Water Contents of Habitable Zone Rocky Planets Around M dwarfs

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- Tong Li (Construct Line-by-line RT model)
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- Xianglei Huang
- Yi Huang
- Chuhong Mai

Outline

- Potential Problems on Habitability of M Dwarf Planets

- Biosignature of Exoplanets

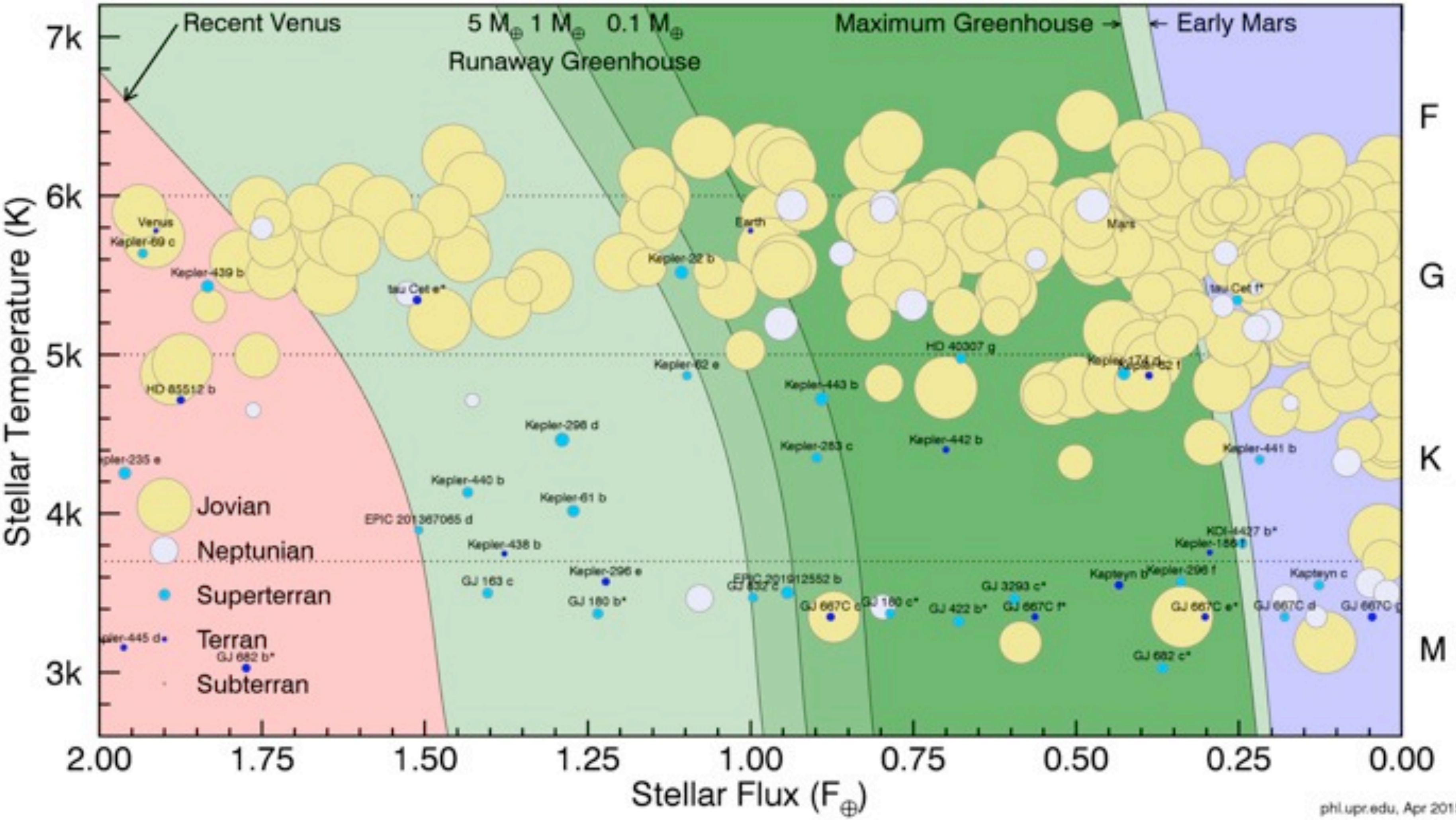
To build a habitable planet, you need:

- 1) elements important to life as we know it: CHONPS + metals (Fe, Cu, Ni, Mo, Mn, etc.)
  - Seems to be readily available

- 2) sunlight
  - Underground life is not well understood and hard to find around other stars
  - Seems to be readily available except for rogue planets

- 3) liquid water (universal solvent)

Planets Near the Liquid Water



http://phl.upr.edu/projects/habitable-exoplanets-catalog

Potential Water Problems with

D. Apai’s talk this morning: they are not necessarily dry!

Pre-Main Sequence M dwarfs were Brighter!

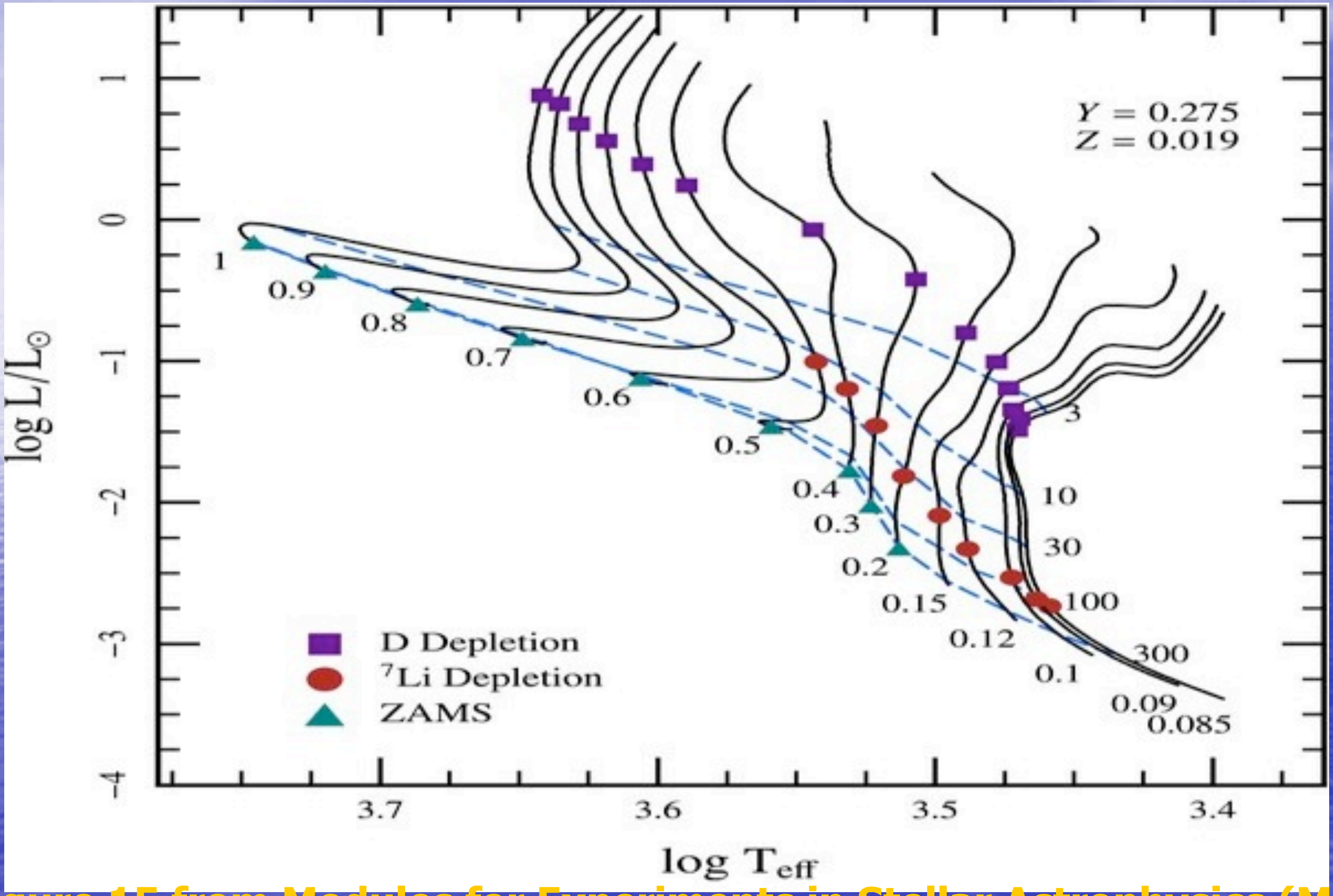


Figure 15 from Modules for Experiments in Stellar Astrophysics (MESA)
Bill Paxton et al. 2011 ApJS 192 3 doi:10.1088/0067-0049/192/1/3

The Astrophysical Journal Letters, 797:L25 (8pp), 2014 December 20

THE HABITABLE ZONES OF PRE-MAIN-SEQUENCE STARS

Ramses M. Ramirez[1,2,3] and Lisa Kaltenegger[1,2]

