Reconnection near Black Hole Engines

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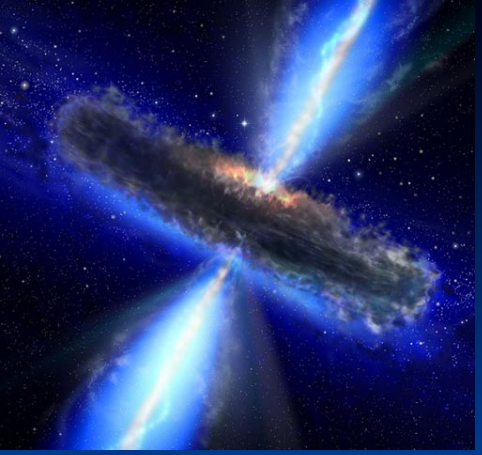
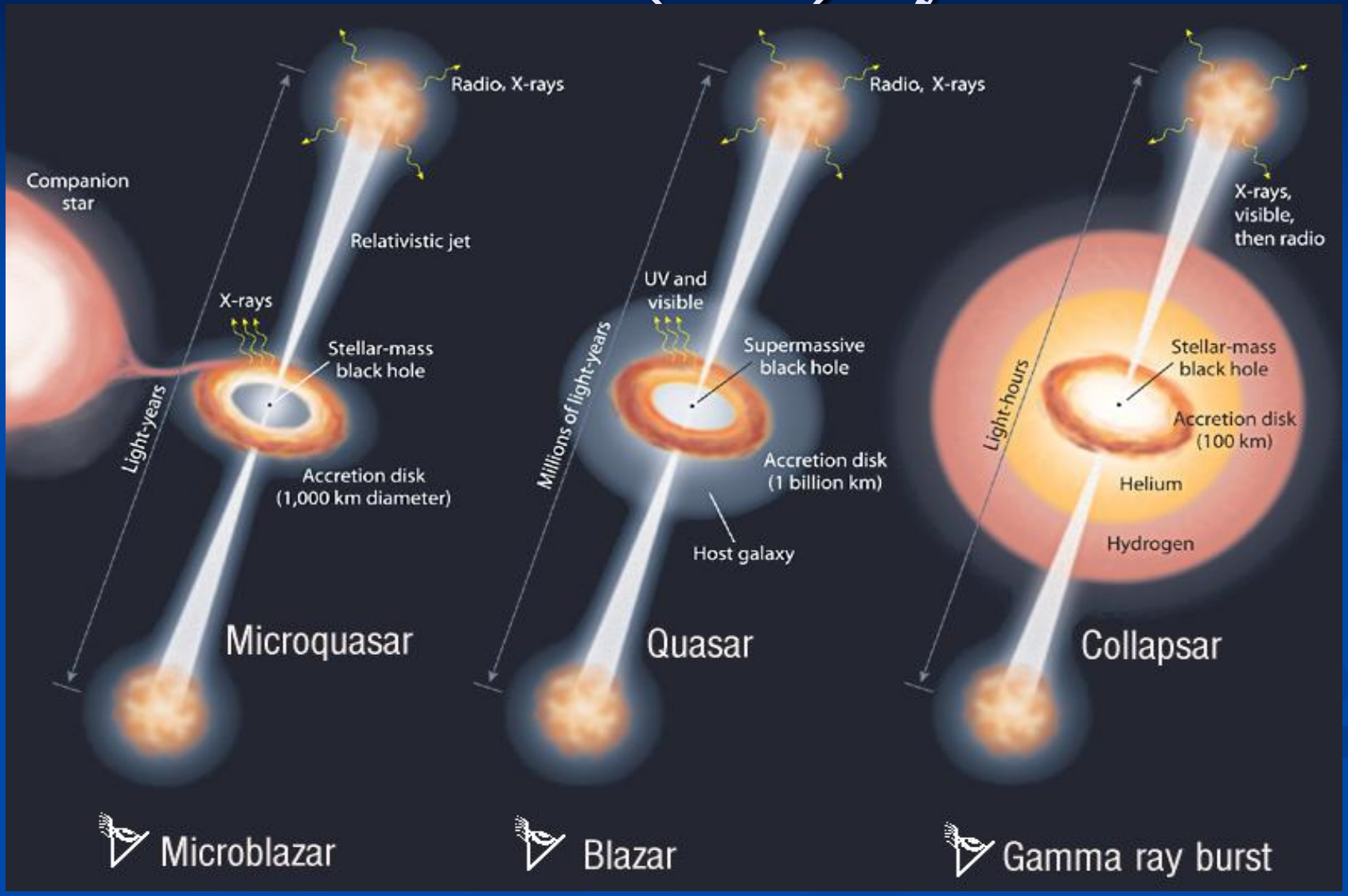


ESA/NASA (Beckmann)

