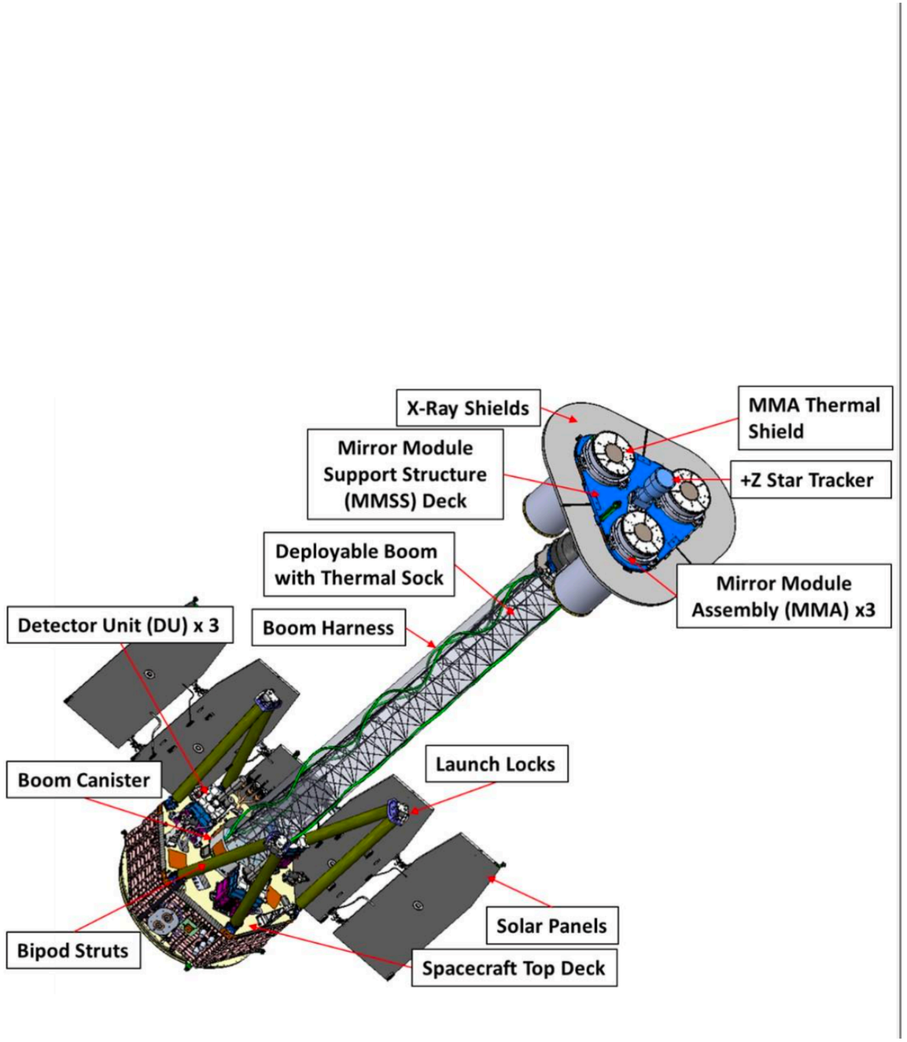
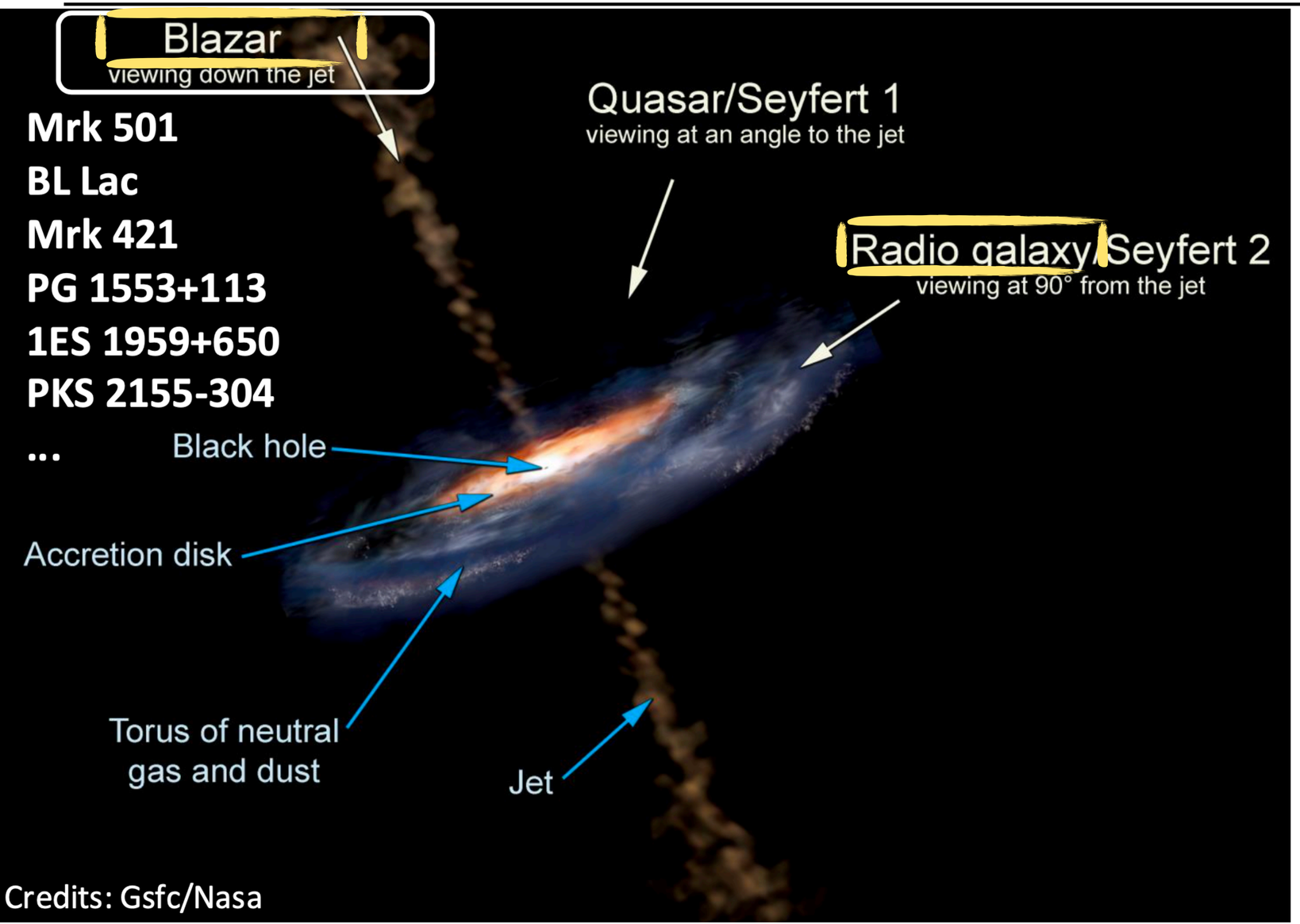

IXPE
Imaging
X-Ray
Polarimetry
Explorer
Marshall Space Flight Center
Agenzia Spaziale Italiana
On the polarized light from active galactic nuclei observed by IXPE
Riccardo Middei
OAR
SSDC
SPACE SCIENCE DATA CENTER

# The “first” X-ray polarized light

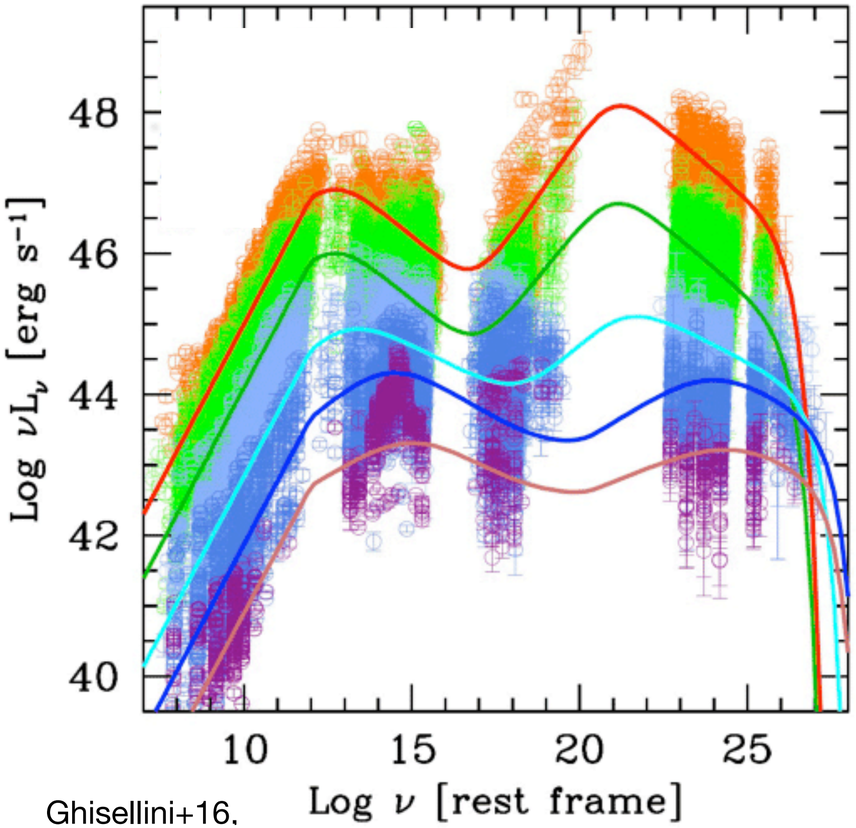



# Active Galactic Nuclei



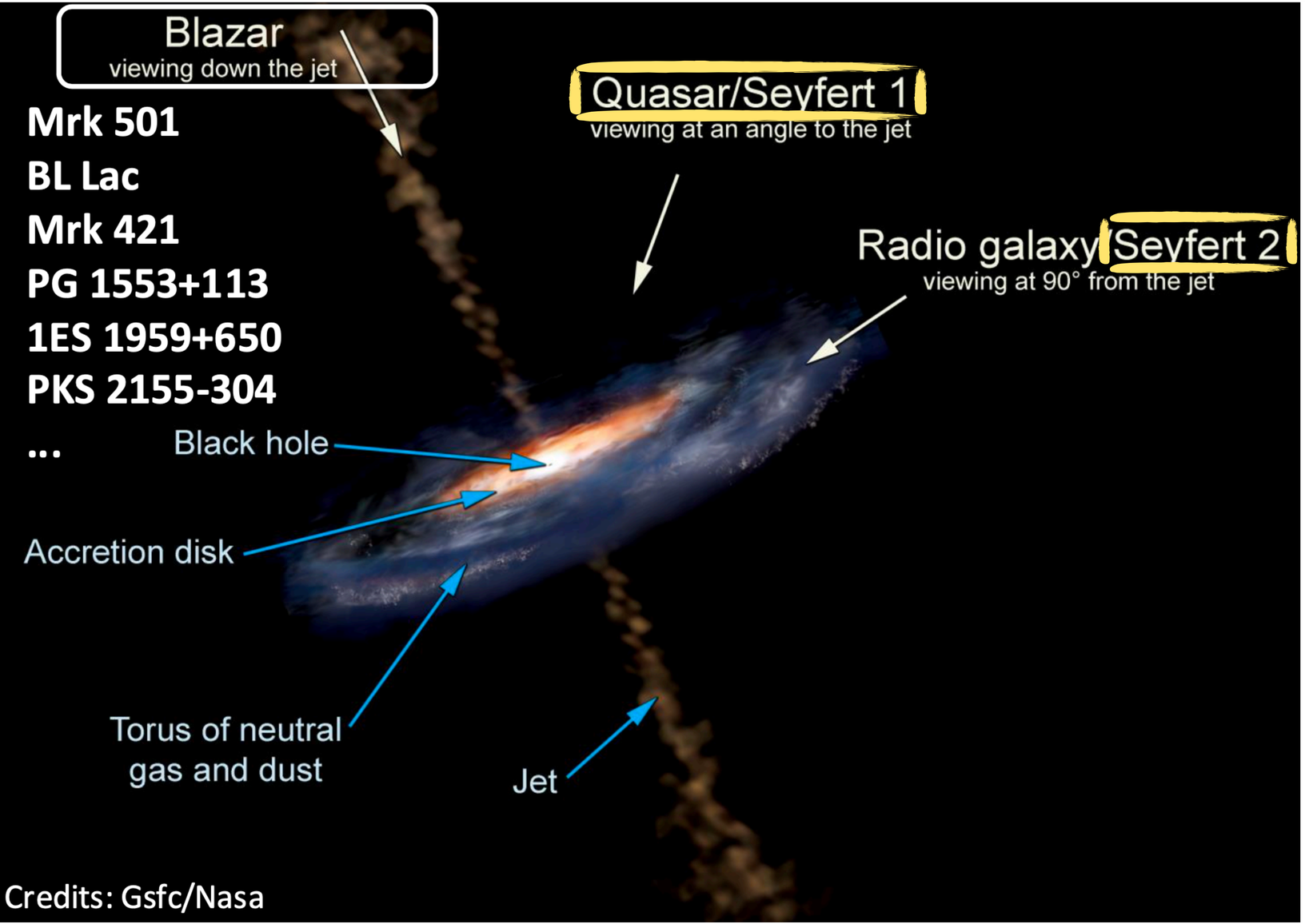

## Radio loud

## Broadband Emission



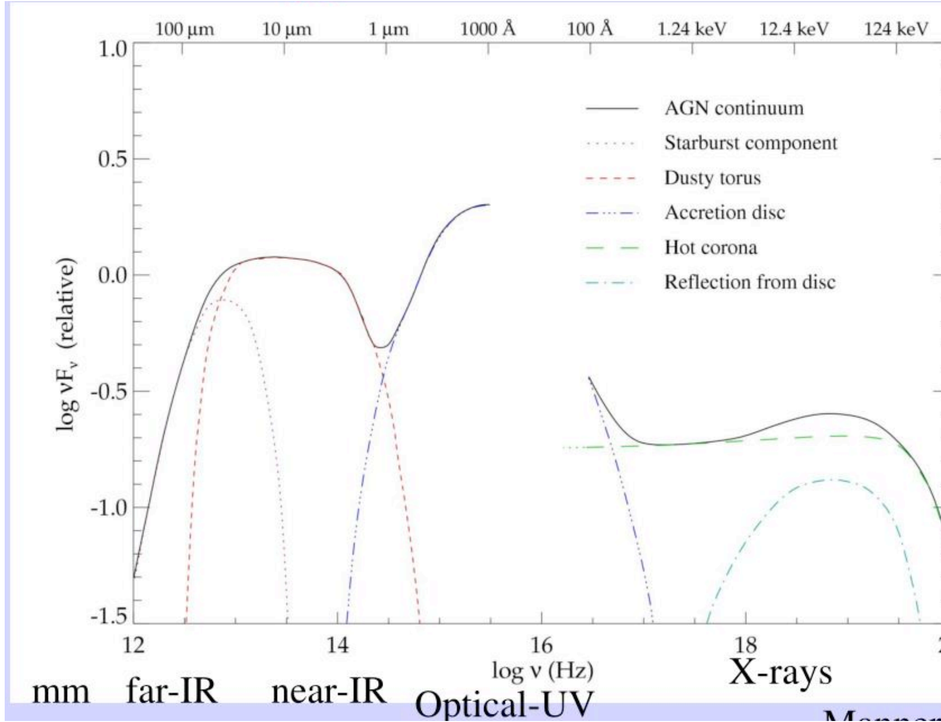

Ghisellini+16,

# Active Galactic Nuclei



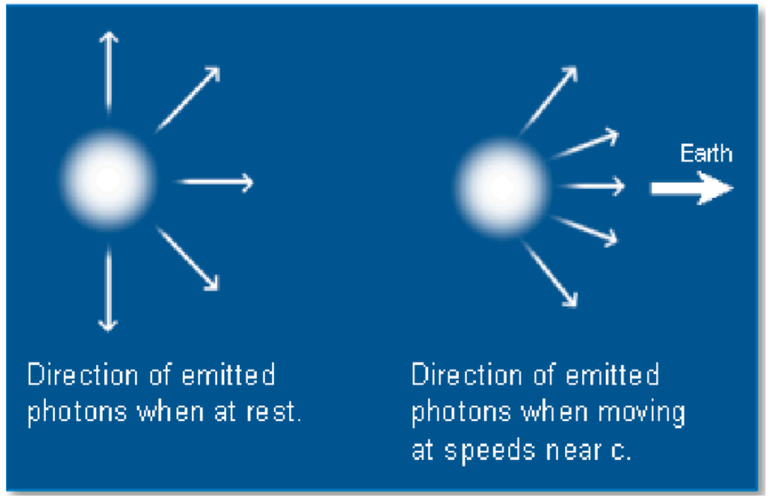

## Radio quiet

## Broadband Emission



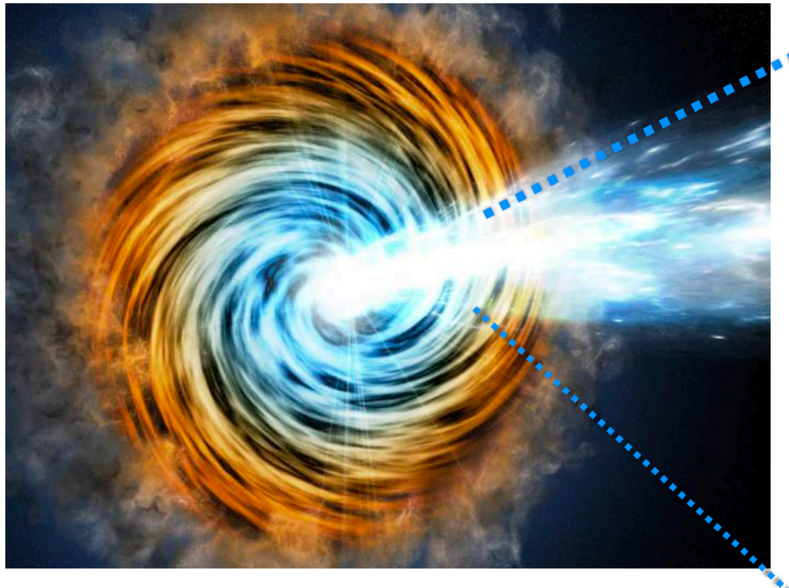
# Blazars

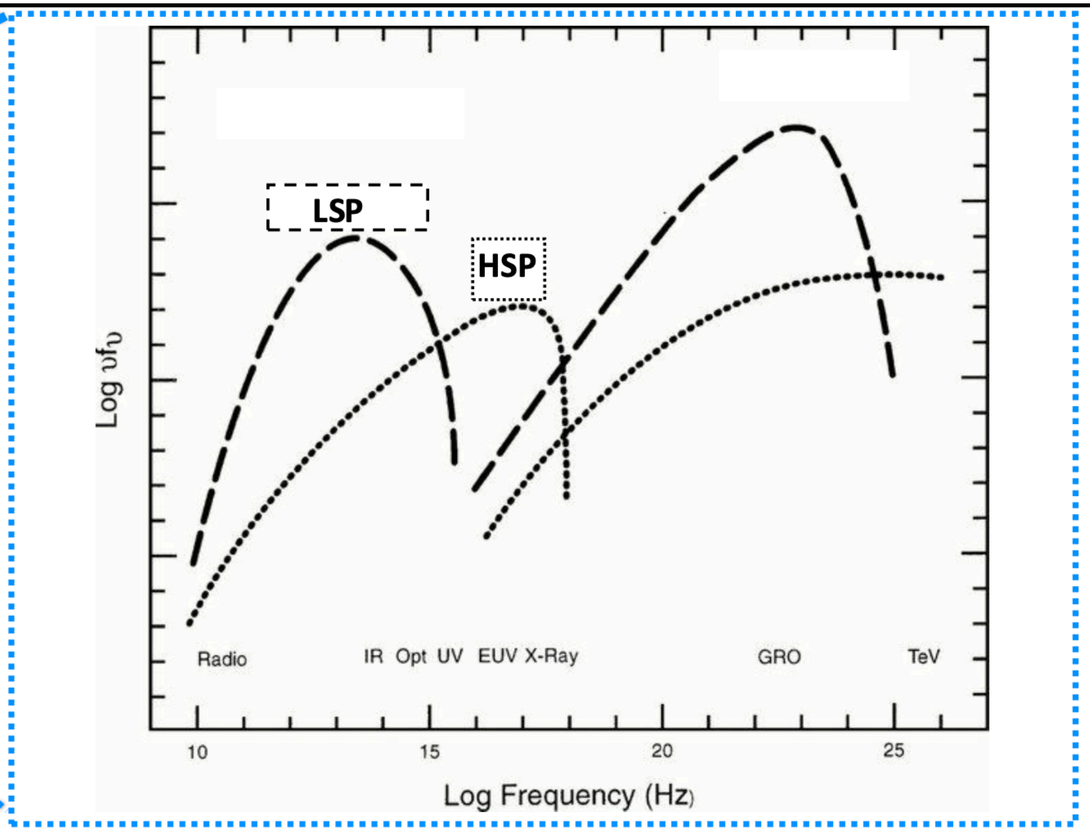
Blazars are Active Galactic Nuclei with a jet directed towards us




