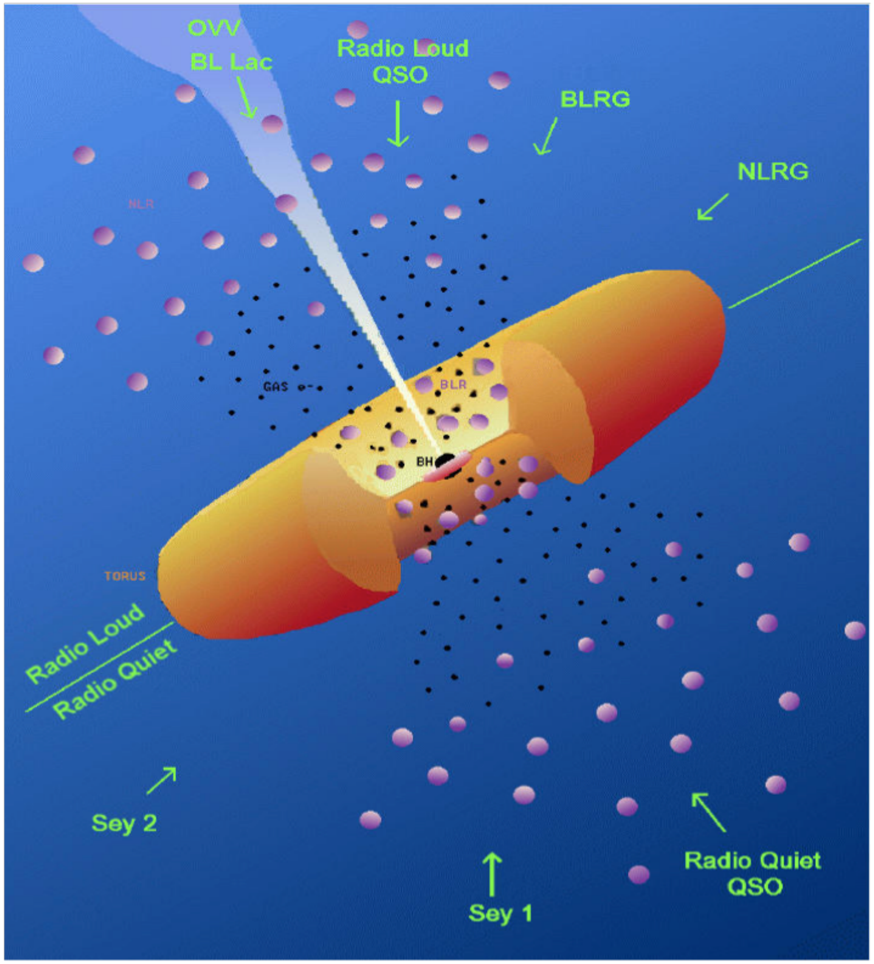
Models of γ-ray emission from active galactic nuclei

Matteo Cerruti
CNRS, LPNHE, Paris

Paris
29/11/17

ACTIVE GALACTIC NUCLEUS



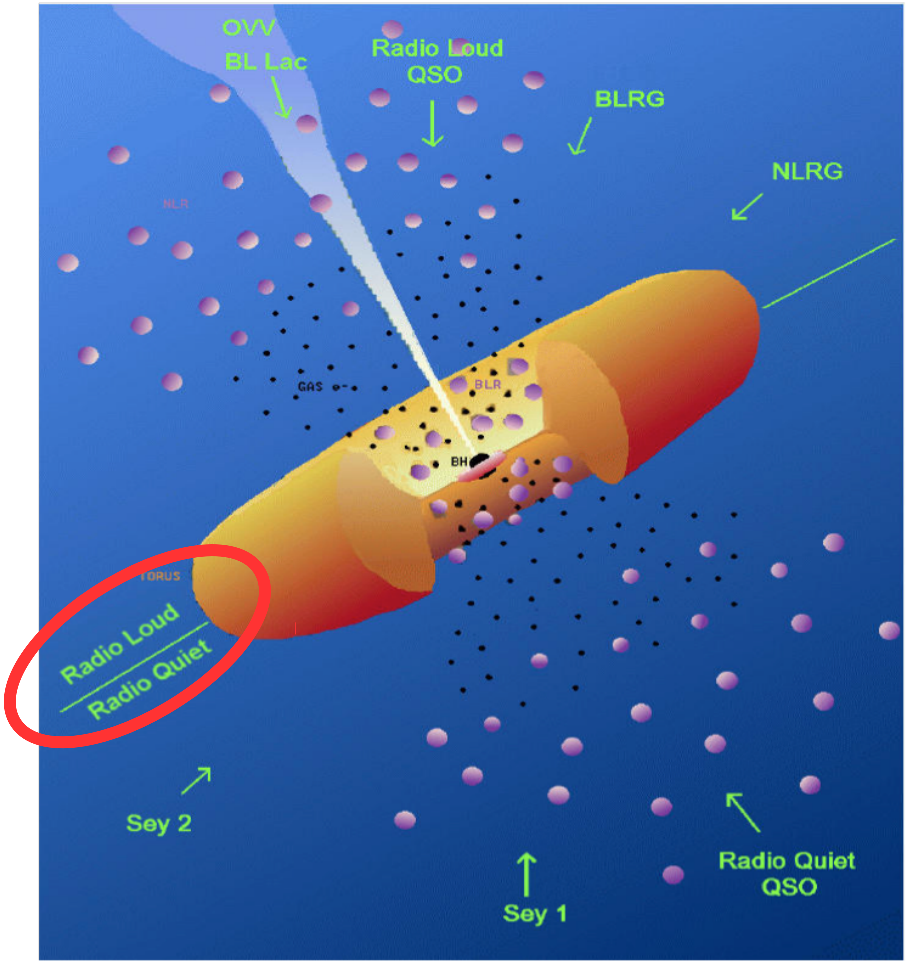
Observational effect of interaction of matter with a super-massive black-hole ($M_{\bullet} \sim 10^{8-9} M_{\odot}$)

Key features:

- Accretion disk
- Dusty torus
- Ionized clouds (Broad-Line & Narrow-Line Regions)

All different AGN observational classes are driven by the orientation of the system with respect to the Earth

ACTIVE GALACTIC NUCLEUS



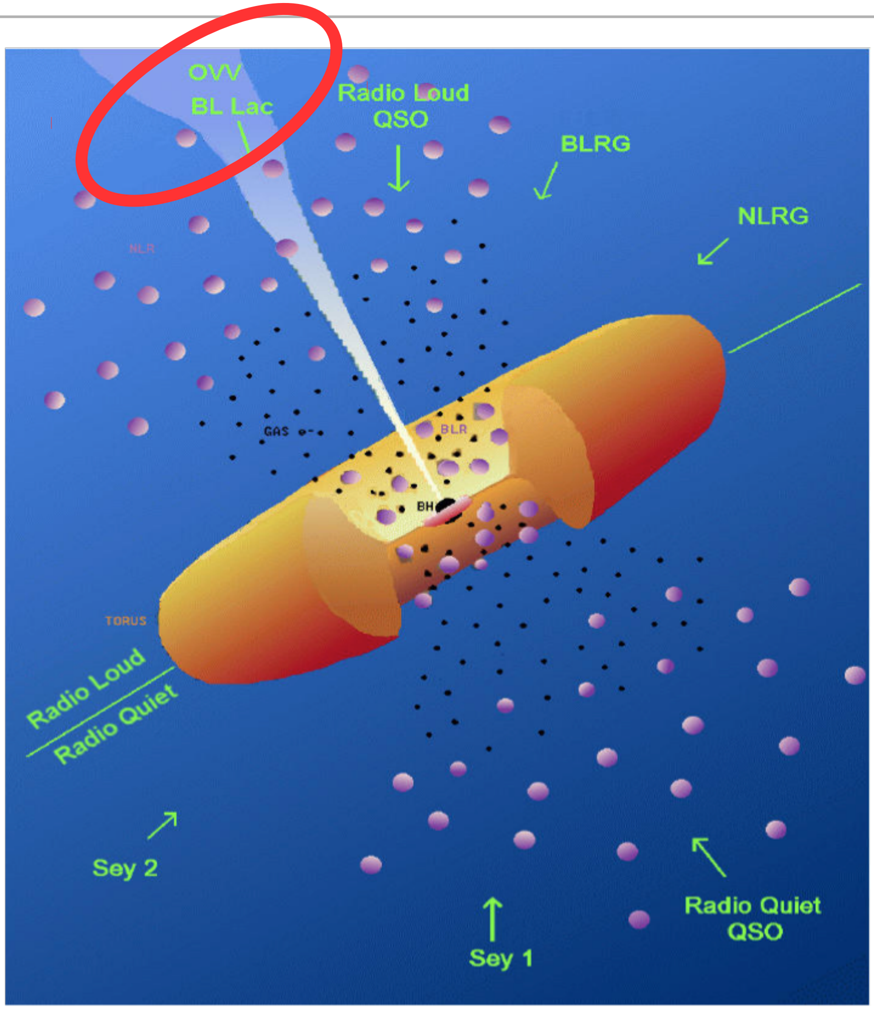
Observational effect of interaction of matter with a super-massive black-hole ($M_\bullet \sim 10^{8-9} M_\odot$)

Key features:
- Accretion disk
- Dusty torus
- Ionized clouds (Broad-Line & Narrow-Line Regions)

Dichotomy in observations:
- Radio-loud (~15%): f_{rad}/f_{opt} flux > 10
- Radio-quiet all the rest

The presence/absence of an outflow in the form of a highly collimated relativistic jet explains the radio dichotomy
(does the black hole spin play a role?)

