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 $\rightarrow$ 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 $\vec{L}$ $\rightarrow$ 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 $\rightarrow$ 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
Dust-cyclotron damping mechanism

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Disk initial conditions

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

Energy used to heat the disk:

$$F_{\text{tot}} = F_\nu + F_A = \sigma T^4$$

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

$$F_A = \int_0^{H/2} \frac{F_A}{L} \, dz$$
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Initial parameters

**Star & disk**

- **T Tauri star:**
  - $M_*= 0.5 \, M_\odot$
  - $R_*= 2 \, R_\odot$
  - $\dot{M} = 10^{-8} \, M_\odot/\text{yr}$

- **Grain characteristics**
  - $a_1 = 0.005 \, \mu m$
  - $a_2 = 0.250 \, \mu m$
  - $\rho_{\text{gas}} / \rho_{\text{dust}} = 100$

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

\[ \mathcal{F}_A^{z=0} \propto v_A (fB)^2 \]
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Results: temperature profiles

\[ T \propto R^{-q} \]

- \( f = 0.00 \quad q = 0.75 \)
- \( f = 0.05 \quad q = 0.71 \)
- \( f = 0.10 \quad q = 0.69 \)
- \( f = 0.20 \quad q = 0.67 \)

\( \alpha \)-model \( q = \frac{3}{4} \)

MMSN \( q = \frac{1}{2} \)

Andrews & Williams (2007)
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![Graph showing temperature profiles](image)

- Red line: Viscous
- Blue line: Alfvenic

- Anomalously high viscosity
- Alfvenic

**Axes:**
- **T (K)**: Temperature in Kelvin
- **r (AU)**: Radius in Astronomical Units

**Data Points:**
- At 0.1 AU, T ≈ 500 K
- At 1.0 AU, T ≈ 200 K
- At 10.0 AU, T ≈ 100 K

**Conclusion:**
MHD waves act as a source of heating in accretion disks.
Results: simple estimate of the dead zone size

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

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

Size of the dead zone:

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

Considering Alfvén waves:

$$0.65 \lesssim r(\text{AU}) \lesssim 3.7$$
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- Dissipation of Alfvén waves
  - flattens the temperature profile of the disk compared to the $\alpha$-model
  - and causes a more significant increase in $T$ at large distances from the star
  - reduces the size of the dead zone (simple estimates)

- The region we study in this work will be accessible with ALMA, whose observations will place hard constraints on the disk structure.
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