Exoplanety

Lecture 4
Vybrané kapitoly z astrofyziky
AI MFF UK
4.11.2015

Outline

- What are we looking for?
- Biomarkers, biosignatures
- Future prospects
- And a Kepler mystery

The habitable zone

- Kastings definition?

click for up

Remote life-detection criteria, habitable zone boundaries, and the frequency of Earth-like planets around M and late K stars

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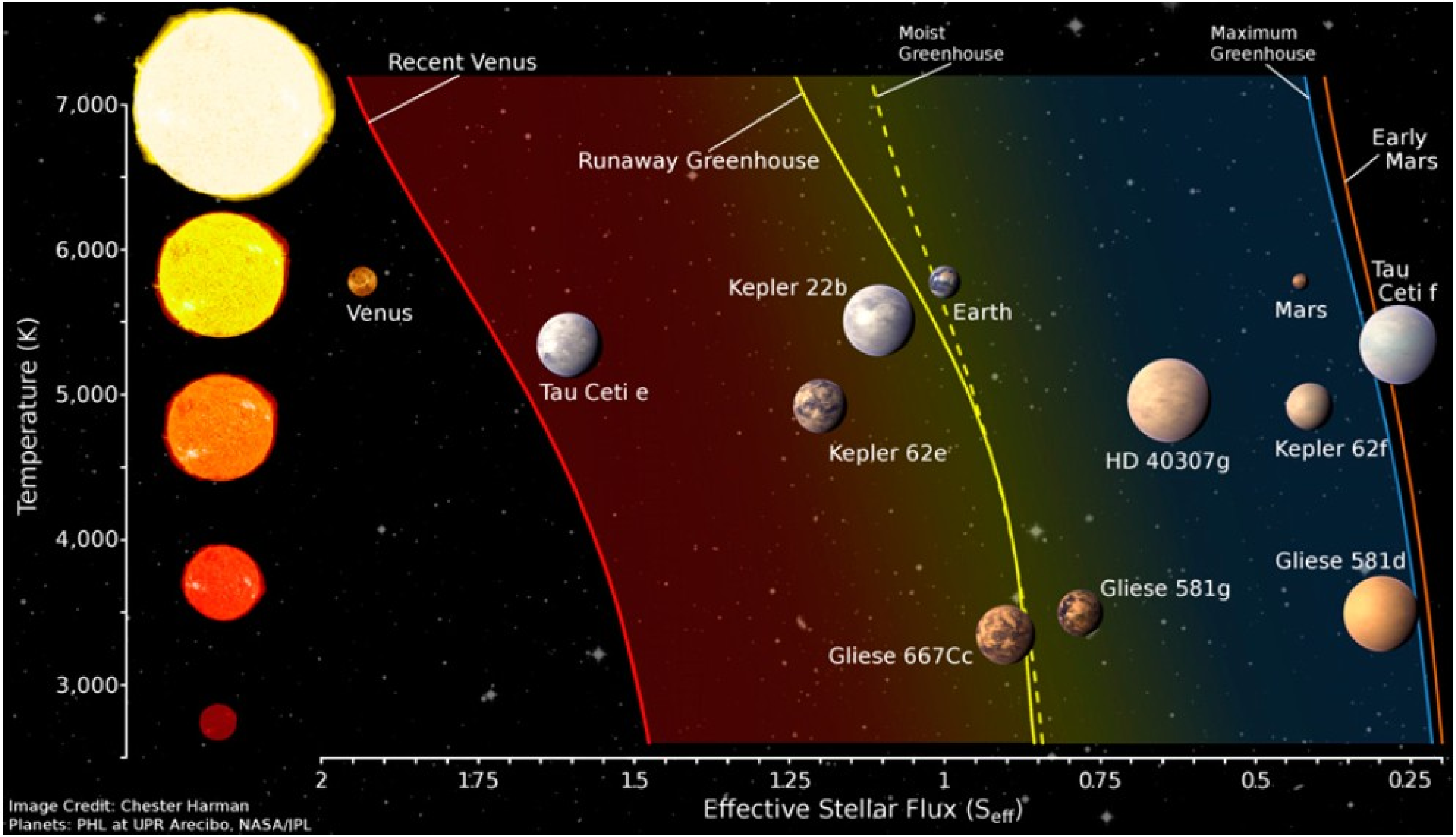
Edited by Adam S. Burrows, Princeton University, Princeton, NJ, and accepted by the Editorial Board October 31, 2013 (received for review May 13, 20

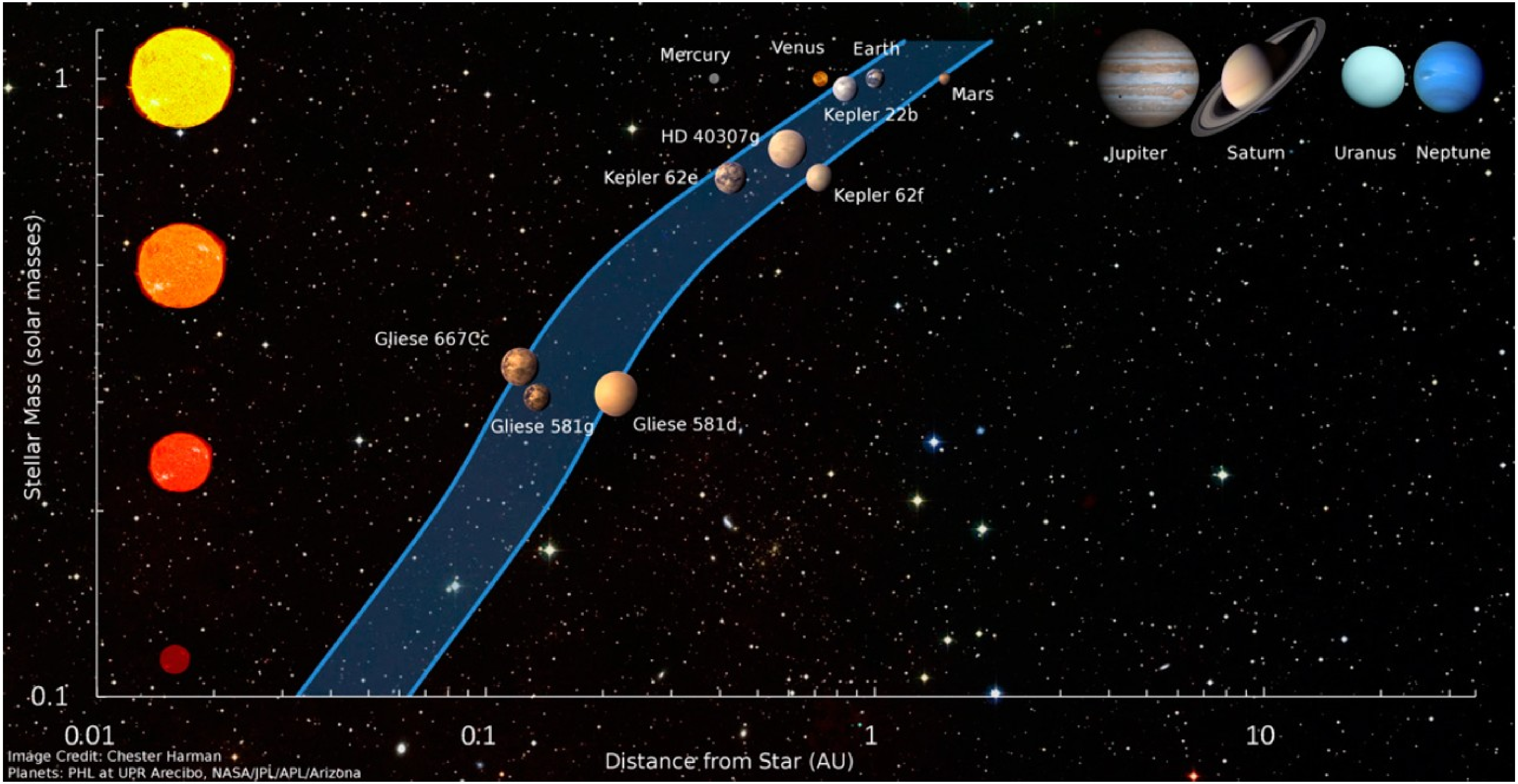
The habitable zone (HZ) around a star is typically defined as the region where a rocky planet can maintain liquid water on its surface. That definition is appropriate, because this allows for the possibility that carbon-based, photosynthetic life exists on the planet in sufficient abundance to modify the planet's atmosphere in a way that might be remotely detected. Exactly what conditions are needed, however, to maintain liquid water remains a topic for debate. In the past, modelers have restricted themselves to water-

around other stars by performing remote sensing of the plan atmospheres, so to them the biologists' definition of life is particularly useful. Instead, what they need is a way to recogn life from a great distance. It was realized many years ago that best way to do this is by looking for the byproducts of meta lism. As early as 1965, Lederberg (6) suggested that the b remote signature of life was evidence for extreme thermo namic disequilibrium in a planet's atmosphere (but see critic

Kasting et al., 2013, PNAS: http://www.pnas.org/content/111/35/12641.full.pdf



Kasting et al., 2013, PNAS: http://www.pnas.org/content/111/35/12641.full.pdf

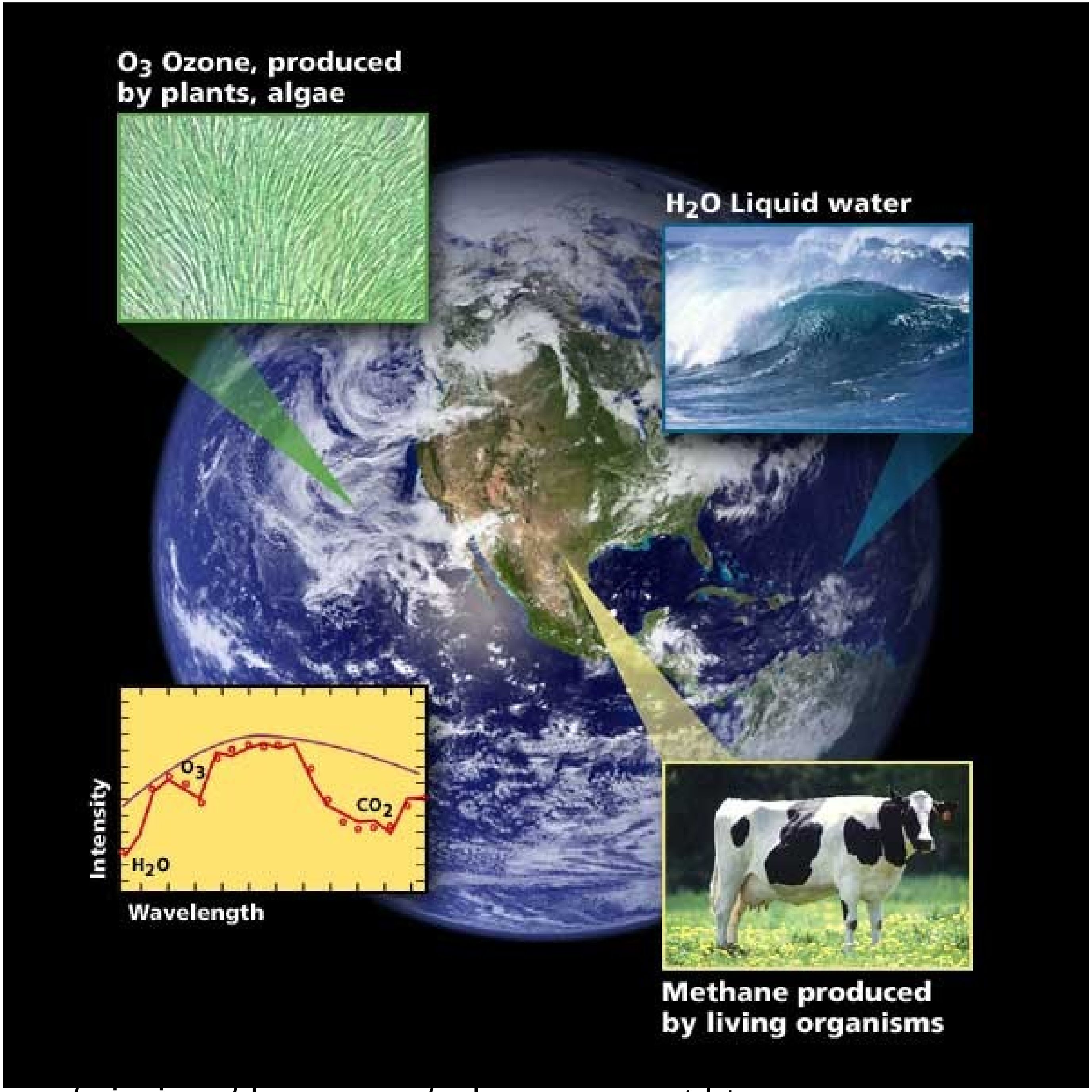


Kasting et al., 2013, PNAS: http://www.pnas.org/content/111/35/12641.full.pdf

Where to look?

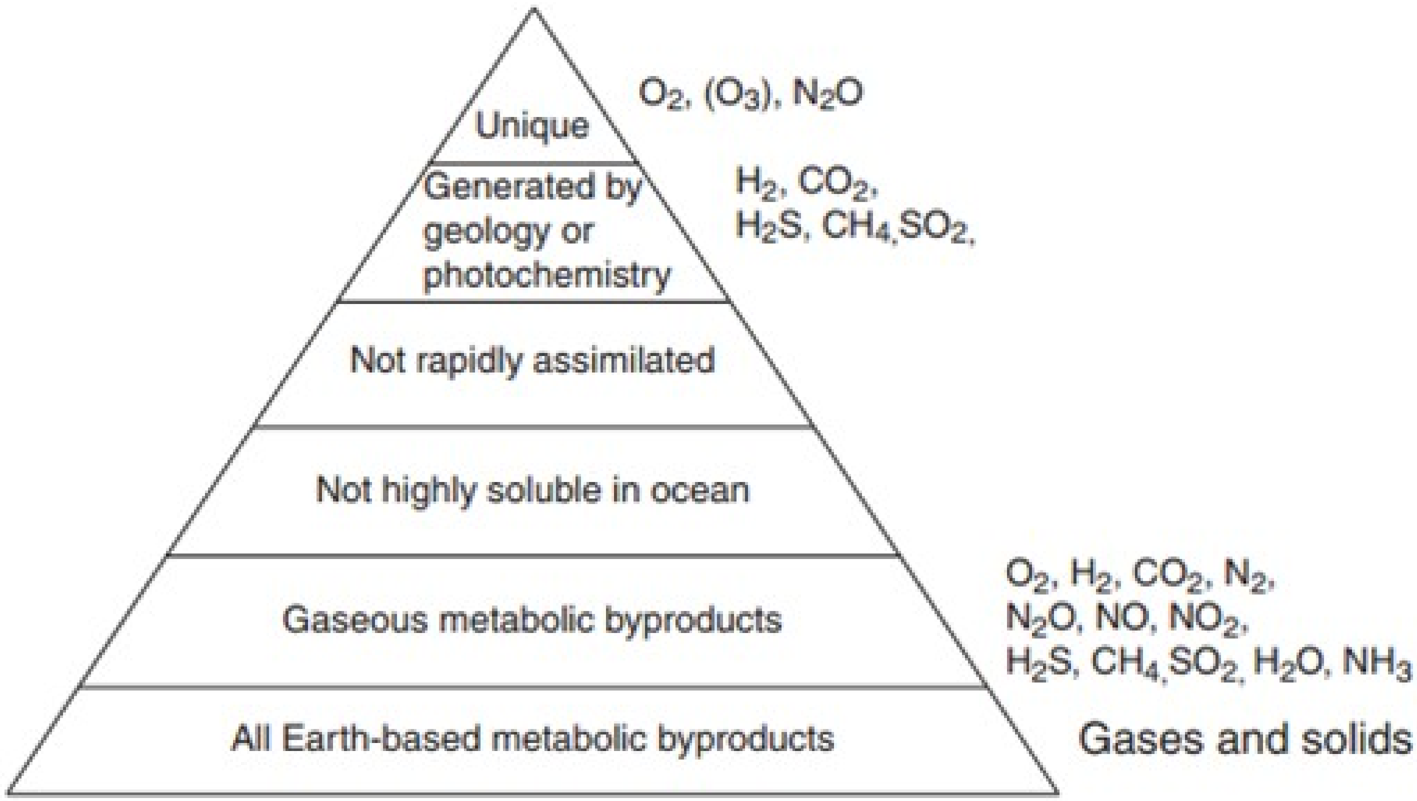
- M stars vs. G stars?
- Solar type stars, solar analogues, solar twins or rather red dwarfs?
- And actually what about exo-moons?
- What are we searching for?

