DISK-JET CONNECTION IN BLACK HOLE SOURCES

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ABSTRACT

Several AGN and microquasars exhibit interesting observational behavior in which significant dips in the X-ray light curve are followed by ejections of plasmoids at radio frequency that move at relativistic speeds. We envisage the plasmoids as pre-existing current carrying magnetic flux ropes that were initially anchored in the accretion disk-corona. The plasmoids are ejected outwards via a mechanism called the toroidal instability (TI). Our detailed model predictions compare favorably with a representative set of multi-epoch observations of radio emitting knots from the radio galaxy 3C 120.

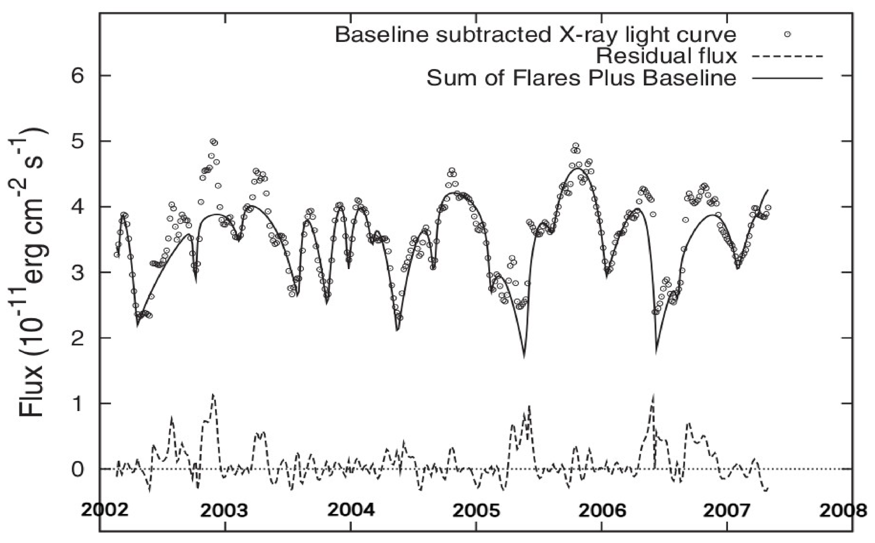
On the other hand, a rapid collapse of the inner, hot accretion disk (which is thought to emit X-rays), can occur over the radial infall time-scale of the inner accretion disk. However, estimates of this time-scale are hindered by a lack of knowledge of the operative viscosity in the collisionless plasma. We use published simulation results for cosmic ray diffusion through turbulent magnetic fields to arrive at a viscosity prescription appropriate to hot accretion disks. We construct simplified disk models using this viscosity prescription and estimate disk collapse time scales for 3C 120, 3C 111, and GRS 1915+105.

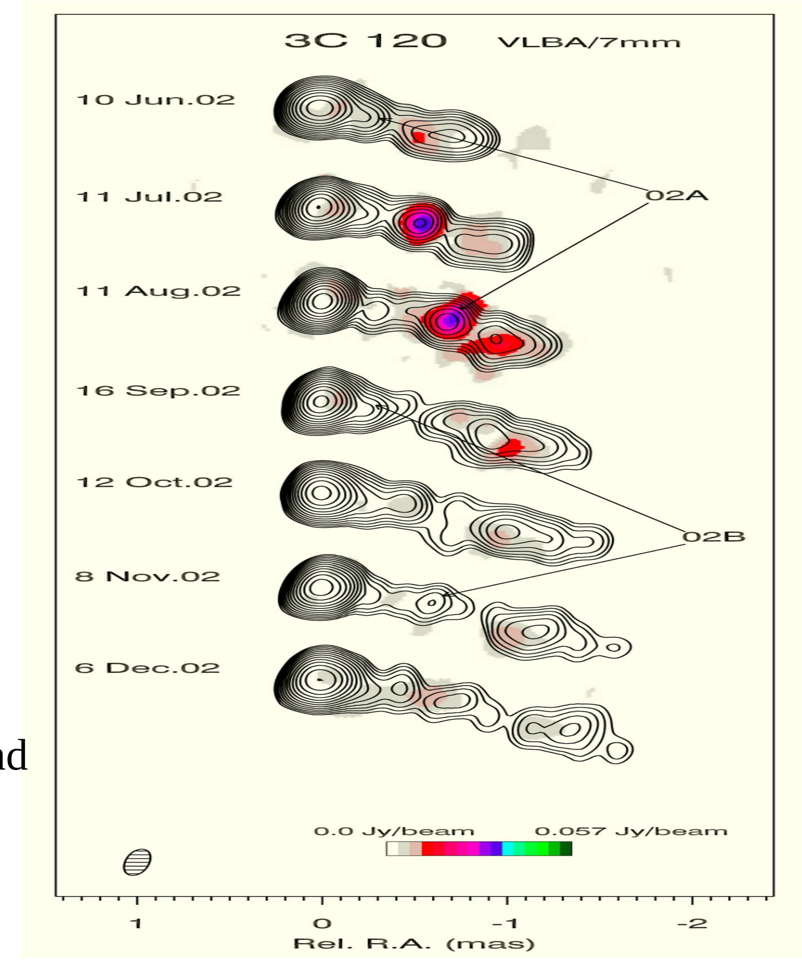
Combining, our work outlines a plausible scenario for episodes of (inner) disk collapse accompanied by blob ejection.

