A multi-frequency study of sub-parsec relativistic jets with the Event Horizon Telescope

HERA 2026
Black holes at different flavors

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Main collaborators:

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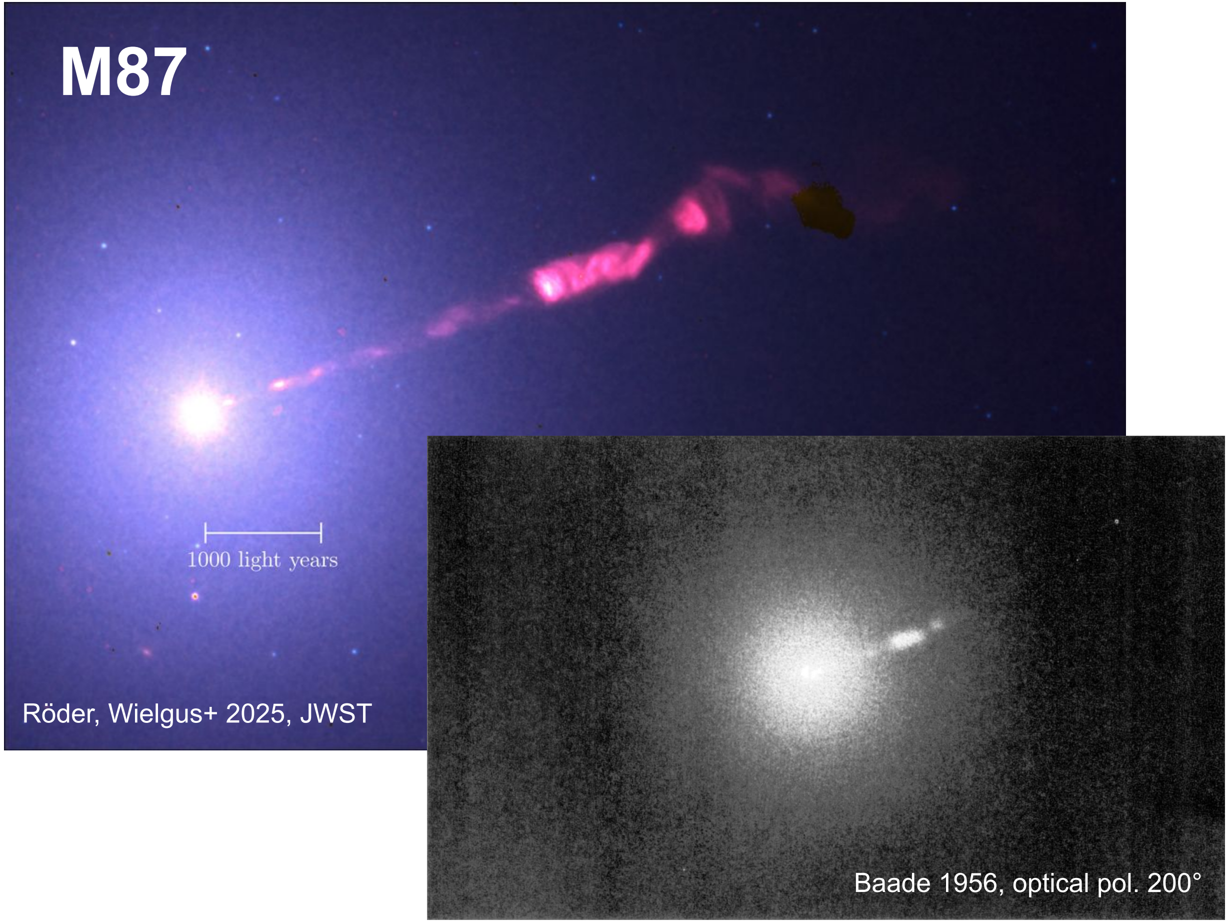
Max-Planck-Institut für Radioastronomie

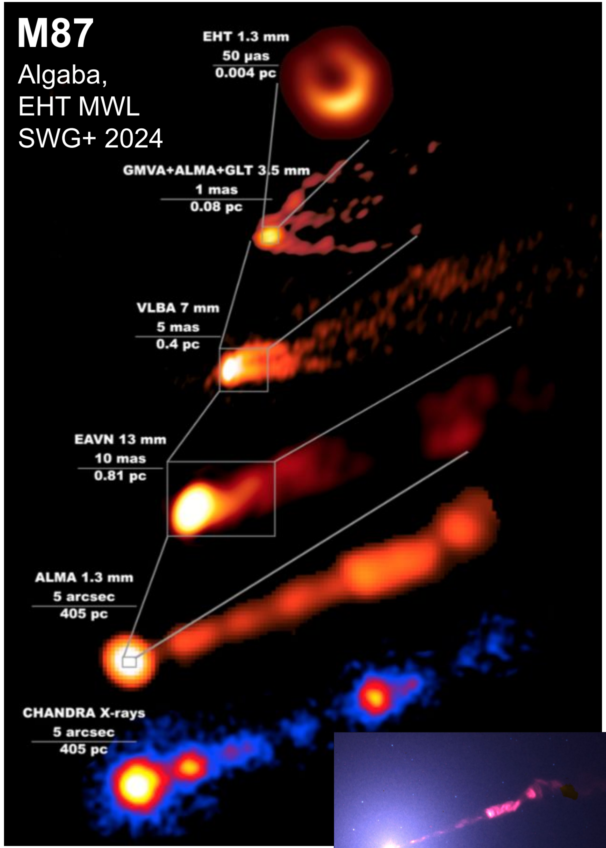
M2 FINDERS

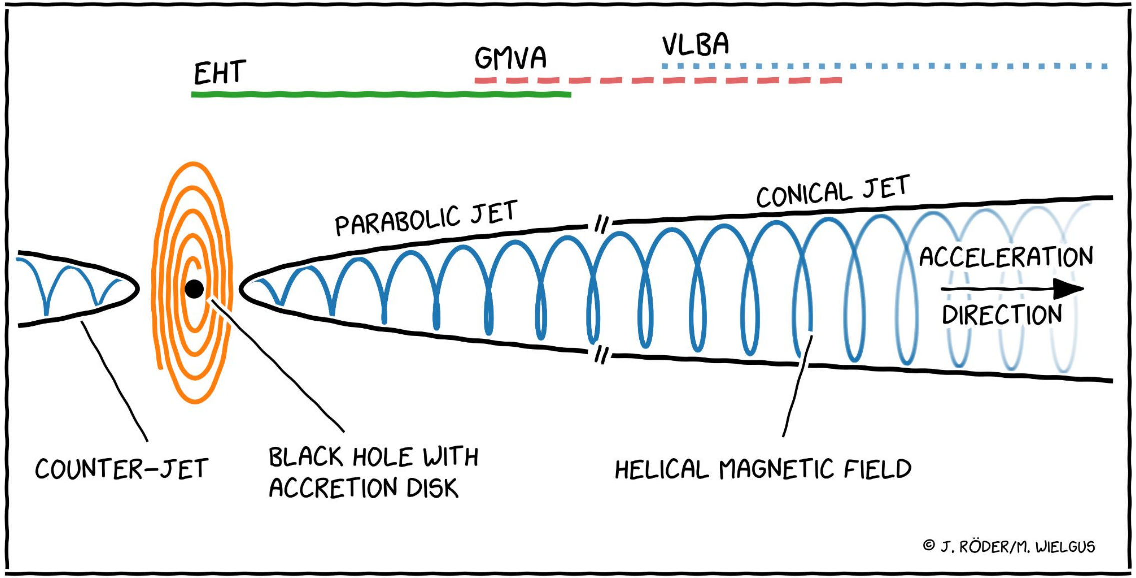


"No possibility exists at this time of forming any hypothesis on the formation of the jet, the physical state of its material, and the mechanism which connects the existence of the jet with the observed radio emission"

Baade & Minkowski, 1954

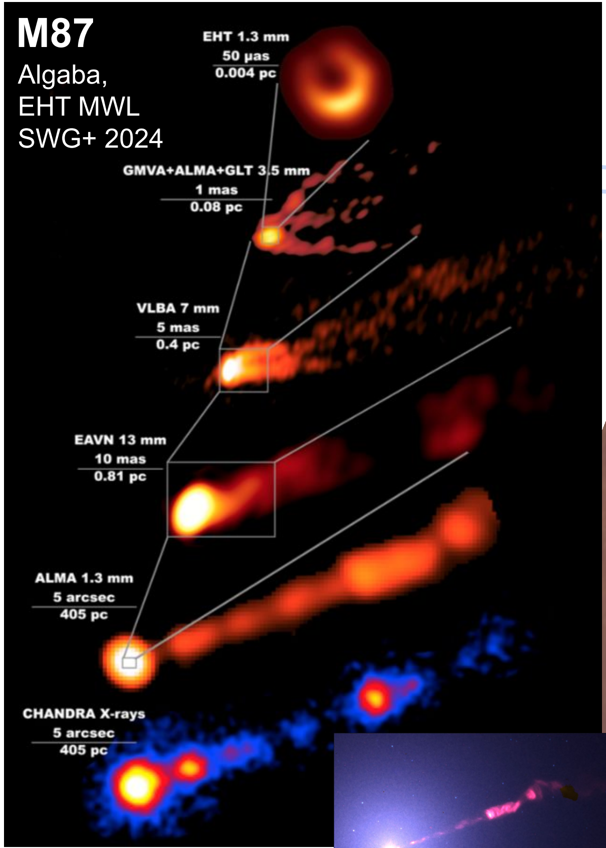
AGN anatomy: jet launching & upstream structure

