Deciphering colors of a pale blue dot

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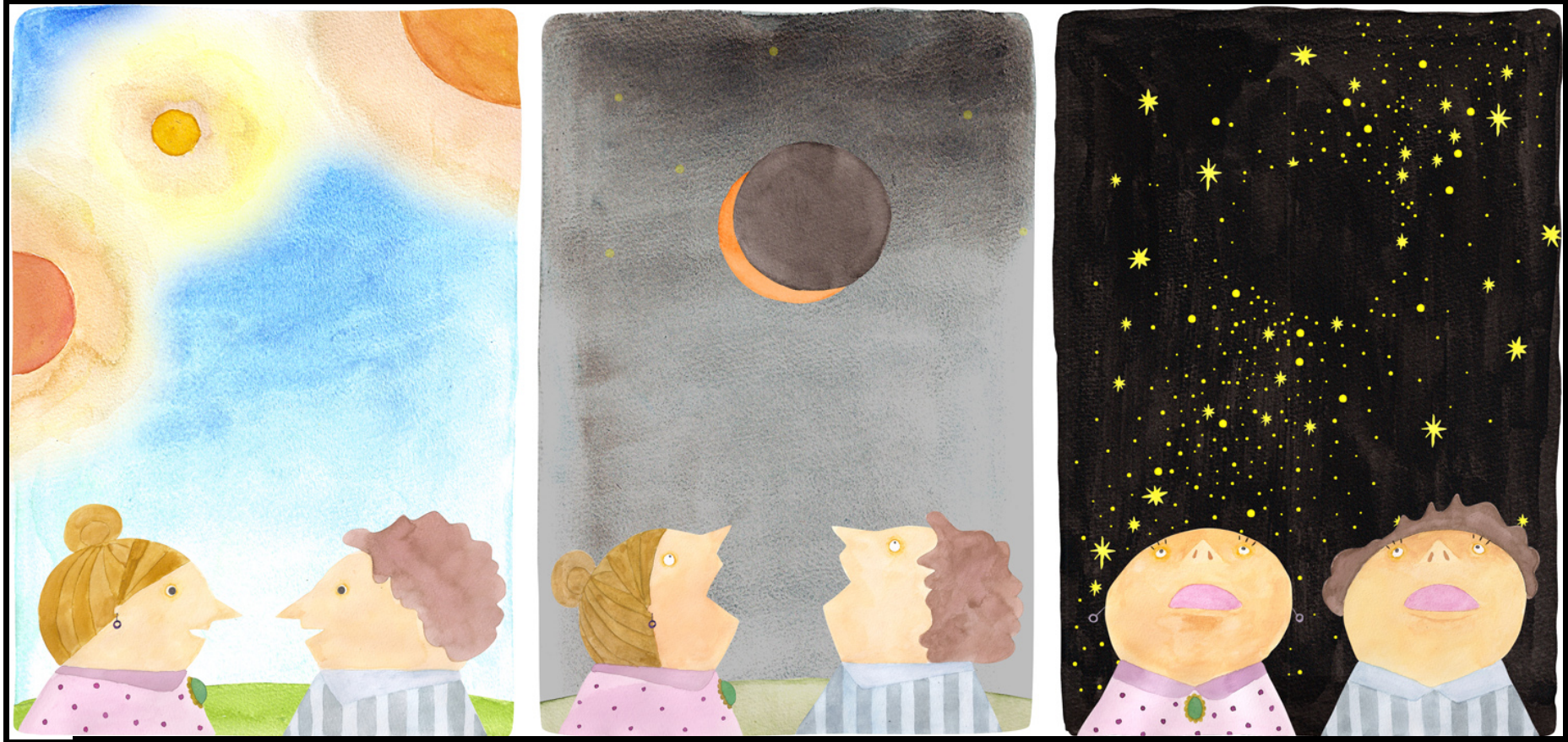
ICRR seminar@#601 15:30- November 8, 2012

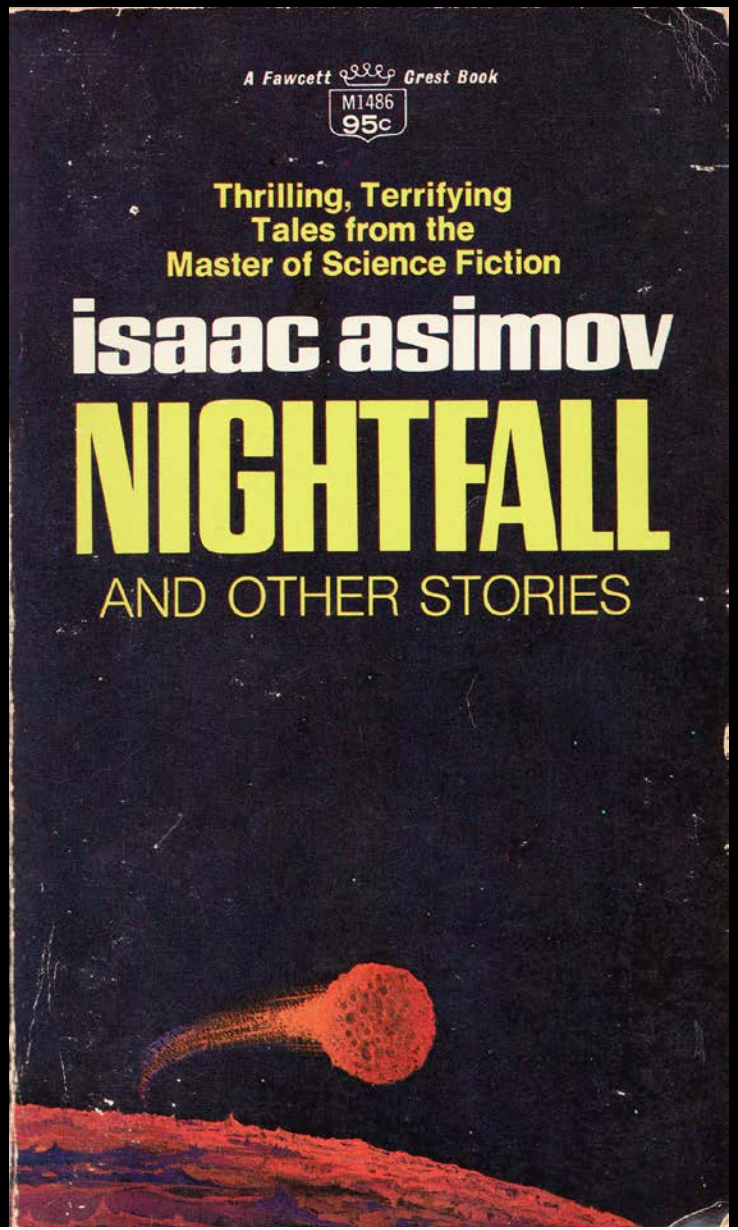
Nightfall: We didn't know anything



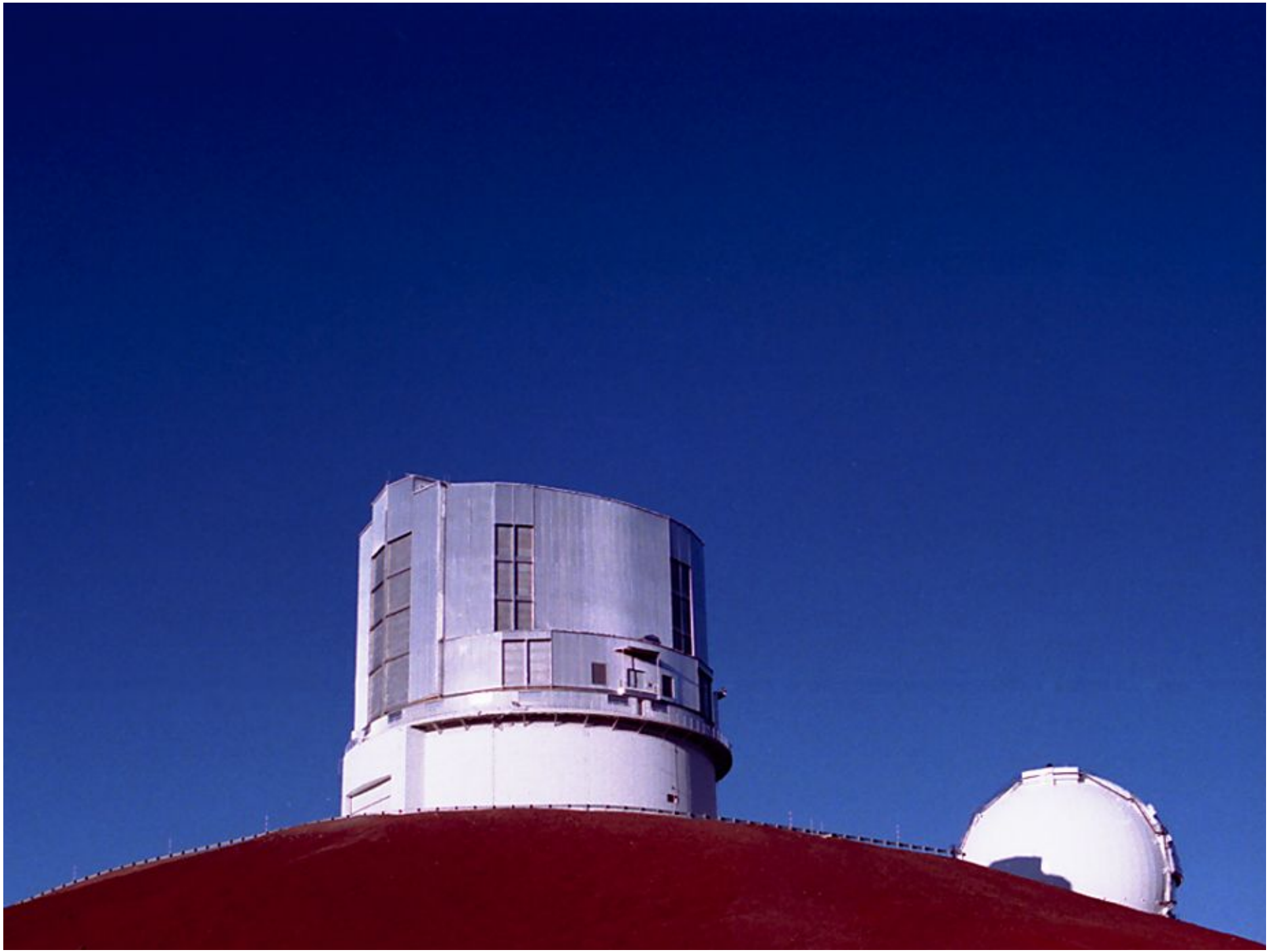
(Alisa Haba)

- No "night" except the total eclipse due to another planet every 2049 years on the planet "Lagash"
- People realized the true world for the first time through the darkness full of stars

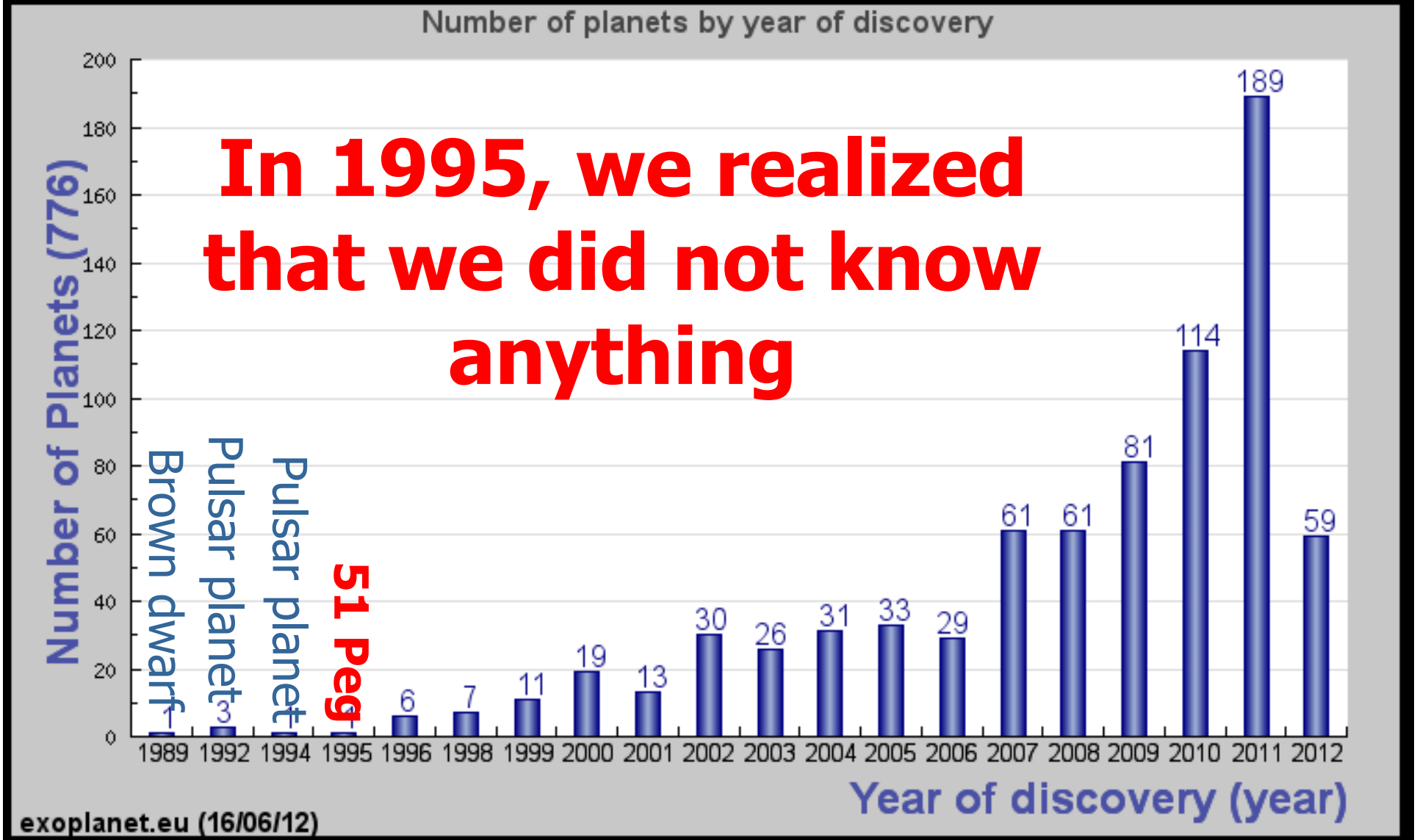
Issac Asimov: Nightfall



- "Light !" he screamed. Aton, somewhere, was crying, whimpering horribly like a terribly frightened child.
  "Stars -- all the Stars -- we didn't know at all. We didn't know anything."



