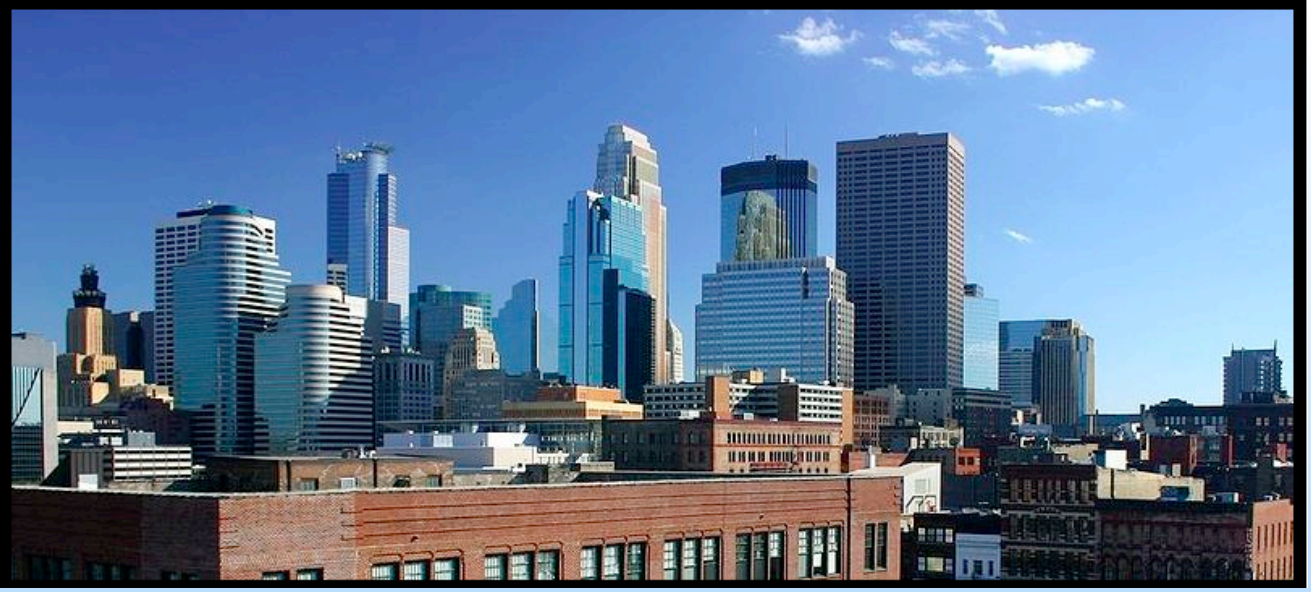


VERITAS Contributions to CF6
Cosmic rays, Gamma-rays and Neutrinos

Jamie Holder

Bartol Research Institute/Department of Physics and Astronomy

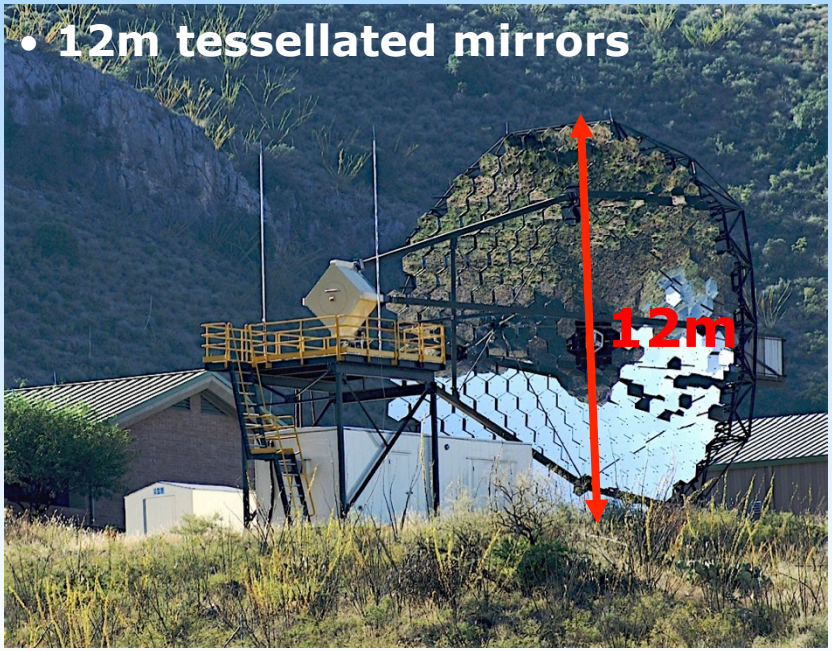
University of Delaware

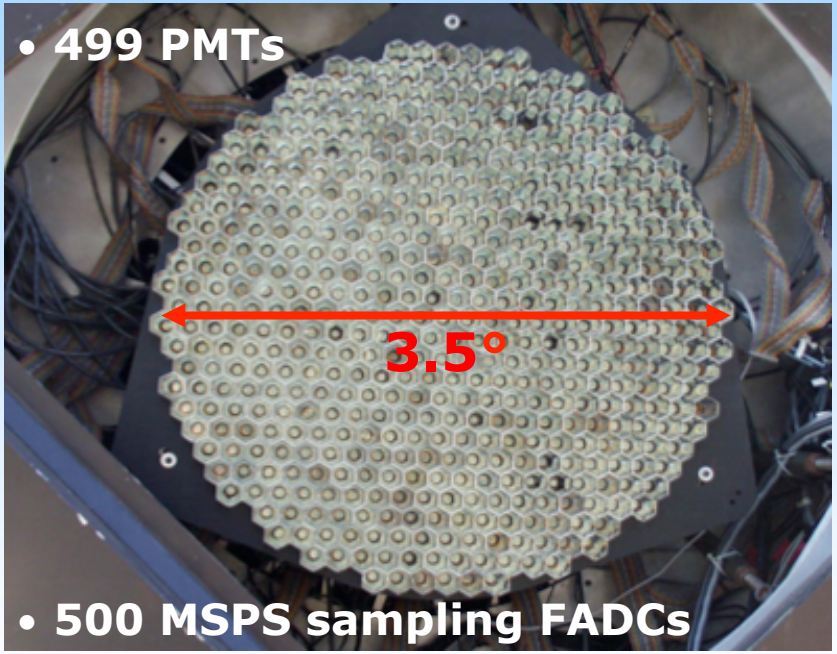
Snowmass on the Mississippi
Minneapolis, August 2013

- Smithsonian Astrophysical Observatory
- Purdue University
- Iowa State University
- Washington University in St. Louis
- University of Chicago
- University of Utah
- University of California, Los Angeles
- McGill University, Montreal
- University College Dublin
- University of Leeds
- Adler Planetarium
- Argonne National Laboratory
- Barnard College
- University of Minnesota
- DePauw University
- Bartol Research Institute/ University of Delaware
- Grinnell College
- University of California, Santa Cruz
- University of Iowa
- University of Massachusetts
- Cork Institute of Technology
- Galway-Mayo Institute of Technology
- National University of Ireland Galway
- DESY/Potsdam
- Pennsylvania State University
- ~100 Members
- +35 Associate Members

