Super-Earths & Life
A interdisciplinary puzzle

Biomarkers of Habitable Worlds

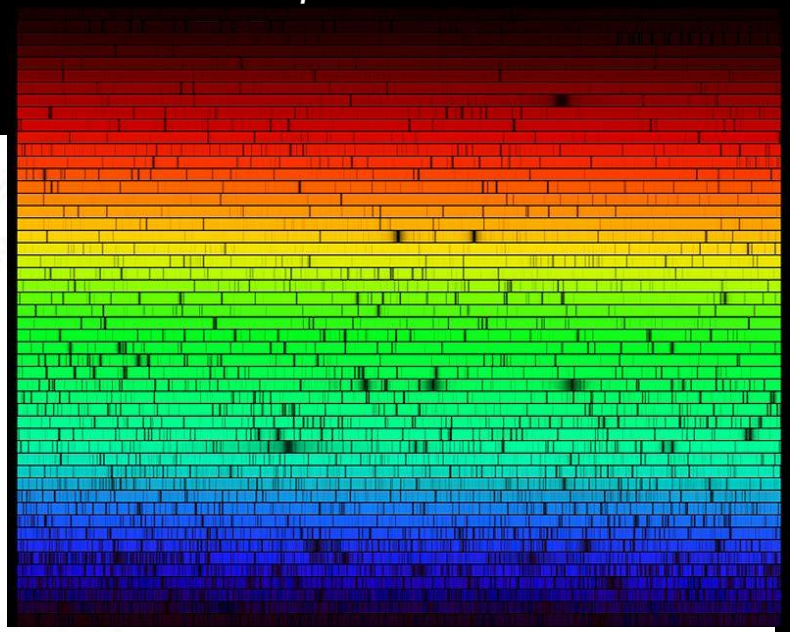
Lisa Kaltenegger, MPIA/CfA

Toledo, June 2 2011

NASA/STS-125 Photo

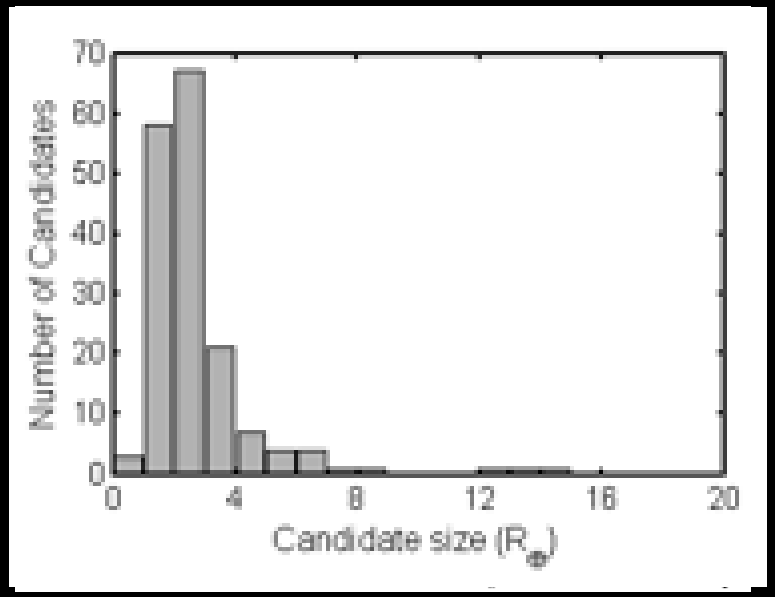
a dot of light = astronomy

We will never know how to study by any means the chemical composition of stars
Auguste Comte (1835)



Planets... 500+

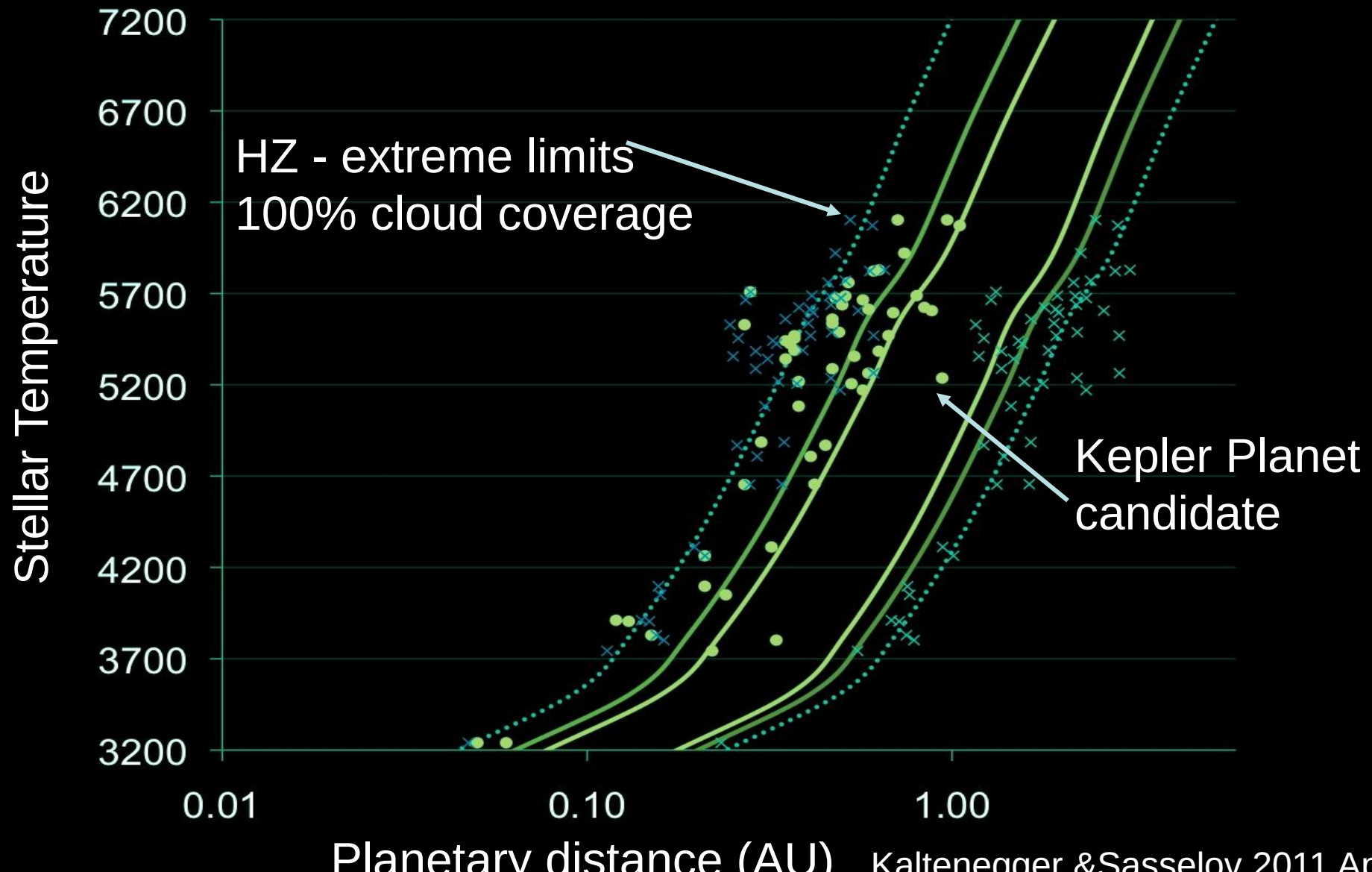
(1000)*age of statistics*



The real question:

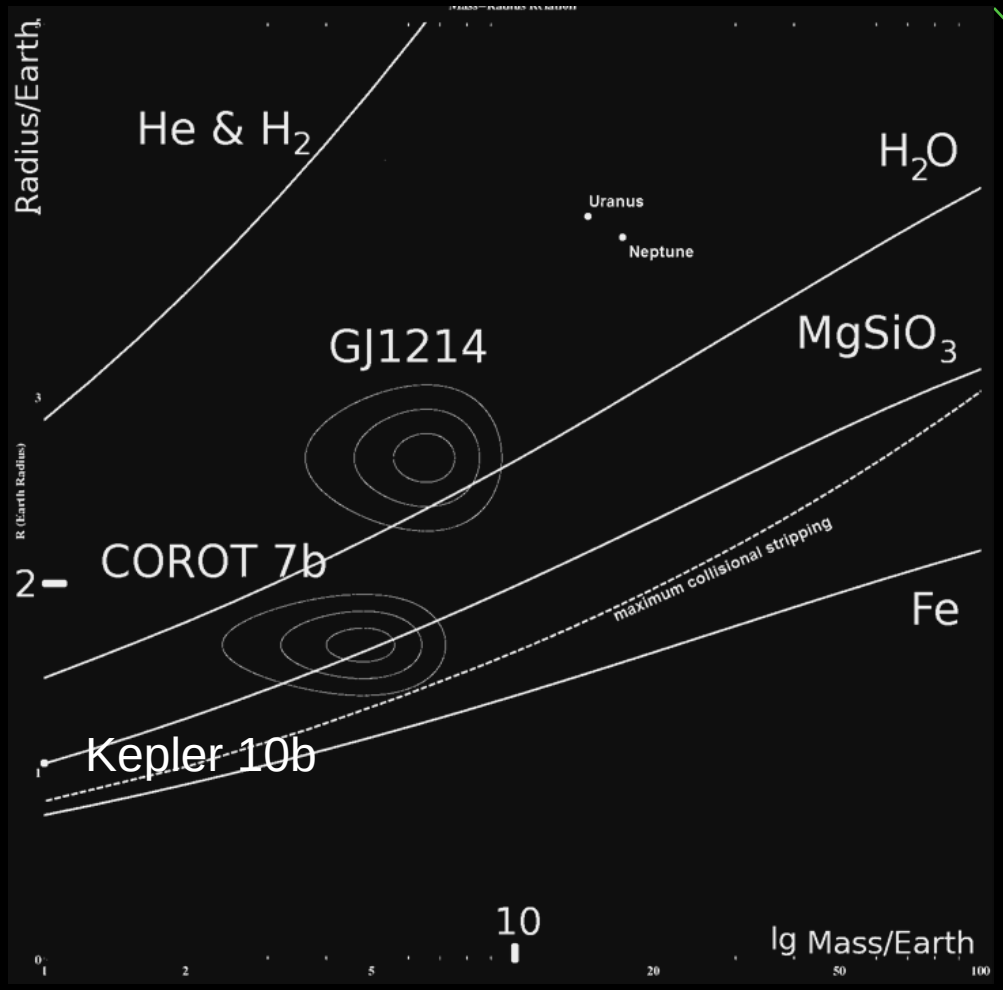
What are they like?

Habitable Zone: Kepler's pot. habitable planets explored

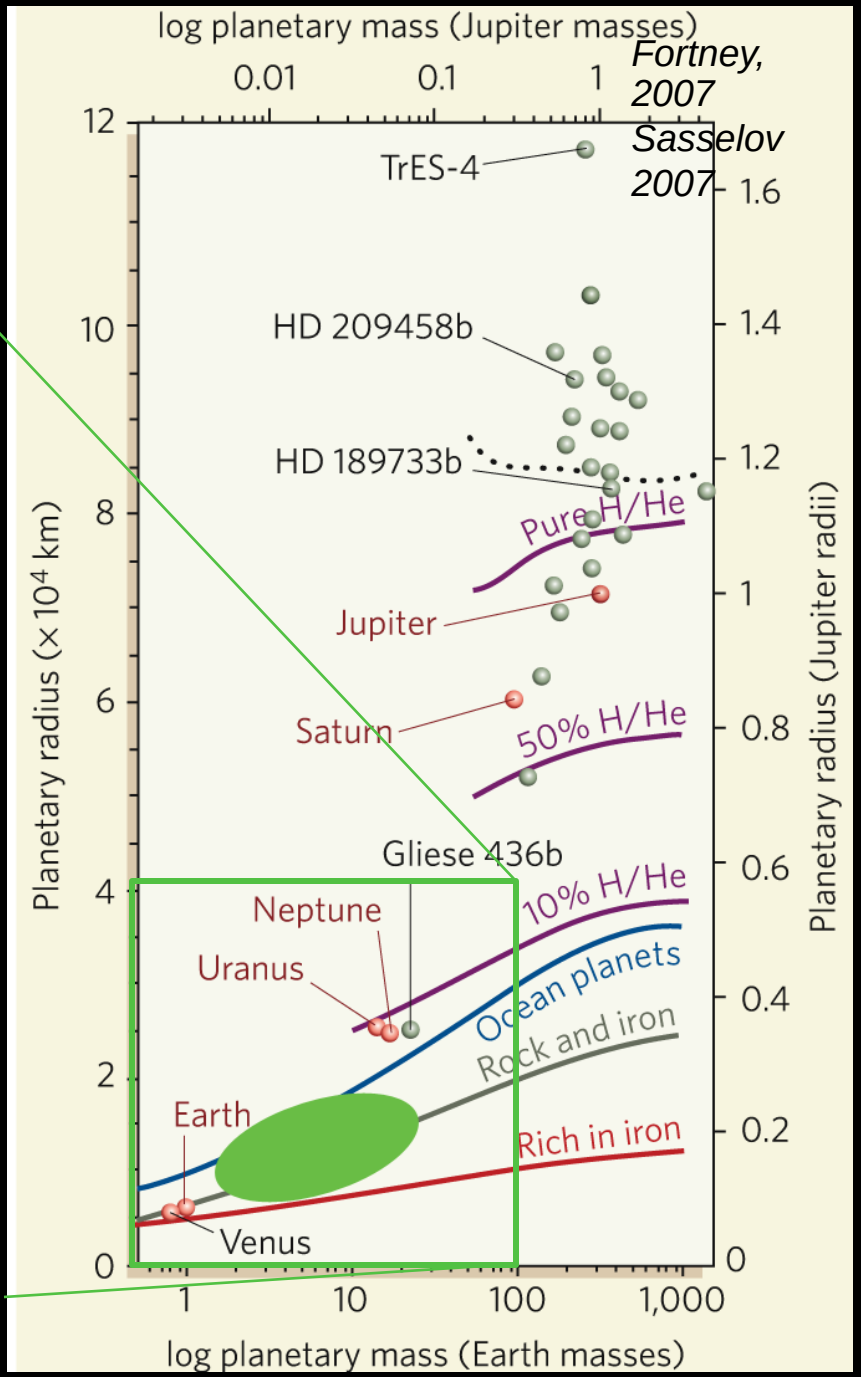


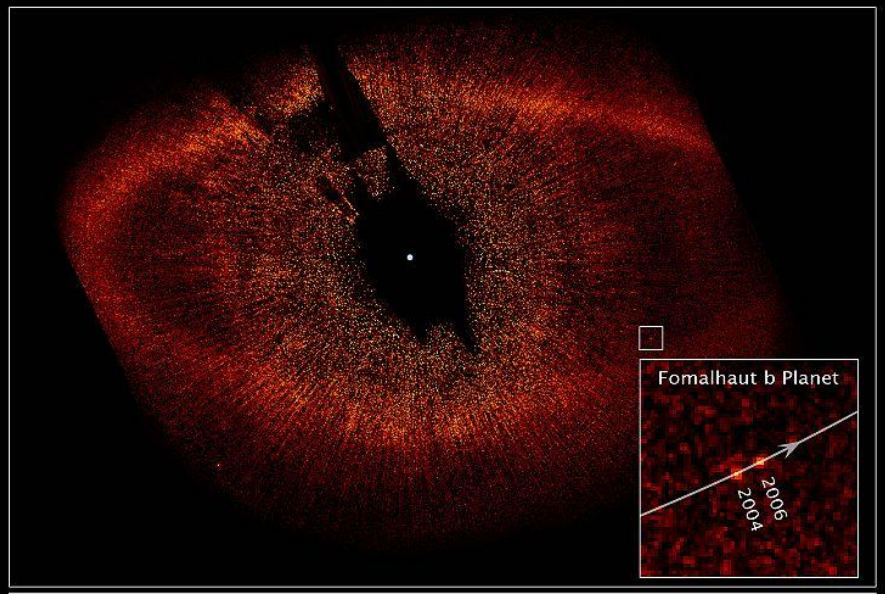
Kaltenegger &Sasselov 2011 ApJ

RV & Transits: density



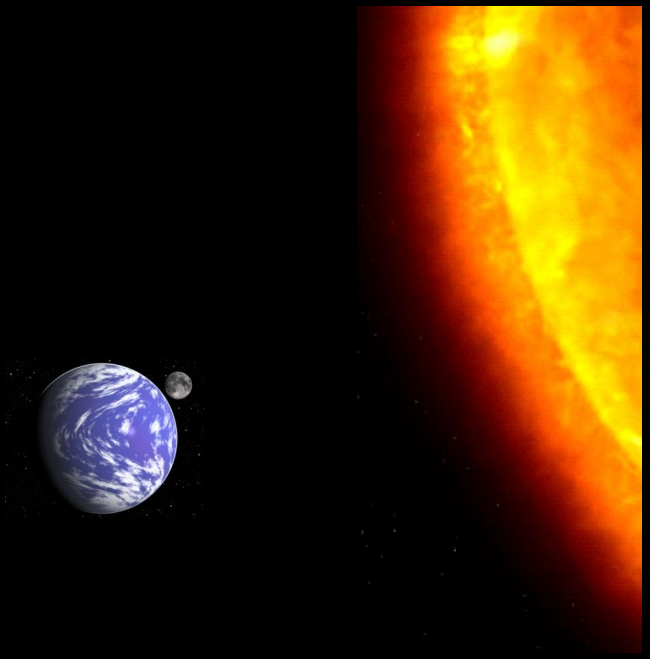
Zeng & Sasselov (in press)

