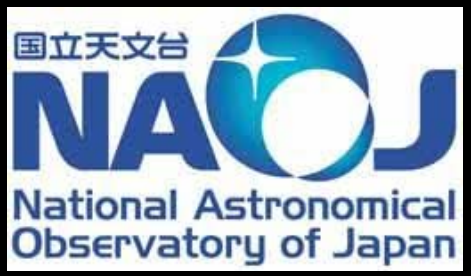
多波長 VLBI 観測によるクェーサー 3C 273 のジェット収束領域の特定

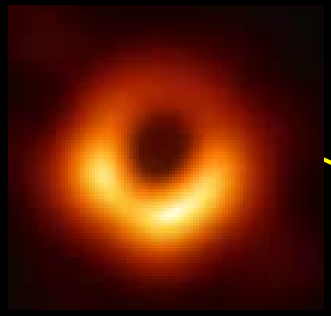
沖野 大貴（東京大学 / 国立天文台）

共同研究者の方々
秋山 和徳 (NRAO/MIT), 浅田 圭一 , 中村 雅徳 (ASIAA),
秦 和弘 , 本間 希樹 (NAOJ), Jose L. Gomes (IAA),
GMVA+ALMA 3C 273 Collaboration



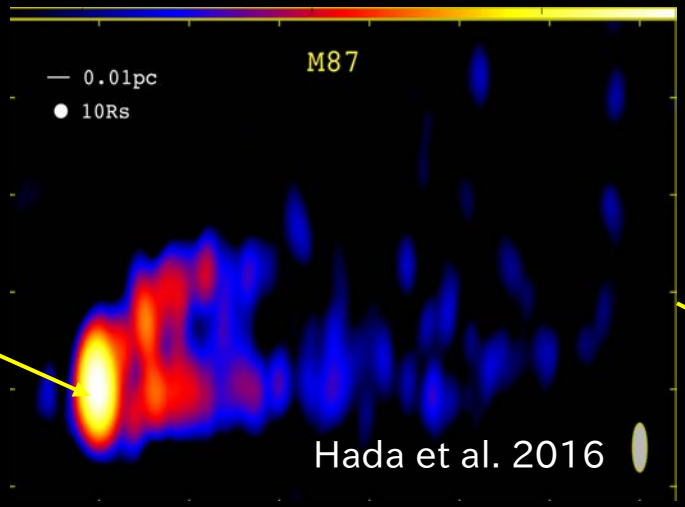
Open questions for AGN Jets

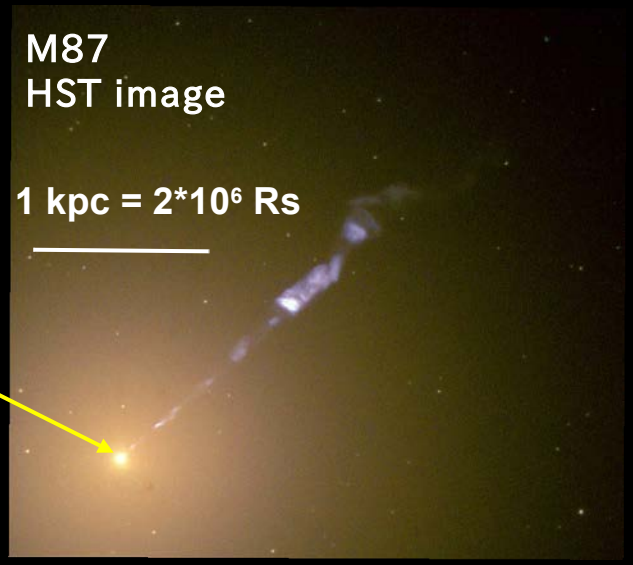
Event Horizon Telescope
230 GHz



EHT Collaboration

VLBA+GBT 86 GHz



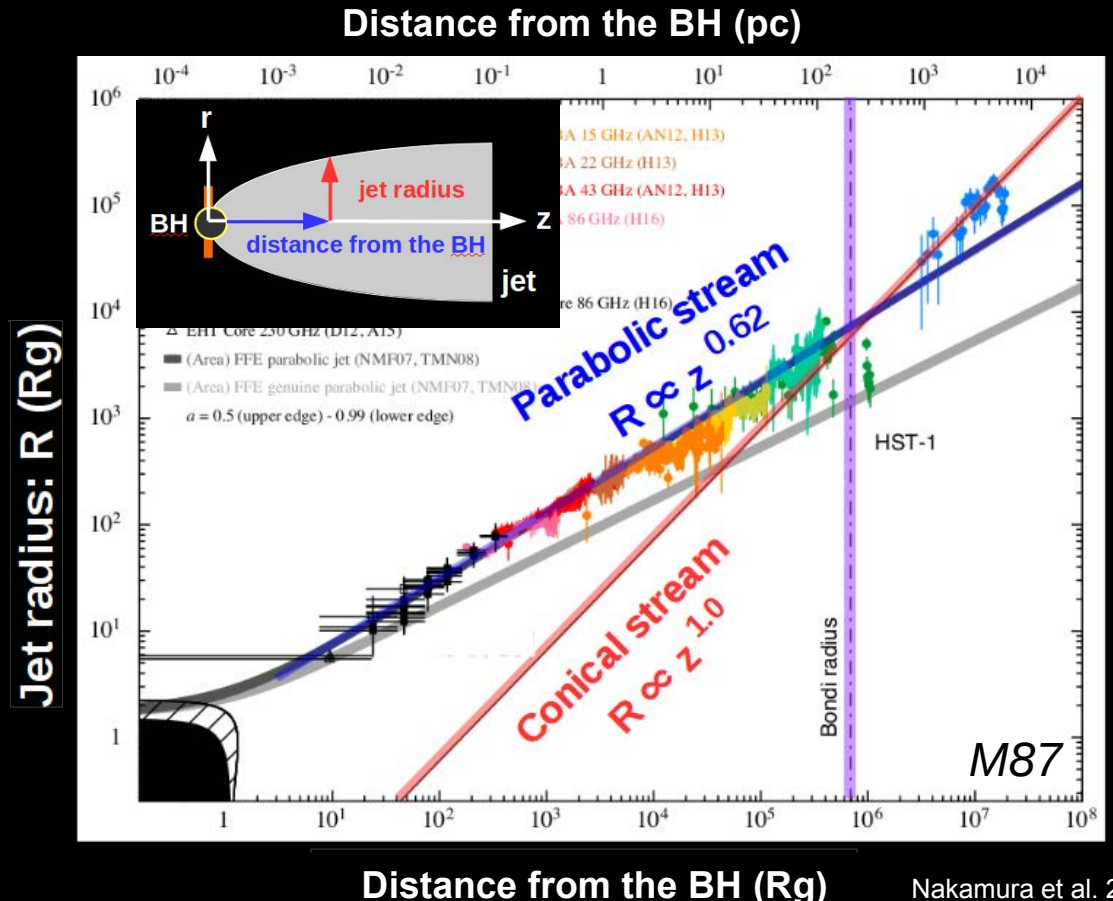


Credit:NASA and The Hubble Heritage Team (STScI/AURA)

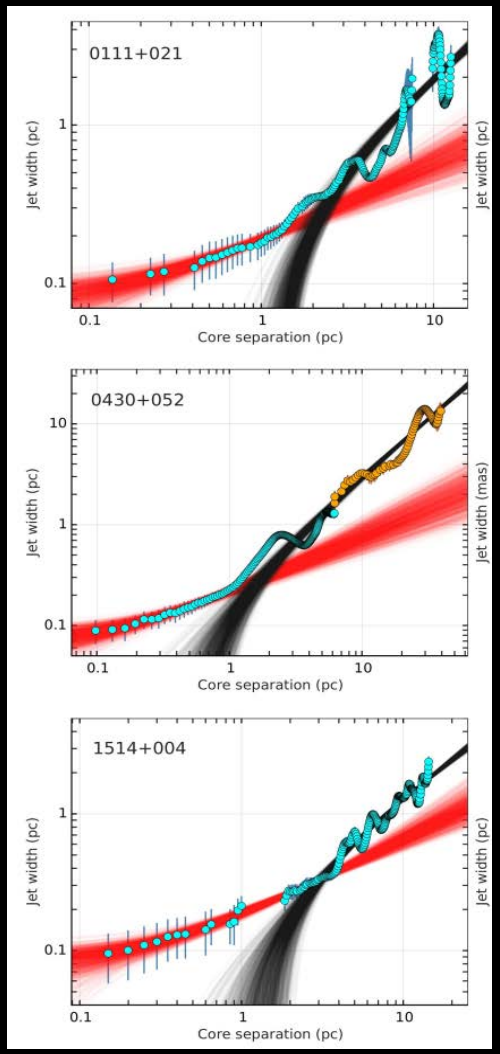
- Collimation
- Acceleration
- AGN feed back

