Collisionless and collisional effects on MRI in accretion disks

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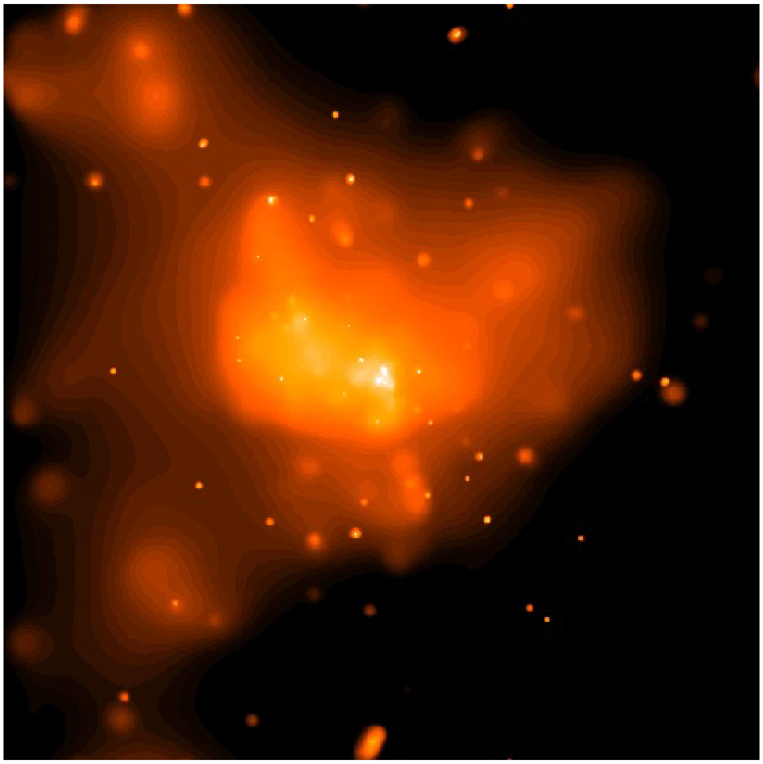
Black hole accretion



http://chandra.harvard.edu/photo/cycle1/sgr_a/

- center of Milky Way in X-ray (*Chandra*)
- 3×10^6 M$_o$, $L \sim 10^{36}$ ergs s^{-1} ≈ 300 L$_o$
- $T_p \sim 100$ MeV $\gg T_e \sim 1$ MeV, $n \sim 10^9$ cm^{-3}, B $\sim 10^3$ G
- luminosity determined by amount of electron heating

Collisionless magneto-rotational instability

- MRI explains enhanced transport in accretion disks (Balbus & Hawley 1992)
  collisionless MRI for hot, non-radiative accretion flows

- to interpret observations of low-luminosity X-ray binaries & AGNs

- some models:

  - Advection Dominated Accretion Flows (ADAF), Narayan & Yi 1995

  - ion torus model, Rees et al. 1982

- $T_e \sim 10^9 - 10^{10}$ K, $T_i \sim 10^{12}$ K, $\nu \ll t_{adv}^{-1}$, $\beta = P_g/P_{mag} \geq 1$

- MHD not good for collisionless plasma

Kinetic MHD (Kulsrud 1961, Kruskal & Oberman 1958)

- $$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0, \quad \frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{U} \times \mathbf{B}),$$
  $$\rho \frac{D\mathbf{U}}{Dt} = \frac{(\nabla \times \mathbf{B}) \times \mathbf{B}}{4\pi} - \nabla \cdot \mathbf{P},$$
  $$P = p_\perp \mathbf{I} + (p_\perp - p_\parallel)\hat{\mathbf{b}}\hat{\mathbf{b}}$$

- Drift-kinetic eqn. (DKE) for anisotropic pressure

$$\frac{\partial f}{\partial t}(\mathbf{x}, v_\parallel, \mu, t) + \left(v_\parallel \hat{\mathbf{b}} + \mathbf{v}_E\right) \cdot \nabla f +$$
$$\left(-\hat{b}\frac{D\mathbf{v}_E}{Dt} - \mu \hat{b} \cdot \nabla B + \frac{e}{m} E_\parallel\right) \frac{\partial f}{\partial v_\parallel} = C_{BGK}(f)$$

