An inconvenient truth about biosignatures on Earth-like exoplanets

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“There are infinite worlds both like and unlike this world of ours.”

Epicurus (341-270 B.C.)

“So far, we’ve found 1787 other worlds.”

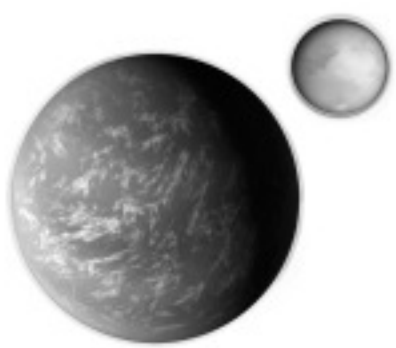
Open Exoplanet Catalogue (2014)

Demo

The Exoplanet App is available
for free on the AppStore.

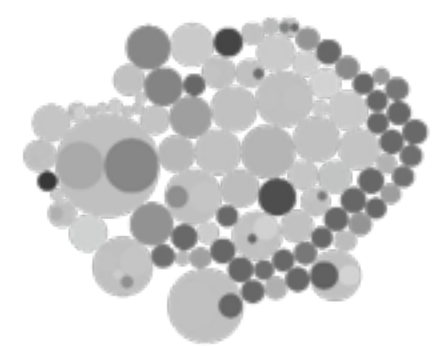
Biosignatures

Spectral resolution



Planet/moon false positive

Open Exoplanet Catalogue



Biosignatures

A search for life on Earth from the Galileo spacecraft

Carl Sagan[*], W. Reid Thompson[*], Robert Carlson[†], Donald Gurnett[‡] & Charles Hord[§]

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[†] Atmospheric and Cometary Sciences Section, Jet Propulsion Laboratory, Pasadena, California 91109, USA
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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.