→ **Shape** of the Jets

Jet collimation profiles of LLAGN



Nakamura et al. 2018



Kovalev et al. 2019

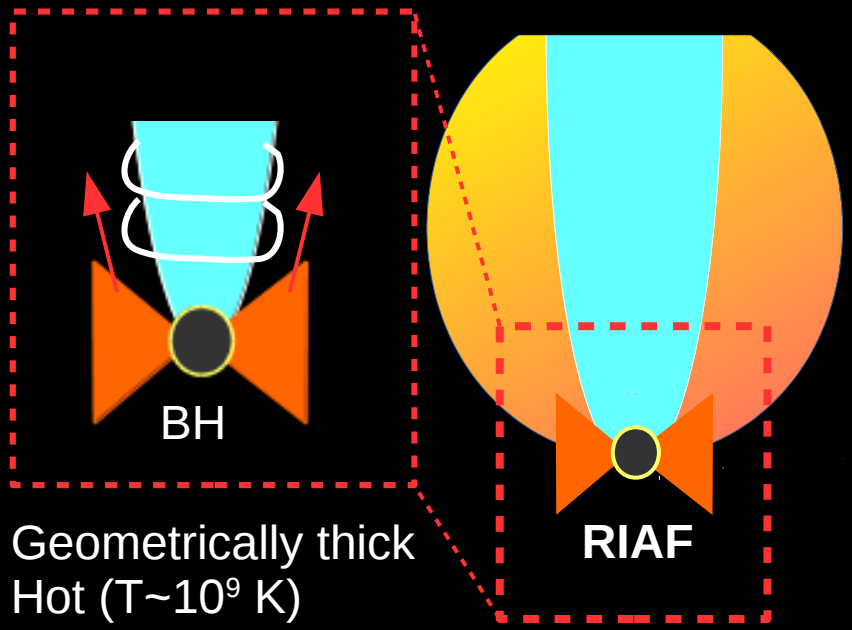
- Transition of the jet shape at $10^{5\text{-}6}$ Rs from conical to parabolic
- A universal property of AGN Jets?
  (e.g., NGC4261(Nakahara+2018); Cygnus A (Boccardi+ 2016))

LLAGN vs Quasar

Jets are confined by ...

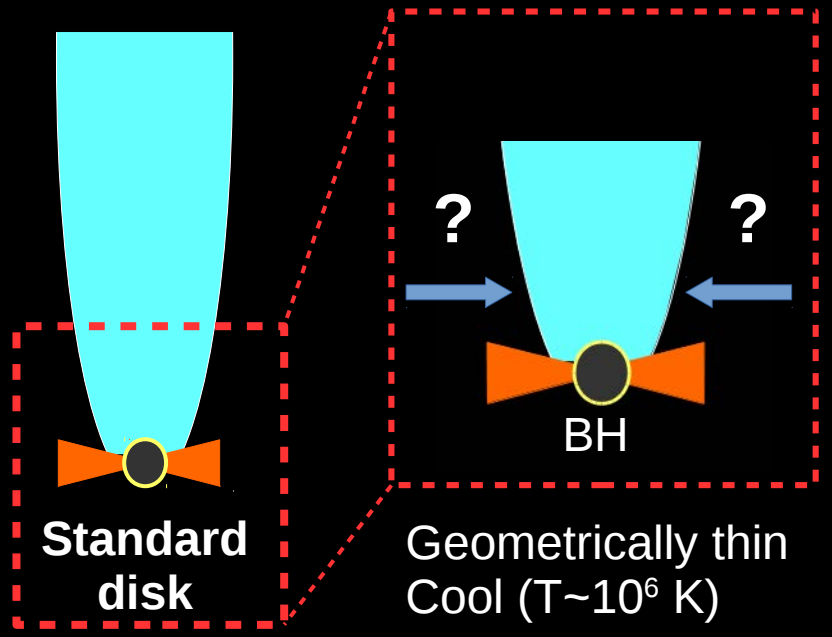
- Geometrically thick disk
- Disk winds
- Magnetic field
- External medium

LLAGN (M87)



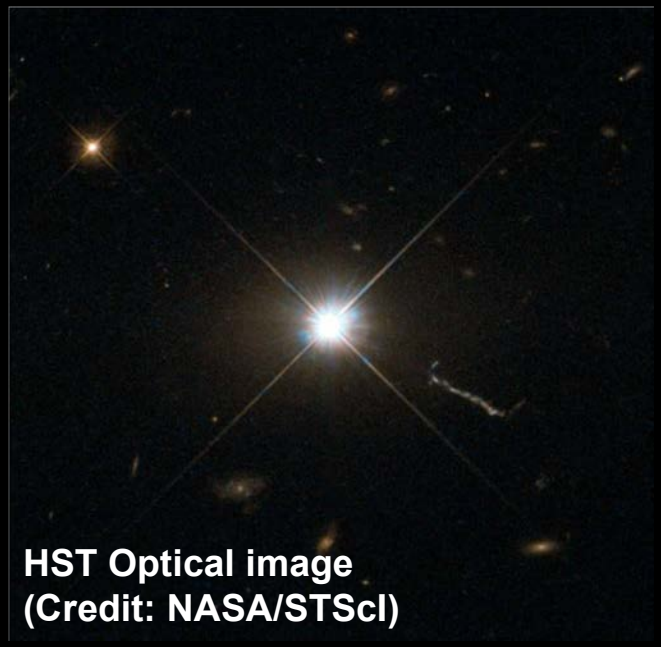
Geometrically thick
Hot (T~10^9 K)

Quasar



Geometrically thin
Cool (T~10^6 K)

Target source: quasar 3C 273



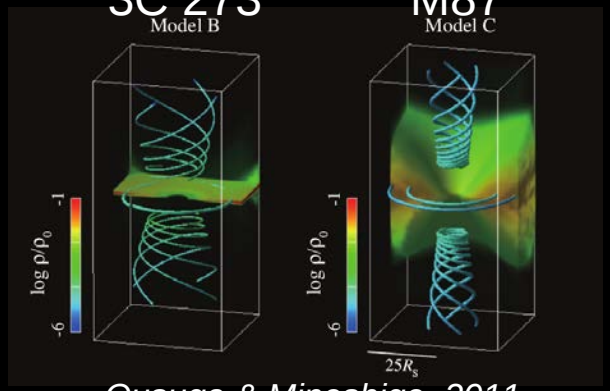
HST Optical image
(Credit: NASA/STScI)

- Relativistic jet
- $z = 0.158$
- $M_{BH} \sim 2.6 \times 10^8 M_{sun}$ (GRAVITY Collaboration 2018)

  $\longrightarrow$ 1 mas ~ 2.7 pc ~ $1.2 \times 10^5 R_s$
- Bolometric Luminosity

  $L_{bol} \sim 0.8 L_{Edd}$ (Park & Trippe 2017)

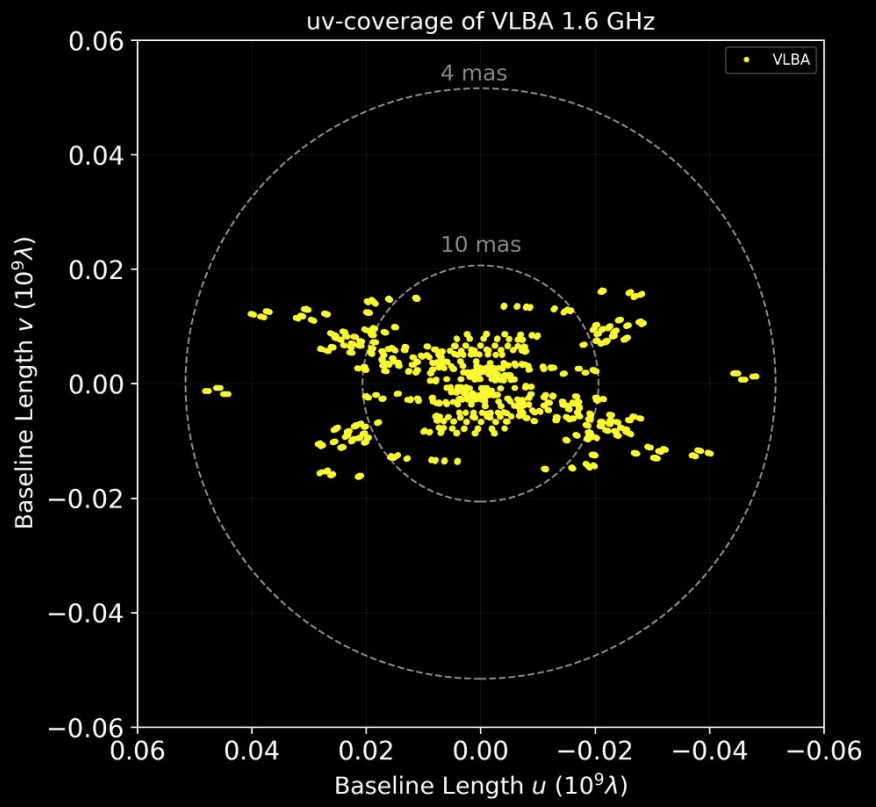
  For M87,
  $L_{bol} \sim 10^{-6} L_{Edd}$ (Prieto et al. 2016)



