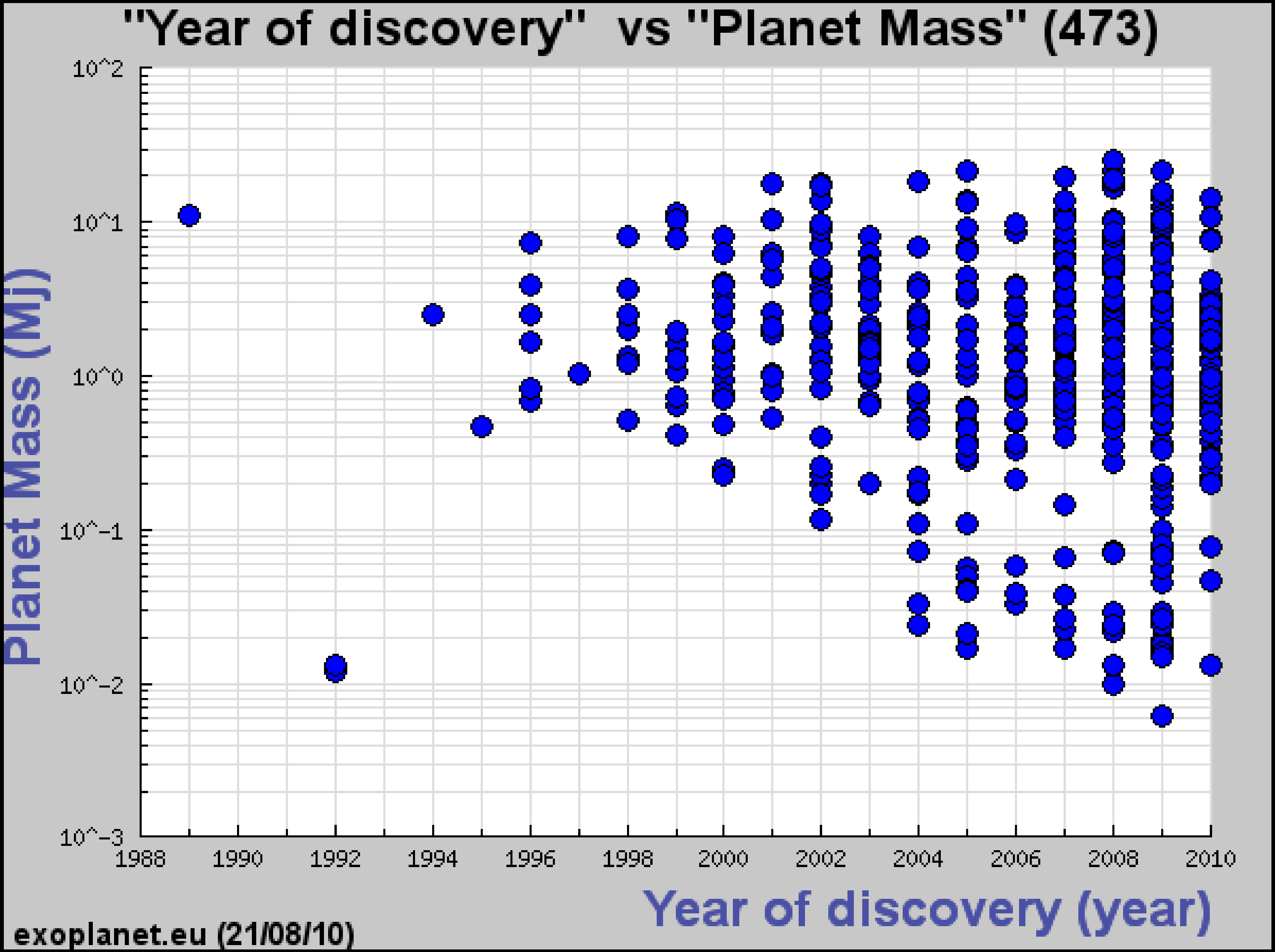
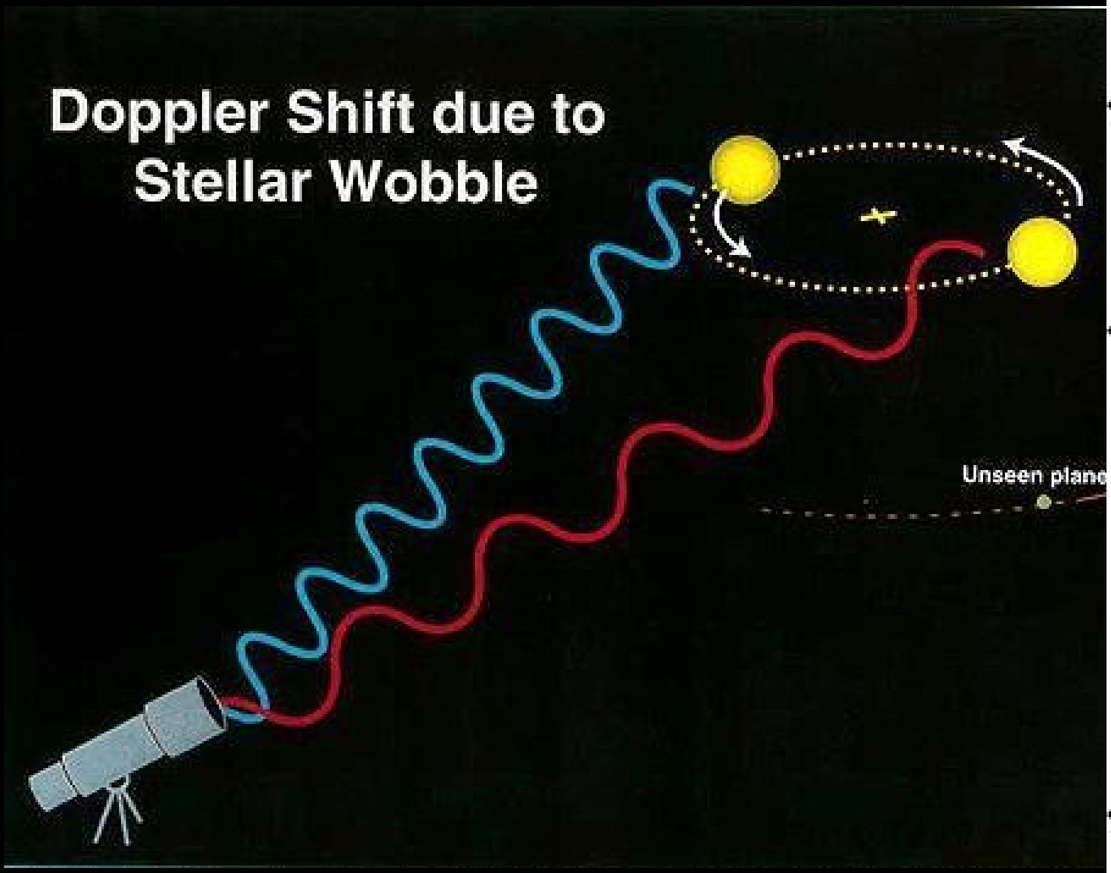
What makes a planet habitable ?

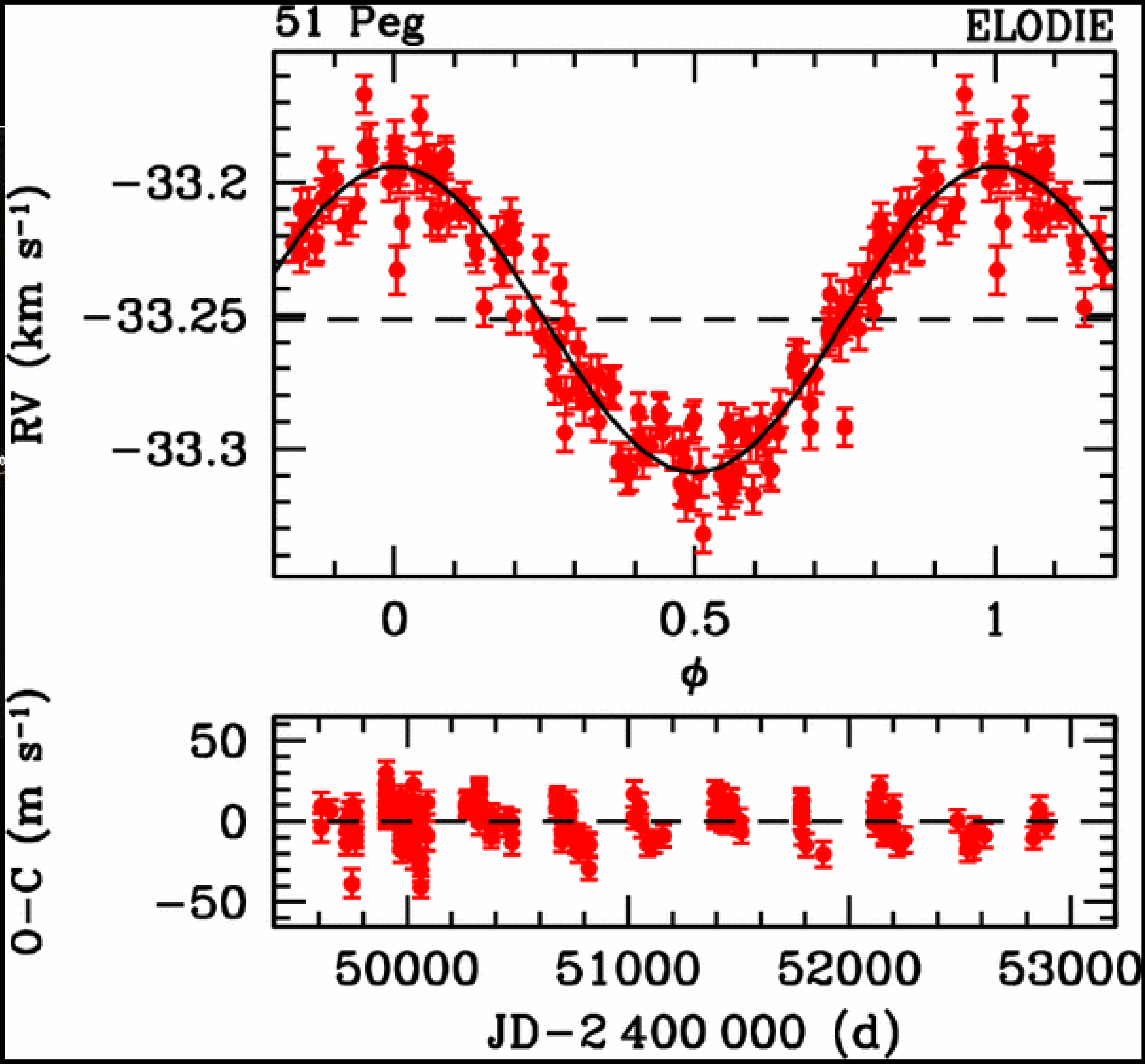


"Year of discovery" vs "Planet Mass" (473)
10^2
10^1
10^0
10^-1
10^-2
10^-3
Planet Mass (Mj)
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year of discovery (year)
exoplanet.eu (21/08/10)

How to detect planets ?

