



Modelling Super-Earth Atmospheres

Sarah McKenzie-Picot

Physics & Astronomy, McMaster University

Supervisor: Ralph Pudritz

Introduction

Super-Earths, whose properties are outlined below [1], dominate the observed exoplanet population (~60% of 3268), and are of interest due to their potential habitability.

- 1-10 Earth masses
- Rocky cores
- Diverse atmospheres
 - Wide range of atmospheric mass and composition from gas envelope accretion and outgassing
 - Outgassing dependent on planet formation history

We are developing a new self-consistent model of Super-Earth atmospheres that will iteratively determine the temperature and pressure structure and chemical composition as a function of altitude and planet formation history.

Model

- 1-D plane-parallel geometry
- Radiatively heated, hydrostatic equilibrium
- Assumptions:
 - Local thermodynamic equilibrium
 - No scattering
- Molecular absorption cross-sections from Exomol, HITRAN [2]

Governing Equation [3]

$$T(\tau)^4 = \frac{3}{4} T_{int}^4 \left[\tau_{IR} + \frac{2}{3} \right] + \mu_0 T_0^4 \left[-\frac{3}{4} \frac{\mu_0}{\gamma} e^{-\frac{\gamma \tau_{IR}}{\mu_0}} + \frac{3}{2} \left(\frac{2}{3} + \left(\frac{\mu_0}{\gamma} \right)^2 - \left(\frac{\mu_0}{\gamma} \right)^3 \ln \left(1 + \frac{\gamma}{\mu_0} \right) \right) \right]$$

Exoplanet Data

- Selected potentially habitable exoplanets from literature[4]
 - Rocky, likely maintain surface water
 - Gravitational acceleration 10 – 20 m/s²
 - Incoming flux 0.29 – 1.11 F_{Earth}
- Kept atmospheric opacity constant, tested effects of changing atmosphere mass, gravity and incoming flux