BLAZARS



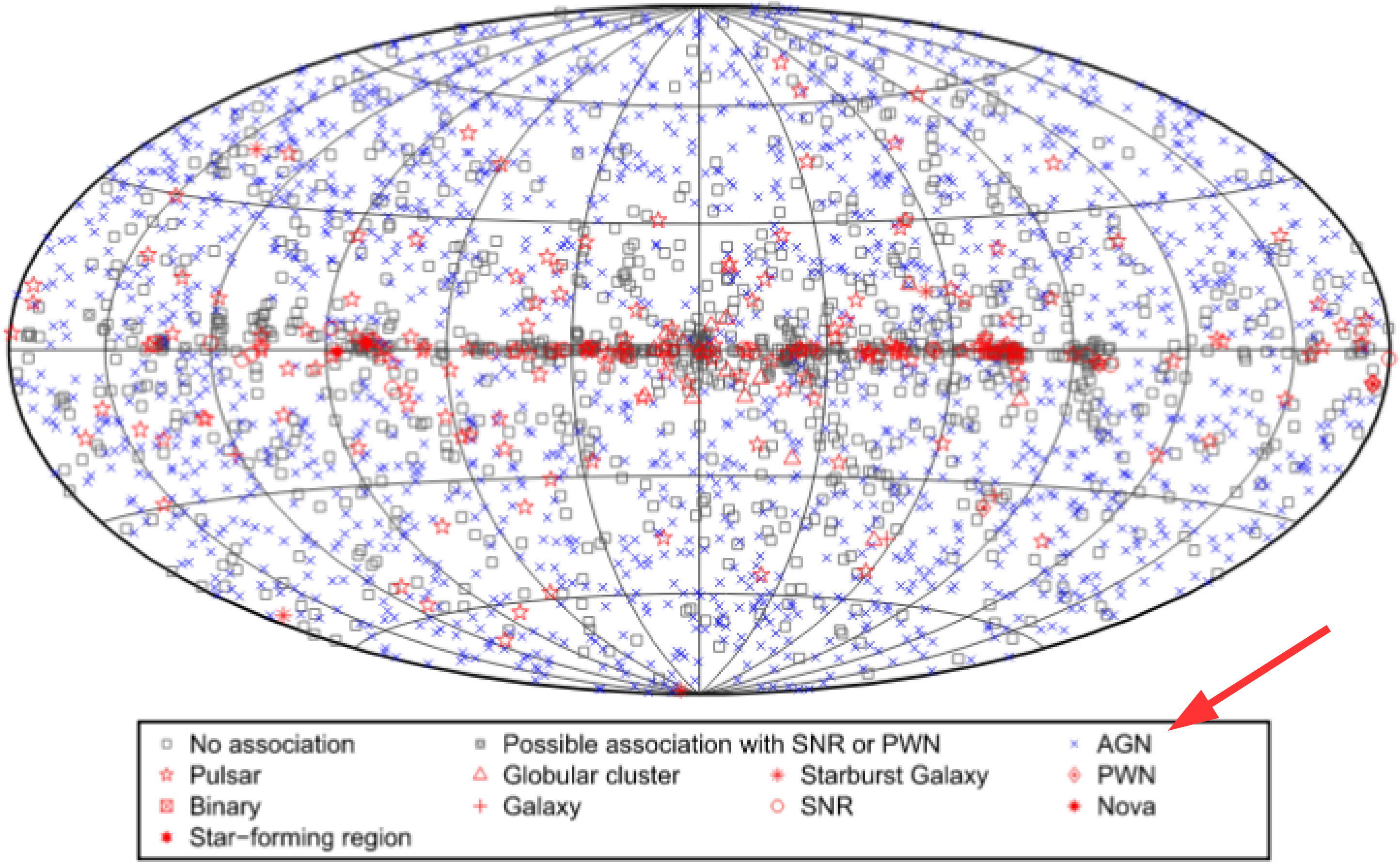
Blazar : radio-loud AGN whose relativistic jet points in the direction of the observer

→ emission from the jet dominates over any other AGN component (the disk, the BLR, the X-ray corona,…)

→ non-thermal emission from radio to gamma-rays, and extreme variability

- Flat-Spectrum-Radio-Quasars: optical spectrum with broad emission lines
- BL Lacertae objects : optical spectrum featureless

γ-LOUD AGN



From 3FGL : the extragalactic γ-ray sky is dominated by AGN

γ-LOUD AGN

Table 6
LAT 3FGL Source Classes

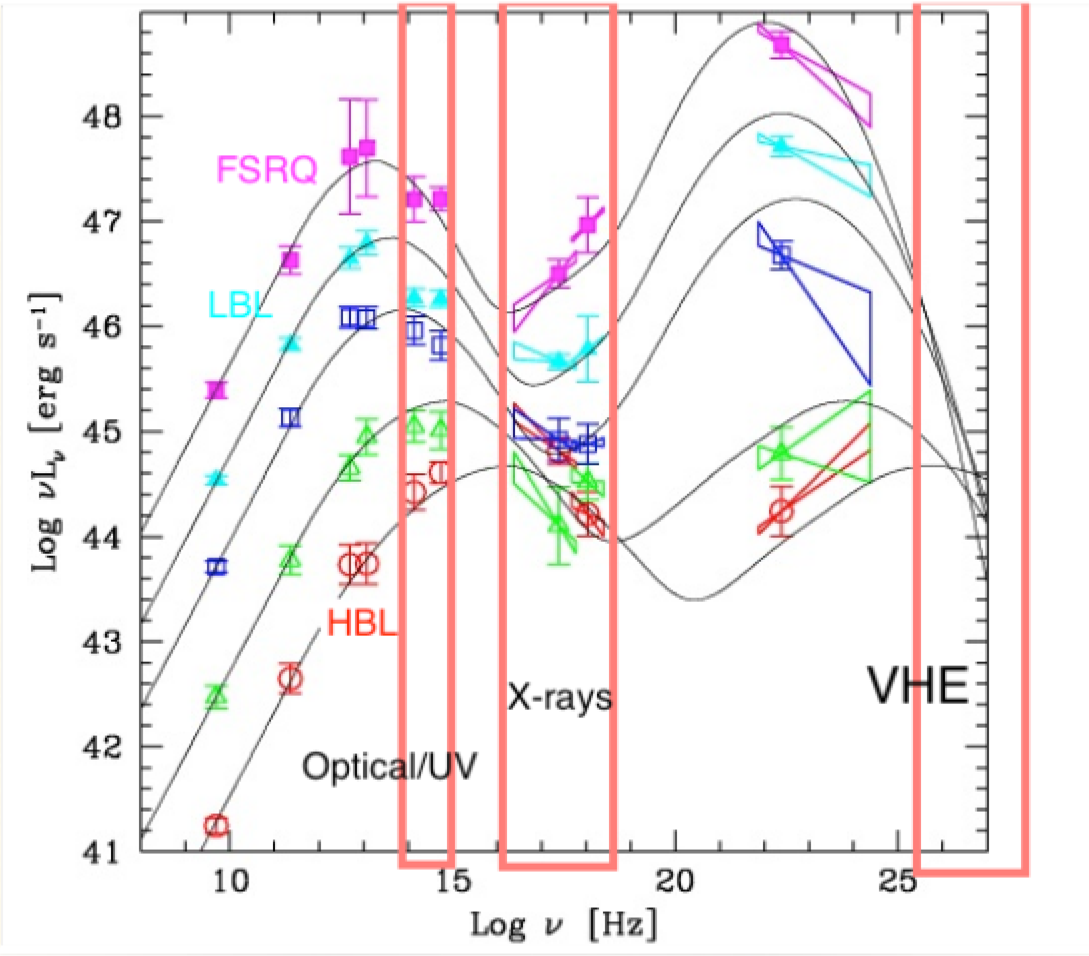
Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	143	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	24
Pulsar wind nebula	PWN	9	pwn	2
Supernova remnant	SNR	12	snr	11
Supernova remnant/pulsar wind nebula	...	...	spp	49
Globular cluster	GLC	0	glc	15
High-mass binary	HMB	3	hmb	0
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
Star-forming region	SFR	1	sfr	0
Compact steep spectrum quasar	CSS	0	css	1
BL Lac type of blazar	BLL	18	bll	642
FSRQ type of blazar	FSRQ	38	fsrq	446
Non-blazar active galaxy	AGN	0	agn	3
Radio galaxy	RDG	3	rdg	12
Seyfert galaxy	SEY	0	sey	1
Blazar candidate of uncertain type	BCU	5	bcu	568
Normal galaxy (or part)	GAL	2	gal	1
Starburst galaxy	SBG	0	sbg	4
Narrow-line Seyfert 1	NLSY1	2	nlsy1	3
Soft-spectrum radio quasar	SSRQ	0	ssrq	3
Total	...	238	...	1785
Unassociated	...	...	...	1010

The γ-loud AGN are essentially:

- blazars (or blazar candidates)

- few nearby radio-galaxies

BLAZARS



Fossati et al. 1998

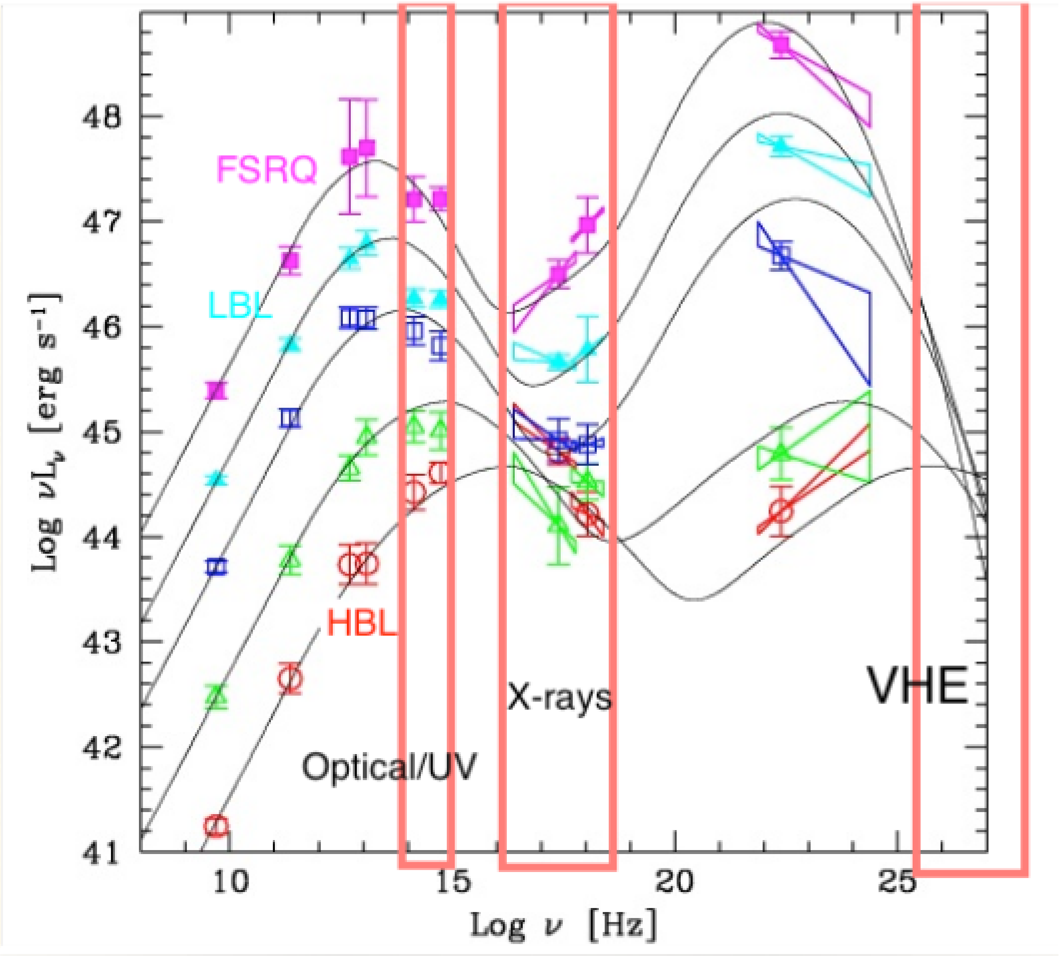
Spectral energy distribution (SED) two distinct components

