Resolving the Geometry of the Innermost Relativistic Jets in AGN Using Core Shift Measurements

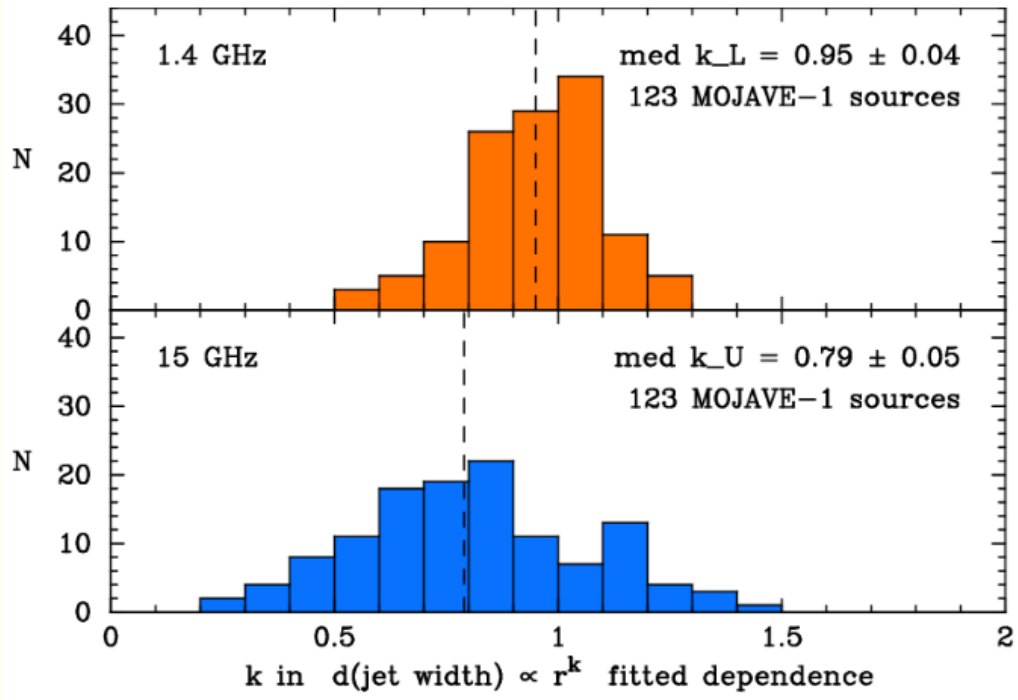
Juan-Carlos Algaba

M. Nakamura, K. Asada & S. S. Lee

APRIM 2017, July 3rd - 7th , Taipei

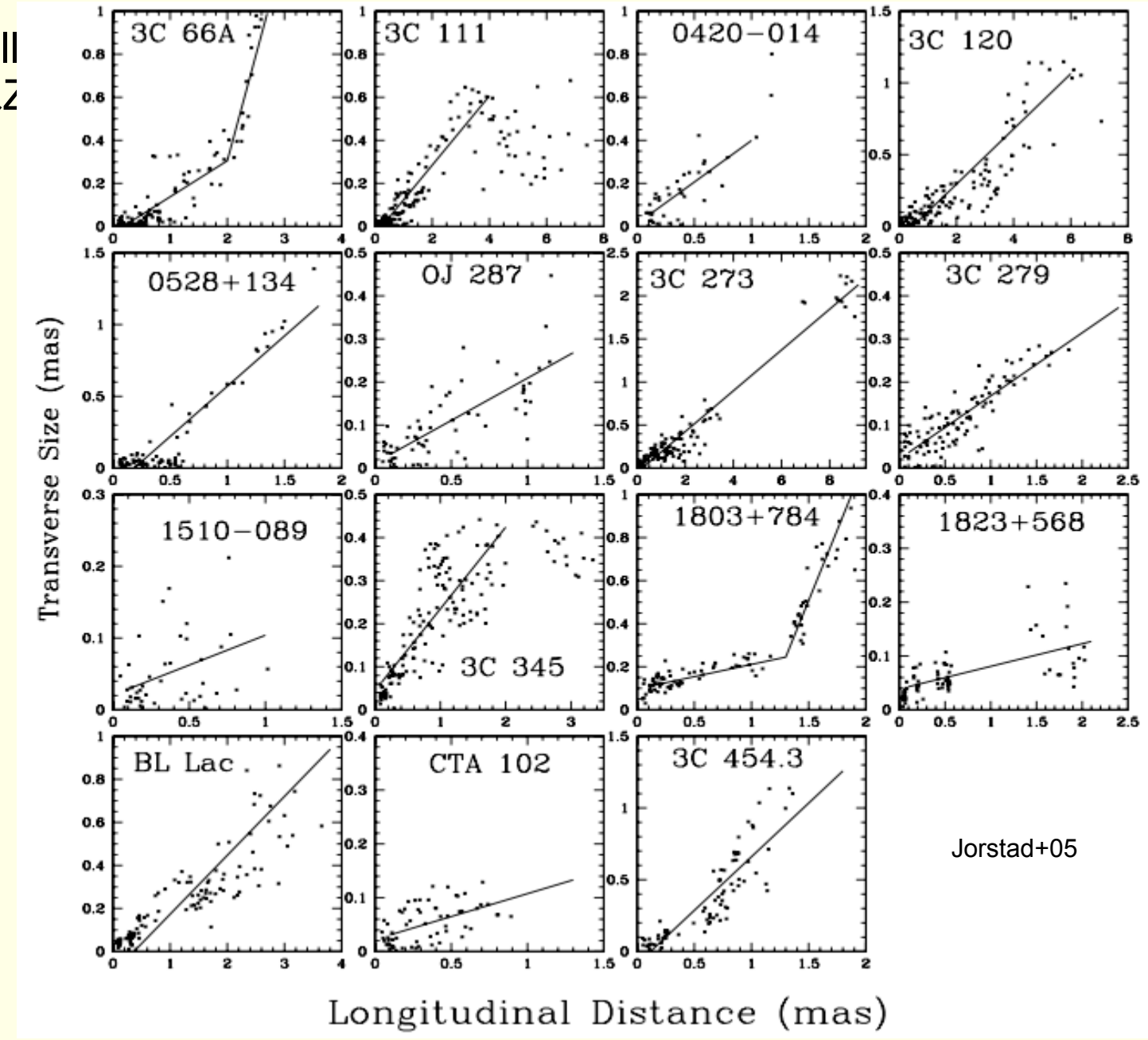
AGN Jet Geometry

- Jets have typically been considered to have a conical geometry (e.g. Blandford&Znajek77, Blandford&Payne82,...)
- BUT:
  - Inner parabolic, outer conical jet models match SED (Ghisellini85, Potter&Cotter13)
  - Indications of more active collimation at higher frequencies (Pushkarev+12)