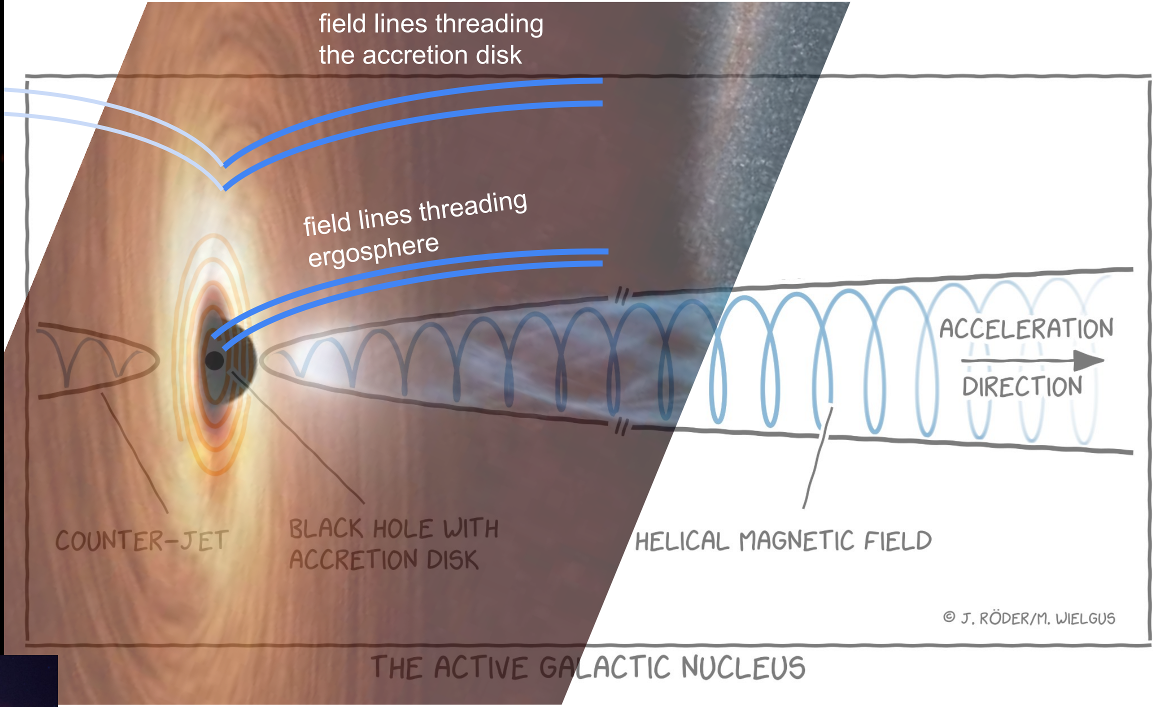




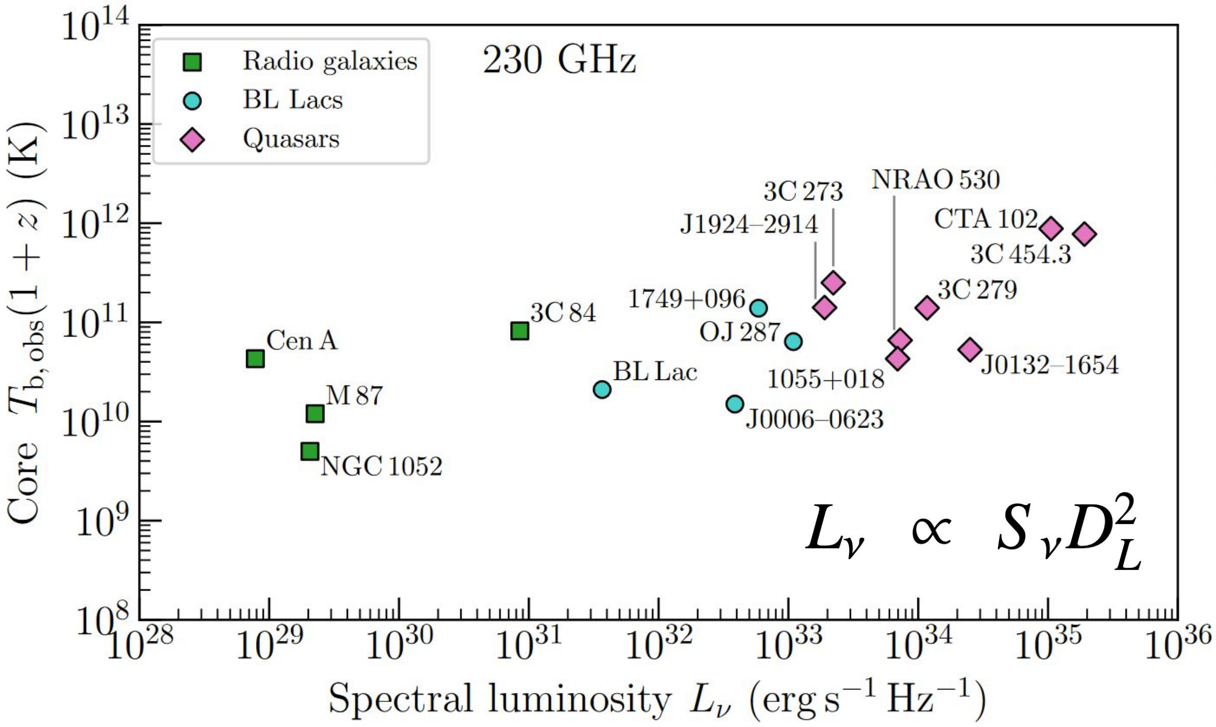
THE ACTIVE GALACTIC NUCLEUS

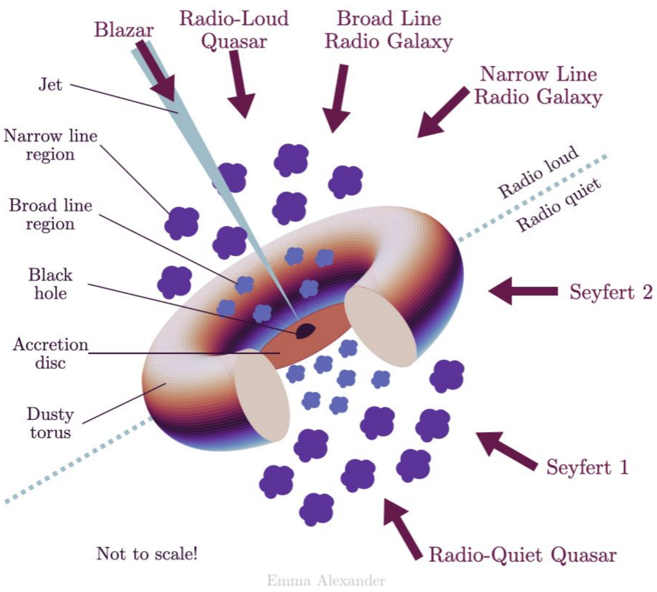
AGN anatomy: jet launching & upstream structure



