Acceleration & Collimation Zone of FSRQ 1928+738

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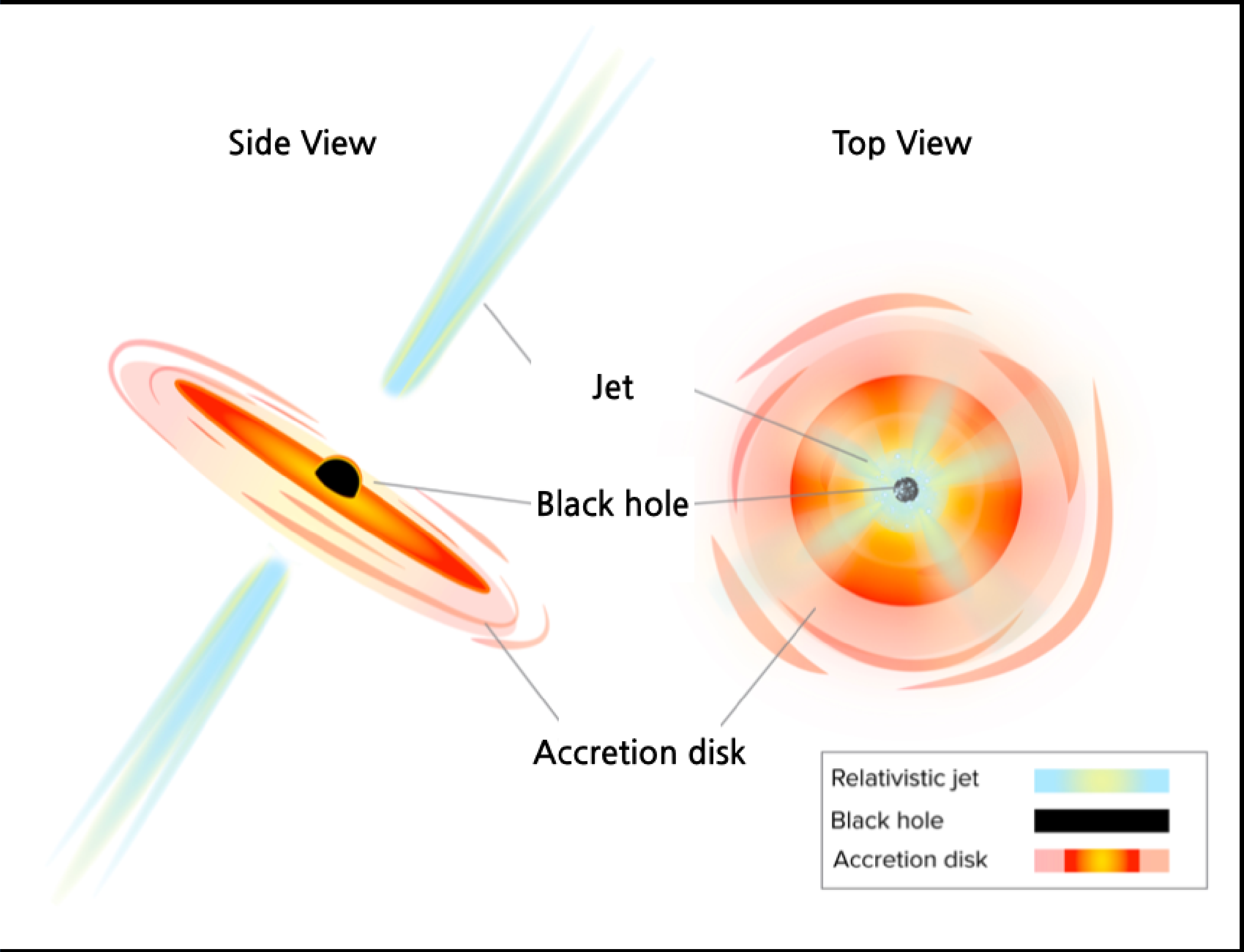
Jets from Flat Spectrum Radio Quasars

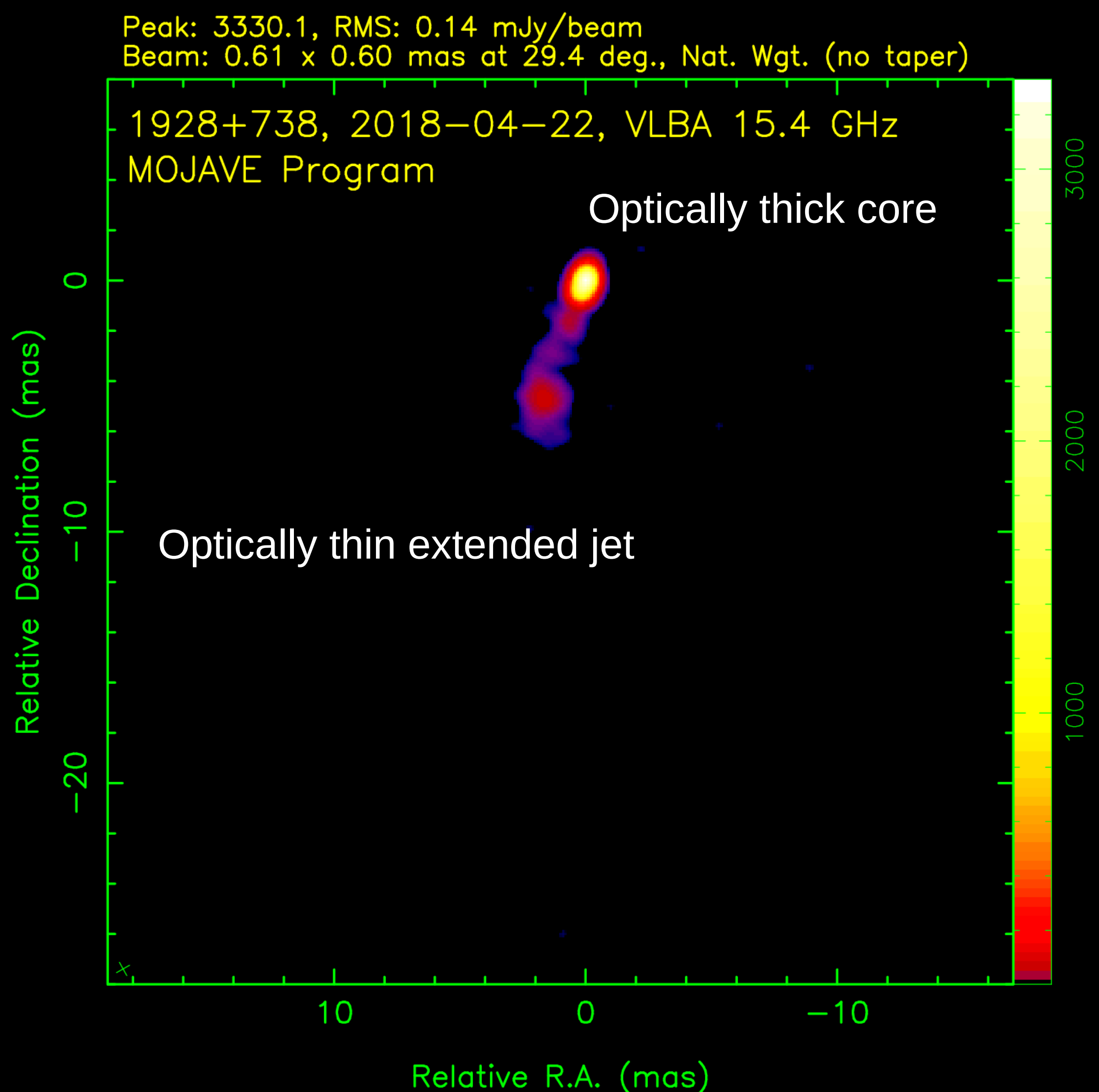


- Flat Spectrum Radio Quasar (Top View)
- Relativistic jet (v ~ c)
- Narrow angle ($\theta_{op} < 1^{\circ}$)
- Massive Black Hole
  $(10^{8} - 10^{9} M_{\odot})$
- High accretion rate
  $(\dot{M}_{BH} / \dot{M}_{Edd} = 0.1 \sim 0.5)$
- Mostly in distant universe

Image Credit : Sophia Dagnello, NRAO/AUI/NSF

Basic information of FSRQ 1928+738

MOJAVE 15 GHz Image



- Common Name : 4C +73.18
- Radio Brightness $S_{43} > 3\,Jy$
- High Dec (+73)
- → Ease of observation
- z ~ 0.3, $M_{BH} \sim 10^{8.57} M_{\odot}$, $\theta_v \sim 12.8^{\circ}$

  $\rightarrow\ 1\ mas \sim\ 5 \times 10^{5} R_s$

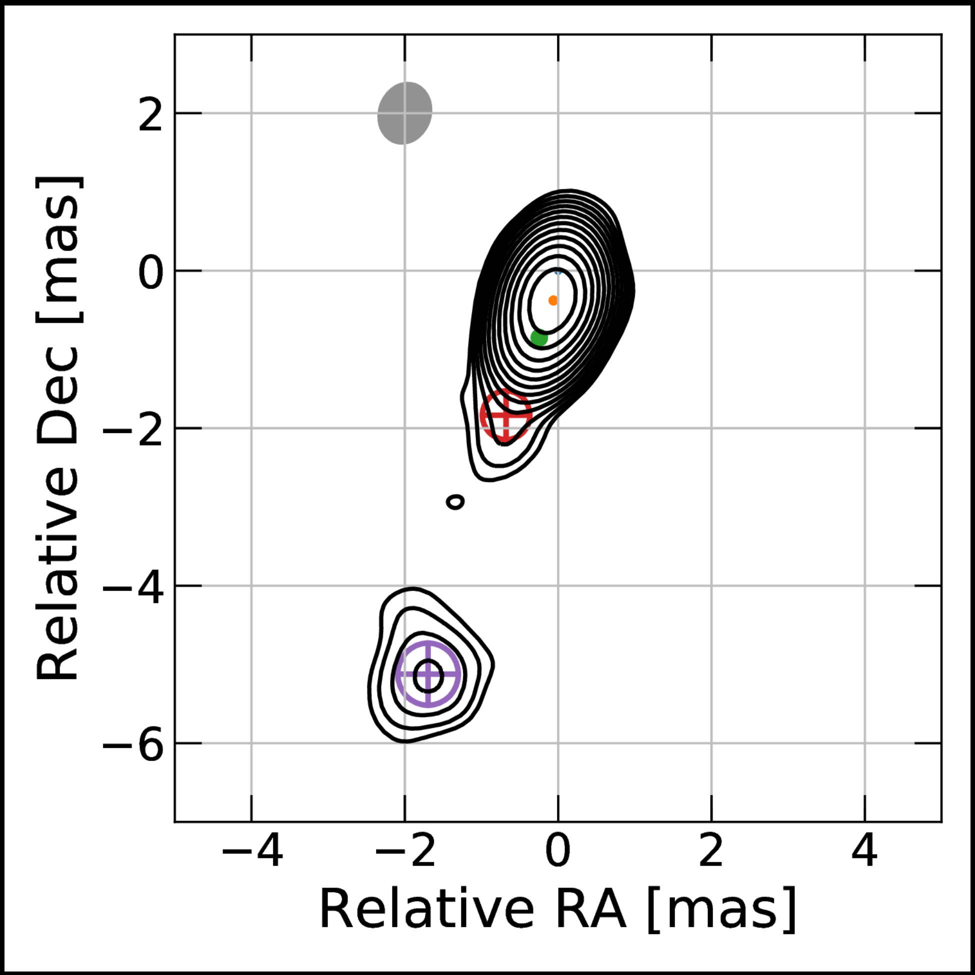
✔ Good target to explore inner jet

Nakamura-san's talk

http://www.physics.purdue.edu/astro/MOJAVE/sourcepages/1928+738.shtml

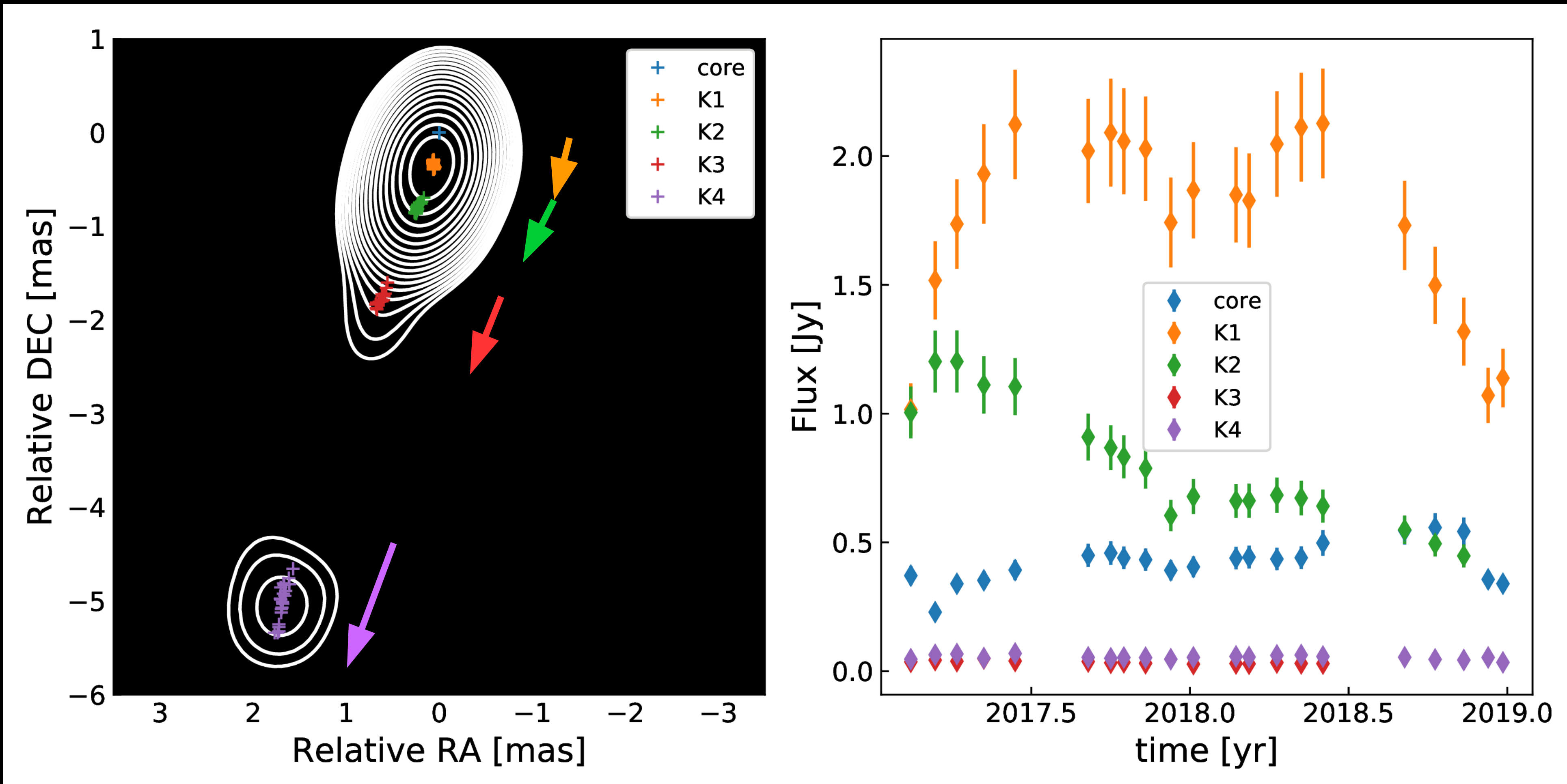
KaVA Monitoring of FSRQ 1928+738

KaVA 43 GHz Image



- KaVA Q band 43 GHz
- 2017 Feb ~ 2019 Jan (~2yr)
- Monthly interval
- Main Goals
  - (1) Exploring its jet kinematics
  - (2) its variability

