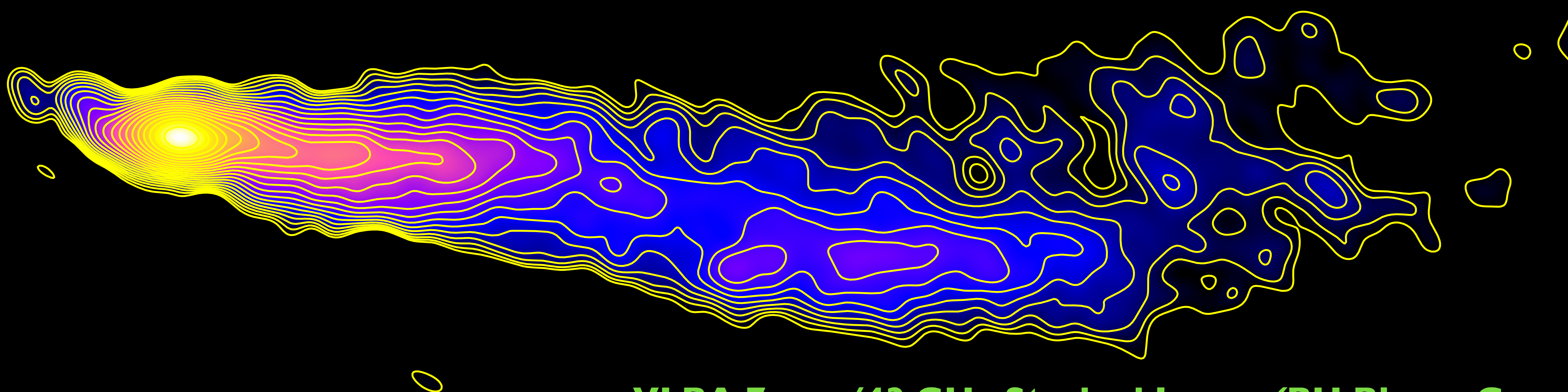
The Global "Radio" Structure of the Archetypical Quasar 3C 273



VLBA 7 mm/43 GHz Stacked Image (BU Blazar Group)

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Shep Doeleman (MIT Haystack/CfA) et al.

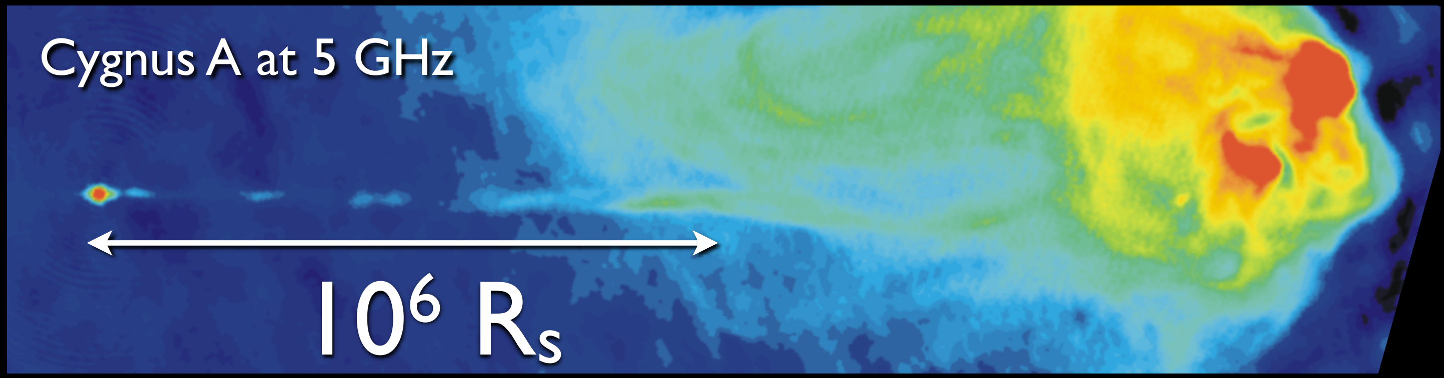
HAYSTACK OBSERVATORY

Jet Collimation: Central questions

- Highly collimated outflow

  Opening Angle: ~ few degree

  How? Where?



- Theoretical Paradigm:

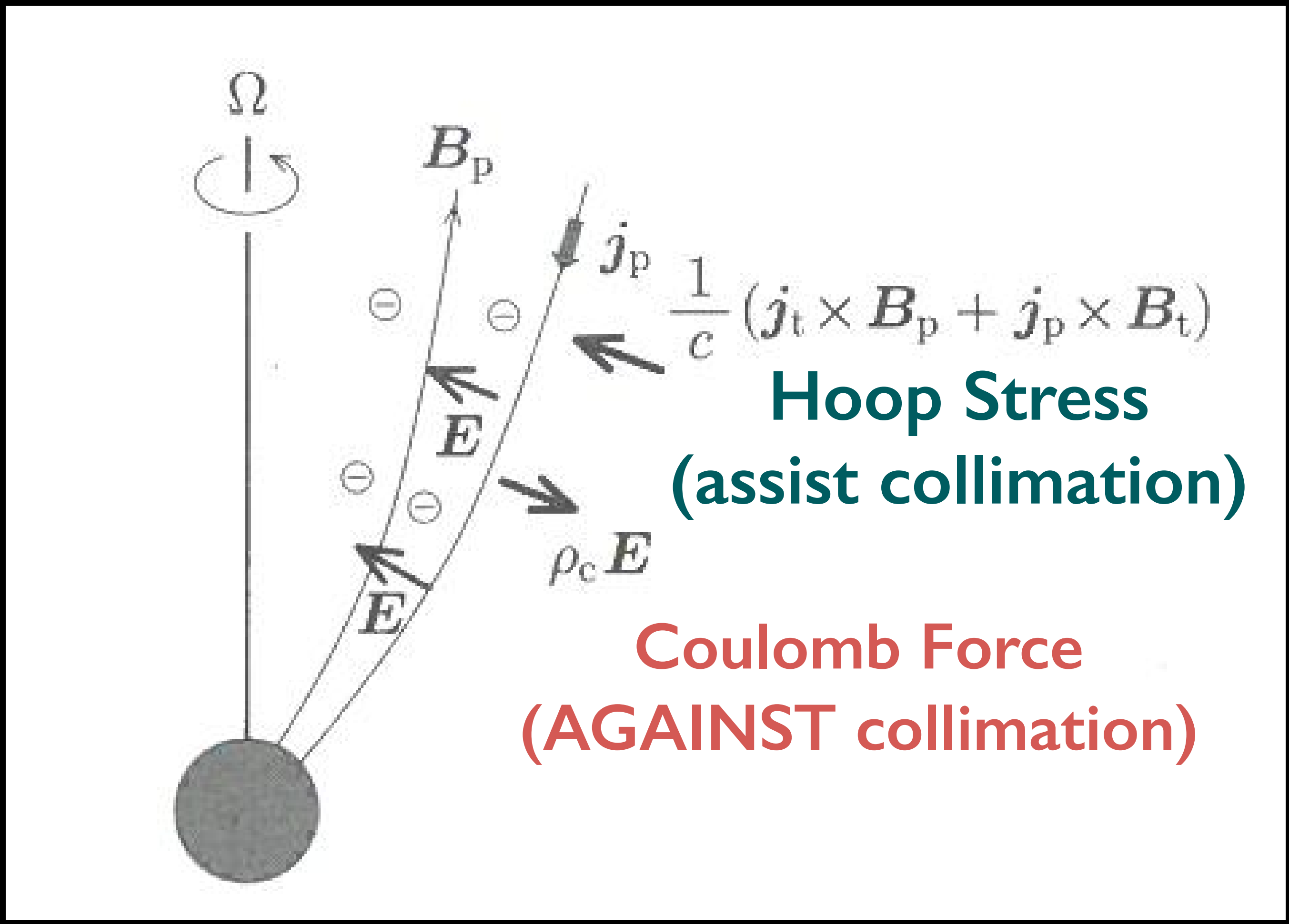
  Self Collimation
  by Magnetic Hoop Stress
  (Blandford & Payne 82, Sakurai 85, ….)

