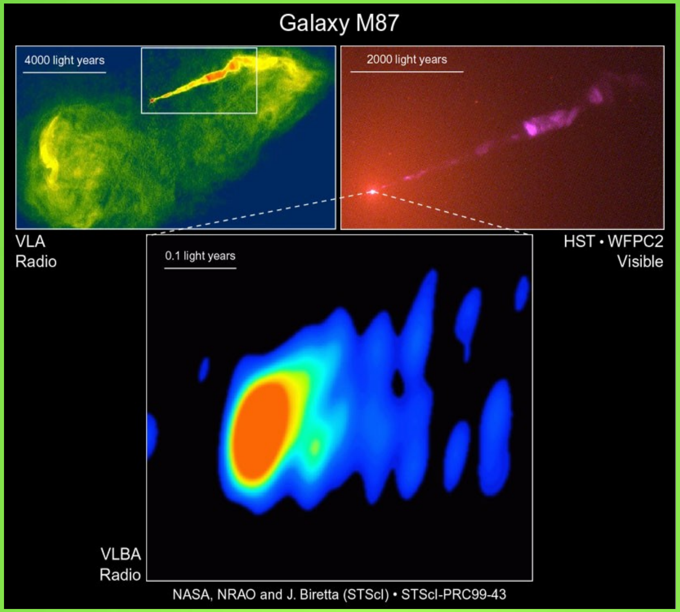
How spin may affect jets from accretion discs around black holes



Wideband Spectral&Timing Studies of Cosmic X ray sources: TIFR, Jan10-13, 2017

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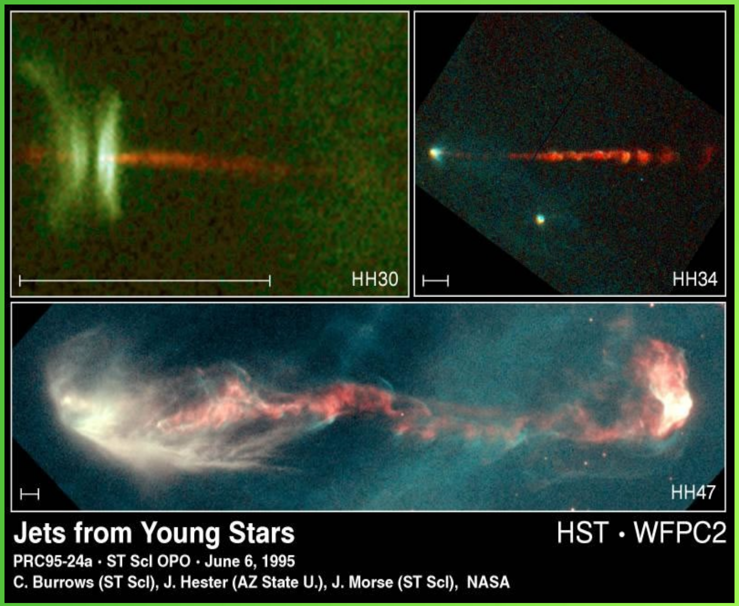
Plan of the talk:

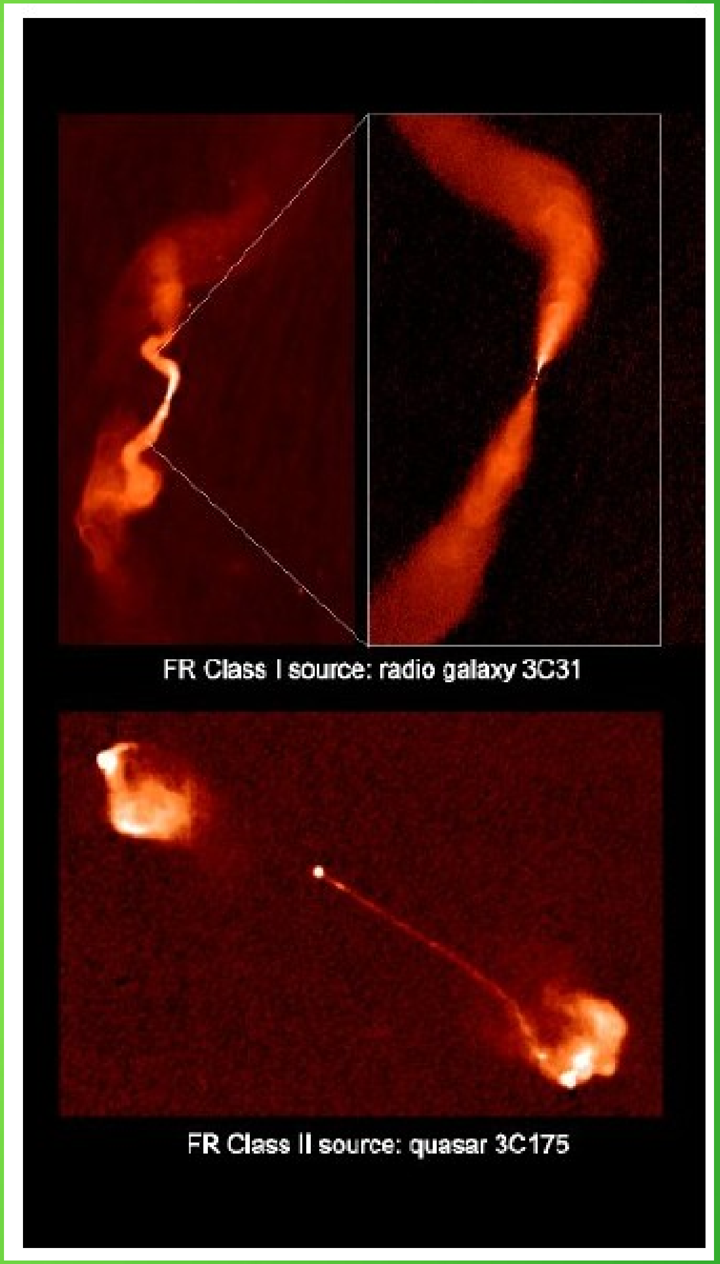
- ❖ Motivation
- ❖ Background on accretion disc theory and possible jet ejection mechanism.
- ❖ What simulations show.
- ❖ Concluding remarks

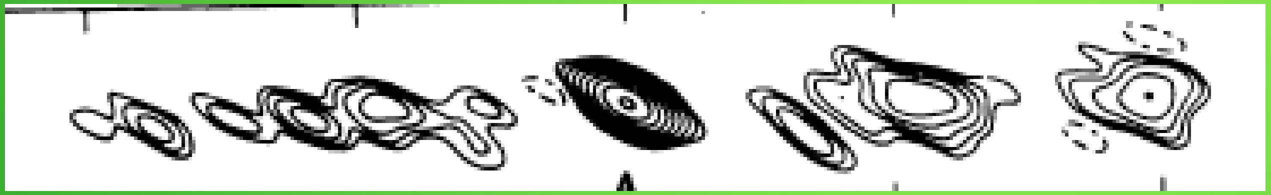
- Jets are ubiquitous and doesn't need a black hole to drive it.



YSO

AGN jets





Microquasar-GRO J 1655-40

Although there is morphological similarity between AGN jets, microquasar jets and YSO jets, but the length scale and energetics vary widely.

AGN jets size ~ kpc to fewX100 kpc, Microquasar jets are about ~ fewX100 AU, but AGN and microquasar jet speeds v/c ~ fewX0.1c – c, while YSO v/c $<10^{-3}$.

The standard approach is that these jets are ejected due to the influence of magnetic field and that the tapping the rotational energy of an extreme Kerr BH does the trick.

Two major processes:
(1) Penrose process (1969): In ergosphere, particles due to collision, decay acquire negative energy (at infinity), while the other particles acquired positive energy and flies away to produce jets. *Variation : Lorentz force can push particles in orbits, MHD Penrose process … tentative success by Koide et. al. 2002, Koide 2003.*

(2) Blandford Znajek process (1977): Monopolar MD model, where the horizon is touted to play the role of a conductor. Energy is extracted by the magnetic torque, and transferring EM energy out as Poynting flux.

Komissarov (2005) did extensive simulation on both these process. Penrose process cease to be effective on larger dynamical time scale. BZ process was more stable, but could not generate large scale relativistic jets.

Since observed astrophysical jets are expected to be matter dominate Harris (2006) so either BZ process should generate particle jets, or should convert EM to particles!!!!

