Title: Rethinking The Black Hole Corona as an Extended, Multizone Outflow

Speakers: Lia Hankla

Collection/Series: Magnetic Fields Around Compact Objects Workshop

Subject: Strong Gravity

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Abstract:

Observations of luminous black holes in X-ray binaries and Seyfert galaxies show power-law emission, thought to originate from photons that inverse Compton scatter off a hot electron cloud. If the coronal electrons are heated by magnetic dissipation, i.e. reconnection or turbulence, then one might expect to observe direct synchrotron emission in the radio/mm from these electrons. However, because timing studies
constrain the X-ray emission to be within ~10 rg of the central black hole, the direct synchrotron emission from this compact volume would be strongly self-absorbed until much further away from BH. In this talk, I will question the de facto definition of the corona as a compact, X-ray-emitting region and shift instead to a paradigm where the corona encompasses multiple layers with distinct spectral components. Motivated
by highly-magnetized winds found in GRMHD simulations, I will present a model for such an extended, outflowing corona. I will discuss this model in the context of radio-quiet AGN, where recent observations have demonstrated the presence of compact mm emission.

Rethinking The Black Hole Corona

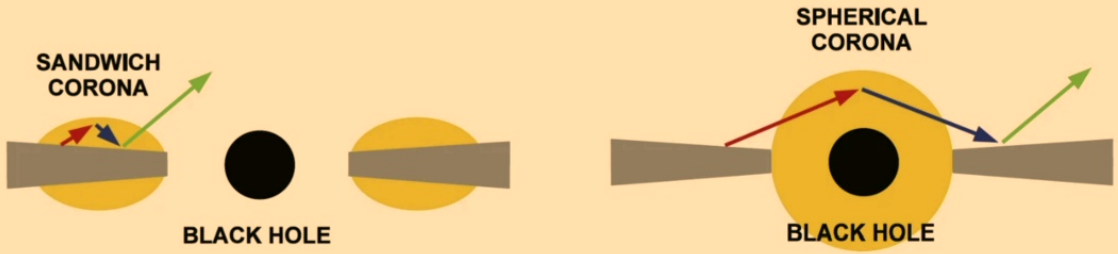
Lia Hankla
Rostom Mbarek
Sasha Philippov
University of Maryland, College Park

What is the (AGN) Corona?

- A region that emits a certain type of radiation?

  Phenomenological definition:
  source of X-rays -- defining feature
  of AGN

  - Compact (within $10r_g$), hot (10^9 K)



Bambi+ 2020

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- A region with a certain magnetic field geometry?

  Historical analogy with the solar
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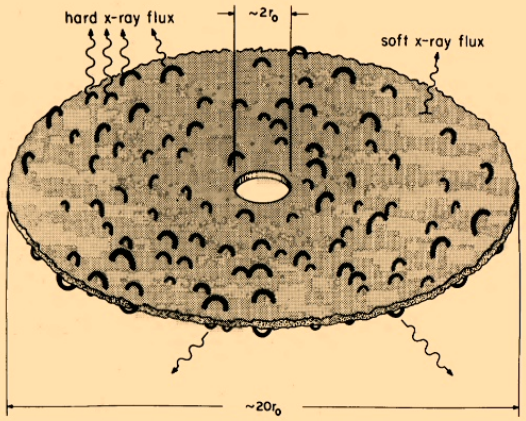
  - Magnetic field geometry?
    Reconnection-powered flares?



Galeev+ 1979

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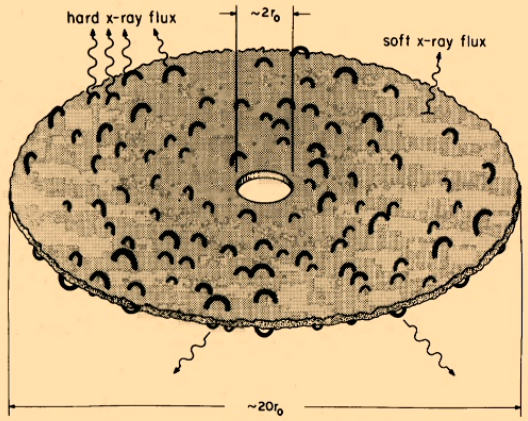


Galeev+ 1979

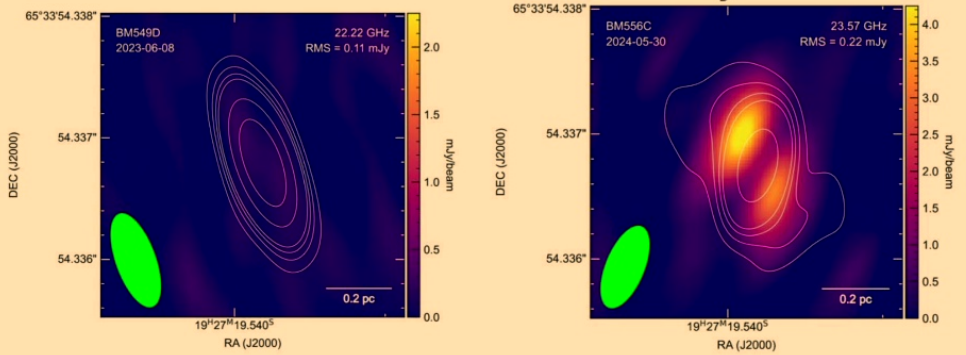
Redefine: region accelerating particles

Whatever it is, the corona could be important for...

