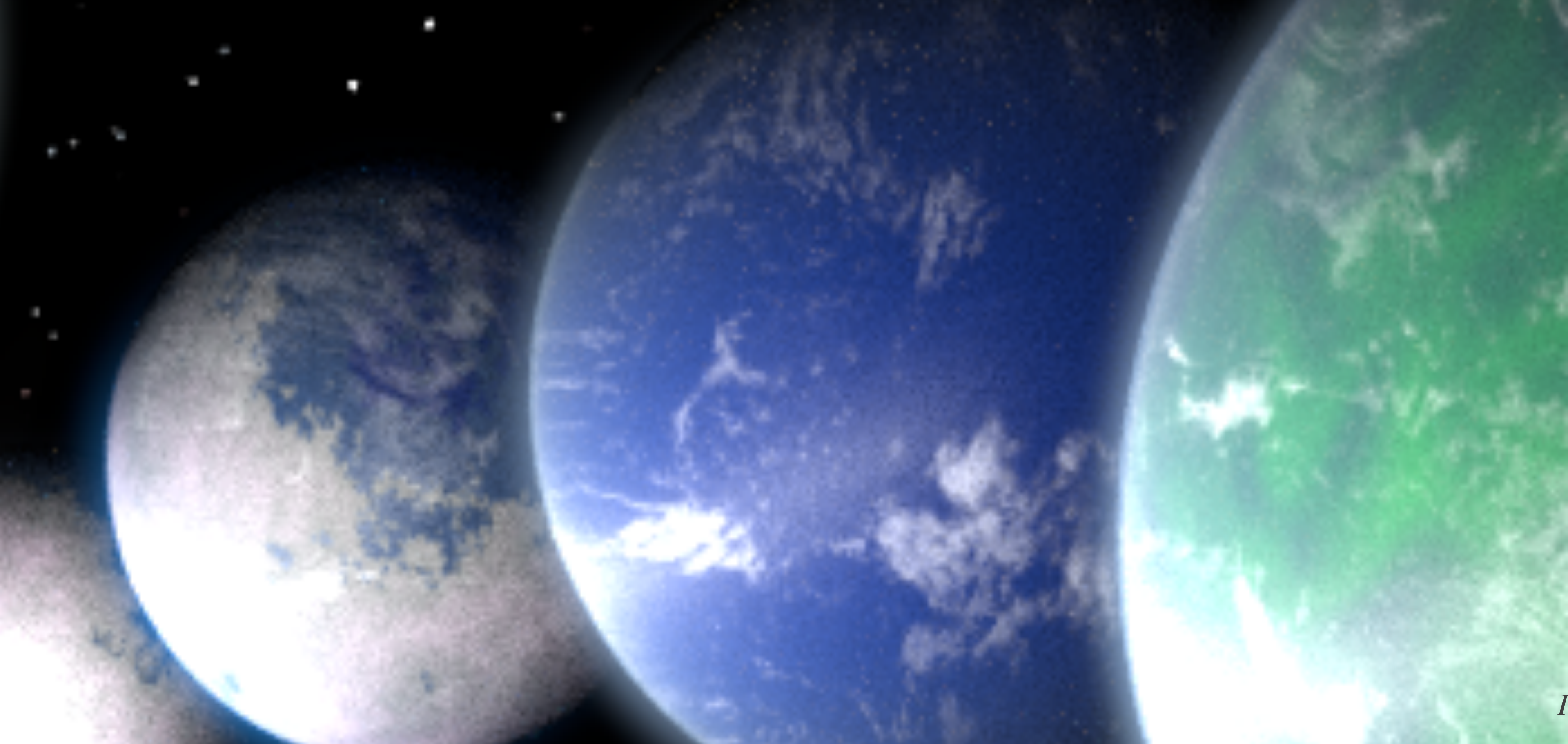
Perspectives of Exoplanet Detection & Characterization

Lisa Kaltenegger, Director Carl Sagan Institute at Cornell



12 departments at Cornell, base in Astronomy & Planetary Science

26 faculty (Bio, Chemistry, Astro, EAS, Science Comm., Civil-, MAE, Bio- Eng. etc)

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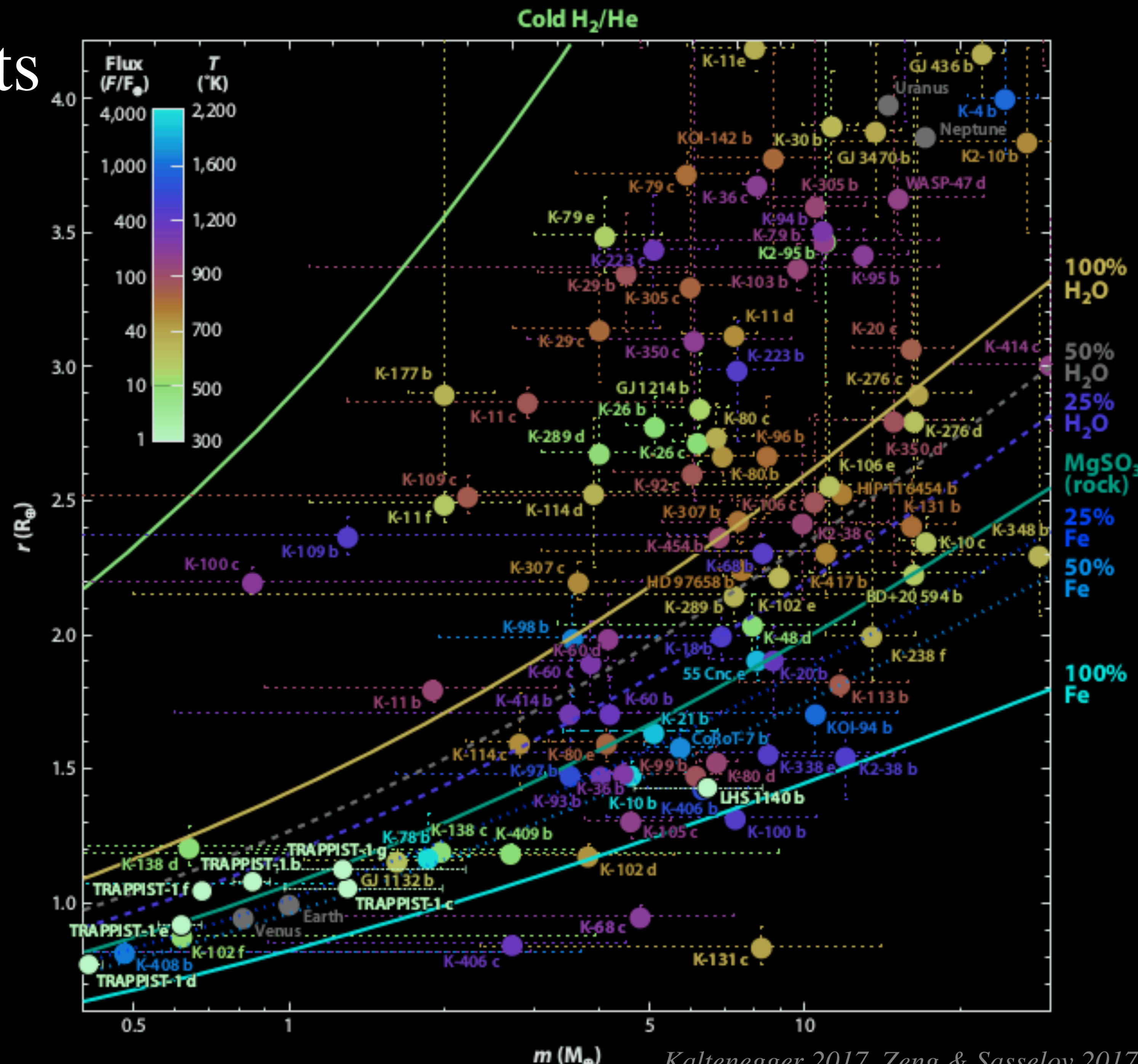
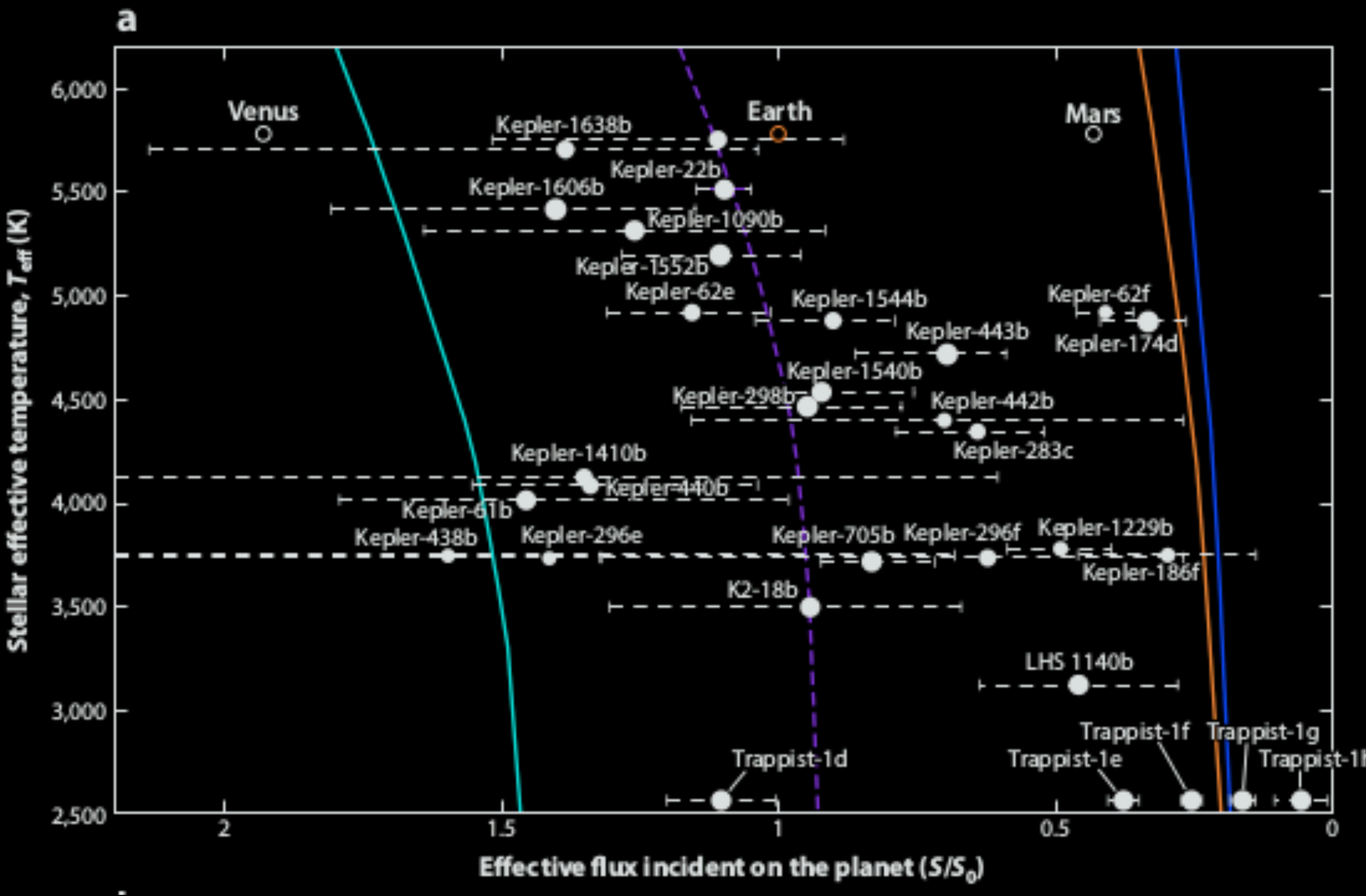
CARL SAGAN INSTITUTE

THE PALE BLUE DOT & BEYOND.

