Variation of Protoplanetary Disk Response with Adiabatic Index, Viscosity and Mass.

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Abstract

The protoplanetary disk is under constant perturbing forces that influences its evolution. Previous simulations studies have tried to model such a disk comprising of gas and dust for different Equation of State that completes the N- S equations solved in such a numerical approach. Along with it viscosity in the materials of such disk are studied as key parameter. We reproduced such scenarios of the disk under different host stellar mass, Kinematic viscosity 'ν' and Adiabatic Index 'γ' and found that no dependence exist for 'ν' with host mass and also the disk mass. Final state of the disk after evolving for a period in time varied with 'γ', describing the Adiabatic Equation's dependence. The variation of the disk repsonse was higher for the lower mass star.

Introduction

- The Protoplanetary disk around a Central Star under observation, reveals annular structures which are thought to be formed by planets present in the disk. Gas and Dust containing disk are under continuous perturbation which results in variation of density and angular momentum resulting in migration, gap formation and other related phenomenon.
  The work draws its inspiration from, Rafikov et al. (2017) [1], who probed the possibility of the protoplanetary disk being a viscous disk and also, Bitsch et al.(2013) [2], who probed into the variation of disk response with Adiabatic Index 'γ'.

Methods

- We started with a protoplanetary disk, modeled with central star in the center and a planet comparable in mass with "Jupiter". Parameterized in terms of the gravitational potential. "γ" variation changes the sound speed '$\mathbf{c_s}$', in the material of density, ρ as,

$$\mathbf{P} = \frac{\rho \mathbf{C}^2_{\mathbf{s,adia}}}{\gamma} \tag{1}$$

  The basic form of Navier-Stokes Equations are solved in each grid point under the given physical parameters stated in Table. The detailed description of the equation and model used can be found in Mignone et al. [3].
- We first considered the Adiabatic E.O.S with $\gamma \sim \mathbf{1.01(Isothermal), 1.4\&1.67}$, for three models where the Central Star mass was set to 0.5, 1.0 & 10 Solar mass $\mathbf{M_{solar}}$.
- We changed the Kinematic Viscosity as $\nu \sim \mathbf{10^{14}\&10^{16}}$. The previous models in E.O.S is run under $\nu \sim \mathbf{10^{15}}$.
  Resultant simulated disk are shown in the figures where (a) is for γ variation and (b) is for ν .

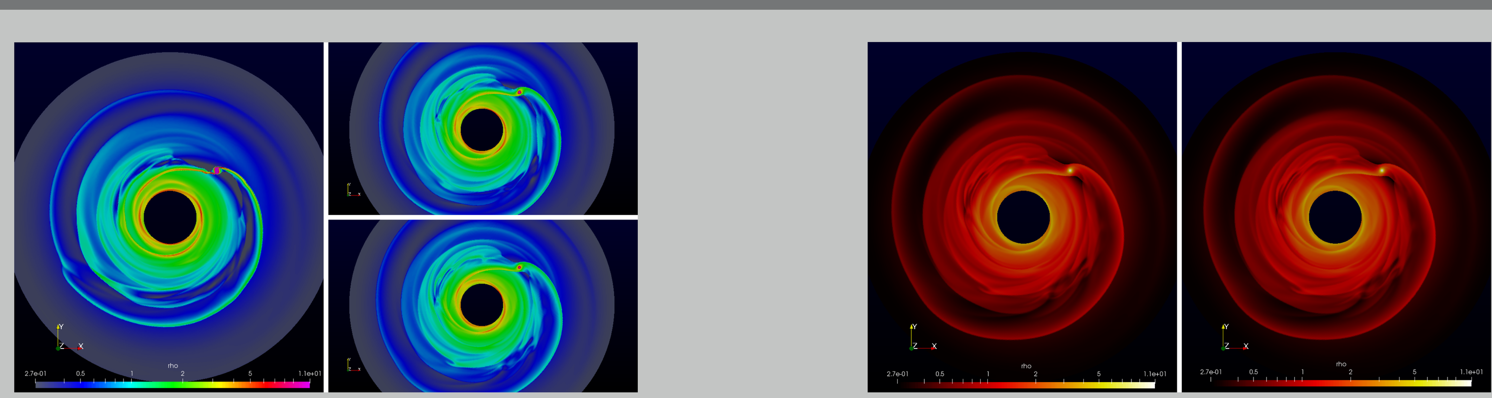
Table

Parameter	Value (in cgs)
Planet Mass ($\mathbf{m_p}$)	320$\mathbf{m_{earth}}$
Surface Density Slope	0.5
Aspect Ratio,(H/r)	0.05
Uniform Kinematic Viscosity,ν	1.0e15
Disk Radial range	0.4-2.5 AU
No. of Radial Cells	256
No. of Azimuthal Cells	768
Disk Mass	0.01 $\mathbf{M_{solar}}$
Planet position	1 AU