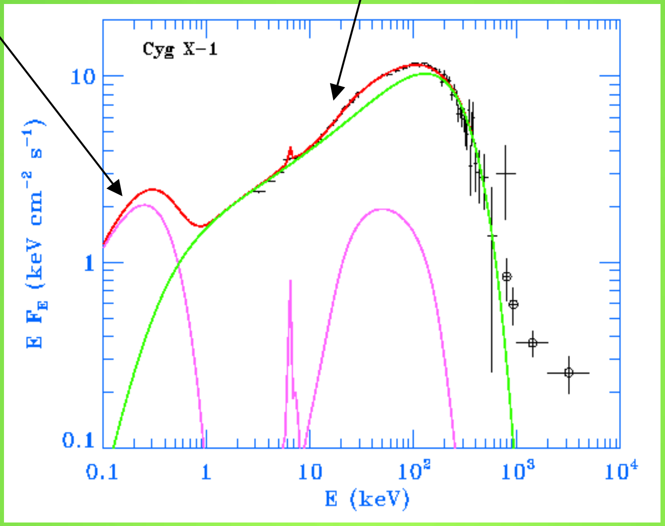
In this talk I would concentrate mainly on fluid flow on to rotating BH s.

(Ref: Kuldeep's talk on magnetised flow around NS type stars).

Most of BH astrophysics research is done in pseudo-Newtonian (pN) limit.

What has been achieved so far in pN limit?

- (1) While Sakura_Sunyaev disc explained the modified black body type spectra, non-thermal emission found a natural explanation in advective disc where post-shock part may produce it.



- (2) Finite jet base observed for M87 jet is naturally explained by the finiteness of the shock location.
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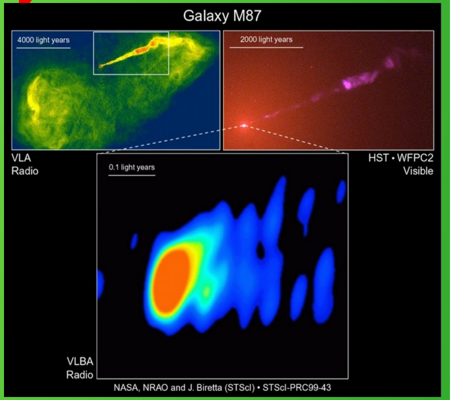
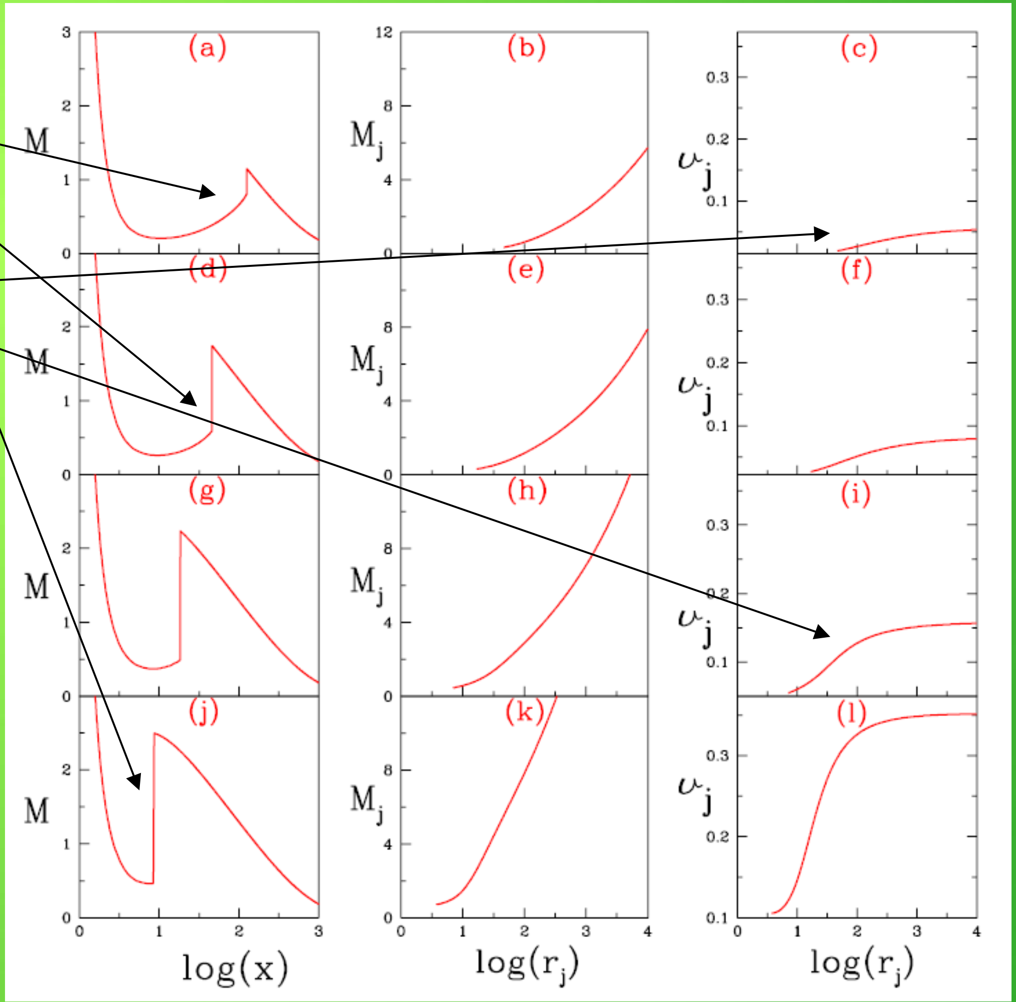


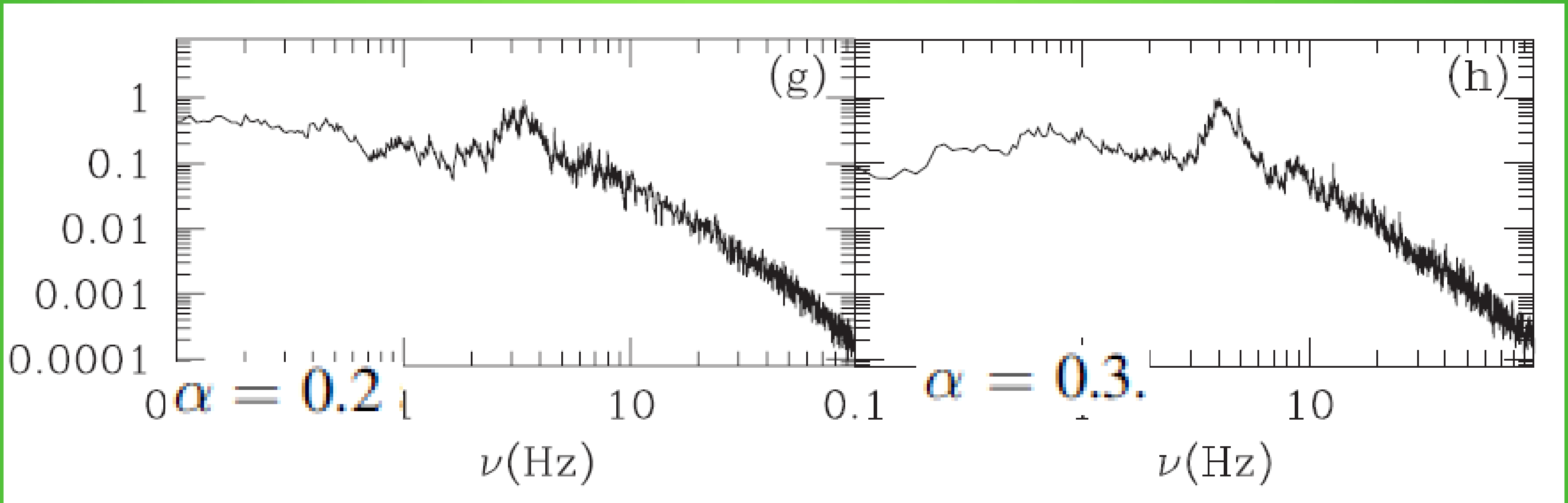
(3) Oscillating shock location can explain QPOs naturally.