ASTROBIOLOGY
Volume 15, Number 2, 2015

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Extreme Water Loss and Abiotic O_2 Buildup on Planets Throughout the Habitable Zones of M Dwarfs

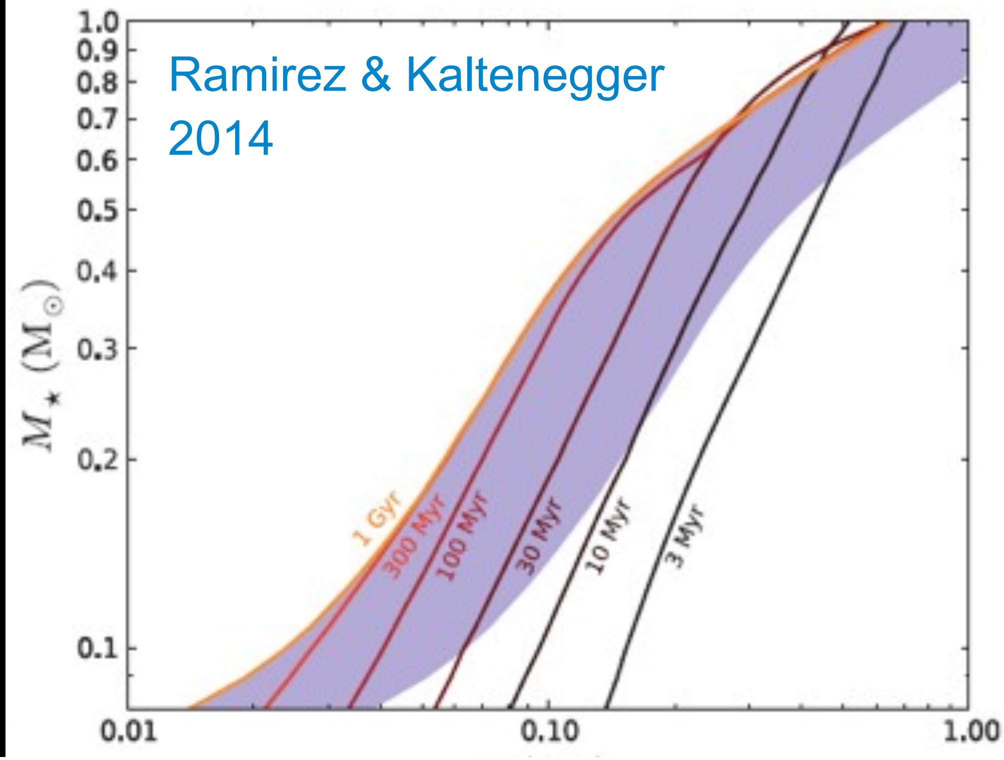
R. Luger[1,2] and R. Barnes[1,2]

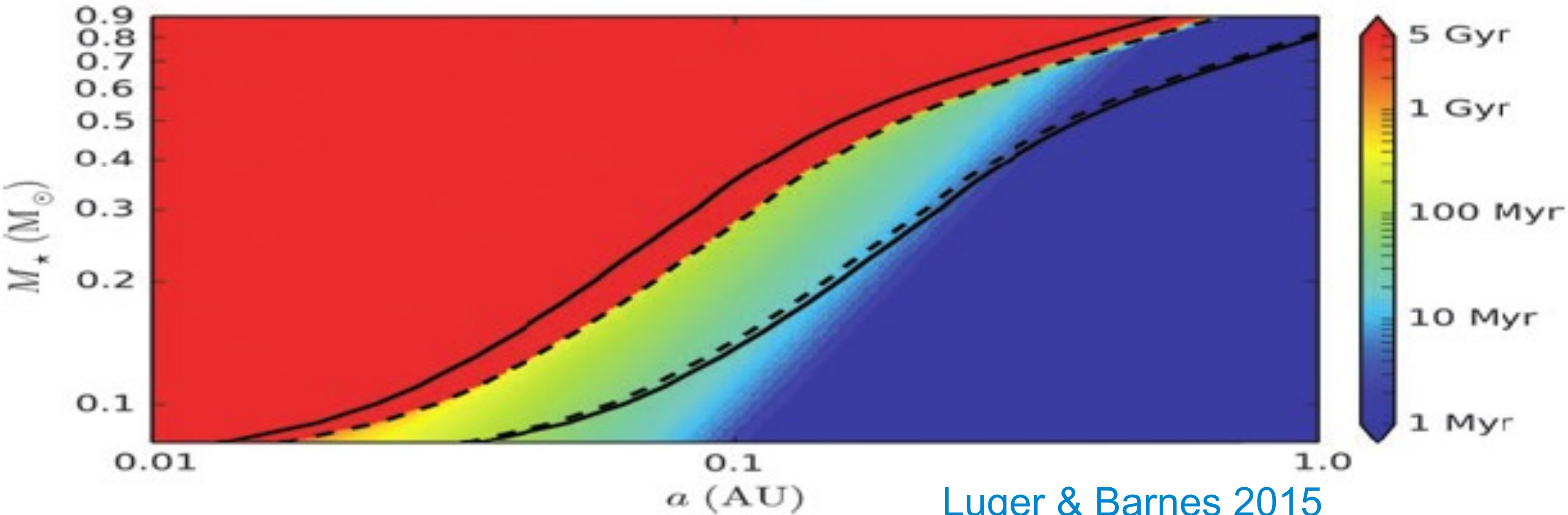
nature geoscience
LETTERS
PUBLISHED ONLINE: 16 FEBRUARY 2015 | DOI: 10.1038/NGEO2372

Water contents of Earth-mass planets around M dwarfs

Feng Tian[1]* and Shigeru Ida[2]

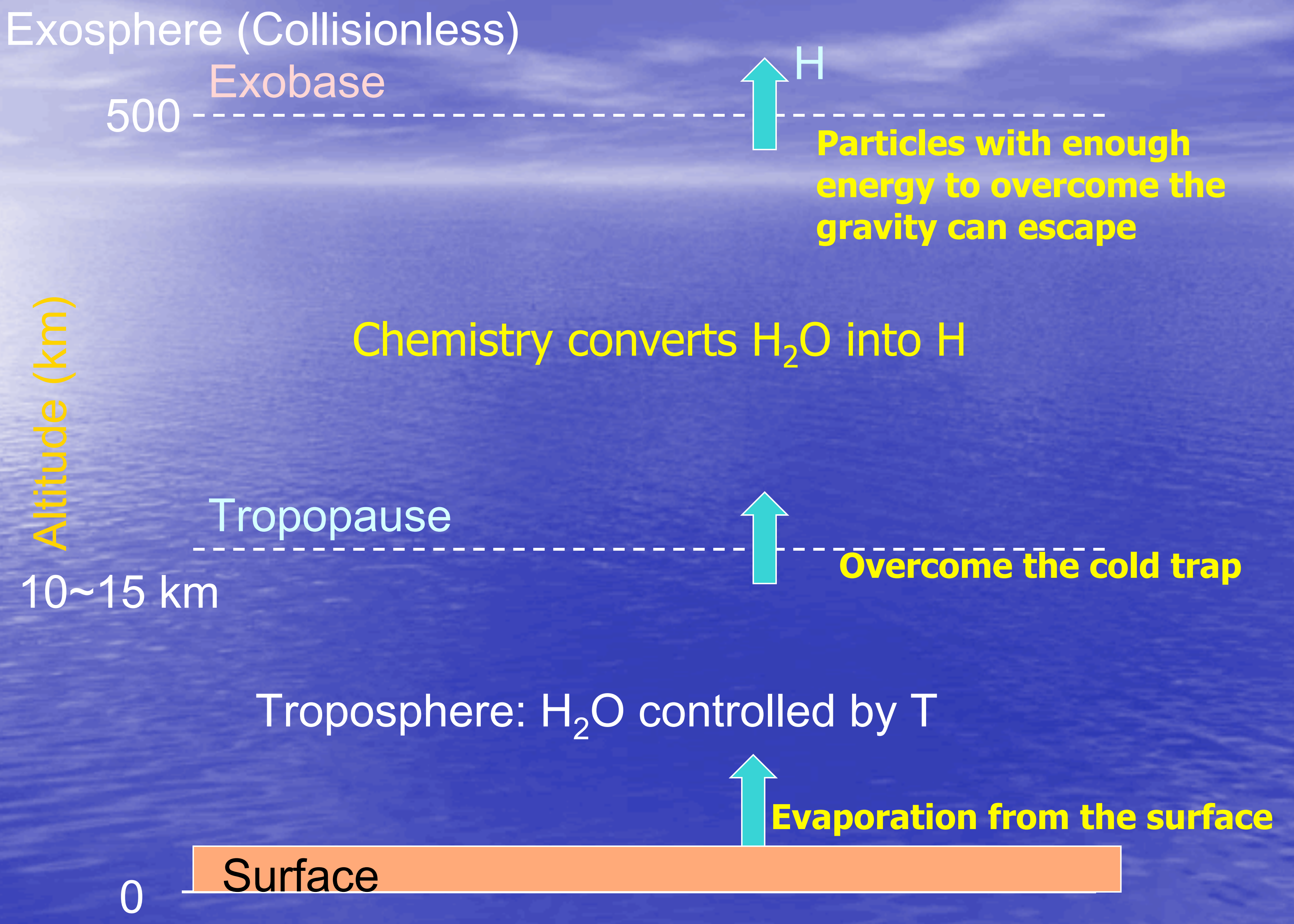
The HZ of M dwarfs migrates inward significantly during PMS phase!
-- in danger of losing



