Very High Energy gamma-ray radiogalaxies and blazars

Hélène Sol

Paris Observatory, CNRS

JD6, The connection between radio properties and High-Energy emission in AGNs

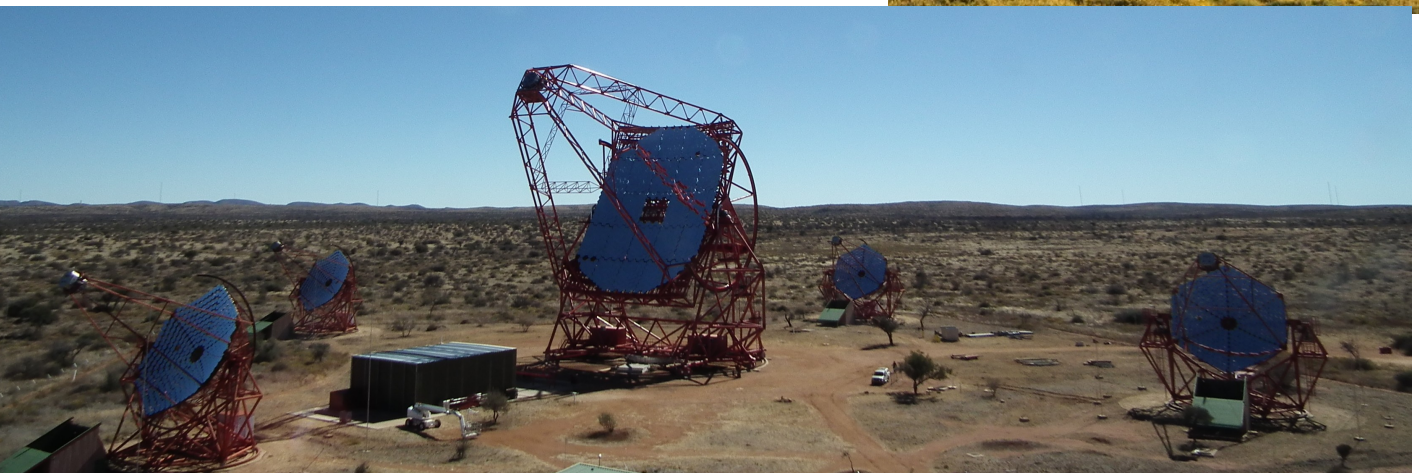
Outline

- The sample of AGN currently seen at VHE: the « known », the « unknown » …
- … and the « amazing » : the radio-VHE elusive connection
- Important synergy between present and future radio and VHE instruments

VERITAS

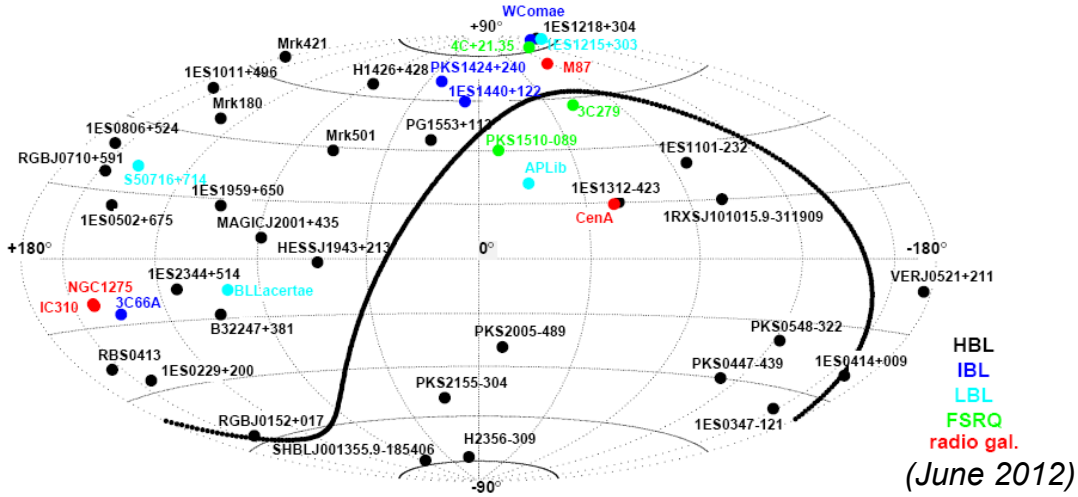
MAGIC

Current ground-based Imaging Atmospheric Cherenkov Telescopes have detected more than 50 Active Galactic Nuclei at Very High Energies, up to redshift ~ 0.6.



HESS I,
and
HESS II (July 2012)

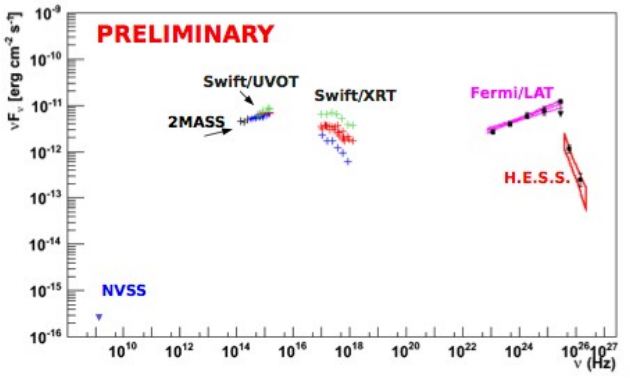
The AGN sample at VHE: the known



(June 2012)

Now at least 53 firmly known TeV AGN, with
- 47 blazars
- 4 radiogalaxies
- 1 AGN of unknown type [+ possibly Sgr A* ?]

