The VHE extra-galactic sky & UHECR

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Caveat Lector!

The following talk will be biased!

- I'll focus on blazars (no starburst galaxies...)
- I'll focus on TeV blazars
- I'll focus (slightly) on TeV Veritas blazars

The VHE extra-galactic sky

Blazar SED modeling

- Leptons models
- Hadronic models

Observations

Conclusions

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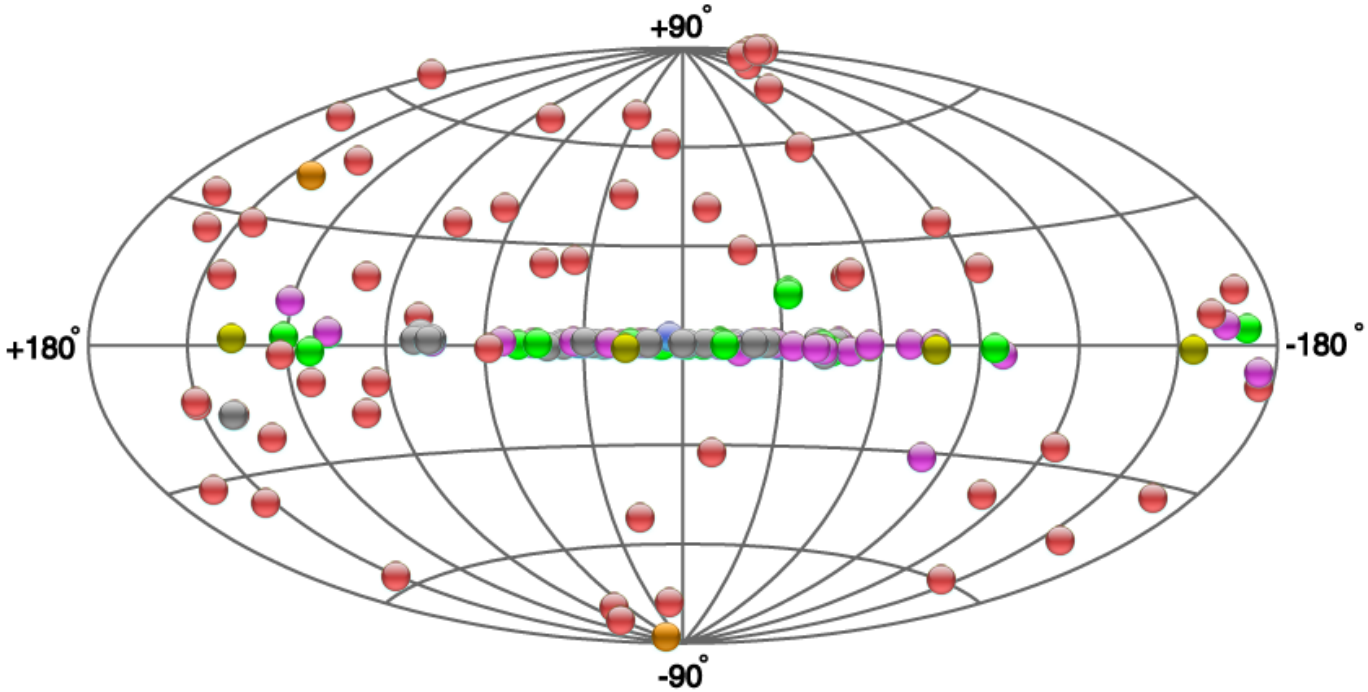
The VHE extra-galactic sky

Today 145 very-high-energy (VHE; E> 100 GeV) sources
and among them 58 are extragalactic



http://tevcat.uchicago.edu

The VHE extra-galactic sky

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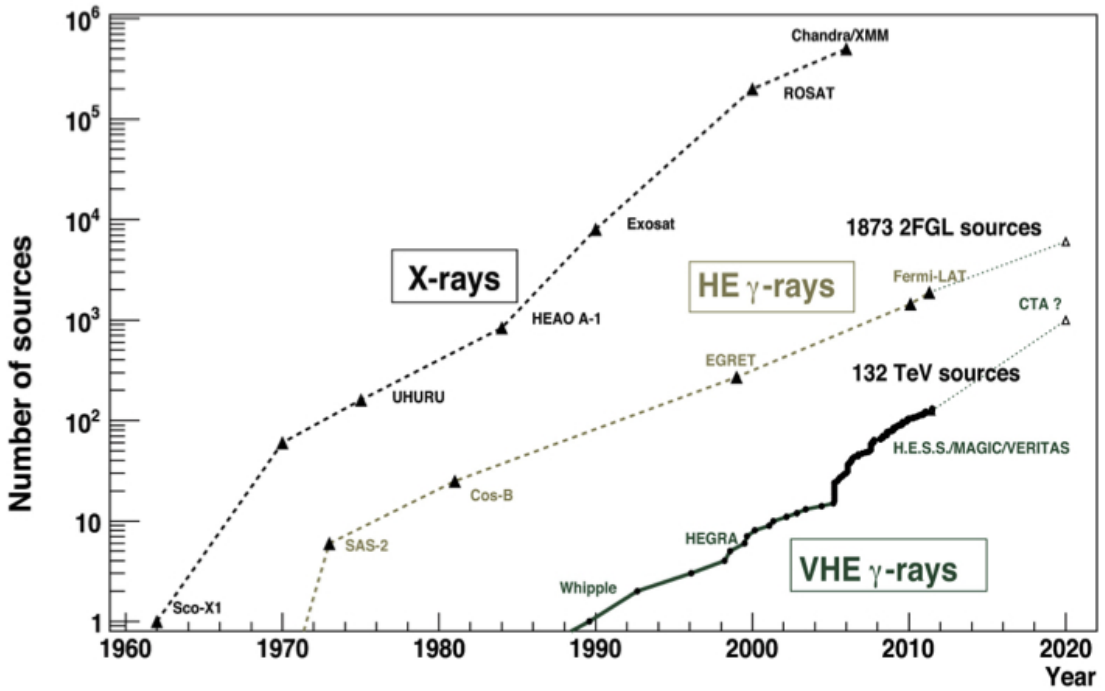