Due to relativistic aberration,
the jet emission dominates over other emission components

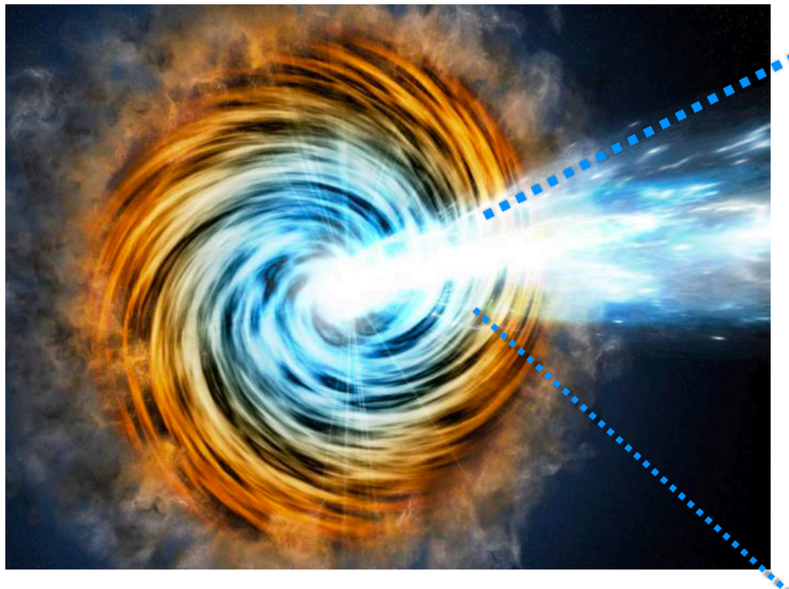
# Blazars classification

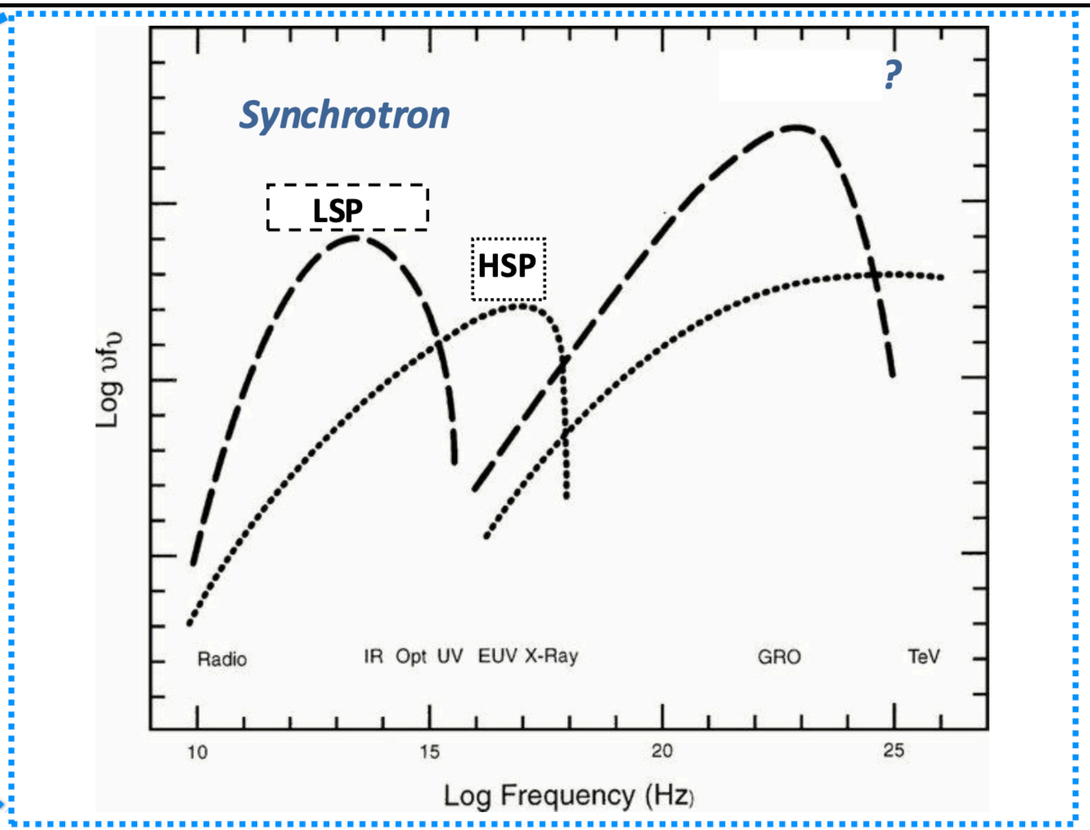





The spectral energy distribution shows two broad bumps.

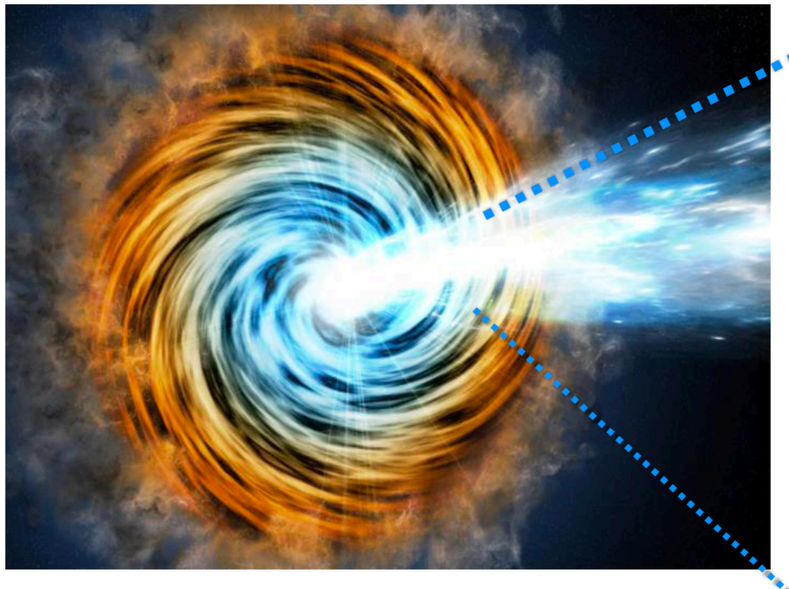
# Blazars classification

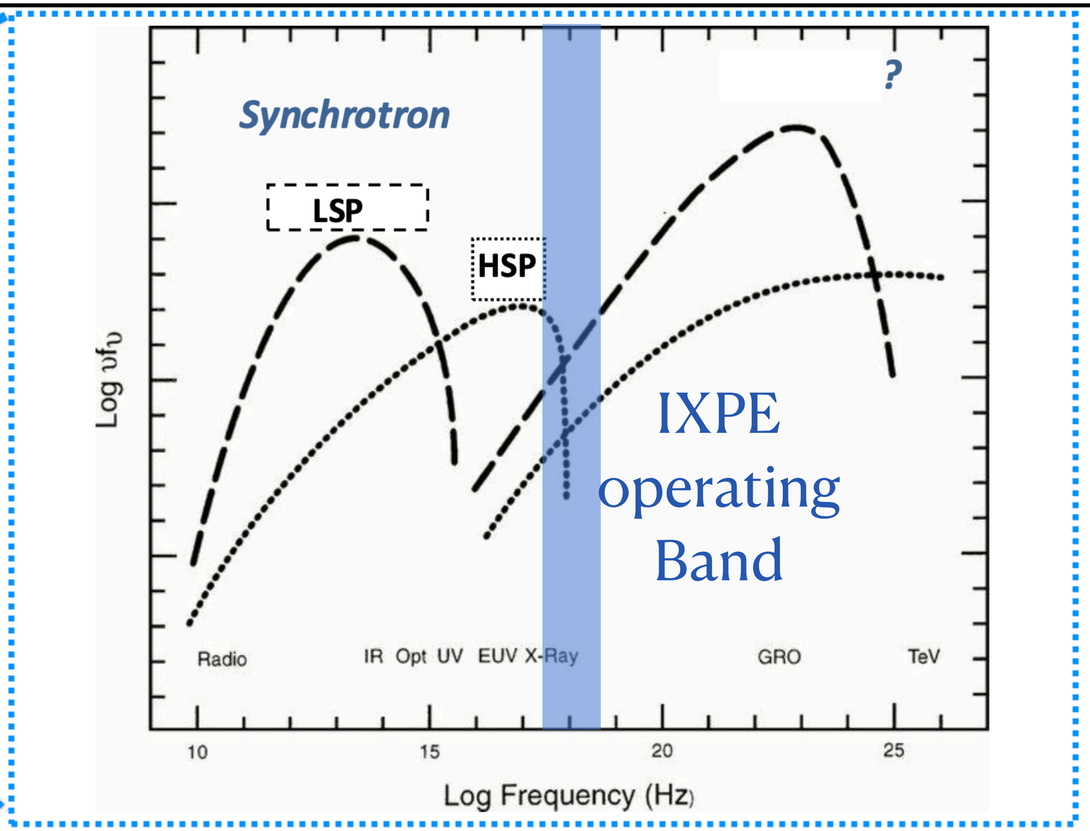





The spectral energy distribution shows two broad bumps.
The low-energy bump is produced by synchrotron emission of the jet.
--> **Low Synchrotron Peaked (LSP)** and **High Synchrotron Peaked (HSP)**.

# Blazars classification



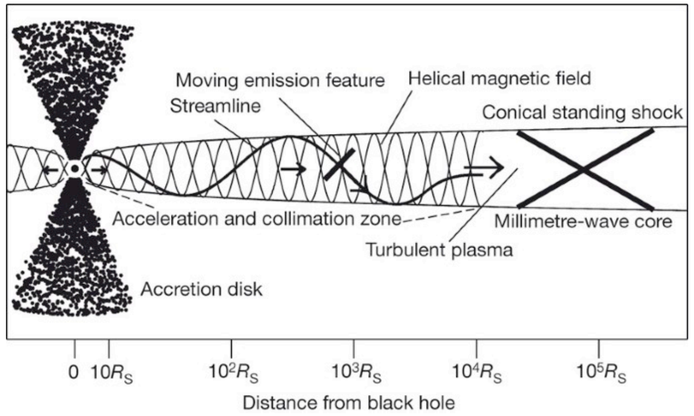



The spectral energy distribution shows two broad bumps.
The low-energy bump is produced by synchrotron emission of the jet.
--> **Low Synchrotron Peaked (LSP)** and **High Synchrotron Peaked (HSP)**.

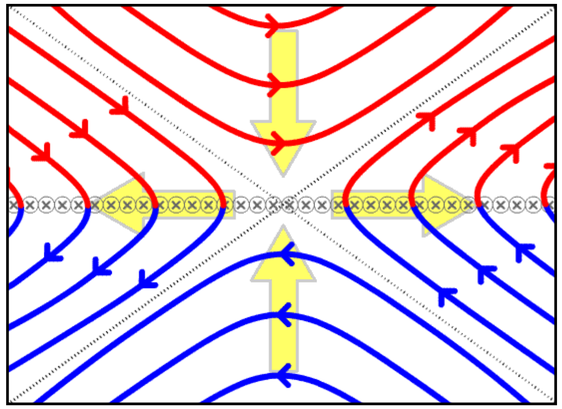
# Blazars open questions

## How are particles accelerated?

Shocks?



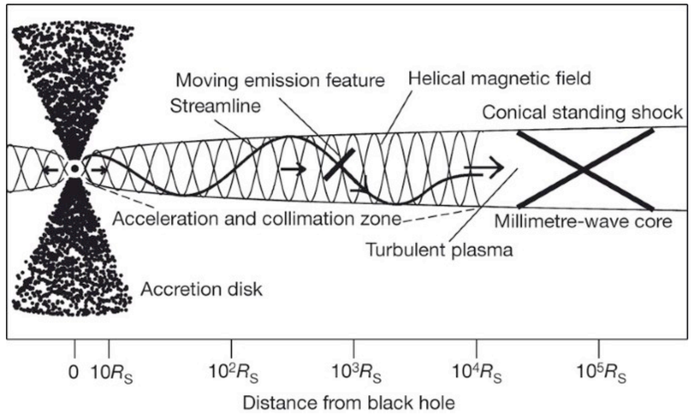

Magnetic Reconnection?



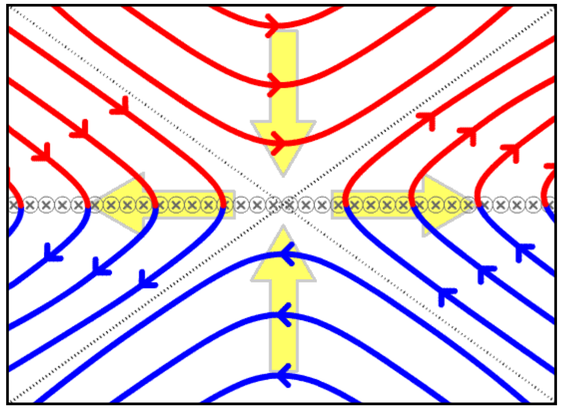
# Blazars open questions

## How are particles accelerated?

Shocks?



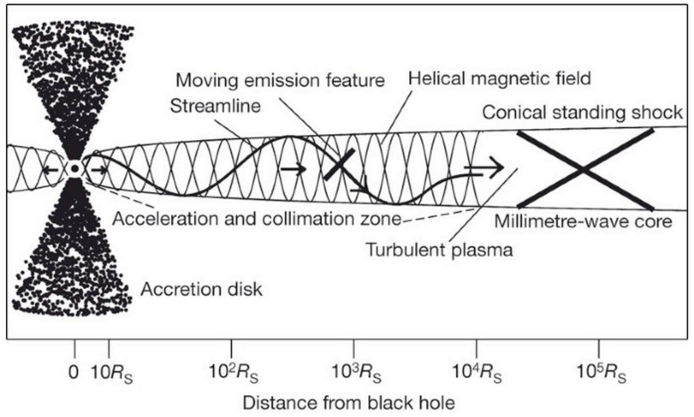

Magnetic Reconnection?



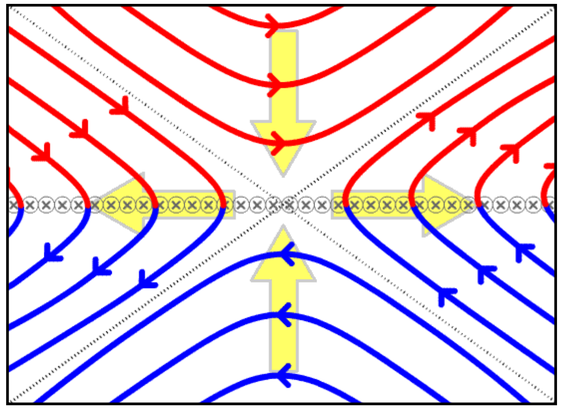
# Blazars open questions

## How are particles accelerated?

Shocks?

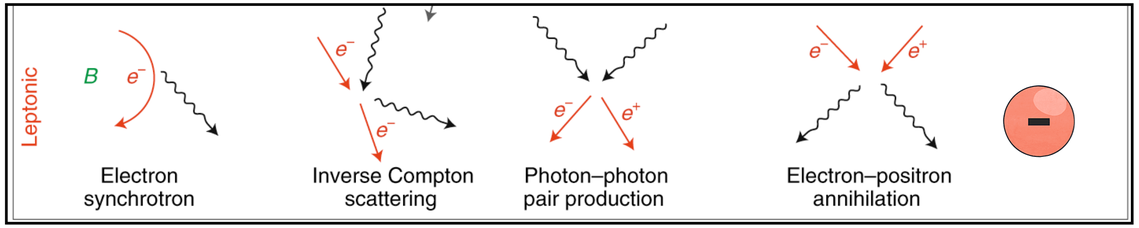



Magnetic Reconnection?

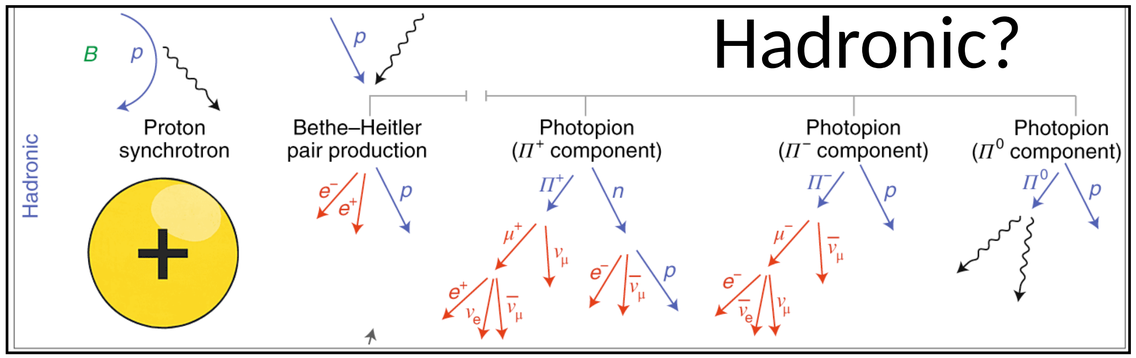


## What is the origin of the 2nd hump?

Leptonic?



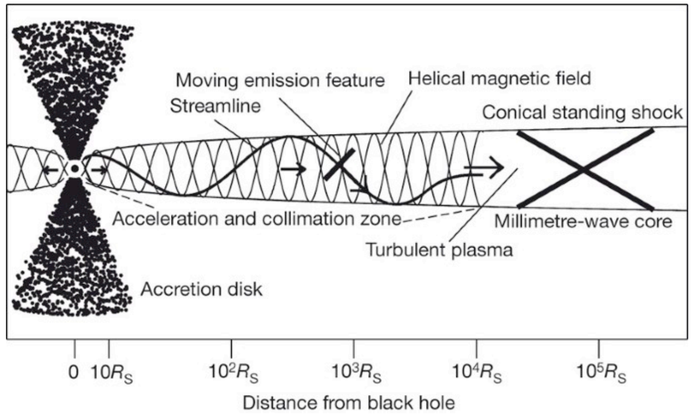

Hadronic?



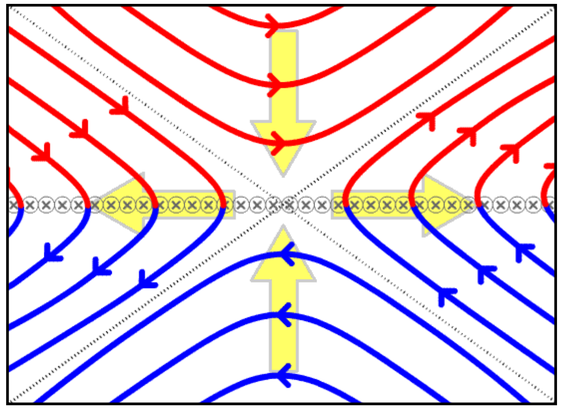
# Blazars open questions

## How are particles accelerated?

Shocks?

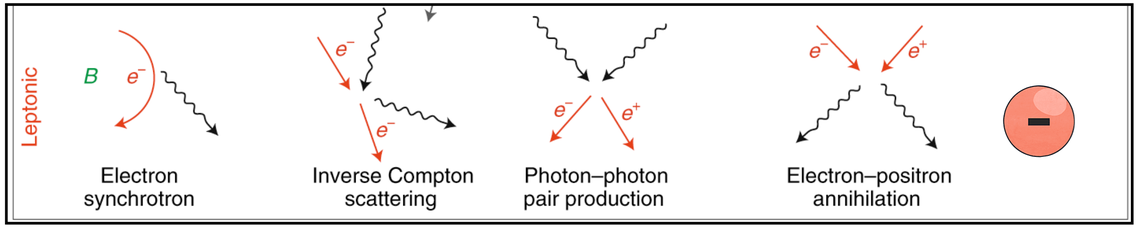



Magnetic Reconnection?

