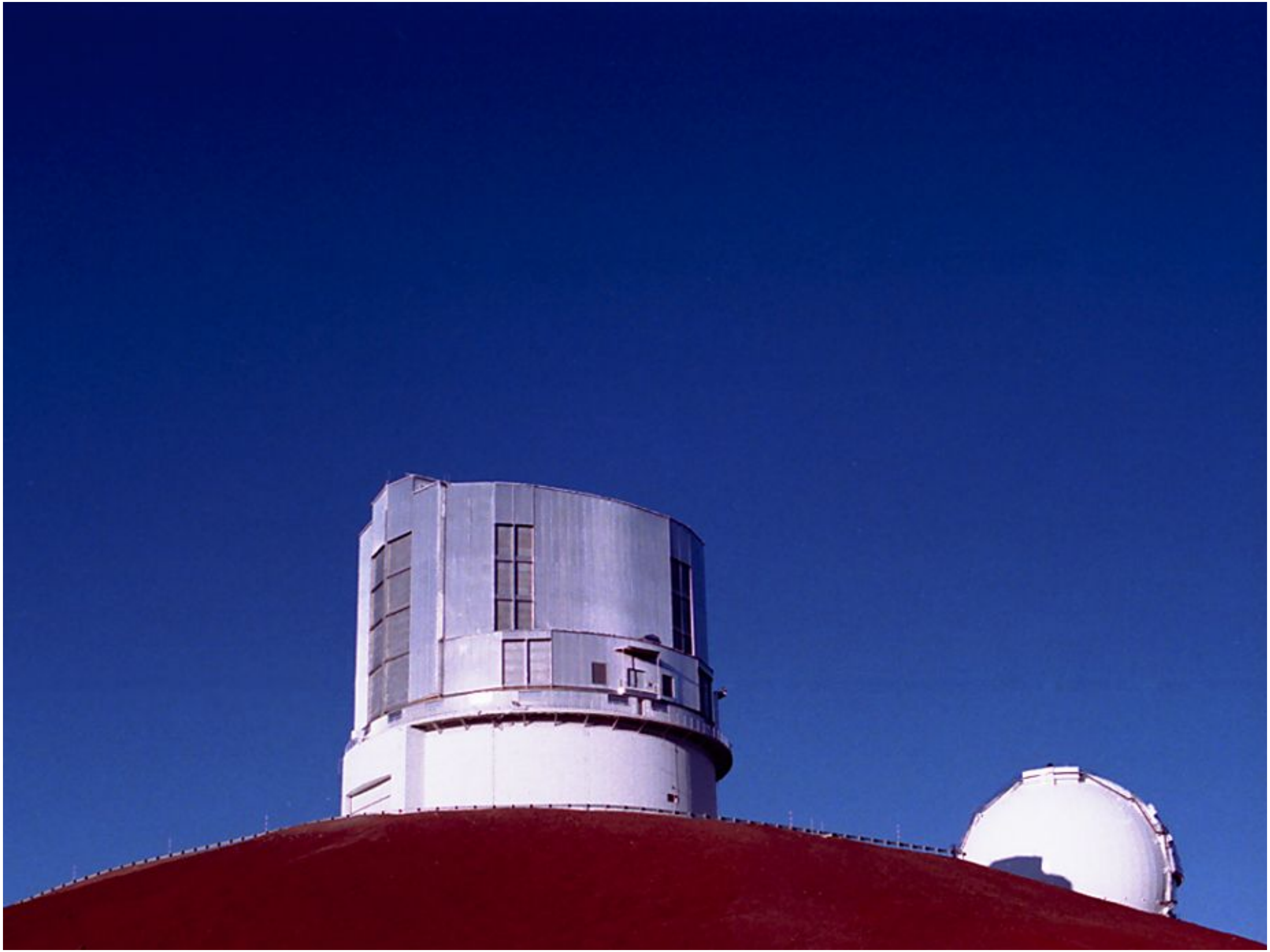
Colors of a second Earth

Yasushi Suto (須藤 靖)

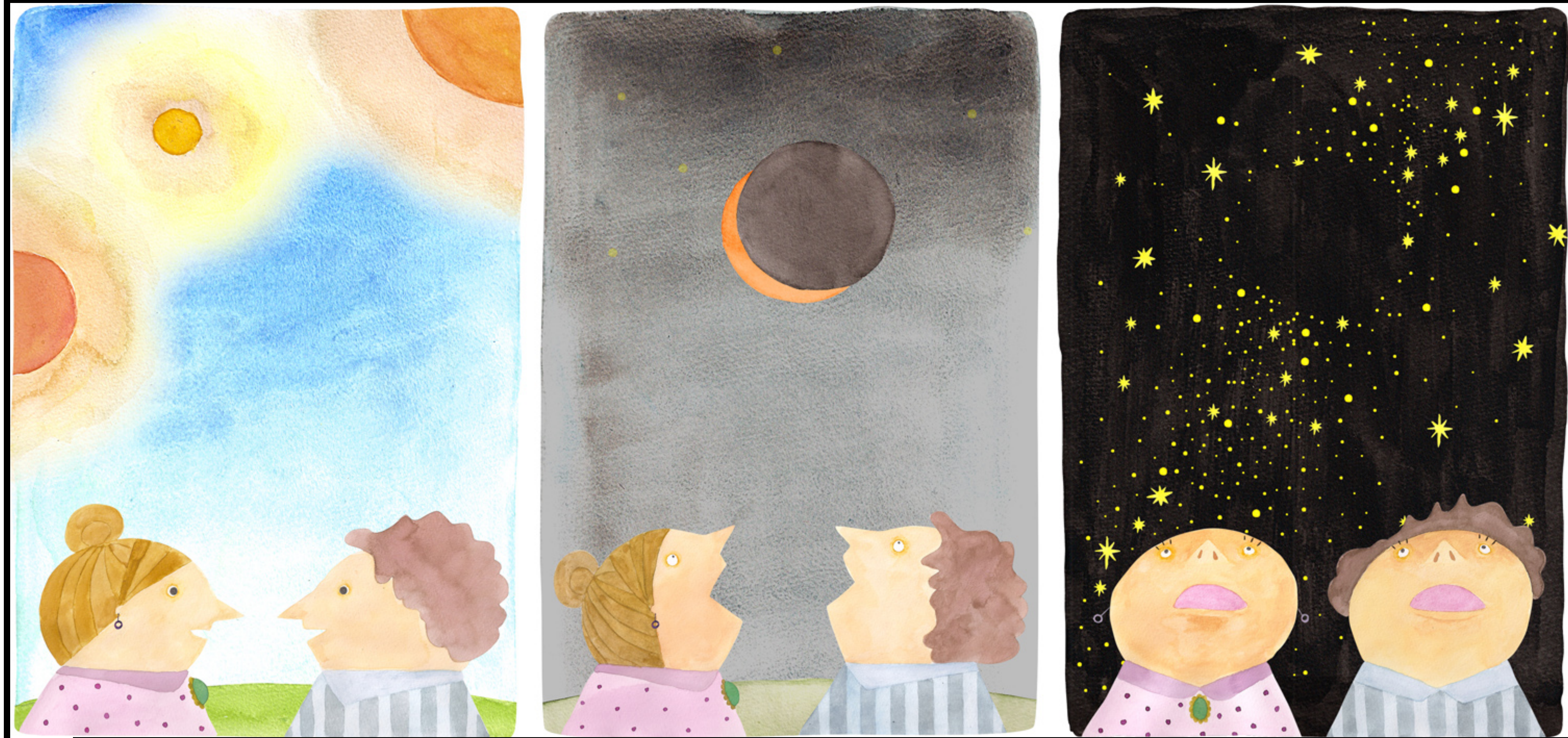
Dept. of Physics, Univ. of Tokyo

& Global Scholar, Dept. of Astrophys. Sci, Princeton Univ.

ASIAA colloquium 14:00- February 3, 2012



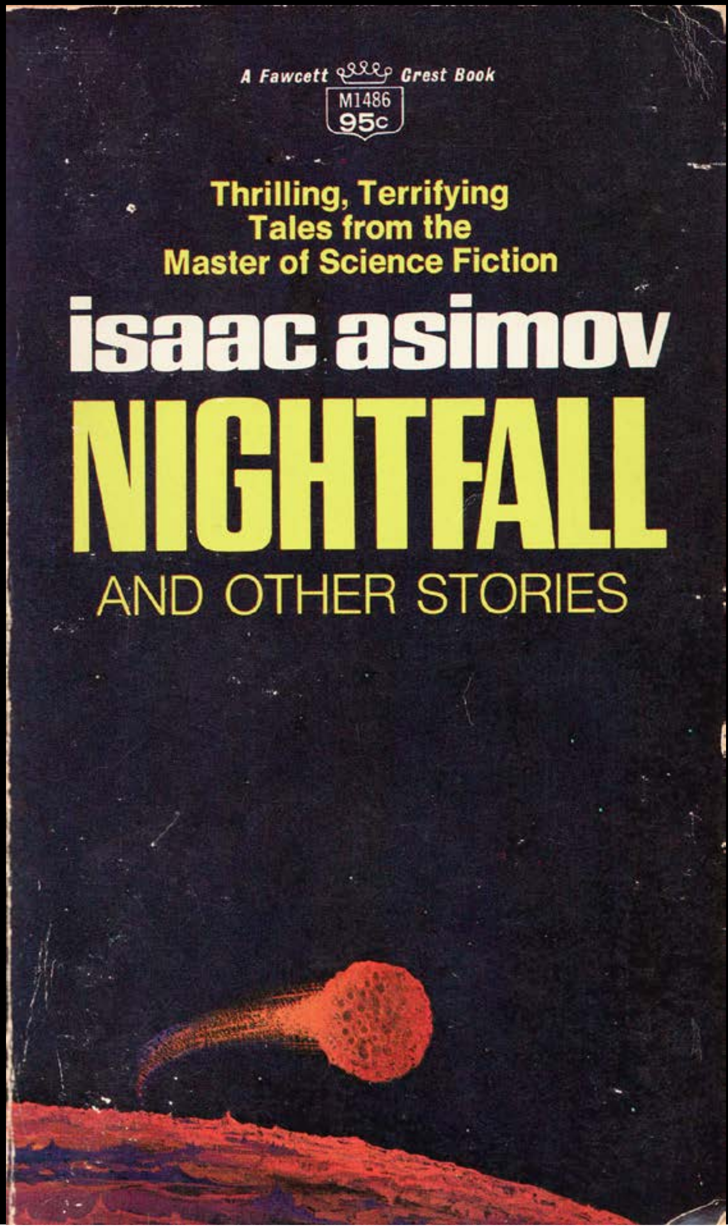
Nightfall: We didn't know anything



(Alisa Haba)

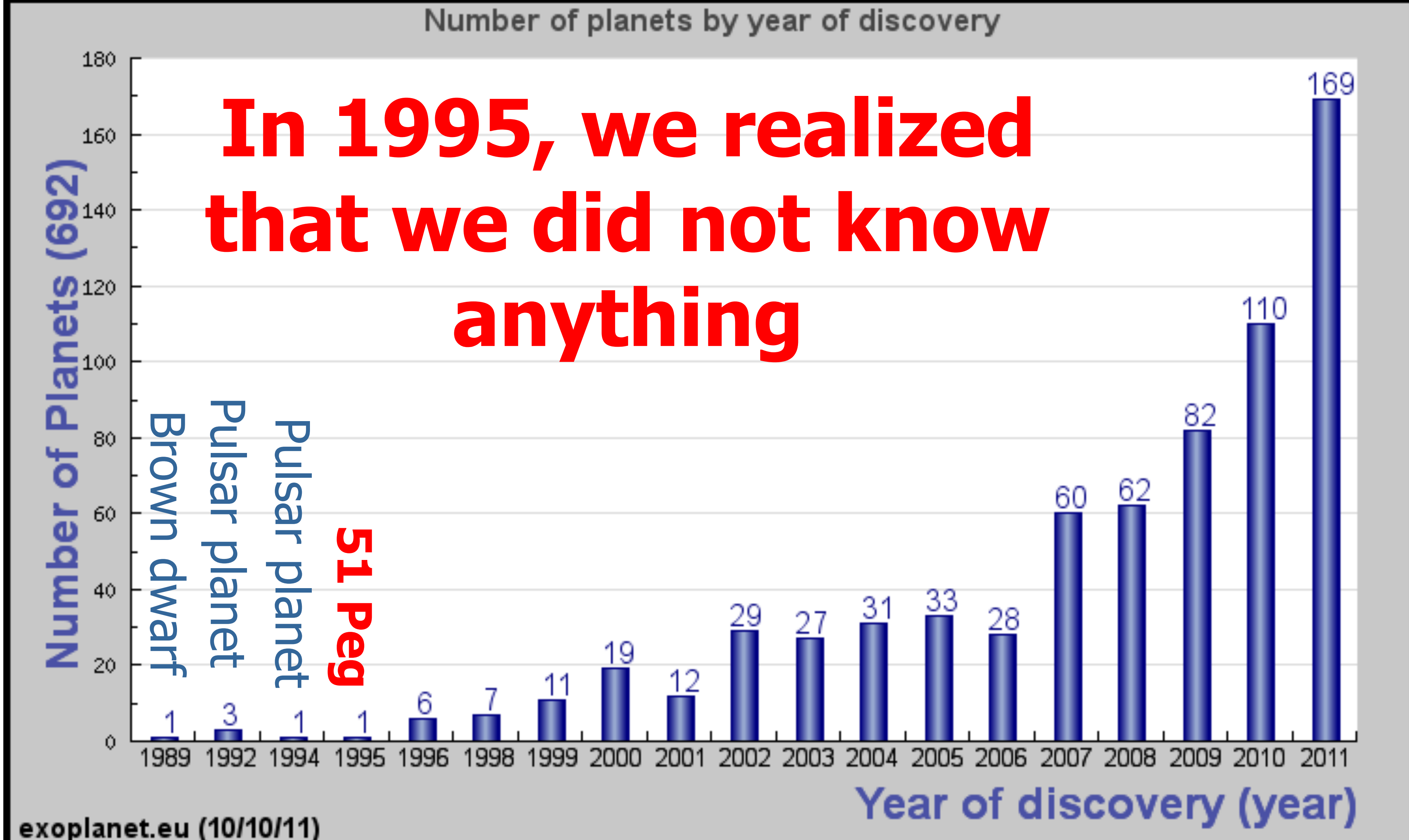
- No "night" except the total eclipse due to another planet every 2049 years on the planet "Lagash"
- People realized the true world for the first time through the darkness full of stars

