A Likelihood Procedure for Dark Matter Searches of the Galactic Center with VERITAS

Nathan Kelley-Hoskins, for the VERITAS Collaboration

TAUP 2015, Torino, Italy

DESY

VERITAS

HELMHOLTZ ASSOCIATION

Alliance for Astroparticle Physics

HUMBOLDT-UNIVERSITÄT ZU BERLIN

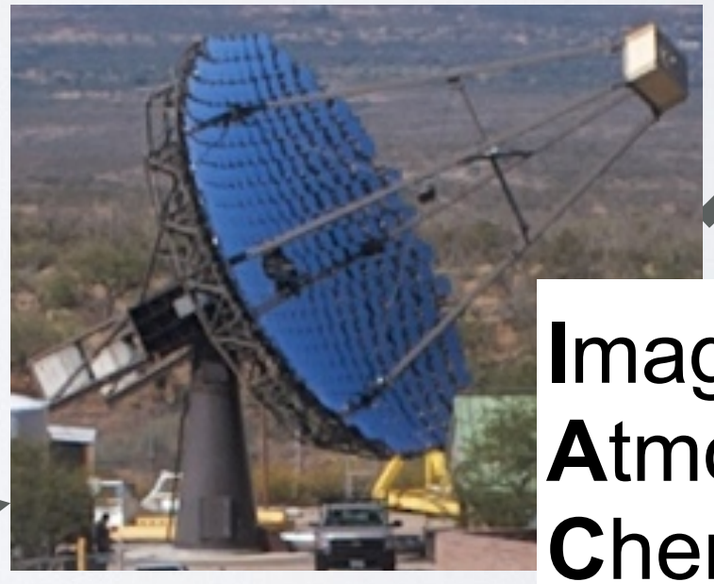
Indirect Detection

Galactic Center
Dark Matter

Decays/
Annihilates
To

Gamma Rays

Are Detected By



Imaging
Atmospheric
Cherenkov
Telescopes

Likelihood
Analysis

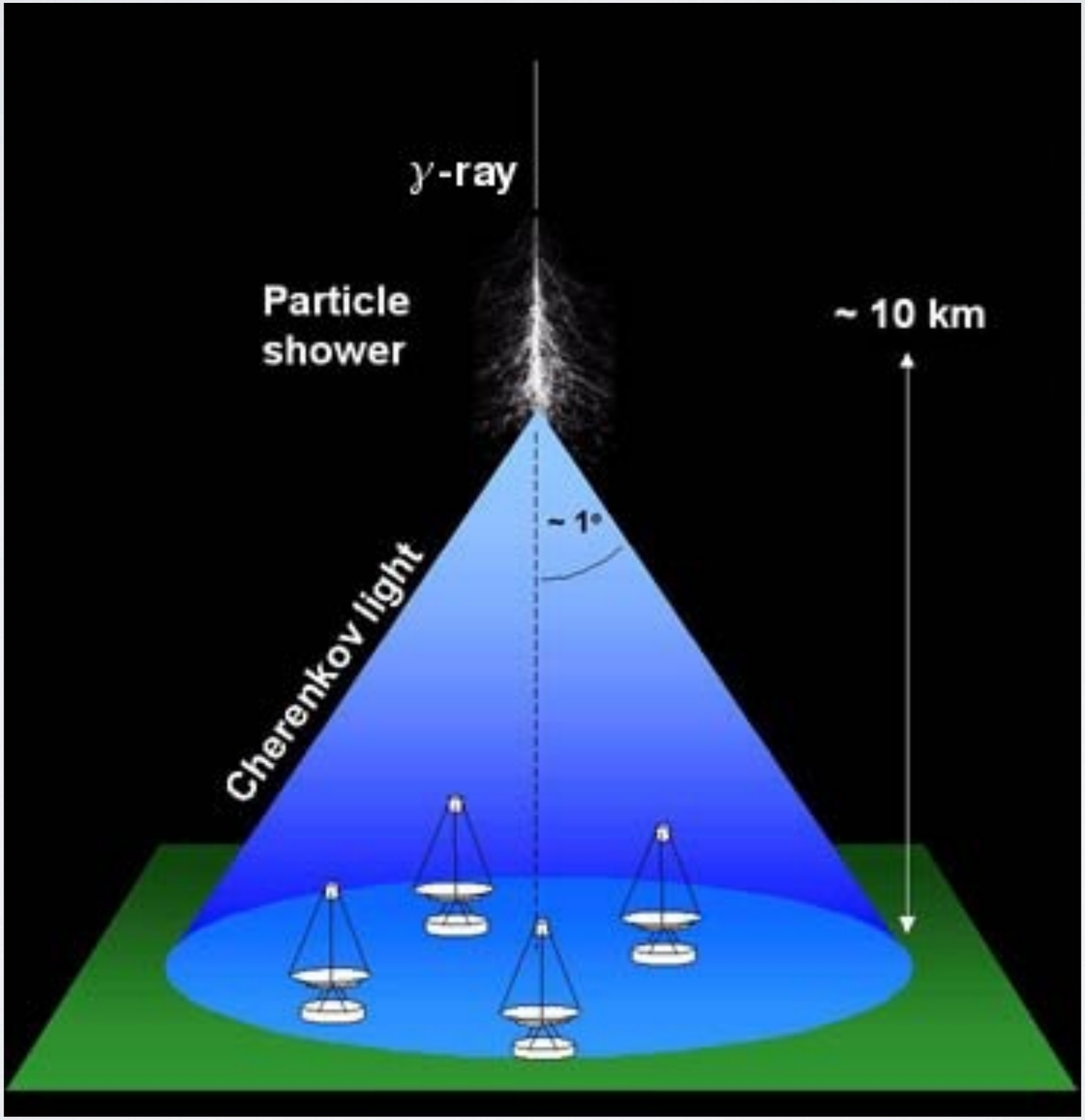
Improved
DM Limits

VERITAS

Observes Gamma Rays :	85 GeV - >30 TeV
Energy Resolution :	15-25%
PSF :	Containment$_{68\%}$ < 0.1 deg at 1 TeV
Sensitivity :	1% Crab in ~25 Hours

Monday: "Highlights of recent results from the VERITAS gamma-ray observatory", Lucy Fortson