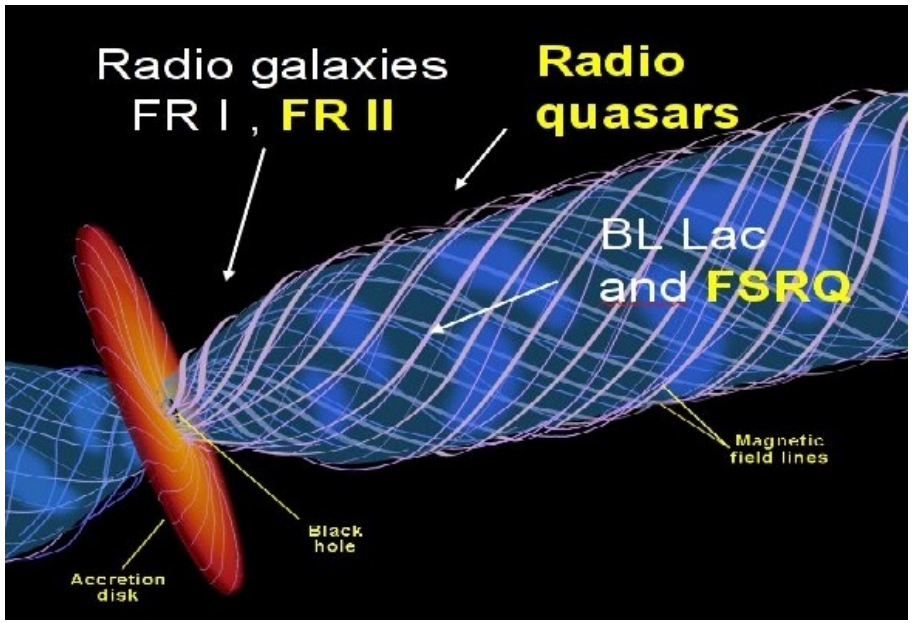
from Funk, S. 2012,arXiv:1204.4529

The VHE extra-galactic sky

VHE extra-galactic sources: AGN + 2 starburst galaxies

The VHE extra-galactic sky

VHE extra-galactic sources: AGN + 2 starburst galaxies
VHE AGN: blazars + 3 radio-galaxies



EBL absorption $\rightarrow z \leq 0.6$

Blazars

Blazar characteristics :

- high polarization
- extreme variability

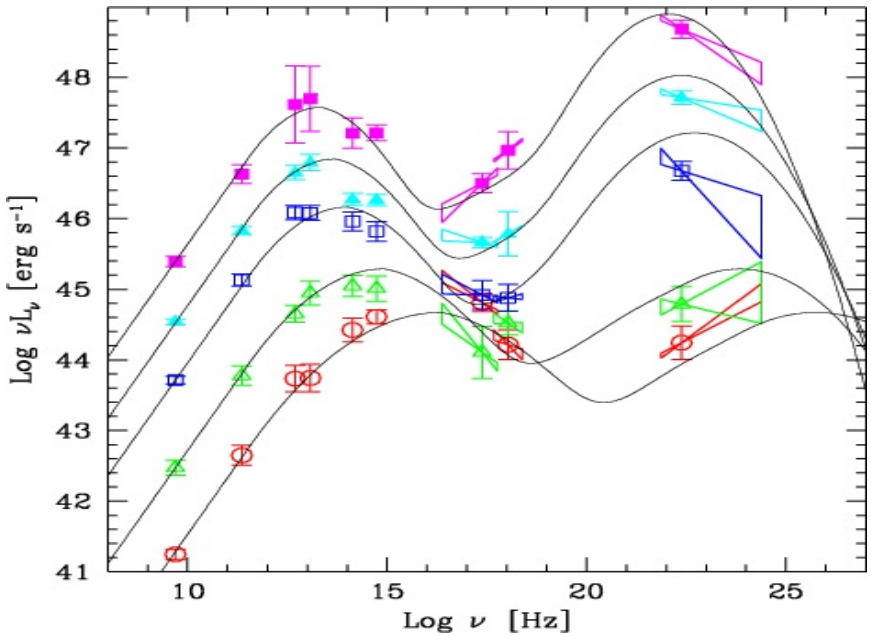
Blazar classification according to the strength of disc emission / broad emission lines with respect to the continuum

- detection of emission lines in optical/UV spectrum (FSRQs)
- spectrum dominated by non-thermal continuum (BL Lacs)

