Disk Coronae, Reconnection, & Angular Momentum Transport

Jeremy Goodman

Dmitri Uzdensky

Center for Magnetic Self-Organization in Laboratory & Astrophysical Plasmas
Princeton University, Department of Astrophysical Sciences

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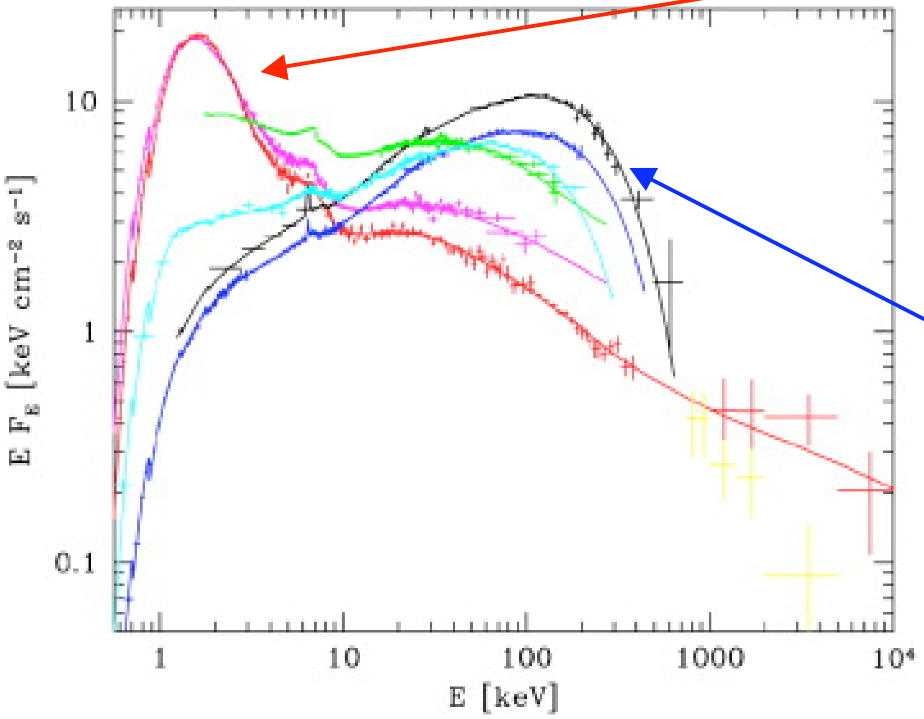
Main Points

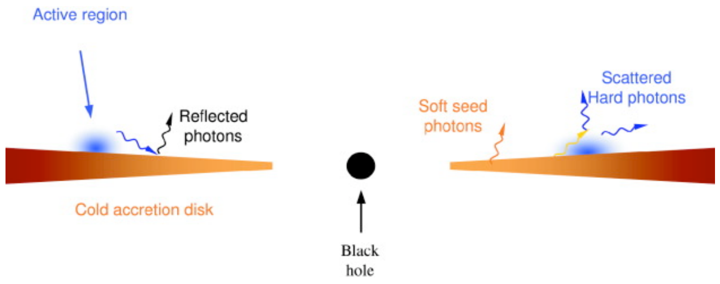
- **A**ccretion-**D**isk **C**oronae are invoked to explain power-law X-ray spectra.
- Dominance of this emission component (in some states) suggests ADC may dominate transport too.
- Standard model for the spectrum (*Comptonization*) suggests ADC are marginally collisionless.
- Direct MRI simulations of disks do not support dominant ADC (to date), but this may be due to promiscuous reconnection.

X-ray Evidence

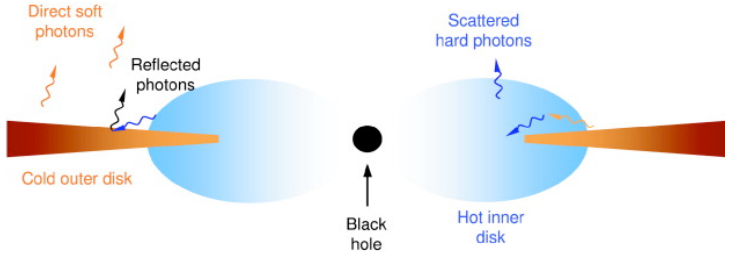
Variable spectra of accreting black-hole systems (*Cyg X-1 shown here*) are interpreted as Comptonization in a corona w. $kT_e \sim 100$ keV