Issac Asimov: Nightfall



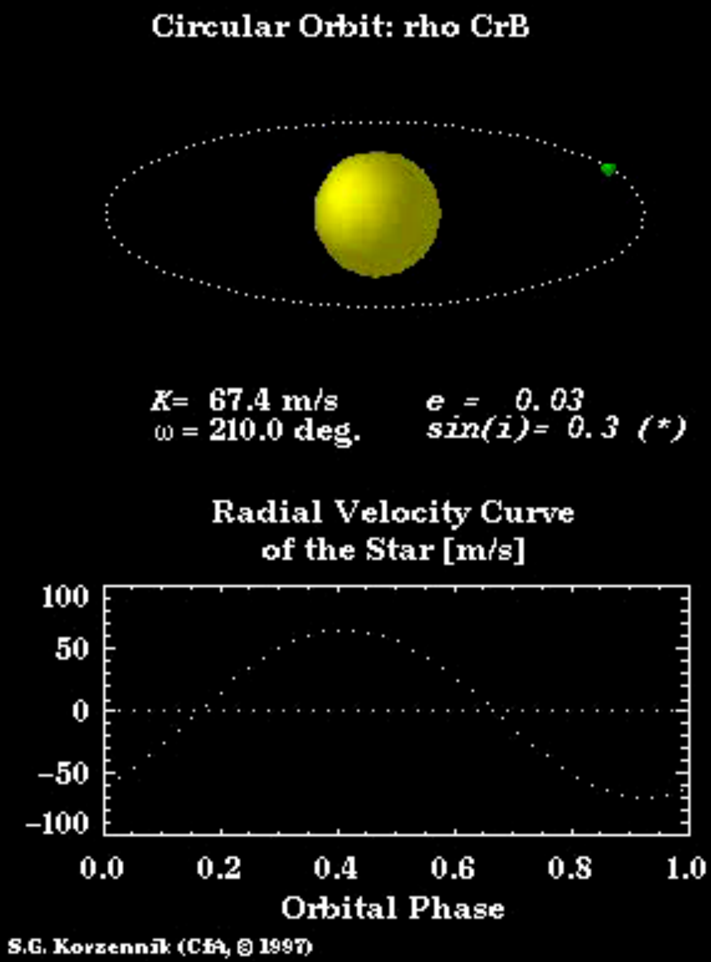
- "Light !" he screamed. Aton, somewhere, was crying, whimpering horribly like a terribly frightened child. *"Stars -- all the Stars -- we didn't know at all. We didn't know anything."*

History of exoplanet discovery



Radial velocity of a star perturbed by a planet

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

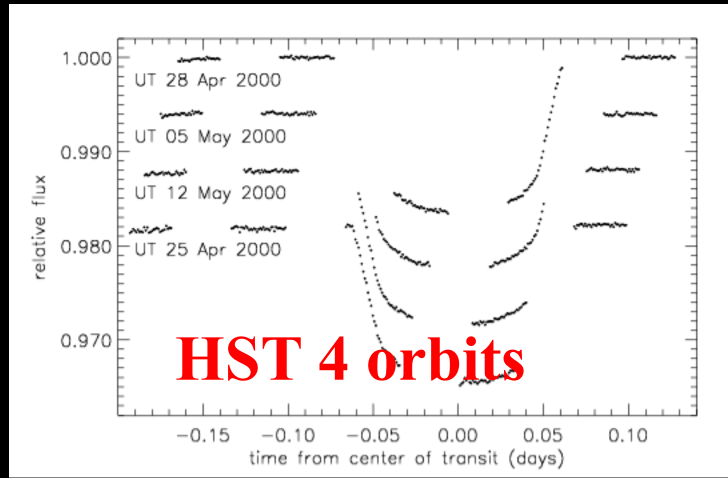


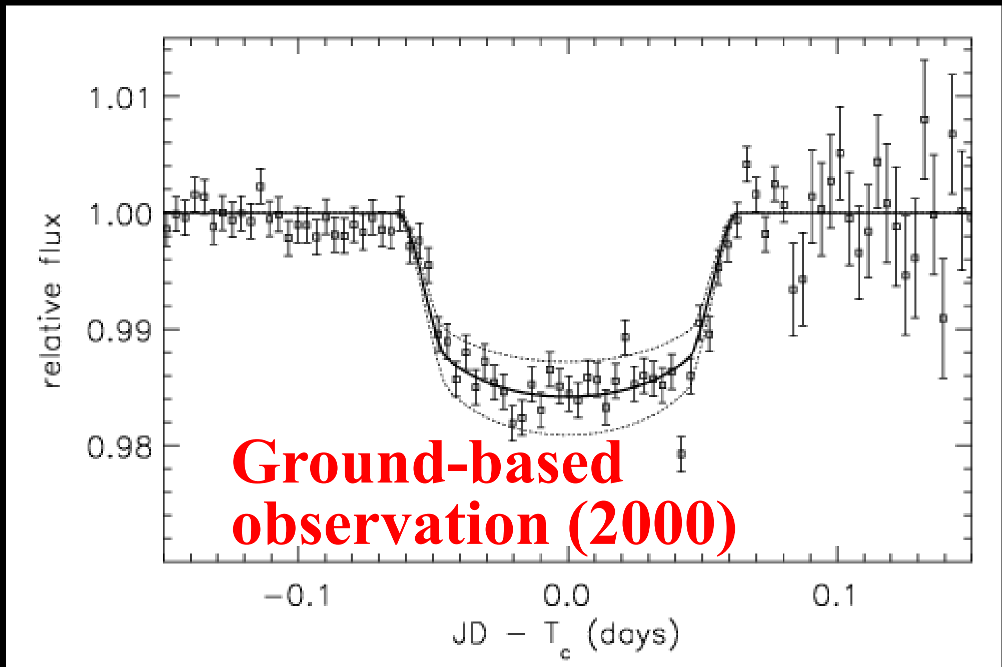
- velocity modulation of the Sun:
  - 12.5 m/s (Jupiter)
  - 0.1 m/s (Earth)
- an accuracy of 0.3m/s now achieved from the ground observation

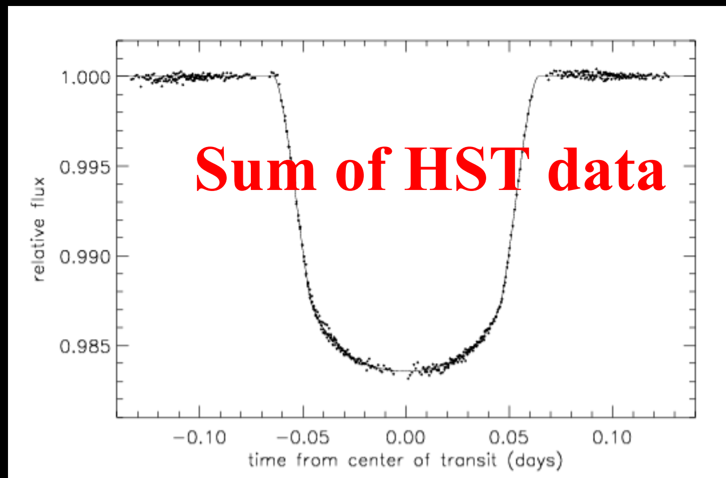
⇒ the major method of (Jovian) planet search

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)

exoplanet projects in my group at the University of Tokyo

- Constraining the stellar spin and the planetary orbital axes from the Rossiter-McLaughlin effect
  - analytic perturbation formulae (Ohta et al. 2005, ApJ, 622, 1118; Hirano et al. 2010, ApJ, 709, 458; 2011 ApJ, 742, 69)
  - First accurate detection (Winn et al. 2005 ApJ, 631, 1215)
  - application to ring detection (Ohta et al. 2009, ApJ, 690, 1)
- Colors of a second earth
  - Estimating the fractional areas of surface components from simulated photometry data (Fujii et al. 2010 ApJ, 715, 866;2011 ApJ, 738, 184)

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 ?

Search for extrasolar planets

- the ***final*** goal: ***Are we alone ?***
  - origin of the Earth
  - origin of the Solar System
  - ***habitable*** planets ⇒ origin of life
  - signature of extra-terrestrial life ?

    ⇒ extra-terrestrial intelligence ?

"Where are they ?" E.Fermi (1950)

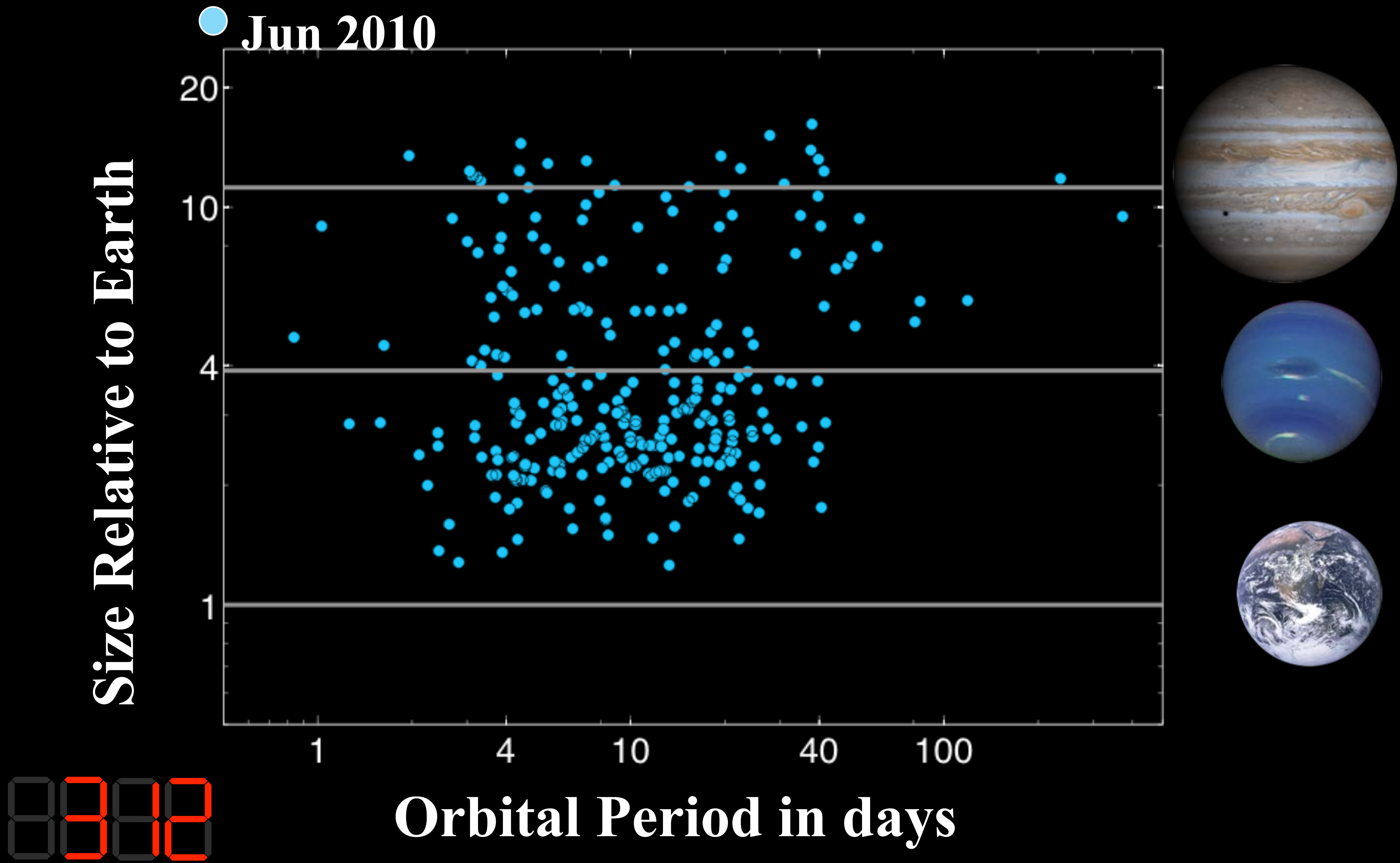
Kepler mission (March 6, 2009 launch)

