THE SEARCH FOR LIFE AS WE (DON'T) KNOW IT

Credit: Scientific American , Vol. 298, No. 4 (April 2008), pp. 48-55

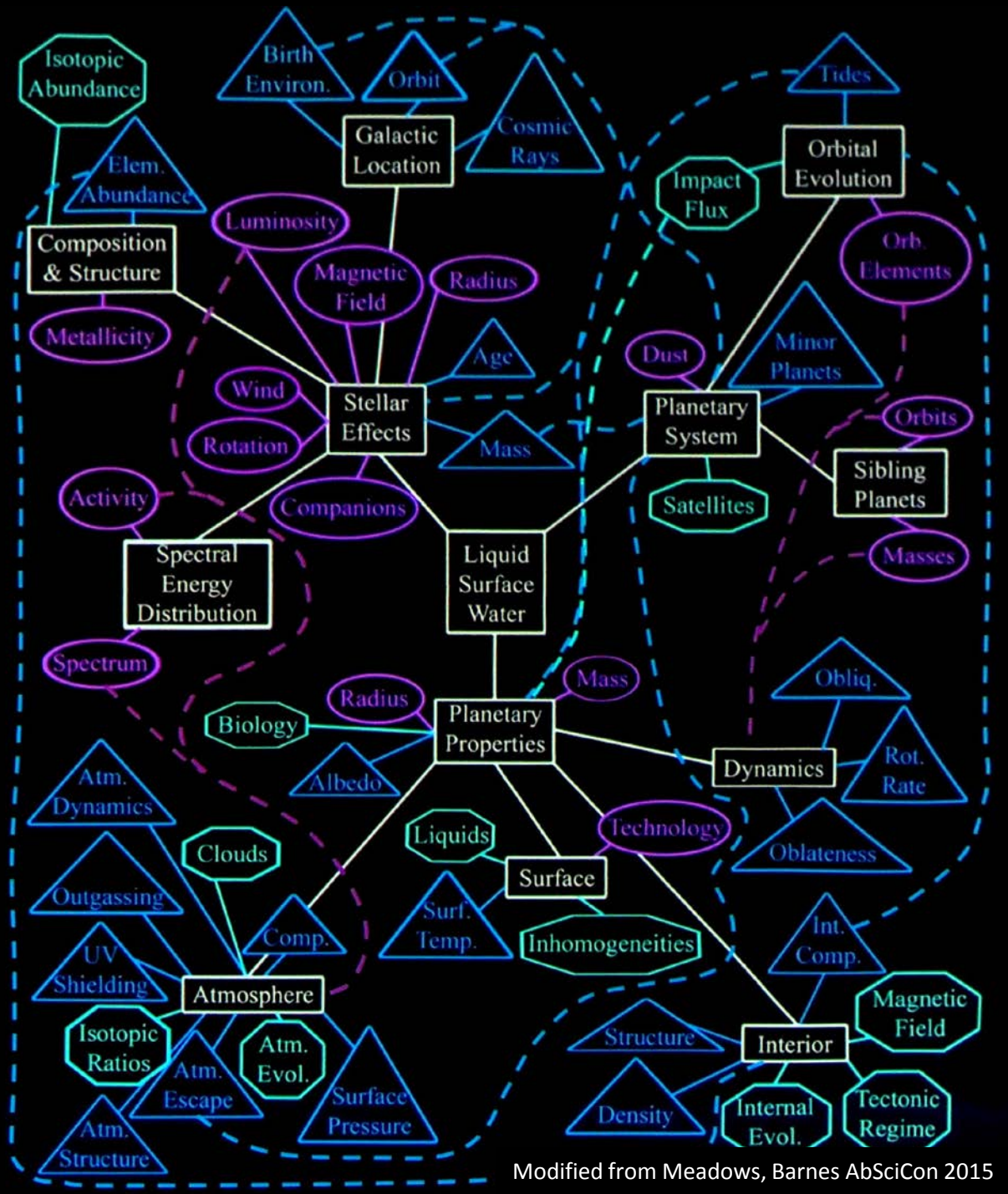
jjpetkow@mit.edu Janusz J. Petkowski, MIT

What is Astrobiology?

Astrobiology: interdisciplinary scientific field concerned with the origins, early evolution, distribution, and future of life in the universe. Astrobiology considers the question of whether extraterrestrial life exists, and if it does, how humans can detect it.

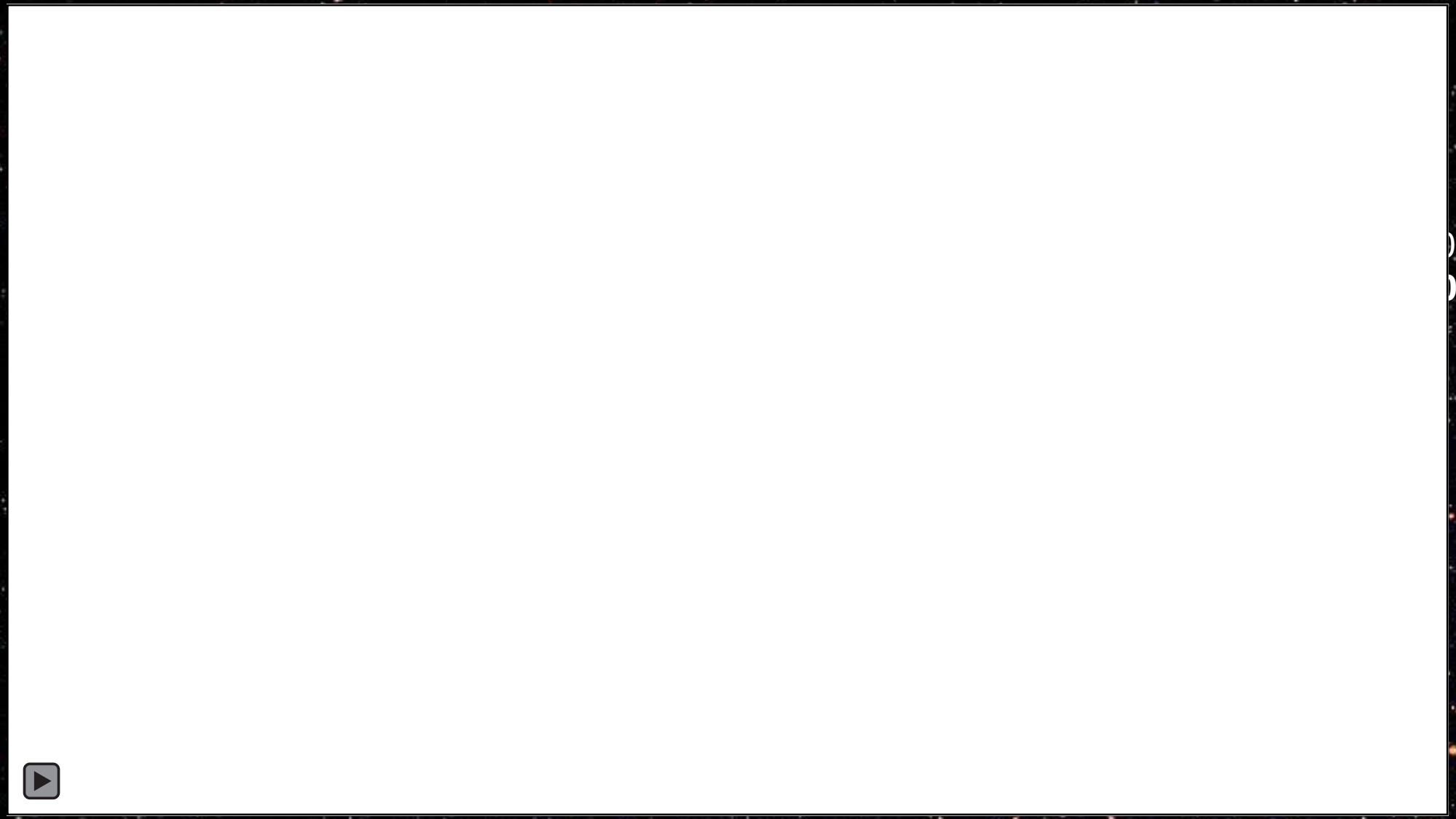
Where do we even start?

Let's find (habitable) planets first!



Modified from Meadows, Barnes AbSciCon 2015


Credit: Sara Seager



10^3 km
10^5 km

)
000

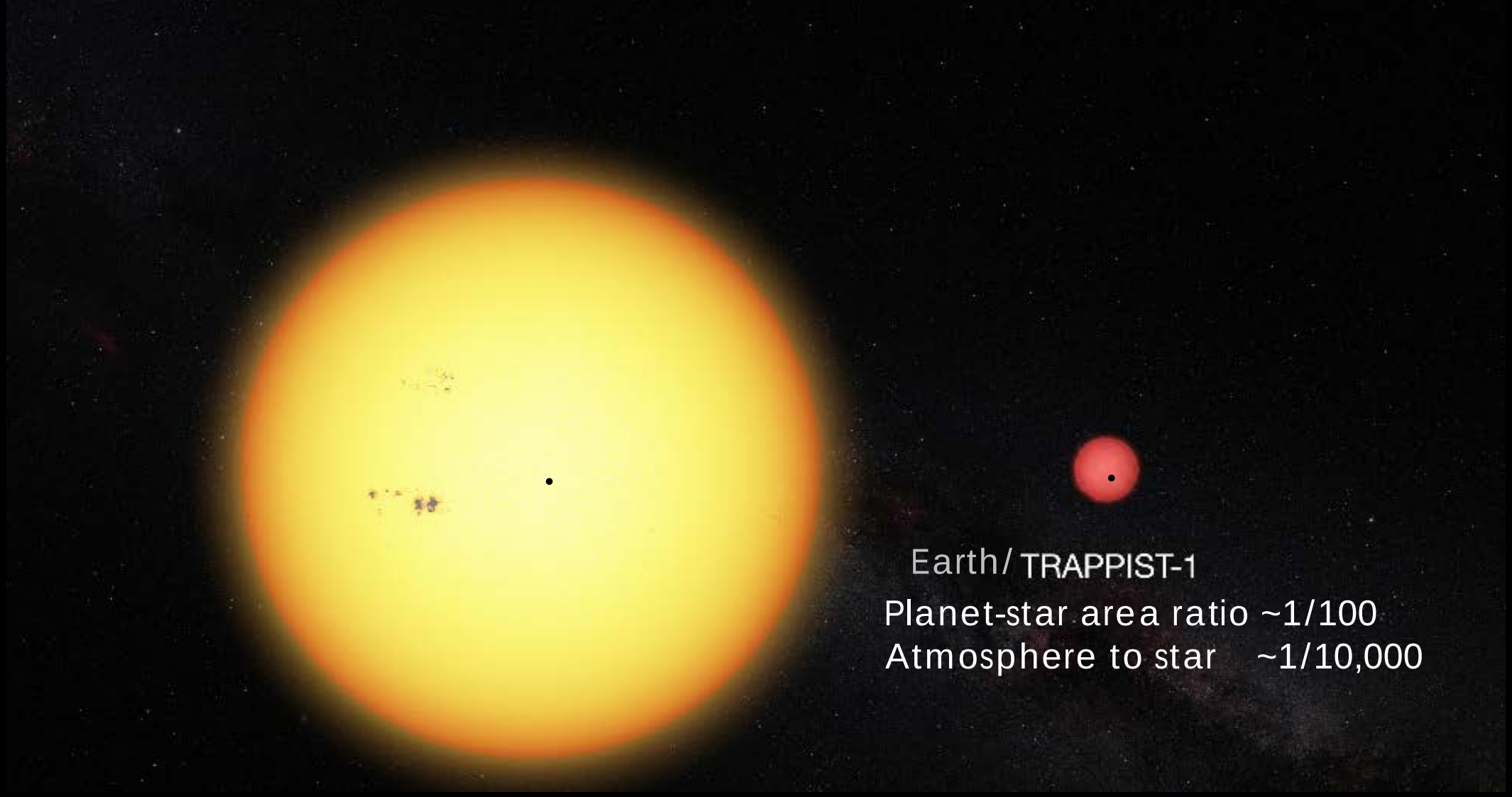
Animation credit: NASA

Credit: Sara Seager

Earth is
100 times smaller
300,000 times less massive
10,000,000,000 times fainter
than the sun

Habitable world: a planet that is about Earth size, receives about the same amount of energy from its star that Earth does from the Sun, and has liquid water