soft state:
disk-dominated



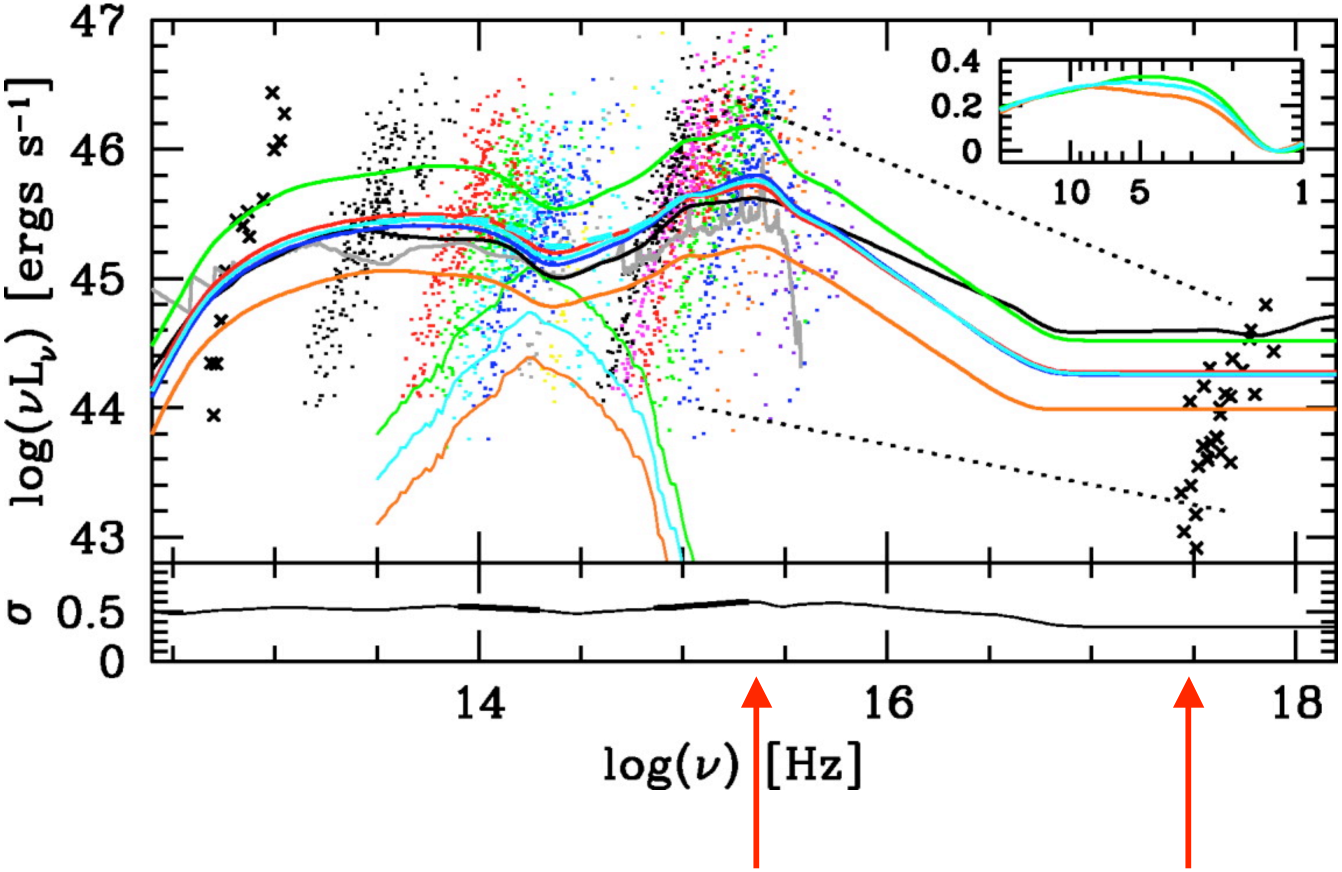


hard state:
corona-dominated



Zdziarski et al. ApJ 578, 357 (2002)

Quasar Spectral Energy Distributions



10 eV

1 keV

Richards et al. 2006

Inferred coronal parameters

Moderate optical depth: $\tau \equiv n_e \sigma_T \Delta z \sim 0.1-1$

Quasi-relativistic electrons: $\vartheta_{\mathrm{e}} \equiv \dfrac{kT_e}{m_e c^2} \sim 0.1-0.5$

$$\Rightarrow \quad y \equiv 4\tau\vartheta_e \sim 1$$

Small radius: $r \equiv \dfrac{R}{R_S} \sim$ a few, $\quad R_S \equiv \dfrac{2GM}{c^2}$

Large vertical scale height: $h \equiv \dfrac{\Delta z}{R} \sim 1$

based on Compton model for X-rays rather than dynamics.

