Internal Gravity Waves & Cloud Evolution in Substellar Atmospheres

NUMERICAL SIMULATIONS & FUTURE CAPABILITIES

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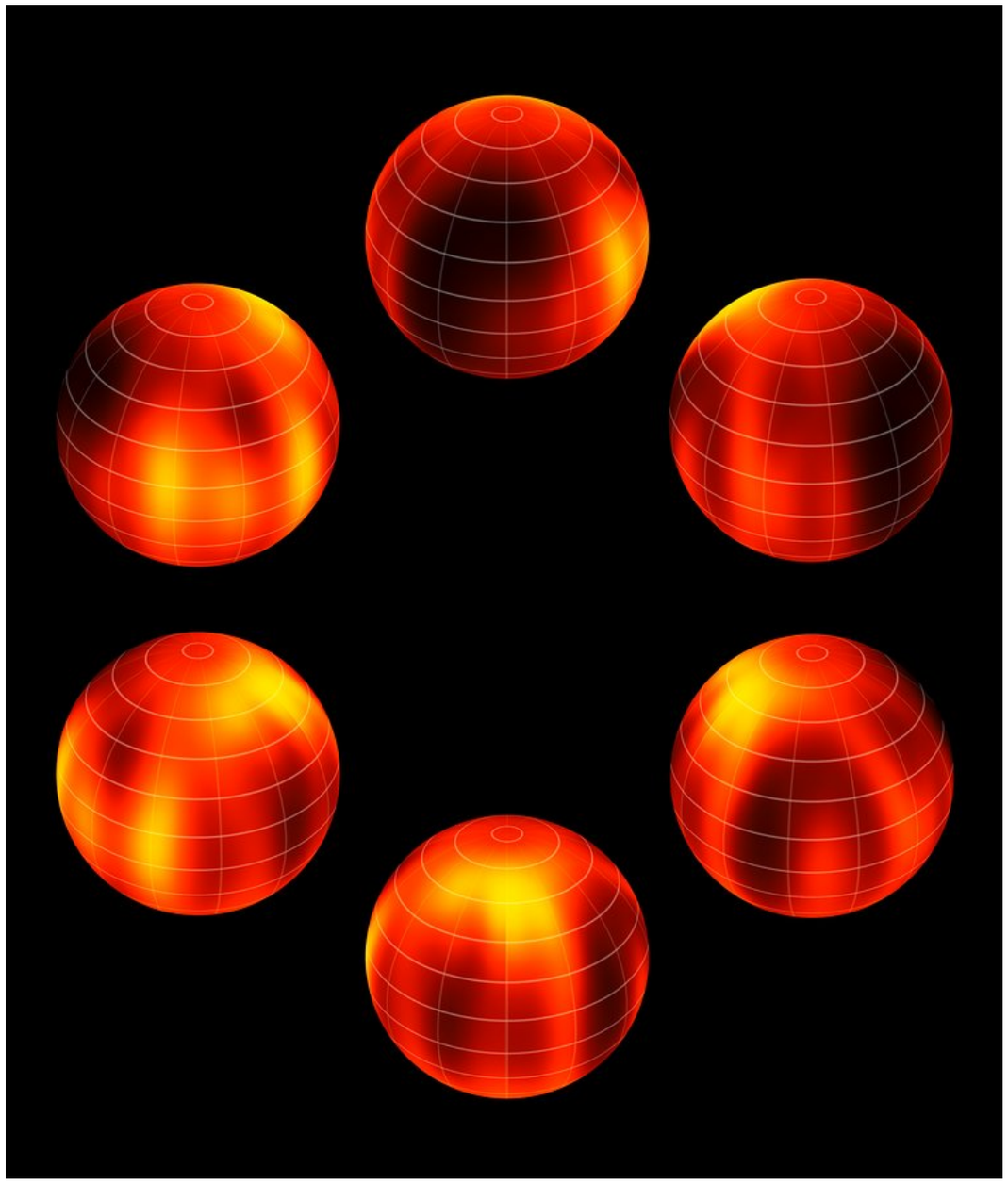
Clouds in Brown Dwarfs