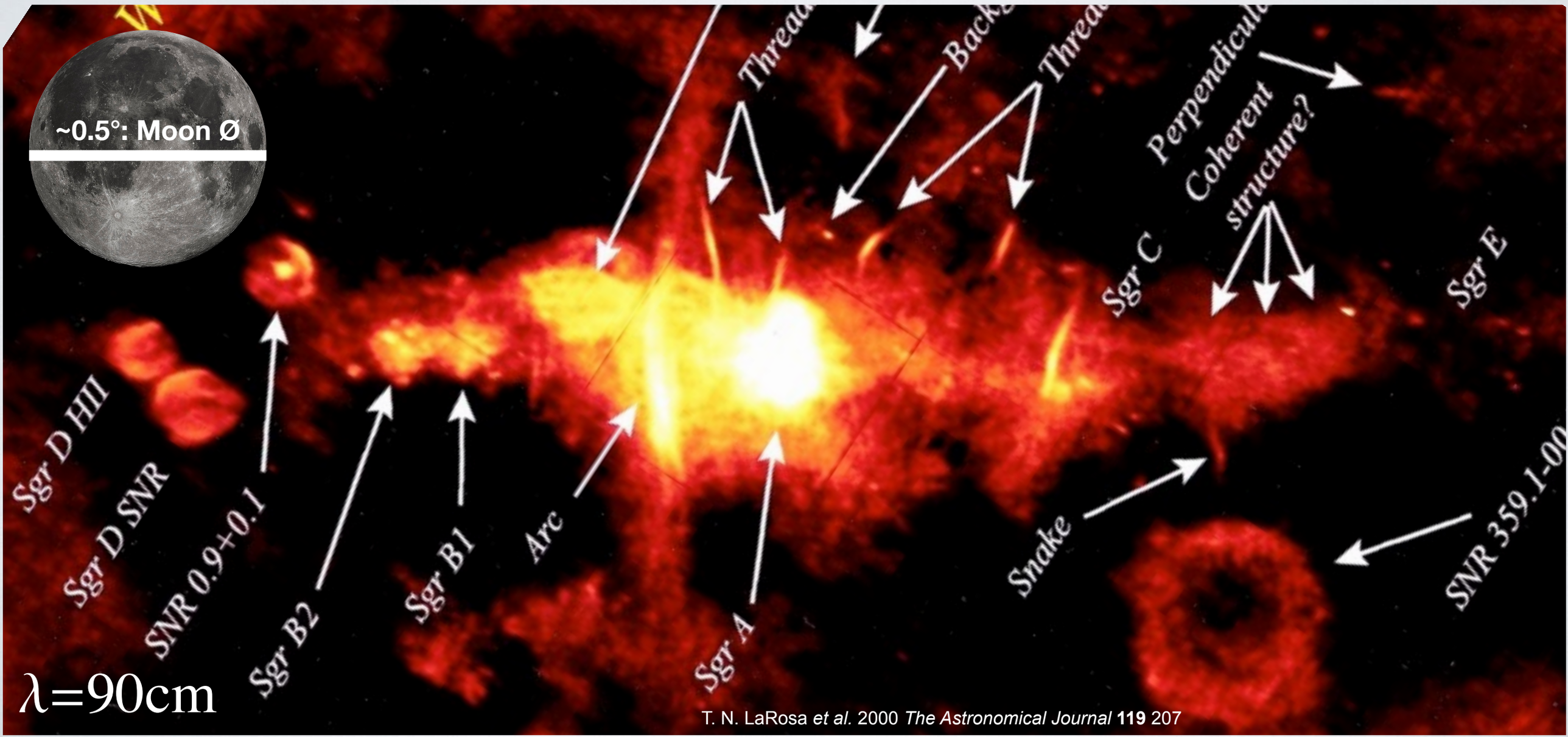
Detecting Gamma Rays



http://community.dur.ac.uk/~dph0www4/images/detection.jpg

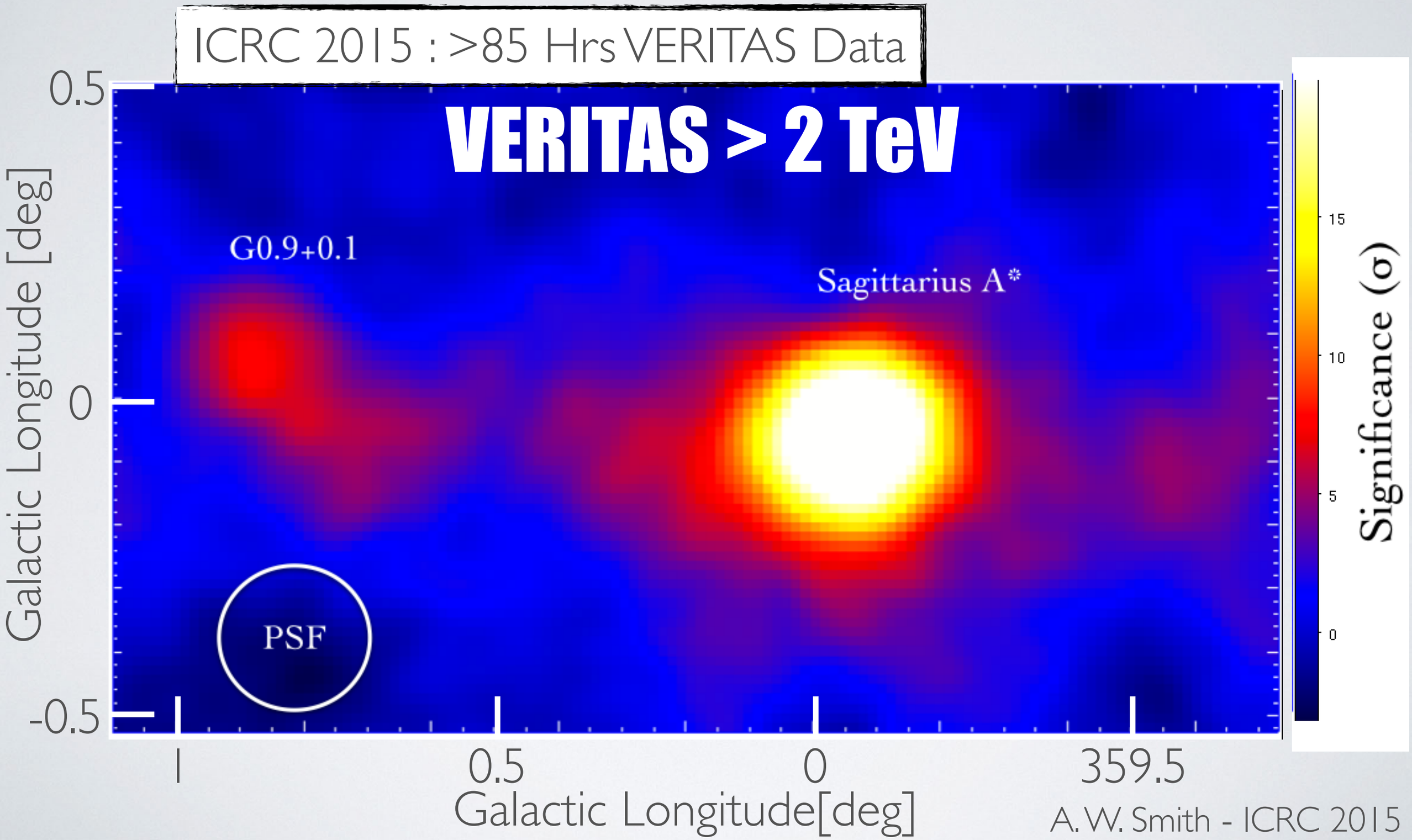
Galactic Center

- Huge J-Factor (2 Orders of Magnitude Higher Than Dwarf Galaxies)
- Many non-DM sources



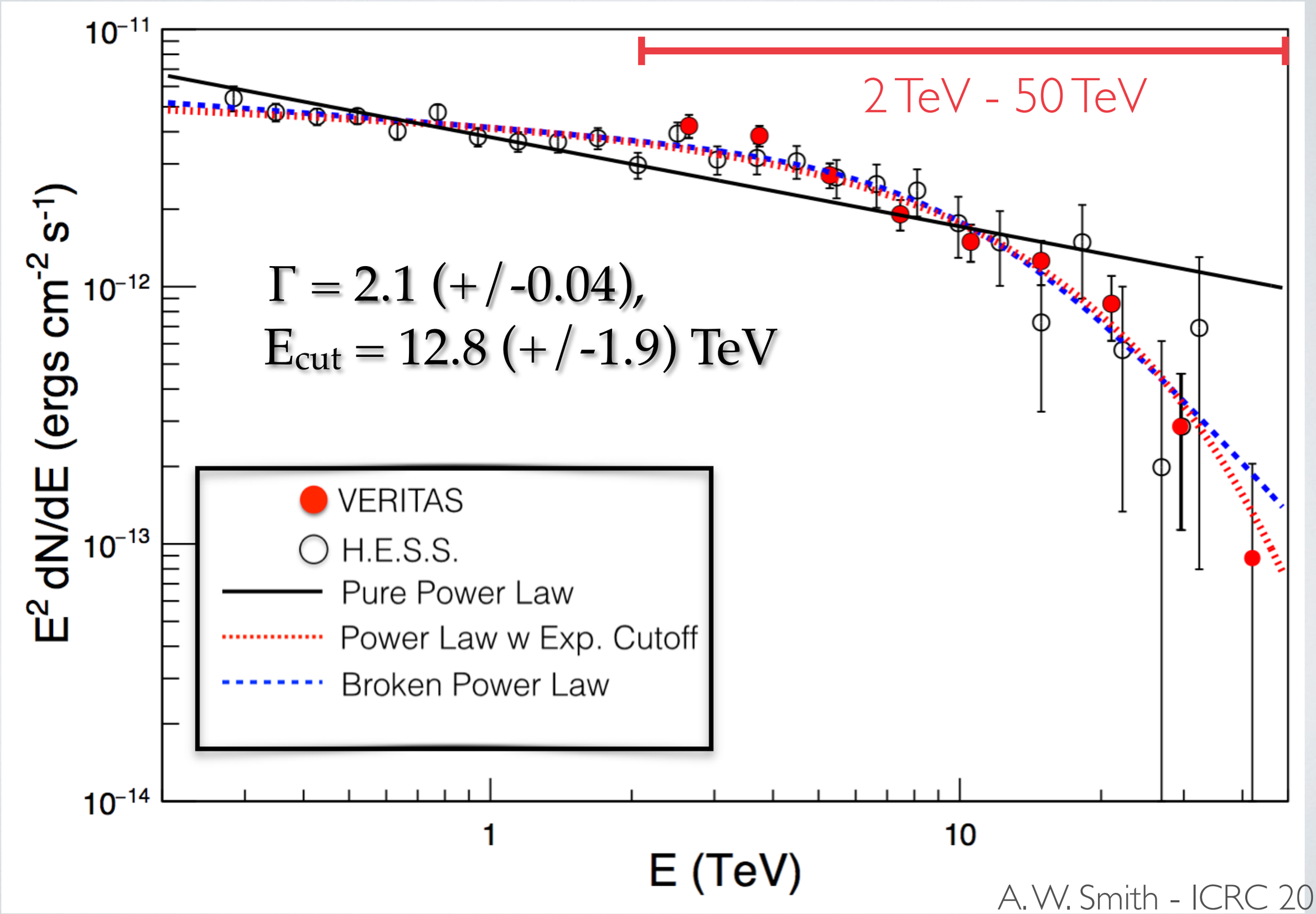
T. N. LaRosa *et al.* 2000 *The Astronomical Journal* **119** 207