Biosignature



http://www.nasa.gov/missions/deepspace/cyberspace_prt.htm

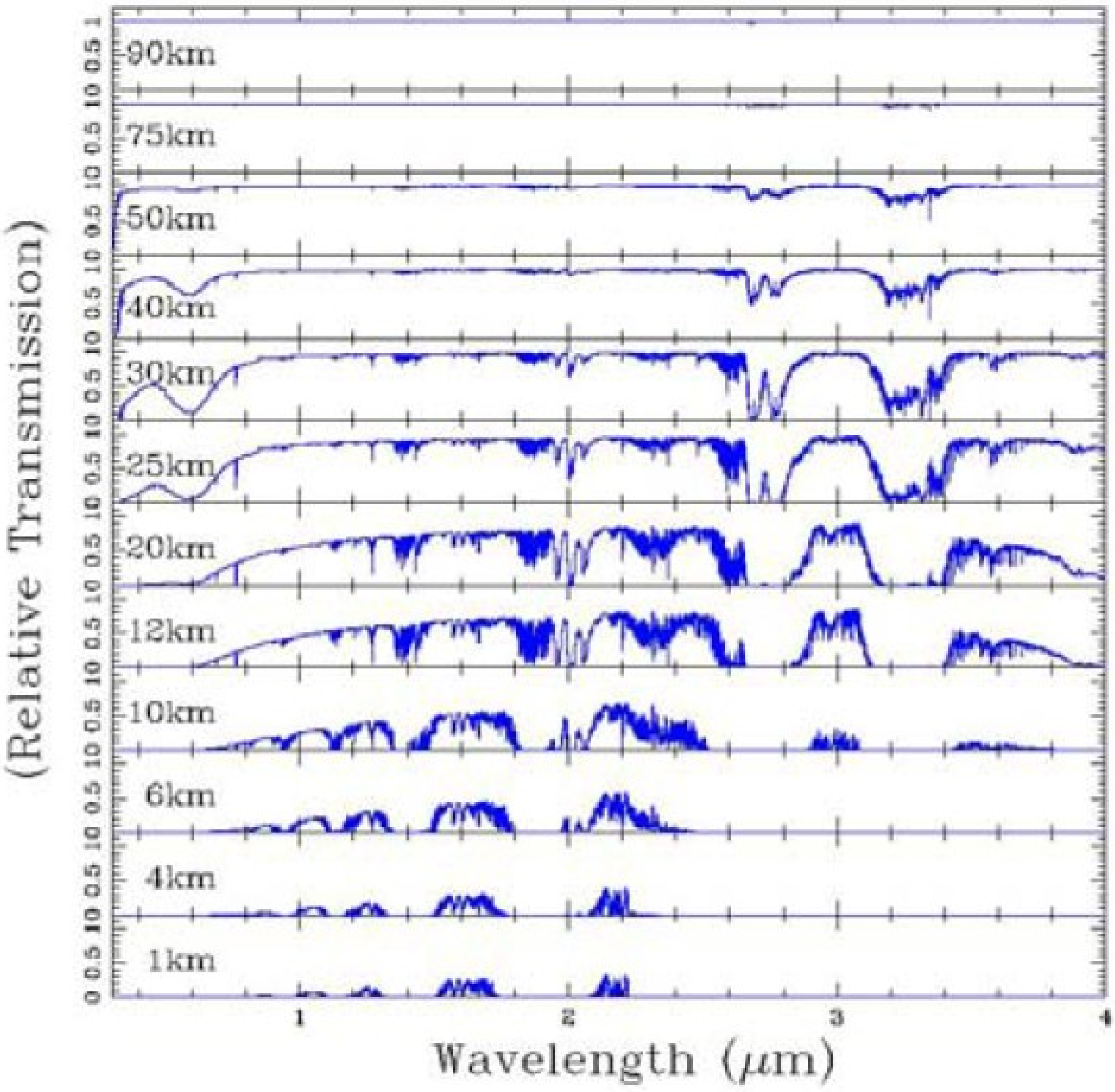
Some examples



Sara Seager, Matthew Schrenk, and William Bains. An Astrophysical View of Earth-Based Metabolic Biosignature Gases. ASTROBIOLOGY Volume 12, Number 1, 2012

Spectrum of Earth

Transmission of Earths atmosphere



Kaltenegger et al., 2009, http://arxiv.org/ftp/arxiv/papers/0903/0903.3371.pdf

What to expect in terms of sensitivity needed (the Earth)?

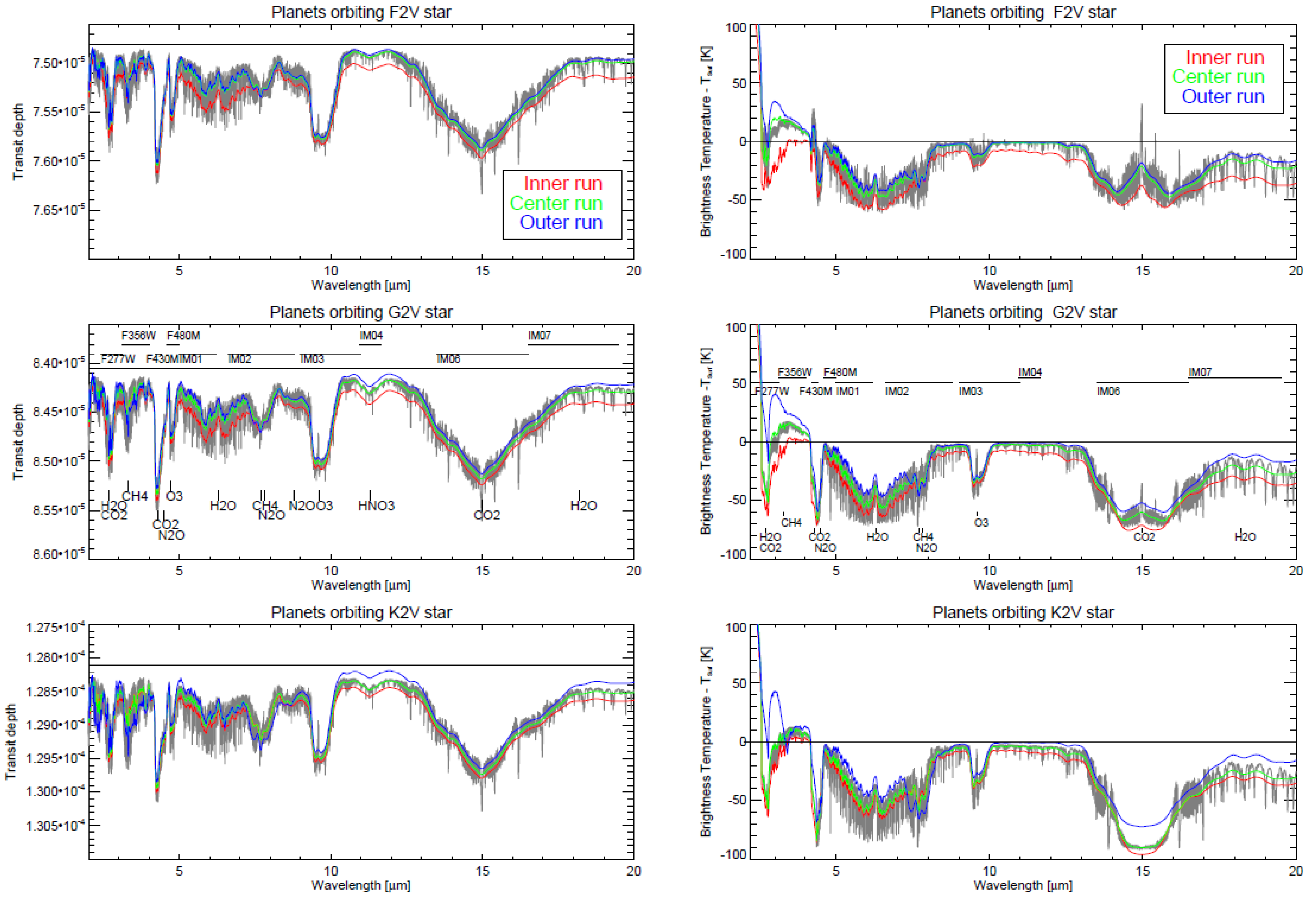
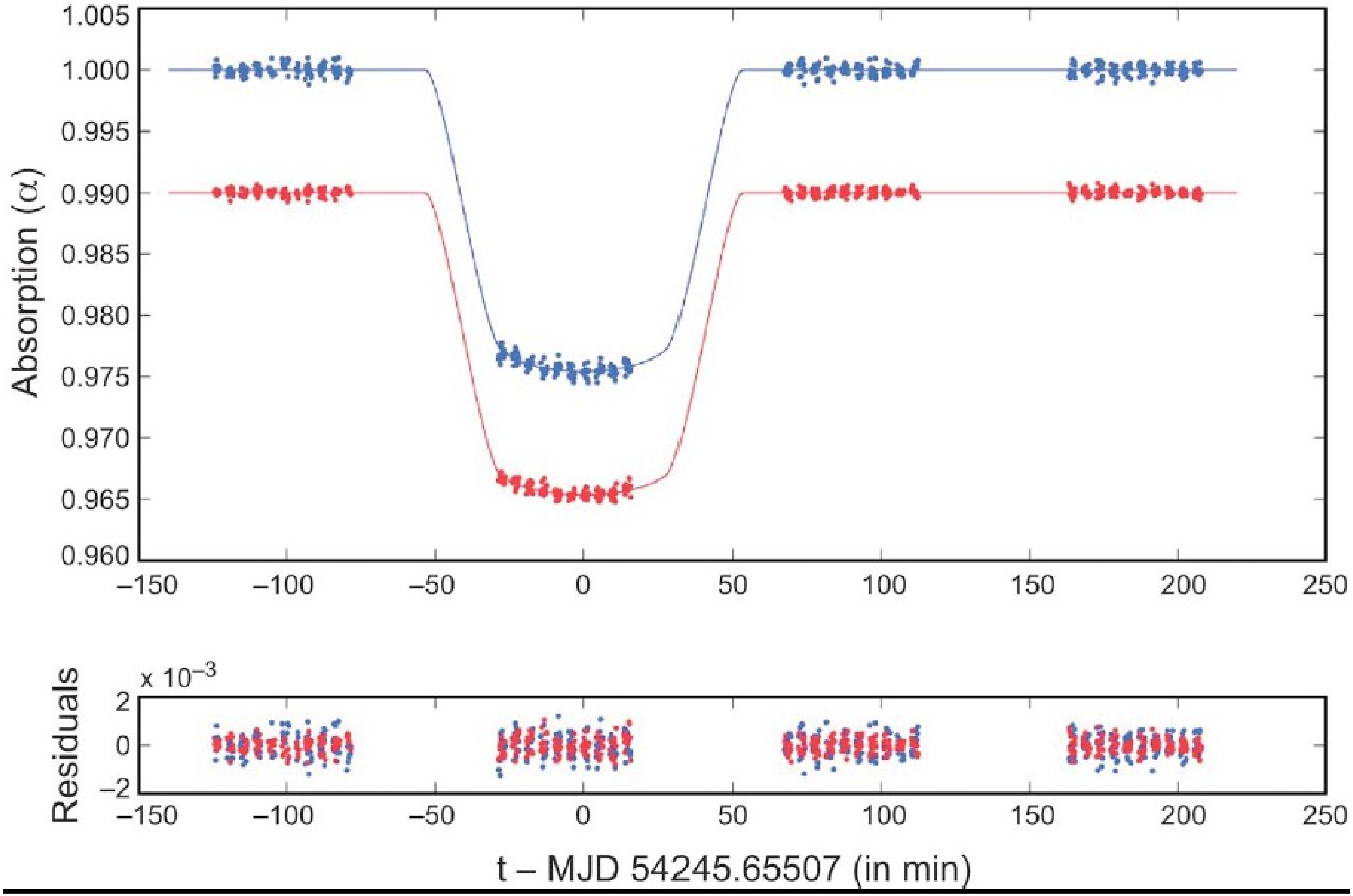


Fig. 4. Transit depth during primary eclipse (left) and brightness temperature difference with respect to the calculated surface temperature spectrum during secondary eclipse (right) for the scenarios considered. The spectral resolution is $R = 100$. Each center run with $R = 3\,000$ is shown in grey. The geometric transit depth (see Sect. 3.3) is indicated by a horizontal line for transmission spectra. The brightness temperature spectra include the reflected stellar component in the near-IR. Furthermore the bandpass of the filters considered in this work are shown.

