

IXPE's Breakthrough Observations of Blazars

I. Liodakis

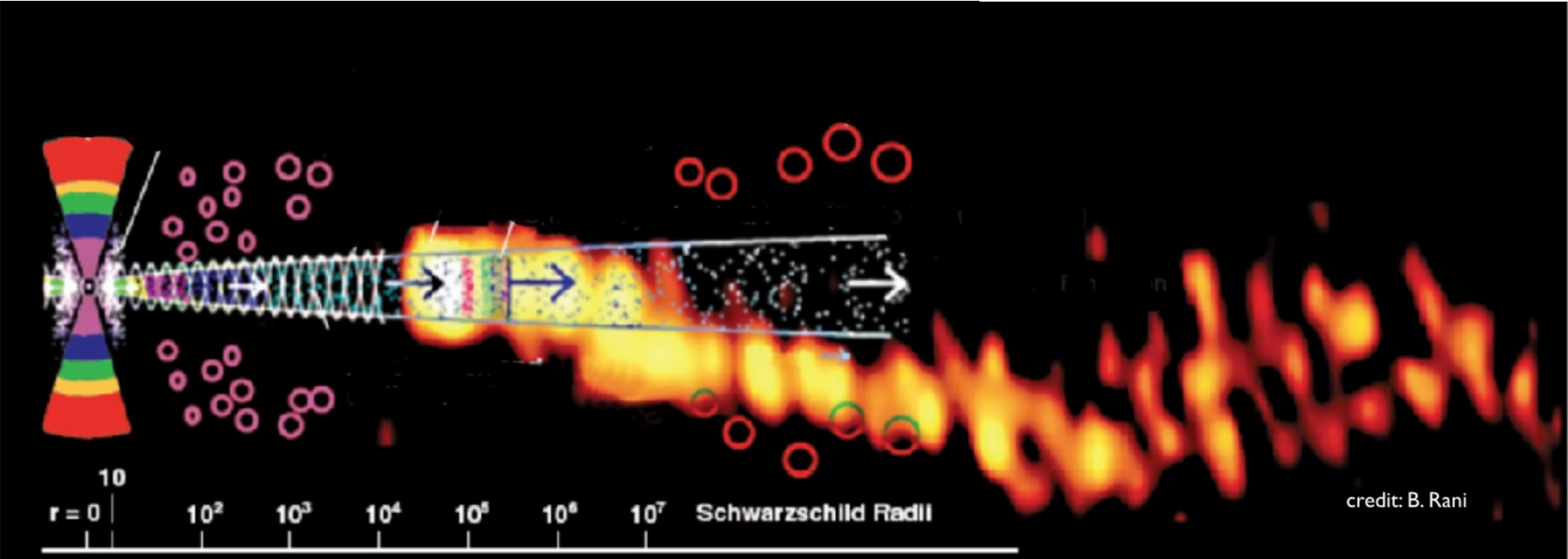
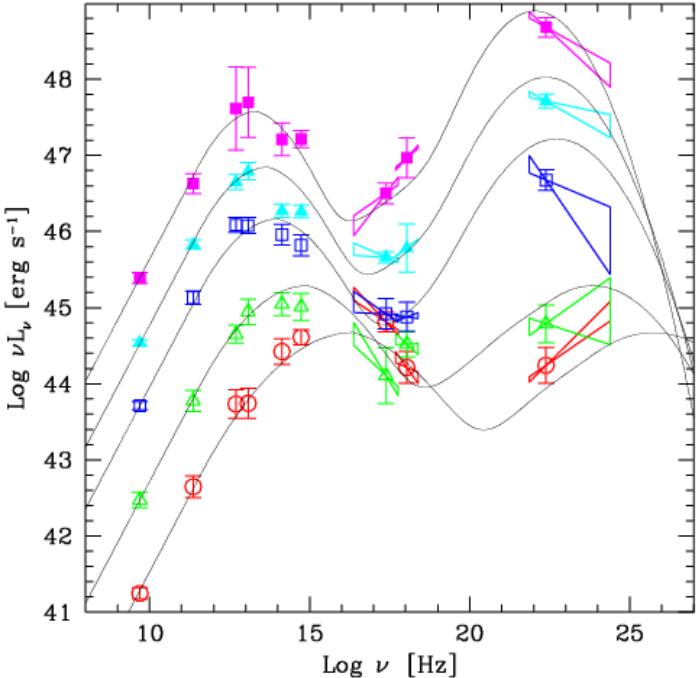
Institute of Astrophysics – FORTH



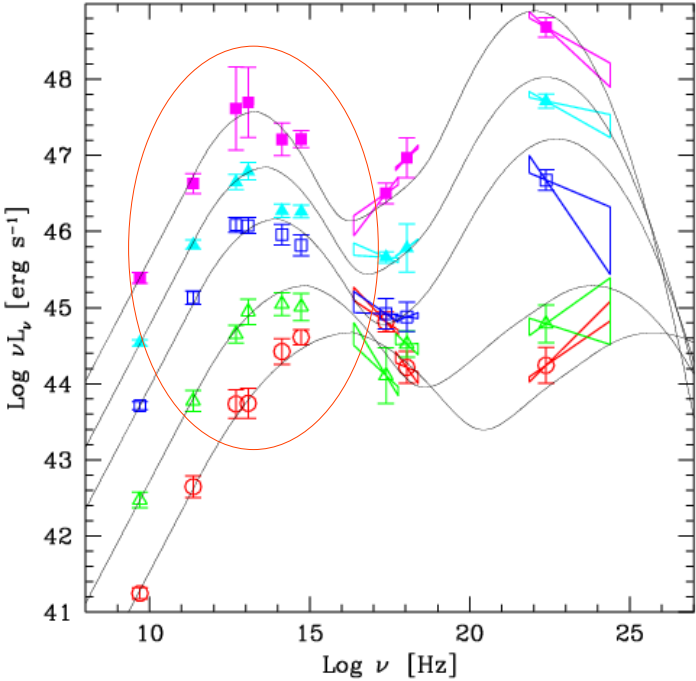
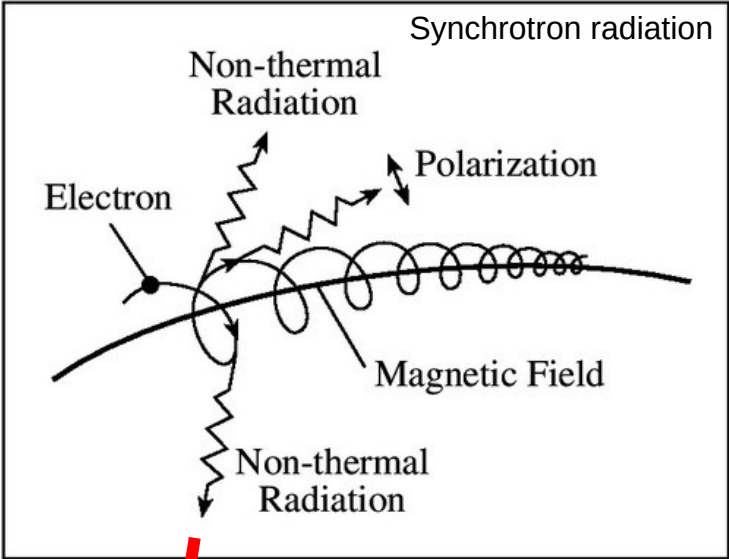
SCIENCE COMMUNICATION LAB



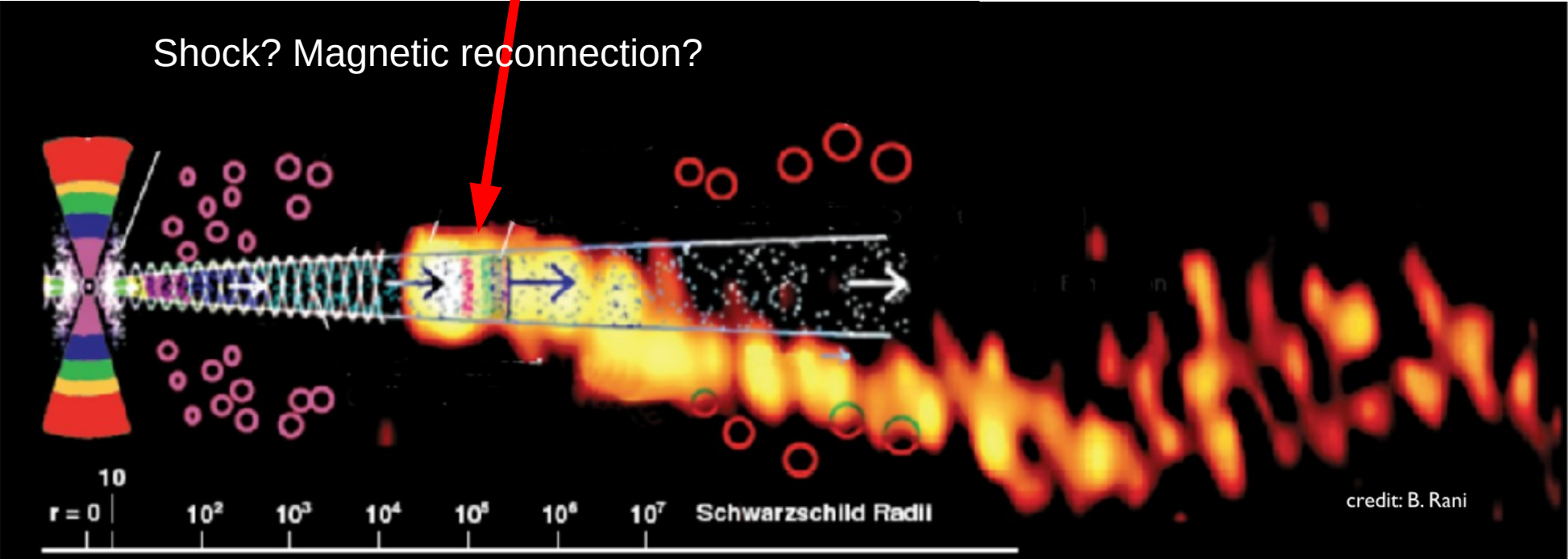
How do blazars make light?



How to blazars make light?

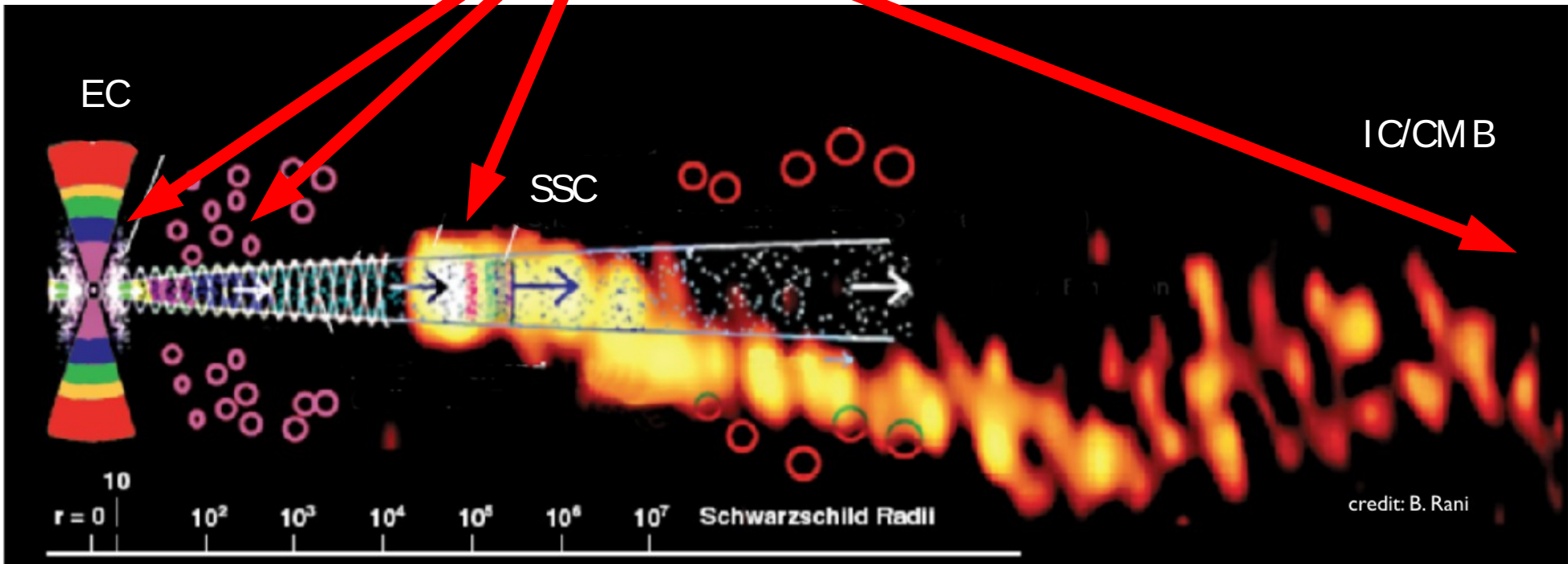
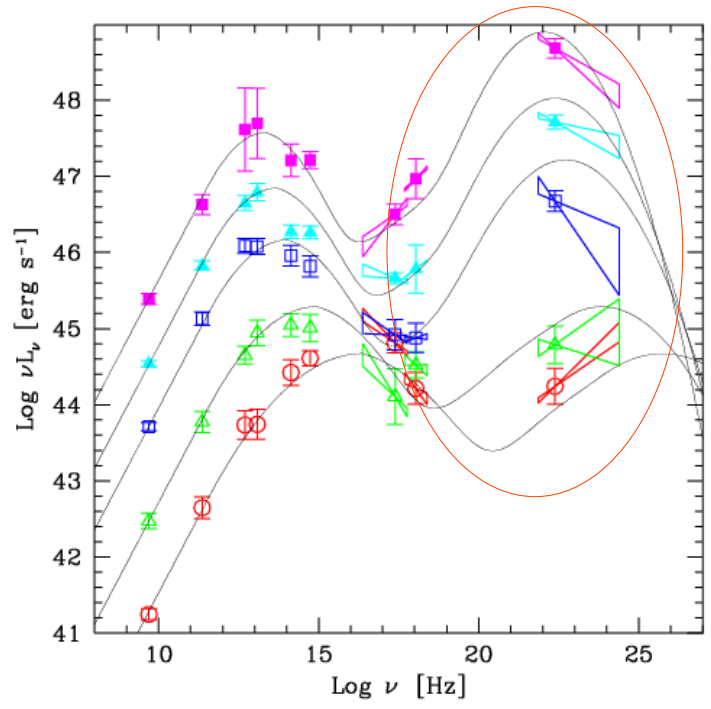
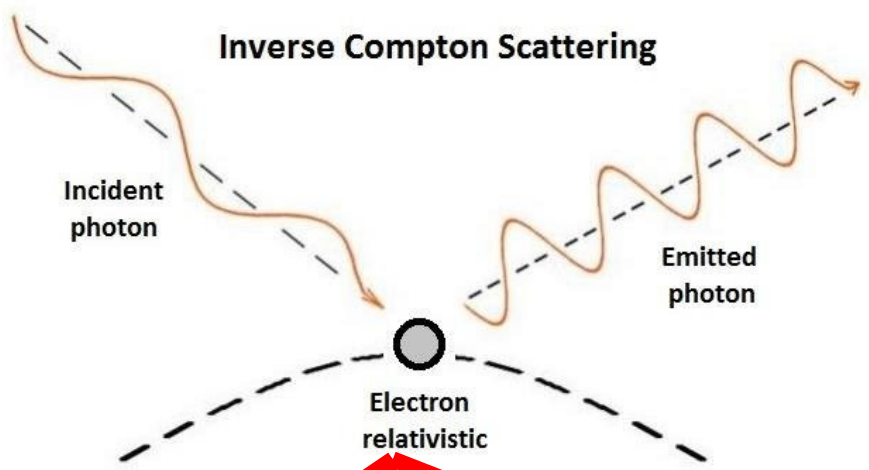