FSRQs show a peak in IR

BL Lac objects are classified in:

- peak in optical : Low-frequency peaked (LBLs)
- peak en UV/X : High-frequency peaked (HBLs)
- peak >10 KeV : Ultra-high-frequency peaked (UHBLs)

BLAZARS



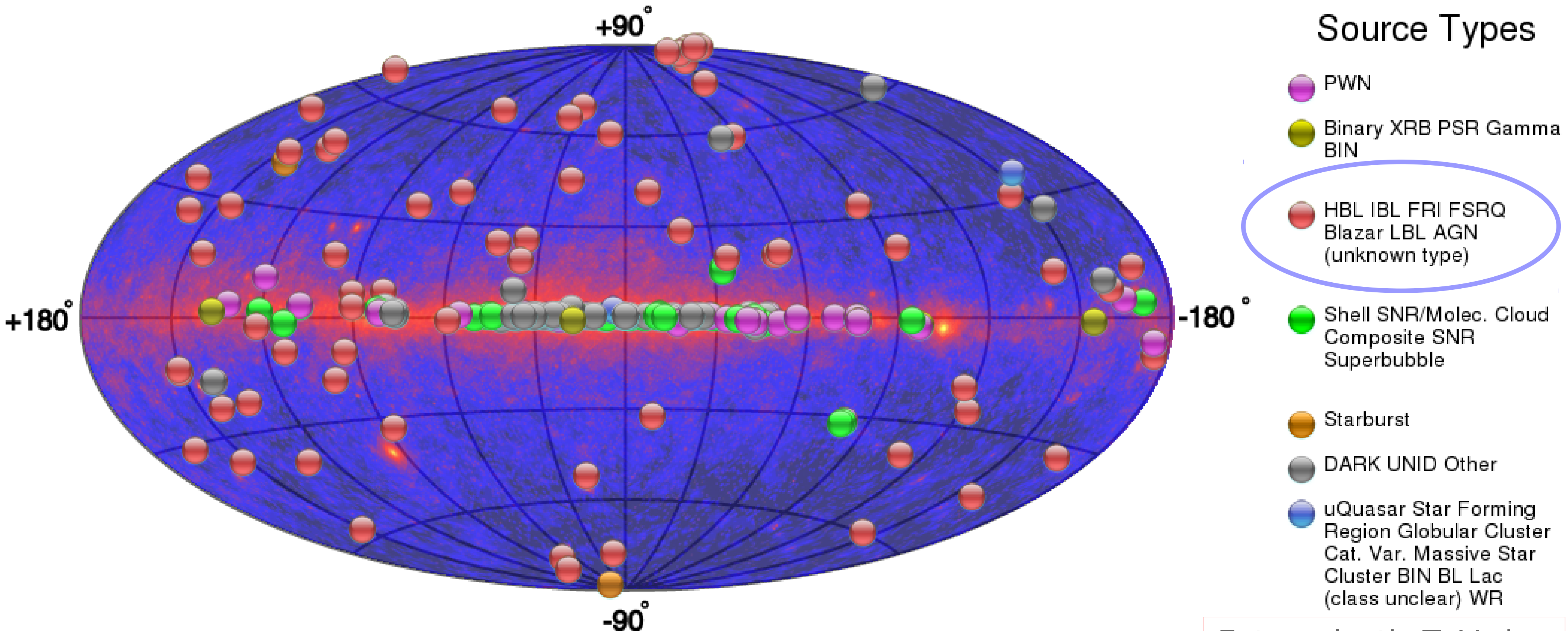
Fossati et al. 1998

In whichever band you observe, you 'select' a blazar with a given peak frequency

→ Radio blazar catalogs and X-ray blazar catalogs don't 100% overlap!

At TeV energies we are dominated by ***high-frequency-peaked blazars***

THE TeV SKY

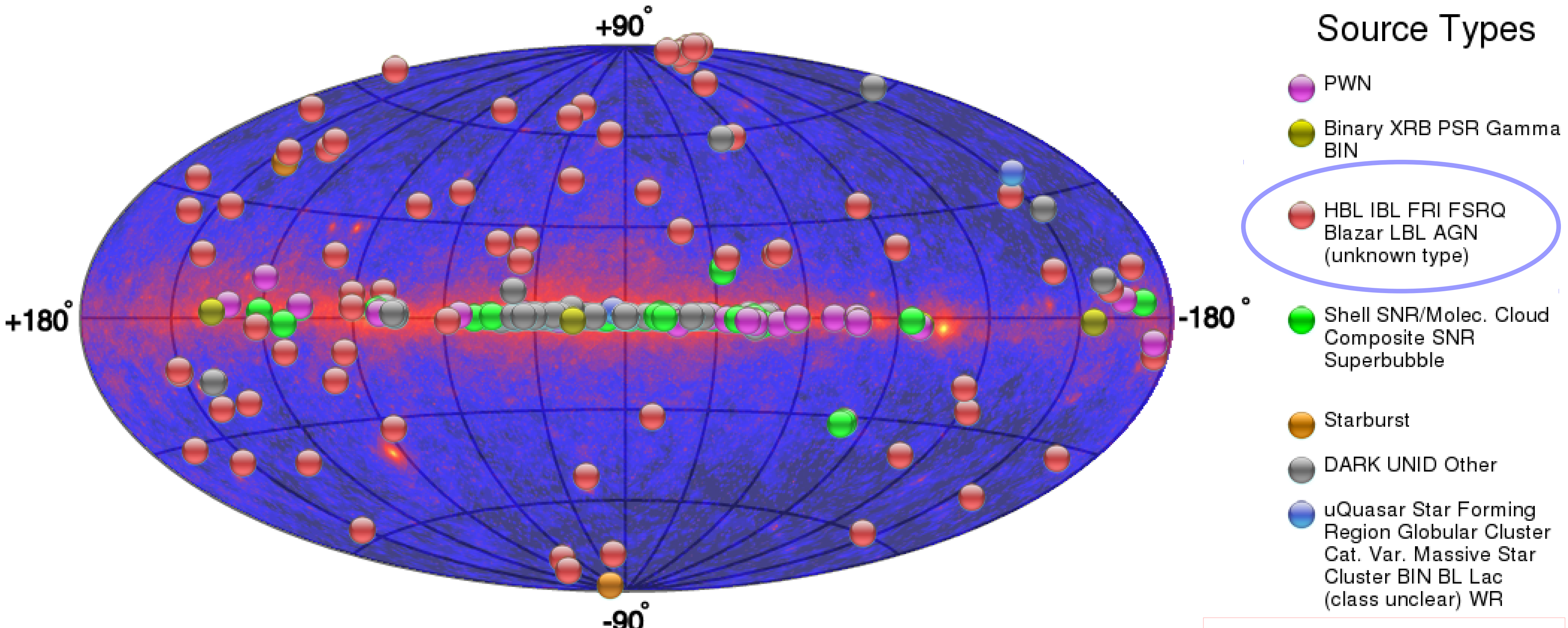


From TeVCAT

Extragalactic TeV sky:

2 starburst galaxies
4 radio-galaxies
66 blazars

THE TeV SKY



From TeVCAT

Extragalactic TeV sky: of these 66 blazars
49 are HBLs
11 are I/LBLs
6 are FSRQs

TeV BLAZAR MODELING

Scenario A: emission at the source

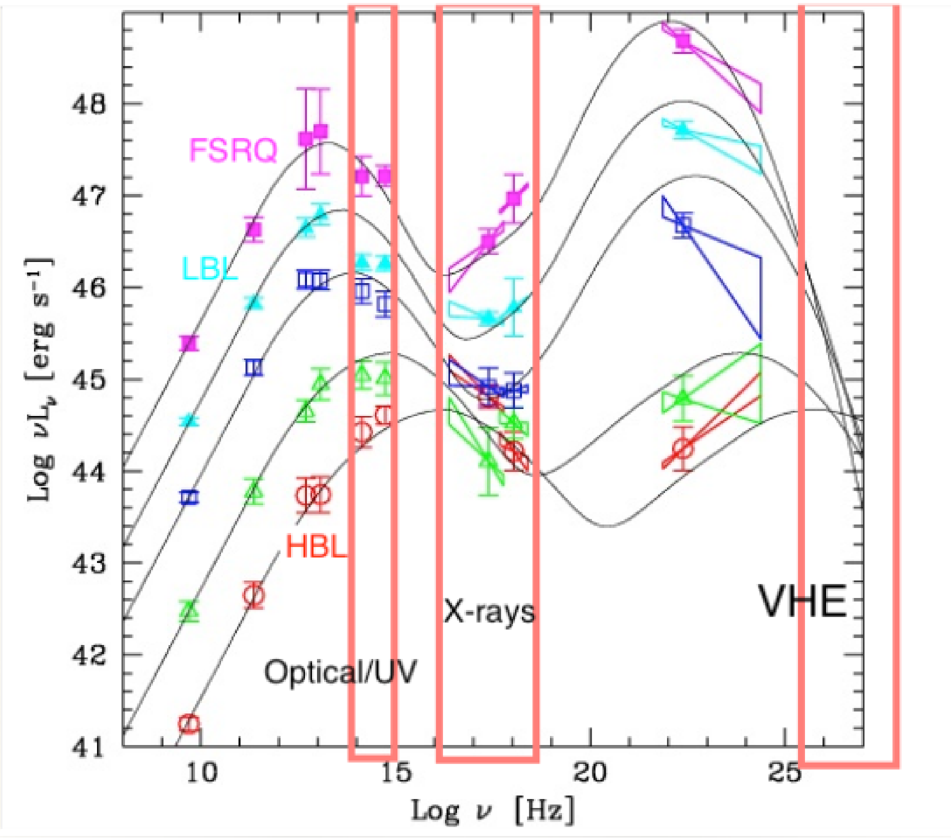
A1: stationary* emission
(i.e. study of MWL SED)

A2: flaring emission
(i.e. study of MWL light-curves)
(few words only! See next talk)