http://arxiv.org/pdf/1302.5516v2.pdf

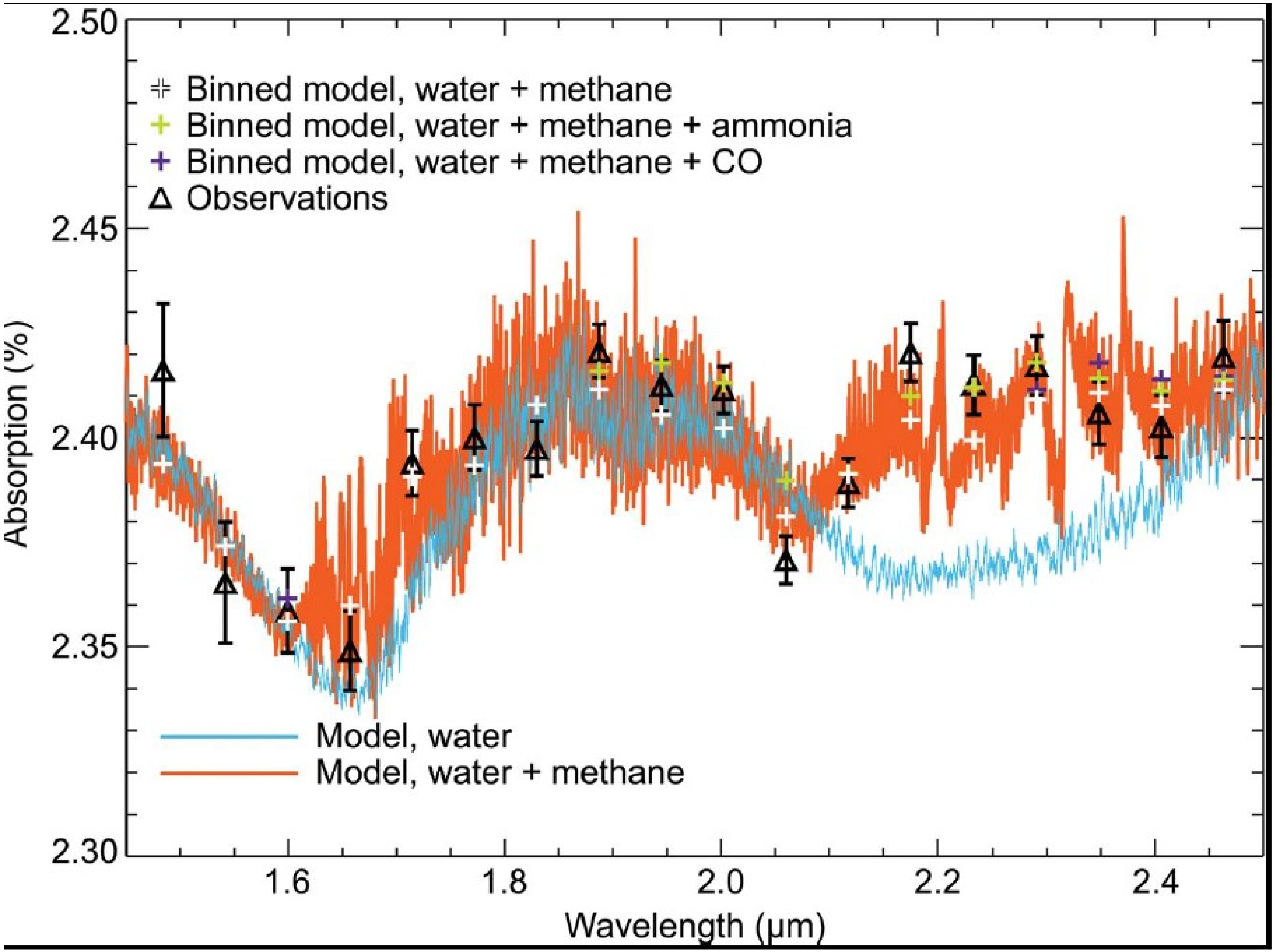
And hot-Jupiters?

HD189733b - HST



Swain et al., 2008, Nature
http://www.spacetelescope.org/static/archives/releases/science_papers/Nature_methane_accepted.pdf

HD189733b



Swain et al., 2008, Nature

http://www.spacetelescope.org/static/archives/releases/science_papers/Nature_methane_accepted.pdf

Wasp-12b – Rayleigh scattering

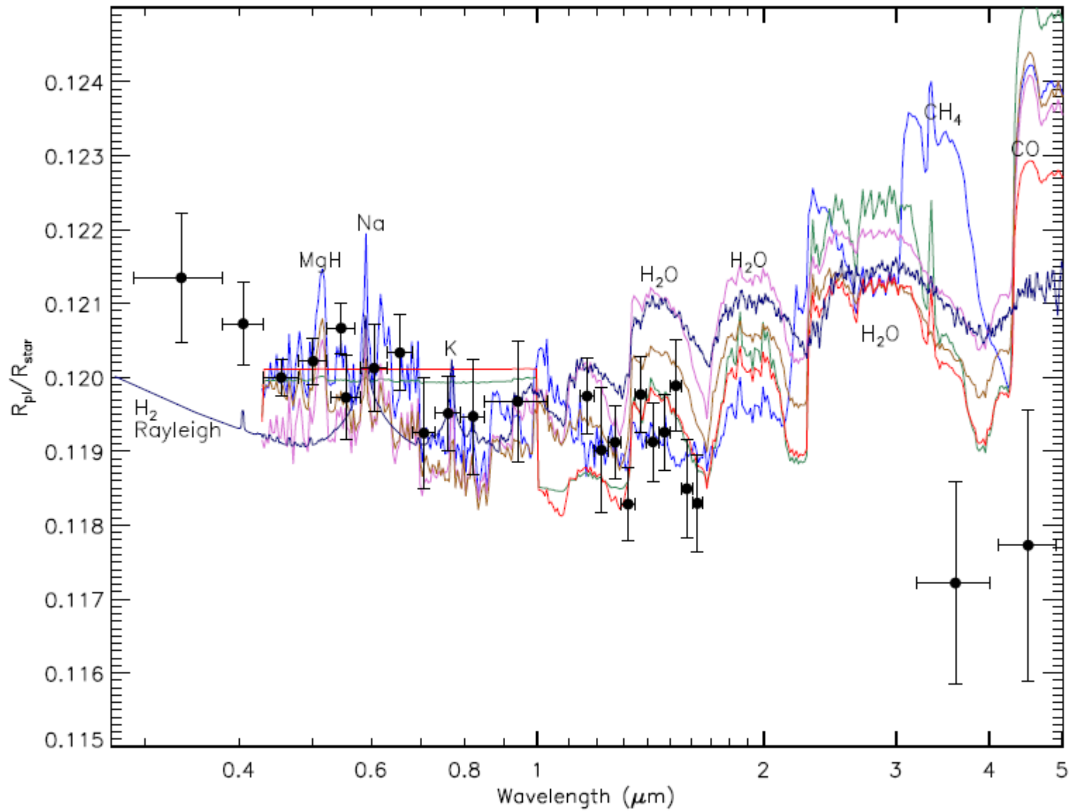


Figure 12. Plotted is the broadband transmission spectral data compared to 6 different clear atmosphere models (which lack TiO) listed in Table 5, including Burrows-ExtraAbsorber_10×solar (red), Burrows-MetalHydrides_0.01×H2O (light blue), Burrows-ExtraAbsorber_10×CO (green), Burrows-Isothermal3000_0.1×solar (brown), Burrows-Isothermal2500 (orchid), and Fortney-Isothermal2250_noTiO (dark blue). All of these models have a particularly hard time simultaneously fitting for the near-IR WFC3 and *Spitzer* data.

Sing et al. 2013, MNRAS, http://arxiv.org/pdf/1309.5261v1.pdf

Wasp-31b (clouds, haze, scattering)

14 *D. K. Sing et al.*

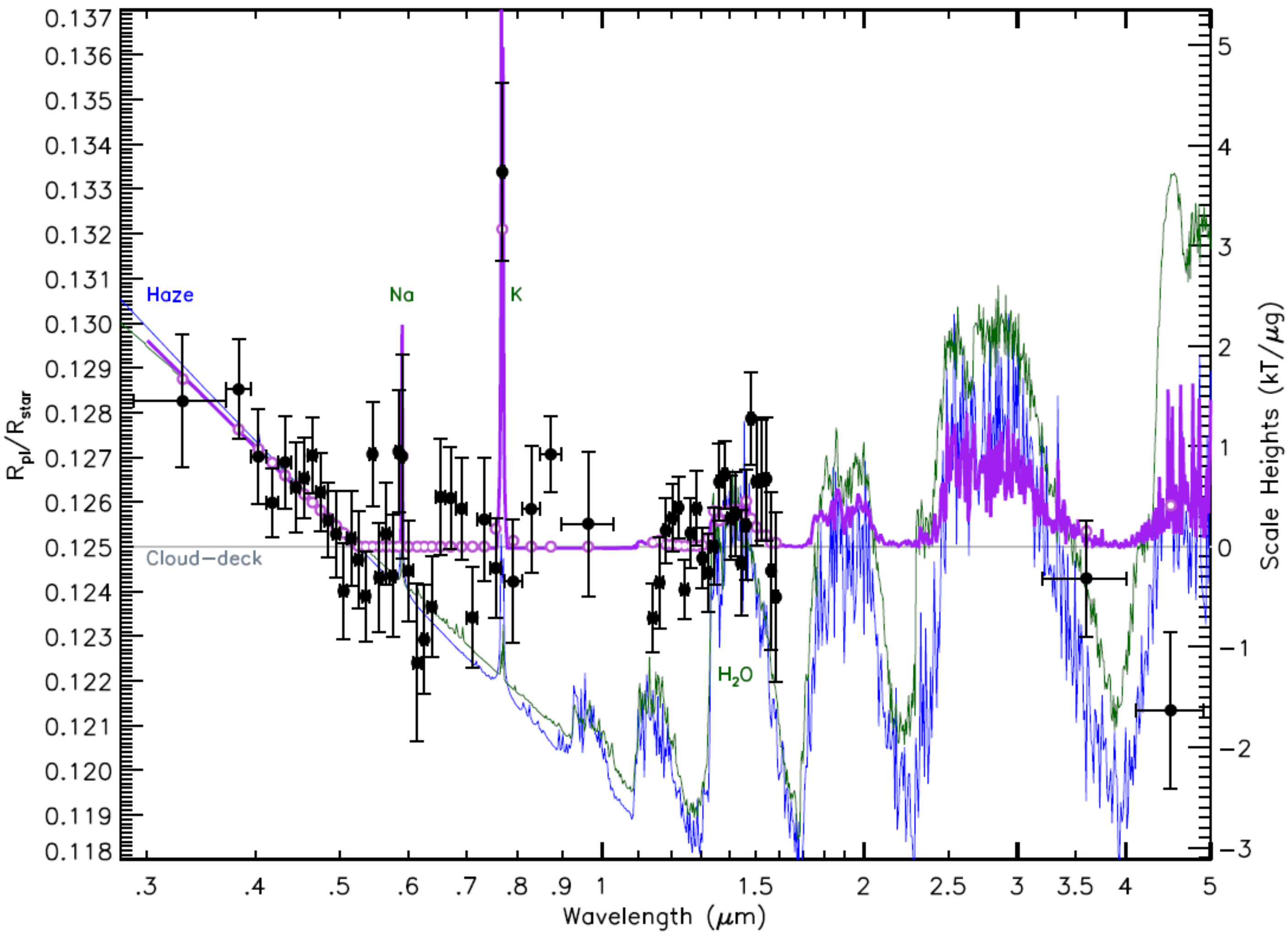


Figure 12. Plotted is the broad-band transmission spectral data along with atmospheric models. Two solar-composition models containing a scattering haze are shown from the modeling suits of Burrows et al. (green) and Fortney et al. (blue). Our best fit model is also plotted (purple) containing a Rayleigh scattering haze, a grey cloud-deck at low pressures, non-pressure broadened Na and K features, and an obscured H_2O feature. The band-averaged model points are indicated with open circles.

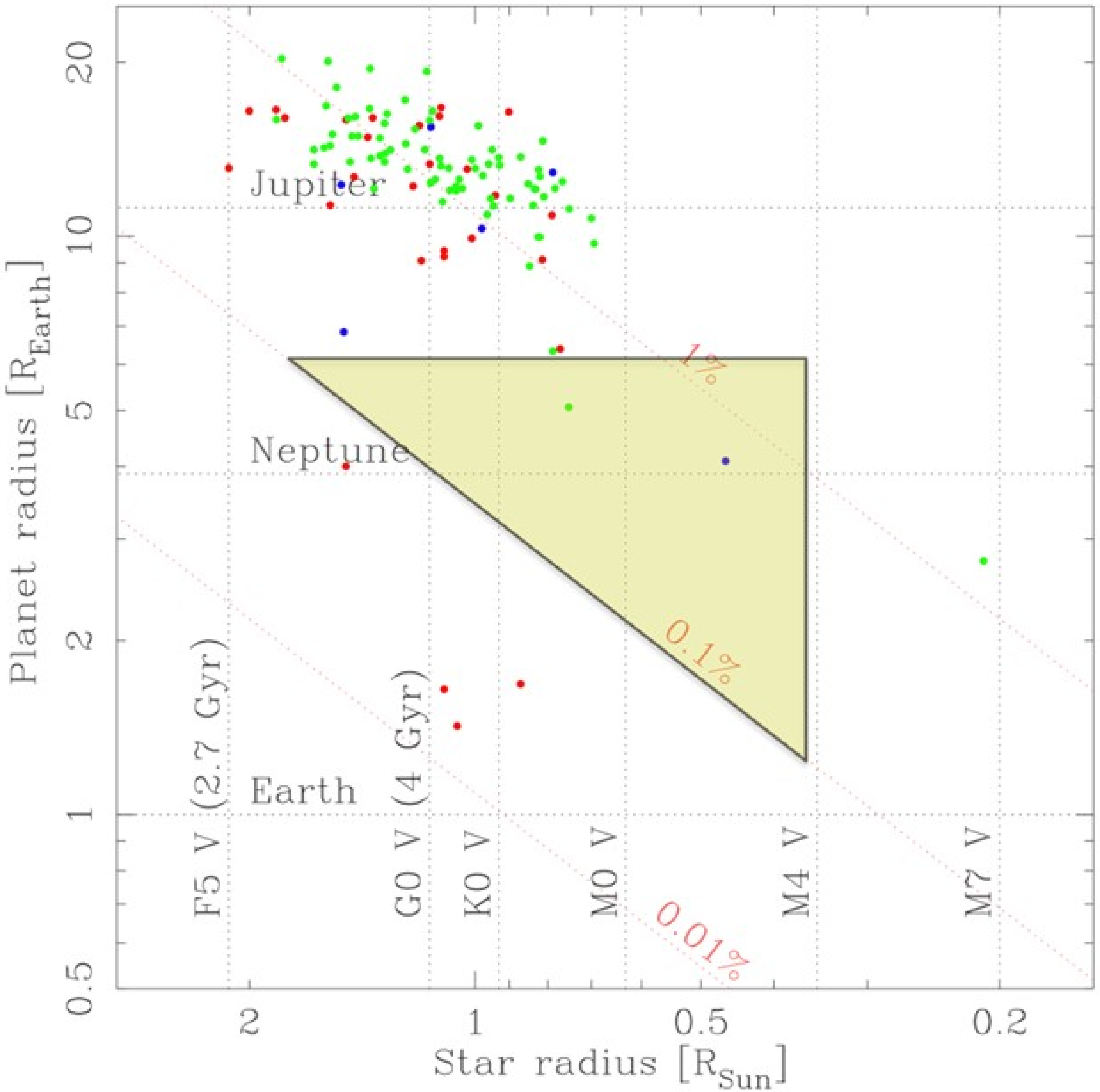
Sing et al. 2014, http://arxiv.org/abs/1410.7611

And projects for the future?

