Dissipative Accretion Flow Around Black Holes

Santabrata Das, IIT Guwahati

Collaborators:

Biplob Sarkar, IITG
Ramiz Aktar, IITG
Indu K. Dihingia, IITG
Anuj Nandi, ISAC
Samir Mandal, IIST
Toru Okuda, Hokkaido University of Education

Fundamental Concepts of Black Hole Accretion

- Flow angular momentum < Keplerian value at MS and therefore, sub-Keplerian at the inner part of the disc.

- At the event horizon, radial velocity reaches at speed of light while sound speed remains lesser.

- At large distance, the flow may be at rest while still having some temperature (non zero sound speed).

- Therefore, flow is supersonic at the horizon and subsonic at a large distance (Transonic).

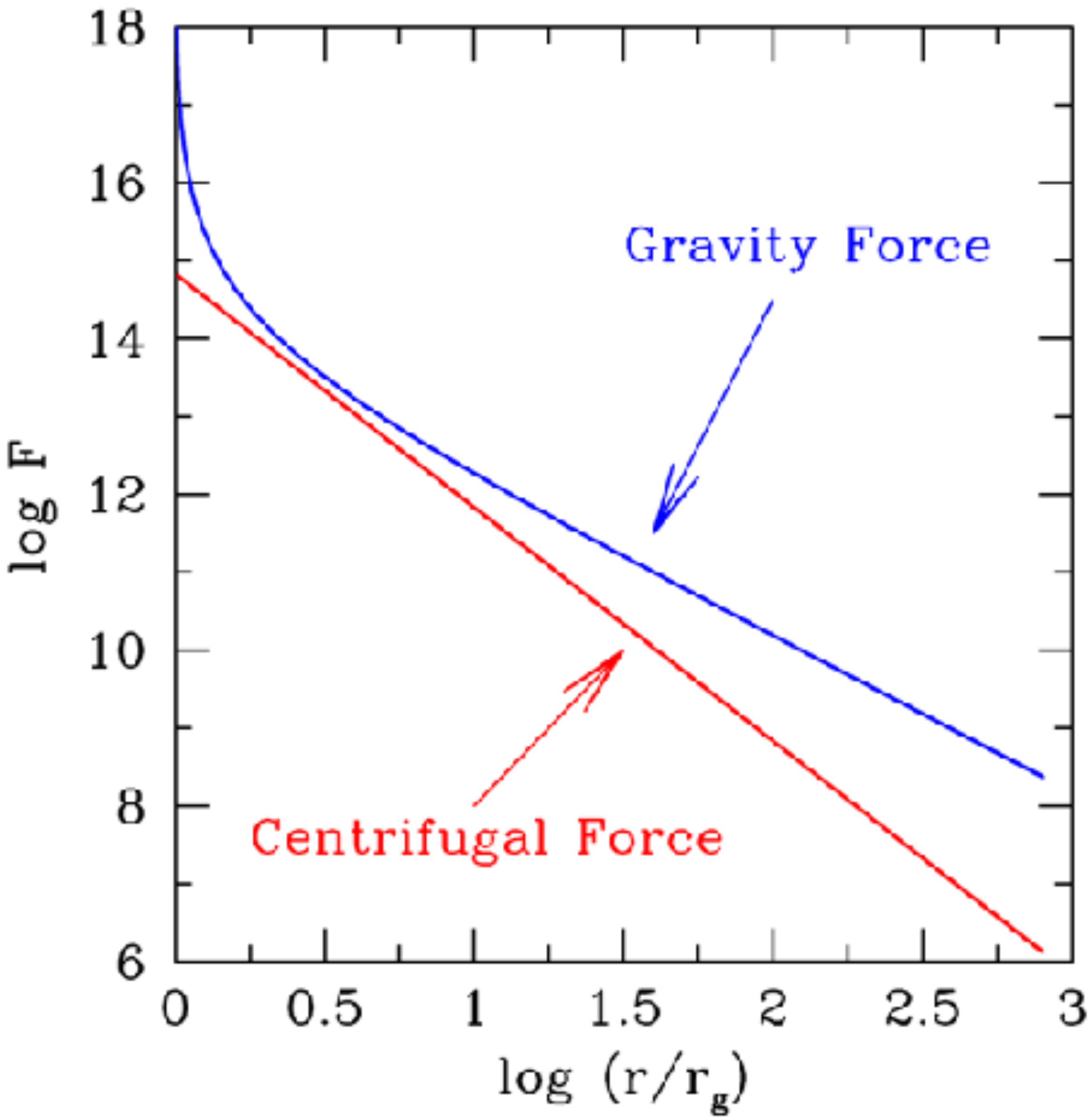
Fundamental Concepts of Black Hole Accretion

- Flow must pass through at least one sonic point and presumably more, in presence of even a small angular momentum.

- In presence of multiple sonic points, flow is richer in topological properties and may contain dynamically important shock waves.

Background Theory of Accretion Disc

- Advective accretion process is the competition between gravitational force (F_{GR}) and centrifugal force (F_{CEN}).

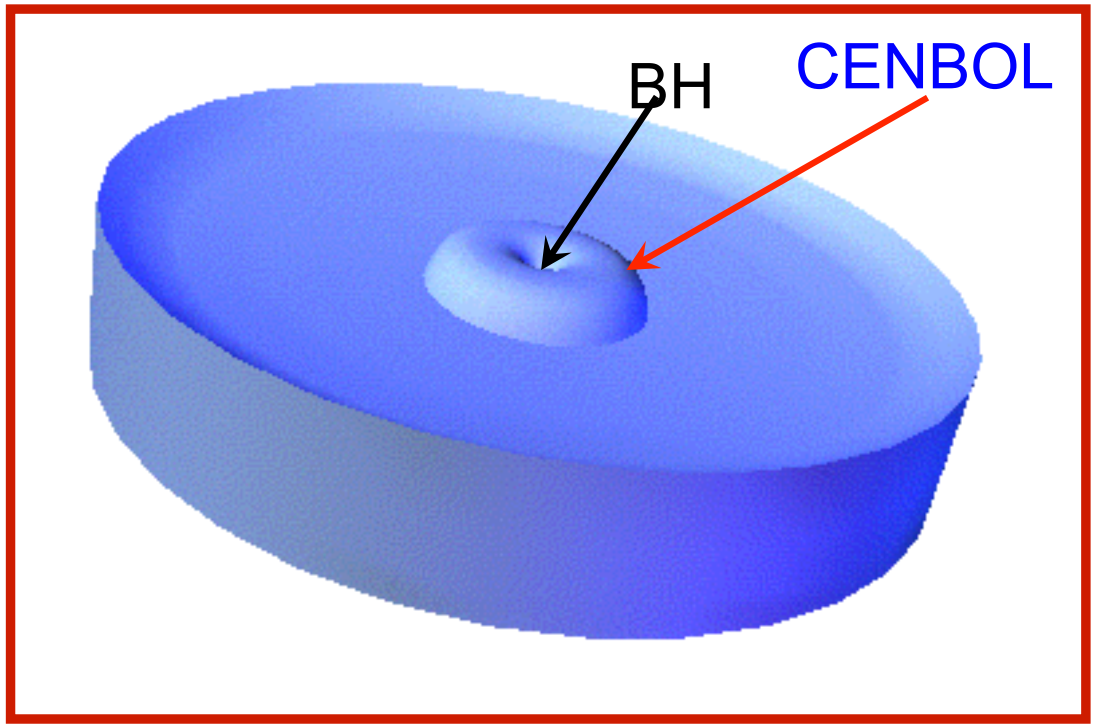


- $F_{GR} \sim -\dfrac{1}{(r - r_g)^2}$.
- $F_{CEN} \sim \dfrac{1}{r^3}$
- $F_{GR} >> F_{CEN}$ at $r \sim r_g$ & $r \sim \infty$.
- At intermediate distance

  $F_{GR} \sim F_{CEN}$
- $u \downarrow$ and $\rho \uparrow$.

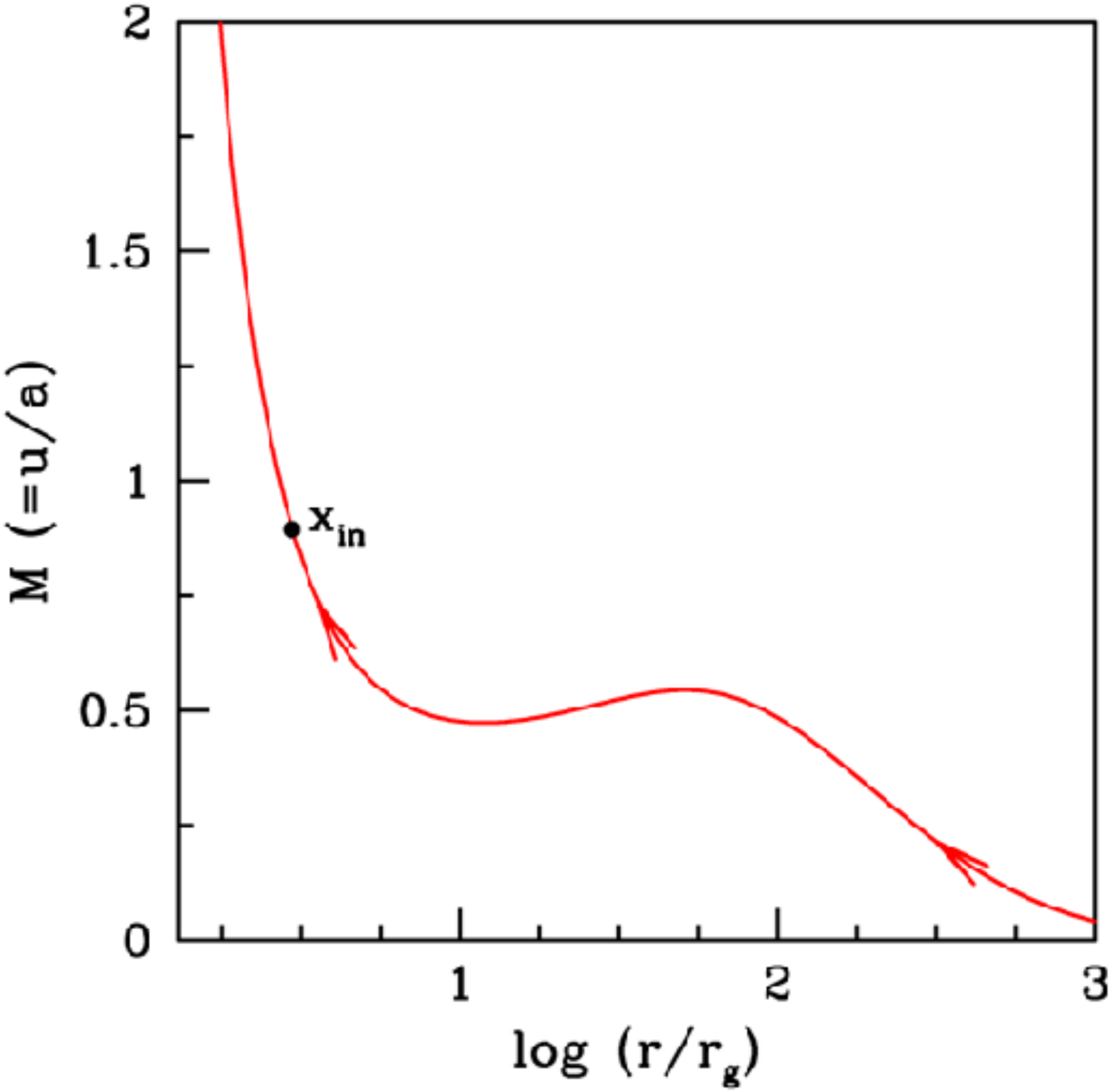
- Slowed down inner part of the disc act as an effective boundary layer of BH.