History of exoplanet discovery

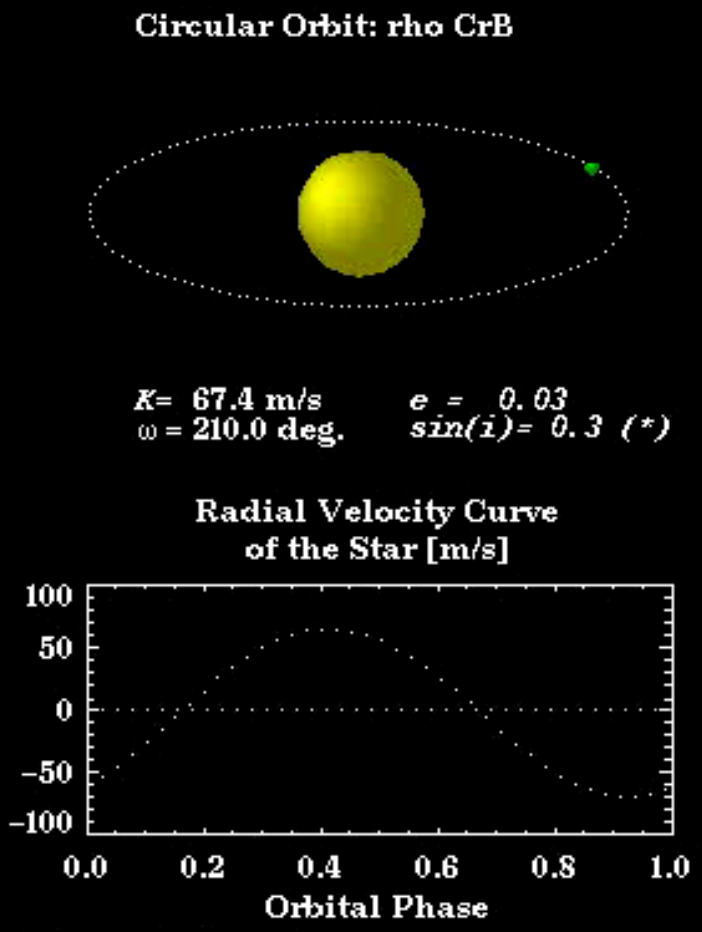


In 1995, we realized that we did not know anything

As of June 16, 2012 http://exoplanet.eu/

Radial velocity of a star perturbed by a planet

- Even if planets are not directly observable, their presence can be inferred dynamically

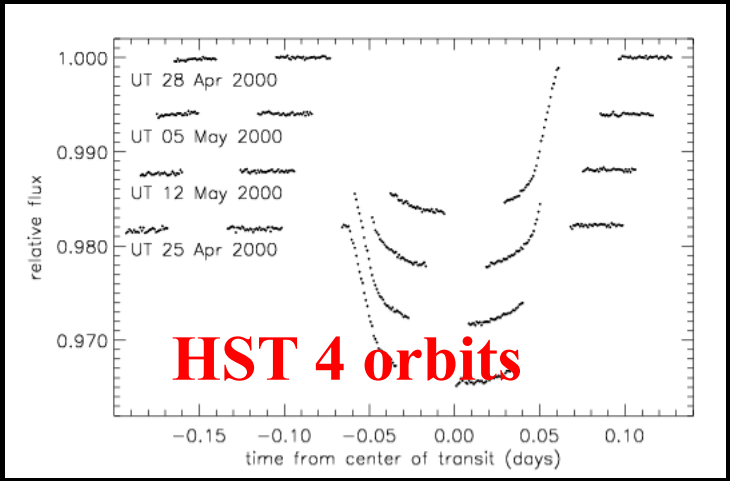


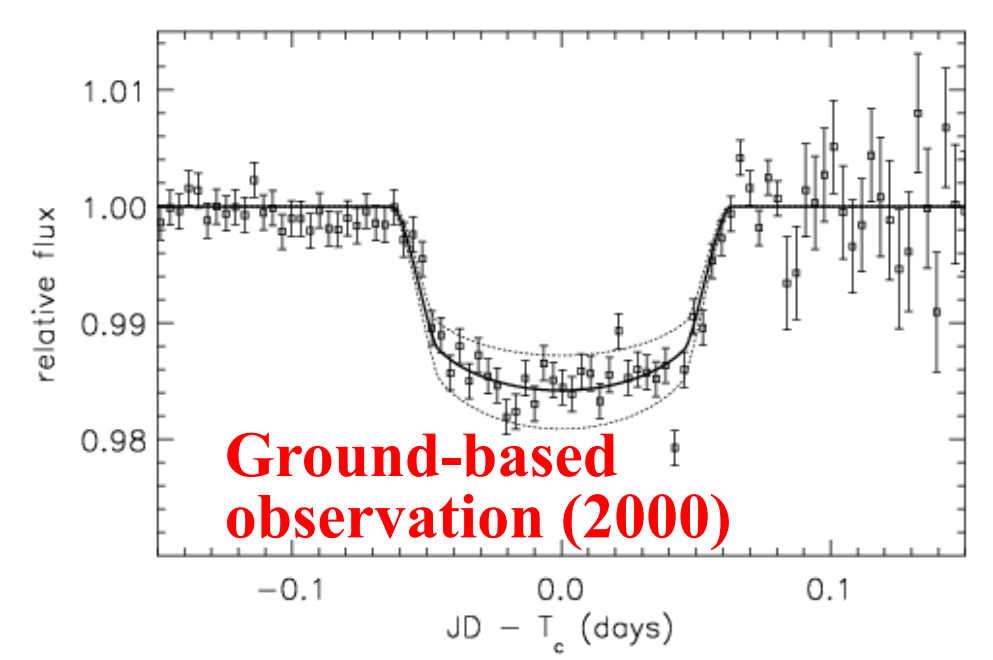
- **velocity modulation of the Sun:**
  - **12.5 m/s（Jupiter）**
  - **0.1 m/s（Earth）**
- **an accuracy of 0.3m/s now achieved from the ground observation**

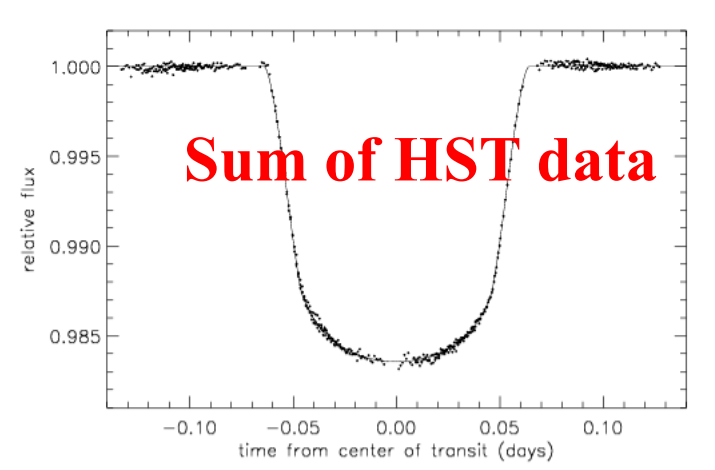
⇒ the major method of (Jovian) planet search

the first discovery of a transiting planet: HD209458

- detected the light curve change at the phase consistent with the radial velocity (Charbonneau et al. 2000, Henry et al. 2000)







Brown et al. (2001)

What we have learned so far…

- Planets are not rare, but fairly common
  - >30 percent of sun-like stars have planets
- Diversity of planetary systems
  - Hot Jupiter, super earth,,,
  - Prograde/retrograde/polar-orbit planet
- Various observational approaches
  - High-dispersion spectroscopy (radial velocity), precise photometry (transit, micro-lens), direct imaging
  - Planetary atmosphere
  - Reflected light from planet

What's next ?

Kepler mission (March 6, 2009 launch)

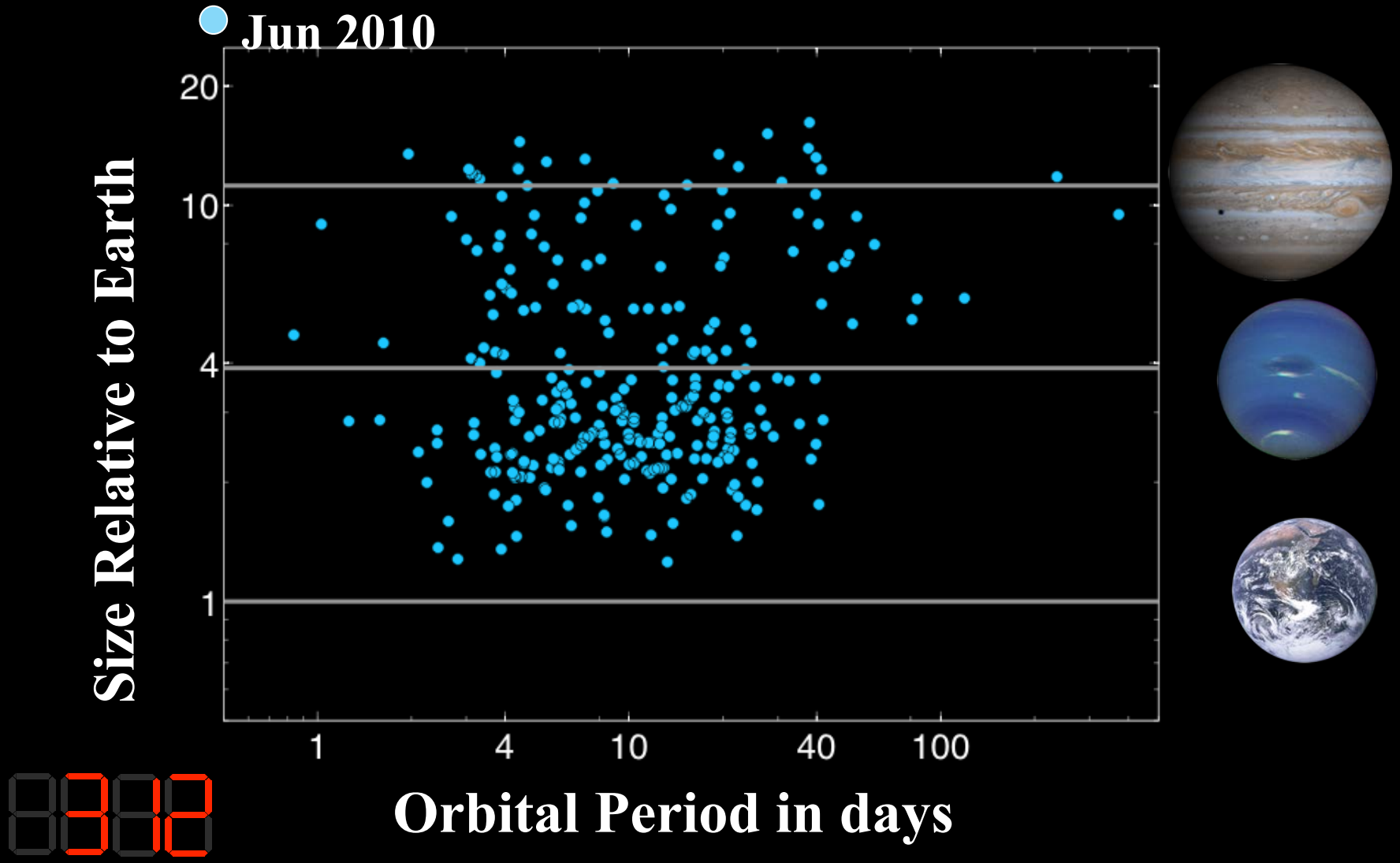
Photometric survey of transiting planets