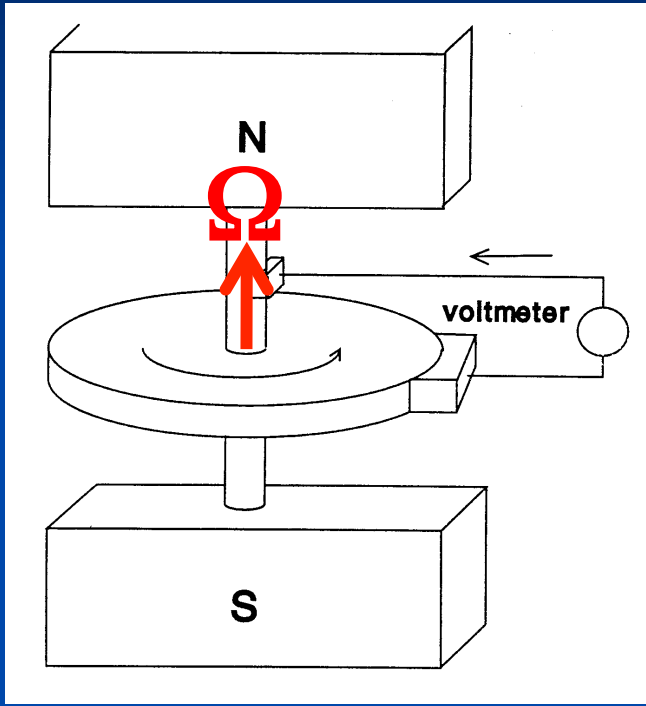
Road Map

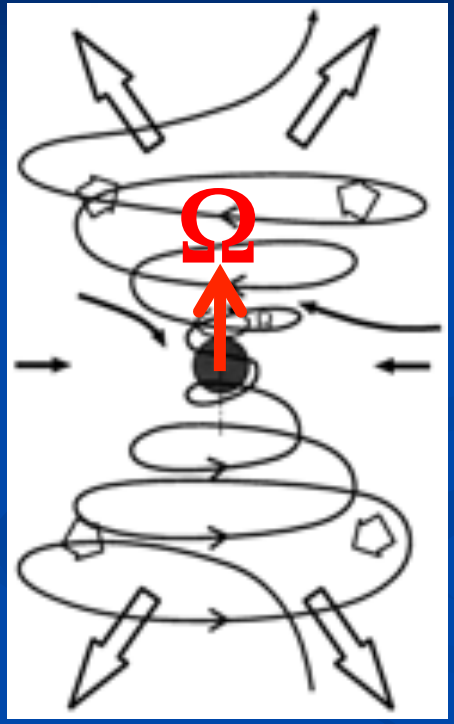
- Magnetic Field Accumulation near Black Holes
- Magnetic Field Destruction via Reconnection
- Summary

Black Hole (BH) Systems



BH as Faraday Disk
(homopolar or unipolar generator)





Force = q v£ B / V = IR

Power = P = IV = I^2 R

P / R B^2 Ω^2

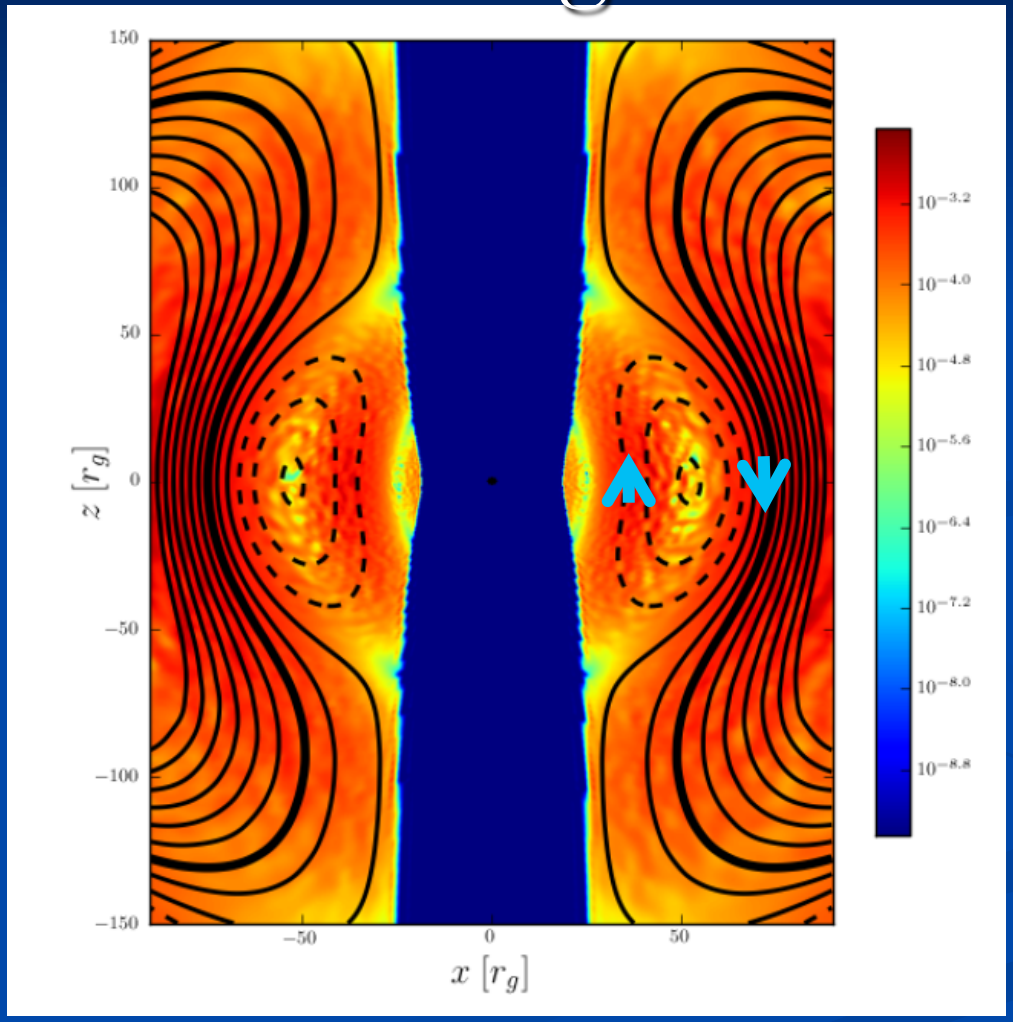
Membrane Paradigm: (Thorne et al.)