Redshifts from 0.00183 (Cen A) to 0.536 (3C279),
but possibly new record at high redshifts:
z = 0.61 with KUV 00311-1938
recently announced by HESS at > 5 σ
(Becherini et al, 2012; Pita et al, 2012)



The AGN sample at VHE: beaming

47 blazars, including
- 34 HBL *[High frequency peak BL Lac objects]*
- 4 IBL : 3C66A, W Comae, PKS1424+240, 1ES1440+122
- 4 LBL : BL Lac, AP Lib, 1ES1215+303, S5 0716+714
- 3 FSRQ : 3C279, PKS1510-089, 4C +21.35
- 2 newly announced BL Lac

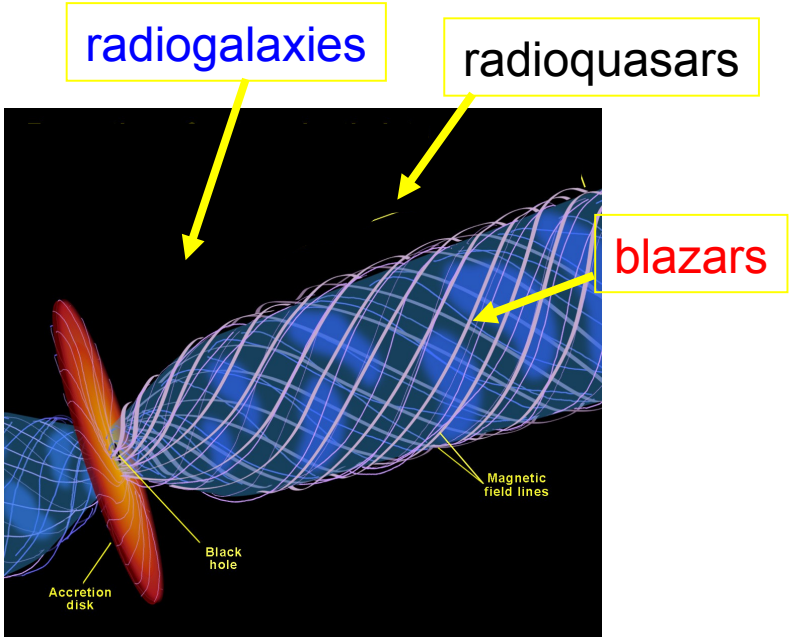
4 radiogalaxies (M87, Cen A, NGC1275, IC130)

1 AGN of unknown type (VER J0521+211)

~90% of presumably beamed sources !

→ Sample highly biaised towards **sources with relativistic beaming** and strong Doppler boosting (factor ~ δ^4)

→ High δ also help to accomodate fast variability and to avoid strong intrinsic absorption



The AGN sample at VHE: variability

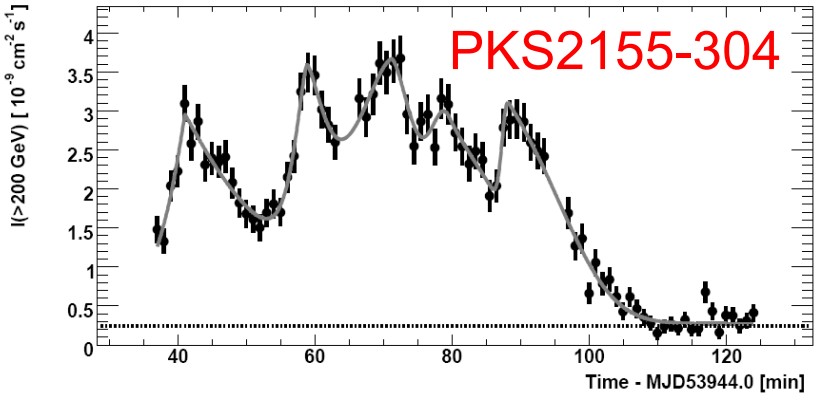
Most of the AGN appear variable at VHE (despite poor time coverage)

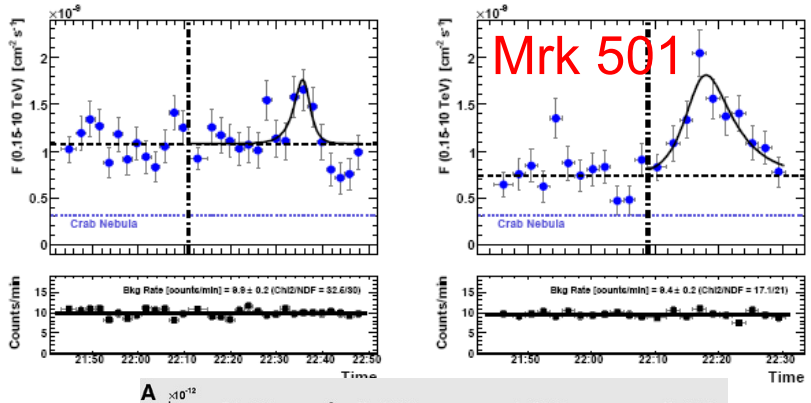
Variability time scales: from a few minutes to months and years.

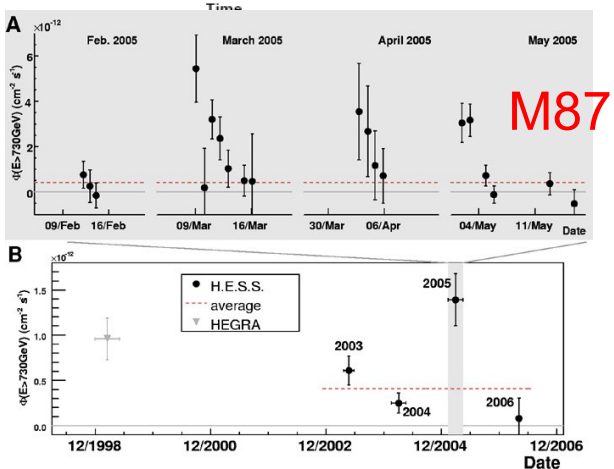
When detected, fast variability implies very small emitting VHE zones, from causality argument. Sizes can become critical compare to BH Schwarzschild radius, for some flares $R < c\, t_{var}\, \delta / (1+z)$ even for high δ.

Examples : PKS2155-304, Mrk 501 (HBLs) and M87 (radiogalaxy)

Sample possibly biaised towards active states, due to sensitivity limits and strategy of observations (ToO). However stationary states are detected for some of the brightest sources (ex: PKS2155-304).

