MOSCOW INSTITUTE OF PHYSICS AND TECHNOLOGY

Evidence for parabolic jet shapes in distant AGN

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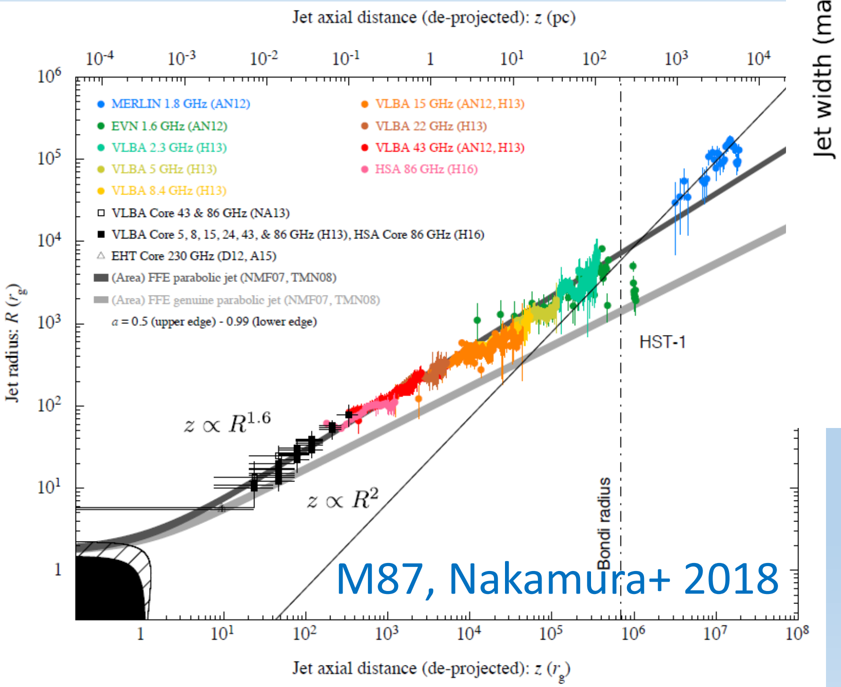
MNRAS (2020) **495**, 3576

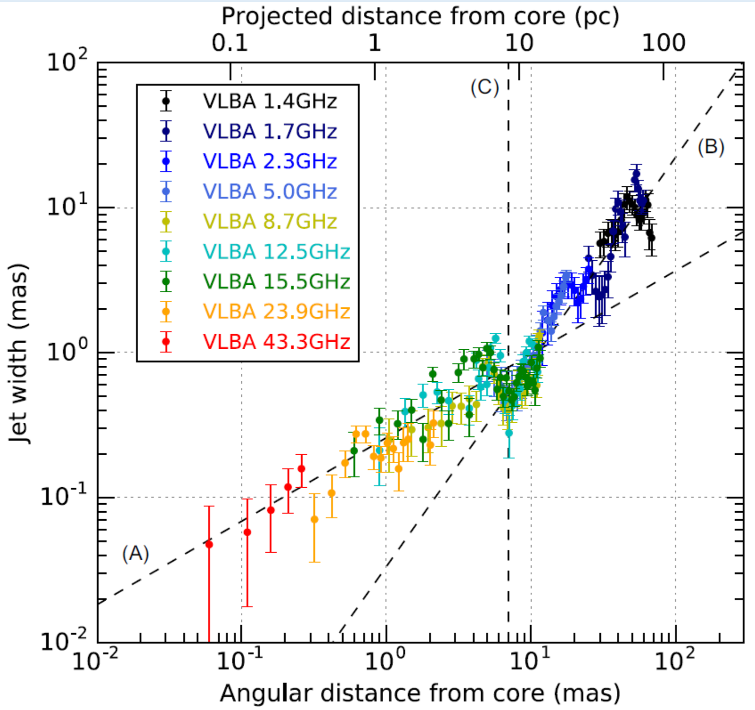
MNRAS (2020) **498**, 2532

Break in jet shapes

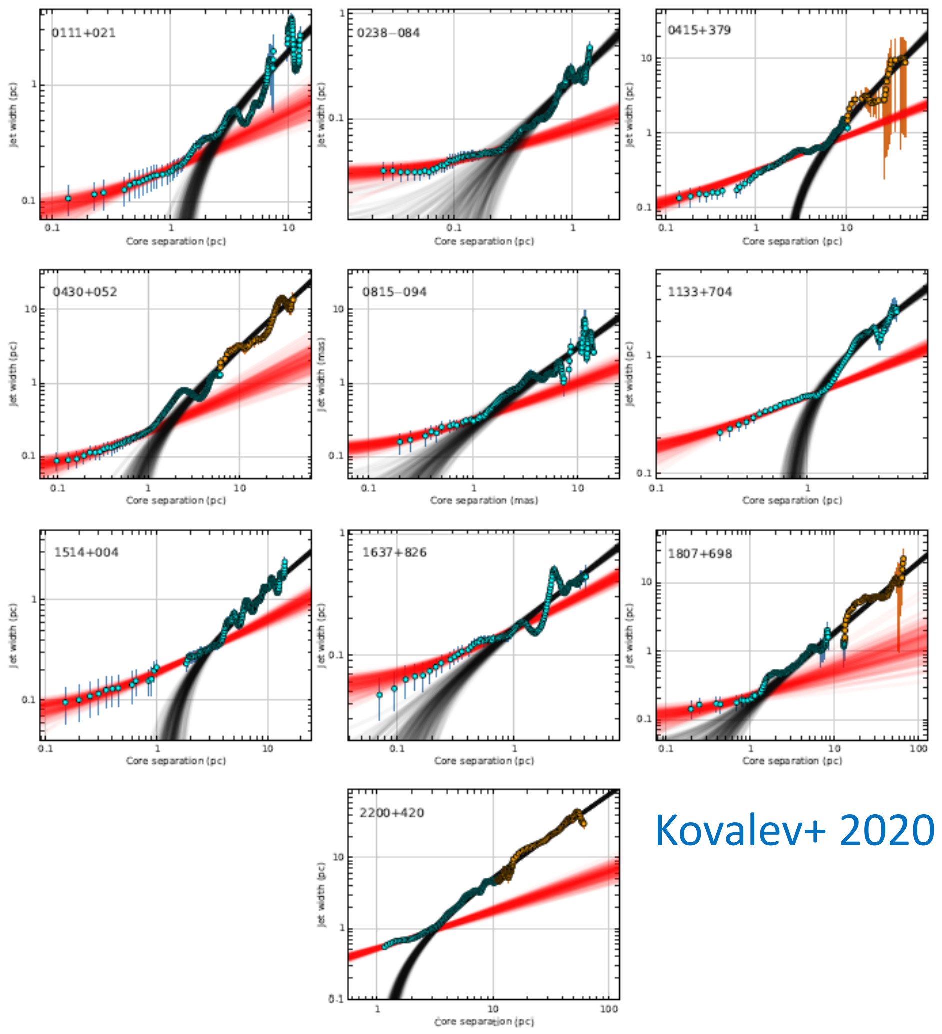
- Found in a dozen of sources (radio galaxies, blazars, narrow line Seyferts) (FRI, FRII)
- All of the are nearby: red shift < 0.1
- All of them with large enough observational angle