Exoplanets Detected

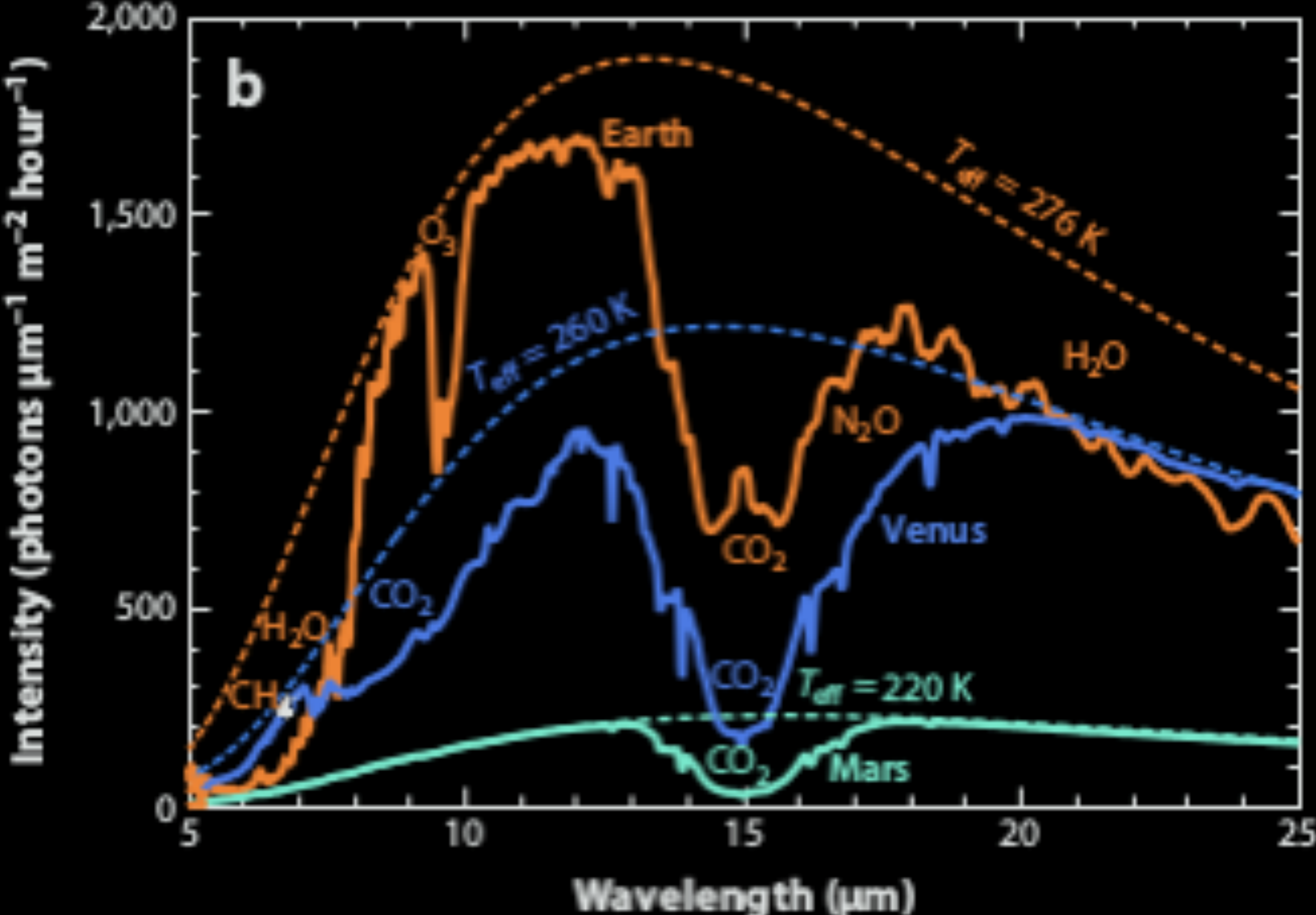


Kaltenegger 2017, Zeng & Sasselov 2017

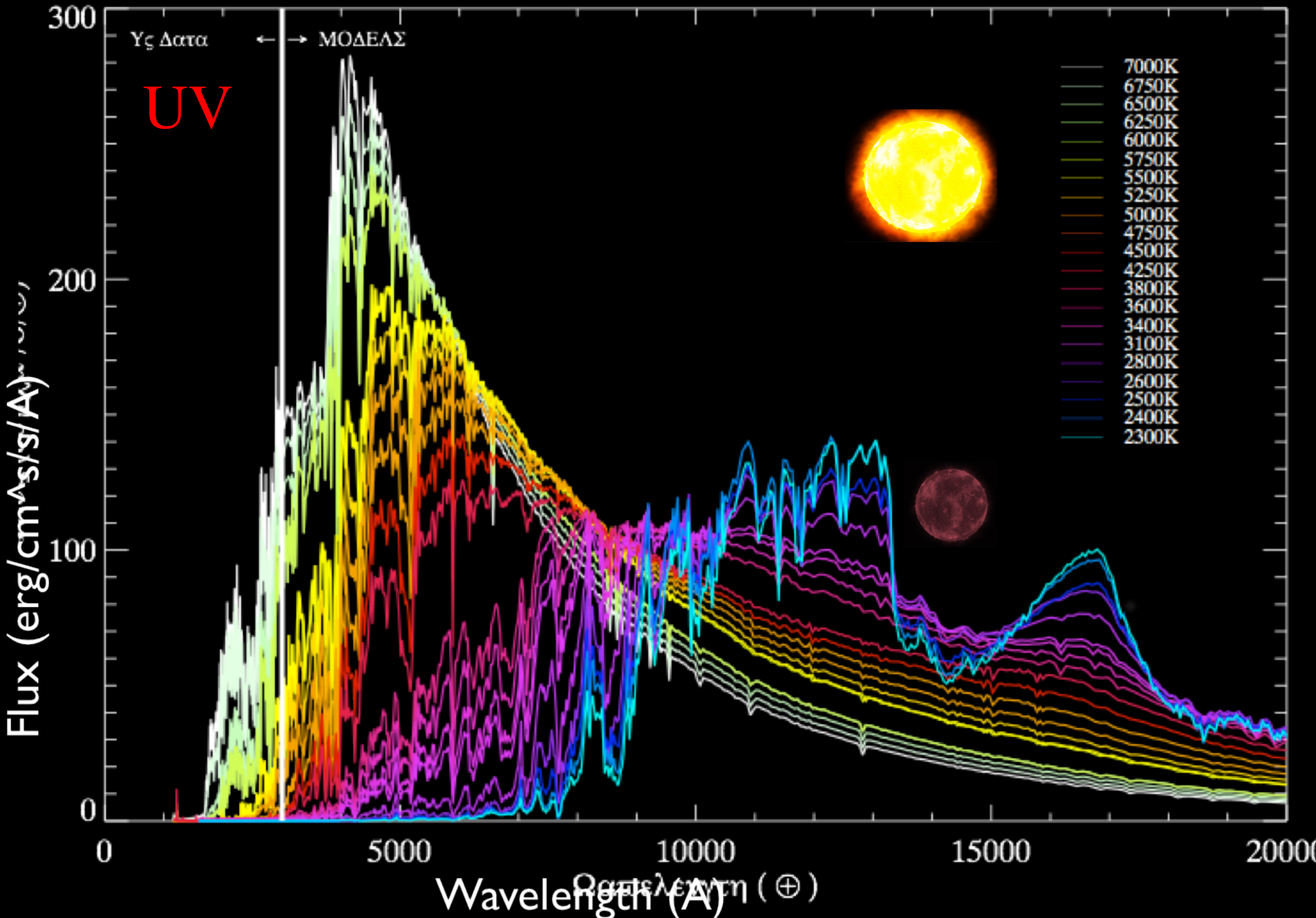


Transiting Exoplanets (radii < 2)