Dimensionless parameters

$$r \equiv \frac{R}{R_S}, \quad h \equiv \frac{\Delta z}{R}, \quad \tau \equiv n_e \sigma_T \Delta z, \quad \vartheta_e \equiv \frac{kT_e}{m_e c^2} \quad \text{(as before)}$$

$$\dot{m} \equiv \frac{\dot{M}}{4\pi G M m_p / \sigma_T c} \ : \ \text{Accretion rate rel. to Eddington}$$

$f \leq 1$: Coronal fraction of torque (or dissipation)

Coronal field strength

Angular-moment balance requires, at each radius

$$\dot{M}\Omega R^2 + 2\pi R\int_{-\infty}^{\infty}\frac{B_R B_\phi}{8\pi}dz \approx 0 \quad \text{(actually } \dot{J}_{BH}\text{, but small)}$$

$$\Rightarrow \quad \frac{V_A{}^2}{c^2} \approx f\dot{m}\tau^{-1}r^{-3/2} \quad \text{in the corona}$$

$$\Rightarrow \quad \beta \equiv \frac{V_s{}^2}{V_A{}^2} \approx \tau(f\dot{m})^{-1}h^2 r^{1/2} \quad \text{since } V_s{}^2 \approx (\Omega\Delta z)^2$$

∴ Corona may be marginally force-free

Resistivity & Lundquist Number

$$\eta_{\mathrm{Spitzer}} \approx c r_e \vartheta_e^{-3/2} \ln\Lambda, \qquad r_e \equiv \frac{e^2}{m_e c^2}$$

$$\eta_{IC} \approx c r_e \vartheta_e \frac{m_p}{m_e} \varepsilon \dot{m} \tau^{-1} h r^{-1}, \quad \varepsilon \equiv \frac{L_{\mathrm{disk}}}{\dot{M} c^2}$$

$$S_{\mathrm{Spitzer}} \approx \frac{R_{\mathrm{S}}}{r_e \ln\Lambda} \vartheta_e^{3/2} \left(f\dot{m}/\tau \right)^{1/2} h r^{1/4} \quad \sim 10^{17} \left(M/M_{\mathrm{Sun}} \right)$$

$$S_{IC}/S_{\mathrm{Spitzer}} \approx \frac{m_e \ln\Lambda}{m_p} \vartheta_e^{-5/2} \frac{\tau}{\varepsilon \dot{m}} \frac{r}{h}$$

Collisionality of Reconnection Layer

Collisionless regime: $\delta_{\text{Sweet-Parker}} < \delta_{\text{ion skin depth}}$

$$\delta_{\text{SP}} \equiv S^{-1/2}\Delta z, \quad \delta_i \equiv \frac{c}{\omega_{pi}}$$

$$\frac{\delta_{\text{SP}}}{\delta_i} \approx \left(\frac{m_e \ln\Lambda}{m_p}\right)^{1/2} \vartheta_e^{-3/4} (f\dot{m})^{-1/4} \tau^{3/4} r^{3/8} \quad \text{if } \eta = \eta_{\text{Spitzer}}$$