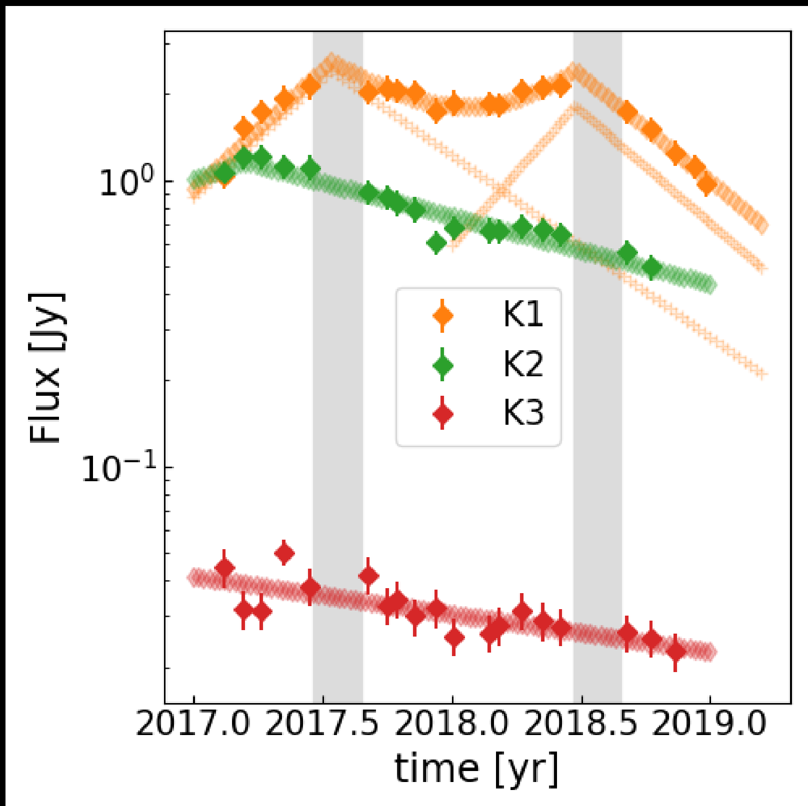
KaVA Monitoring of FSRQ 1928+738

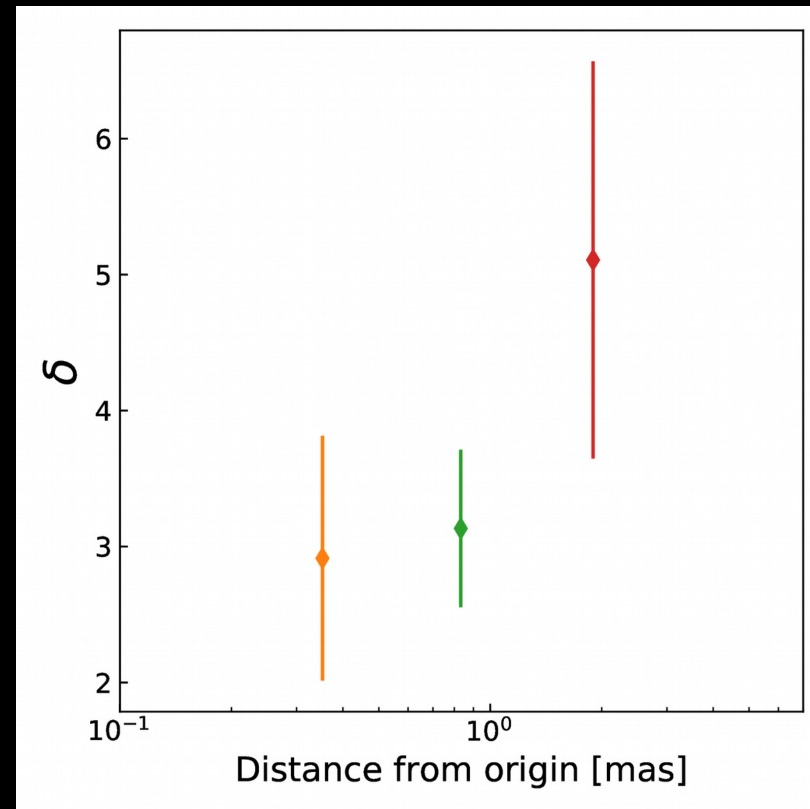


(1) Jet kinematics → Proper motion analysis

(2) Exploring its variability → Light curve analysis

KaVA Monitoring of FSRQ 1928+738

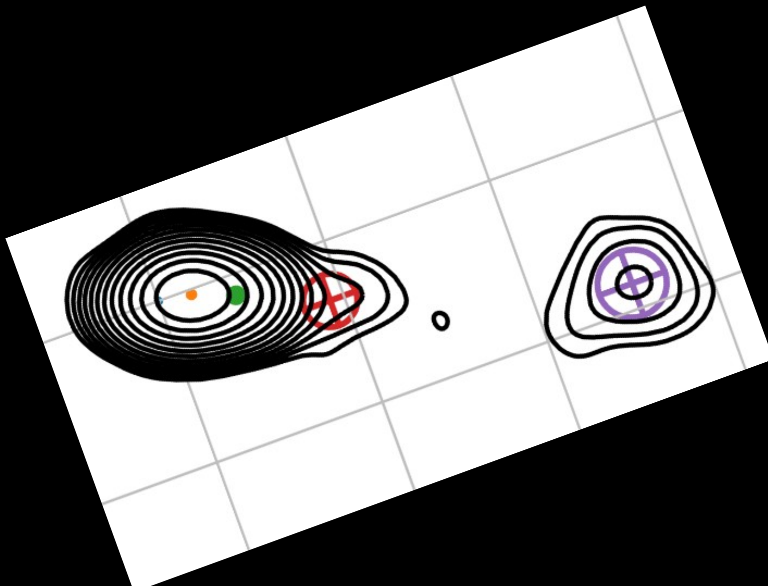


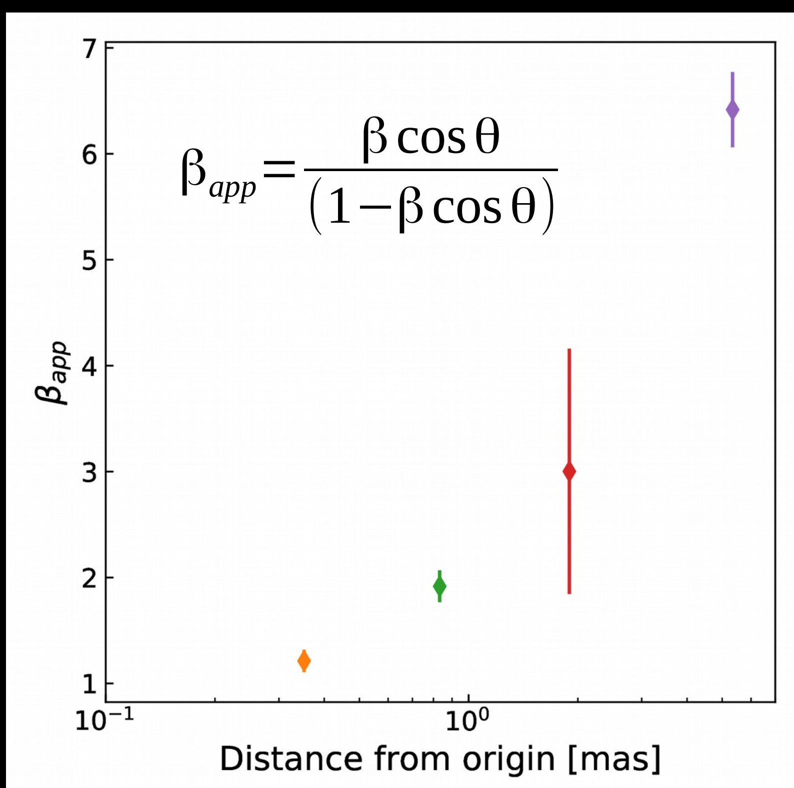


$$\delta_{var} = \frac{sD_L}{c\,\Delta t_{decay}(1+z)}$$

Jorstad et al. (05, 17)

Jet Kinematics of FSRQ 1928+738





- Jet kinematics

  : β_{app} increases

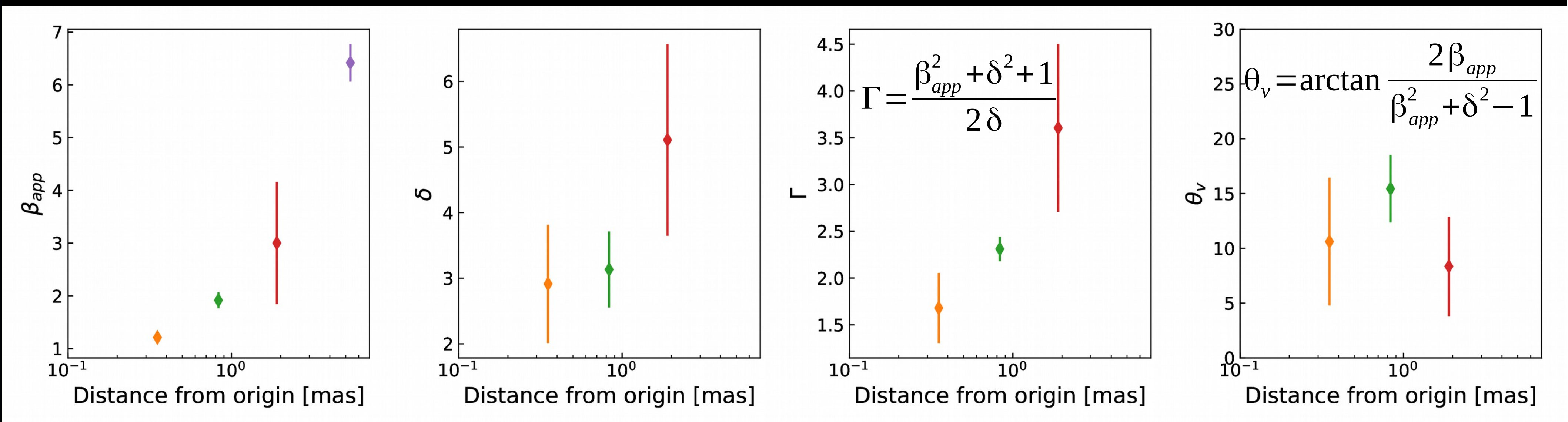
  as a function of distance

- β & θ : coupled

  - Real acceleration?

    or projection effect?

Jet Kinematics of FSRQ 1928+738



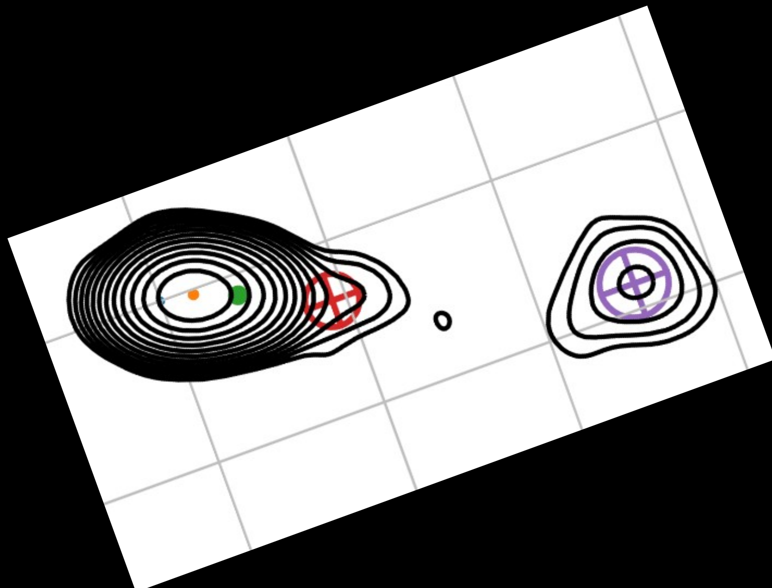
- Observed Parameters

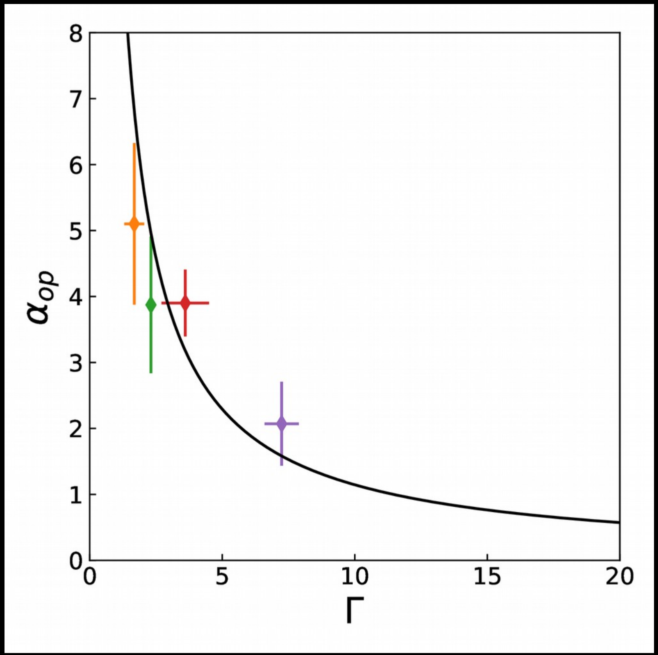
- β_{app} & δ increase as a function of distance
- Due to Real Acceleration!

