

The Galactic Center Region Imaged by VERITAS

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The Galactic Center (GC)

- **Galactic center:**

- SgrA* (radio source): $\sim 4 \times 10^6$ solar mass BH

- **Cosmic rays, SNR & plerions:**

- Increased level of CR activity & MCs

Aharonian et al., Nature, 439, 695 (2006)

- SNRs (e.g. Sgr A East) or plerions in GC

Wang et al., MNRAS, 367, 937 (2006)

- **Transients:**

- 5 X-ray transients: 2-10 keV peak: $\sim 10^{35}$ ergs/s

- Recent flares (X-ray/MeV/GeV):

Swift/XRT, MAXI/GCS, Fermi/LAT, Integral

ATels: 2690, 2770, 2770, 3123, 3162, 3163, 3183

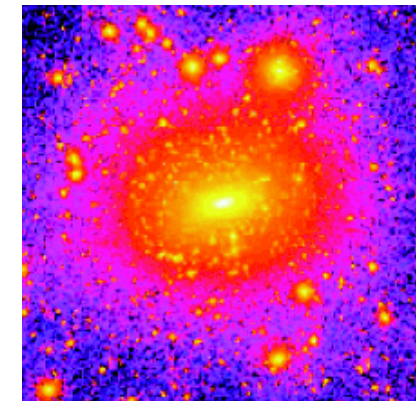
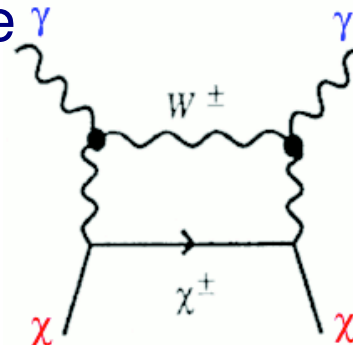
- **Dark matter(?):**

- Neutralino annihilation: γ -ray continuum+line γ

Jungman et al., Phys.Rep., 267, 195 (1996)

- γ -ray flux calculations for NWF halo profile:

Bergstrom et al, Aph,9,137(1998)



Kassim et al. (1999)

Previous GeV/TeV γ -ray observations of the GC

● **EGRET: 3EG J1746-2851** (Hartman et al. 1999)

● **CANGAROO-II (2001/02):**

- Steep spectrum ($dN/dE \sim E^{-46}$), 10% Crab
Tsuchiya et al., ApJ, 606, L115 (2004)

● **Whipple 10m (1995-2003, LZA):**

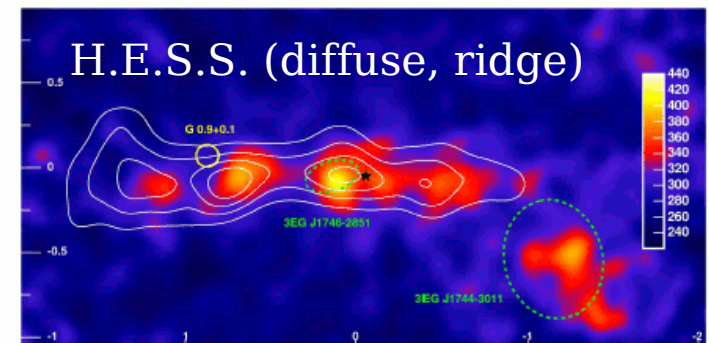
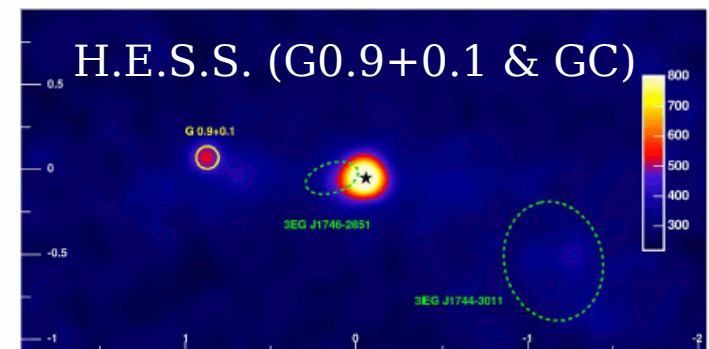
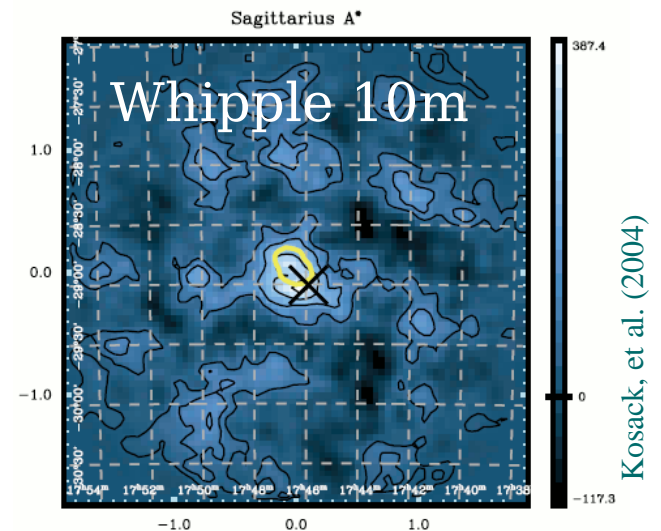
- Evidence for GC emission: 3.7 std.dev.
Kosack, et al., ApJ, 608, L97 (2004)