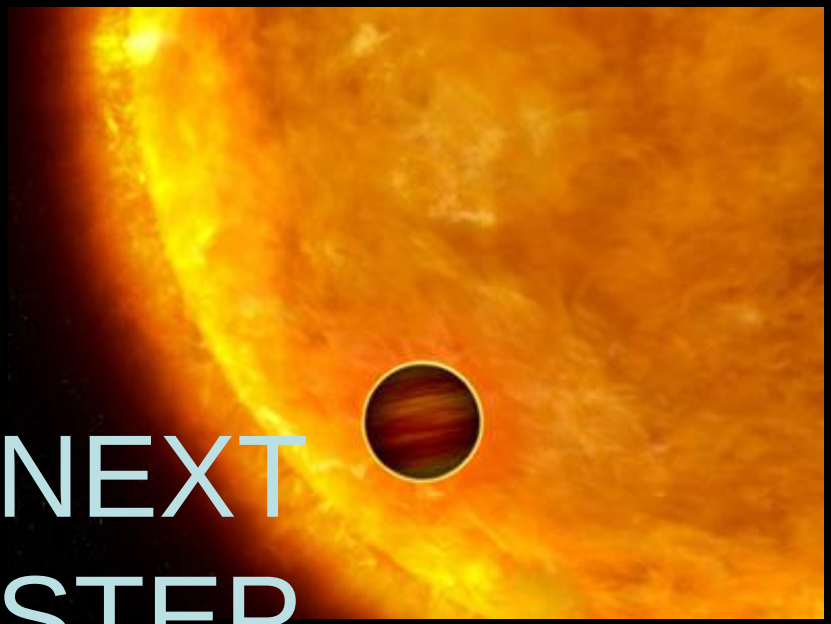




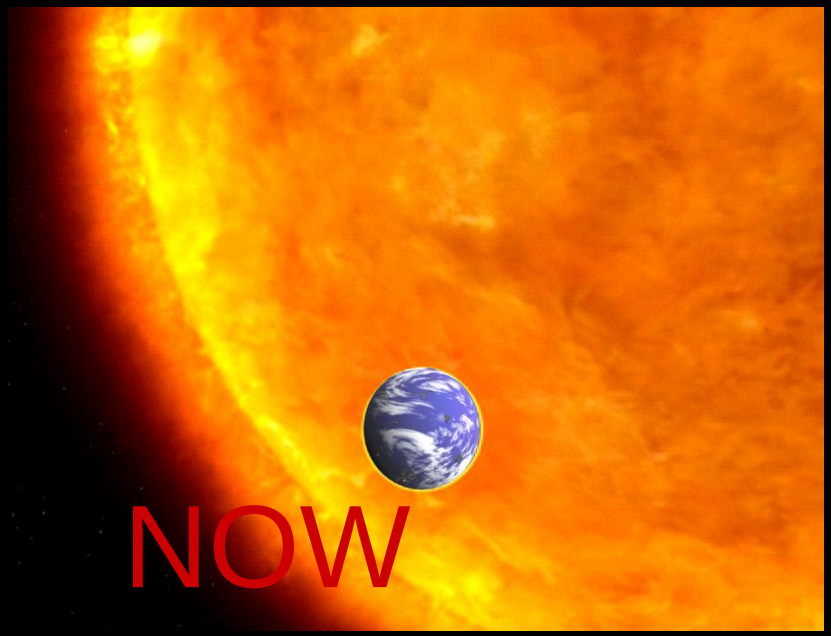
Fomalhaut System
Hubble Space Telescope • ACS/HRC

NASA, ESA, and P. Kalas (University of California, Berkeley) STScI-PRC08-39a





NEXT STEP

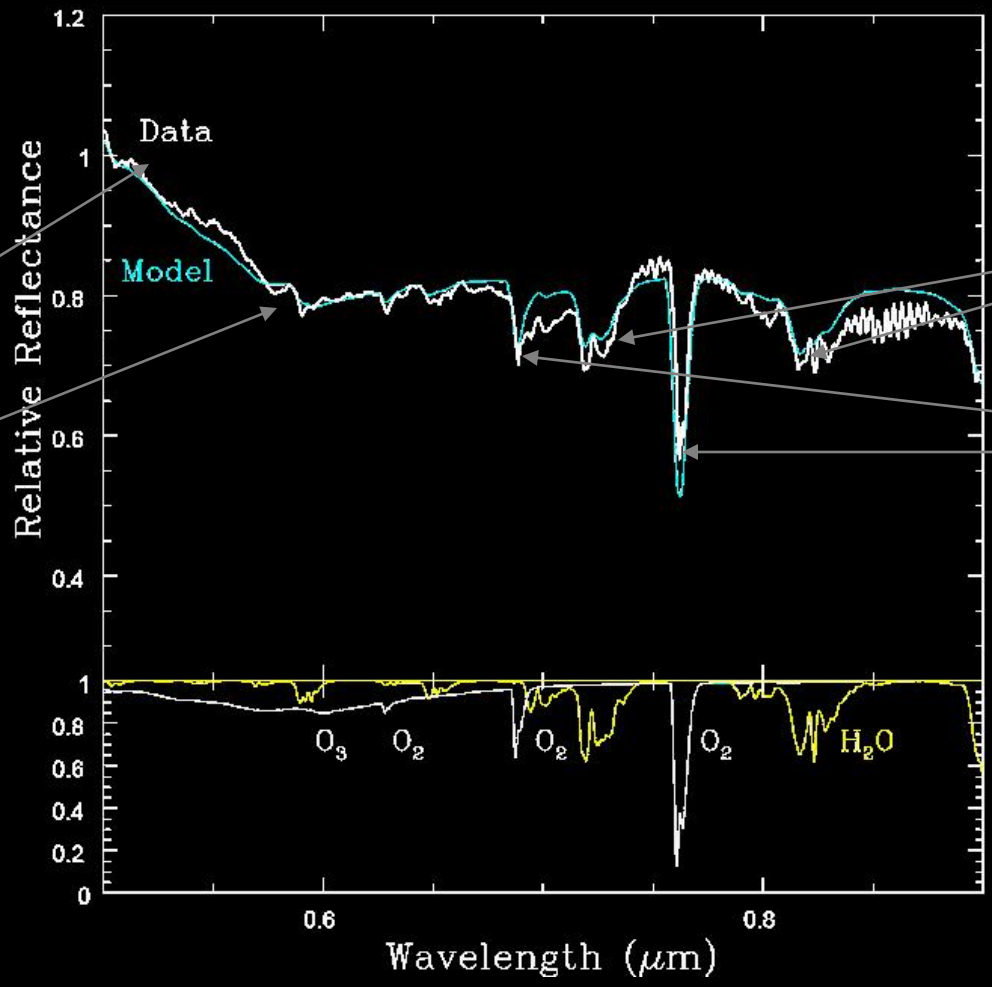


NOW

Visible spectrum of Earth

Rayleigh

Ozone O_3



Water H_2O

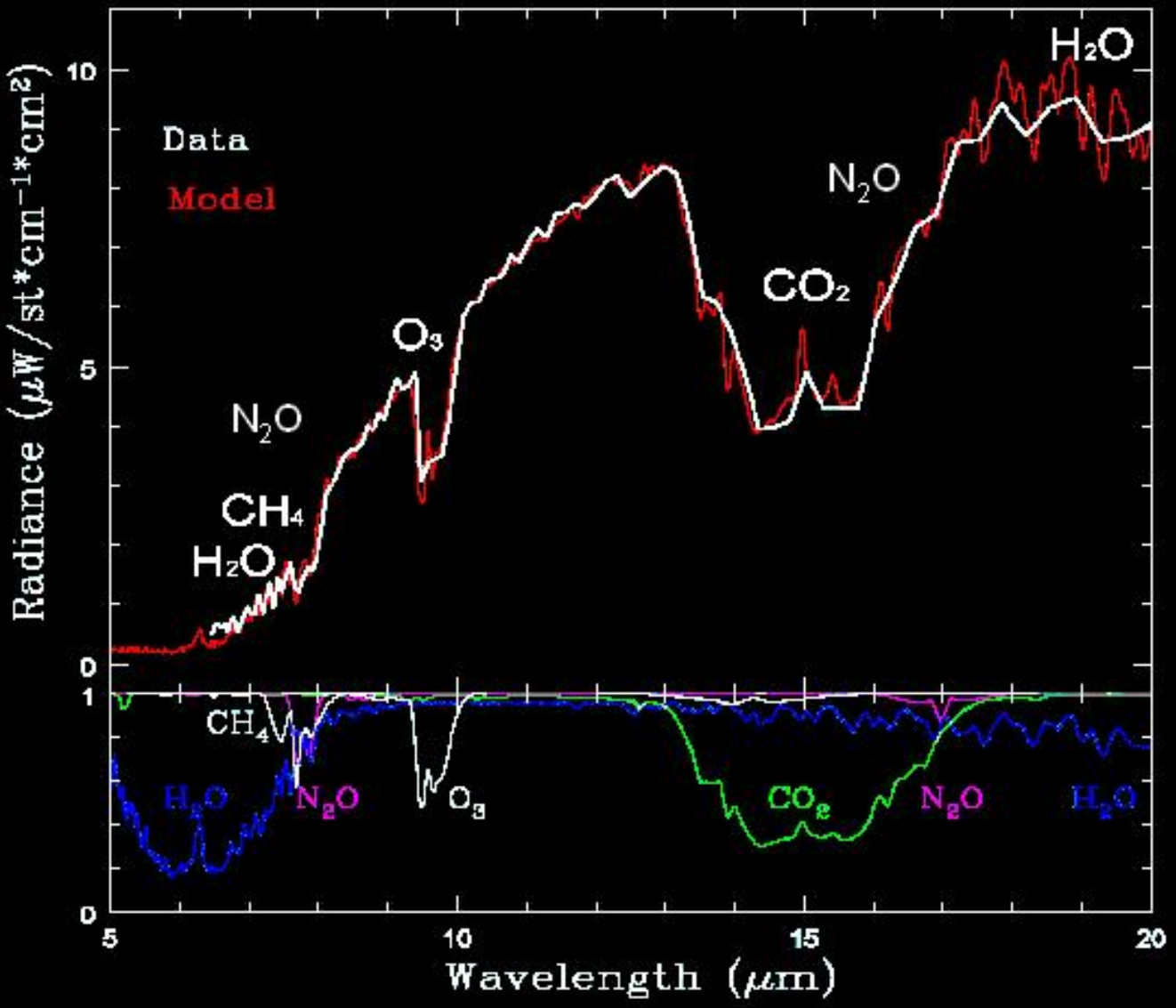
Oxygen O_2

Observed Earthshine, reflected from dark side of moon.

Ref.: Kaltenegger et al 2007, ApJ 574, 2007

see also e.g.: Montanez-Rodrigez 2005, 07, Arnold 2002, 06, 09; Turnbull 06

Earth IR-emission



Kaltenegger, Traub, Jucks 2007 (ApJ)

TES data; Christensen 2004

Signs Of Life On An Earth-like Planet

Ozone & Methane (or other reducing gas) Biomarker
Oxygen

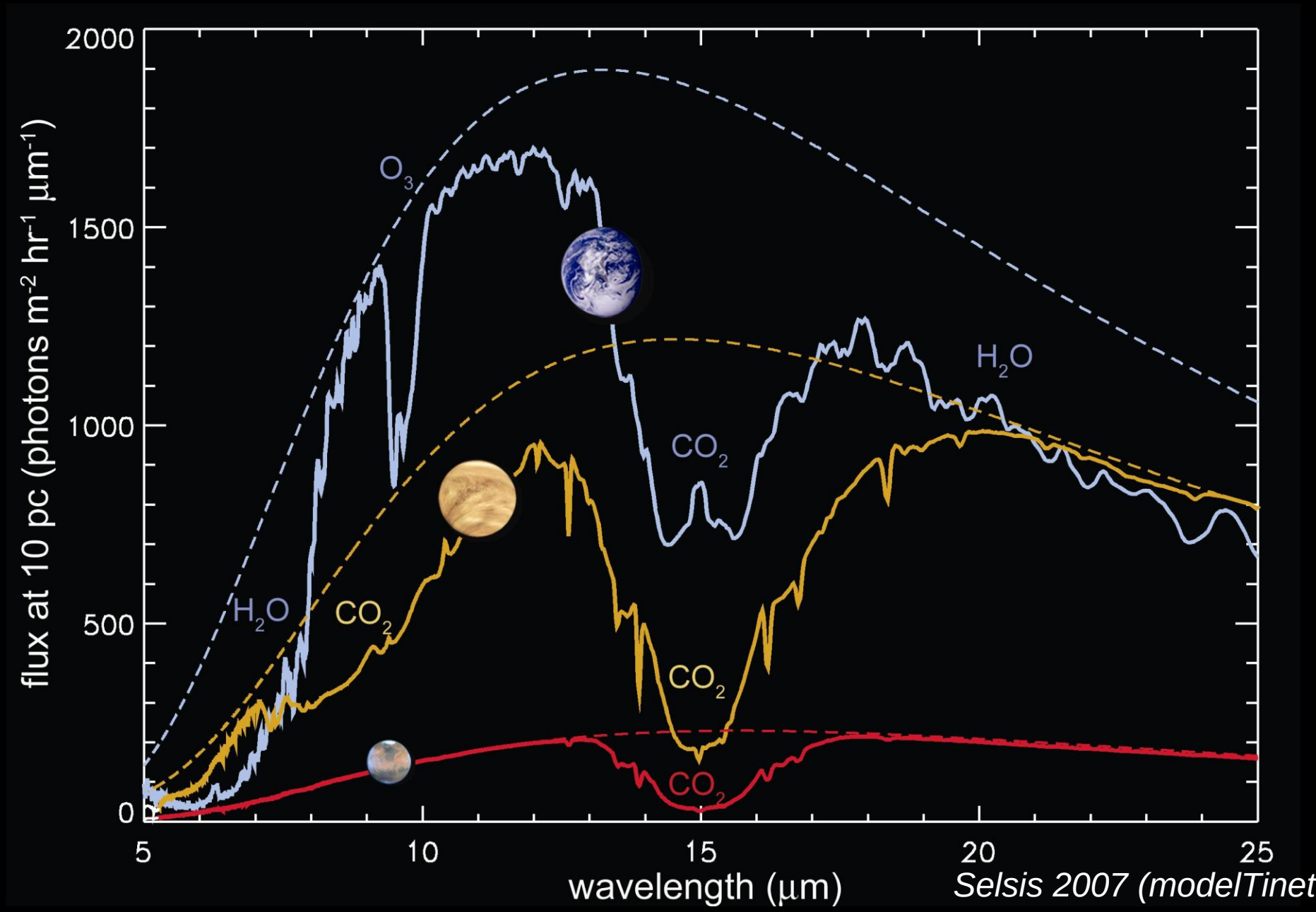
Nitrous oxide

Water makes Oxygen – WITHOUT life Bio-indicators

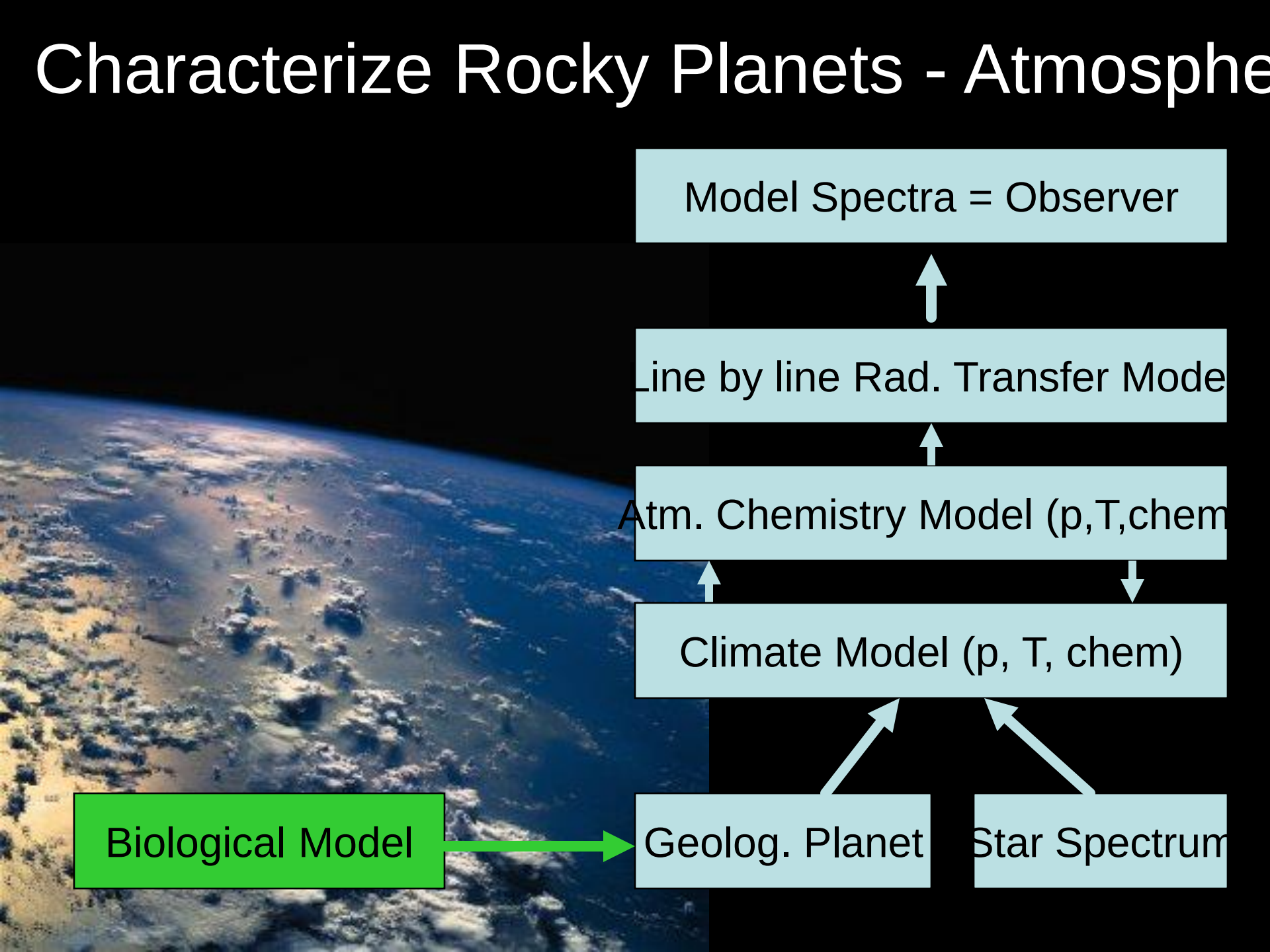
Carbon dioxide - greenhouse & HZ extend

Surface/Vegetation– good enough SNR per 1/20 of planet‘s rotation to detectsurfacefeature

Features: 1) observables & 2) unique ?