1) Deficiency of flux in the red spectrum

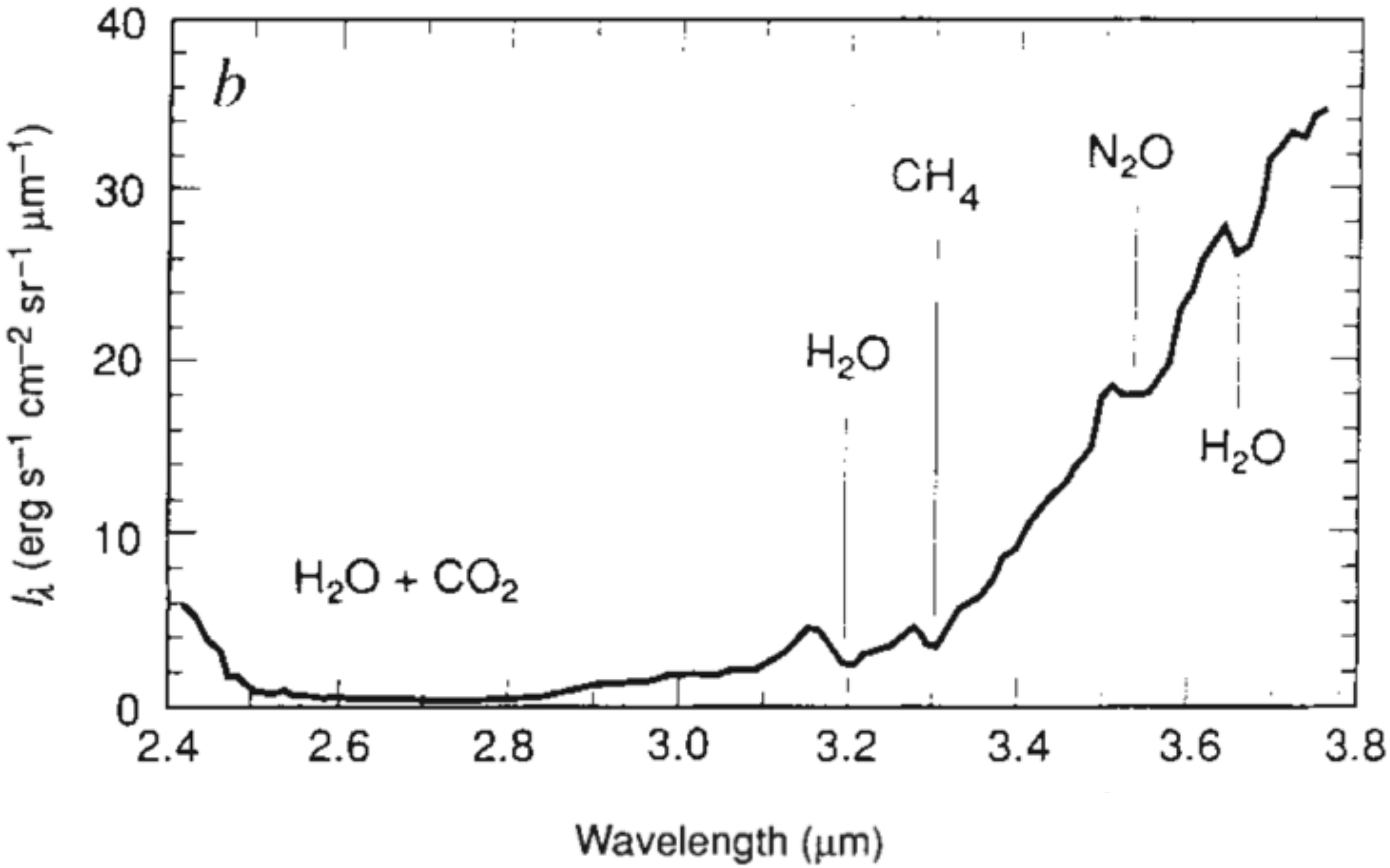
2) Individual chemical species

O_2 / CH_4

3) Multiple chemical species

$$O_2 + CH_4$$

Spectrum of Earth

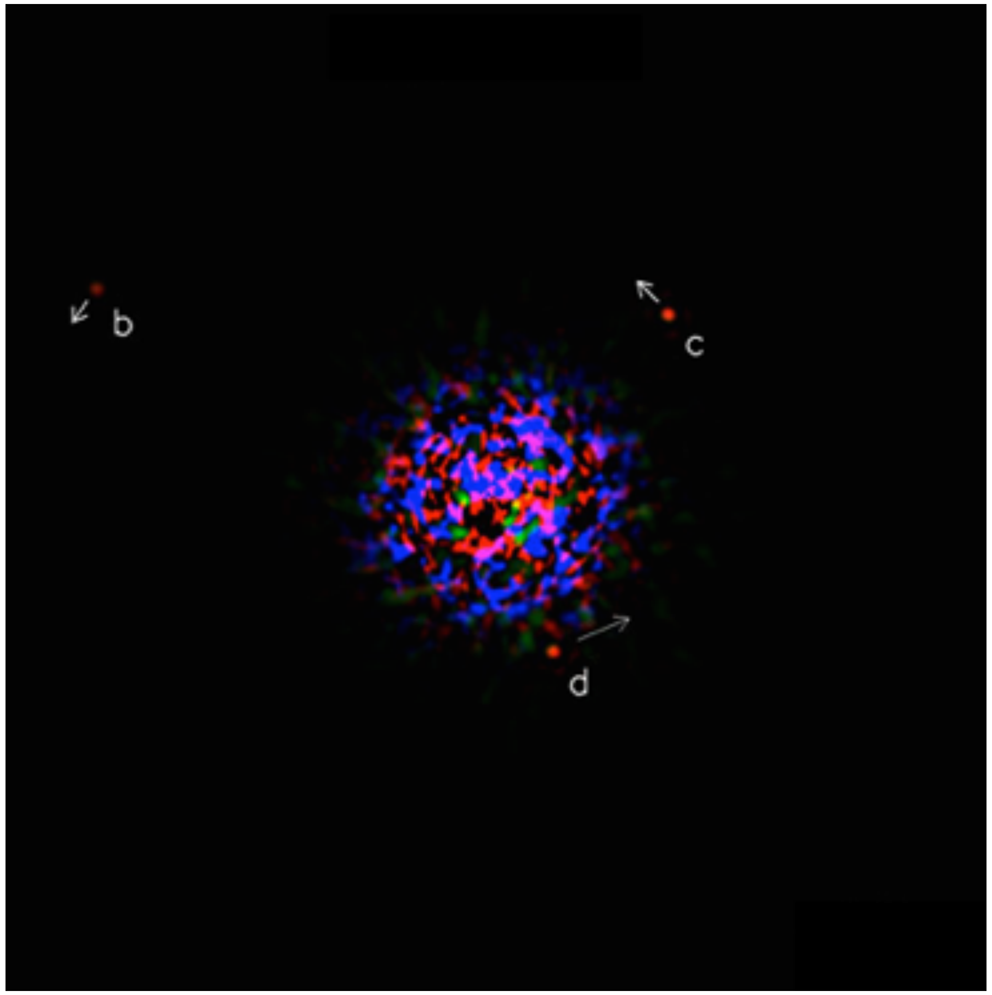


Sagan et al (1993).