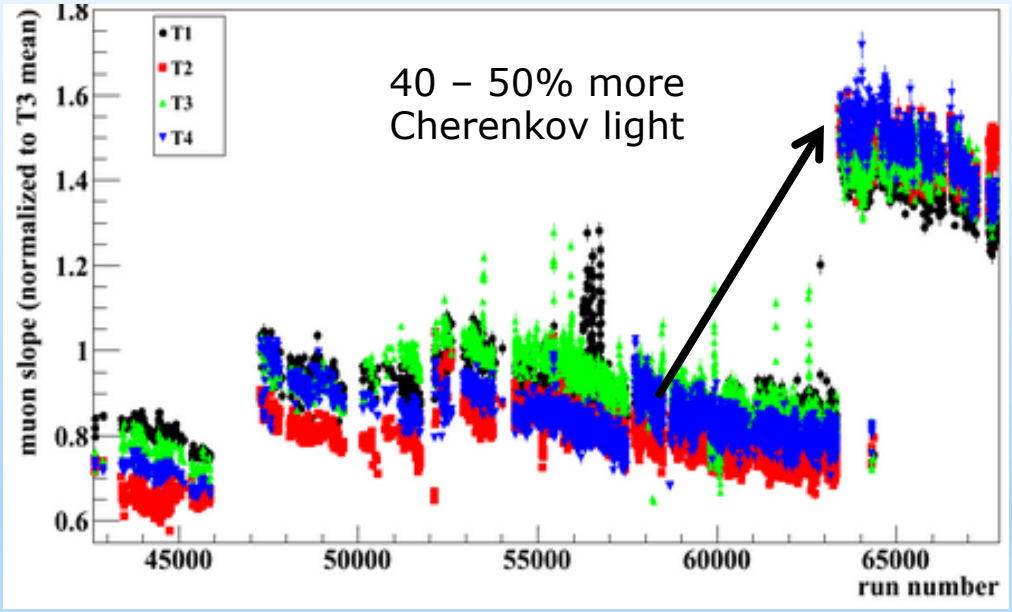
VERITAS

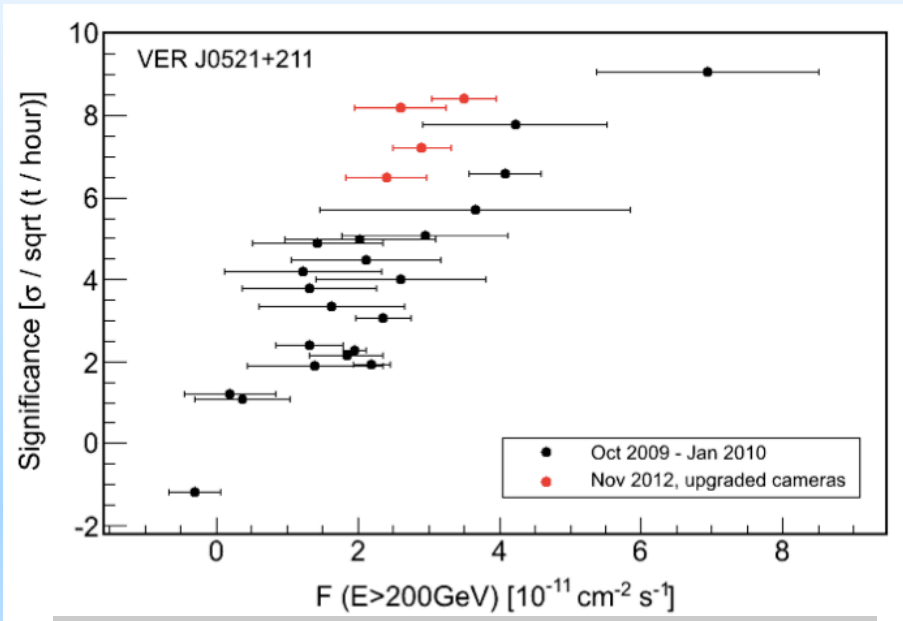
- Situated at 1250m altitude at the Whipple Observatory in Arizona
- Started in 2007, T1 moved in 2009, camera and trigger upgrade in 2011/12





VERITAS

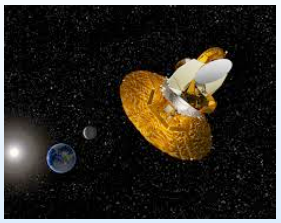


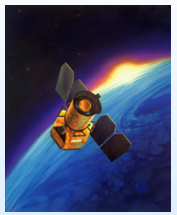
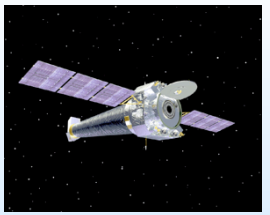


Detect soft spectrum sources twice as fast as in 2009

- Energy range: ~100 GeV - 30 TeV
- Sensitivity: 1% Crab in ~25h
- Energy resolution: 15-25%
- Angular resolution: R_68% < 0.1 deg

