Recent Results with Atmospheric Cherenkov Detectors

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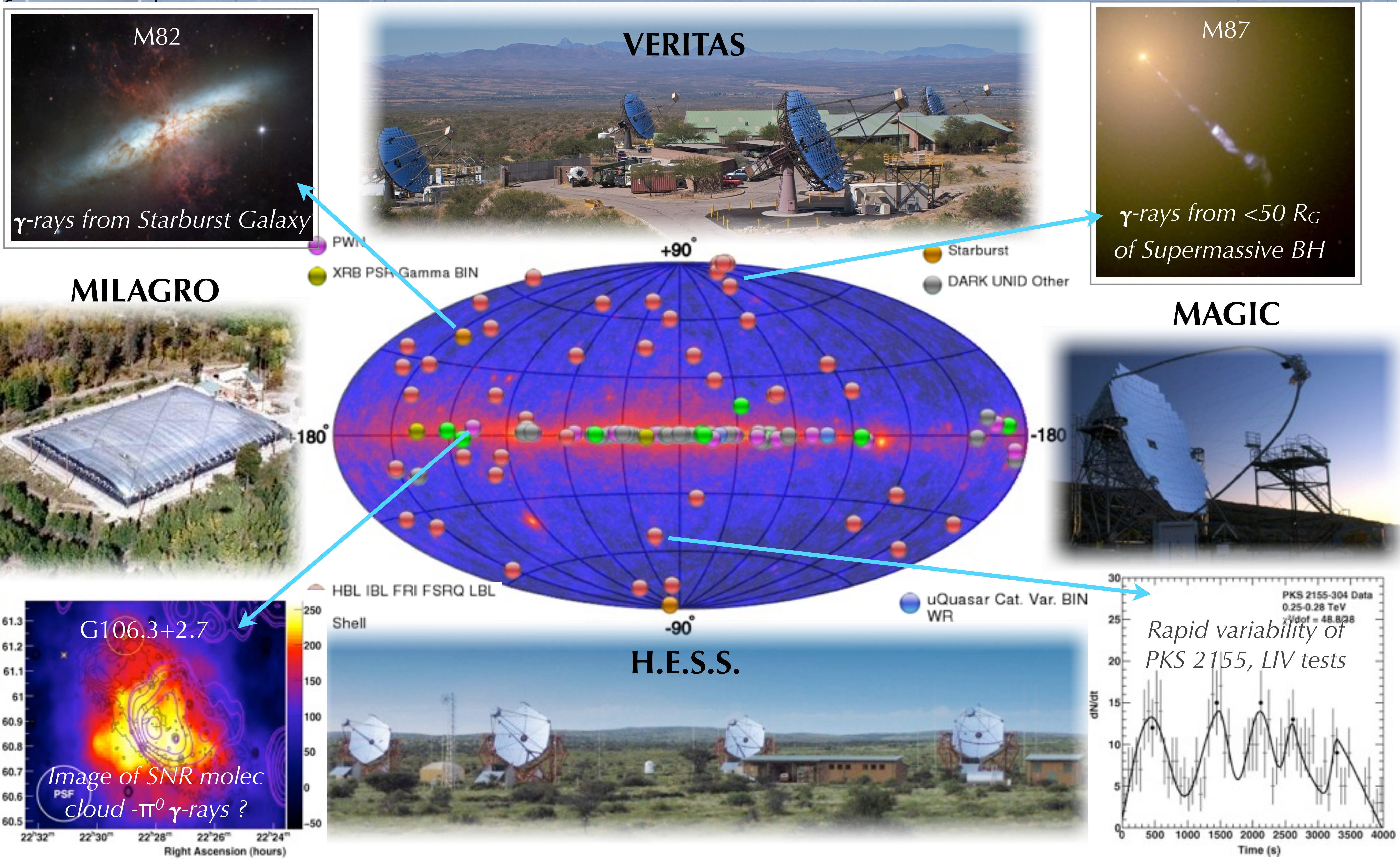
Washington University in St. Louis

- IACT Experiments
- Indirect Dark Matter Searches
- Hadronic/Leptonic Particle Accelerators - CR Origin
- Probes of Fundamental Physics and Cosmology

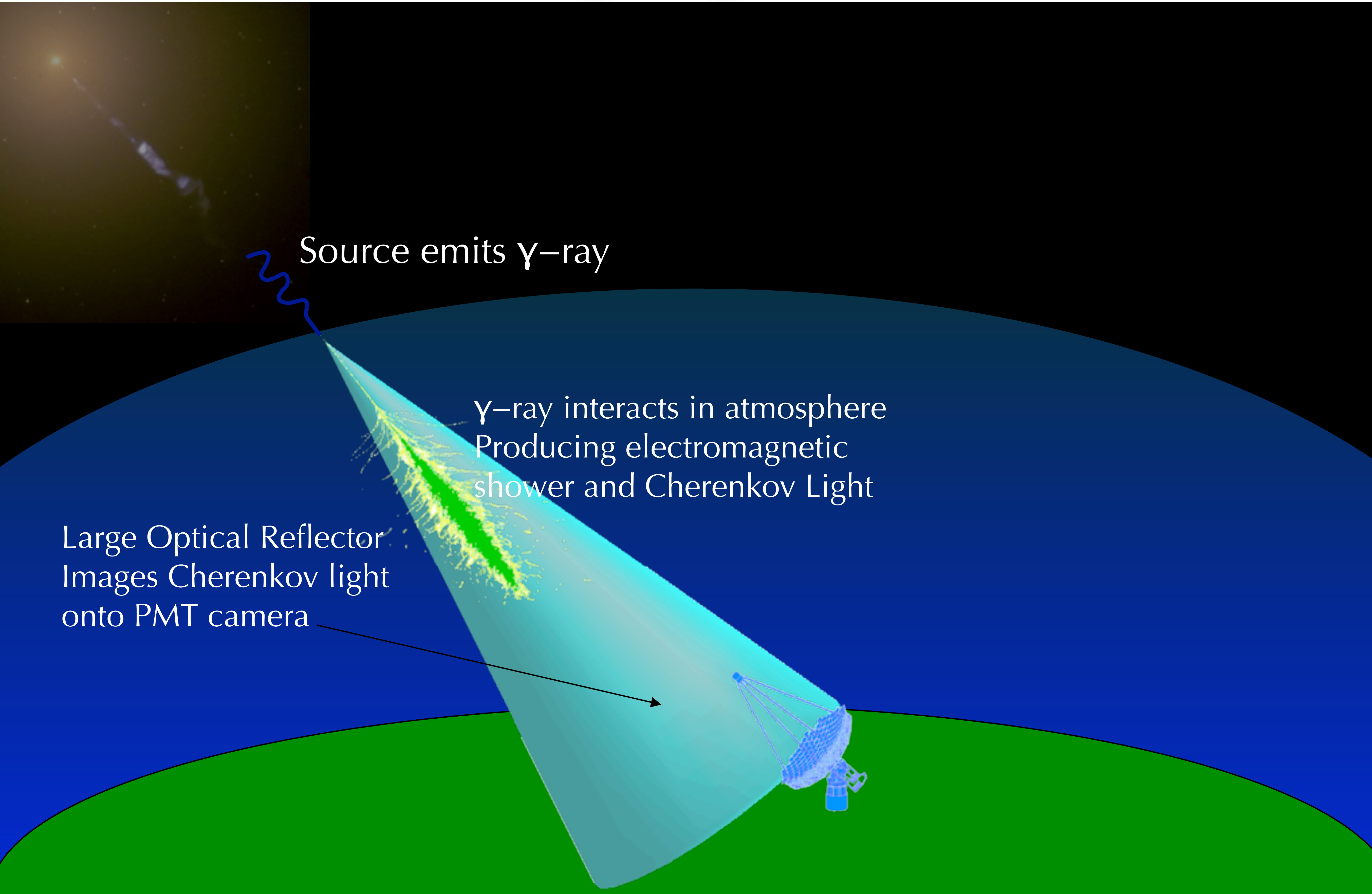
TeVPA Stockholm, August 3, 2011

VHE Gamma-Ray Status



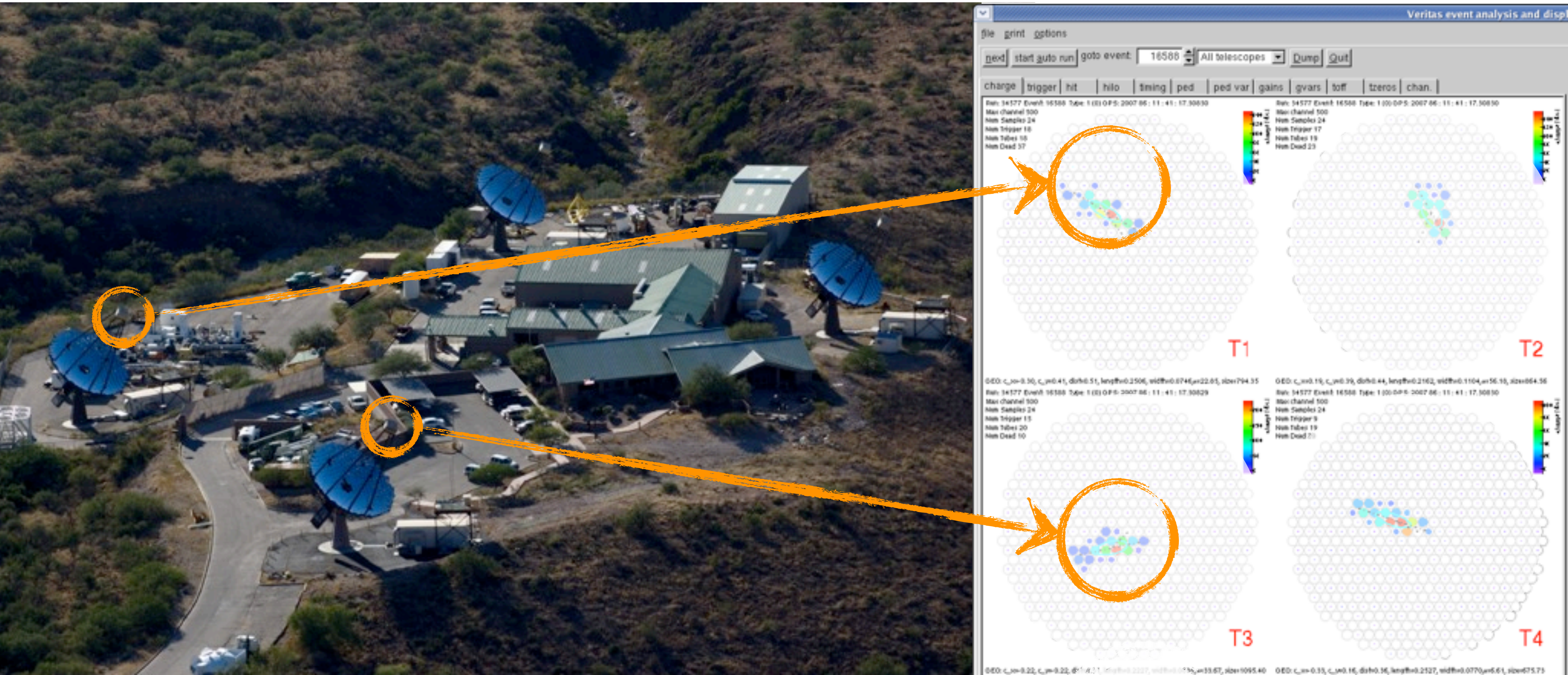

Atmospheric Cherenkov
Telescopes

Imaging ACTs

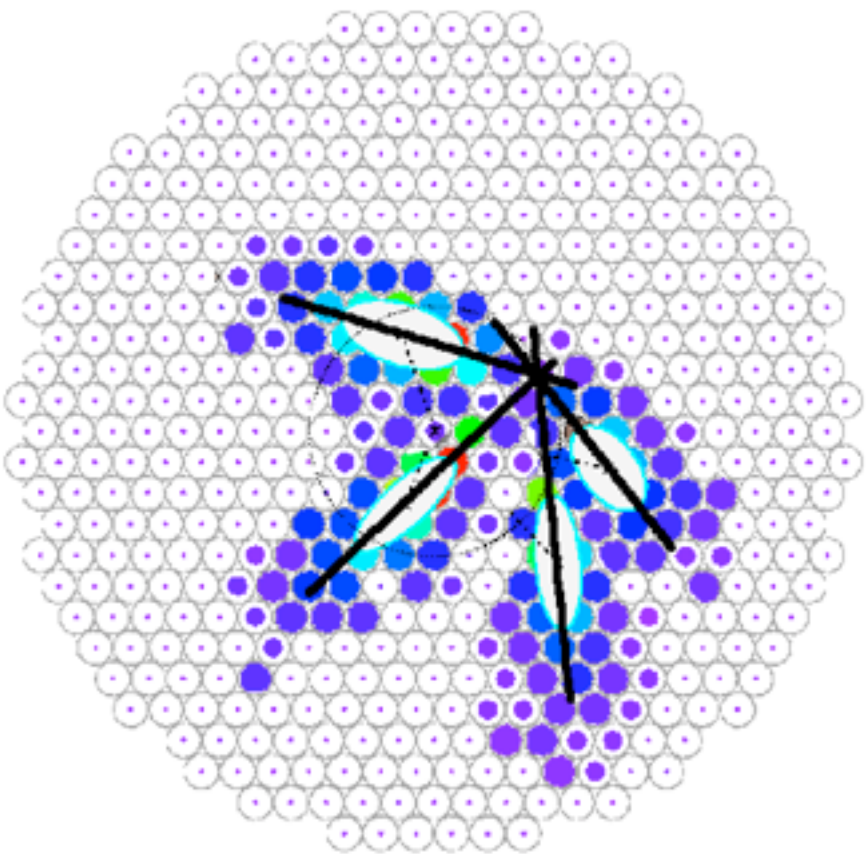


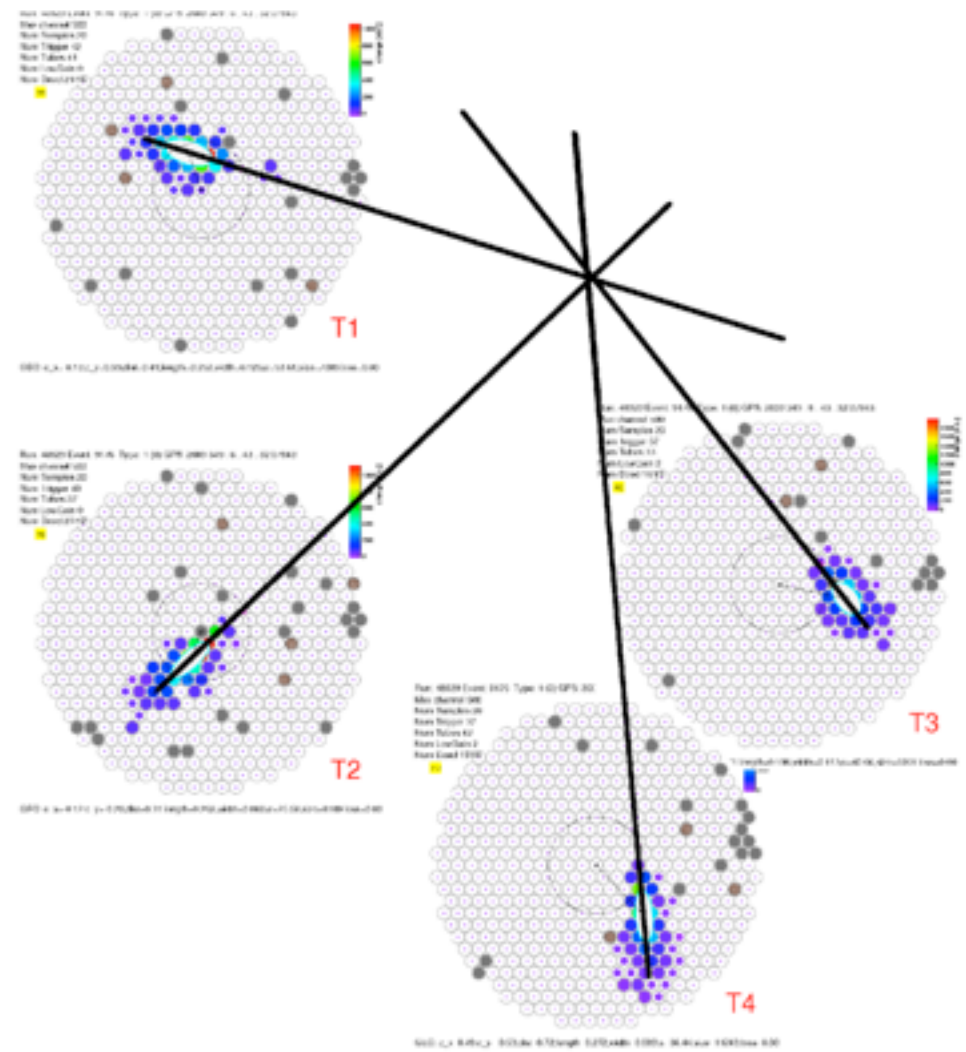
VERITAS Array, e.g.

- *10 mCrab sensitivity* - 5σ detection at 1% Crab (2×10^{-13} erg cm^{-2} s^{-1} @ 1 TeV) in 28 hrs.
- *Effective area 10^5 m^2* above 500 GeV
- *Angular resolution <0.1 deg*
- *Energy range 150 GeV - 30 TeV, 15% resolution* (for spectral measurements)



IACT Arrays





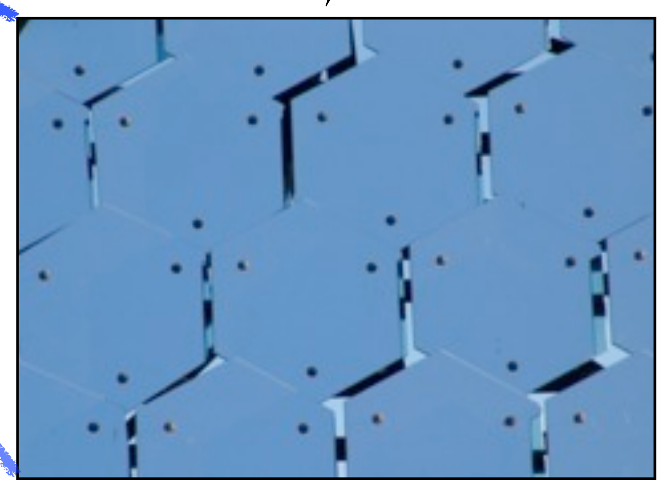
- Stereoscopic reconstruction provides point of origin of gamma-rays from intersection of images (like convergence of lines of perspective)

- Images also converge on impact point on the ground, together with multiple samples of total light providing corrections for the Cherenkov light lateral distribution and good calorimetry

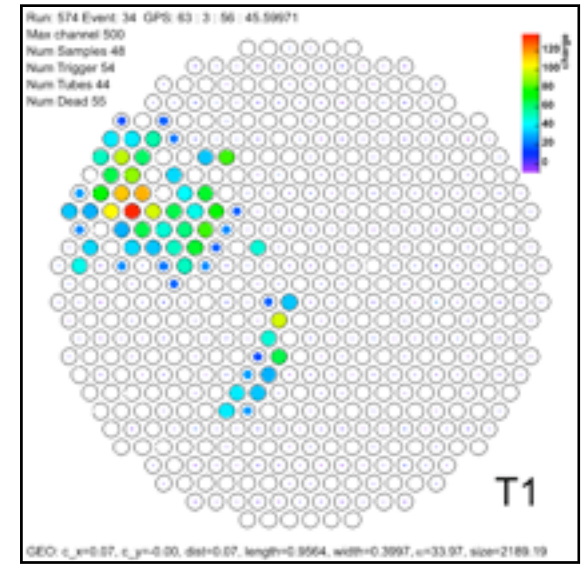
Technical Details

Telescope (x 4)
12-m diameter Davies-Cotton
f 1.0, 110 m2 area

Camera (x 4)
499 PMTs, 3.5° FOV



Mirror Facets (x 350)
Reflectivity ~ 88%
(Recoated every 2 years)



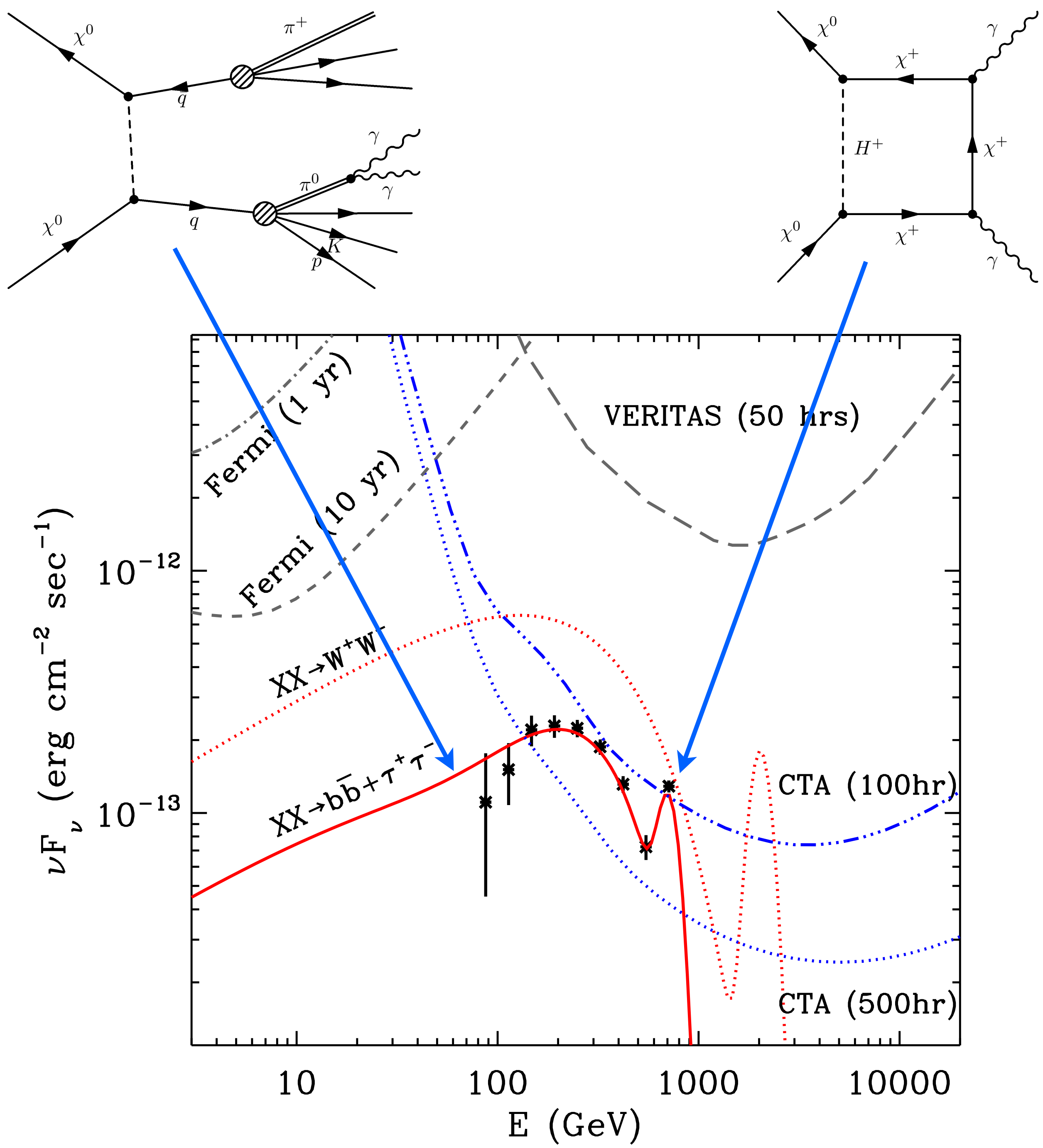
Electronics
500 Msp FADC, CFD trigger, 3-fold adjacent pixels and 2/4 telescope coincidence

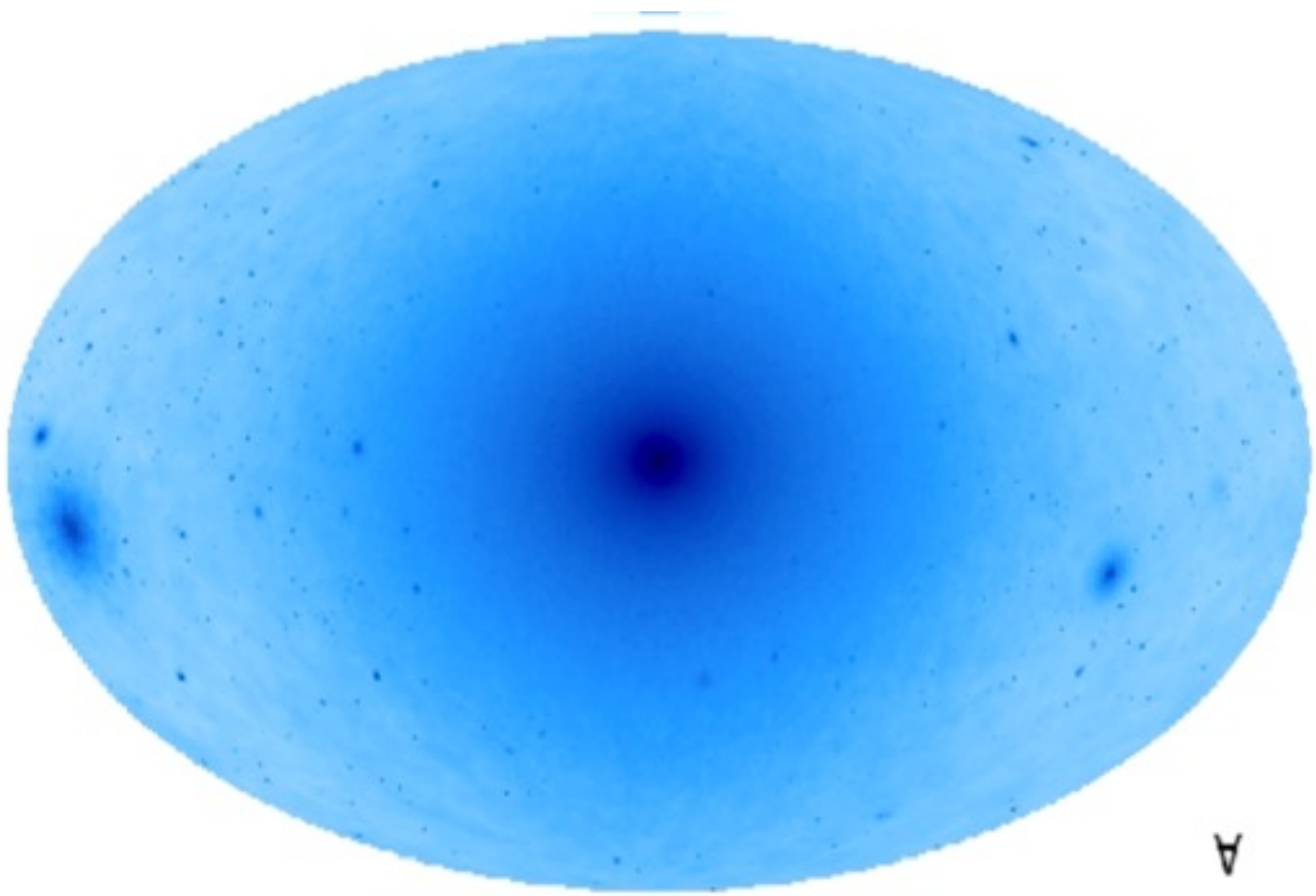
Indirect Dark Matter Searches

Gamma-rays from DM

$$E_\gamma \Phi_\gamma(\theta) \approx 10^{-10} \underbrace{\left(E_{\gamma,\mathrm{TeV}} \frac{dN}{dE_{\gamma,\mathrm{TeV}}}\right) \left(\frac{\langle \sigma v \rangle}{10^{-26} \mathrm{cm}^{-3} \mathrm{s}^{-1}}\right) \left(\frac{100\,\mathrm{GeV}}{M_\chi}\right)^2}_{\text{Particle Physics Input}} \underbrace{J(\theta)} \; \mathrm{erg\,cm^{-2} s^{-1} sr^{-1}}$$

$$J(\theta) = \underbrace{\frac{1}{8.5\,\mathrm{kpc}} \left(\frac{1}{0.3\,\mathrm{GeV/cm^3}}\right)^2 \int_{\text{line of sight}} \rho^2(l) dl(\theta)}_{\text{Astrophysics/Cosmology Input}}$$

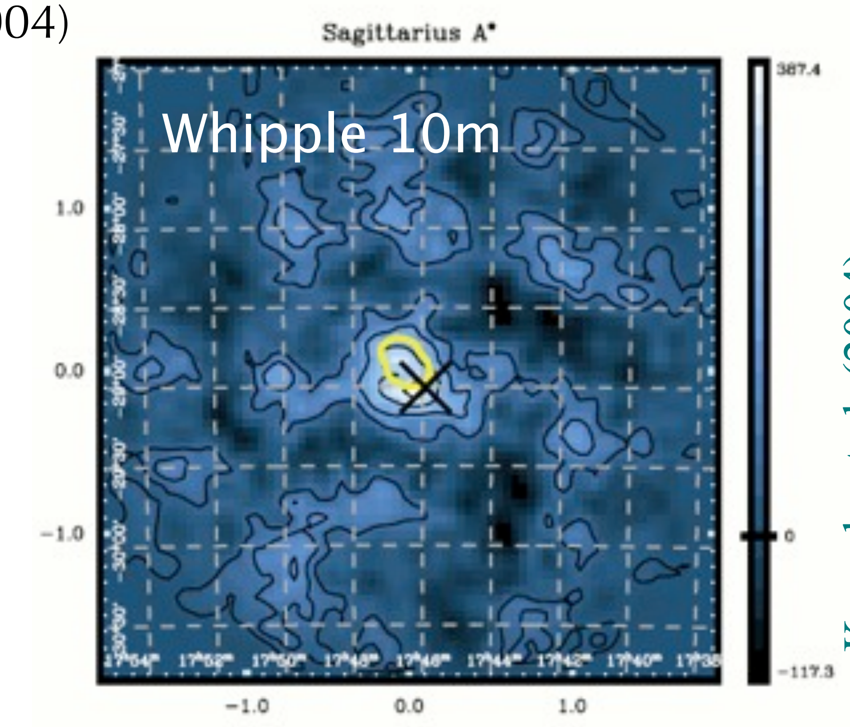




Line-of-sight integral of ρ^2 for a Milky-Way-like halo in the VL Lactea II ΛCDM N-body simulations (Kuhlen et al.)