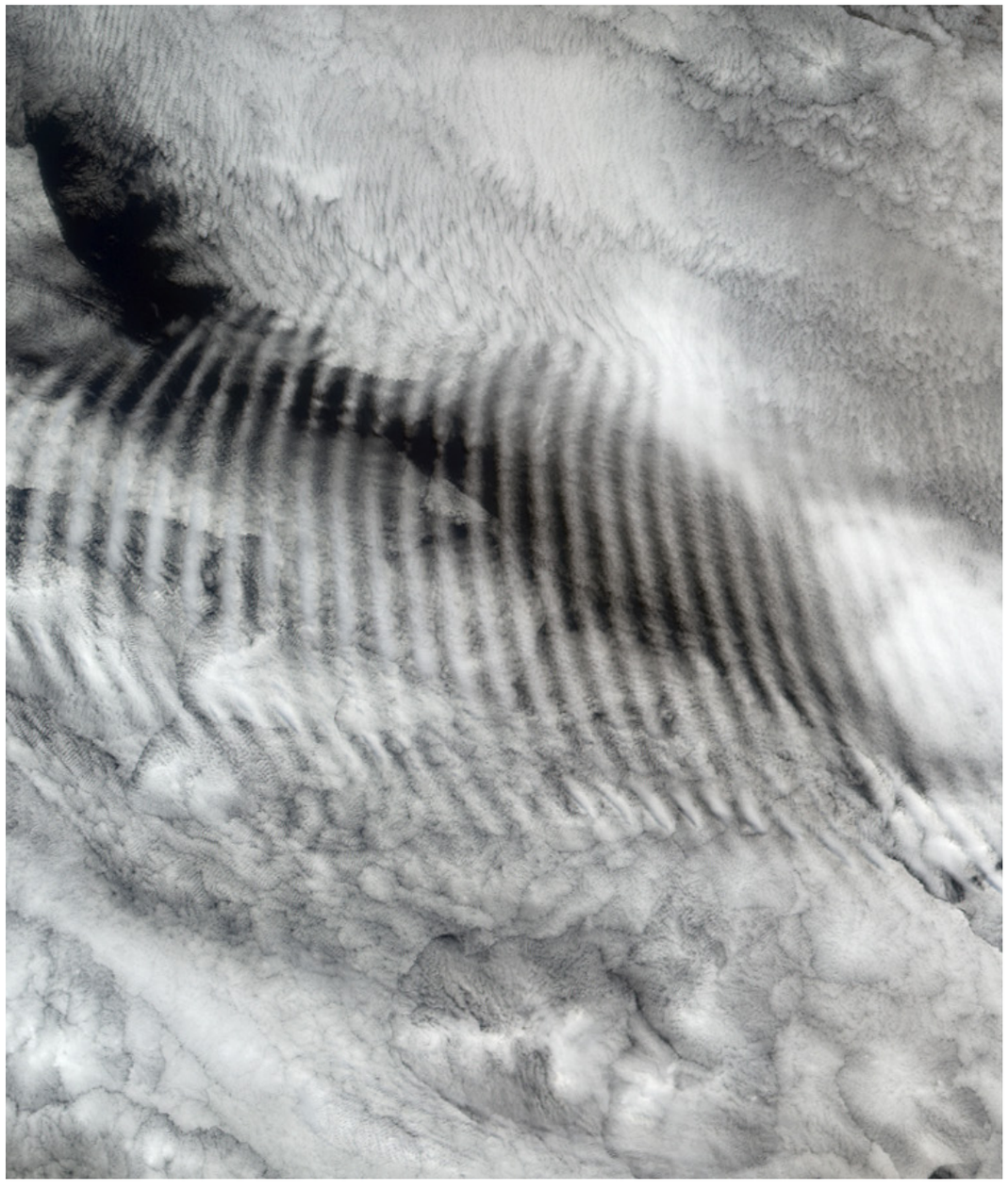
- Photometric variability observed in brown dwarfs, mapped (Crossfield+ 2014)
- Current atmosphere models suggest variability is due to dust clouds (Helling+ 2008)
- *Models suggest internal gravity waves impact cloud evolution (Freytag+ 2010)*



Cloud map of Luhman-16B
Crossfield et al. 2014, Nature, 505, 654.