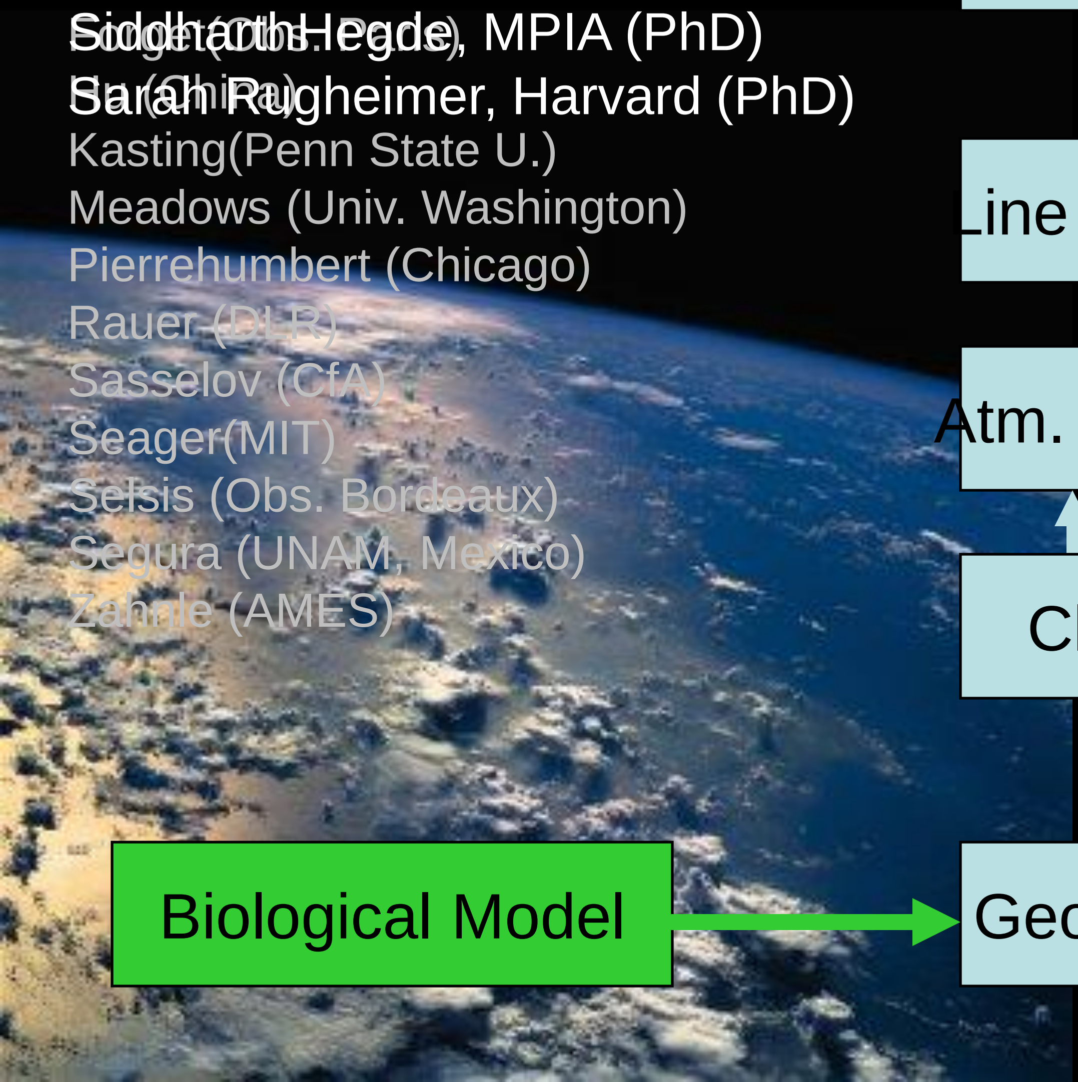


Characterize Rocky Planets - Atmosphe



“Characterize ” => Spectra UNIQUE?

Kaltenegger (MPIA/CfA)
Andras Zsom MPIA (Postdoc)
Yamilla Miguel MPIA (Postdoc)
Siddharth Hegde, MPIA (PhD)
Forget (Obs. Paris)
Sarah Rugheimer, Harvard (PhD)
Lu (China)
Kasting(Penn State U.)
Meadows (Univ. Washington)
Pierrehumbert (Chicago)
Rauer (DLR)
Sasselov (CfA)
Seager(MIT)
Selsis (Obs. Bordeaux)
Segura (UNAM, Mexico)
Zahnle (AMES)



Model Spectra = Observer

Line by line Rad. Transfer Mode

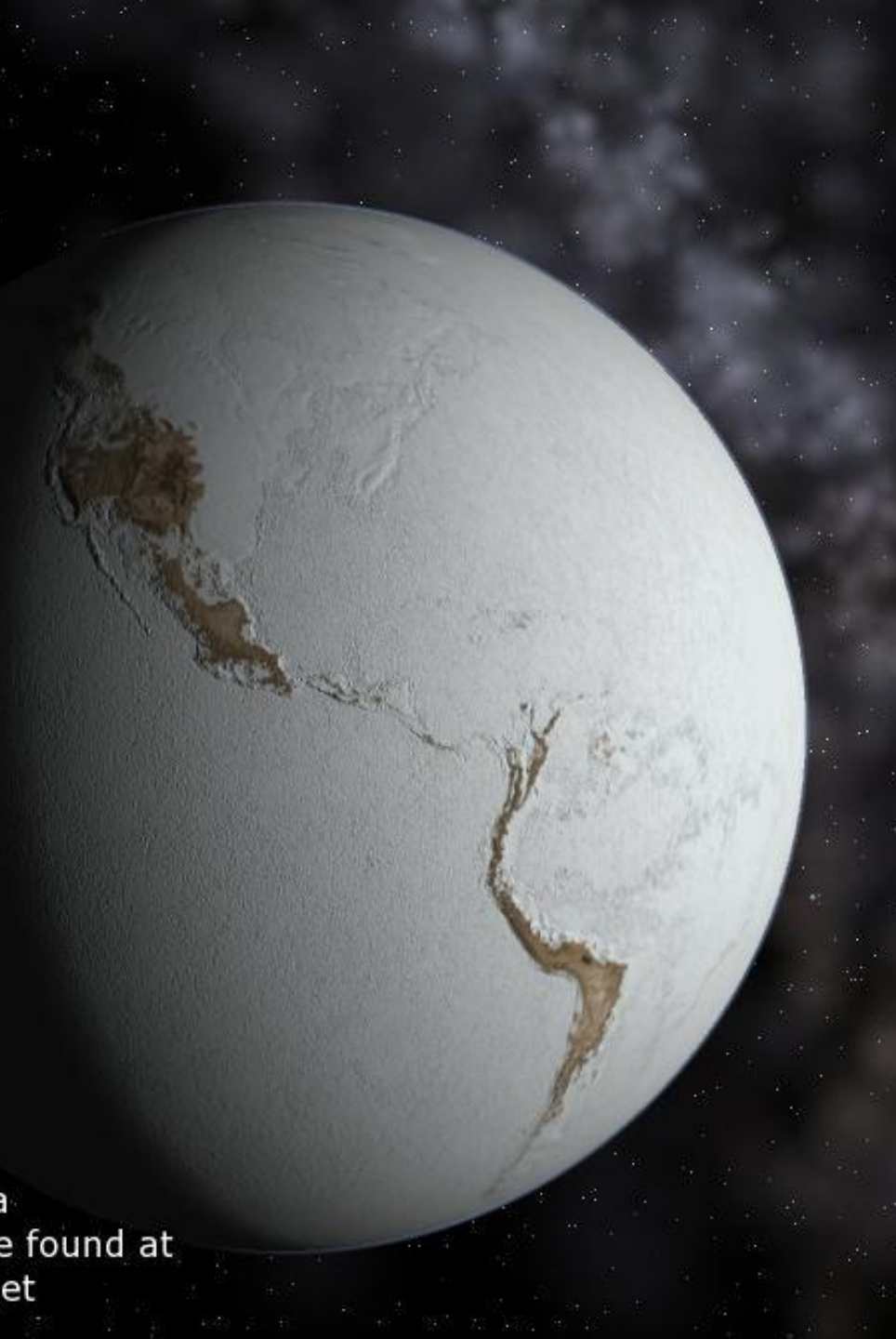
Atm. Chemistry Model (p,T,chem

Climate Model (p, T, chem)

Geolog. Planet

Star Spectrum

Biological Model

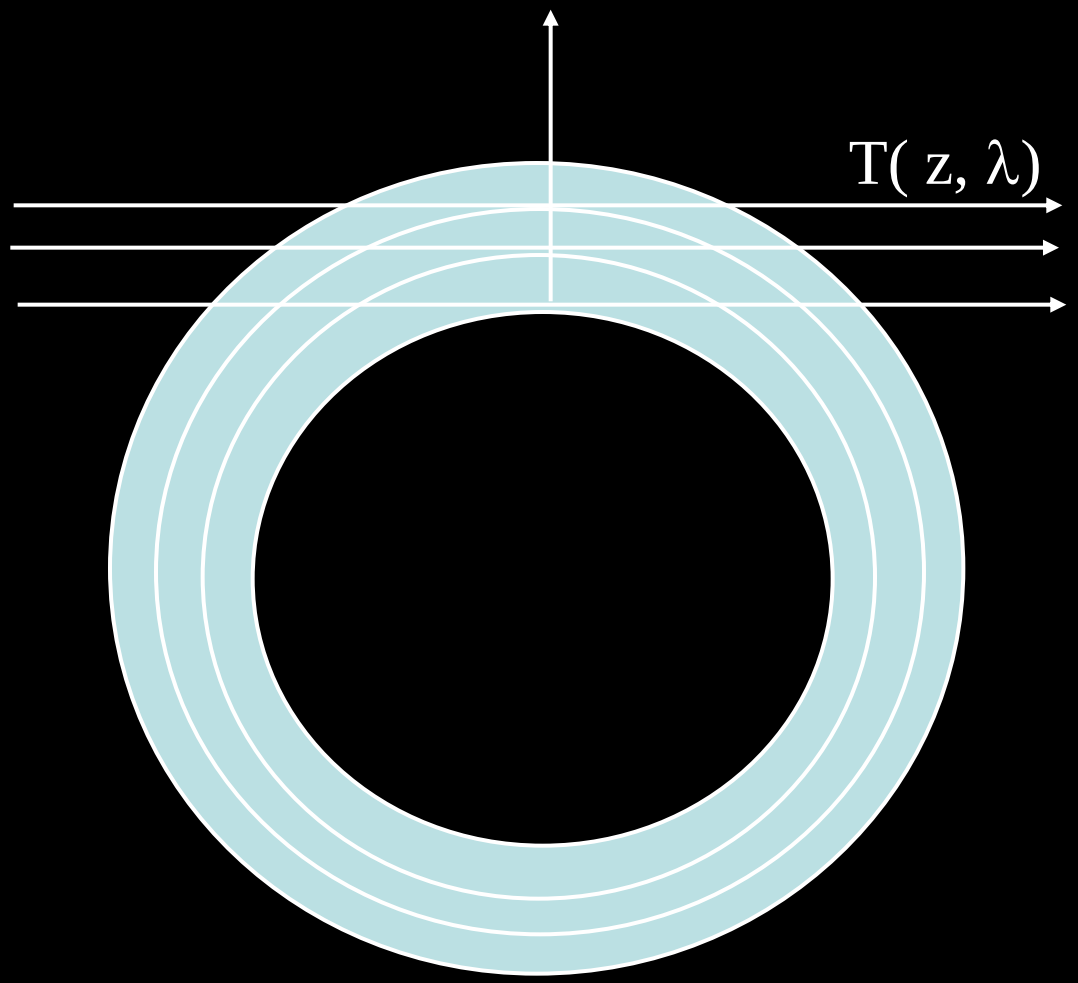


Different evolution state / age / mass / etc.

THE TEST:
GRID of Spectra of different planets
– Exoplore underlying physics
- Unique?
- Detectable?
- Inst. requirements
- Retrieval from

Transit Geometry

$H \approx h \approx T/(g\,\mu)$



h is the effective height of an opaque atmosphere:

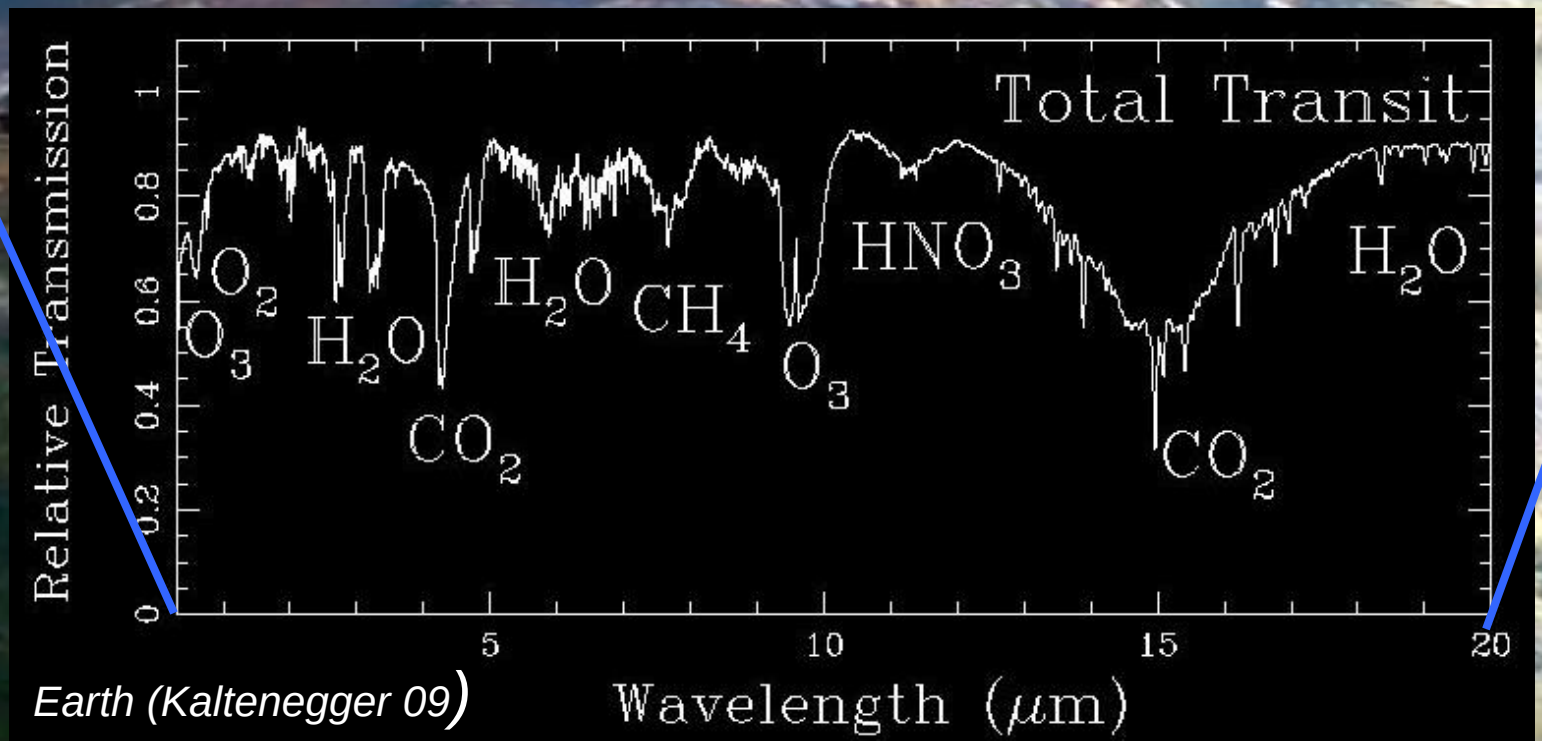
$$h(\lambda) = \int (1-T)\, dz$$

So

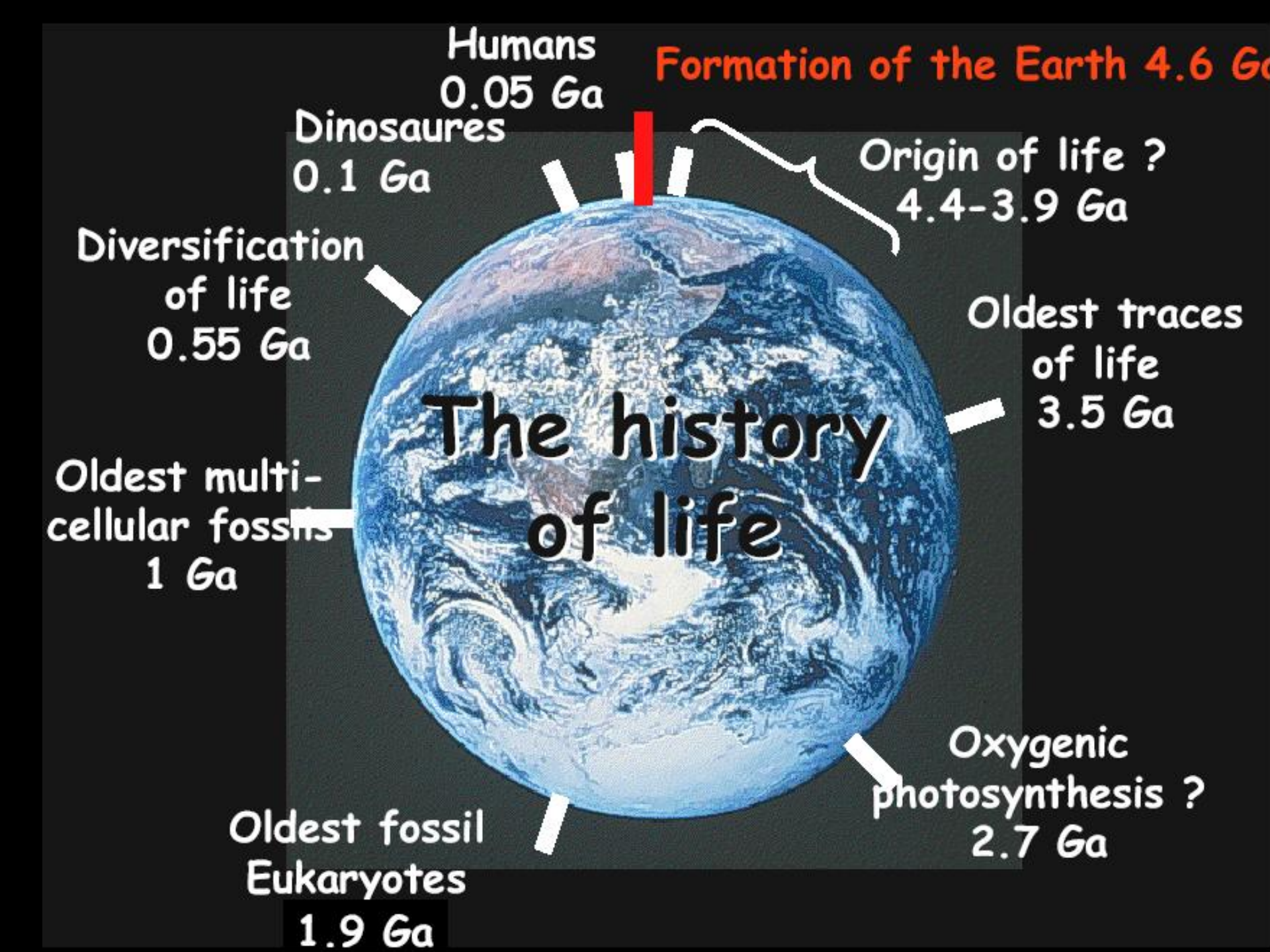
$$R(\lambda) = R_0 + h(\lambda)$$

$$\mathbf{f_p(\lambda) = 2\pi R_p * h(\lambda) / \pi R_s^2}$$

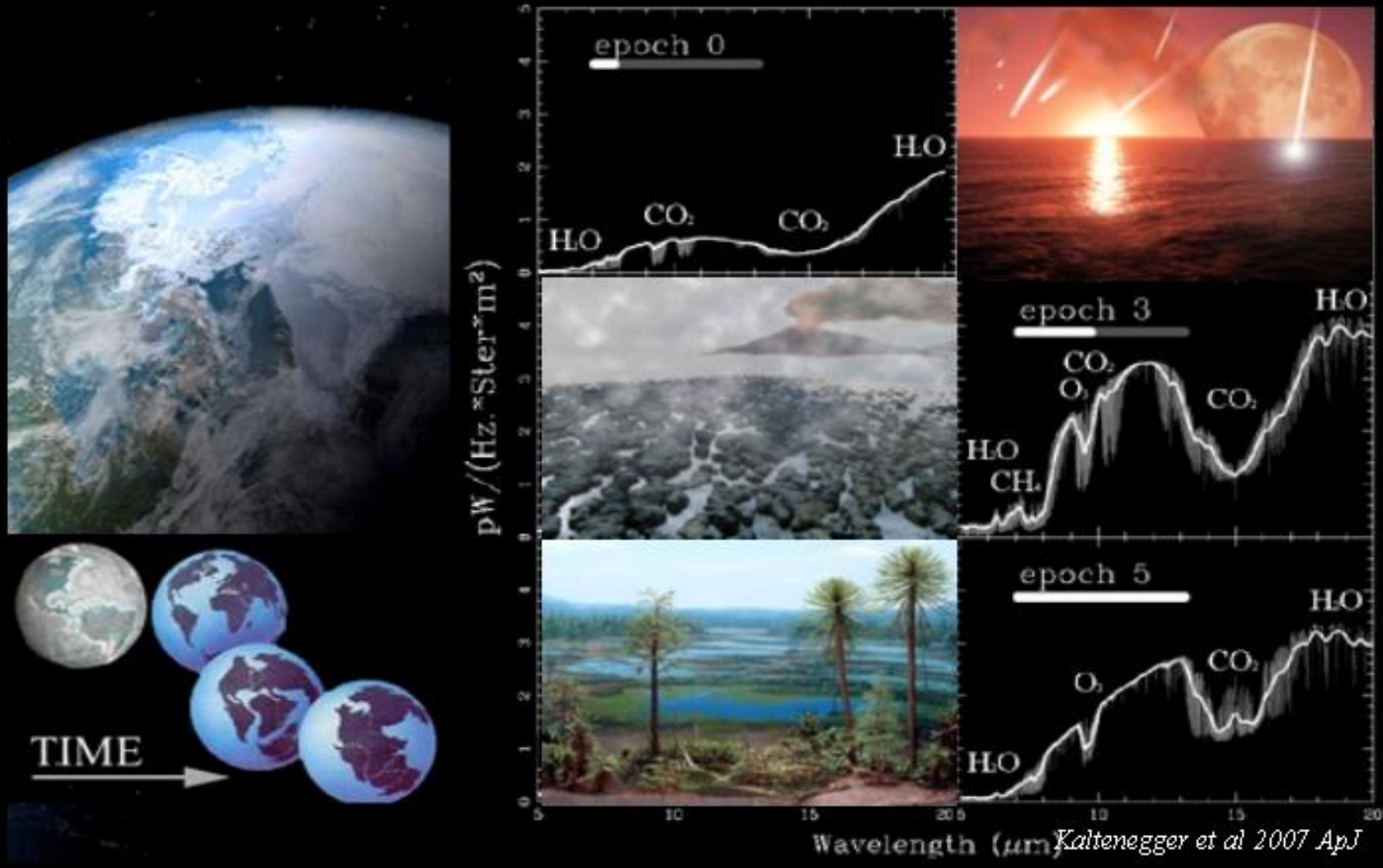
NASA/STS-125 Photo



Earth (Kaltenegger 09)


Humans
0.05 Ga
Formation of the Earth 4.6 Ga
Dinosaures
0.1 Ga
Origin of life ?
4.4-3.9 Ga
Diversification
of life
0.55 Ga
Oldest traces
of life
3.5 Ga
The history
of life
Oldest multi-
cellular fossils
1 Ga
Oxygenic
photosynthesis ?
2.7 Ga
Oldest fossil
Eukaryotes
1.9 Ga

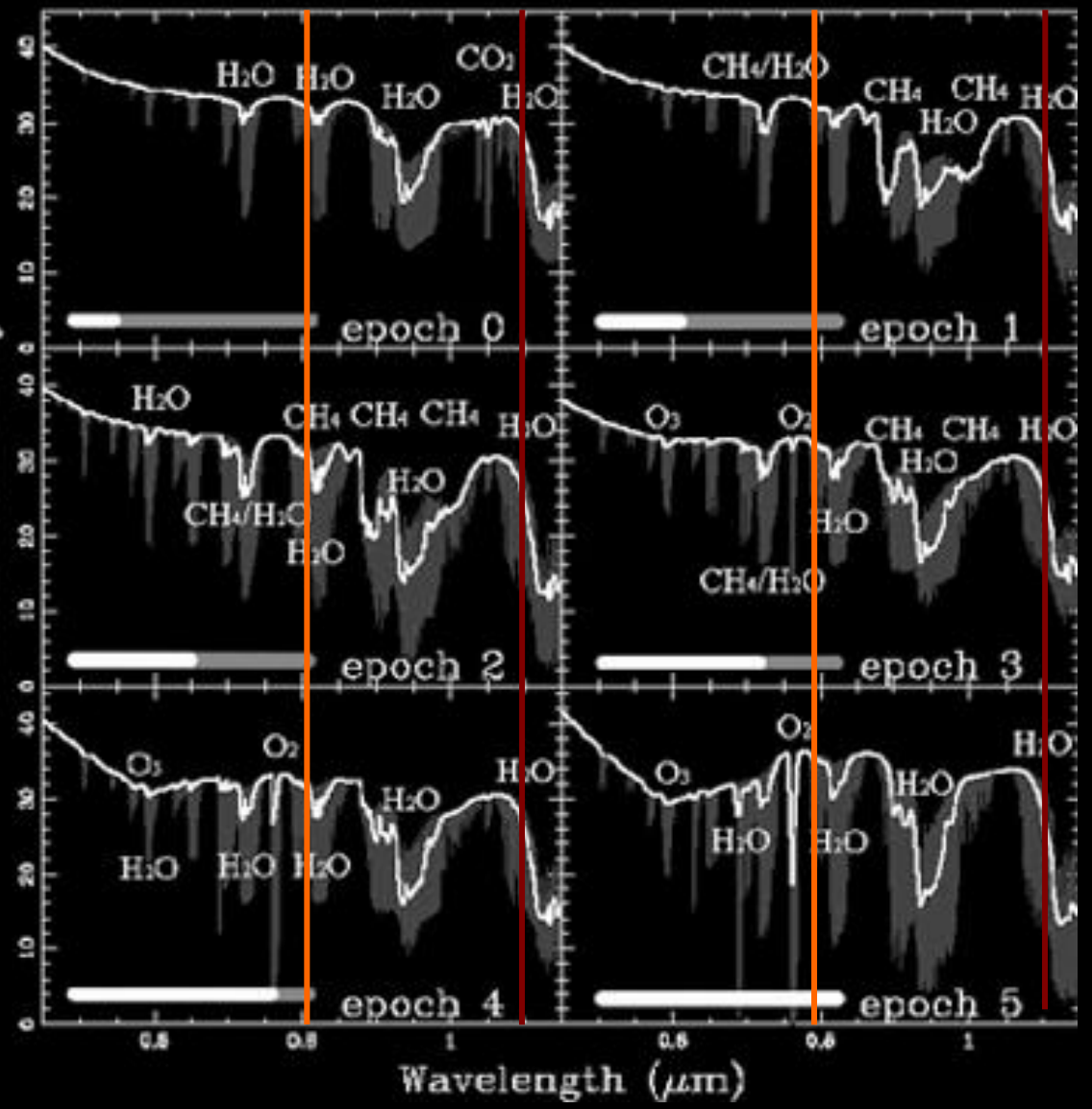
Earth Evolution over geological time - CSI



mid IR (5-20μm): Res = 25

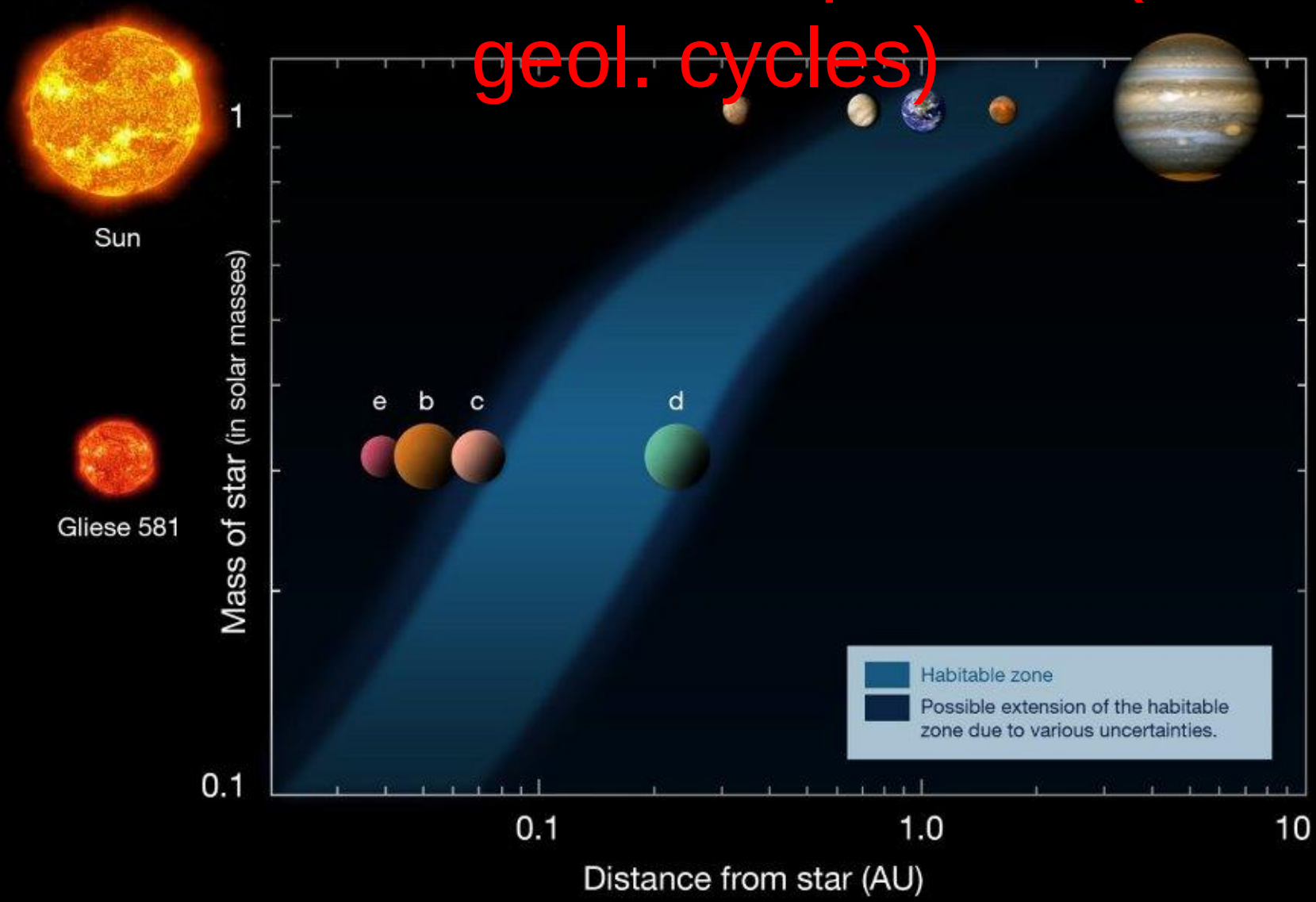
Kaltenegger et al 2007 ApJ

Earth Evolution over geological time - CSI



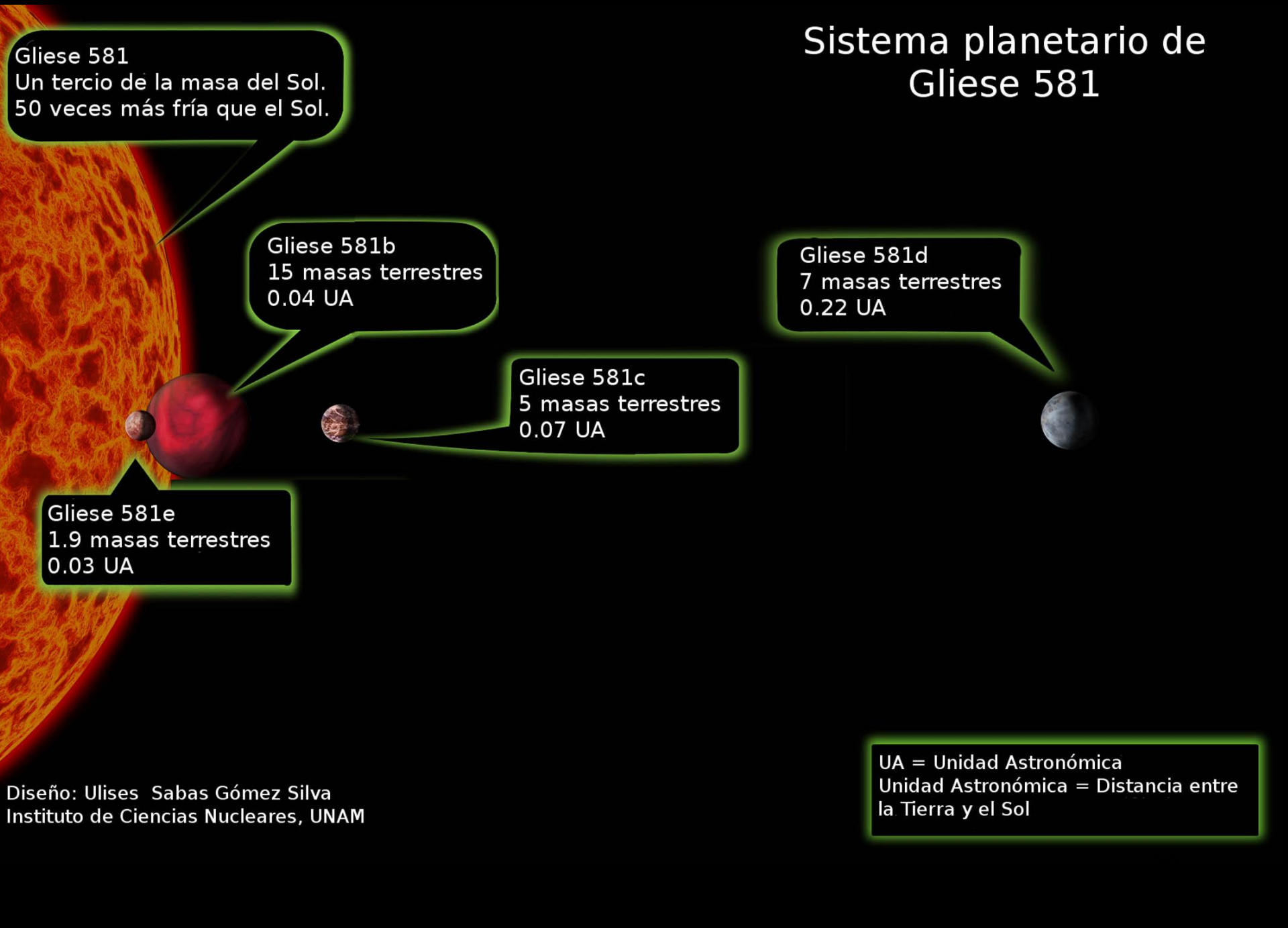
Kaltenegger, Traub Jucks 2007 ApJ

Habitable Zone – water pot.liquid on surface of Earth-like planets (= incl. geol. cycles)