  Not sufficient for relativistic jets

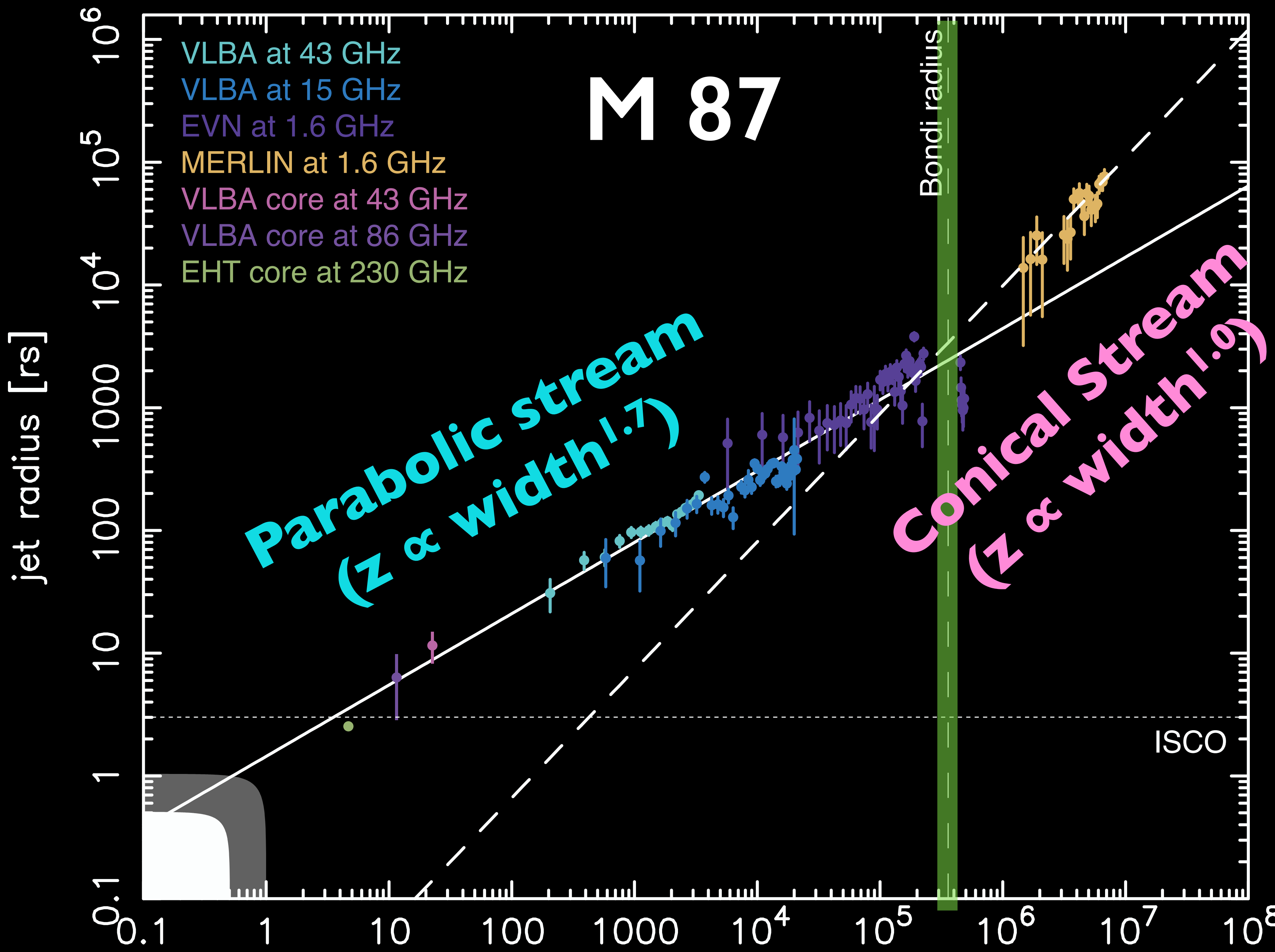
  ↓

  External confinement
  by the circum-jet medium

  (e.g. Nakamura+06, Komissarov+07,
  Tchekhovskoy+10, Toma & Takahara 13)



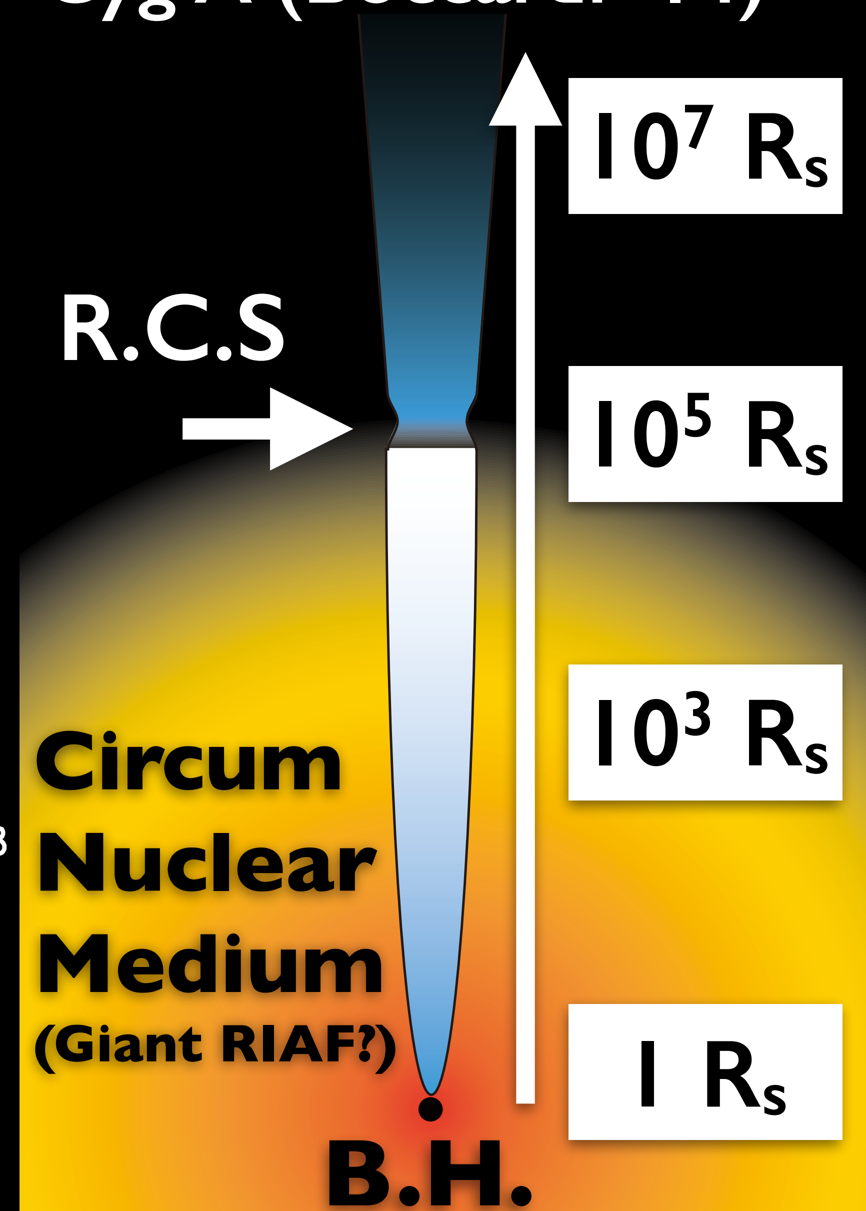
Lessons from Nearby Low Luminosity Radio Galaxies



(Asada & Nakamura 12; Doeleman+12, Nakamura & Asada 13; Hada+13, 16)

Collimation inside Bondi radii (~10^5 R_s)

M 87 (Asada+, Hada+)
3C 84 (Nagai+14)
Cyg A (Boccardi+14)



The Stream Line in Blazars (particularly Quasars)

Many intriguing questions but NO measurements

Historically the conical jet has been assumed for modeling emission
(e.g. Blandford & Konigl 1979; Marcher & Gear 1985; many papers in literature)

Visible region in the jet could be different to LLRGs (Spine vs Sheath)
(e.g. Ghisellini et al. 2005; Tavecchio & Ghisellini 2014; Sikora et al. 2016)

The geometry of the accretion flow would be different for quasars

LLAGN: Giant RIAF? (Narayan &Fabian 11; Hot quasi-spherical flow)

— pressure can be balanced with the jet pressure (M87; Hada+2016)