AGN Jet Geometry

- Jets have typicall
  (e.g. Blandford&Z
- BUT:
  - Indications of jet geometry transitions

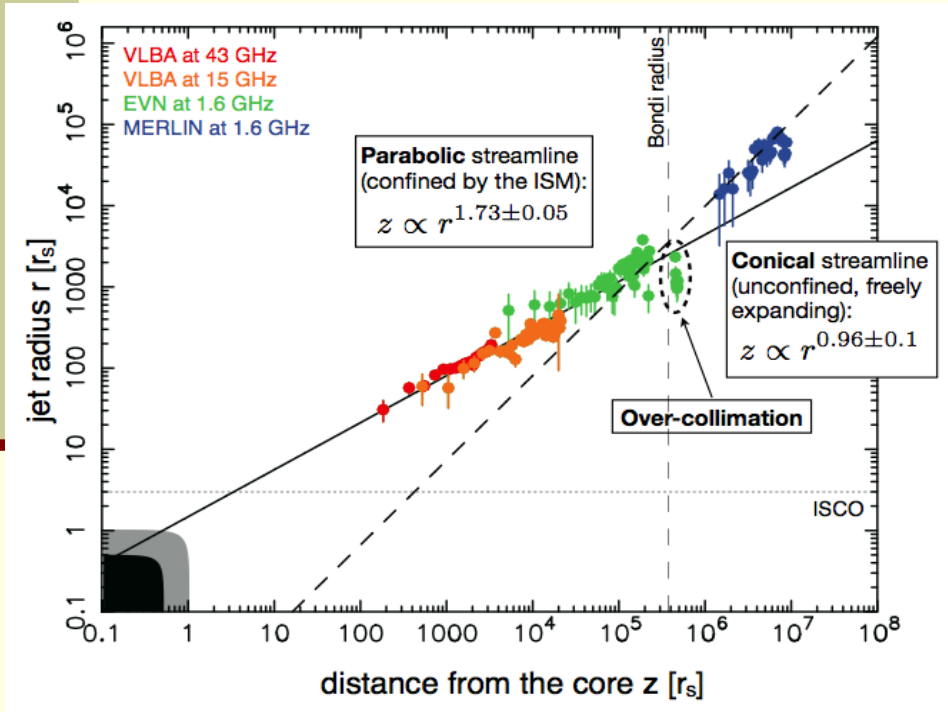


Jorstad+05

AGN Jet Geometry

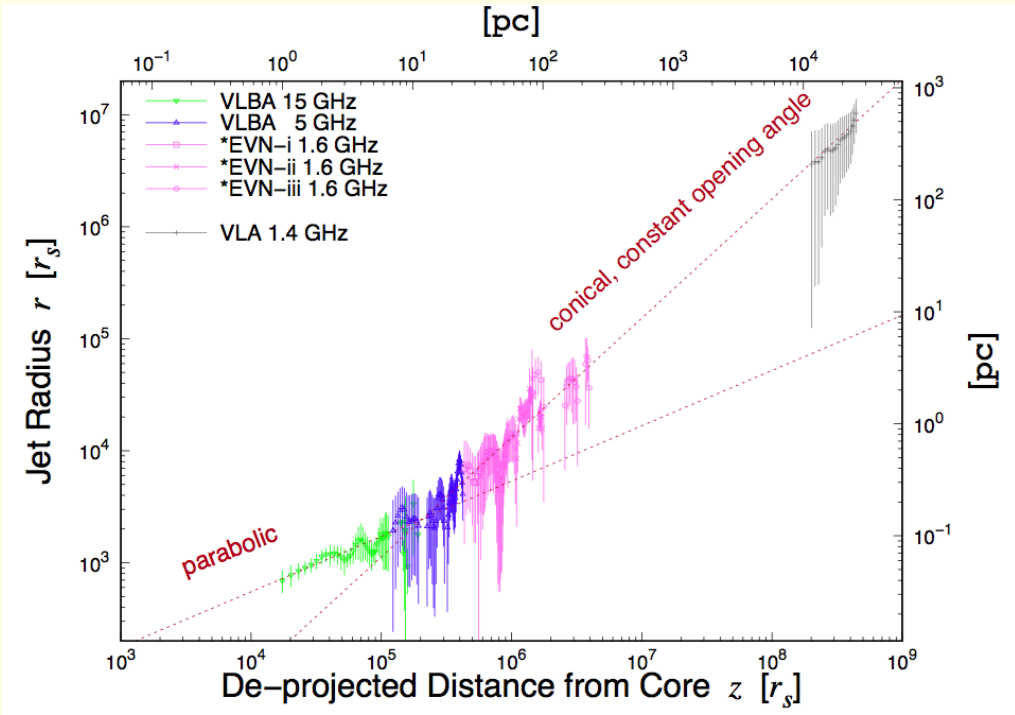
- Jets have typically been considered to have a conical geometry (e.g. Blandford&Znajek77, Blandford&Payne82,...)
- BUT:
  - Indications of jet geometry transitions