Blazars

Spectral Energy Distribution characterized by a double bump
BL Lac object distinguished according to the energy of the first peak :

- peak in optical: Low-frequency peaked (LBLs)
- peak in UV/X-rays : High-frequency peaked (HBLs)



Fossati et al., 1998

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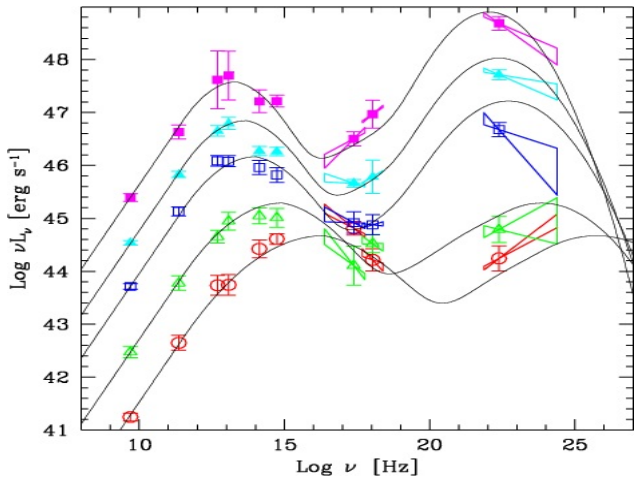
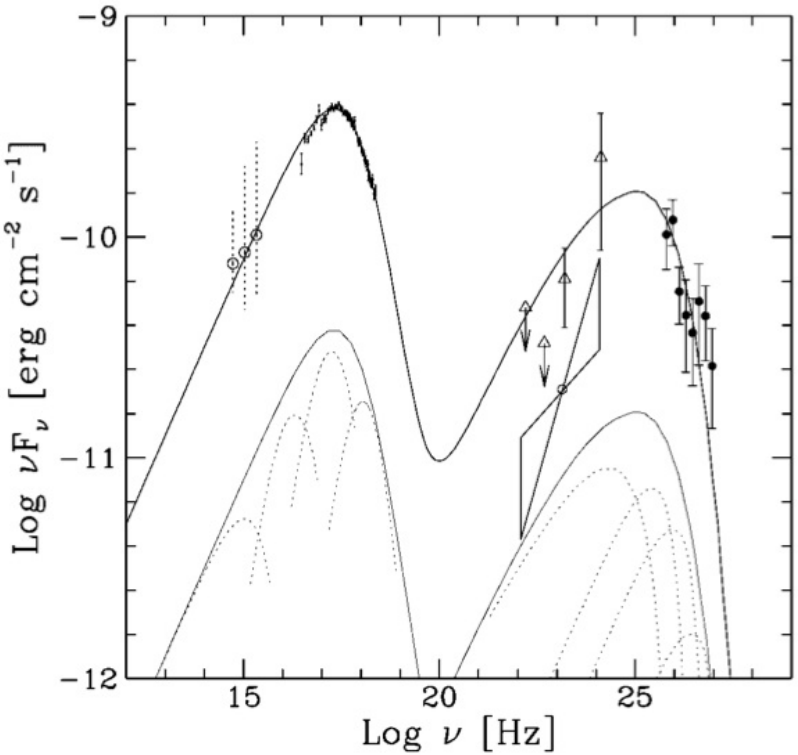
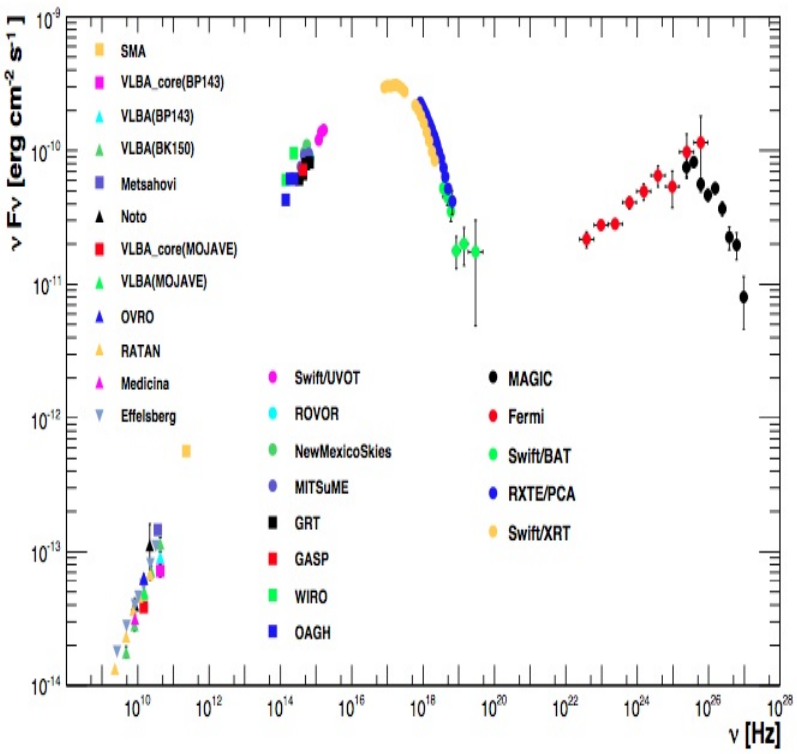


The VHE sky is (by far) dominated by HBL

What are we learning from the γ-ray sky?