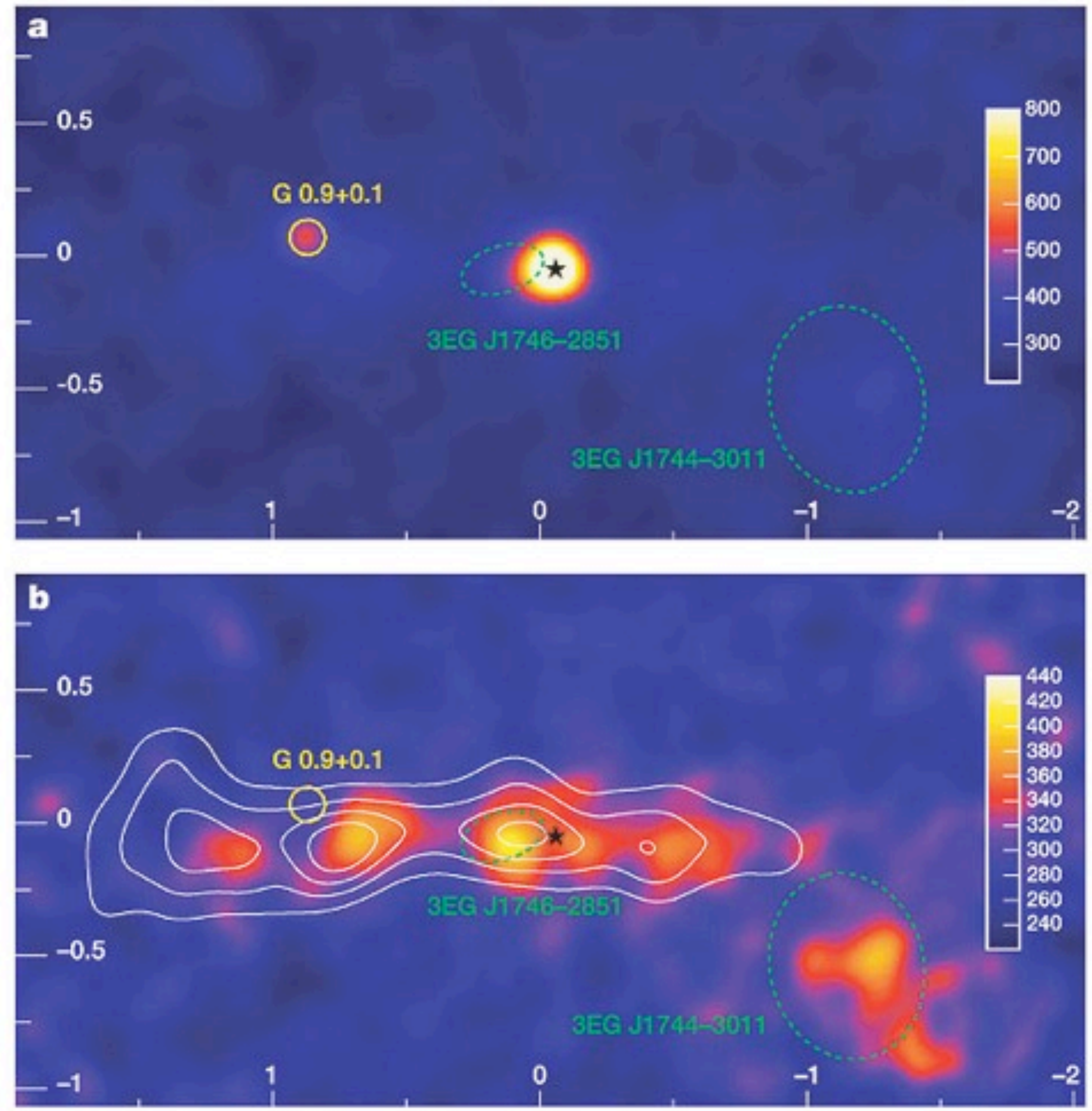
Galactic Center Region

- **EGRET:** 3EG J1746-2851 (Hartman et al. 1999)
- **Whipple 10m (1995-2003, LZA)** - Evidence for GC at 3.7 std. dev., flat spectrum source (Kosack et al. ApJ, 608, L97 2004)



Kosack, et al. (2004)

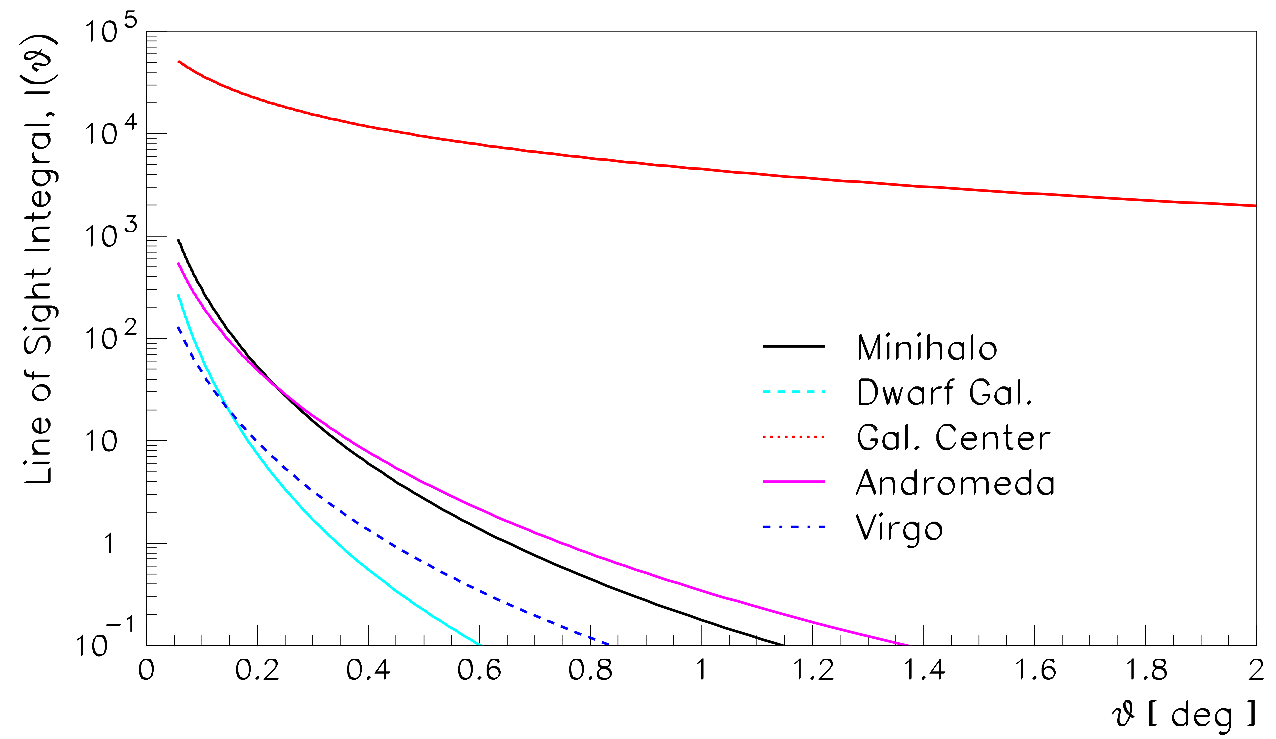
- **CANGAROO-II (2001-2002)** - steep spectrum source ($dN/dE \sim E^{-4.6}$) - not same as Whipple/HESS source (Tsuchiya et al., 2004, ApJ, 606)
- **H.E.S.S. (2004-2006)** - Now >60 std. dev, $dN/dE \sim E^{-2.1}$ cutoff ~15 TeV, no variability, within 15 arcsec Sgr A*?, PWN? diffuse emission from molec. clouds $dN/dE \sim E^{-2.3}$ (Aharonian et al., 2004, A&A, 425, L13; 2006, Nature, 439, 695)
- **MAGIC (2004-2005, LZA, 25hr)** - 7.3 std. dev, conf. HESS spectrum (Albert et al., 2006, 638, L101)

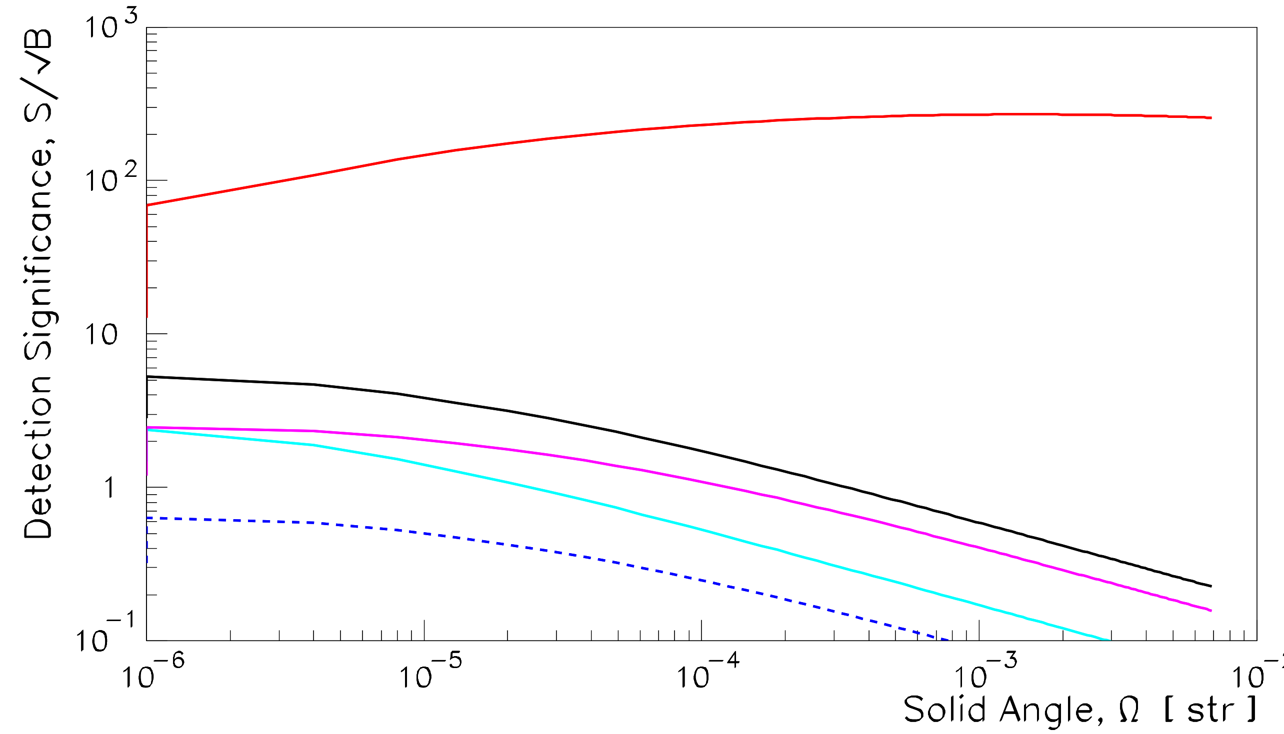


HESS GC region (Aharonian et al., 2006, Nature 439, 695)

Large Astrophysical Backgrounds for DM Search!

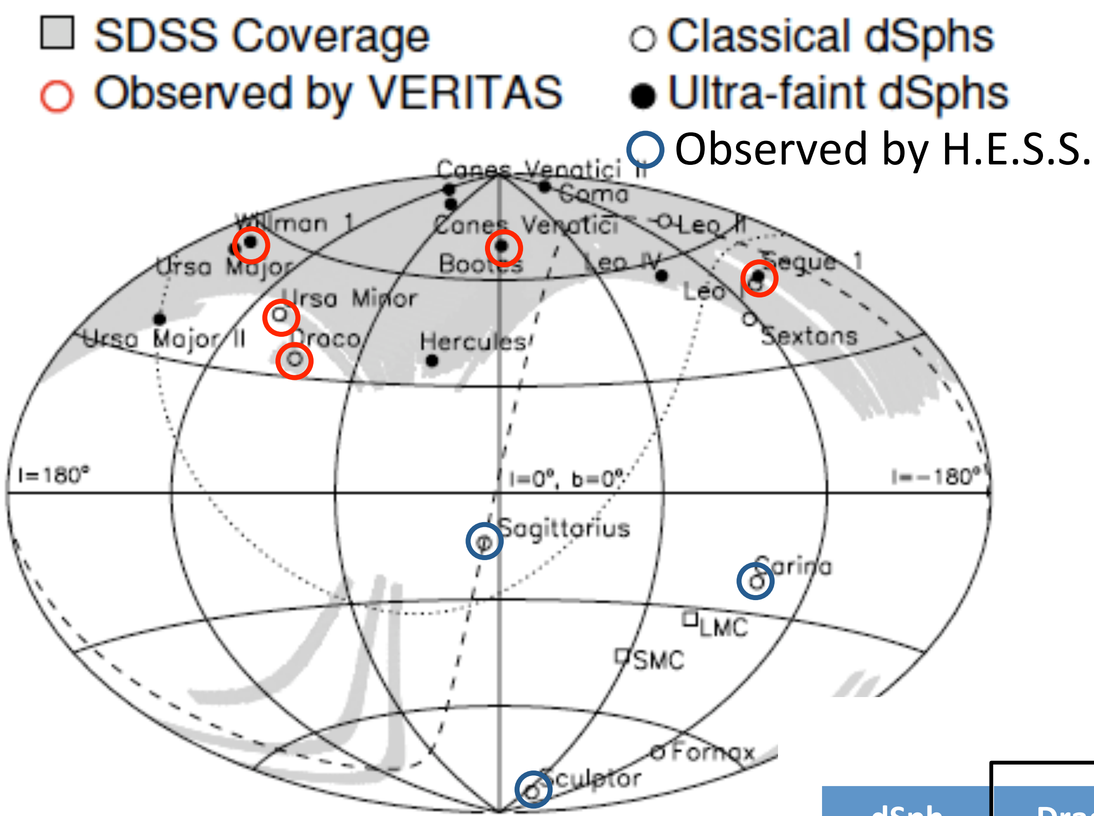
Where to Look Next?





JB 2002

Dwarf Upper Limits



Belokurov et al. (2007)

- Dwarf satellites of the Milky Way are the most promising DM targets outside of the Galactic Center
- Dark-Matter dominated objects with mass to light ratios of more than 100
- DM Distribution is tightly constrained by stellar velocity dispersion measurements the map out the DM gravitational potential
- Clean sources with limited uncertainties, but currently one to two orders of magnitude beyond the reach of Fermi, VERITAS or HESS

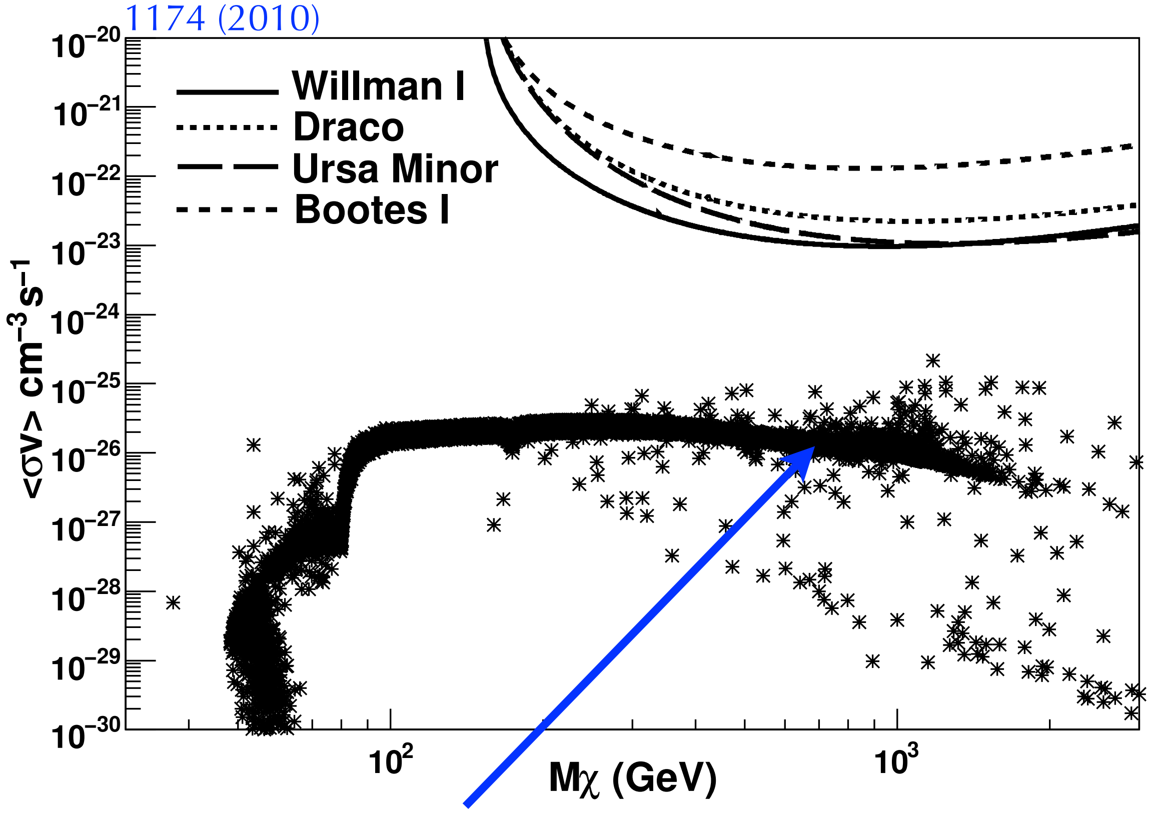
(Talk by Luis Reyes later at this meeting)

	VERITAS					HESS			
dSph	Draco	Ursa Minor	Bootes I	Willman	Segue I	Sgr	Carina	Sculptor	Canis Major
Distance (kpc)	82	66	62	38	23	24	101	79	8
DM profile	NFW	NFW	NFW	NFW	Einasto	NFW/ Core	NFW	NFW	NFW
$\mathrm{Log}_{10}\langle J\rangle$ ($\mathrm{GeV}^2\ \mathrm{cm}^{-5}$)	18.2	18.4	18.1	18.9	19	19.3/ 20.8	17.6	18.5	18.0
T_{obs} (h)	18.4	18.9	14.3	13.7	25.0	11.0	14.8	11.8	9.6
Ann. channel	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	$\tau^+\tau^-$, bbar	W^+W^-	W^+W^-	W^+W^-	W^+W^-
$\langle\sigma v\rangle^{95\%}$ ($\mathrm{cm}^3\ \mathrm{s}^{-1}$)	5×10^{-23}	2×10^{-23}	5×10^{-22}	10^{-23}	8×10^{-24}	10^{-23}/ 2×10^{-24}	2×10^{-22}	6×10^{-23}	10^{-23}

VERITAS Dwarf Limits

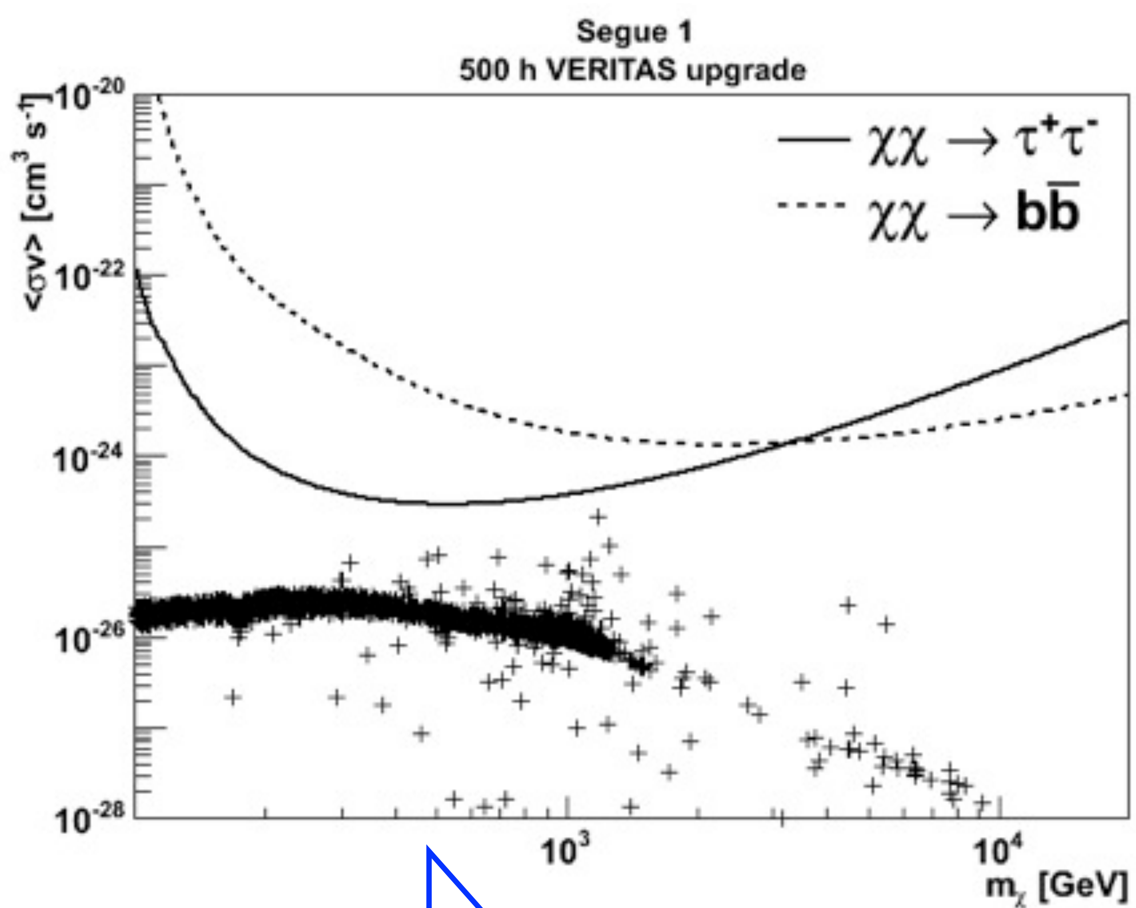
Thanks to DARKSUSY, Gondolo, Edsjo, Bergstrom, Ullio, Schelke, Baltz, Bringmann and Duda !

Acciari, V.A. et al. (for the VERITAS collaboration) ApJ, 720, 1174 (2010)



Detection σ ~ decoupling σ⇒ narrow spread

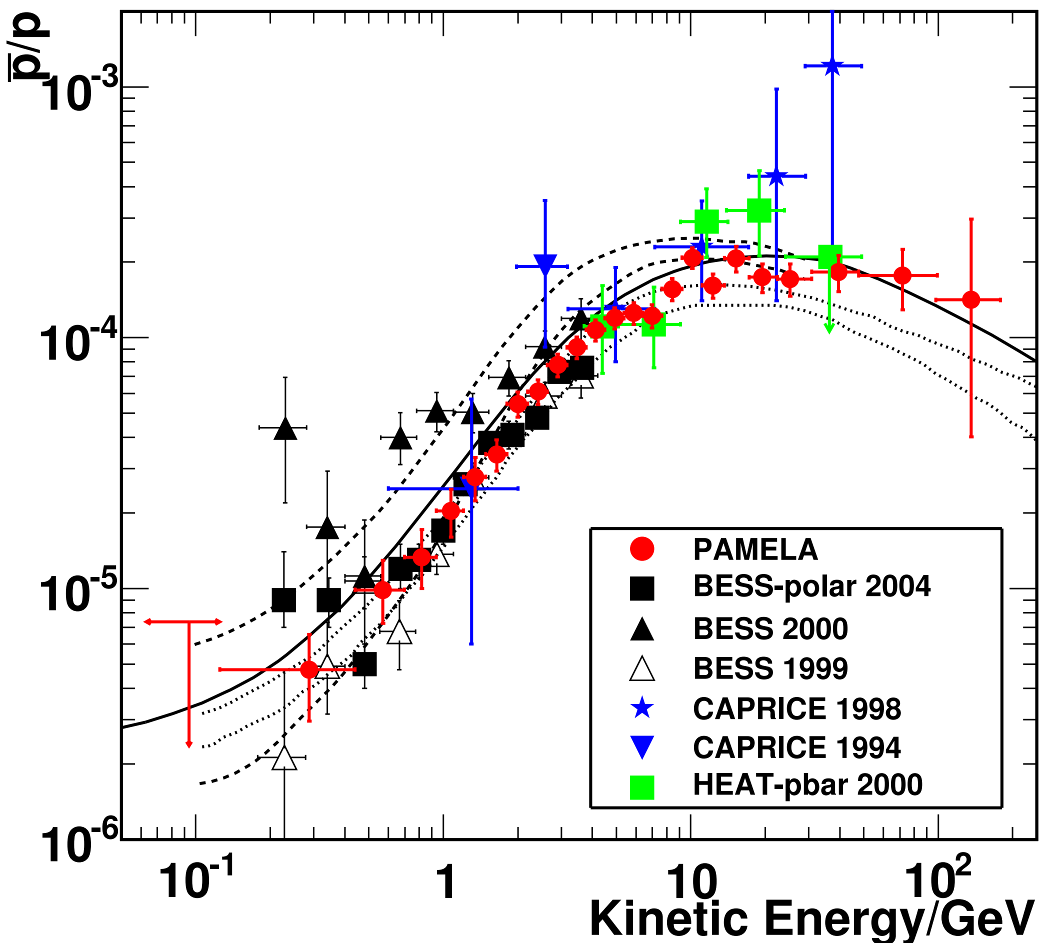
Projected Sensitivity

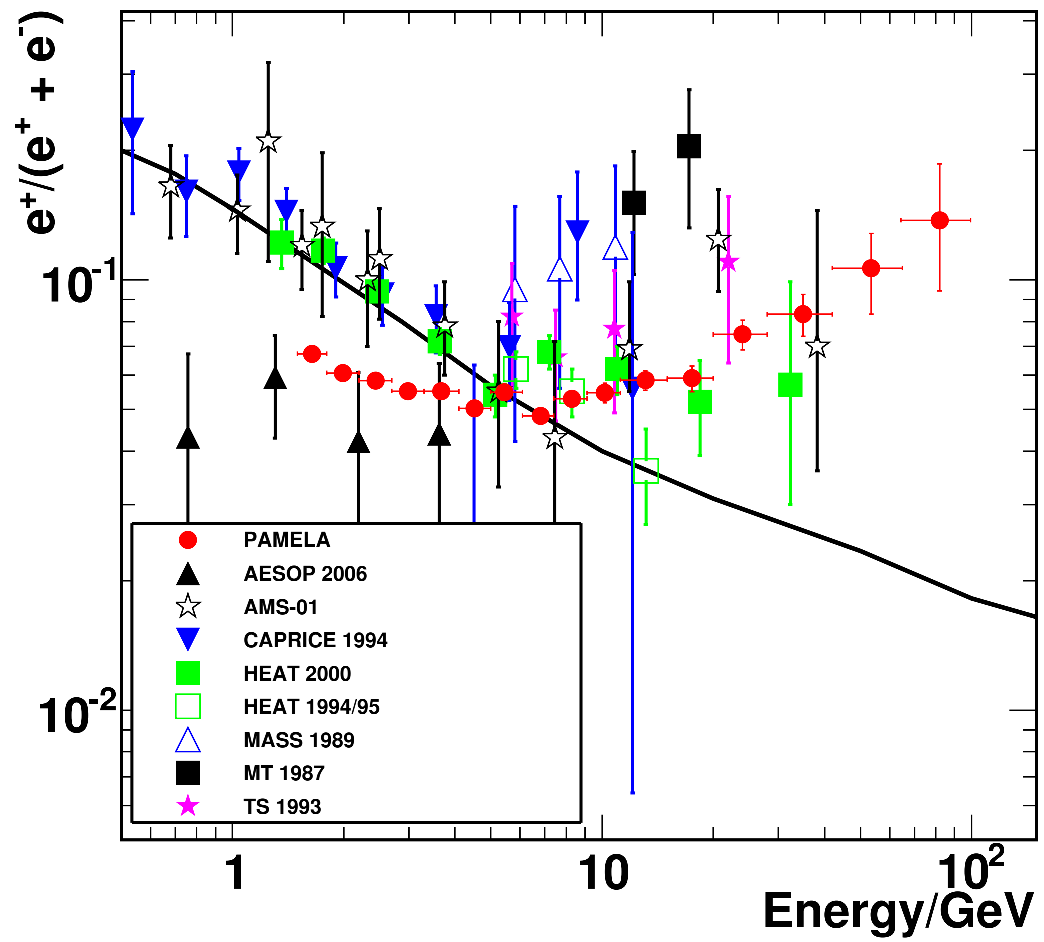


Projected limits for 5 year exposure

- Limits fall several orders of magnitude from natural models. Longer exposures will help but are limited by systematics
- For VERITAS, combining observations of several sources over 5 years will bring upper limits within one order of magnitude of the natural cross section

Positrons and Antiprotons

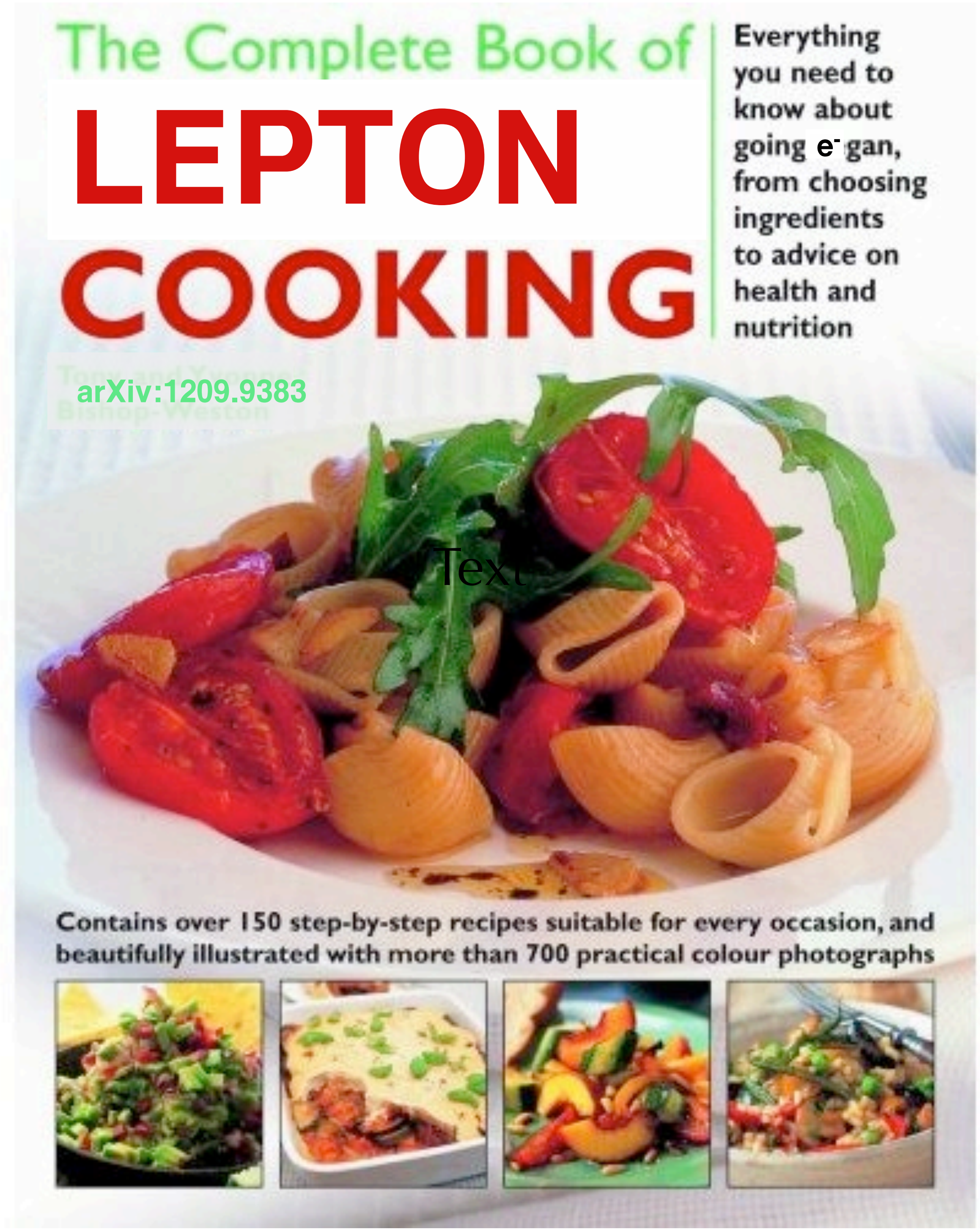




- Positron excess but no antiprotons motivated leptophillic models to boost electron production, while suppressing hadronic channels.