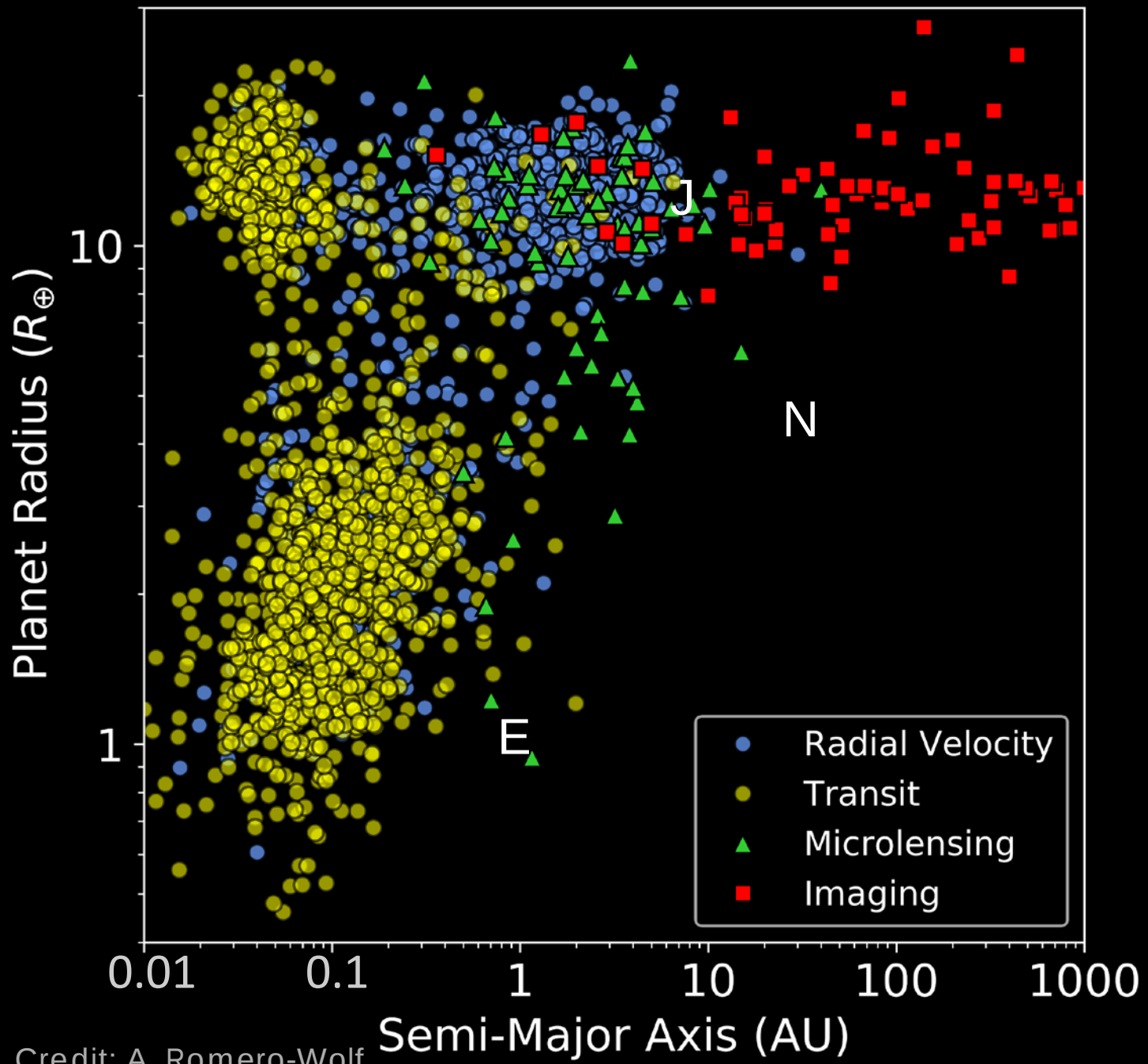
Credit: Sara Seager



Earth/Sun
Planet-star area ratio ~1/10,000
Atmosphere to star ~1/50,000,000

Credit: Sara Seager

Planet Detection



Credit: A. Romero-Wolf

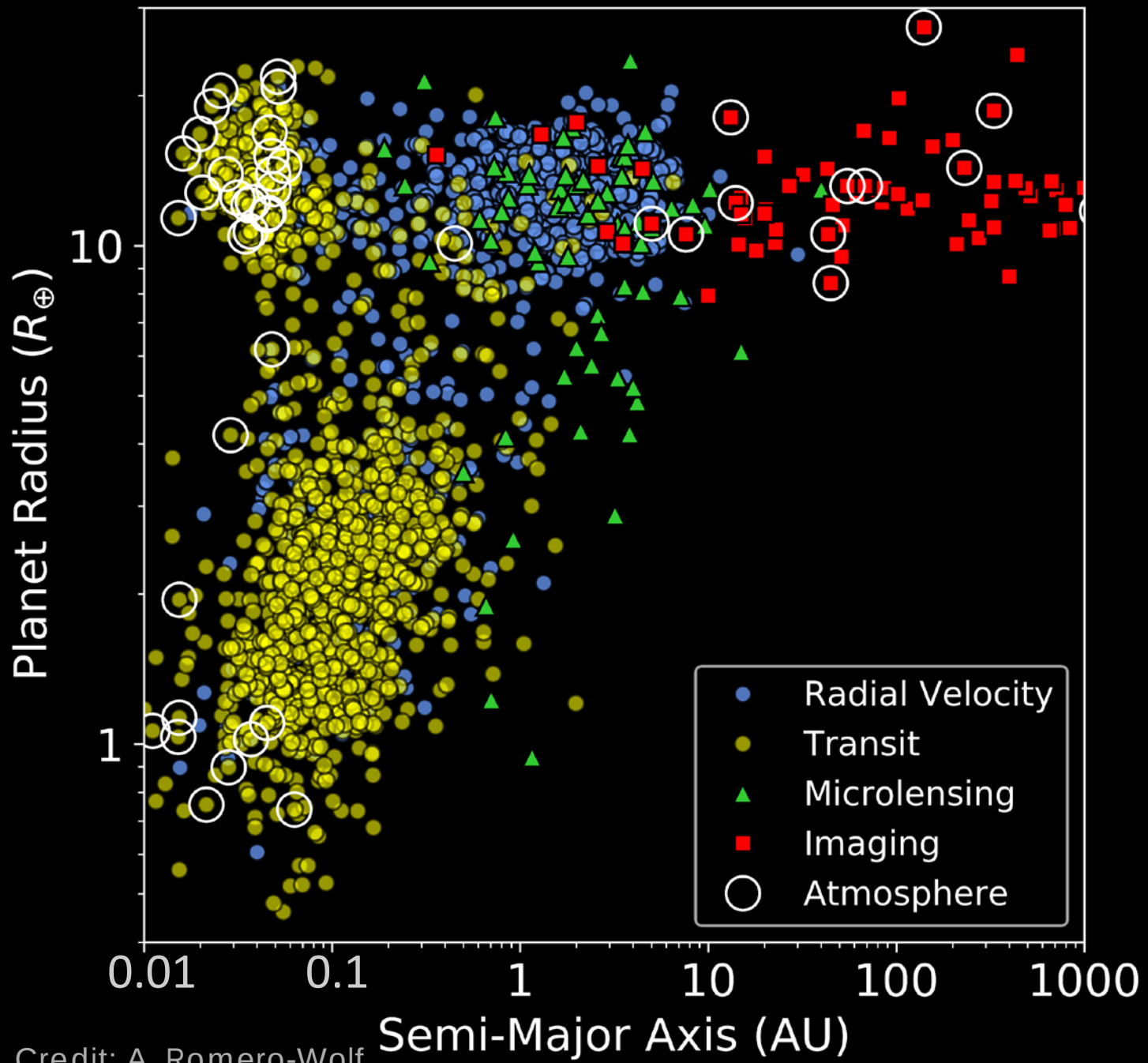
Exoplanets are diverse with a range of planet size, mass, and orbits

The discovery of Earth twin planets is not yet in reach

Not shown is that planet mass and size give average density and a clue to planet bulk composition

Credit: Sara Seager

Planet Detection



Credit: A. Romero-Wolf

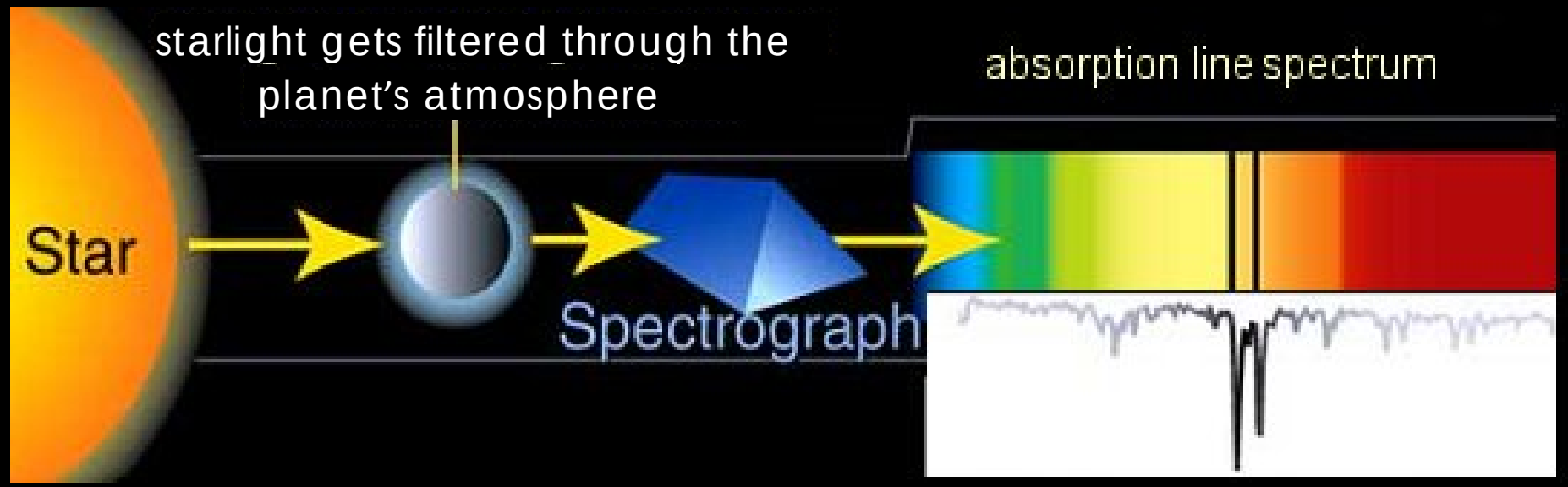
Exoplanets are diverse with a range of planet size, mass, and orbits

Venus and Earth would look the same to any planet-finding technique

Atmosphere studies are key

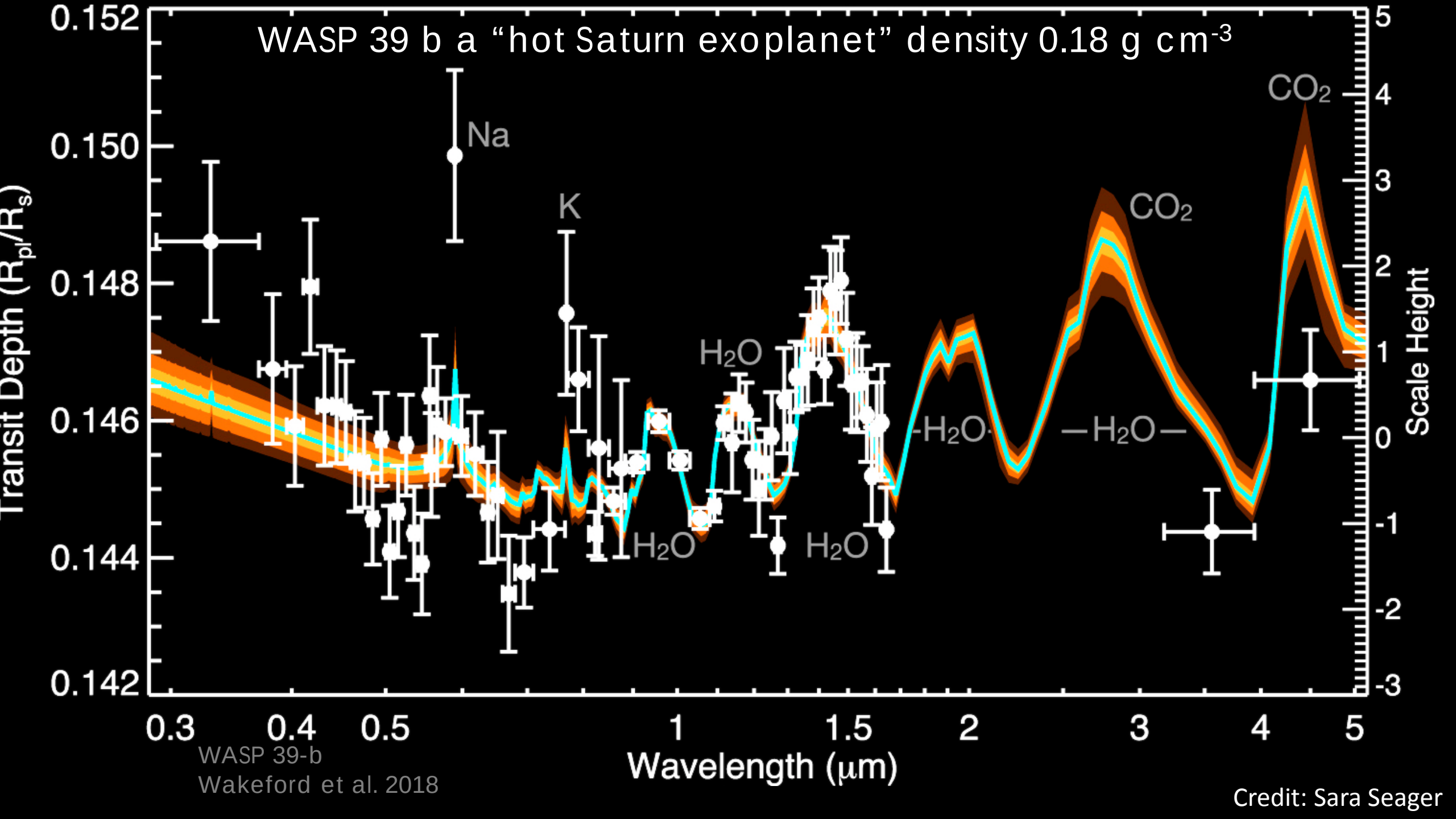
Credit: Sara Seager

Exoplanet Transmission Spectroscopy

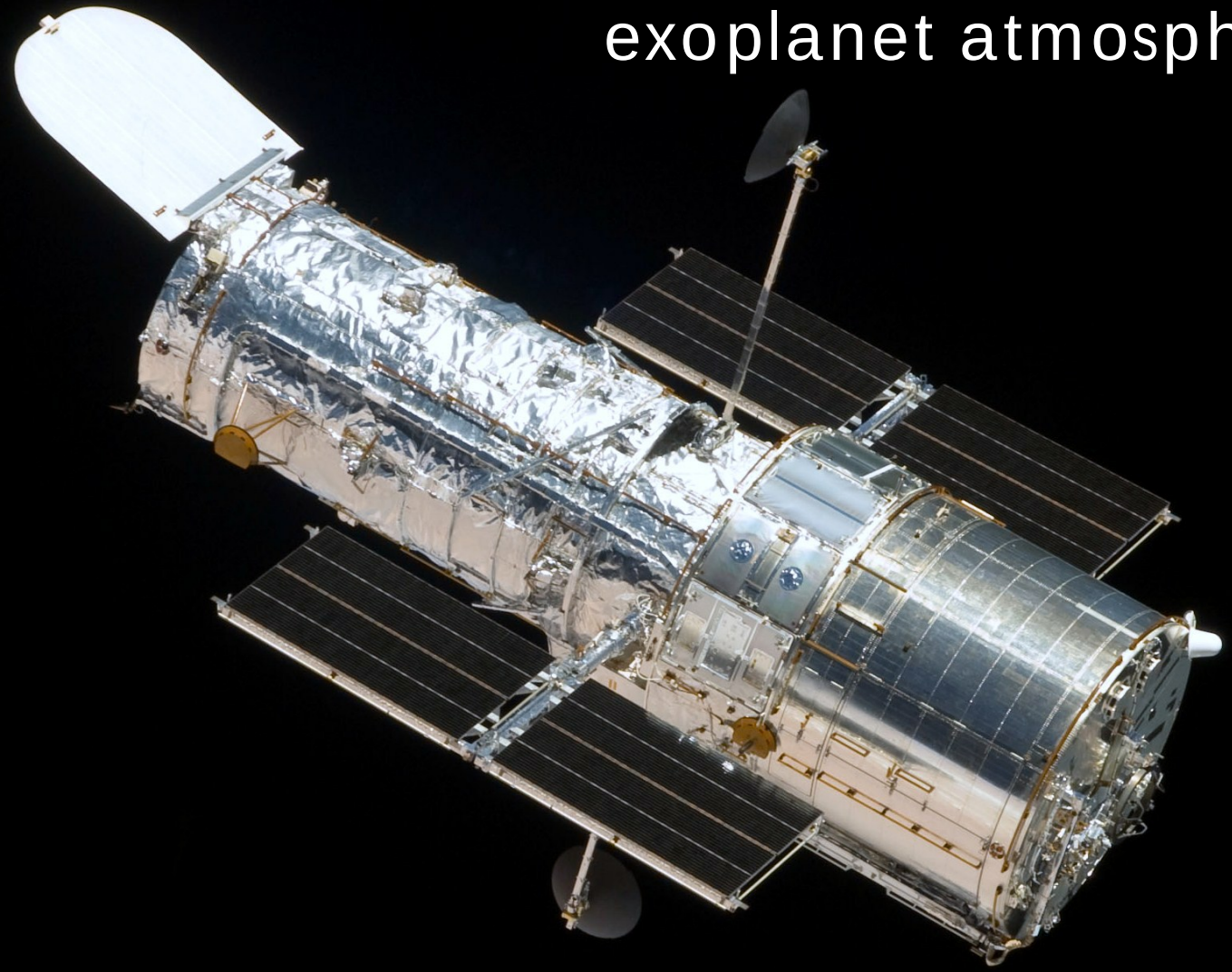


The problems is that only a tiny fraction of the star's light goes through the planet's atmosphere.