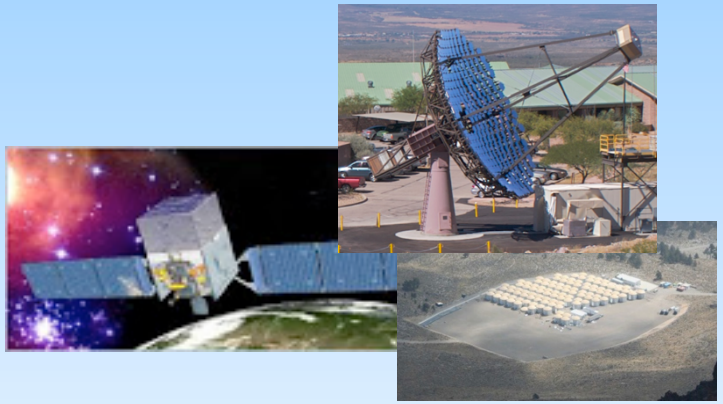
- 500 MSPS sampling FADCs

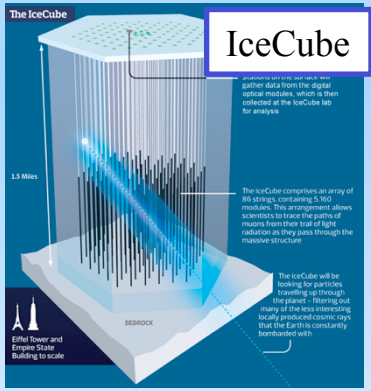



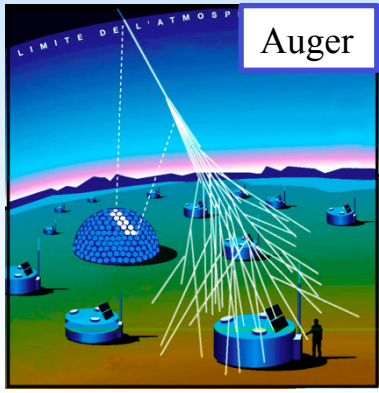




10^{3} 10^{1} 10^{-1} 10^{-3} 10^{-5} 10^{-7} 10^{-9} 10^{-11}

radio microwave infra-red optical UV X-RAY

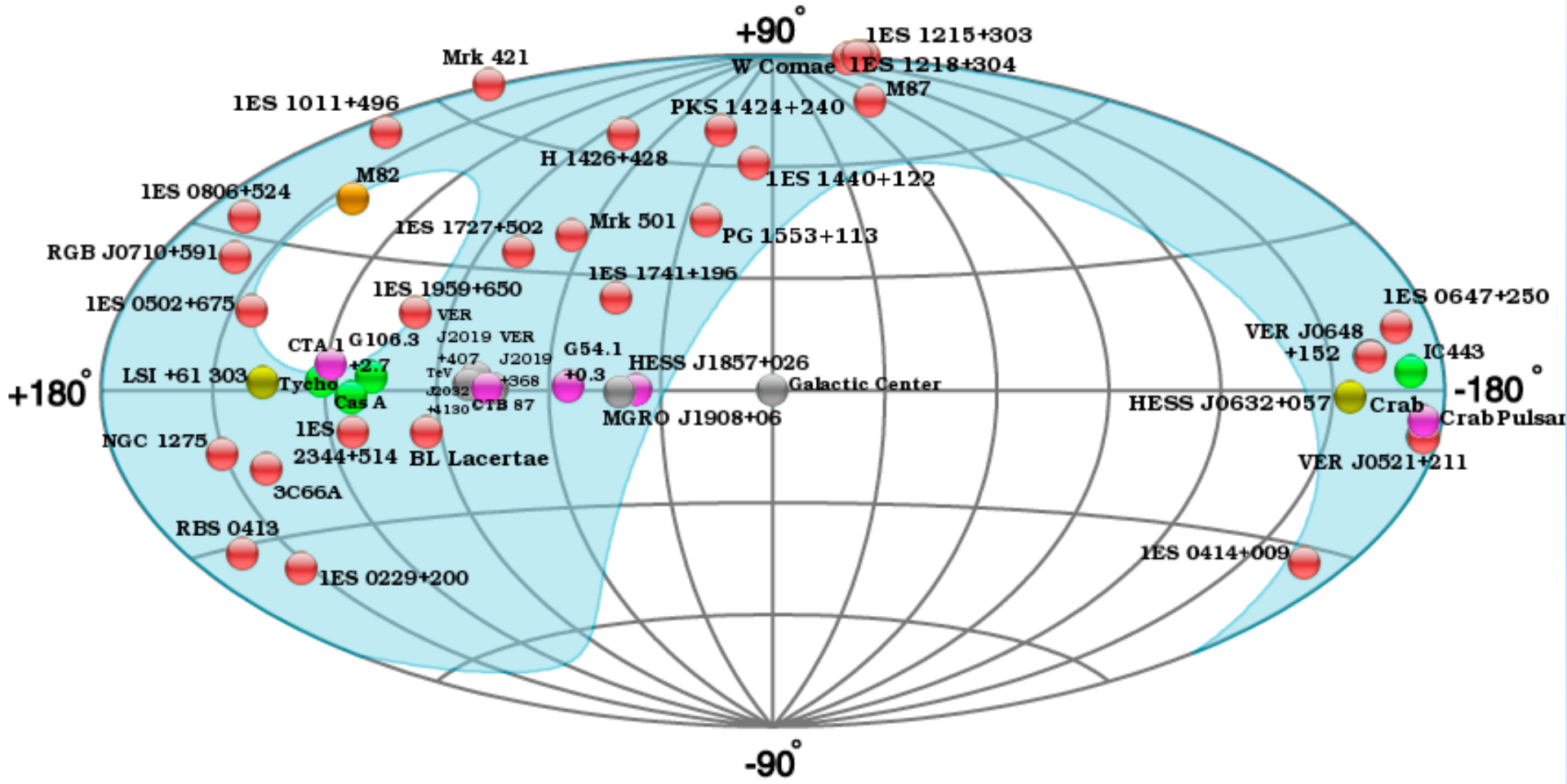




10^{-12} 10^{-14} 10^{-16} 10^{-18} 10^{-20}

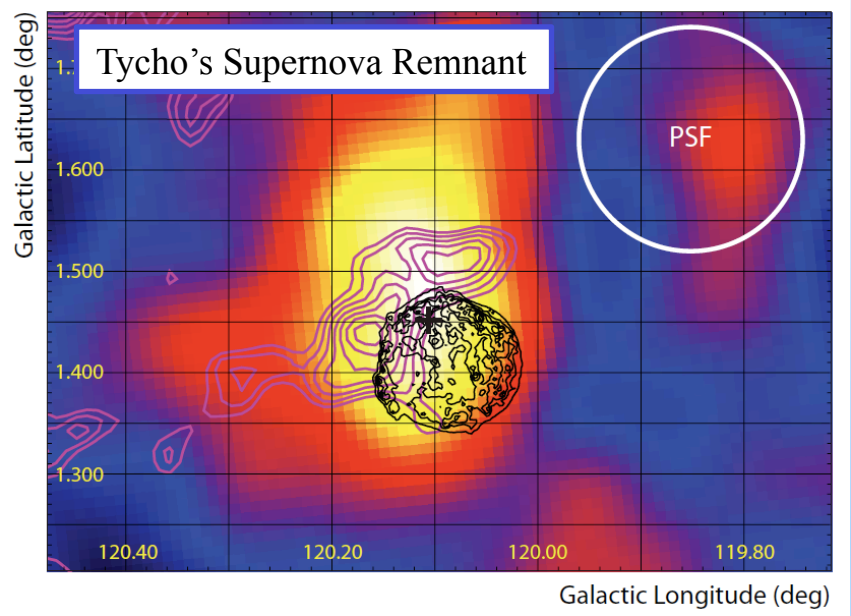
GBM LAT VERITAS HAWC

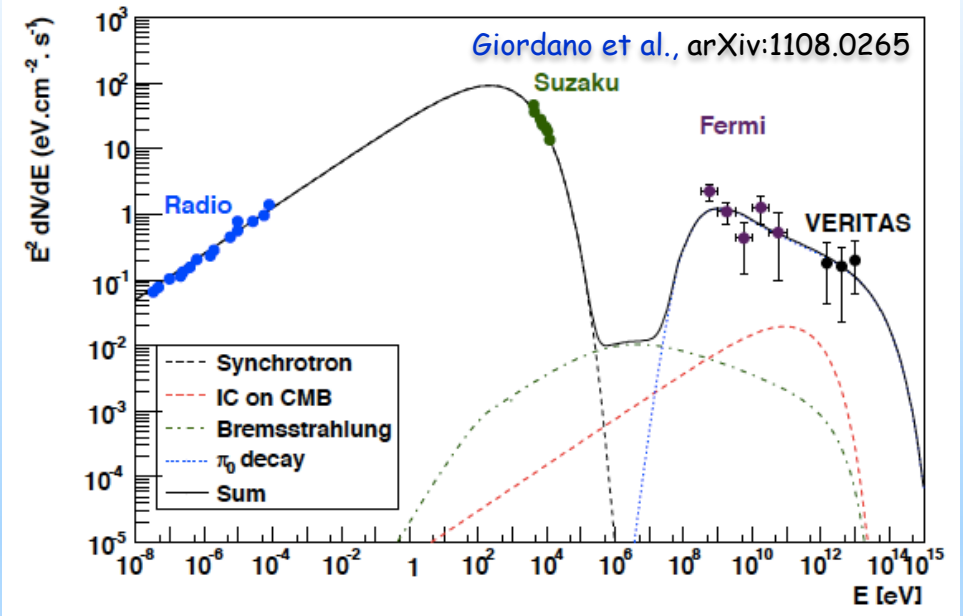
Bread and Butter…

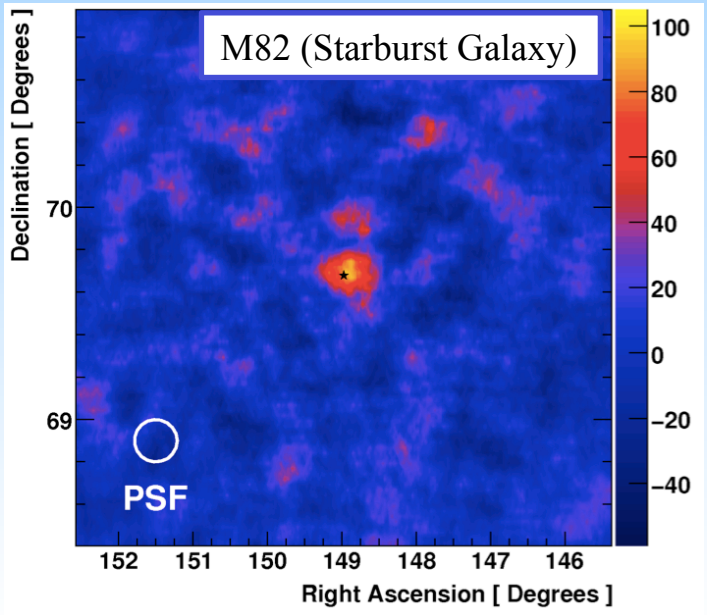


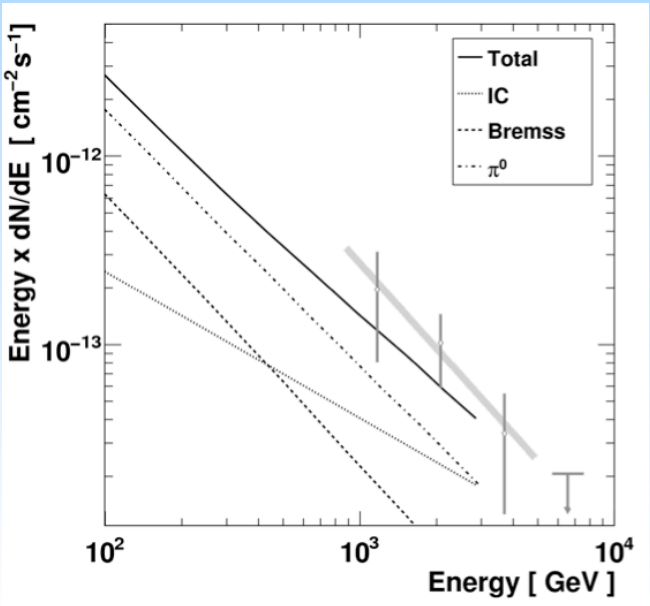
- 46 sources detected by VERITAS (over half are new discoveries)
- Multiple classes: Blazars, radio galaxies, starburst galaxy, pulsar, pulsar wind nebulae, binary systems, supernova remnants, unidentified sources.