M87, Nakamura+ 2018

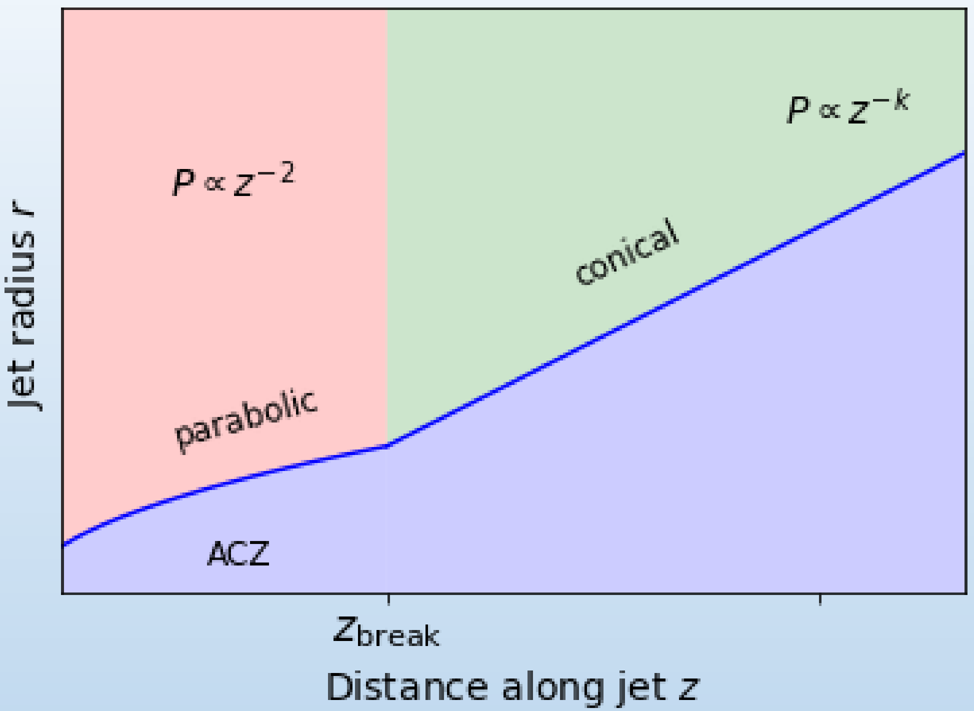


1H 0321+342, Hada+ 2018



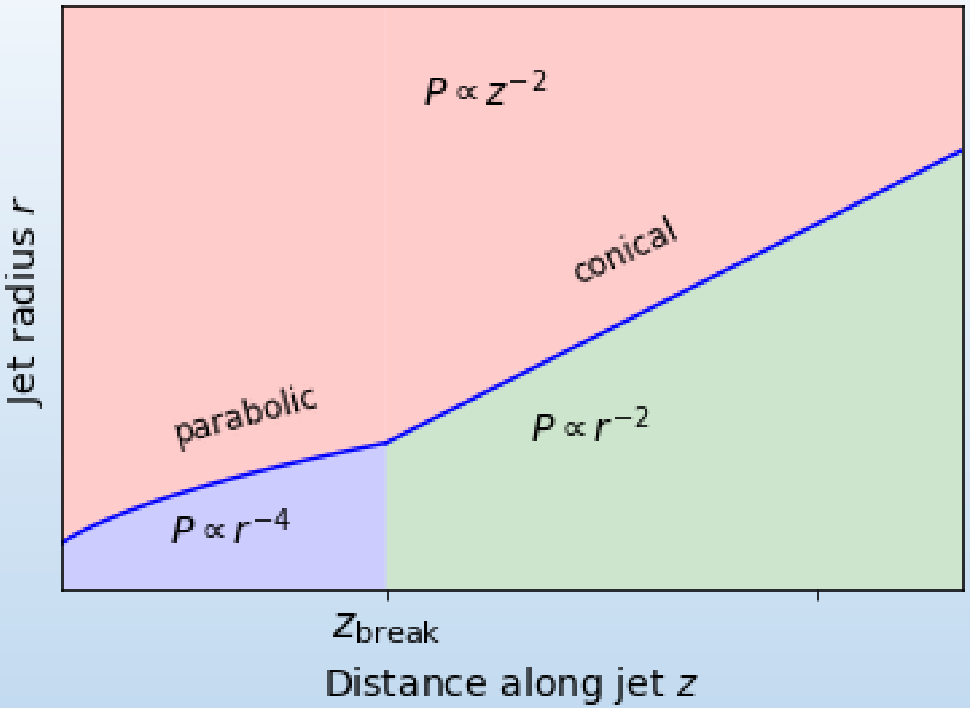
Kovalev+ 2020

Break due to change in ambient medium pressure profile:



Asada & Nakamura 2012, Levinson & Globus 2017, Boccardi+ 2021

Break due to inner jet conditions:



Lyubarsky 2009, Beskin+ 2017, Kovalev+ 2020

Break is an instrument for learning about

- ambient medium
- jet acceleration / magnetization / collimation

Is a break universal or a feature of nearby sources?

While **direct** measurements of more distant sources are limited by the resolution, we may employ the **implicit method**

Method

Measurements:

- cores at 8 & 15 GHz positions
- velocities by delays in flares in 15 & 8 GHz cores (Kudryavtseva+ 2011) – we suppose they reflect maximum velocities
- sources – high variability due to maximization of Doppler factor (Kutkin+ 2019, K19)

