

Jetted AGN at TeV: slopes, peaks and valleys from MHz to PeV

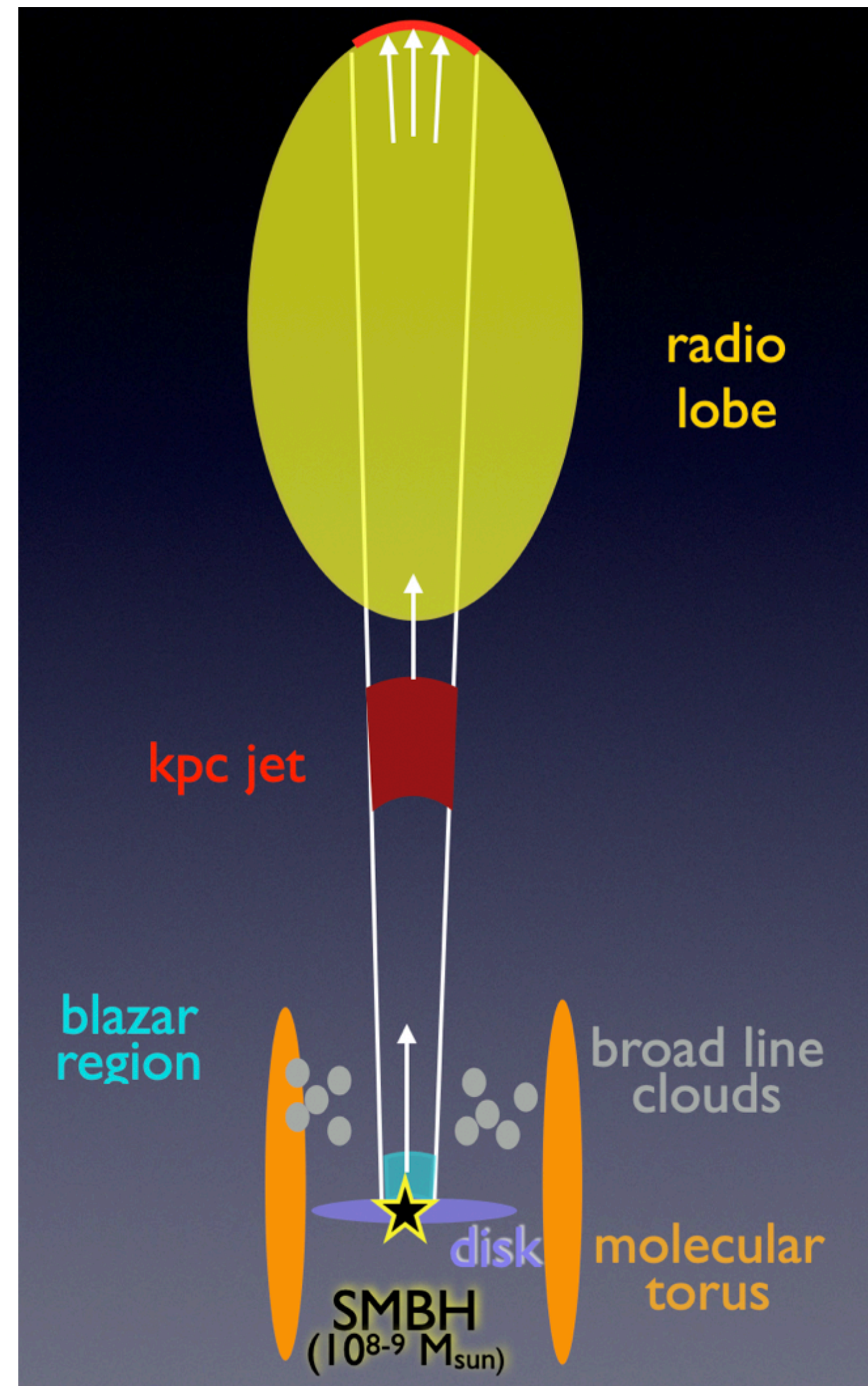
Giulia Migliori
INAF-IRA



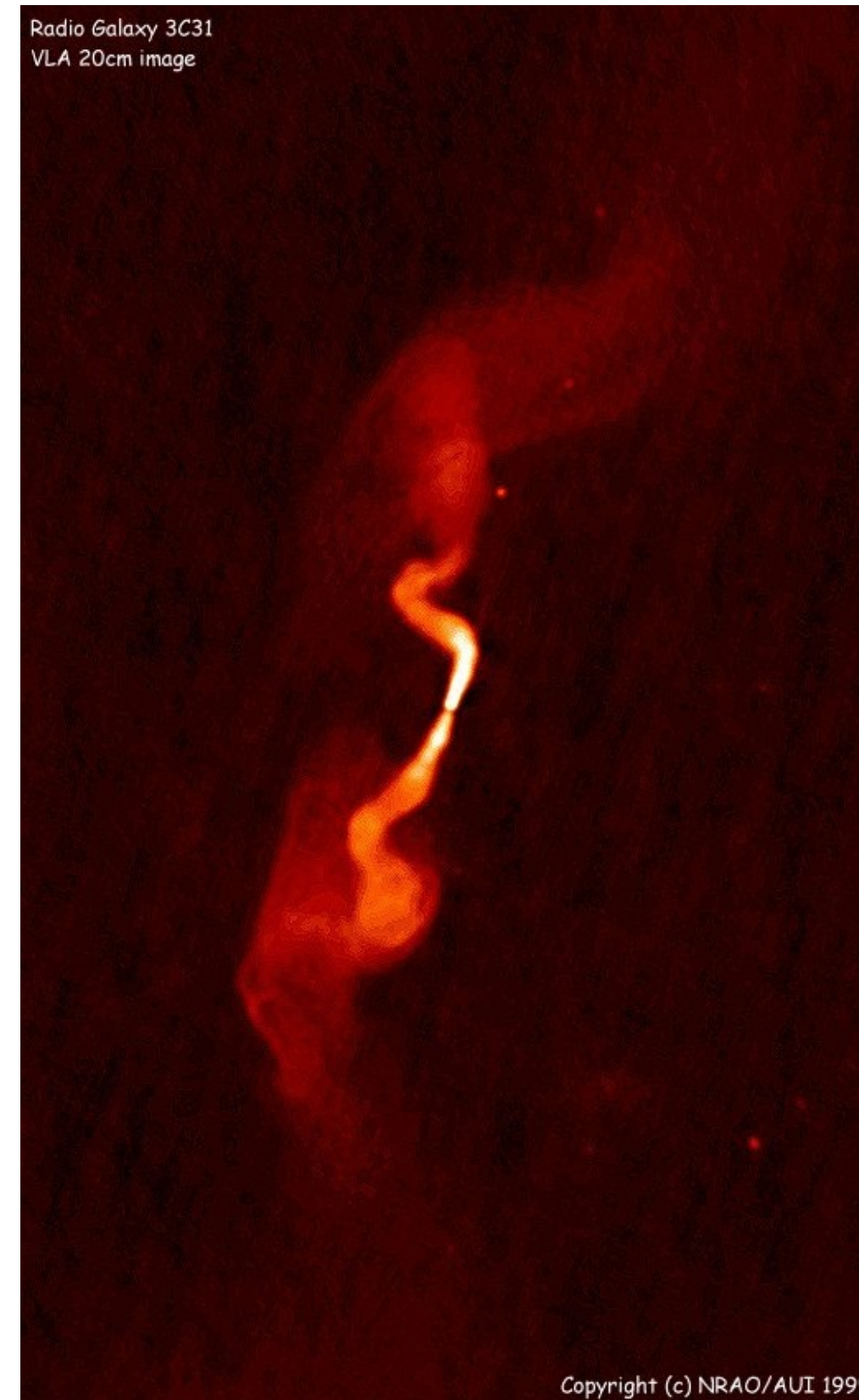
Outline

- Jets in AGN
- The power of synergies
 - Blazars
 - Misaligned AGN
 - Radio galaxies at TeV
 - New classes LLAGN & compact sources
- Conclusions & future

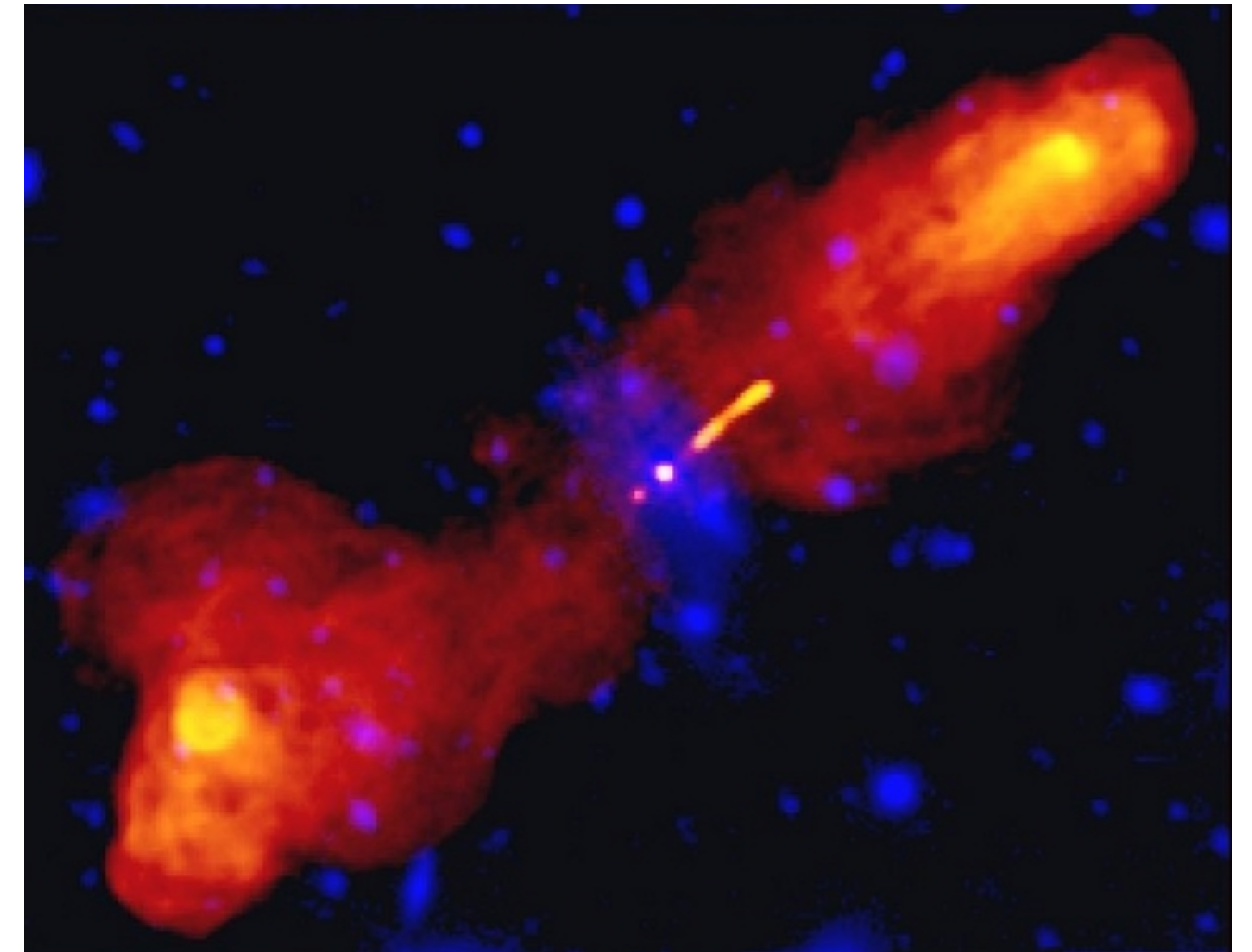
Jets in AGN



Radio view:



Low power

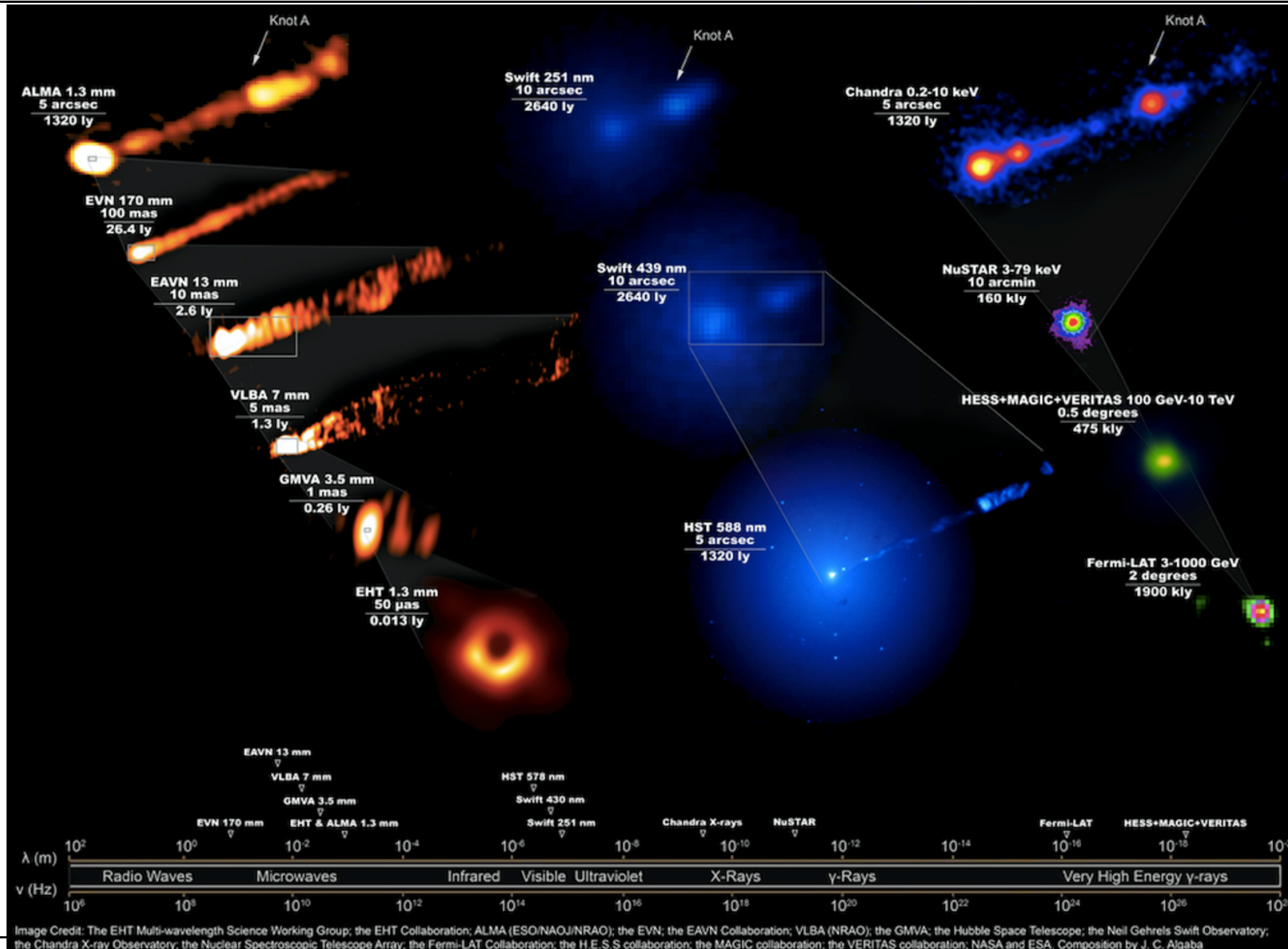


High power

$$P_{178\text{MHz}} \sim 10^{25} \text{ Watt Hz}^{-1} \text{ sr}^{-1}$$

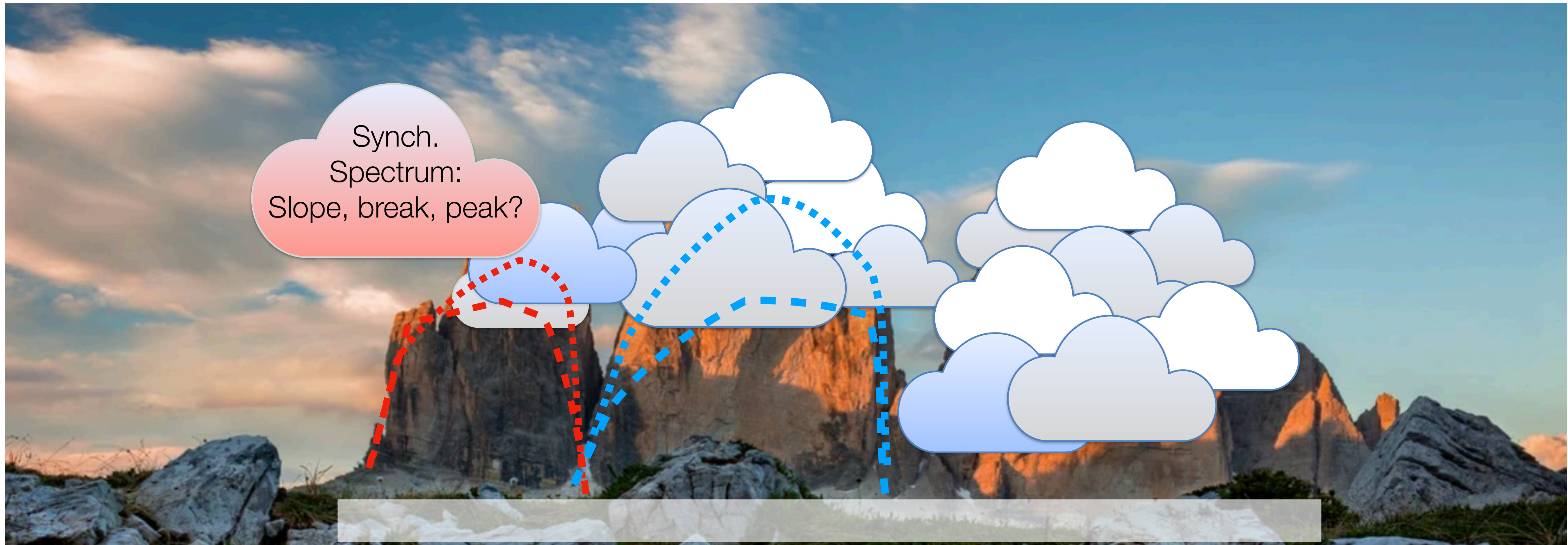
Jets in AGN

A multi-scale and multi-wavelength phenomenon



Jets in AGN

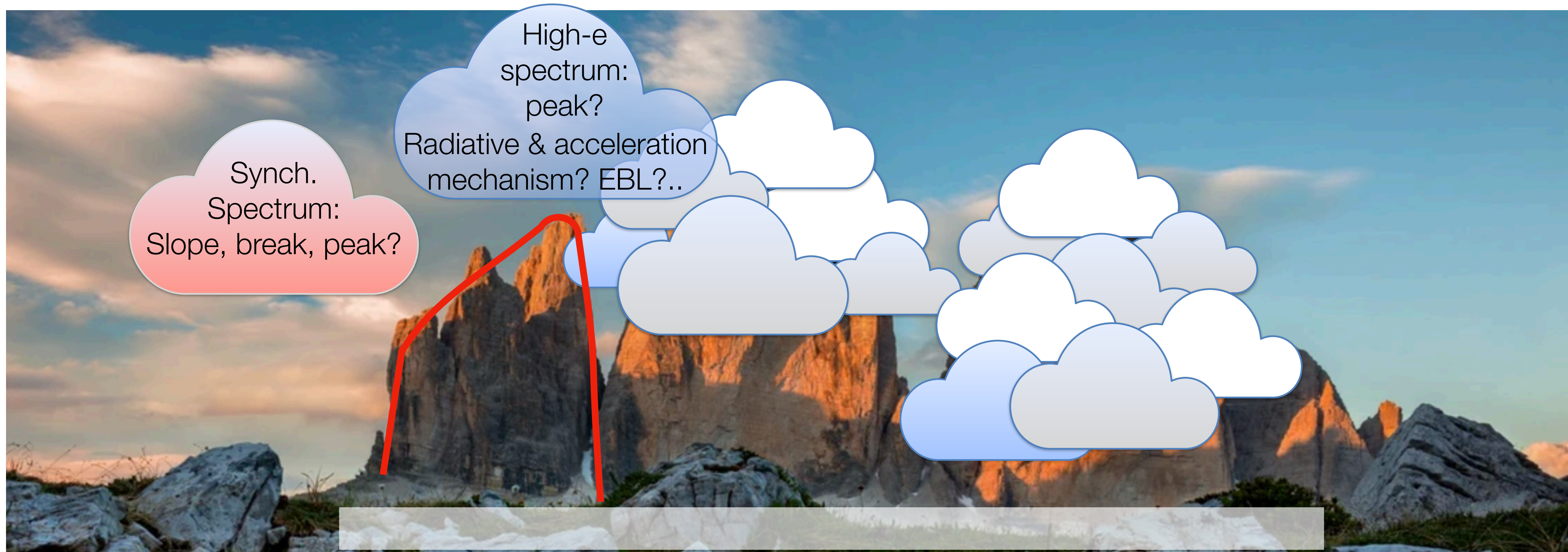
A broadband radiative output



A multi-wavelength approach is needed to address the main open questions

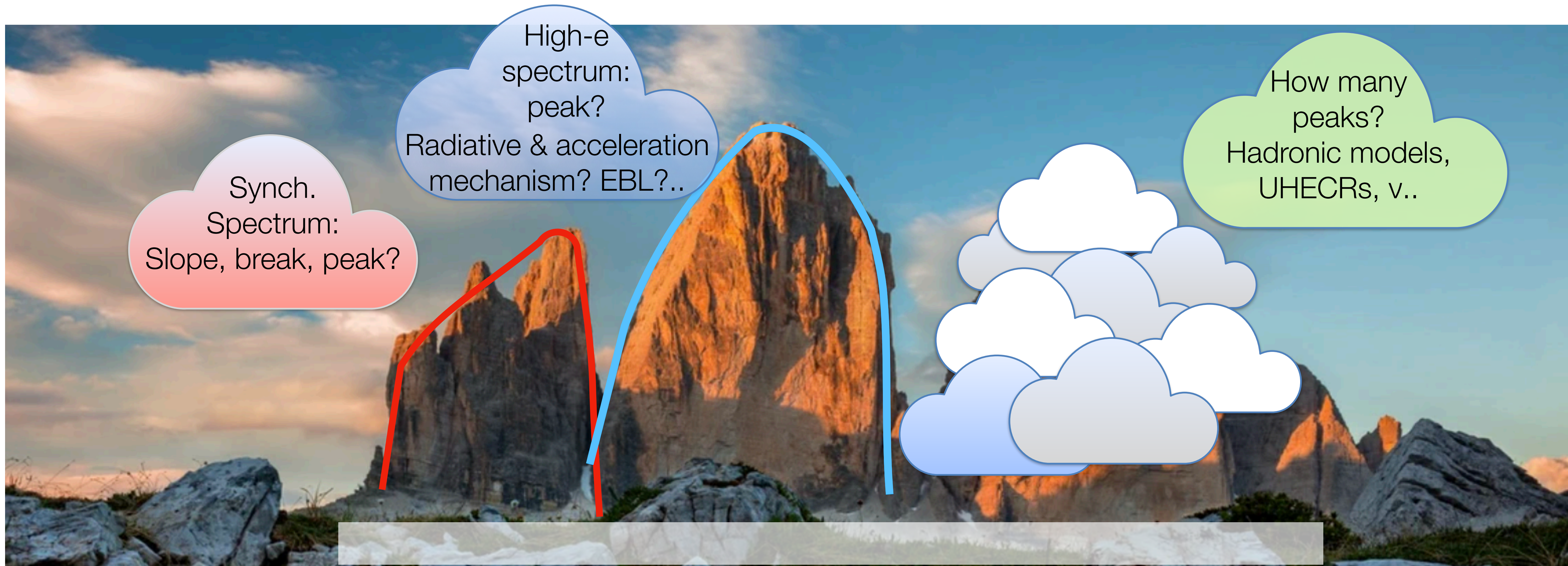
Jets in AGN: MW view

A broadband radiative output



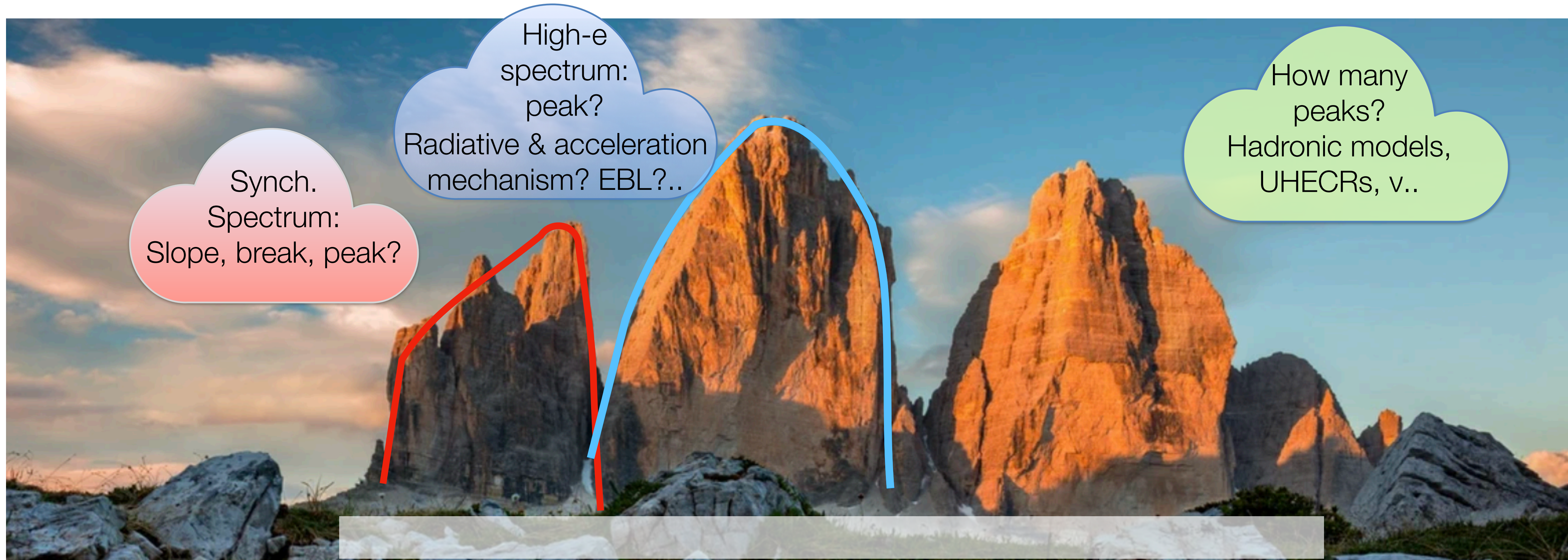
Jets in AGN: MW view

A broadband radiative output



Jets in AGN: MW & MM view

A broadband radiative output



A multi-wavelength & multi-messenger approach is needed to address the main open questions

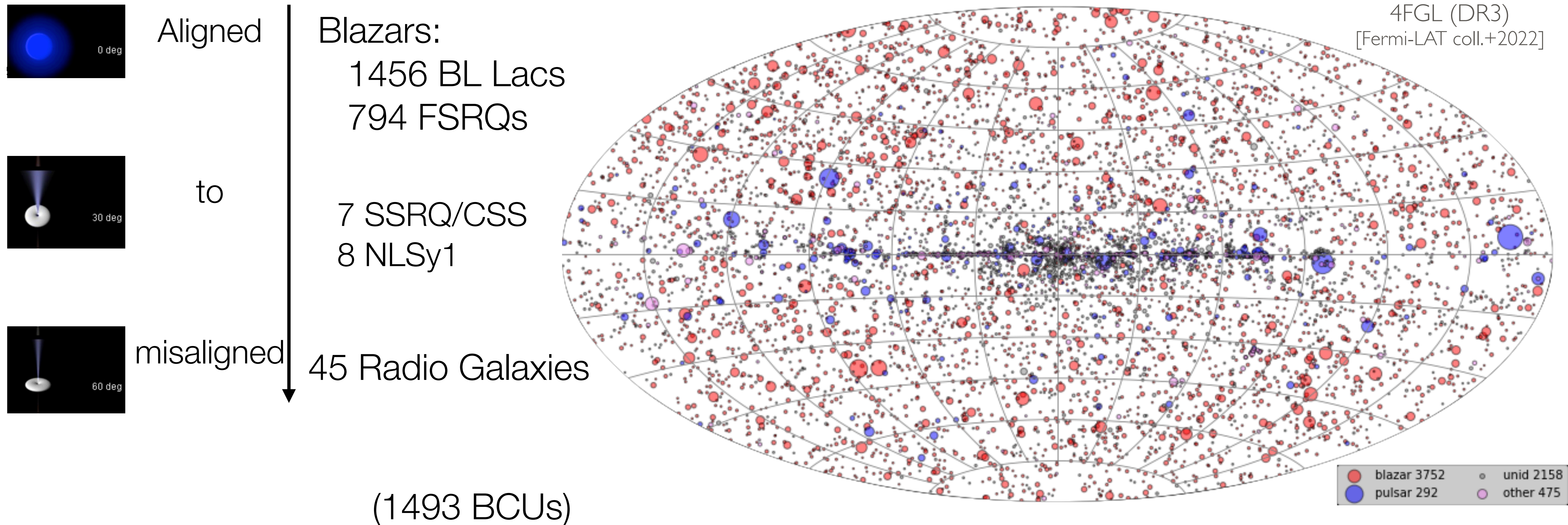
Jets in AGN



New physics..
or..
too many schnapps

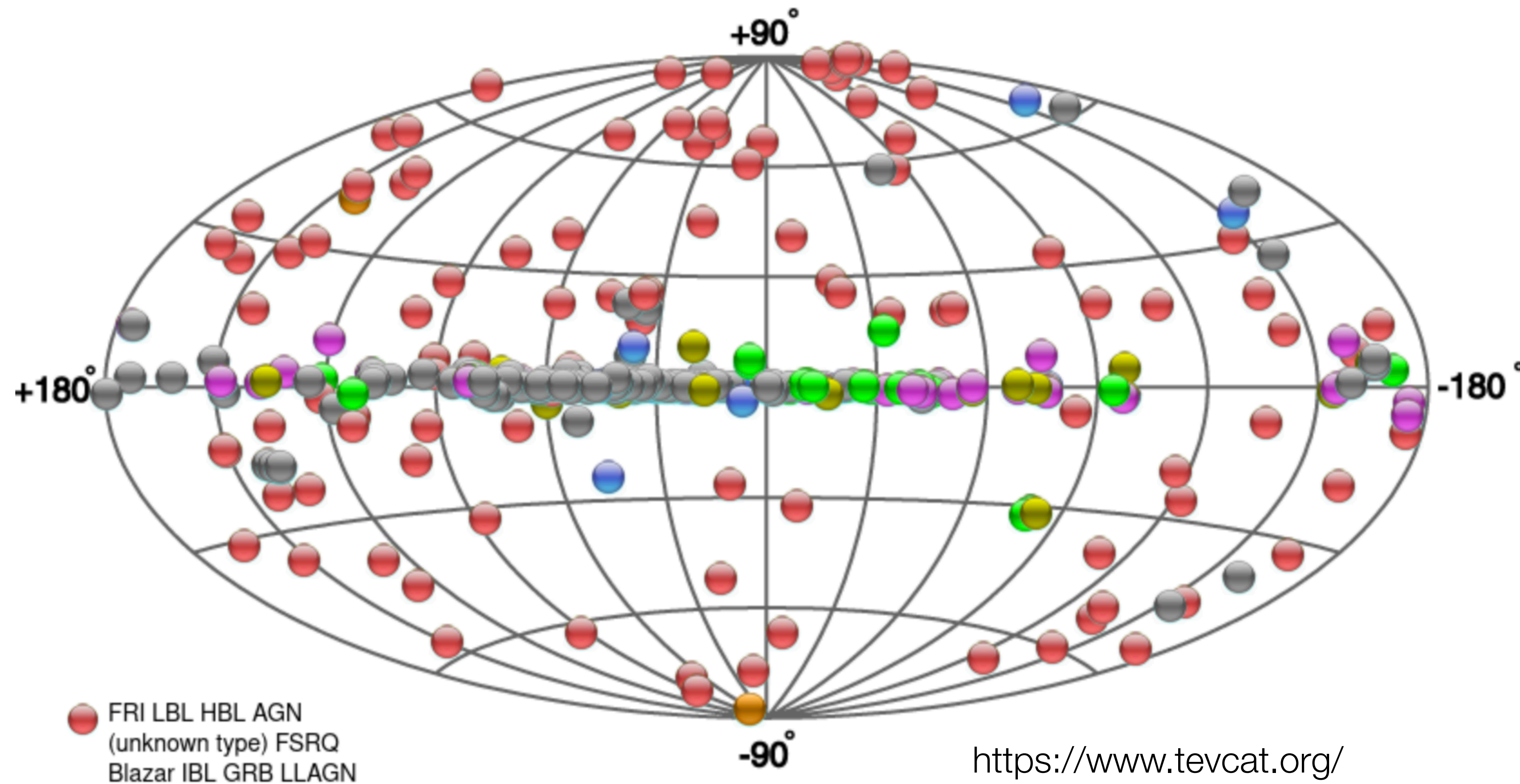
Jets in AGN: GeV-TeV observations

Jetted AGN seen by Fermi-LAT:



Jets in AGN: GeV-TeV observations

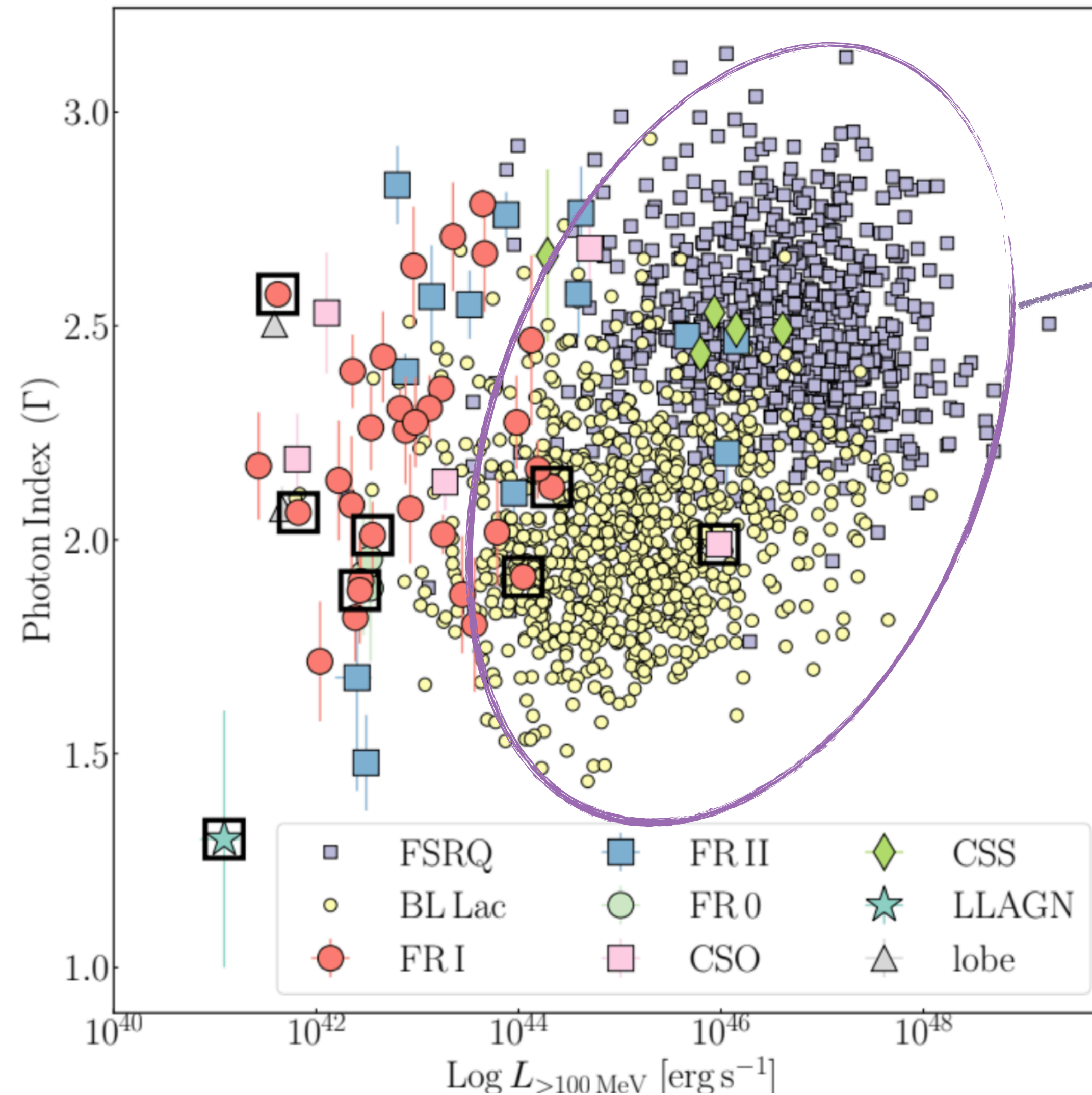
Jetted AGN at TeV:



Aligned Jets - Blazars:
73 BL Lacs
12 FSRQs

Misaligned Jets:
5 RGs
2 AGN (unknown type)
1 LLAGN

Jets in AGN: GeV-TeV observations



Aligned jets:
Detection favored by
relativistic effects
↓
well-represented in early/
core science programs
(talks Vercellone, Carosi, Zech)

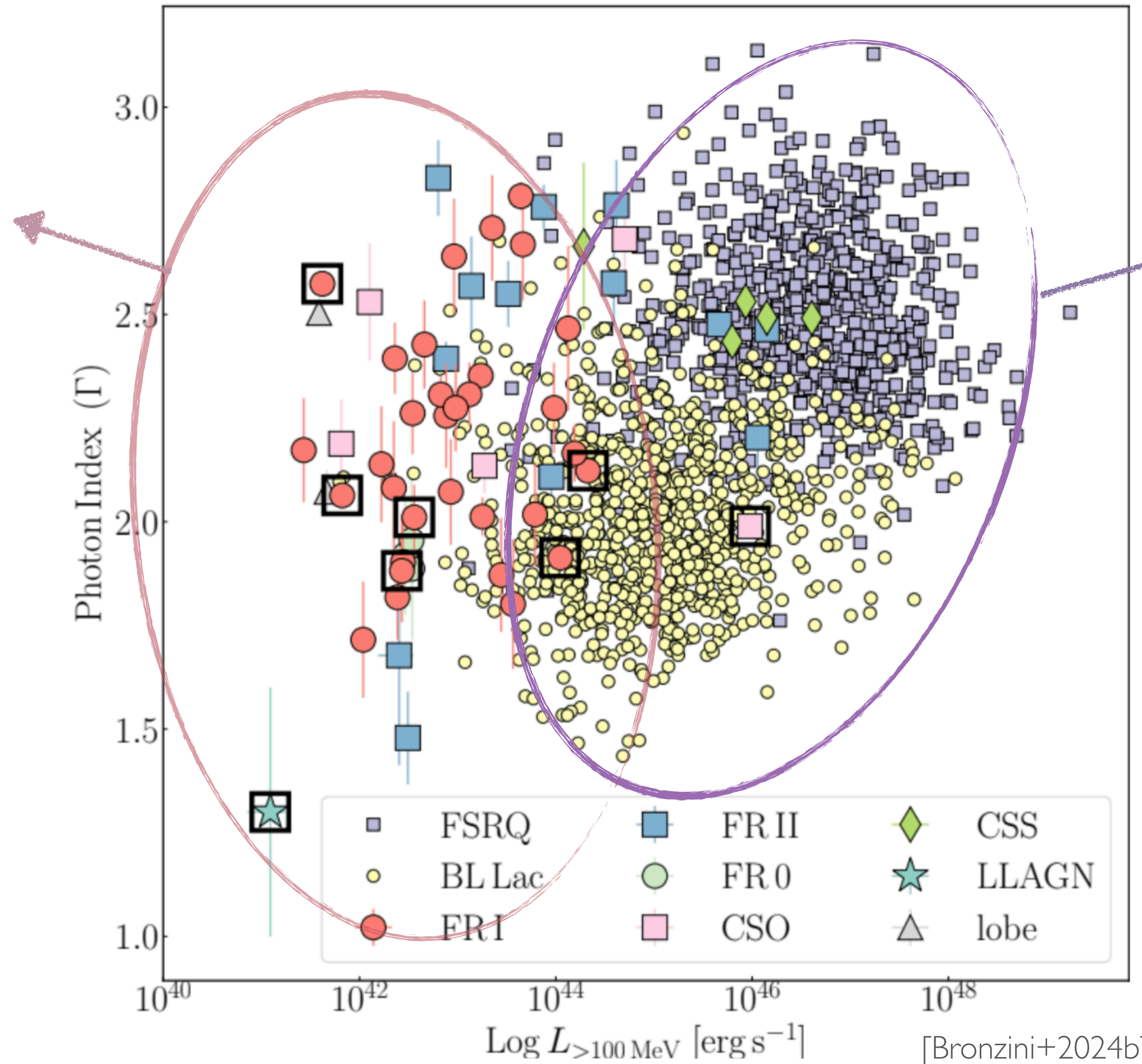
Jets in AGN: GeV-TeV observations

Misaligned jets:
more challenging



but rising
and rewarding!