Shock? Magnetic reconnection?



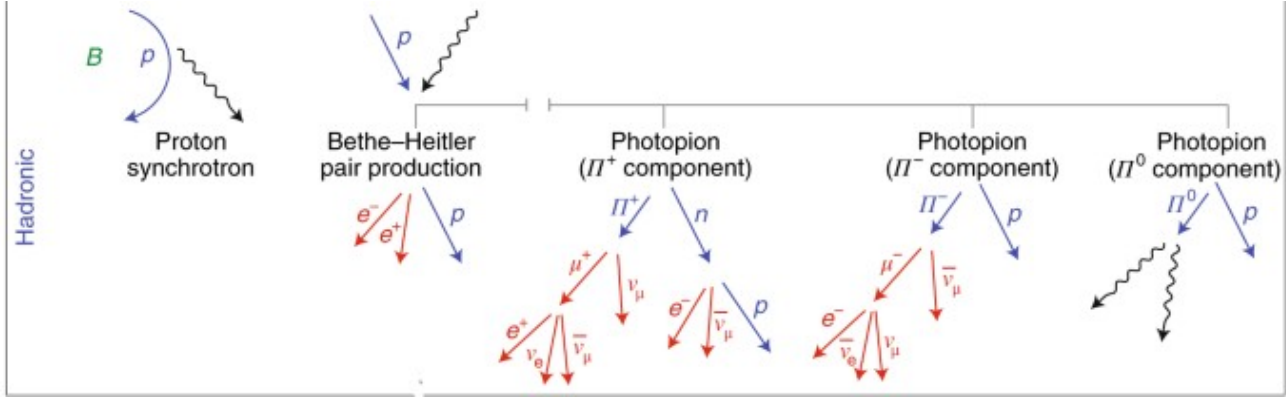
credit: B. Rani

How to blazars make light?

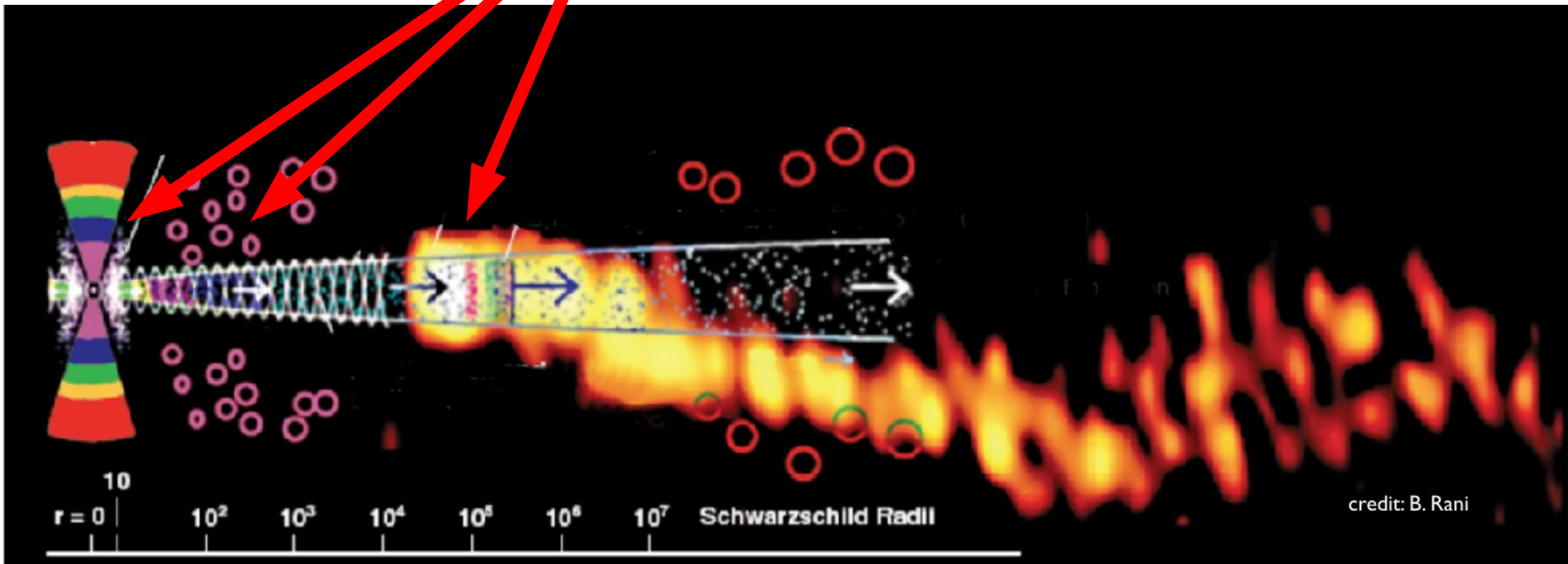
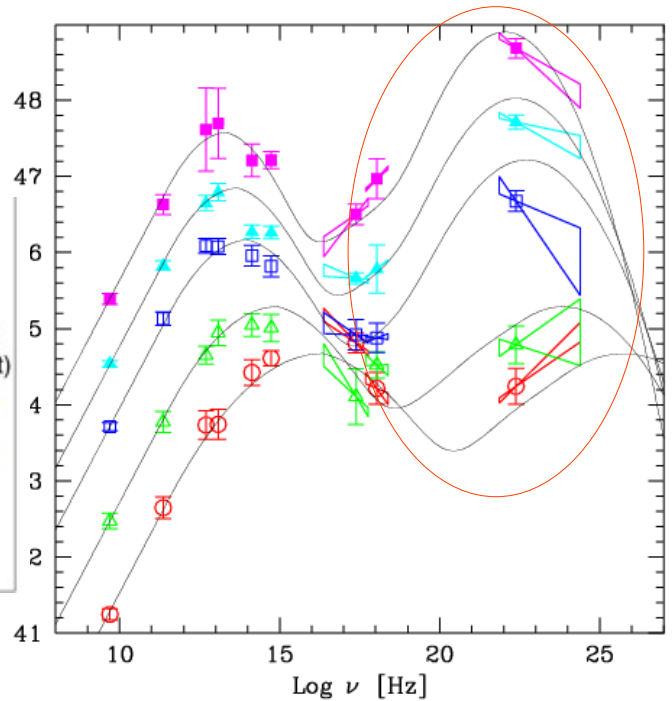


credit: B. Rani

How to blazars make light?



???



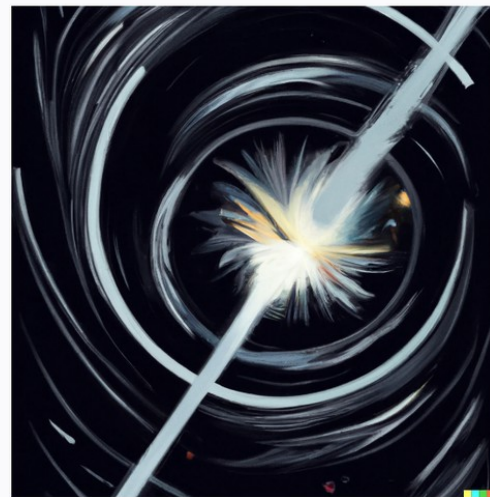
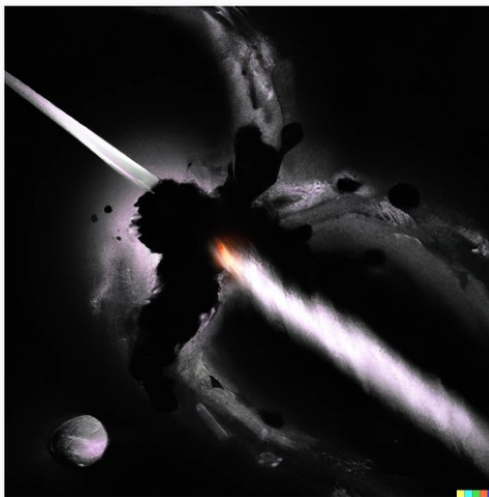
Blazar-IXPE key science question v1:

How are particles accelerated?

Blazar-IXPE key science question v2:

What is the origin of their high-energy emission?

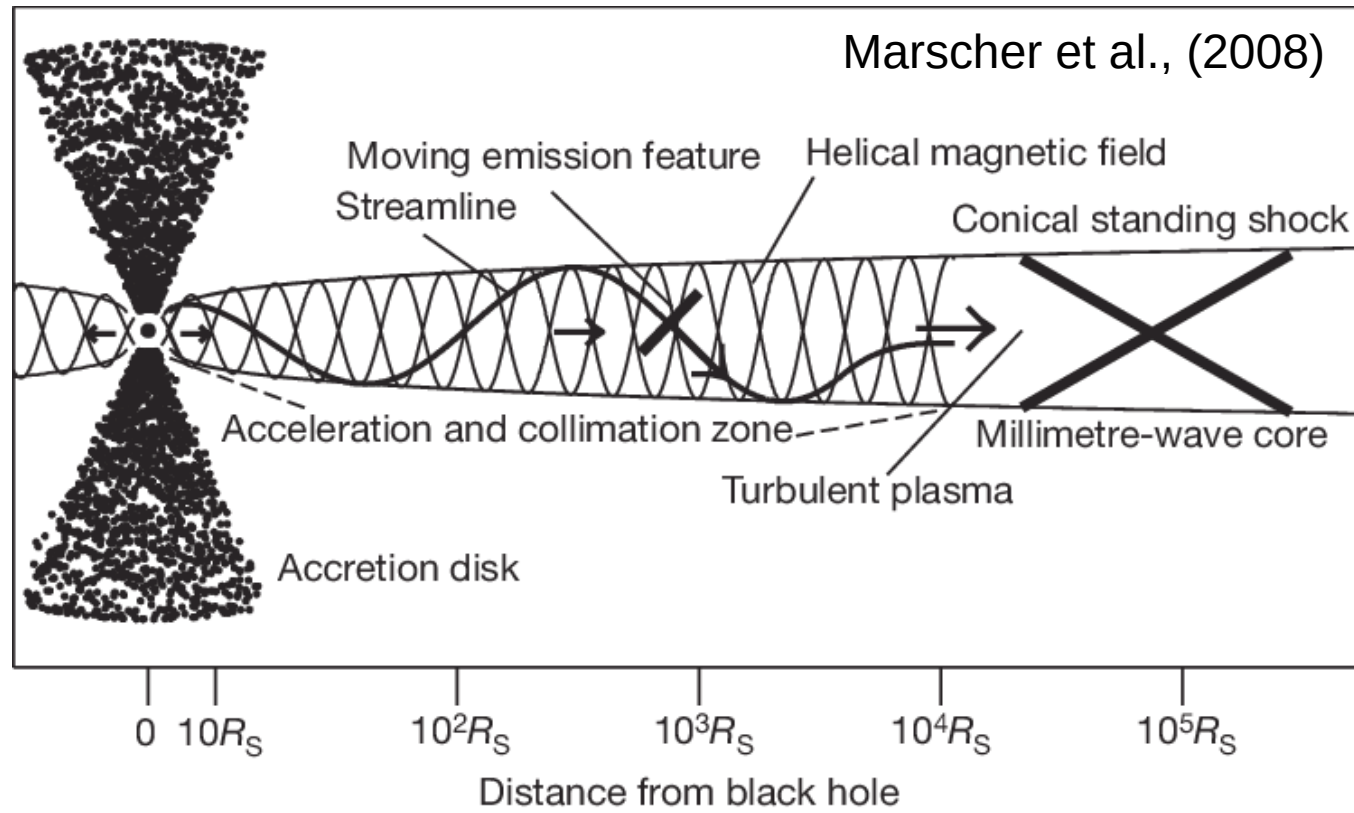
What is the composition of the jets?