Galactic Center



A. W. Smith - ICRC 2015

Galactic Center



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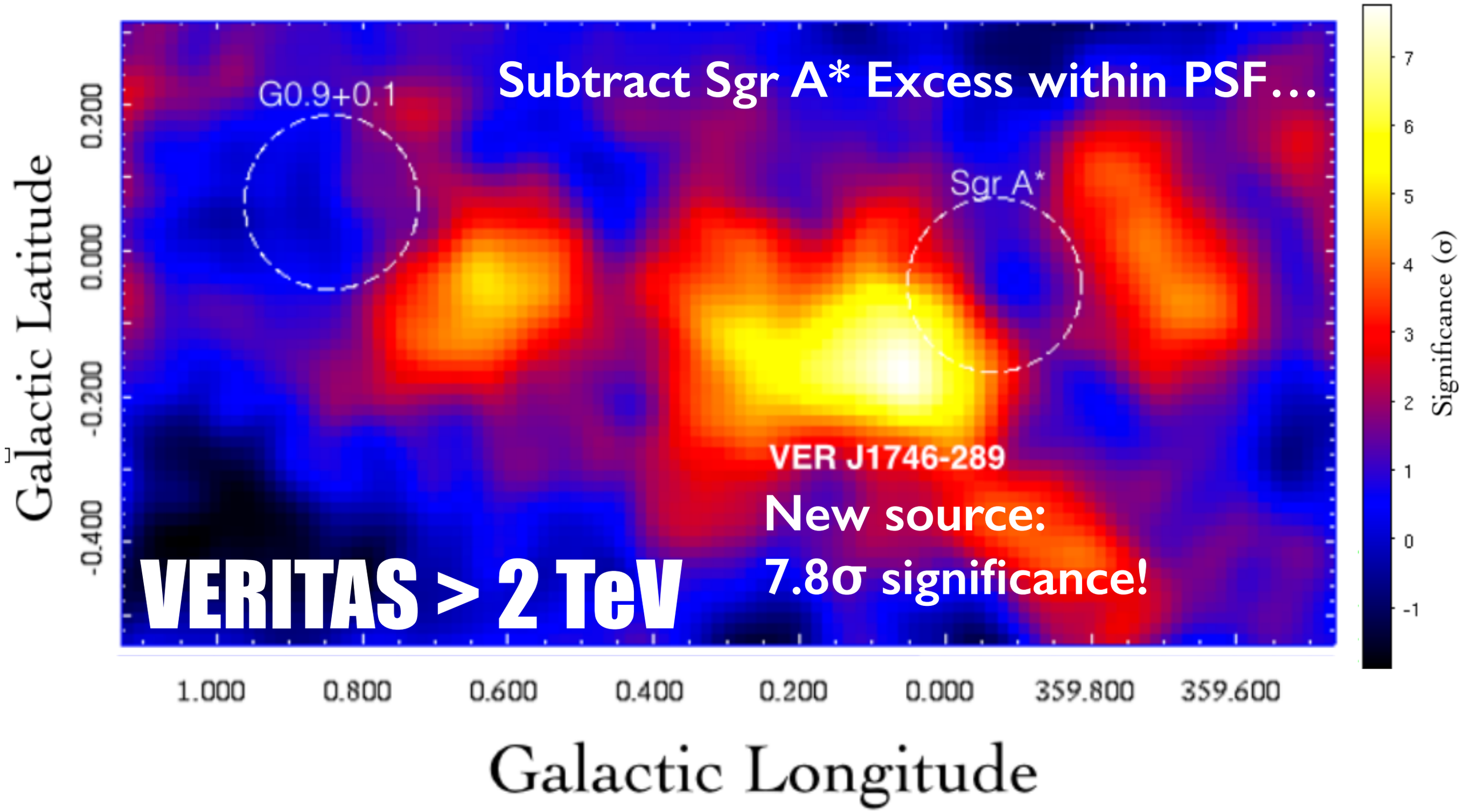
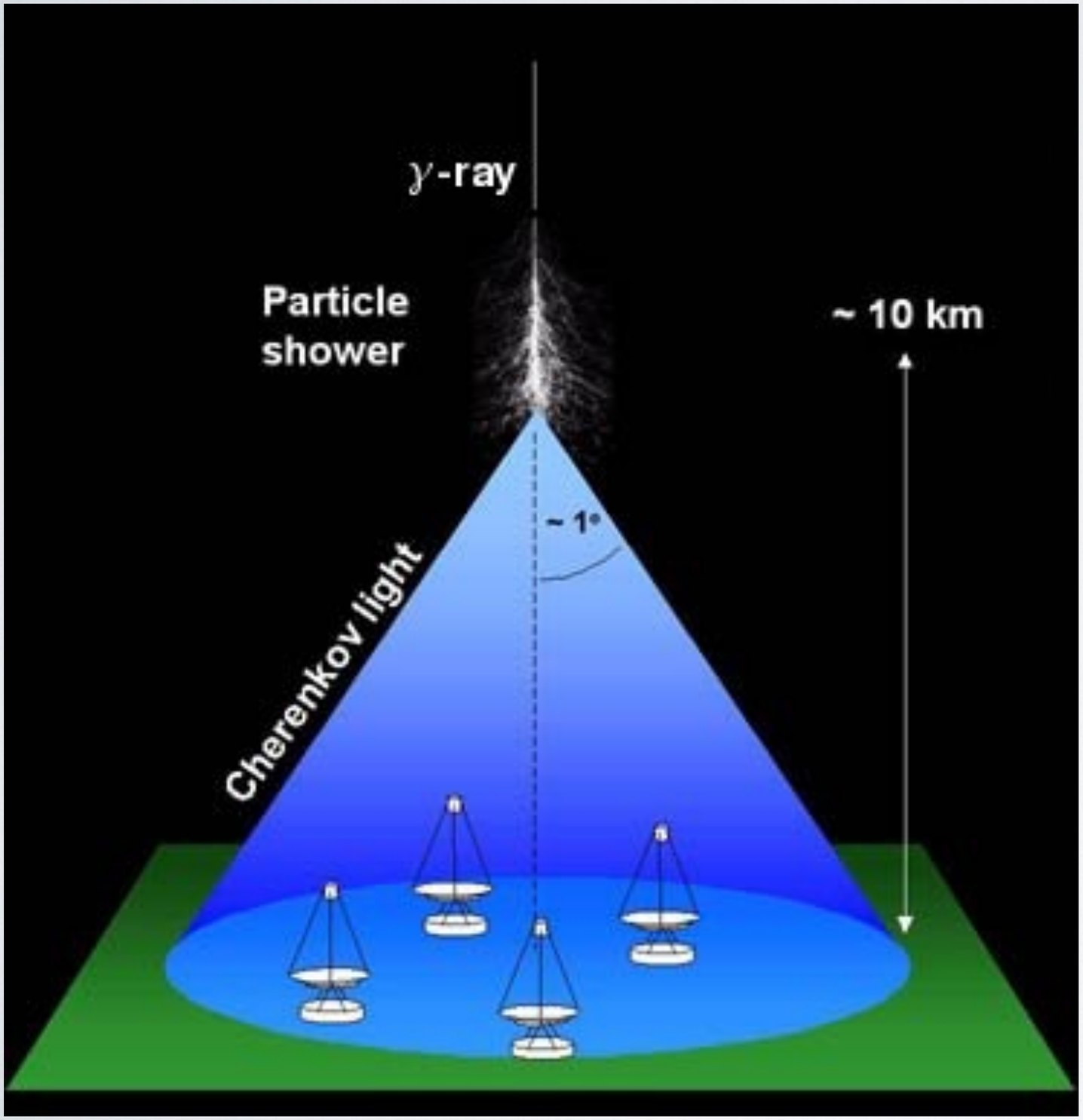
Galactic Center