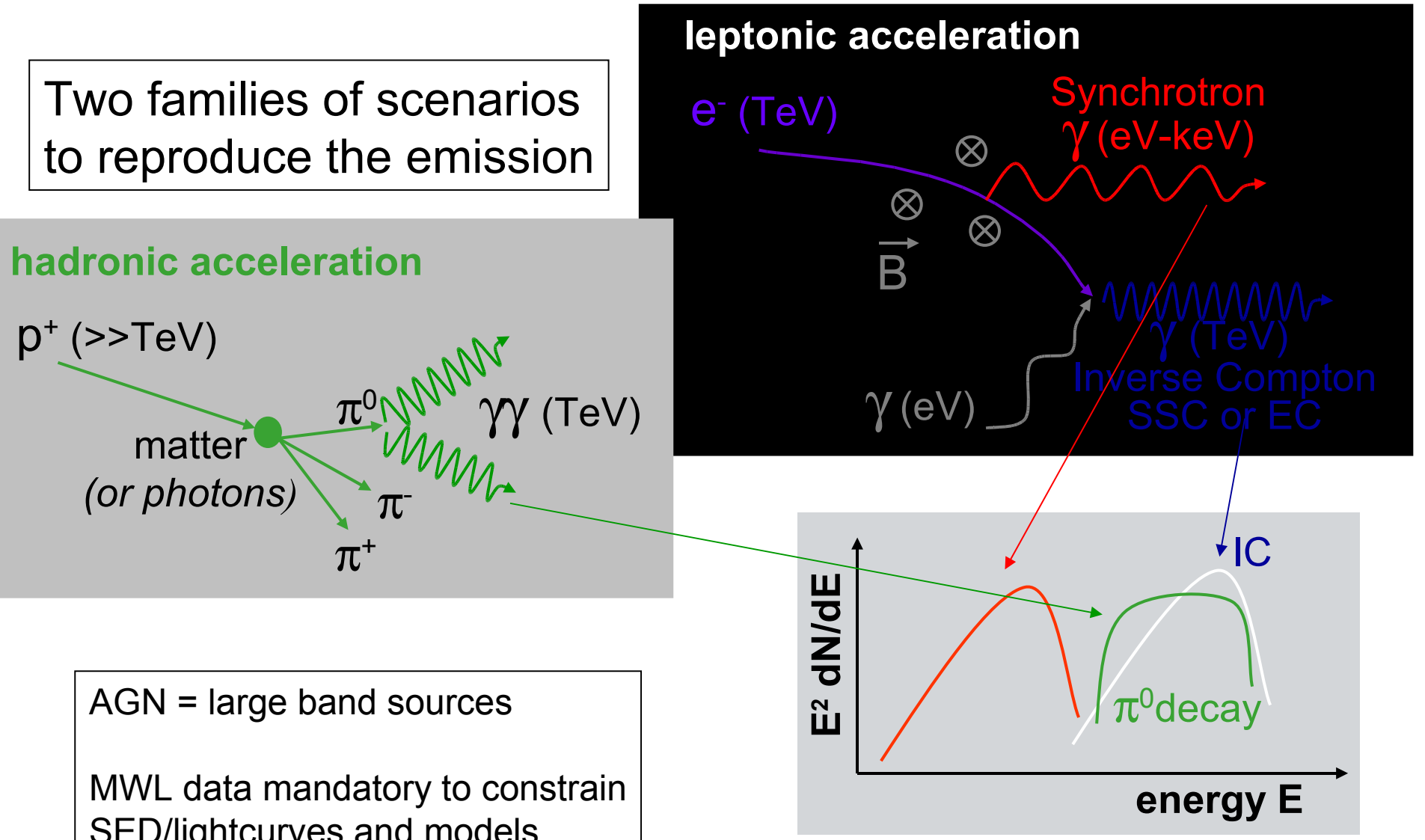






The AGN sample at VHE: models

Two families of scenarios to reproduce the emission

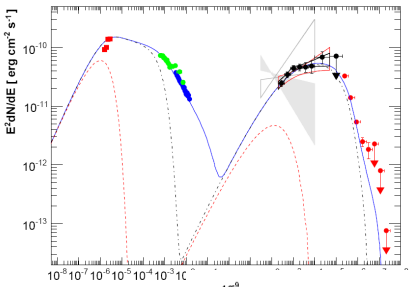


AGN = large band sources

MWL data mandatory to constrain SED/lightcurves and models

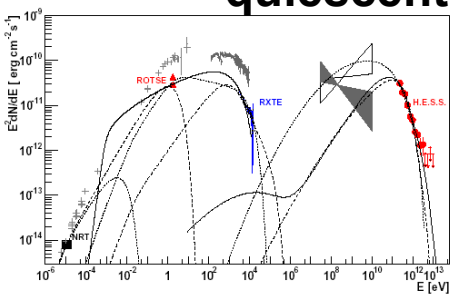
The AGN sample at VHE: models

- « Basic » leptonic models quite successful for « simple » cases and « simple » data sets [ie number of model free parameters ~ number of observational constraints]



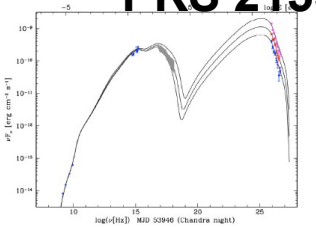
PKS 2155 quiescent

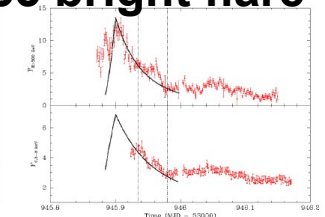
- Hadronic models can also reproduce most of the **stationary states**. Time dependent models more problematic.



- Multi-zone SSC models can reproduce most HBL stationary states - and even « **single flares** » when time-dependent -, from radio to VHE. Require some developments for others blazars and radiogalaxies (EC component, shayered jet; jet opening angle, jets-in-jet…), or for very detailed data sets

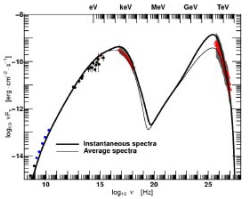
PKS 2155 bright flare

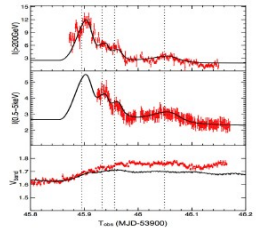




Light curves

SED





The « unknown »

- The increasing complexity of the VHE and MWL data emphasizes the limits of the emission scenarios: available models are only efficient « elementary bricks », not yet part of a coherent global picture

- In particular, we fail to know:

- the location, geometry and dynamics of the emitting zone(s) : BH magnetosphere, base of jets, inner or larger beams and jets …
- the origin and place of the acceleration : Fermi processes in shocks and turbulence, magnetic reconnection, direct electric forces, centrifugal force …
- the origine of power and variability. And the nature of the multiplicative process deduced from analysis of the fast variability pattern in PKS 2155 *(Giebels, Degrange, 2009).*

The « amazing » : four VHE radiogalaxies quite different in the radio range

The 2 closest radiogalaxies:

- **M87** (center of Virgo cluster) and **Cen A**: double large scale radio structure (**Wide Double Source**), with misalignment between inner and extended jets. **Superluminal** motion seen in M87 one-sided jet. Cen A has a counterjet