Radial velocity

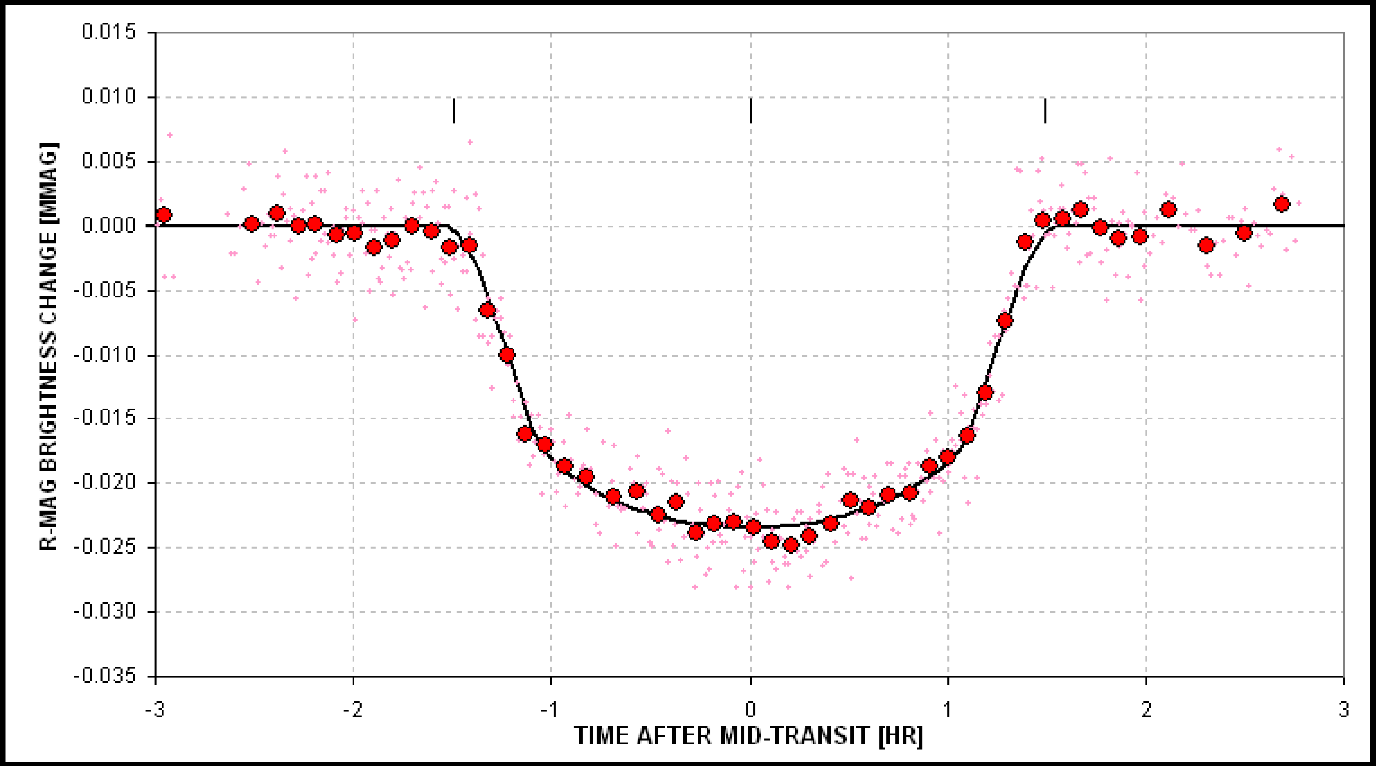




Transits

Planet moves in front of star

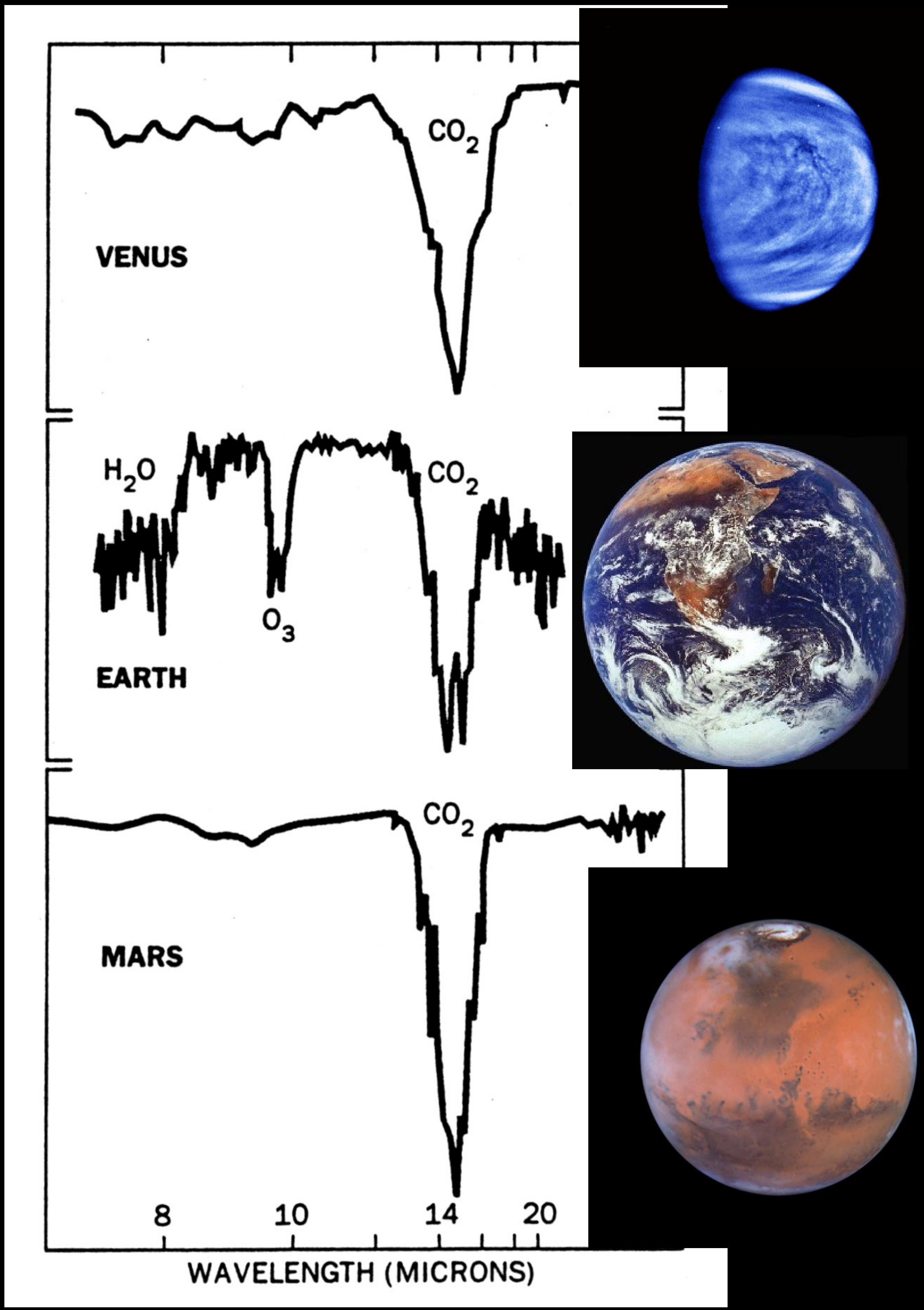
-> star gets dimmer

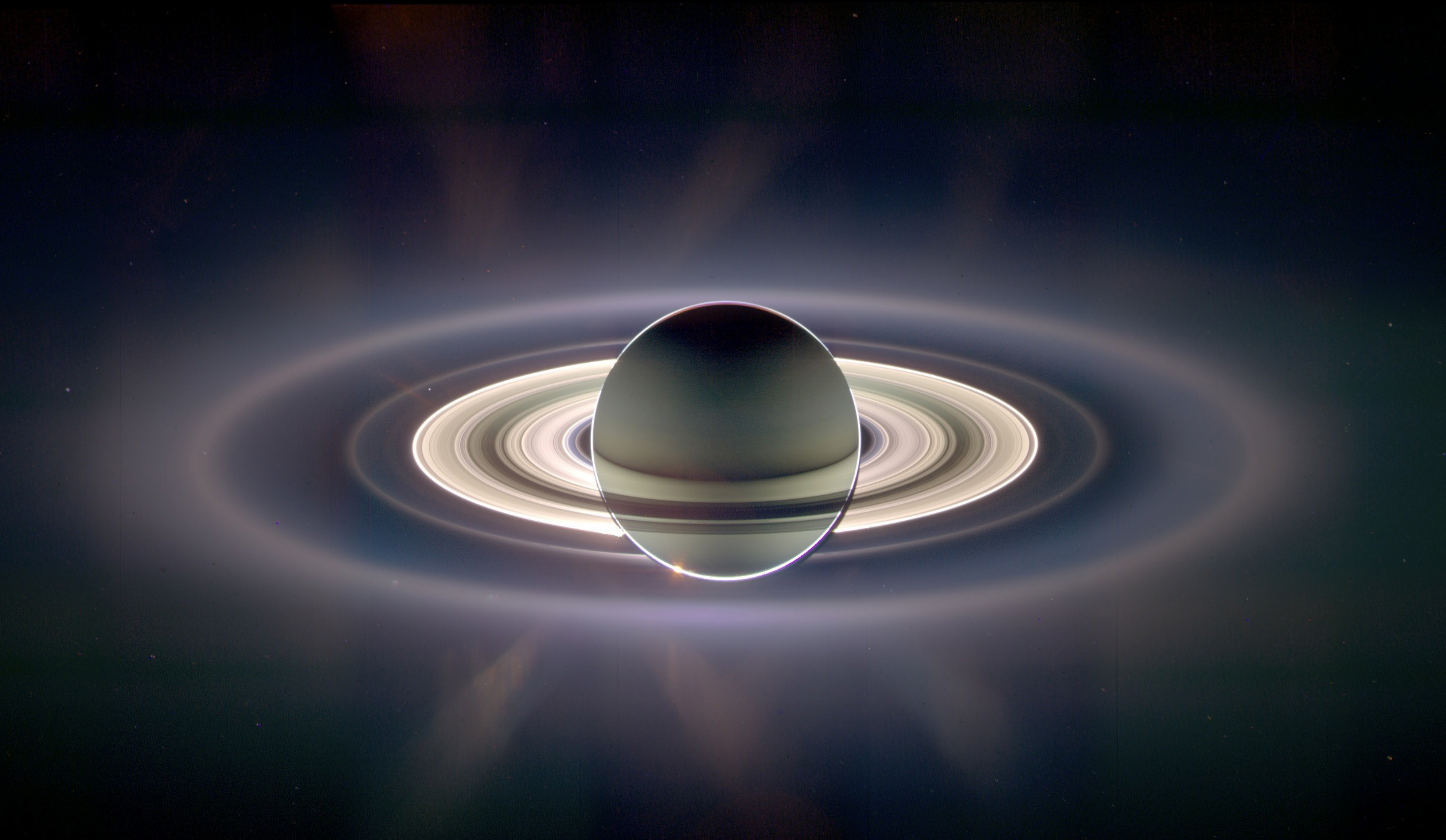


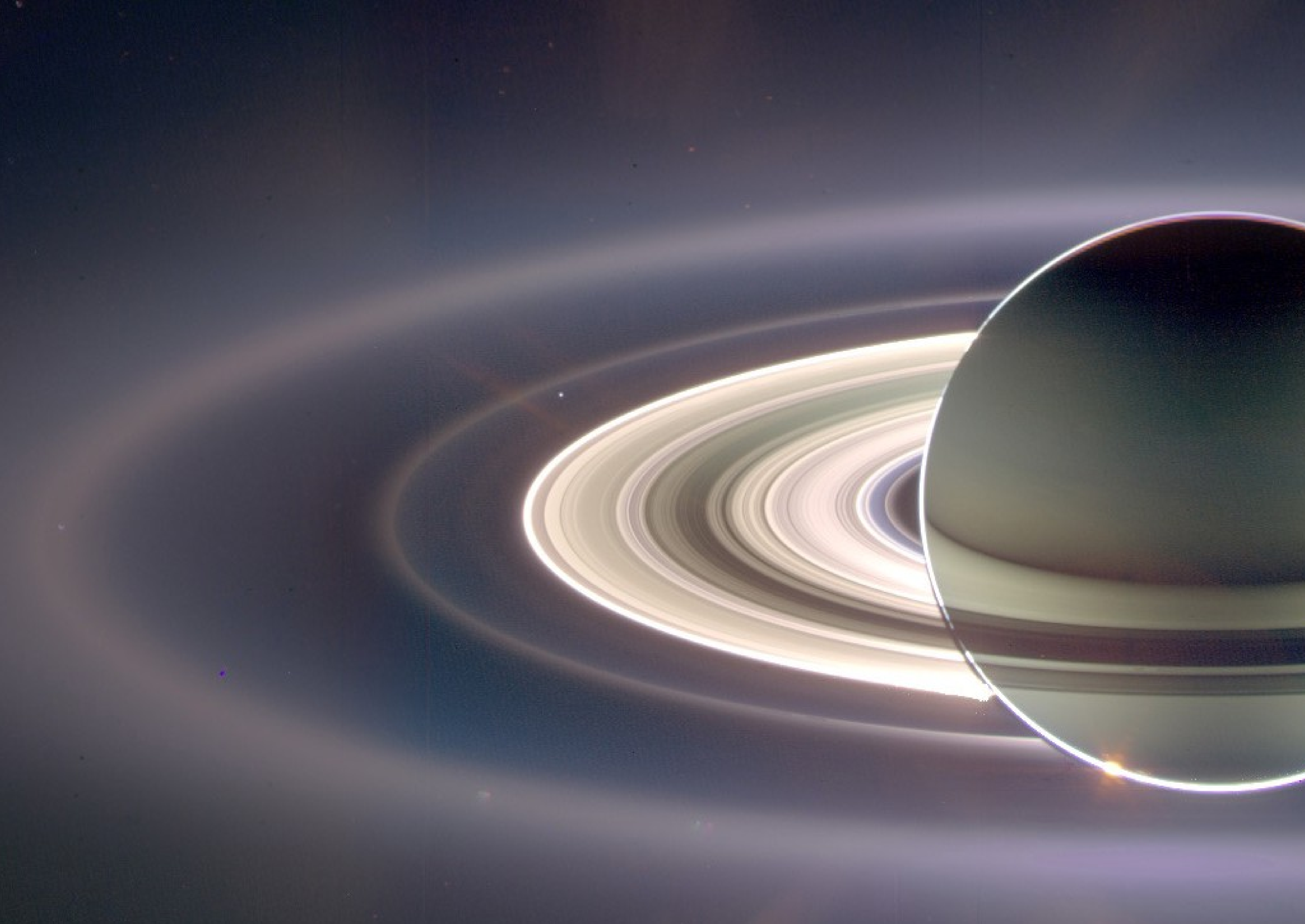