Cosmic ray acceleration to the knee

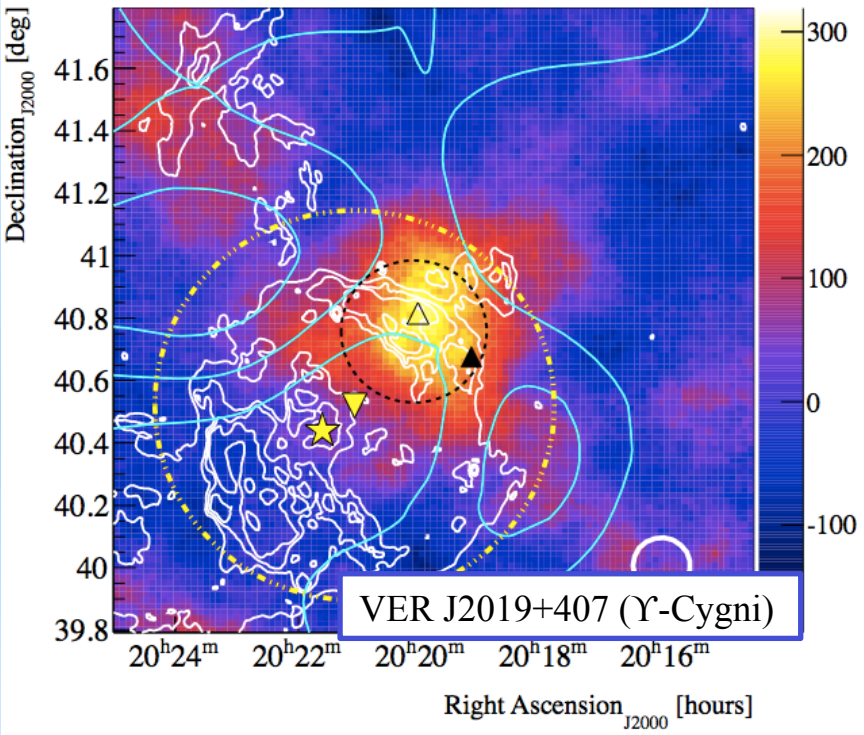


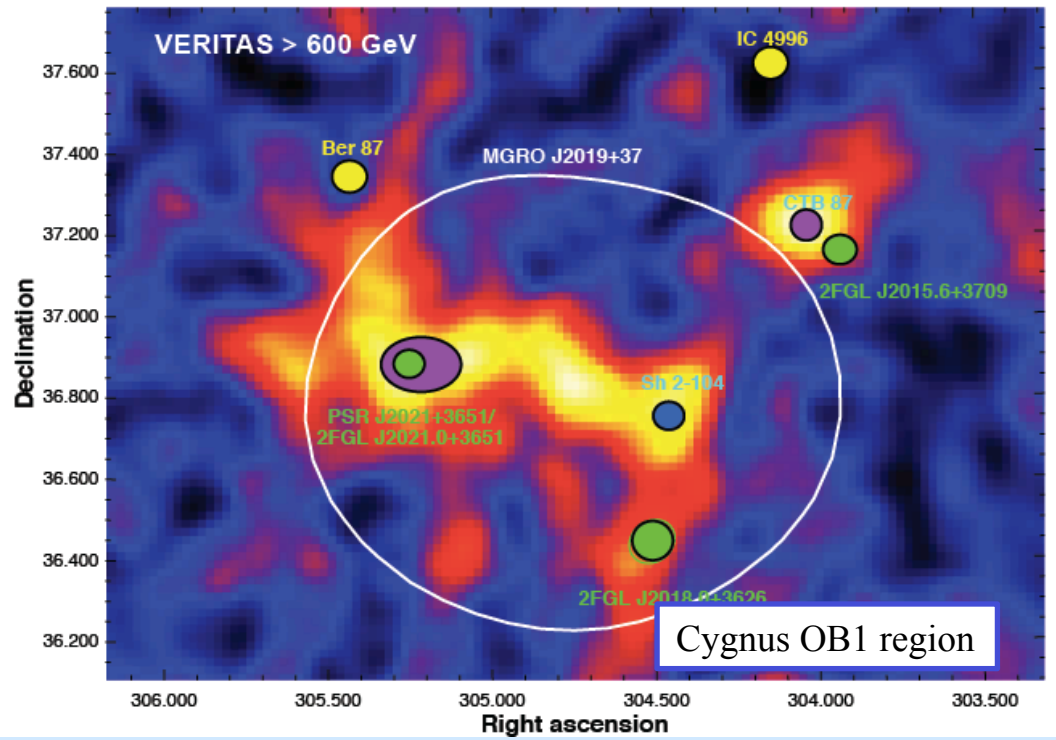






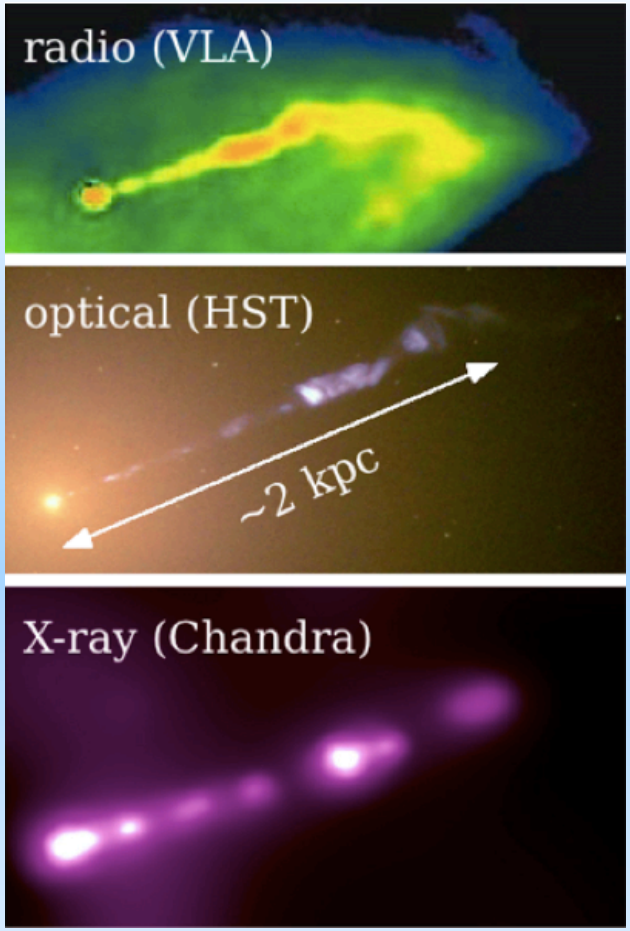
Disentangling CR acceleration regions in our Galaxy

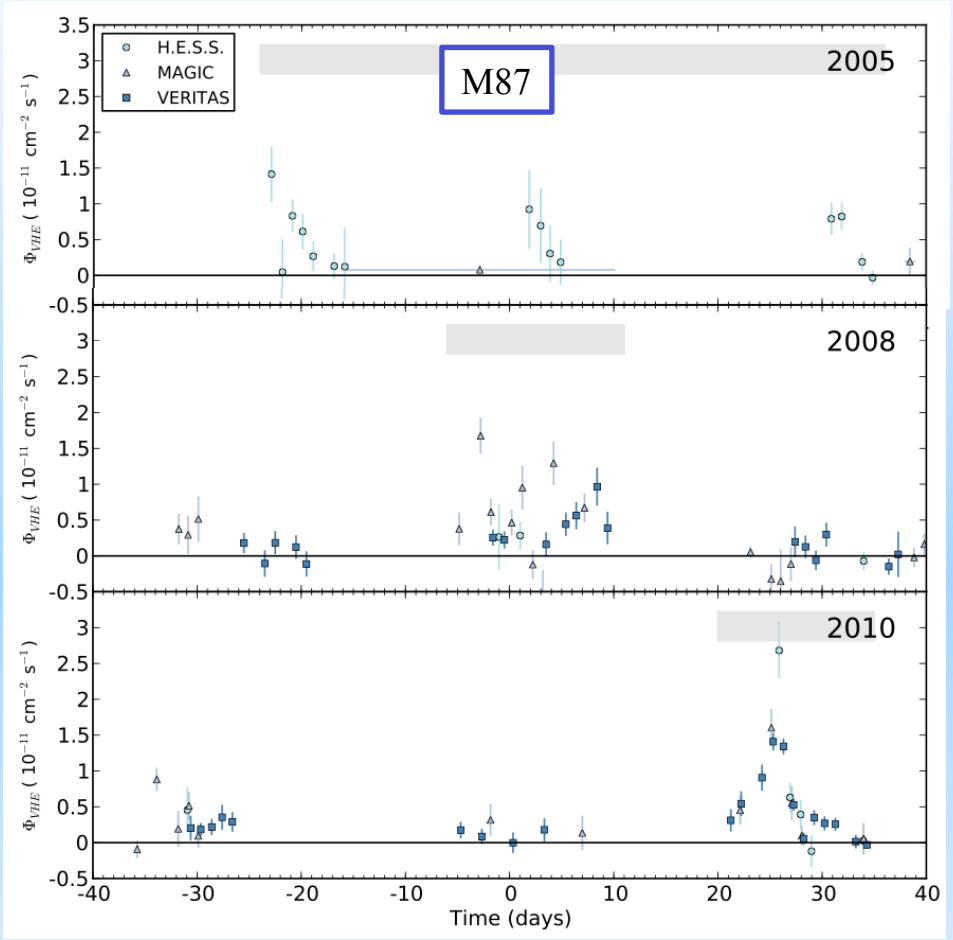




- IACTs such as VERITAS provide good angular resolution (~0.1° / event)
- Allows energy dependent study of complex regions, and deconvolution of multiple overlapping (associated or unassociated) sources.

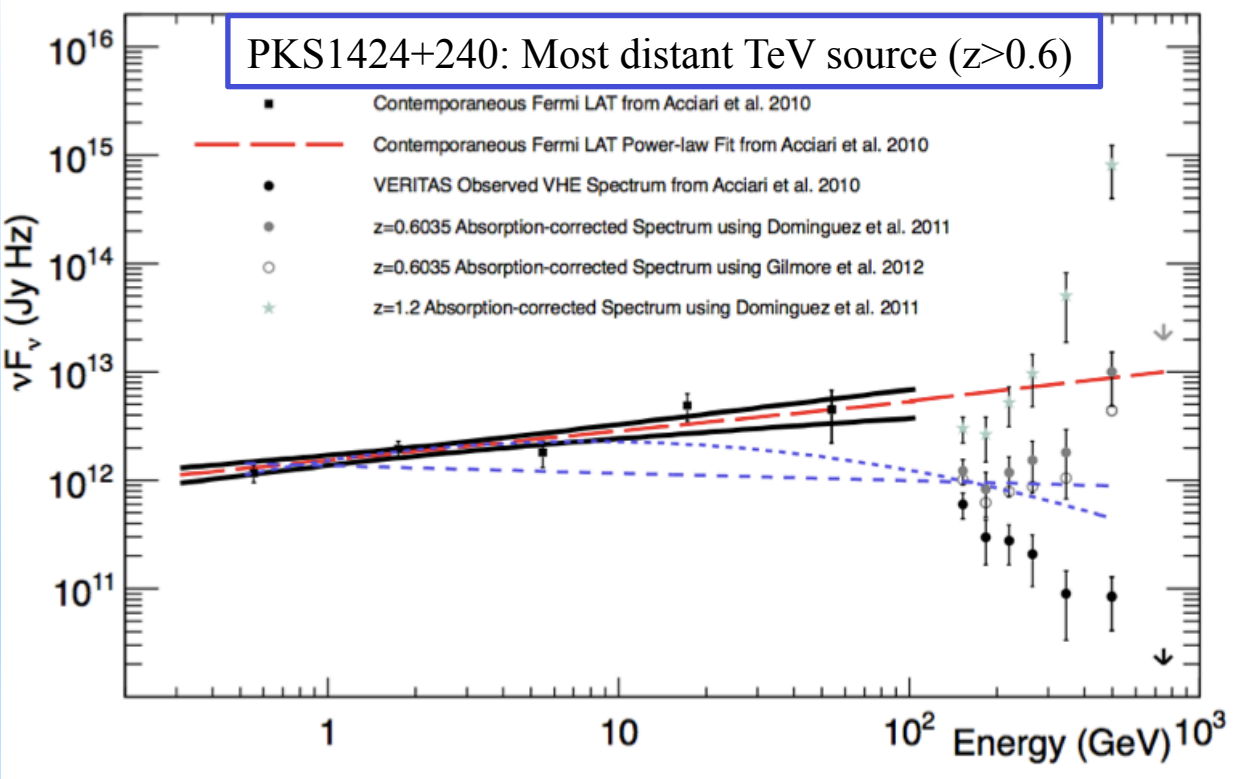
Particle Acceleration in AGN Jets





- The VERITAS blazar catalog now includes 25 sources.
- Contemporaneous multiwavelength data allow detailed time-resolved modeling
- Population is broadening, with HBLs, IBLs, LBLs, and FSRQs
- Study of radio galaxies/ nearby blazars allows cross-correlation of gamma-ray light curves with jet features.