Searching for terrestrial/habitable planets

Kepler
A Search For Habitable Planets

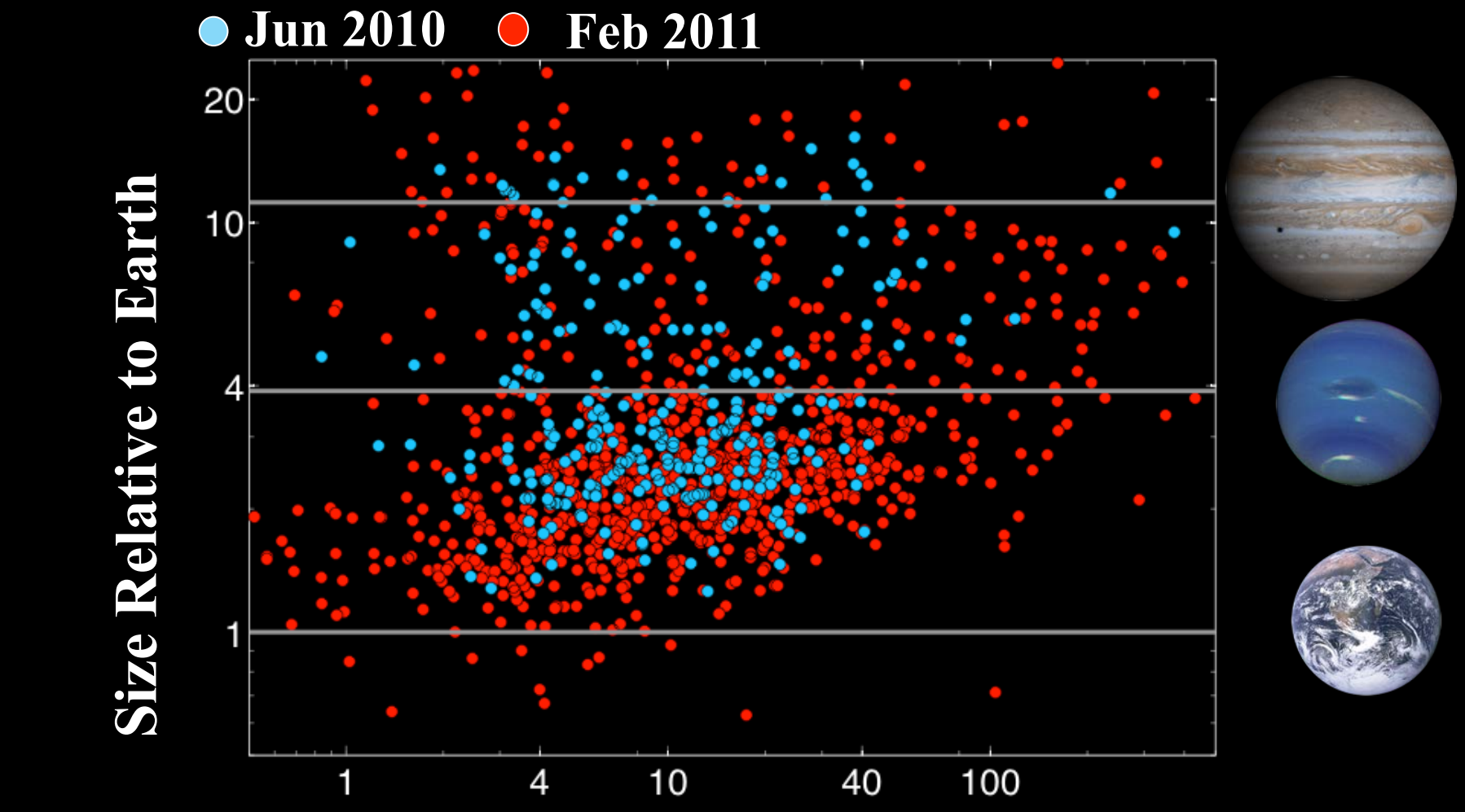
http://kepler.nasa.gov/

Planet Candidates as of June 2010



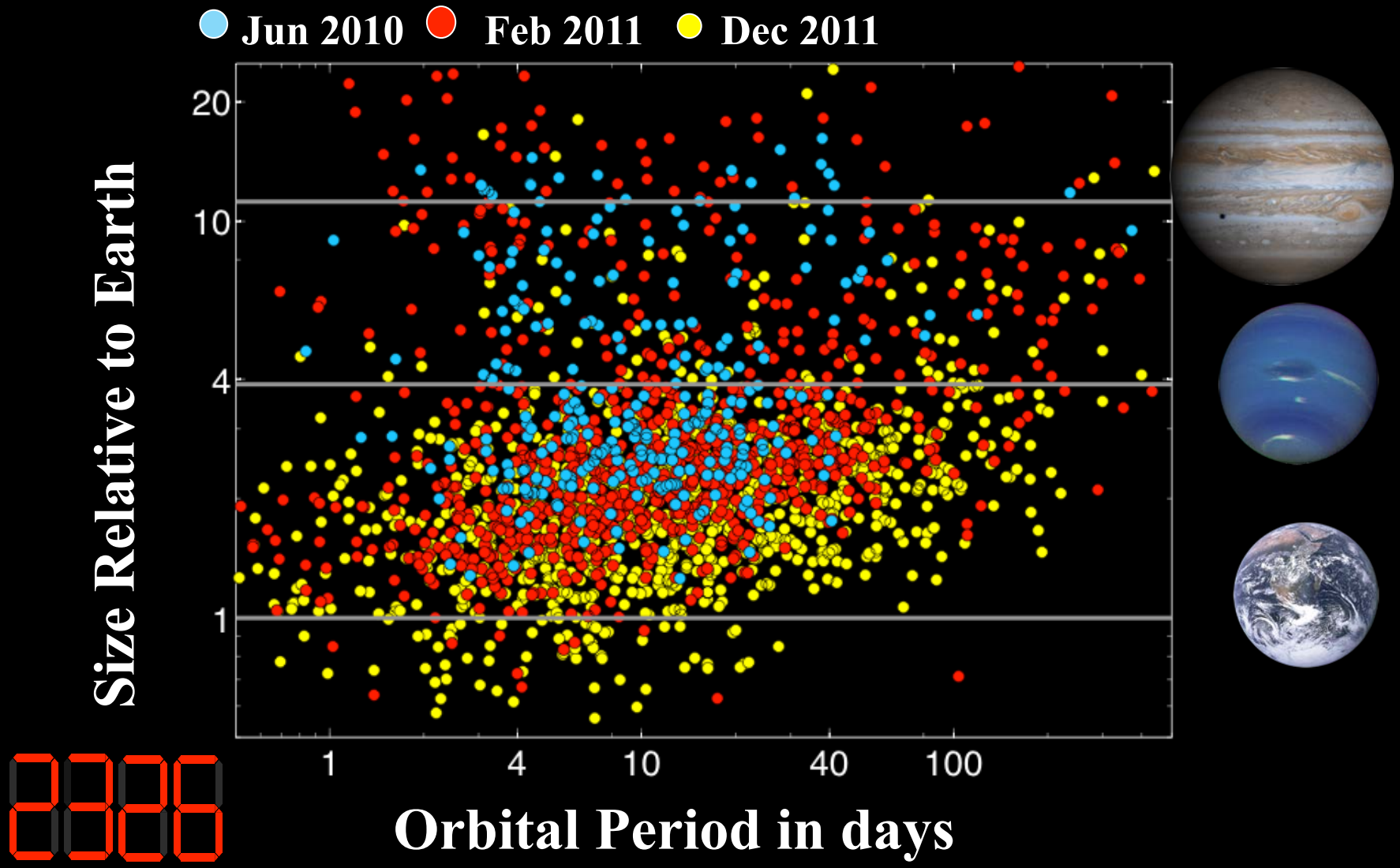
Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

Planet Candidates as of Feb 2011



Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

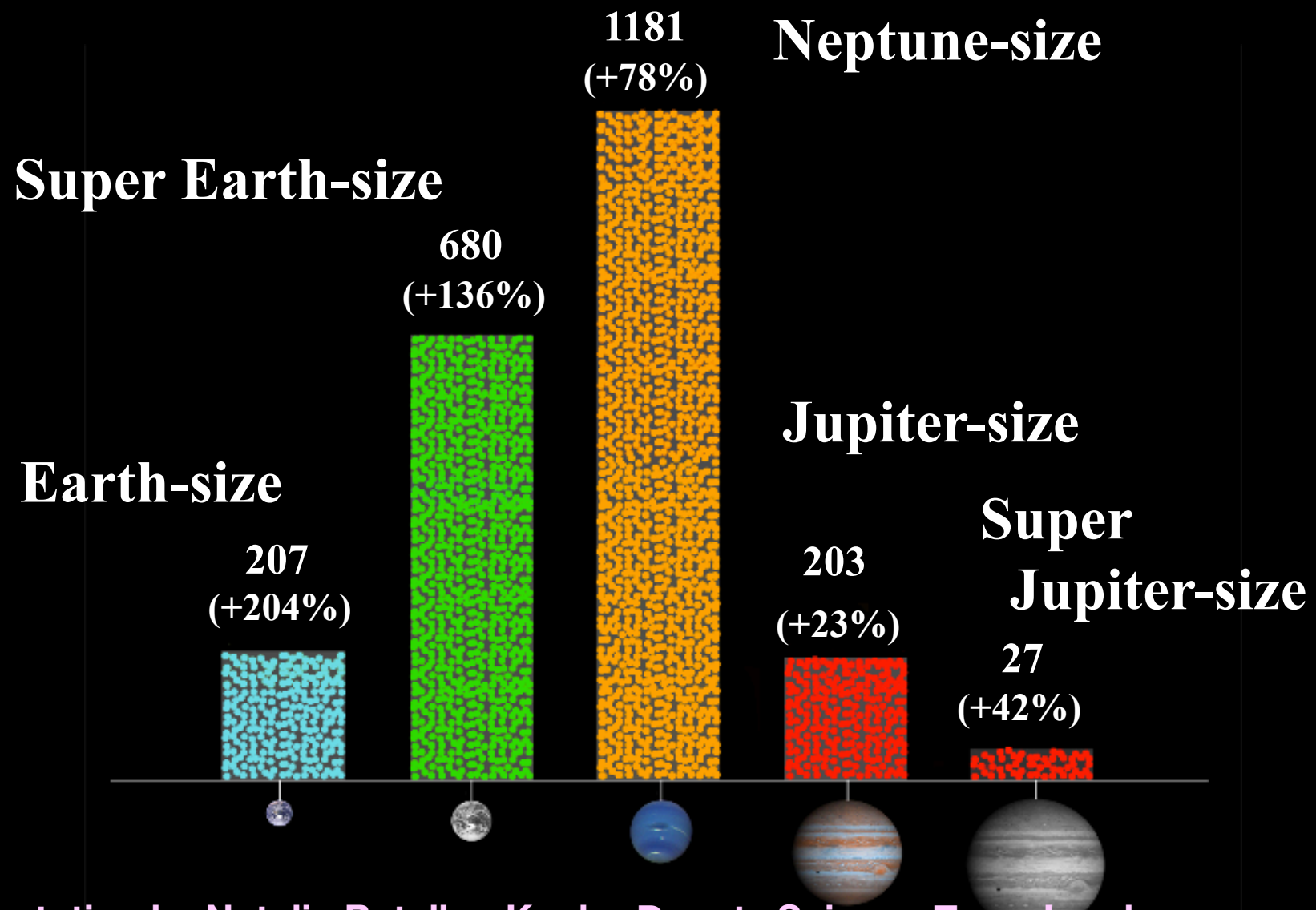
Planet Candidates as of Dec 2011



2008

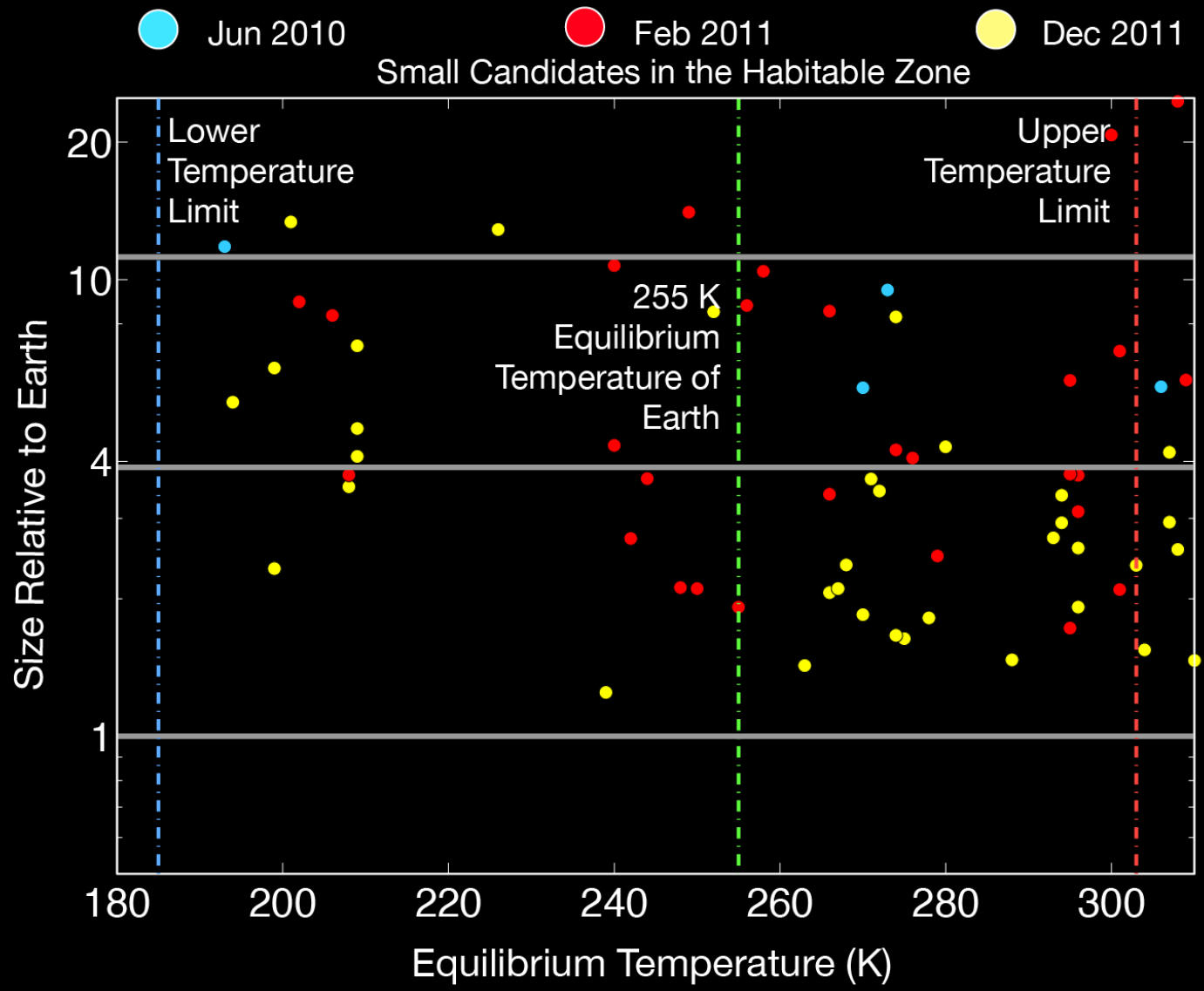
Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

Sizes of Planet Candidates



Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

First Confirmed Kepler Planet in the Habitable Zone

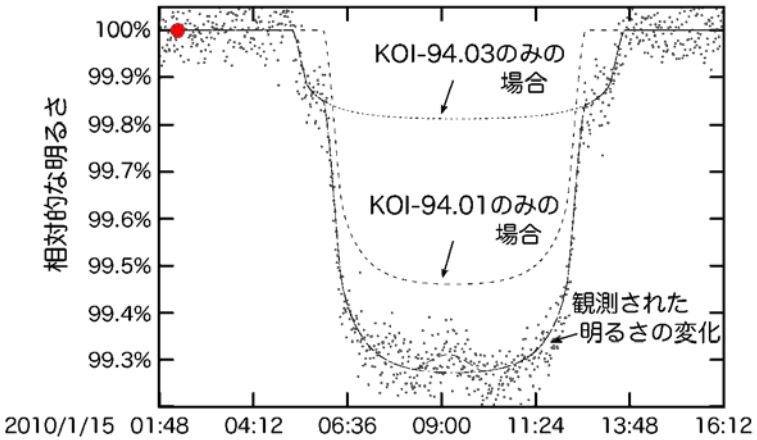


Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

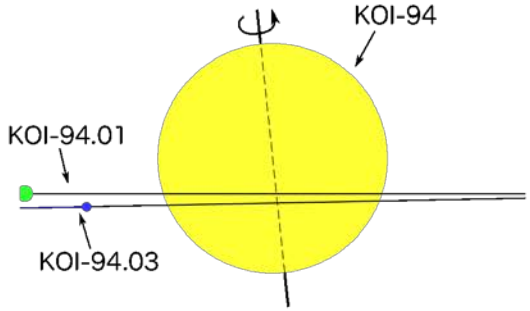
First habitable earth-like planet?

Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

KOI-94: the first planet-planet eclipse of 4 transiting planetary system



2010/1/15 02:16:48

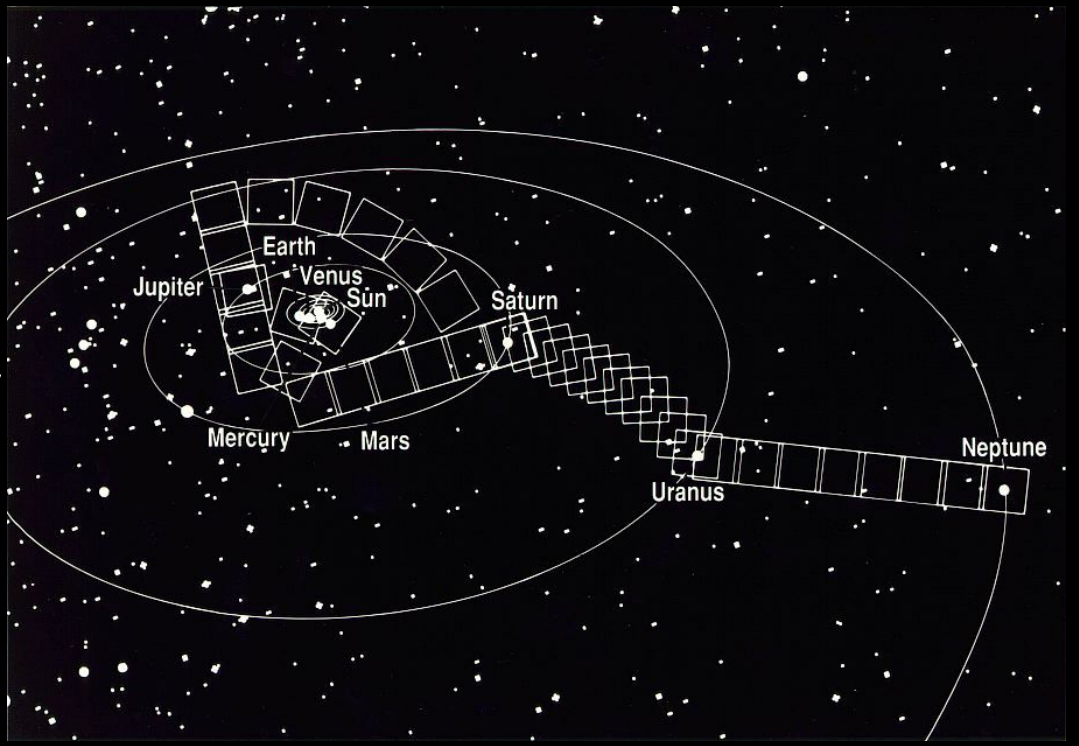


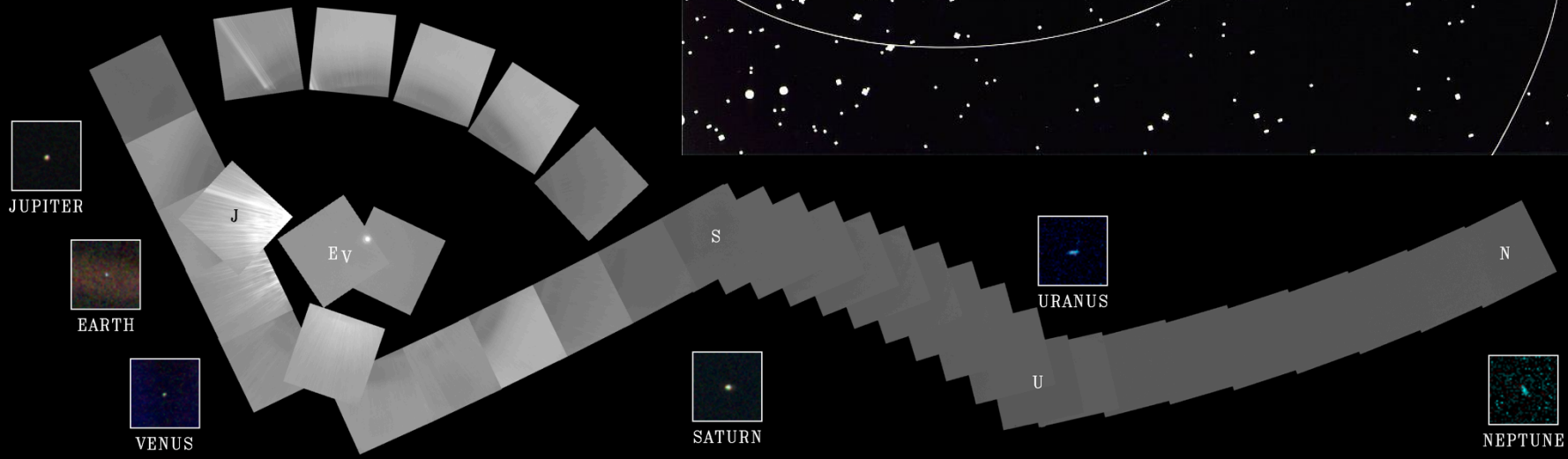
Miraculous alignment ! Next planet-planet eclipse predicted in 2026 !

Hirano et al. ApJL 759(2012)L36 November 10th issue with Kepler archive + Subaru radial velocity

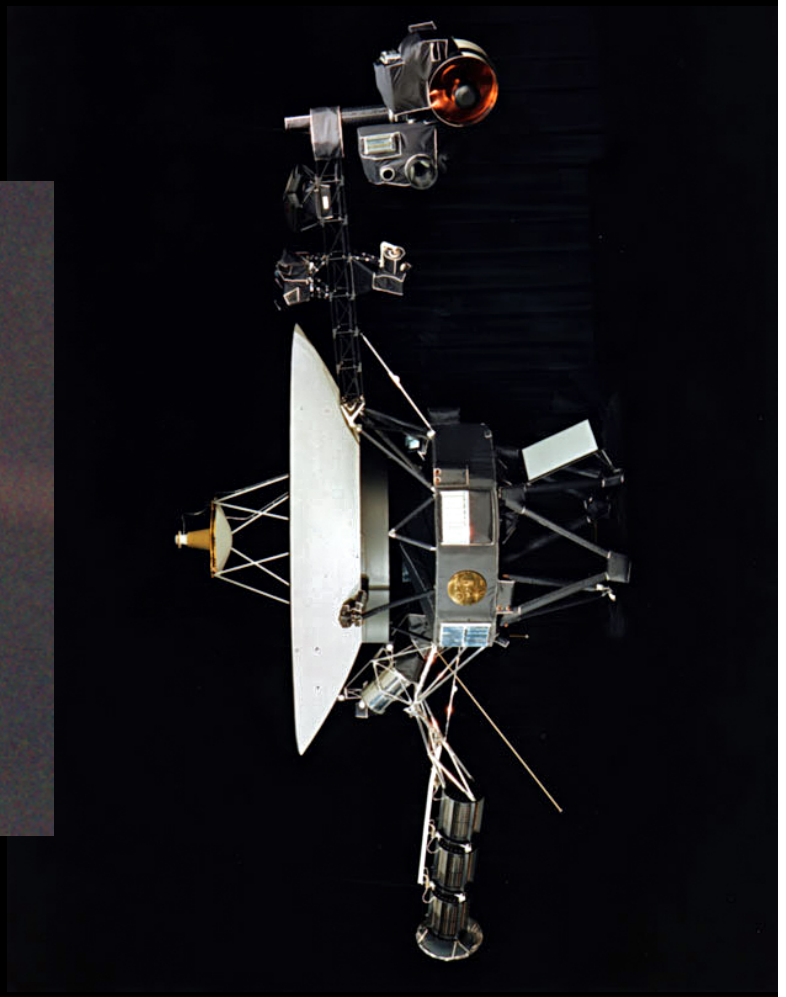
Solar planets imaged by Voyager 1

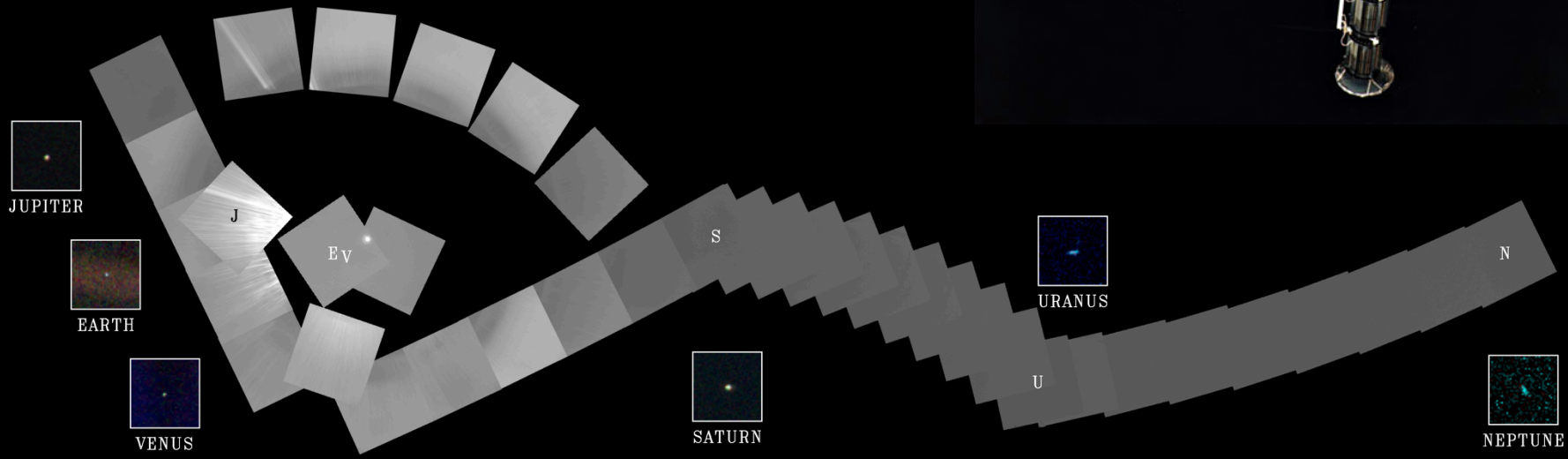
- Earth imaged at 40 AU away (February 14, 1990)
  - Pale Blue Dot by Carl Segan





Pale Blue Dot



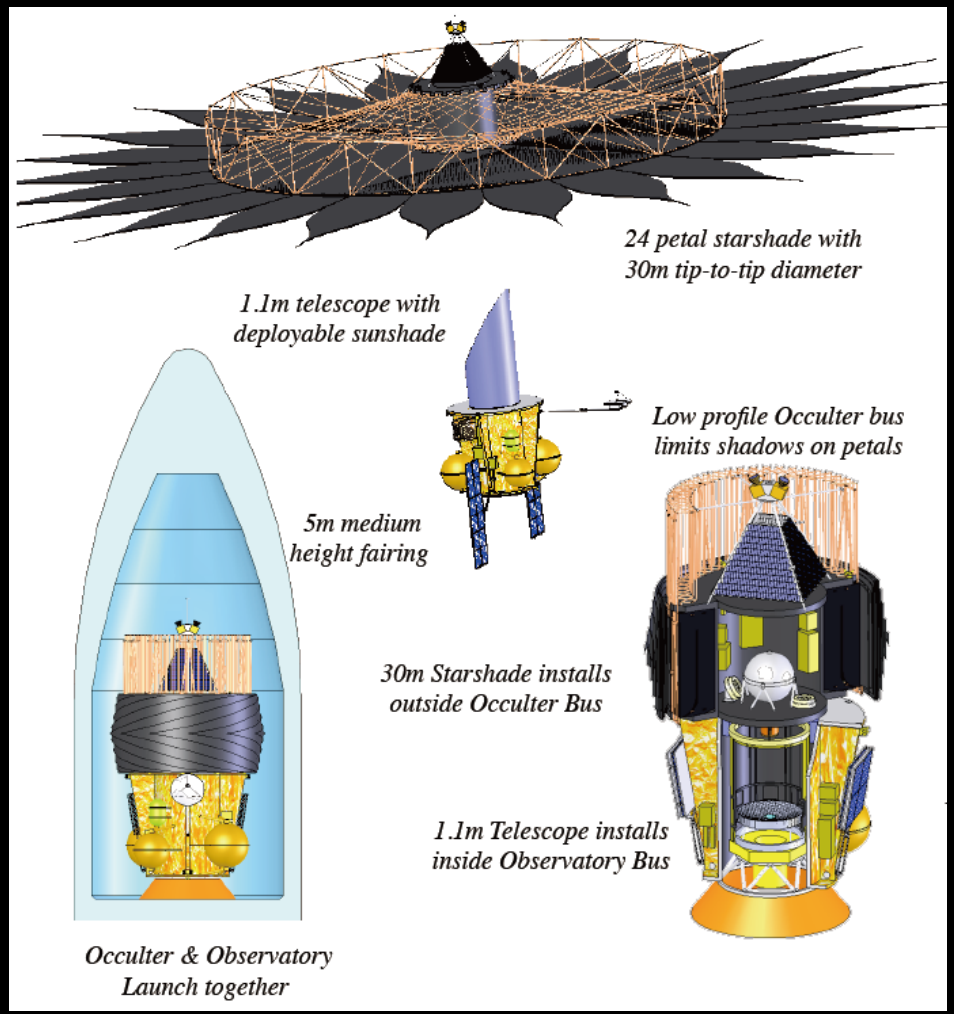


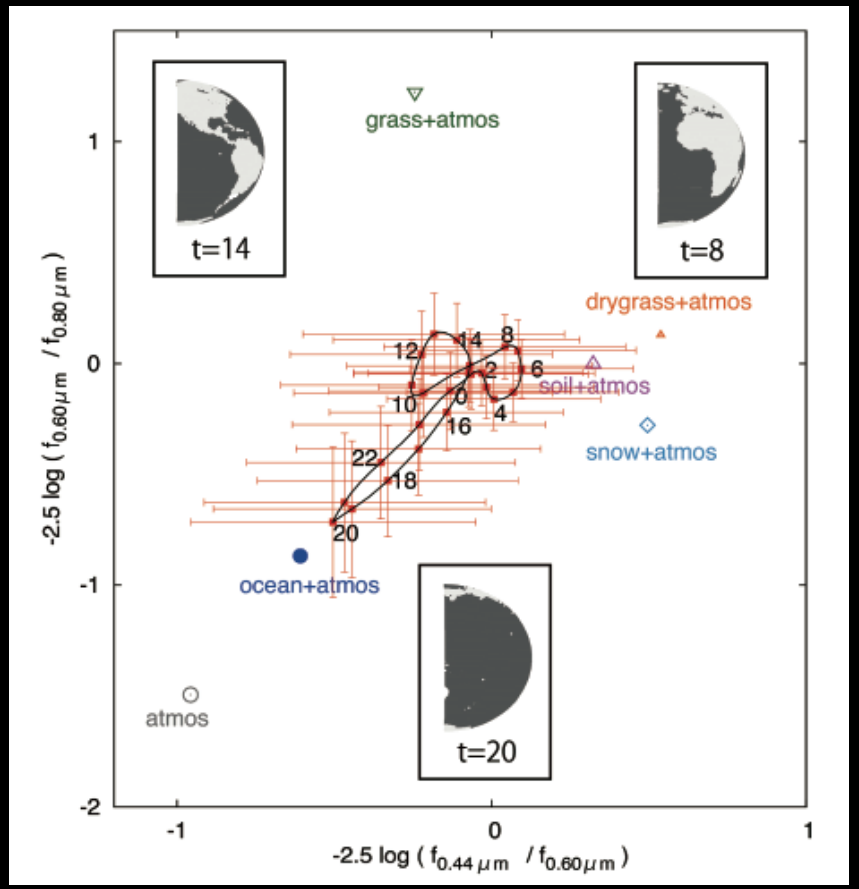
O_3: The Occulting Ozone Observatory

O_3: The Occulting Ozone Observatory

N. Jeremy Kasdin[1], David N. Spergel[1], P. Doug Lisman[2], Stuart B. Shaklan[2], Dmitry Savransky[1], Eric Cady[1], Edwin L. Turner[1], Robert Vanderbei[1], Mark W. Thomson[2], Stefan R. Martin[2], K. Balasubramamian[2], Steven H. Pravdo[2], Yuka Fujii[3], Yasushi Suto[3]

