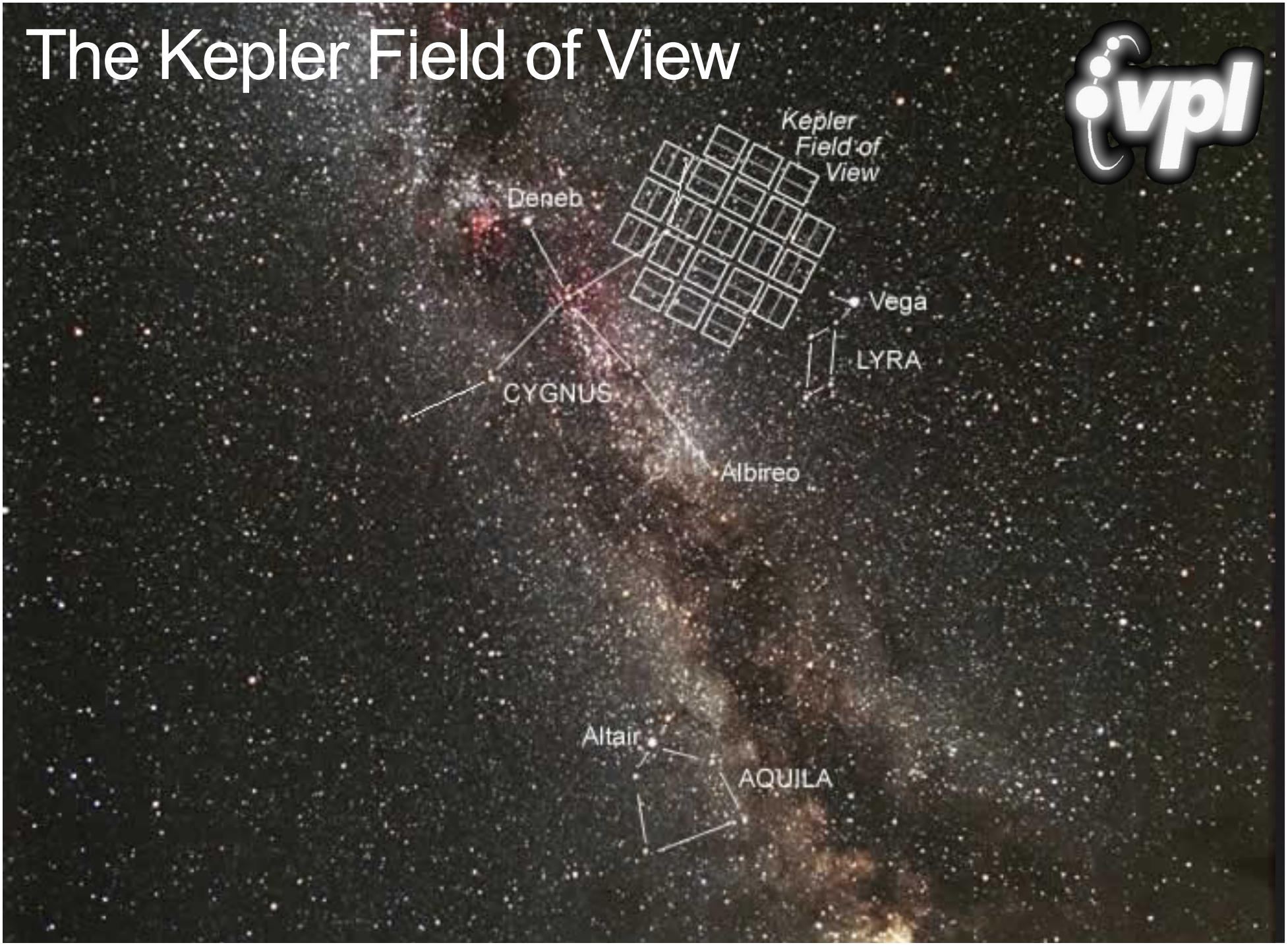
The Earth Through Time as an Extrasolar Planet

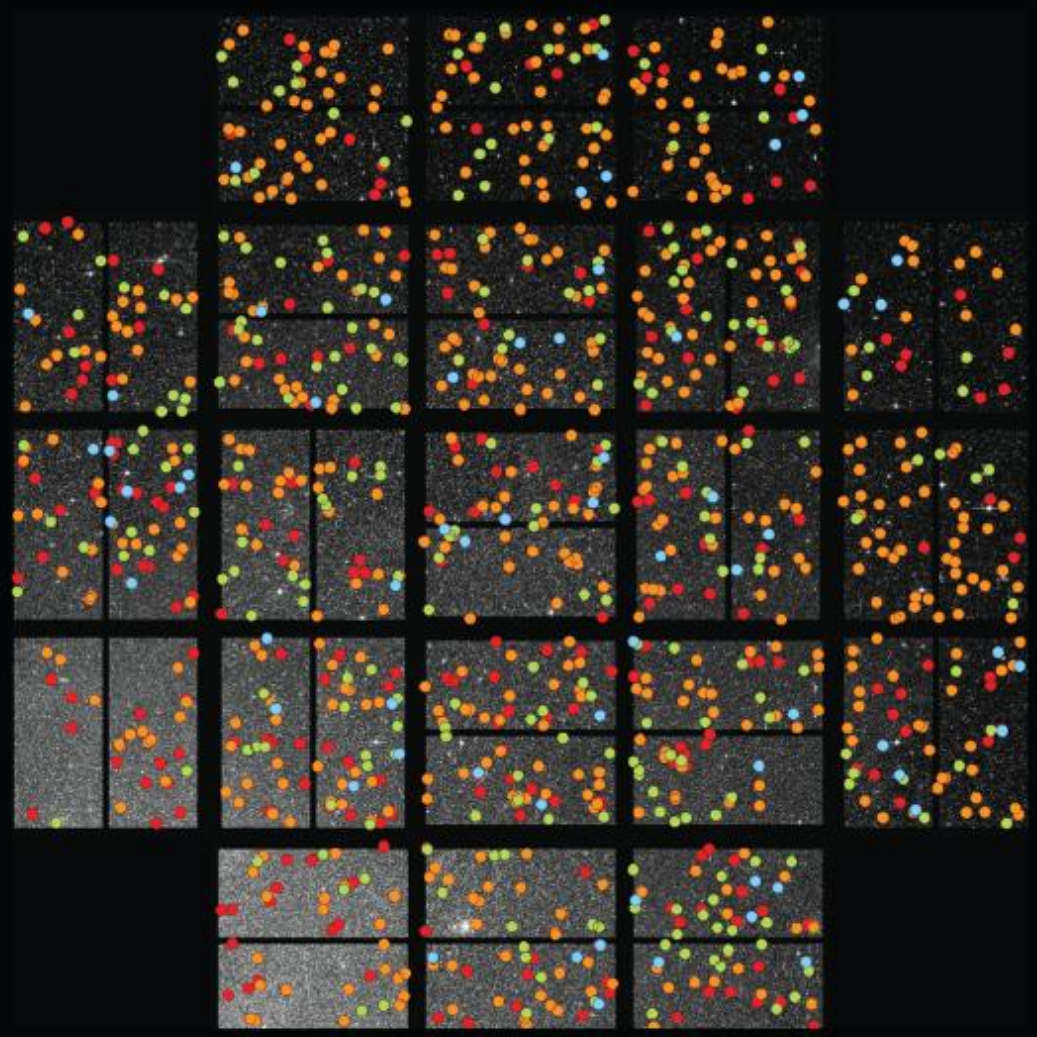
Shawn Domagal-Goldman
NASA HQ, VPL @ UW…
GSFC (699) as of May 21!

The Kepler Field of View



Locations of Kepler Planet Candidates

- Earth-size
- Super-Earth size
  1.25 - 2.0 Earth-size
- Neptune-size
  2.0 - 6.0 Earth-size
- Giant-planet size
  6.0 - 22 Earth-size



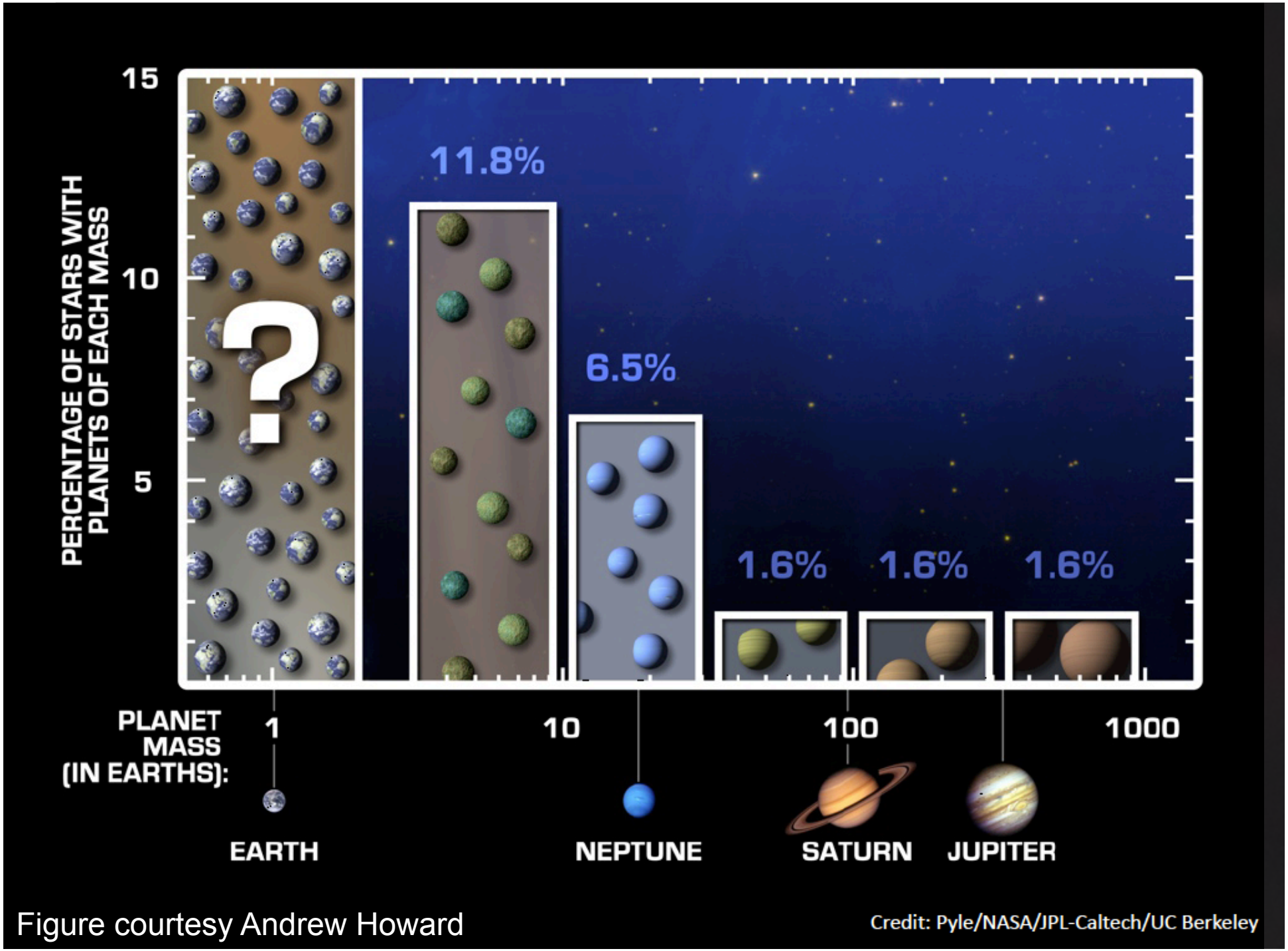
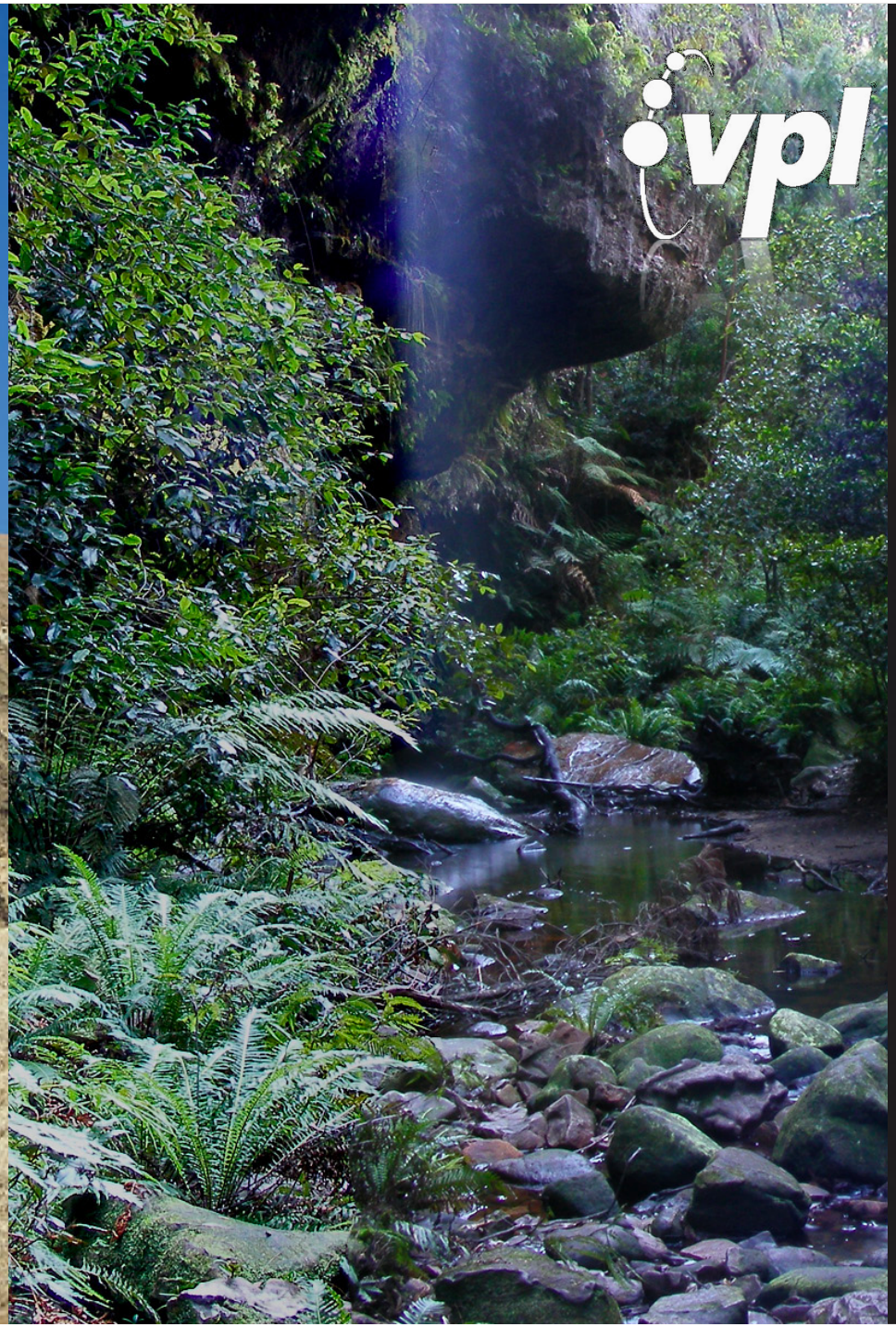
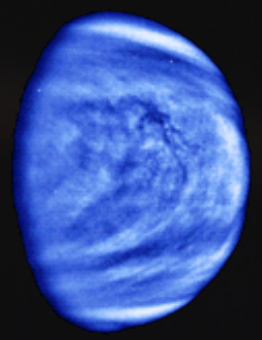
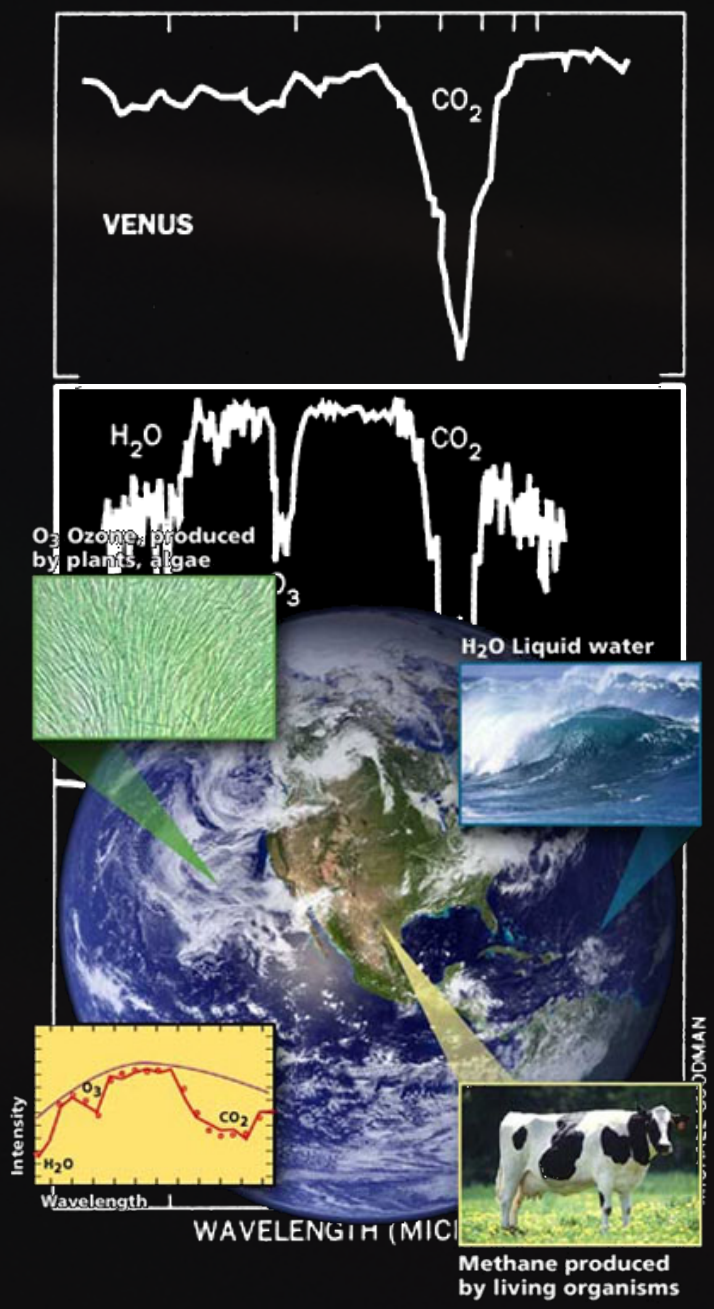