Scenario B: emission in the line of sight

* stationary = not flaring / slowly varying
(i.e. there's no "ground base" emission)

TeV BLAZAR MODELING



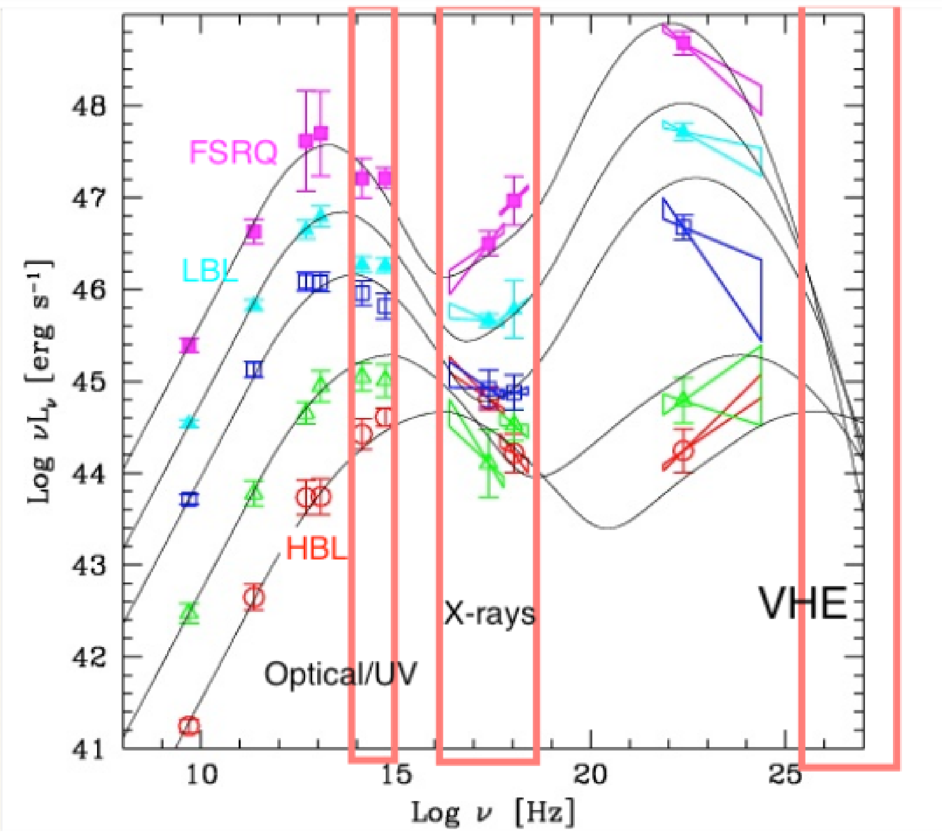
Low energy bump
(radio-to-X)

IS synchrotron emission by leptons

- spectral properties match well theoretical predictions (index, low-energy cutoff)

- polarization measurements

TeV BLAZAR MODELING



High energy bump
(X-to-gamma)

Leptonic vs Hadronic

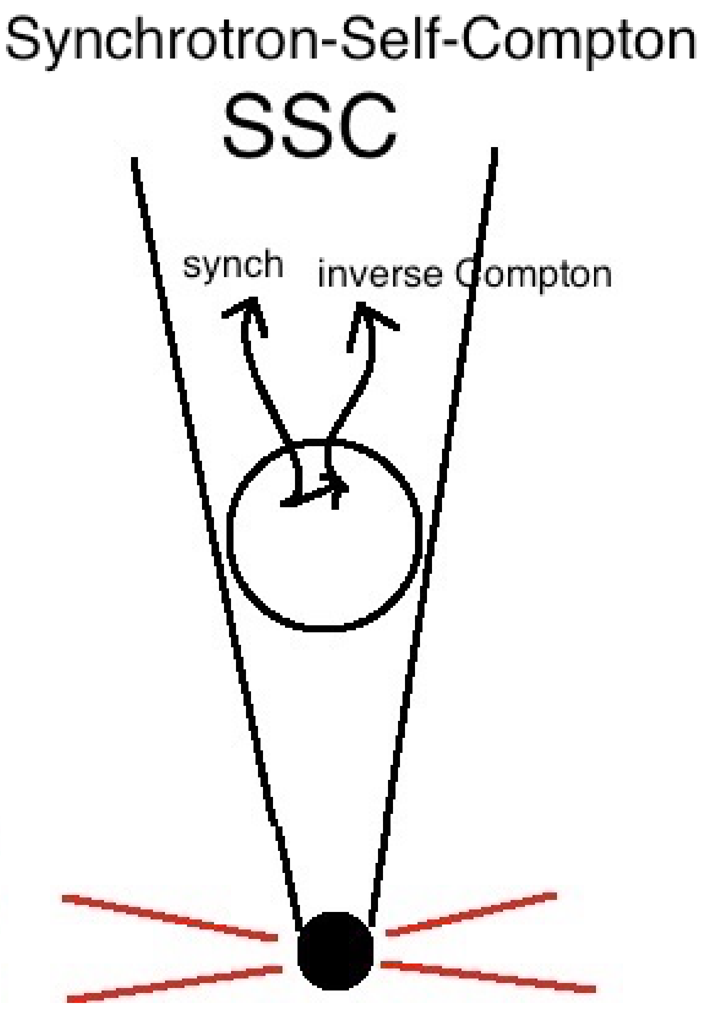
- leptonic scenario: inverse Compton scattering

Same leptons producing synchrotron
+ their own synchrotron radiation (SSC)
+ an external photon field (EIC)

General consensus on the fact that HBLs → SSC
LBLs , FSRQs → EIC

TeV BLAZAR MODELING

Leptonic modeling of HBLs
(one-zone synchrotron self-Compton)



Can be fully constrained if the two SED components are well sampled
→ it works for HBLs, but

- in several cases the electron distribution is NOT what we expect from shock acceleration + synchrotron cooling (more complex acceleration / escape / cooling mechanisms)

-for extreme HBLs, it requires high Doppler factor, and a low-energy cut-off in the electron distribution (no cold electrons?)

TeV BLAZAR

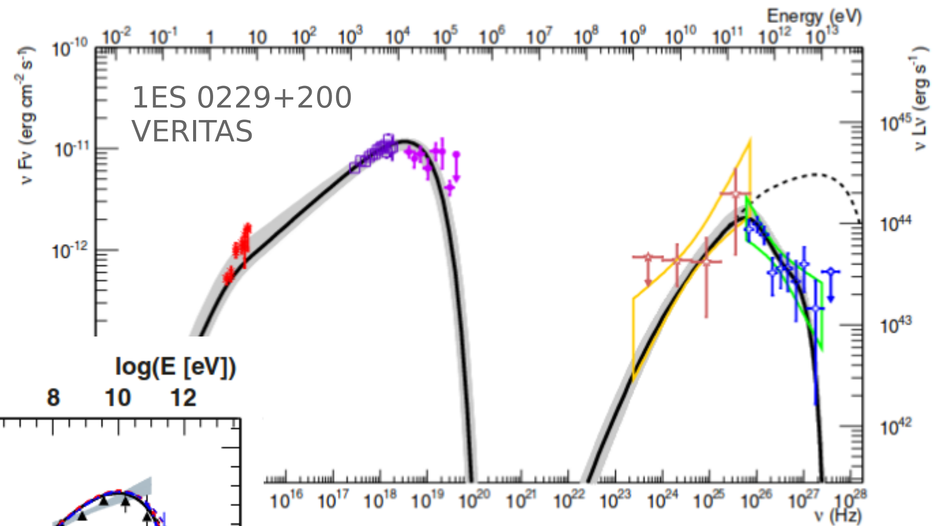
Leptonic modeling of HBLs

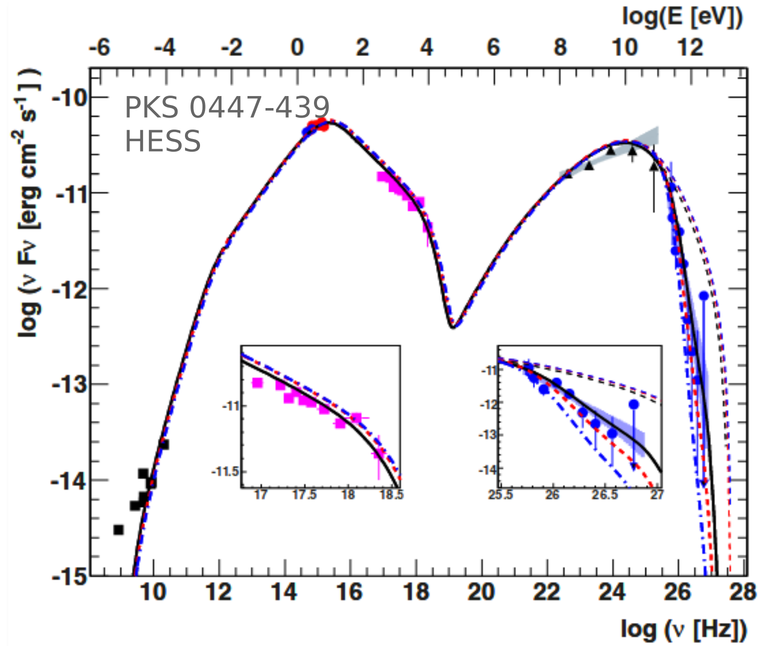
(one-zone sync

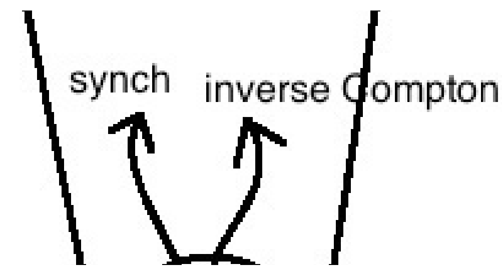
Can be fully constr
components are w
→ it works for HBLs

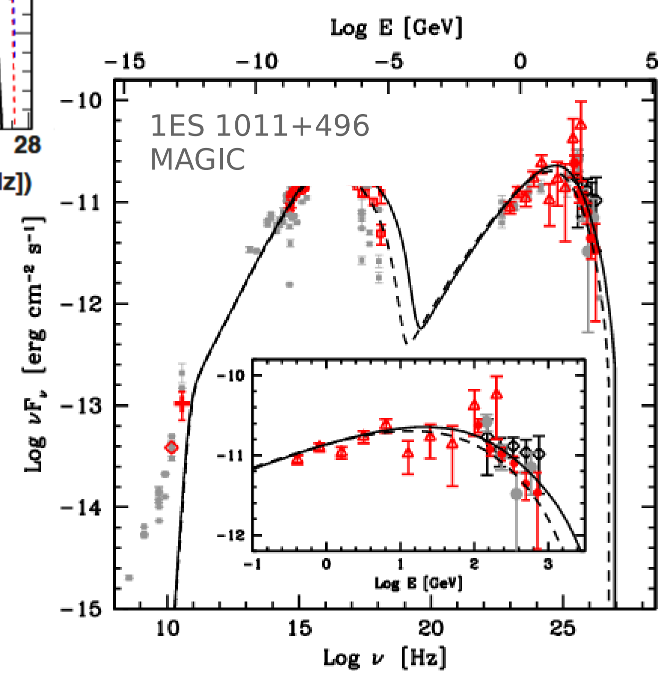
- in several cases the
what we expect from
synchrotron cooling (more complex
acceleration / escape / cooling mechanisms)

-for extreme HBLs, it requires high Doppler factor, and a low-energy cut-off in the electron distribution (no cold electrons?)