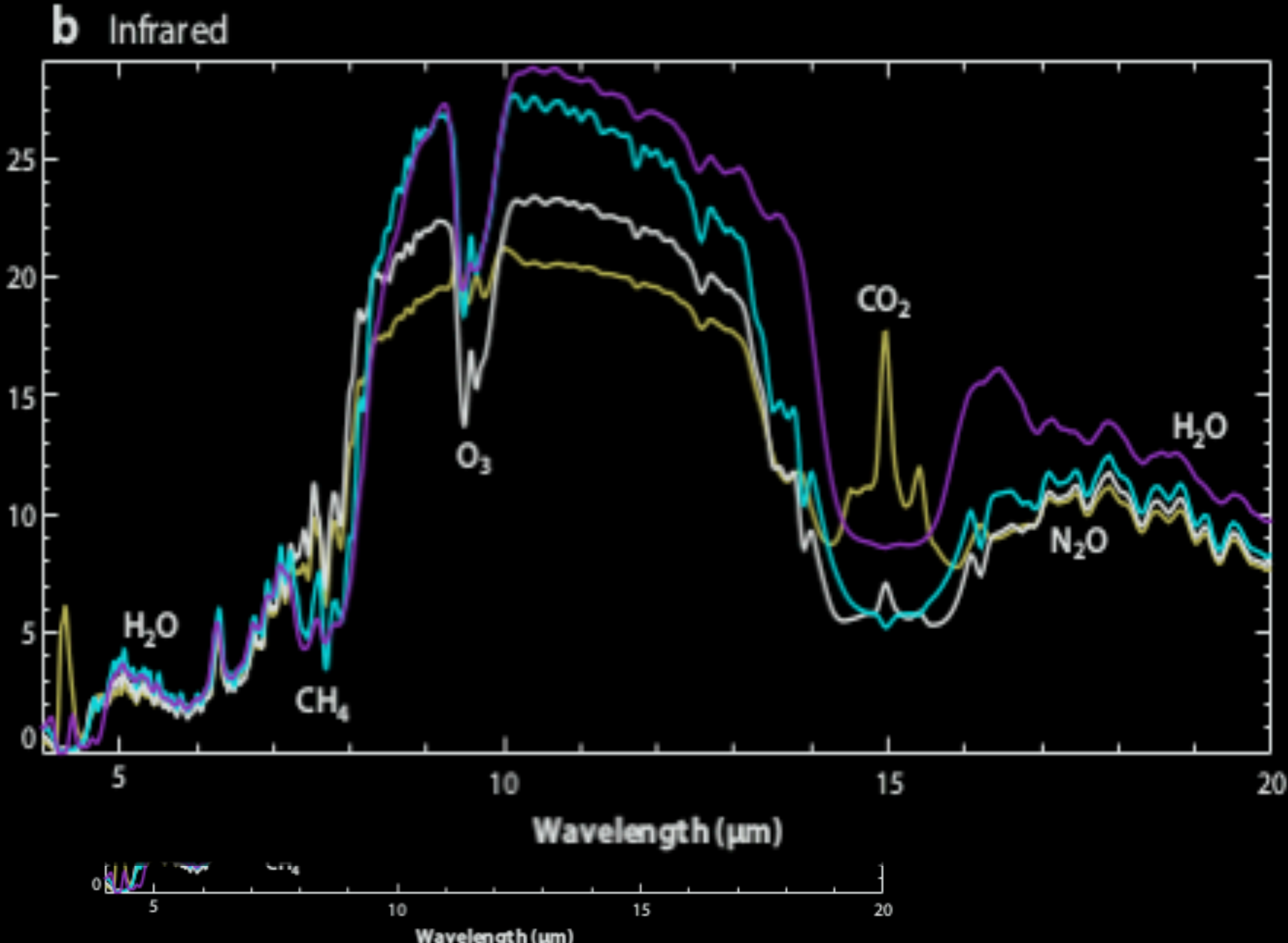
Kaltenegger 2017



b
2,000
1,500
1,000
500
0
5
10
15
20
25
Intensity (photons µm⁻¹ m⁻² hour⁻¹)
Wavelength (µm)
Earth
T_{eff} = 276 K
O_3
T_{eff} = 260 K
H_2O
N_2O
CO_2
Venus
CO_2
H_2O
CH_4
CO_2
T_{eff} = 220 K
CO_2
Mars



Rugheimer, Kaltenegger et al. 2013, 2015



b Infrared
25
20
15
10
5
0
5
10
15
20
Wavelength (μm)
H2O
CH4
O3
CO2
N2O
H2O

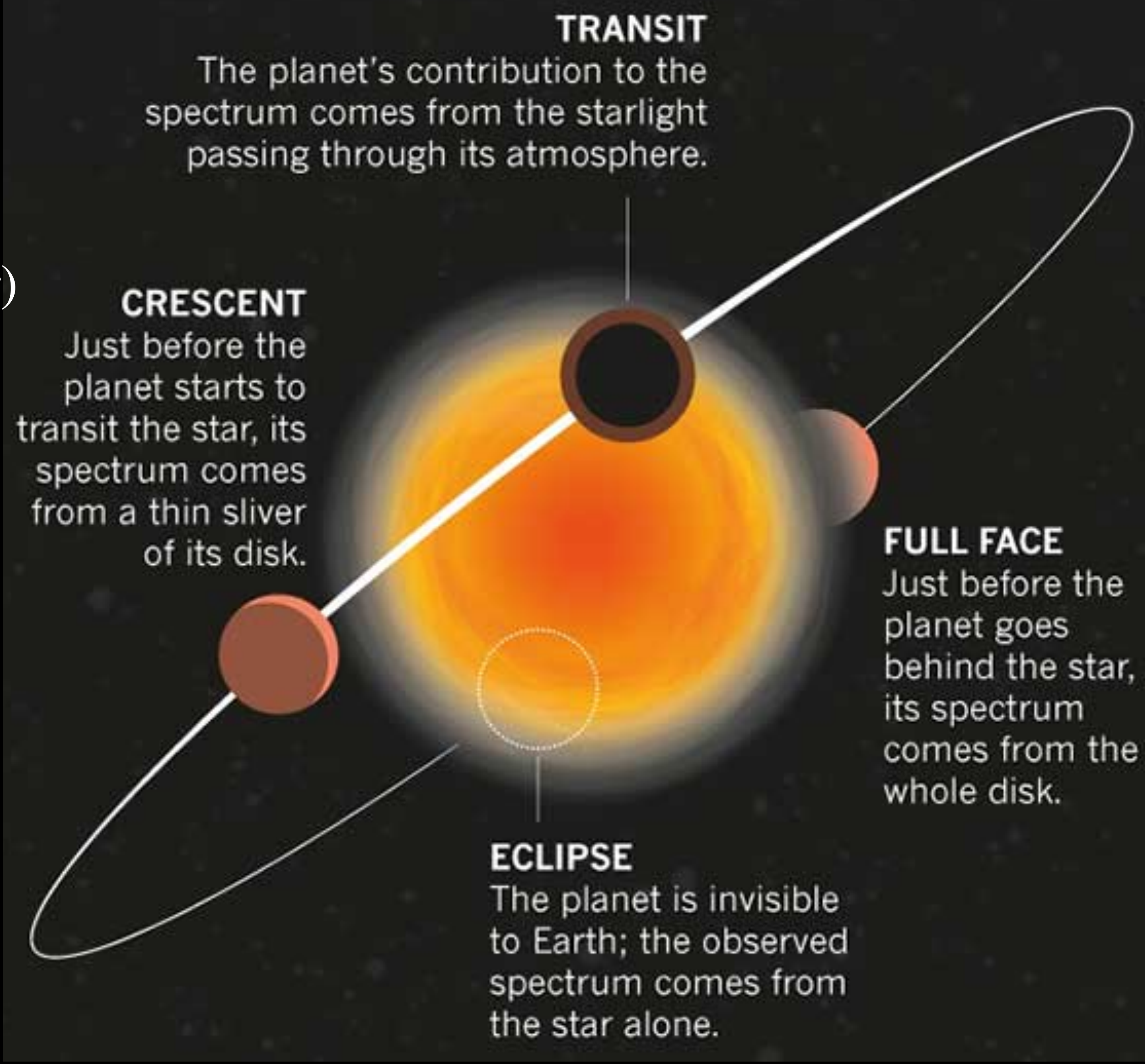
Exoplanets

Primary transit
(probes terminator)

Secondary eclipse
(probes dayside)

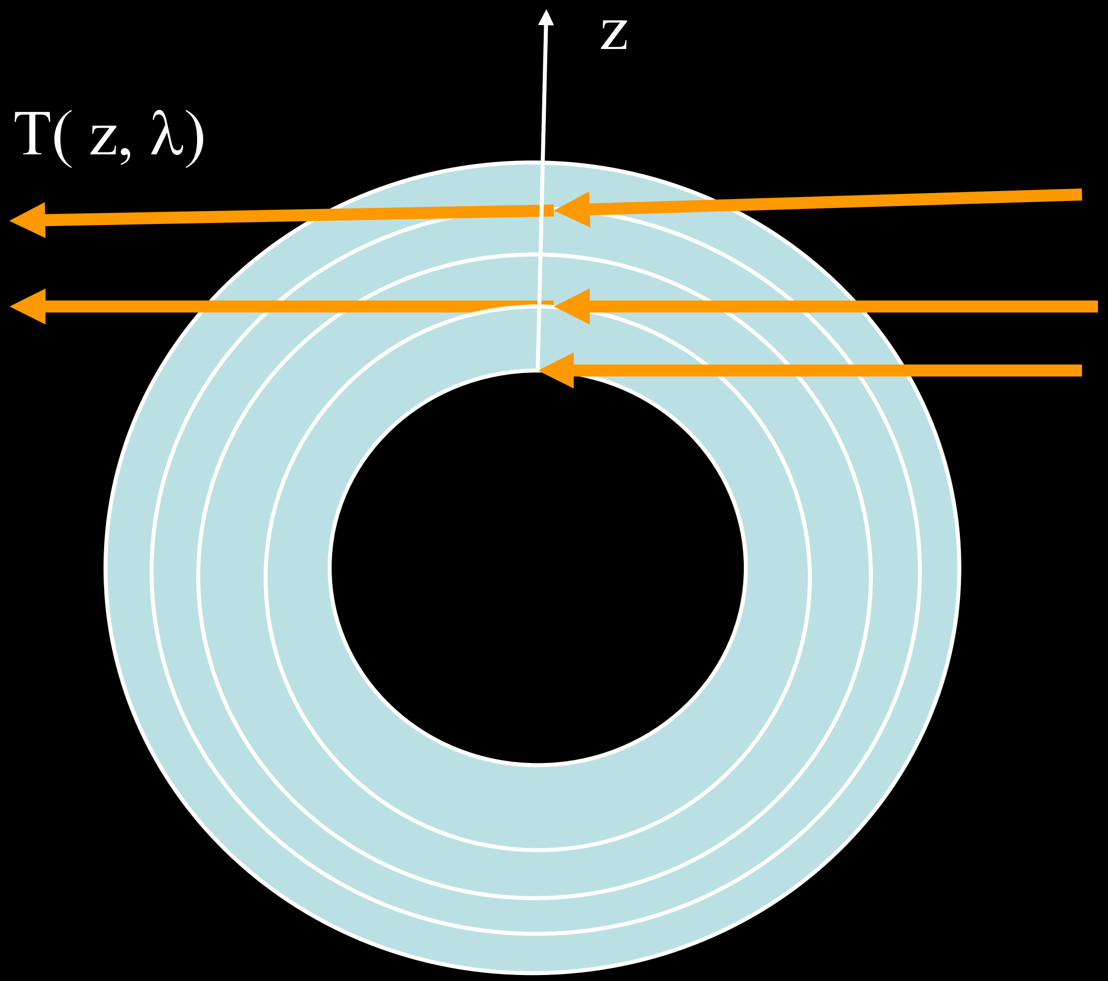
Direct imaging
(probes day & nightside)