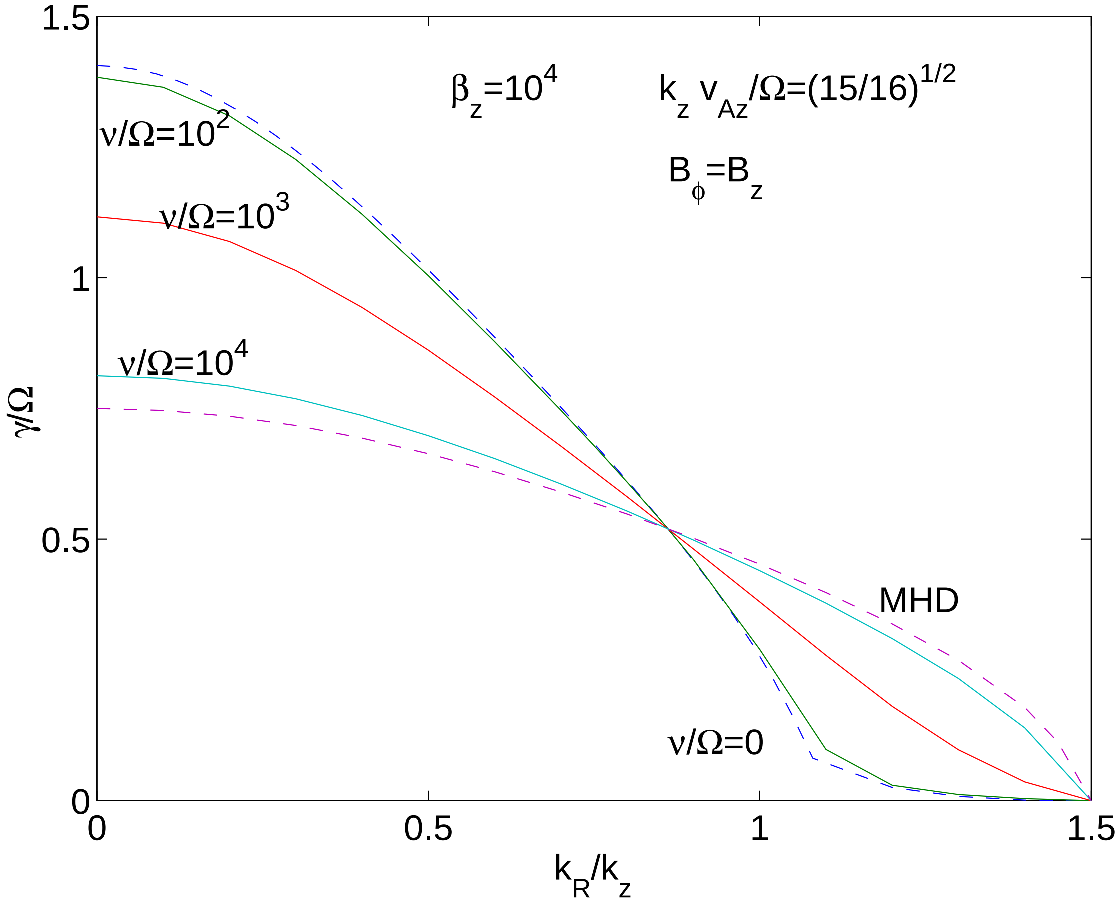
- Or Landau fluid (LF) closure approximation for heat fluxes: (Snyder, Hammett & Dorland 1997)

$$q_\parallel \approx -n \frac{v_t^2}{|k_\parallel| v_t + \nu} \nabla_\parallel T_\parallel$$
$$q_\perp \approx -n \frac{v_t^2}{|k_\parallel| v_t + \nu} \nabla_\parallel T_\perp$$

- LF scheme gives MRI growth rate consistent with DKE in collisional and collisionless regimes