Credit: http://www.stellarplanet.co.uk/2011/10/

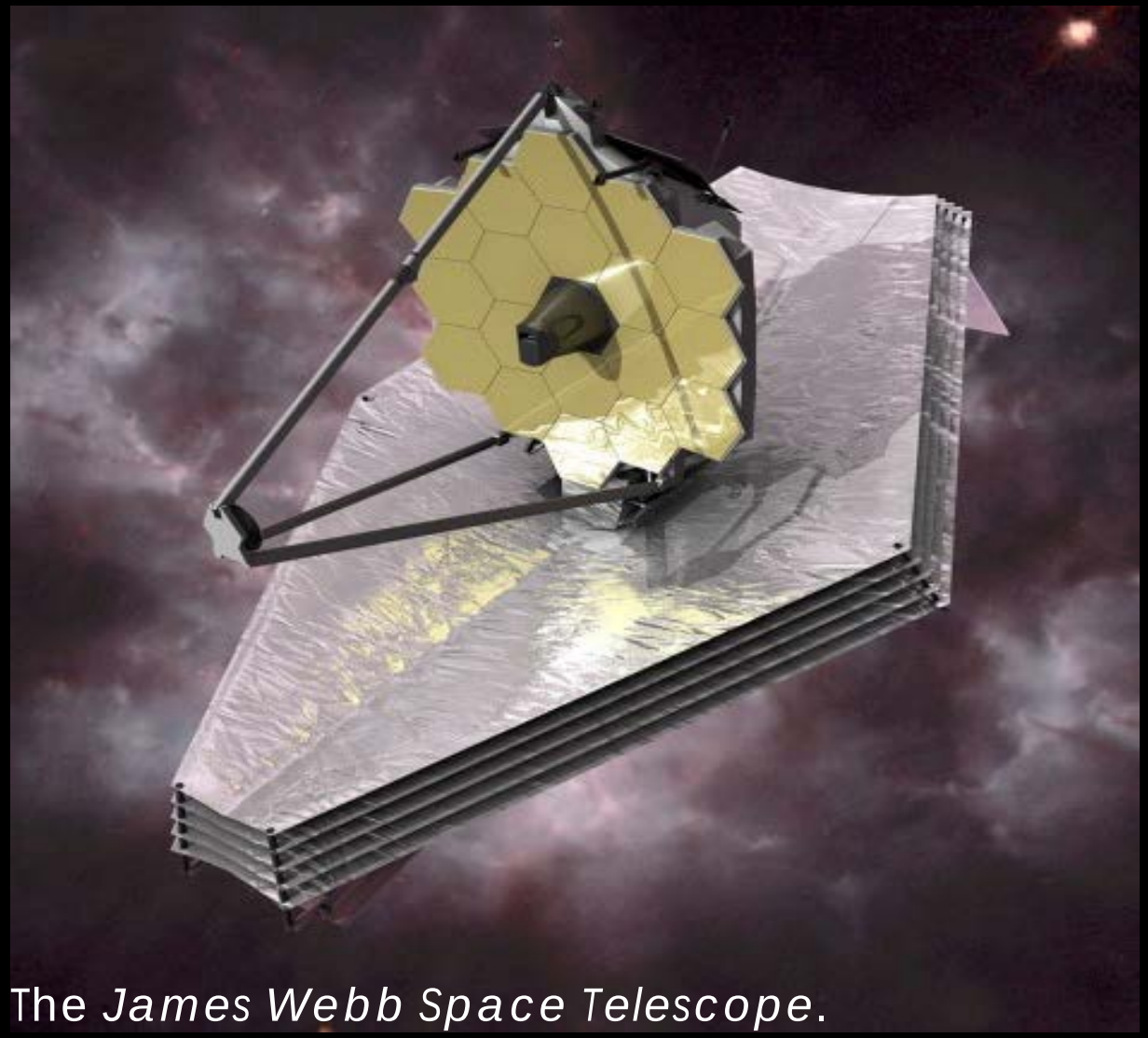

WASP 39 b a “hot Saturn exoplanet” density 0.18 g cm-3
Na
K
H2O
H2O
H2O
H2O
H2O
CO2
CO2
Transit Depth (Rpl/Rs)
Scale Height
Wavelength (μm)
0.152
0.150
0.148
0.146
0.144
0.142
0.3
0.4
0.5
1
1.5
2
3
4
5
WASP 39-b
Wakeford et al. 2018
Credit: Sara Seager

Today we use the Hubble Space Telescope to study hot giant exoplanet atmospheres



Credit: Sara Seager

In the near future we will use the James Webb Space Telescope to push down to small rocky exoplanet atmospheres

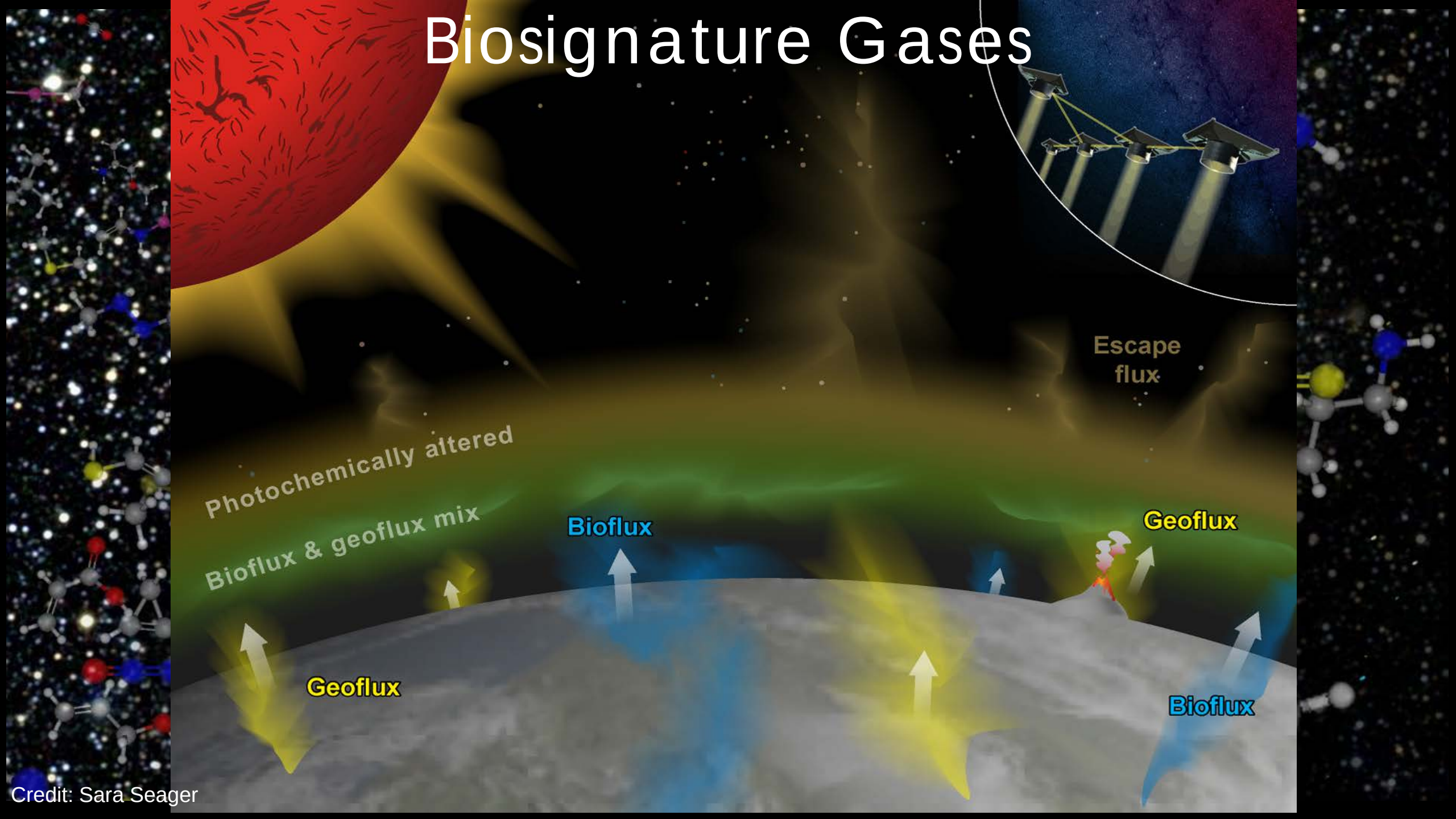


The *James Webb Space Telescope*. Astronomers will study atmospheres of small rocky exoplanets. NASA/ESA/CSA. Prime contractor Northrup Grumman Corporation.

GSFC 4/24/2017
https://jwst.nasa.gov/

Credit: Sara Seager

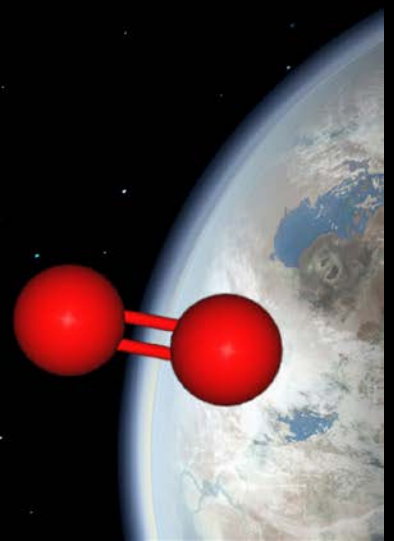
Biosignature Gases



Credit: Sara Seager

Oxygen remains the favored biosignature gas

Oxygen should not be in the atmosphere unless it is continually produced

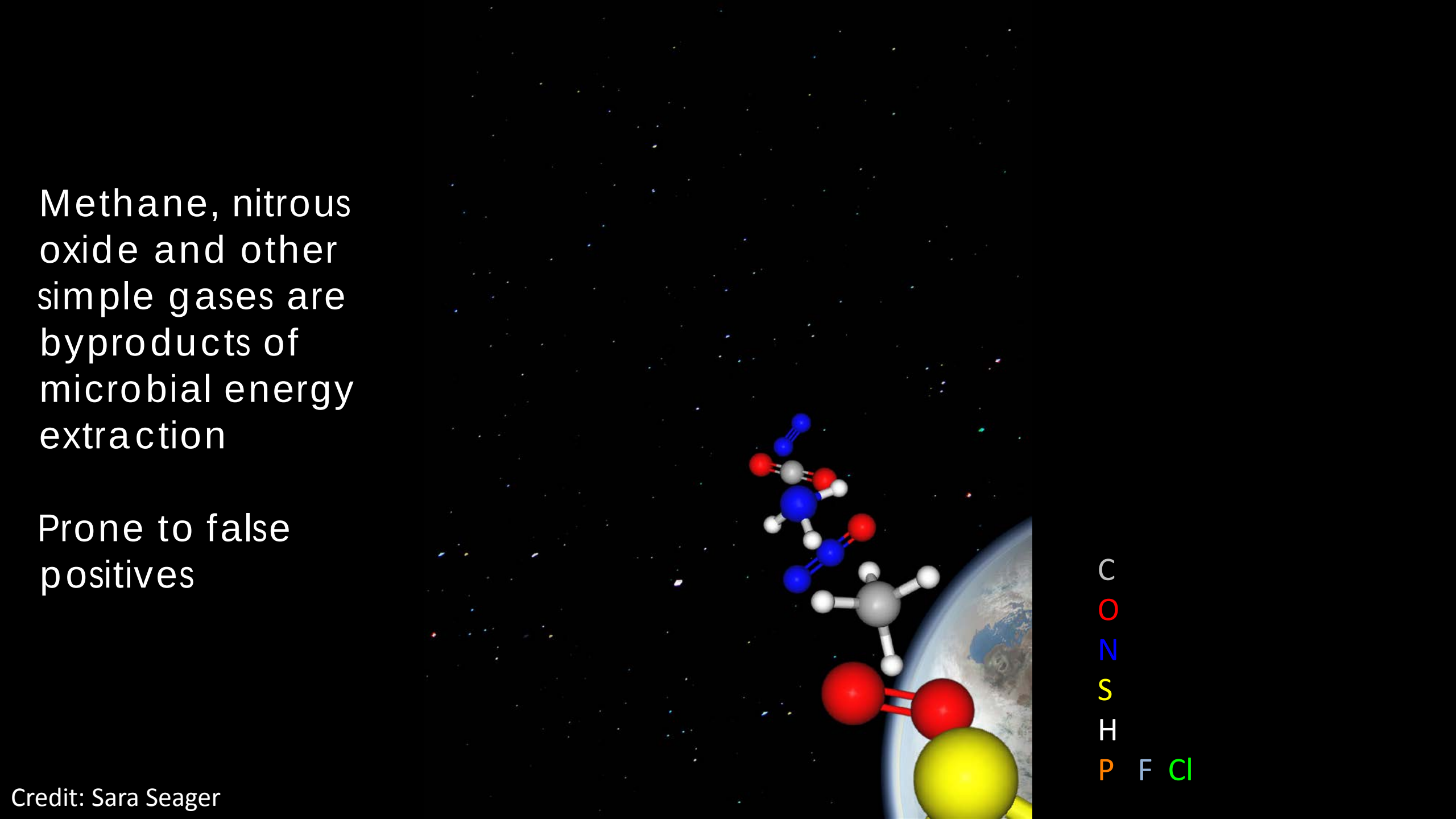


C
O
N
S
H
P F Cl

Credit: Sara Seager

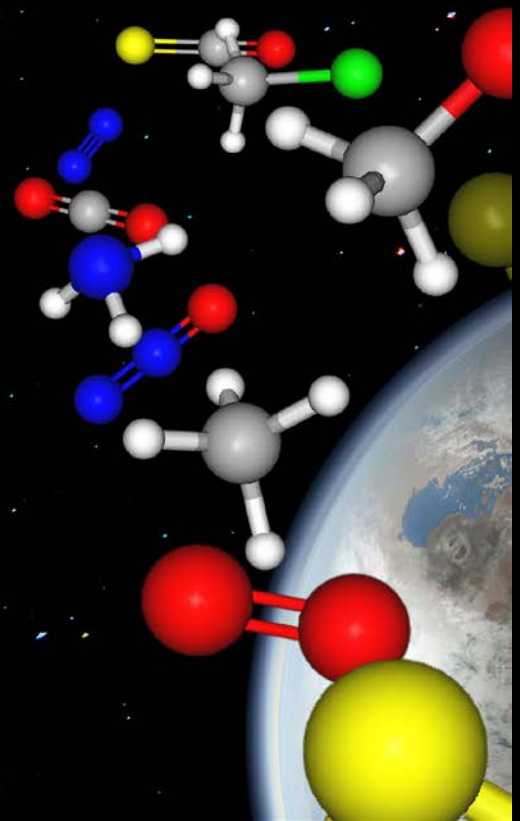
Methane, nitrous oxide and other simple gases are byproducts of microbial energy extraction

Prone to false positives



Credit: Sara Seager

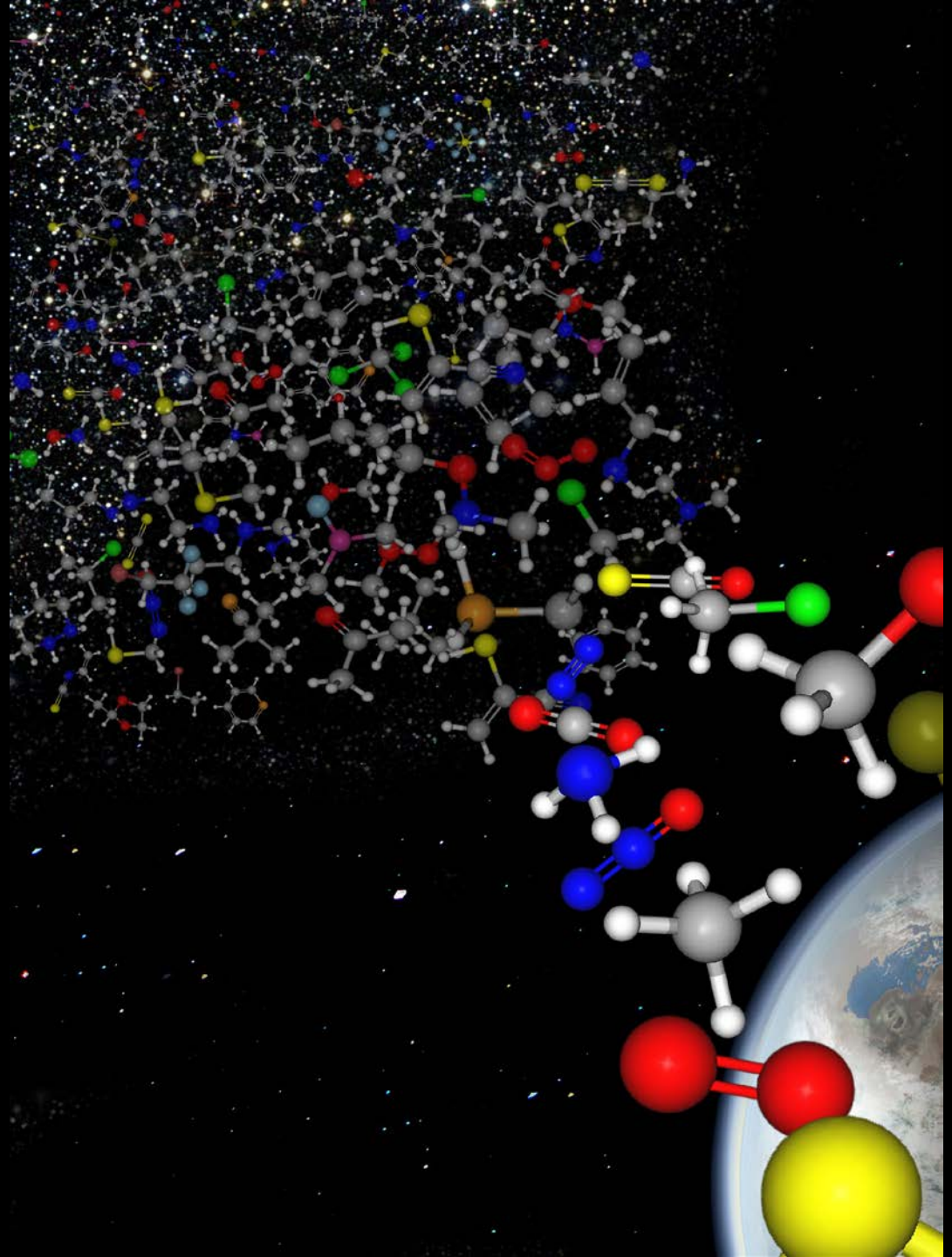
Yet life produces more complex molecules, most for unspecified reasons