Apart from these general, broad agreements of observation and theoretical prediction. We made few more progresses; (1) We showed with the increase of viscosity the shock location moves to a shorter distance. (Chattopadhyay & Das 2008, Das Chattopadhyay 2008, Kumar & Chattopadhyay 2013, Kumar et. al. 2014)

As xsh becomes smaller, the disc becomes more luminous. Which drives and produces stronger jets.



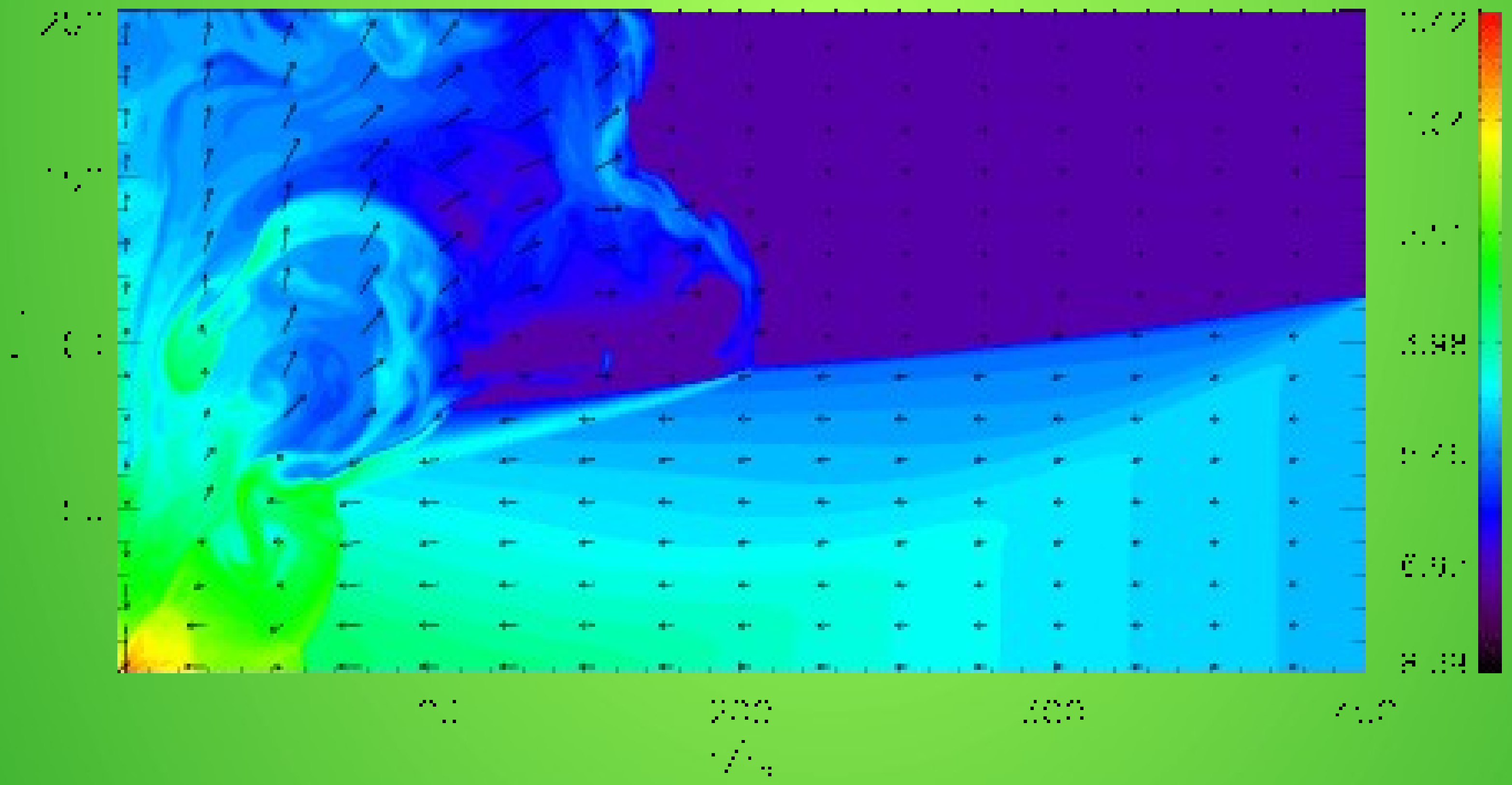
(2) Smaller x_{sh} means larger QPO frequency



(Lee et. al. ApJ 2016)

Regular oscillation means sharp PDS, irregular oscillation means broad peaks in QPO.

Multiple colliding shocks



But can BH astrophysics be entirely described in the pN regime?

Problems of pN regime:

(I) Infinite effective potential on the horizon but in GR it is zero.

(2) Viscous tensor in pN is $\propto d\Omega/dr$, but in GR it depends on u^r its derivatives, u_φ and its derivative, expansion etc.

(3) Surfaces of constant angular momentum is von Zeipel surfaces (VZS). Abramowicz 1971, Kozlowski et al. 1978, Chakrabarti 1985

(4) Flow velocity diverges on the horizon, on GR it remains finite albeit c.

Obtaining viscous accretion solutions is and ardous task.

(I) Shear tensor looks bad $$2\sigma^r_\phi = u^r_{;\phi} + g^{rr} u_{\phi;r} + a^r u_\phi + a_\phi u^r - \frac{2}{3}\Theta_{\exp} u^r u_\phi$$

(2) The Sonic point is not known.

(3) The angular momentum on the horizon (L_0) is not known.

We used Frobenius method to expand accretion solution in a series, supplied the generalized relativistic Bernoulli parameter

$$E = \frac{h\gamma_v \sqrt{1-\frac{2}{r}}}{\exp(X_f)},$$

$$X_f = \int \left[\left(\frac{r-3}{r-2} \right) \frac{l^2}{r^3 \gamma_v^2} - \frac{u^r (L - L_0)^2}{2\nu h r (r-2)} \right] \mathrm{d}r.$$

& angular momentum very close to the horizon. Assume the 3-vel there very close to freefall, using which in the supplied values, we obtain a cubic eqn on temperature at that point. With these values and using the fact the flow is close to inviscid allows us to calculate L_0.

Once jet shock is obtained we obtain jet streamline by identifying VZS parameters defined as

$$Z_\phi = \left(\frac{\vartheta_\phi}{\vartheta^\phi}\right)^{1/2} = \left(-\frac{g^{tt}}{g^{\phi\phi}}\right)^{1/2} = \frac{r_\mathrm{j}\sin\theta_\mathrm{j}}{(1-2/r_\mathrm{j})^{1/2}}$$

