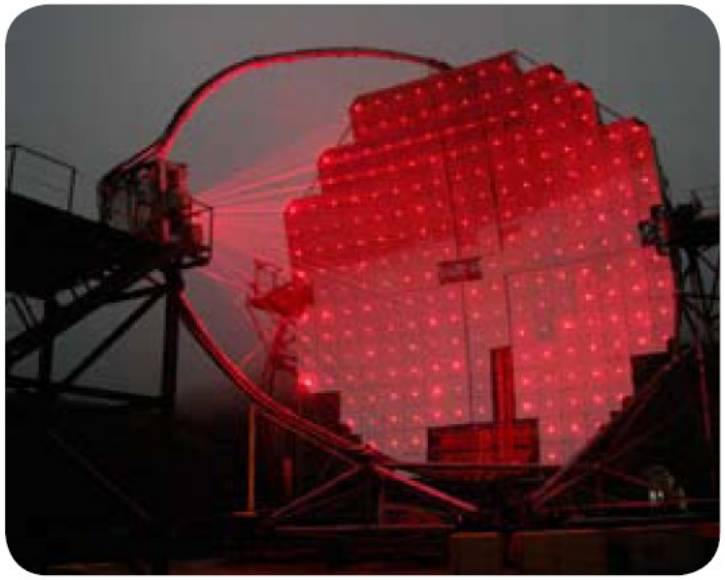
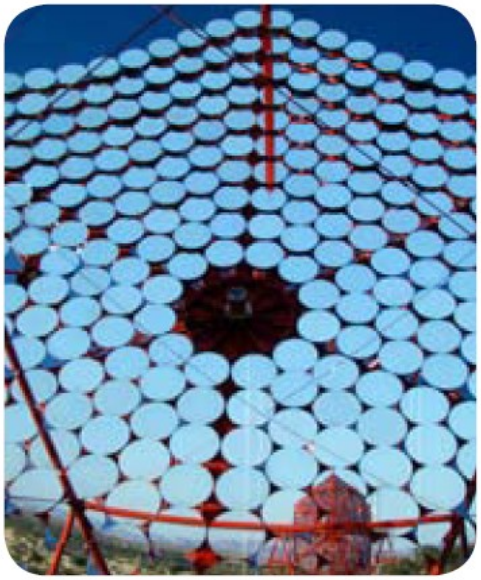
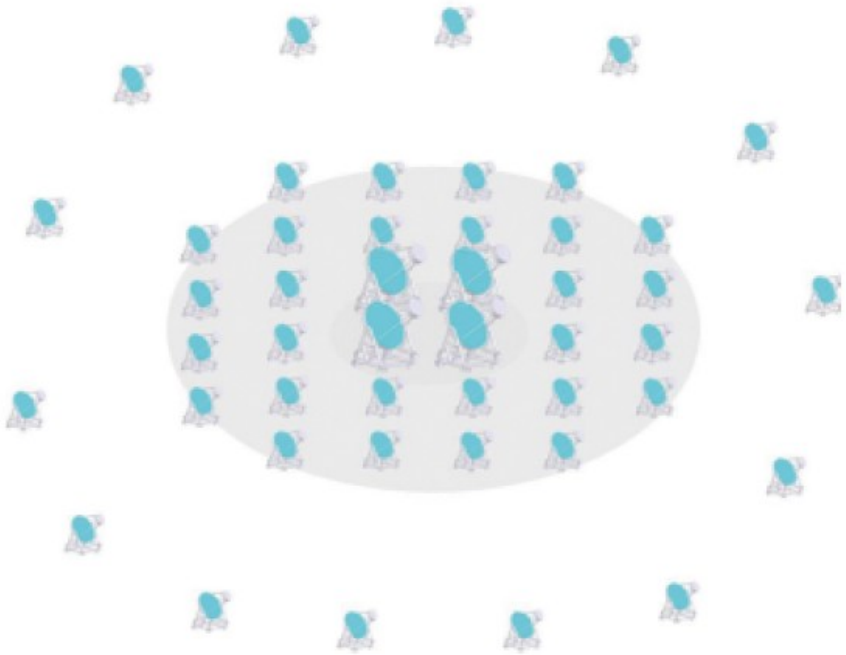
# The AGN science case for CTA







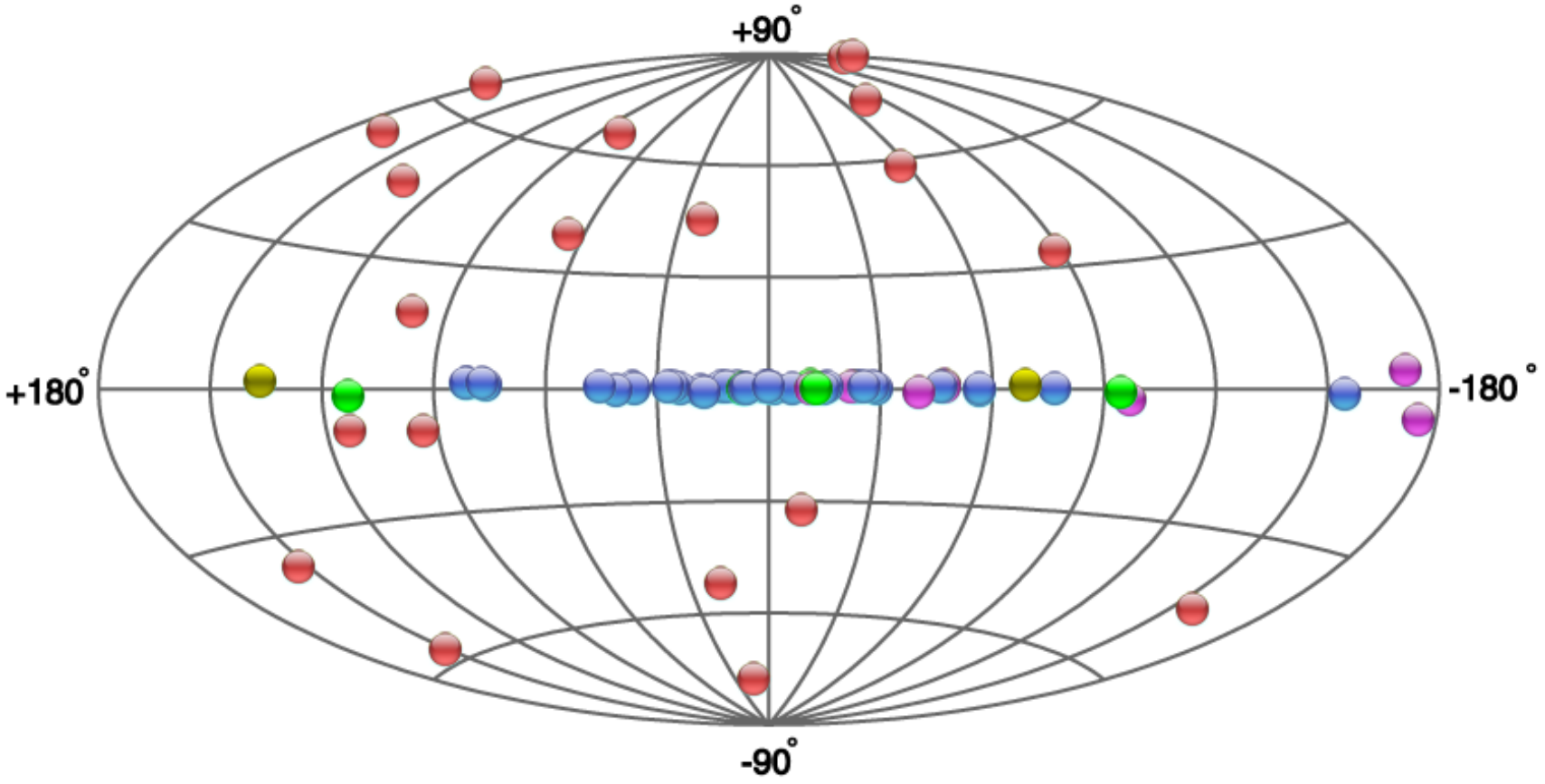
*H. Sol, LUTH, Observatoire de Paris*

*Paris, December 9th, 2008*

# Plan

- Context and recent results at VHE
- AGN science with CTA
  - Physics of AGN
  - Statistical studies
- CTA science with AGN …