- Planet size
- Planet orbit
- Large atmosphere ?

Imaging

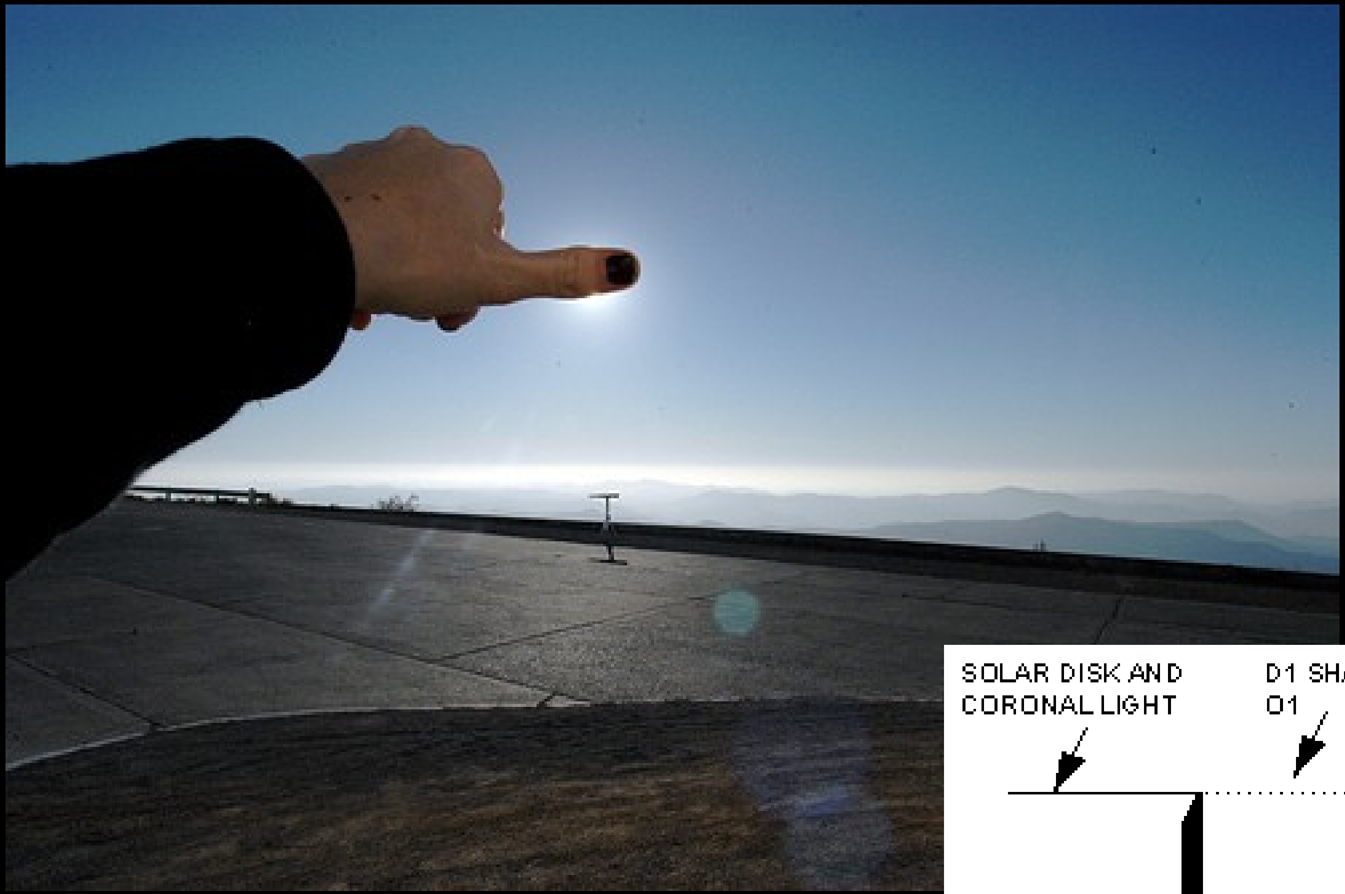
- Orbit
- Atmosphere composition
- Continents vs. Oceans ?
- Rotation period
- Weather patterns
- Planetary environment :
  Planets + dust

