

Radiative Magnetohydrodynamic Shocks around Kerr Black Holes

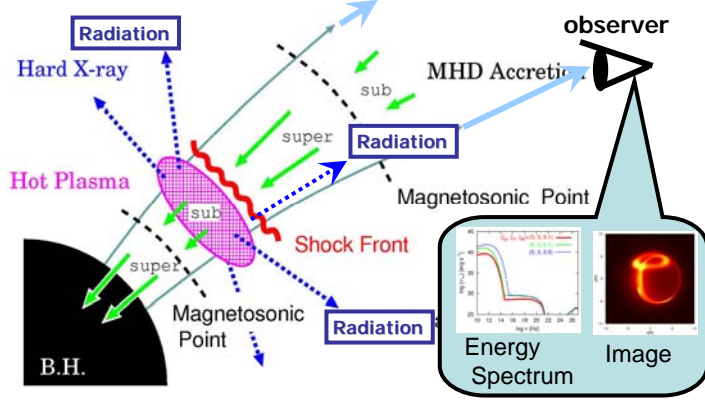
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Abstract

We study the radiative magnetohydrodynamic (MHD) shocks in the accretion flow around Kerr black hole. We present the formalism of the radiative MHD shocks in the global solutions of the trans-magnetosonic flow, the local and observed energy spectrum of the fast and slow magnetosonic shocks and the observed apparent images of the shocks in the vicinity of the black holes are calculated.

1. Introduction

Energy and angular momentum are dissipated at shocks.



<Assumptions>

Kerr BH, Stationary Radiative Shocks, Fixed Magnetic Field, Pre-&Post-shock : adiabatic cold trans-magnetosonic flow

• conserved quantities along flow

Energy

$$E \equiv \mu u_t - \frac{\Omega_F B_\phi}{4\pi\eta}$$

Angular momentum

$$L \equiv -\mu u_\phi - \frac{B_\phi}{4\pi\eta}$$

Angular velocity of magnetic field

$$\Omega_F \equiv -\frac{F_{t\phi}}{F_{\phi r}}$$

Particle number flux par magnetic tube

$$\eta \equiv -\frac{nu^r}{Br} G_t$$

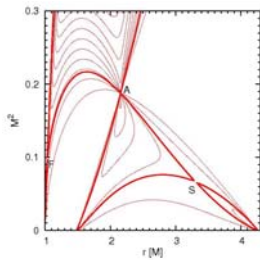
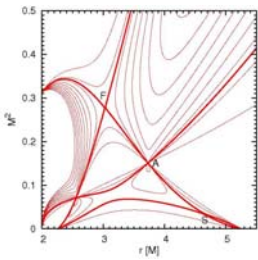
2. Transmagnetosonic Flows

- Poloidal equation (relativistic Bernoulli equation).
- Fast magnetosonic point \rightarrow Alfvén point \rightarrow Slow magnetosonic point (in this order)

• Examples

a/M=0 (no rotating BH)

a/M=1 (max. rotating BH)



3. Radiative MHD Shocks around Kerr Black Holes

(1) GR Radiative Shocks

• Shock conditions $[T^{rt}] = 0$ and $[T^{r\phi}] = 0$

$$T^{rt} = T_{\text{fluid}}^{rt} + T_{\text{EM}}^{rt} + T_{\text{rad}}^{rt} = \left(\frac{nu^r}{\rho_w^2}\right) [g_{\phi\phi}(E_{\text{fluid}} + E_{\text{EM}} + E_{\text{rad}}) + g_{t\phi}(L_{\text{fluid}} + L_{\text{EM}} + L_{\text{rad}})]$$

$$T^{r\phi} = T_{\text{fluid}}^{r\phi} + T_{\text{EM}}^{r\phi} + T_{\text{rad}}^{r\phi} = \left(\frac{nu^r}{\rho_w^2}\right) [-g_{t\phi}(E_{\text{fluid}} + E_{\text{EM}} + E_{\text{rad}}) - g_{t\phi}(L_{\text{fluid}} + L_{\text{EM}} + L_{\text{rad}})]$$

$$T_{\text{rad}}^{\mu\nu} = u^\mu q^\nu + u^\nu q^\mu \quad (q^\mu : \text{flux four vector})$$

\rightarrow dissipated energy and angular momentum at shocks

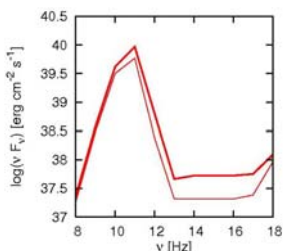
$$E_{\text{rad}} = \frac{1}{nu^r} (u_r q_t + q_r u_t) \quad \& \quad L_{\text{rad}} = -\frac{1}{nu^r} (u_r q_\phi + q_r u_\phi)$$

q^μ is specified by radiation mechanisms (e.g. synchrotron radiation, etc.) at the fluid rest frame.

(3) Images

- q^μ fluid rest frame \rightarrow ZAMO frame \rightarrow Boyer-Lindquist frame
- gravitational lensing effects + Doppler effects + redshifts
- synchrotron radiation & images seen at submillimeter wavelength
- 3D radiative transfer calculations
- BH rotation \rightarrow frame dragging effects
- inclination angle (between rotation axis & observer direction) : 0 (top), 45 (middle), 85 (bottom) (in units of [deg])
- Shock location : r=4M (left 2 column), 6M (right 2 column)

(2) Energy Spectrum



• synchrotron radiation
 • Here, we use physical parameters (BH mass, distance, etc.) of massive BH in Sgr A*.