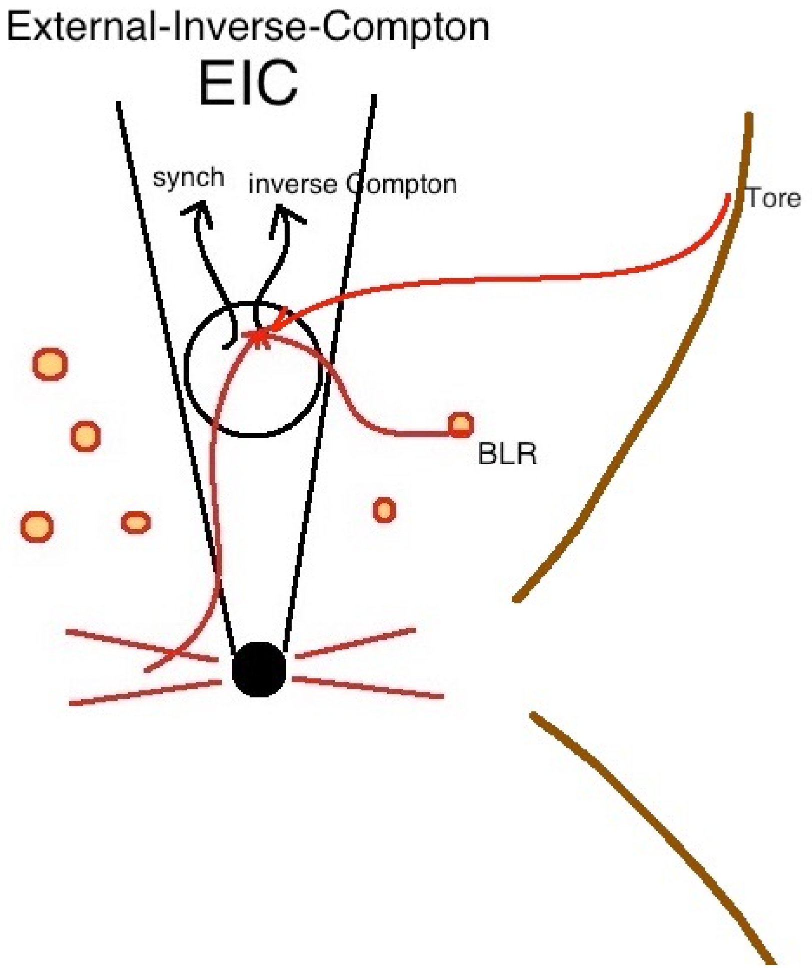






TeV BLAZAR MODELING

Leptonic modeling of LBLs/FSRQs
(one-zone external-inverse Compton)

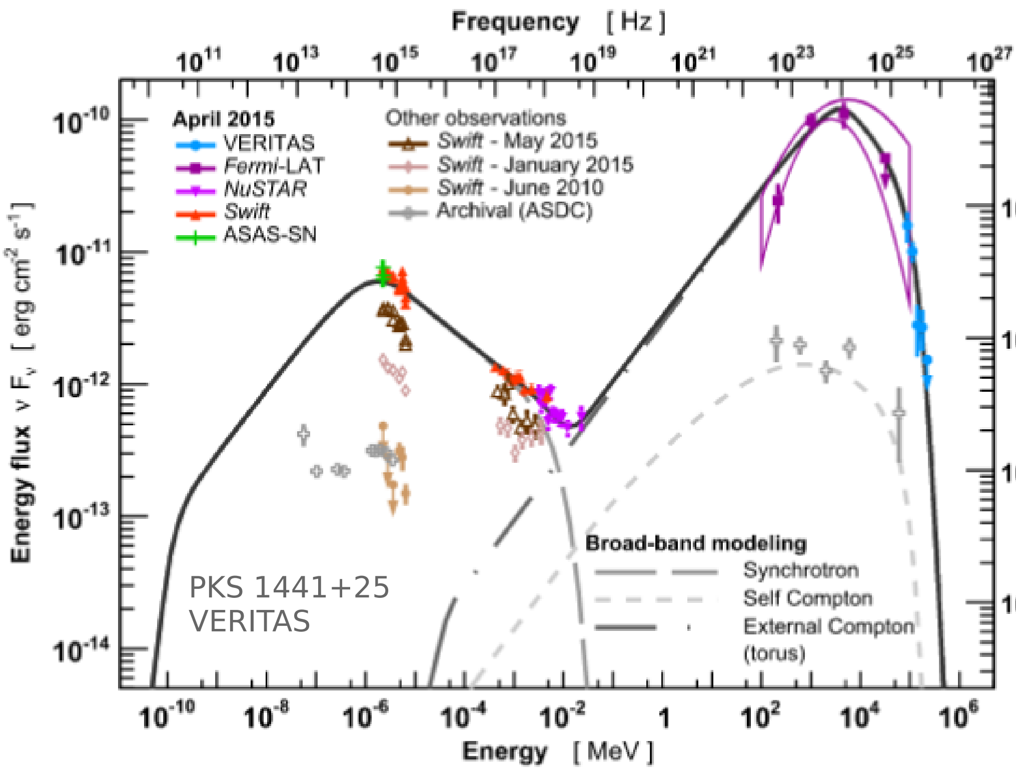


- Radiative output depends on the external photon field (and thus on the location of the emitting region)

- Too many free parameters: we need to make additional hypotheses to force a solution (i.e. impose equipartition, location in the jet, …

Gamma-gamma pair-production at the source
- if emitting region at the jet basis,
  absorption on BLR → no VHE;
- if within a few pc,
  absorption on the torus → no multi-TeV photons

...MODELING

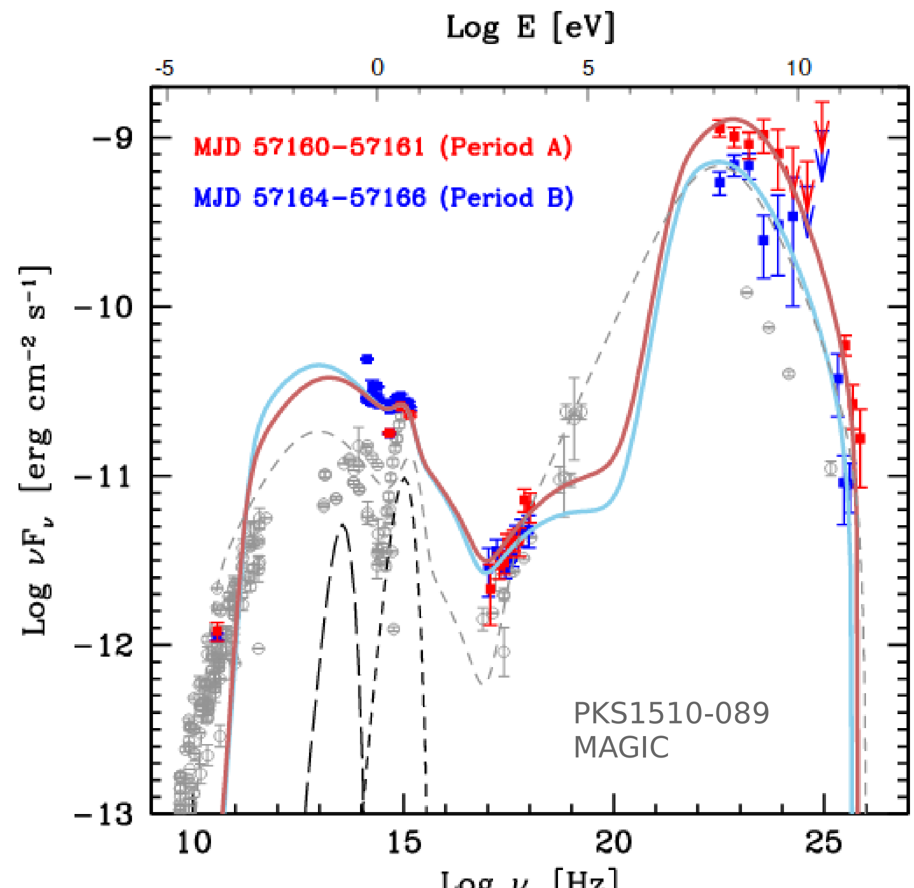


)

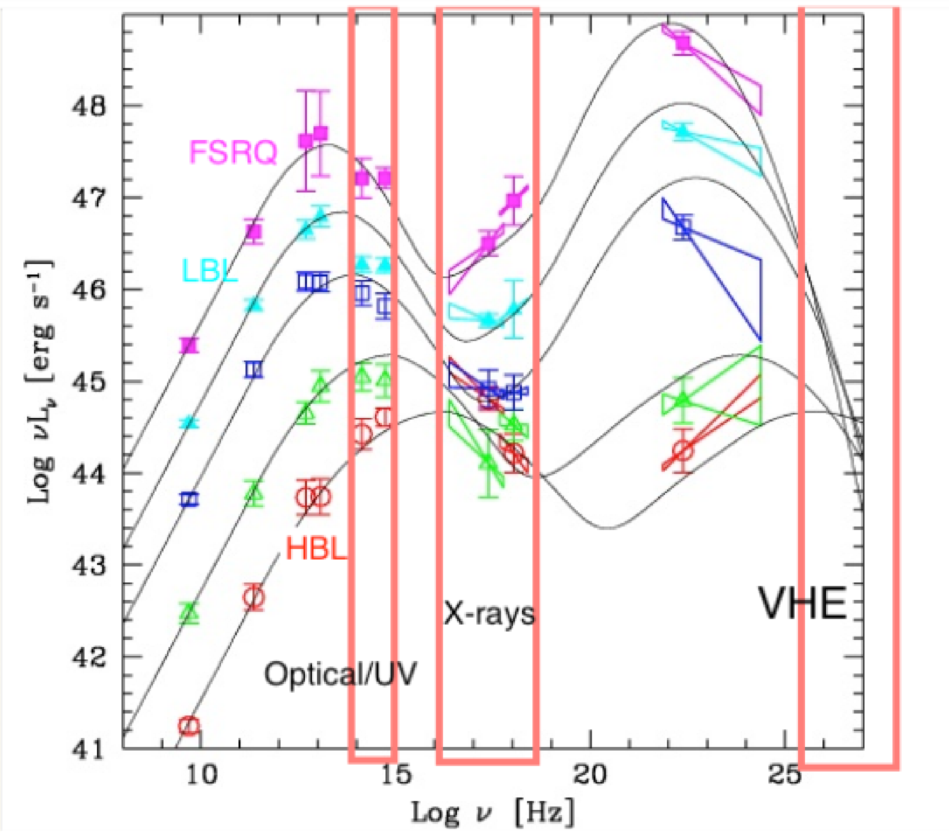
External-Inverse-Compton
EIC

(i.e. impose equipartition, location in the

Gamma-gamma pair-production at the so
- if emitting region at the jet basis,
absorption on BLR → no VHE;
- if within a few pc,
absorption on the torus → no TeV ph