- These typically require astrophysical or particle physics boosts, electrons produce IC photons - these models can already be constrained by gamma-ray measurements.

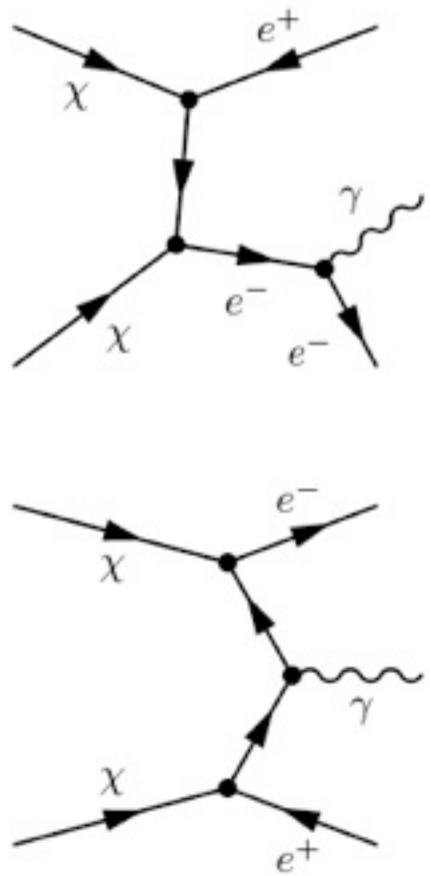
Building Leptonic Models



Boosting Electrons

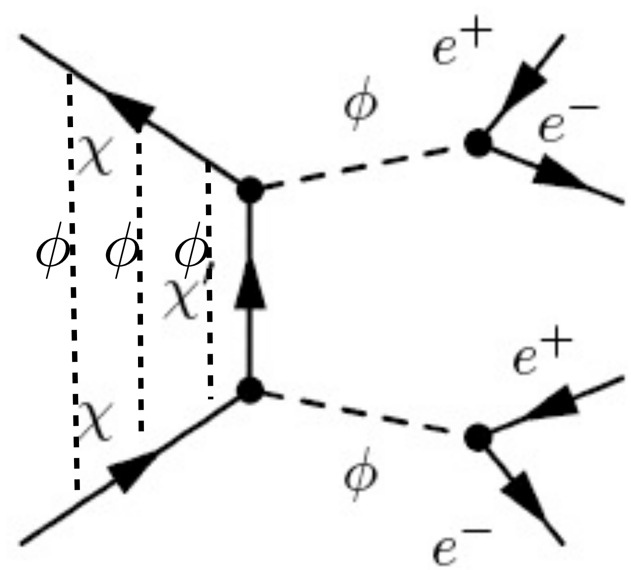
Annihilation into light leptons is helicity suppressed with respect to annihilation into heavier fermions

$$R \sim \underbrace{\left(\frac{m_e}{m_f}\right)^2}_{\text{spin flip penalty}} \underbrace{\left(\frac{m_\chi^2 - m_e^2}{m_\chi^2 - m_f^2}\right)^2}_{\text{phase space}}$$



(Bringmann, Bergström and Edsjö, 2009, JHEP, 01, 049)

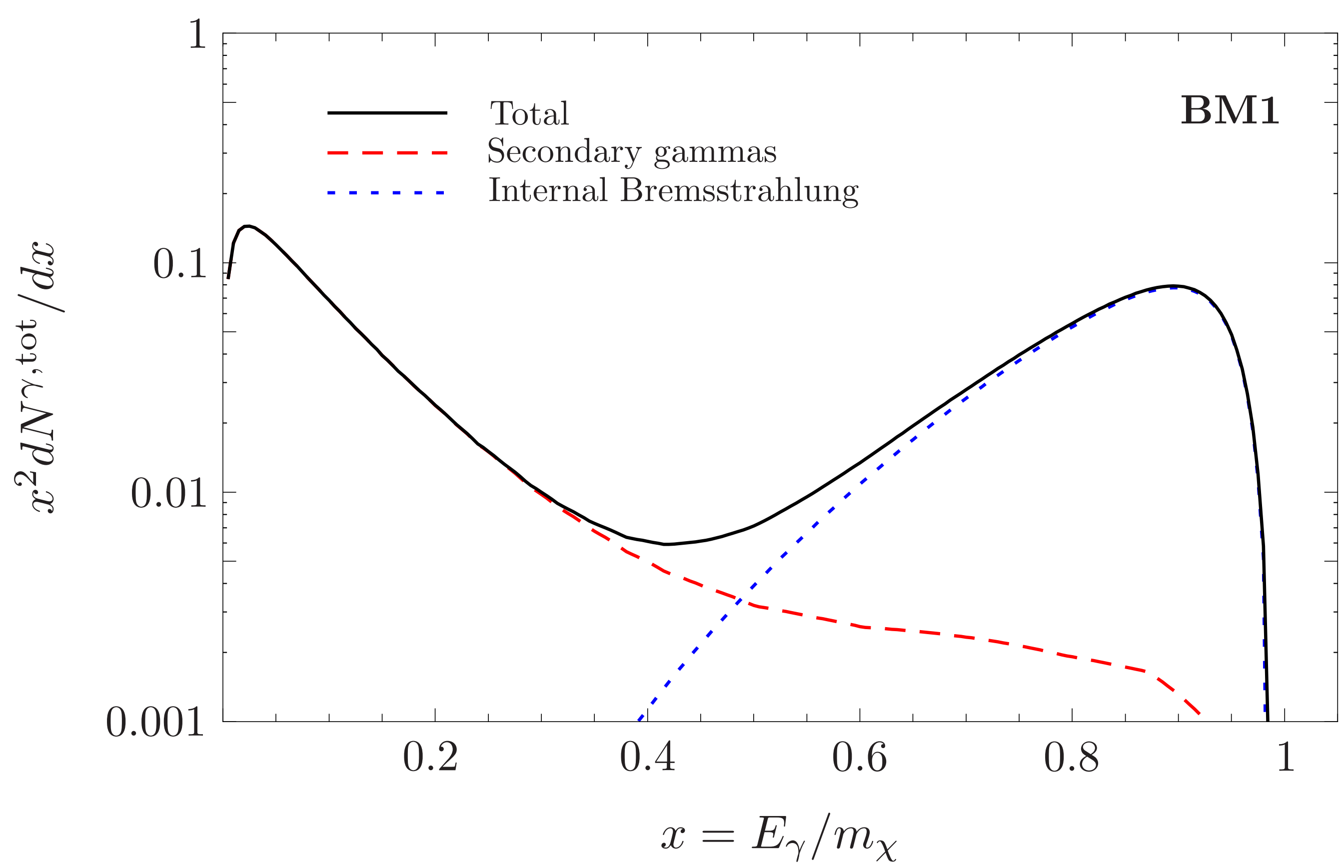
New scalar fields with appropriate mass can allow electron-production, but make hadronic production kinematically forbidden. Sommerfeld enhancement by exchange of ϕ can result in a further boost in cross section



(e.g.,Arkani-Hamed, Finkbeiner, Slatyer, and Weiner, 2009, PRD 79, 015014)

Internal bremmstrahlung can circumvent helicity suppression, but electromagnetic IB gives gamma-rays near kinematic maximum and $W^\pm, Z$ bremmstrahlung can overproduce antiprotons

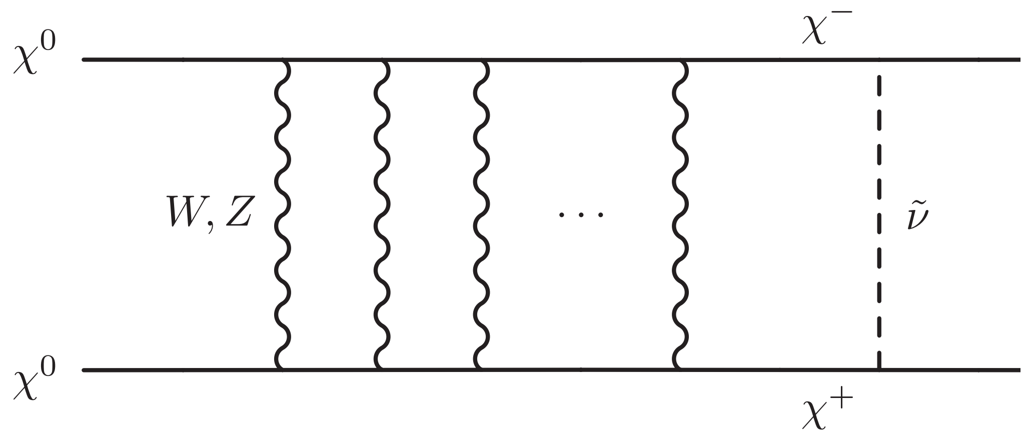
Internal/Final State Brems



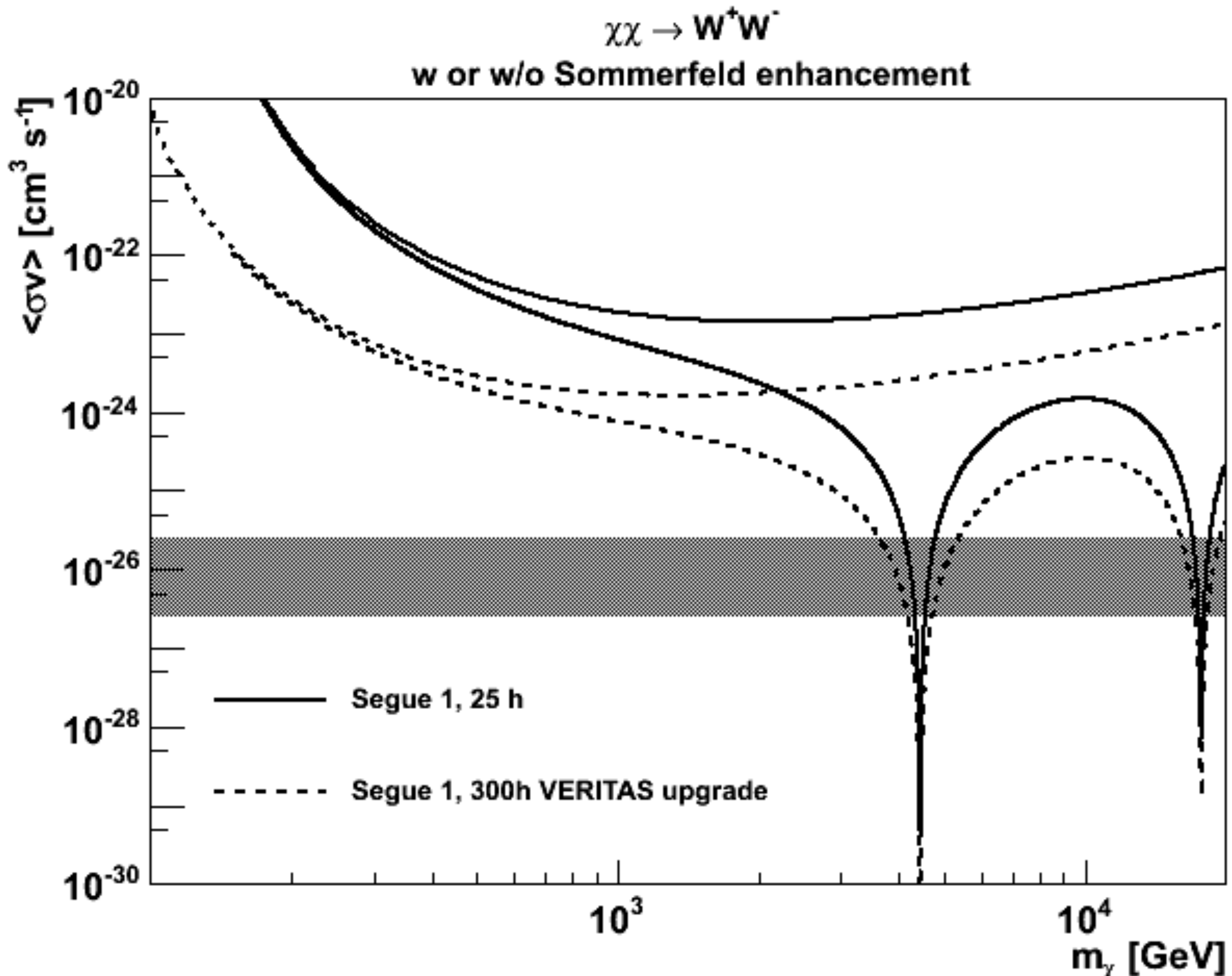
- Internal Bremsstrahlung (or final-state bremss) would boost the signal in VHE gamma-ray experiments - for such scenarios ground-based instruments would be competitive with Fermi constraints down to lower energies (a few hundred GeV).

Sommerfeld Enhancement

At sufficiently high neutralino masses, the W and Z can act as carriers of a long-range (Yukawa-like) force, resulting in a velocity dependent enhancement in cross section (1/v or even $1/v^2$ enhancement near resonance)



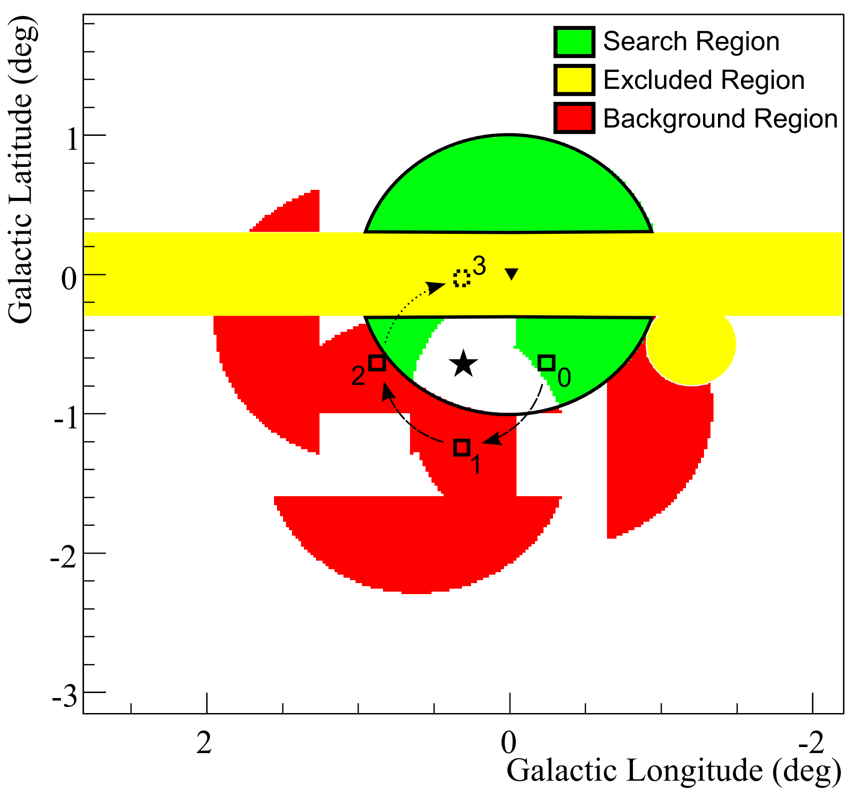
Lattanzi and Silk, PRD 79, 083523 (2009), Profumo (2005)

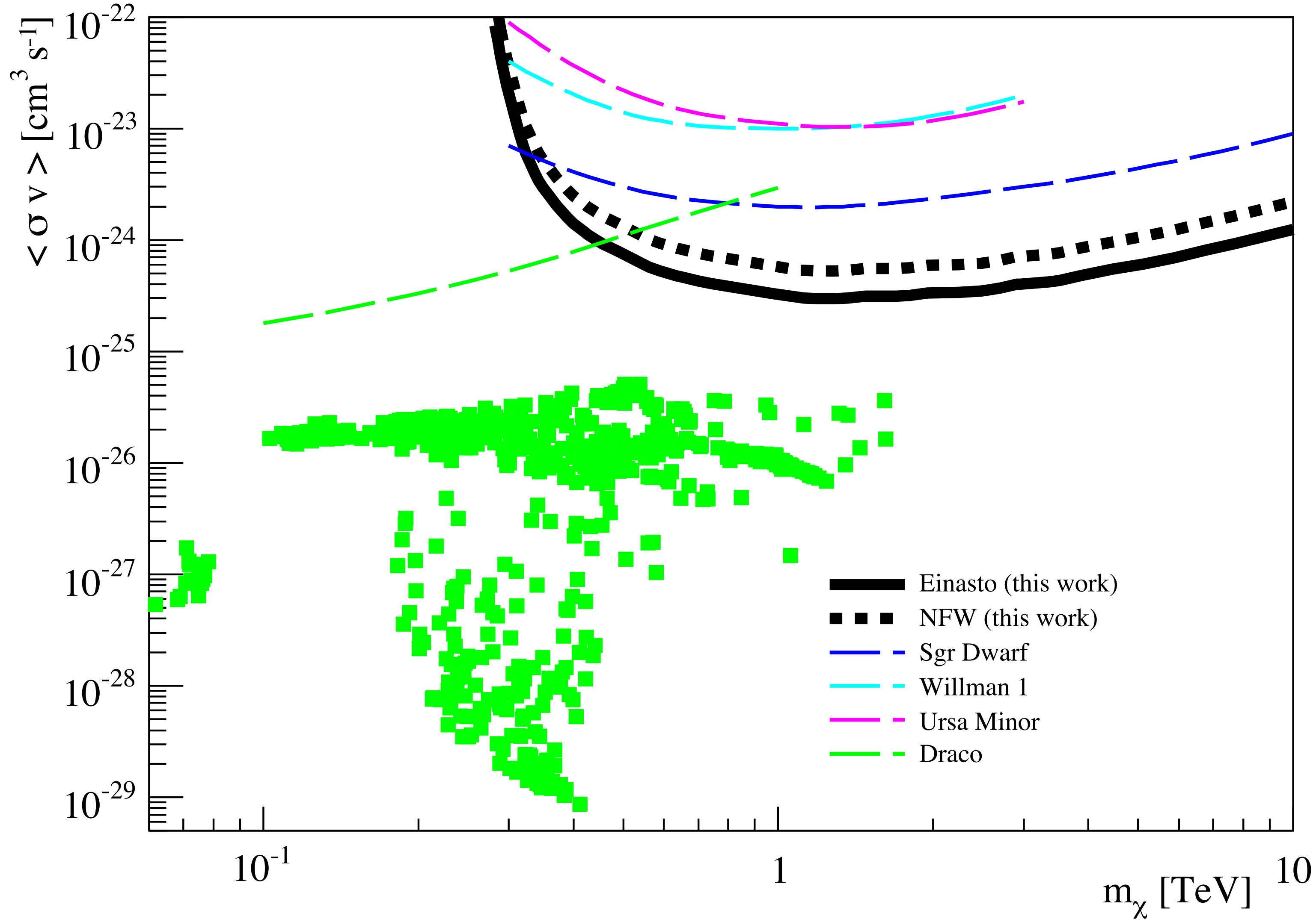


(Matthieu Vivier et al. for the VERITAS Collaboration, 2011, ICRC proceedings)

- At high mass, expect Sommerfeld enhancement from W, Z exchange for standard neutralinos can give large enhancement in cross section, larger at small velocities in smaller halo substructure (e.g., Dwarfs)

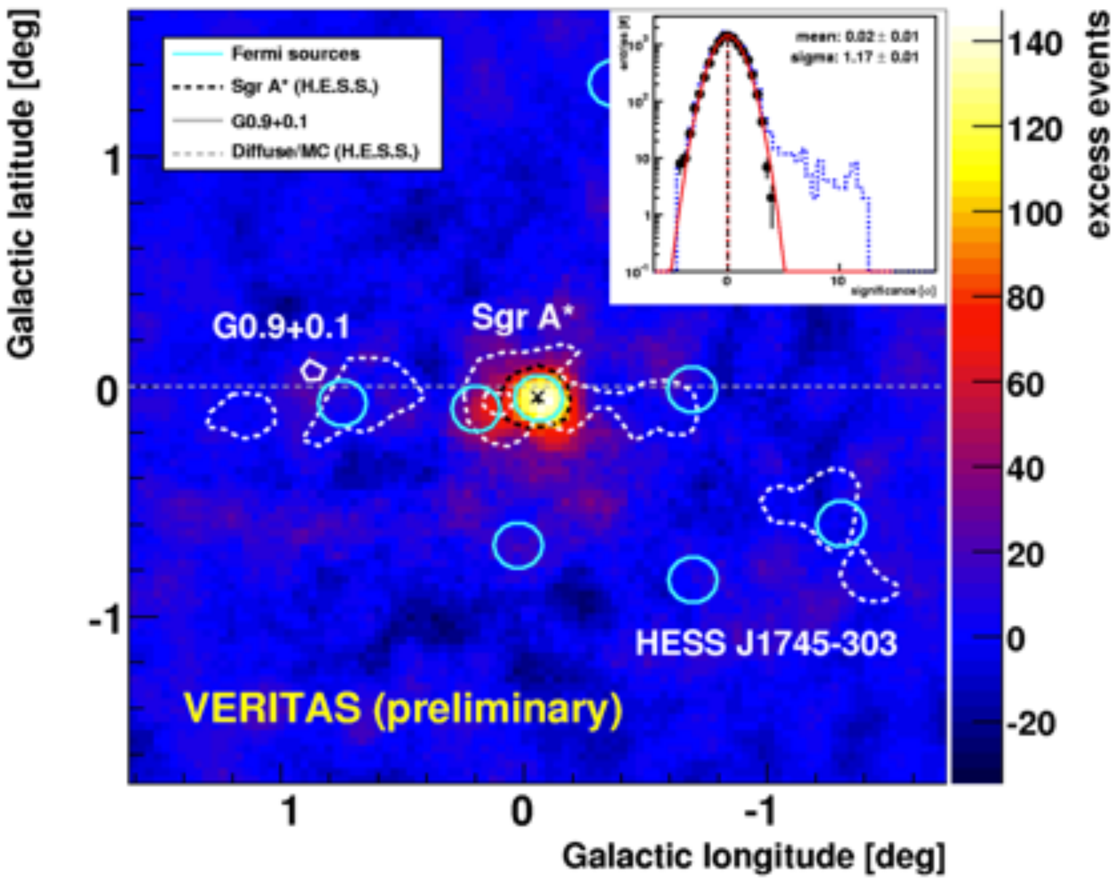
Galactic Center Revisited

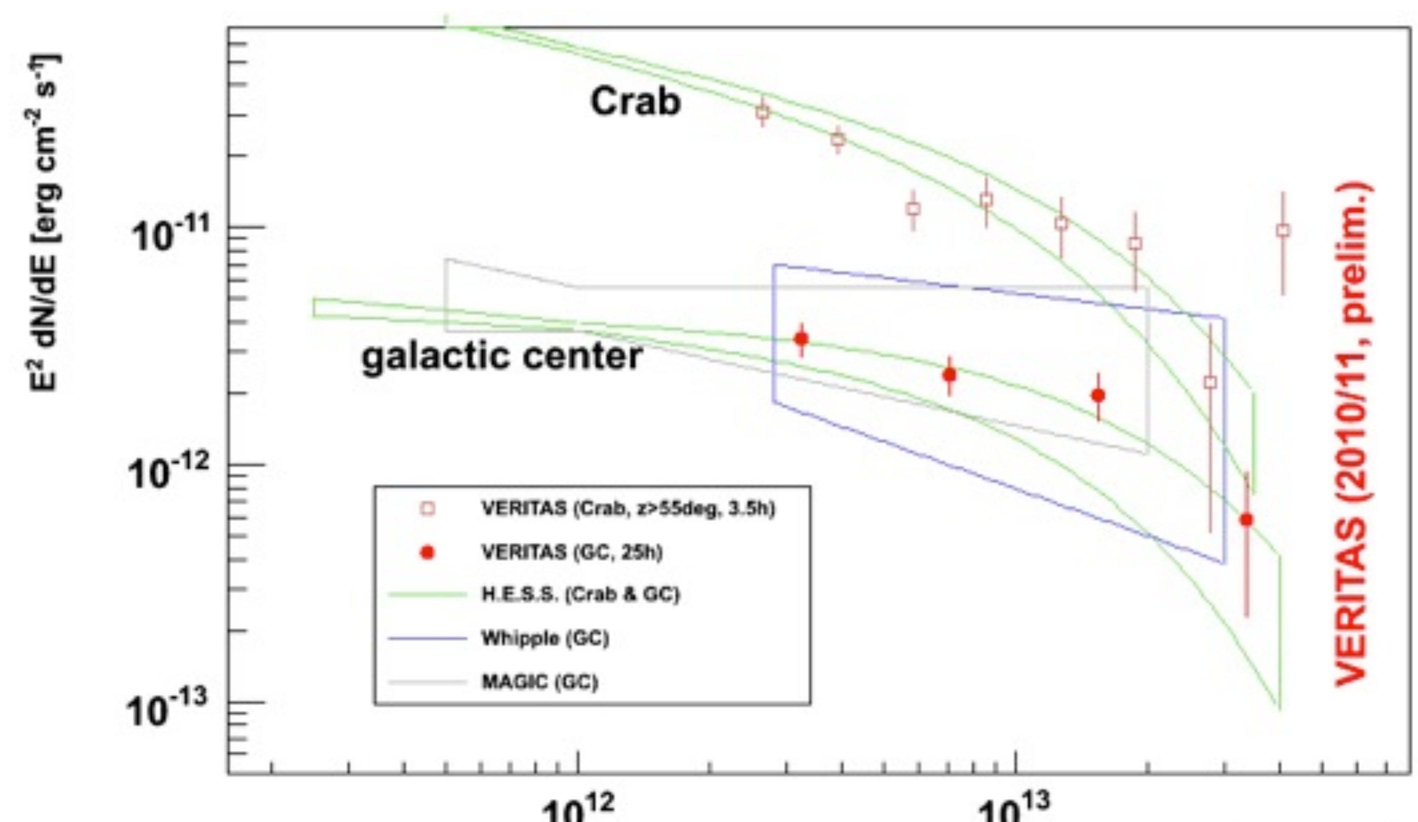




- Even though bright source at GC, can still get better limits from region around GC (Aharonian et al. for the HESS collaboration, PRL 106, 1301)

VERITAS Galactic Center

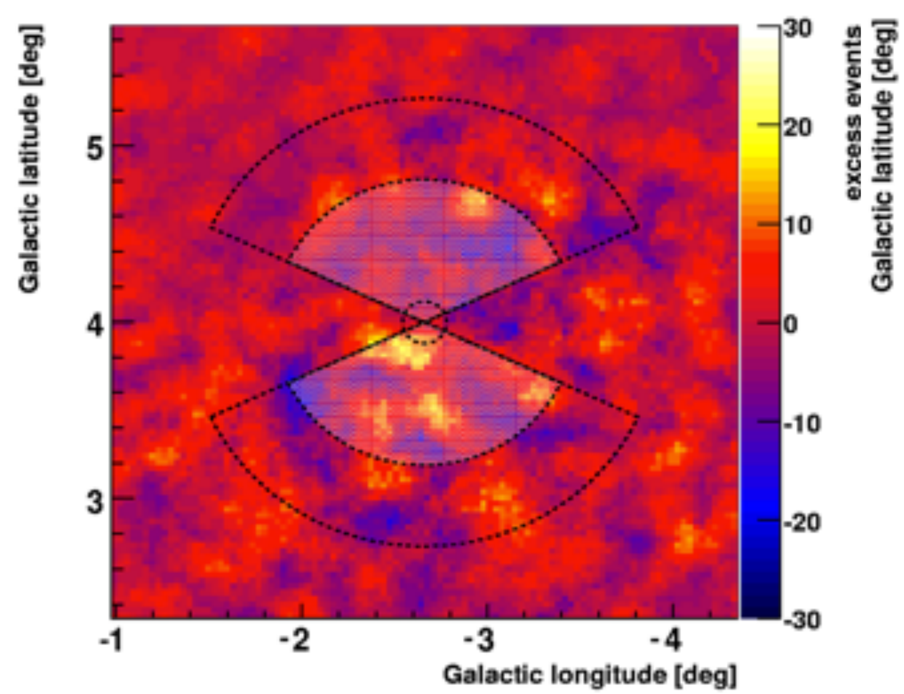


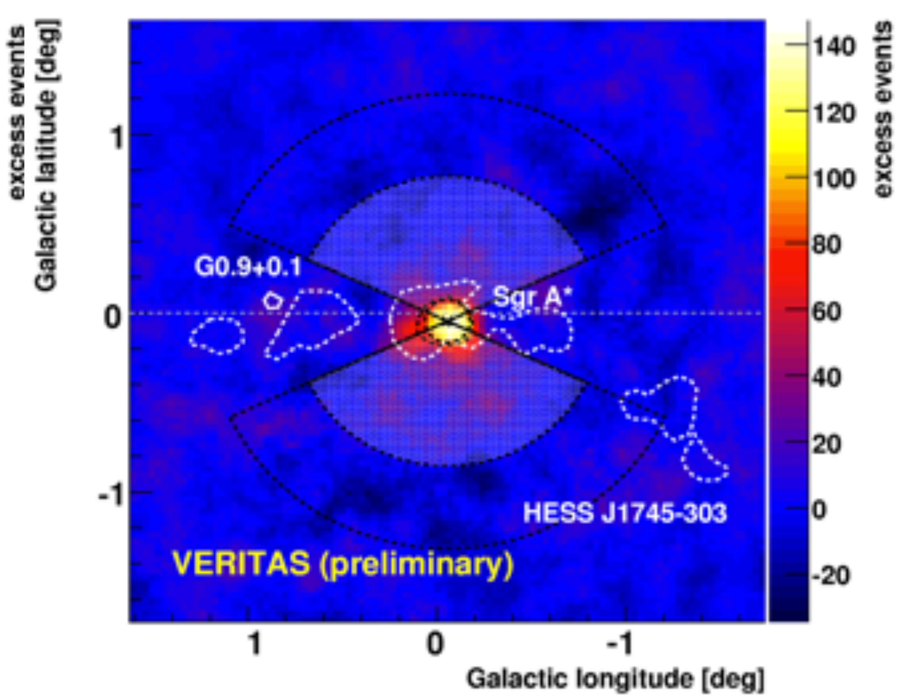


Beilicke, M. for VERITAS Collaboration, Fermi Symposium, May 2011

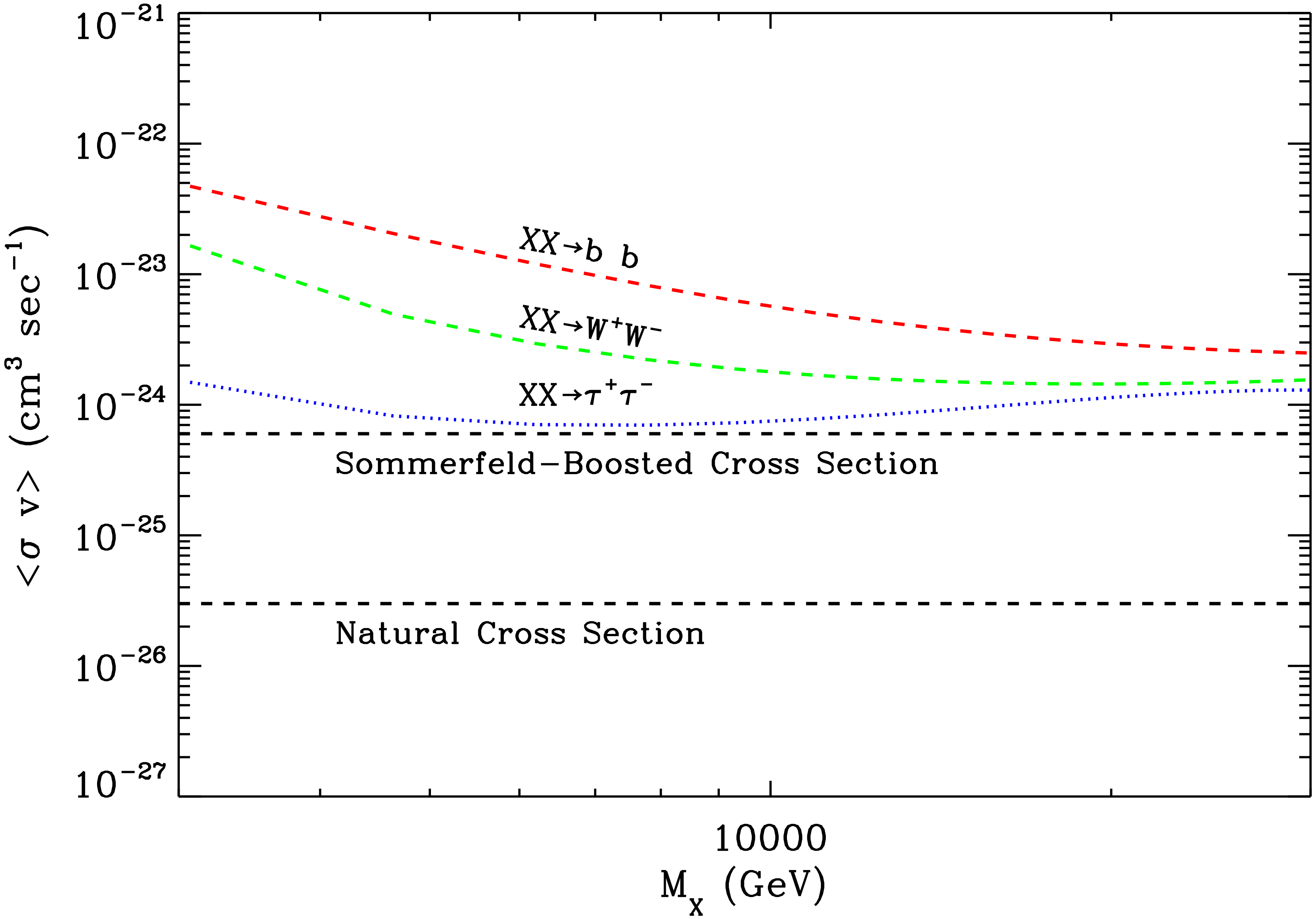
Galactic Center appears to have a strong Astrophysical source, but can still cut out a region around center