Figure courtesy Andrew Howard

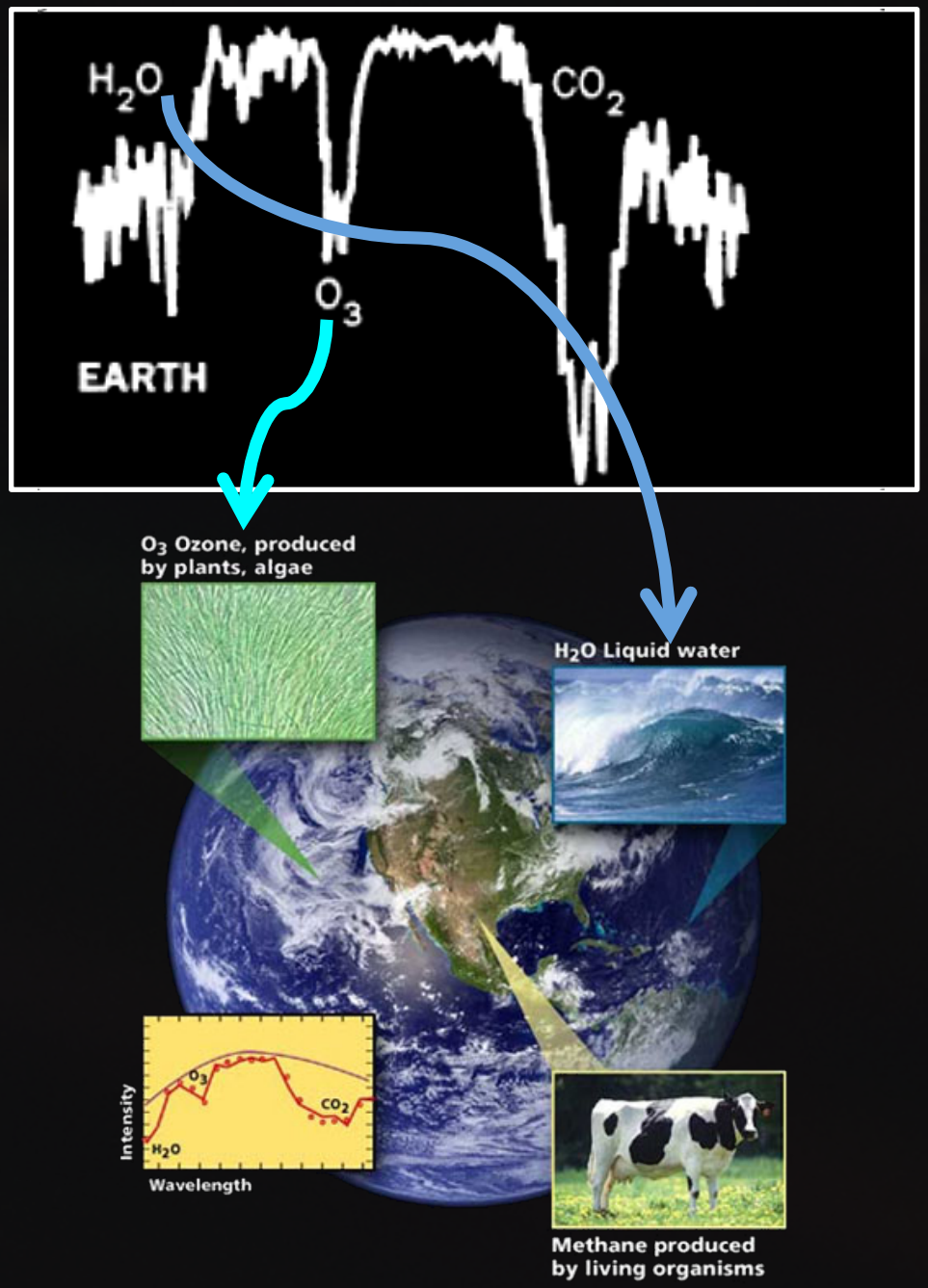

vpl

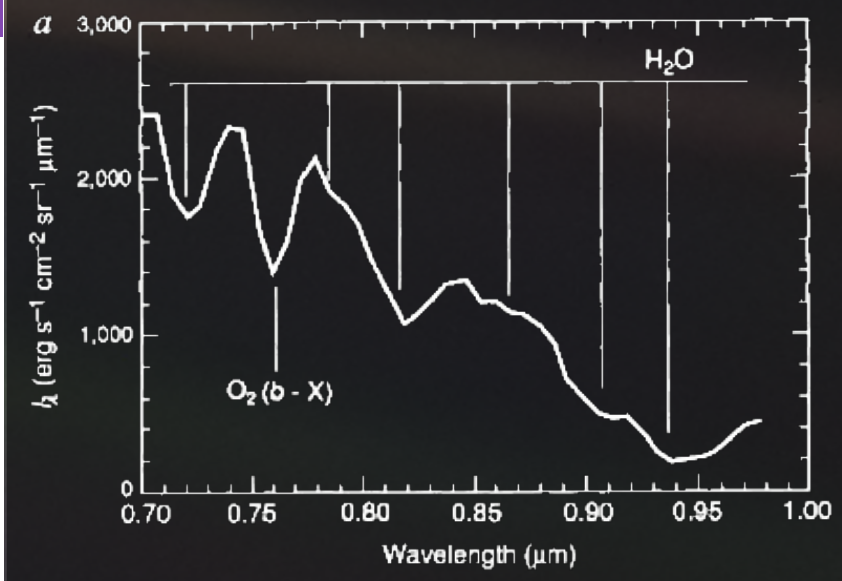
Beichman, Woolf, and Lindensmith, 1999

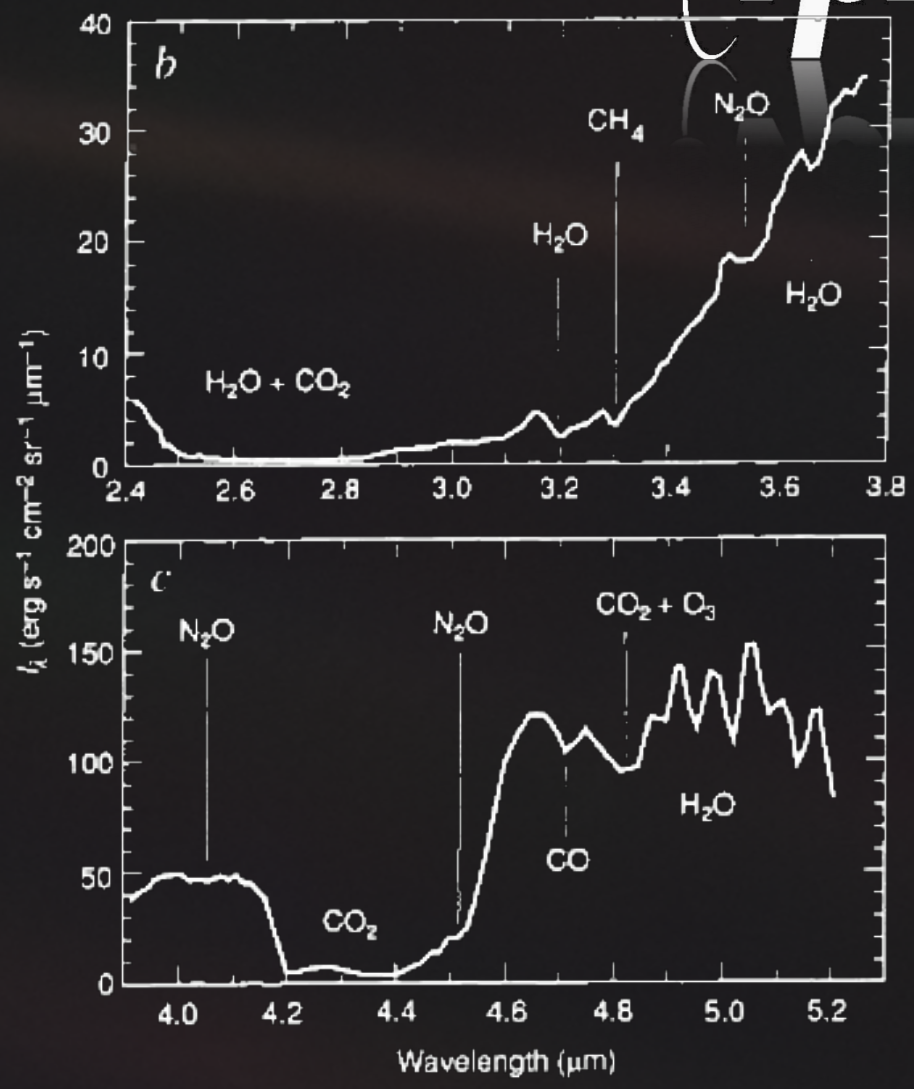




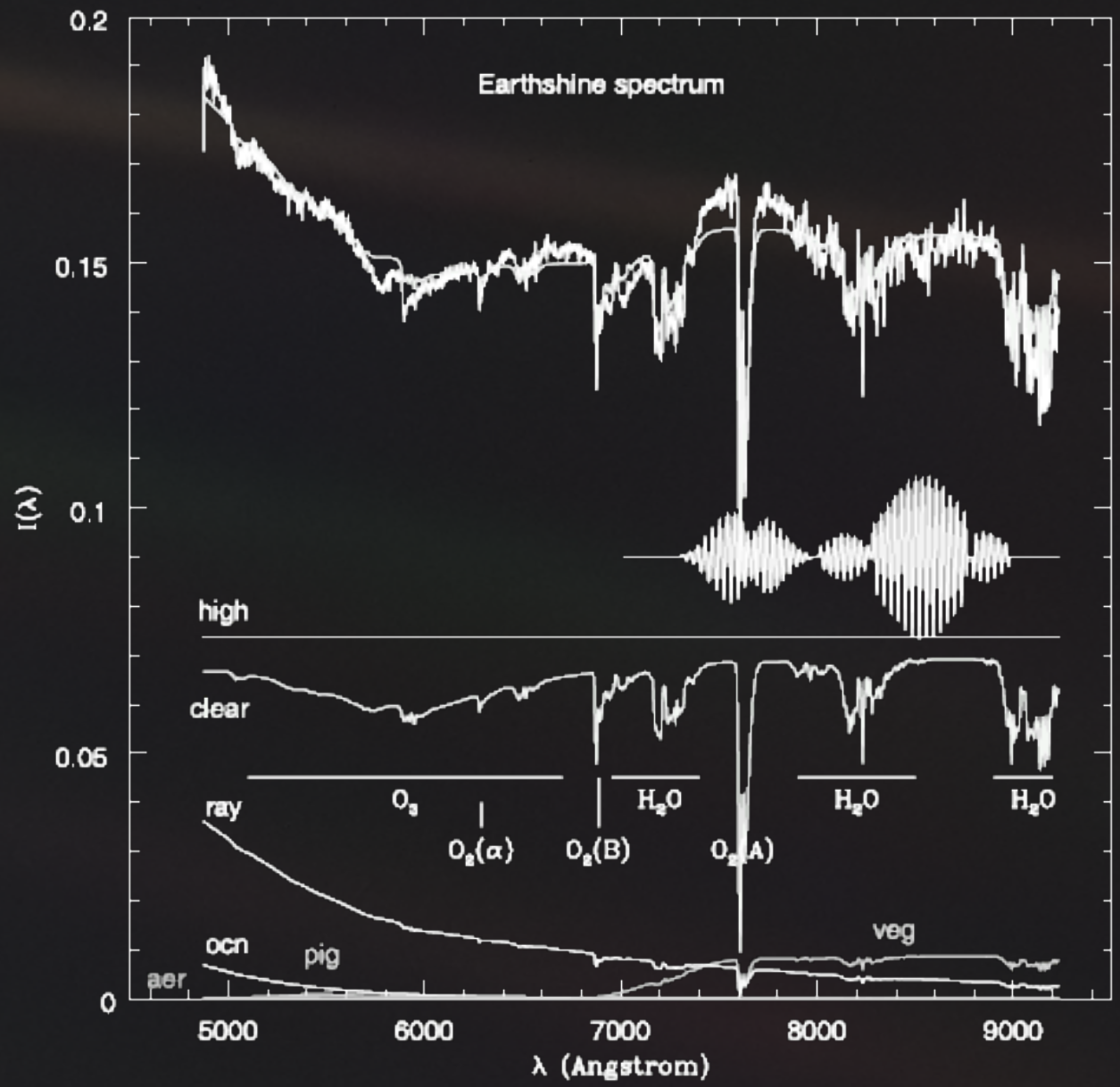
Beichman, Woolf, and Lindensmith, 1999



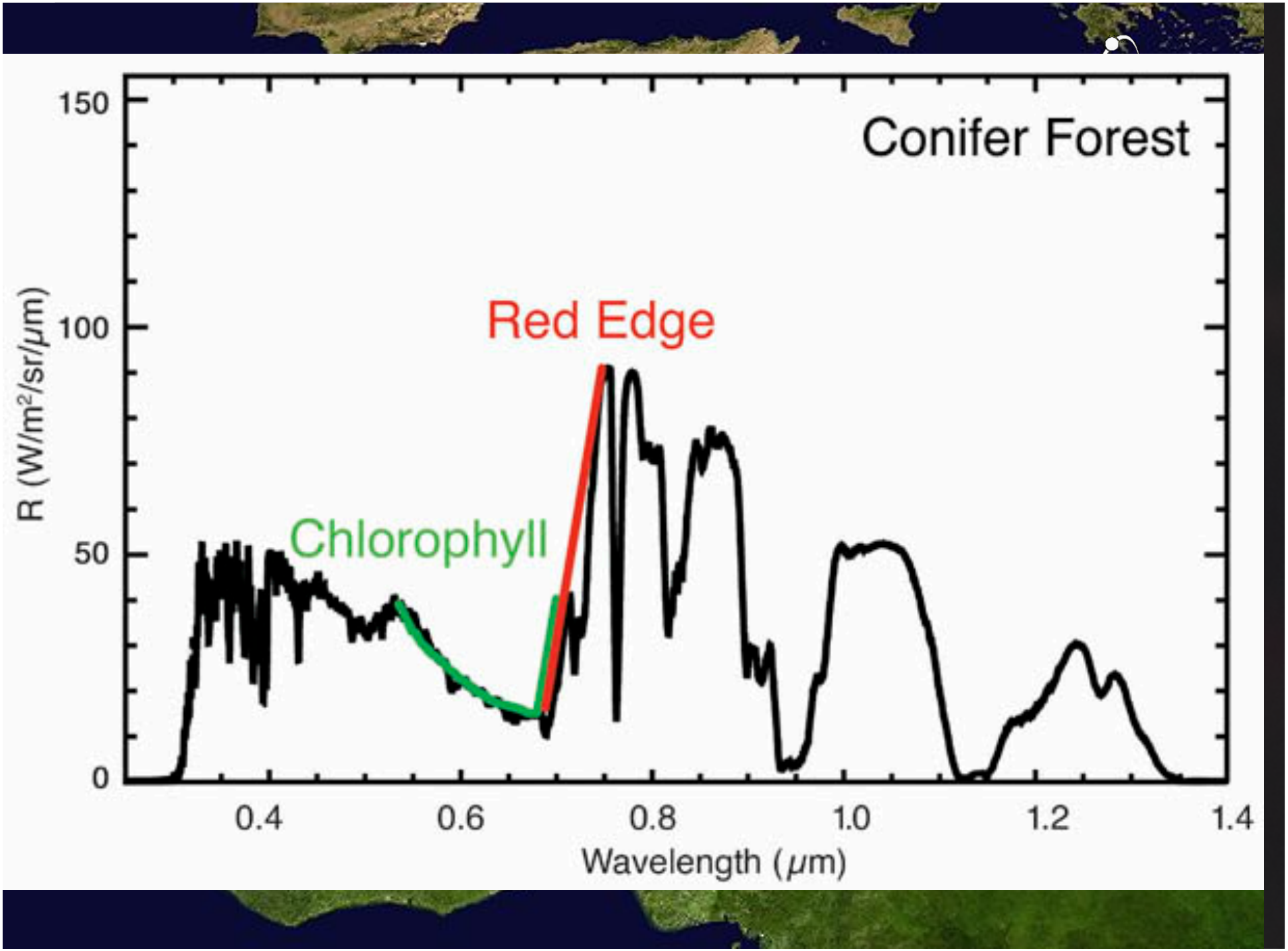




Sagan, et al., 1993



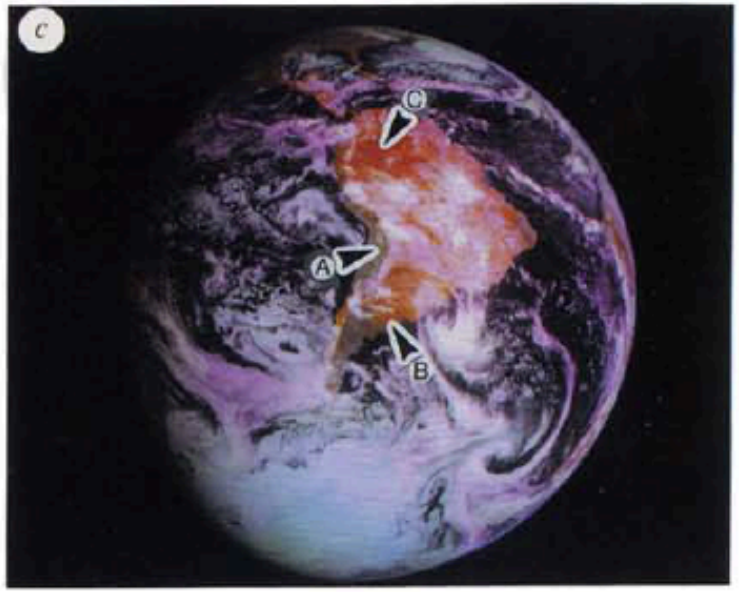
Woolf, et al., 2002

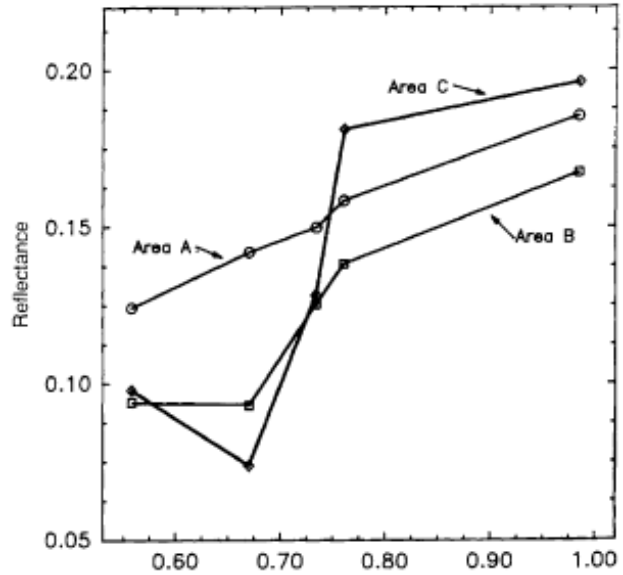

Conifer Forest
Red Edge
Chlorophyll
R (W/m²/sr/μm)
150
100
50
0
0.4
0.6
0.8
1.0
1.2
1.4
Wavelength (μm)

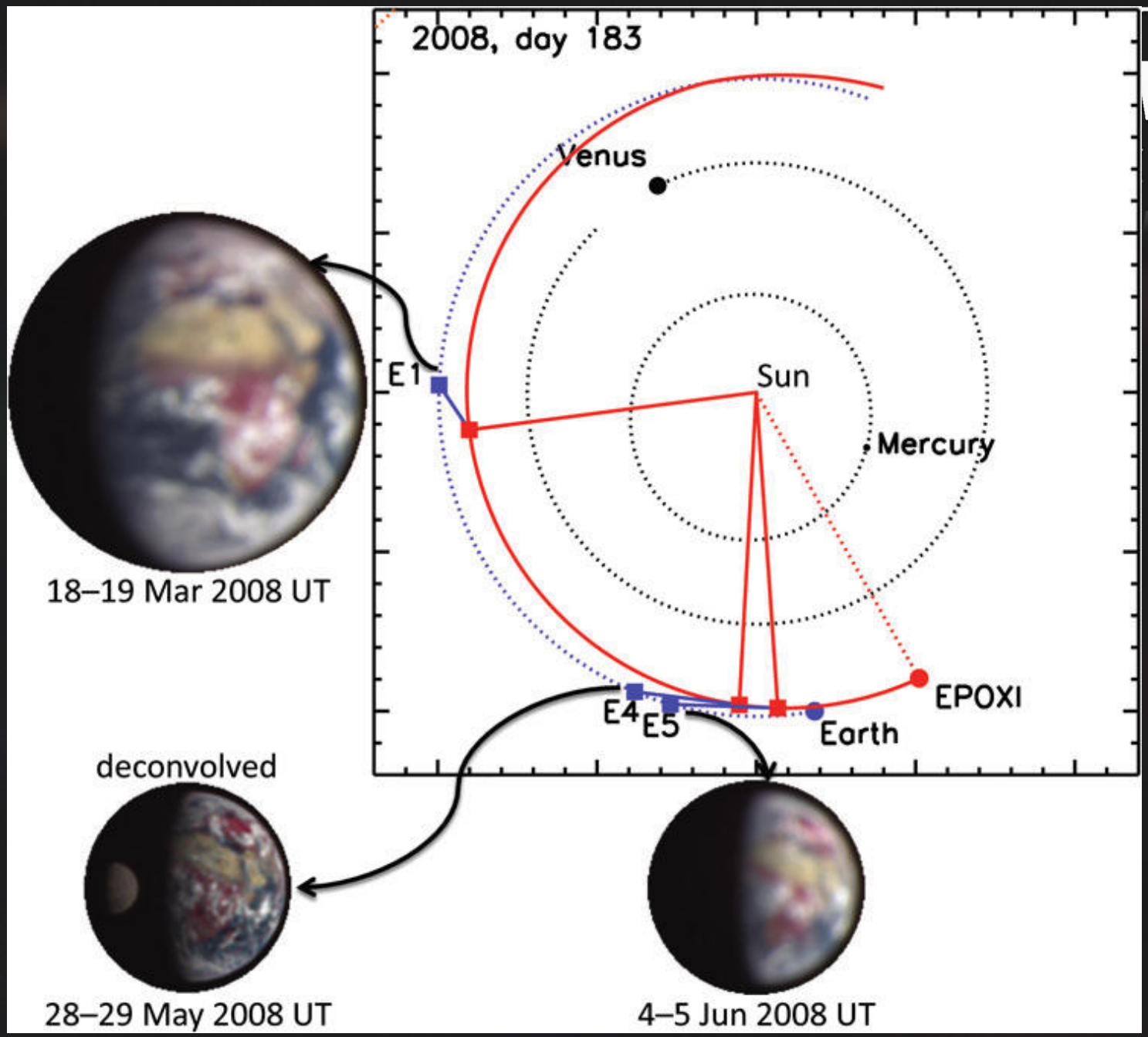
EPOXI MISSION
JPL, Ball Aerospace, University of Maryland
Comet
Hartley 2
National Aeronautics and Space Administration
DEEP IMPACT EXTENDED INVESTIGATION