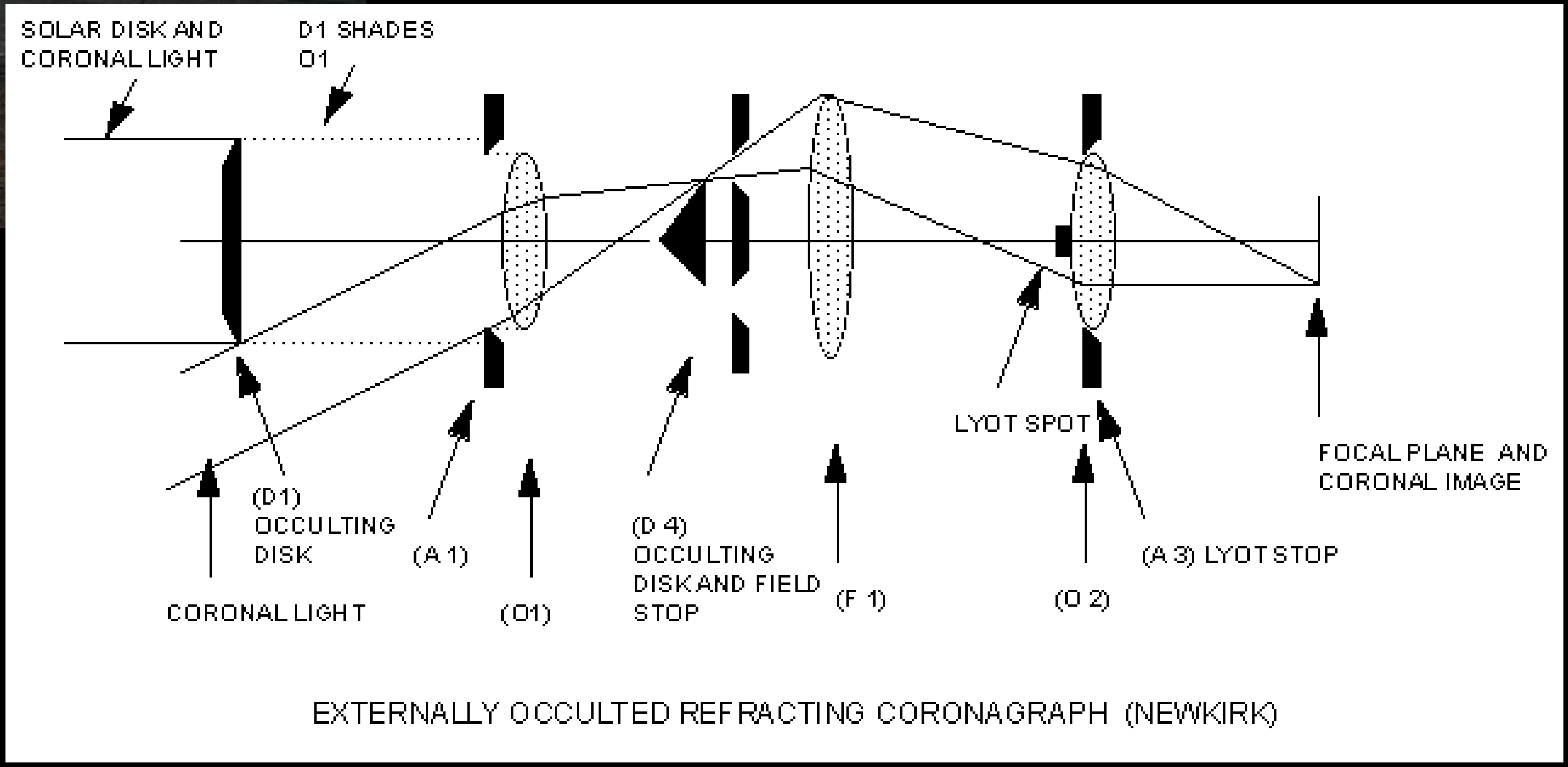


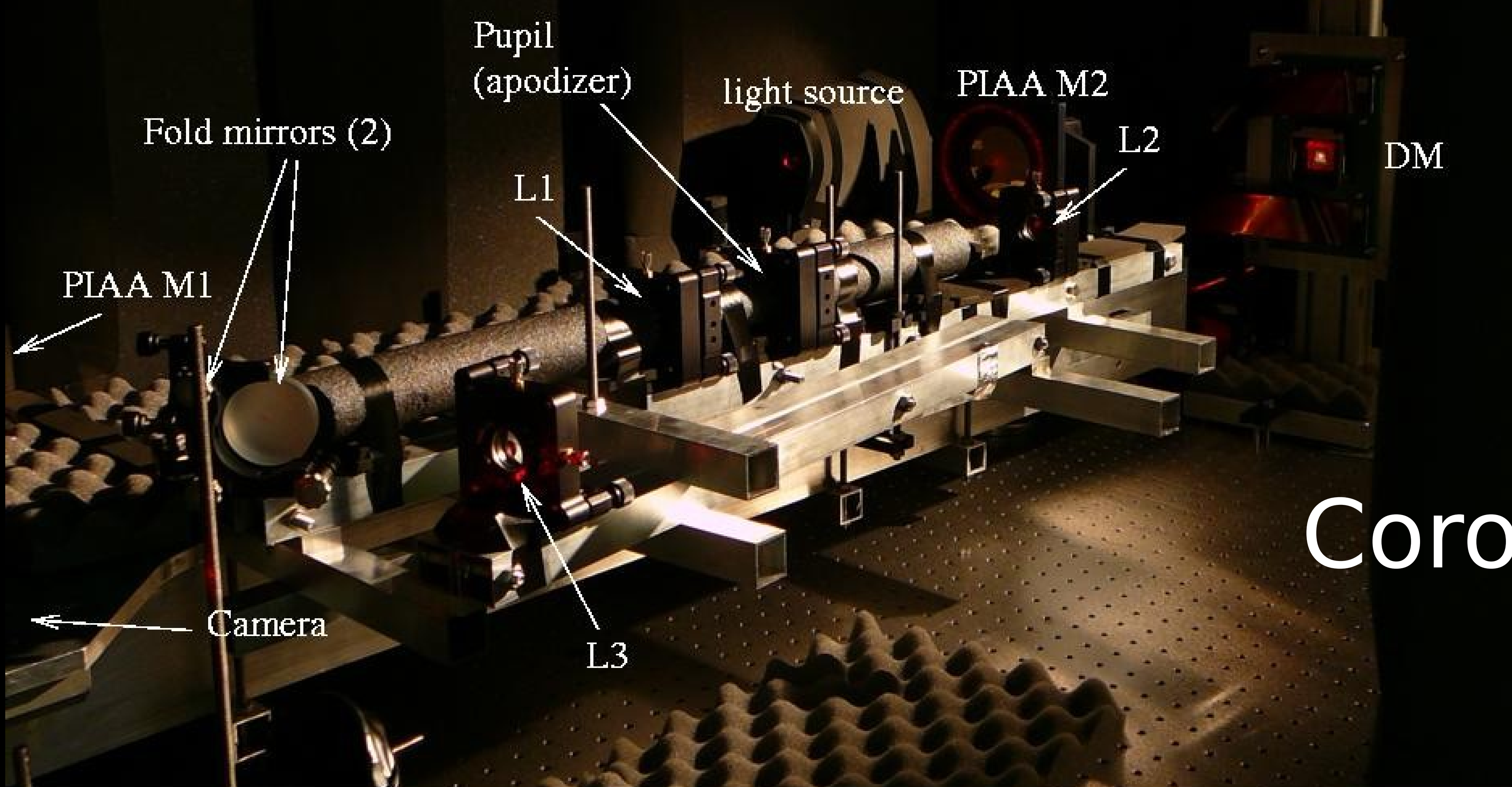




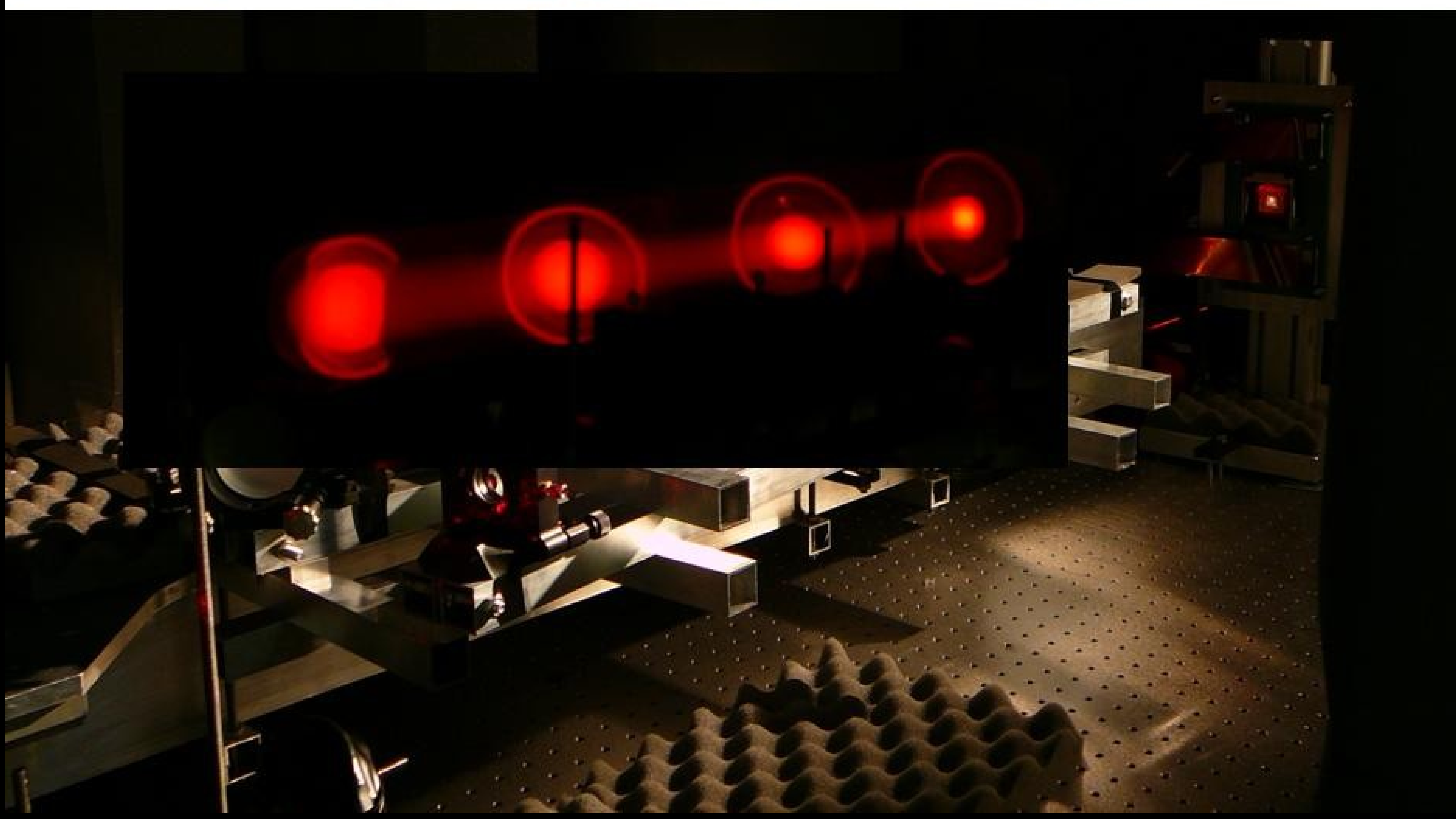
Coronagraphs







Coronagraphs



Spectral signatures of plants: "Red edge"