TeV BLAZAR MODELING



High energy bump
(X-to-gamma)

Leptonic vs Hadronic

- hadronic scenario:

proton synchrotron and/or emission by secondaries produced in p+γ interactions

WHY HADRONS? Natural link with UHECR and neutrinos
HADRONIC BLAZAR MODELING IS MULTI-MSN

TeV BLAZAR MODELING

Hadronic modeling of FSRQs:

Major problem is energetic
we need energy in protons which is higher
(by orders of magnitude)
than the Eddington luminosity

Several authors came to the same conclusion:
Sikora et al. 09, Zdziarski and Bottcher 15,
Petropoulou and Dimitrakoudis 15,
+++

N.B. Hadronic models can still be ok for flares!

TeV BLAZAR MODELING

Hadronic modeling can still work for HBLs and UHBLs with reasonable energy budget (i.e. at most $L \sim L_{Edd}$)

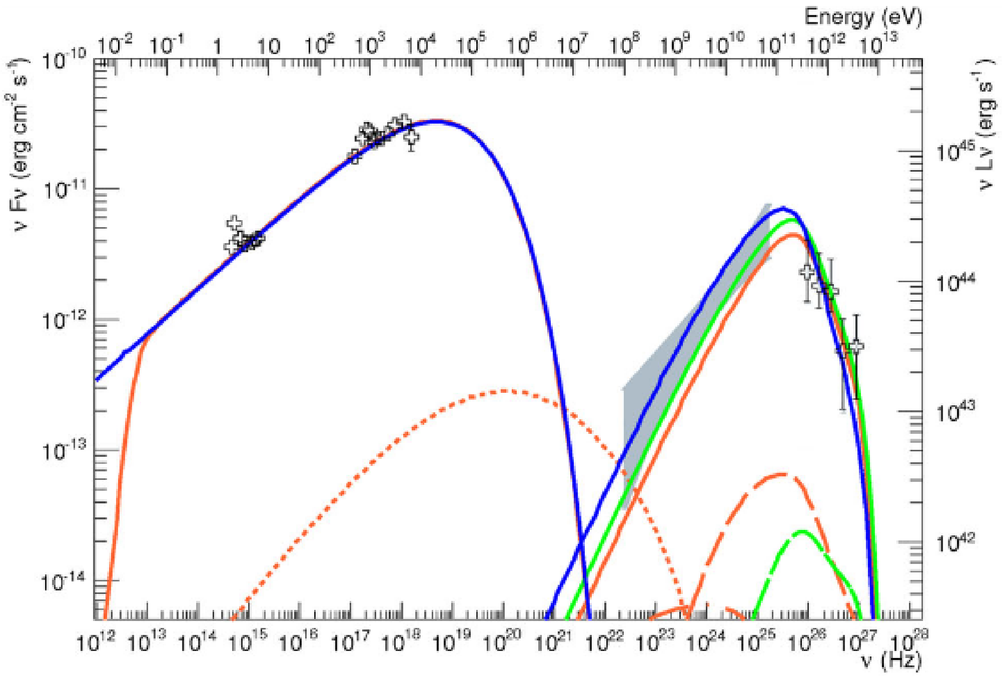
UHBLs, interesting observing properties:

* high-frequency SED peak in TeV band
* NOT flaring!
* if modelled with SSC scenario, they face some issues
    - Doppler factor is higher than for ‚standard' HBLs
    - they require a high value of E_{min} for electrons

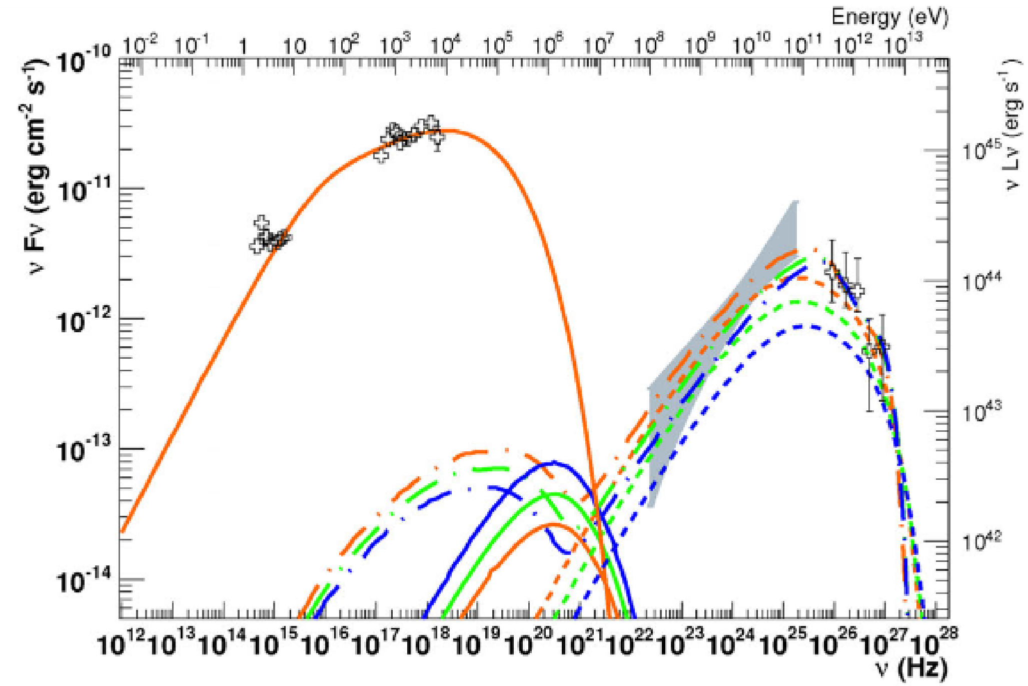
TeV UHBLs MODELING

Hadronic modeling of RGB J0710+591 (typical UHBL)

$\delta = 30$



Proton-synchrotron scenario
$\gamma_{p,Max} = 10^{9\text{-}10}$
$L = 10^{45\text{-}47}$ erg s^{-1}



Lepto-hadronic scenario
$\gamma_{p,Max} = 10^{8}$
$L = 10^{46}$ erg s^{-1}

Cerruti et al 2015

TeV BLAZAR MODELING

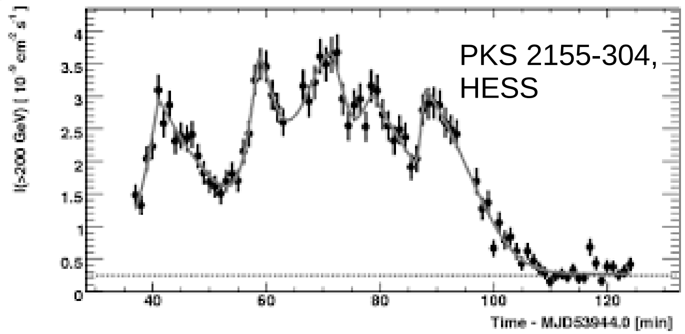
Scenario A: emission at the source

A1: stationary emission
(i.e. study of MWL SED)

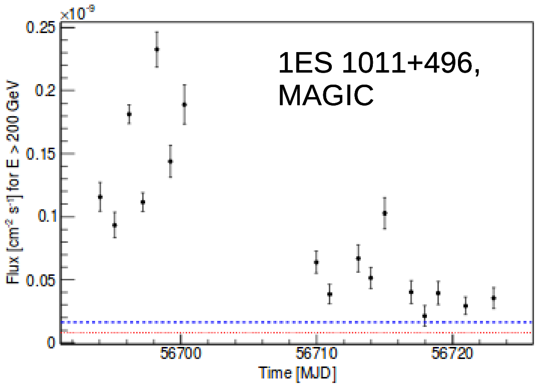
A2: flaring emission
(i.e. study of MWL light-curves)

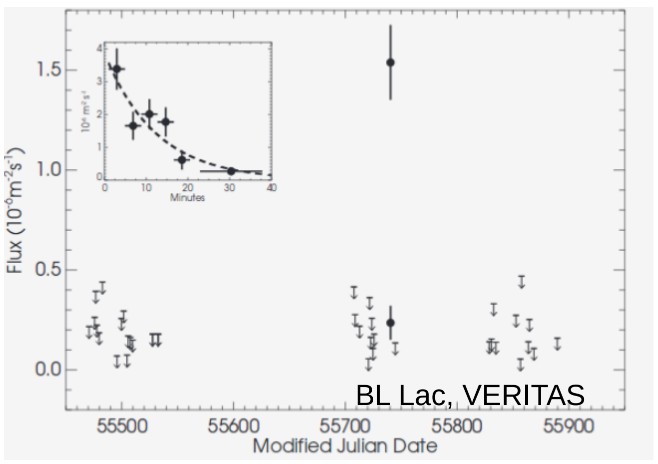
Scenario B: emission in the line of sight