a

b

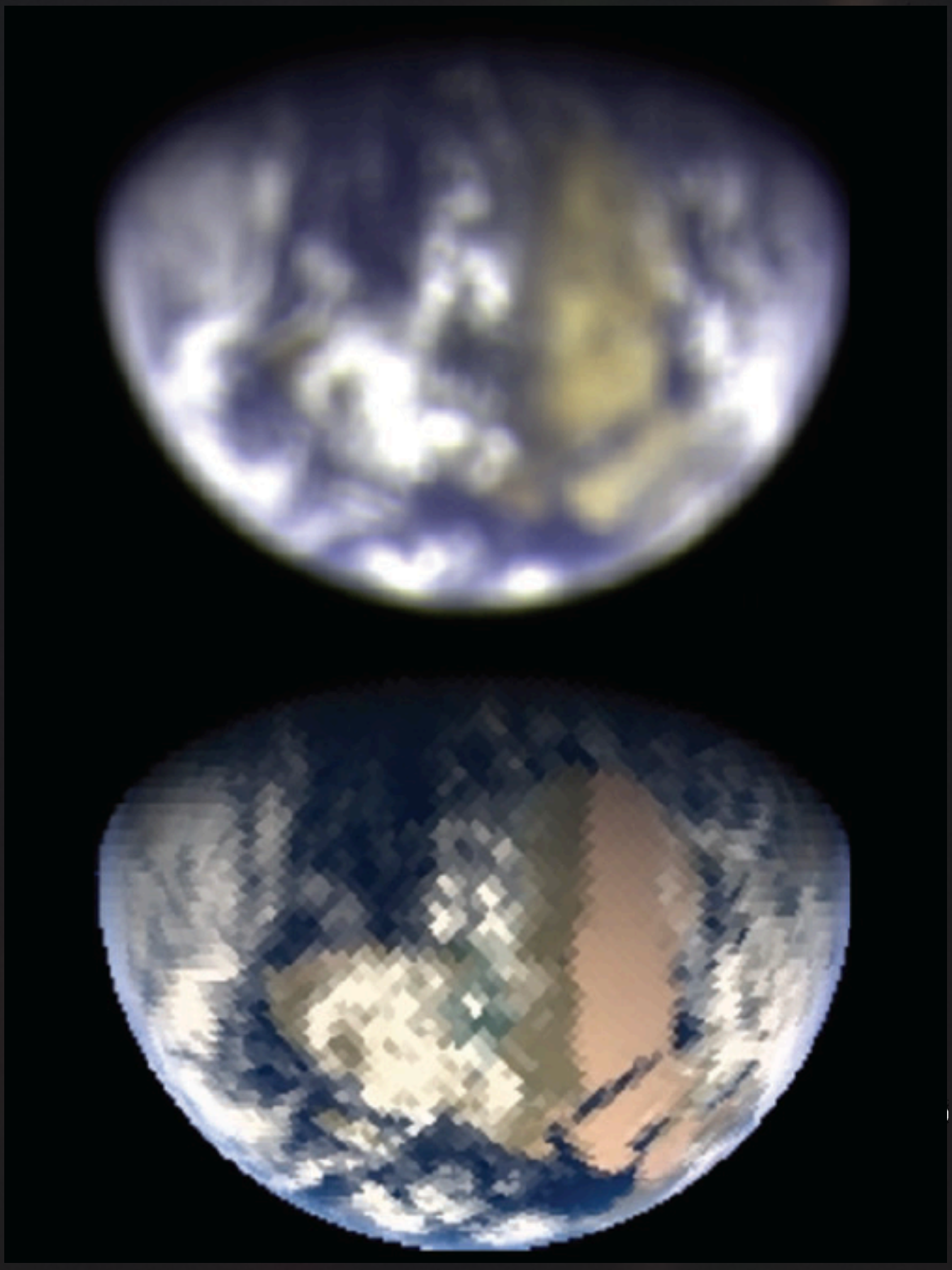

c
A
B
C

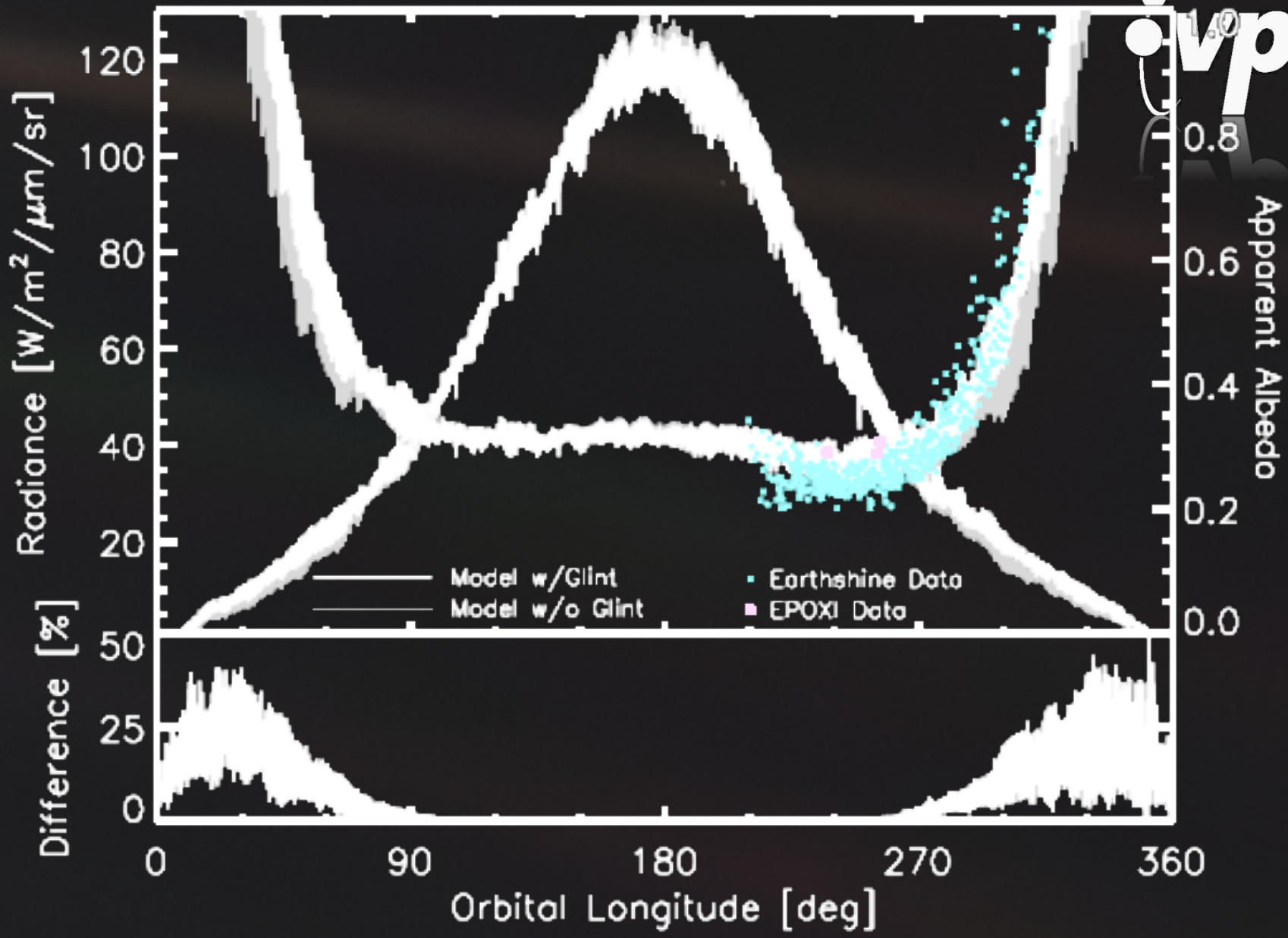

Reflectance
0.20
0.15
0.10
0.05
0.60
0.70
0.80
0.90
1.00
Area A
Area B
Area C



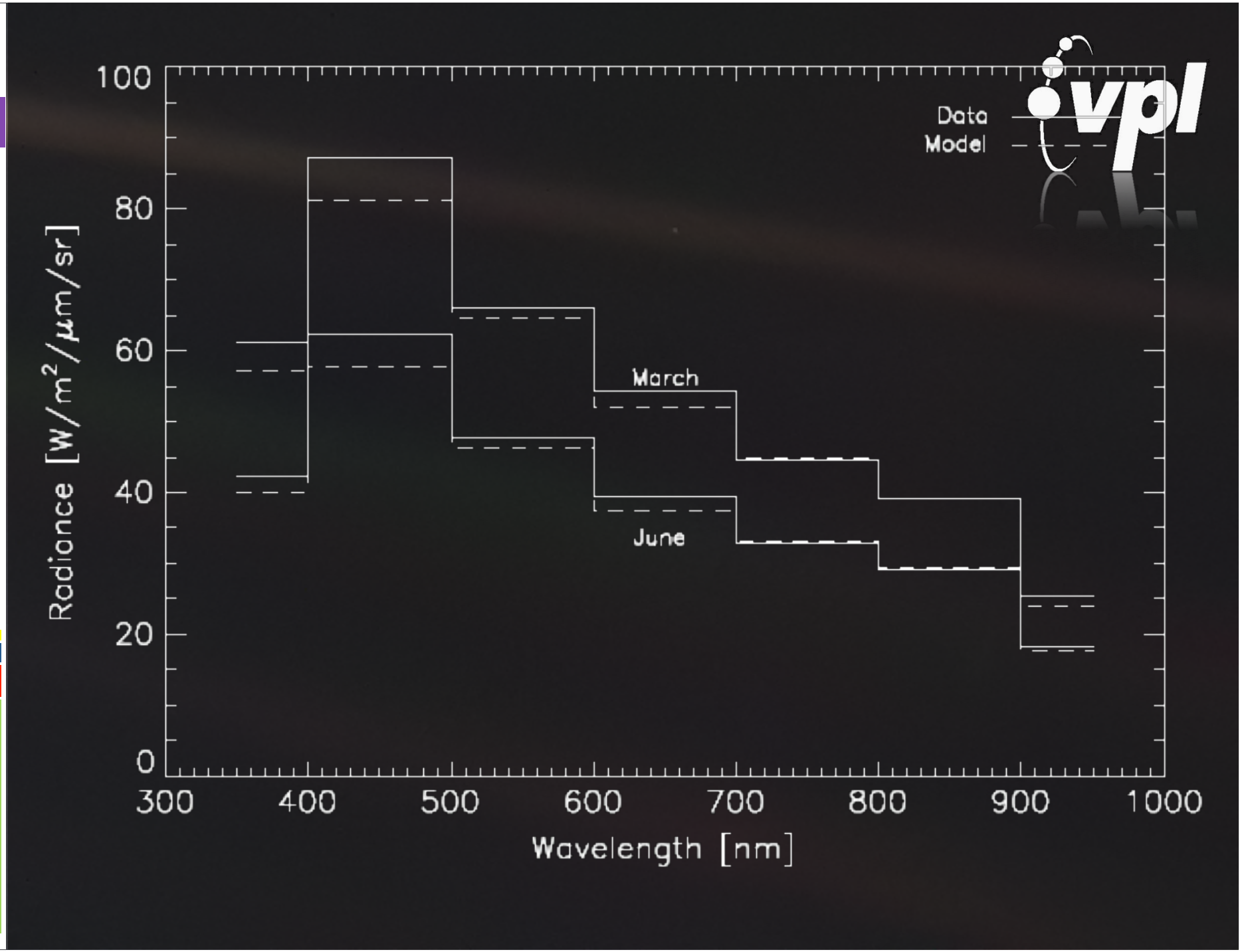
Livengood, et al., 2012

Robinson, et al., 2012

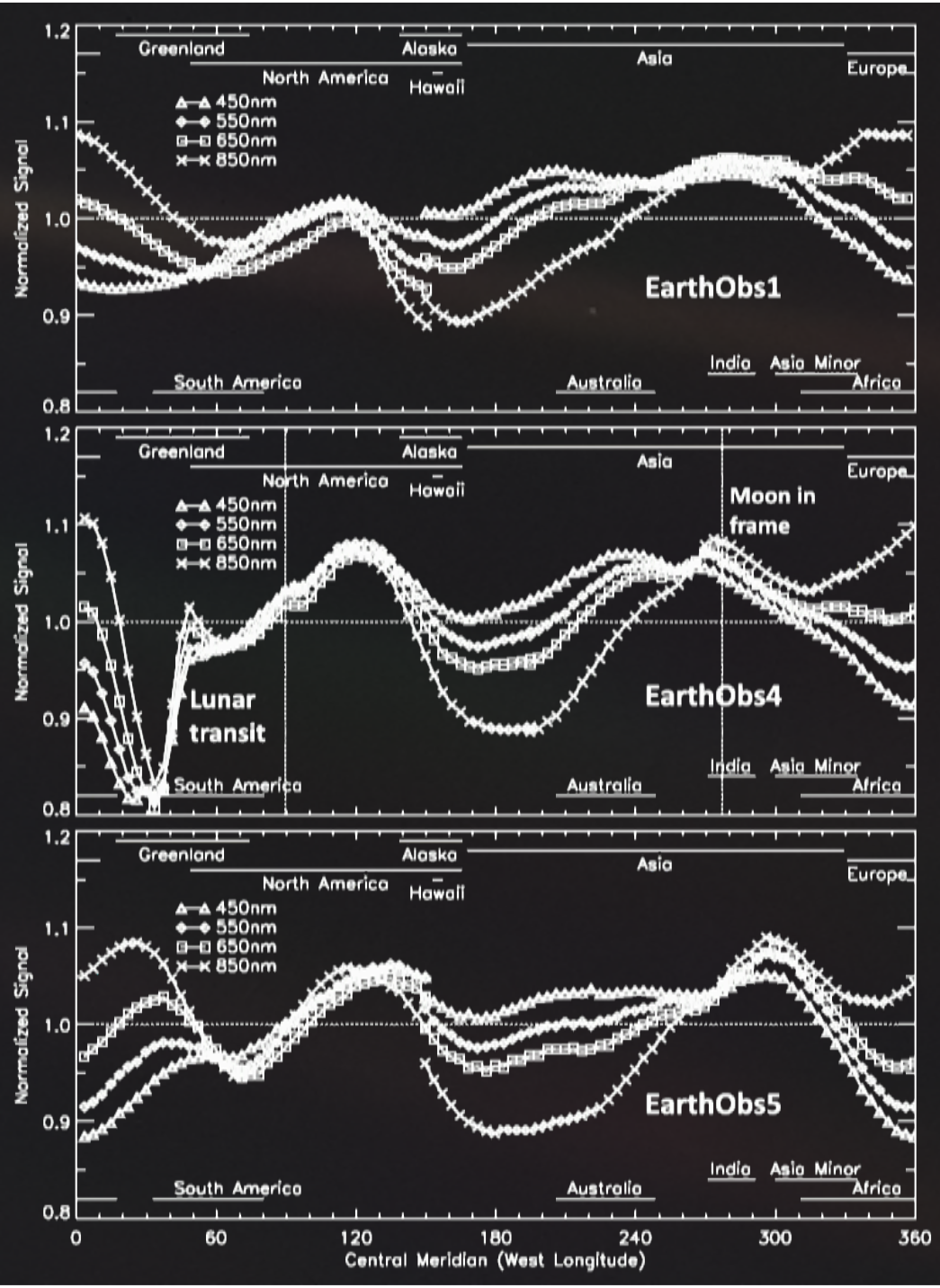


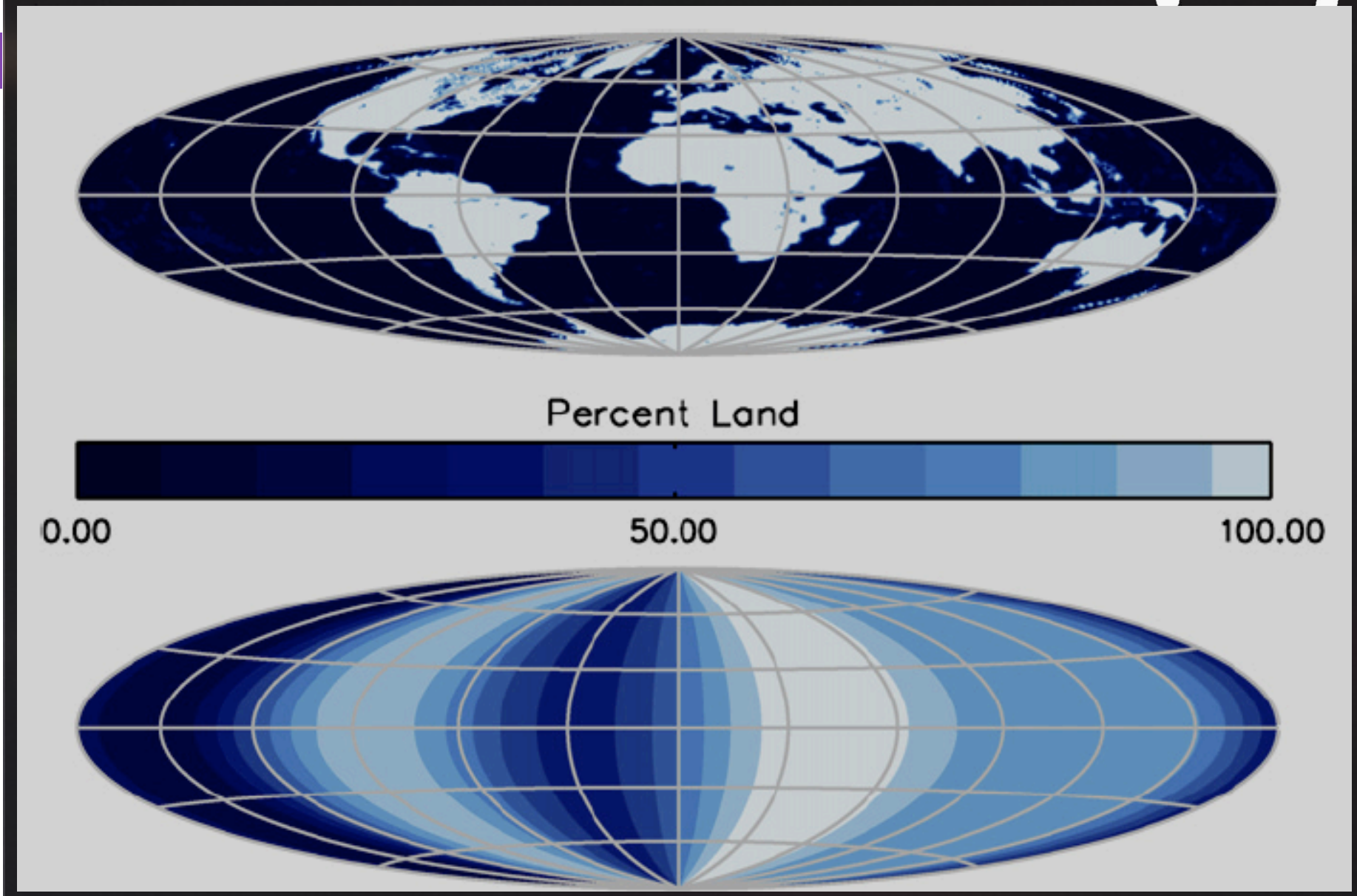


Robinson, et al., 2010



Robinson, et al., 2012

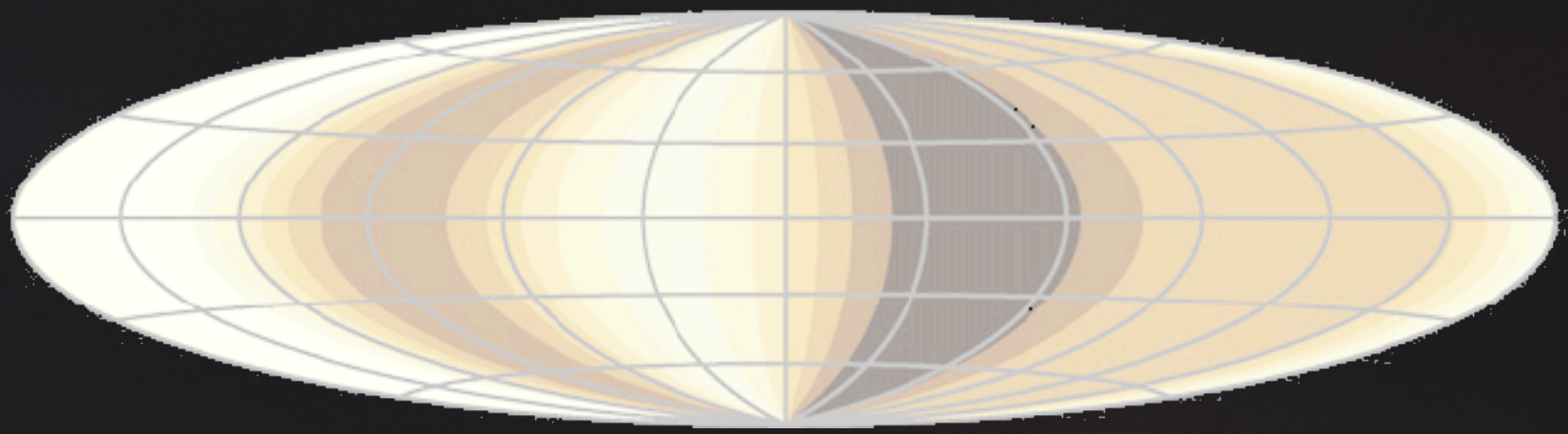