# More than 20 AGN detected in VHE gamma-rays at the moment



# Two main γ–rays emission mechanisms and acceleration processes

- Leptonic scenarios : synchrotron and Inverse-Compton (IC) radiation of relativistic electrons (positrons)

  $e + B \rightarrow e + B + \gamma$, in magnetic field B

  $e + \gamma_0 \rightarrow e + \gamma$, with $h\nu \sim \min [\gamma_e^2 h\nu_0, \gamma_e m_e c^2]$,IC on synchrotron emission (SSC) or on external photon field (EC)

- Hadronic scenarios : Interaction of energetic protons (CR) with local gas and radiation backgrounds

  $p + p \rightarrow N + N + n_1(\pi^+ + \pi^-) + n_2\, \pi^0$ ( N = p or n)

  $p + \gamma \rightarrow p + \pi^0, n + \pi^+$, others (for $\gamma_p h\nu > m_\pi c^2$); or $p + e^+ + e^-$ (for $\gamma_p h\nu > 2m_e c^2$)

  Then decay **$\pi^0 \rightarrow 2\ \gamma$ produce VHE photons with $E_\gamma \sim E_\pi /2 \sim 10\%\ E_{p,i}$**

  + Decay pions → muons → *secondary electrons and neutrinos*

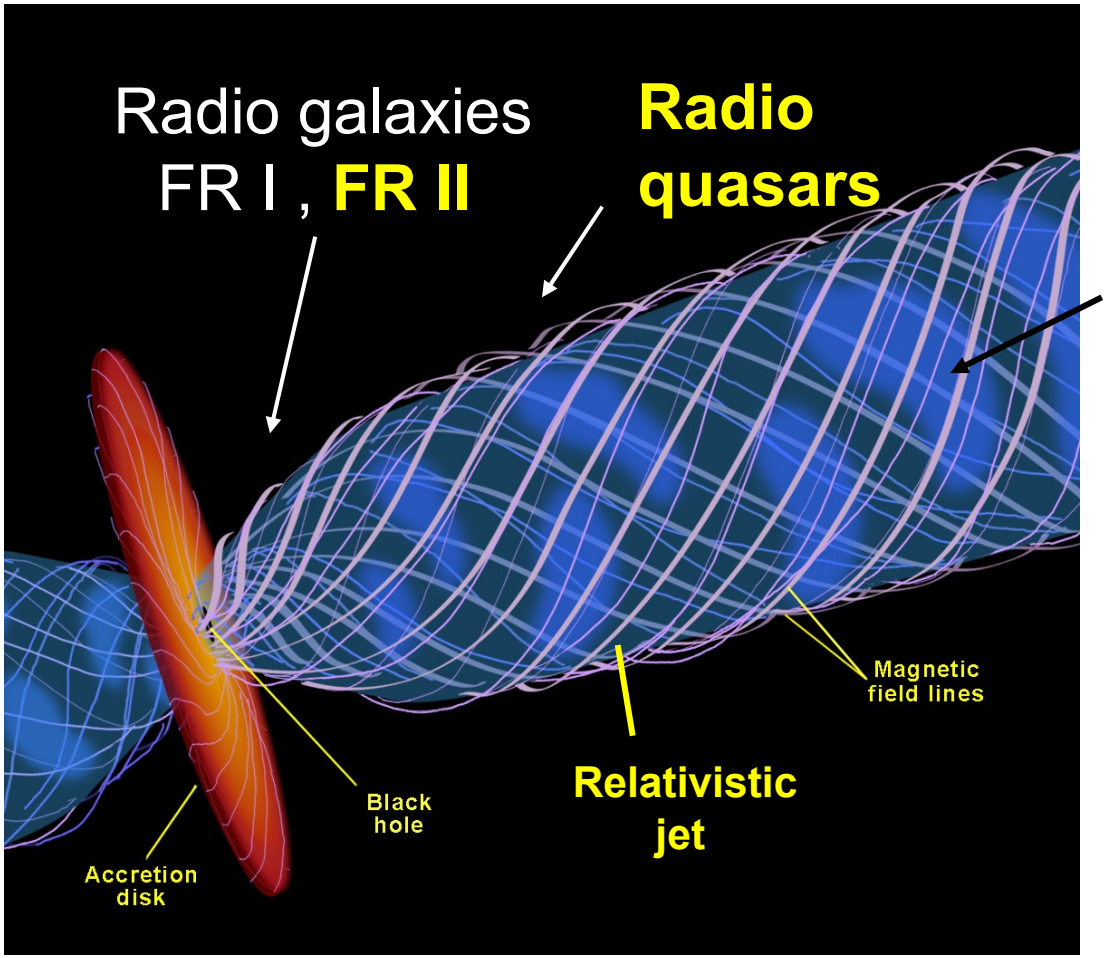
  Alternatives : curvature and synchrotron radiation of VHE protons.

→ Needs : **efficient particle acceleration processes**

**Fermi acceleration : 1st and 2nd order processes in shocks and turbulence, expected in powerful inflow-outflow of AGN. But details ?**

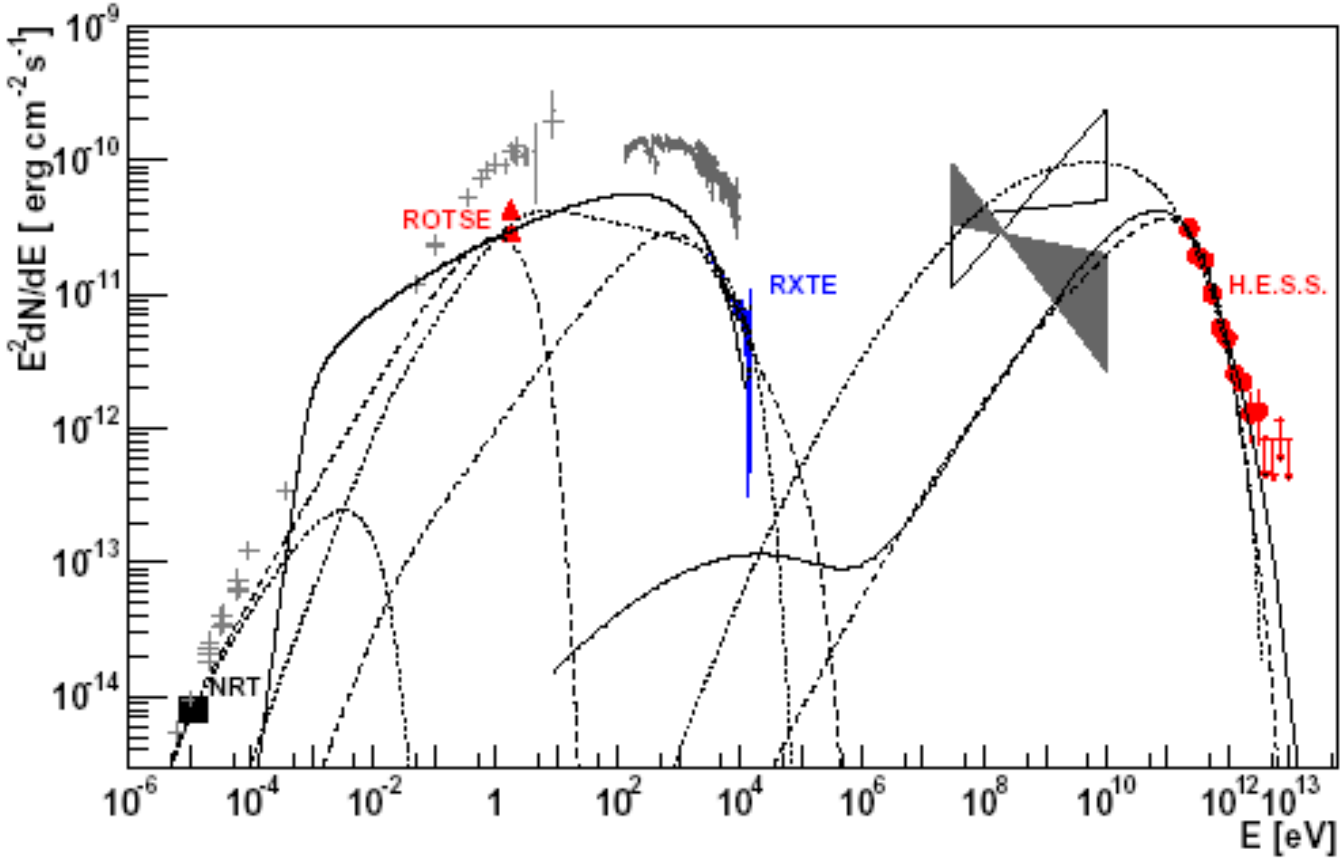
Alternatives : magnetic reconnection, direct electric forces, centrifugal force, others ?