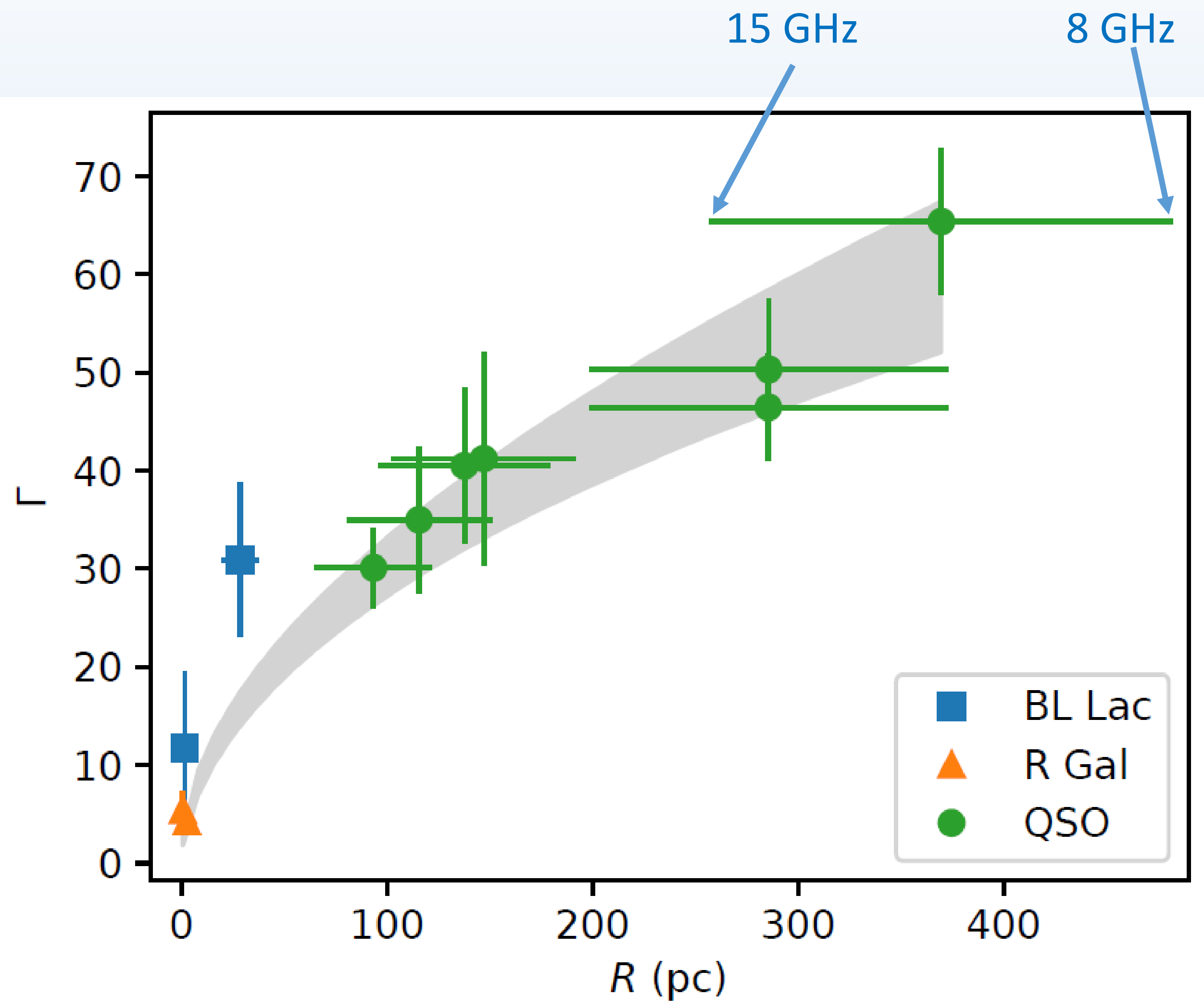


Figure 8. Lorentz factors on various de-projected jet scales. The shaded area shows 95% of posterior samples obtained with MCMC. The horizontal bars denote $R_{15} - R_8$ distance.

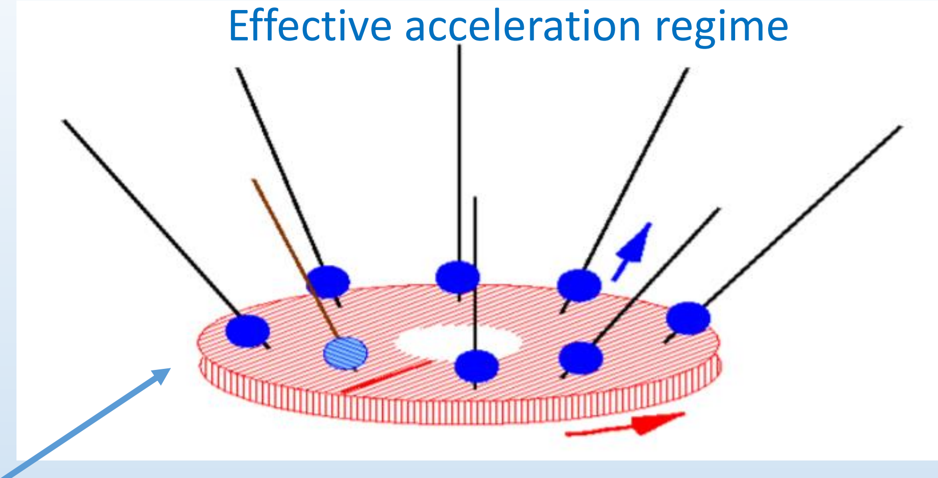
Kutkin+ 2019 (K19)

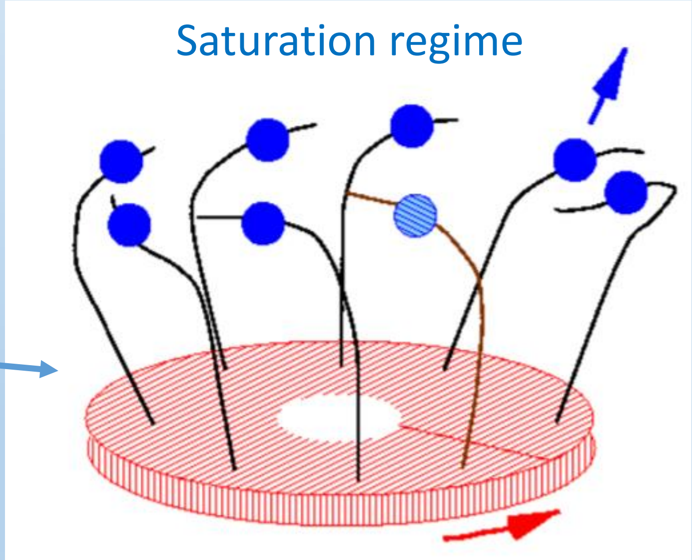
Method

Theory:

Analytical, semi-analytical, numerical models for acceleration:

$$\Gamma = \begin{cases} \dfrac{r}{R_L}, & r < \Gamma_{max} R_L/2, \\ \dfrac{\Gamma_{max}}{2}, & r > \Gamma_{max} R_L/2. \end{cases}$$





