The search for bio and technosignatures

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Technosignatures vs biosignatures

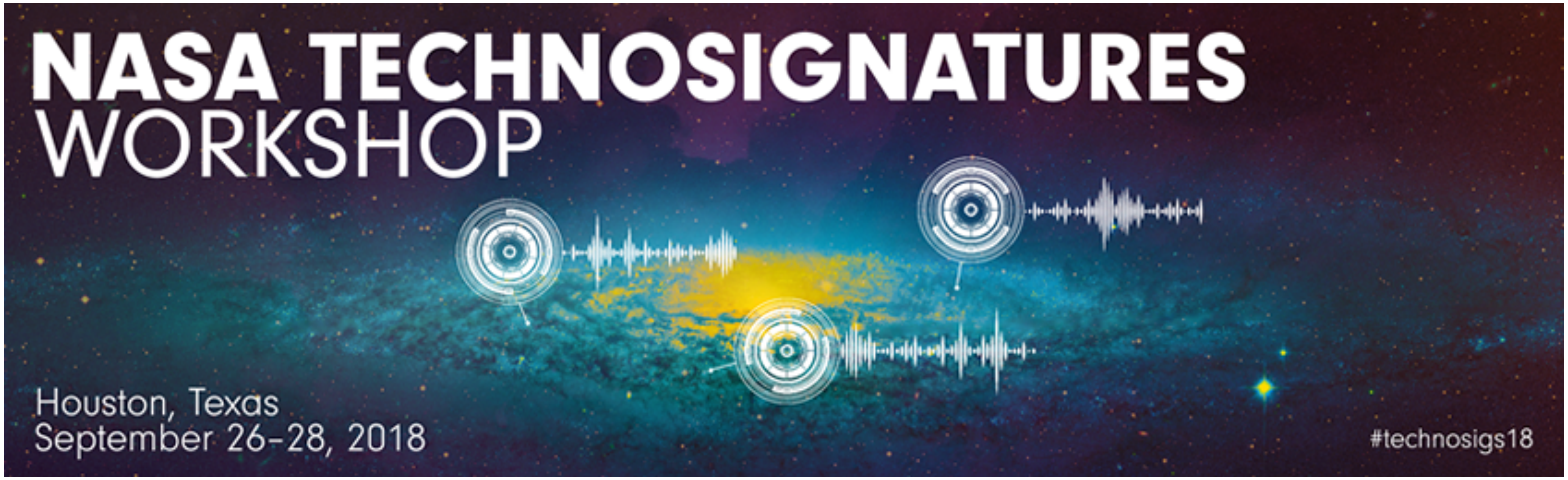
- The presence of a biosphere on a planet results in signatures that can, in principle, be investigated remotely either as spectral lines or as generic chemical imbalance or thermodynamical disequilibrium (as in Krissansen-Totton et al 2016; see also Lovelock 1965, Kleidon 2010)

- Two classes:

  - Biosignatures are sign or signals that would allow us to infer the existence of life elsewhere in the universe

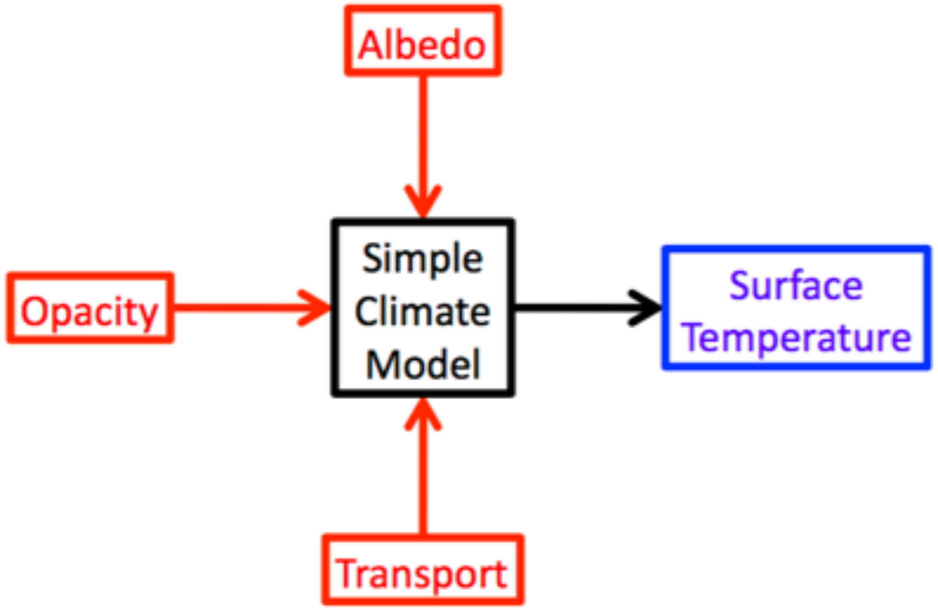
  - Technosignatures are sign or signals that would allow us to infer the existence of *technological* life elsewhere in the universe

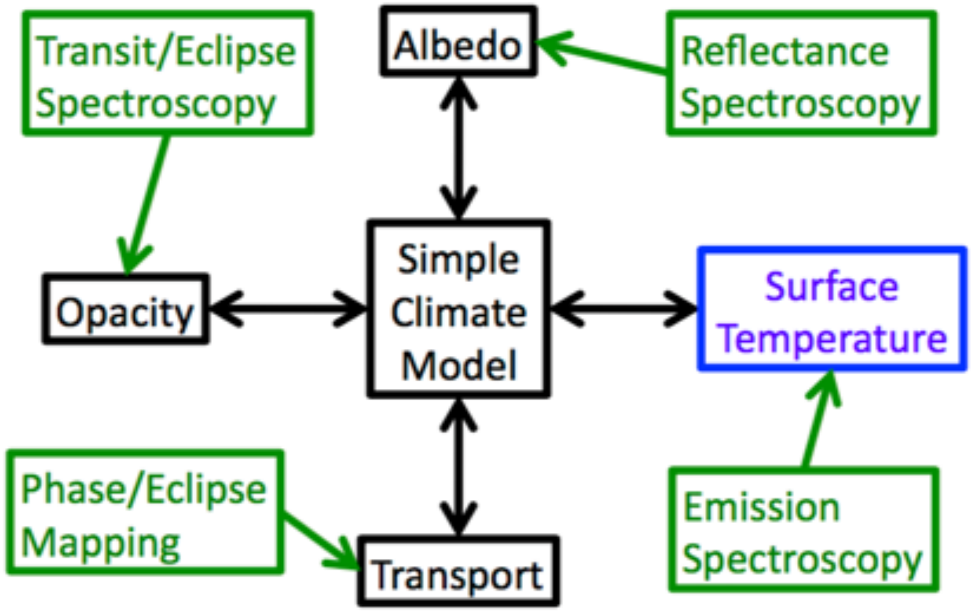
- In the past, the search for technosignatures was mainly restricted to radio or optical communications, either intentional (e.g. beacons) or unintentional (leakage)