For 12σ VERITAS detection, optimum region is between 0.34 and beyond the edge of the FoV (around 3 deg)



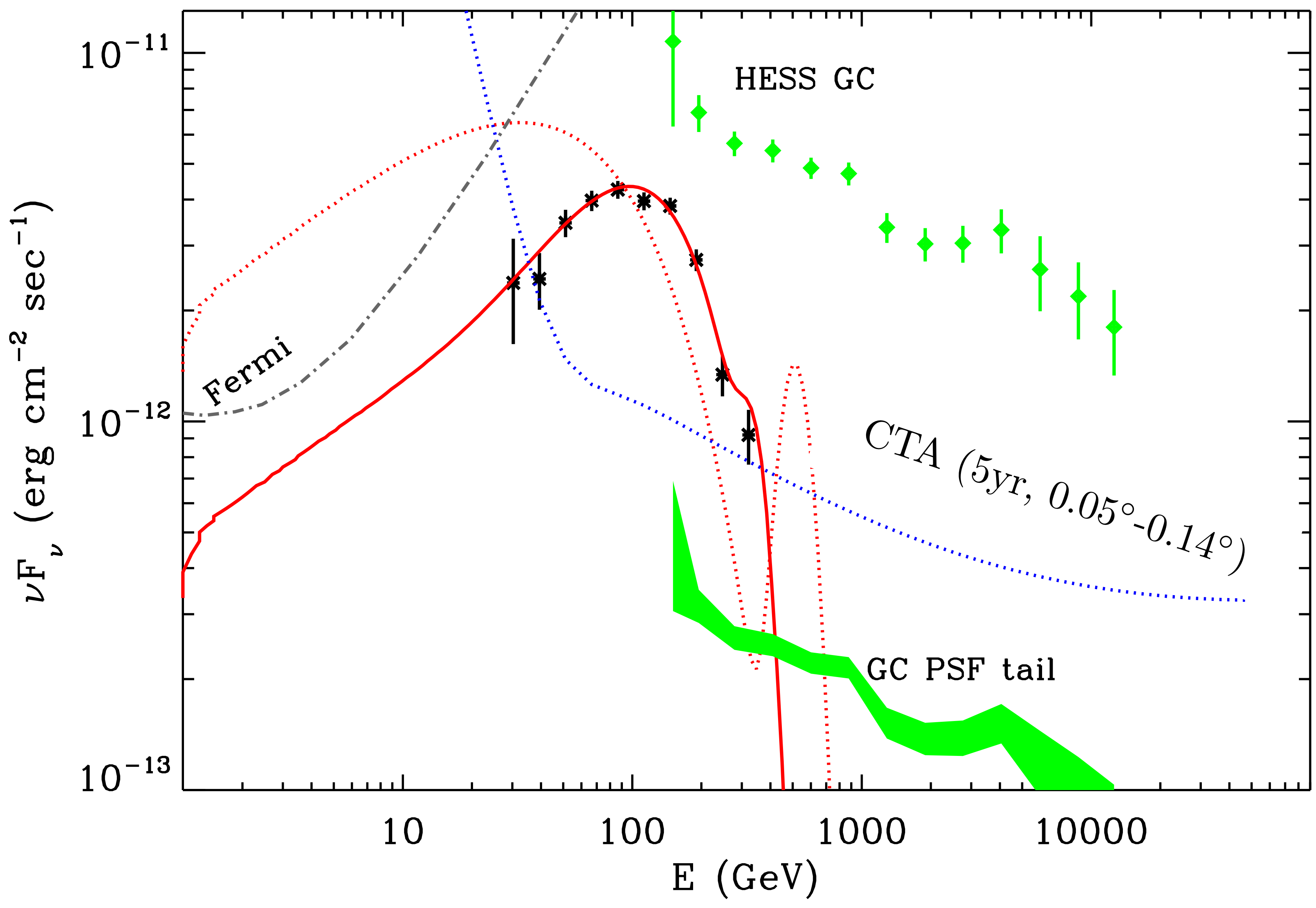


Projected VERITAS Sensitivity



- Estimated upper limits for 5 years of VERITAS LZA data based on probability observed number of counts given NFW halo convolved with angular resolution, mass-dependent fits to Pythia spectra convolved with energy resolution.

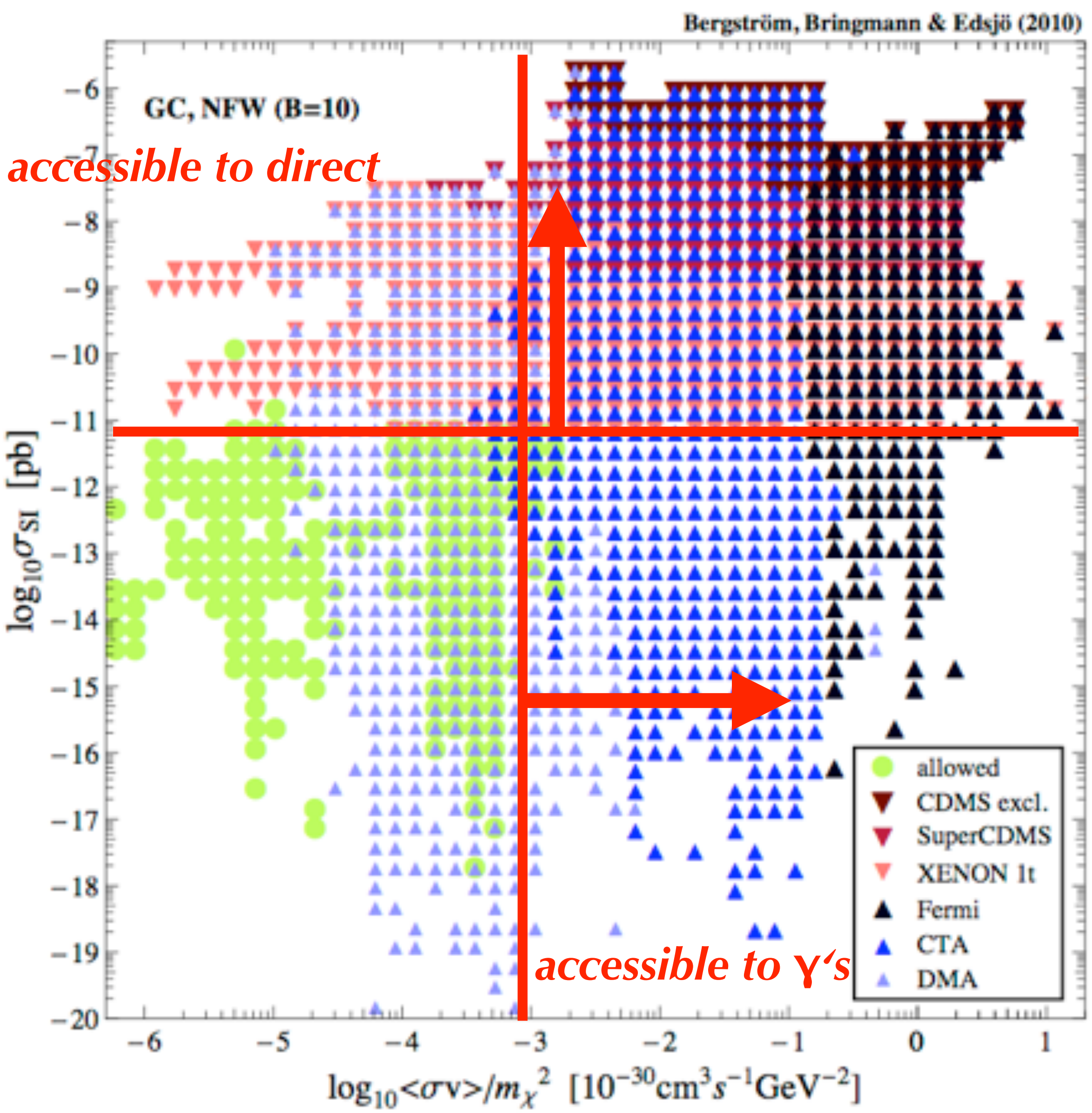
GC DM Prospects

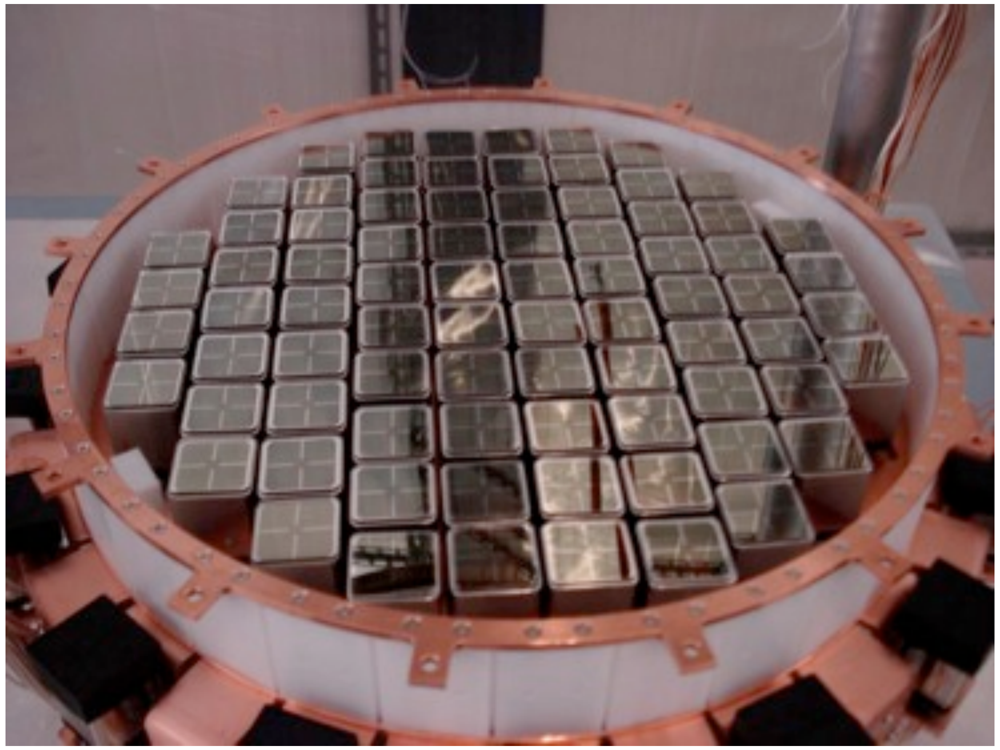


- For CTA (a future large ground-based array) lower threshold, improved angular resolution and larger field of view could result in spectral measurements for generic cross-section with no boost.

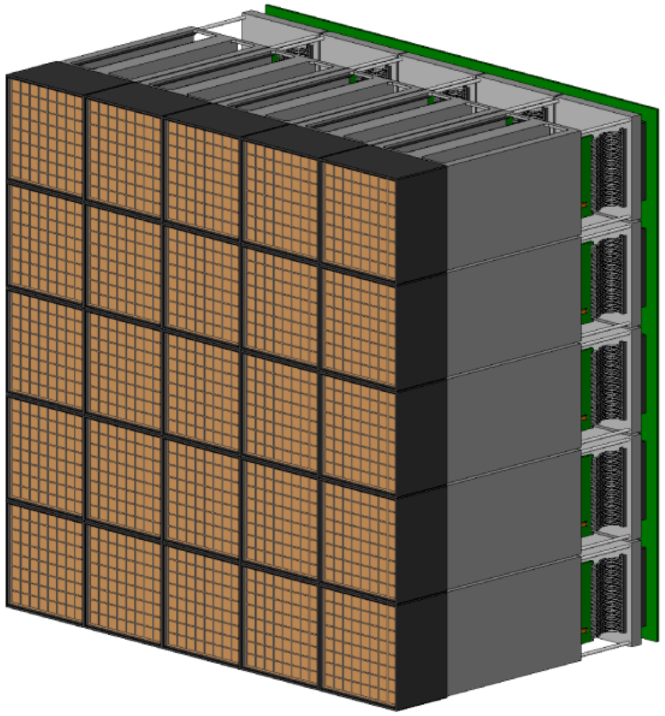
Direct and Indirect Detection

[hep-ph] arXiv:1011.4514 L. Bergstrom et al.





Xenon100 Detector



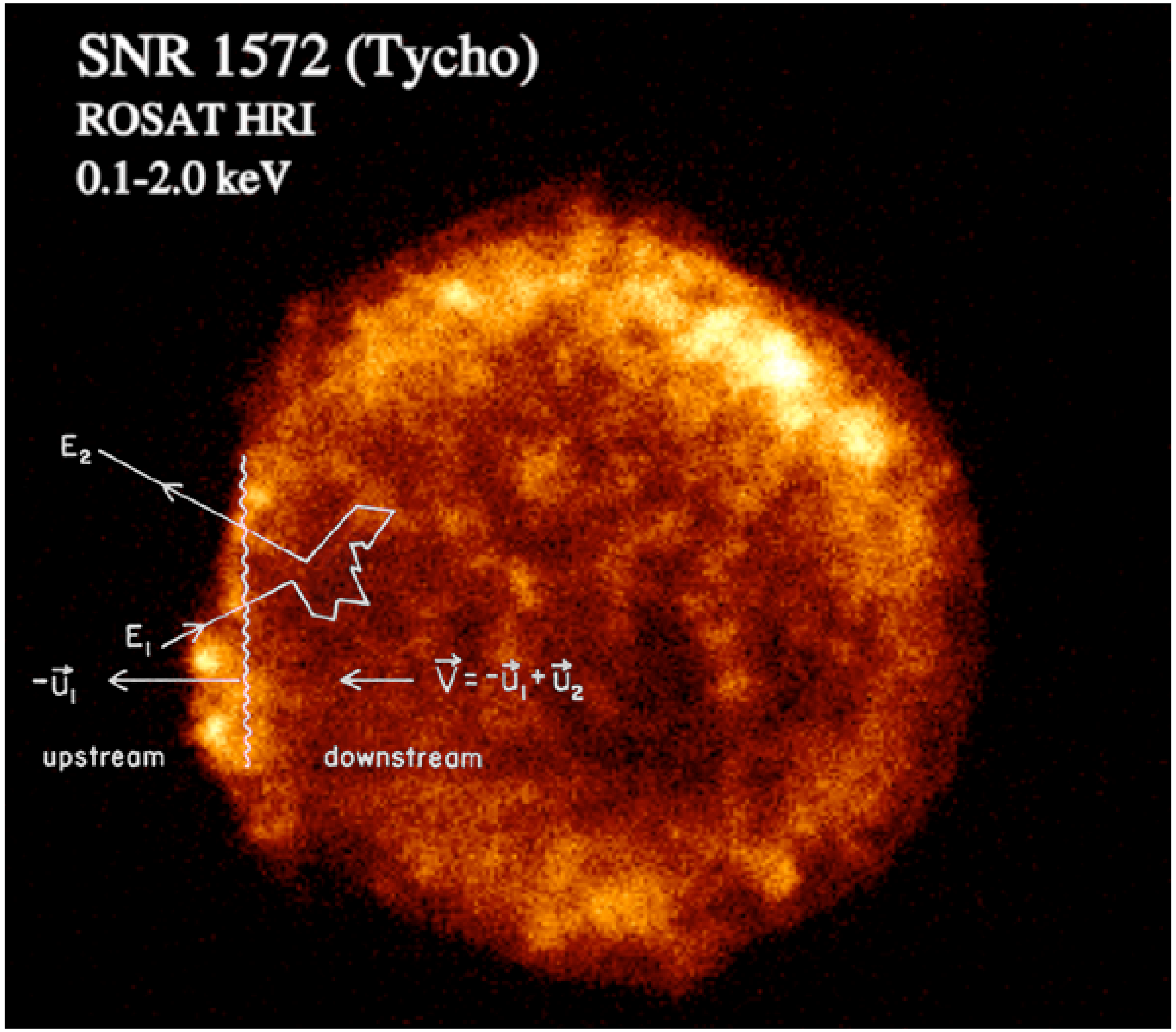
Proposed CTA SC camera module with 25 2″ MAPMTs

- Scientific complementarity
- Technical complementarity

Galactic Particle Accelerators

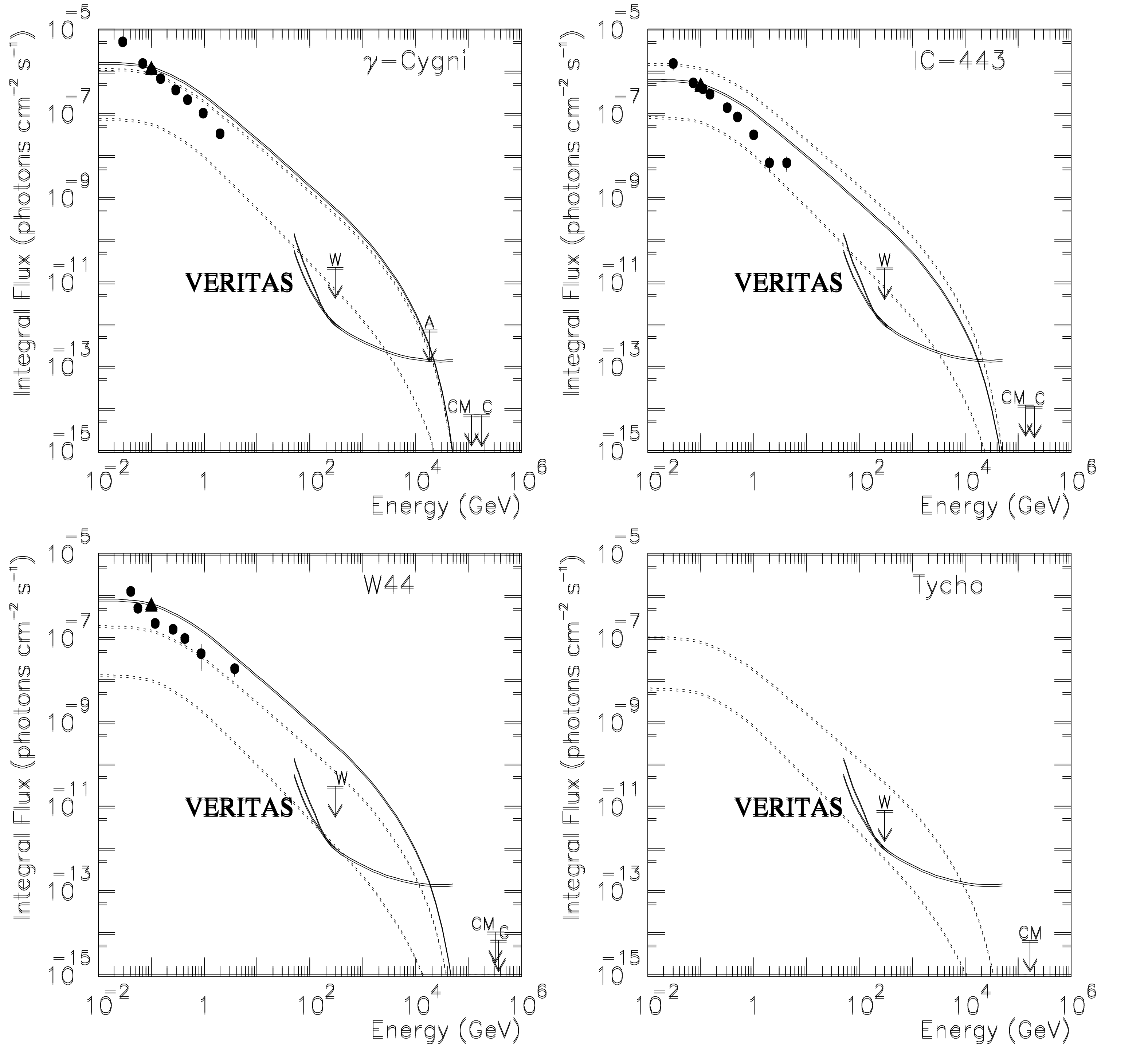
Origin of Cosmic Rays

Do SNR blast shocks really provide the sites for CR acceleration?



Predicted SNR Signal

- Drury, Aharonian and Volk predicted gamma-ray signal from pion production in cosmic ray sources
- Looked with Whipple, and saw nothing!
- One of the original motivations for VERITAS was that we should either detect SNR or produce difficulties for an SNR origin of GCRs.



HESS SNR Images

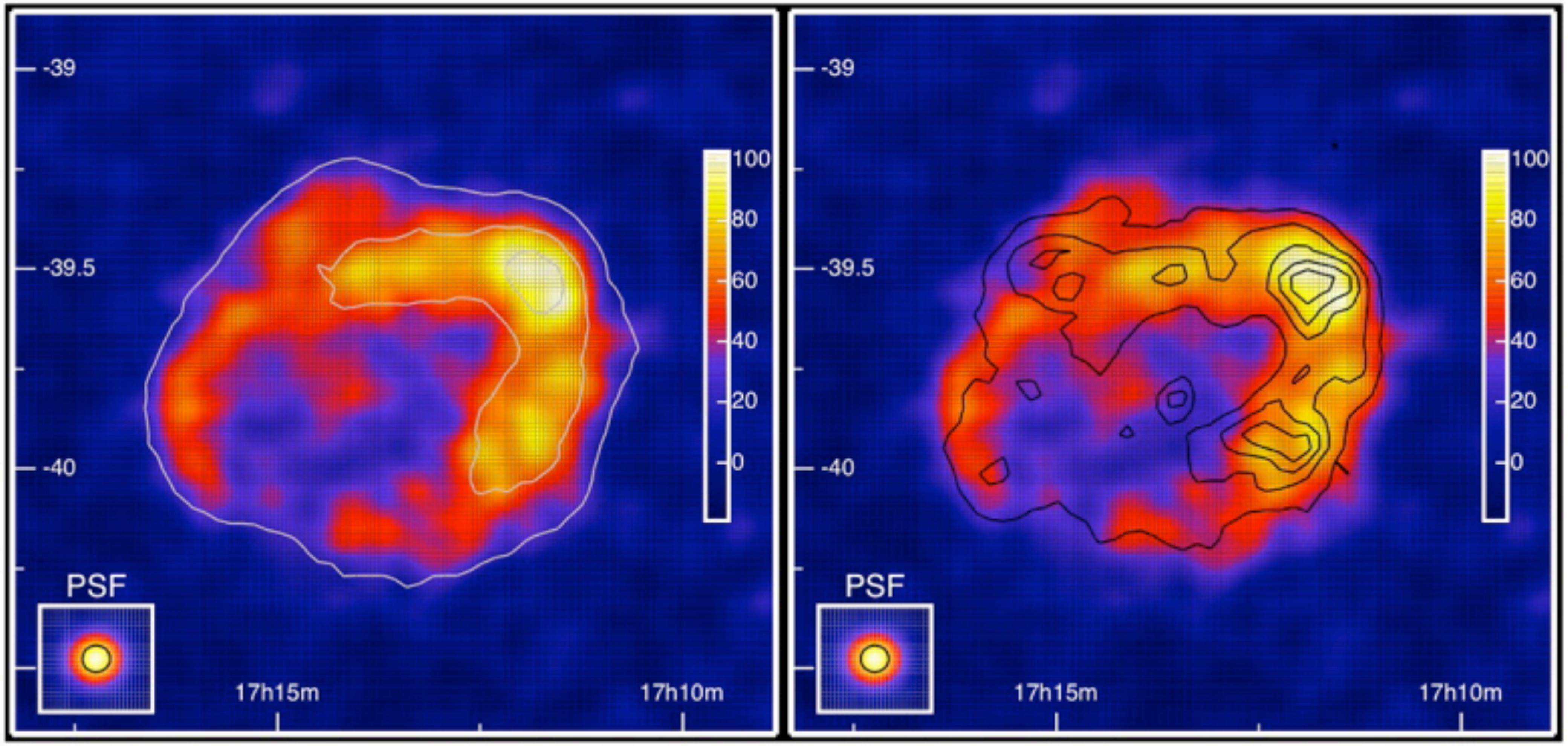
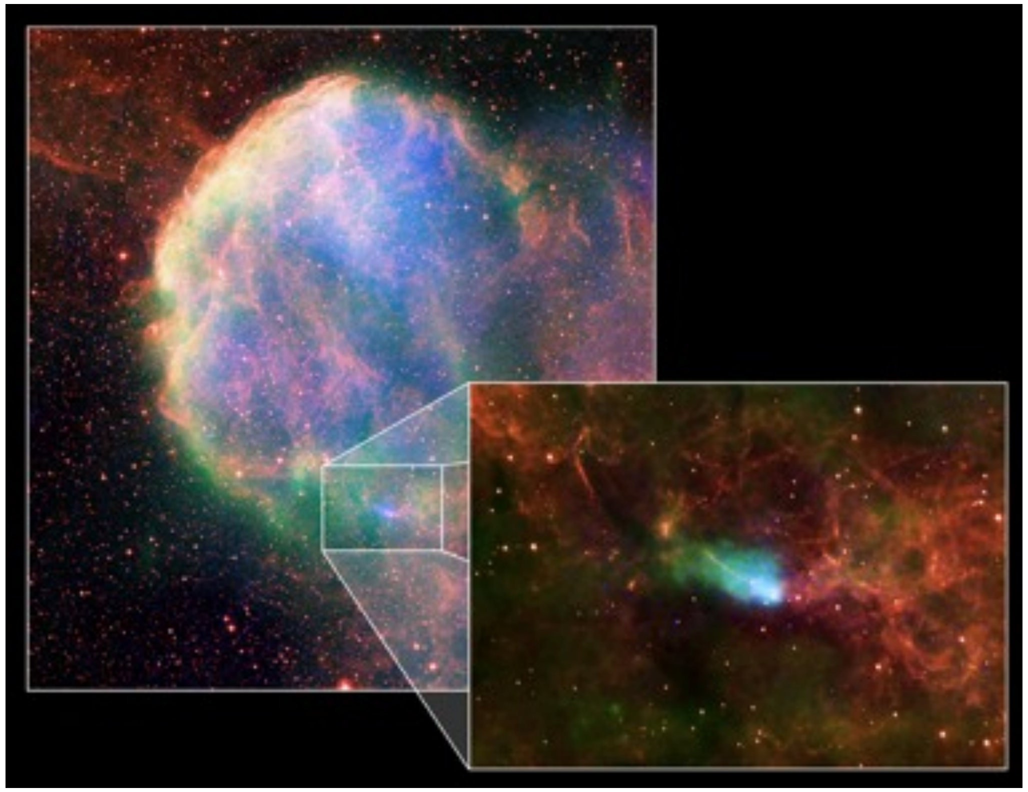


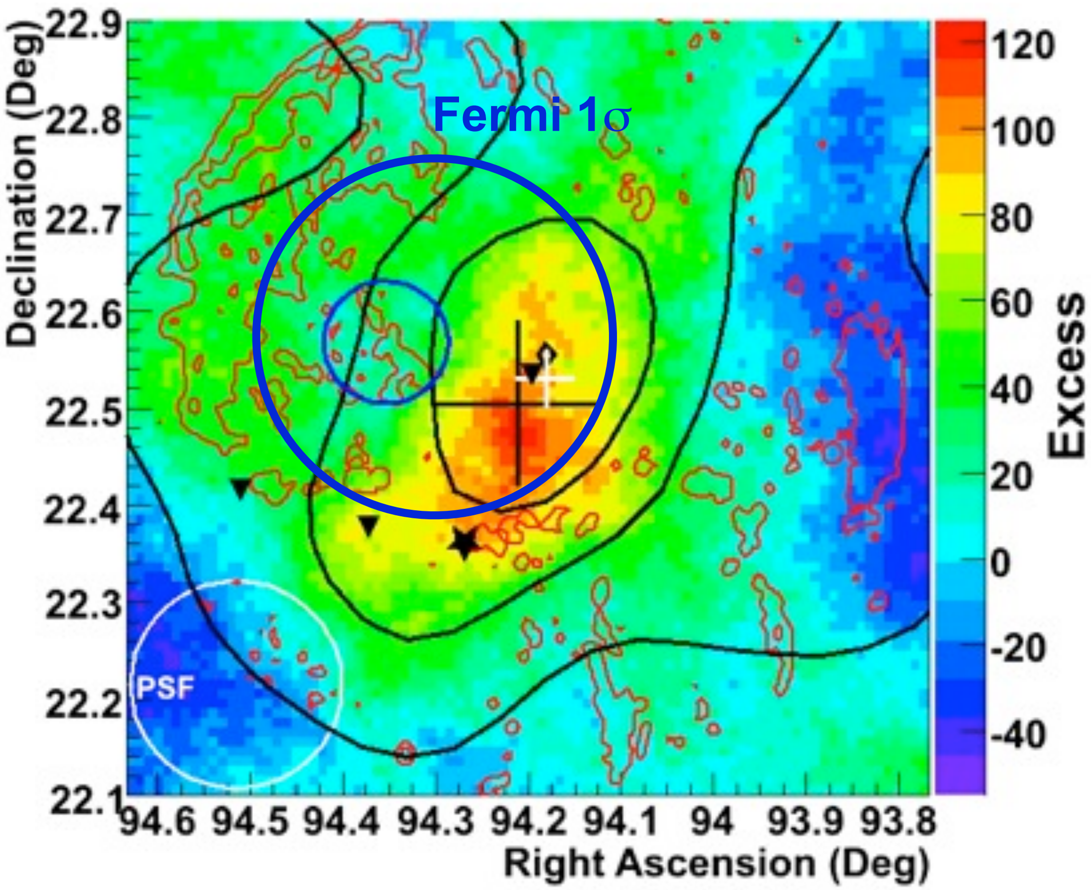
FIGURE 8. These are two remarkable representations of the H.E.S.S. observations of RX J1713.7-3946 [12]. The images are smoothed with a Gaussian of 2 arc-min. On the left, the overlaid light contours show the significance levels of the different features. The levels are at 8, 18, and 24σ. On the right the X-ray ASCA contours are shown as black lines. The full detail can only be seen in the color version of the figure in the original publication

- HESS observations of SNR resulted in the first resolved images in TeV energies.
- Morphology similar to X-ray emission, subsequent constraints point to leptonic emission.

