Constraining the accretion processes from radio spectra of low-luminosity AGNs

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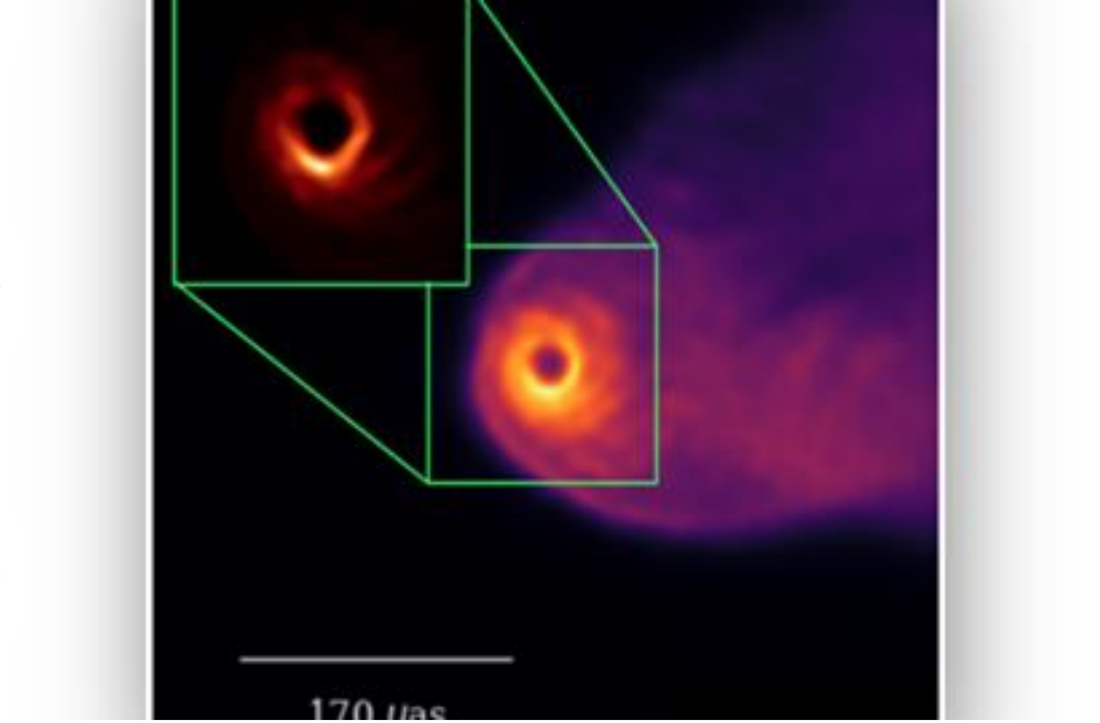
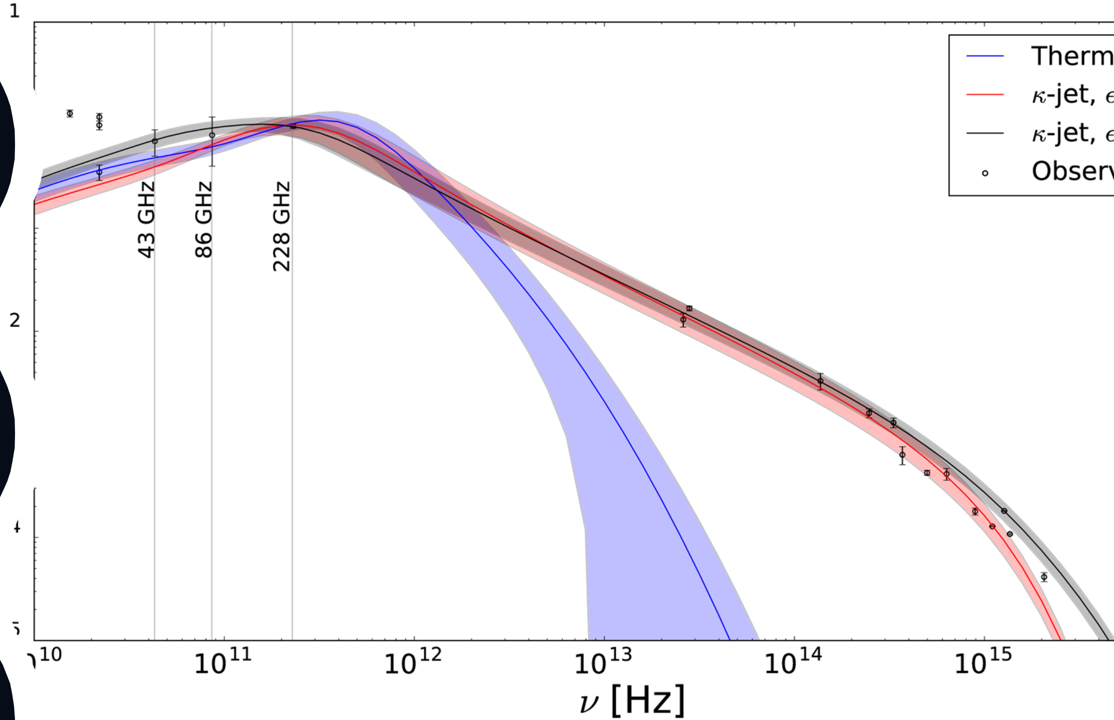
EHT Collaboration