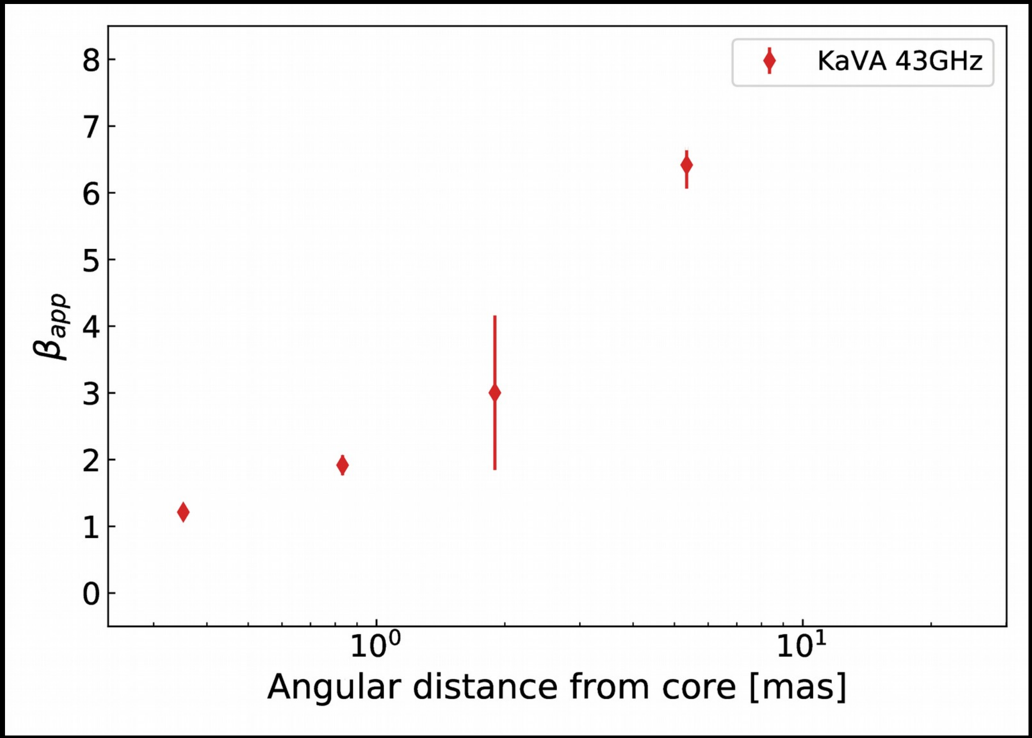
- Intrinsic Parameters

- Real Acceleration
  → Acceleration Zone
- $\theta_v \sim 12.8^\circ$ Hovatta et al. 2009
- No significant jet bending !

Jet Kinematics of FSRQ 1928+738







- $\Gamma \times \alpha = [0.15, 0.16, 0.25, 0.25]$

  Γ : *Lorentz factor* , α : *half opening angle* (*de – projected*)

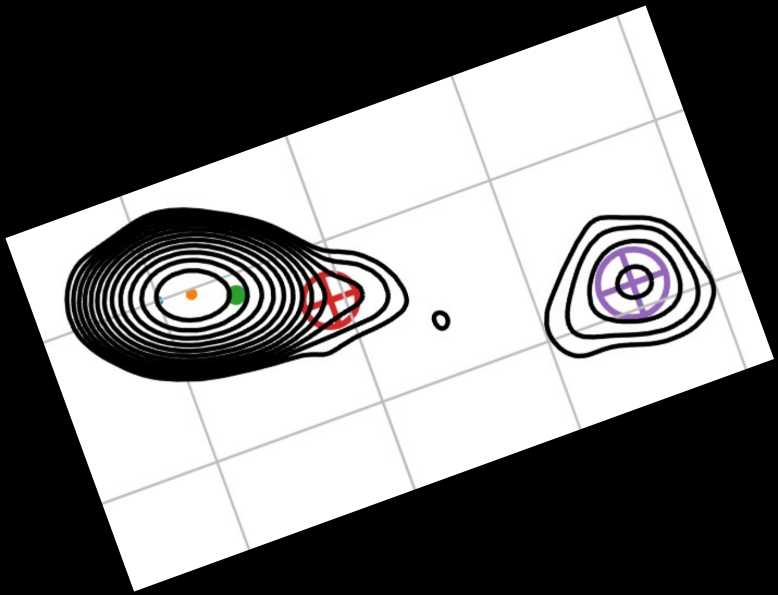
- $\Gamma \times \alpha = 0.2$ *in average*

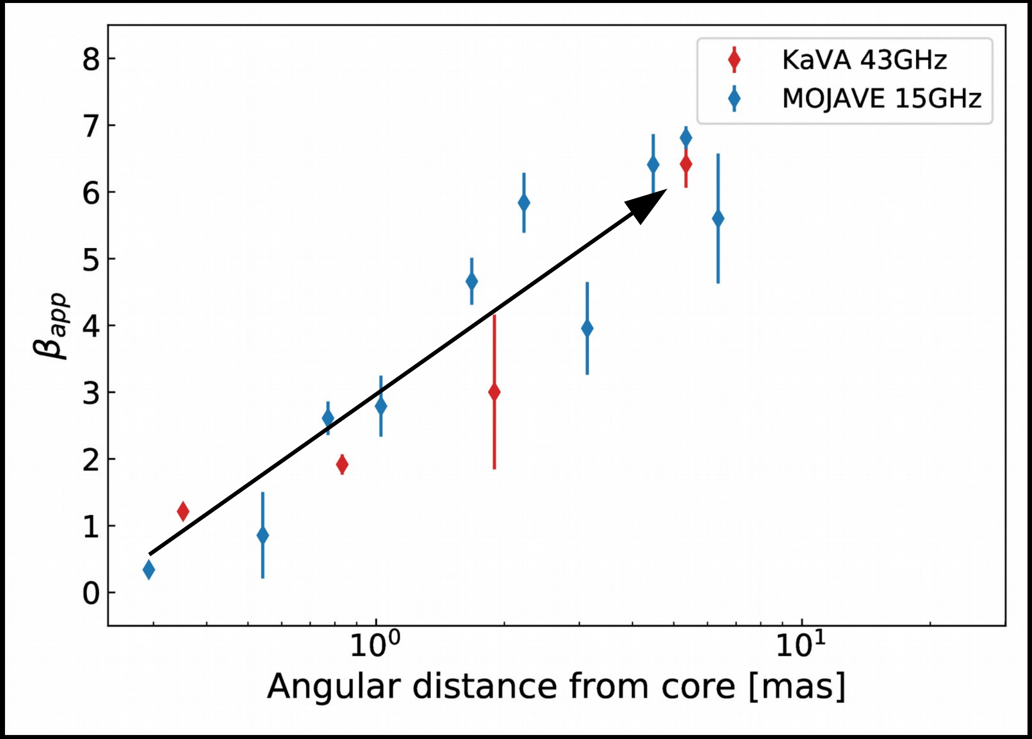
  : Acceleration & Collimation

  → Causal Connected

Jorstad+ (05,17), Pushkarev+ (09,17)

Jet Kinematics of FSRQ 1928+738





Cross-Check

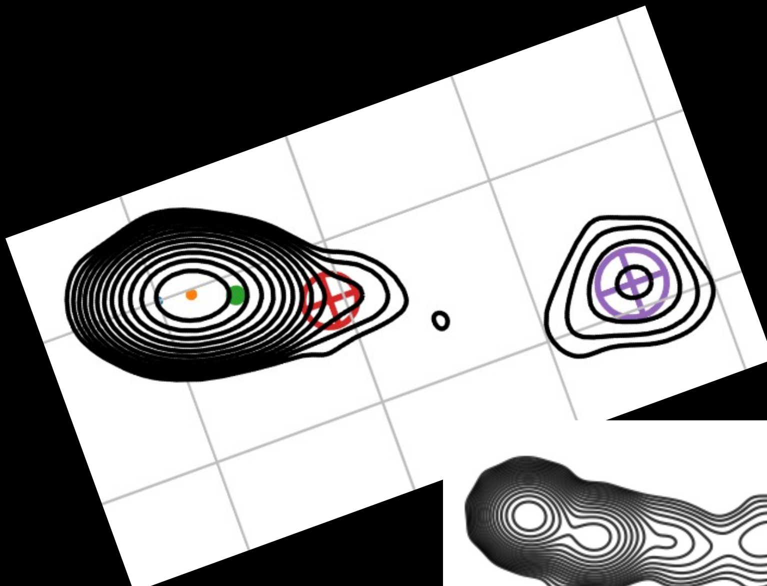
- More knotty structure on 15 GHz
- Both data shows acceleration
- Acceleration Zone (0 ~ 6 mas region)

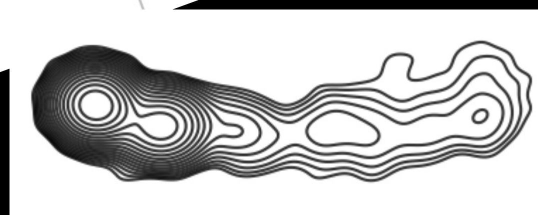
Q1) Acceleration keep going?

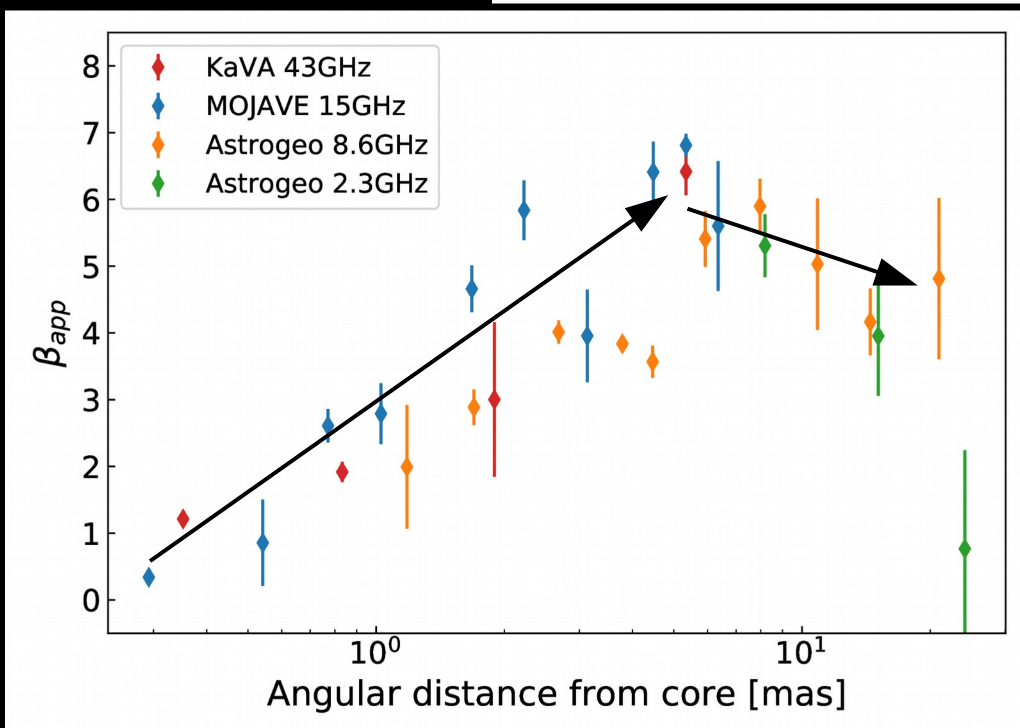
Q2) Max of β_{app} ?

Q3) Collimation Zone ?

Jet Kinematics of FSRQ 1928+738







Cross-Check

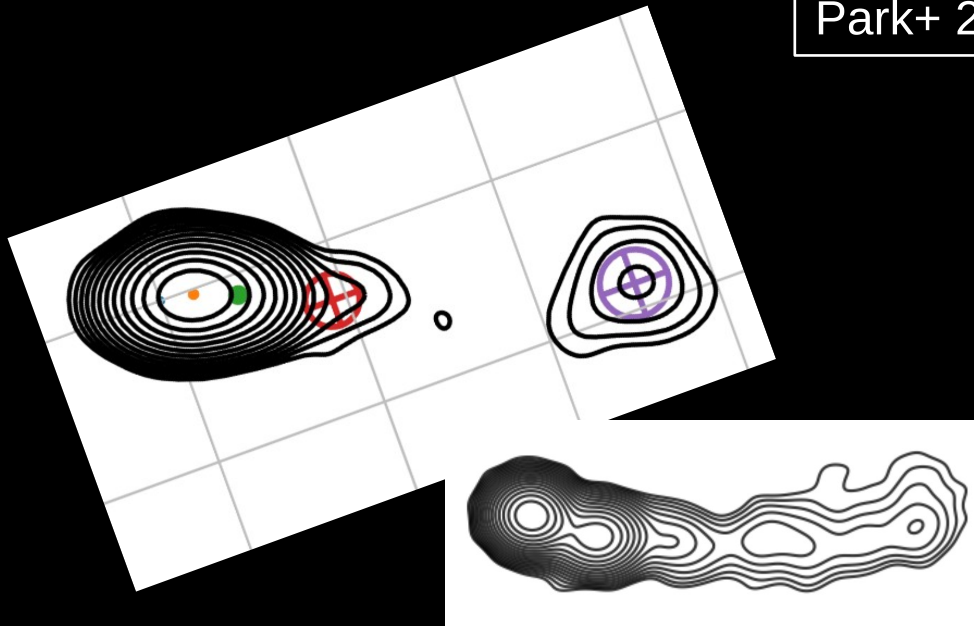
- Jet Kinematics (~20 mas)
  - Acceleration → Deceleration
- Transition @~ 5 mas

✔ Q1) Acceleration keep going?