From lectures by Beuther & Fendt

Method

Universal MHD acceleration(centrifugal) – linear with jet radius

$$\Gamma = \frac{r}{R_L}$$

+

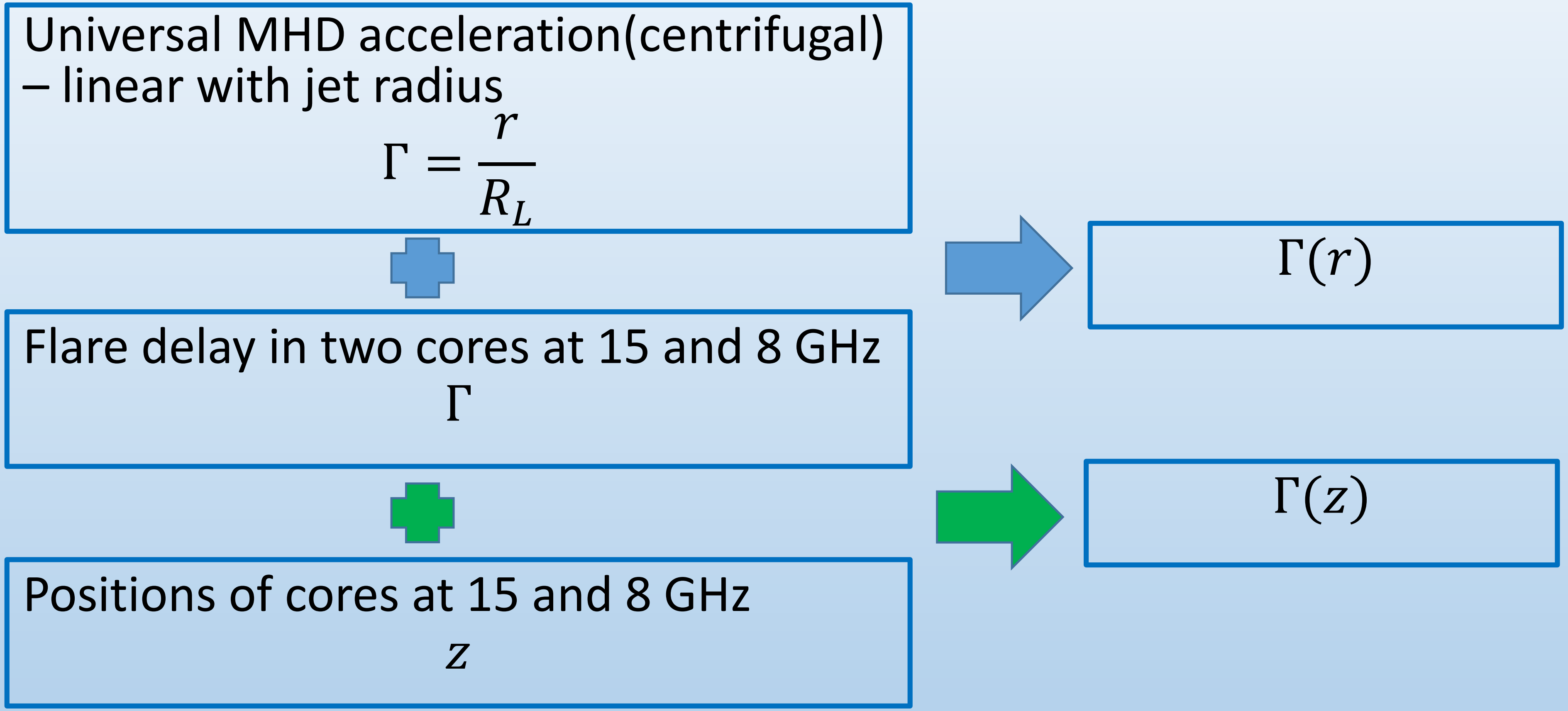
Flare delay in two cores at 15 and 8 GHz