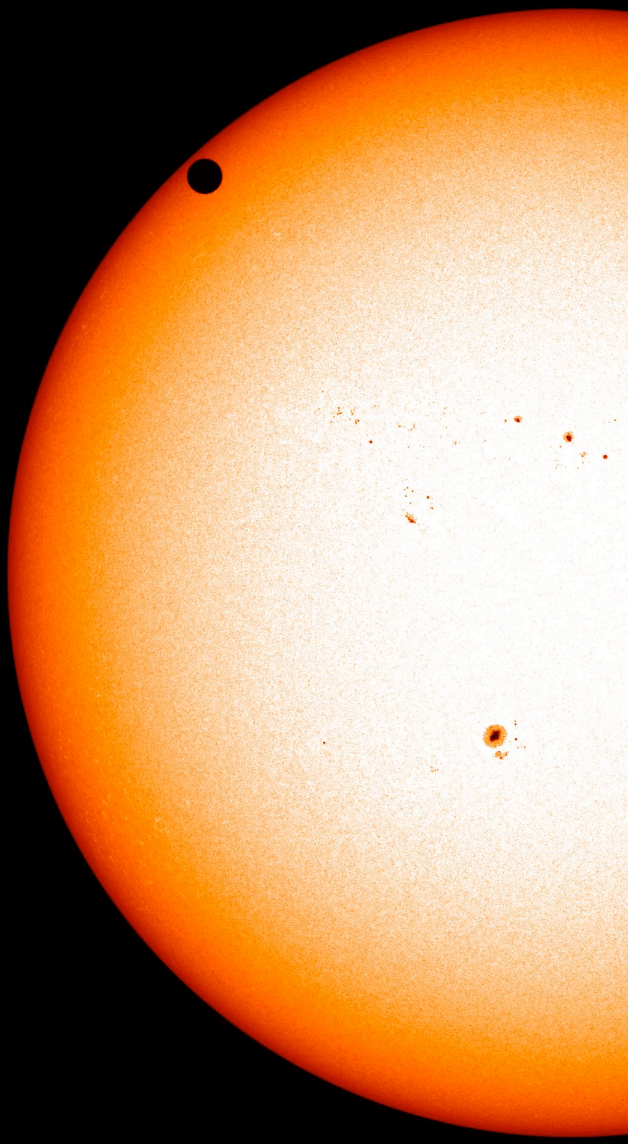
Lightcurves
can indicate further patterns (time consuming)



review Burrows 2014, Crossfield 2015

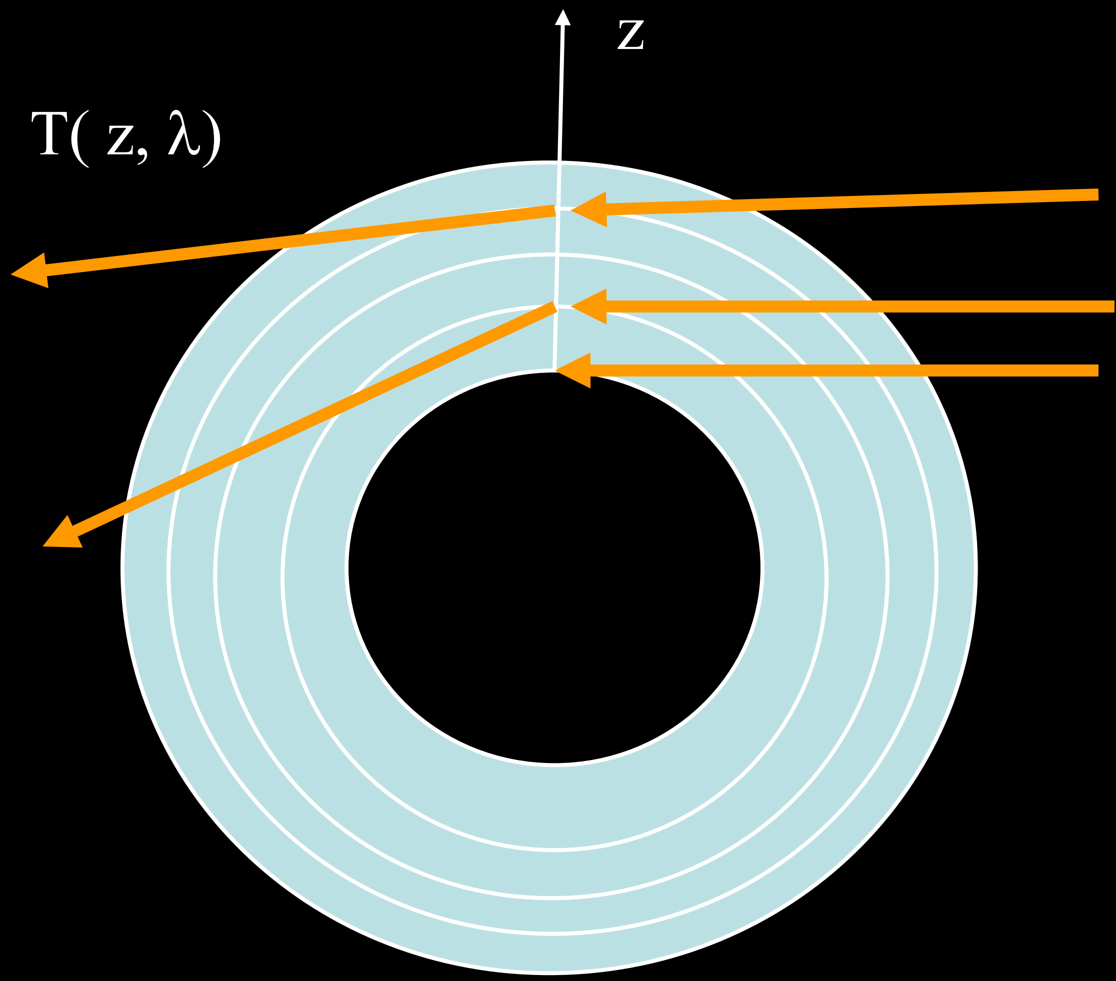
Transits: How deep can you probe an atm?

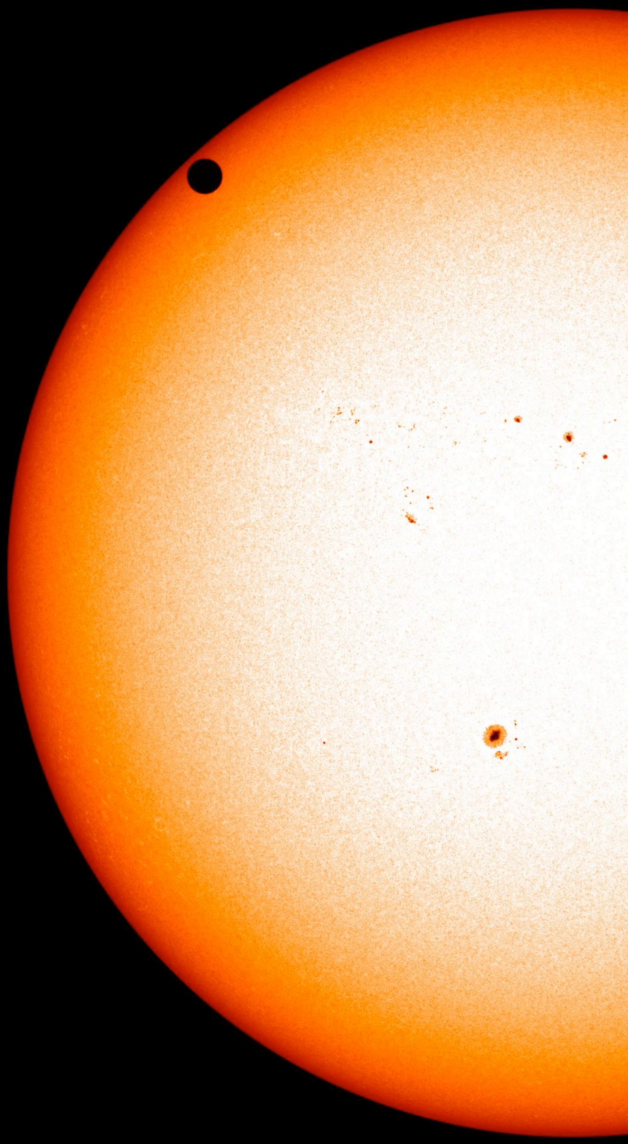




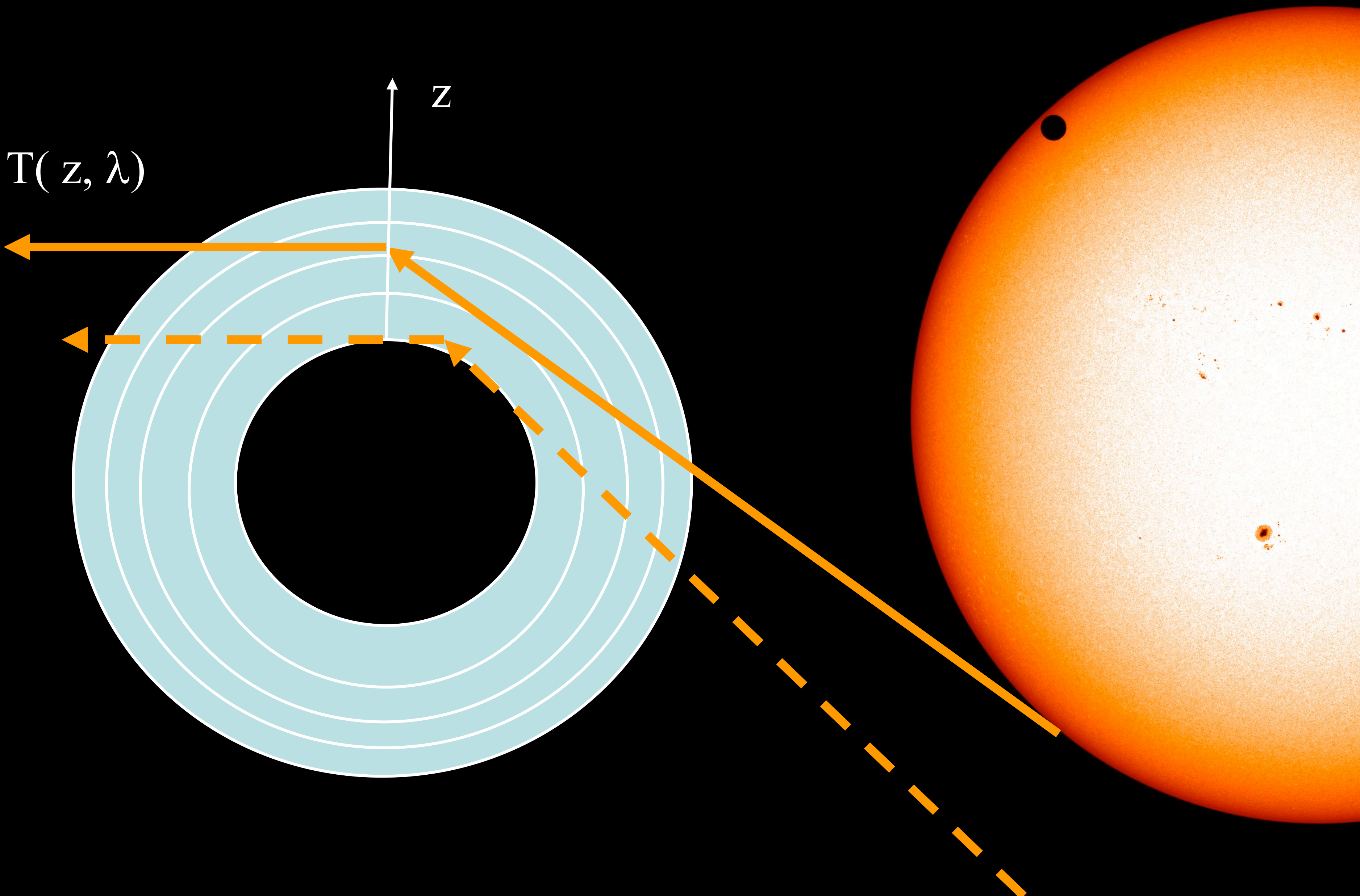
Betremieux & Kaltenegger 2013, 2015, Misra et al 2013