In the Perseus cluster:

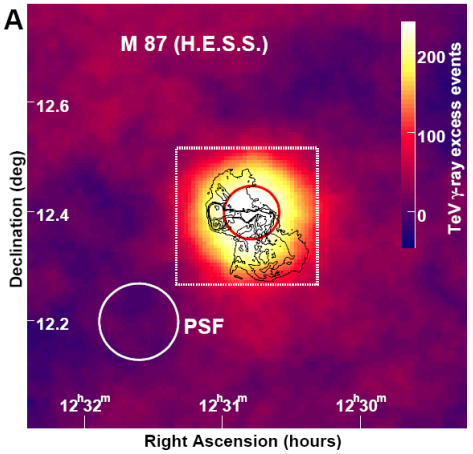
- **NGC 1275** (z = 0.0172): a **core-dominated compact** radio source (Compact Symmetric Object). Possibly a young or embedded radiogalaxy. **Subluminal** expansion of radio lobes seen at VLBI.
- **IC310** (z = 0.0189): first classified in radio as a Narrow Angle Tail or **head-tail** galaxy, with a rather weak nuclear radio flux. Although possibly a galaxy with one-sided radio jet.

All four located in rich environment (can favour activity)

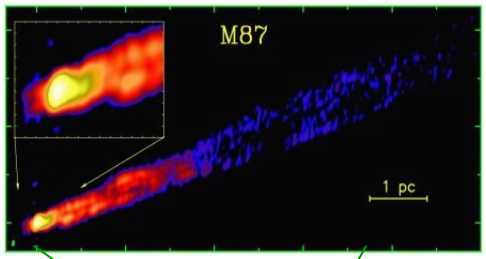
All four have shown some BL Lac-like events in the past

→ Could be at intermediate viewing angle with moderate Doppler boosting ?

The radiogalaxy M87

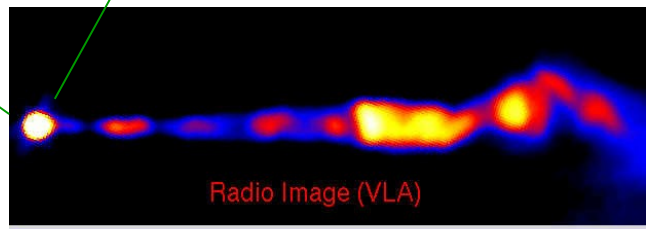


VHE

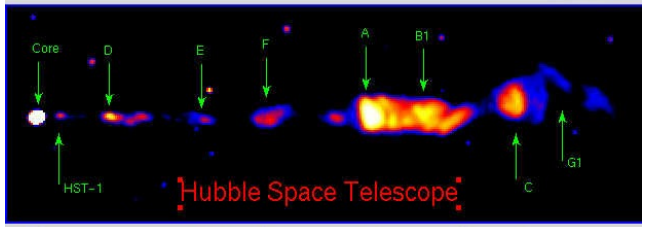


radio

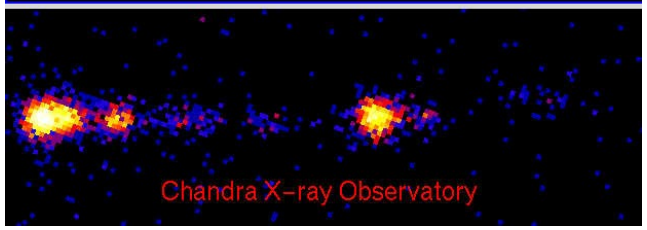
M87 : VHE day variability
→ 3 possible VHE emitting zones :
- The peculiar knot HST-1 at ~ 65 pc from the nucleus
- The inner VLBI jet
- The central core and the black hole magnetosphere