**TeV emitting zone(s)** : in a jet or outflow with highly relativistic bulk motion



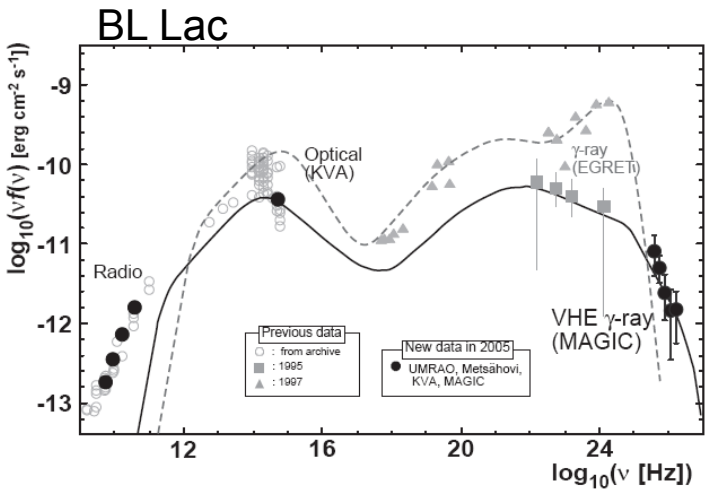

**Strong relativitic boosting** (~ factor $\delta^4$) favours detection of blazars

**Active Galactic Nuclei** :
**~ 20 blazars of the HBL type detected at TeV**

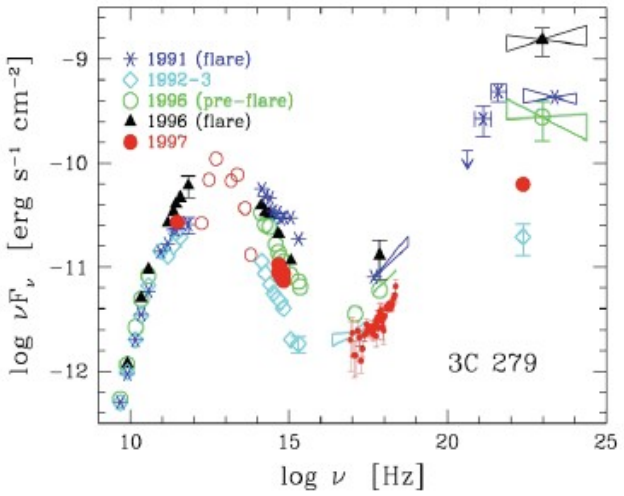


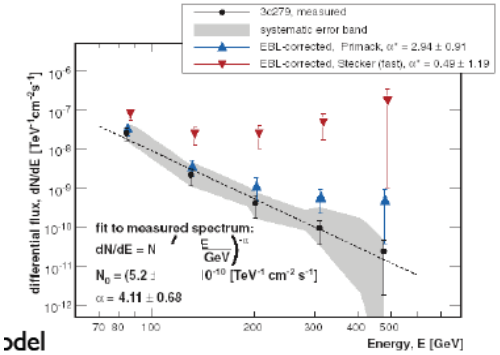

Various hadronic and leptonic models can often fit present available spectra of HBL *ex : SED of PKS2155-304 in quiescent state*

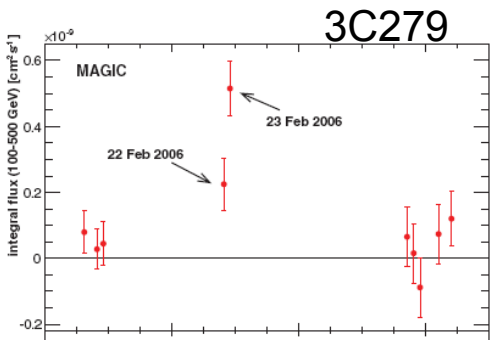
# Active Galactic Nuclei :
# ~ a few blazars of others types (LBL, IBL and FSRQ) detected at TeV



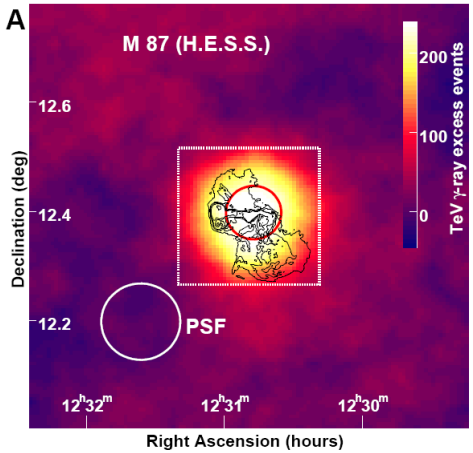

High variability and broad band spectra
→ Require coordinated HE and multi-lambda monitoring to constrain SED and evolution.



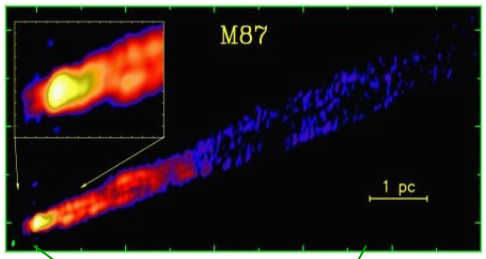



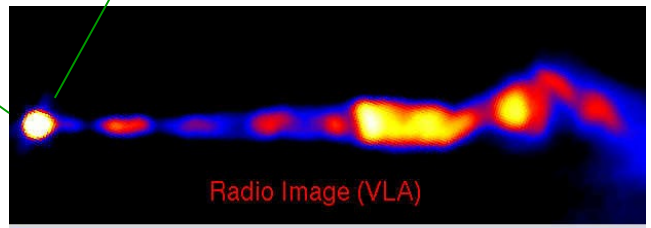
**Active Galactic Nuclei** :
one first **radiogalaxy** detected at TeV energies, M87.