Nuclear demographics of galaxies

- The central engine of most galaxies consist of a supermassive black hole
- Feeding and feedback processes of gases in the nuclear region translate to the accretion and jet/wind scenarios

Low-luminosity AGNs:

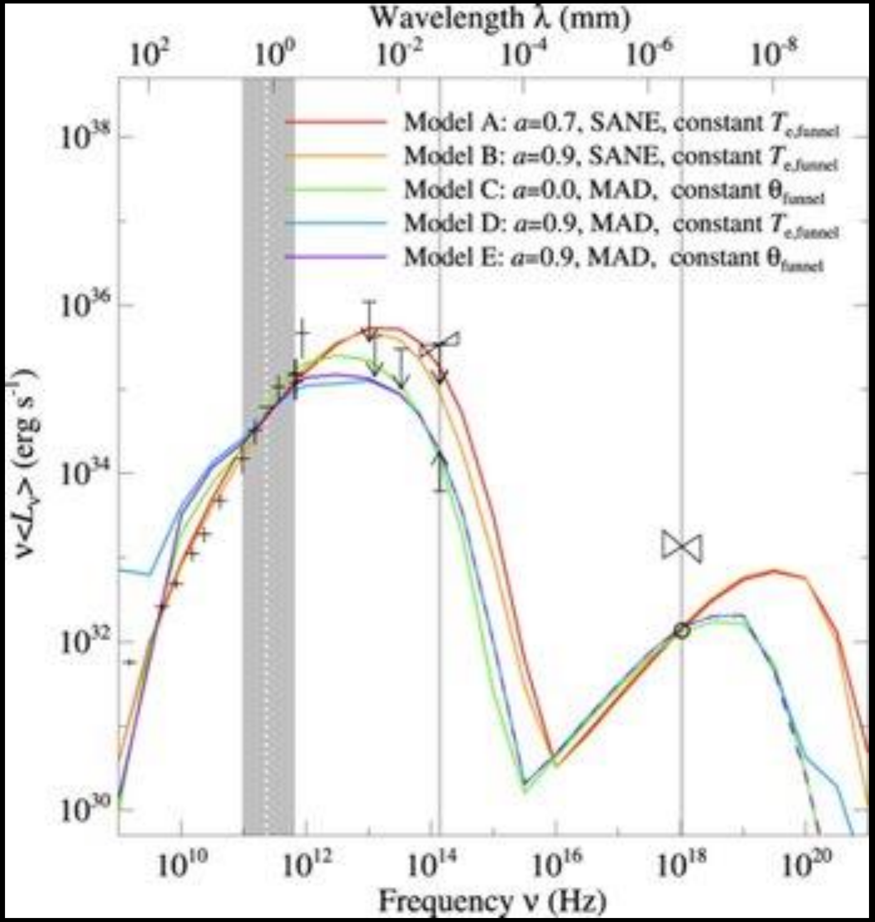
- Those with low nuclear accretion rates: 10^{-8} L_{Edd}
- Lower ratio of radiated energy to accretion mass, <10% associated to most radio-loud AGNs
- Incentive to advection and convection-dominated accretion models

ADAF / Standard-disk models

	ADAF	Standard-disk
opacity	thin	thick
geometry	thick	thin
Radiative efficiency	low	high
temperature	High as prescribed by ion & electron temperature profiles	low

Sagittarius A*

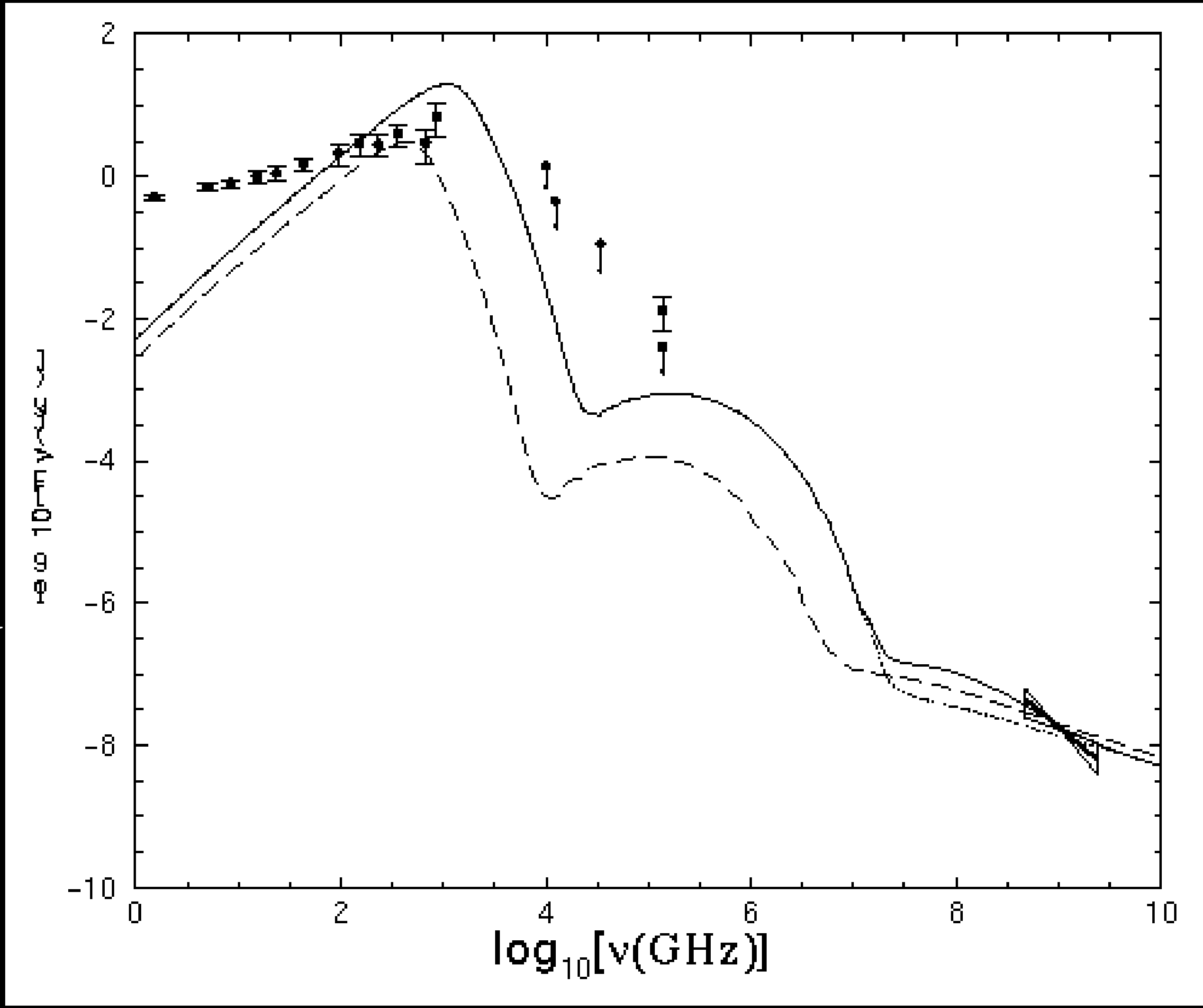
- Supermassive black hole ~ 4 x 10^6
- Radio spectrum consists of a low-frequency power-law and a submm bump
- Luminosity ~10^{-9} L_{Edd}
- A low radio efficiency ~10^{-6}