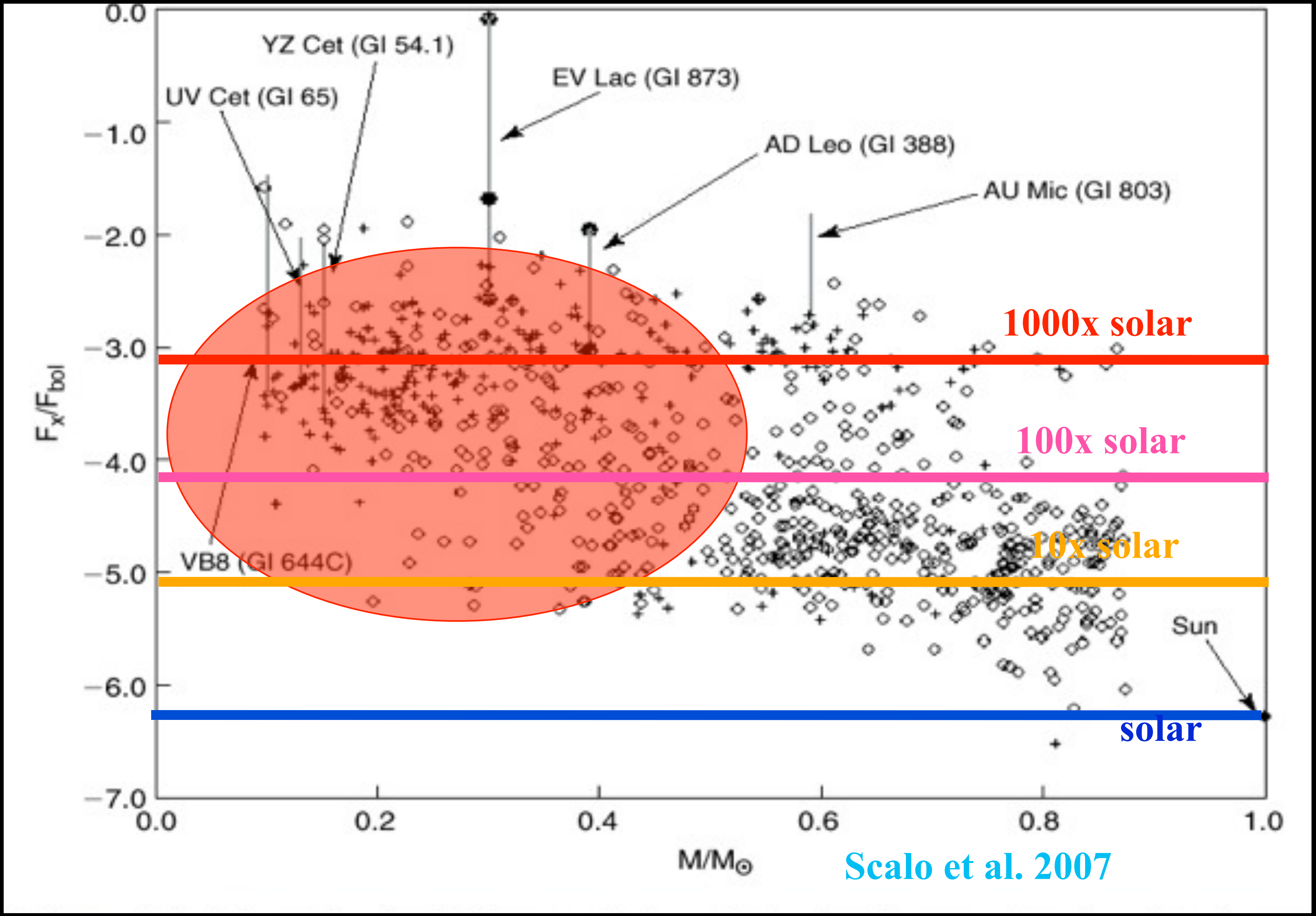


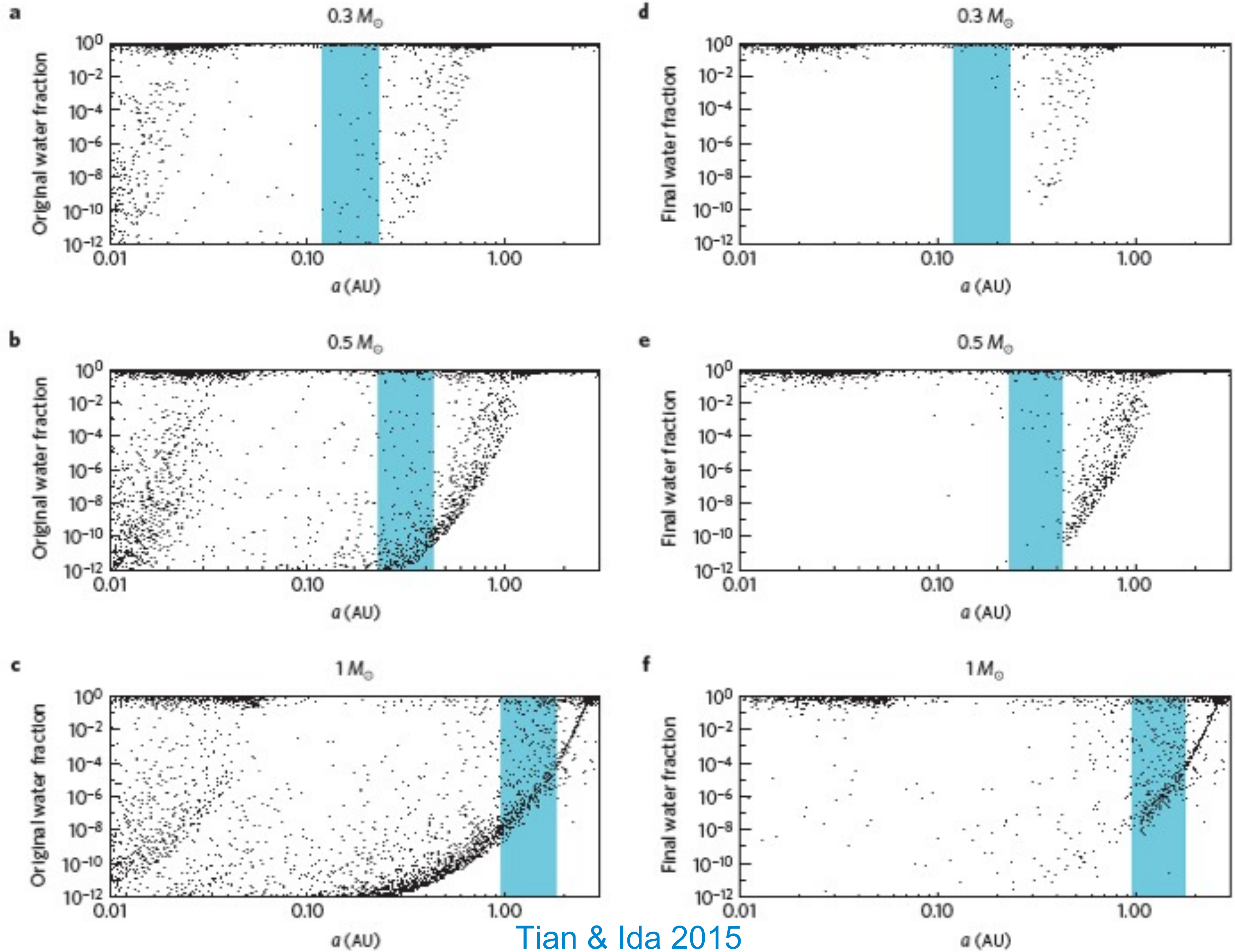
Luger & Barnes 2015

Water loss has 3 bottlenecks

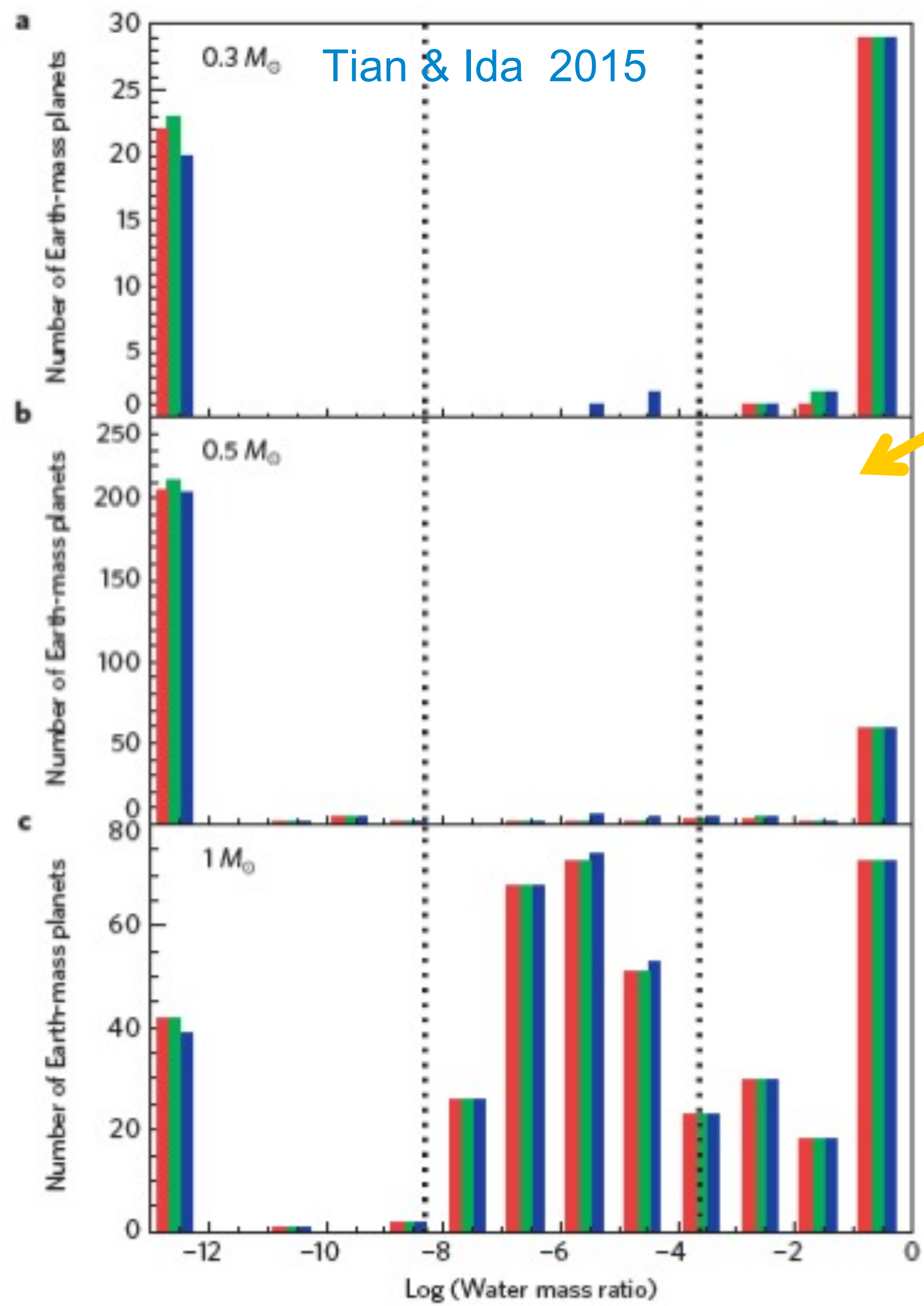


M dwarfs are stronger XUV emitters than the Sun (Sanz-Forcada talk this morning), potentially destabilizing planetary atmospheres.





Tian & Ida 2015



For Eric:

Even early M dwarfs are

模式计算的每千颗恒星周围的行星统计

a:类地行星定义为质量在0.1到10地球质量范围的行星

Planet Statistics Around 1000 Stars

Stellar Mass(Solar Mass)	# of All Planets	# of Earth-mass planets	# of HZ Earth-mass planets	# of HZ Ocean Planets	# of HZ Dune Planets	# of Earth-twins
0.3	69000	5000	55	31	23	1