Internal Gravity Waves

- Density or velocity perturbations create atmospheric oscillations;
- IGW lead to banded structures in clouds on Earth & Solar System Planets
- *Can similar structures teach us about brown dwarf atmospheres?*



Gravity Waves Ripple over Marine Stratocumulus Clouds
NASA/GSFC/LaRC/JPL, MISR Team

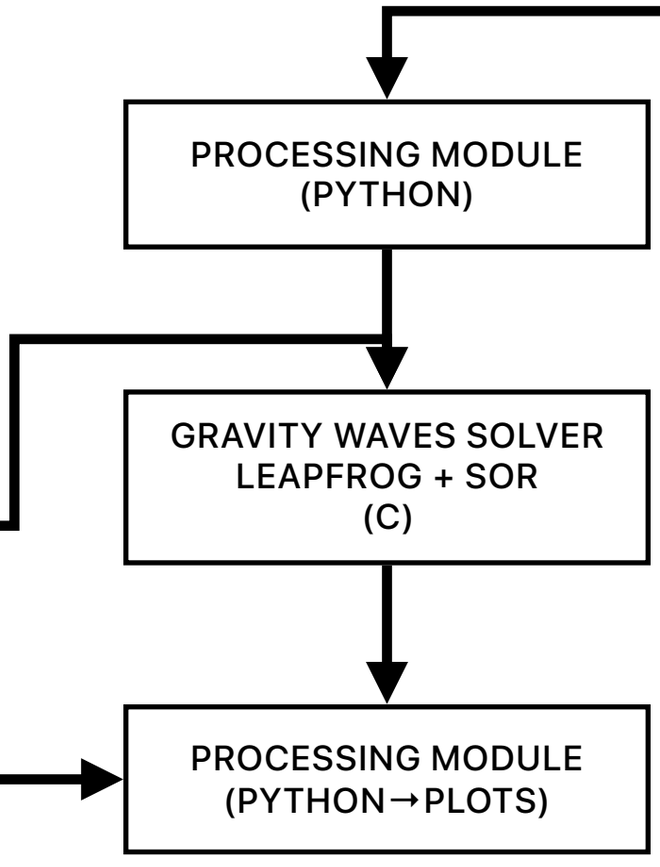
Numerical Simulations/Methods

$$\frac{\partial \zeta}{\partial t} = -\frac{g}{\rho_0}\frac{\partial \rho}{\partial x}$$

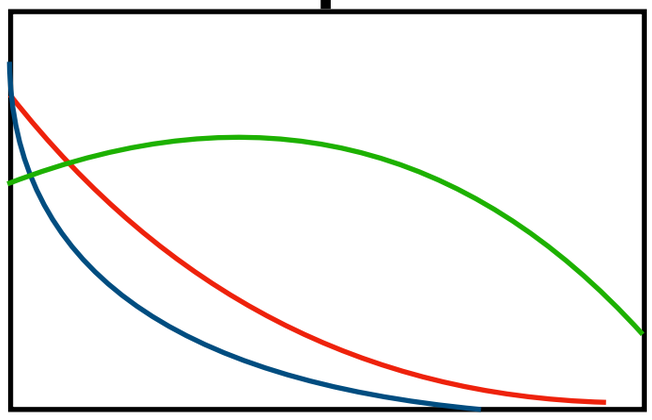
$$\frac{\partial \rho}{\partial t} = \frac{\partial \rho_0}{\partial y}\frac{\partial \psi}{\partial x}$$

$$\zeta = -\frac{\partial^2 \psi}{\partial x^2} - \frac{\partial^2 \psi}{\partial y^2}$$

2D Linear Model



Dust Equations
(Gail+ 1984; Whittet 2003)