● **H.E.S.S. (2004-2006):**

- > 60 std.dev., $dN/dE \sim E^{-21}$, cutoff ~ 15 TeV,
- no variability, Sgr A* (BH) - not Sgr A East
- Diffuse emission: $\sim E^{-23}$, CR/MC interaction?
Aharonian et al.: A&A,425,L13 (2004) & Nature,439,695 (2006)

● **MAGIC (2004/05, LZA, 25h):**

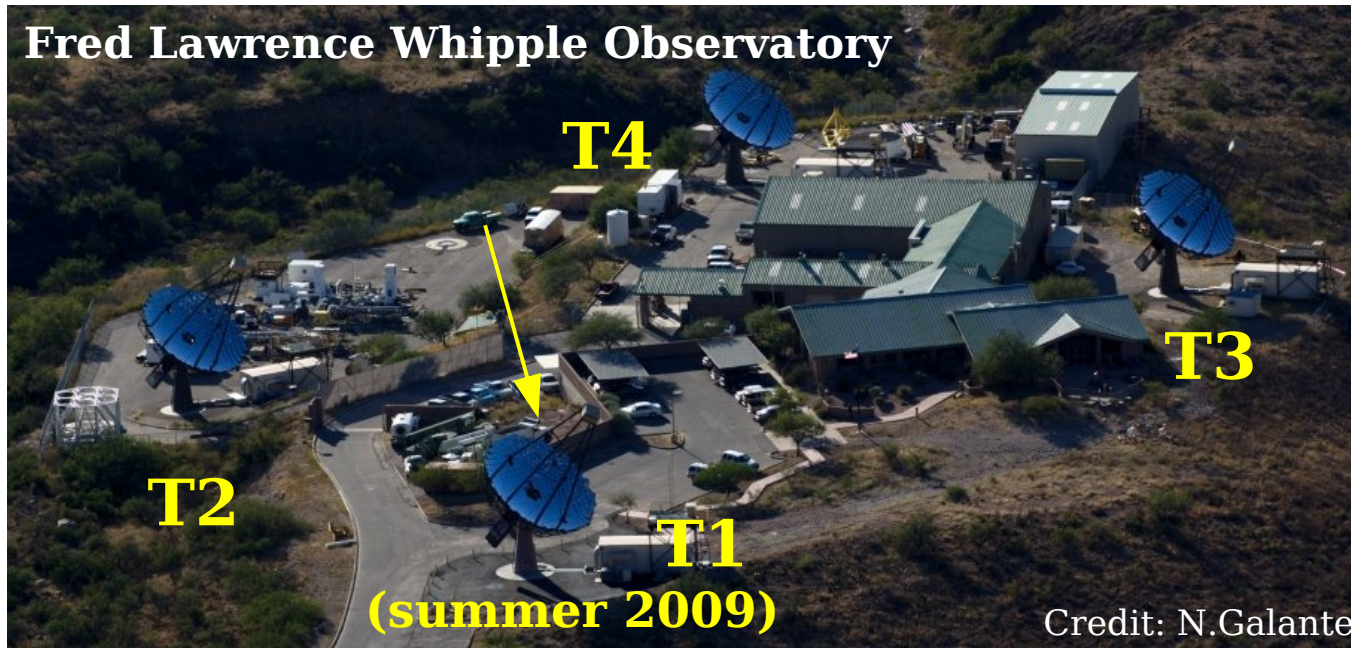
- 7.3 std.dev., confirms H.E.S.S. Spectrum
Albert et al.: ApJ, 638, L101 (2006)