How are particles accelerated?

Shocks?

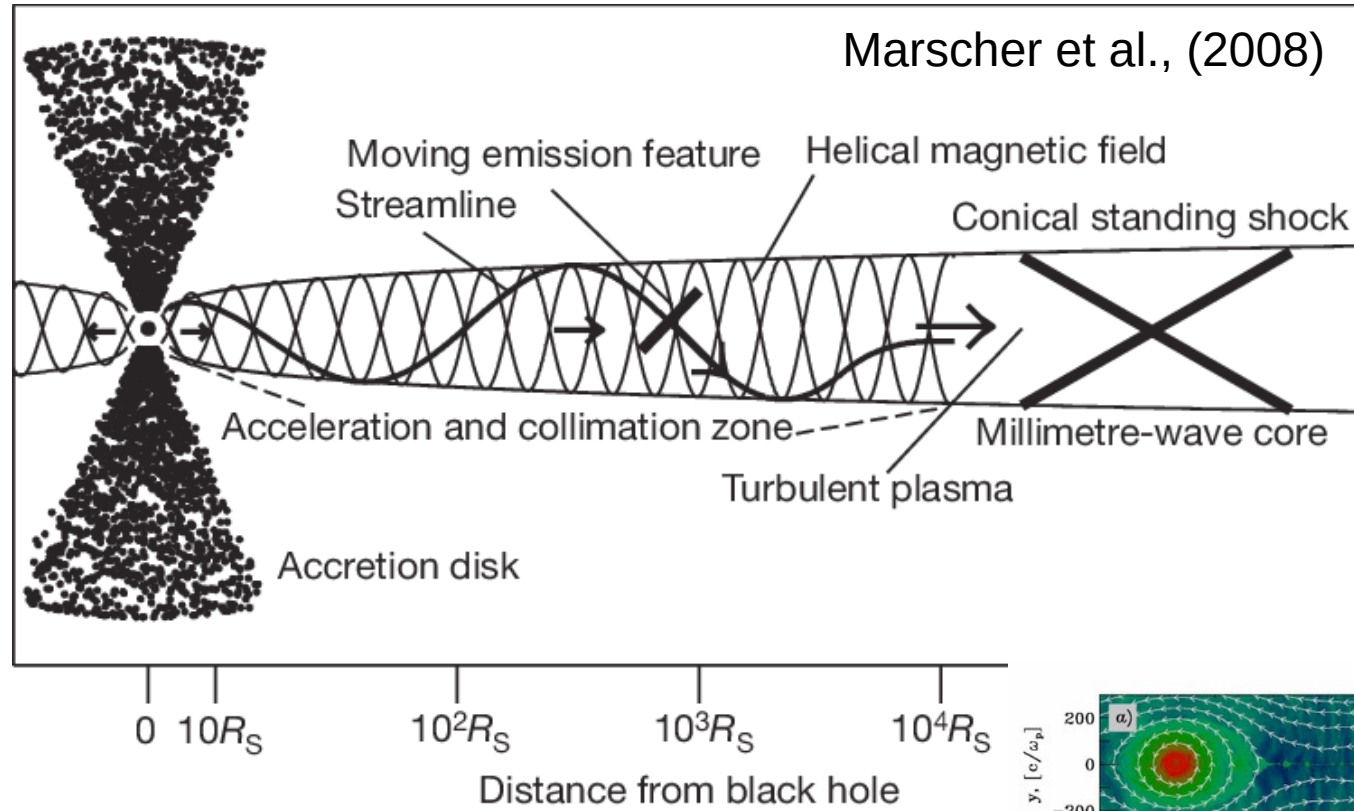
Marscher et al., (2008)



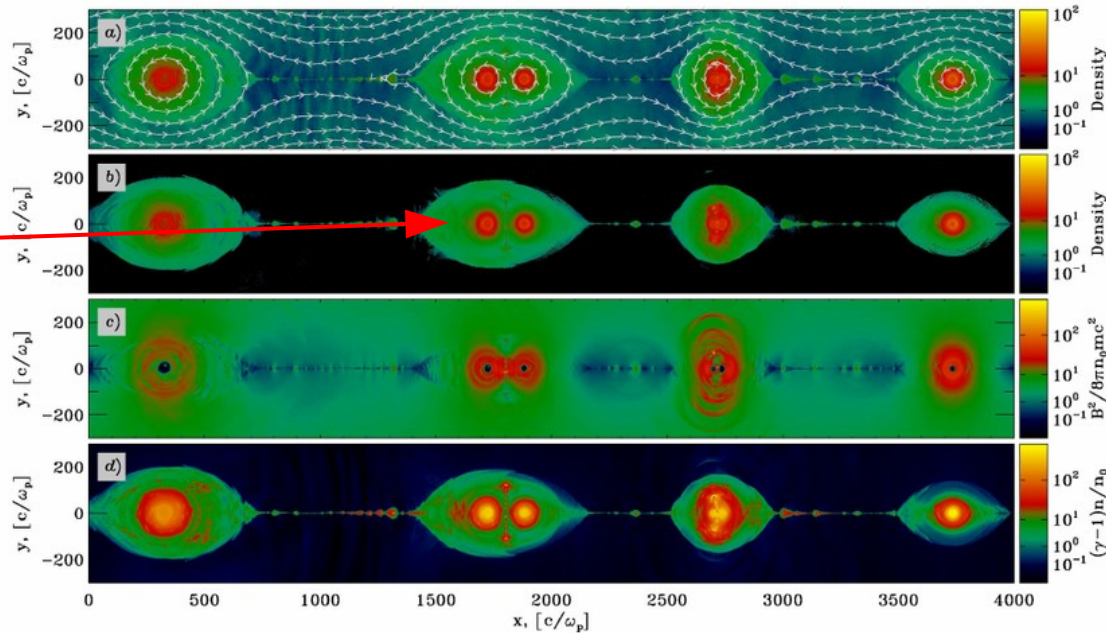
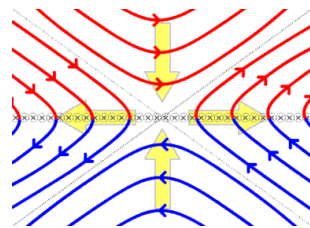
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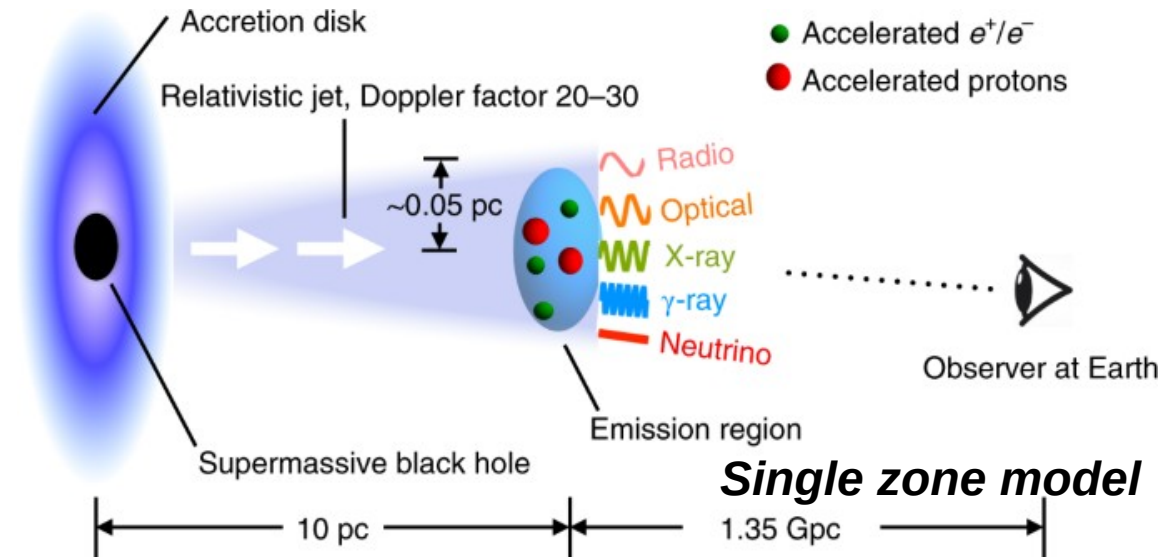


Magnetic reconnection?
Sironi et al., (2013)



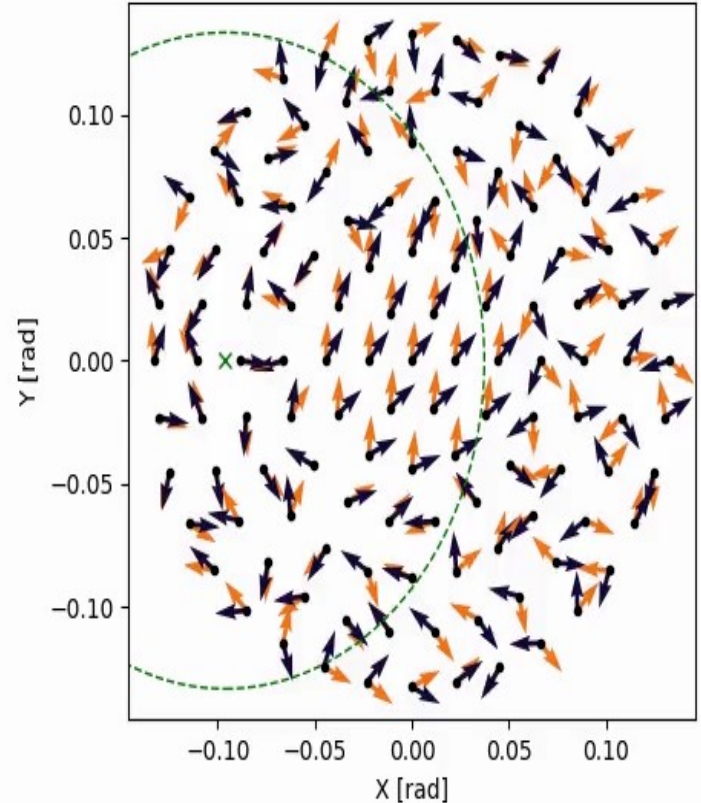
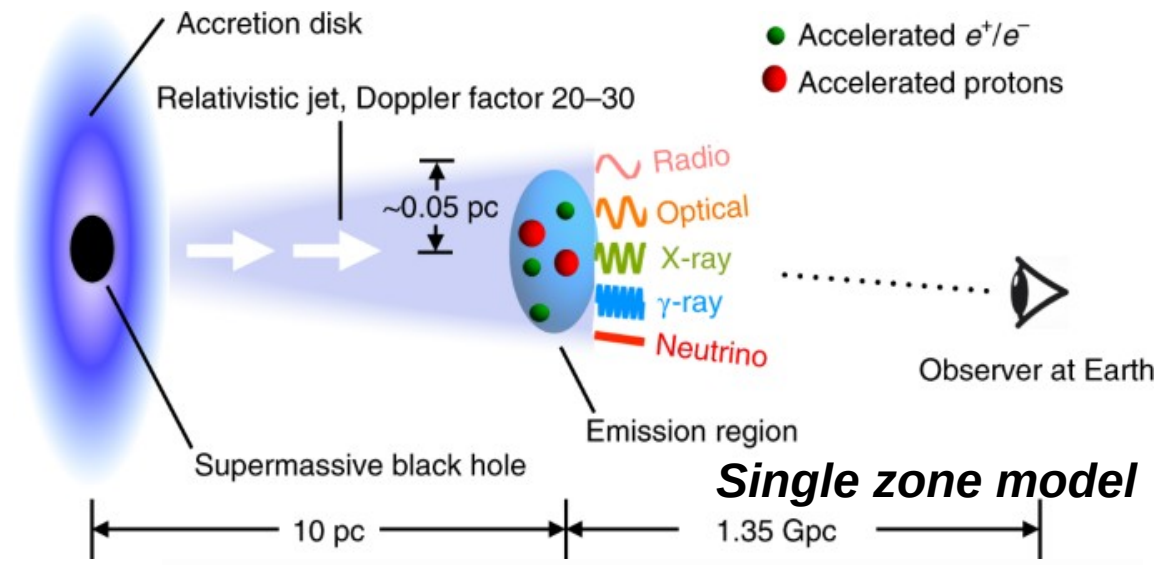
Models of particle acceleration in blazars

Image: Gao et al., (2018)