$$\vartheta_\phi = c_\phi Z_\phi^n$$

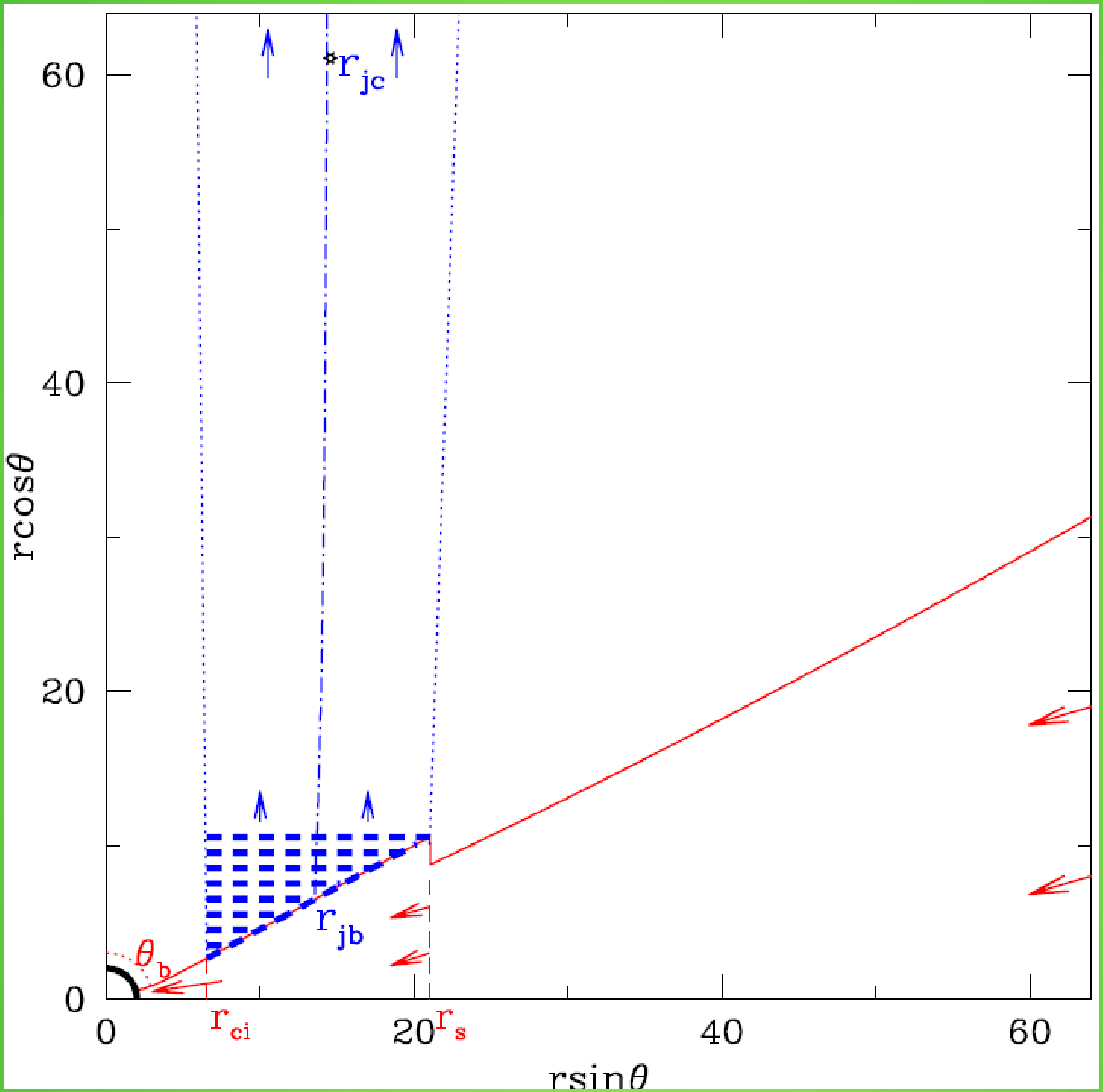
(Chakrabarti 1985)

Effective Bernoulli parameter for jet is

$$\Re_\mathrm{j} = -h_\mathrm{j} u_{t\mathrm{j}}[1 - c_\phi^2 Z_\phi^{(2n-2)}]^\beta$$

And jet streamline vel is

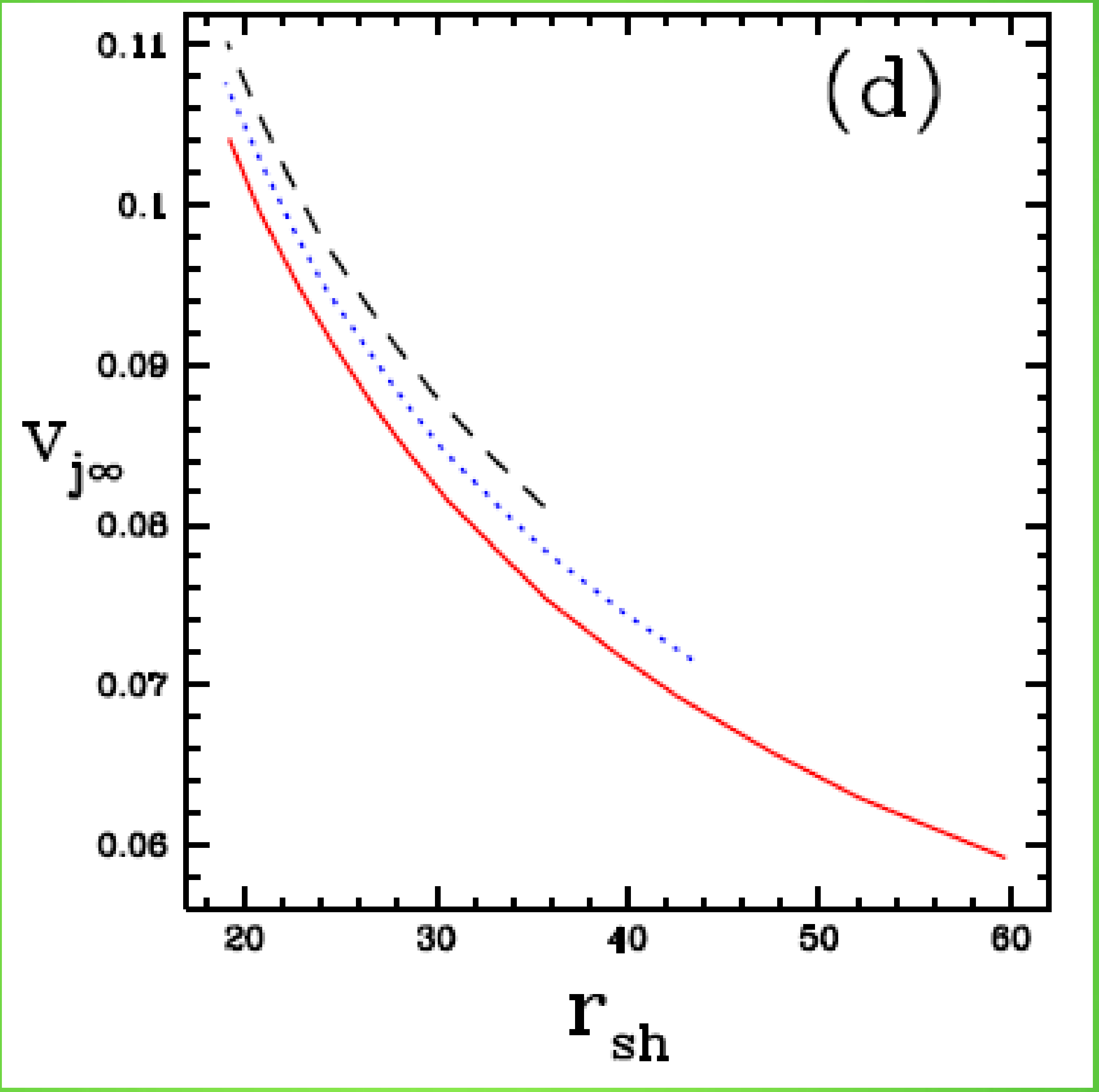
$$v_p^2 = \vartheta_r \vartheta^r + \vartheta_\theta \vartheta^\theta$$



Non-rotating BH, Electron-proton flow

$E = 1.0001,\ L_0 = 2.92,\ \alpha = 0.01$ and $\xi = 1$

Chattopadhyay & Kumar 2016



We also showed with viscosity shock decreases and jet velocity increases.

Something quite dramatic happens for rotating BH.
Let us concentrate on the jet eqn…

$$\frac{dv_j}{dr_j} = \frac{\mathcal{N}_j}{\mathcal{D}_j} = \frac{a_j^2(\mathcal{A}_j)^{-1} d\mathcal{A}_j/dr_j - a_j^2 h_p{}^{-1} dh_p/dr_j - X_g}{v_j \gamma_{vj}^2 [1 - a_j^2/v_j^2]},$$