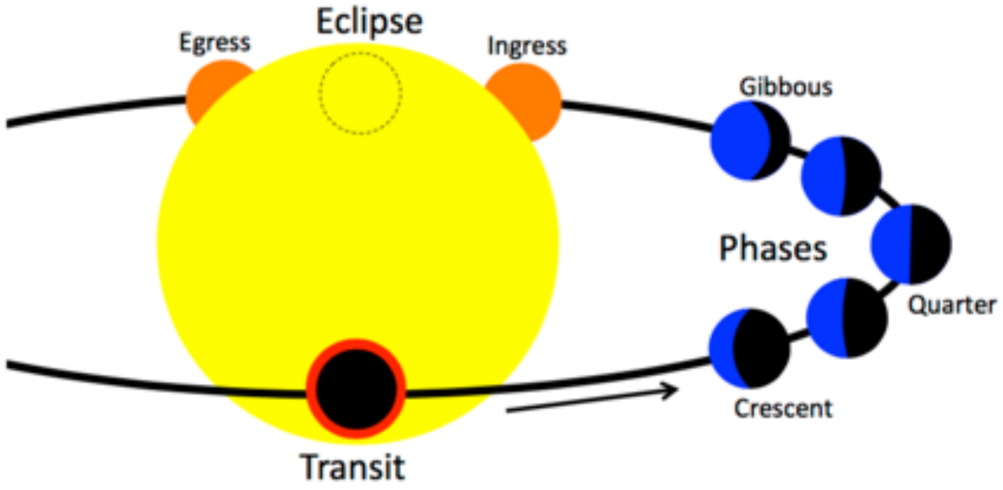


- ~50 invited participants
- Current state + near and future goals
- NASA role and partnerships

Next step: characterization





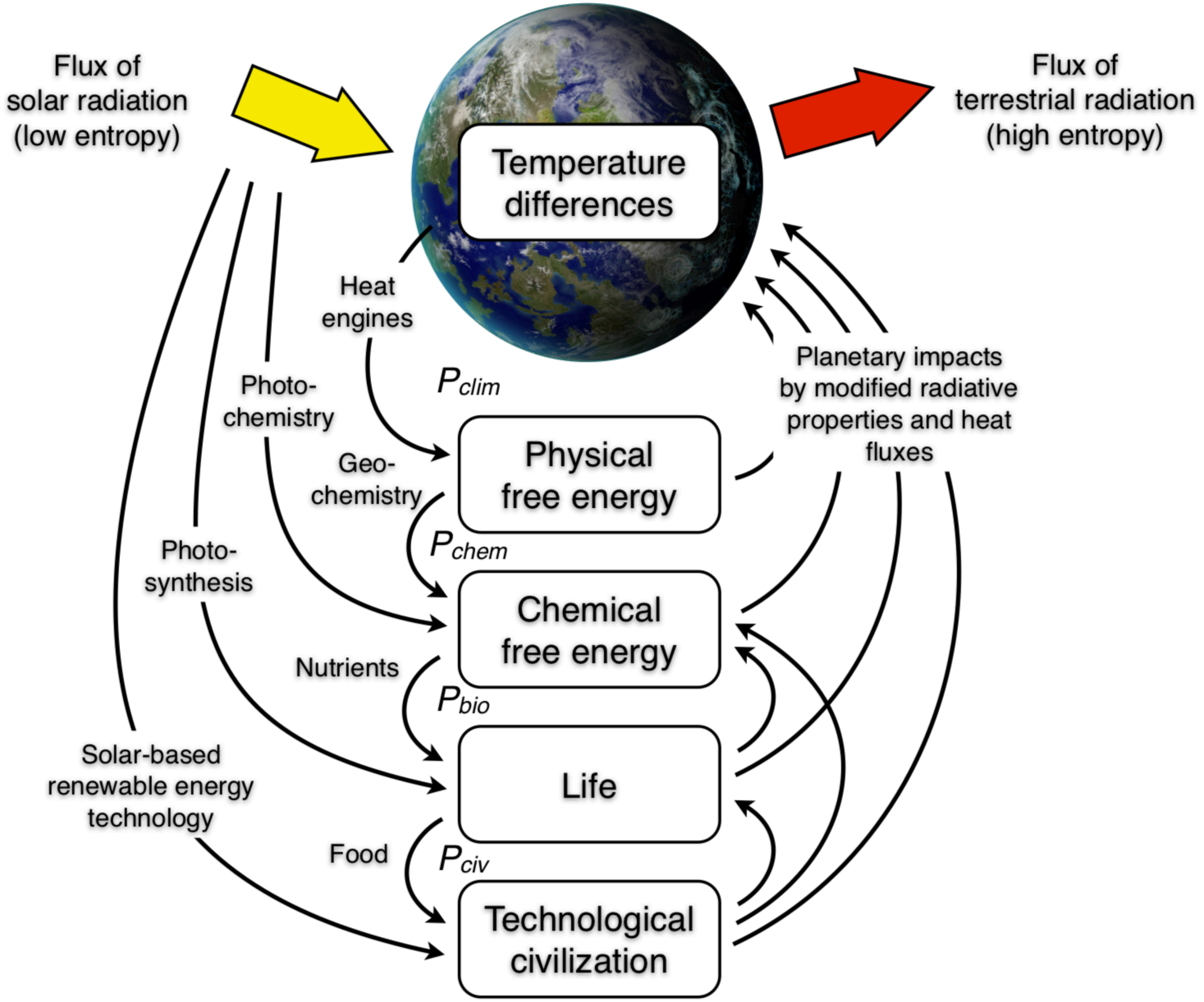


Cowan et al. 2015

in principle, the main factors influencing the climate of exoplanets can be empirically determined by photometric and spectroscopic observations

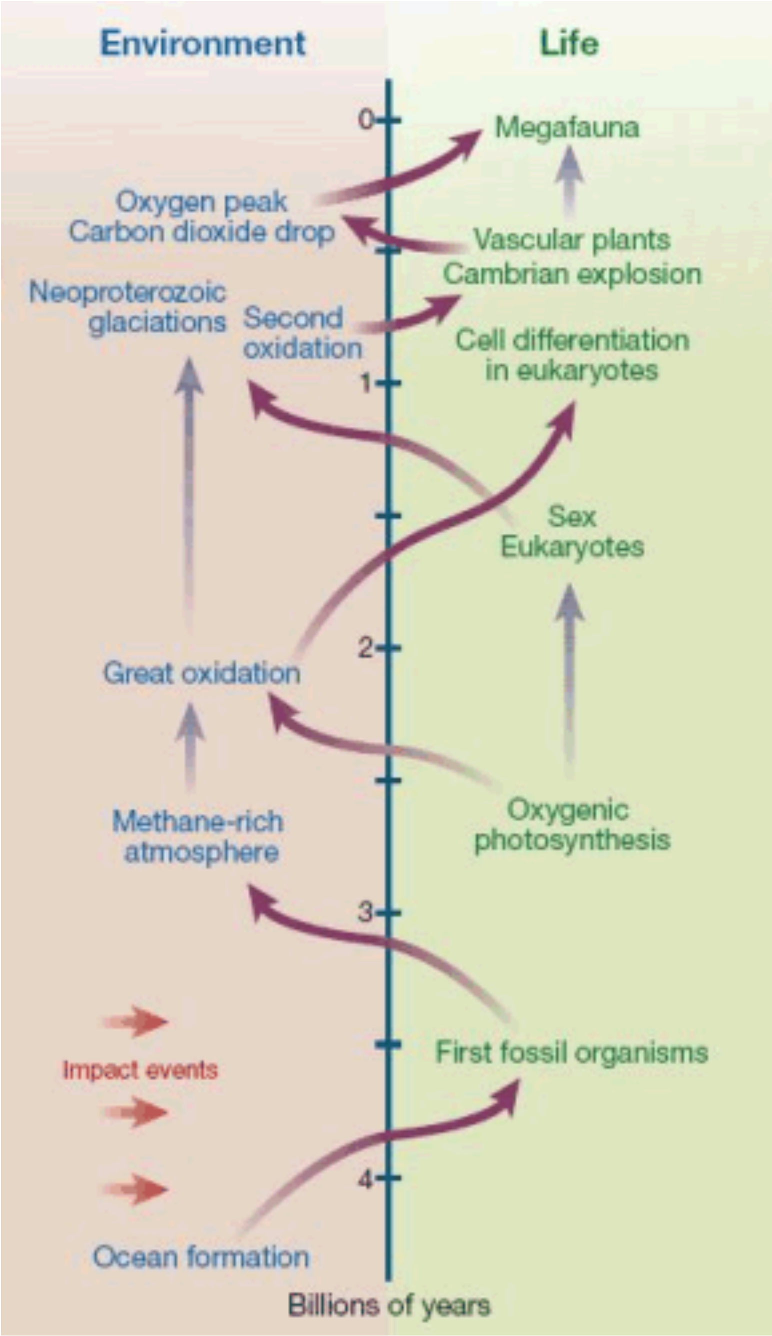
for terrestrial planets this will be extremely difficult, but might be within the reach of next-decade instruments (JWST, E-ELT)