Models of particle acceleration in blazars

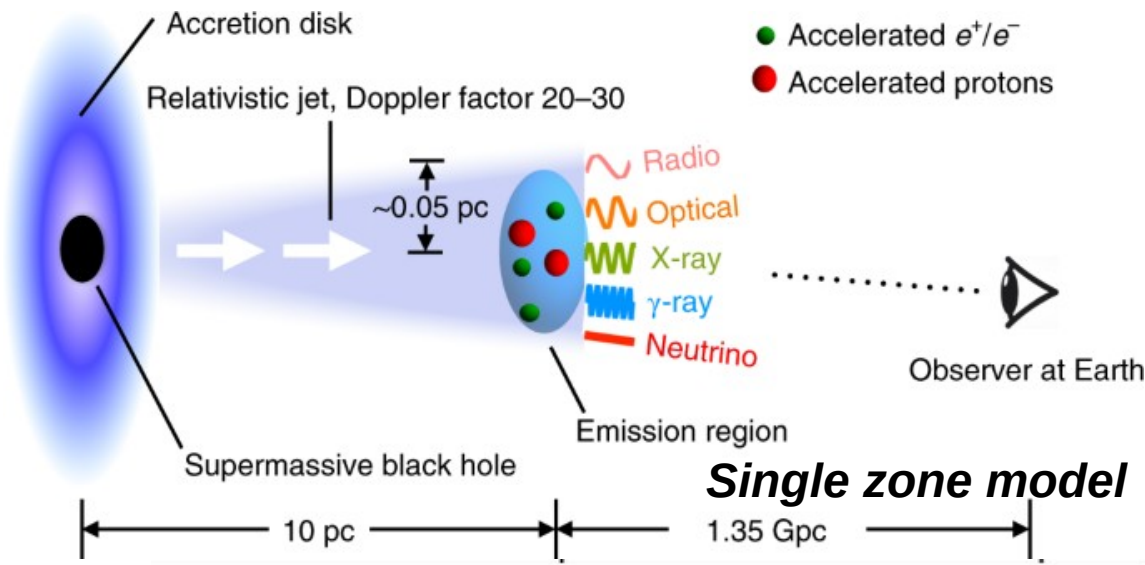
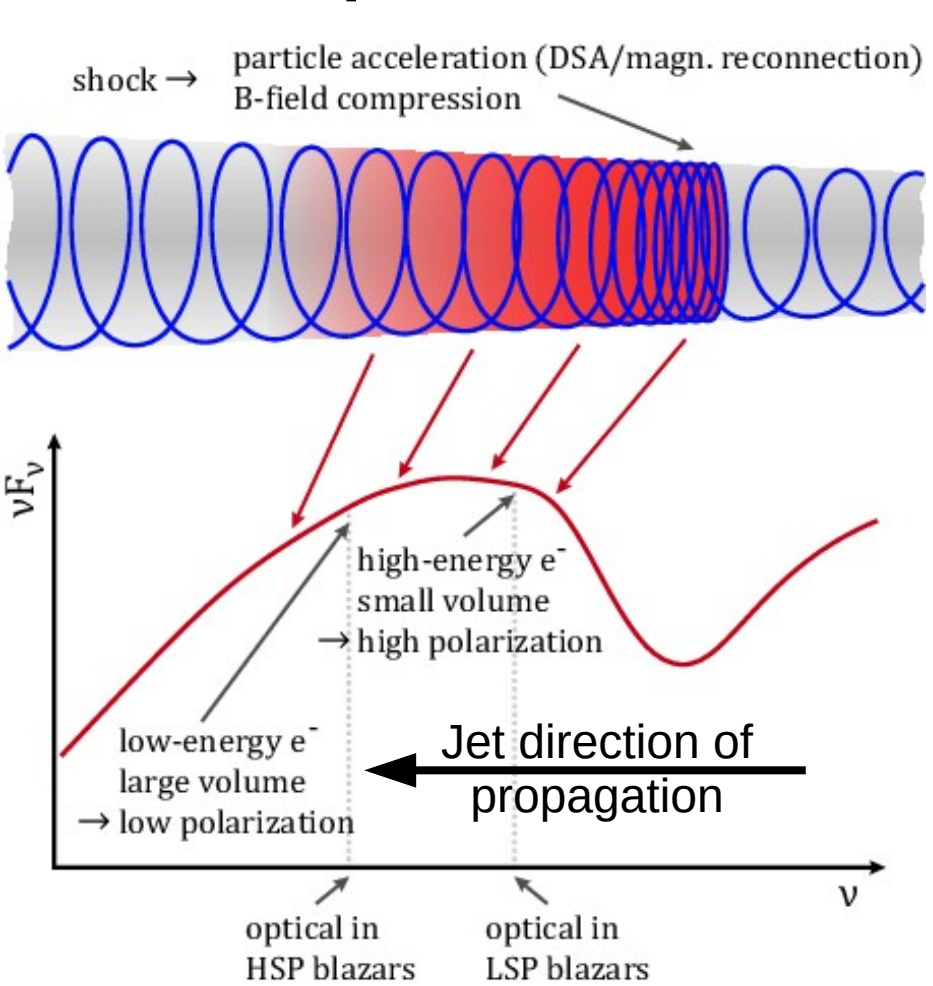
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Marscher (2014)
Peirson & Romani (2018,2019)

Models of particle acceleration in blazars

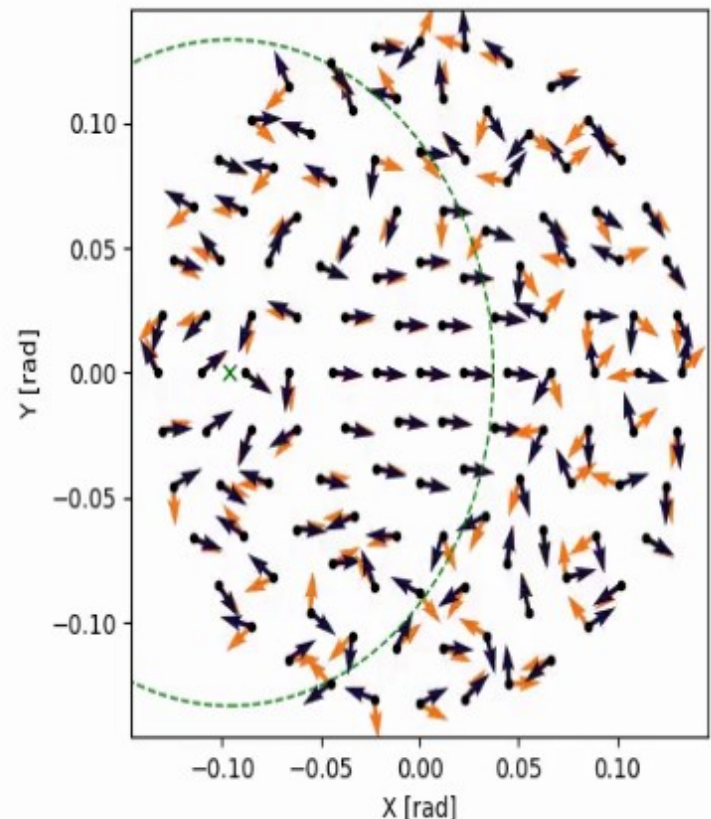
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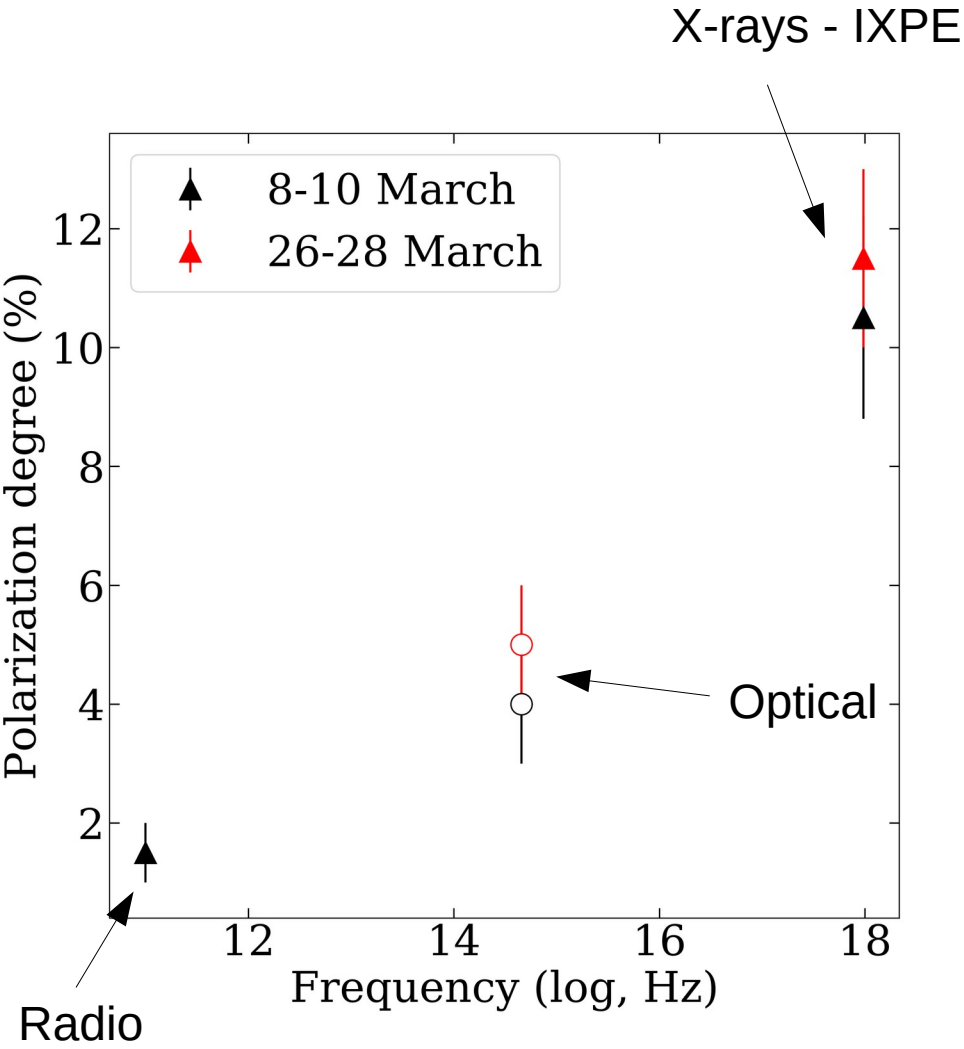
Energy-stratified electron population

Marscher & Gear (1985)
 Angelakis et al.[+Lioudakis] (2016)
 Tavecchio et al., (2018)

Marscher (2014)
 Peirson & Romani (2018,2019)

