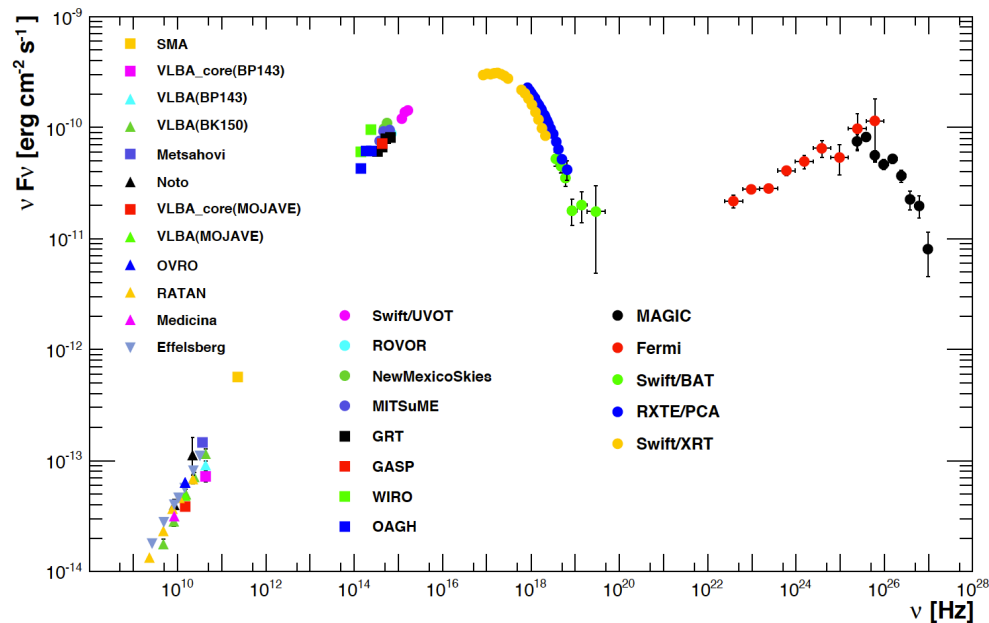


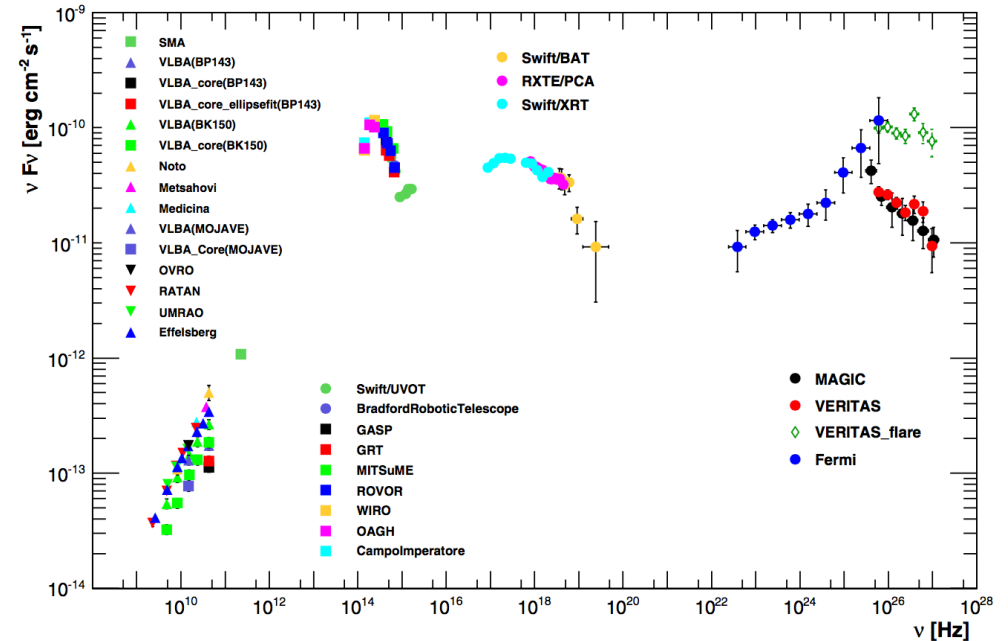
Historical Scientific Highlights and Impressions from 15 Years of MAGIC Operation

David Paneque

Mrk421



Mrk501



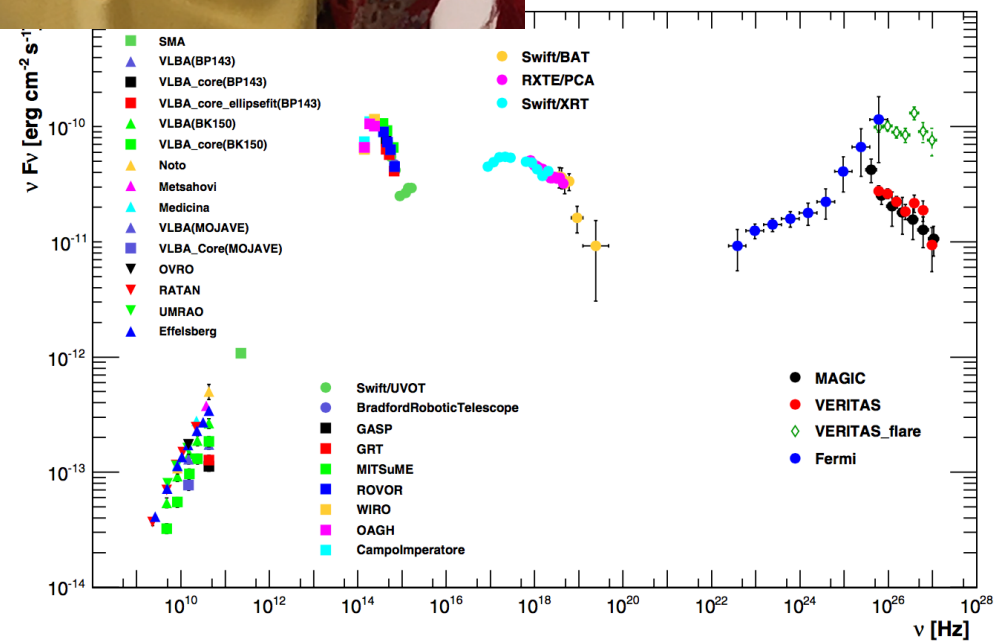
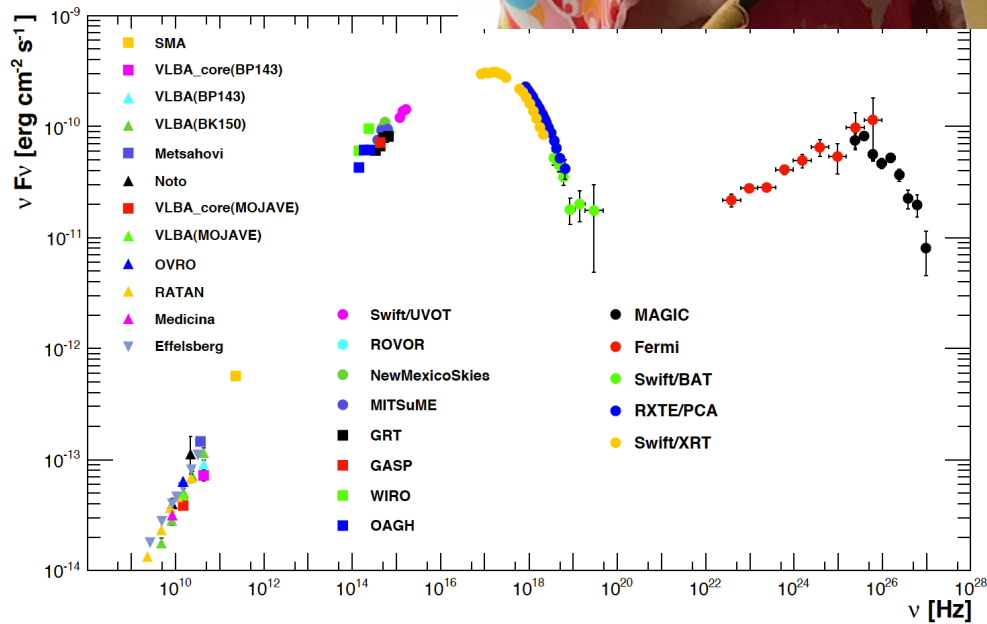
Historical Spectra from

Compressions of



Mrk421

Mrk501



Instrumentation for gamma-ray astronomy (the big picture)

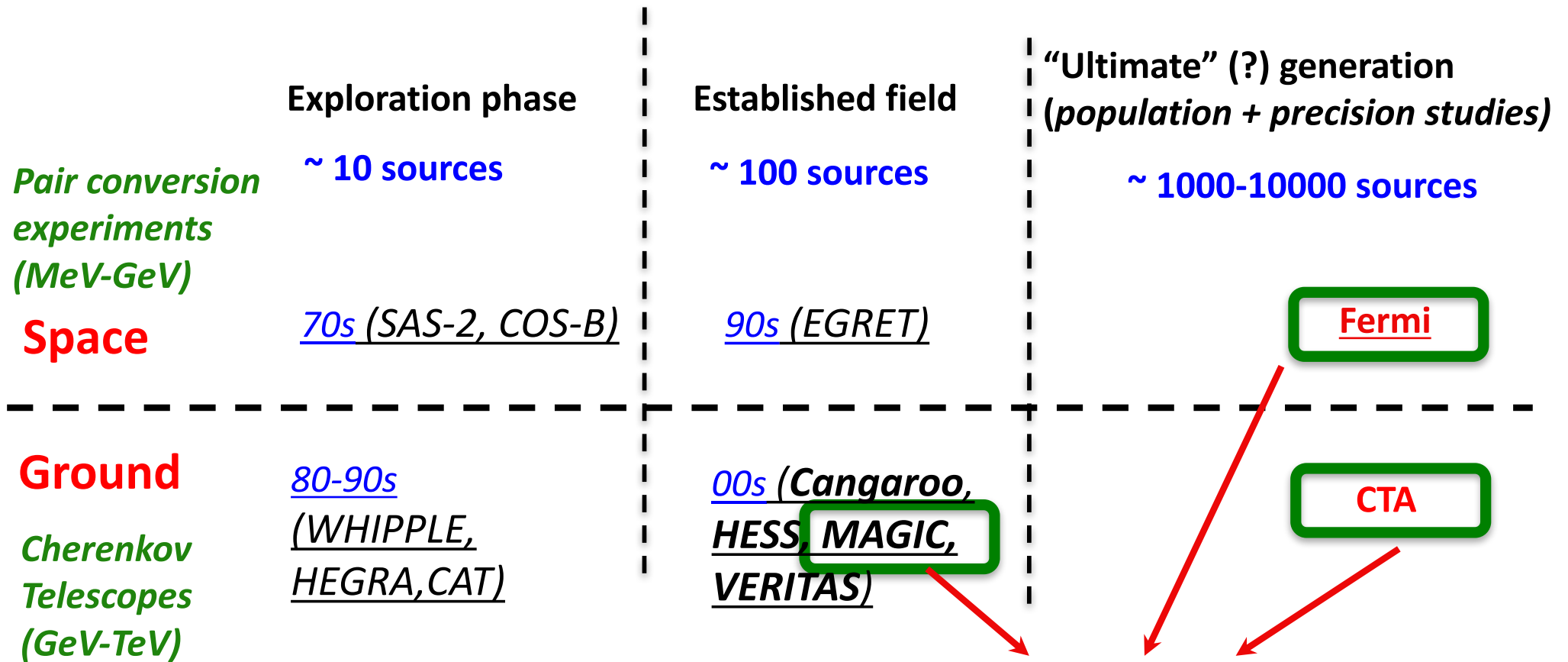
	Exploration phase	Established field	“Ultimate” (?) generation (<i>population + precision studies</i>)
<i>Pair conversion experiments (MeV-GeV)</i>	~ 10 sources	~ 100 sources	~ 1000-10000 sources
Space	<u>70s (SAS-2, COS-B)</u>	<u>90s (EGRET)</u>	Now Fermi
Ground	<u>80-90s (WHIPPLE, HEGRA, CAT)</u>	<u>00s (Cangaroo, HESS, MAGIC, VERITAS)</u>	future CTA
<i>Cherenkov Telescopes (GeV-TeV)</i>			



lots of room for improvement and potential discovery

Now **MAGIC II HESS II VERITAS upgraded**

Instrumentation for gamma-ray astronomy (the big picture)