0.5	75000	9000	292	60	220	12
1	38000	8000	407	91	45	271

Earth-mass planets are defined to have mass between 0.1 and 10 Earth masses

Earth-twins are defined as Earth-mass planets with surface water between Venus water content and 1% mass fraction.

- M dwarfs:
  - 0.1%~1% probability to have Earth-twins (0.1-10 M_{earth} + Water fraction >1e-8 and < 1e-2)

- Sun-like Stars:
  - 10% probability

Potential problems with too much water:

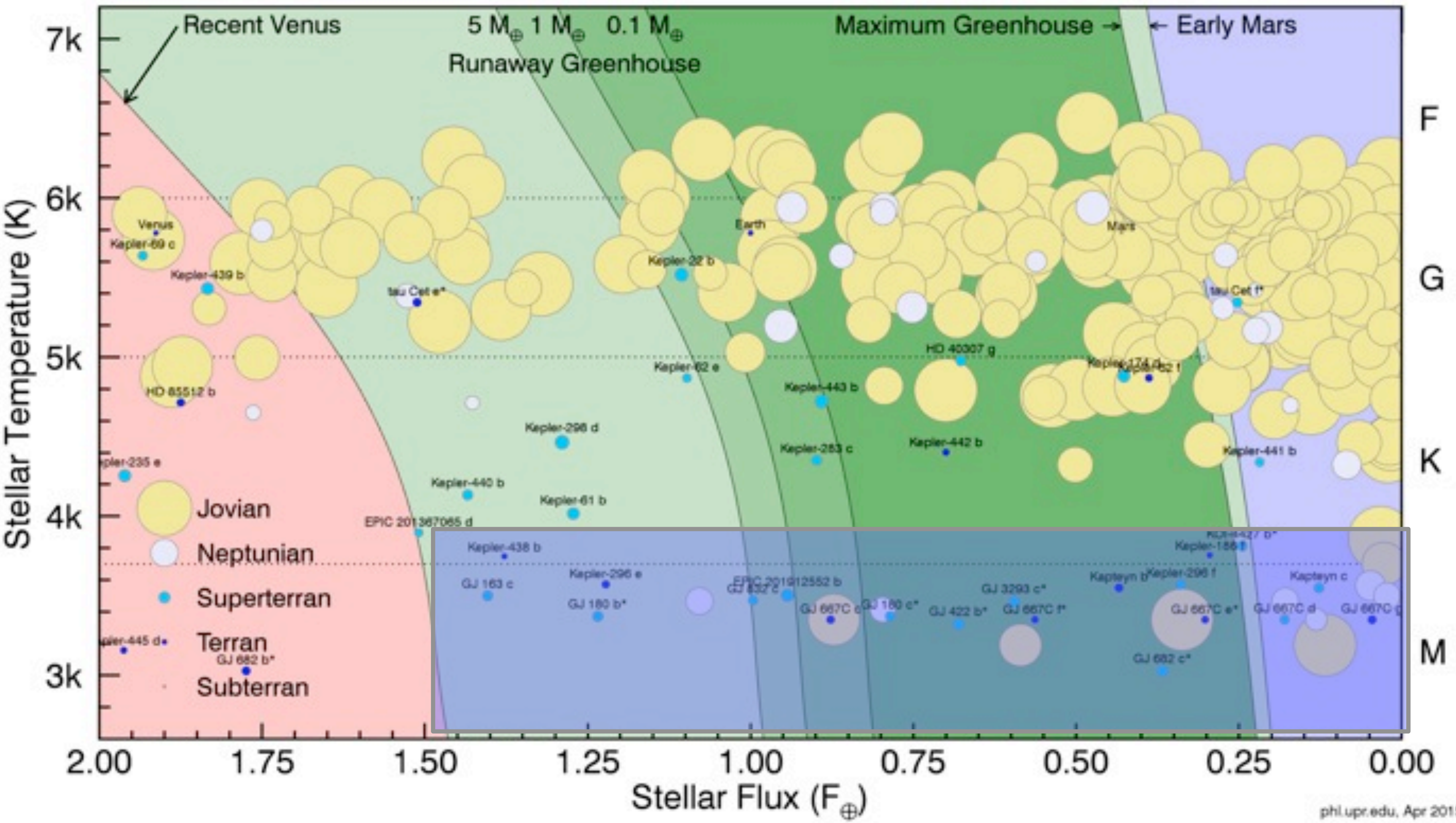
1) Climate instability (Cowan&Abbot 2014, Abbot+ 2012, see also Kitzmann+ poster in this confernece)
2) Limited nutrients for surface life (Dohm & Maruyama 2015)