IC443 SNR

Chandra image of IC443 and Pulsar wind nebula

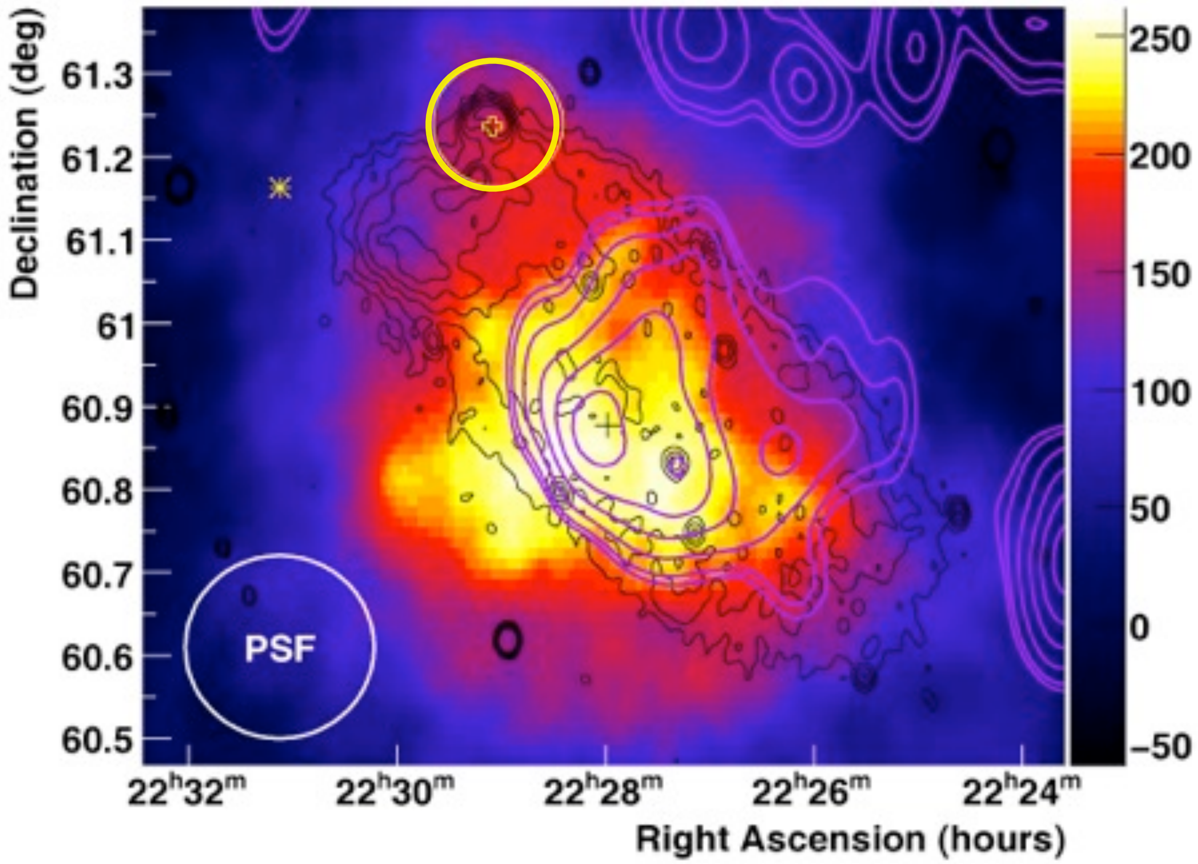




- IC443 SNR, radio/x-ray bright remnant with maser emission indicating interaction with molecular cloud.
- VERITAS/MAGIC discovery in 2007, Fermi detection of extended emission
- VERITAS detection 37h, 8.2σ, 3.2% Crab with extended emission
- Spectral index: $\mathbf{\Gamma = 2.99 \pm 0.38_{stat} \pm 0.30_{sys}}$
- Clear extension, overlap with CO (molecular cloud), PWN tail pointing in wrong direction $\Rightarrow \pi^0$ emission?

(Analysis by Humenski and Bugaev)

G106.3 +2.7 SNR



- Energetic pulsar PSR J2229+6114 and SNR/PWN with E-dot ~ 2 x 10^{37} erg/s, age ~ 10 kyr.
- Fermi-LAT source J2229.0+6114 consistent with PWN

- VERITAS detection in SNR region, away from PWN (V. A. Acciari et al., ApJ, 2009)
- 33 hr data in 2008, 6.0σ , ~5% Crab.
- Clearly extended emission, peak overlaps CO.
- $\Gamma = 2.3 \pm 0.3\text{stat} \pm 0.3\text{sys}$, consistent with power law to 35 TeV.
- Milagro reports > 10 TeV emission from region (Abdo et al., 2009).
- *With IC443, and W28 (HESS detection) several sources show correlation with molecular clouds => π^0 emission and build the case for SNR as acceleration sights of cosmic ray nuclei!*

(Scott Wakely)

Tycho SNR

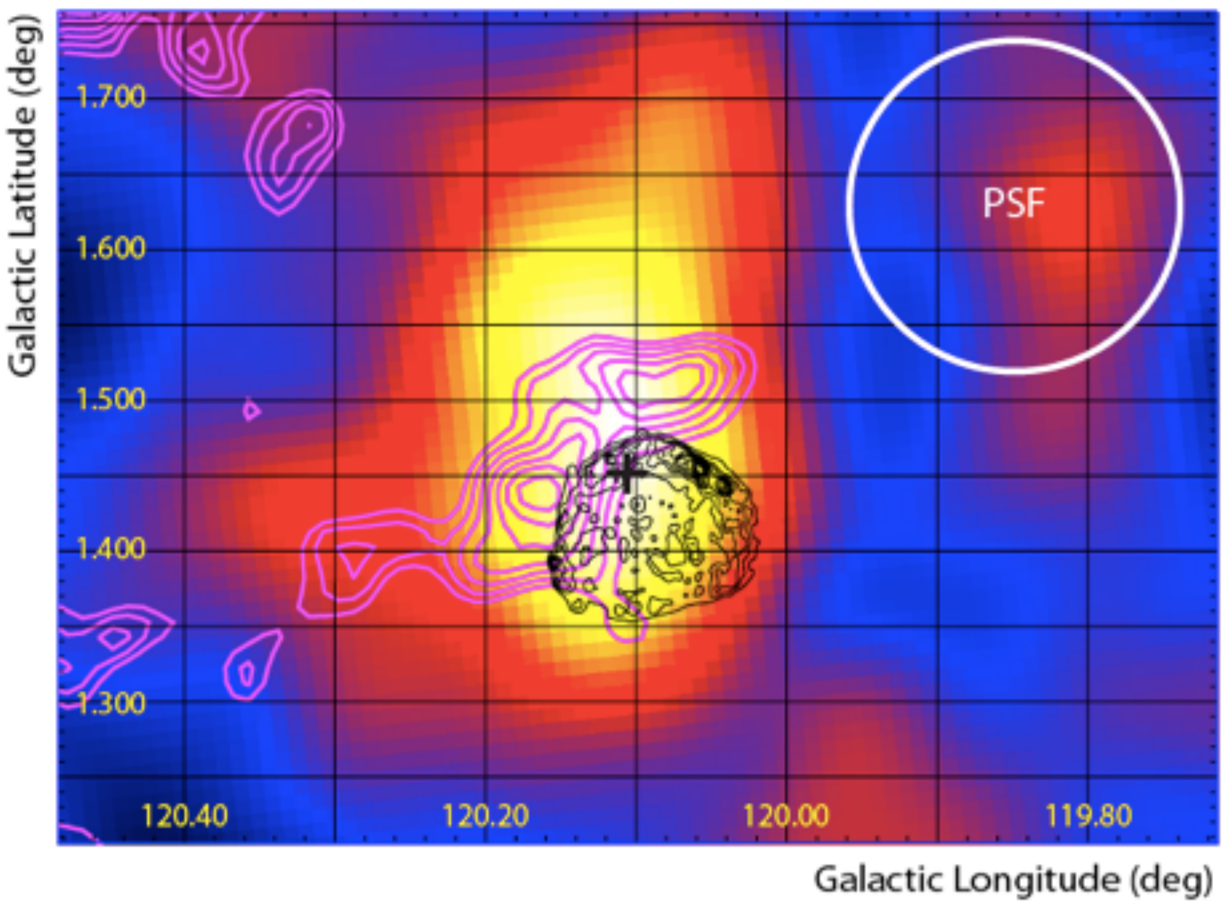
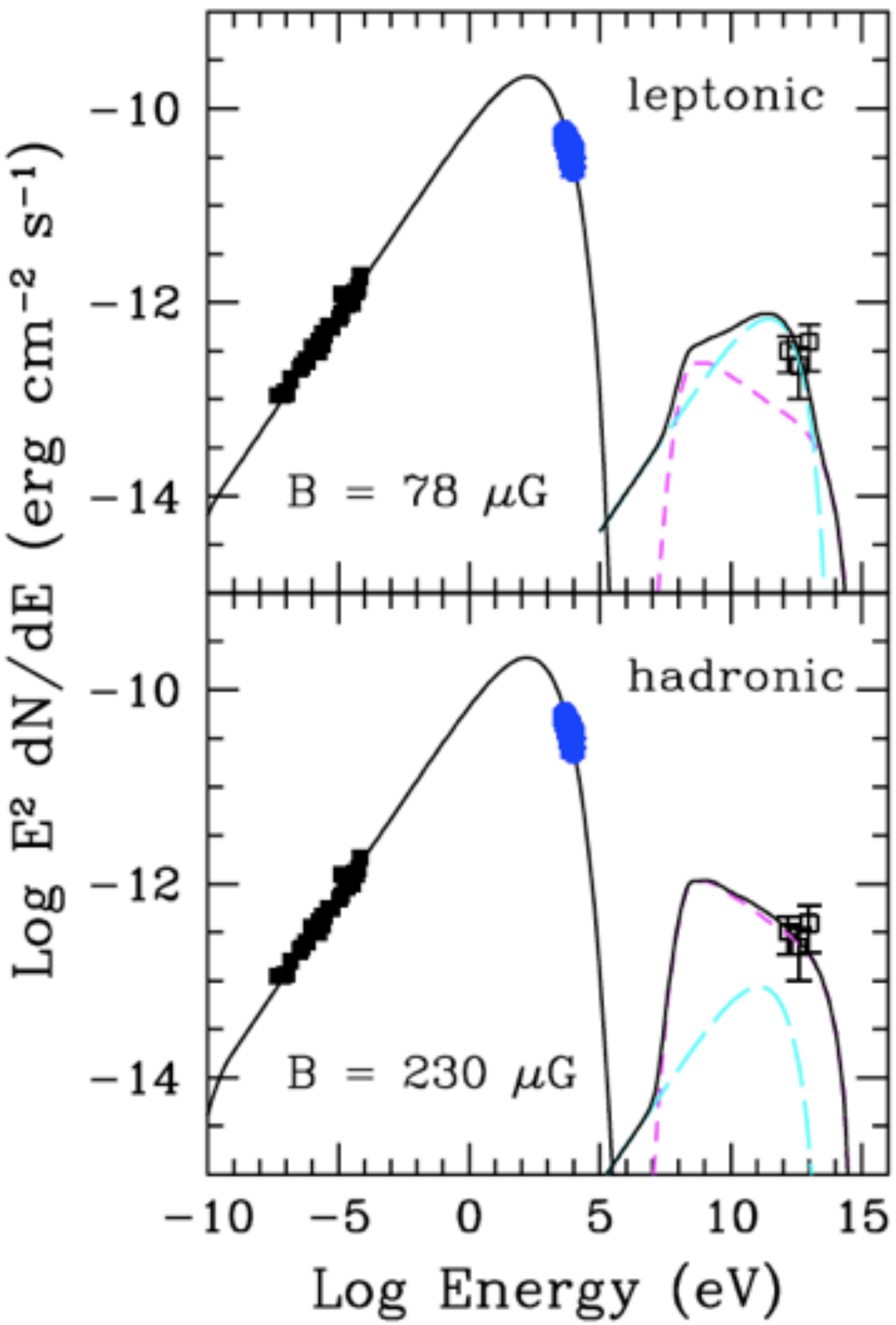
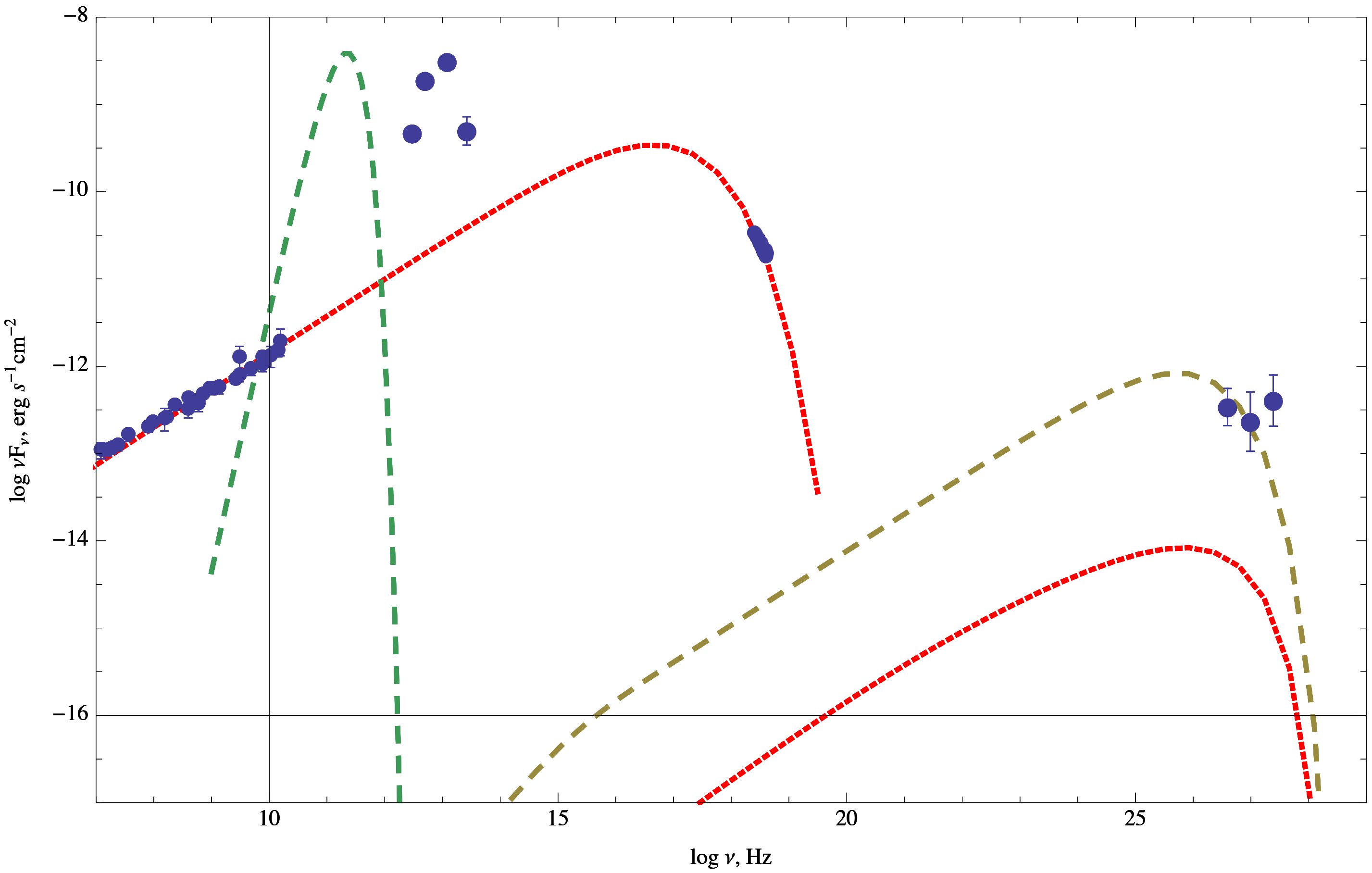


Figure 1. VERITAS TeV gamma-ray count map of the region around Tycho's SNR. The color scale indicates the number of excess gamma-ray events from a region, using a squared integration radius of 0.01 deg^2 for the 2009/2010 data and 0.015 deg^2 for the 2008/2009 data. The centroid of the emission is indicated with a thick black cross. Overlaid on the image are X-ray contours from a Chandra ACIS exposure (thin black lines; Hwang et al. 2002) and ^{12}CO emission (J=1-0) from the high-resolution FCRAO Survey (magenta lines; Heyer et al. 1998). The CO velocity selection is discussed in the text. The VERITAS count map has been smoothed with Gaussian kernel of size 0.06°. The point-spread function of the instrument (see text) is indicated by the white circle.



(Acciari et al. for VERITAS, ???)

Leptonic Fit



Electron energy density : $\eta = u_e/u_B = 0.9$

Total electron energy : $E_e = 5.7 \times 10^{47}$ erg

Magnetic Field : $B = 70\mu$G

Maximum electron energy (cooling limit)

Magnetic turbulence : $\zeta \equiv \lambda_{\rm mfp}/r_g = 4$

Shock velocity : $u_s = 2150\,{\rm km/sec}$

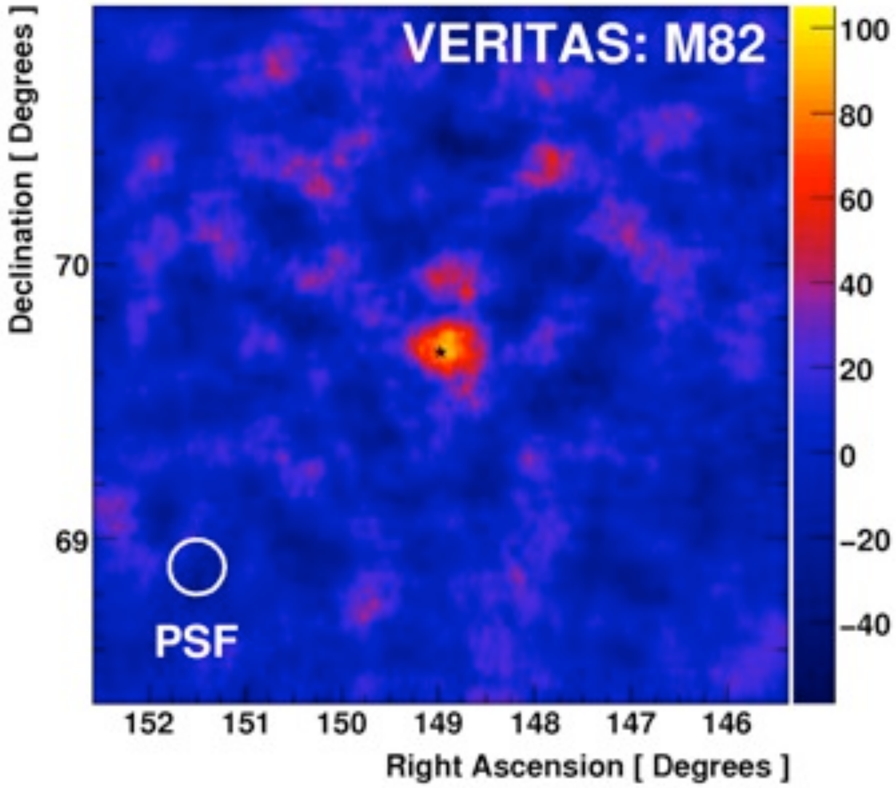
$\zeta = 1$ (Bohm limit), $u_s = 1075\,{\rm km/sec}$

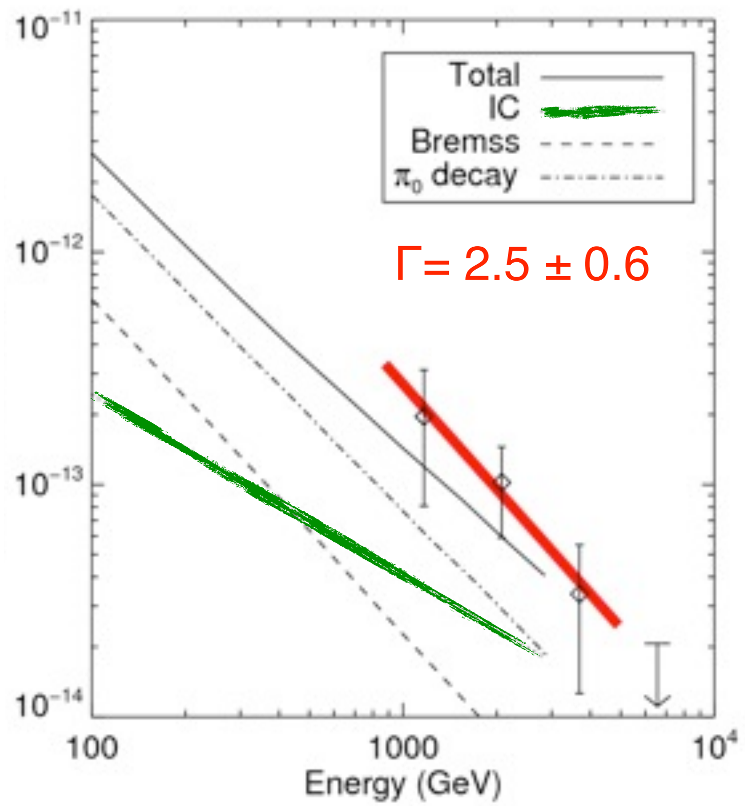
$E_{e,{\rm max}} = m_e \gamma_{\rm max,cool} c^2 = 9.7\,{\rm TeV}$

For the same parameters, the maximum proton energy is limited by the finite age of the remnant, and is given by

$$E_{p,{\rm max}} = 16.4\,{\rm TeV}$$

Starburst Galaxy: M82

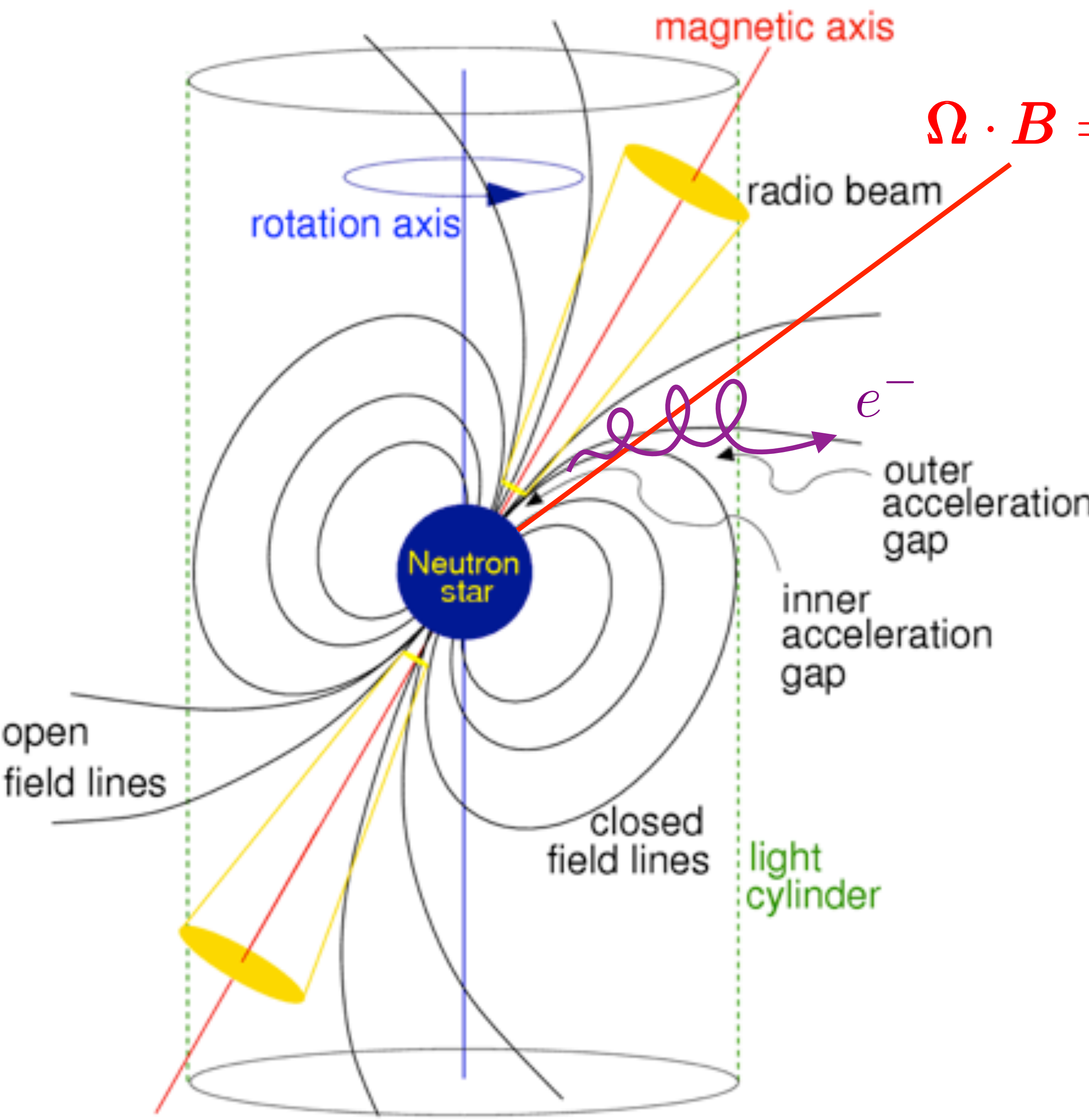




- M82 - classic starburst galaxy
  - high star formation rate: ~10x Milky Way
  - SNR rate: ~0.1-0.3/year,
  - CR density: 100x MW (from radio-synchrotron)
  - gas density >150 cm^{-3}
- VERITAS Detection (2007-09):
  - ~137 h live time, point-like excess of 91 γ; 5.0σ excess, F(>700 GeV)=$(3.7 \pm 0.8_{stat} \pm 0.7_{syst}) \times 10^{-13}$ cm^{-2} s^{-1} (V. Acciari et al., Nature, 2009)
  - 0.9% Crab Nebula, 0.7 gammas/hour above 700 GeV.
  - *Flux and spectrum consistent with expectations from CR interactions*

Pulsar Emission

Solutions for the magnetosphere around a misaligned magnetized neutron-star require charge to be stripped from the surface of the star, and a steady state charge density given by the Goldreich-Julian charge density:



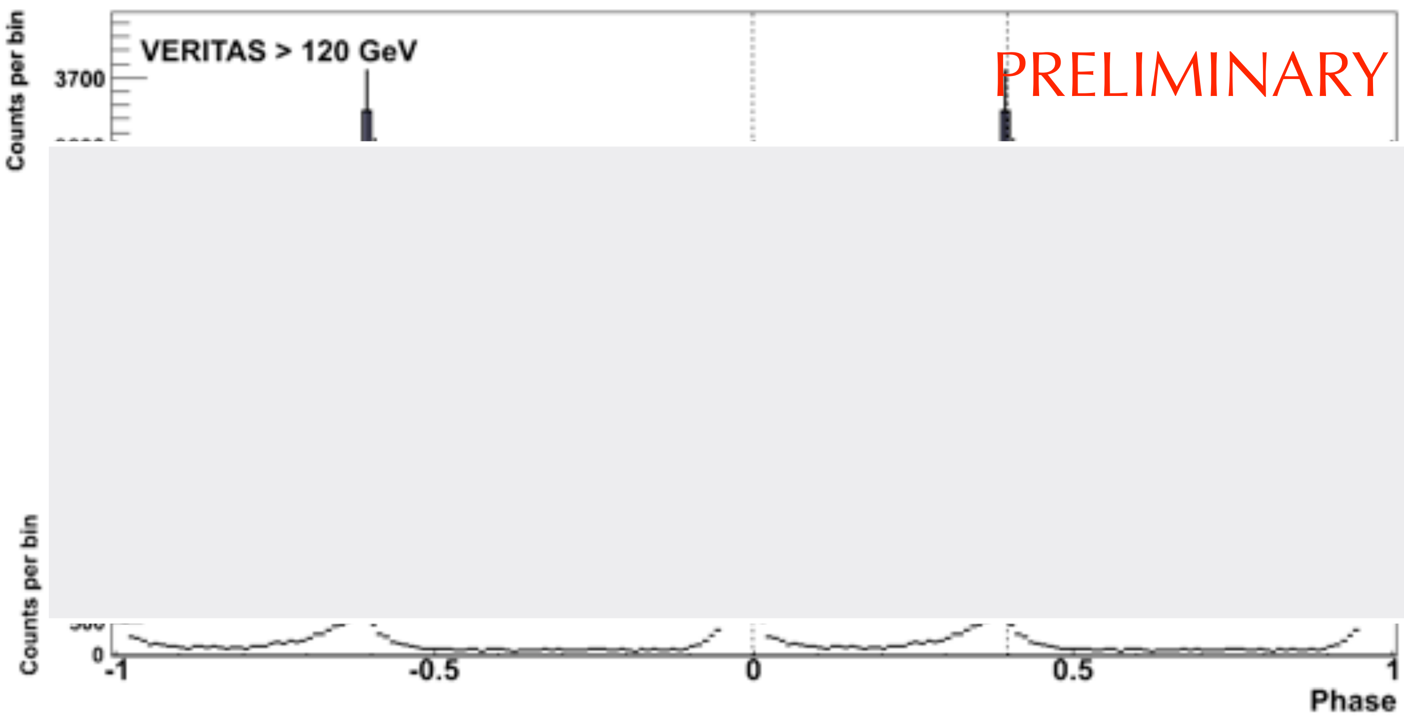
$$\boldsymbol{E} \cdot \boldsymbol{B} = 0 \Rightarrow \quad \rho_{\mathrm{GJ}} \equiv -\frac{\boldsymbol{\Omega} \cdot \boldsymbol{B}}{2\pi c}$$