Spectral resolution

Spectral resolution

Directly imaged planets



Transiting planets

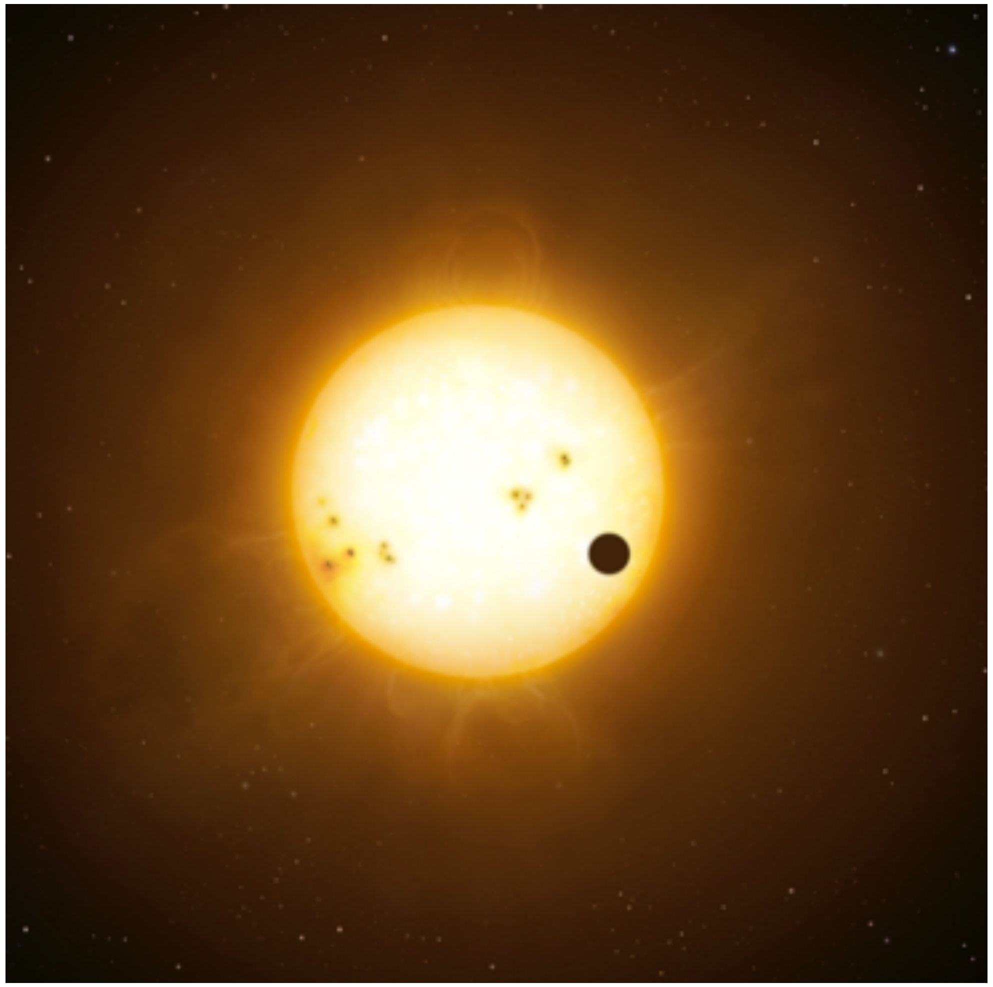
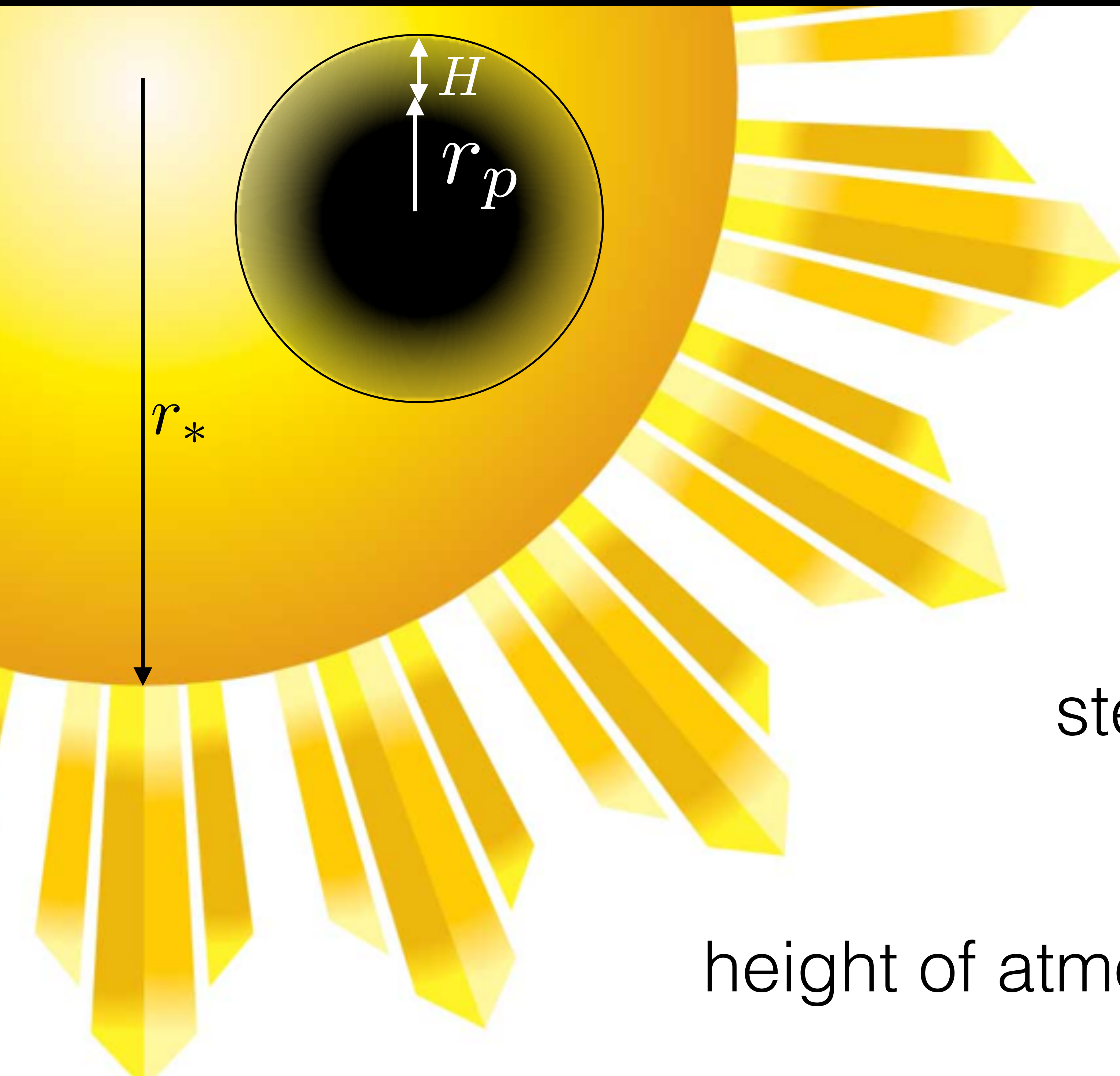


Image credit: STSCI, Keck Observatory, Ben Zuckerman

Spectral resolution

Spectral resolution is
ultimately photon noise limited.

Transiting planet

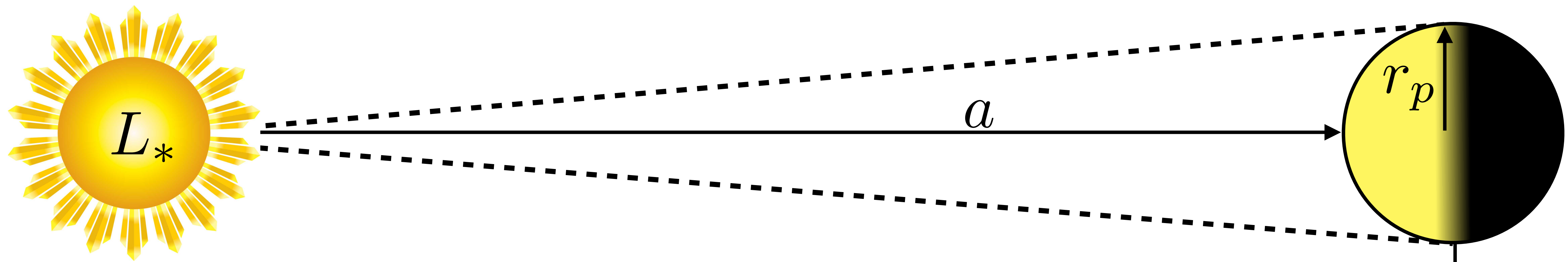


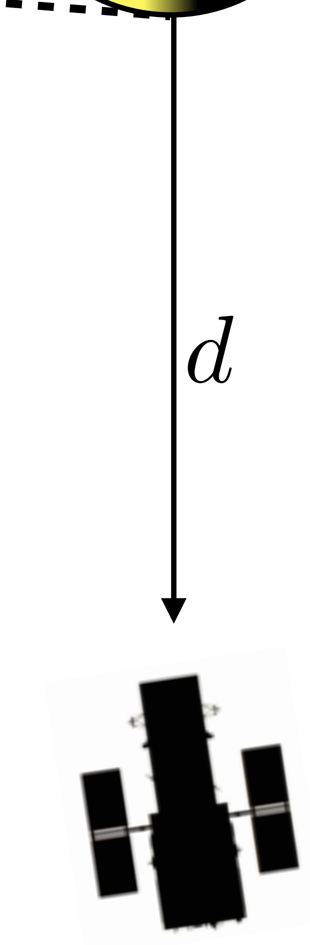
stellar flux $$F_* = \frac{L_*}{4\pi d^2}$$

height of atmosphere $$H \sim 39 \text{ km}$$

flux through atmosphere $$F_{\text{transit}} = \frac{(r_p + H)^2 - r_p^2}{r_*^2} F_*$$