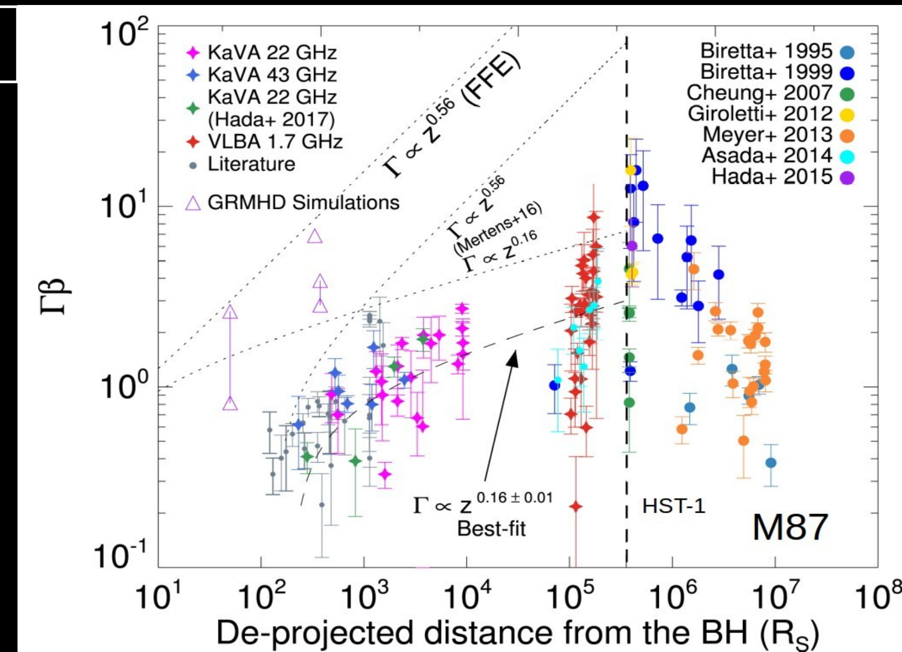
✔ Q2) Max of β_{app} ?

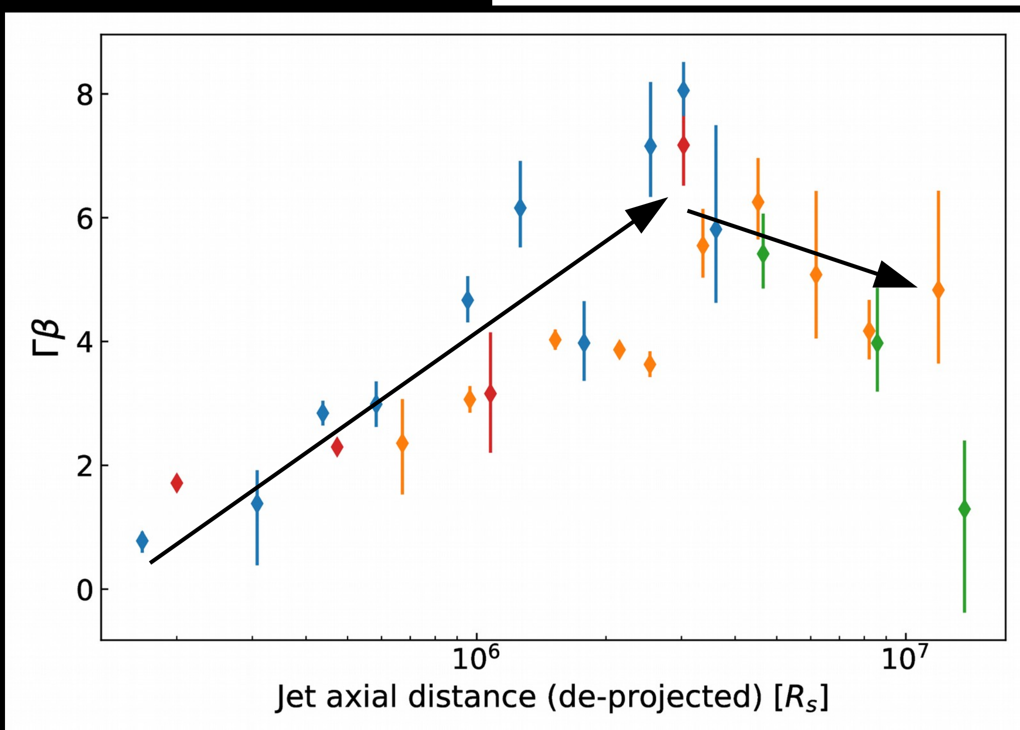
✗ Q3) Collimation Zone ?

Jet Kinematics of FSRQ 1928+738



Park+ 2019





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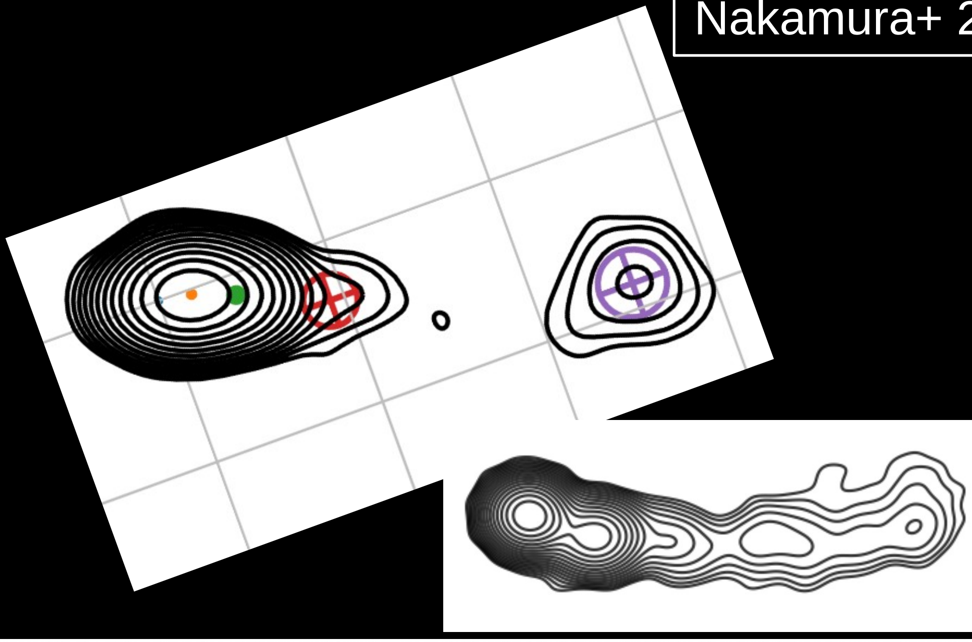
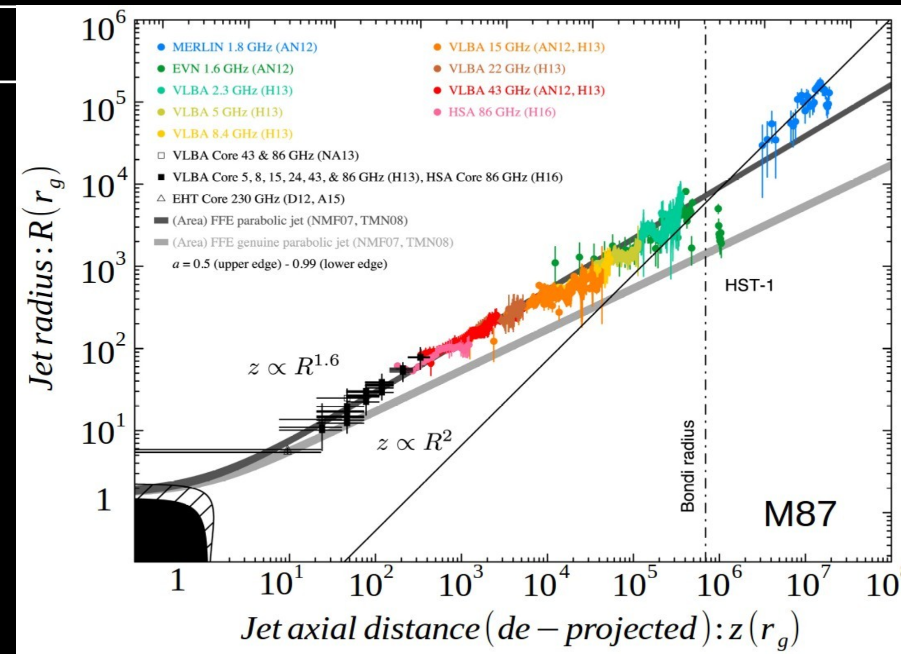
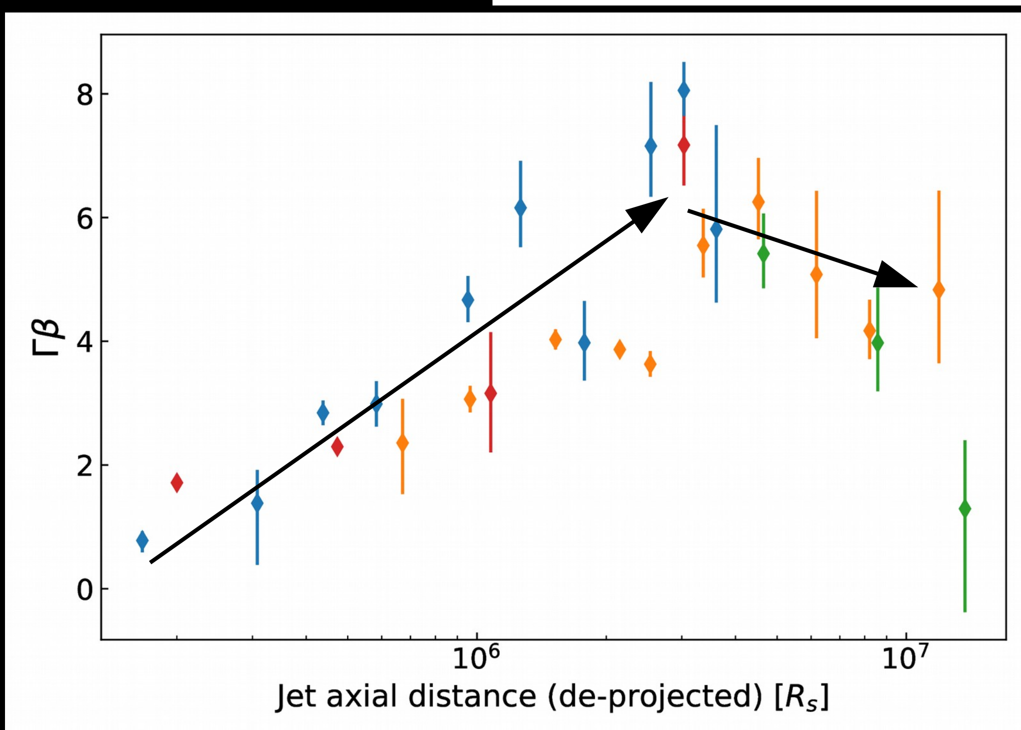
Jet Kinematics of FSRQ 1928+738



Nakamura+ 2018





Cross-Check

- Jet Kinematics (~20 mas)
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✔ Q1) Acceleration keep going?

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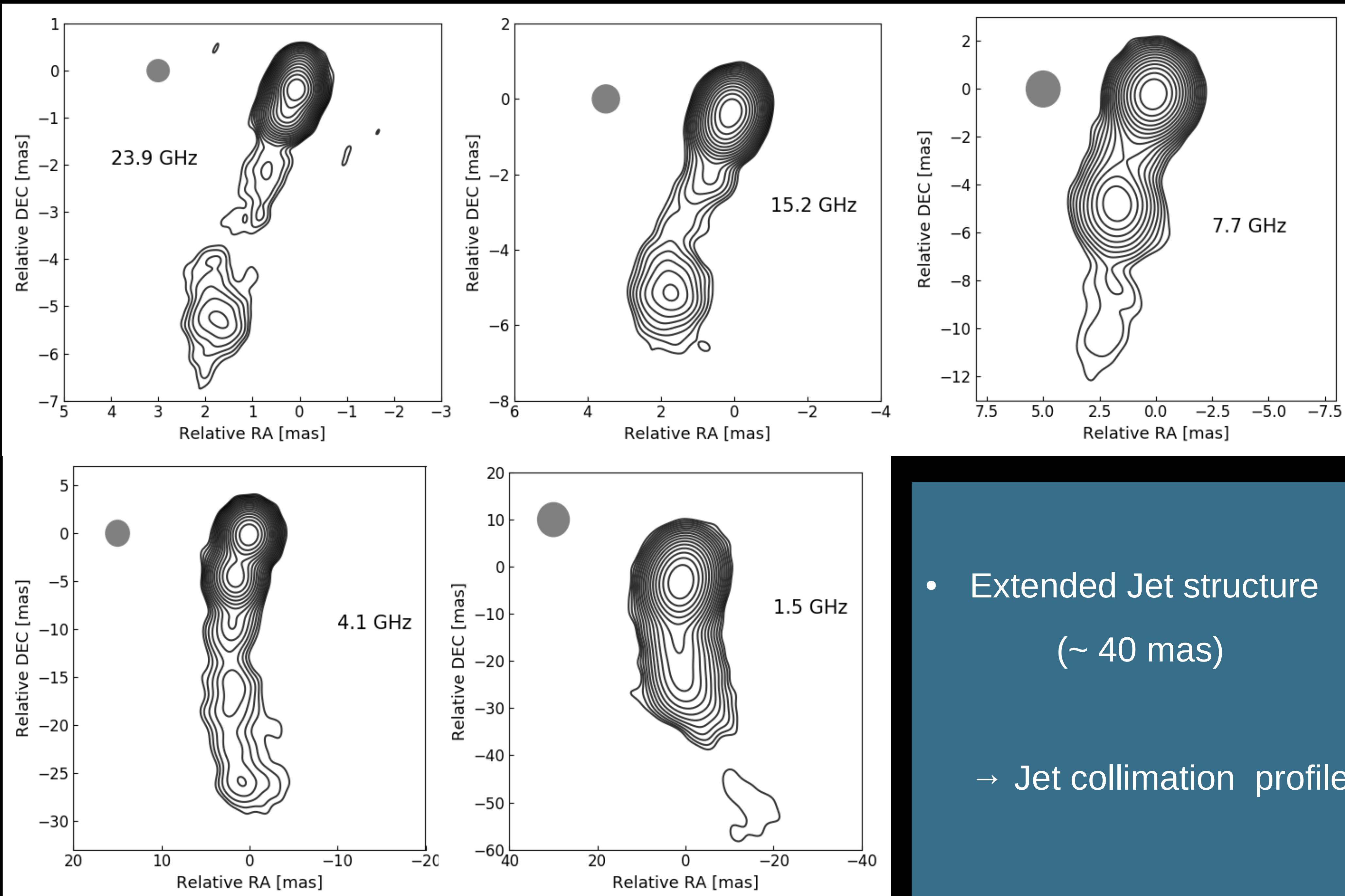
✗ Q3) Collimation Zone ?