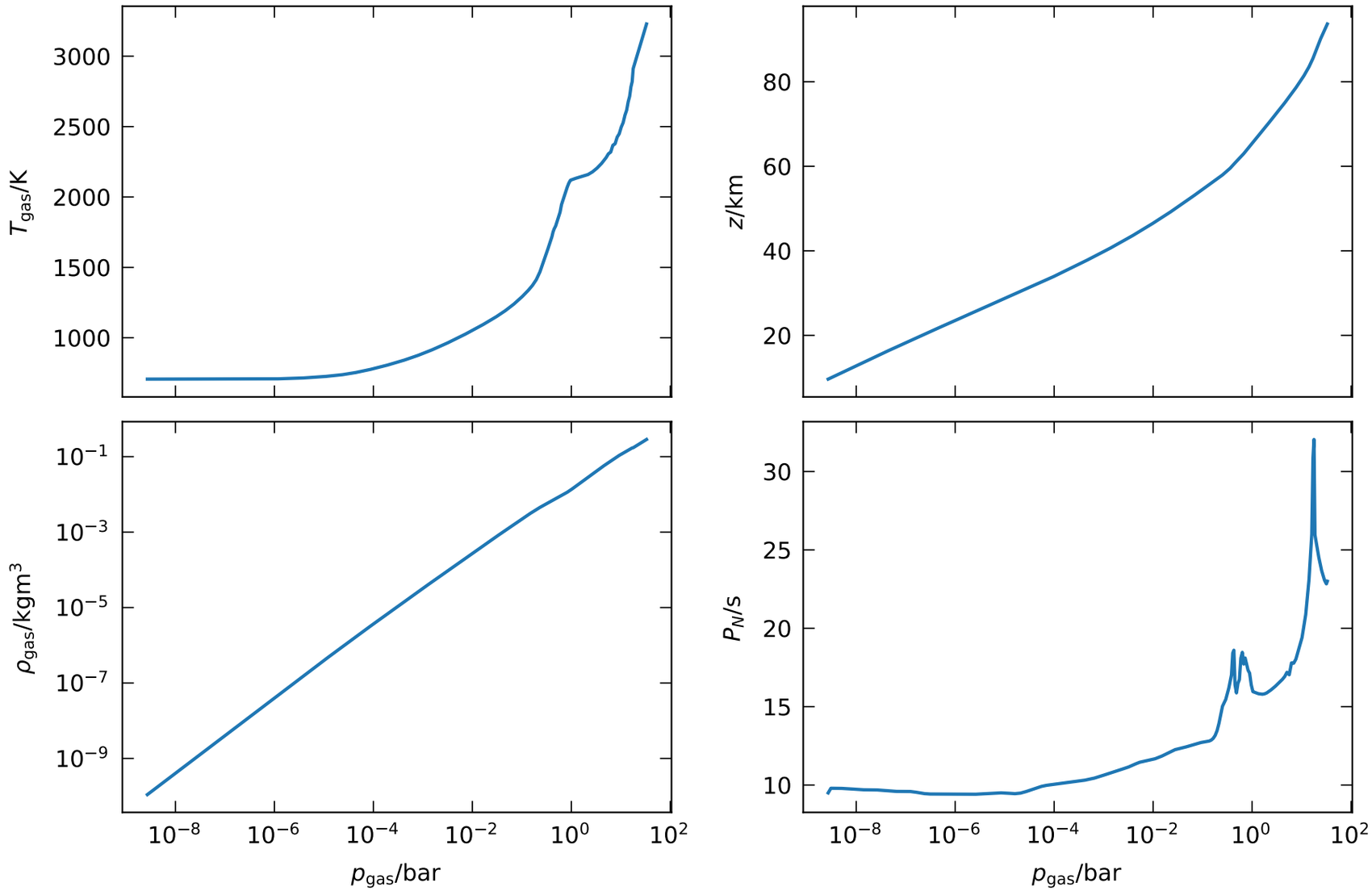


Available published brown dwarf model data

$$\gamma = \frac{f_x \rho_{\text{gas}} v_{\text{rel},x}}{4\rho_{\text{dust}}}$$

$$J_* = \frac{n_x}{\tau} Z \exp\left[(N_* - 1)\ln S - \left(\frac{T_\Theta}{T}\right)\frac{N_* - 1}{(N_* - 1)^{1/3}}\right]$$

