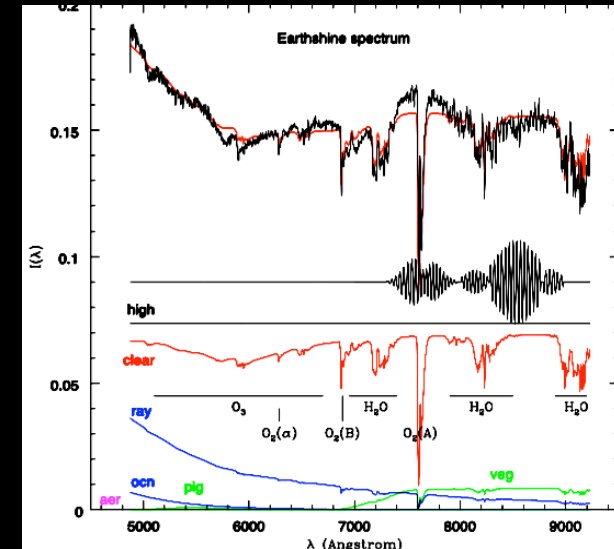# *SAG 4 – exoplanet science Short update*

L. Kaltenegger & J. Kasting & the SAG4 team:
Abbot, Betremieux, Cowen, Domagal-Goldman,
Forget, Green, Kopparapu, Meadows,
Pierrehumbert, Rauer, Robinson, Rugheimer,
Sasselov, Seager, Segura, Selsis, Traub (& you!)
ExoPAG, Oct 5 2013

SAG 4. Planetary Measurements Needed for Exoplanet Characterization

- **Objective:** Determine
  - which measurements are needed to characterize large and small exoplanets,
  - how accurate they must be,
  - how difficult they are to obtain, and
  - which might be done from the ground

- **Participants:** Atmospheric and surface modelers, ground and space observers, and exoplanet mission teams

- SAG4 team: Abbot, Betremieux, Cowen, Domagal-Goldman, Forget, Green, Kaltenegger, Kasting, Kopparapu, Meadows, Pierrehumbert, Rauer, Robinson, Rugheimer, Sasselov, Seager, Segura, Selsis, Traub (& you!)

SAG 4. Planetary Measurements Needed for Exoplanet Characterization

- **Products:**
  - List of measurements and required precisions needed to understand a planet's state to different levels of completeness
  - List of measurement techniques that look over different time frames, and which of these can only be done from space

- Timeline
  - Report draft (LK & JK) send to team mid Nov
  - Comments due mid Dec (team)
  - Report sent to ExoPAG EC end Dec
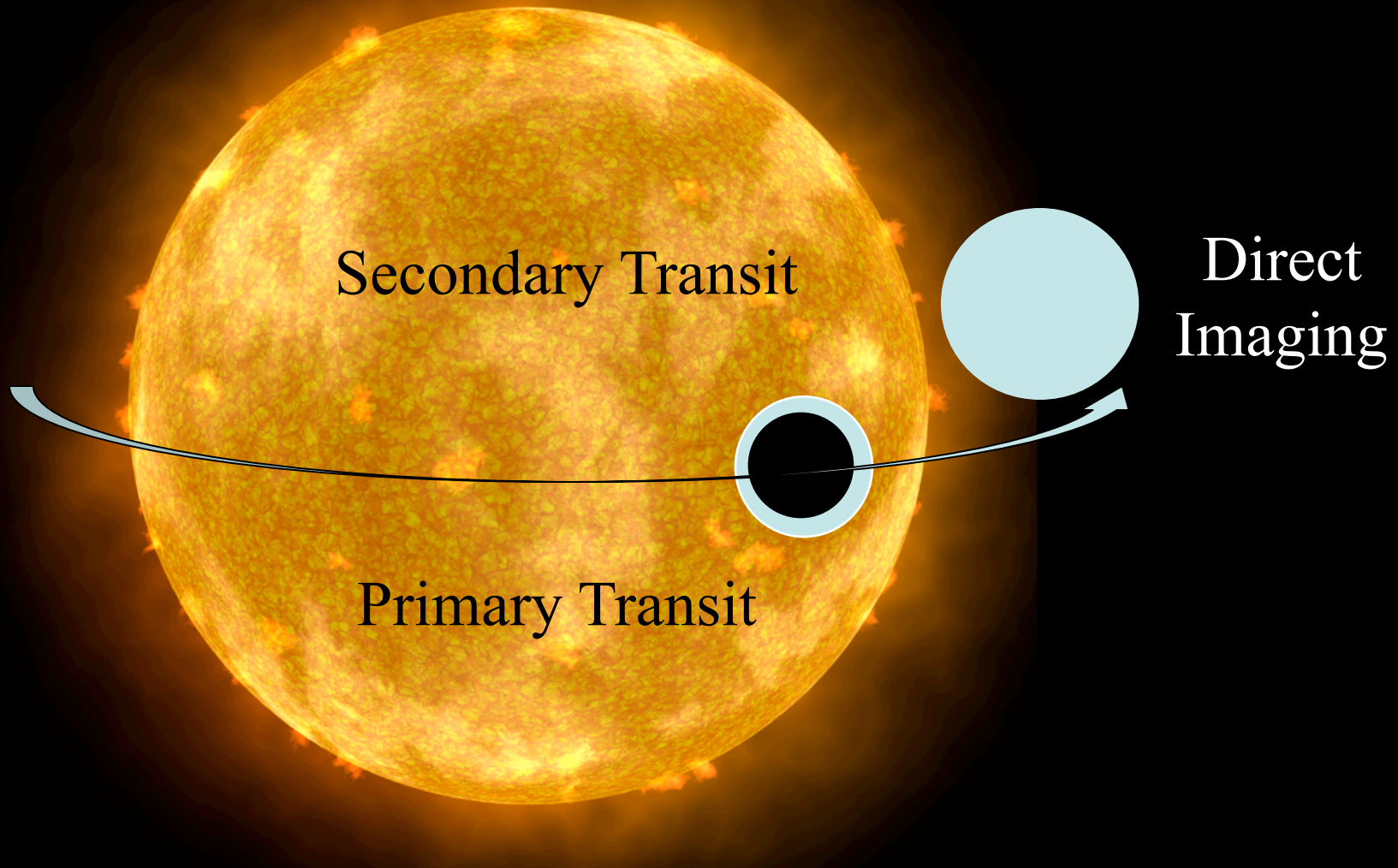 - Presentation of the SAG 4 Report at ExoPAG 9 @ AAS

