UNIVERSITY of CALIFORNIA
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THERMAL EVOLUTION OF URANUS WITH CONDENSATION-INHIBITED CONVECTION

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in

ASTROPHYSICS

by

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Abstract

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This will be the last section written, once we have finished our analysis.

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To Who,

the owl

Acknowledgements

I'd like to thank my attorney, Bob Loblaw

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Introduction

Observations of Uranus show a planet that appears to be in thermal equilibrium with the Sun. Observation has also shown that Uranus is cooler than its more distant neighbor, Neptune. Meanwhile, thermal evolution models for Uranus have not matched observation, instead predicting a warmer effective temperature during the current epoch(Fortney et al., 2011), (M. Podolak, 1991), (W.B. Hubbard, 1995), (L. Scheibe, 2019) [There are other papers by Nettelmann 2013, Linder 2019 that I haven't looked at yet].

There have been various attempts to model the underluminous Uranus. [how much should i go into work done with different EOS's?] The formation of stable layers, trapping internal energy in the the interior of Uranus and Neptune was proposed by (M. Podolak, 1991). Work on the formation of stable condensation zones, inhibiting convection, have been investigated by (Friedson & Gonzales, 2017), (Leconte et al., 2017), and (Guillot, 1995).

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Methodology

Begin with discussion of interiror model when there is no condensation. The temperature-pressure profile follows a dry adiabat, given by ∇_{ad}:

$$T(P > P_{\mathrm{base}}) = T_{\mathrm{base}} + \int_{P_{\mathrm{base}}}^{P} \left(\frac{dT}{dP}\right)_{\mathrm{ad}} dP \tag{2.1}$$

Condensation is inhibited when $\alpha < 1$, where is α is given by:

$$\alpha = 1 + \xi(q_s L/R_W T_0) \tag{2.2}$$

If condensation is found to be inhibited, the pressure-temperature follows a moist adiabat. Need to add equations for that here. Also, need to look at when moist adiabat is calculated. I recall it being calculated down to 1200 bars, but this changed with inclusion of radiative layer.

At pressure where $\alpha < 1$, the cloud base of the water condensation zone forms. This thin, stable radiative layer has a temperature that is governed by:

$$T(P) = T_{\rm top} + \int_{P_{\rm top}}^{P} \left(\frac{dT}{dP}\right)_{\rm rad} dP \tag{2.3}$$

$$\left(\frac{dT}{dP}\right)_{\rm rad} = \frac{T}{P}\nabla_{\rm rad} = \frac{T}{P} \times \frac{3}{16}\frac{\kappa_R P}{g}\frac{T_{\rm int}^4}{T^4} \tag{2.4}$$

$$T_{\rm base} \equiv T(P + \Delta P) = T_{\rm top} + \left(\frac{dT}{dP}\right)_{\rm rad} \Delta P. \tag{2.5}$$

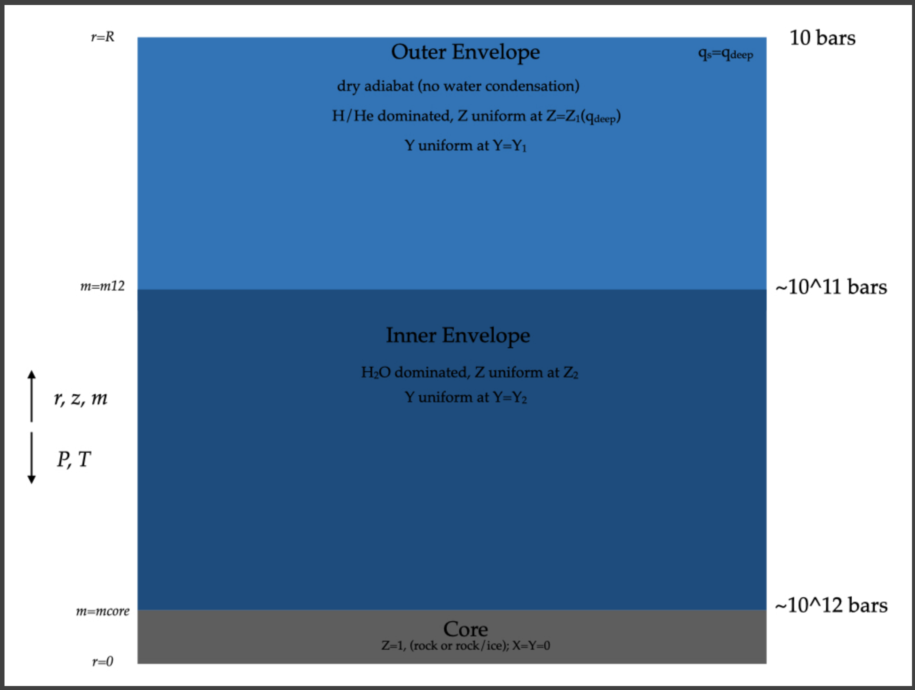
$$x_{\rm vap}(P, T) = x_{\rm vap}^{\rm sat}(P, T) = \frac{e_s(T)}{P}, \qquad P < P_{\rm base}. \tag{2.6}$$