BTW, the probability for H2-rich atmospheres

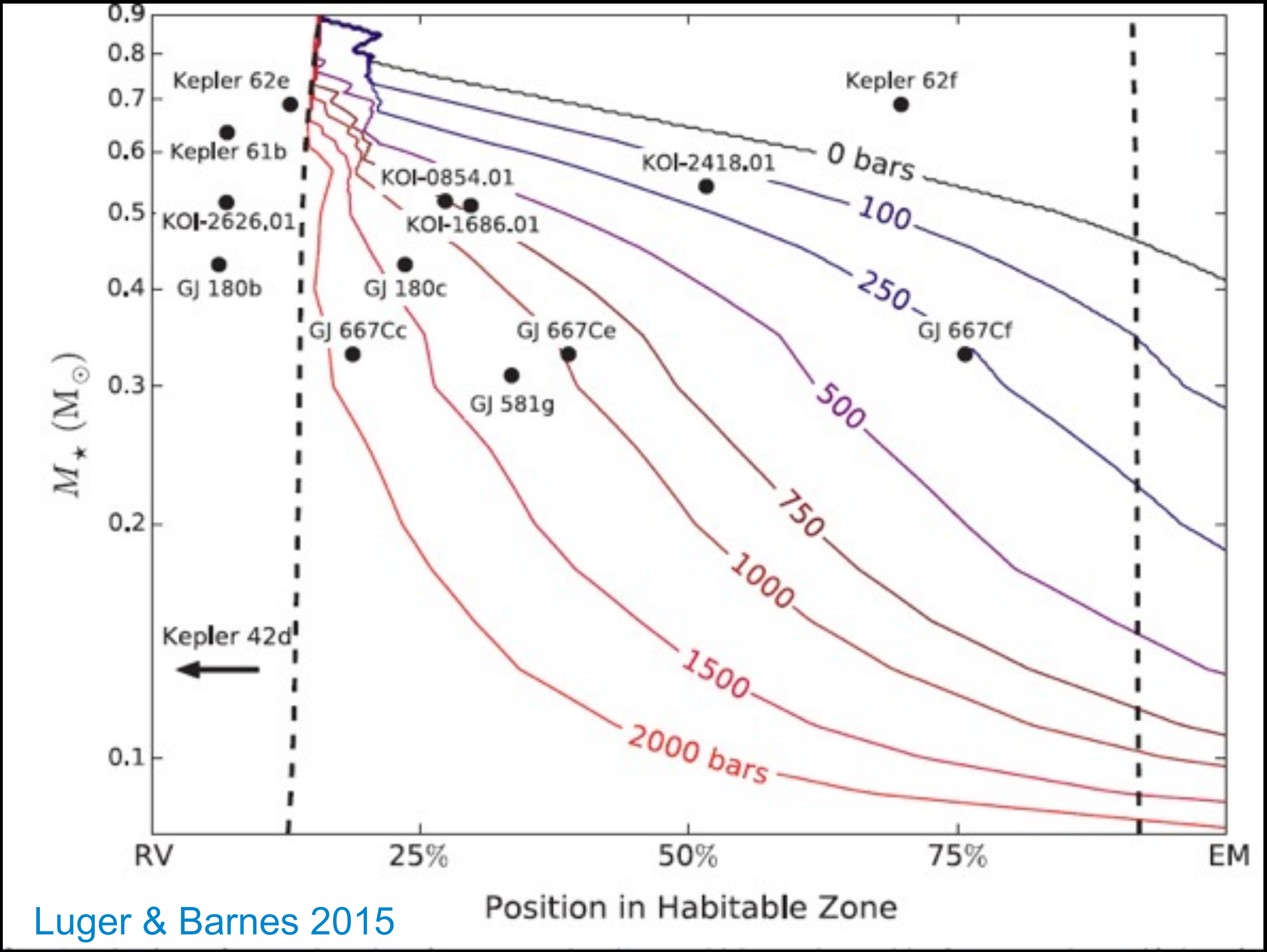
Uncertainties

- Late Delivery of Water…
  - Greaves talk
  - How much could be delivered?
  - Impacts = high exozodiacal light? – if so, bad for characterization
- Store water in the interior… why doesn't Venus have water?

Earth-mass planets in the HZ of M dwarfs are either water worlds or dune planets.

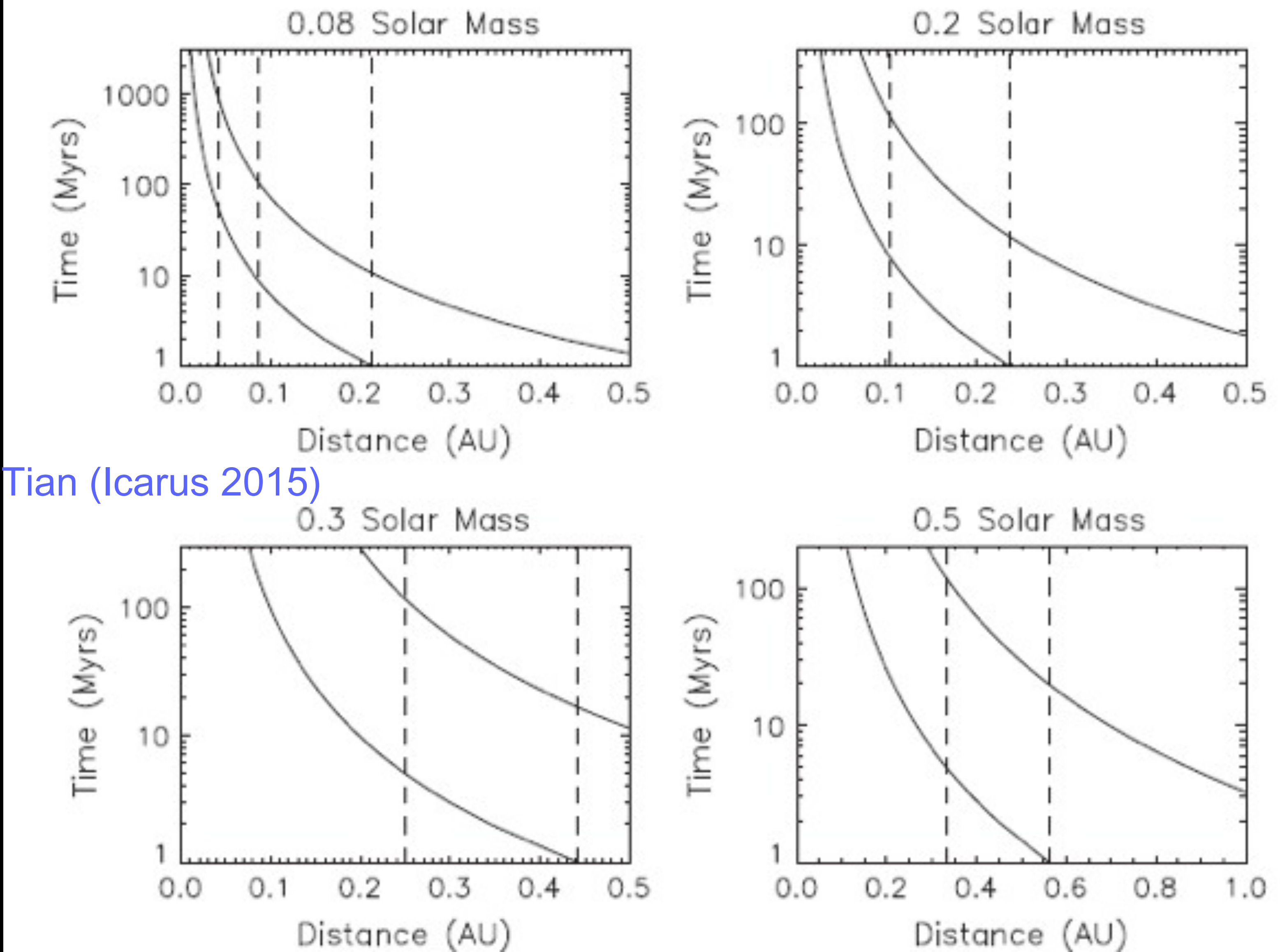


Severe water loss may lead to O2 buildup! Observing rocky planets around PMS M dwarfs could provide key insight on planet evolution.