OBSERVATIONAL MOTIVATION

- Interesting observational features about 3C 120 (Chatterjee et al. 2009), and 3C 111 (Chatterjee et al. 2011)

Dips in the X-ray luminosity (Decrease in the coronal plasma density) → Ejection of superluminal radio component from the core of the jet





- Suggests that inner part of the disk is being periodically "emptied" and "refilled"
- Some fraction gets ejected in the form of the jet and remaining swallowed by the black hole

Comparison with multi-epoch observations of blobs in 3C 120

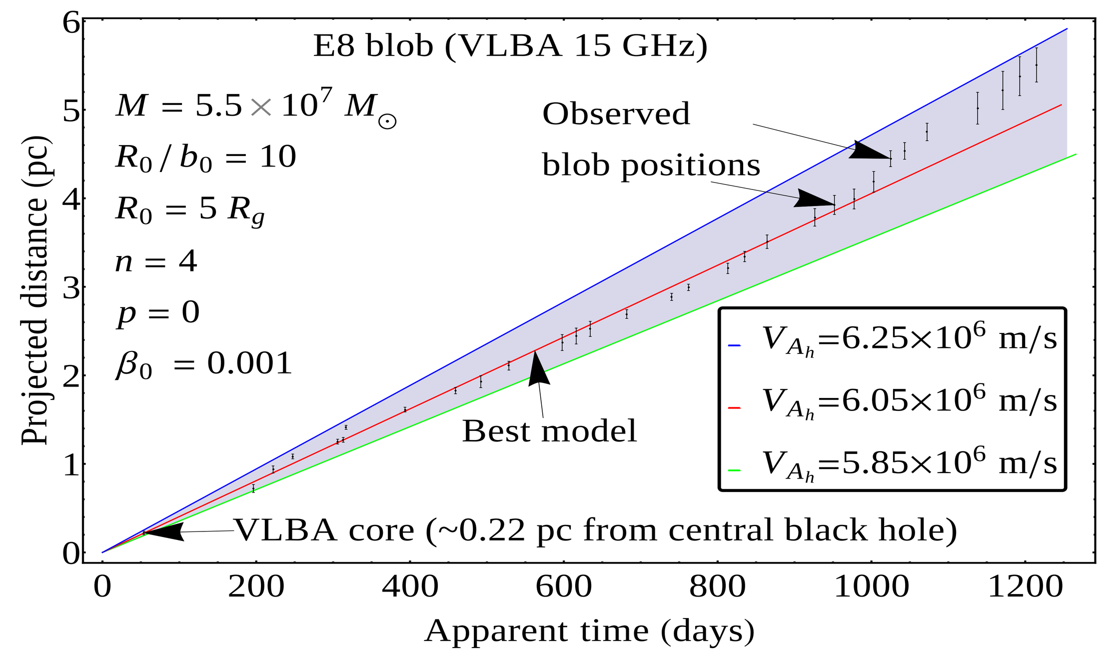


Figure : Height–time profile of a representative plasmoid for different values of V_{A_h} compared with observations of blob E8 of 3C 120

