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 explain the underluminous Uranus. The formation of stable layers, trapping internal energy in the the interior of Uranus and Neptune was proposed by (M. Podolak, 1991). There has also been much work done investigating the formation of stable condensation zones that inhibit convection (Friedson & Gonzales, 2017), (Leconte et al., 2017), and (Guillot, 1995).

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Methodology

When modeling the thermal evolution of gas and ice giants, it has long been recognized that model atmospheres constitute an outer boundary condition for interior structure models, providing key inputs that impact cooling times for interior structure models. Our work considers both the Graboske 1975 (Harold C. Graboske & Olness, 1975) and Fortney 20111 (Fortney et al., 2011) model atmospheres. Unless otherwise stated, our results will utilize the Graboske model atmospheres.

Below the atmosphere, our model of the interior structure is represented by three layers, seen schematically in Figure (2a) and (2b). There is an outer envelope, which is H and He dominated with trace amounts of H_2O. For the outer envelope, our implementation utilizes the MH13SCVH EOS (Y. Miguel & Fayon, 2018). The inner envelope is H_2O dominated with uniform amounts of H and He, using the MAZEVET EOS (S. Mazevet & Potekhin, 2019). The core is .....

Previous interior models have assumed a dry adiabatic interiror. In this case, the temperature-pressure profile follows a dry adiabat, given by $\nabla_{\rm ad}$:

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

Our model adds a moist adiabatic layer to the outer envelope when conditions are suitable for the formation of a stable water condensation zone. Condensation is inhibited when $\alpha < 1$, where is α (Friedson & Gonzales, 2017) 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 prfile follows a moist adiabat. Include equations for q_s, latent heat, xi, saturation vapor pressure, ... other equations that define the moist adiabat.

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

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

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

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

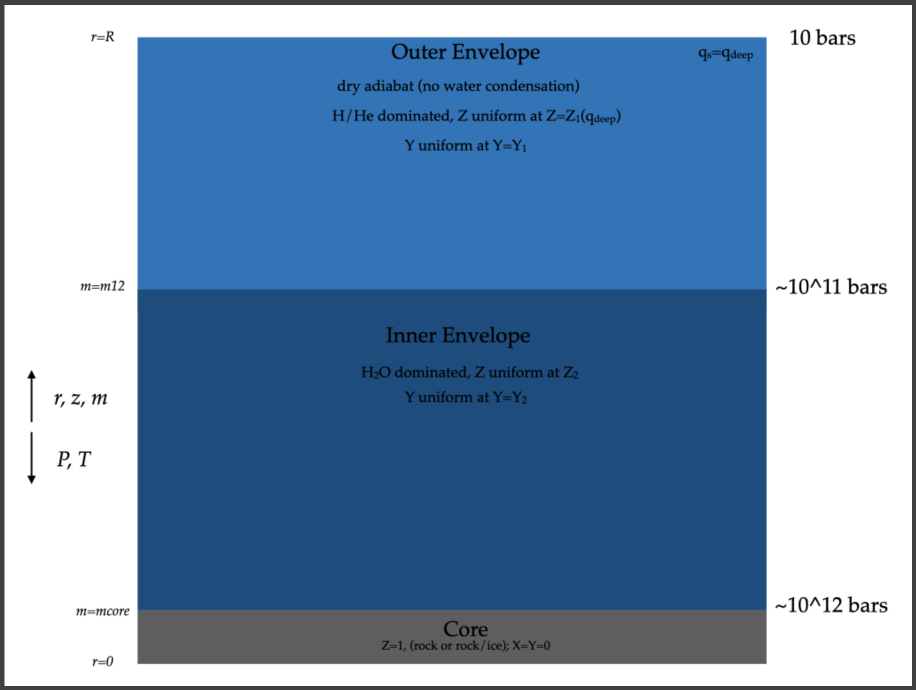
$$x_{\text{vap}}(P,T) = x_{\text{vap}}^{\text{sat}}(P,T) = \frac{e_s(T)}{P}, \qquad P < P_{\text{base}}. \tag{2.6}$$