$$\Gamma$$

→

$$\Gamma(r)$$

Method



Universal MHD acceleration(centrifugal) – linear with jet radius

$$\Gamma = \frac{r}{R_L}$$

Flare delay in two cores at 15 and 8 GHz

Γ

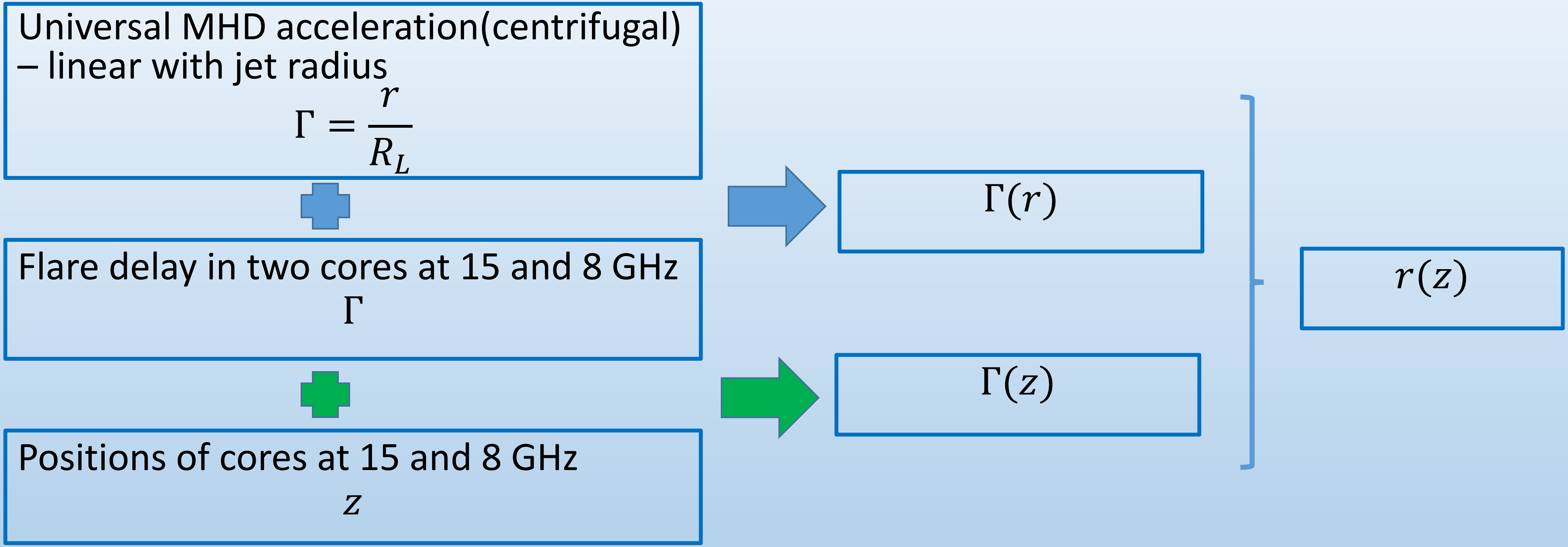
Positions of cores at 15 and 8 GHz

z

$\Gamma(r)$

$\Gamma(z)$

Method



Universal MHD acceleration(centrifugal) – linear with jet radius

$$\Gamma = \frac{r}{R_L}$$

Flare delay in two cores at 15 and 8 GHz

$$\Gamma$$

Positions of cores at 15 and 8 GHz

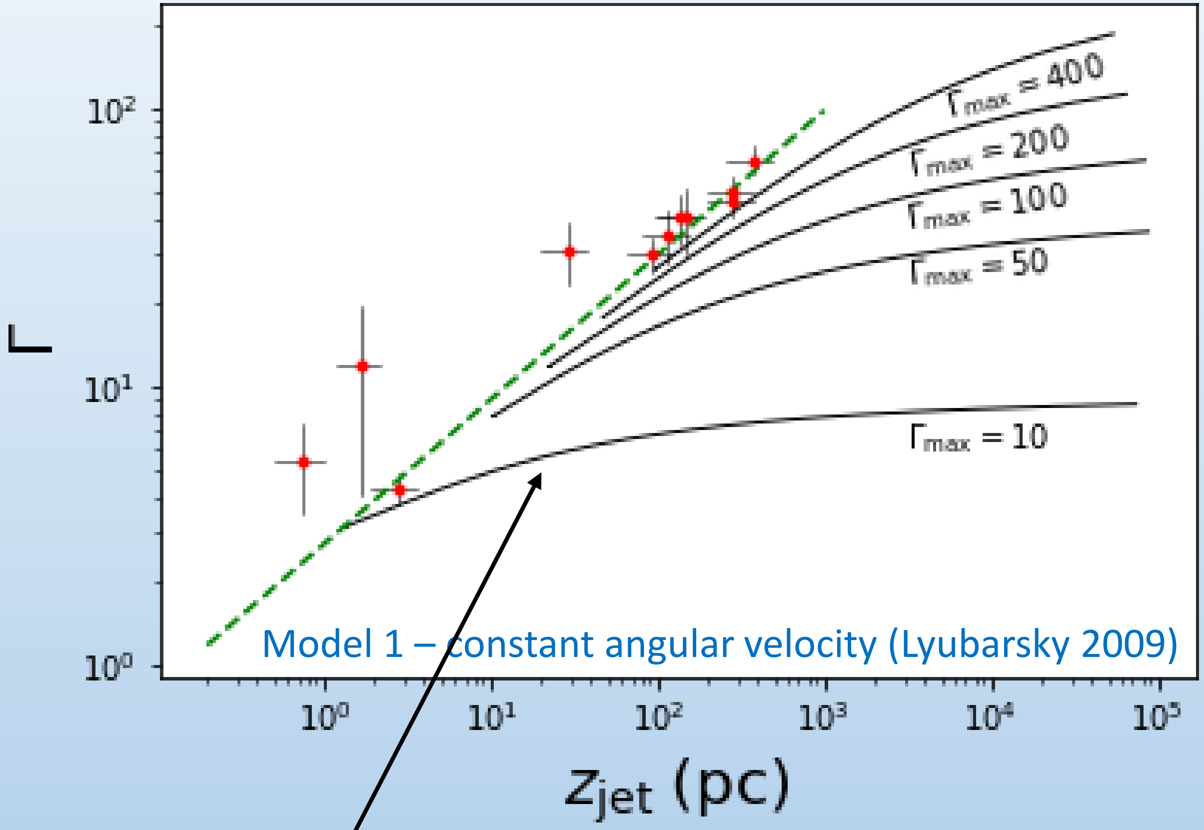
$$z$$

$$\Gamma(r)$$

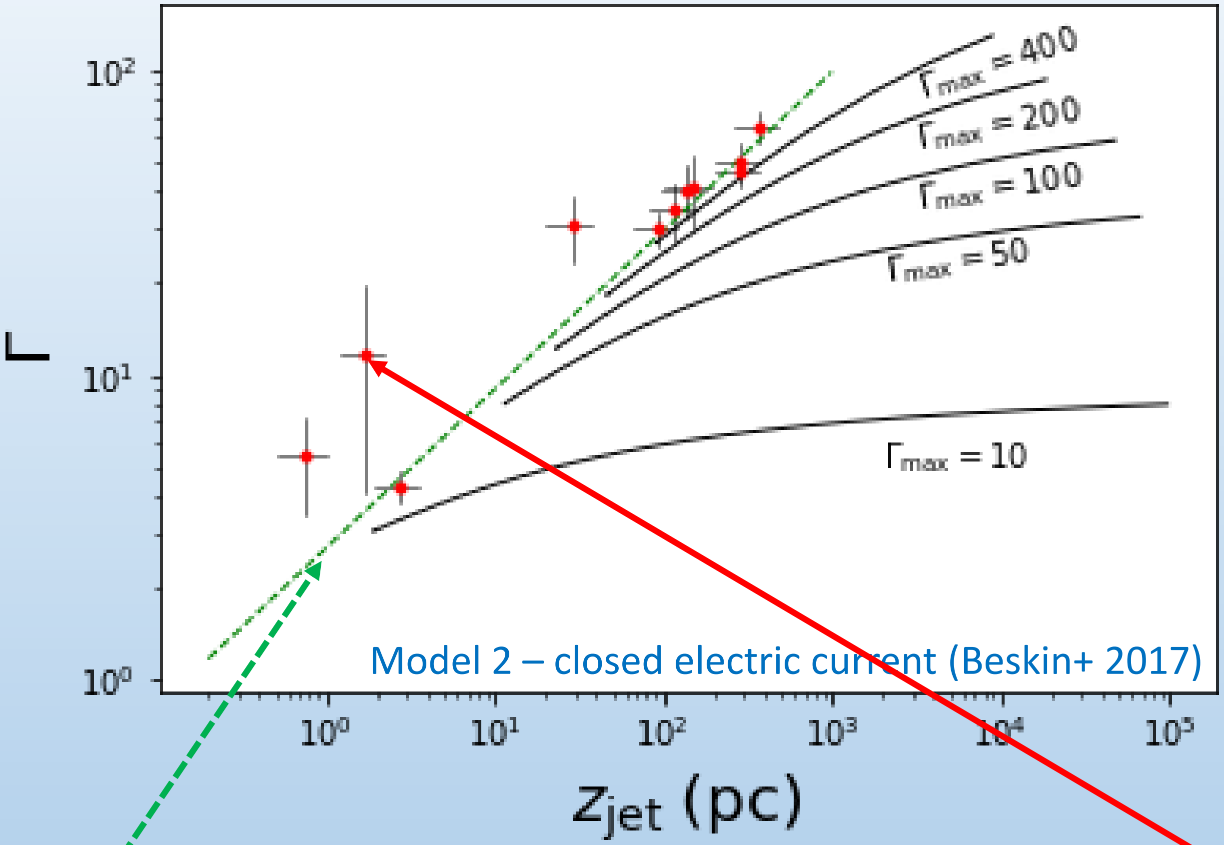
$$\Gamma(z)$$

$$r(z)$$

Results



Model 1 – constant angular velocity (Lyubarsky 2009)



Model 2 – closed electric current (Beskin+ 2017)