- Centrifugal barrier triggers the formation of shock.



- When dynamically possible, shock induced global accretion solutions are preferred according to the Second Law of Thermodynamics.

We consider a steady, thin, viscous axisymmetric accretion flow around a black hole



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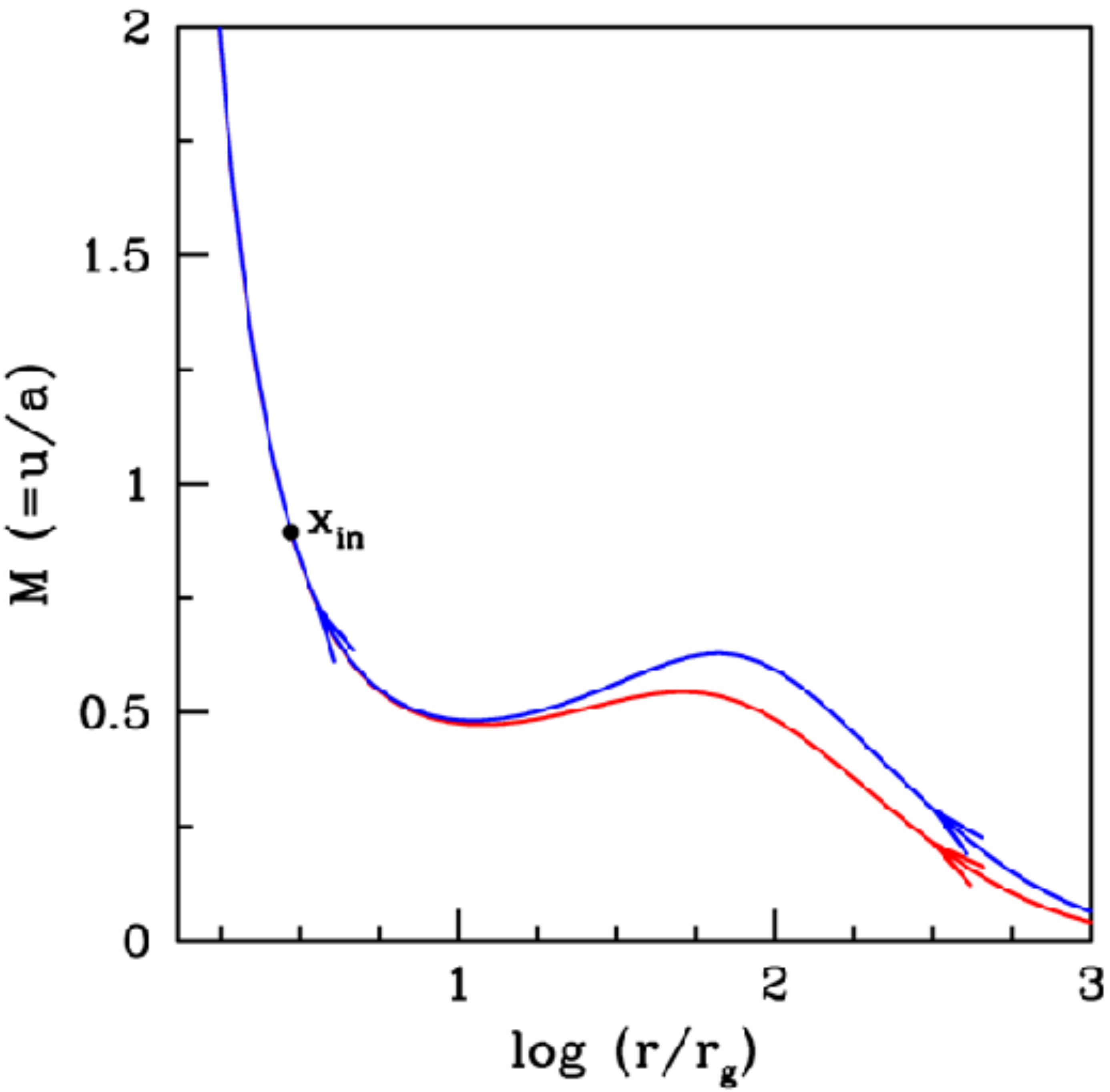

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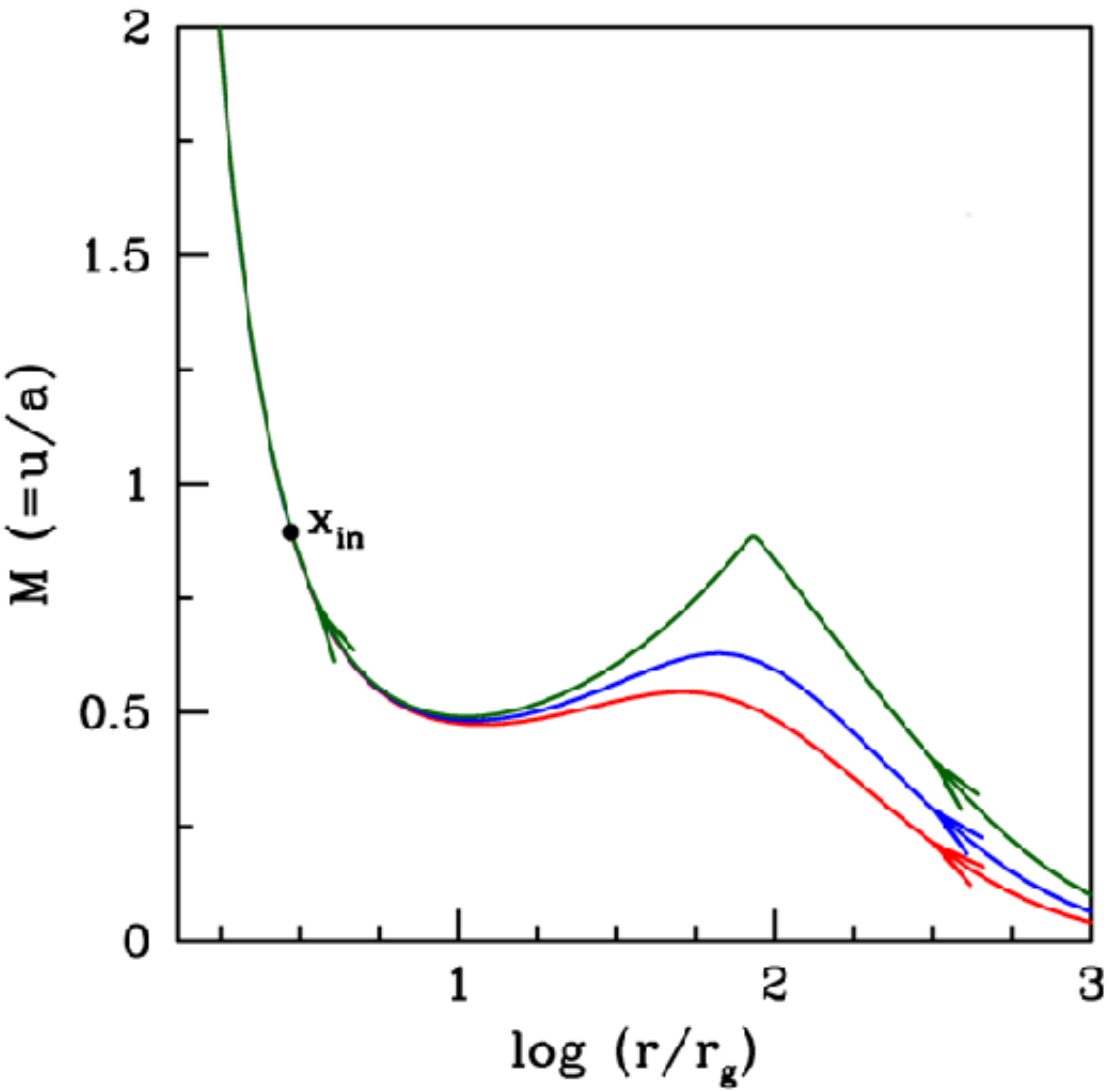