Parameter			% change in β_{app}
V_{A_h}	Best fit	6050 km/s	
	% change	-3.31	-12.63
	% change	+2.14	+16.15
β_0	Best fit	0.001	
	% change	-99	-0.02
	% change	+900	+0.1
n	Best fit	4	
	% change	-10	+1.41
	% change	+10	-0.93
R_0	Best fit	5 R_g	
	% change	-0.8	+16.94
	% change	+1	-15.16
R_0/b_0	Best fit	10	
	% change	-4	-12.25
	% change	+4	+16.15

Table : Analysis of how the asymptotic β_{app} for Blob E8 Changes with Model Parameters

Publication: Shende et al. (2019), ApJ, 877,130

LAUNCHING OF EPISODIC JETS

- We draw analogies with the triggering of Coronal Mass Ejections (CME) from the solar corona
- We treat episodic plasmoids as current carrying flux ropes similar to the CMEs from the Sun

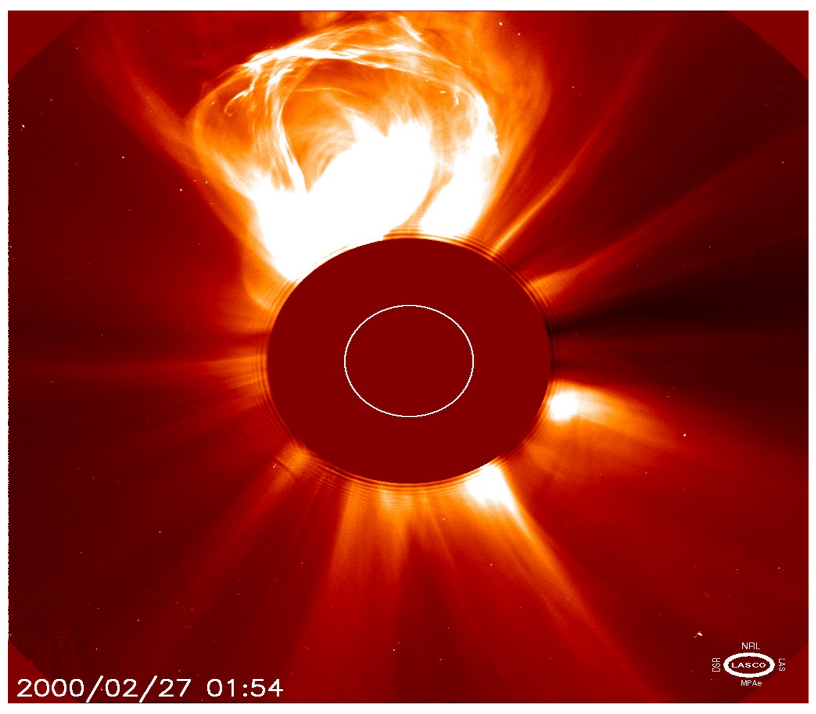


Figure: CME (from SOHO/LASCO database)