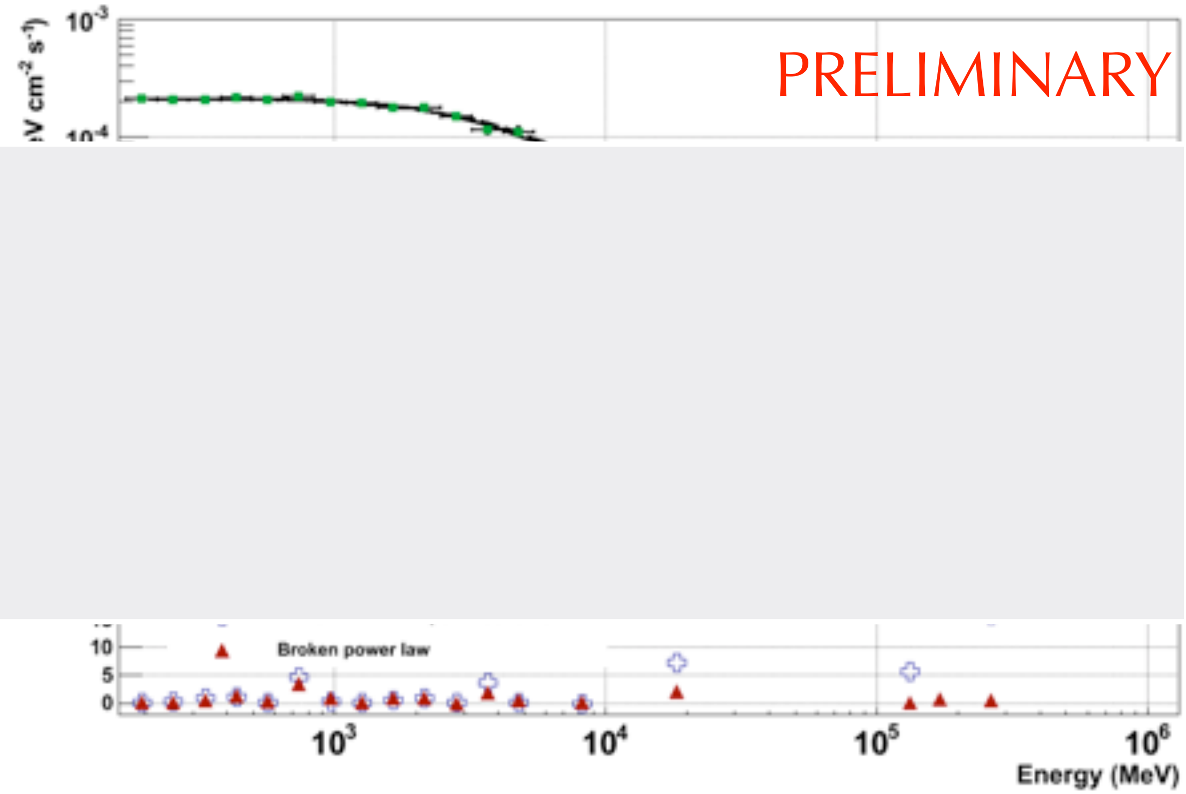
The light cylinder is the point that field lines can no longer corotate without $\Omega\, r > c$

Solutions allow for formation of a charge depletion region or gap, where a potential accelerates electrons and positrons resulting in high energy γ-rays by curvature radiation and inverse Compton

Pair absorption $\gamma_{\mathrm{TeV}} + \gamma_B \rightarrow e^+ e^-$ strongly attenuates VHE electrons

Crab Pulsar

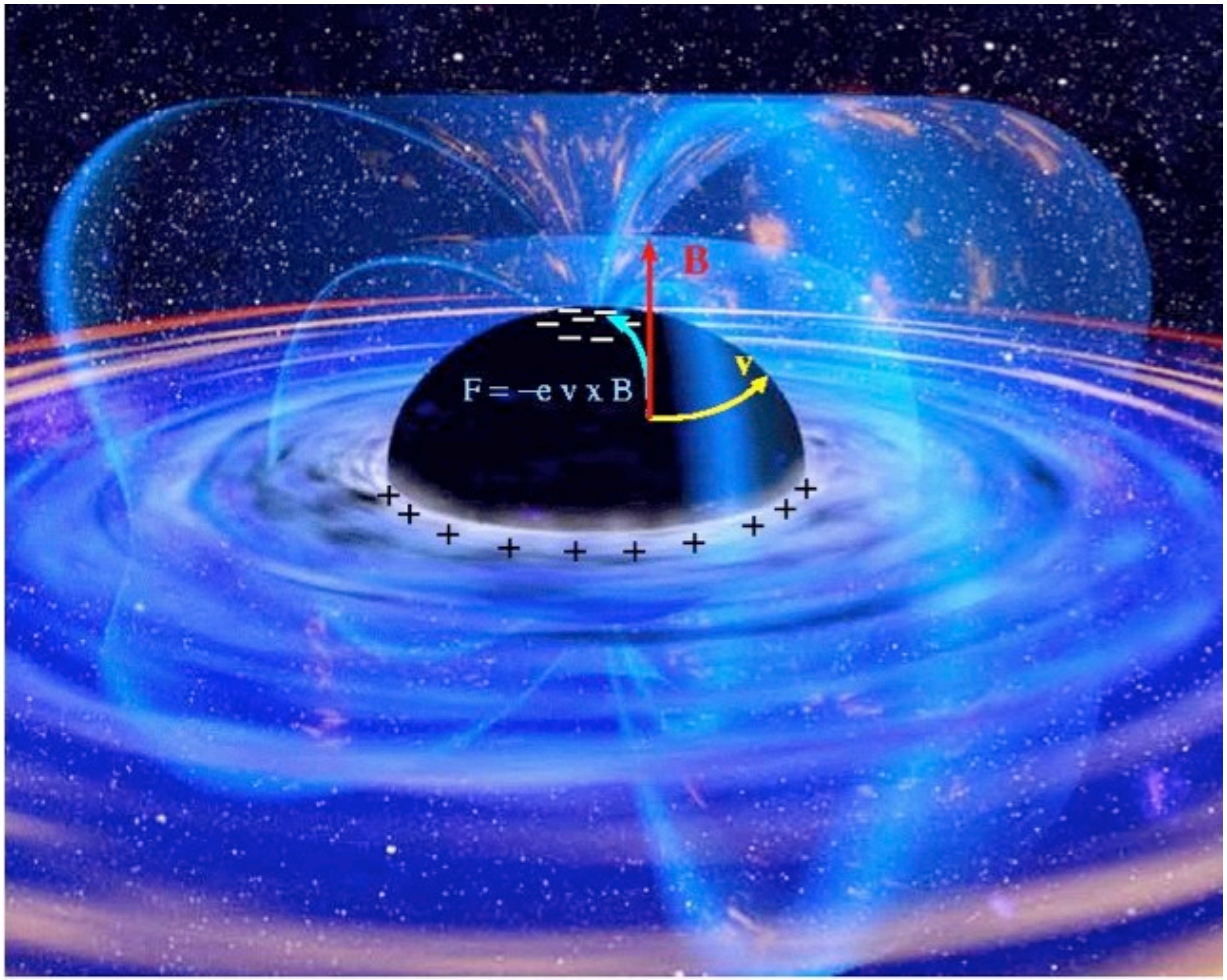




- VERITAS sees narrow pulse profile with spectrum extending up to >100 GeV
- This implies a small emission region, well away from the polar cap or typical outer gap radius where pair-attenuation would result in a strong cutoff of the high energy emission

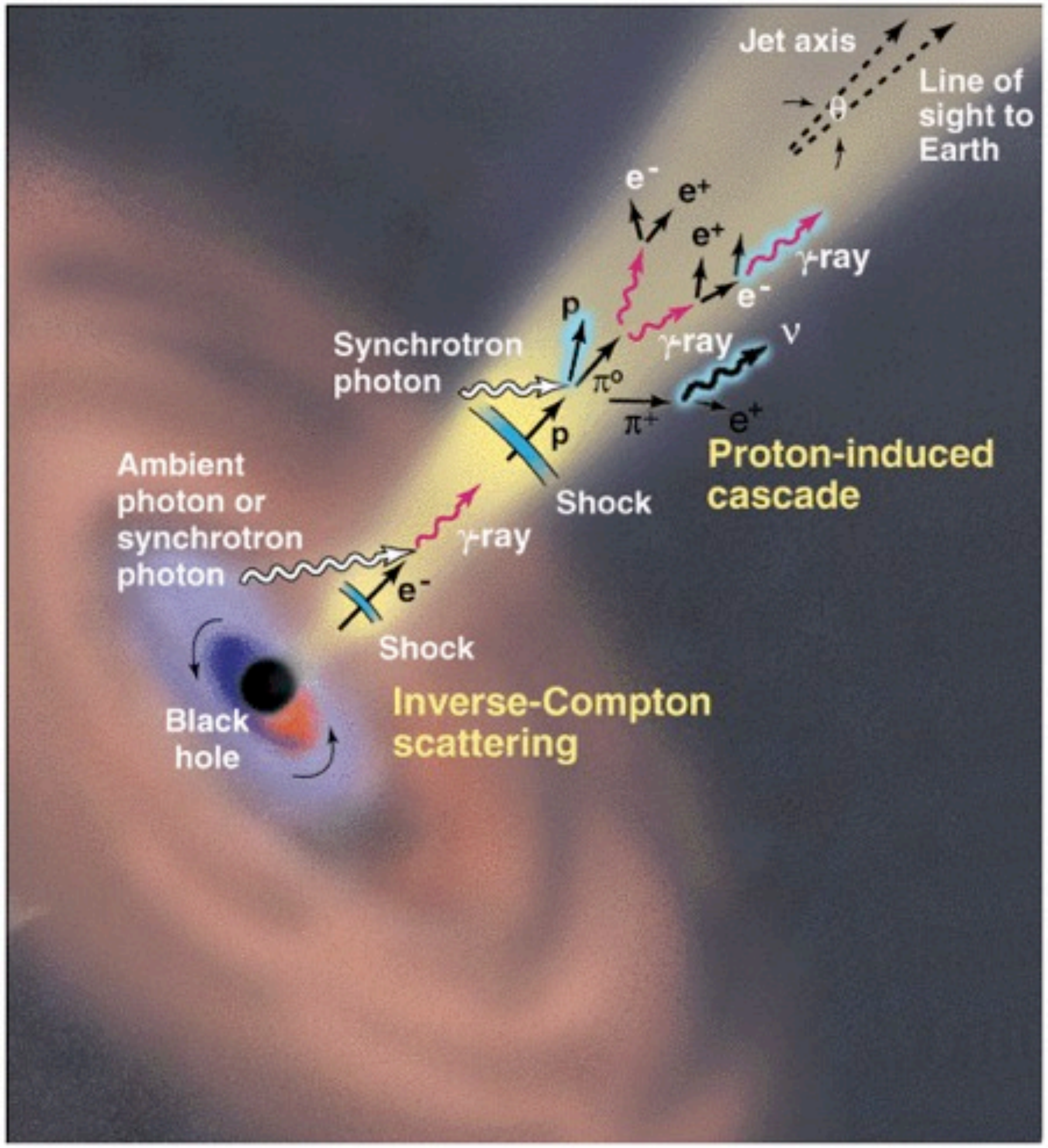
Extragalactic Particle Accelerators

AGN Central Engine



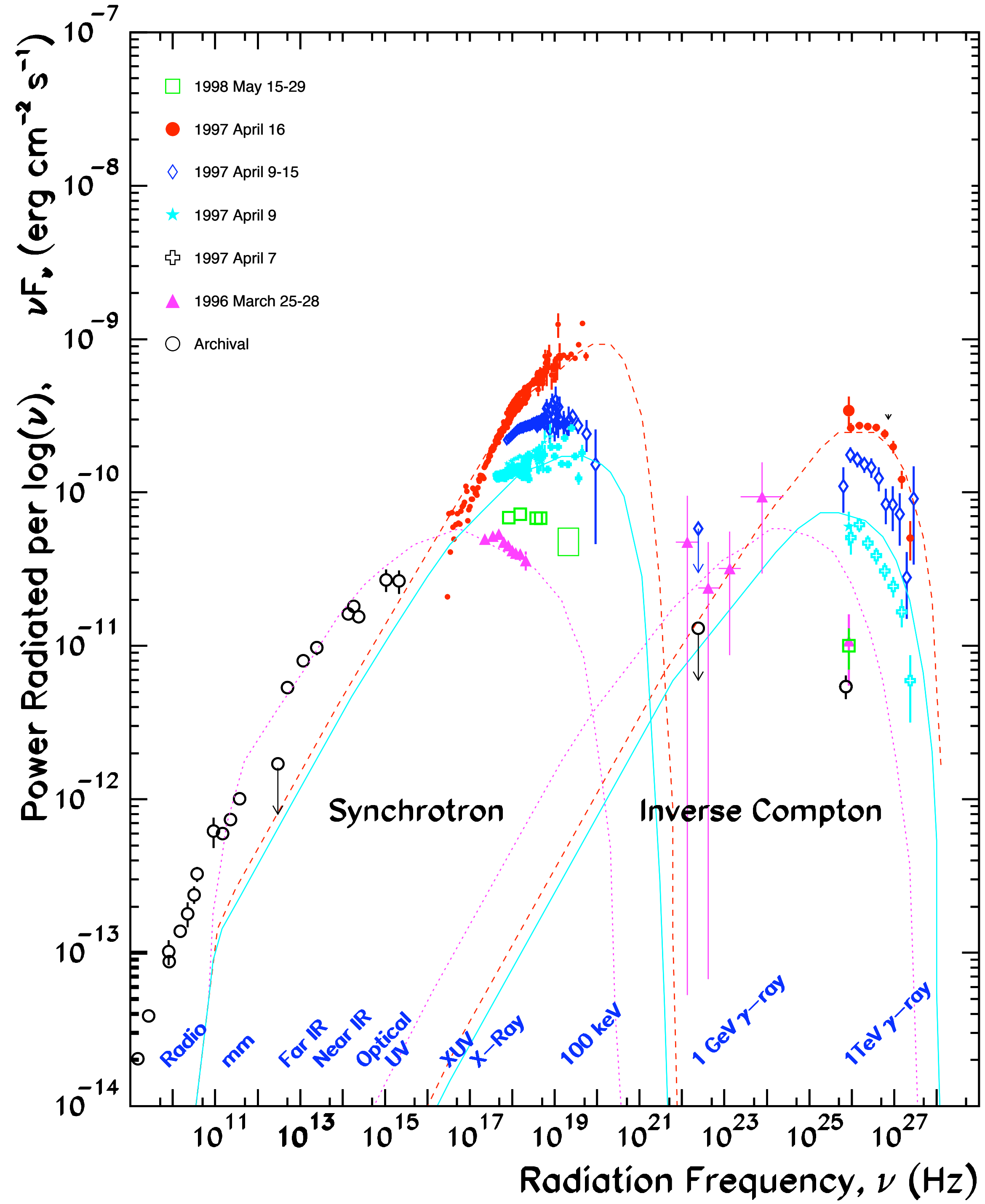
Spinning blackhole or accretion disk in external magnetic field - 10^{20} V Generator!
(Blandford and Znajek, Blandford and Lovelace)

AGNs

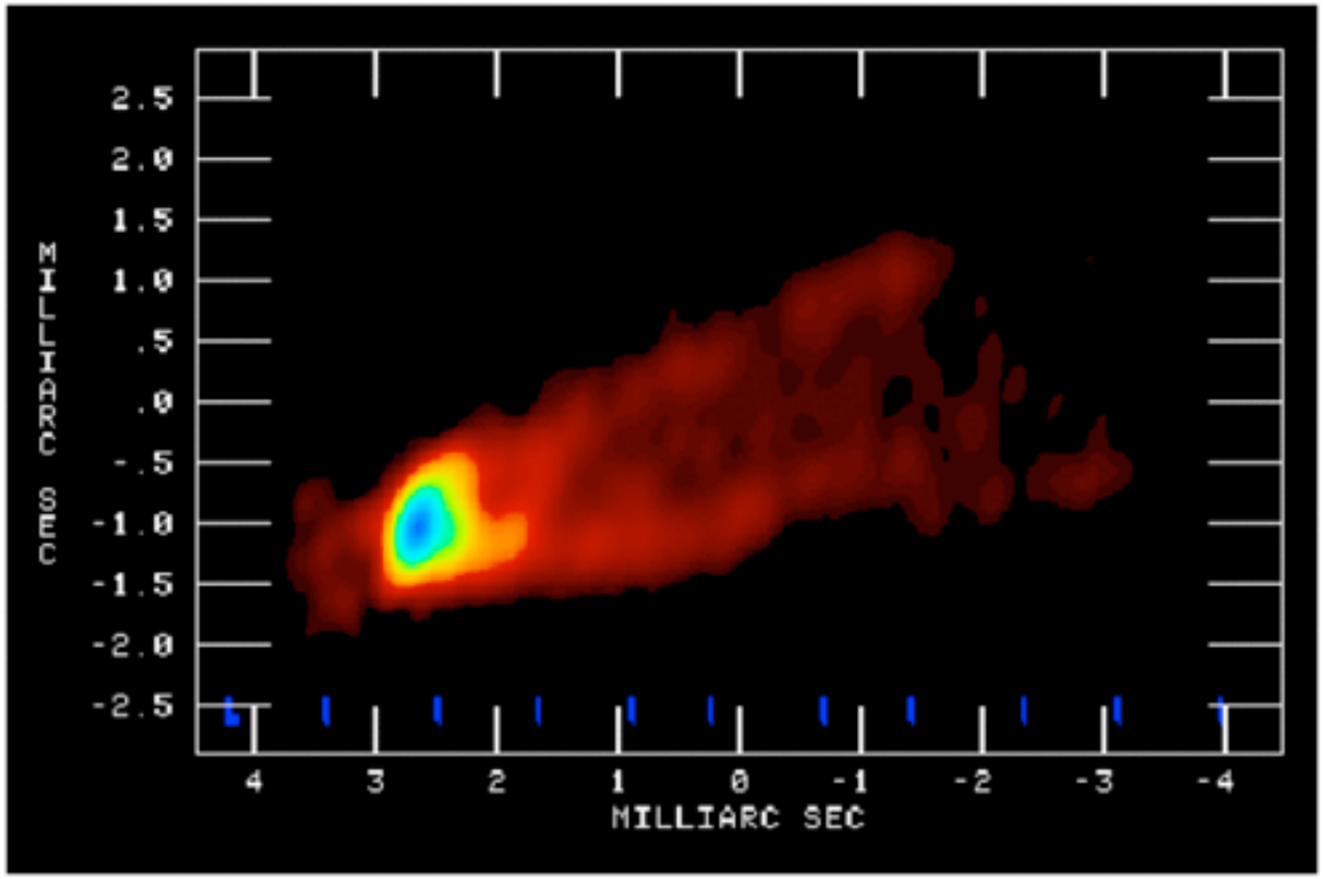


(Adapted from Buckley, Science, 1998)

Markarian 501 SED

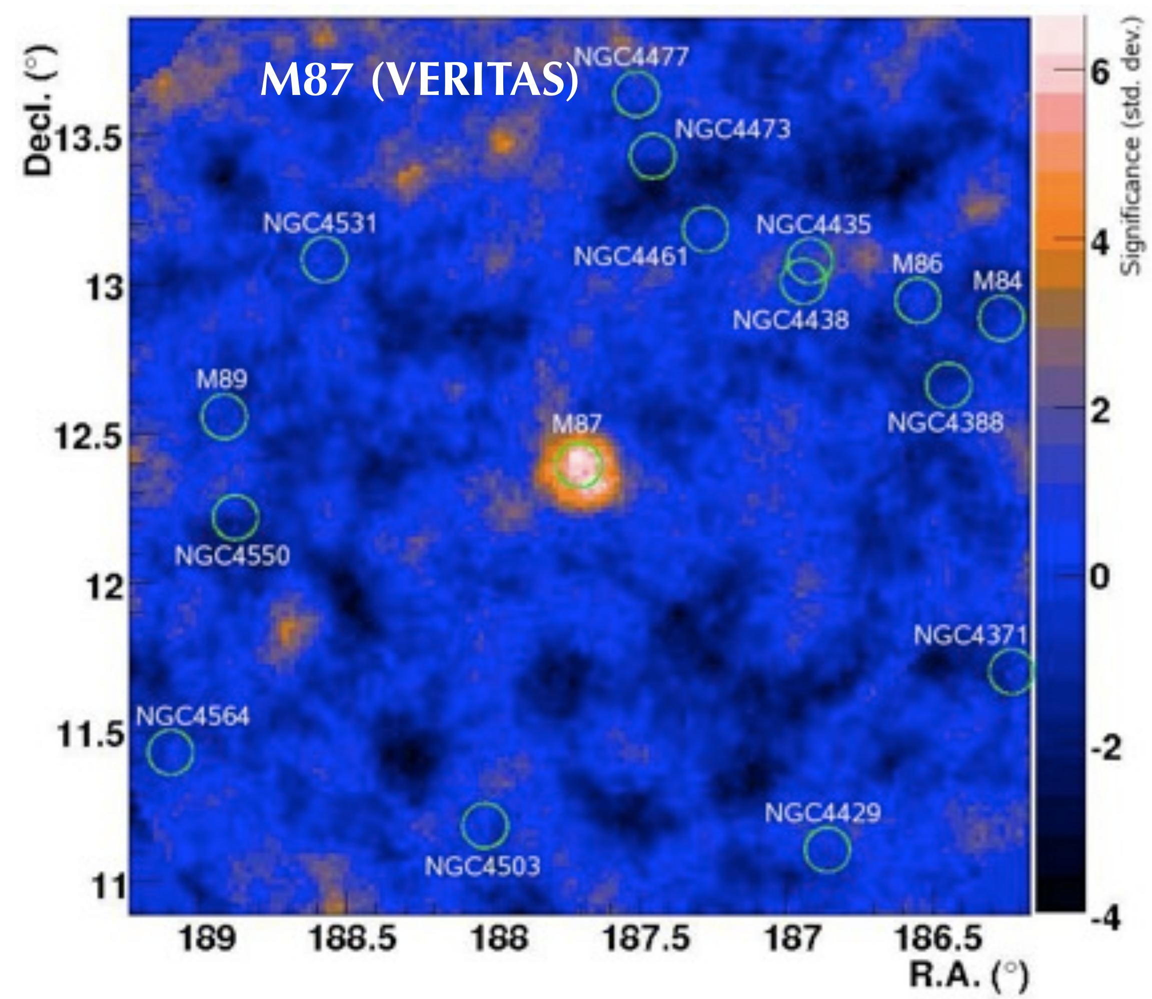


M87: Radio Galaxy



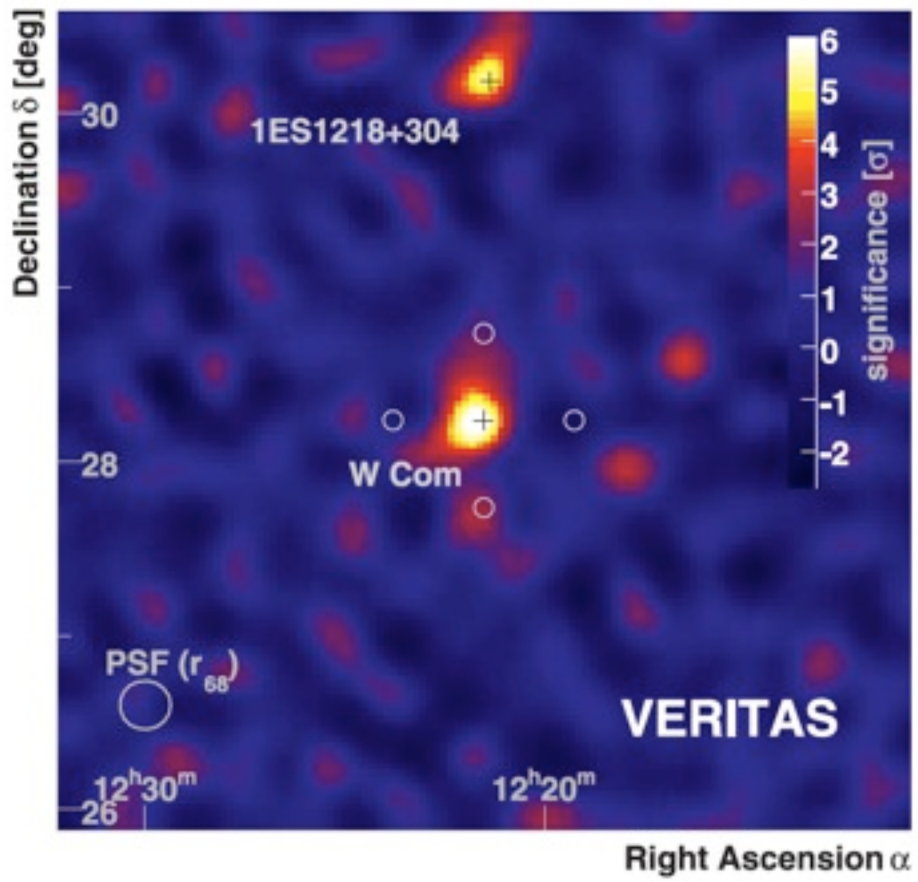
Walker, Lee, Junor & Hardee, 2007 43GHz VLBA data (1 Rs=0.37 mas, 1mas=0.078 pc)

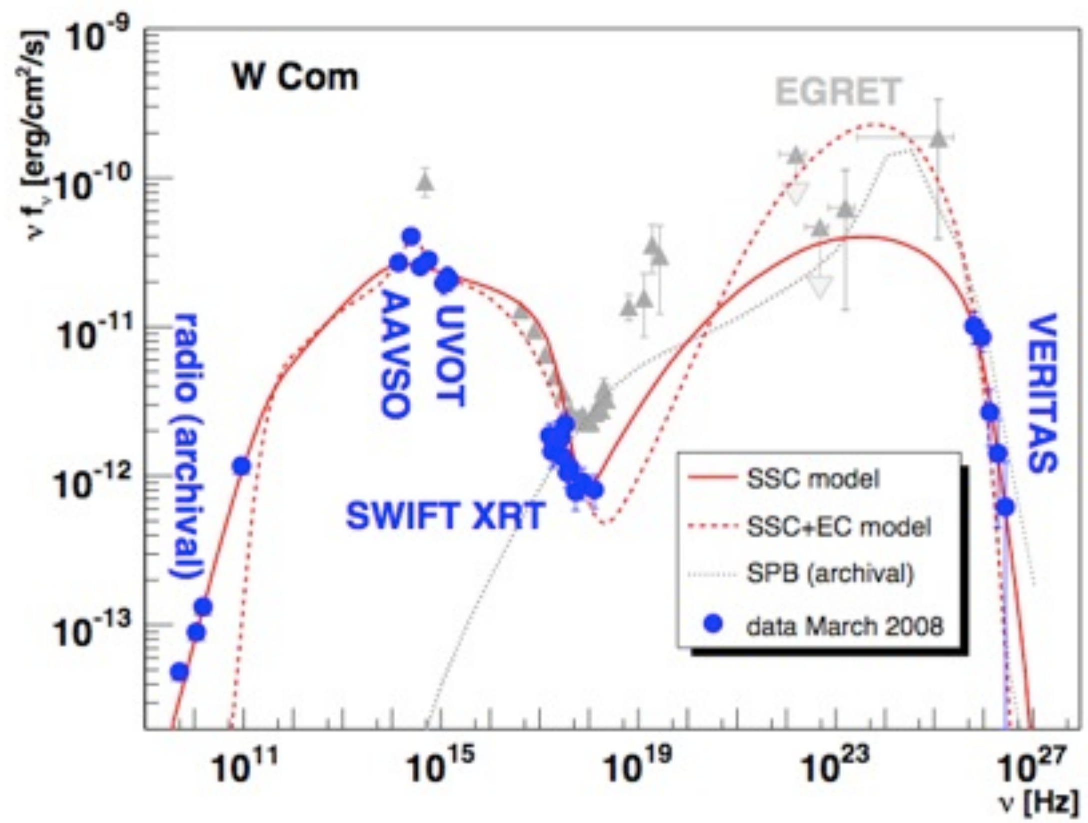
- M87 one of the nearest active galaxies. VLBI reveals the innermost jet, but the central engine is still obscured due to synchrotron self-absorption, resolution limits



- VERITAS, HESS and MAGIC have detected flares from M87 - correlations with Radio reveal clues about the inner-most emission region