Greenland
Alaska
Asia
Europe
North America
Hawaii
450nm
550nm
650nm
850nm
EarthObs1
South America
Australia
India
Asia Minor
Africa
Moon in frame
Lunar transit
EarthObs4
EarthObs5
Normalized Signal
1.2
1.1
1.0
0.9
0.8
0
60
120
180
240
300
360
Central Meridian (West Longitude)



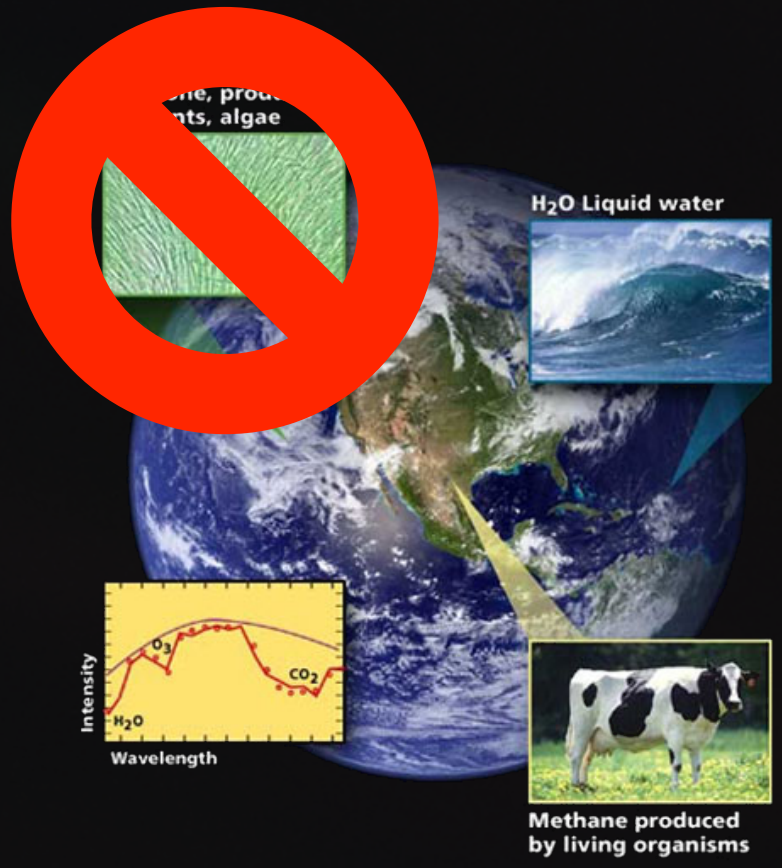
Cowan, et al., 2011

Percent Land

0.00 50.00 100.00



What if a biosphere doesn't have O_2/O_3?