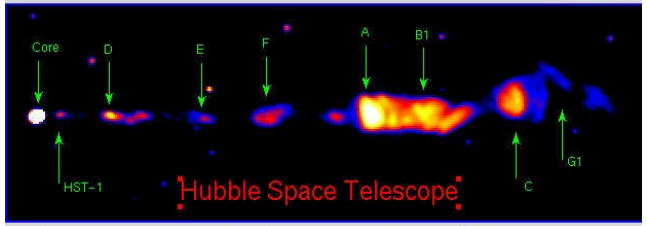



**TeV**

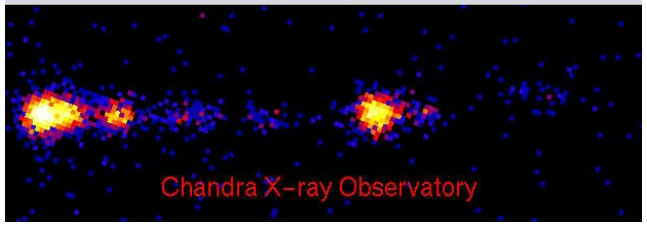



**radio**




**HST**



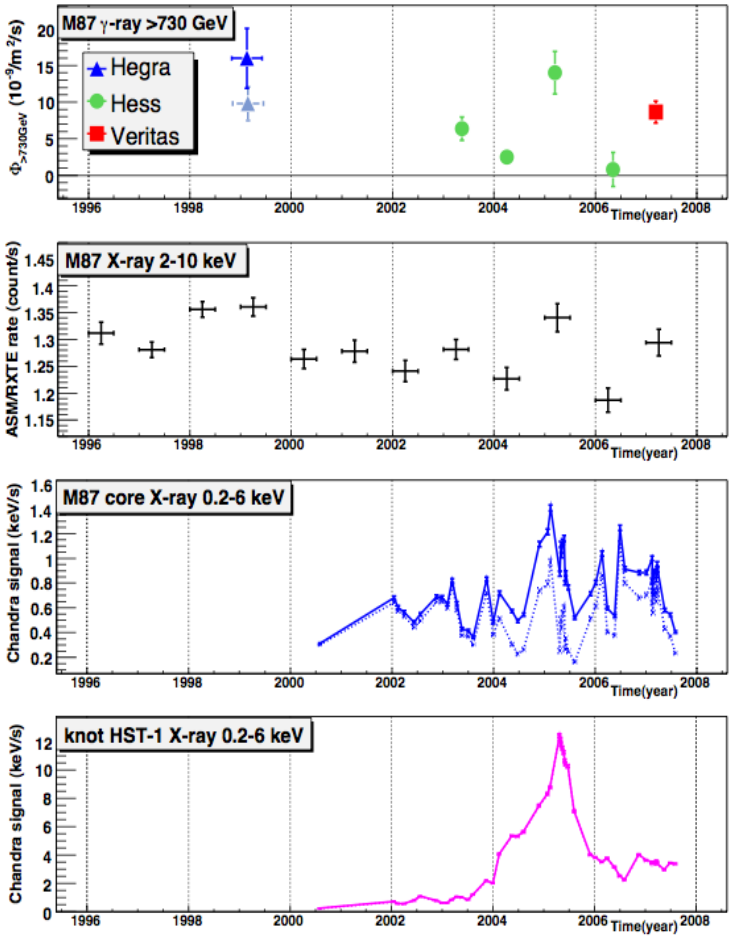

**X**

3 possible TeV emitting zones
- The peculiar knot HST-1
  at ~ 65 pc from the nucleus
- The inner VLBI jet
- The central core and the
  black hole environment

# M 87 : HST-1 versus core scenarios ?

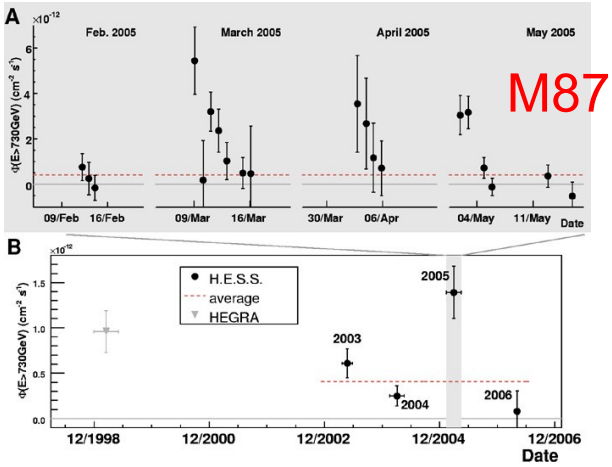
X-ray light curve of HST-1 obtained by Chandra in 2008 does not follow the TeV one *(VERITAS)*

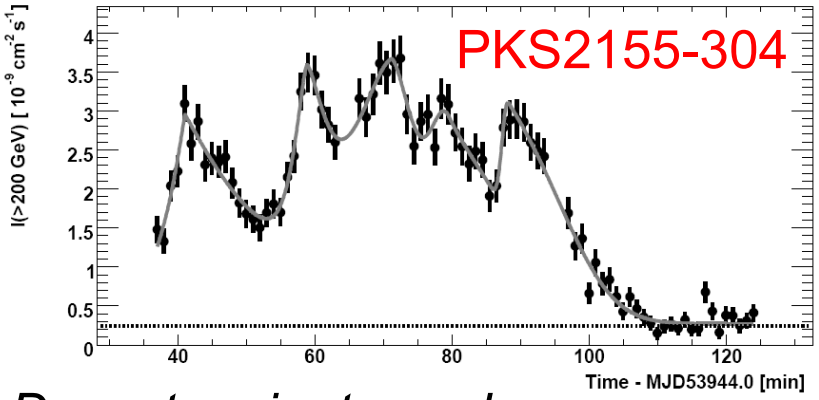
→ favours scenarios with TeV emission from inner jet or central core.



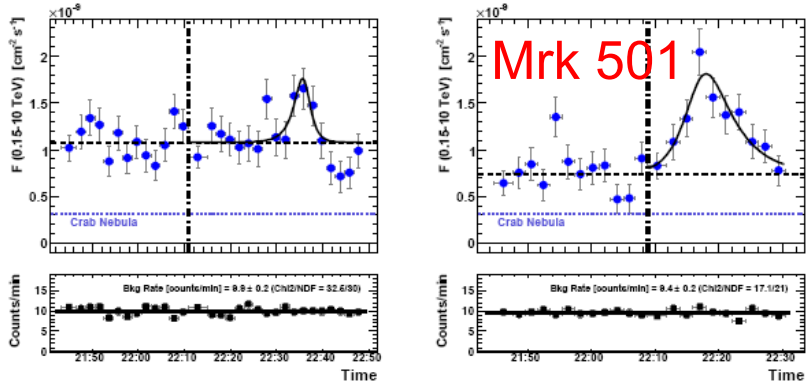

- Recent inner jet scenarios, *adapted from standard TeV models for HBL but at larger viewing angles*

- New core scenarios, with particle acceleration in turbulent accretion disks or in rotating magnetosphere (centrifugal force, or direct E in gaps)



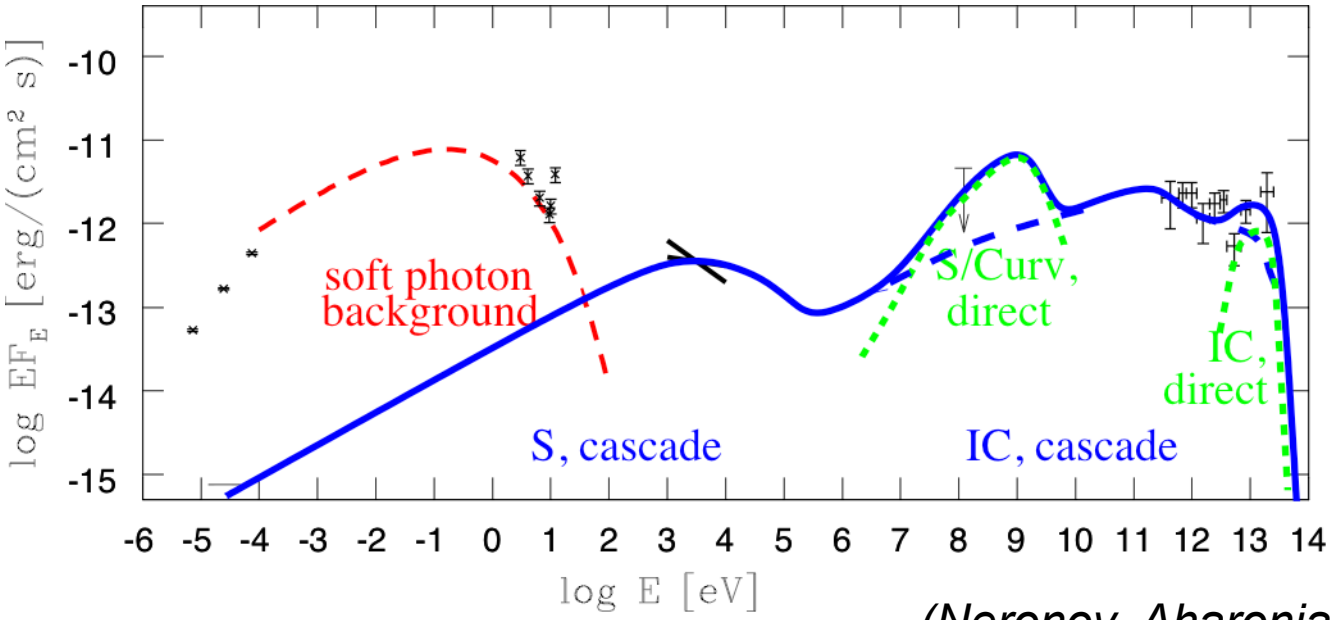

*Down to minute scale*




## Size constraints from variability

- TeV variability of M87, PKS2155-304 and Mrk501 also requires very small emitting zones, of the order of a few $r_g$ (even for high δ) under causality argument.
- Challenge to efficiently accelerate particles in such small zones (core around BH, or very inner jet).
- Study of close BH environment
- Fast and correlated variations of X and VHE emission would favor SSC scenarios.
- Possibly a mixture of hadronic and leptonic processes → requires further observationnal multi-lambda constraints.