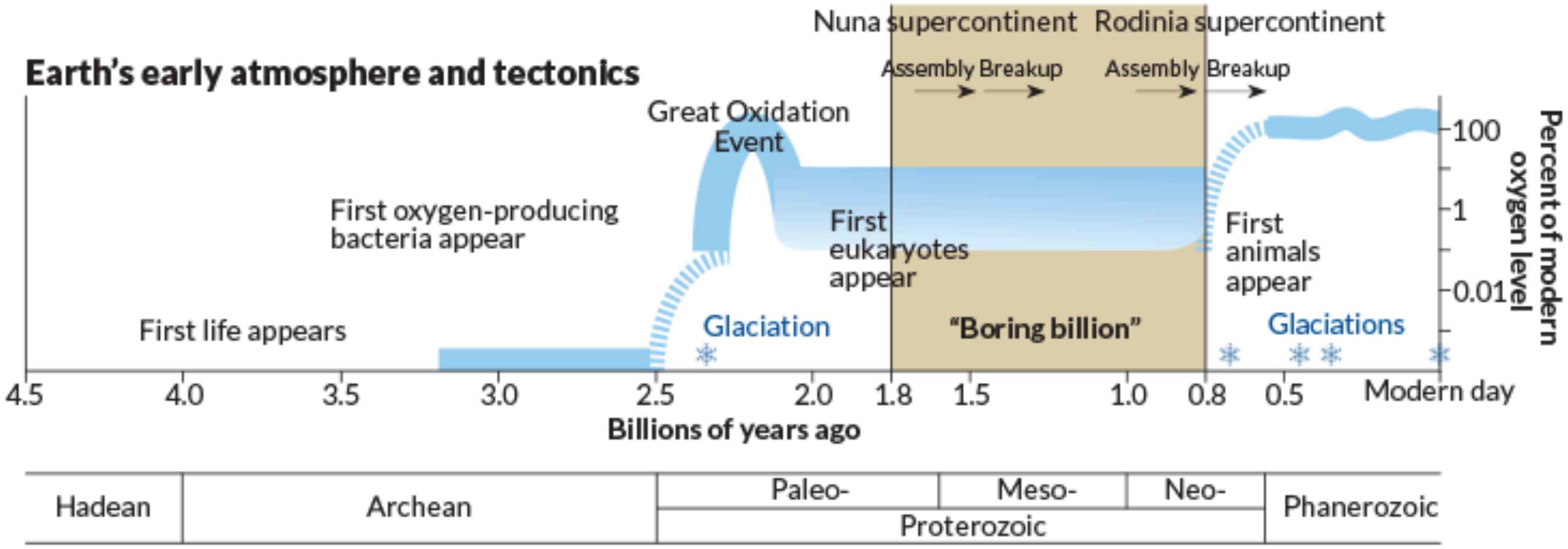
Thermodynamics and life



Frank, Kleidon & Alberti 2017

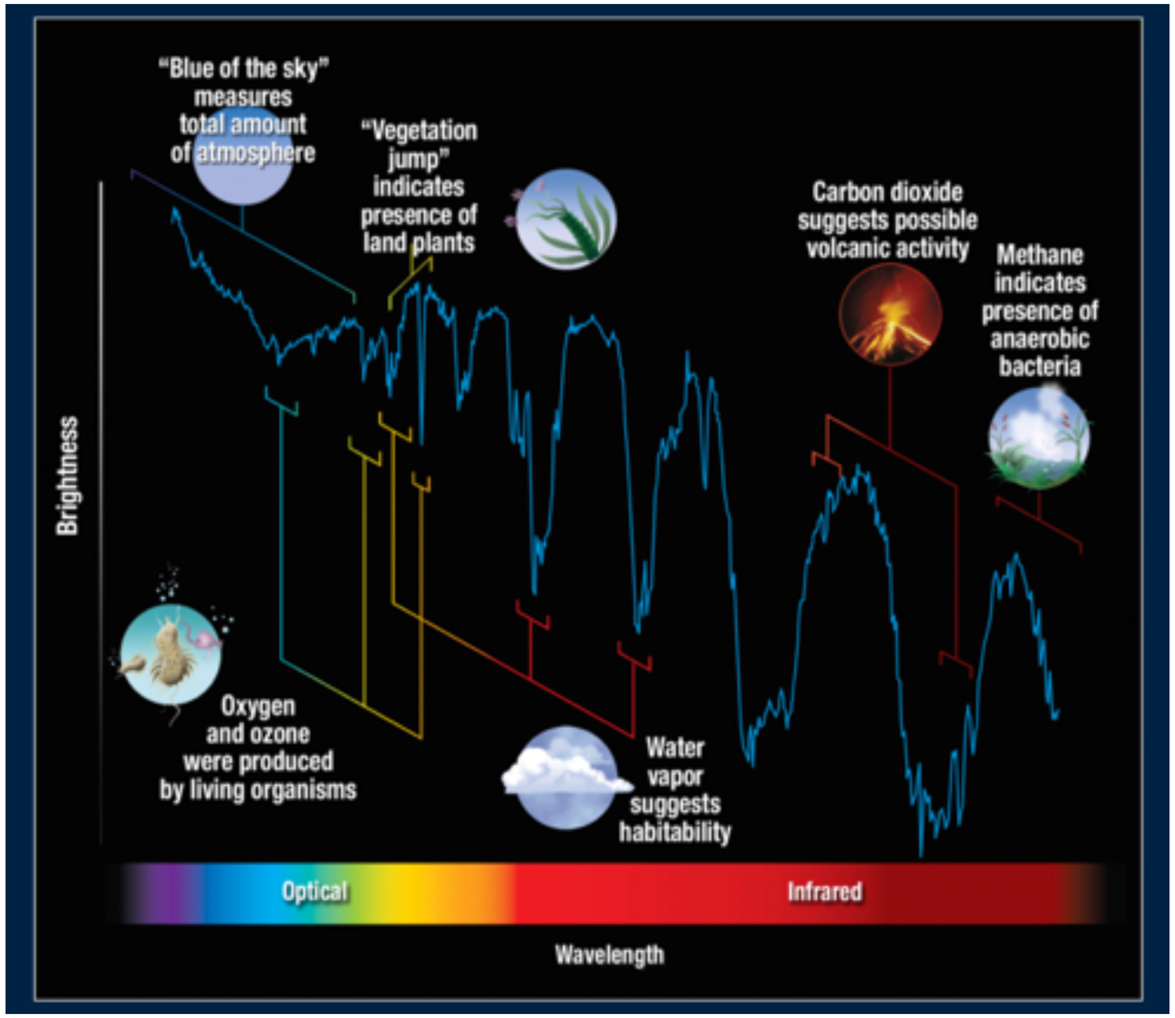
Coevolution of life and planetary environment



