Collimation, Acceleration, and Recollimation Shock in the Jet of Gamma-Ray Emitting Radio-loud NLS1 Galaxy 1H 0323+342

- ***Hada, Doi, Wajima, D'Ammando, Orienti, Giroletti, Giovannini, Nakamura & Asada 2018, ApJ in press (on astro-ph)***
- ***Doi, Hada, Kino, Wajima & Nakahara, 2018 ApJL, 857, L6***

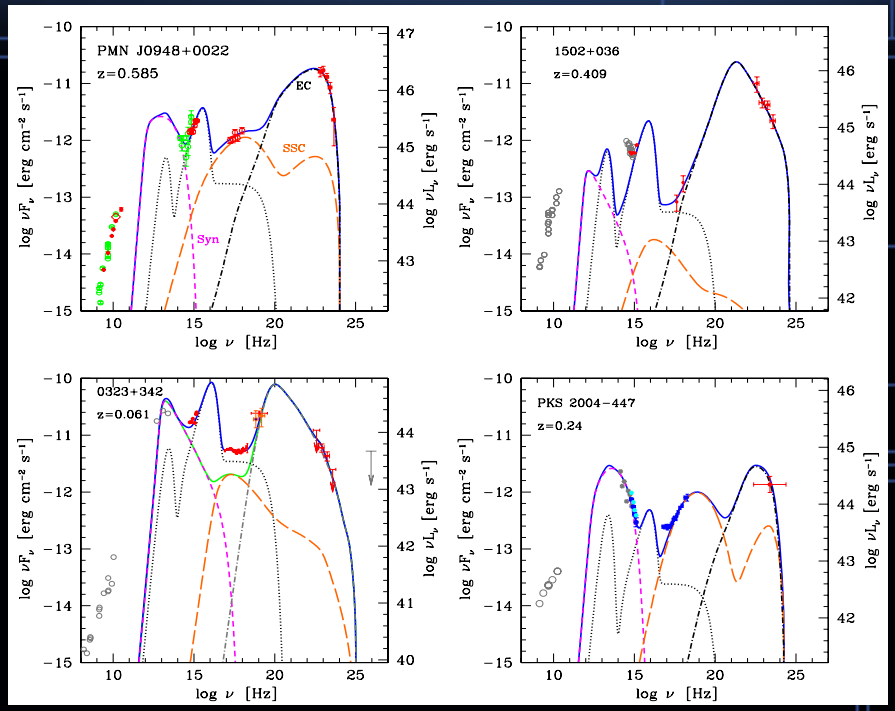
Half a Century of Blazars and Beyond,
June 11-15 2018, Torino

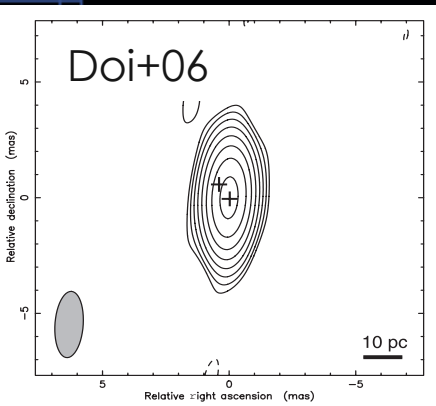
Kazuhiro Hada (NAOJ)

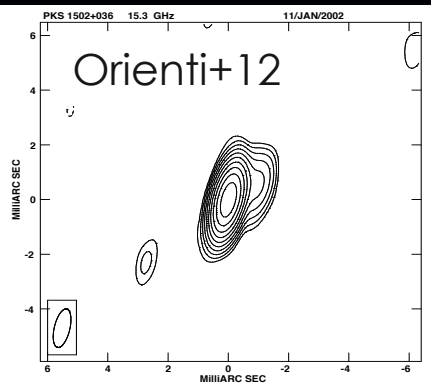
Relativistic jets in NLS1

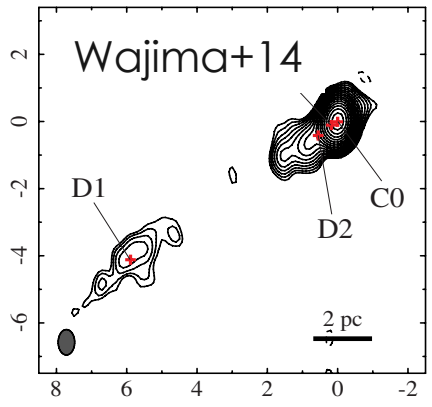
- Discovery of γ-ray emission in NLS1 by Fermi-LAT
- Possible new class of AGN producing powerful jets after blazars & radio galaxies