NGTS

http://www.ngtransits.org/survey.shtml

NGTS



http://www.ngtransits.org/survey.shtml

CHEOPS

- 32cm telescope
- Launch 2017

Credit: ESA

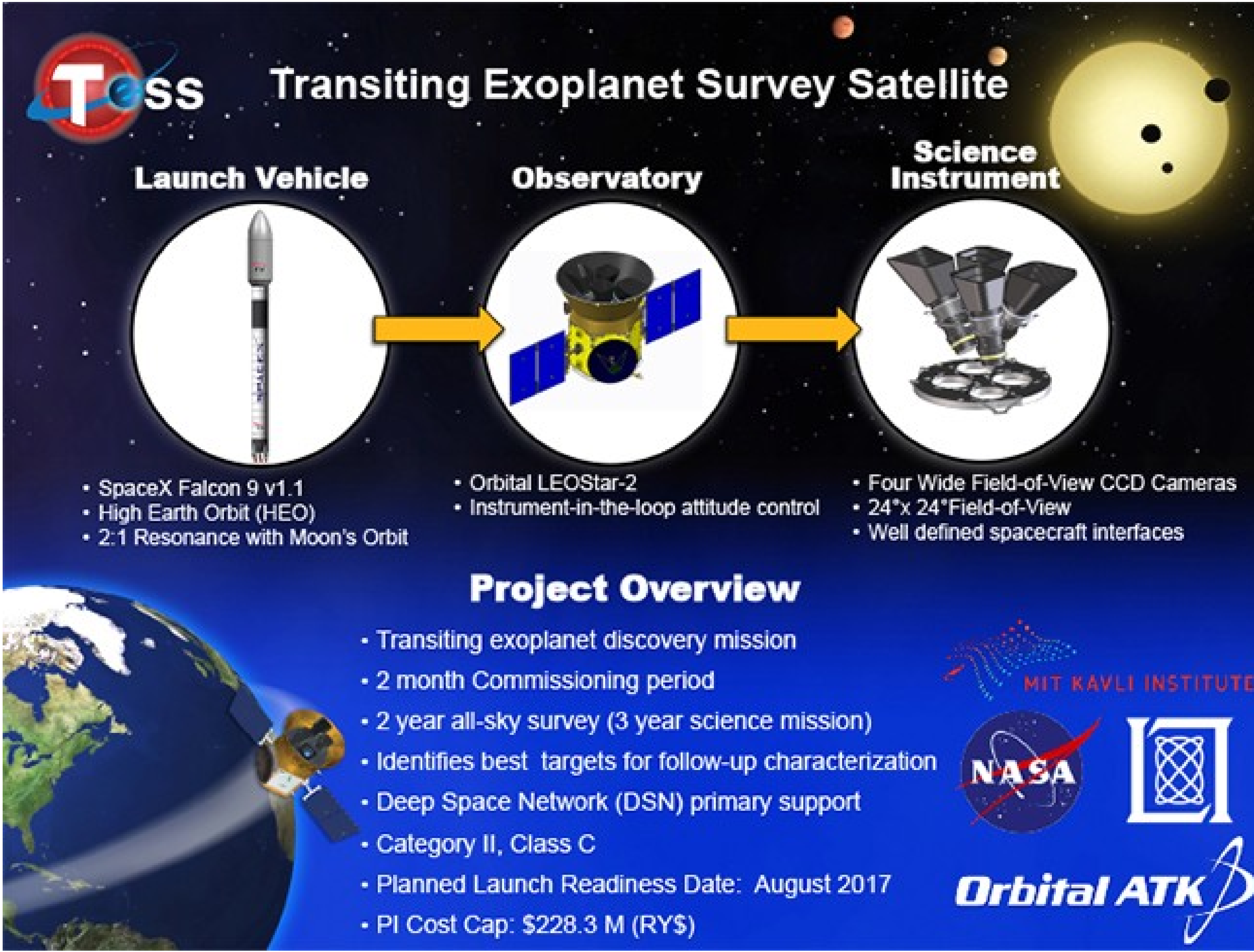
- http://sci.esa.int/cheops/54032-spacecraft/
- http://cheops.unibe.ch/

CHEOPS

- The main science goals of the CHEOPS mission will be to study the structure of exoplanets with radii typically ranging from 1-6 REarth orbiting bright stars. With an accurate knowledge of masses and radii for an unprecedented sample of planets, CHEOPS will set new constraints on the structure and hence on the formation and evolution of planets in this mass range. In particular, CHEOPS will:

- Determine the mass-radius relation in a planetary mass range for which only a handful of data exist and to a precision never before achieved.
- Probe the atmosphere of known Hot Jupiters in order to study the physical mechanisms and efficiency of the energy transport from the dayside to the night side of the planet.
- Provide unique targets for future ground- (e.g. E-ELT) and space-based (e.g. JWST, EChO) facilities with spectroscopic capabilities. With well-determined radii and masses, the CHEOPS planets will constitute the best target sample within the solar neighbourhood for such future studies.
- Offer up to 10% of open time to the community to be allocated through competitive scientific review.
- Identify planets with significant atmospheres as a function of their mass, distance to the star, and stellar parameters. The presence (or absence) of large gaseous envelopes bears directly on fundamental issues such as runaway gas accretion in the core accretion scenario or the loss of primordial H-He atmospheres.
- Place constraints on possible planet migration paths followed during formation and evolution for planets where the clear presence of a massive gaseous envelope cannot be discerned.

TESS


TESS
Transiting Exoplanet Survey Satellite
Launch Vehicle
Observatory
Science Instrument
• SpaceX Falcon 9 v1.1
• High Earth Orbit (HEO)
• 2:1 Resonance with Moon's Orbit
• Orbital LEOStar-2
• Instrument-in-the-loop attitude control
• Four Wide Field-of-View CCD Cameras
• 24°x 24°Field-of-View
• Well defined spacecraft interfaces
Project Overview
• Transiting exoplanet discovery mission
• 2 month Commissioning period
• 2 year all-sky survey (3 year science mission)
• Identifies best targets for follow-up characterization
• Deep Space Network (DSN) primary support
• Category II, Class C
• Planned Launch Readiness Date: August 2017
• PI Cost Cap: $228.3 M (RY$)
MIT KAVLI INSTITUTE
NASA
Orbital ATK

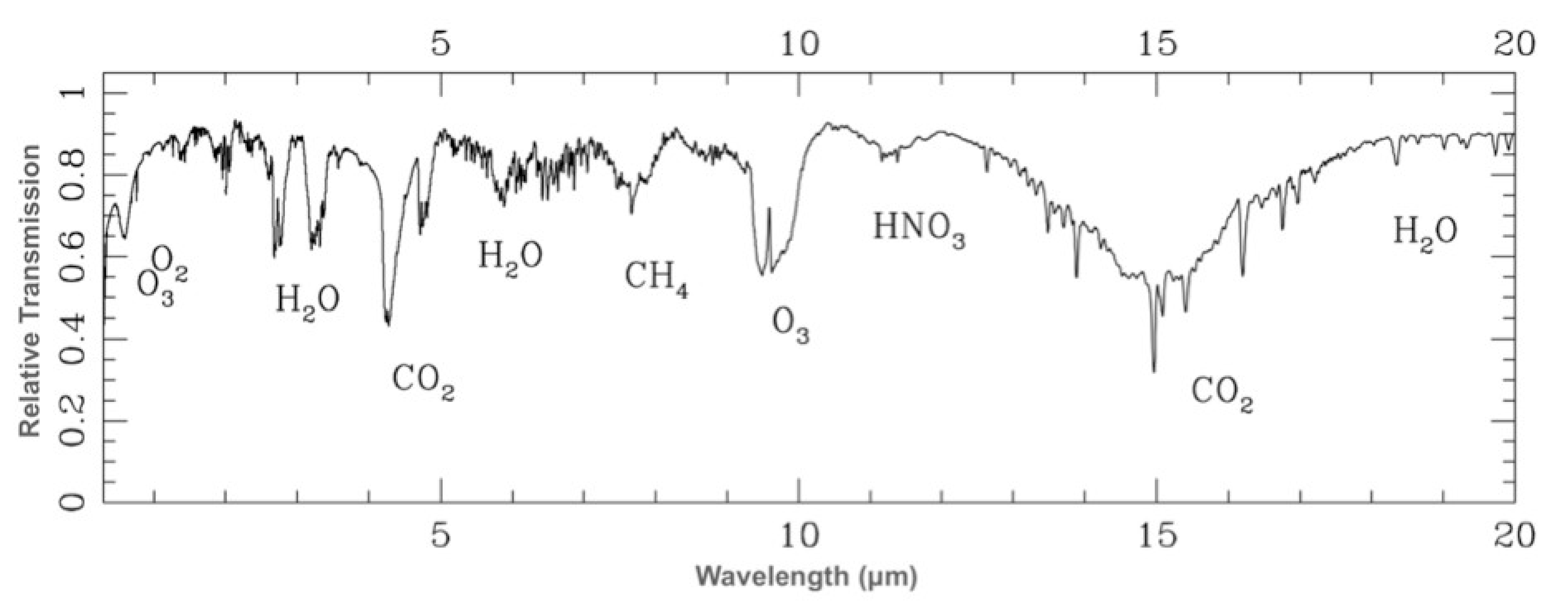
TESS

- TESS is designed to:

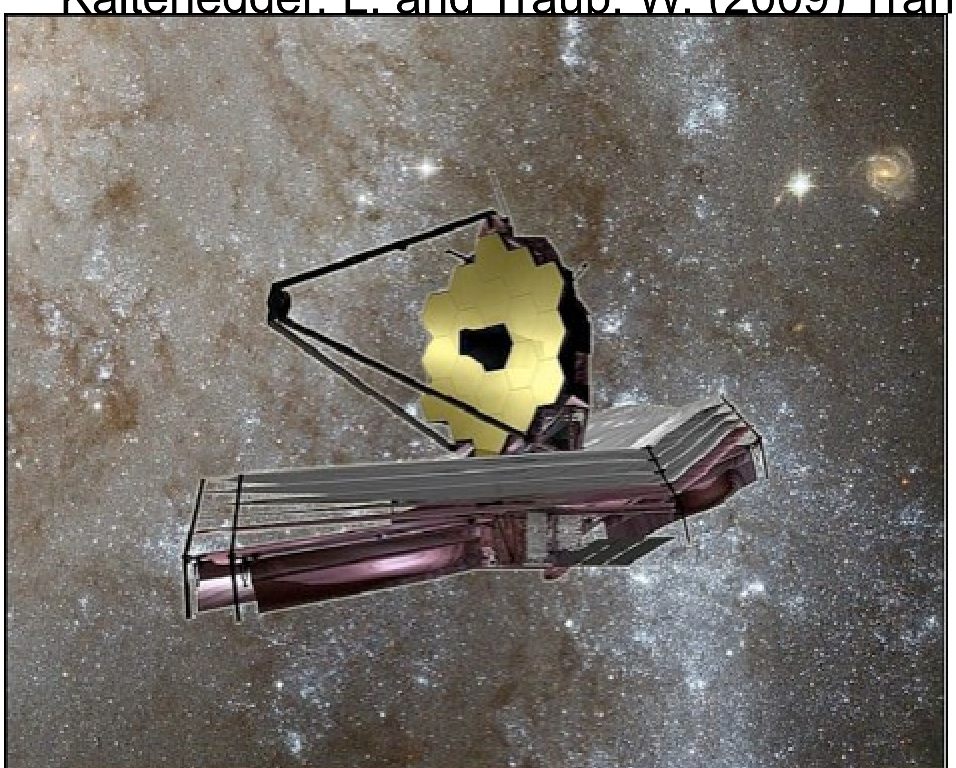
- Monitor 200,000 nearby stars for planets
- Focus on Earth and Super-Earth size planets
- Cover 400× larger sky area than Kepler
- Span stellar spectral types of F5 to M5

JWST

- MIRI - mid-IR camera
- NIRI – near-IR camera
- NIRSpec – near-IR spectrograph
- NIRISS – near-IR imager and slitless spectrogr.
- Exoplanets and Solar systém one of the key themes
- Launch date 2018

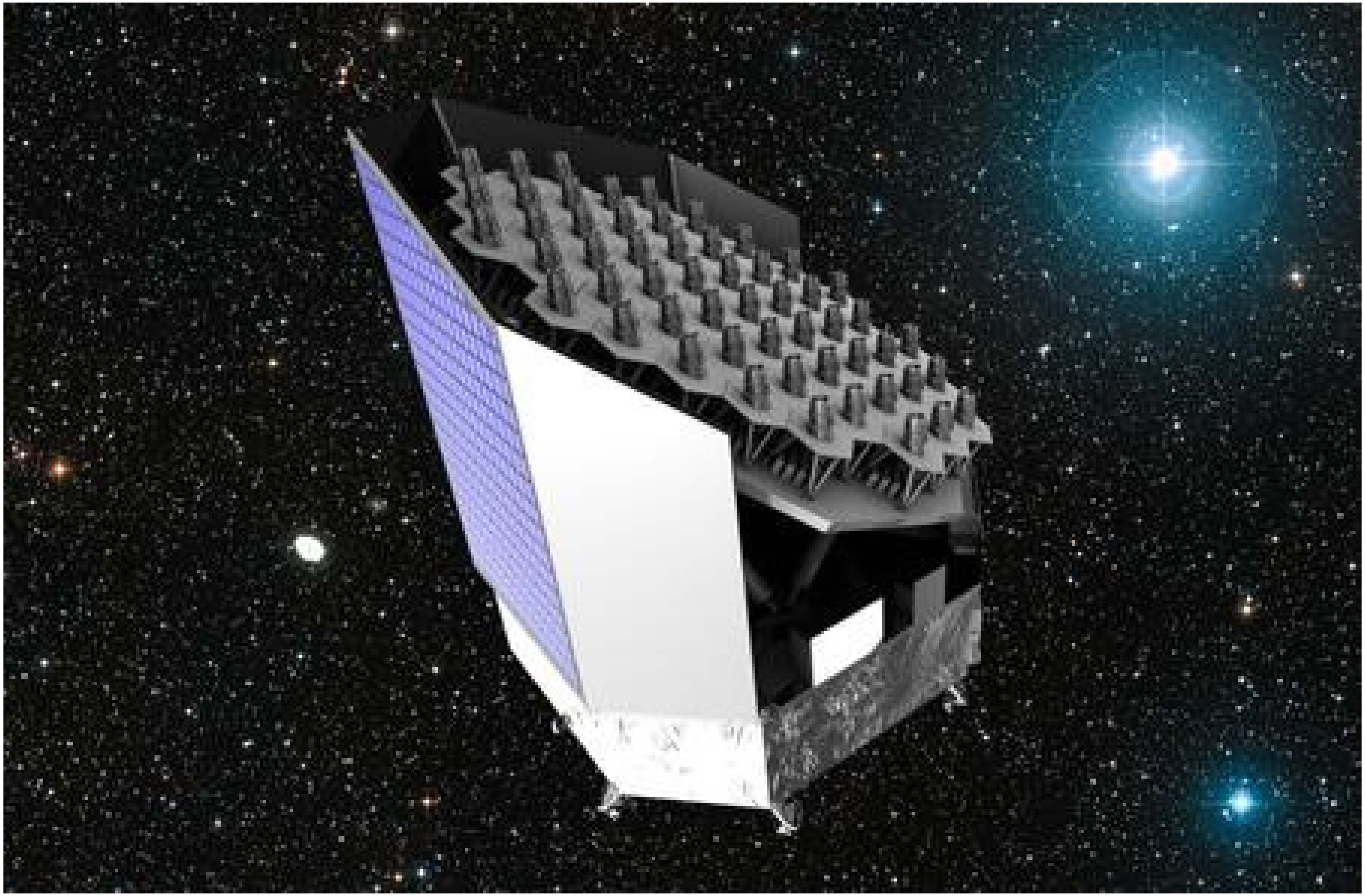


Kaltenegger, L. and Traub, W. (2009) Transits of Earth-Like Planets. Astrophysical Journal