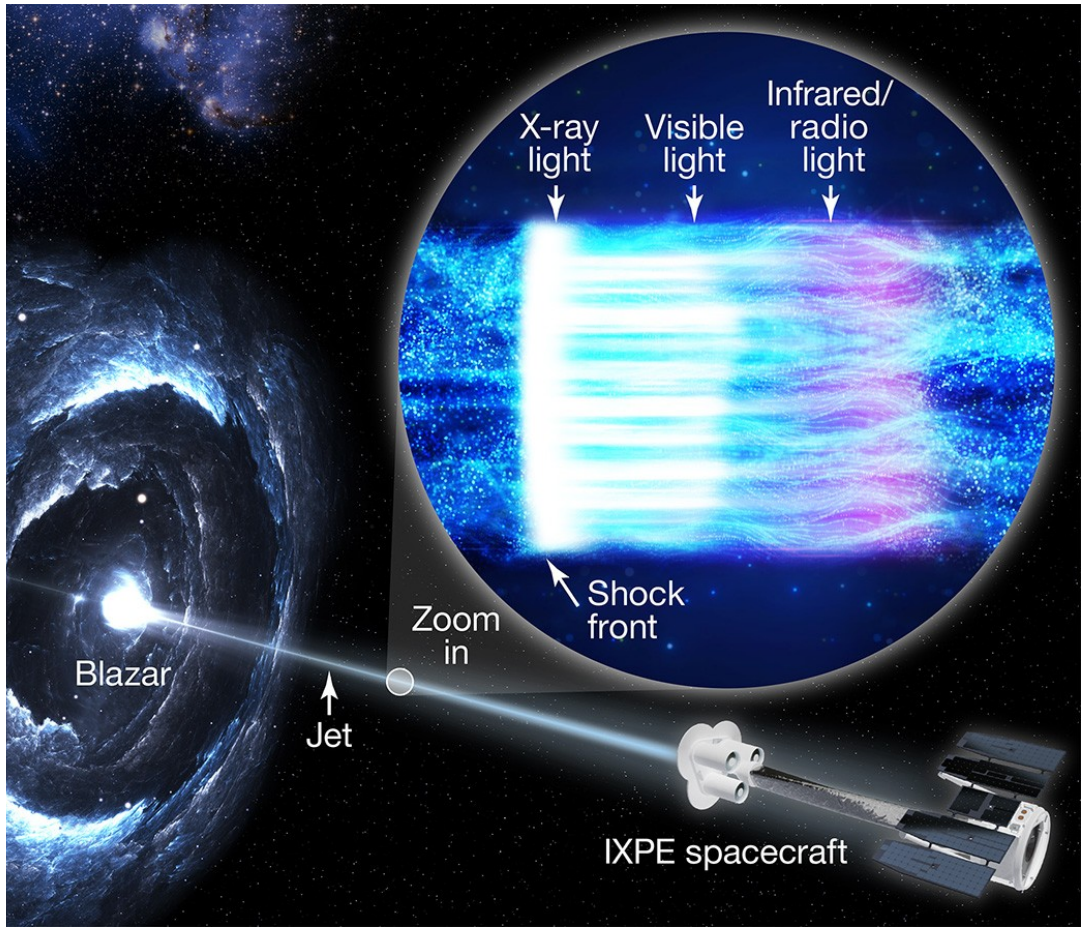
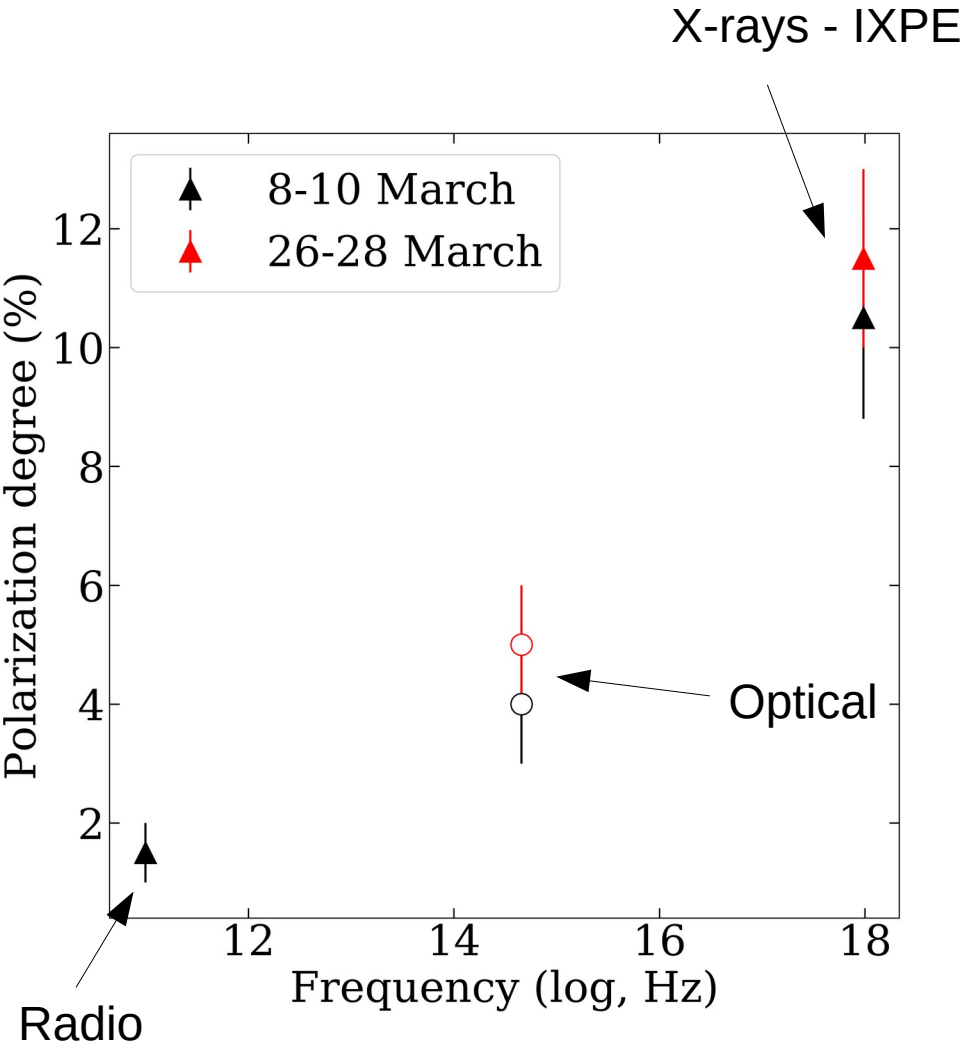


First detection of X-ray polarization from a supermassive black hole!



Markarian 501
Liodakis et al., (2022)

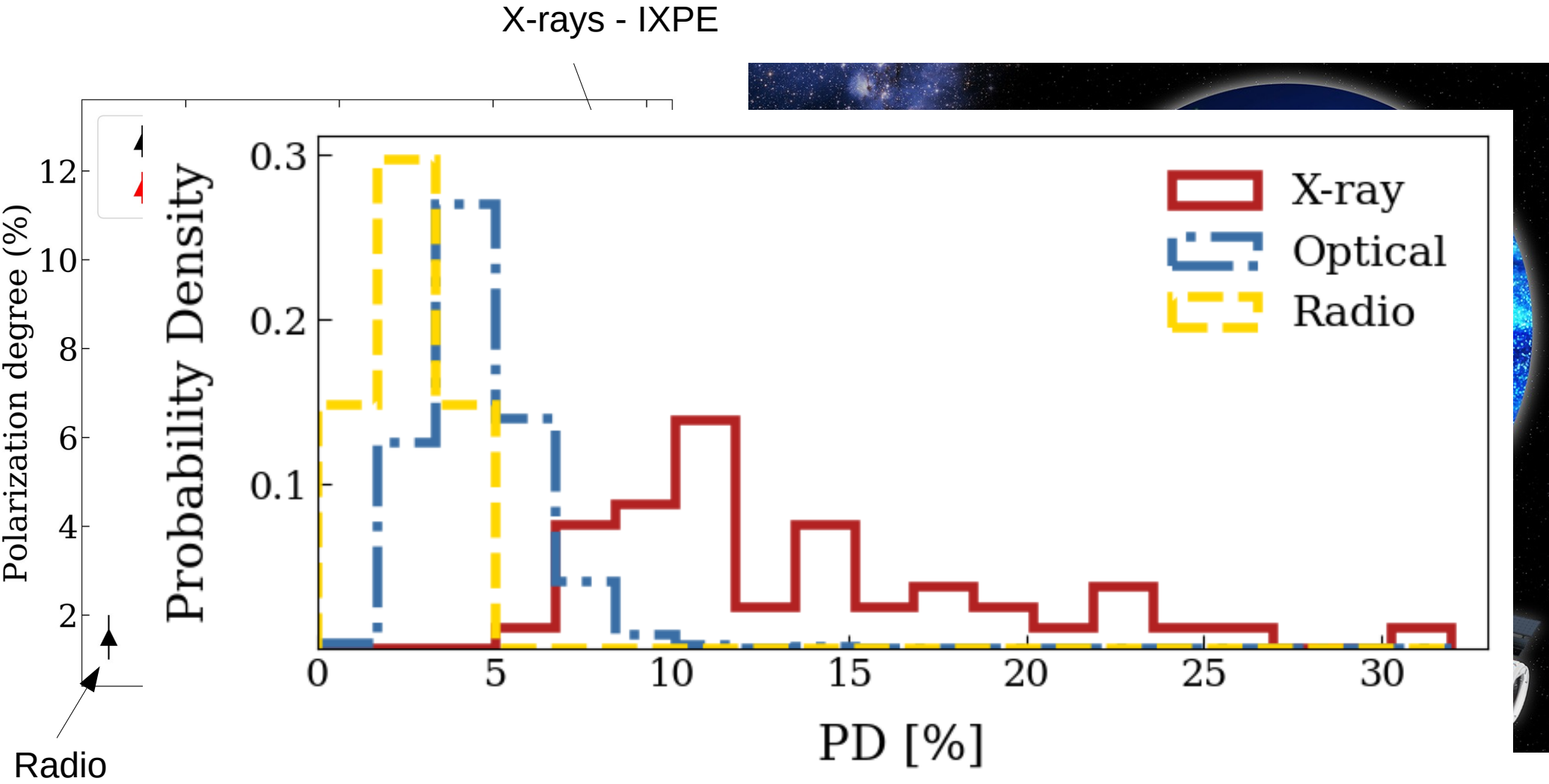
First detection of X-ray polarization from a supermassive black hole!



Credit: Pablo Garcia

Markarian 501
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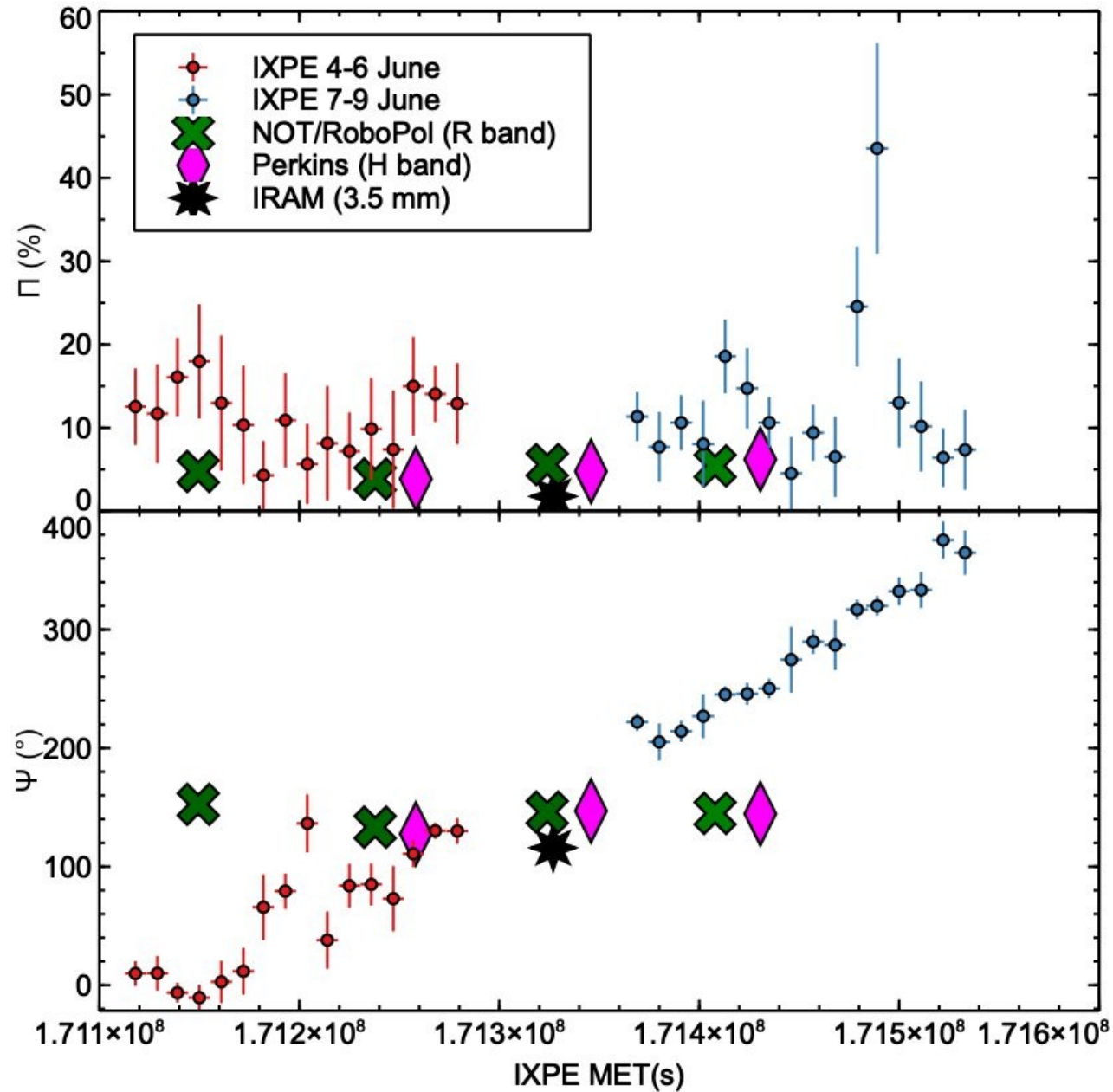
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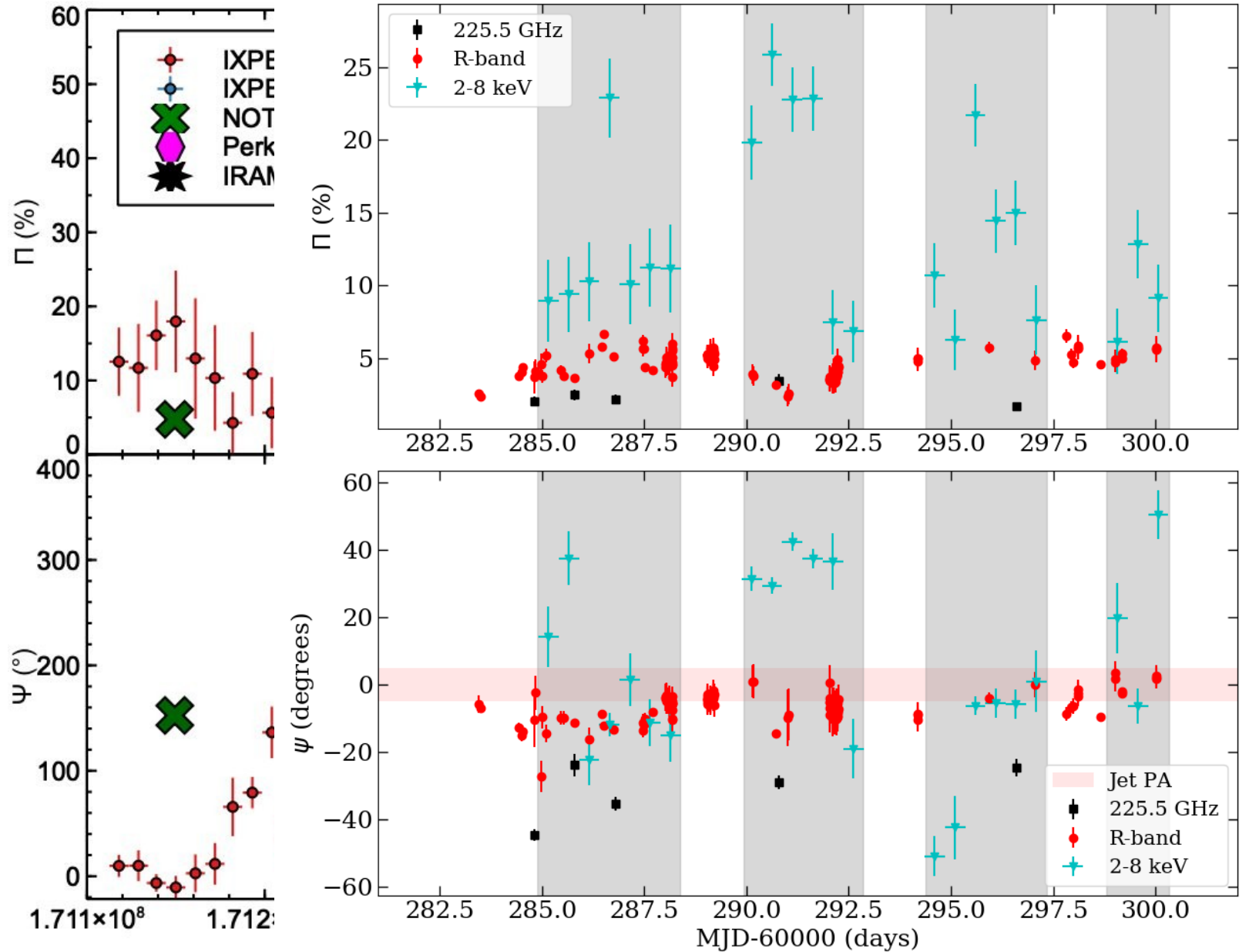
Markarian 501
Liodakis et al., (2022)