Gravity+cross-section   metric+thermal   gravity

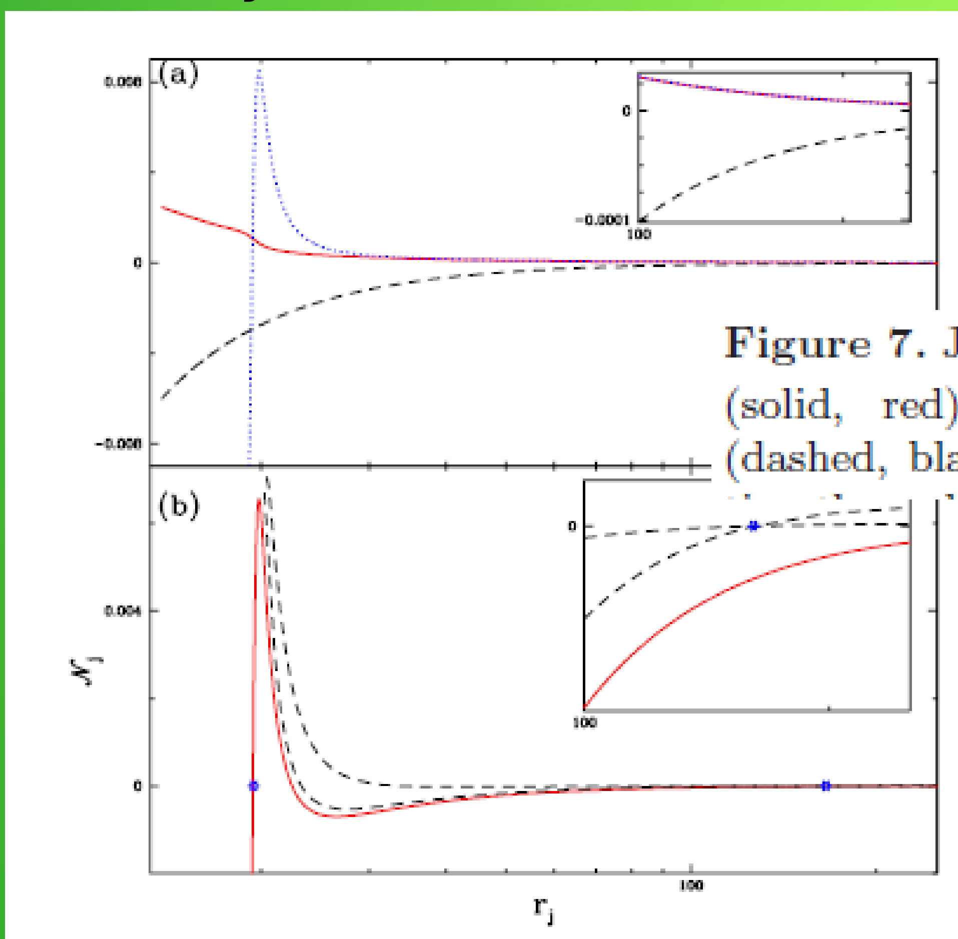
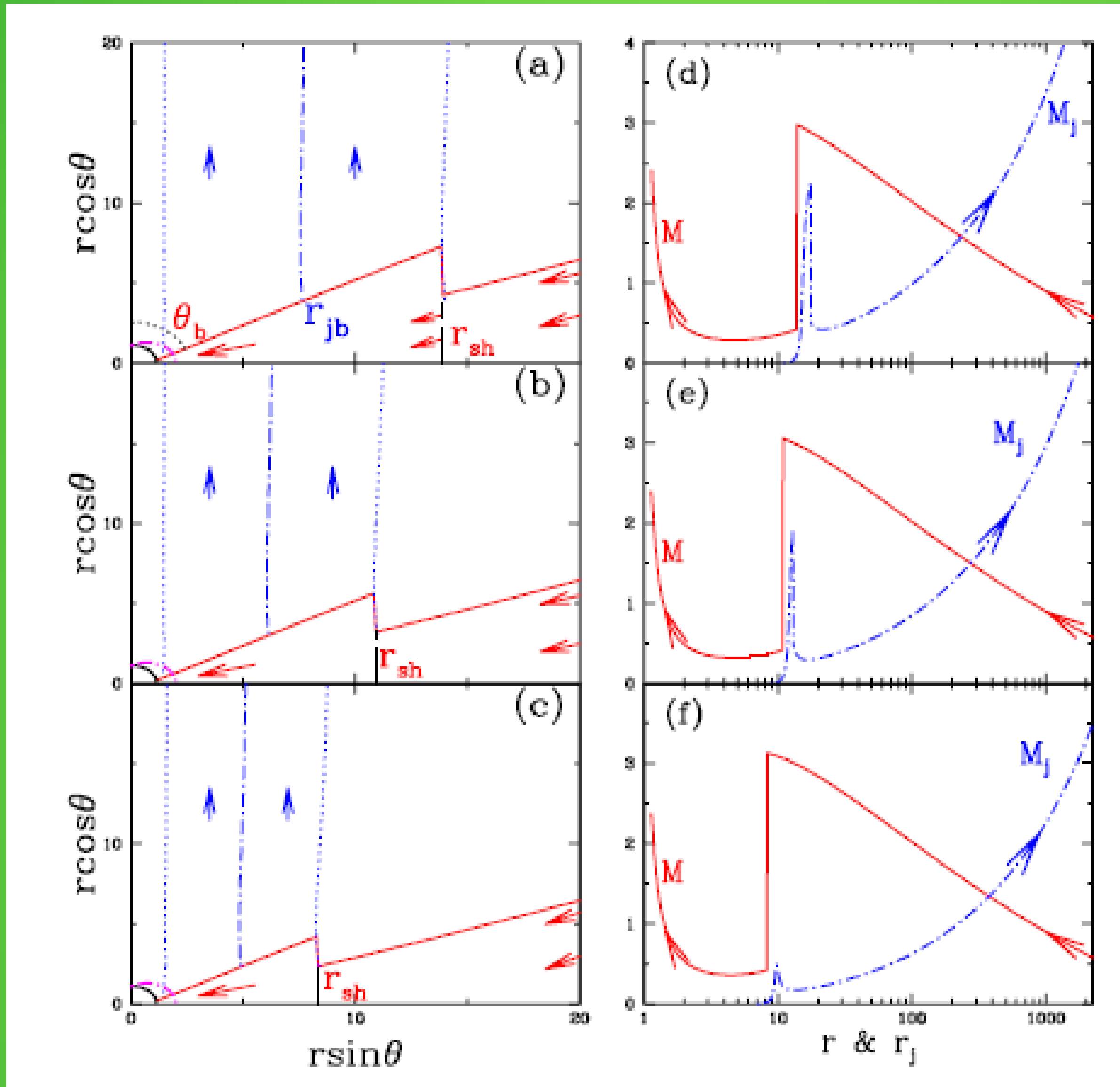
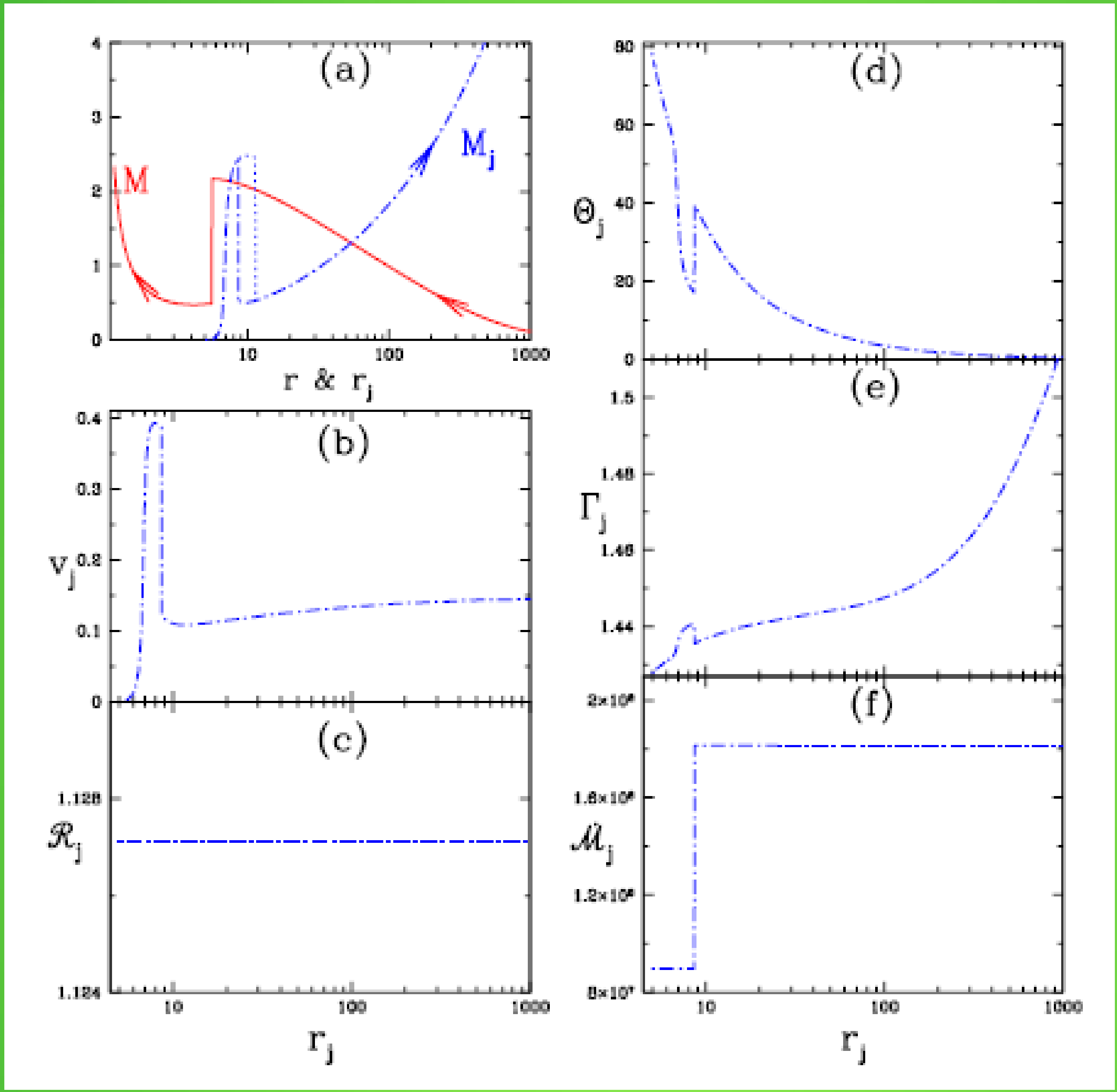