Resolved planet





stellar flux

$$F_* = \frac{L_*}{4\pi d^2}$$

luminosity of planet

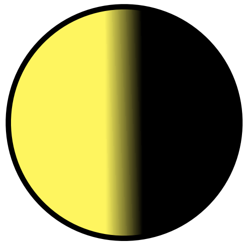
$$L_{\text{reflected}} = \frac{L_* \pi r_p^2}{4\pi a^2}$$

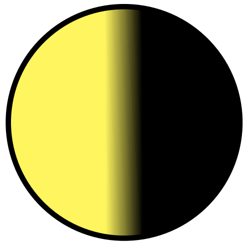
planetary flux

$$F_{\text{reflected}} = \frac{L_{\text{reflected}}}{4\pi d^2} = \frac{L_* A r_p^2}{16\pi a^2 d^2}$$

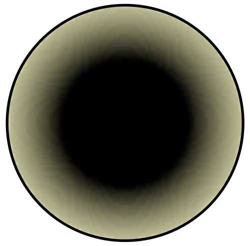
Signal/Noise

Directly imaged planet

Signal: 

Noise: 

Transiting planet

Signal: 

Noise: 

Maximum

Directly imaged planet

$$R^{\max}_{\text{reflected}} = \frac{\lambda}{d\lambda} = \frac{\lambda}{d\lambda}\,\frac{\dot{N}_{\text{reflected}}\Delta t}{\text{SNR}^2}$$

$$= \underbrace{\frac{\pi}{64\sigma hc}}_{\text{constants}}\;\underbrace{\frac{A\,r_p^2}{a^2}}_{\text{planet}}\;\underbrace{\frac{L_*\lambda^2\,B_\lambda[T_*]}{T_*^4}}_{\text{star/band}}\;\underbrace{\Delta t\,\frac{D^2}{d^2}\,\text{SNR}^{-2}}_{\text{telescope}}$$

$$= 1683\left(\frac{d}{10\text{pc}}\right)^{-2}\left(\frac{D}{6.5\text{m}}\right)^{2}\left(\frac{\Delta t}{12\text{hrs}}\right)\left(\frac{\text{SNR}}{10}\right)^{-2}.$$

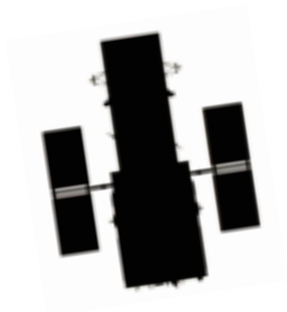
Transiting planet

$$R^{\max}_{\text{transit}} = \frac{\lambda}{d\lambda} = \frac{\lambda}{d\lambda}\,\frac{\dot{N}^2_{\text{transit}}/\dot{N}_*}{\text{SNR}^2}\Delta t$$

$$= \underbrace{\frac{\pi}{4\sigma hc}}_{\text{constants}}\;\underbrace{r_p^2 H^2}_{\text{planet}}\;\underbrace{\frac{L_*\lambda^2\,B_\lambda[T_*]}{r_*^4 T_*^4}}_{\text{star/band}}\;\underbrace{\Delta t\,\frac{D^2}{d^2}\,\text{SNR}^{-2}}_{\text{telescope}}$$

$$= 12.2\left(\frac{d}{10\text{pc}}\right)^{-2}\left(\frac{D}{6.5\text{m}}\right)^{2}\left(\frac{\Delta t}{12\text{hrs}}\right)\left(\frac{\text{SNR}}{10}\right)^{-2}.$$

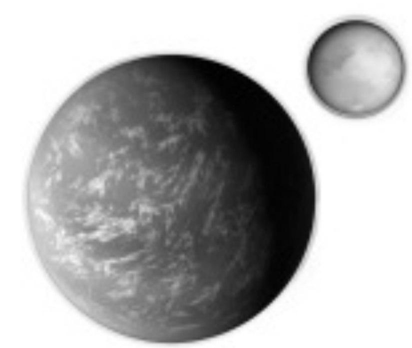
Making it worse



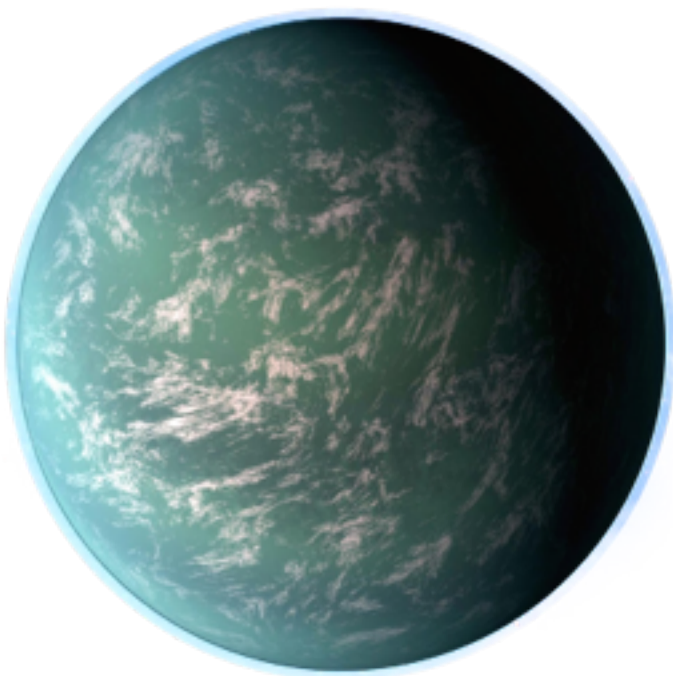
- Telescope photon efficiency
- Spectrograph photon efficiency
- Systematic instrumental error

- Zodiacal light
- Exozodiacal light
- Star spots
- Background sources
- Upper limit on integration time
- Transiting planets on average 6 times further away

