# Reconfinement Shocks in Relativistic Jets

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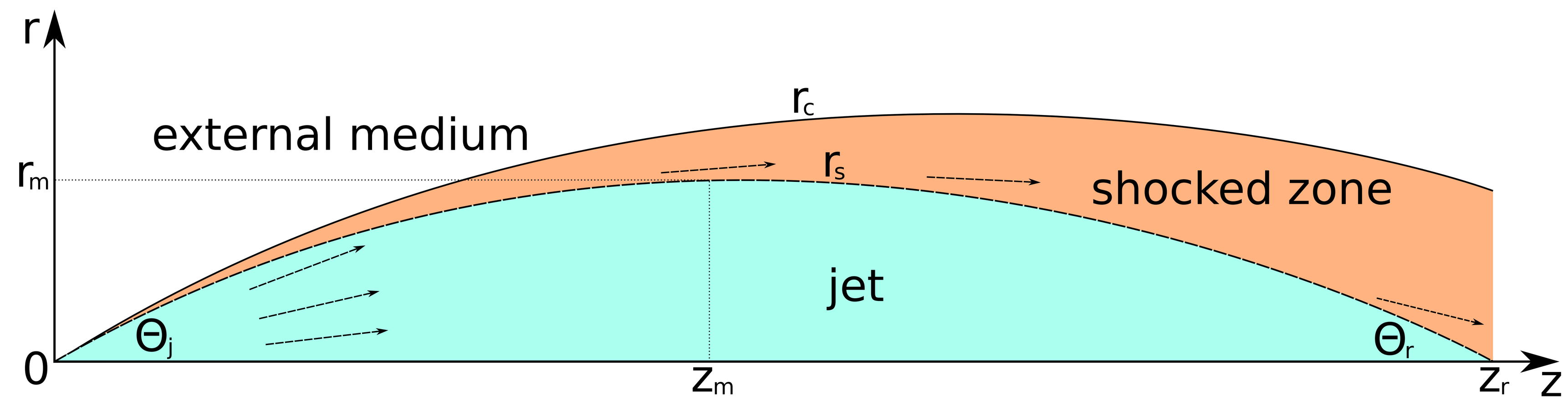
We studied the structure, dissipation efficiency and polarimetric signatures of the relativistic reconfinement shocks. We show that the efficiency depends strongly on a single parameter, which may explain the difference between jet properties in AGNs and GRBs. We calculate polarimetric maps for chaotic and/or helical magnetic field configurations.