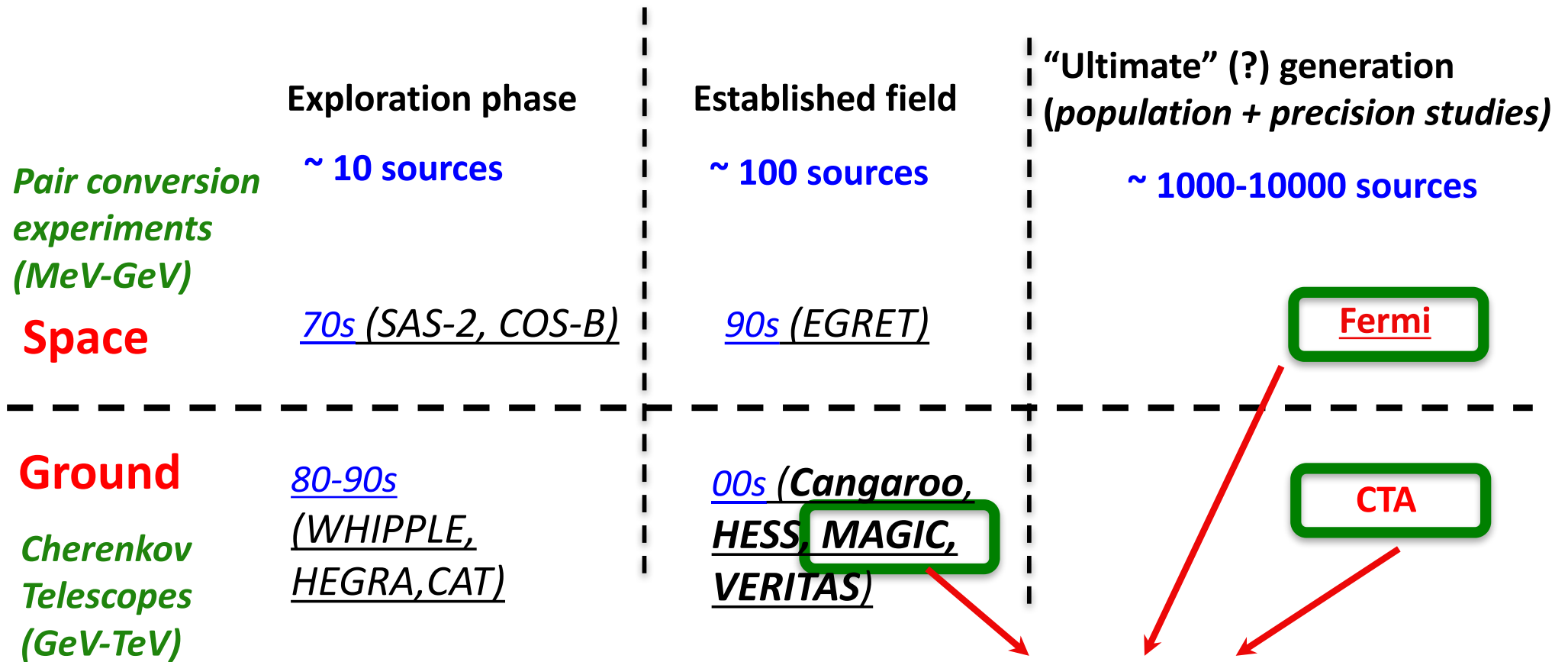


Novel discipline

I have been involved in three projects that have been (and will be) at the **forefront of experimental gamma-ray astronomy**

lots of room for improvement and potential discovery

Instrumentation for gamma-ray astronomy (the big picture)



Novel discipline

I finished university studies at UAB and started my PhD at IFAE in 1998 (20 years ago !).
MAGIC collaboration was much smaller.
Scientifically, I grew up with MAGIC
Fantastic experience (personal & professional)

MAGIC started to operate scientifically in 2004/2005

With a new instrument, the goal is naturally to discovery new things

“New things” was translated by many MAGICians (including very senior and outstanding scientists like Eckart) into

“observing new objects”

Not much expected from the “old/classical” TeV blazars Mrk421/501, which had been observed many times by Whipple/HEGRA/CAT.

Not easy to convince people (and later on TAC) to provide time to perform a systematic monitoring of these two classical TeV objects.

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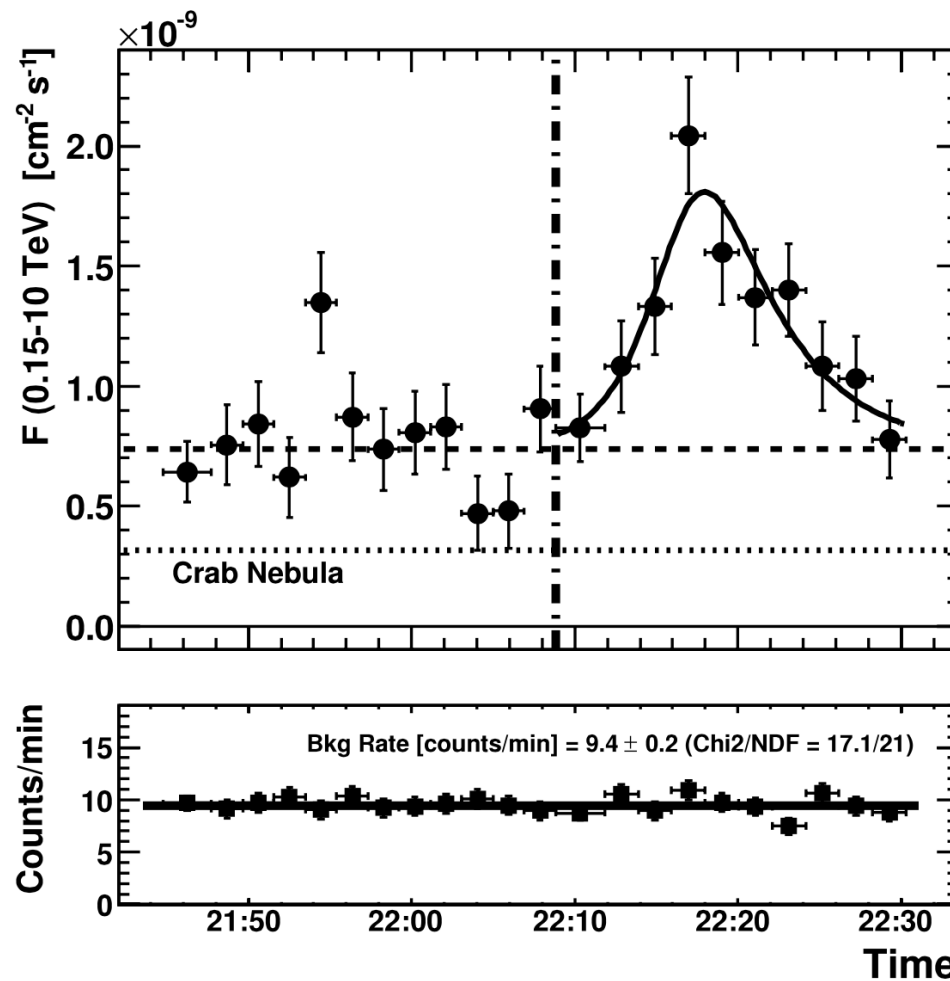
Not much expected from the “old/classical” TeV blazars Mrk421/501, which had been observed many times by Whipple/HEGRA/CAT.

Not easy to convince people (and later on TAC) to provide time to perform a systematic monitoring of these two classical TeV objects.

The voyage of discovery is not in seeking new landscapes but in having new eyes (Marcel Proust)

MAGIC started to operate scientifically in 2004/2005

15 years later, MAGIC data on Mrk421/Mrk501 have produced more than 20 papers (*including most cited MAGIC publication*).



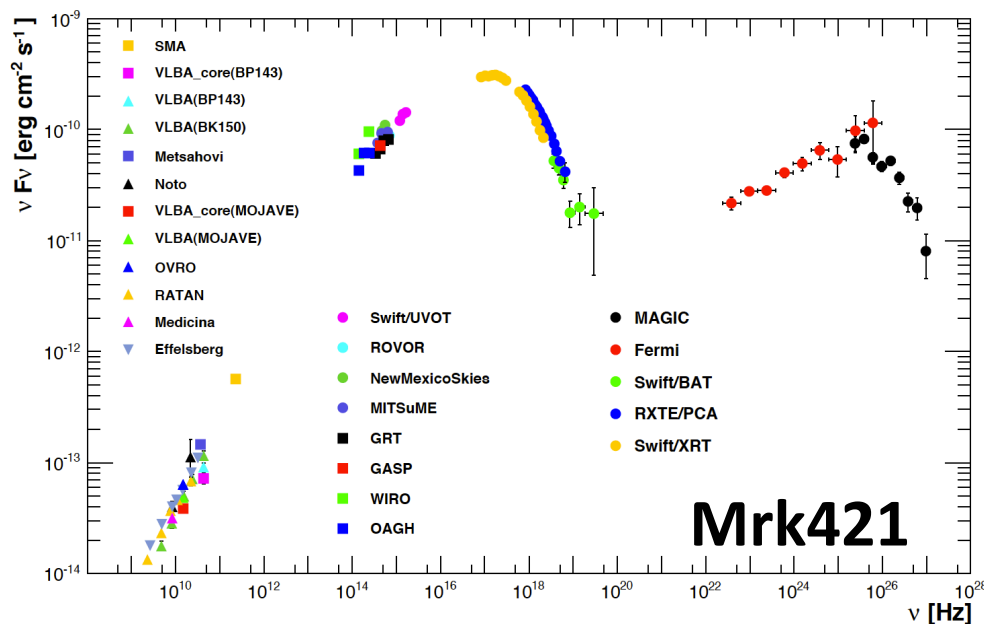
Albert et al 2007,
ApJ 669, 862

MAGIC started to operate scientifically in 2004/2005

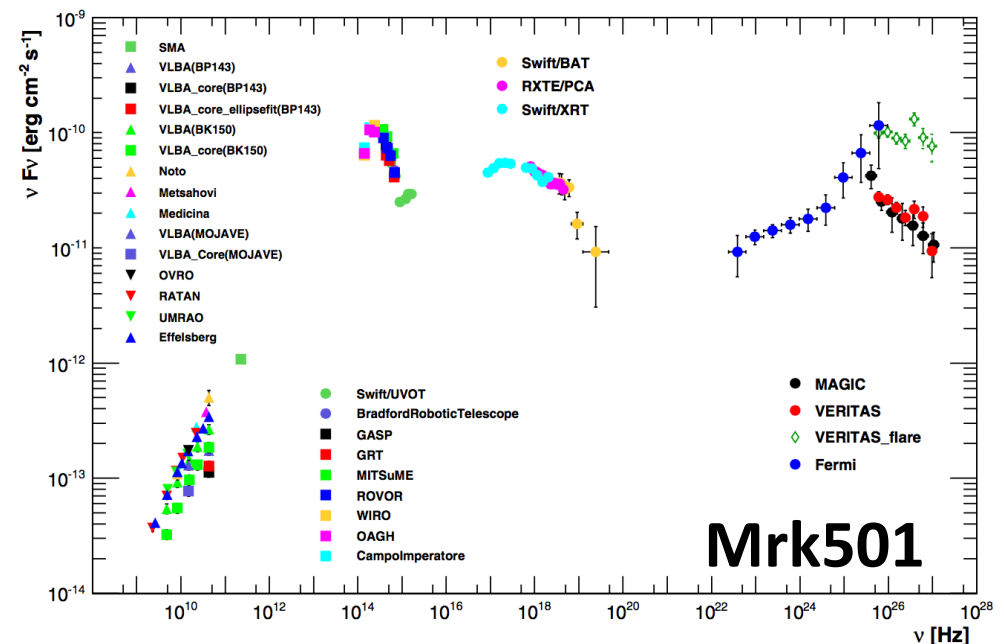
15 years later, MAGIC data on Mrk421/Mrk501 have produced more than 20 papers (*including most cited MAGIC publication*).

The scientific results are very often achieved throughout the combination of many instruments. MAGIC covers a small fraction of wide-energy range where these blazars emit

Abdo et al 2011, ApJ 736, 131



Abdo et al 2011, ApJ 727, 129



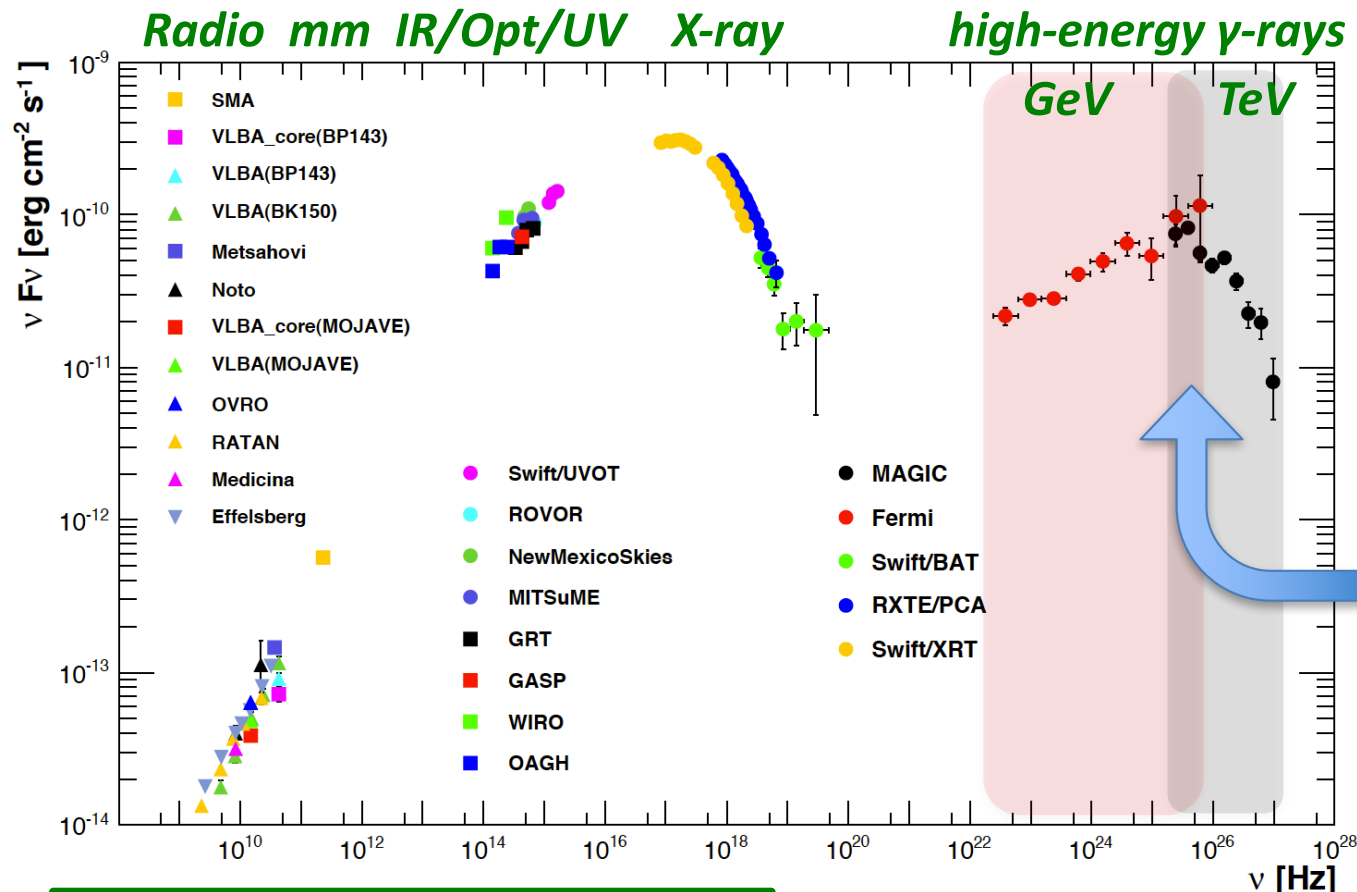
Blazars emit over a very wide energy range and show variability