Credit: Chan+ 2015

Sagittarius A*

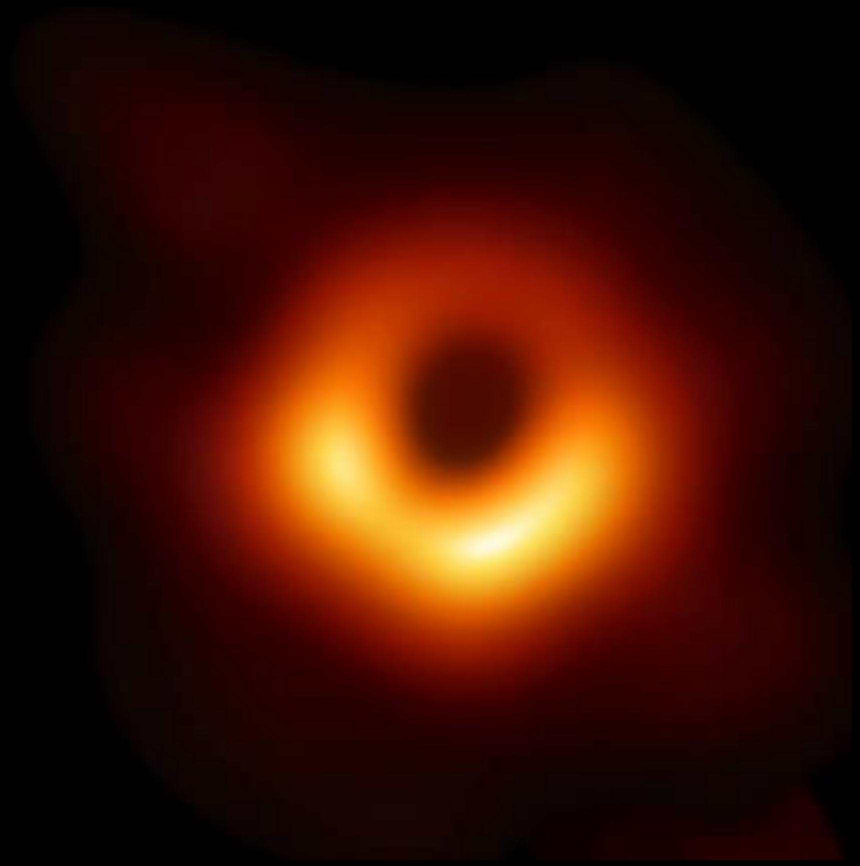
- Supermassive black hole ~ 4 x 10^6
- Radio spectrum consists of a low-frequency power-law and a submm bump
- Luminosity ~10^{-9} $L_{\rm Edd}$
- A low radio efficiency ~10^{-6}
- ADAF model with different viscosity parameters that dictates the angular momentum
- Requires additional component to model the low-frequency radio component