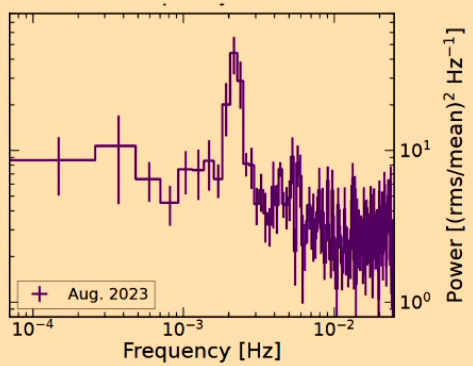
- Determining properties of the plasma close to the black hole
- Studying particle acceleration processes
  - Reconnection + turbulence
- Mediating magnetic field transport and structure
  - Jet launching: 1ES 1927
  - Impact on angular momentum transport?

June 2023 | May 2024

Meyer+ 2025



"Coronal" Quasi-Periodic Oscillation (QPO)



Masterson+ 2025

Lia Hankla

A Magnetically-powered X-ray corona

- Compact: $R_c \simeq 10$ rg from timing, reverberation studies
- Hot: $T_e \simeq 10^9$ K
- Dissipated magnetic energy = X-ray luminosity: $L_X \leq \frac{B_0^2}{8\pi} 4\pi R_c^2 c$

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Reconnection or turbulence accelerates nonthermal particles

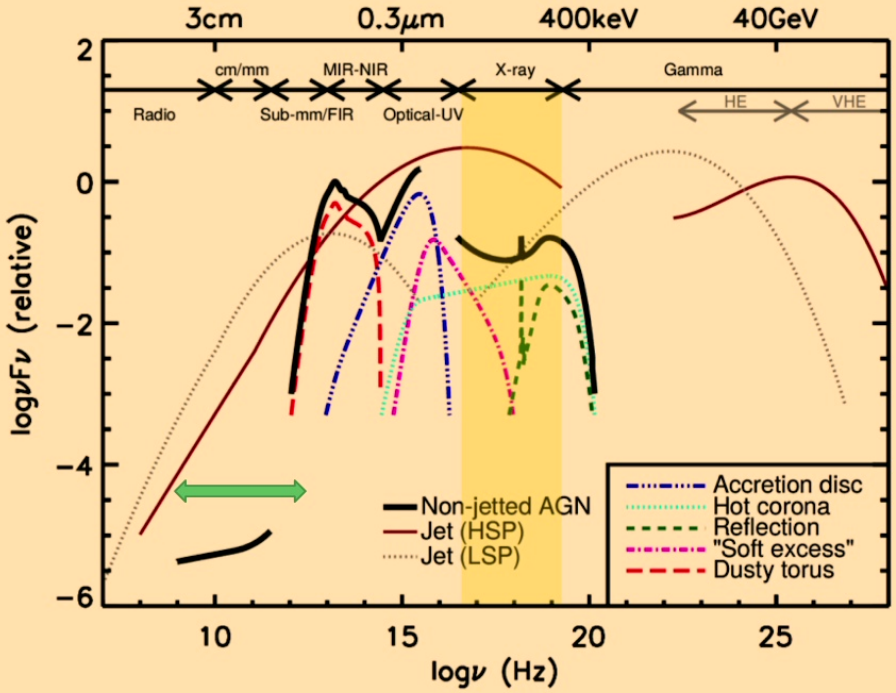
Where is the synchrotron emission?