R = 4¼/c » 377Ohms

Blandford & Znajek (1977)

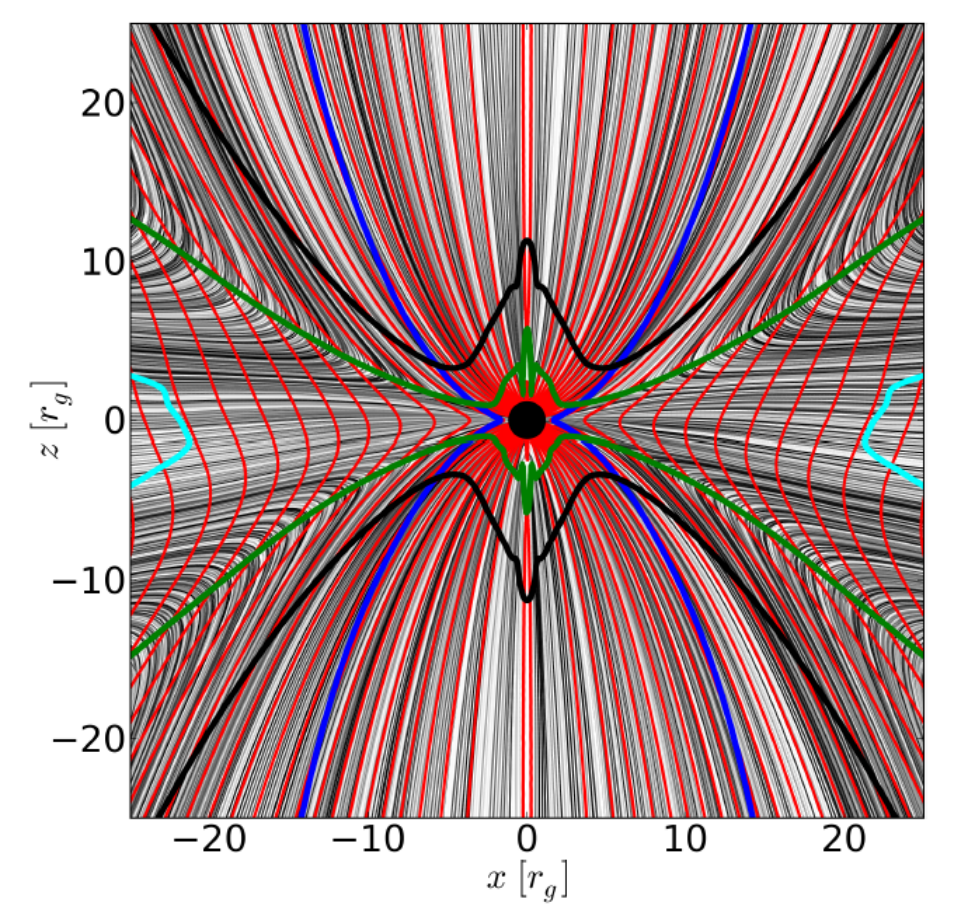
P / B_r^2 Ω^2_H

GR-MHD Simulations of Disks with Lots of Magnetic Flux



EM Energy Density & Field Lines

Magnetically Choked Accretion Flow



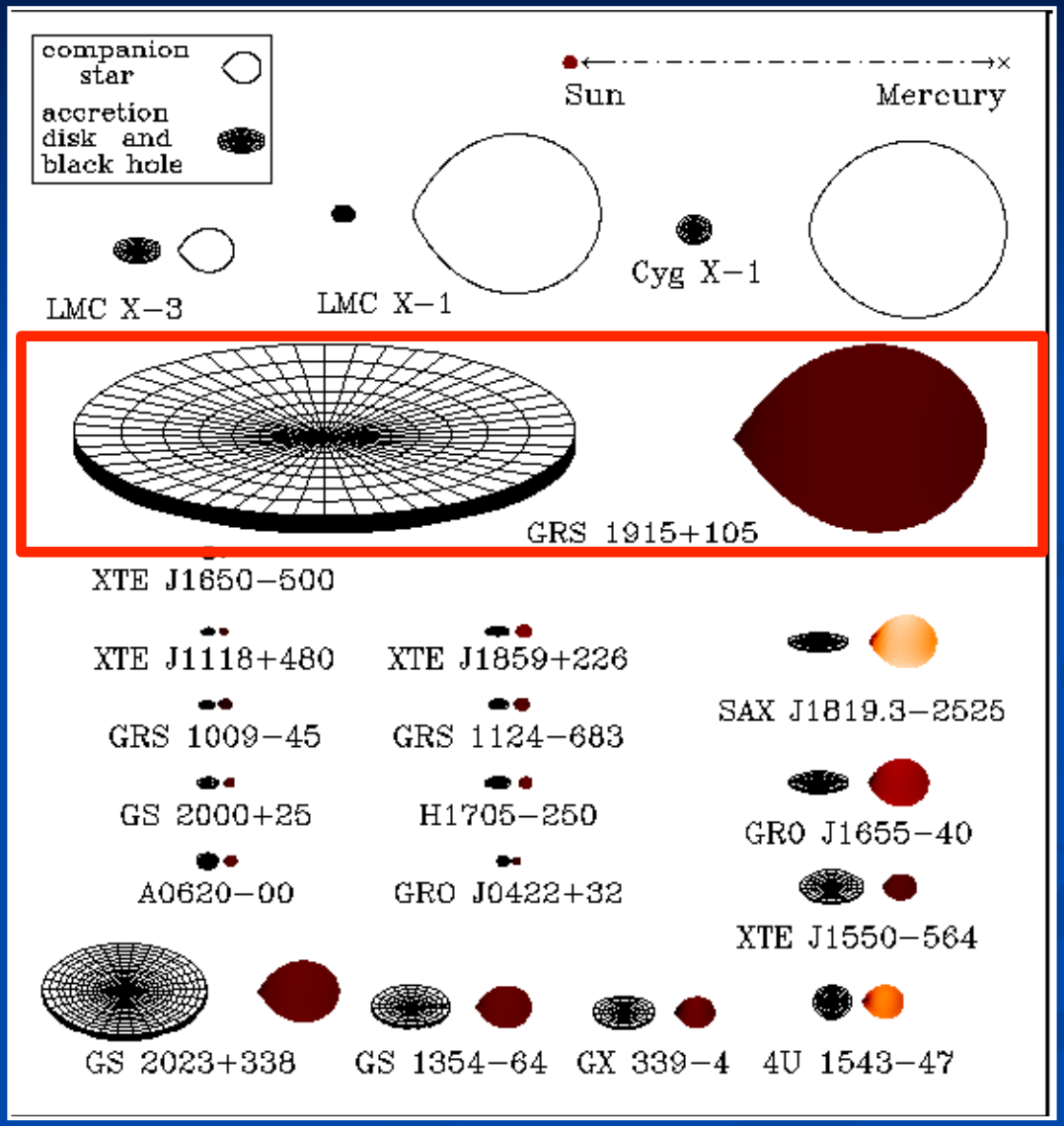
Time-Azimuthal Average:

Red: Magnetic Field Lines
Gray: Velocity Stream Lines

- **Magnetic Flux Saturates to Natural Limit**
- **Force Balance between Ram/Gravity and Magnetic Flux**

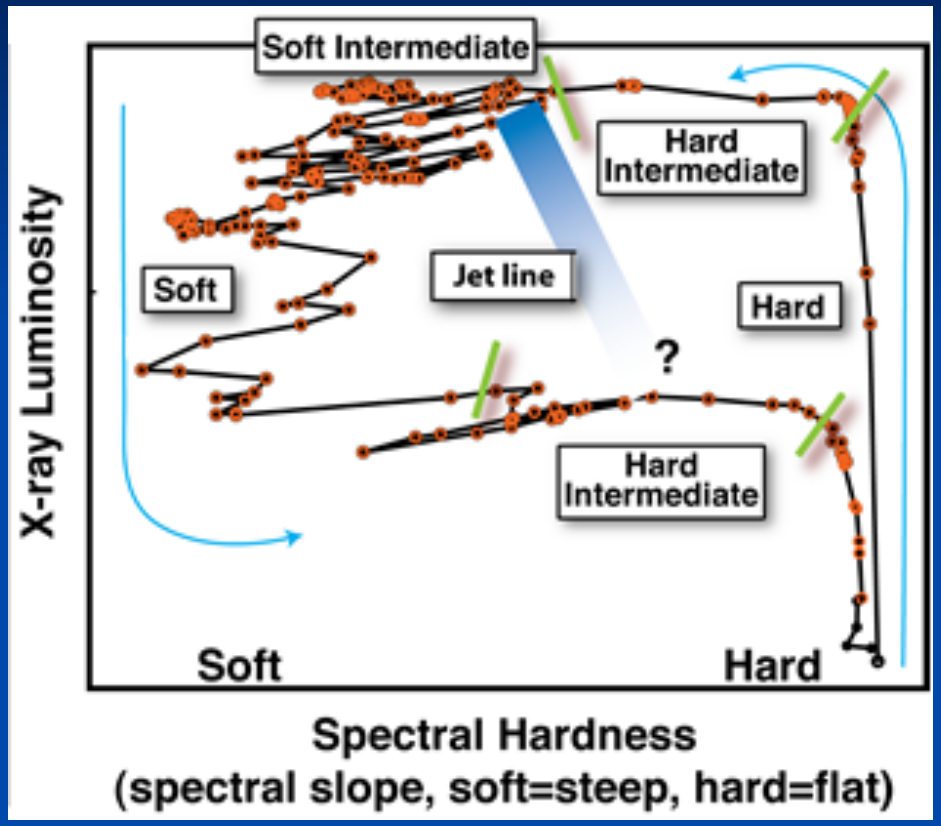
Igumenshchev et al. (08,09), Tchekhovskoy et al. (11,12), McKinney et al. (12)

BH X-Ray Binaries

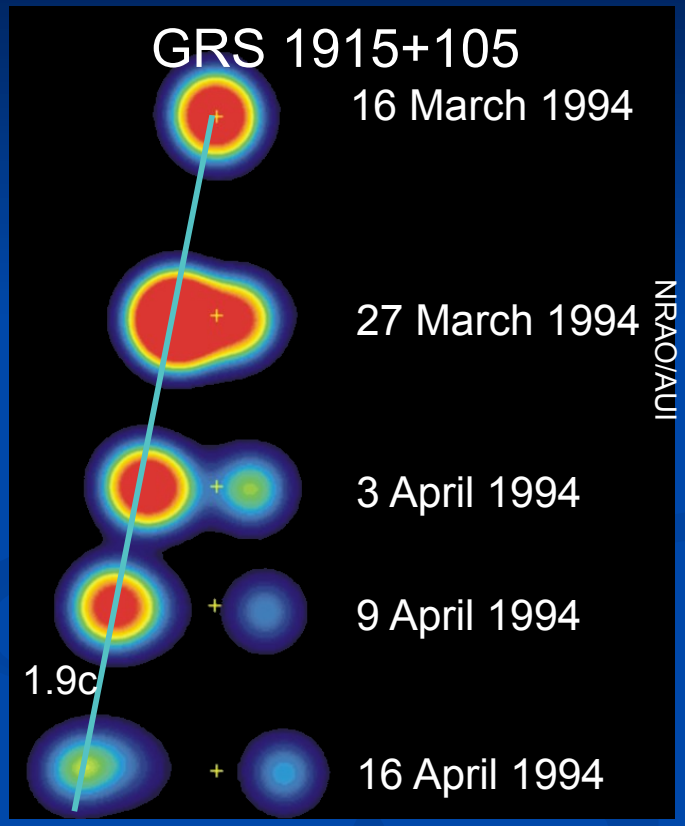


Orosz

BH X-Ray Binaries



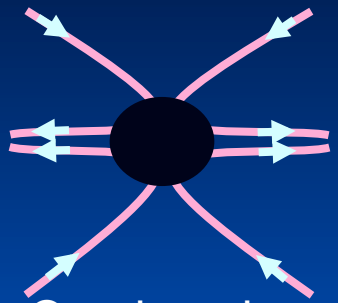
Belloni et al.