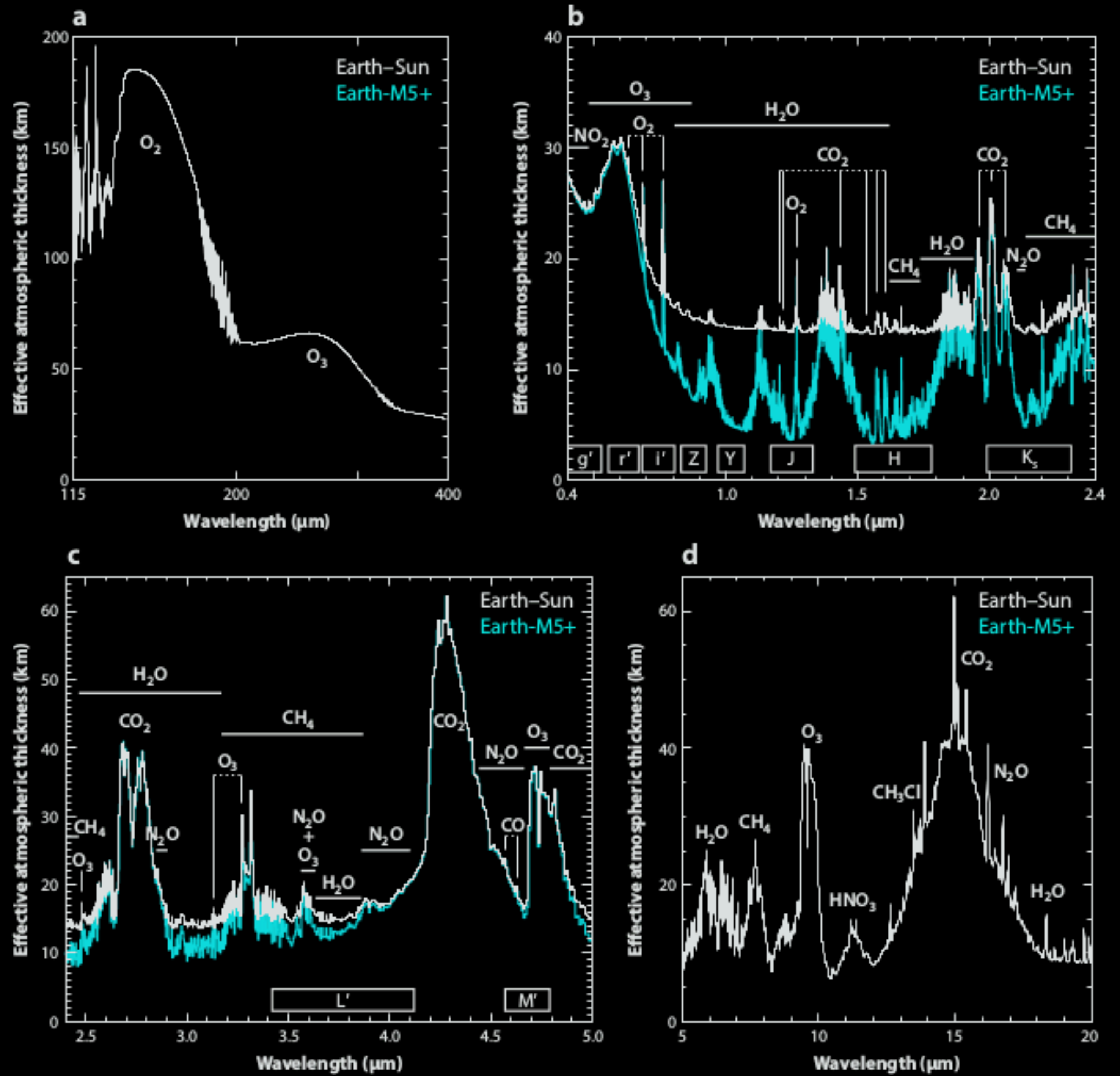
How deep can you probe the atmosphere?

