Accretion in Radiative Equipartition (AiRE) Disks

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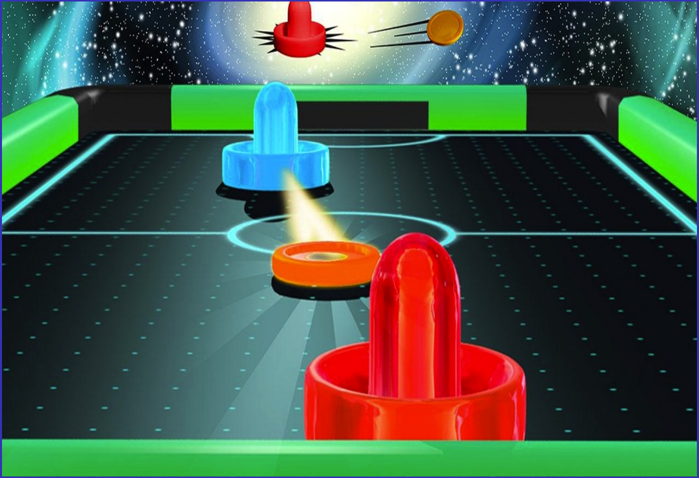

Why We Need New Models

New models are necessary to better understand accretion disks.

- Thermal instability in current thin and slim disk models.
- Incomplete understanding of the source of viscosity.
- Incomplete understanding of disk spectra.
  - Spin estimates from Continuum Fitting and Fe Line methods are sometimes in tension.
  - Discrepancies between standard predictions for disk sizes and direct measurements.

Some well known analytic and semi-analytic disk solutions [1]

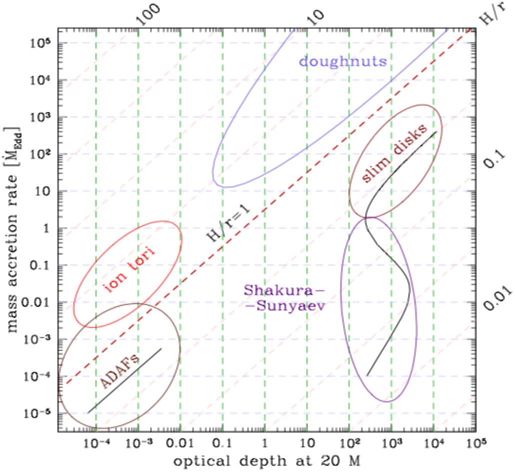

Figure: Locations approximately correspond to $\alpha = 0.1$ and $r = 20M$.

[1] A. Sadowski, 2011, arXiv:1108.0396.

Disk physics described by four equations:

1) Conservation of Mass: $\dot{M} = -2\pi\Sigma\sqrt{\Delta}\frac{v}{\sqrt{1-v^2}}$
2) Conservation of angular momentum:

$$\frac{\dot{M}}{2\pi}(\mathcal{L} - \mathcal{L}_{in}) = -2hr^2 t_{r\phi}, \qquad t_{r\phi} = \alpha p$$

3) Vertical equilibrium: $h^2\Omega^2 = \frac{p}{\rho}$
4) Energy balance: $Q^{vis} = Q^{rad}$

Thermally unstable because $Q^{vis} \propto T^8$ while $Q^{rad} \propto T^4$ in the inner regions.

AiRE disk solution to thermal instability: $P_{gas} = P_{rad}$ in inner region.

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4) Radiative Equipartition: $P_{gas} = P_{rad}$

Equipartition Radii

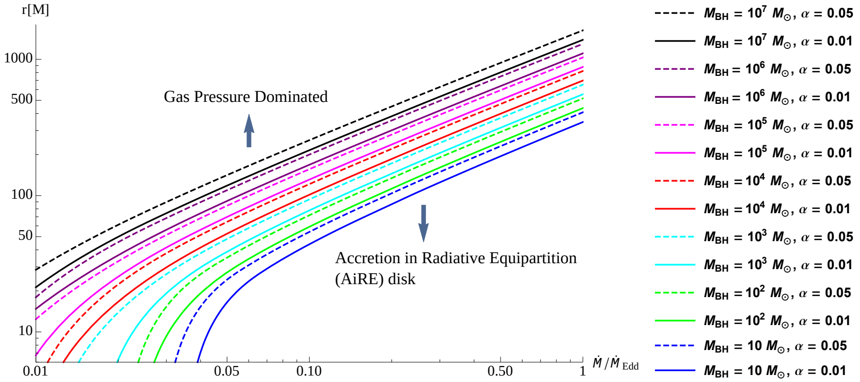


Figure: The equipartition radius, where the AiRE disk replaces the standard SS thin disk model.

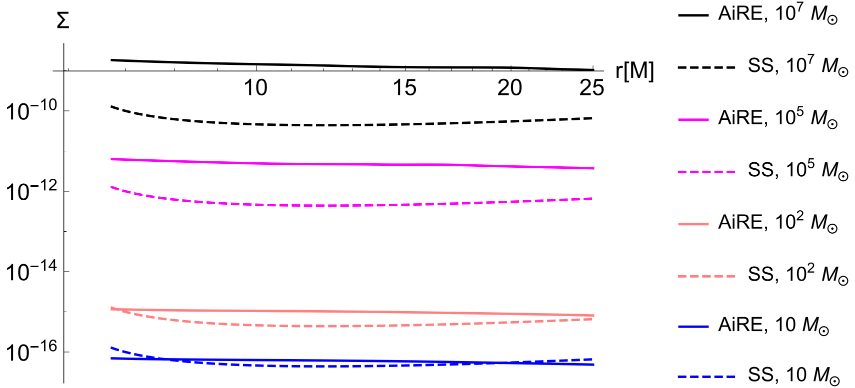


Figure: Surface density of AiRE disks and SS disks for different black hole masses. $\dot{M}/\dot{M}_{Edd} = 0.1$ and $\alpha = 0.01$.