Photometric survey of transiting planets

Searching for terrestrial/habitable planets

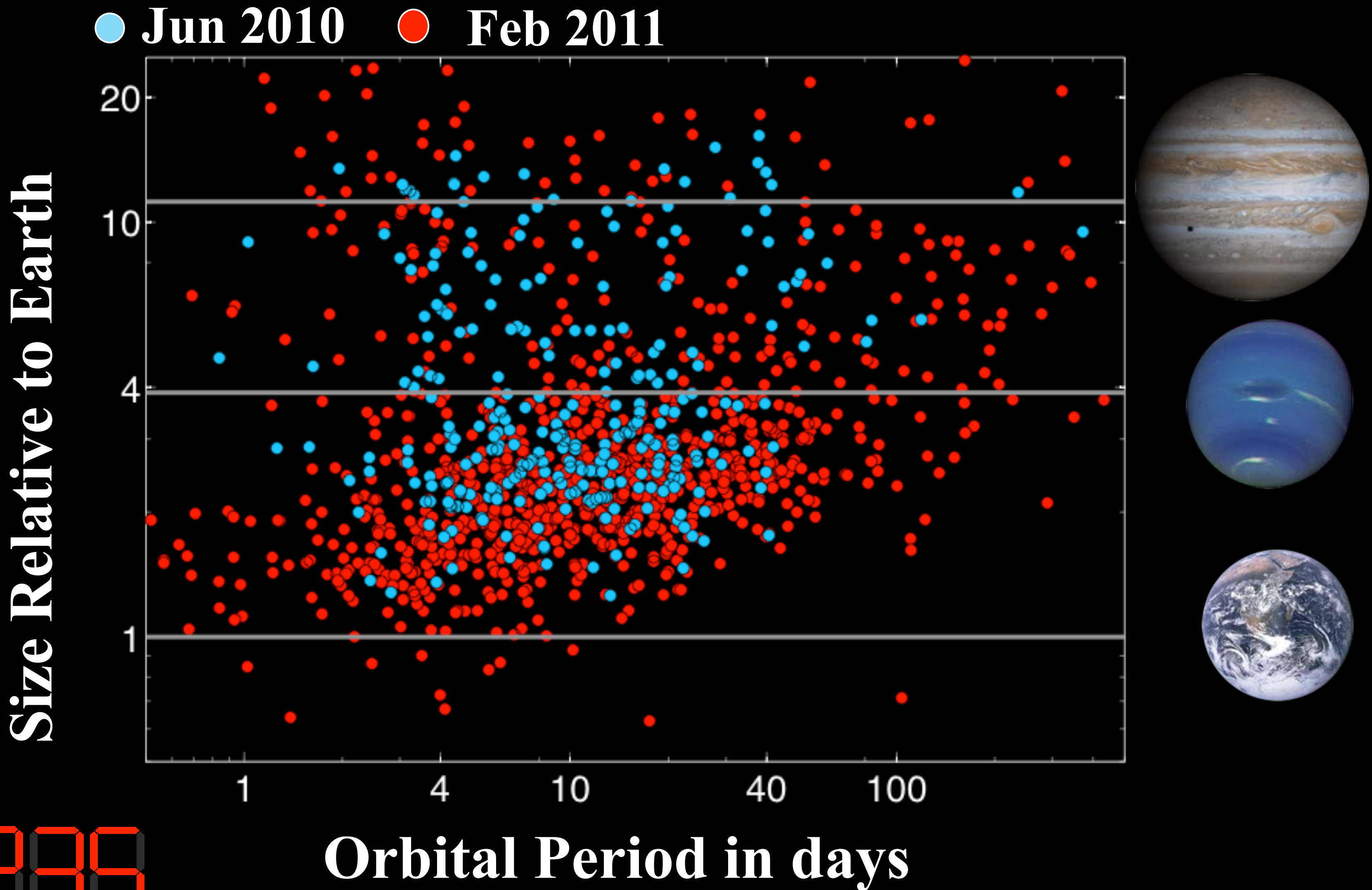
http://kepler.nasa.gov/

Planet Candidates as of June 2010



Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

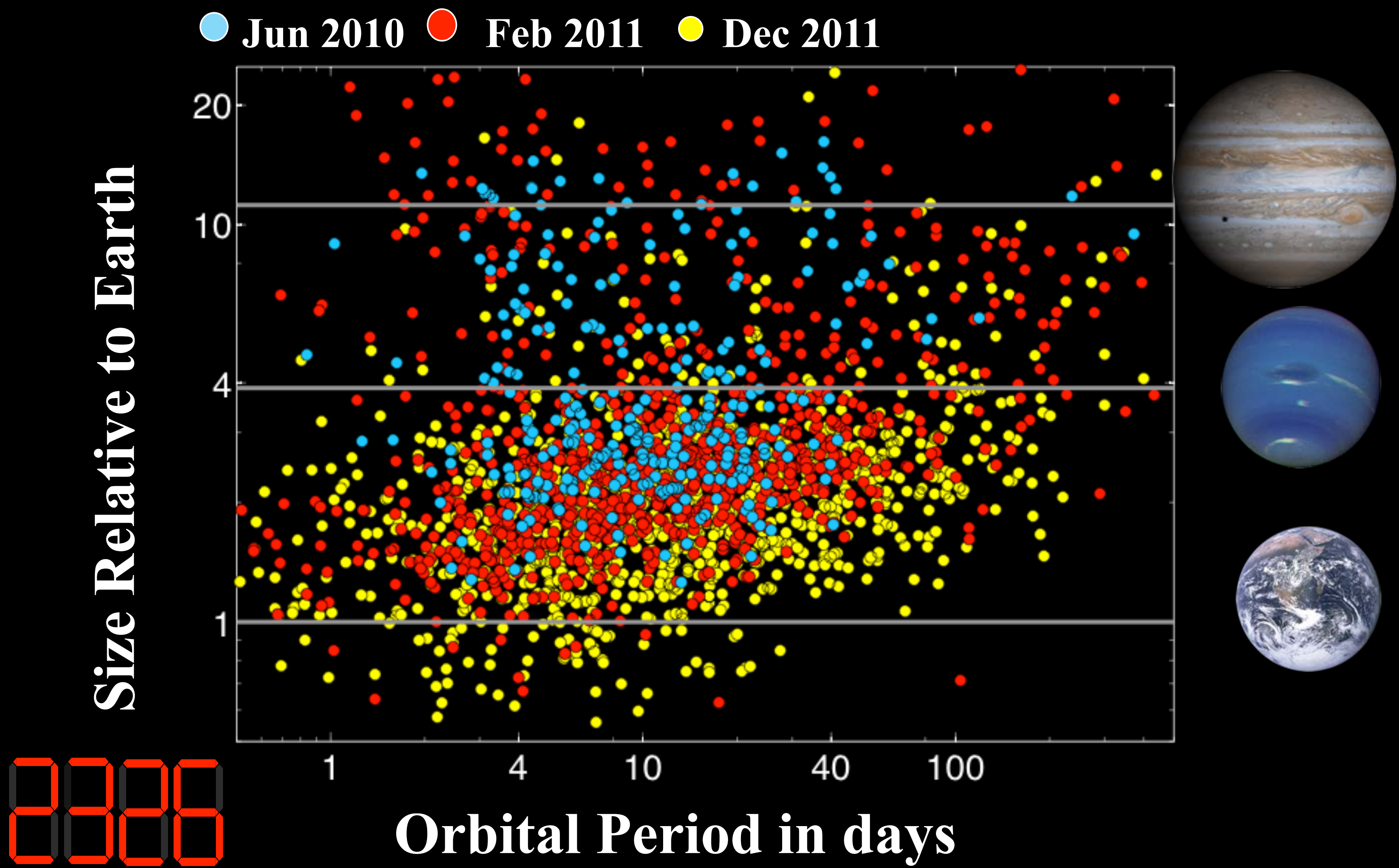
Planet Candidates as of Feb 2011



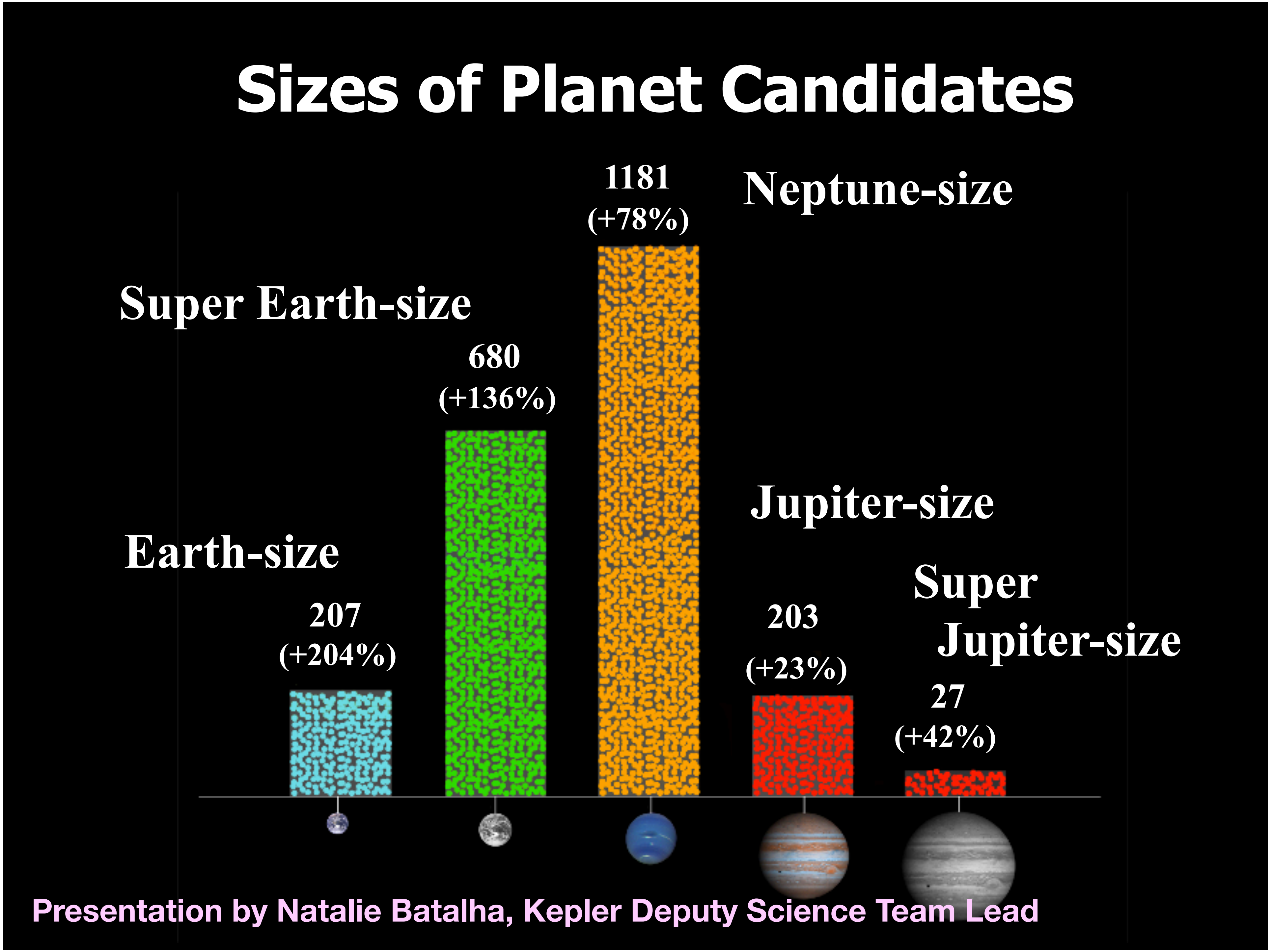
1235

Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

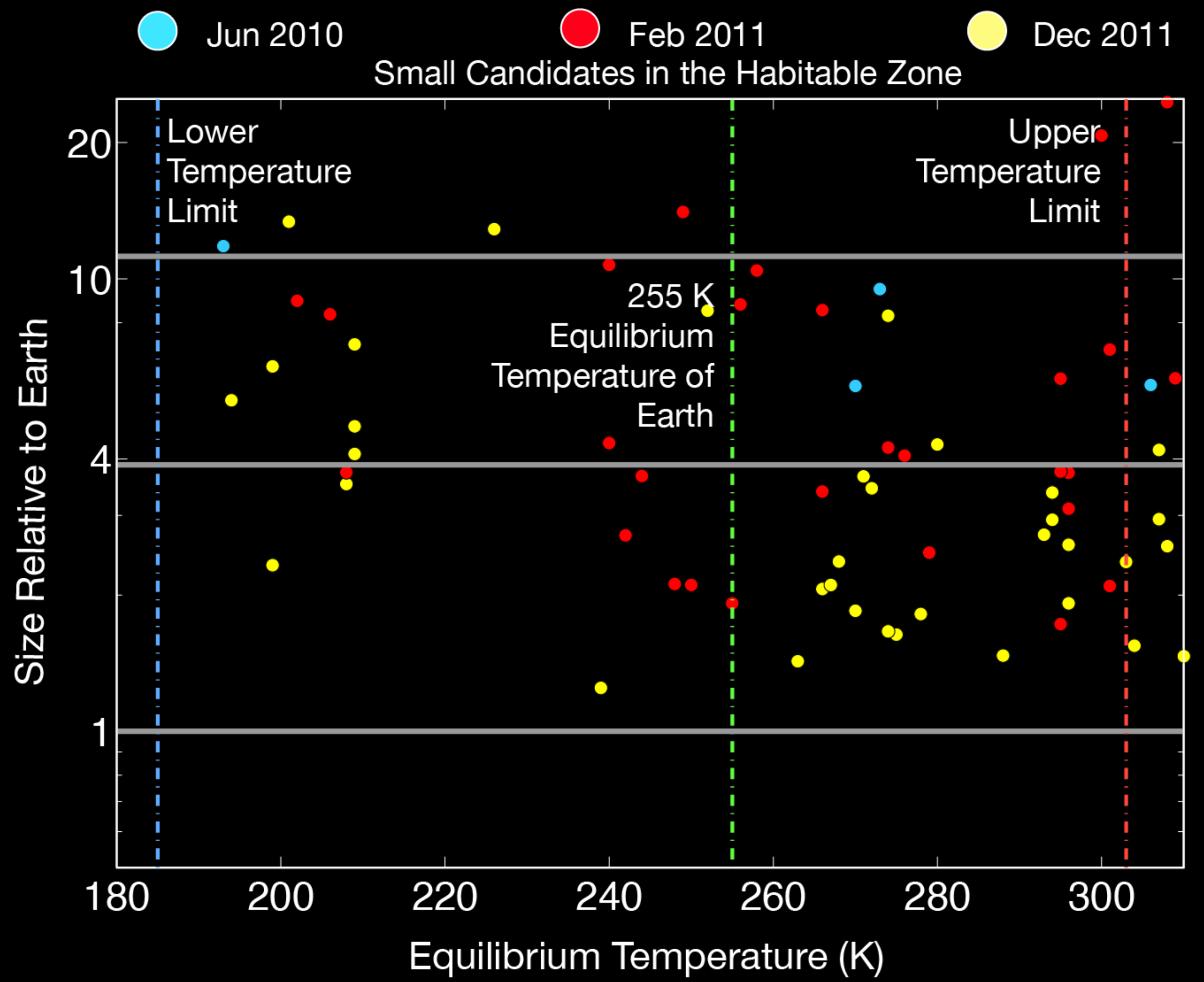
Planet Candidates as of Dec 2011



Presentation by Natalie Batalha, Kepler Deputy Science Team Lead


Sizes of Planet Candidates
Earth-size
207
(+204%)
Super Earth-size
680
(+136%)
1181
(+78%)
Neptune-size
Jupiter-size
203
(+23%)
Super
Jupiter-size
27
(+42%)
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?

A second Earth ? Life ?