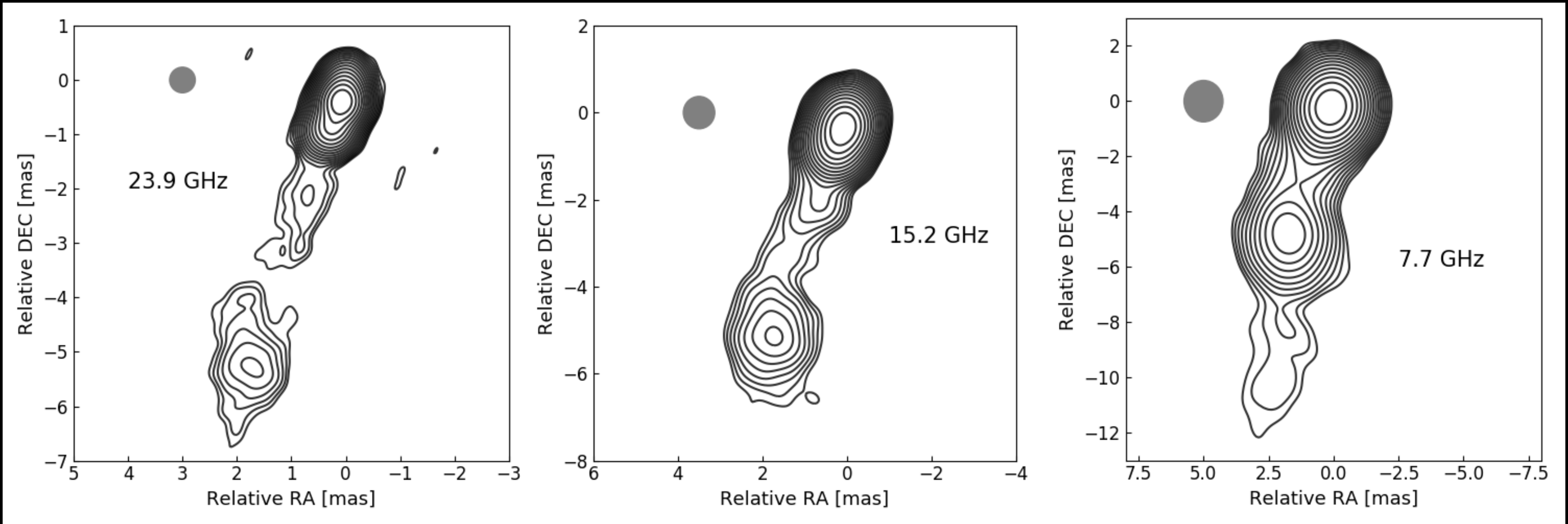
Jet Collimation of FSRQ 1928+738

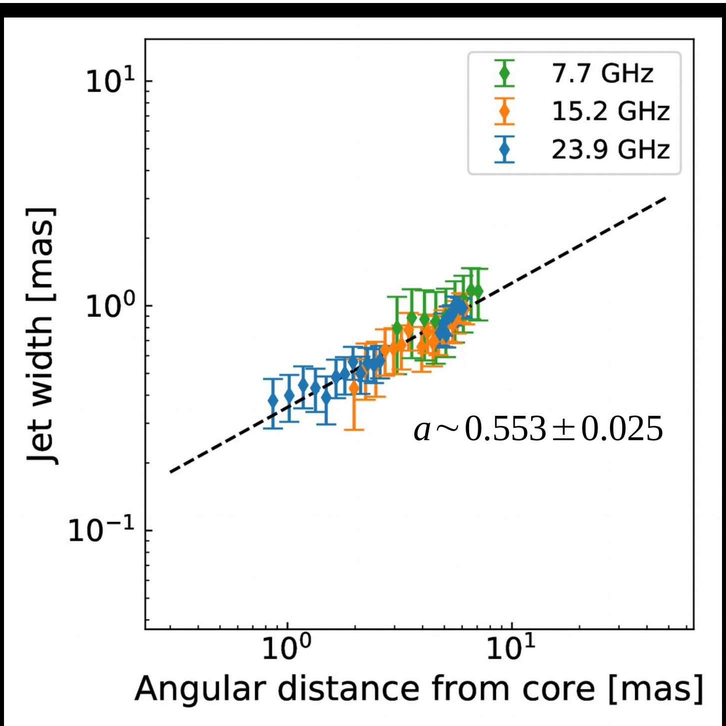


- Extended Jet structure (~ 40 mas)

→ Jet collimation profile

Jet Collimation of FSRQ 1928+738





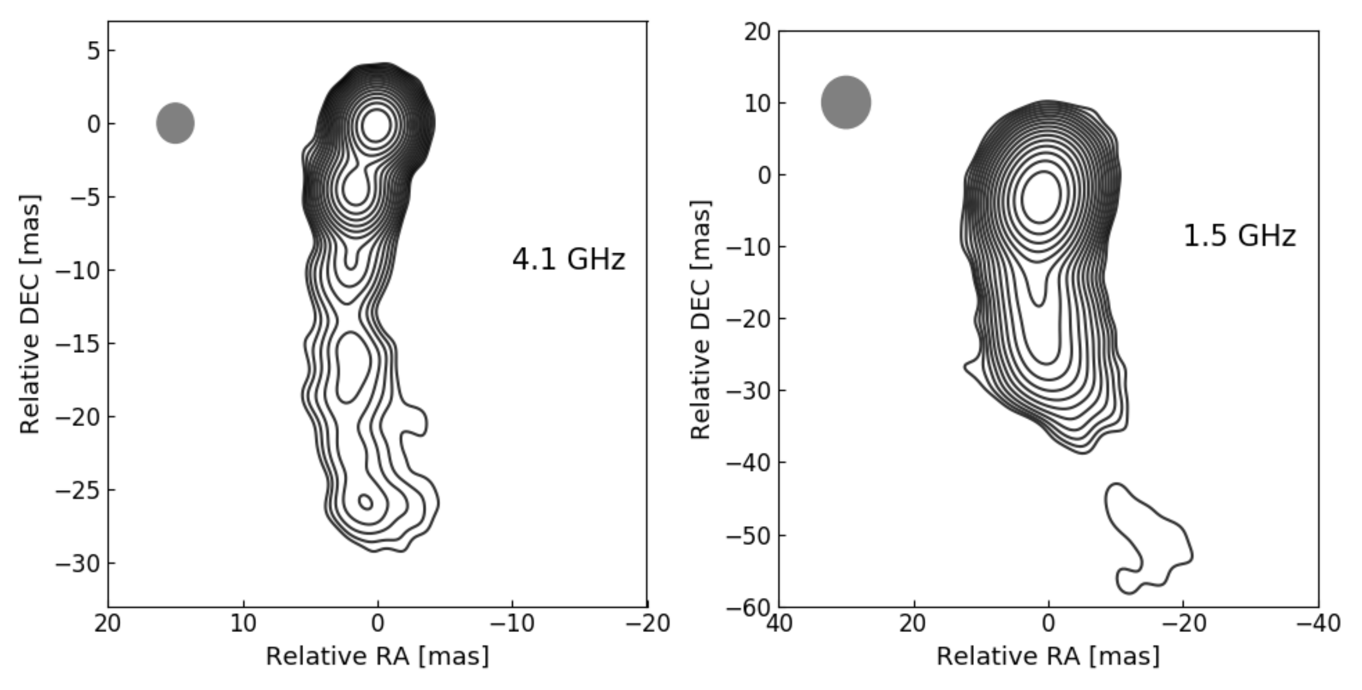
High-freq data

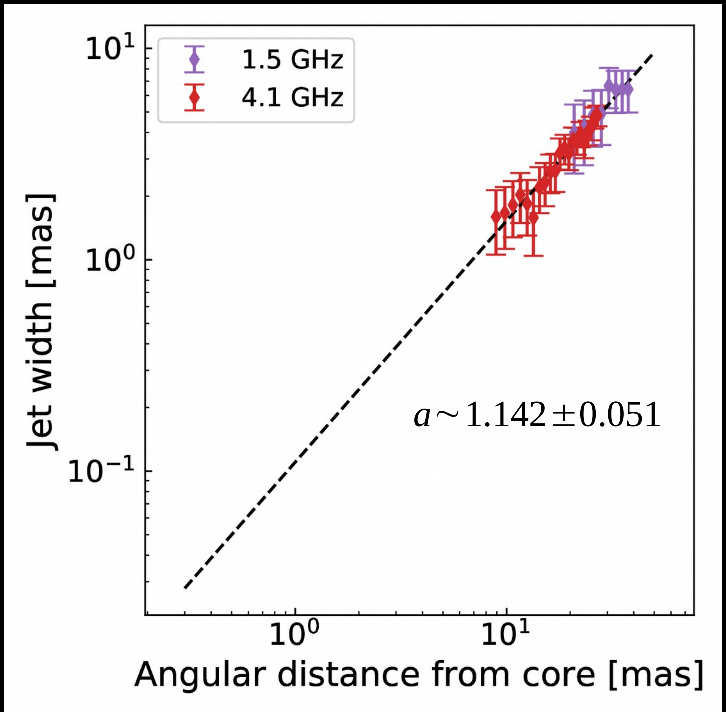
- Extended Jet structure

  (~ 8 mas)
- $W(z) \propto z^a, \ a \sim 0.553$
- Jet collimation

  : parabolic jet (being collimated)

Jet Collimation of FSRQ 1928+738

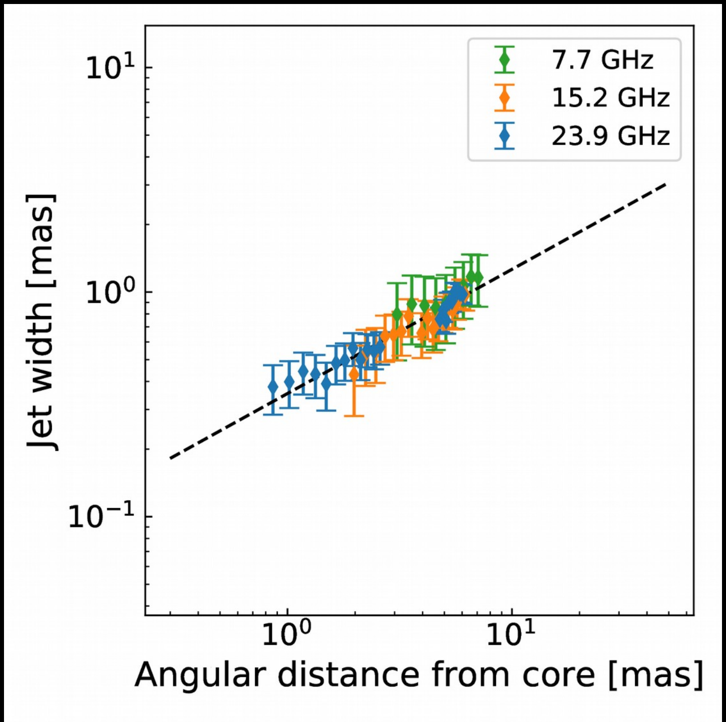


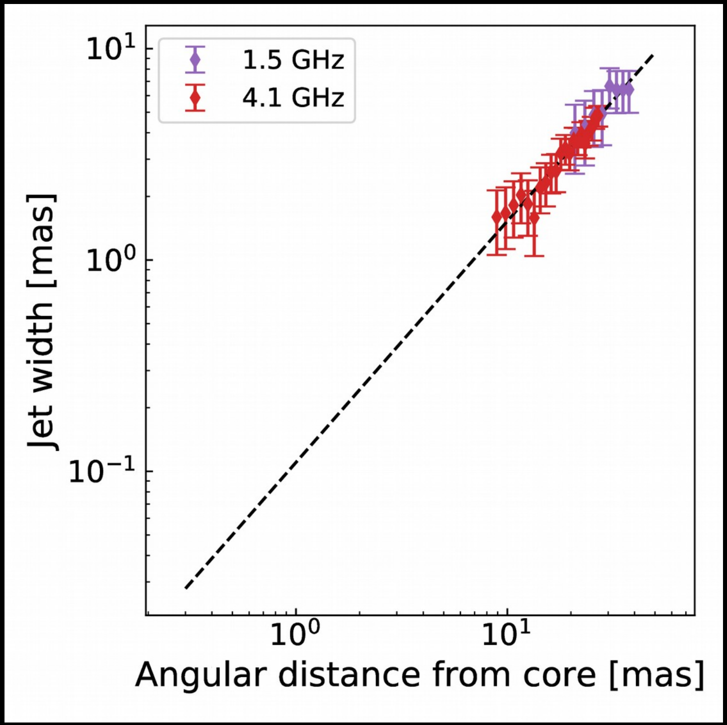


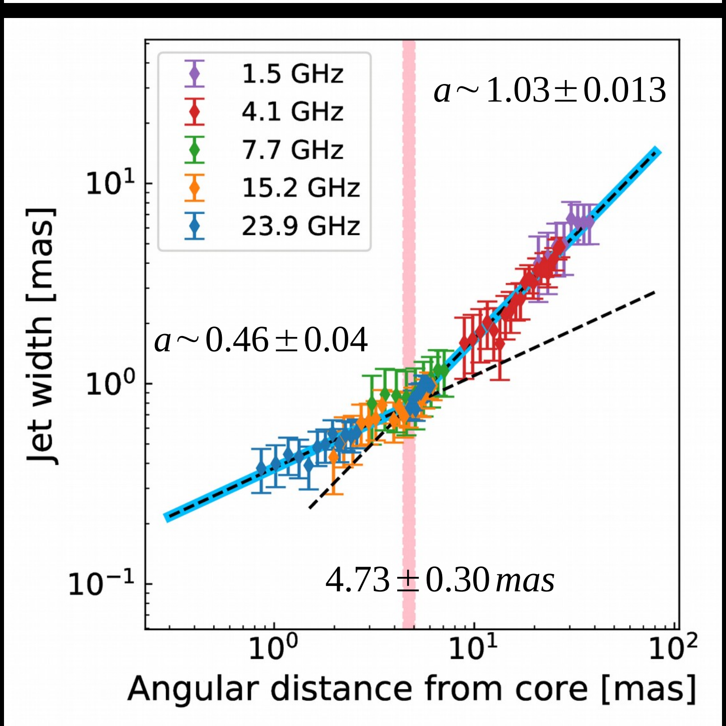
Low-freq data

- Extended Jet structure (~ 40 mas)
- $W(z) \propto z^a, \ a \sim 1.142$
- Jet collimation : conical (/ hyperbolic) jet (free expansion)