Emission at different energies could be produced by same particles

→ *Need simultaneous observations from many instruments*

→ *The gamma-ray emission fully characterized “only” since 2009*

→ *Connectivity among astronomers also grew in last decade*



Fermi – **IACt** spectra cover, for the first time, the complete high energy component over 5 orders of magnitude without gaps

→ *Crucial for the theoretical modeling of the broad emission*

Abdo et al 2011, ApJ 736, 131

David Paneque
Fermi – IACT

Bright blazars as our Extreme Cosmic Accelerators

LHC

vs

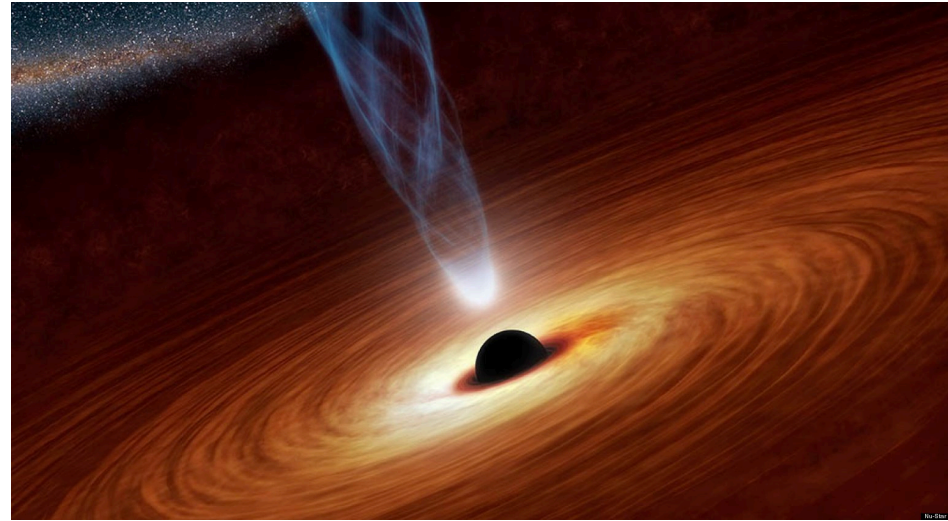
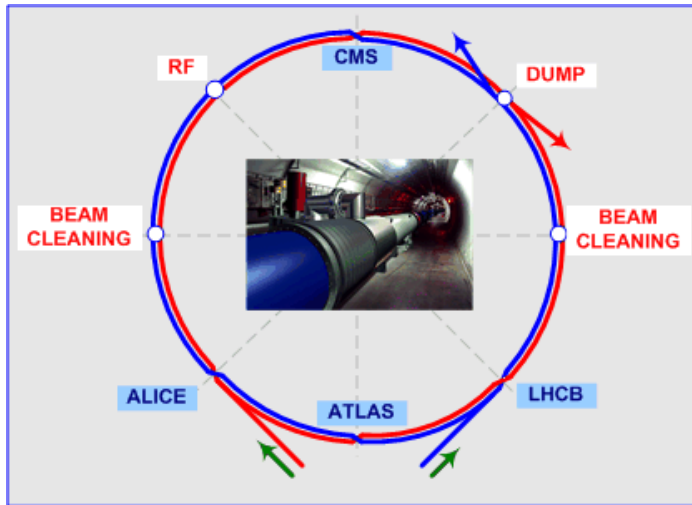
bright blazar

ATLAS/CMS

MAGIC/VERITAS/Fermi

LHCb + Alice

NuSTAR/Swift + Optical + radio



Bright blazars as our Extreme Cosmic Accelerators

LHC

ATLAS/CMS

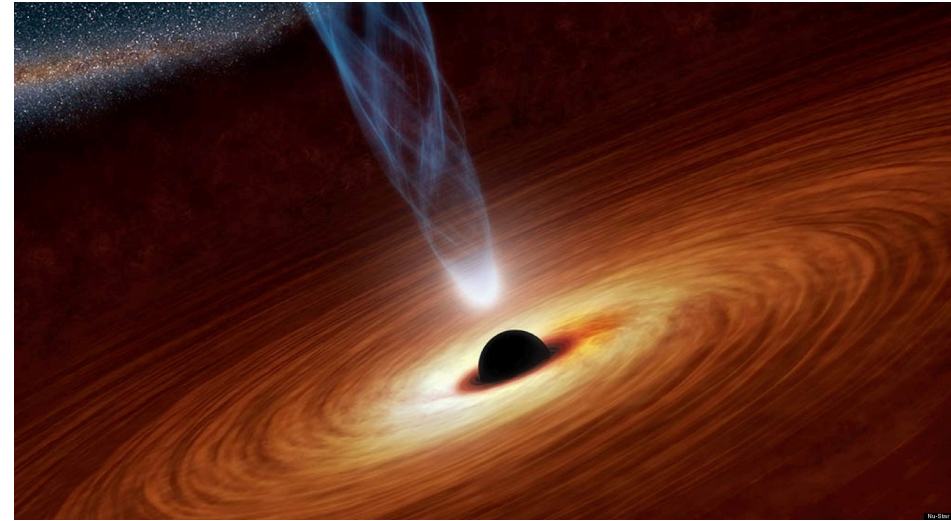
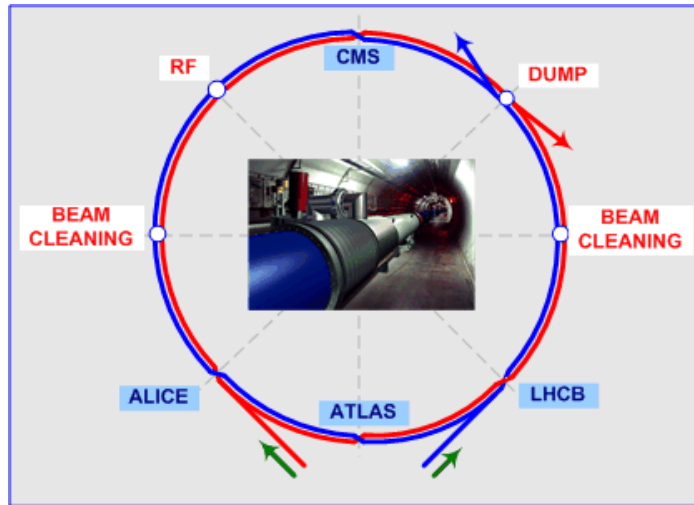
LHCb + Alice

vs

bright blazar

MAGIC/VERITAS/Fermi

NuSTAR/Swift + Optical + radio



Physics studies with cosmic particle accelerators

Disadvantage: Cannot play with knobs in controlled environment

Advantage: Study extreme processes and environments

Much cheaper (*no need to build the accelerator...*)

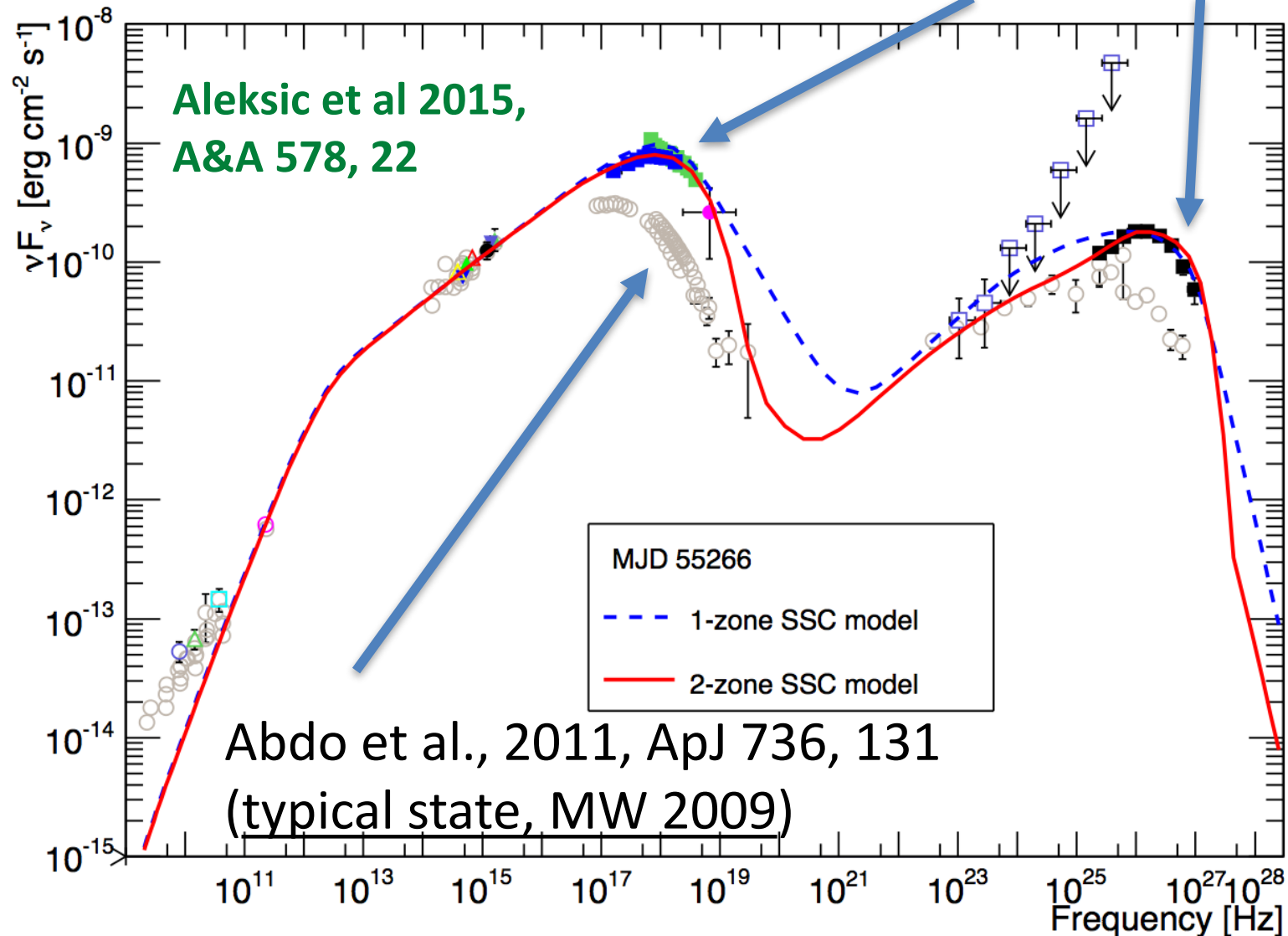
The project requires “observing” over many years in order to integrate over sufficient data/effects → **long-term multi-instrument observations.**