Extragalactic background light (EBL)

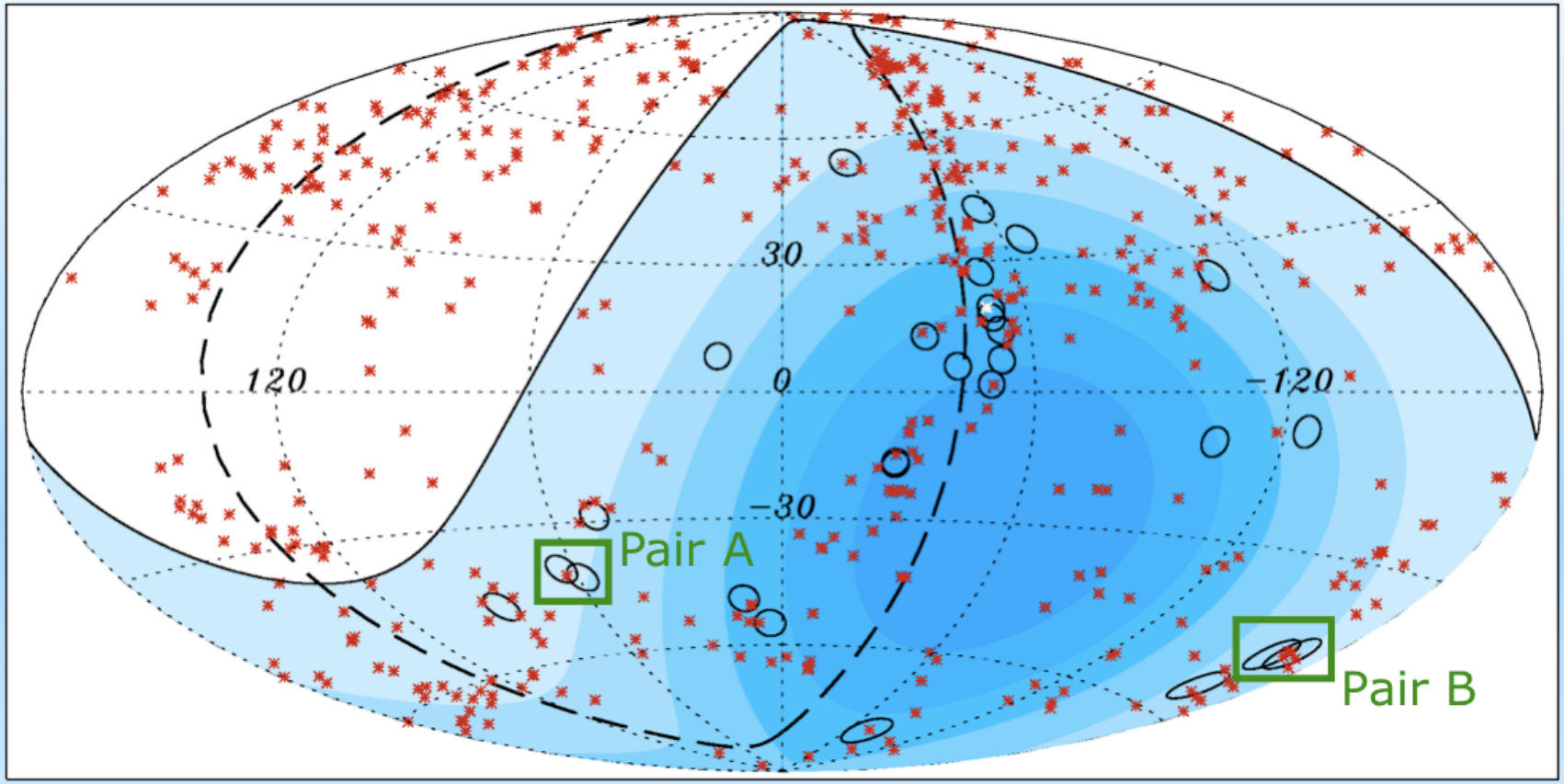


- TeV photons pair-produce with photons of the infra-red EBL
- Studying the spectra of distance sources allows us to measure or limit the EBL.
- Important parameters are the redshift and energy range.
- VERITAS uses 3 complementary approaches

$$F_{\rm obs}(E) = F_{\rm int}(E)\,{\rm e}^{-\tau(z,E)}$$

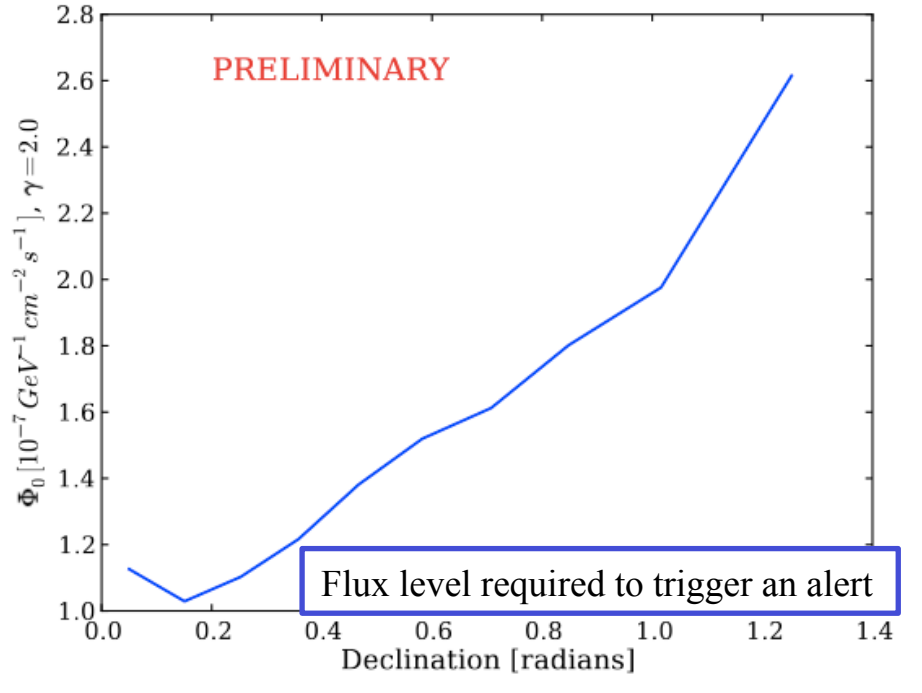
  - Discovery observations of very distant blazars (but still *z*<1.0)
  - Monitoring of brightest blazars for major flares (for measurements >20TeV)
  - Deep observations of "hard" spectrum (Γ~2.7), "distant" (z>0.1) blazars.