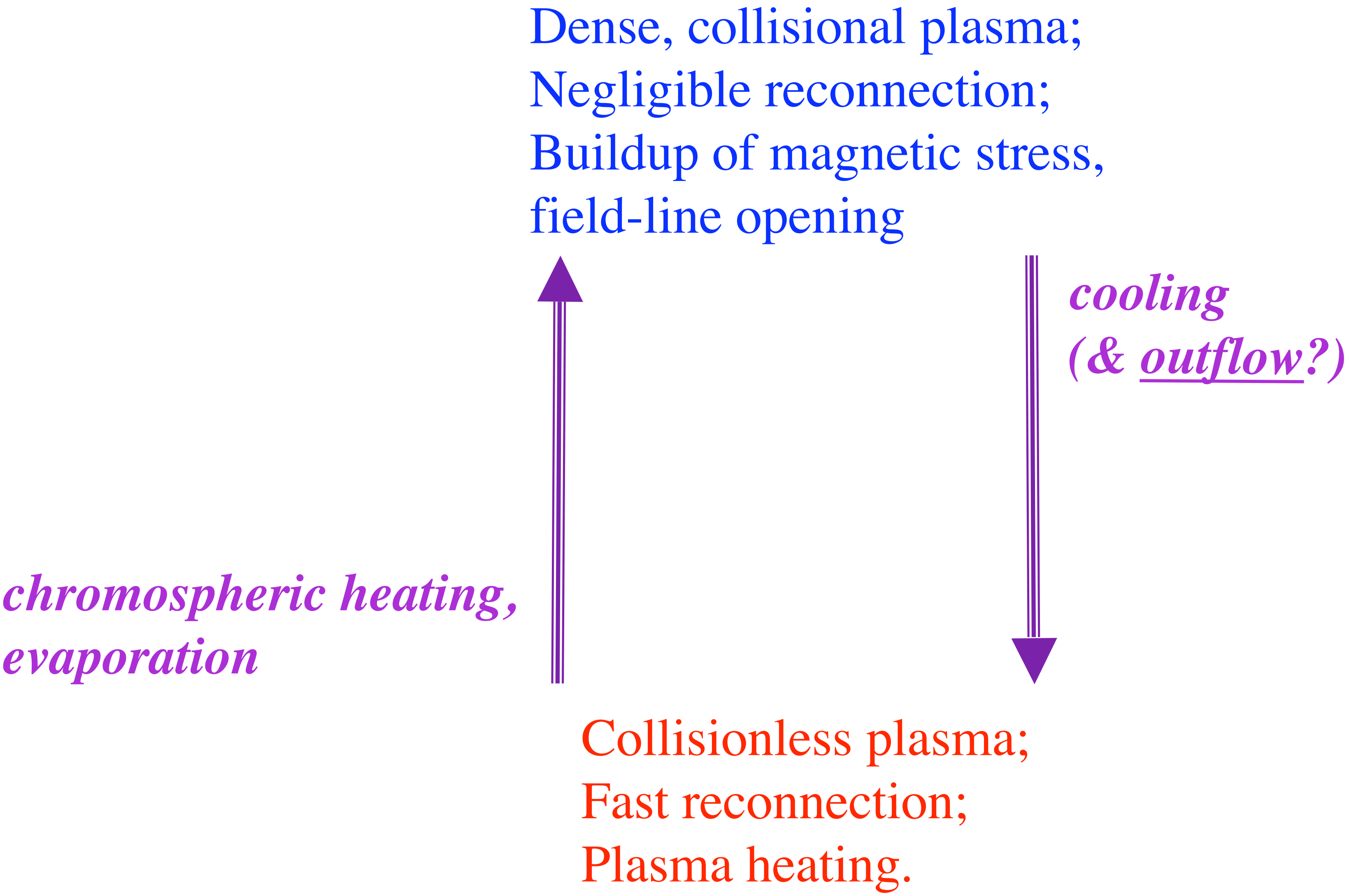
$$\approx \vartheta_e^{1/2} f^{-1/4} \varepsilon^{1/2} \dot{m}^{1/4} \tau^{1/4} h^{1/2} r^{-1/8} \quad \text{if } \eta = \eta_{\text{IC}}$$

∴Marginally collisionless reconnection (?)

Questions

- Is it a coincidence that $\delta_{\mathrm{SP}} \sim \delta_i$, or self-regulation, and if so, how does this work?

Coronal Collisionality Cycle



Dense, collisional plasma;
Negligible reconnection;
Buildup of magnetic stress,
field-line opening

cooling
(& outflow?)

chromospheric heating,
evaporation

Collisionless plasma;
Fast reconnection;
Plasma heating.

Uzdensky 2007

Questions

- Is it a coincidence that $\delta_{SP} \sim \delta_i$, or self-regulation, and if so, how does this work?
- What differences between solar and disk coronae are most important?
  - Relativistic temperatures, $e^{\pm}$ pairs, large-scale shear, inverse-Compton drag, ...?
- If collisional reconnection is strongly suppressed when $S >> 1$, what does this mean for MRI saturation?