Power-law of electrons

Coronal Synchrotron Emission in the mm range

Optically thin synchrotron expected in radio, mm wavelengths

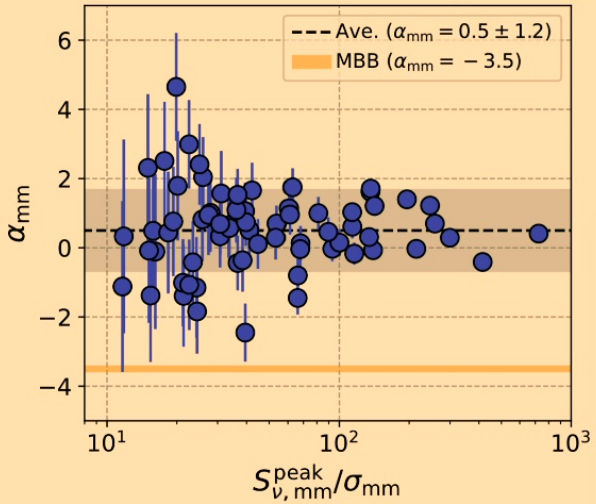
- Radio-quiet AGN: no jet contamination



Padovani+ 2017

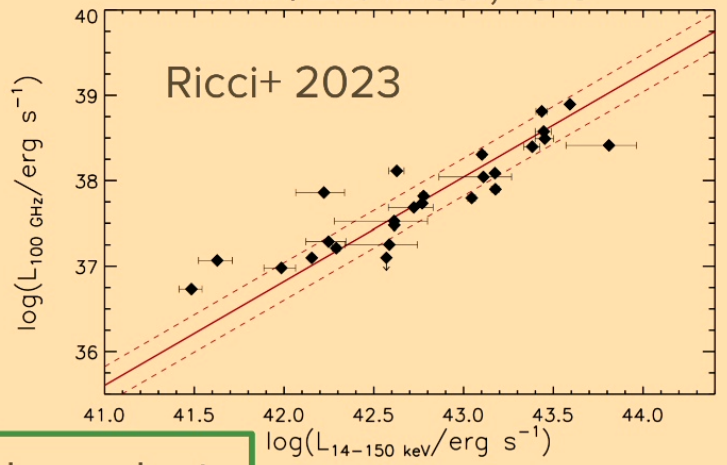
Observational Characteristics of Excess mm emission in RQ AGN

Flat Spectral Slope $F_\nu \sim \nu^{-\alpha}$

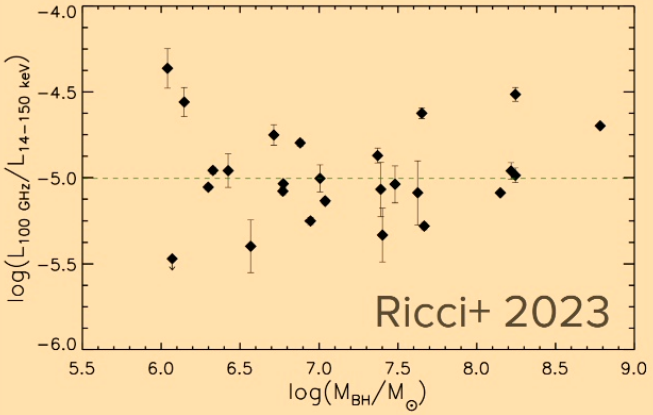


Kawamuro+ 2022

Lmm/LX: linear, 1e-5



Lmm/LX: mass-independent



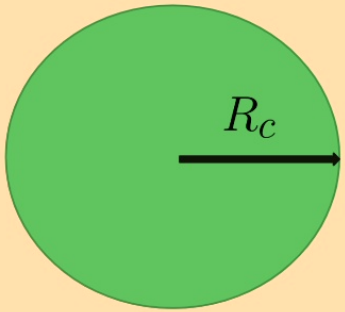
Also:
variability

Lia Hankla

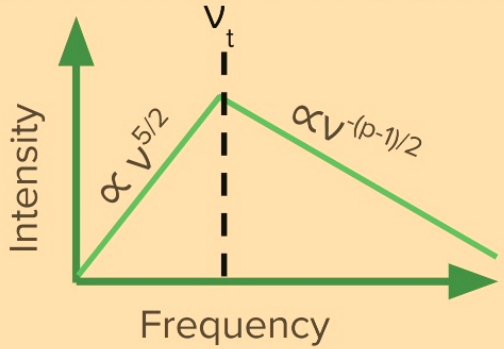
“Coronal” Synchrotron Emission is Not Optically Thin

IF X-ray-emitting and synchrotron-emitting electrons are colocated, must be:

- Compact -- close to 10 rg



Synchrotron self-absorption



$$\nu_t = 10^{13}\,\mathrm{Hz}\left(\frac{R}{10 r_g}\right)^{1/3}\left(\frac{B}{10^3\,\mathrm{G}}\right)^{2/3}$$

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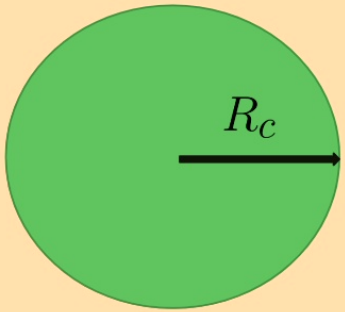