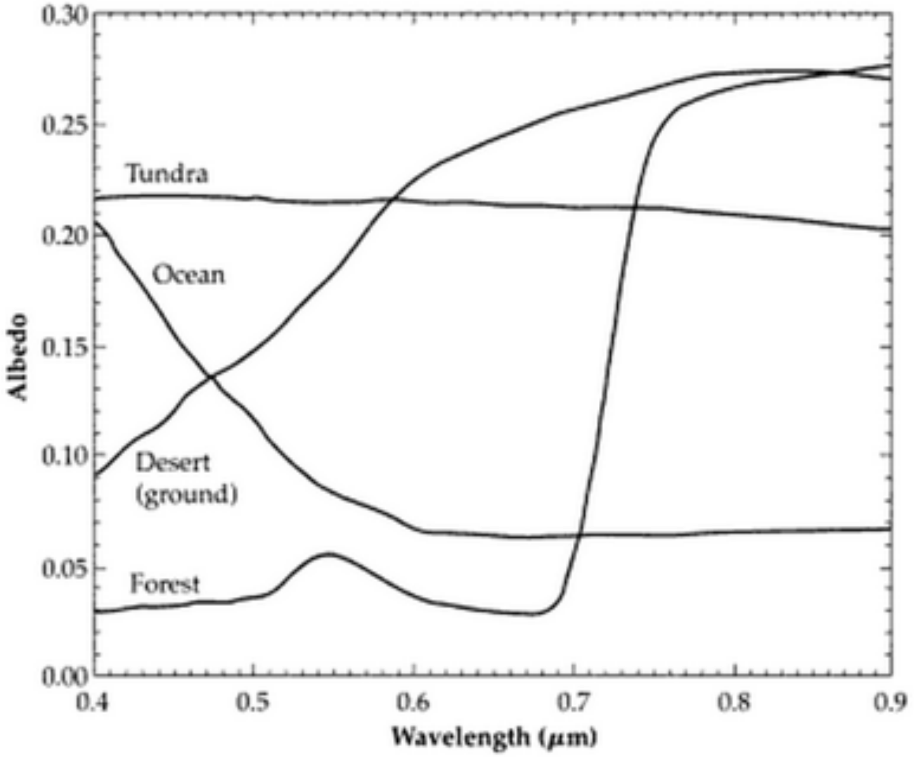


How to look for life: biosignatures

atmospheric spectrum



surface spectrum



- look for atmosphere with gases out of thermochemical redox equilibrium (ideally, redox pairs such as O_2—CH_4)
- caveats:
  - biosignatures can change significantly over time (cfr. past Earth history)
  - false positives are possible (e.g. O_2 from photodissociation of H_2O)

Earth as an exoplanet

before leaving for the Jupiter system, the Galileo probe was used to look for biosignatures from Earth

A search for life on Earth from the Galileo spacecraft

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In its December 1990 fly-by of Earth, the Galileo spacecraft found evidence of abundant gaseous oxygen, a widely distributed surface pigment with a sharp absorption edge in the red part of the visible spectrum, and atmospheric methane in extreme thermodynamic disequilibrium; together, these are strongly suggestive of life on Earth. Moreover, the presence of narrow-band, pulsed, amplitude-modulated radio transmission seems uniquely attributable to intelligence. These observations constitute a control experiment for the search for extraterrestrial life by modern interplanetary spacecraft.

AT ranges varying from ~100 km to ~100,000 km, spacecraft have now flown by more than 60 planets, satellites, comets and asteroids. They have been equipped variously with imaging systems, photometric and spectrometric instruments extending from ultraviolet to kilometre wavelengths, magnetometers and charged-particle detectors. In none of these encounters has compelling, or even strongly suggestive, evidence for extraterrestrial life been found. For the Moon, Venus and Mars, orbiter and lander observations confirm the conclusion from fly-by spacecraft. Still, extraterrestrial life, if it exists, might be quite unlike the forms of life with which we are familiar, or present only marginally. The most elementary test of these techniques—the detection of life on Earth by such an instrumented fly-by spacecraft—had, until recently, never been attempted.

Galileo is a single-launch Jupiter orbiter and entry probe currently in interplanetary space and scheduled to arrive in the Jupiter system in December 1995. It could not be sent directly to Jupiter; instead, the mission incorporated two close gravitational assists at the Earth and one at Venus. This greatly lengthened the transit time, but it also permitted close observations of the Earth. The

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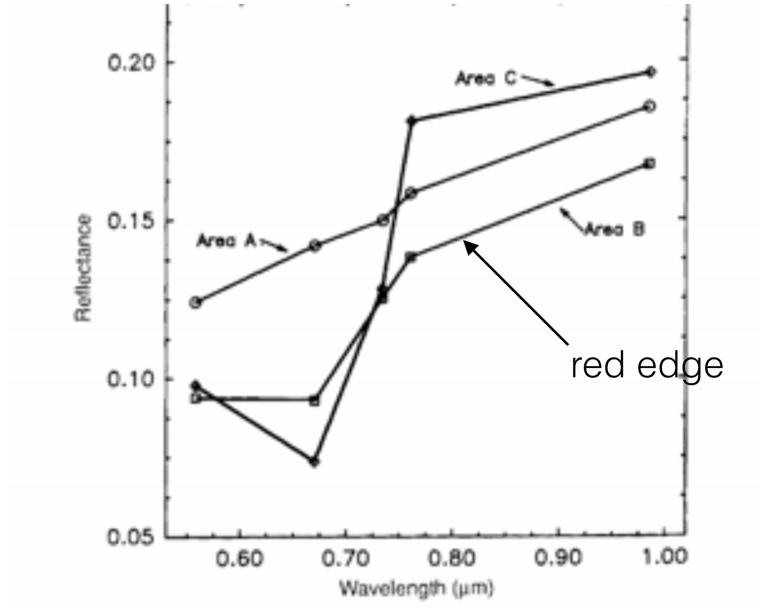


FIG. 3 Representative spectra from three areas on the land surface (see Fig. 2c). A gently sloping spectrum (circles, Area A) is consistent with any of several types of rock or soil. An intermediate spectrum (squares, Area B) shows some evidence of an absorption band near 0.67 μm (RED). Substantial areas on the surface have an unusual spectrum (diamonds, Area C) with a strong absorption in the RED band and a steep band edge just beyond 0.7 μm. This spectrum is inconsistent with all likely rock and soil types, and is plausibly associated with photosynthetic pigments (see text).