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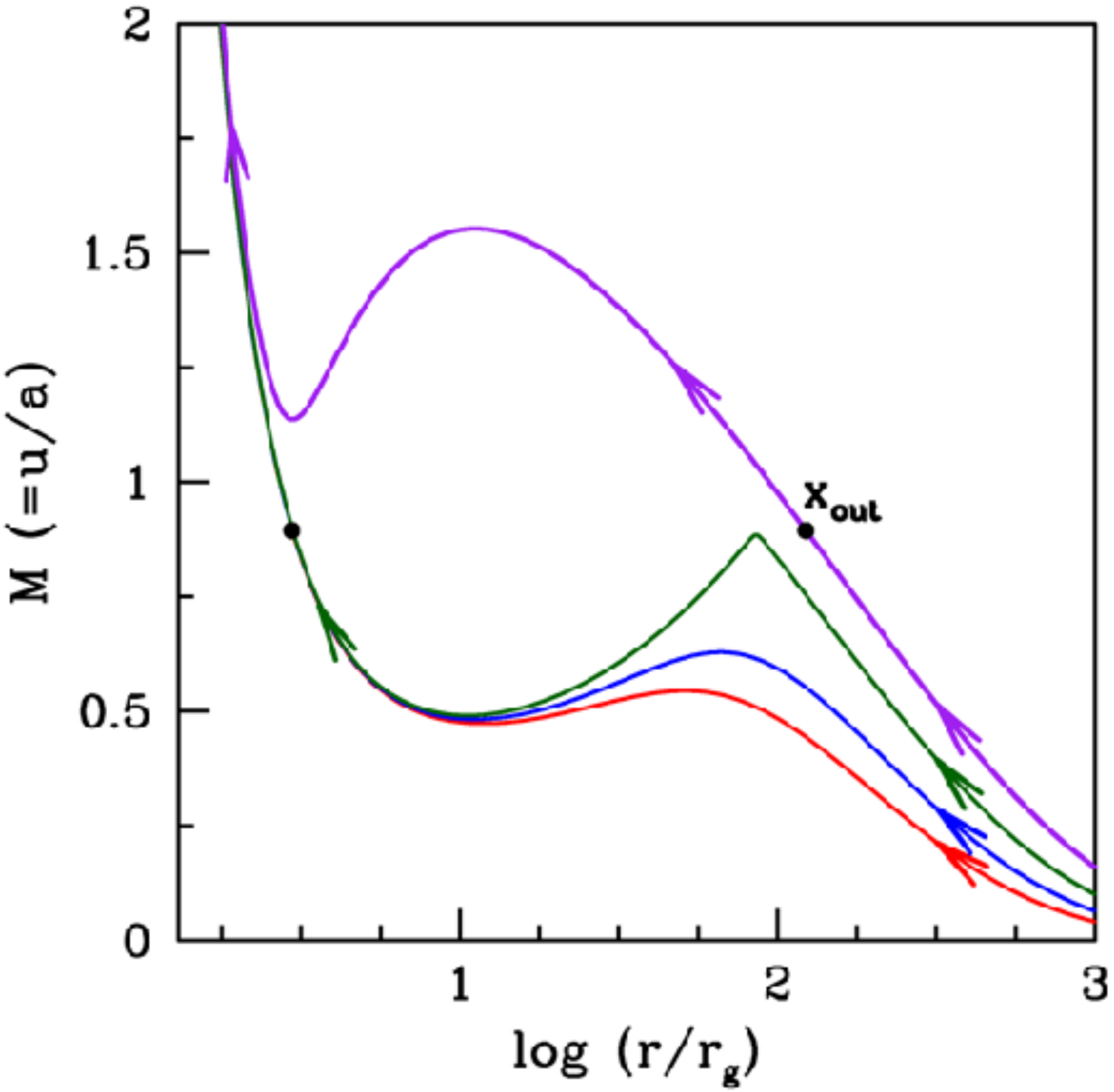