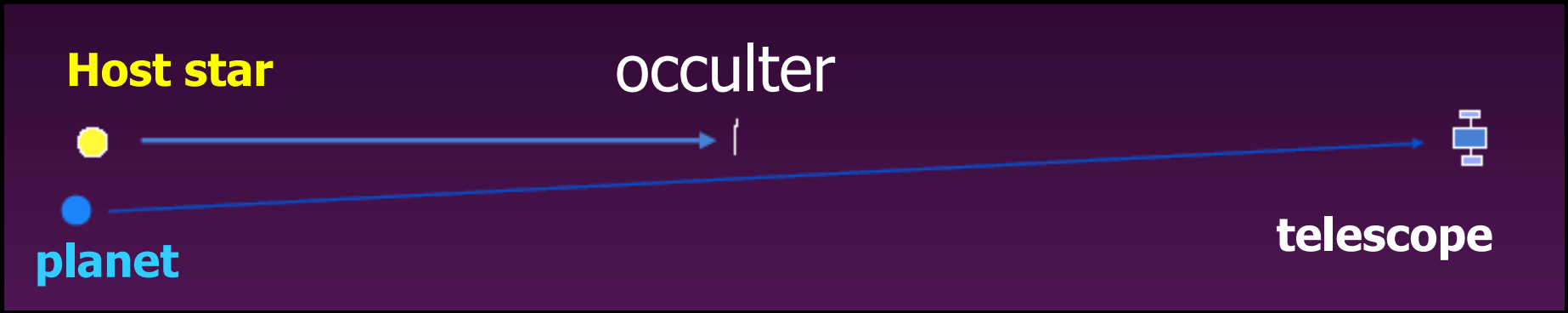
[1]Princeton University, [2]Jet Propulsion Laboratory, [3]University of Tokyo





- Princeton+JPL+…

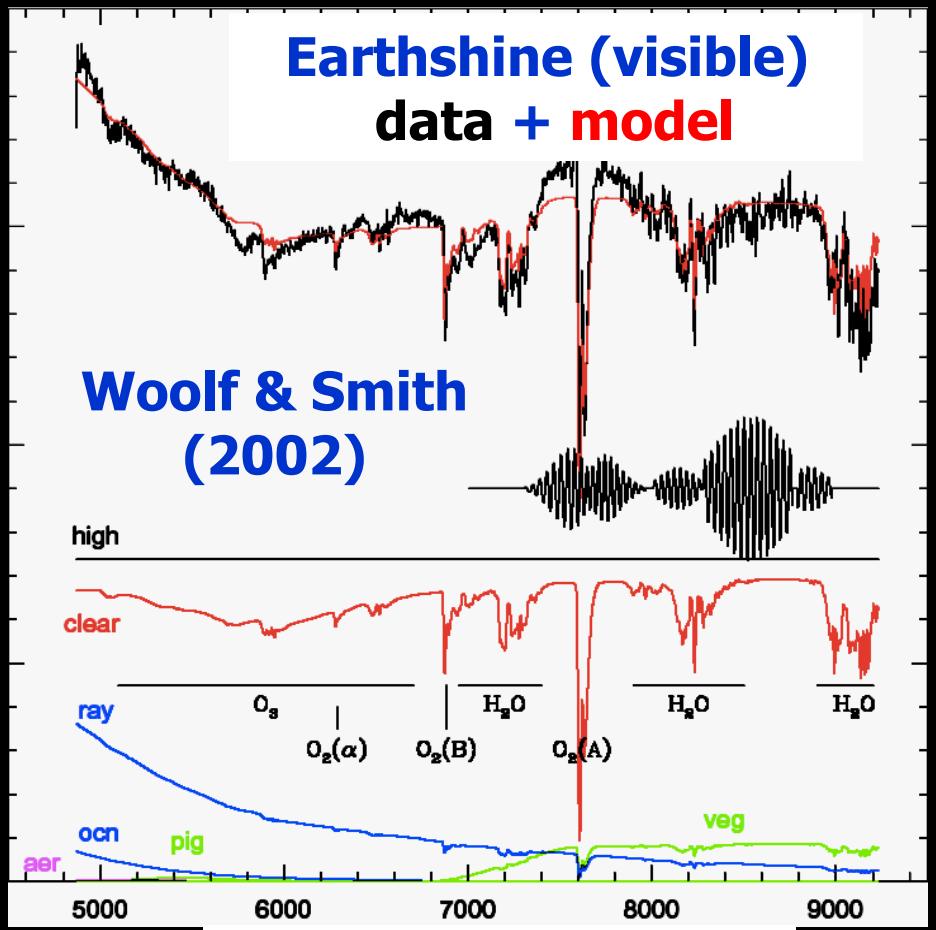
The New Worlds Mission: search for terrestrial planets



http://newworlds.colorado.edu/

- Visible-band mission with 2-4m apertuer@L2
  - Occulter mission @7x10^{4}km away
  - Photometric and spectroscopic monitor of planets
  - Search for biomarker
  - US+UK project; Univ. of Colorado

Conventional biomarkers (signature of life)

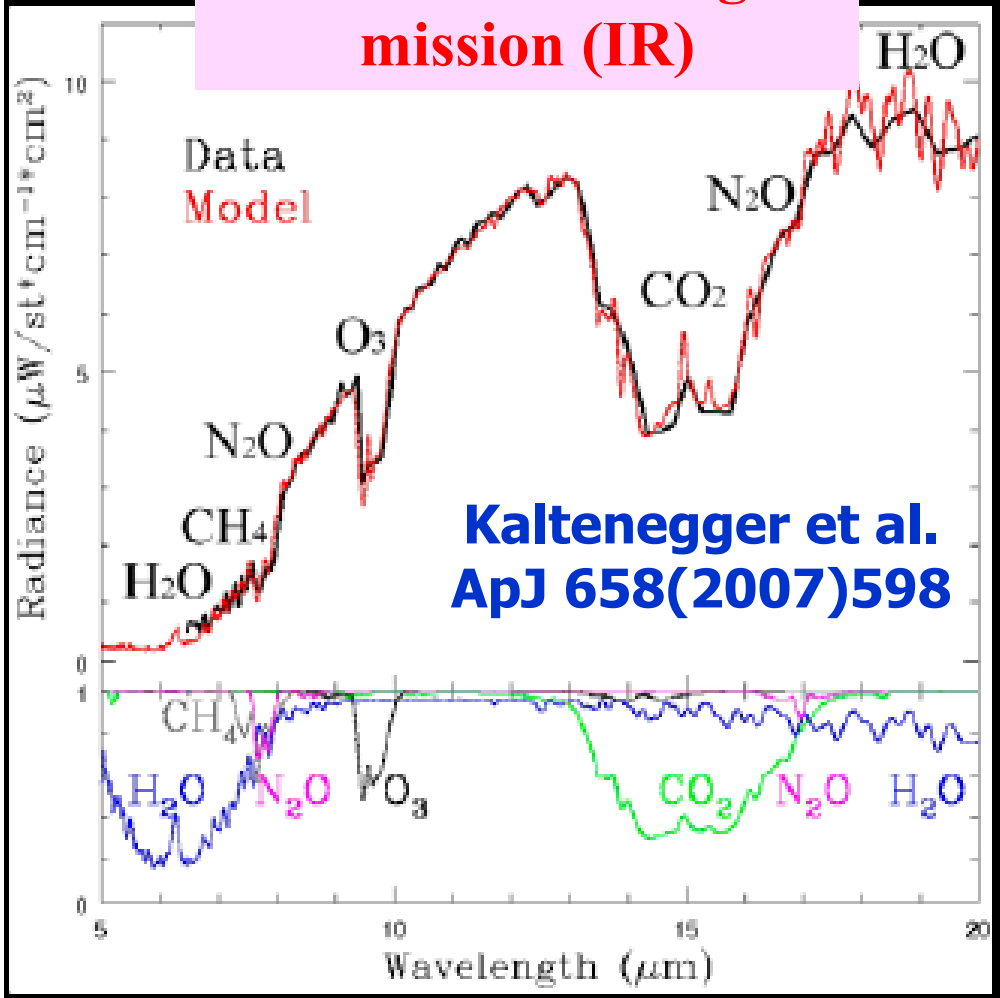


- O_2
  - A-band@0.76 μ m
  - B-band@0.69 μ m
- H_2O
  - 0.72, 0.82, 0.94 μ m
- O_3
  - Chappuis band @(0.5-0.7) μ m
  - Hartley band @(0.2-0.3) μ m

Kasting et al. arXiv:0911.2936
"Exoplanet characterization and the search for life"

Earth's IR spectrum and biomarkers

Earth observing mission (IR)

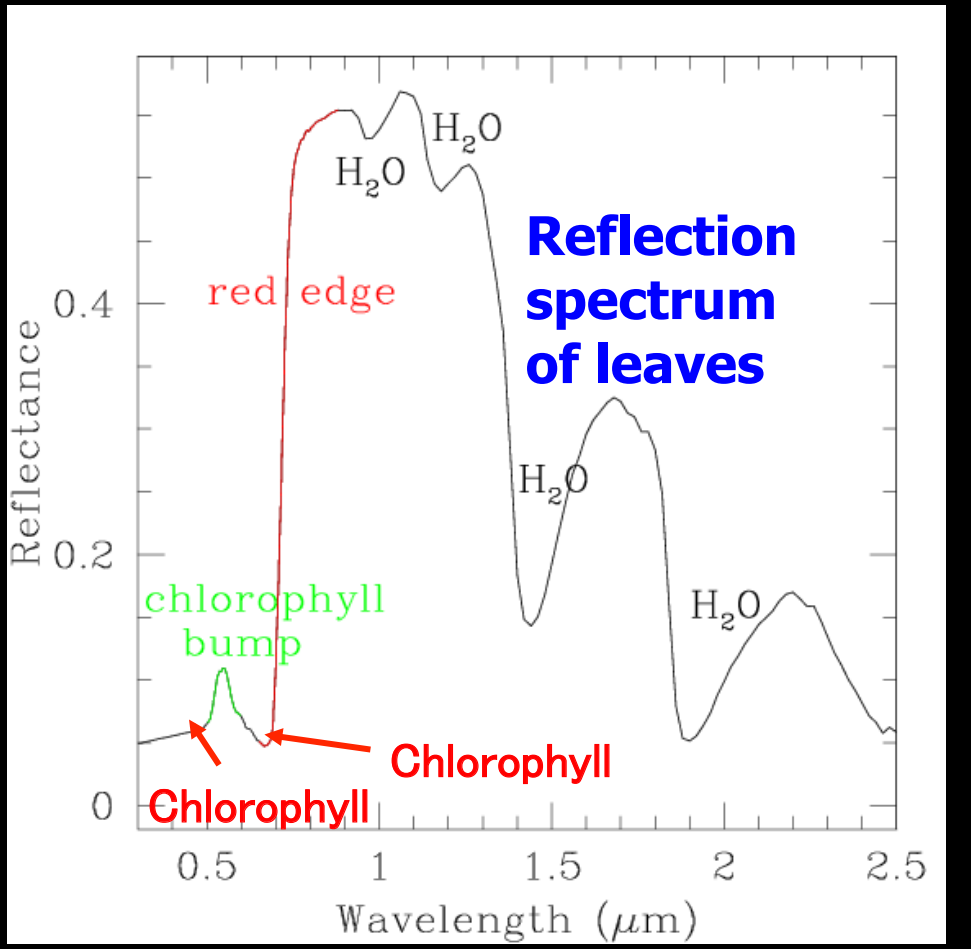


- O_3@9.6 μ m
  - Good tracer of O_2
- H_2O @<8 μ m,>17 μ m
- CH_4@7.7 μ m
  - Biotic origin?

Kasting et al. arXiv:0911.2936
"Exoplanet characterization and the search for life"

Red edge of *(extrasolar) plants:* a biomarker in *extrasolar planets*

- **Red-edge**
  - Significant increase of reflectivity of leaves on Earth (terrestrial planets) for λ >7000Å
- An interesting and unique biomarker ?
- Widely used in the remote-sensing of our Earth



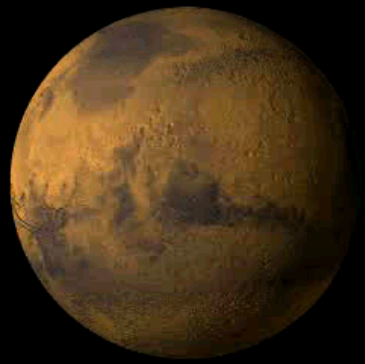
Seager, Ford & Turner astro-ph/0210277

Vesto Melvin Slipher (1875-1969)

Red-edge as a biomarker (at least) in 1924 !

- Discovered redshifts of "spiral nebulae" now known as galaxies

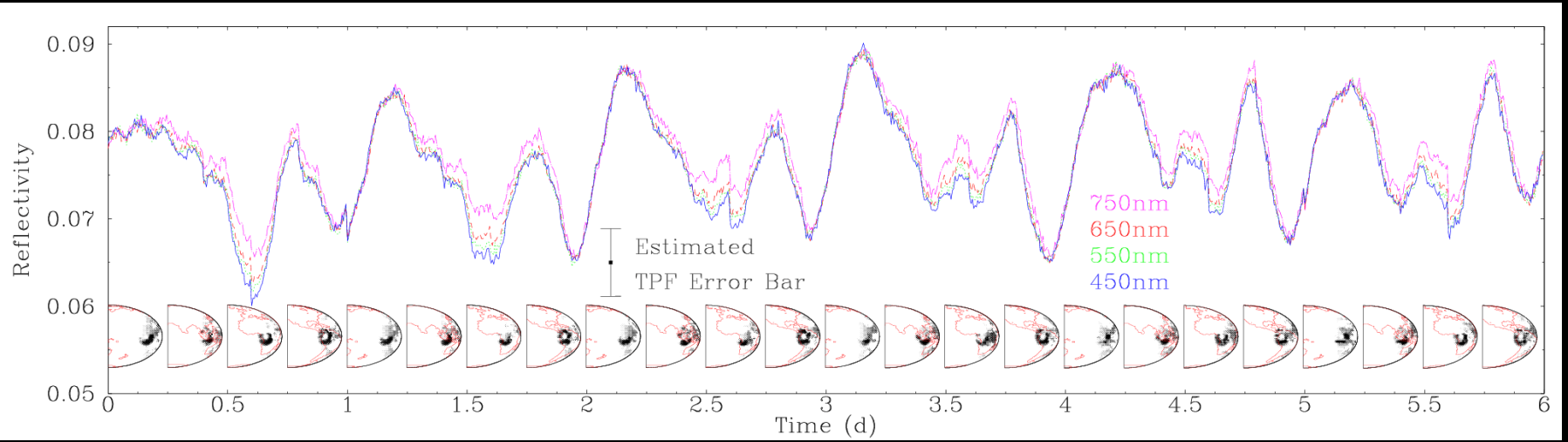
"Observations of Mars in 1924 made at the Lowell Observatory: II spectrum observations of Mars' ' PASP 36(1924)261



reflection spectrum. The Martian spectra of the dark regions so far do not give any certain evidence of the typical reflection spectrum of chlorophyl. The amount and types of vegetation required to make the effect noticeable is being investigated by suitable terrestrial exposures.

Astrobiology indeed in 1924 !