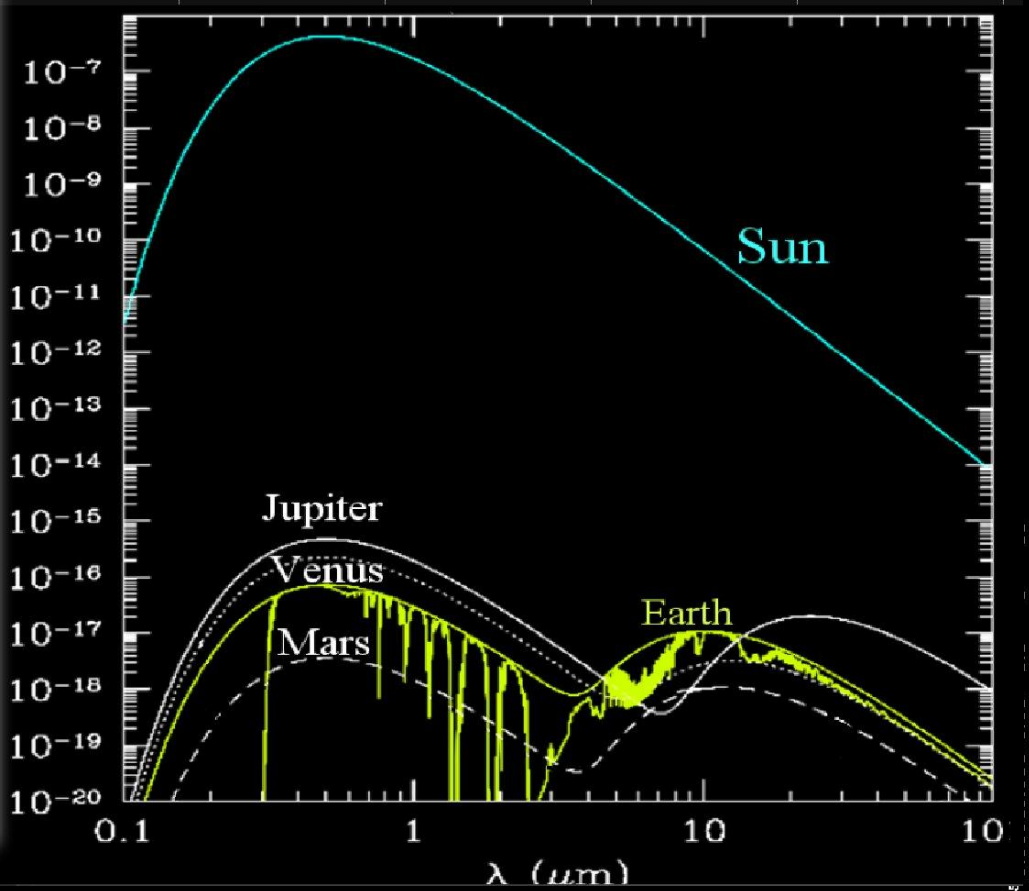
Kalteneggeret al 2011,Wordsworth et al. 2011, von Paris et al 2010, von Bloh et al 2007, Selsis et al

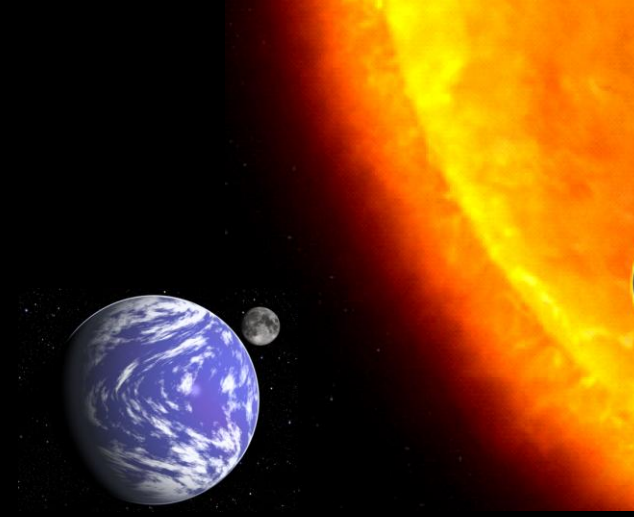
Sistema planetario de Gliese 581

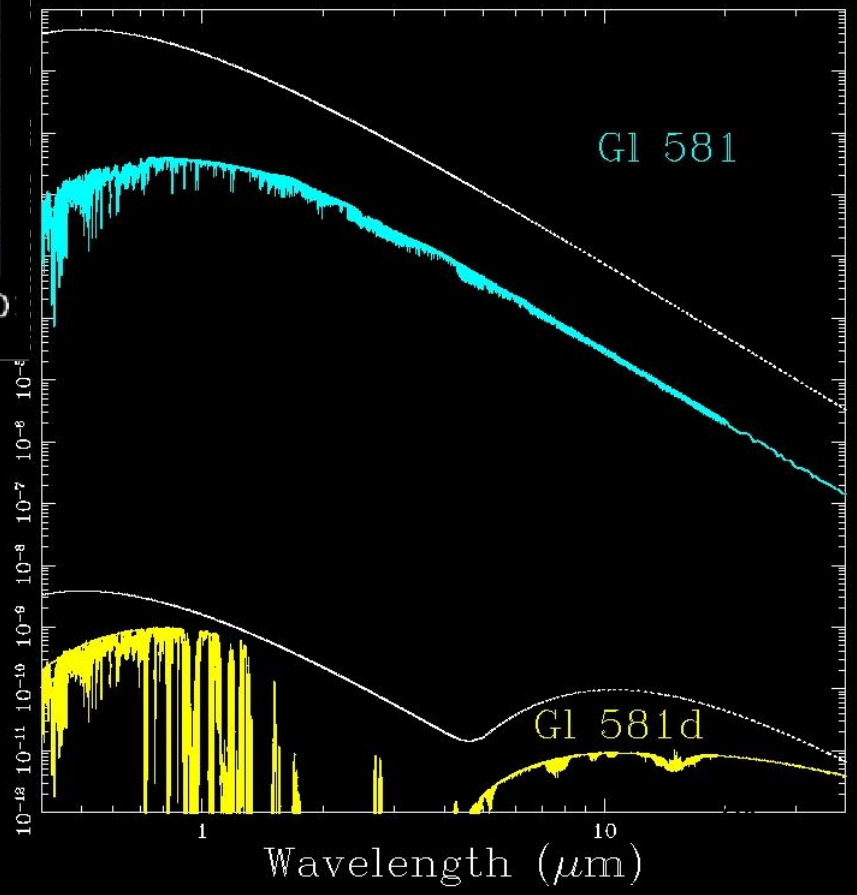


Diseño: Ulises Sabas Gómez Silva
Instituto de Ciencias Nucleares, UNAM

UA = Unidad Astronómica
Unidad Astronómica = Distancia entre la Tierra y el Sol





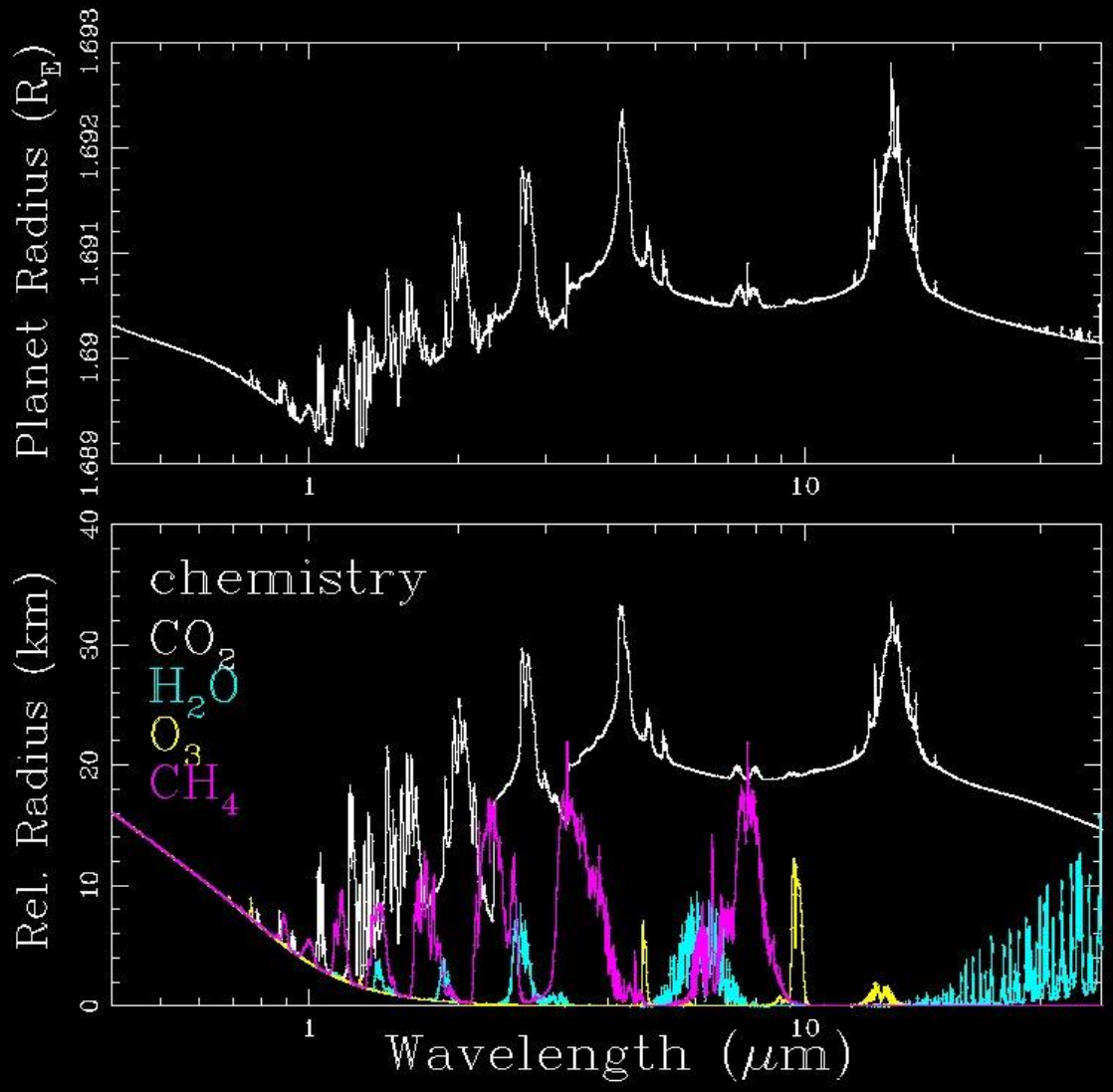


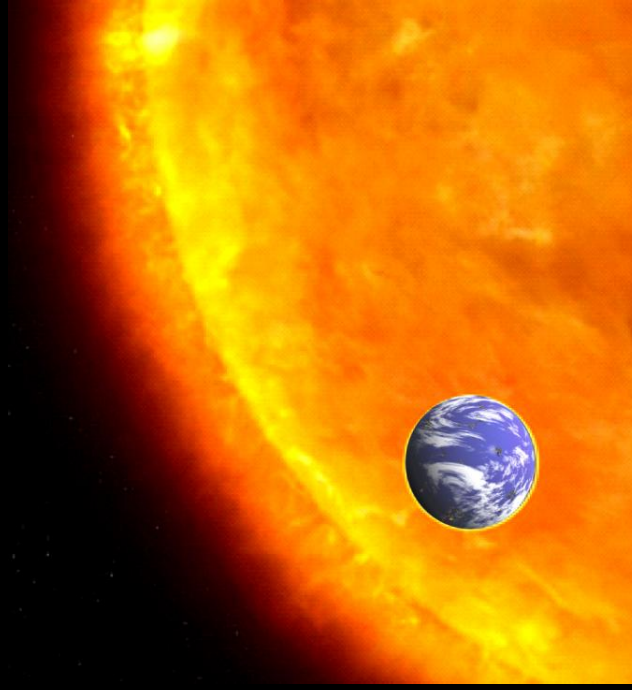
Gl 581d spectra

& star/planet contrast ratio

Kaltenegger, Mohanty& Segura ApJ 20

Spectra (0.1 - 100 μm): Resolution 150



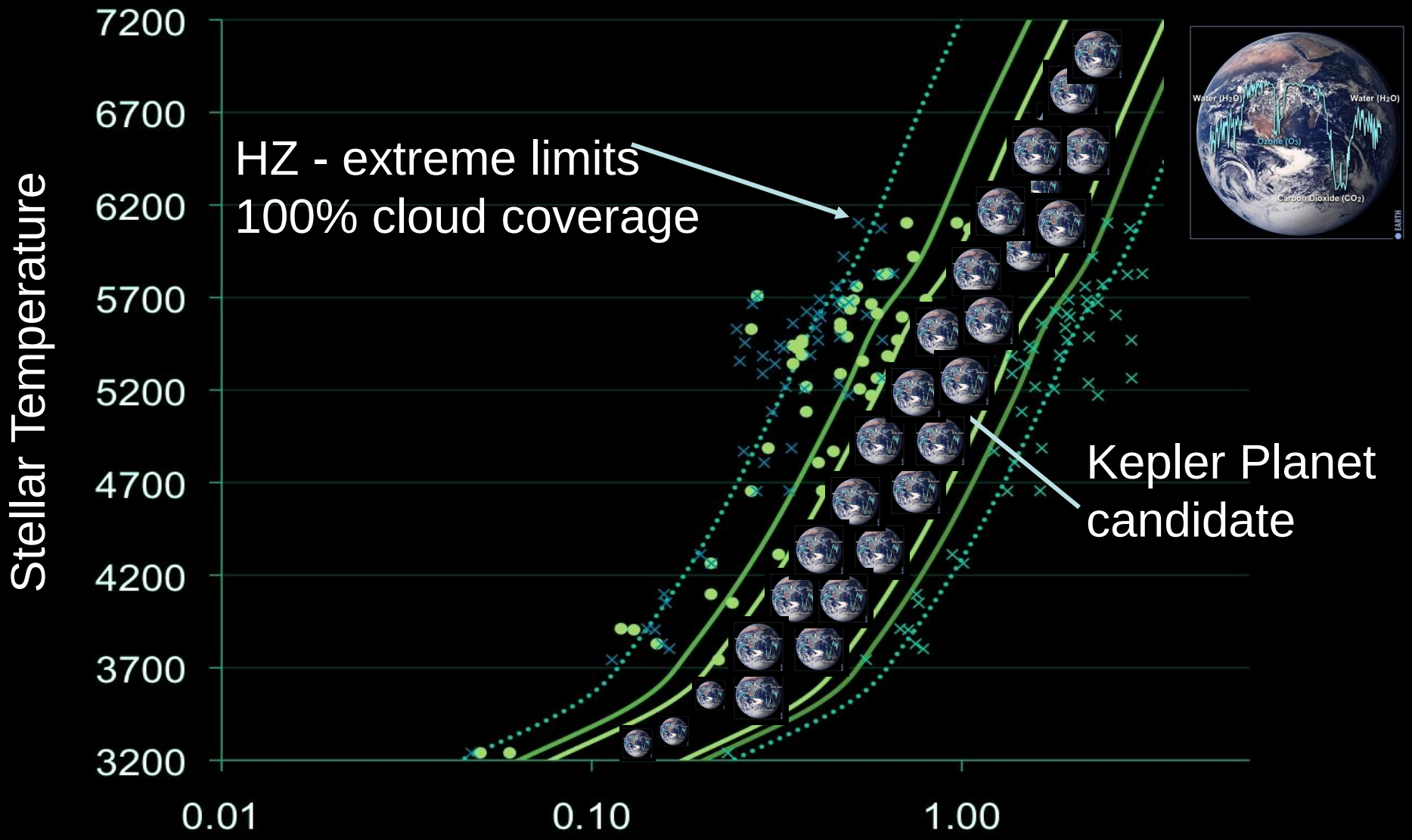


Gl 581d Transit Spectra

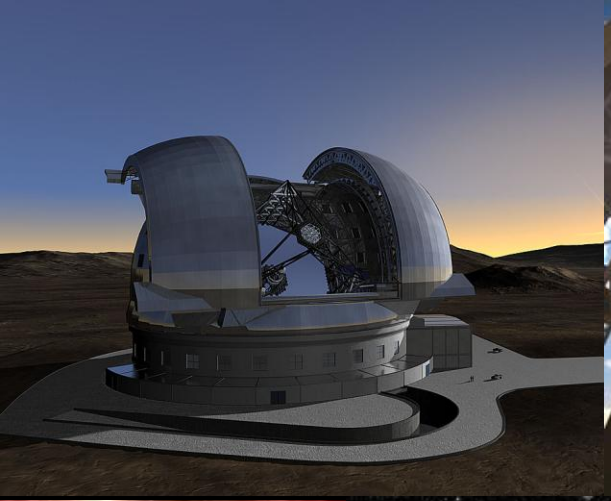
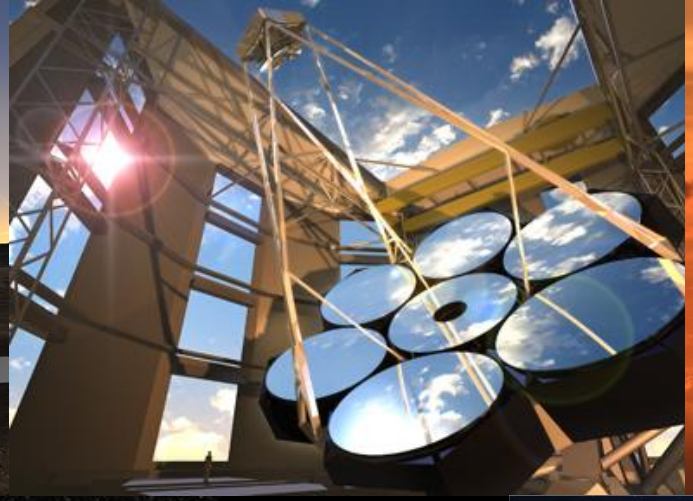
in planetary radius *Kaltenegger, Mohanty& Segura ApJ 2011*

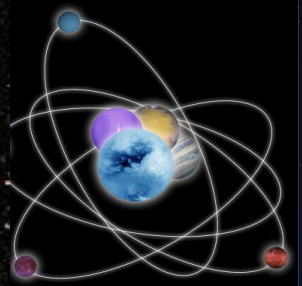
Spectra (0.4 - 40 μm): Resolution 150

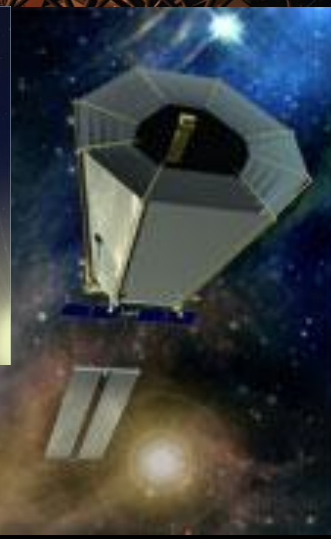
Future HZ: Kepler's pot. habitable planets explored