JWST
Launch 2018
Ideal for characterization of small planets in infrared
Image NASA

Plato Space mission



Credit: Thales Alenia Space

PLATO Space mission

- PLAnetary Transits and Oscillations of stars
- Theme: What are the conditions for planet formation and the emergence of life?
- Primary Goal Detection and characterisation of terrestrial exoplanets around bright solar-type stars, with emphasis on planets orbiting in the habitable zone.
- Photometric monitoring of a large number of bright stars for the detection of planetary transits and the determination of the planetary radii (around 2% accuracy)
- Ground-based radial velocity follow-up observations for the determination of the planetary masses (around 10% accuracy)
- Asteroseismology for the determination of stellar masses, radii, and ages (up to 10% of the main sequence lifetime)
- Identification of bright targets fr spectroscopic follow-up observations of planetary atmospheres with other ground and space facilities

- LAUNCH 2024

PLATO Space mission

- The instrument consists of 32 "normal" telescopes
- Stars with mV > 8. Two additional “fast” cameras with high read-out cadence (2.5 s) will be used for stars with mV ~4–8
- Each camera has an 1100 deg2 FoV and a pupil diameter of 120 mm and is equipped with a focal plane array of 4 CCDs each with 45102 pixels of 18 μm size

E-ELT - 2024

- EPICS – Exoplanet imagng camera and spectrograph

  https://www.eso.org/sci/libraries/SPIE2010/7735-84.pdf

- METIS - The Mid-infrared E-ELT Im. and Spectr. - 3–20 μm

  Low-resolution (R < 1,000) at L,M,N

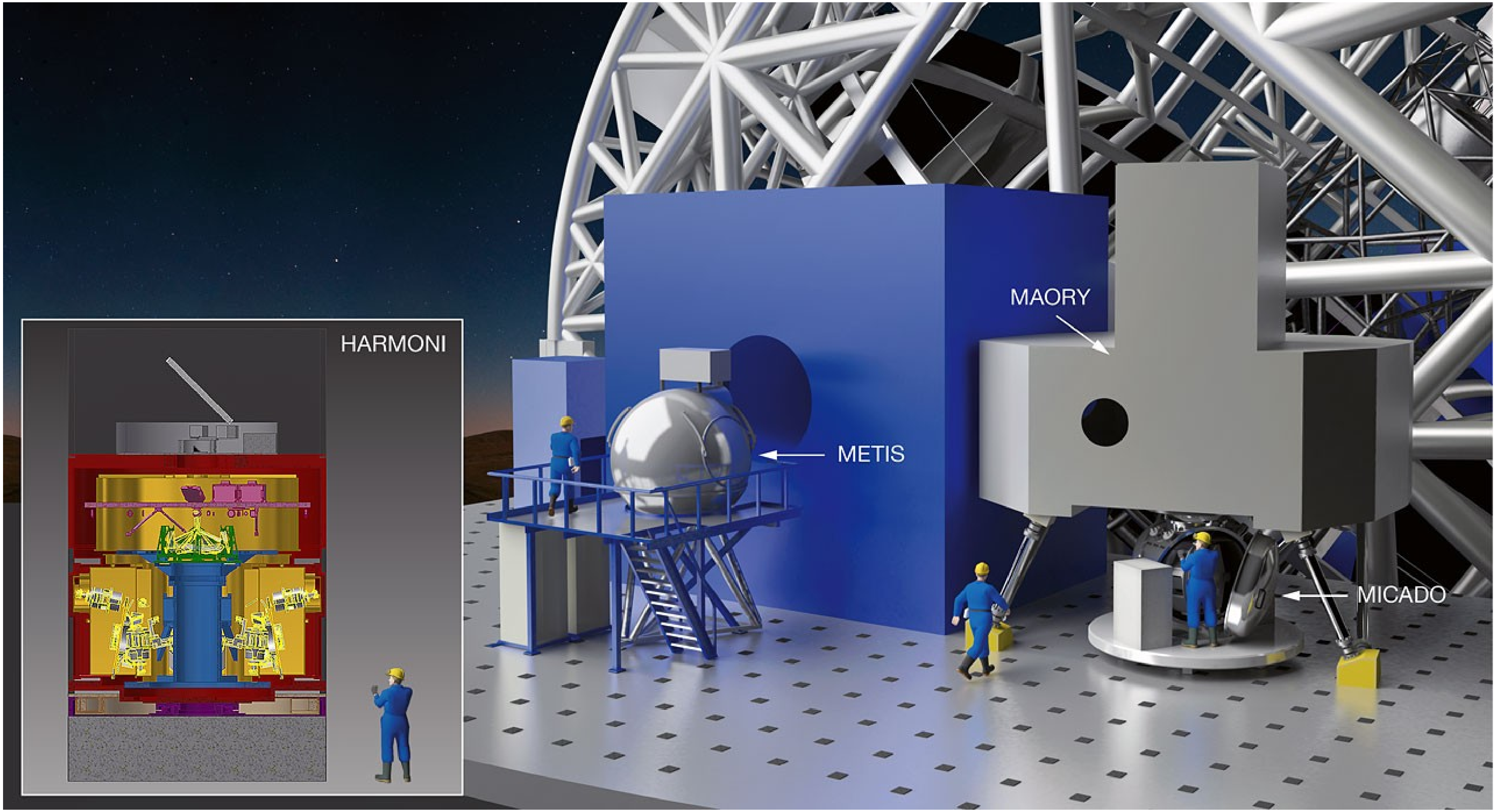
  Medium-resolution (R <10,000) at N

  High-resolution (R~100,000) IFU at L,M

- HARMONI - is a visible and near-infrared (0.47 to 2.45 μm) integral field spectrograph, providing the E-ELT's core spectroscopic capability, over a range of resolving powers from R ($\equiv\lambda/\Delta\lambda$) ~500 to R~20000.

https://www.eso.org/public/images/ann15056a/

E-ELT



Credit: ESO

And now some fun at the end

How could aliens look like?
How to see aliens?

- Dyson spheres
- Giant structures around planets and transit light curve
- How a Moon would be seen in the light curve?
- Life as we know it from the Earth?

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 32: 737–755, 1976 December

PARTICLES, ENVIRONMENTS, AND POSSIBLE ECOLOGIES IN THE JOVIAN ATMOSPHERE

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Center for Radiophysics and Space Research, Cornell University
Received 1975 December 11; revised 1976 June 1

ABSTRACT

The eddy diffusion coefficient is estimated as a function of altitude, separately for the Jovian troposphere and mesosphere. The growth-rate and motion of particles is estimated for various substances: the water clouds are probably nucleated by NH_4Cl, and sodium compounds are likely to be absent at and above the levels of the water clouds. Complex organic molecules produced by the Lα photolysis of methane may possibly be the absorbers in the lower mesosphere which account for the low reflectivity of Jupiter in the near-ultraviolet. The optical frequency chromophores are localized at or just below the Jovian tropopause. Candidate chromophore molecules must satisfy the condition that they are produced sufficiently rapidly that convective pyrolysis maintains the observed chromophore optical depth. Organic molecules and polymeric sulfur produced through H_2S photolysis at $\lambda > 2300$ Å probably fail this test, even if a slow, deep circulation pattern, driven by latent heat, is present. The condition may be satisfied if complex organic chromophores are produced with high quantum yield by NH_3 photolysis at $\lambda < 2300$ Å. However, Jovian photoautotrophs in the upper troposphere satisfy this condition well, even with fast circulation, assuming only biochemical properties of comparable terrestrial organisms. Unless buoyancy can be achieved, a hypothetical organism drifts downward and is pyrolyzed. An organism in the form of a thin, gas-filled balloon can grow fast enough to replicate if (i) it can survive at the low mesospheric temperatures, or if (ii) photosynthesis occurs in the troposphere. If hypothetical organisms are capable of slow, powered locomotion and coalescence, they can grow large enough to achieve buoyancy. Ecological niches for sinkers, floaters, and hunters appear to exist in the Jovian atmosphere.

Subject headings: planets: atmospheres — planets: Jupiter

Nice reading

- http://www.nature.com/scitable/blog/postcards-from-the-universe/the_curious_idea_of_jovian

- Carl Sagan - Cosmos

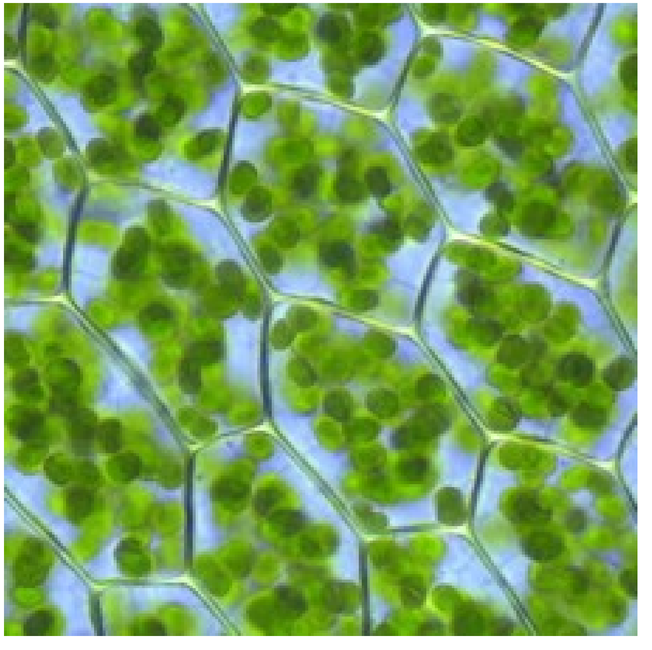
Sinkers and floaters in Jupiter atmosphere

- https://www.youtube.com/watch?v=uakLB7Eni2E

Why are the plants green?