Mirabel & Rodriguez (1994,1999)

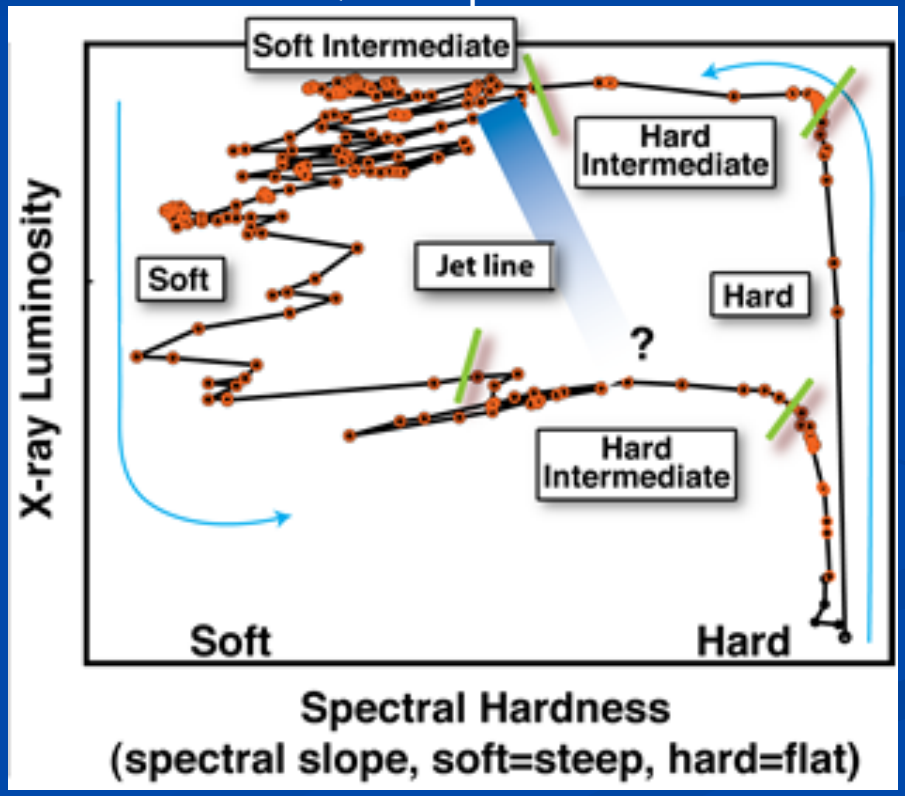
- Mass Accretion Rate sets luminosity?
- But then how to explain case of 2 states at same luminosity?

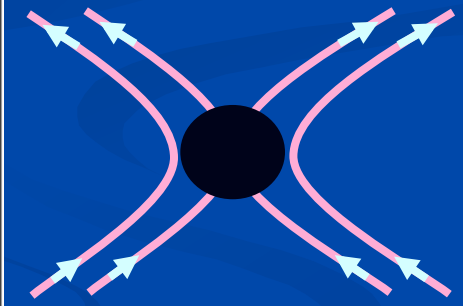
Origin of States and Transient Jet?



Quadrupolar

No Ordered Field





Dipolar

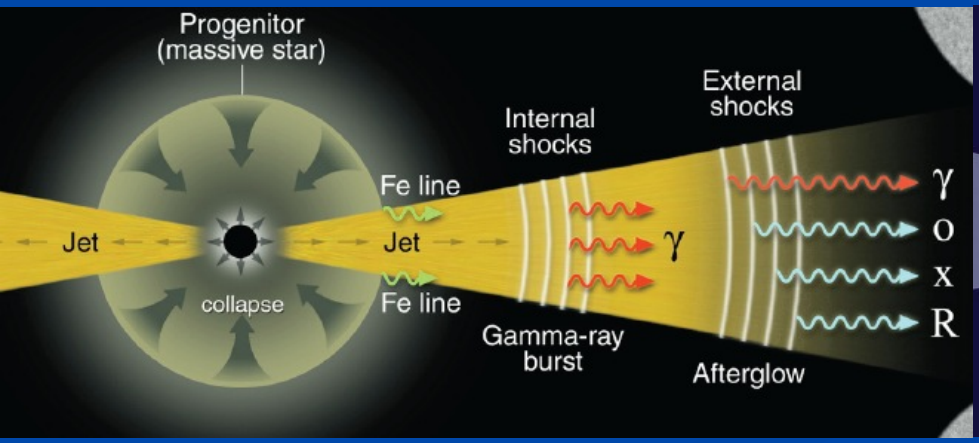
Igumenshchev (2009) McKinney & Blandford (2009), McKinney, Tchekhovskoy, Blandford (2012)

Prompt Activity in Gamma-Ray Bursts (GRBs)