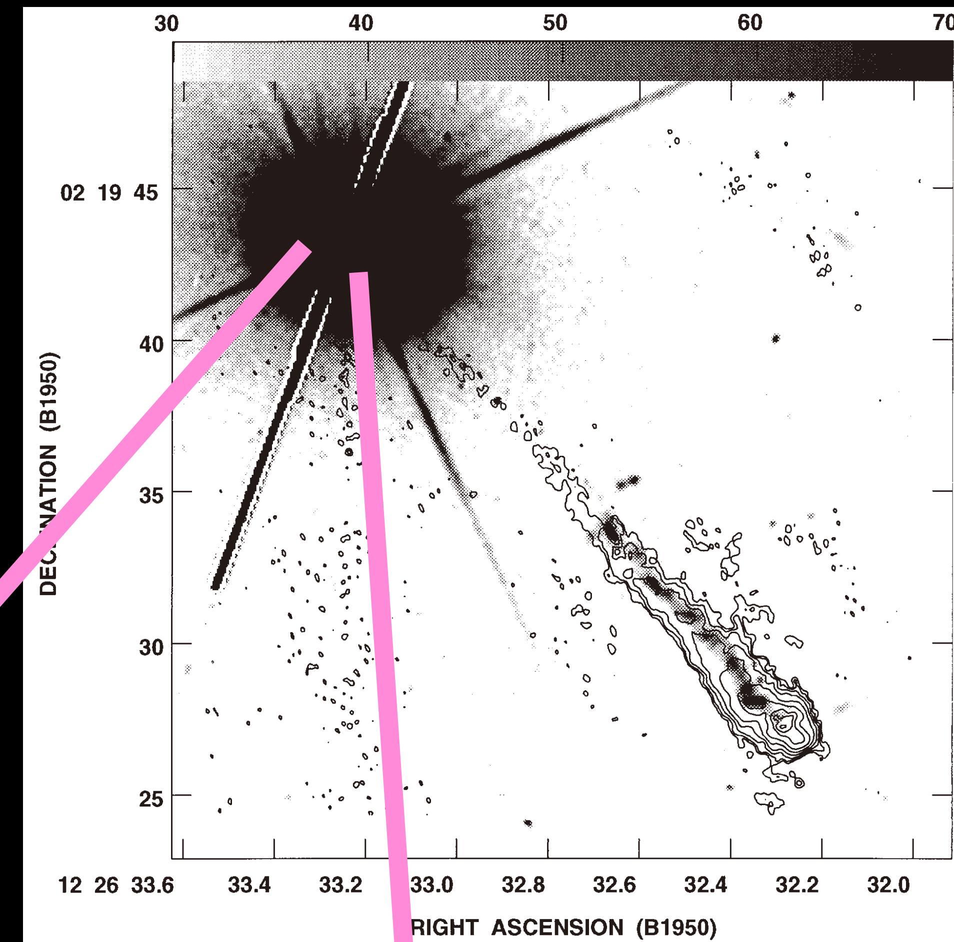
Quasars: Thin or Slim Disk

— The disk can not confine the jet. Need winds?

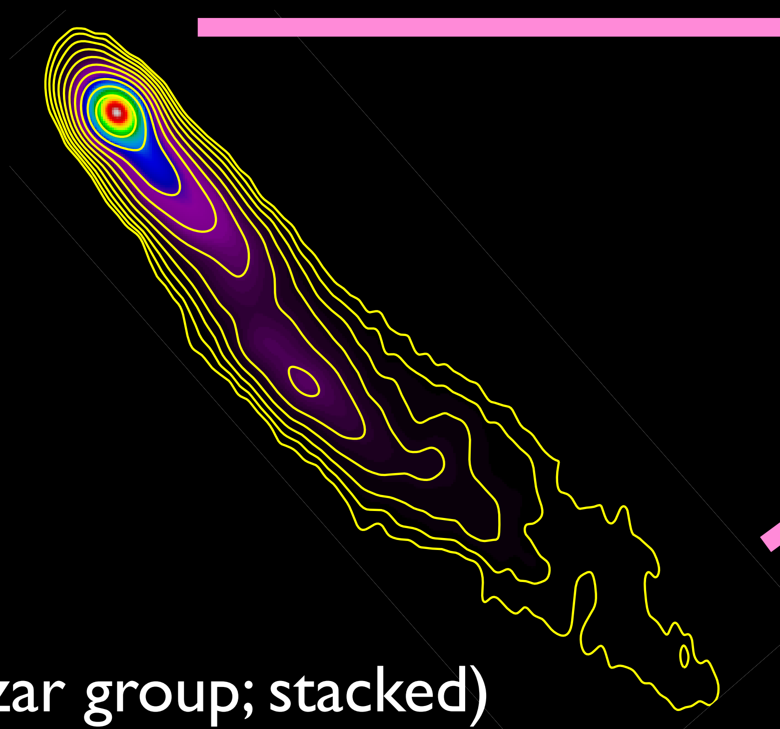
The jet power is also different for quasars