Figure 7. Jet: Various terms of $\mathcal{N}_j$ like (a) $a_j^2(\mathcal{A}_j)^{-1}(d\mathcal{A}_j)/(dr_j)$ (solid, red), $-a_j^2 h_p{}^{-1}(dh_p)/(dr_j)$ (dotted, blue) and $-X_g$ (dashed, black) are plotted with r_j. (b) $\mathcal{N}_j$ for the global solu-

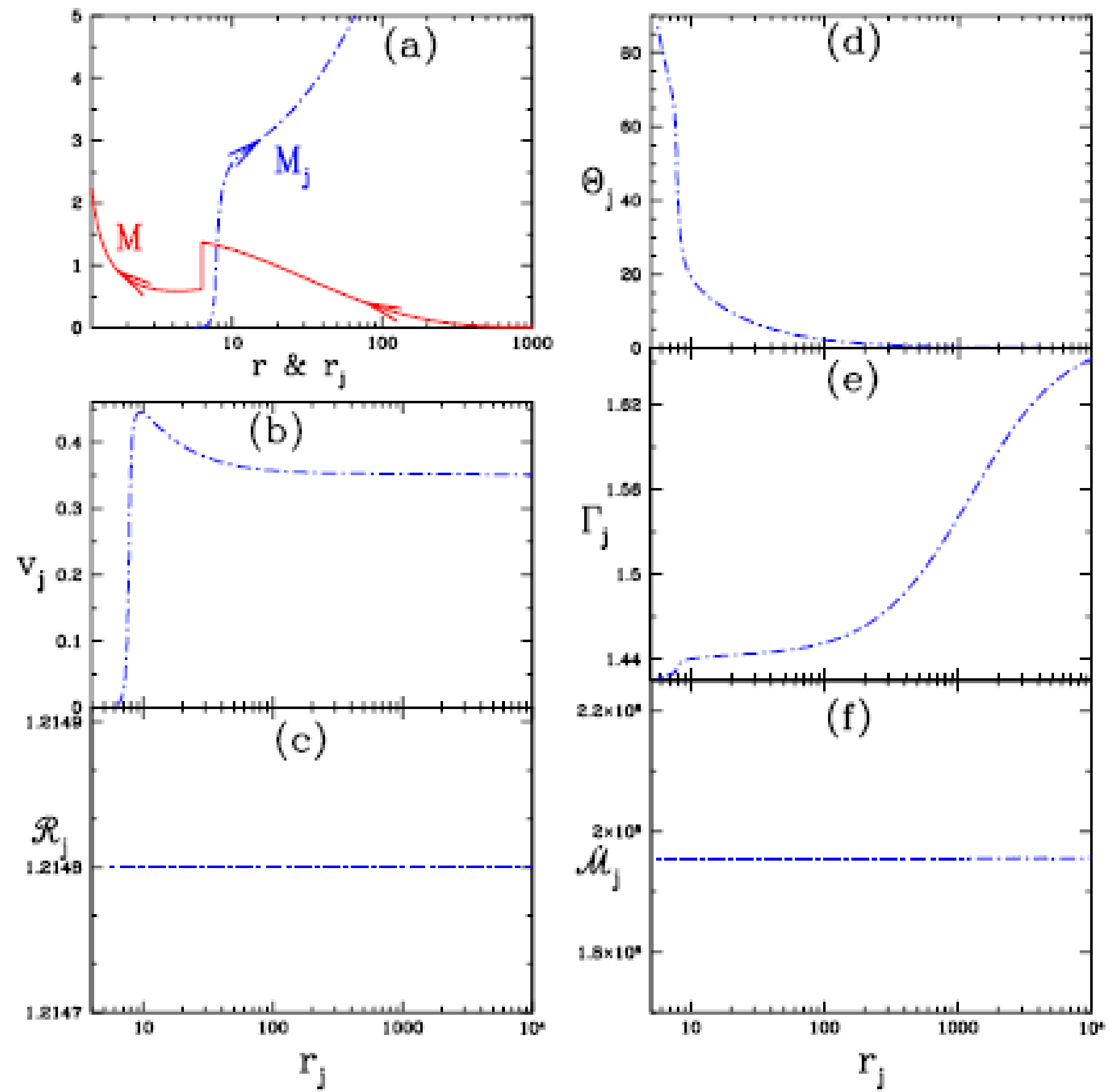
Metric term is <0
close to base
…accelerating



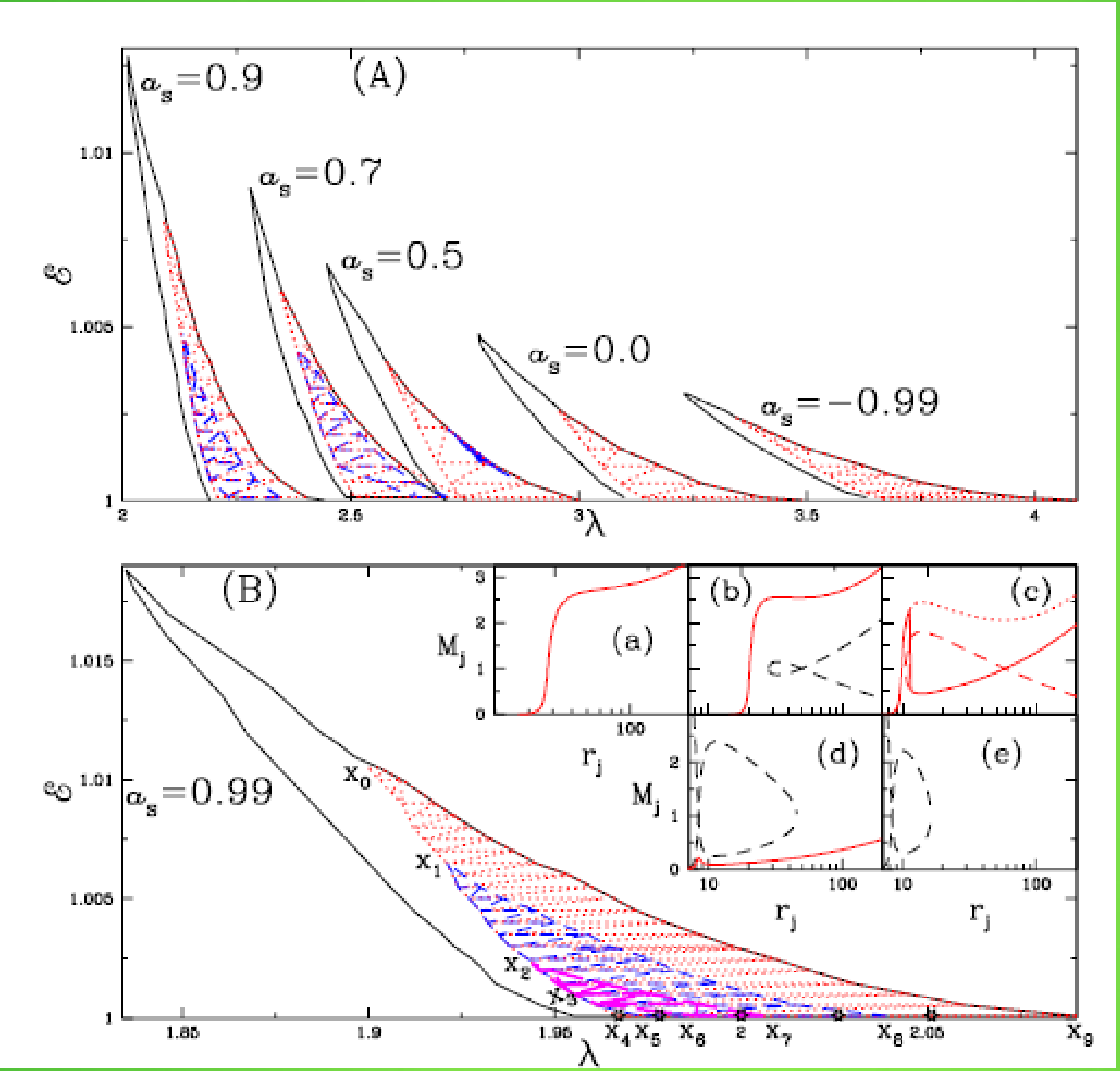
geometry. Each pair of right-left panels are plotted for $\lambda = 2$ (a, d), $\lambda = 1.99$ (b, e) and $\lambda = 1.98$ (c, f). Accretion shocks are produced at $r_{sh} = 13.8308$ (a, d), $r_{sh} = 10.8179$ (b, e) and $r_{sh} = 8.2275$ (c, f). The arrows show flow direction. For all the panels $\mathcal{E} = 1.0001, \xi = 1.0$ and $a_s = 0.99$.