Jet Collimation of FSRQ 1928+738







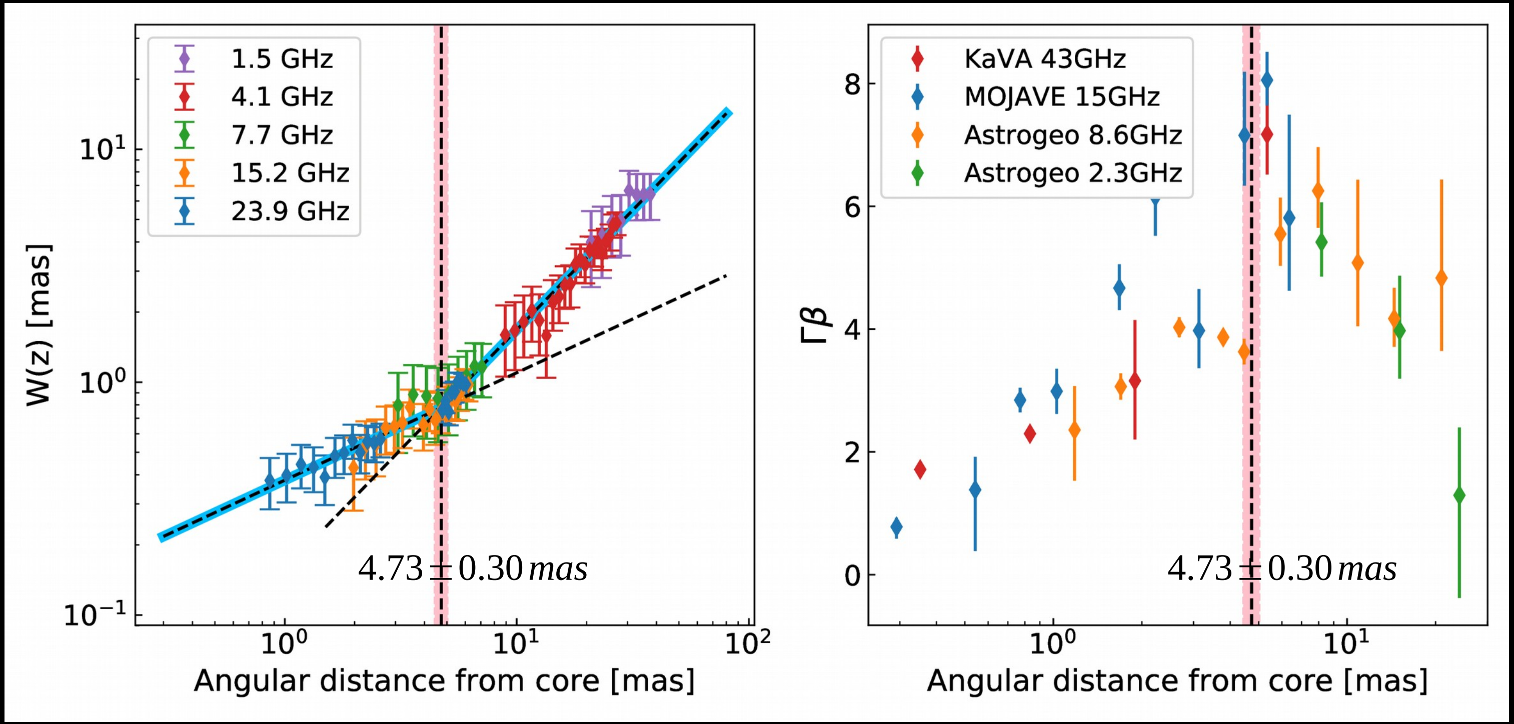
Broken – Power Law Fit

- $W(z) \propto z^{a1} (z < b)$
- $W(z) \propto z^{a2} (z \geq b)$
- b : transition site

→ parabolic to conical transition

(Jet Geometry)

Acceleration & Collimation of FSRQ 1928+738

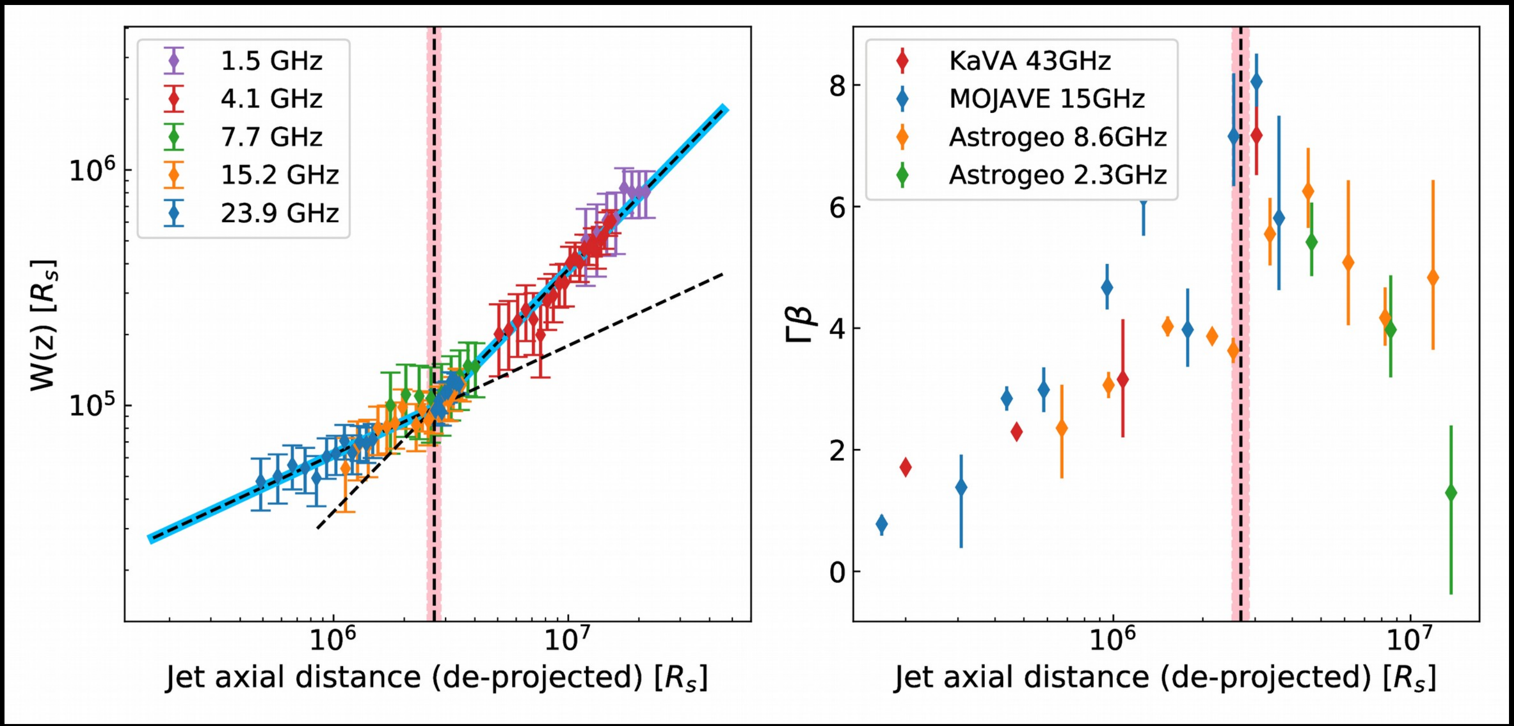


- Jet Geometry
- Jet Kinematics

- Collimation Zone ~ Acceleration Zone → ACZ
- Jet Kinematics : acceleration → deceleration
- Jet Geometry : parabolic → conical

  (= Jet Collimation Break)
- Both transition @ 5 mas

Jet Collimation Break @ Sphere Of Influence



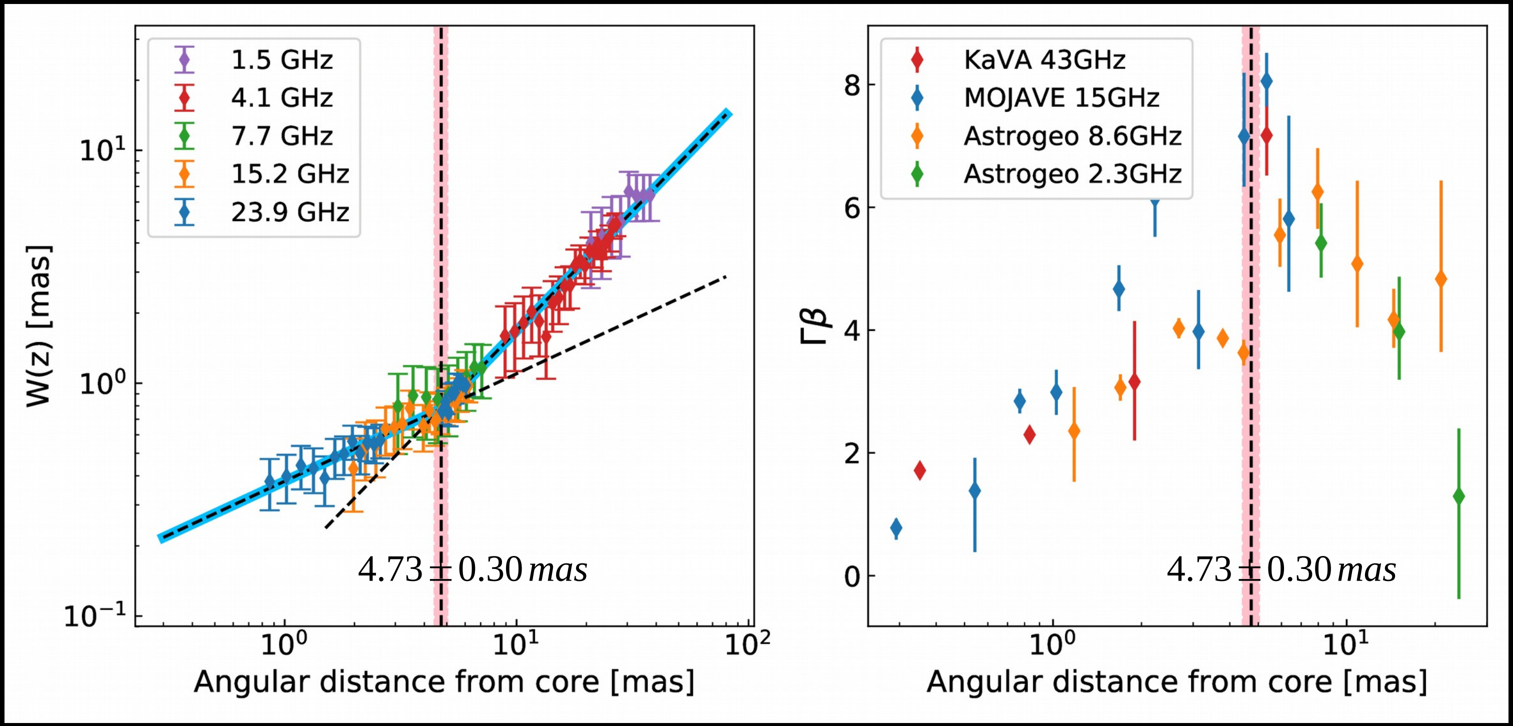
- Jet Geometry
- Jet Kinematics

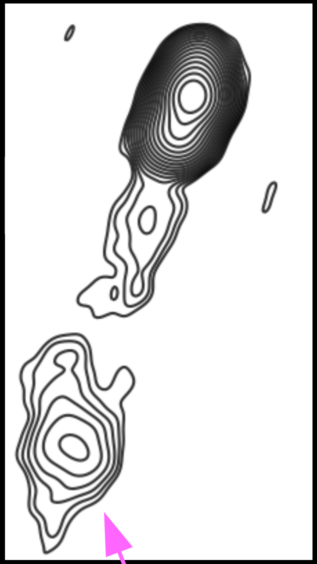
- $M_{BH} \sim 10^{8.57} M_{\odot}$, $\theta_v \sim 12.8^{\circ}$ Park 2017, Hovatta+ 09
- $r_{S.O.I} \equiv GM_{BH}/\sigma^2_{star}$
- $\sigma_{star} \sim \sigma_{[OIII]} = 128-166\, km/s$ Bian & Zhao 2004

$\rightarrow r_{S.O.I} \sim 1.6-2.8\times10^6 r_s$, $(r_{JCB} = \sim 2.7\times10^6 r_s)$

: coincident !!

