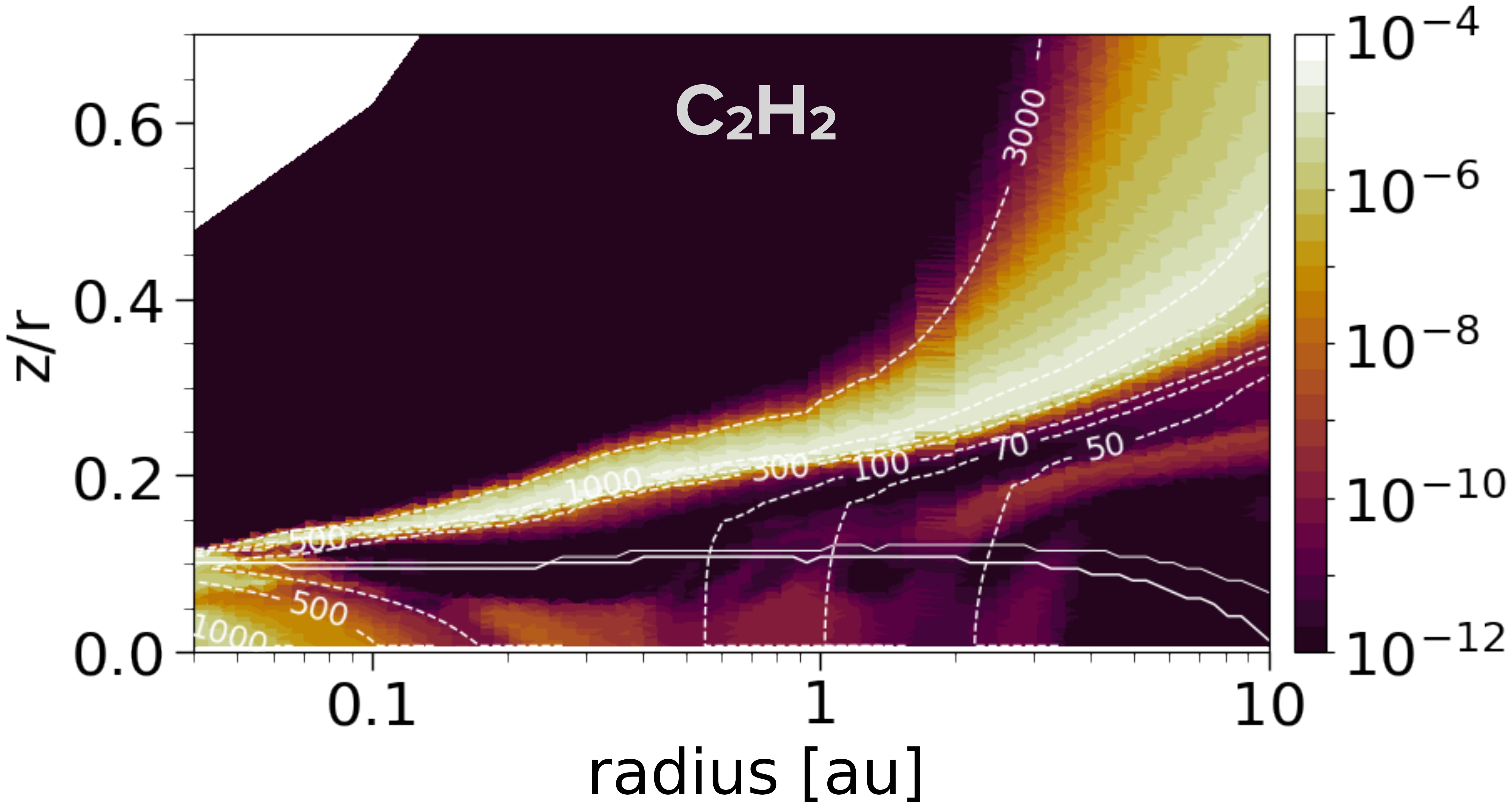
Chemical network
6173 gas-phase reactions involving 467 species!
Includes **gas-phase** reactions, **gas-grain** interactions and **grain-surface** chemistry.

CHEMICAL MODELS

FRACTIONAL ABUNDANCE MAPS: C_2H_2

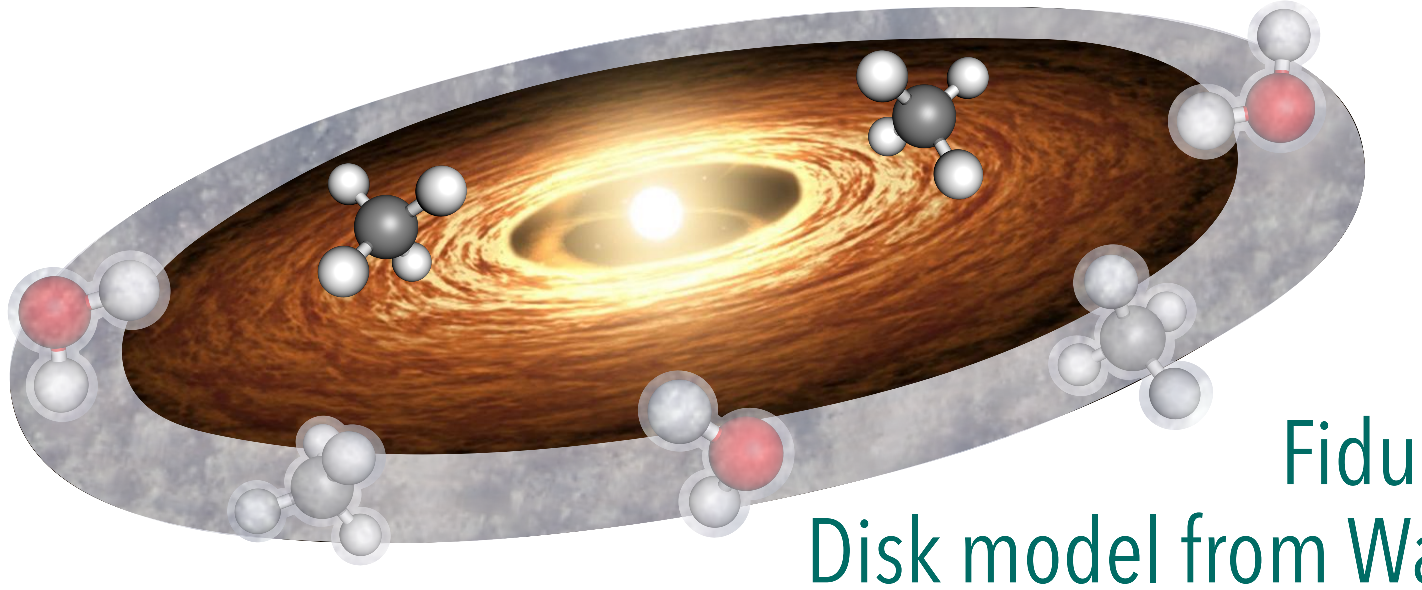


Fiducial model:
Disk model from Walsh+2015

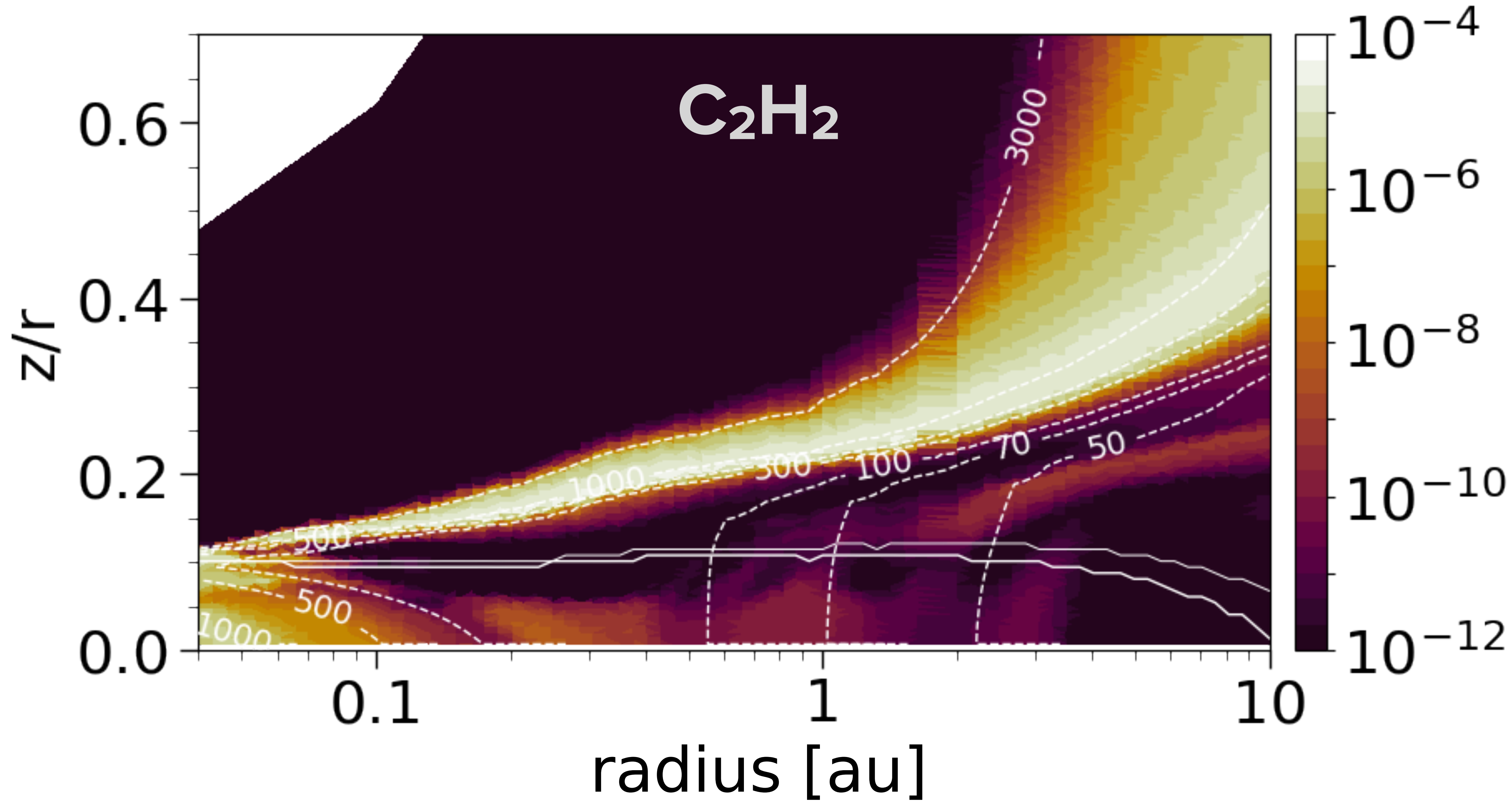


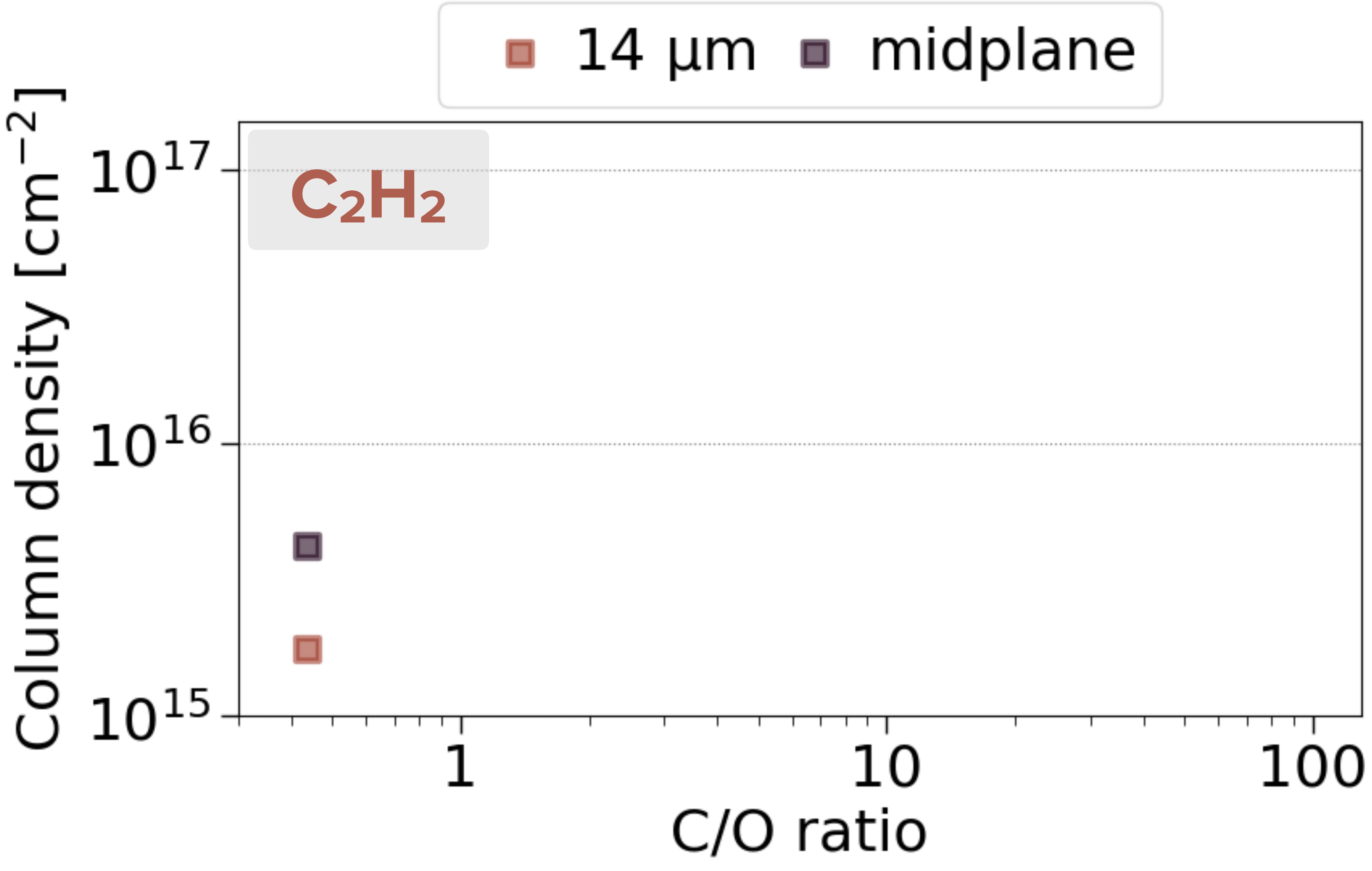
Díaz-Berríos+in prep.