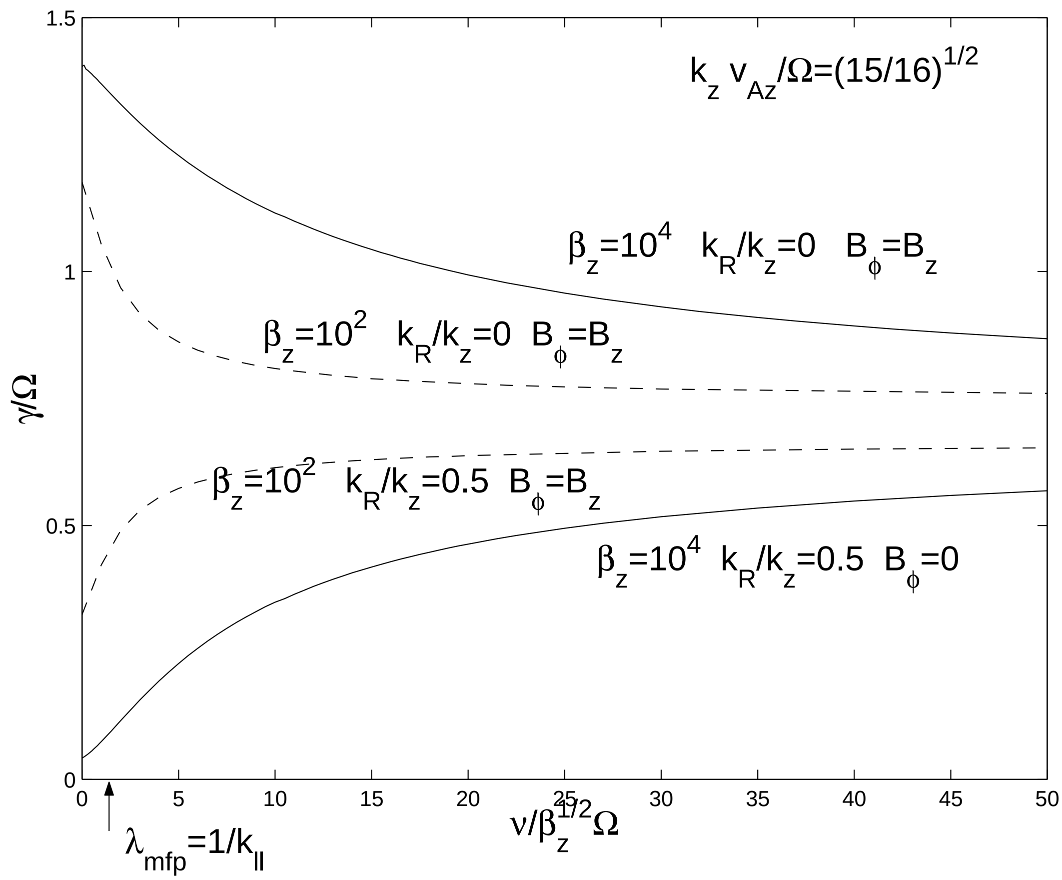
- LF scheme looks like a ‘good enough’ fluid model for non-linear simulations of non-radiative accretion flows

Effect of collisionality on MRI growth rate



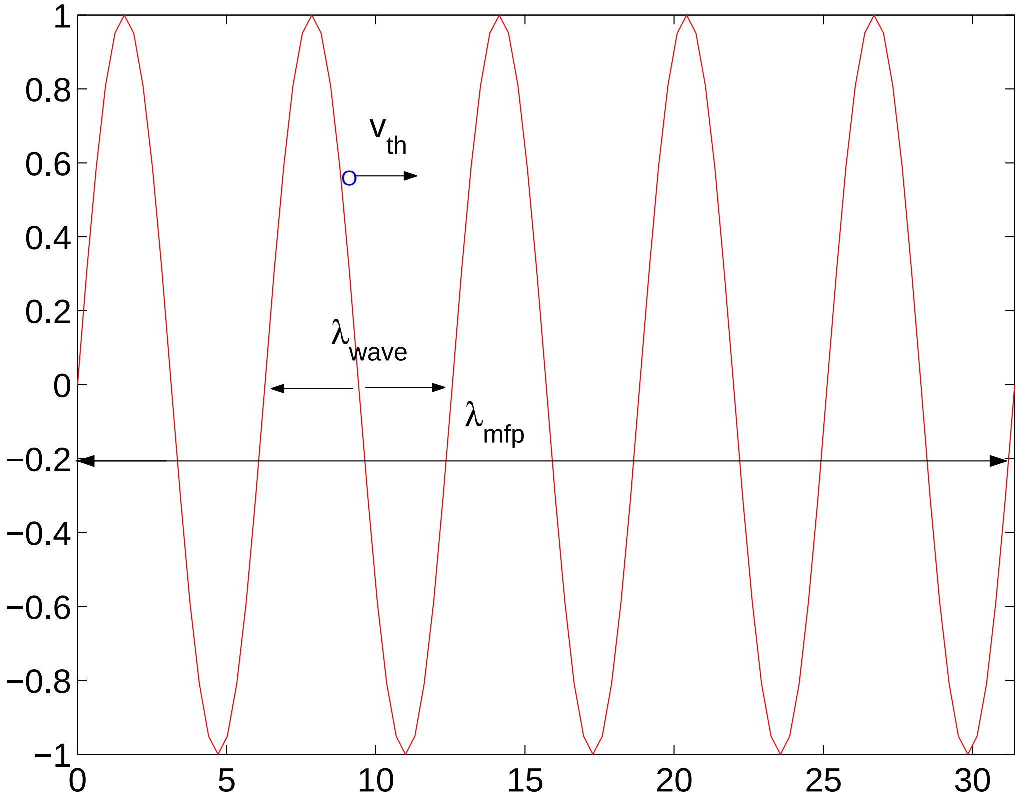
- $\nu = 0$ Quataert, Dorland & Hammett 2002
- MRI growth rate vs. k_R/k_z for different ν's
- γ increases for small k_R's and decrease for large
- two effects: azimuthal anisotropic pressure, collisionless damping

