# High Energy Radiation From Accreting Black Holes


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IRISH RESEARCH COUNCIL
An Chomhairle um Thaighde in Éirinn

# Outline

- Jet signatures (O' Riordan, Pe'er, & McKinney, 2016, ApJ, 819, 95)
  - $\gamma$-rays $\sim 10^{23}$ Hz from scattering in jet
  - Break in optical/UV $\rightarrow$ disk to jet dominated
  - Synchrotron peak $\lesssim 10^{14}$ Hz $\Rightarrow$ jet dominates X-rays
- Spin signatures (O' Riordan, Pe'er, & McKinney, 2016, in prep.)
  - X-ray power strongly depends on spin and viewing angle
  - Disk emission $\Rightarrow$ does not follow $P \sim a^2$
  - $P_X/P_{\rm NIR} \rightarrow$ observational signature of spin in low/hard state

# Motivation

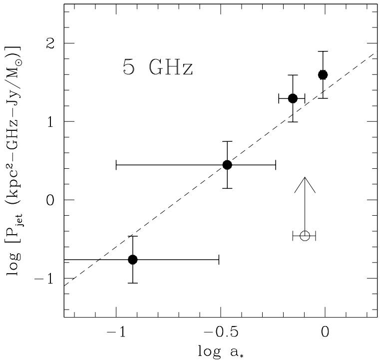
- High-energy emission in XRBs
  $\rightarrow$ disk or jet origin?

- Radio observations of XRBs $\Rightarrow$ jets powered by rotational energy of black holes?

  (Narayan, & McClintock 2012)

- Jet power $P \sim a^2$?

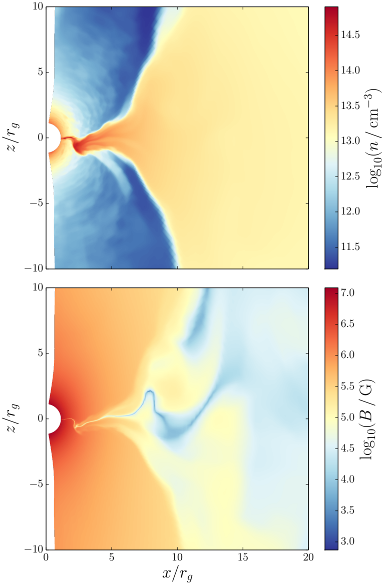
  (Blandford, & Znajek 1977)




(Narayan, & McClintock 2012)

# Motivation

- GRMHD simulations ⇒ efficient jet launching by BZ mechanism (Tchekhovskoy et al. 2011; McKinney et al. 2012)
- Gap between simulation results (fluid dynamics) and observations (radiation)
- General-relativistic radiative transport (e.g., Dolence et al. 2009)

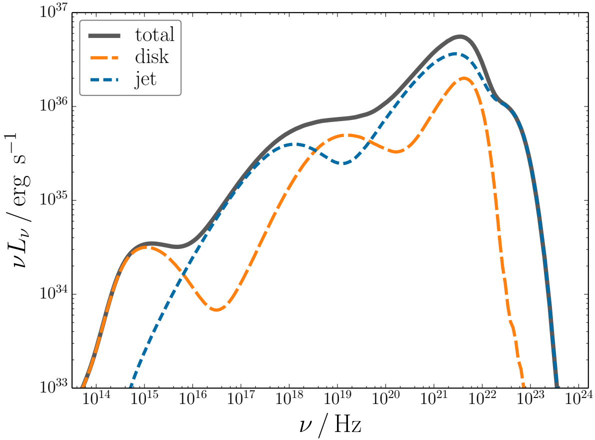


# Radiative Transport

- General-relativistic radiative transport code based on grmonty (Dolence et al. 2009)
- Synchrotron emission and absorption
- Compton scattering
- Thermal distribution of relativistic electrons
- Vary $\mathcal{T} = T_p / T_e$ independently in disk and jet
- Disk $\Rightarrow b^2/\rho < 1$, jet $\Rightarrow b^2/\rho \geq 1$
- Radiatively inefficient accretion $\Rightarrow$ post-processing