We did not know anything

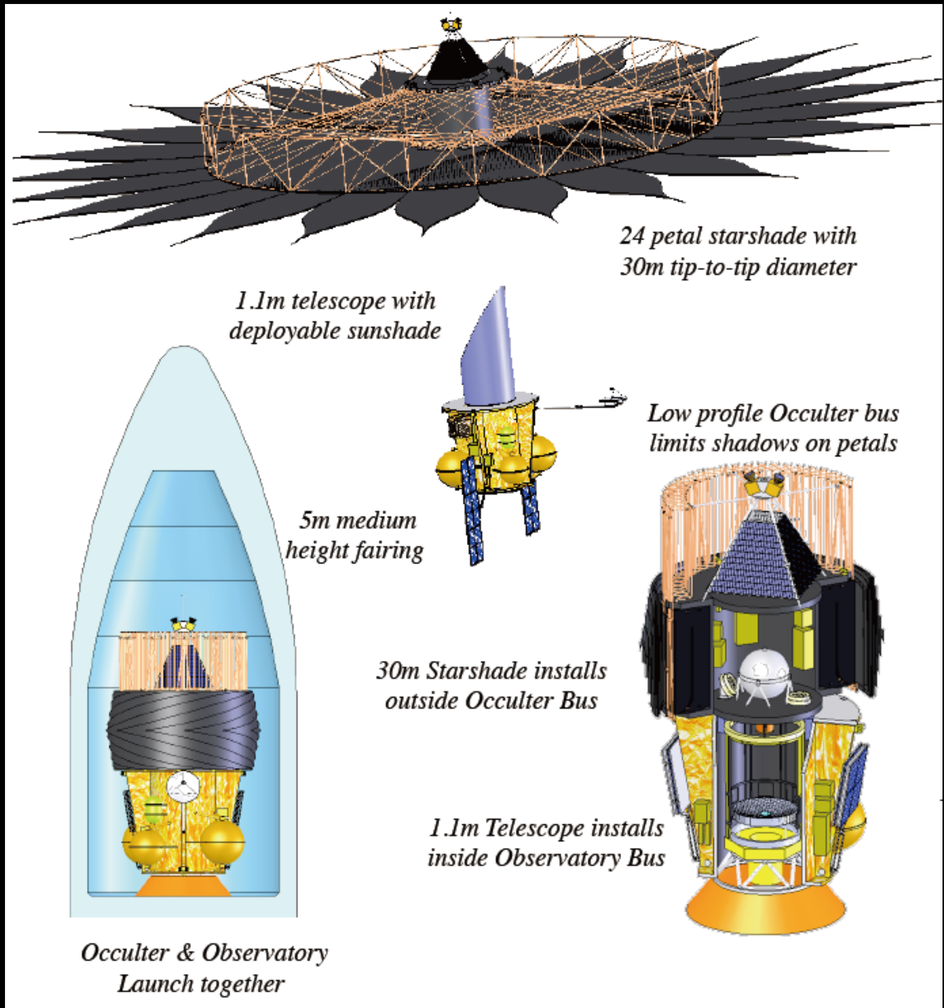
Presentation by Natalie Batalha, Kepler Deputy Science Team Lead

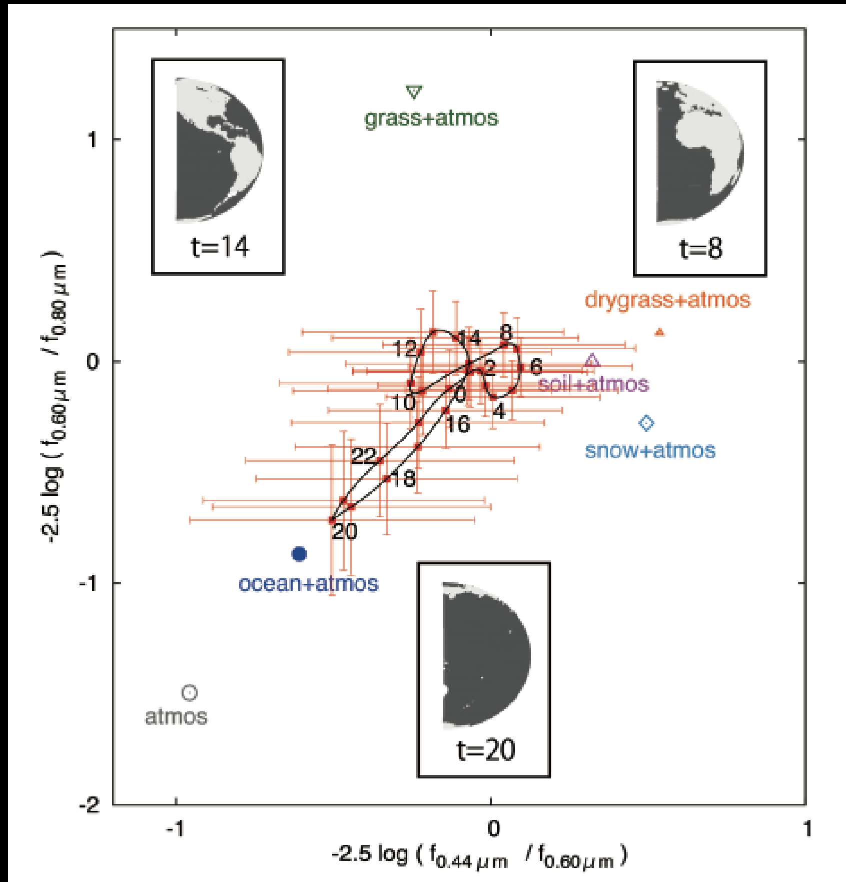
O_3: The Occulting Ozone Observatory

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]

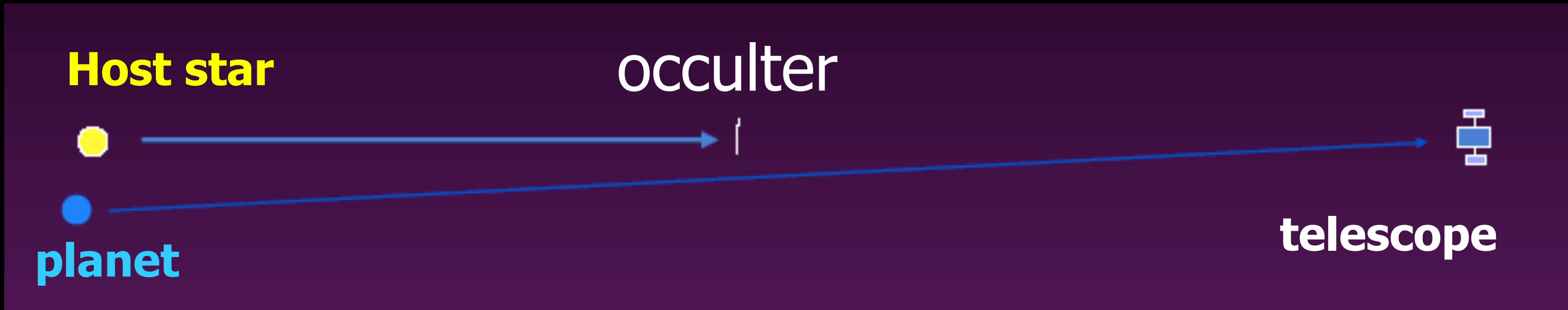
[1]Princeton University, [2]Jet Propulsion Laboratory, [3]University of Tokyo





- Princeton+JPL+…

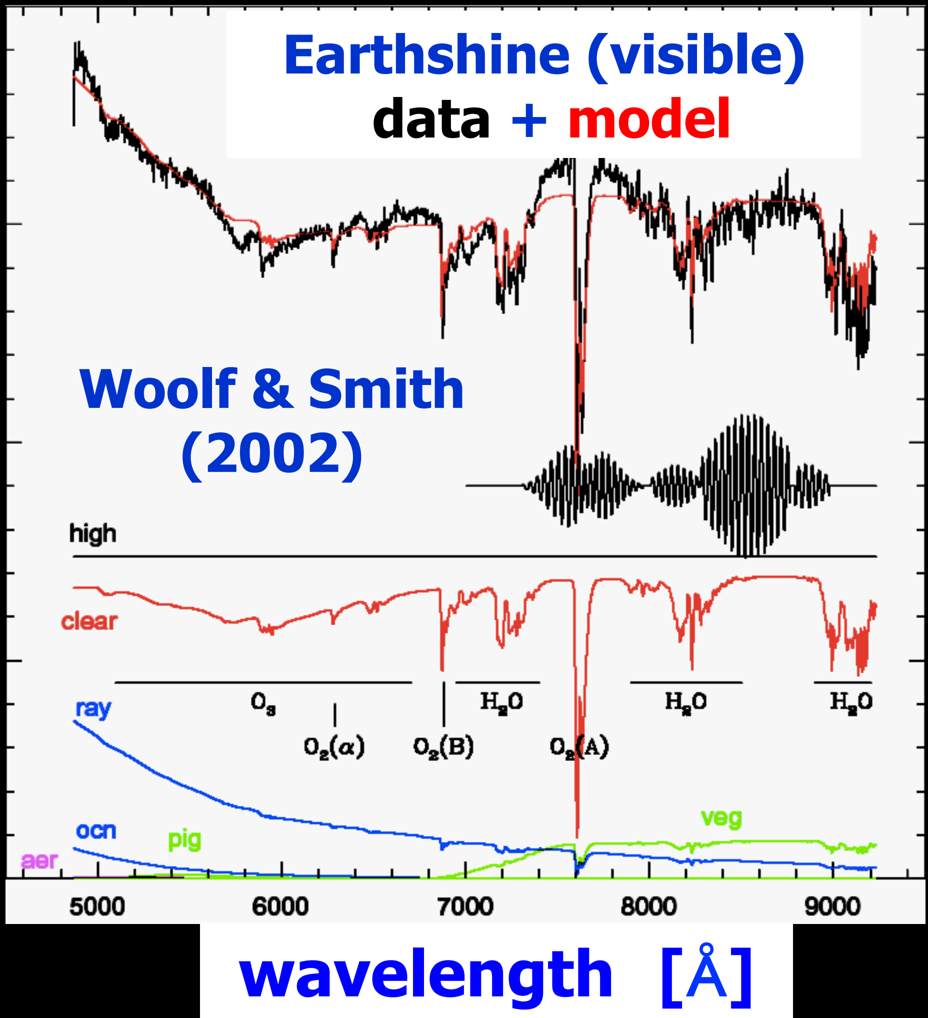
The New Worlds Mission: search for terrestrial planets



http://newworlds.colorado.edu/

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

Conventional biomarkers (signature of life)

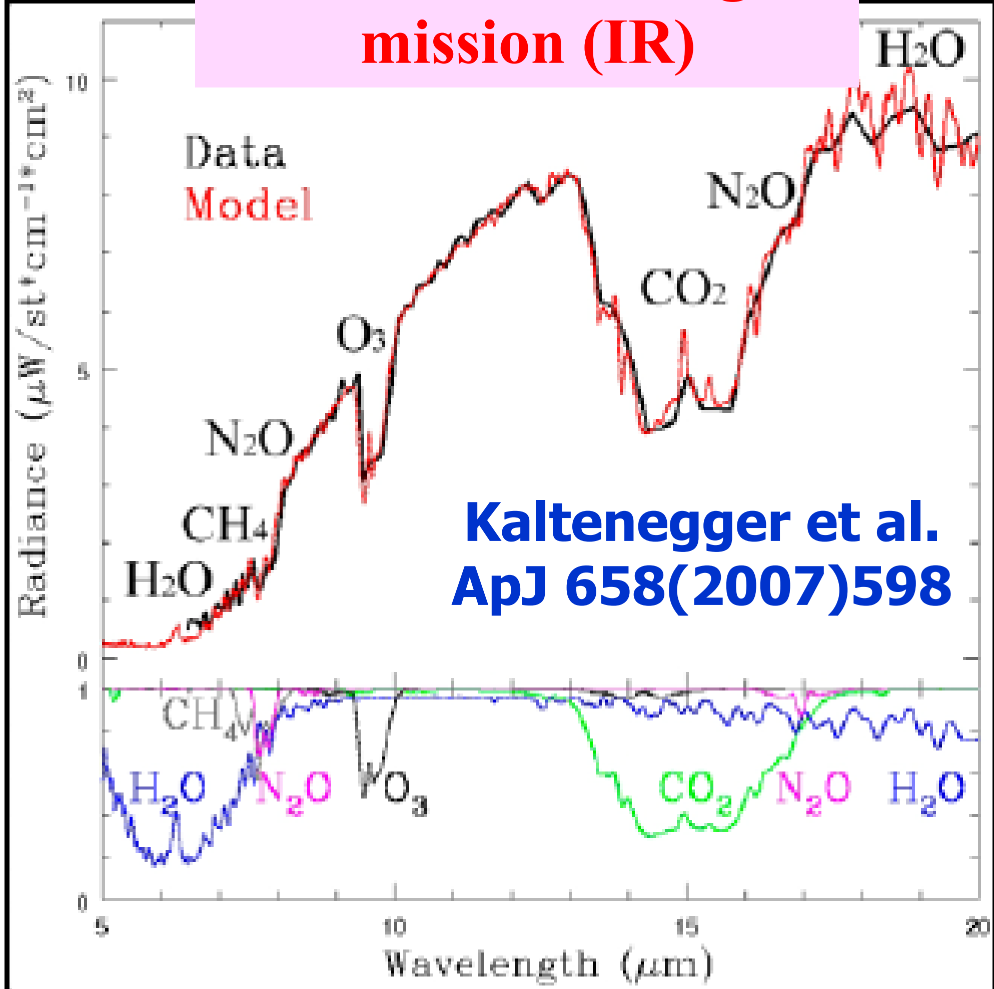


- O_2
  - A-band@0.76 μm
  - B-band@0.69 μm
- H_2O
  - 0.72, 0.82, 0.94 μm
- O_3
  - Chappuis band @(0.5-0.7) μm
  - Hartley band @(0.2-0.3) μm

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

Earth’s IR spectrum and biomarkers

Earth observing mission (IR)



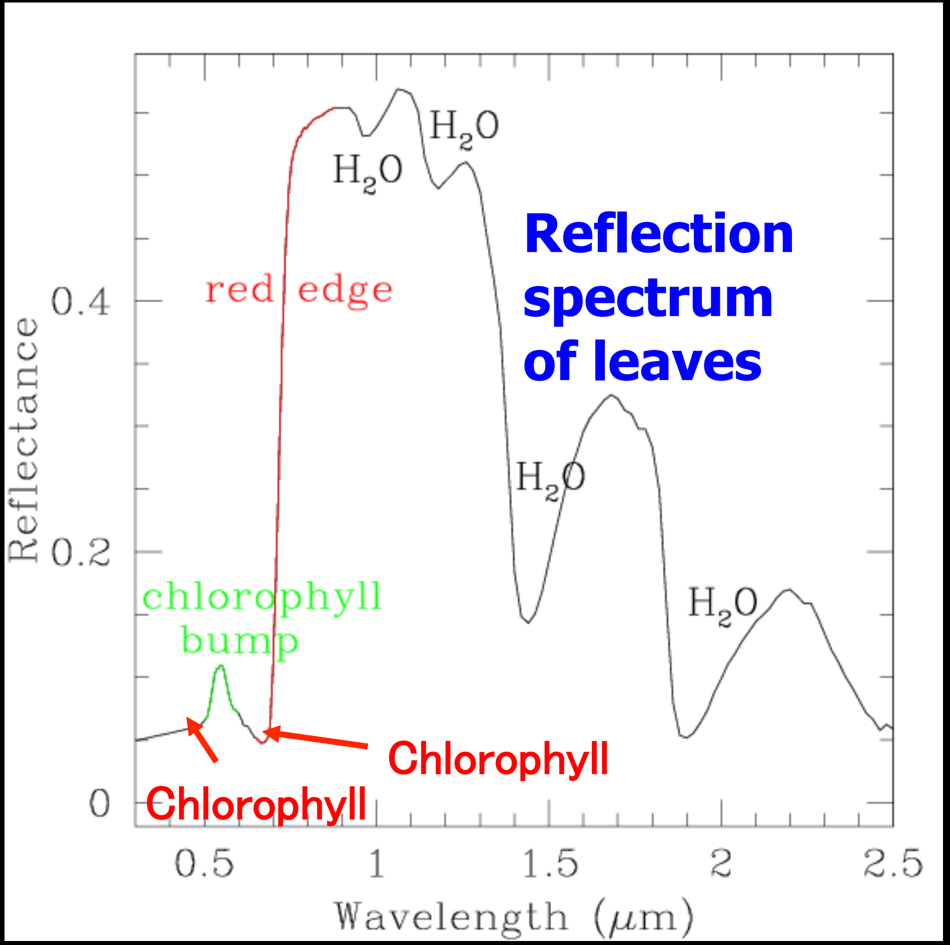
Kaltenegger et al. ApJ 658(2007)598

- O_3@9.6μm
  - Good tracer of O_2
- H_2O @<8μm,>17μm
- CH_4@7.7μm
  - 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