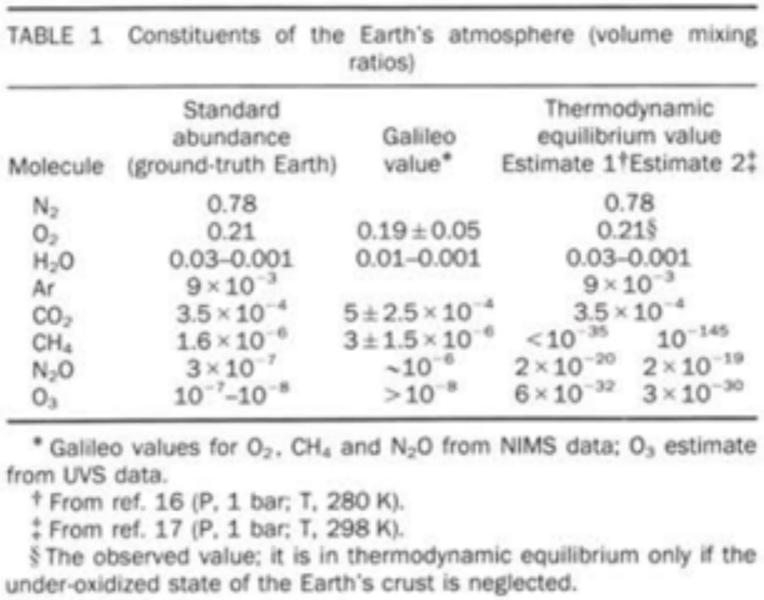


TABLE 1 Constituents of the Earth's atmosphere (volume mixing ratios)

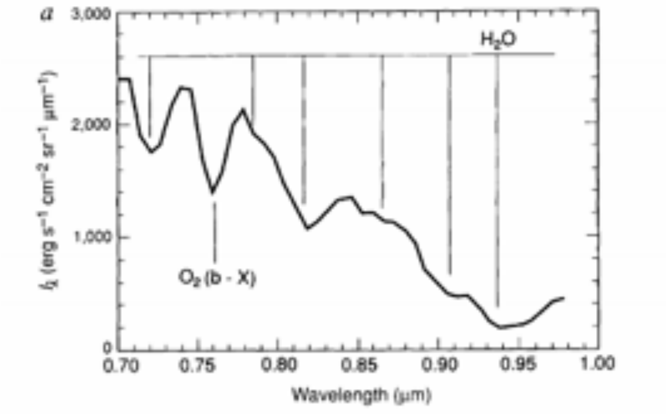
Molecule	Standard abundance (ground-truth Earth)	Galileo value*	Thermodynamic equilibrium value Estimate 1†	Estimate 2‡
N_2	0.78		0.78	
O_2	0.21	0.19 ± 0.05	0.21§	
H_2O	0.03–0.001	0.01–0.001	0.03–0.001	
Ar	9×10^{-3}		9×10^{-3}	
CO_2	3.5×10^{-4}	$5 \pm 2.5 \times 10^{-4}$	3.5×10^{-4}	
CH_4	1.6×10^{-6}	$3 \pm 1.5 \times 10^{-6}$	$< 10^{-35}$	10^{-145}
N_2O	3×10^{-7}	$\sim 10^{-6}$	2×10^{-20}	2×10^{-19}
O_3	10^{-7}–10^{-8}	$> 10^{-8}$	6×10^{-32}	3×10^{-30}

* Galileo values for O_2, CH_4 and N_2O from NIMS data; O_3 estimate from UVS data.

† From ref. 16 (P, 1 bar; T, 280 K).

‡ From ref. 17 (P, 1 bar; T, 298 K).

§ The observed value; it is in thermodynamic equilibrium only if the under-oxidized state of the Earth's crust is neglected.



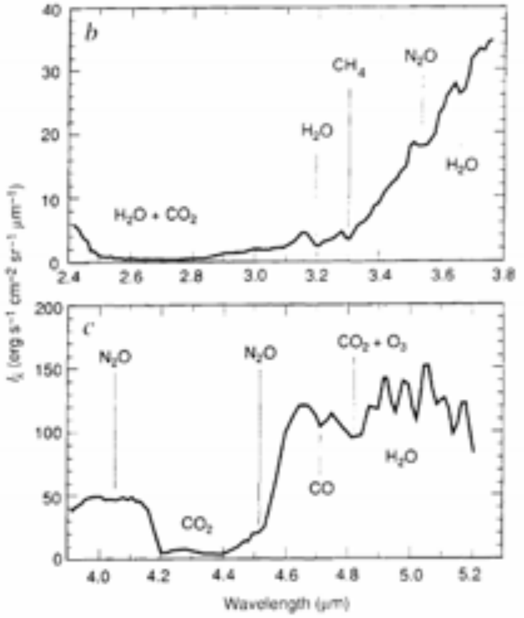
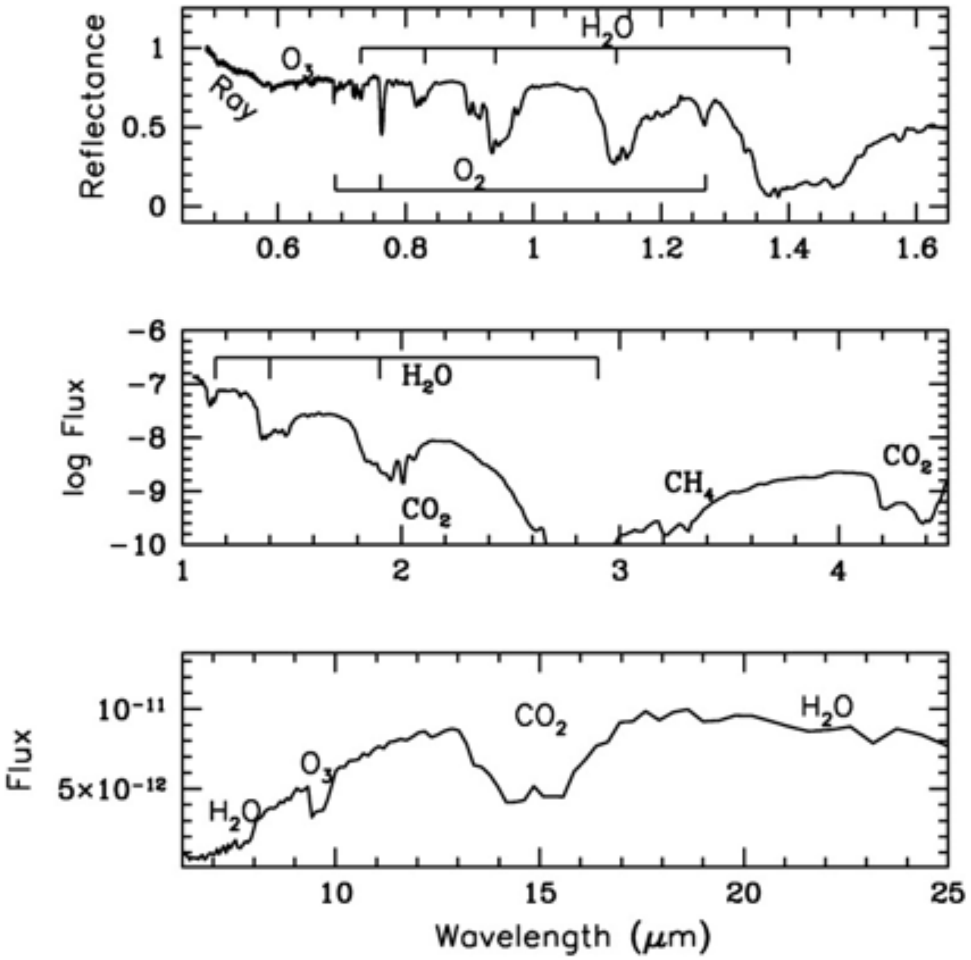


FIG. 1 a, Galileo long-wavelength-visible and near-infrared spectra of the Earth over a relatively cloud-free region of the Pacific Ocean, north of Borneo. The incidence and emission angles are 77° and 57° respectively. The $(b^1\Sigma_g^+ - X^3\Sigma_g^-)$ 0–0 band of O_2 at 0.76 μm is evident, along with a number of H_2O features. Using several cloud-free regions of varying airmass, we estimate an O_2 vertical column density of 1.5 km-amagat ± 25%. b and c, Infrared spectra of the Earth in the 2.4–5.2 μm region. The strong υ_3 CO_2 band is seen at the 4.3 μm, and water vapour bands are found, but not indicated, in the 3.0 μm region. The υ_3 band of nitrous oxide, N_2O, is apparent at the edge of the CO_2 band near 4.5 μm, and N_2O combination bands are also seen near 4.0 μm. The methane (0010) vibrational transition is evident at 3.31 μm. A crude estimate[10] of the CH_4 and N_2O column abundances is, for both species, of the order of 1 cm-amagate (≡1 cm path at STP).