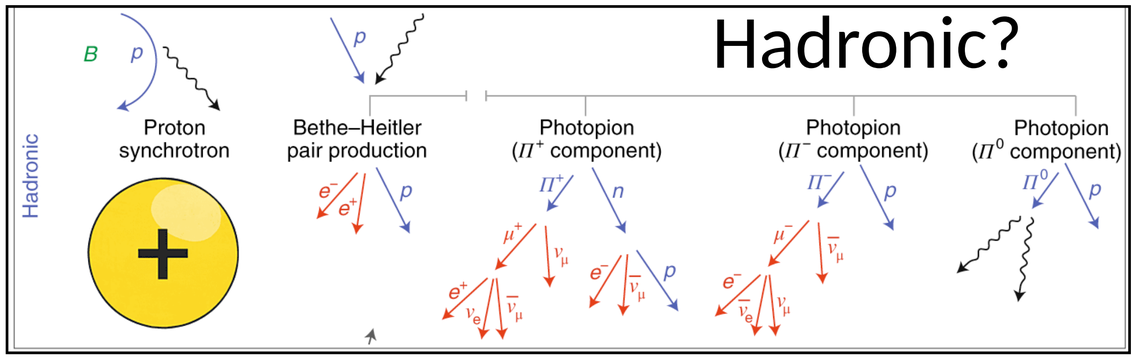


## What is the origin of the 2nd hump?

Leptonic?



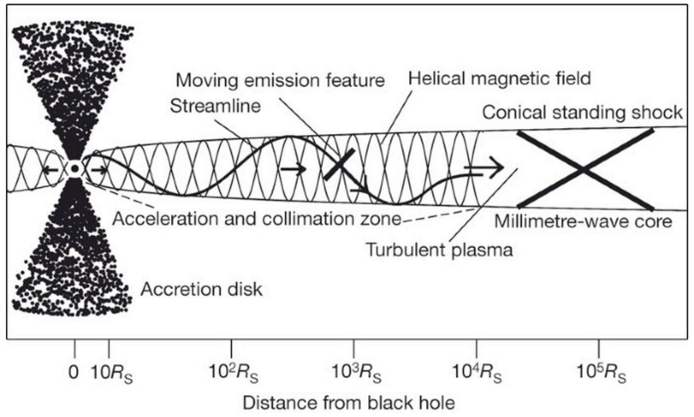

Hadronic?



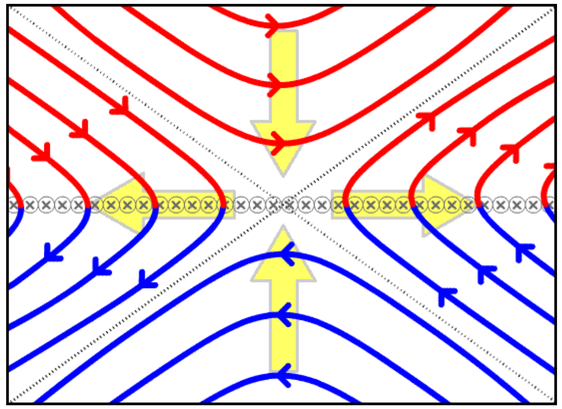
# Blazars open questions

## How are particles accelerated?

Shocks?



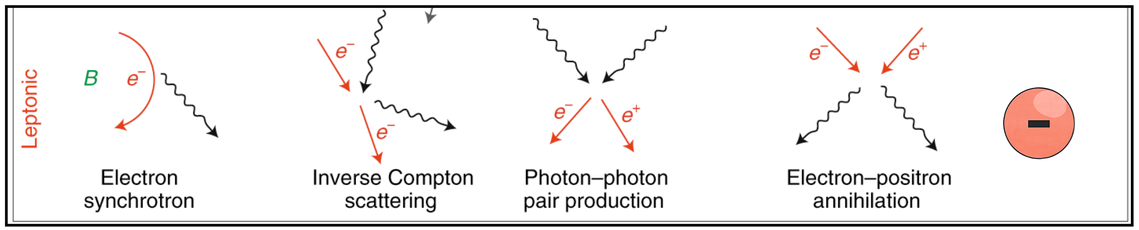

Magnetic Reconnection?



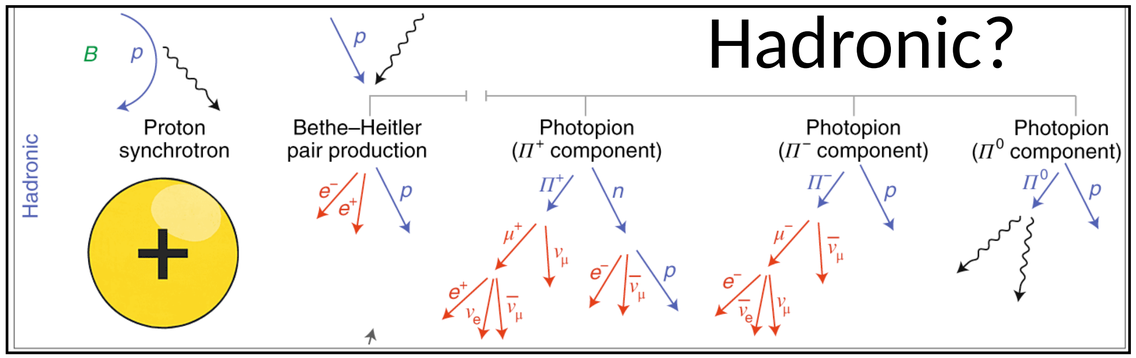
IXPE observations of HSP

## What is the origin of the 2nd hump?

Leptonic?




Hadronic?

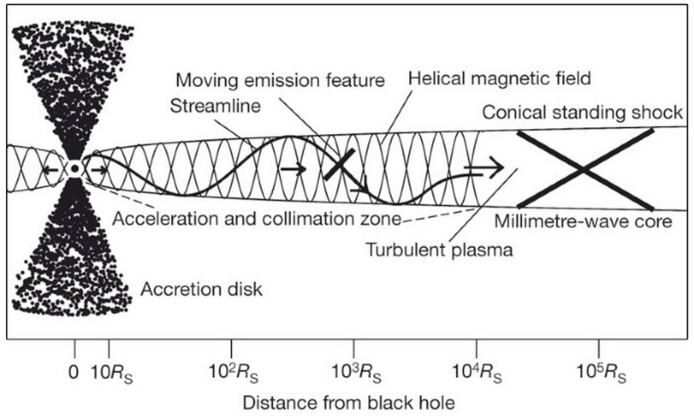



IXPE observations of LSP

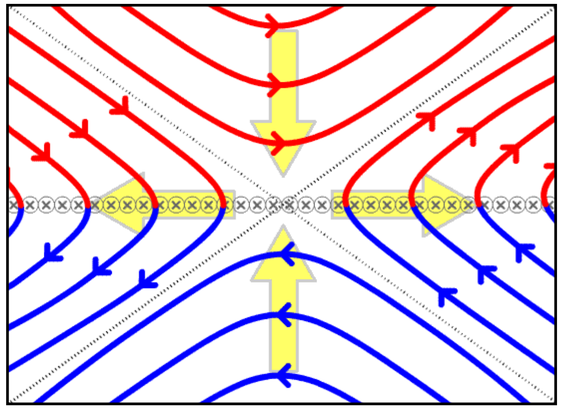
# Blazars open questions

## How are particles accelerated?

Shocks?



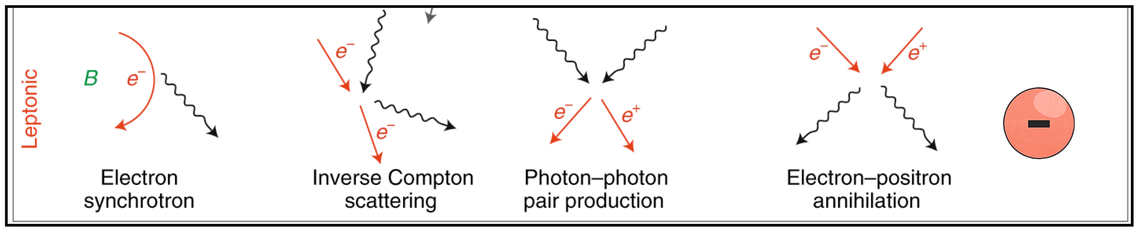

Magnetic Reconnection?



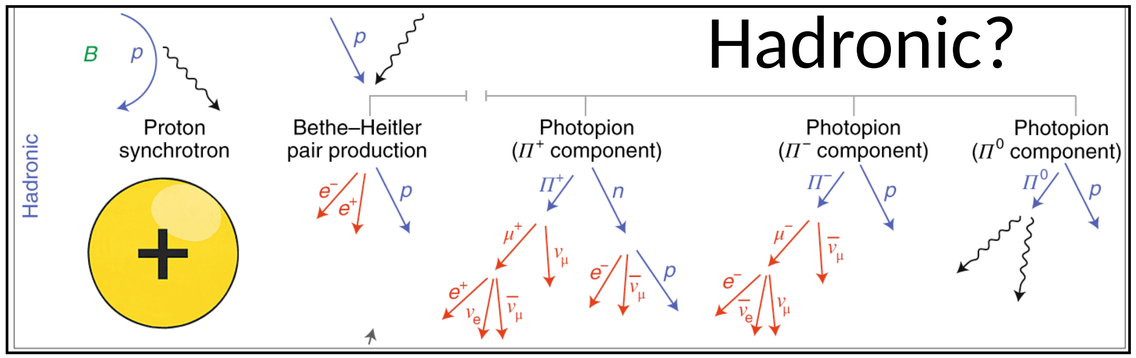
IXPE observations of HSP

## What is the origin of the 2nd hump?

Leptonic?

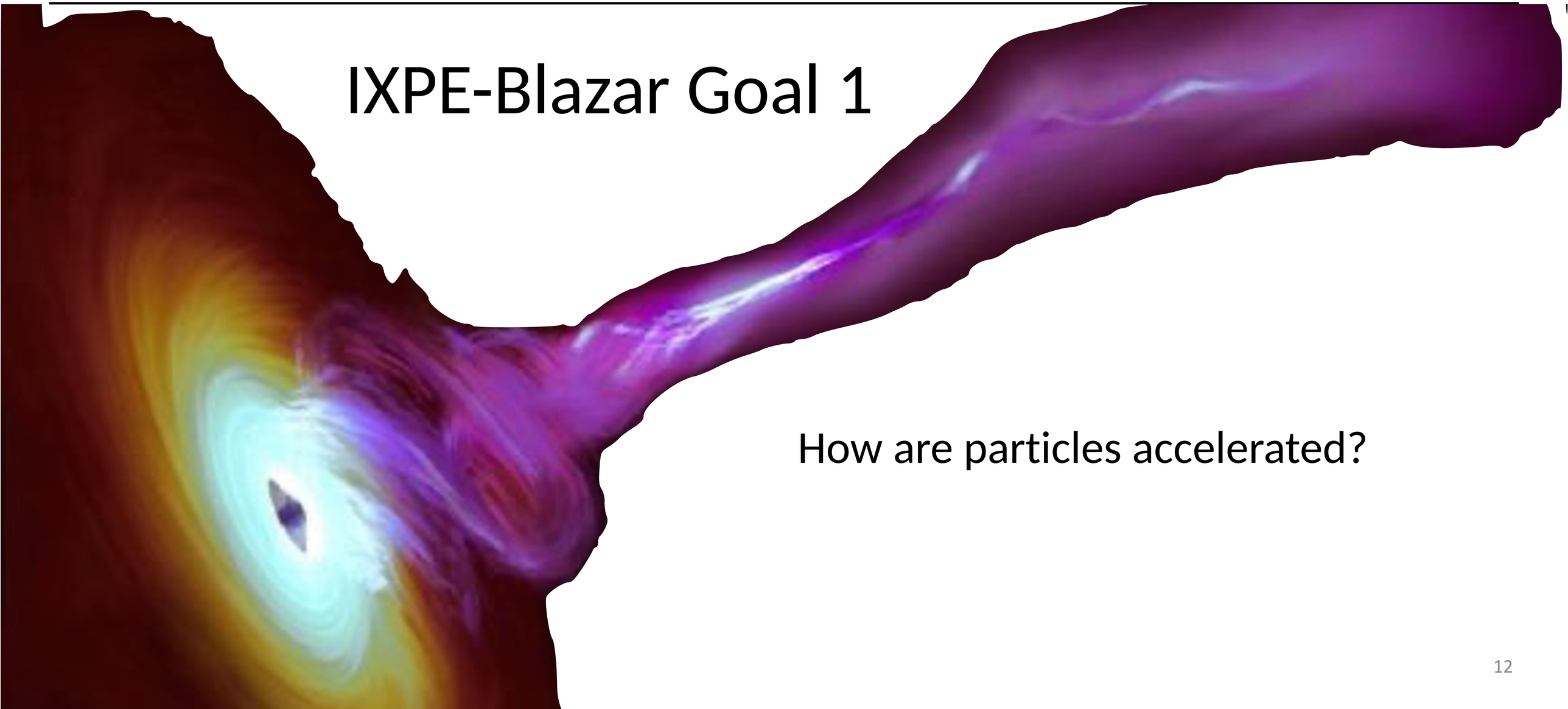



Hadronic?




IXPE observations of LSP

# IXPE observations revolutionize our knowledge



## IXPE-Blazar Goal 1

How are particles accelerated?

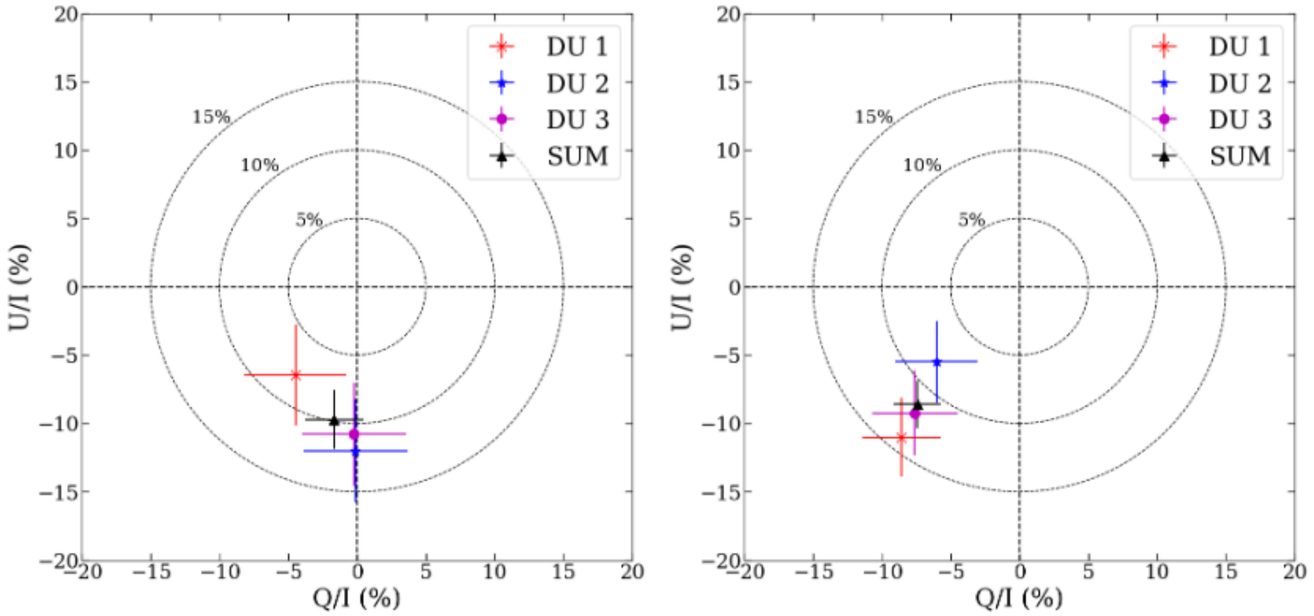
# Solid picture of what we may expect

| Model | Multiwavelength polarization | X-ray polarization variability† | X-ray polarization angle |
|---|---|---|---|
| Single-zone | constant* | slow | any |
| Multi-zone | mildly chromatic | high | any |
| Energy stratified (shock) | strongly chromatic | slow | along the jet axis |
| Magnetic reconnection (kink instability) | constant | moderate | perpendicular to jet axis |

*There is a slight dependence on the slope of the emission spectrum.
†Slow variability = a few days to week, moderate variability = days, high variability $\leq$ 1 day.

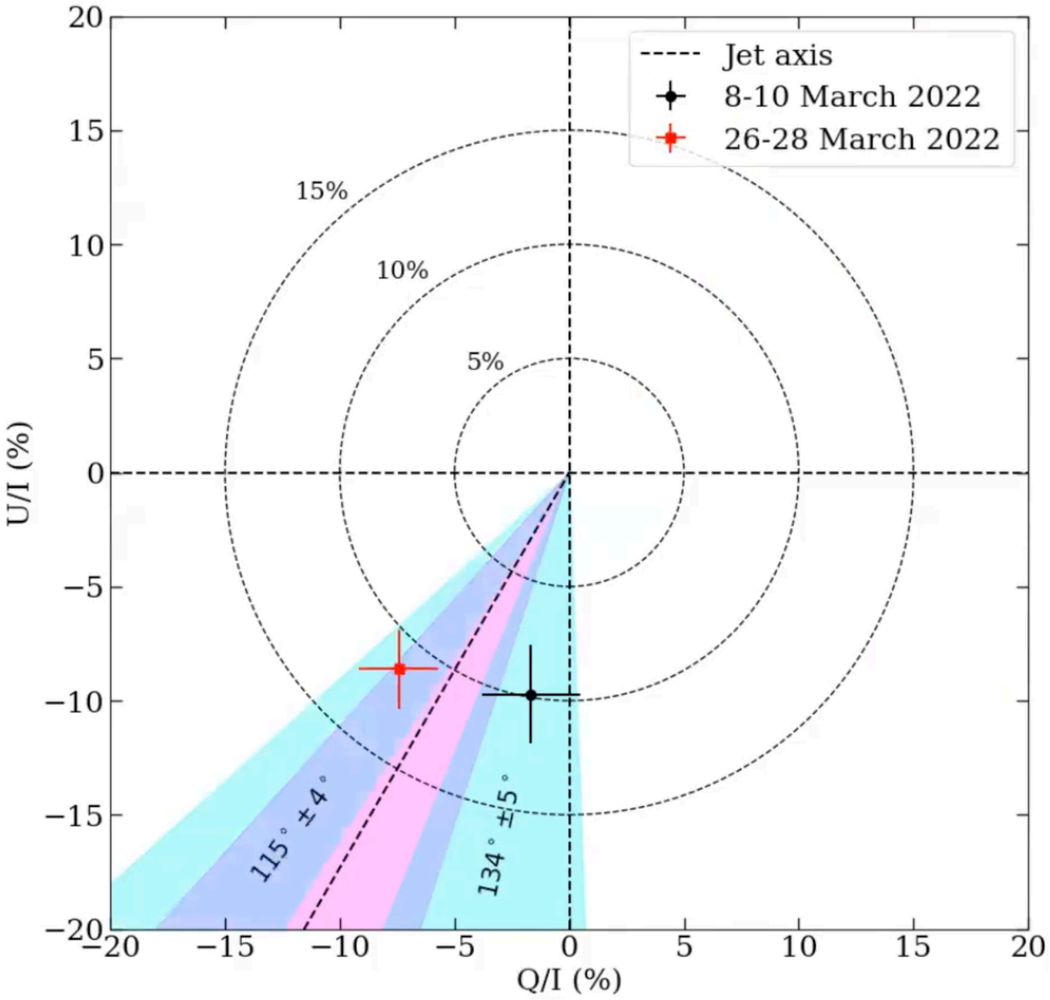
# Mrk 501: the first X-ray polarized light for a blazar

| Date | Method | $\Pi$ (%) | $\psi$ (degrees) |
|---|---|---|---|
| 8-10 March | Model-independent | 10.5±2.1 | 130±6 |
| | XSPEC | 10.5±1.8 | 135±5 |
| | MLS | $10.6^{+1.7}_{-1.6}$ | 135±5 |
| 26-28 March | Model-independent | 11.5±1.6 | 115±4 |
| | XSPEC | 10.7±1.5 | 115±4 |
| | MLS | 10.6±1.5 | 115±4 |