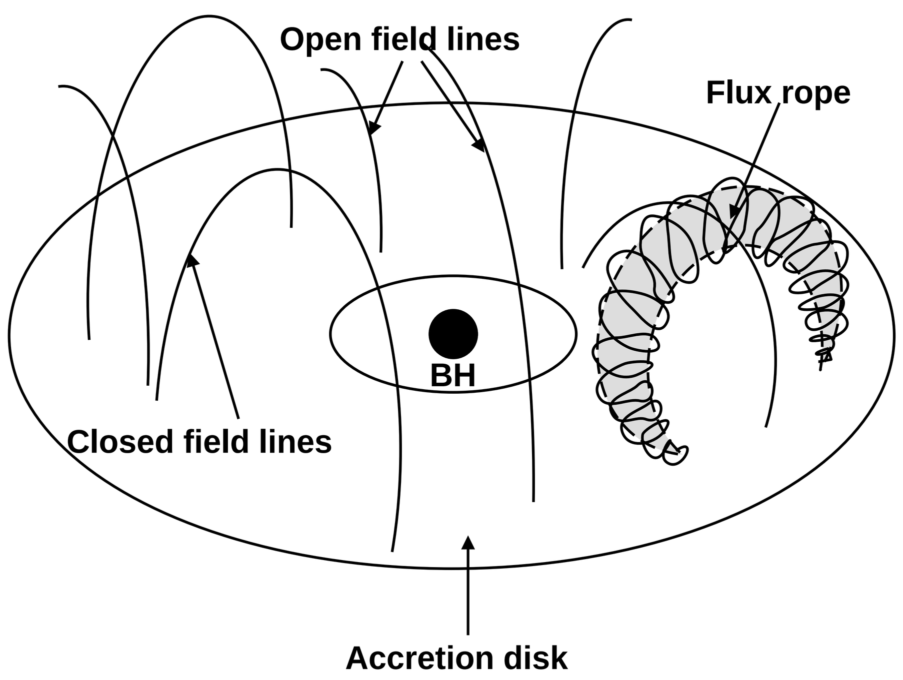


Figure: Blob/plasmoid as a flux rope

Toroidal instability of flux rope plasmoid

- We adopt the toroidal instability (TI) model of Kliem and Török (2006) to our situation and prescribe the following equation of motion for a flux rope plasmoid:

$$\Gamma\rho_m\frac{d^2R}{dt^2} = \underbrace{\frac{I^2}{4\pi^2b^2R^2}\left(L+\frac{\mu_0 R}{2}\right)}_{\text{Lorentz self force (radially outward)}} - \underbrace{\frac{IB_{\rm ext}(R)}{\pi b^2}}_{\text{Restoring force due to } B_{\rm ext}} - \underbrace{\frac{\rho_m GM}{(R-R_{\rm sch})^2}}_{\text{Gravitational force (pseudo-Newtonian)}}$$

where ρ_m is the mass density, I is the flux rope current, L is the inductance of the flux rope and $R_{\rm sch}$ is the schwarzschild radius

- We assume that $B_{\rm ext} = \widehat{B}R^{-n}$, and the flux rope becomes unstable against expansion if the self force overcomes the restoring forces

Results – velocity and acceleration profiles

- We solved the EOM assuming self-similar expansion and using initial conditions starting with equilibrium distance R_0 from the black hole and some value of launching velocity (β_0)

