Explanation of a "0.1 bar Tropopause Rule" in Thick Atmospheres of Planets and Large Moons. T. D. Robinson[1] and D. C. Catling[2], [1]Astronomy Department, University of Washington (Box 351580, Seattle, WA 98195-1580; robinson@astro.washington.edu) [2]Department of Earth and Space Sciences, University of Washington (Box 351310, Seattle, WA 98195-1310; dcatling@u.washington.edu).

Introduction: Tropopause temperature minima in planetary atmospheres are fundamental for understanding atmospheric structure. A variety of shortwave absorbers (e.g., ozone, organic hazes) produce temperature inversions in the stratospheres of Earth, Jupiter, Saturn, Titan, Uranus, and Neptune. These inversions lead to temperature minima that, remarkably, all occur near 0.1 bar, despite these worlds being disparate with regards to insolation, atmospheric composition, gravity, and internal heat flux. We explain this common 0.1 bar tropopause, and discuss the conditions for, and utility of, a physically based "0.1 bar tropopause rule" for worlds with thick atmospheres [1].

Methods: We analyze the atmospheric thermal structure of the solar system worlds with thick atmospheres using an analytic 1-D radiative-convective model [2]. This model assumes that thermal radiative transfer is gray, and that the shortwave radiative transfer is divided into two channels: a stratospheric channel, which allows for inversions, and a tropospheric channel for solar heating at depth and at the surface. We assume that a convective profile sits below the portion of the atmosphere that is in radiative equilibrium, and we ensure that temperature and upwelling thermal flux are continuous across the radiative-convective boundary. In the convective region, we assume that the temperature profile follows an adiabat that has been adjusted to account for condensation. Finally, we assume a simple power-law scaling between the gray infrared optical depth, τ_{IR}, and pressure, p, with $\tau \propto p^n$. Here, n equal to 2 is appropriate for the troposphere, where the infrared opacity tends to be dominated by collision-induced absorption and/or strong pressure broadening of absorption lines.

Results: For the worlds of the solar system, the tropopause temperature minimum always lies in the radiative regime, above the radiative-convective boundary. Thus, the shared 0.1 bar tropopause arises from the common physics of infrared radiative transfer. Model fits to the solar system worlds show that the gray infrared optical depth where the tropopause minimum occurs, τ_{tp}, is $D\tau_{\mathrm{tp}} \sim 0.1$, where D, the diffusivity parameter, accounts for integration of radiance over a hemisphere. Furthermore, the gray infrared optical depths at a pressure of 1 bar are typically of order a few. Thus, given the aforementioned scaling between pressure and infrared optical depth, with $p \propto \tau^{0.5}$, we see that the tropopause pressure must be near 0.1 bar.

Discussion: Moving beyond the solar system, our model shows that the typical gray infrared optical depth of the tropopause is roughly 0.1 for a very wide portion of parameter space. This value is special as it marks the transition into the upper regions of the atmosphere that are relatively transparent to thermal radiation. Here, shortwave absorption can dominate the temperature profile and, thus, create an inversion and corresponding temperature minimum. This preferred value of τ_{tp} indicates that the common 0.1 bar tropopause levels seen in the solar system are actually more universal. Thus, provided that (i) a simple scaling between pressure and infrared optical depth holds and (ii) that the infrared optical depth is of order 1-10 at a pressure of 1 bar, then a common 0.1 bar tropopause emerges.

Conclusions: We hypothesize that many exoplanets will possess a 0.1 bar tropopause. Additionally, our proposed "tropopause rule" may be useful in remote sensing of planetary atmospheres. Such a rule provides a useful first guess for the location of a tropopause temperature minimum when performing a retrieval of a temperature profile, and could allow for improved estimates of surface pressures or temperatures when used in simple models.

References: [1] Robinson, T. D. and Catling, D. C. *submitted*. [2] Robinson, T. D. and Catling, D. C. (2012) *Astrophys. J.*, 757, 104.