Beichman, Woolf, and Lindensmith, 1999

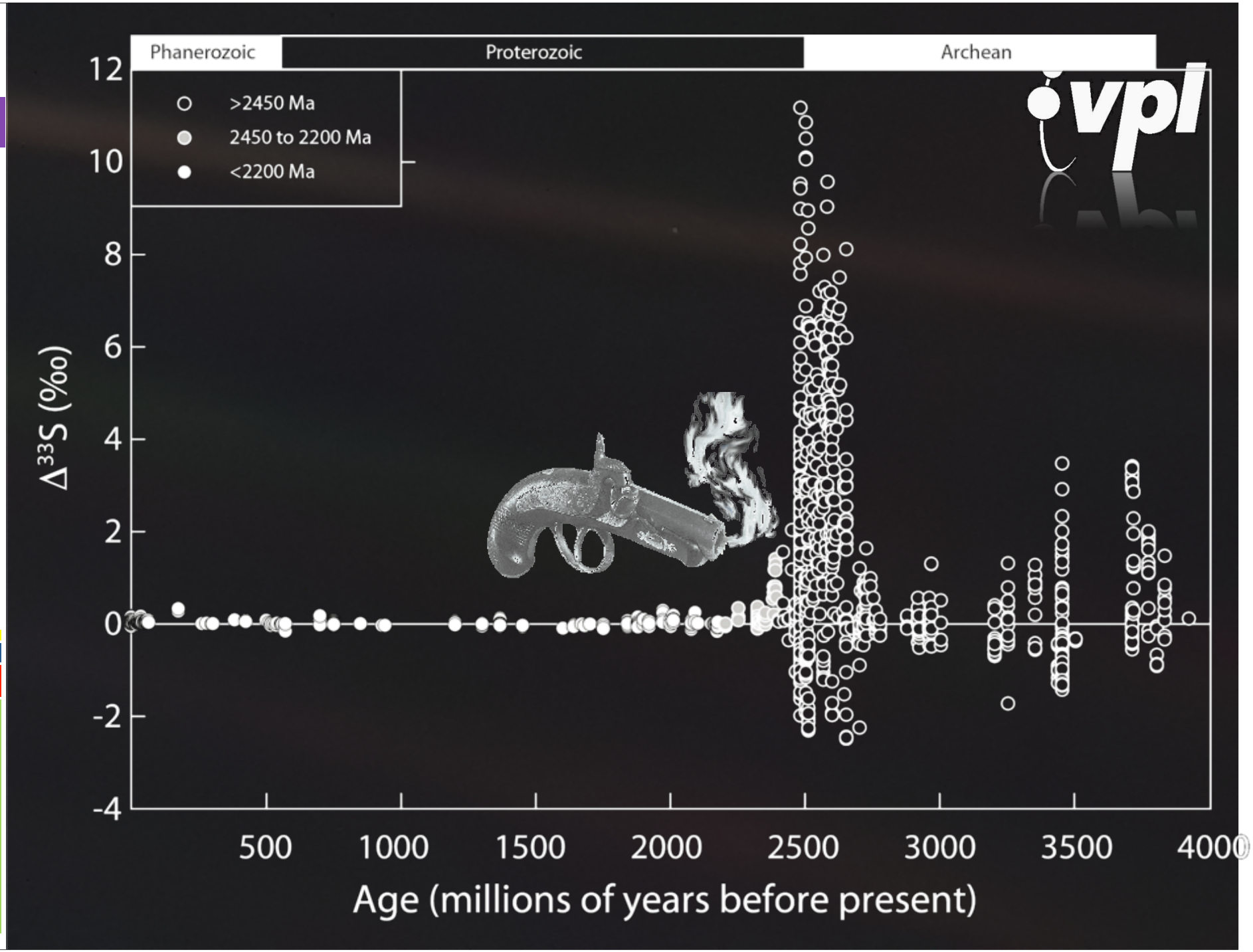
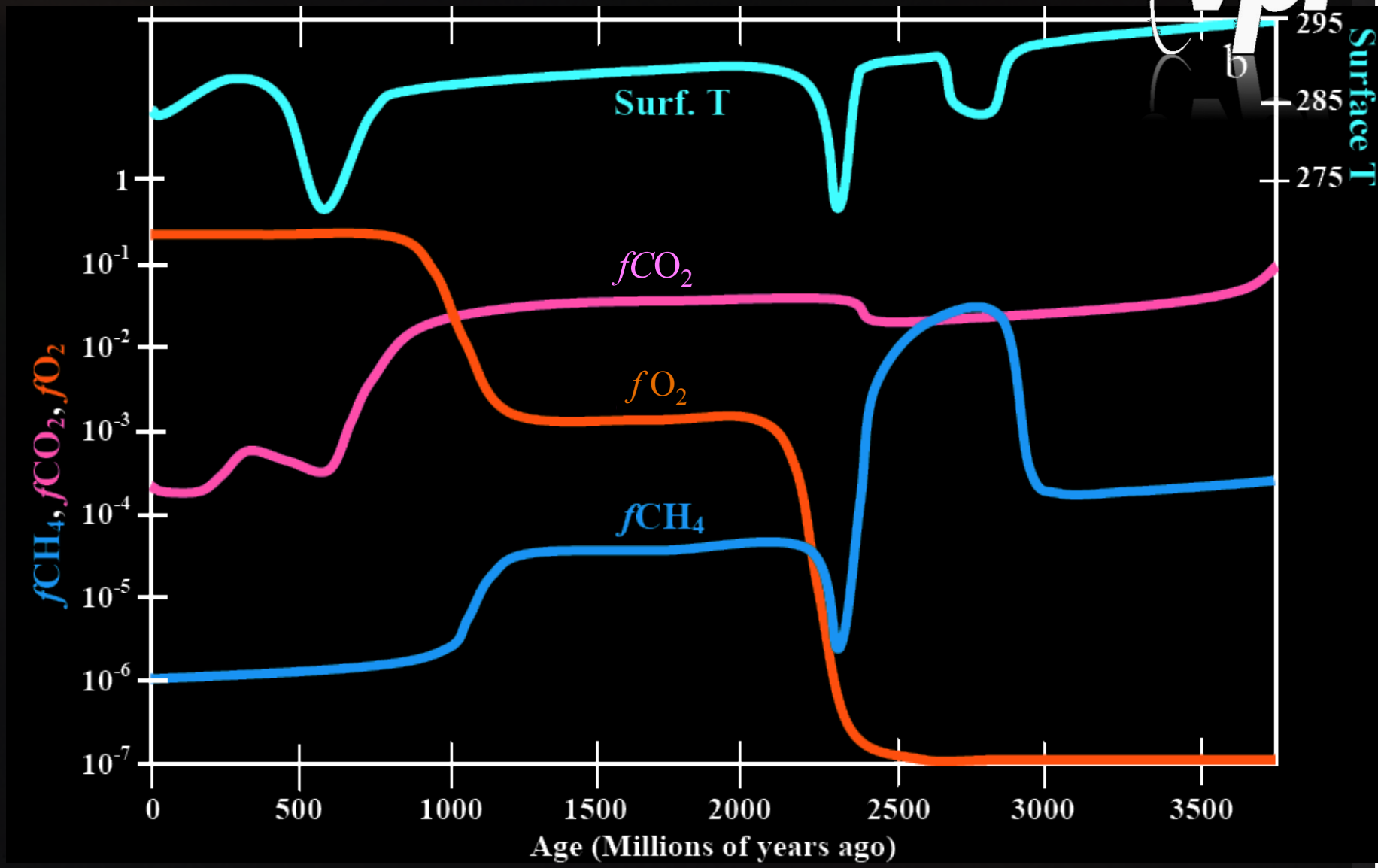
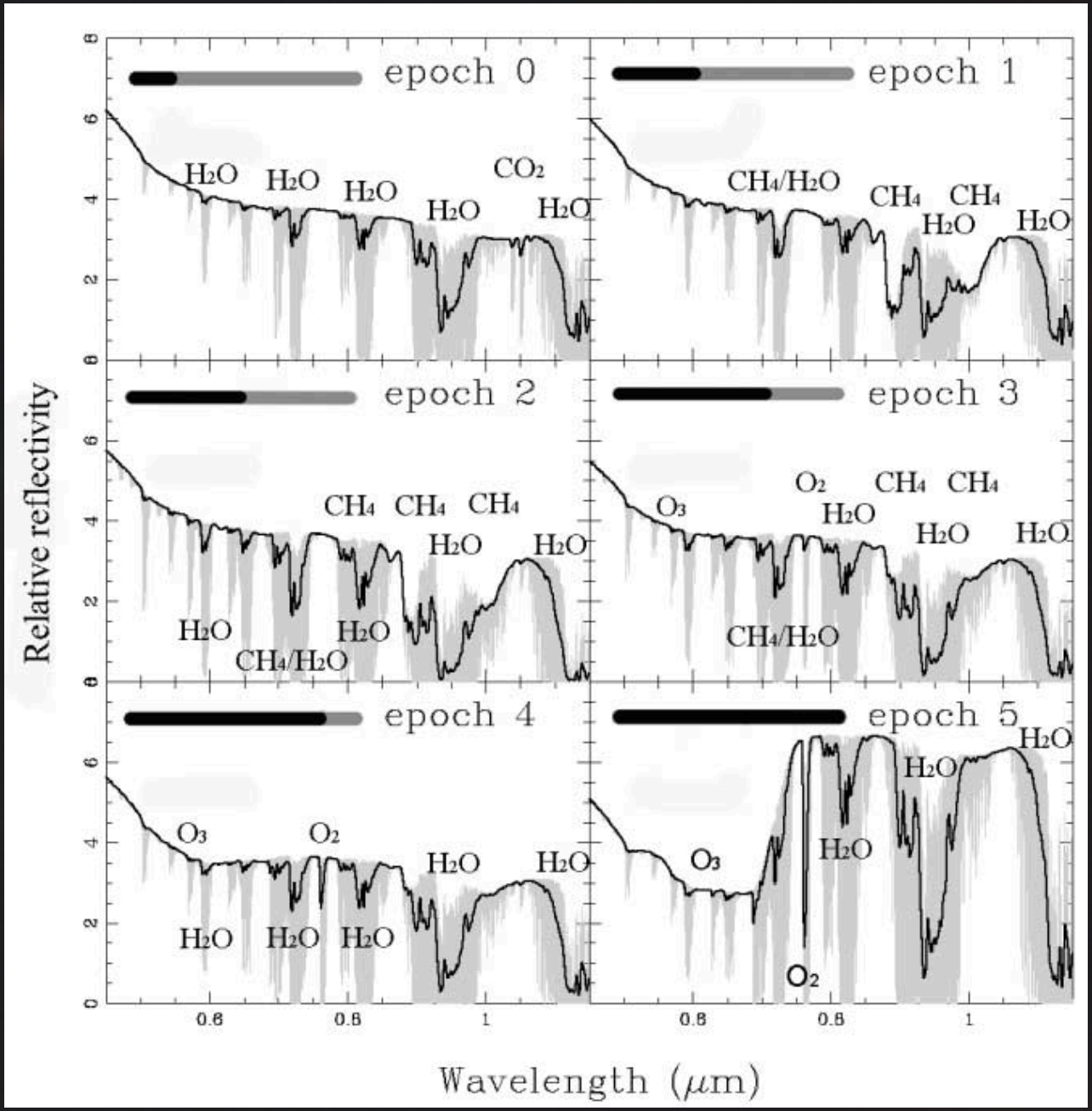