M87



Asada&Nakamura12

NGC 6251



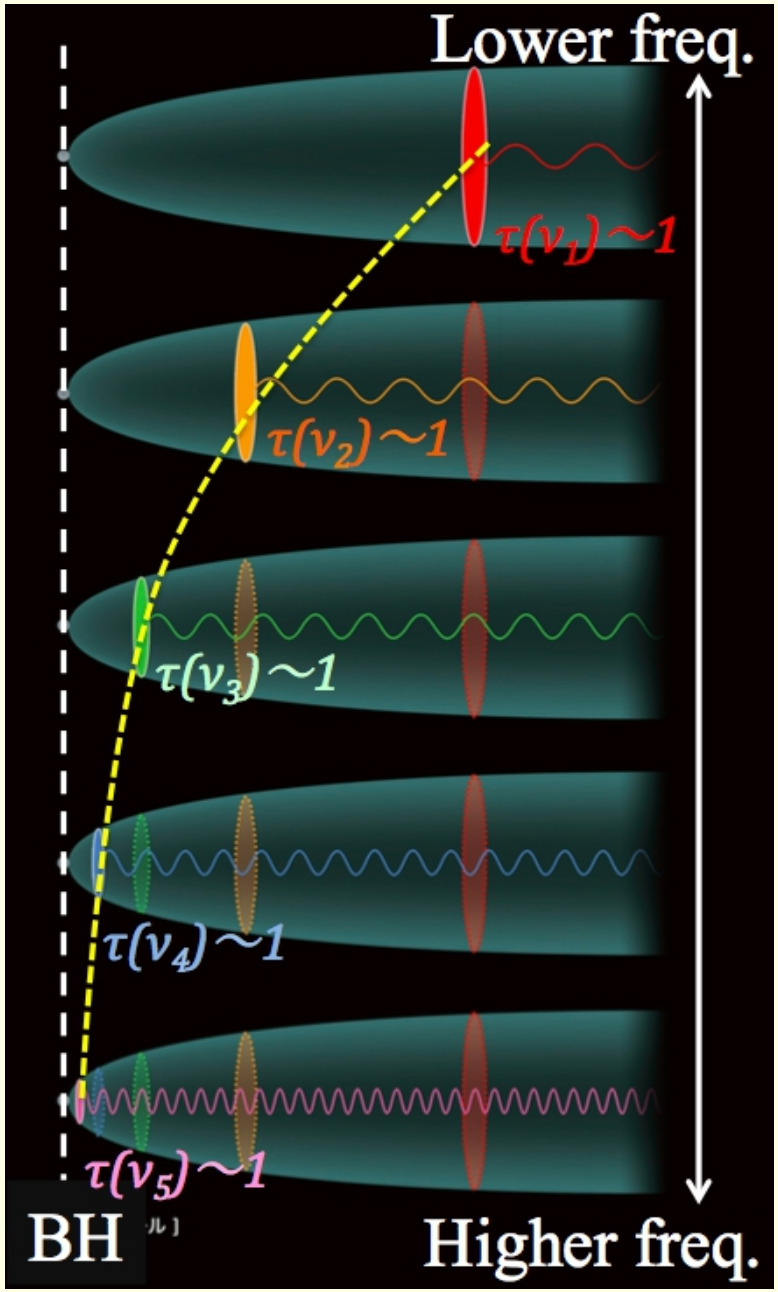
Tseng,...,Algaba et al 2016

AGN Jet Geometry

- Jets have typically been considered to have a conical geometry (e.g. Blandford&Znajek77, Blandford&Payne82,...)
- BUT:
  - Indications of jet geometry transitions
- QUESTION:
  - Are these isolated particular cases?
  - Is that an AGN paradigm?
    (just unresolved for sources further away)
- Possibility to answer using the properties of the core

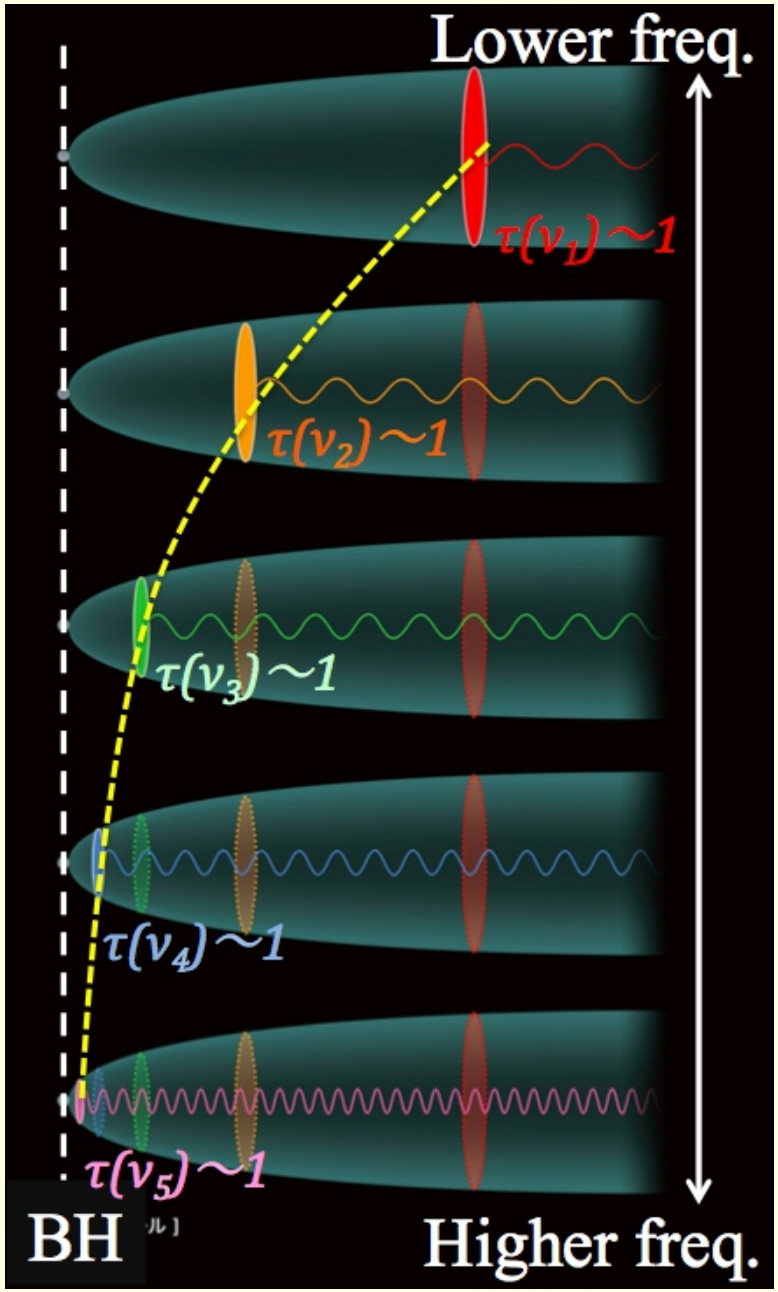
Core Shift in AGN

- Dependence of the τ=1 surface with freq. (Blandford & Konigl '79, Konigl'81)
- Core position moves with frequency
  - $r_{core}(\tau_{\nu,ssa}=1) \propto \nu^{-\alpha}$