Baseline: Earth &
Different evolution state /
age / mass / etc.

WORKING QUESTIONS:
-Resolution needed for
detection of atm &
Biosignature?
- Alternative Biomarkers?
- Detectable (SNR, λ)?
- Temp? Radius?
-Inst. Requirements
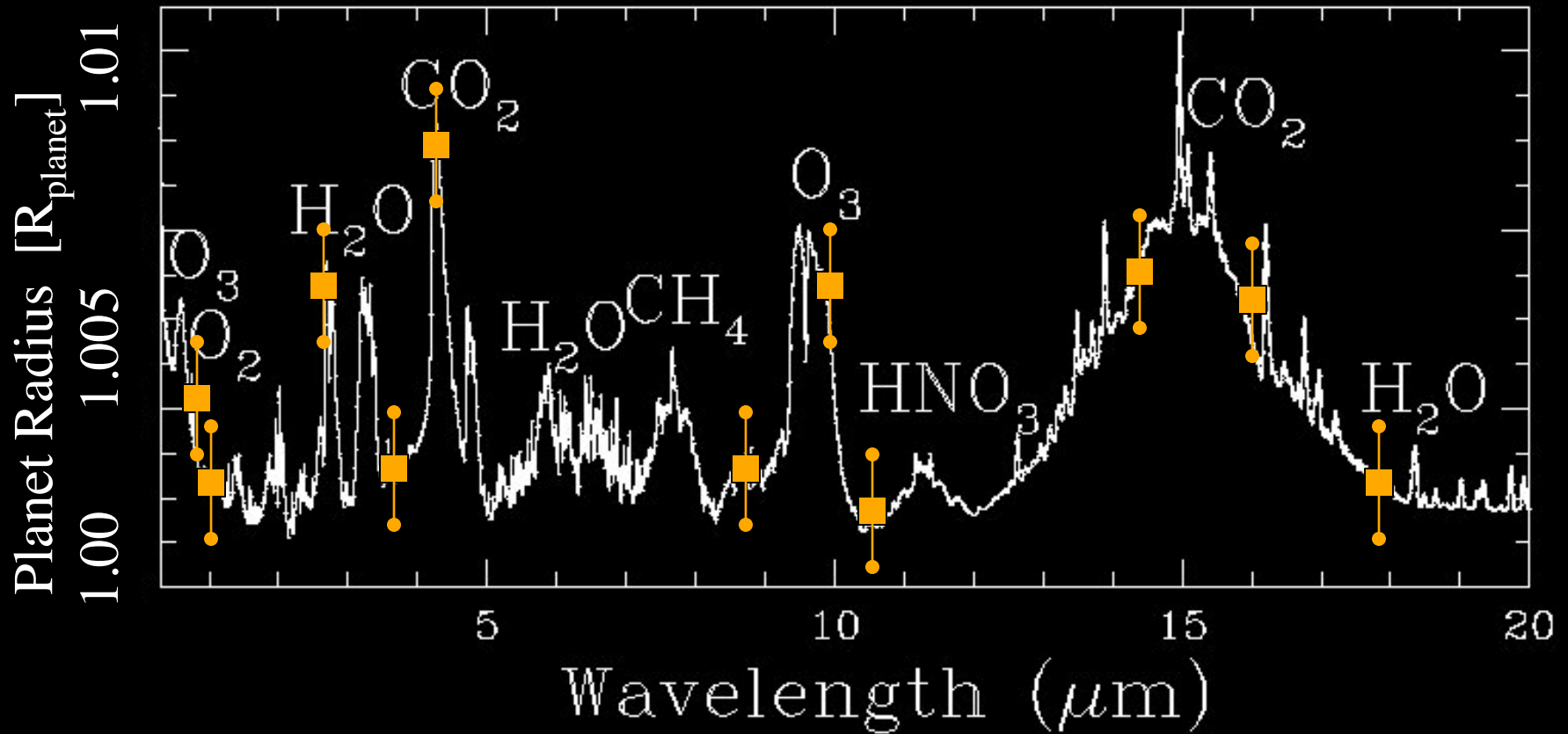   e.g. JWST, E-ELT