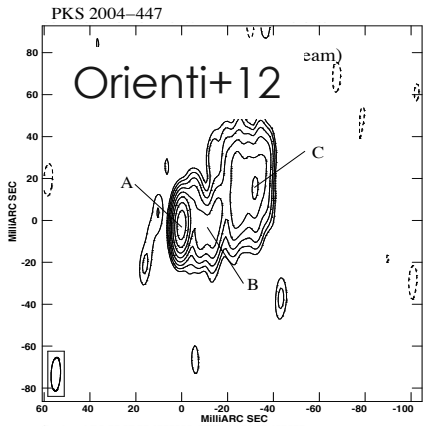
Abdo+2009







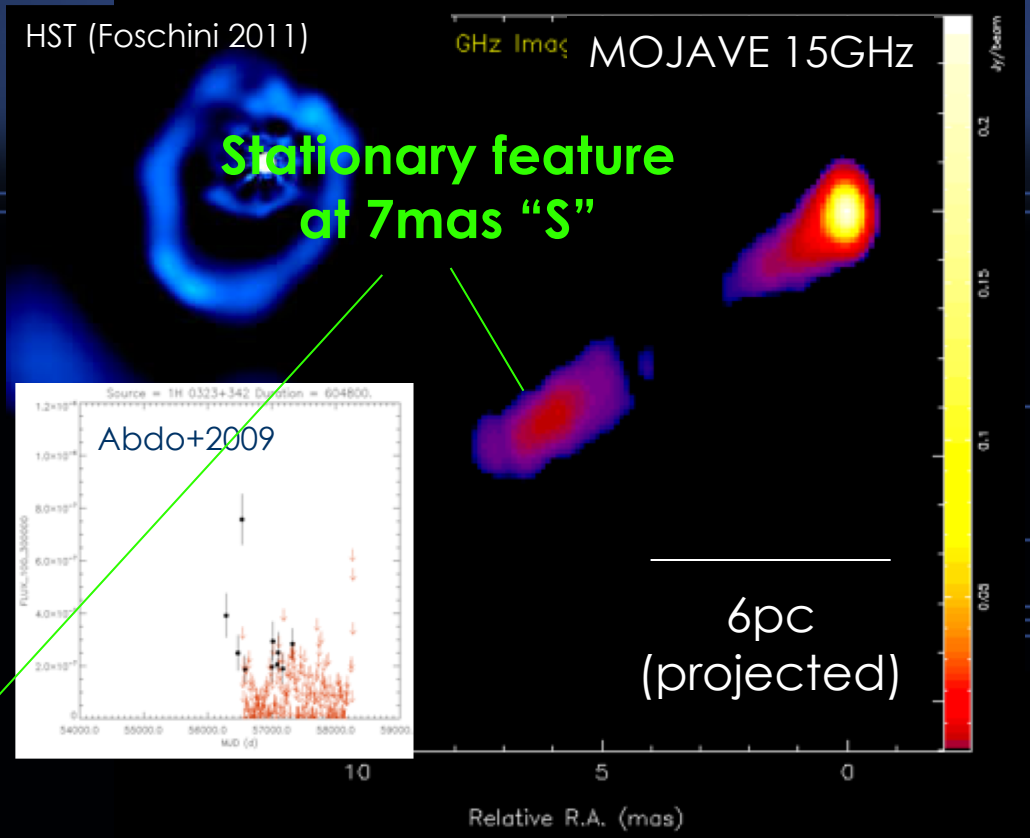


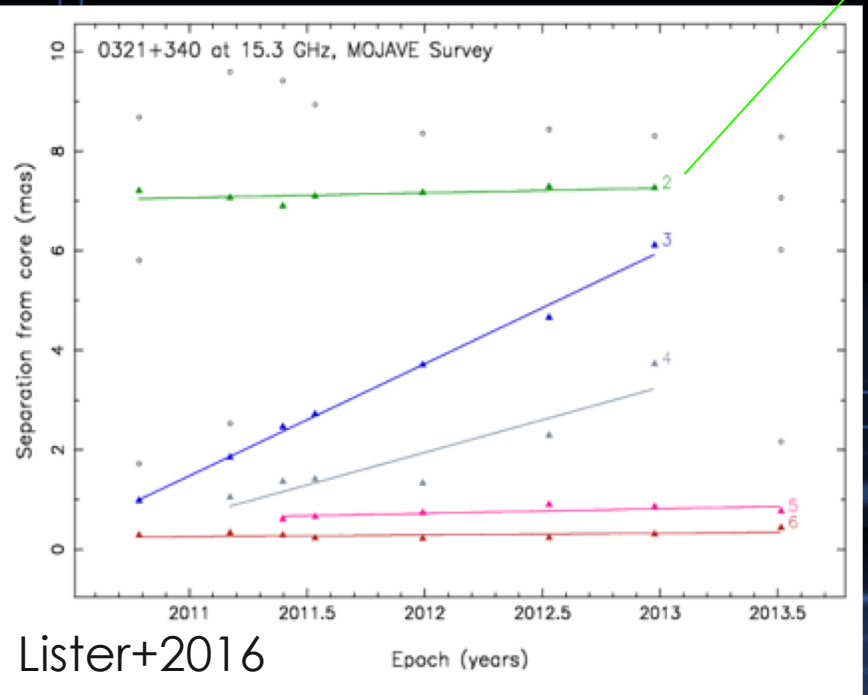


- Parsec-scale morphology very compact or one-sided core-jet
  - Similar to blazars
- Detailed properties of NLS1 jets still poorly understood due to the lack of VLBI studies

1H 0323+342 (z = 0.063)

- **Nearest γ-ray detected NLS1**
  - Host galaxy spatially resolved
- Pc-scale jet well resolved
  - 1mas = 1.2pc (projected)



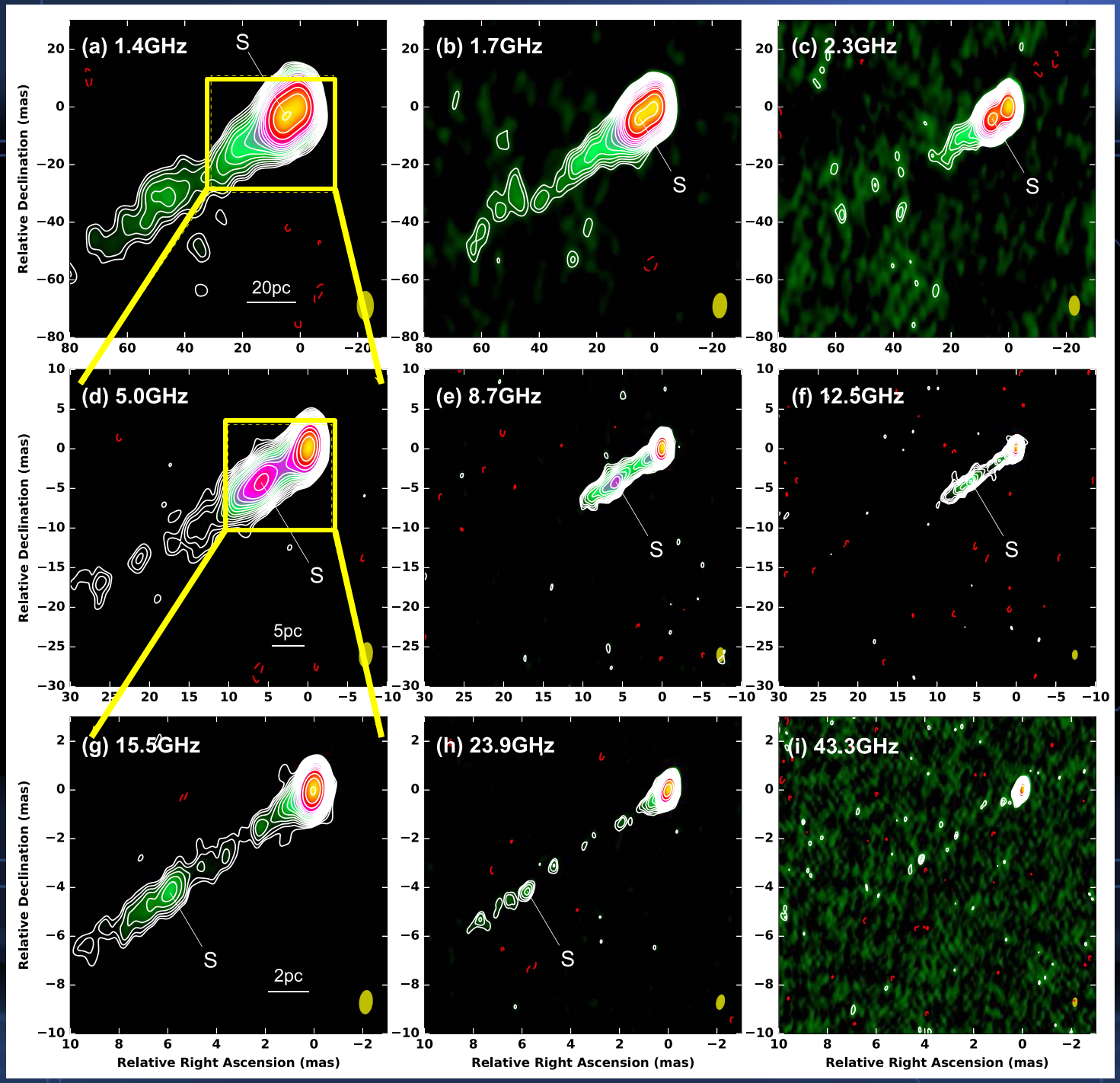


- Max v_{app}~9c → θ_{view}<12° (Lister+16)
- Radio variability analysis θ_{view}~4° (Fuhrmann+16)

- **Rebrightened feature at 7mas "S"**
  - Stationary over > a decade (Wajima+2014)

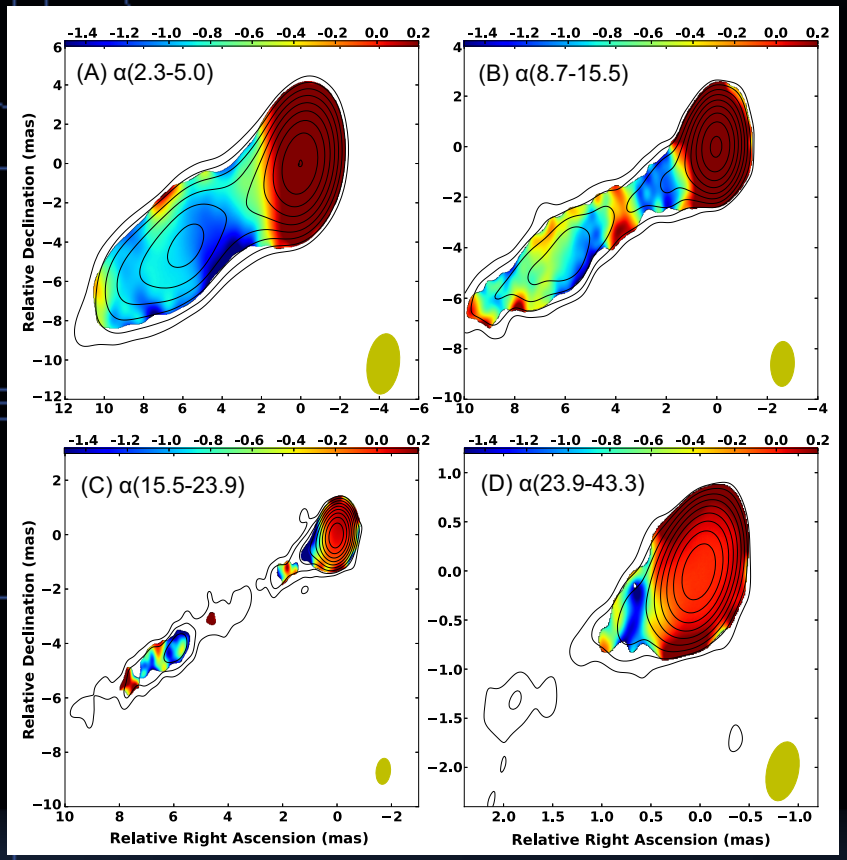
New VLBI study of 1H 0323+342: Motivation