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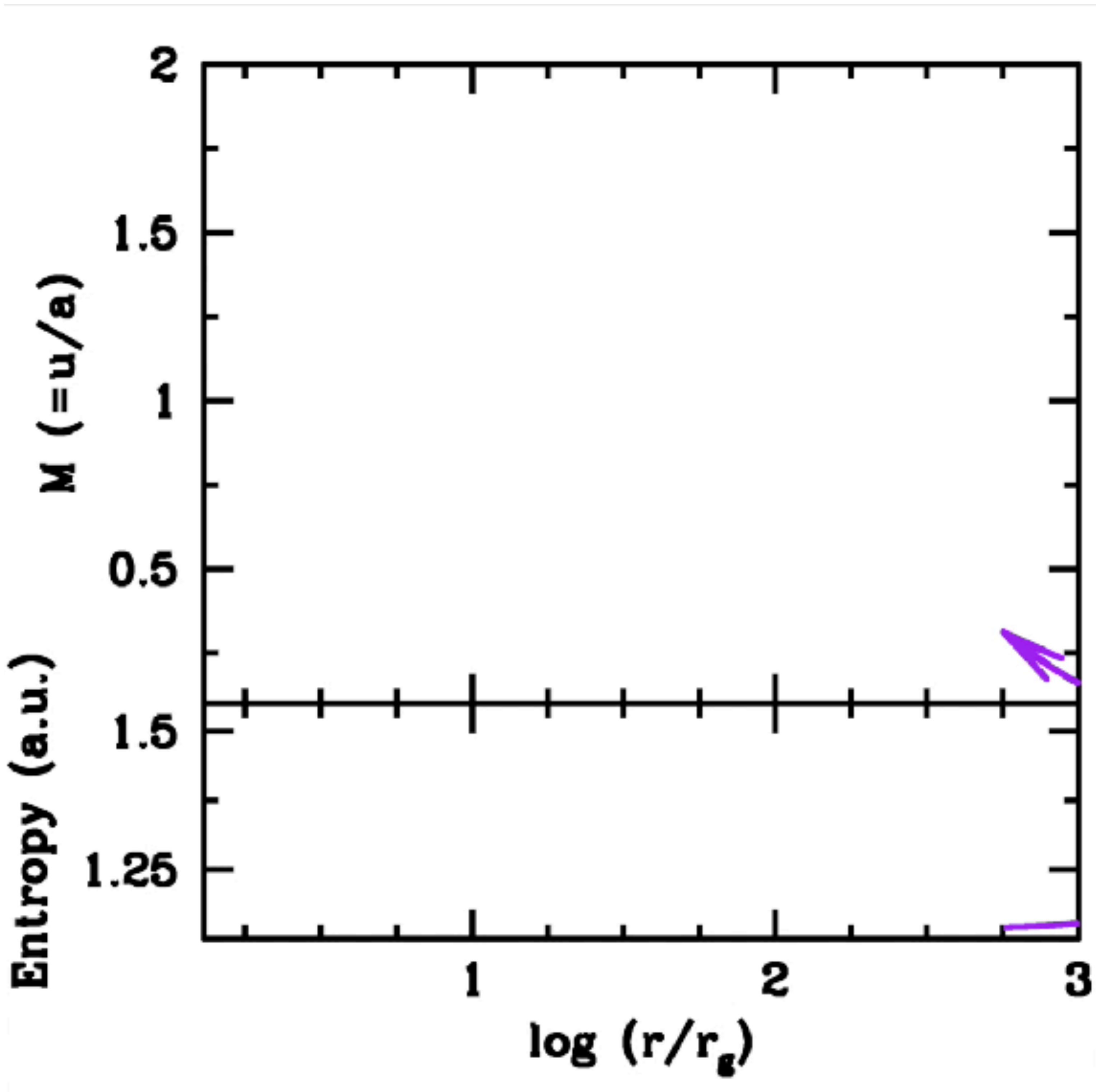
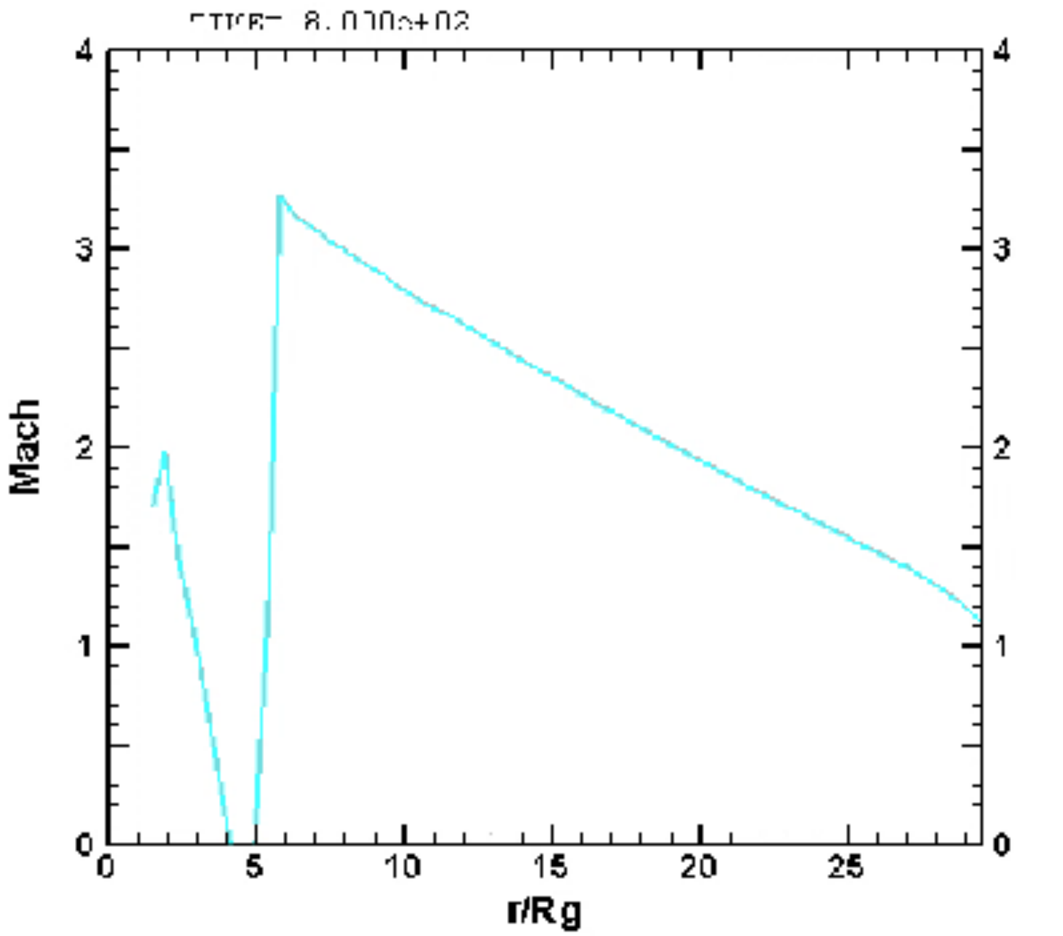
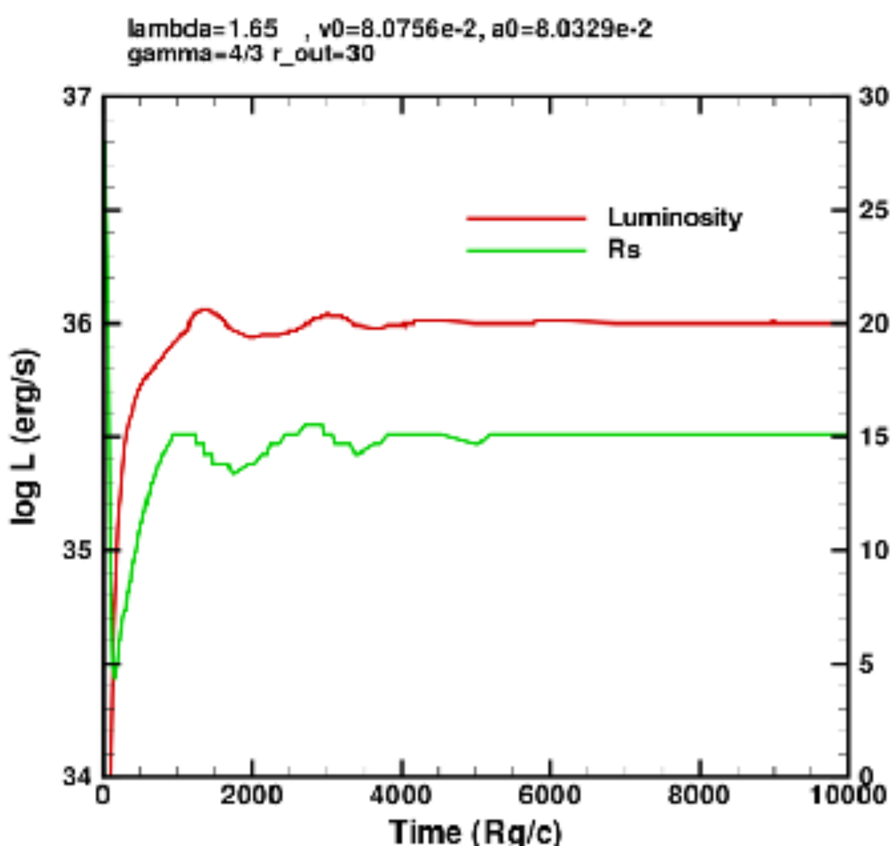
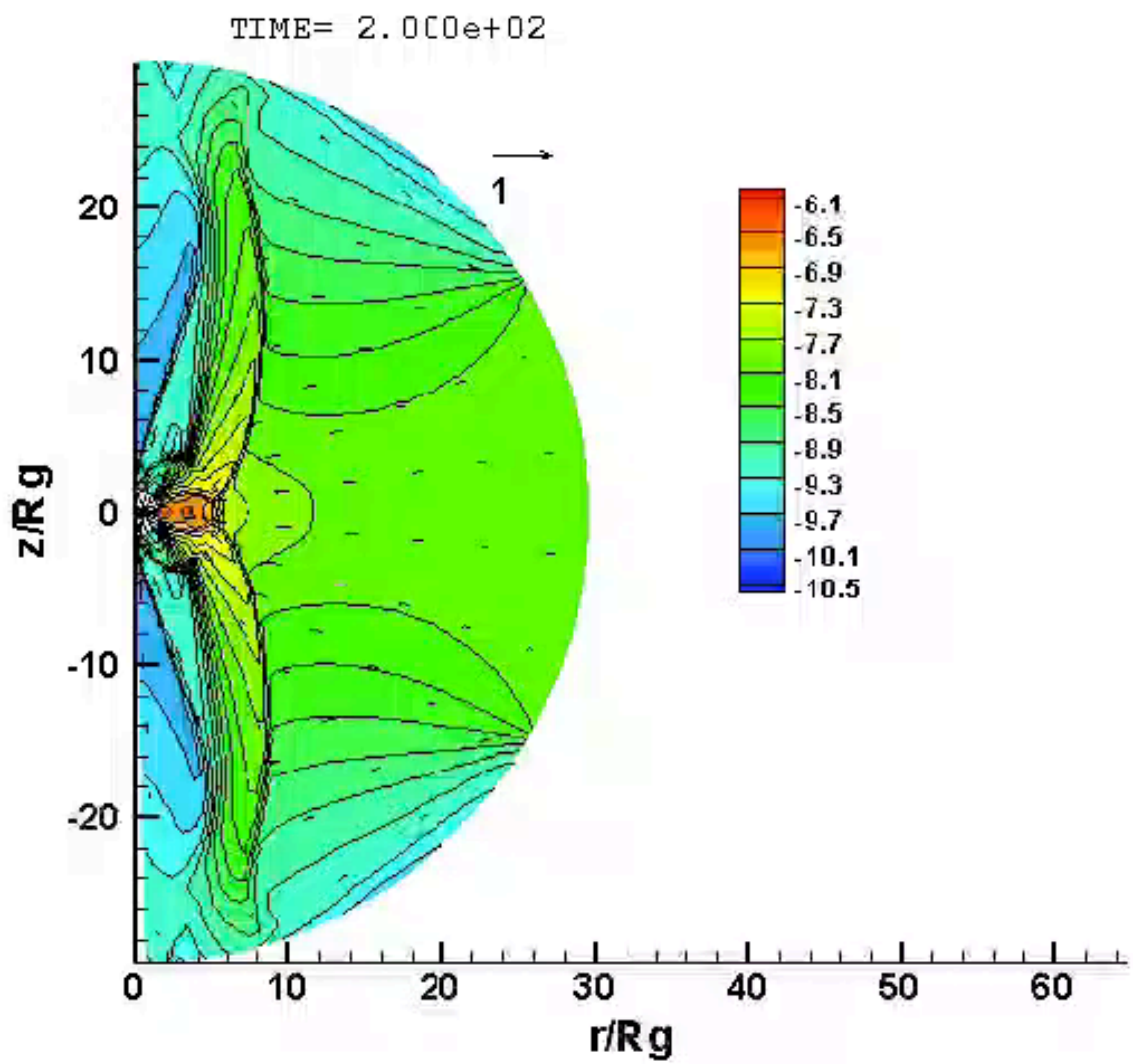


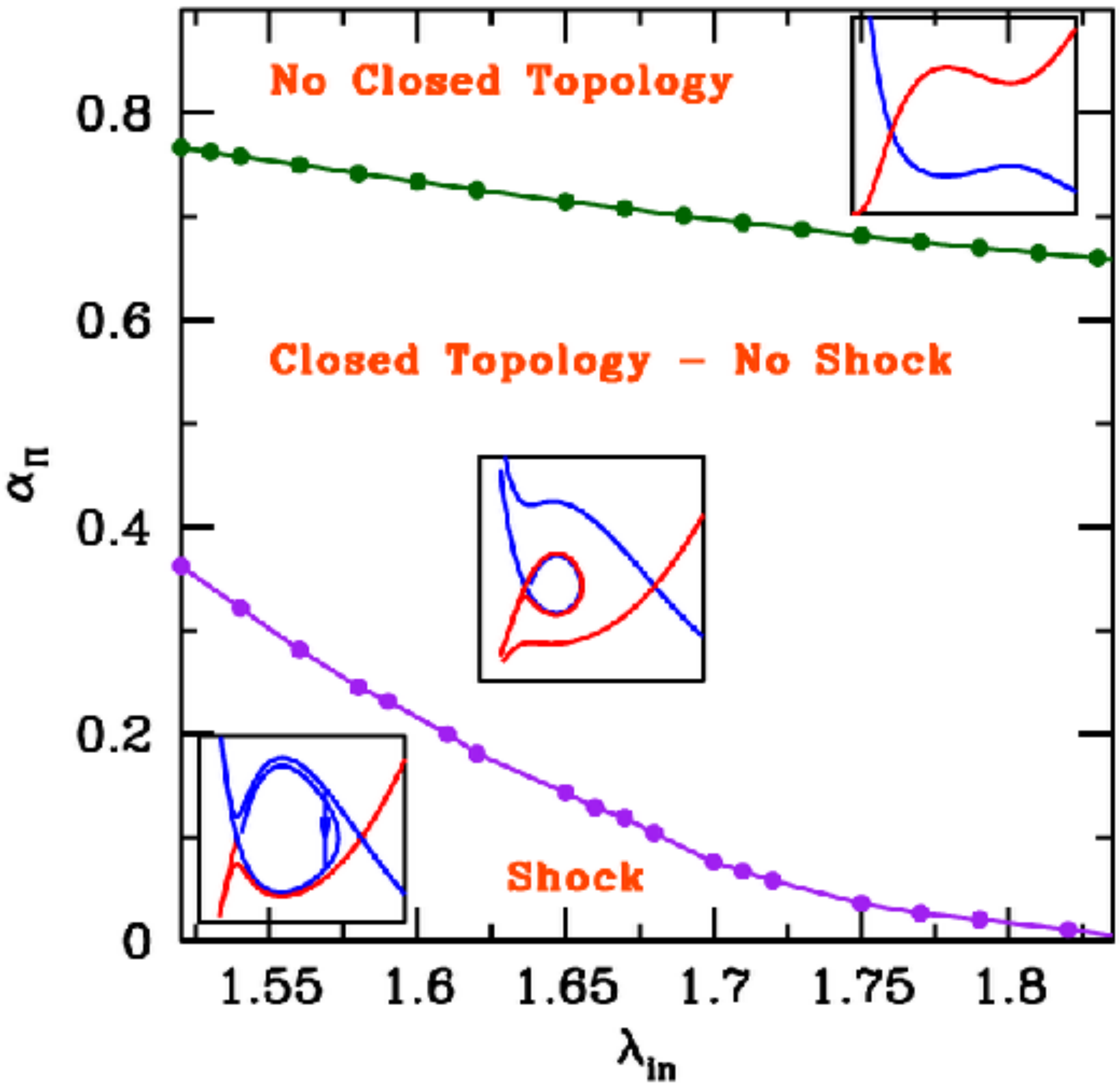
Time dependent accretion solution containing shock