Semi-analytical modelling

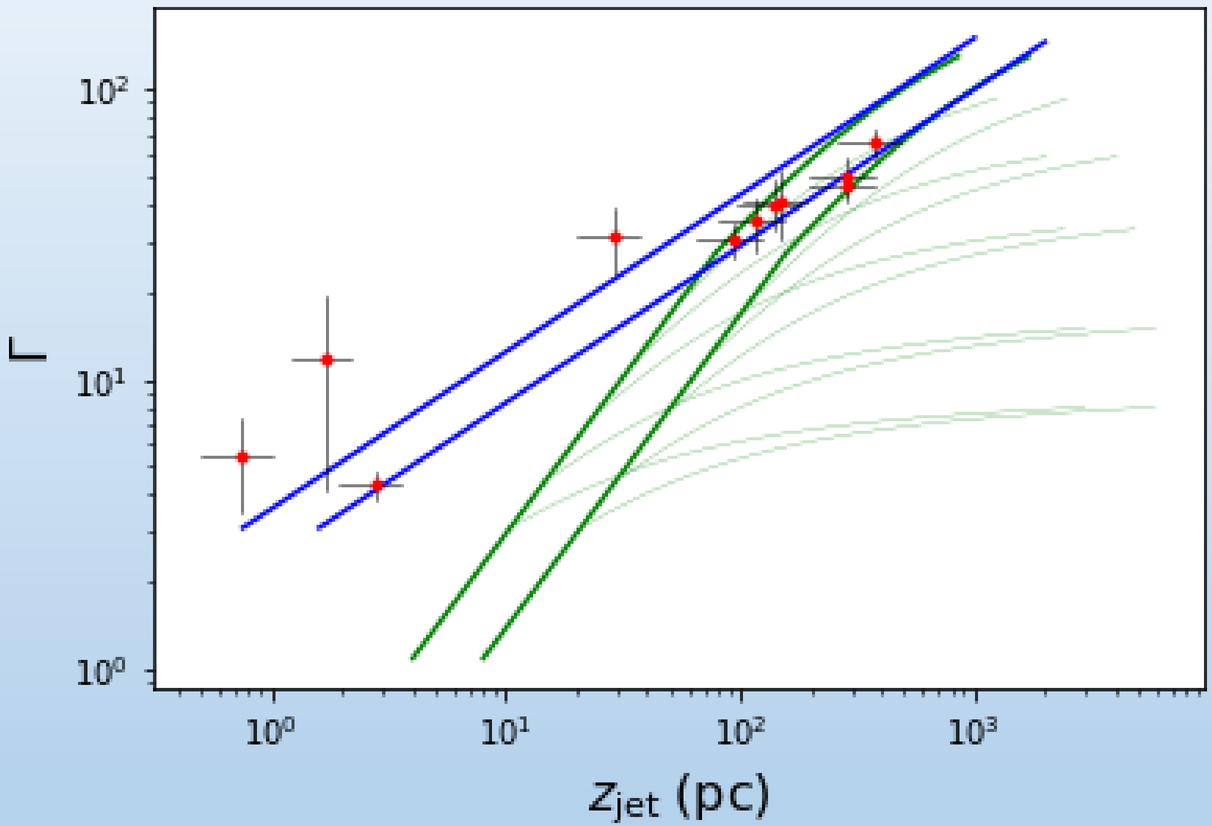
Envelope

Data

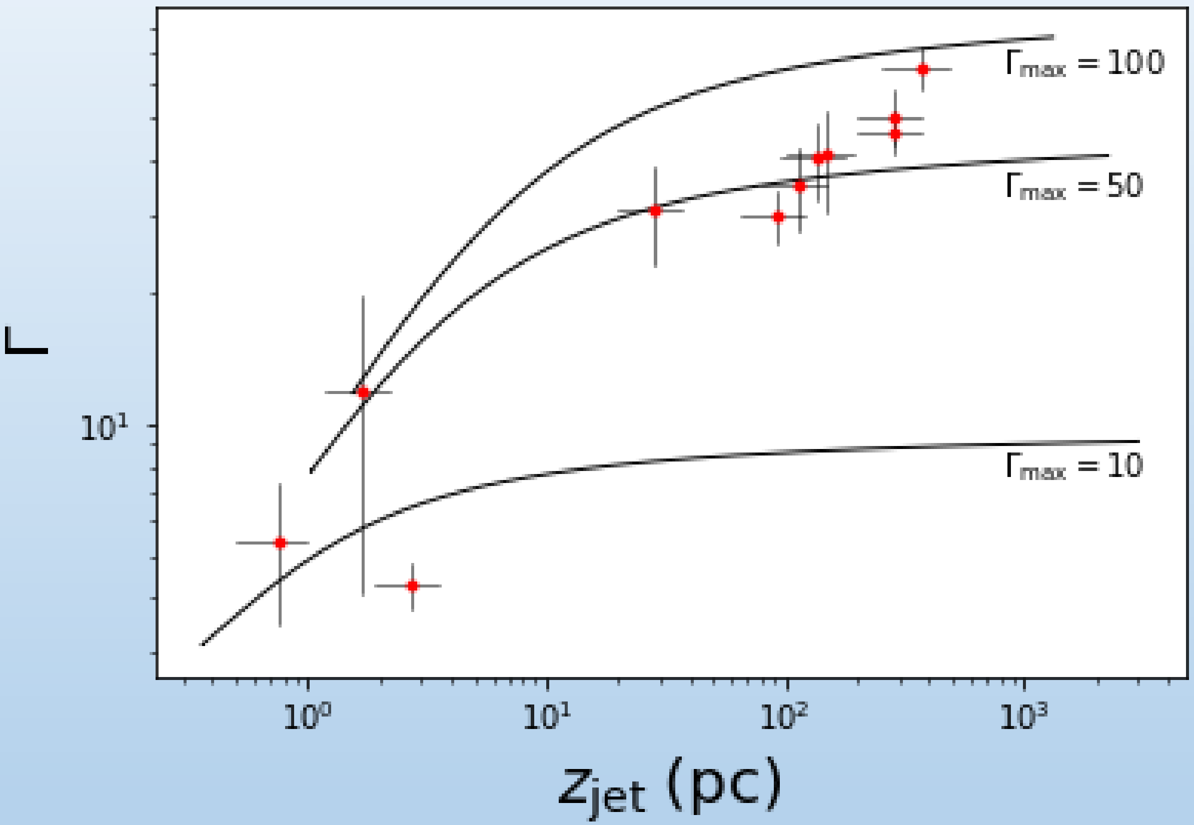
The data is fully consistent with core being in parabolic region in effective acceleration regime