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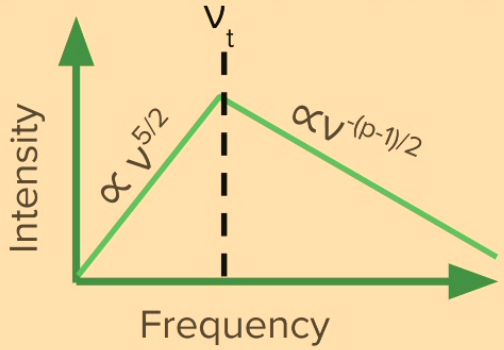
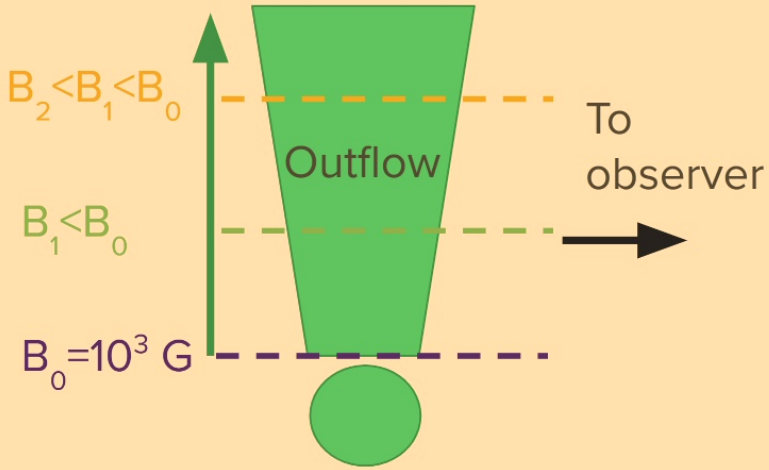


$$\nu_t = 10^{13}\,\mathrm{Hz}\left(\frac{R}{10 r_g}\right)^{1/3}\left(\frac{B}{10^3\,\mathrm{G}}\right)^{2/3}$$

Wipes out synchrotron emission from coronal electrons! Unless...

Proposal: an extended (coronal) outflow

- Magnetic field gradient: higher frequencies from smaller radii (higher B)
- Mildly relativistic (no beaming), as in winds in GRMHD simulations, solar wind



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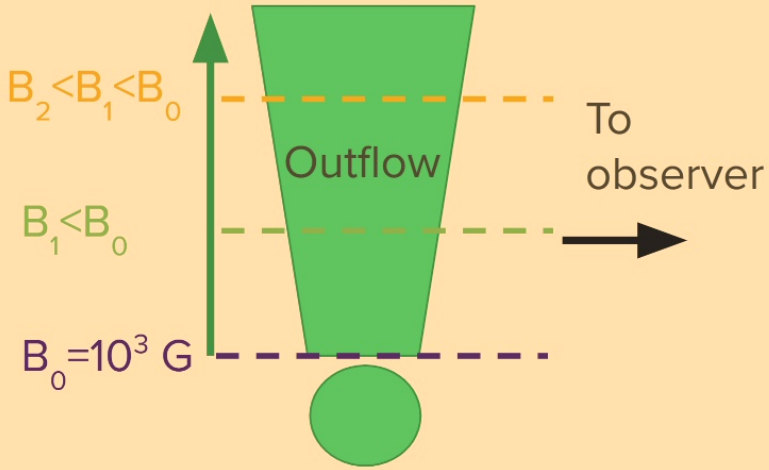
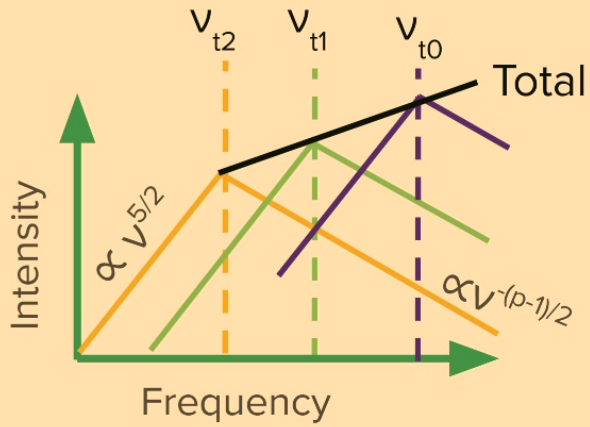