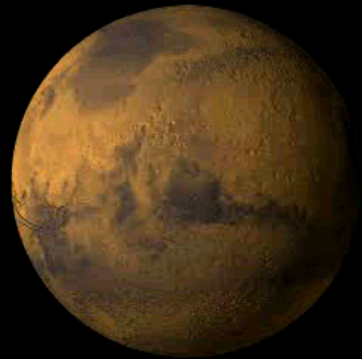
Seager, Ford & Turner astro-ph/0210277

Vesto Melvin Slipher (1875-1969)

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

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

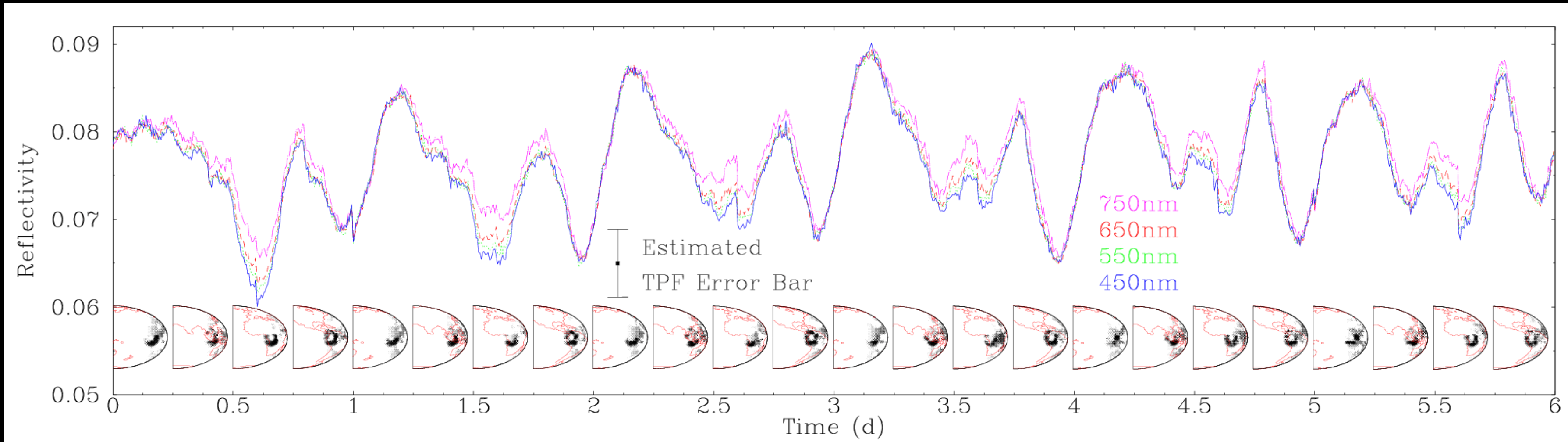
"Observations of Mars in 1924 made at the Lowell Observatory: II spectrum observations of Mars" PASP 36(1924)261



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

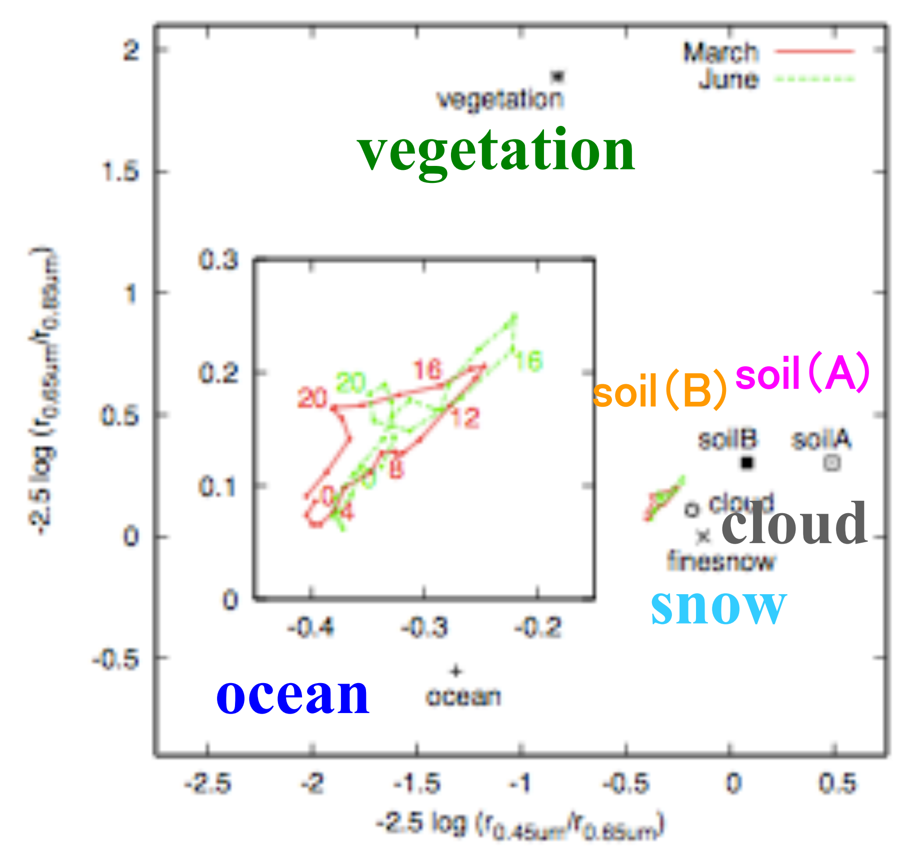
Colors of a Second Earth. II: Effects of Clouds on Photometric Characterization of Earth-like Exoplanets

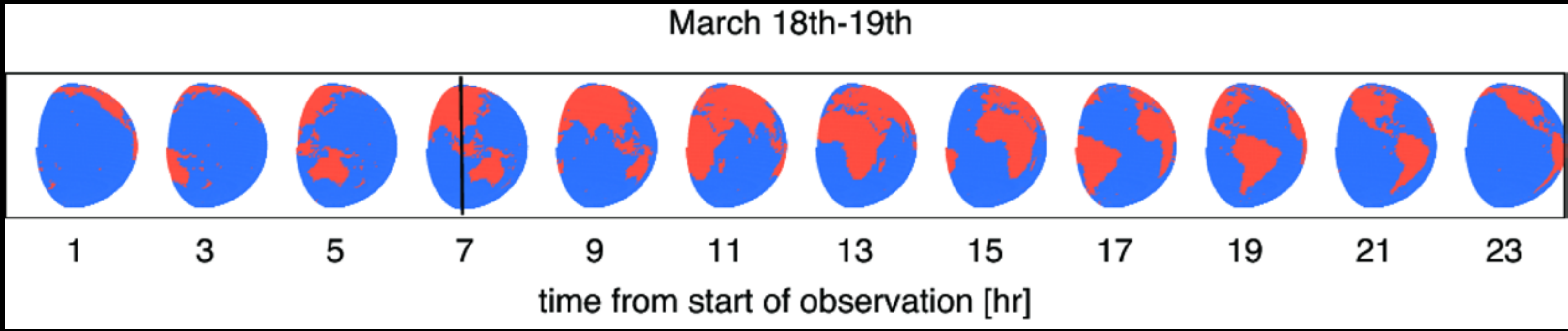
ApJ. 738(2011)184, arXiv:1102.3625

- 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.)

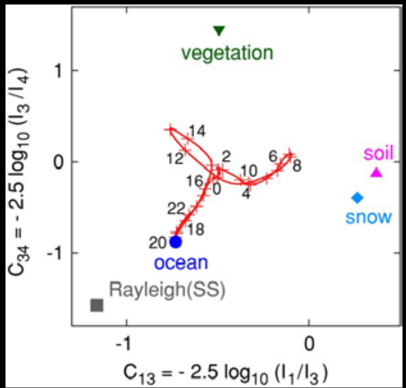
http://www.space.com/scienceastronomy/color-changing-planets-alien-life-100513.html

Colors of our earth

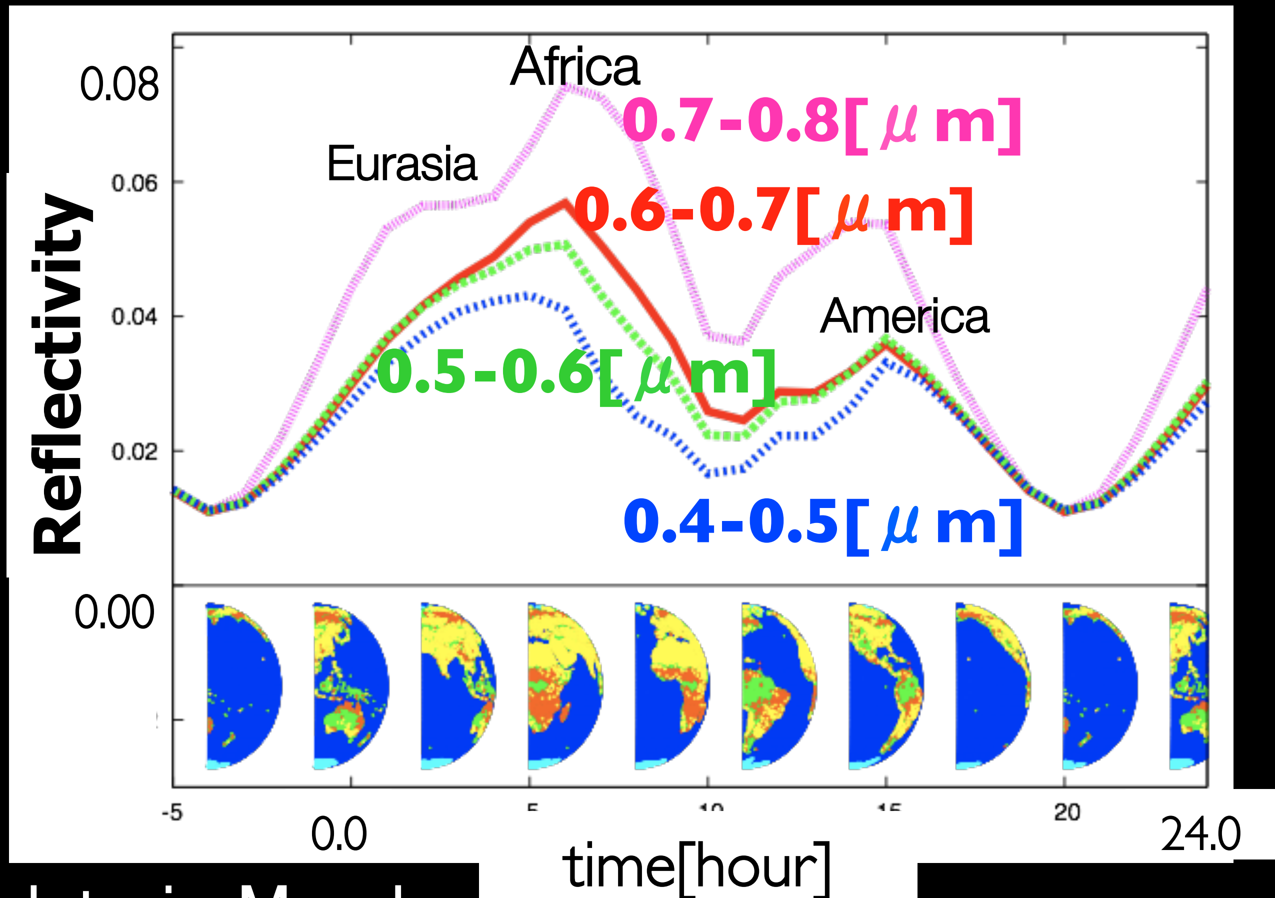




A pale blue dot ? Not really



Simulated photometric light-curves of Earth



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

Fujii et al. (2010)

Color-Changing Planets Could Hold Clues to Alien Life: posted on 13 May 2010 (Adam Hadhazy, SPACE.com staff writer)

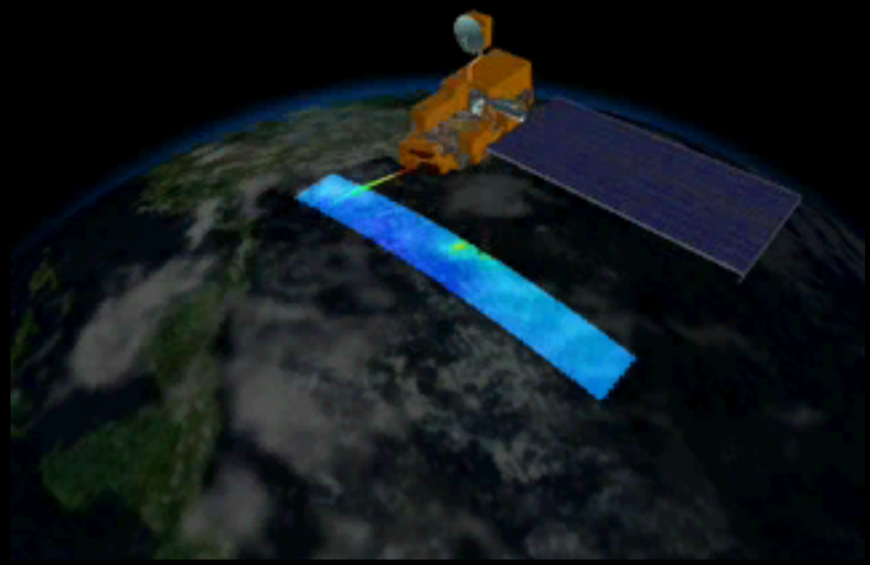
- A new way of comparing the color and intensity changes of light reflected off of Earth's surface to the flickers from exoplanets may help reveal the presence of oceans, continents and – possibly – life on alien worlds.
- By comparing the changes in observed hues of an alien planet as it rotates to this distinct Earthly color palette, "we can infer the surface composition of the [exo]planet," said Yuka Fujii, a doctoral student at the University of Tokyo and lead author of a paper published in the May 4 issue of the Astrophysical Journal.

