Spectral appearance and detectability of terrestrial extrasolar planetary atmospheres

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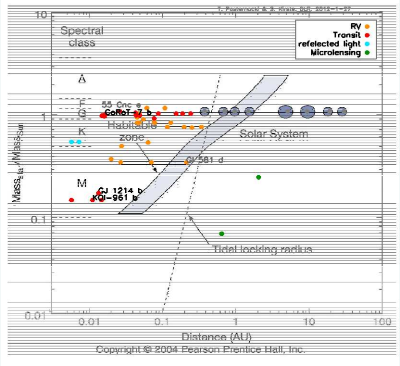
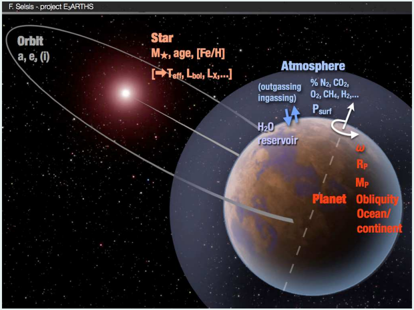
Motivation

Extrasolar planets



Based on Kasting et al. (1993) and exoplanet.eu (Msin(i)$\leq$10M$_{Earth}$)

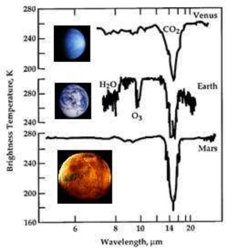
Terrestrial planetary atmospheres



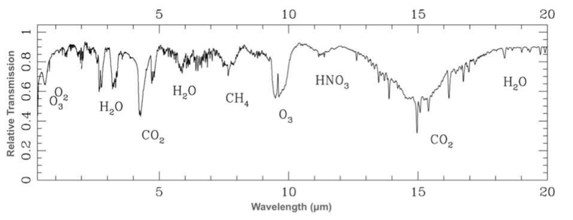
Atmospheric biomarker molecules

Ozone produced by O_2-photolysis
O_2 on Earth mainly from photosynthesis
Biomarker and related compounds: CH_4, H_2O, CO_2, N_2O

Ozone as a biomarker



Earth's atmosphere



Kaltenegger and Traub 2009

Computational details

Atmospheric model

original code based on Kasting et al. (1984), Segura et al. (2003)

- 1D radiative-convective climate model $\rightarrow$ T-p, and H_2O-profiles
- 1D photochemical model $\rightarrow$ concentration profiles of 55 species

Our model extensions:

- IR radiative transfer for N_2, CO_2, H_2O for 100K$\leq$T$\geq$700K and p$\leq$1000bar(von Paris et al. (2010))
- H_2O cloud parametrization in radiative transfer with feedback on climate (Kitzmann et al. (2010))
- inclusion of Rayleigh scattering of H_2O, CH_4, H_2, He
- adapted chemistry for hot terrestrial atmospheres
- quantitative analysis of chemical pathways

Lbl radiative transfer model - SQuIRRL

Schreier and Schimpf 2001, high-resolution emission and transmission spectra and SNR

Scenarios

CO_2 dominated atmospheres and biomarkers

Case study of Gl 581d

Spectral appearance, von Paris et al. (2011)

Clouds in Earth-like atmospheres around different types of stars

Parameter study of the influence of water droplet and ice clouds upon planetary spectra

Broad band spectral appearance, Kitzmann et al. (2011)

Super-Earths around Mdwarfs

Parameter study for Earth-like and Super-Earth planets around M-type stars including photochemistry

Spectral appearance and detectability, Rauer et al. (2011)

Case study of Gl 581d

Planetary & stellar parameter

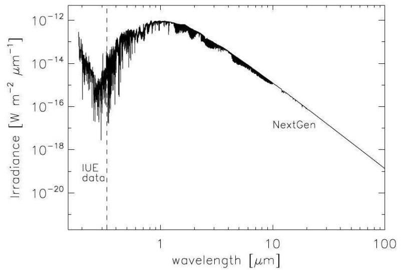
- found by RV method + no transits
- Msini=6.06M_{Earth}, P=66.6days
- M-type star, M_*=0.31M_{Sun}