3C 273: the Archetypical Quasar

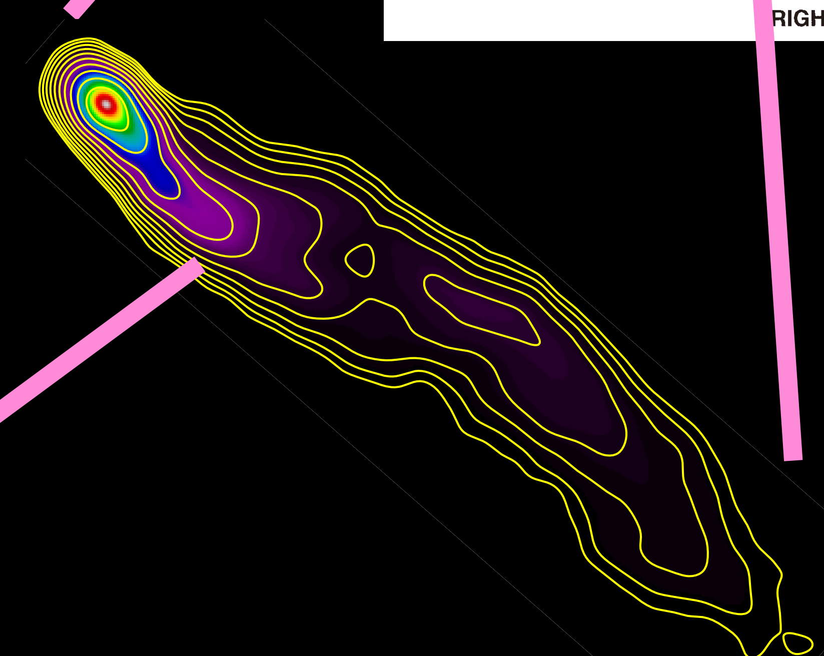
- One of the First Quasars (Schmidt 1963)
- One of the nearest radio-loud quasars (z = 0.158)
- Hosts a very massive black hole (6.6×10^9 M_{solar} ;Paltani & Turler 2005)
- Linear scales (1 mas=2.7 pc=4.8×10^3 Rs)
- One of the brightest sources in radio regimes
- Resolved transverse structure on wide ranges of spatial scales



(Bahcall et al. 1995)



(BU Blazar group; stacked)



(MOJAVE; stacked)

Observational Data

kilo pc ($z \sim 10^8$-10^9 R_s)

VLA 22 GHz

MERLIN 1.6 GHz

100 pc ($z \sim 10^6$-10^7 R_s)

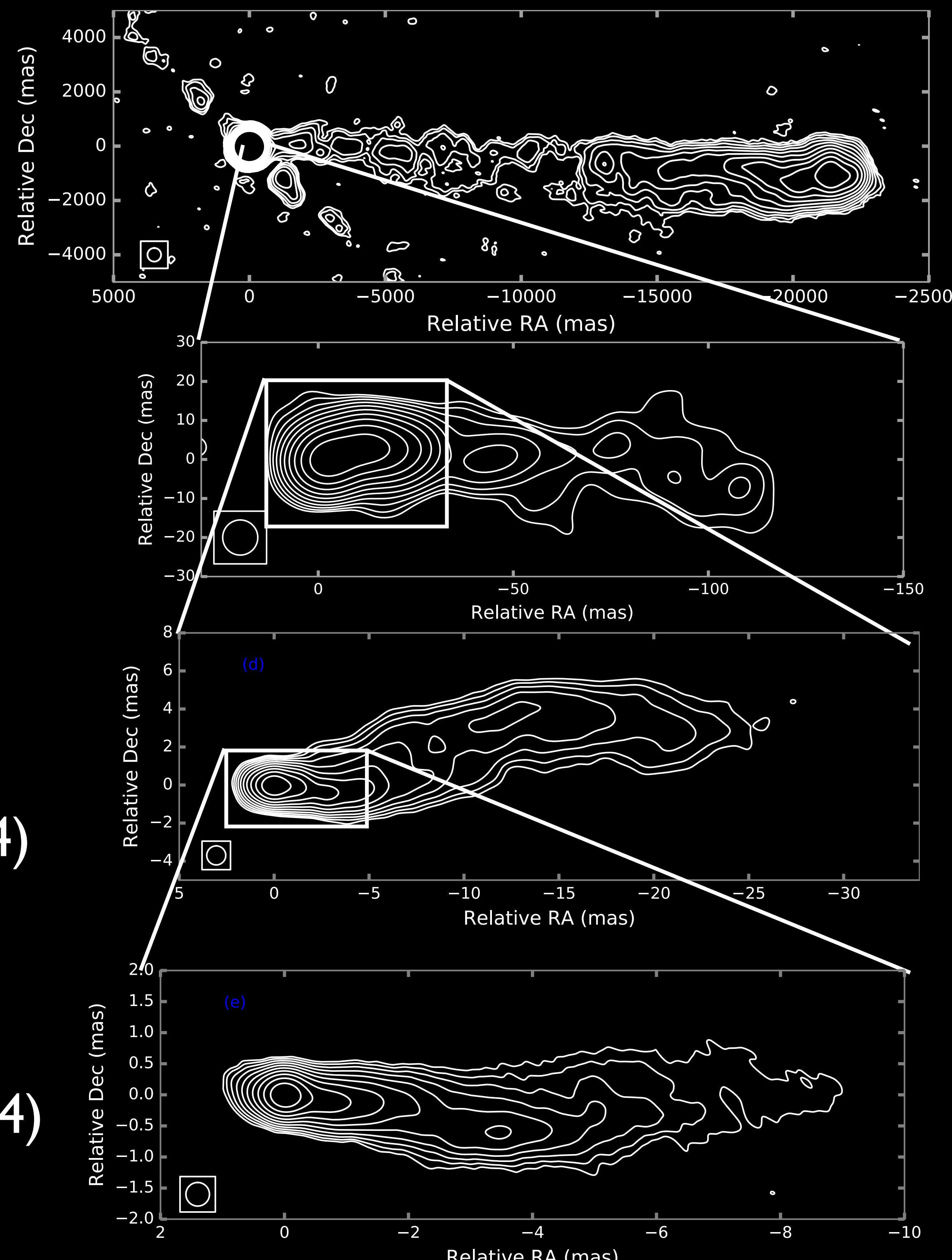
VLBA 1.6 GHz
(8 epochs from 2008, 2009, 2011)