# Jet Signatures

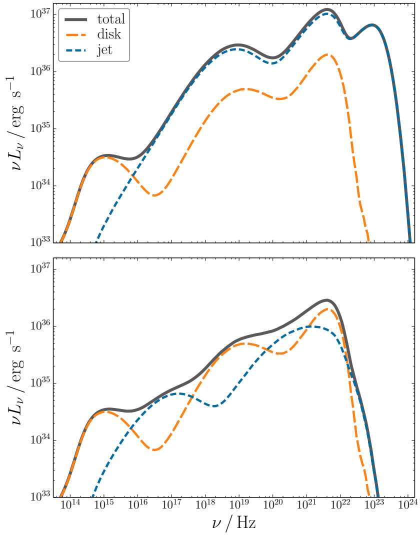
- $\boxed{\gamma\text{-ray peak} \sim 10^{23}\ \text{Hz}}$
  $\Rightarrow$ scattering in jet
- $\boxed{\text{Break at} \sim 10^{16}\ \text{Hz}}$
  $\Rightarrow$ transition from disk to jet dominated




$\mathcal{T}_d = \mathcal{T}_j = 10$

# Jet Signatures

- Variations in $\mathcal{T}$ change relative jet/disk contributions
- $\boxed{\gamma\text{-ray peak at } \sim 10^{23}\text{ Hz}}$
  $\Rightarrow$ strongly jet dominated




$\mathcal{T}_d = 10$, $\mathcal{T}_j = 3$ (top), $\mathcal{T}_j = 30$ (bottom)

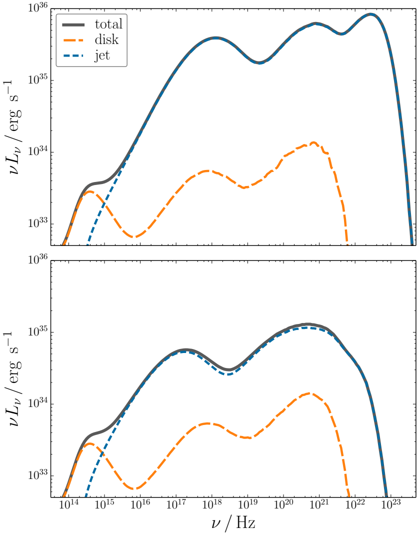
# Jet Signatures

- $\boxed{\text{Disk synchrotron peak} \lesssim 10^{14}\,\text{Hz}}$

  $\Rightarrow$ X-rays dominated by jet for a range of $\mathcal{T}_j$

- Also holds for non-MAD disks

  (O' Riordan et al. 2016)




$\mathcal{T}_d = 30$, $\mathcal{T}_j = 10$ (top), $\mathcal{T}_j = 30$ (bottom)

# Spin Signatures

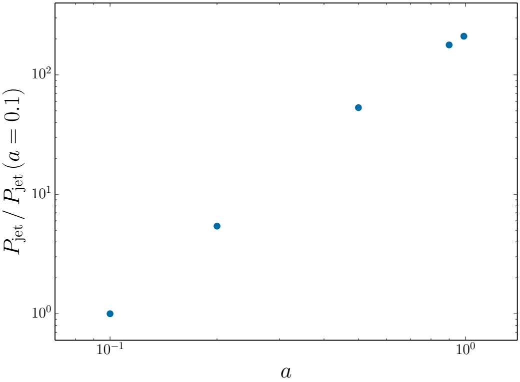
- Spin measurements $\Rightarrow$ high-energy emission in high/soft state (McClintock et al. 2011)
- Jets in low/hard state (with transient jets during state transitions) (Fender et al. 2004)
- Jet power vs spin? $P \sim a^2$? (Narayan & McClintock 2012)
- Effects of spin on high-energy radiation in low/hard state?