Mrk421 has shown X-ray and VHE spectral variability during flares

X-ray and VHE spectra becomes harder when flaring

- peaks shift to high energies
- highest variability at X-ray and VHE

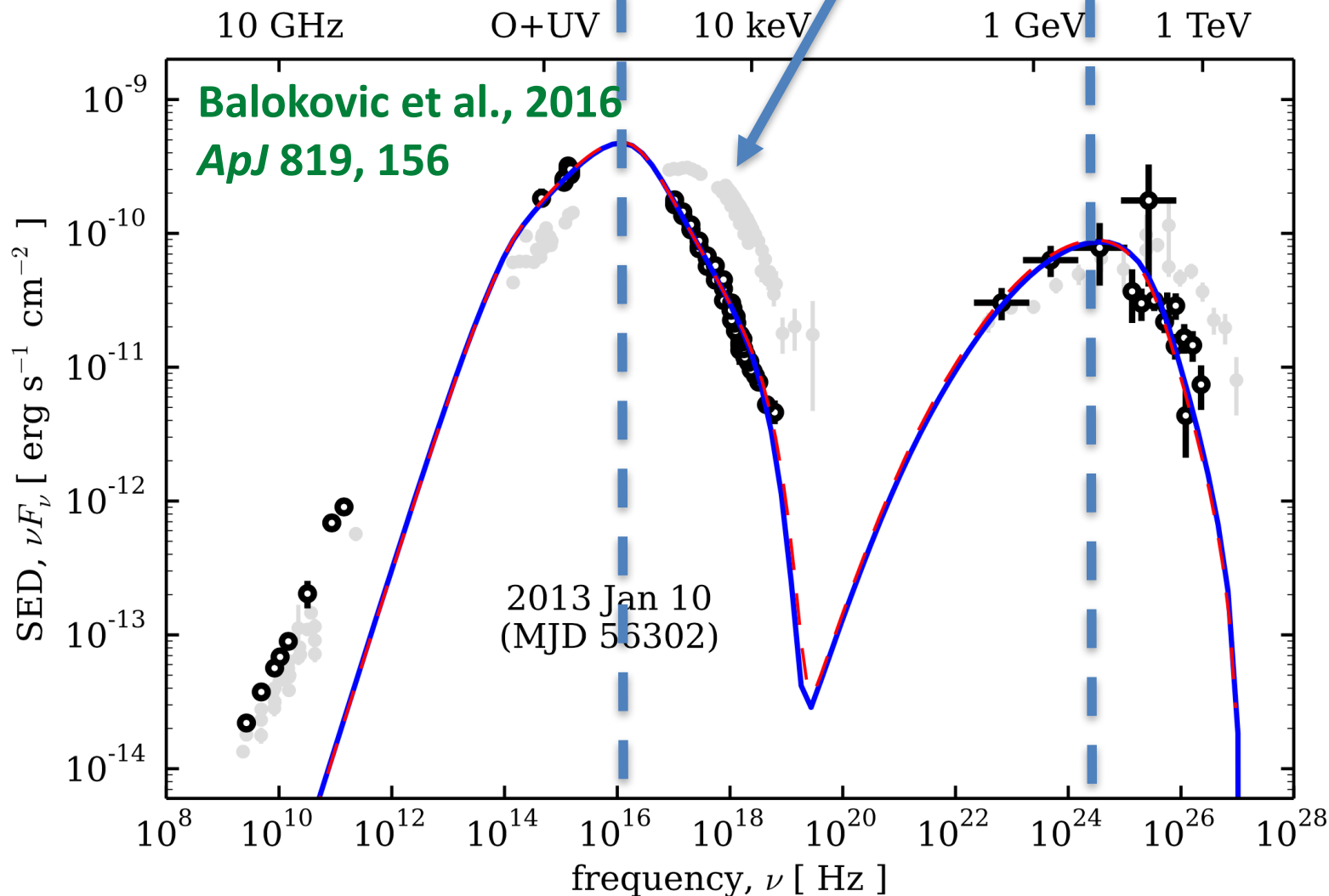
Flare from MW 2010



Mrk421 suffers a personality crisis (in 2013)

Peak position at $\sim 10^{16}$ Hz (~ 40 eV)
Factor 10 lower than typical
 \rightarrow "HBL moving towards IBL"

-Abdo et al., 2011, ApJ 736, 131
(typical state)



Low activity softened the X-ray and VHE spectra, but did not bring spectral cutoffs.
 \rightarrow Electrons accelerated to highest energies

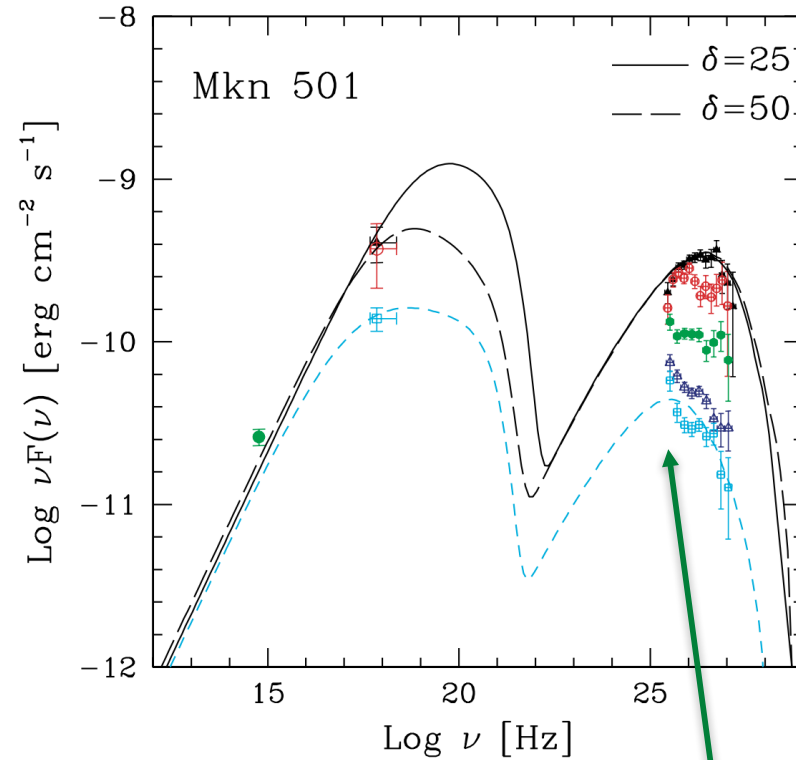
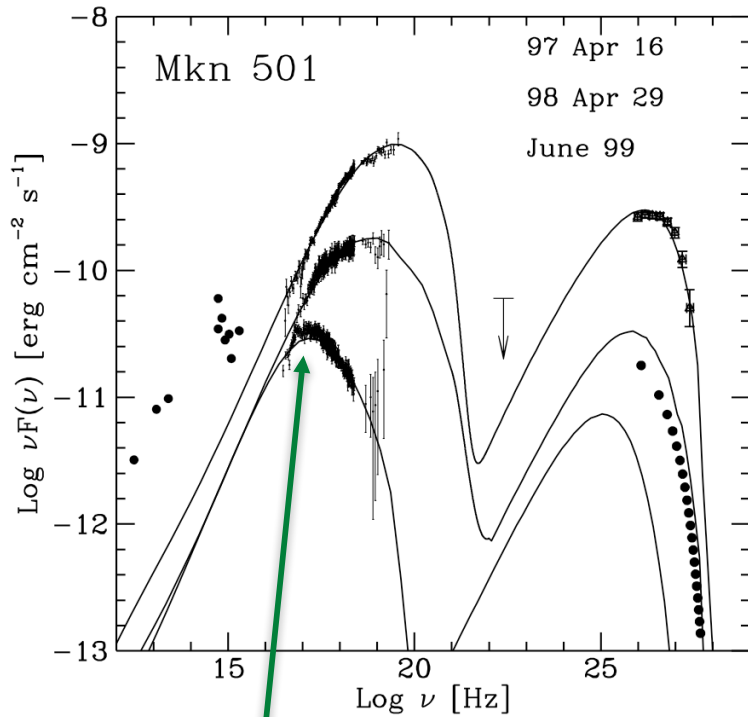
Mrk501 has shown X-ray and VHE spectral variability during flares

(Historical) flare in 1997

Tavecchio et al., 2001, ApJ 554,725

(fast variability) flare in 2005

Albert et al., 2007, ApJ 669,862



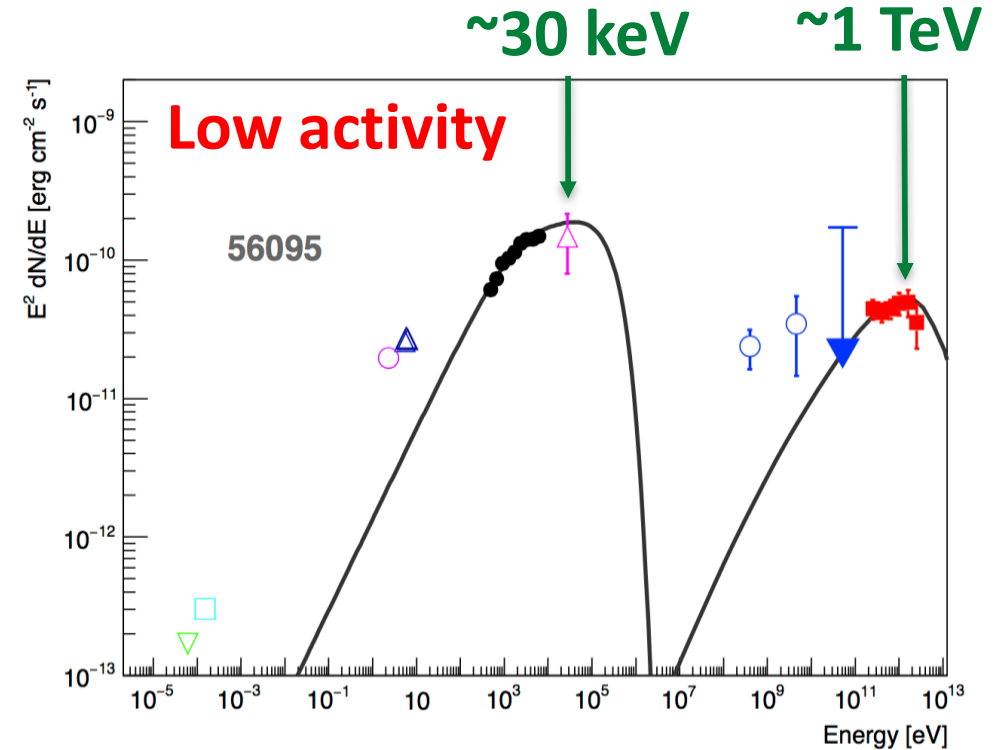
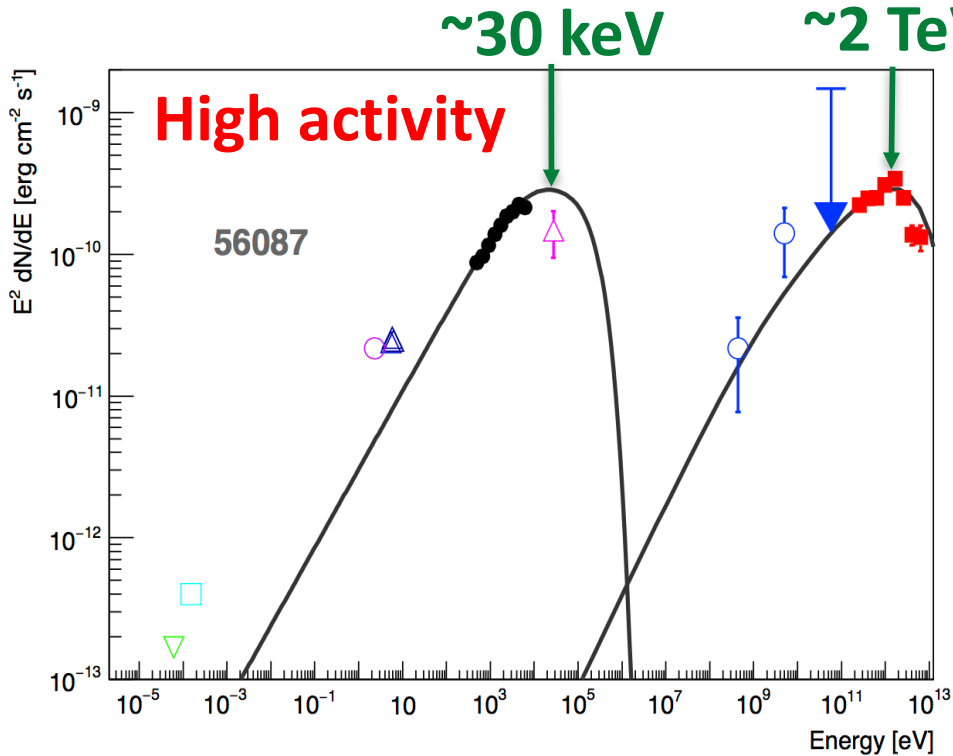
Hard spectra in Mrk501 not observed during low states,

< 1 keV

< 0.1 TeV

Mrk501 suffers a personality crisis (in 2012)

VERY hard spectral index in X-rays and VHE gamma rays, regardless of activity (during MW 2012)



Radio:

OVRO

Metsahovi

X-ray:

Swift/XRT

Swift/BAT

Gamma ray:

Fermi-LAT

MAGIC

Ahnen et al., Submitted to A&A

Optical/UV:

R-band (WEBT+)

Swift/UVOT

Mrk501 suffers a personality crisis (in 2012)

VERY hard spectral index in X-rays and VHE gamma rays,
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Ahnen et al., Submitted to A&A

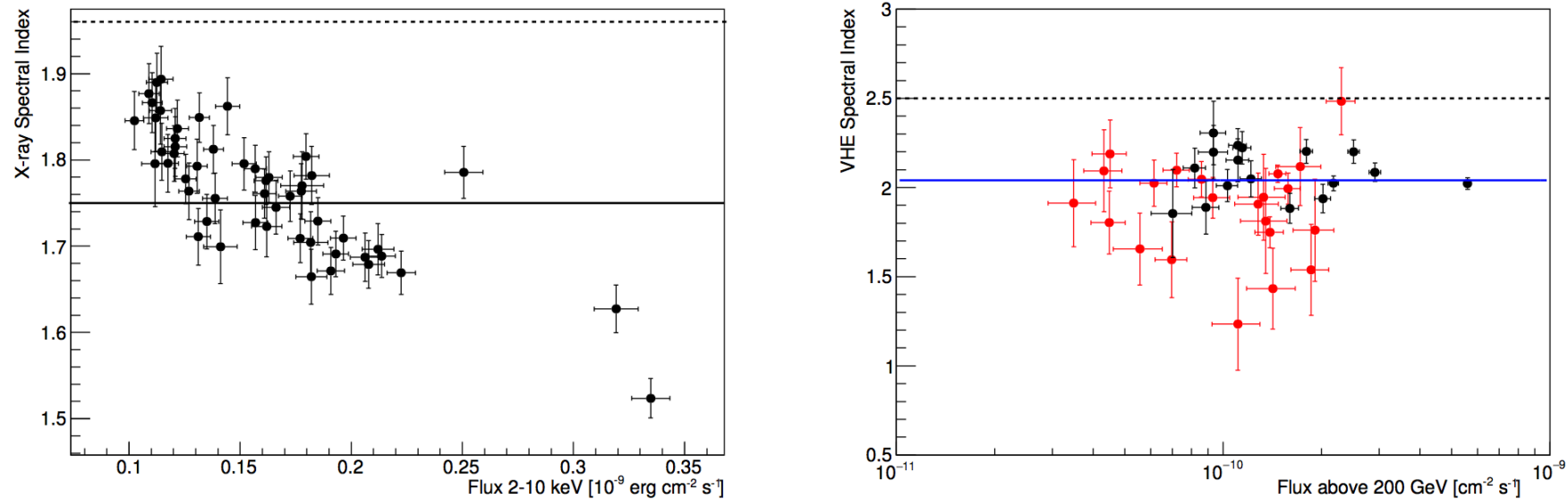


Fig. 4. Left Panel: *Swift*/XRT X-ray power-law spectral index vs flux in the 2-10 keV band. Right Panel: Measured VHE power-law spectral index vs VHE Flux above 0.2 TeV. Red points represent VERITAS data and black points MAGIC data. The data are EBL corrected using Franceschini et al. (2008). The *Swift*/XRT spectrum of Mrk 501 is often curved, and can be described at keV energies with a spectral index that is typically between 1.8 and 2.1, while the VHE spectral index measured with MAGIC and VERITAS during typical non-flaring activity is about 2.5 (Abdo et al. 2011; Aleksić et al. 2015a). The typical spectral indices at X-ray and VHE are marked with a dashed line. For comparison purposes, the panels depict with solid lines the result of a fit with a constant to the X-ray and VHE spectral indices.