C
O
N
S
H
P F Cl

Credit: Sara Seager

Life on Earth produces thousands of molecules albeit in tiny quantities



C
O
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S
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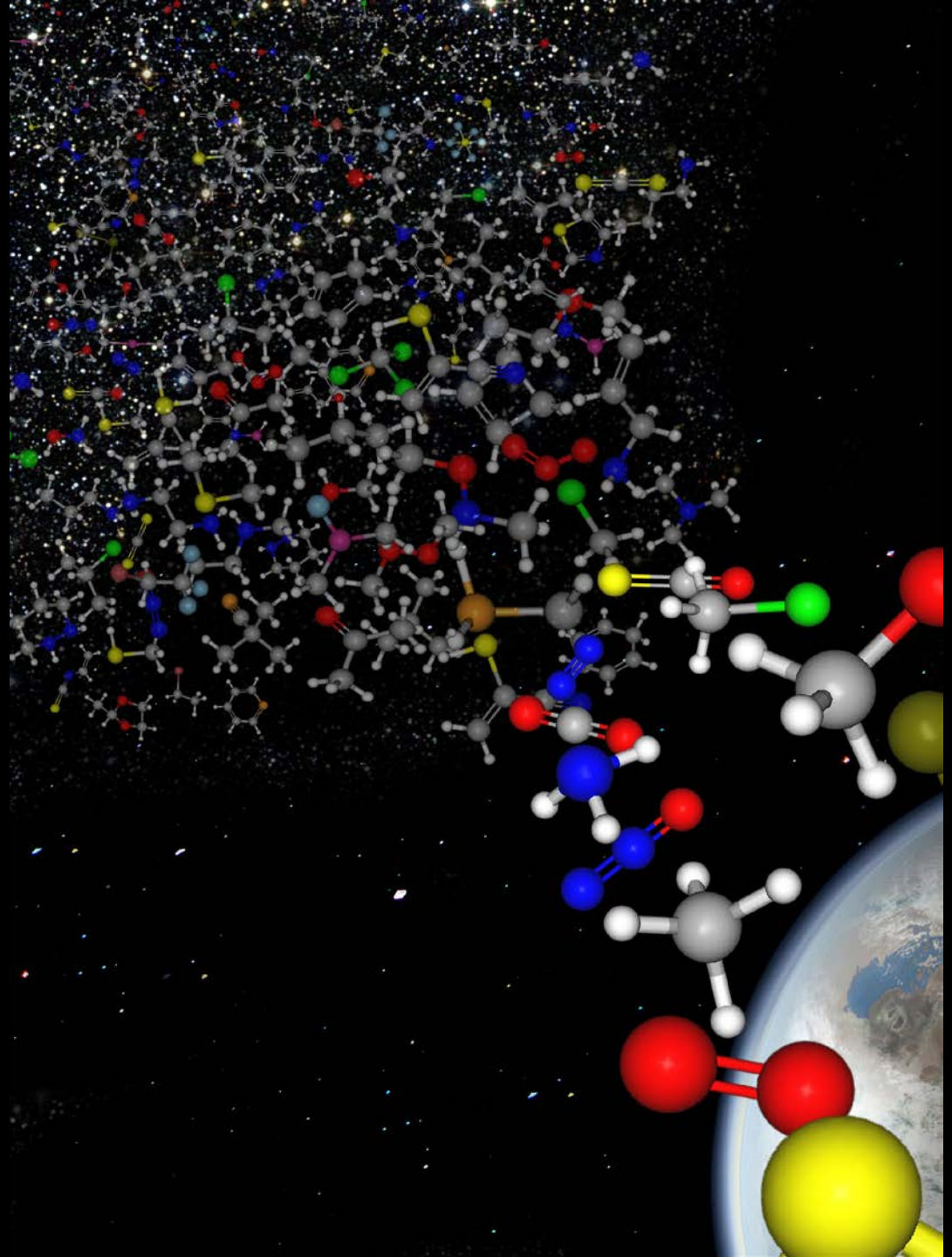
P F Cl

Credit: Sara Seager

Life on Earth produces thousands of molecules albeit in tiny quantities

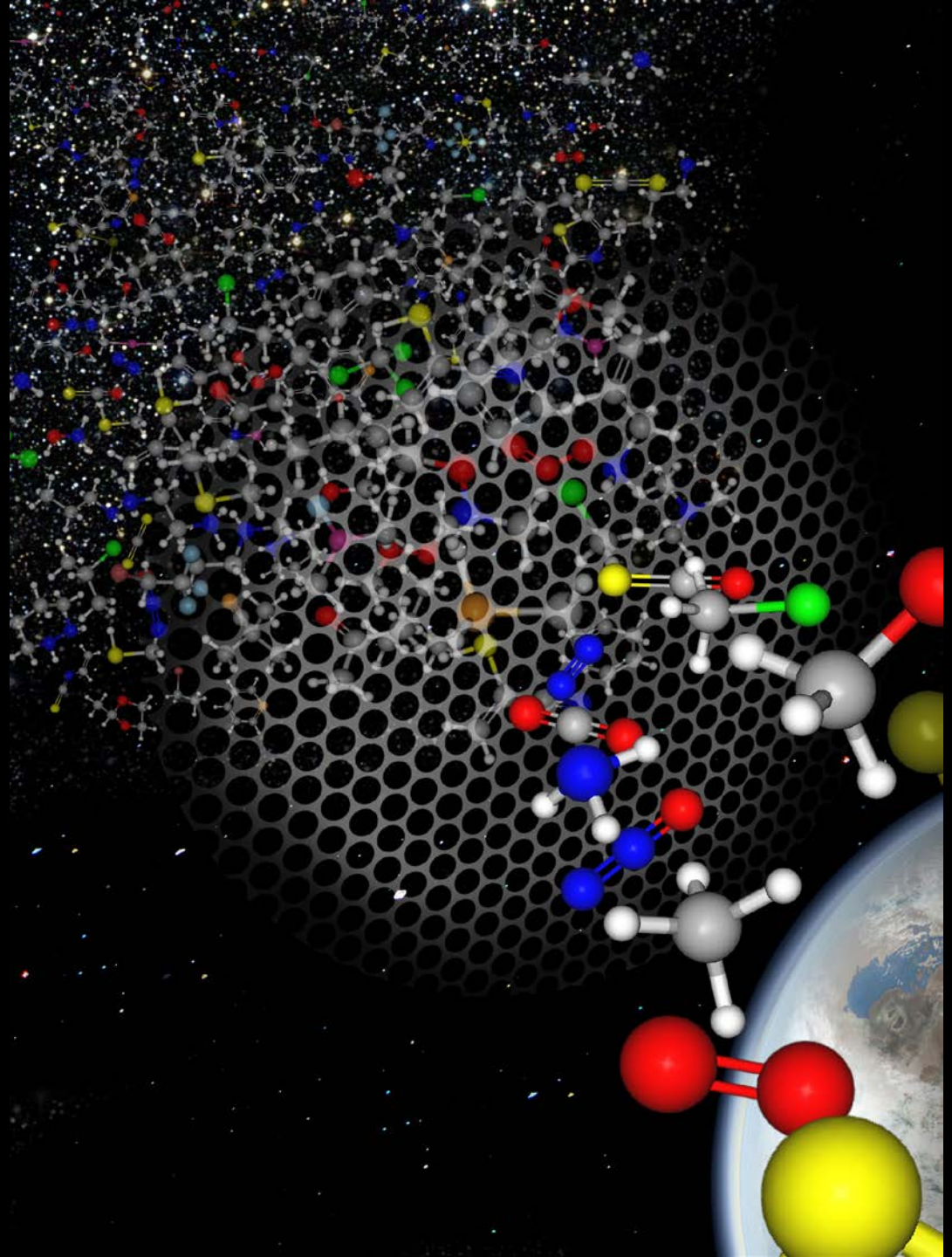
C
O
N
S
H
P F Cl



The biosignature gases may be very different on other worlds.

Credit: Sara Seager

Create algorithms to assess their biosignature potential…



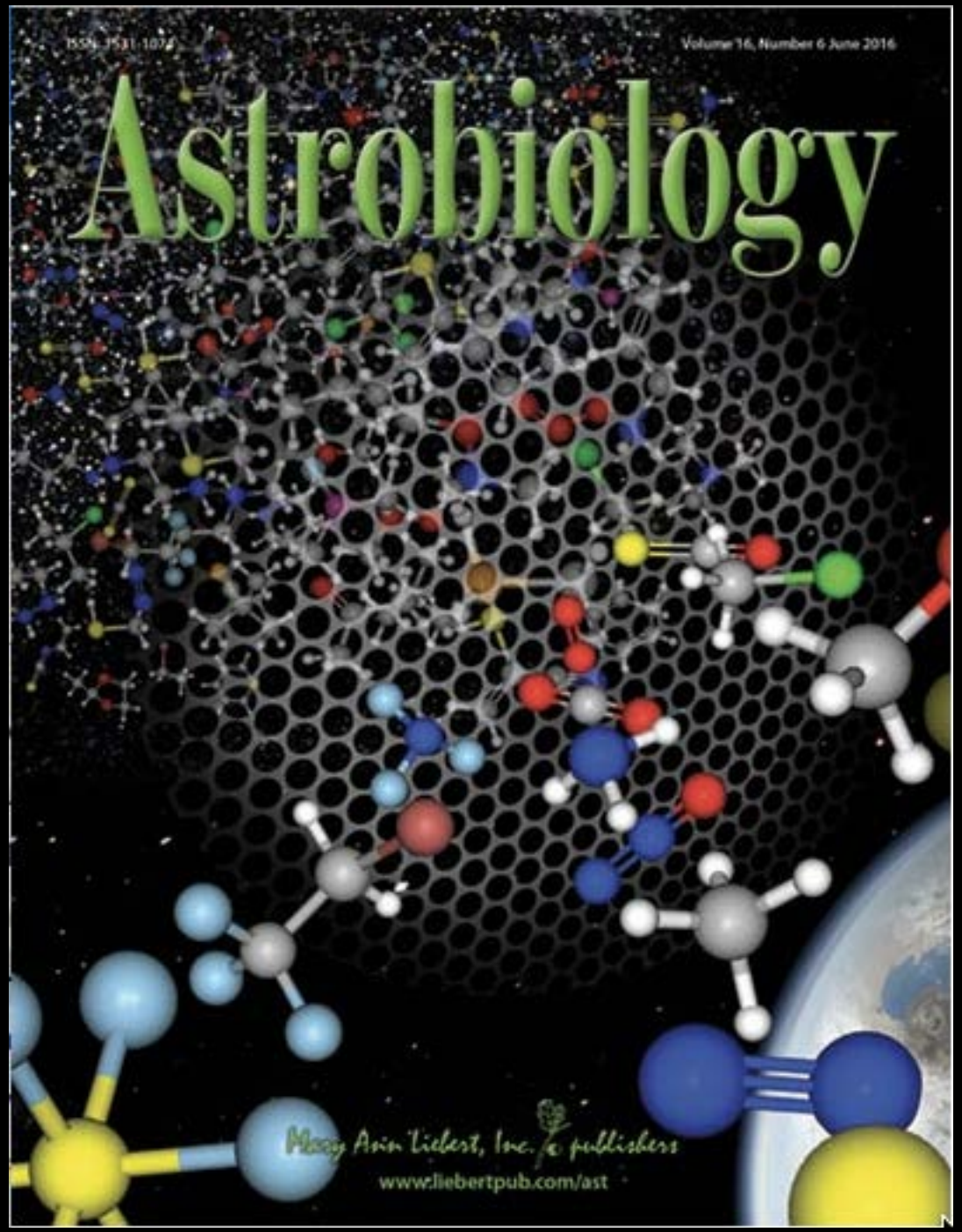
C
O
N
S
H
P F Cl

Seager, Bains, Petkowski
Astrobiology 2016

Credit: Sara Seager

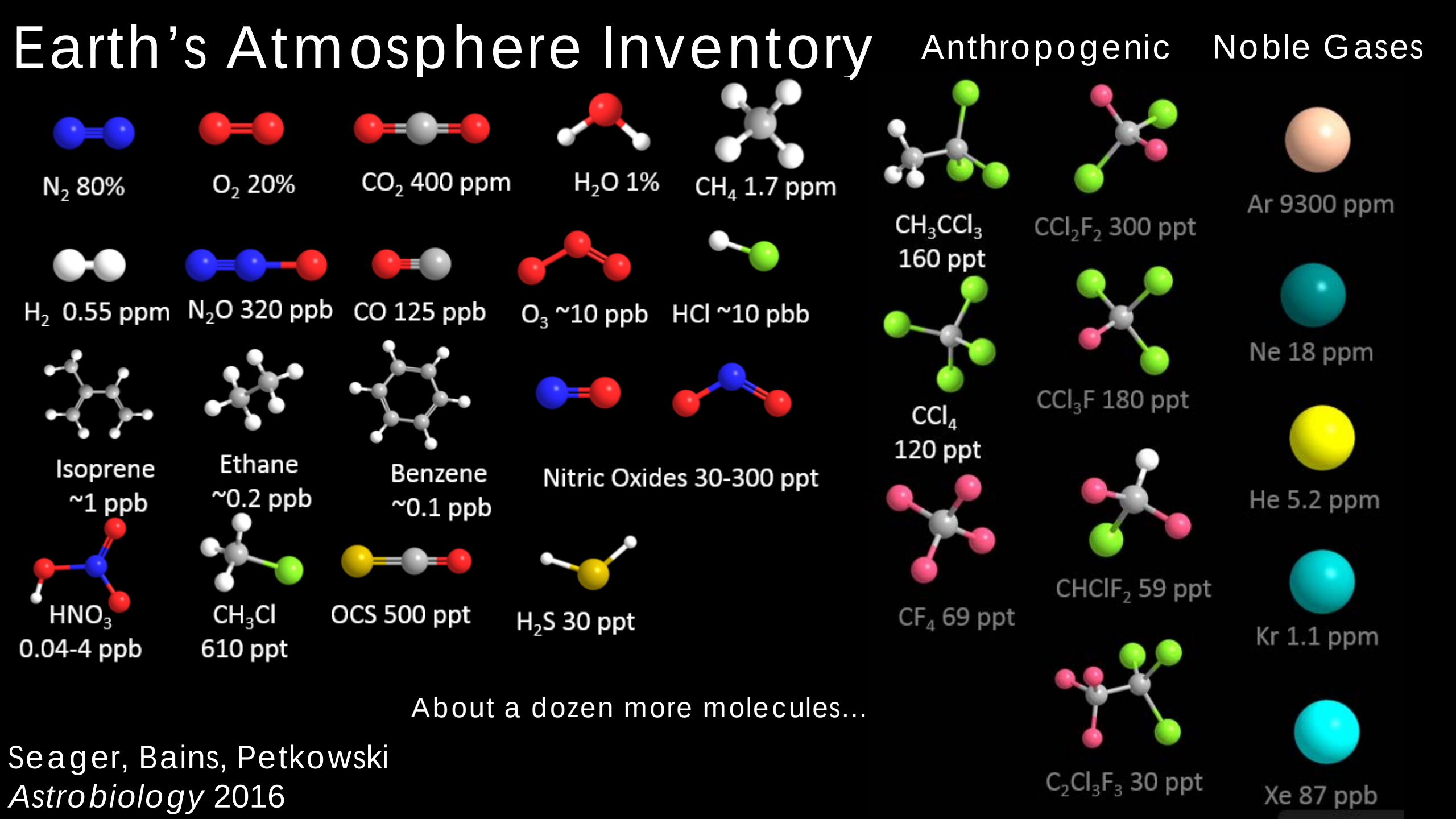
...so that we can be prepared to search for and identify biosignature gases of any kind