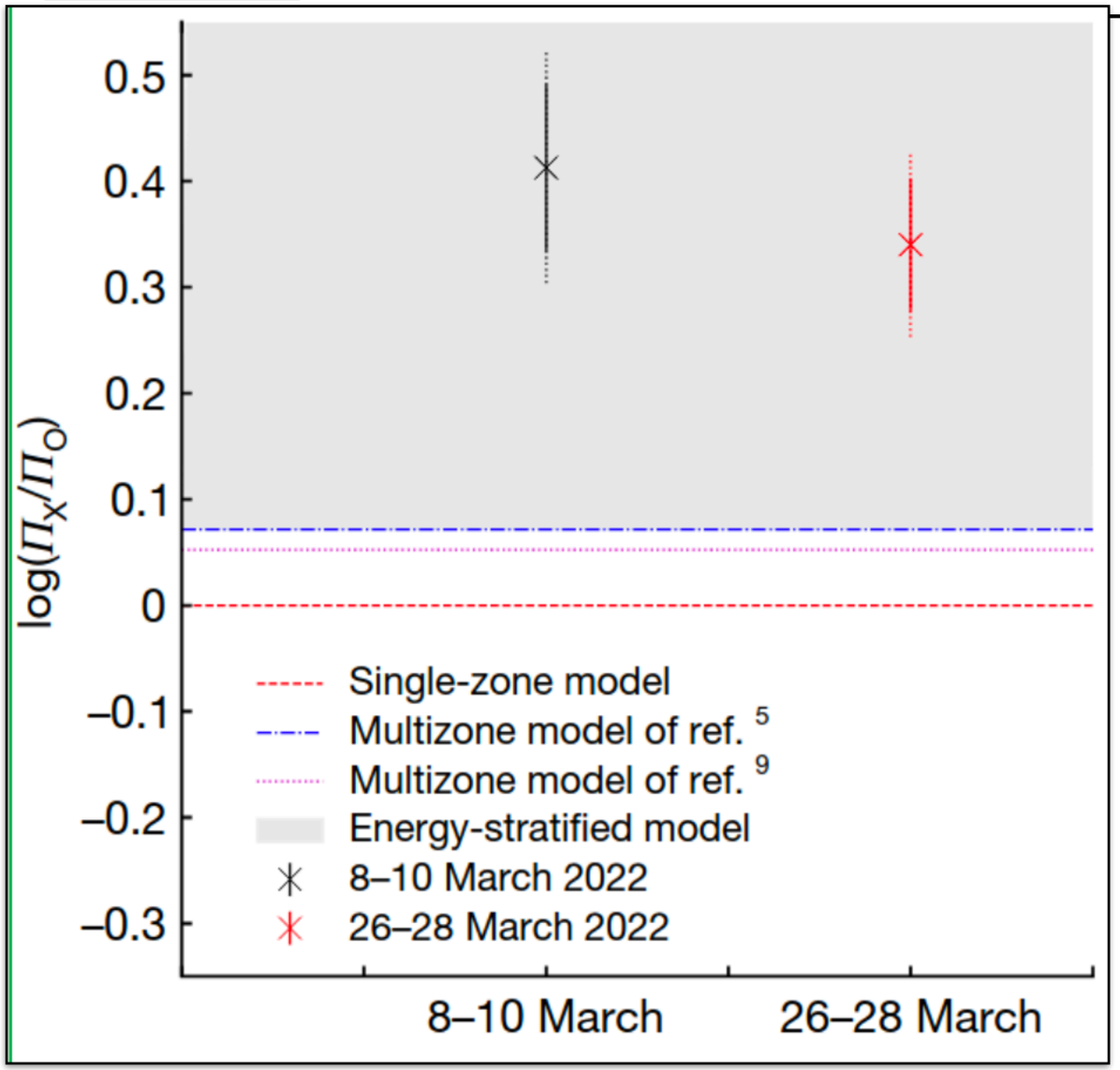


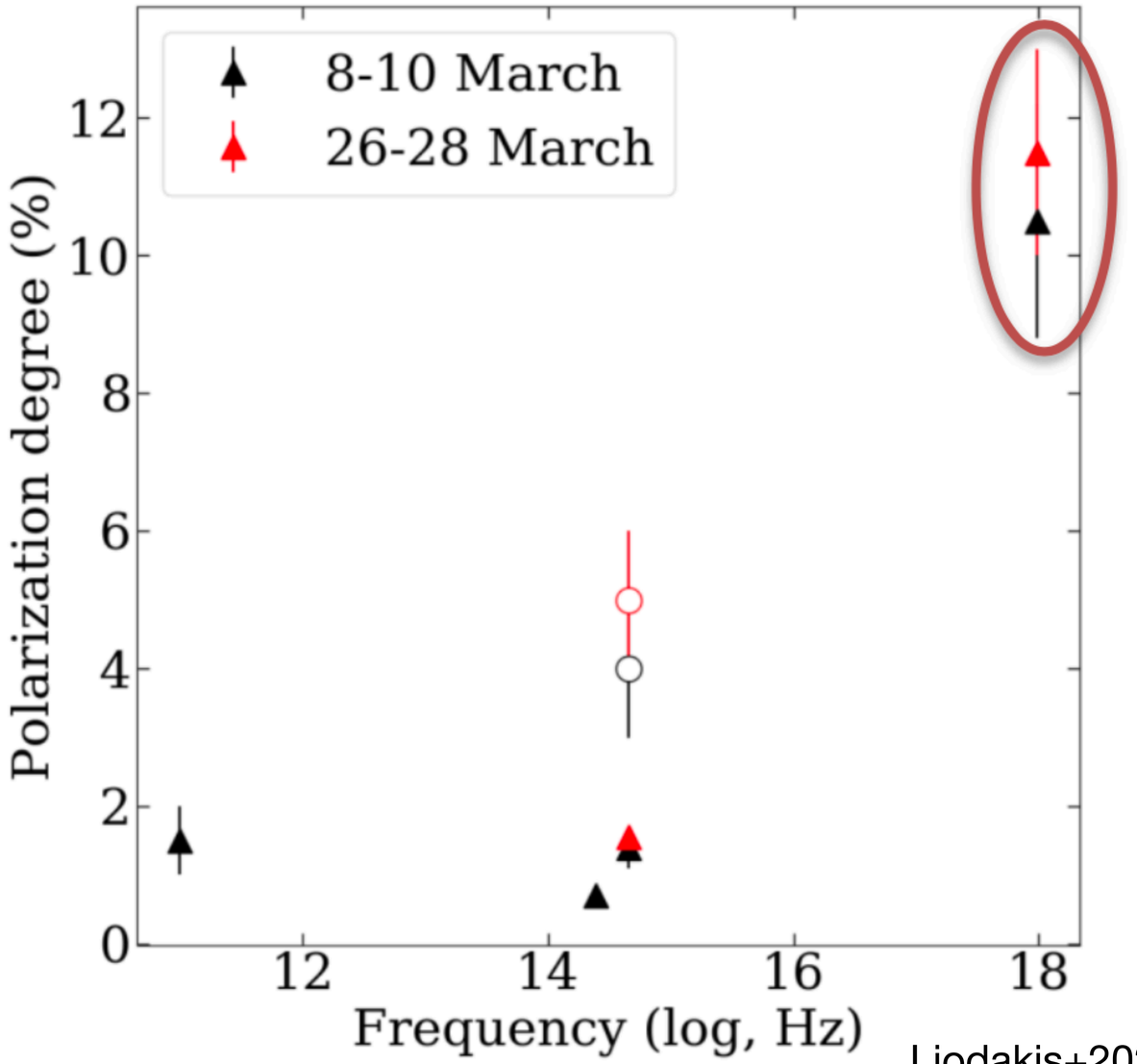





Liodakis+2022

# Mrk 501: the first X-ray polarized light for a blazar




Liodakis+2022

# Mrk 501: the first X-ray polarized light for a blazar V

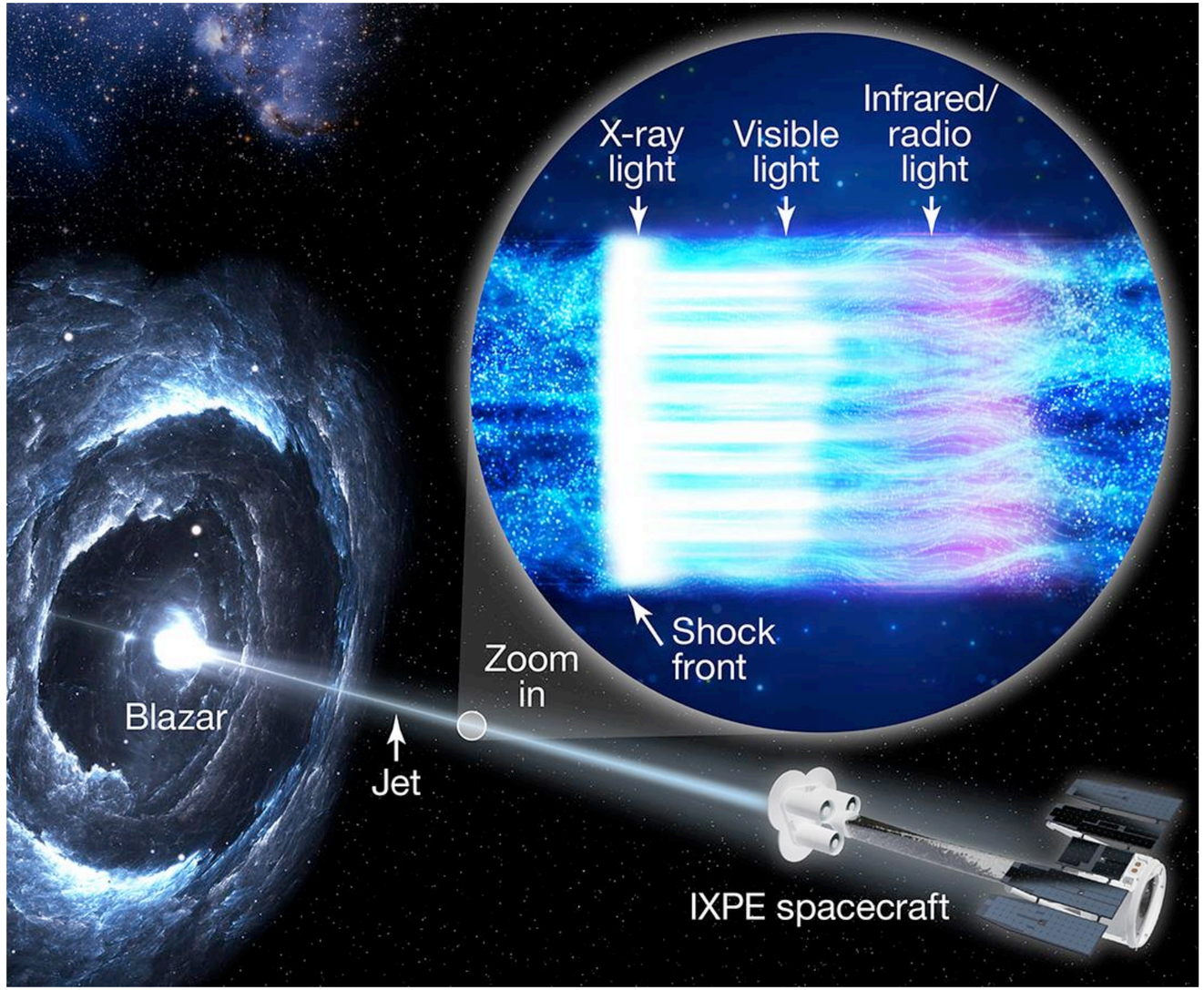
Liodakis+2022

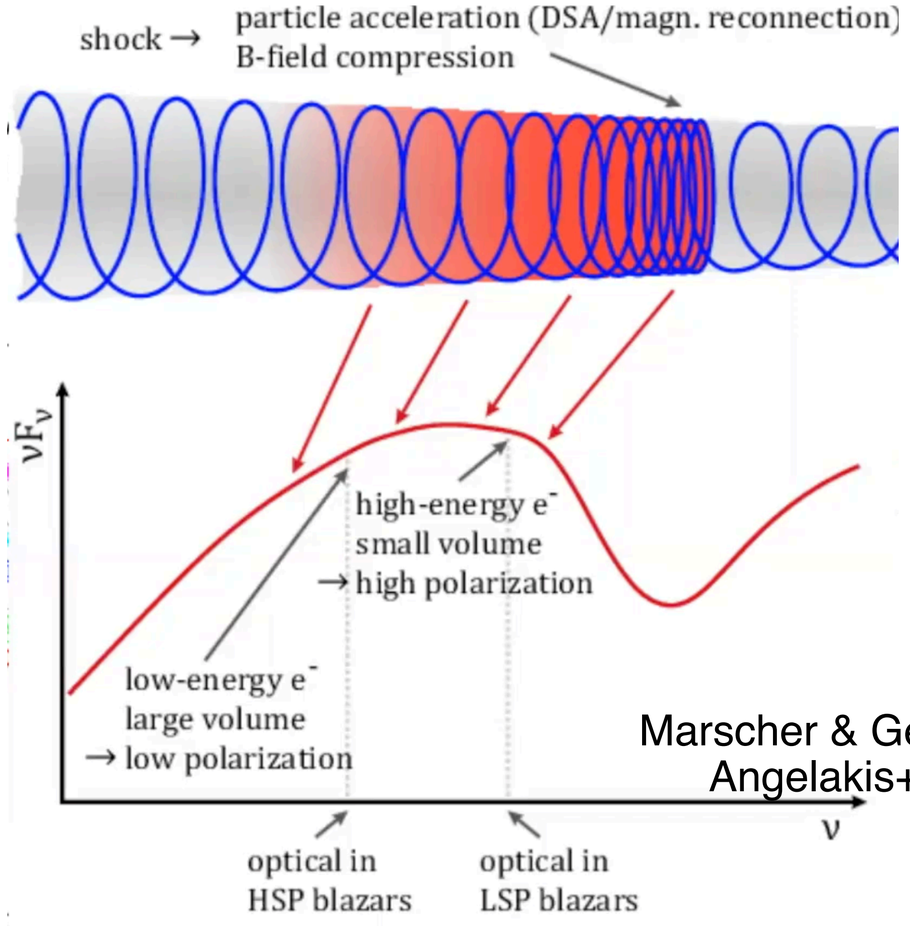
| Model | Multiwavelength polarization | X-ray polarization variability† | X-ray polarization angle |
|---|---|---|---|
| Single-zone | constant* | slow | any |
| Multi-zone | mildly chromatic | high | any |
| Energy stratified (shock) | strongly chromatic | slow | along the jet axis |
| Magnetic reconnection (kink instability) | constant | moderate | perpendicular to jet axis |

*There is a slight dependence on the slope of the emission spectrum.
†Slow variability = a few days to week, moderate variability = days, high variability $\leq$ 1 day.

But see Zhang+2024 for a different perspective

# Mrk 501: the first X-ray polarized light for a blazar VI



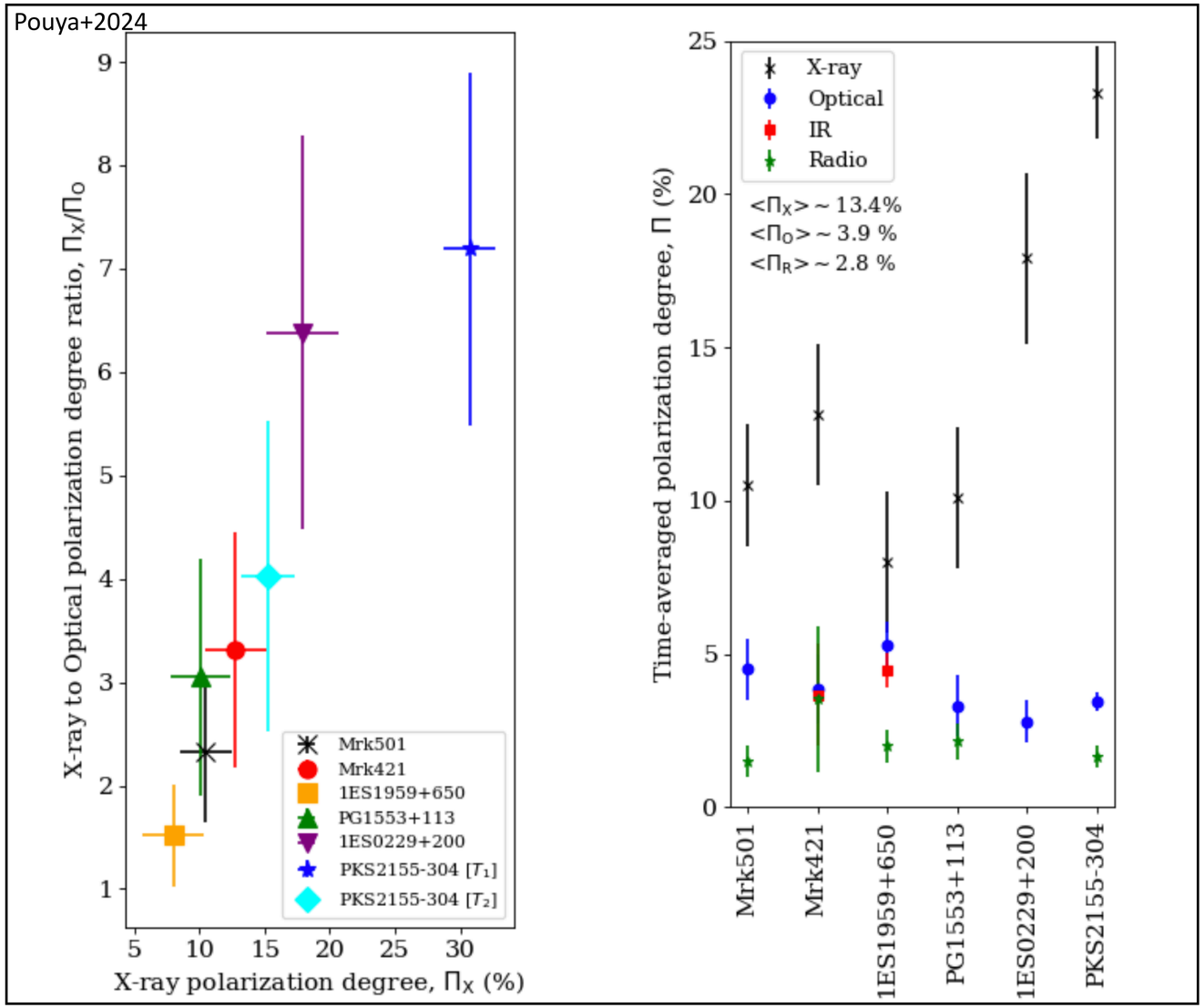

Marscher & Gear 1985, Angelakis+2016

Particles are likely accelerated in shocks,

Jet's emission is energy stratified

# Do other Blazars behave the same?

Pouya+2024




$$\Pi_r < \Pi_o < \Pi_X$$

YES!