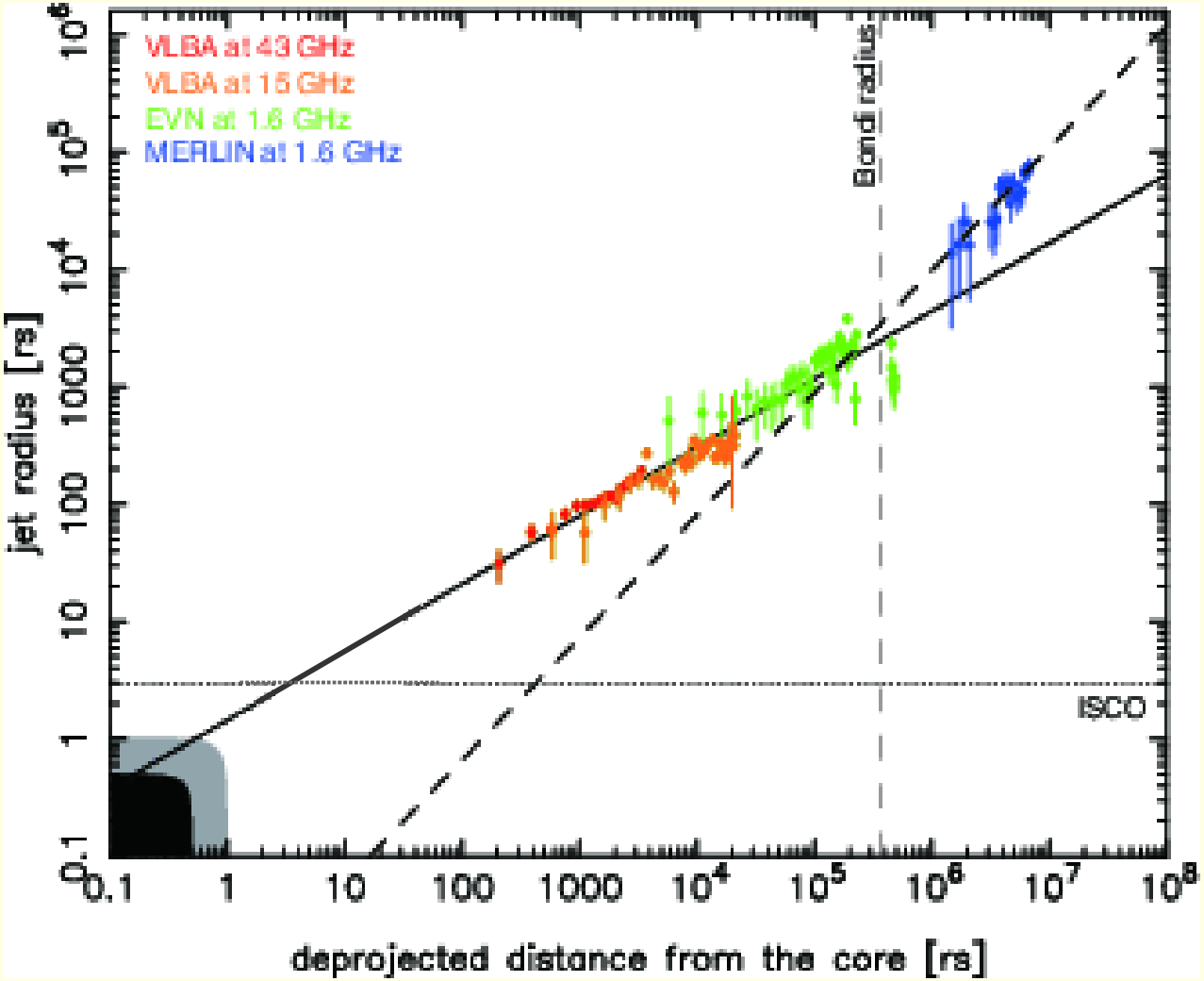
Core Shift in AGN

- Dependence of the τ=1 surface with freq. (Blandford & Konigl '79, Konigl'81)
- Core position moves with frequency
  - $r_{core}(\tau_{\nu,ssa}=1) \propto \nu^{-\alpha}$
- If the core is the throat of the divergent jet (Blandford&Konigl79)...
  - Properties of the core = properties of the upstream jet at r_{core}.
  - We can probe physical properties of the upstream unresolved jet!