10 pc ($z \sim 10^5$-10^6 R_s)

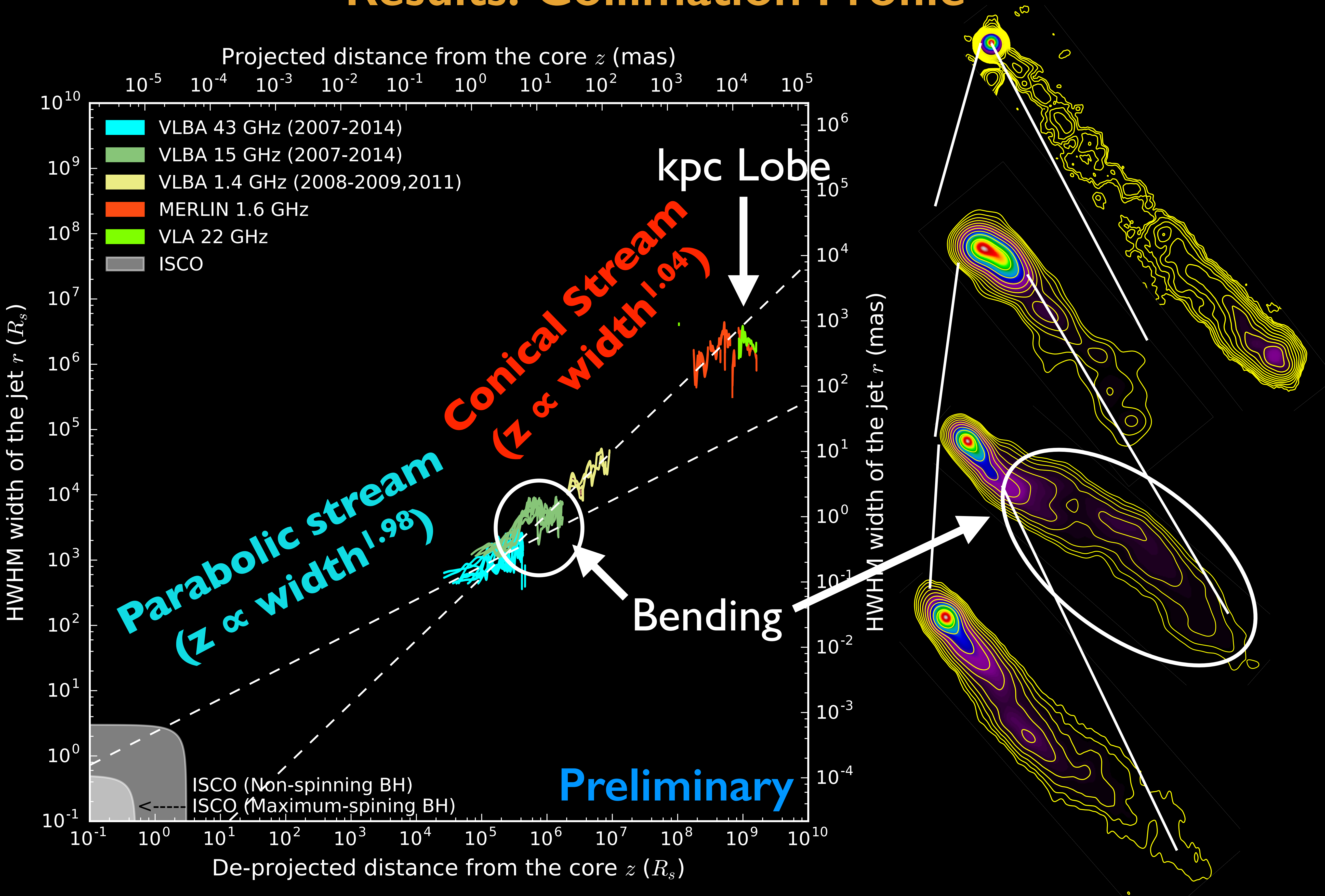
VLBA 15 GHz
(MOJAVE: 65 epochs during 2007-2014)

1 pc ($z \sim 10^4$-10^5 R_s)