# Jet Power Estimate

- Estimate of jet power based on fluid energy fluxes

  (McKinney et al. 2012)

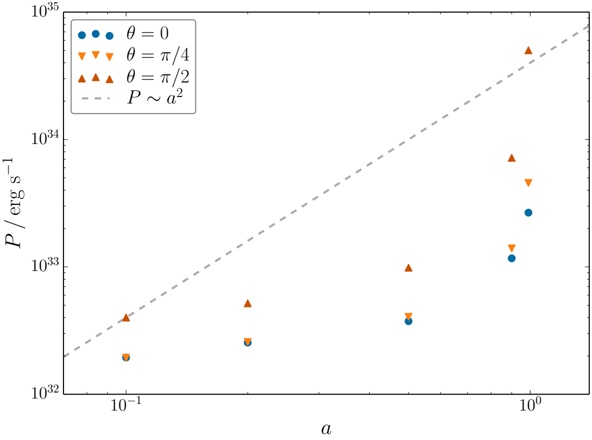
- $\eta = \left(\dot{E} - \dot{M}\right) / [\dot{M}]_t$




$$\dot{M} = \left| \int \sqrt{-g}\,\mathrm{d}x^\theta \mathrm{d}x^\phi \rho u^r \right| \qquad \dot{E} = -\int \sqrt{-g}\,\mathrm{d}x^\theta \mathrm{d}x^\phi\, T^r_t$$

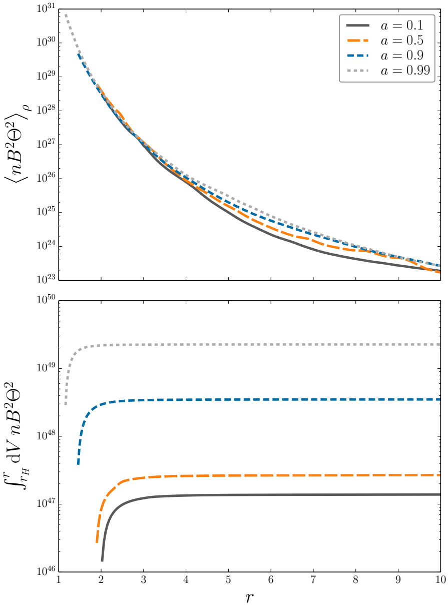
# Power vs Spin

- Strong dependence on spin and viewing angle
- $\boxed{P \propto a^2}$
- Max for observers perpendicular to spin axis



# Synchrotron Emissivity

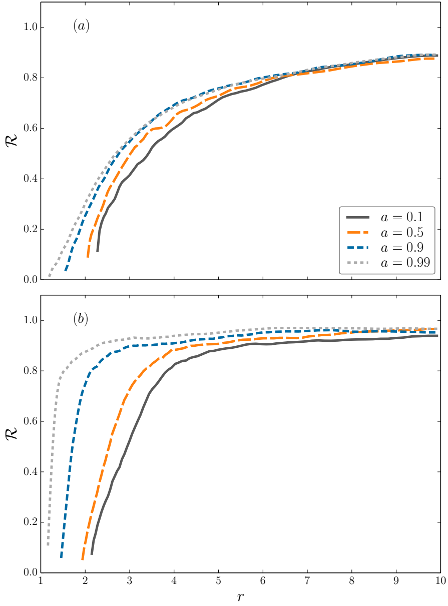
- Peak synchrotron emissivity $\nu\, j_\nu \sim nB^2\Theta^2$
- $\boxed{\text{Dominated by near-horizon region}}$
- Horizon radius decreases with spin $r_H = 1 + \sqrt{1 - a^2}$



# Redshift

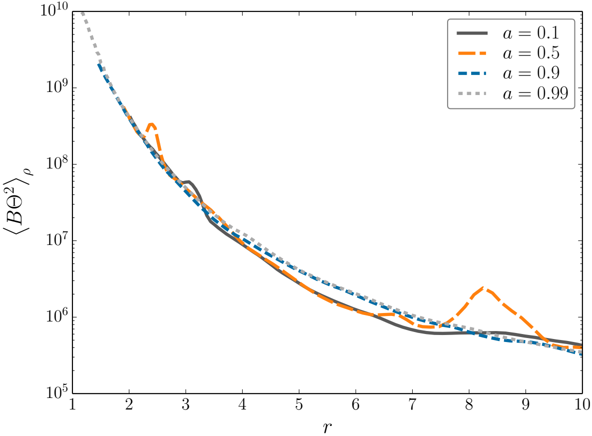
$$\boxed{\mathcal{R} = \frac{E_\infty}{E} = \frac{p_t}{u^\mu p_\mu}}$$