Seager, Bains, Petkowski, June 2016
Figure: J. Petkowska



Credit: Sara Seager

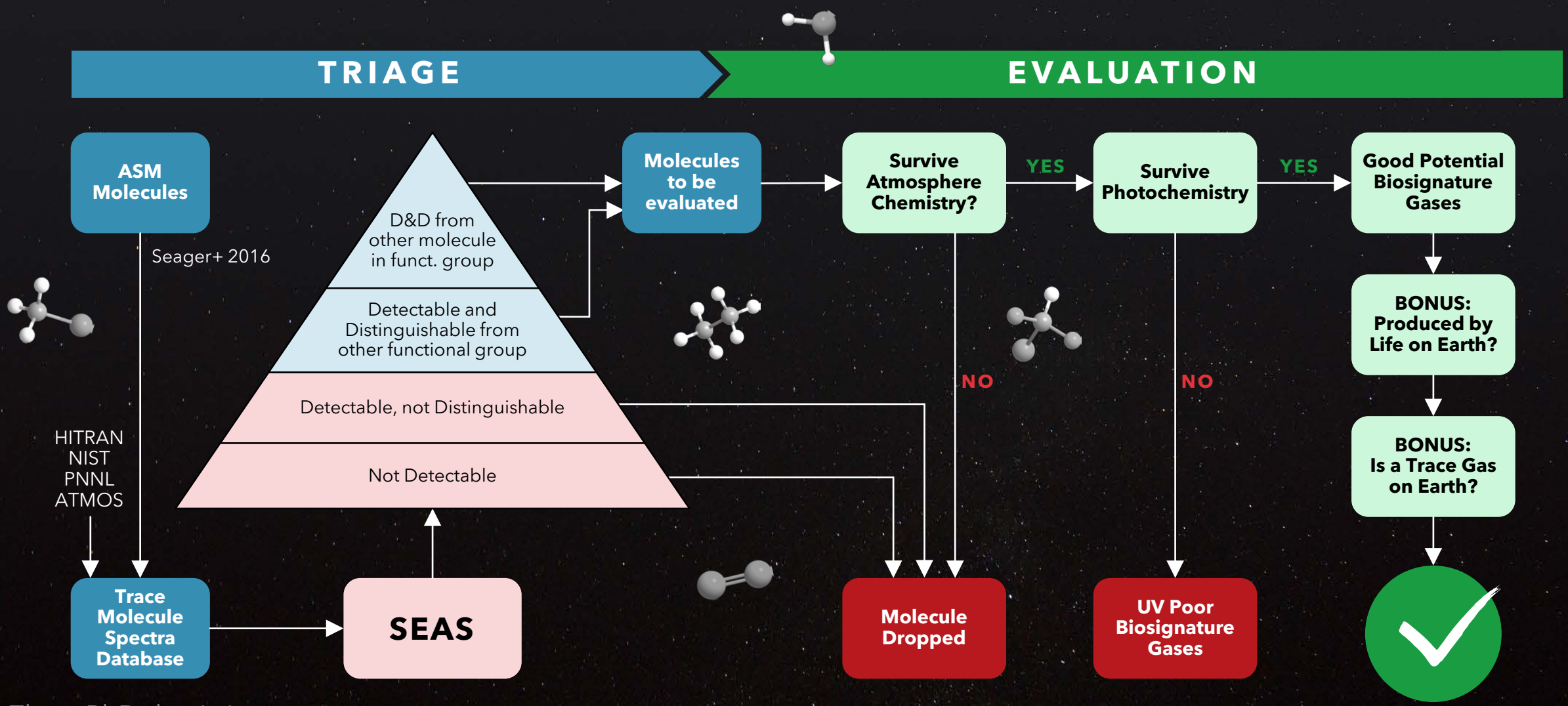
Earth's Atmosphere Inventory



About a dozen more molecules...

Seager, Bains, Petkowski
Astrobiology 2016

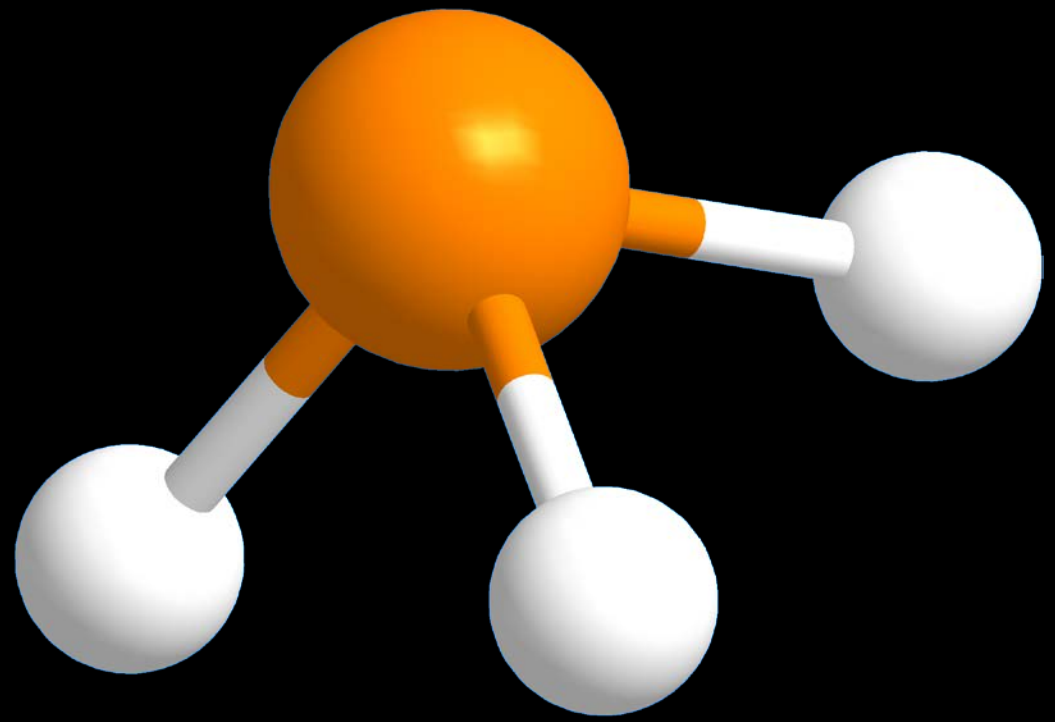
Assessment of Biosignature Potential of Volatile Gases



Zhan, PhD thesis in prep.

Credit: Sara Seager

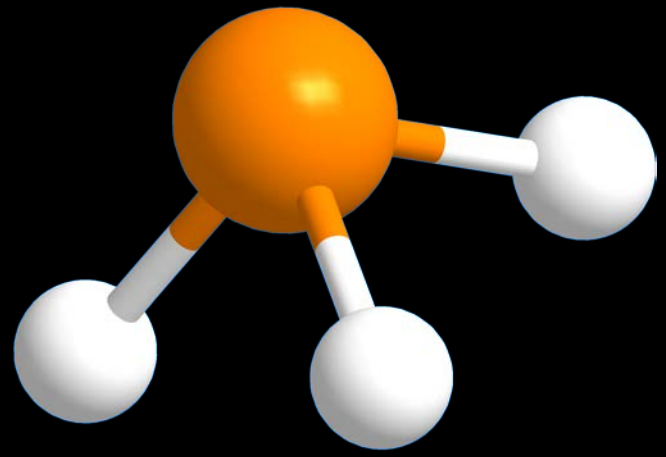
Assessment of Biosignature Potential of Volatile Gases



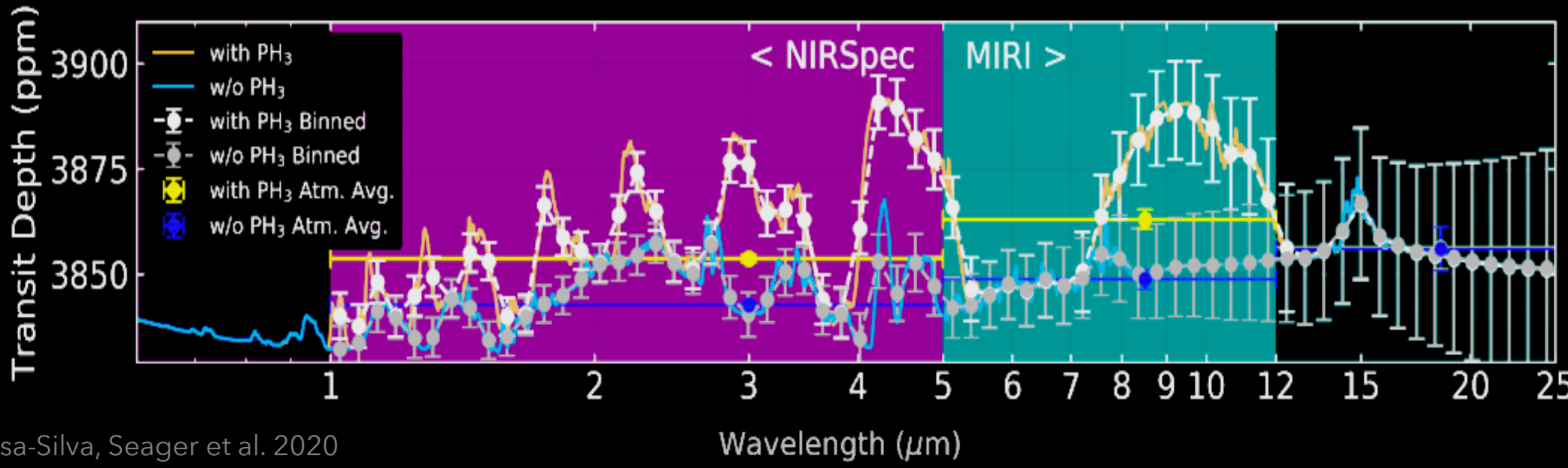
Sousa-Silva, (…), **Petkowski** et al, *Astrobiology*, 2020

What is Phosphine?

- Phosphine is the simplest gas containing phosphorus – with a molecular formula of PH_3
- Phosphine is common on giant planets like Jupiter and Saturn (made in deep layers of the atmosphere)
- On Earth phosphine is a biosignature (or technosignature) that is exclusively associated with anaerobic (oxygen-fee) life
- Phosphine is extremely toxic to O_2-dependent life



Simulated Atmospheric Spectra with Phosphine



PH_3 has strong distinguishable spectral features

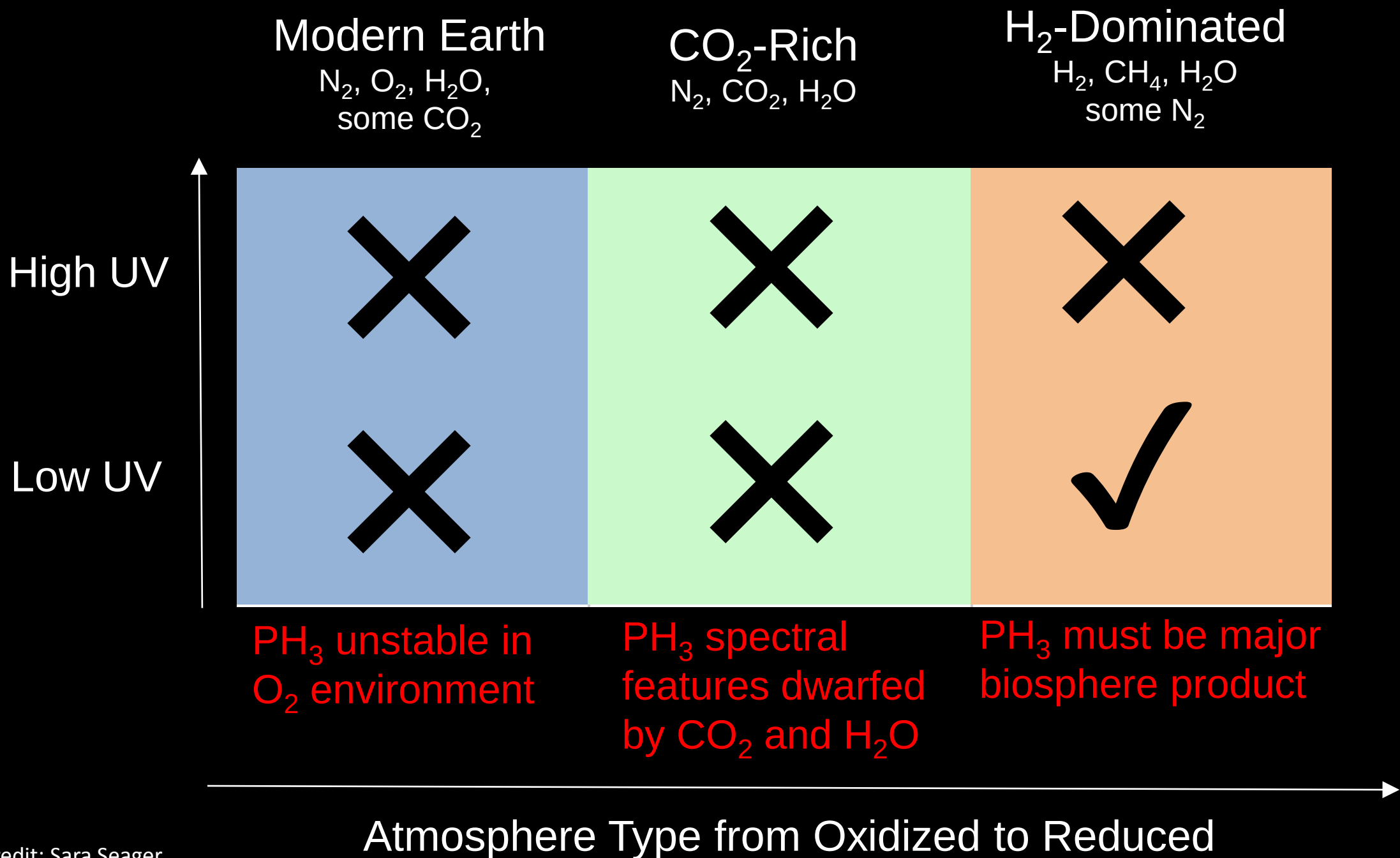
Sousa-Silva, Seager et al. 2020

Theoretical transmission spectrum for a 10 M_{Earth} 1.75 R_{Earth} planet with a 1 bar atmosphere composed of 90% H_2 and 10% N_2

PH_3 can accumulate in an anoxic atmosphere → PH_3 has no known false positives → Unfortunately, huge production rates are required on order 10^{12} cm^{-2} s^{-1} for a planet orbiting an M star host

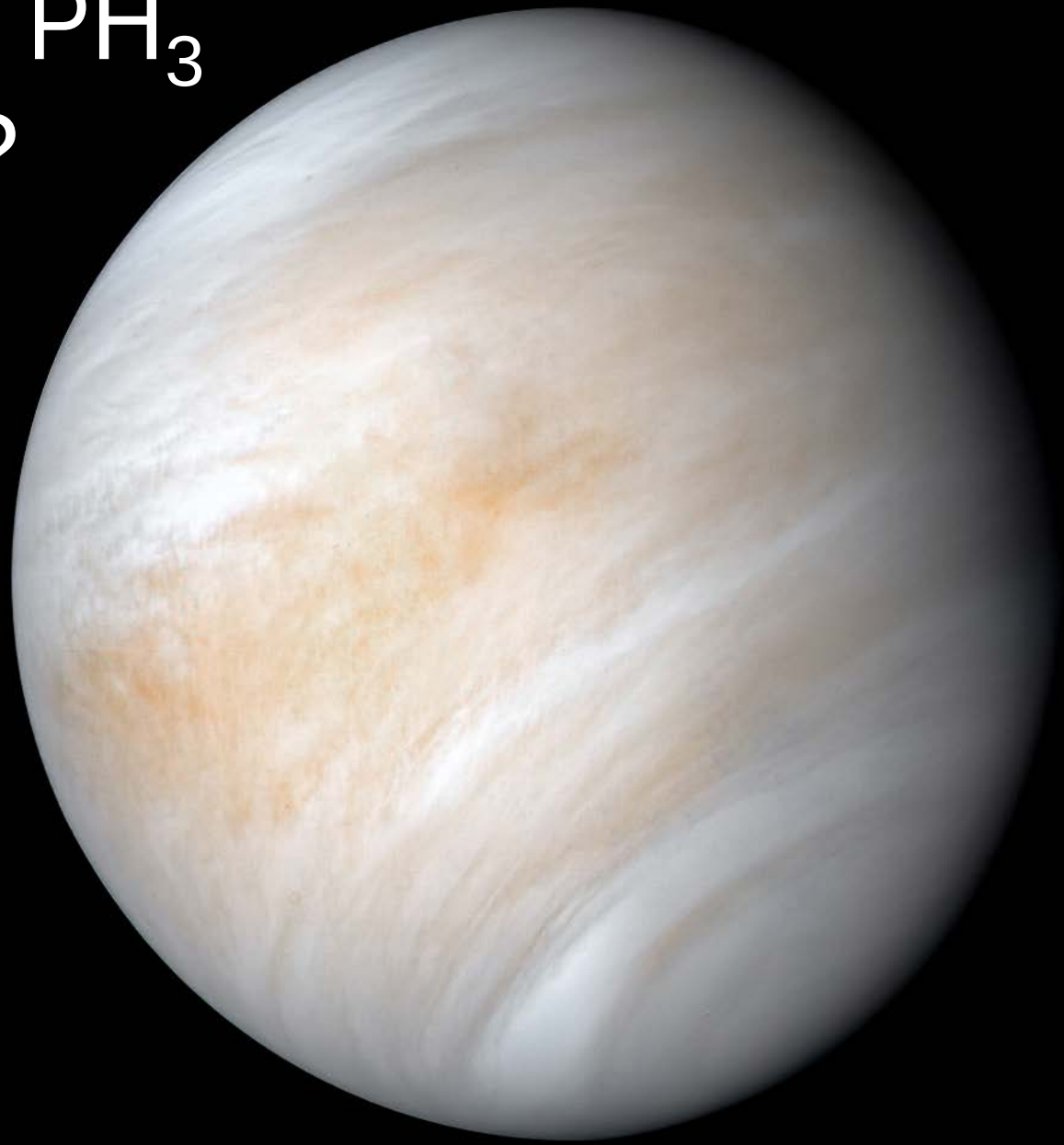
Ranjan et al., in prep.