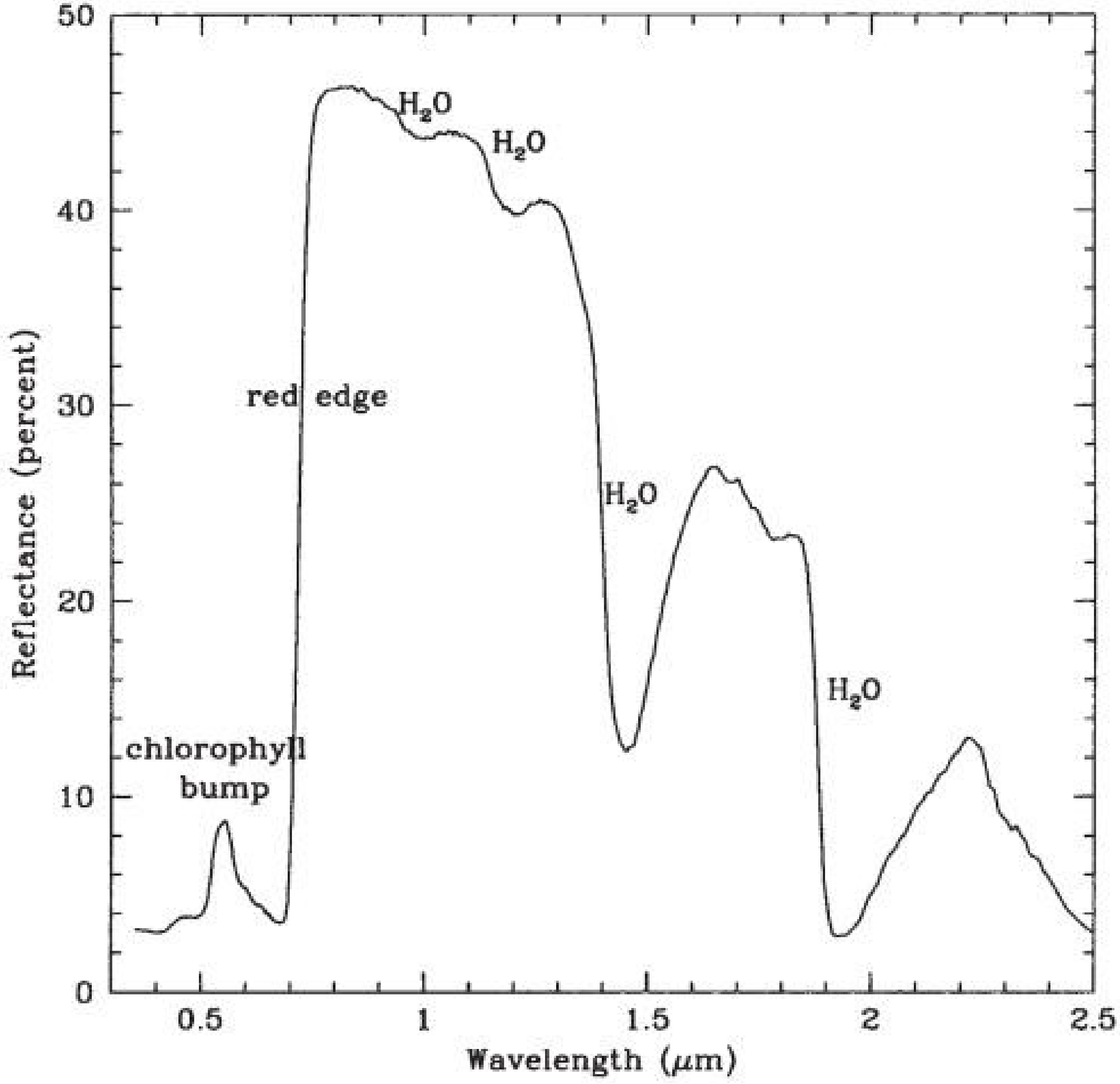
Phosynthesis

$$6\,CO_2 + 6\,H_2O \rightarrow C_6H_{12}O_6 + 6\,O_2$$



Chlorophyll - Credit: Wikimedia Commons

Red edge



Kaltenegger et al., 2009, http://arxiv.org/ftp/arxiv/papers/0903/0903.3371.pdf

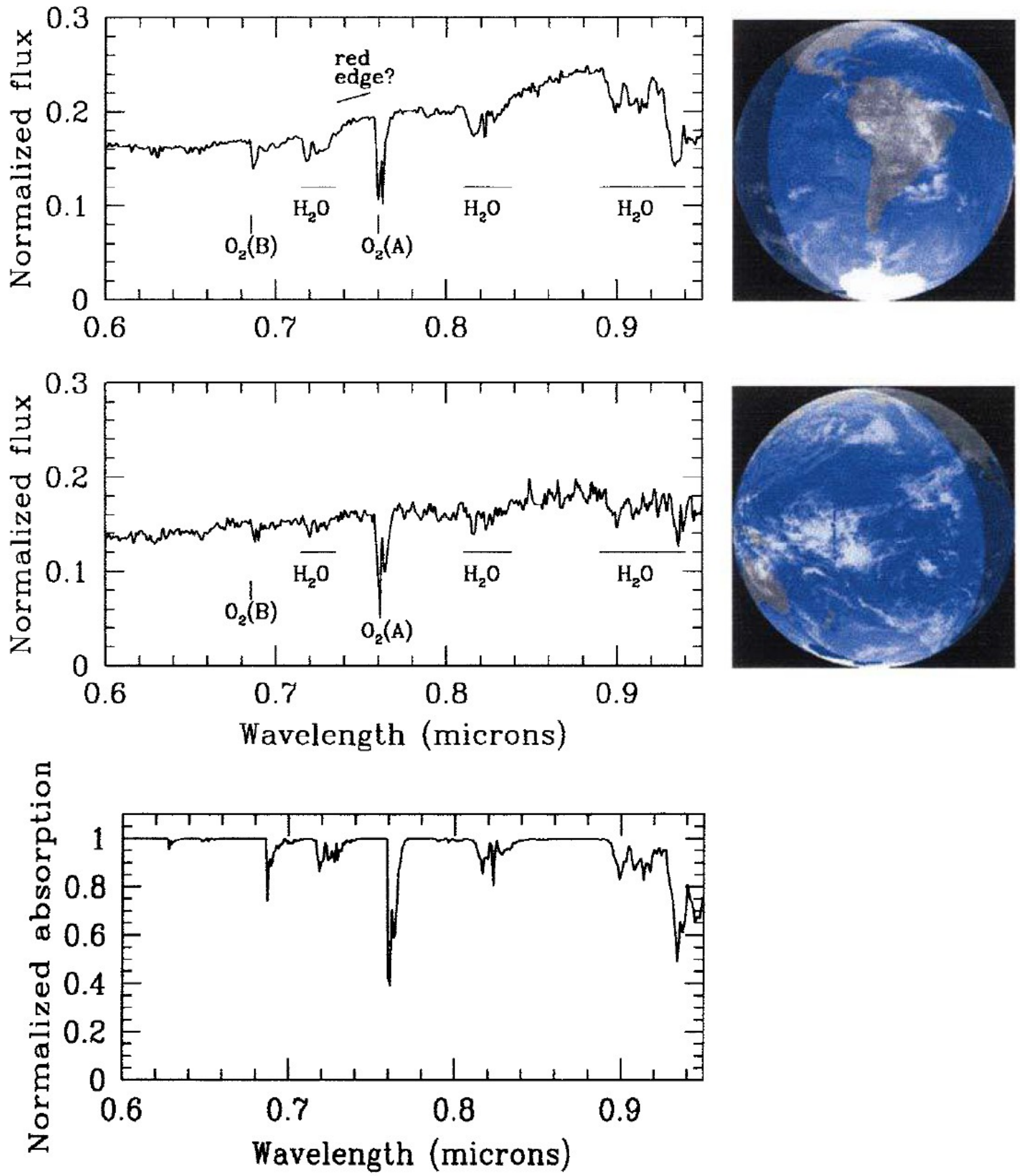
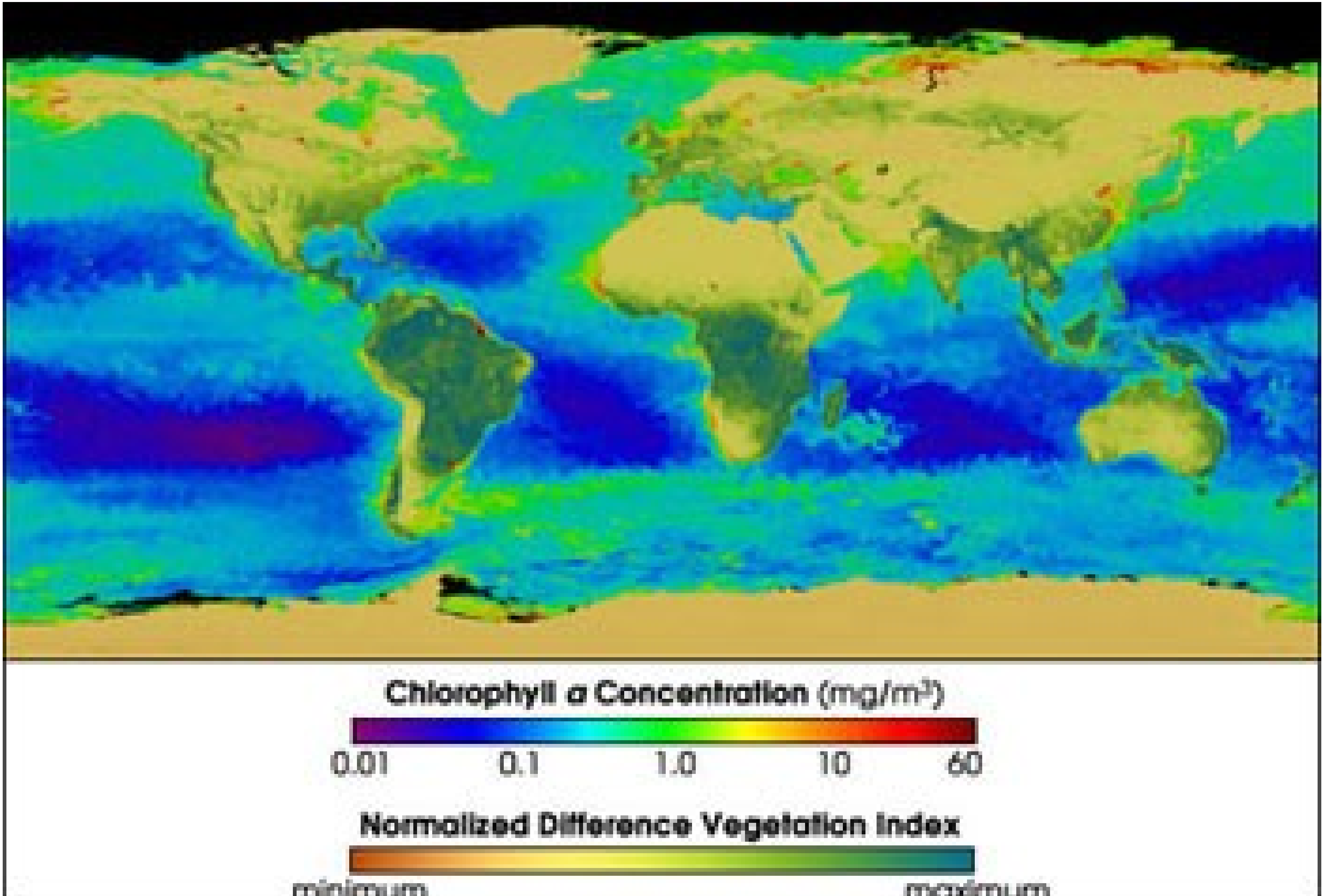


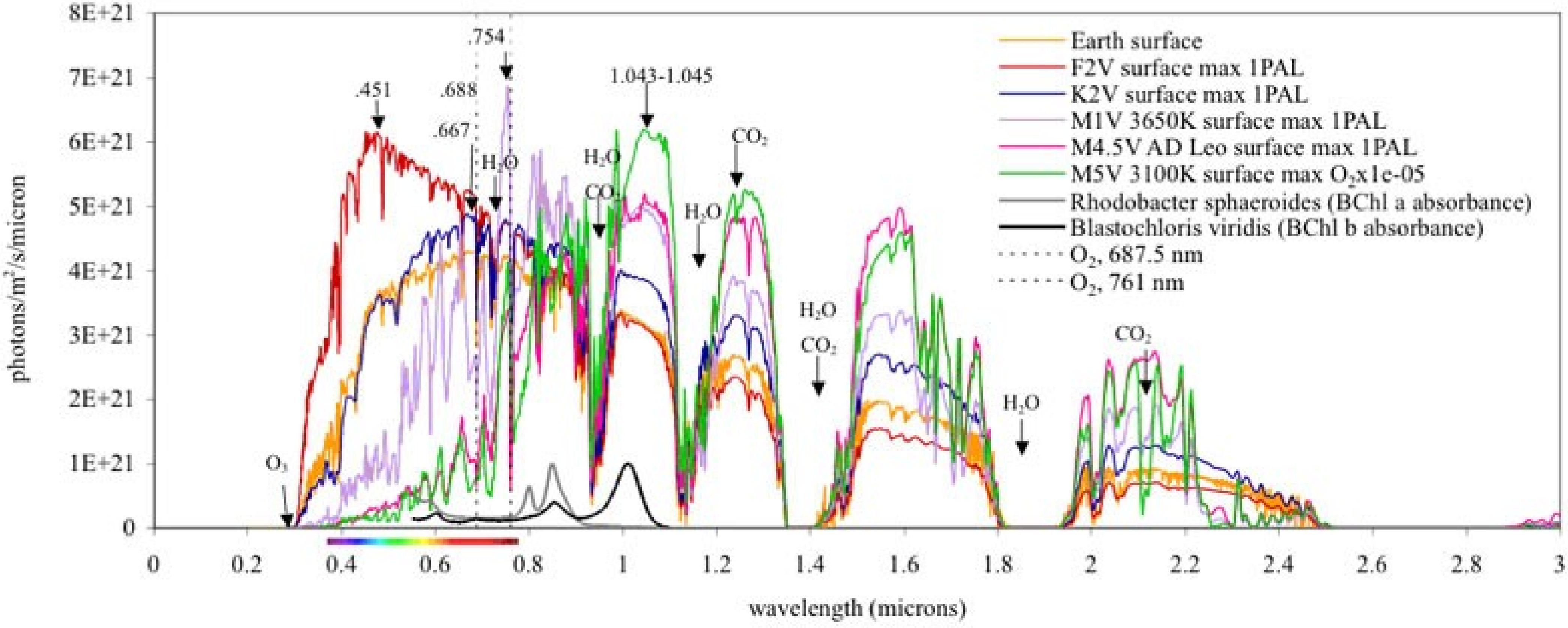
FIG. 4. Earthshine observations from APO. Top panel: Earthshine observations on 8 February 2002. The viewing geometry (including cloud coverage at the time of observations) of Earth from the Moon is shown in the right image (http://www.fourmilab.ch/earthview/vplanet.html). **Middle panel:** Same as the top panel for 16 February 2002. The viewing geometry of Earth includes much more vegetation in the top panel than in the middle panel. **Bottom panel:** An absorption spectrum through Earth's atmosphere from Kitt Peak National Observatory (ftp://ftp.noao.edu/catalogs/atmospheric/transmission/) smoothed to approximately the same resolution as the APO Earthshine data. Note the different *y*-axis on the absorption spectrum; the spectral features are much deeper than in the Earthshine spectrum, and there is no red edge feature.

https://www.cfa.harvard.edu/~kchance/EPS238-2012/refdata/Seager-red-edge-2005.pdf



Credit: http://www.giss.nasa.gov/research/news/20070411/

Different colours of plants?



Credit: http://www.giss.nasa.gov/research/news/20070411/

Credit: http://www.giss.nasa.gov/research/news/20070411/

Artificial transiting structures

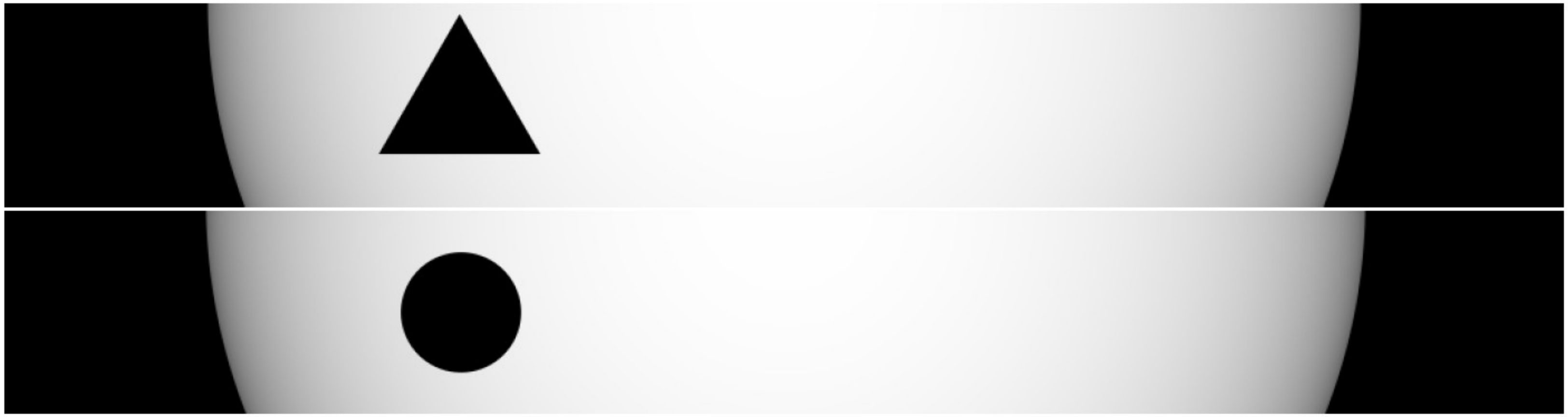


Fig. 1.— Transiting objects: A triangular equilateral object (upper strip) and the best-fit spherical planet and star (lower strip, same scale as upper strip). The star model for the triangle transit is HD209458 with limb darkening coefficients $u_1 + u_2 = 0.64$ and $u_1 - u_2 = -0.055$ (Brown et al. 2001). The triangle edge length is 0.280 stellar radius. The object impact parameter is $b = 0.176$ (transit center). The best-fit sphere has an impact parameter of $b = 0.19$ and a radius of $r_p = 1.16\ R_{Jupiter}$. Best-fit star has $u_1 + u_2 = 0.66$, with $u_1 - u_2$ set to zero, and a non-significant radius increase of 0.5%. Fitting object oblateness f, either with zero or 90° obliquity to maintain lightcurve symmetry, converges to solutions not significantly different from the case $f = 0$.

Arnold, 2005, ApJ

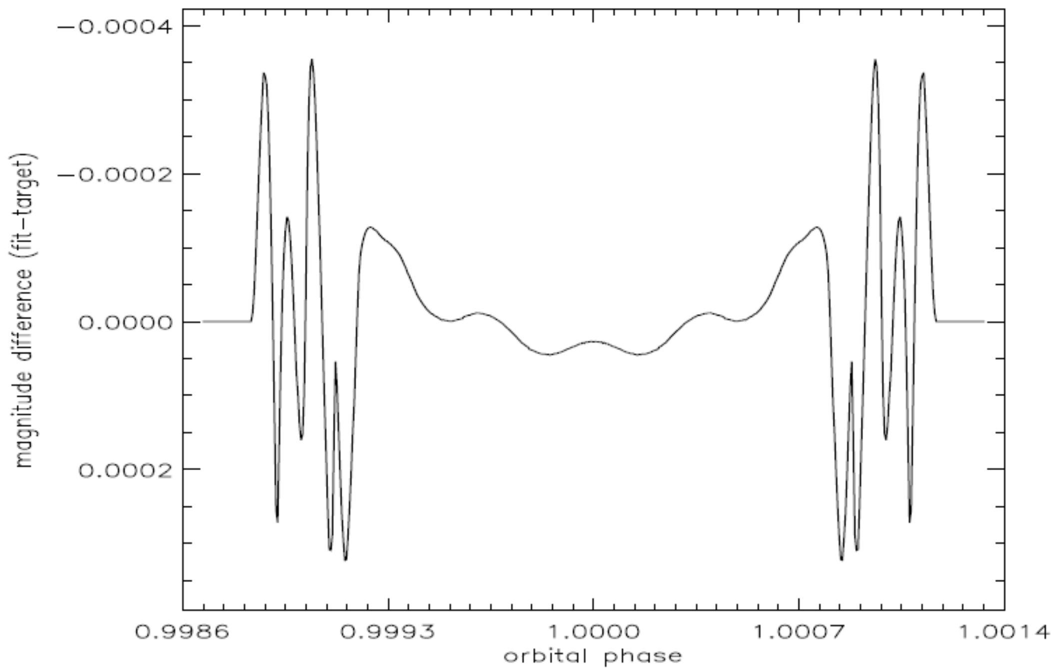


Fig. 3.— Magnitude difference between the transit of a rotating triangular object (same as shown Fig.1) and the best-fit spherical planet and star. The triangle makes seven turns on itself during the transit of HD209458 at $b = 0.5$. The fit gives a transiting sphere of 1.17 $R_{Jupiter}$ at $b = 0.51$ and a star with $u_1 + u_2 = 0.67$, $u_1 - u_2 = 0$ and $R_\star$ increased by 1%. Here, the curve is symmetric because the rotating object is in a symmetric position at transit center with respect to object orbital plane. If it would not be the case, then the curve would be asymmetric.