AGN W Comae

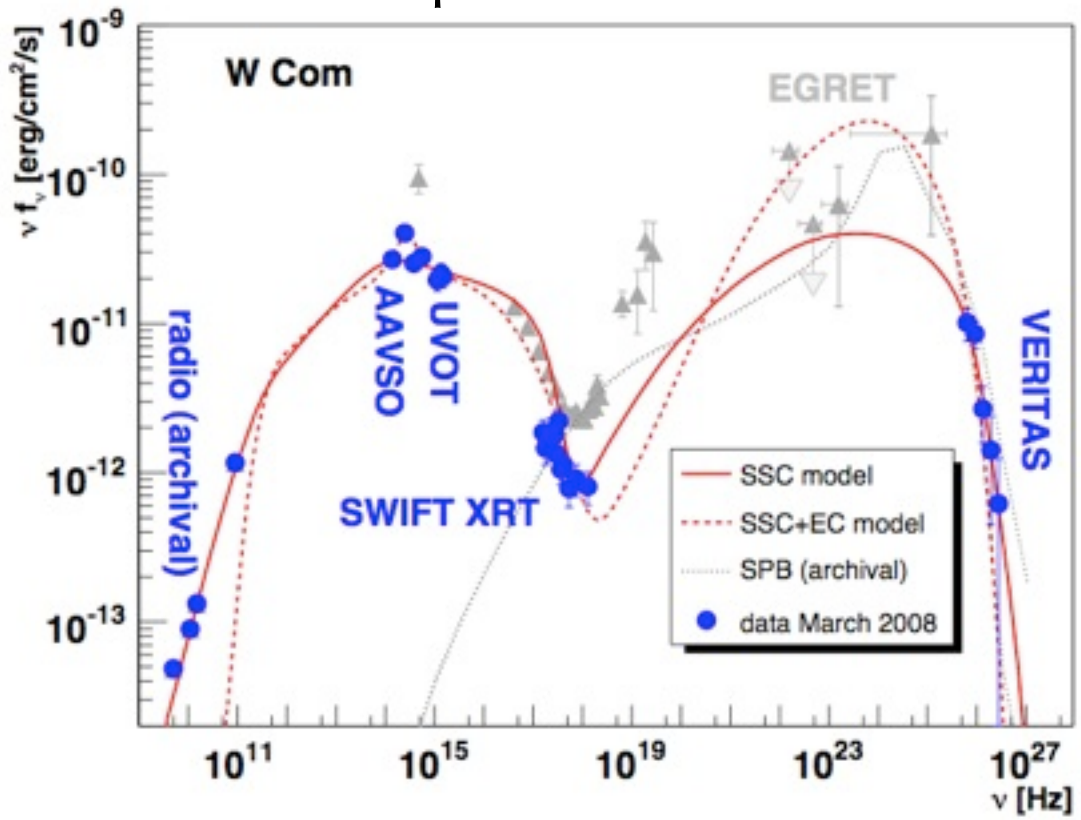




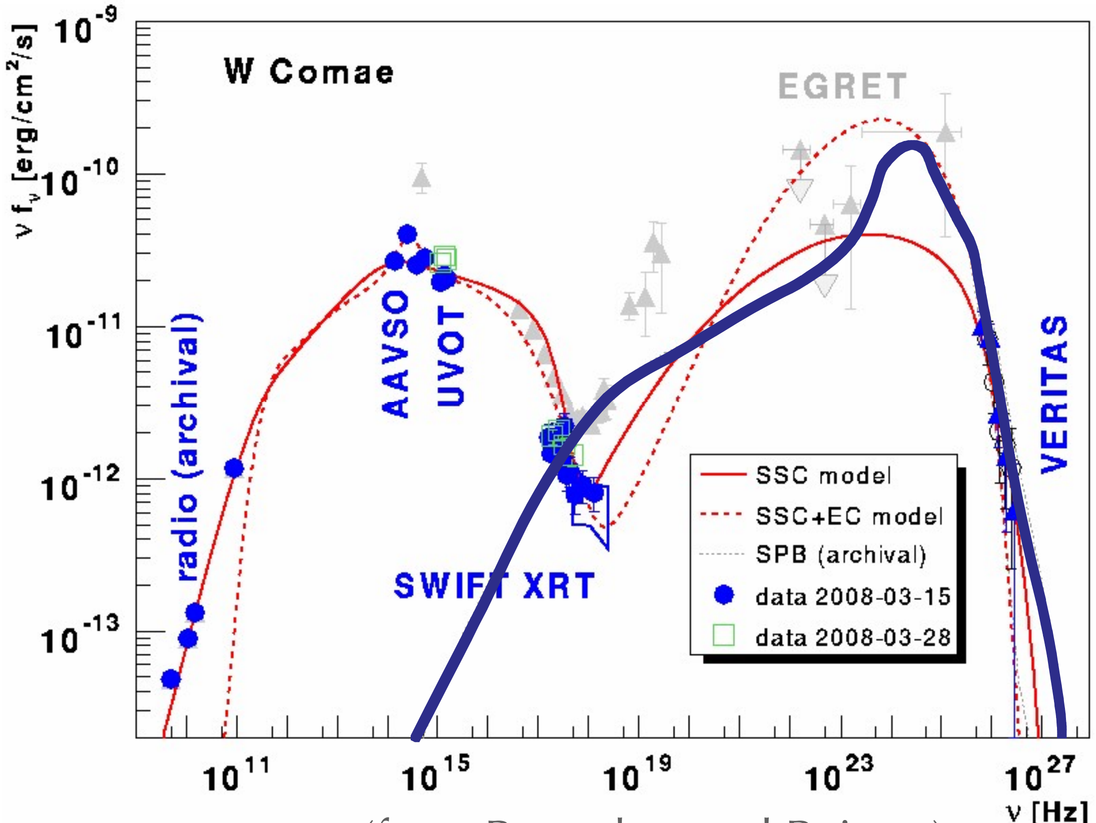
- z=0.102 Intermediate-Peaked BL Lac (IBL) detected by EGRET as a very hard-spectrum gamma-ray source
- Discovery by VERITAS on March 2008 (Acciari et al., 2008, 684, L73) at ~8 σ , soft spectrum .
- Mixed SSC+External Compton give more natural parameters (equipartition, etc.). With Fermi, can discriminate proton cascade models

W Comae

Leptonic Models



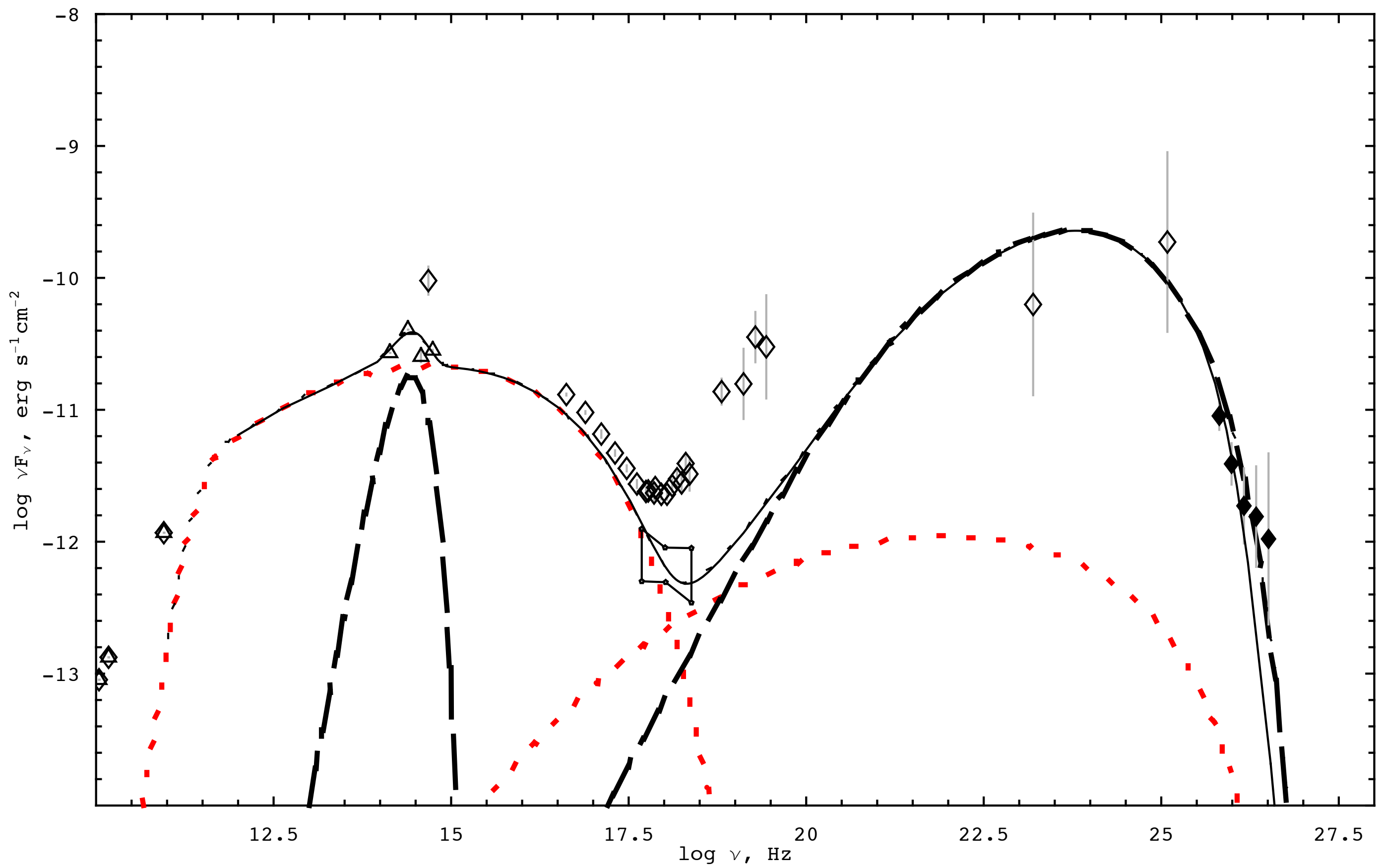
Hadronic Models



(from Boettcher and Reimer)

- With hard-Xray/INTEGRAL+Fermi, can discriminate leptonic models (left) from proton cascade models (right) (e.g., Boettcher and Reimer.)

W Com SSC+EIC fit



$$\boxed{\begin{aligned} \delta_{\rm jet} &= 30 \\ B &= 0.3\,{\rm G} \end{aligned}}$$

$$d_L = 457\ {\rm Mpc}$$

$$\lambda_{\rm bb} = 1.5\,\mu{\rm m}$$

$$\gamma_{\rm min} = 30\ \ \text{(input param.)}$$

$$\gamma_{\rm max} = \frac{v_{\rm shock}}{c}\left(\frac{9eB}{80(u_{\rm mag}+u_{\rm ph})\sigma_T\zeta}\right)^{1/2} = 3.4\times10^4$$

$$\zeta \equiv \frac{l_{\rm mfp}}{r_g} = 3000$$

$$\gamma_{\rm break} = \frac{3mc^2}{4(u_{\rm mag}+u_{\rm ph})\sigma_T\ R} = 750$$

$$\boxed{R \approx 400\ R_{\rm grav}}$$

$$\boxed{\frac{u_e}{u_B} = 1.0\ \ \text{(i.e., equipartition)}}$$

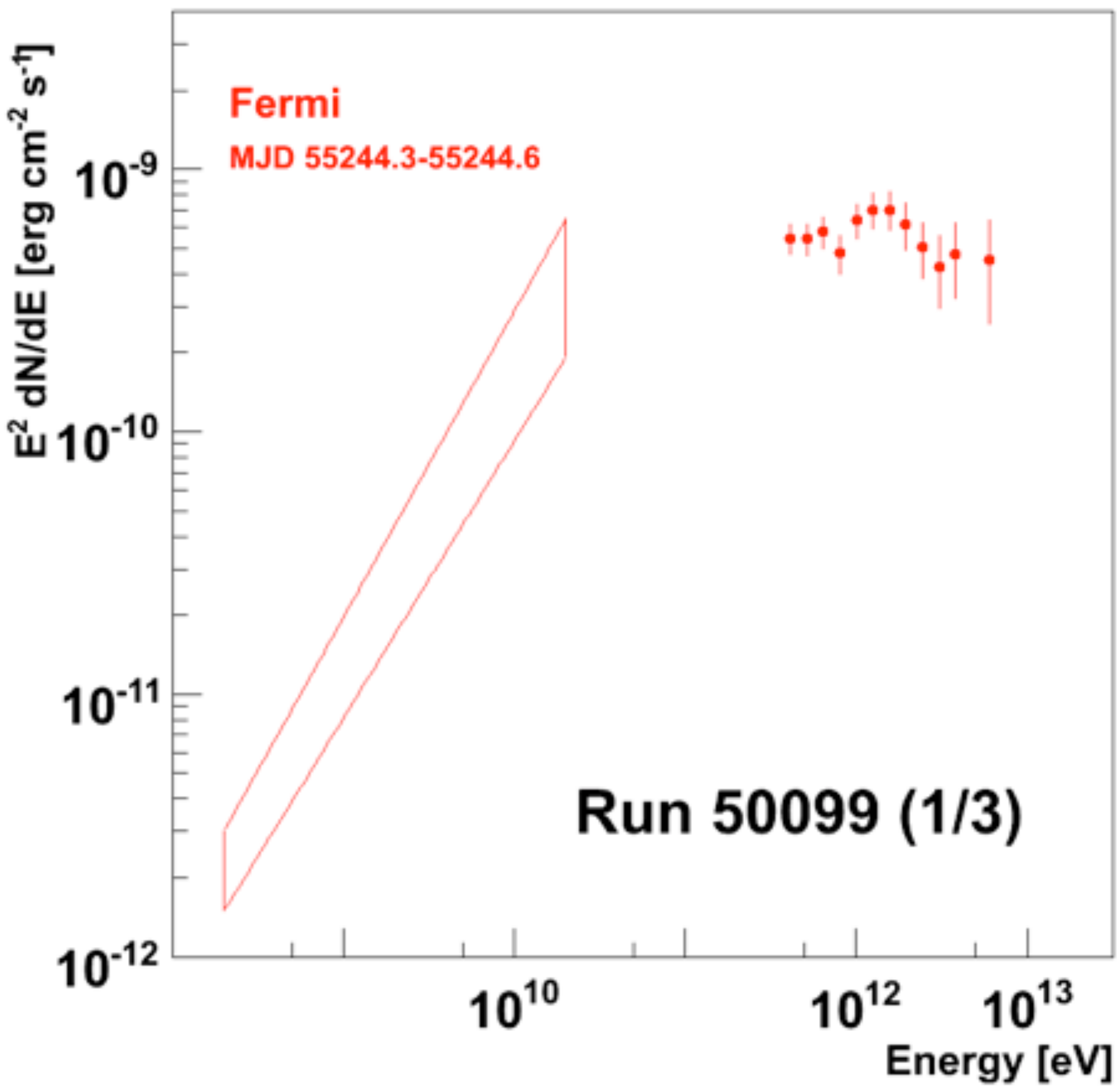
$$\tau_{\rm cool} = \frac{3mc/\delta}{4(u_{\rm mag}+u_{\rm phot})\sigma_T\gamma}$$

$$\tau_{\rm accel} = \frac{20\zeta\gamma mc^3/\delta}{3eBv_{\rm shock}^2}$$

$$\boxed{\begin{aligned} \tau_{\rm cool,\ min} &= \tau_{\rm accel}(\gamma_{\rm max}) = 7.2\ {\rm min} \\ \tau_{\rm light\ crossing} &= \frac{R}{c\delta} = 330\ {\rm min} \end{aligned}}$$

$$\frac{dN_e}{dE} \sim \frac{E^{-2}e^{-\gamma/\gamma_{\rm max}}(1-e^{-\gamma/\gamma_{\rm min}})}{1+\gamma/\gamma_{\rm break}}$$

AGN Spectral Evolution

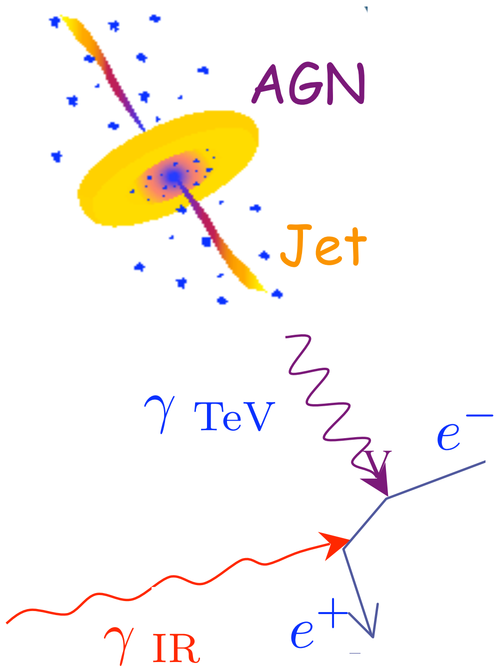


VERITAS Mrk 421 spectral evolution over a period of 7 hours
(M. Beilicke)

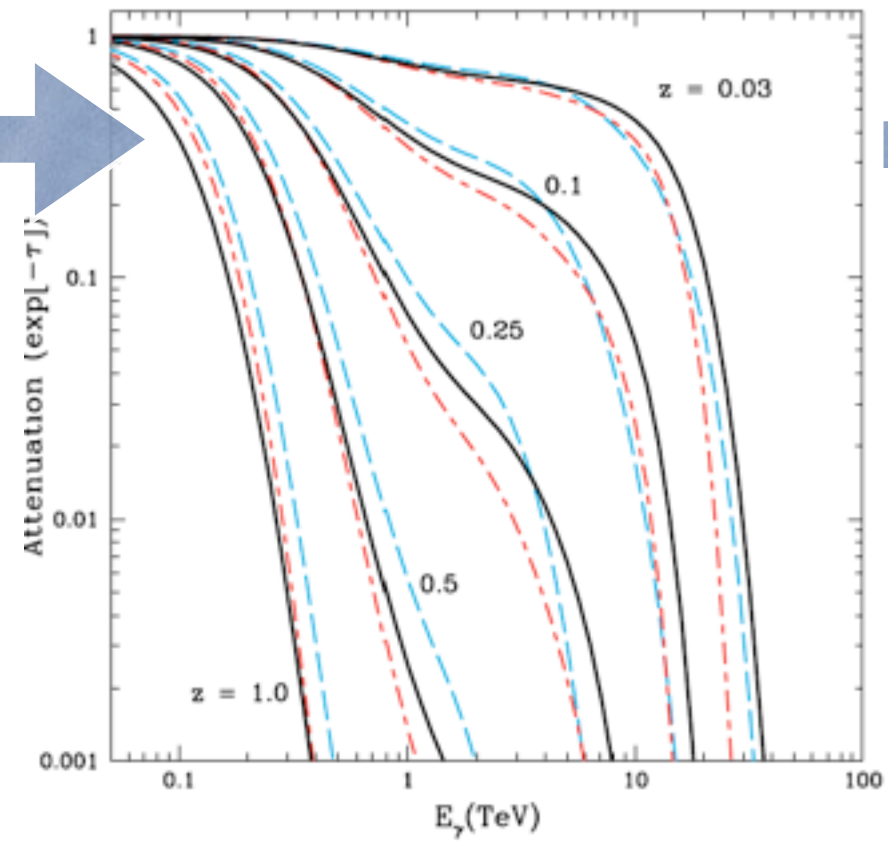
- IACTs provide the very large effective area required to form spectra on sufficiently small timescales to resolve the rapid flaring activity

AGN as probes of Fundamental Physics and Cosmology

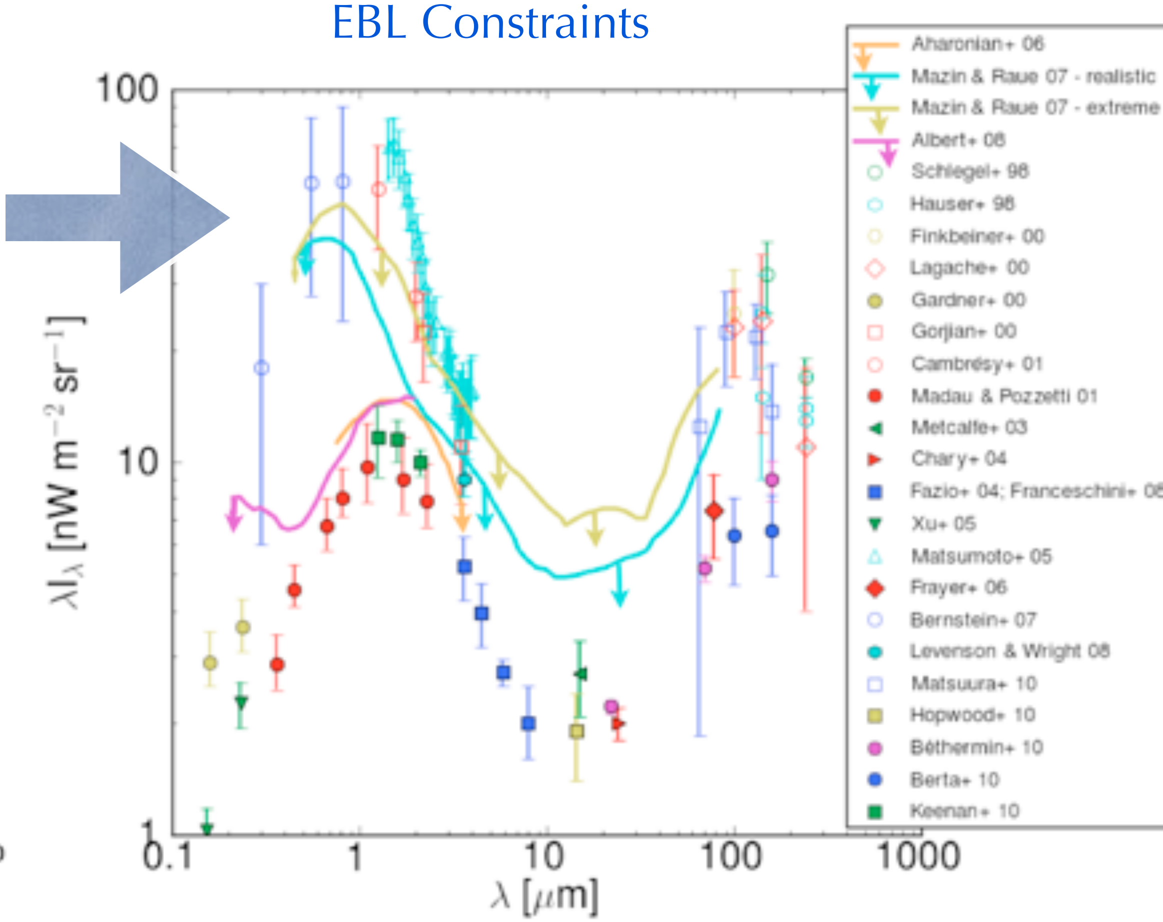
Extragalactic Background Light



Survival probability for gamma-rays



EBL Constraints

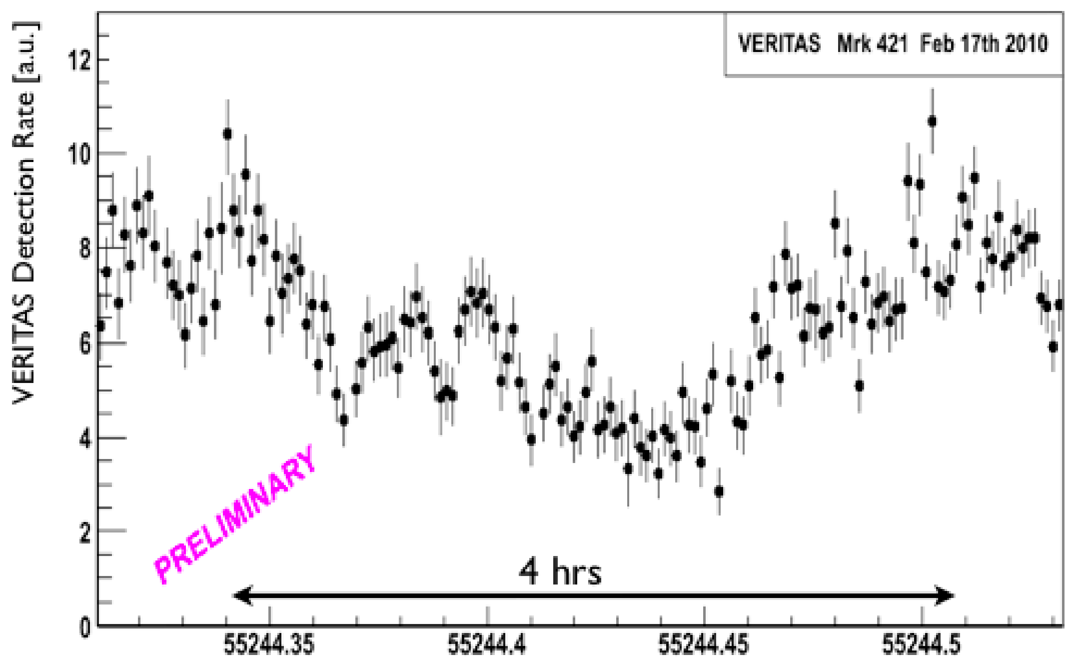


(Primack, Dominguez, Gilmore and Somerville, 2011, arXiv:1107.2566)

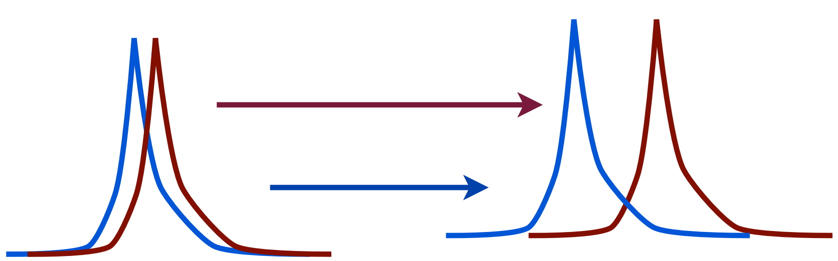
- Intergalactic space is filled with redshifted primordial starlight (UV to IR) imprinted with the integral with all radiative processes that occurred after decoupling - *a cousin of the CMB.*
- Pair-production in intergalactic space causes absorption and spectral cutoffs that move to lower energy as the redshift increases.
- If one knows something about the source spectrum, can constrain, even measure, the spectrum of the EBL.
- Can do cosmology by constraining star formation history and any new particle physics scenarios that yield a contribution to the EBL - *the ultimate calorimeter of all eV-scale physics!*

Lorentz Invariance Violation

February 2010 Observations of Mrk 421



Galante et al. 2011



- GUTs produce effects that are often only observable at the Planck scale, well beyond the reach of terrestrial accelerators.
- In the electromagnetic sector, these effects can show up as a vacuum dispersion relation for the propagation of light - e.g., a speed of light that depends on photon energy and polarization.

$$E^2 = c^2p^2 \ \ or \ \ H = cp$$

$$\text{From hamiltonian mechanics}: \dot{x} = \frac{\partial H}{\partial p} = c$$

$$\text{LIV} \Rightarrow \qquad \dot{x} = \frac{\partial H}{\partial p} \sim c\left(1 \pm \xi \frac{E}{M_{\rm pl}} + \mathcal{O}\left(\frac{E}{M_{\rm pl}}\right)^2\right)$$

$$\Delta t = \frac{\xi \Delta E}{2M_{\rm pl}^2 H_0}\int_0^z \frac{(1+z')dz'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}} + \frac{3\zeta\Delta E^2}{2M_{\rm pl}^2 H_0}\int_0^z \frac{(1+z')^2dz'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}$$

- To best constrain these effects, one should look for the *shortest transients at the highest energies from the most distant sources.*

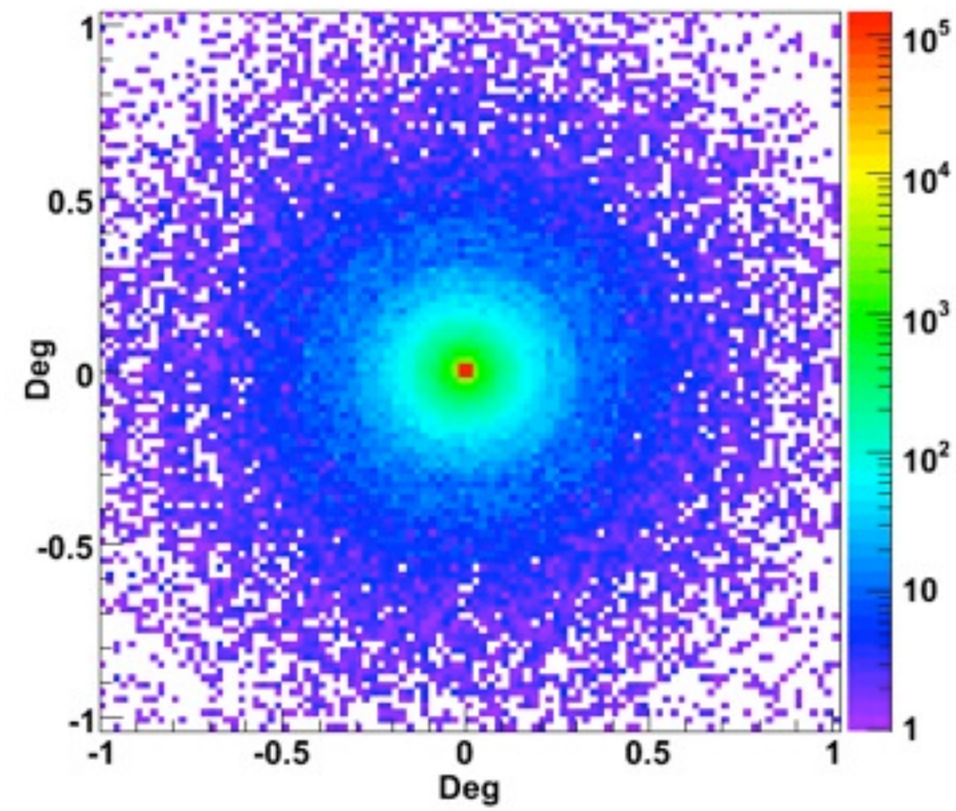
Table 1: Estimated sensitivity to the energy scale of LIV from observations of GRBs, blazars flares and pulsars with *Fermi* and VERITAS.