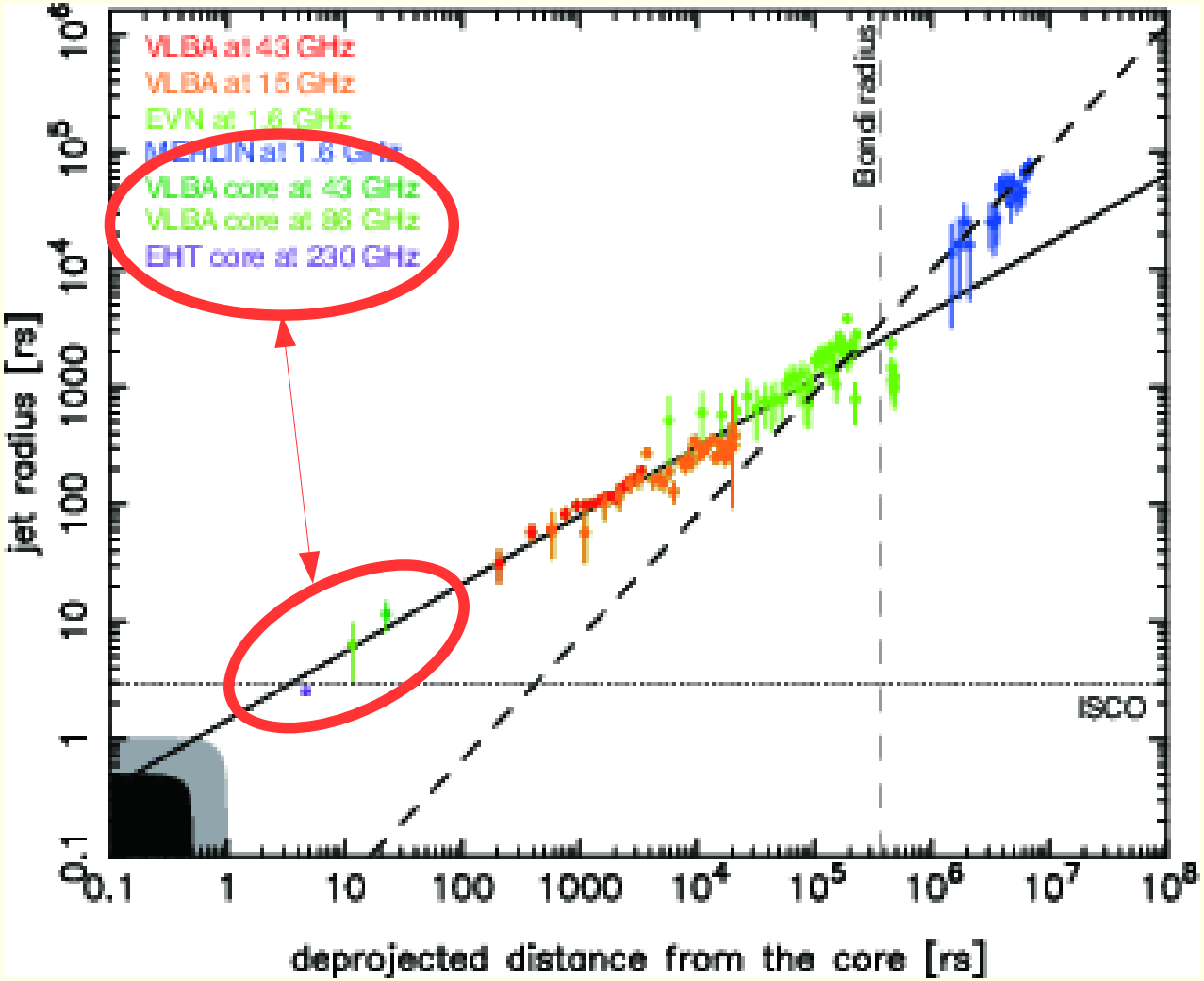
Core Shift in AGN

- Possibility to answer using the properties of the core
- Example: M87



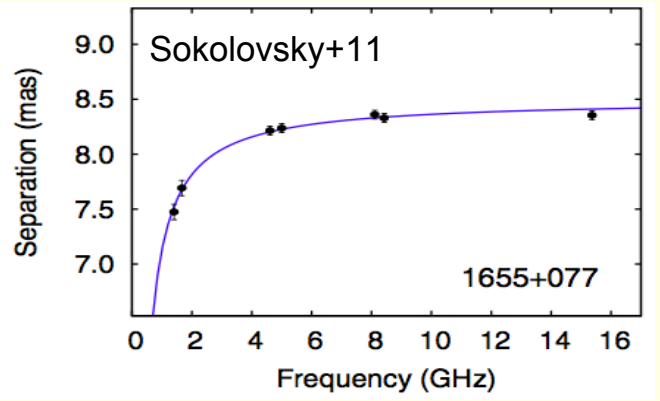
Core Shift in AGN

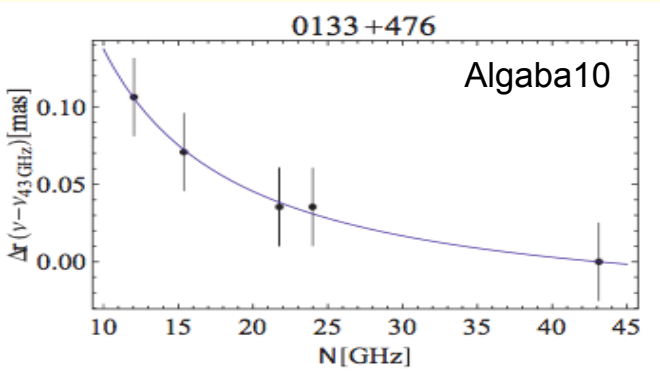
- Possibility to answer using the properties of the core
- Example: M87