CHEMICAL MODELS
FRACTIONAL ABUNDANCE MAPS: C_2H_2



Fiducial model:
Disk model from Walsh+2015

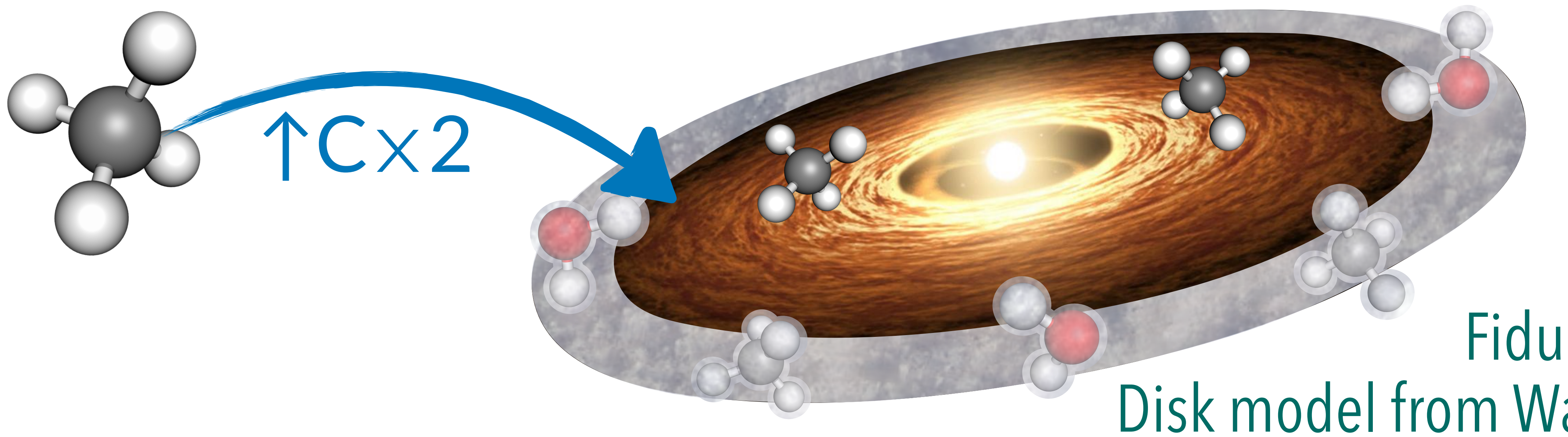




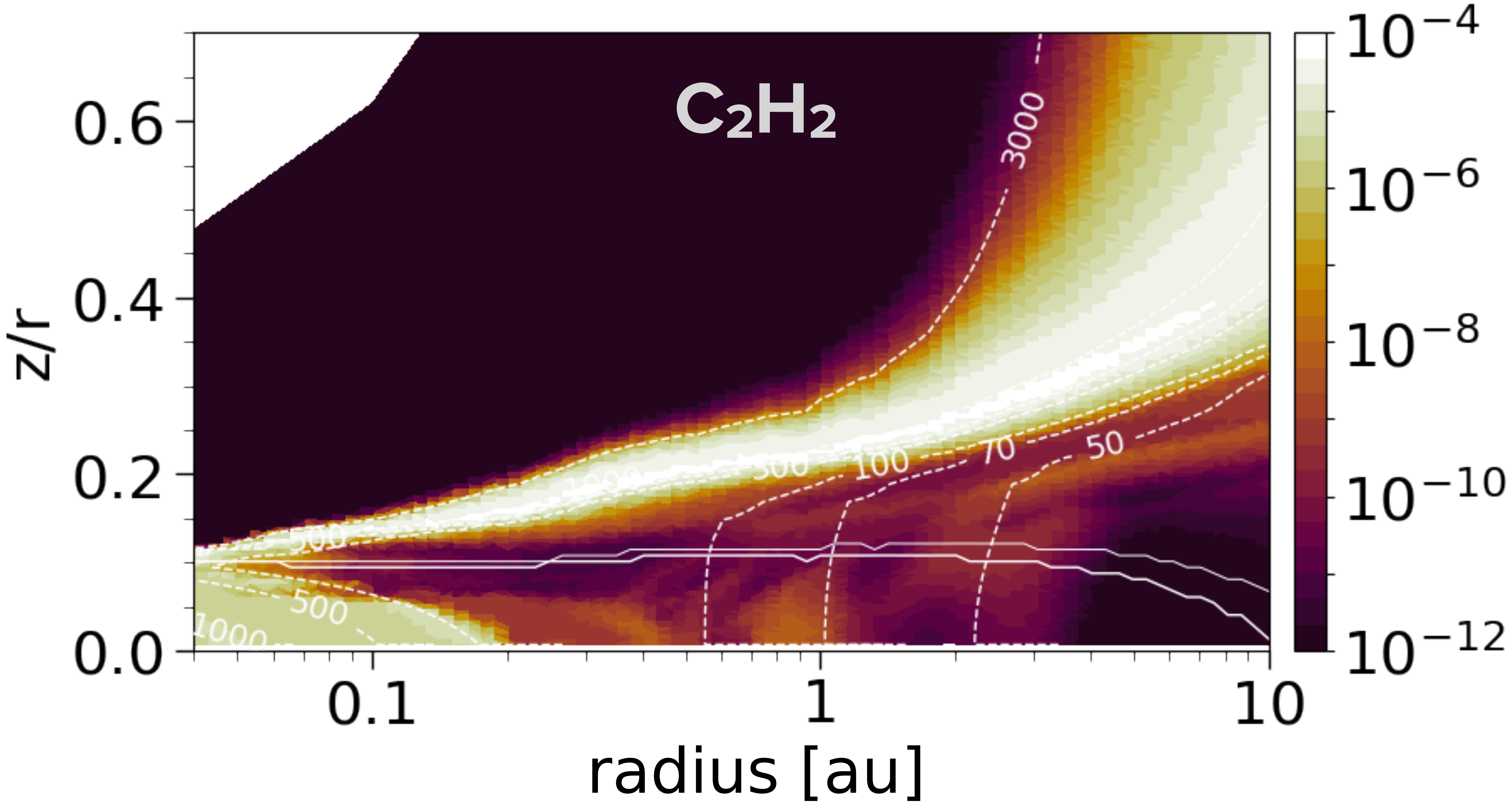
Díaz-Berríos+in prep.