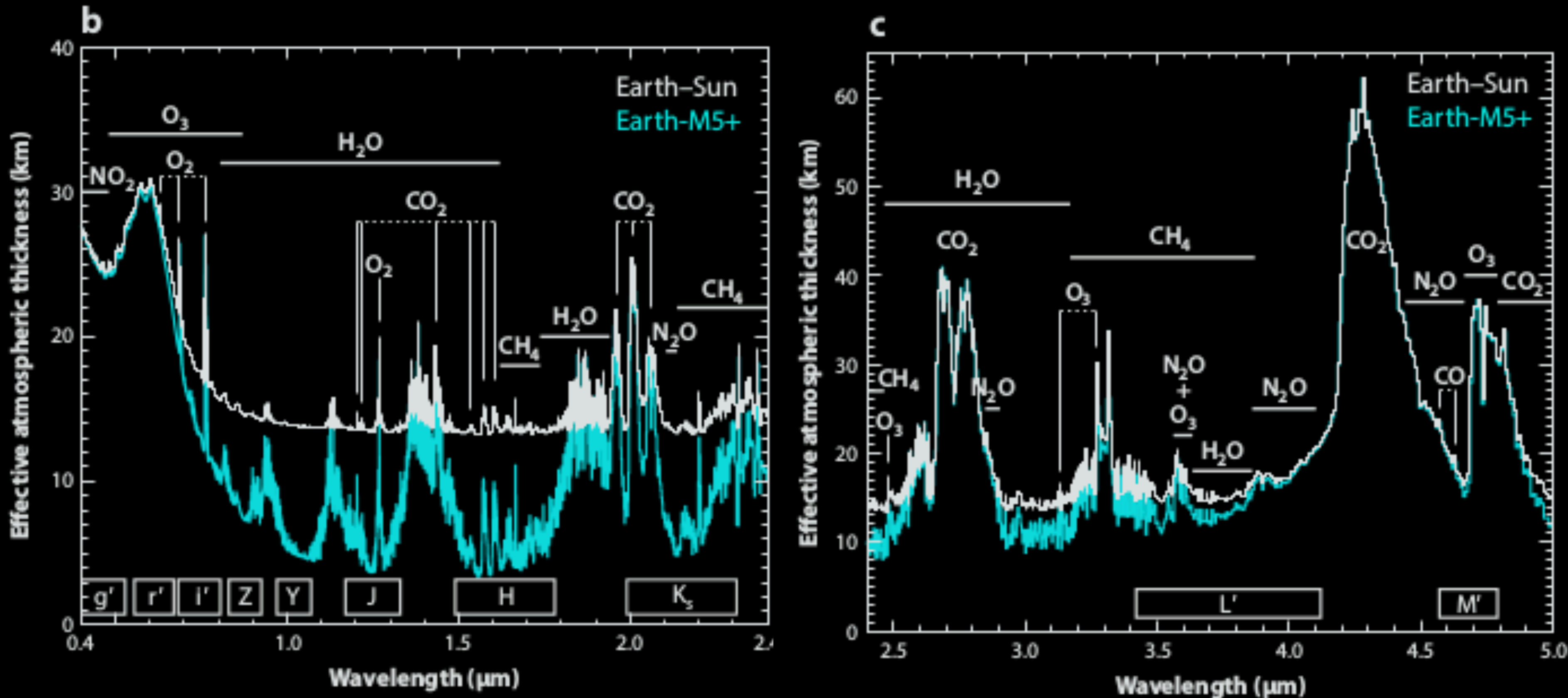


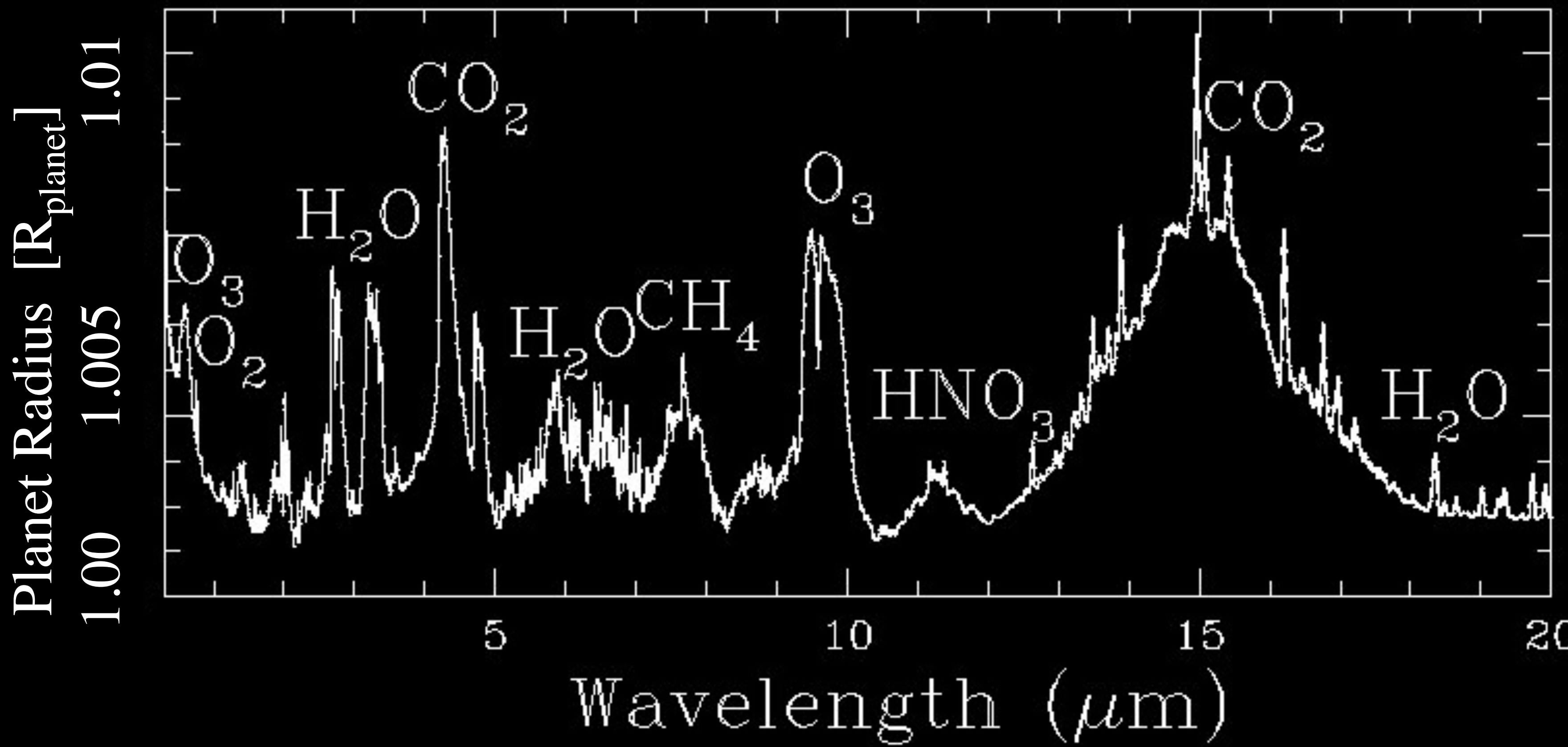


How deep can you probe the atmosphere?




a
Earth–Sun
Earth-M5+
O_2
O_3
Effective atmospheric thickness (km)
Wavelength (μm)
b
Earth–Sun
Earth-M5+
O_3
H_2O
NO_2
O_2
CO_2
O_2
CO_2
CH_4
H_2O
CH_4
N_2O
g′ r′ i′ Z Y J H K_s
Effective atmospheric thickness (km)
Wavelength (μm)
c
Earth–Sun
Earth-M5+
H_2O
CO_2
CH_4
CO_2
O_3
N_2O
O_3
CO_2
CH_4
O_3
N_2O
N_2O + O_3
N_2O
CO
H_2O
L′ M′
Effective atmospheric thickness (km)
Wavelength (μm)
d
Earth–Sun
Earth-M5+
CO_2
O_3
N_2O
CH_3Cl
H_2O
CH_4
HNO_3
H_2O
Effective atmospheric thickness (km)
Wavelength (μm)


b
Earth–Sun
Earth-M5+
Effective atmospheric thickness (km)
Wavelength (µm)
0
10
20
30
40
0.4
1.0
1.5
2.0
O_3
NO_2
O_2
H_2O
CO_2
O_2
CH_4
H_2O
CO_2
N_2O
CH_4
g′
r′
i′
Z
Y
J
H
K_s
c
Earth–Sun
Earth-M5+
Effective atmospheric thickness (km)
Wavelength (µm)
0
10
20
30
40
50
60
2.5
3.0
3.5
4.0
4.5
5.0
H_2O
CO_2
CH_4
CH_4
O_3
N_2O
O_3
N_2O + O_3
H_2O
N_2O
CO_2
N_2O
O_3
CO_2
CO
L′
M′

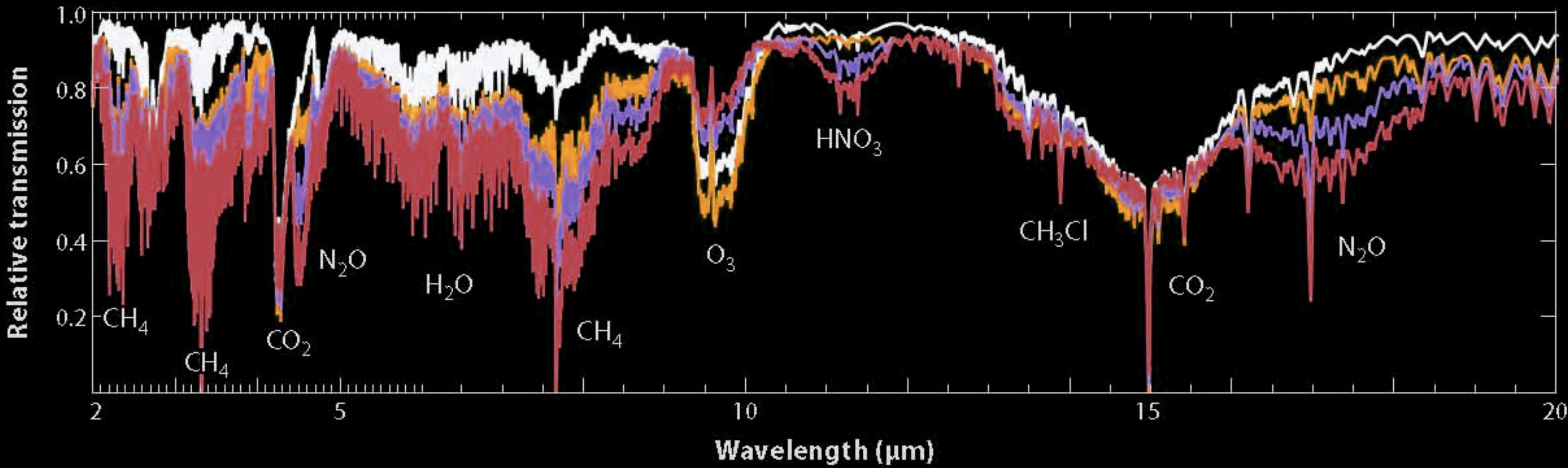


If you want Earths: Wavelength critical:

7.6μm CH_4, 9.6μm O_3, 15μm CO_2, H_2O 17μm+

O_3 in combination with CH_4 is biosignature

Kaltenegger & Traub 2009, Palle et al 2010, Betremieux & Kaltenegger 2013, Misra et al 2014



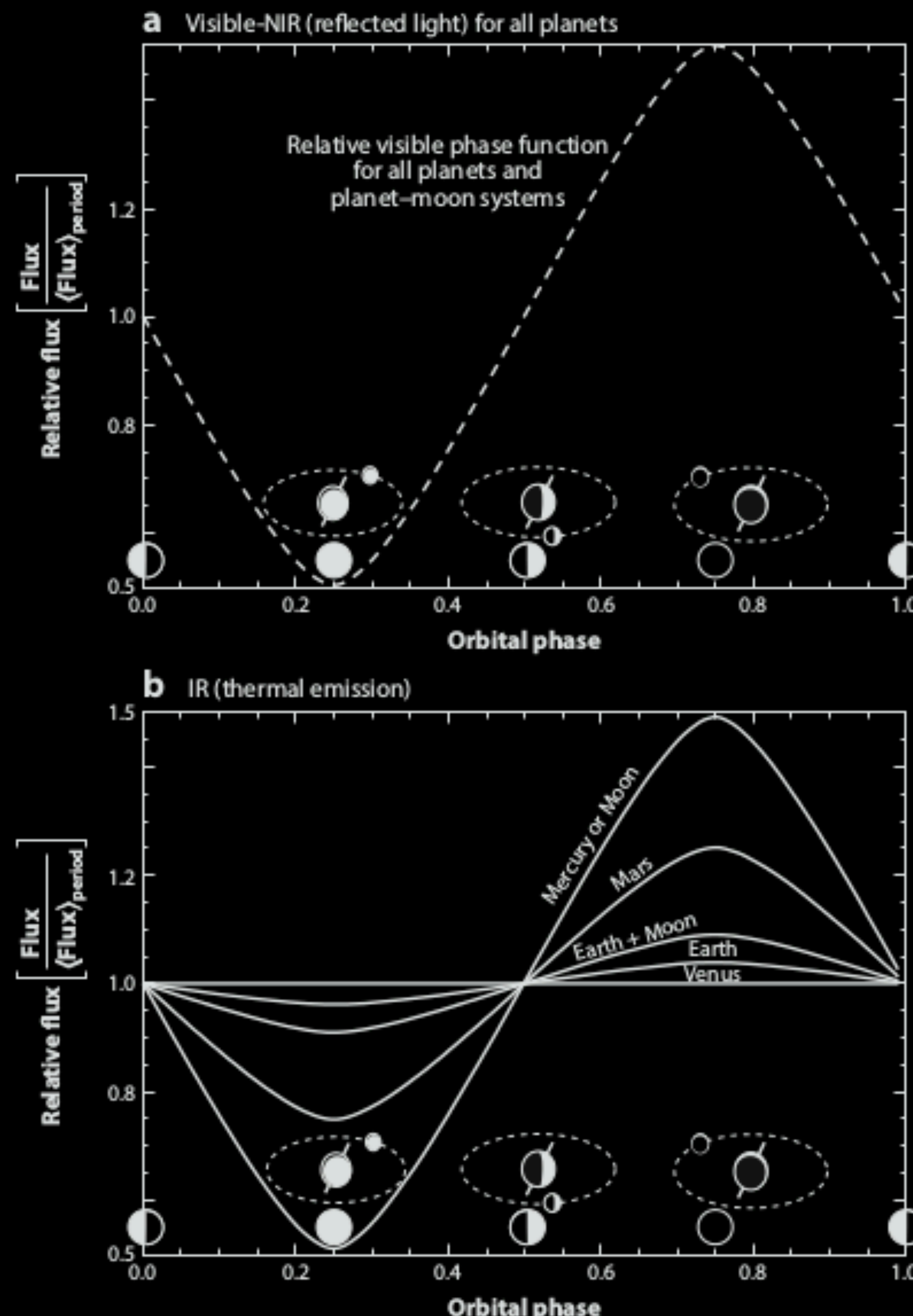
Spectral feature (or planet's effective height) get easier to detect for cool M stars (white=Sun, yellow to red M0 to M7 stars): 7.6µm CH_4, 9.6µm O_3, 15µm CO_2, H_2O 17µm+