→ **Mrk 501 behaved as Extreme HBL!**

*Similar X-ray/VHE spectra as
1ES 0229+200, 1ES 0347-121
(Peaks at ~10 keV and ~1TeV)*



**Being "extreme HBL" may be a
temporal state, rather than
intrinsic blazar characteristic**

Conclusions

15 years and 20 papers later,
we have learnt that Mrk421/501 are
“**complicated cosmic animals**”

This complexity would be hidden if dealing
with poor sensitivity and
limited **energy&time** coverage



And we keep learning new things (*see talk from Becerra*)

Conclusions

15 years and 20 papers later,
we have learnt that Mrk421/501 are
“**complicated cosmic animals**”

This complexity would be hidden if dealing
with poor sensitivity and
limited **energy&time** coverage



And we keep learning new things (*see talk from Becerra*)

- **Pathfinder to some of the extragalactic science
that will be possible with CTA (in 2022+).**

→ *We have VHE spectra from Mrk421/Mkr501 with a resolution
comparable to full CTA for the typical blazar (“<5% Crab blazars”)*

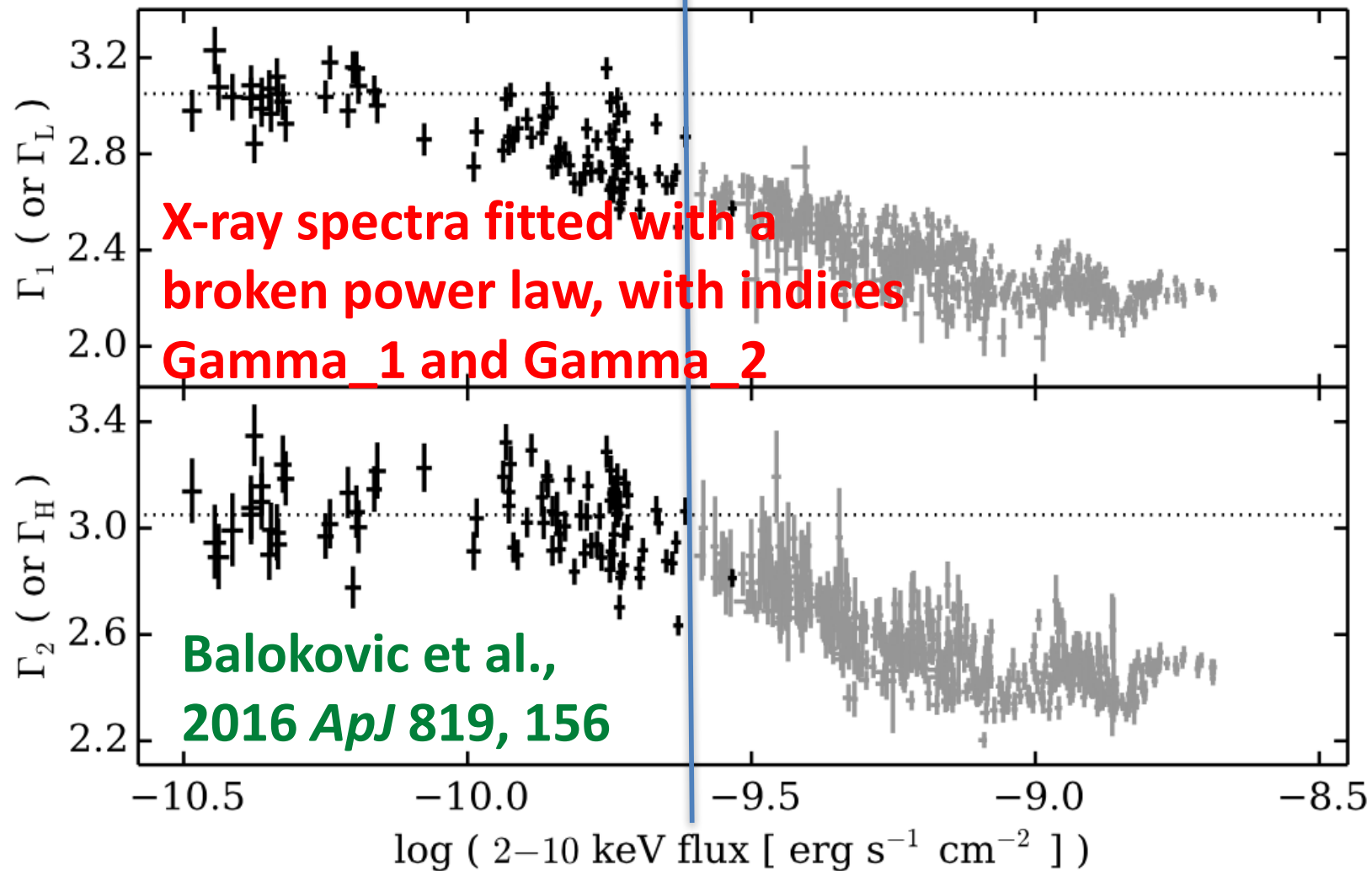
→ *Studies done TODAY on Mrk421/Mrk501 will be
repeated in 5+ years on other blazars with CTA*

Backup

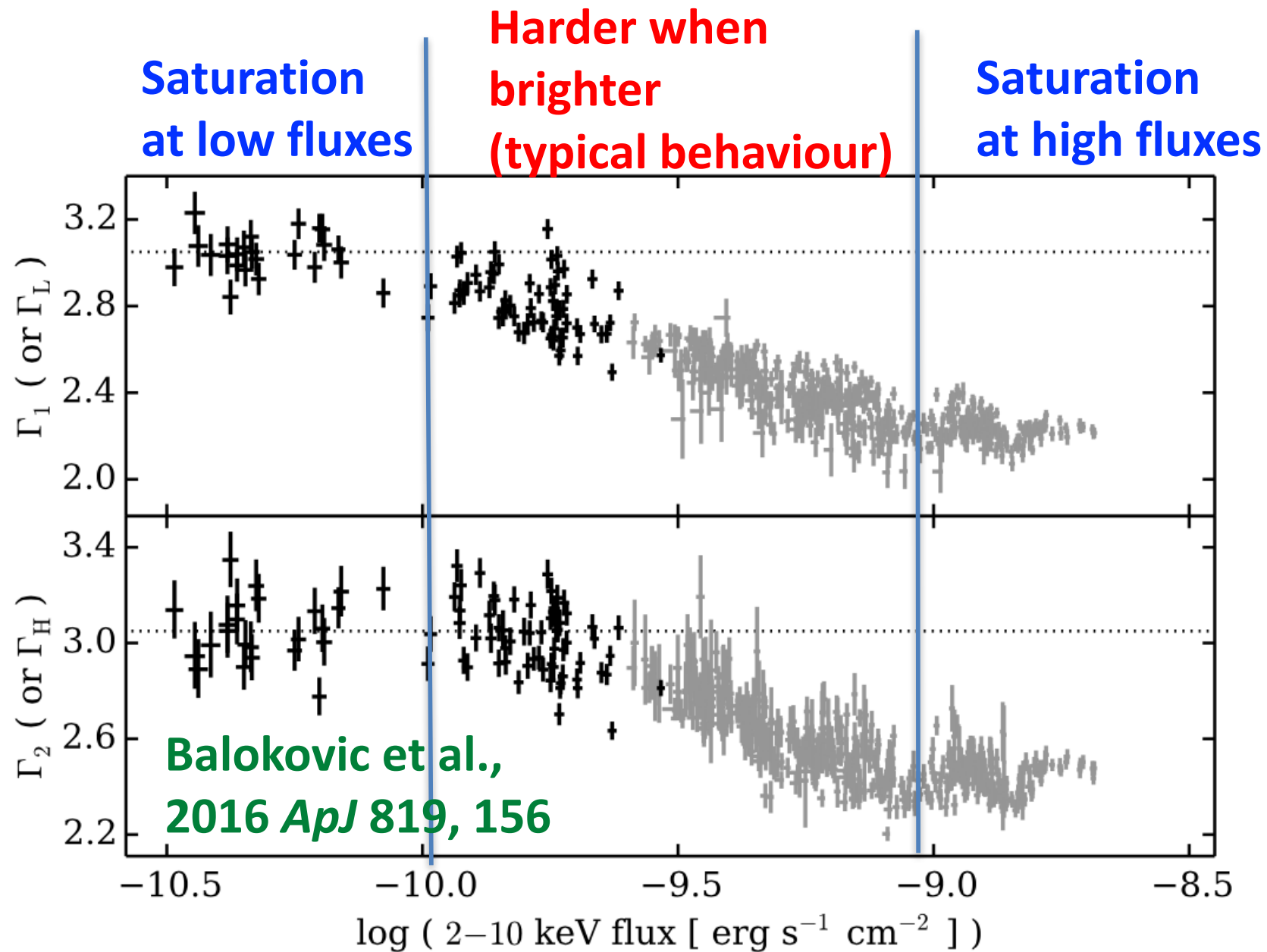
X-ray spectral shape vs. X-ray flux for Mrk421

NuSTAR spectra
(2013 campaign)