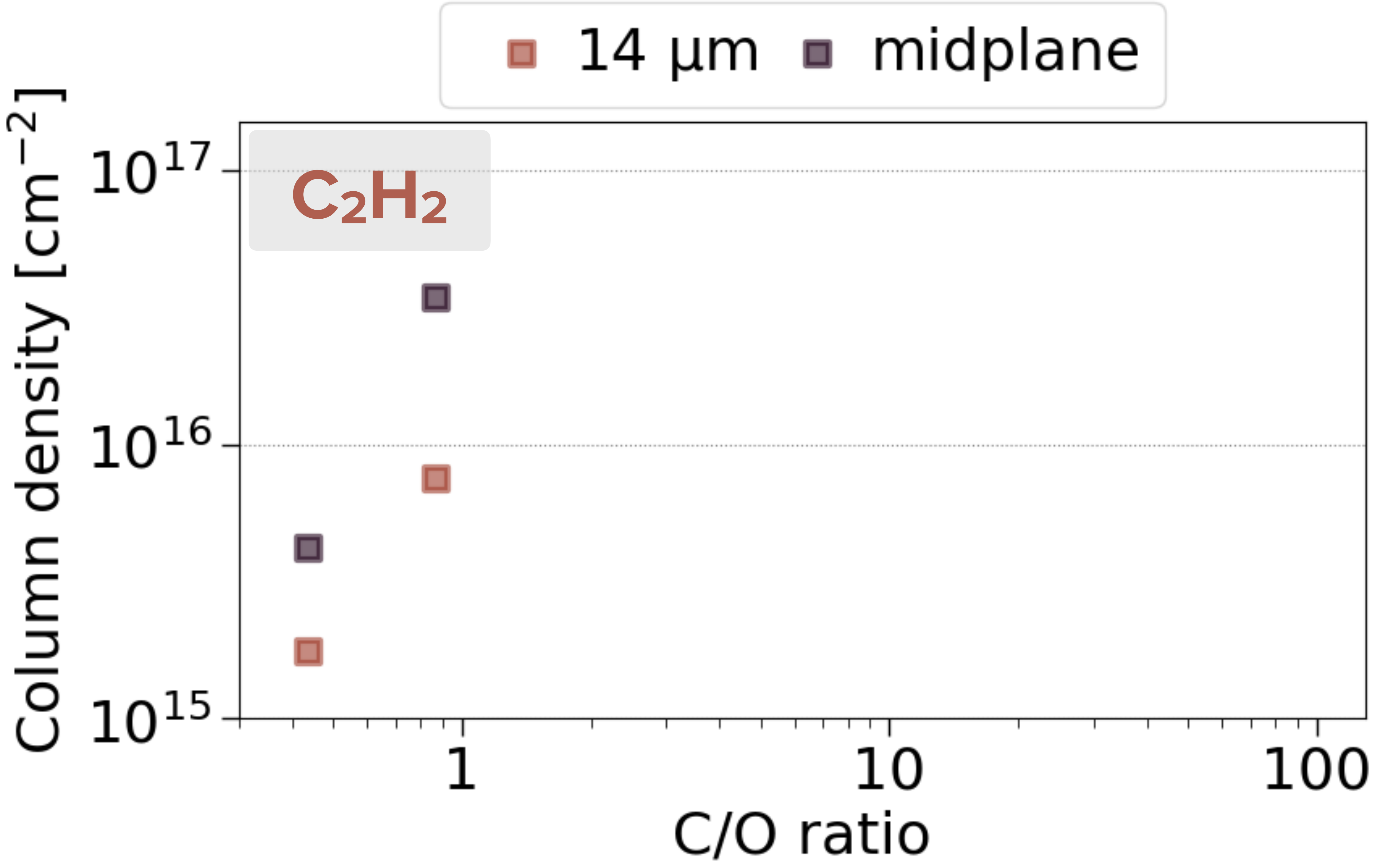
CHEMICAL MODELS

FRACTIONAL ABUNDANCE MAPS: C_2H_2



Fiducial model:
Disk model from Walsh+2015

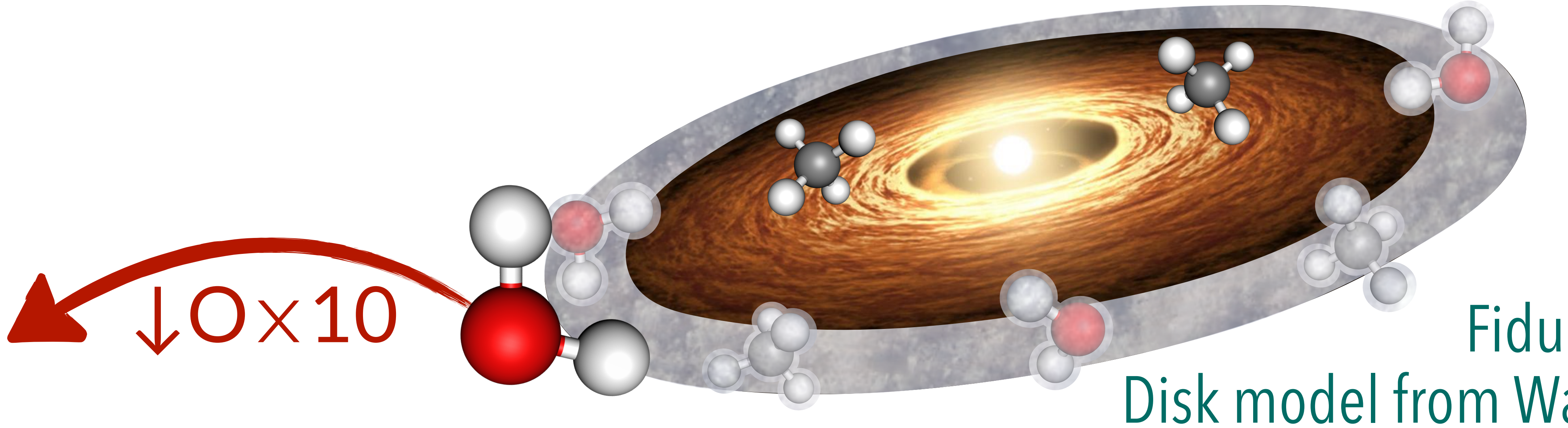




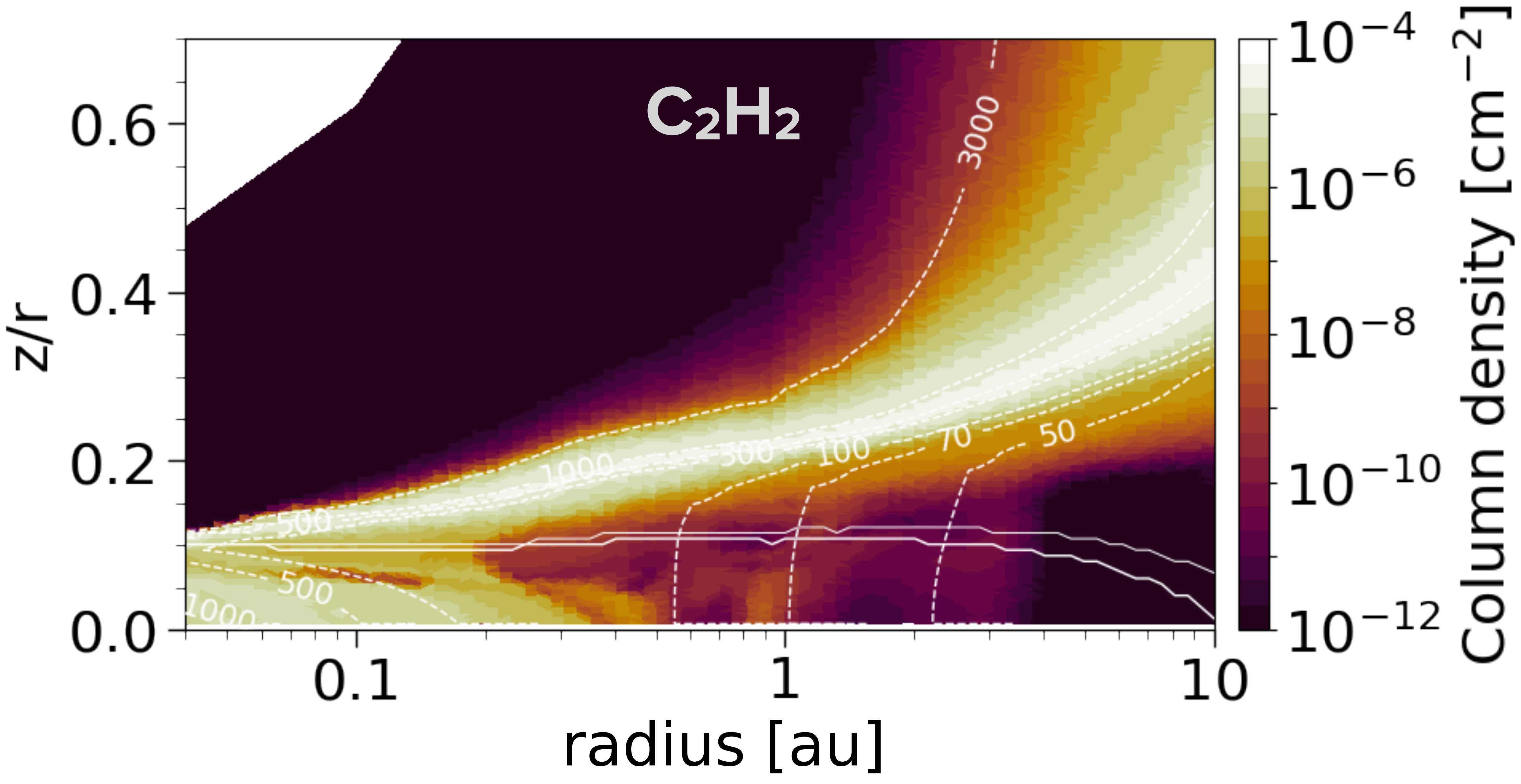
Díaz-Berríos+in prep.

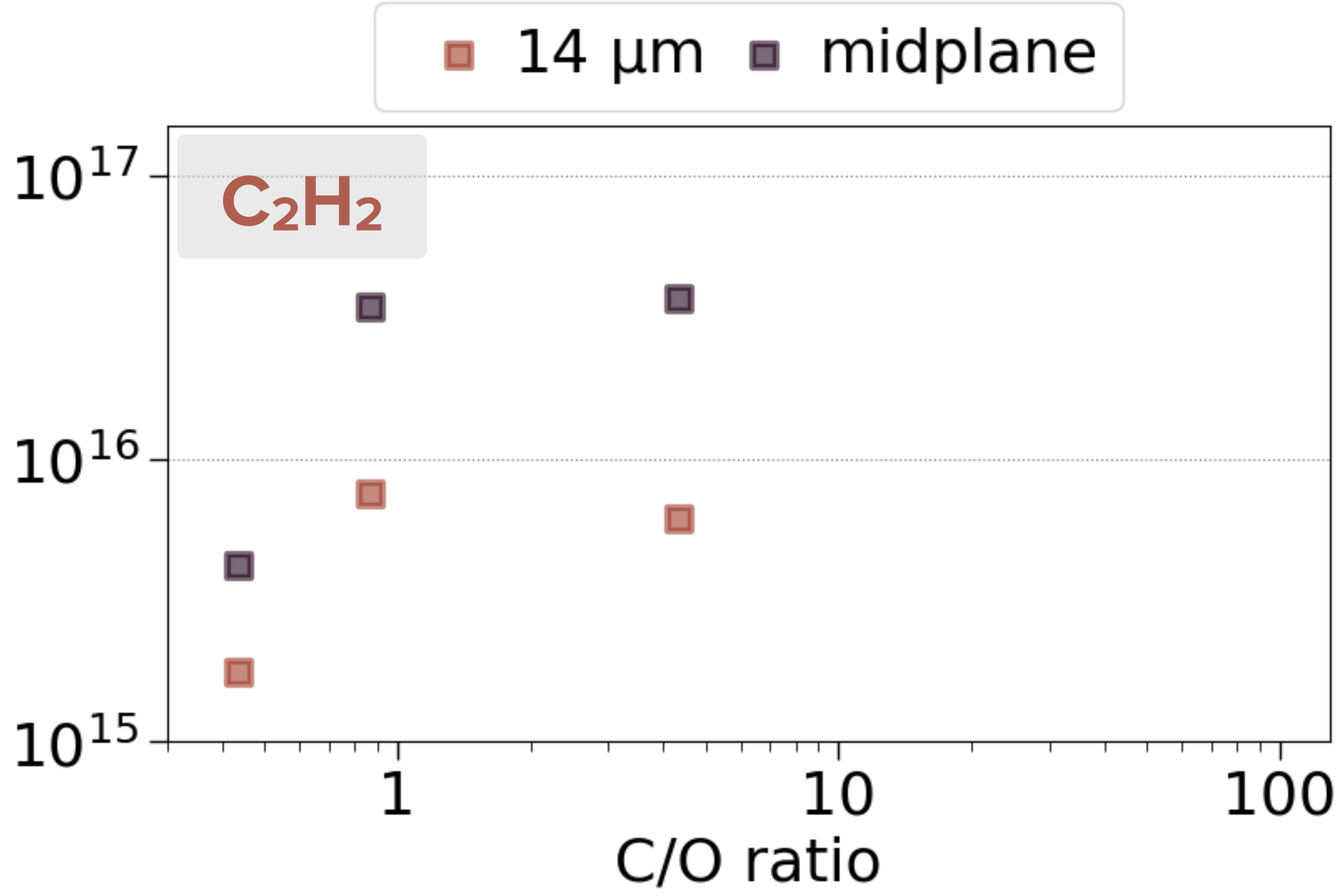
CHEMICAL MODELS

FRACTIONAL ABUNDANCE MAPS: C_2H_2



Fiducial model:
Disk model from Walsh+2015

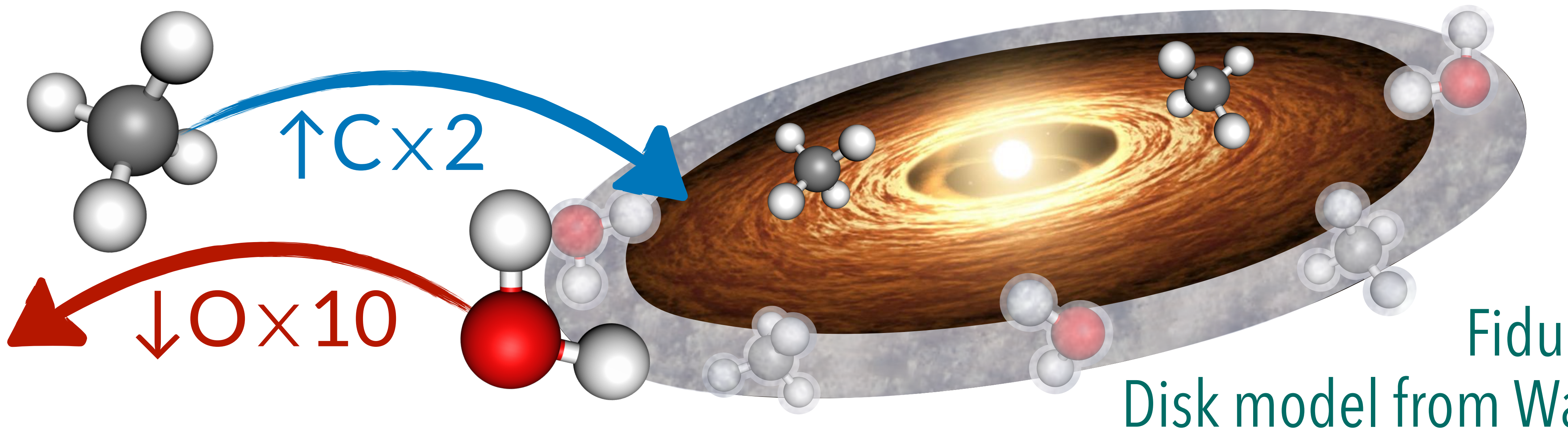




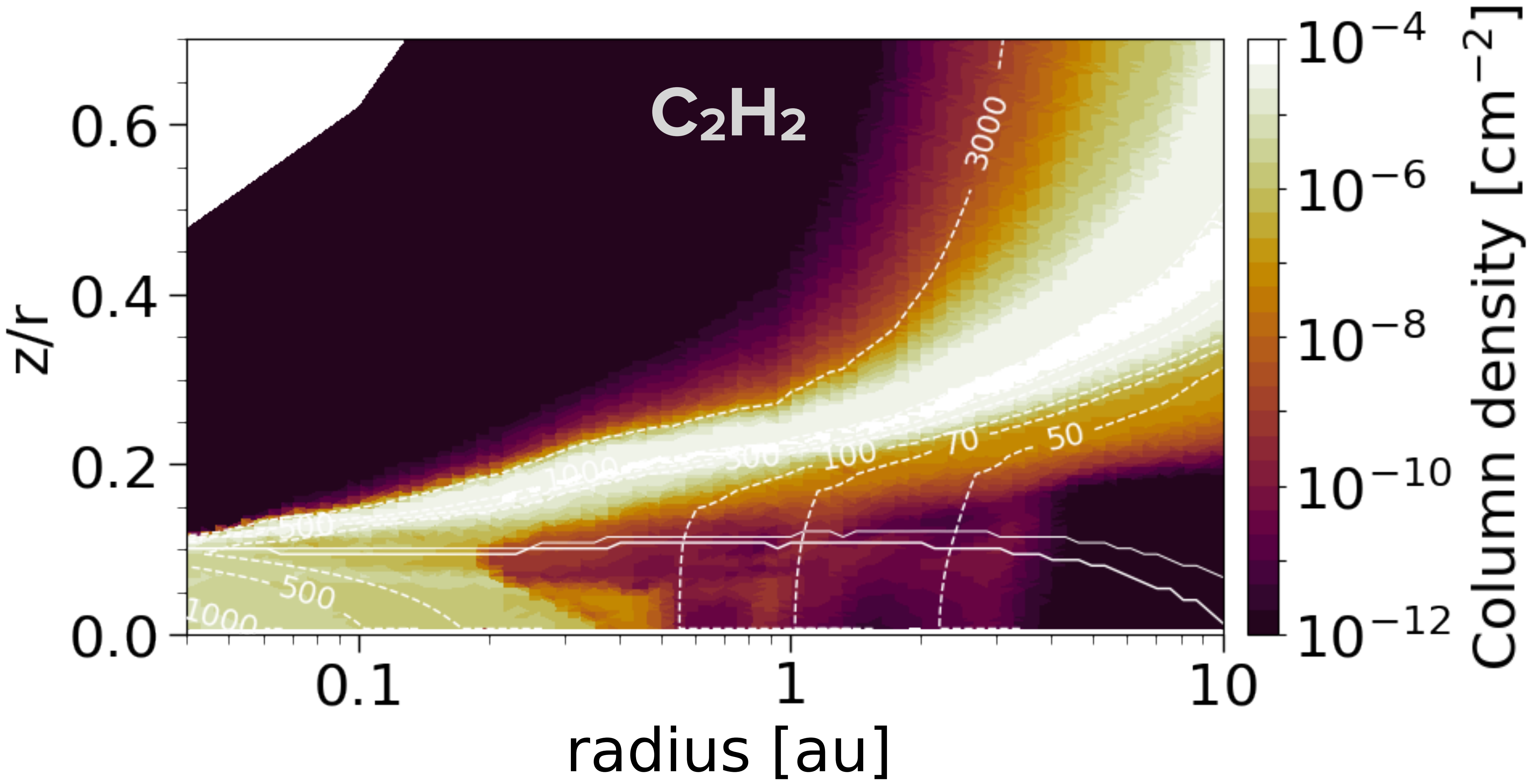
Díaz-Berríos+in prep.