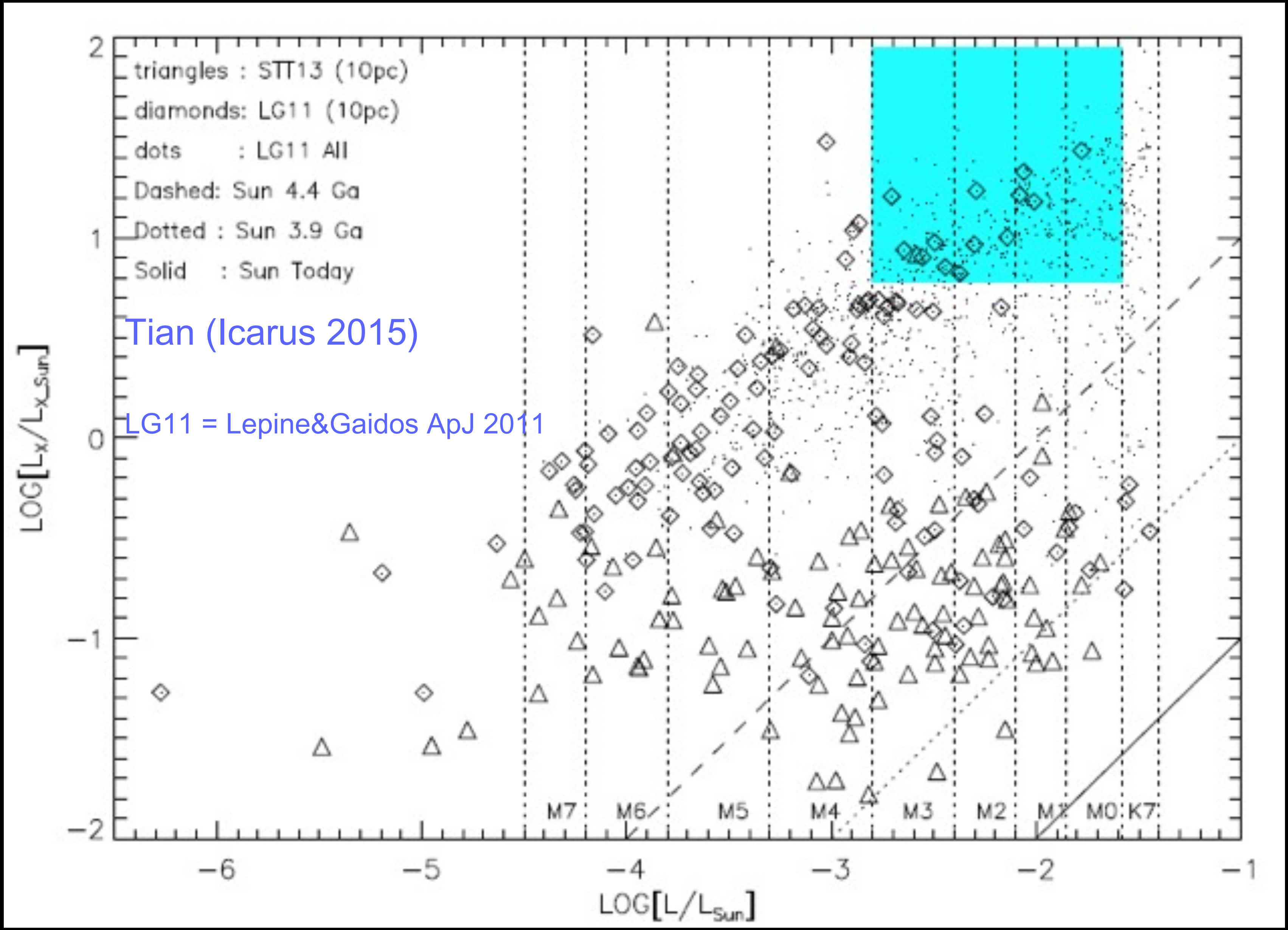
Luger & Barnes 2015

The Probability of Observing Exoplanets around PMS M dwarfs

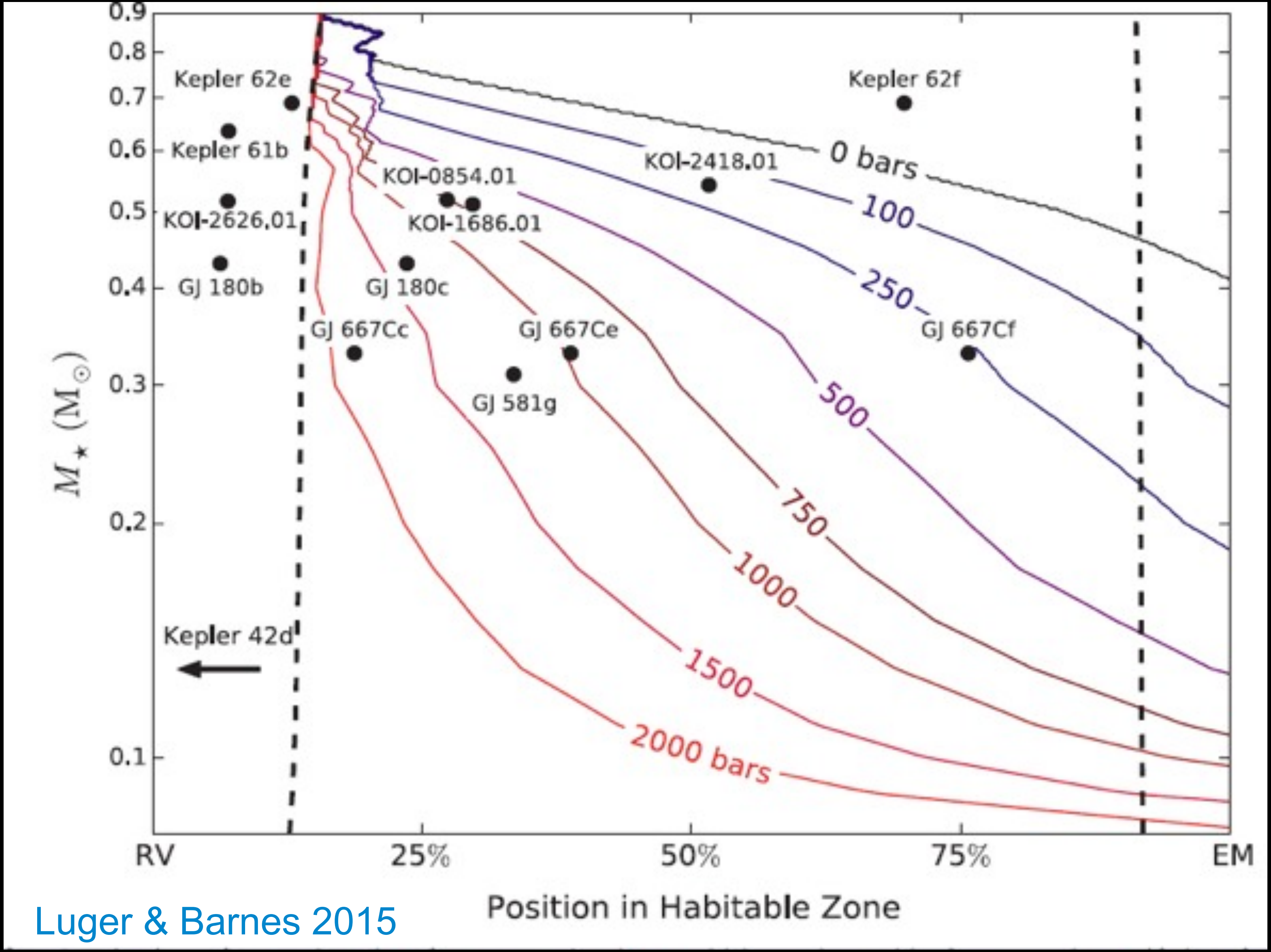


Tian (Icarus 2015)

How many nearby PMS M dwarfs are there?