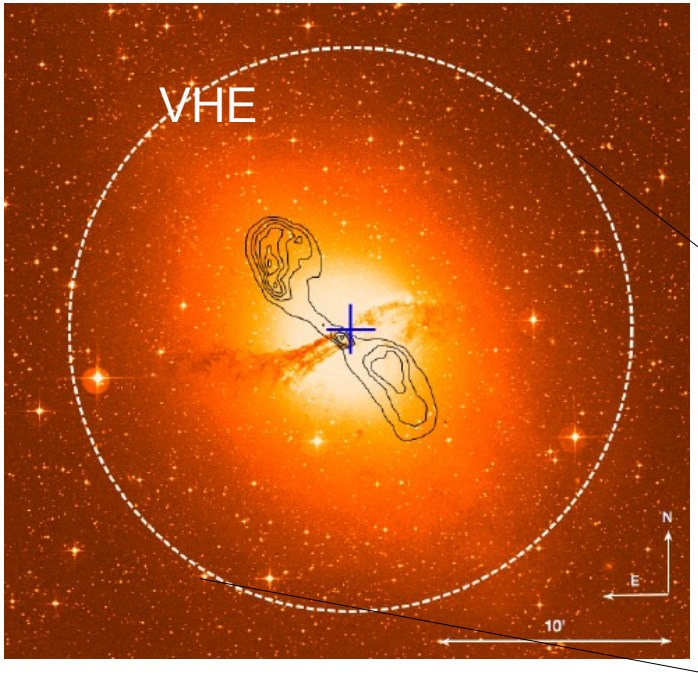


HST

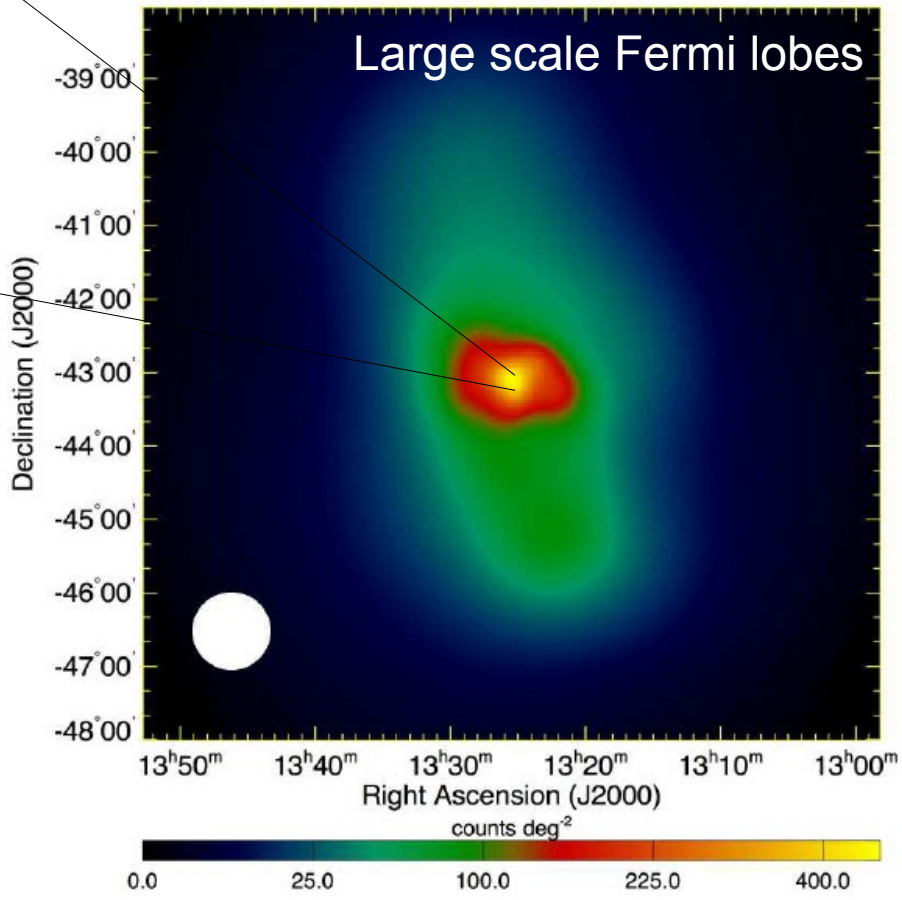


X





Cen A : Origin of the VHE emission ?
Compatible with radio core
and inner kpc jets

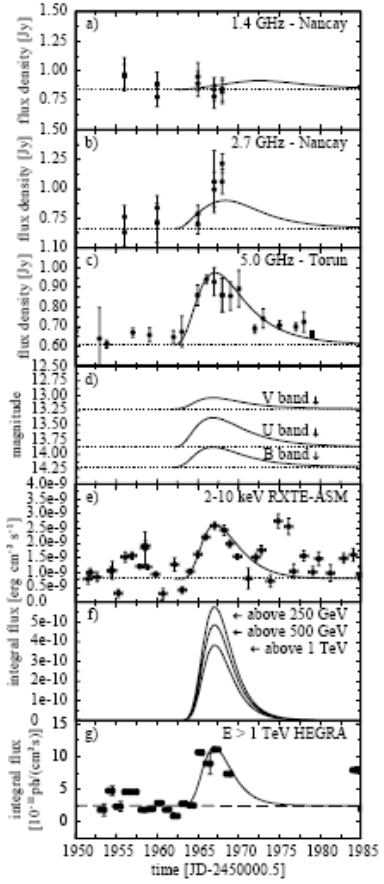


Possible VHE zones :
- BH magnetosphere
- base of jets
- jets and inner lobes
- pair halo in host galaxy

VHE properties # M87
(and link to UHECR ?)

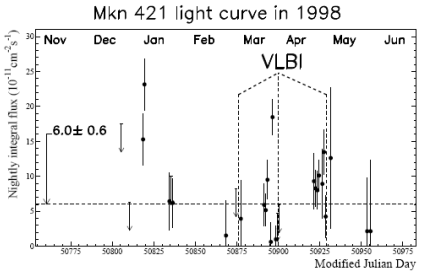
The « amazing » : the elusive radio-VHE connection

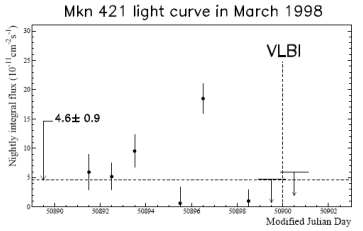
- MWL monitoring of individual sources are very complex to interpret : correlations appear for some events, for some bands, not for others. Orphan flares remain a possibility.
- A first example : Mark 421
- Radio monitoring (Nançay and Torun) in 2001, showed a well-defined radio outbusrt associated with some X-ray (RXTE) and a VHE flare (HEGRA) → a MWL event well fitted by SSC modeling *(Katarzynski, HS, Kus, 2003)*
- **First evidence for a firm radio-VHE conection**, the radio being the low-frequency counterpart of the SSC VHE flare.

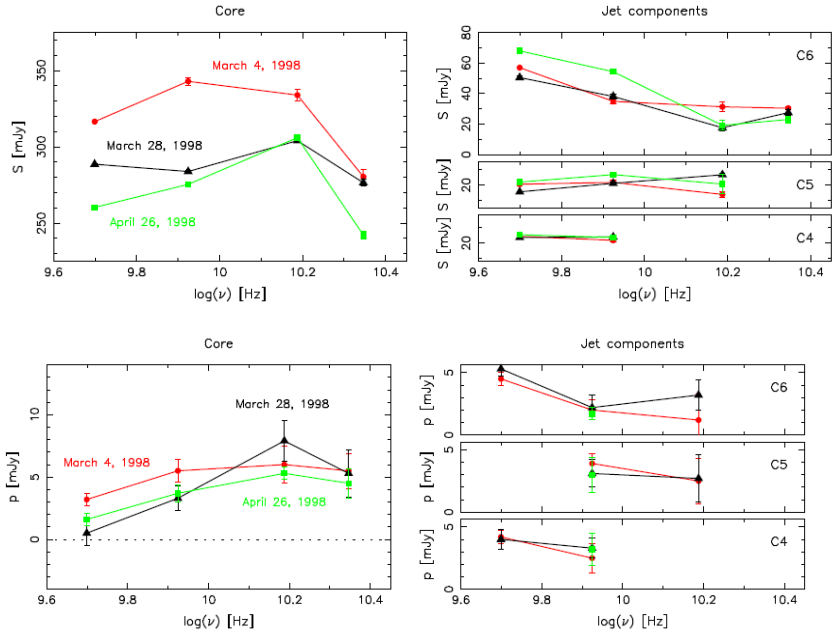


- Mrk 421 activity in March-April 1998 : strong evidence of complex **variability in total and polarized fluxes of the VLBI core, at a time of increasing TeV activity** (and one VHE flare detection) → suggests a correlation between TeV activity and VLBI core variability.
- In flux, VLBI core could be the self-absorbed radio counterpart of the SSC emission at high energies *(Charlot, Gabuzda, HS et al, 2006).*

3 epochs in VLBI



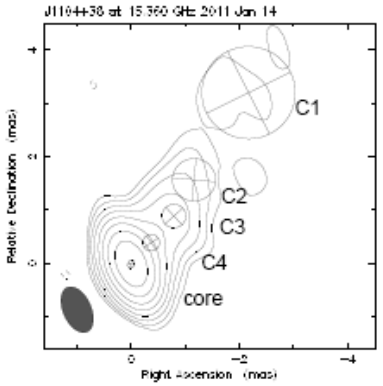




Complex evolution of spectra and polarized fluxes of VLBI core and jet components in Mrk 421 in 1998.