Transit & Direct Imaging & Lightcurves

Secondary Transit

Direct Imaging

Primary Transit

Earth: Seen as an exoplanet
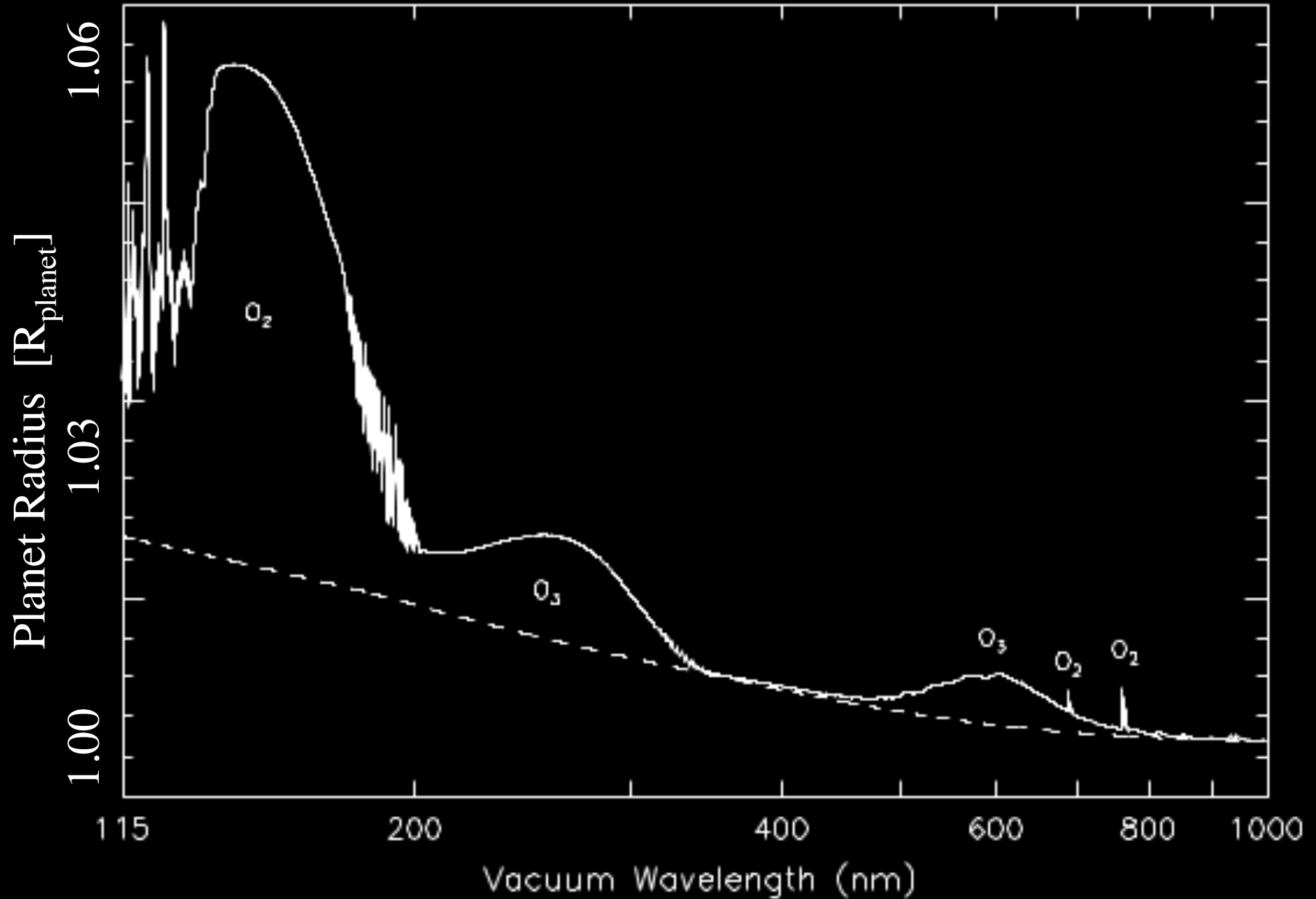(Data = Shuttle, EPOXI, Earthsshine, TES)