RXTE-PCA spectra from
Giebels et al., 2007, A&A, 462, 29

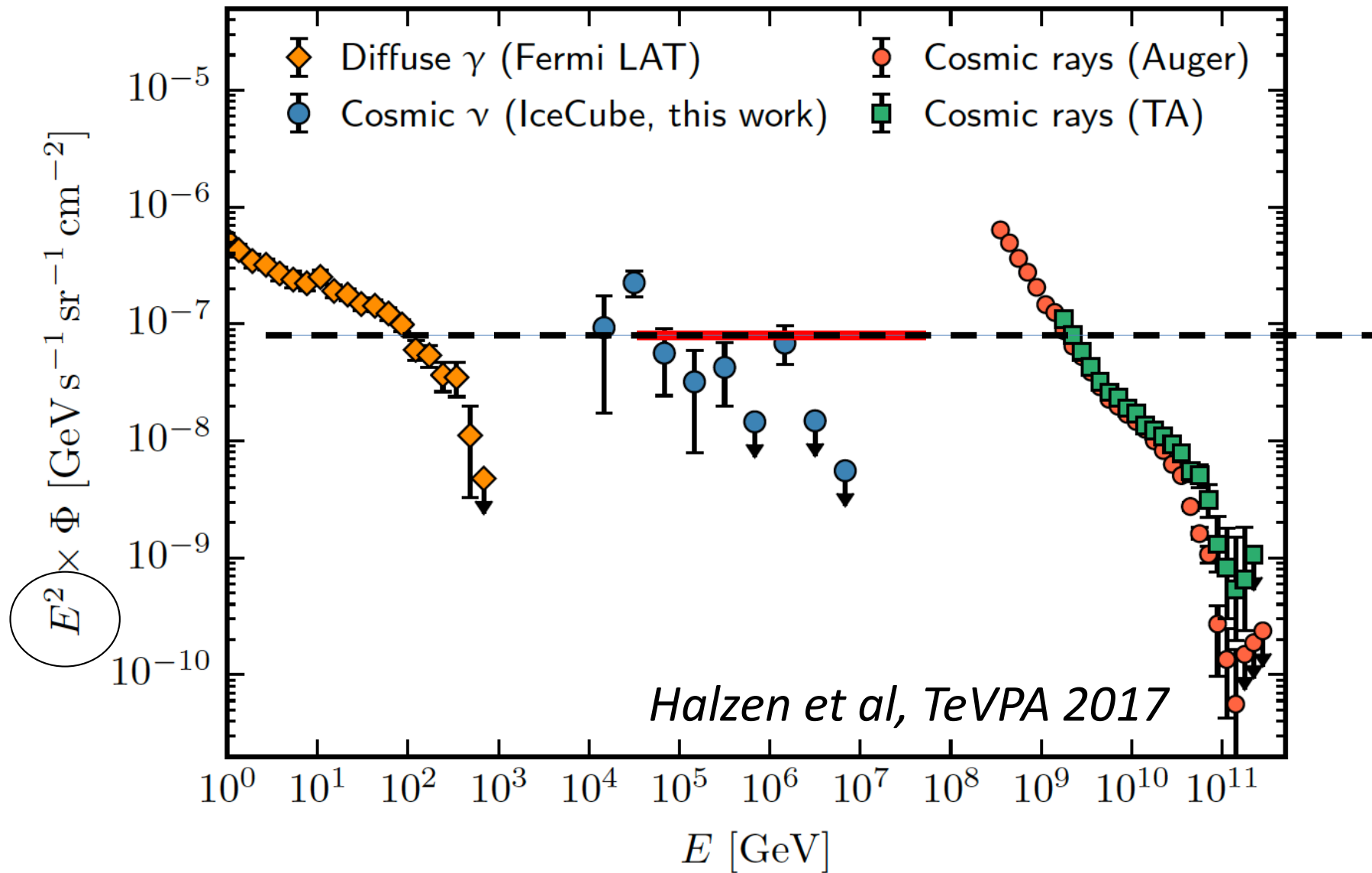


X-ray spectral shape vs. X-ray flux for Mrk421



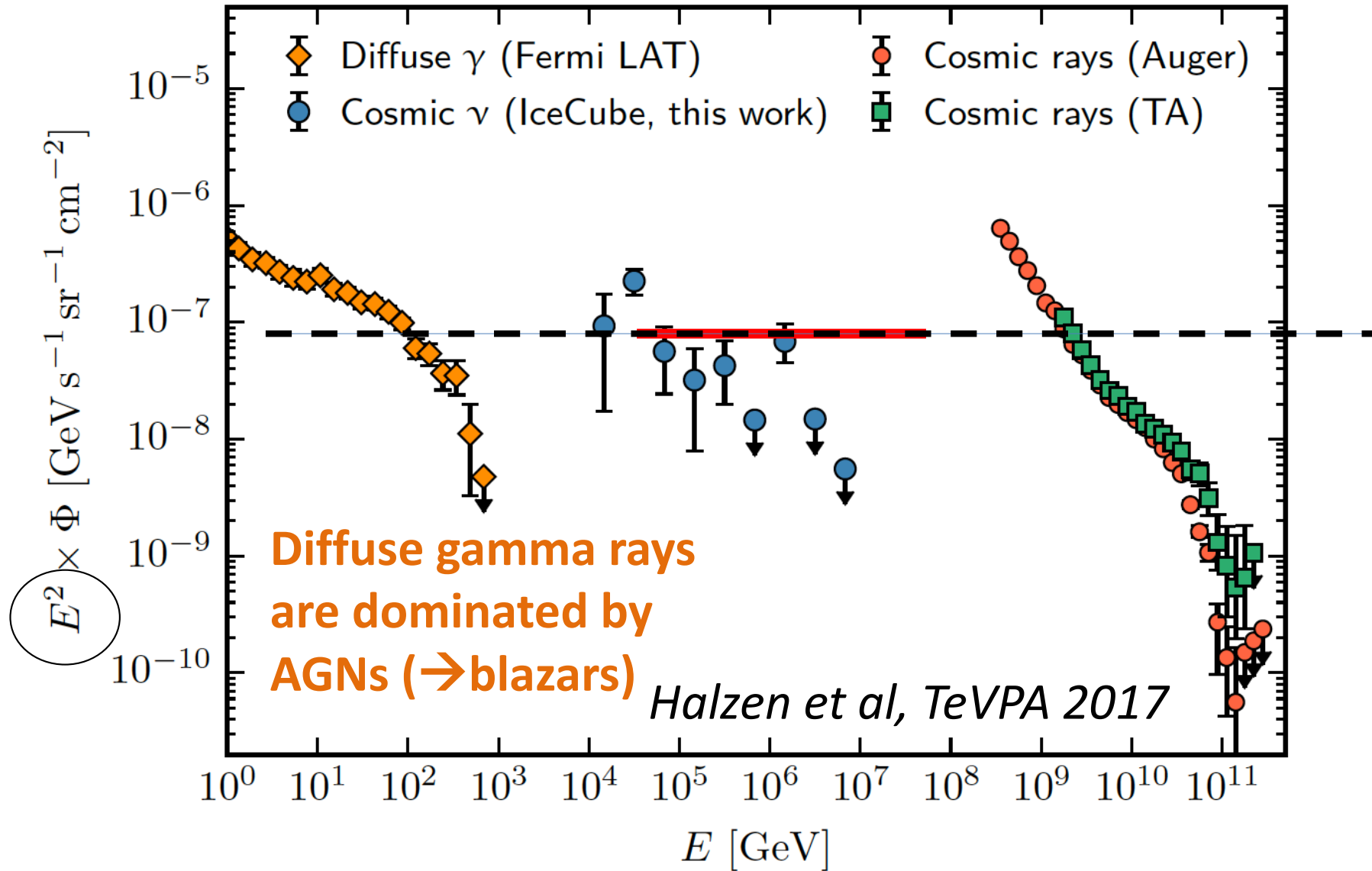
Energy in the Universe in

gamma rays, **neutrinos,** and **Cosmic Rays**

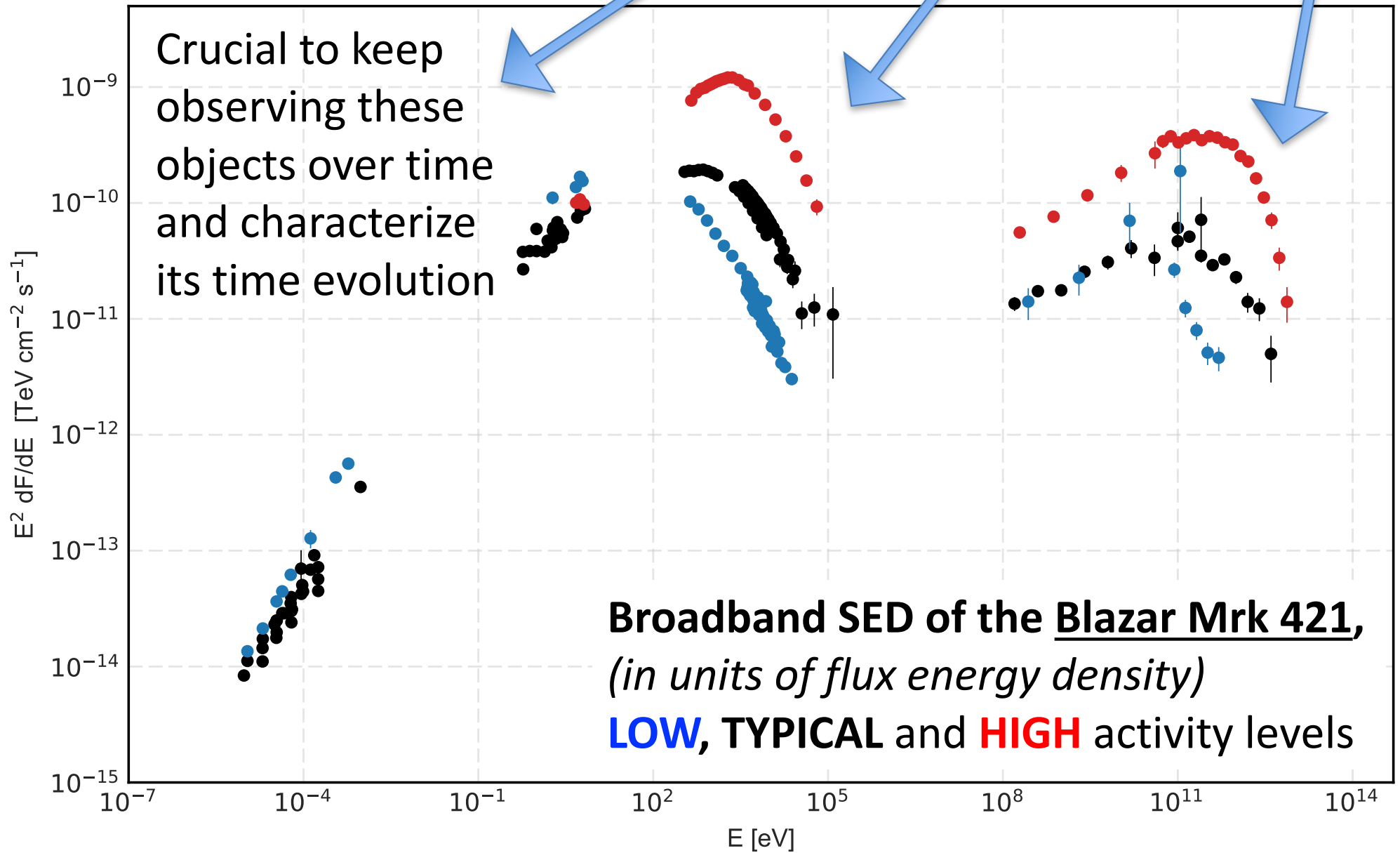


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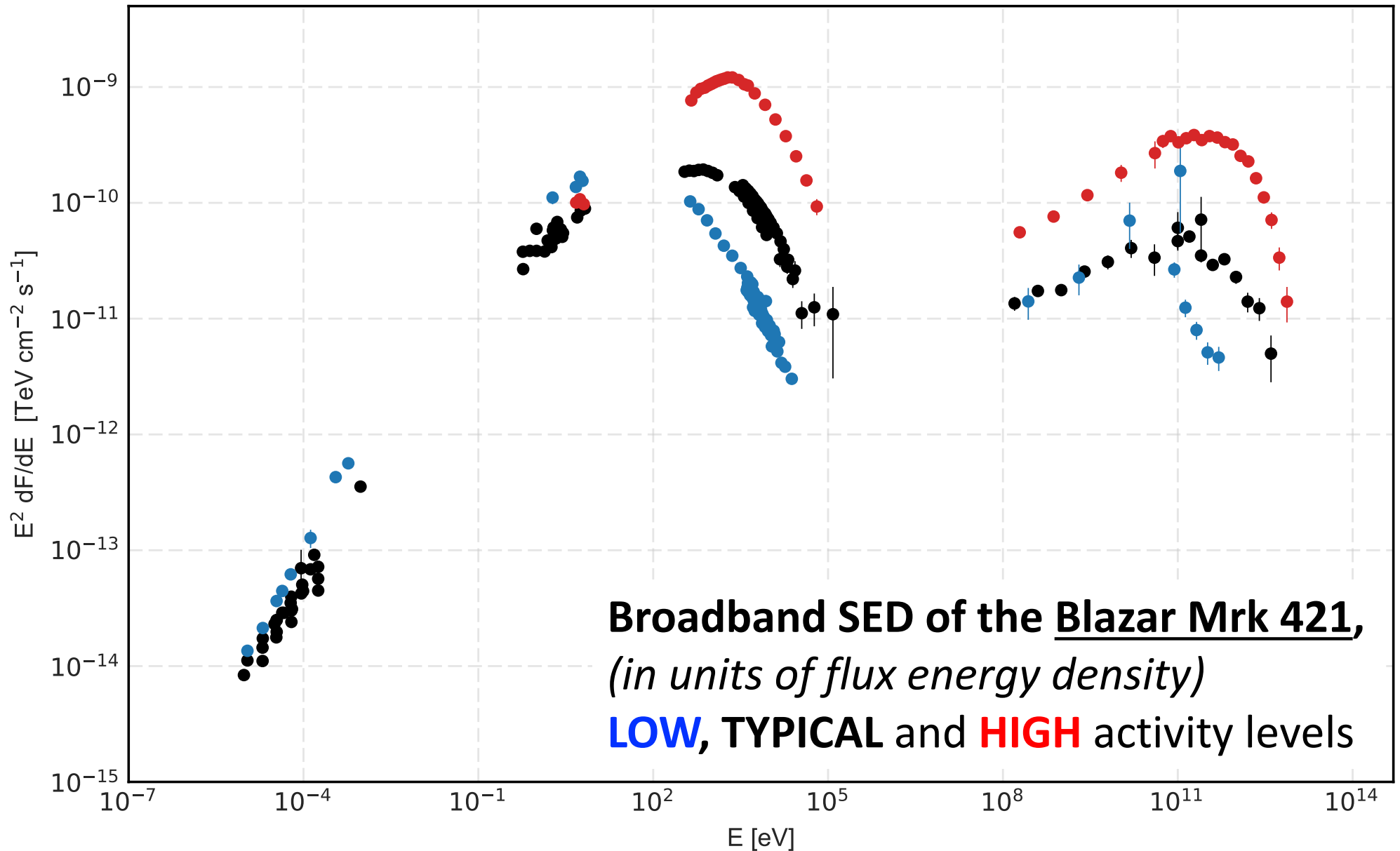
Change of energy flux by 2 orders of magnitude at X-rays and Gamma rays



Multi-band variability easier to explain with leptonic models

But the story is still at its beginning ...