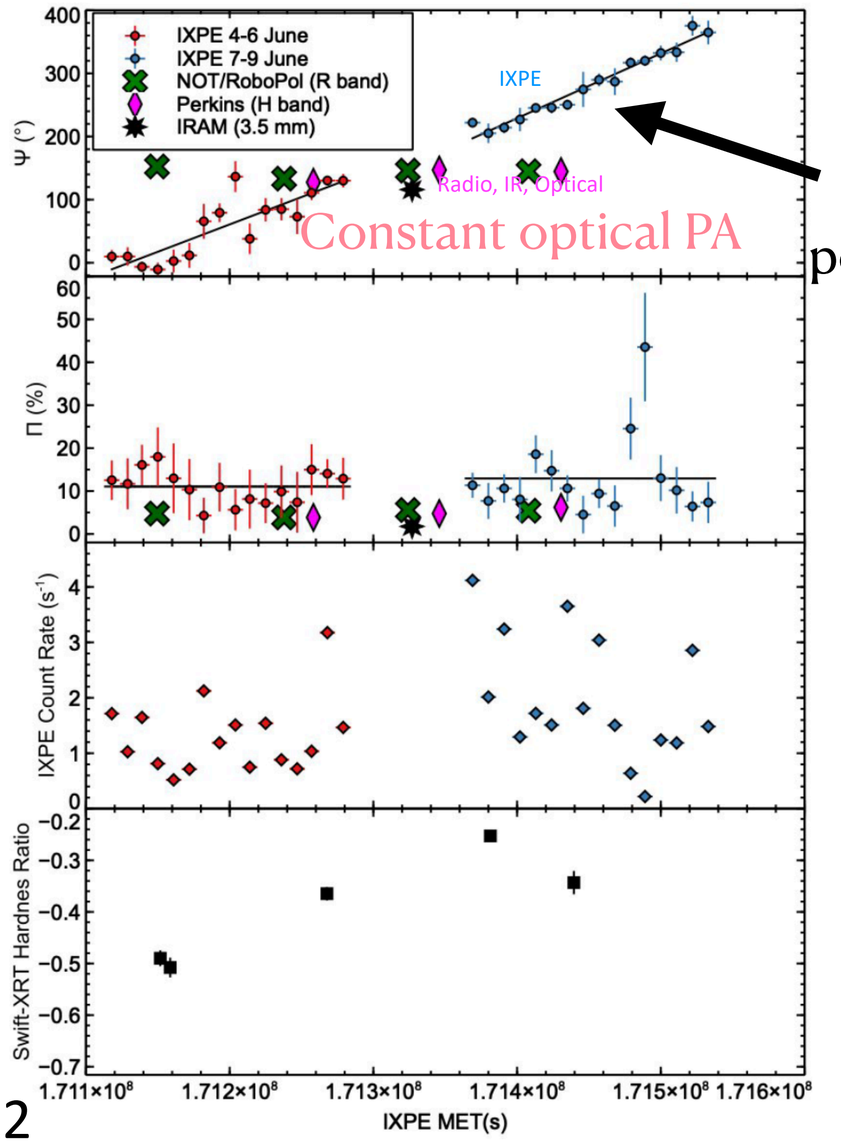
Emission is energy is stratified in the jet

$$\psi_x // jet$$

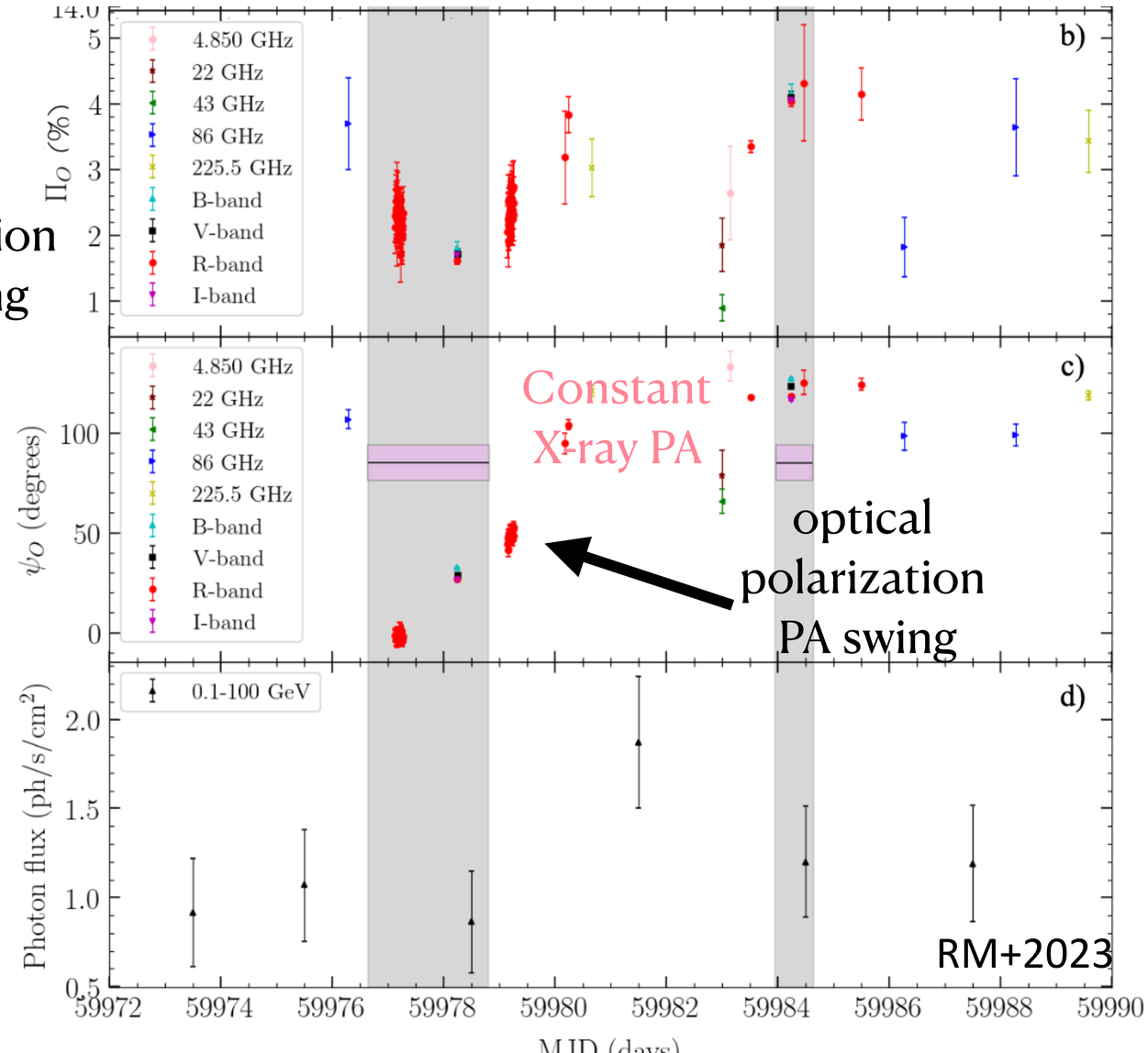
almost YES!

Mrk421(Di Gesu+2022,Kim+2024,Maksym+in prep)
Mrk510 (Liodakis+2022,Chen+2024,Lisalda+ sub)
Pg1553+113 (Middei+2023)
PKS 2155–304 (Pouya+2024)
1ES 0229+200 (Ehlert+2024)
1ES 1959+650 (Errano+2024,Pacciani+2024)

# Mrk 421 X-ray & PG 1553+113
# the first EVPA rotation observed at X-ray and optical WLs

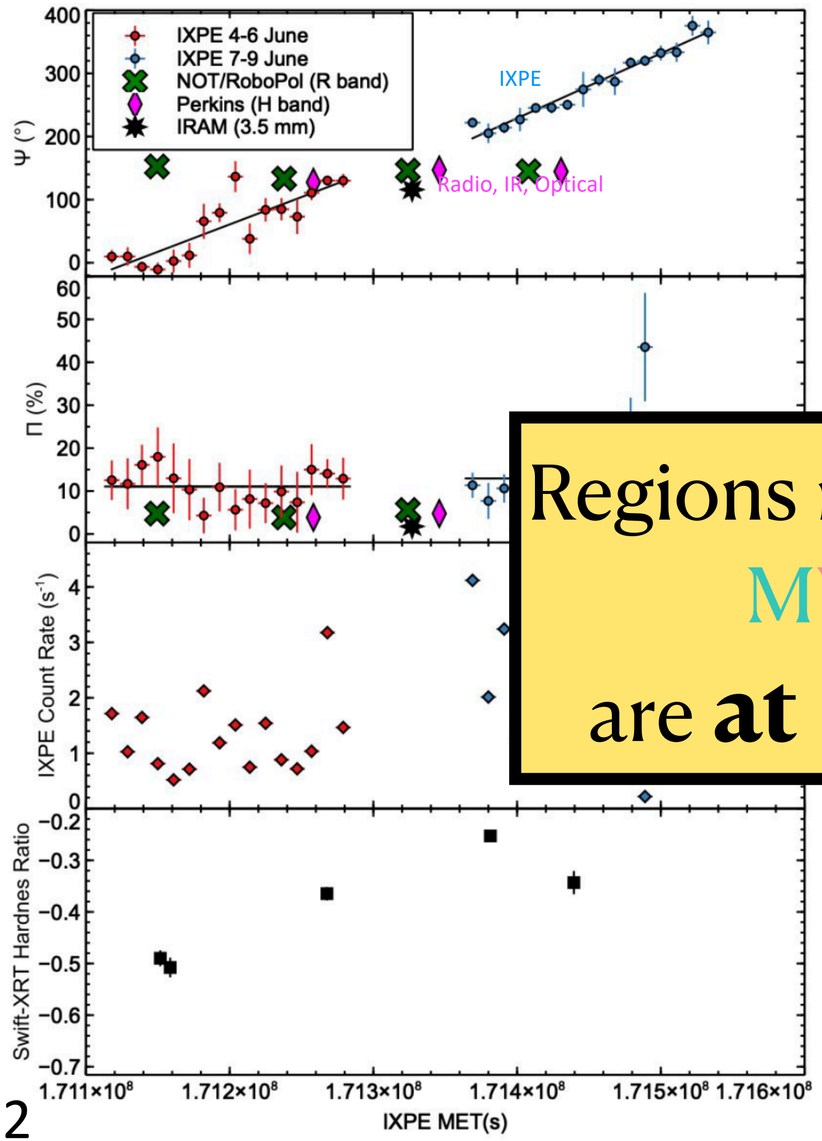


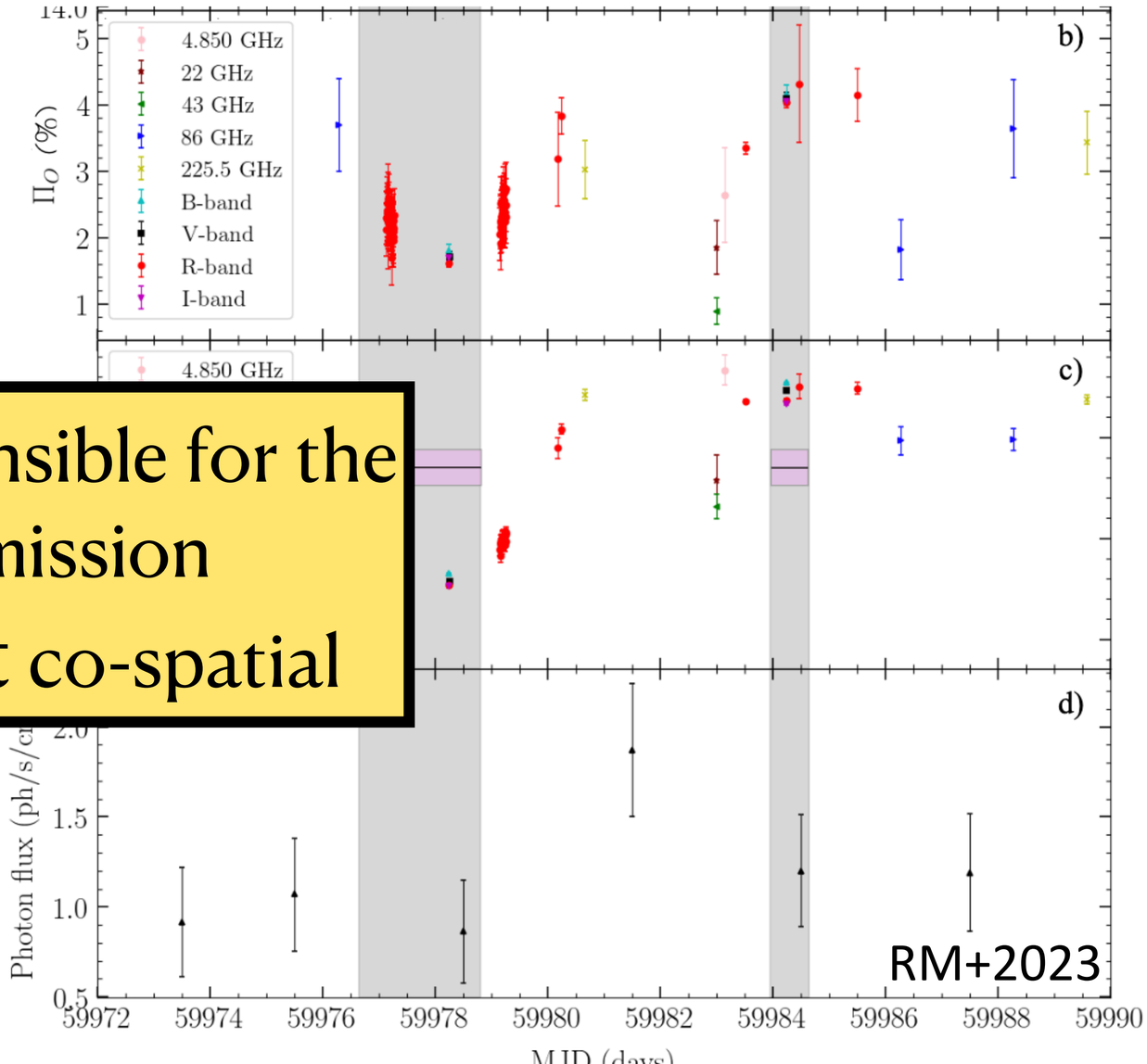

X-ray polarization PA swing




De Gesu+22

# Mrk 421 X-ray & PG 1553+113
# the first EVPA rotation observed at X-ray and optical WLs

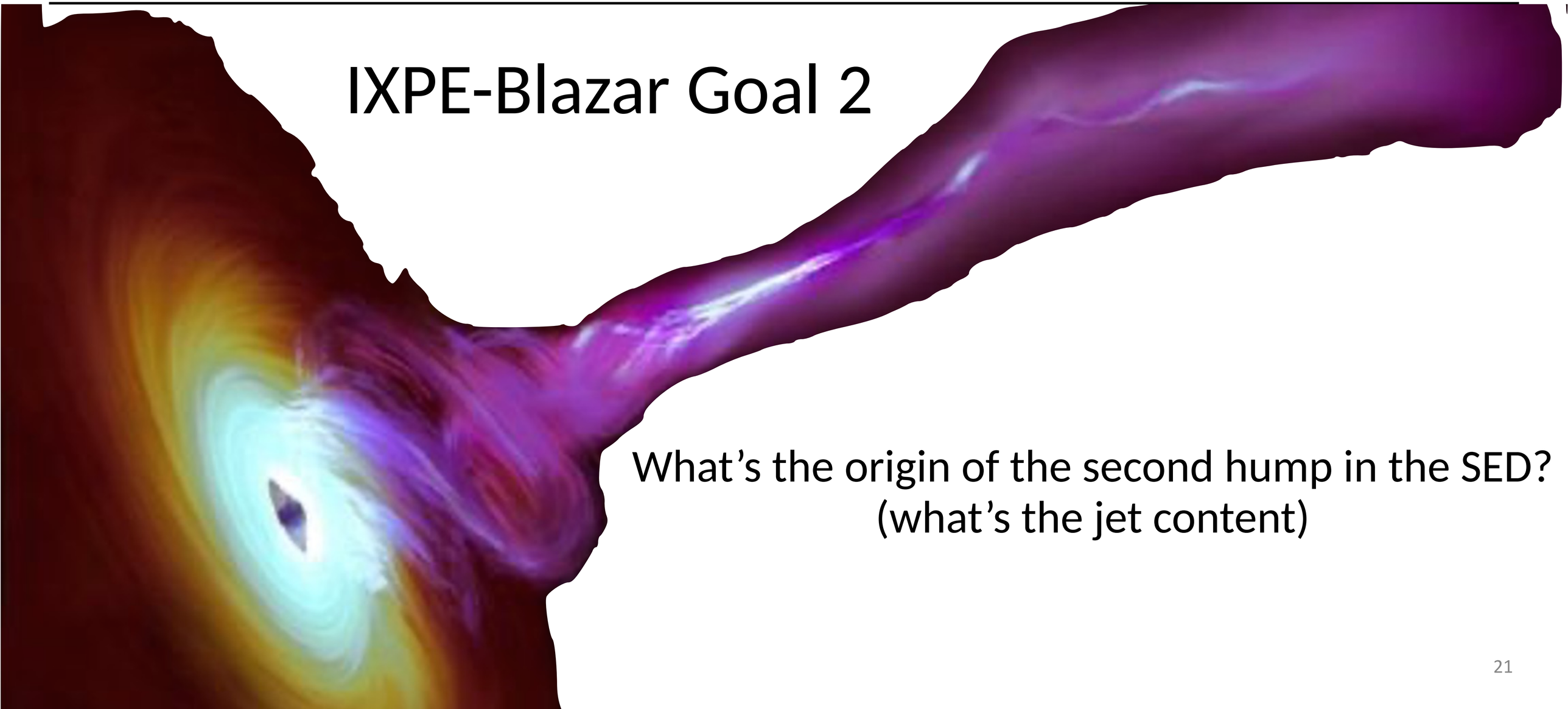



Regions responsible for the MWL emission are **at most** co-spatial

De Gesu+22

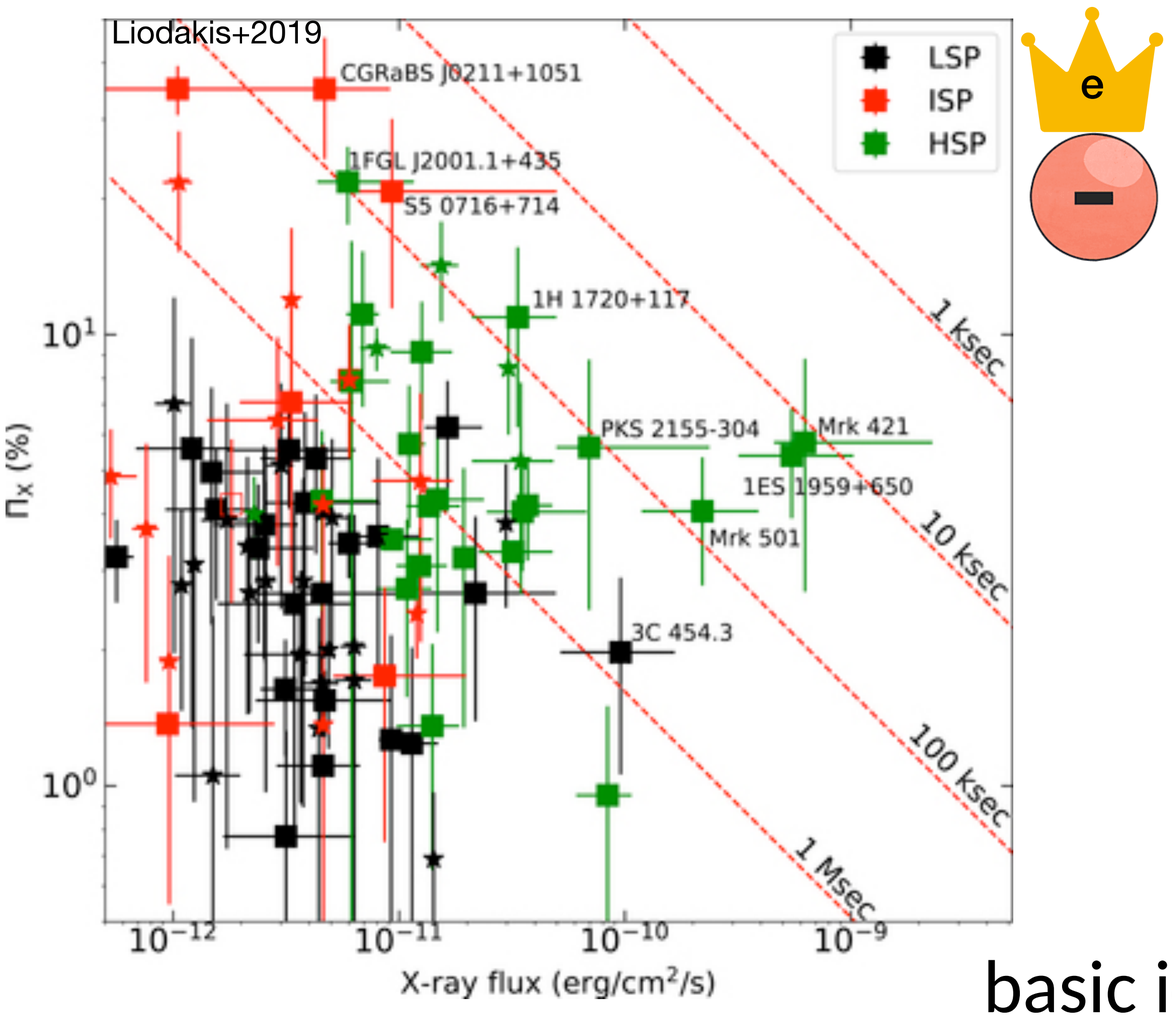
# IXPE observations revolutionize our knowledge