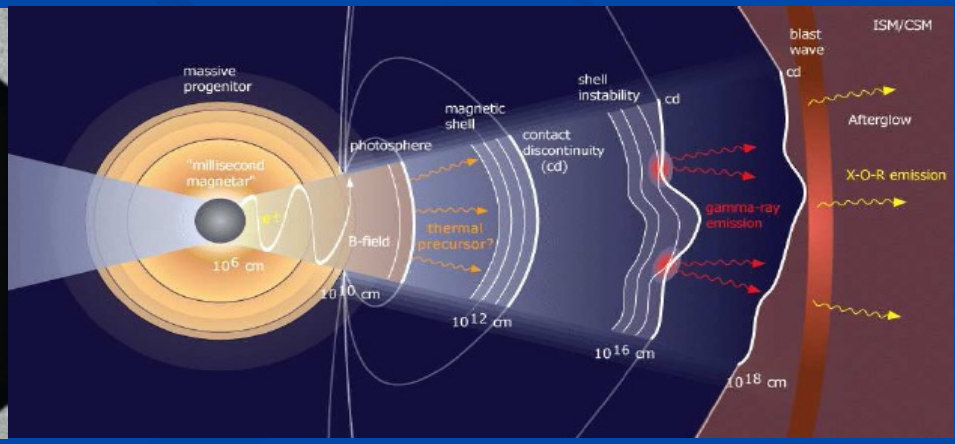
- HD Fireball driven by neutrino annihilation. Emission via Shocks (need huge relative relativistic motion)

Vs.

- MHD Jet driven by BZ mechanism. Emission via Reconnection (need oscillating field and delayed reconnection)

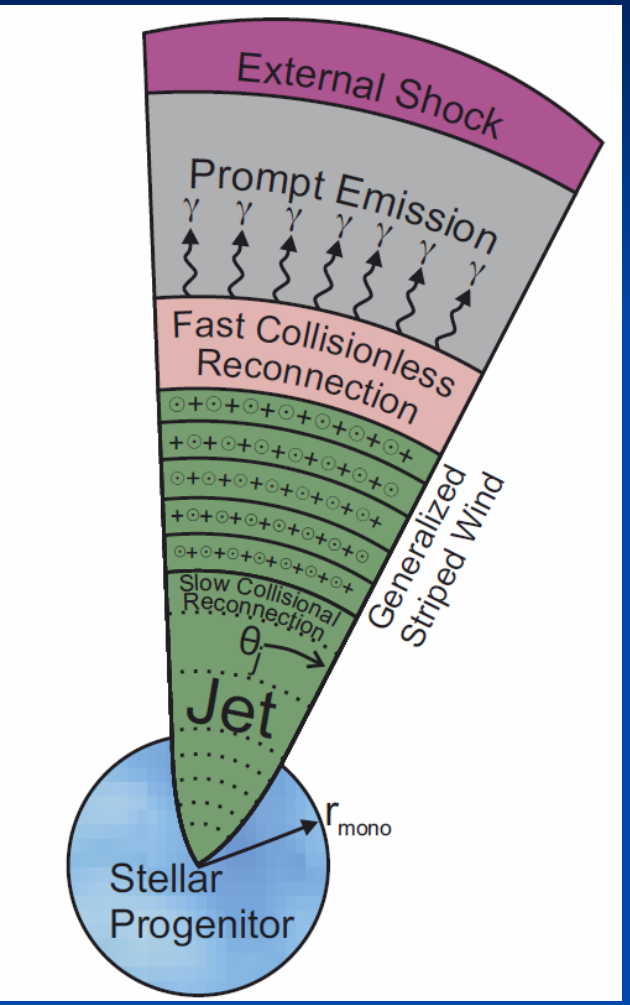


Fireball Model (Sari, Piran, Meszaros, Rees >1993)

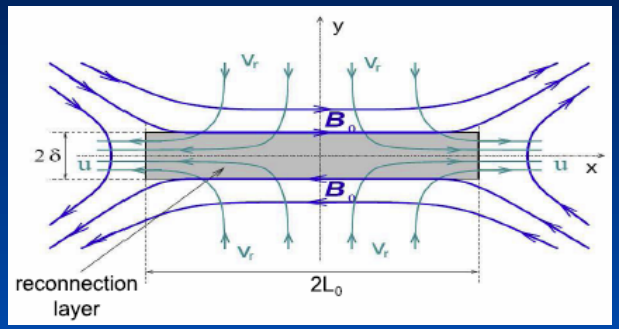


ElectroMagnetic Model (Lyutikov & Blandford 2003)

GRB Reconnection Switch Mechanism

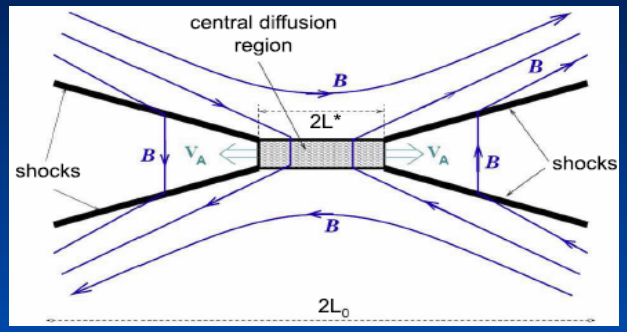


McKinney & Uzdensky (2012)



Slow Sweet-Parker-like (Collisional)

Thickness: Dsp



Very Fast Petschek-like (Collisionless)