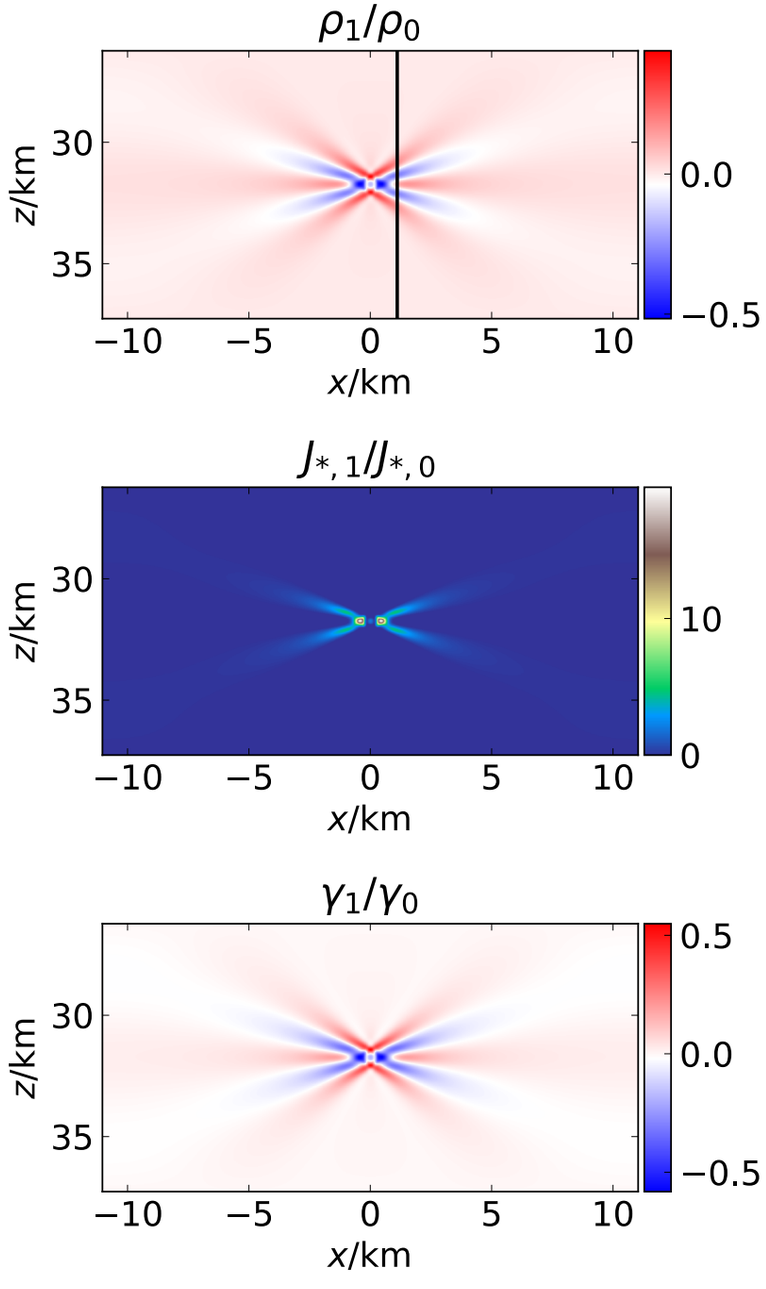
Numerical Simulations/Data

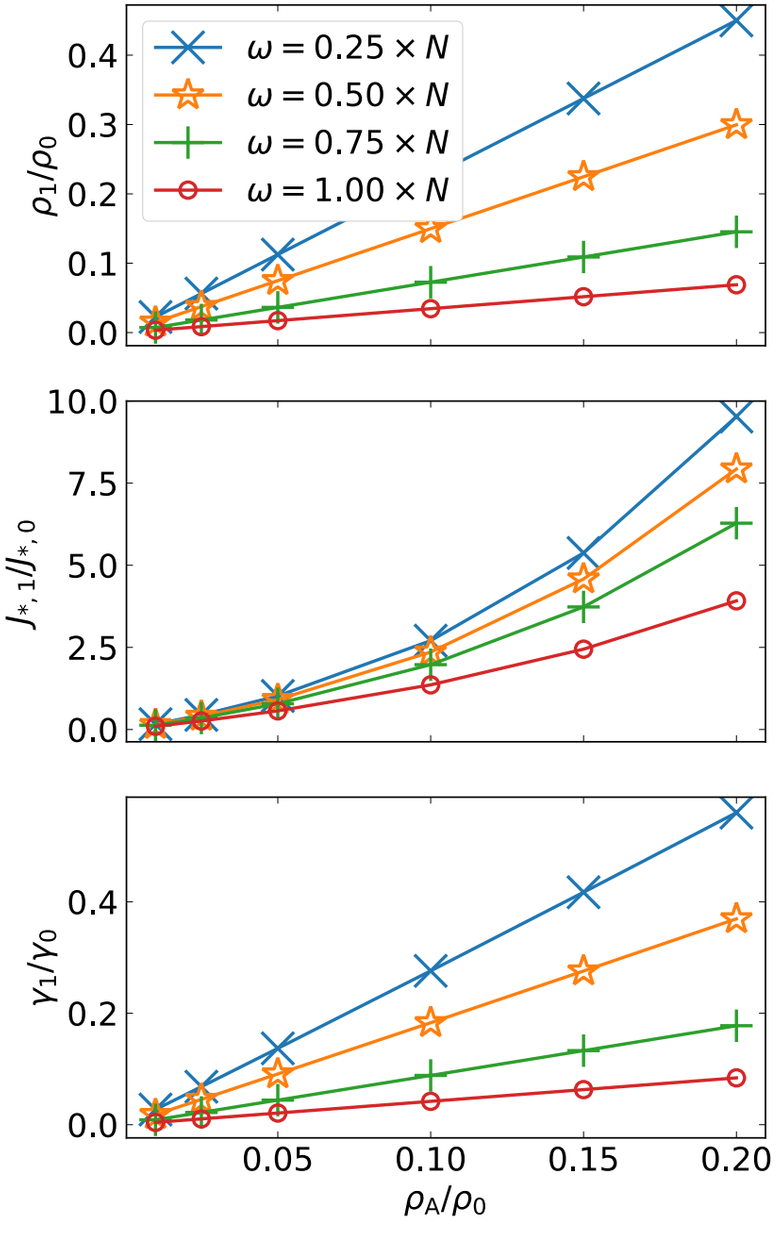


$$T_{\rm eff} = 1500\,{\rm K}, \log g = 5.0$$

(Stark+ 2013; Rodríguez-Barrera+ 2018)