Ousuga & Mineshige, 2011

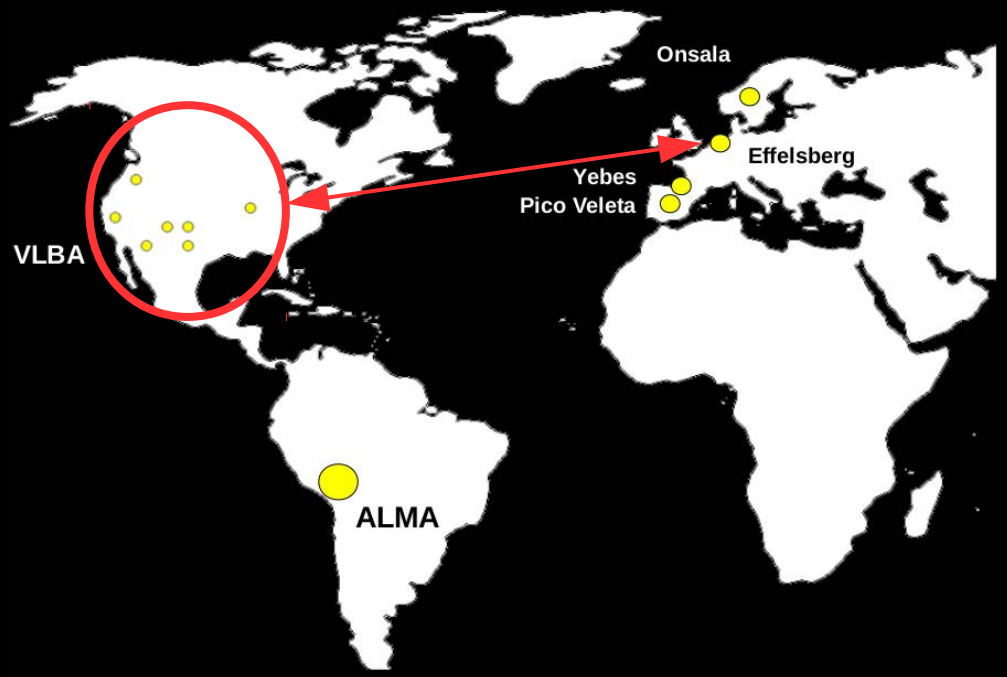
Observation

Map: Courtesy of Sara Issaoun



- *1.6 GHz* VLBA

Observation



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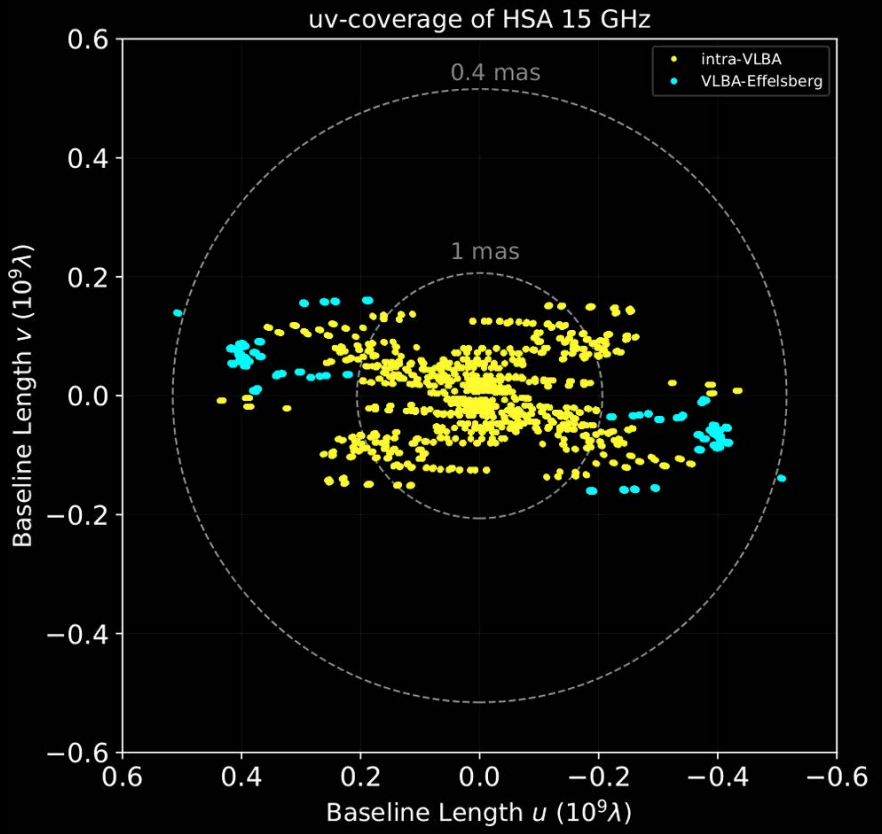
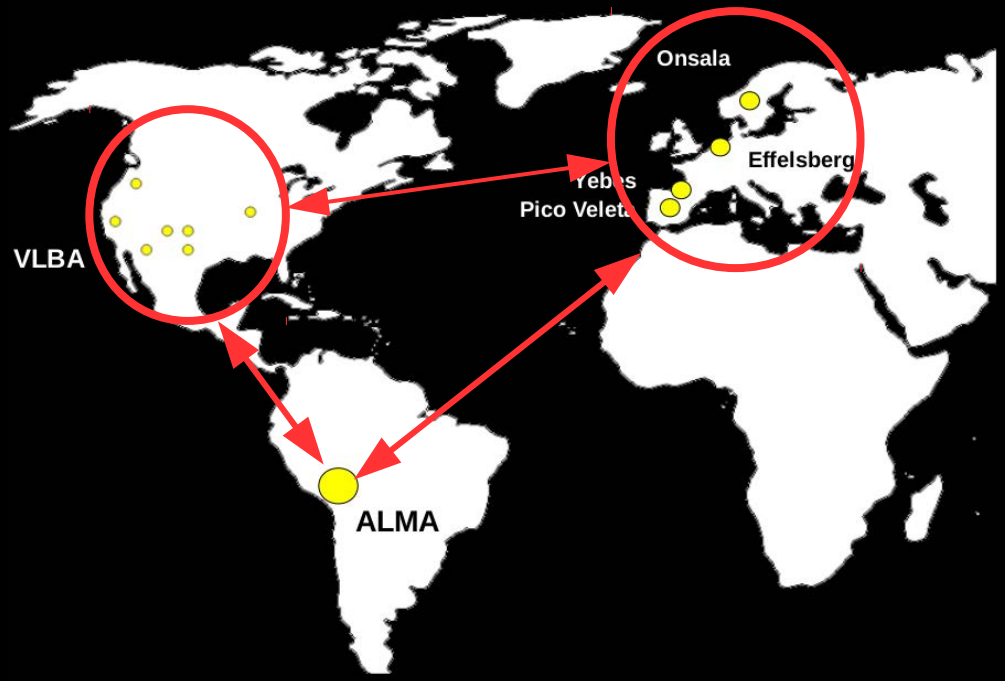


- *1.6 GHz* VLBA
- *15 GHz* HSA (VLBA+Effelsberg)
- *22 GHz* HSA (VLBA+Effelsberg)
- *43 GHz* HSA (VLBA+Effelsberg)

Observation



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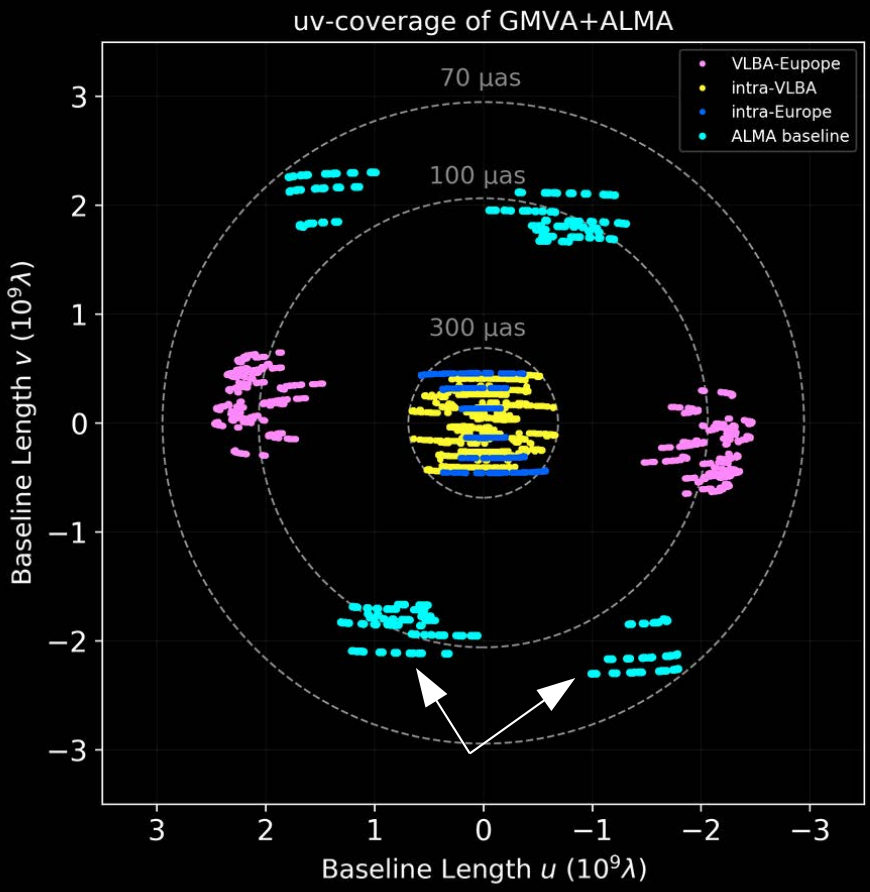