[see the SKA WB chapter on
 γ -ray RG, Bruni+2026]



Aligned jets:
Detection favored by
relativistic effects

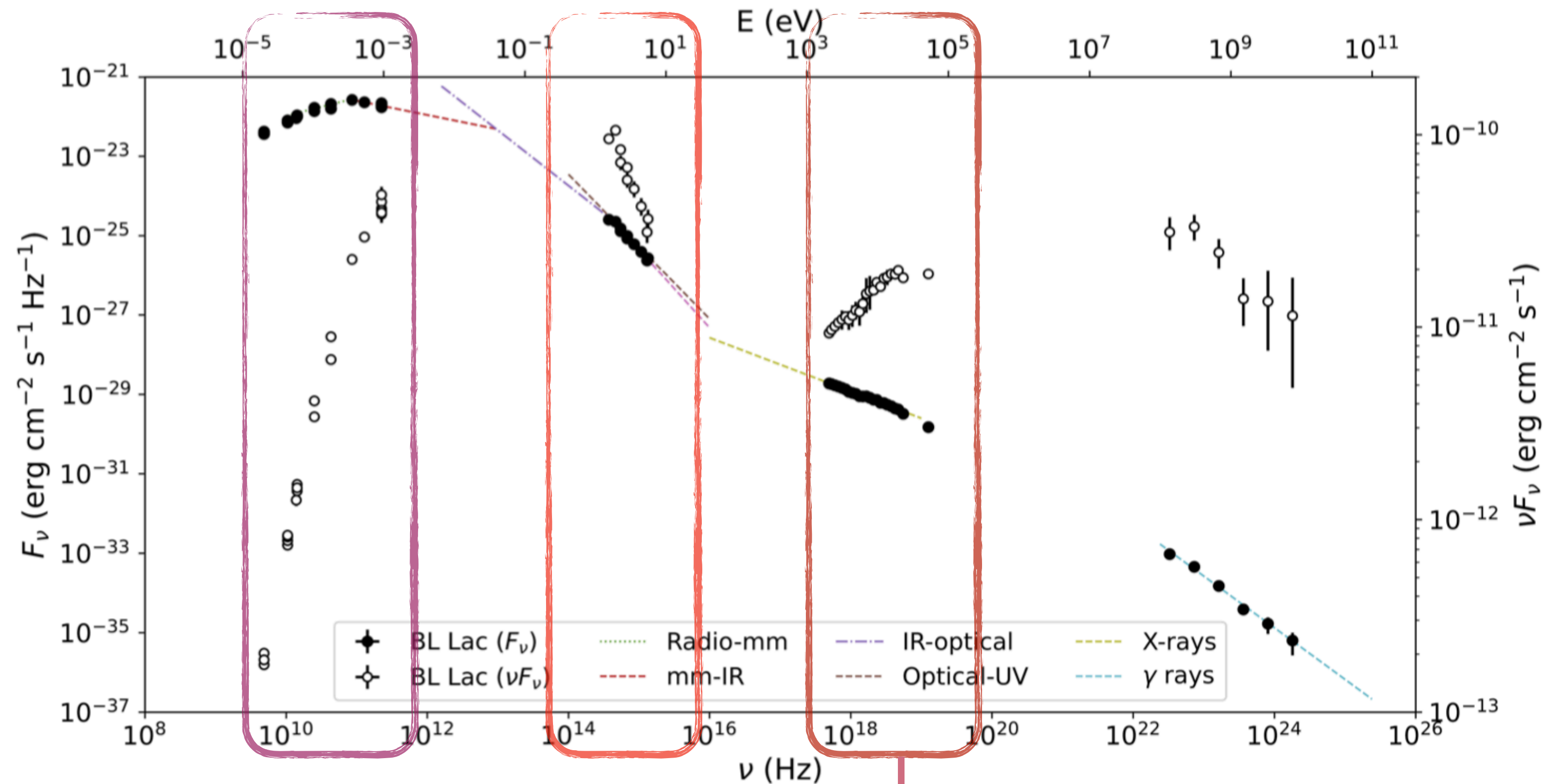


well-represented in early/
core science programs
(talks: Vercellone, Carosi, Zech)

Synergies - aligned jets

MW polarization:

BL Lac mw campaign [Agudo+2025]:

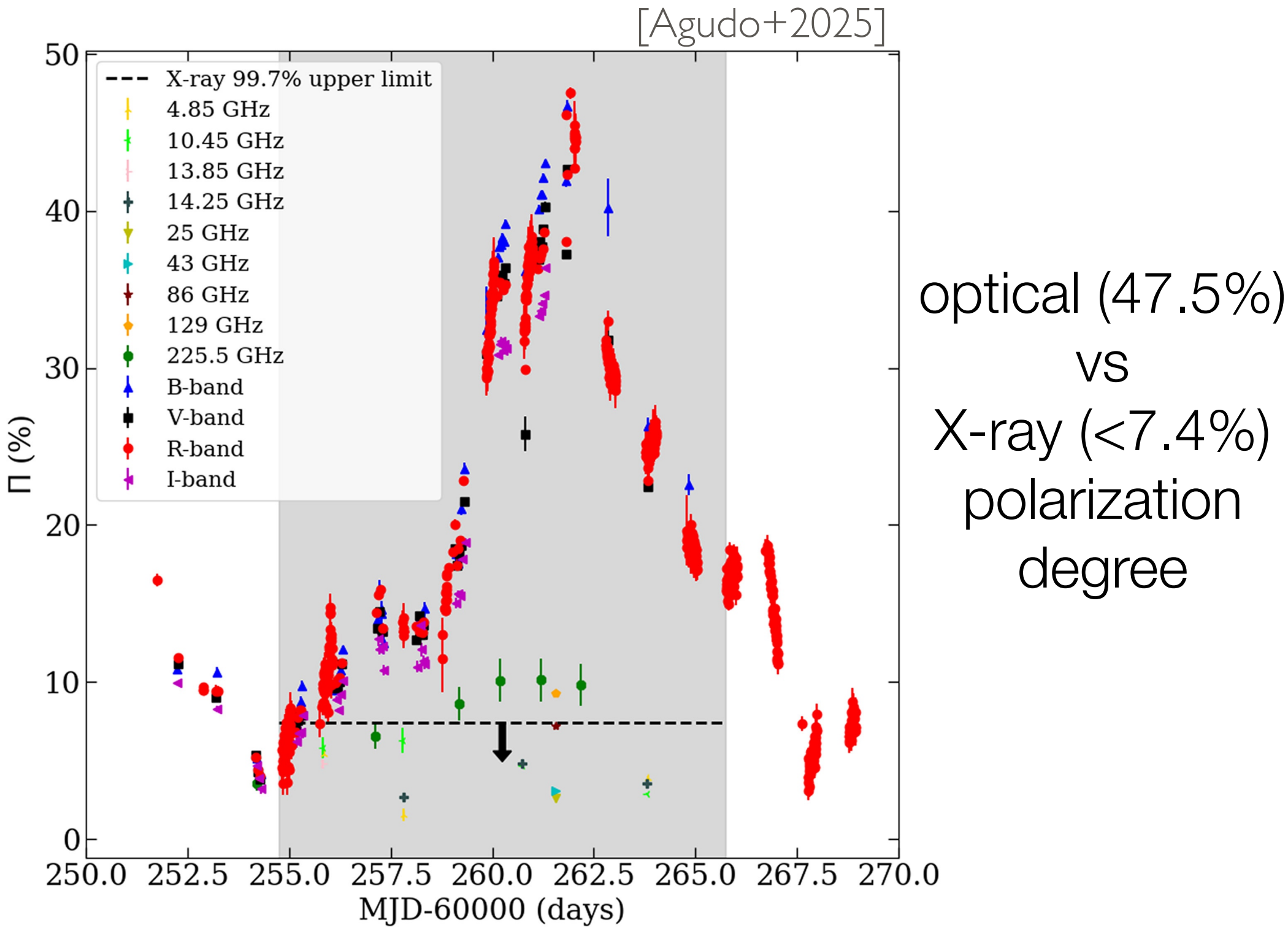


X-ray window opened up by IXPE

Synergies - aligned jets

- Model predictions of different mw polarimetric behaviour:

Model	X-Ray Polarization Degree	X-Ray Polarization Variability
Single-zone leptonic (EC)	Unpolarized	...
Single-zone leptonic (SSC)	$0.5 \times \Pi_O$	Similar to optical
Energy-stratified/multizone leptonic (SSC)	$\leq 0.3 \times \Pi_O$	Similar to millimeter
Single-zone hadronic	$\approx \Pi_O$	Less variable than optical
Energy-stratified/multizone hadronic (flare)	$\approx \Pi_O$	Less variable than optical
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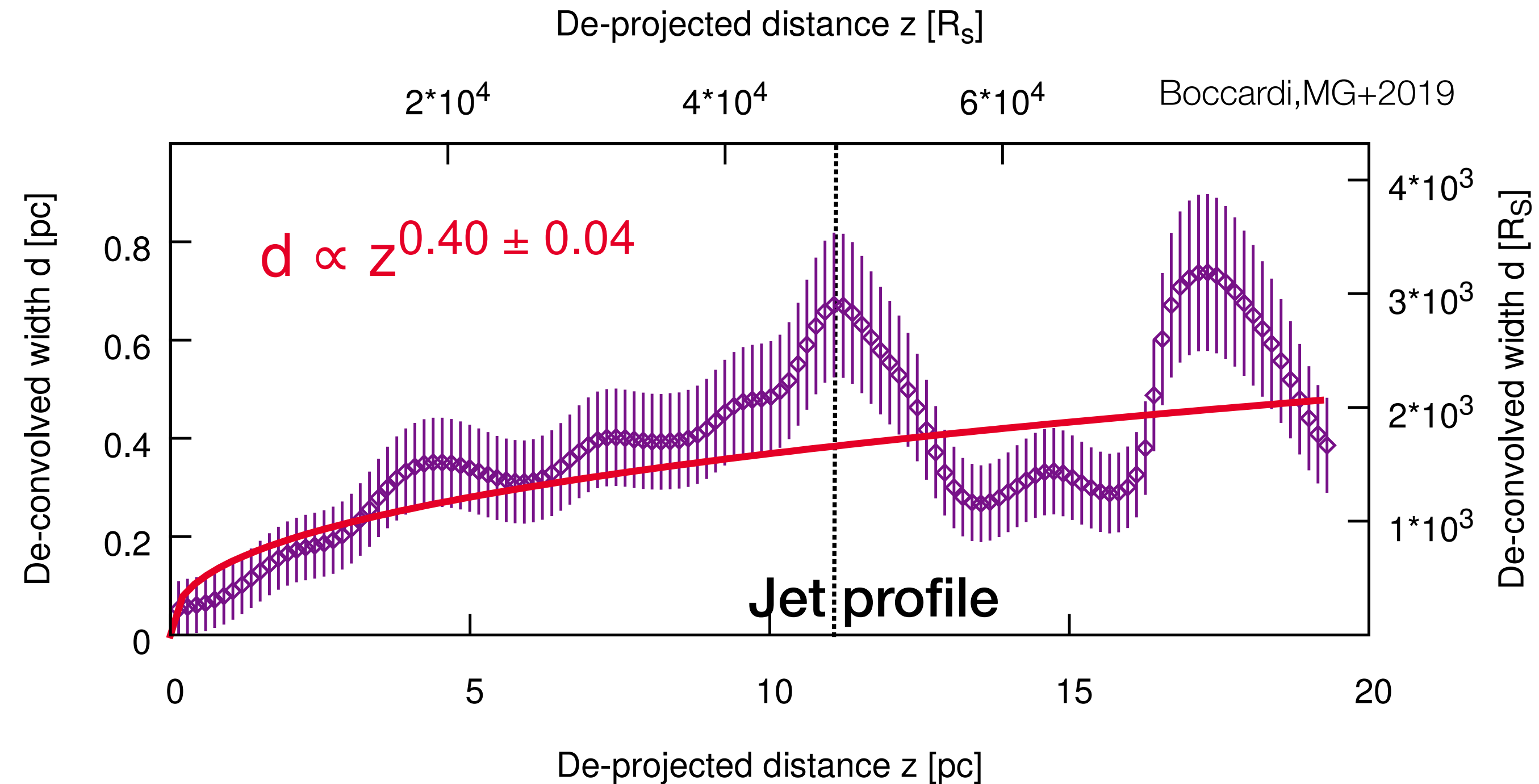
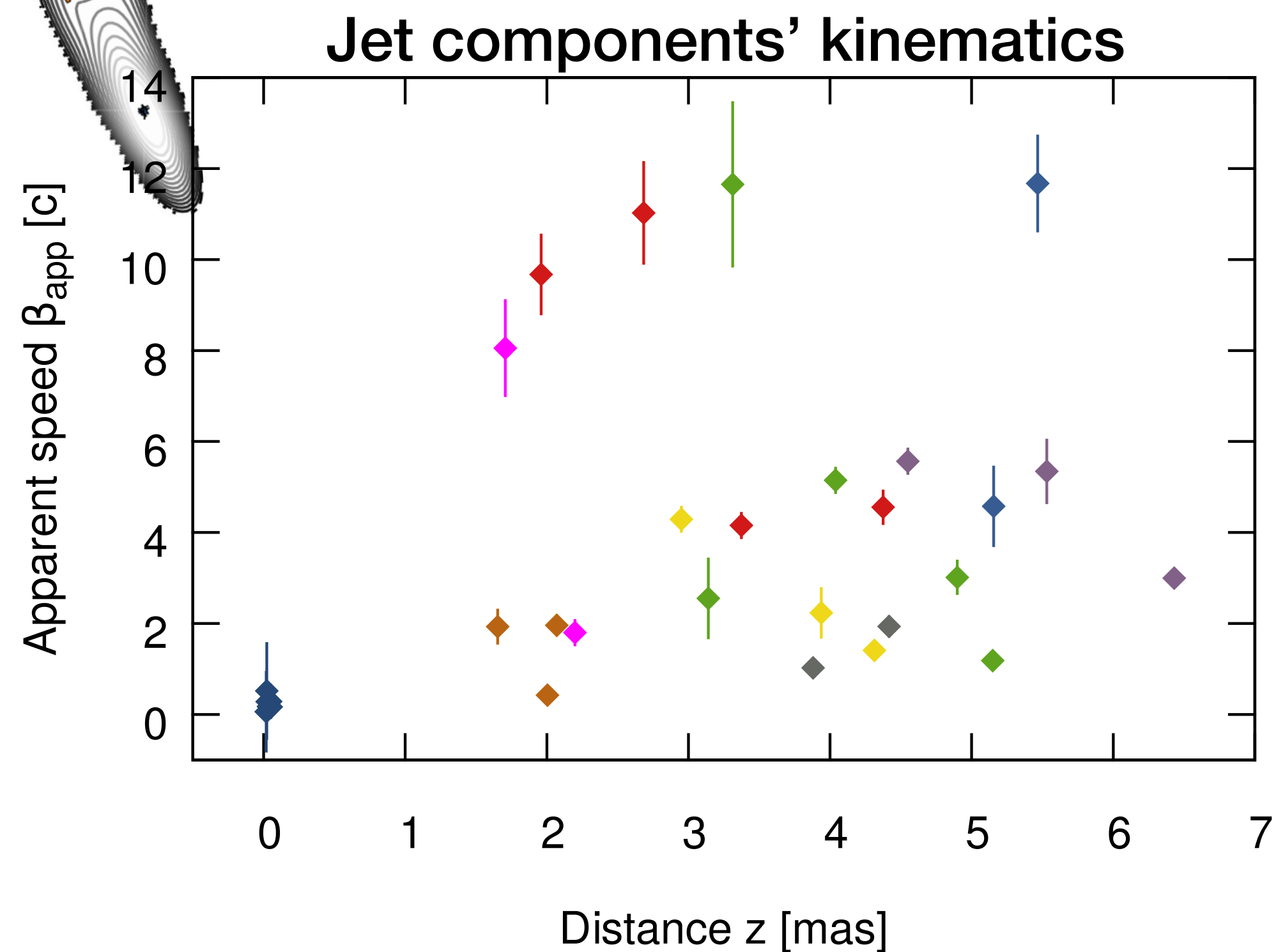
Support to leptonic (IC) models?

(but see e.g. Tavecchio+2025 and
Wednesday sessions for assumptions &
hadronic models)

Synergies - misaligned jets

Probing the connection between the jet structure & dynamics and VHE emission

VLBI mapping of the jet of the TeV-detected radio galaxy 3C 264

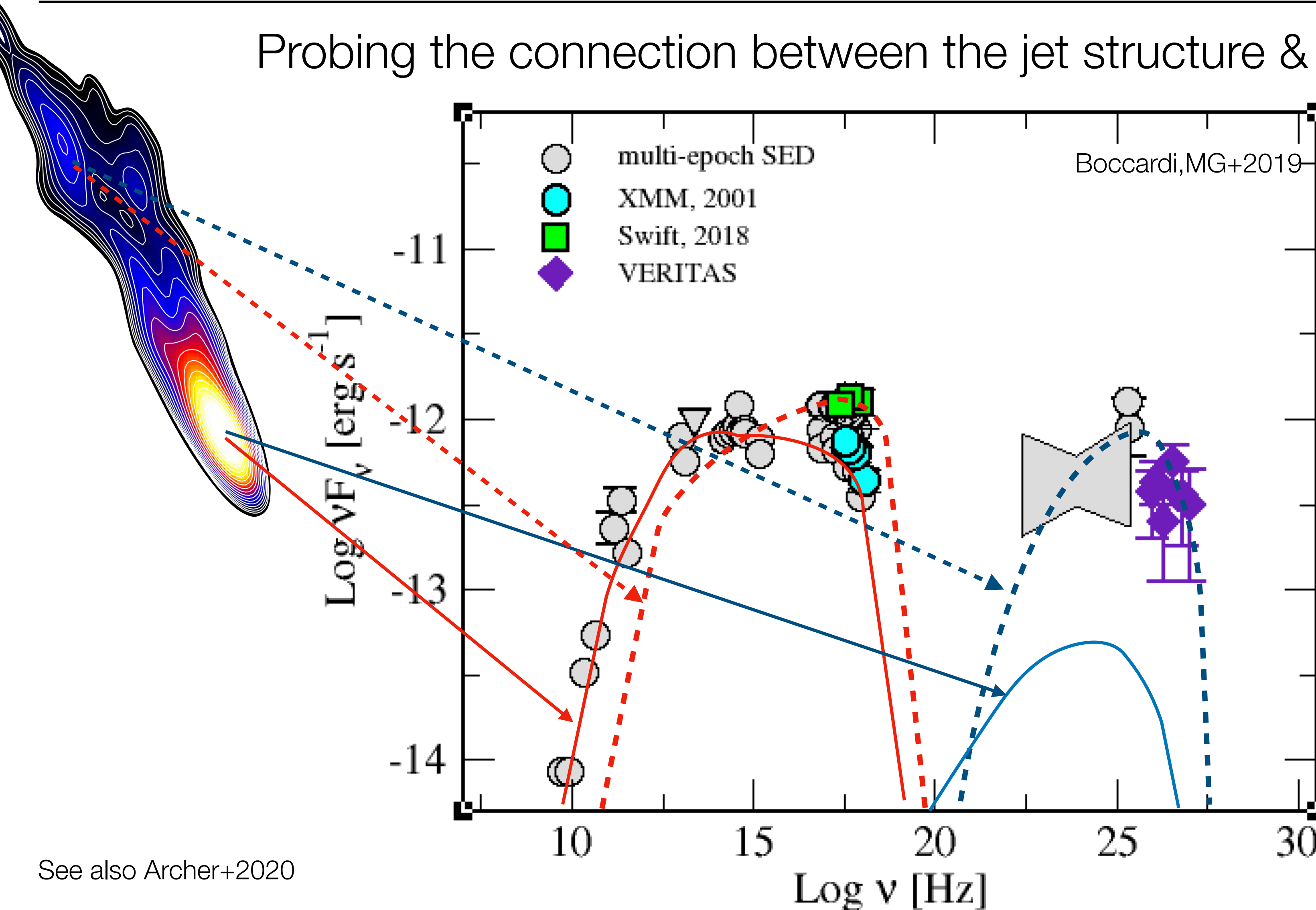


See also Giovannini+2018,
Nakamura+2018, Hada+2024

collimation & acceleration take place over the same scales

Synergies - misaligned jets

Probing the connection between the jet structure & dynamics and VHE emission



Multi-zone model:

- ✓ Steady/low state emission in a Poynting flux dominated region of the core
- ✓ High/VHE emission at the end of the acceleration region (particle dominated);



Need to move from sparse mw observations to more systematic & coordinated monitoring to test it

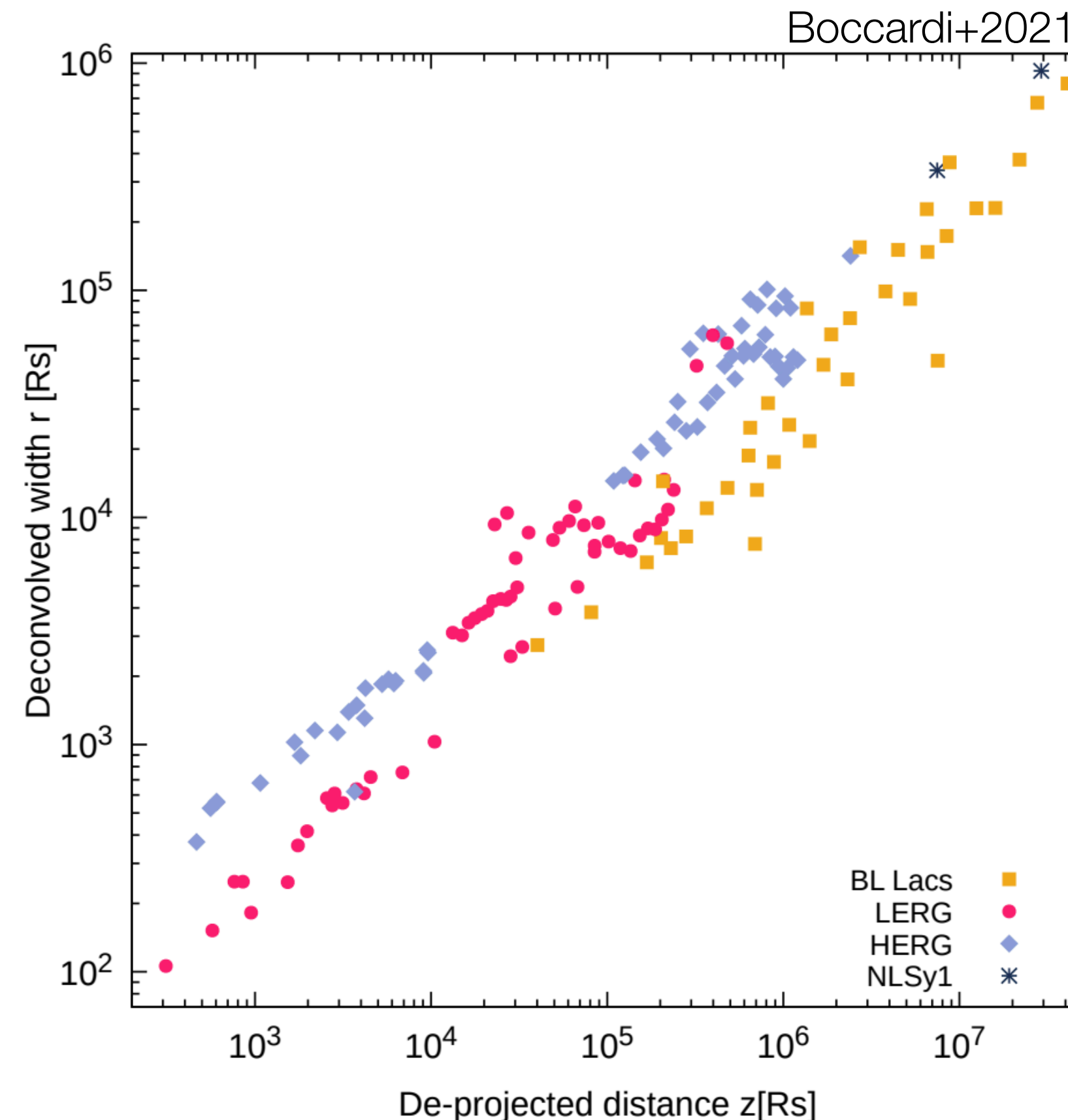
See also Archer+2020

Synergies - misaligned jets

Accretion modes & ejection connection:

HERG (high excitation radio galaxies/efficiently accreting):

- “thicker jets”
- launched at larger disk radii?
- jet collimation over larger scales
- role of disk winds?