- The source offers a privileged opportunity to study the details of jet formation in NLS1 (nearby, bright, resolved)
- Despite this observational advantage, now absent from MOJAVE list, and only a few basic jet properties have been constrained yet
  - What is the nature of "S"?
  - What is the difference from or similarity to jets in blazars / radio galaxies?
  - Spectral properties?
  - Collimation / Acceleration properties?
  - Where is the location of γ-ray emission?
  - Any hints on BH mass (~$10^7 M_{sun}$ vs >$10^8 M_{sun}$)?
    - Leon Tavares+14, D'Ammando+18
- To address these questions in more detail, we started a new multi-frequency VLBA program on this jet

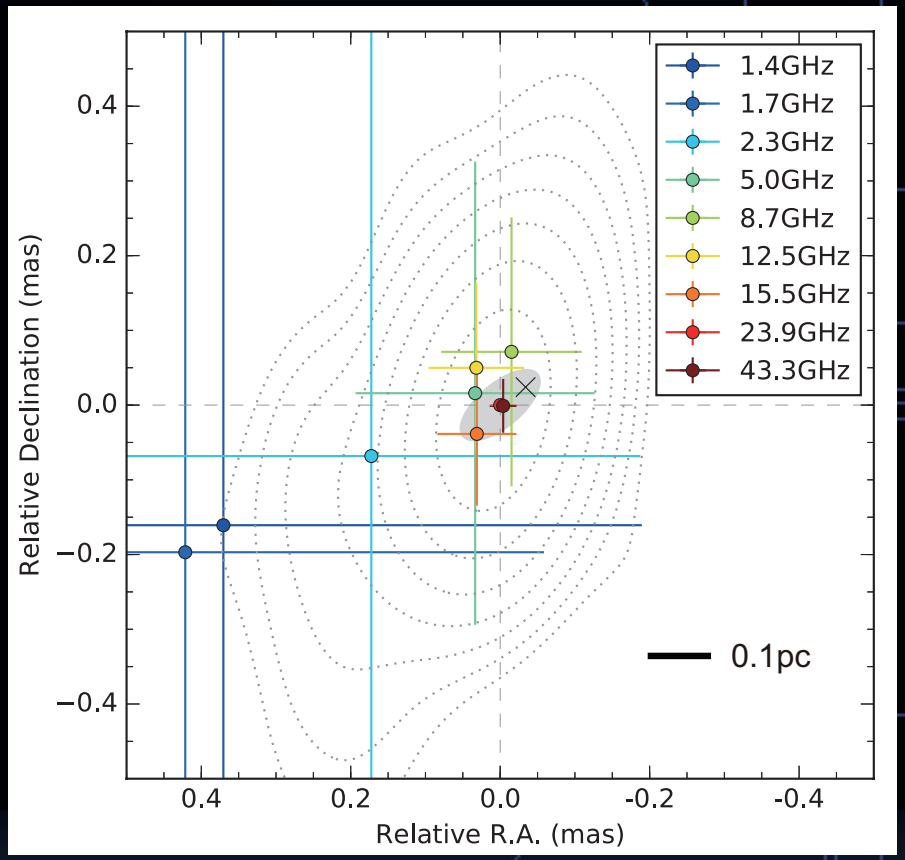

(a) 1.4GHz
S
20pc
(b) 1.7GHz
S
(c) 2.3GHz
S
(d) 5.0GHz
S
5pc
(e) 8.7GHz
S
(f) 12.5GHz
S
(g) 15.5GHz
S
2pc
(h) 23.9GHz
S
(i) 43.3GHz
Relative Declination (mas)
Relative Right Ascension (mas)