Earthshine

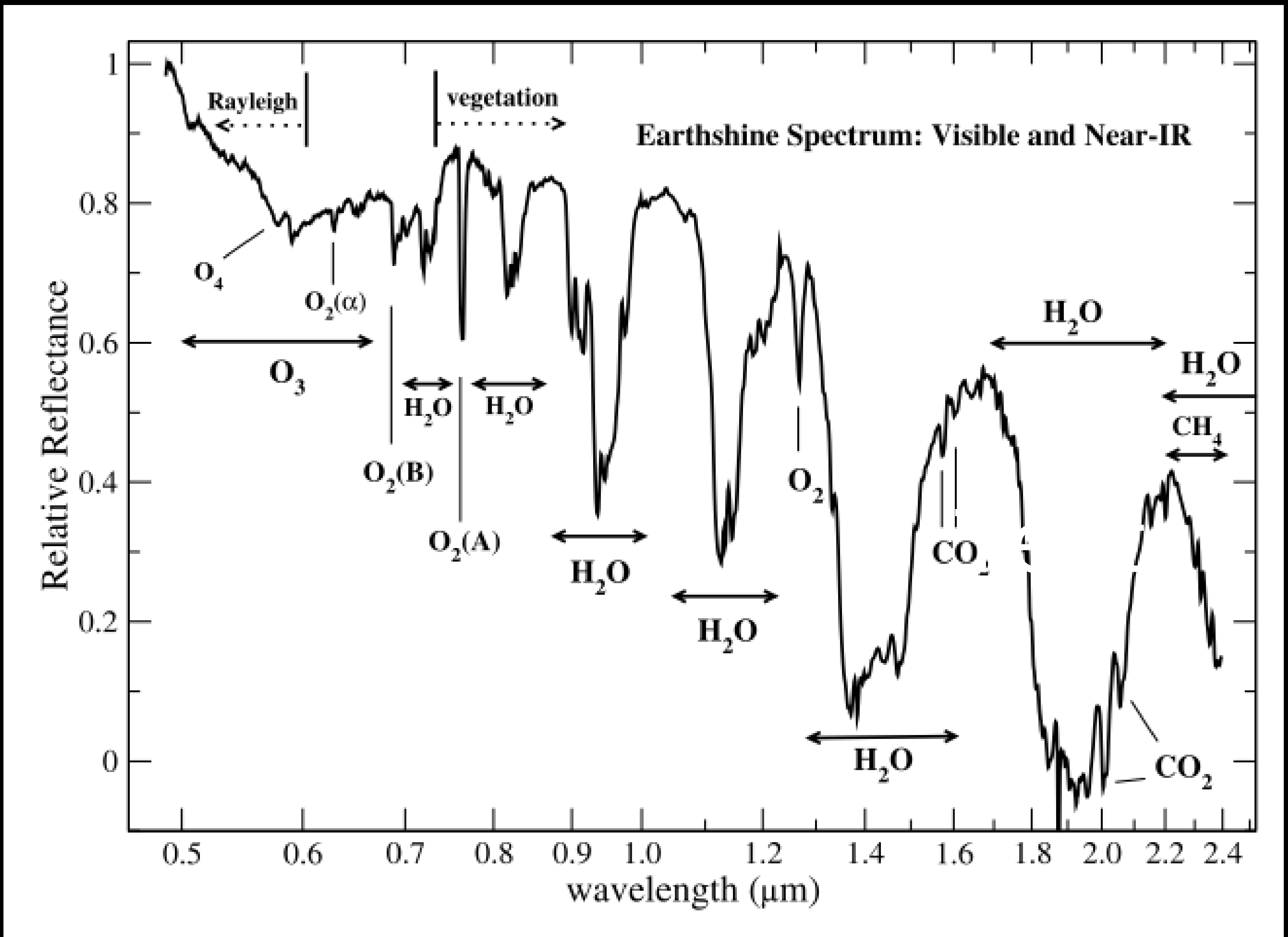
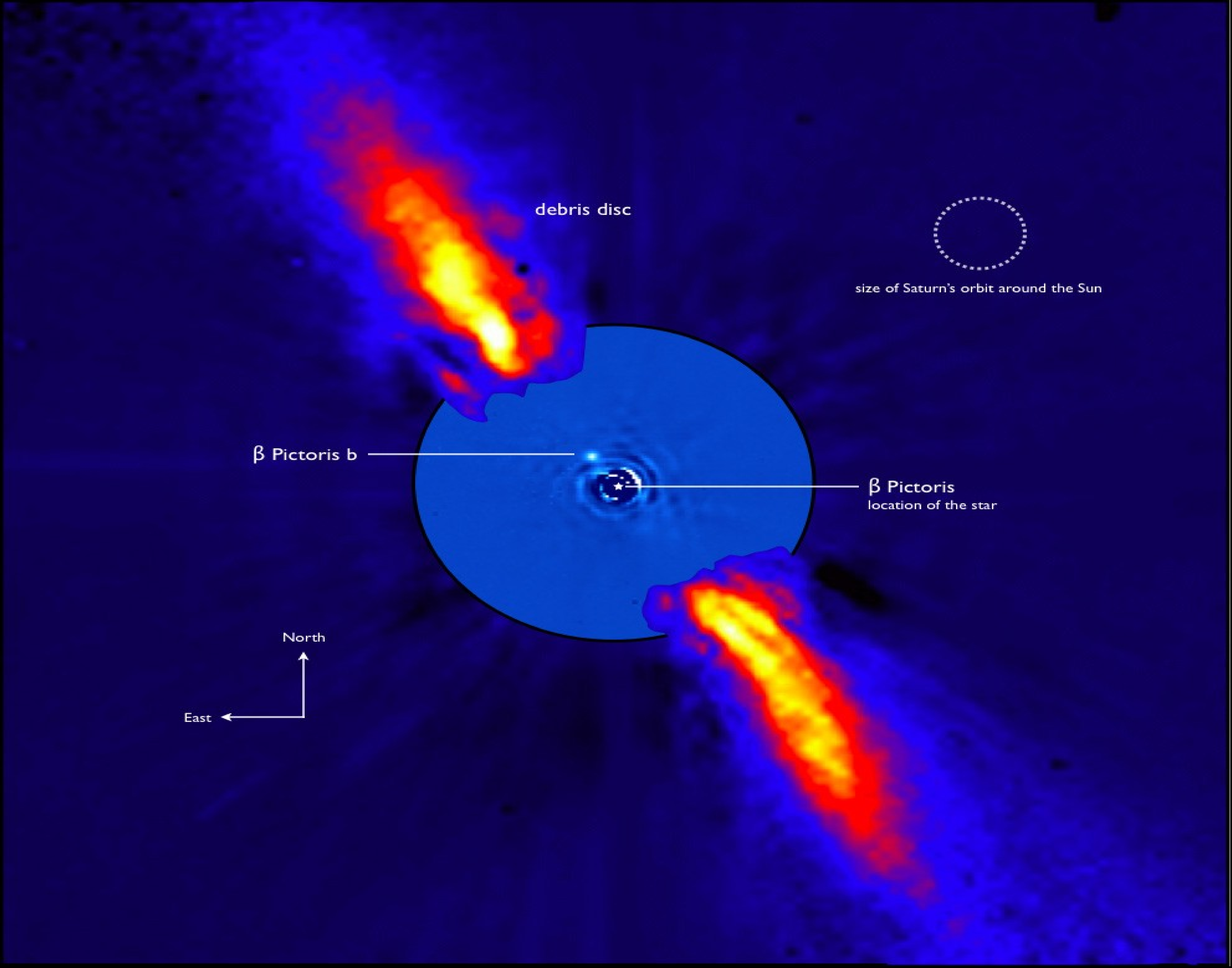


FIG. 7.—Earth's observed reflectance spectrum, at visible and near-infrared wavelengths, created from a composite of the data in this paper (0.8–2.4 μm) and the data presented in Paper I (0.5–0.8 μm). The strongest molecular signatures are indicated, as are the wavelengths where Rayleigh scattering and vegetation reflection are most significant.