# Generating SED of M 87 from compact core TeV emission




*(Neronov, Aharonian, 2007)*

Various core models developped for M87 suggest that radio-quiet or even « dormant » (but rotating) AGN could be VHE emittors.

*Here : example of fit of SED by synchrotron, curvature radiation and IC of ultrarelativistic $e^+e^-$ pairs on IR + electromagnetic cascades via pair production; particle acceleration in gaps. Others possibilities, as IC upscattering of ADAF disk photons by centrifugally accelerated particles* (*Rieger, Aharonian, 2008*).

# AGN science with CTA

- TeV observations *disentangle non-thermal effects from thermal ones* possibly present at others wavelengths → provide a simplified view of the physics at the highest energies.

- Explore *variability at the shortest time scales (down to second scale)*

  → jet physics; particle acceleration, constrain Fermi mechanisms (in turbulent jets and shocks) and look for peculiar spectra suggesting alternative accelerations (in disks, in BH magnetospheres ?) in extreme conditions; compare with recent PIC codes; identify radiation processes, leptonic versus hadronic scenarios; search for VHE emission from large scale radio jets and hot spots (long term emission); constrain jet power.

  → physics of supermassive Black Hole environnement; constraints on accretion physics

  (*Importance of multi-lambda and multi-messenger approaches to constrain the global picture; VLBA, X, opt. polar, VHE … cf Marscher et al, 2008; emergence of blobs versus VHE flares).*

***but how to really disentangle various paths for radiation ?***

**i.e. how to solve the inverse problem and deduce acceleration processes and source properties from *fluxes, light curves and spectra ?***

→ *are timing limits enough ? Secondary emission ? Multi-lambda correlation ? Neutrinos ?* ***Can we expect fully model-independent infos ?***

SED →

leptonic → SSC, EC →

hadronic → pp, pγ, p curvature, p synchrotron, leptonic (cascades) →

Fermi 1 shocks ?
Fermi 2 turbulence ?
other acceleration ?
which B, which V ?
which background radiation ?
which local gas ?

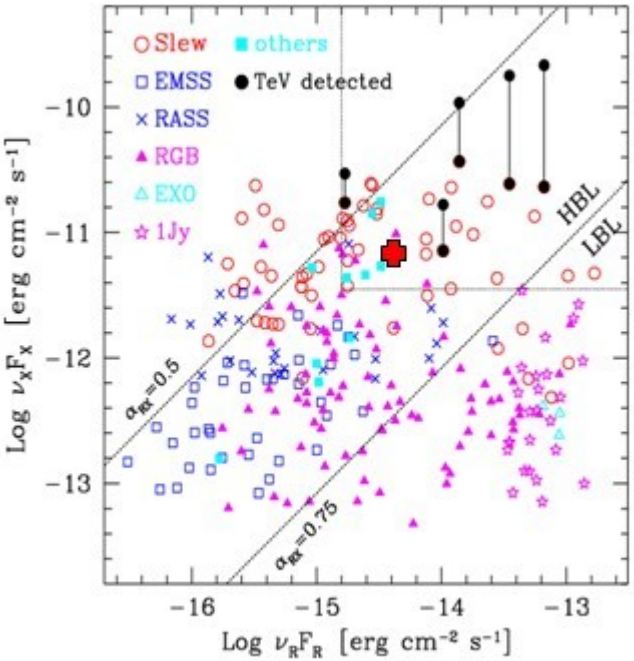
*others ?*

# AGN science with CTA

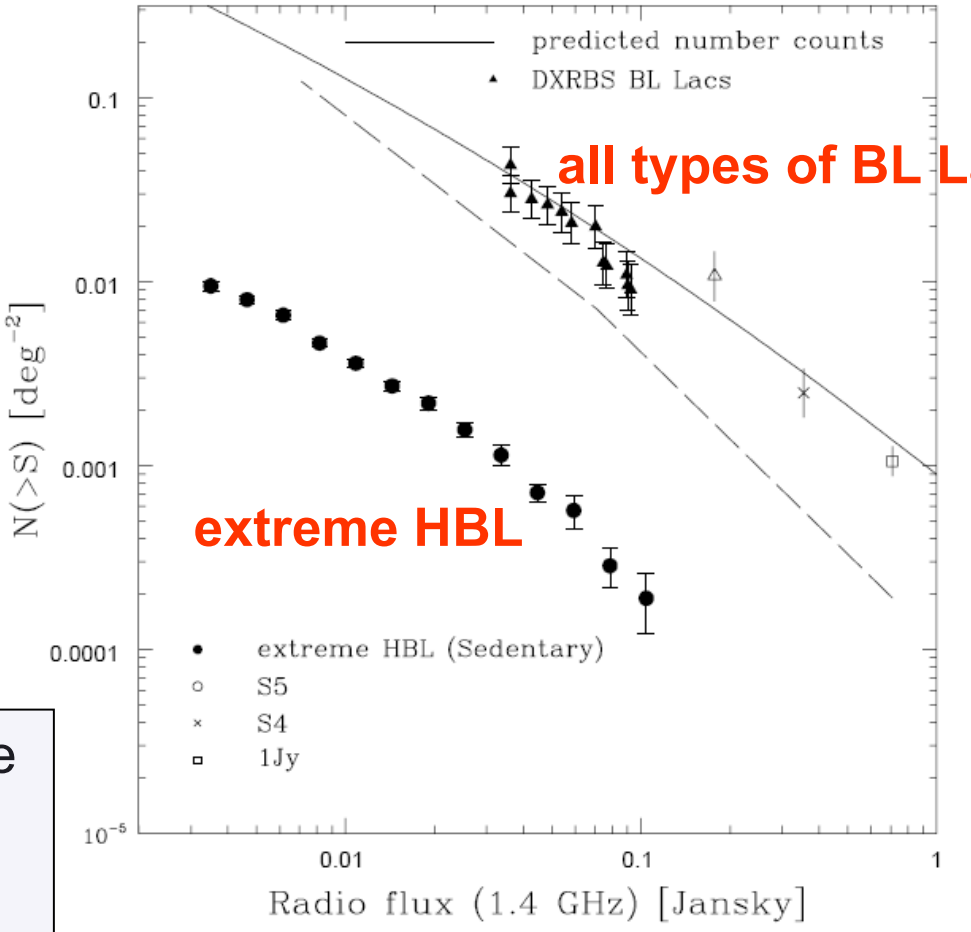
- Gather samples of different AGN types to allow *statistical studies* for classification, unification schemes, AGN evolution. Check the 'blazar sequence', probe the quiescent states … Identify weak FERMI sources and possibly non-photonic sources.
- Look for VHE emission from « dormant » BH or « dead » quasars (could provide evidences for missing SMBH) → Studies of *AGN and SMBH evolution*, AGN feedback and co-evolution with host-galaxies.

# Towards statistical analysis of AGN samples at VHE

→ ~ 200 HBL, 30 IBL/LBL ??