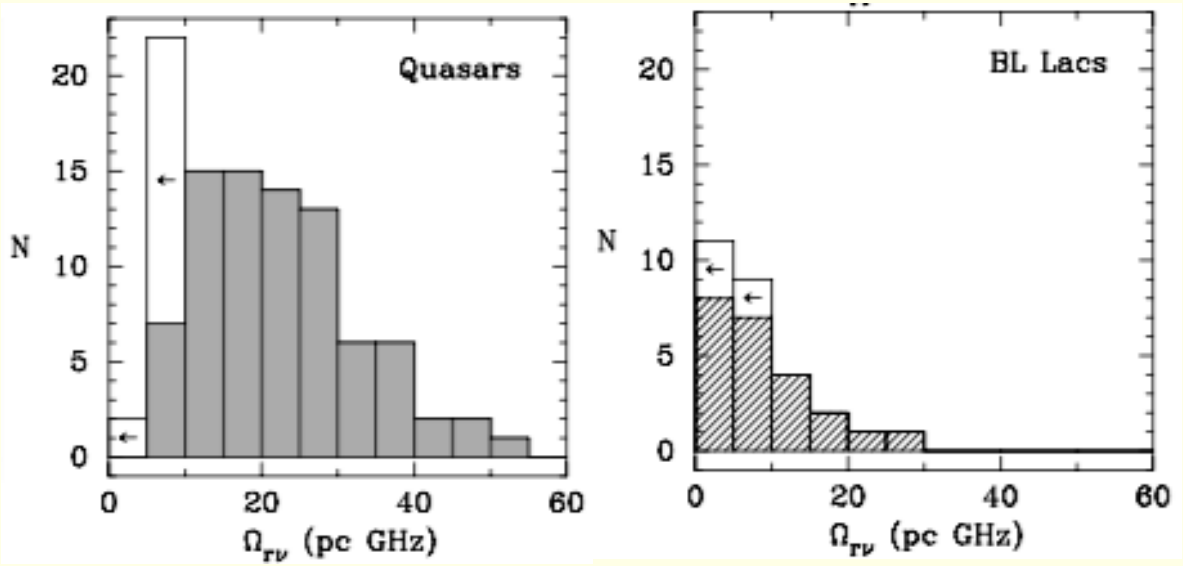
Core Shift in AGN

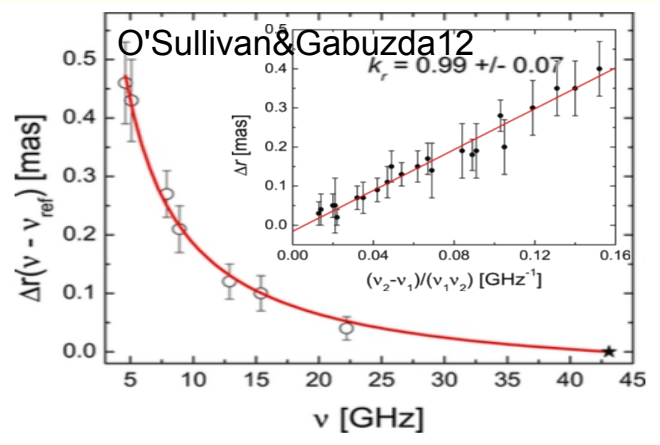
- Plethora of data in the recent years
  - Lobanov98 (7 sources)
  - Sokolovsky+11 (20 sources)
  - Rioja+05,Jung+15,Algaba11,O'Sullivan+12,...
  - Important sources (Hada+11, Cho+17,...)
  - Pushkarev+12 MOJAVE IX (163 sources)
- Can start an statistical analysis





Pushkarev+12





Upstream Jet Geometry

- Methodology
  - Obtaining core shift values
  - Obtaining core sizes at different frequencies
- Caveats
  - Small number of data
  - Core-jet blending
  - Time variability
- Advantages
  - Access regions otherwise unresolved
  - Large sample, statistical analysis

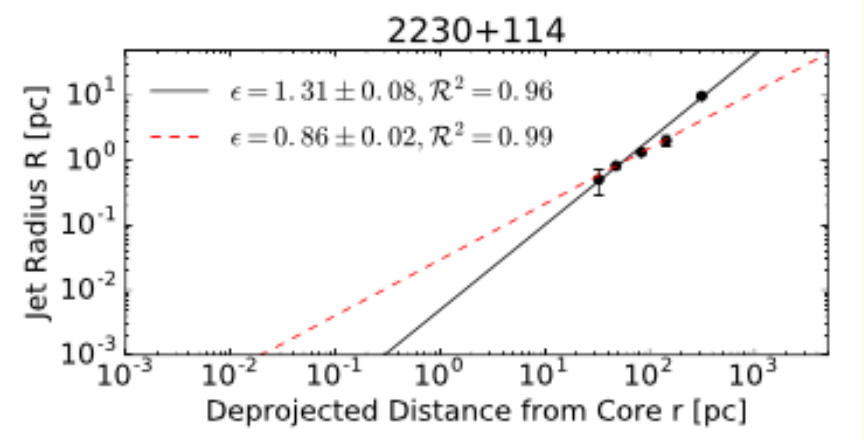
TABLE 1
VLBI SURVEYS USED IN THIS WORK.

Freq. (GHz) (1)	Instrument (2)	Epoch (3)	References[1] (4)
1.6	11-16×VLBI[2]	1990-1991	P95,TH95
2.3	VLBA	1998-2003	P12
5.0	VSOP	1997-2002	S04,D08
8.6	VLBA	1998-2003	P12
15	VLBA	1994-2003	L05
22	6×VLBI[2]	1993	M96
86	GMVA	2001-2002	L08

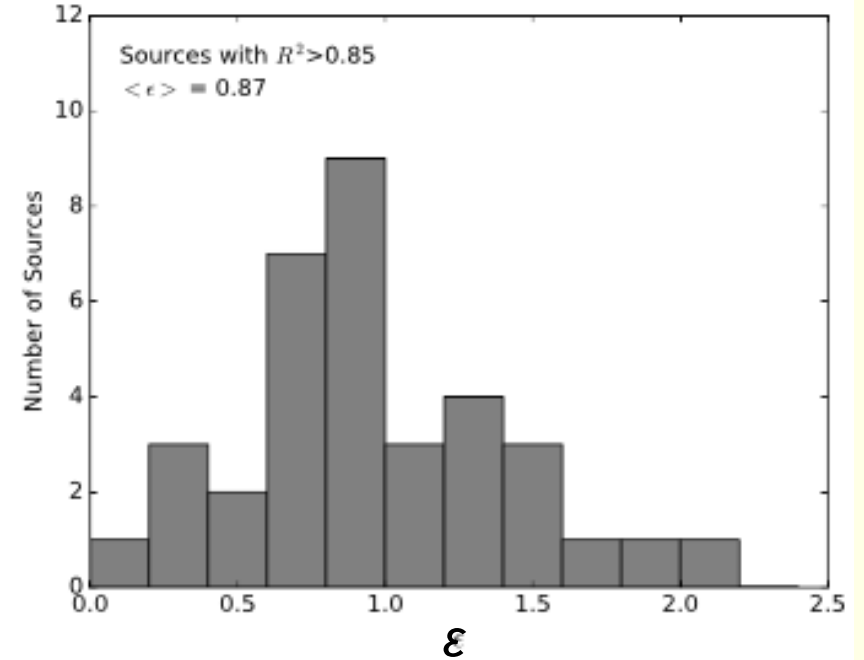
Algaba+16

Upstream Jet Geometry

- Results
  - Obtained core size & core distance
  - for at least 4 freqs in 56 objects
  - Fitted for $r \sim R^{\varepsilon}$.
    - ε=1 conical
    - ε=0.5 parabolic
    - ε=0 cylindrical
  - Median <ε>=0.85
- In agreement with Pushkarev+12
- Jet collimation break, quasi-parabolic to conical transition?