Jan 2016

Spectral index distributions



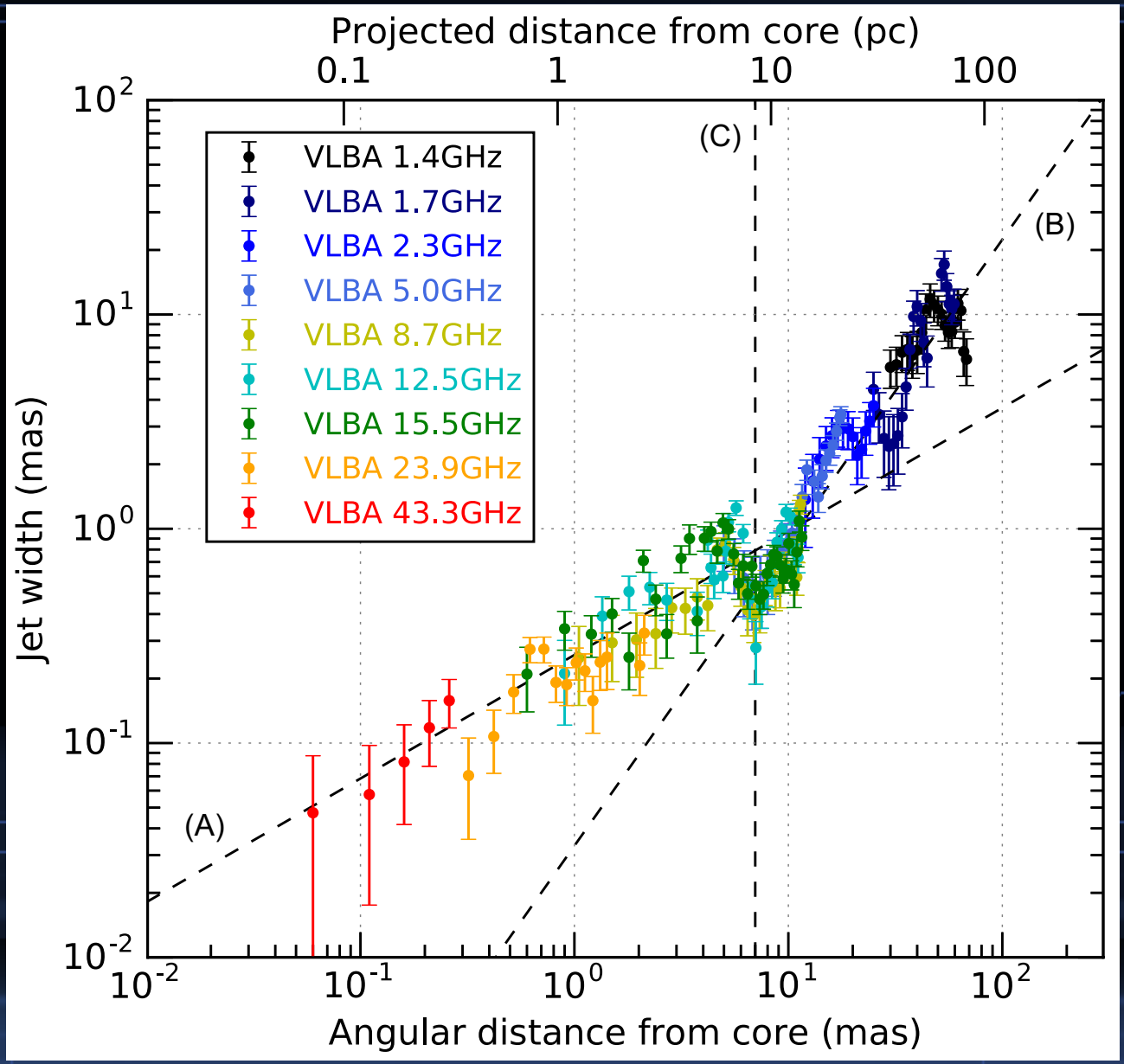
Core shift



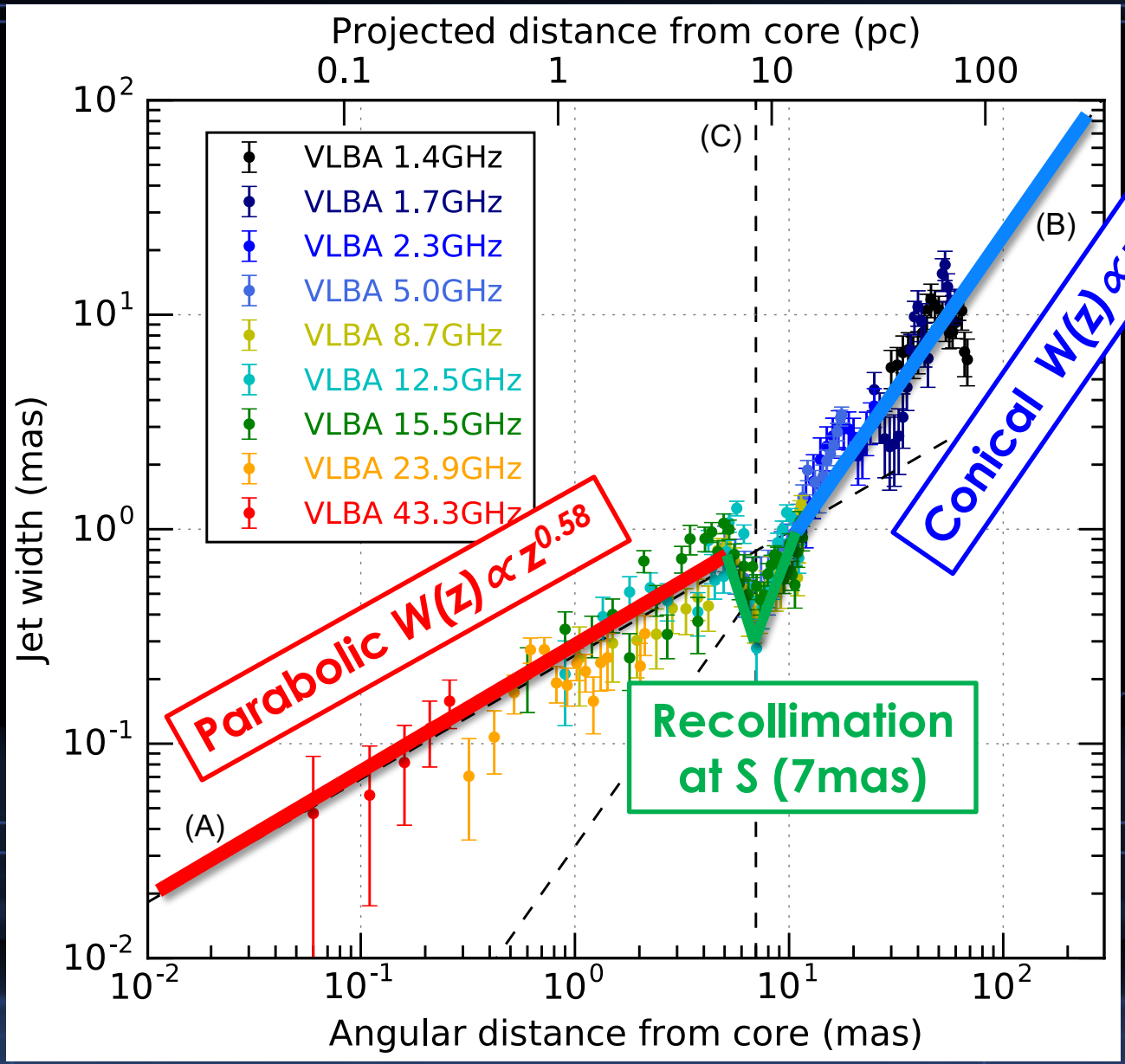
Phase-referencing mode

- Flat-spectrum core, optically-thin jet
- Small core-shift (<100uas between 5 and 43GHz)
  - Small jet viewing angle
- Similar to many other blazars. Nothing special?