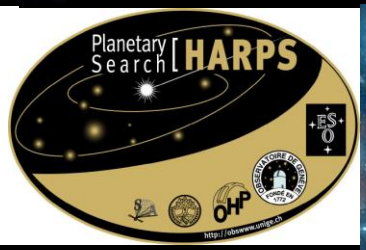


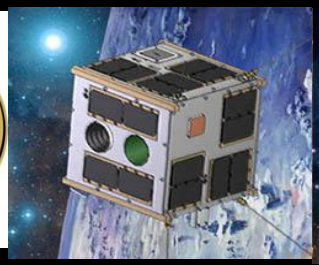
Kaltenegger &Sasselov 2011 ApJ

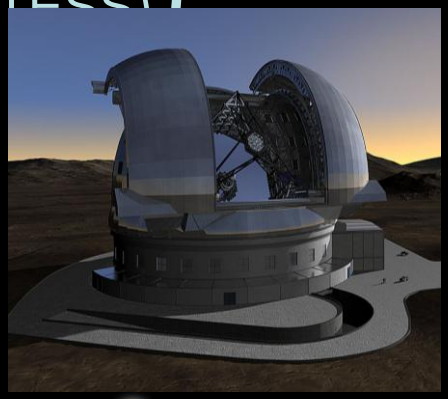


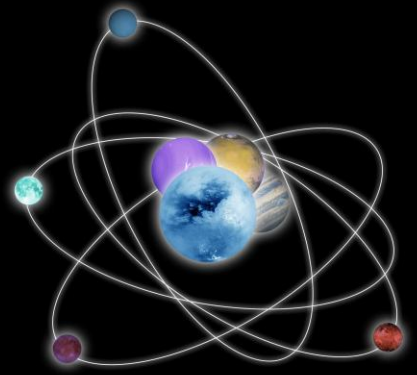
EXOPAG(NASA) – get involved Mtg June 1/2

Exoplanet Exploration Program Analysis Group (Chair: J. Kasting)

JWST

(SPITZER, SPICA SMALL SPACE MISSIONS (e.g. EChO, TESS))





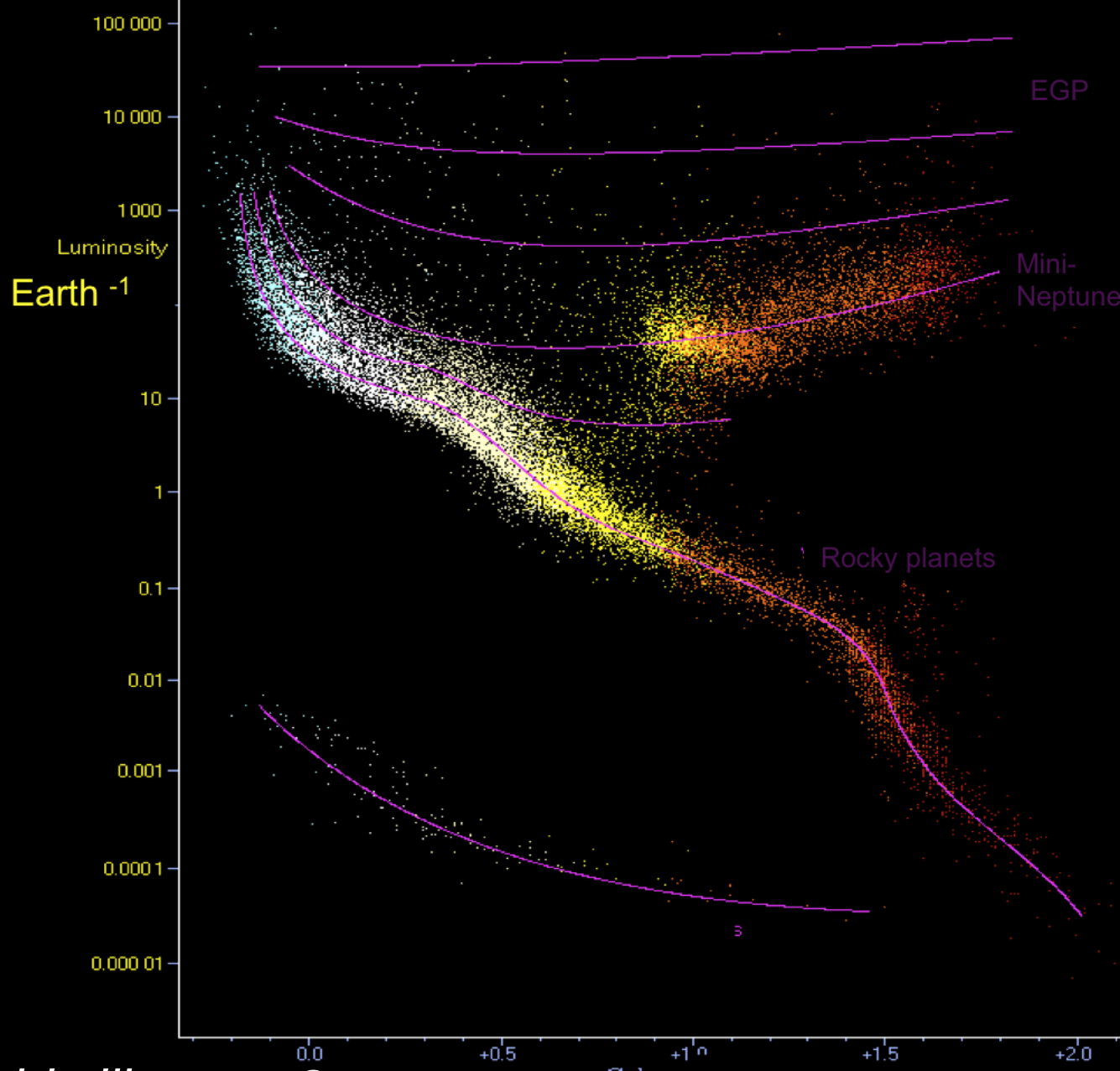
Not just FIND... (POS VIEW ☺)

Characterizerockyexoplanets

-composition	0– 50+ years
-habitability	8 – 50+years
-stage of evolution	8 – 50+ years
-geochemicalcycles	8 – 50+ years
- HR Diagram of planets	20 – 50+

IAP MPIA ETH INAF IEEC SRON JPL UCL
France Germany Switzerland Italy Spain Netherlands US UK

Are there other worlds like ours? *Epicurius (c. 300 B.C)*
2300 years and counting.... Let‘s



Are there other worlds like ours? *Epicurius (c. 300 B.C)*

2300 years and counting....

Let‘s


WAL★MART
SUPERCENTER
Open 24 Hours
Food Center
Signs of Life?

TEST = observe

The Pale Blue Dot

Voyager image, 4 bil. km

The IDEA: Line of Evidence

LIFE ?

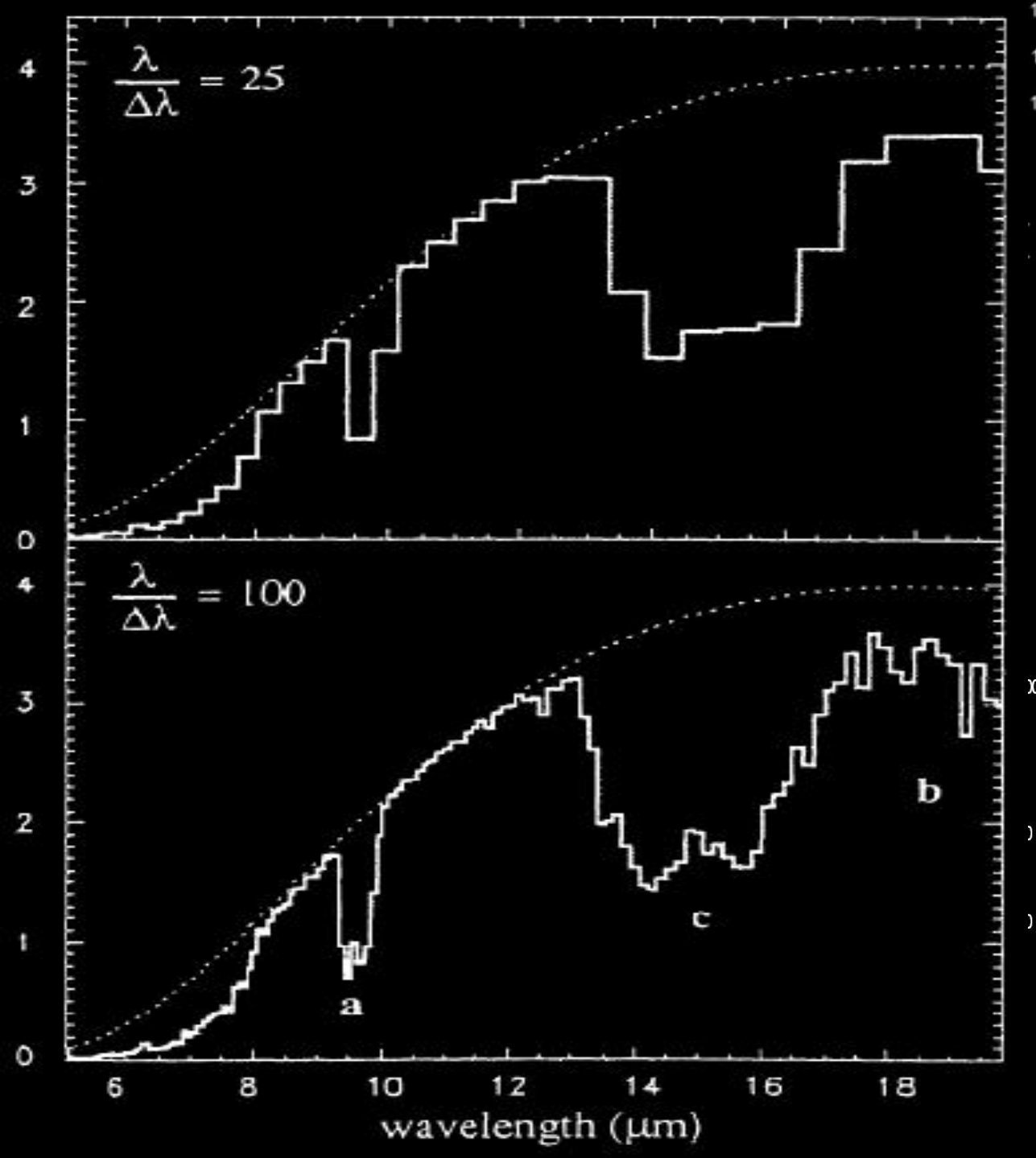
ATMOSPHERE

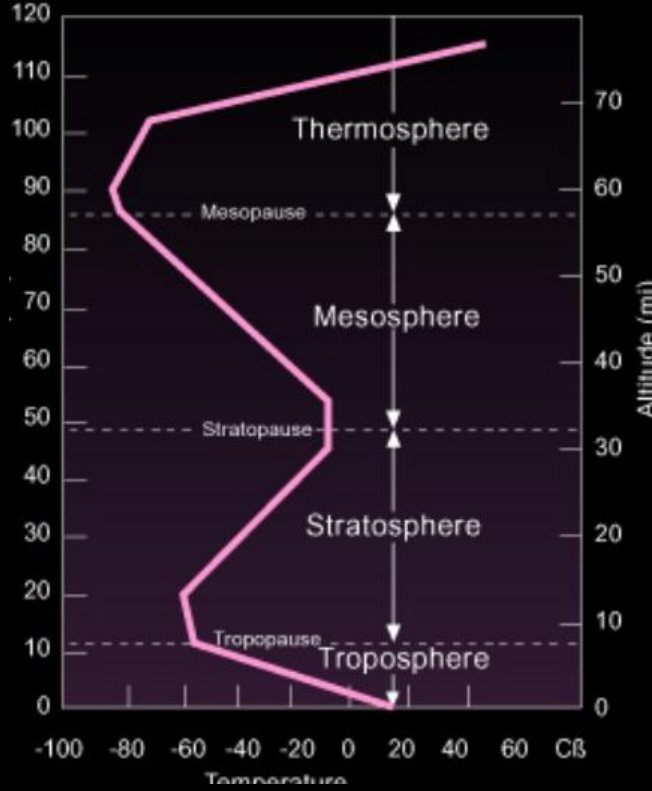
INTERIOR

FIND

WHAT KIND

FORMATION


λ/Δλ = 25
λ/Δλ = 100
a
b
c
wavelength (μm)

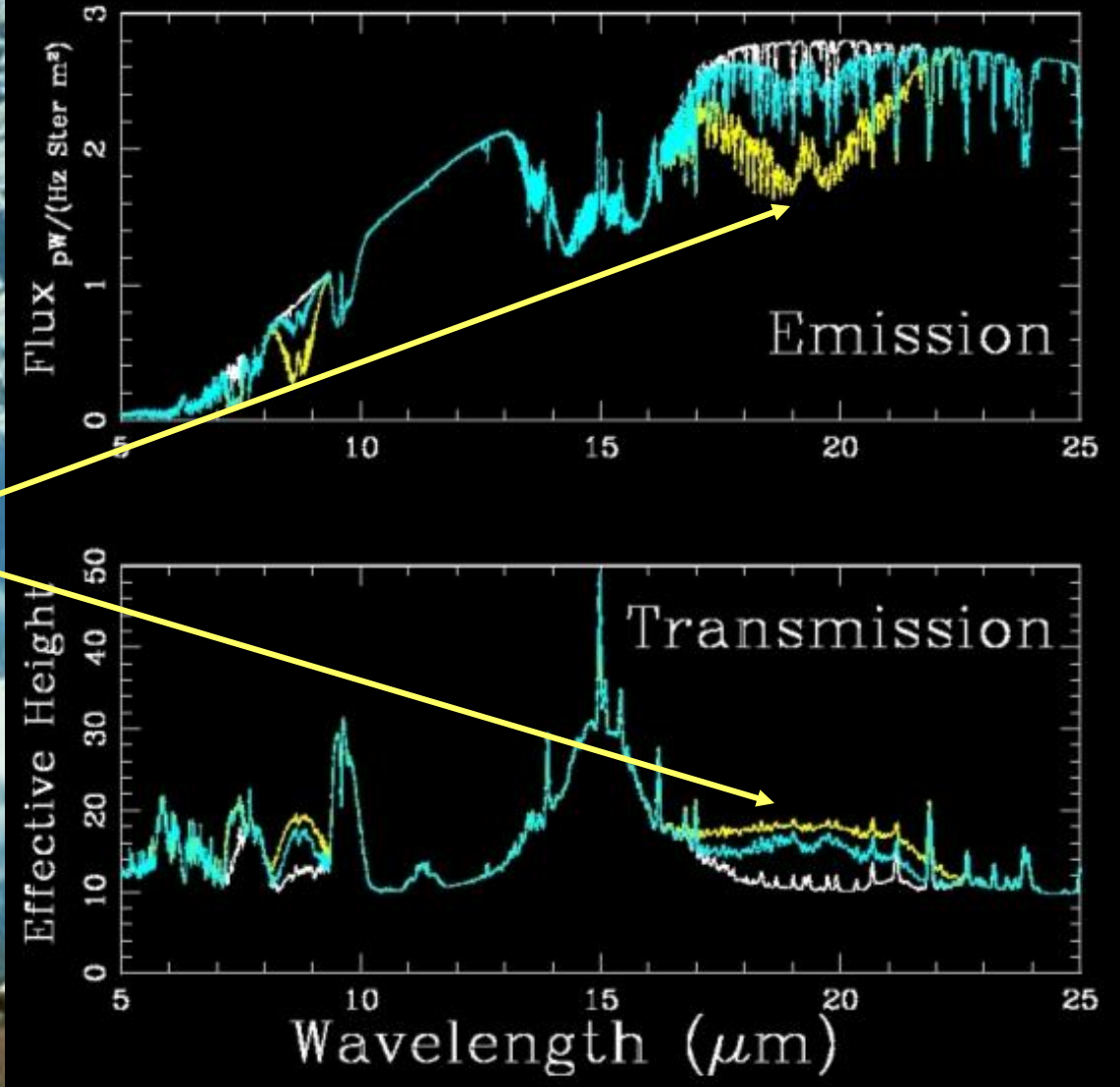

Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
Altitude [km]

Earth

Titan

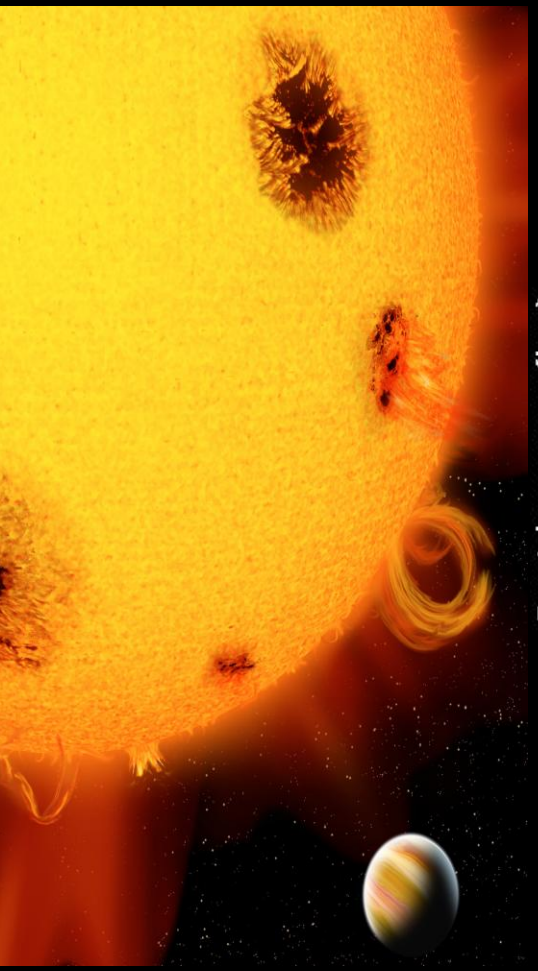
TEST: GEOLOGY = Exo-Volcanos ?