$$x_{\rm vap}^{\rm sat}(P_{\rm base}, T_{\rm base}) = \frac{e_s(T_{\rm base})}{P_{\rm base}} = x_{\rm vap}^{\rm deep} \Longrightarrow \Delta P \equiv P_{\rm base} - P_{\rm top} = \frac{e_s(T_{\rm base})}{x_{\rm vap}^{\rm deep}} - P_{\rm top} \tag{2.7}$$

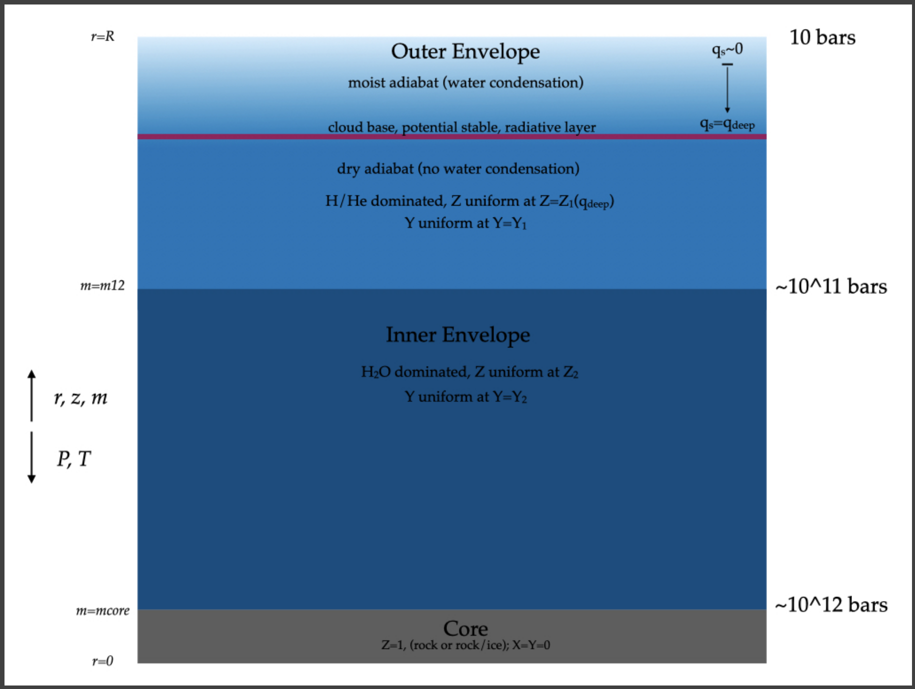
$$T_{\rm base} = T_{\rm top} + \left(\frac{dT}{dP}\right)_{\rm rad} \left(\frac{e_s(T_{\rm base})}{x_{\rm vap}^{\rm deep}} - P_{\rm top}\right) \tag{2.8}$$

Below the base of the radiative layer, the temperature-pressure profile again follows a dry adiabat, given by $\nabla_{\rm ad}$ (replace with reference to original equation:

$$T(P > P_{\rm base}) = T_{\rm base} + \int_{P_{\rm base}}^{P} \left(\frac{dT}{dP}\right)_{\rm ad} dP \tag{2.9}$$



(a) The interiror structure for dry adiabat. This can also represent the situation in which the water condensation zone has eroded and the interior becomes fully convective.



(b) The interior structure when a condensation zone has formed, creating a potentially stable, radiative layer. This represents the cloud base. It's depth decreases with a decrease in T_{10}.

Figure 2.1: Interior structure model for Uranus

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Results

3.1 Condensation-inhibited Convection

Talk about Figure 3.1.

3.2 Formation of Radiative Layer

Talk about Figure 3.2.

3.3 Thermal Evolution

Talk about Figure 3.3.