## IXPE-Blazar Goal 2

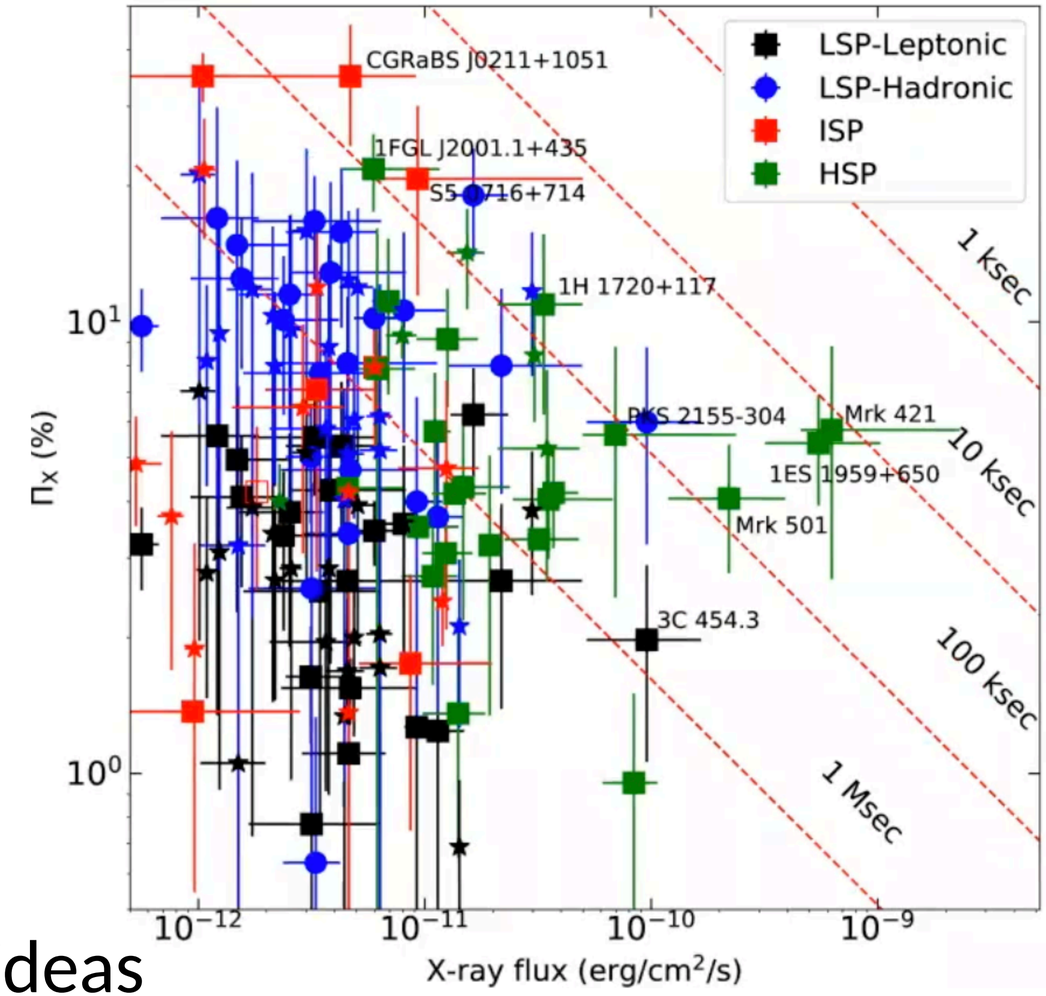
What's the origin of the second hump in the SED?
(what's the jet content)

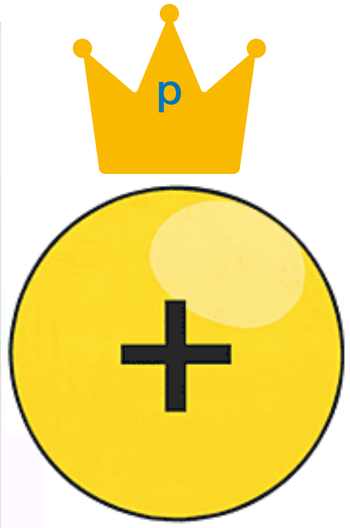
# What's the origin of the second hump in the SED? (what's the jet content)









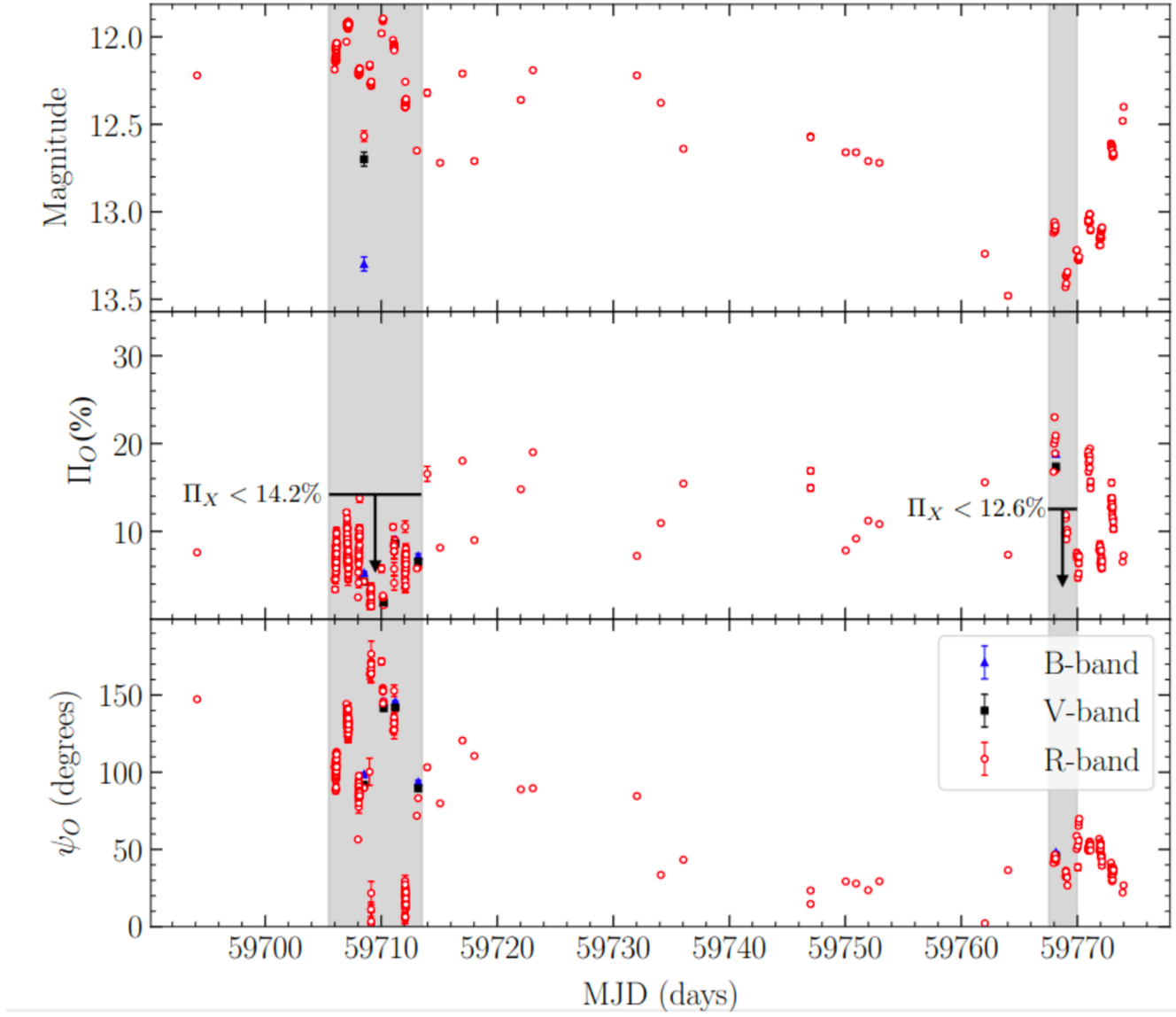




basic ideas

**Predict high pol. $\Pi_x < \Pi_{optical}$**

**Predict high pol. $\Pi_x \geq \Pi_{optical}$**

# BL Lac observation back to 2022

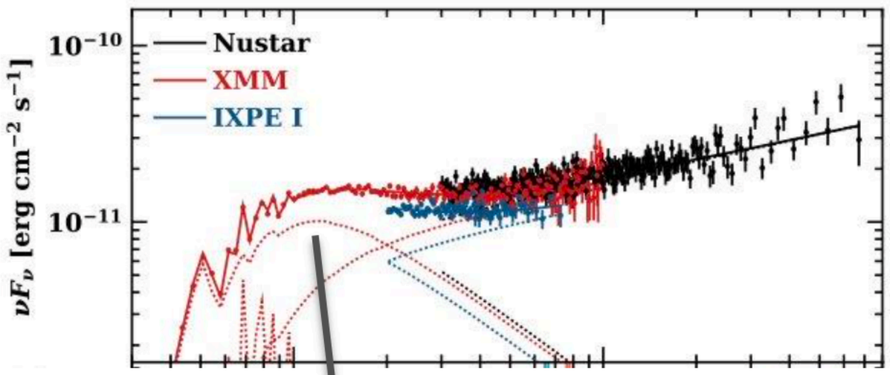



**$\Pi_X$ < 12.6% i.e. lower than $\Pi_{optical}$ and compatible with $\Pi_{radio}$**

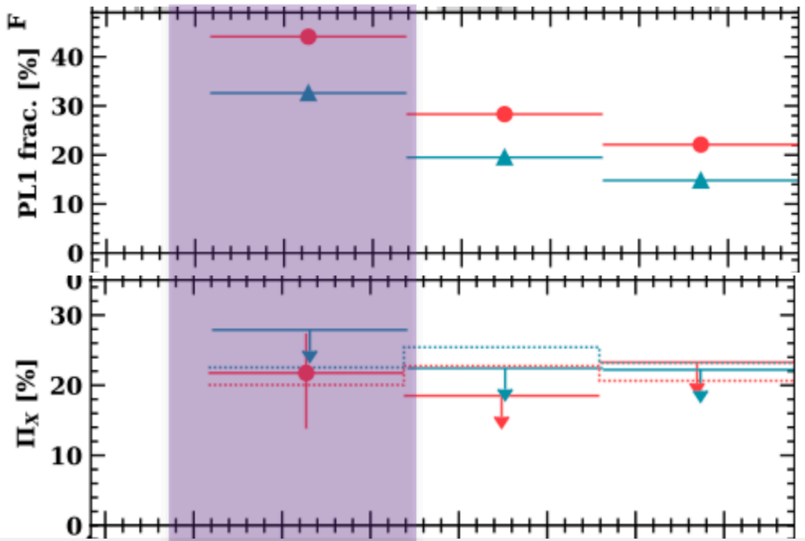
**Leptonic models (SSC) are favored over hadronic**

See also Marshall+23, ApJ

# BL Lac in Flare




Peirson+2023

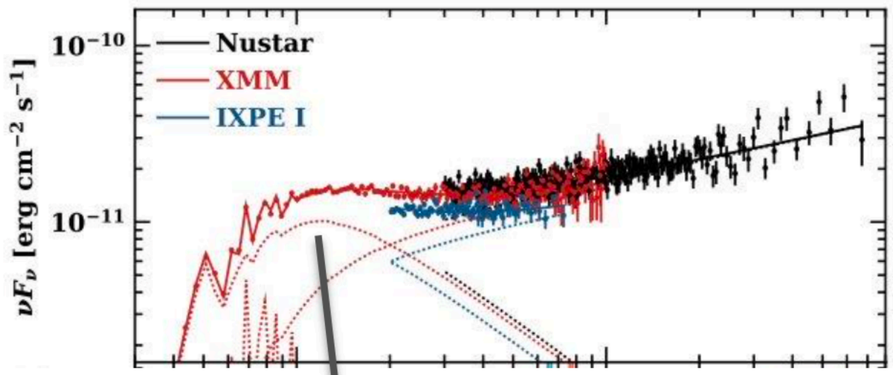



**Source seen in intermediate state (ISP)**
**--> Mixture of synchrotron and Compton**

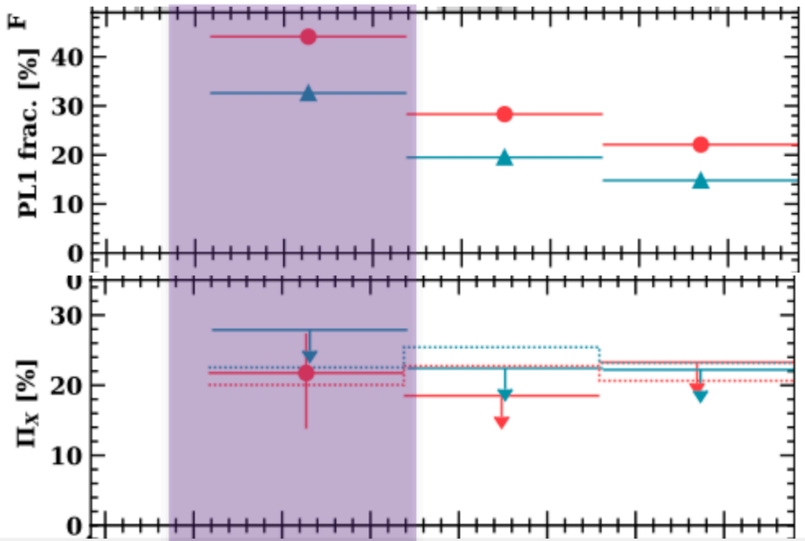
**Significant detection of X-ray polarization when the synchrotron component is stronger: PD~20% (2-4keV)**

| 2-4 keV | 4-8 keV |
|---|---|
| e- Synch | no p Synch |

# BL Lac in Flare and more…




Peirson+2023




….soon more thanks to a 4rd IXPE obs

**Source seen in intermediate state (ISP)**
**--> Mixture of synchrotron and Compton**

**Significant detection of X-ray polarization when the synchrotron component is stronger: PD~20% (2-4keV)**

| 2-4 keV | 4-8 keV |
|---|---|
| e- Synch | no p Synch |

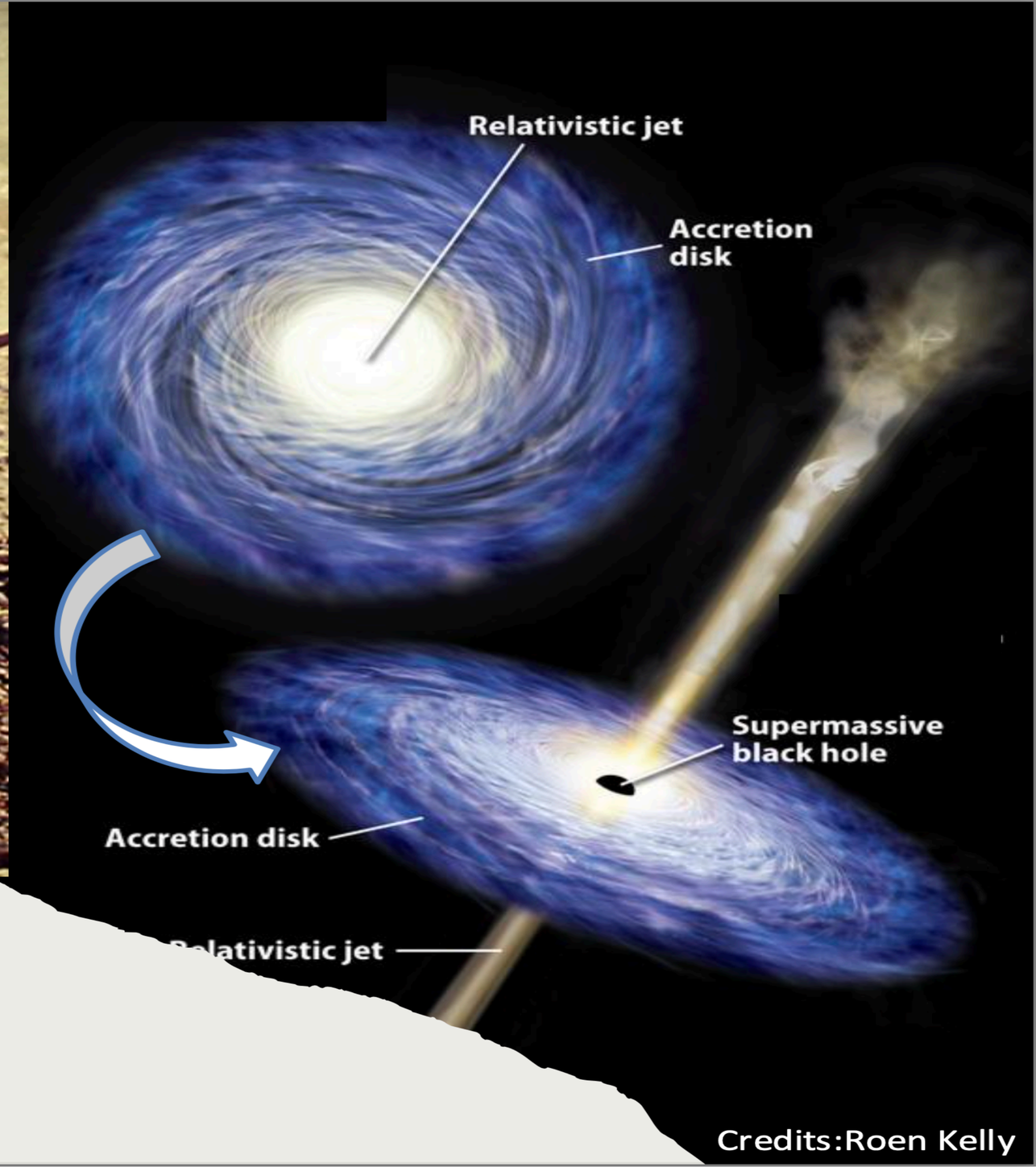
# Take home 1/2

IXPE opened a new eye on the Universe
Polarization gives us a unique view on the energetic processes in AGN

The Synchrotron emission from blazars is likely due to particles accelerated in shocks and it is stratified in energy

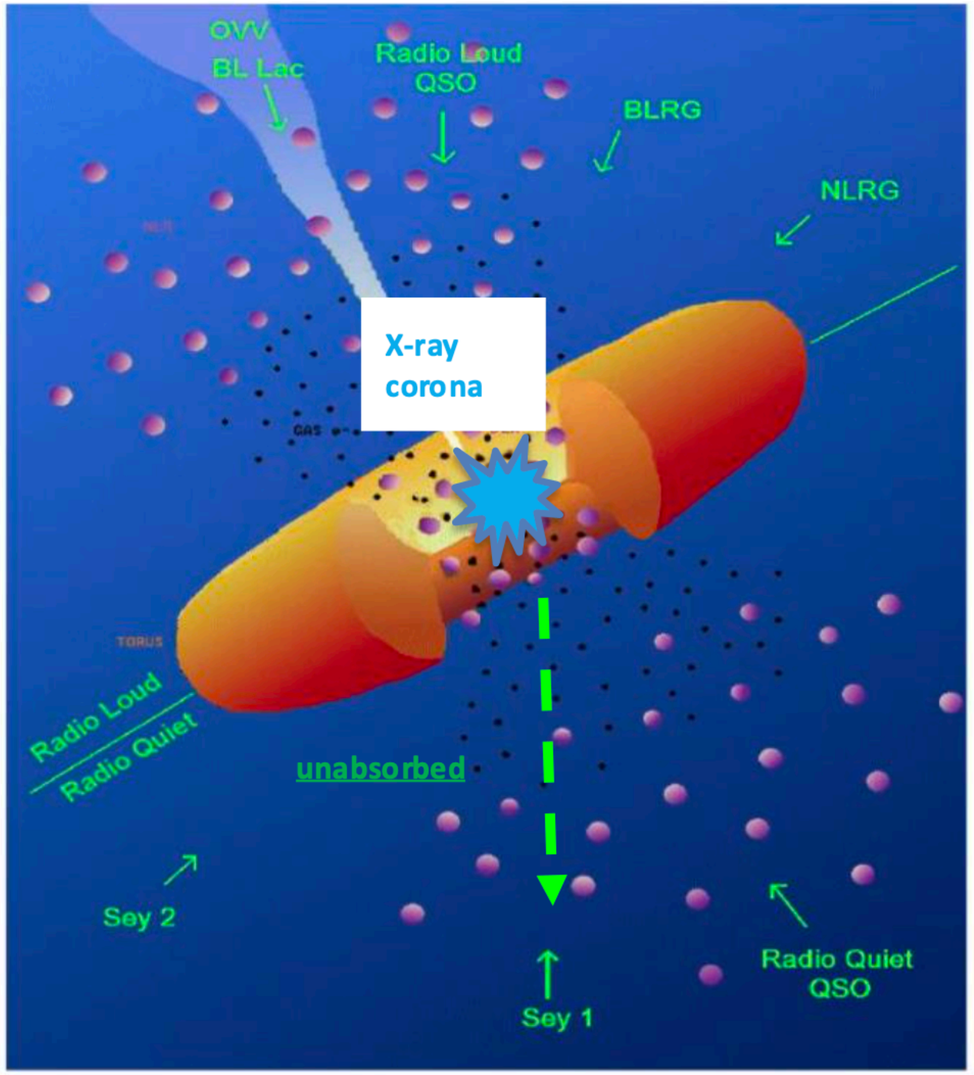
The high energy component in relativistic jets is likely dominated by a Compton (SSC) process involving electrons