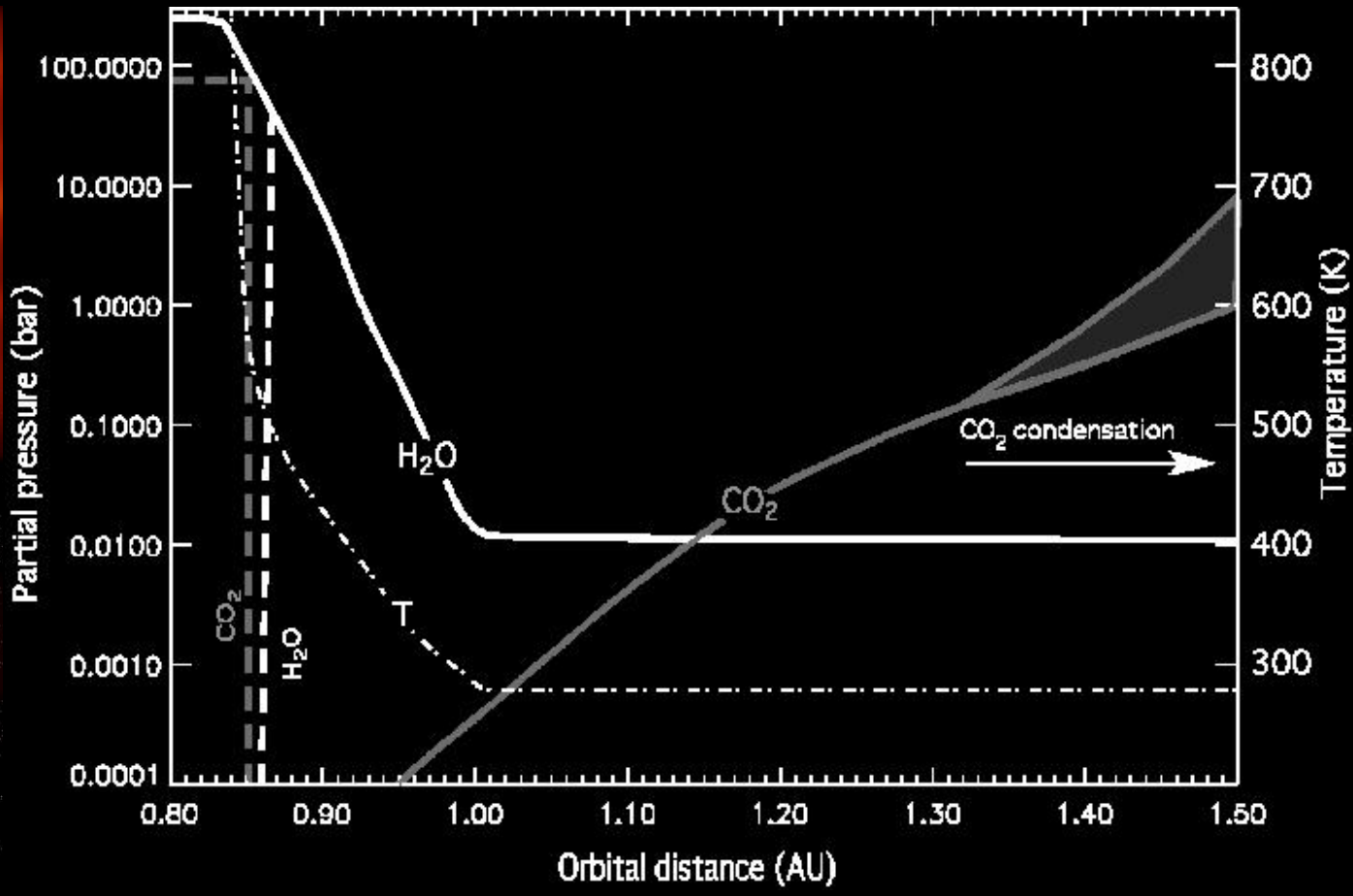
Res = 150, SNR calc. for JWST (pure photon noise, template input for



Kaltenegger & Sasselov (ApJ 09), Kaltenegger & Henning (ApJ 2010)

Habitable Zone... Goldilocks Zone





Kaltenegger & Selsis 2007

Importance EU: ASTRONET 2007

ASTRONET 2007: Vision for European Astronomy 07

5 sections:

4) diversity of planetary systems & signs of life of exoplanets *Astrophysics & EXO-P & AOPP & Earth Science*

5) How do we fit in?

EN at MPIA

Astrophysics & MPIA – instrument design & detect

EXO-P – instrument design & interpretation

Earth Science - input detailed atmosphere & ocean

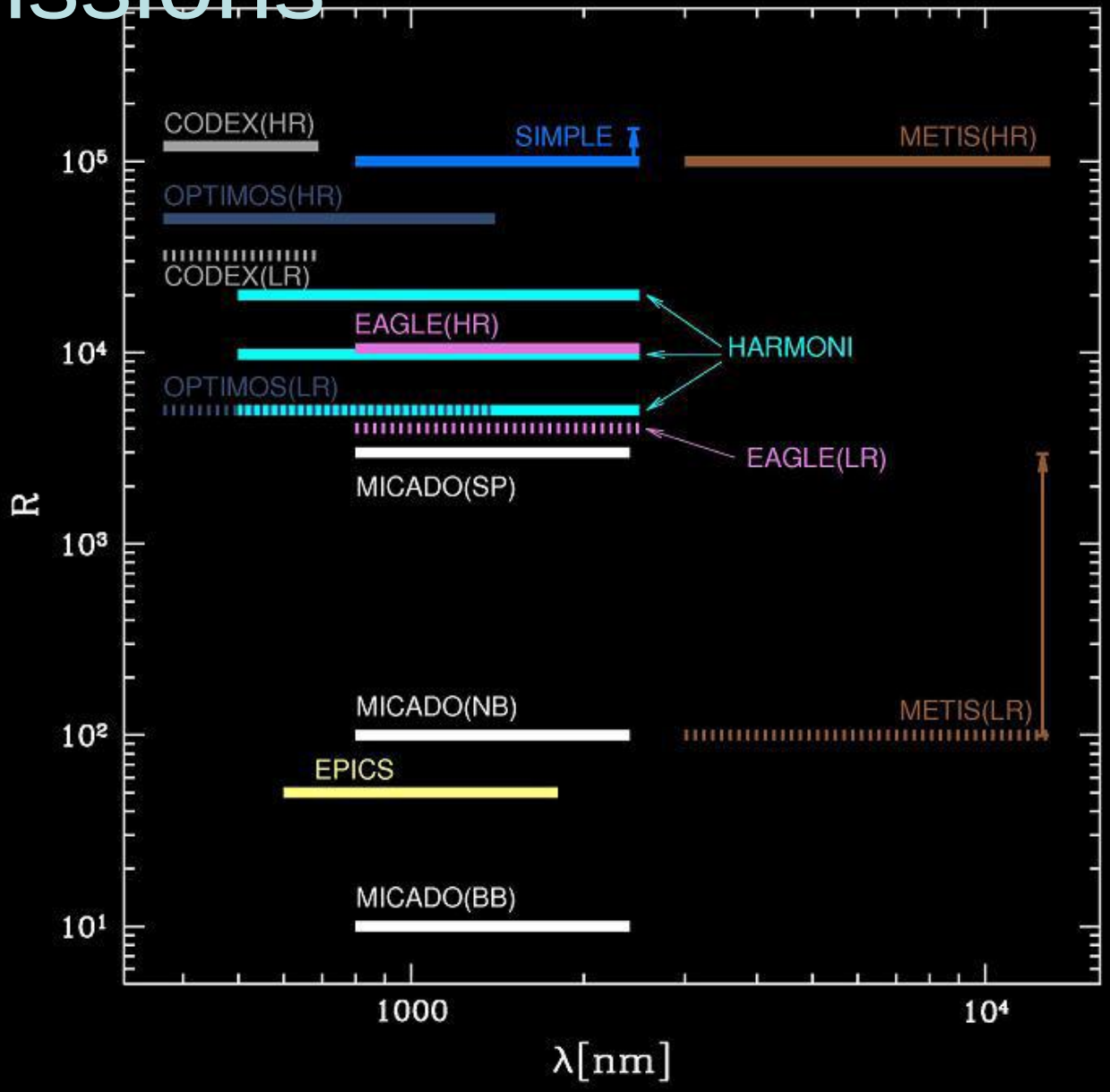
Recommendations

- **1. Cross disciplinary requirements !**

Future ground & space missions

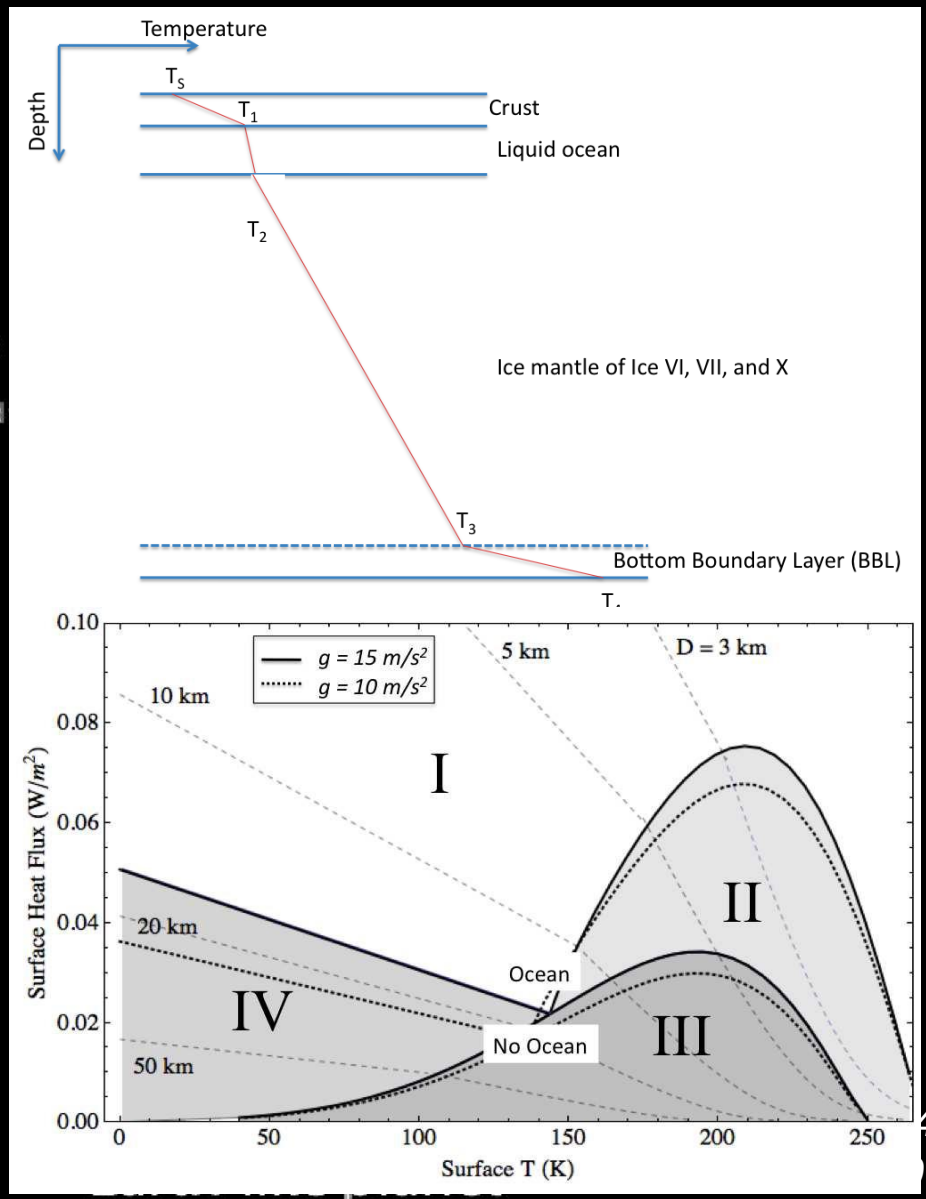
- JWST (2014)
- E-ELT (2017+?)
- GMT, TMT
- SPICA

- Proposed:
- PLATO (CV1)
- ECHO (CV2)
- TESS (NASA)
- NEAT (CV2)
- TPF/Darwin ??



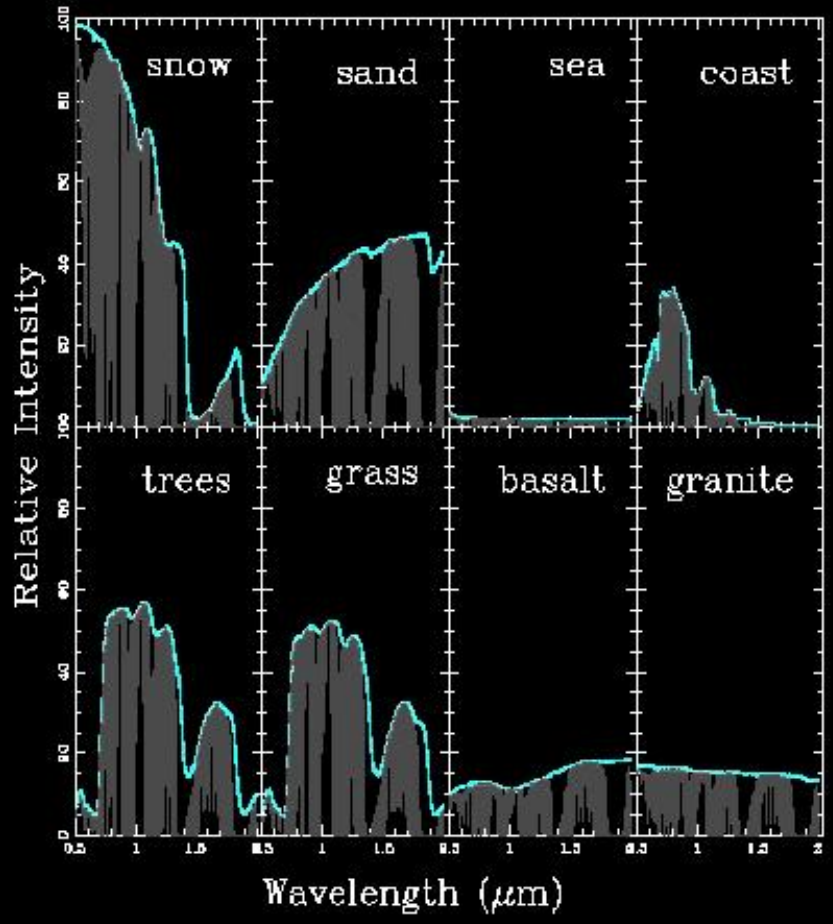
Earth part of the puzzle...