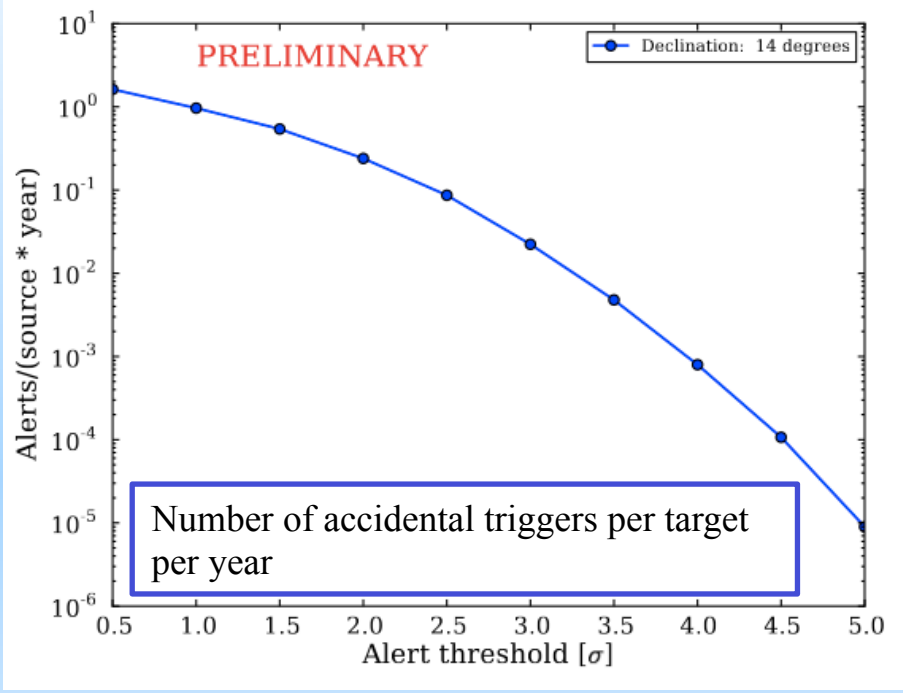
UHECR anisotropy follow-up



Source Name	*ON-source* (events)	*OFF-source* (events)	Background Normalization	99% confidence upper limits (events)	(ph m^{-2} s^{-1} > 500 GeV)
Q 2207+0122	4	78	0.10	4.6	8.6×10^{-9}
Q 2207+0121B	4	78	0.10	4.6	9.6×10^{-9}
Q 2205+0120	7	73	0.10	9.5	2.3×10^{-8}
SDSS J22064+0106	7	34	0.10	13.4	4.9×10^{-8}
Q 2212+0215	3	35	0.10	7.0	3.9×10^{-8}
Q 2213+0218	0	10	0.10	3.8	3.8×10^{-8}
NGC 1358	26	179	0.10	19.1	1.4×10^{-8}
SDSS J03302-0532	13	170	0.10	6.1	4.9×10^{-9}
SDSS J03349-0548	13	137	0.10	10.8	8.3×10^{-9}

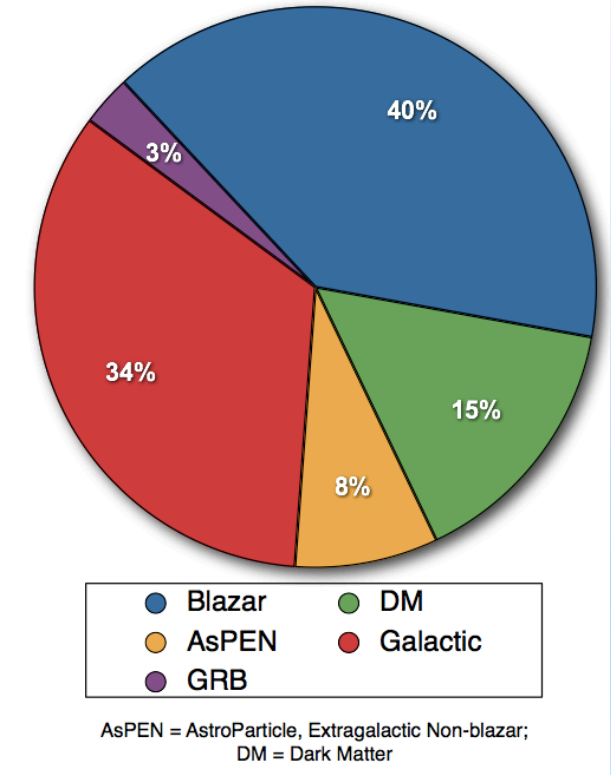
Neutrino alerts and follow-up

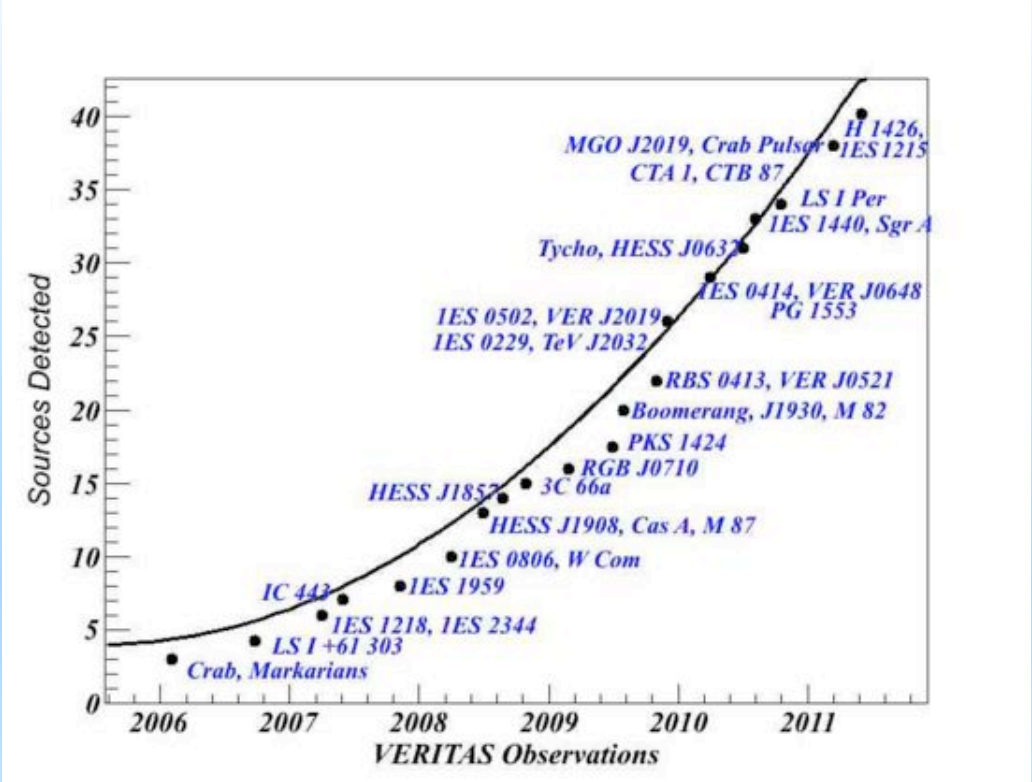




- Established target-of-opportunity alert system for
  - A list of 22 IceCube selected gamma-ray sources
  - All known potentially variable TeV sources with declination $\delta > 0°$
  - All sources in the "Fermi monitored sources" list with declination $\delta > 0°$
  - One trigger so far (in two years). No signal.
- Follow-up observations of astrophysical neutrino hotspots are also envisaged

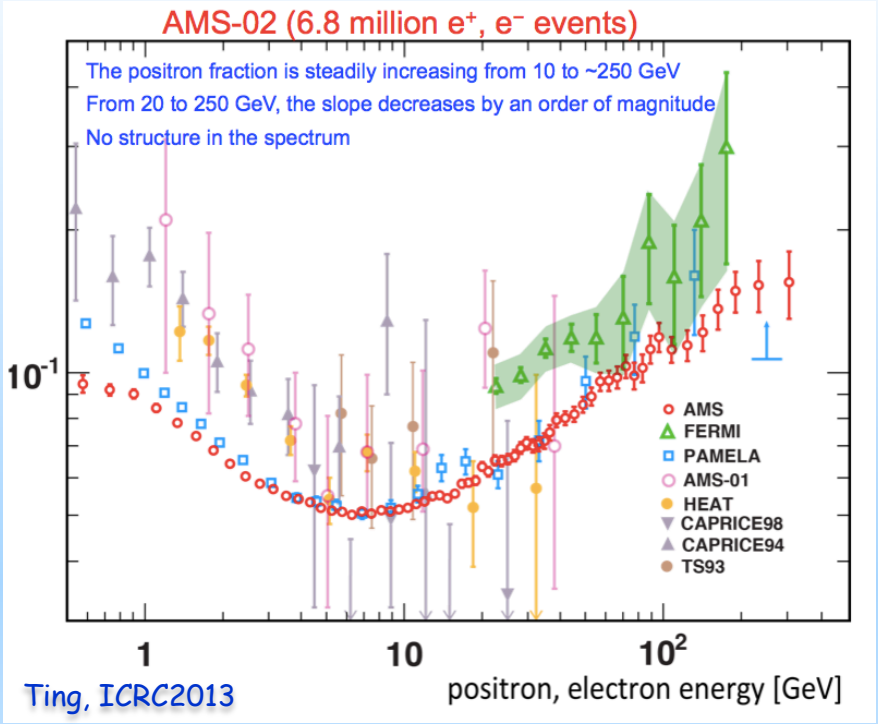
What else?