in addition for cold stars

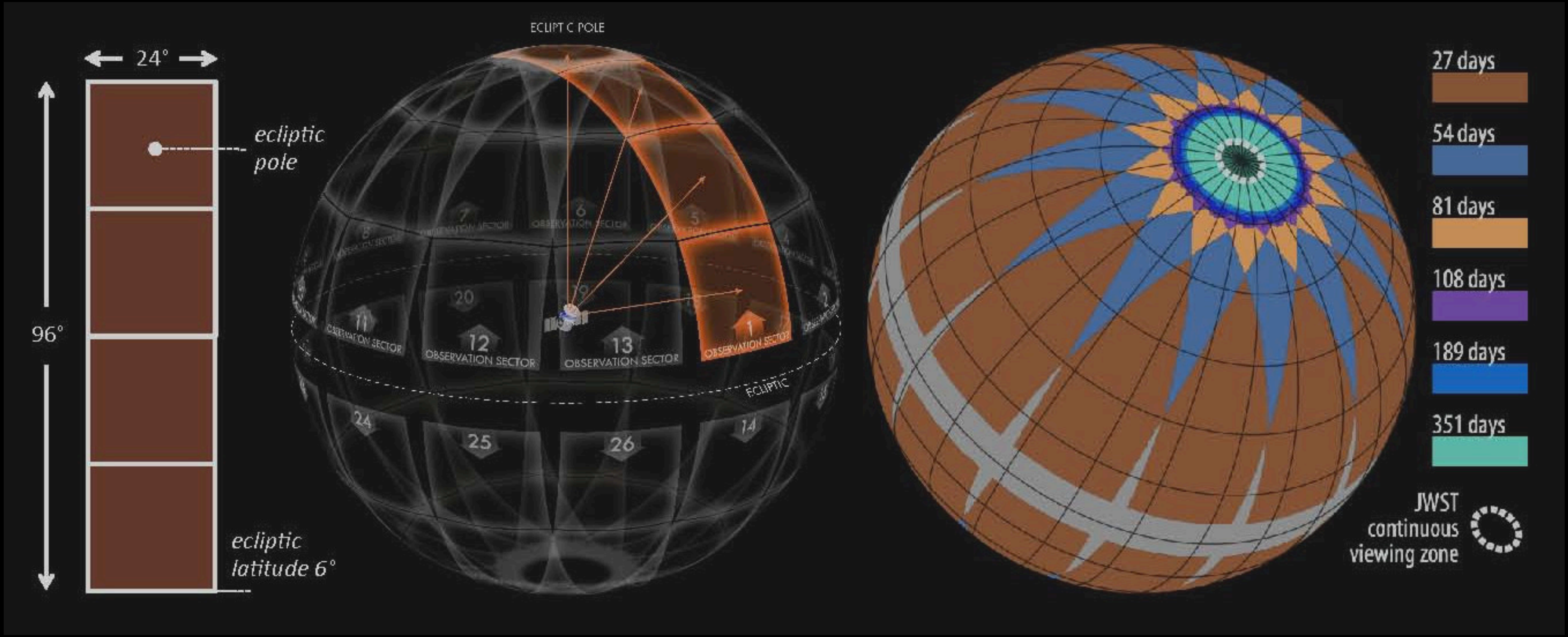
N_2O 17.6 µm should becomes detectable

O_3 <u>in combination</u> with CH_4 is biosignature

O_3 <u>in combination</u> with N_2O is biosignature


a Visible-NIR (reflected light) for all planets
Relative visible phase function
for all planets and
planet–moon systems
Relative flux [Flux / ⟨Flux⟩period]
1.2
1.0
0.8
0.5
0.0
0.2
0.4
0.6
0.8
1.0
Orbital phase
b IR (thermal emission)
1.5
1.2
1.0
0.8
0.5
Mercury or Moon
Mars
Earth + Moon
Earth
Venus
Relative flux [Flux / ⟨Flux⟩period]
0.0
0.2
0.4
0.6
0.8
1.0
Orbital phase

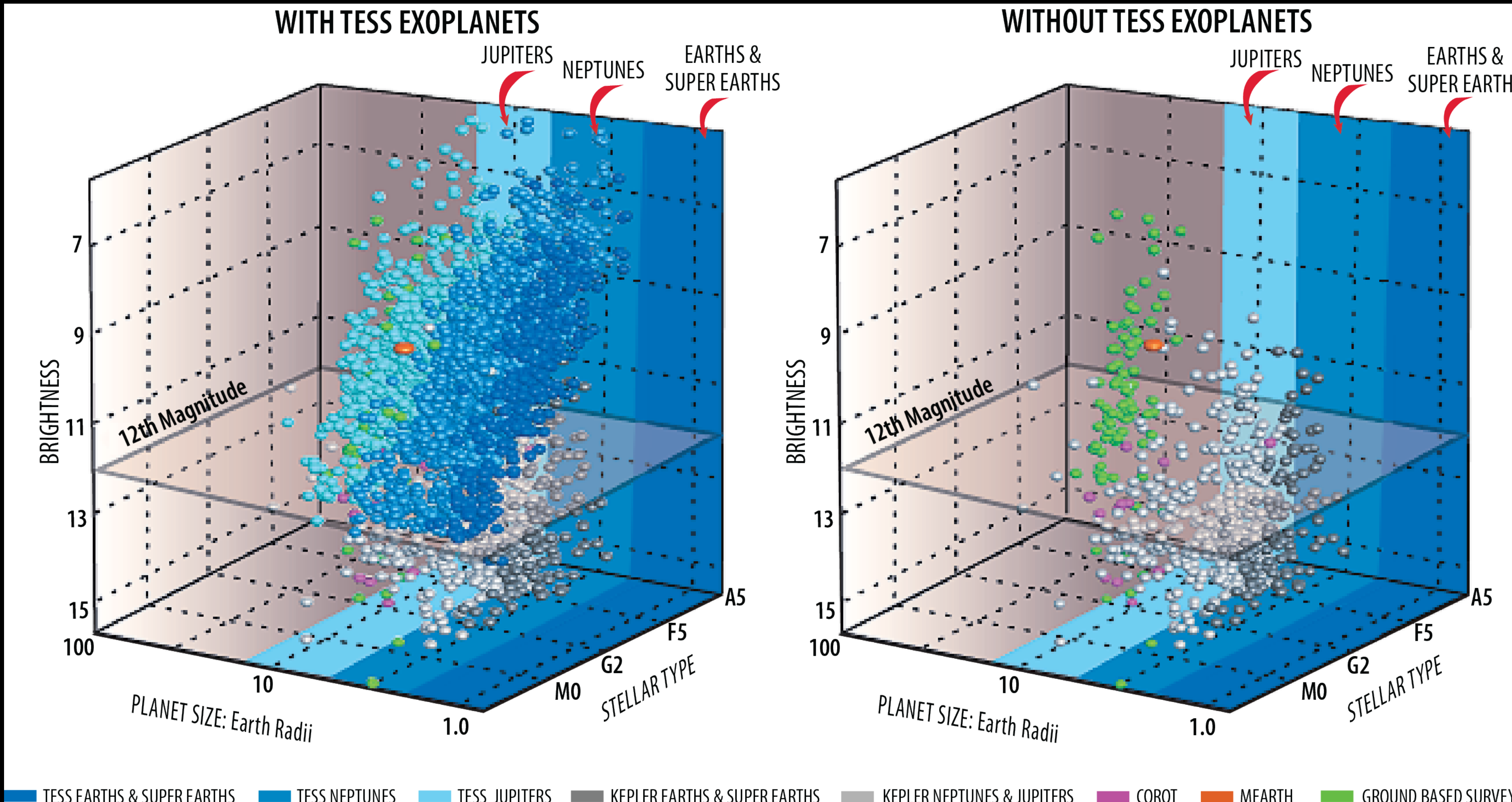

Exoplanets & TESS, JWST, ELTs
TESS: Transiting Exoplanet
Survey Satellite
launch mid 2018



Anticipating thousands of close by planets, dozens of Earths-sized planets, Earth & Super-Earths in the HZ of cool stars

Ricker et al., 2014

Find best Targets: Close by exoplanets



TESS – NASA explorer (PI G. Rucker MIT)

Transiting Exoplanet Survey Satellite, 2018 launch, 1 Mio stars

PLATO – ESA M-class (PI H. Rauer)

Planetary Transit & Oscillation of Stars, 2024 launch, 10 Mio stars

Exoplanets & OST (9m IR in space 6-25microns)

Tracing the Signatures of Life and the Ingredients of Habitable Worlds

The Origins Space Telescope will map the trail of water through all stages of star and planet formation and characterize the atmospheres of potentially habitable worlds.