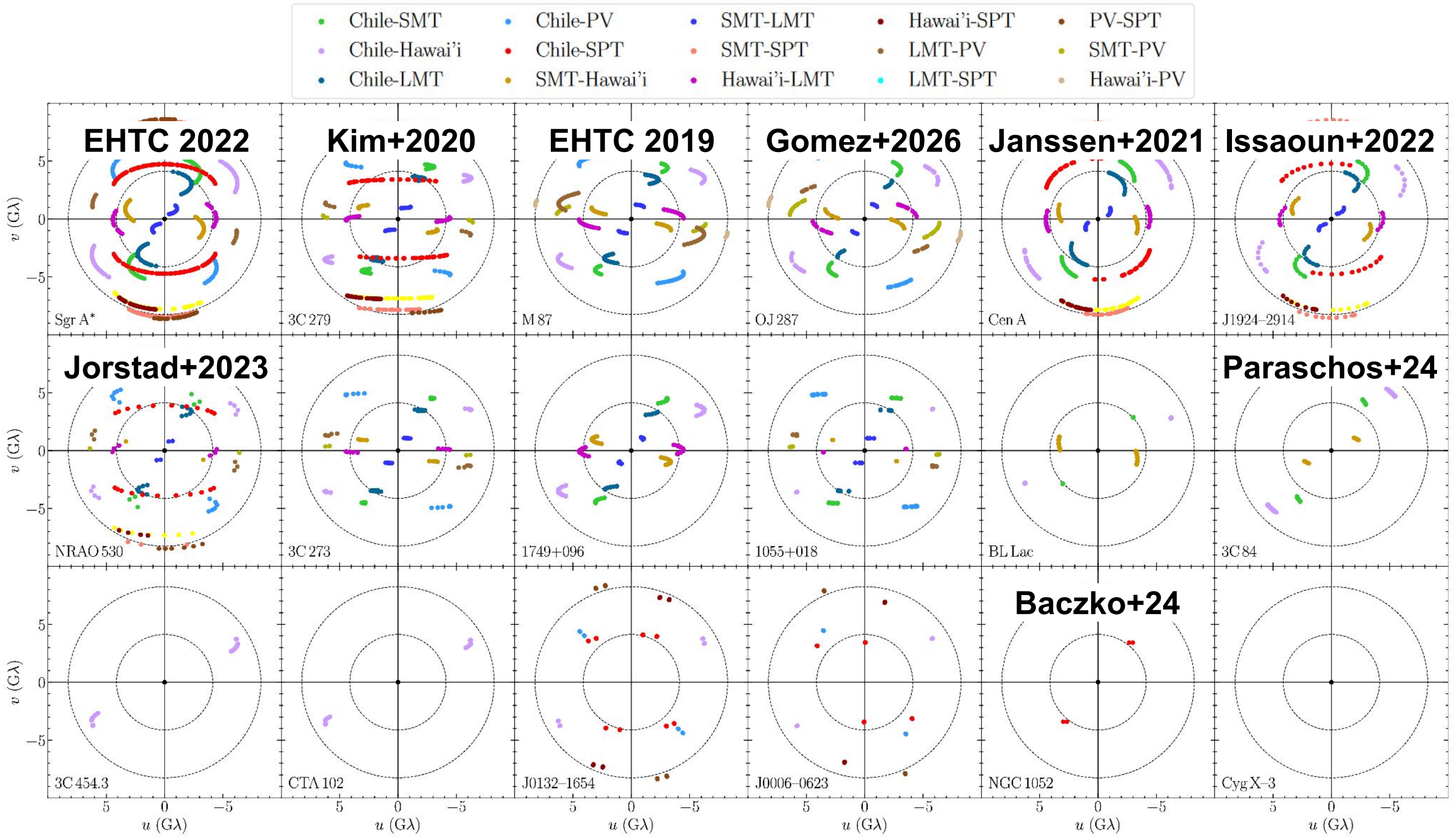


The first EHT campaign (2017): AGN sample

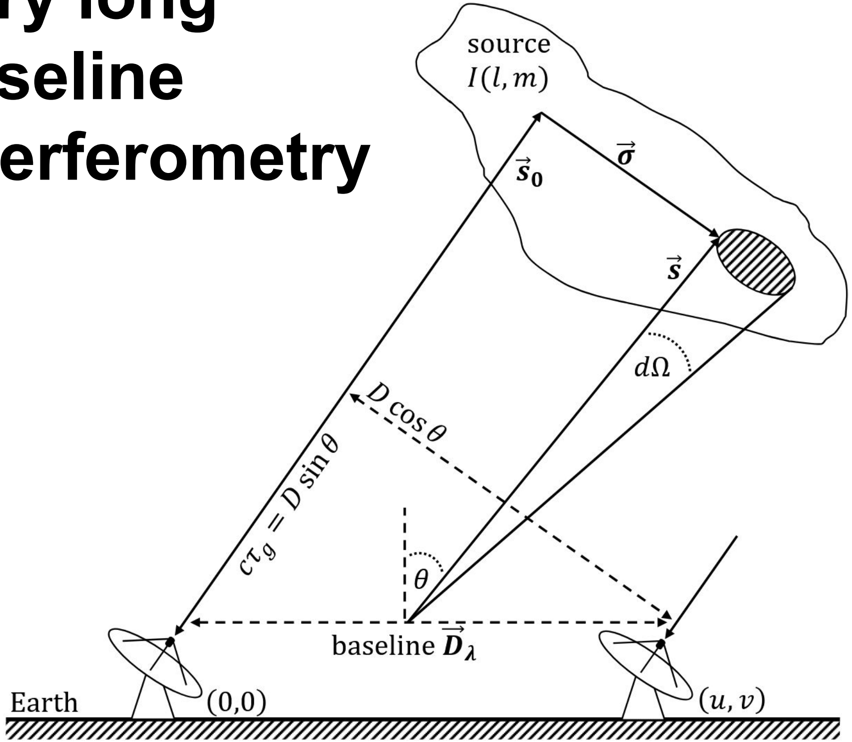


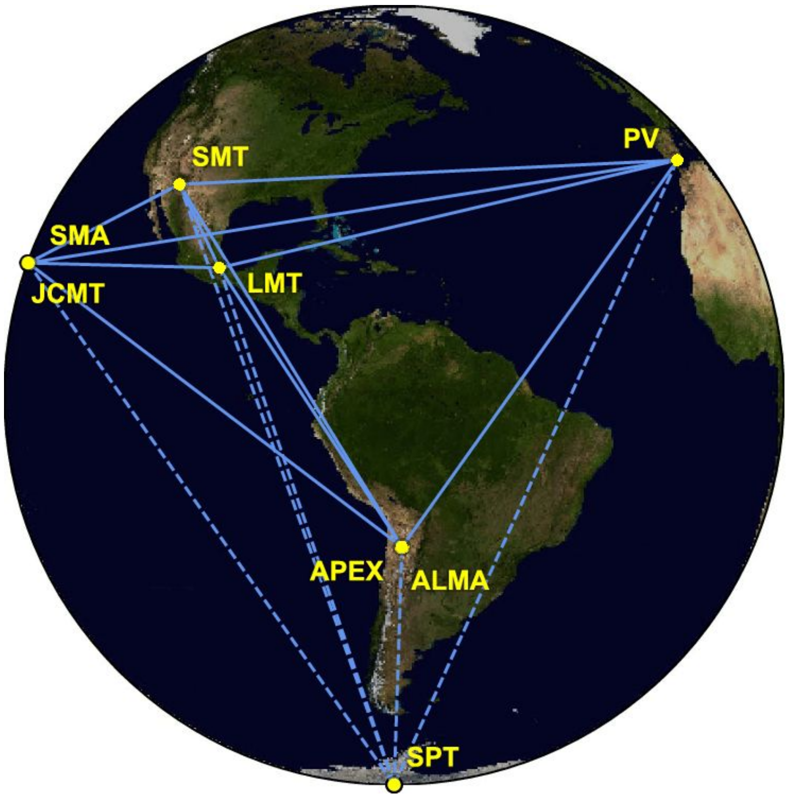


The first EHT campaign (2017)