- Redshift profiles depend strongly on spin and viewing angle
- Observers with $\theta = \pi/2$ effectively "see" closer to the horizon



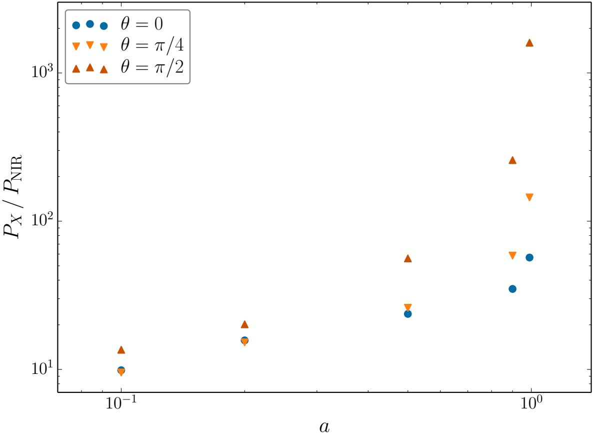
# Synchrotron Frequency

- Synchrotron peak frequency $\nu_{\text{syn}} \sim B\Theta^2$
- $\nu_{\text{syn}}$ increases towards $r_H \Rightarrow$ power dominated by high-energy emission

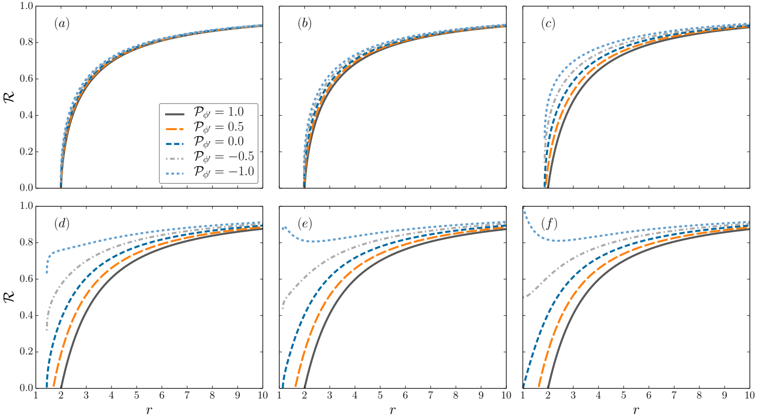


# Power vs Spin

- X-rays from near horizon
- NIR emission from further out in disk/jet
- $\boxed{P_X/P_{\rm NIR}}$ observational signature of spin



# Redshift (ZAMO)




- $\boxed{\mathcal{R} = \alpha - \Omega \sqrt{g_{\phi\phi}}\, \mathcal{P}_{\phi'}}$ $\qquad \mathcal{P}_\phi = p_\phi / p_t \qquad -1 \leq \mathcal{P}_{\phi'} \leq +1$
- Photons emitted in the $+\phi$ direction suffer little net redshift

# Summary

- Jet signatures (O' Riordan, Pe'er, & McKinney, 2016, ApJ, 819, 95)
    - High-energy $\gamma$-rays ($\sim 10^{23}$ Hz) from scattering in jet
    - Break in optical/UV $\rightarrow$ disk to jet dominated
    - Synchrotron peak near or below $\sim 10^{14}$ Hz $\Rightarrow$ jet likely dominates any observed X-ray emission
- Spin signatures (O' Riordan, Pe'er, & McKinney, 2016, in prep.)
    - X-ray power strongly depends on spin and viewing angle
    - Disk emission $\Rightarrow$ does not follow $P \sim a^2$
    - $P_X/P_{\rm NIR} \Rightarrow$ observational signature of spin in low/hard state