Credit: Yuan+ 2002

M87

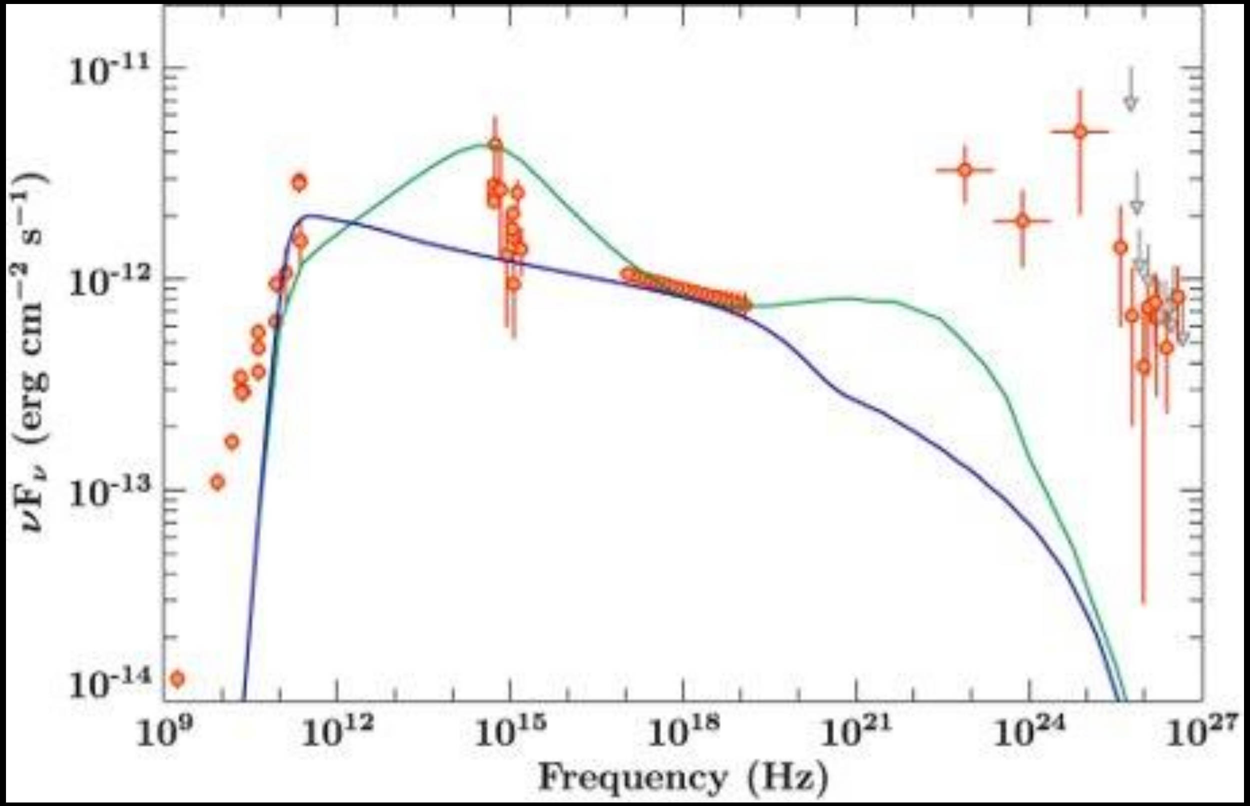
- Supermassive black hole: 6.5×10^9
- Diameter of the crescent: 42 micro-arcsec
- Accretion rate: $\sim 1.4 \times 10^{-6}$
- Jet power: $2.3\text{-}8.8 \times 10^{42}$ erg/s



Credit: EHT Collaboration 2019

M87

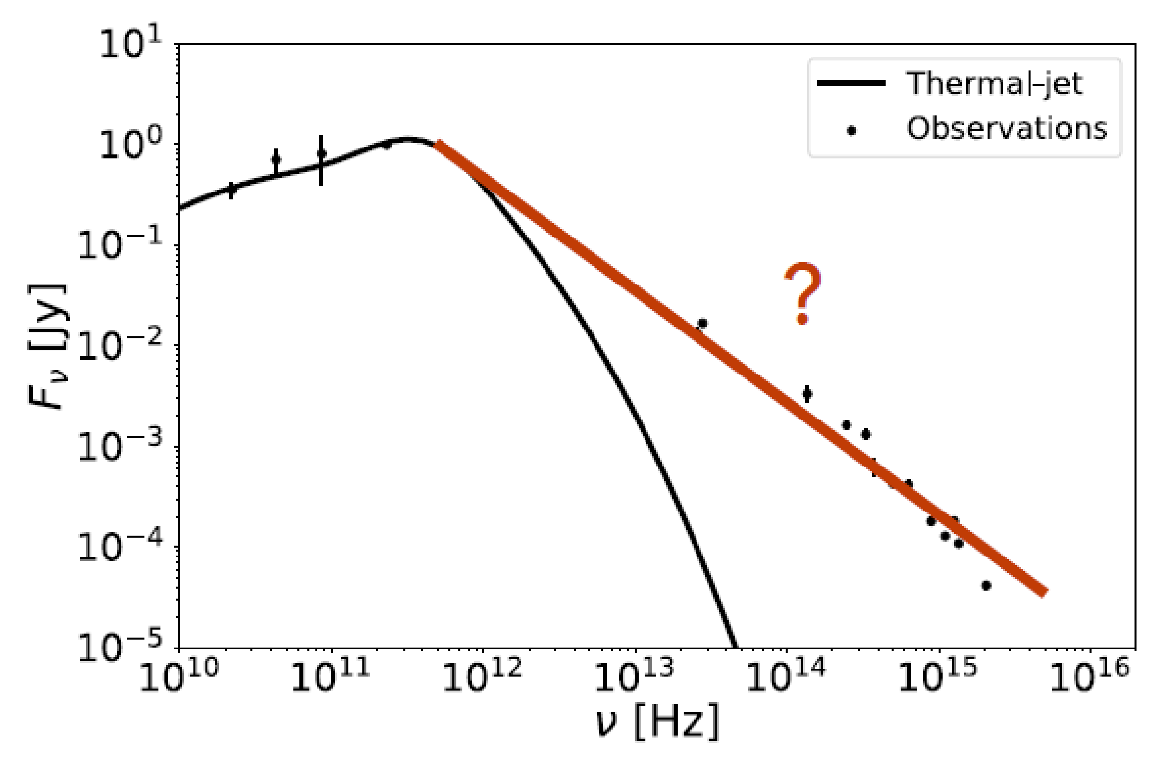
- Nature of the broadband SED cannot be constrained by a single-zone model
- The jet power and magnetic field at the base of the jet cannot be reconciled with the existing models