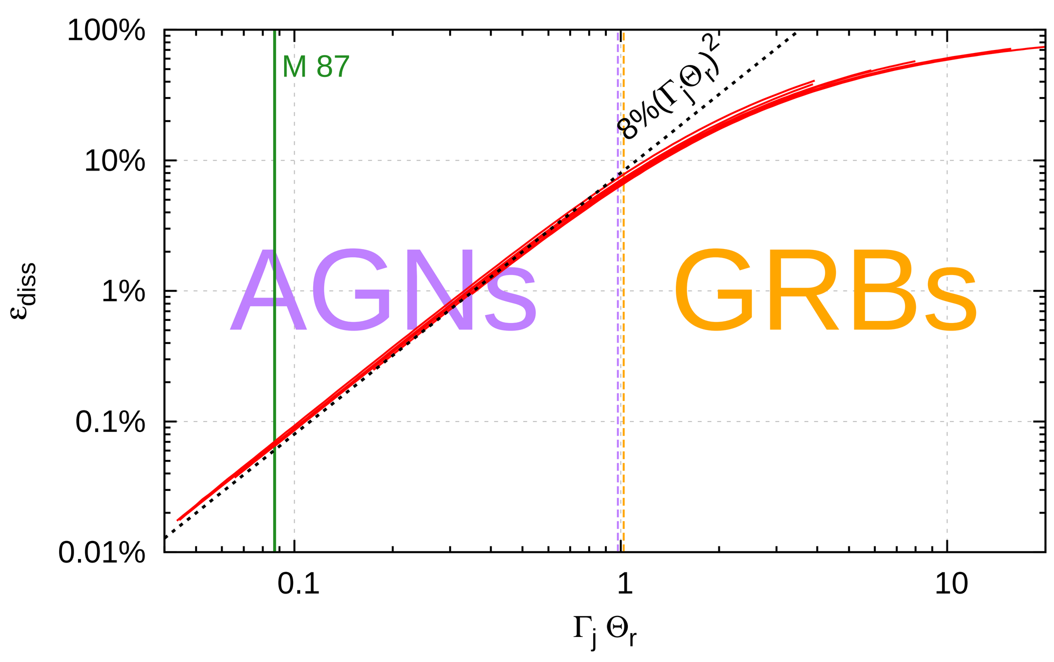

## Parameters

- reconfinement length $z_r$
- jet opening angle $\Theta_j$
- reconfinement angle $\Theta_r$
- jet Lorentz factor $\Gamma_j$
- jet power $L_j$
- external pressure $p_{ext} \sim p_0(z/z_0)^{-\eta}$

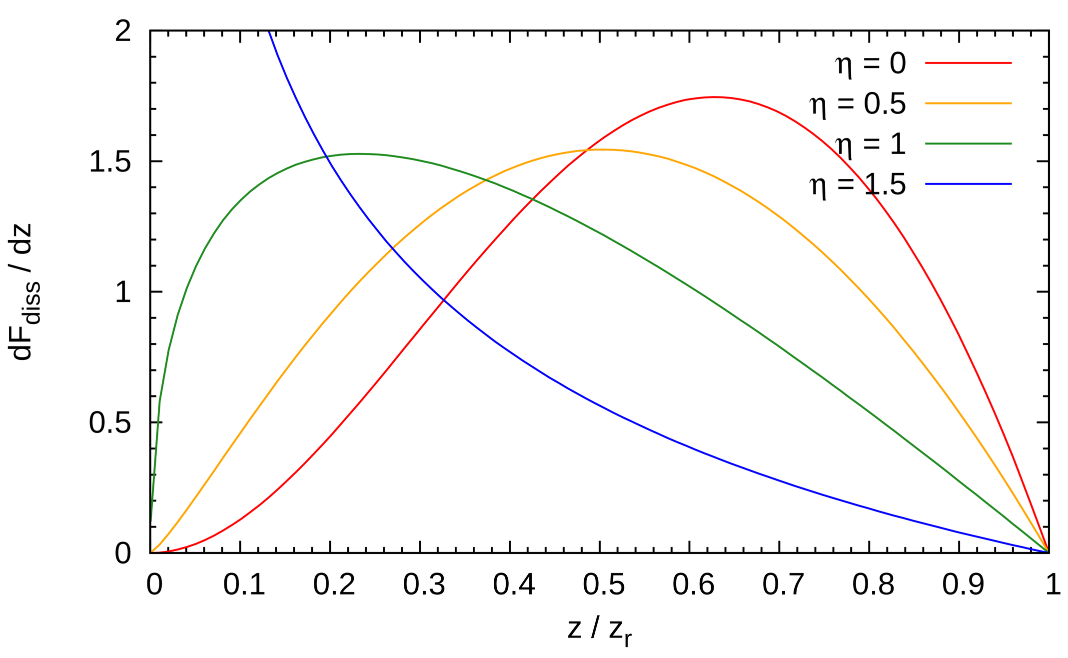
## Known results

- Reconfinement effective for $\eta \le 2$.
- For $\eta = 0$, the reconfinement length scales like $z_r \propto \sqrt{L_j/p_0}$.
- The reconfinement angle is $\Theta_r \sim (1-\eta/2)\Theta_j$.

## Efficiency




Energy dissipation efficiency for a wide range of $\Gamma_j$, $\Theta_j$ and $\eta$ depends on parameter $\Gamma_j\Theta_r$.




Distribution of dissipated energy flux along the jet. For $\eta \gtrsim 1.3$ the flux peaks at the jet origin.