Transition from collisionless to MHD regime



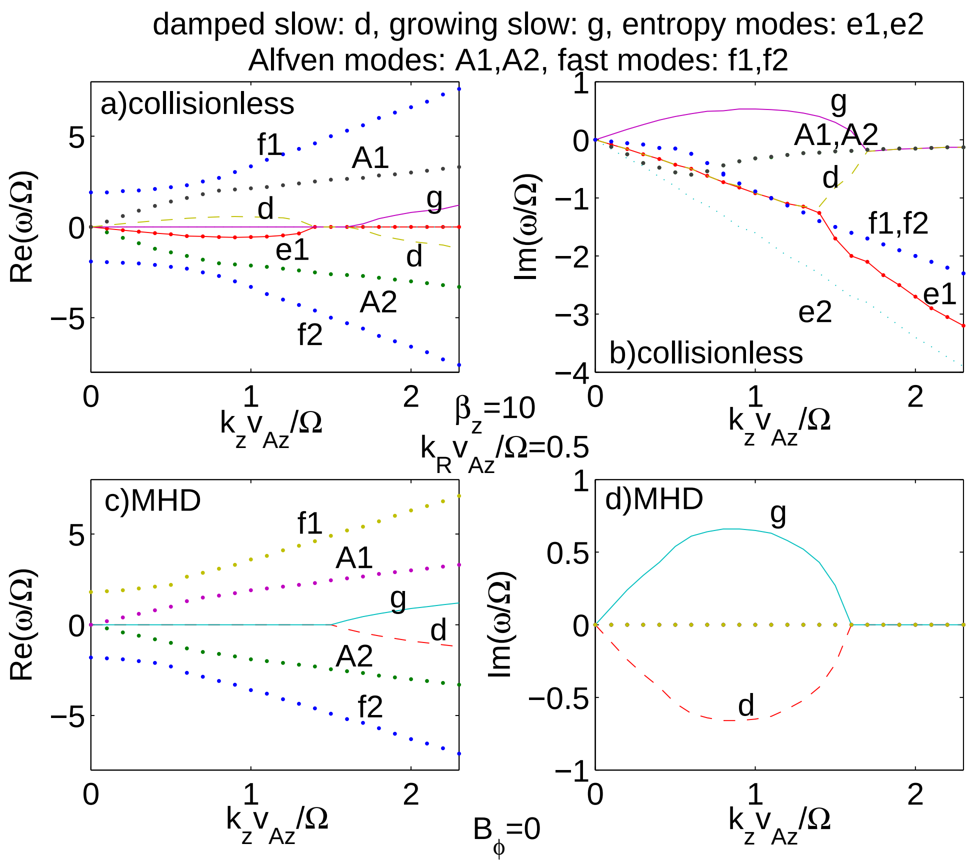
- MRI growth rate vs. ν for two wavenumbers, β_z's
- transition occurs around $\nu \sim k_{\|} v_{th}$ or $\nu/\Omega \sim \sqrt{\beta}$

Wave-particle interaction



- for $\lambda_{wave} \ll \lambda_{mfp}$, free streaming particles
- TTM damping of $\nabla_{\|}B$ waves mainly on ions
- electrons heated by Landau damping as $E_{\|} \neq 0$

Waves: MHD vs. collisionless



- collisional MHD: viscous damping only at high k
  kinetic-MHD: collisionless damping at all scales
- damped modes may explain ion heating

Conclusions

- same range of $(k_\perp, k_\parallel)$ for instability

- transition to MHD for $\nu \sim k_\parallel v_{th} \gg \omega$, $\lambda_{mfp} \sim 1/k_\parallel$

- LF closure is good for MRI in linear regime

- presence of damped modes in kinetic-MHD

Future work

- extend nonlinear MHD simulations with LF models

- useful to verify with kinetic codes

- coupling to damped modes at low k vs. cascade of undamped modes to high k

- accretion non-axisymmetric in general

- inclusion of FLR effects