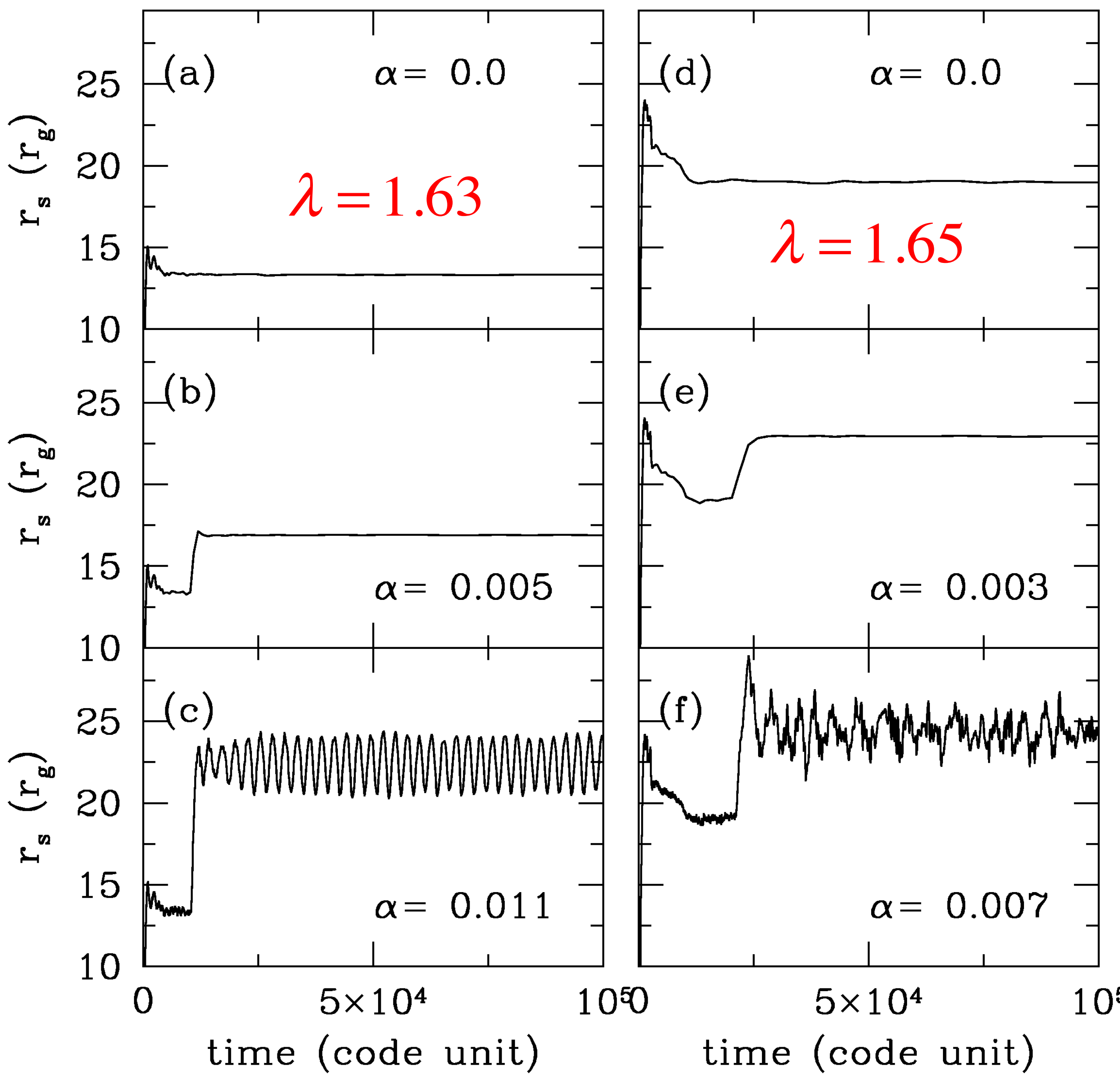




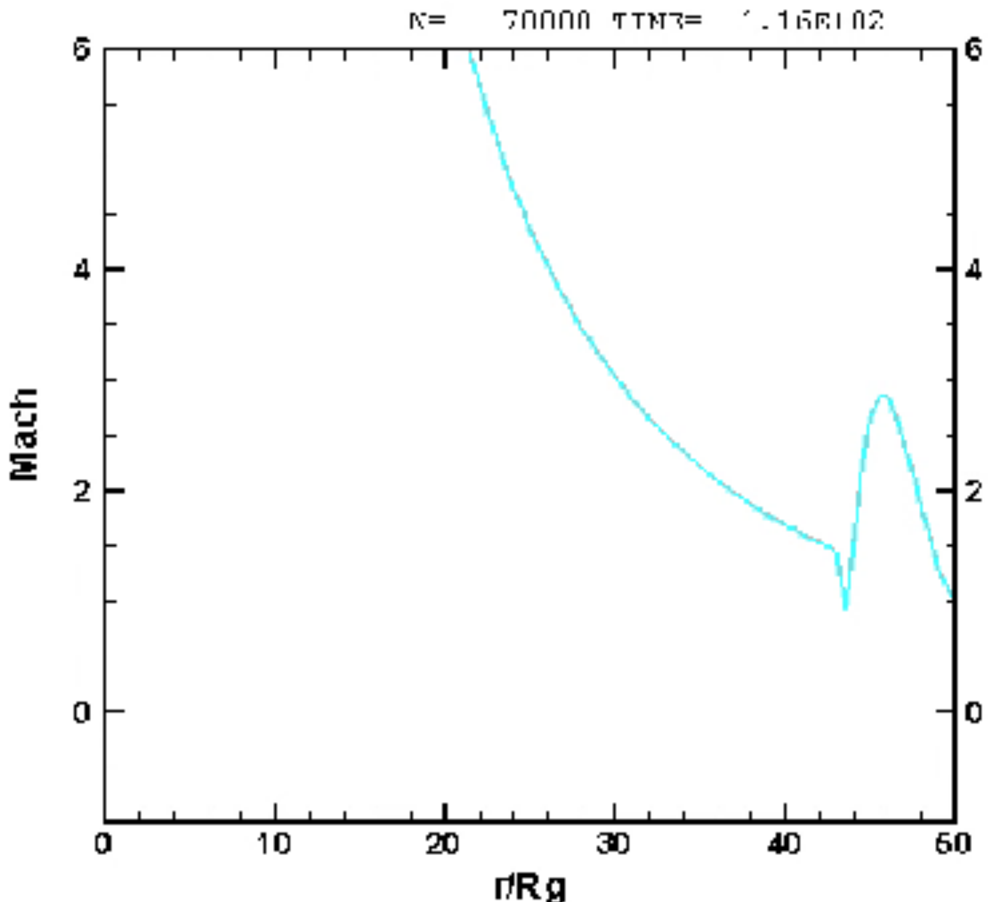


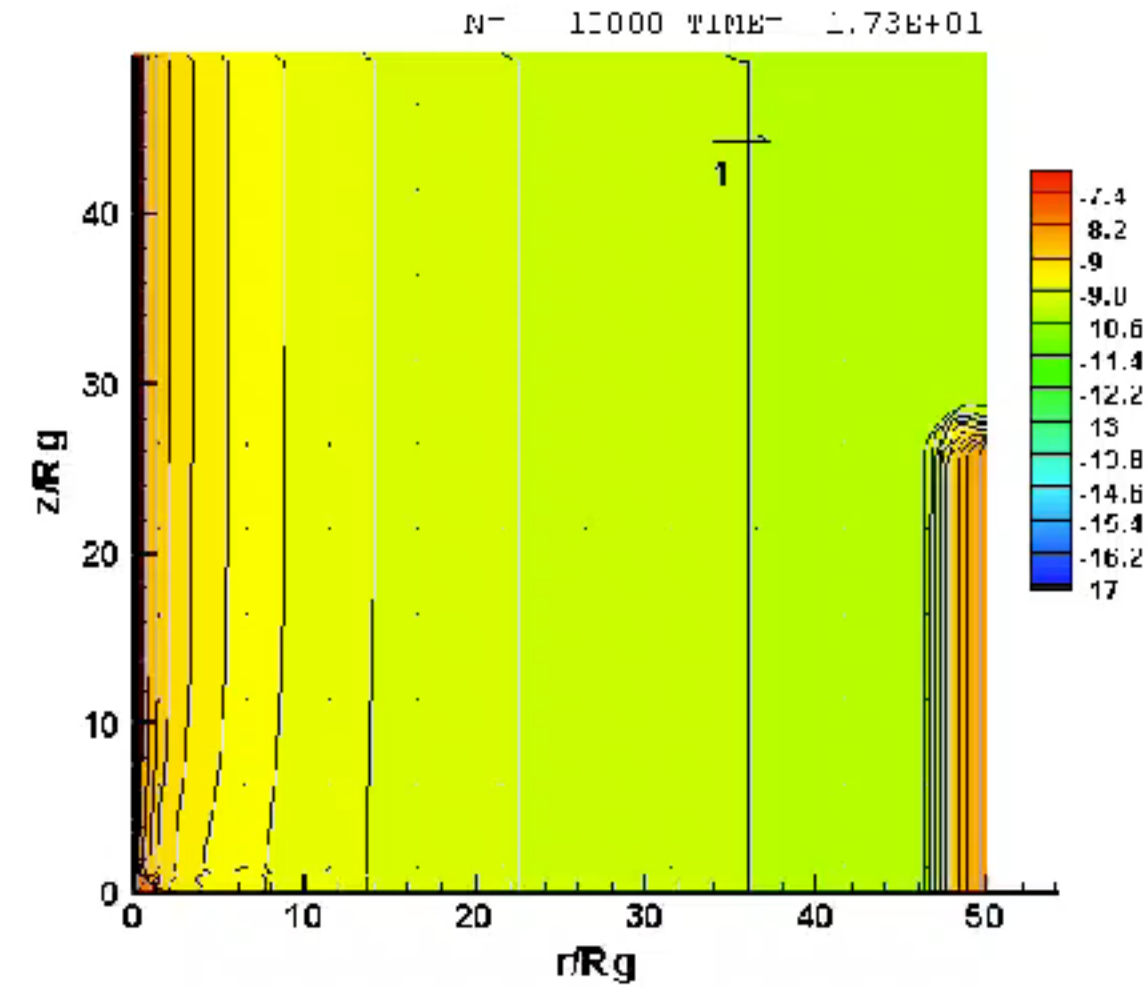
Critical values of viscosity parameter

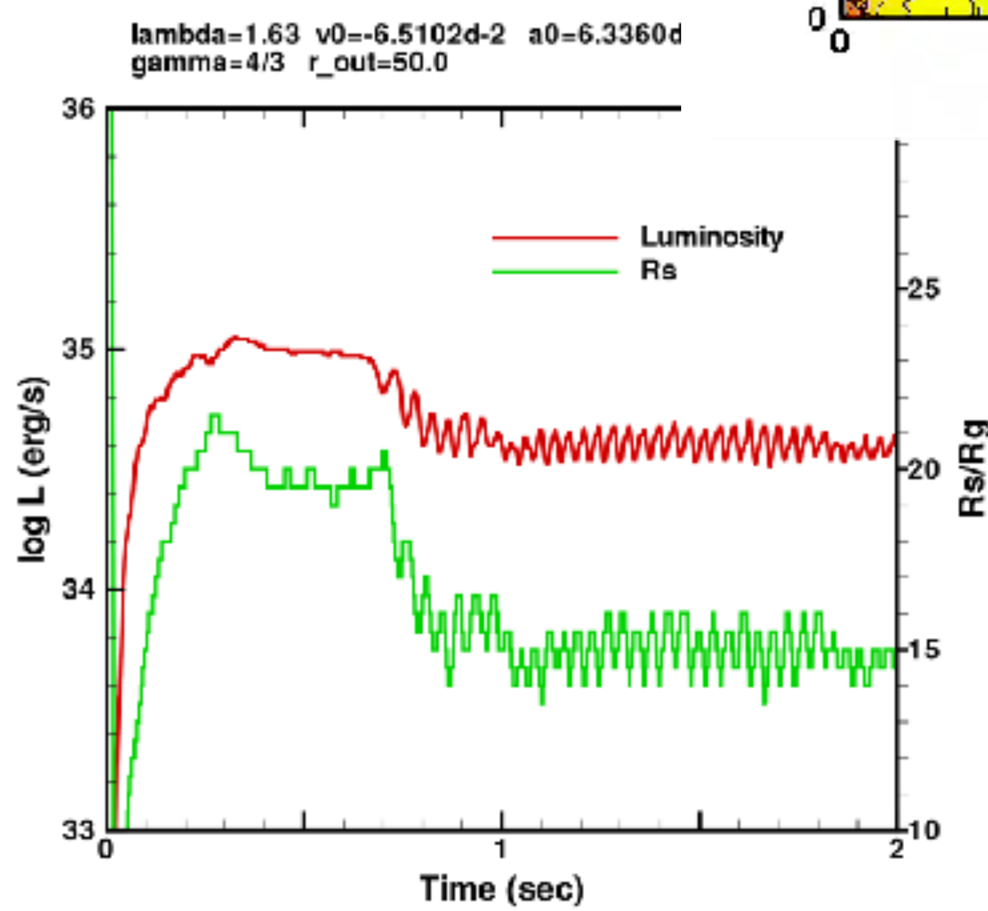




Accretion Solution Containing Oscillating Shock

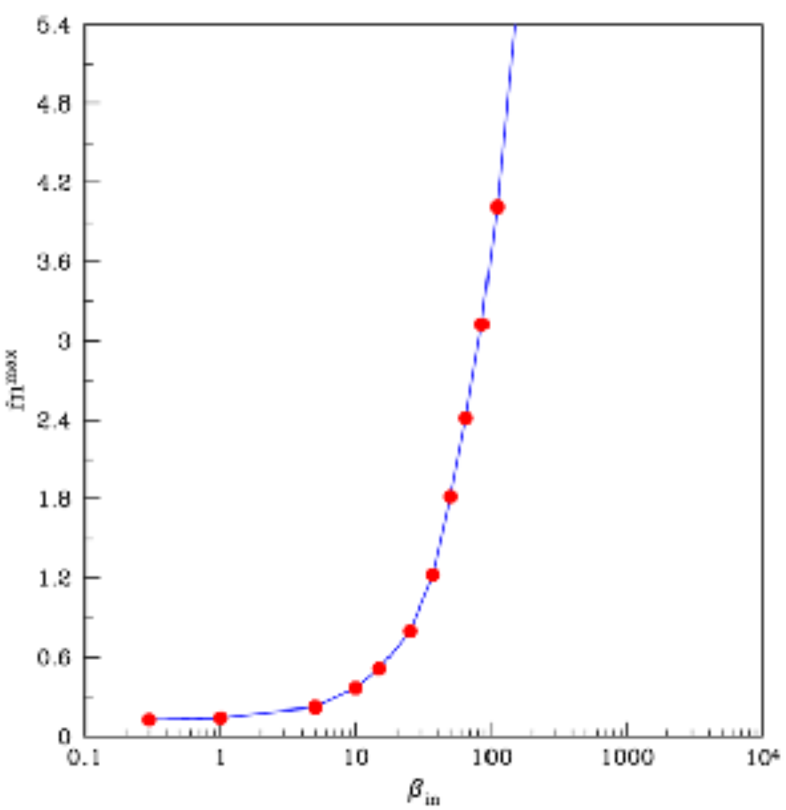


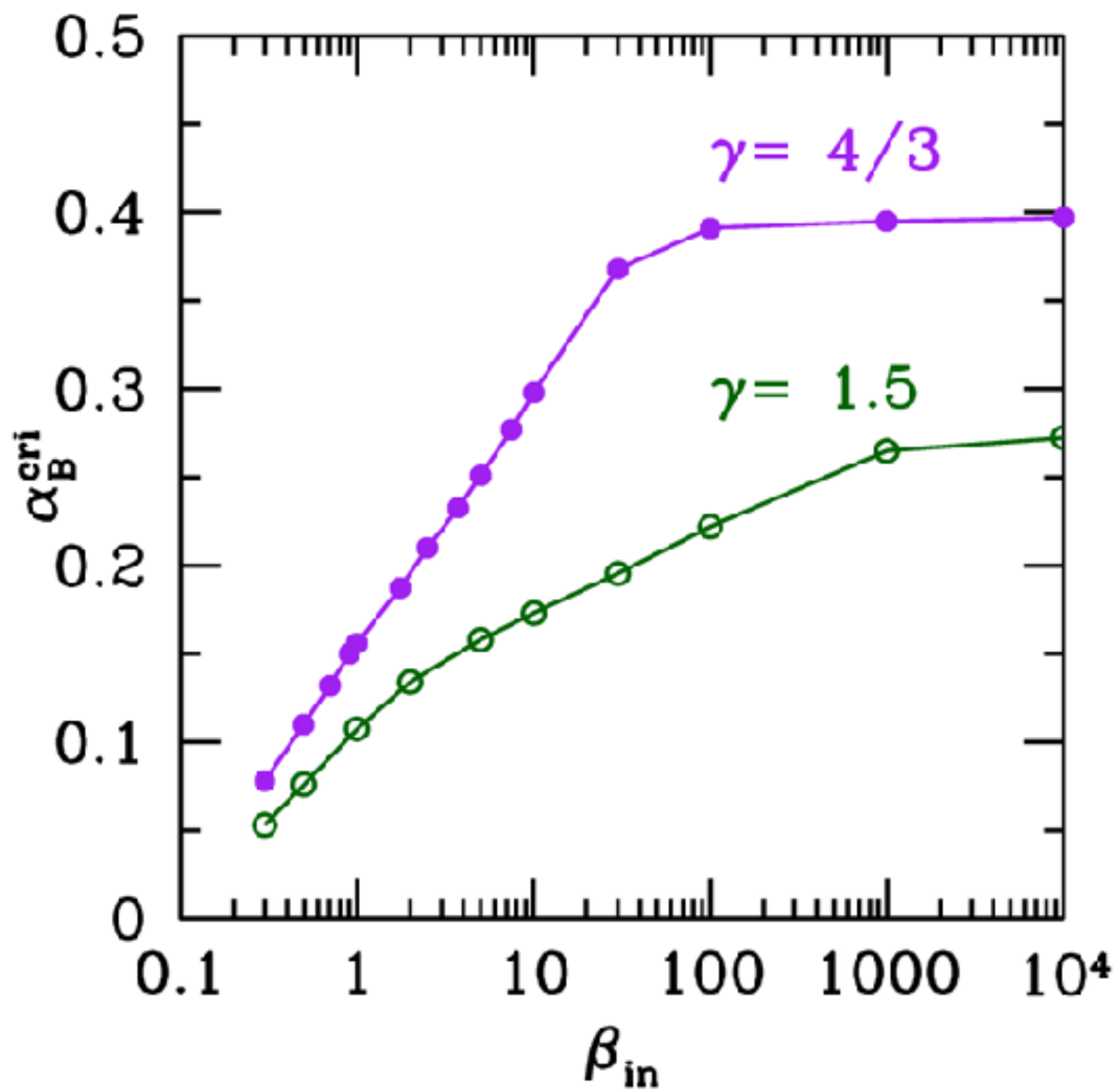




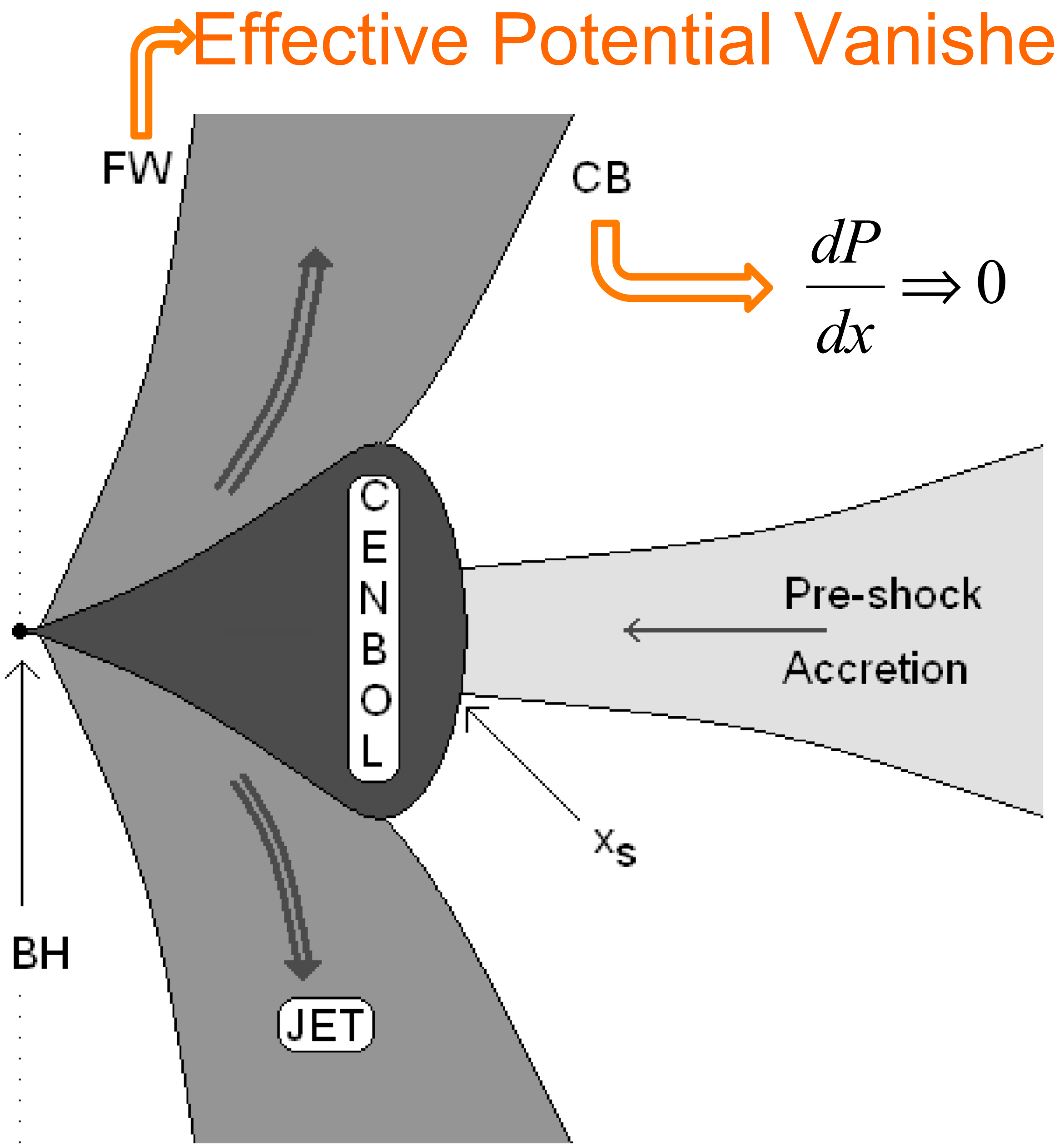
Critical viscosity parameter for a magnetically supported accretion disc

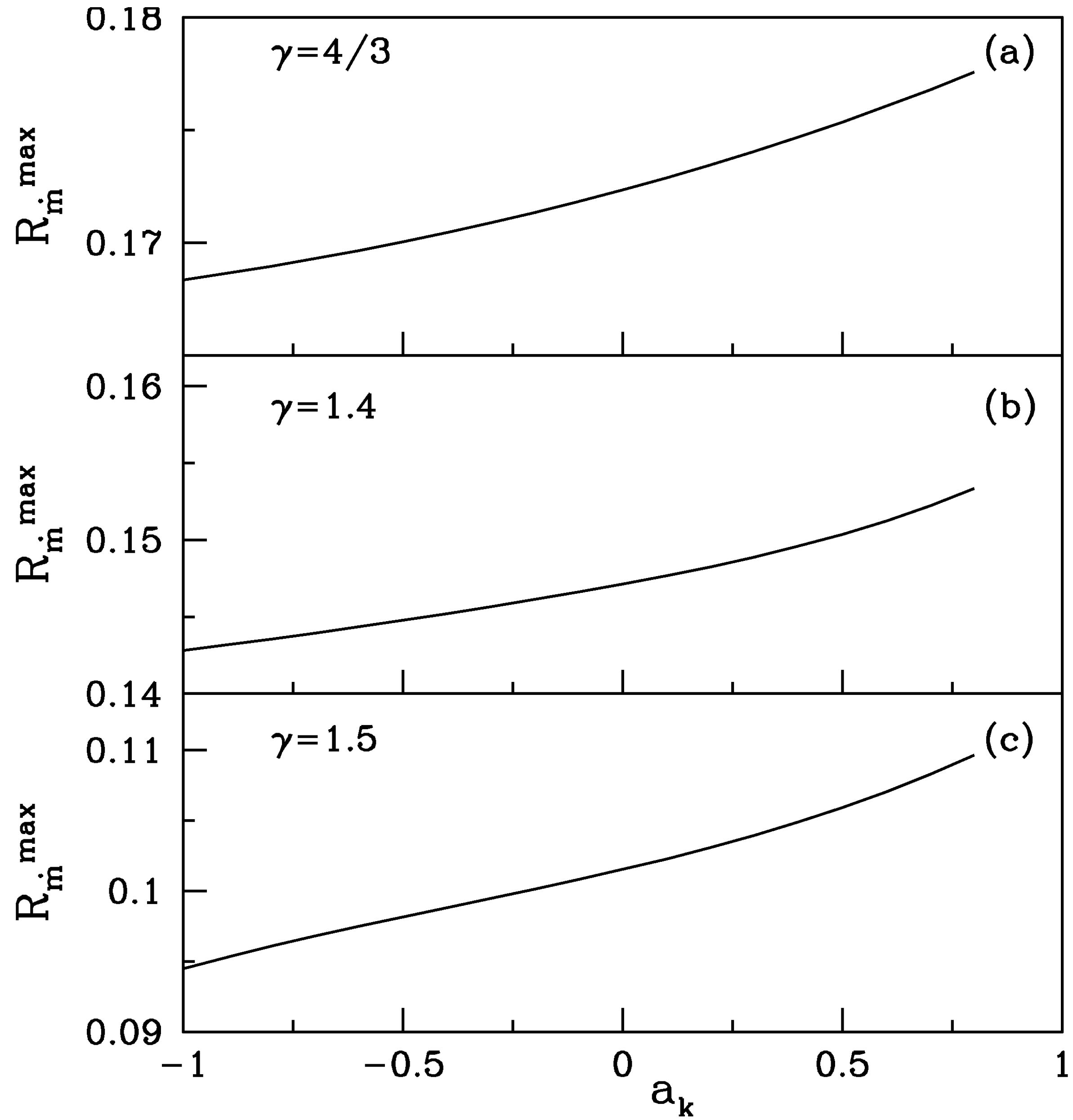
- Radiative process: Synchrotron Cooling
- $T_{x\phi} = \frac{< B_x B_\phi >}{4\pi} h = -\alpha_B (W + \Sigma v^2)$
- $\beta = \frac{P_{gas}}{P_{mag}}$