Arnold, 2005, ApJ

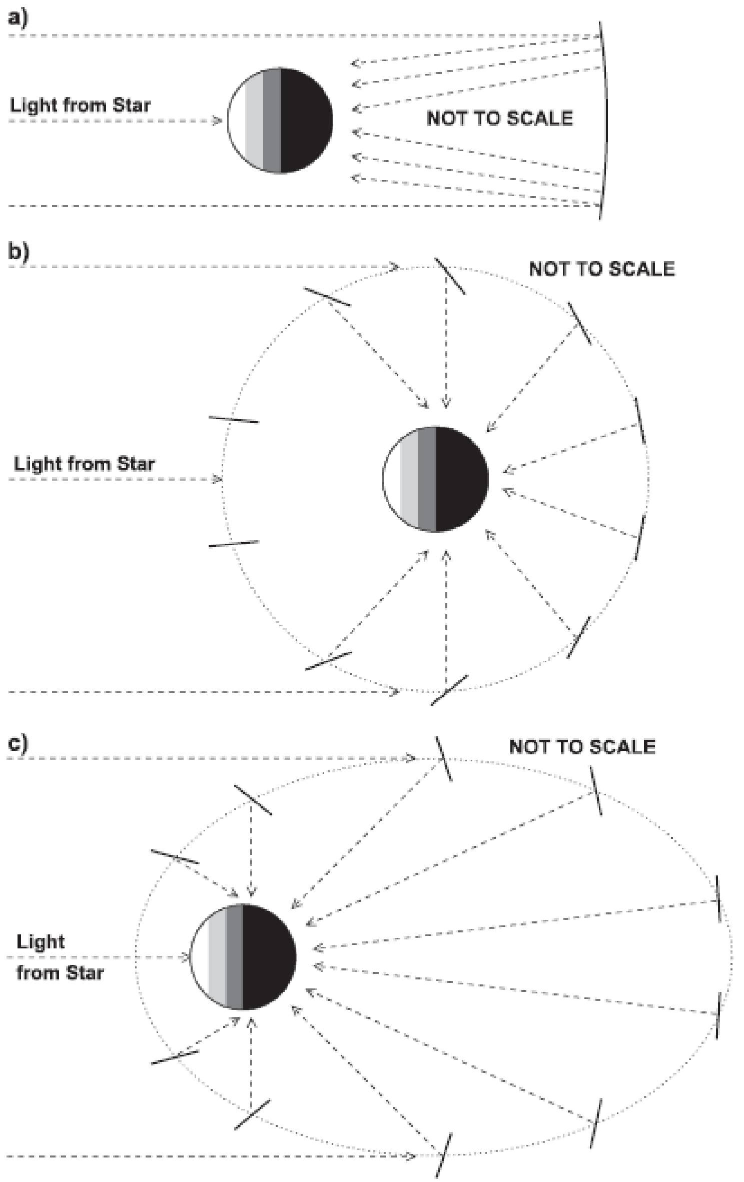


Figure 1. Schematic illustration of three methods of dark-side illumination (not to scale). Planetary grayscale bands indicate different levels in stellar illumination. In the three cross-sectional drawings, (a) shows a large circular or annular mirror stationed at the L2 Lagrange point, (b) shows multiple small mirrors in circular orbits, (c) shows multiple small mirrors in elliptical orbits designed to maximize the duty cycle of the mirrors.

The Astrophysical Journal, 809:139 (13pp), 2015 August 20

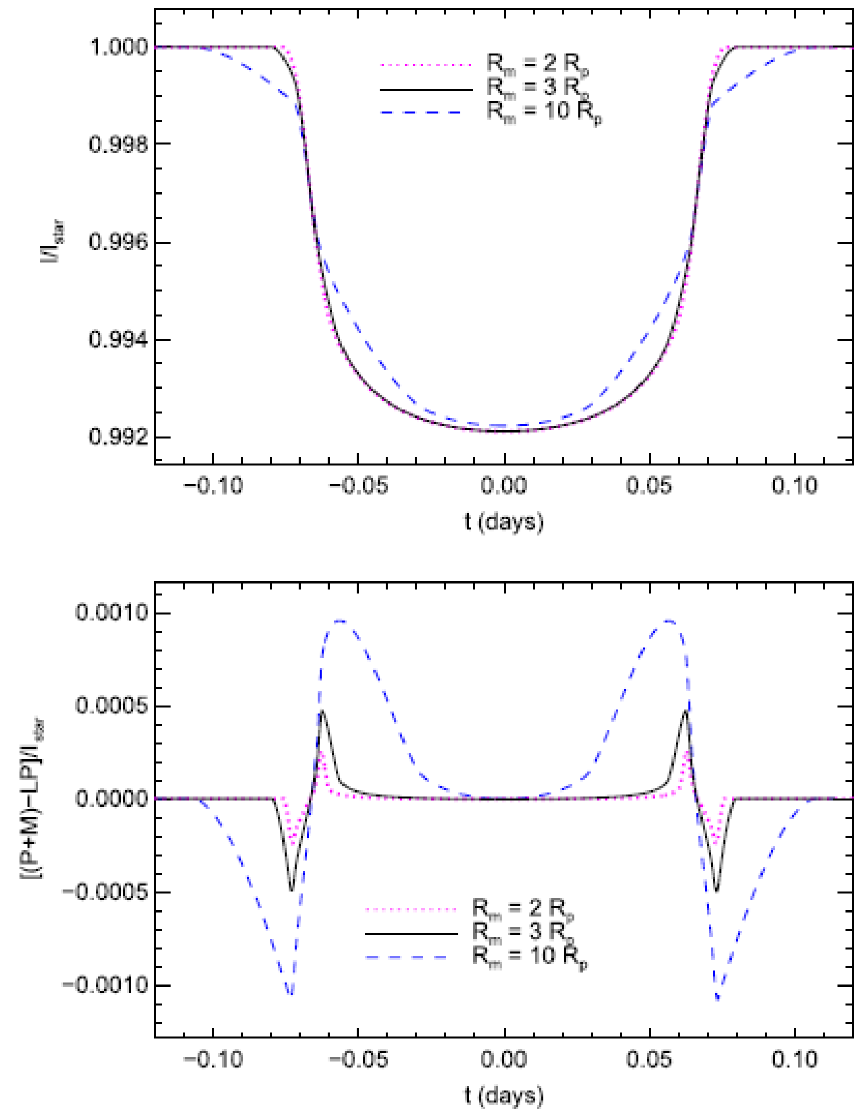
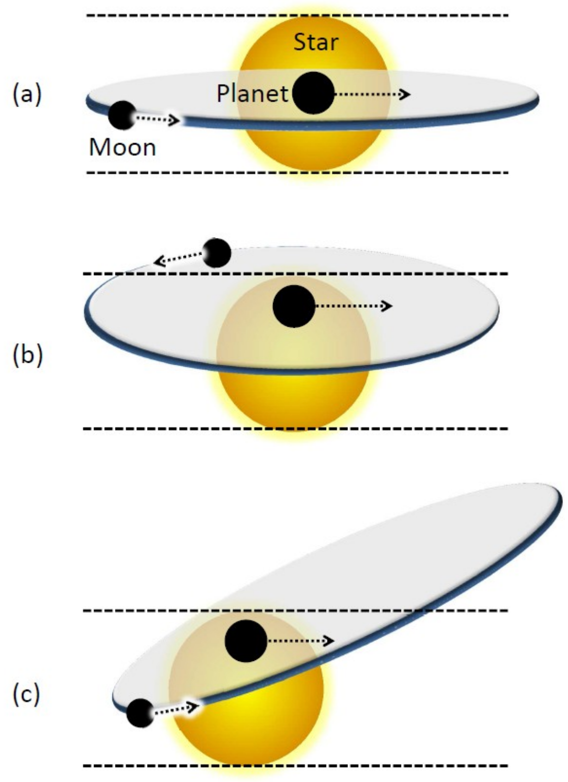
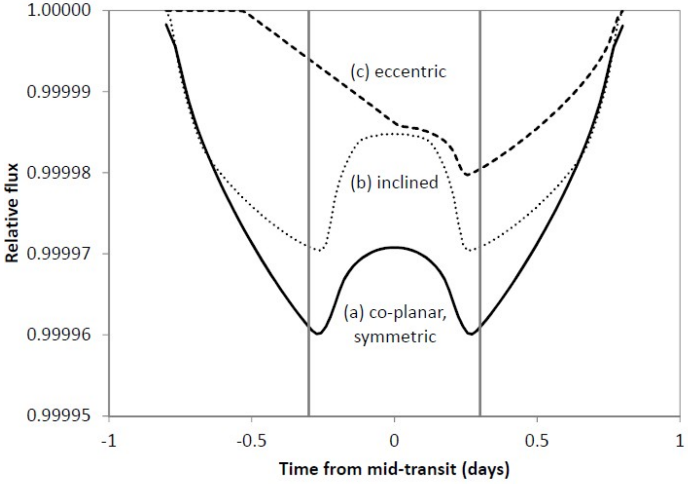


Figure 5. Top panel: transit light curves that result when a planet with $R_p = 2R_{\rm Earth}$, located in the middle of the star's HZ, passes in front of an M5 star. In all cases the planet is surrounded by a constant-absorptance mirror fleet, with $R_m = 3R_P$ (solid), $R_m = 2R_p$ (dotted), or $R_m = 10R_p$ (dashed). Bottom panel: difference between the mirror fleet transit light curve $(P + M)$ and the one for a solitary larger planet (LP) that would produce the same depth of transit, relative to the stellar intensity, for the same situations.

http://iopscience.iop.org/article/10.1088/0004-637X/809/2/139/pdf

Exo-moons





Hippke, 2015, ApJ - http://arxiv.org/pdf/1502.05033v2.pdf

Kepler star
www.planethunters.org

Kepler star

- Why is so unique?
- Why caught attention?

    - IRREGULARITY

KIC8462852

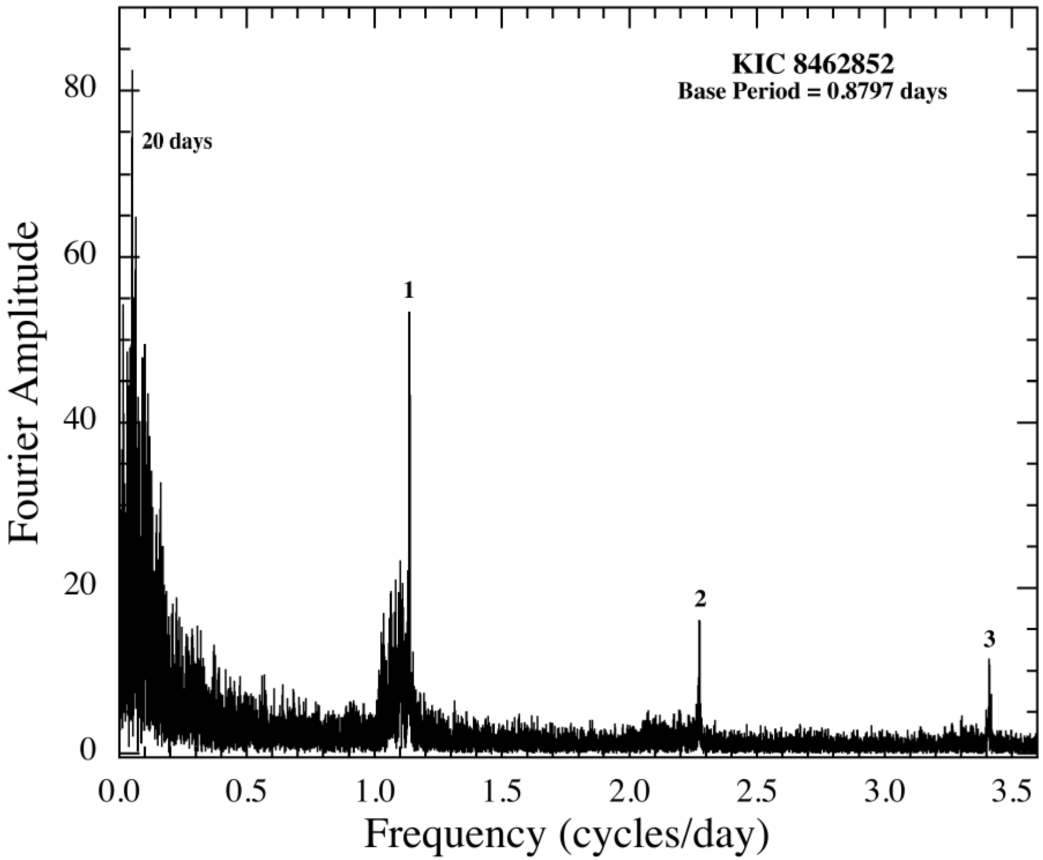


Figure 2. Fourier transform for KIC 8462852. The peaks are labeled with the harmonic numbers starting with 1 for the base frequency. Refer to Section 2.1 for details.