Ocean Planet



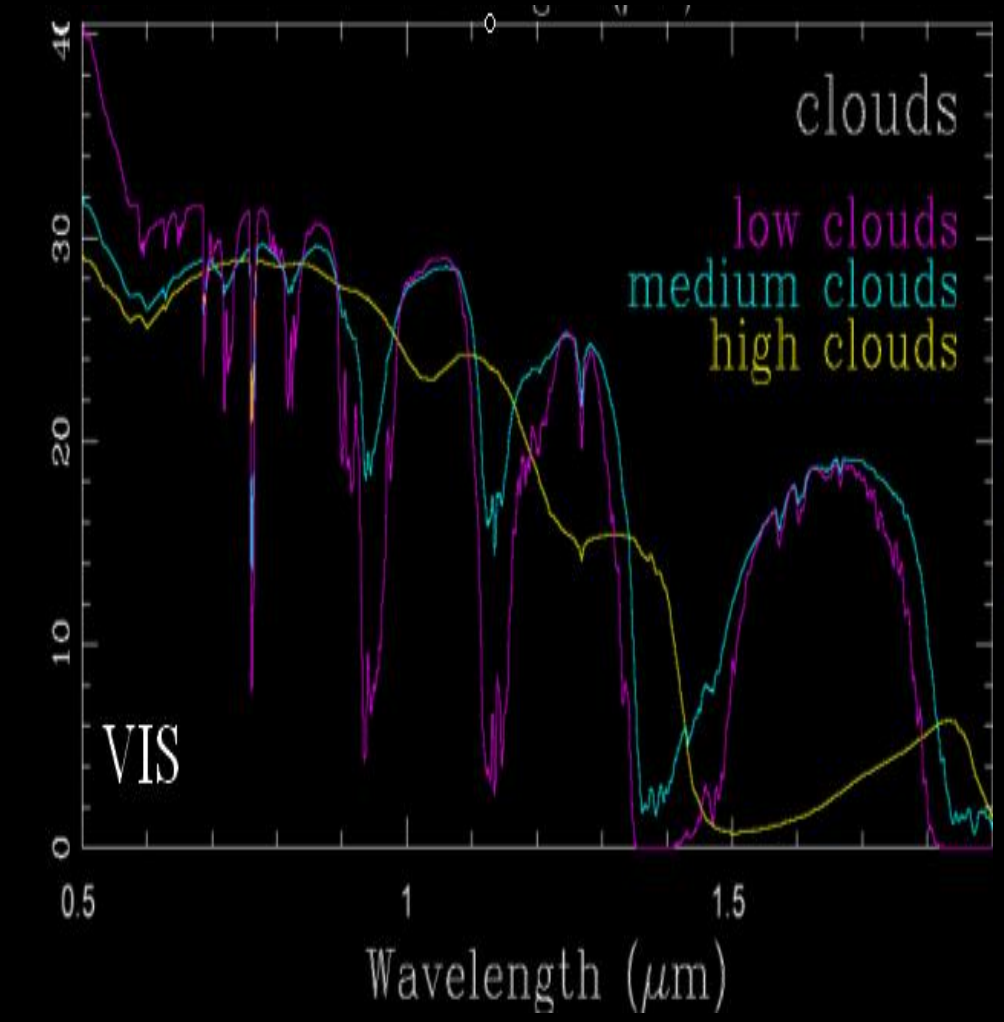
Kaltenegger& Fu 2009

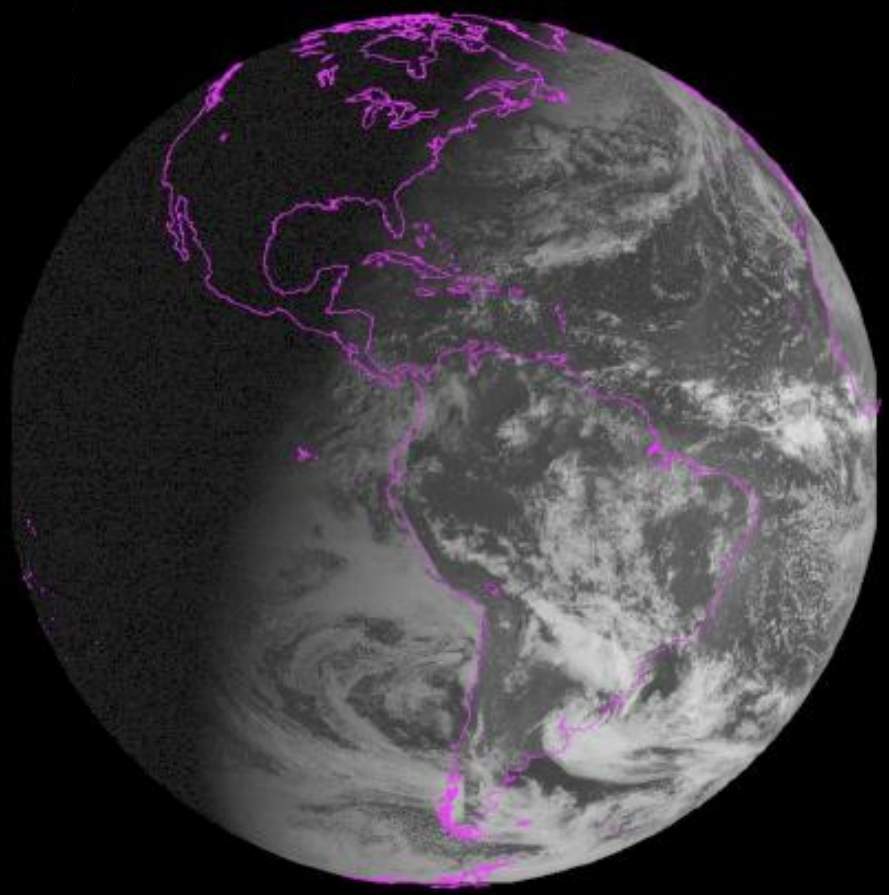
DETAILS: Albedos & Clouds



Kaltenegger 07

Clouds VIS = bright!: Earth avg 60%

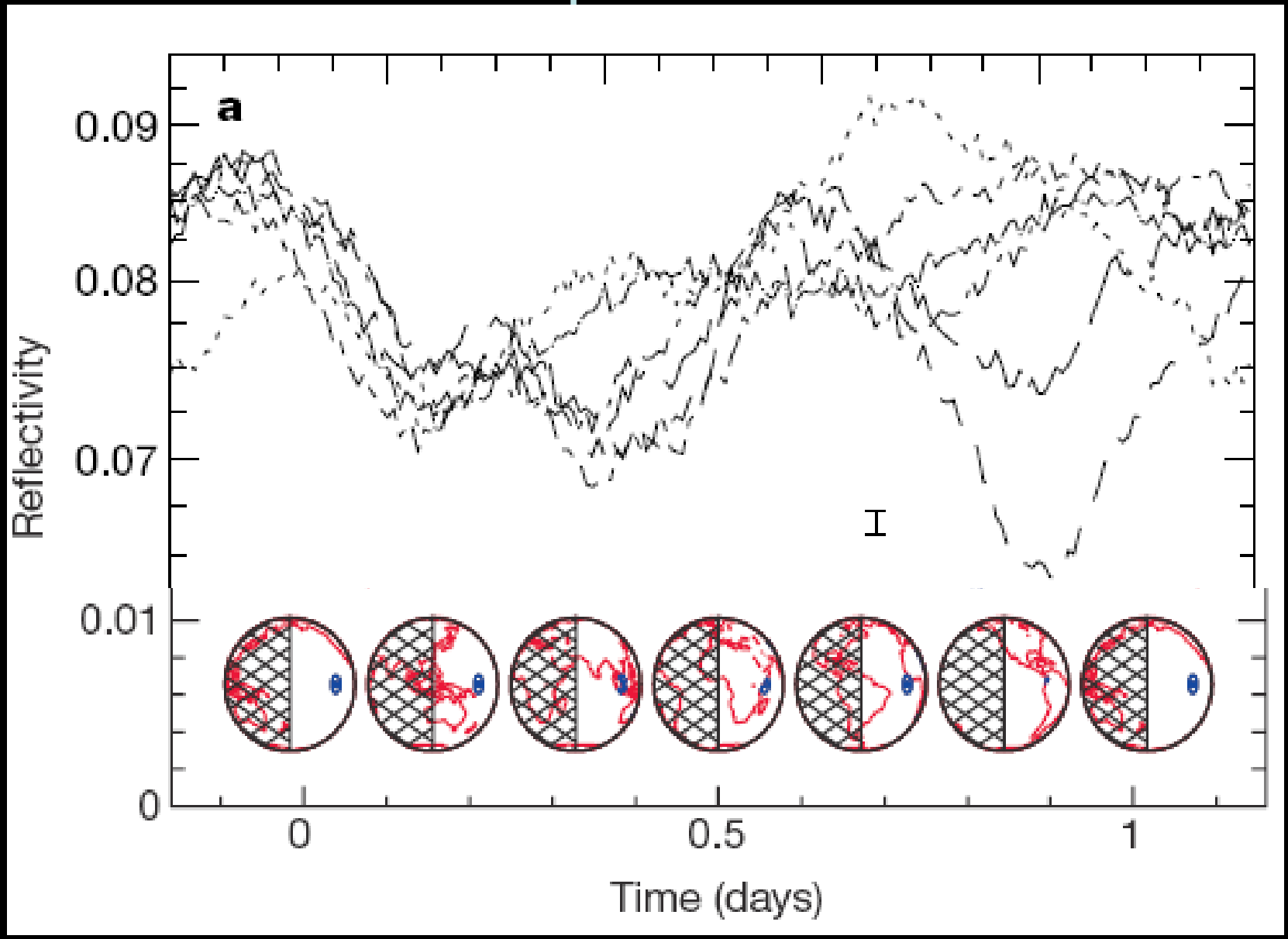




Kaltenegger 07

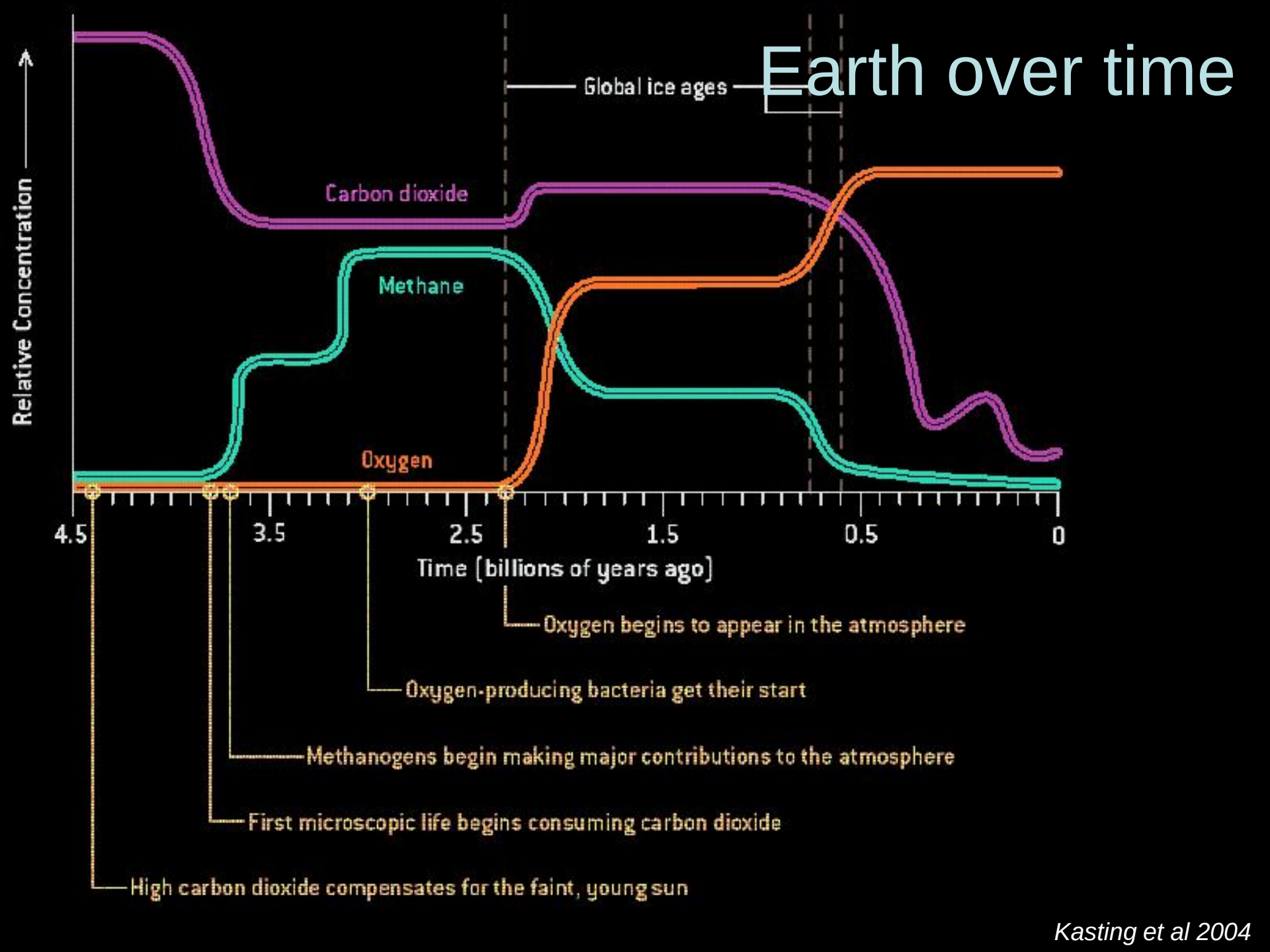
Surface? Measure every 1/20 of rotation period

Palle et al. 200



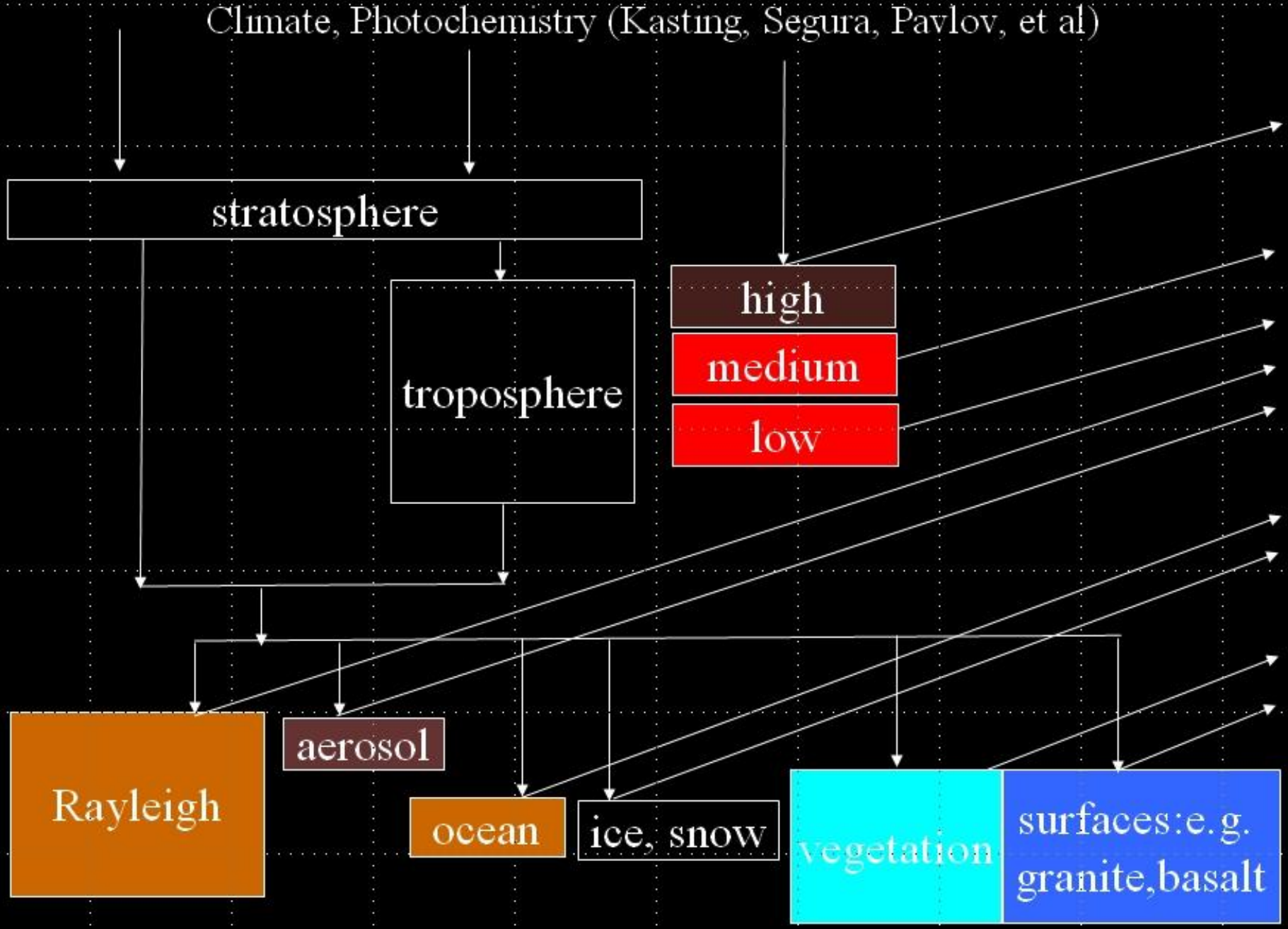
Ford et al. 2001, Cowan et al 2009, Fujii et al 20

Earth over time

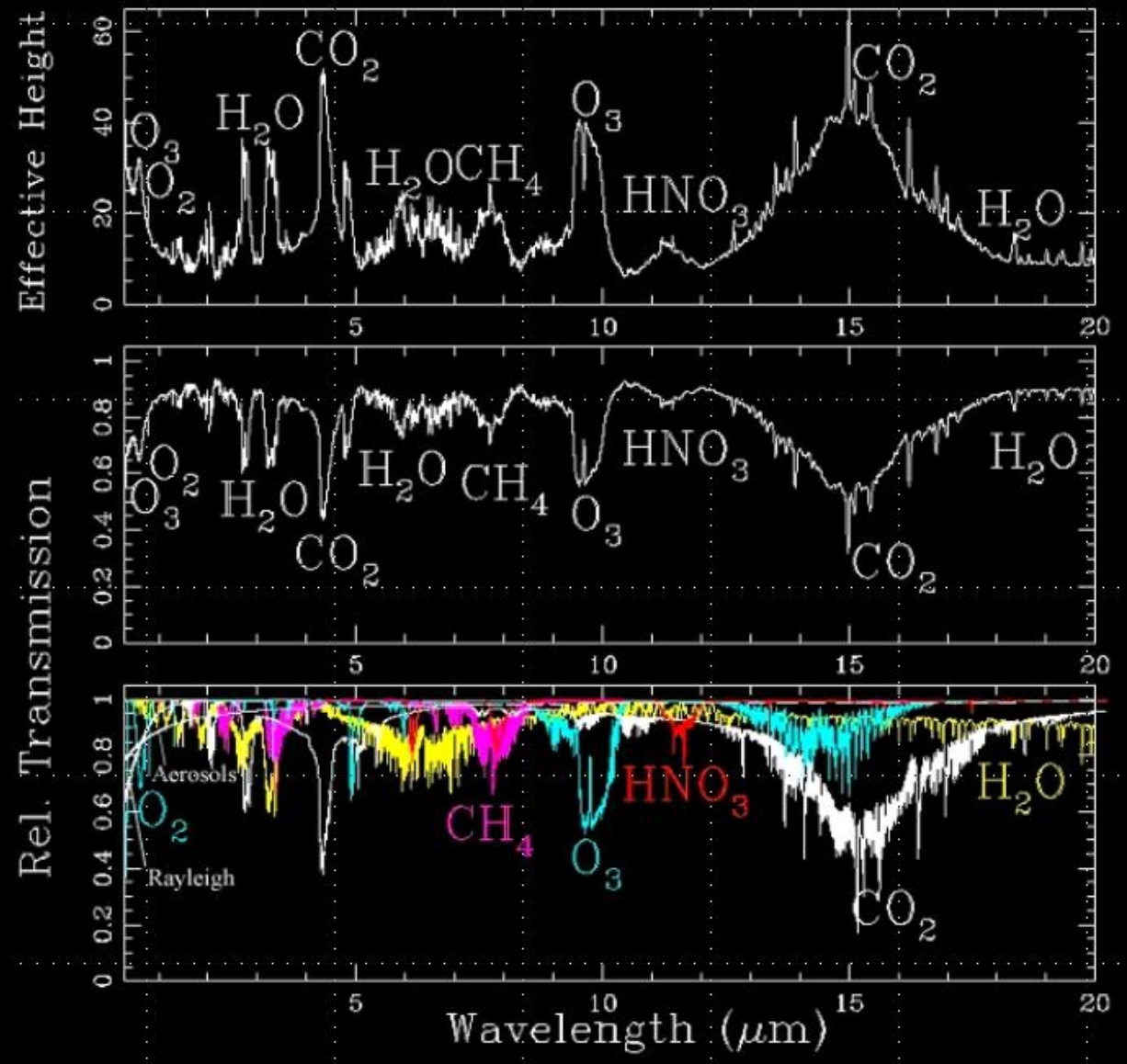


Kasting et al 2004

Our model: RT, 24 layers, 4 streams



Composite transmission spectrum & effective height



Effective height for spectral range 0.3 – 20 μ

Composite relative transmission.

Individual components