Credit: Sara Seager



Credit: Sara Seager

What if we looked for PH_3 much closer to Earth?



Credit: JAXA/AKATSUKI

What if we looked for PH_3 much closer to Earth?

Venus Atmosphere Basic Facts

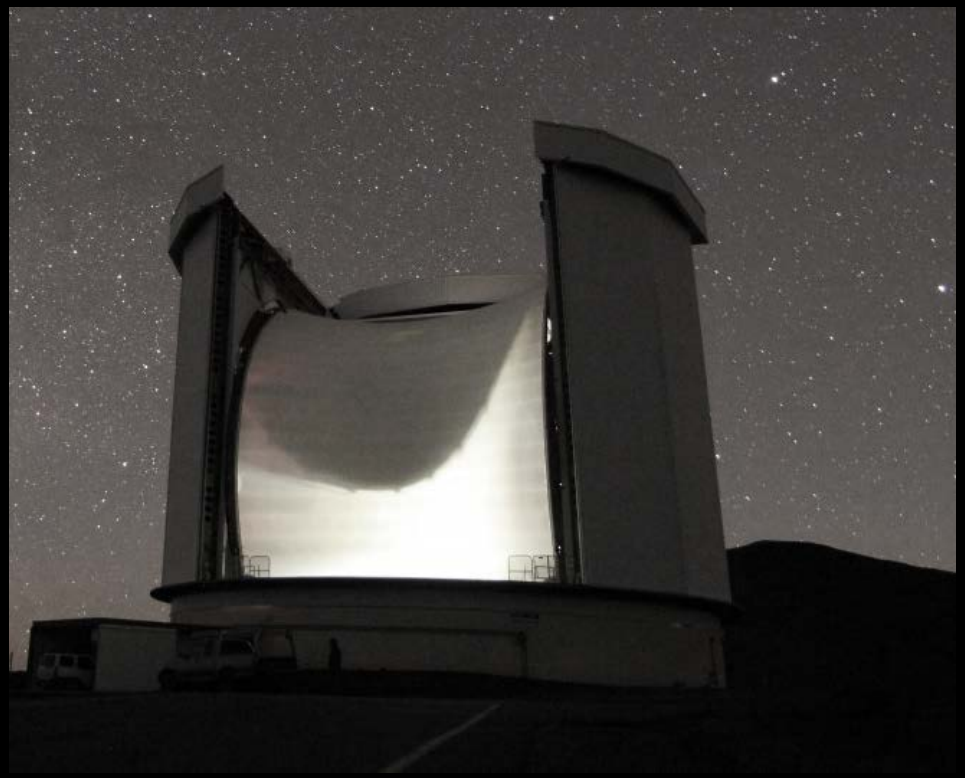
Main Venus atmosphere composition	CO_2 - 96.5%; N2 - 3.5%
Temperate cloud deck - altitude range (km)	48-60 km
Temperate cloud deck - temp. range (C)	80°C (at 48 km) - 0°C (at 60 km)
Temperate cloud deck - pressure range (bar)	2 (at 48 km) - 0.4 (at 60 km)
Hydrogen depletion (ratio of D to H)	The ratio is ~100 times higher than elsewhere in the Solar System - i.e. Venus is very H-depleted.

Venus Basic Facts

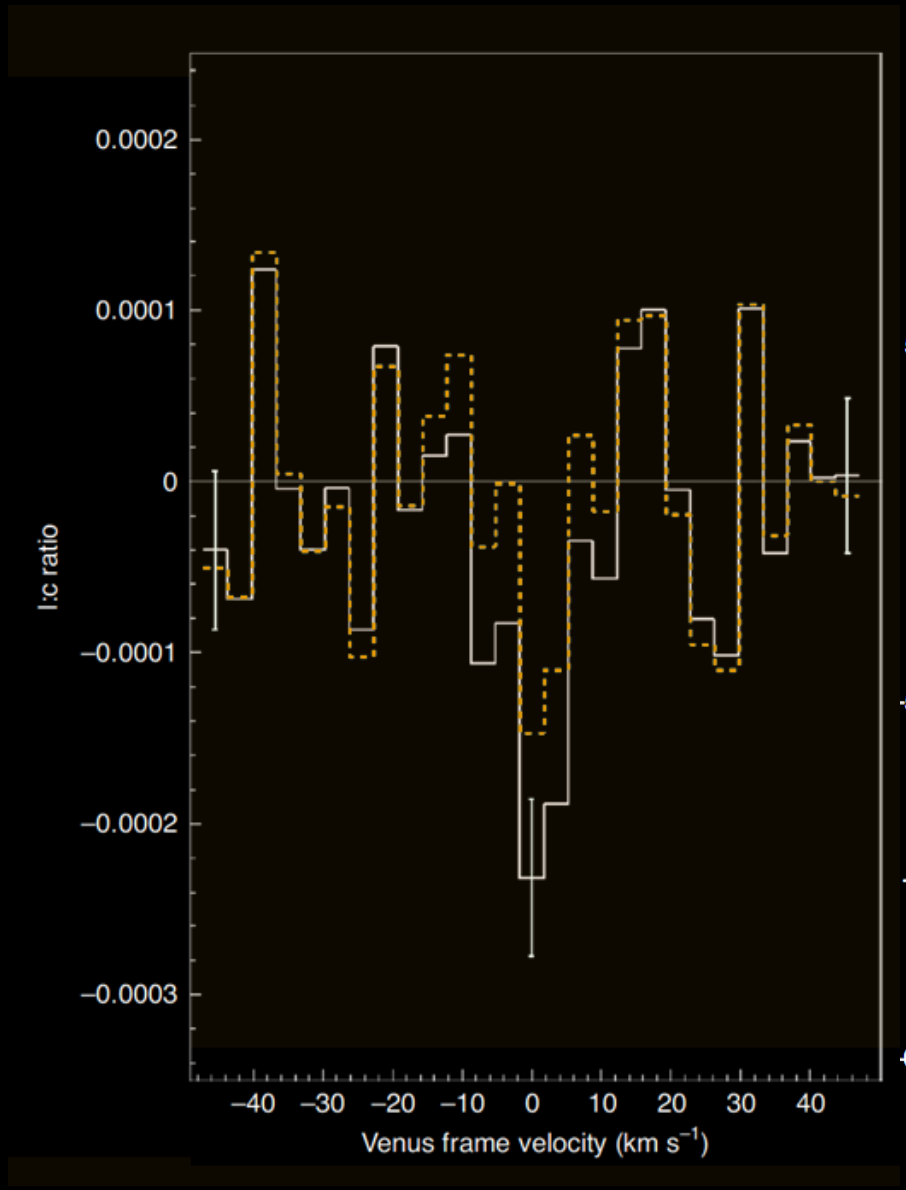
Mass	0.82 Earths
Radius	0.95 Earths
Surface gravity	0.9g
Distance from the Sun (km)	108 million (152 million for Earth)
Spacecraft travel time (months)	3-4
Year length (days)	225
Day length (one rotation on its axis)	243 Earth days (in the opposite direction)
Temperature on the surface (C/F)	465/900 (hottest planet in the Solar System)
Surface pressure (bar)	92
Wind speeds (km/h)	400
Atmospheric superrotation (days)	4 Earth days

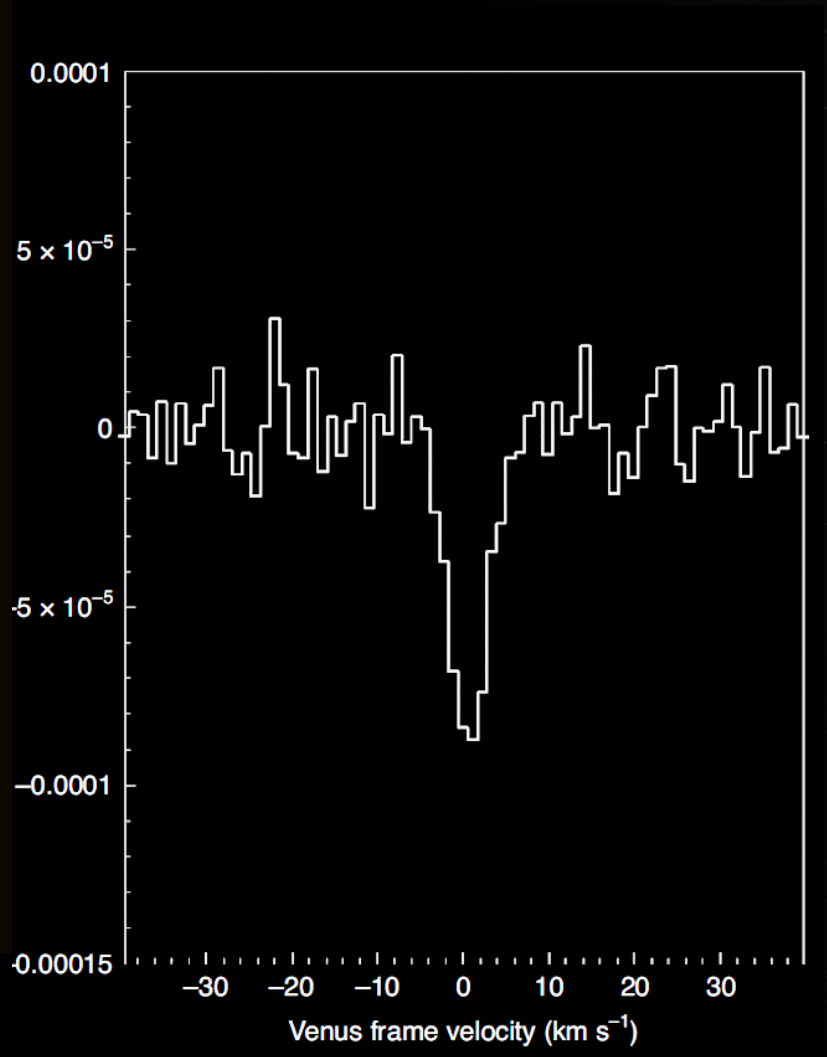
Credit: JAXA/AKATSUKI

JCMT and ALMA Observations of PH_3 on Venus



Phosphine on Venus



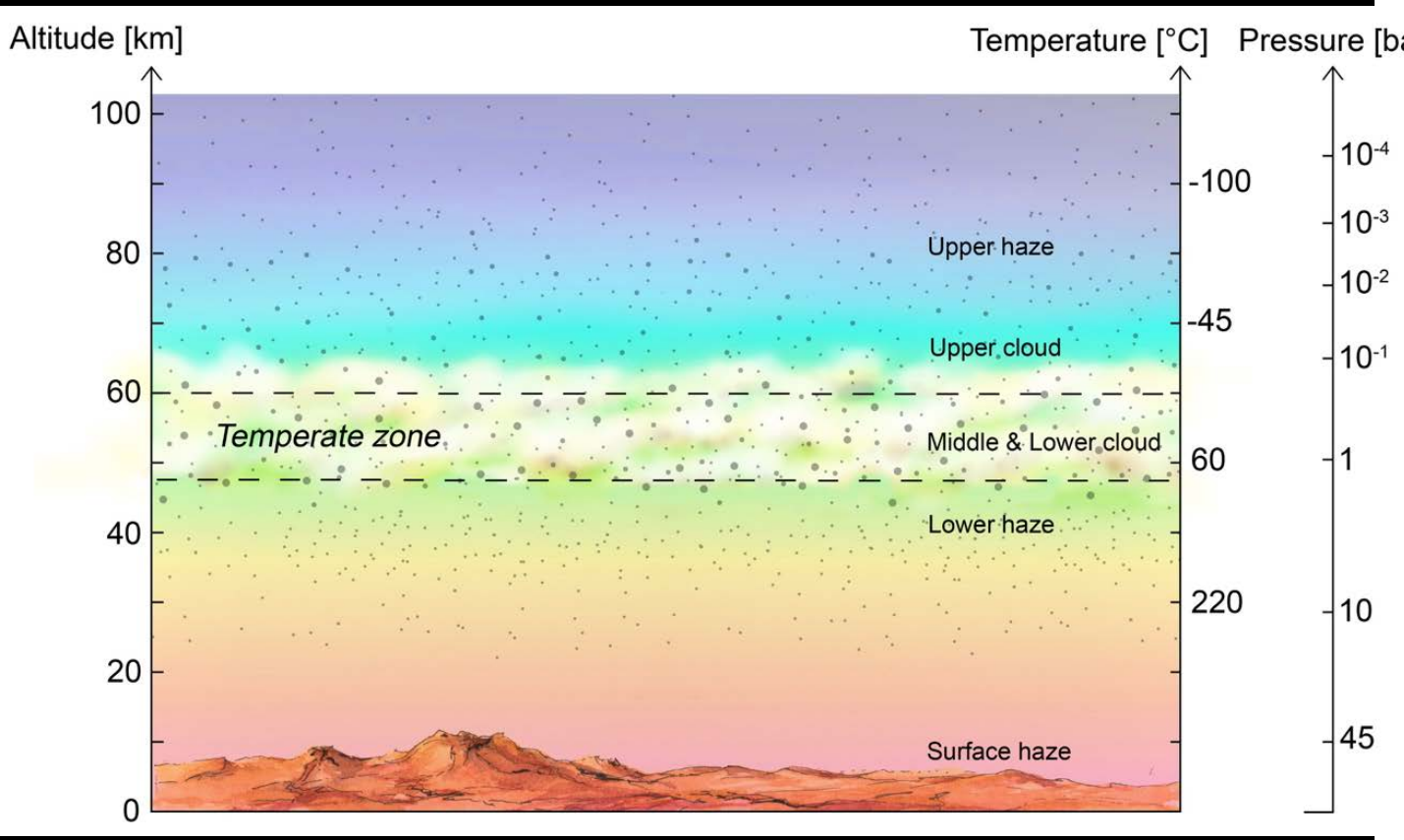


Thermal emission from Venus, with an absorption line

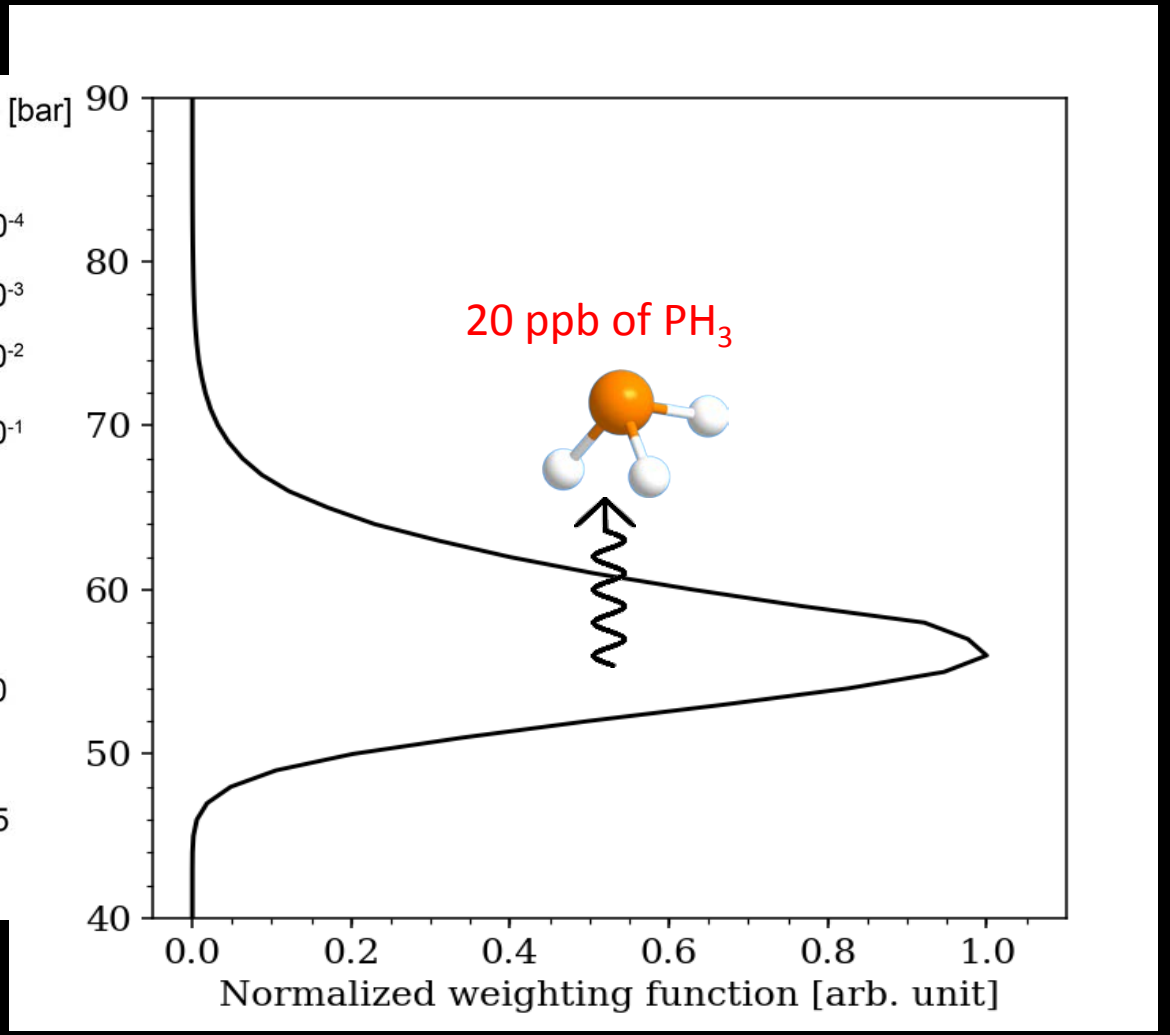
JCMT and ALMA data of the PH_3 1–0 rotational transition at 1.123 mm wavelength.