Planet/moon false positive



The basic idea



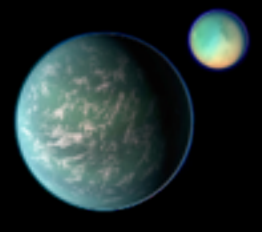
O_2

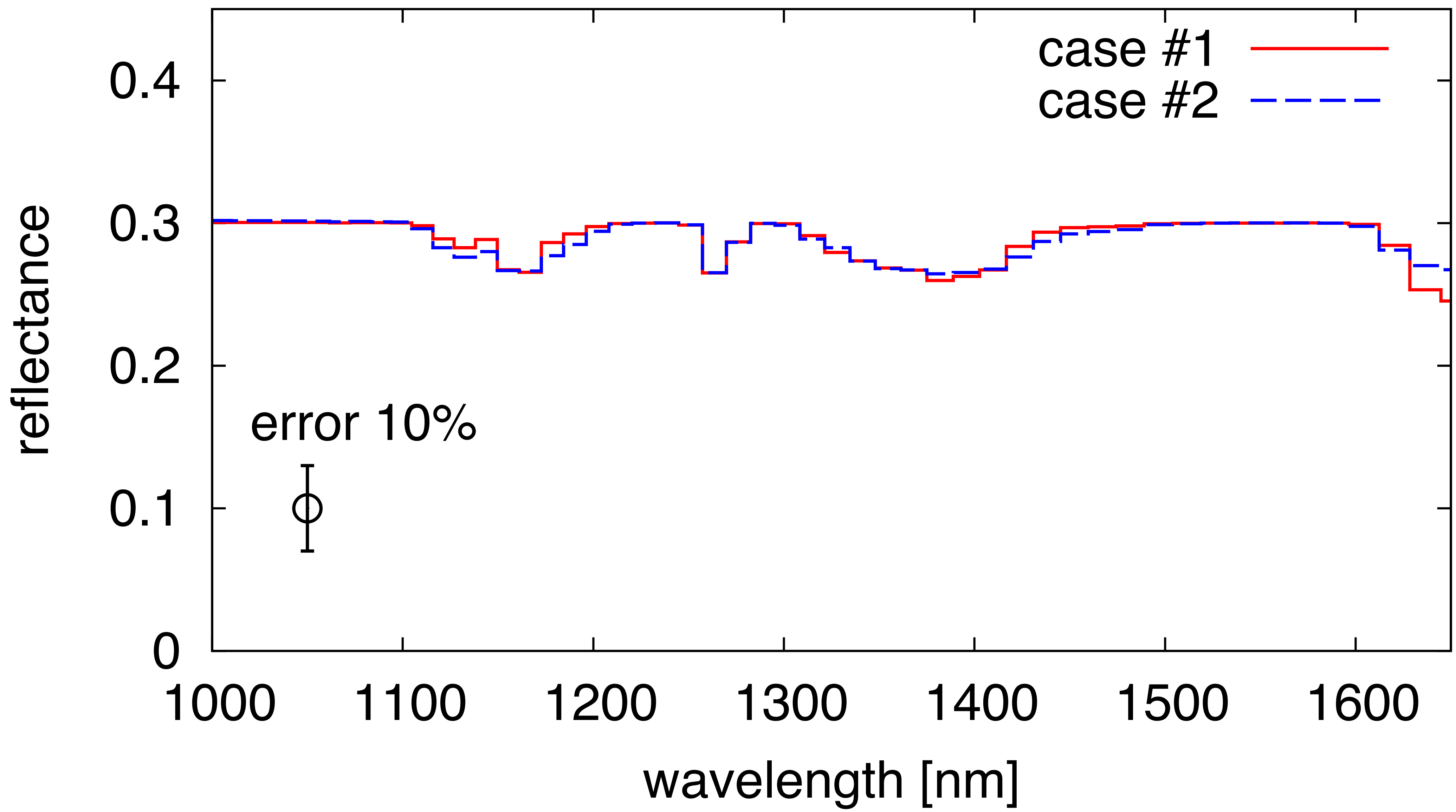
CH_4

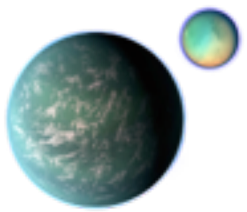
=

$CH_4 + O_2$

Model spectra

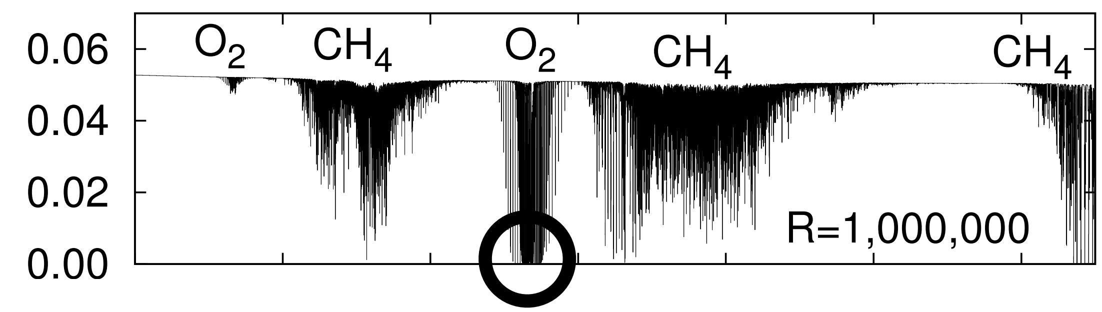




This is not the end of the story. 

Possible ways to break degeneracy

Deep absorption features



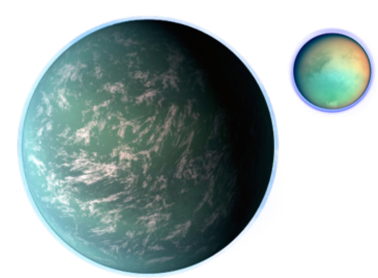
Very close-by planet

$$R \sim d^{-2}$$

Single molecule biosignature

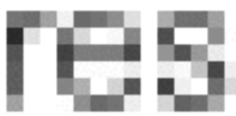
O_2 / CH_4

Time variability

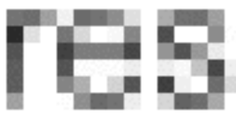


Relax Earth-Sun twin

Conclusions

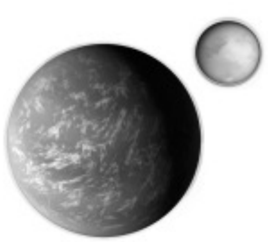


Spectral resolution of exoplanet atmospheres is limited by photon noise.