Mrk 421: past and current generation of γ-ray instruments





Maraschi et al., 1999 - Abdo et al., 2012

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Leptonic Models

- Low-energy component of the SED
  - Synchrotron emission by electrons/positrons in the jet
- High-energy component of the SED
  - Inverse Compton scattering off the synchrotron photons (SSC)
  - Inverse Compton scattering off external photons (EIC)

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SED fitting suggests that SSC works well for HBL,
EIC required for LBL/FSRQ

Hadronic models

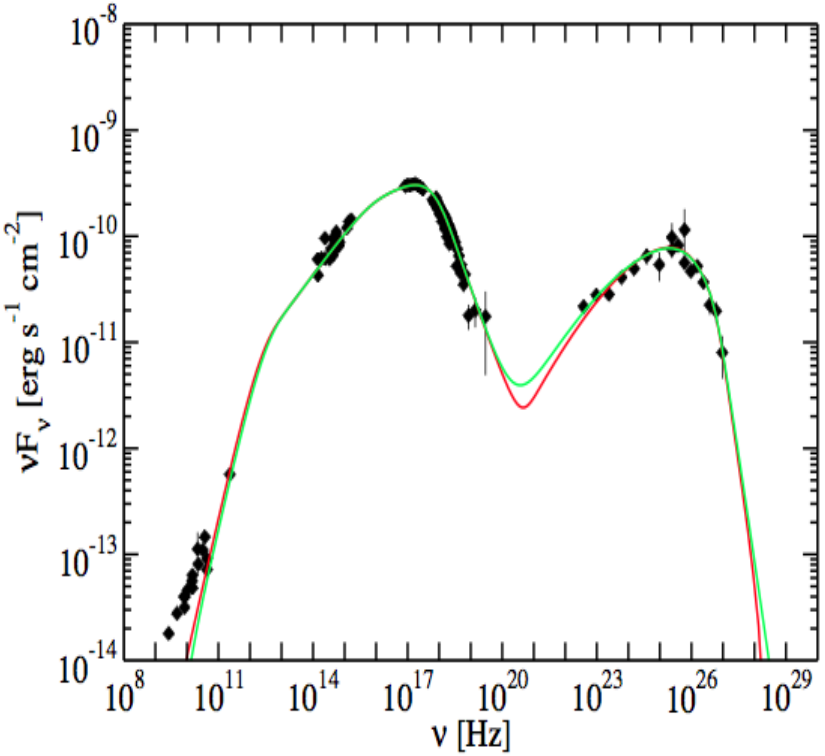
In hadronic models the high-energy bump is ascribed to emission associated with *protons* in the emitting region

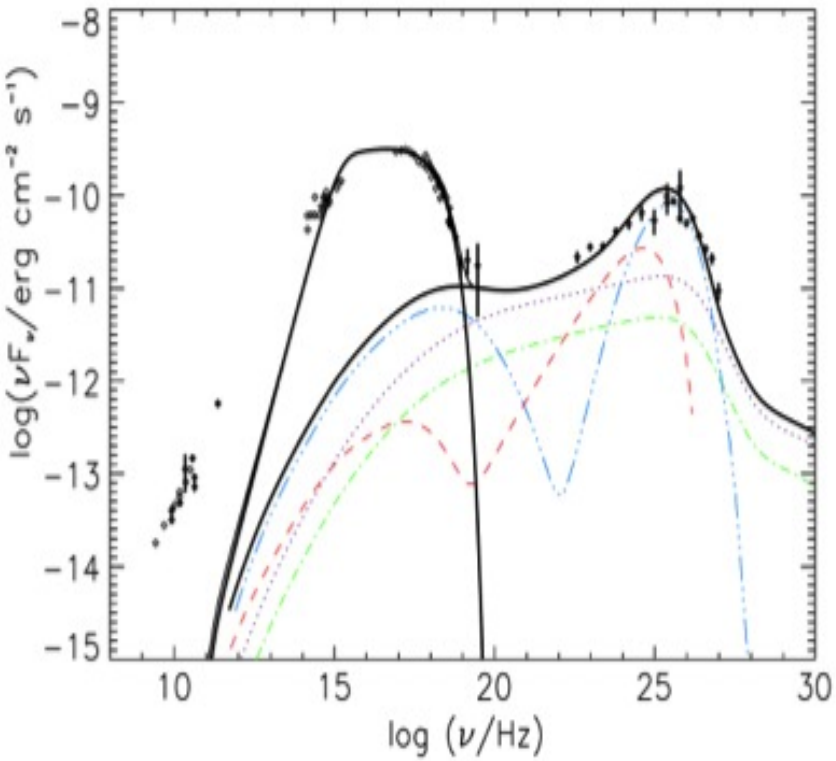
- synchrotron emission from protons
- secondary particles coming from p-γ and p-p interactions

Interesting also for the possible links with the extra-galactic cosmic rays and neutrino astronomy

Modelling Mrk 421 Emission

Example of leptonic/hadronic modeling of Mrk 421 (Abdo et al.2011)