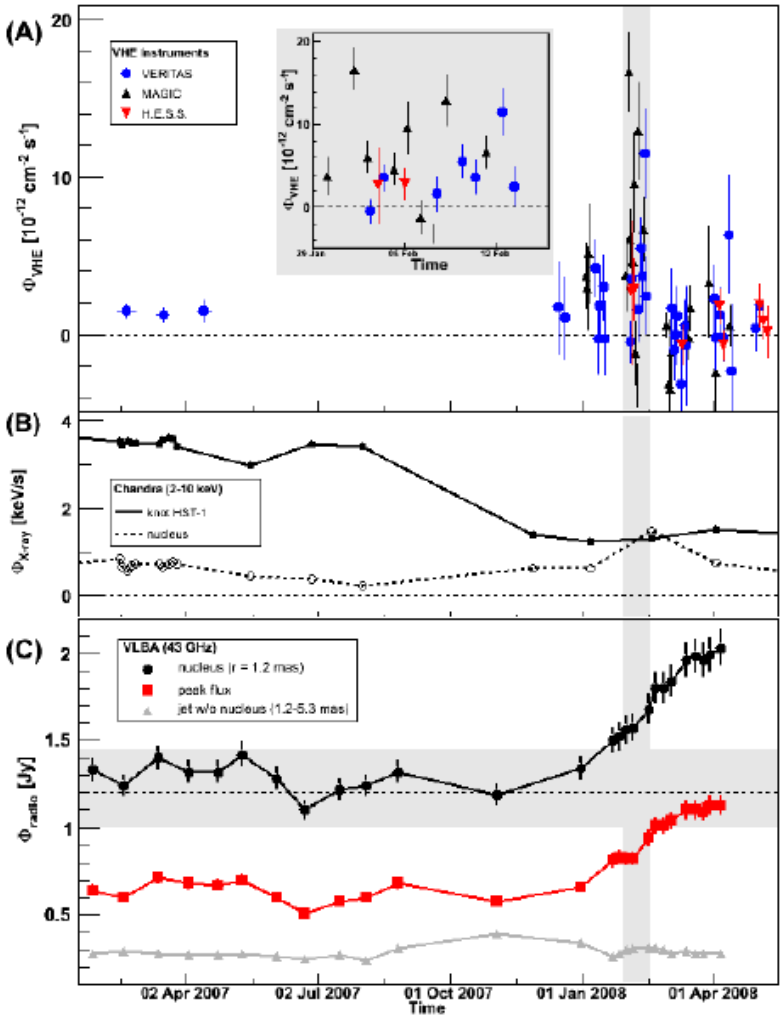
Recent MWL and VLBA campaigns on Mrk 421

- TeV and ML in 2006-2008 : bright TeV flares in May, with variability detected in all other bands, except radio ! **No correlations between TeV and radio fluxes**. However, small **structural changes** are apparent in the MOJAVE 15GHz VLBI images *(Acciari et al, 2011; Aleksic et al, 2012)*
- Ambitious **VLBA monitoring** started to clarify such issues: geometry and kinematics of jet and VHE zone, Doppler factor « crisis », emission processes, variability … *(Lico et al, 2012)*



Component	Apparent speed (mas/month)	$\beta_{\rm app}$
C1	0.06 ± 0.02	1.3 ± 0.5
C2	0.04 ± 0.02	0.9 ± 0.4
C3	0.01 ± 0.01	0.3 ± 0.2
C4a	-0.01 ± 0.02	-0.3 ± 0.4
C4b	0.00 ± 0.01	0.0 ± 0.2

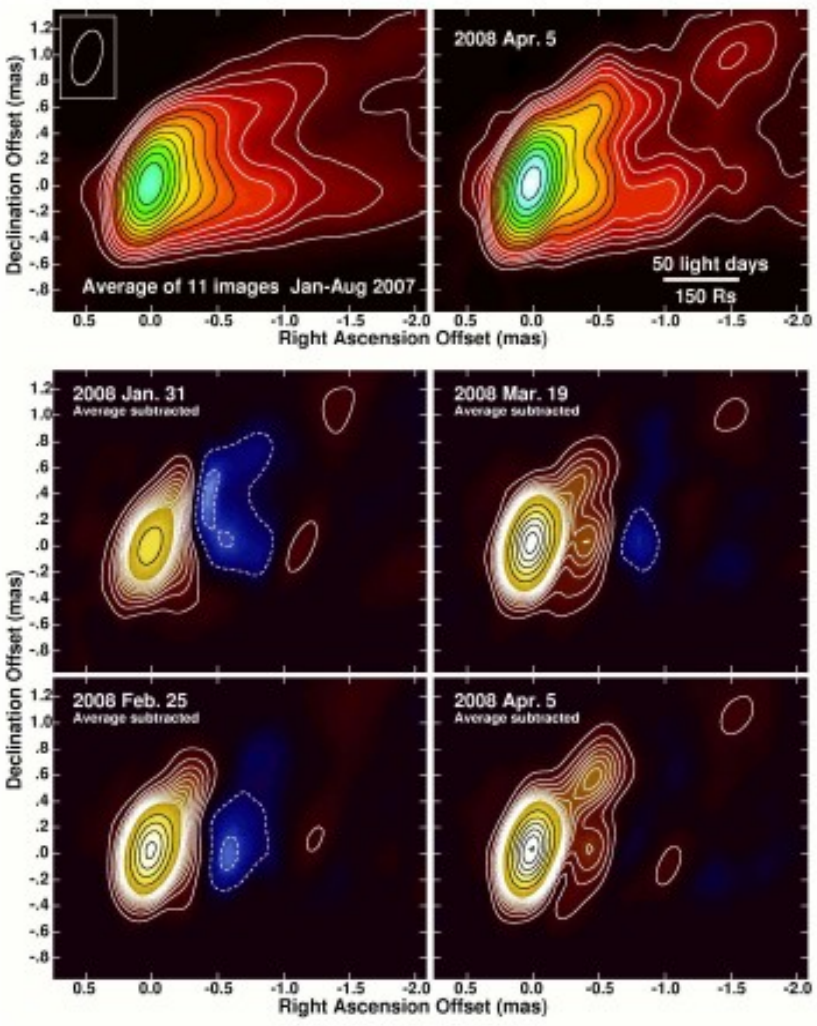
The complex MWL case of M87



(Acciari etal, 2009; Harris et al, 2009)

MWL campaign in **2005** : correlation between a VHE flare and an X-ray outburst of HST-1.