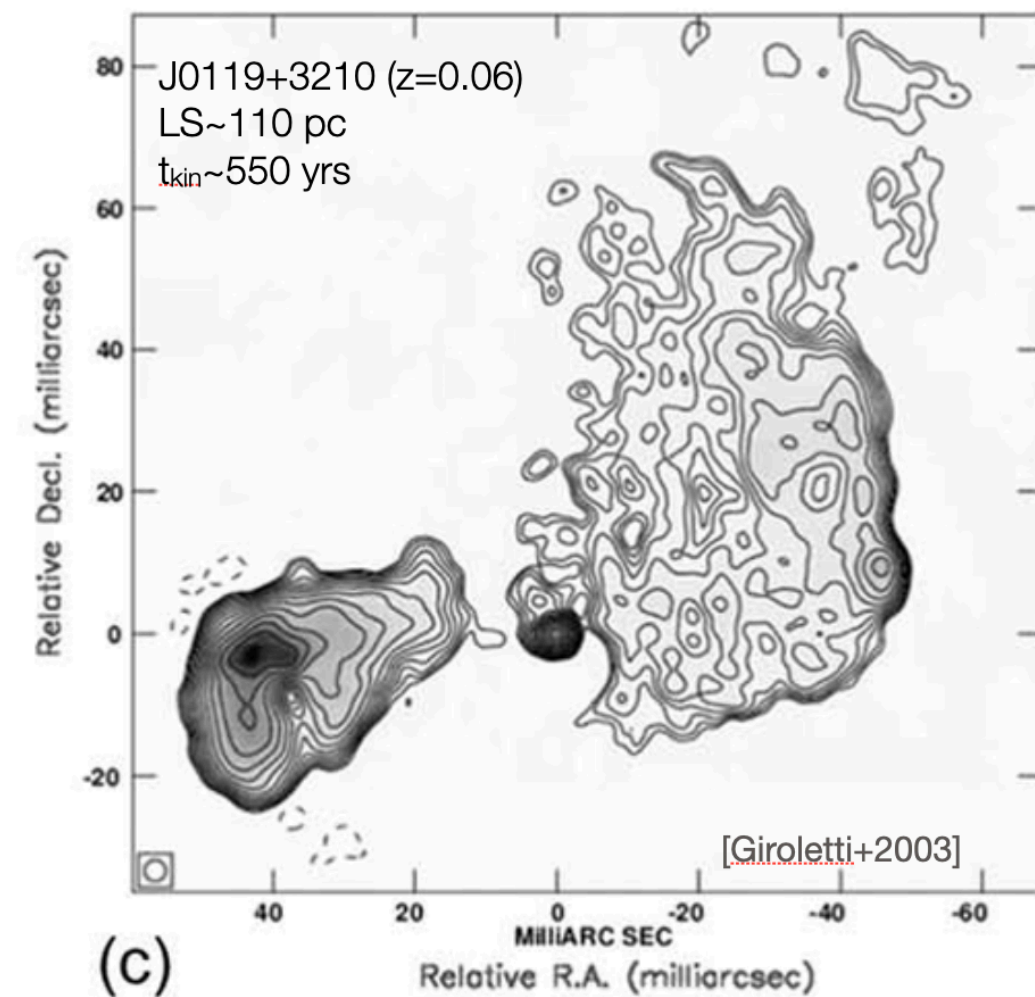
LERG (low excitation radio galaxies/inefficiently accreting):

- jets launched by hot flows (ADAF-like) anchored in the innermost regions;
- Collimation completed at smaller scales than HERG.

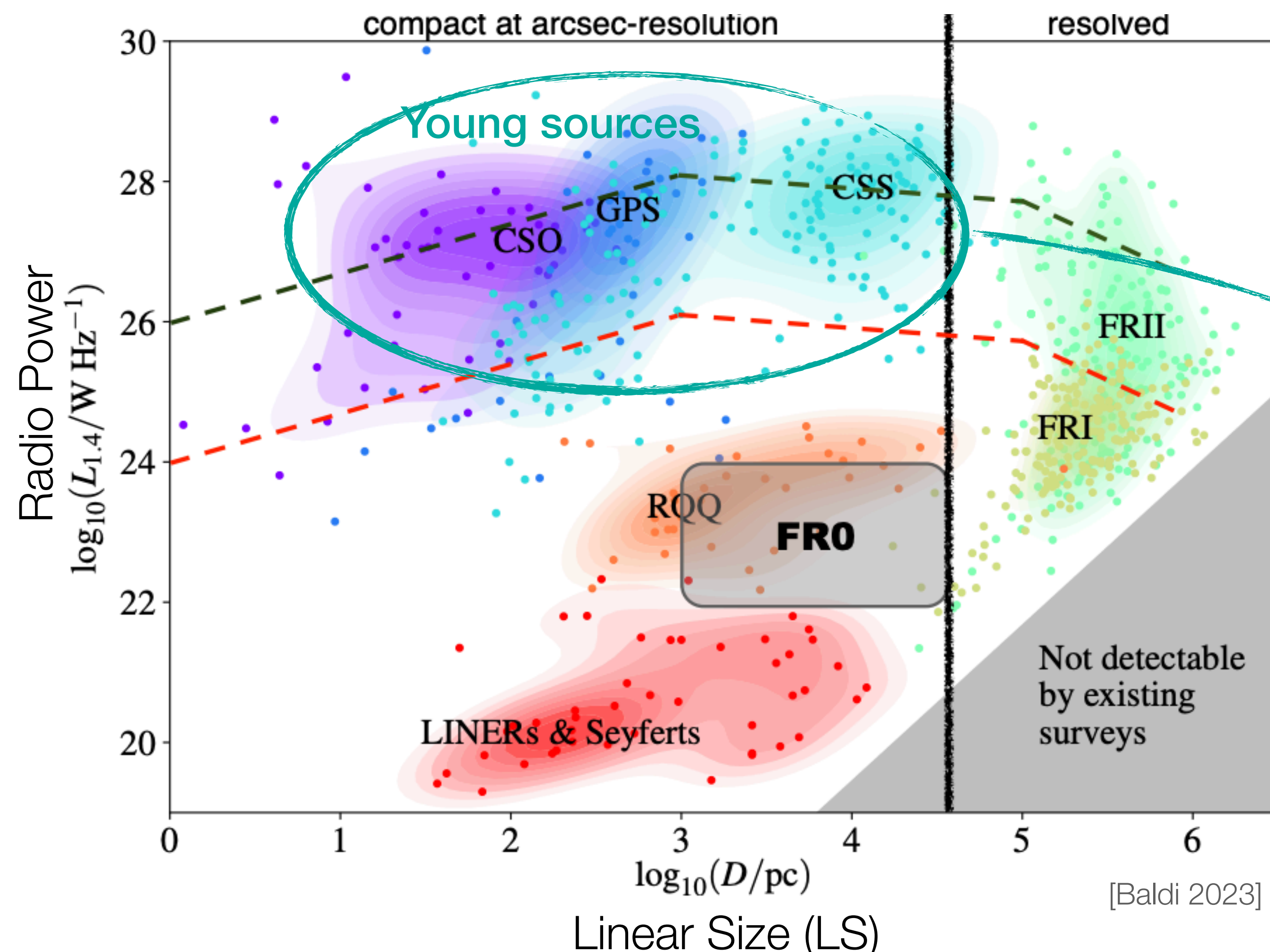
Indications of a relation between the properties of the jet acceleration & collimation region and of the accretion flow

Synergies: young radio sources

Radio duty cycle:



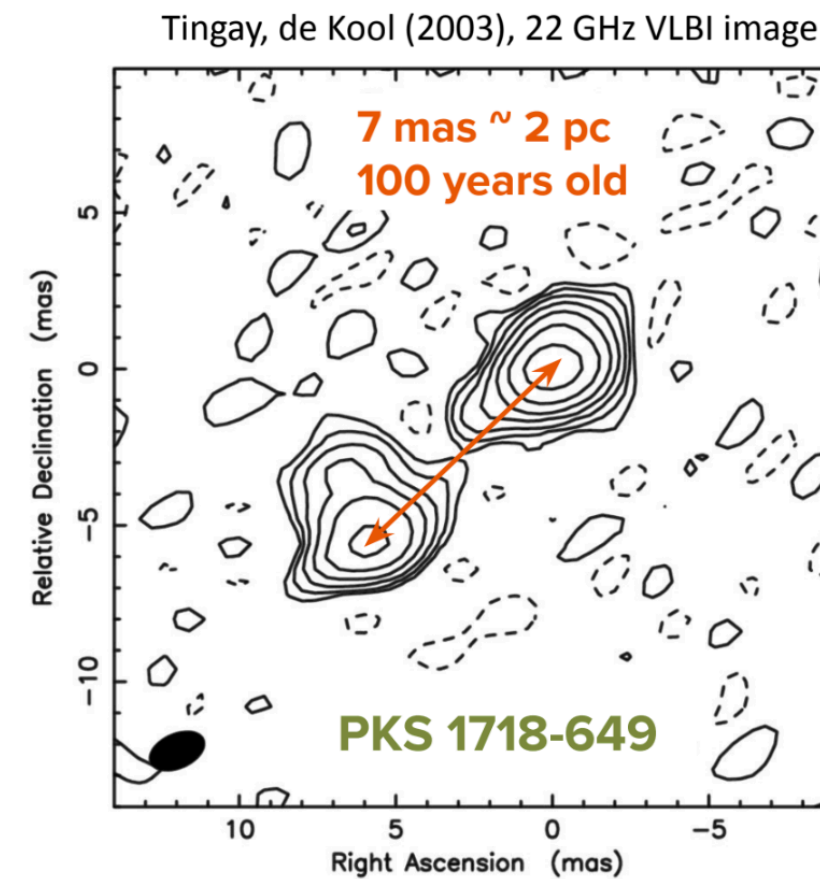
CSO/Young source



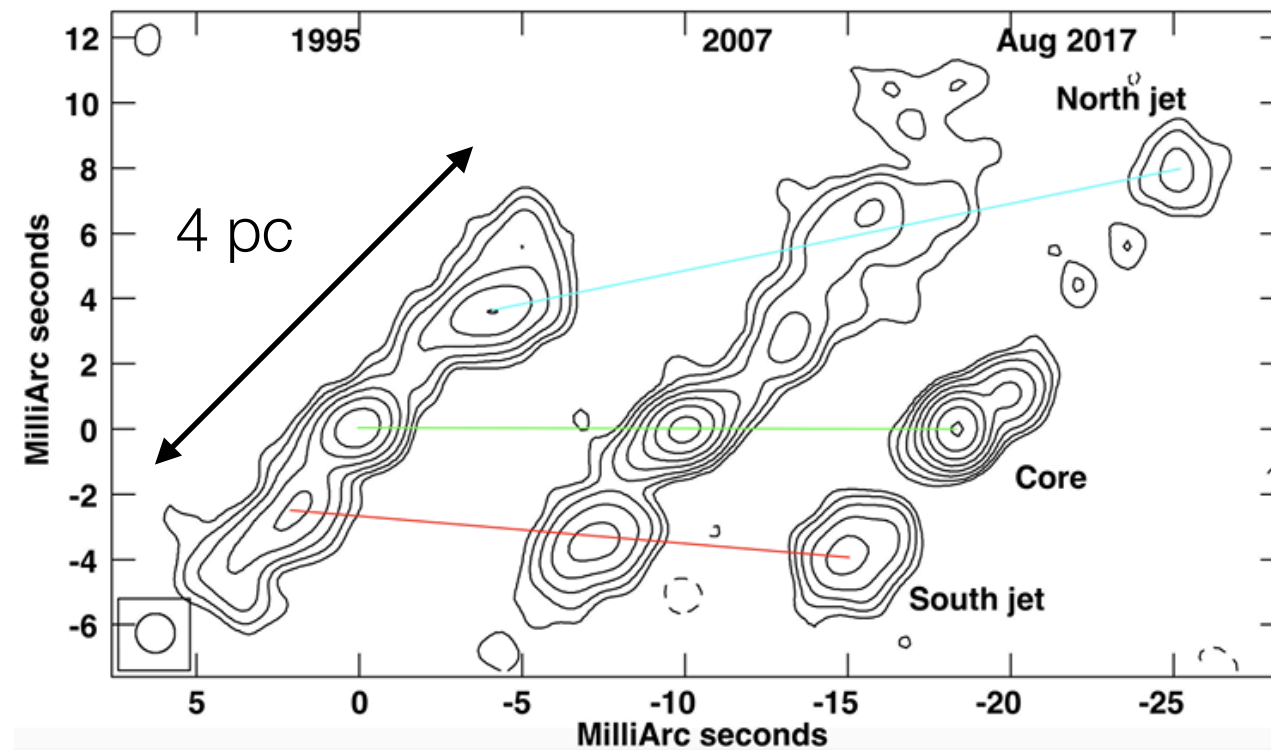
Detection of HE emission in compact radio sources: constraints on the jet physics in the first stages of the evolution of radio galaxies

Synergies: young radio sources

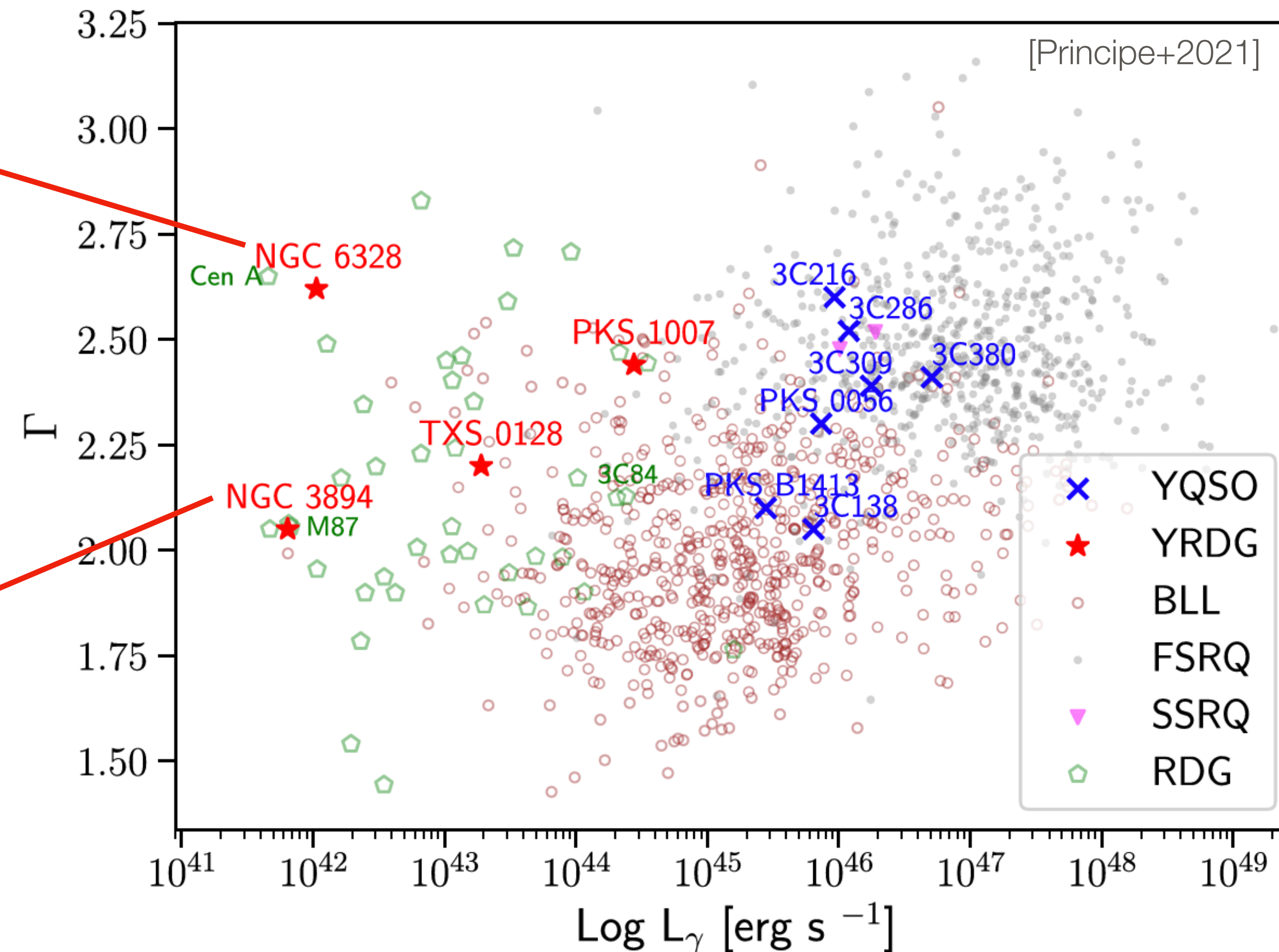
CSOs/YRGs typically gamma-ray weak but not silent:
(Migliori+2016; Principe+2020,2021; Lister+2020; Bronzini+2024a; Swain+2025)



γ -rays from the mini-lobes (IC/UV)?



γ -rays from the mini-jets (SSC)?