Detecting Gamma Rays



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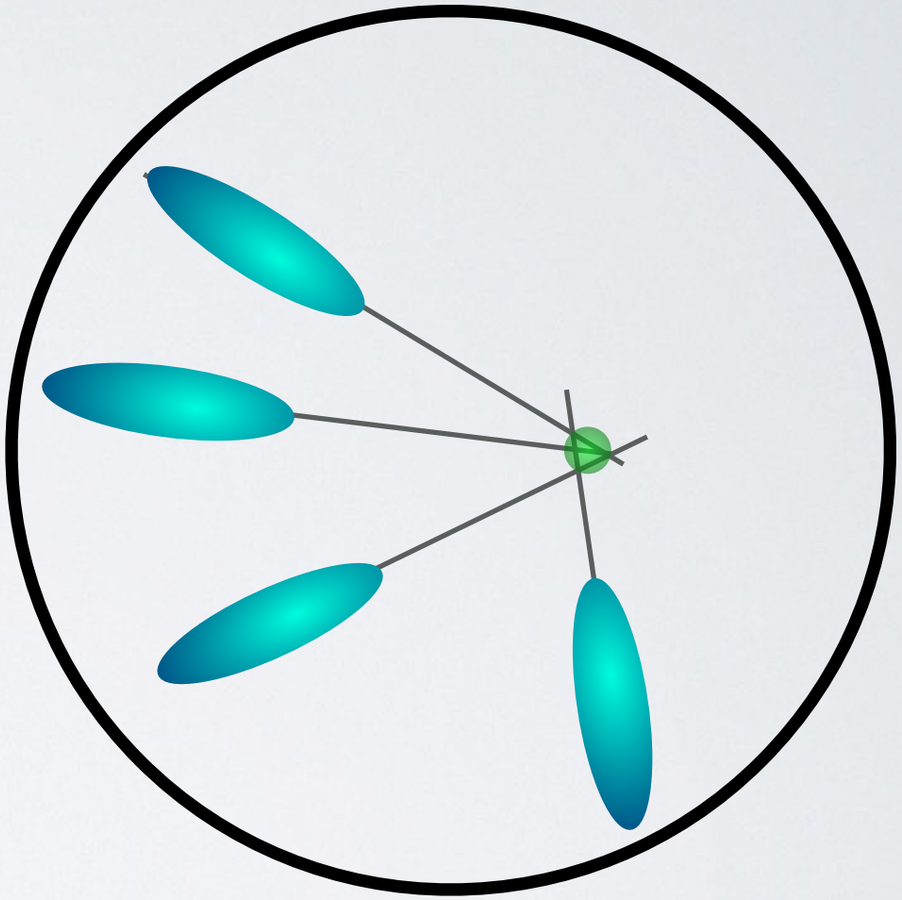
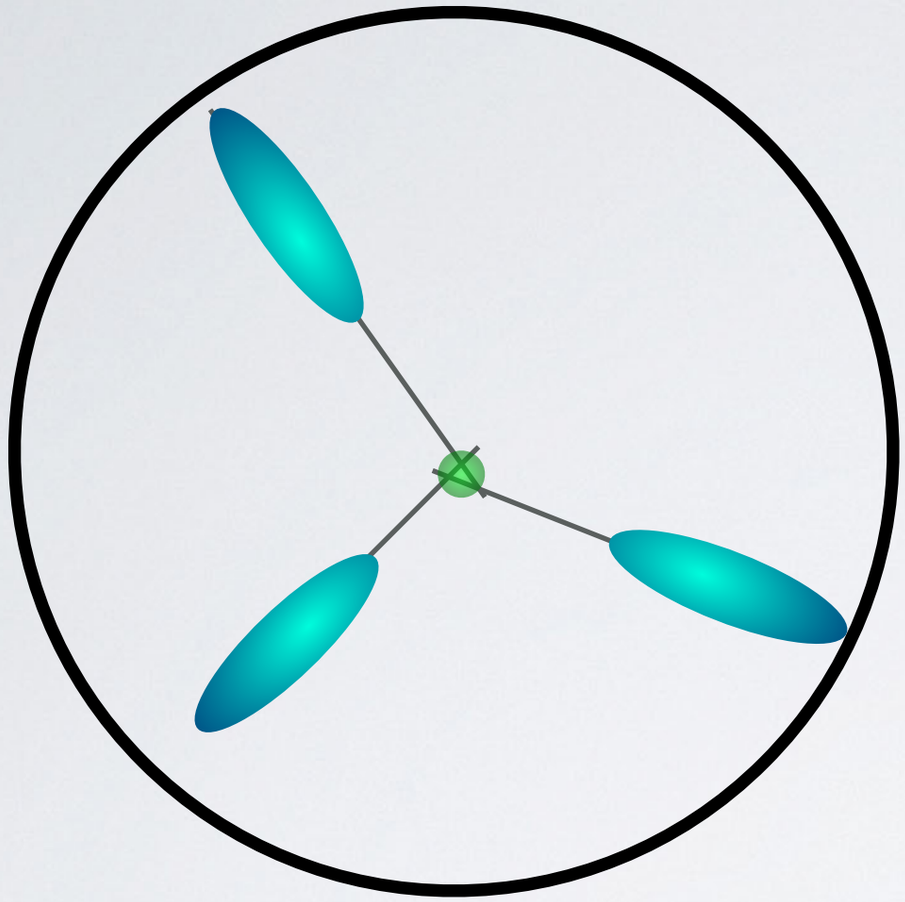
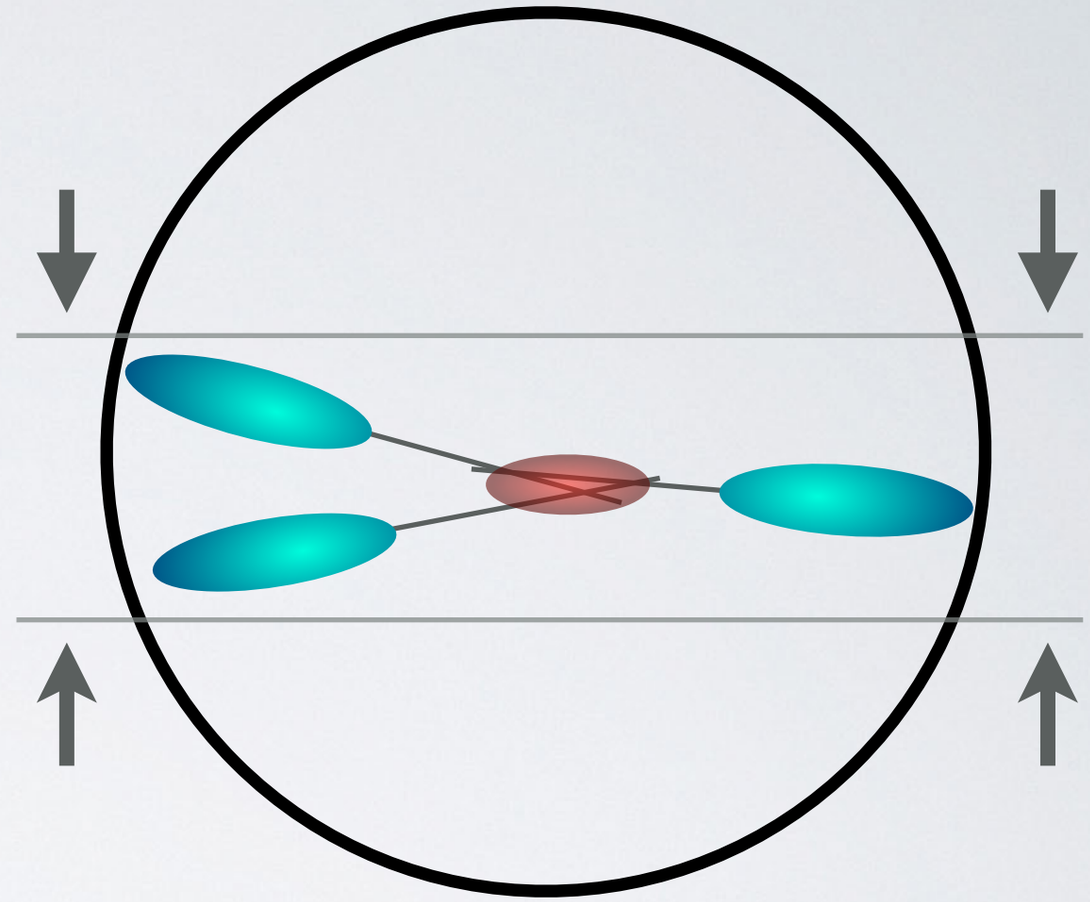