Expected daily change of the reflected light from the earth



Ford, Seager & Turner: Nature 412 (2001) 885

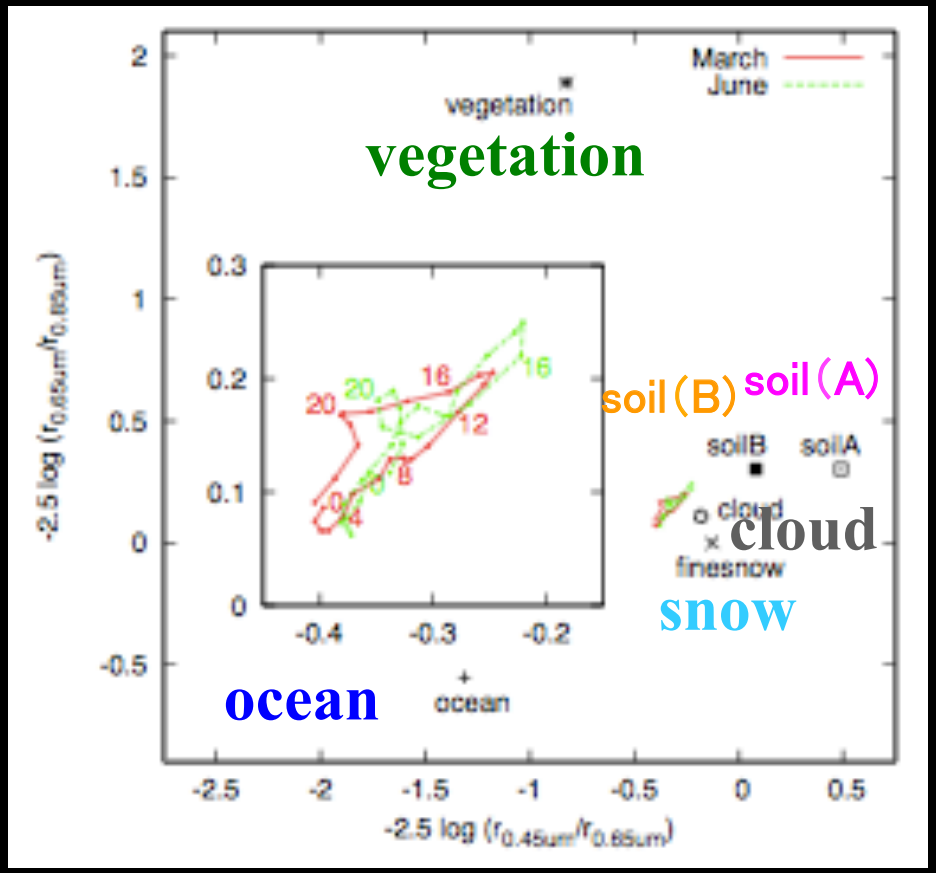
- ***Assume*** **that the earth's reflected light is completely separated from the Sun's flux !**
  - **TPF (Terrestrial Planet Finder) in 10 years from now ?**
- ***Periodic change of 10% level*** **due to different reflectivity of land, ocean, forest, and so on**
- **Cloud is the most uncertain factor:** ***weather forecast !***

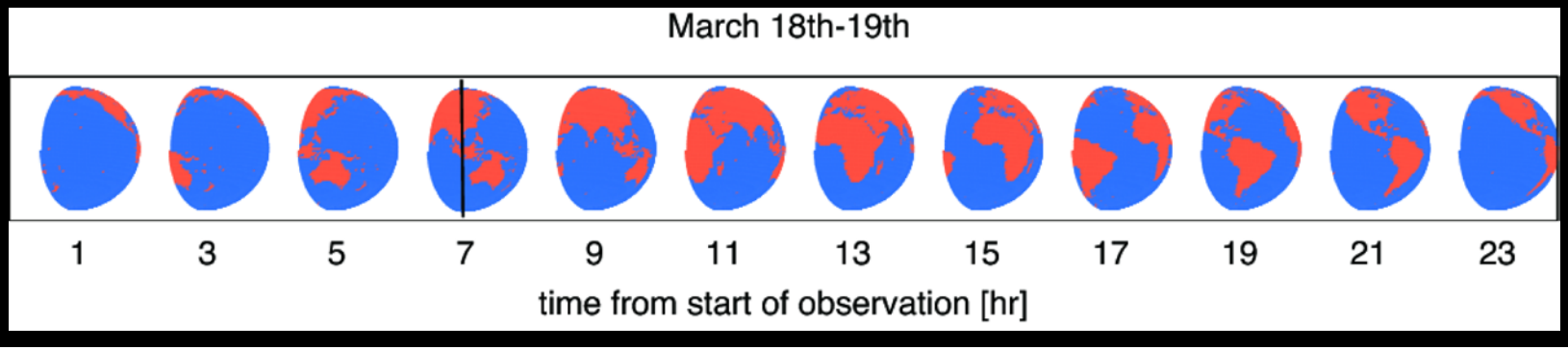
Colors of a Second Earth: estimating the fractional areas of ocean, land and vegetation of Earth-like exoplanets
ApJ. 715(2010)866, arXiv:0911.5621
Colors of a Second Earth. II: Effects of Clouds on Photometric Characterization of Earth-like Exoplanets
ApJ. 738(2011)184, arXiv:1102.3625

- Yuka Fujii, H.Kawahara, A.Taruya, Y.Suto (Dept. of Phys., Univ. of Tokyo), S.Fukuda, T.Nakajima (Univ. of Tokyo, Center of climate system research), Edwin Turner (Princeton Univ.)

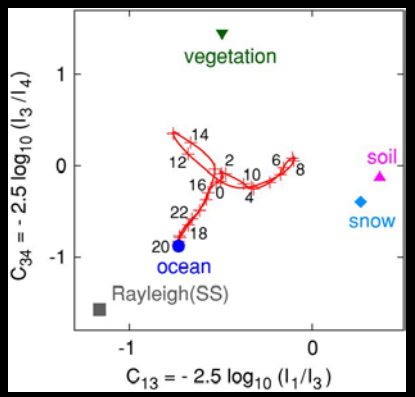
http://www.space.com/scienceastronomy/color-changing-planets-alien-life-100513.html

Colors of our earth

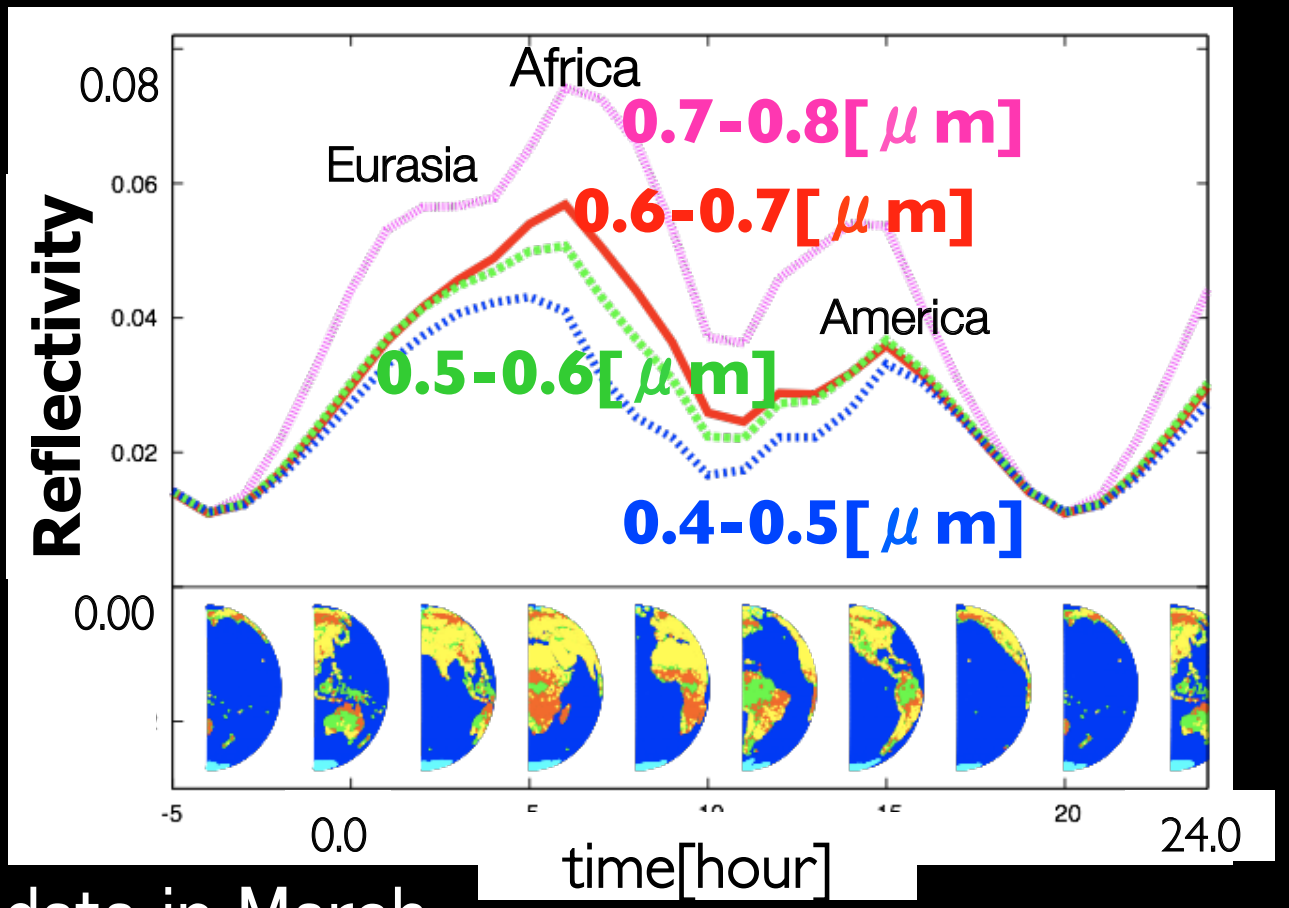




A pale blue dot ? Not really



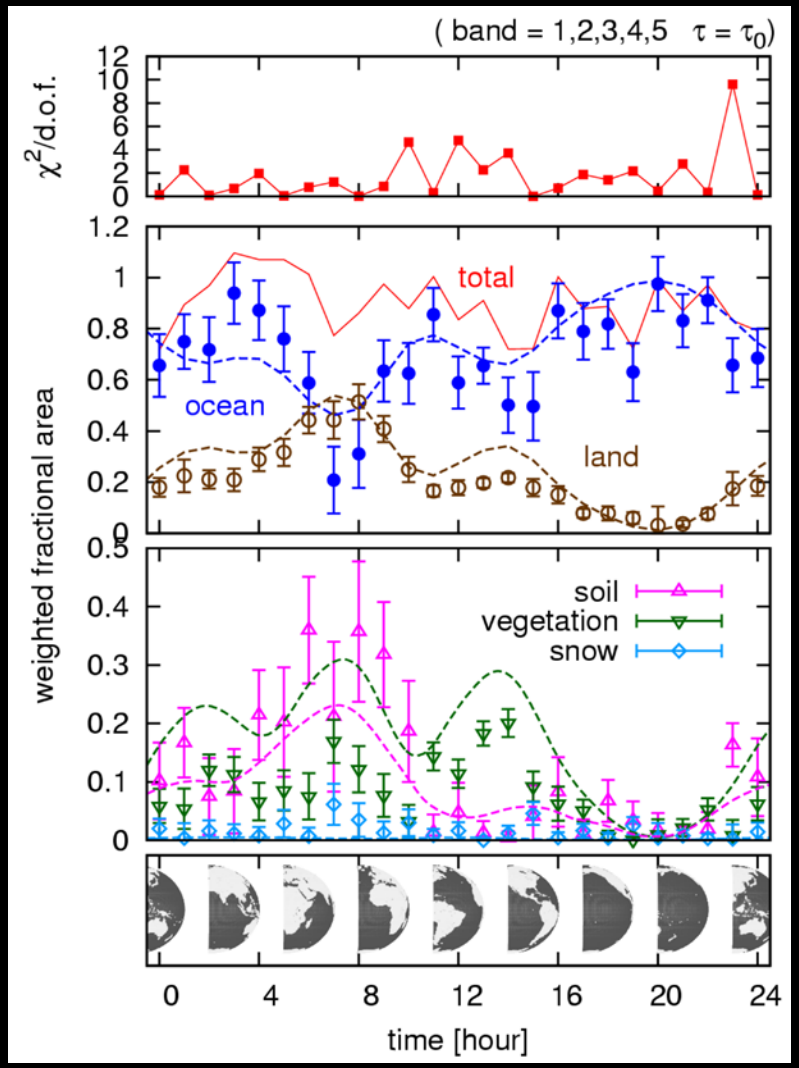
Simulated photometric light-curves of Earth



- Adopted Earth data in March
- Spin inclination = 0 (vernal equinox)
- cloudless

Fujii et al. (2010)

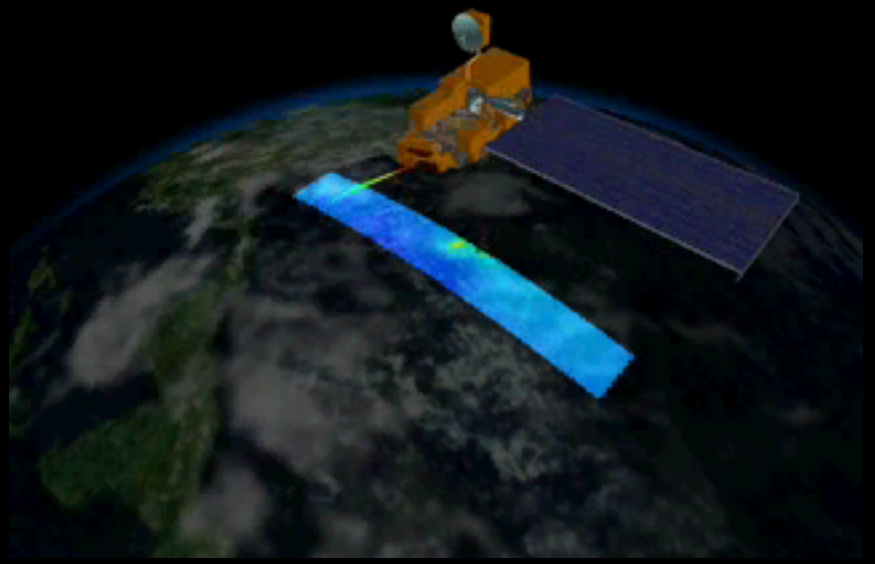
Idealized cloudless earth



Fujii et al.（2010）

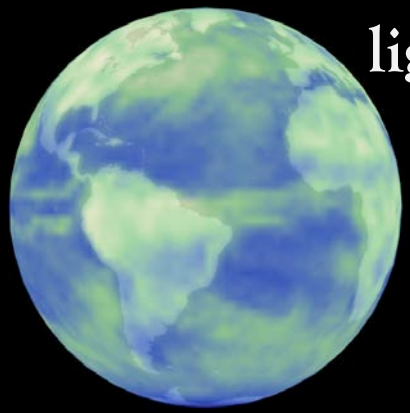
- Input data
  - 5 light-curves using anisotropic scattering (BRDF) model
  - 2 week observation of a cloudless Earth at 10 pc away
- Inversion assumptions
  - Ocean, soil, vegetation and snow only (with atmosphere)
  - Isotropic scattering assumed
- Results
  - Estimated areas (symbols) vs Surface classification data (dashed line)
  - Reasonably well reproduced.
  - Can identify vegetation !