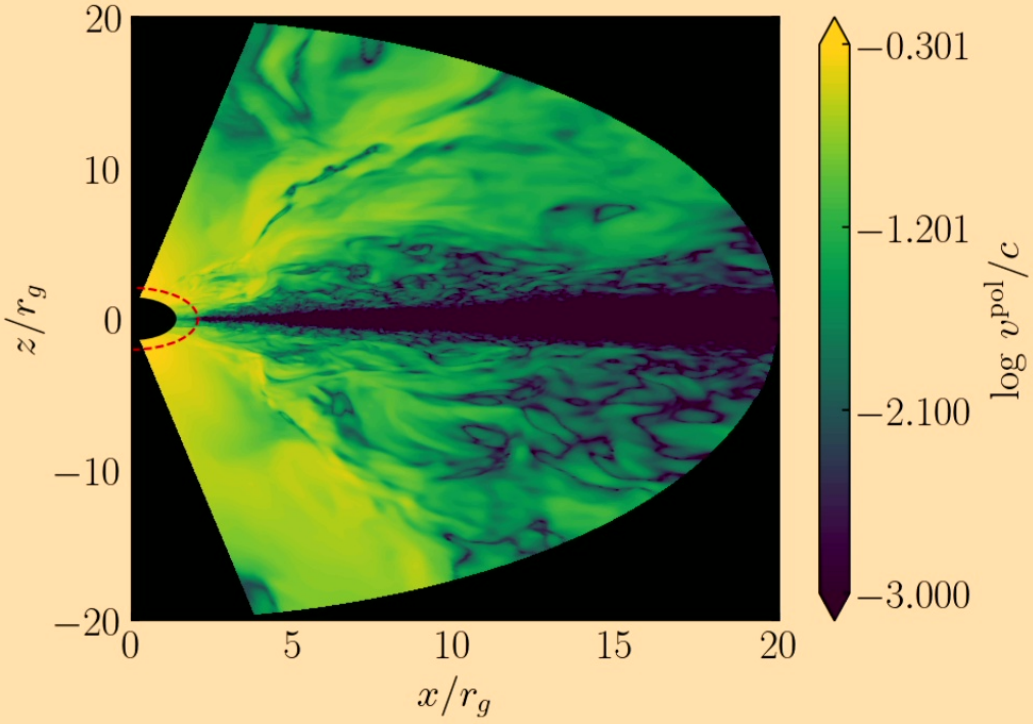


A la Blandford & Koenigl 1979

Motivation: GRMHD Simulations

Liska+ 2022: RADTOR thin disk

- H/r=0.03
- Two-temperature
- Radiation: M1 closure



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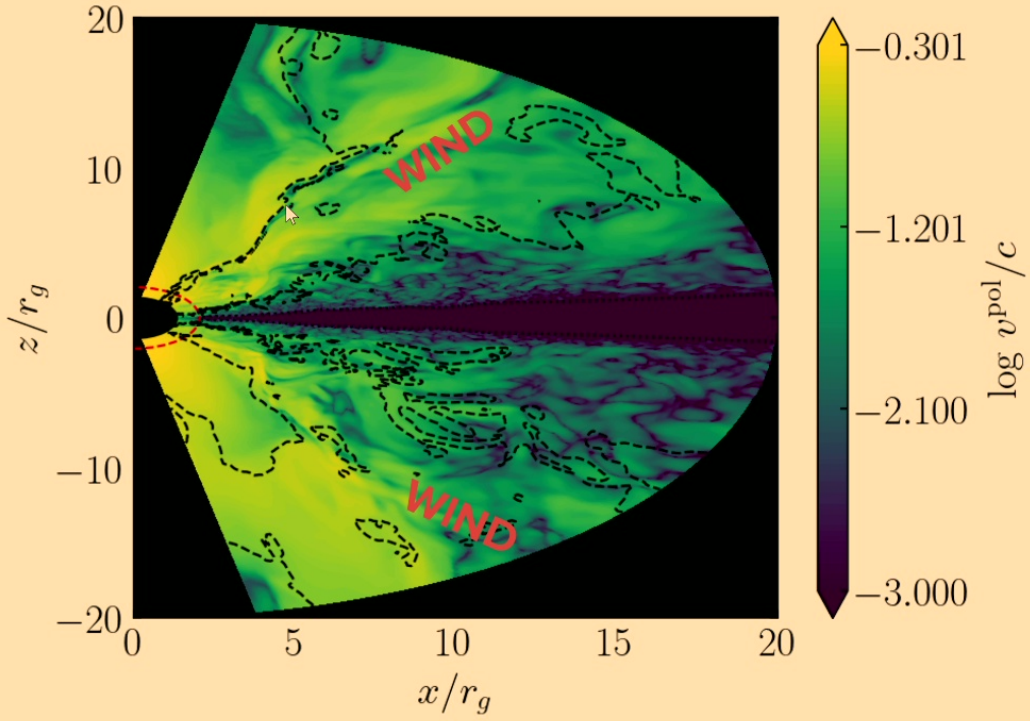
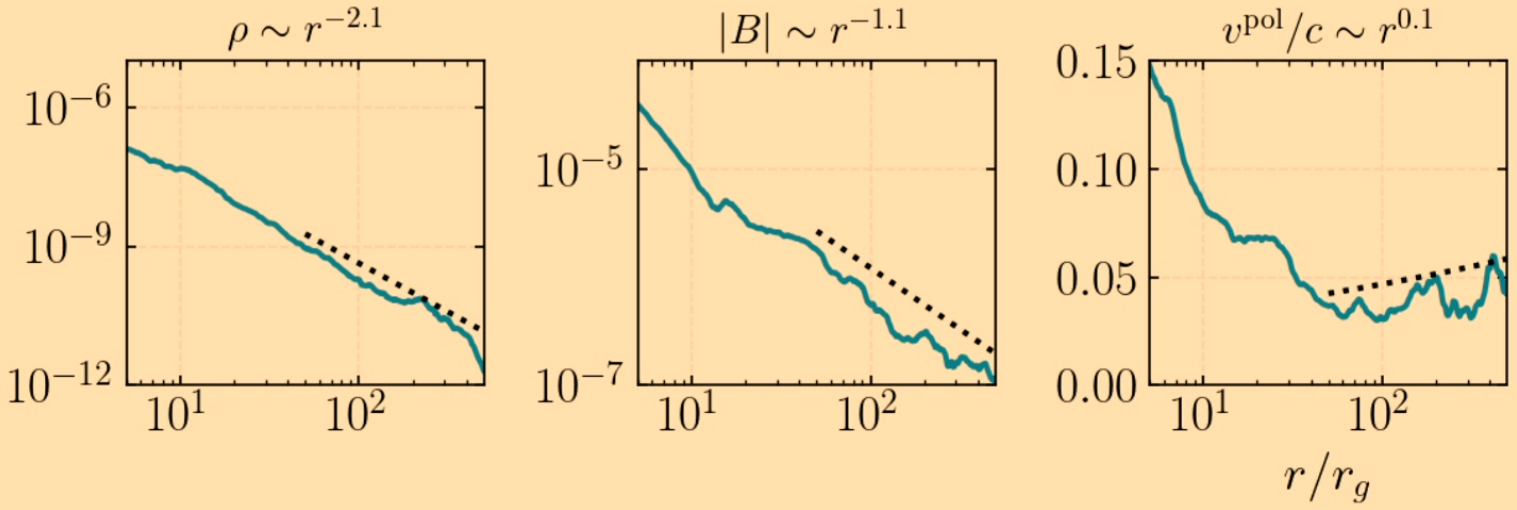