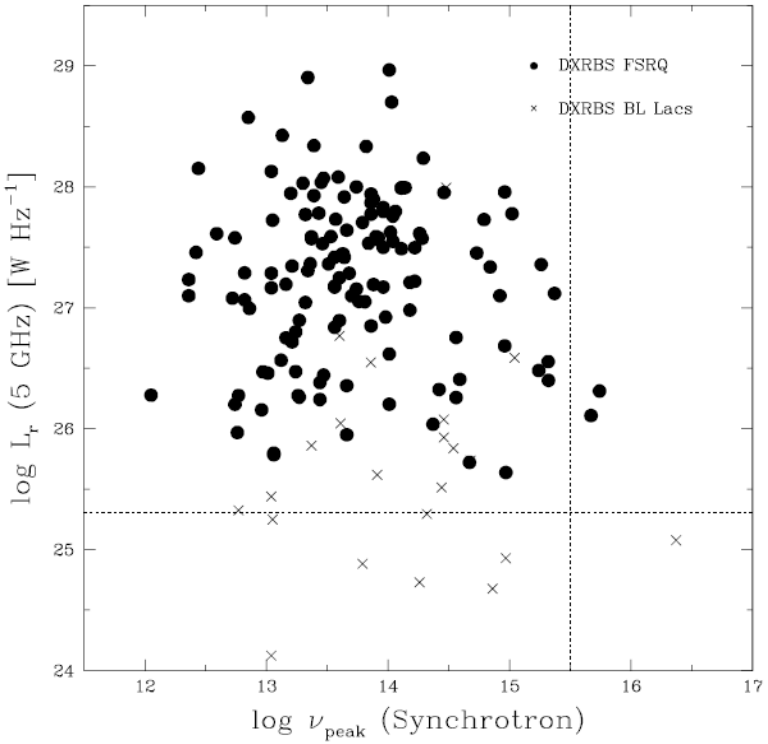

*(Costamente et al)*



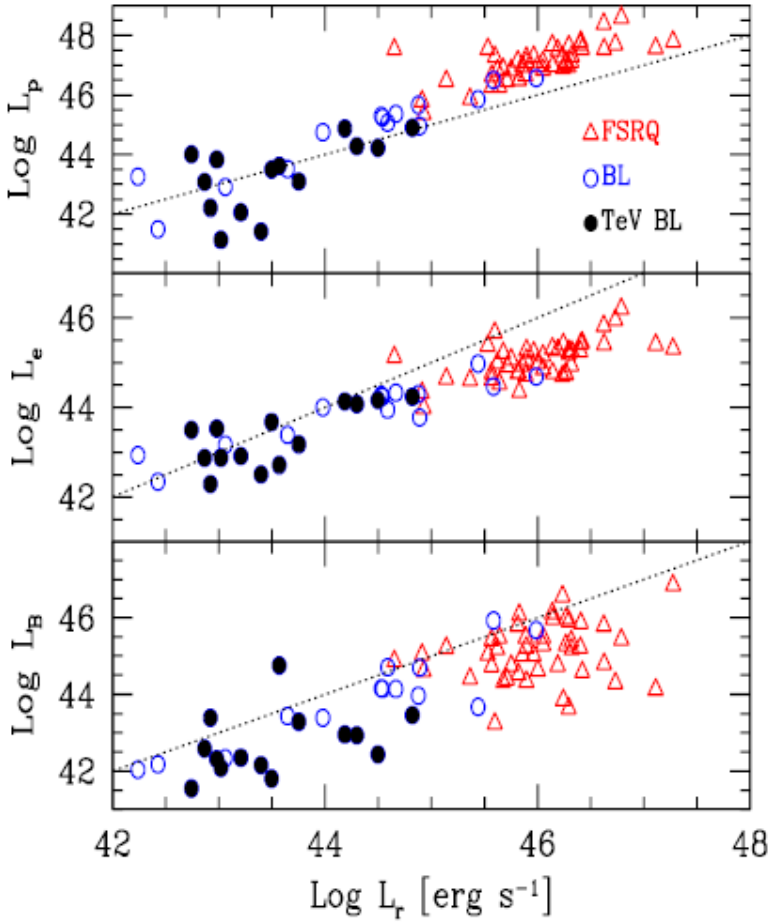

→ factor 10 within HBL sample

Also x 10 for other types of BL Lac if TeV emittors (cf : TeV detection of BL Lac and W Com)

*Warning : influence of high variability …*




FSRQ have synchrotron bump peak at frequencies comparable to global BL Lac samples *(Padovani, 2006).*

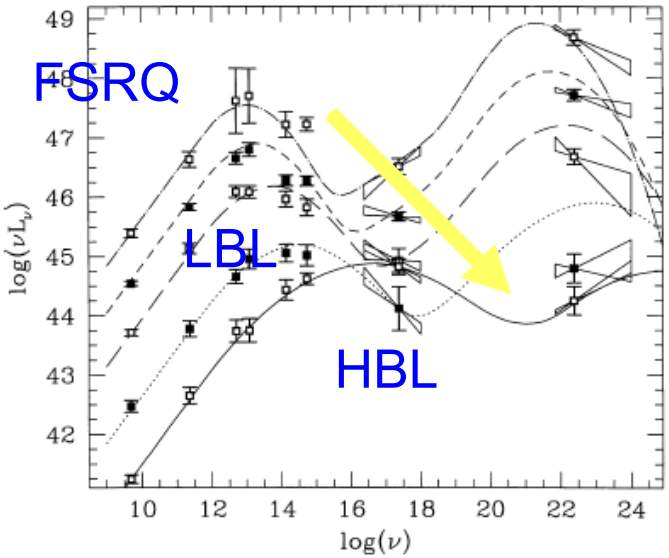



Smooth change of jet physical parameters from BL Lac to FSRQ *(Celotti, Ghisellini, 2008)*

**→FSRQ are potential TeV sources (cf : 3C279) which may be detected at low enough redshifts**

# What about the 'blazar sequence' ?

## → Should be fixed by CTA data




Average SED for a sample of 126 blazars binned according to $L_{radio}$
(*Fossati et al, 1998*)

Suggested a continuous sequence from the most powerful FSRQ, through LBL, to the weaker HBL although the most powerful TeV emittors.

**However** : new data and survey analyses **questionned its validity**.
New class of FSRQ : HFSRQ have been found
(*Padovani et al, 2003; Caccianiga, Marcha, 2004; Padovani, 2006).*
Still growing evidences that not all objects fit the trend (*Nieppola et al, 2008*)

→ **A revisited sequence** :
Modelling all SED as a function of $M_{BH}$ and accretion rate
*(Ghisellini, Tavecchio, 2008)*

# Outcomes from M87 TeV core scenarios

If their true existence is confirmed, TeV core scenarios :

- may shed new light on accretion regime, jet formation, and various particle acceleration processes in BH surroundings
- show that 'dormant' but rotating SMBH can accelerate particles (*cf Boldt, Ghosh, 1999; Boldt, Loewenstein, 2000; Levinson, 2000*)

→ important issues for CR physics, UHECR and recent AUGER results

→ Links to AGN and Galactic Nuclei evolution

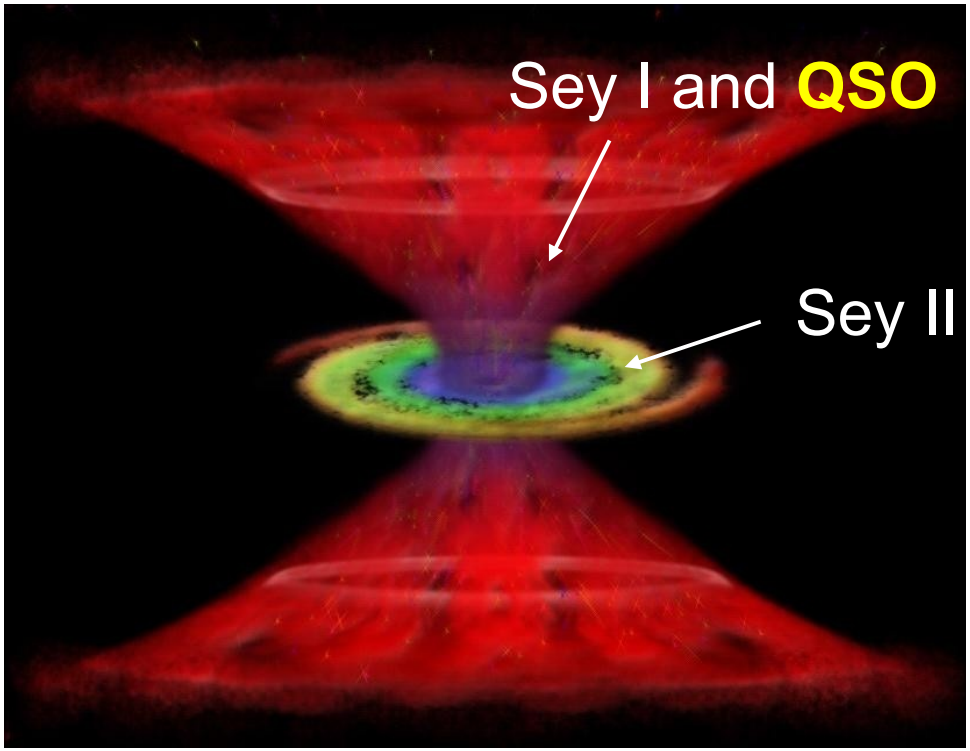
→ Links to feedback effects of GN to host galaxy physics