- *1.6 GHz* VLBA
- *15 GHz* HSA (VLBA+Effelsberg)
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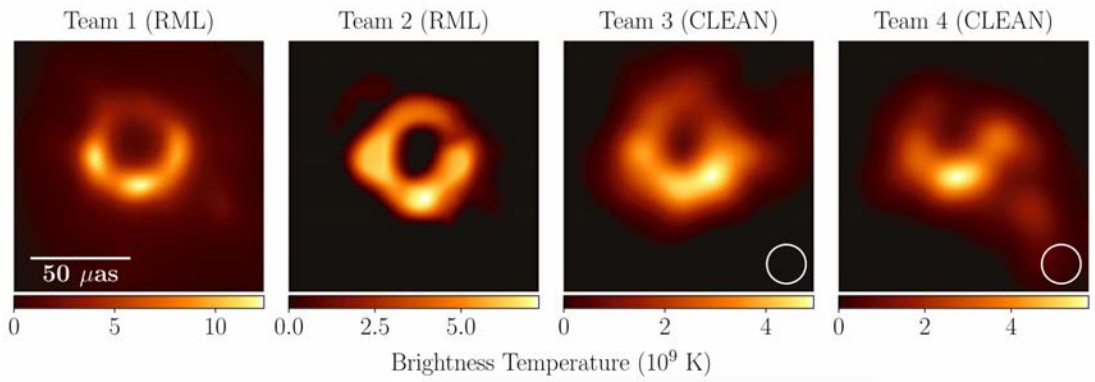
- *43 GHz* HSA (VLBA+Effelsberg)
- *86 GHz* GMVA + ALMA