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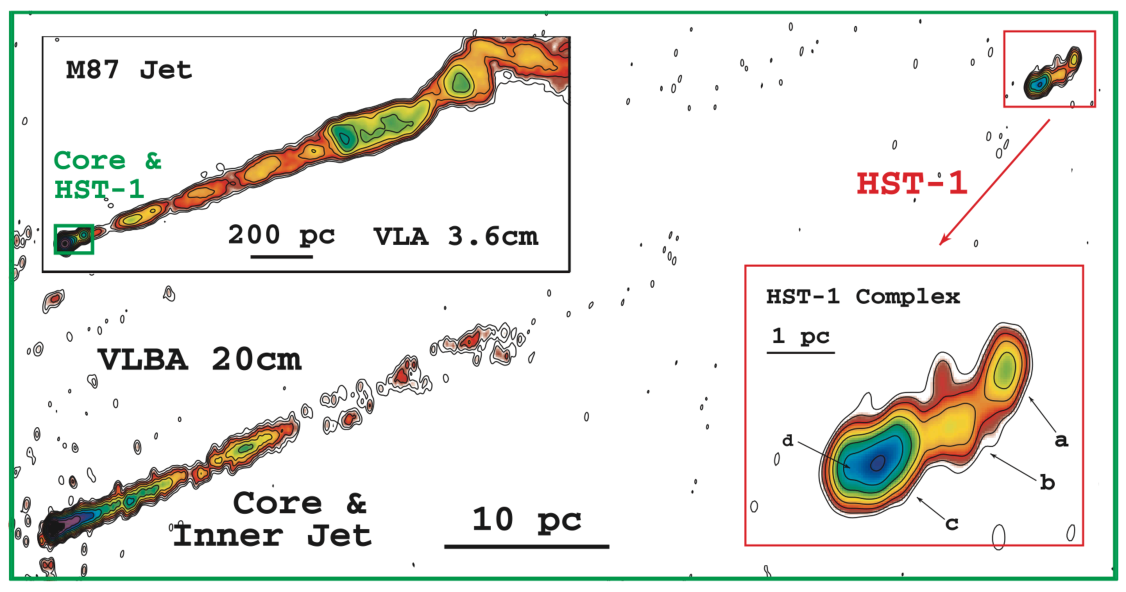



We use this radio map from [2] to estimate the efficiency of a reconfinement shock upstream the HST-1 structure. Following [7], we adopt jet Lorentz factor $\Gamma_j \sim 6$, viewing angle $\theta_{obs} \gtrsim 20^\circ$, reconfinement length $z_r \sim 180$ pc, external pressure distribution $p(z) = p_B(z/r_B)^{-1.2}$, where $p_B \sim 1.5\times10^{-9}\ \mathrm{dyn\,cm^{-2}}$ and $r_B \sim 230$ pc.

- We note that $\eta = 1.2$ is consistent with the radio emission profile peaked at the nucleus.
- On the map, we measure the projected aspect ratio $(2r_m/z_r)_{proj} \sim 0.026$.
- We estimate the reconfinement angle $\Theta_r \sim 0.83^\circ$.
- We find $\Gamma_j\Theta_r \sim 0.09$, thus we estimate the dissipation efficiency at $\epsilon_{diss} \sim 6\times10^{-4}$.
- Jet power can be estimated at $L_j \sim 5\times10^{44}\ \mathrm{erg\,s^{-1}}$, hence the predicted observed luminosity of the inner jet is $L_{obs} \sim 6\times10^{41}\ \mathrm{erg\,s^{-1}}$.

## GRBs

The prompt phase of gamma-ray bursts is characterized by very high radiative efficiency, up to $\sim 90\%$. Dissipation via internal shocks is insufficient. Several alternatives have been proposed [9, 5]. We argue that reconfinement shocks provide a natural solution.