Earth: Transmission Spectrum (VIS-IR)

Kaltenegger & Traub 2009
Betremieux & Kaltenegger 2013
Data: ATMOS B. Irion 2002

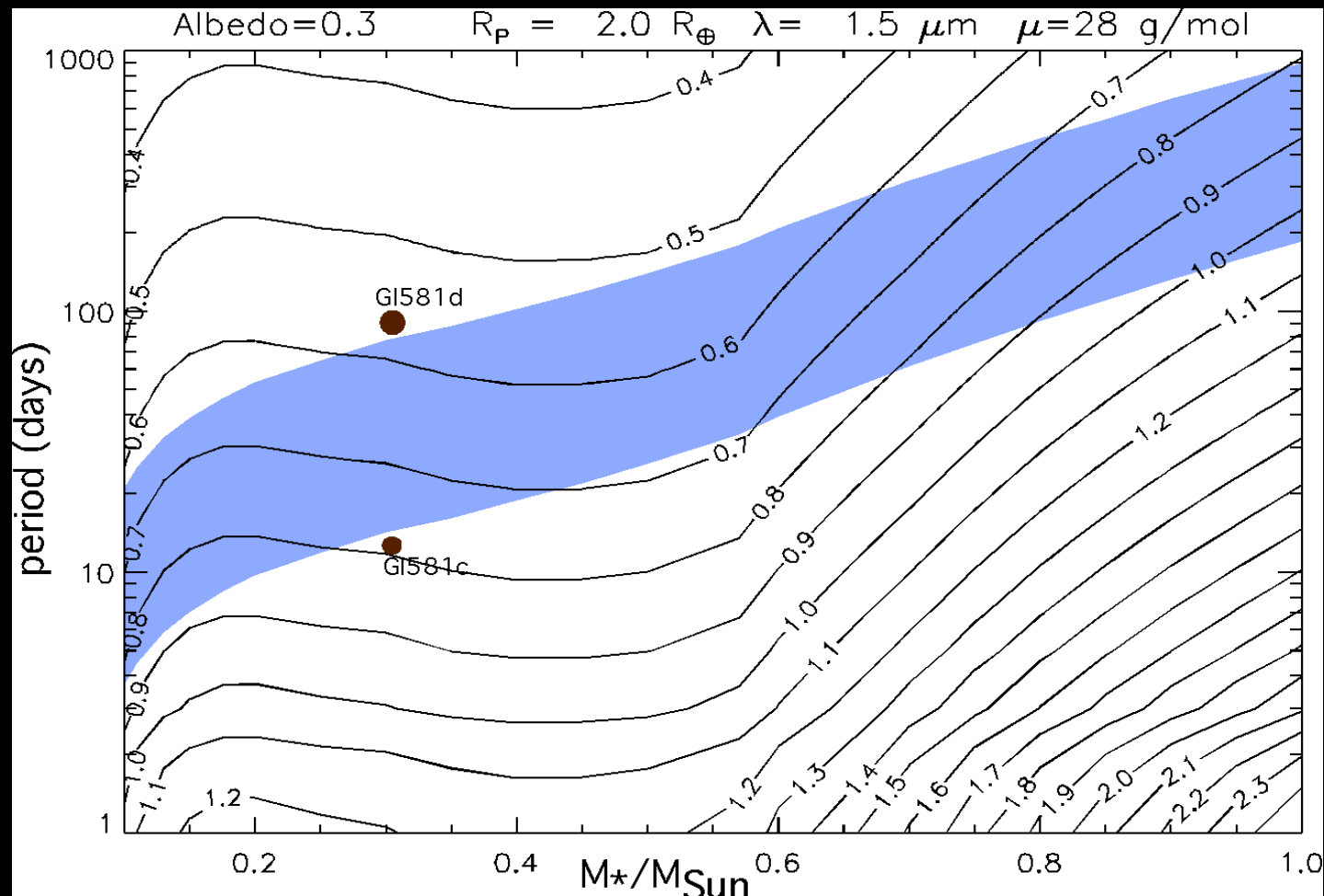**Earth: Transit Spectrum (UV-VIS)** — UV less star flux

Planet Radius [R_{planet}] vs. Vacuum Wavelength (nm)

Labeled features: O_2, O_3, O_3, O_2, O_2

Betremieux & Kaltenegger 2013

First examples: JWST (work in progress)