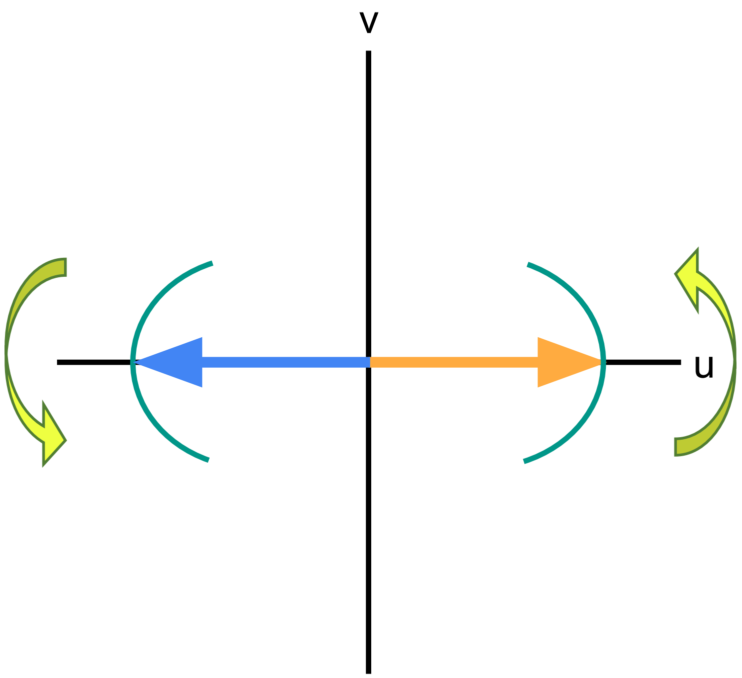


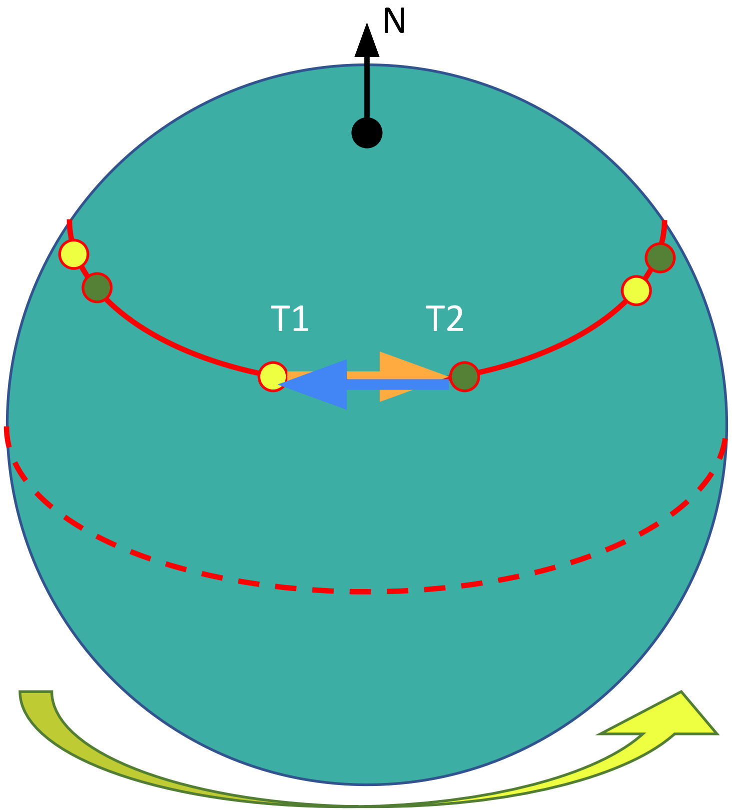
Very long baseline interferometry



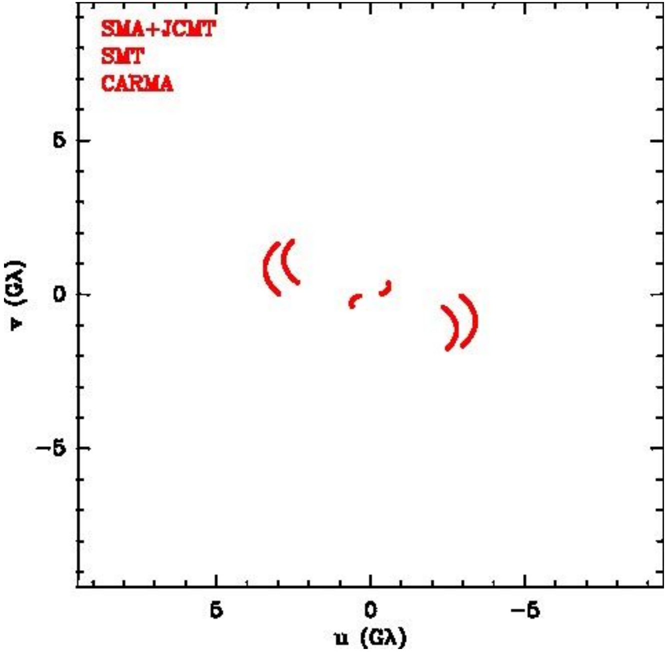


(u, v)-coverage

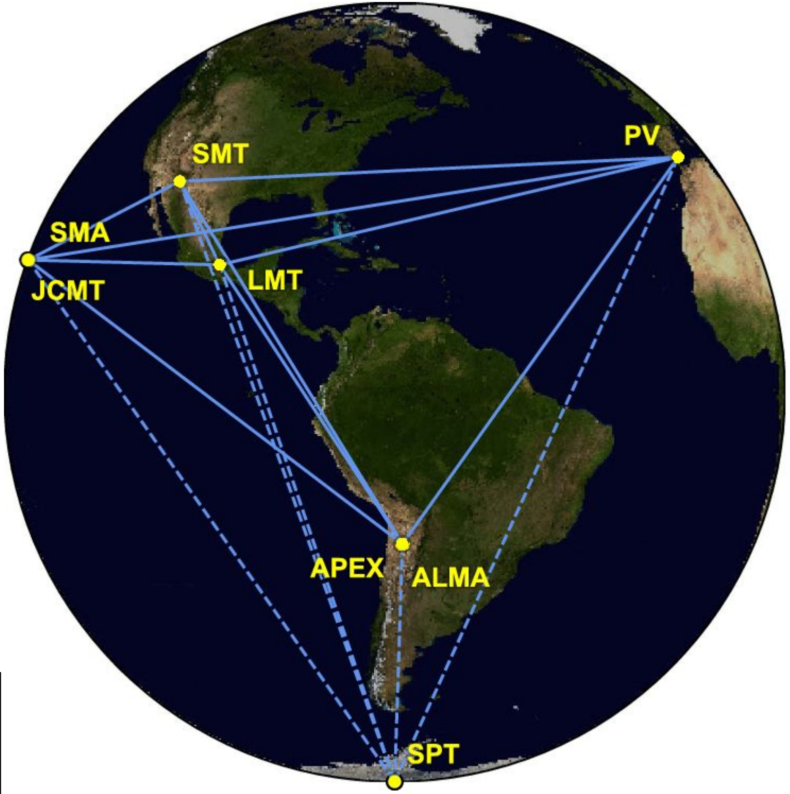




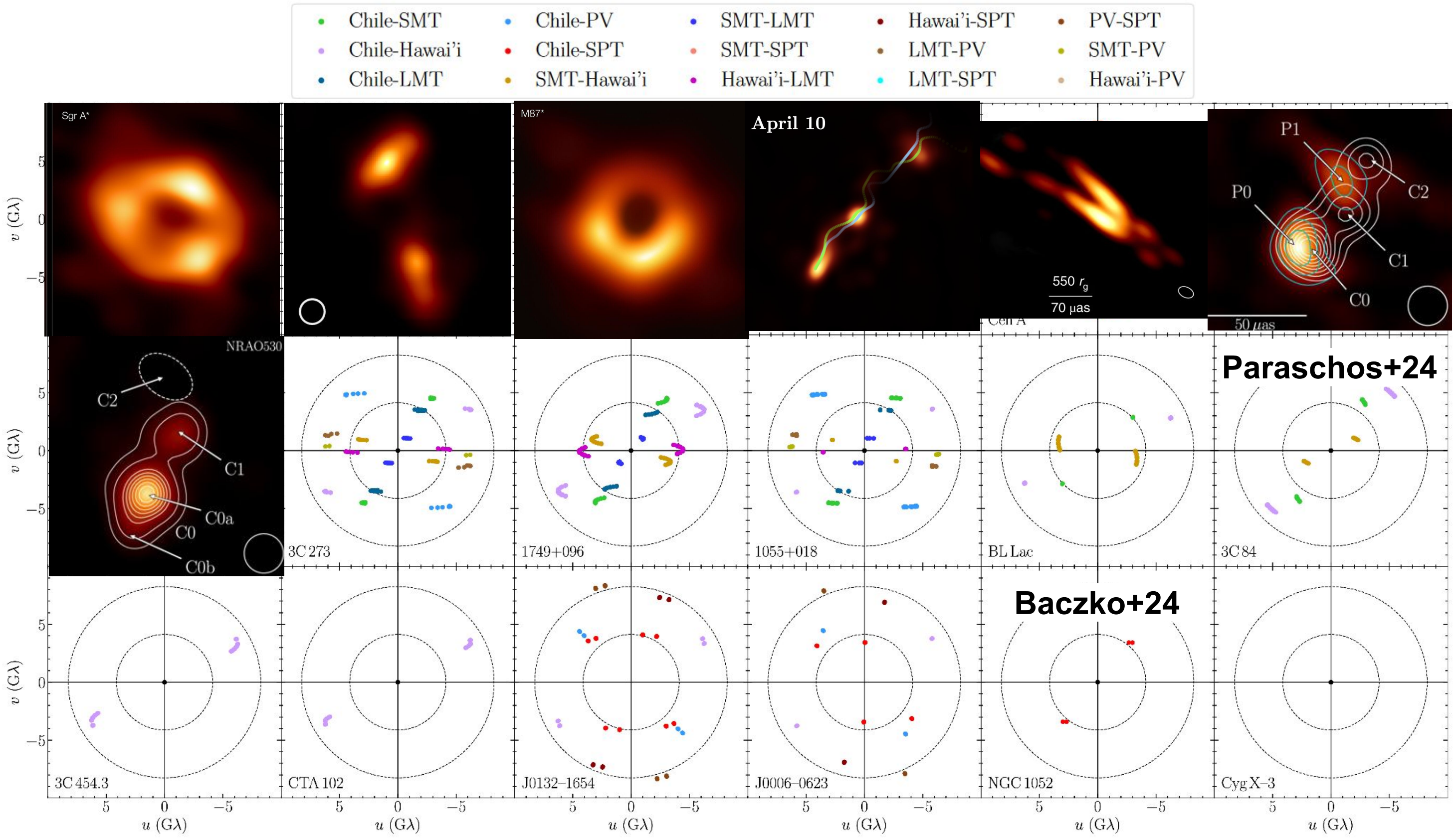
(u, v)-coverage



$$V_{ij} = \iint I(x,y)\, e^{-2\pi i(ux+vy)} dx\, dy$$



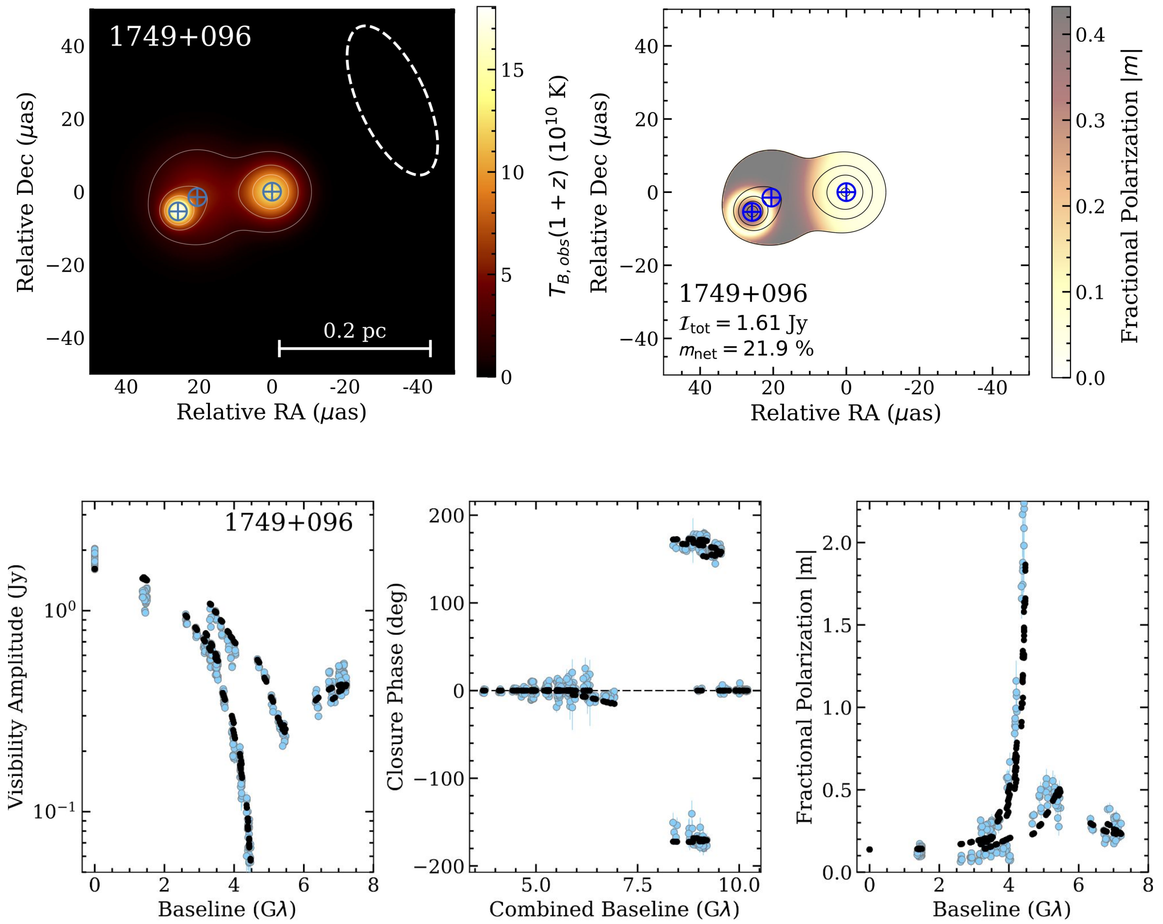
The first EHT campaign (2017): Highlights