of the flow. Disc parameters are $\mathcal{E} = 1.002$, $\lambda = 1.903, \xi = 1.0$ and $a_s = 0.99$. The accretion shock location is at $r_{\rm sh} = 5.9827$. The relative mass outflow rate is $R_{\dot{m}} = 0.061378$.



tion of the flow. Disc parameters are $\mathcal{E} = 1.0105, \lambda = 1.903, \xi = 1.0$ and $a_s = 0.99$ and accretion shock formed at $r_{\rm sh} = 6.2941$. The $R_{\dot{m}} = 0.054495$.



(M_j) with r_j for different (a) $\lambda = 2.05$ from region $x_0x_1x_8x_9x_0$; (b) $\lambda = 2.025$ from $x_1x_5x_8x_1$; (c) $\lambda = 2.0$ from $x_2x_6x_7x_2$, (d) $\lambda = 1.98$ from $x_3x_5x_6x_3$; and (e) $\lambda = 1.97$ from $x_3x_4x_5x_3$. The accretion disc parameters are $\mathcal{E} = 1.0001, \xi = 1.0$.

1. Jets are stronger in GR because of couplig of thermal and metric term.
2. The metric term along the VZS rapidly changes sign resulting in rapid acceleration of jet.
3. This cause multiple sonic point to form and even shock.

4. Multiple sonic point in jets form for as>0.5 and starts to form shock at as>0.6.

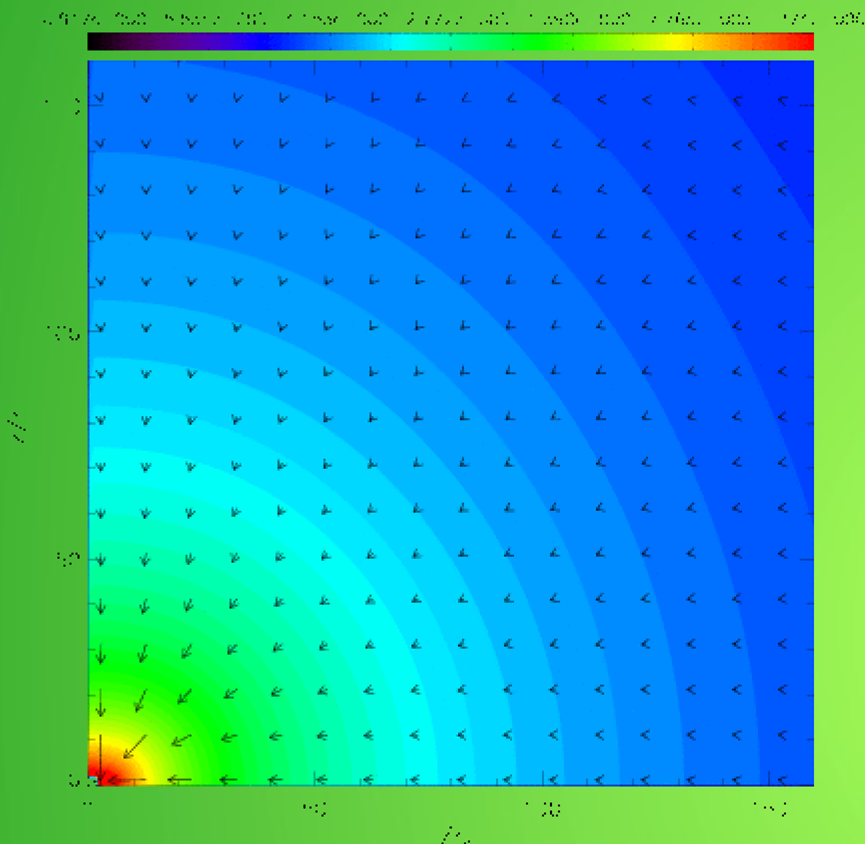
5. At some regions of the shock parameter space jets don't form as a result of BH spin, while for some other disc parameters jets have shock too.

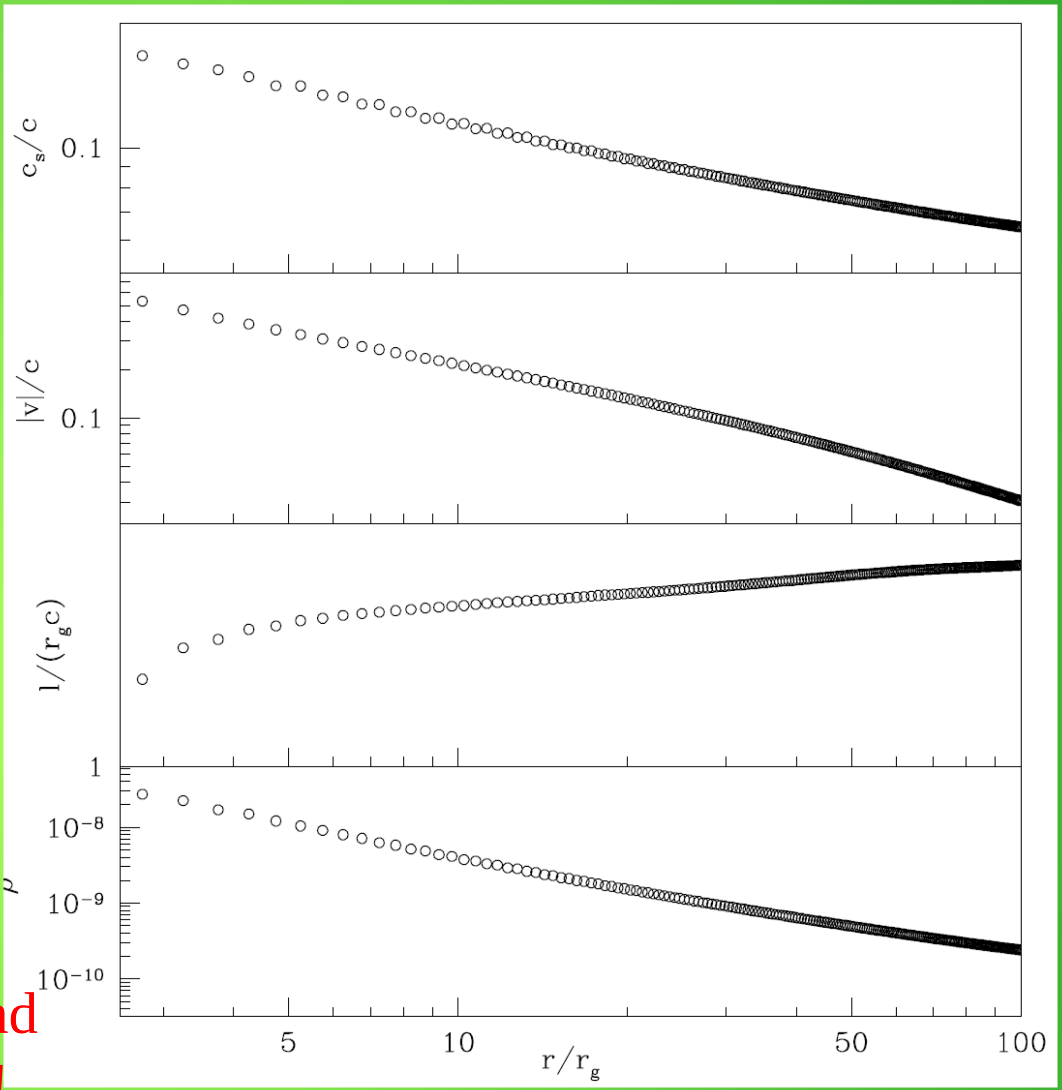
6. Shock in jet so close to the horizon can explain some of the high energy emission (Laurent et. al. 2011)