Earth observing satellite Trace (Transition Region and Coronal Explorer) + detector Modis (Moderate Resolution Imaging Spectroradiometer)

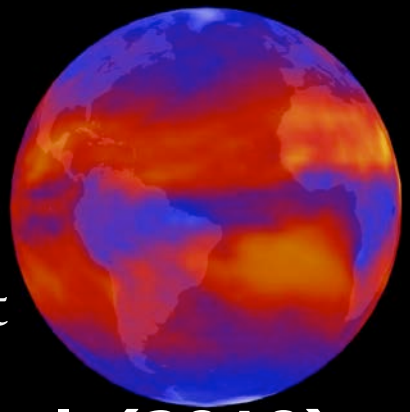


Reconstruction of planetary surface areas with clouds

reflected light

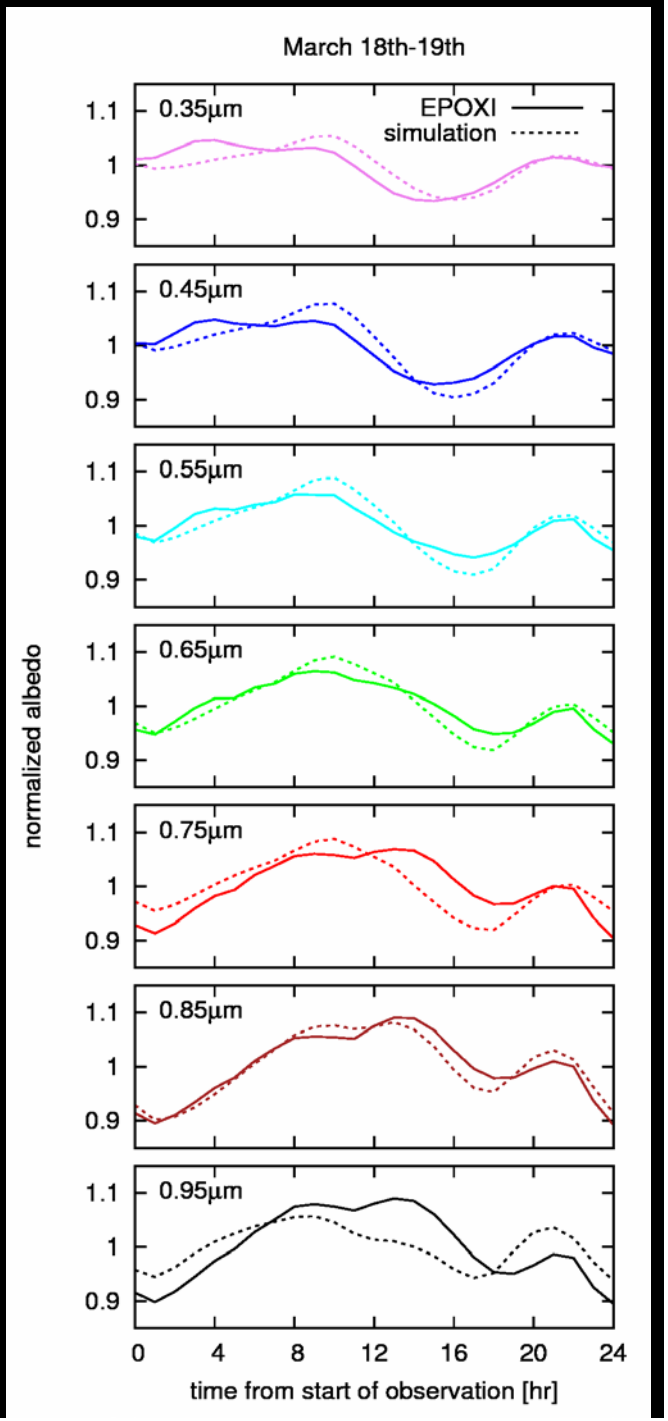


emission light



Vazquez et al. (2010)

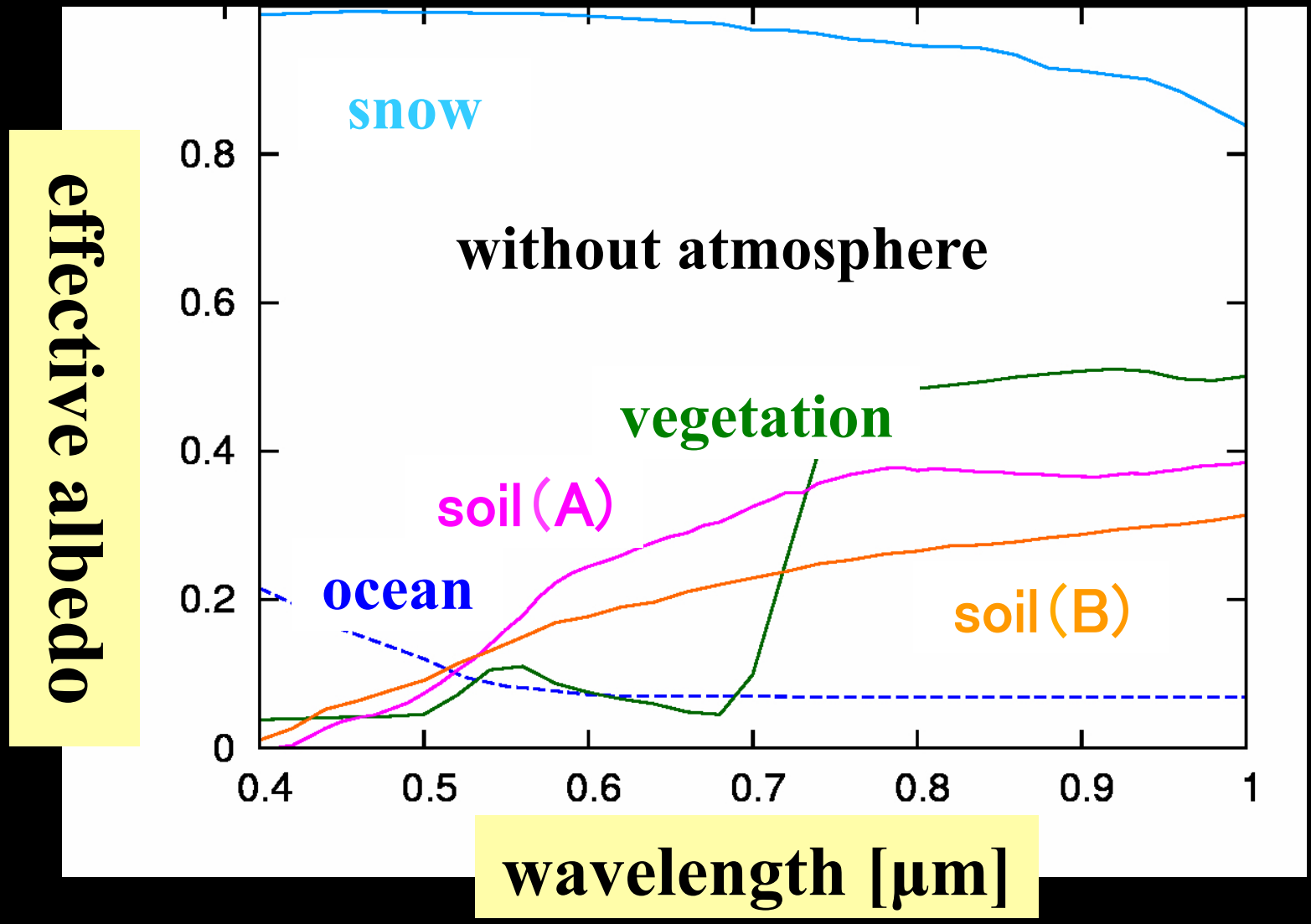
Fujii et al. (2010)



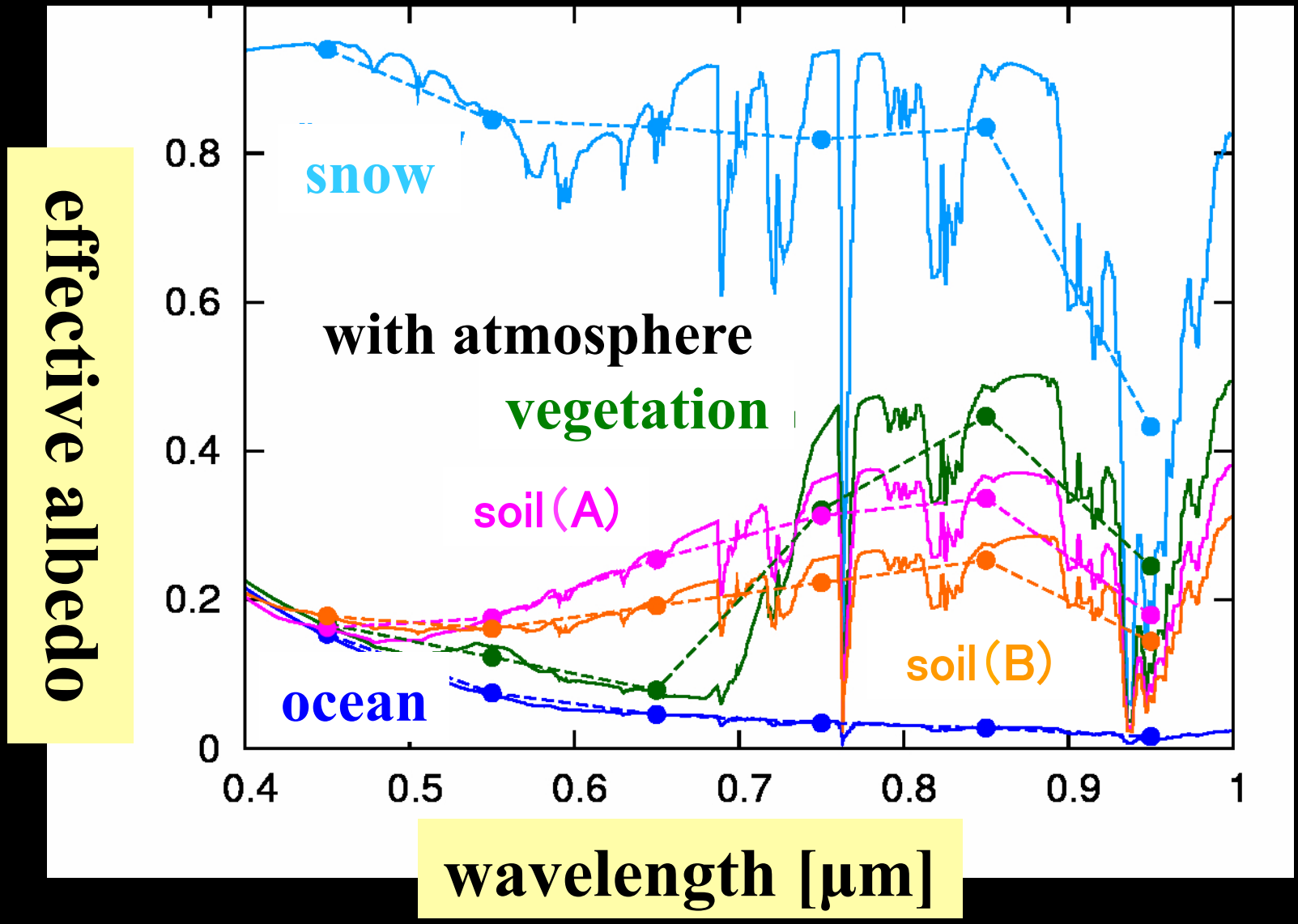
Inverse procedure: estimation of fractional areas of surface components

- Fitting the EPOXI data to a simplified model (isotropic scattering with ocean, soil, vegetation, snow and cloud)
  - Neglect light from the central star
  - Neglect the spin and orbital rotation during each exposure
  - A simple cloud model with the same optical depth τ (=10 fiducially)
  - US standard atmosphere: compositions, pressure and temperature profiles

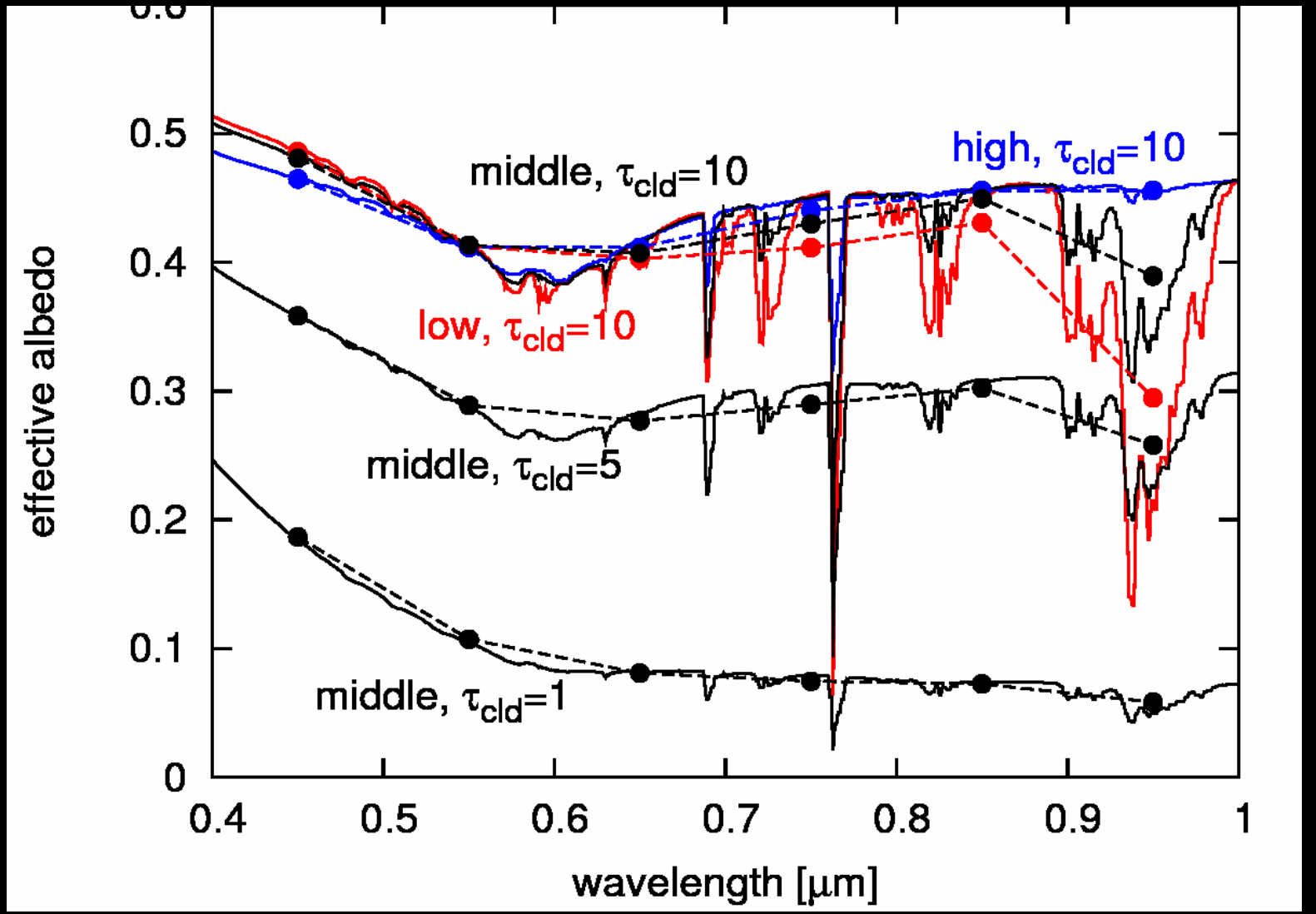
Albedo of surface components: isotropic approximation w/o atmosphere