Capecchiacci, Liodakis et al., (2025)

First X-ray polarization angle rotation!



First X-ray polarization angle rotation!



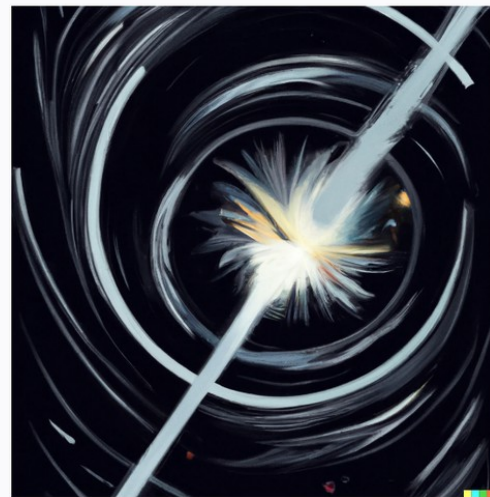
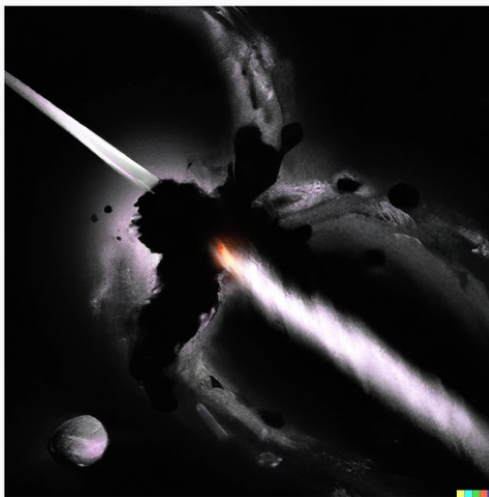
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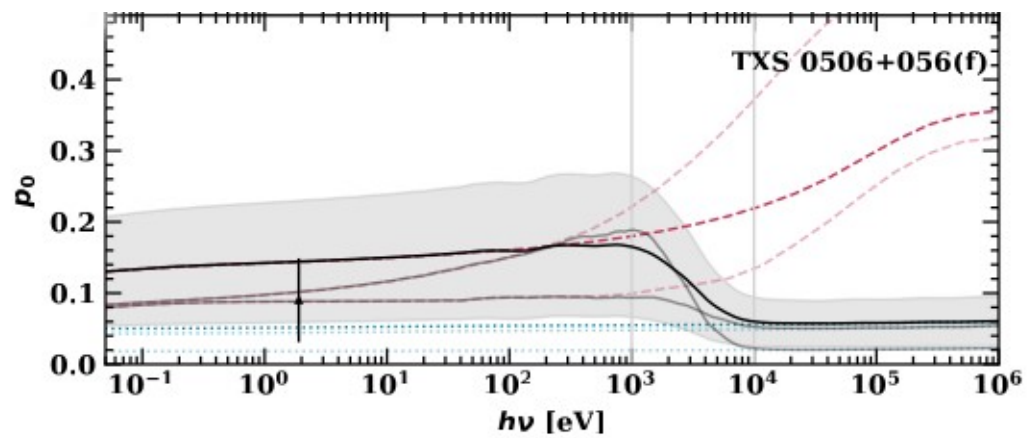
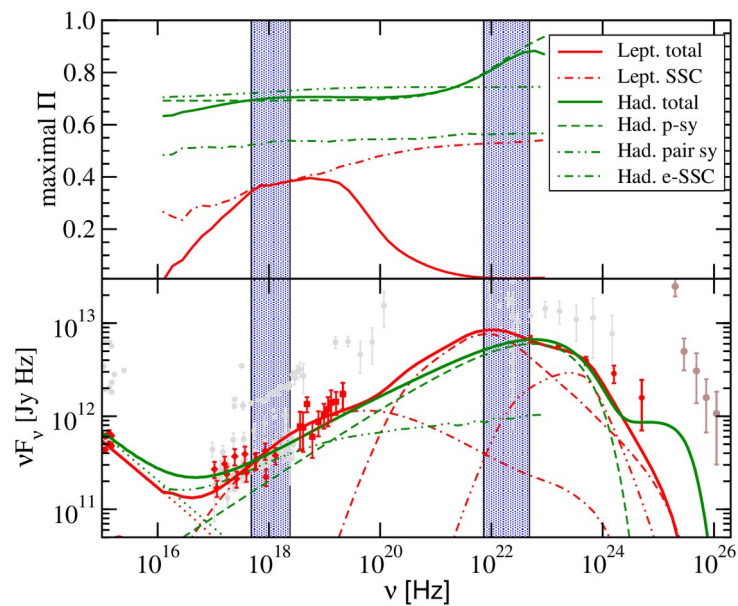
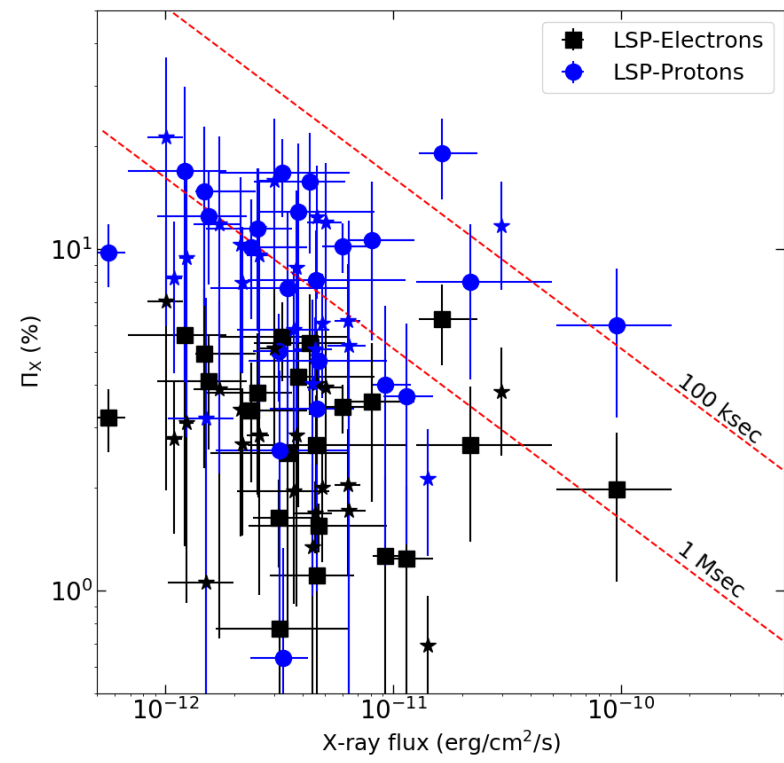
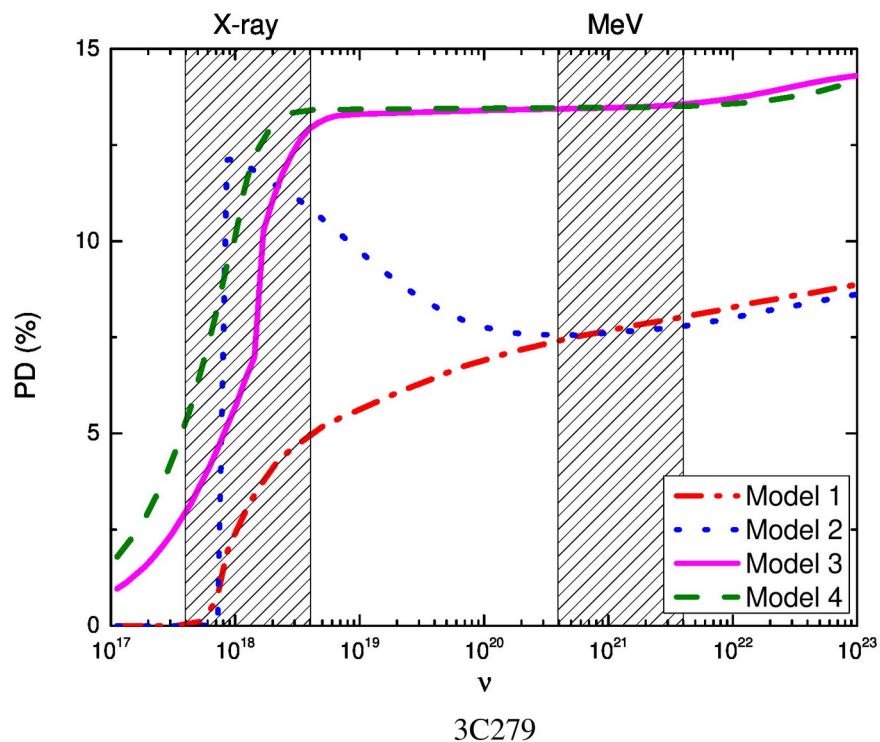
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High-energy polarization predictions.

Lioudakis et al., 2019

Peirson, Lioudakis et al., 2022



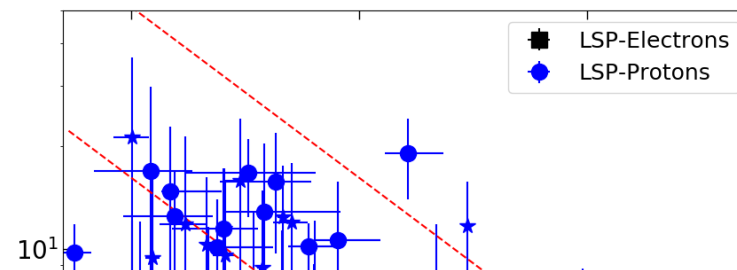
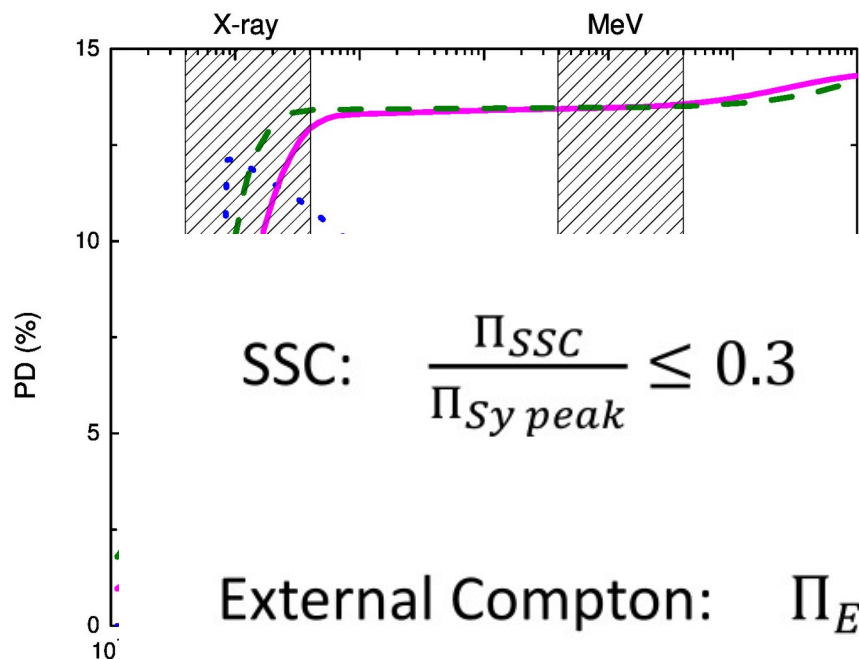
Zhang & Boettcher 2013