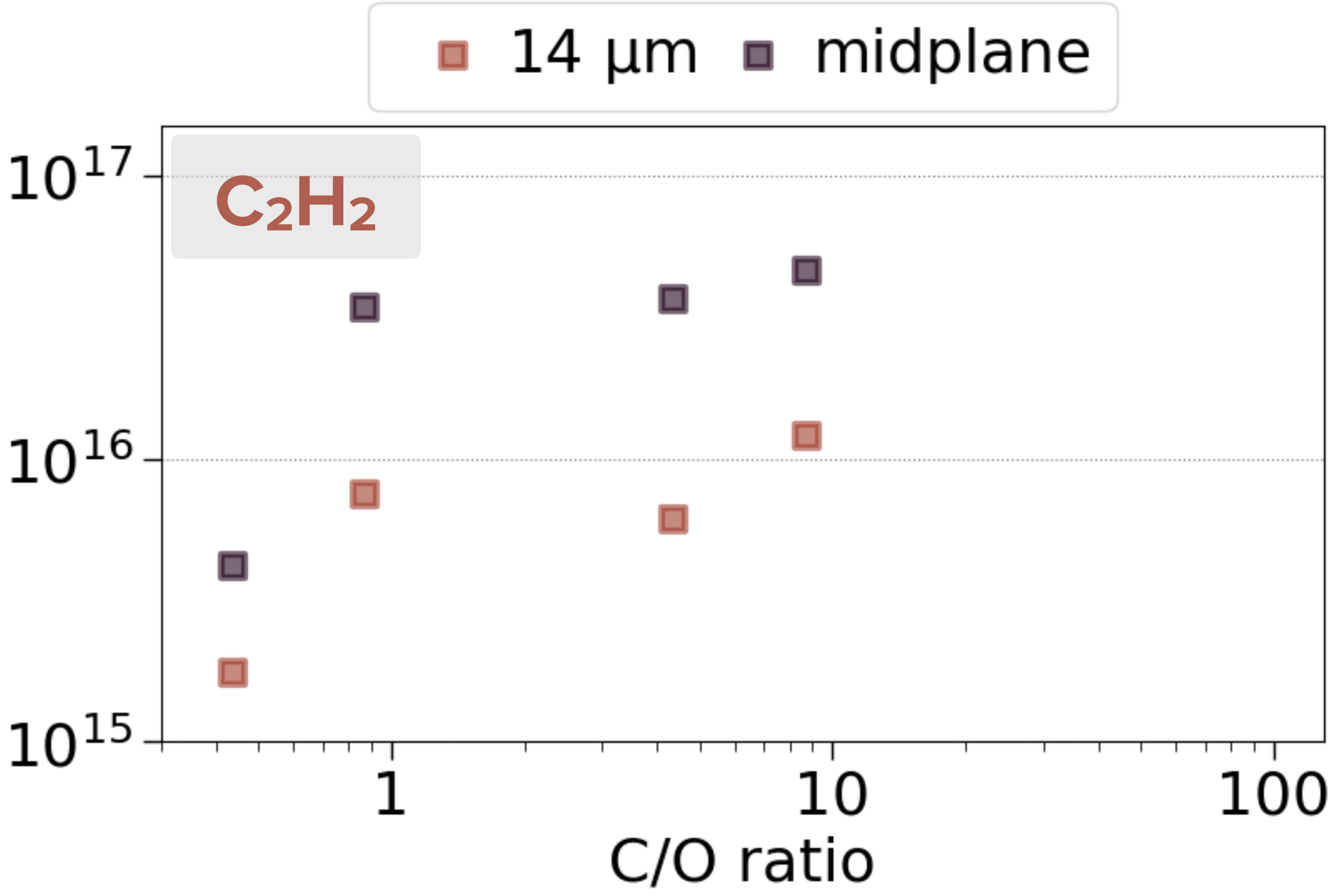
CHEMICAL MODELS

FRACTIONAL ABUNDANCE MAPS: C_2H_2



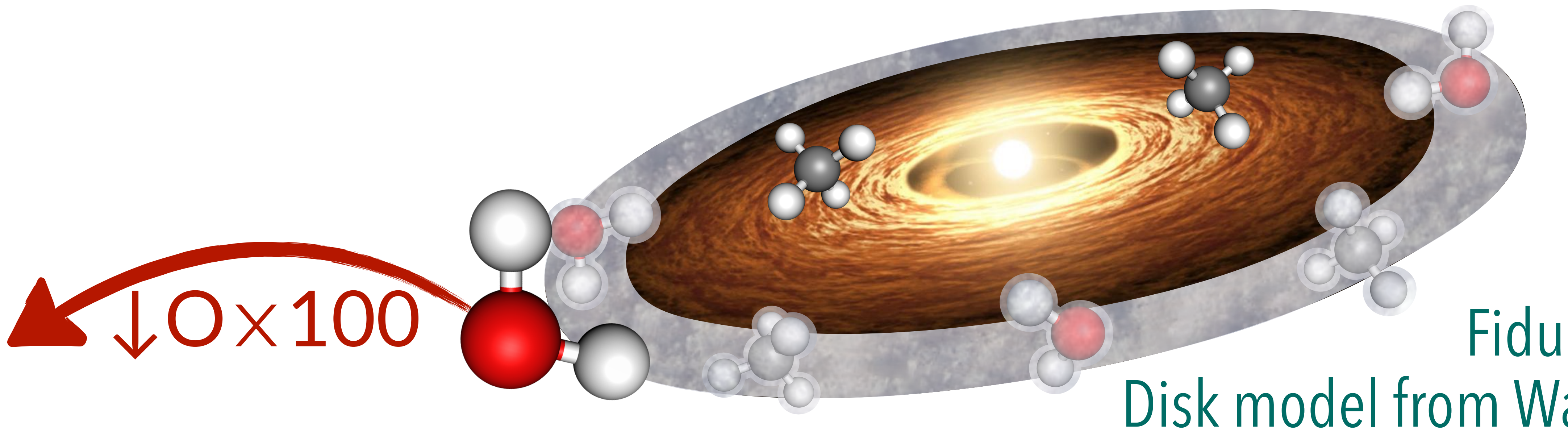
Fiducial model:
Disk model from Walsh+2015



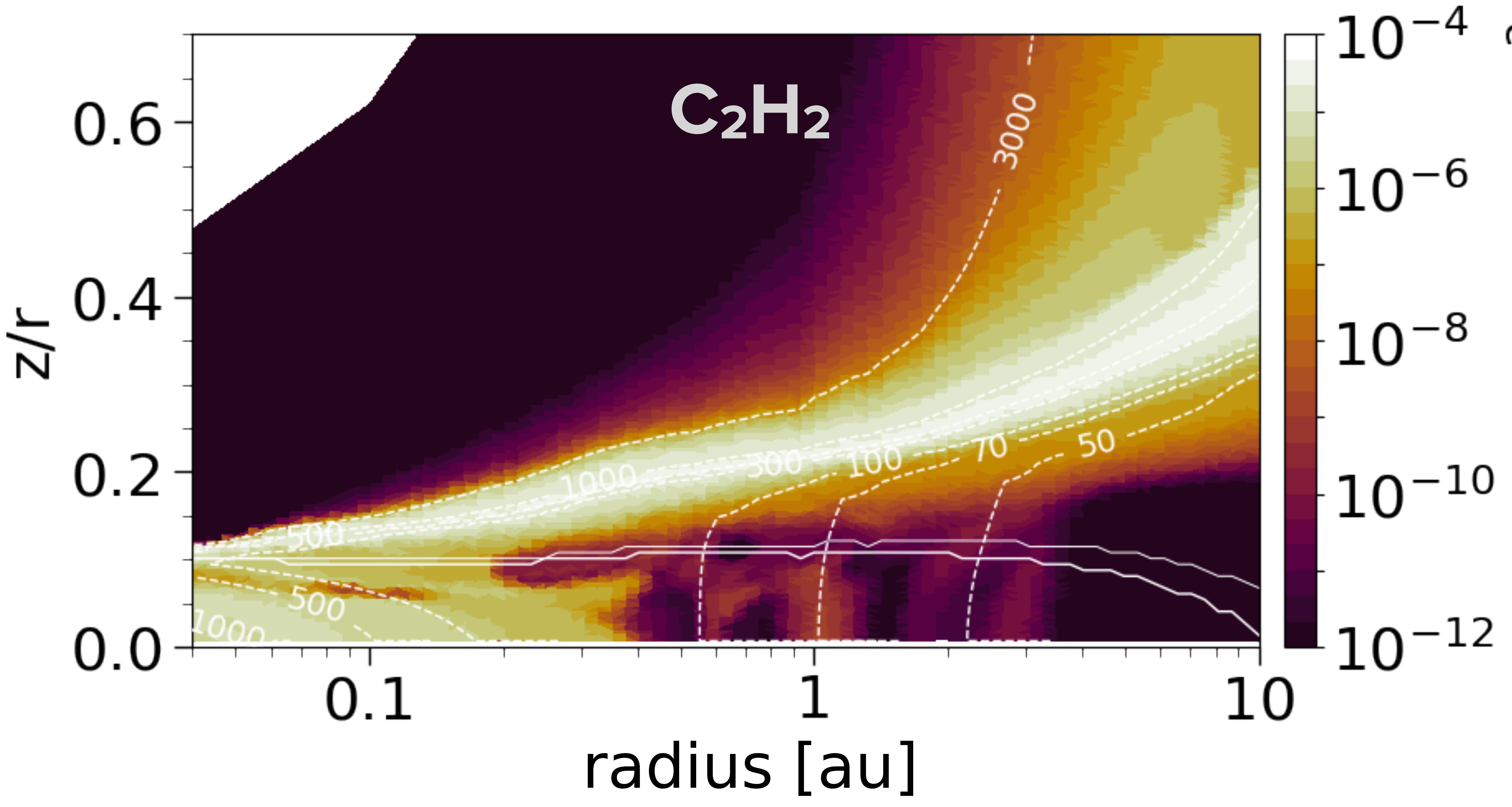


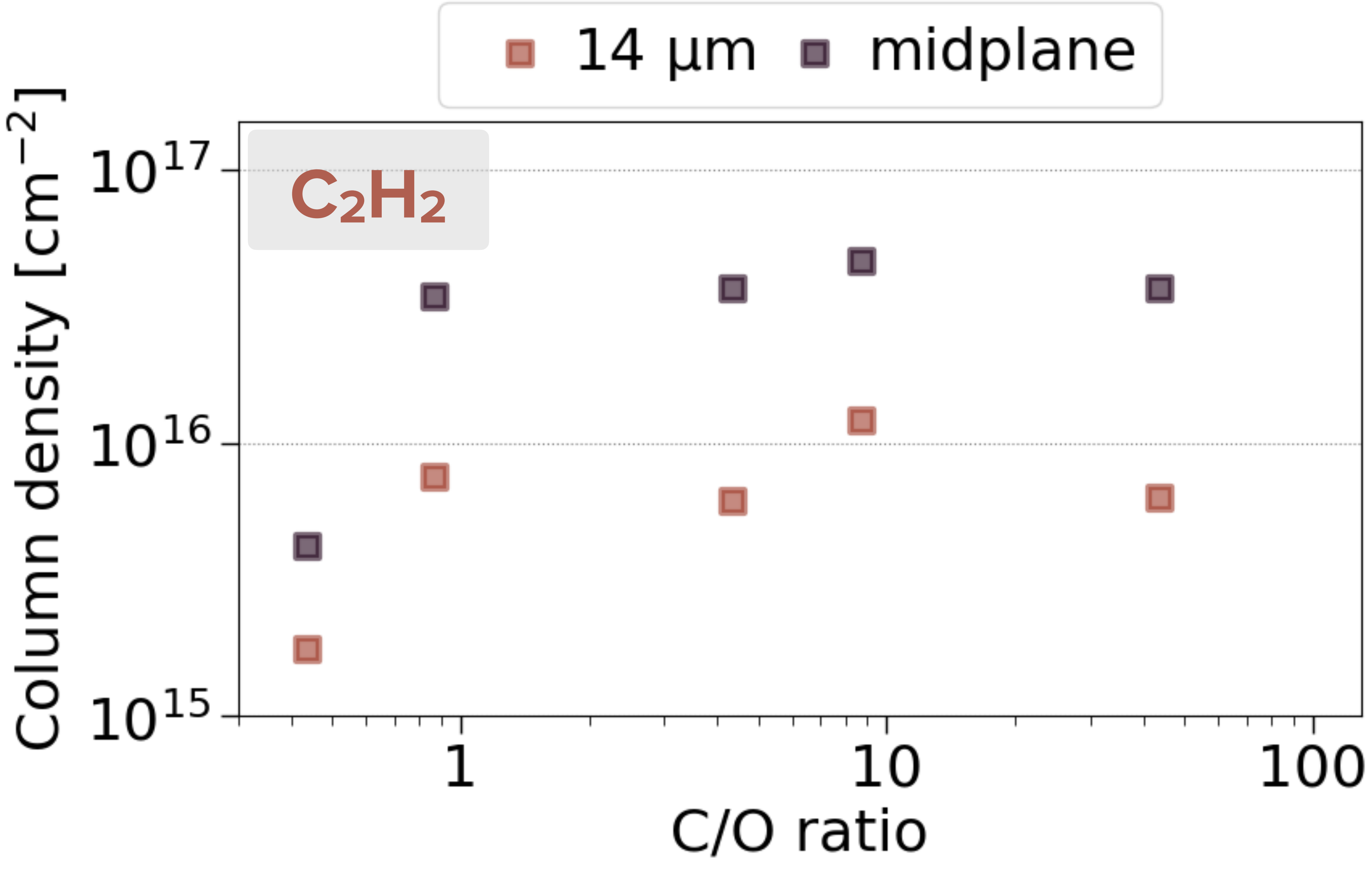
Díaz-Berríos+in prep.