Accretion-ejection solutions





Estimation of Jet Kinetic Power

$$\dot{M}_{acc} = 2.99 \times 10^{-16} \left(\frac{F_x\, d^2}{c^2}\right) \left(\frac{M_{BH}}{M_\odot}\right)^{-1} \dot{M}_{Edd}.$$

$$L_{jet}^{max} = R_{\dot{m}}^{max} \times \dot{M}_{acc} \times c^2 \text{ erg s}^{-1}.$$

Objects	M_{BH} ($M_\odot$)	d (kpc)	a_k	Observation (3–30 keV) States	F_x (erg cm^{-2} s^{-1})	$\dot{M}_{acc}$ ($\dot{M}_{Edd}$)[a]	$R_{\dot{m}}$ (per cent)	L_{jet} (erg s^{-1})	L_{jet}^{Obs} [c] (erg s^{-1})
XTE J1859+226	7	11	0.4	LHS	5.71×10^{-9}	0.304	9.83	2.52×10^{37}	
(1999 Outburst)				HIMS	12.79×10^{-9}	0.680	17.5	1.08×10^{38}	
									1.82×10^{38} (1)
GRO J1655−40	6.3	3.2	0.7	LHS	3.19×10^{-9}	0.016	9.98	1.18×10^{36}	
(2005 Outburst)				HIMS	8.02×10^{-9}	0.040	17.68	5.79×10^{36}	
									3.01×10^{36} (2)
GX 339−4	7.5	15	0.4	LHS	15.71×10^{-9}	1.450	9.98	1.29×10^{38}	
(2002 Outburst)				HIMS[b]	12.12×10^{-9}	1.118	17.5	1.90×10^{38}	
									2.92×10^{38} (1)
H 1743−322	8	8.5	0.2	HIMS	4.03×10^{-9}	0.112	17.35	2.01×10^{37}	
(2009 Outburst)									1.08×10^{38} (3)
GRS 1915+105	12.4	8.6	>0.98†	LHS	20.33×10^{-9}	0.373	9.98	5.99×10^{37}	
(1997 Observation)									8.06×10^{37} (1)

Notes. [a] $\dot{M}_{Edd} = 1.44 \times 10^{17}(\frac{M_{BH}}{M_\odot})$ g s^{-1}.