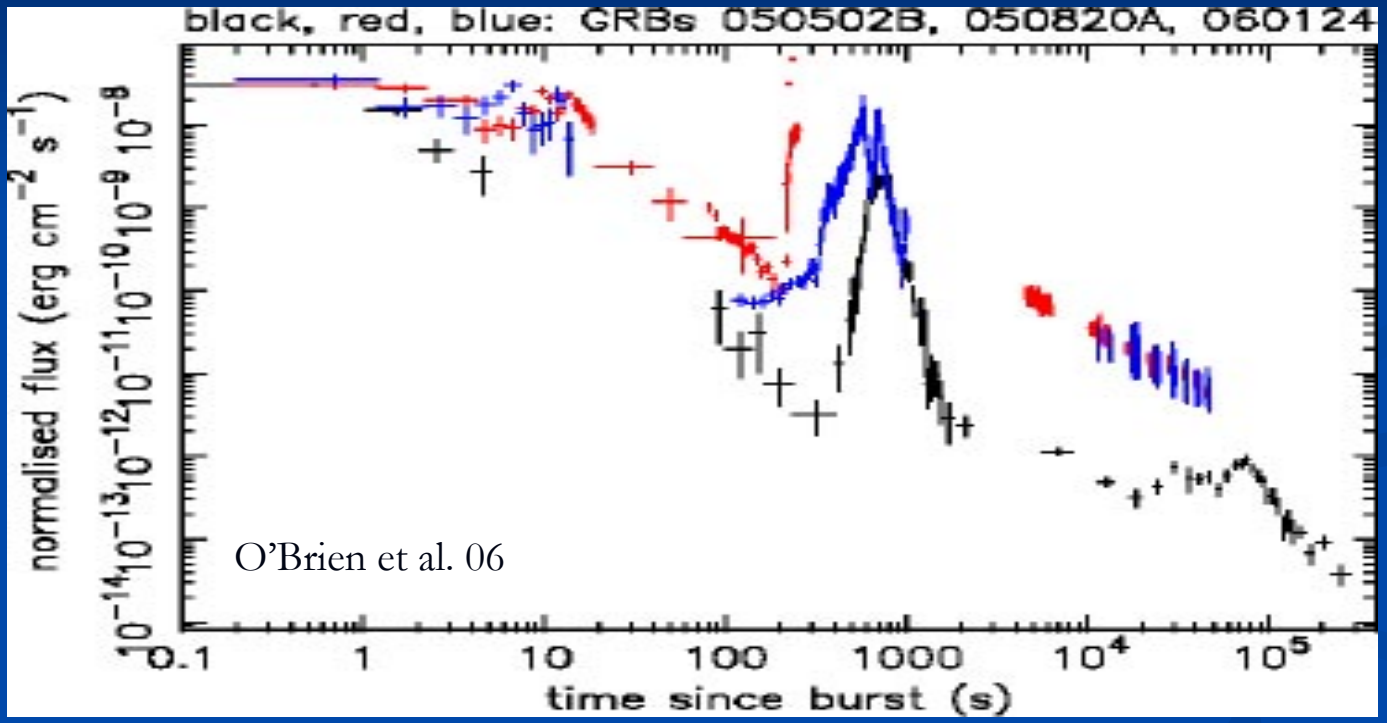
Thickness: Dpet

Larger scale dominates smaller scale

Fast EM dissipation starts when Dsp=Dpet

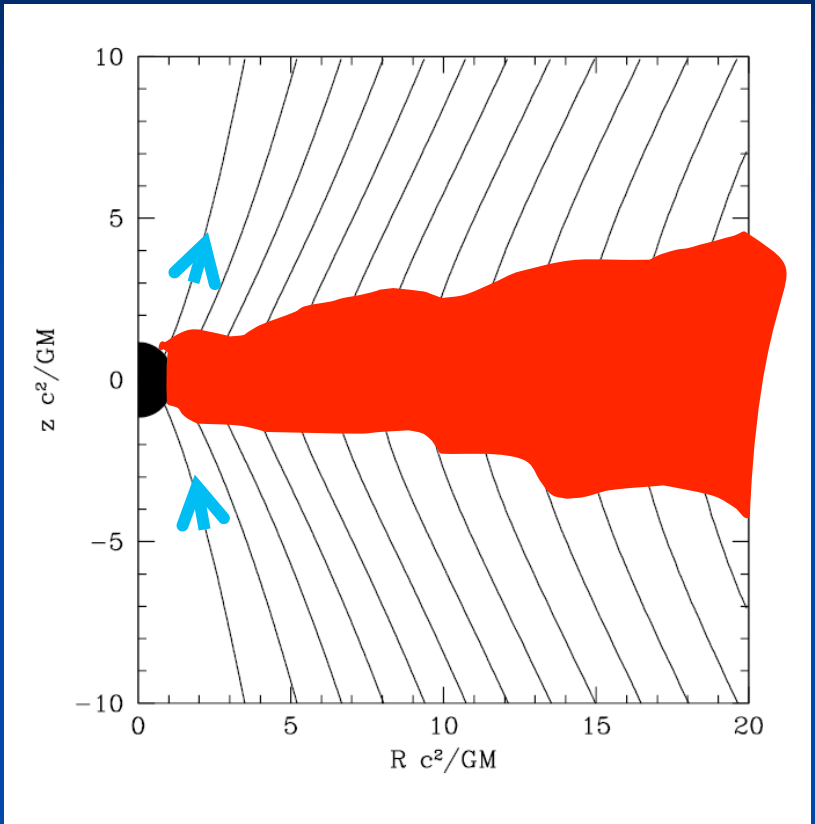
(Consistent with Princeton Plasma Physics Lab experiments, but Need computer simulations.)