Figure courtesy Boz Wing

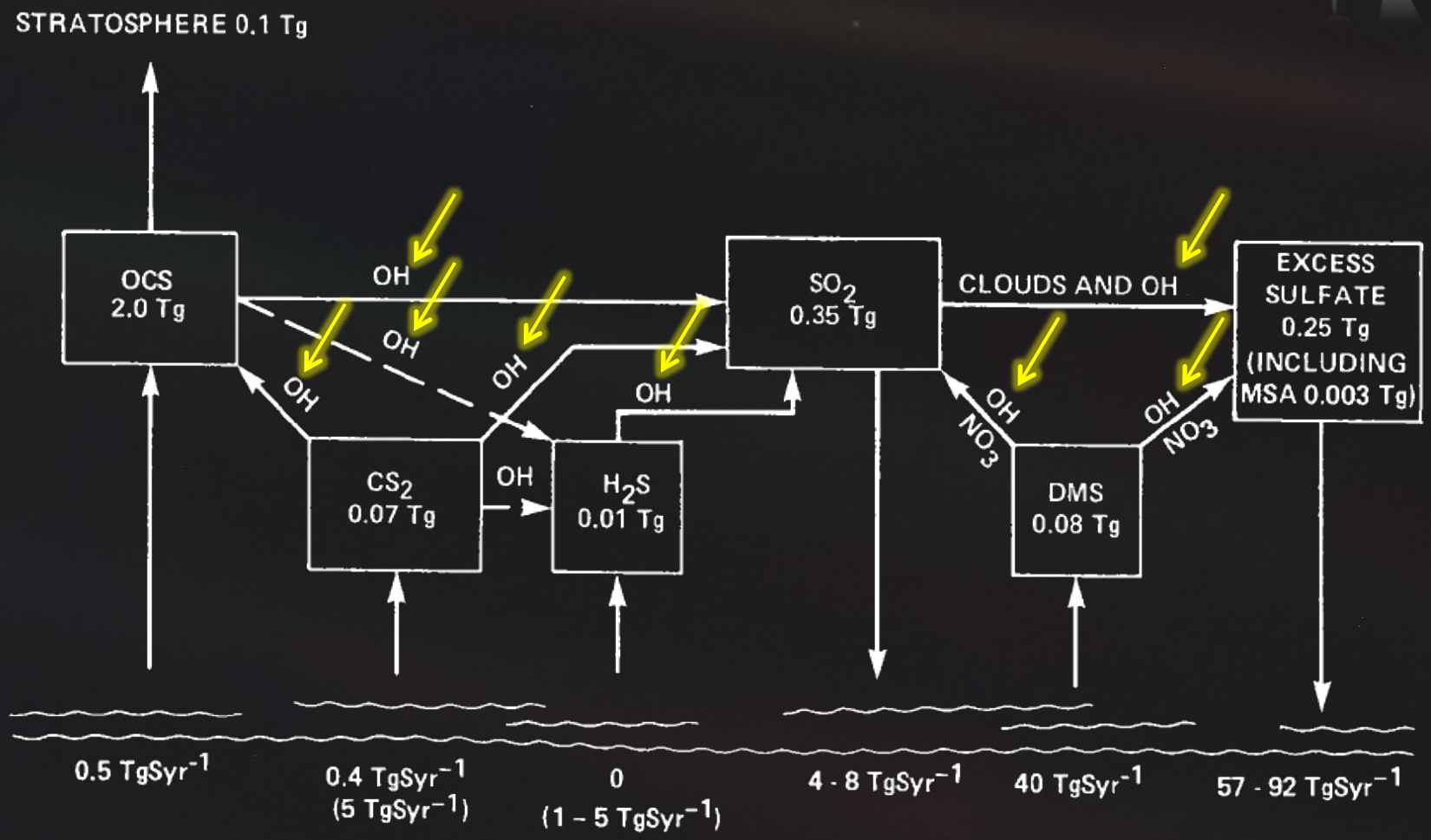


Domagal-Goldman, 2007



Kaltenegger, et al., 2007

FALSE NEGATIVES FOR LIFE: ANOXIC BIOSIGNATURES



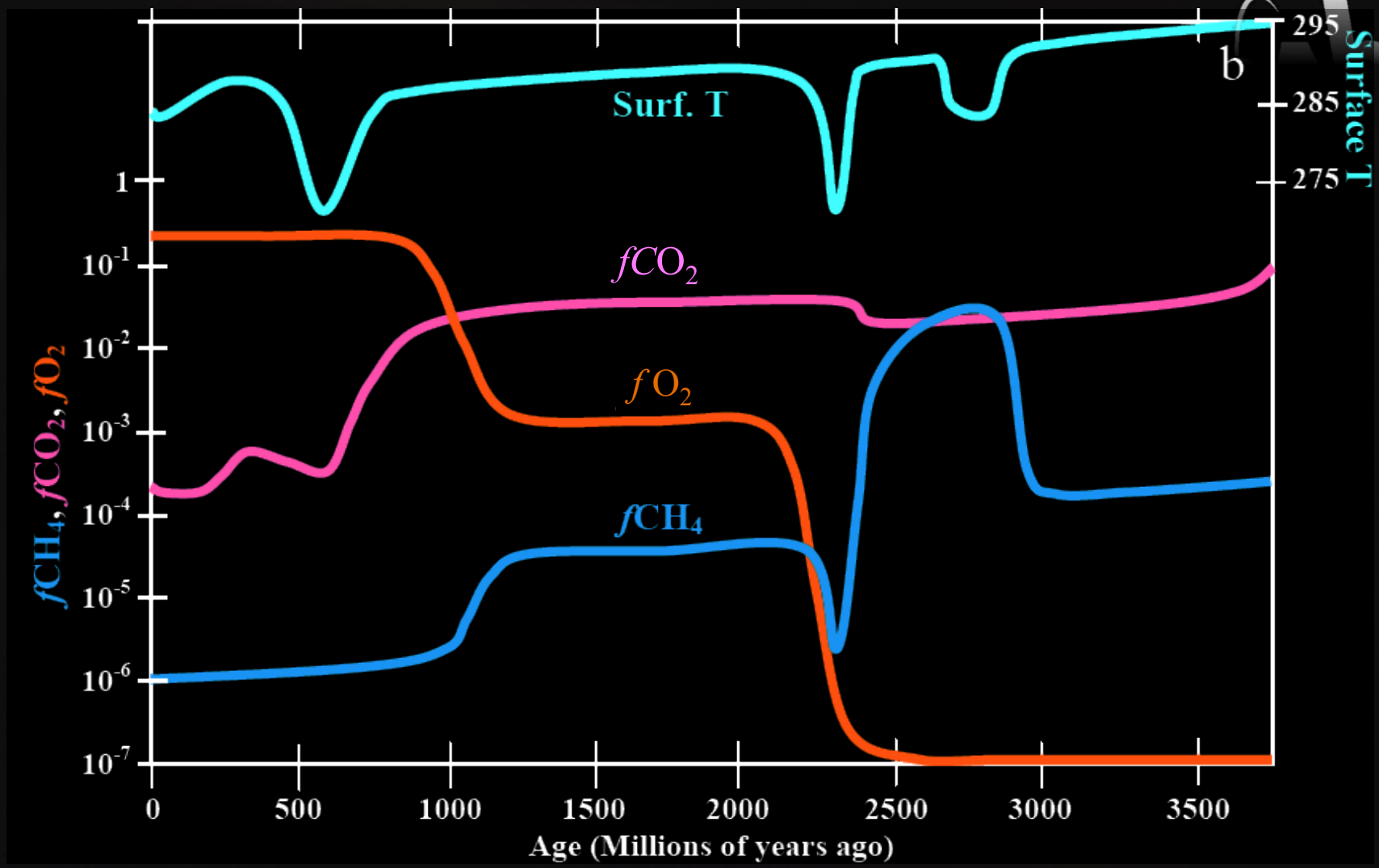
Toon et al., *1987*

Photo courtesy Brandon Goldman, 2008

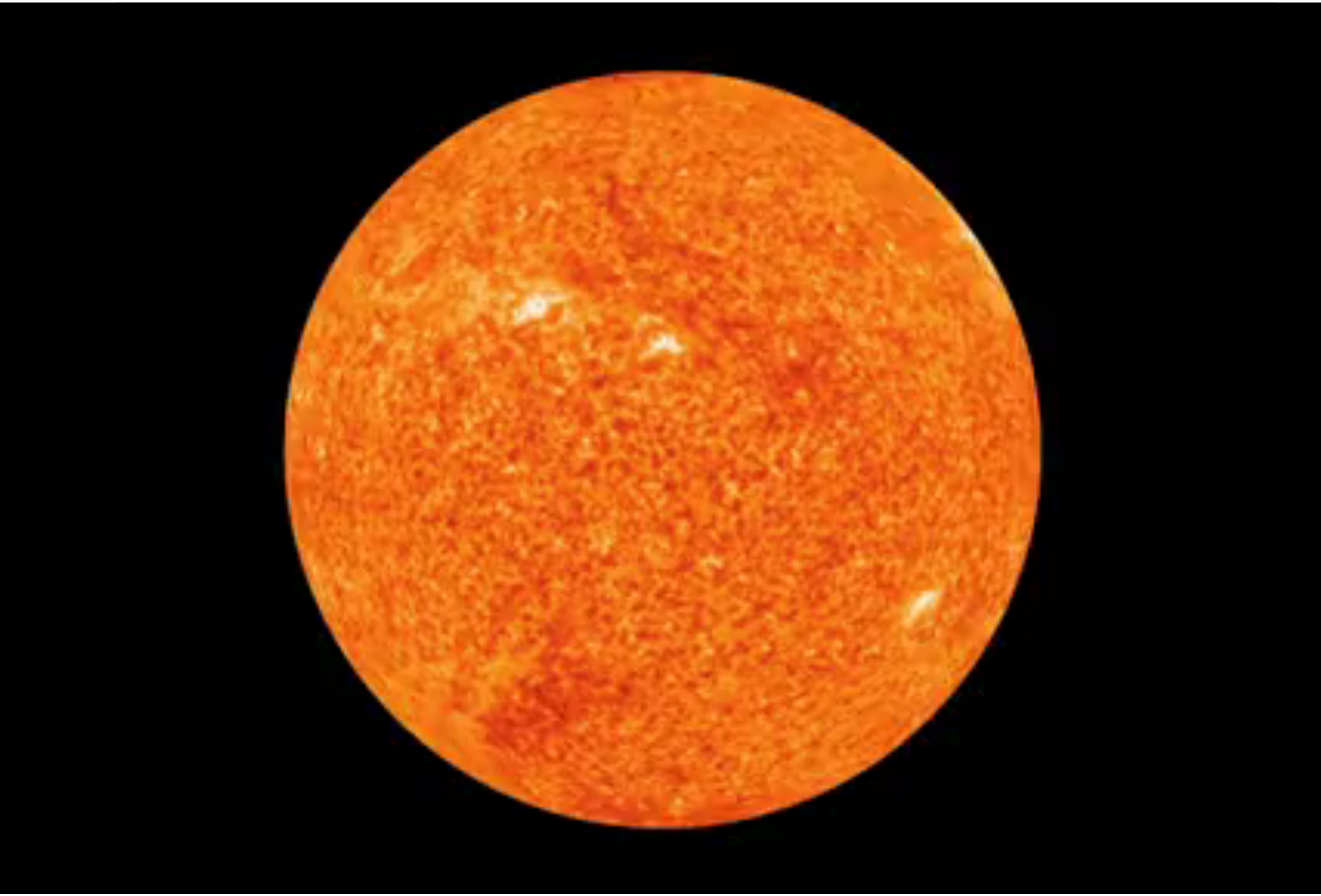
S_{org} on modern-day Earth

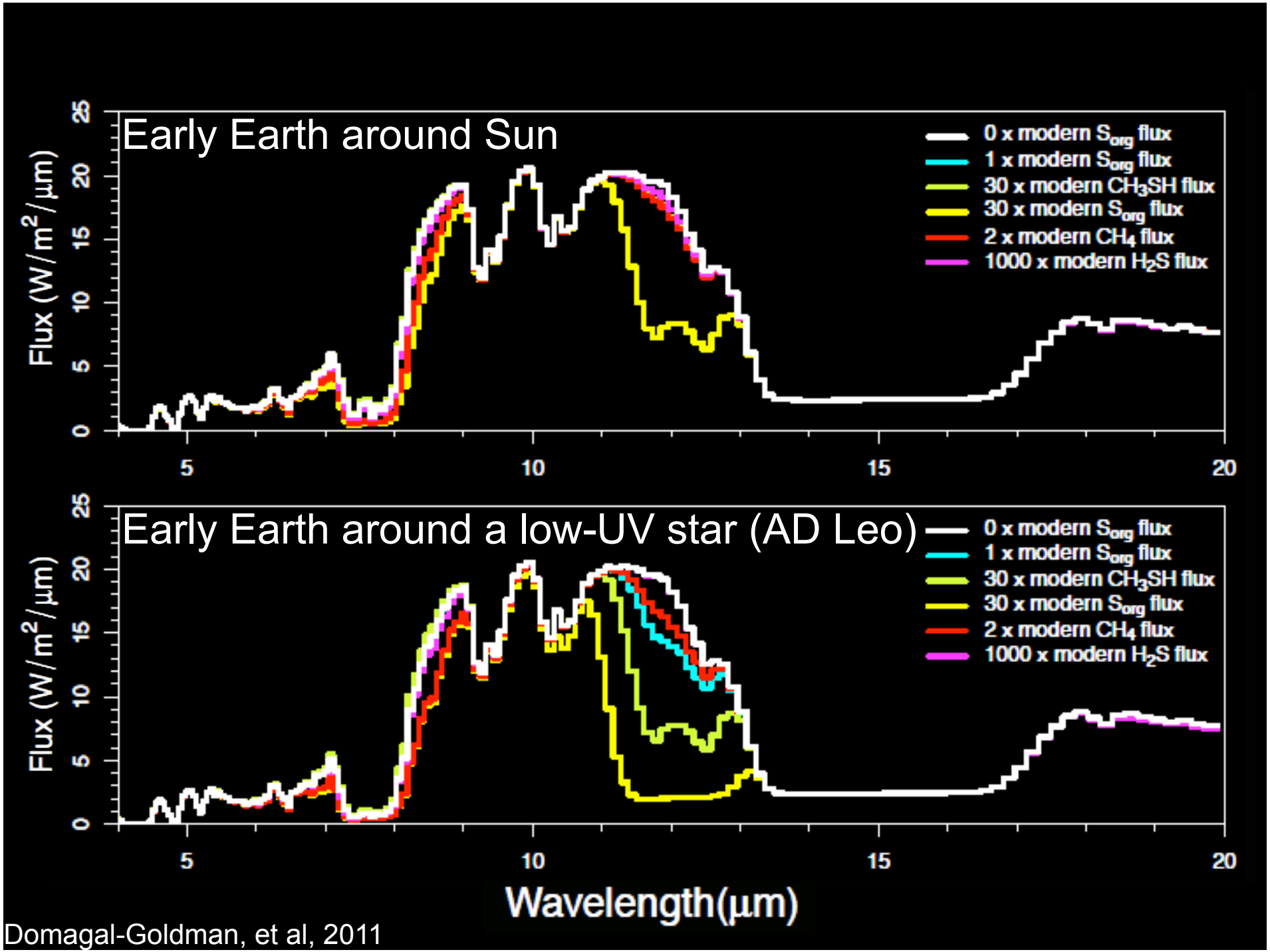
S_{org} on ancient Earth?

Futurama, *1999*



Domagal-Goldman, 2007



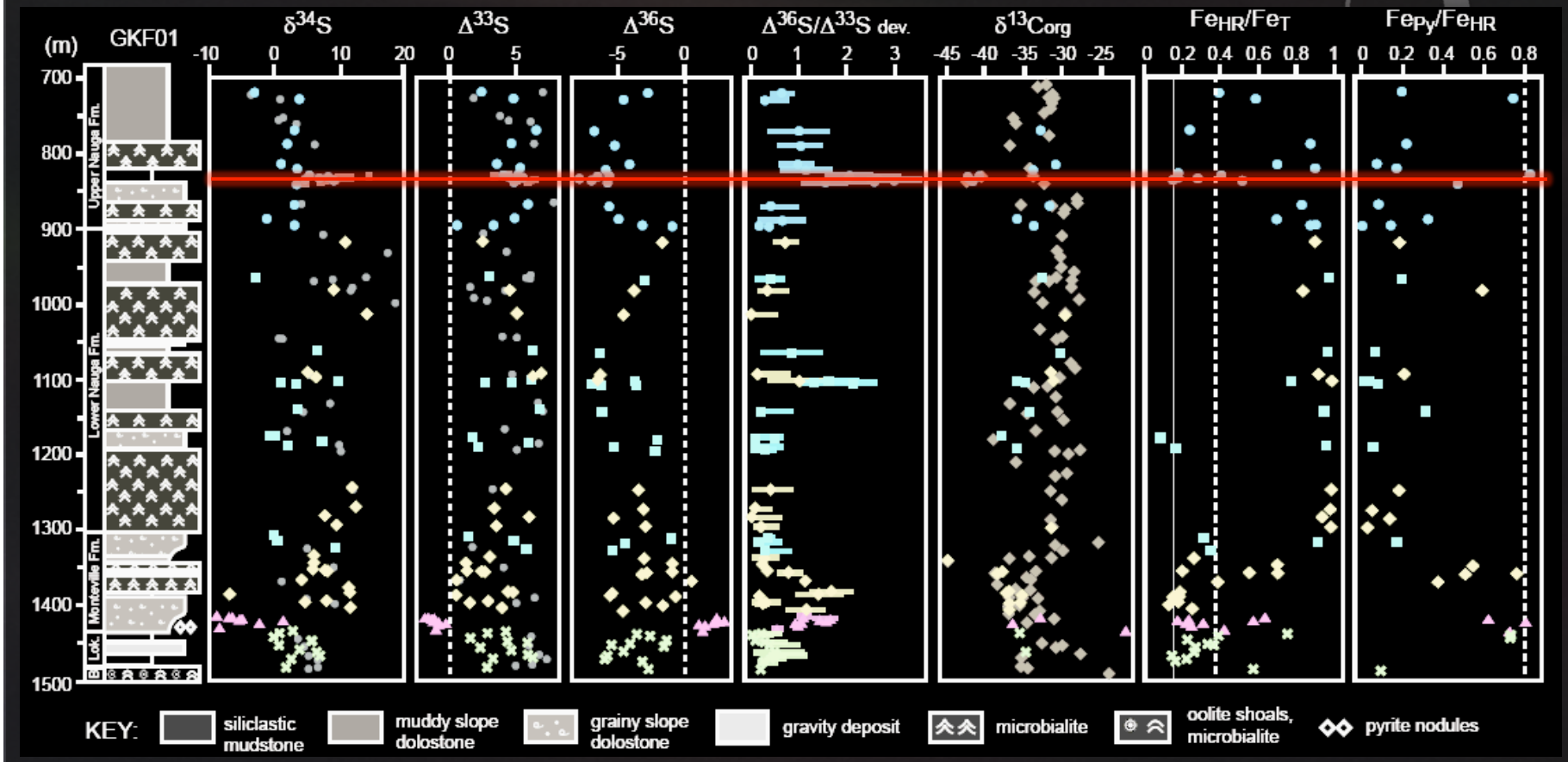


Domagal-Goldman, et al, 2011

Can Sorg gases be used to detect anoxic biospheres?

Yes. But direct signals only for planets that orbit M-dwarfs with low stellar activity.

Indirect signals (from C_2H_6) may exist on planets around Sun-type stars.



Zerkle et al., 2012

Can O_3 build up on planets without biological O_2 production?

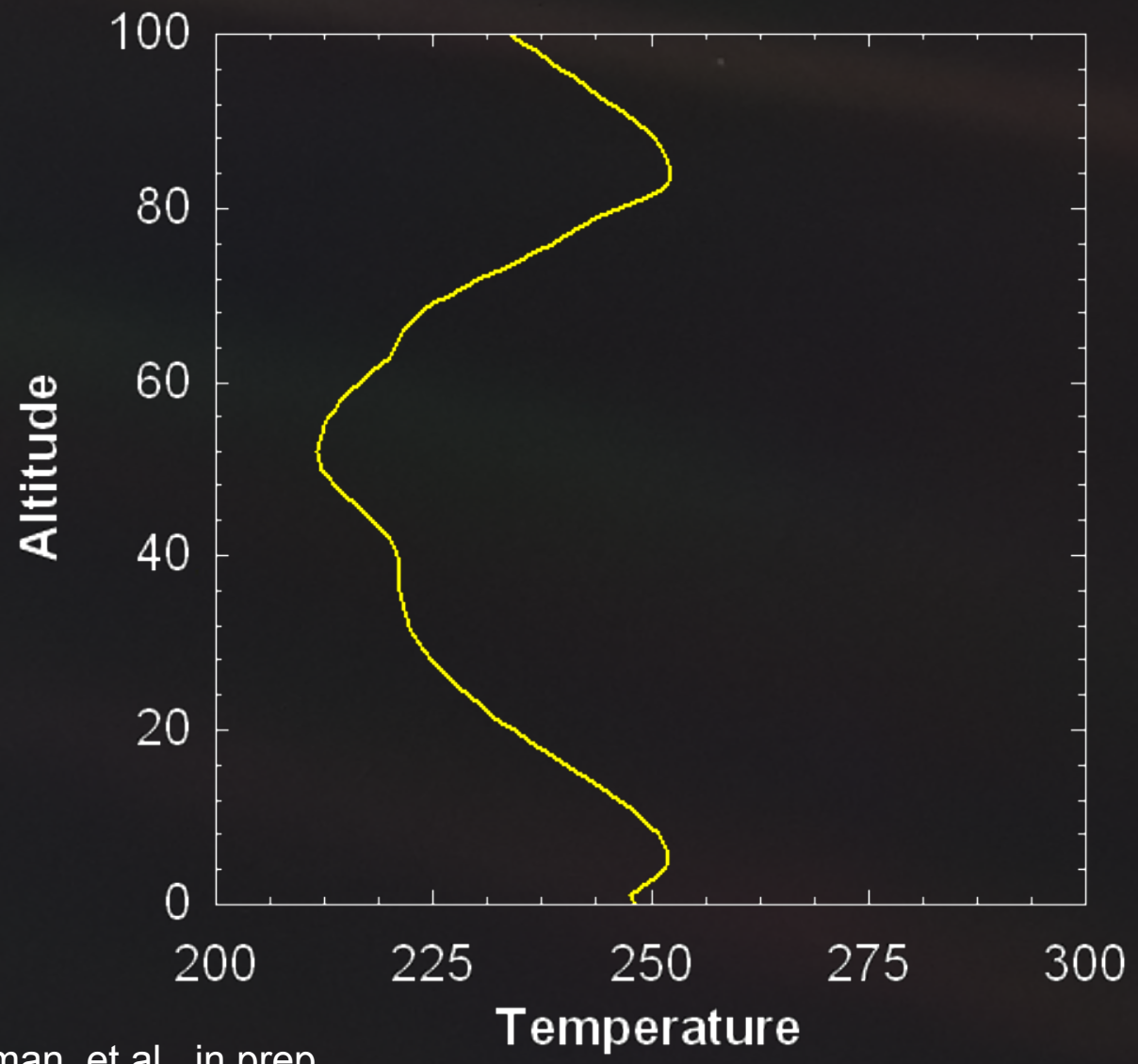
Yes, but it requires two conditions:

1. The planet must be orbiting an active M-dwarf, such as AD Leonis
2. The planet must be shielded by an organic haze layer

The brings us to another question:

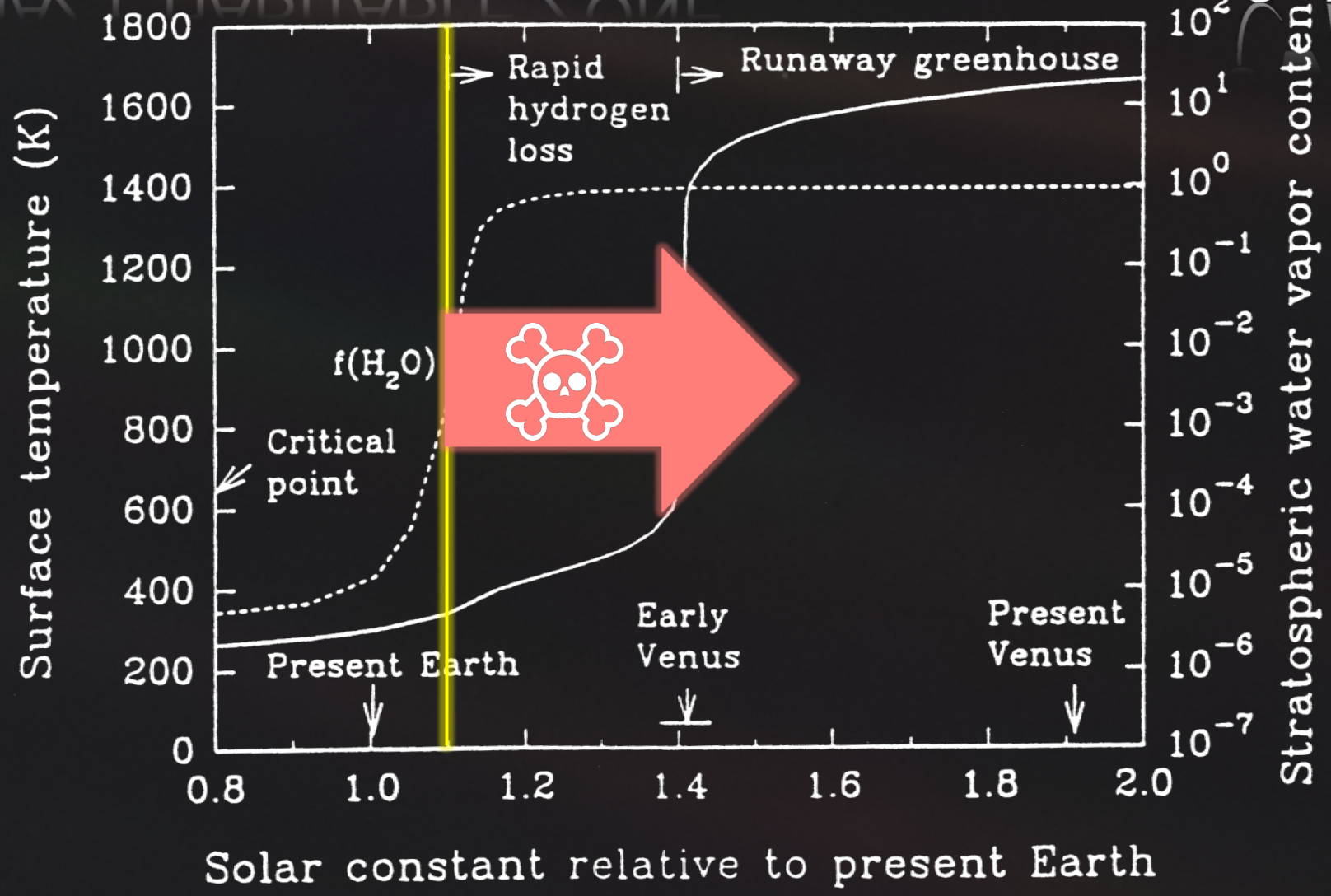
If hazes exist on planets, what are the climatic implications? What are the implications for the inner-edge of the habitable zone?

THE INNER EDGE OF THE "HAZY HABITABLE ZONE"



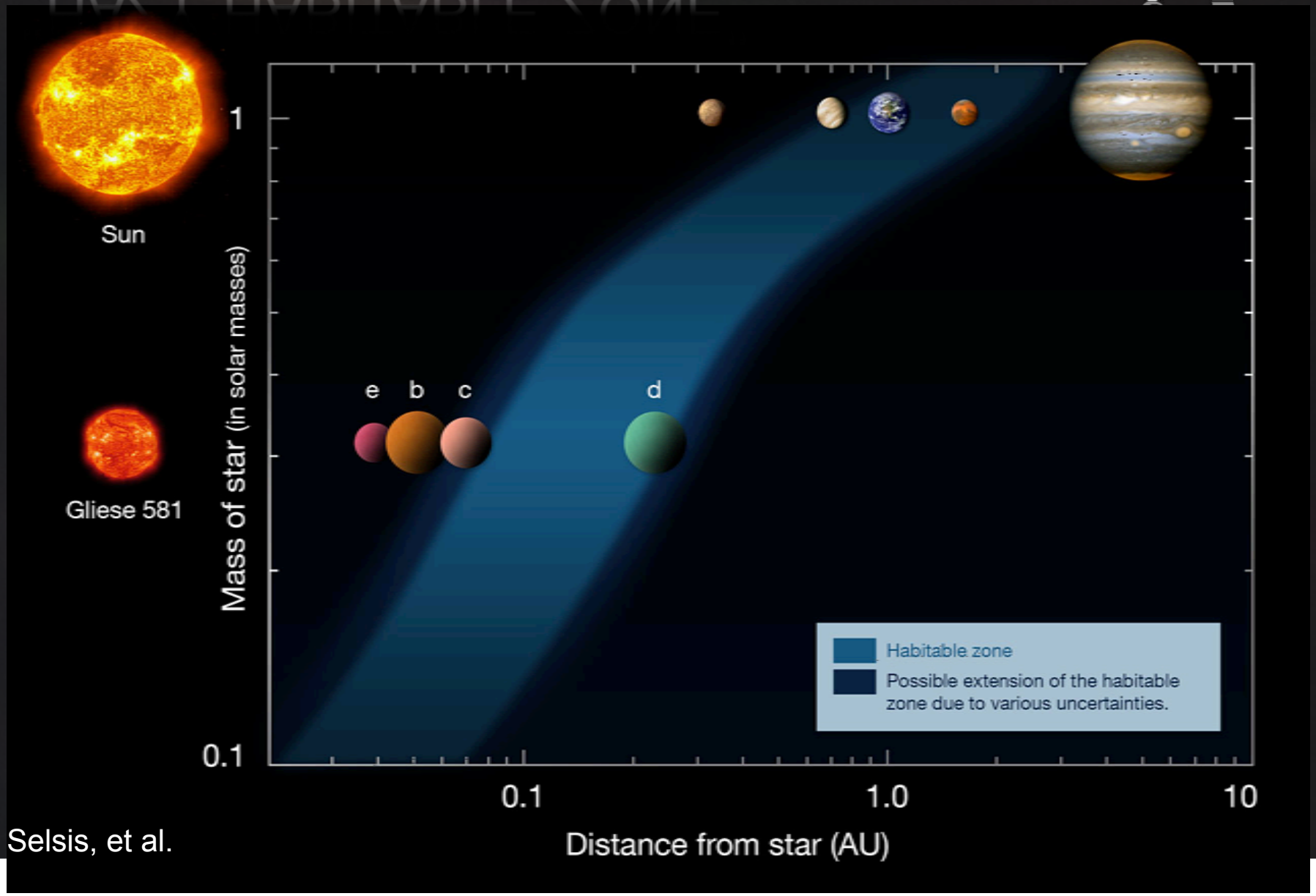
omagal-Goldman, et al., in prep

THE INNER EDGE OF THE "HAZY HABITABLE ZONE"



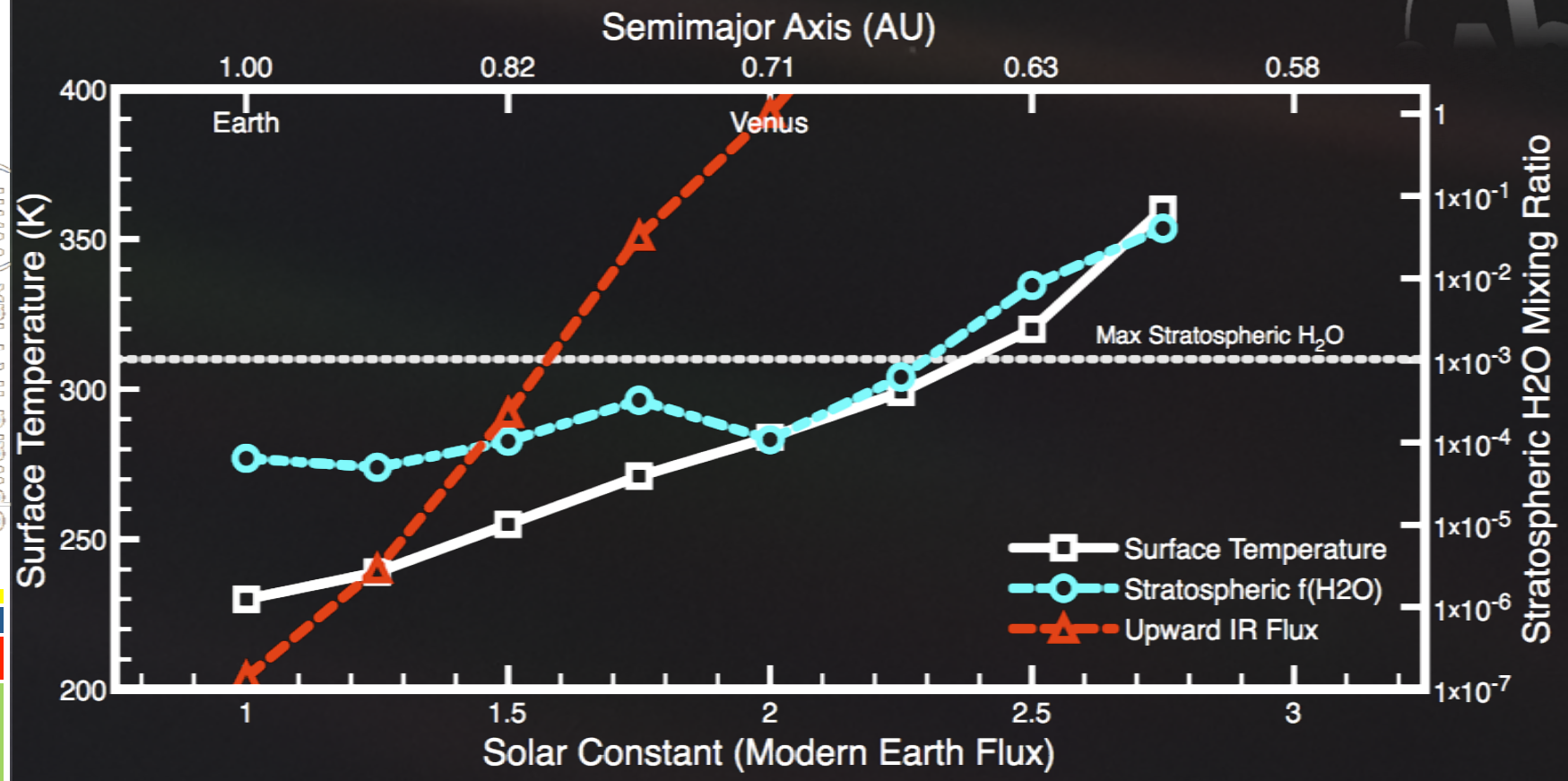
asting, et al., 1993

THE INNER EDGE OF THE "HAZY HABITABLE ZONE"



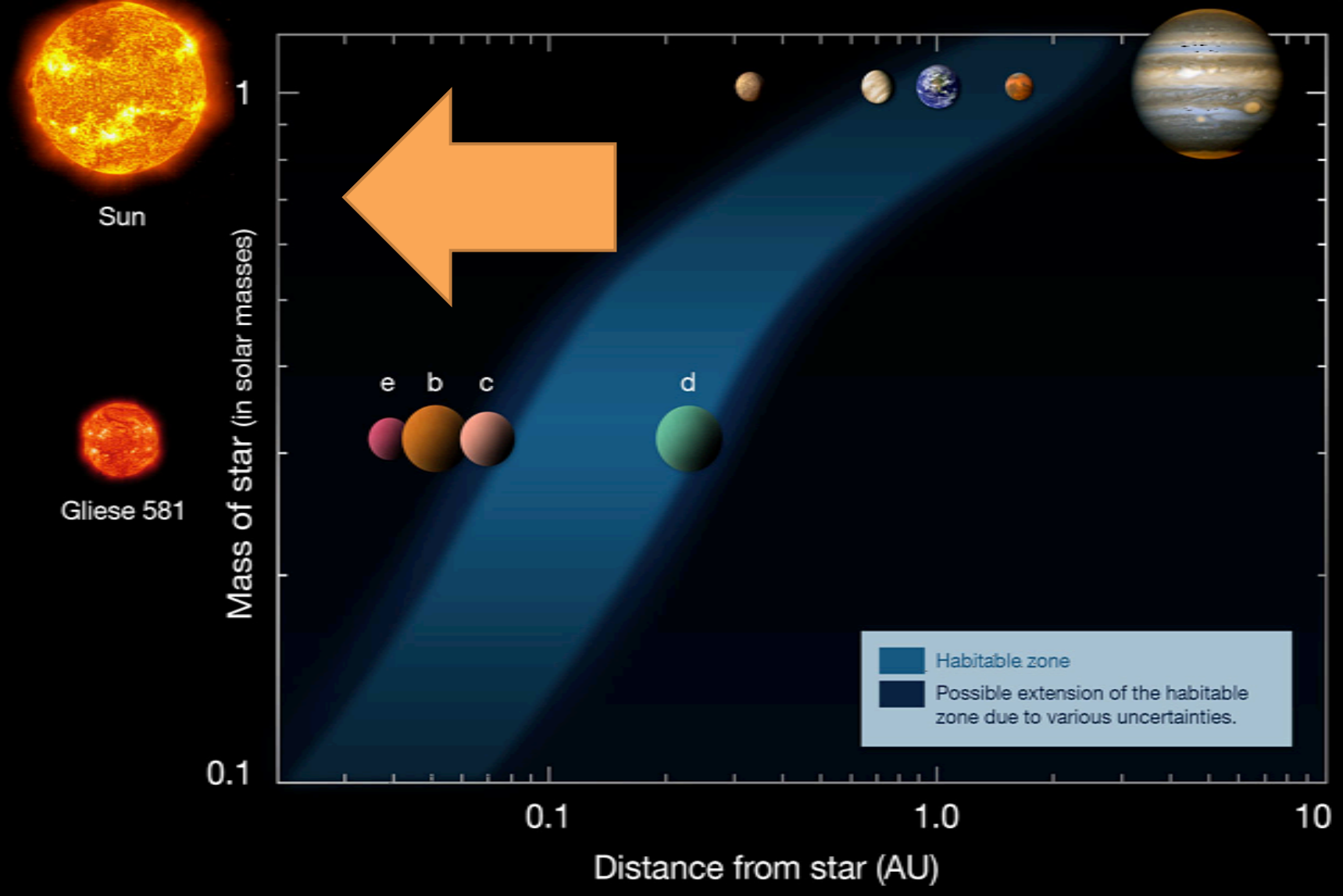
Selsis, et al.