Combined Telescope Shower Images

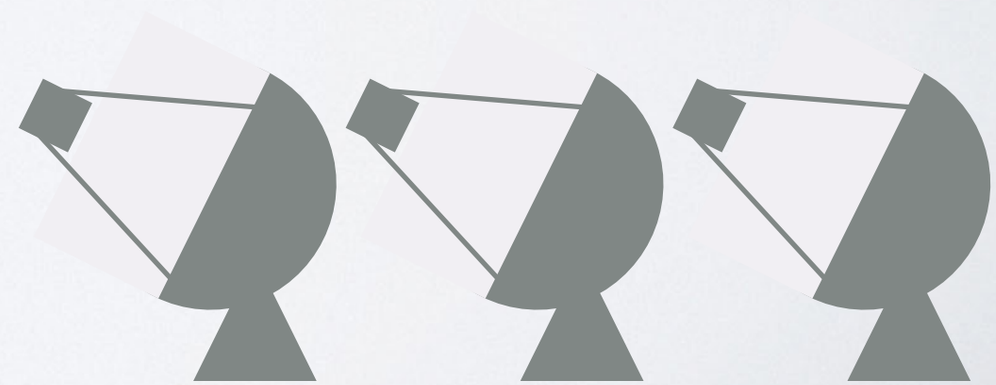
Zenith Angle



Small Zenith

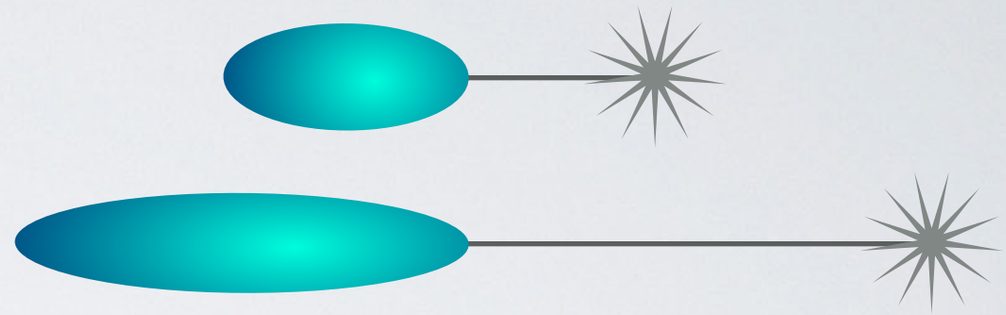


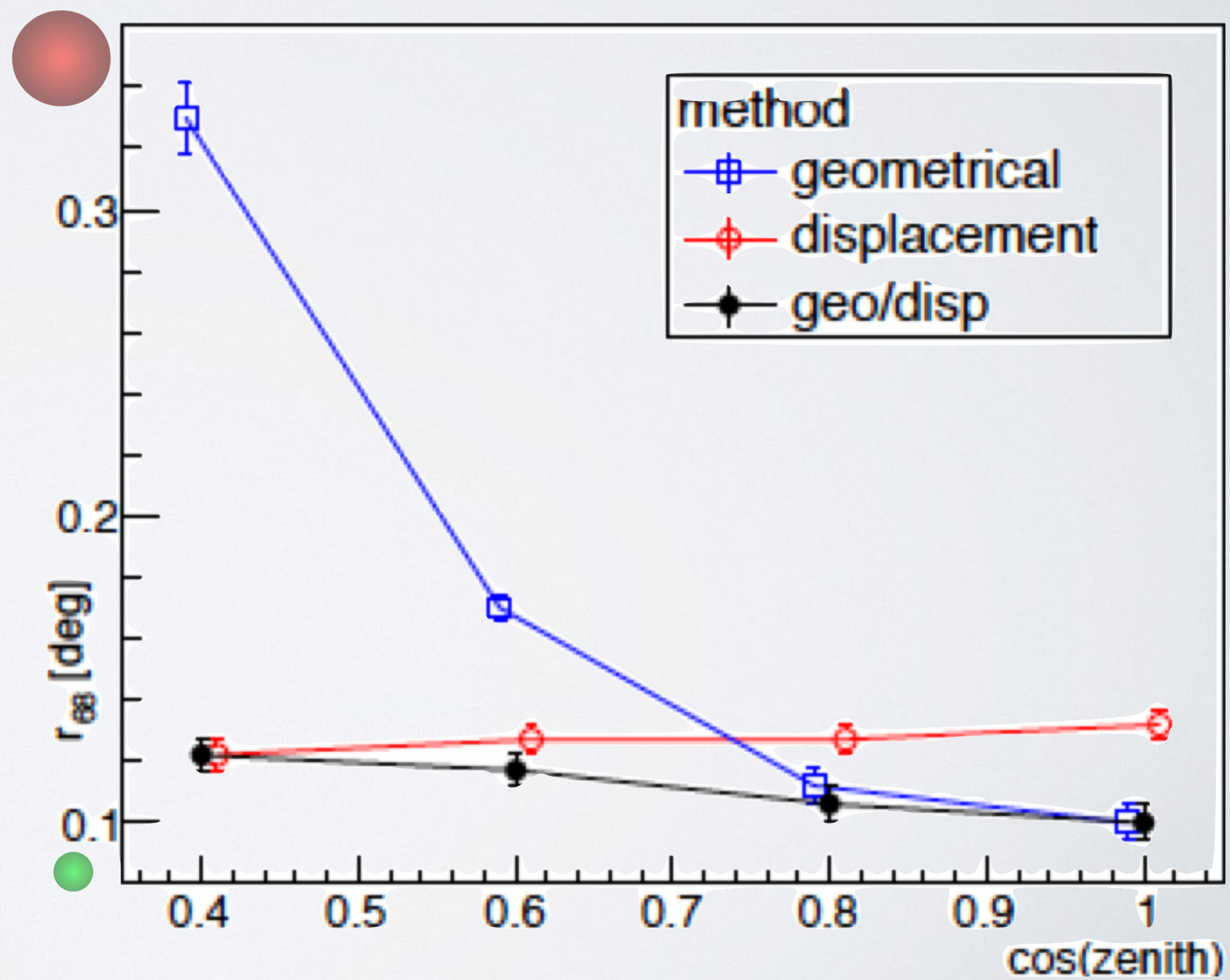
Large Zenith



DISP + Large Zenith Angle

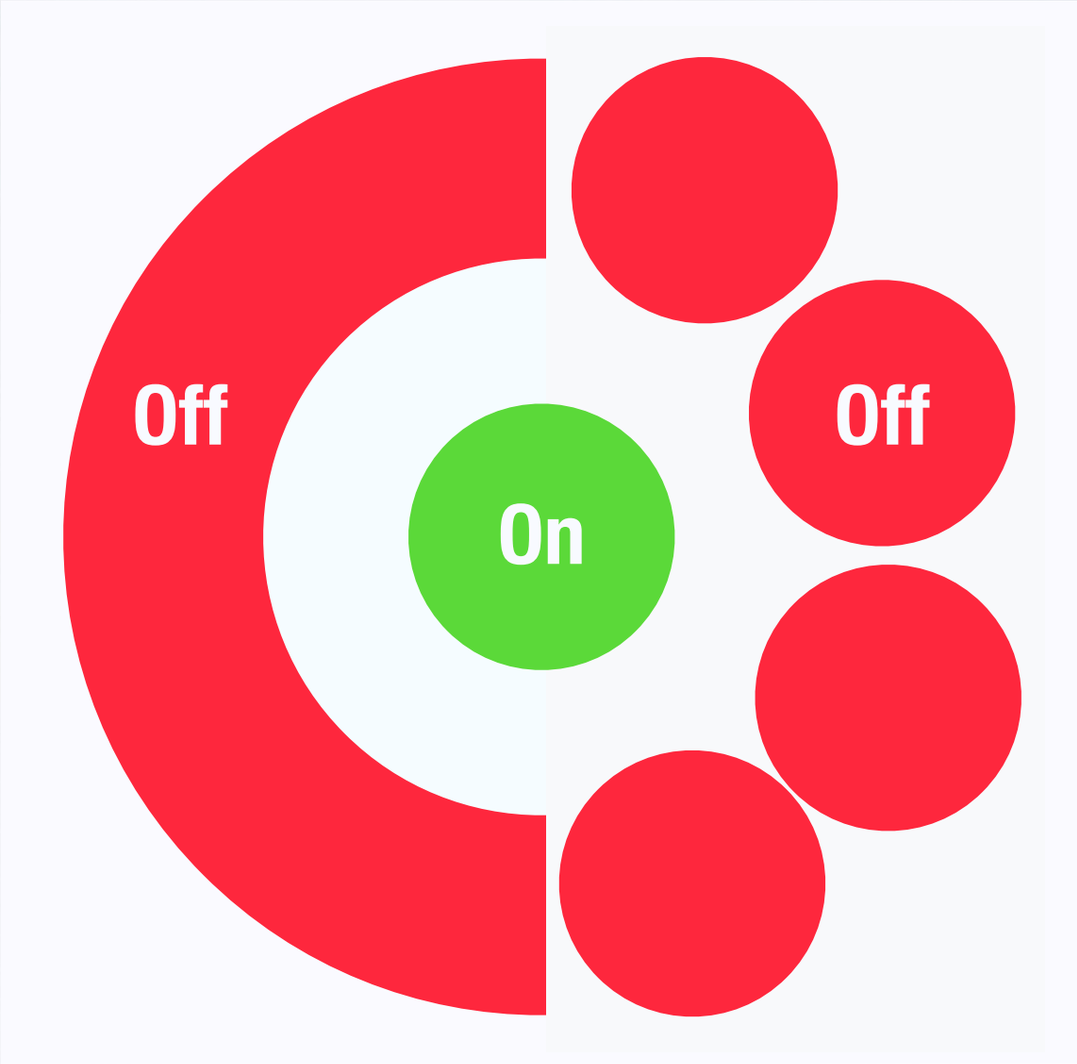
- DISP
  - Better Angular Resolution
- Low Zenith Angle
  - Shifts energy threshold to 2 TeV
- Both Great for Galactic Center at Zenith > 60°





Li and Ma

- Pick **On** Sky Region
- Pick **Off** Sky Region
- Count Gamma Rays in Each Region