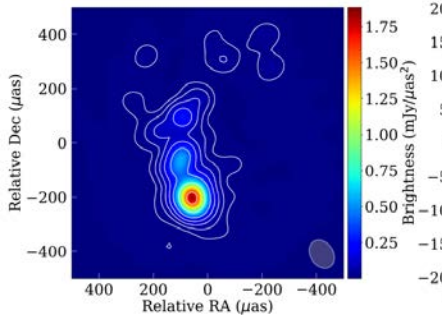
RML Imaging

Central black hole of M87

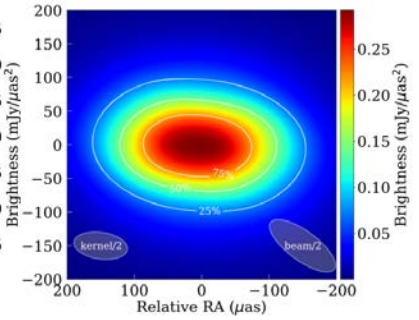


EHT Collaboration 2019, paper IV

NRAO 530



Sgr A*

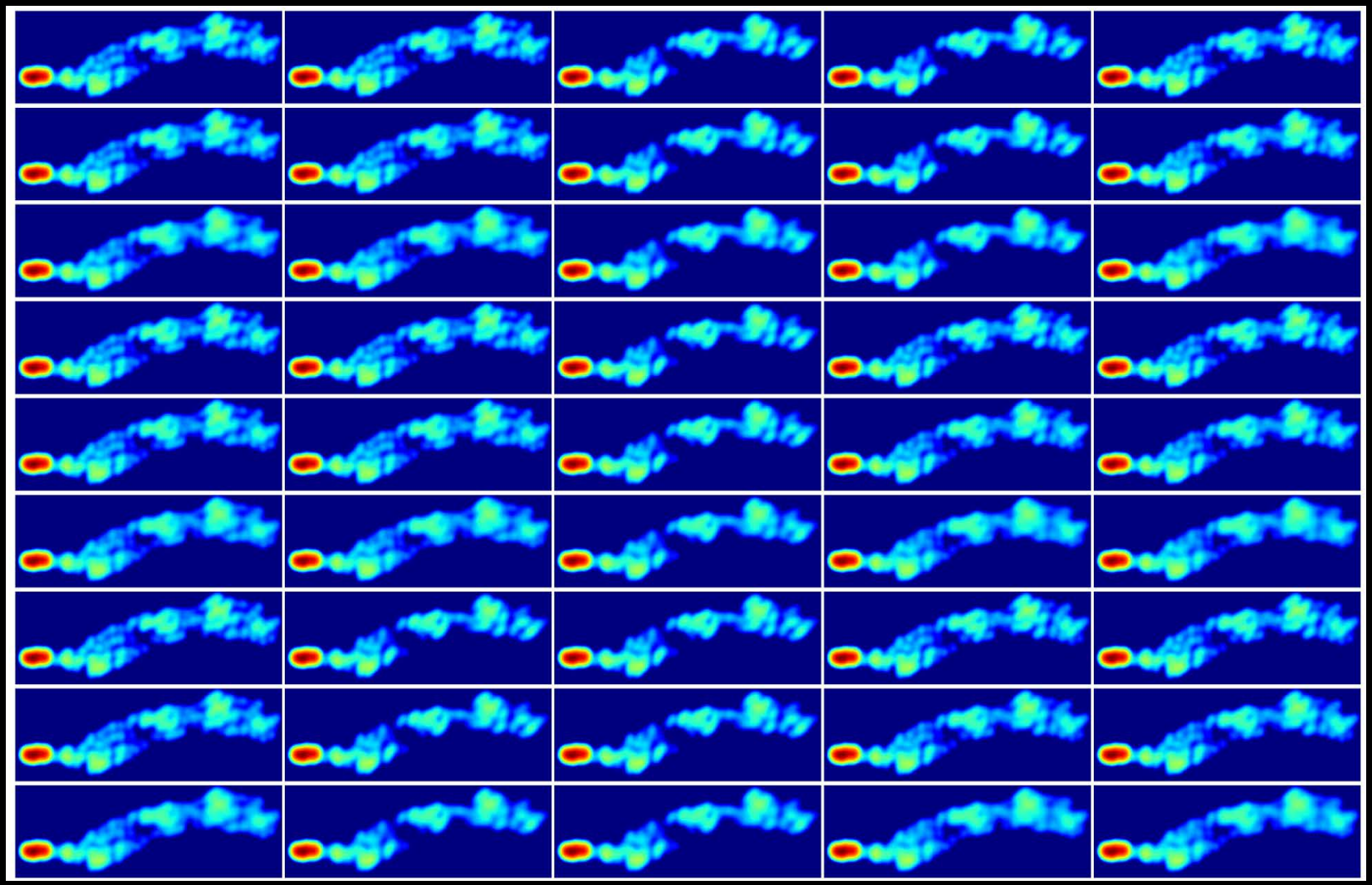


Issaoun et al. 2019

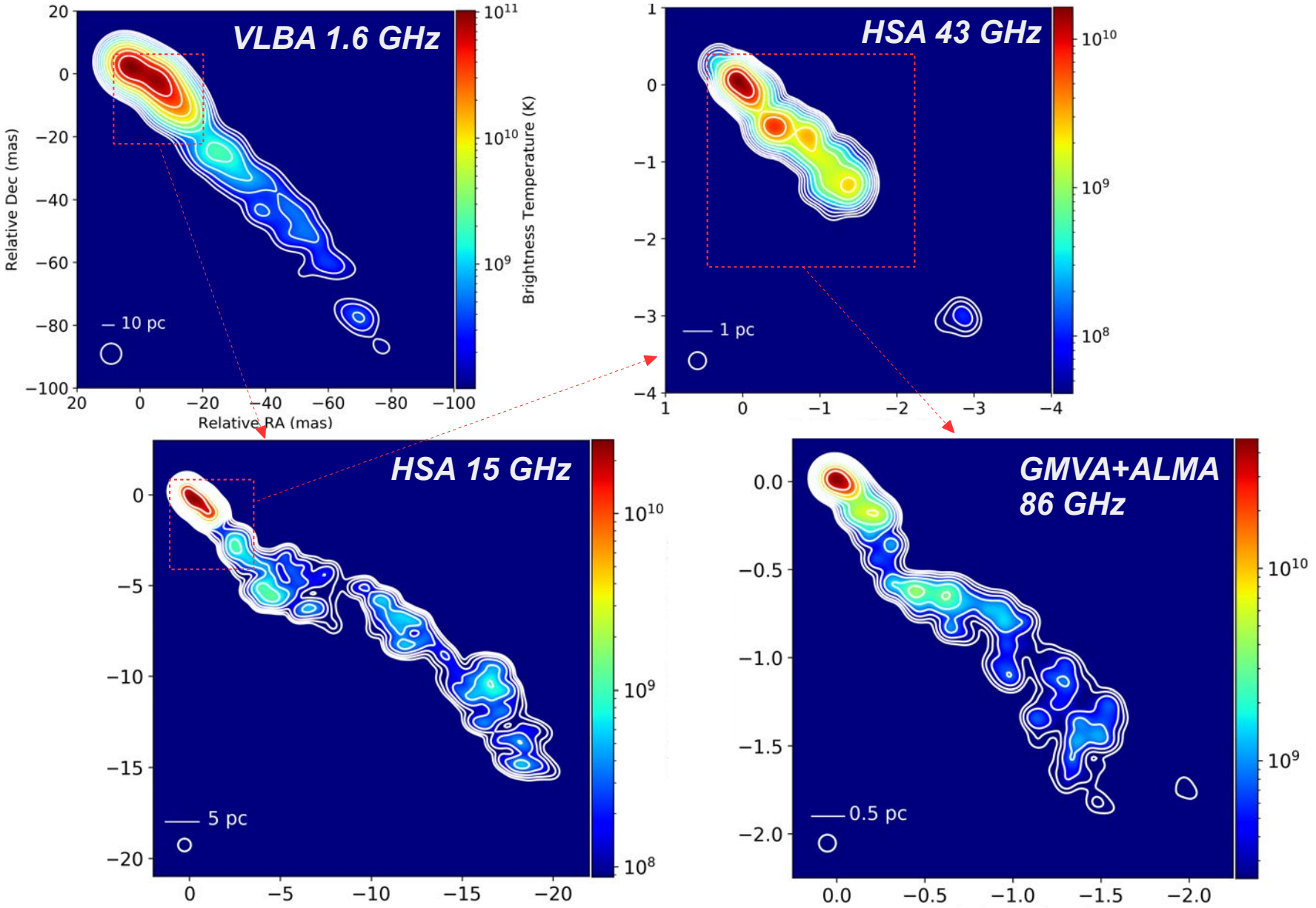
$$J(I) = \sum_{\text{data terms}} \alpha_D \chi^2_D(I) - \sum_{\text{regularizers}} \beta_R S_R(I).$$

- Regularized Maximum Likelihood (RML) methods
- Robust imaging using closure amplitudes and closure phases
- Wide range of imaging parameters with multiple regularizations (~100)
- Images with good fit to data (**χ^2<1.5**) were used in further analysis