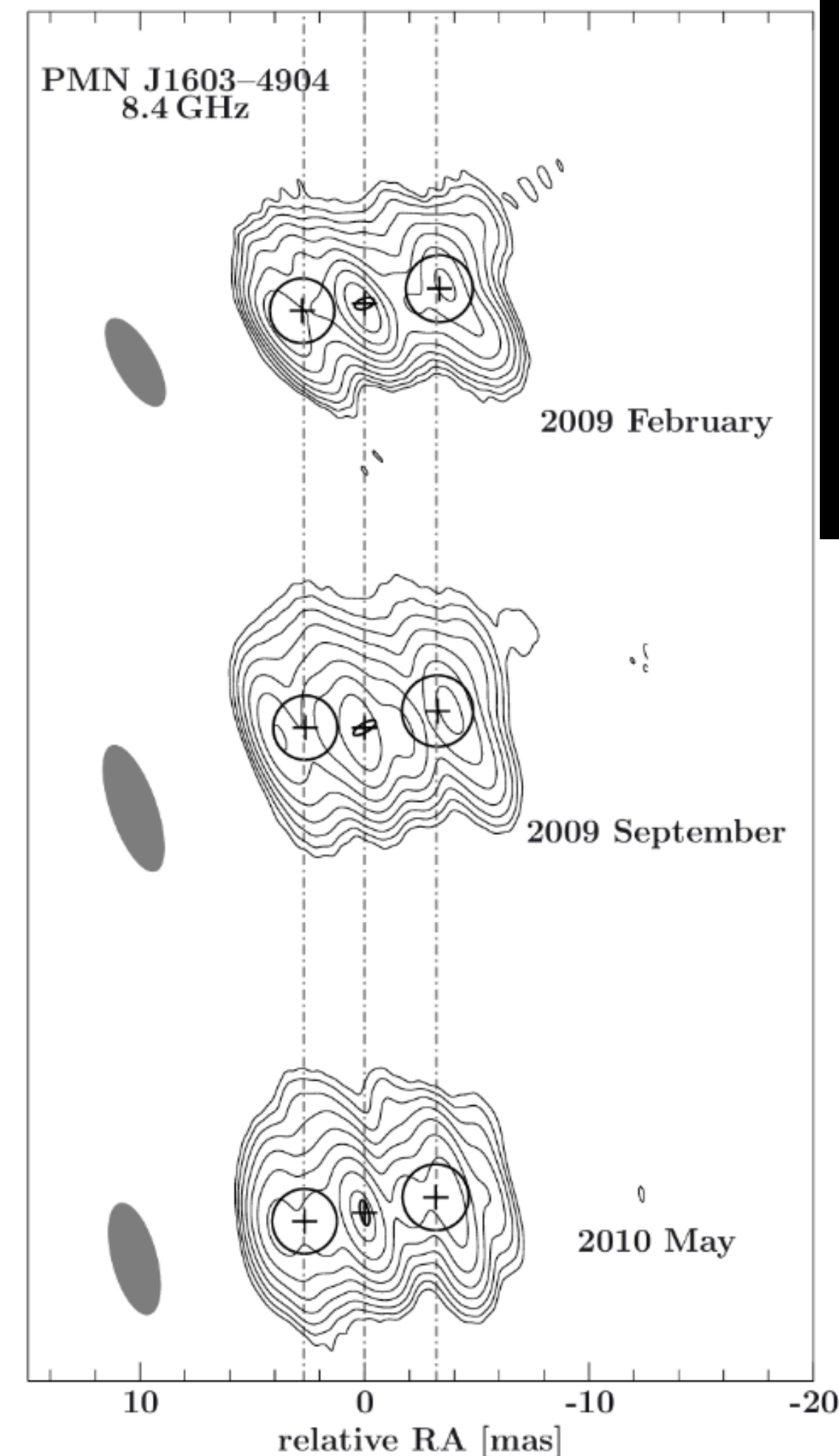


Daring targets
for ASTRI & SST
but..

Synergies: young radio sources

TeV detection of a CSO candidate ($z=0.023$):

[Müller+2014]



H.E.S.S. detection of the CSO PMN J1603-4904 at very-high-energy gamma rays

ATel #17205; **Stefan J. Wagner (U Heidelberg, Germany), for the H. E.S. S. collaboration**

on 25 May 2025; 17:09 UT

Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

- 9σ HESS detection in $<5h$
- 3FHL source
- Fermi-LAT hard spectrum $\Gamma_\gamma \sim 1.2$

Ongoing MW follow-up led by
G. Bruni (INAF-IAPS)

Continued monitoring of PMN J1603-4904 with MeerKAT and H.E.S.S.

ATel #17307; **G. Bruni (INAF-IAPS), M. Brienza, G. Migliori, M. Giroletti, E. Liuzzo (INAF-IRA), E. Bronzini (U. Bologna & INAF-OAS), M. Kadler (U. Wuerzburg), L. Hernandez-Garcia (U. Valparaíso), F. Panessa, J. Rodi (INAF-IAPS), E. Torresi, P. Da Vela (INAF-OAS), M. Cerruti (U. Paris Cite), , C. Reynolds (CSIRO), and S. J. Wagner (U. Heidelberg), for the H. E. S. S. collaboration**

on 25 Jul 2025; 09:36 UT

Credential Certification: Gabriele Bruni (gabriele.bruni@inaf.it)

Continued monitoring of PMN J1603-4904: further MeerKAT, NuSTAR, and H.E.S.S. epochs

ATel #17410; **G. Bruni (INAF-IAPS), M. Brienza (INAF-IRA), J. Rodi (INAF-IAPS), G. Migliori, M. Giroletti, E. Liuzzo (INAF-IRA), E. Bronzini (U. Bologna & INAF-OAS), M. Kadler (U. Wuerzburg), L. Hernandez-Garcia (U. Valparaíso), F. Panessa, E. Torresi, P. Da Vela (INAF-OAS), M. Cerruti (U. Paris Cite), , C. Reynolds (CSIRO), P. Goswami (LSW, U. Heidelberg) and Stefan J. Wagner, for the H. E.S. S. collaboration**

on 22 Sep 2025; 10:50 UT

Southern target for CTA (possibly SST?)

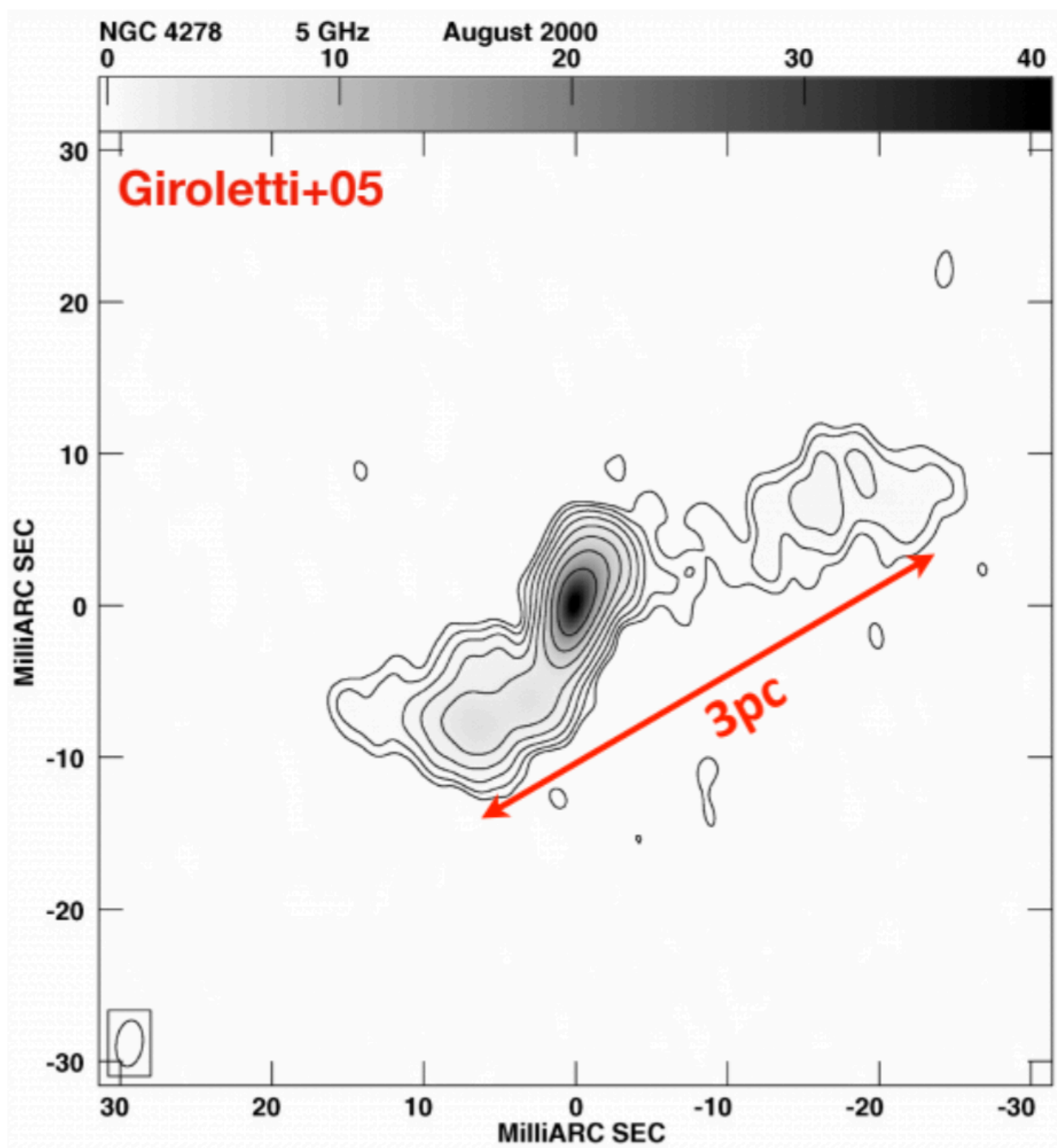
+

synergies with SKA and
Meerkat band5b (8-15GHz)

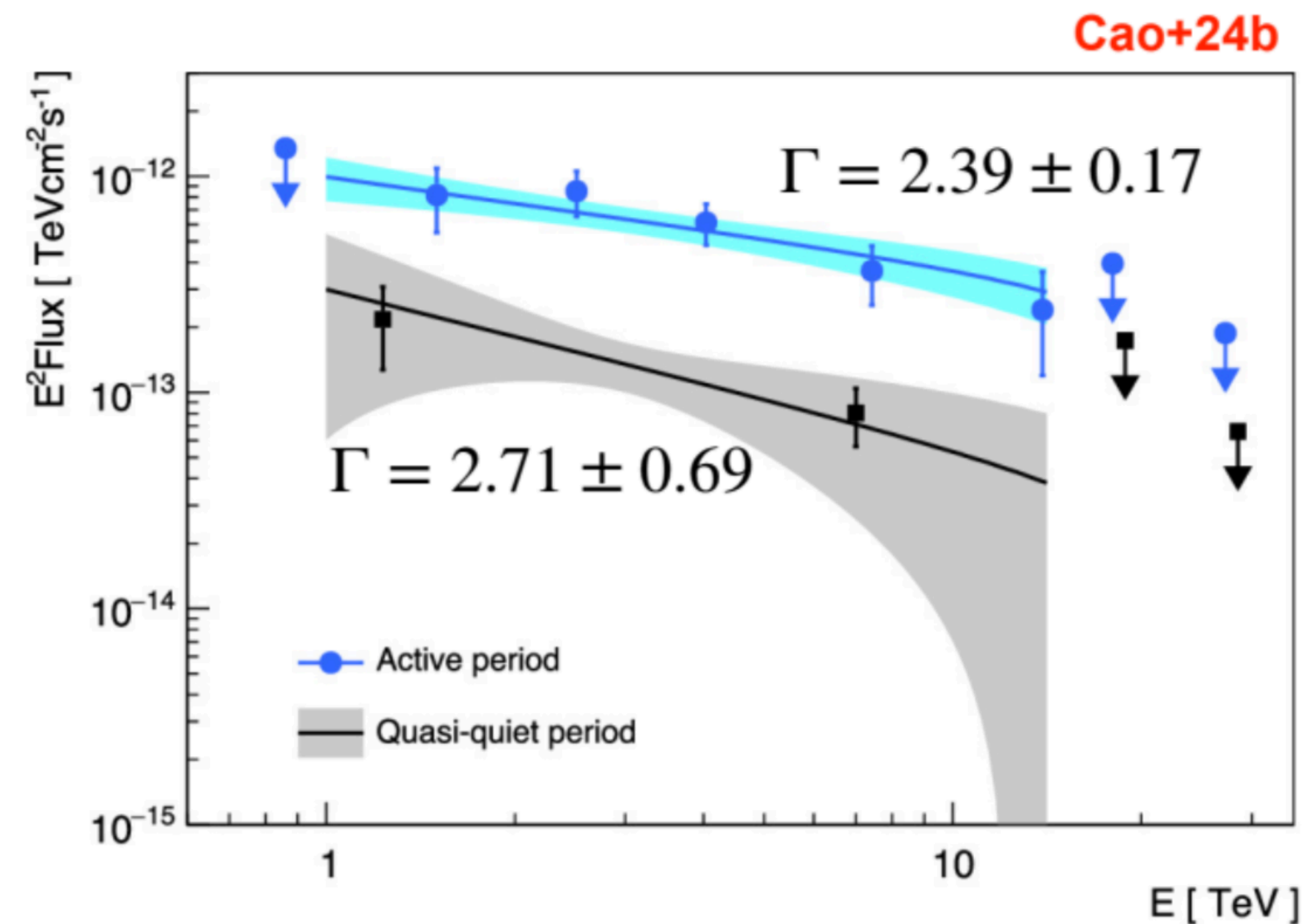
Synergies - LLAGN

New TeV classes: Low-luminosity AGN

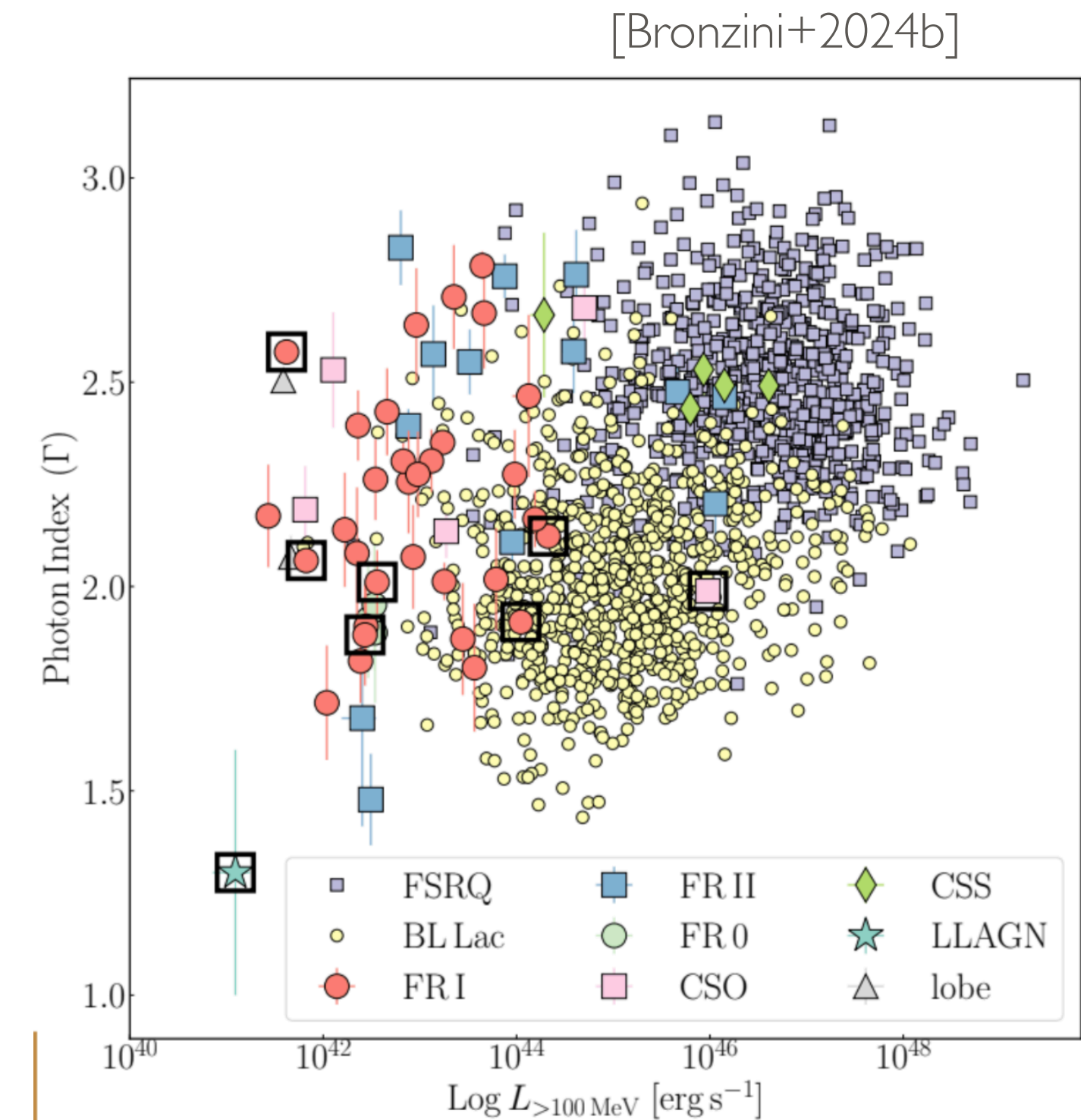
NGC4278 (d~16.4 Mpc, LS~3pc, $L_{5\text{GHz}} \sim 10^{38} \text{ erg s}^{-1}$)



CSO radio morphology



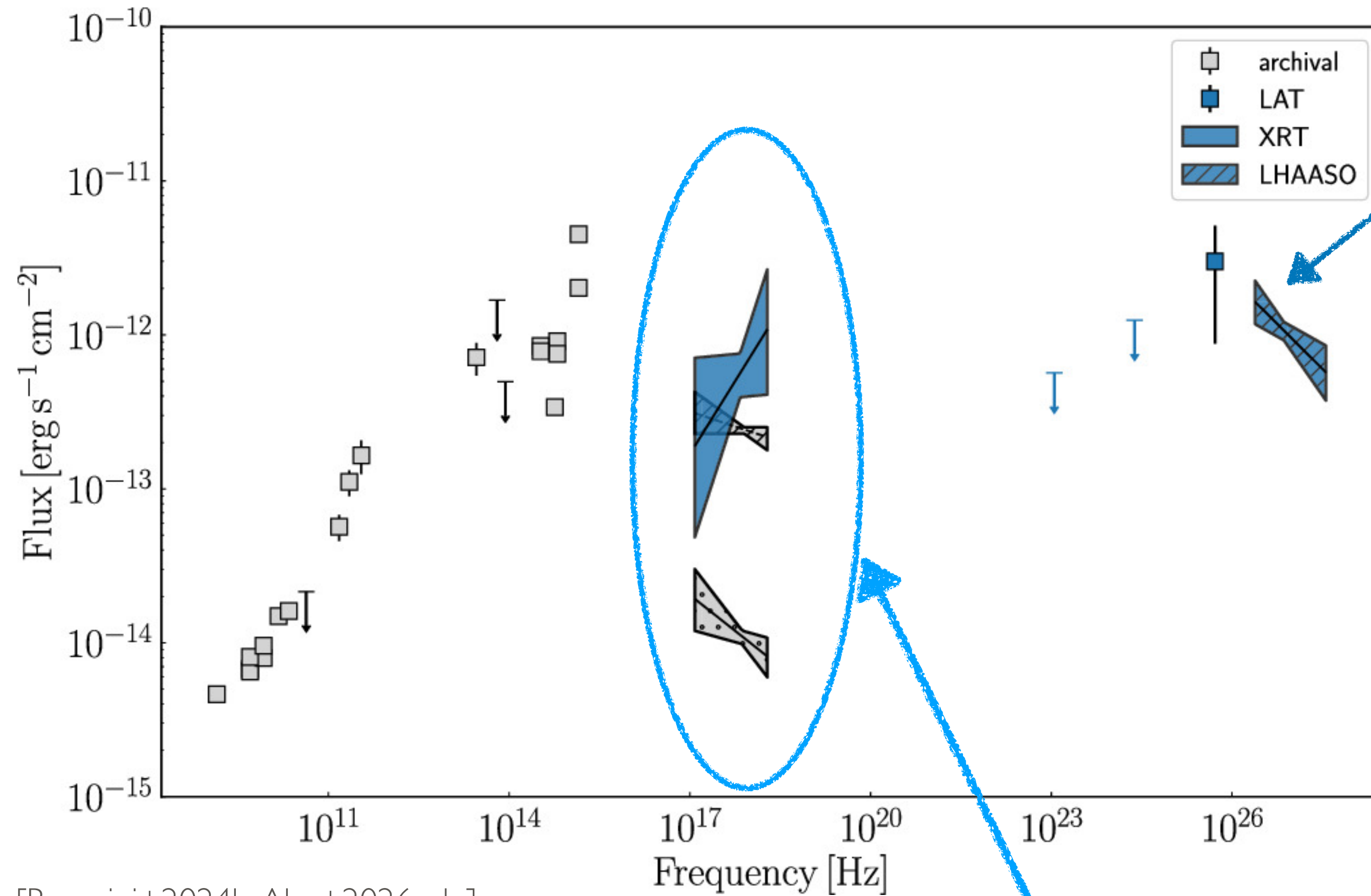
LHAASO



Fermi-LAT

Synergies - LLAGN

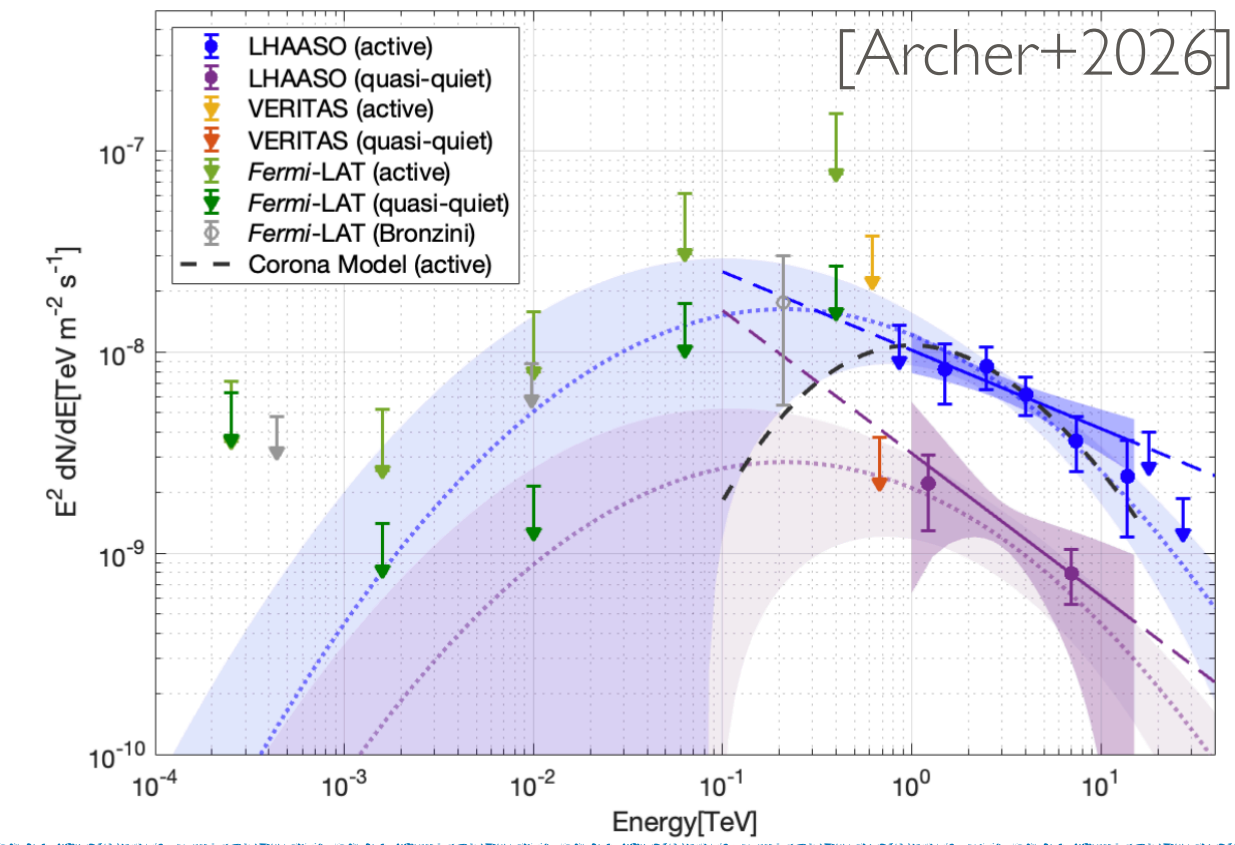
NGC4278 SED:



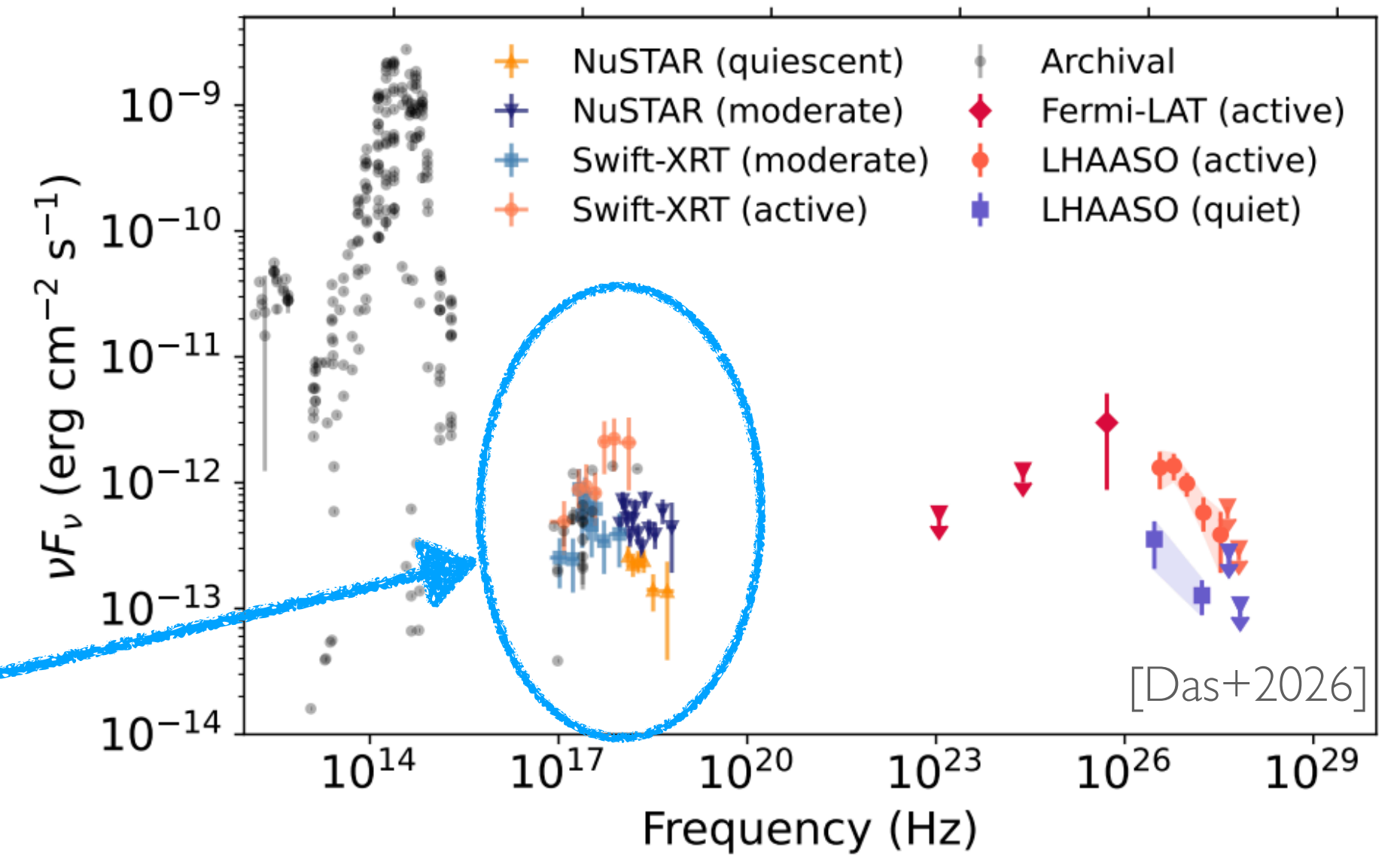
[Bronzini+2024b, Abe+2026sub.]

broad-band X-rays to catch
the VHE active phase

Hard rise in the HE domain



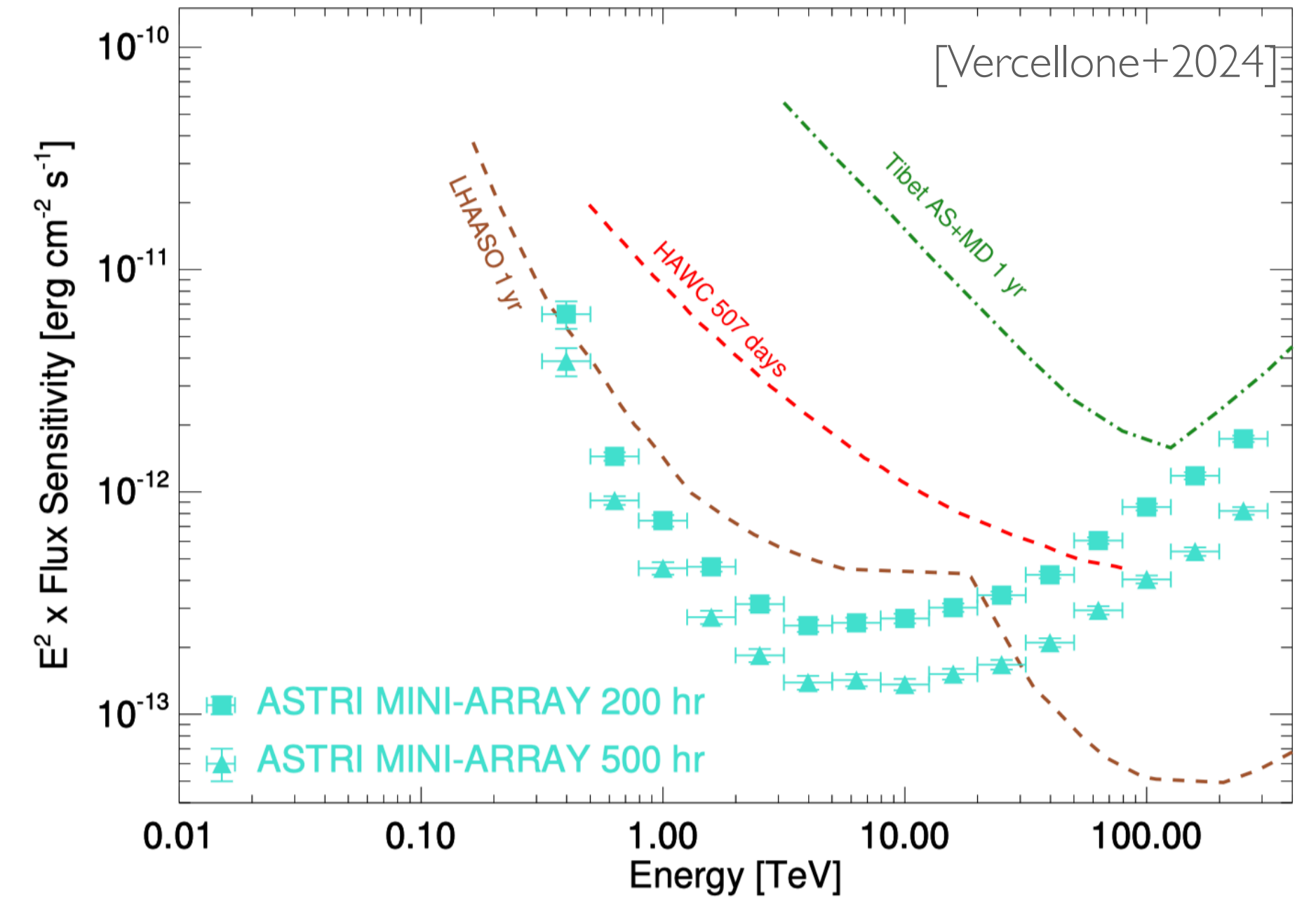
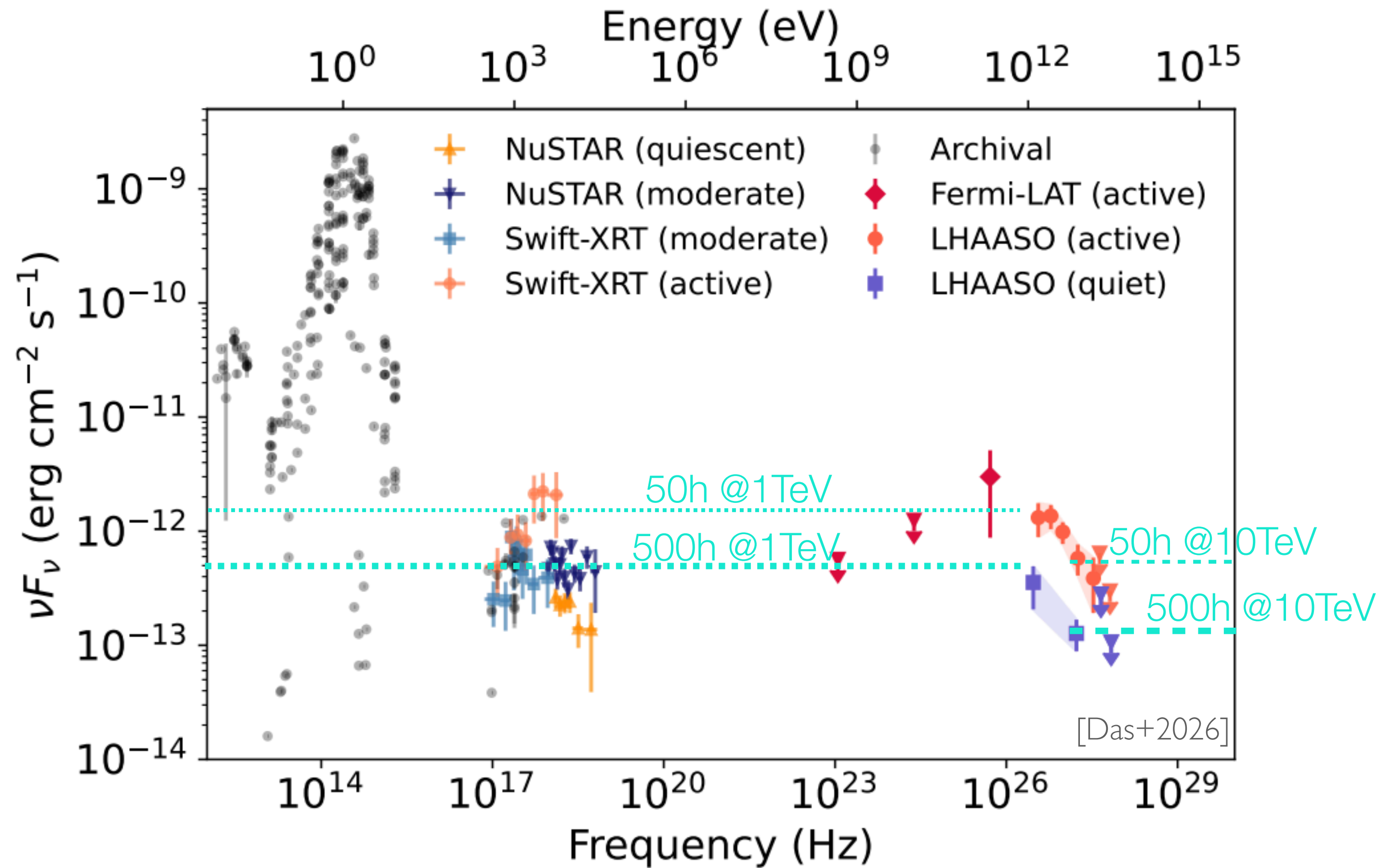
[Archer+2026]



[Das+2026]

Synergies - LLAGN

NGC4278 SED:



Potentially at reach of
ASTRI
+
angular resolution is important

Conclusions & Future perspectives

- Multi-wavelength synergies are needed to address the main open questions of jetted AGN
 - MW polarization observations give indication on the radiative & particle acceleration mechanisms
 - High-resolution VLBI observations can map the ACZ and probe the site of the VHE emission
- Not only aligned jets:
 - Radio galaxies offer the chance to investigate the accretion&ejection link and the multi-scale jet;
 - “New” gamma-ray classes hold potential for future VHE studies:
 - CSO/young sources?
 - LLAGN

Conclusions & Future perspectives



MW Polarization

Table 1

Summary of the Multiwavelength Polarization Expectations for Different X-Ray Emission Scenarios Outlined in the Text

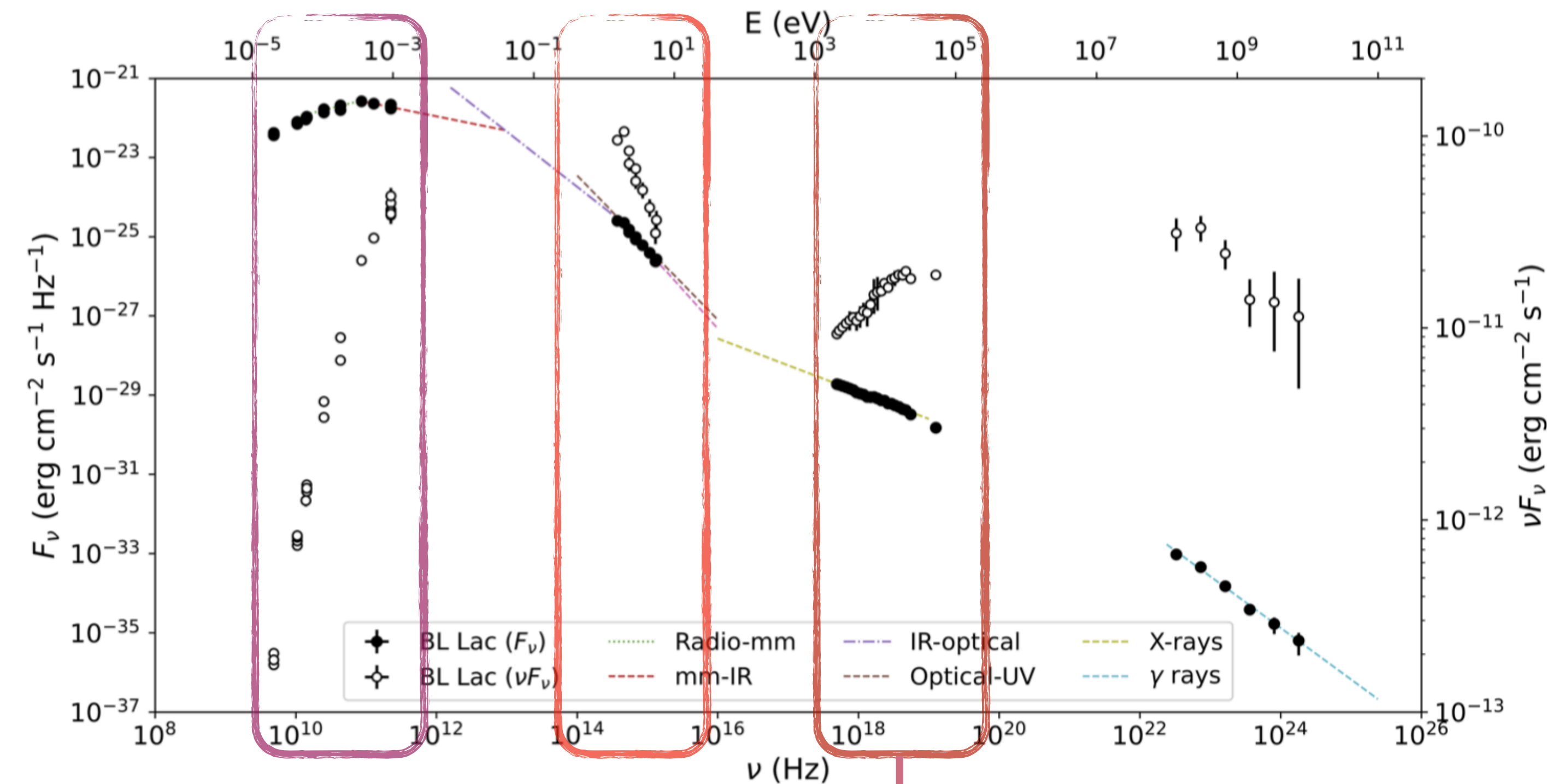
Model	X-Ray Polarization Degree	X-Ray Polarization Variability
Single-zone leptonic (EC)	Unpolarized	...
Single-zone leptonic (SSC)	$0.5 \times \Pi_O$	Similar to optical
Energy-stratified/multizone leptonic (SSC)	$\leq 0.3 \times \Pi_O$	Similar to millimeter
Single-zone hadronic	$\approx \Pi_O$	Less variable than optical
Energy-stratified/multizone hadronic (flare)	$\approx \Pi_O$	Less variable than optical
Energy-stratified/multizone hadronic (nonflare)	$\approx \Pi_{mm}$	Similar to millimeter

[Agudo+2025]