Spectra of Earth-like exoplanets



(*Top*) Visible wavelength spectrum from Earthshine measurements plotted as normalized reflectance (Turnbull et al 20067).

(*Middle*) Near-IR spectrum from NASA's Extrasolar Planet Observation and Deep Impact Extended Investigation mission, with flux in units of watts meter−2 micrometer−1 (Robinson et al. 2011).

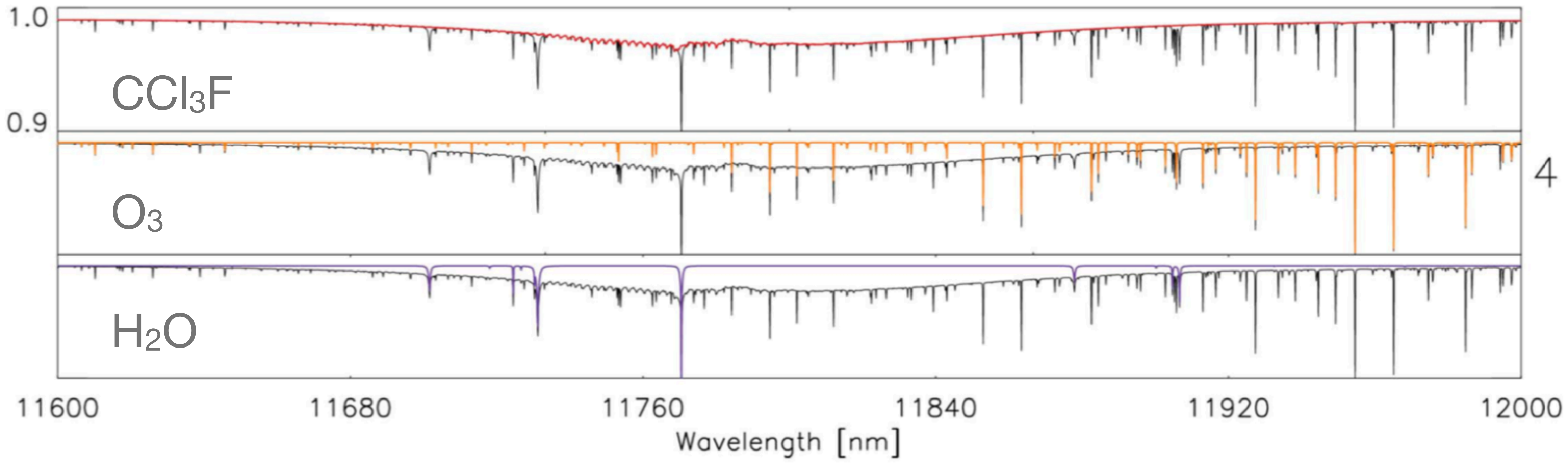
(*Bottom*) Mid-IR spectrum as observed by Mars Global Surveyor en route to Mars, with flux in units of Watts meter−2 Hertz−1 (Christensen et al 1997)

Seager 2014

- obtaining atmospheric spectra for Earth-like planets is not a near-term goal
- some nearby super-Earth atmospheres around M-dwarfs might be observable in a ten-year time span (e.g. from JWST or ground based large telescopes)
- lots of theoretical modeling + laboratory measurements needed in the meantime

Artificial atmospheric constituents (AAC)

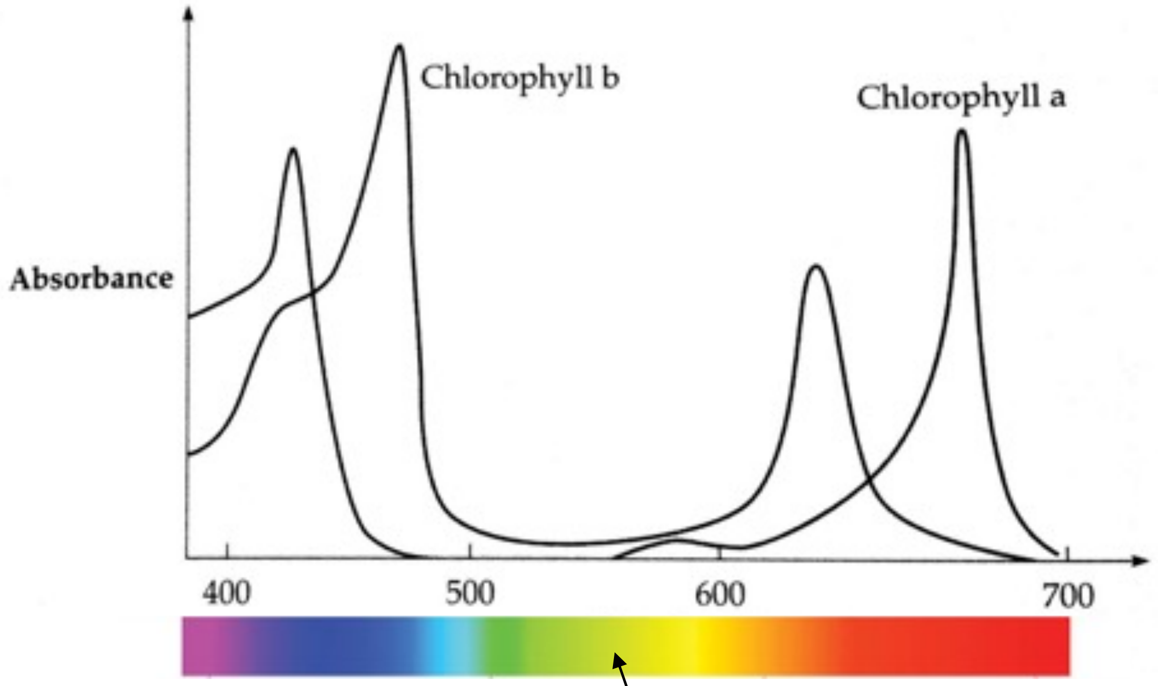
- Pollutants (eg. CFC [Schneider et al. 2010, Lin et al. 2014], greenhouse gases from fossil fuel combustion), deliberate geo-engineering, cataclysmic events (Stevens et al 2016)

