MHD Waves as a Source of Heating in Accretion Disks

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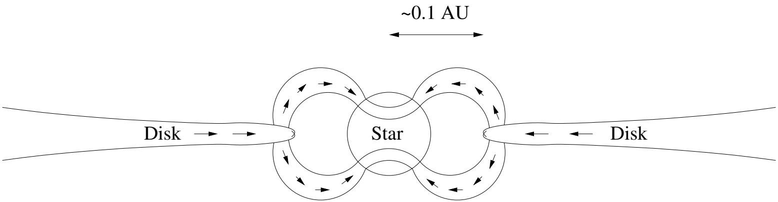
Introduction: Angular momentum transport



- Understanding $\vec{L}$ transport is the first step towards an understanding of accretion

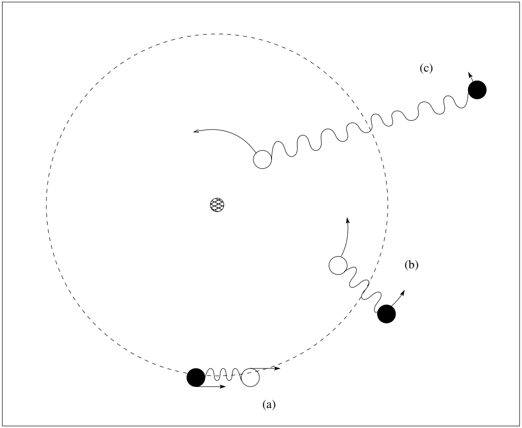
The magneto-rotational instability

MRI: differential rotation energy $\longrightarrow$ turbulence (Balbus, Hawley)

- the magnetic field destabilizes the disk

$$\frac{\partial^2 \vec{\xi}}{\partial t^2} = -(\vec{k} \cdot \vec{v}_A)^2 \vec{\xi}$$

- MHD turbulence arises
- radial transport of $\vec{L}$ $\longrightarrow$ accretion of particles



The magneto-rotational instability

Keys to the mechanism existence

- weak magnetic field
- differential rotation (e.g. Keplerian rotation)
- (partially) ionized plasma

Minimum ionization fraction $\longrightarrow$ **coupling** between magnetic field and disk particles

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Our model

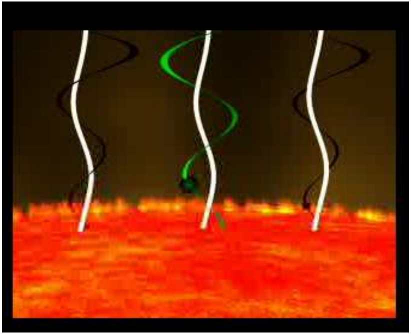
We know...

- disks are magnetized systems
- dust grains are present
- usually grains immersed in a plasma are charged
- charged grains can damp Alfvén waves

Aim:

Determine if the dissipation of Alfvén waves due to the interaction with grains is a significant source of heating.

Dust-cyclotron damping mechanism



Illustrative movie of Alfvén waves in the solar wind (S. Cranmer)

broad band of resonance frequencies

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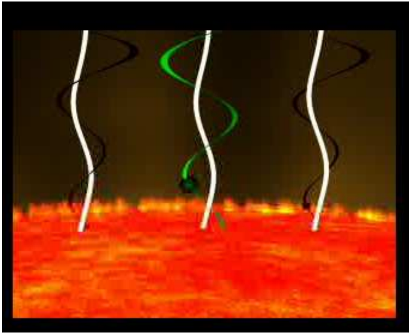

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$\boxed{\text{broad band of resonance frequencies}}$

Disk initial conditions

- steady-state and axisymmetric
- optically thick
- geometrically thin
- Keplerian rotation

Energy used to heat the disk:

$$\mathcal{F}_{\rm tot} = \mathcal{F}_\nu + \mathcal{F}_A = \sigma T^4$$

$$\mathcal{F}_\nu = \frac{3\Omega_K^2 \dot{M}}{8\pi}\left[1 - \left(\frac{R_i}{R}\right)^{1/2}\right]$$

$$\mathcal{F}_A = \int_0^{H/2} \frac{\mathcal{F}_A}{L} dz$$

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Initial parameters

Star & disk

- T Tauri star:
  - $M_\star = 0.5 \ M_\odot$
  - $R_\star = 2 \ R_\odot$
  - $\dot{M} = 10^{-8} \ M_\odot/\mathrm{yr}$
- Grain characteristics
  - $a_1 = 0.005 \ \mu\mathrm{m}$
  - $a_2 = 0.250 \ \mu\mathrm{m}$
  - $\rho_{\rm gas}/\rho_{\rm dust} = 100$