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

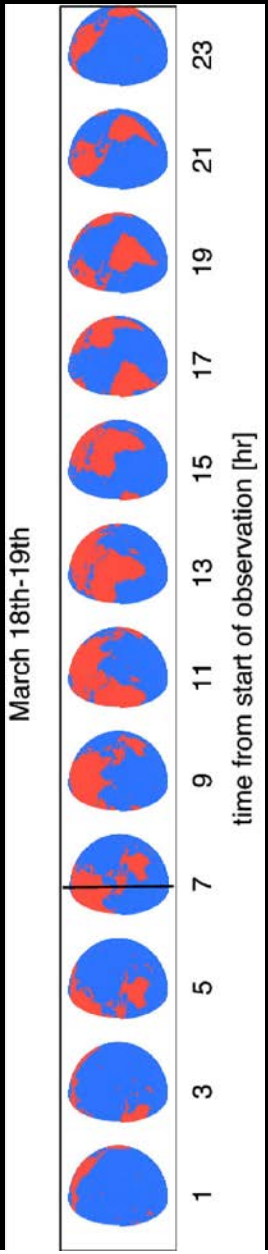
Forward procedure: reflected light model of the earth

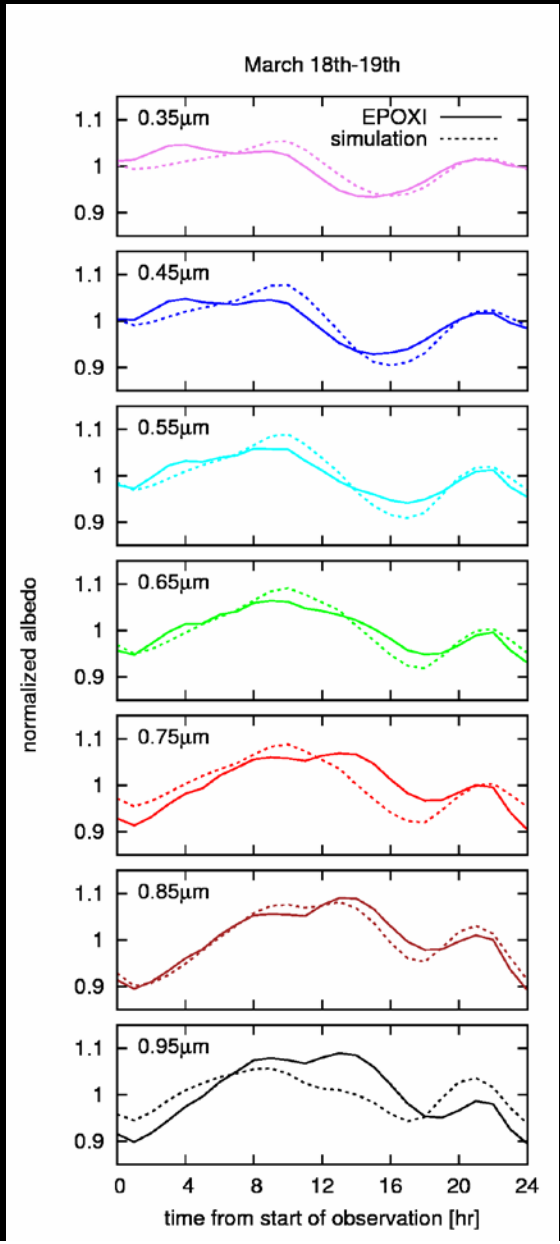
- Simulated light-curves of the earth in 7 photometric bands
  - land： BRDF (Bidirectional Reflectance Distribution Function） model from earth-observing satellite Terra/MODIS on 2.5°x2.5° pixels
  - ocean: BRDF model of Nakajima & Tanaka (1983)
  - snow: real data of the month
  - cloud： real data of the day
  - Atmosphere and cloud: radiation transfer solved with rstar6b
- Comparison with the real data observed by EPOXI

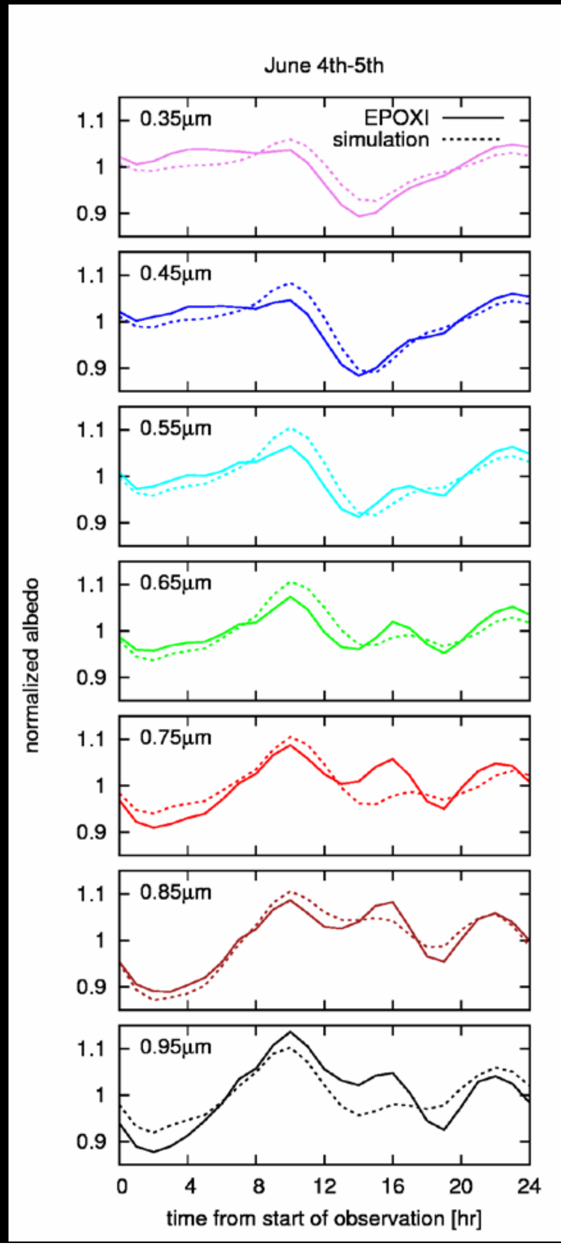
Earth observing satellite Trace (Transition Region and Coronal Explorer) + detector Modis (Moderate Resolution Imaging Spectroradiometer)

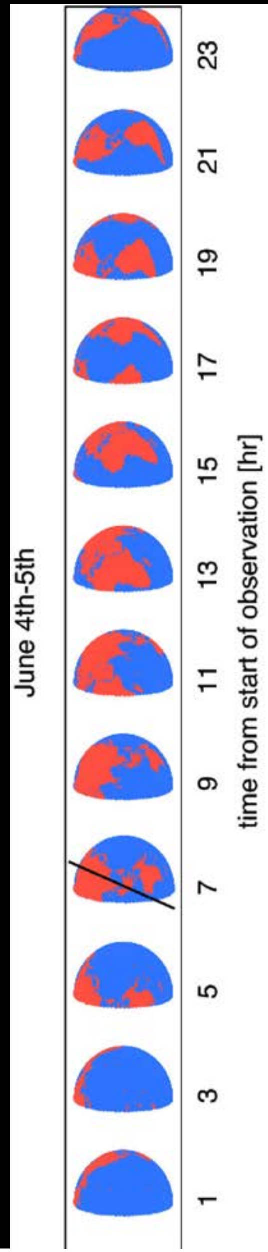


Simulated light-curves vs. EPOXI data





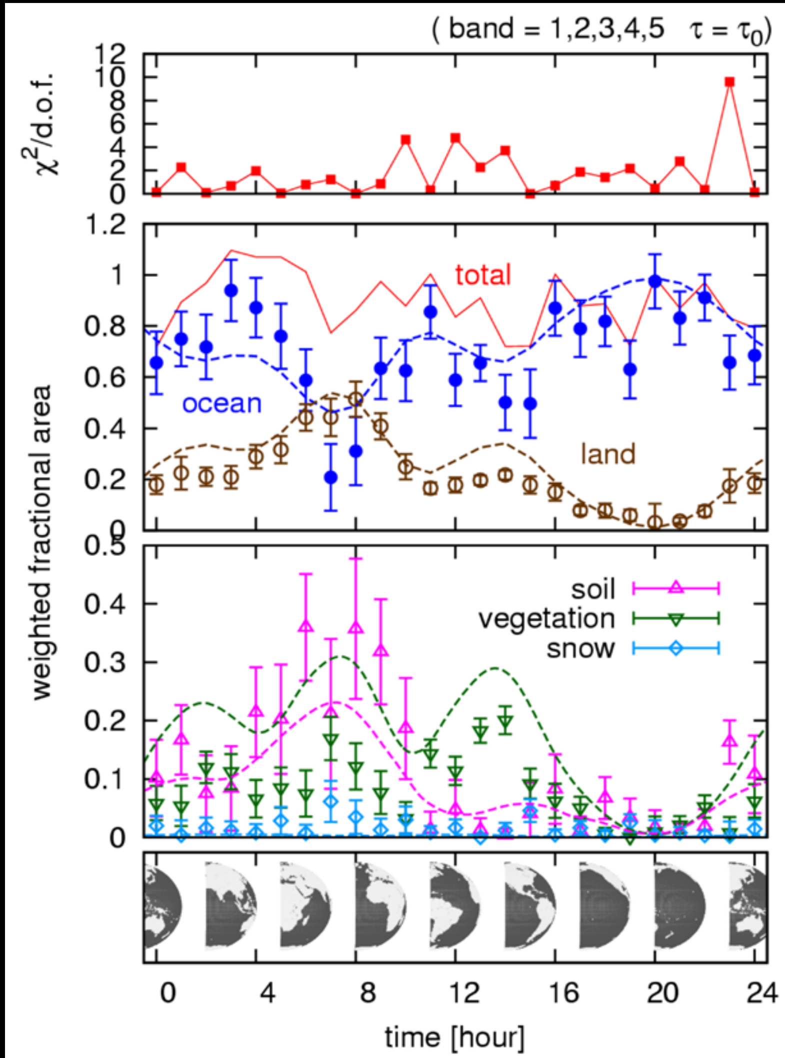




Inverse procedure: estimation of fractional areas of surface components

- 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

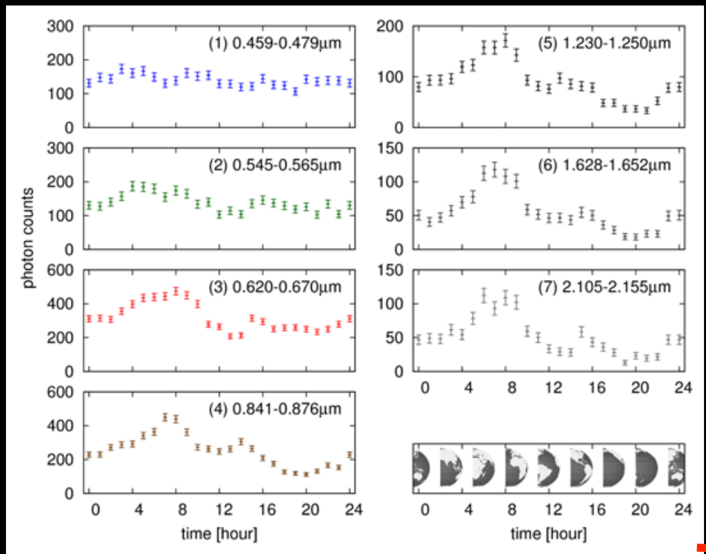
Idealized cloudless earth



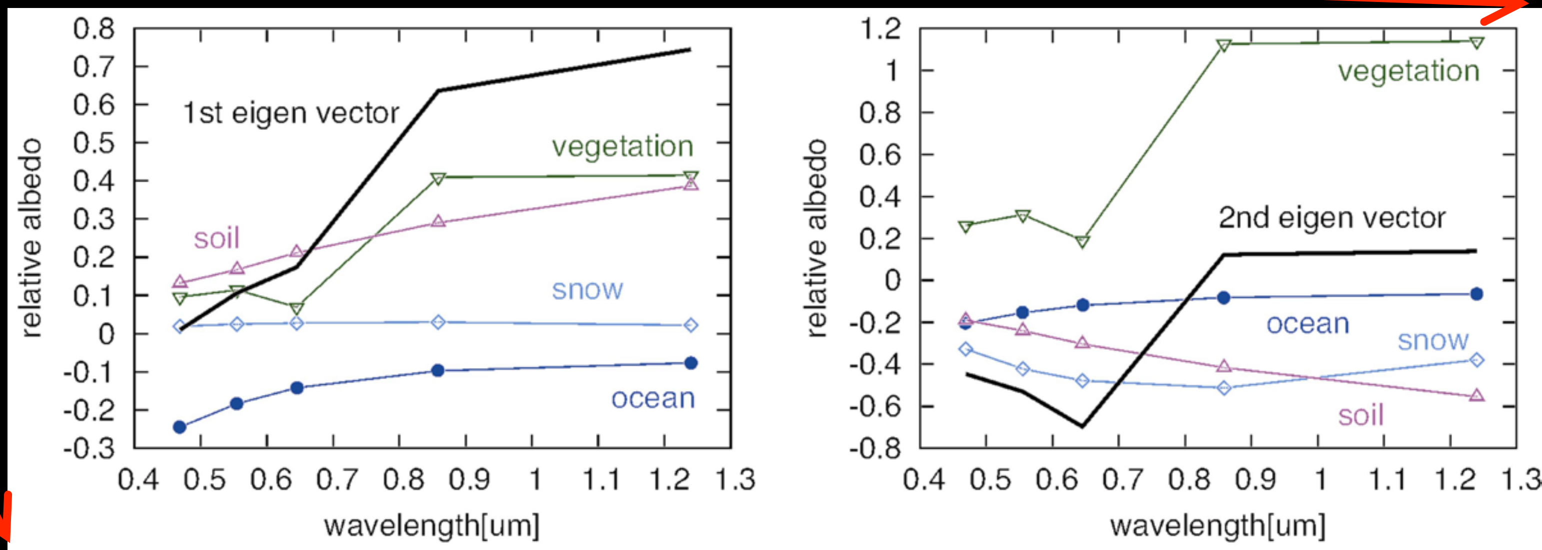
Fujii et al. (2010)

- 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 !