Credit: EHT Collaboration 2021

Electron distribution function (eDF)

- Current models consider electrons in thermal distribution
- NIR and optical observations prefer power-law that are not adequately modelled by the thermal distribution



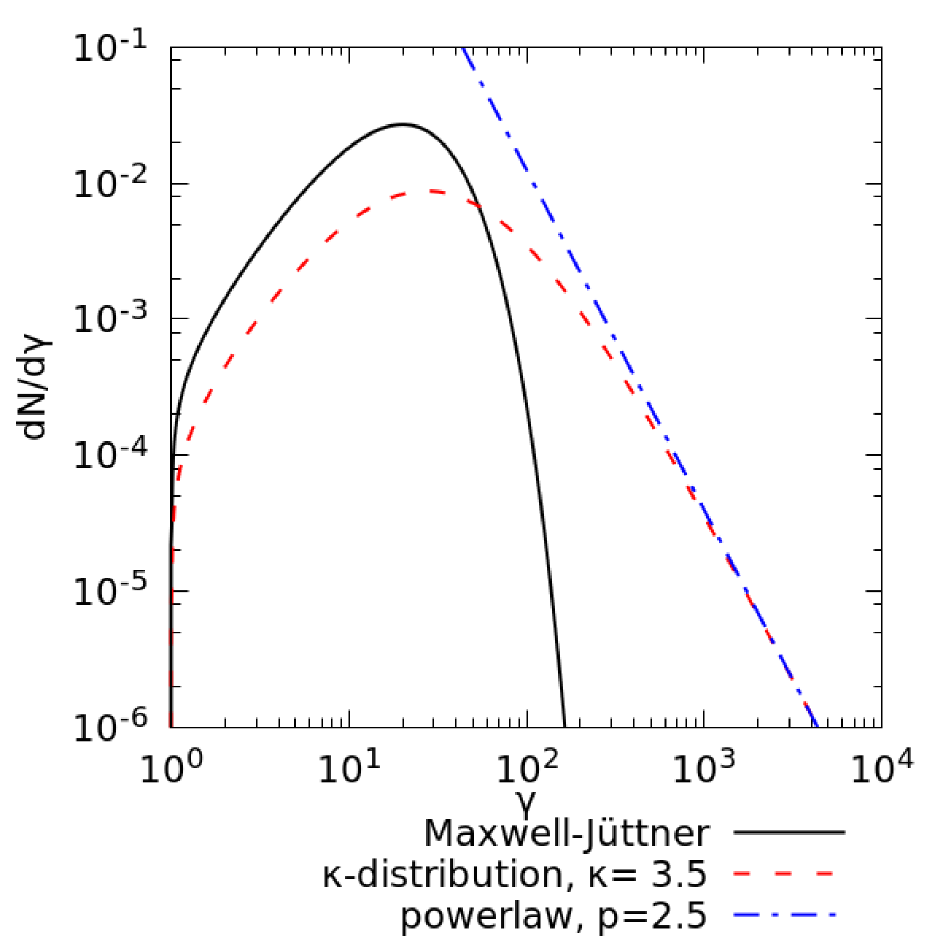
Credit: Davelaar+ 2019

kappa-distribution function

- Combination of thermal and k-distributed electron population.

$$\frac{dn_e}{d\gamma} = N\gamma\sqrt{\gamma^2 - 1}\left(1 + \frac{\gamma - 1}{\kappa w}\right)^{-(\kappa+1)}$$

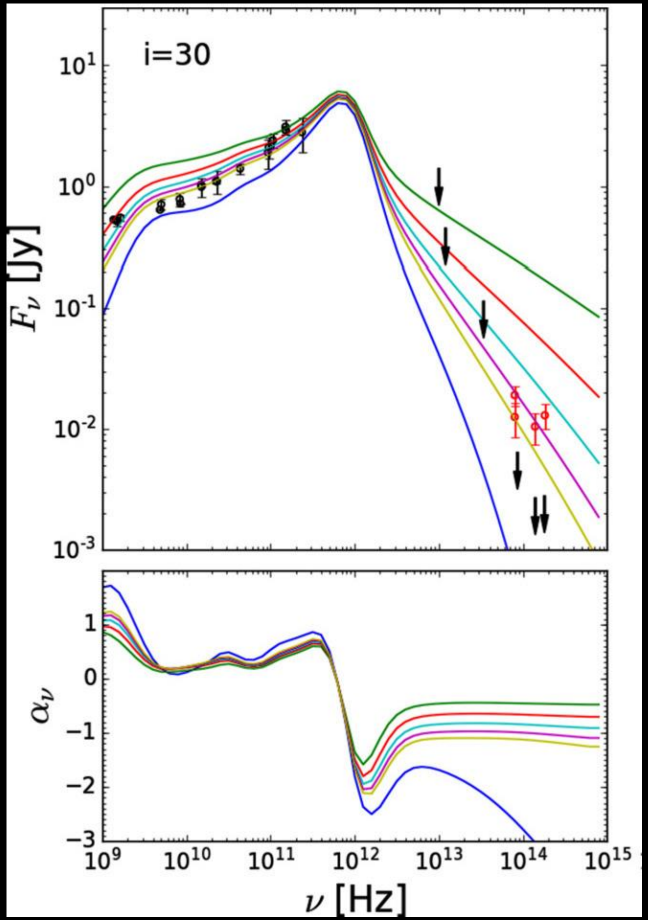
- eDF of accretion disk in thermal distribution; a combination of thermal and k-distributed electrons for the jet