Signal / [stellar photon noise]   1 transit - *Super Earth*

(R=2R$_{Earth}$, A=0.3, **λ=1.5 μm**, λ/Δλ=10, dist=10 pc, μ=28g mol, fixed T: 270K, JWST)

$$SNR \propto (N_{transits})^{1/2} \times [10 \text{ pc} / \text{dist}]$$

Selsis

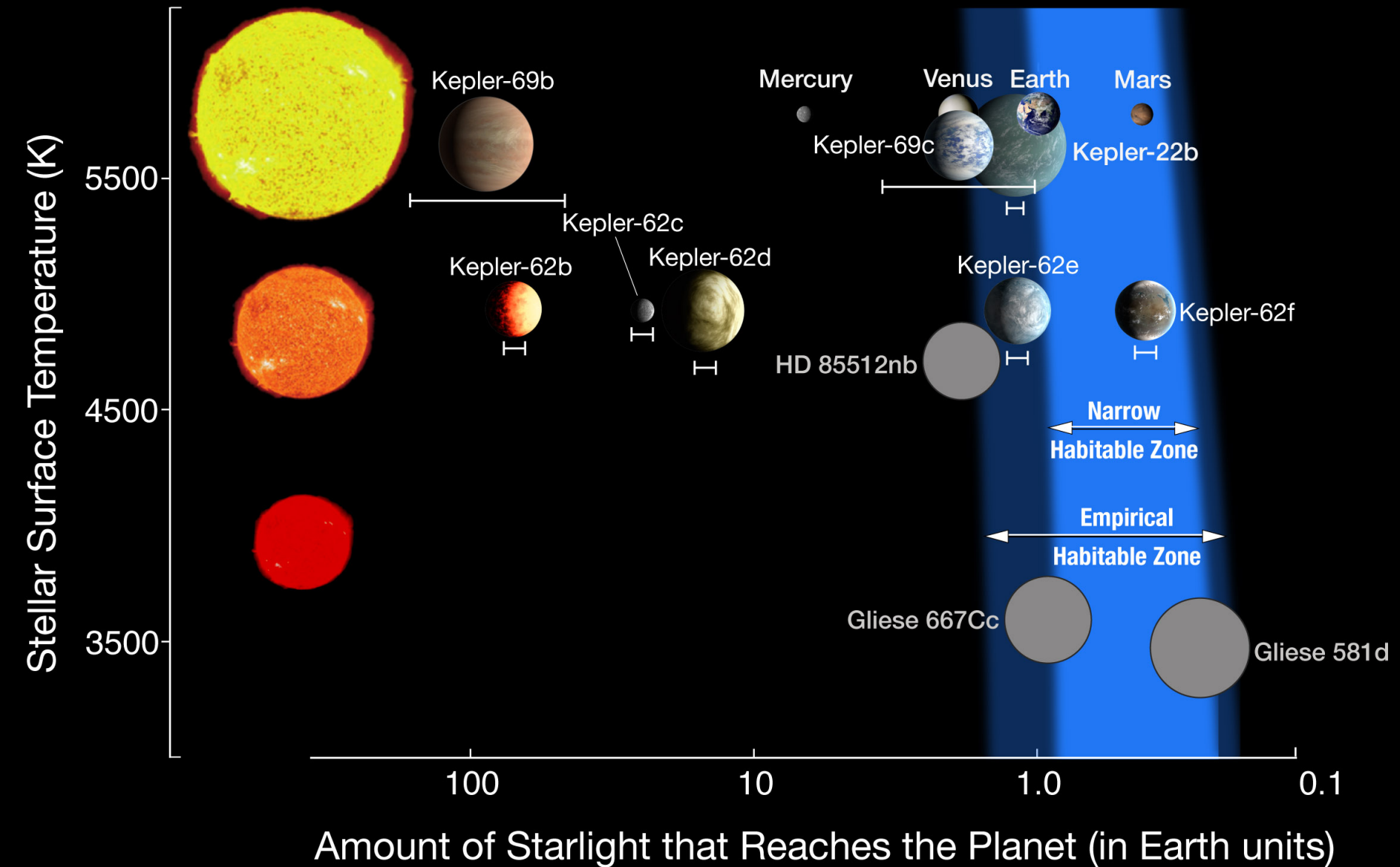Signal / [stellar photon noise]   1 transit -
Super Earth