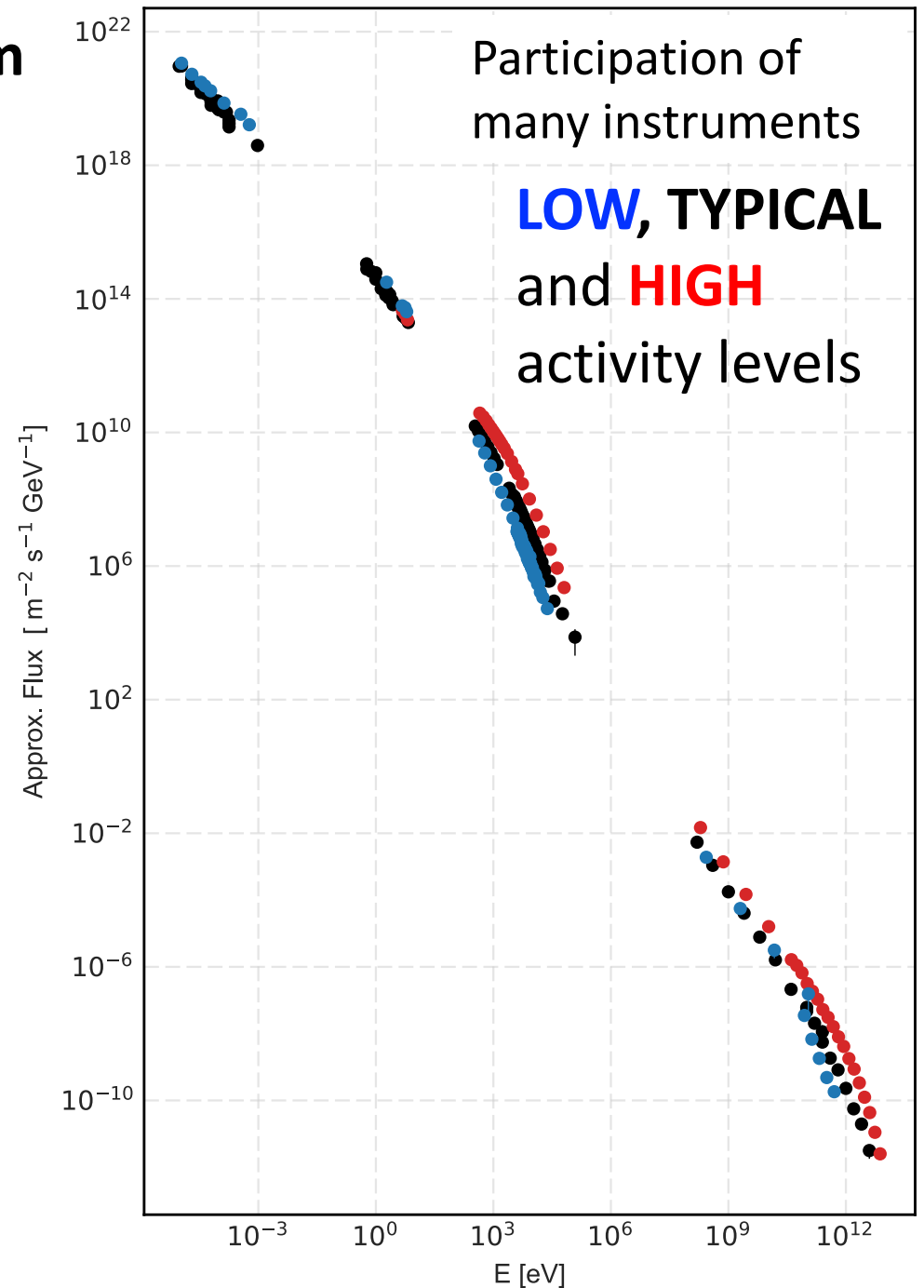
→ still accumulating data (and effects) and refining our tools



Broadband SED can be converted into a a sort of photon flux spectrum
(representation often used to display the CR particle flux)

In this representation, the **Low, Typical** and **High** activities do not “look” that different ...

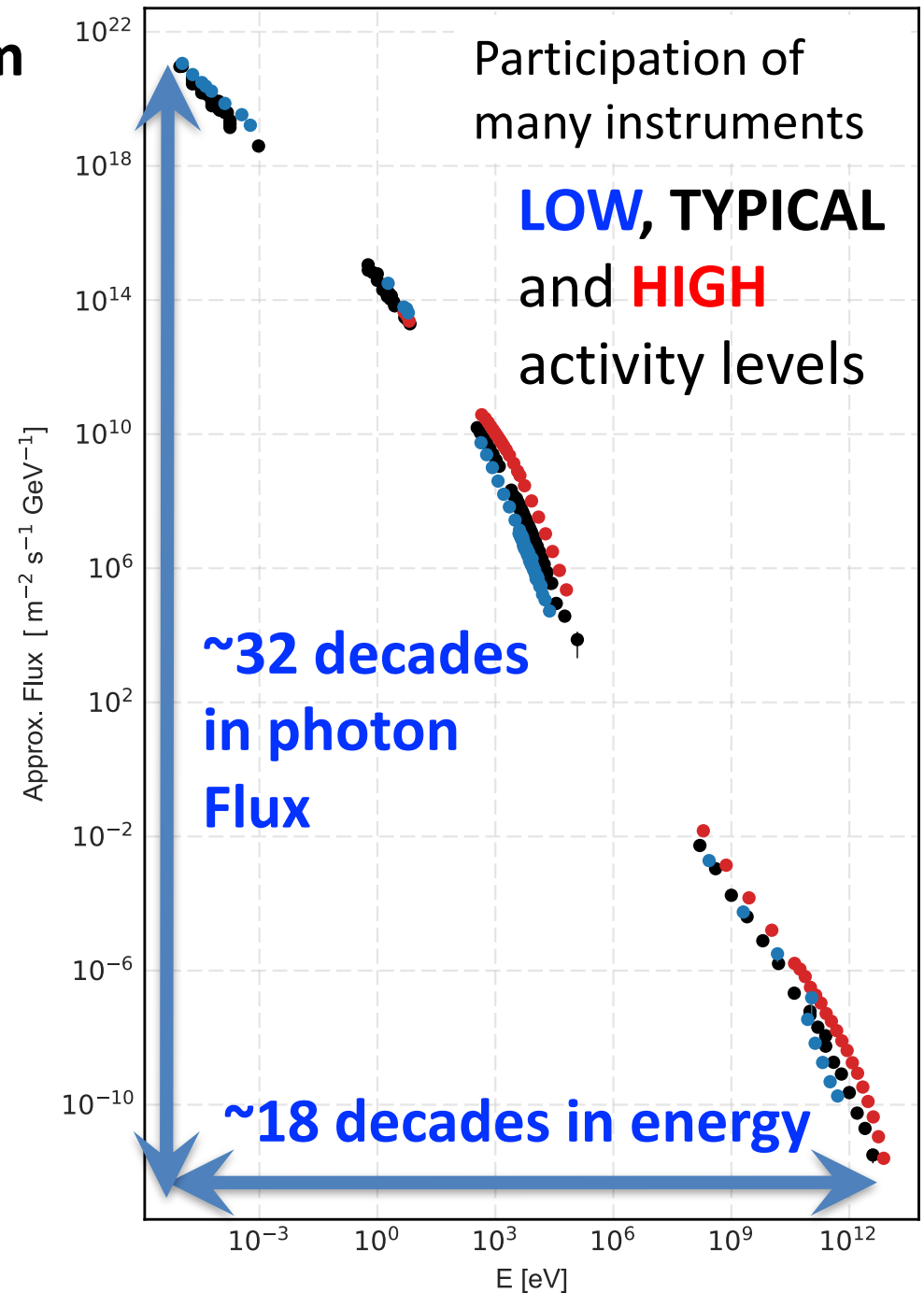
Mrk421 photon flux spectrum



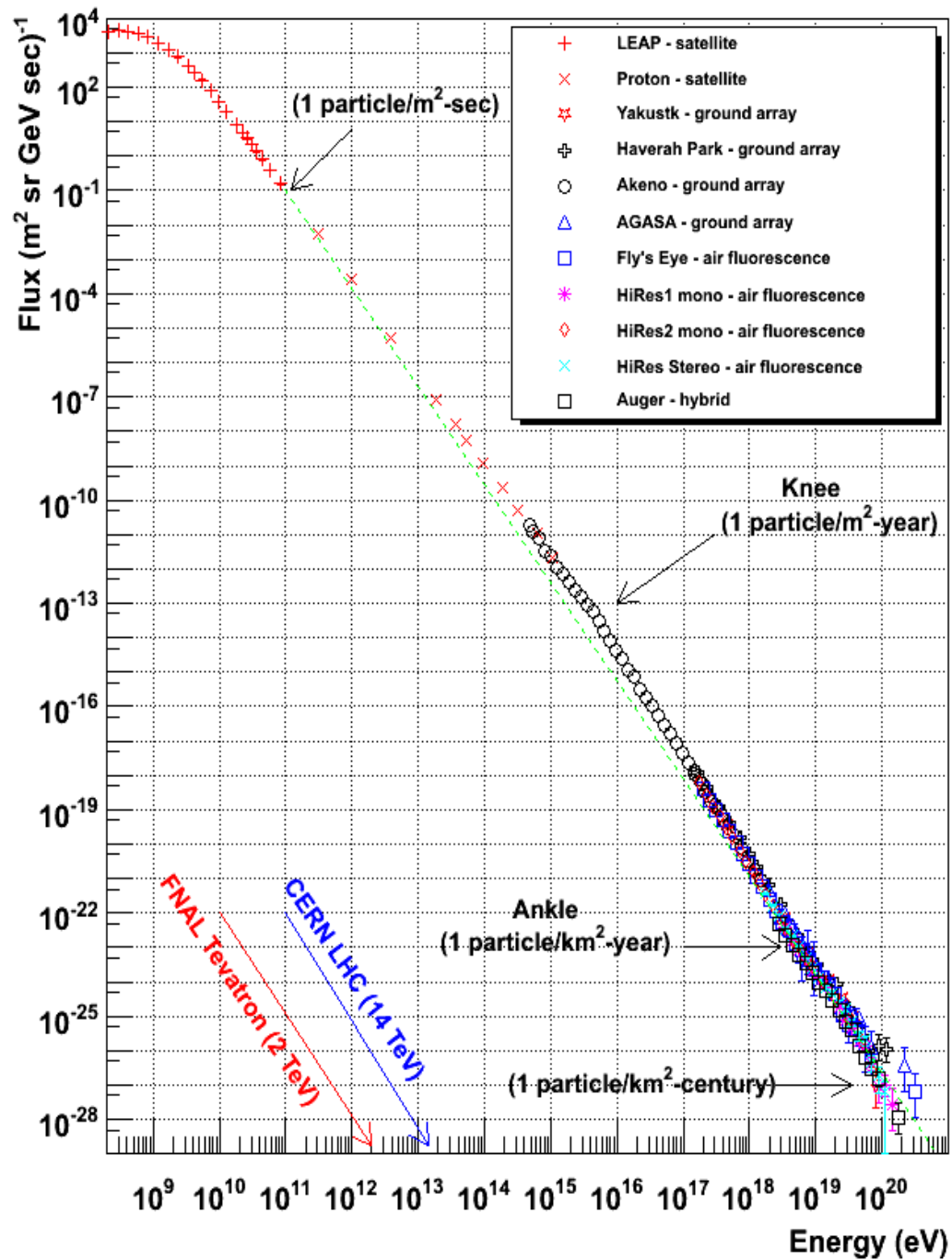
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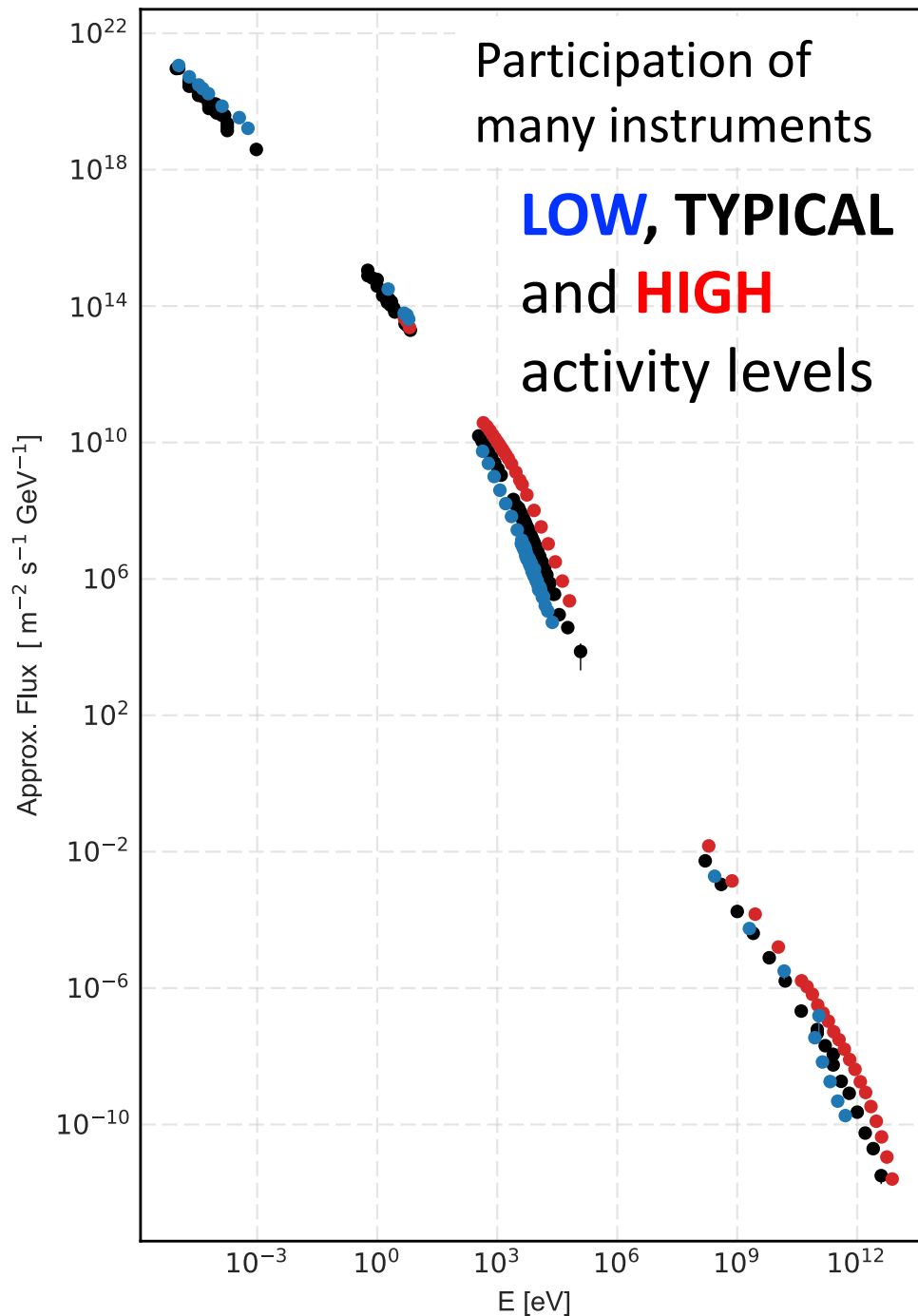
Mrk421 photon flux spectrum