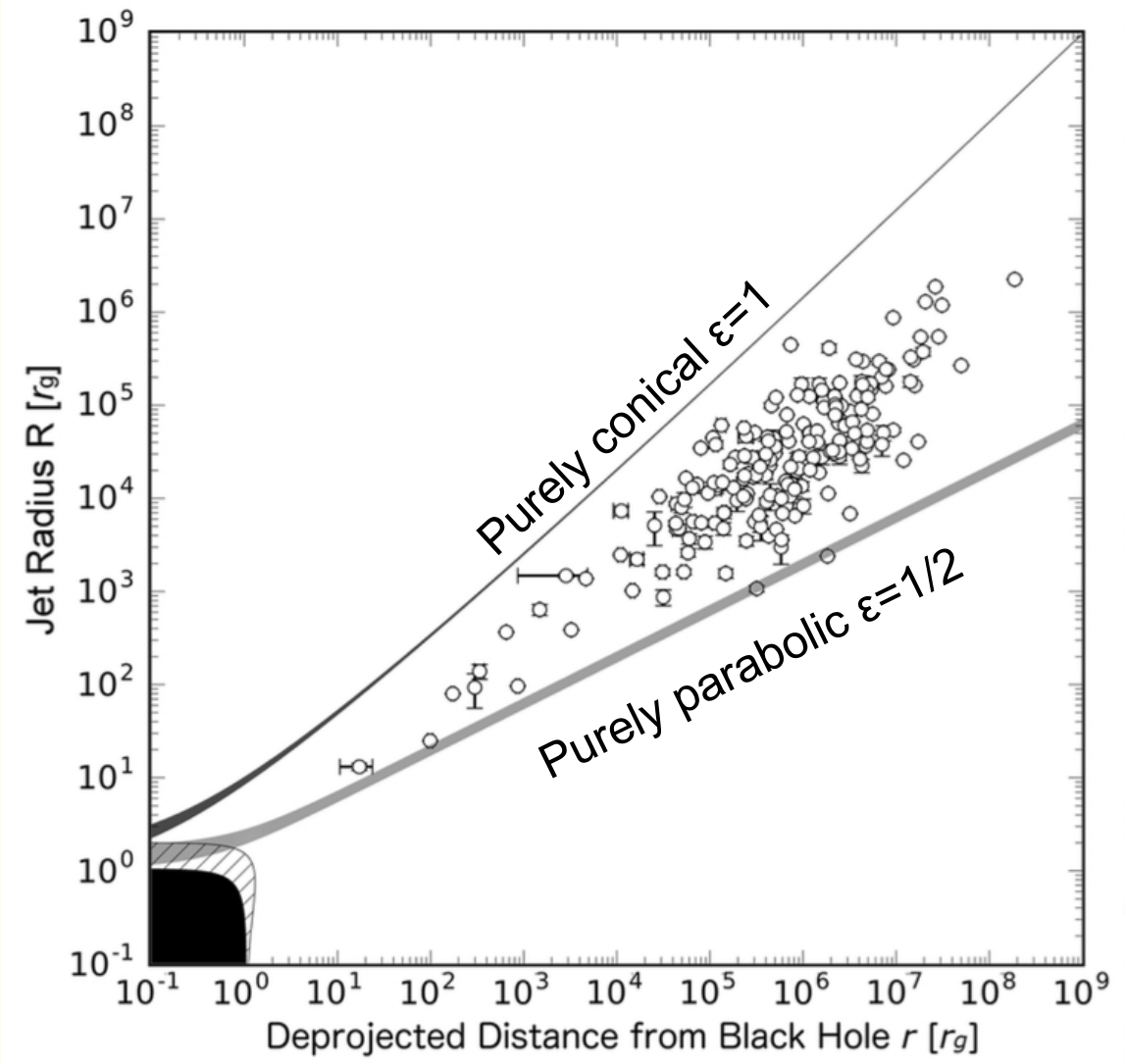


Algaba+16



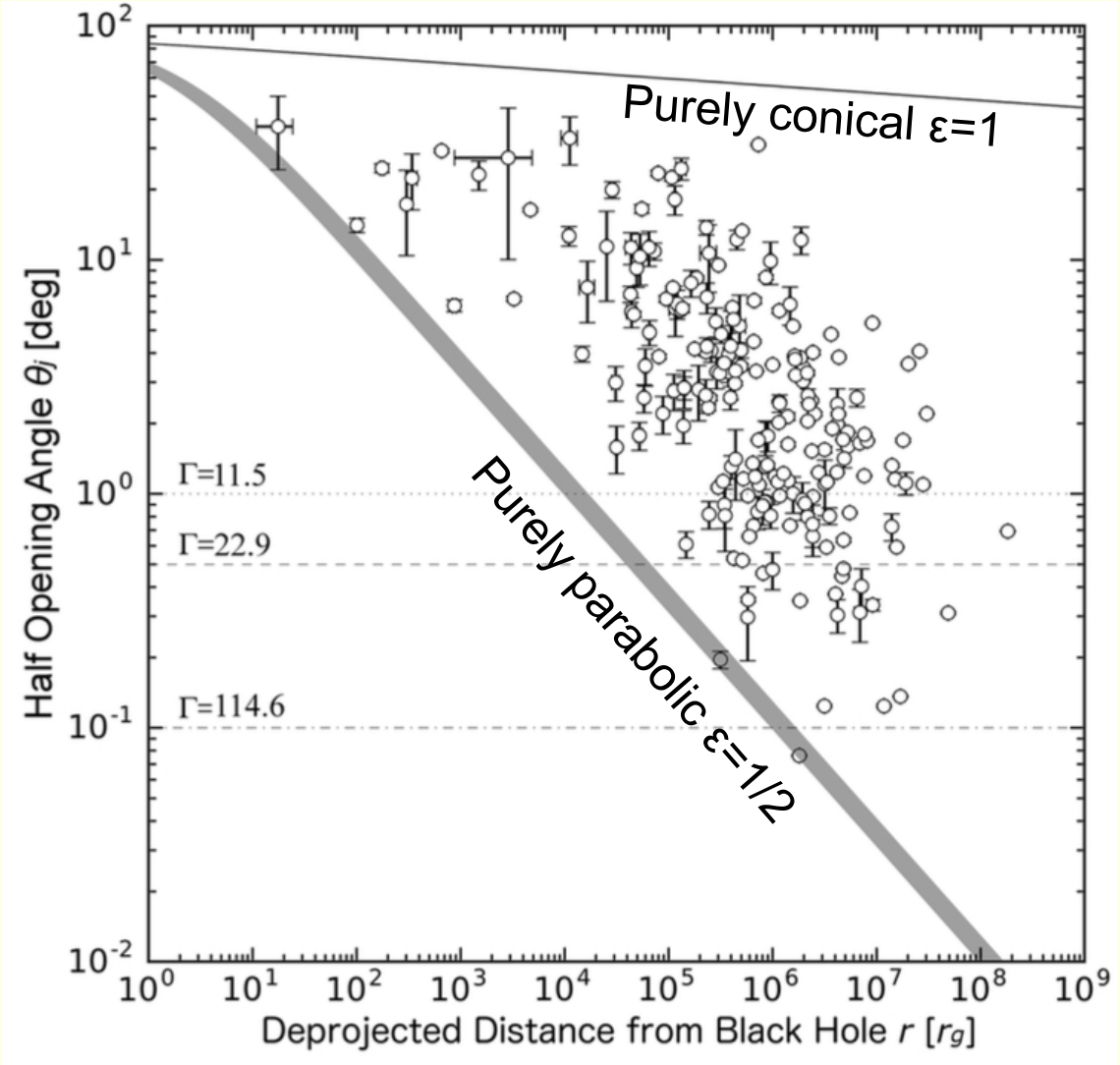
Upstream Jet Geometry

- Global view in terms of r_g.
- Jet starts neither conical nor parabolical
- Intermediate semi-parabolic
- If jet break exists, at ~$10^{5\text{-}6}$ r_g
  - Mixture of geometries?
  - Proper fit unreliable
- Consistent with GRMHD numerical calculations