Credit: Davelaar+ 2019

eDF in SgrA*

- Better approximation of the spectrum by kappa-distribution (colours of varying exponents) over the thermal one (blue)
- Size of radio-emitting region, flux and spectral-index increase with decreasing values of kappa suggesting a larger amount of accelerated electrons
- About 5 – 10% of electrons are accelerated in jet during flares



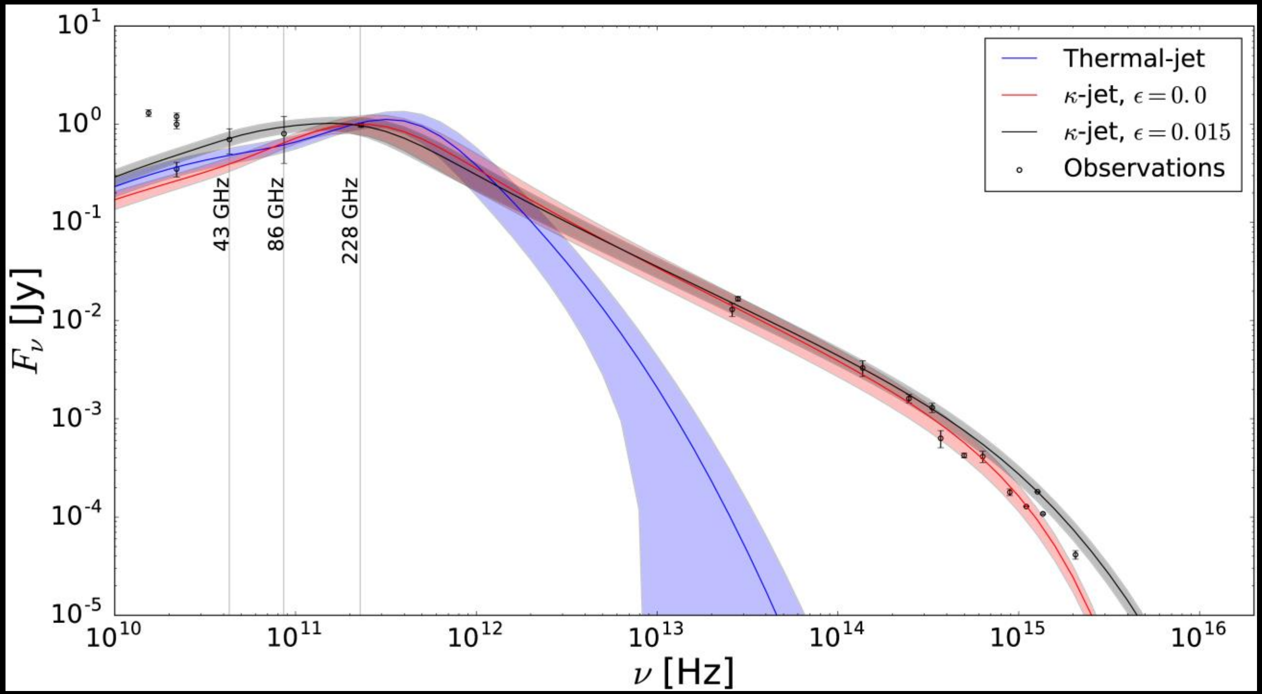
Credit: Davelaar+ 2018

eDF in M87

- kappa-models reproduce the radio to optical spectra very well

	43 GHz	86 GHz	228 GHz
Thermal-jet	8.3 ± 2.2	2.3 ± 0.6	0.4 ± 0.1
κ-jet, $\epsilon = 0.0$	2.6 ± 0.7	0.9 ± 0.2	0.3 ± 0.09
κ-jet, $\epsilon = 0.015$	2.6 ± 0.7	1.1 ± 0.3	0.5 ± 0.2