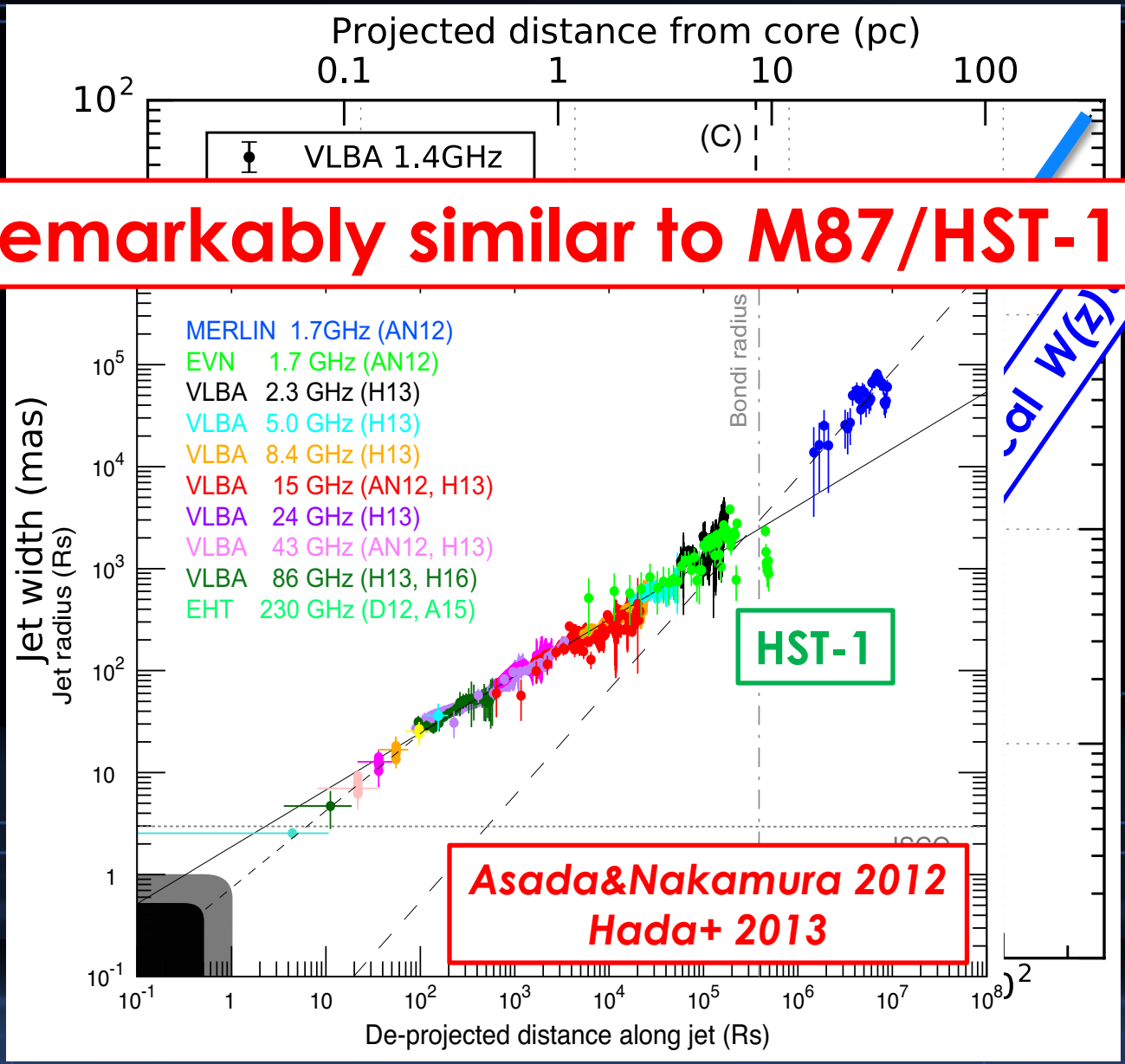
Jet width (collimation) profile



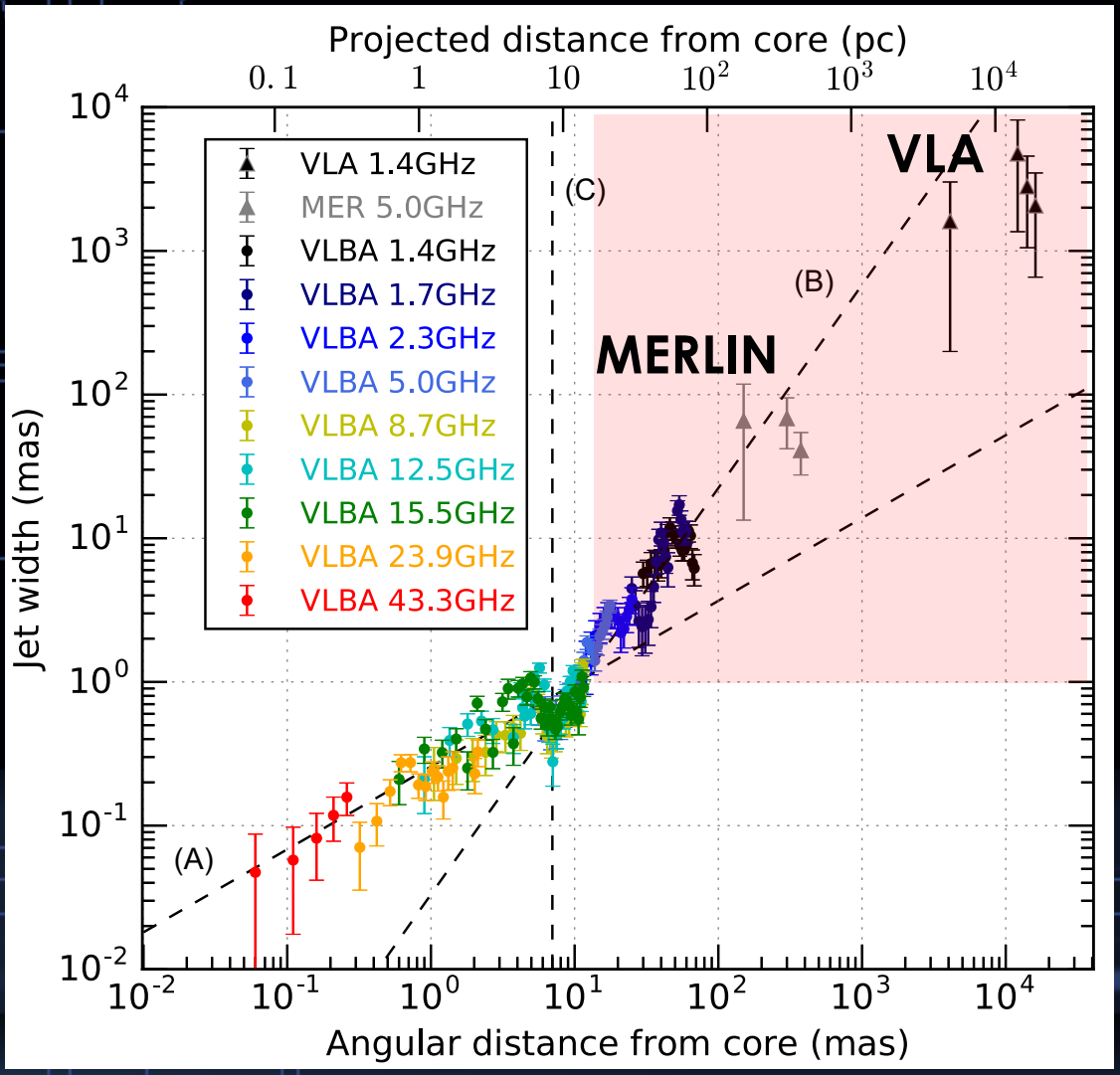
Jet width (collimation) profile

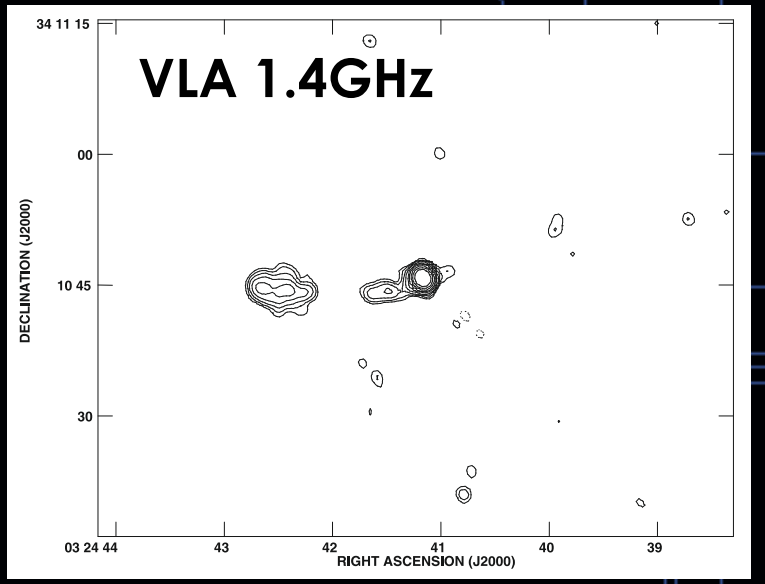


Jet width (collimation) profile



Large(kpc)-scale jet



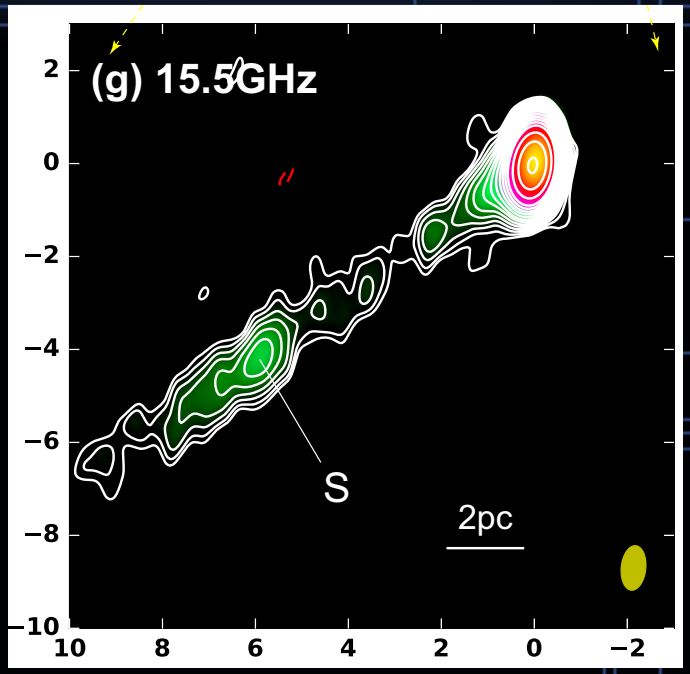


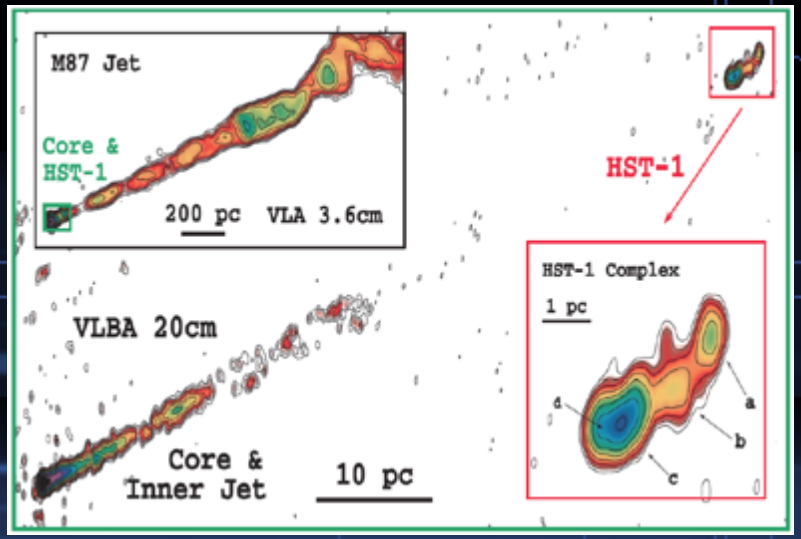
Anton+2008

Large-scale jet similarly follows conical expansion

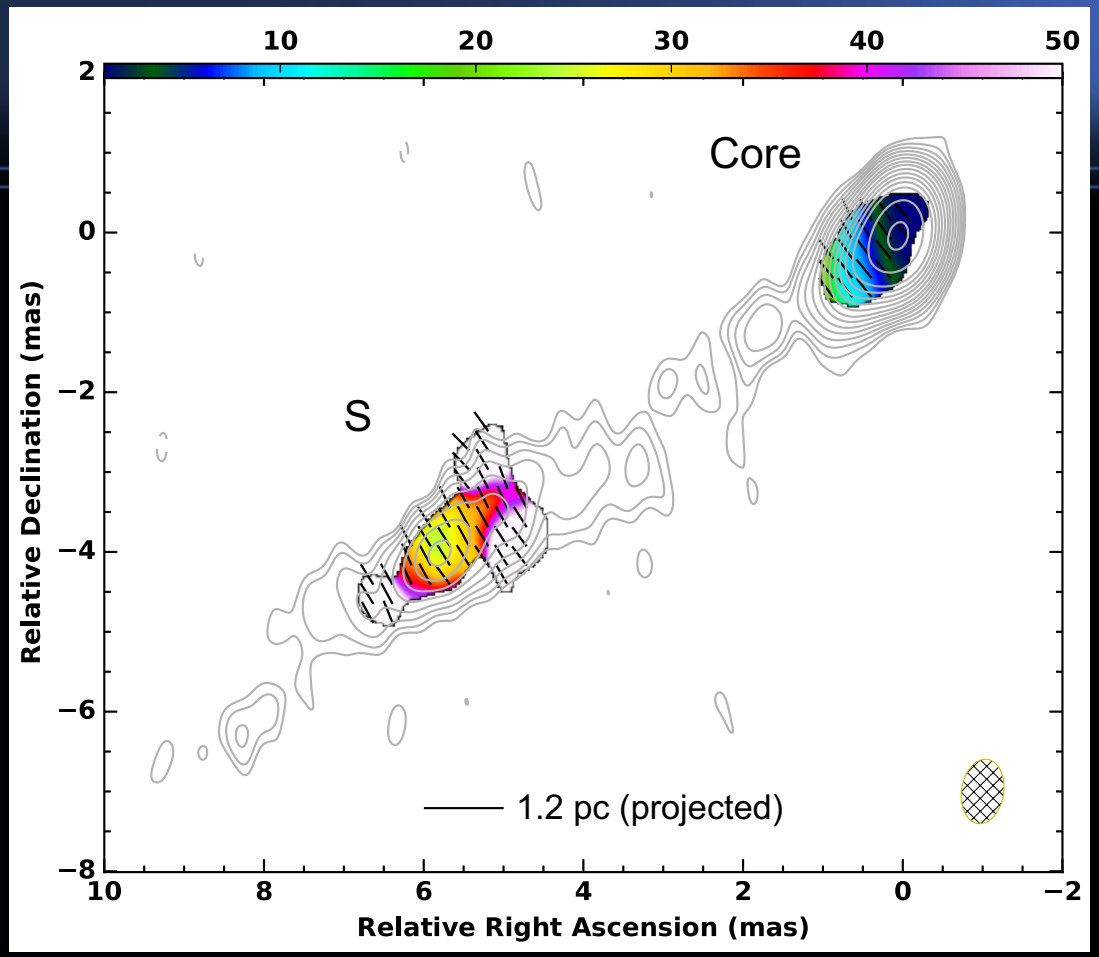
Nature of S ?

- The observed jet collimation profile strongly suggests that the parabolic-to-conical transition originates in S