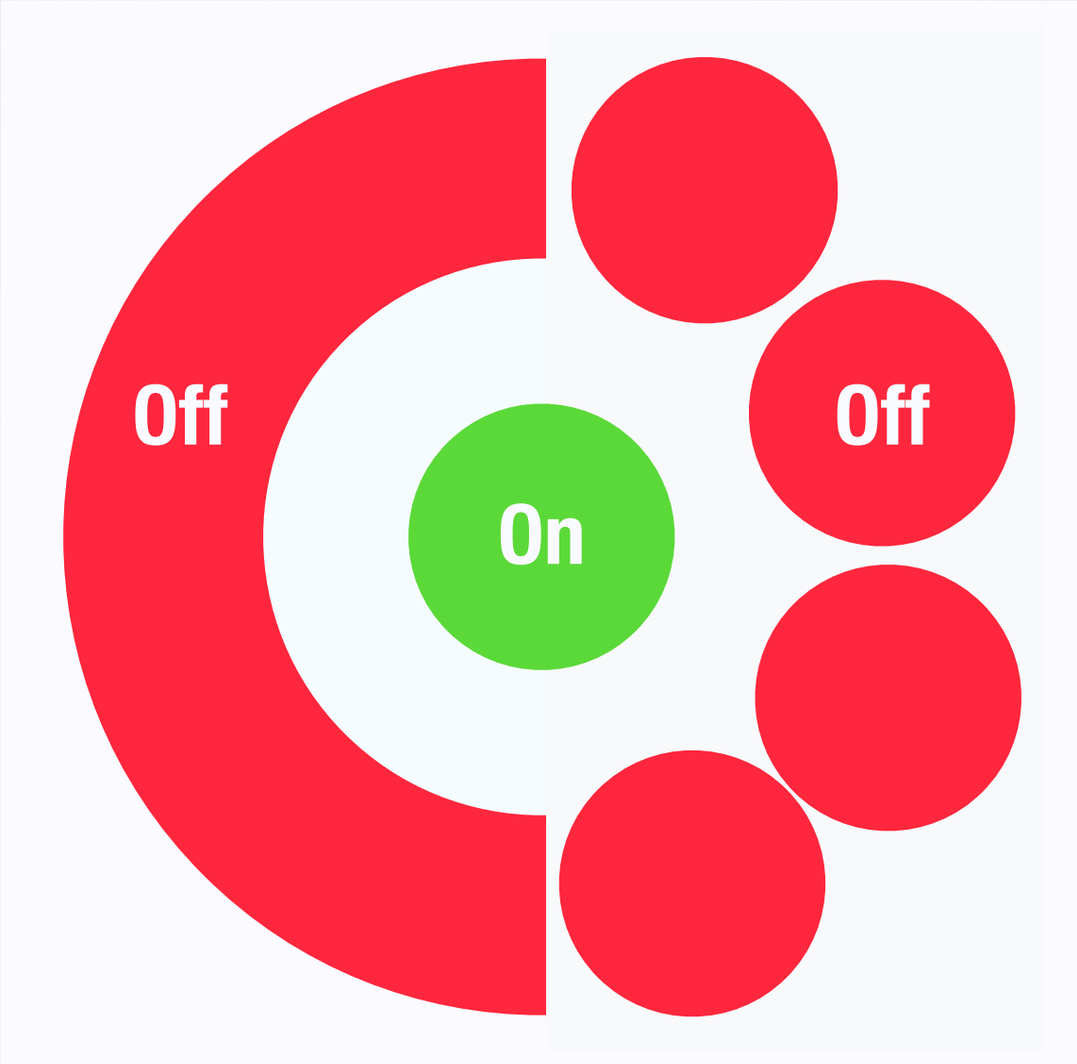
Li and Ma

☑ **Great**

For Point Sources
With Clean Off Regions

❑ **Not So Great**

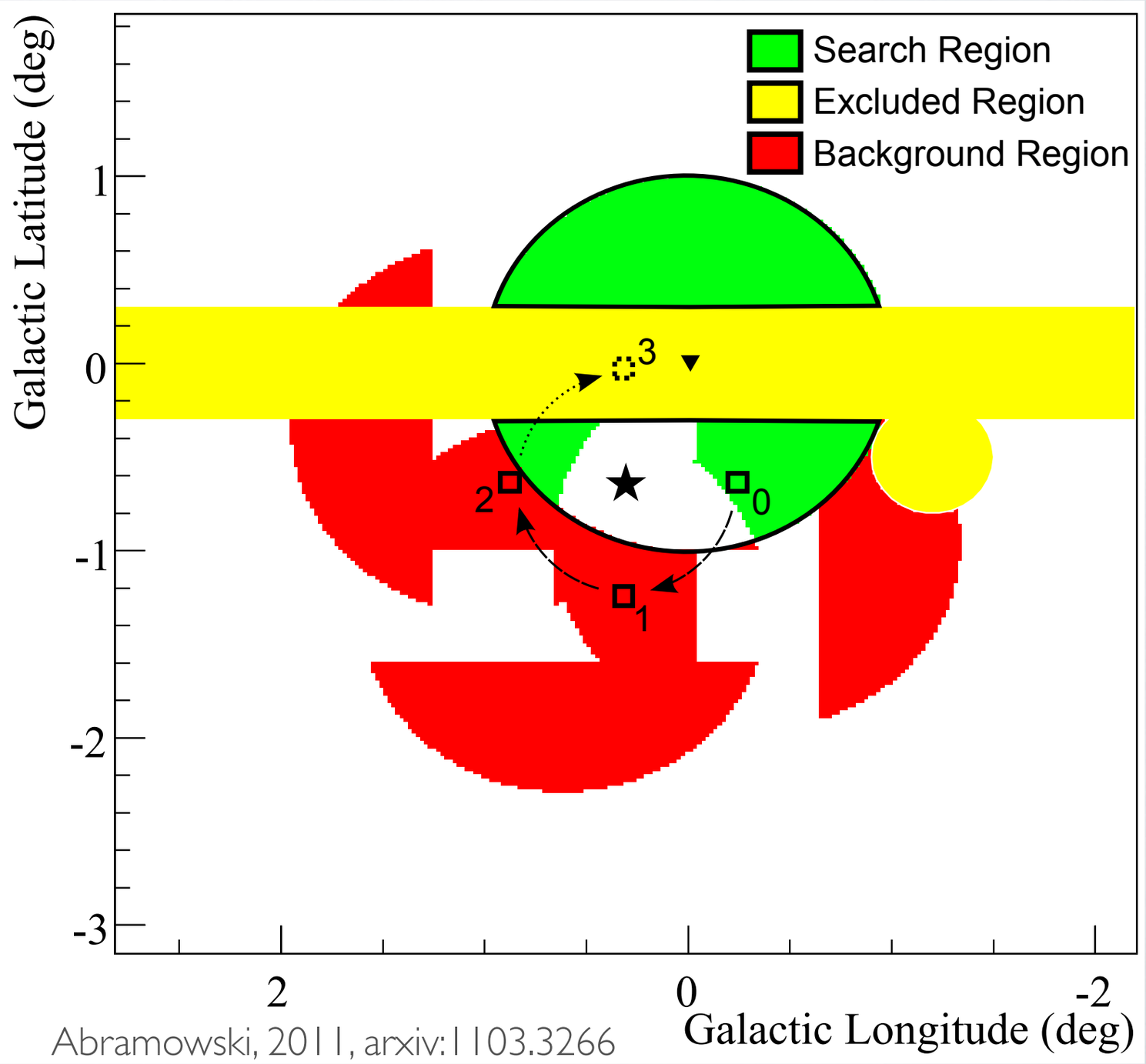
- If Too Many Gamma-Ray Sources Crowding The Off Regions
- If Background Has Diffuse Sources



GC with HESS

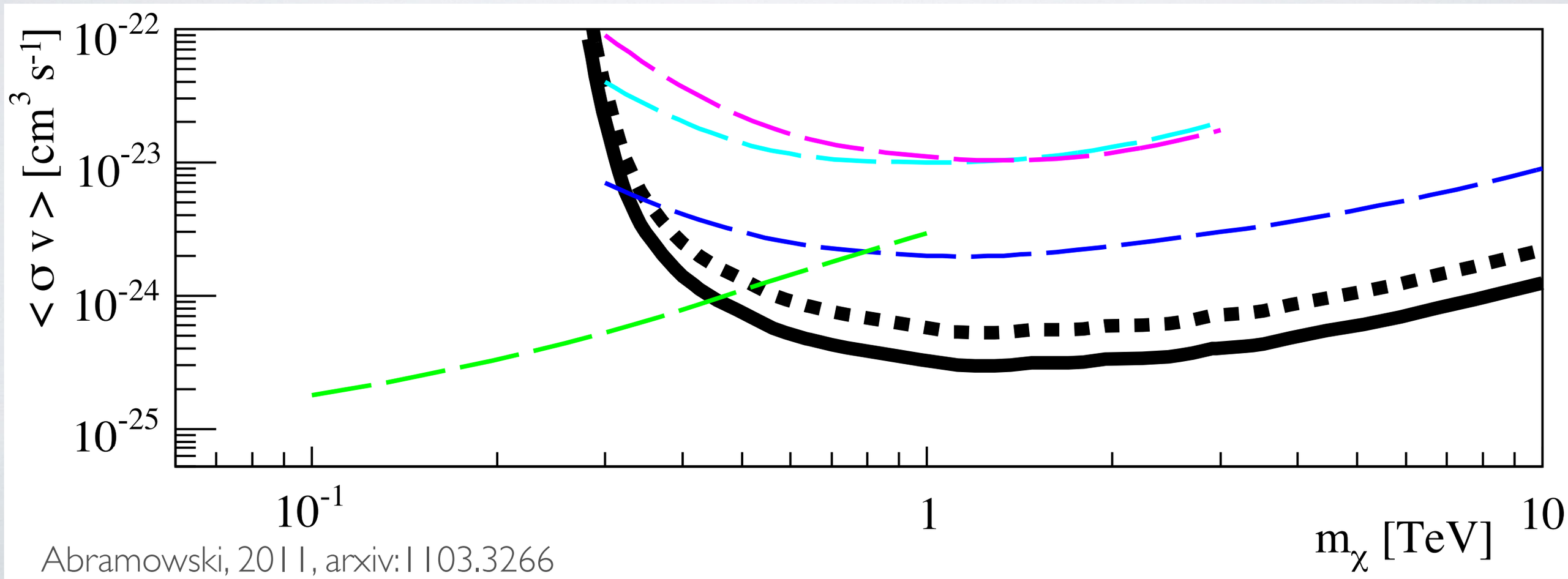
HESS paper 2011:

- Excluded Large Areas (source crowding)
- Complex Off Regions



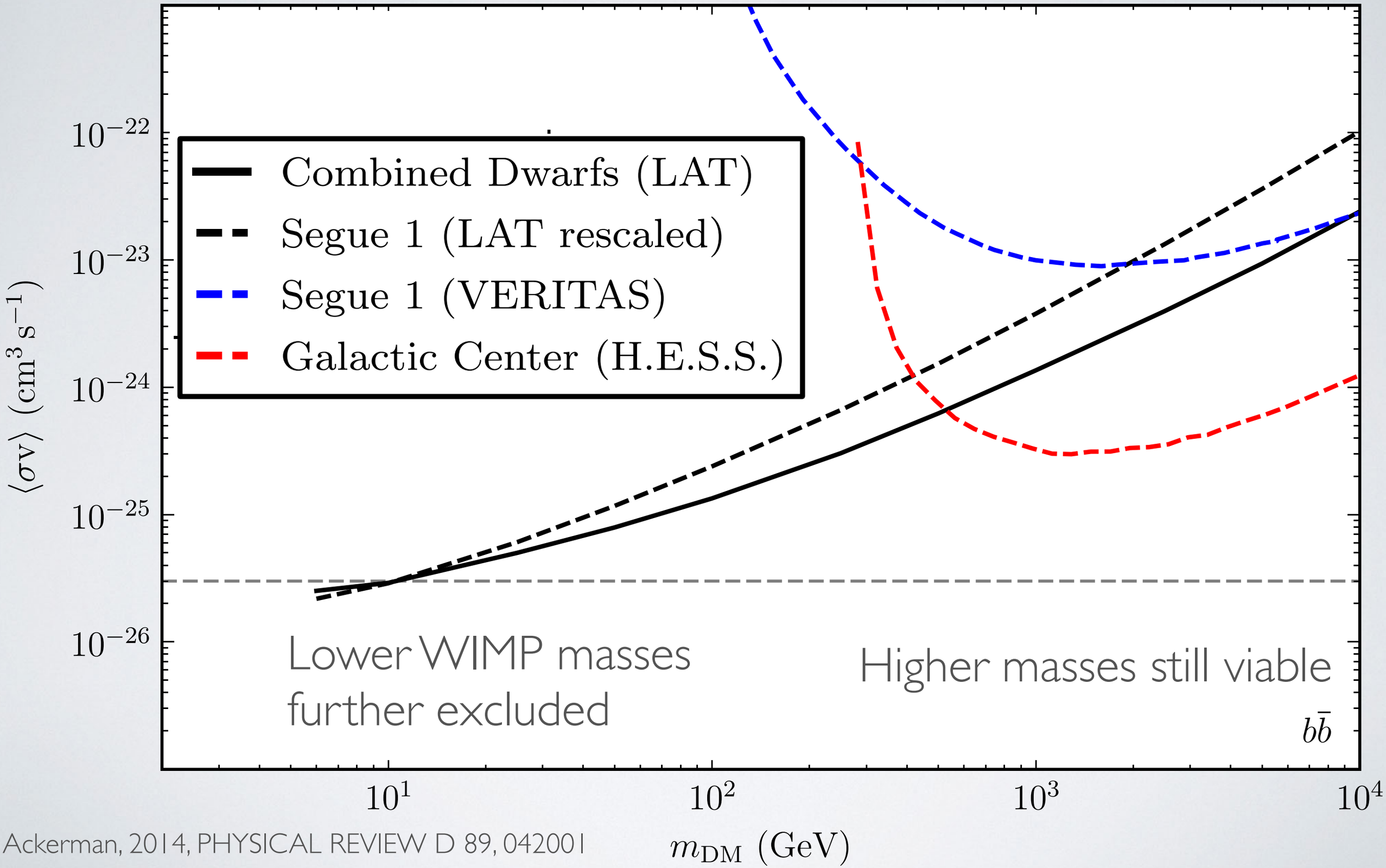
Abramowski, 2011, arxiv:1103.3266

GC with HESS



Abramowski, 2011, arxiv:1103.3266

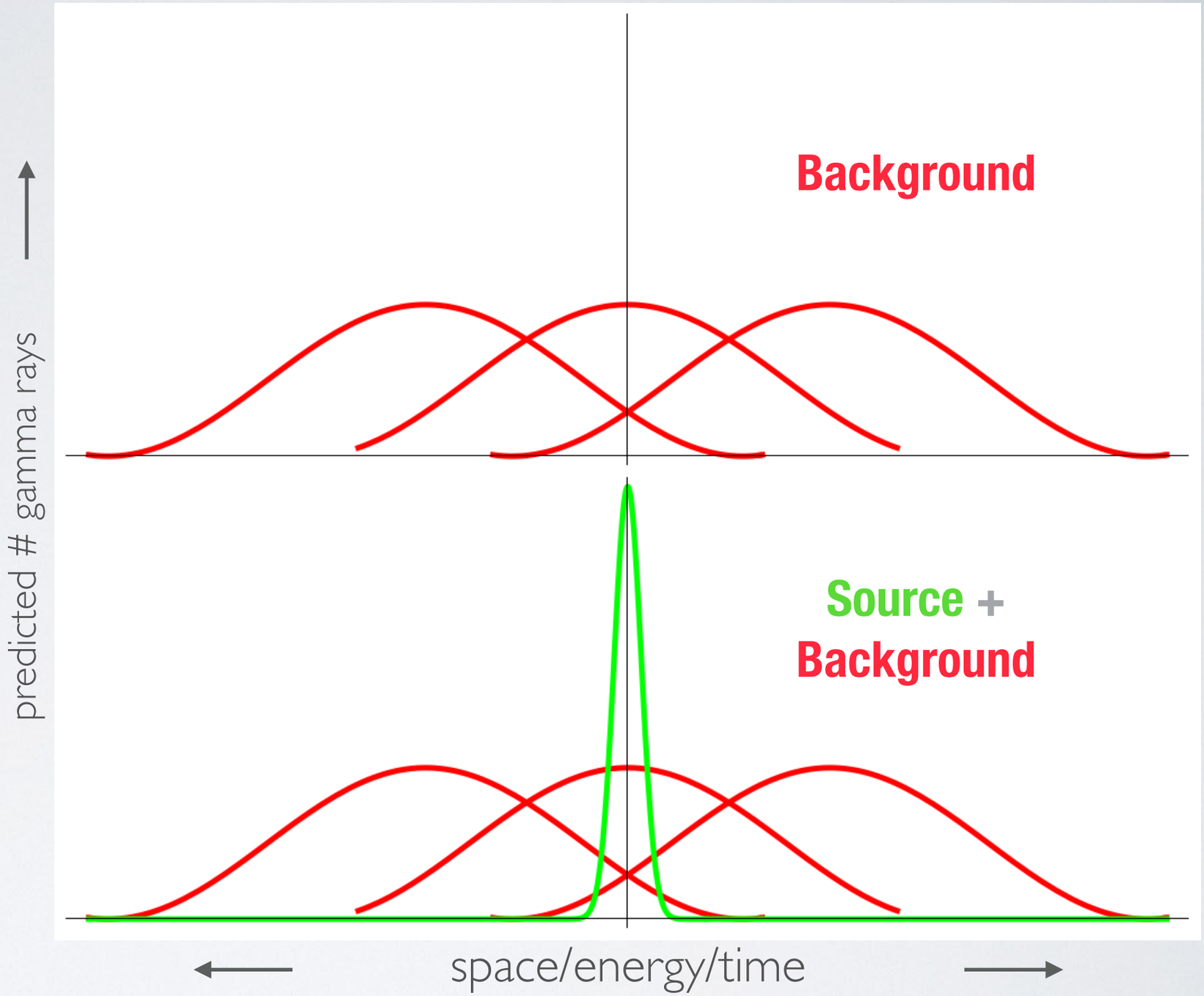
GC with Fermi



Ackerman, 2014, PHYSICAL REVIEW D 89, 042001

Likelihood

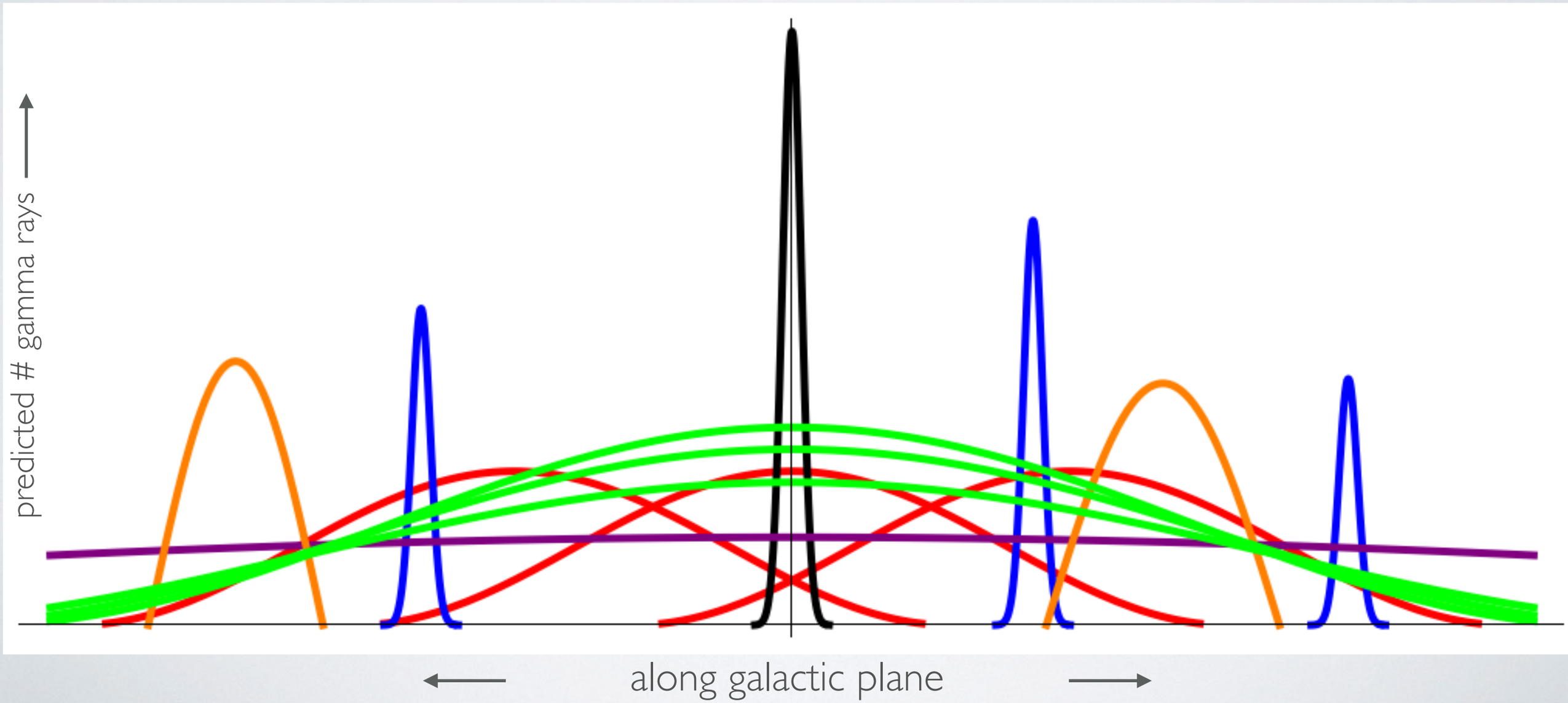
- Two model groups (hypotheses)
- Maximize Likelihoods
- Test Statistic



$$TestStatistic = -2 * ln\left(\frac{L_{background}}{L_{source+background}}\right)$$

Modelling the Backgrounds

Proton Backgrounds, Pulsar Wind Nebulae, Supermassive Black Hole, Diffuse Emission, Supernova Remnants, Dark Matter? (Ein/NFW/Isotherm)