Top set images at 15 GHz

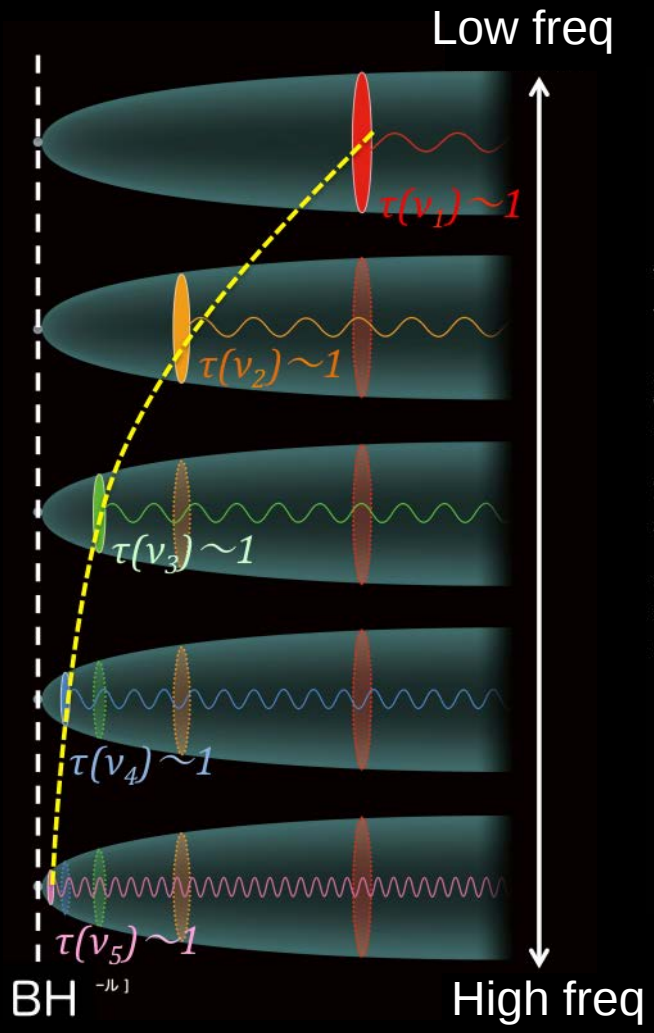


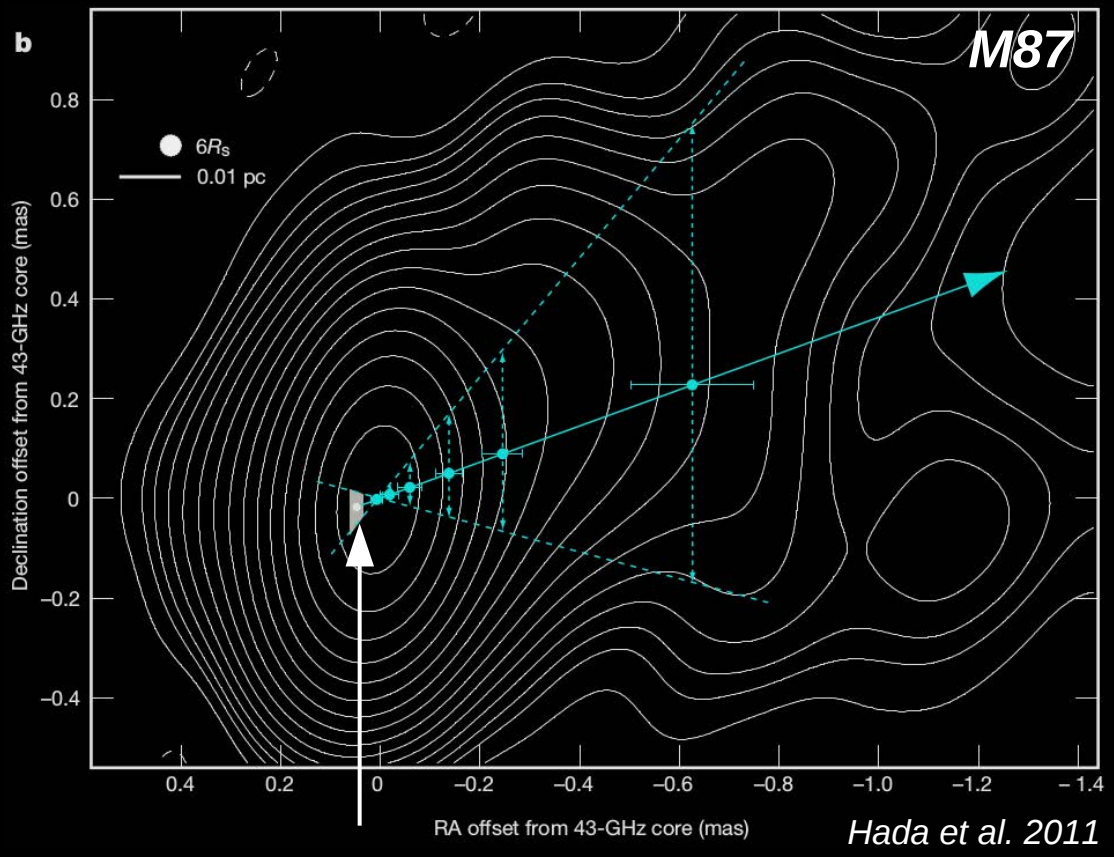
Multi-frequency 3C 273 images



Core shift

Blandford & Königl 1979
Lobanov 1998



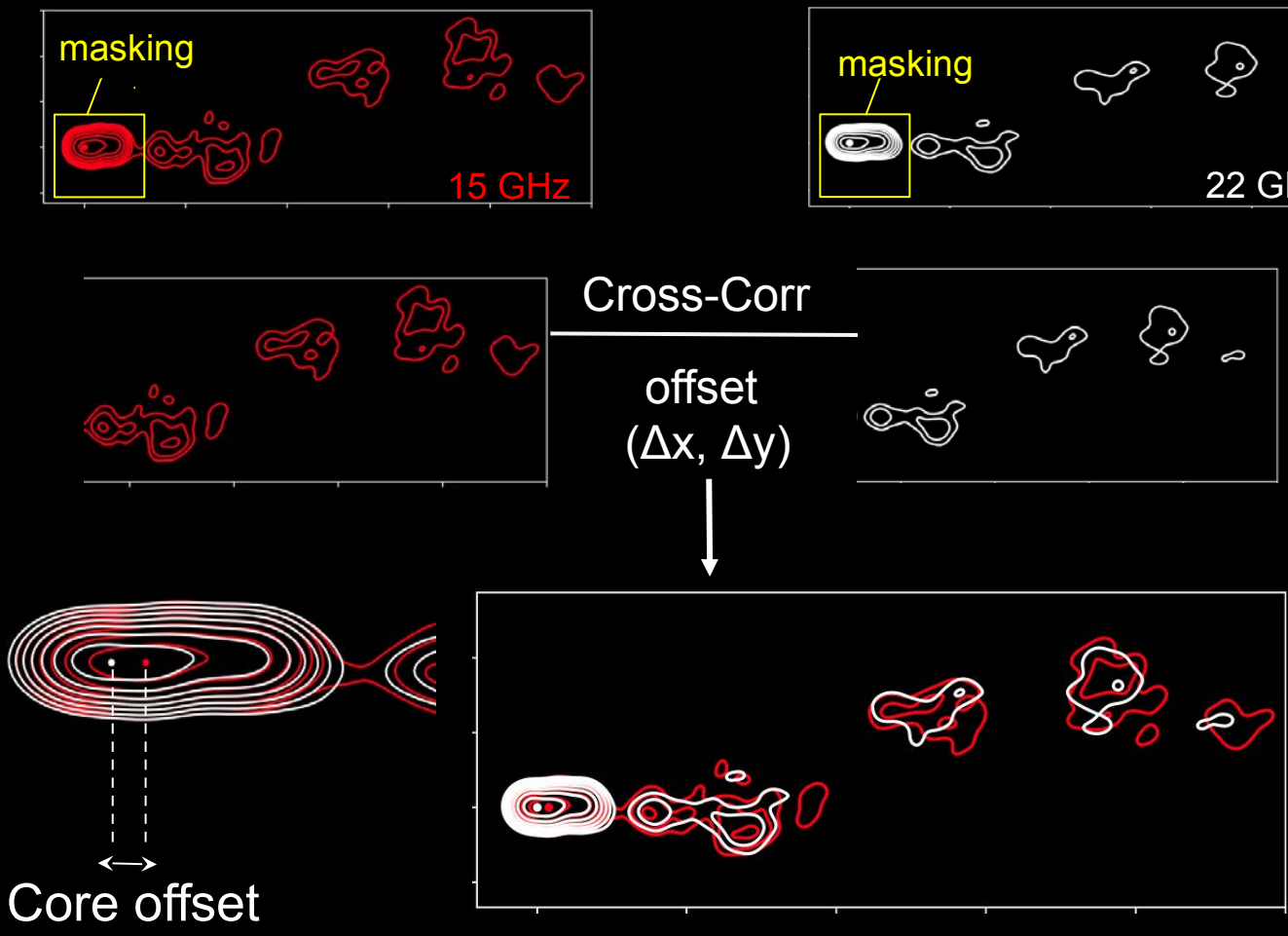


Hada et al. 2011

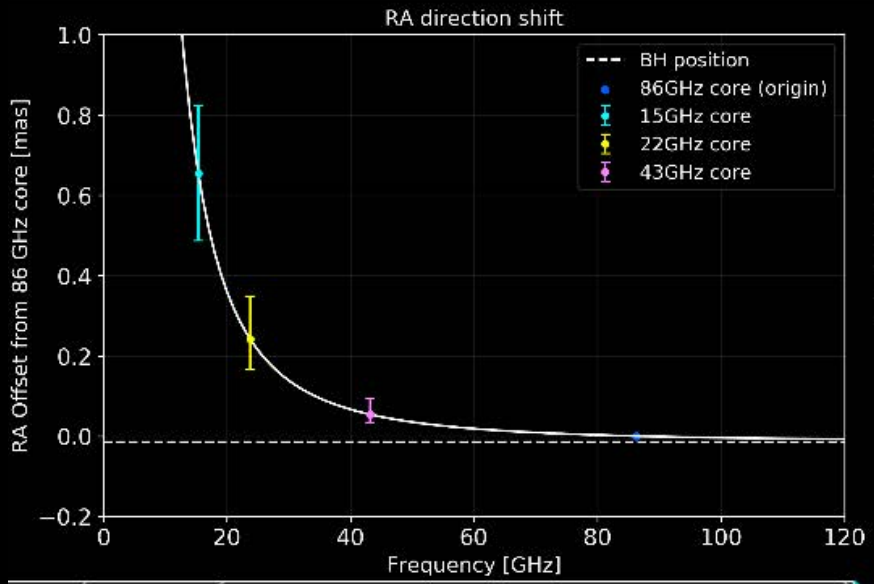
Black hole position

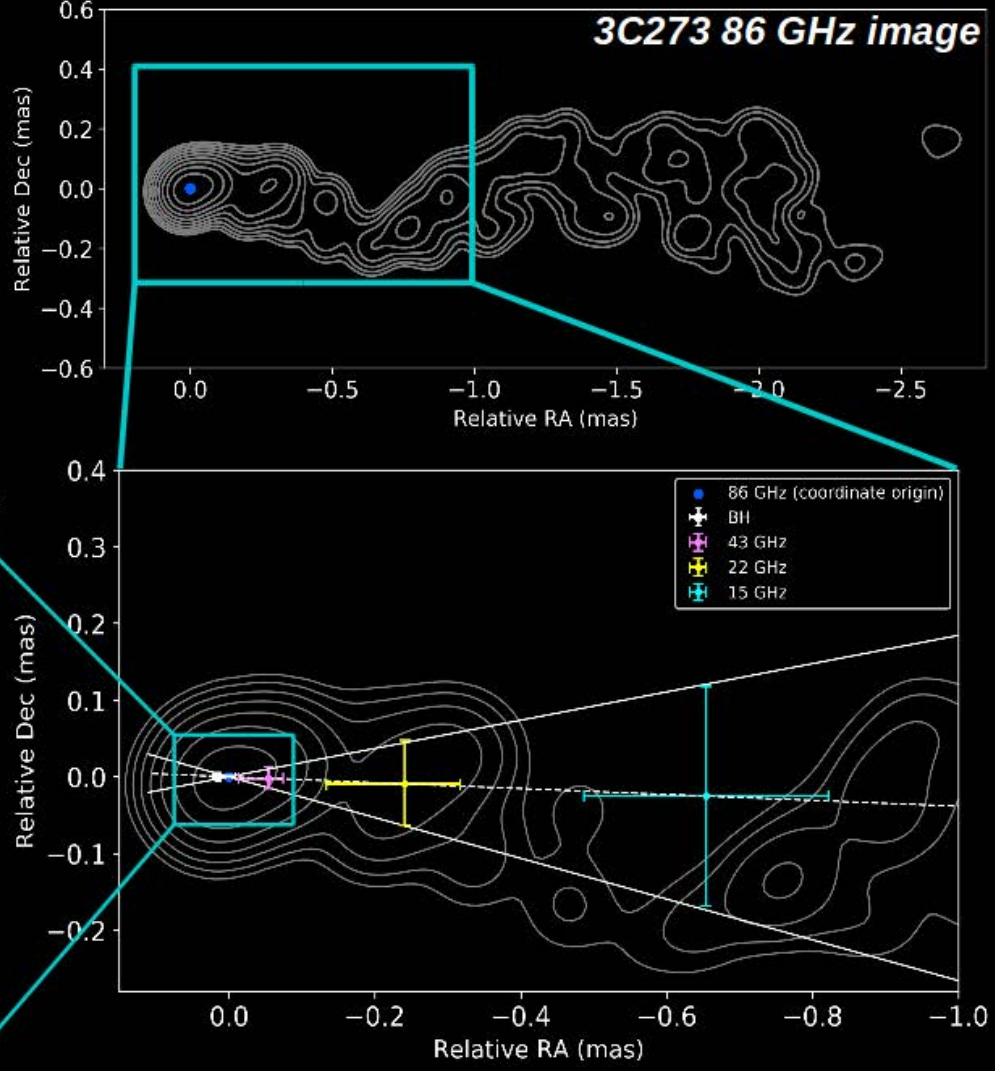
Core shift measurements

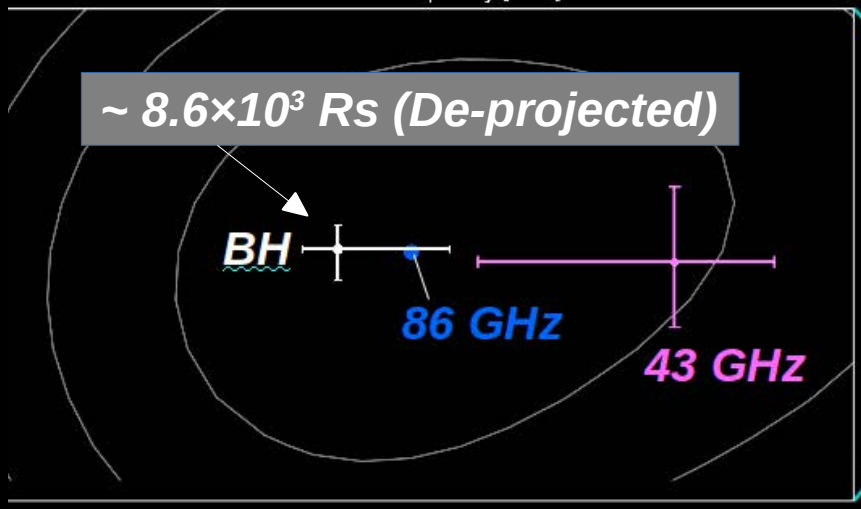
- 2D cross-correlation method
  (eg. Croke & Gabuzda 2008, Pushkarev+ 2012, Fromm+ 2013)