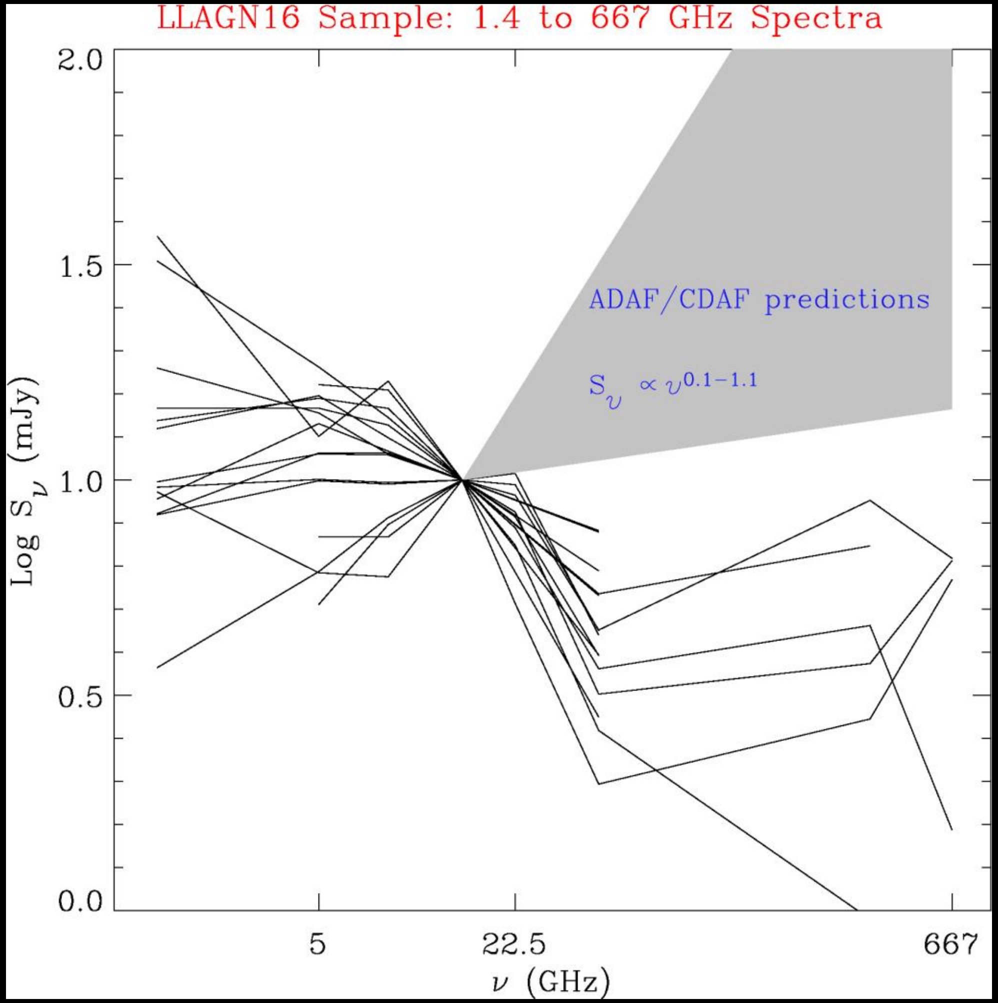
- Significance of the models are reflected in the forward jet-to-counterjet ratios



Credit: Davelaar+ 2019

Current state of other LLAGNs

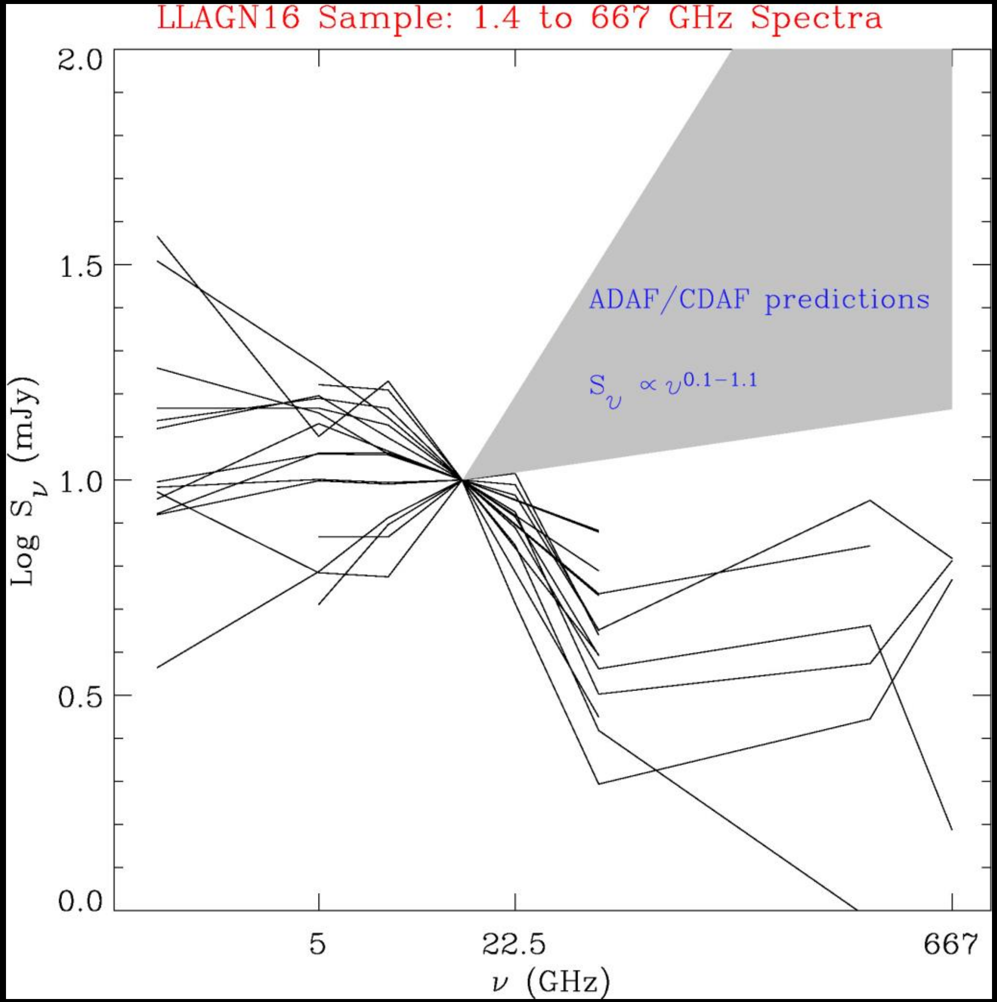
- LLAGNs show several properties analogous to gigahertz-peaked spectrum sources:
- there is some evidence for a peak in the 1–20 GHz range. This peak could be at lower frequencies for LLAGNs with extended emission and is higher for LLAGNs with the most compact radio emission