- Very similar to HST-1 in many aspects
  - Quasi-stationary
  - Location from the core (~100pc)
  - Compressed and rebrightened
- Recollimation shock at the end of collimation zone is likely





Cheung+07



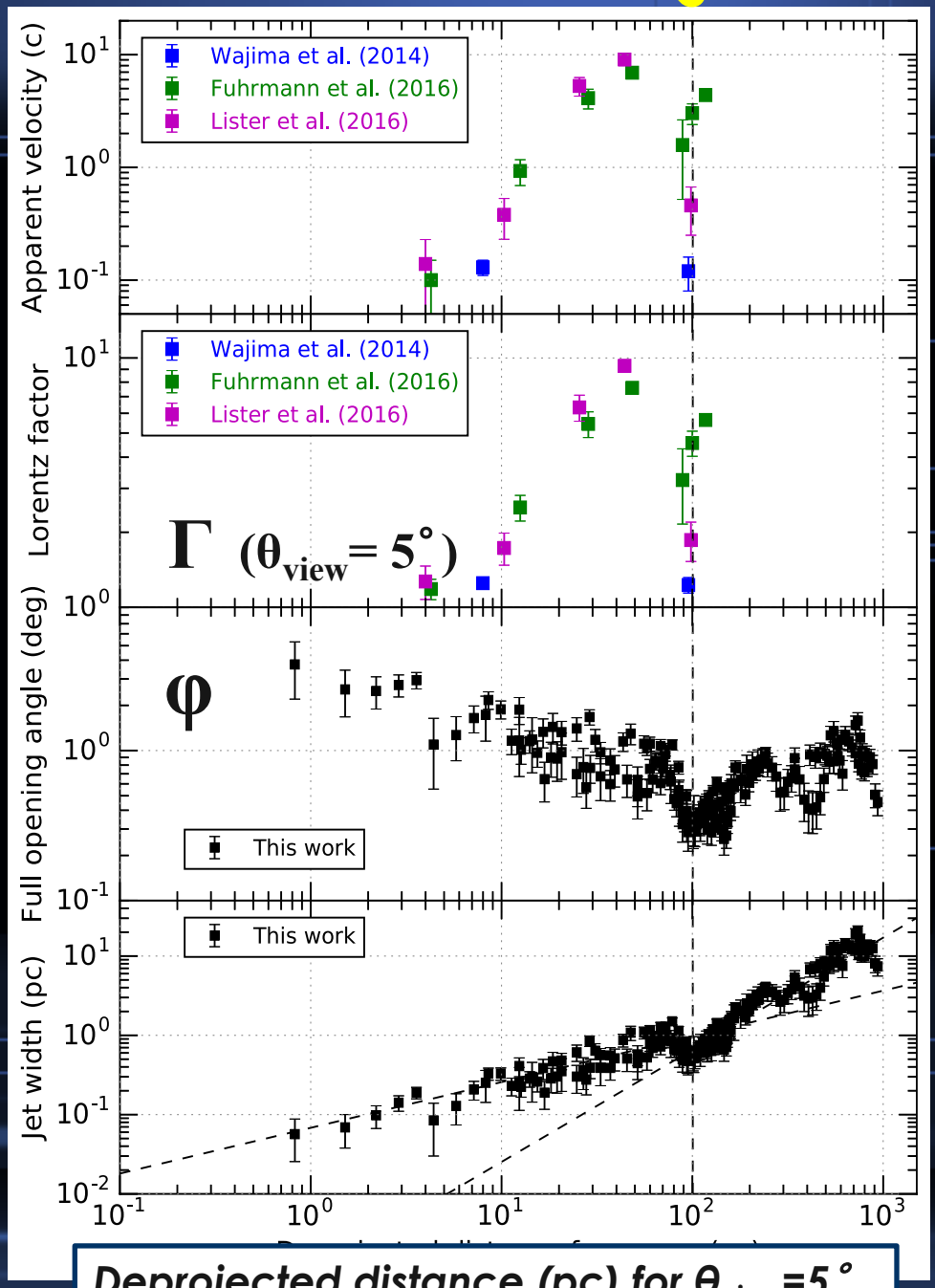
Bars are EVPA

EVPA NOT RM-corrected

- We further searched for any polarimetric signature associated with S using MOJAVE data
- **Strongly polarized feature on S (FP ~30%)**
- **Highly ordered B-fields**

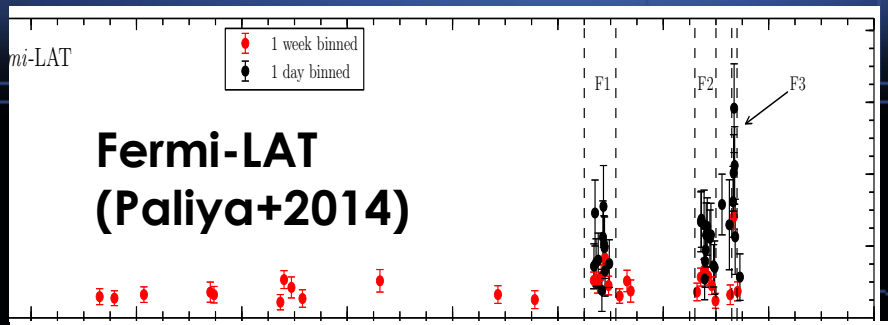
Coexistence of jet collimation & acceleration