Credit: Greaves et al 2020

Distribution of PH_3 in the atmosphere of Venus

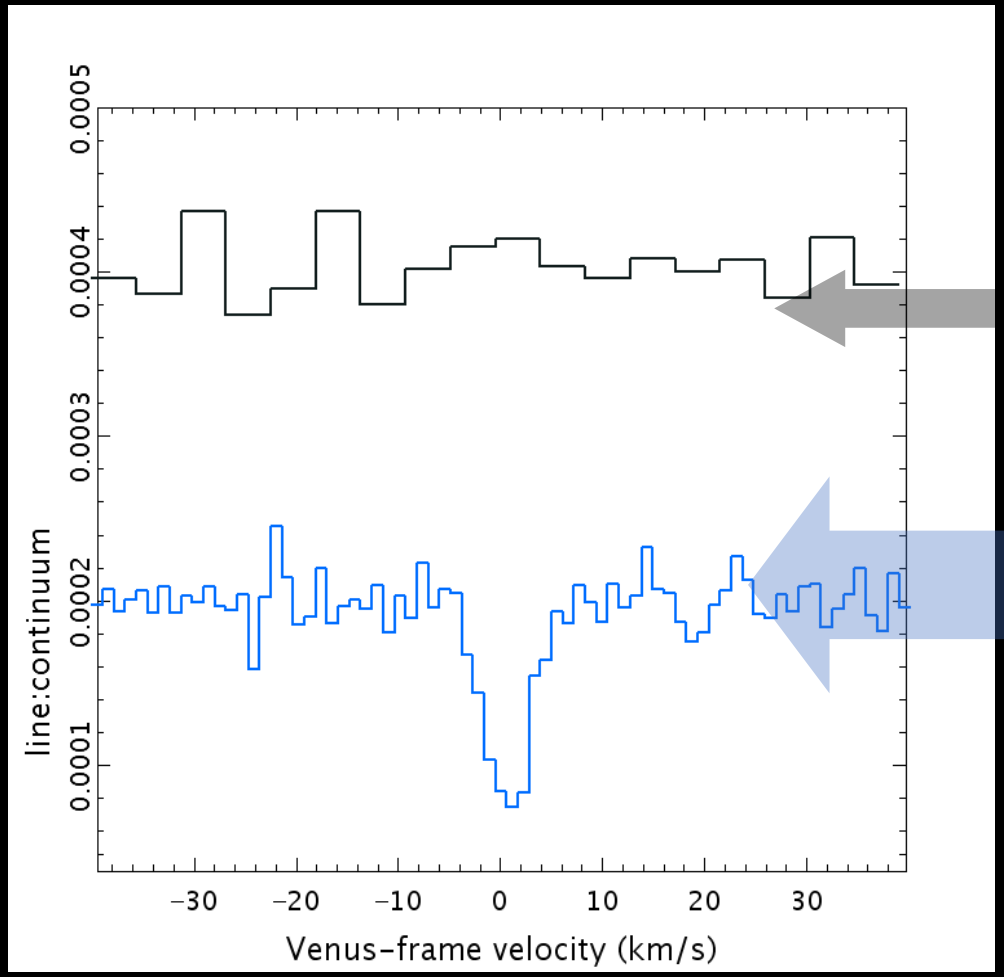


Bains et al 2020



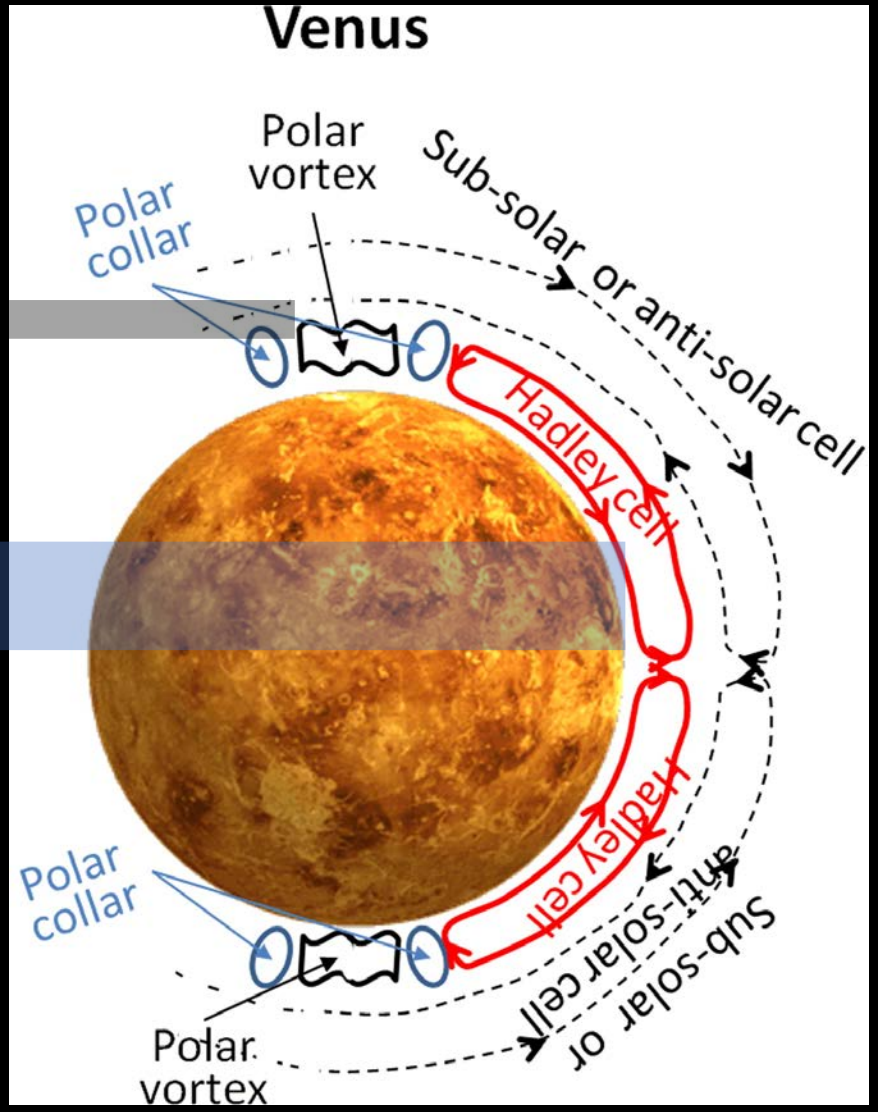
Greaves et al 2020

Distribution of PH_3 in the atmosphere of Venus



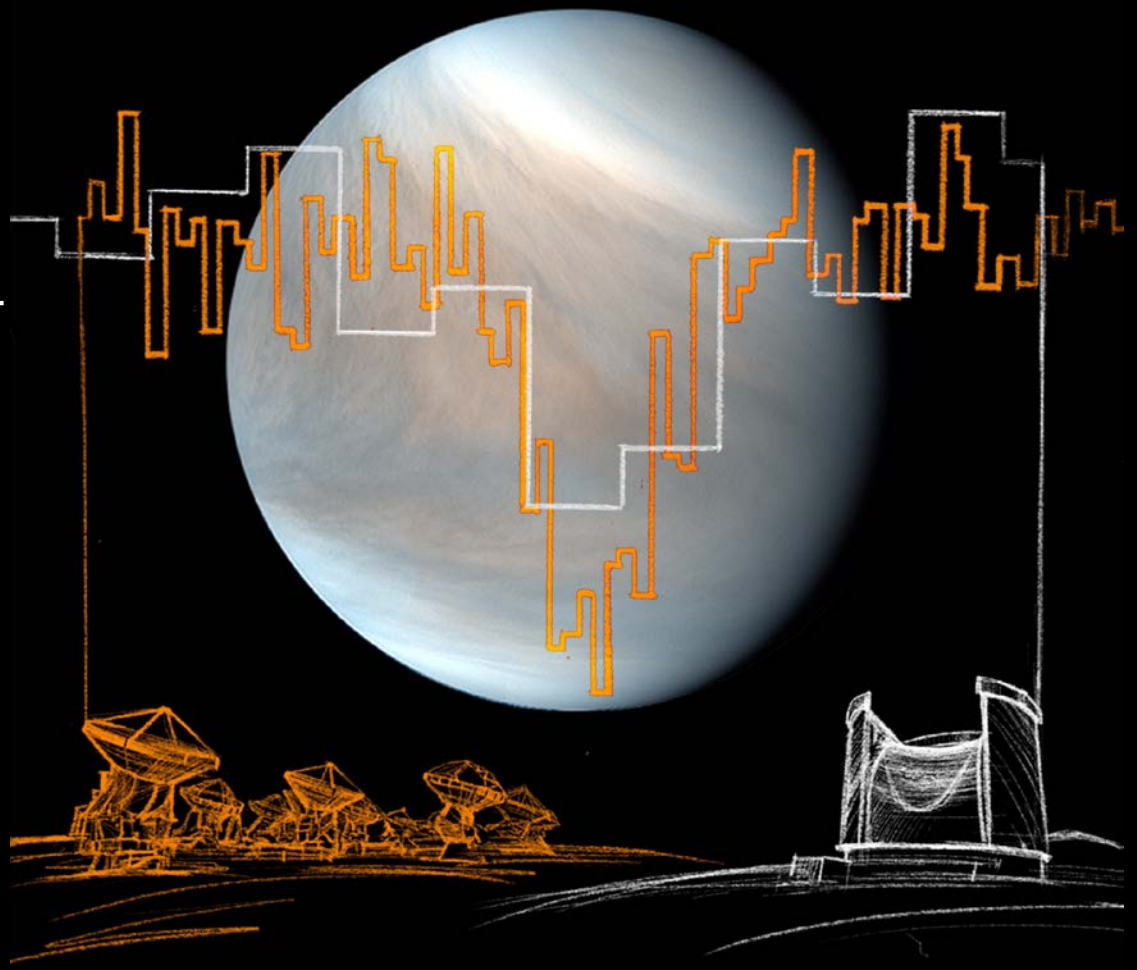
ALMA spectra of different latitude-bands on Venus

Greaves et al 2020



Is the detection real?

- Phosphine line absorption has been seen, at comparable line depth, with two independent facilities – JCMT and ALMA
- Phosphine line measurements are consistent under varied and independent processing methods
- Overlap of spectra from the two facilities (JCMT and ALMA) shows no other such consistent negative features
- There is no other known reasonable candidate transition for the absorption other than phosphine



Credit: JAXA/AKATSUKI

Credit: Joanna Petkowska

Is the detection real?

Astronomy & Astrophysics manuscript no. venus-ph3-v12
October 16, 2020

LETTER TO THE EDITOR

A stringent upper limit of the PH_3 abundance at the cloud top of Venus

T. Encrenaz[1], T. K. Greathouse[2], E. Marcq[3], T. Widemann[1], B. Bézard[1], T. Fouchet[1], R. Giles[2], H. Sagawa[4], J. Greaves[5], and C. Sousa-Silva[6]

Astronomy & Astrophysics manuscript no. alma_venus
October 19, 2020

Re-analysis of the 267-GHz ALMA observations of Venus

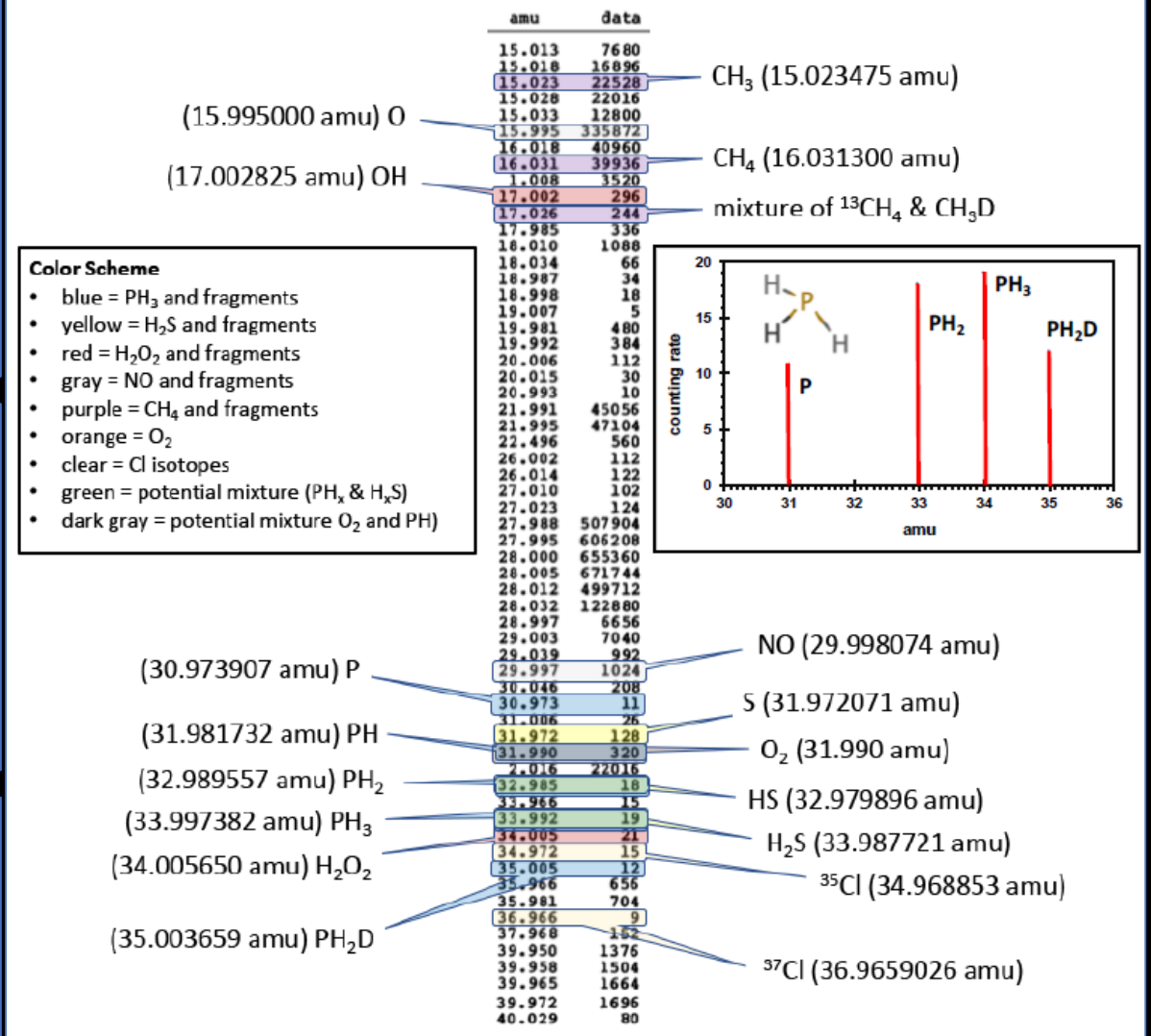
No statistically significant detection of phosphine⋆