Cosmic Ray Spectra of Various Experiments



Mrk421 photon flux spectrum



Broadband SED can be converted into a a sort of photon flux spectrum
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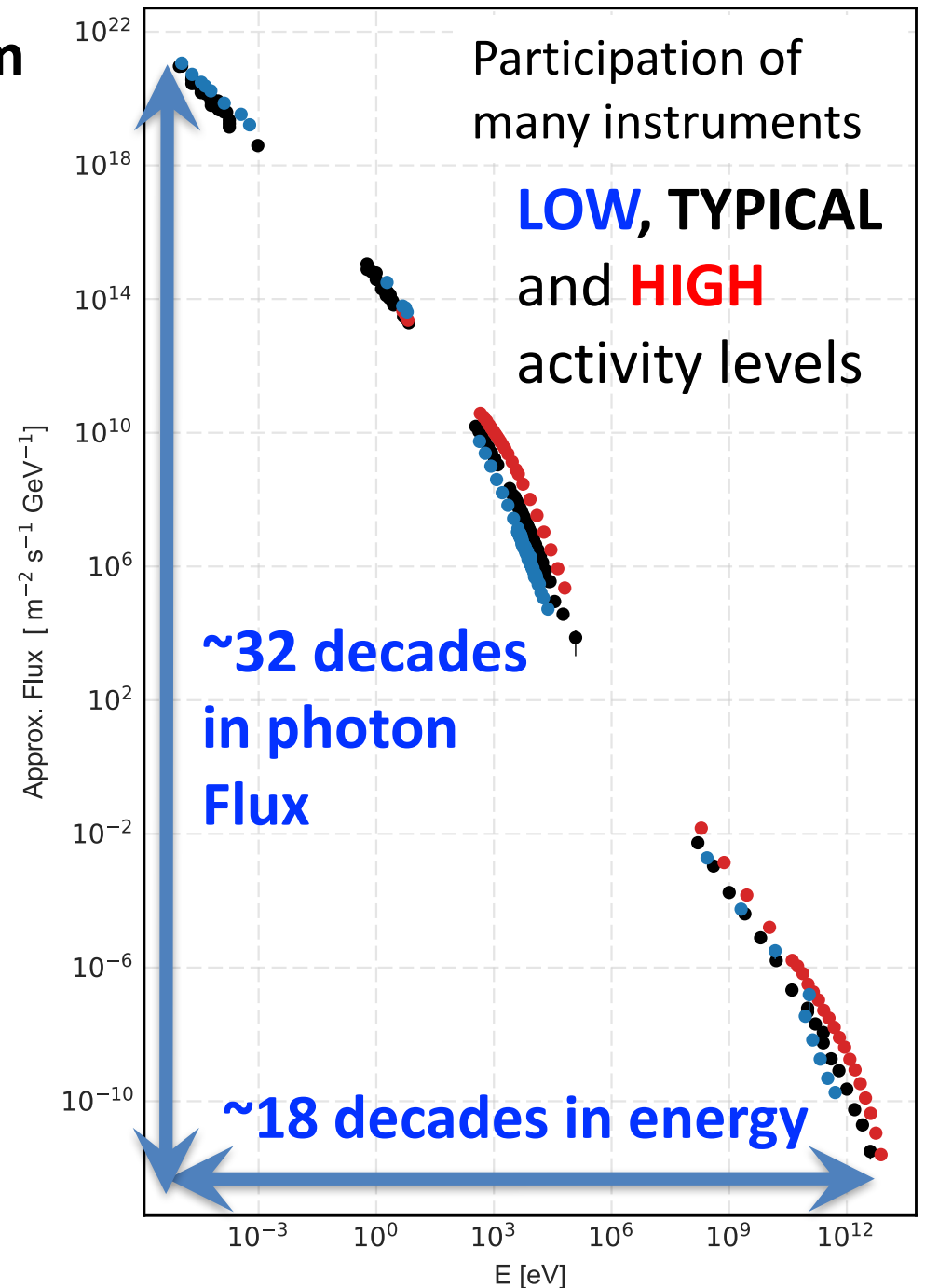
Similar energy and photon (\rightarrow particle) flux span than that of the CR spectrum

Flux : 32 vs 32 decades

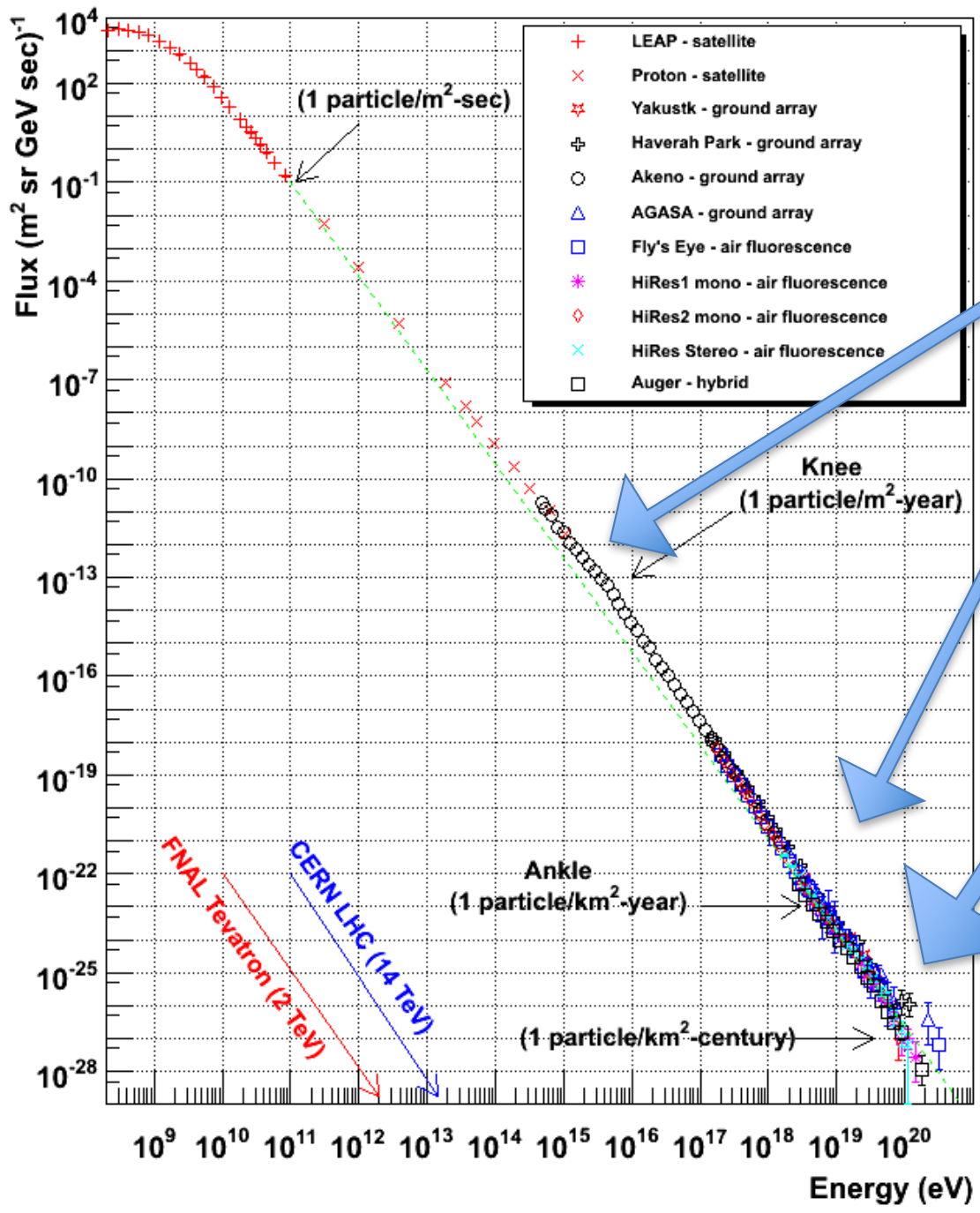
Energy: 12 vs 18 decades

In this representation, the **Low, Typical** and **High** activities do not “look” that different ...

Mrk421 photon flux spectrum



Cosmic Ray Spectra of Various Experiments



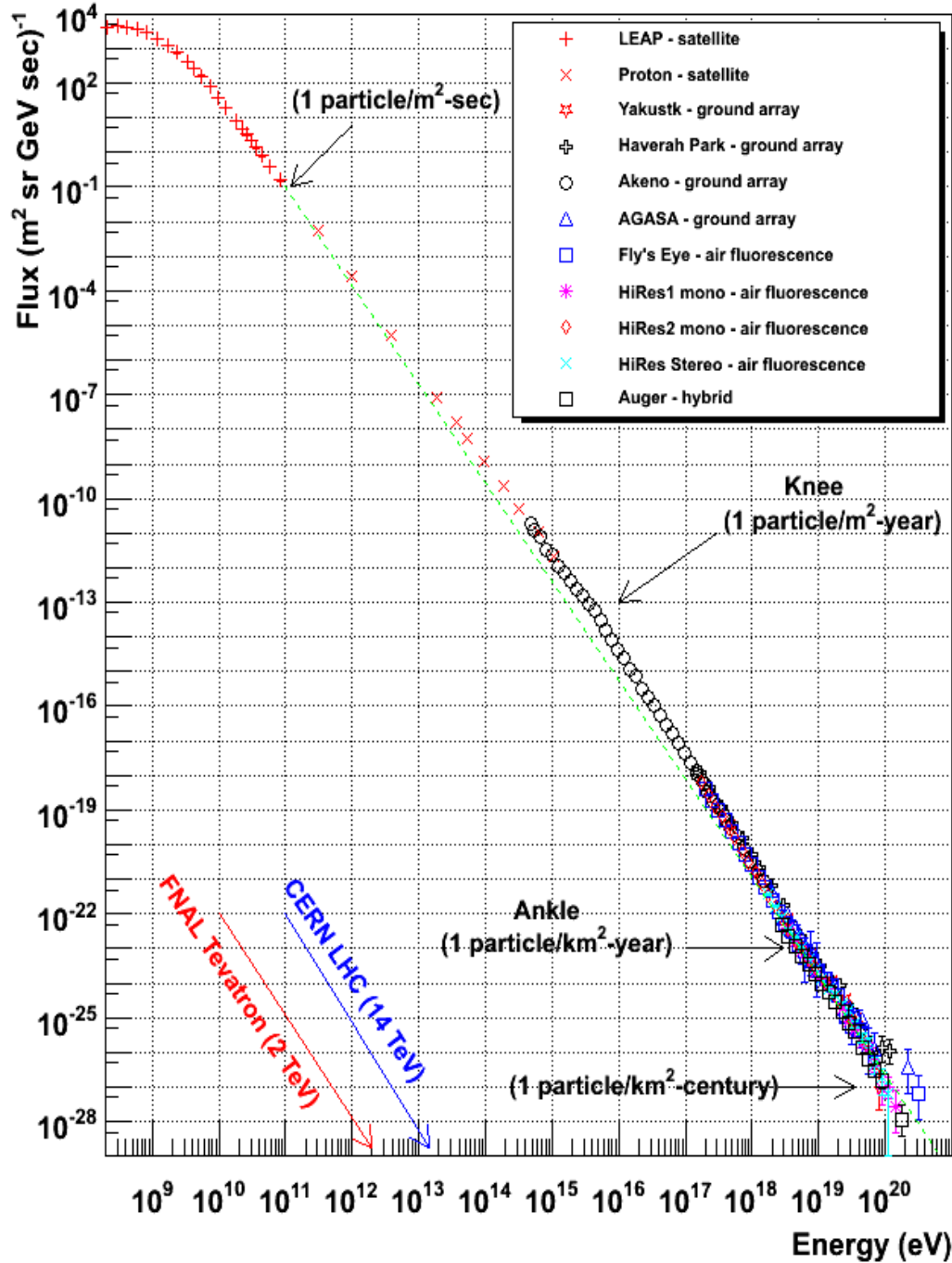
The “knee” may indicate the end of some CR population (*purely Galactic*)

The “ankle” may indicate the dominance of some other CR population (*purely extragalactic*)

Cutoff energy

Propagation in the CMB (GZK effect $p\gamma \rightarrow p\pi^0$ or $n\pi^+$)
 Additionally, can it be that the sources run out of power ?

Cosmic Ray Spectra of Various Experiments



Mrk421 photon flux spectrum

