Estimating AGN jet parameters from observations of a jet shape break

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Overview

1. Jet boundary shape break — observations
2. Jet model with a break in a jet shape
3. Jet, black hole, and outer pressure parameters estimates
4. Conclusions

Jet in M87

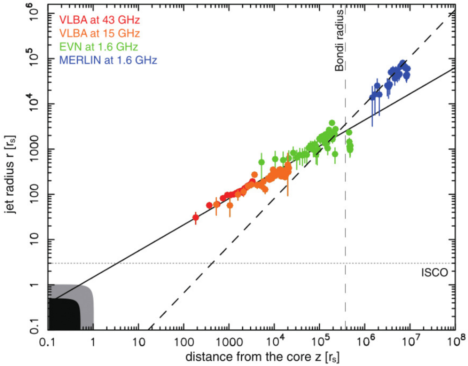

Figure: From Asada & Nakamura (2012).

The flow starts as a parabolic $r \propto d^{1.7}$ After break it is conical $d \propto r$.

1H0323+34

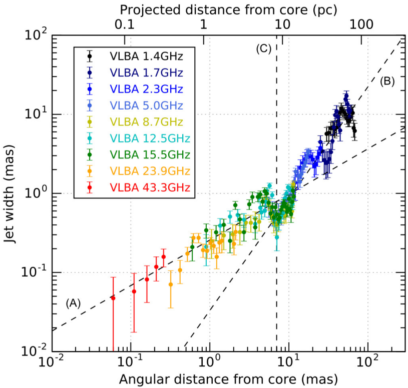

Figure: From Hada et al. (2018).

The flow starts as a parabolic $r \propto d^{1.78}$ After break it is hyperbolic $r \propto d^{0.71}$.

Model with current closure

Standart explanation: the abrupt change in outer pressure porfile.

Can we reproduce this effect without this assumption?

In many solutions the total current does not close inside a jet. The jet pressure at the boundary is magnetic and is balanced by the outer medium pressure. In this case the current sheet is assumed at the boundary.

Model with current closure

The model proposed by Beskin et al. 2017:

- The total current equals to zero at the jet boundary.
- The total velocity and magnetic field goes to zero at $d_{\rm jet}$.
- The pressure at the jet boundery is thermal.

For this model we calculate the jet cross sections and obtain the outer pressure $P_{\rm ext}$ as a function of $d_{\rm jet}$.

Pressure dependence on radius

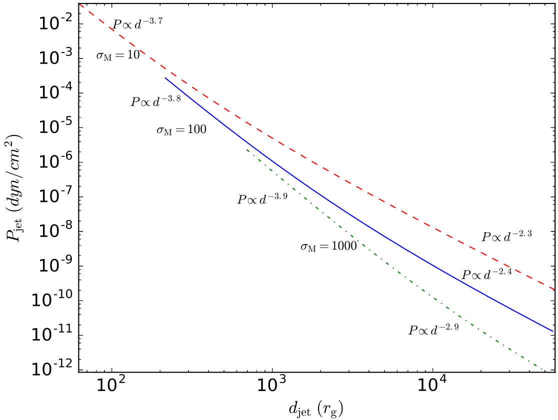

Figure: Ambient pressure $P_{\rm ext}$ as a function of jet radius d_{jet} (pc) for for different magnetization parameters $\sigma_{\rm M}$. The position of a break in a power law depends on the flow initial magnetization.

Pressure profile

The Bondi accretion predicts (Quataert & Narayan 2000, Shcherbakov 2008, Narayan & Fabian 2011) a pressure profile

$$P = P_0 \left(\frac{r}{r_0} \right)^{-2.5}.$$

Putting this in our model, we predict a change from parabolic to conical jet boundary shape, as the flow transits from magnetically dominated regime to equipartition.

We show that the change in a jet shape may be due to internal jet properties, and, thus, generic for the jets.

Jet form vs magnetization

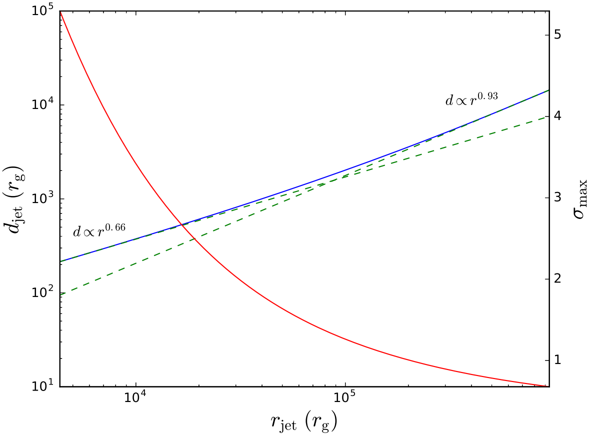

Figure: The form of a jet boundary for $\sigma_{\rm M} = 100$. The transition from one power law to the other for the jet boundary roughly coincides with the point where the outflow transits from the magnetically dominated to particle dominated (equipartition) regime.