Radial Profiles of the GRMHD Wind

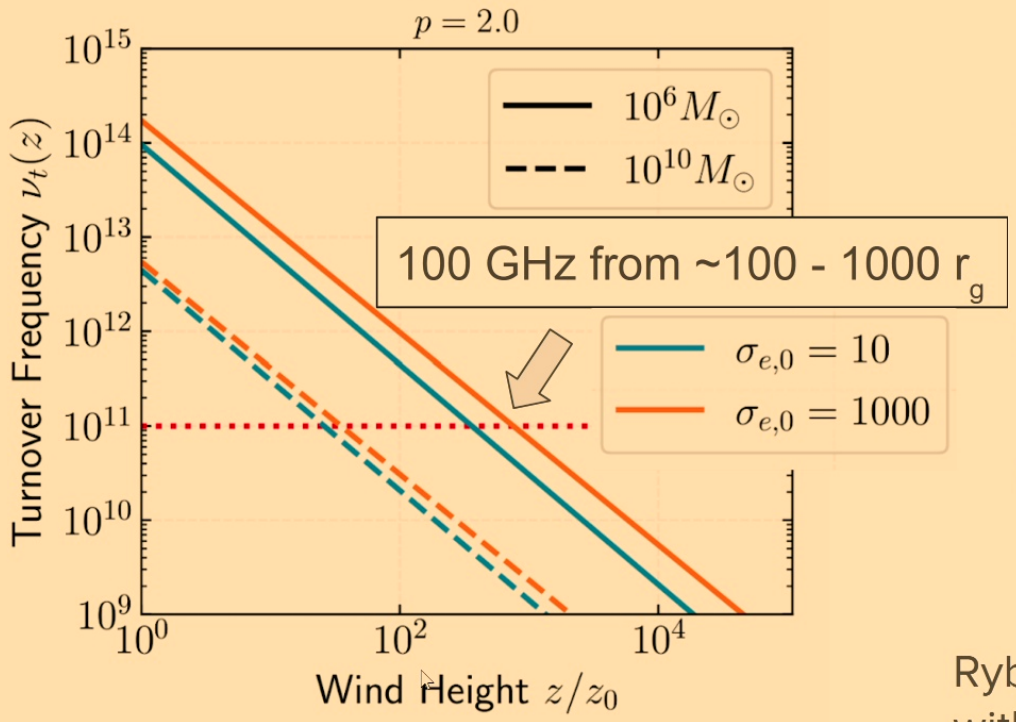
Liska+ 2022: RADTOR thin disk



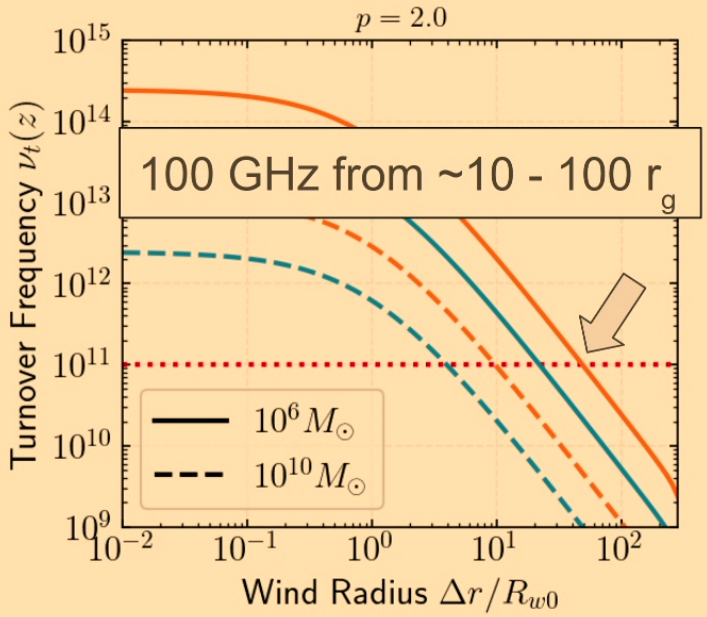
Use $\rho \sim r^{-2}$, $|B| \sim r^{-1}$, $v^{pol} \sim$ const.

Where does the mm emission come from?

Side-on



Face-down



Rybak+ 2025: 100 GHz within ~100 r_g

Analytic Prediction for Flux Spectral Index