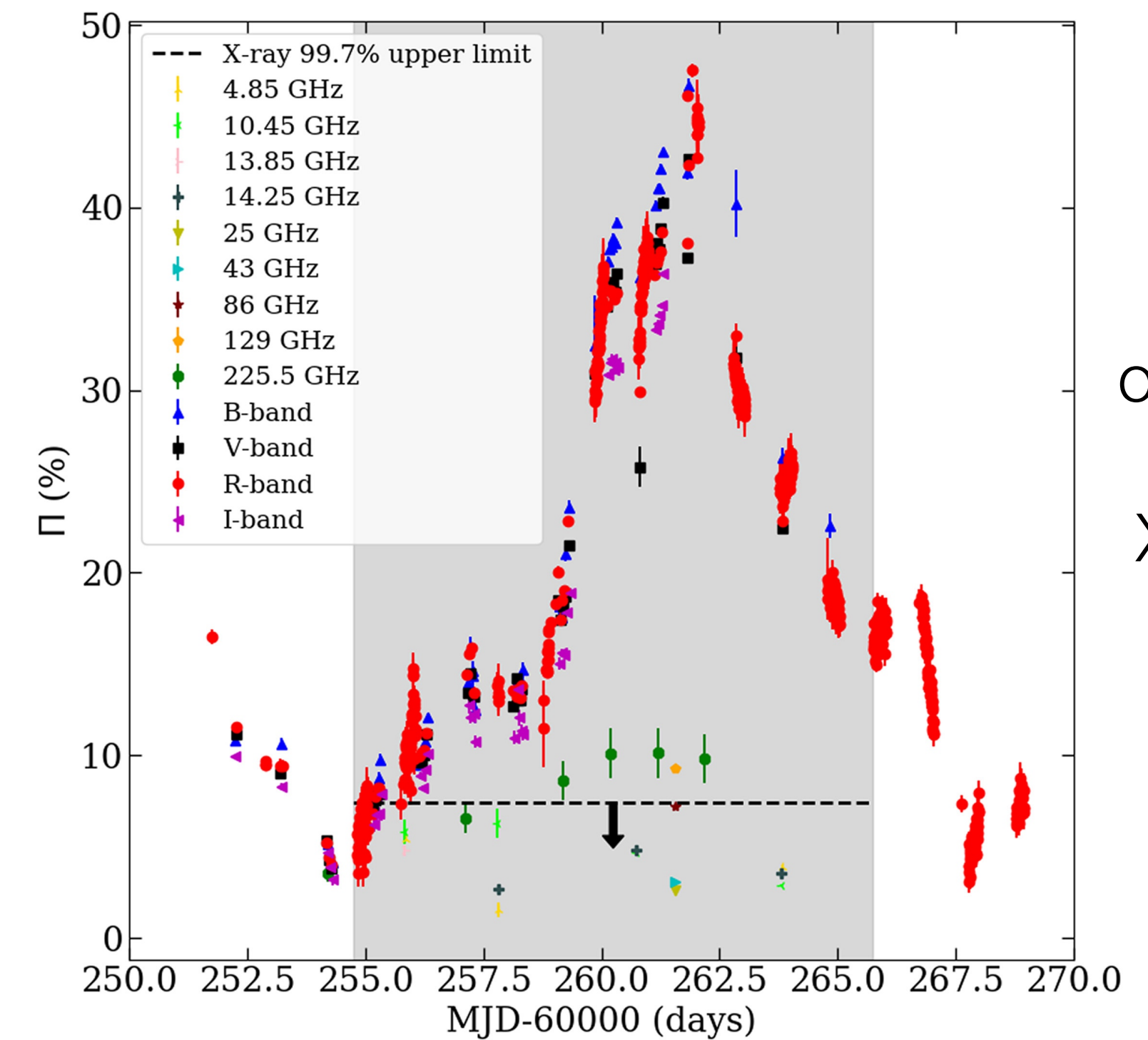
Synergies - aligned jets

MW polarization:

BL Lac mw campaign [Agudo+2025]:



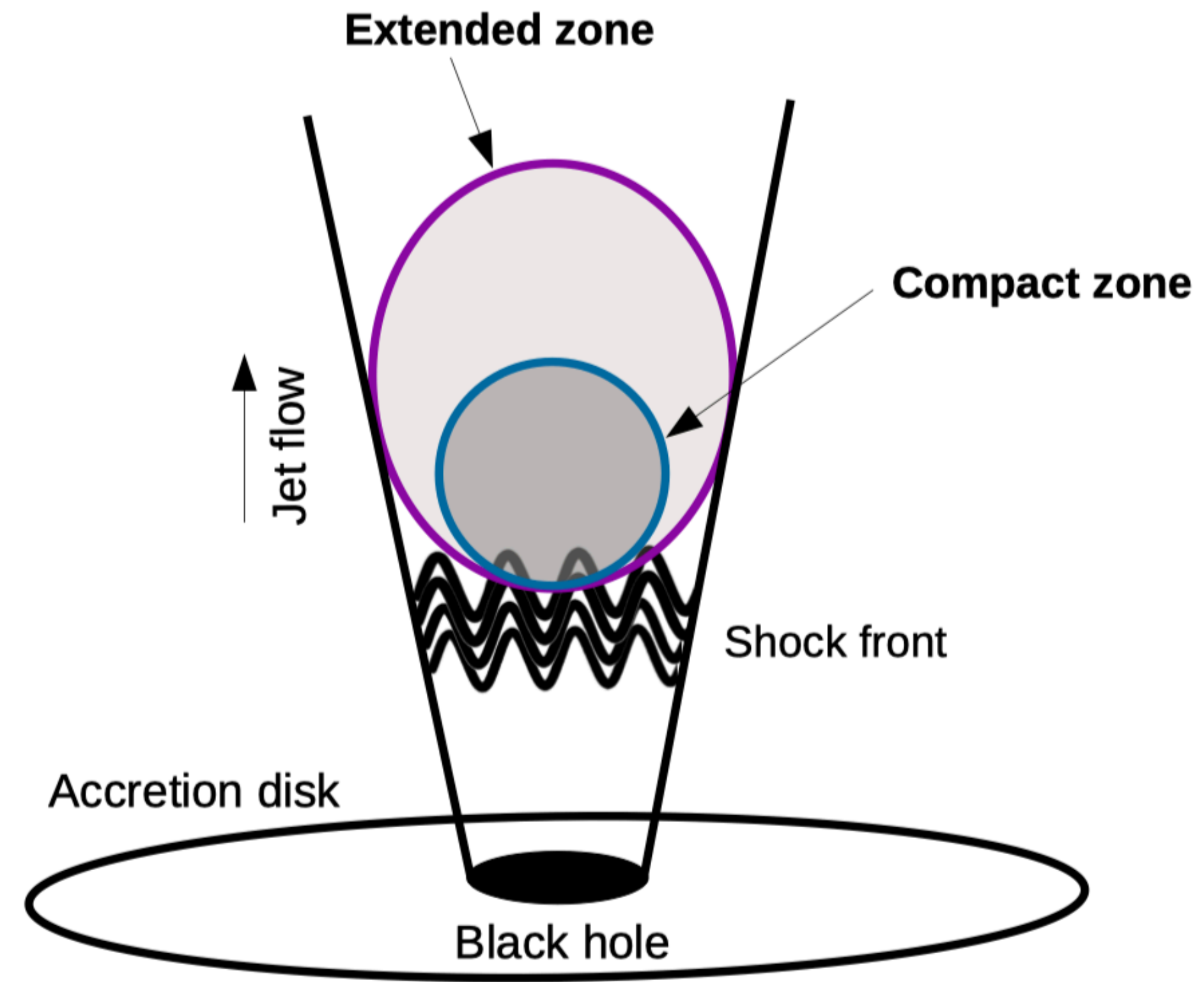
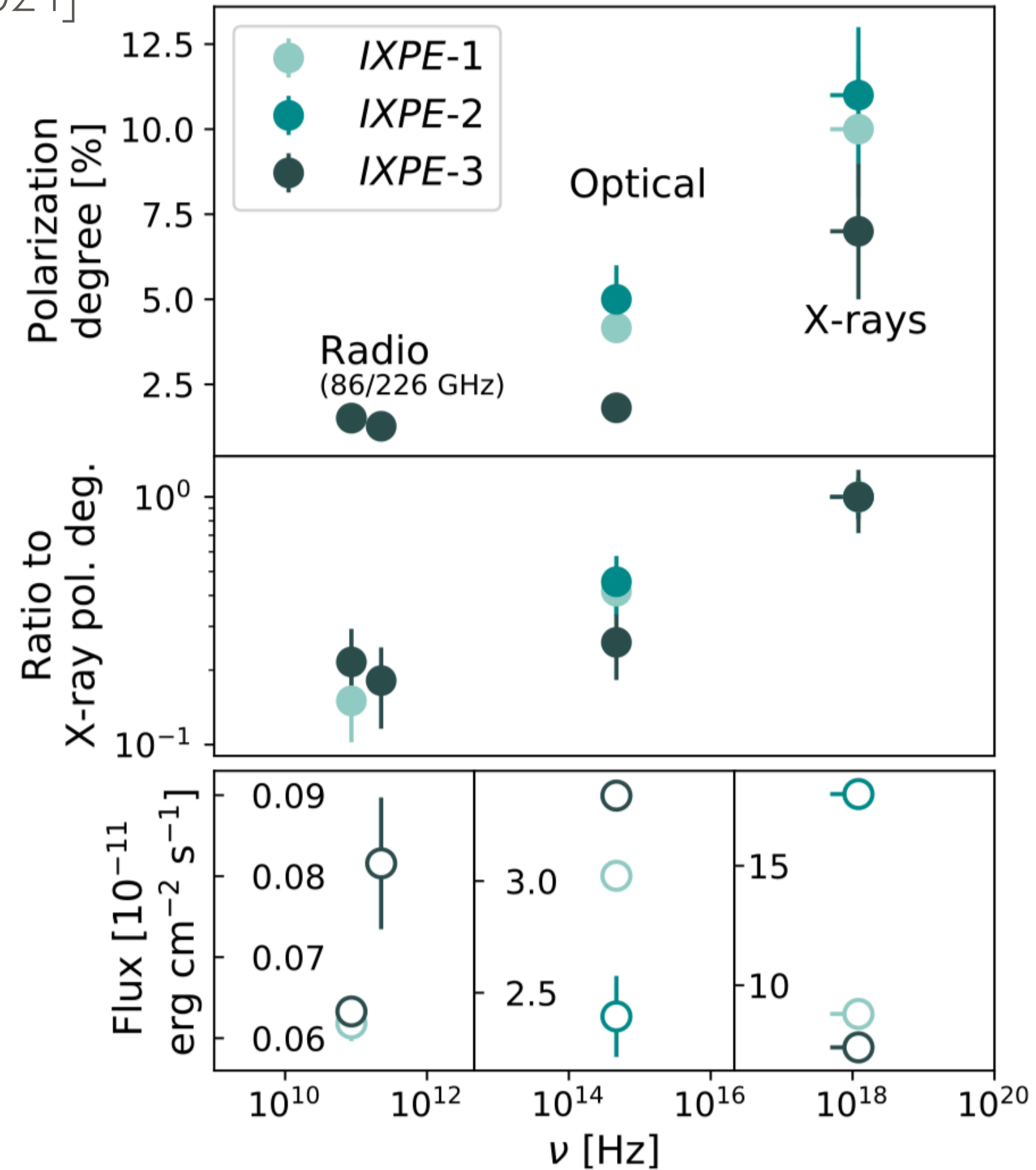
X-ray window opened up by IXPE



optical (47.5%)
vs
X-ray (<7.4%)
polarization
degree

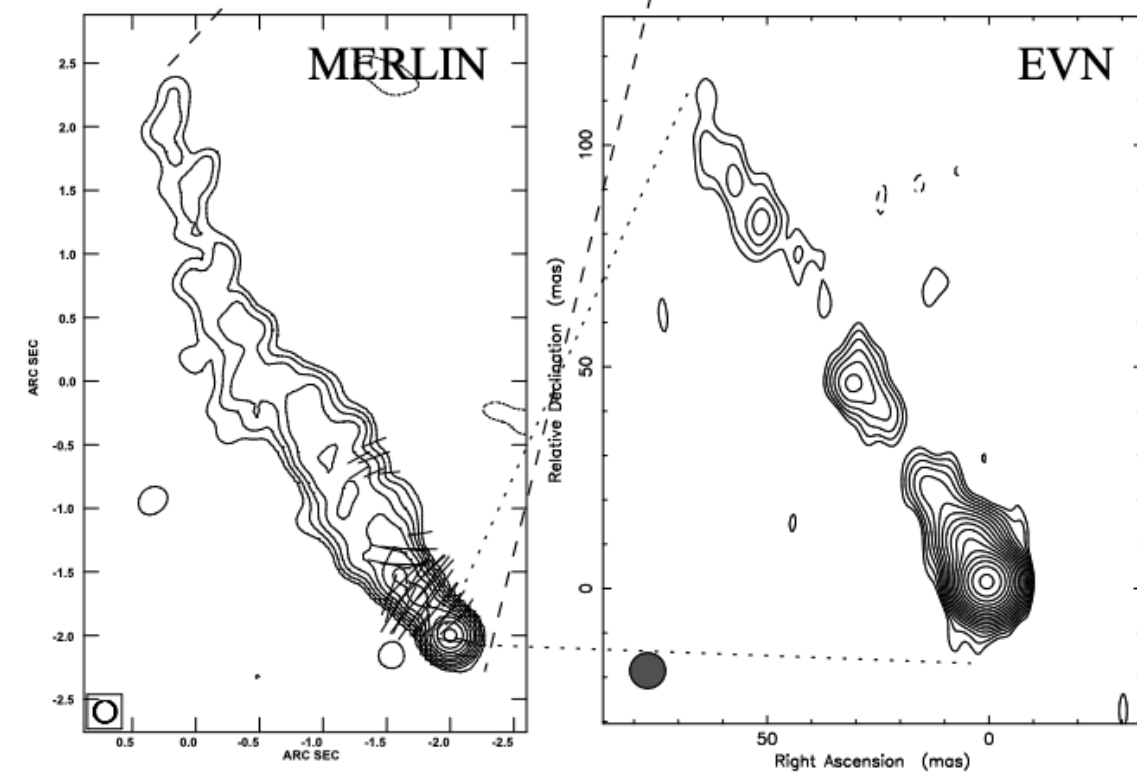
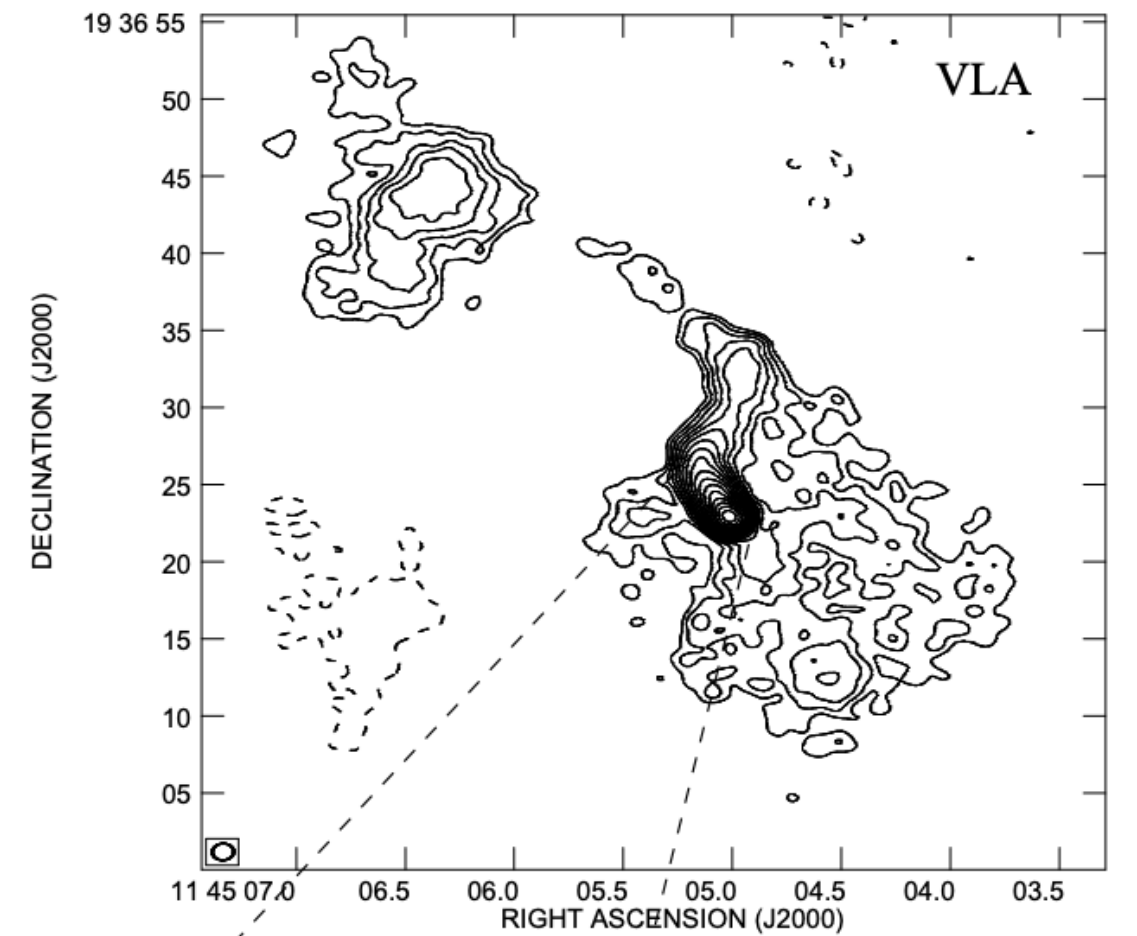
Synergies - aligned jets

[MAGIC coll.+2024]



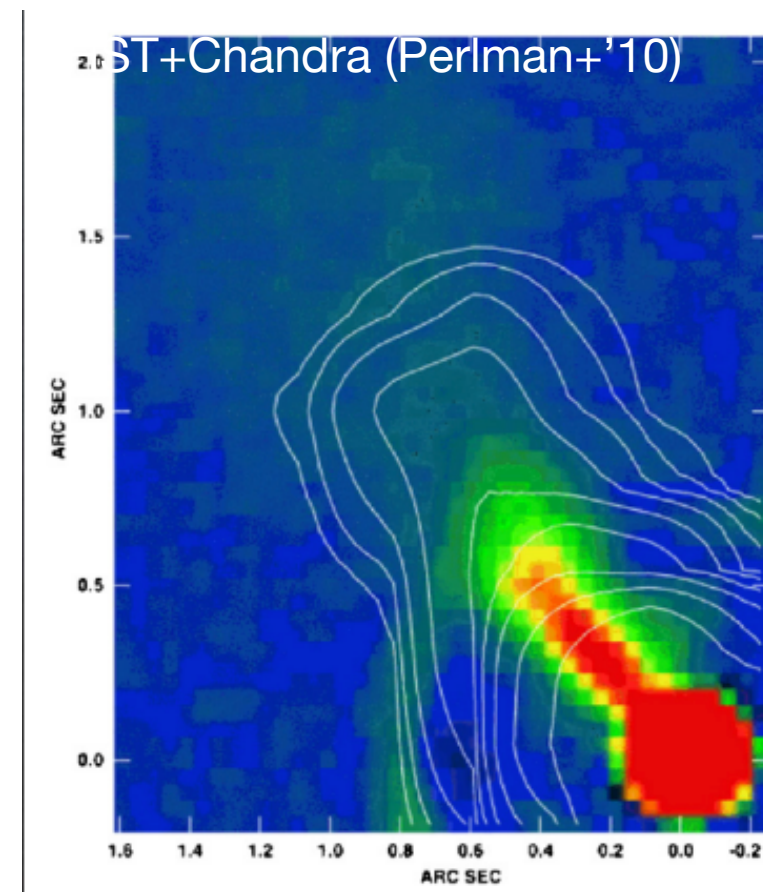
- campaign on the TeV blazar Mkn 501: chromatic polarization degree and variability suggest an energy stratified jet

3C 264

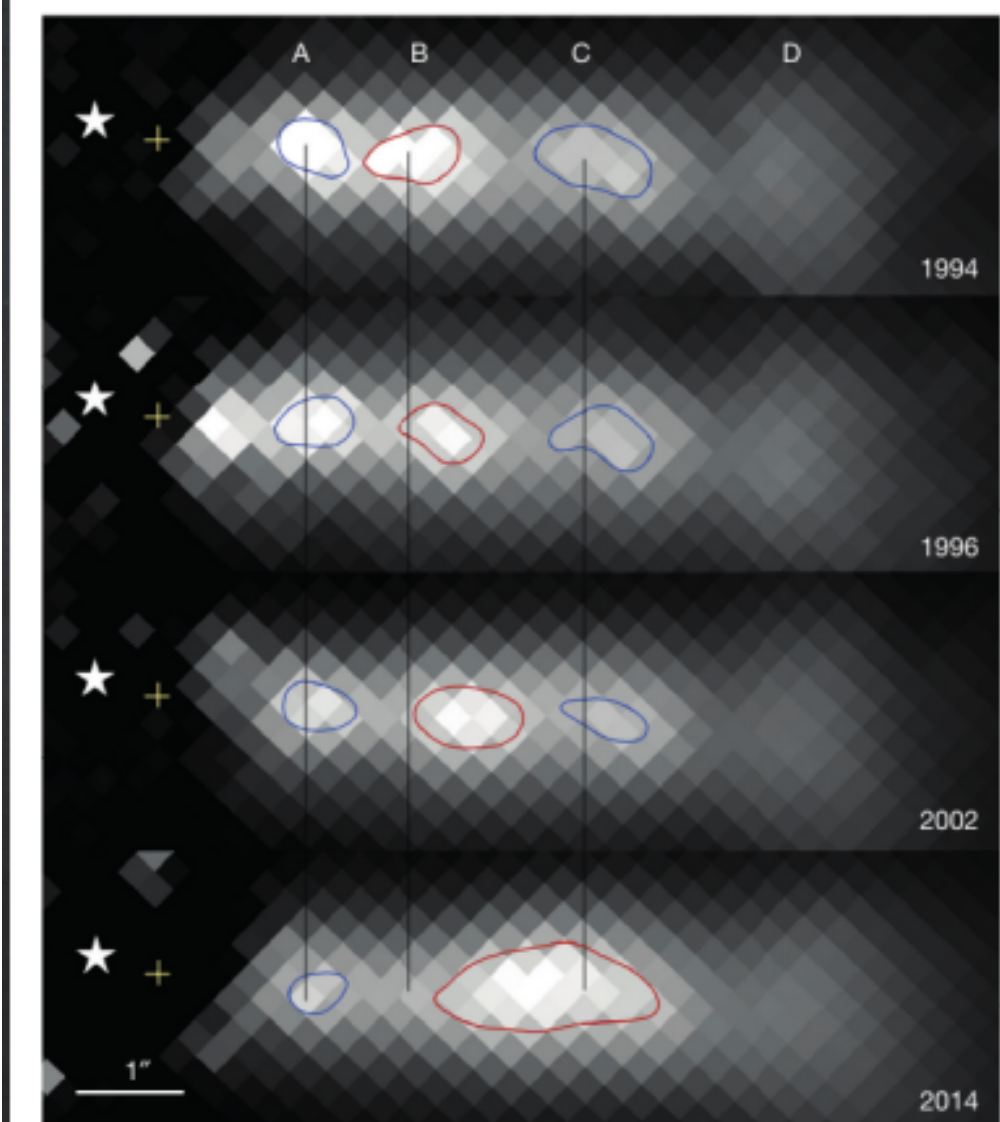


(Lara+'04)