Changing Incoming Flux

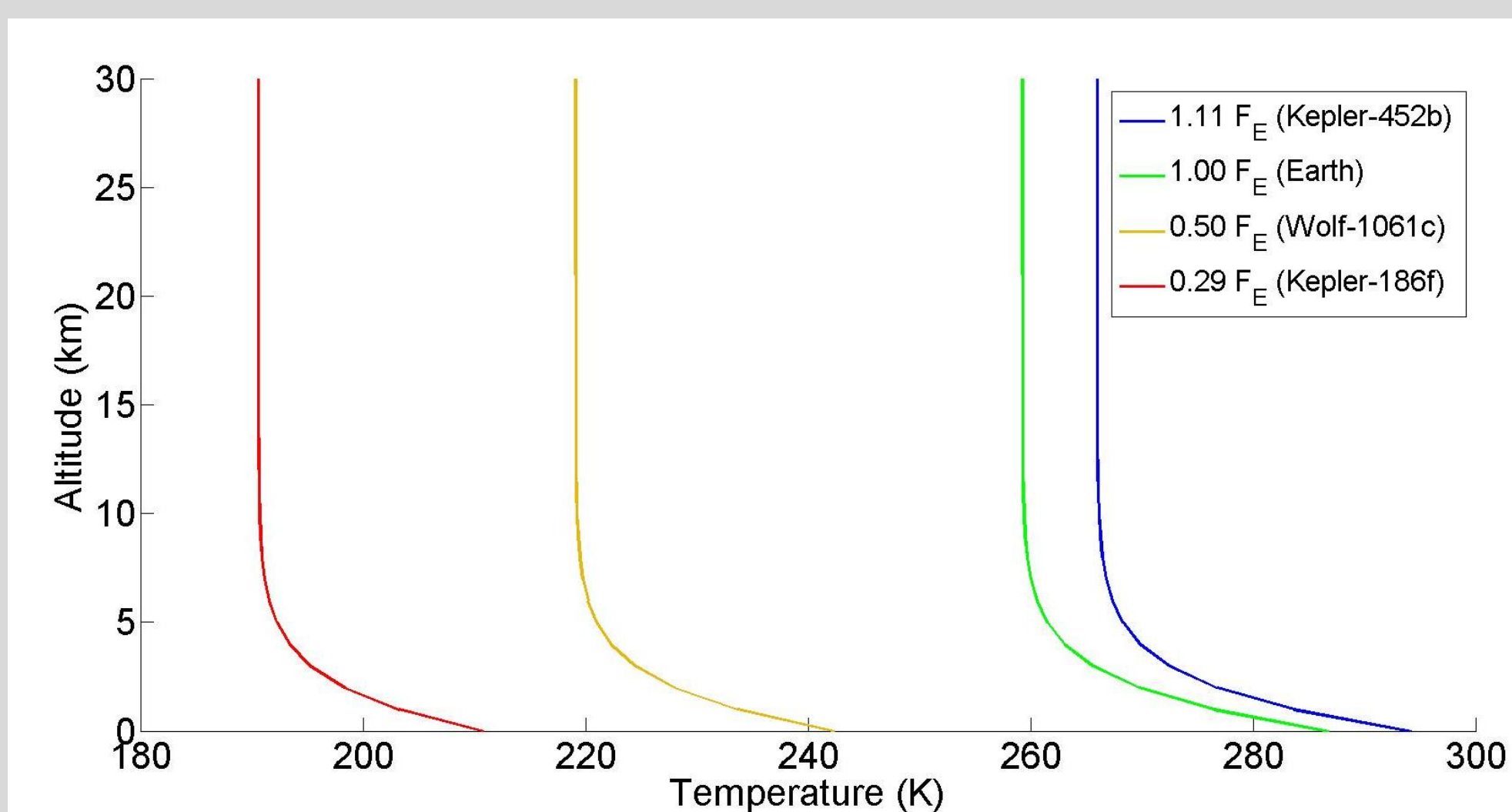


Figure 1: The effects of changing incoming flux, or semi-major axis. As expected, a planet that receives less flux has a lower surface temperature.

Changing Surface Gravity

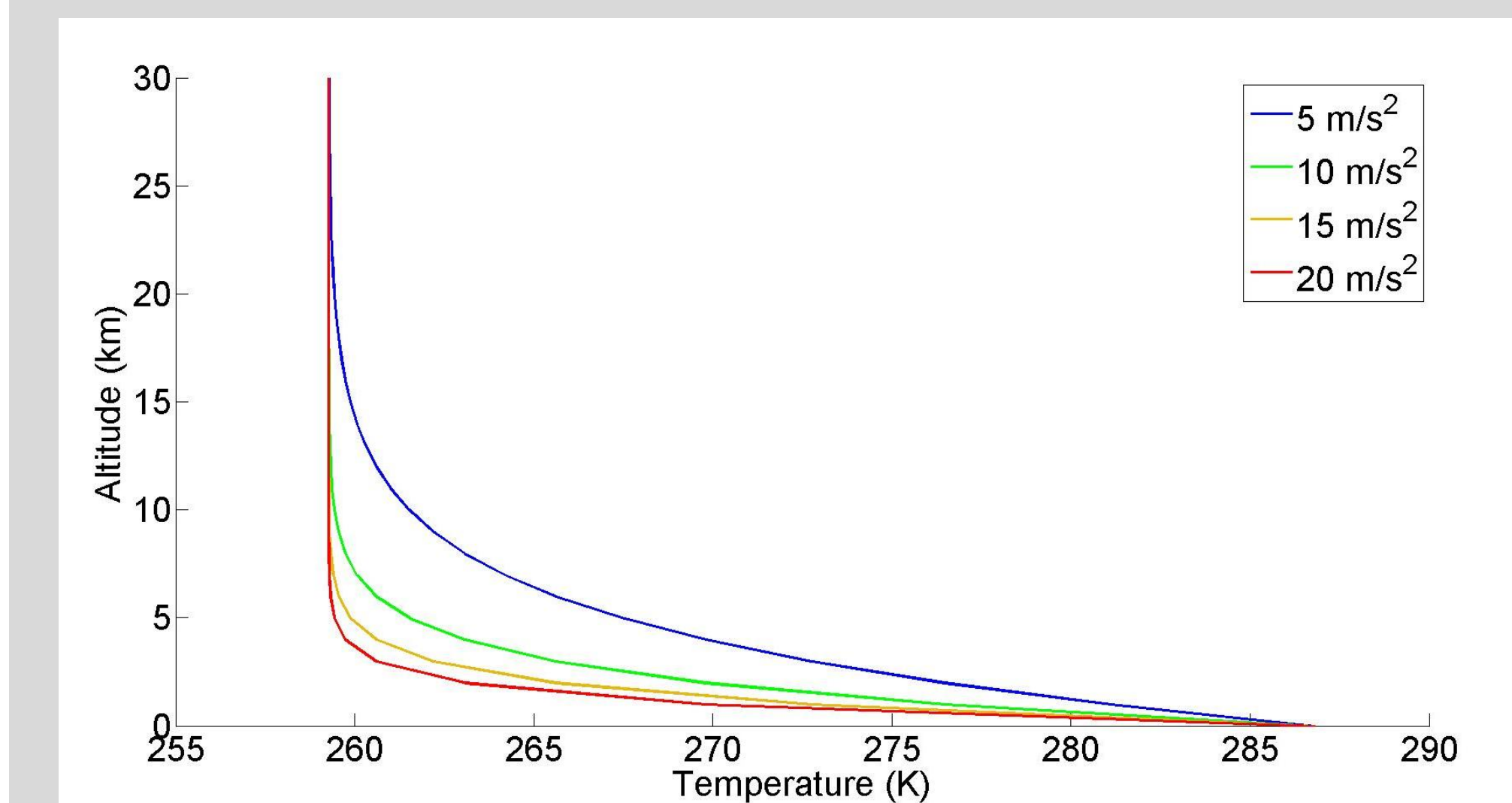


Figure 3: The effects of surface gravity while keeping atmospheric properties constant. Surface gravity impacts temperature distribution but not surface temperature.