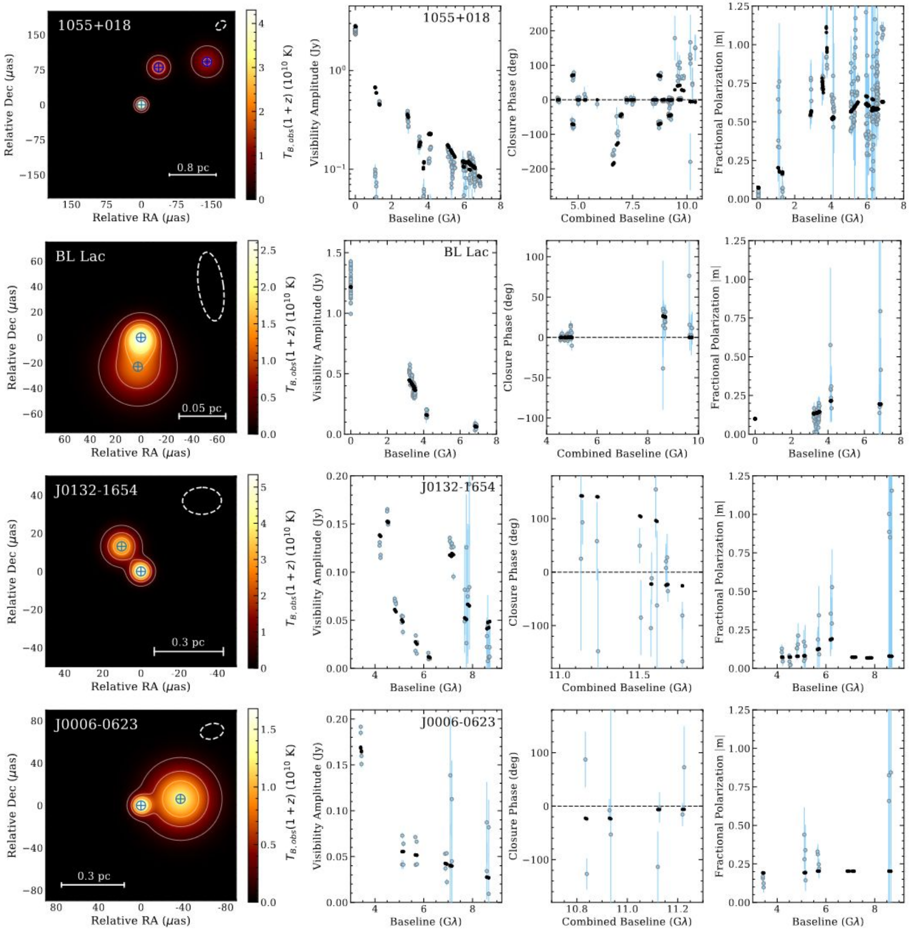
Paraschos+24

Baczko+24

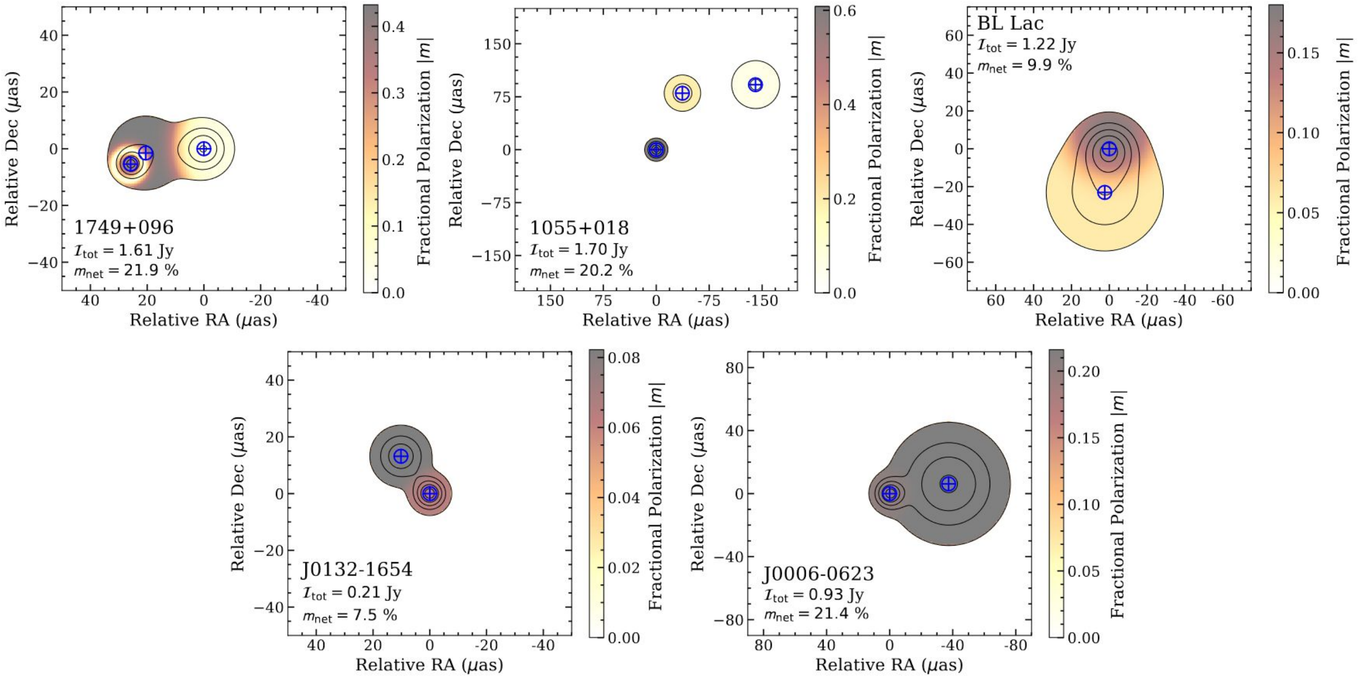
Geometric model fitting (Stokes I + fLP)



Total intensity modeling



Fractional linear polarization



Brightness temperature

$$T_b = 1.22 \times 10^{12} \, \frac{S_\nu}{\theta^2 \nu^2} (1+z) \; [K]$$

- blackbody equivalent temperature
- independent of distance to source

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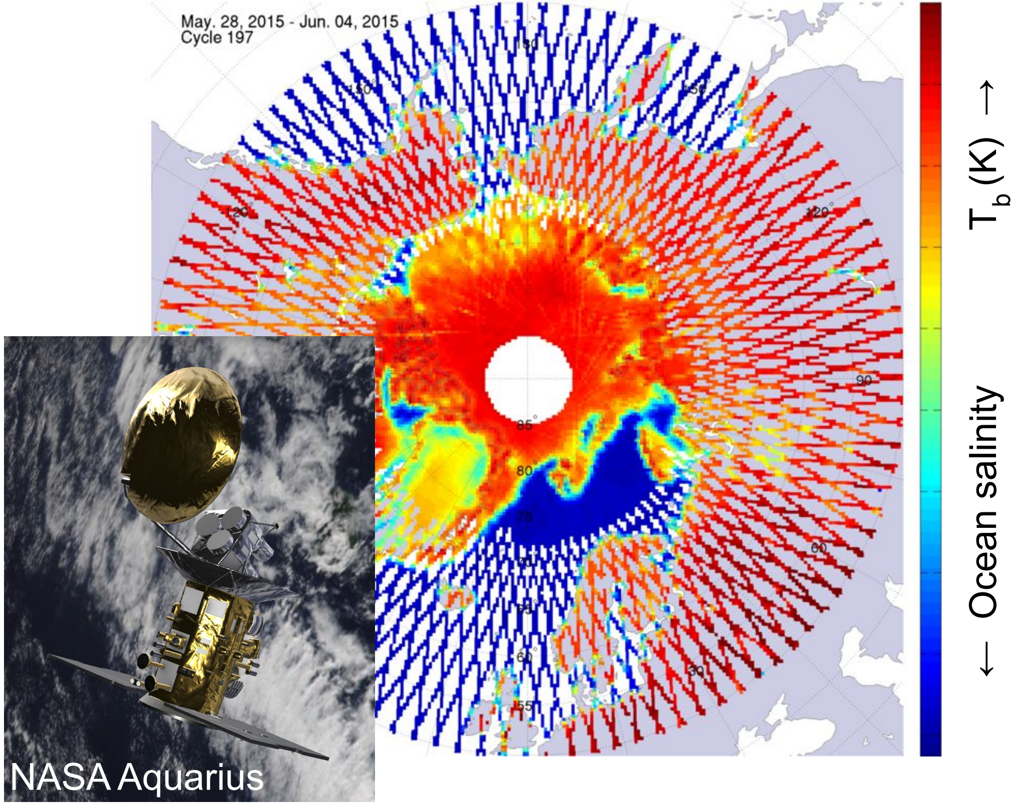
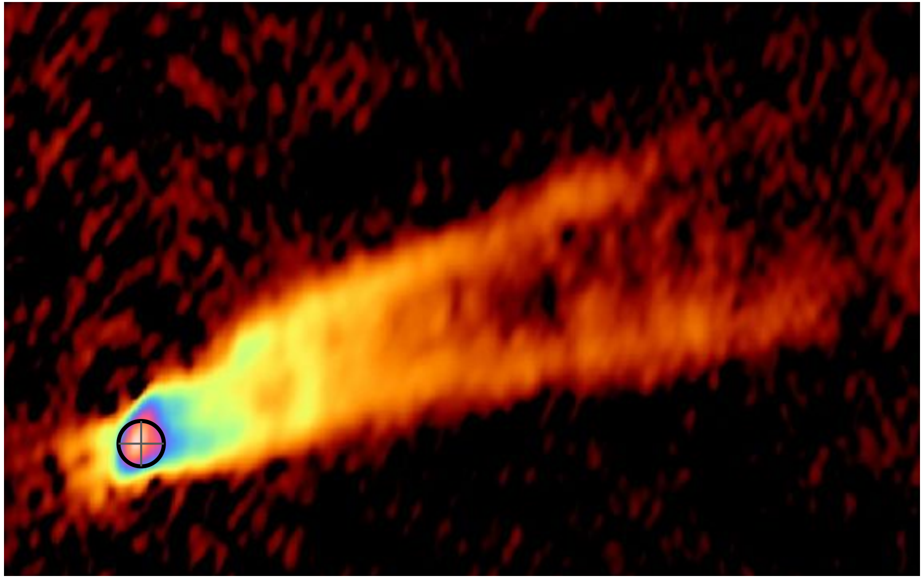