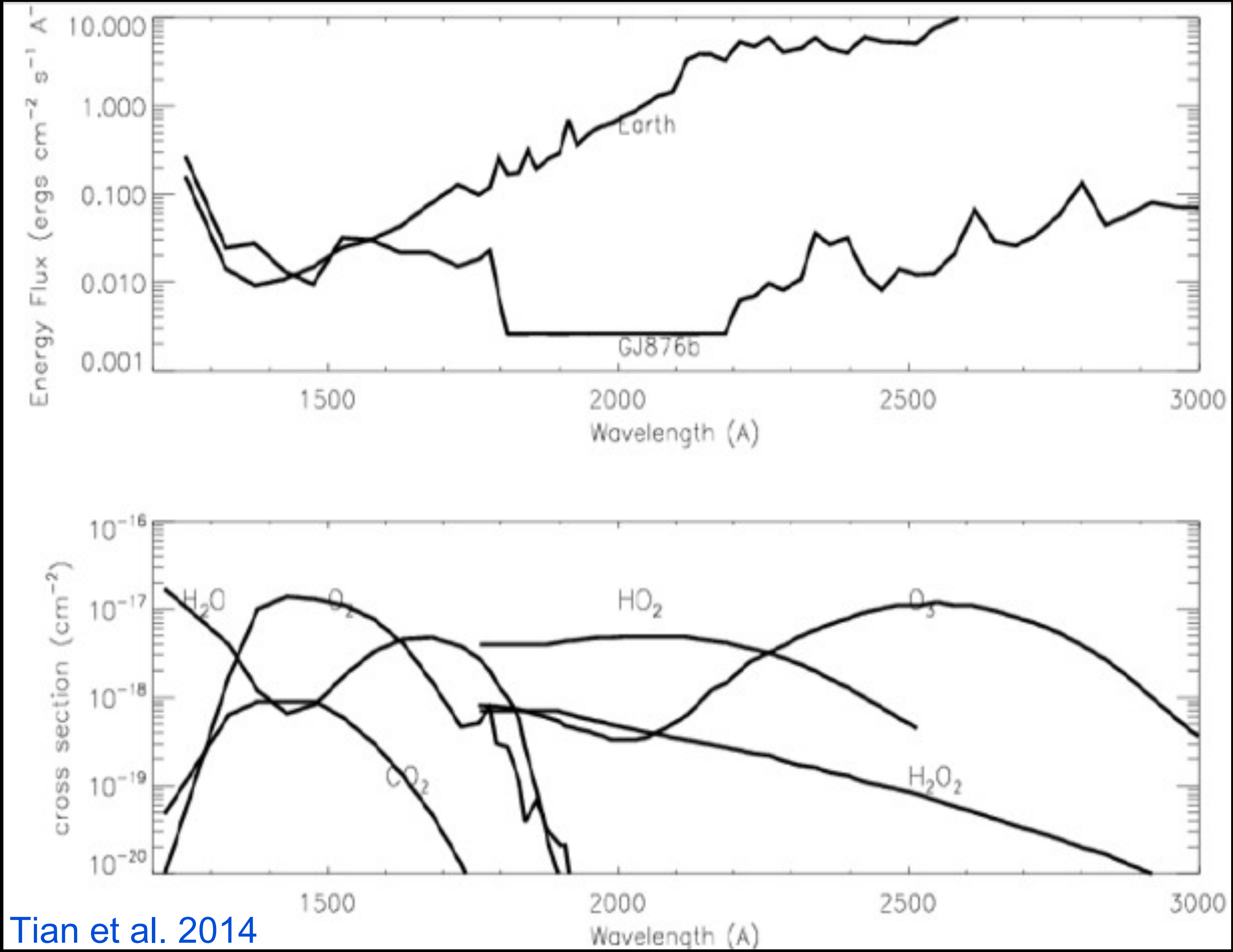


Biosignature Detection: O_2



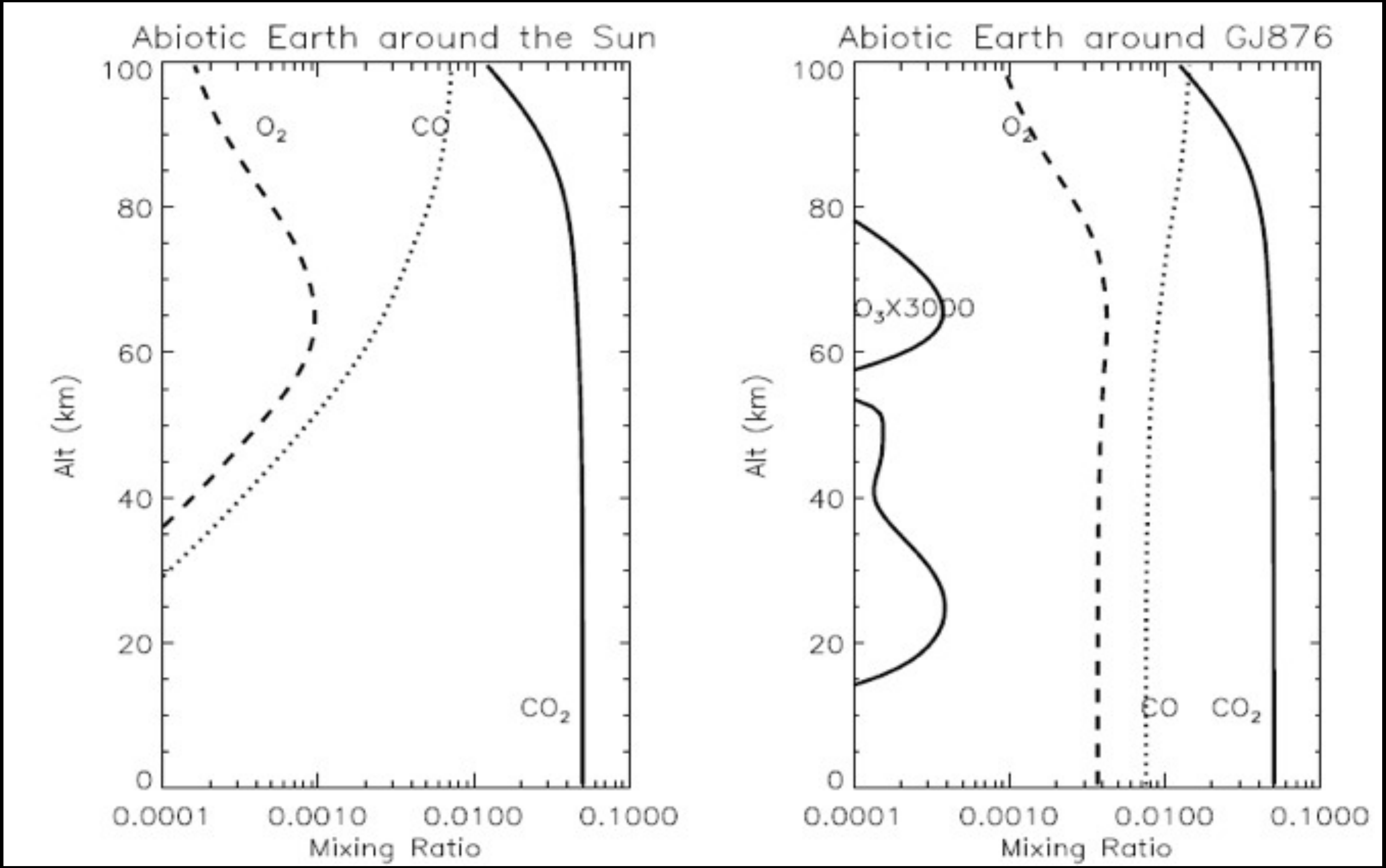
Luger & Barnes 2015

Different FUV/NUV ratio changes chemistry



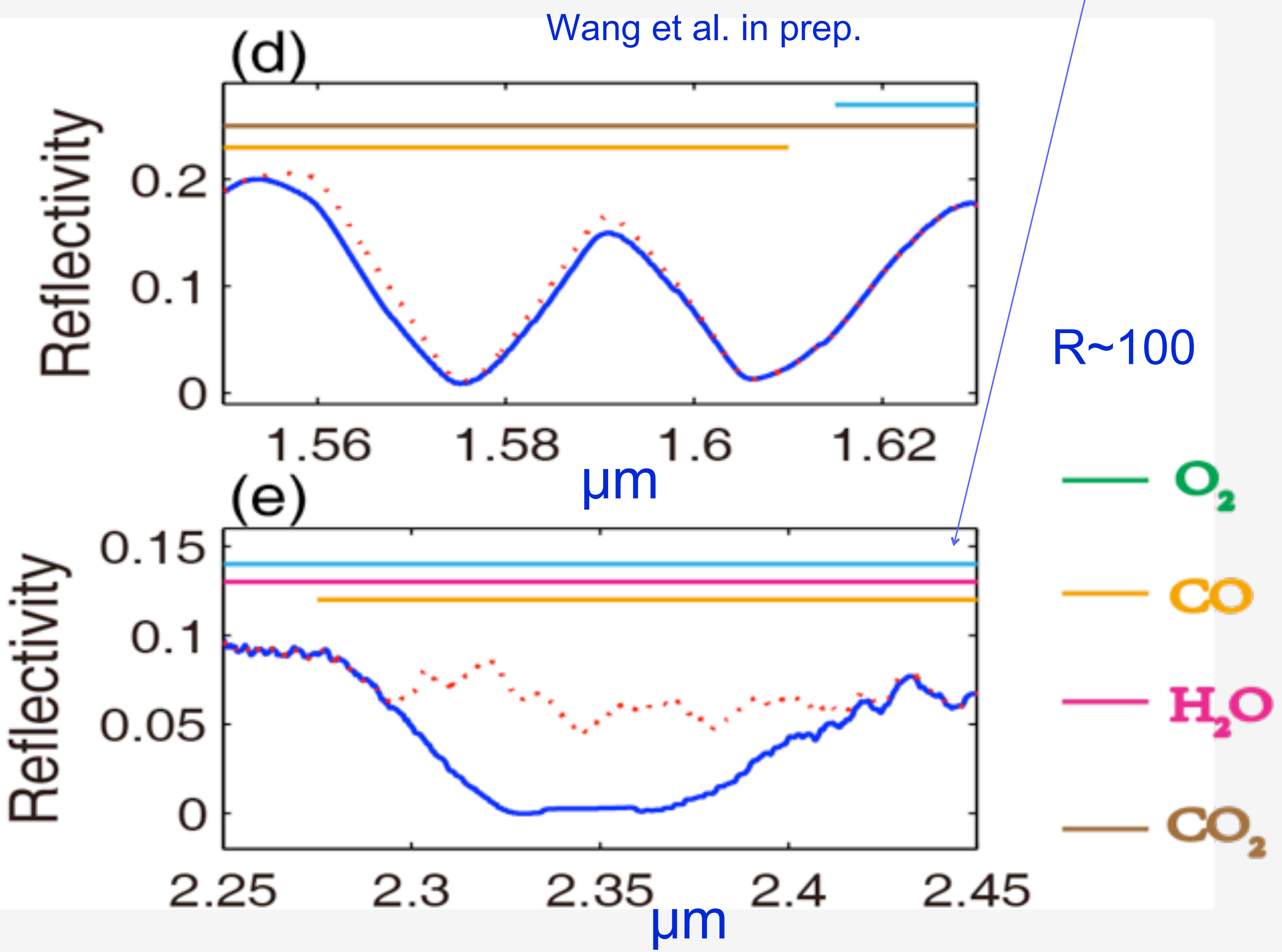
Tian et al. 2014

As a result of high FUV/NUV ratio, abiotically produced O_2 and O_3 could be maintained in the atmosphere.