→ May concern radio-quiet sources

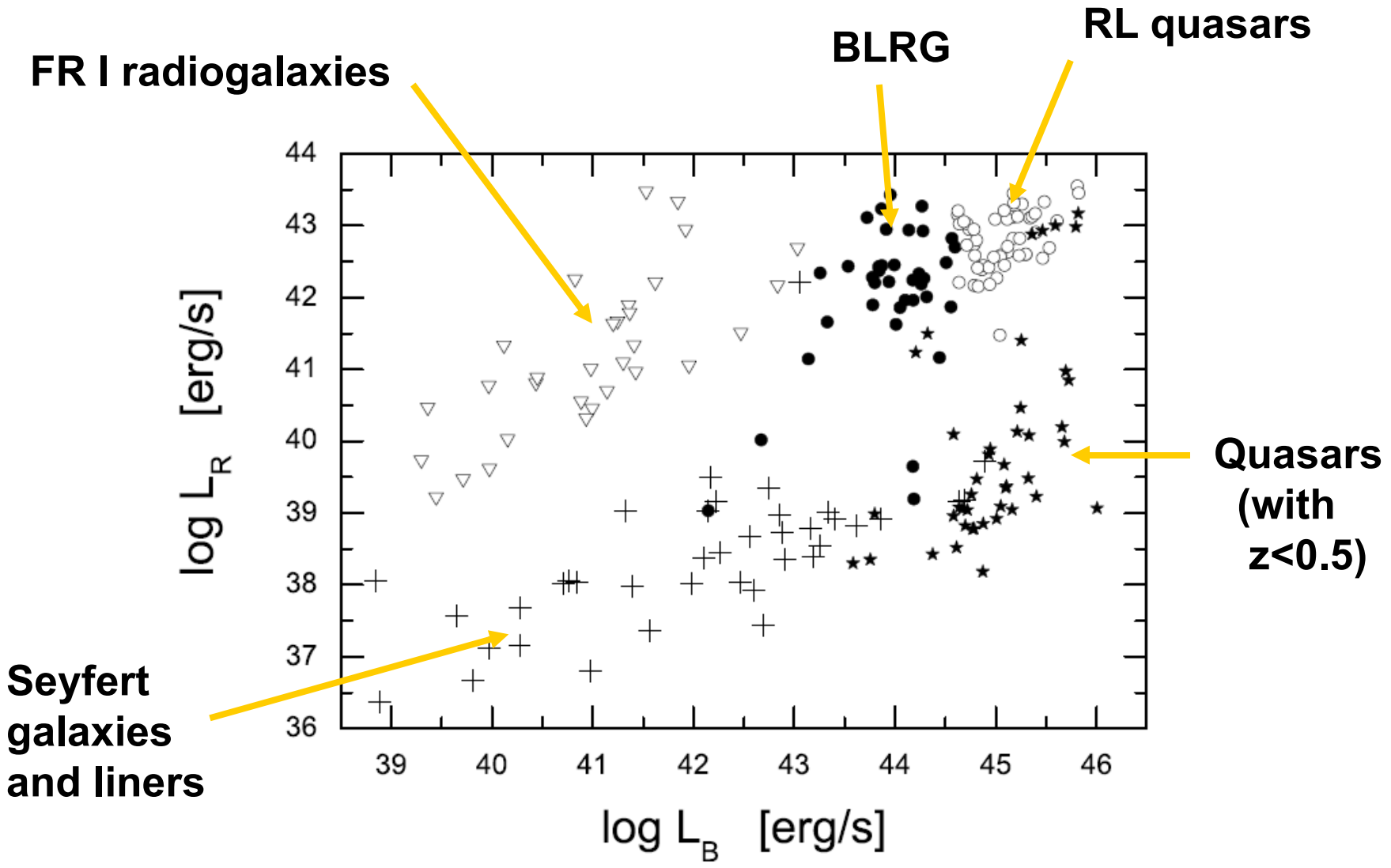
→ May reveal 'dormant' BH.

→

## Radio-quiet AGN appear as potential TeV emittors




Radio-quiet objects, namely ~ 90% of ‘average’ AGN !




*(Sikora et al, 2007)*

# BH in normal galaxies

- $M_{BH} \sim 0.002\ M_{bulb}$ (*Ferrarese, Merritt; Gebhard et al; Tremaine et al*)
  → a common formation/evolution of SMBH and host galaxies

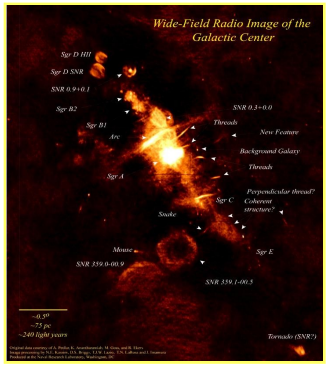
- A large % of galaxies habour a SMBH

- Dead quasars and passive SMBH in 'normal' galactic nuclei (Seyfert nuclei are not numerous enough to host all quasar remnants)

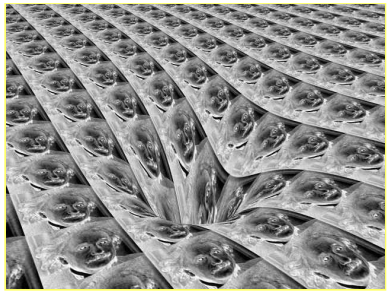
→ are dormant BH emittors at TeV energies ?
A question for CTA …

# Now, CTA science with AGN …

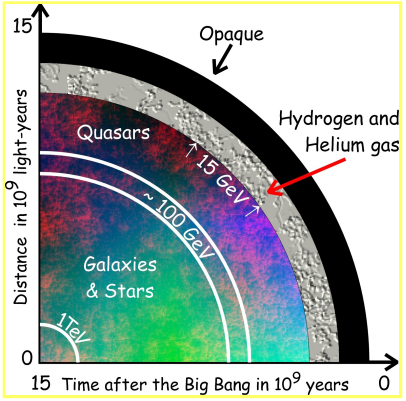
Cosmic Rays




Dark Matter



Space-time and relativity




Cosmology

**High discovery potential** in fundamental physics

*- Hadronic scenarios → non-photonic sources; sources of extragalactic CR and neutrinos. Identification of non-photonic sources possibly detected by AUGER, KM3Net, LISA …*

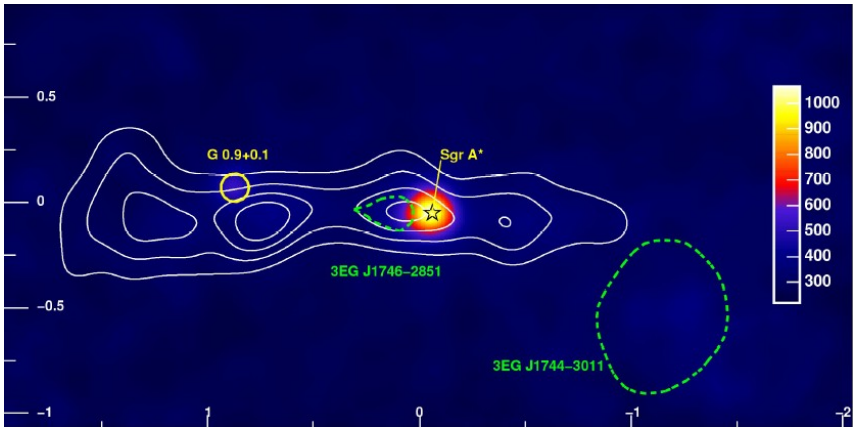
*- Samples of AGN at different redshifts → analyse EBL and formation of cosmic structures 'stars and galaxies'; check validity of Lorentz invariance with flaring AGN*