- Collimation profile seems to be closely correlated with jet velocity profile !
  - Parabolic – acceleration
  - Jet speed saturates near ***S***
- *Γφ ~ 0.01 <<1*
  - Collimation/acceleration causally connected (Clausen-Brown+13)
- Consistent with magnetic collimation and acceleration scenarios

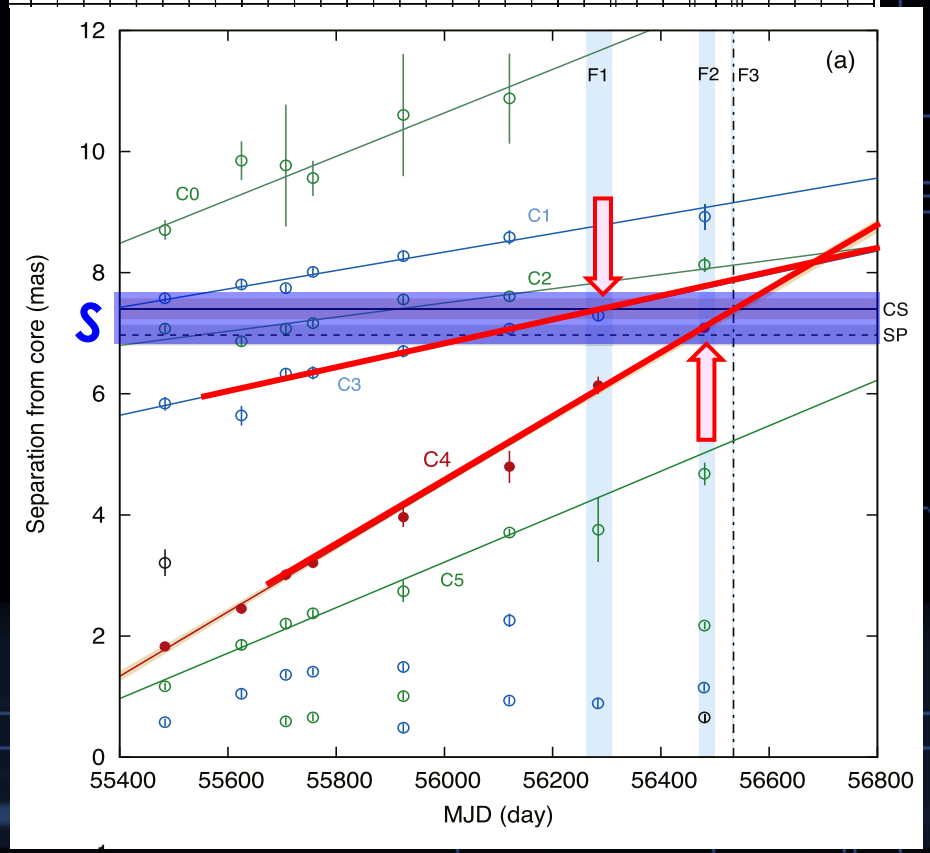


G-ray production at ~100pc??

- Feature S (z ~ 100pc for θ_{view}=5)
  - Counterpart of HST-1
  - Maximally beamed at the end of ACZ
- Previous GeV flares coincided with the passing of superluminal components through S
- Issues
- t_{var}~ R(1+z)/cδ ~ 30days
  - Too large to explain day-scale G-ray variabilities
  - More compact substructures in S (like HST-1)?
- What's the source of seed photons?

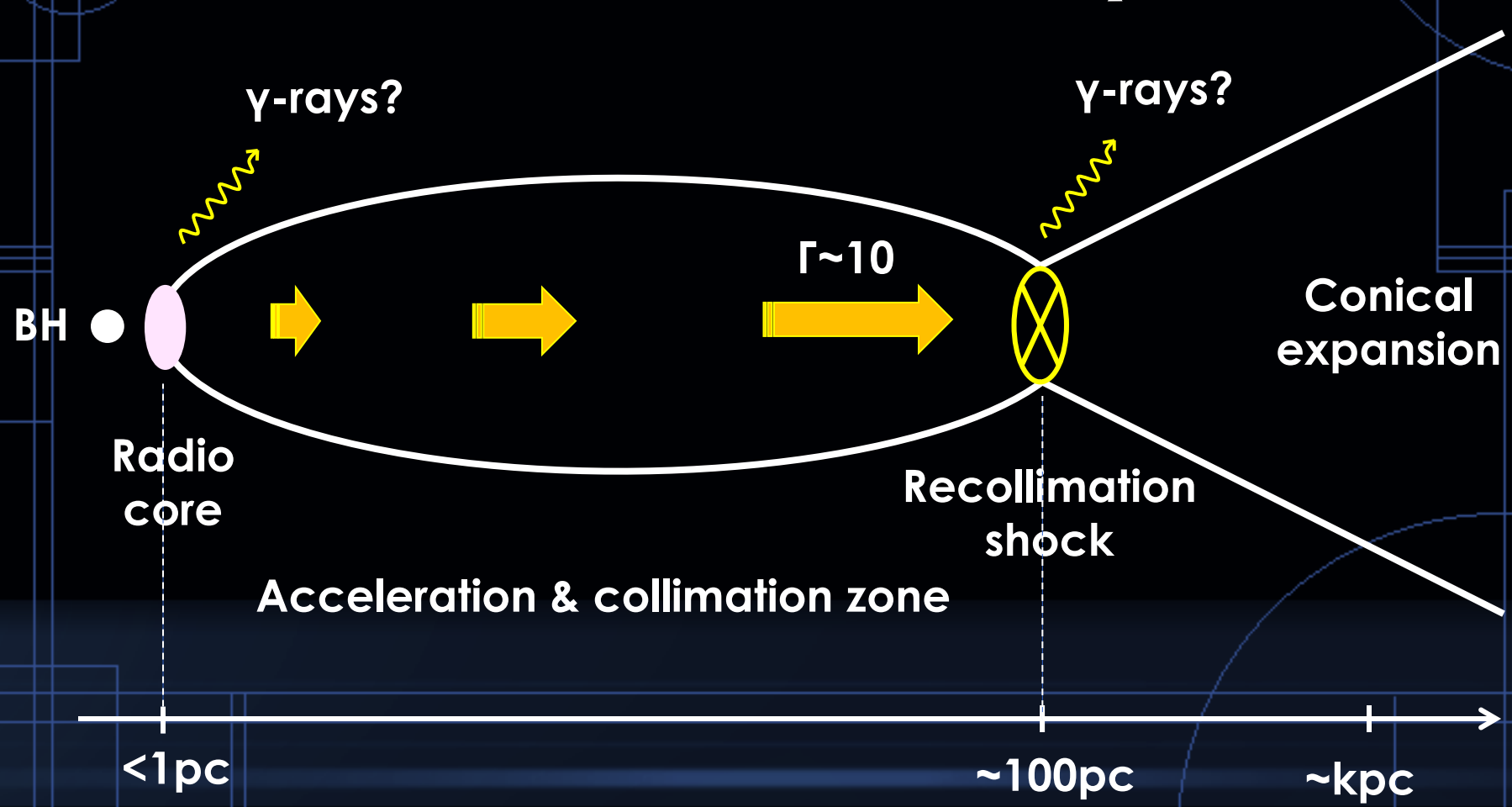


Fermi-LAT (Paliya+2014)