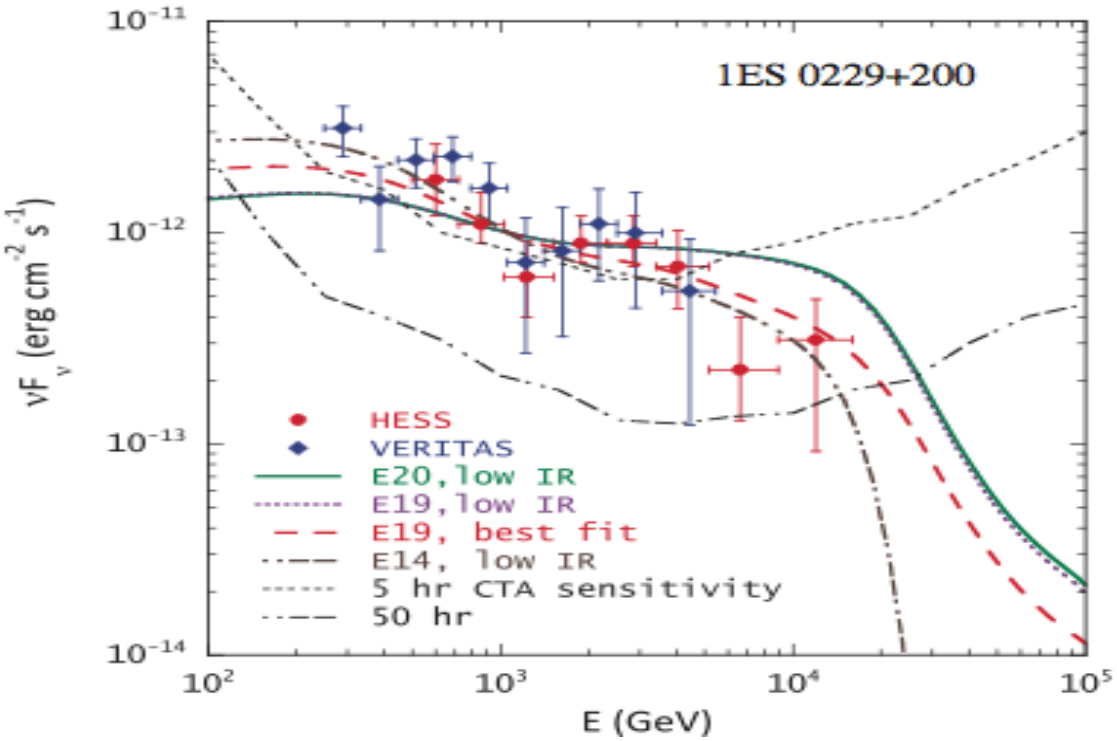




Hadronic cascades

Valid (and appealing) alternative:

- cosmic rays escaping the blazar produce γ-ray in the path (see previous talks)



(Murase, K et al., 2012)

Hadronic signatures

What observables should we look for?

- hardening of VHE spectra
- detection of high-z sources
- variability study (see previous talks)

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VHE observational constraints

Can the current generation of IACT test hadronic scenarios?

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Focus on some recent interesting results