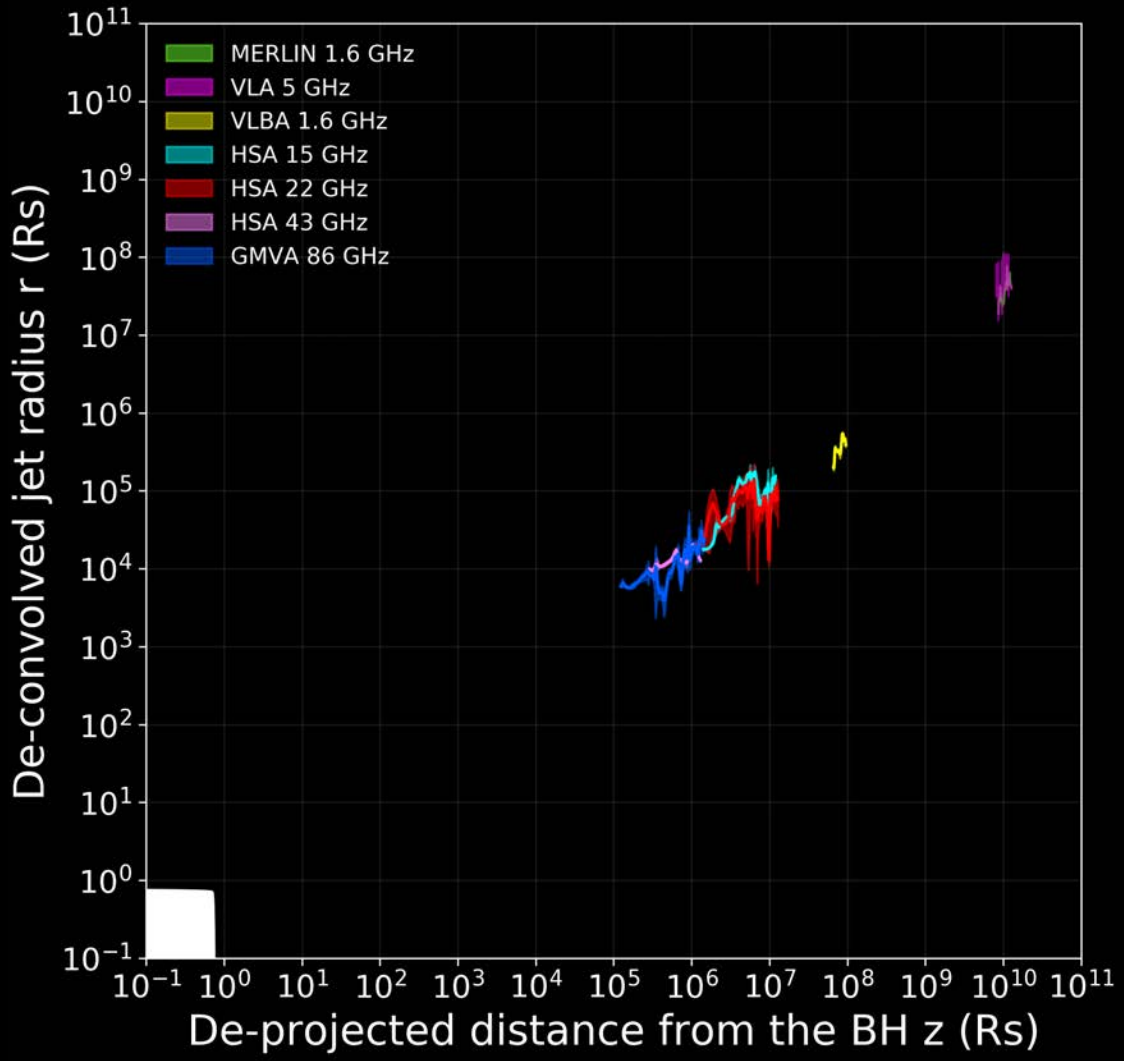
Results: Core shift







Results: 3C 273 Collimation profile



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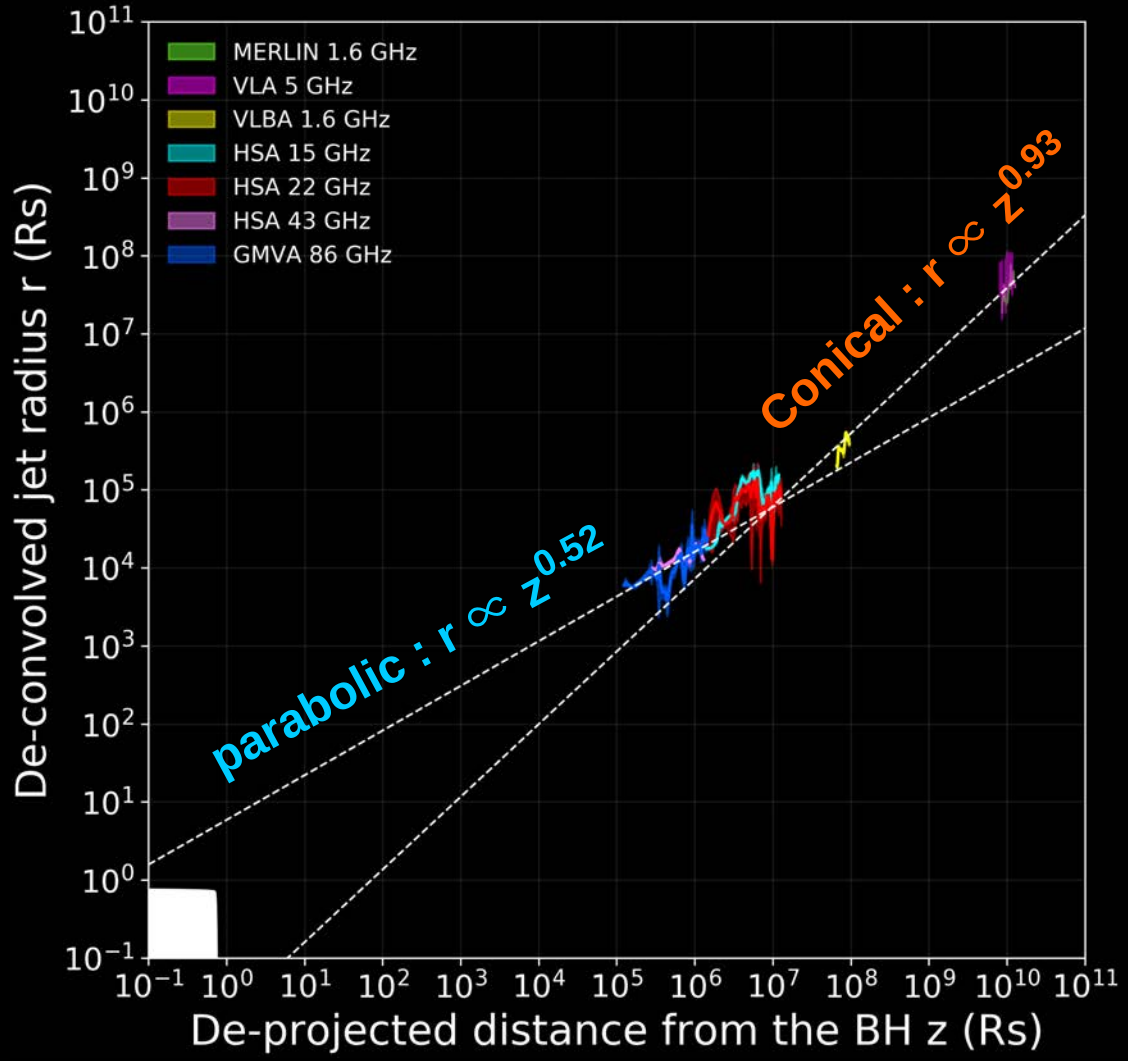

- Transition in the shape from conical to parabolic shape at ***~ 10^6 Rs***.