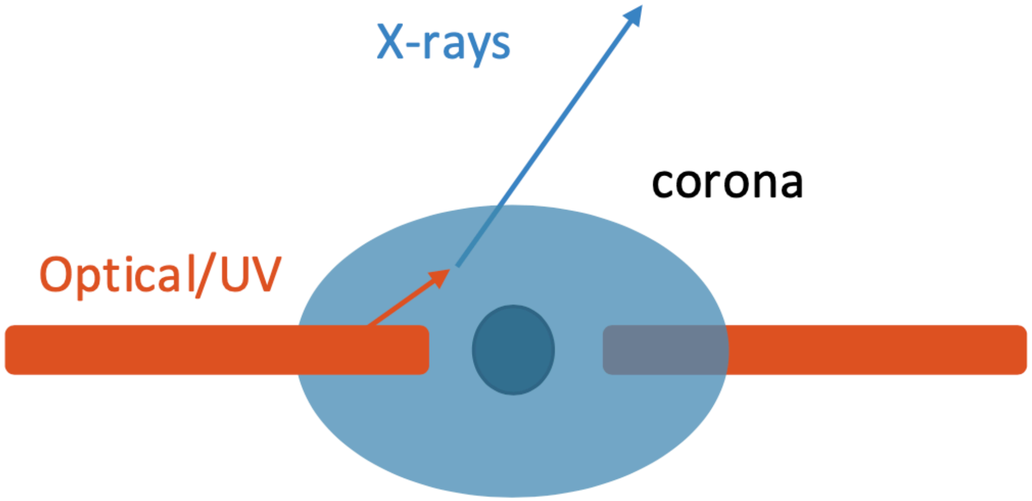
*And now, for something completely different...*




Credits:Roen Kelly

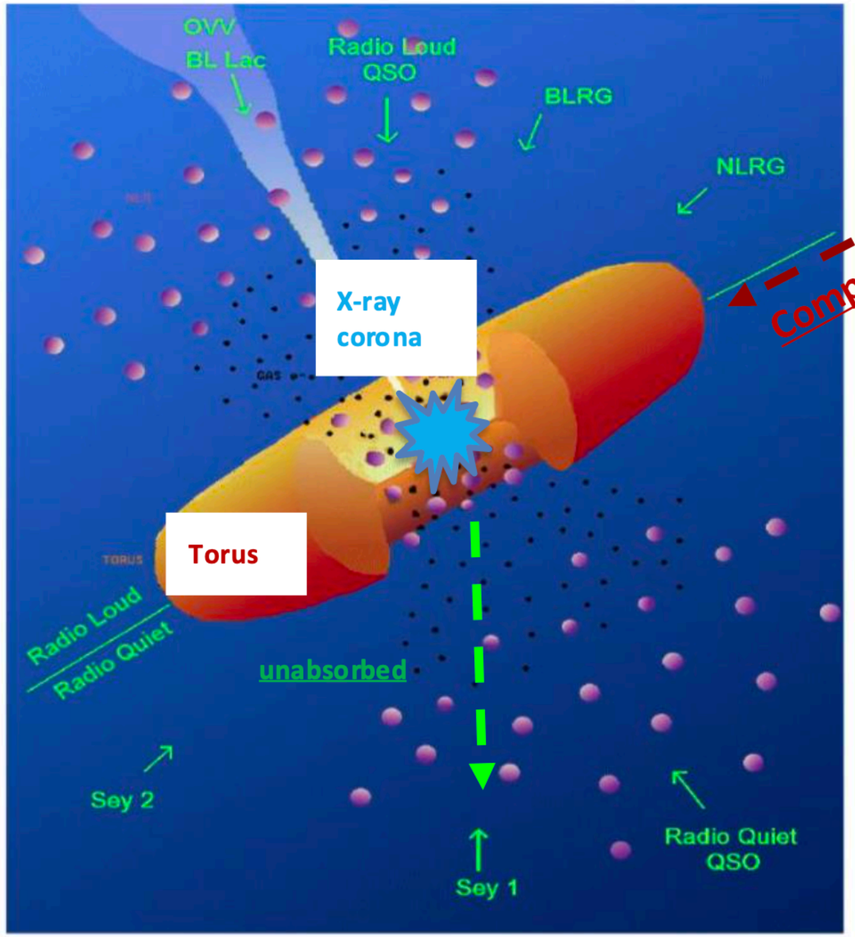
# Radio quiet AGN 1/2

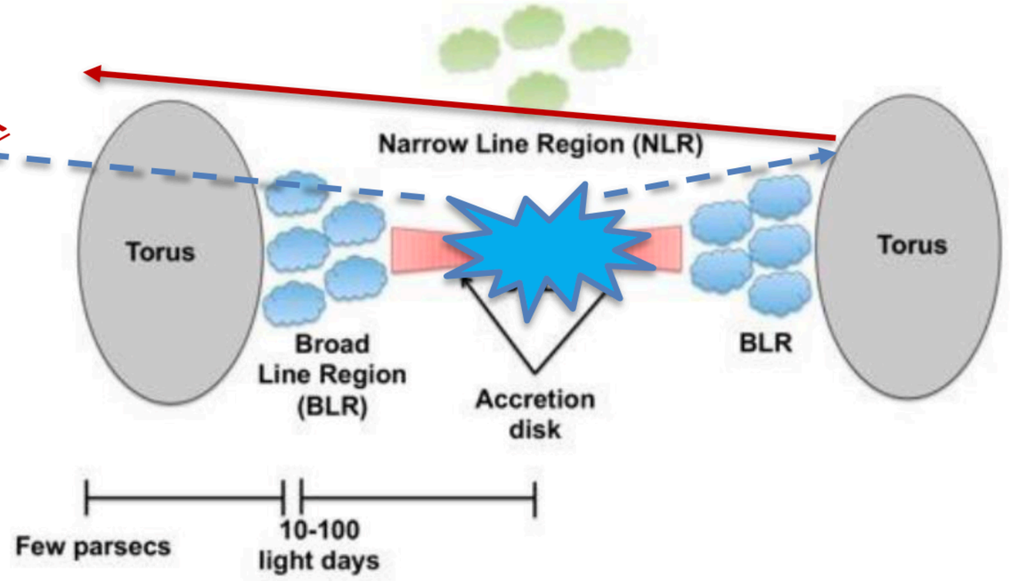



The primary X-ray emission of radio-quiet (non-jetted) AGN is due to thermal Comptonization in a hot corona with a temperature of ~10—100 keV.

# Radio quiet AGN 2/2

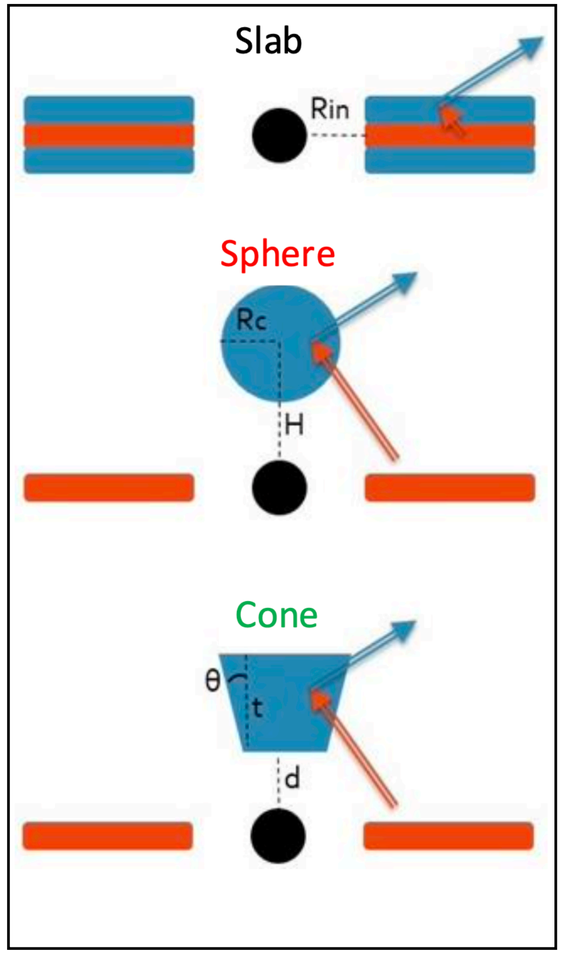



Many AGN are obscured in the X-rays. In **Compton-thick**, the primary continuum up to 10 keV is completely absorbed. According to the Unification Model, this is an orientation effect due to a pc-scale **torus.**

# AGN radio quiet open questions

What's the geometry of the hot plasma




Different predictions In terms of PD and PA

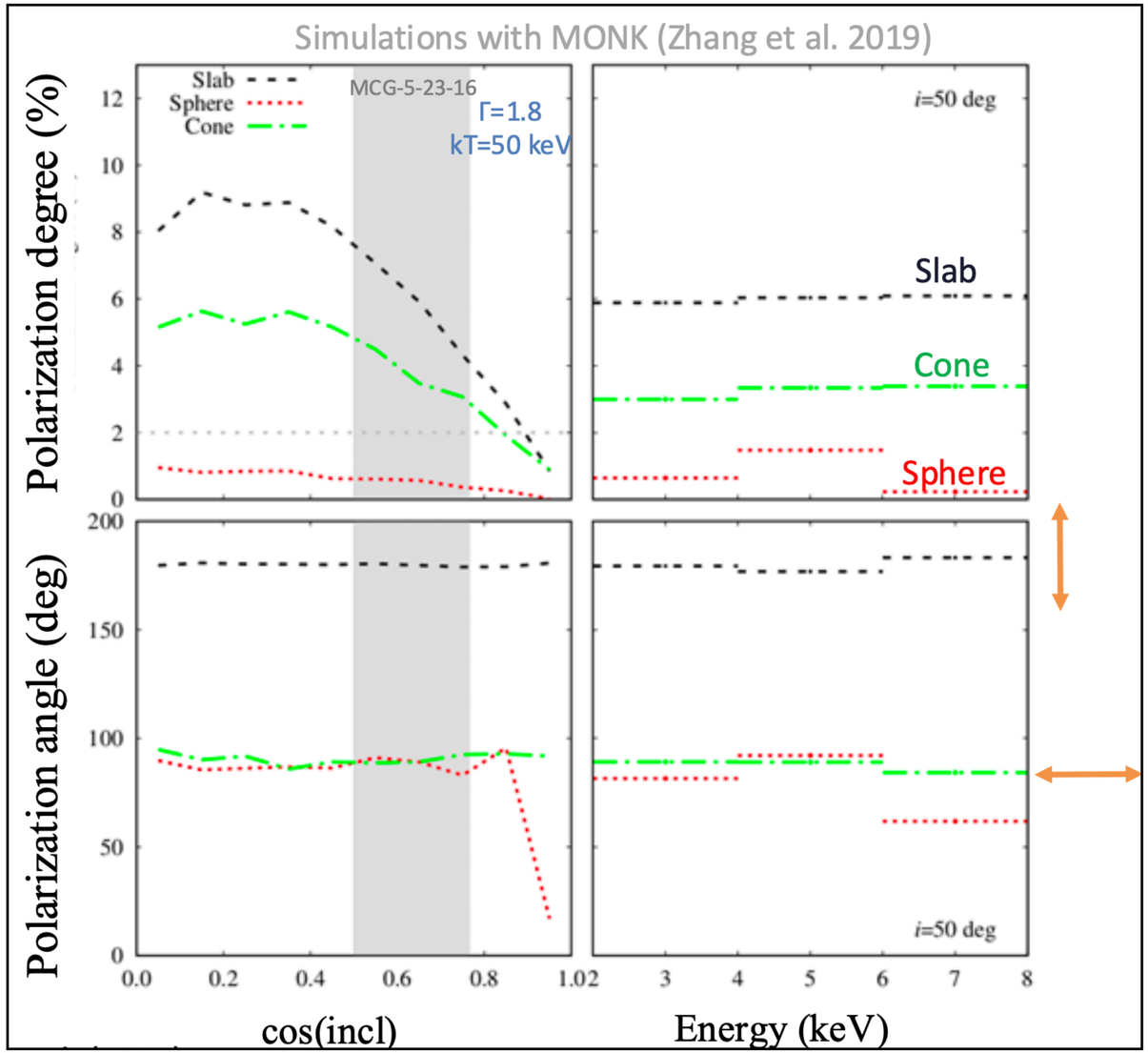
Obscuring Torus shape?

# Basic ideas

The radiation is polarized perpendicularly to the scattering plane

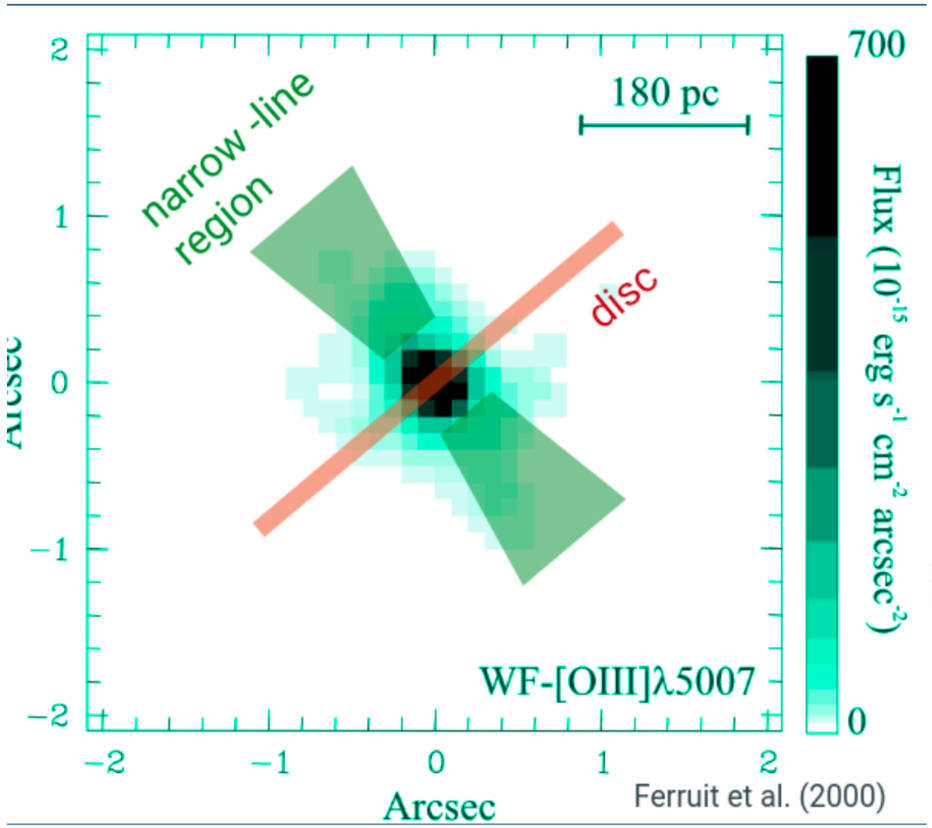
High degree of anisotropy high polarization expected (highly inclined systems)

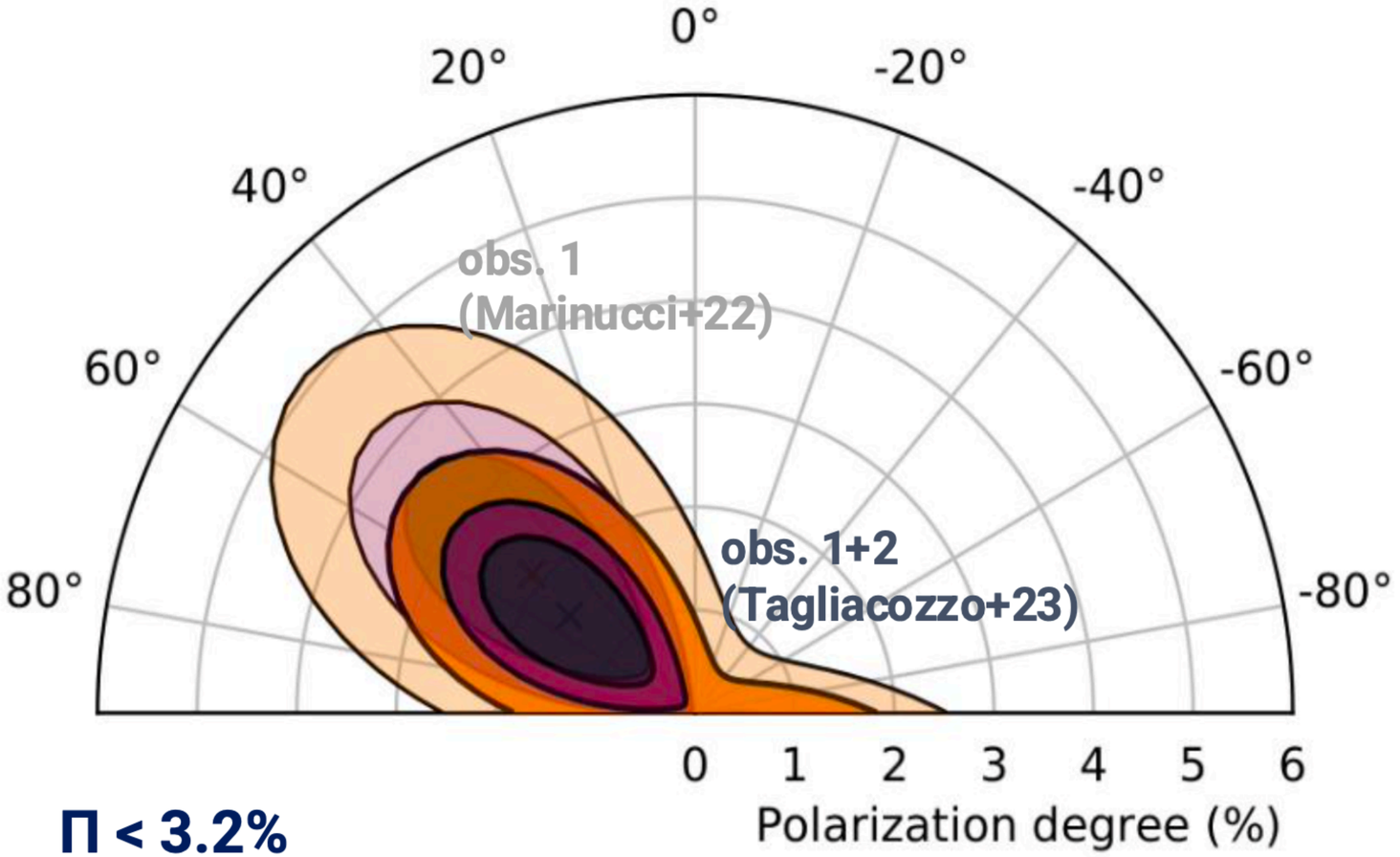
High degree of symmetry low polarization expected (~face-on systems)