http://arxiv.org/pdf/1509.03622v1.pdf

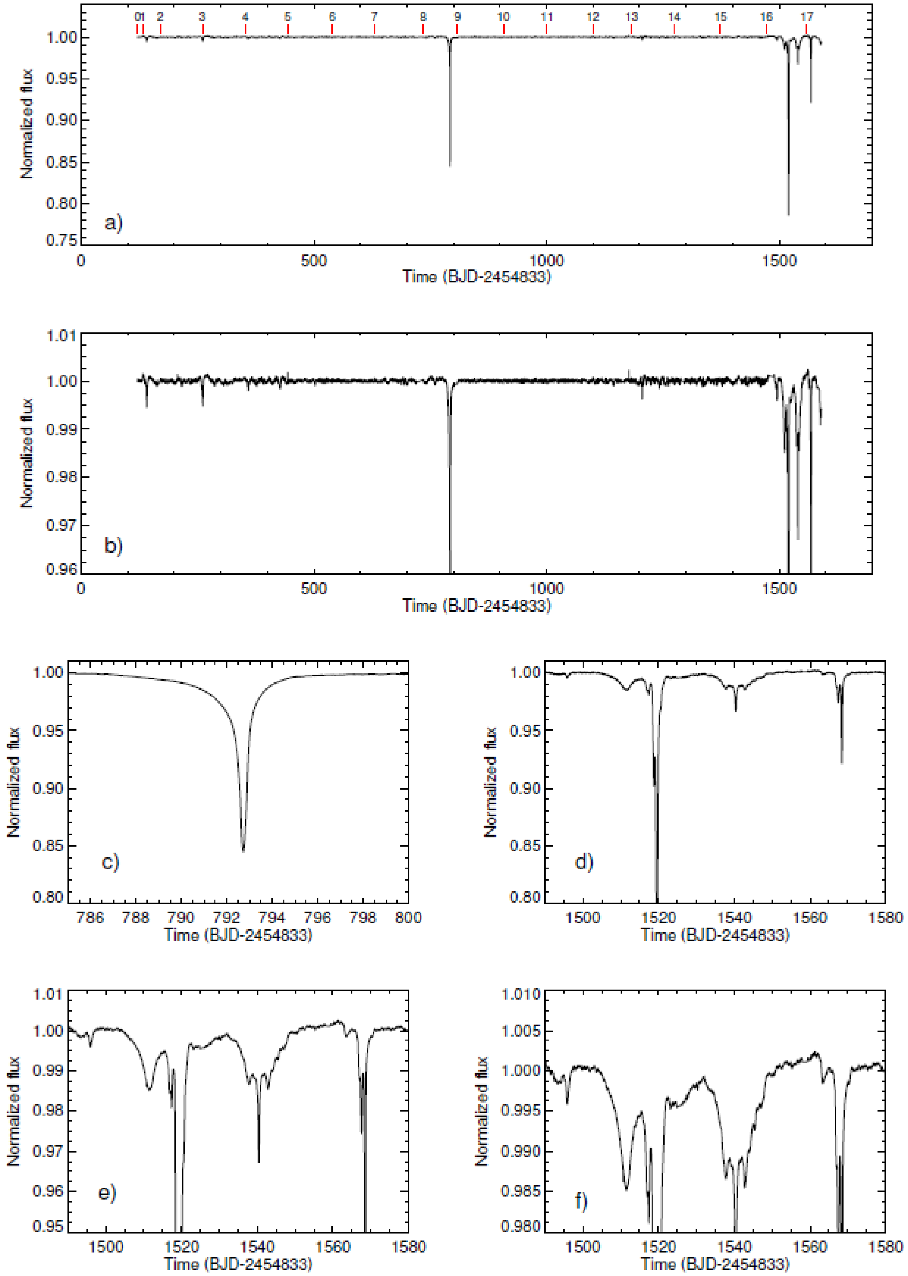


Figure 1. Montage of flux time series for KIC 8462852 showing different portions of the 4-year *Kepler* observations with different vertical scalings. The top two panels show the entire *Kepler* observation time interval. The starting time of each *Kepler* quarter is marked and labeled with a red vertical line in the top panel '(a)'. Panel '(c)' is a blowup of the dip near day 793, (D800). The remaining three panels, '(d)', '(e)', and '(f)', explore the dips which occur during the 90-day interval from day 1490 to day 1580 (D1500). Refer to Section 2.1 for details. See Section 2.1 for details.

http://arxiv.org/pdf/1509.03622v1.pdf

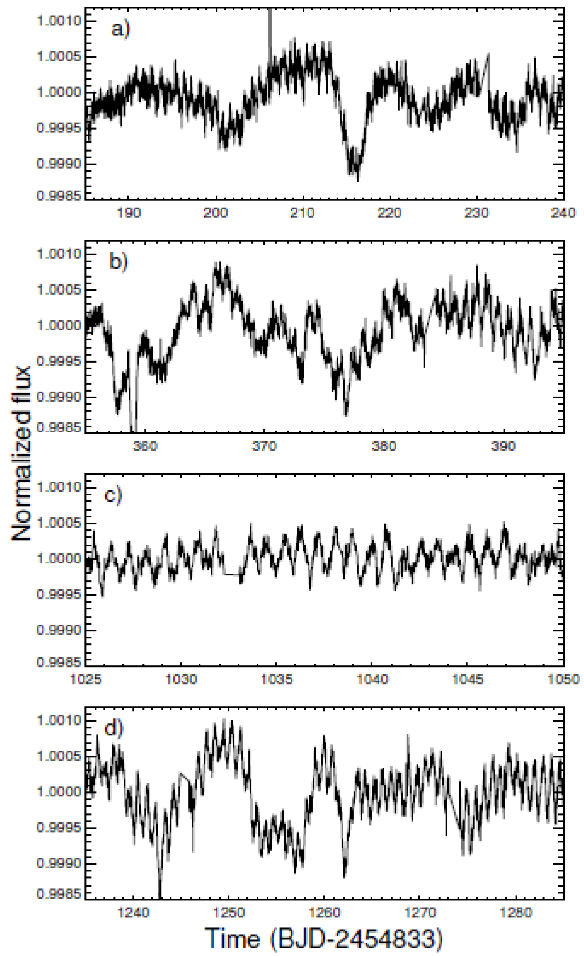


Figure 4. Stacked plots showing a zoomed-in portion of the *Kepler* light curve. The star's rotation period of 0.88 d is seen in each panel as the high-frequency modulation in flux. With the exception of panel 'c)', a longer term (10 – 20 day) brightness variation is observed, also present in the FT shown in Figure 2. Refer to Section 2.1 for details.

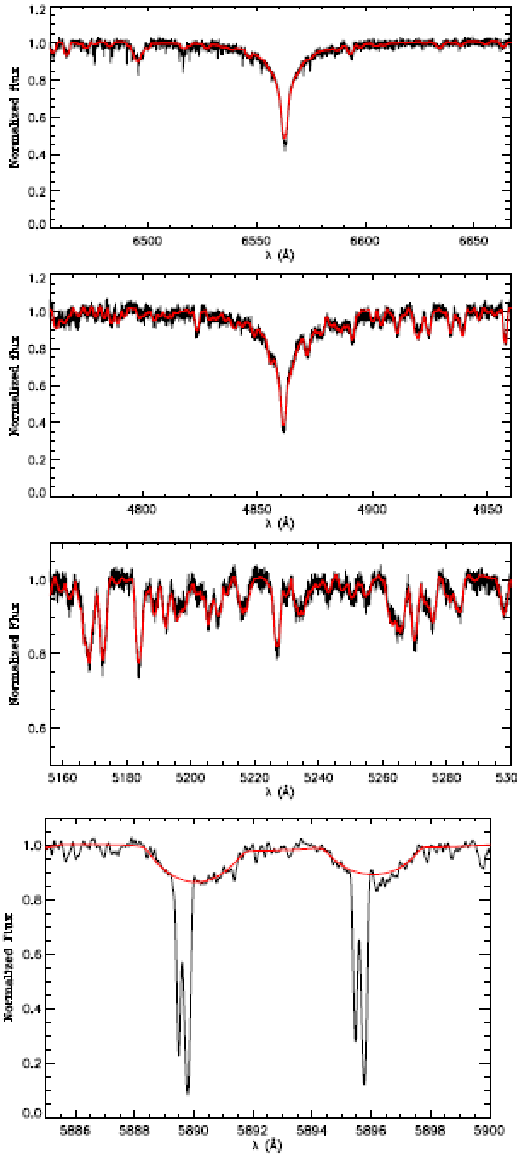


Figure 5. NOT spectrum closeups for KIC 8462852, the best fit stellar model shown in red. Panels show region near H α, H β, Mg, and Na D (top to bottom). The bottom panel shows both the stellar (broad) and interstellar (narrow) counterparts of the Na D lines. Refer to Section 2.2 for details.

tional velocity, and rotation period (Section 2.1), we determine a stellar rotation axis inclination of 68 degrees.

http://arxiv.org/pdf/1509.03622v1.pdf

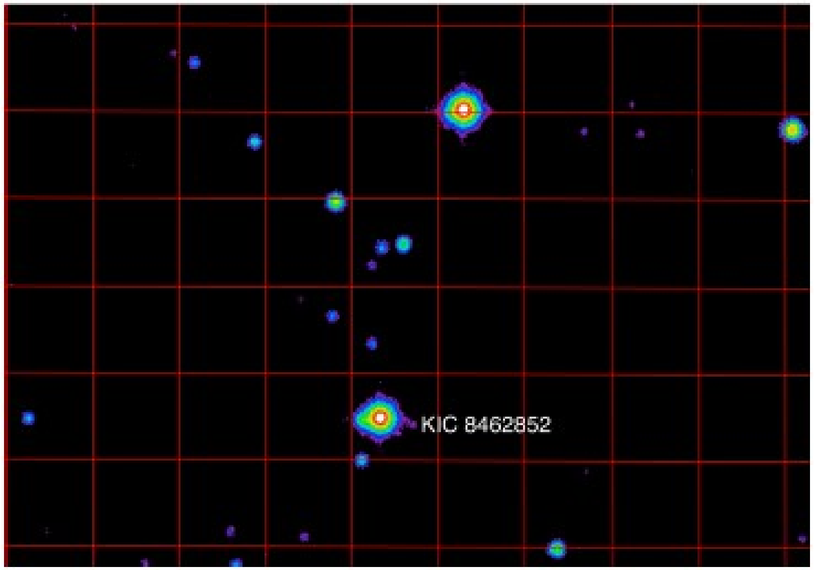


Figure 6. UKIRT image for KIC 8462852 and another bright star for comparison, showing that it has a distinct protrusion to the left (east). For reference, the grid lines in the image are $10'' \times 10''$. Refer to Section 2.3 for details.

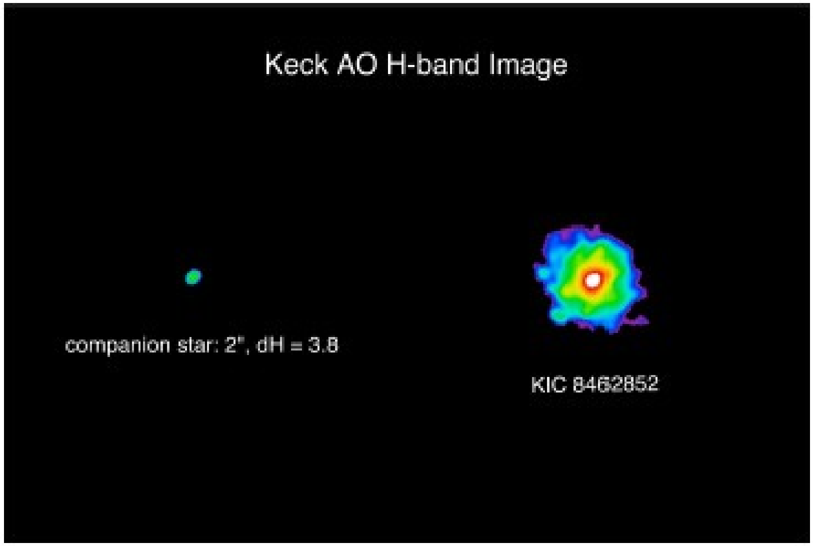


Figure 7. Keck AO H-band image for KIC 8462852 showing the companion was detected with a $2''$ separation and a magnitude difference $\Delta H = 3.8$. Refer to Section 2.3 for details.

http://arxiv.org/pdf/1509.03622v1.pdf

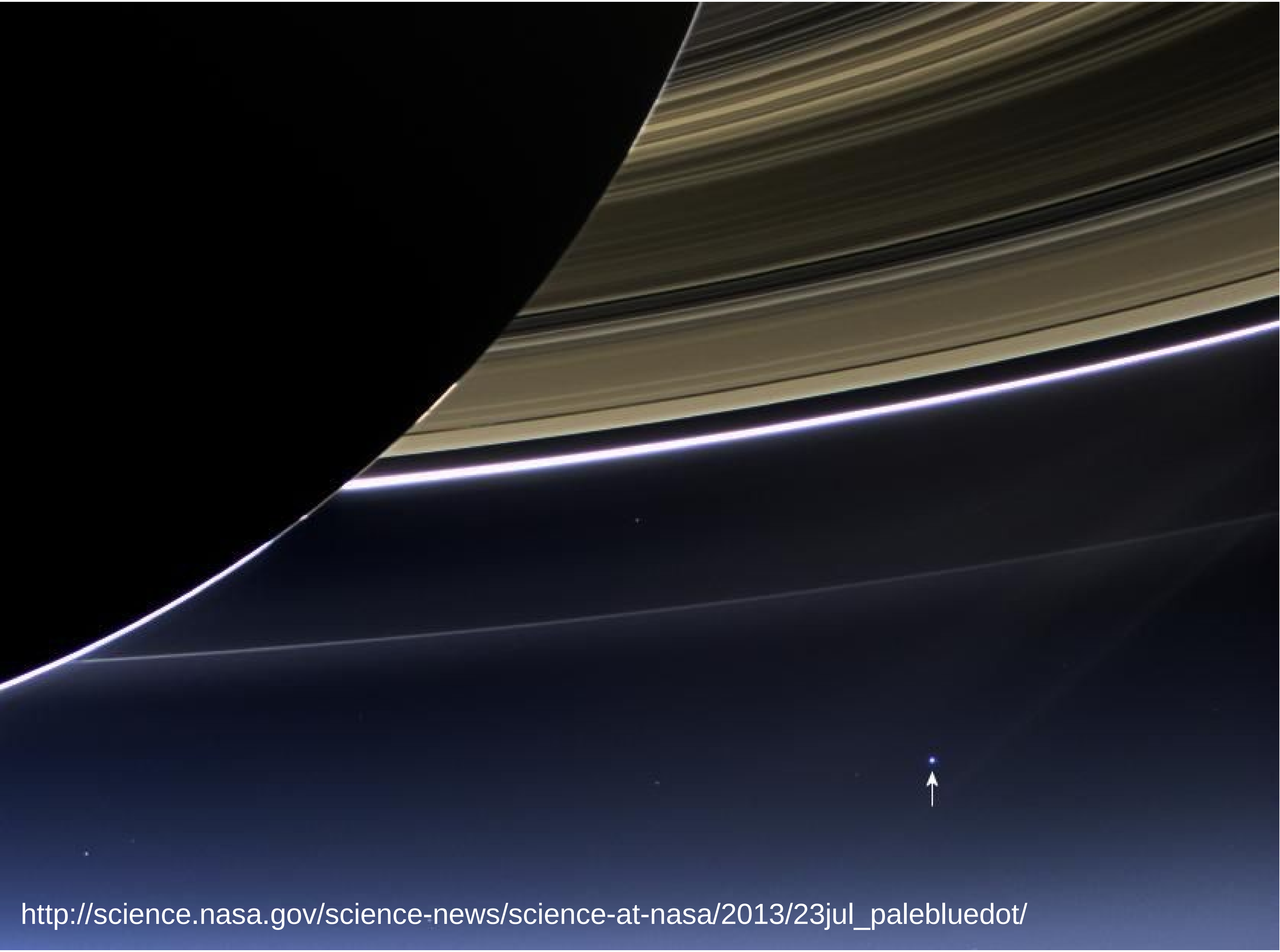
Explanations of a Kepler star mystery?

- Probably a comet which broke apart and now is orbiting a star
- A result of a collison of large bodies – however no IR excess observed
- Aliens? - perhaps not, not yet

How would the Earth look from space?

Pale blue dot

http://daleandersen.seti.org/Dale_Andersen/A_Pale_Blue_Dot.html


http://science.nasa.gov/science-news/science-at-nasa/2013/23jul_palebluedot/

Thank you very much