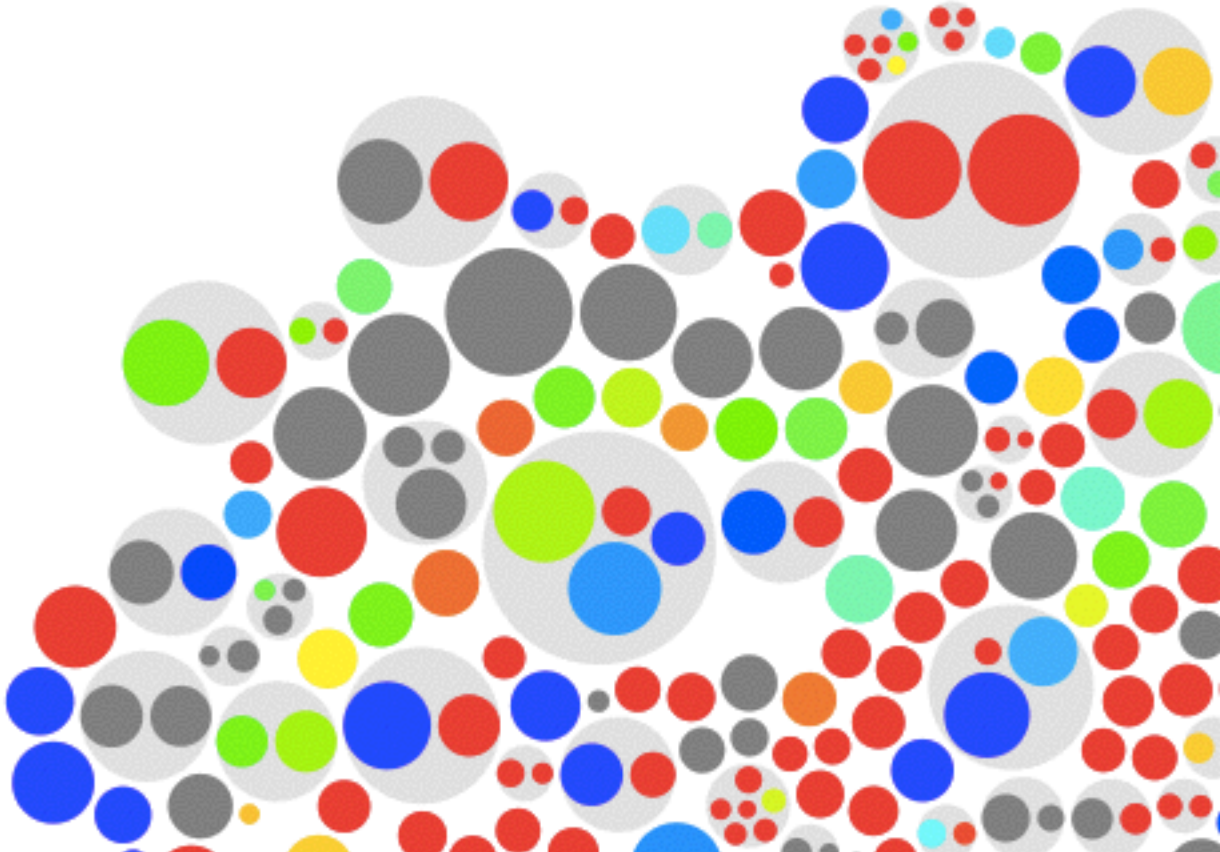
Strong upper limit of 100-1000 in the most ideal case.

Forget about Earth-Sun analogues. Look elsewhere.



A new false positive: planet and moon. Impossible to identify in low resolution spectra