Jet Collimation Break @ Sphere Of Influence





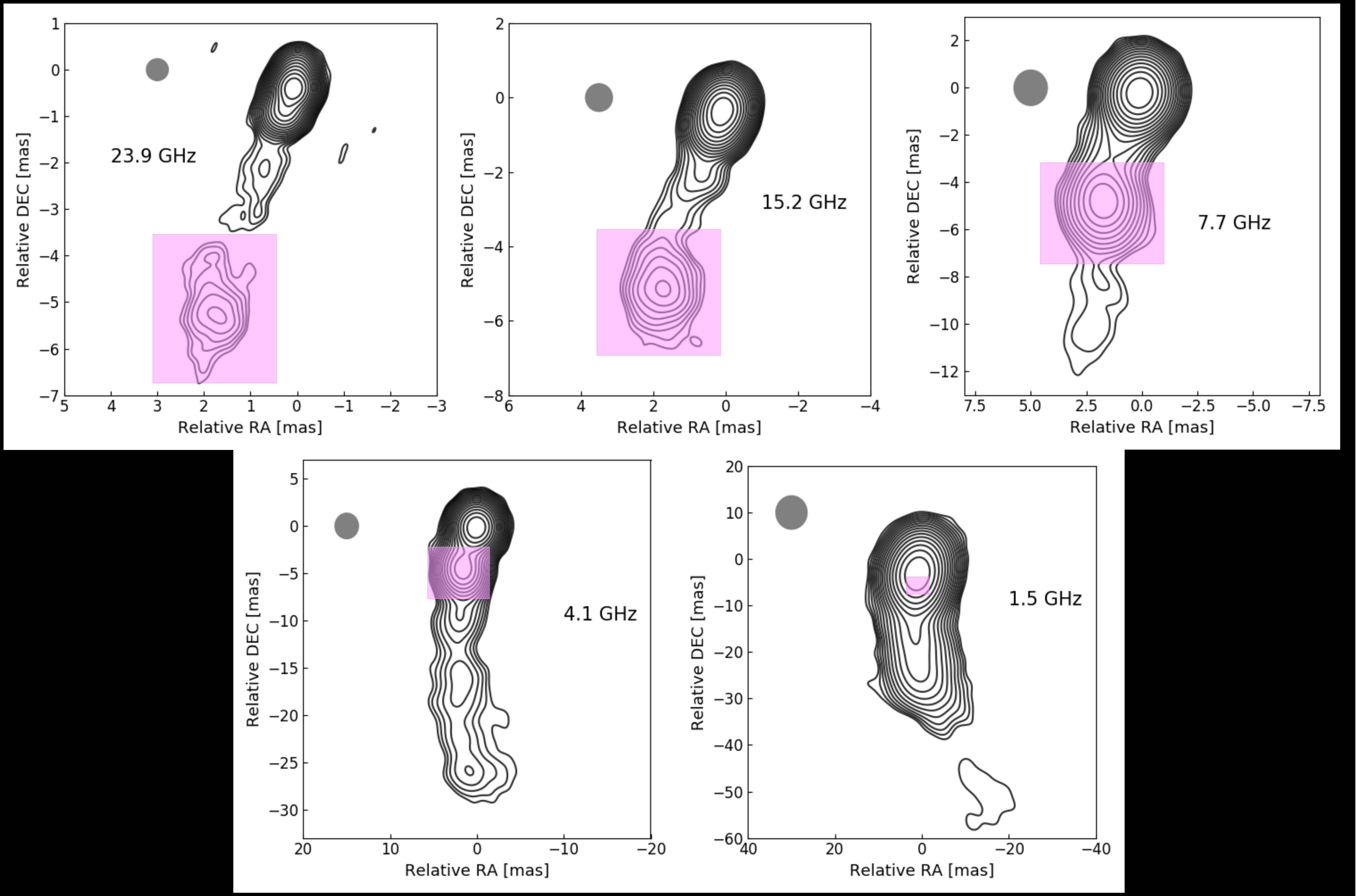
- Jet Geometry
- Jet Kinematics

JCB site

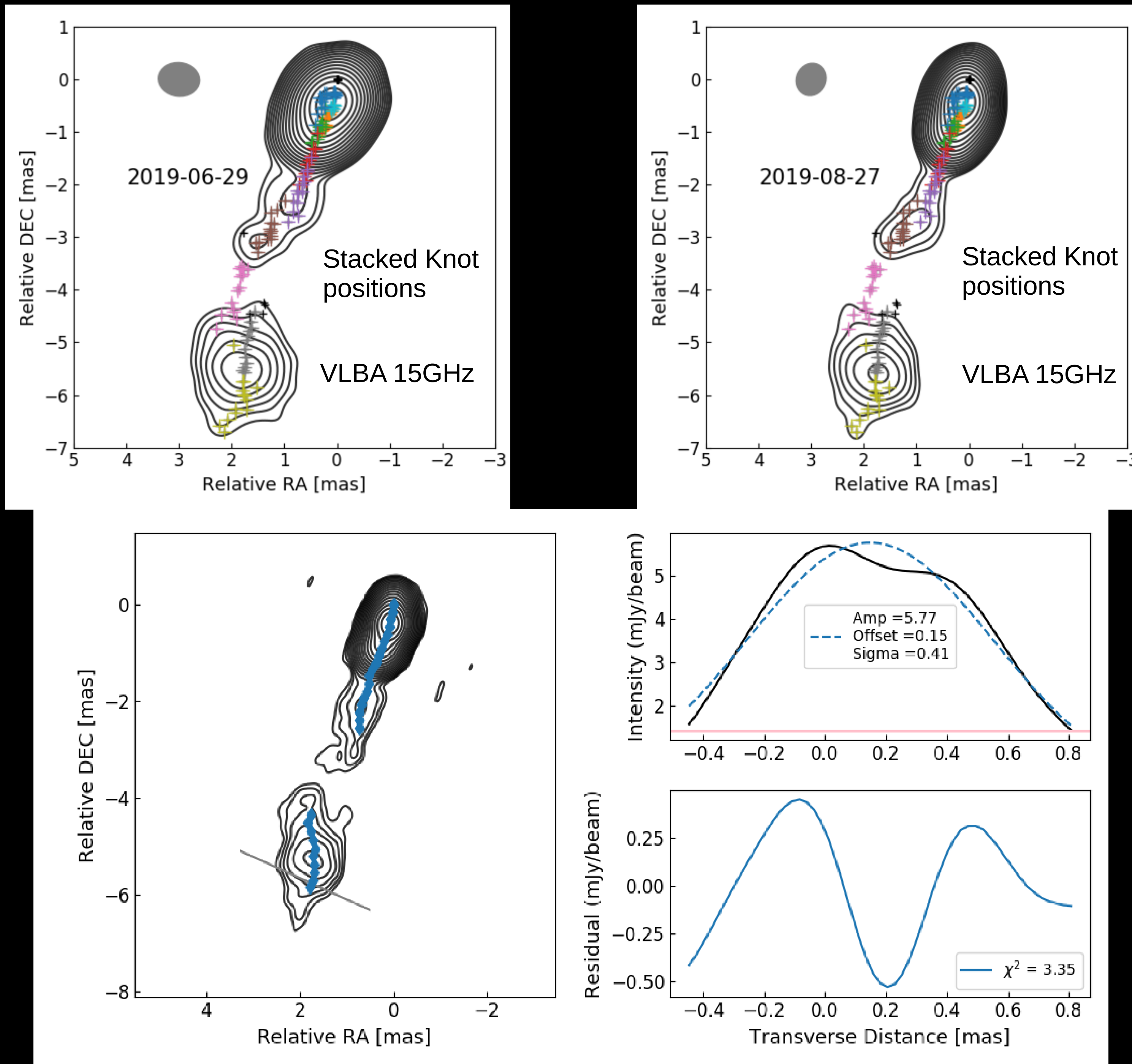
- Collimation Zone ~ Acceleration Zone → ACZ
- JCB (& Kinematics transition) @ S.O.I
- ACZ : Inside S.O.I of the SMBH
- JCB site (End of ACZ) : resembles HST-1 & S region ?

M87, 1H0323+342

JCB site : Brightness Enhanced



JCB site : Limb-Brightening



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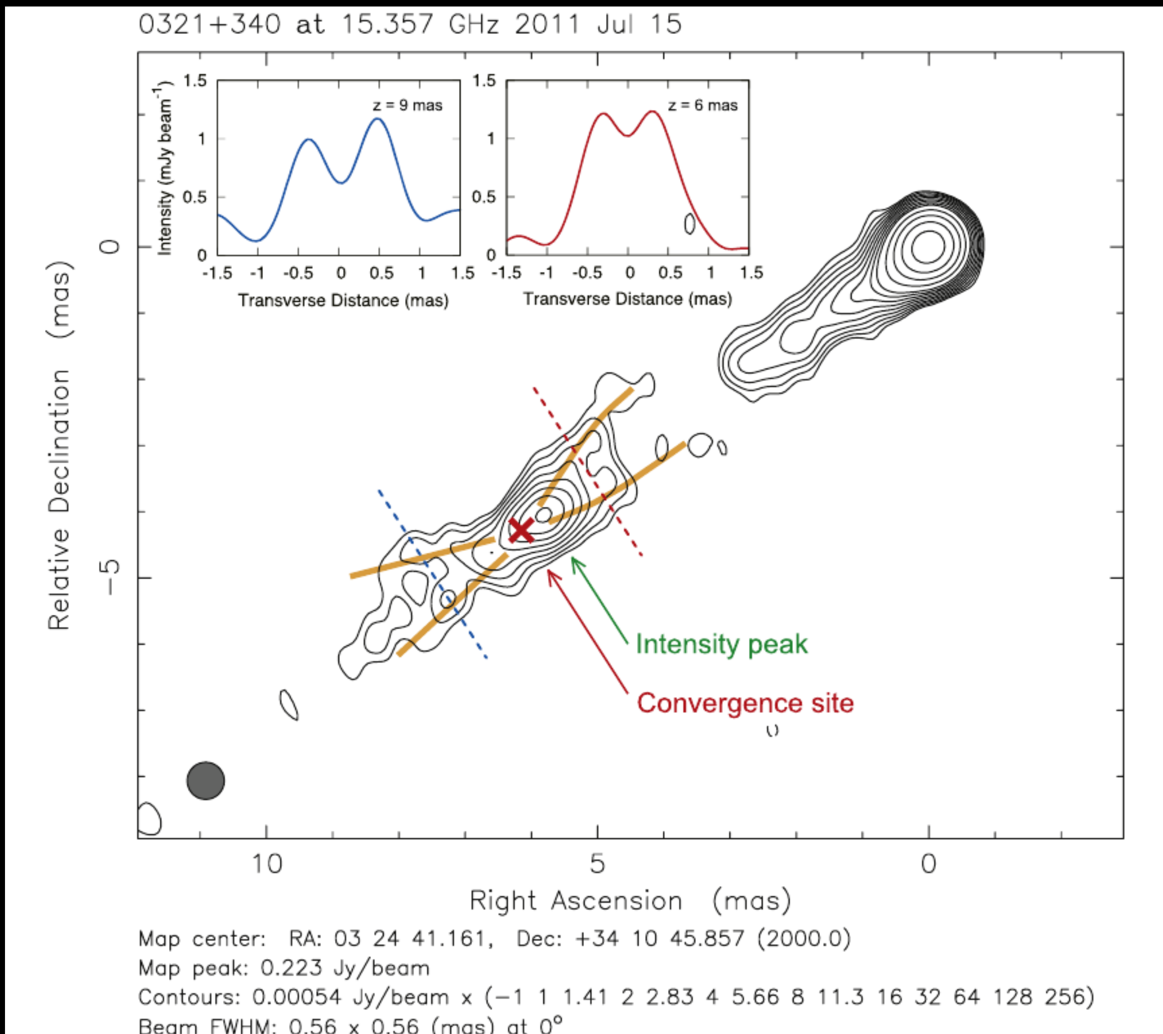


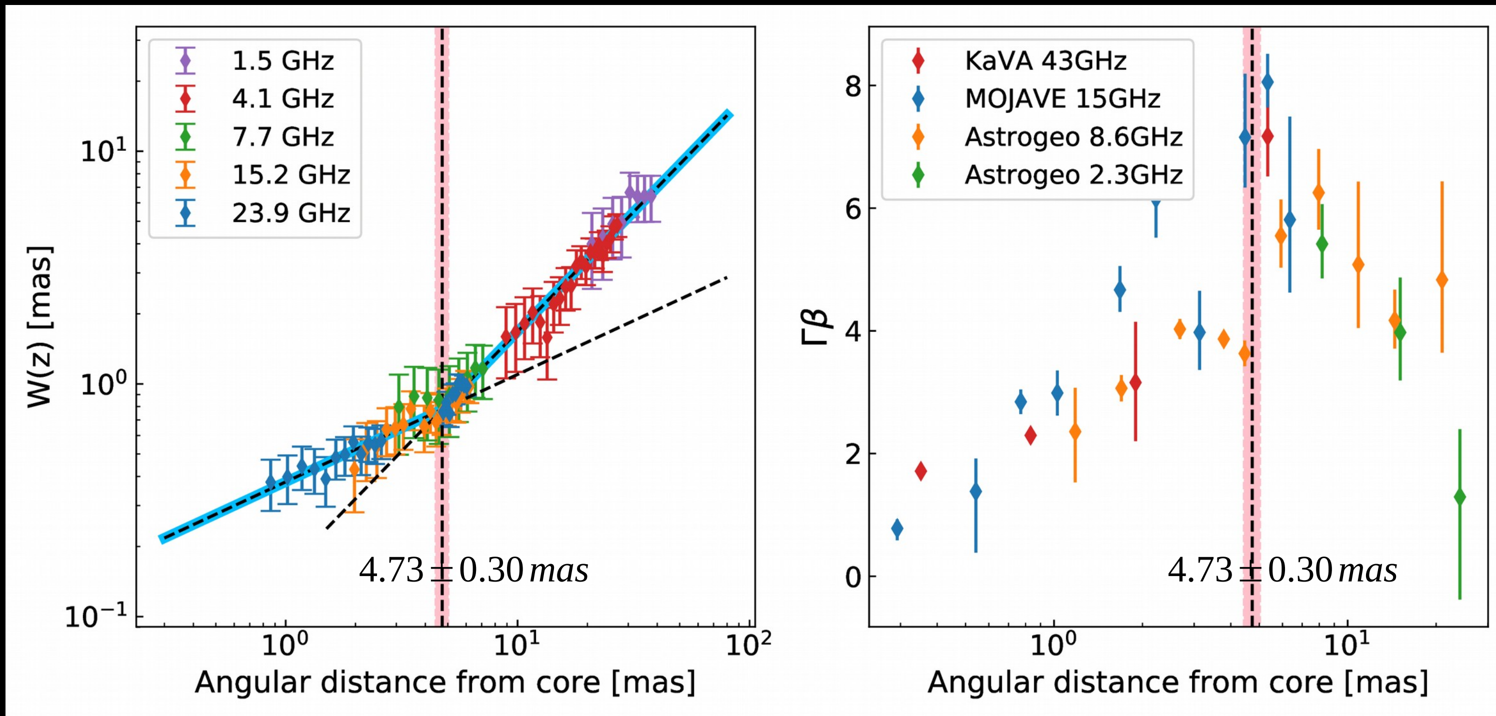
NLS1 1H0323+342 : Doi+2018

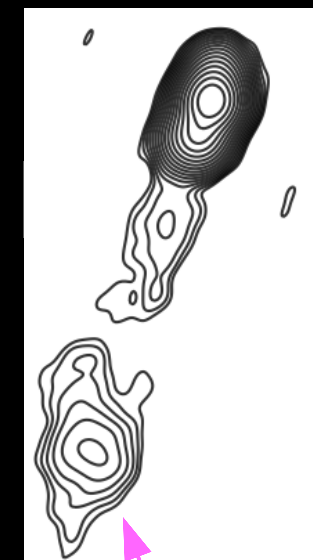
(1) Enhanced Intensity

(2) Limb-brightening

→ Re-collimation shock

ACZ & JCB : Conclusion





- Jet Geometry
- Jet Kinematics

JCB site

- Collimation Zone ~ Acceleration Zone → ACZ
- JCB (& Kinematics transition) @ S.O.I
- ACZ : Inside S.O.I of the SMBH
- A re-collimation shock candidate @ S.O.I

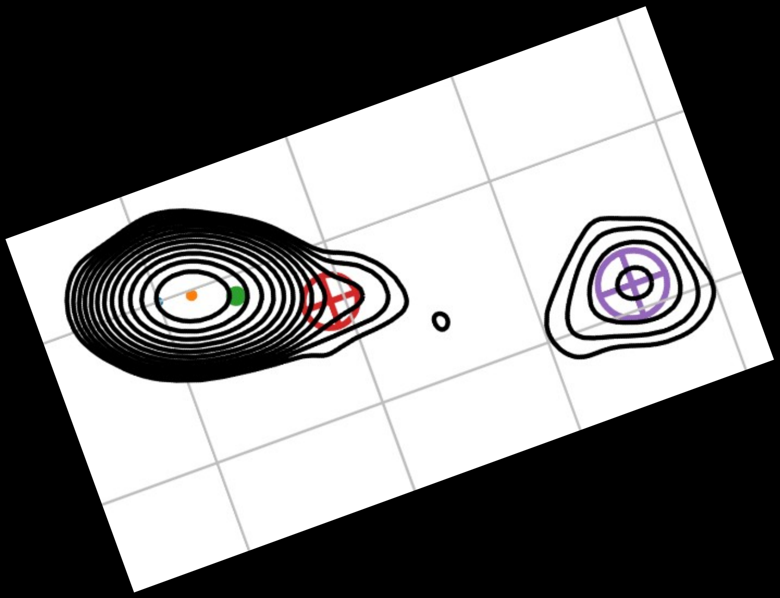
  : pressure imbalance likewise

M87, 1H0323+342

Summary

- We discovered (spatially resolved) the ACZ in the jet of FSRQ.
  - showing both acceleration & collimation
  - ACZ : inside the S.O.I of the SMBH
- We discovered the two transitions @ S.O.I
  - Acceleration → Deceleration in jet kinematics
  - Parabolic → Conical in jet geometry
- We detected re-collimation shock (candidate) @ S.O.I
  - Locally enhanced brightness
  - Limb-brightening feature

Deeper understanding the ACZ ?