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

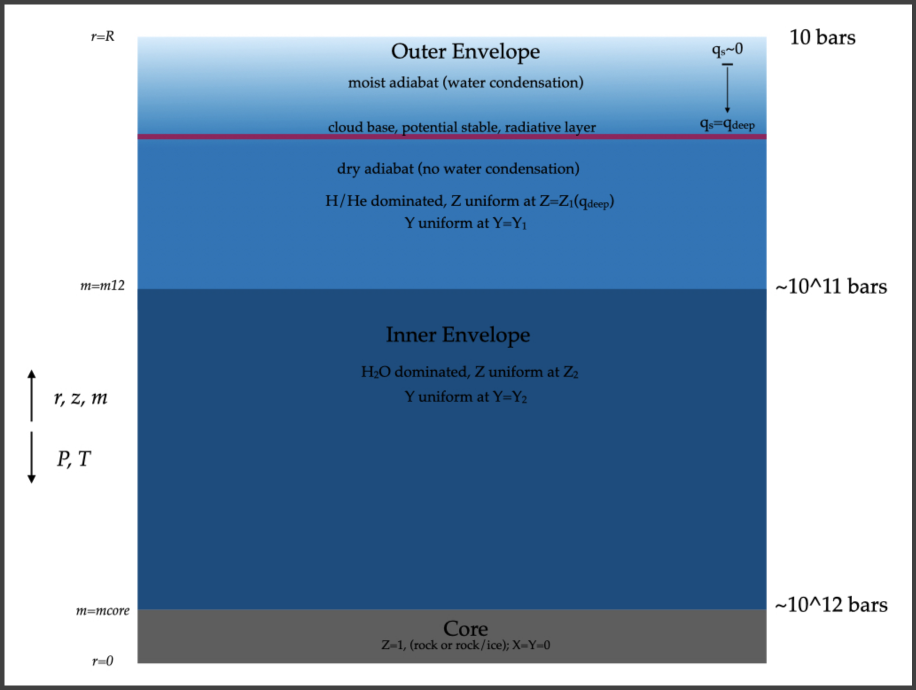
$$T_{\text{base}} = T_{\text{top}} + \left(\frac{dT}{dP}\right)_{\text{rad}} \left(\frac{e_s(T_{\text{base}})}{x_{\text{vap}}^{\text{deep}}} - P_{\text{top}}\right) \tag{2.8}$$

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

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



(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.