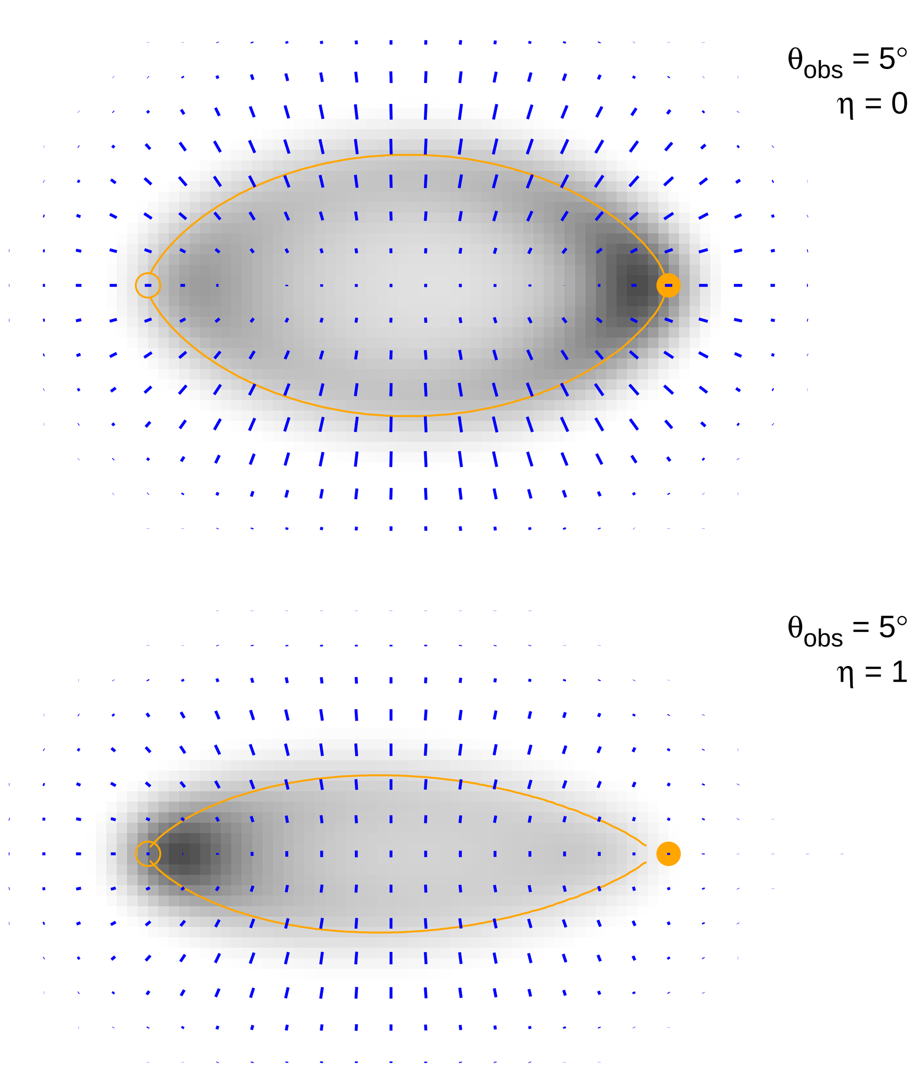
- Achromatic breaks in the afterglow light curves indicate $\Gamma_j\Theta_j \gg 1$.
- This condition can be satisfied when a jet breaks out of its progenitor star [8, 3].
- We predict that reconfinement shocks in such jets can be very efficient.
- This is supported by numerical simulations [4].