Turnbull et al. 2006

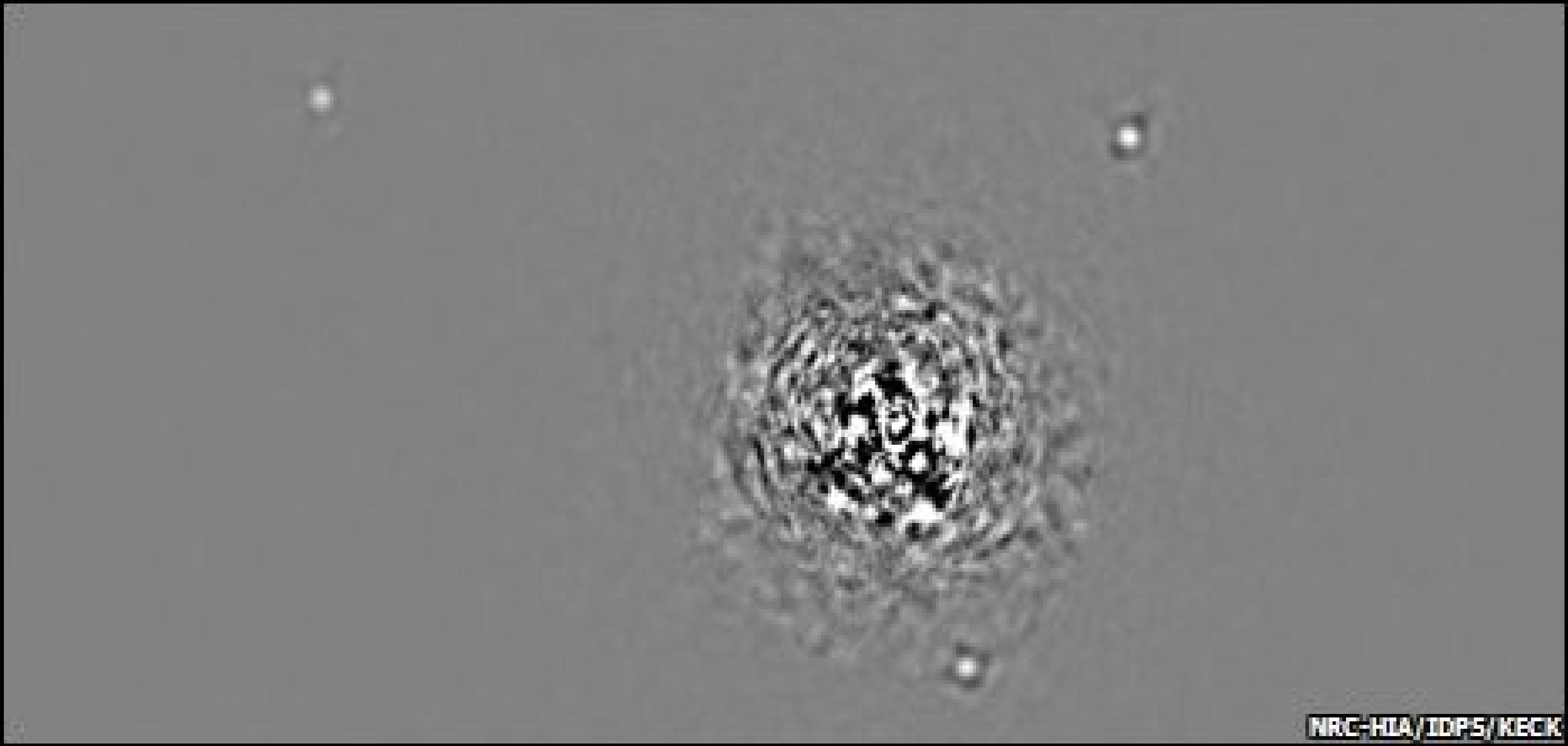
A few examples

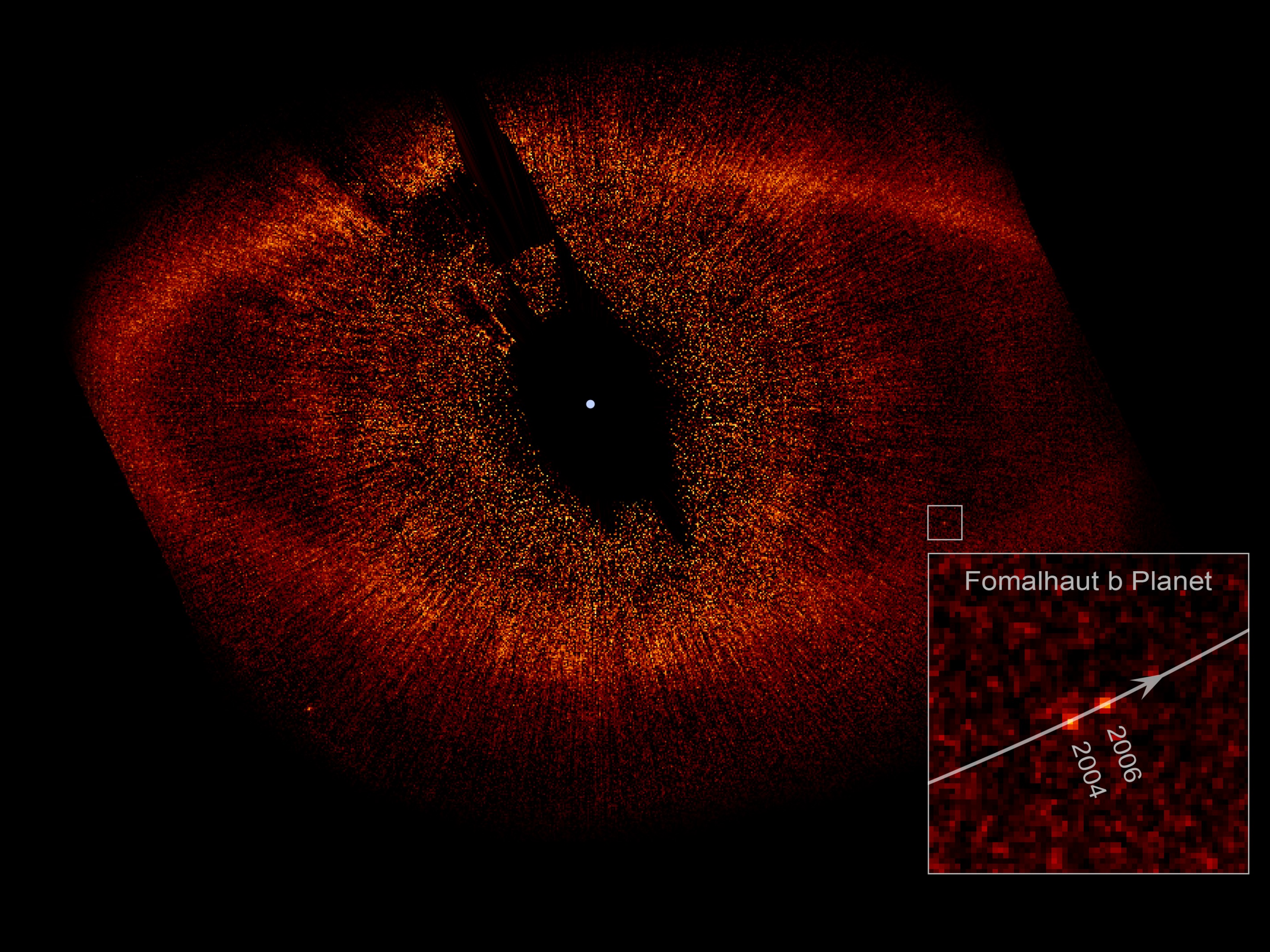
- 51 Peg b [RV]: Hot Jupiter, first discovery (*)
- HD209458 b [RV + transit]: Hot Jupiter, 3.5 day period, 0.045 AU, 0.69 MJ, 35% larger in diameter, atmosphere blown by star (Na, H, C, O, CO_2, H_2O, CH_4 detected), powerful storms
- Gl 581 b,c,d,e [RV]: habitable planets ? Only 20 light year away, 4 planets. Gl 581 e (closest to star) is only 1.9 Earth Mass. Gl 581 b is Neptune-mass. Gl 581 c is a super-Earth (>5 Me) at the inner edge of the habitable zone, probably with a Venus-like greenhouse effect. 581 d is a super-Earth (~10 Me), potentially habitable, probably giant ocean. Stellar irradiance is slightly less than Mars, but thicker atmosphere.
- GJ1214 b [transit + RV]: 6.5 Me, 2.7 Re, 1.6 day period. Low density, large fraction of gas or water (could be an ocean planet, 75% water, 25% rock)
- Corot 7-b [transit + RV]: 1.7 Earth radius, 4.8 Earth mass, 20 hr period. Rocky planet with less iron and/or more water. Tidally locked: night side is cold, day side very hot (possibly lava).
- OGLE-2005-BLG-390L b [microlensing]: ~5.5 Me, at 2.6 AU from a red dwarf. Very cold word (like pluto)
- HR8799 [imaging]: planetary system, 24 to 68 AU, giant planets, ~10 MJ each
- Beta Pictoris b [imaging]: young planet cought just after formation, Saturn-like orbit, 8MJ, 8 AU (*)
- Fomalhaut b [imaging]: mysterious object, too bright to be just a planet: large disk (*)
- (*): naked-eye star



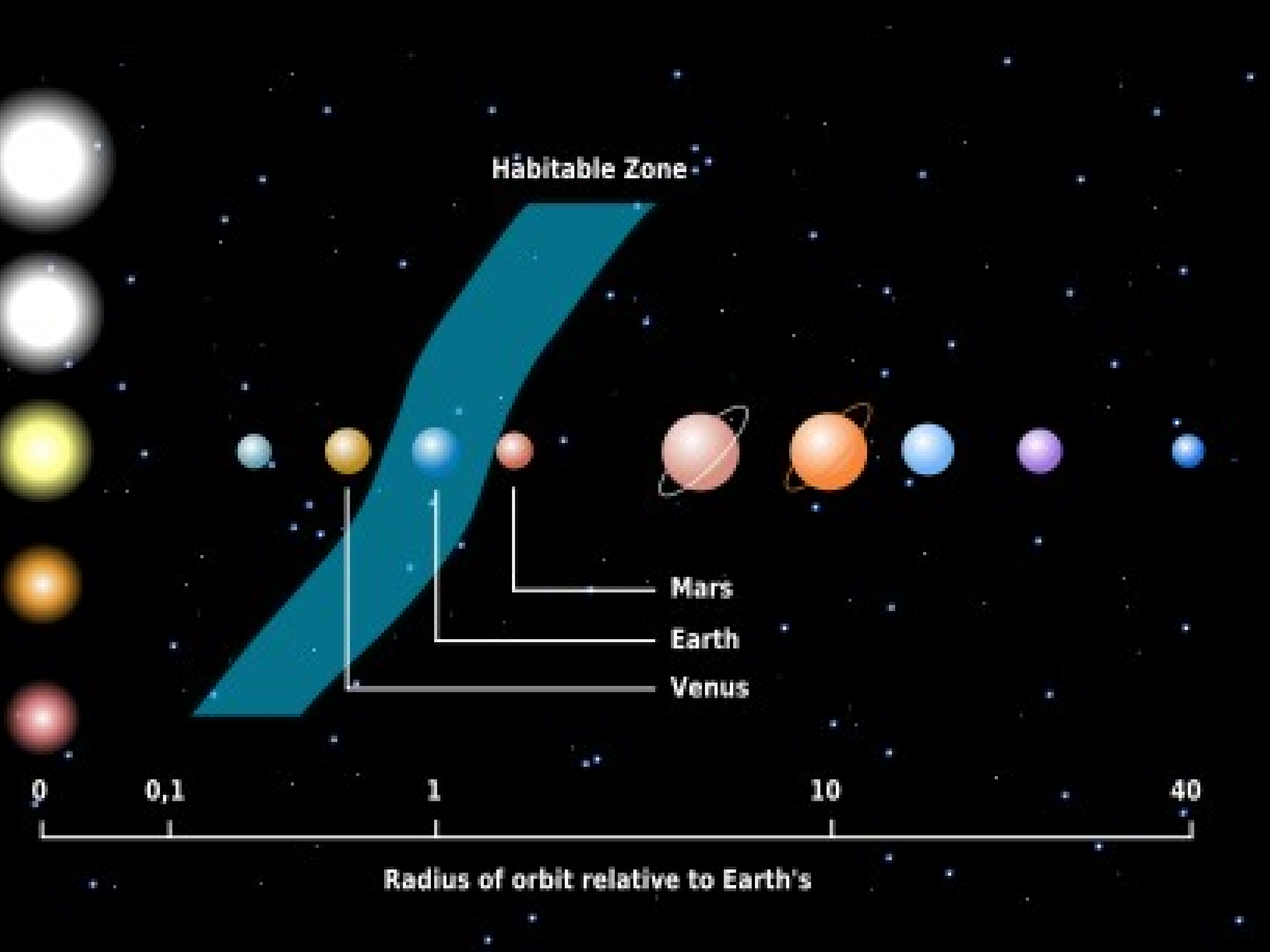
debris disc
size of Saturn's orbit around the Sun
β Pictoris b
β Pictoris
location of the star
North
East