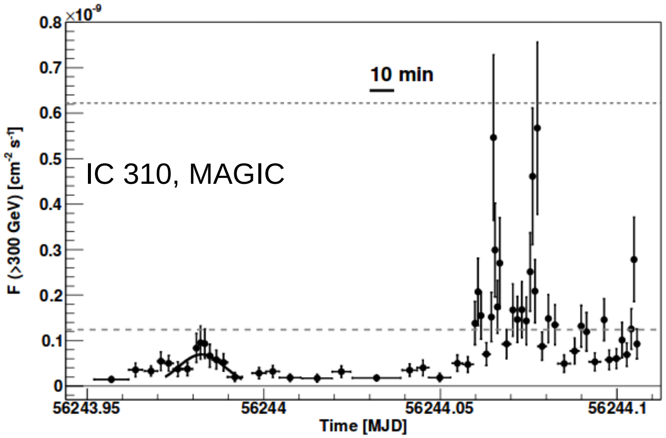
BLAZARS

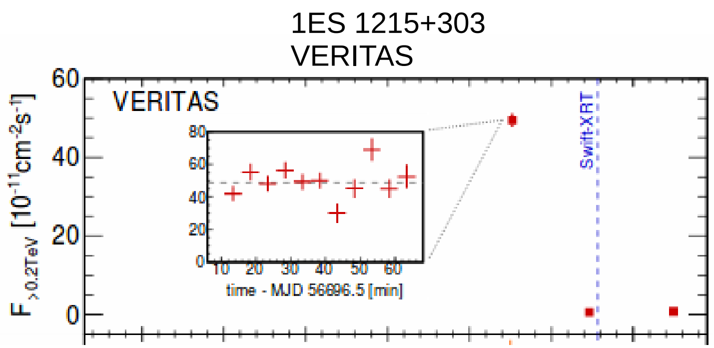


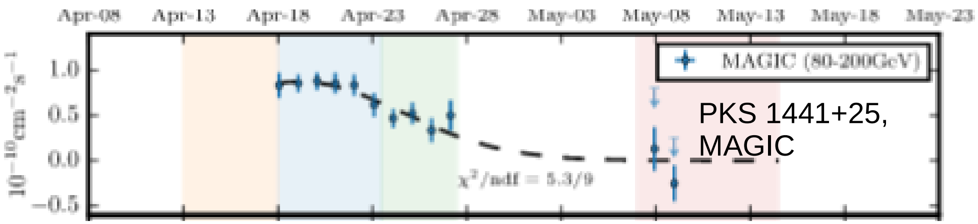
Blazars are variable, at all wavelengths and on different timescales!







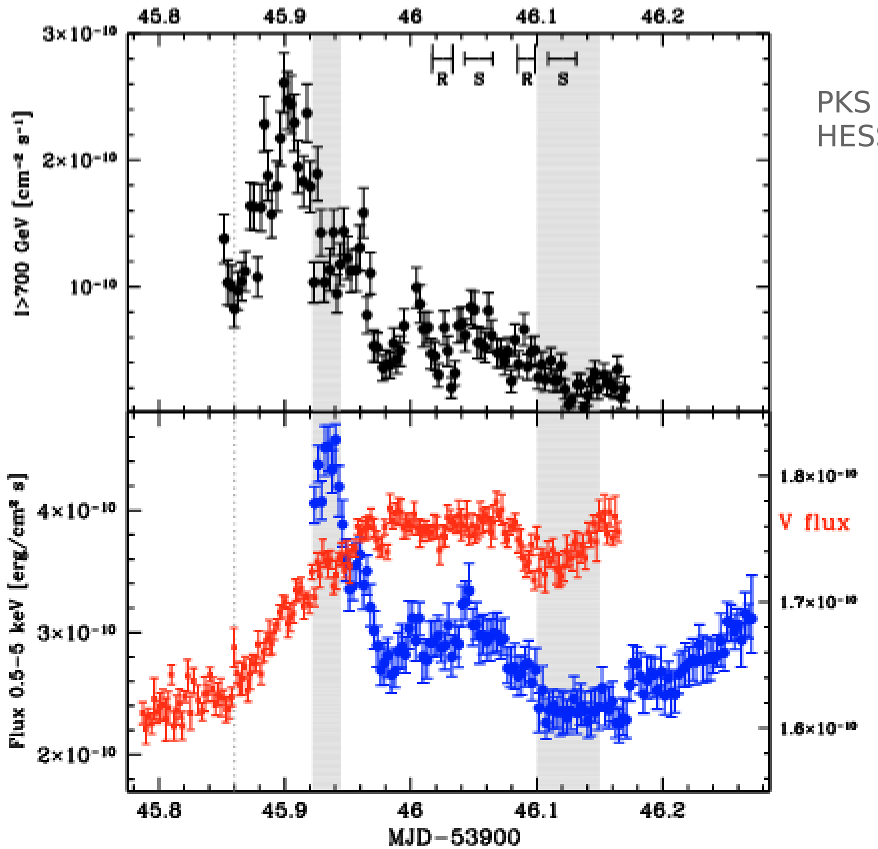




TeV BLAZAR MODELING

Flares provide additional information to constrain models

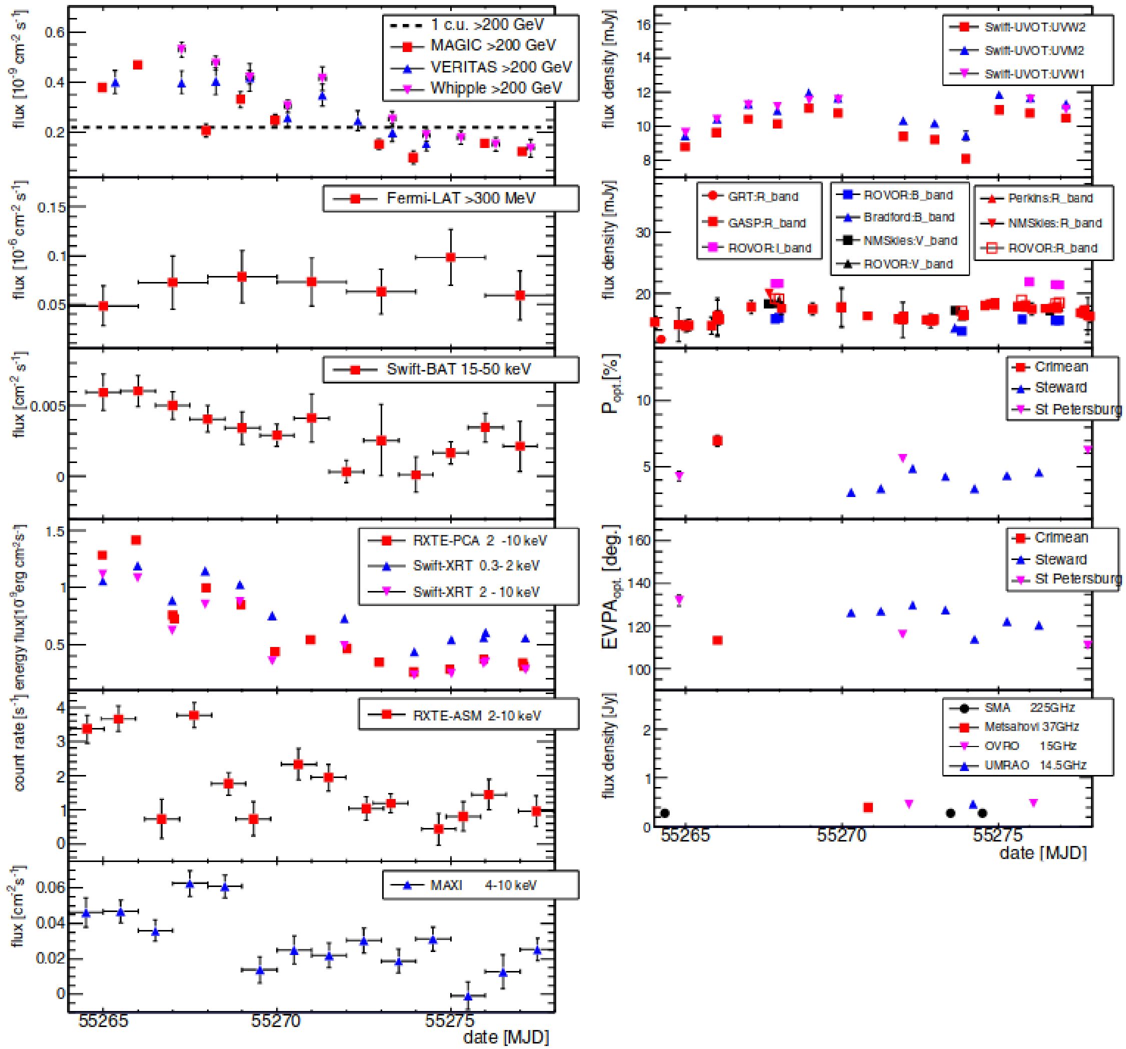
- fit of light-curves
- multi-wavelength correlations
- time-dependent SEDs



PKS 2155-304
HESS

TeV BLAZAR MODELING

Flares provide additional information to constrain models



Markarian 421
MAGIC & VERITAS

TeV BLAZAR MODELING

What are the flares?

Simplest scenario: flaring and non-flaring activity is similar
- same acceleration process
-same emitting region
-same radiative mechanism

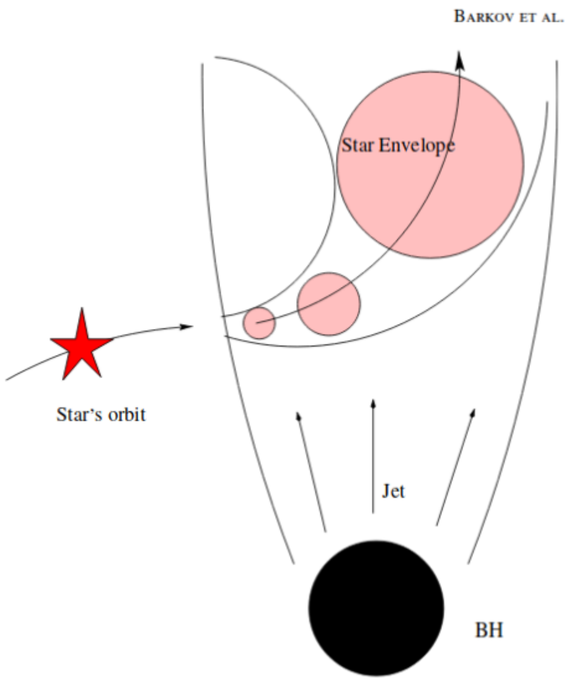
The flare is a sudden increase in the particle injection

→ We can use what we learned from non-flaring SEDs concerning leptons/hadrons; radiative mechanisms

TeV BLAZAR MODELING

or… the emission during eruptions is INTRINSICALLY different (another emitting region located elsewhere; another radiation mechanism; another kind of particle)

Example: star-jet interaction models for the PKS 2155-304 flare (Barkov et al. 2012)