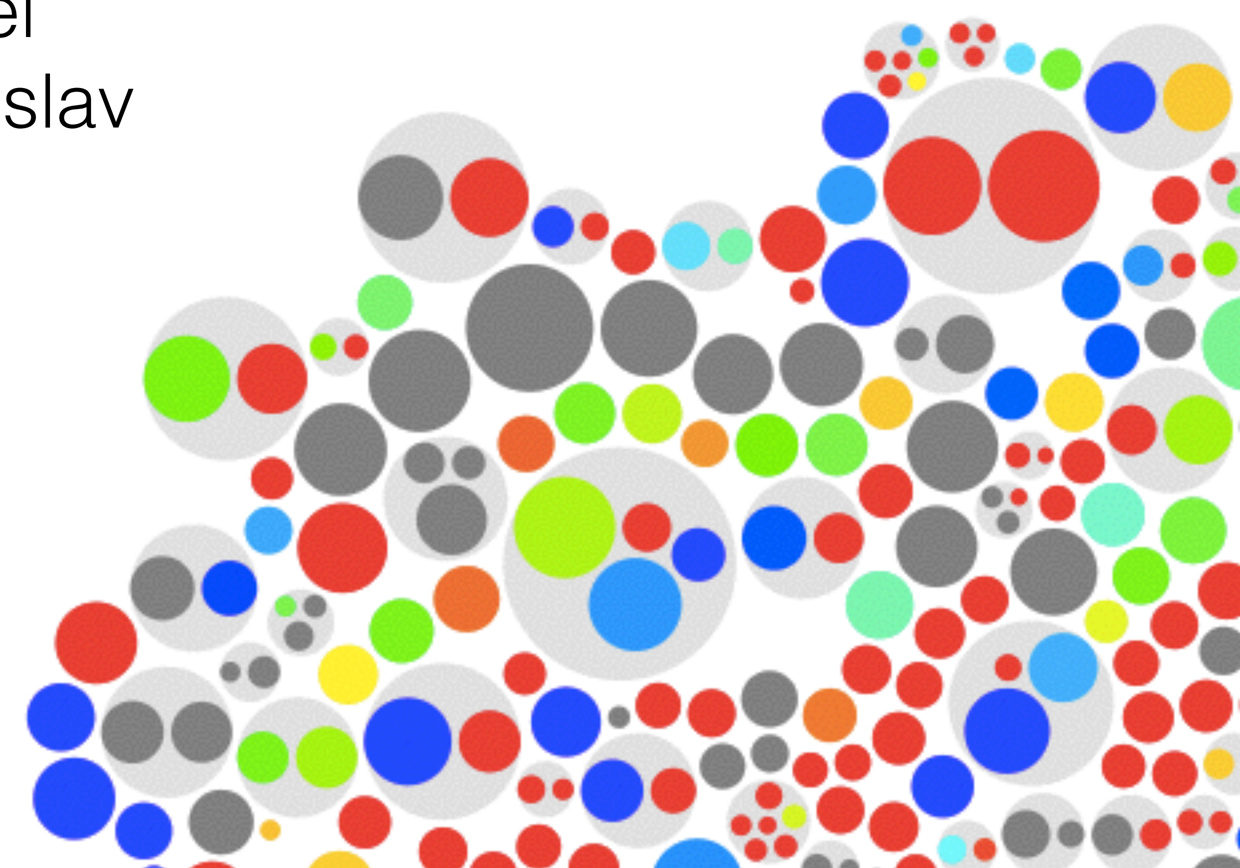
Open Exoplanet Catalogue



Community

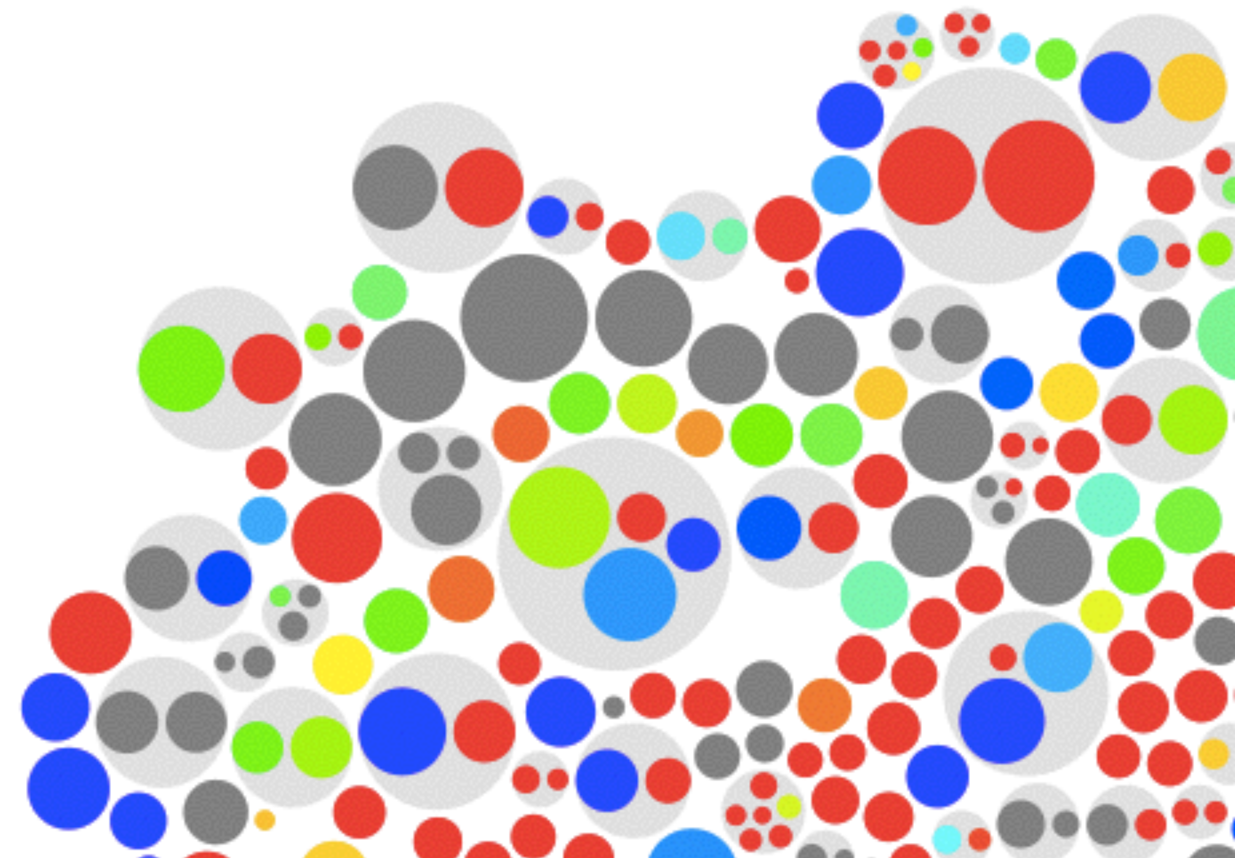
This project can only be a success if we can build a community.

Hanno Rein, Marc-Antoine Martinod, Andrew Tribick, Kenneth Cott, Ryan Varley, Miguel De Val-Borro, Marc-Antoine, Jaroslav Merc, Tobias Mueller, Dave Spiegel Shoszowski, Allen Davis, Knutover, James Gregory, Dave, Allen Davis, Callum Rodwell, Anonymous