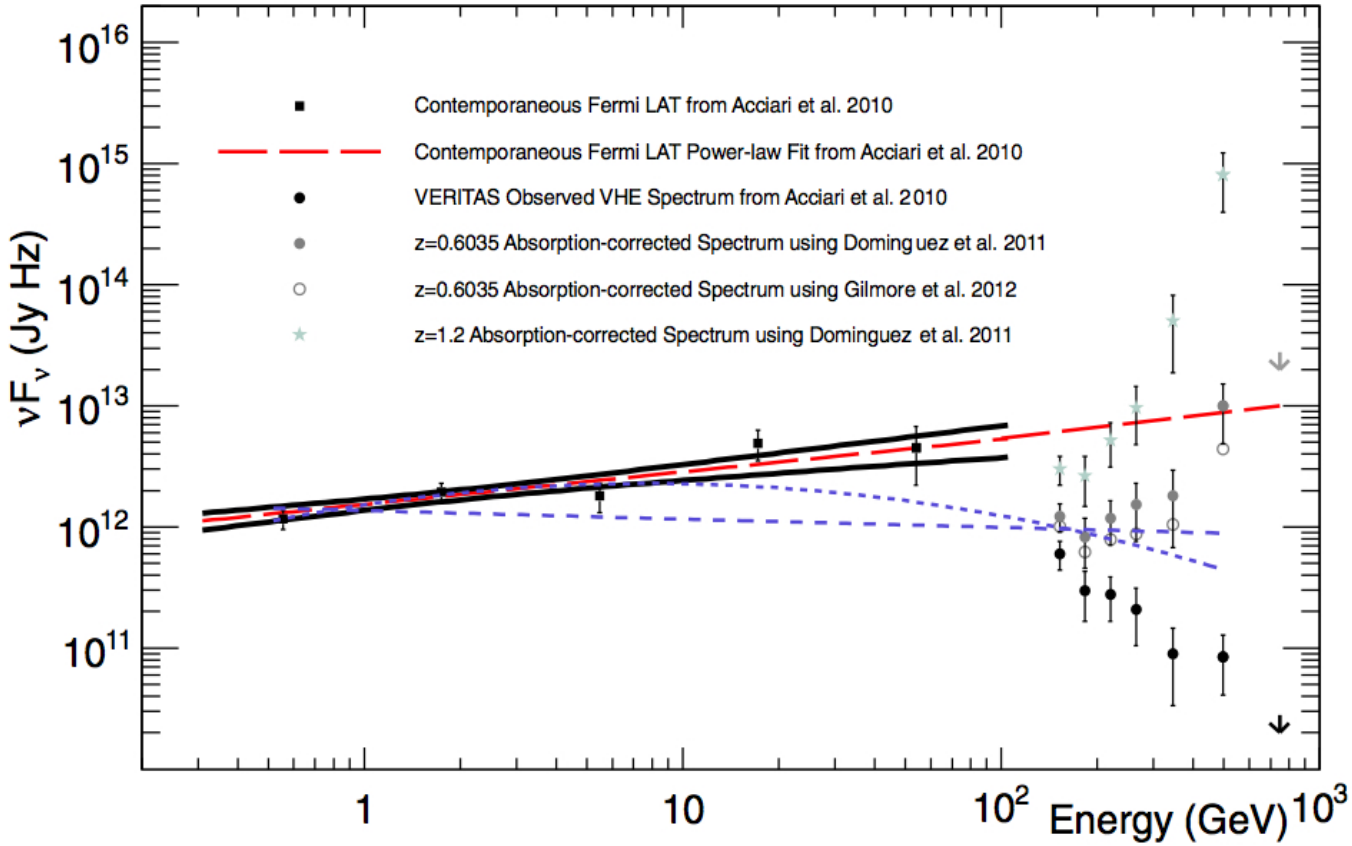
PKS 1424+240

HBL/IBL detected at VHE by VERITAS in 2010
Upper limit on the redshift based on simultaneous observations with Fermi-LAT: $z \leq 0.66$

New HST/COS observations: $z \geq 0.6035$
(Furniss, A. 2013)
$\rightarrow$ most distant BL Lac so far!

Deep campaign on PKS 1424+240 this season:
more than 70 hours of new data coming

PKS 1424+240



(Furniss, A. et al., 2013)

What's the problem?

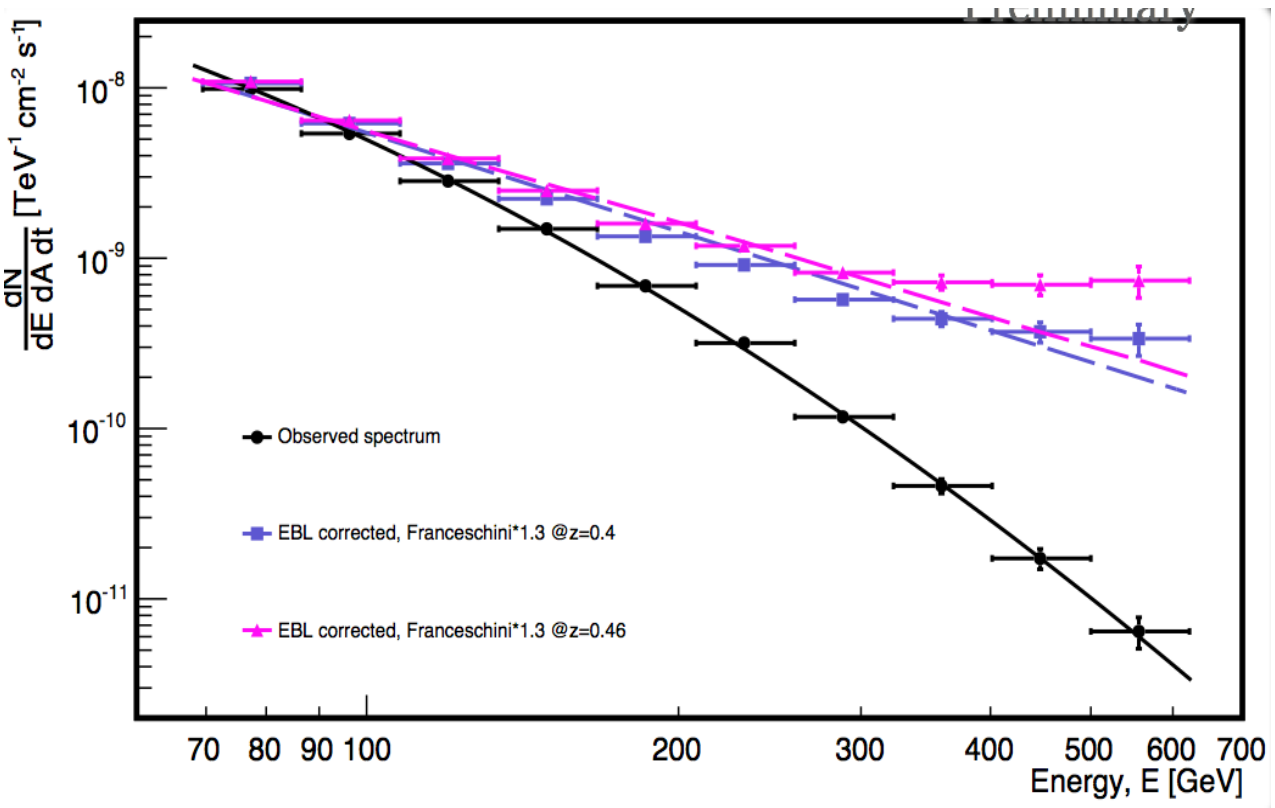
PG 1553+113

HBL detected at VHE by HESS in 2006

- Redshift uncertain, but the latest estimates (Danforth 2010) put it at 0.43-0.58
- Seen by Fermi, with stable flux over 4 years
- Detection of a flare by MAGIC in 2012
  - log-parabola preferred over simple PL