Zhang et al., 2019

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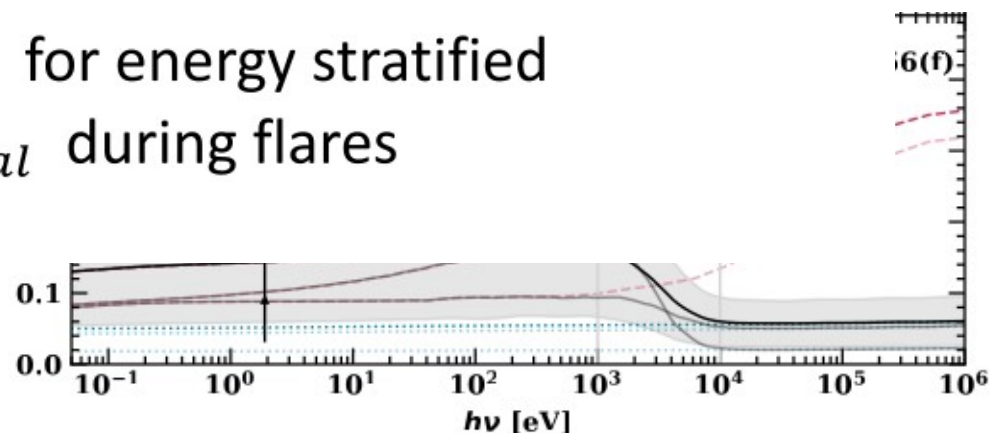
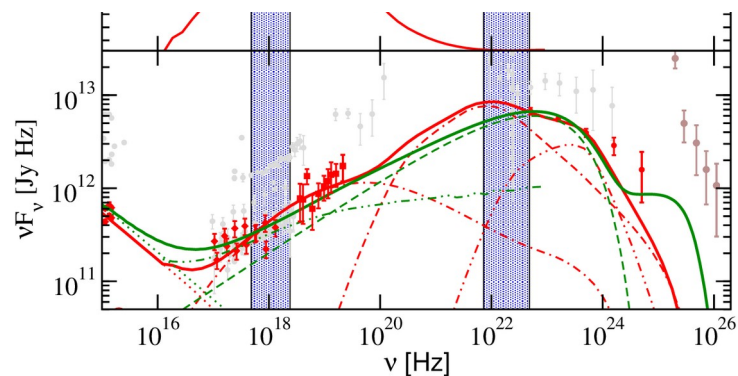
Peirson, Lioudakis et al., 2022



Zhang, Boettcher, Lioudakis 2024

Hadronic: $\Pi_{X, had} \approx \Pi_{radio}$ for energy stratified

$\Pi_{X, had} \approx \Pi_{optical}$ during flares



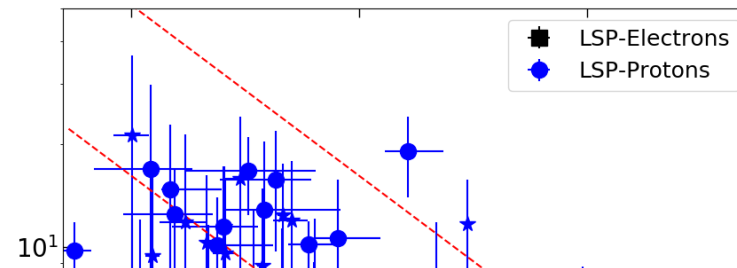
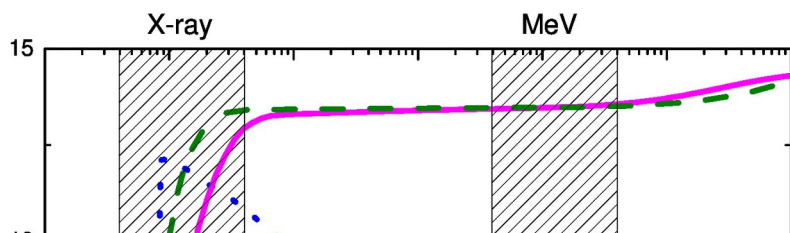
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PD (%)

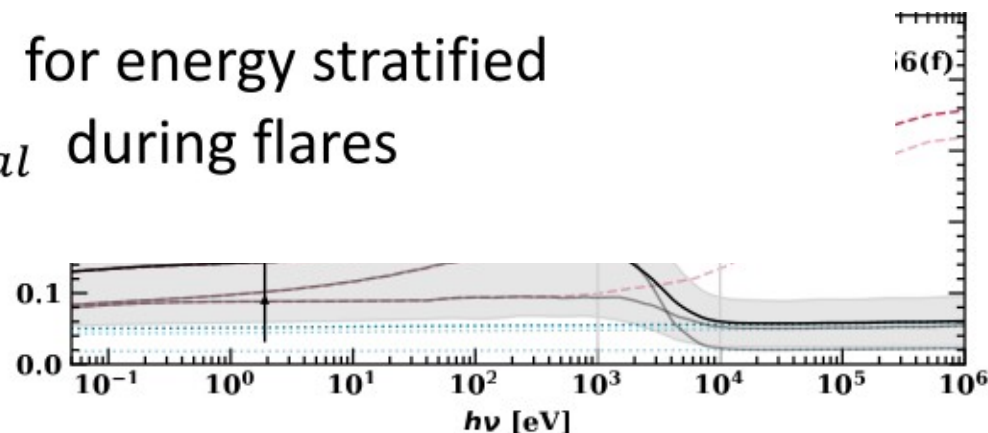
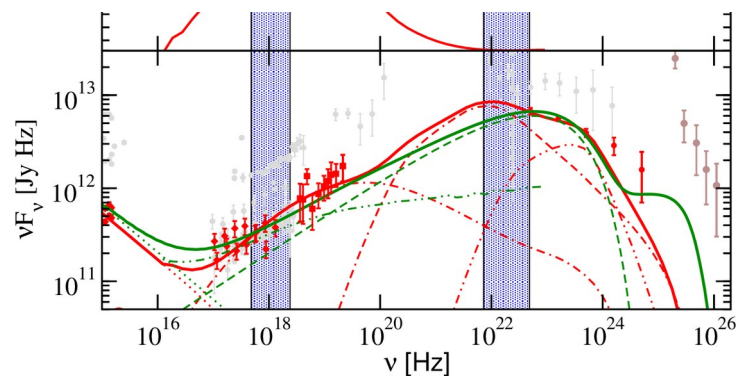
$$\text{SSC: } \frac{\Pi_{SSC}}{\Pi_{Sy\ peak}} \leq 0.3$$

External Compton: $\Pi_{EC} = 0$ if seed photons are unpolarized

Zhang, Boettcher, Lioudakis 2024

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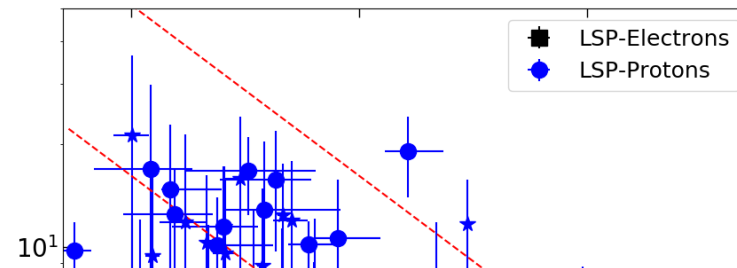
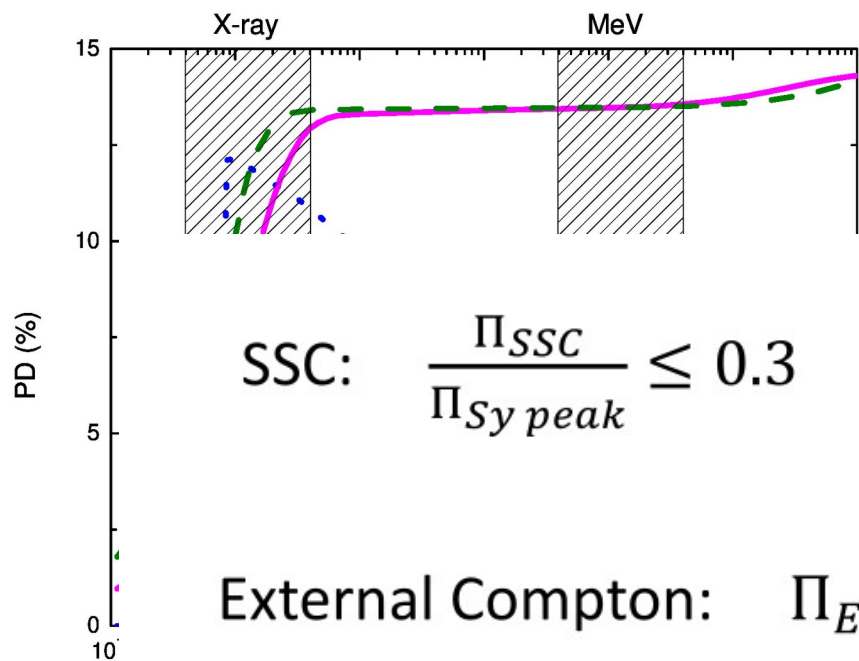


Zhang & Boettcher 2013
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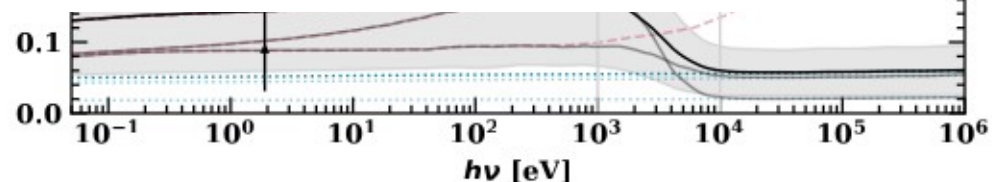
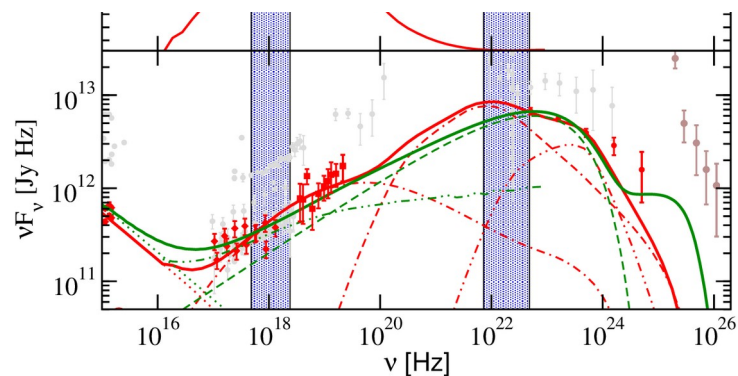
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Zhang & Boettcher 2013
 Zhang et al., 2019

IXPE observations so far:

3C 454.3 (x2)

3C 273

3C 279

S5 0716+714

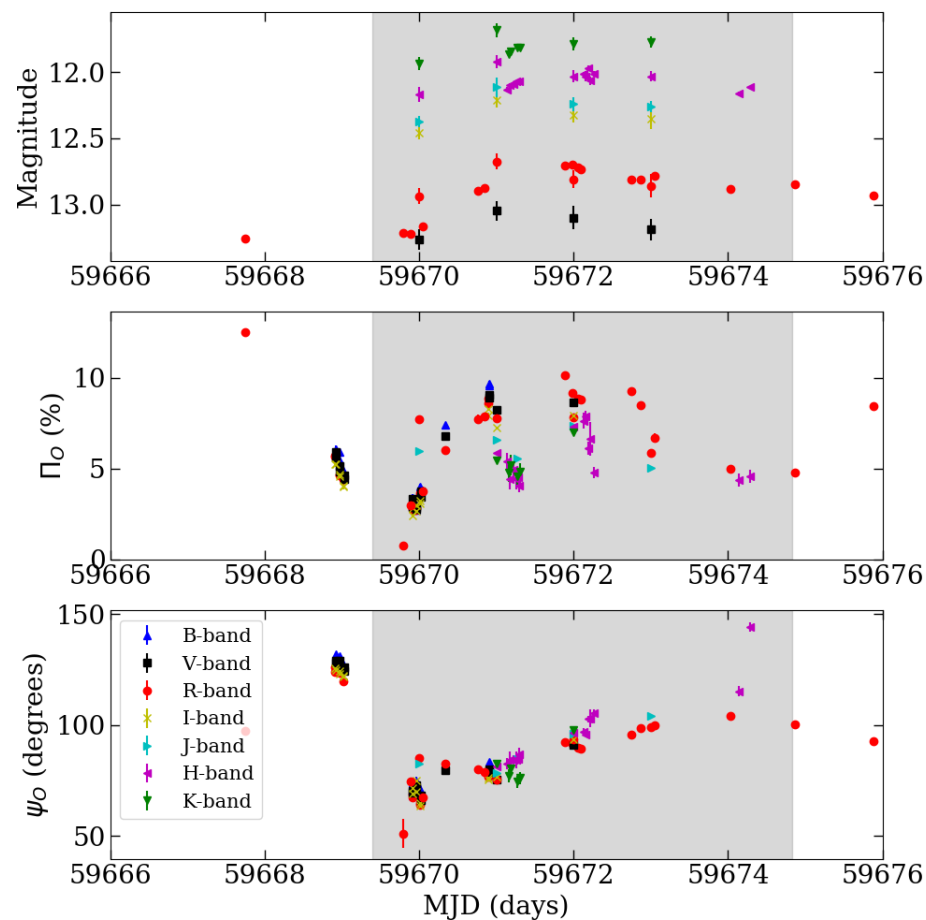
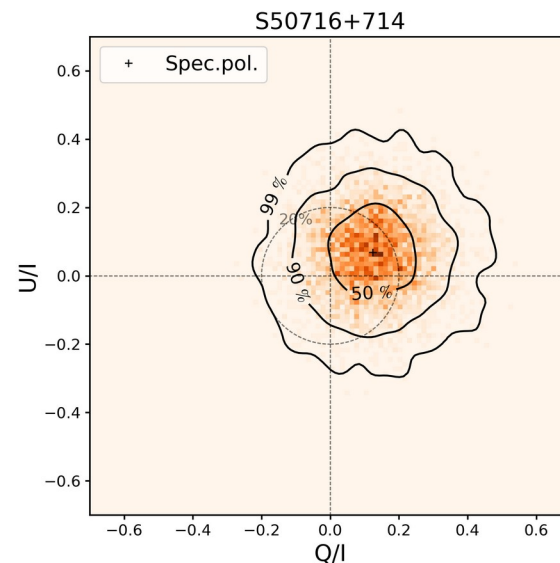
BL Lac (x4)