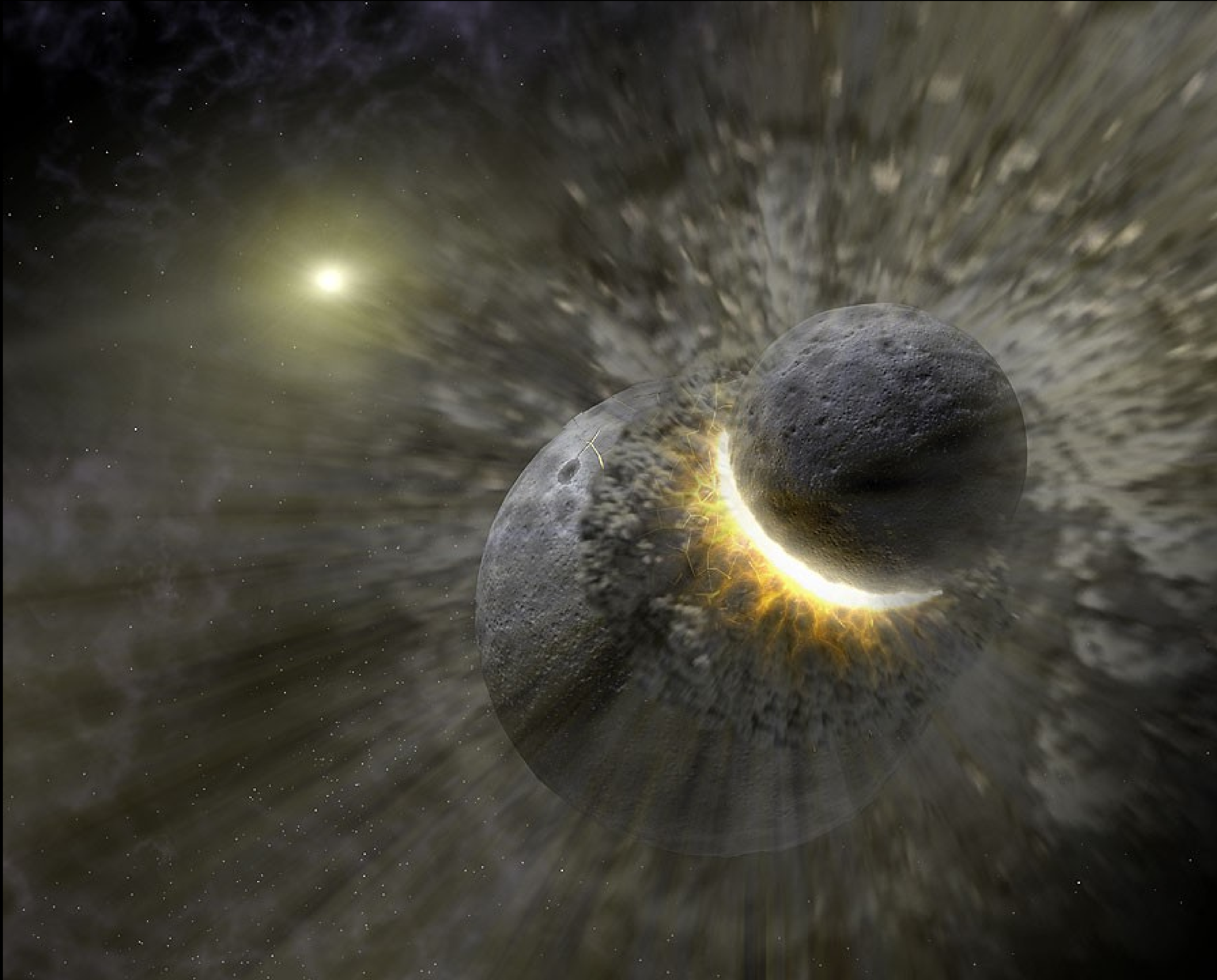
HR 8799 planets imaged by Keck




Fomalhaut b Planet
2006
2004

Life on other planets ?


Habitable Zone
Mars
Earth
Venus
0
0,1
1
10
40
Radius of orbit relative to Earth's



When is a planet habitable ?

- Too many collisions in the first few 100 Myr
- Stellar activity decreases with time -> challenge for life around young stars
- Stars get brighter with time -> HZ moves out !

We have ~400 Myr left before CO_2 cycle fails to regulate Earth’s temperature

- Magnetic field is a good thing, but WILL “freeze away” with time

Water...

Mars & Venus lost their oceans

H2O -> Hydrogen + Oxygen

Oxygen oxydizes rocks (Mars is red), Hydrogen escapes in space

Why not Earth ??? Right size, right spot.

~2 billion years ago Oxygen concentration went up (bacteria) -> recaptures Hydrogen, stops H2O loss.

Carbon cycle regulates temperature on Earth

- Production:

Volcanos & direct emission from Earth’s crust (~0.5 Gt/yr)

Humans burning fossil fuels (~6 Gt/yr)

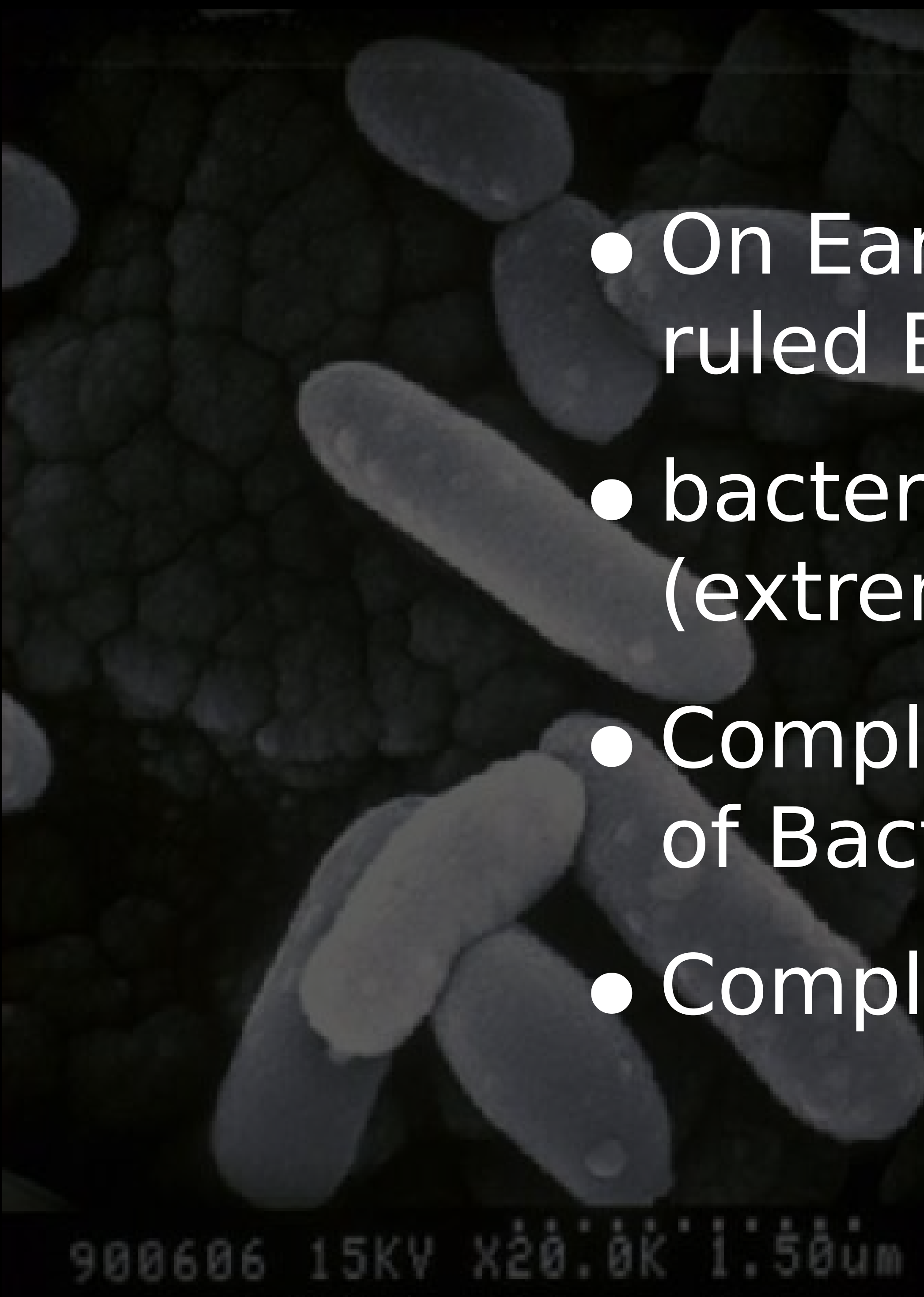
- Removal (depletion in 10 000 yrs for atmosphere, 500 000 yrs for atm+oceans):

Silicate wheathering

Carbonate deposition

Burial of organic matter

What kind of life ?



ASM Biofilms Collection. Kobayashi

- On Earth, bacteria got an early start and ruled Earth for the first 2 billion yrs
- bacteria live in many environments (extremophiles)
- Complex life started with unlikely merging of Bacteria + Archaea -> Eukaryote
- Complex life may be rare event ...

How much time needed to have complex life ?