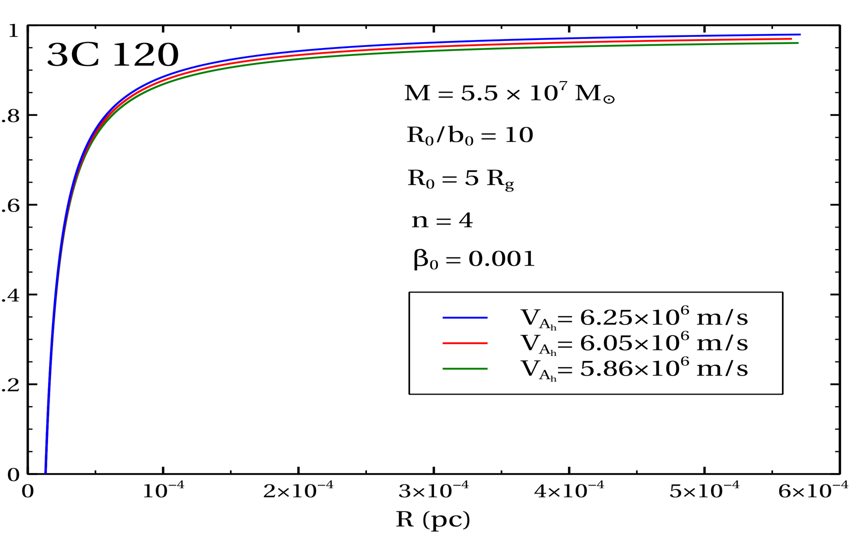


Figure : velocity – distance profile of a blob

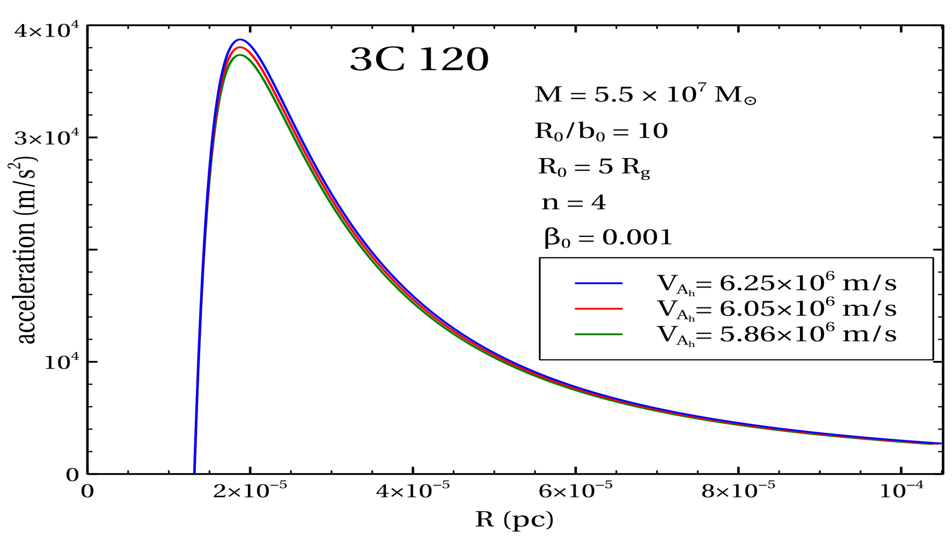


Figure : acceleration – distance profile of a blob

VISCOUS INFALLING TIMESCALES OF INNER ACCRETION DISKS

- X-ray dip durations : 3C 120 : 5-120 days, 3C 111 : 73-402 days, GRS 1915+105 : 5-6 s
- Suggests that accretion disk corona is periodically "emptied" and "refilled"

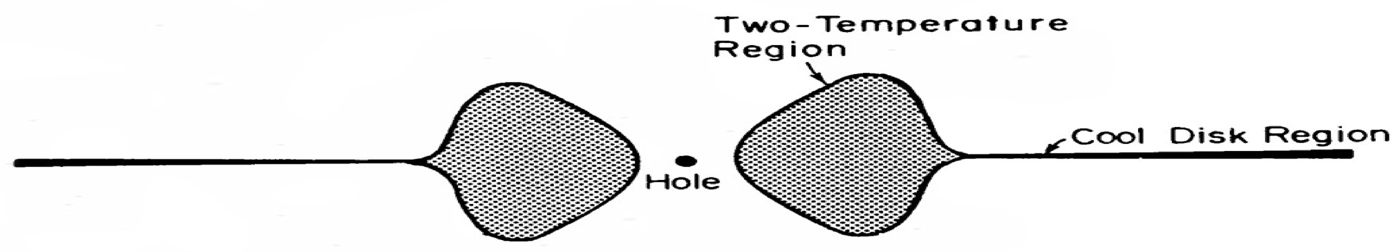


Figure : Two-temperature disk (Shapiro, Lightman & Eardley 1976)

- We address these timescales as viscous infalling timescale in our model

$$t_{\rm infall} = \frac{R}{v_R} = \frac{R^2}{\nu} = \frac{R^2}{\alpha c_s H}$$

- We give physical prescription for viscosity instead of specifying the values of α
- Using published simulation results for cosmic ray diffusion through turbulent magnetic fields (Candia and Roulet 2004)
- Assumption – large scale toroidal field embedded in the accretion disk, in addition to tangled field
- $D_\perp$ (diffusion coefficient perpendicular to large scale field) gives viscous angular momentum transport
- We calculate the coefficient of hybrid viscosity and the viscosity parameter as

$$\eta_{\rm hyb} = N_i m_p D_\perp \qquad\qquad \alpha_{\rm hyb} = 2.63 f_1^{-1/2} D_c$$

where N_i is the proton number density, f_1 is the relativistic correction factor, and D_c depends on the parameters of turbulence (Candia and Roulet 2004)

Results and comparison with observations

- Parameters used : $\rho = r_L/H$: ratio of Larmor radius of protons to disk height, σ^2 : ratio of magnetic energy density in turbulent field to that of large scale field, and $R_{\rm out}$: size of the corona