$$f = \frac{\sqrt{\langle(\delta B)^2\rangle}}{B}$$

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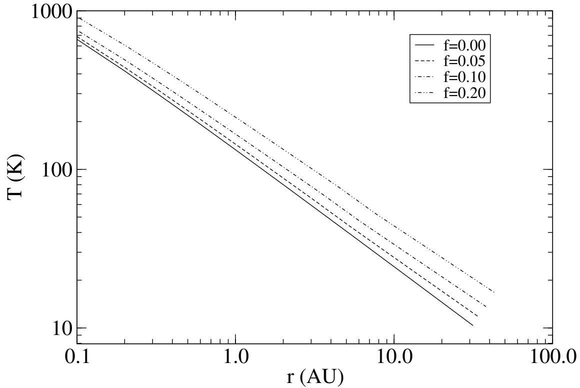
Results: temperature profiles



$$T \propto R^{-q}$$

$f = 0.00$	$q = 0.75$
$f = 0.05$	$q = 0.71$
$f = 0.10$	$q = 0.69$
$f = 0.20$	$q = 0.67$
α-model	$q = 3/4$
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Andrews & Williams (2007)

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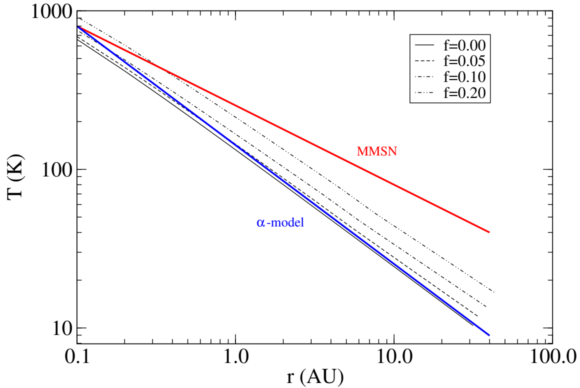

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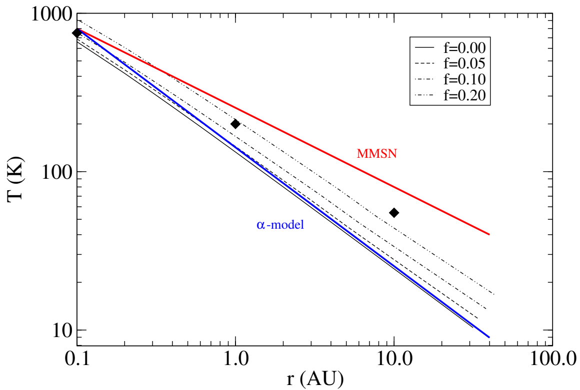

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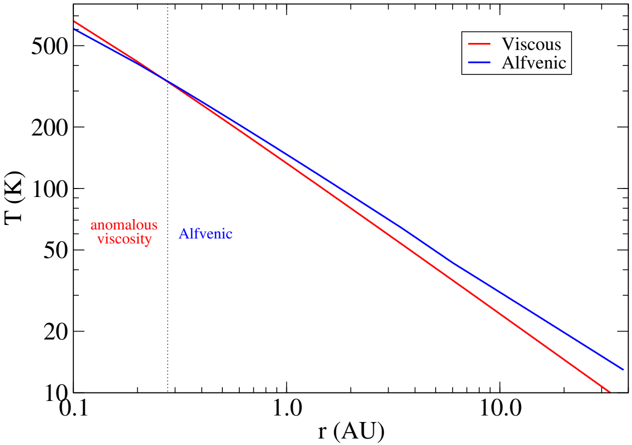


Results: simple estimate of the dead zone size

Following Gammie (1996) ($x \gtrsim 10^{-13}$):

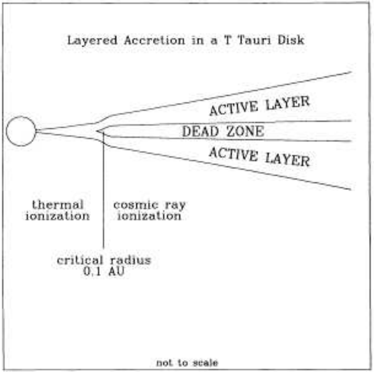
- $\Sigma \lesssim 100$ g cm^{-2}
- $T \gtrsim 10^3$ K

Size of the dead zone:

$$0.1 \lesssim r(\mathrm{AU}) \lesssim 6$$

Considering Alfvén waves:

$$0.65 \lesssim r(\mathrm{AU}) \lesssim 3.7$$



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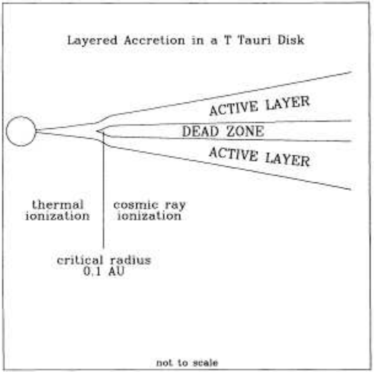

Conclusions

- Dissipation of Alfvén waves
    - flattens the temperature profile of the disk compared to the α-model
    - and causes a more significant increase in T at large distances from the star
    - reduces the size of the dead zone (simple estimates)

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