CHEMICAL MODELS
FRACTIONAL ABUNDANCE MAPS: C_2H_2



Fiducial model:
Disk model from Walsh+2015

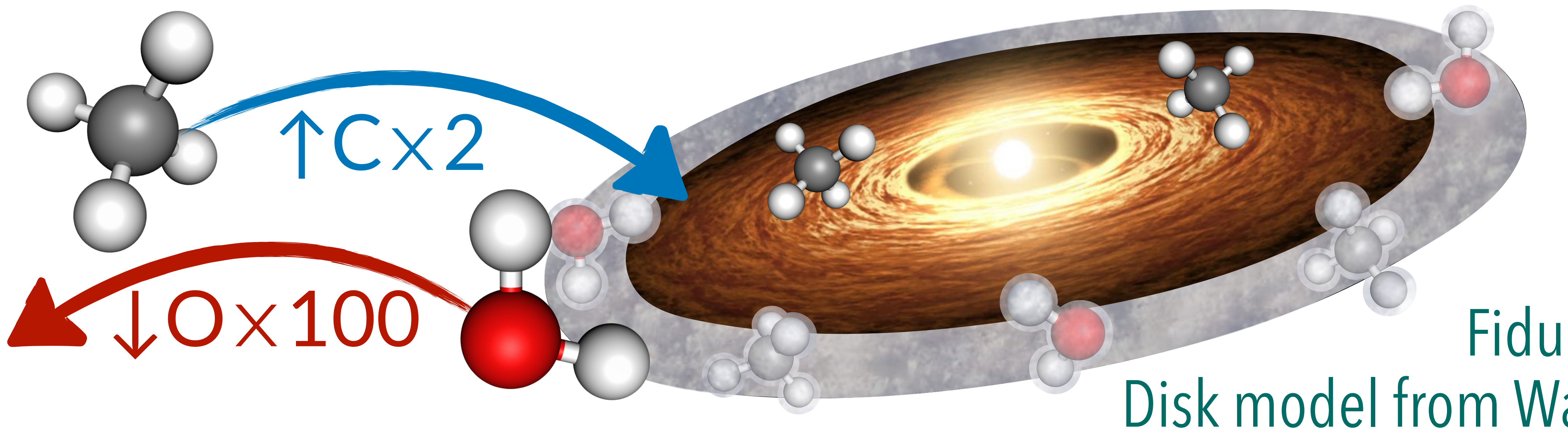




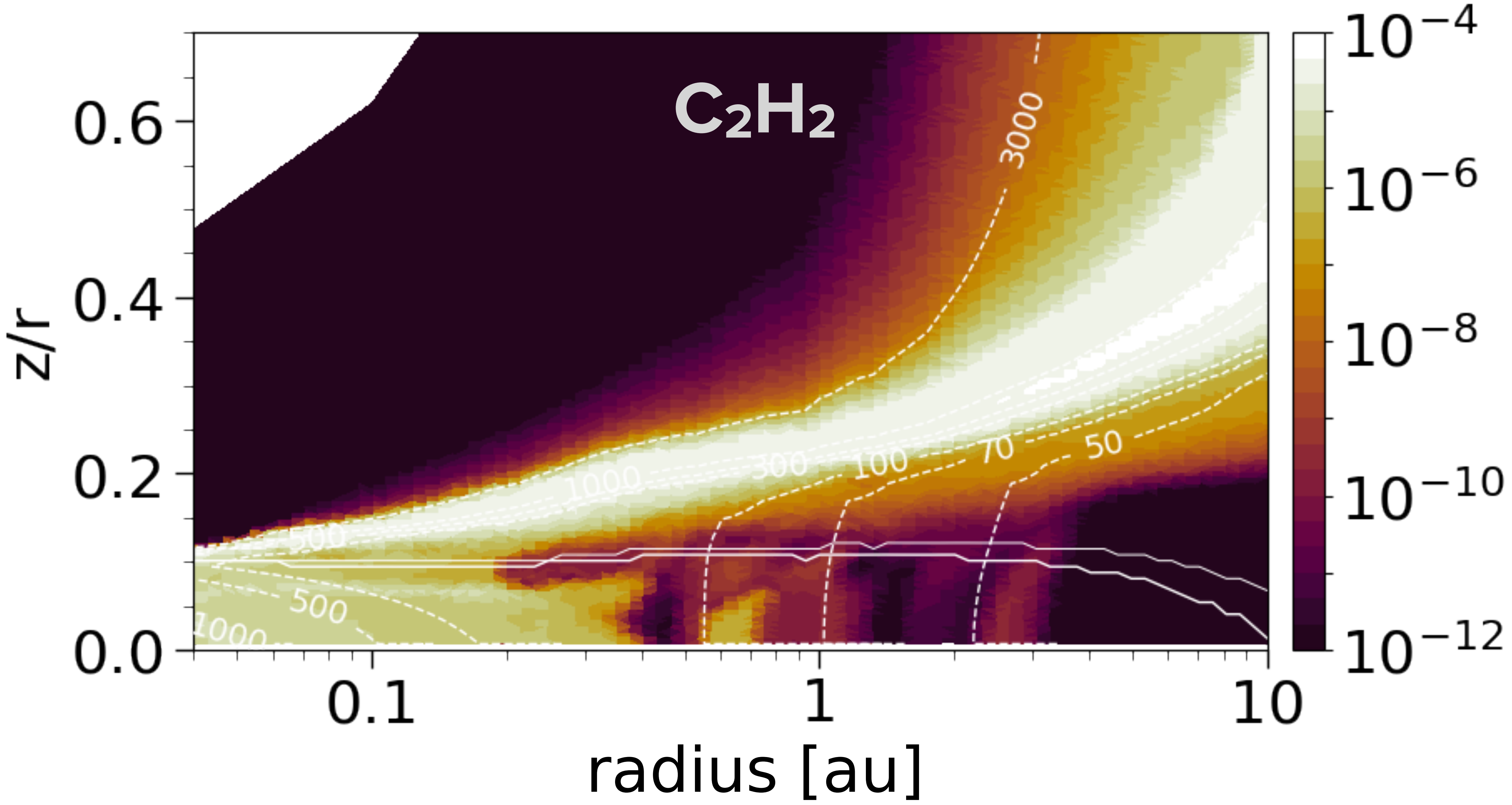
Díaz-Berríos+in prep.