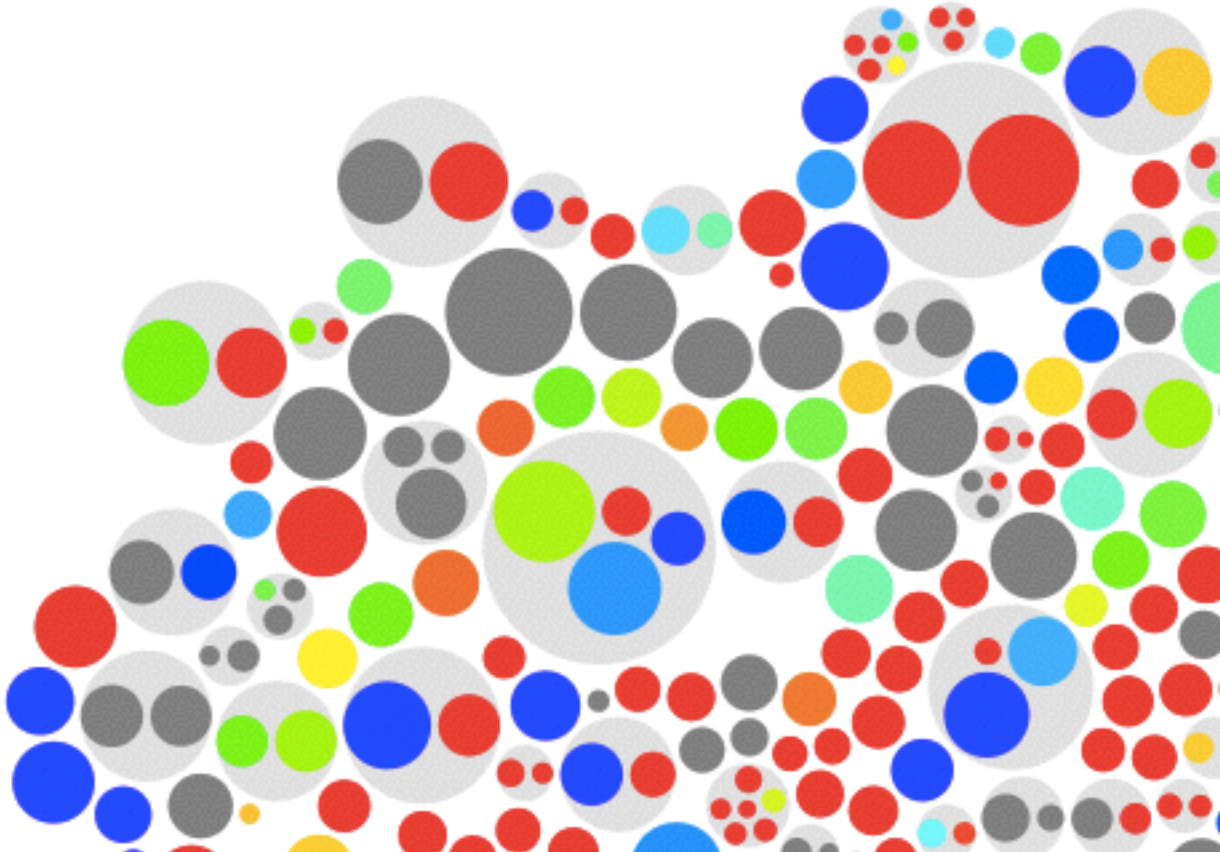
Open

Open ecosystem
Permissive Open source license (MIT)
Decentralized (no server)
Multiple branches
Every can contribute



Better

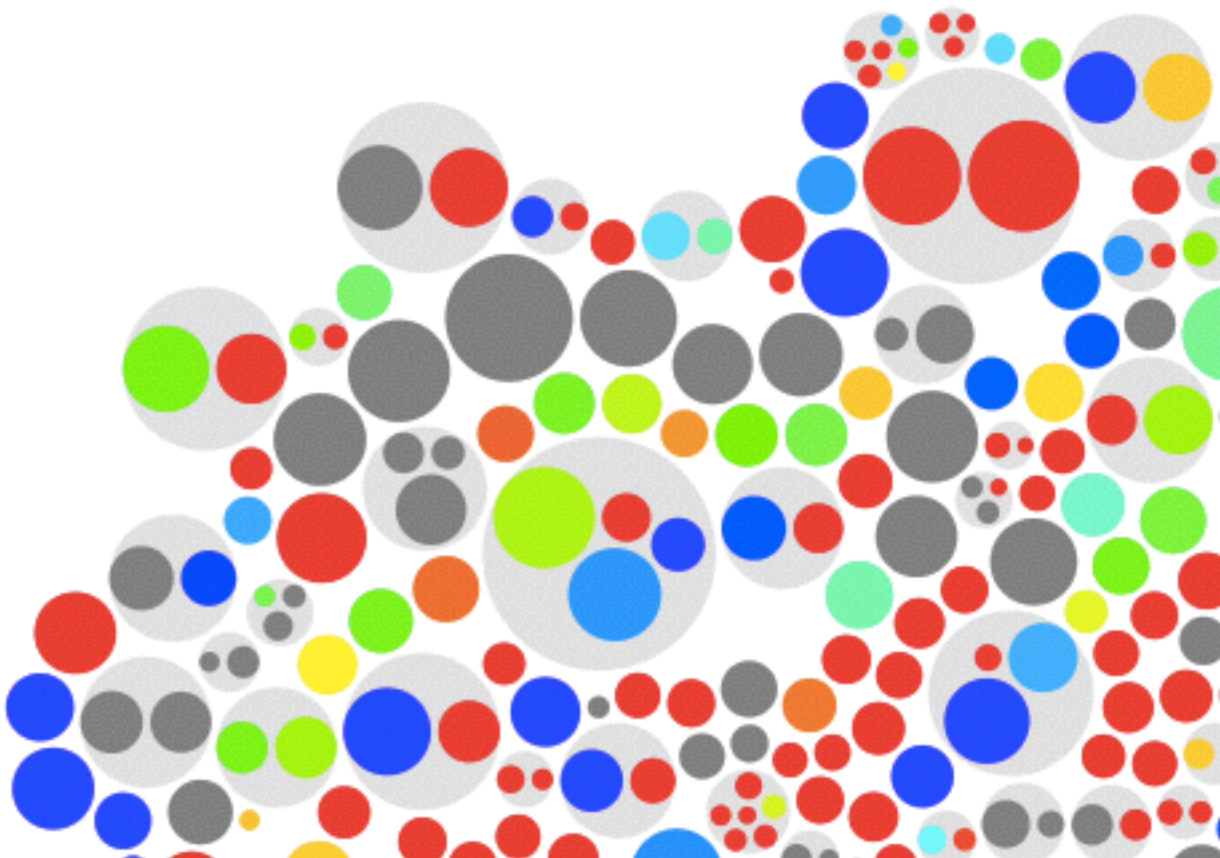
Faster updates
More contributors
Less error prone
More accountability
More credit
More democratic



Technology

Data storage, git
- Distributed version control system
- Keeps track of history
- Rich toolchain (github)

Data format, XML
- Hierarchical
- Human readable
- Flexible
- Future-proof



```
import xml.etree.ElementTree as ET, urllib, gzip, io
oec =  ET.parse(gzip.GzipFile(fileobj=io.BytesIO(
         urllib.urlopen(“http://git.io/26EvSA").read()
       )))

for planet in oec.findall(".//planet"):
    print [planet.findtext("mass"), planet.findtext("radius")]
```