(R=2R$_{Earth}$, A=0.3, **λ=10 μm**, λ/Δλ=10, dist=10 pc, ΔT$_B$=50K, fixed T: 270K JWST)
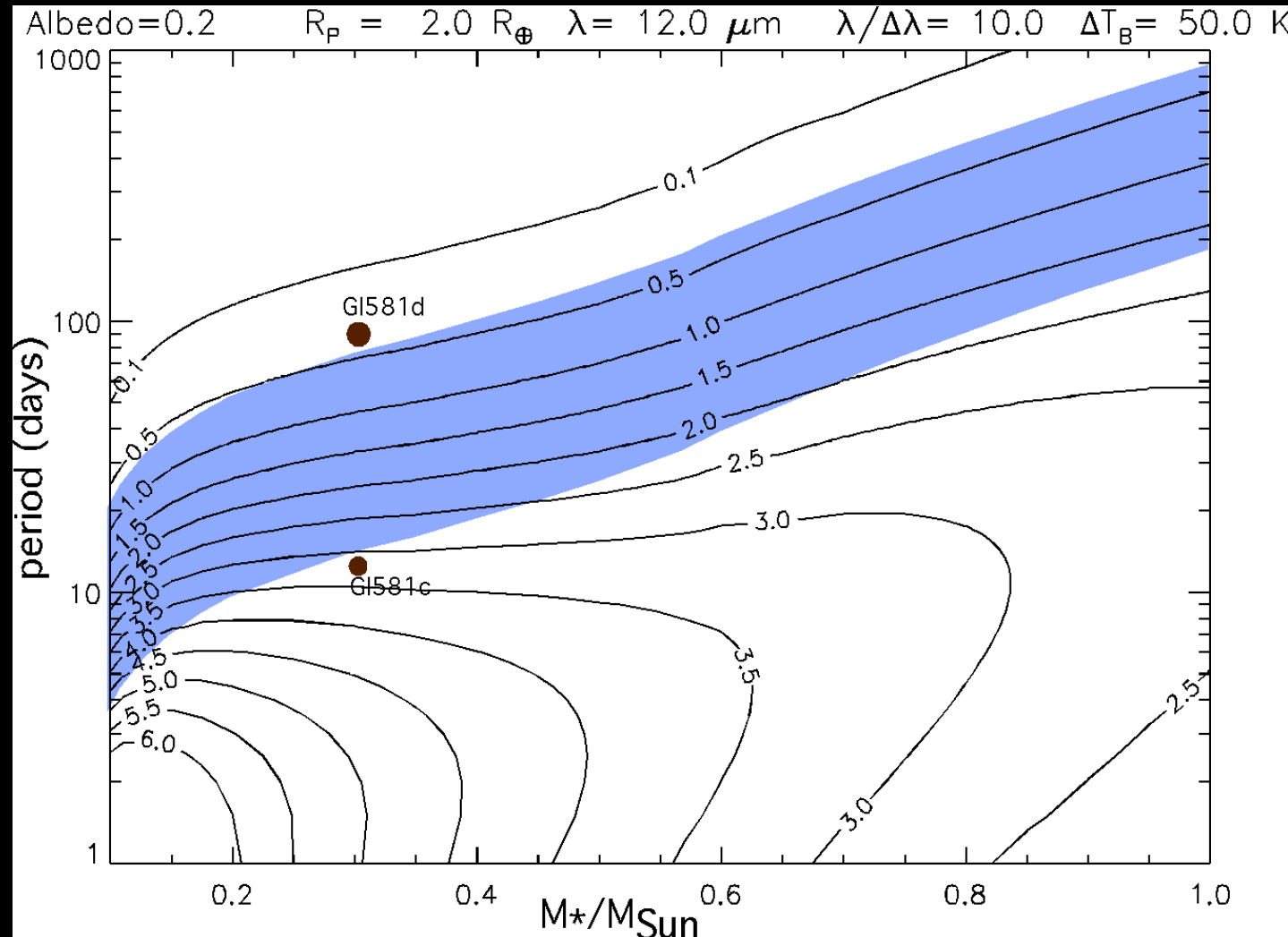
$$\text{SNR} \propto (N_{transits})^{1/2} \times [10 \text{ pc} / \text{dist}]$$
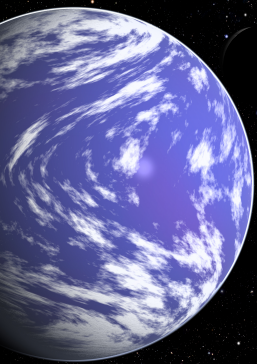
Selsis

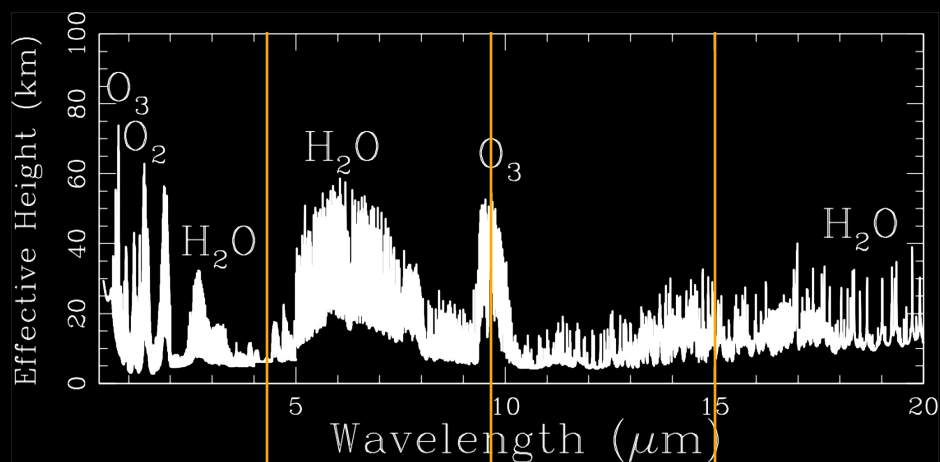# We use pot. rocky planet models in HZ $(R < 2\ R_{earth})$

