Magnetized Disk Coronae

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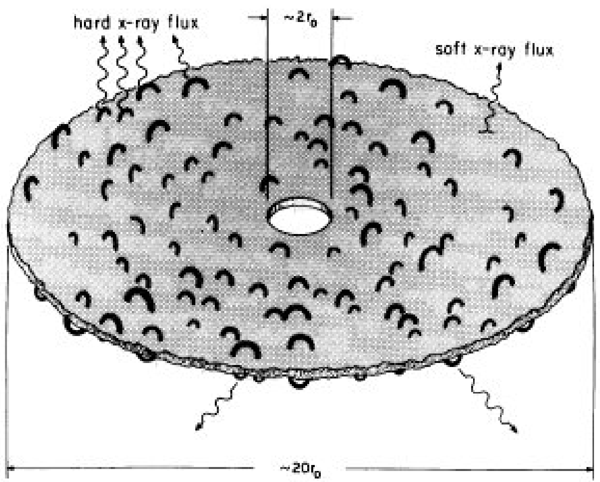


Galeev, Rosner, & Vaiana, ApJ, **489**, 865 (1979)

PPPL
23 September 2003

Dynamical Motivations

Cylindrical coordinates (R, θ, z).
Accretion speed $-V_r \ll V_\theta \equiv R\Omega \approx \sqrt{\frac{GM}{R}}$.

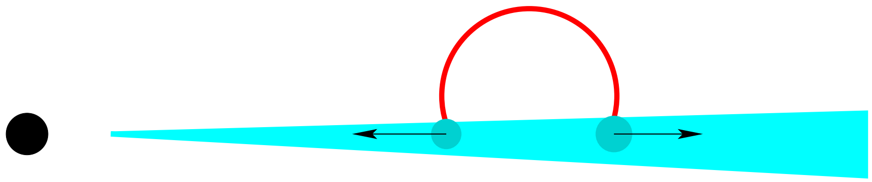
Steady Accretion:

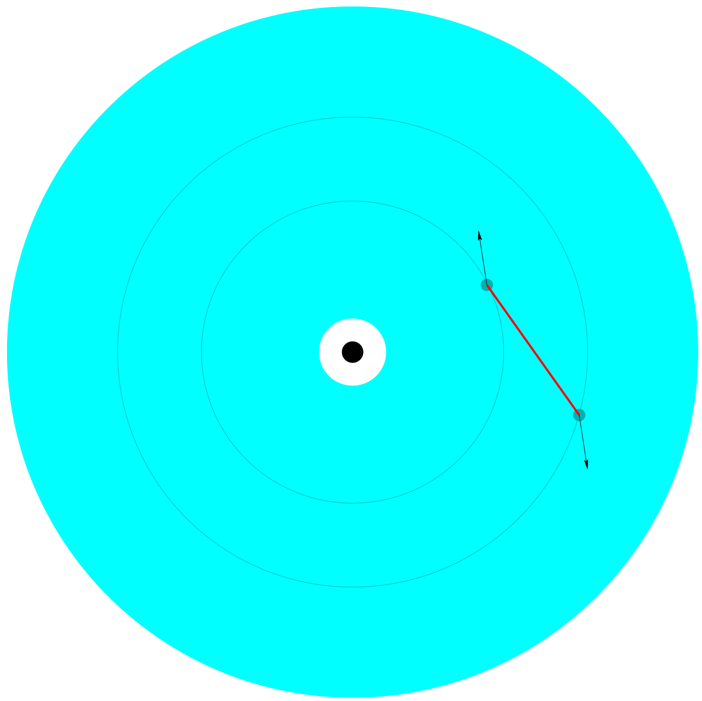
$$\dot{M}(R,t) \equiv -\int_{-\infty}^{\infty} dz \int_{0}^{2\pi} d\theta\, \rho R V_R = \text{constant}.$$

$$\dot{J}(R,t) \equiv \dot{M} R^2 \Omega - \int_{-\infty}^{\infty} dz \int_{0}^{2\pi} d\theta\, R^2 \underbrace{T_{R\theta}}_{-\frac{B_R B_\theta}{4\pi}} \approx 0.$$

$$\Rightarrow \quad \dot{M}\Omega \lesssim \left\langle \mathbf{B}^2 \right\rangle_{z,\theta} \times H_B$$

Coronal MRI

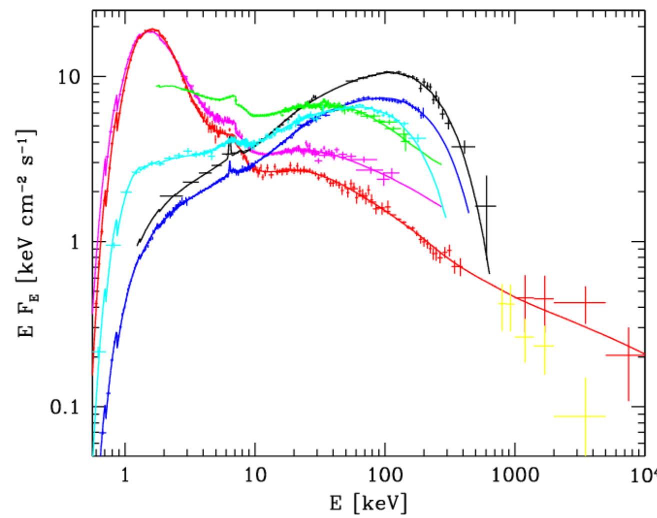




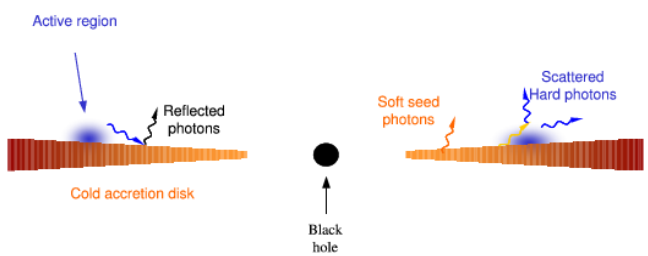
- *inverse cascade* to larger flux tubes
- $B_{\text{max}} \propto$ tube length
- $H_B \sim$ largest tubes; $\gg H_\rho$?