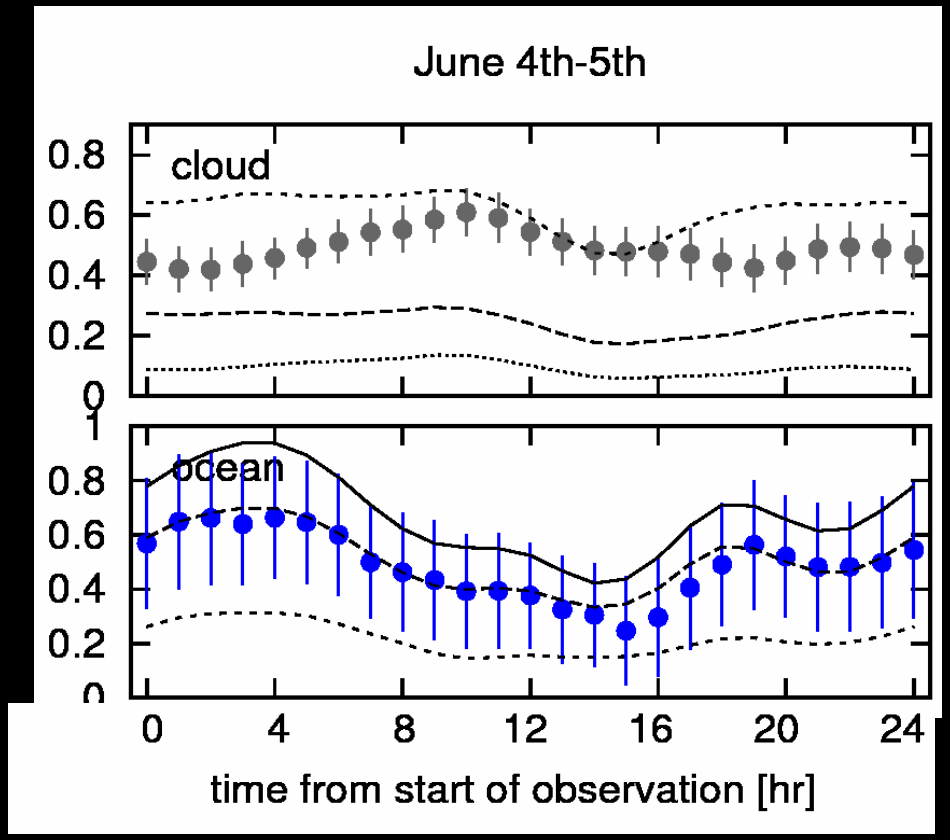
Albedo of surface components: isotropic approximation with atmosphere

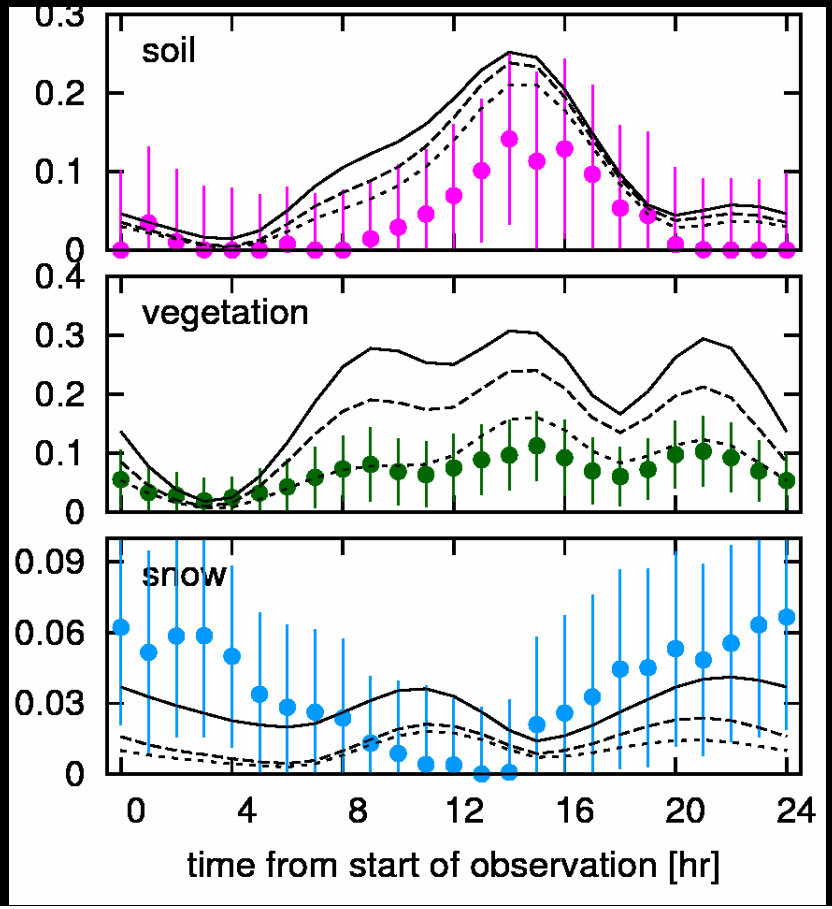


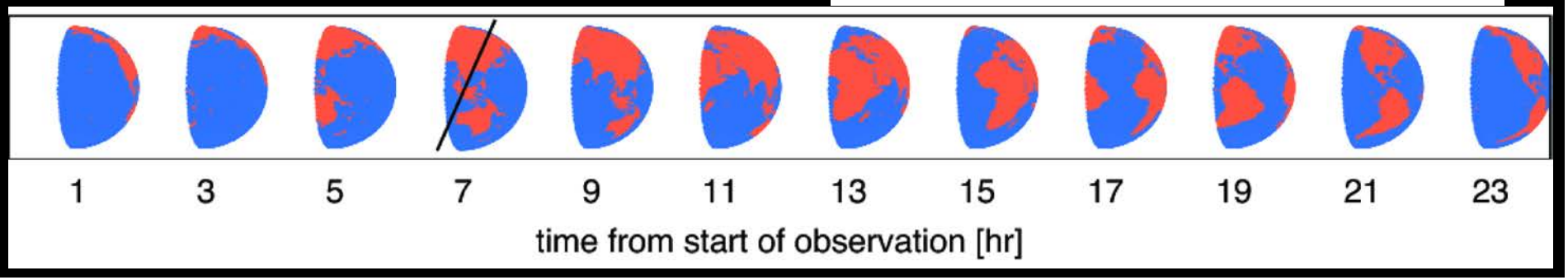
Albedo spectra of clouds: model dependence



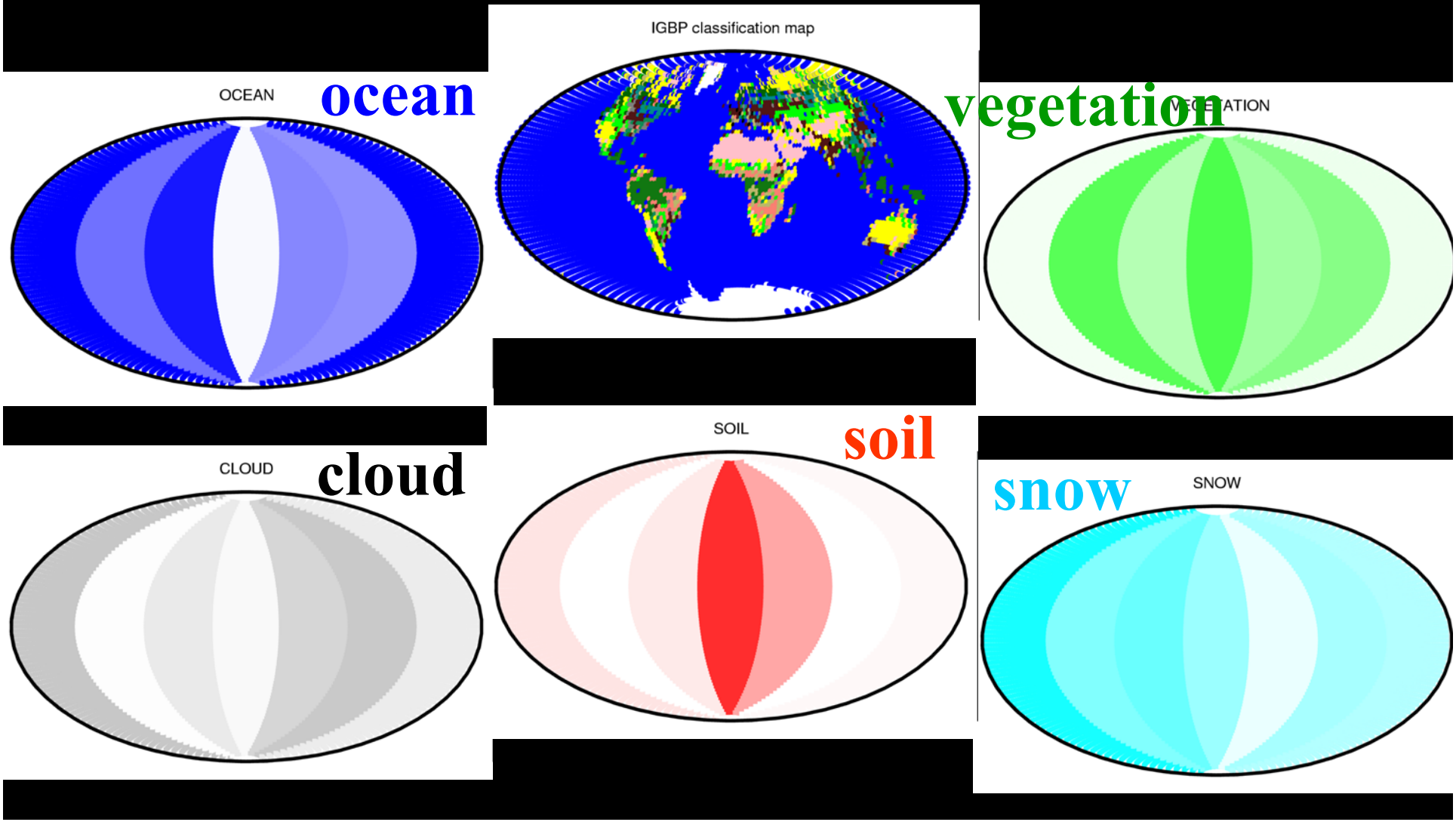
Fractional areas estimated from EPOXI data





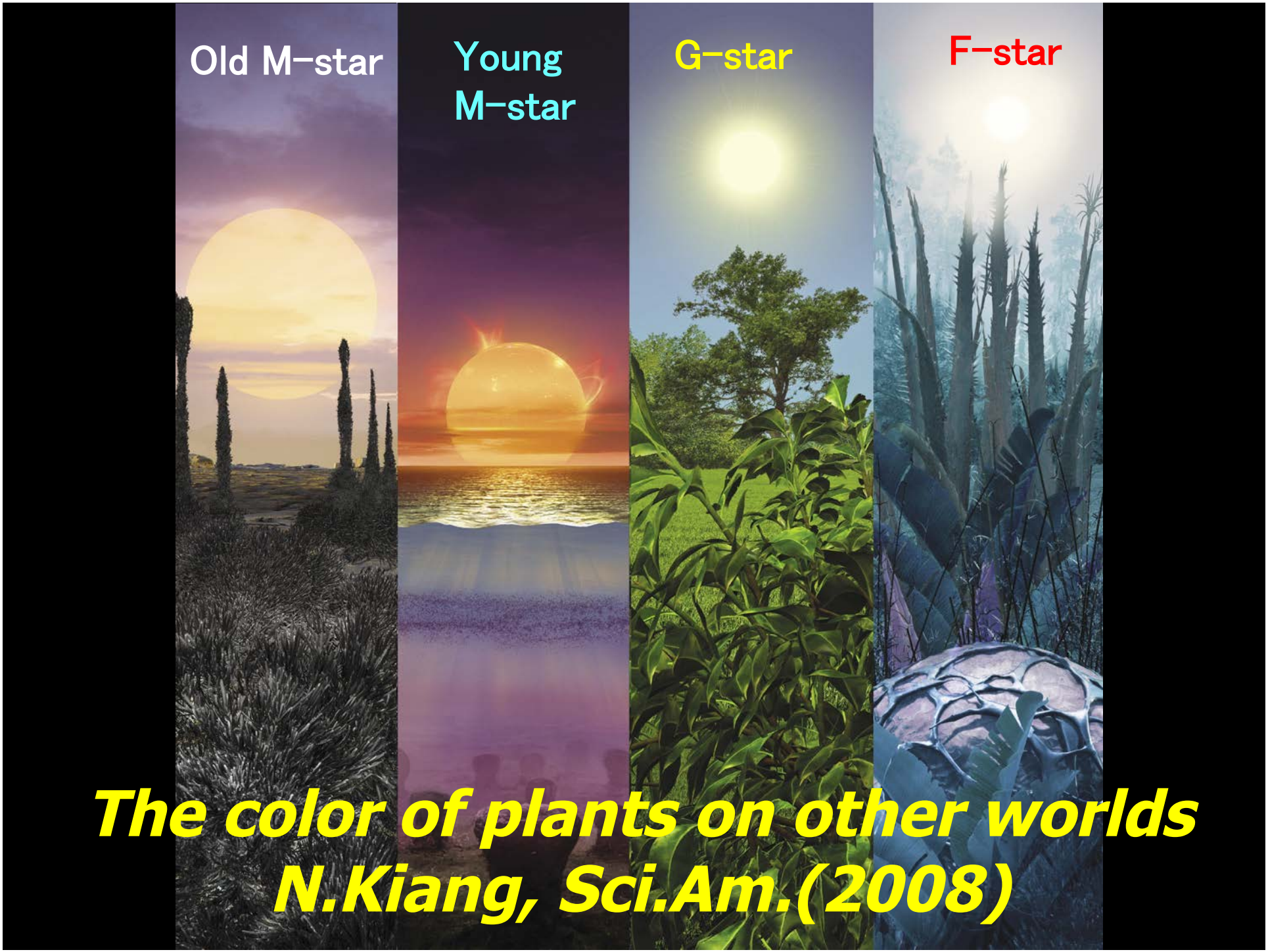


Surface latitude map estimated from EPOXI data



Summary:
A pale blue dot? Not really !

- Future direct imaging of daily change of colors of exo-Earths would reveal the presence of ocean, land, cloud, and/or even vegetation on their surface.
- The color of plants on different environment than that of our Earth should be explored towards astrobiology.
- Detection of a second Earth may not be a mere fairly tale nor a science fiction any more.


Old M-star
Young M-star
G-star
F-star
The color of plants on other worlds
N.Kiang, Sci.Am.(2008)

The Little Prince
(by Antoine de Saint Exupéry)

If someone loves a flower, of which just one single blossom grows in all the millions and millions of stars, it is enough to make him happy just to look at the stars. He can say to himself, "Somewhere, my flower is there ..."