	Observatory	**z (d_L)**	**Δt**	**ΔE**	**E_l**	**E_q**
GRB	*Fermi*	0.900 (1.8×10^{26} m)	1 s	30 GeV	$\mathbf{1.8 \times 10^{19}}$ **GeV**	$\mathbf{2.3 \times 10^{10}}$ **GeV**
GRB	VERITAS	0.500 (8.7×10^{25} m)	10 s	200 GeV	$\mathbf{0.6 \times 10^{19}}$ **GeV**	$\mathbf{3.4 \times 10^{10}}$ **GeV**
Mrk 421	VERITAS	0.030 (4.0×10^{24} m)	60 s	1 TeV	$\mathbf{2.0 \times 10^{17}}$ **GeV**	$\mathbf{2.0 \times 10^{10}}$ **GeV**
Crab Pulsar	VERITAS	2.0 kpc (6.2×10^{19} m)	10^{-3} s	100 GeV	$\mathbf{2.1 \times 10^{17}}$ **GeV**	$\mathbf{1.4 \times 10^{9}}$ **GeV**

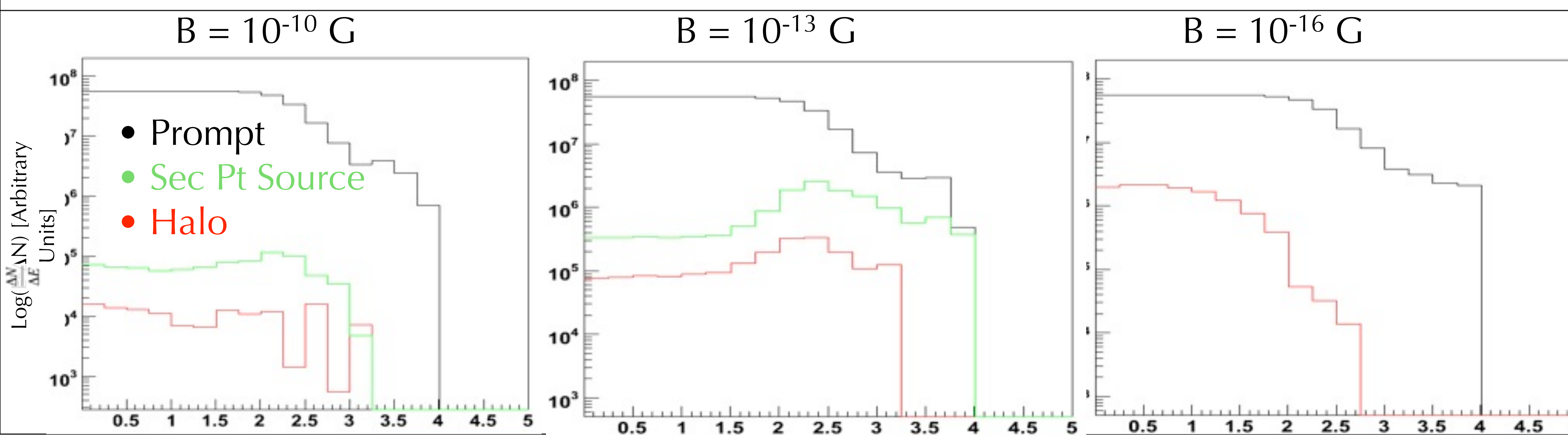
Intergalactic Magnetic Fields

Simulated angular distribution and spectrum for pair halo

$$z = 0.032, \quad B = 10^{-14}\,\mathrm{G}, \ \frac{dN}{dE} \sim E^{-2}, \ \Gamma = 10$$



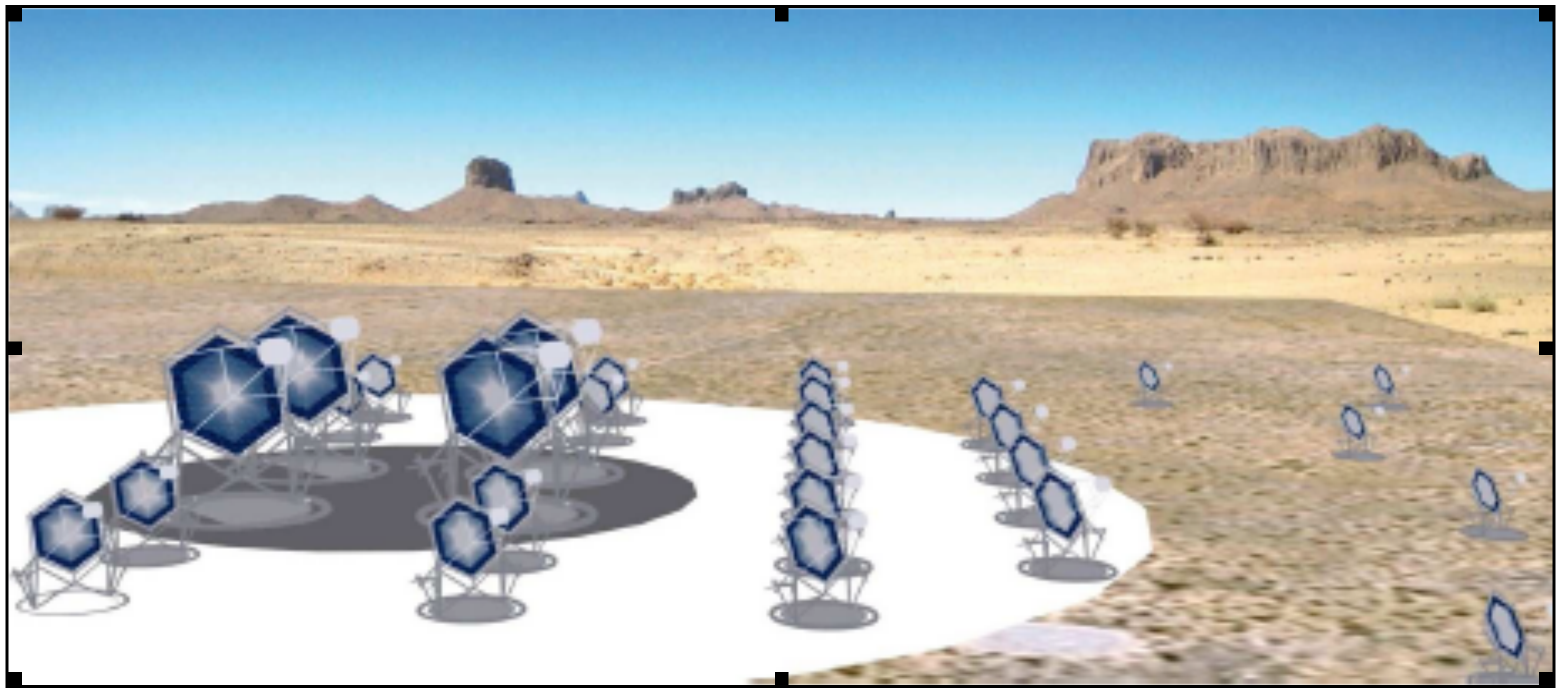
(from Tim Arlen, UCLA)



Future Ground-based Gamma-ray Experiments

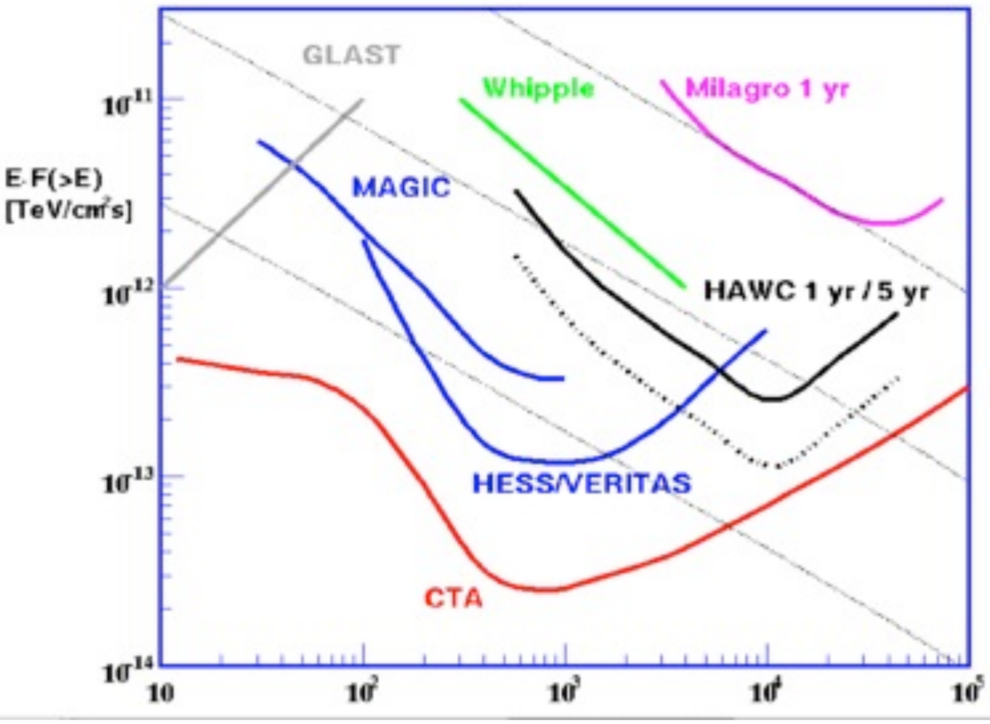
Future Experiments

CTA



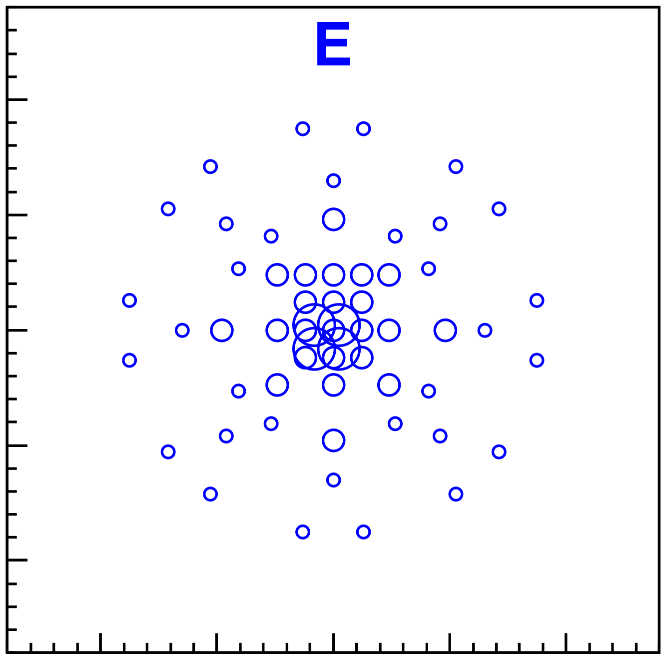
HAWC

- CTA baseline design consists of
  - 4 x 24m Large Size Telescopes (LSTs) for the lowest energies
  - 23 x 12m Mid-Size Telescopes (MSTs) for medium energies (100 GeV - 10 TeV)
  - 50 x 6m Small-Size Telescopes (SSTs) for high energies (>10 TeV)
- CTA-US will supplement this with 36 more MST telescopes
- HAWC will consist of 300 water tanks at 4100m a.s.l toprovide all-sky survey observations above TeV energies
- As MILAGRO guided HESS, MAGIC and VERITAS HAWC will guide CTA

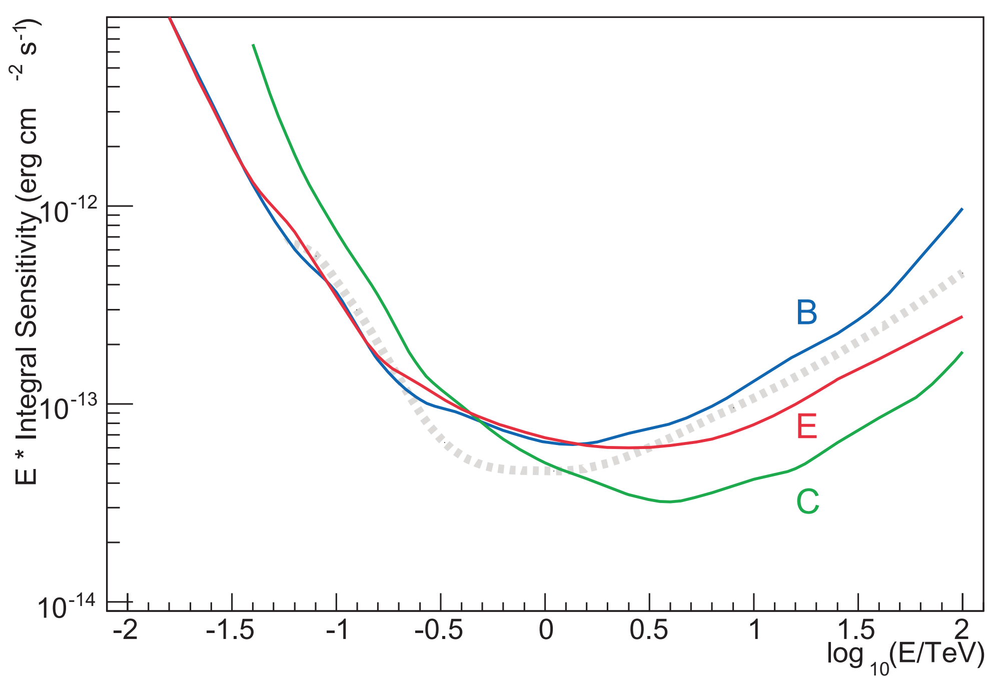


CTA Performance

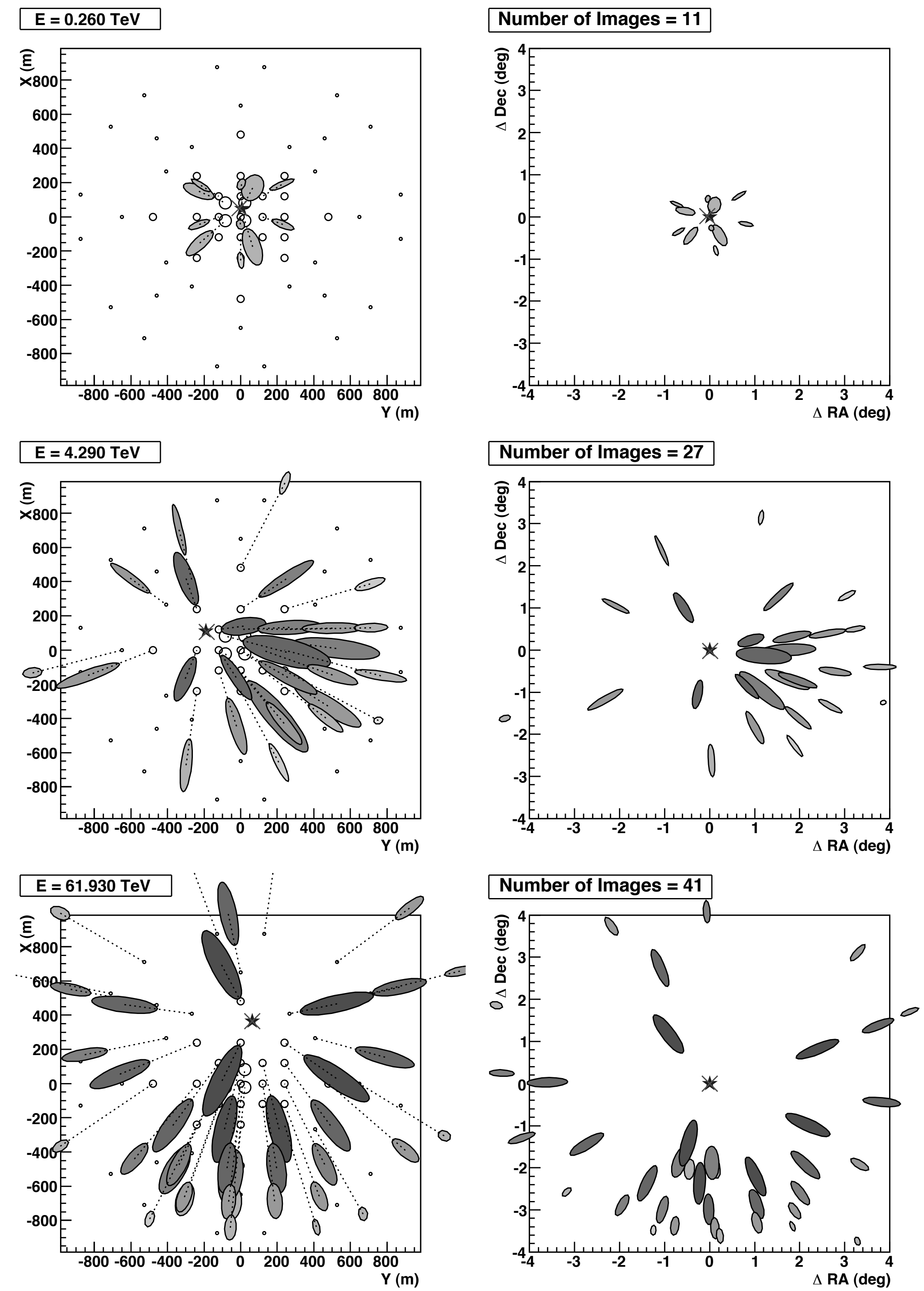
Possible CTA array configuration



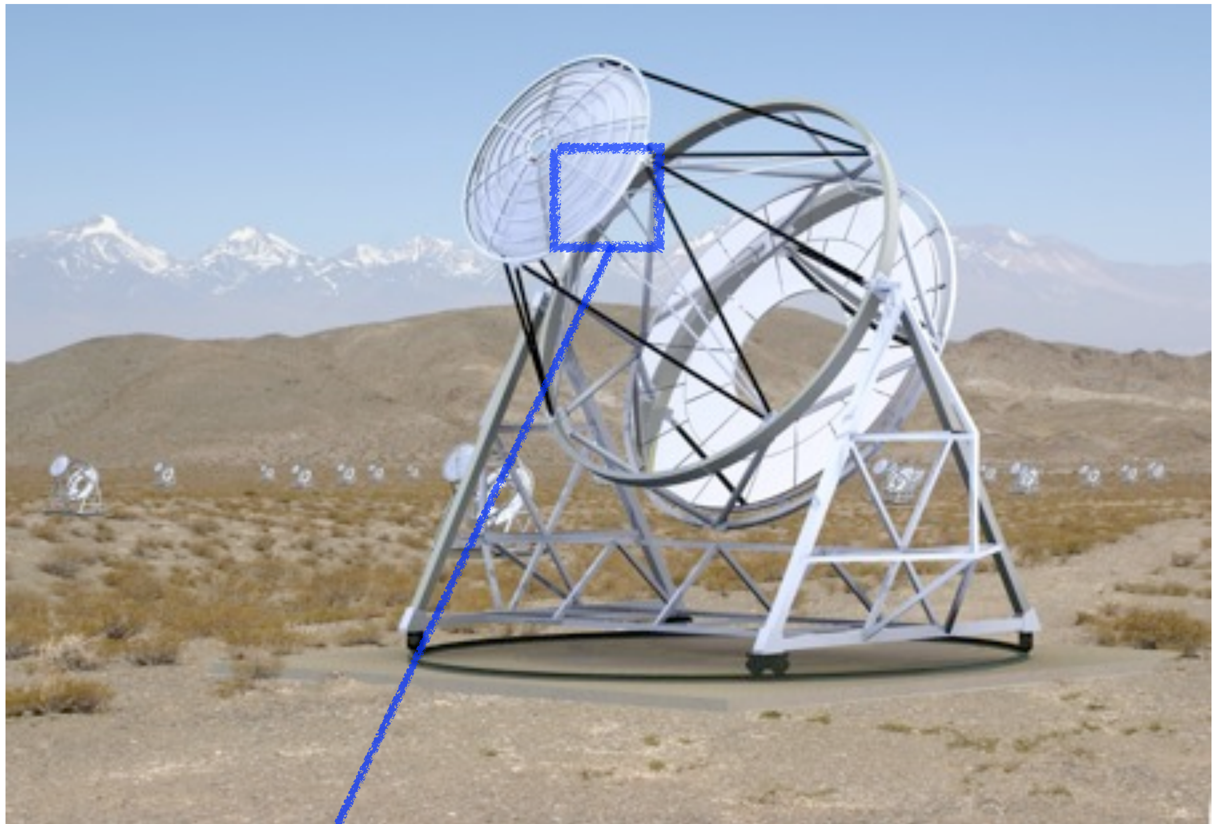
Differential Sensitivity for 50 hrs



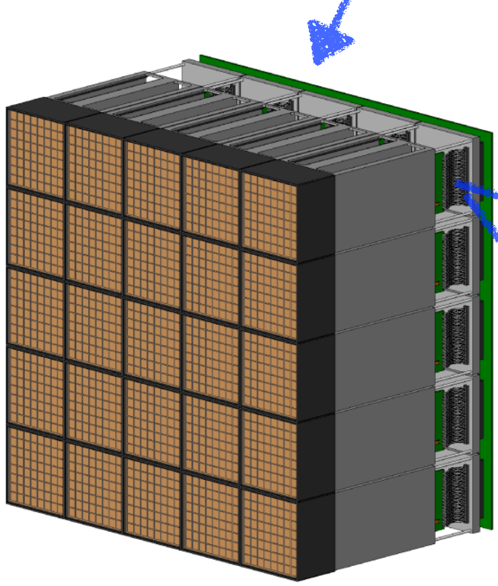
Events for 260 GeV to 62 TeV gamma-rays



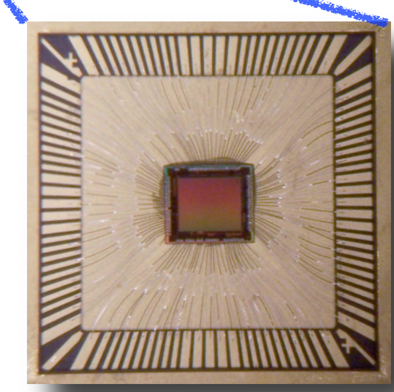
CTA-US Technology R&D



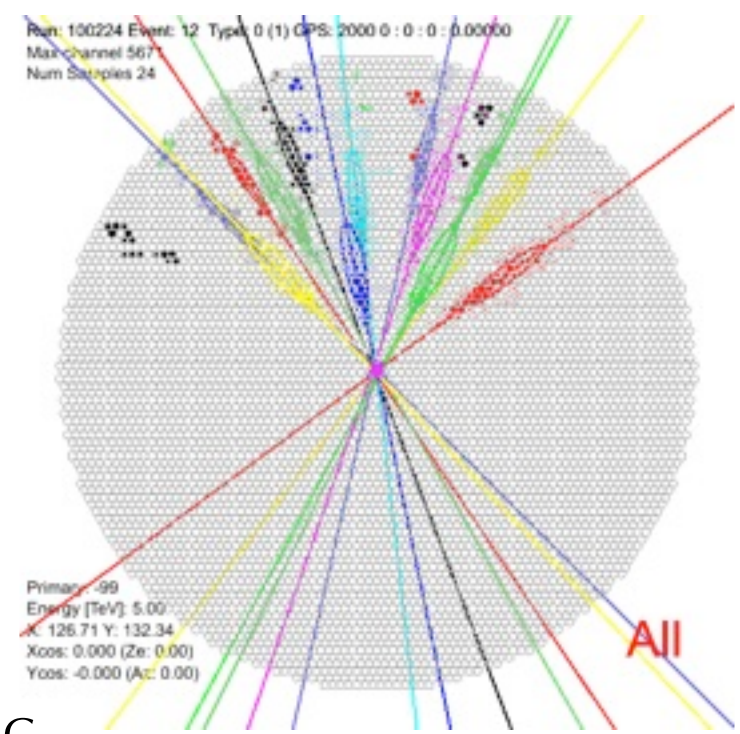
- Add 36 telescopes to existing 24-scope mid-sized telescope array.
- Collective effects in combining experiments - in large array, higher percentage of showers fall between scopes than beyond edge - lower energy threshold, better angular resolution, better sensitivity
- CTA-US group exploring Schwarzschild-Coulder for plate-scale reduction (MAPMTs), angular resolution, large corrected FOV (8 degree)
- Modular camera with SCA ASIC giving 16000 0.056 deg pixels with Gsps waveform sampling for ~$1M

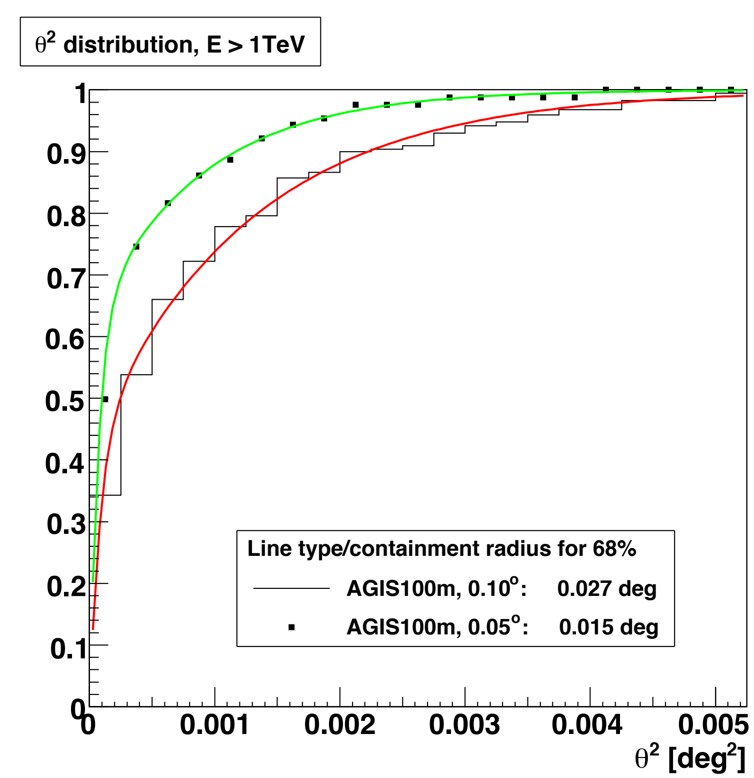


Modular MAPMT camera



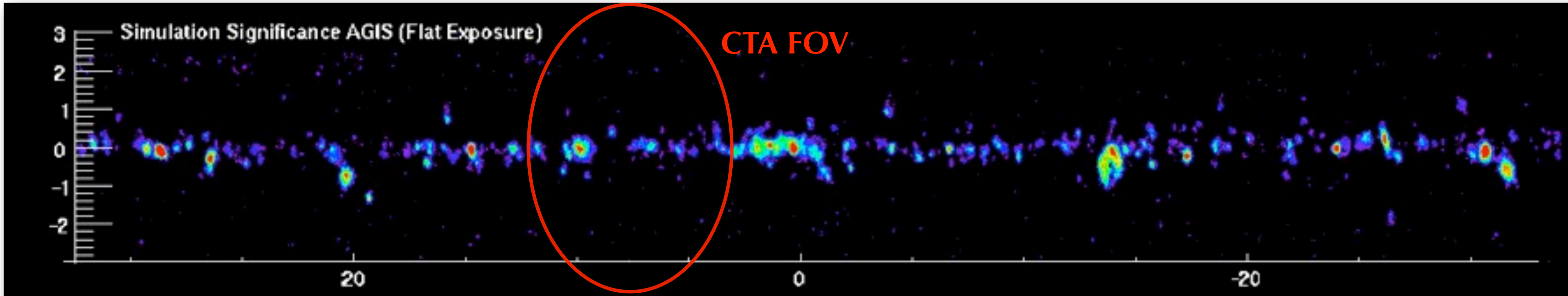
Switched-Capacitor-Array ASIC





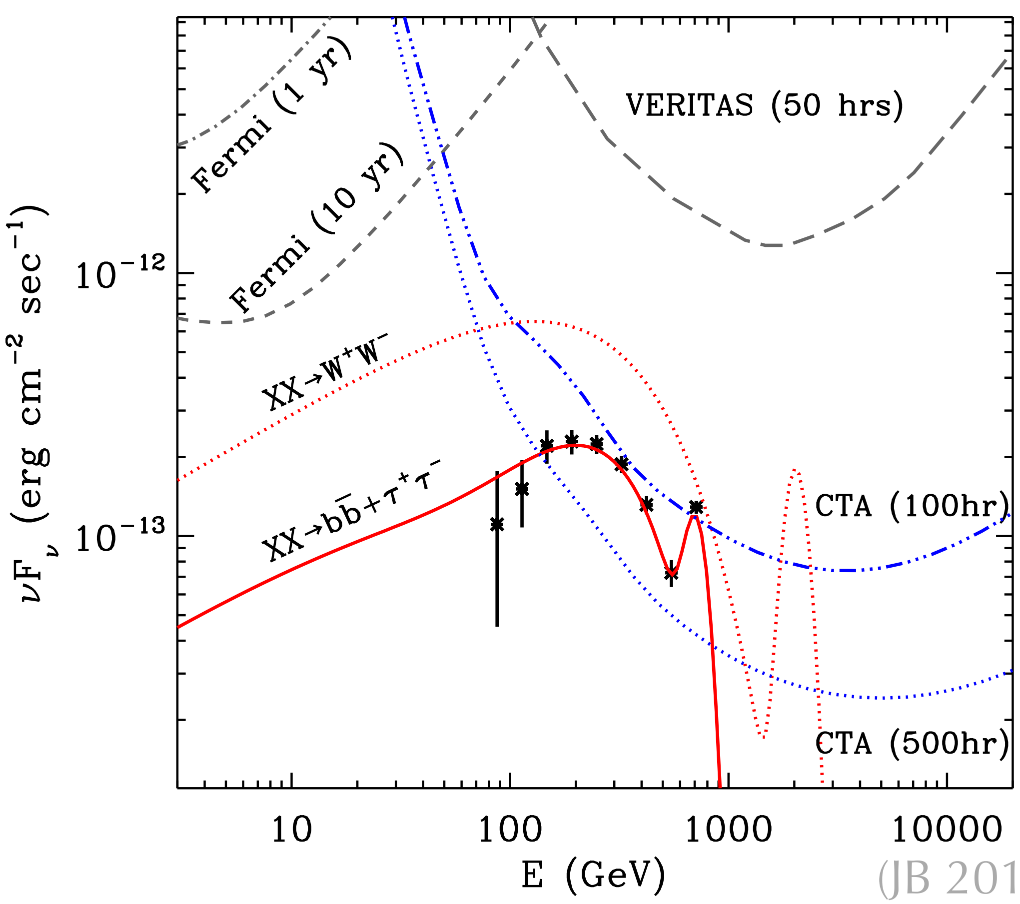
CTA Prospects

Wider field of view, better sensitivity, better angular resolution for Astrophysics and DM searches



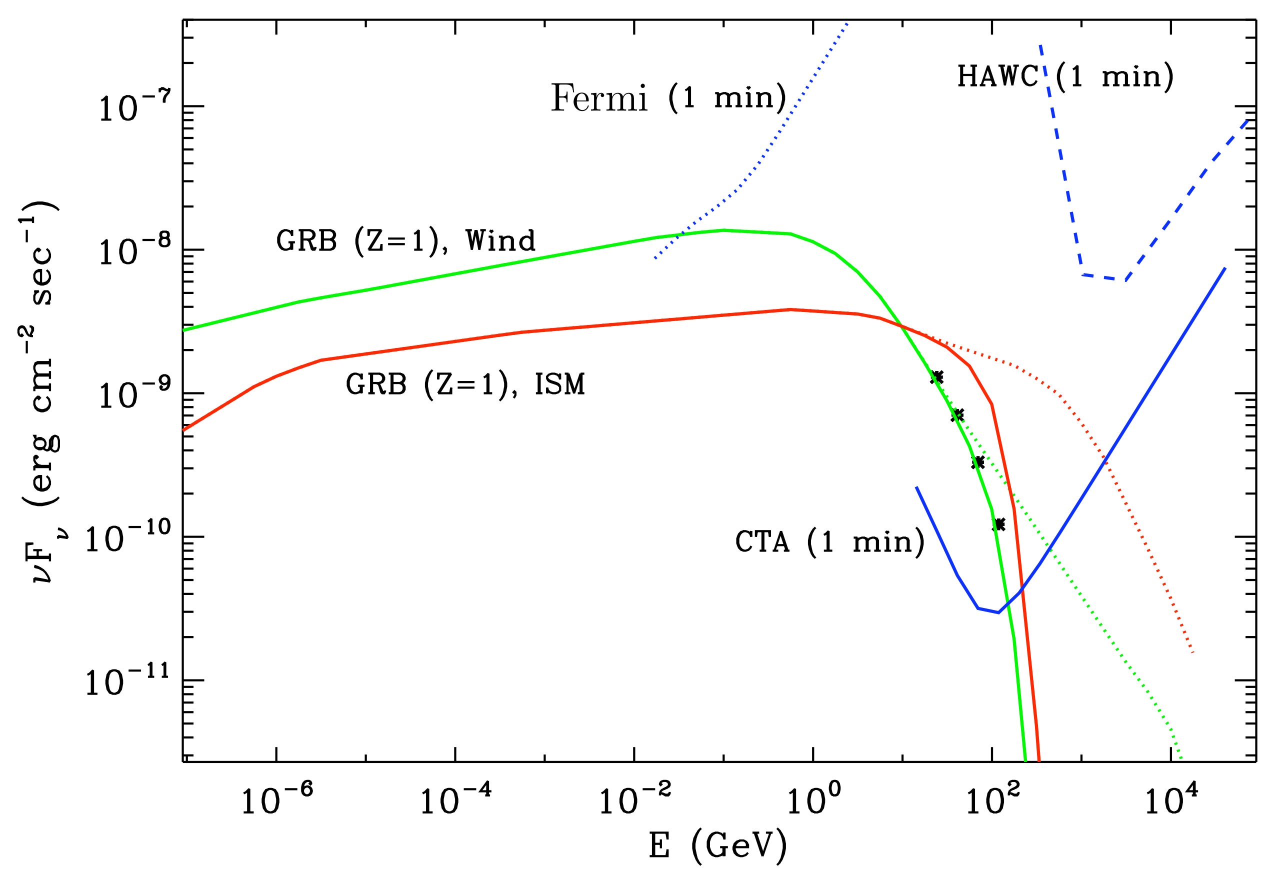
Simulated Sky Map with Improved Angular Resolution, FoV, Sensitivity   Digel, Funk and Hinton

Dark Matter



(JB 2011)

Gamma-Ray Bursts



Conclusions

- Gamma-ray measurements are providing important new probes of particle acceleration providing quantitative constraints, and beginning to discriminate between hadronic and leptonic scenarios.
- VHE gamma-ray sources also serve as probes of the diffuse infrared radiation fields (imprinted with star formation history) as well as LIV effects at TeV to Planck scales.
- For DM searches, gamma-rays provide good calorimetry for all annihilation channels - the detection cross-section is closely linked to the total annihilation cross-section in the early universe. Dwarf Galaxy halos sufficiently constrained to make robust predictions.
- The universal DM annihilation spectrum is imprinted with the particle mass and annihilation channels. Gamma-rays could also provide a measurement of the halo distribution linking a new DM particle to structure formation.
- Gamma-ray experiments are still more than an order of magnitude away from natural cross-section, but CTA (with long exposures dedicated to DM studies) will be sensitive to the natural cross-section.
- Gamma-ray astronomy is a rich field, providing new data on astrophysical sources, cosmology and particle physics.

Backup Slides