Numerical Simulations/Results





Core Findings

- X-shaped patterns, with banded areas of perturbed pressure, density and temperature
- Adiabatic process:
  - Lower $\rho_{\text{gas}}, T_{\text{gas}}$ → higher S_x → *stronger nucleation rate*
  - Higher $\rho_{\text{gas}}, T_{\text{gas}}$ → higher $v_{\text{rel},x}, \rho_{\text{gas}}$ → *faster mantle growth*

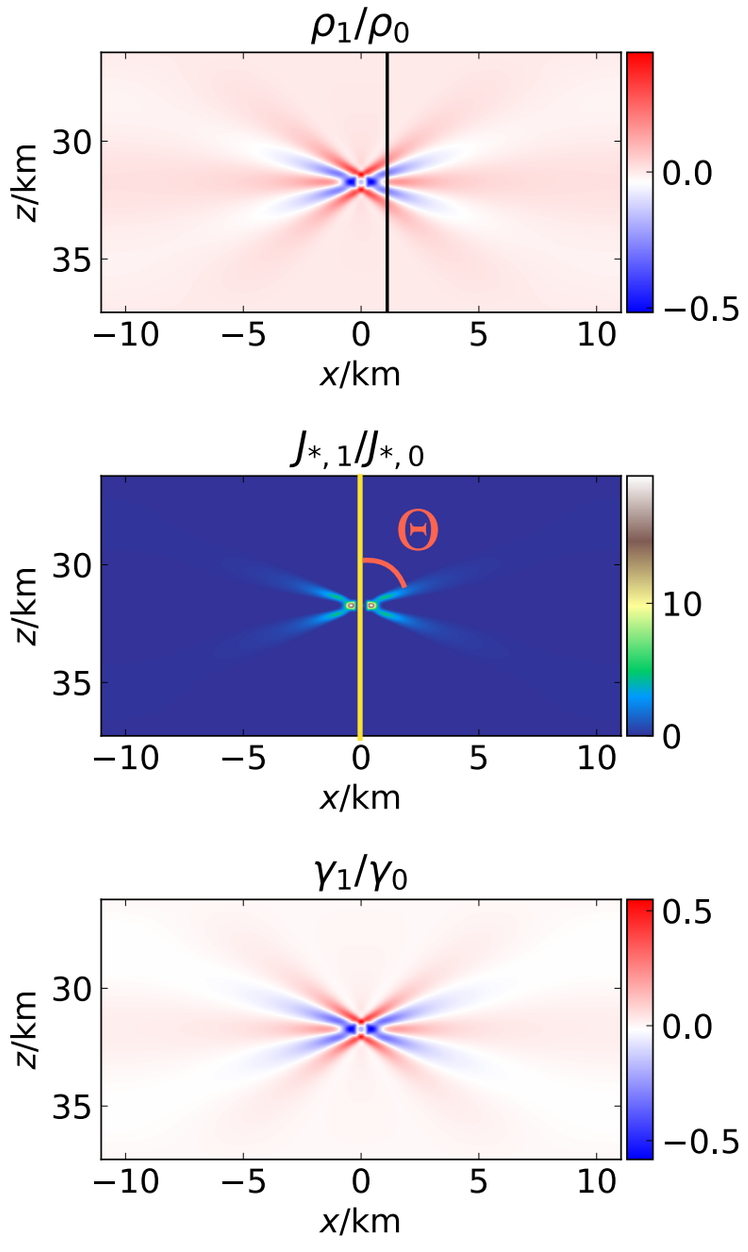
Gravity waves → banded areas of faster cloud formation

Next Steps

Linking (future) observable characteristics (magnitude, periodicity) to atmospheric density profile

$$\omega^2 = -\frac{g}{\rho_0}\frac{\partial \rho_0}{\partial y}\cos^2\Theta$$

$$\rho_0 \propto f(\Delta y, \Delta m, g, \omega, J_*)$$



Thank you! Questions?

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