PG 1553+113

MAGIC spectrum, as shown at ICRC'13



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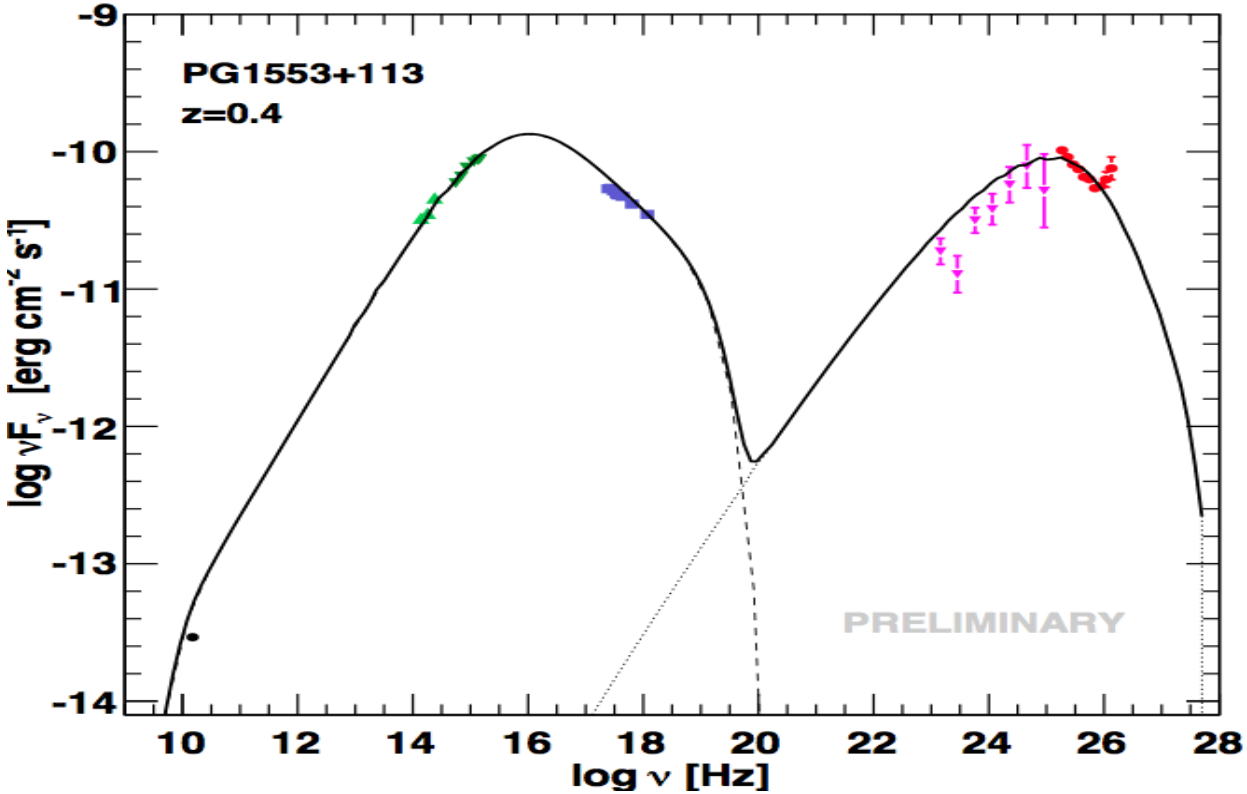