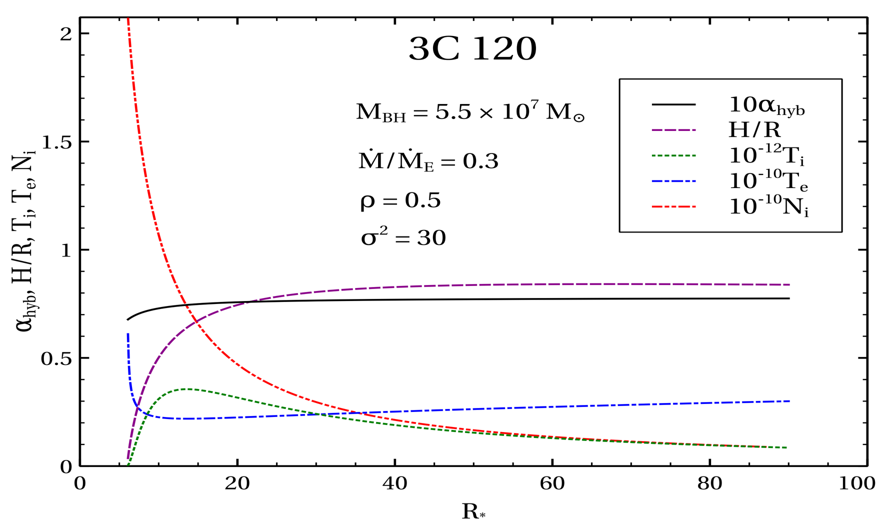


Figure : Representative accretion disk model for 3C 120

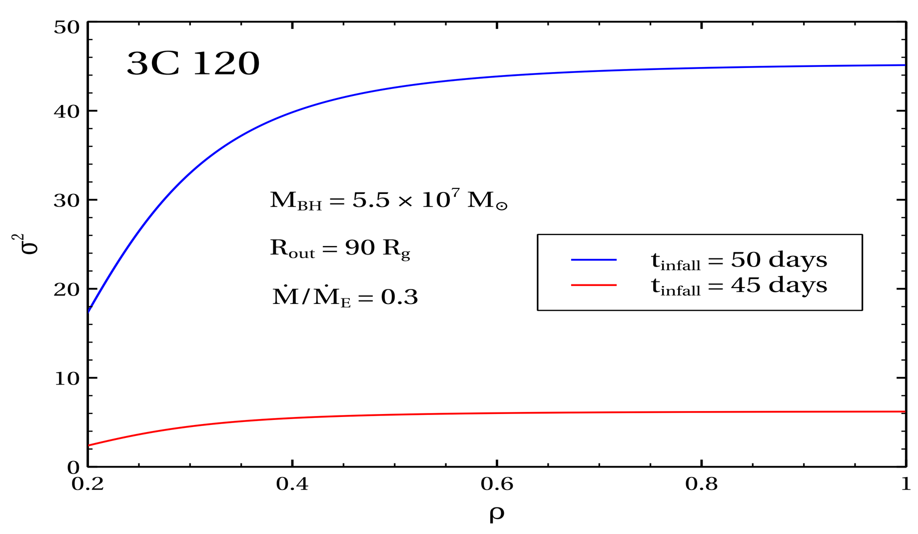


Figure : Parameter space corresponding to X-ray dip in the range 45–50 days in 3C 120

Viable parameter space corresponding to the sources considered is

3C 120: $0.2 \lesssim \rho < 1$, $1 \lesssim \sigma^2 \lesssim 30$ ($0.04 < \alpha_{\rm hyb} < 0.07$) and $14R_g \lesssim R_{\rm out} \lesssim 175R_g$

3C 111: $0.2 \lesssim \rho < 1$, $1 \lesssim \sigma^2 \lesssim 40$ ($0.02 < \alpha_{\rm hyb} < 0.08$) and $13R_g \lesssim R_{\rm out} \lesssim 38R_g$

GRS 1915+105: $0.2 \lesssim \rho < 1$, $1 \lesssim \sigma^2 \lesssim 25$ ($0.03 < \alpha_{\rm hyb} < 0.07$) and $75R_g \lesssim R_{\rm out} \lesssim 250R_g$

Publication: Shende et al. (2021), MNRAS, 501, 3741

CONCLUSIONS

- Model predictions for the time evolution of plasmoids agree well with the observed trajectories
- Instead of specifying the values of α, we give the physical prescription for viscosity in the hot, inner disk
- We found the parameter space that yields models with infall timescales that match the observed X-ray dip timescales
- Broad conclusion : Our work outlines a plausible scenario for episodes of (inner) disk collapse accompanied by blob ejection