Changing Atmosphere Mass

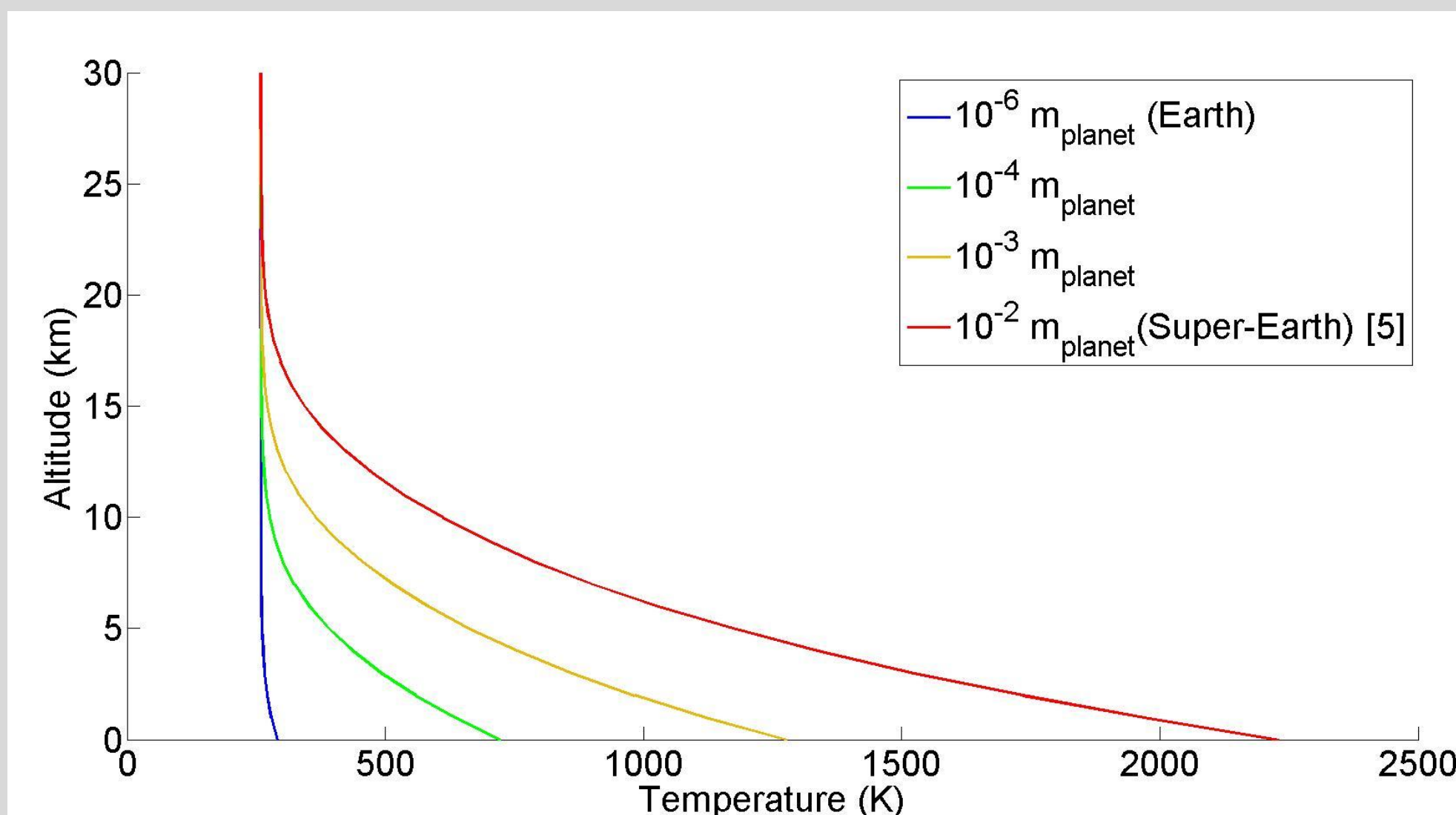


Figure 2: The effects of changing atmosphere mass while keeping stellar flux and atmosphere composition constant. This test indicates that a Super-Earth should be further from its host star than an Earth-sized planet to maintain potential habitability.

Conclusions and Future Work

- Proof-of-concept model that shows the sensitivity of surface conditions to planet and stellar properties
- Initial atmospheric composition will be determined by accretion history of migrating Super-Earth cores which is computed by our group [5]
- Will add more complex atmosphere compositions for potentially habitable planets (equilibrium chemistry)

References

- [1] Seager, S. & Deming, D., 2010, ARAA, 48, 631
- [2] Molliere, P., et al. 2015, ApJ, 813, 47
- [3] Seager, S. Exoplanet Atmospheres: Physical Processes, 2010
- [4] Planetary Habitability Laboratory, Univ. of Puerto Rico
- [5] Wolfgang, A. & Lopez, E. 2015, ApJ, 806, 183
- [6] Alessi, M., Pudritz, R. & Cridland, A., 2016, MNRAS, arXiv: 1606.09174