Thank you

Januray 21, 2016

Viscous flow α=0.05, shock-free `boring' solution

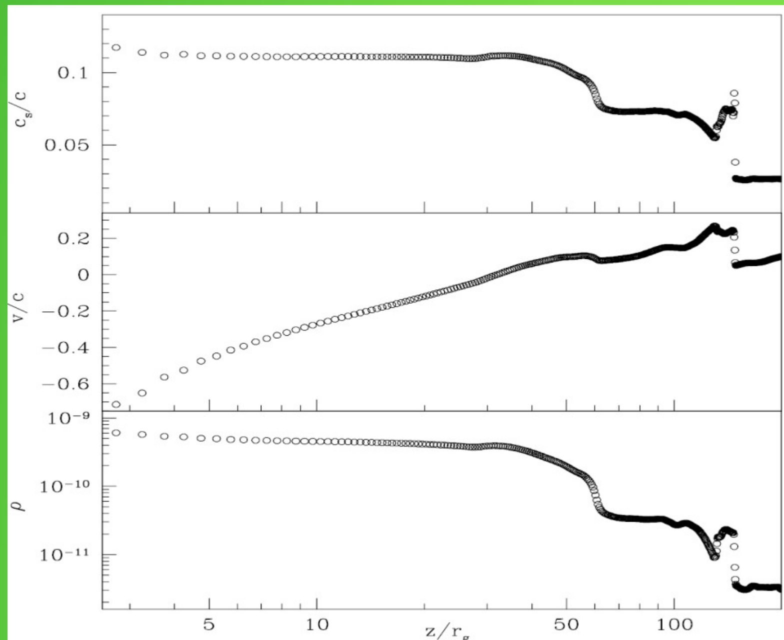


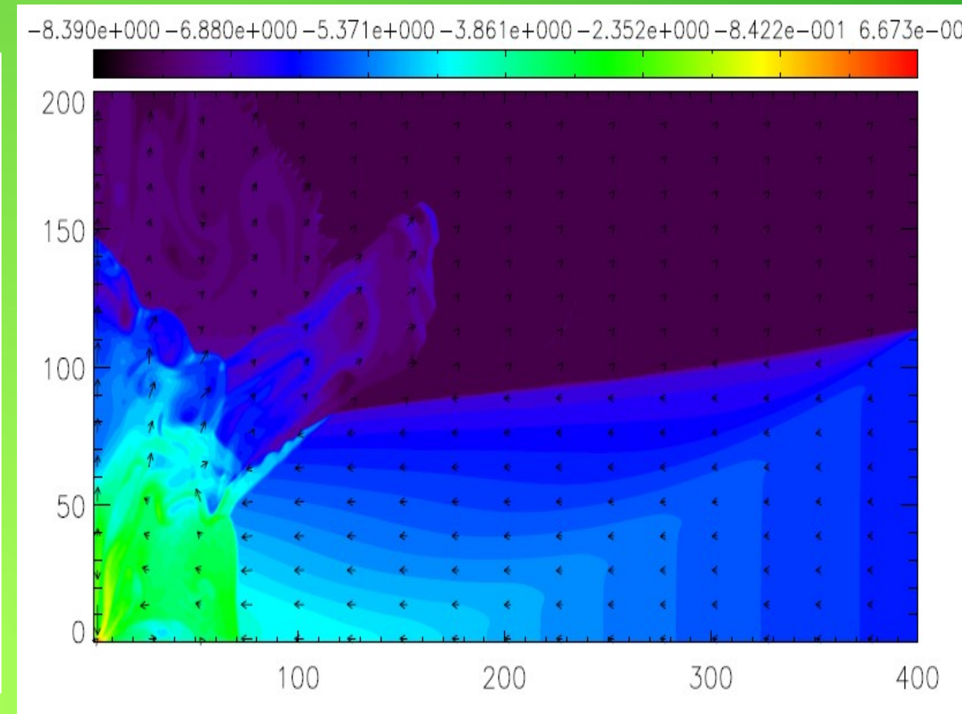


No Jets, even for higher α!! And no question of QPOs, this is steady state! For QPO pls follow Santabrata

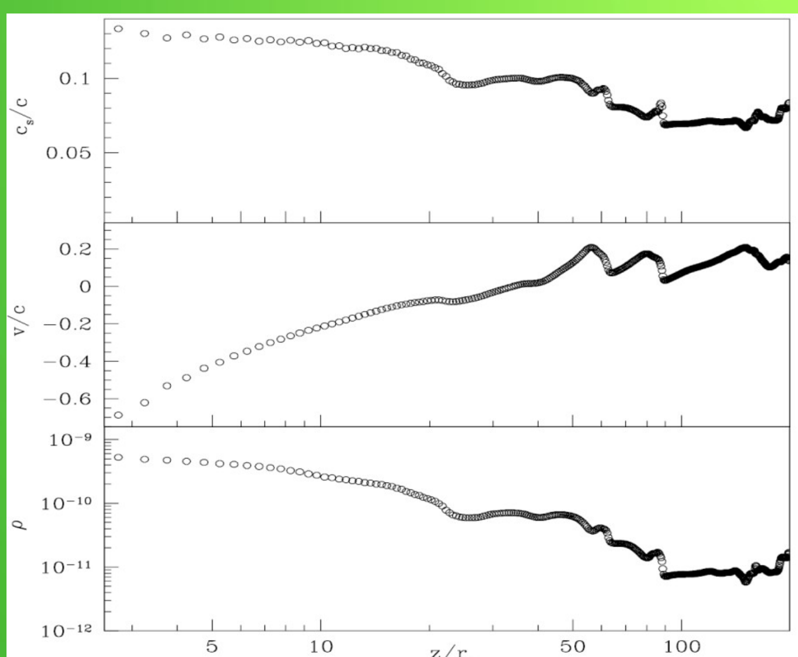
(Similar for higher α)

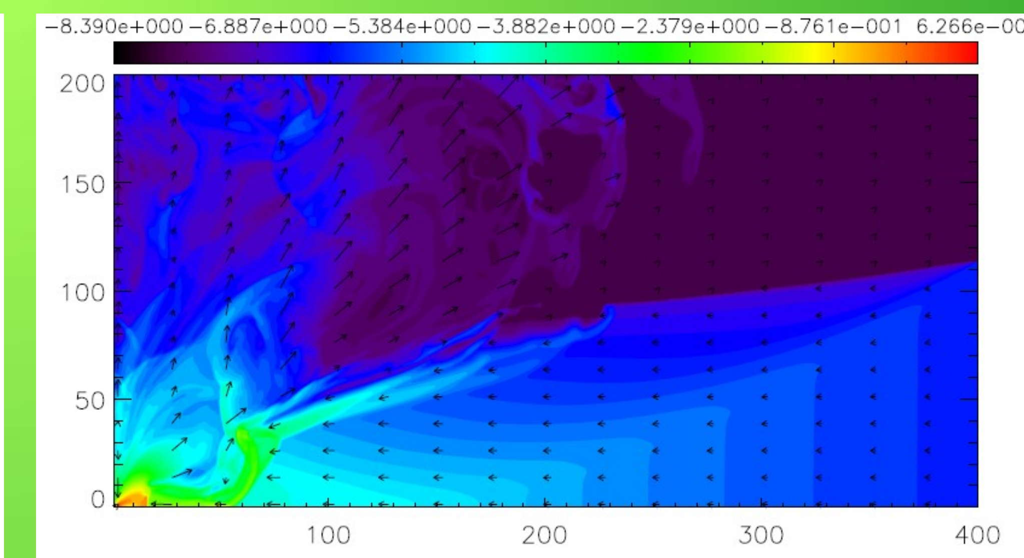
Jet-off





Jet-on





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