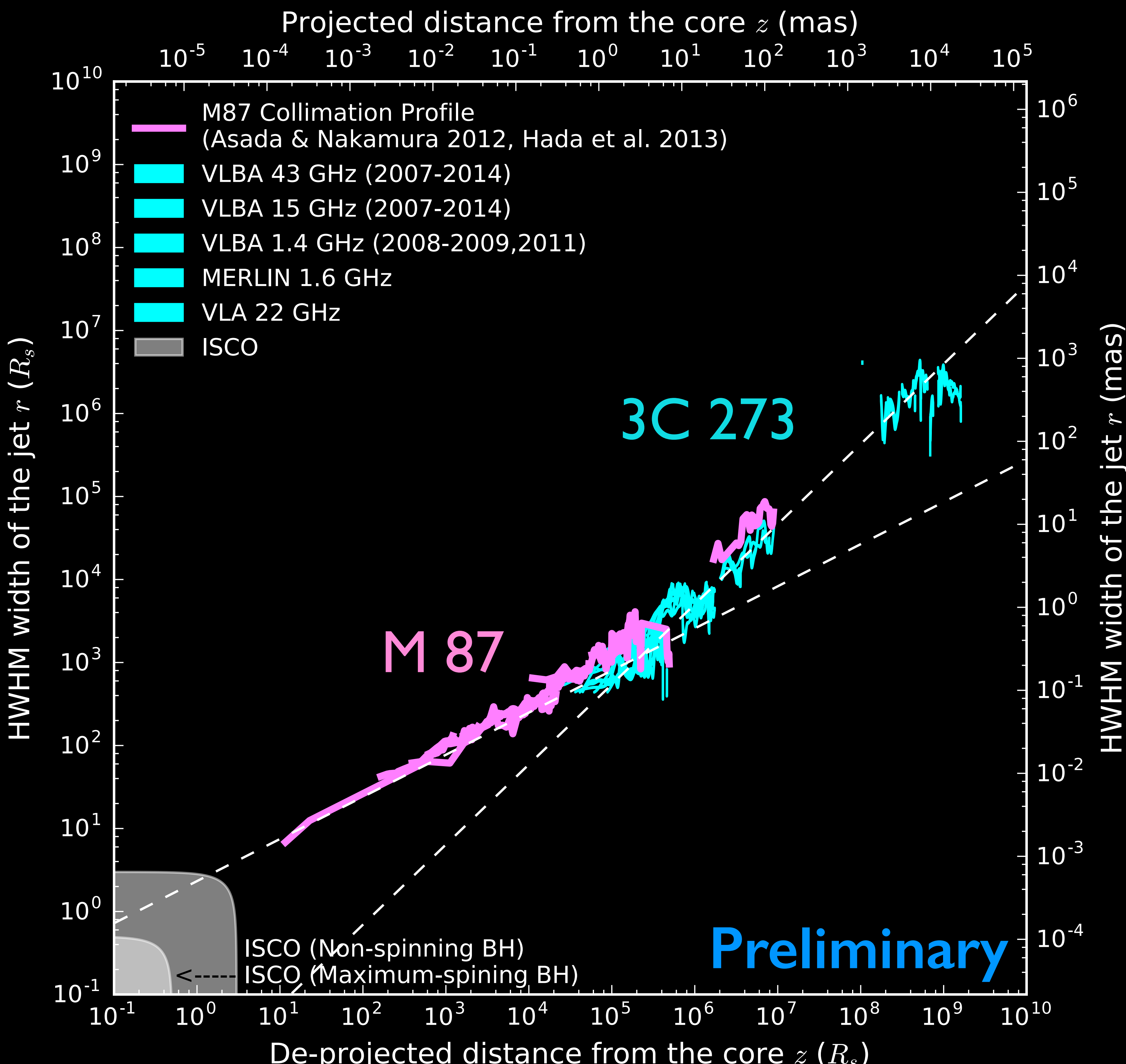
VLBA 43 GHz
(BU Blazar; 76 epochs during 2007-2014)