Life on Earth does not evolve at a constant pace

BIG jumps forward :

~2 Gy ago: Eukaryotes appear

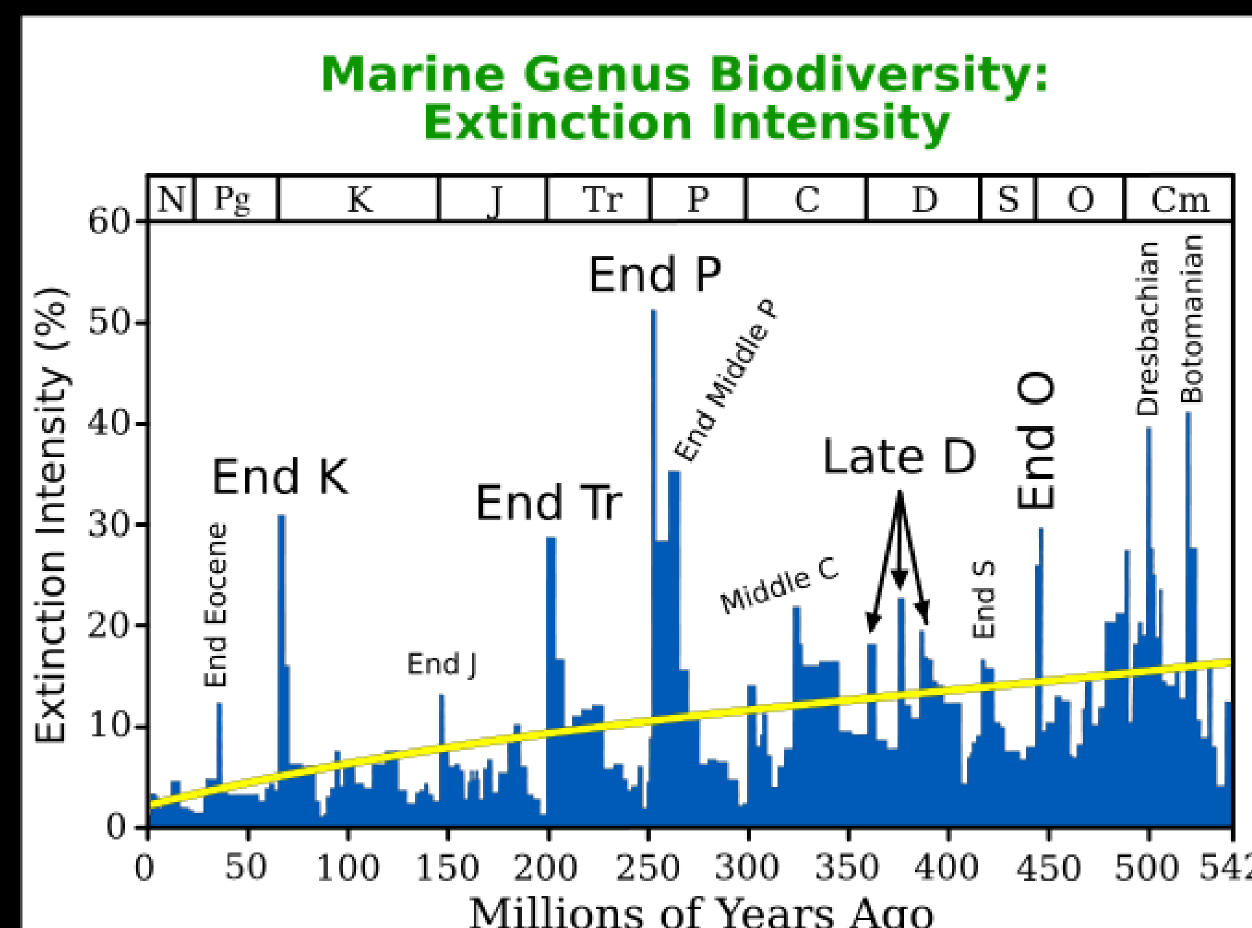
560 Myr ago: Cambrian explosion

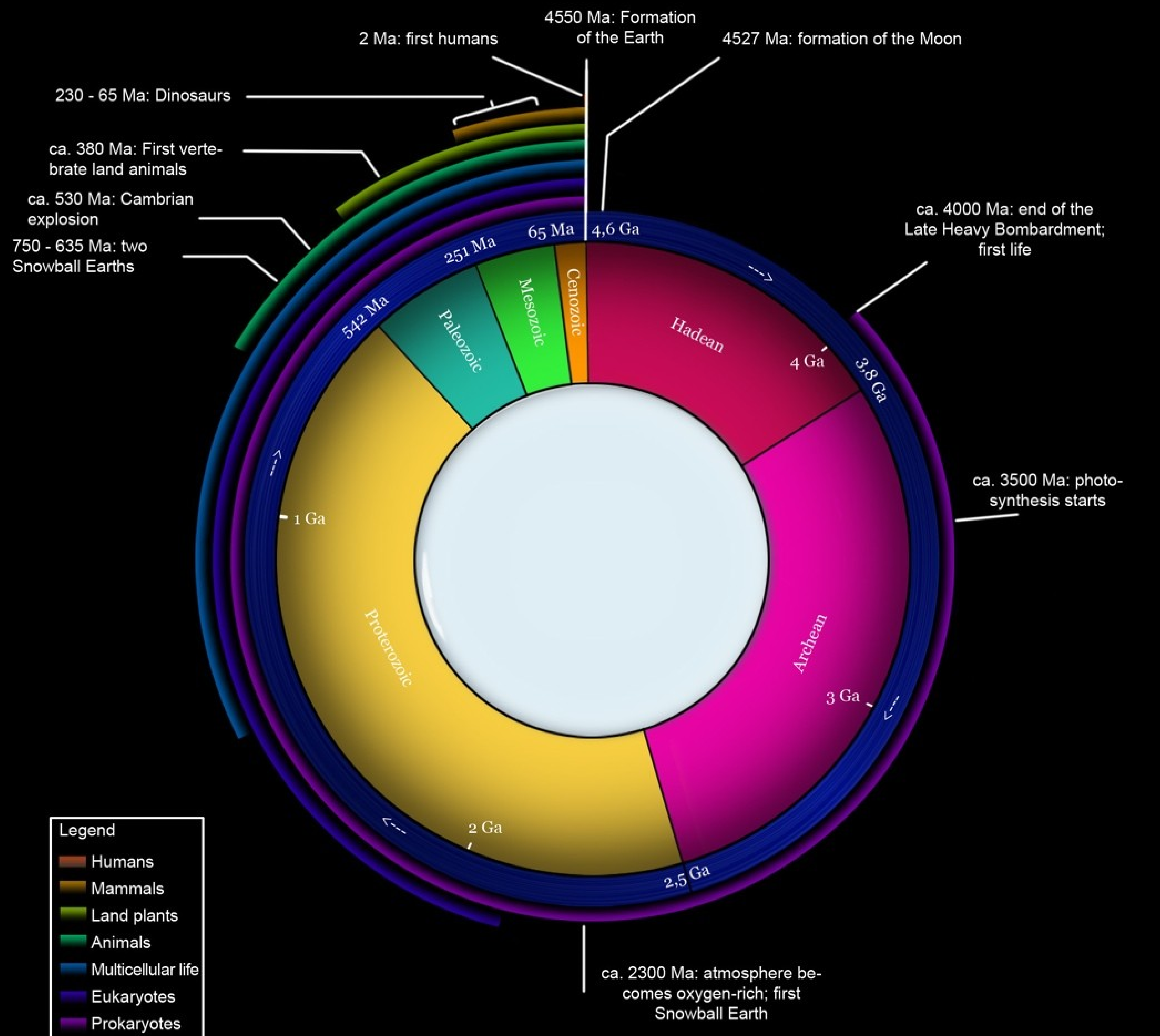
But also...

"Snowball Earth" episodes 2.3 Myr and 790 to 630 Myr ago

Several mass extinctions since Cambrian explosion

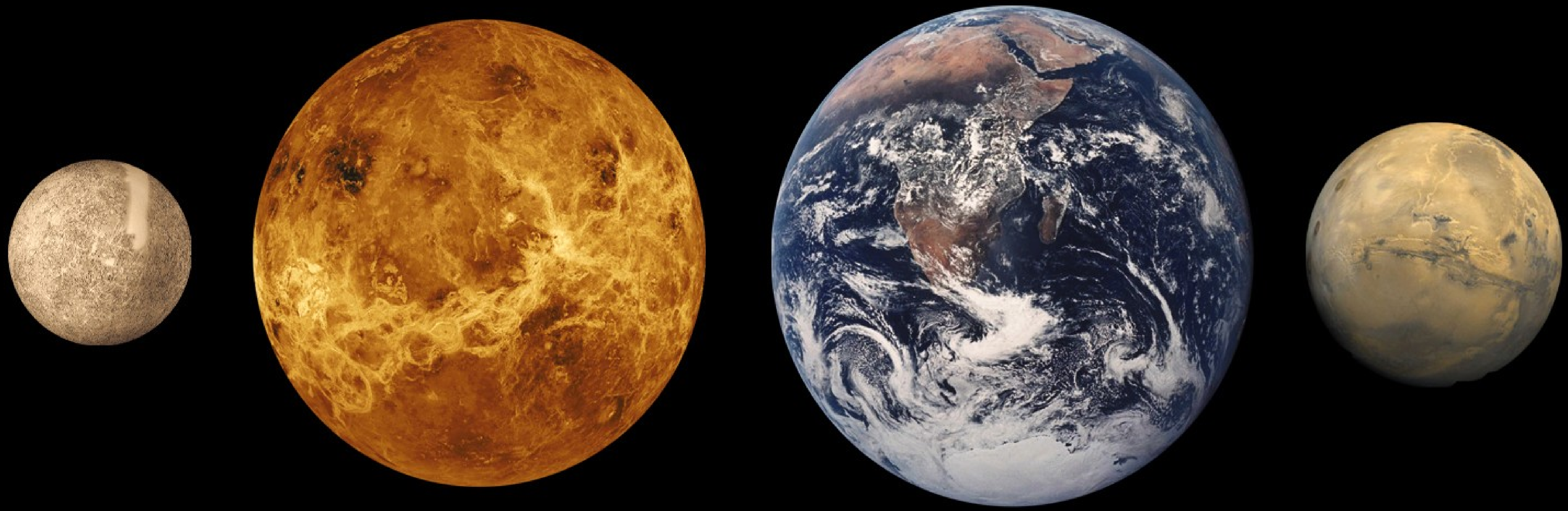
(large impact, massive volcanic eruption...)





4550 Ma: Formation of the Earth
2 Ma: first humans
4527 Ma: formation of the Moon
230 - 65 Ma: Dinosaurs
ca. 380 Ma: First vertebrate land animals
ca. 530 Ma: Cambrian explosion
750 - 635 Ma: two Snowball Earths
ca. 4000 Ma: end of the Late Heavy Bombardment; first life
ca. 3500 Ma: photosynthesis starts
ca. 2300 Ma: atmosphere becomes oxygen-rich; first Snowball Earth
65 Ma
4,6 Ga
251 Ma
542 Ma
Cenozoic
Mesozoic
Paleozoic
Hadean
4 Ga
3,8 Ga
Archean
3 Ga
2,5 Ga
2 Ga
Proterozoic
1 Ga
Legend
Humans
Mammals
Land plants
Animals
Multicellular life
Eukaryotes
Prokaryotes

Solar system rocky planets



Conclusions

COMPLEX life, AS WE KNOW IT requires special conditions on planet

simple life forms (bacteria / Archaea) might be much more common

BUT many many “suitable” planets in our galaxy, and many many galaxies... (Drake equation)

Within next decades, we will finally be able to probe for life on exoplanets not too different from Earth