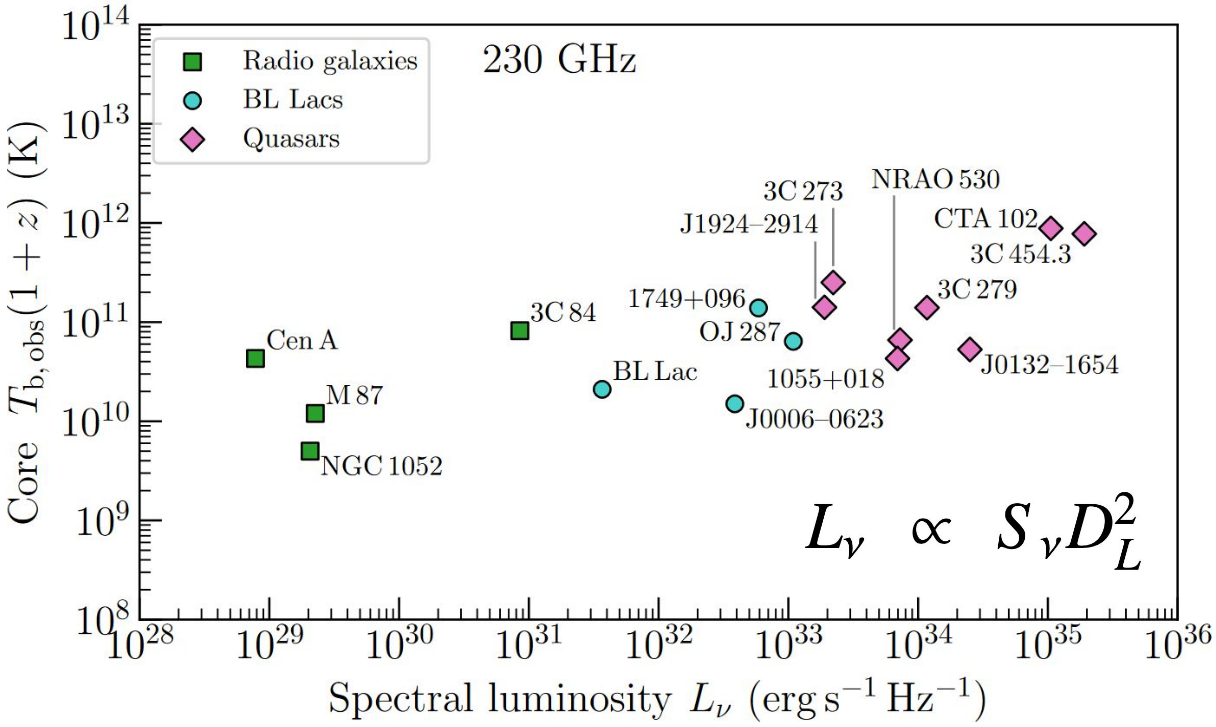
Brightness temperature

$$T_b = 1.22 \times 10^{12} \, \frac{S_\nu}{\theta^2 \nu^2} (1+z) \; [K]$$

- blackbody equivalent temperature
- independent of distance to source
- proxy for temperature of synchrotron emitting electrons

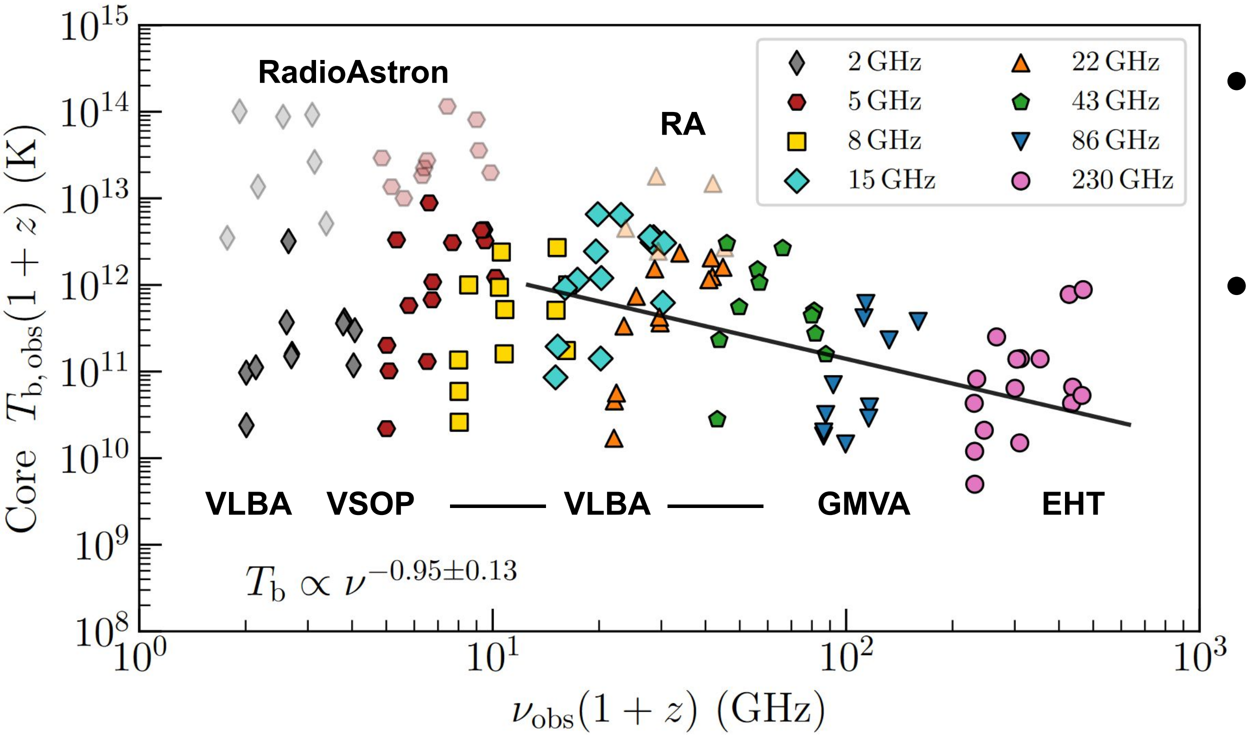


AGN sample



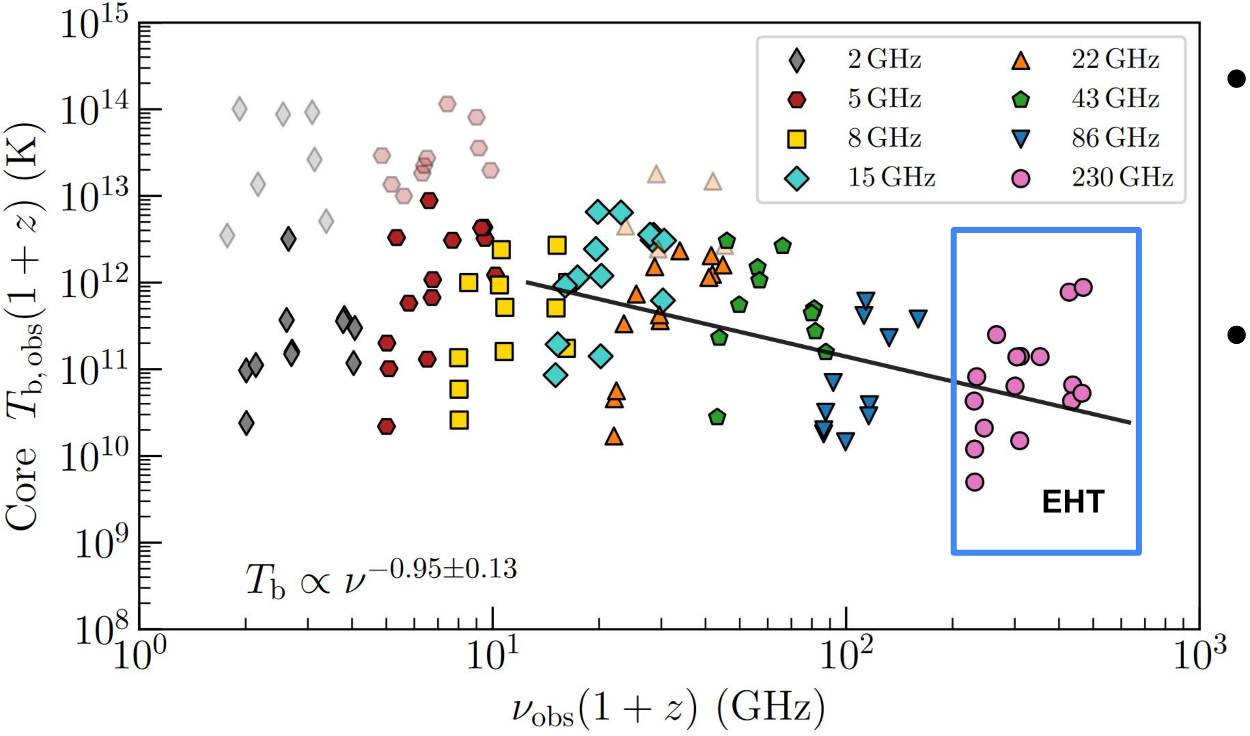
- sources have **distinct individual properties** (distance, viewing angle,...)