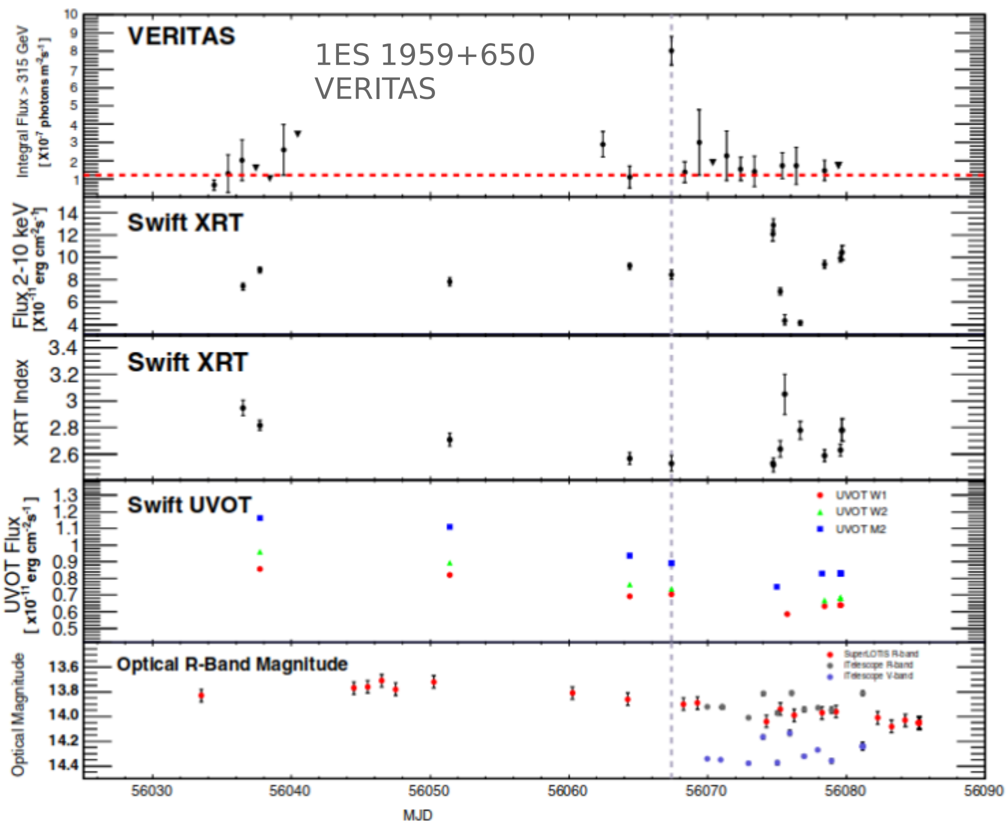


Stationary-state emission is SSC,
Flare emission can be EIC, or
hadronic

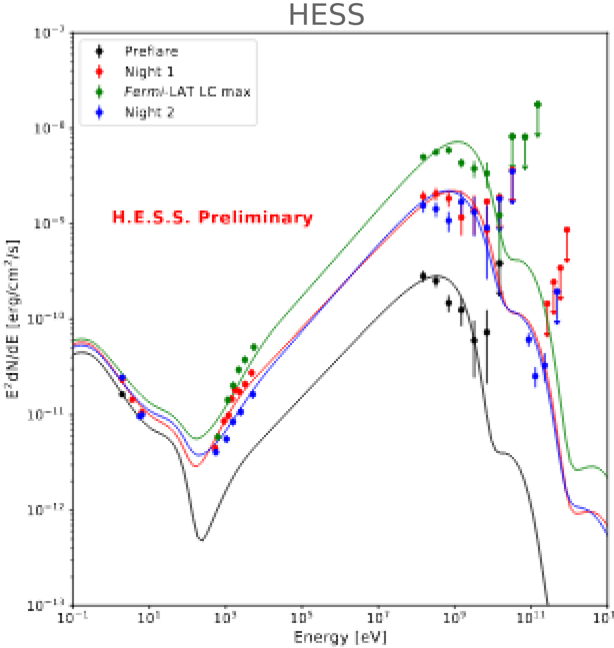
TeV BLAZAR MODELING

or… the emission during eruptions is INTRINSICALLY different (another emitting region located elsewhere; another radiation mechanism; another kind of particle)

Example: orphan gamma-ray flare ares more likely hadronic



3C 279
HESS



TeV BLAZAR MODELING

Scenario A: emission at the source

A1: stationary emission
(i.e. study of MWL SED)

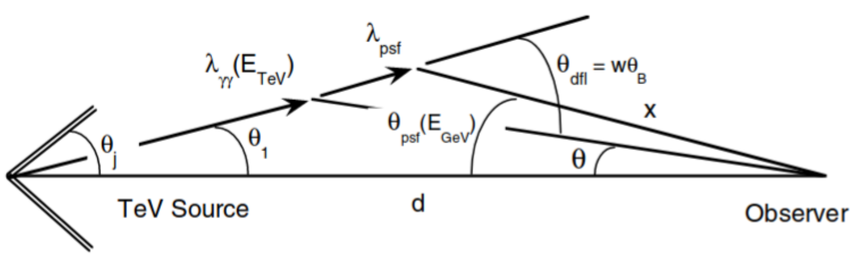
A2: flaring emission
(i.e. study of MWL light-curves)

Scenario B: emission in the line of sight

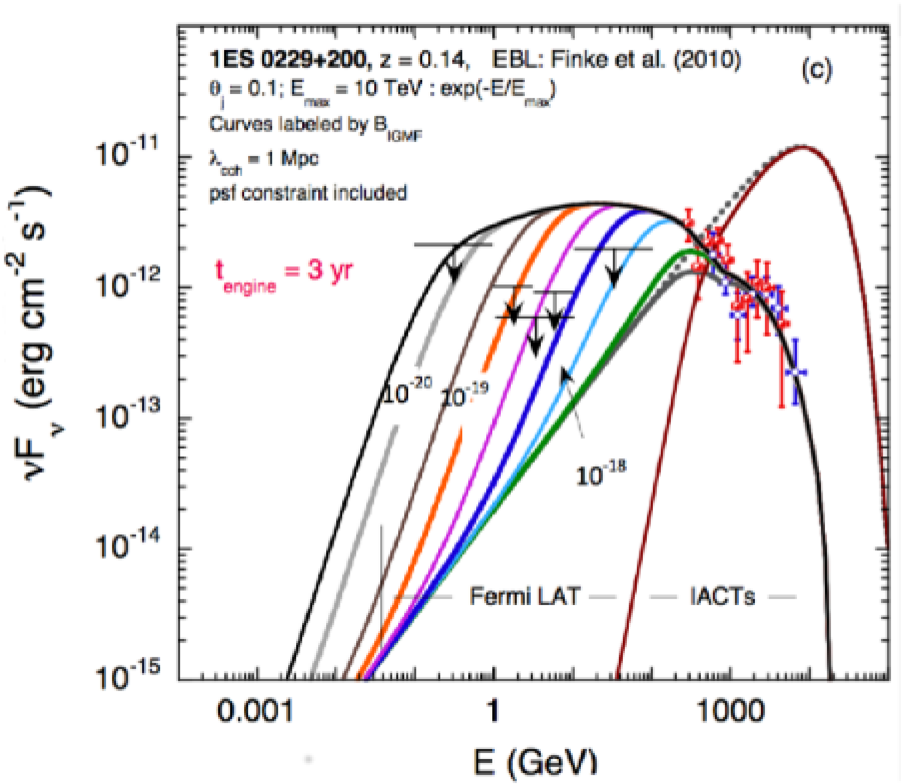
TeV BLAZAR MODELING

Propagation effects (beyond simple absorption on the EBL) can alter the gamma-ray emission

1) Pair-cascade in the line of sight can modify the g-ray spectrum
   (in the GeV band, depending on the strength of the IGMF)



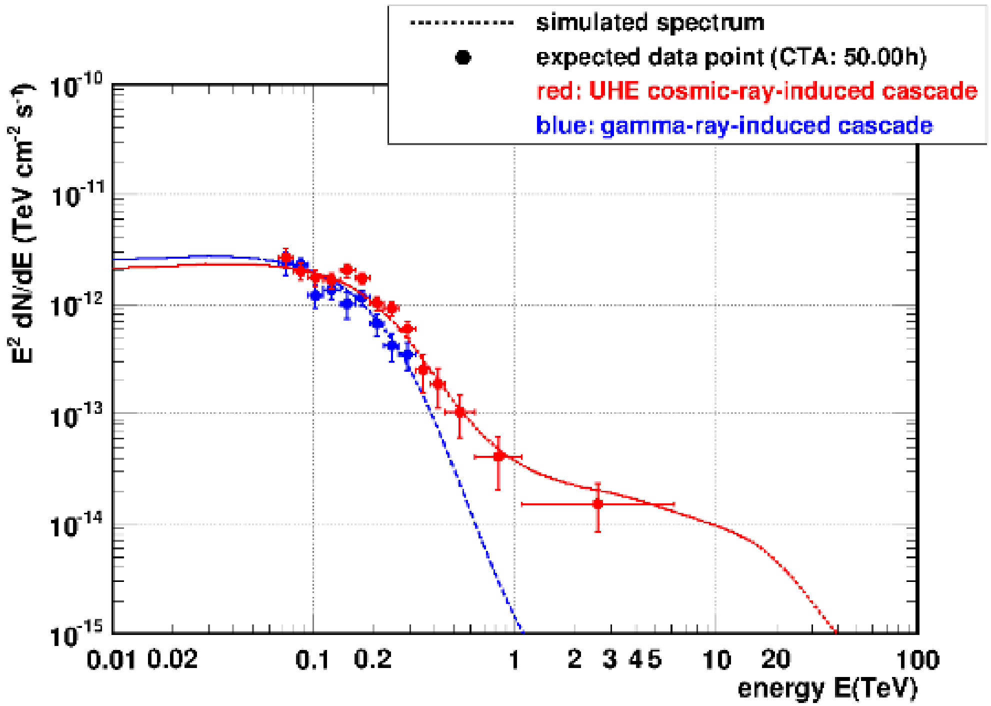
Dermer et al., 2011



TeV BLAZAR MODELING

Propagation effects (beyond simple absorption on the EBL) can alter the gamma-ray emission

2) If the AGN emits UHECR, emission along the line of sight can modify the g-ray emission (in the TeV band)



The CTA Consortium, 2017

CONCLUSIONS

γ-loud AGNs are mainly blazars

Non-flaring states:

origin of the γ-ray emission is
-leptonic (External-Inverse-Compton) for FSRQs
-leptonic (Synchrotron-Self-Compton) or hadronic for HBLs

Rapid flares:

Simplest scenario is to use what we learn from SED modeling, and vary injection (same processes for flaring and non-flaring)

But flaring and non-flaring emission may be different!

Keep in mind that propagation effects can affect γ-ray emission