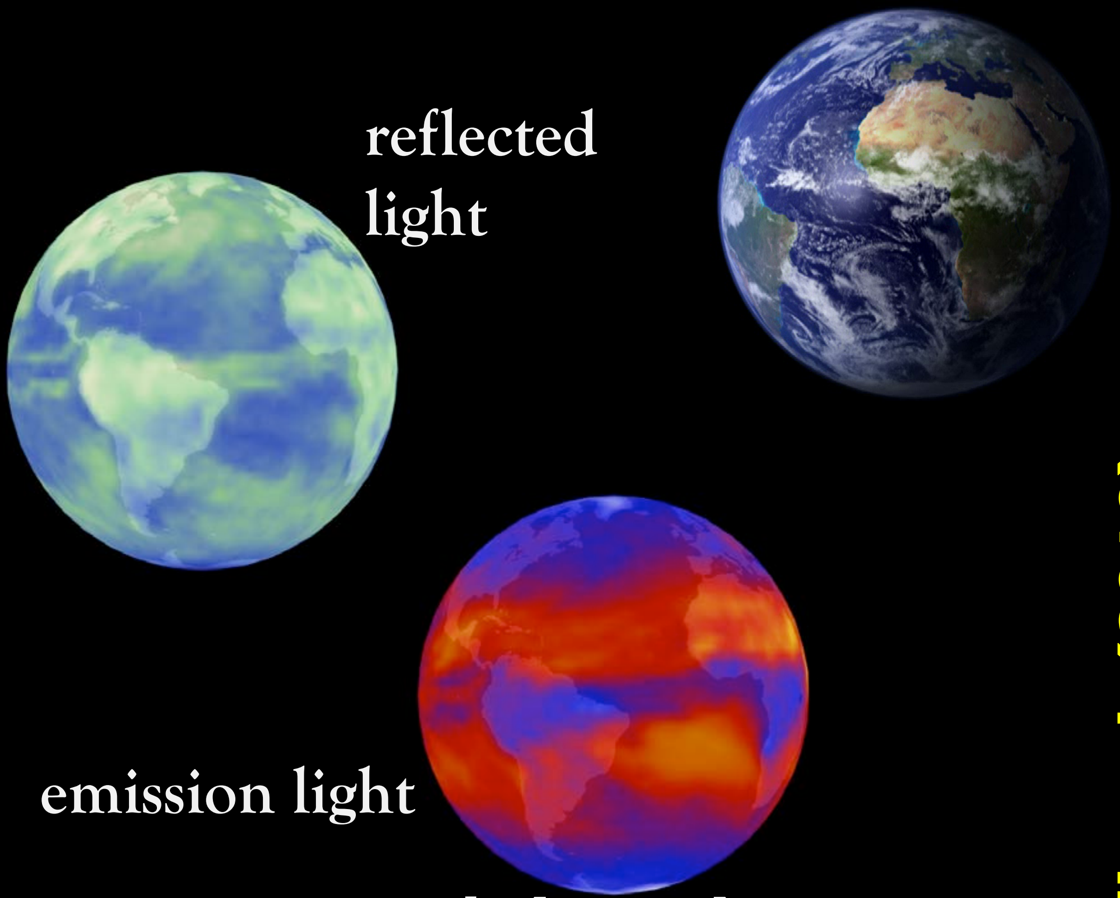
PCA (principal component analysis)



- 1^{st} eigen vector
  - ≒ soil + vegetation – ocean
- 2^{nd} eigen vector
  - ≒ vegetation – soil – ocean – snow

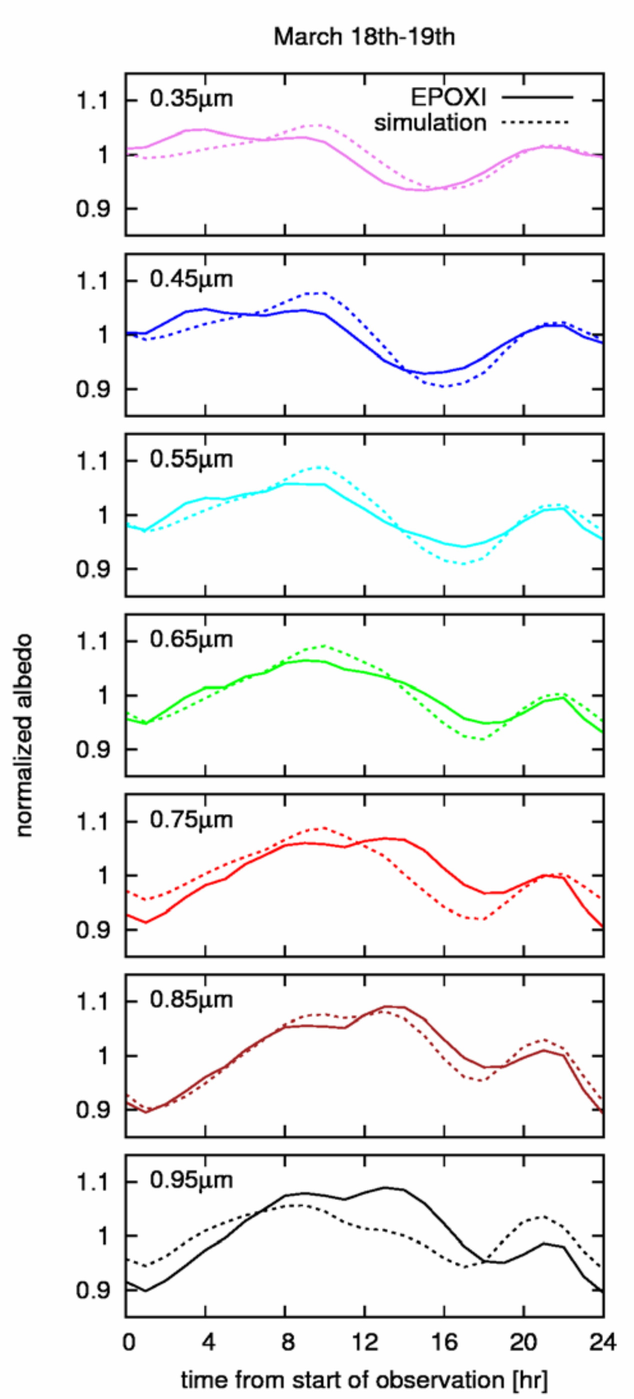


Reconstruction of planetary surface areas with clouds

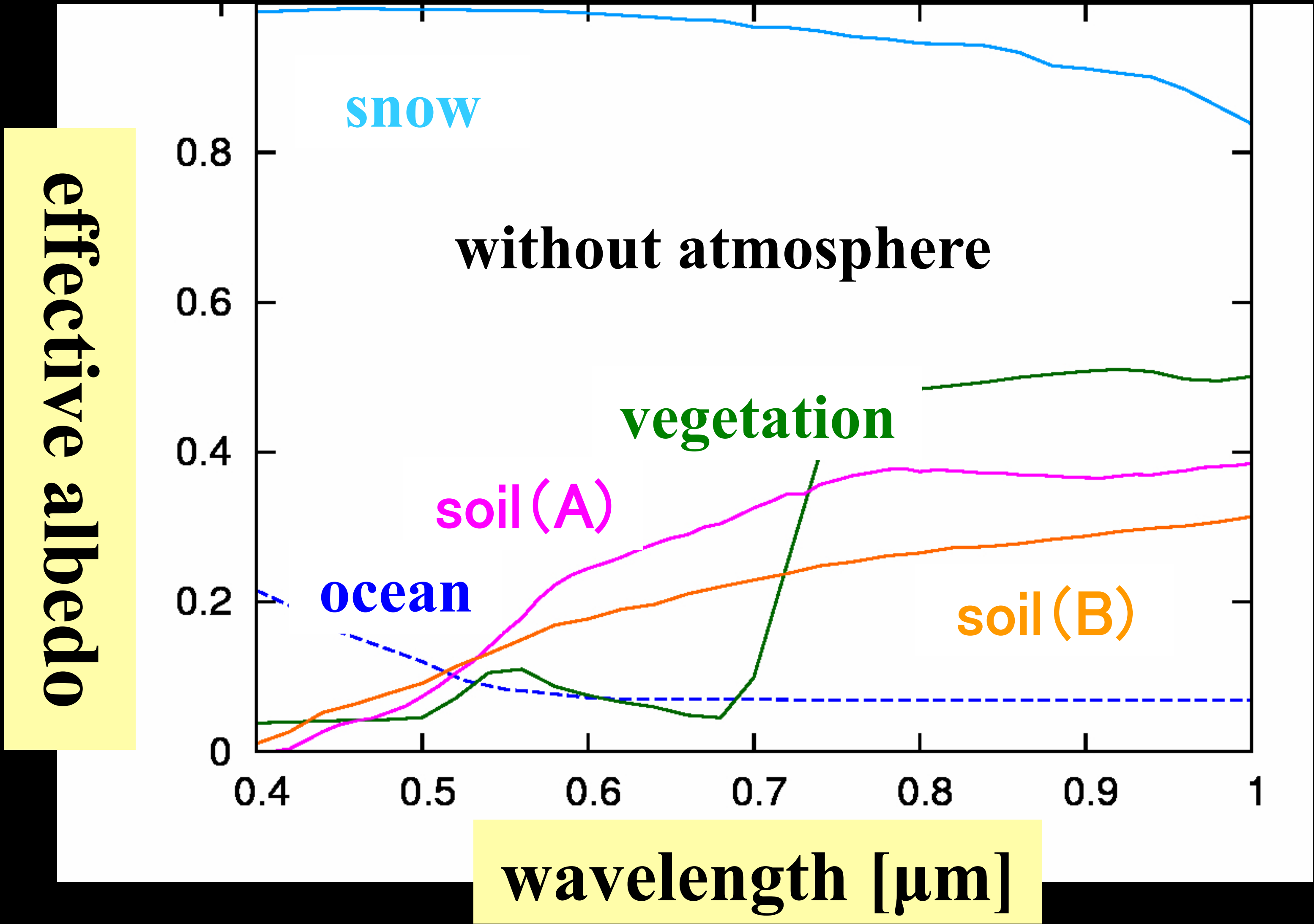


Vazquez et al. (2010)

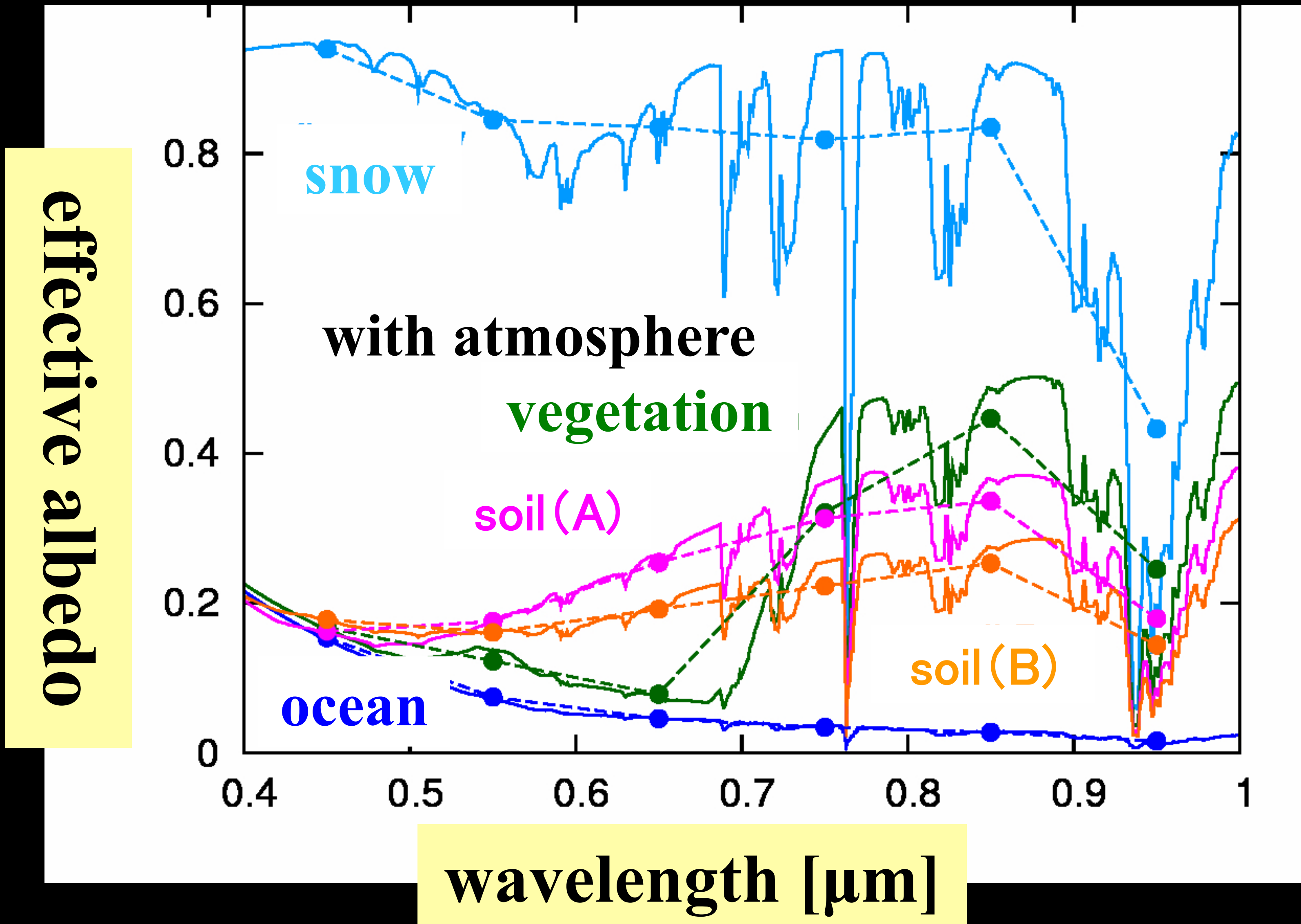
Fujii et al. (2010)