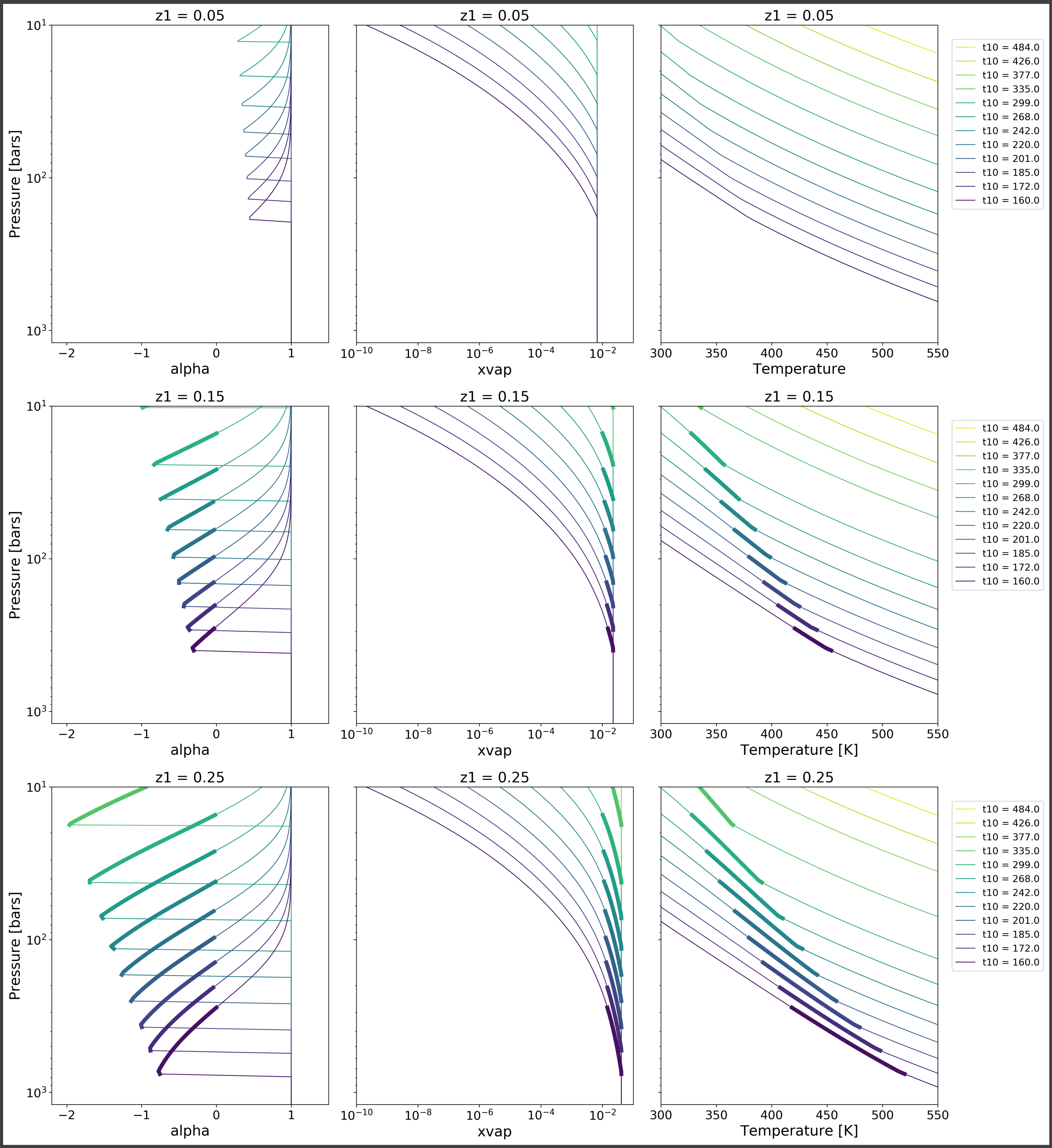

Figure 3.1: add description re: moist adiabat, when/where convection is inhibited and where the radiative zone base is in these plots. explain differences

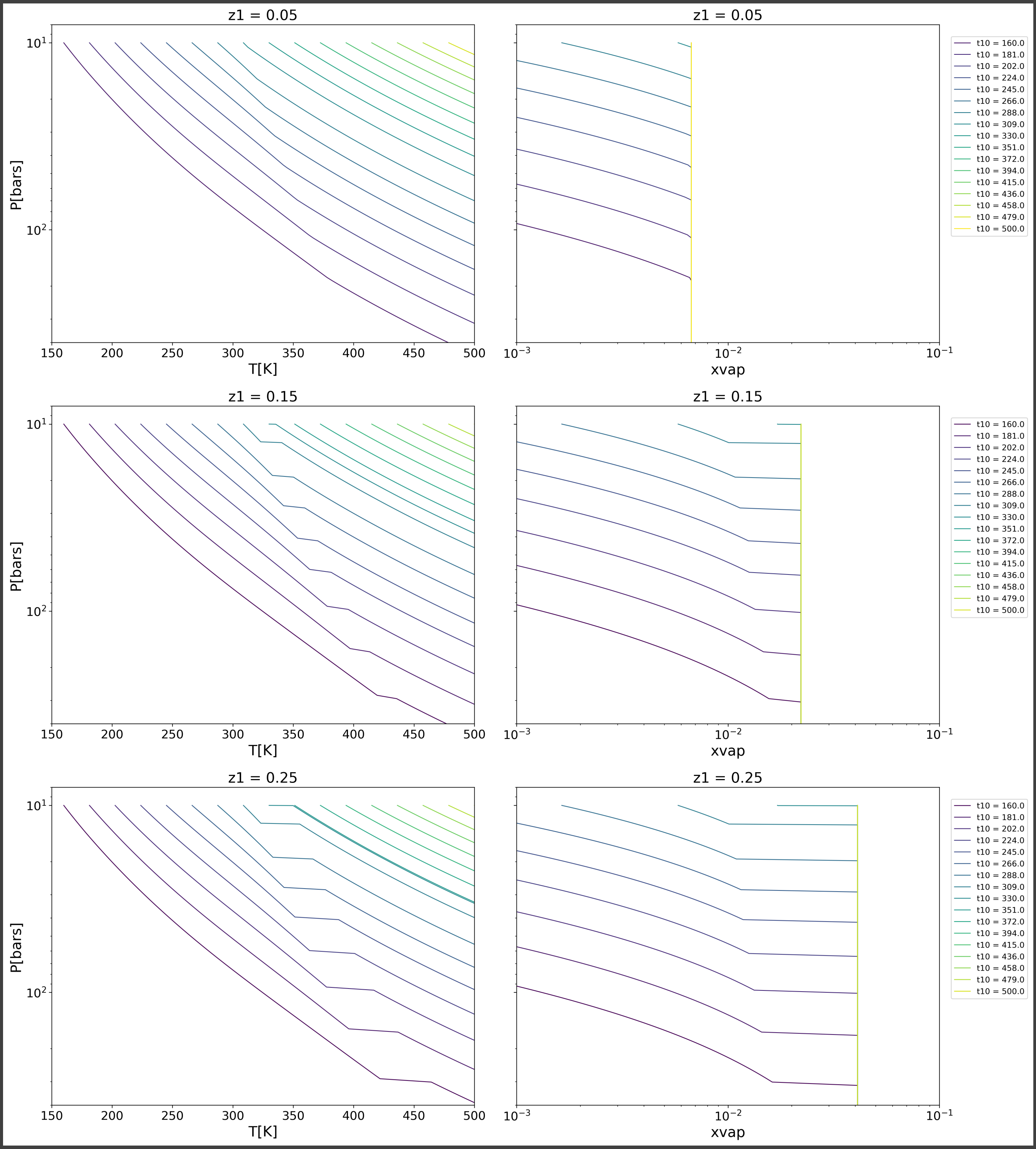

Figure 3.2: add description these plots. explain differences

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Discussion and Conclusions

Appendix A

Some Ancillary Stuff

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