S4 0954+65

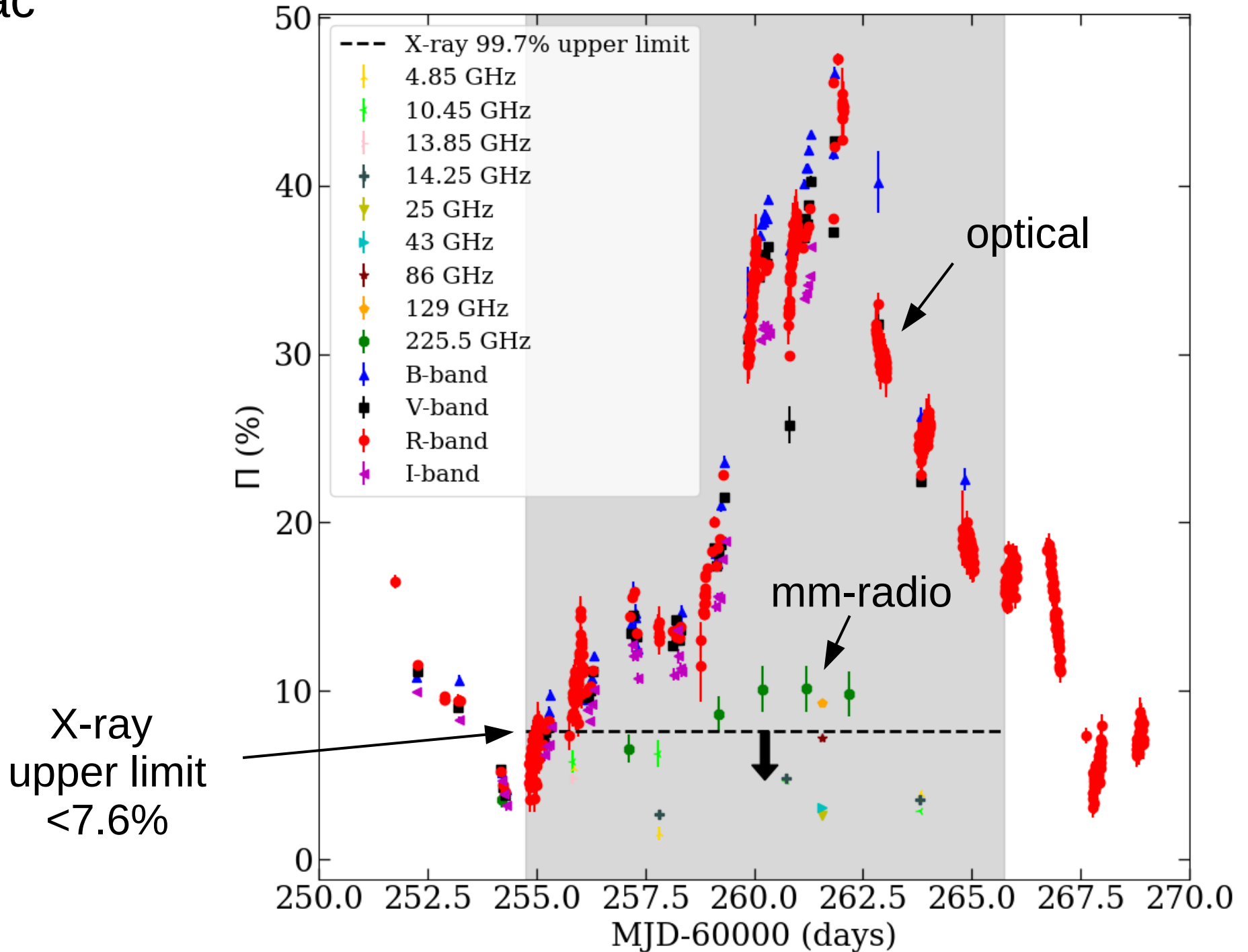
The X-ray polarization remains undetected at typically $<15\%$

Middel, Liodakis et al., 2023

Marshall, Liodakis et al., 2024



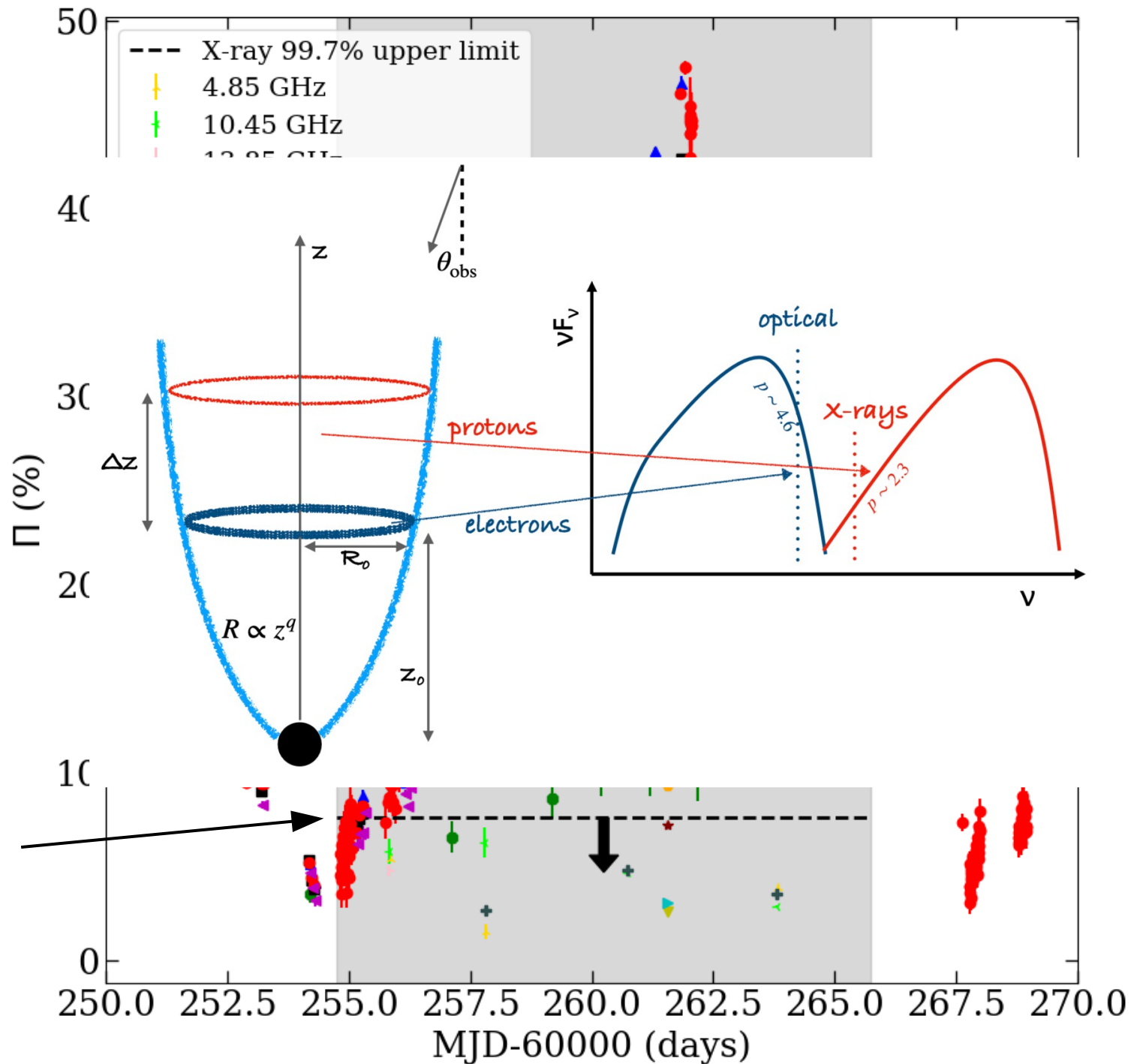
BL Lac



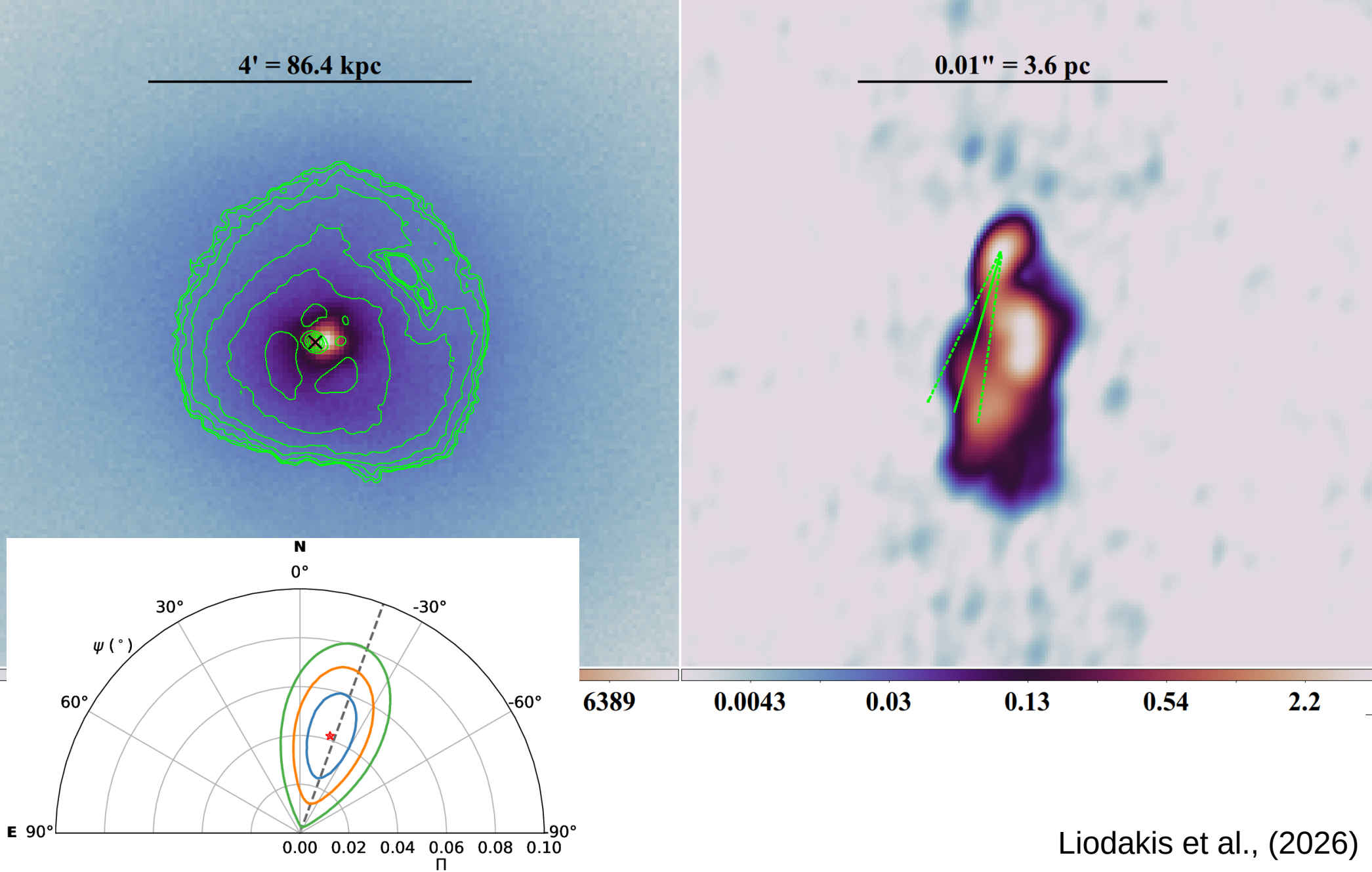
BL Lac

See Tavecchio et al., 2025 for alternative interpretation

X-ray upper limit <7.6%



First detection of Compton Scattering in 3C 84





Take home messages (for now...)

Synchrotron mission in blazars is energy stratified!
(and likely comes from shocks...)

X-rays in blazars likely come from electrons
(likely Sychrotron Self-Compton...)

**More MWL campaigns are necessary and especially
finding more PA rotations...**