THE INNER EDGE OF THE "HAZY HABITABLE ZONE"



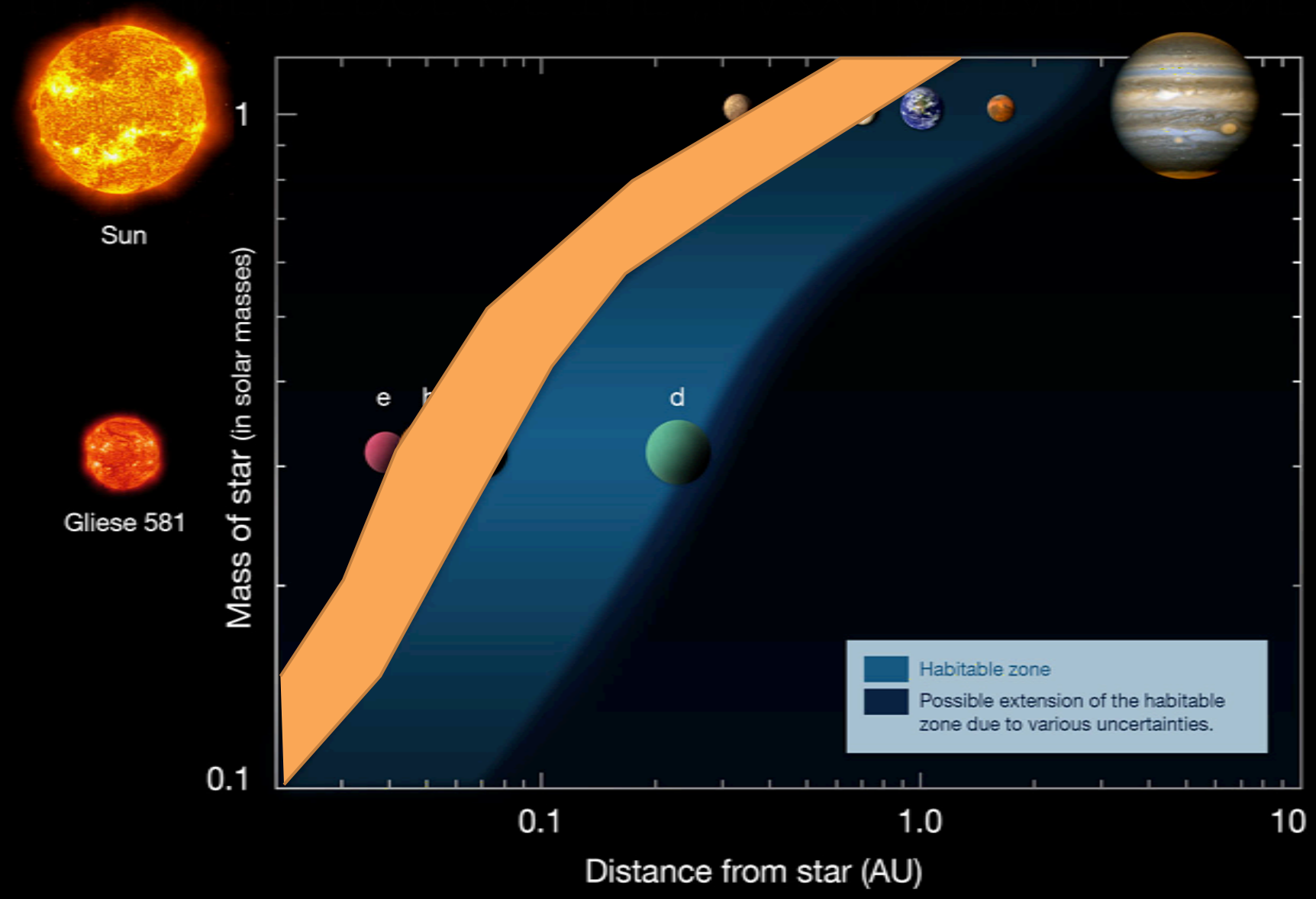
Upward IR Flux (W/m²)

THE INNER EDGE OF THE "HAZY HABITABLE ZONE"

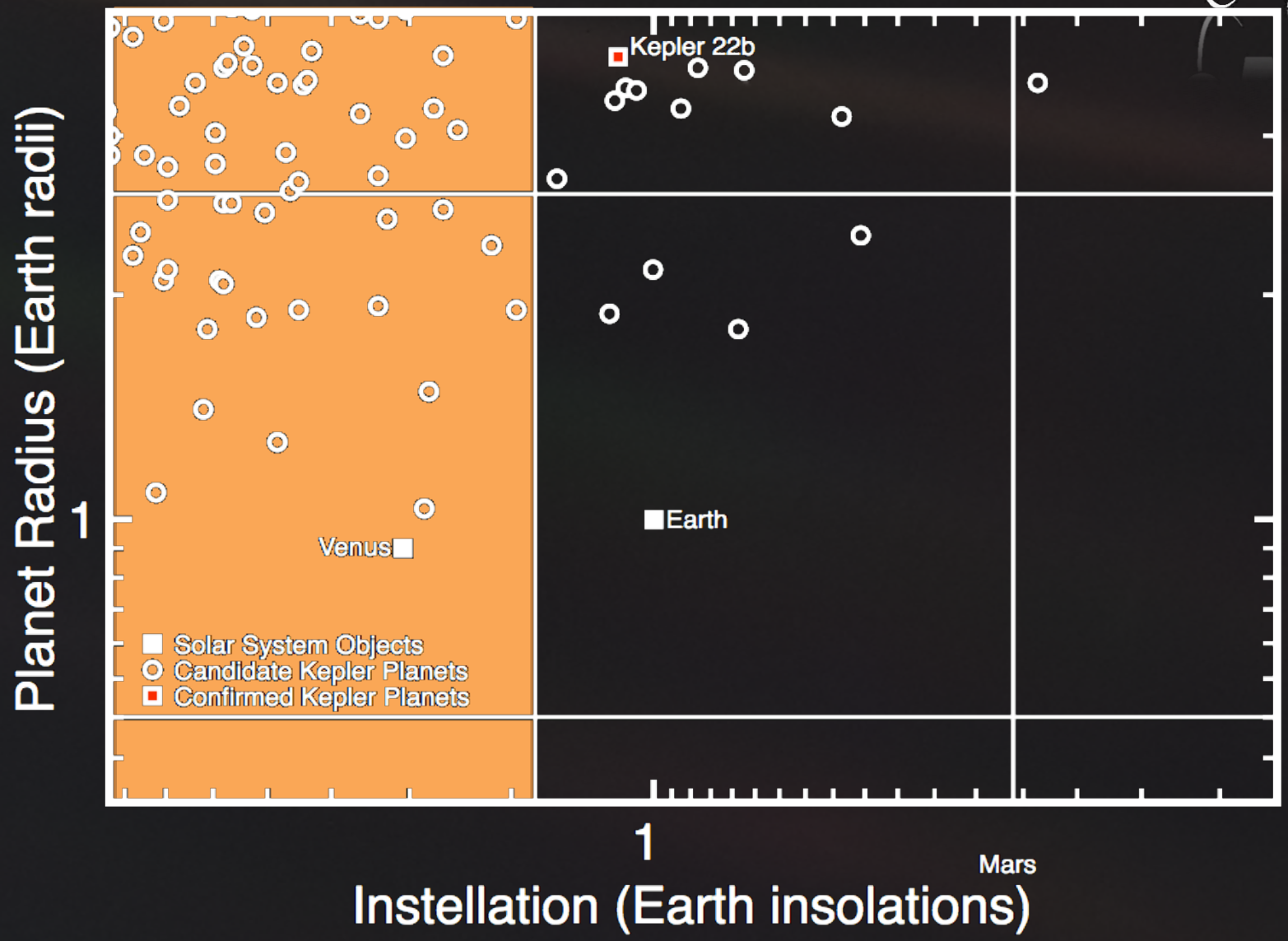


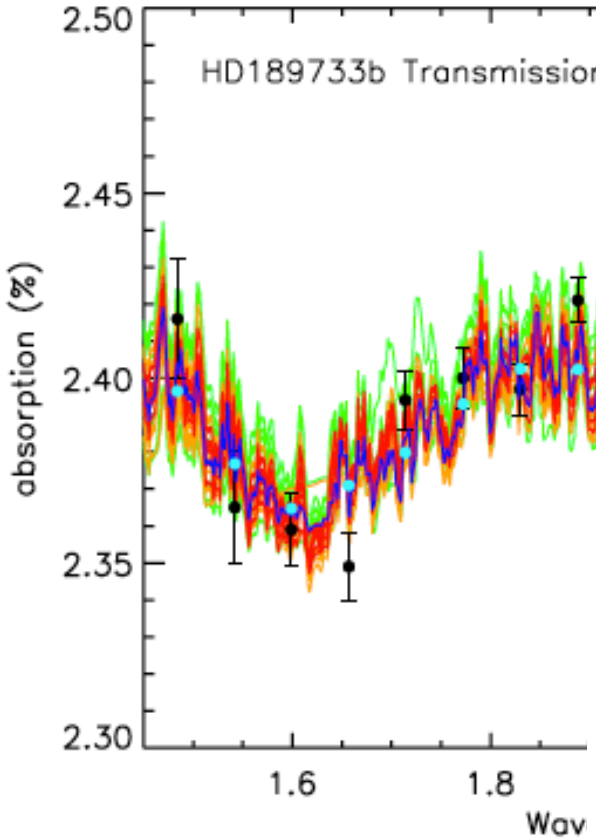
Selsis, et al.

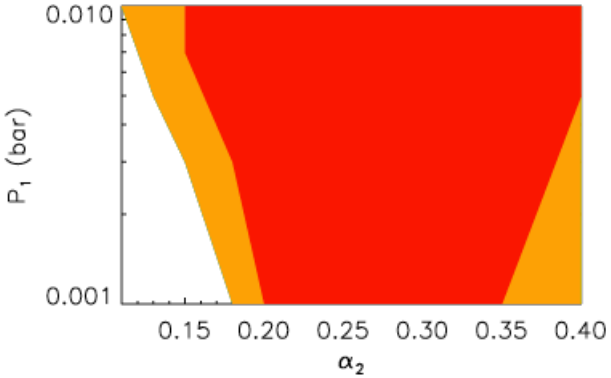
THE INNER EDGE OF THE "HAZY HABITABLE ZONE"

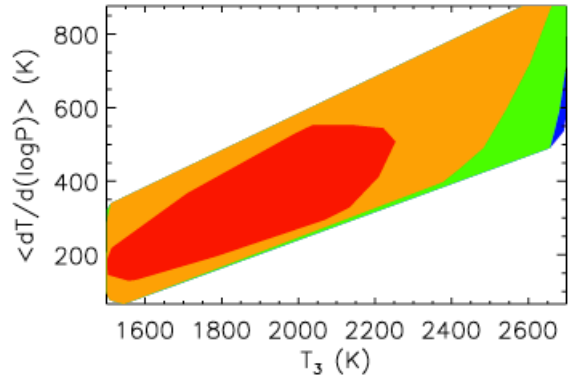


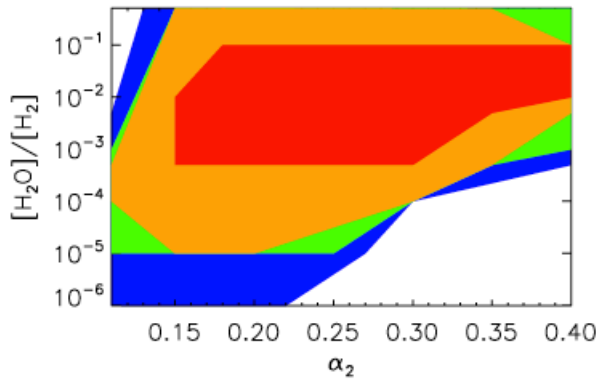
Selsis, et al.

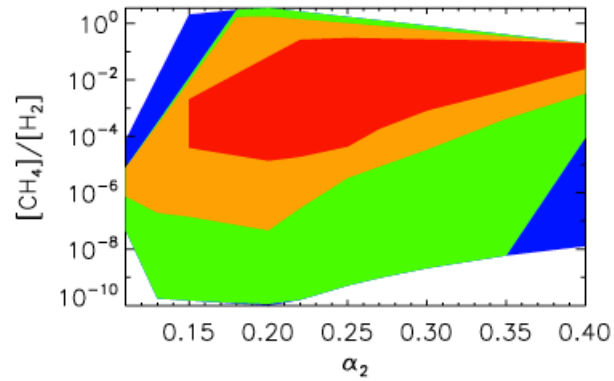

Kepler 22b
Earth
Venus
Solar System Objects
Candidate Kepler Planets
Confirmed Kepler Planets
Planet Radius (Earth radii)
1
1
Mars
Instellation (Earth insolations)



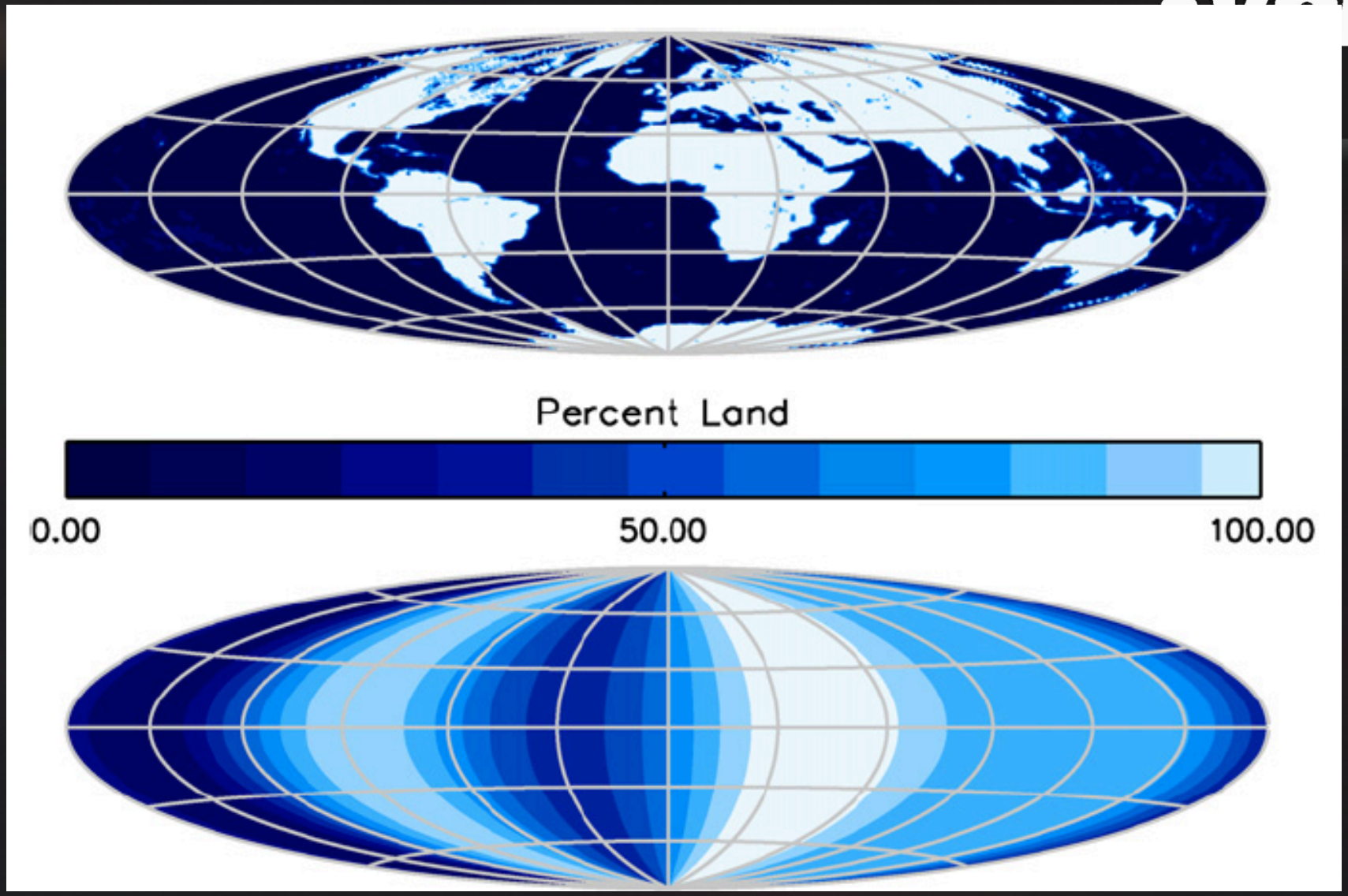








Madhusudhan et al., *2012*



Cowan, et al., 2011

Questions?