But light curve of HST-1 obtained by Chandra in **2008** does not follow the TeV one … and radio and X-ray emission from the core are correlated with the VHE flux.



Monitoring of the core of M87 by VLBA at 43 GHz every 5 days

Significant rise in VLBI core at the time of VHE activity and enhanced emission along inner jet in **2008**

But in **2010**, no enhancement of radio flux in the inner region during VHE activity !

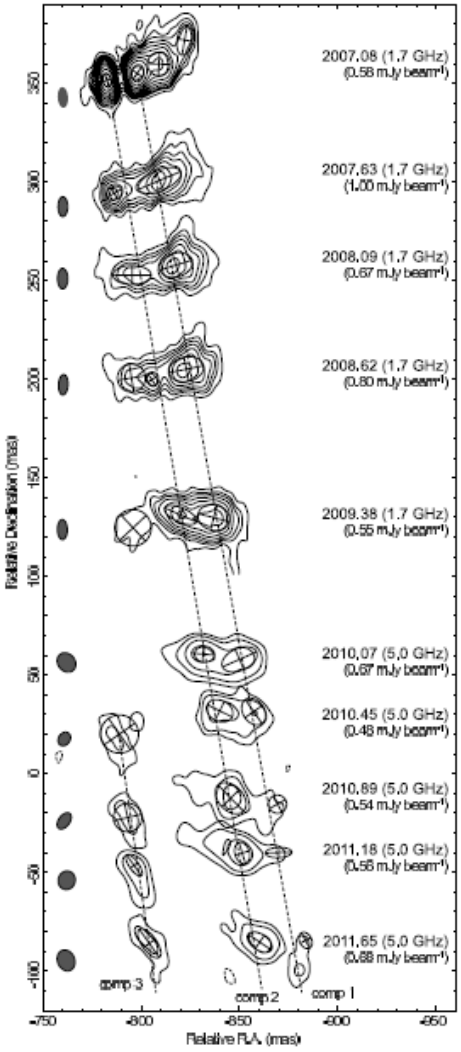
→ **No unique, common MWL signature of VHE flares** *(Abramowski et al, 2012)*

→ Existence of different types of VHE events ?

0.5 mas = 0.04 pc = 140 R_s

VHE zone = HST-1 or M87 core and inner jet ?
→ three *very different groups of emission models*

- Kinematics of HST-1: VLBI structural changes could be related to VHE events *(Giroletti et al, 2012)*
  → Models by Stawarz et al
- Core-VHE correlation: favours BH magnetosphere models
  → various models by Aharonian, Rieger, Neronov, Levinson
- Inner jet-VHE correlation
  → Models by Lenain et al, Tavecchio, Ghisellini, Giannos et al



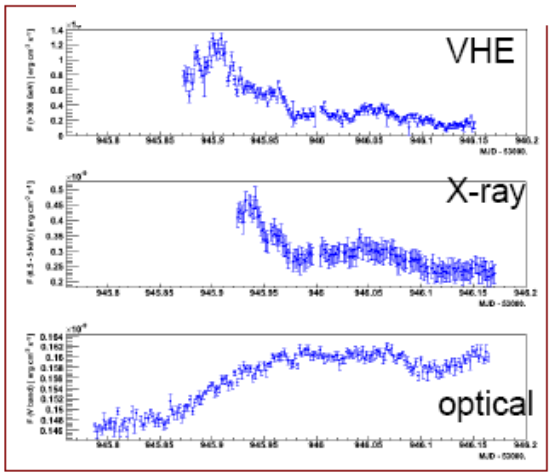
The « amazing » : which relation between various timescales and frequencies ?

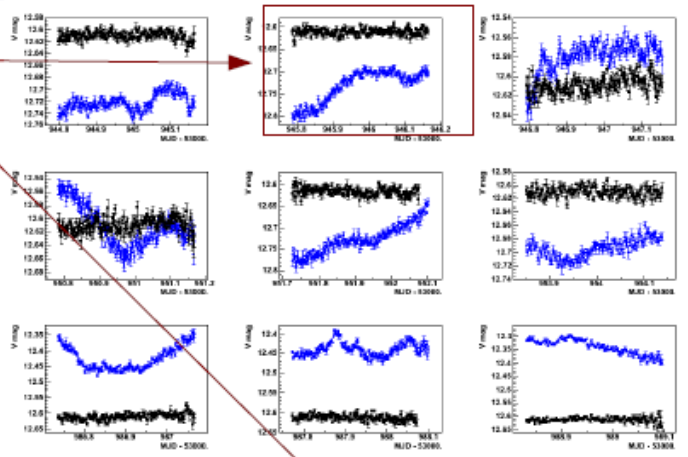
- The striking example of PKS 2155, with a long term increase of radio flux over months, starting at the time of a spectacular activity at VHE (with two highly variable big flares in 2006).

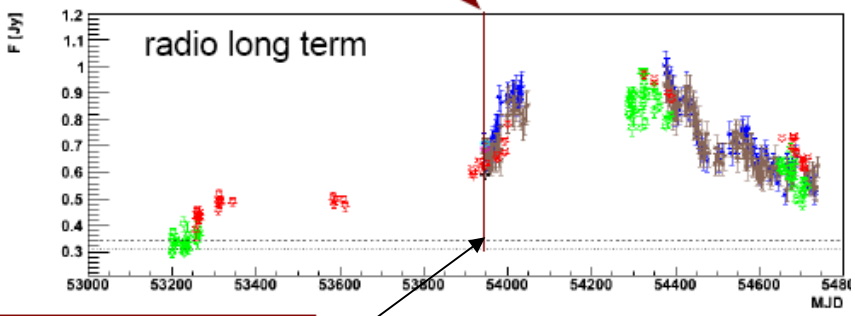
The HBL PKS 2155-304

An extremely active state seen at VHE

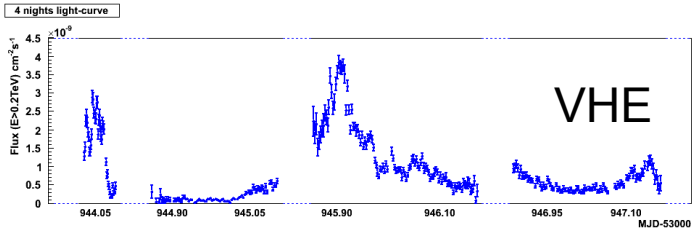
→ some clues for a radio-VHE connection







- correlation VHE - X
- overall increase in the optical
- long term increase in radio