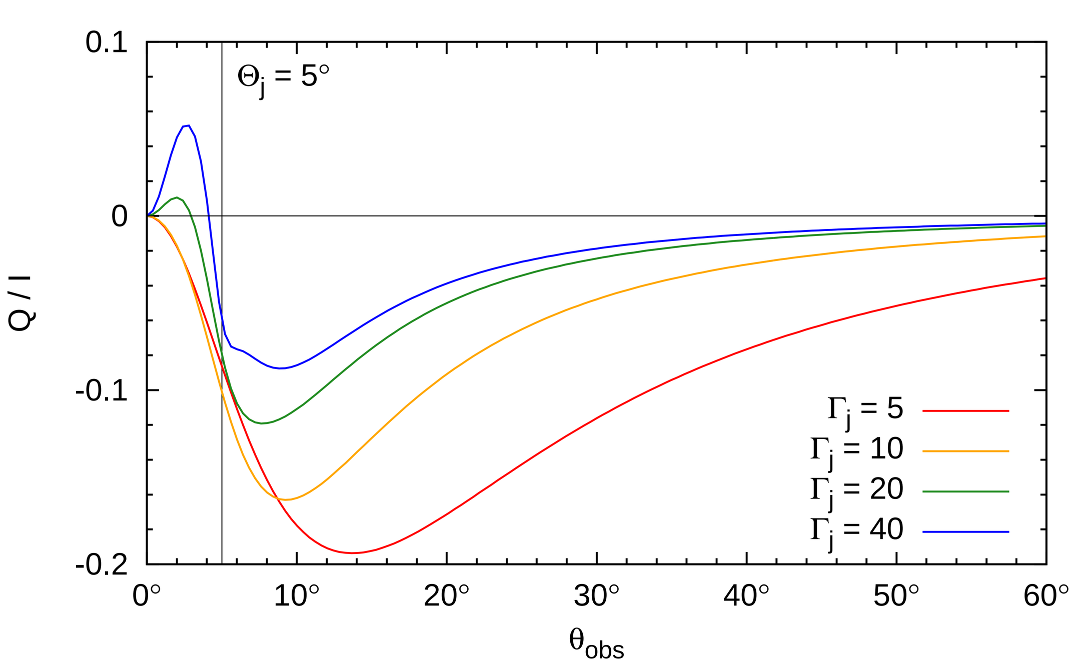
## AGNs

- Typical radiative efficiency of the order of $10\%$.
- Uninterrupted collimation results in $\Gamma_j\Theta_j \ge 1$.
- We predict dissipation efficiency up to $\sim 8\%$.

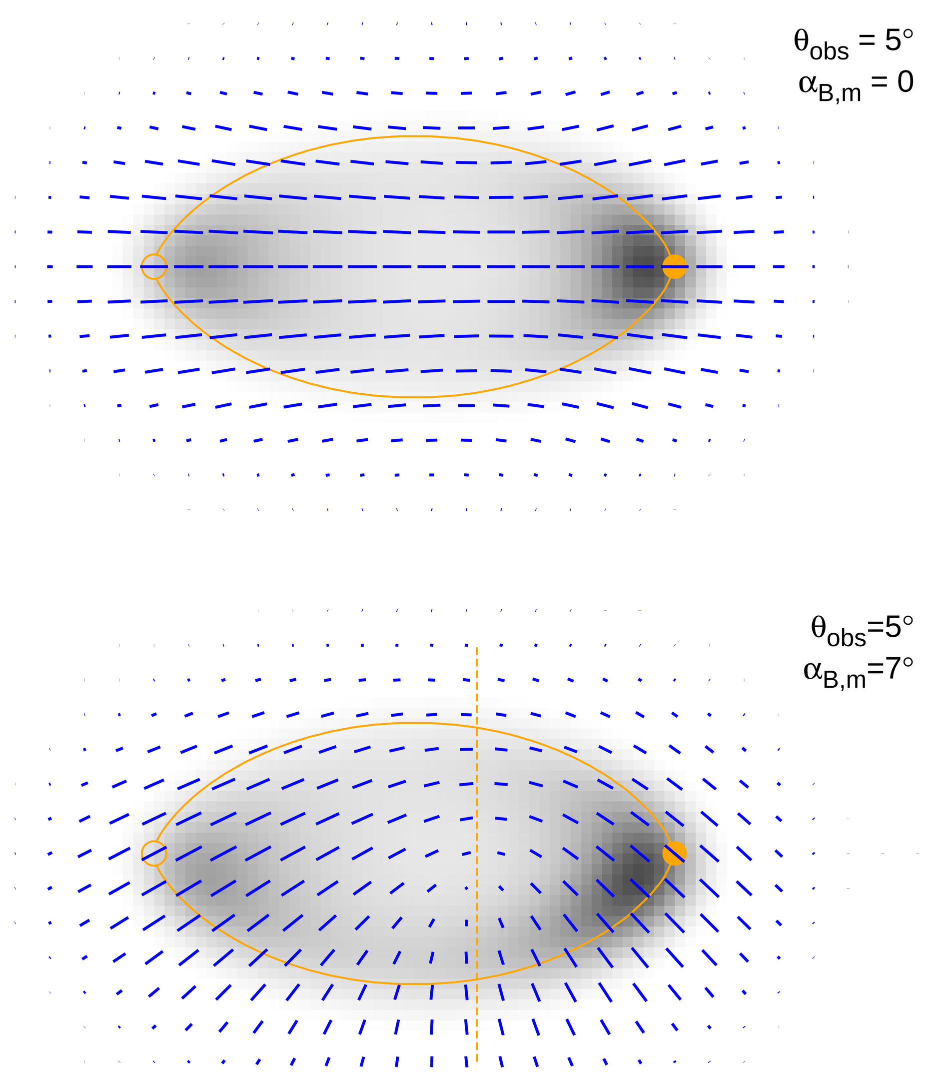
**The dissipation efficiency of relativistic reconfinement shocks can explain jet emission in both AGNs and GRBs**