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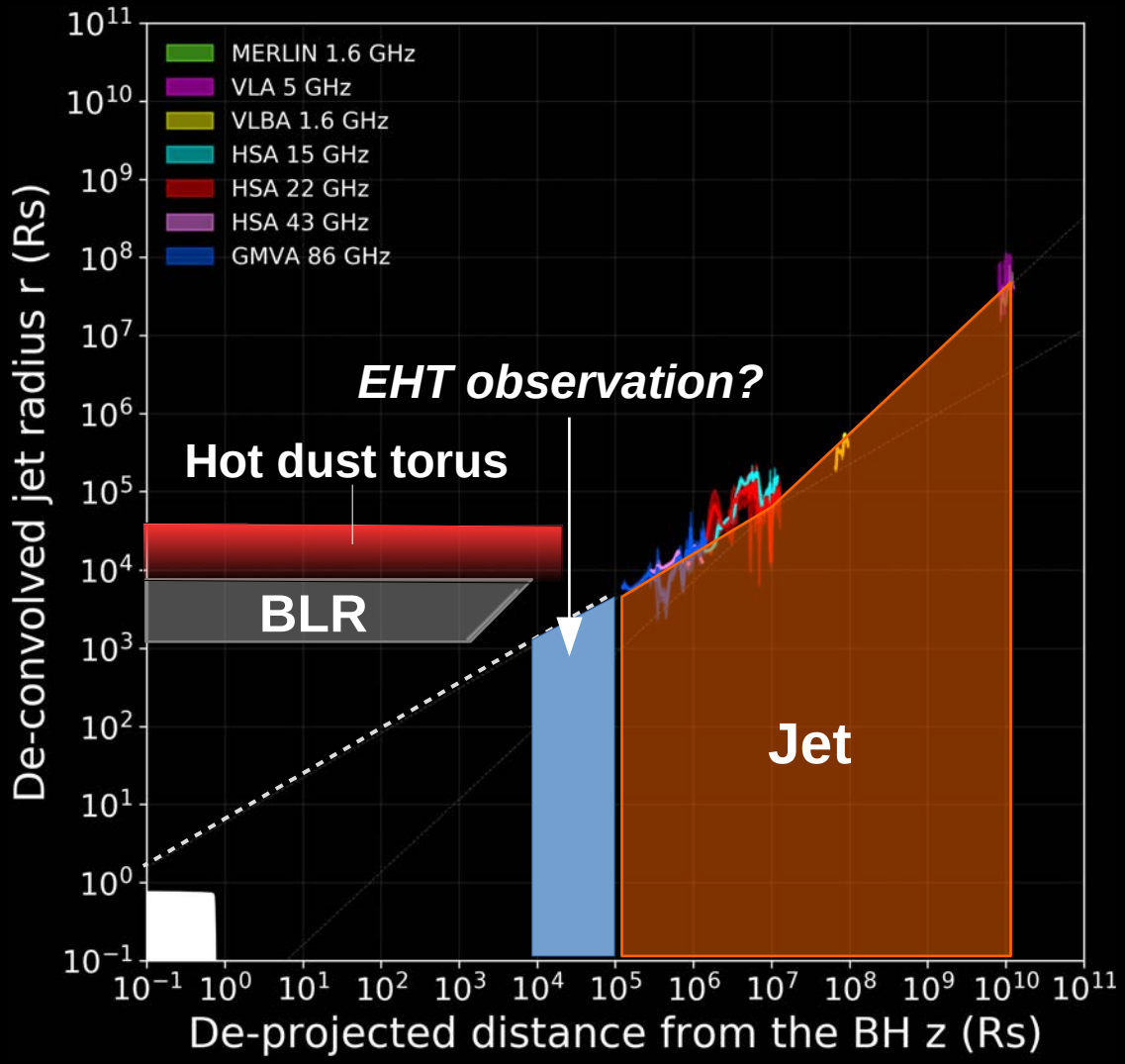

- Transition in the shape from conical to parabolic shape at ***~ 10^6 Rs***.
- Jet may propagate inside the broad line region and hot dust torus.

  R_{BLR} ~ 46μas ~ 5.5×10^3 Rs

  (GRAVITY Collaboration, 2018)

  R_{Dust} ~ 150μas ~ 1.8×10^4 Rs

  (Kishmoto et al. 2011; GRAVITY Collaboration, 2019)

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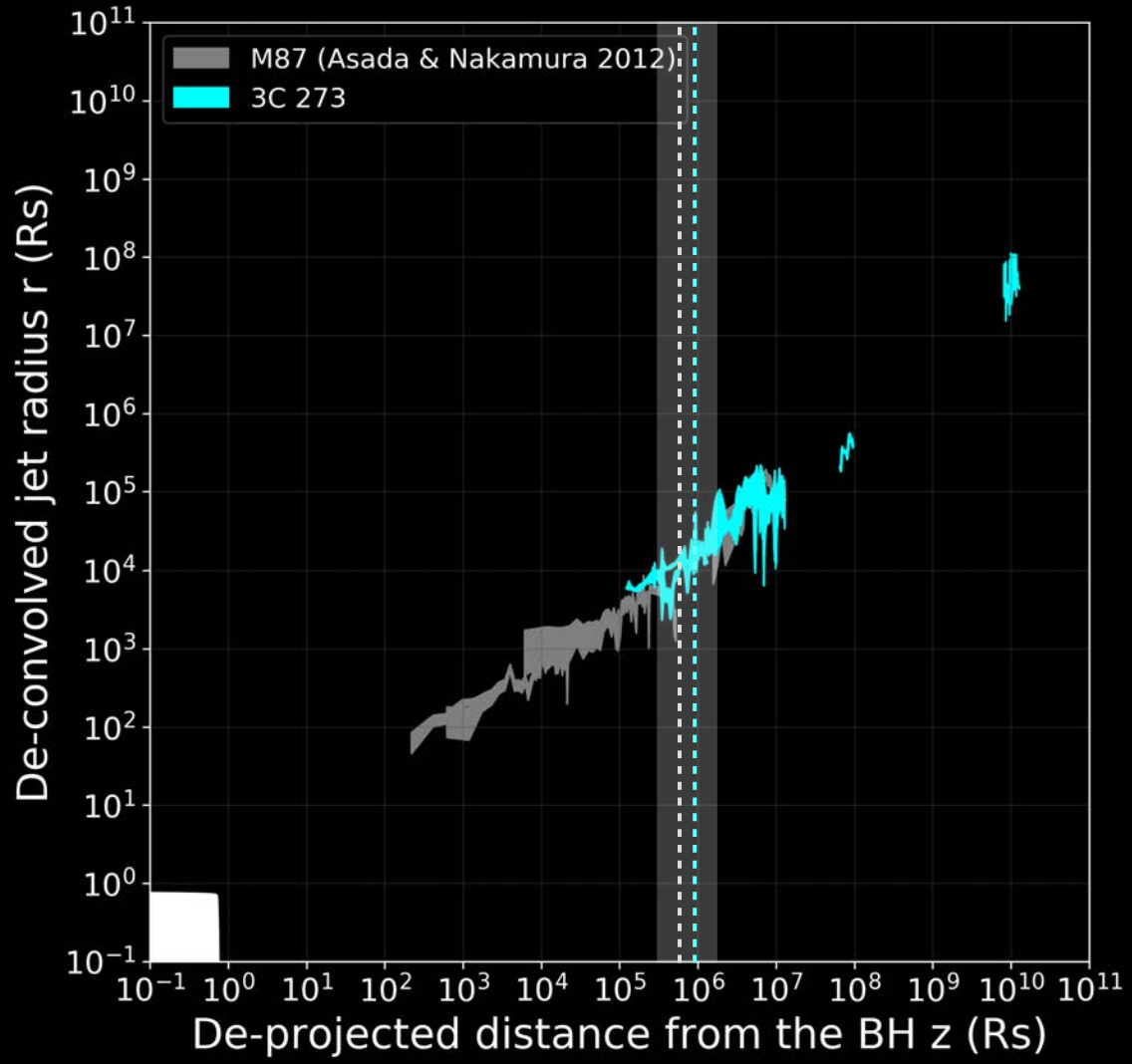

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  R_{Dust} ~ 150μas ~ 1.8×10^{4} Rs

  (Kishmoto et al. 2011; GRAVITY Collaboration, 2019)
- Similar profile to LLAGN M87

  Bondi radius ~ 3.8×10^{5} Rs

  (Allen et al. 2006)

Summary and future work

- We performed multi-frequency observations of the nearby quasar 3C 273 at 15, 22, 43 and 86 GHz with HSA and GMVA+ALMA.
- The jet structures on a wide range of scales (10^5 - 10^8 Rs) were successfully imaged with the state-of-the-art RML imaging techniques.
- The core shift and jet radius were measured with many multi-frequency images.
- The transition of the jet shape was robustly confirmed in a quasar jet with a surprising similarity to the LLAGN jet in M87.
- Future work: multi-frequency polarimetry to probe the 3D magnetic structure and circum jet material.