Ramakrishnan+ (in prep)

Current state of other LLAGNs

- milli-arcsec resolution radio imaging often shows a “core-jet” or symmetric parsec-scale jets
- Some AGNs have sub-pc scale radio jet and spectral peaks in the 5–10 GHz range. They thus extend the relationship between linear size and turnover frequency in GPSs and Compact Steep Spectrum Sources to higher frequencies



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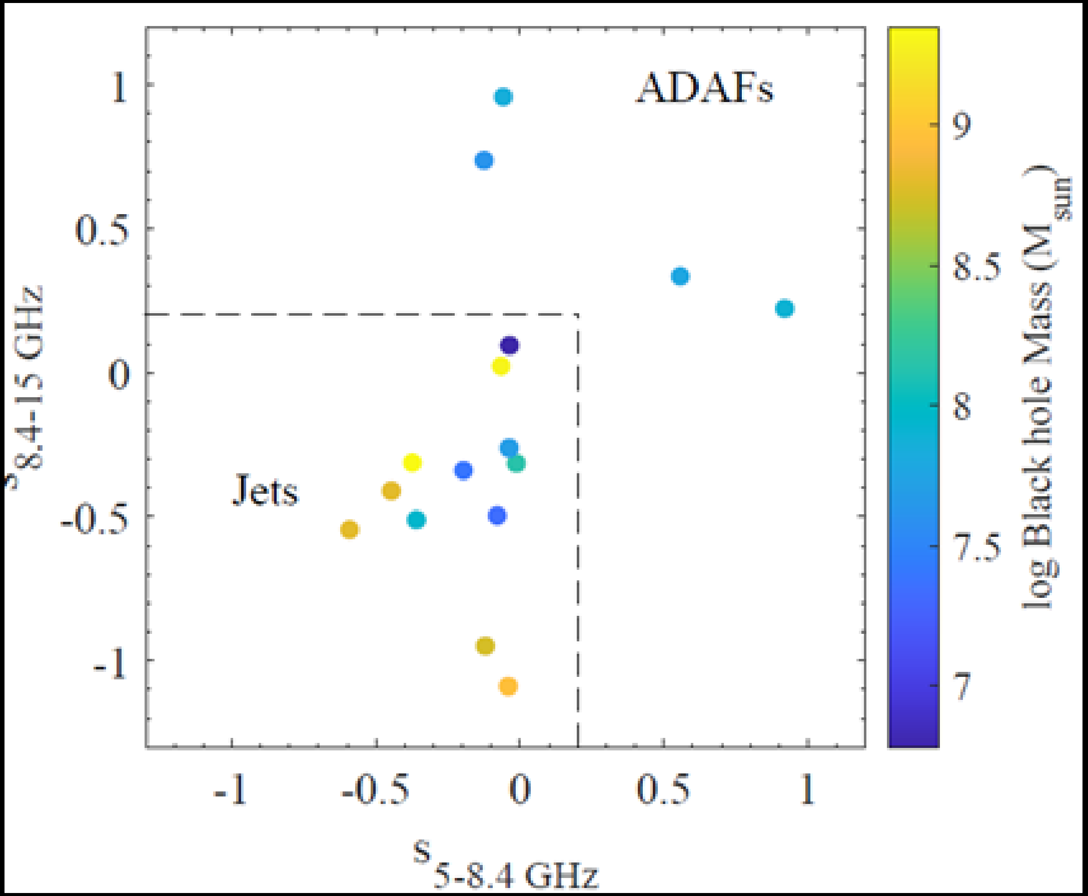
Current state of other LLAGNs

- Spectral index at 5 – 8.4 GHz versus those at 8.4 – 15 GHz with colour coded black hole masses of LLAGNs.
- The result shows the observed flat spectrum for the sample to be unlikely caused by higher accretion rates as compared to elliptical galaxies.
- The possible explanation for this trend is the non-thermal electrons within the ADAF.
- This and many questions still pose a great challenge in delineating the accretion and jet properties of galaxies



Credit: Nagar+ 2005

Future implications to EHT observations

- A more consistent study of the radio spectrum of a large sample of AGNs is required
- Observations at different spatial resolutions are particularly useful at radio frequencies to constrain the effect of jet
- More dedicated modelling of the spectra driven by GRMHD and ray tracing algorithms will provide stringent constraints on the particle acceleration processes in the accretion disk and jet of these galaxies

Future implications to EHT observations

- VLBI observations at multiple frequencies complemented by the images rendered by the eDF studies are vital to enhance our understanding of General Relativity
- Characterising the turnover frequency and spectral index in LLAGNs can help us understand the missing synchrotron flux for billion-mass black holes