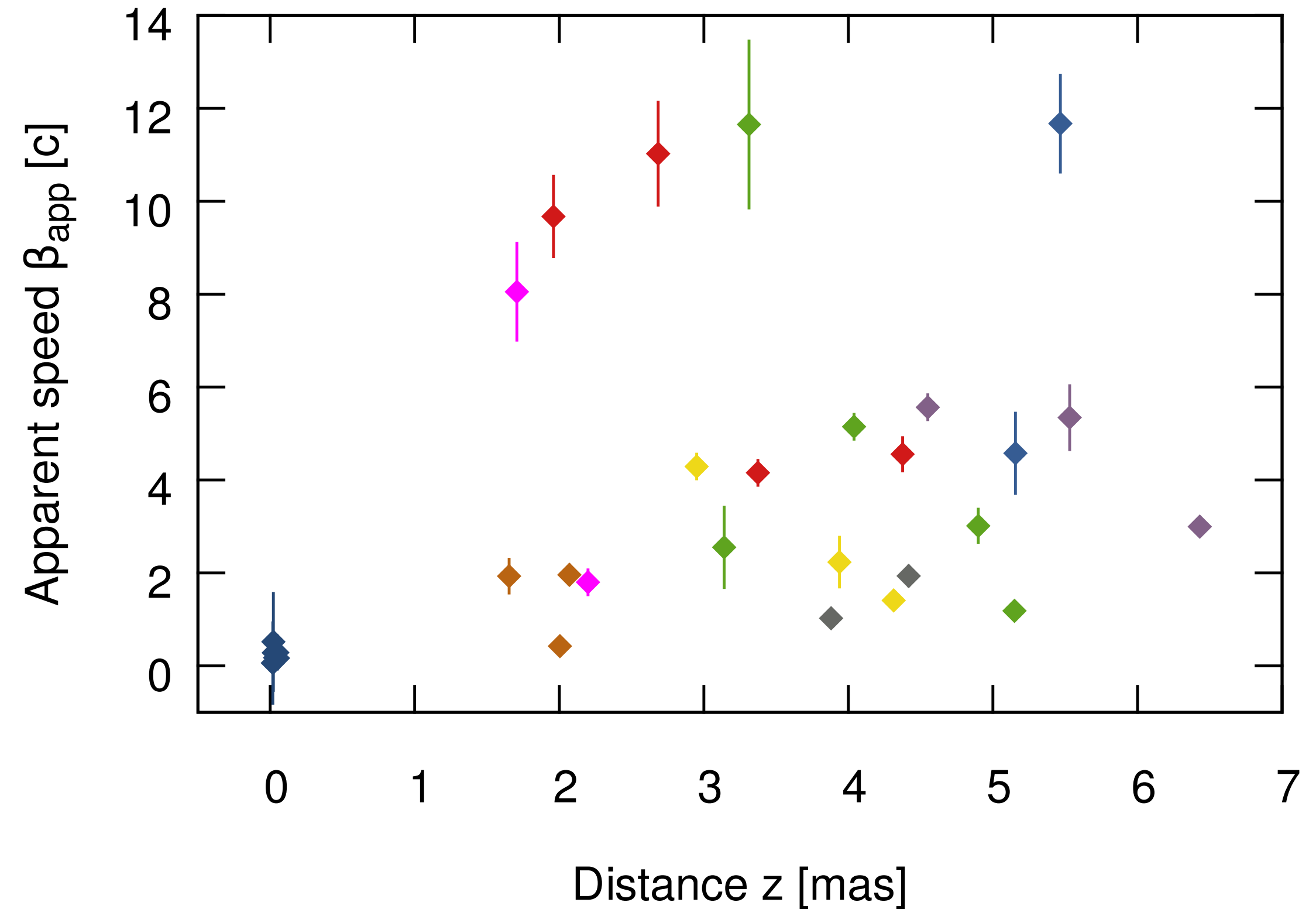
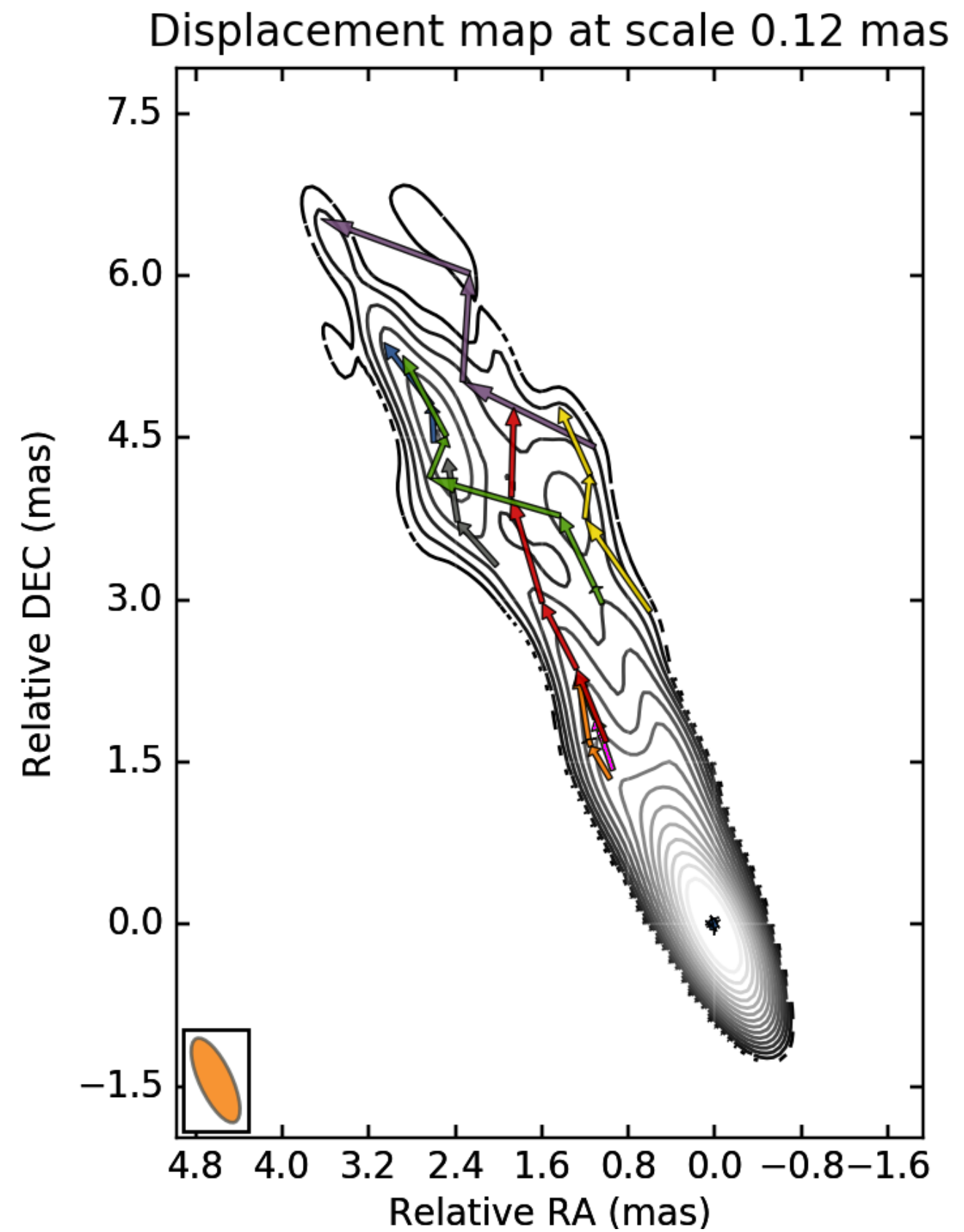
- FRI/LERG radio galaxy ($D_L=94$ Mpc) in Abell 1367 cluster;
- Head-tail kpc structure with extended radio, optical, X-ray jet (Lara+'97, Perlman+'10, Meyer+'15);
- Gamma-ray detected by Fermi ($\Gamma=1.94\pm0.10$, $F_{1-100\text{GeV}}=(2.85 \pm 0.40) \times 10^{-10}$ phot s $^{-1}$ cm $^{-2}$);
- VHE candidate (Angioni+'17)=> MAGIC proposal (PI:Angioni)



Optical jet: app. superluminal motion (Meyer+'15)



VLBI mapping of the ACZ

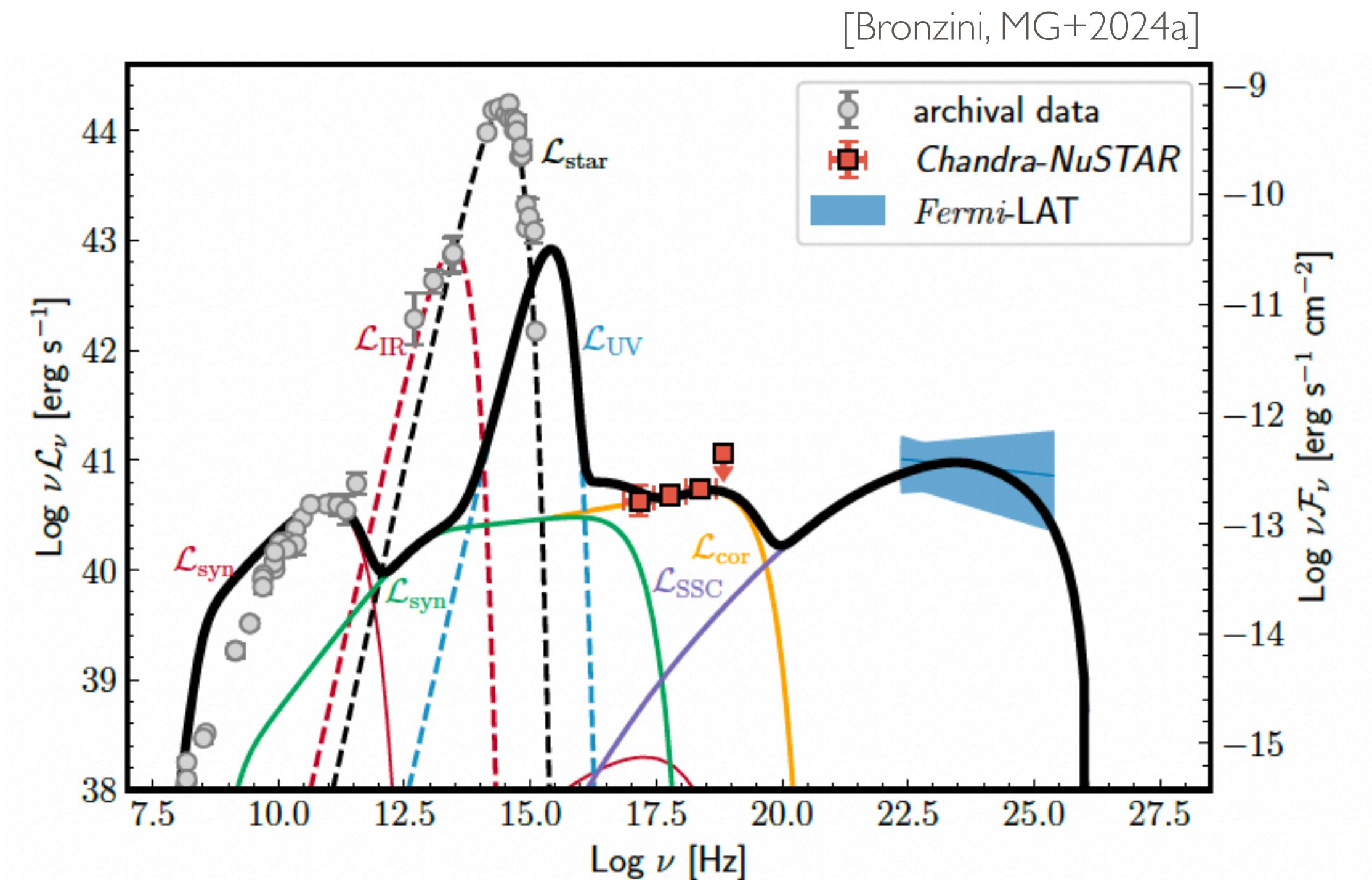
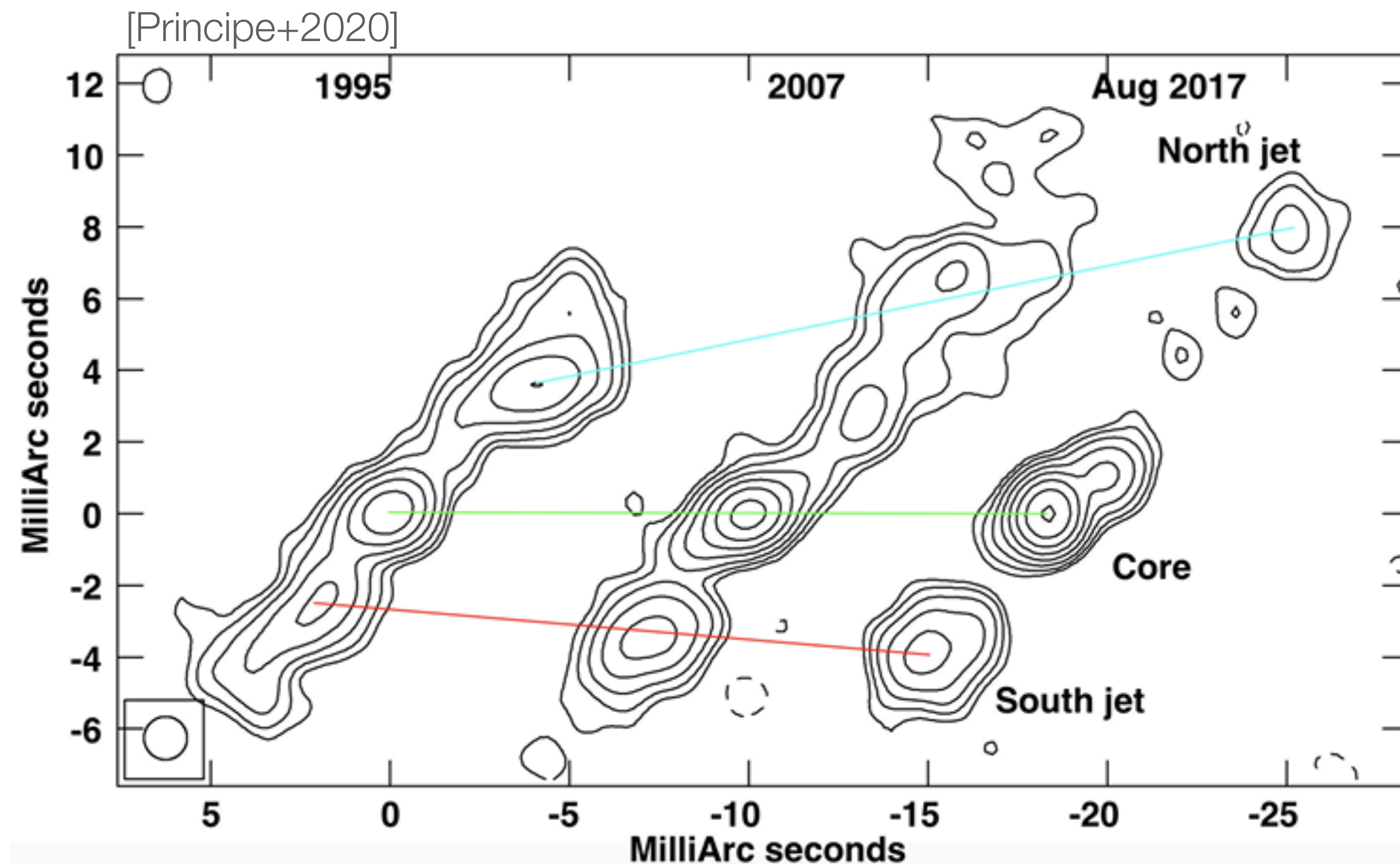


- Apparent bulk flow speed increases up to $11c$:
 - constraints on the jet viewing angle ($\theta_{\text{max}} \approx 10^\circ$) and bulk motions ($\Gamma_{\text{bulk}} \sim 5-15$)
- Acceleration zone extends to 11 pc ($\sim 5 \times 10^4 R_S$).

Synergies: young radio sources

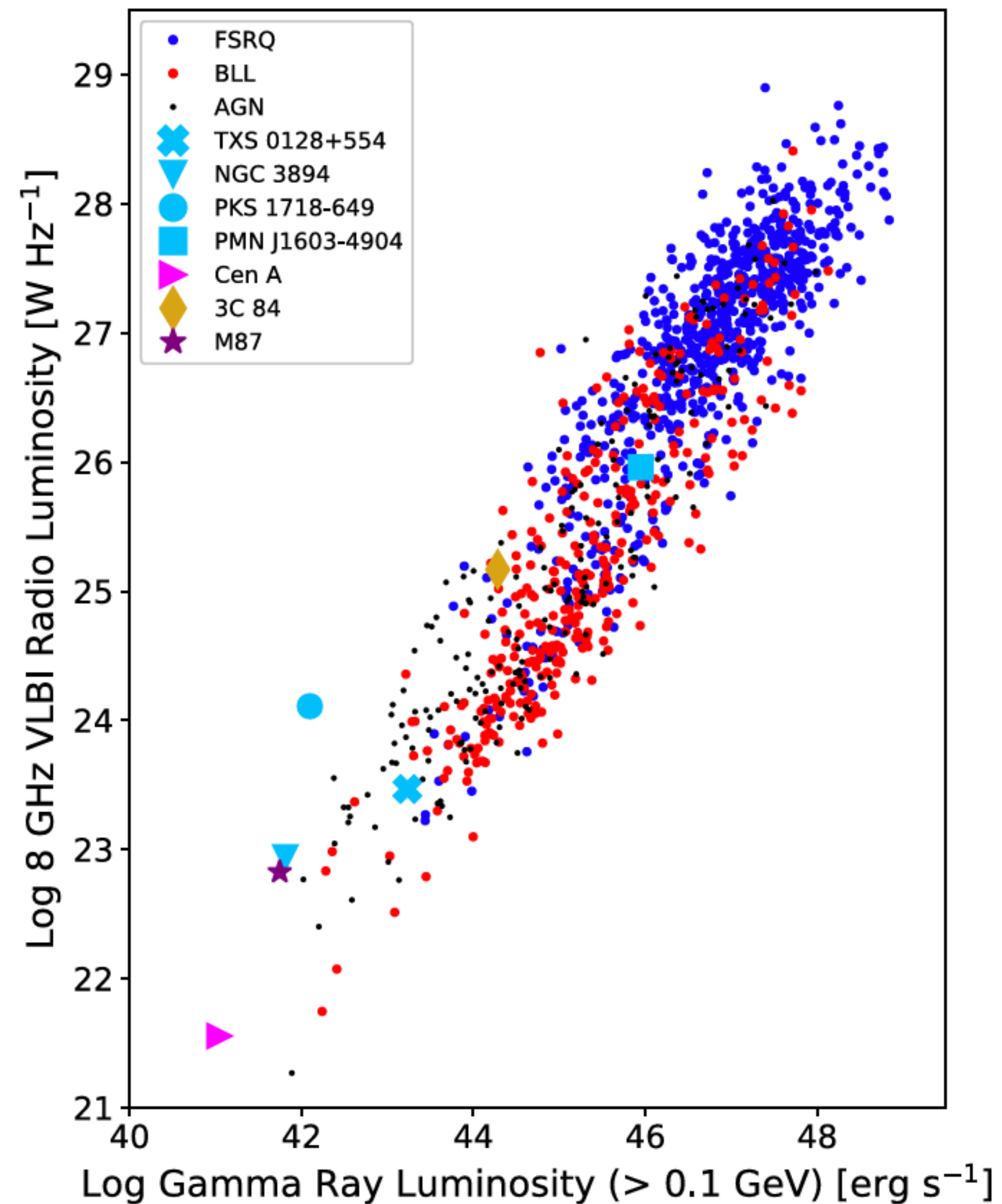
Compact Symmetric Objects (CSOs):

NGC3894 ($z=0.0108$, $t_{\text{kin}} \sim 60$ yr):



- gamma-rays $\rightarrow$ non-thermal HE output (SSC) of the mini-jets;
- X-rays from an inefficient accretion-flow (ADAF-like);
- Inferred jet power $L_{\text{jet}} \sim 10^{41-42}$ erg s $^{-1}$

Observations: gamma-rays



Gamma-ray detected CSOs:
relatively low radio powers in comparison
with other GPS/CSOs

[Lister+2020]