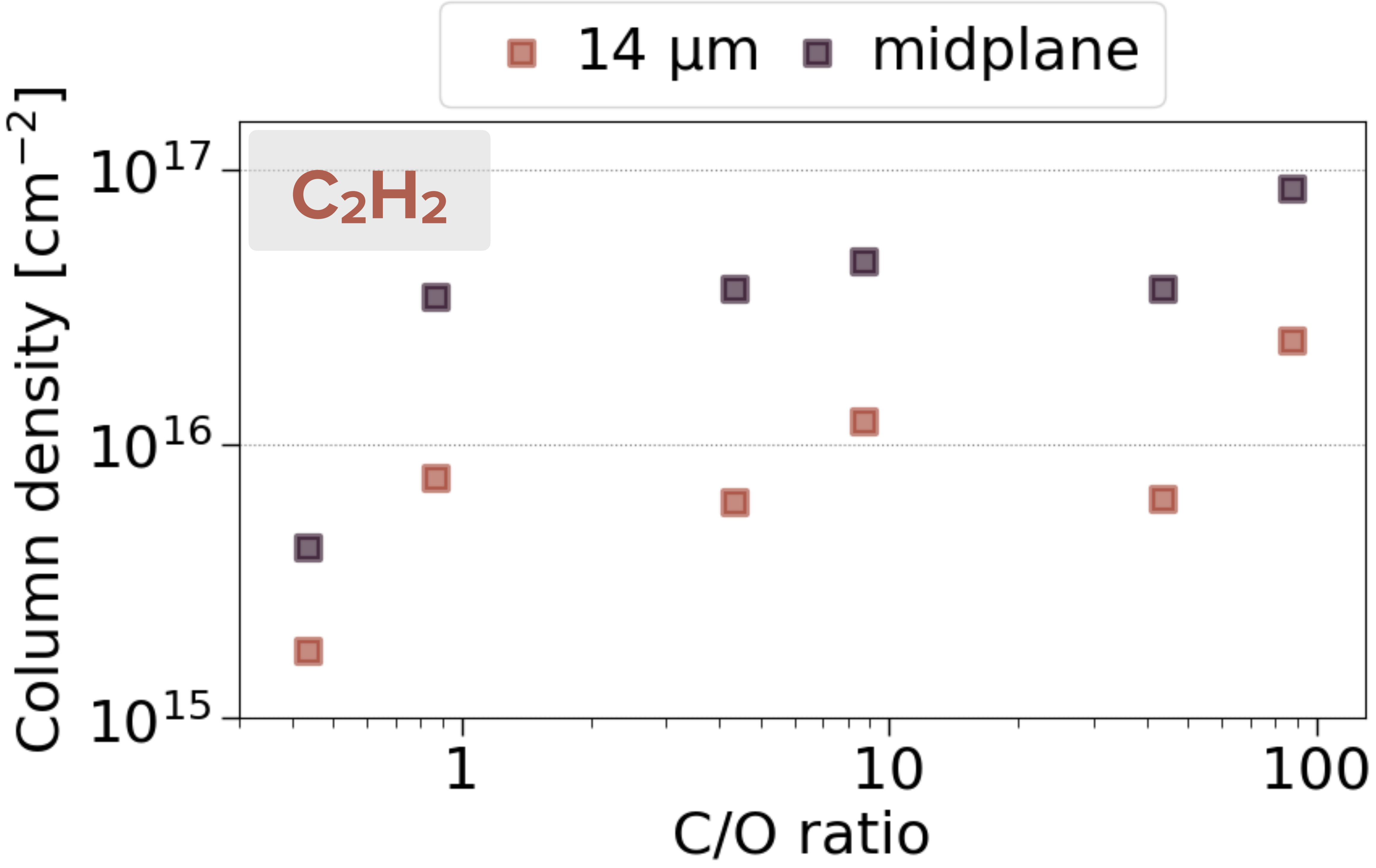
CHEMICAL MODELS

FRACTIONAL ABUNDANCE MAPS: C_2H_2



Fiducial model:
Disk model from Walsh+2015

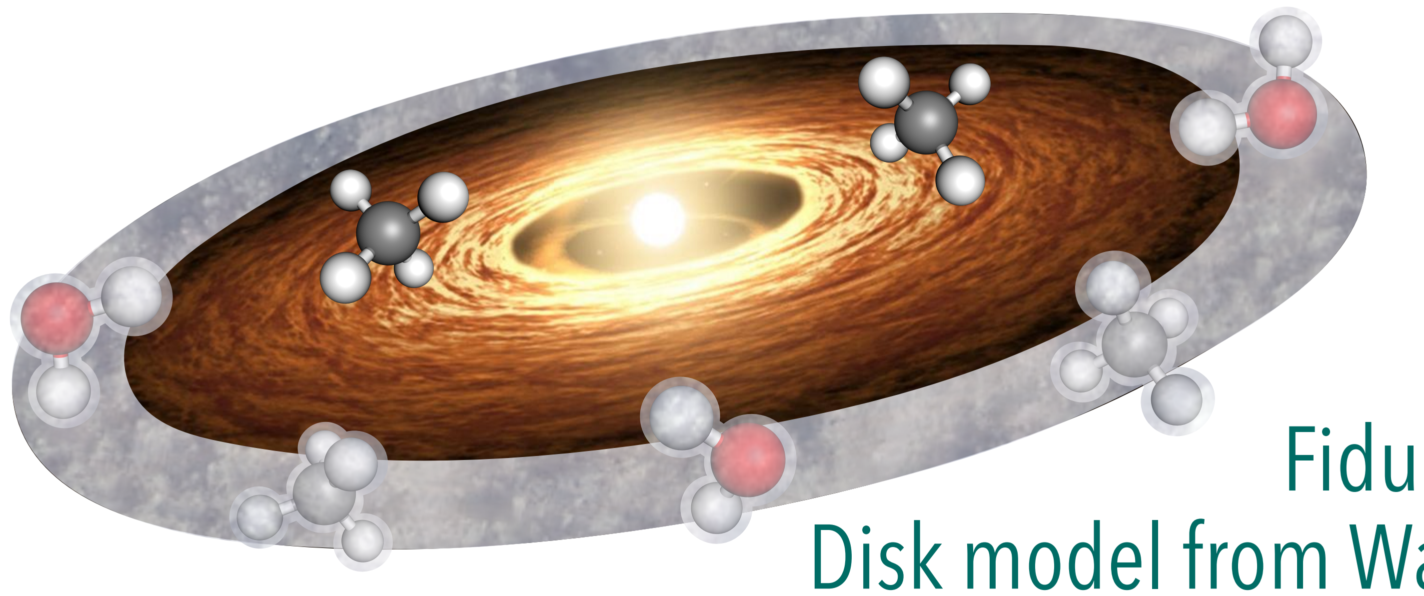




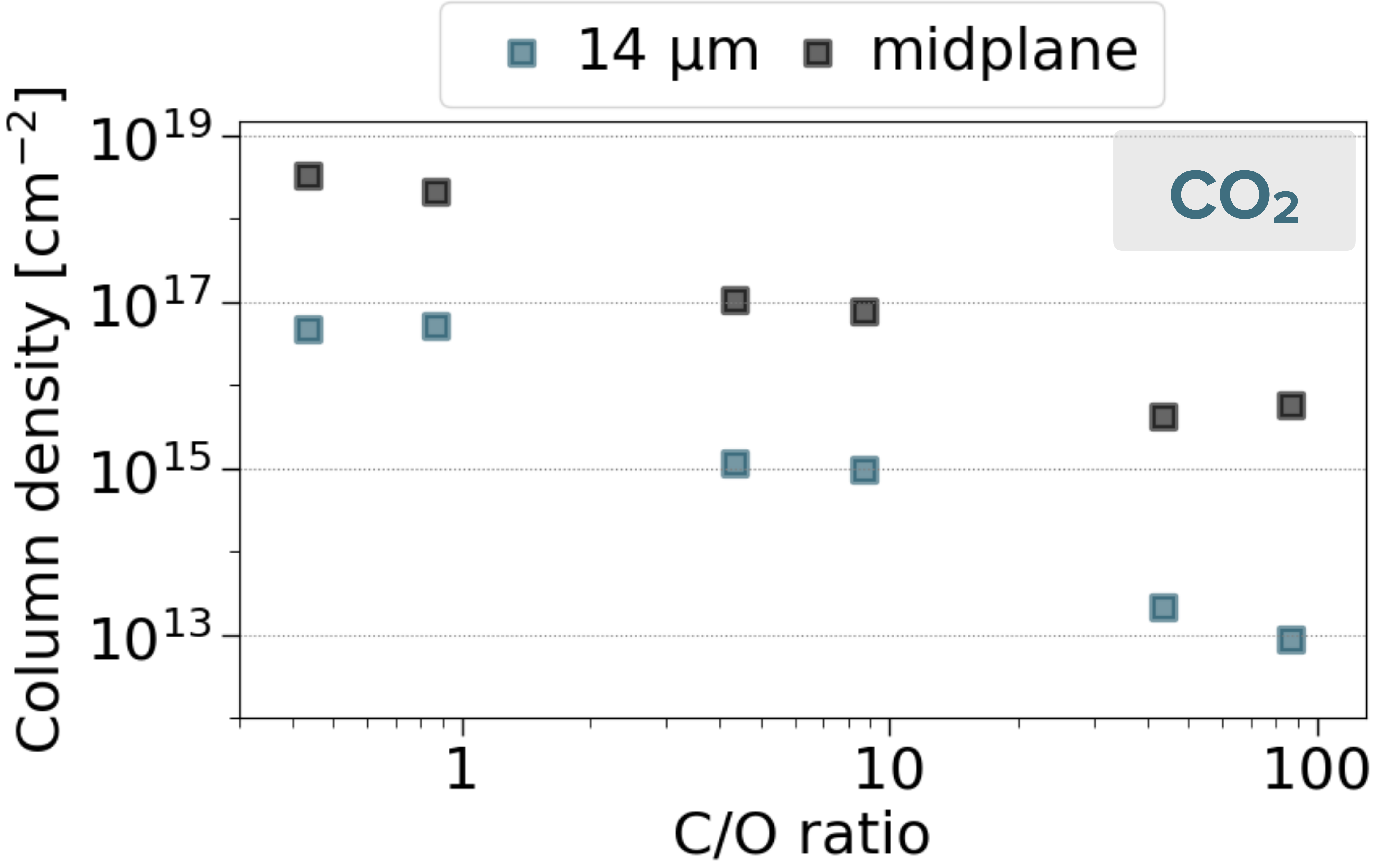
Díaz-Berríos+in prep.

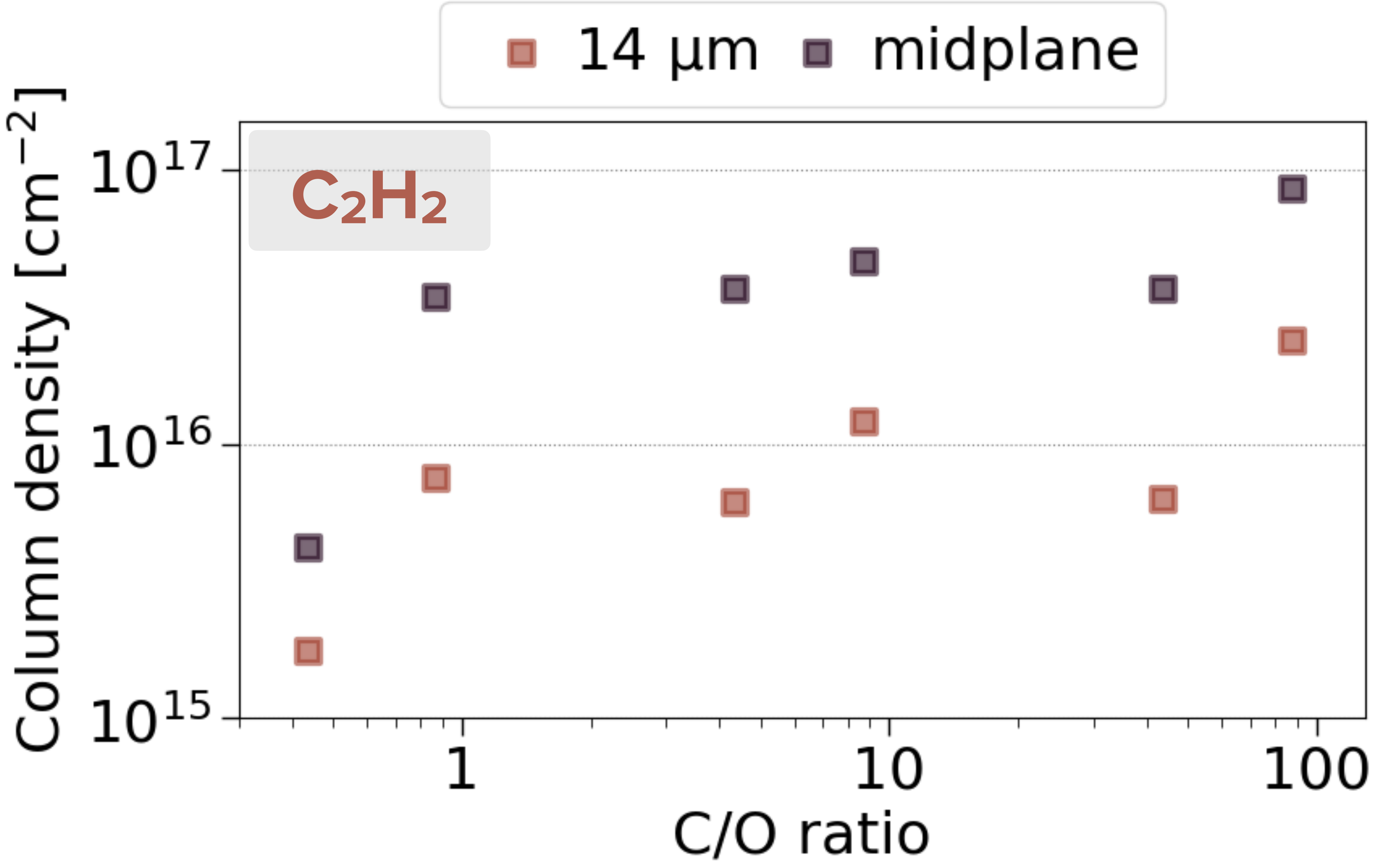
CHEMICAL MODELS

COMPARING CO_2 AND C_2H_2



Fiducial model:
Disk model from Walsh+2015

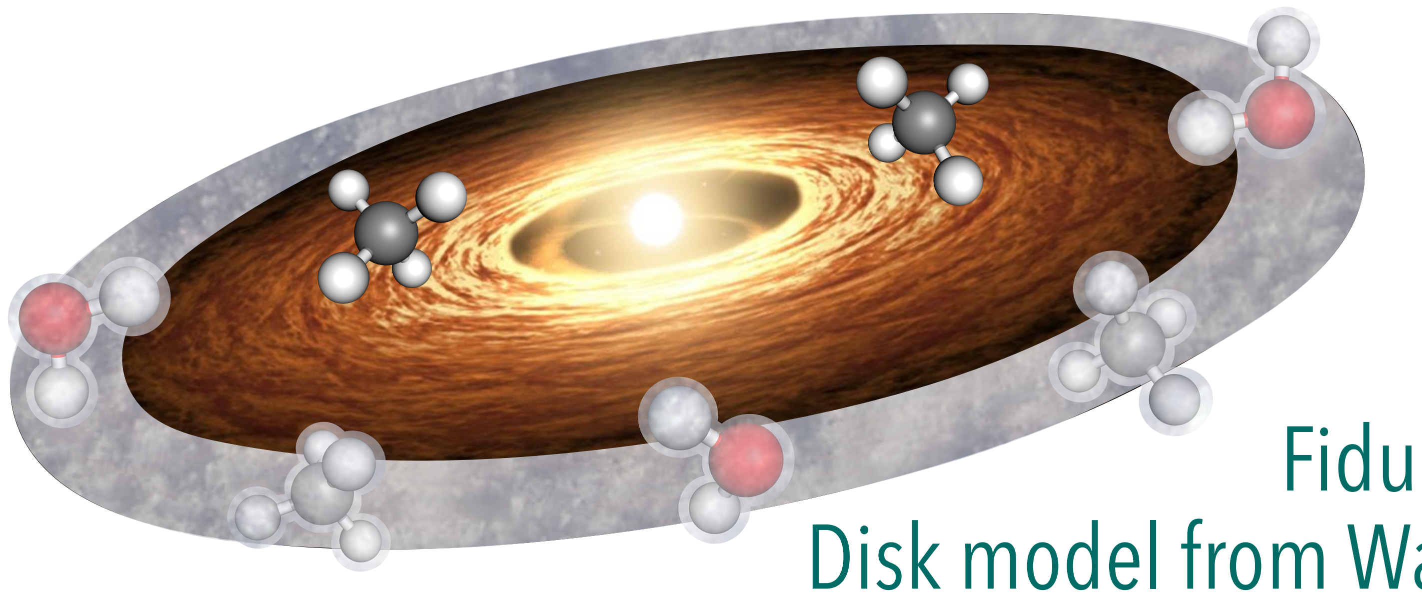




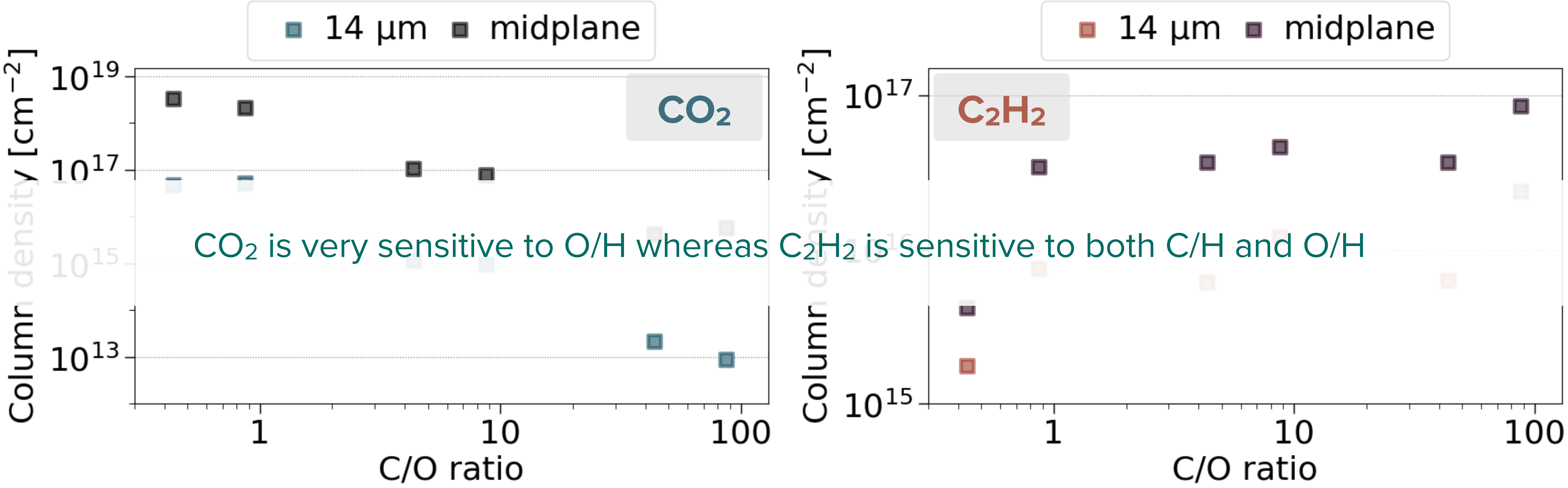
Díaz-Berríos+in prep.