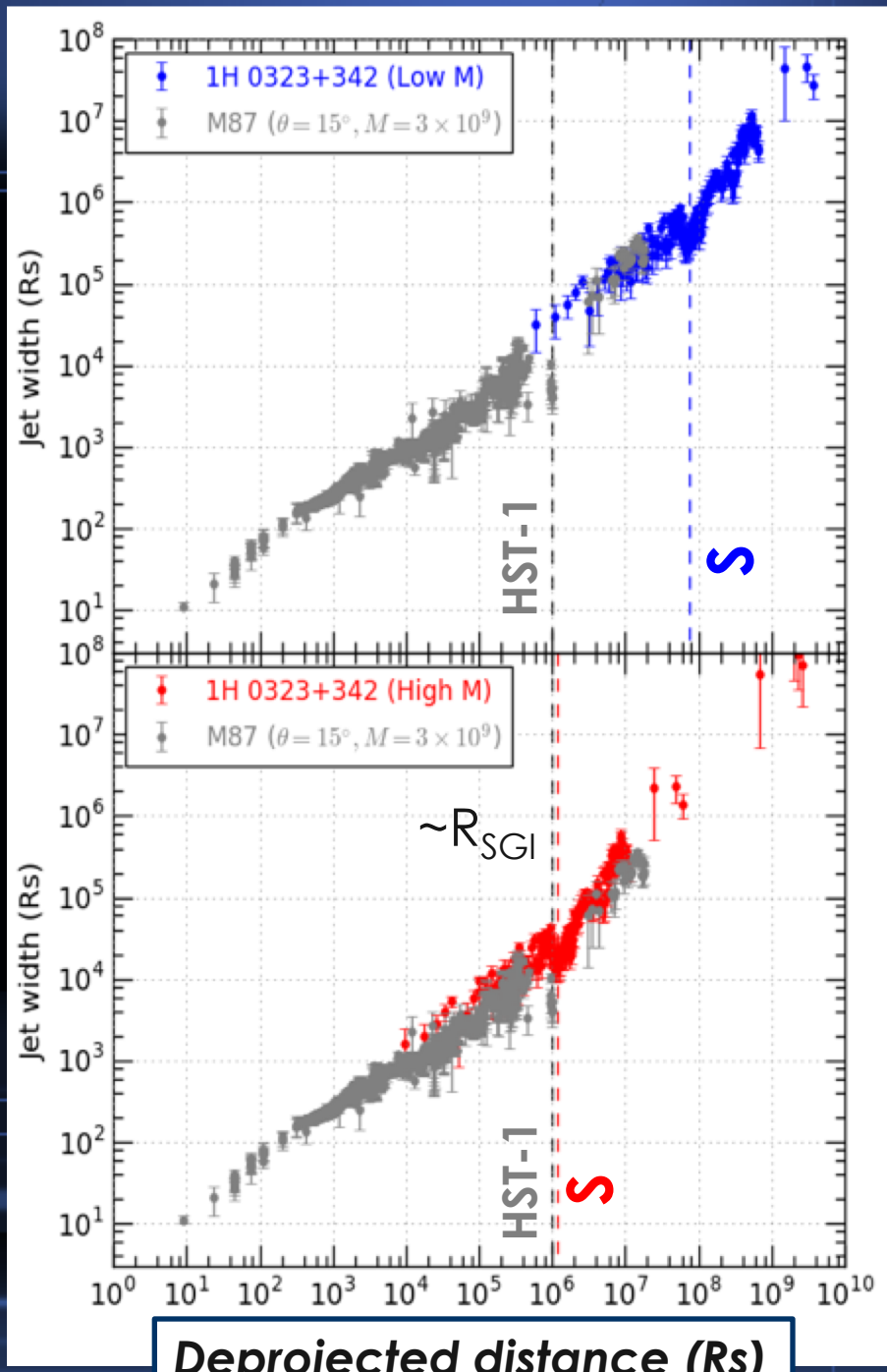
Doi, KH+2018

Suggested picture of 1H 0323 jet



BH mass: low or high ?

- If $M_{BH} \sim (1\text{-}3) \times 10^7 M_{sun}$
  - Suggested by optical/X-ray studies (eg, Zhou+07, Landt+17)
  - Jet collimation must be maintained over 100000000Rs from BH !
- If $M_{BH} \sim (3\text{-}5) \times 10^8 M_{sun}$
  - Consistent with M-σ relation (eg, Leon Tavares+14)
  - Jet shapes of 1H & M87 overlap also in Rs domain
  - Jet collimation break occurs near the sphere of gravitational influence of SMBH ($R_{SGI} = GM_{BH}/\sigma^2 \sim 10^6 R_s$)

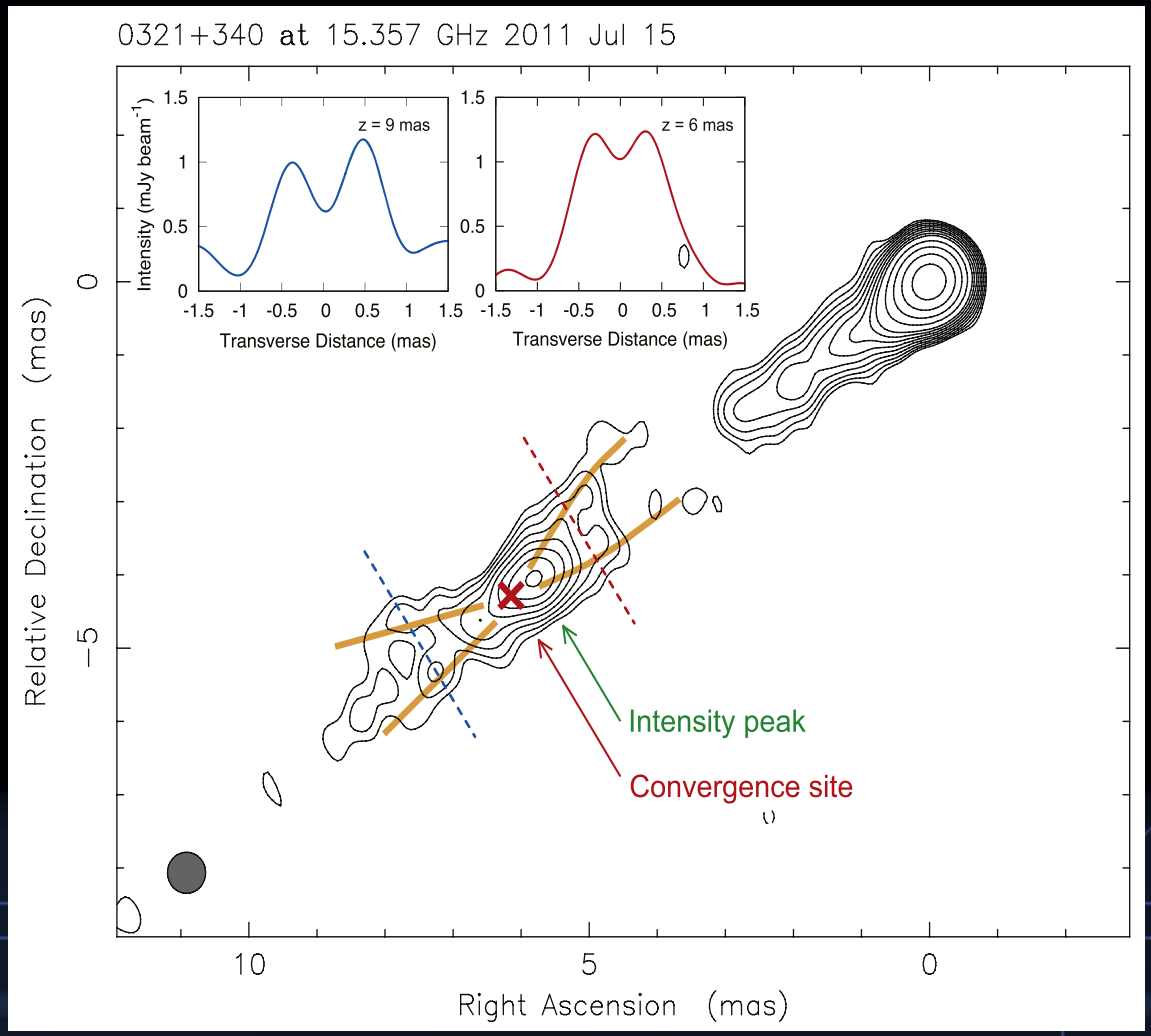


Summary

- We studied the detailed radio structures of the pc-scale jet of 1H 0323+342 using multi-frequency VLBA
- A number of exciting discoveries !
  - Highly polarized, recollimation shock feature S
  - Jet collimation break at the recollimation shock
  - Coexistence of jet collimation and acceleration
  - Possible gamma-ray production at ~100pc
- Overall, the pc-scale jet of 1H0323+342 is remarkably similar to M87/HST-1 (as well as some blazars), suggesting that a common jet formation mechanism may be at work
- Link between jet collimation break and BH mass?
- 1H 0323+342 provides a privileged opportunity to study the jet formation in NLS1
- Future
  - Multi-frequency polarimetry (RM analysis)
  - Comparisons with RMHD simulations (Mizuno+15, Fuentes+18) may also be interesting

Supplementary material

Limb-brightening structure



Doi, KH+2018