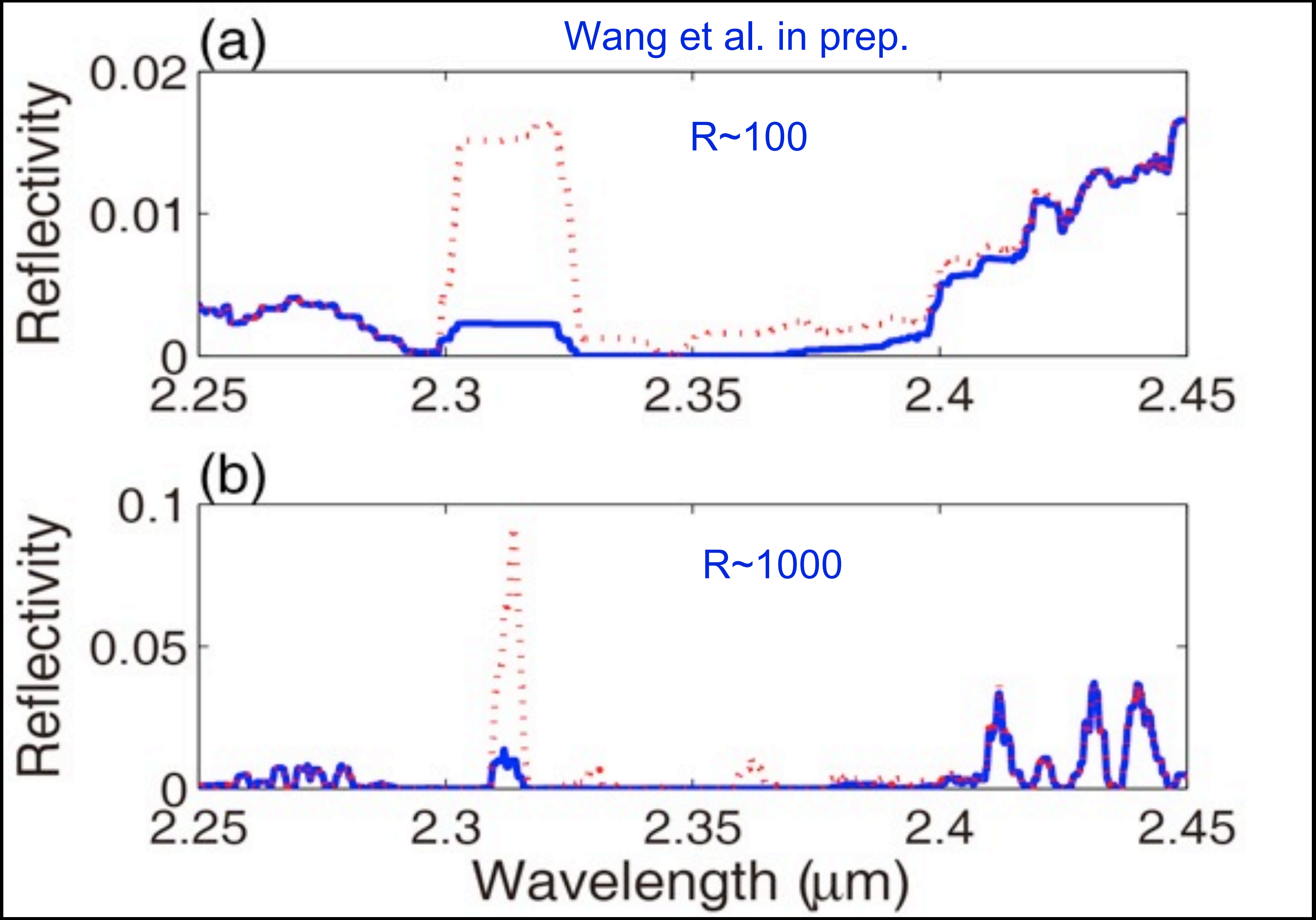


Tian+EPSL 2014; also see Dogmal-Goldman + 2014, Gao+ 2015, Harman+ 2015

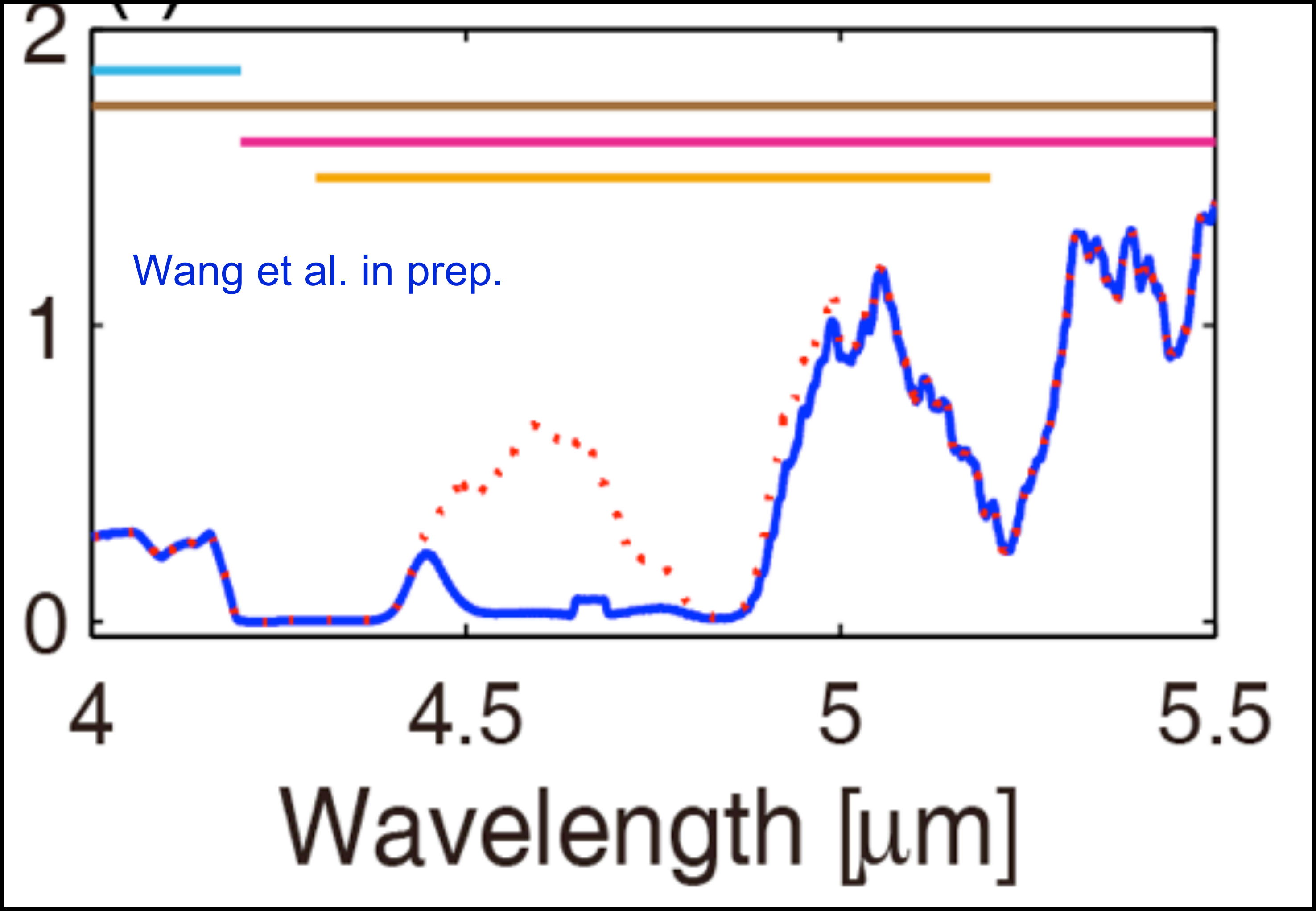
Detectability of CO… but CH_4



Detectability of CO in the



So observations in multiple wavelengths will probably be the solution -- even 5 μm can be



If stellar light and instrument

$$\Delta t = t_0 \left(\frac{A}{0.3}\right)^{-1} \left(\frac{r_p}{r_E}\right)^{-2} \left(\frac{F_*}{1367}\right)^{-1} \left(\frac{d}{10\ pc}\right)^{2} \left(\frac{D}{6.5\ m}\right)^{-2} \left(\frac{SNR}{10}\right)^{2} \left(\frac{R}{100}\right)$$

$$t_0 = 6.87 \times 10^{-15} \times \frac{T_*^{\,4}}{\lambda^2 B_\lambda(T_*)} \text{ hours}$$

For fO_2 ~10^{-3} on exoplanets with Earth-like climate, The integration time needed for CO

Table 2. Integration Time Δt (hours) for the Detection of O2 and CO

Exoplanets with Earth-like Climate				
λ (μm)	A with O2	A without O2	SNR	Δt
0.69	0.274	0.279	112	148
0.76	0.254	0.28	22	5
1.27	0.253	0.255	255	329
λ (μm)	A with CO	A without CO	SNR	Δt
1.58	0.175	0.2	16	2
2.34	0.01	0.08	3	0.2
4.67	0.03	0.66	3	0.03

Not for imaging!

Wang et al. in prep.

Conclusions

- Rocky planets in the Liquid Water Habitable Zone of Main Sequence M dwarfs may be inhabitable – evolution matters!
  - But these planets offer opportunities to understand the evolution of solar system planets.

- It is possible to distinguish photochemically

Thank you!

- Questions? please email tianfengCO@mail.tsinghua.edu.cn