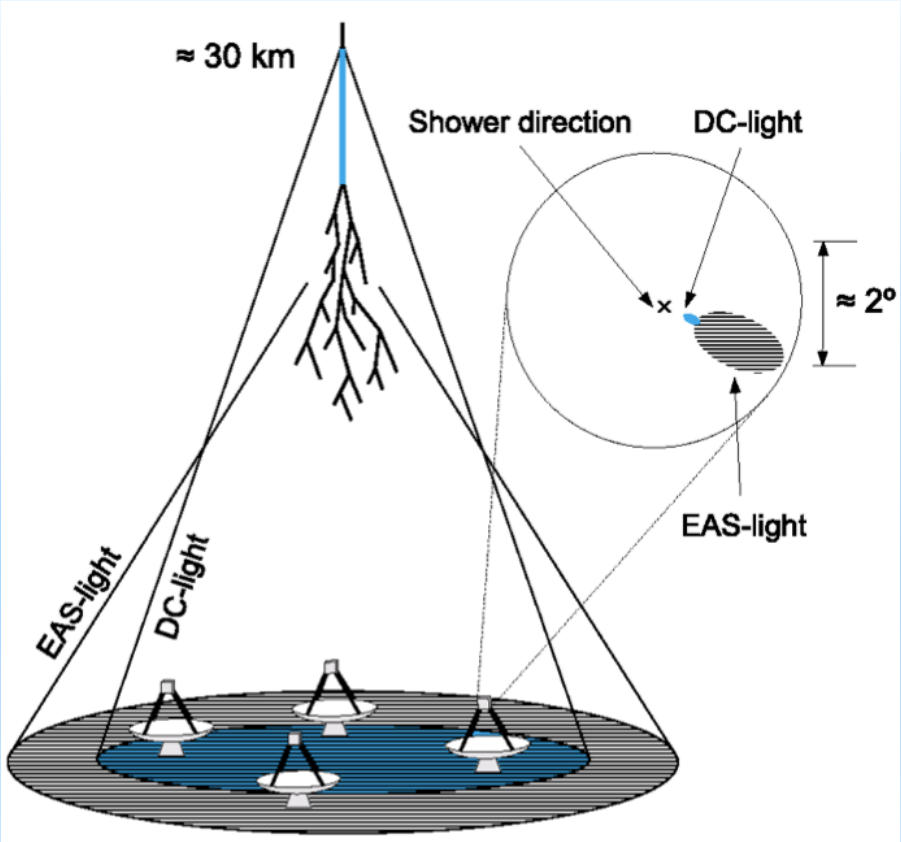
- VERITAS started operations in 2007
- The data archive is now large (>3500 hours) and the experiment is stable, well-calibrated and well-understood.
- At this point in the experiment, more observing time becomes available for long-term and/or exploratory projects.
- With much of the astrophysical 'low-hanging fruit' now published, more manpower can also be devoted to these topics.

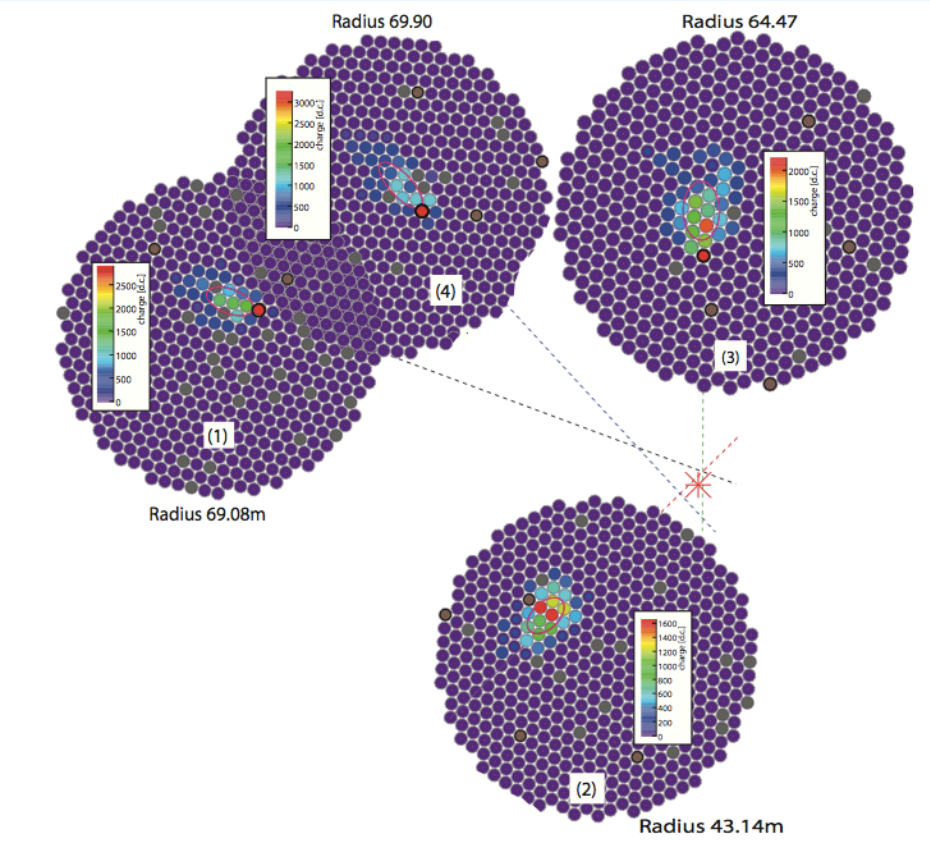
Positron fraction at high energies



- Use the Earth – moon system as spectrometer (Colin, 2009)
- The moon creates a 'hole' in the isotropic electron/positron flux
- Charged particles are deflected by the Earth's magnetic field
- The position of the hole is offset with respect to the moon.
- Offset depends on particle charge and energy (typically ~2°)
- Problem – the moon is bright! Need filters – and observing time is limited
- Difficult and speculative – but potentially allows a complementary measurement of the positron fraction > 1TeV

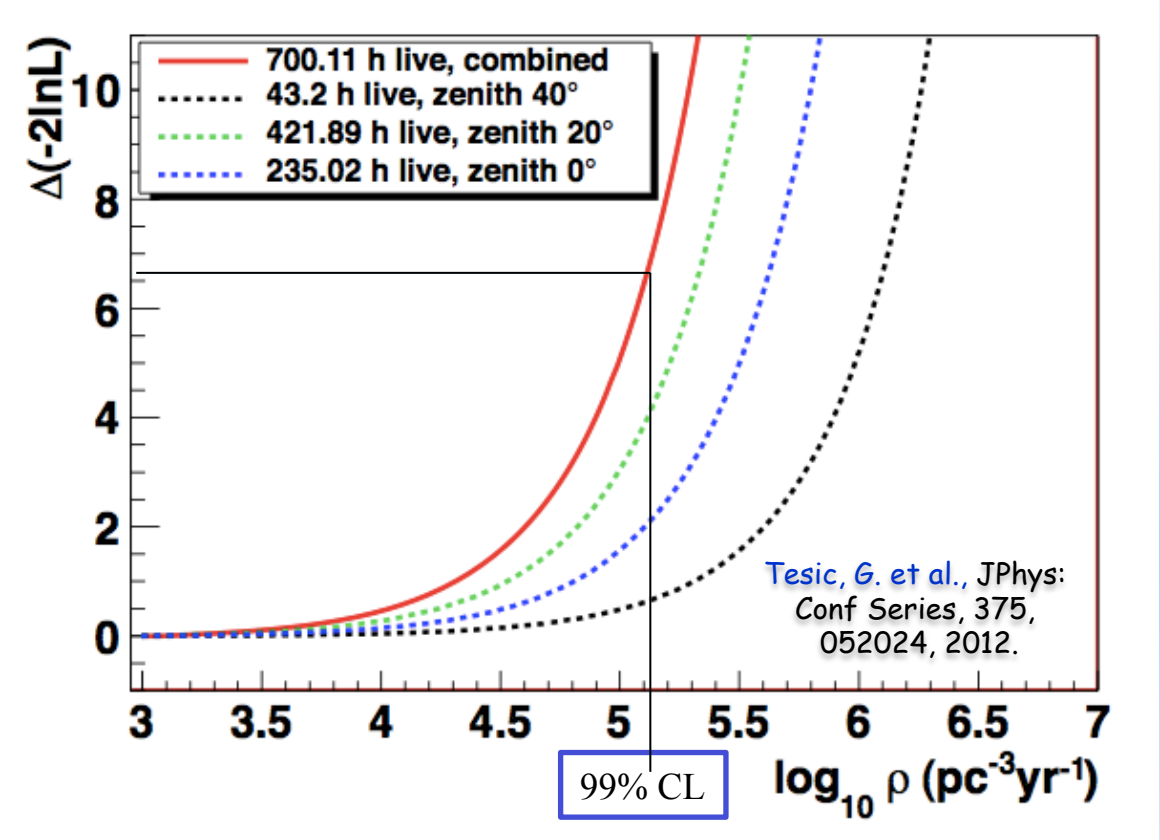
Heavy nuclei with direct Cherenkov light





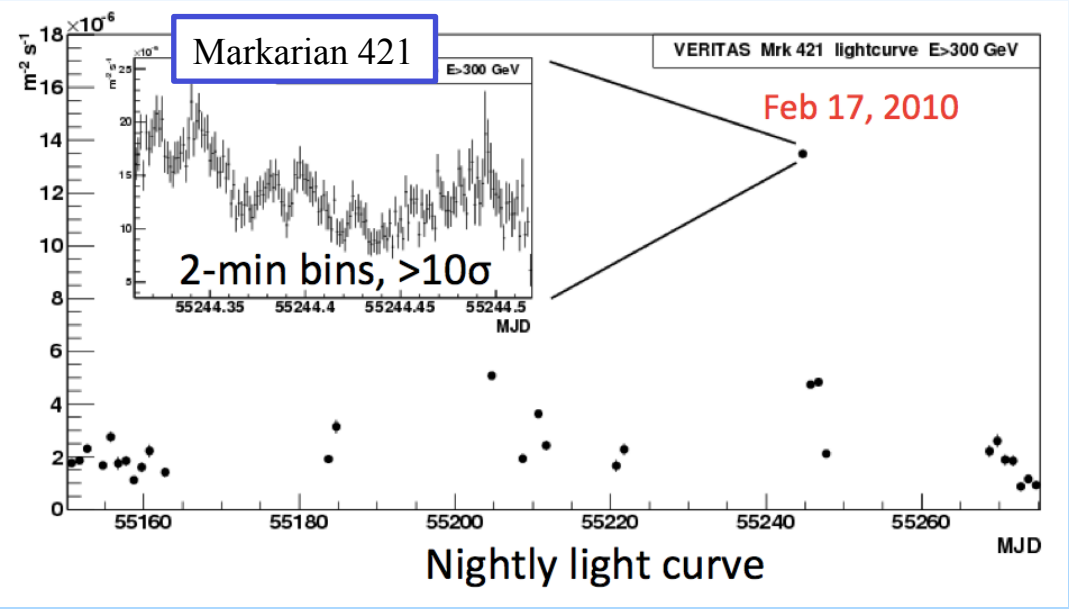
- Intensity of Cherenkov emission from the primary is proportional to Z^2
- Heavy primary nuclei produce a clear signal (Kieda et al., 2001)
- Effective above ~10 TeV
- Results from H.E.S.S. in the literature (Aharonian et al. 2007). VERITAS studies underway.