**Different experiments may...
not necessarily see same source**

The VERITAS Cherenkov Telescope Array (Very Energetic Radiation Imaging Telescope Array System)

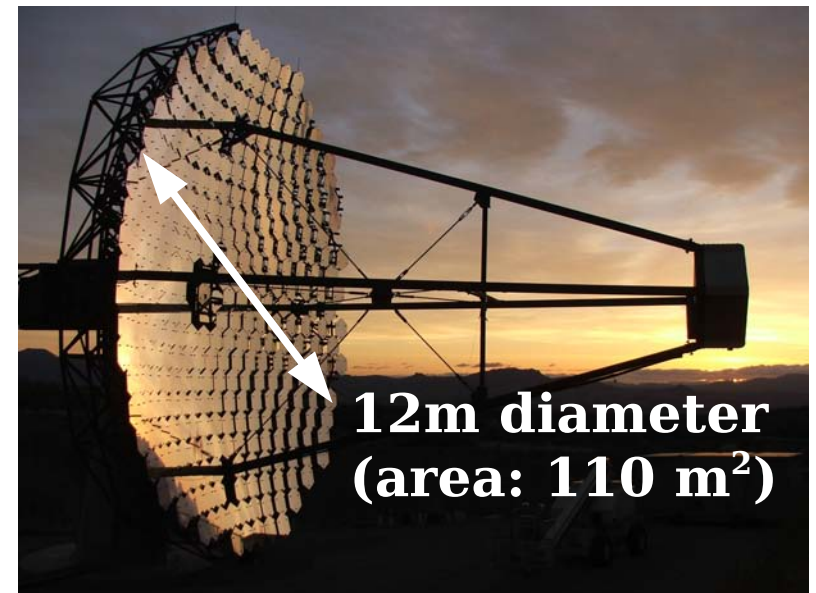
Fred Lawrence Whipple Observatory



Supported by:

DOE
NSF
SAO (U.S.)
STFC (U.K.)
NSERC (Canada)
SFI (Ireland)

- Array fully operational since spring 2007
- Each camera: 499 PMT pixels
- Energy range: 0.1-30 TeV ($\Delta E/E < 20\%$)
- 2009: T1 move & improved PSF:
~30% sensitivity increase
- Sensitivity: 0.1(0.01) Crab in 0.5h (26h)



Improvement of large zenith-angle (LZA) sensitivity: Displacement method

LZA observations:

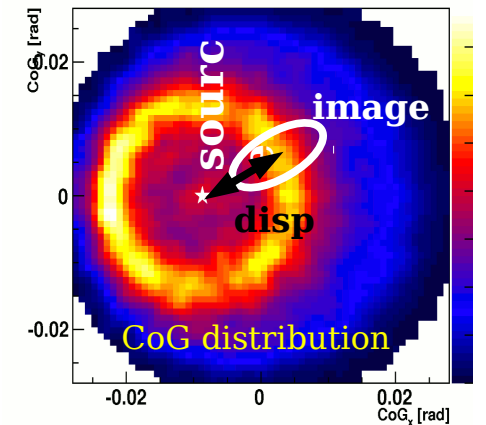
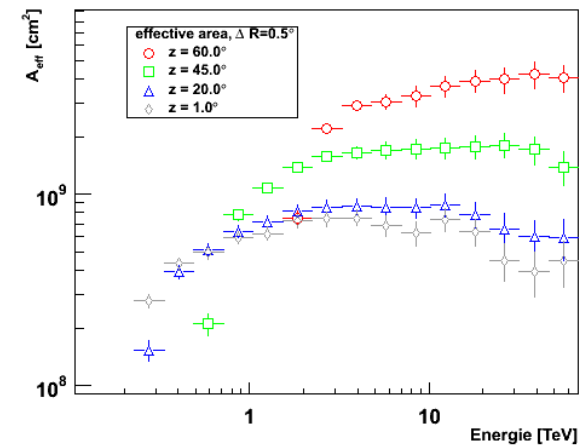
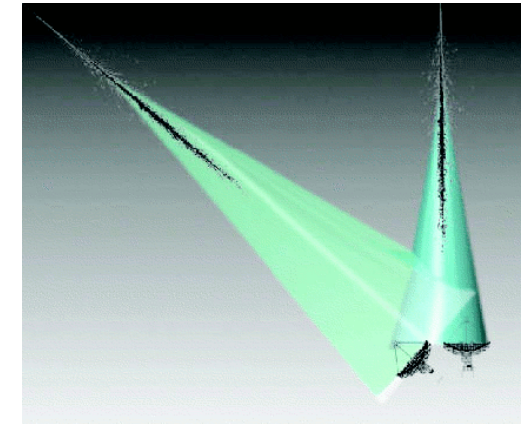
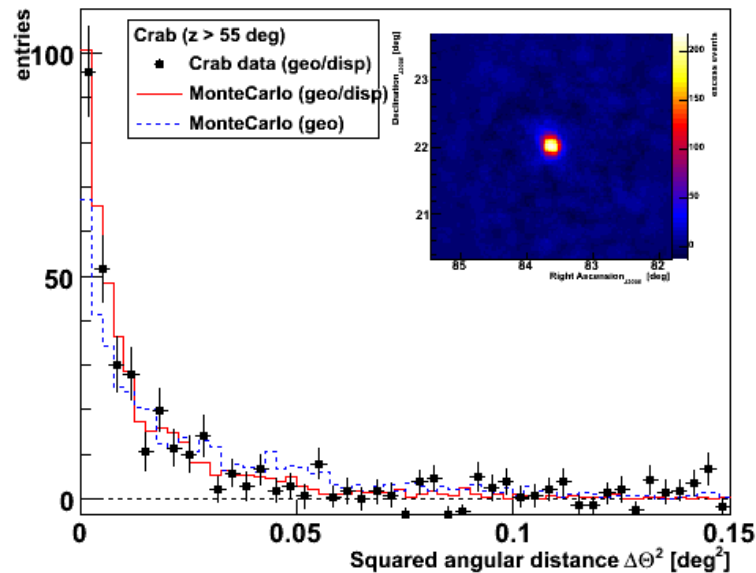
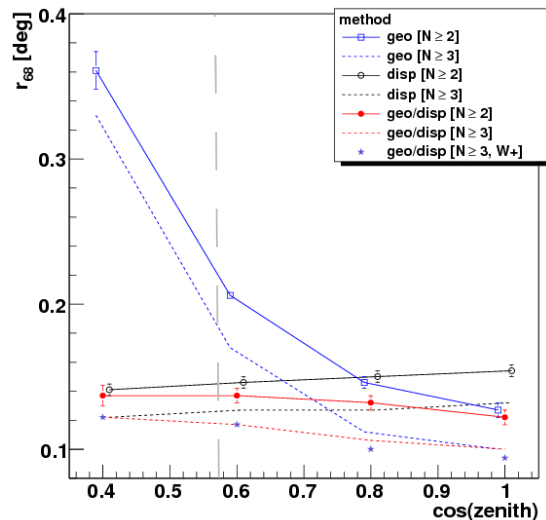
- **Advantage:** increased effective area for high energies
- **Disadvantage:** (1) incr. threshold (2) decr. angular recons.
reason for (2): projection [stereo angle] & larger impact distances

Improvement: disp method Buckley et al, A&A, 329, 639 (1998)

- disp parameter: Use 6-dim look-up table from MC
=> angular resolution: **~independent of zenith angle**
- Combine with standard geometrical method

Test/confirm on LZA Crab data:

- Improved TeV angular resolution (up to x2) & sensitivity
=> Method works!