M87 jet form

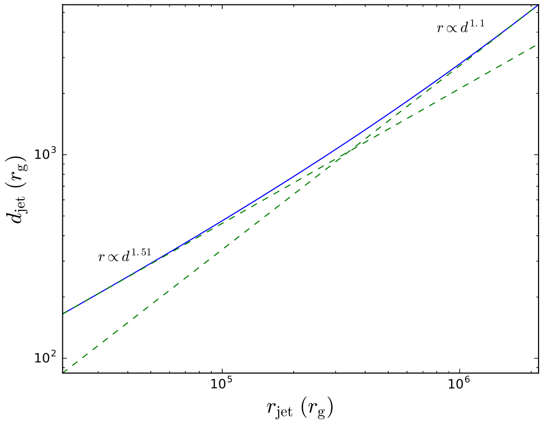

Figure: The M87 jet form obtained for $\sigma_{\rm M} = 100$, and $M = 6.6 \times 10^9$.

Jet parameter through the break position

We calculate from our modelling:

the jet width at the break

$$d_*(\sigma_{\rm M}) = \frac{d_{\rm break}}{R_{\rm L}}; \quad R_{\rm L} = R_{\rm L}(M_{BH},\ a_*);$$

pressure at the break

$$P_*(\sigma_{\rm M}) = P_{\rm break}\left(\frac{\Psi_0}{2\pi R_{\rm L}^2 \sigma_{\rm M}}\right)^{-2};$$

the position of a break along a jet

$$r_{break} = r_0\left[\frac{P_*}{P_0}\left(\frac{\Psi_0}{2\pi R_L^2 \sigma_{\rm M}}\right)^2\right]^{-0.4}.$$

We know

1. Jet width at break d_{break}
2. Position of a break r_{break}
3. BH mass
4. Pressure P_0

We obtain

1. BH spin a_*
2. Jet power W_j
3. Magnetic flux in a jet Ψ_0

Derived parameters for M87

Mass $M_{\rm BH} = 6.6 \times 10^9$ (Gebhardt et al. 2011).
Pressure amplitude $P_0 = 1.92 \times 10^{-9}\ {\rm dyn/cm^2}$ at $r_0 = 1.8 \times 10^5\ {\rm r_g}$ (Russell et al. 2015).

$\sigma_{\rm M}$	$W_{\rm j}$ (10^{42} erg/s)	a_*	$\Gamma\theta_{\rm j}$	Ψ_0 ($10^{33}\ {\rm G\,cm^2}$)
10	0.26	0.081	0.022	2.44
20	0.78	0.142	0.040	2.45
30	1.45	0.194	0.055	2.46
100	5.69	0.343	0.130	2.69

Table: Derived parameters for M87.

Notes: $\Gamma\theta_j \sim 0.17$ (Pushkarev et al. 2017); $\Gamma_{\rm max} \sim 2.5$ (Mertens et al. 2016); $W_j \sim 10^{43}$ (Levinson & Globus 2017).

Derived parameters for 1H0323+34

Mass $M_{\rm BH} = 2 \times 10^7$ (Landt et al. 2017) — by reverberation mapping. Total jet power $W_j = 5.82 \times 10^{44}$ erg/s (Cavagnolo et al. 2010; Rengelink et al. 1997). The viewing angle $\theta_{\rm obs} = 4^\circ$ (Lister et al. 2016) and 12° (Fuhrmann et al. 2016).

$\theta_{\rm obs}$ ($^\circ$)	$\sigma_{\rm M}$	a_*	$\Gamma\theta_{\rm j}$	Ψ_0 (10^{34} G cm^2)	P_0 (10^{-7} dyn/cm^2)
4	20	3.3×10^{-4}	0.05	8.8	3.7
12	50	6.4×10^{-4}	0.3	4.6	0.9

Table: Derived parameters for 1H0323+34.

Derived parameters for 1H0323+34

Hada et al. (2018): the mass may be underestimated. The break is at the same position in r_g as the one in M87, the mass must be $10^{8.6}\ M_\odot$ or $10^{9.5}\ M_\odot$. We can estimate mass within our model. Let us assume $a_* = 0.1$.

$\theta_{\rm obs}$ ($^\circ$)	$\sigma_{\rm M}$	$\lg(M/M_\odot)$	$\Gamma\theta_{\rm j}$	Ψ_0 (10^{34} G cm^2)	P_0 (10^{-7} dyn/cm^2)
4	20	9.78	0.15	8.7	3.7
12	50	9.50	0.31	4.6	1.0

Table: Derived parameters for 1H0323+34.

Conclusions

- The model by Beskin et al. (2017) explains the observed jet shape break due to internal jet properties.
- We think that the jet shape break must be generic.
- This interpretation allows to recover jet, BH, and outer pressure properties from the jet shape break position.
- For M87 we recover BH spin, total magnetic flux, and total jet power.
- For 1H0323+34 we recover mass, total magnetic flux, and an amplitude of outer pressure.

Thank you for your attention!