Results

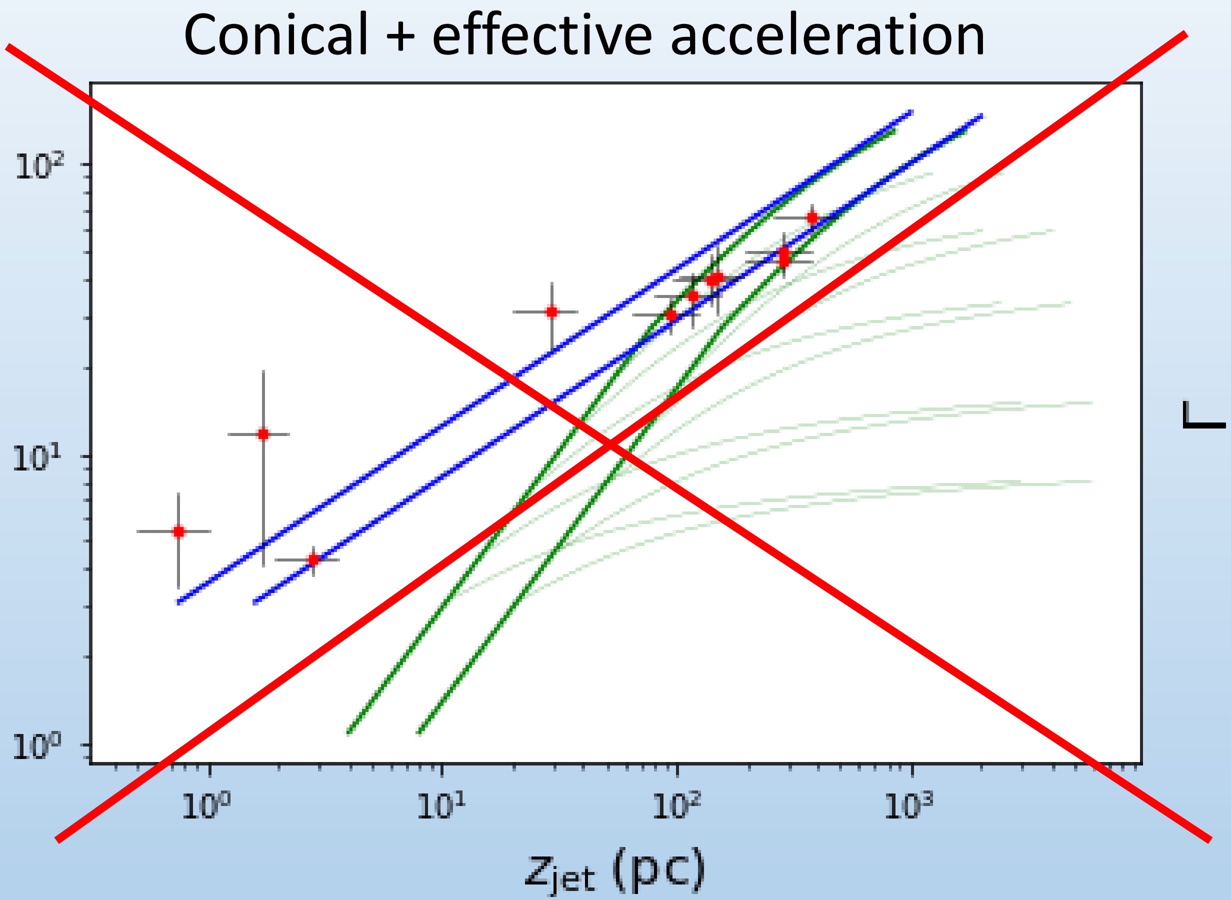
Conical + effective acceleration

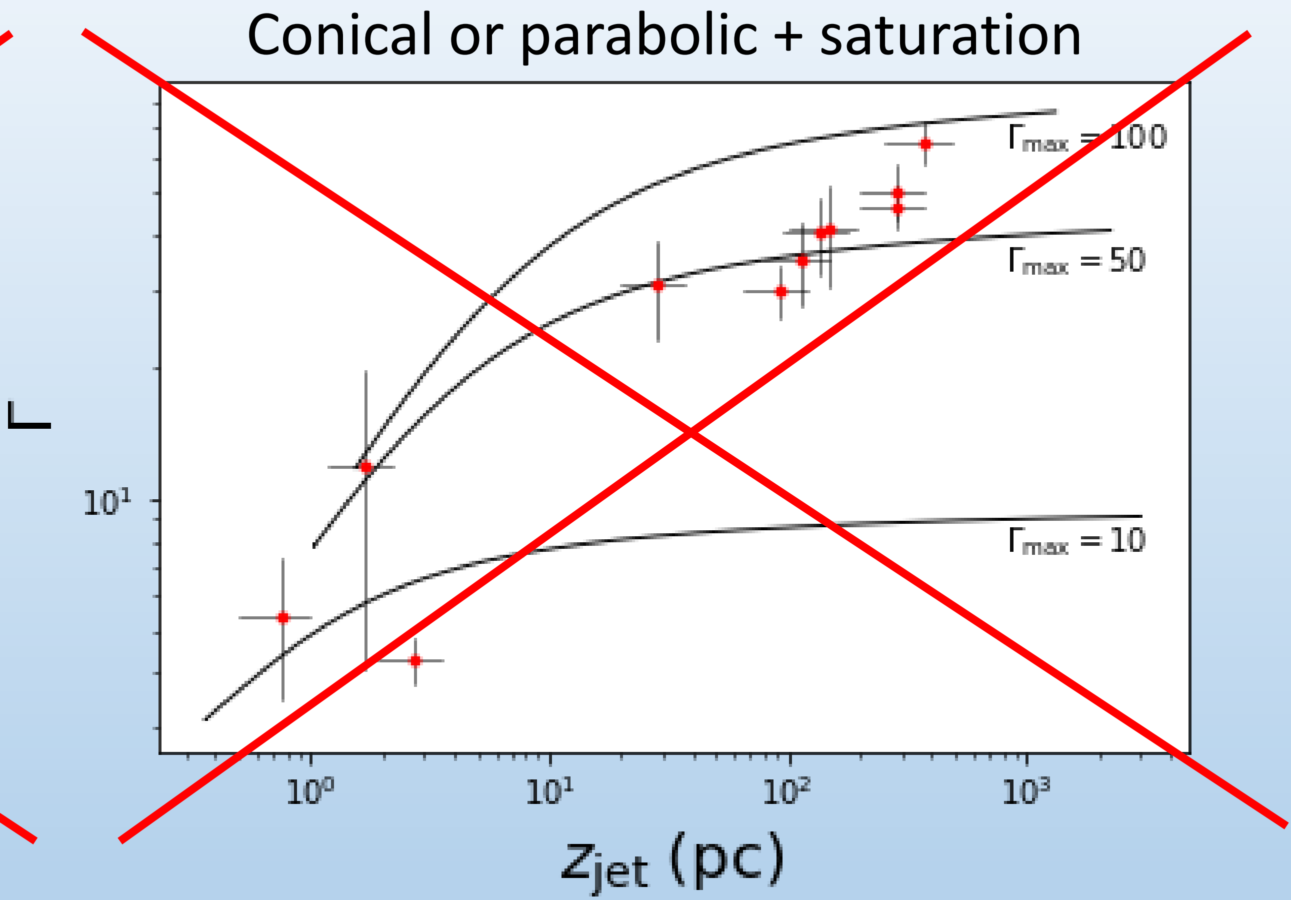


Conical or parabolic + saturation



Results


Conical + effective acceleration
10^2
10^1
10^0
Γ
10^0
10^1
10^2
10^3
$z_{\rm jet}$ (pc)


Conical or parabolic + saturation
$\Gamma_{\rm max} = 100$
$\Gamma_{\rm max} = 50$
$\Gamma_{\rm max} = 10$
10^1
Γ
10^0
10^1
10^2
10^3
$z_{\rm jet}$ (pc)