[radio data from Nançay, HartRAO, and ATCA]

High VHE flares at the beginning of long term increase of radio flux

(Abramowski et al, 2012)

Important synergy between present and future radio and VHE instruments

Explore the non-thermal universe at the two extreme parts of the electromagnetic spectrum

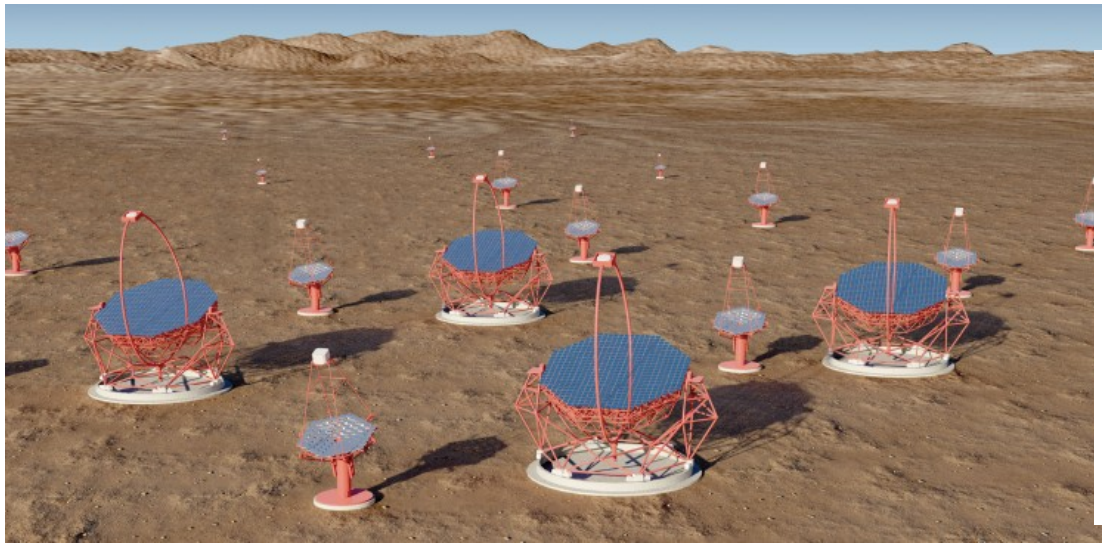
- Synergy between large scale infrastructures in astrophysics, with LOFAR, SKA and precursors, and VHE/CTA, HAWC, LHAASO
- [Also MWL: FERMI, ALMA, AUGER, ELT … + Importance of X-ray missions]

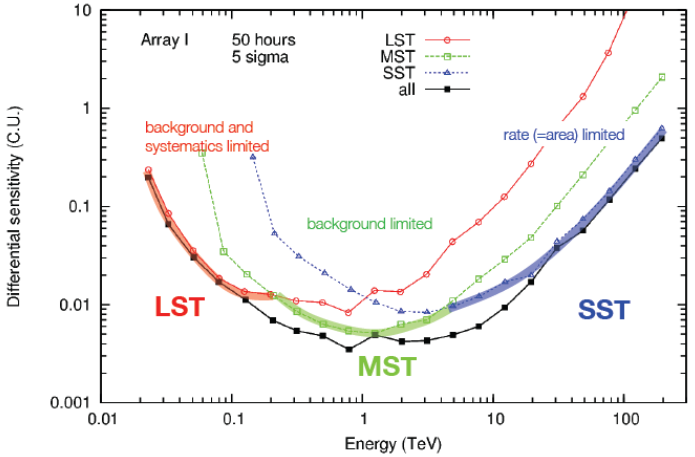
A complex situation in radio versus VHE → gather VHE data in coordination with radio data with sensitivity on all time scales, flux, polarisation, and VLBI resolution when possible. How to optimize ?

Next generation of VHE astronomy : the CTA project, open observatory

- 10-fold increased sensitivity at TeV energies (mCrab)
- 10-fold increased effective energy coverage
- Larger field of view (5° to 10°)
- Improved angular resolution
- Full sky coverage (North and South)

→ Should reach hundreds of AGN of various types





One possible configuration for the future southern array:
- Low-energy section with 4x 23 m parabolic tel (LST) at > some 10 GeV
- Core-energy array with 23 x 12 m DC tel (MST) in the range 100 GeV-10 TeV
- High-energy section with 32 x 5-6 m DC or SC tel (SST) at multi TeV energies.

Conclusion

- Importance of relativistic beaming in VHE AGN. How far decisive ?
- Great variety of VHE radiogalaxies: VHE mostly not related to large scale radio properties.

- Elementary bricks of VHE emission scenarios: ~ OK (although not yet fully constrained). Simple SSC models can fit stationary states and single flares. Require additional complexity as EC component (FSRQ), multi-zone (detailed data), specific geometry (stratified jets, opening angle, …) → seem consistent.
- But global VHE picture, geometry and dynamics: not identified yet. Which acceleration processes and zones, how to handle multiplicative process, which MWL correlations? Correlations with VHE are different even inside the same source, from one epoch to another (in radio, optical and X-rays).

- VHE intermittent flares could be triggered at various places, from BH magnetospheres to relativistic beams and jets, as long as they benefit from Doppler boosting → would explain variety of time scales, sizes and correlations
- Which location for the VHE stationary emission, how to identify it.

Conclusion

Elusive VHE-radio and VHE-MWL connection:

→ VHE explore a new specific facet of the AGNs, not yet self-consistently understood in its global environment, related to extreme processes and variability.

→ Is VHE from AGN mostly (at the moment) a tracer of relativistic beaming ?

→ Explore a missing link between accretion, BH magnetosphere and ejection, with emission from outflows from the BH magnetosphere and from relativistic beams streaming along large scale jets. Signature of the orientation of the central engine.