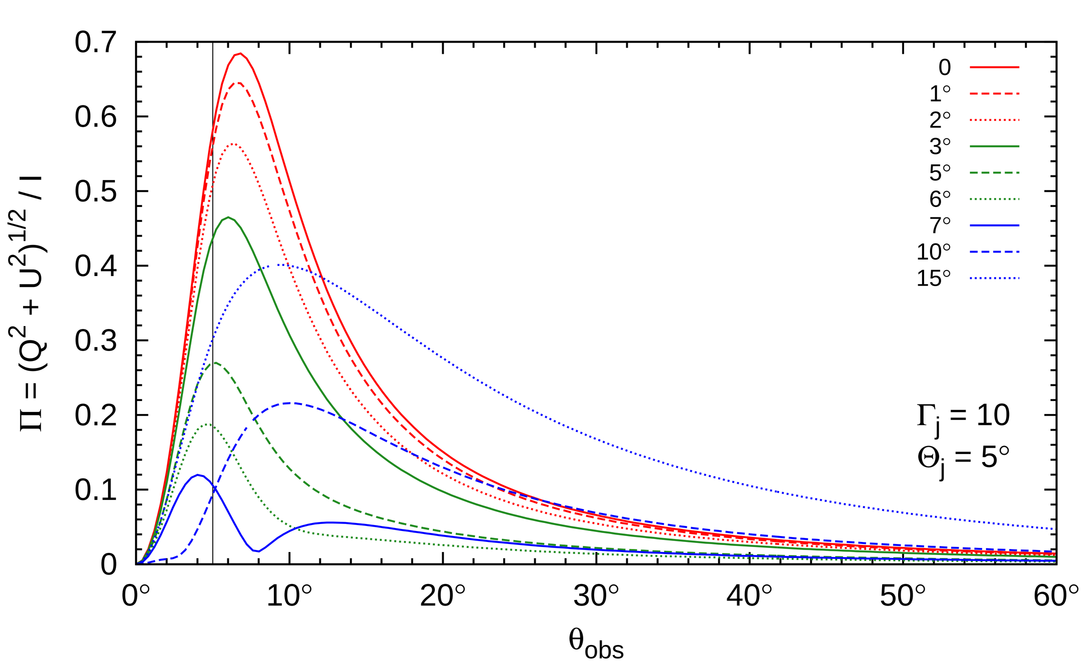
## Polarization (chaotic B-field)




## Polarization (ordered B-field)




We calculated total intensity and polarization maps for different magnetic field configurations. We considered chaotic shock-compressed fields and helical magnetic fields parametrized by the minimum pitch angle $\alpha_{B,m}$. In the case of chaotic magnetic fields, we obtained perpendicular polarization up to $\sim 20\%$. This is larger than the $10\%$ obtained by [1] for conical shocks, because the results depends on whether the upstream flow is parallel or divergent [6]. Parallel polarization requires the presence of ordered magnetic field with $\alpha_{B,m} \lesssim 7^\circ$.

## References

[1] Cawthorne, T. V., Cobb, W. K., 1990, ApJ, 350, 536
[2] Cheung, C. C., Harris, D. E., & Stawarz, Ł., 2007, ApJ, 663, L65
[3] Komissarov, S. S., Vlahakis, N., Königl, A., & Barkov, M. V., 2009, MNRAS, 394, 1182
[4] Lazzati, D., Morsony, B. J., & Begelman, M. C., 2009, ApJ, 700, L47
[5] McKinney, J. C., & Uzdensky, D. A., 2010, arXiv:1011.1904
[6] Nalewajko, K., 2009, MNRAS, 395, 524
[7] Stawarz, Ł., Aharonian, F., Kataoka, J., Ostrowski, M., Siemiginowska, A., Sikora, M., 2006, MNRAS, 370, 981
[8] Tchekhovskoy, A., Narayan, R., & McKinney, J. C., 2010, NewA, 15, 749
[9] Zhang, B., & Yan, H., 2011, ApJ, 726, 90