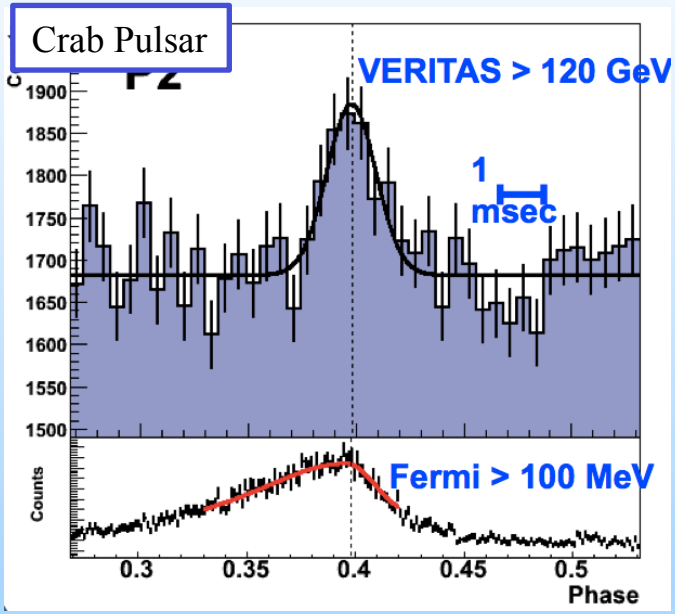
Primordial Black Hole Searches

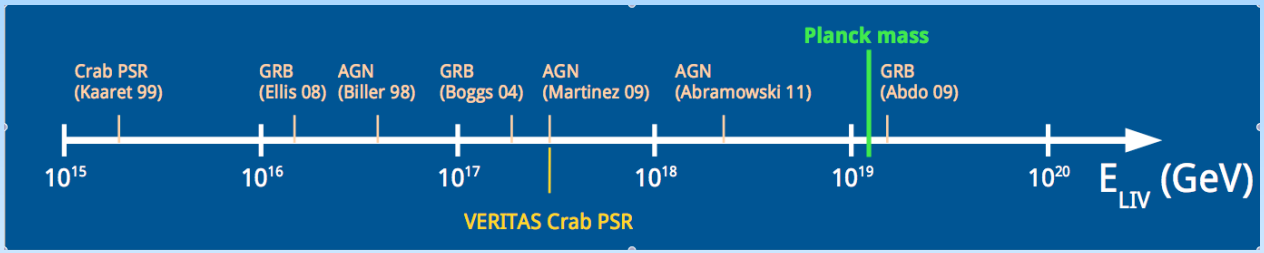


- 700 hours of observations
- Limit on the rate of evaporations is $\rho_{PBH} < 1.29 \times 10^5 pc^{-3} yr^{-1}$ with a search window of 1s
- ~5 times as much data in the archive, plus upgraded sensitivity and refined analysis should improve this substantially.

Lorentz Invariance Violation





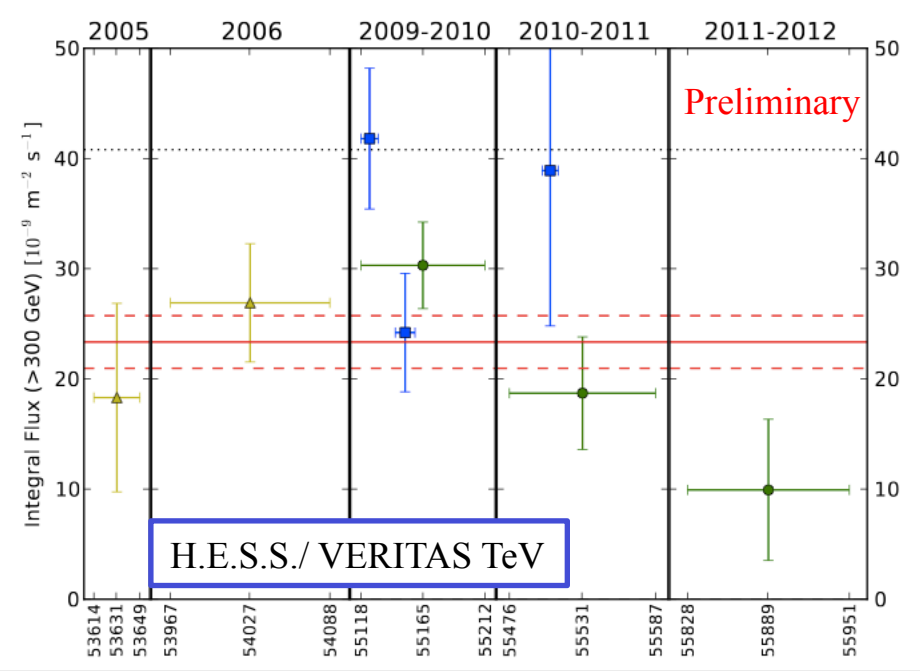


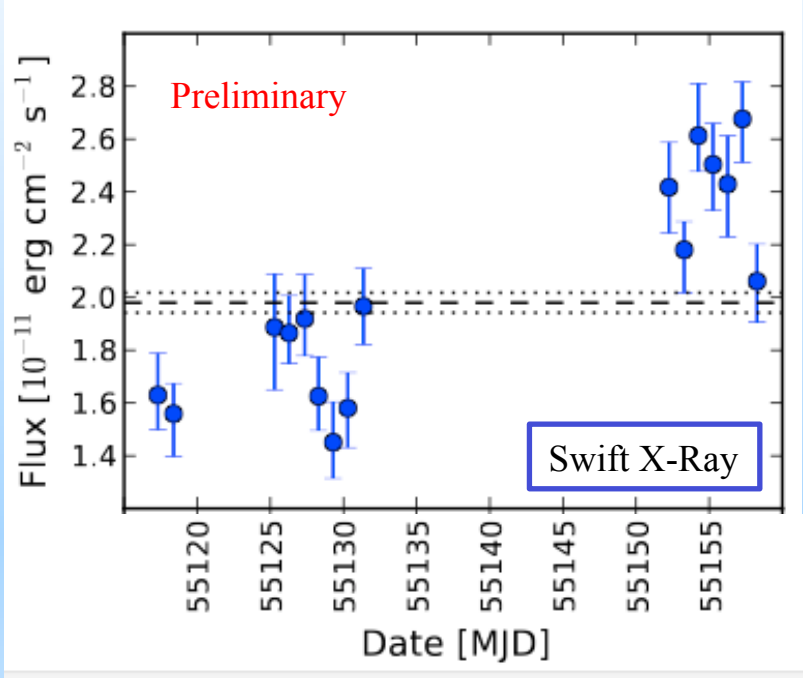
$$c(E) = c_0 \left[1 - s_{\pm} \frac{n+1}{2} \left(\frac{E}{E_{QGn}}\right)^n\right]$$

?????

- Search for an energy dependence of the speed of light
- Can use AGN flares:
  - Bright, distant (~ few 100 Mpc), fast, and high energy (>1TeV)
  - Unpredictable & LIV signal may be masked by physics of flare production
- Alternatively, use pulsars:
  - Very fast, predictable and repeatable. Fairly well understood
  - Soft spectrum (<400 GeV), nearby (2kpc)

Search for the Intergalactic Magnetic Field





- The IGMF cannot be measured directly, but it may leave a signature on the TeV emission from extragalactic sources
- Can be temporal, spatial, or spectral
- Hard-spectrum, distant sources are best
- Numerous authors have attempted to place bounds – an important assumption is long-term flux-stability
- VERITAS is monitoring "IGMF" sources to test this - e.g. 1ES0229+200 shows definite X-ray variability, and a hint of TeV variability (P_{STEADY}=1.6%)

Summary

- VERITAS is a stable instrument, running smoothly after a recent major upgrade.
- Ongoing and planned contributions to CF6-A topics include data-mining our extensive archive, plus new observations.
- The coming 5 years will provide unprecedented wide-band coverage of the gamma-ray sky, along with complementary multi-messenger facilities