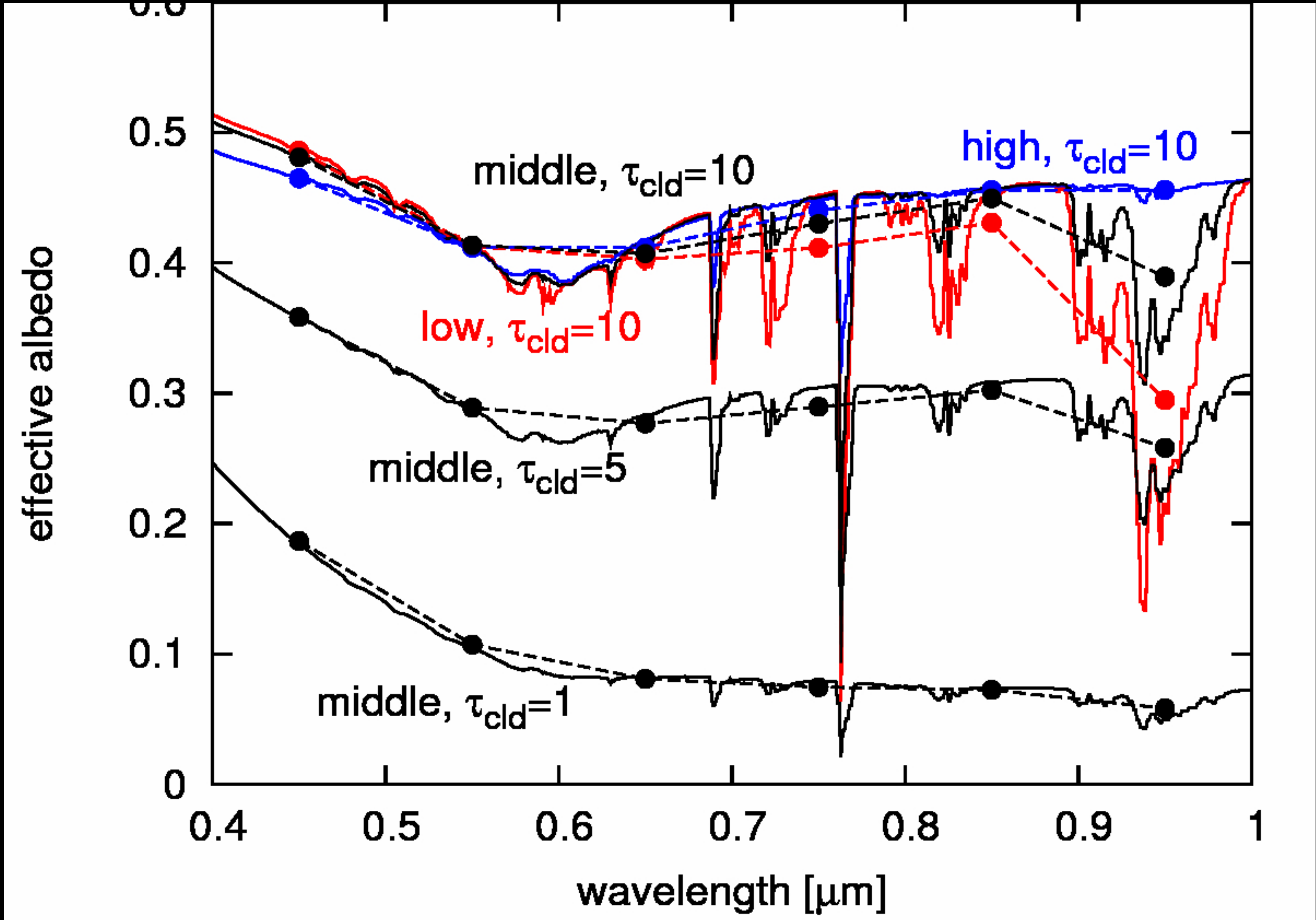
Albedo of surface components: isotropic approximation w/o atmosphere



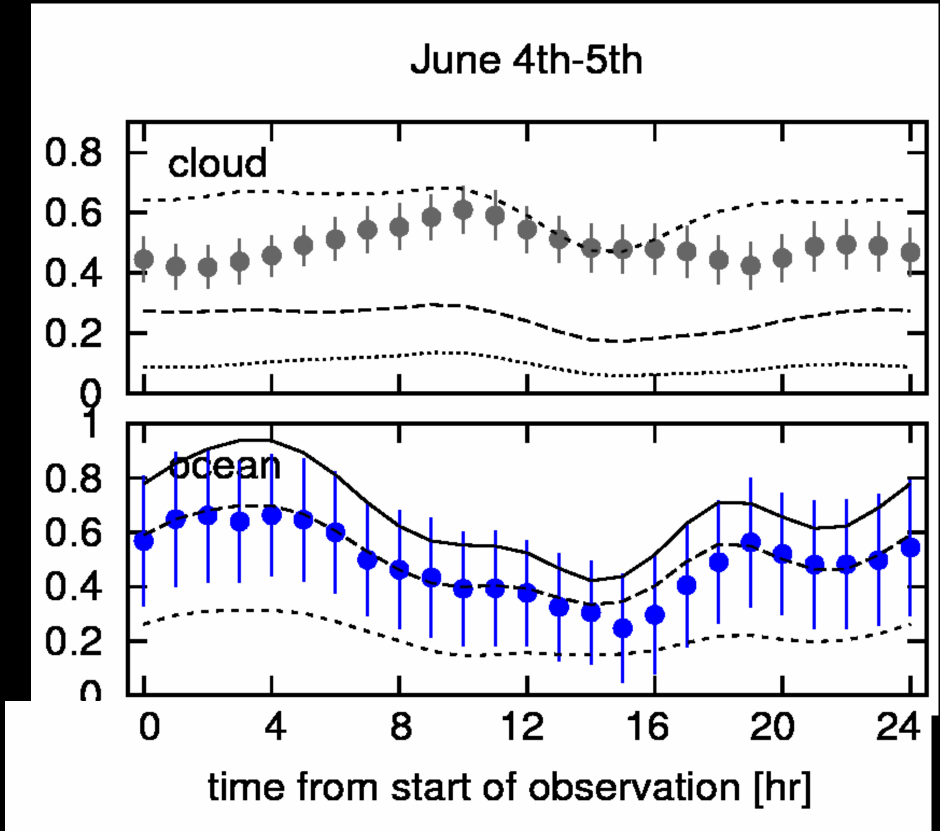
Albedo of surface components: isotropic approximation with atmosphere

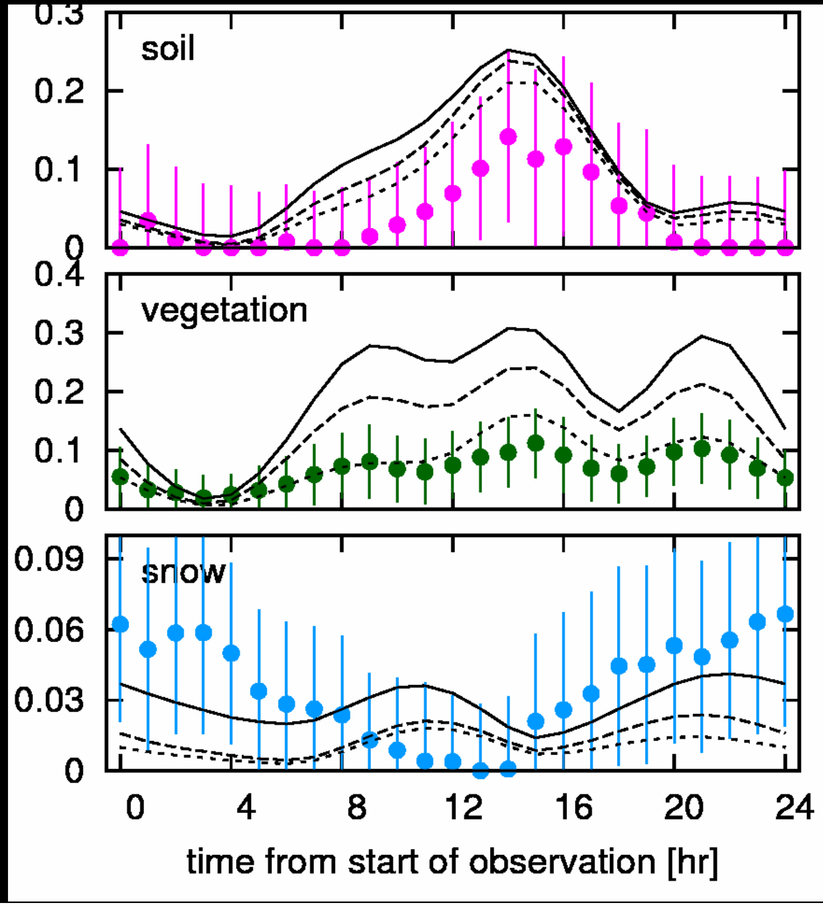


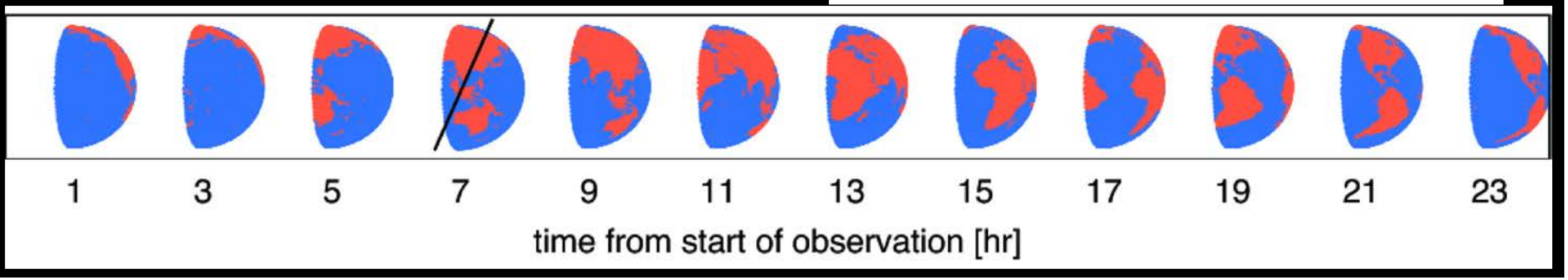
Albedo spectra of clouds: model dependence



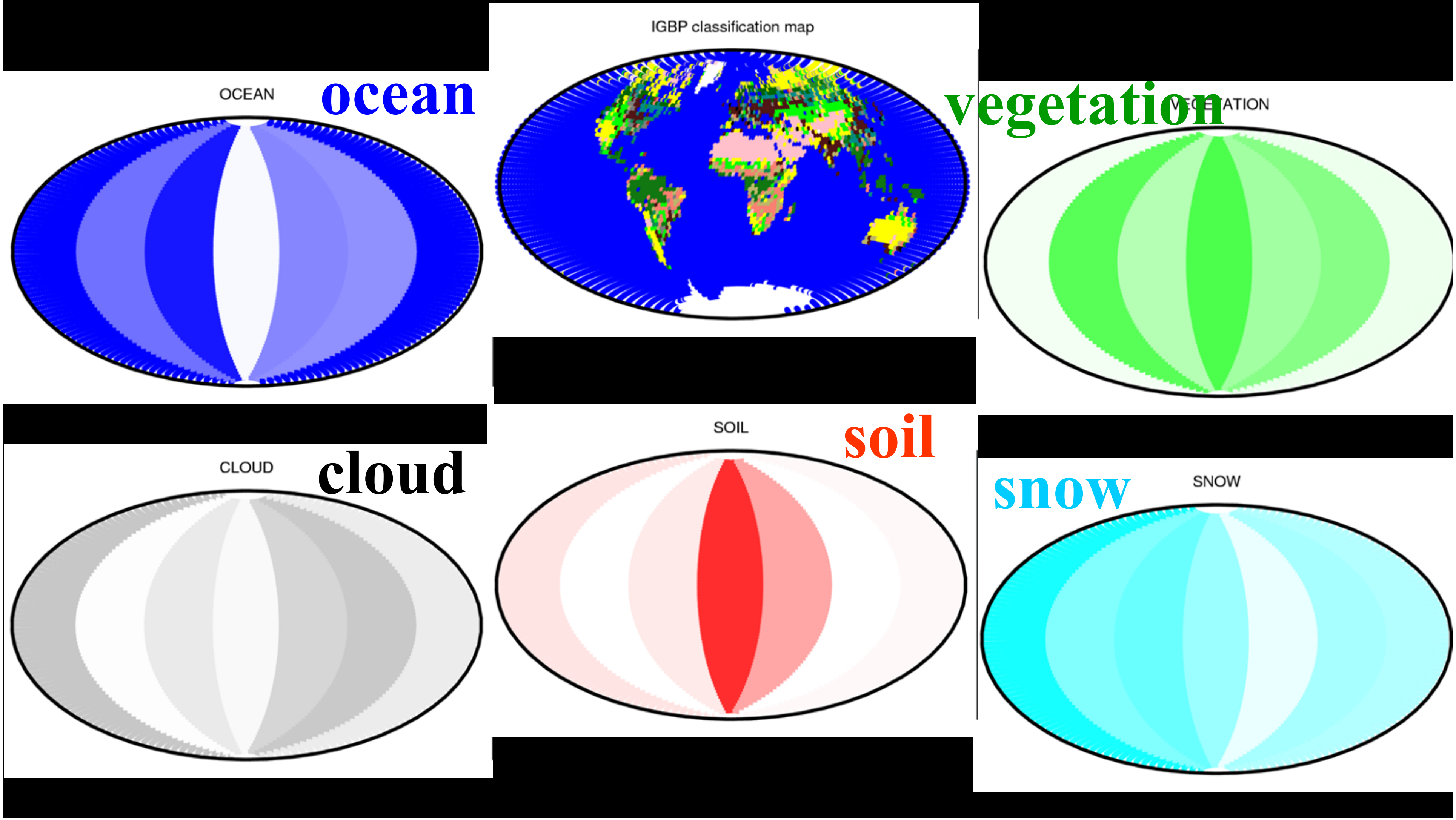
Fractional areas estimated from EPOXI data







Surface latitude map estimated from EPOXI data



The color of plants on other worlds
N.Kiang, Sci.Am.(2008)

Le Petit Prince:
(par Antoine de Saint Exupéry)

Si quelqu'un aime une fleur qui n'existe qu'à un exemplaire dans les millions et les millions d'étoiles, ça suffit pour qu'il soit heureux quand il les regarde. Il se dit: "Ma fleur est là quelque part . . . "

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 …"

宇宙生物学の心
「星の王子様」

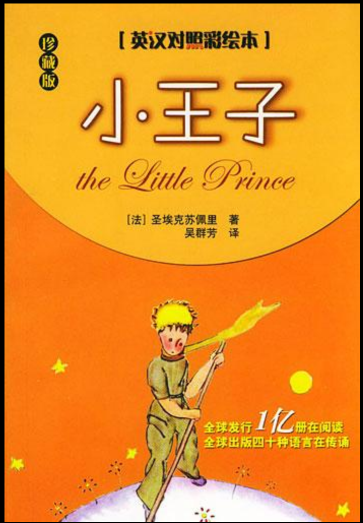
夜空を埋め尽くす無数の星々のどれかに咲く
たった一つの花が好きになれたなら
夜空を見上げるだけで
とっても幸せな気持ちになれる
「僕の花がこの夜空のどこかにあるんだ」
と信じられるだけで

小王子

(安东尼·德·圣-埃克苏佩里)

如果有人爱上了在这亿万颗星星中独一无二的一株花，当他看着这些星星的时候，这就足以使他感到幸福。他可以自言自语地说：'我的那朵花就在其中的一颗星星上……'

http://www.littleducks.cn/book/1/xiaowangzi-14.html



小王子
(安東尼·德·聖埃克絮佩里)

宇宙生物学的心

如果有人愛上了在這億萬顆星星中獨一無二的一株花，當他看着這些星星的時候，這就足以使他感到幸福。他可以自言自語地說：‘我的那朵花就在其中的一顆星星上……’

http://www.zwbk.org/zh-tw/Lemma_Show/115401.aspx