[b] Total flux in HIMS (3–30 keV) is smaller than LHS as the contribution of the hard X-ray flux (>10 keV) in HIMS is less.

[c] $L_{jet}^{Obs} = \eta \dot{M}_{out} c^2$ is used for the source H 1743−322, where $\dot{M}_{out}$ is the outflow rate (see reference). For other sources, $L_{jet}^{Obs} = L_r \times L_{Edd}$ is used, where L_r is the observed jet power (in Edd) (see references) and $L_{Edd} = 1.3 \times 10^{38}(\frac{M_{BH}}{M_\odot})$erg s^{-1}.

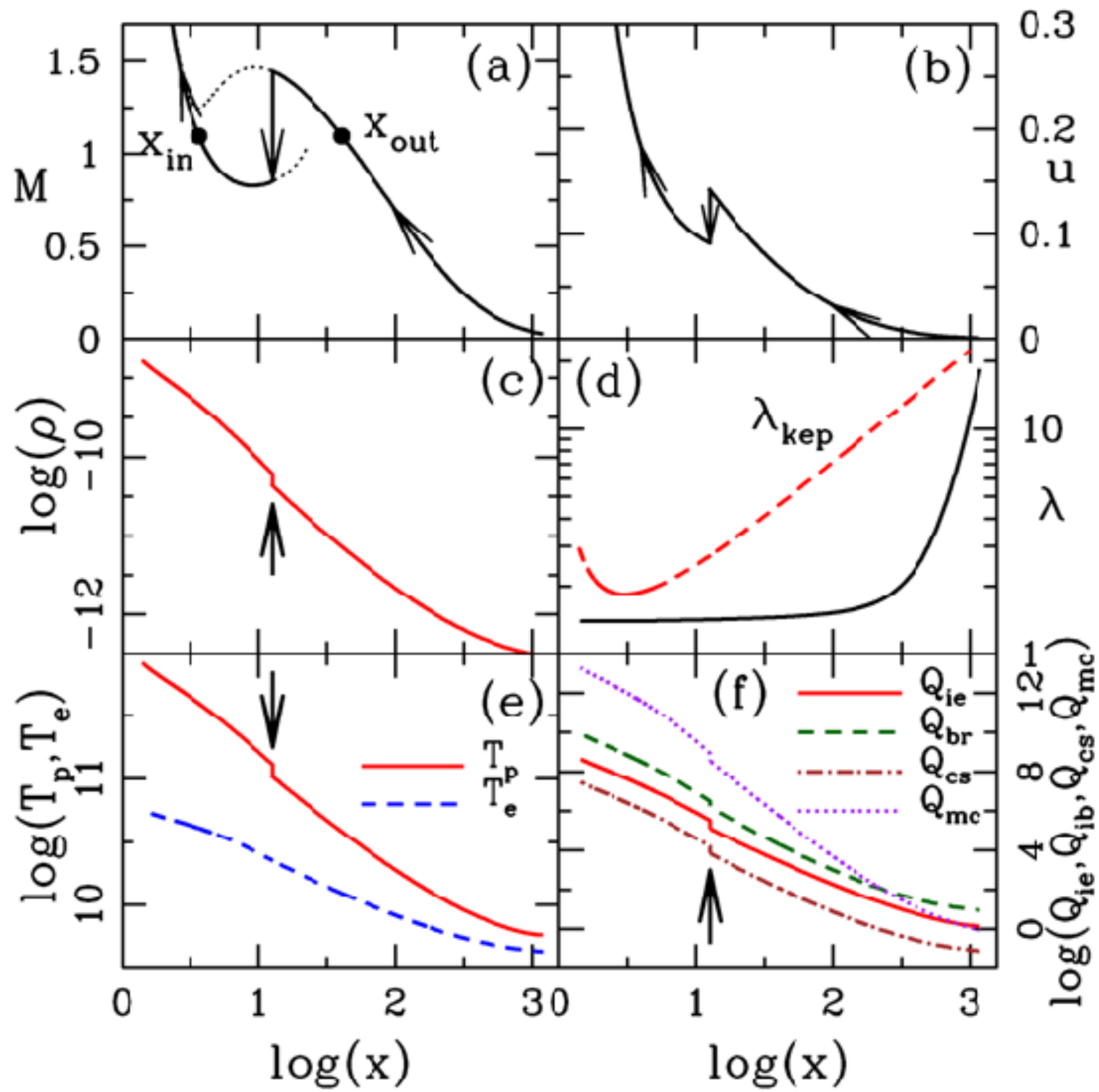
References: (1) Fender et al. (2004), (2) Migliari et al. (2007), (3) Miller et al. (2012).

Prediction of Jet Kinetic Power

Objects	M_{BH} ($M_{\odot}$)	$\dot{M}_{acc}$ ($\dot{M}_{Edd}$)	a_k	$\mathcal{E}$ (c^2)	λ (cr_g)	x_s (r_g)	$R_{\dot{m}}^{max}$ (per cent)	L_{jet}^{max} (erg s^{-1})	$L_{jet}^{Obs\ a}$ (erg s^{-1})
A0620-00	6.60 (*a*)	1.684 (*b*)	0.12 (*b*)	0.004 44	3.25	26.84	17.25	2.48×10^{38}	–
LMC X-3	6.98 (*c*)	2.487 (*d*)	0.25 (*e*)	0.004 76	3.15	25.72	17.35	3.90×10^{38}	–
XTE J1550−564	9.10 (*f*)	0.511 (*g*)	0.34 (*g*)	0.005 30	3.06	22.07	17.43	1.05×10^{38}	3.55×10^{38} (*y*)
M33 X-7	15.66 (*h*)	0.718 (*i*)	0.84† (*j*)	0.008 07	2.61	15.60	17.79	2.59×10^{38}	–
4U 1543−47	9.40 (*k*)	1.315 (*l*)	0.43 (*l*)	0.005 65	2.98	21.07	17.48	2.80×10^{37}	–
LMC X-1	10.90 (*m*)	0.853 (*n*)	0.92† (*n*)	0.008 30	2.58	15.42	17.93	2.16×10^{37}	–
Cyg X-1	14.80 (*o*)	0.061 (*p*)	≥0.95† (*p*)	0.008 35	2.58	15.38	17.98	2.10×10^{37}	3.85×10^{37} (*y*)
Mrk 79	5.24×10^{7} (*q*)	9.82×10^{-2} (*r*)	0.70 (*s*)	0.007 30	2.72	16.73	17.68	1.18×10^{44}	–
M87	3.50×10^{9} (*t*)	1.16×10^{-4} (*u*)	≥0.65 (*v*)	0.007 05	2.76	16.94	17.62	9.25×10^{42}	1.00×10^{45} (*z*)
Sgr A*	4.90×10^{6} (*w*)	7.89×10^{-5} (*x*)	$0.99^{\dagger}$ (*w*)	0.008 59	2.57	14.71	18.09	9.07×10^{39}	1.00×10^{39} (*zz*)

Notes. $^{a}L_{jet}^{Obs} = L_r \times L_{Edd}$, where L_r is the observed jet power (in Edd) (see references).
References: (*a*) Cantrell et al. (2010), (*b*) Gou et al. (2010), (*c*) Orosz et al. (2014), (*d*) Kubota et al. (2010), (*e*) Steiner et al. (2014), (*f*) Orosz et al. (2011a), (*g*) Steiner et al. (2011), (*h*) Orosz et al. (2007), (*i*) Liu et al. (2008), (*j*) Liu et al. (2010), (*k*) Orosz (2003), (*l*) Morningstar & Miller (2014), (*m*) Orosz et al. (2009), (*n*) Gou et al. (2009), (*o*) Orosz et al. (2011b), (*p*) Gou et al. (2011), (*q*) Peterson et al. (2004), (*r*) Riffel, Storchi-Bergmann & Winge (2013), (*s*) Gallo et al. (2011), (*t*) Walsh et al. (2013), (*u*) Kuo et al. (2014), (*v*) Wang et al. (2008), (*w*) Aschenbach (2010), (*x*) Yuan, Markoff & Falcke (2002), (*y*) Fender et al. (2004), (*z*) de Gasperin et al. (2012), (*zz*) Falcke & Biermann (1999).

Two temperature accretion disk structure



Conclusion

- Self-consistently examine the accretion-ejection mechanism around rotating black hole.
- When dynamically possible, shock solutions is preferred which enable outflow production.
- Outflows are possible for a wide range of adiabatic index ranging from 4/3 to 1.5.
- Maximum outflow rate seems to be weakly correlated with the black hole spin.
- Jet kinetic power is estimated for several galactic sources which are in good agreement with the observation.