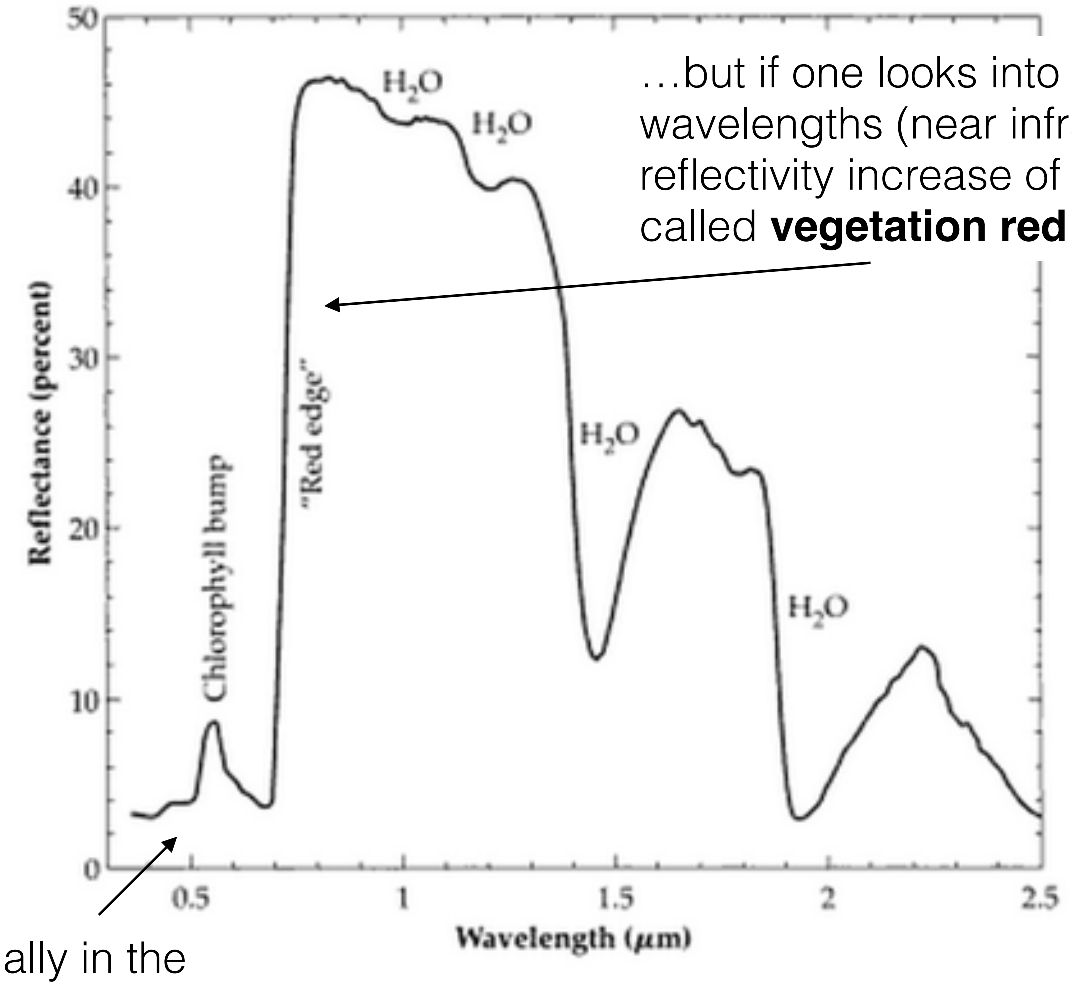


Lin et al. 2014, present day Earth levels, ~2 days integration with JWST

Natural spectral signatures

chlorophyll absorbs light preferentially at wavelengths ~450 nm and ~680 nm…





…but if one looks into even longer wavelengths (near infrared) finds a reflectivity increase of a factor 10 called **vegetation red edge**

… and is reflected preferentially in the green part of the spectrum

the red edge might be a useful biosignature, but there can be abiotic mechanisms producing similar lines; also, photosynthetic life around other stars with different emission spectra can have adapted differently

Just started: ASI Italian Project on astrobiology

Artificial spectral signatures

- Lingam & Loeb 2017: harvesting stellar energy with artificial structures (eg. solar panels) may result in characteristic features in reflectance spectra

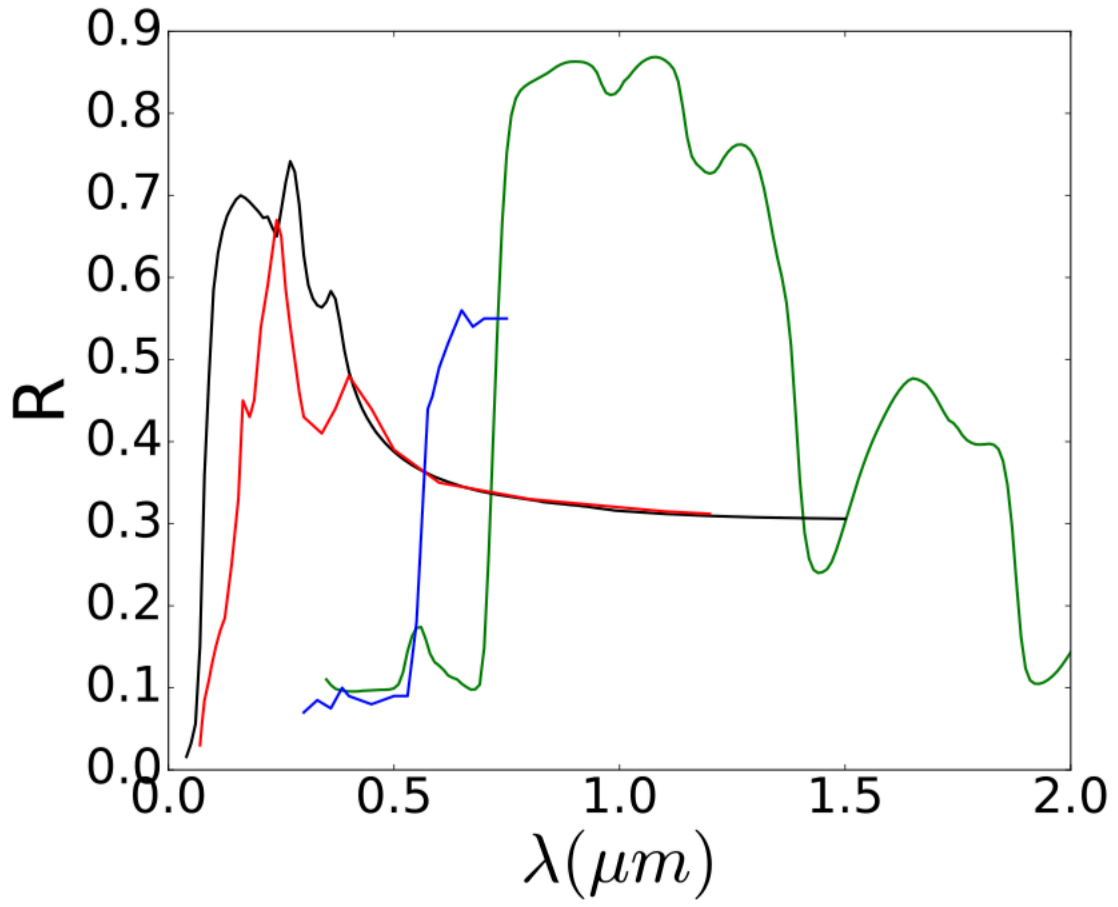


Figure 1. The reflectance R as a function of wavelength λ for silicon (black), gallium arsenide (red), perovskite (blue) and vegetation (green) was adapted from Green (2008), Blakemore (1982), Ryu et al. (2014) and Clark et al. (2007) respectively.