Evidence for Coronae

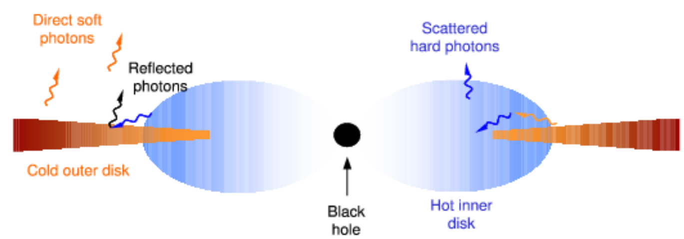
- Comptonized (?) X-ray spectra
  - $\tau_C \equiv \int n_e \sigma_T \, ds \sim 1$
  - $T_e \gg T_{\rm disk}$
  - hard X-rays lag soft
- Signs of reflection
  - continuum bumps
  - Fe Kα fluorescence
- Jets and winds



*Spectra of Cygnus X-1.**



*Notional soft state.**

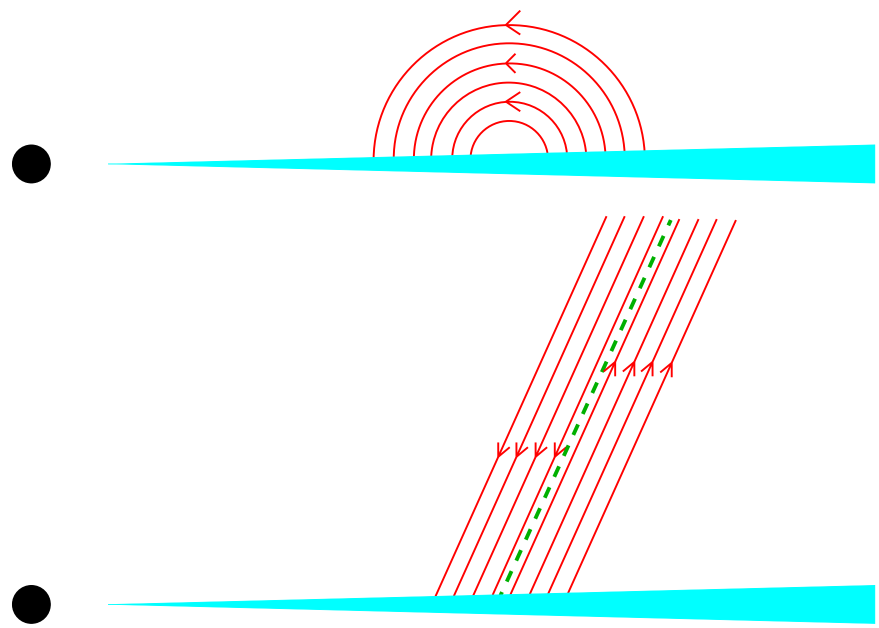


*Notional hard state.**

*Zdziarski et al., ApJ 578, 357 (2002)

Ideal, force-free, MHD

- Field lines open after $\Delta\theta \sim 1$ rad
- Current sheet forms *(green)*
- Torque ends
- *Aly; Boily & Lynden-Bell; . . .*



Reconnection across current sheet restores torque

Some scalings for BH accretion

Dimensionless parameters:

$$\dot{m} \equiv \frac{\dot{M}c^2}{L_{\rm Edd}} = \frac{\dot{M}c\sigma_{\rm T}}{4\pi GMm_p}\,, \qquad \vartheta_e \equiv \frac{k_{\rm B}T_e}{m_e c^2}\,, \qquad \tau_{\rm C} \equiv n_e\sigma_{\rm T}H_B\,,$$

$$m \equiv \frac{M}{M_\odot}\,, \qquad h \equiv \frac{H_B}{R}\,, \qquad r \equiv \frac{R}{R_{\rm S}} \equiv \frac{Rc^2}{2GM}\,.$$

$$S \sim 3\times 10^{18}\, m\dot{m}^{1/2}\tau_{\rm C}^{-1/2}\vartheta_e^{3/2}\; hr^{1/4}$$

$$\beta \sim \dot{m}^{-1}\tau_{\rm C}\; h^2 r^{1/2}$$

$$\frac{\lambda_{\rm mfp}}{H_B} \sim \tau_{\rm C}^{-1}\vartheta_e^2$$

$$\frac{\delta_{\rm SP}}{\delta_i} \sim \left(\frac{m_e}{m_p}\right)^{1/2} \dot{m}^{-1/4}\tau_{\rm C}^{3/4}\vartheta_e^{-3/4}\; r^{3/8}$$

$$\frac{V_{\rm drift}}{V_i} \sim \left(\frac{m_p}{m_e}\right)^{1/2} \dot{m}^{3/4}\tau_{\rm C}^{-5/4}\vartheta_e^{3/4}\; h^{-1}r^{-5/8}.$$

Peroration: *Why study disk coronae?*

1. They seem to exist, sometimes

2. Likely consequence of MRI

3. May ameliorate some problems with accretion

    - $\alpha > 1$
    - $Q > 1$

4. Connects AMT to post-MHD physics

    - $\beta \lesssim 1$
    - $\lambda_{\rm mfp} \gtrsim L$
    - reconnection