Reconnection and MRI saturation

$B_{z,0}$

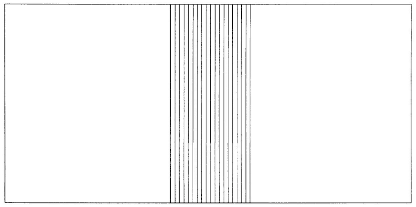


FIG. 3*a*

B_z

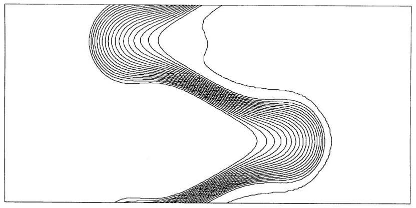


FIG. 3*b*

B_ϕ

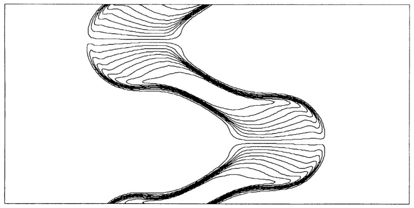
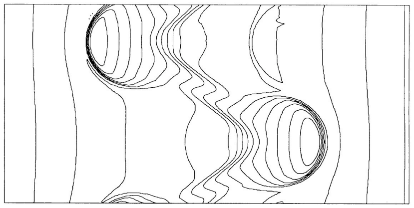
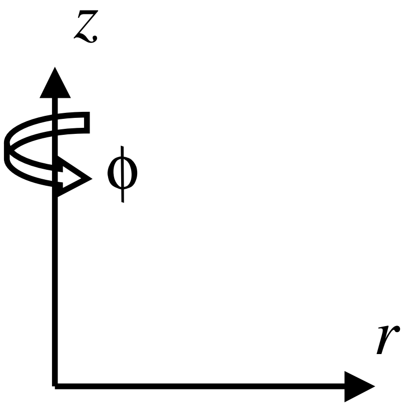


FIG. 3*c*

$\mathcal{J}$





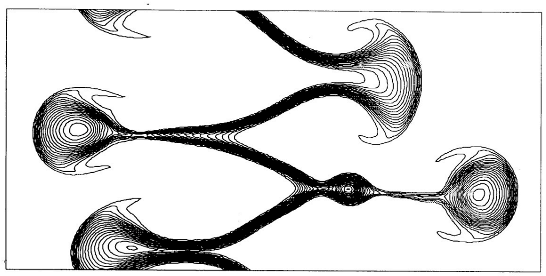


FIG. 5*a*

B_z

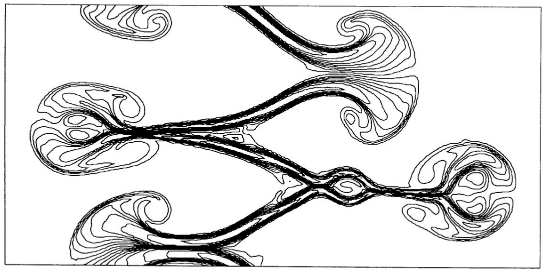
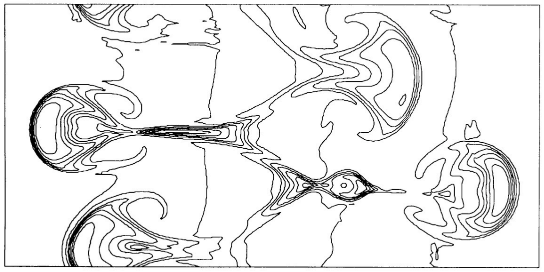


FIG. 5*b*

B_ϕ



$\mathcal{J}$

Hawley & Balbus ApJ ***376****, 223 (1991)*

Main Points

- **A**ccretion-**D**isk **C**oronae are inferred from power-law X-ray spectra.
- Dominance of this emission component (in some states) suggests ADC may dominate transport too.
- Standard model for the spectrum (*Comptonization*) suggests ADC are marginally collisionless.
- Collisionality may be self-regulated by the need for fast reconnection and efficient dissipation.
- Disk-MRI simulations do not support dominant ADC, at least as yet, but this may be due to promiscuous reconnection.