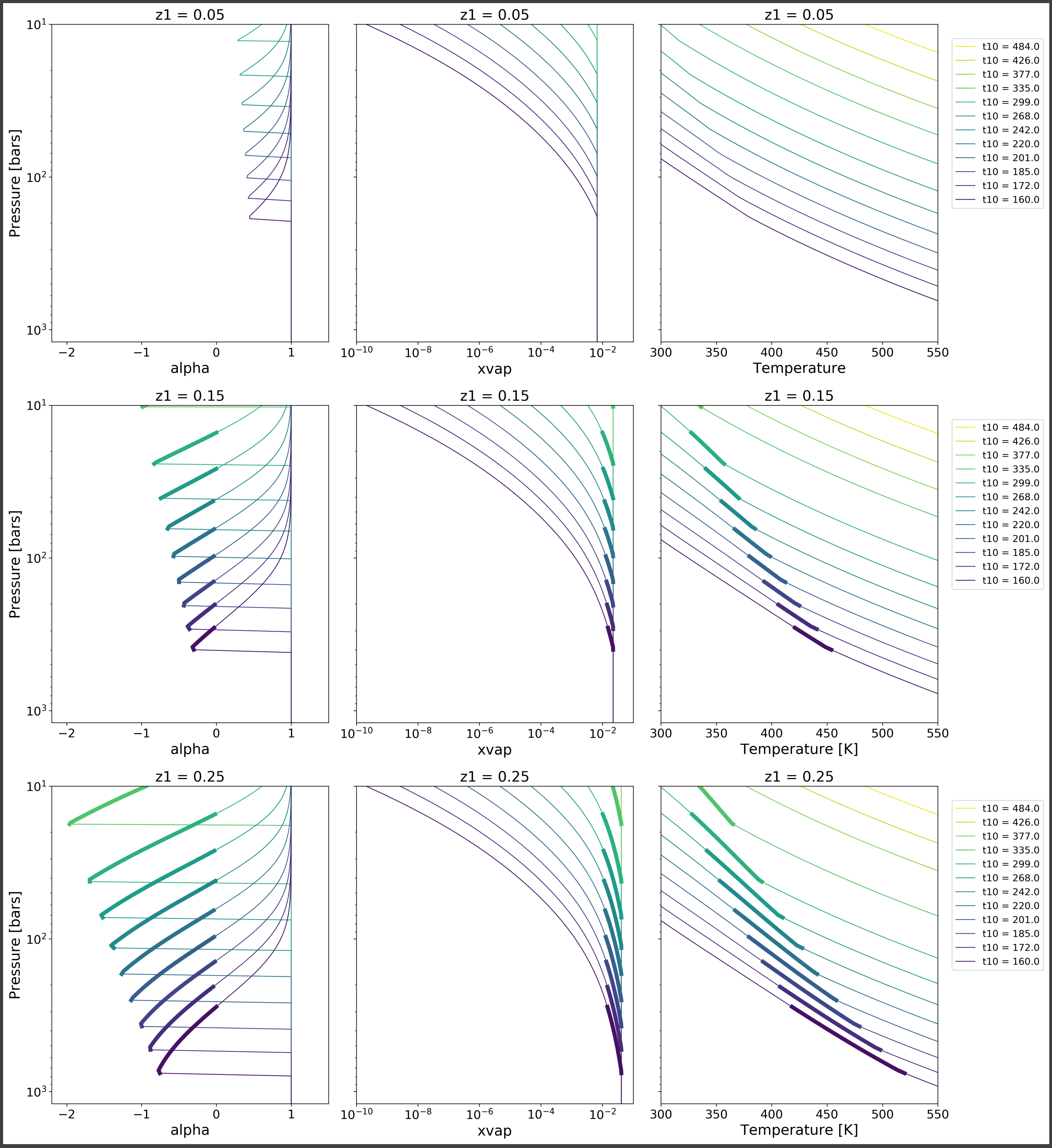

Figure 3.1: Need to add text here

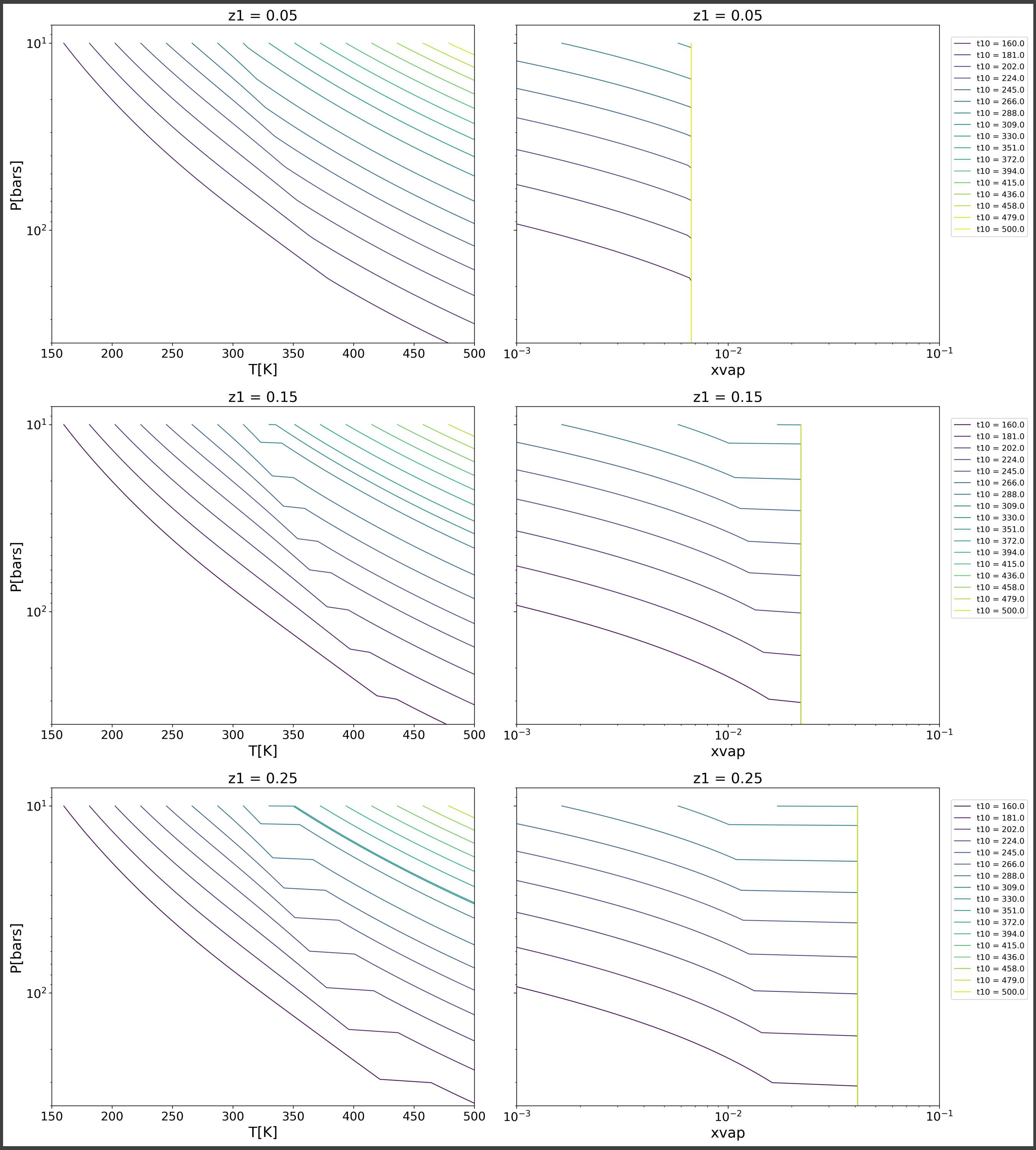

Figure 3.2: Need to add description here

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Discussion and Conclusions

Appendix A

Some Ancillary Stuff

Bibliography

Fortney, J. J., Ikoma, M., Nettelmann, N., Guillot, T., & Marley, M. S. (2011). Self-consistent model atmospheres and the cooling of the solar system's giant planets. *The Astrophysical Journal*, 729, 32.

Friedson, A. J. & Gonzales, E. J. (2017). Inhibition of ordinary and diffusive convection in the water condensation zone of the ice giants and implications for their thermal evolution. *Icarus*, 297, 160–178.

Guillot, T. (1995). Condensation of methane, ammonia, and water and the inhibition of convection in giant planets. *Science*, (pp. 1697–1699).

L. Scheibe, N Nettelmann, R. R. (2019). Thermal evolution of uranus and neptune: Adiabatic models. *Astronomy and Astrophysics*, A70, 632.

Leconte, J., Selsis, F., Hersant, F., & Guillot, T. (2017). Condensation-inhibited convection in hydrogen-rich atmospheres: Stability against double-diffusive processes and thermal profiles for jupiter, saturn, uranus, and neptune. *Astronomy and Astrophysics*, A98, 598.

M. Podolak, W.B. Hubbard, D. S. (1991). Models of uranus' interior and magnetic field. *Uranus, Editors: J.T. Bergstralh, E.D. Miner, M. Shapely Matthews*, (pp.$\tilde{2}$9).

W.B. Hubbard, D. S. (1995). The interior of neptune. *Neptune and Triton, Editor: D.P. Kruikshank*, (pp. 109).