CHEMICAL MODELS

COMPARING CO_2 AND C_2H_2



Fiducial model:
Disk model from Walsh+2015



CO_2 is very sensitive to O/H whereas C_2H_2 is sensitive to both C/H and O/H

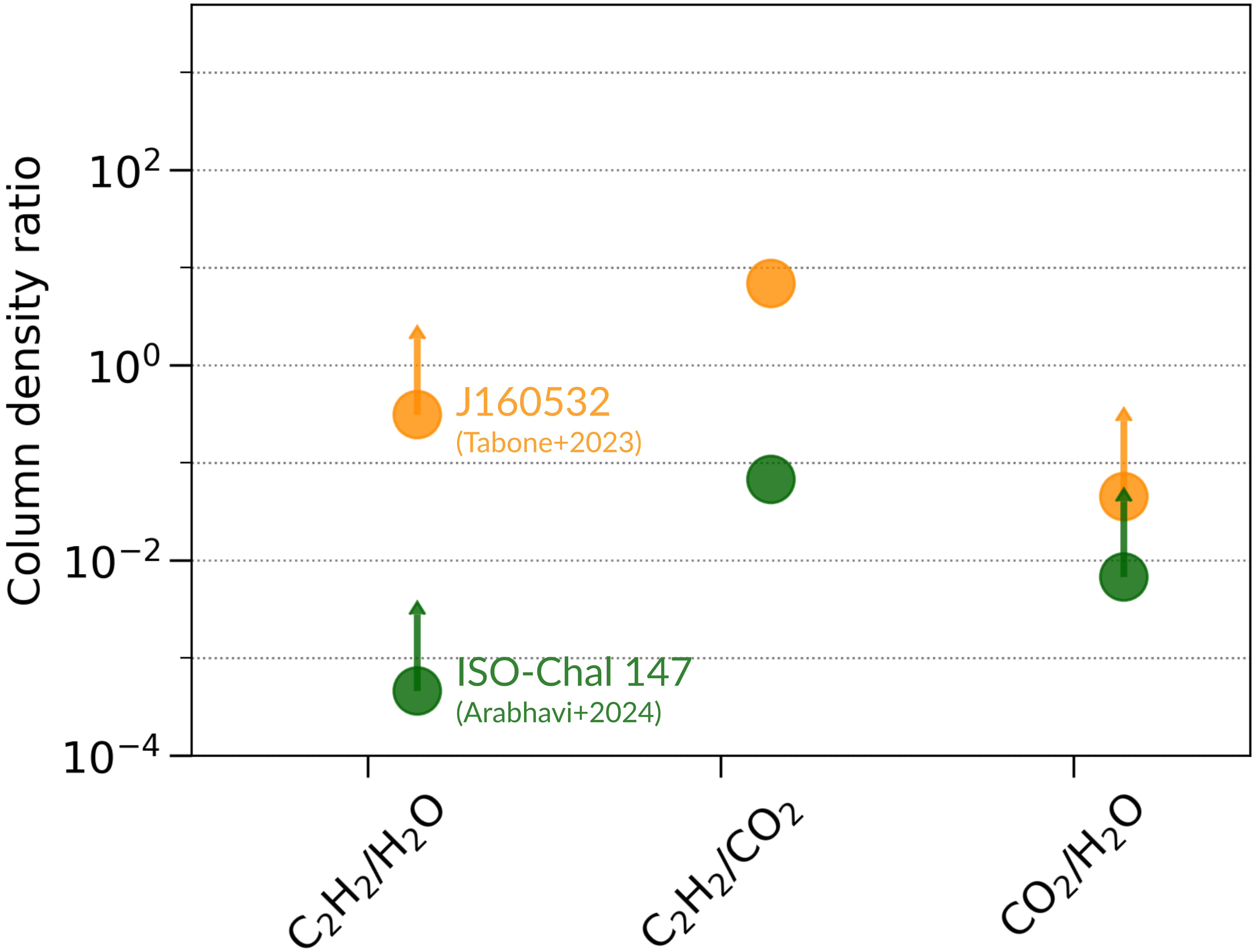
Díaz-Berríos+in prep.

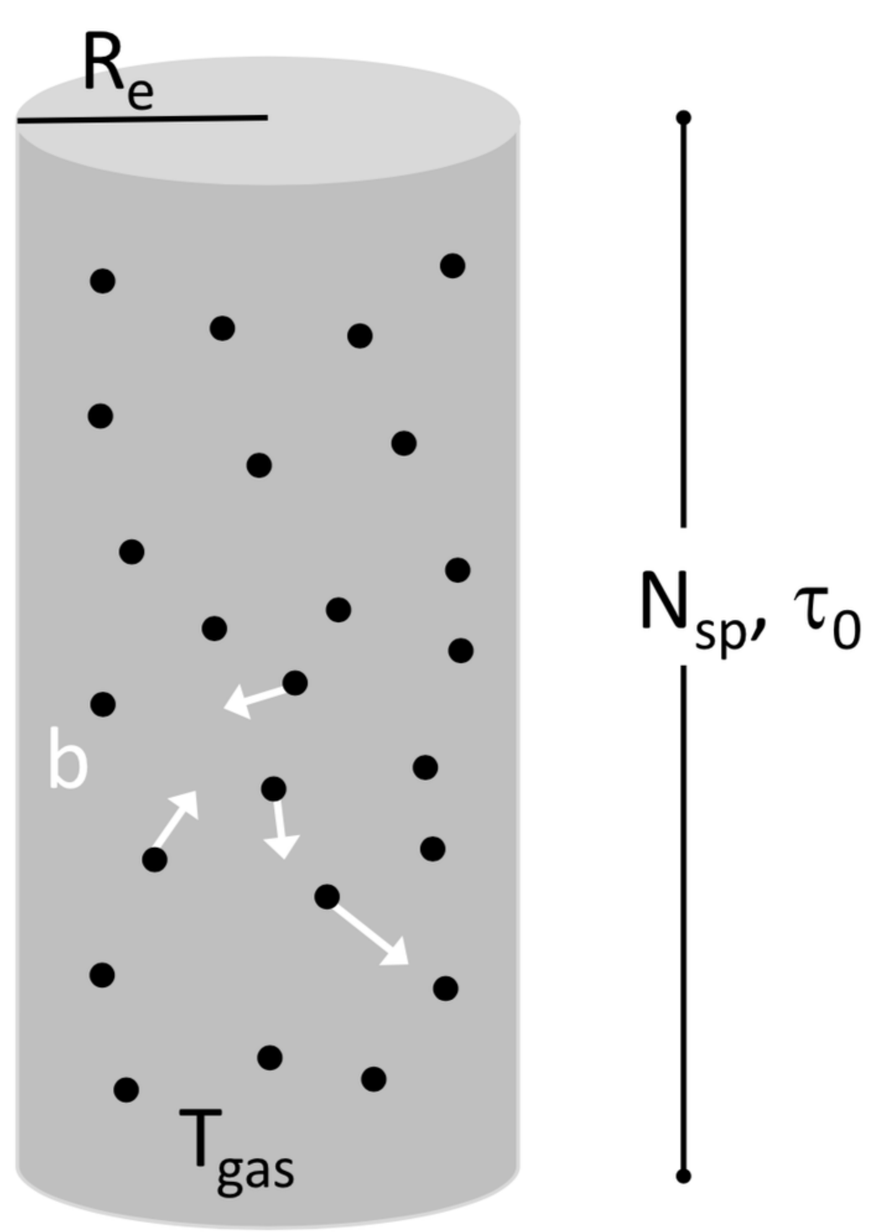
HOW DO THE MODELS COMPARE WITH OBSERVATIONS?

SOME TRENDS: COLUMN DENSITY RATIOS

HOW DO THE MODELS COMPARE WITH OBSERVATIONS?

SOME TRENDS: COLUMN DENSITY RATIOS



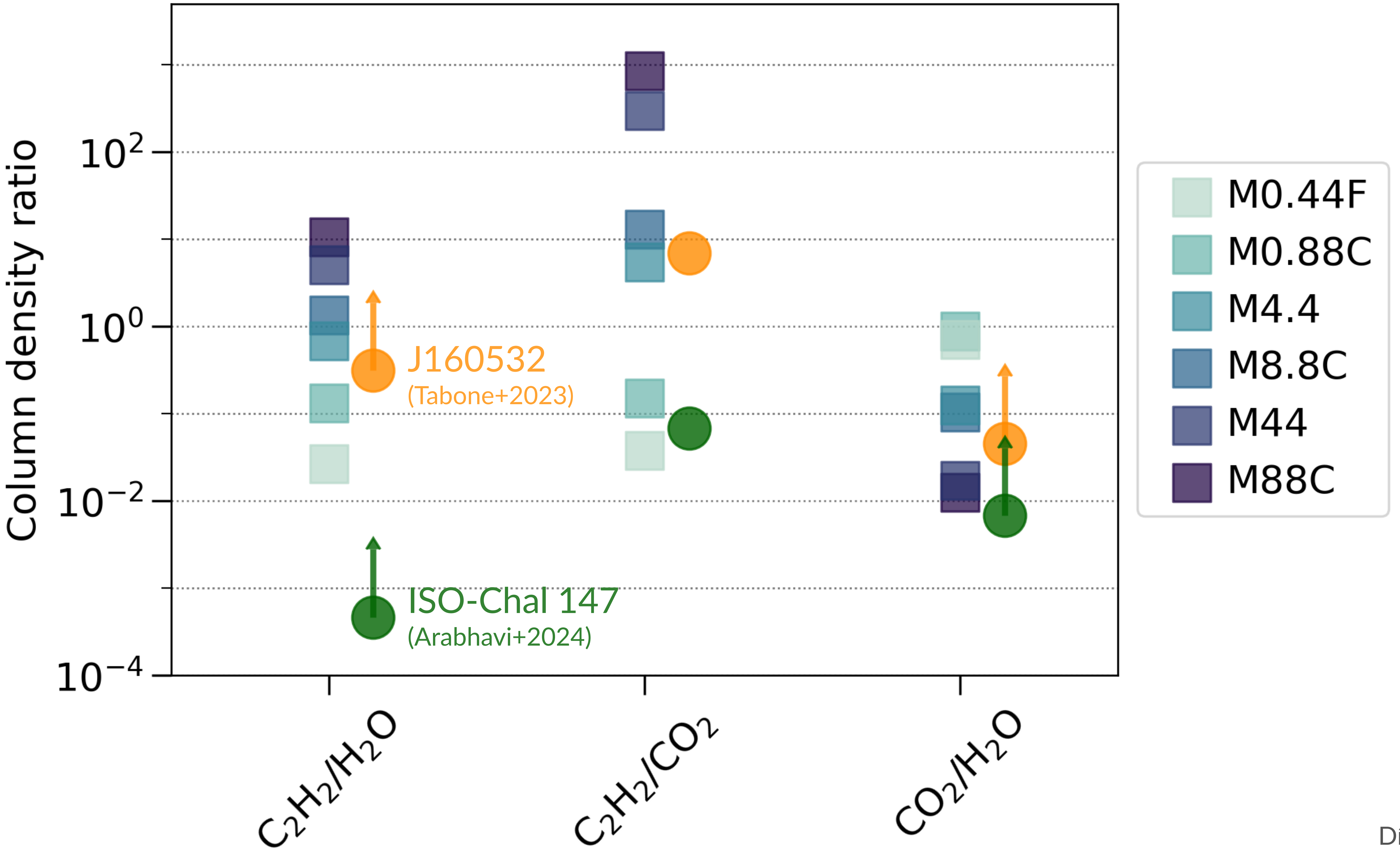


⚠️ We do not know ⚠️ the emission region/size

Díaz-Berríos+in prep.

HOW DO THE MODELS COMPARE WITH OBSERVATIONS?