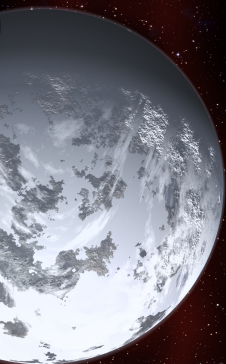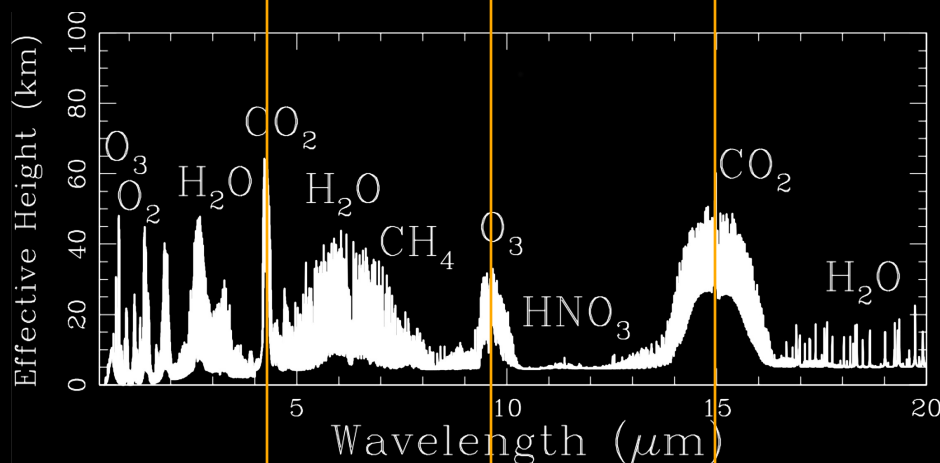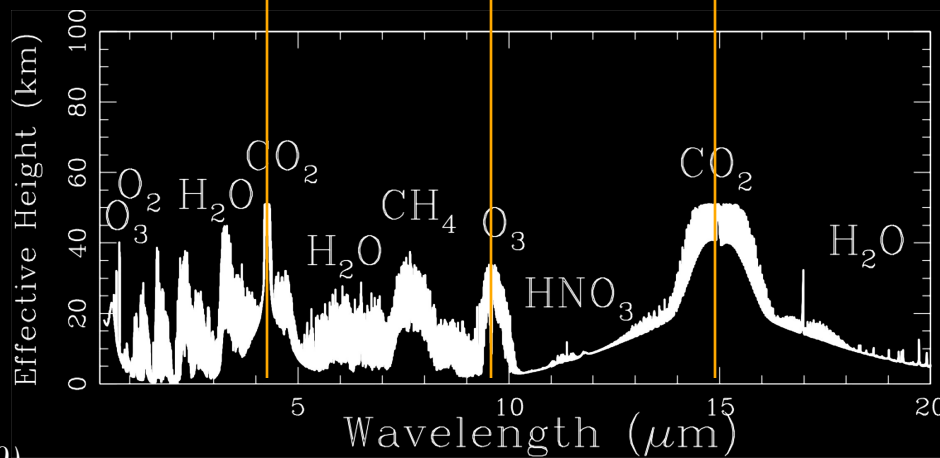*Kasting et al 93, Selsis et al 07, Abe 11, Kaltenegger & Sasselov 11, Kapporapu et al 13, Zsom et al 13...*
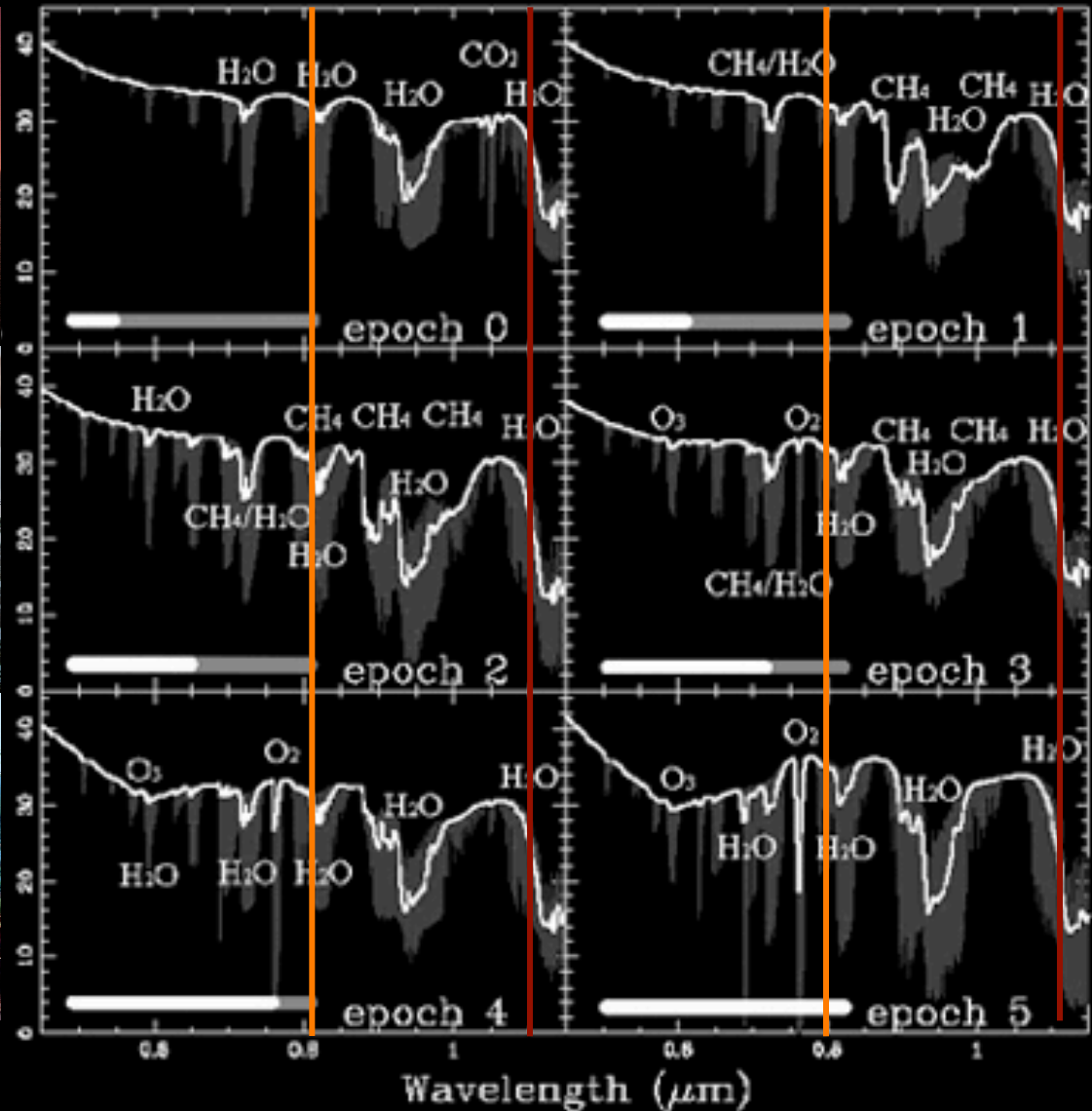
HOT