Table: Physical Parameter

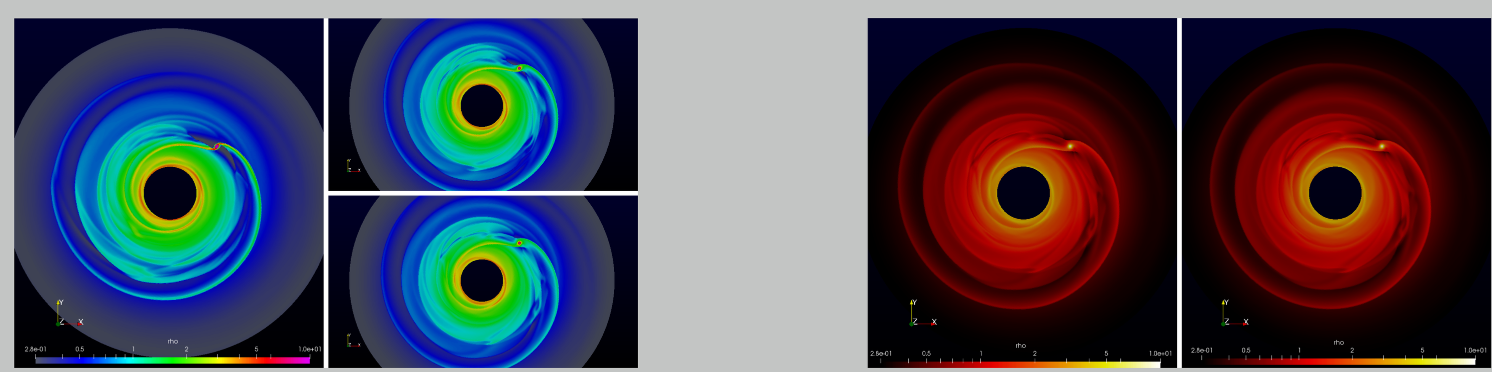
** *(L,R,T,B stands for left, right, top, bottom respectively.)*

Results: Figure



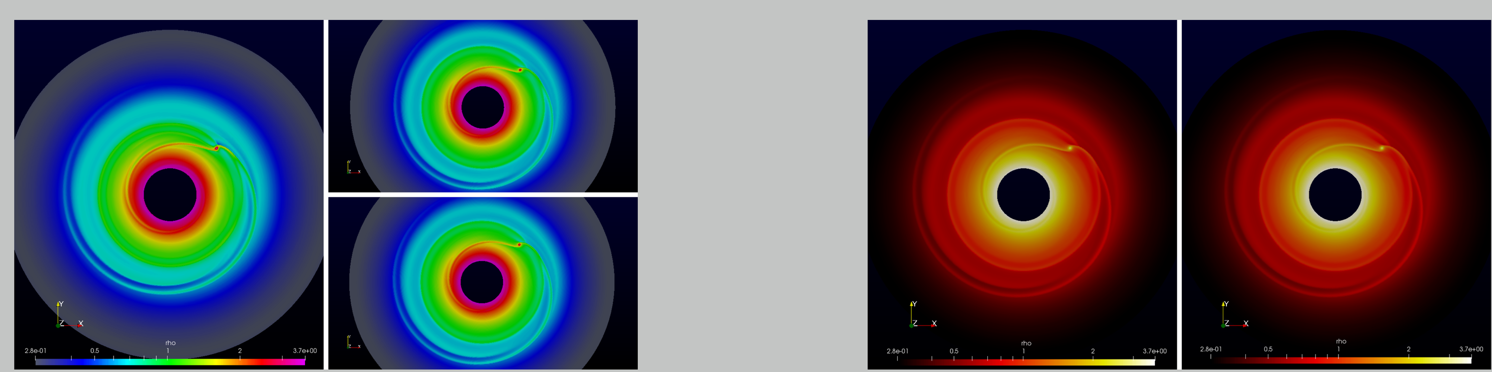
(a) $\gamma \sim \mathbf{1.01(L), 1.4(T)\&1.67(B)}$. (b) $\nu \sim \mathbf{10^{14}(L)\&\ 10^{16}(R)}$, $\gamma \sim \mathbf{1.67}$.

Figure: Simulated Run for a $\mathbf{0.5M_{solar}}$ with a jovian mass planet in its disk. The E.O.S under consideration is Adiabatic with 'γ' and Kinematic Viscosity 'ν'



(a) $\gamma \sim \mathbf{1.01(L), 1.4(T)\&1.67(B)}$. (b) $\nu \sim \mathbf{10^{14}(L)\&\ 10^{16}(R)}$,$\gamma \sim \mathbf{1.67}$.

Figure: Simulated Run for a $\mathbf{1M_{solar}}$ with a jovian mass planet in its disk. The E.O.S under consideration is Adiabatic with 'γ' and Kinematic Viscosity 'ν'



(a) $\gamma \sim \mathbf{1.01(L), 1.4(T)\&1.67(B)}$. (b) $\nu \sim \mathbf{10^{14}(L)\&\ 10^{16}(R)}$,$\gamma \sim \mathbf{1.67}$

Figure: Simulated Run for a $\mathbf{10M_{solar}}$ with a jovian mass planet in its disk. The E.O.S under consideration is Adiabatic with 'γ' and Kinematic Viscosity 'ν'.

Conclusion

- The disk when allowed to evolve for a specific period is seen to be perturbed under the influence of star-planet gravitational potential, while the Adiabatic E.O.S influences the final density distribution in the disk as seen.
- In the Isothermal E.O.S scenario of $\gamma \sim \mathbf{1.01}$, the drastic density depletion around the planet surrounding region was described to be caused by presence of Convection [2]. All the variation was seen to be prominent across all the Stellar Mass cases but higher variation was seen in Lower Mass Star.
- The Kinematic Viscosity was varied as $\nu \sim \mathbf{10^{14}, 10^{15}\&10^{16}}$. As in works of Rafikov et al. (2017) in our case too, no evident relation of variation was seen in between the change in Kinematic Viscosity with that of the Stellar and the Disk mass.

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