Acceleration & Collimation Zone

Observational Strategy

$$1 \ \ mas \sim \ 5 \times 10^5 R_s$$

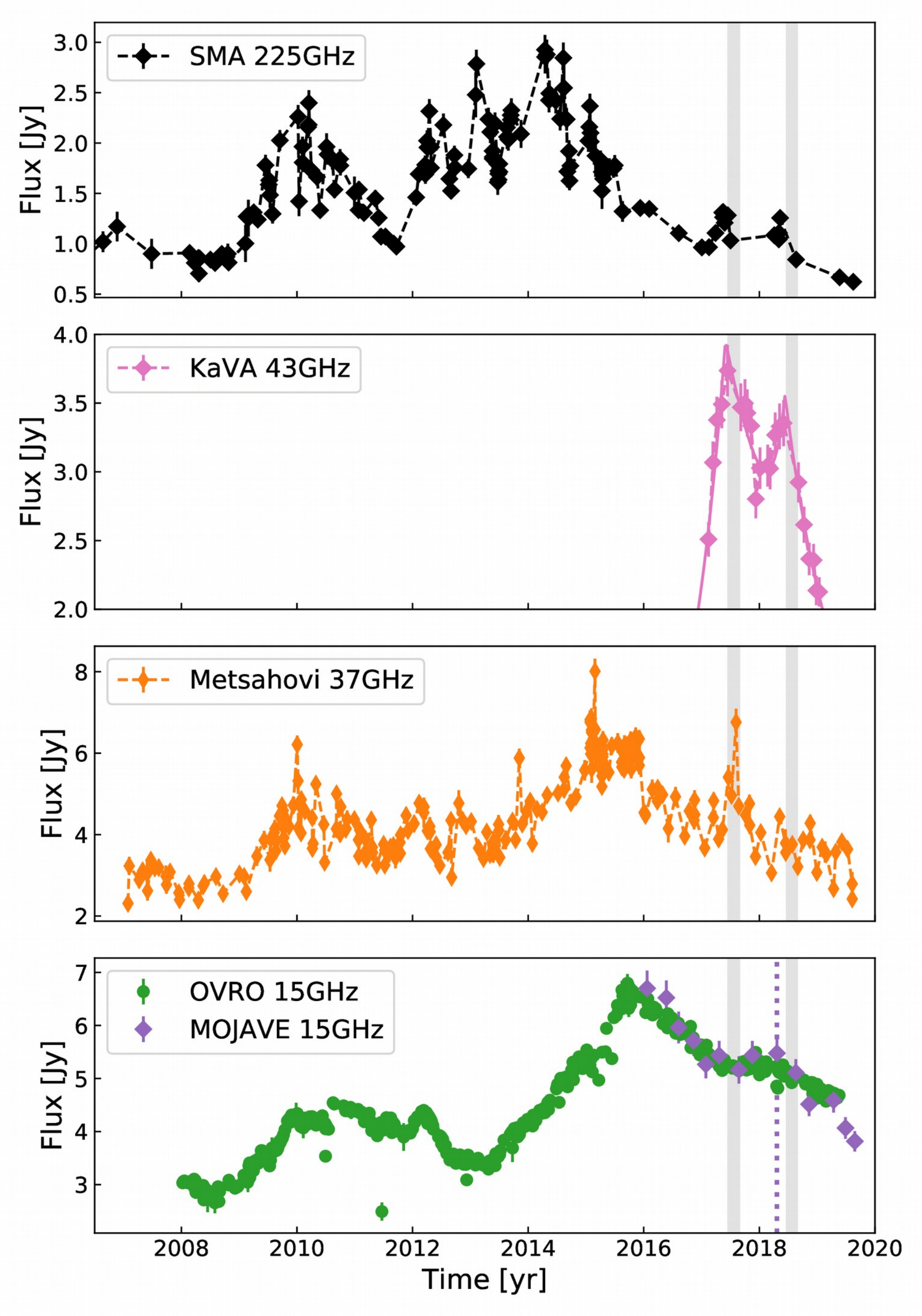
- GMVA / Space - VLBI

  : (in prep)
- Polarimetry

  : (in prep)
- Multi-wavelength light curves

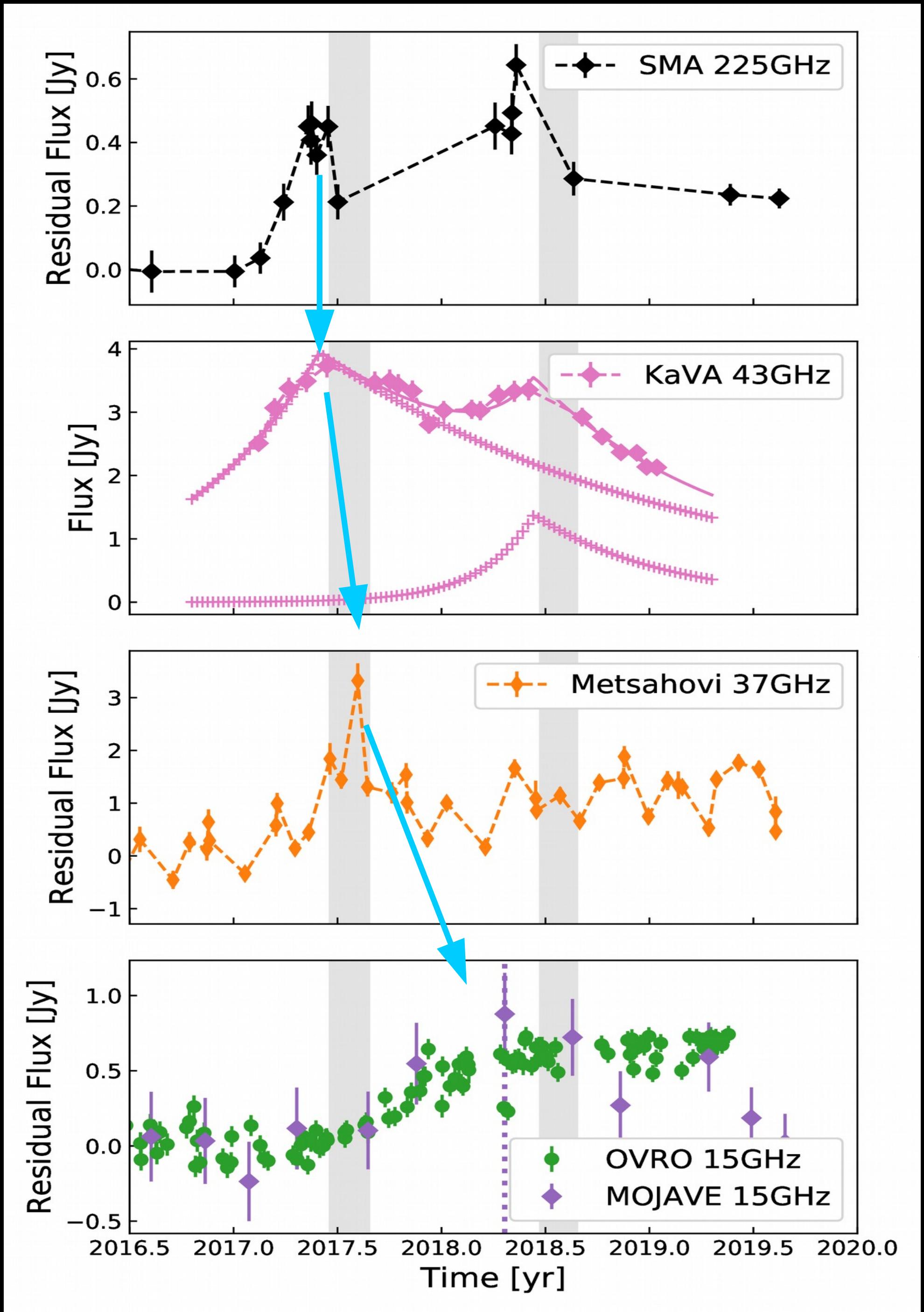
  : (collaterally on-going)

MWL analysis of FSRQ 1928+738



- Long-term perspective (10 yrs ↑)
  - @ 225, 37, 15 GHz
  - large flares
  - flares with yr time scale
  - → Similar Global Trend
- Short-term perspective (~2 yrs)
  - @ 225, 43, 37, 15 GHz
  - 2 (or 1) small flares
  - flares with month time scale

MWL analysis of FSRQ 1928+738



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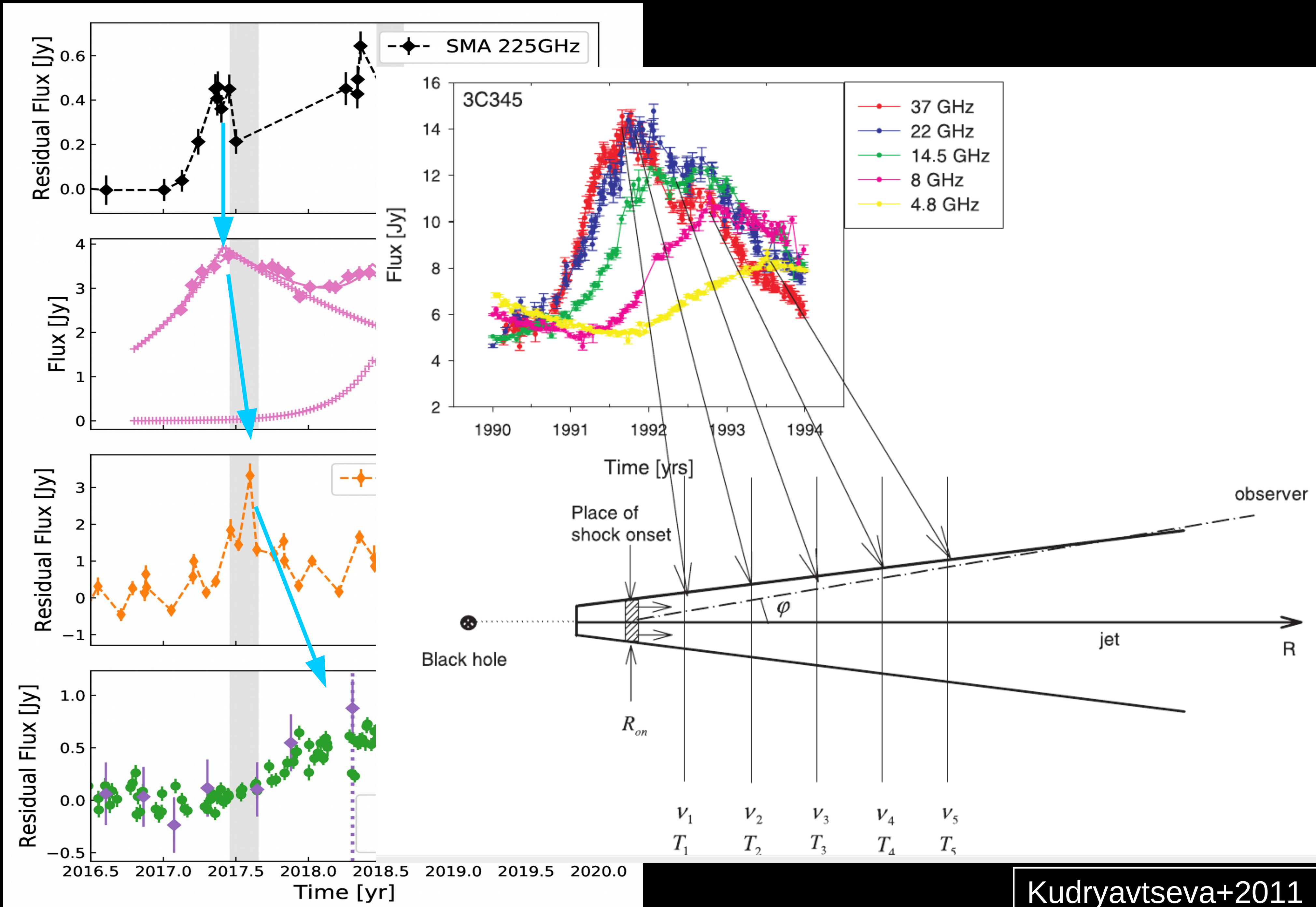
  → Similar Global Trend

- Short-term perspective (~2 yrs)
  - @ 225, 43, 37, 15 GHz
  - 2 (or 1) small flares
  - flares with month time scale

  : Well-constrained Event showing Δt_{lag}

MWL analysis of FSRQ 1928+738



Kudryavtseva+2011

Thank you