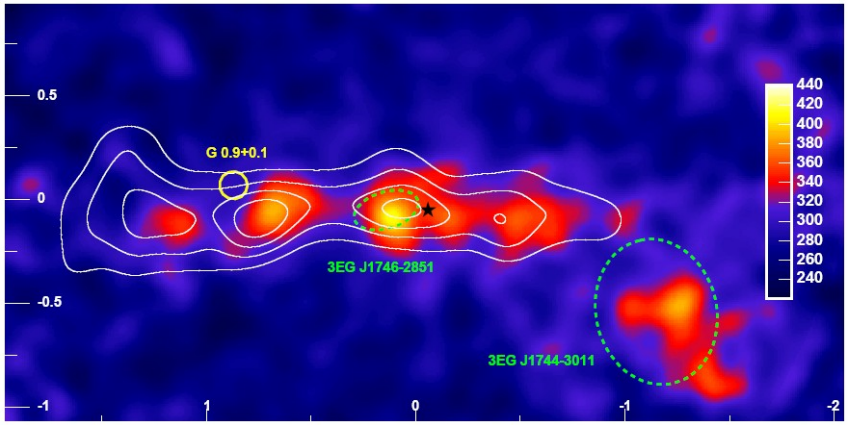
*- Search for pair haloes around AGN (→ intergalactic B)*

*- BH physics, evaporation of primordial BH ? small components of DM ?*

*- Others ?*

# Complements : The galactic center




2 bright TeV sources :
. J1745-290 (Sgr A* ?)
. G0.9+0.1
200 pc, resolution < 6'

Diffuse emission, after subtracting the 2 point sources : VHE fluxes + white contours of CS, a molecular tracer
→ clear correlation VHE-CS
*(Nature, 2006)*

Observed TeV flux requires an energy density of cosmic rays > 3 times the one in the solar environment, and a harder spectrum
→ recent particle acceleration event, < 10 000 years, near the Galactic Center (SNs or active BH).

Several Quantum Gravity models have predicted energy dependence of the speed of light. General parametrization:

$$c' = c\left(1 \pm \xi\frac{E}{E_{\mathrm{P}}} \pm \zeta^2\frac{E^2}{E_{\mathrm{P}}^2}\right) \quad \text{, with } E_{\mathrm{P}} = 1.22 \times 10^{19}\ \mathrm{GeV}$$

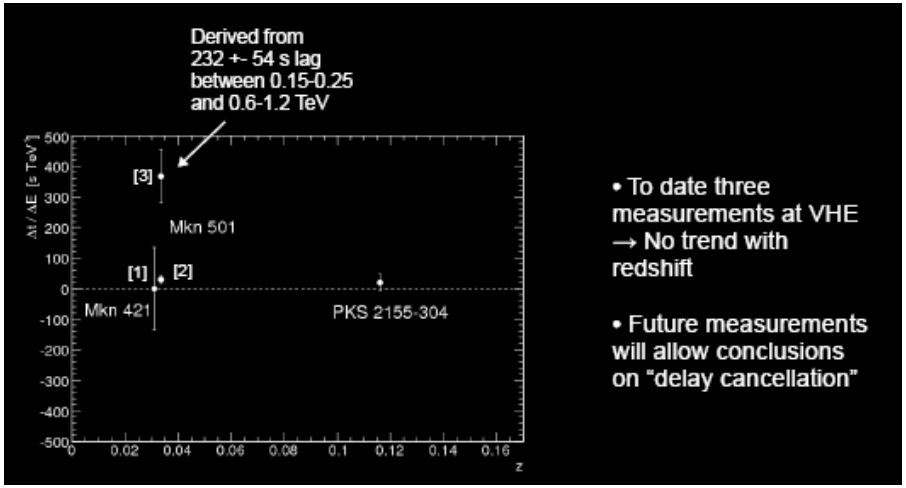

- VHE signal from PKS 2155-304 shows no energy dispersion. This yields the *most constraining limits* on speed of light modifications to date:

$\xi < 17.6$ *(Linear)*

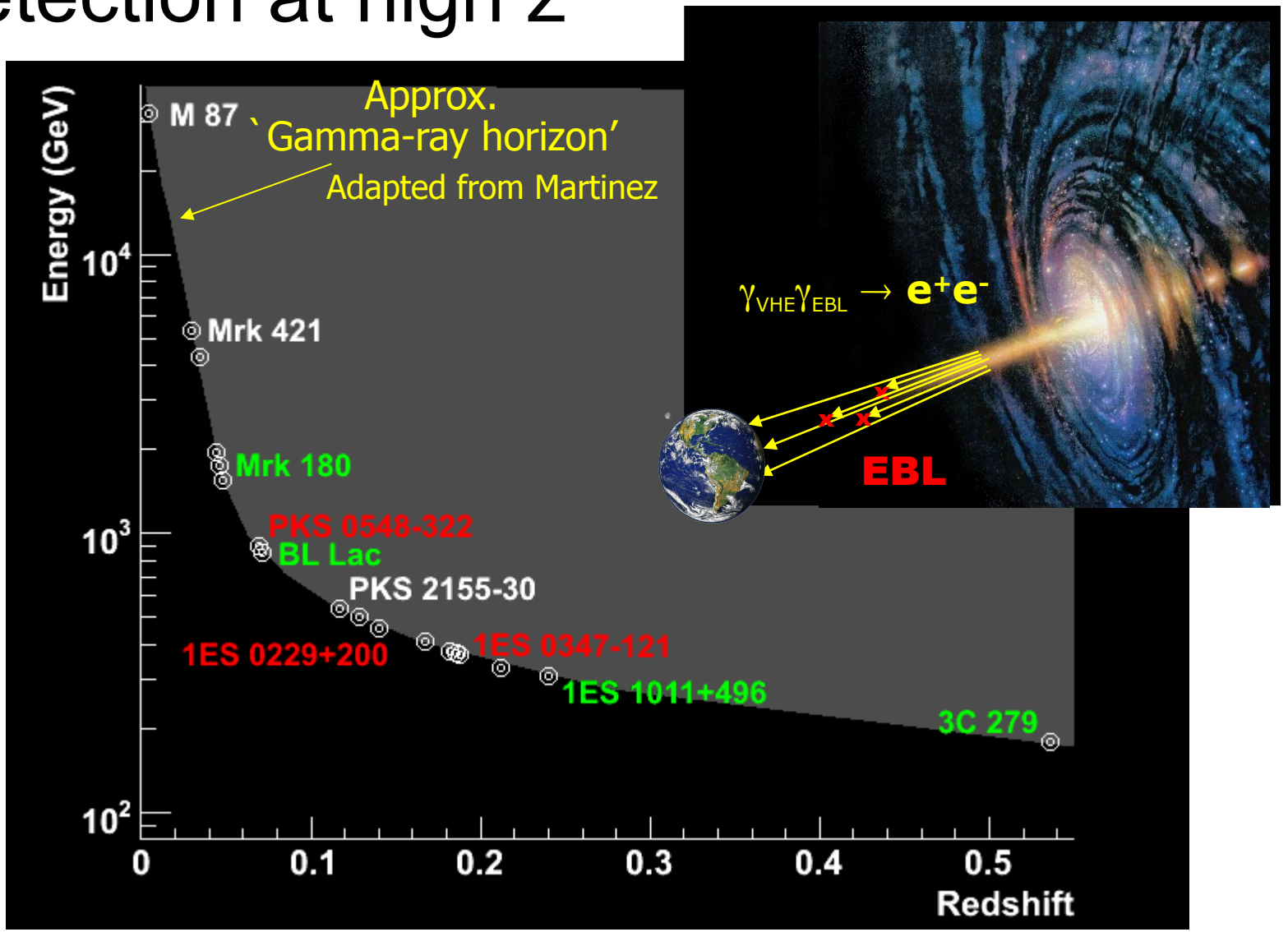
$\zeta < 1.10 \times 10^{10}$ *(Quadratic)*

## *Search for Lorentz invariance violation*

*from Buhler and Jacholkowska, HESS, 2008)*



# EBL absorption limits detection at high z




100 GeV threshold : z < 1

# Constraints on EBL from sample of VHE spectra