# Radio quiet AGN

## 1st hint



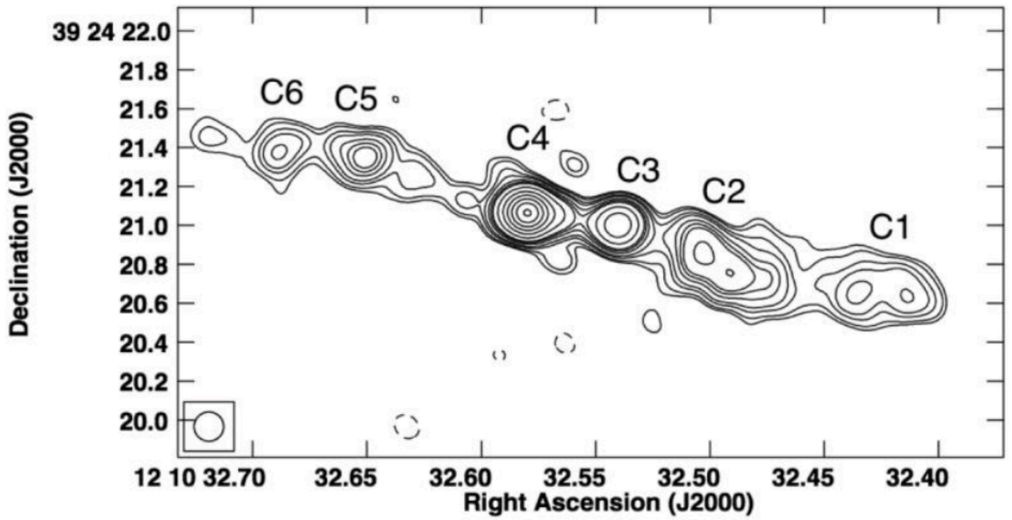

**Π < 3.2%**

**Ψ preferentially aligned with the NLR**

# Radio quiet AGN

## 2nd hint

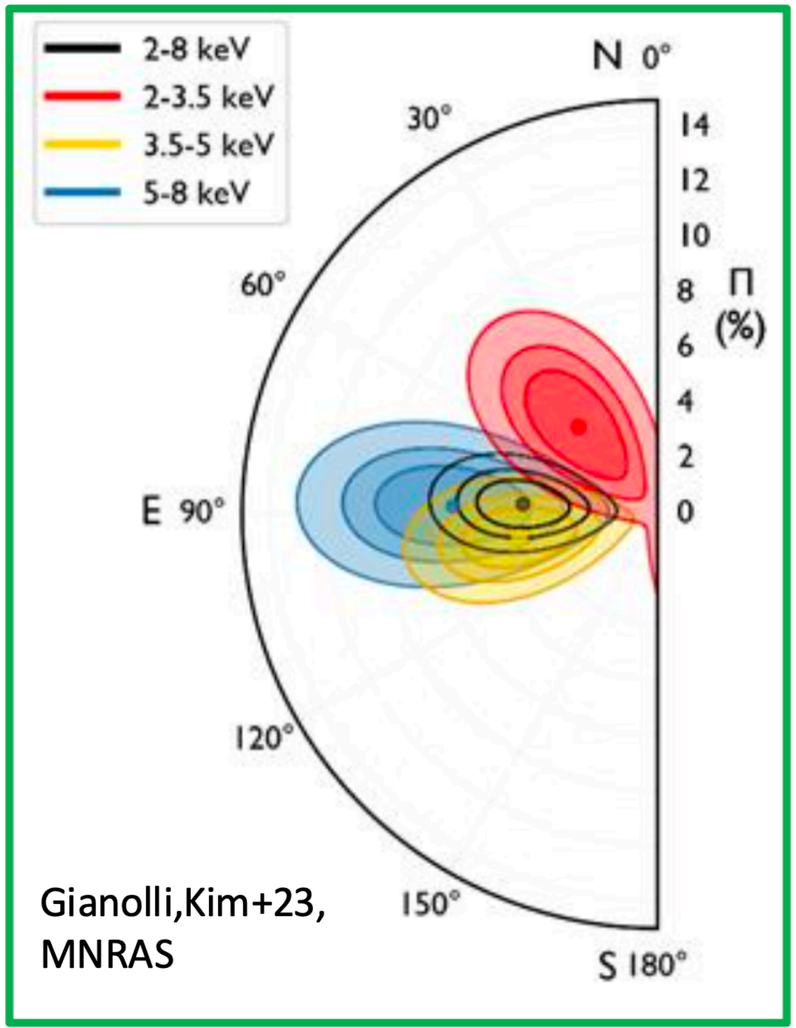
**Π = (4.9±1.1)%  >4σ detection**




Williams et al. (2017)
eMERLIN @1.51 GHz

**ψ = 86°±7°**
**~consistent with the radio jet**

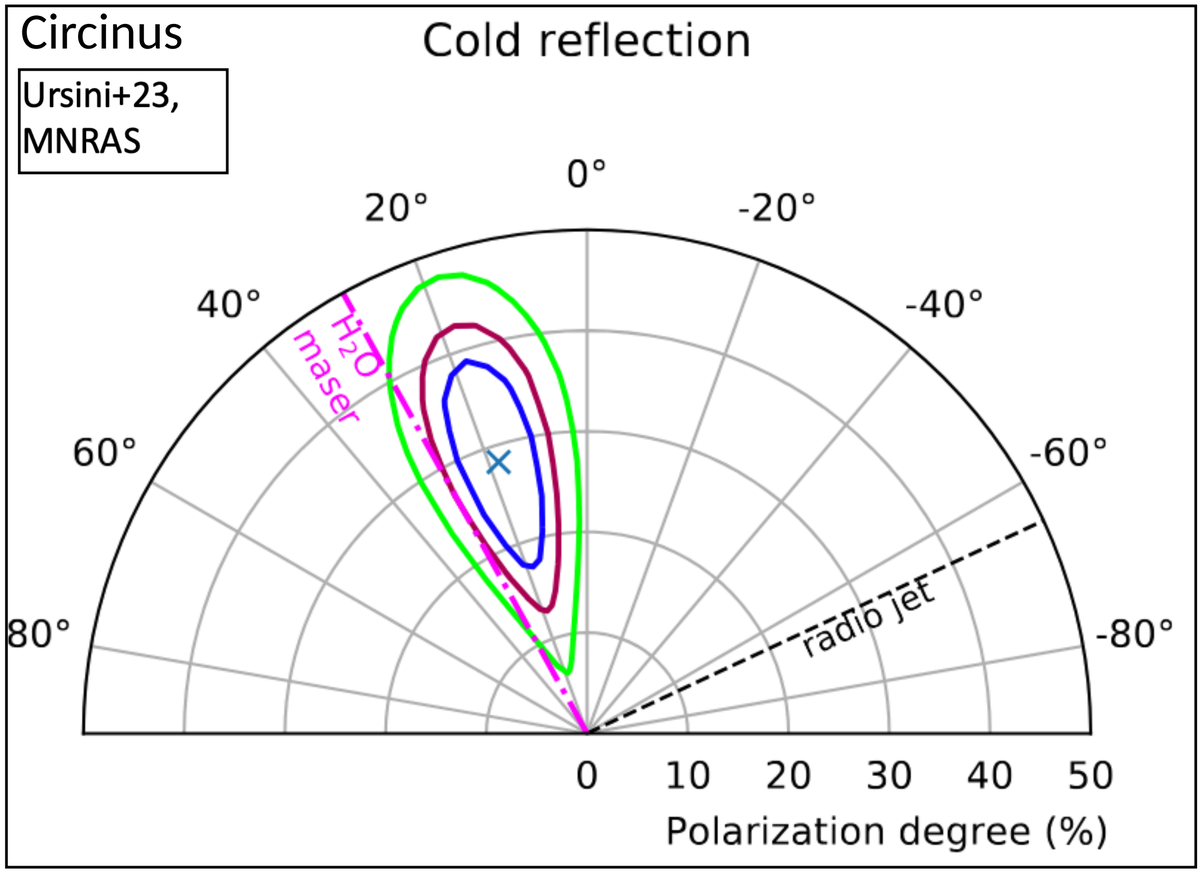
**Hint of a rotation with energy**

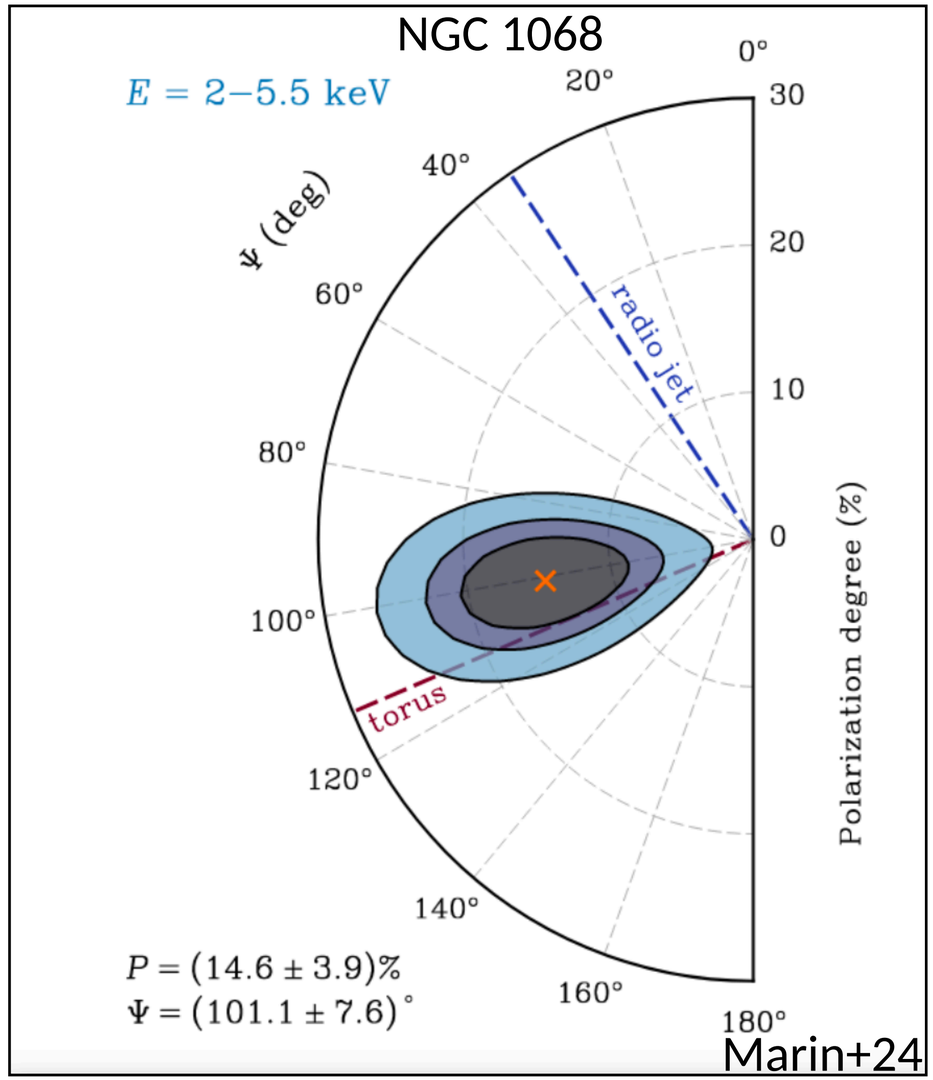



Gianolli,Kim+23, MNRAS

# Radio quiet AGN (Compton-thick)

## Significant detection of the PD
## PA Perpendicular to the Jet

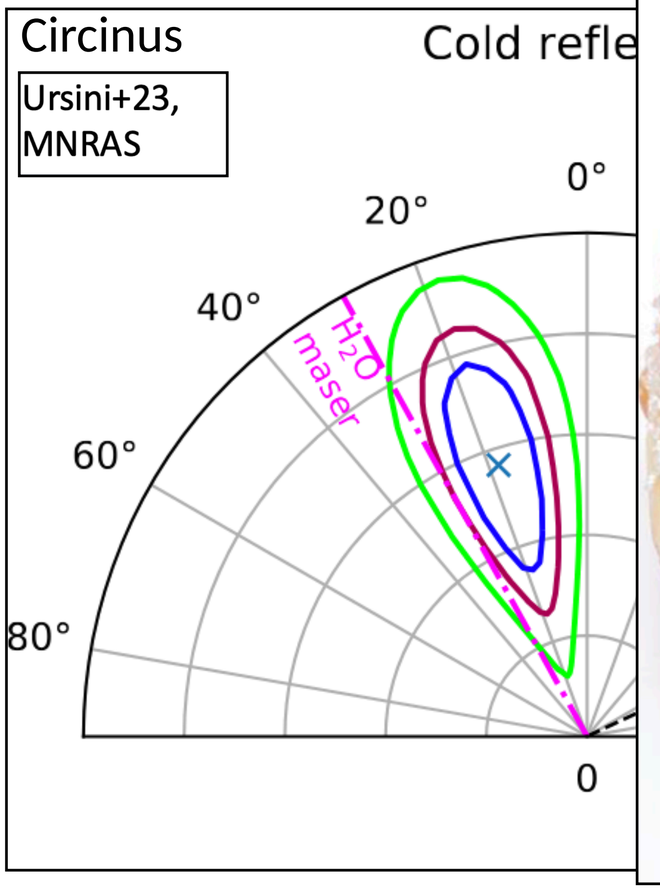


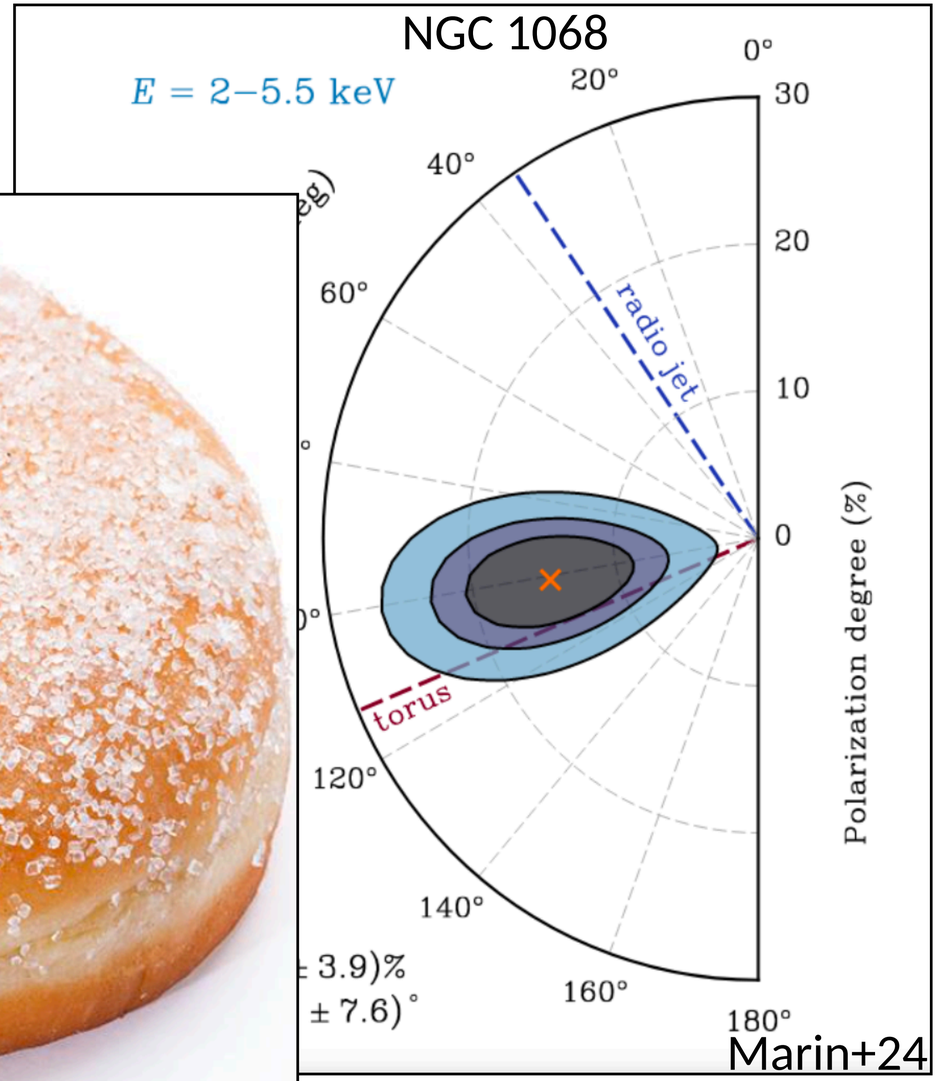




Marin+24

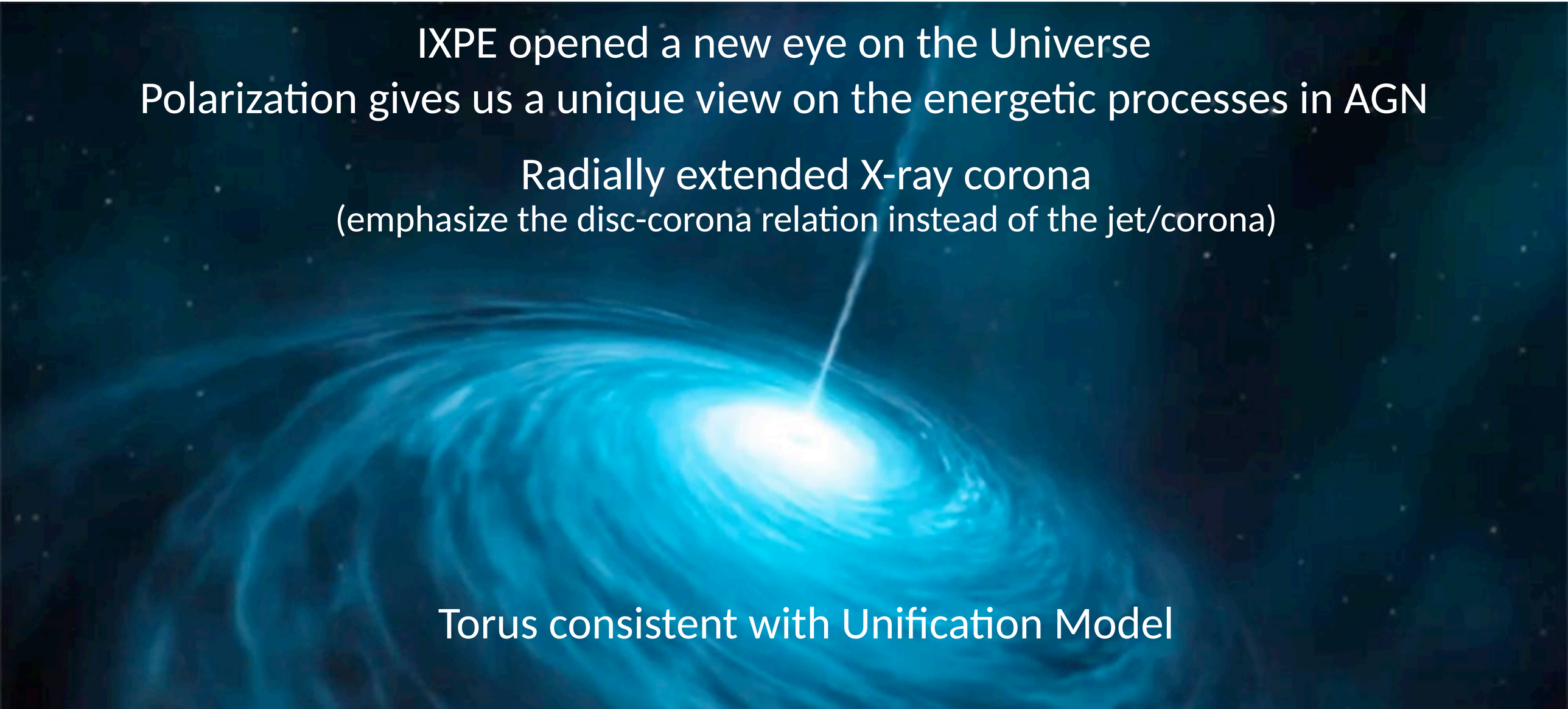
# Radio quiet AGN (Compton-thick)

## Significant detection of the PD
## PA Perpendicular to the Jet



# Take home 2/2



IXPE opened a new eye on the Universe

Polarization gives us a unique view on the energetic processes in AGN

Radially extended X-ray corona

(emphasize the disc-corona relation instead of the jet/corona)

Torus consistent with Unification Model

IXPE
Imaging
X-Ray
Polarimetry
Explorer

# Thank you for your attention