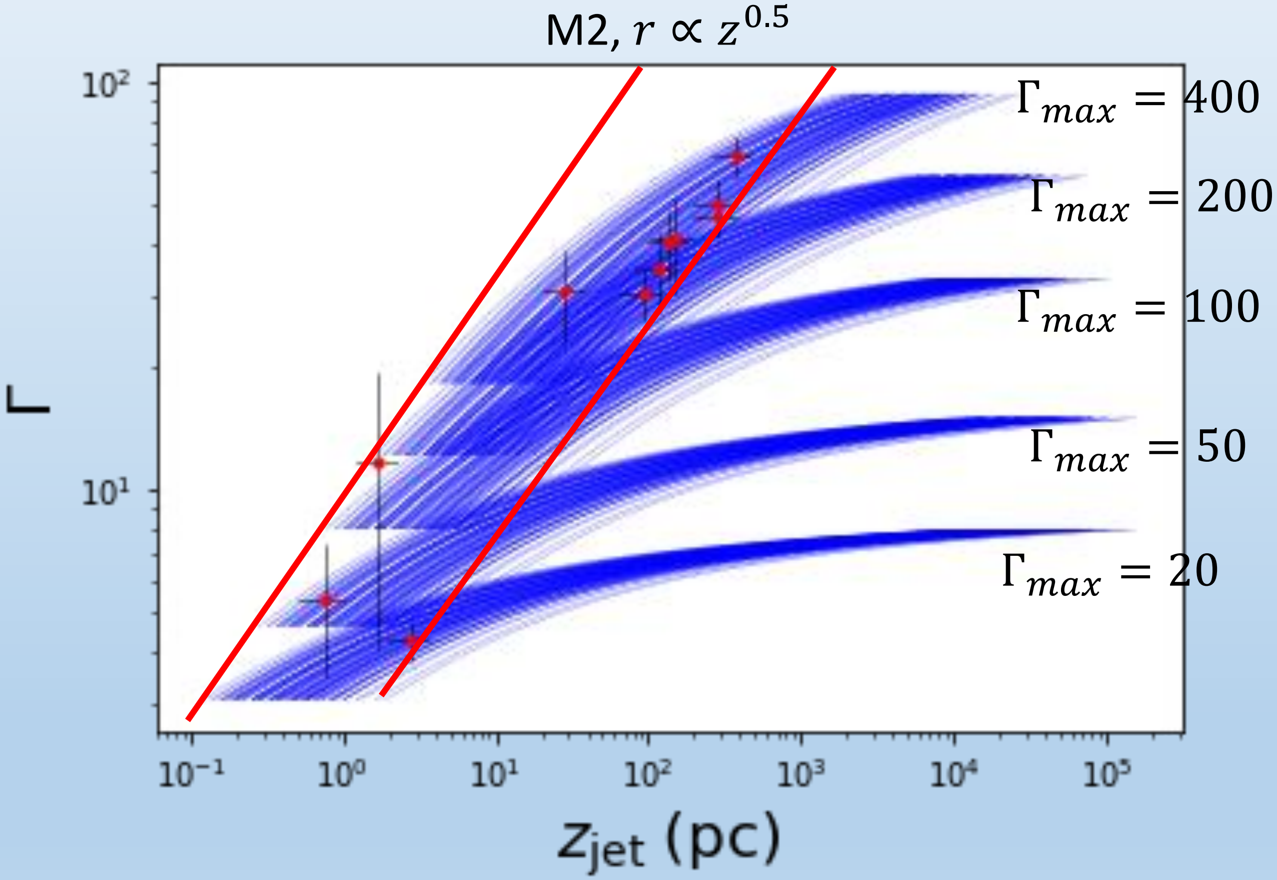
Results

Assumptions:

- parabolic jet shape
- effective acceleration
- pressure is consistent with Bondi accretion

The cores must occupy one “strap”

$$\frac{\Gamma}{\sqrt{z}} = 0.63\left(\frac{B_L^2}{P_0 z_0^2}\right)^{1/4}$$



In figure:

- $\Psi = 10^{32} - 10^{33}\ G \cdot cm^2$
- $R_L = 8 \times 10^{-4} - 4 \times 10^{-3}\ pc$
- $P_{10} = 2.2 \times 10^{-5} - 2.2 \times 10^{-3}\ dyn/cm^2$

Possible applications

It would affect the core shift dependence on frequency $\Delta z \propto \upsilon^{-1/k_r}$.

If all physical parameter (magnetic field, particle number density) depend on jet radius, then for $r \propto z^k$ and the accelerating flow

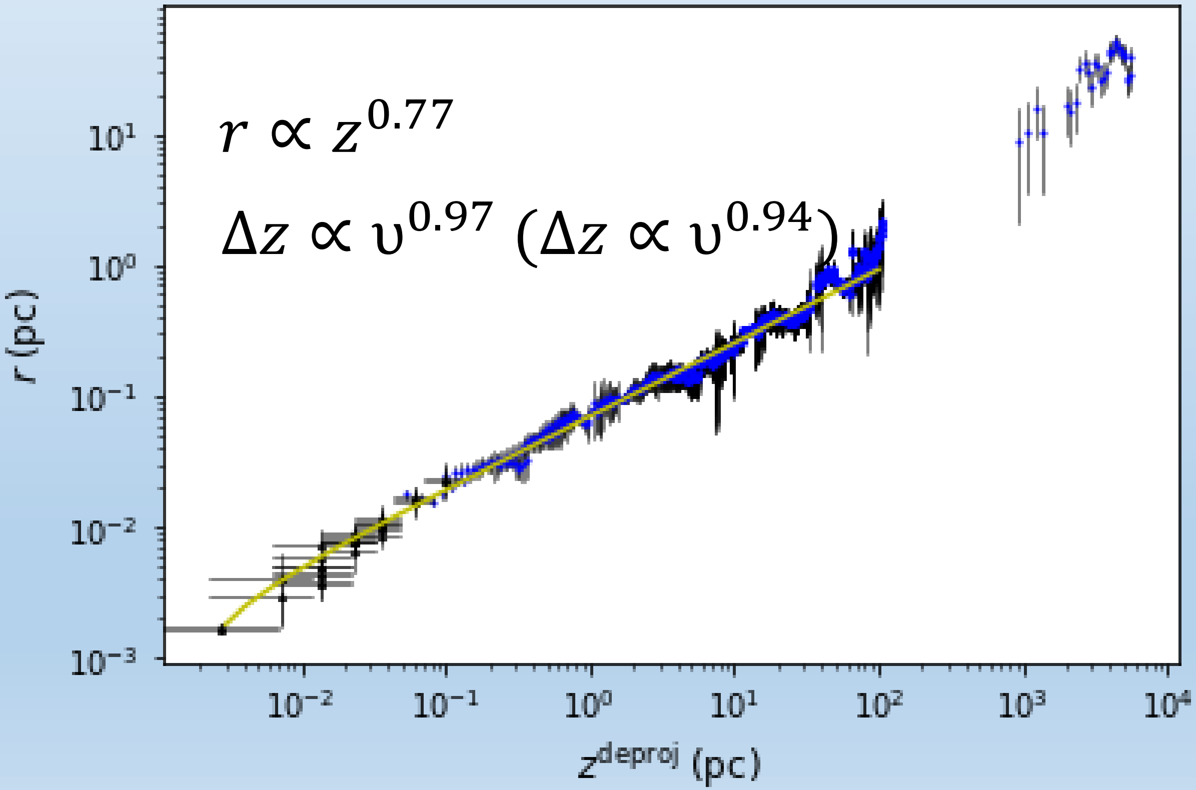
$$\Delta z \propto \upsilon^{-3/4k}$$

It is observed:

- 3C 454.3 $k_r = 0.6 - 0.8$ (Porth+ 2011, Kutkin+ 2014);
- MOJAVE: $\langle k_r \rangle = 0.84$ (Kravchenko+ in prep.);
- NGC 315 $k_r = 0.77$ (Park+ 2021).

The distance to a jet apex may be overestimated

$r = 0.07(z - 0.00153)^{0.56}$ (Hada+ 2011, Hada+ 2013)



Conclusions

1. New implicit method of determining jet shape in cores for distant sources
2. If cores are in parabolic + effective acceleration domain, they must occupy “strap” in $\Gamma - z$ plane. May be (and should be) tested on bigger sample
3. 11 sources sample – fully consistent with parabola + effective acceleration
4. Cone and saturation of acceleration are unlikely
5. We expect higher velocities than measured by kinematics due to de-boosting (hollow jets)
6. Possible biases in core shifts and BH position measurements