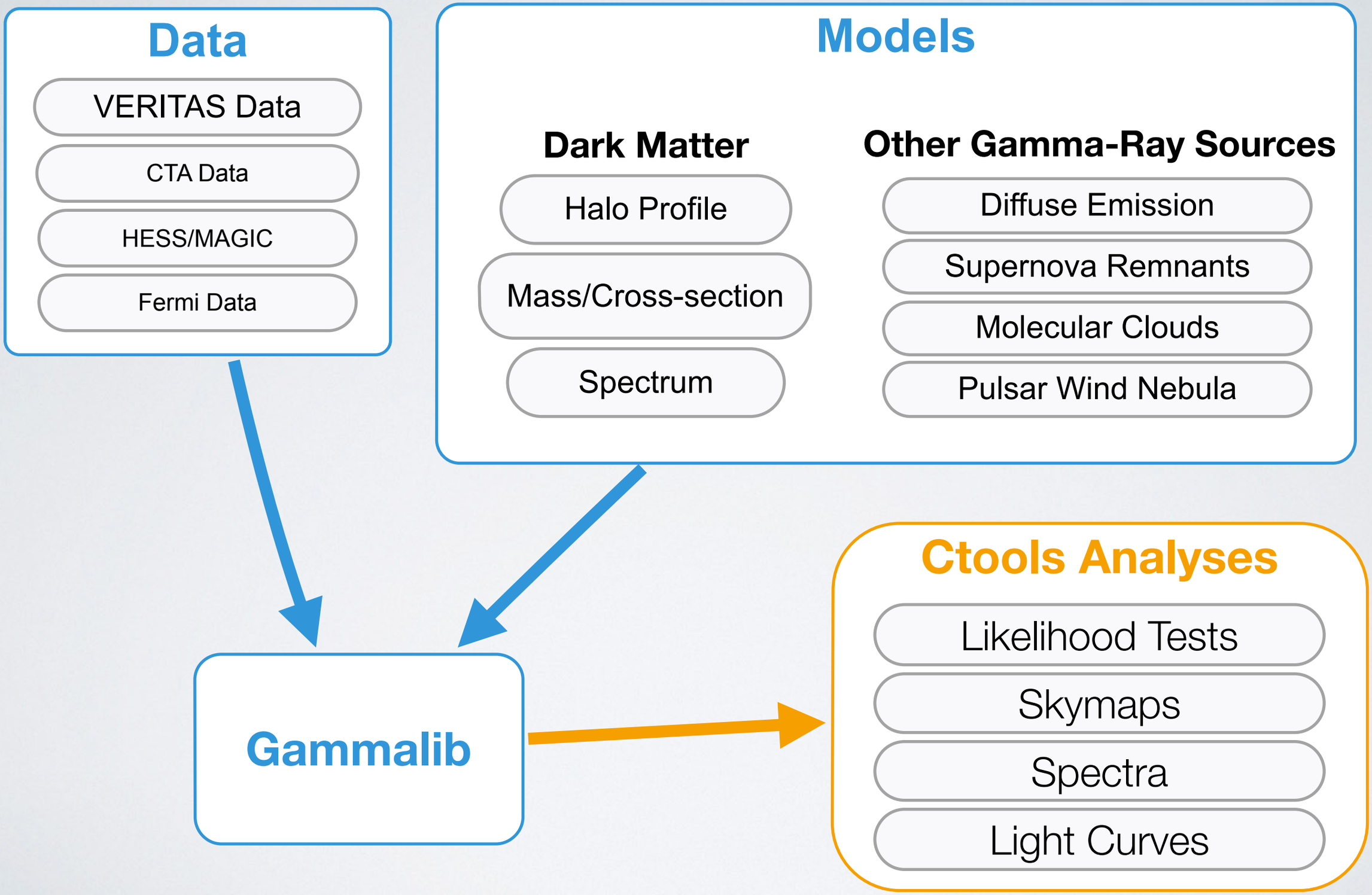


Gammalib and CTOOLS

- Likelihood Toolbox for Gamma-Ray Data
- Binned & Unbinned
- Multiple Spatial/Spectral Models
  - Gaussian Point Source, Shell, Power Law, Broken Power Law, etc
- Currently in Testing by VERITAS, MAGIC and HESS

http://cta.irap.omp.eu/ctools/

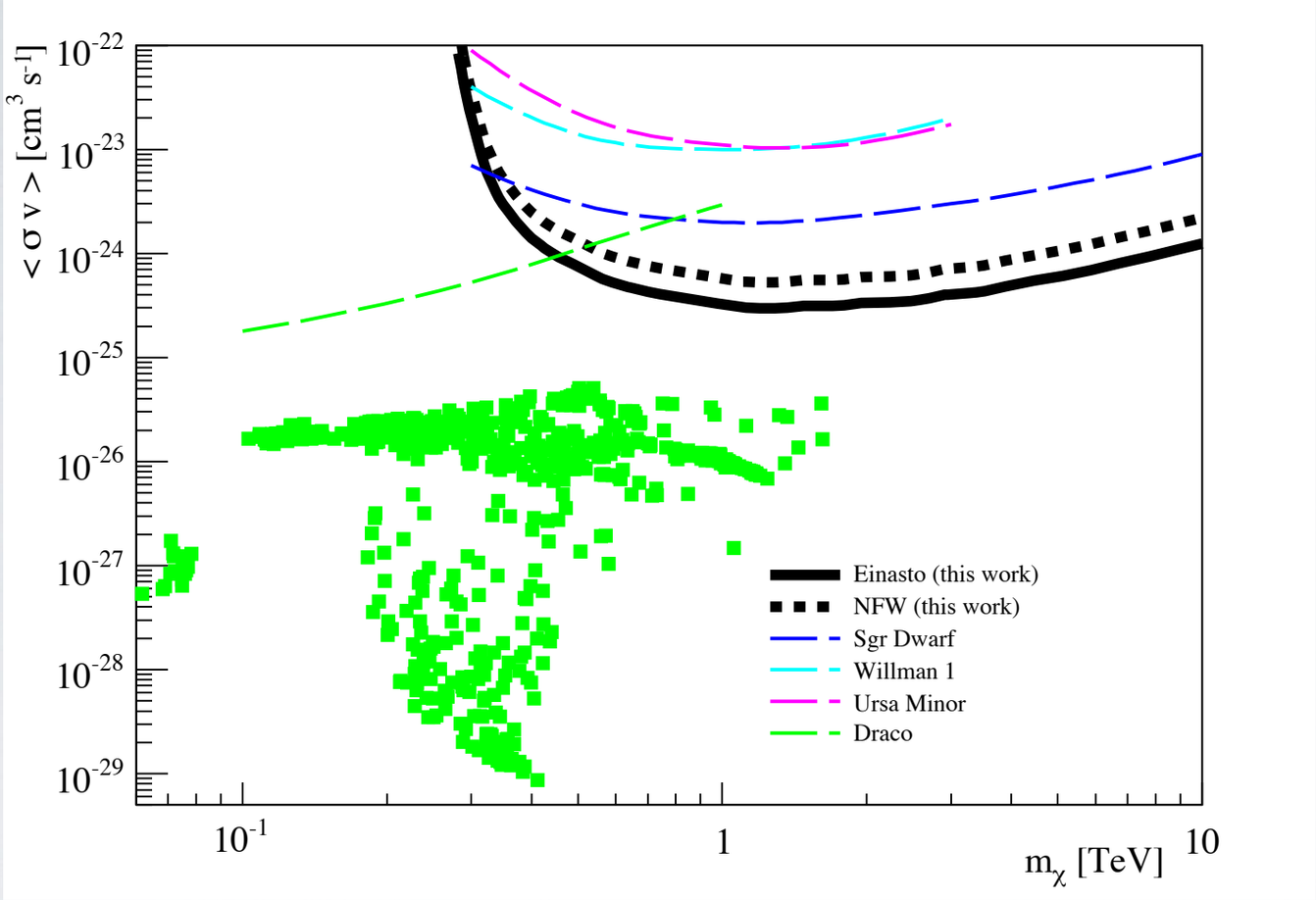
Gammalib and CTOOLS



http://cta.irap.omp.eu/gammalib/ http://cta.irap.omp.eu/ctools/

Conclusions

- New source near GC at 7.8σ above 2 TeV
- Likelihood Modelling of the Galactic Center with VERITAS can probe higher WIMP masses due to the Large Zenith Angle
- Checking Likelihood Results (spectra/significance) With Standard Analysis (Li&Ma) Results
- Next steps: DM and Non-DM Source Modelling



Abramowski 2011

FIG. 4. Upper limits (at 95% CL) on the velocity-weighted annihilation cross-section $\langle \sigma v \rangle$ as a function of the DM particle mass m_χ for the Einasto and NFW density profiles. The best sensitivity is achieved at $m_\chi \sim 1$ TeV. For comparison, the best limits derived from observations of dwarf galaxies at very high energies, i.e. Sgr Dwarf [10], Willman 1, Ursa Minor [15] and Draco [9], using in all cases NFW shaped DM profiles, are shown. Similar to source region of the current analysis, dwarf galaxies are objects free of astrophysical background sources. The green points represent DarkSUSY models [32], which are in agreement with WMAP and collider constraints and were obtained with a random scan of the mSUGRA parameter space using the following parameter ranges: $10\ \mathrm{GeV} < M_0 < 1000\ \mathrm{GeV}$, $10\ \mathrm{GeV} < M_{1/2} < 1000\ \mathrm{GeV}$, $A_0 = 0$, $0 < \tan\beta < 60$, $\mathrm{sgn}(\mu) = \pm 1$.