Sum up contributions from different wind heights.

- Flatter spectrum than $\nu^{5/2}$

$$F_\nu \sim \nu^{-\alpha}$$

Depends on density, B

Observationally:
$\alpha_F = 0.5 \pm 1.2$

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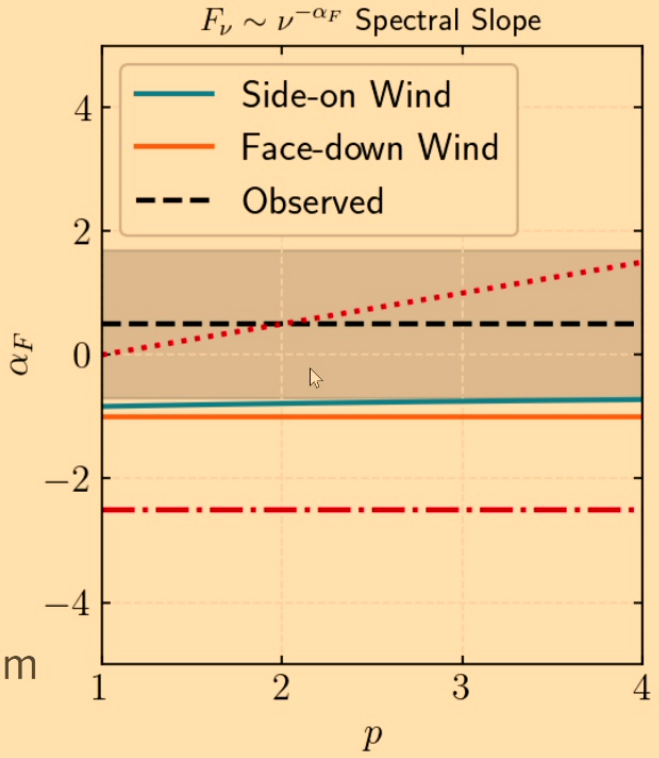
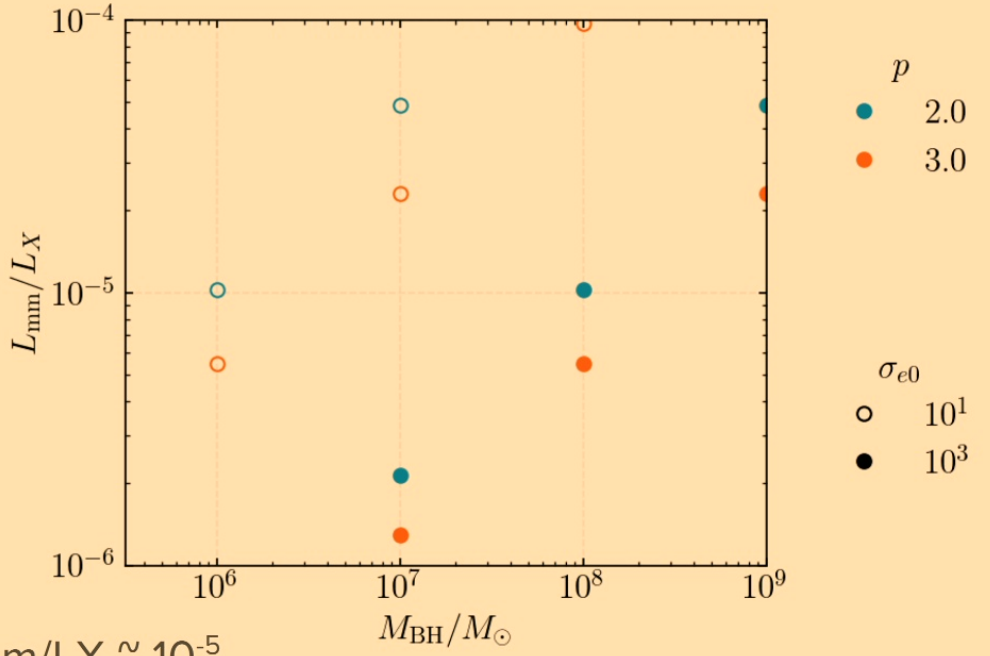
- Contamination from other sources?