WARM

COLD

Kaltenegger, Rugheimer & Sasselov 2013 (Monday DPS 9:10)
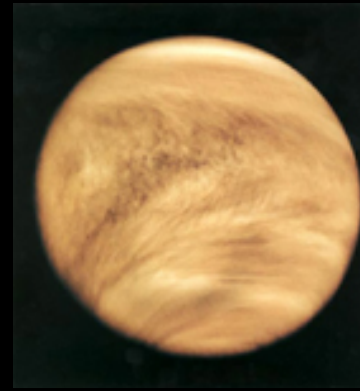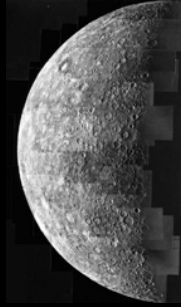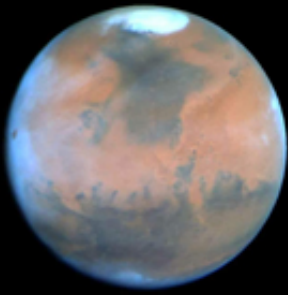
Earth Evolution over geological time - CSI

Reflected light

$$I_{VIS/NIR}(t) \propto \phi(t) \times A \times 2\pi R^2$$

The reflected light (visible-NIR) is modulated by $\phi(t)$
with or without a dense atmosphere

Thermal emission

$$I_{IR}(t) \propto \phi(t) \times BB(T) \times 2\pi R^2 \qquad I_{IR}(t) \propto \phi(t) \times BB(T) \times 2\pi R^2$$

The thermal emission is modulated by $\phi(t)$ <u>only</u> when
there is no (or a thin) atmosphere

Selsis

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- WELCOME TO THE TEAM e-mail: kaltenegger@mpia.de