Late-time GRB Activity

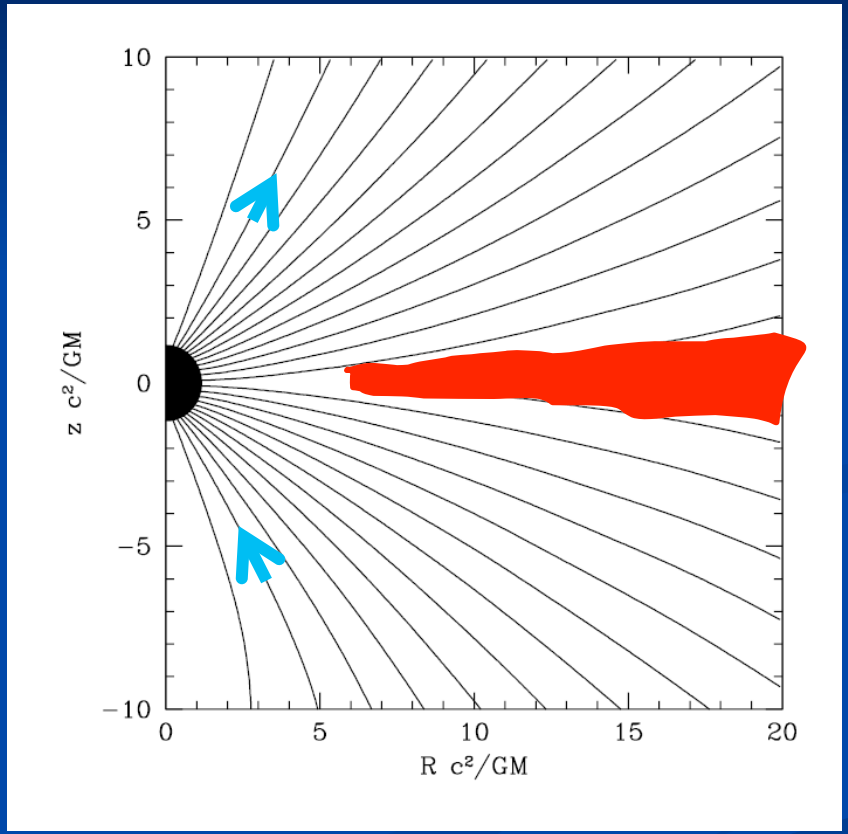


(Di Matteo et al. 02, Gehrels, Beloborodov 08, Zalamea & Beloborodov 10)

Magnetic Field Destruction in GRBs



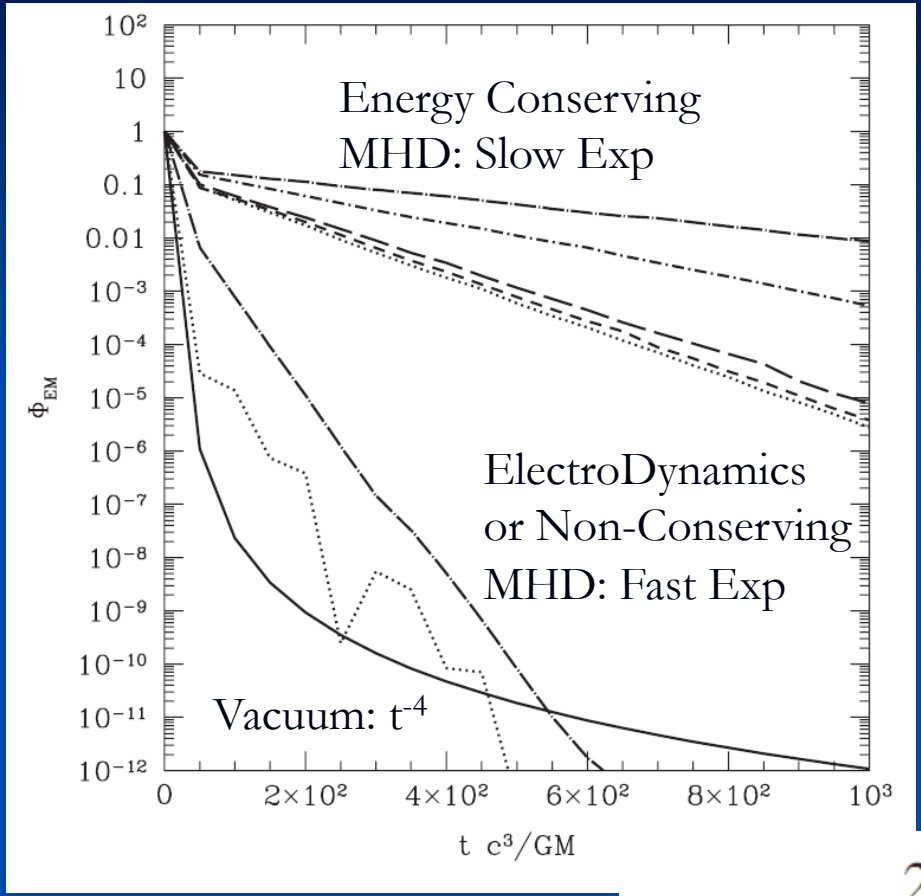
BH with Late-Time Drop in Mass Flux



Split-Monopole and Current Sheet Formation

Lyutikov & McKinney (2011) Lehner et al. (2012)

Magnetic Flux Loss Rate



1) Model Reconnection:
Charge Starvation - Pair Formation

2) Obtain Reconnection Rate to give how much flux stays on BH vs. time

3) Obtain Luminosity of BH via BZ effect

$$L_{\rm BH} \approx \frac{2}{3c}\left(\frac{\Omega_H \Phi_0}{4\pi}\right)^2 = \frac{2\pi^4}{75}\chi^2\frac{c^5}{G^4}\frac{B_{\rm NS}^2 R_{\rm NS}^{10}}{M_{\rm NS}^4 P_{\rm NS}^4}$$

$$\approx 10^{49}\ {\rm ergs}^{-1}\left(\frac{\chi}{0.5}\right)^2\left(\frac{B_{\rm NS}}{10^{15}\ {\rm G}}\right)^2\left(\frac{P_{\rm NS}}{1\ {\rm msec}}\right)^{-4}.$$

Summary

- Field Accumulation around BHs:
  - Magnetic Flux reaches Natural Saturation Point
  - Large Reservoir of Magnetic Energy
  - Can explain most powerful Jets

- Field Destruction near BHs:
  - Powerful Radio Transient Jets in X-ray Binaries?
  - Prompt Activity Jets in GRBs?
  - Late Activity Jets in GRBs?