Evolution of core T_b with ν_{obs}



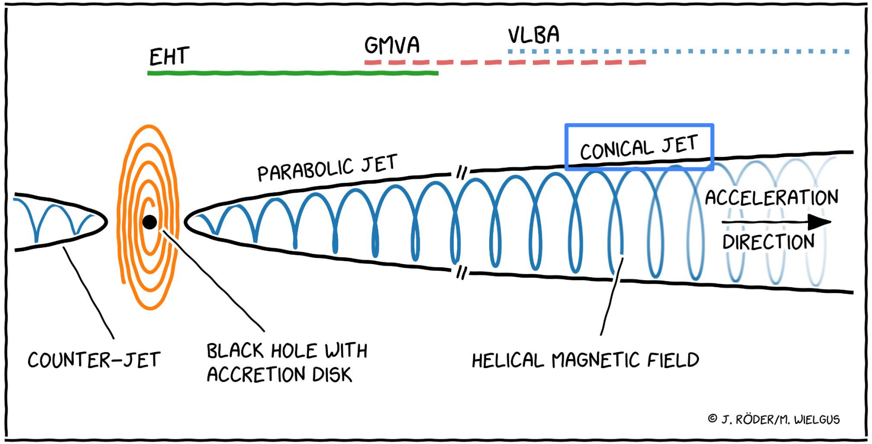
- sources have **distinct individual properties** (distance, viewing angle,...)
- **VLBI core properties** (flux density, size and brightness temperature are **fit on a per-source basis**

Evolution of core T_b with v_{obs}



- **equipartition T_b not exceeded** at 230 GHz considering equipartition Doppler f's <10
- for $T_b \ll 10^{11}$K at 230 GHz: **magnetically dominated inner jet**

The Blandford-Königl model



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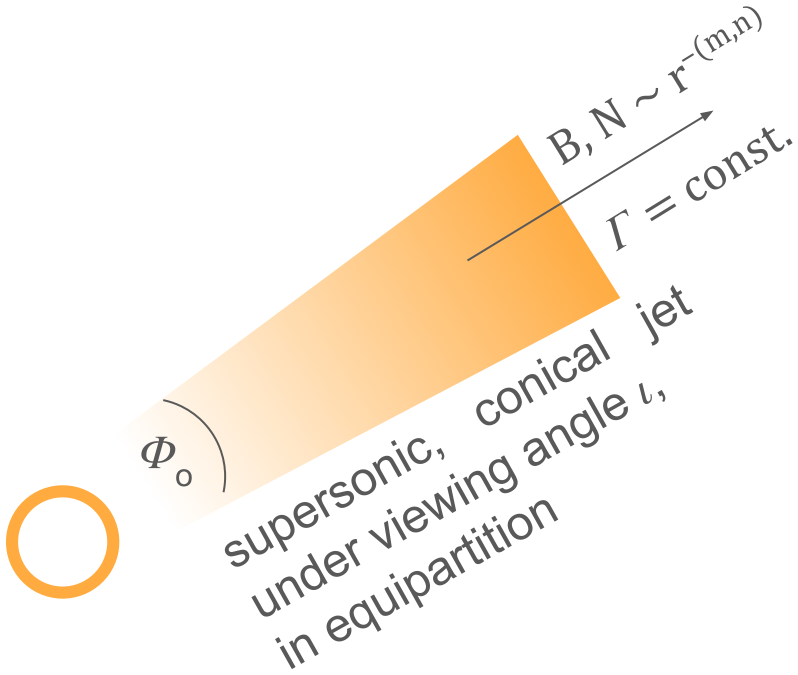
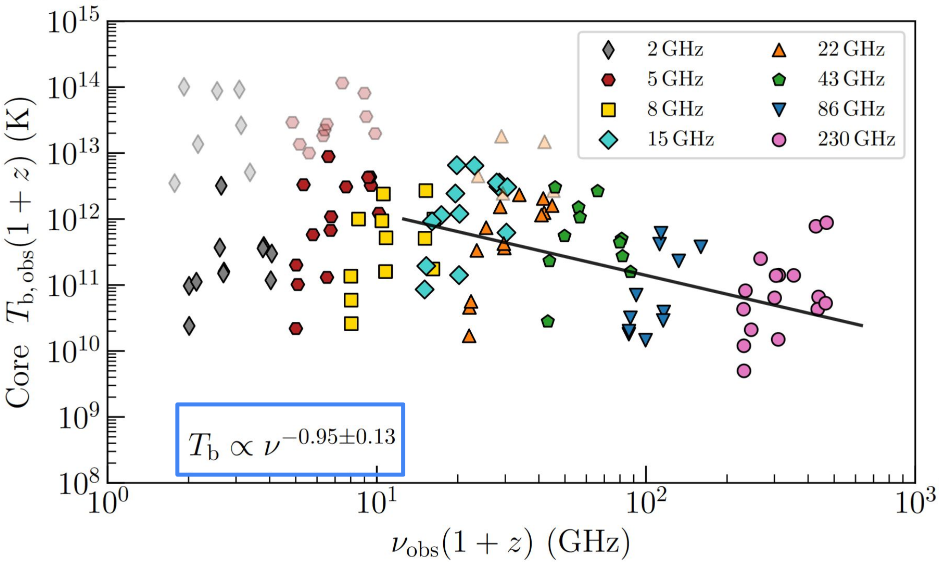
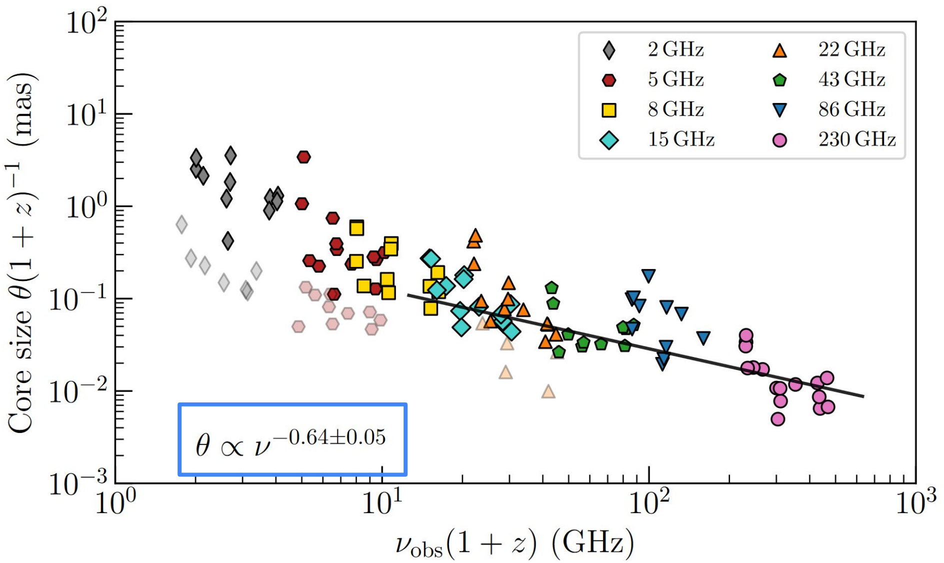
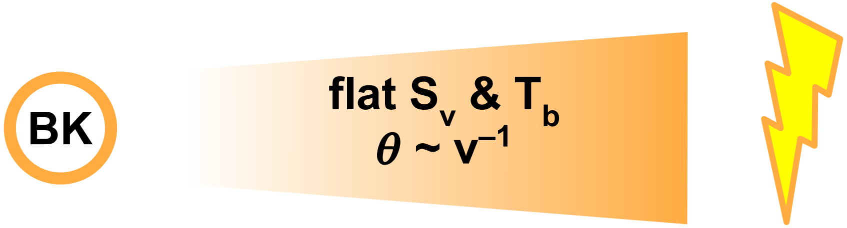


Consistency with the Blandford-Königl model







$T_b \sim \nu^{-0.95}$
$\theta \sim \nu^{-0.65}$
$S \sim \nu^{-0.45}$

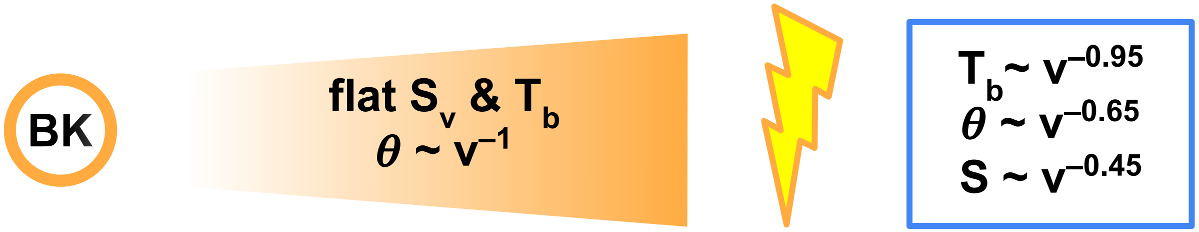
Consistency with the Blandford-Königl model

- Changes in radial evolution of magnetic field strength
  $\Rightarrow$ would alleviate θ-ν-dependency