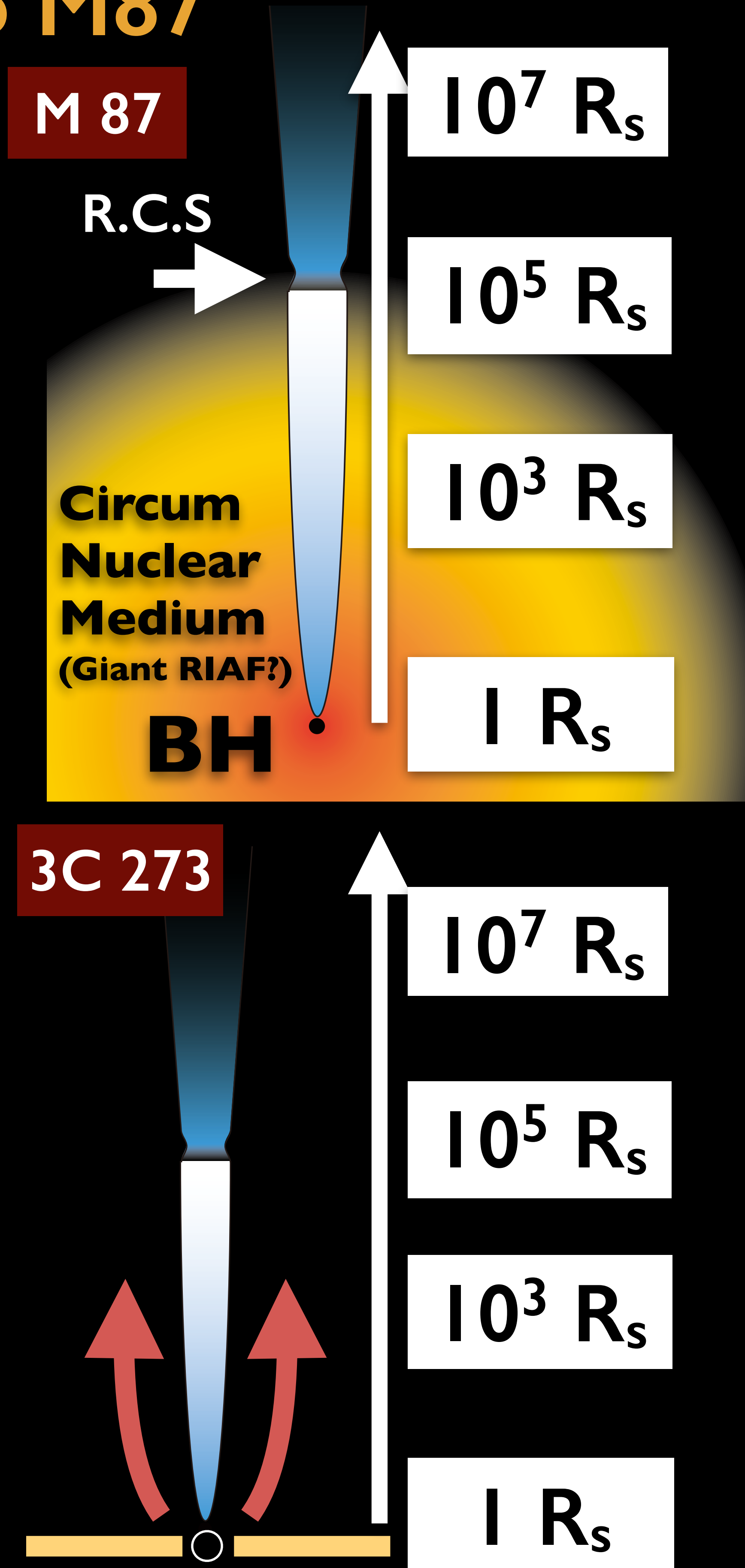


Results: Collimation Profile

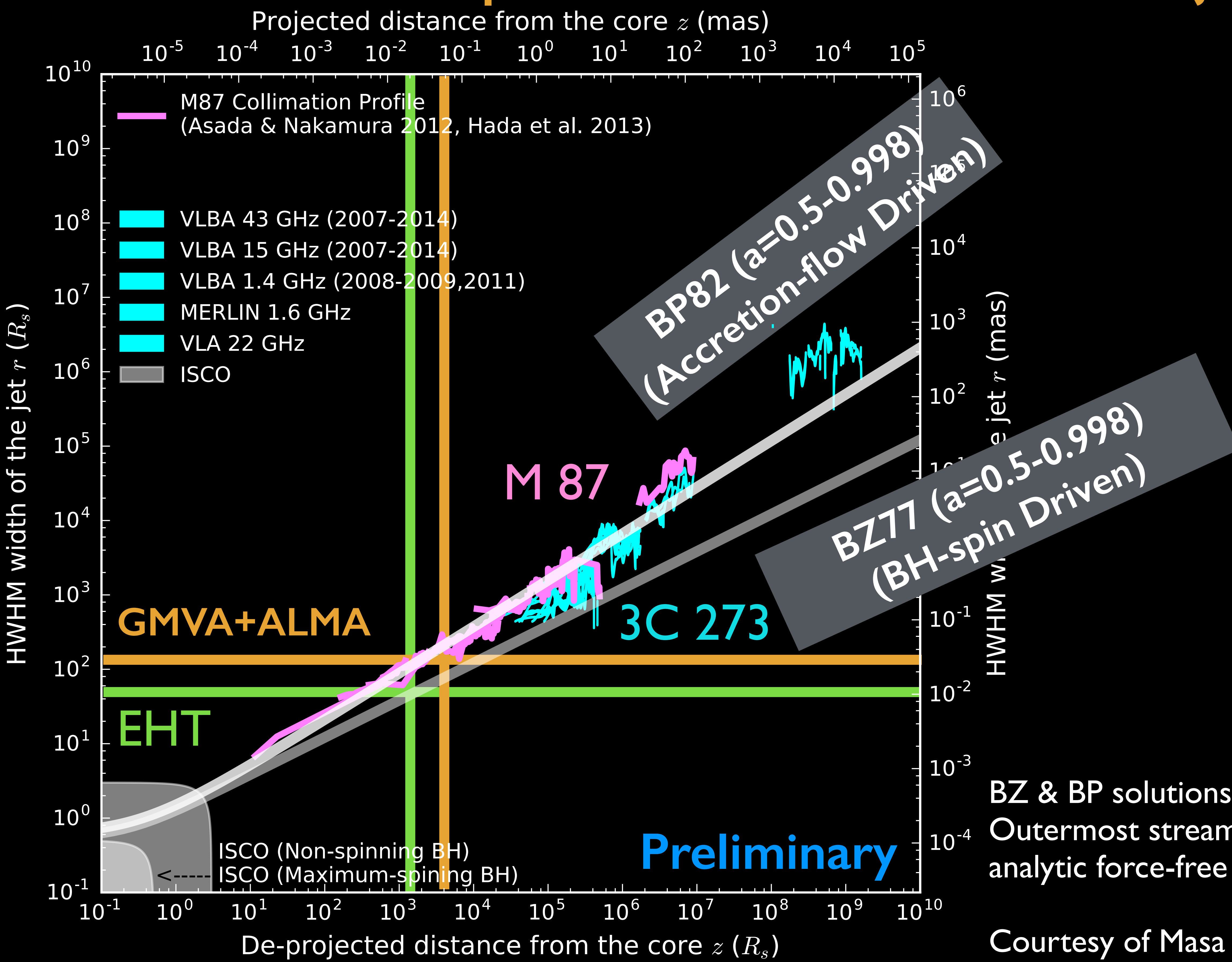


Discussion: Comparison to M87





Discussion: Comparison to classical BP & BZ jets



BZ & BP solutions:
Outermost streamline for analytic force-free solutions

Courtesy of Masa Nakamura

Summary

- We measure the stream line of the global jet in 3C 273 from sub-pc to kpc scales, for the first time among the high-powered quasar sources.

- The global structure of the 3C 273 jet has a break in its stream line very similar to much lower-powered M87

  ~5 mas - 10 arcsec ($>10^5$-10^6 R_s): Conical

  < ~5 mas ($<10^5$-10^6 R_s): Parabolic

- The quasar jets are also collimating at the inner jet as well as LLAGN's jets

  How to collimate the jets from thin/slim disks?
  Detailed comparison to (GR)RMHD simulations will be important

- EHT+ALMA and GMVA+ALMA observations will be extremely important to survey the active collimation region of the quasar jets.

Stream-line Analysis

STEP 1: Circularly slice the image

STEP 2: Measure the position angle profile

STEP 3: Measure the FWHM size of the linear slice