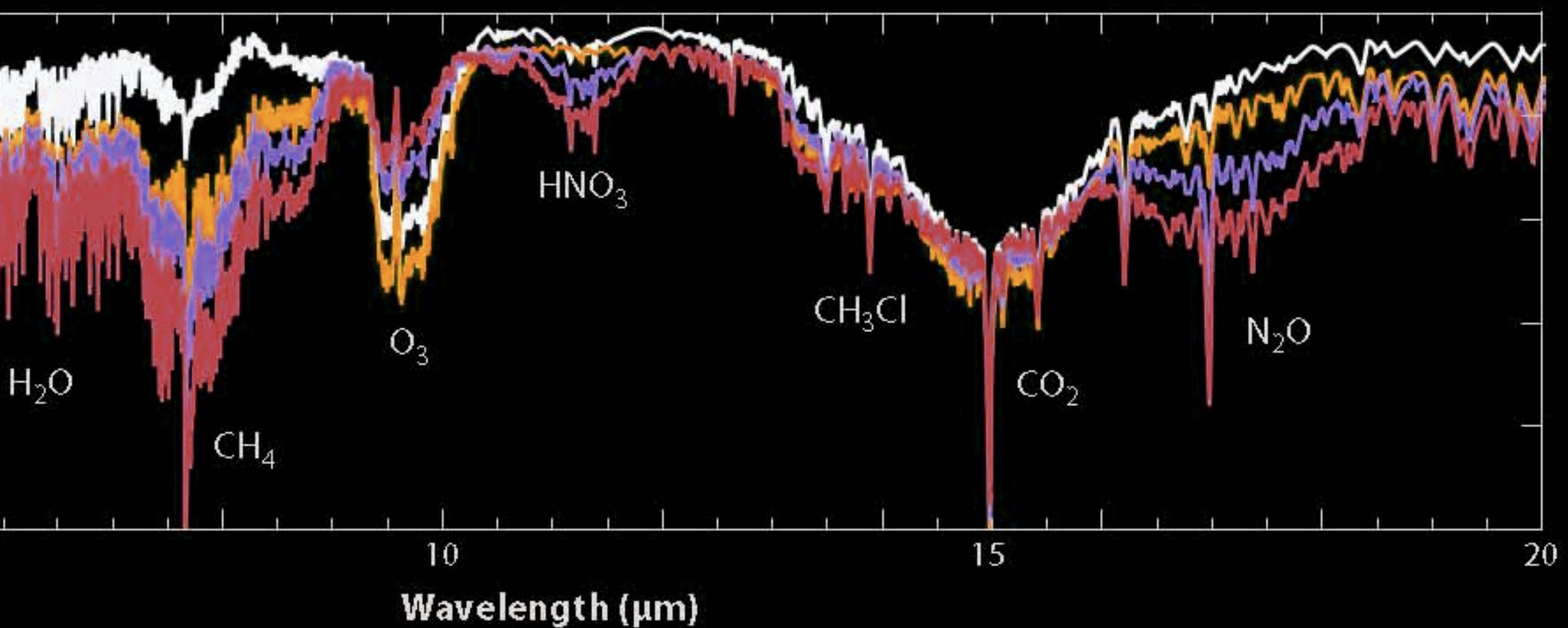
Science cases proposed for OST

1) Transits for exoplanets – HIGH

- TESS (launch early 2018) will identify many transiting rocky planets in the HZ of their cool host stars
- Ground-based searches provides targets like the Trappist-1 system
- JWST will have limited time to characterize
    - "Earths" on limit of technical capability
    - Design requires several visits to observer full interesting IR wavelength band (6-18 microns)

2) Coronagraph – LOW

Direct imaging doe not drive exoplanet science case
Warm Jupiters and Neptunes expand our understanding of our Solar System (not easy to detect otherwise)



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in addition for cold stars N_2O 17.6 μm should becomes detectable

O_3 <u>in combination</u> with CH_4 is biosignature
O_3 <u>in combination</u> with N_2O is biosignature

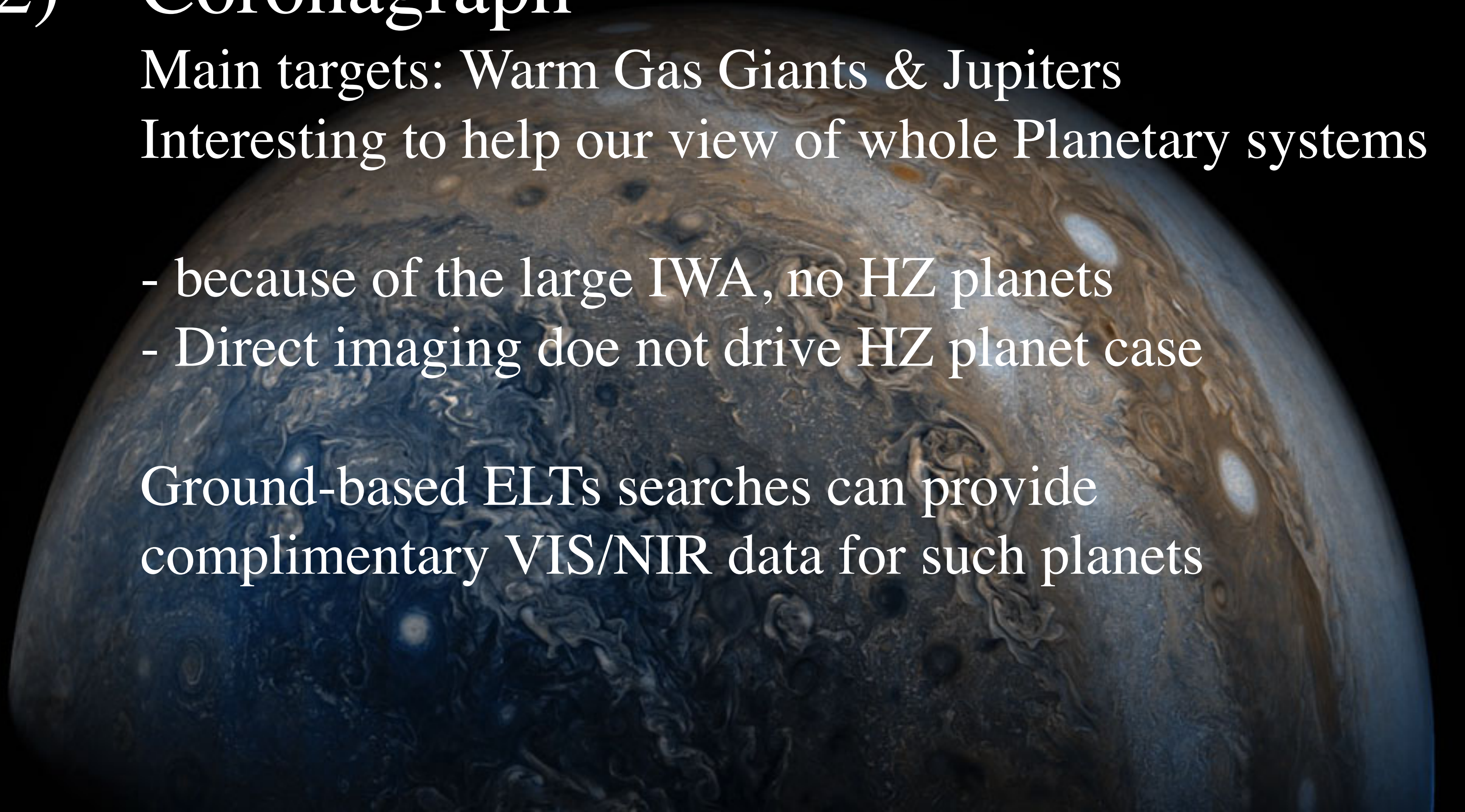
Science cases proposed for OST

2) Coronagraph

Main targets: Warm Gas Giants & Jupiters
Interesting to help our view of whole Planetary systems

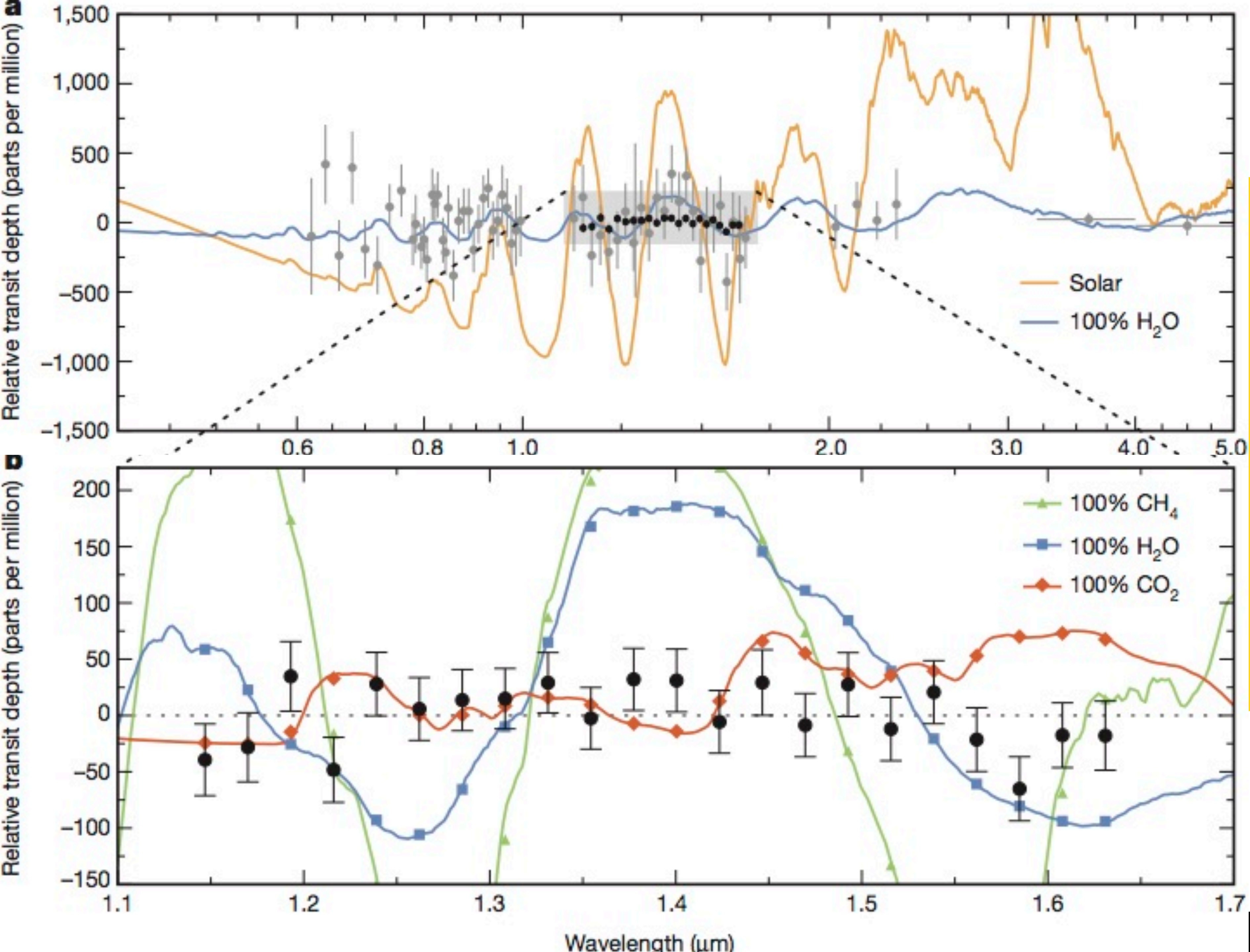
- because of the large IWA, no HZ planets
- Direct imaging doe not drive HZ planet case

Ground-based ELTs searches can provide
complimentary VIS/NIR data for such planets



Perspectives of Exoplanet Detection & Characterization

Hopeful!



a
1,500
1,000
500
0
−500
−1,000
−1,500
Relative transit depth (parts per million)
0.6
0.8
1.0
2.0
3.0
4.0
5.0
Solar
100% H2O
b
200
150
100
50
0
−50
−100
−150
Relative transit depth (parts per million)
100% CH4
100% H2O
100% CO2
1.1
1.2
1.3
1.4
1.5
1.6
1.7
Wavelength (μm)