Gl 581d scenarios

For certain atmospheric scenarios Gl581d could be habitable:

- 95% CO_2 and p$\geq$5 bar
- 5%CO_2 and p$\geq$20 bar
- uninhabitable for low CO_2 concentrations and low pressures

Stellar spectrum

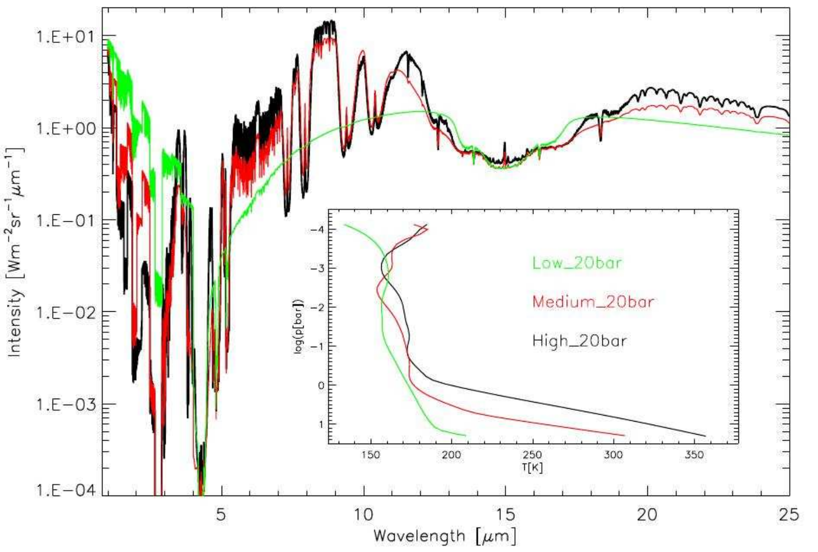


Atmospheric studies of Gl 581d

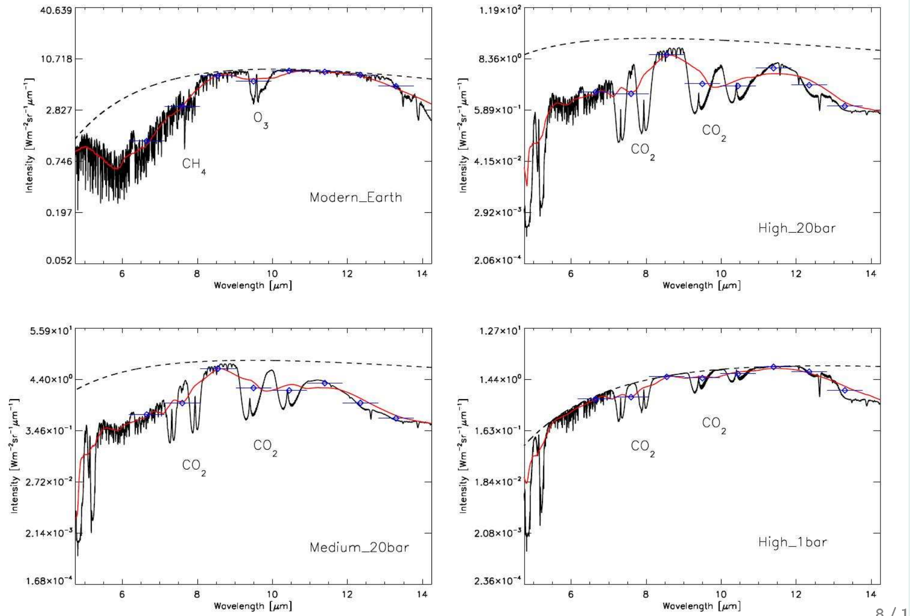
e.g. Wordsworth et al. (2010, 2011), von Paris et al. (2010), Kaltenegger et al. (2011)