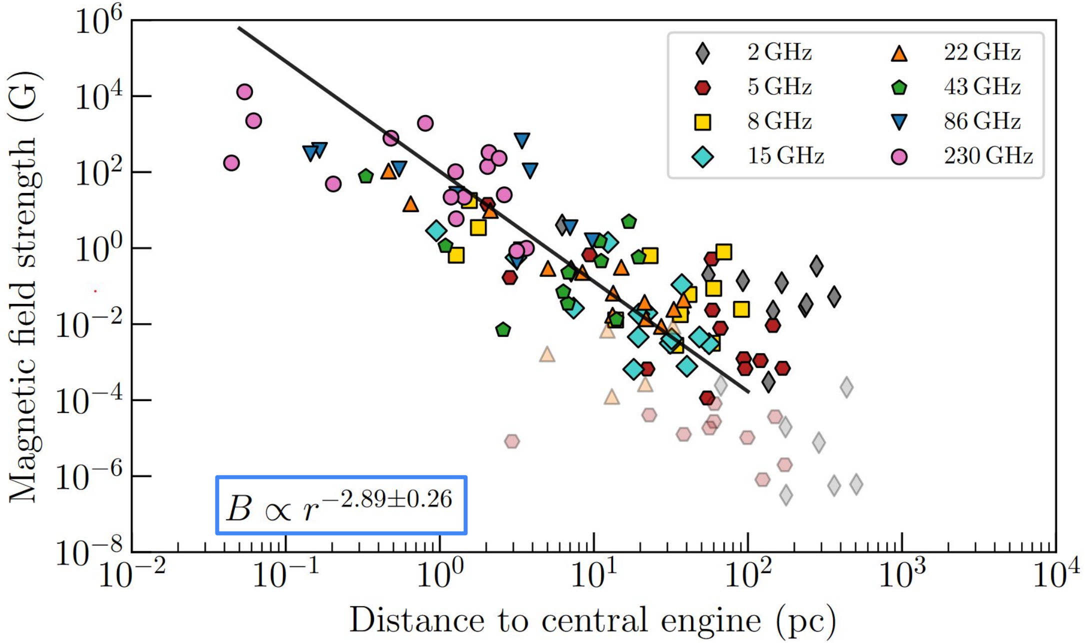
- Deviation from equipartition (particle kinetic energy vs. magnetic energy)
  $\Rightarrow$ would only alleviate impact of θ on T_b, not of S on T_b

- Transition from a parabolic to a conical jet geometry
  $\Rightarrow$ we find $\theta \propto r^{0.7}$; closer to a paraboloid than a cone

- Variable Doppler factor, energy balance and viewing angle along the jet

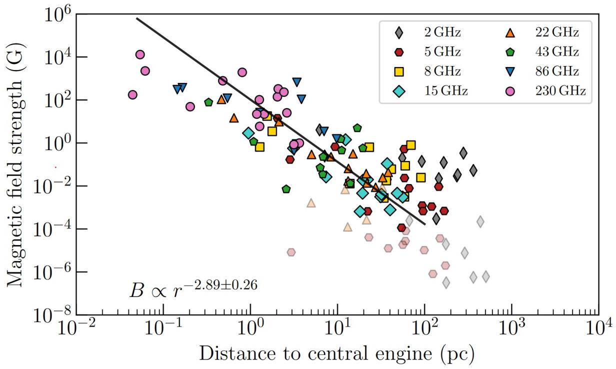


Magnetic field strength along the jet

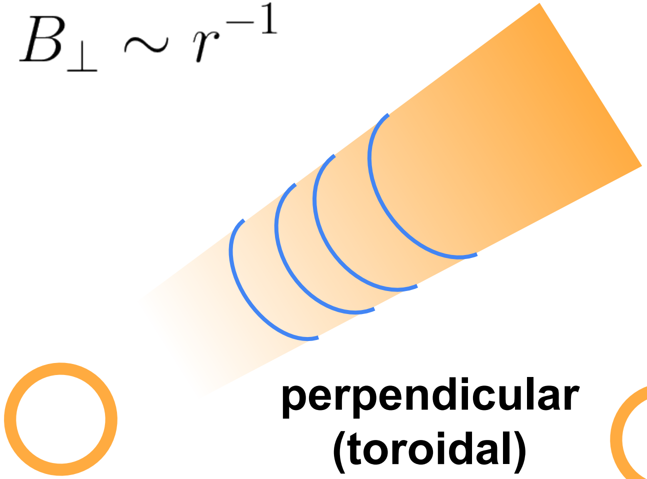


$$B \approx 1.4 \times 10^{21} \left(\frac{\nu_{\mathrm{obs}}(1+z)}{\mathrm{GHz}} \right) \left(\frac{T_{\mathrm{b,\,obs}}(1+z)}{\mathrm{K}} \right)^{-2} \mathrm{G}$$

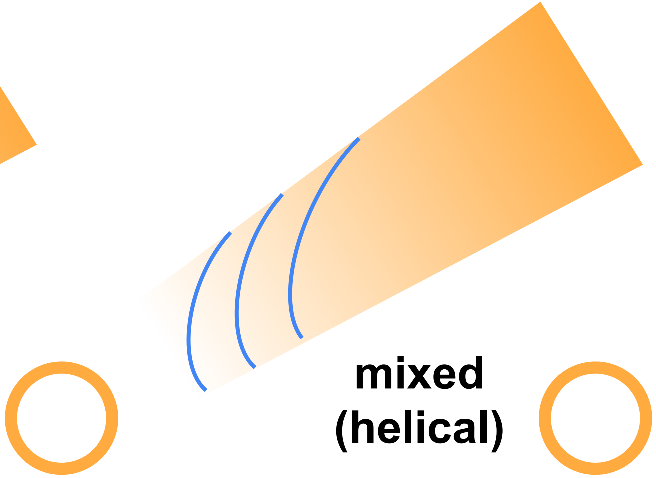
Magnetic field strength along the jet



$B_\perp \sim r^{-1}$

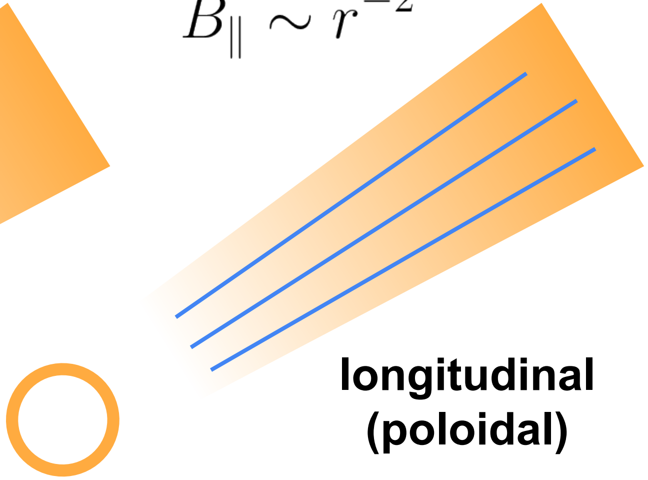


perpendicular (toroidal)



mixed (helical)

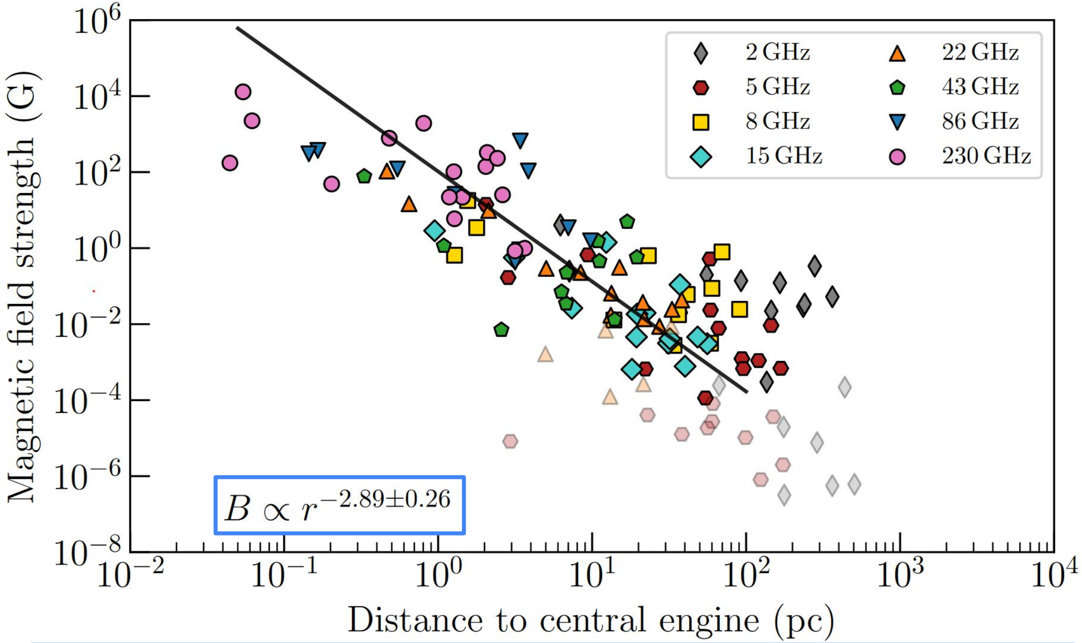
$B_\parallel \sim r^{-2}$



longitudinal (poloidal)

Magnetic field strength along the jet

Consistent with estimates for accretion disks



Consistent with estimates for ambient fields

- efficient energy conversion?
- loss of field coherence at large distances?
- decreased optical depth at high frequencies?

Summary

- Circular Gaussian model fitting
  - total intensity & fractional polarization structure of eight AGN
  - 230 GHz core T_b consistent with low-frequency results
  - RadioAstron improves picture (less resolution limitation at low frequencies)

- Blandford-Königl model insufficient to explain observations
  - variations in radial magnetic field profile
  - parabolic instead of conical geometry near the black hole
  - Deviations from equipartition…
  - …or of the Doppler factor are necessary

What's next?

- **Beyond 2017**
  At least 60 more sources available from
  EHT observations in subsequent years

- **Beyond 230 GHz**
  First set of EHT AGN observations at
  345 GHz (Plavin et al., submitted to ApJ)

- **Beyond the Blandford-Königl model**
  Develop more consistent model
  reflecting observed trend across scales

- **Dedicated proposal?**
  Ensure data consistency for follow-up studies

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