I.A.G. Snellen[1] L. Guzman-Ramirez[1] M.R. Hogerheijde[1,2] A.P.S. Hygate[1] F.F.S. van der Tak[3,4]

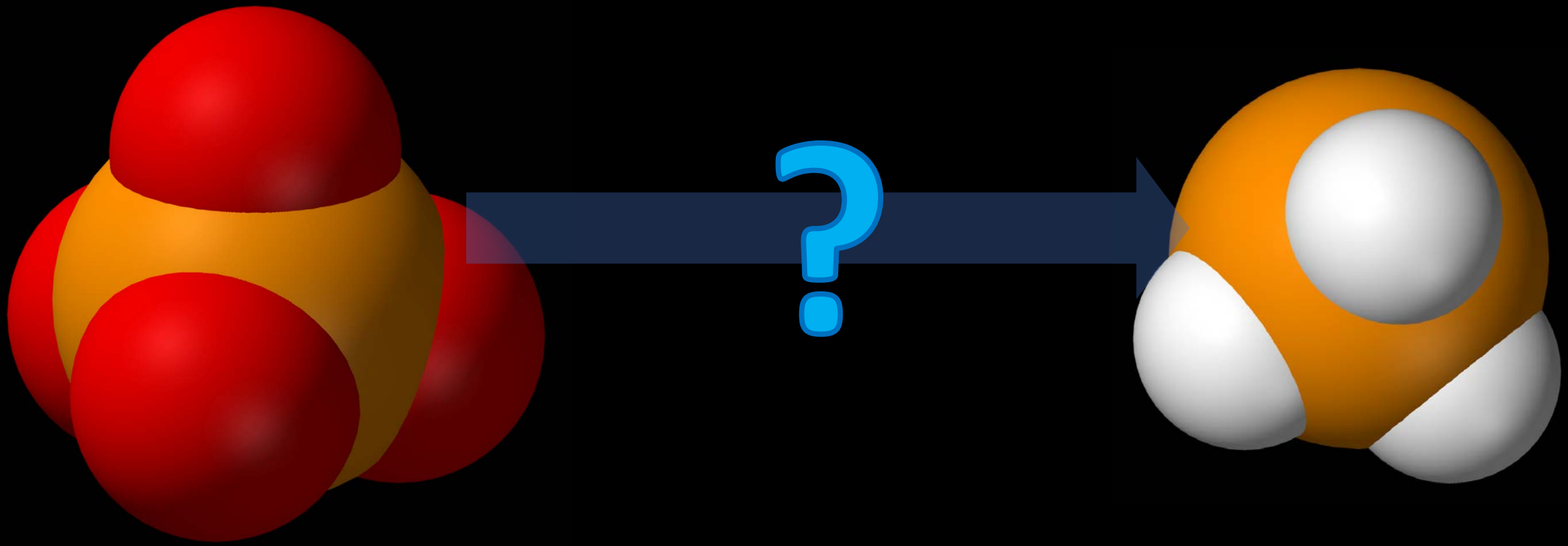
Matters Arising *(Submitted to Nature, Matters Arising, 9/22/2020)*

Is Phosphine in the Mass Spectra from Venus' Clouds?

Rakesh Mogul[1*]; Sanjay S. Limaye[2]; M. J. Way[3,4]; Jaime A. Cordova Jr.[5]



What Process Makes PH_3 on Venus?



PH_3 on Jupiter and Saturn

Credit: Wikipedia

What Process Makes PH_3 on Venus?

- Not abiotically?

Submitted to Astrobiology - Special Collection: Venus

Phosphine on Venus Cannot be Explained by Conventional Processes

William Bains[1, #,], Janusz J. Petkowski[1, #,*], Sara Seager[1,2,3], Sukrit Ranjan[1a], Clara Sousa-Silva[1,2], Paul B. Rimmer[4], Zhuchang Zhan[1], Jane S. Greaves[5], Anita M. S. Richards[6]*

Chem
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thermodynamics.
Reaction between
all atmospheric gas
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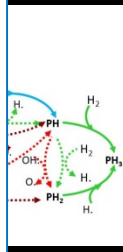
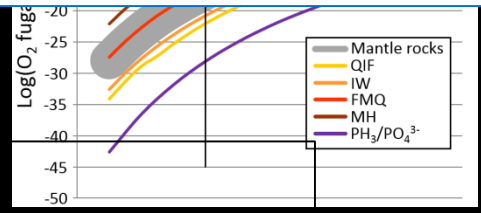


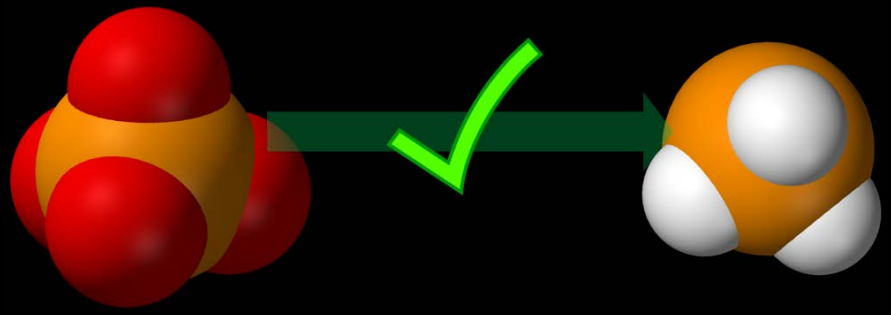


Chemical processes
calculated from rock chemistry

What Process Makes PH_3 on Venus?

- Not abiotically?
- … but not biologically either?

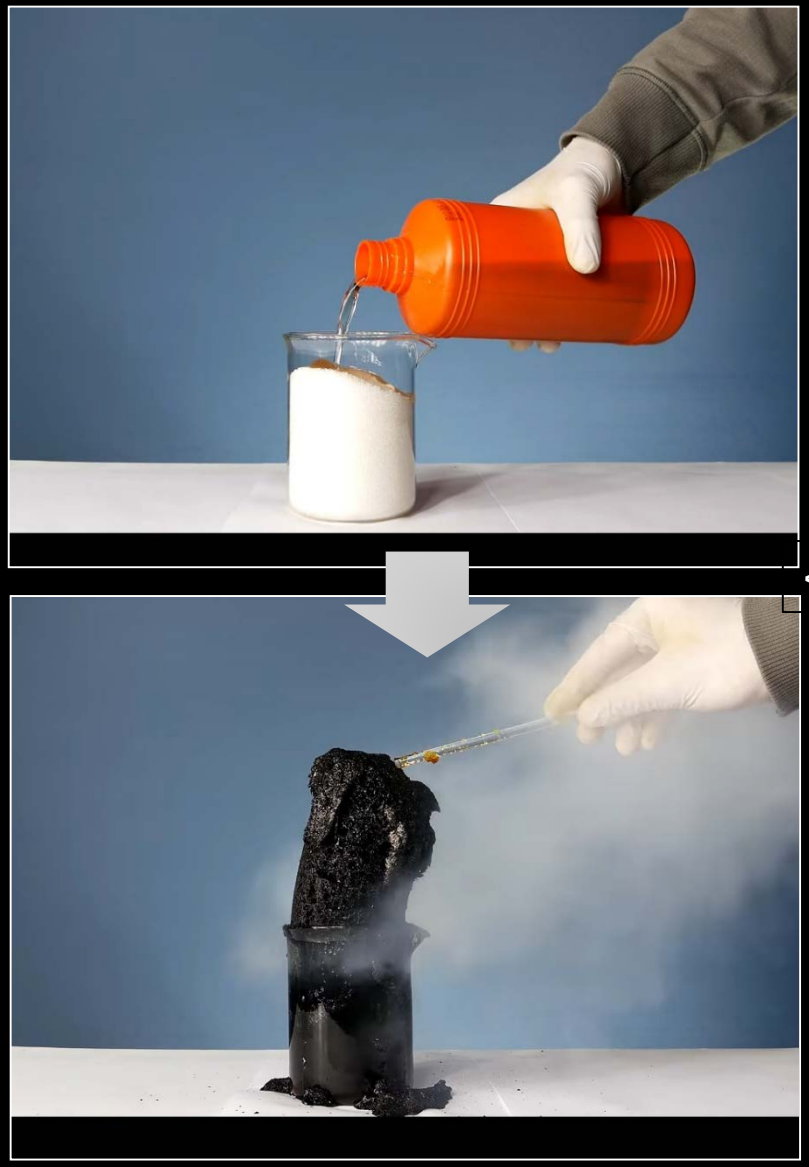
Thermodynamically *possible…*



But physically … ??

80 – 100% Sulfuric acid

- 1000s of times as acid as battery acid
- 100 times drier than the driest place on Earth
- *Smashes* up biological molecules

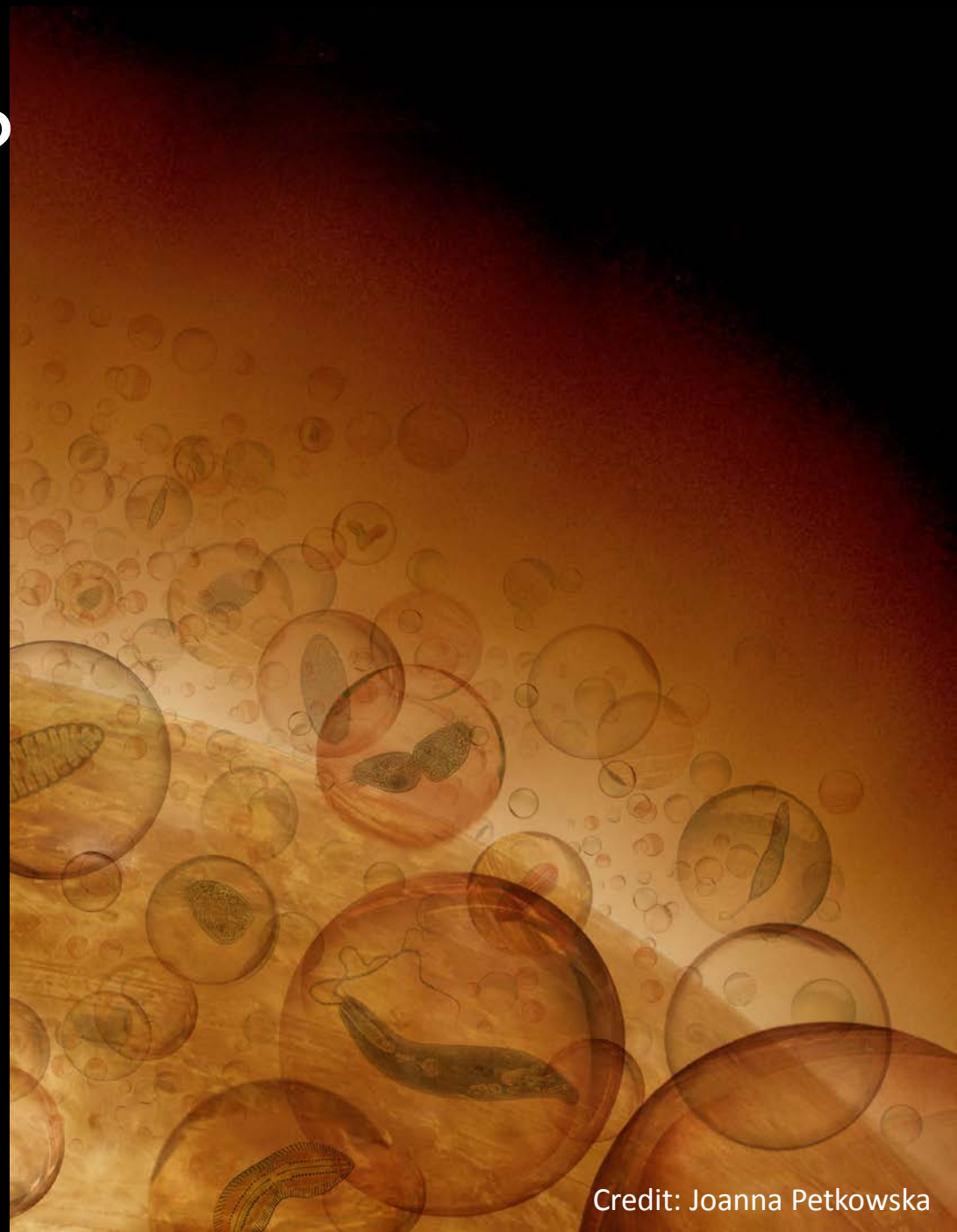


< 1 minute

Credit: William Bains

Life in the clouds of Venus?

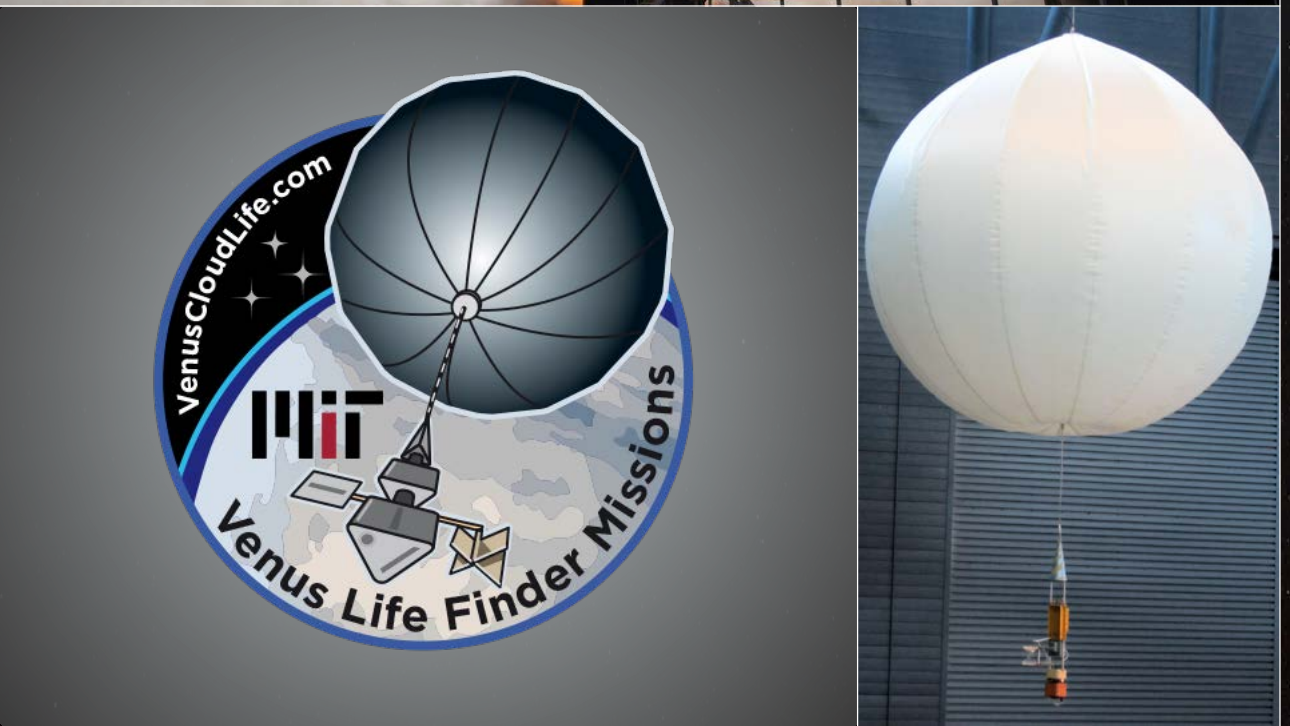
While we cannot rule out life as a source of phosphine on Venus, the hypothesis that phosphine is produced by life cannot a priori be favored over the hypothesis of unknown photochemistry or unknown atmospheric chemistry. All seem equally unlikely, and hence all call for further investigation.



Credit: Joanna Petkowska

Breakthrough Initiatives is sponsoring an MIT-led study of a mission to Venus to search for signs of life and even life itself

SMALL MISSION: PARTNER WITH ROCKET LAB ELECTRON



MEDIUM MISSION: INSPIRED BY RUSSIAN "VEGA" BALLOON MISSION MODEL. GEOFFREY A. LANDIS

Credit: Sara Seager


zoom.us Meeting View Edit Window Help
62% Tue 8:05 PM
Zoom Meeting
Participants (11)
Search
Paul B Rimmer (Host, me)
Anita Richards
Dave Clements
jane greaves
Sukrit Ranjan
Clara Sousa-Silva
Helen Fraser
Hideo Sagawa
Janusz Petkowski
Sara Seager
William Bains
Invite
Mute All