Synthetic spectra for Gl581d

Emission spectra

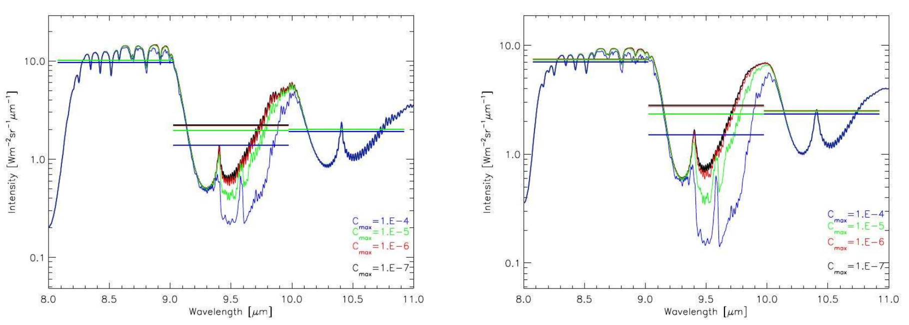


False-positive biomarker signals



Ozone masking by CO_2

Influence of Earth-like ozone profile with different maximum concentrations



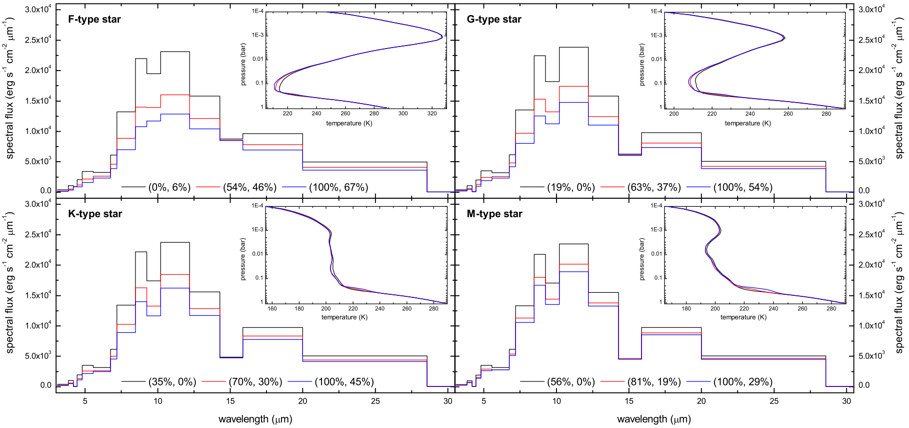
Only for O_3 profiles with larger maximum concentrations as for present Earth O_3 distinguishable from CO_2 at 9.6μm

Influence of clouds upon Earth-like atmospheric spectra

Scenarios

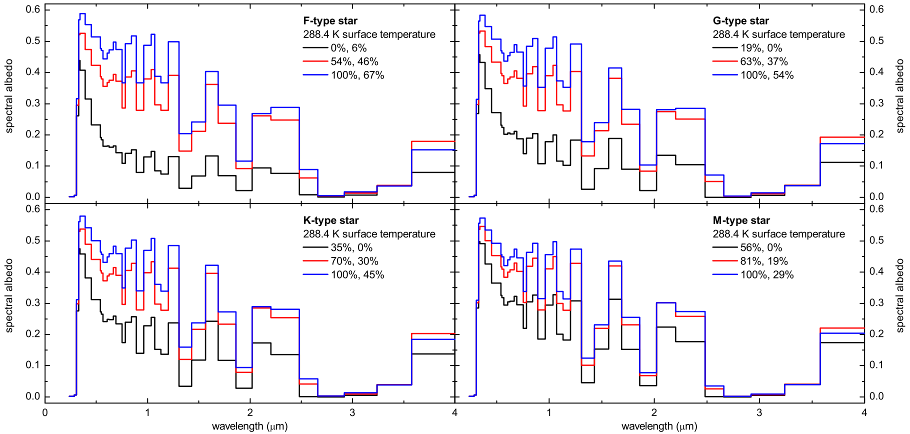
- Extrasolar planets with Earth-like atmospheres around different types of central stars (M, K, G, F-type)
- Earth-like ozone profile
- Multiple Earth-like cloud layers resulting in mean temperature of 288K
- Broad band spectra from climate model in emission and reflection (Kitzmann et al. (2011))
- Climatic effects of clouds Kitzmann et al. (2010)