Analytic Prediction for Lmm/LX

- X-ray luminosity from magnetic reconnection or turbulence: $L_X \sim B_0^2 R_c^2$
- Particle acceleration: depends on plasma magnetization σ_0

$$\frac{L_{\rm mm}}{L_{\rm X}} \sim \nu^{-\alpha+1} \left(\frac{\sigma_{e0}}{M}\right)^{\beta-1}$$



- Lmm/LX ~ 10^{-5}
- Can look mass-independent

Implications for variability, simultaneous X-ray/mm

- Observations of mm variability on 1e4 s time-scales constrain source size to be $<\sim$ 1000 rg (Petrucci+ 2023, Michiyama+ 2024, Shablovinskaya+ 2024)
  - Constrains size of emitting structures

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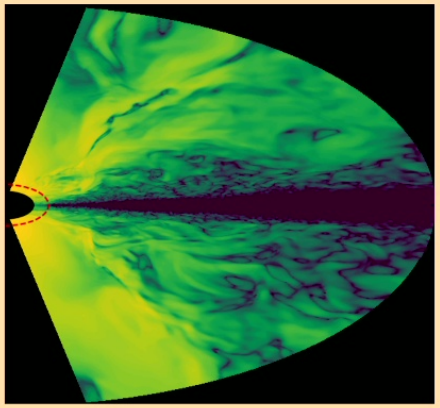
- Correlation between X-ray/mm could be tricky
  - Not the same electrons radiating X-ray and mm. Need to be re-accelerated!
  - Contributions from multiple heights

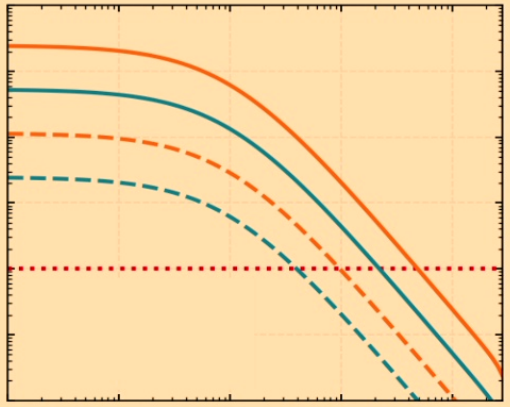
$$t_{\rm sync} = 5 \times 10^3 \ {\rm s} \left(\frac{\gamma}{10}\right)^{-1} \left(\frac{B}{100 \ {\rm G}}\right)^{-2}$$

Conclusions



“Corona” as particle acceleration region: doesn’t just emit X-rays!

- mm emission could probe dissipation close to the black hole



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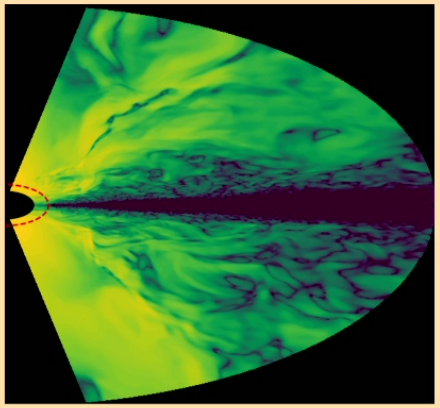

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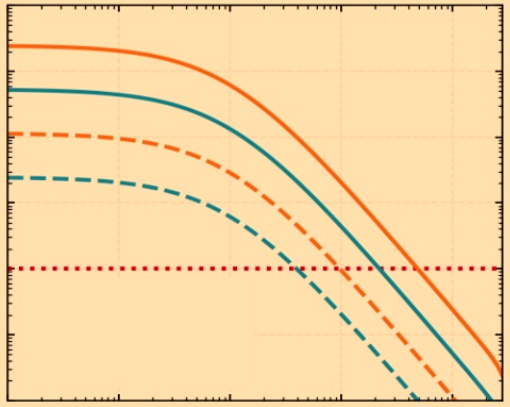

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Questions?