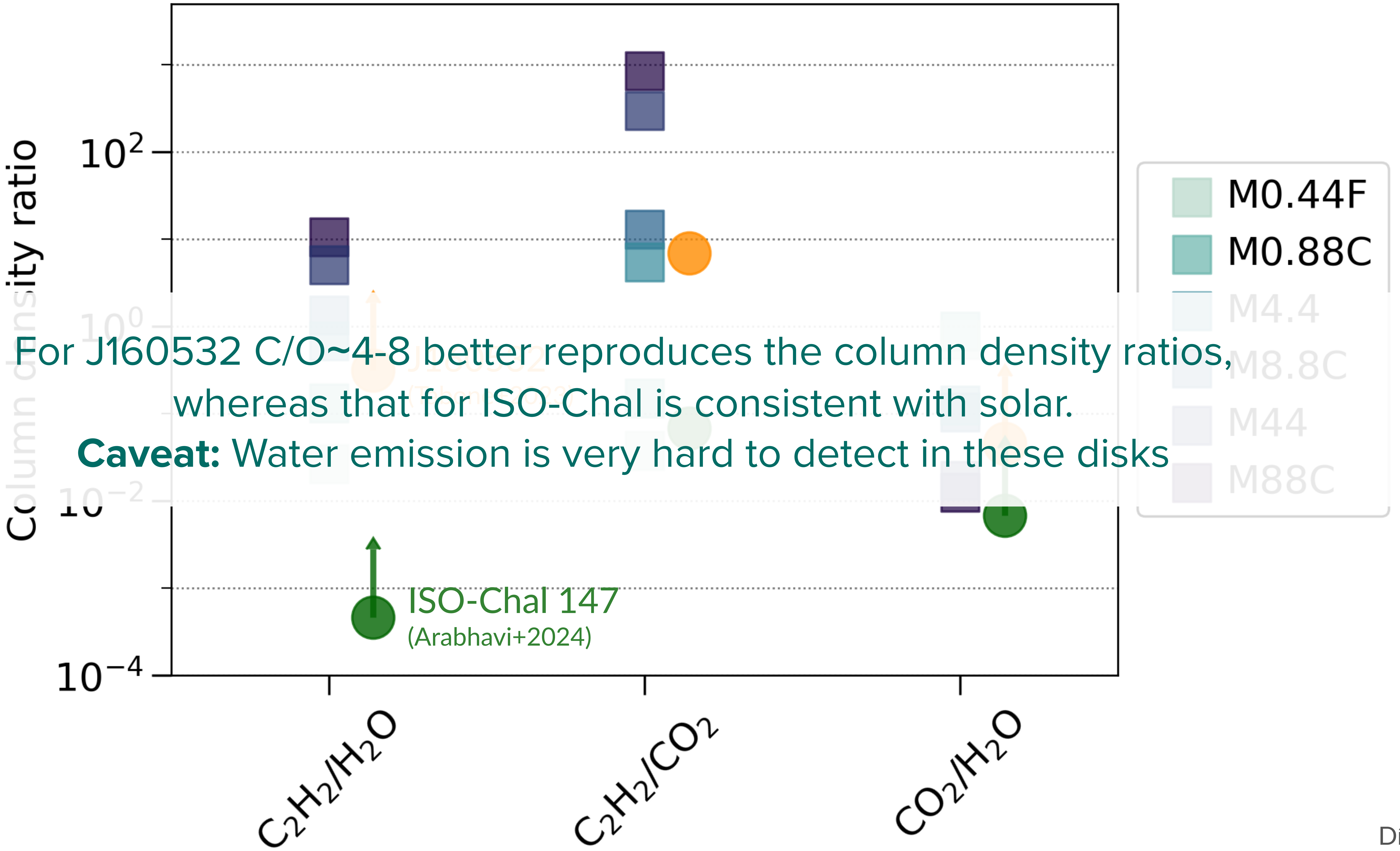
SOME TRENDS: COLUMN DENSITY RATIOS



Díaz-Berríos+in prep.

HOW DO THE MODELS COMPARE WITH OBSERVATIONS?

SOME TRENDS: COLUMN DENSITY RATIOS



For J160532 C/O~4-8 better reproduces the column density ratios, whereas that for ISO-Chal is consistent with solar.

Caveat: Water emission is very hard to detect in these disks

Díaz-Berríos+in prep.

KEY POINTS AND CONCLUSIONS

WHAT DID WE LEARN FROM THE MODELS?

Credits background: NASA/JPL-Caltech

KEY POINTS AND CONCLUSIONS

WHAT DID WE LEARN FROM THE MODELS?

Super-solar C/O value is needed to reproduce the ratios for the J160532 observations.
Solar-like C/O value better reproduce the ratios for the ISO-Chal 147 data.

Which physical mechanisms lead to that particular C/O ratio is still an open question.

KEY POINTS AND CONCLUSIONS

WHAT DID WE LEARN FROM THE MODELS?

Super-solar C/O value is needed to reproduce the ratios for the J160532 observations.
Solar-like C/O value better reproduce the ratios for the ISO-Chal 147 data.

Which physical mechanisms lead to that particular C/O ratio is still an open question.

The systems observed so far show a range C/O and metallicities even if they present similar species detected in their spectra.

Credits background: NASA/JPL-Caltech

KEY POINTS AND CONCLUSIONS

WHAT DID WE LEARN FROM THE MODELS?

Super-solar C/O value is needed to reproduce the ratios for the J160532 observations.
Solar-like C/O value better reproduce the ratios for the ISO-Chal 147 data.

Which physical mechanisms lead to that particular C/O ratio is still an open question.

The systems observed so far show a range C/O and metallicities even if they present similar species detected in their spectra.

What are the implications for planet formation?

If gas giant planets are actively forming in these disks they could be accreting carbon-rich gas.

Interesting to see if any carbon-rich planets are observed in the future.

Credits background: NASA/JPL-Caltech

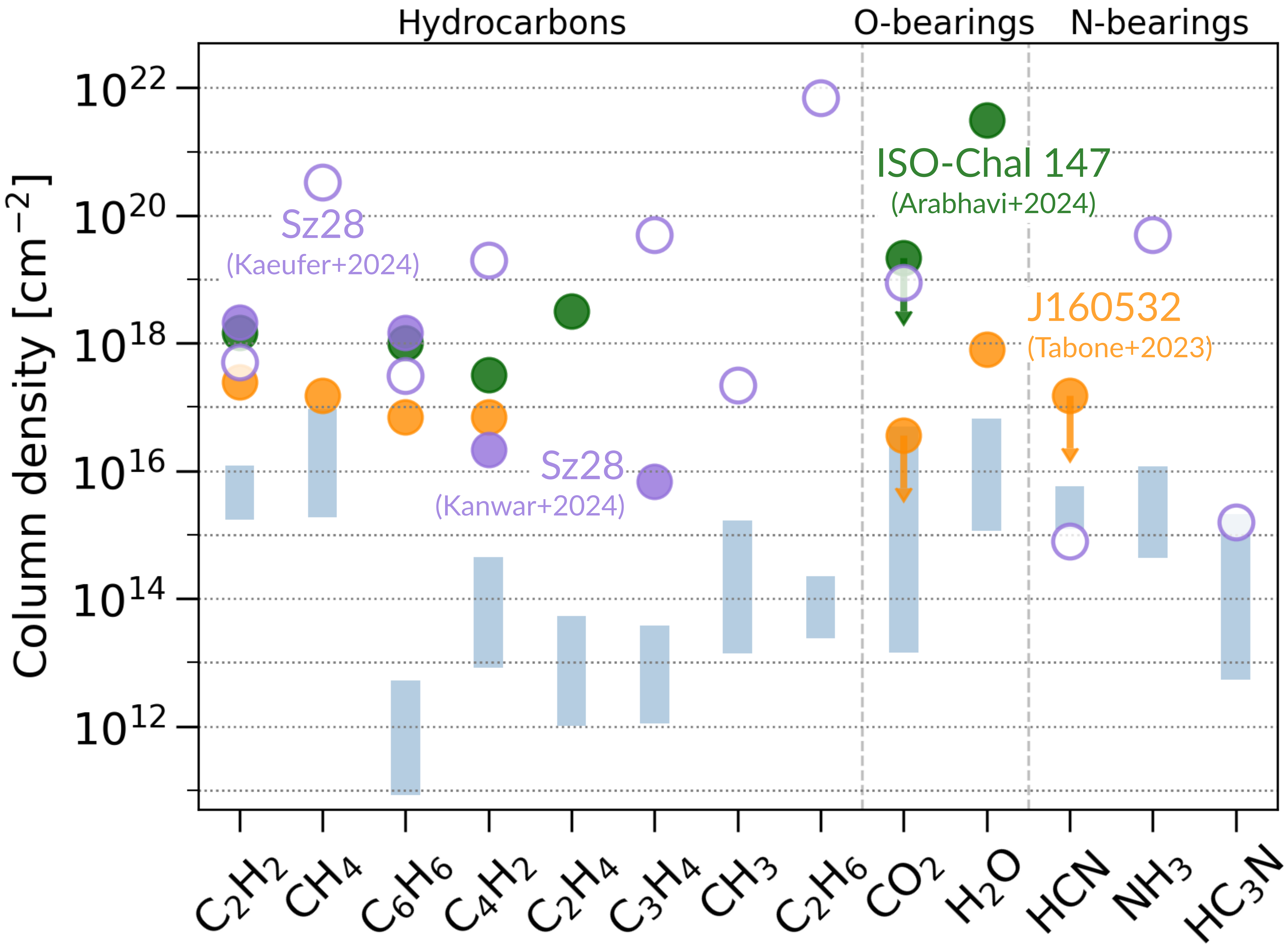

THANK YOU!
QUANTIFYING THE C/O RATIO IN THE PLANET-FORMING ENVIRONMENTS AROUND VERY LOW-MASS STARS
JAVIERA K. DÍAZ-BERRÍOS (PYJKD@LEEDS.AC.UK)
UKI DISCS MEETING, COVENTRY, SEPTEMBER 2024
UNIVERSITY OF LEEDS
Credits background: NASA/JPL-Caltech

CHEMICAL MODELS
PHYSICAL STRUCTURE OF A DISK AROUND A VERY LOW MASS STAR

Walsh+2015, Díaz-Berríos+in prep.

HOW DO OUR MODELS COMPARE WITH OBSERVATIONS?

SOME TRENDS: TOTAL COLUMN DENSITY

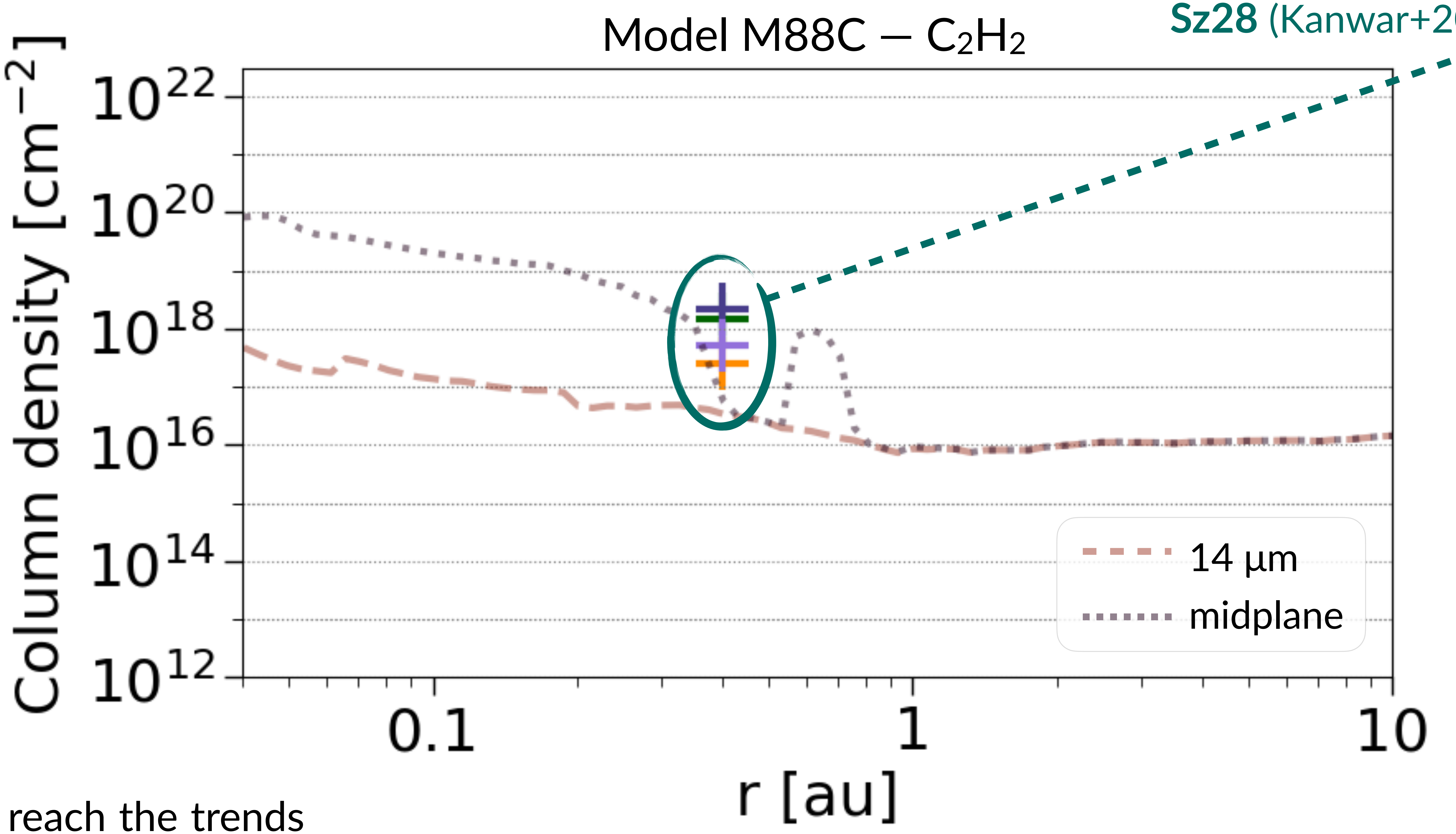


Díaz-Berríos+in prep.

WHAT IF WE CONSIDER THE MIDPLANE?

COLUMN DENSITY PROFILES

Column densities reported for
J160532 (Tabone+2023)
ISO-Chal 147 (Arabhavi+2024)
Sz28 (Kanwar+2024, Kaeufer+2024)



This may help to reach the trends from the observations.

Díaz-Berríos+in prep.