Emission spectra with clouds



- clouds dampen the overall emission
- clouds dampen even spectral features originating above cloud deck, especially strong for F-type star

Reflection spectra - Spectral albedo with clouds

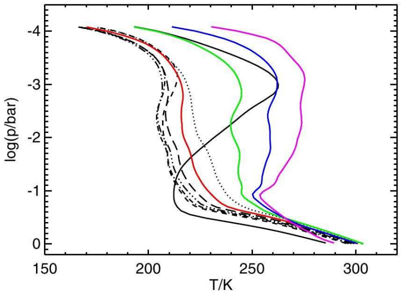


- Clouds enhance the overall reflection
- Reflection enhances the spectral signatures of biomarkers

Super-Earths and Earth-like planets around M dwarf stars

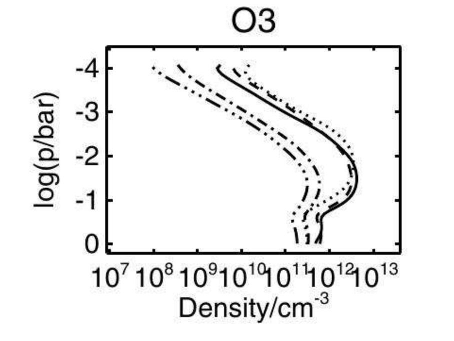
Atmospheric modeling of super-Earths & Earth-sized planets around M dwarfs including photochemistry
Rauer et al. (2011)

temperature-pressure profiles



for Earth-like planets around M dwarfs

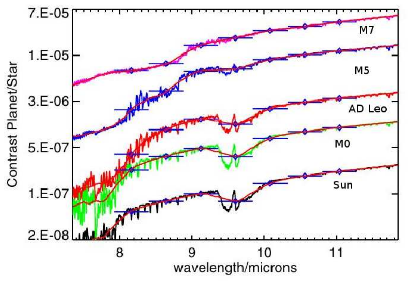
Ozone profiles



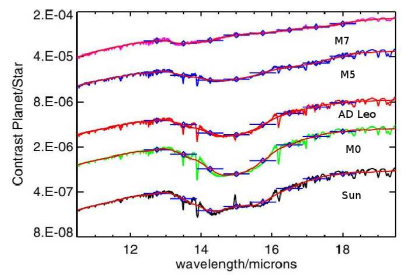
for solar insolation

Emission spectra for planets around M stars

O_3 feature

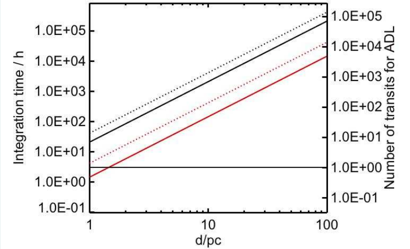


CO_2 feature

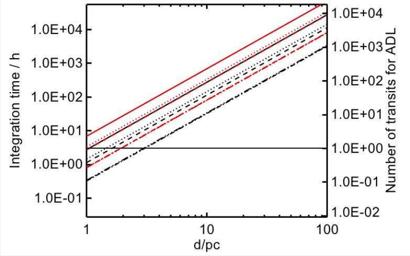


Detectability of spectral features around AD Leo

Emission



Transmission



Integration time needed for photon-limited SNR=3 at R=20 with JWST-like telescope configuration

Summary

- CO_2-dominated atmospheres can produce false-positive & false negative spectral signatures of O_3
- clouds dampen O_3 feature in emission, but enhance the feature in reflection (however low contrast)
- O_3 detection for planets with JWST even around M dwarfs is challenging because of SNR
  $\rightarrow$ needs close by stars and addition of several transit observations
- Outlook: Calculations for E-ELT look more promising (Hedelt et al. (2012), submitted)