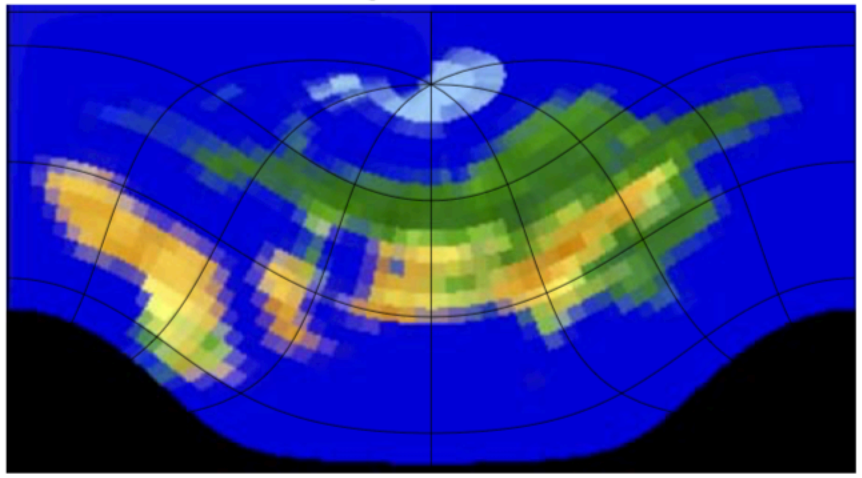
Artificial spectral signatures

- Also, artificial illumination may be detectable remotely (Loeb & Turner 2012)

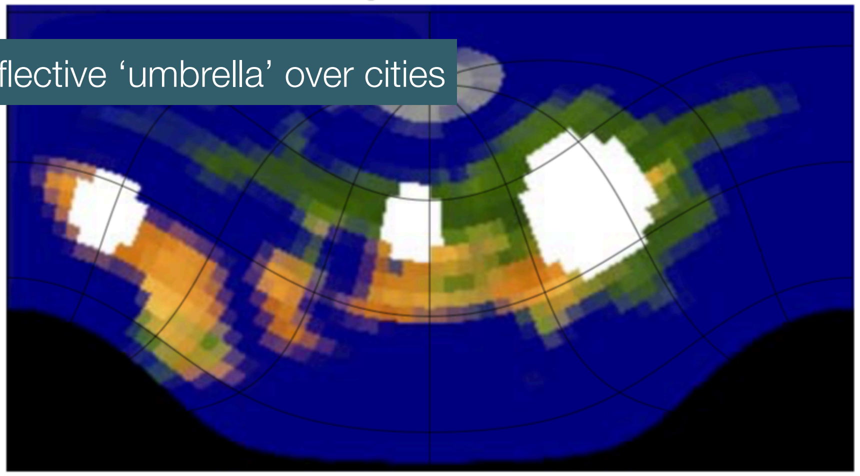
Photometric signatures

- 2D inversion techniques of multi-bands unresolved lighcurves can recover the signature from ‘heat islands’ (cities), global warming, planetary scale features (Kuhn & Berdyugina 2015, Berdyugina & Kuhn 2017)

Original map

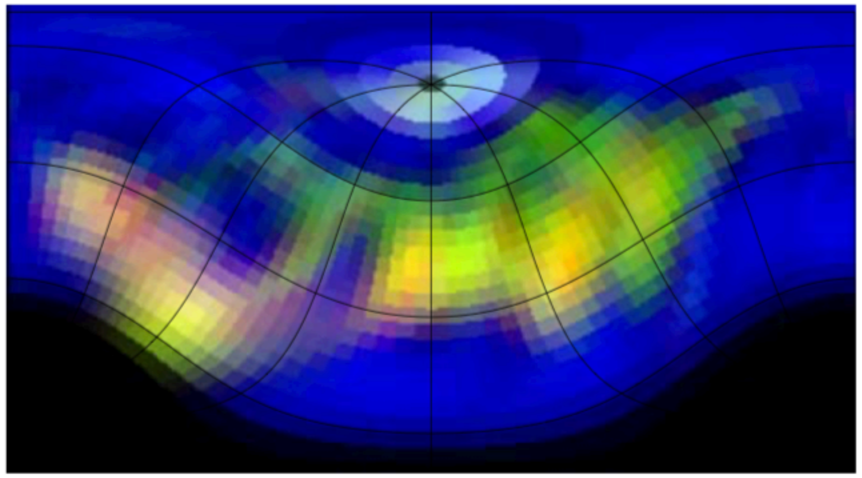


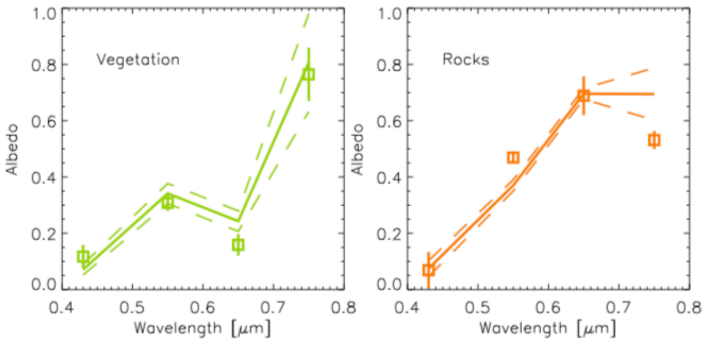
Original map



Reflective ‘umbrella’ over cities

Recovered map





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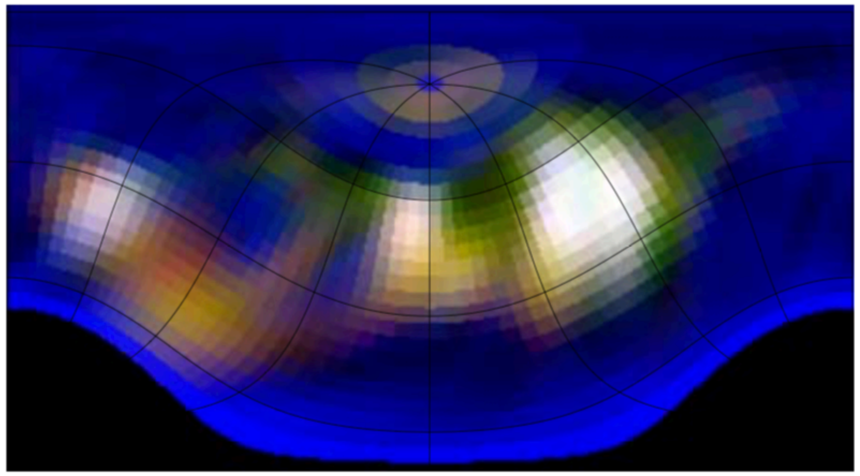

Other possibilities

- Megastructures: Dyson spheres or similar planetary scale artifacts (Dyson 1960, Wright 2015)
- Laser bursts for ligthsail propulsion (Lubin 2016, Lingam & Loeb 2017)
- Satellite belts (Socas-Navarro 2018)

Final remarks

- Nearby targets (< 10 pc) are preferable for future characterization (atmosphere retrieval, direct imaging, etc) for both bio and techno signatures: Alpha Cen is ideal!

- While transmission spectroscopy will require transit, many signatures are available in unresolved reflectance or emission spectra

- Sending probes would open a whole new set of possibilities

- Theoretical modeling needed to predict and classify possible signatures