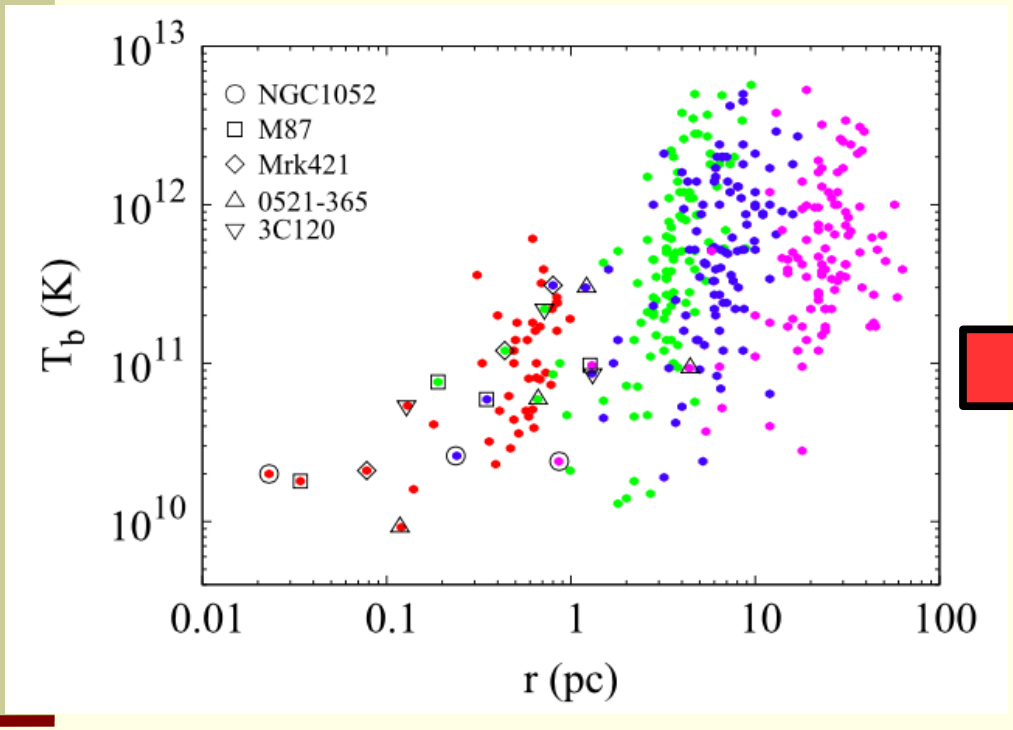
Upstream Jet Geometry

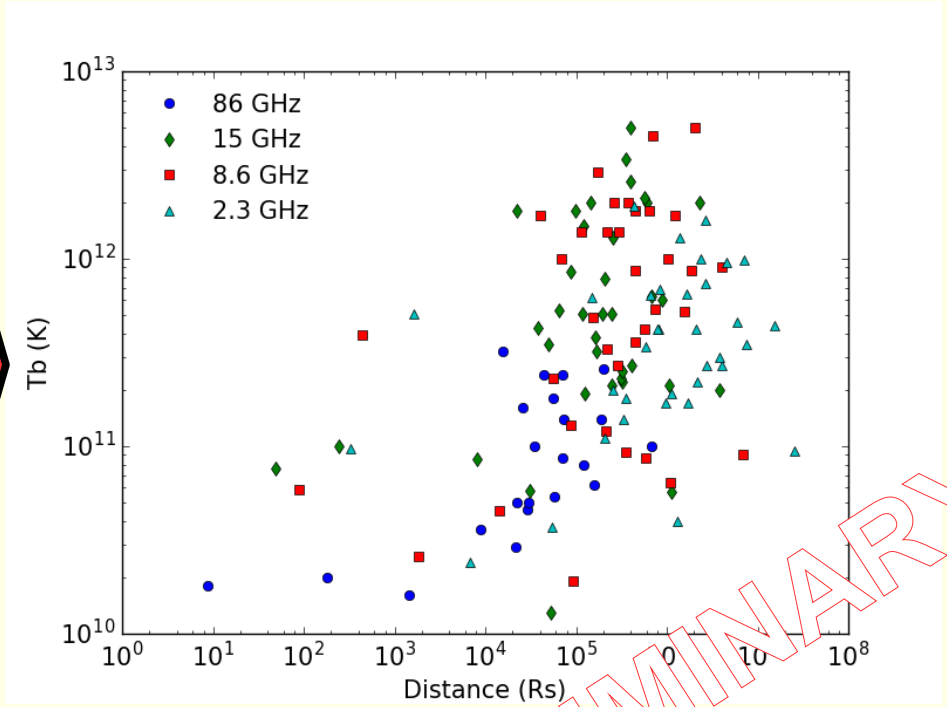
- Global view in terms of r_g.
  - Half opening angle starts very large near SMBH
  - Conical expansion is unlikely near SGI
  - Assuming $\Gamma\theta_j$~0.2 (Clausen-Brown+13) we get Γ consistent with observations



Upstream Jet Geometry

- Global view in terms of r_g.
  - Increase of Tb?





Lee+17

Conclusions

- Upstream unresolved jet geometry can be studied by probing AGN cores plus core shift information
- Inner jet shape is semi-parabolic (in contrast with conical on deca-pc scales)
- Indications of jet geometry break, SGI?
- Conical jet paradigm in AGN to be re-examined

- Thanks