1ES 0229+200

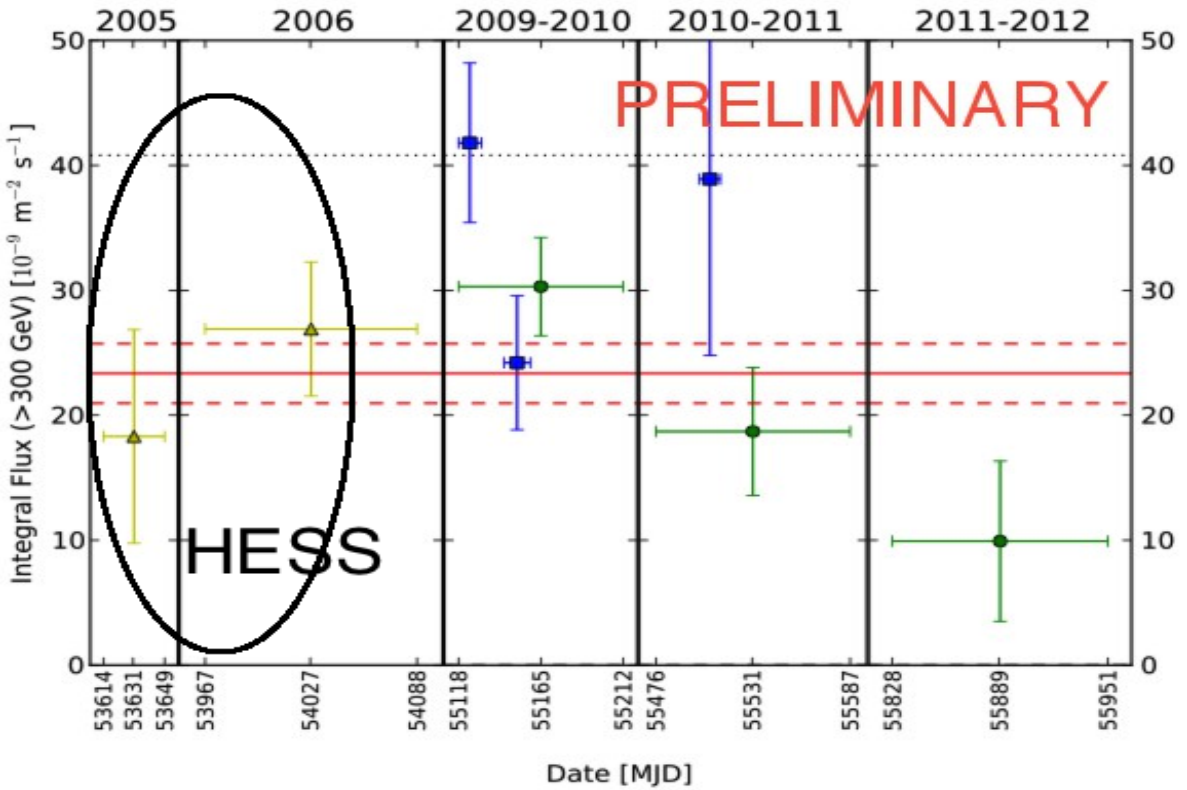
Detected at VHE by H.E.S.S. in 2007
At z=0.1396, with a spectral index $\Gamma \simeq 2.5$
$\rightarrow$ very hard intrinsic emission; high-energy peak $\gtrsim$ 10TeV

VERITAS observations from 2009 to 2012 (ICRC 2013):

- hard TeV spectrum confirmed ($\Gamma = 2.59 \pm 0.12$)
- hint of year-scale variability?

1ES 0229+200

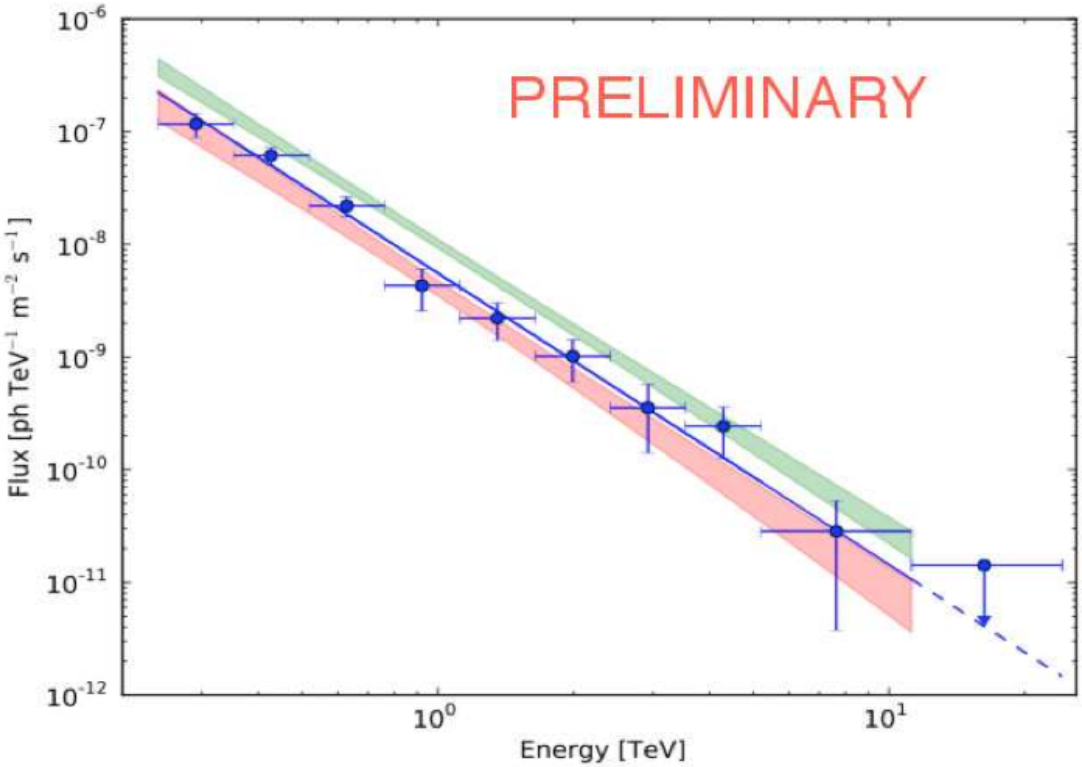
Hint of year-scale variability?



Fit of a constant flux $\rightarrow \tilde{\chi^2} = 8.32/2$ (1.6% probability)

1ES 0229+200

No evidence of spectral variability



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Hadronic models (in-source emission and cascade in the path) can be tested

- several VHE results already challenging for the simple SSC modeling
- variability study can constrain the cascade scenario

Conclusions

What kind of observations do we need?

- high-redshift blazars
- improve statistics in the last significant spectral bin
- long-term monitoring to constrain variability properties

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The future:

- we all will see CTA taking data...
  see tomorrow talk by Andreas Zech for more perspectives

THANKS !