Self-gravity becomes important in disks outside of some radius, r_{sg}. When $r_{sg} = r_{ISCO}$ there will no longer be any accretion.

Toomre criterion for a disk to be stable is $\frac{h\,\Omega^2}{\pi\Sigma} > 1$.

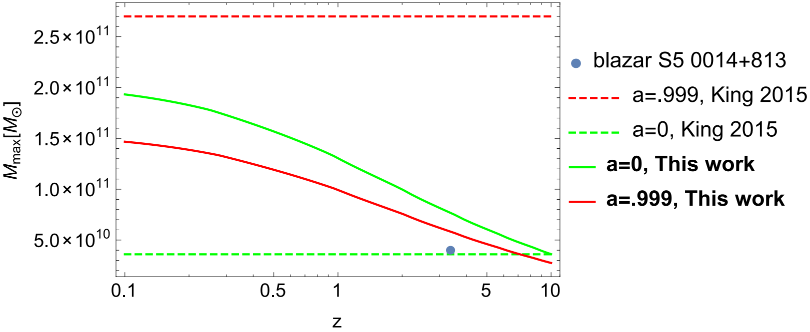


Figure: Upper mass limits for AiRE disks, with $\alpha = 0.1$ and $a = 0, 0.999$.

[2] A. King, arXiv:1511.08502.

Inner Boundary: The Sonic Point

Solve using the shooting or relaxation method.

$$\frac{dv}{dr} = \frac{\mathcal{N}(r, v)}{\mathcal{D}(r, v)} \tag{1}$$

Must continuously go from subsonic to supersonic flow at the sonic point. $\mathcal{D}$ vanishes at the sonic point, so $\mathcal{N}$ must also vanish there:

$$\mathcal{N}\big|_{r=r_{sonic}} = \mathcal{D}\big|_{r=r_{sonic}} = 0. \tag{2}$$

The value of $\mathcal{L}_{in}$ must be chosen carefully to achieve this.

The topology of v differs for solutions with $\mathcal{L}_{in} > \mathcal{L}_{in}^t$ and $\mathcal{L}_{in} < \mathcal{L}_{in}^t$.

Sample Topology change of v with different values of $\mathcal{L}_{in}$

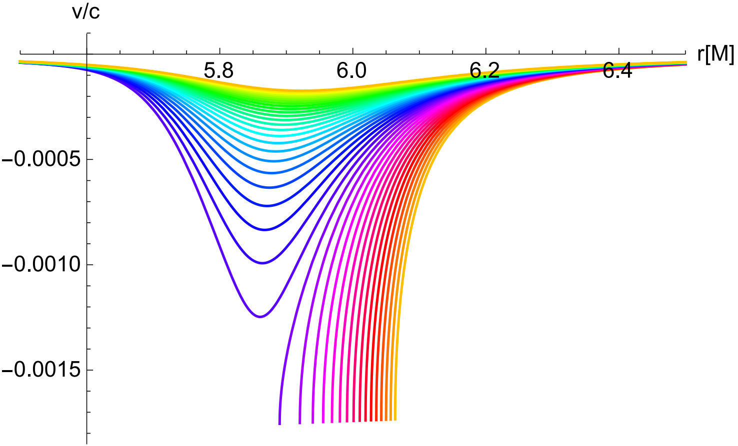
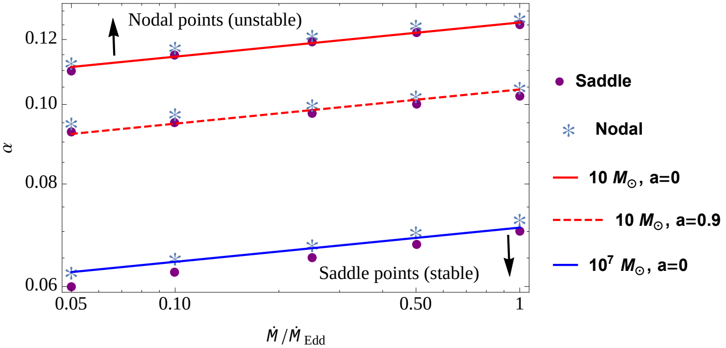


Figure: Topology change of v with different $\mathcal{L}_{in}$. The solution with correct inner boundary conditions lies at the transition point. $\dot{M}/\dot{M}_{Edd} = 0.01$, and $\alpha = 0.1$.

The eigenvalues of the Jacobian $\mathcal{J} = \begin{pmatrix} \frac{\partial \mathcal{D}}{\partial r} & \frac{\partial \mathcal{D}}{\partial v} \\ \frac{\partial \mathcal{N}}{\partial r} & \frac{\partial \mathcal{N}}{\partial v} \end{pmatrix}$, tell us the nature of the sonic point. Same sign: nodal point. Opposite signs: saddle point. Imaginary: spiral (unphysical) point.

Conjecture: Saddle points are stable while Nodal points are unstable. Transition at $\alpha \sim 1.25 \left((1-a)^{2/5} (3+a) \right)^{1/3} \left(\frac{\dot{M}}{M^2} \right)^{1/24}$.



Conclusions

- AiRE disks are a solution to thermal instability in disks.
- AiRE disks modify disk properties such as radial velocity, surface temperature, and the Toomre parameter.
- Work is in progress to make precise the properties of AiRE disks such as their spectra.
- Preliminary results for maximum black hole masses and saddle to nodal transitions.