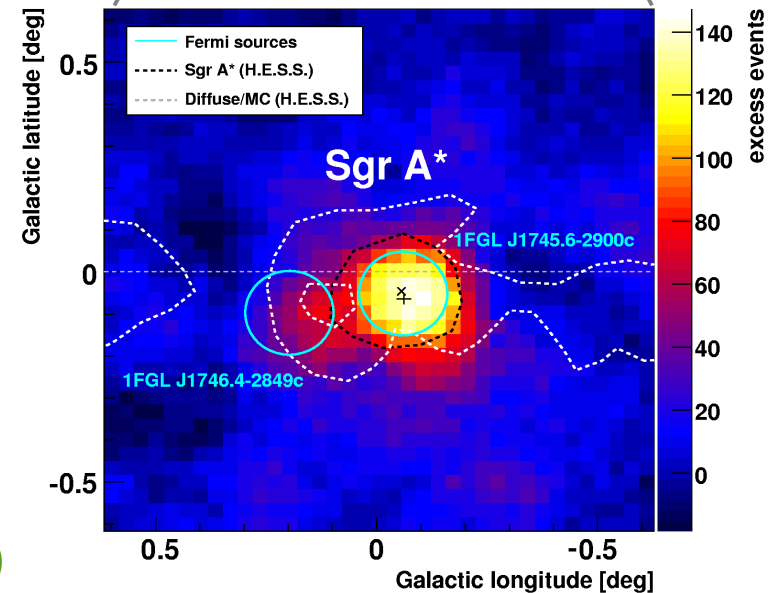
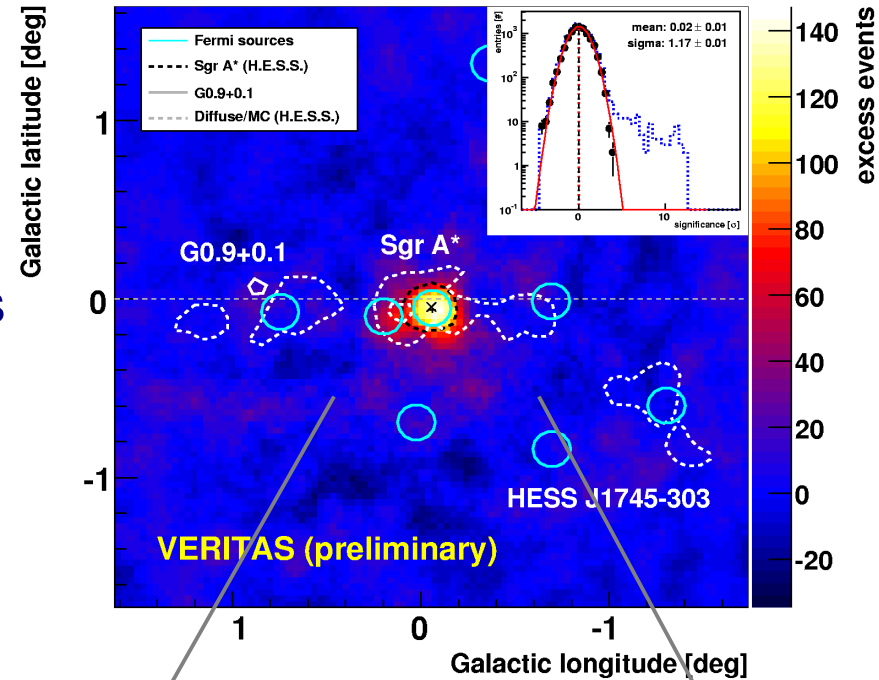
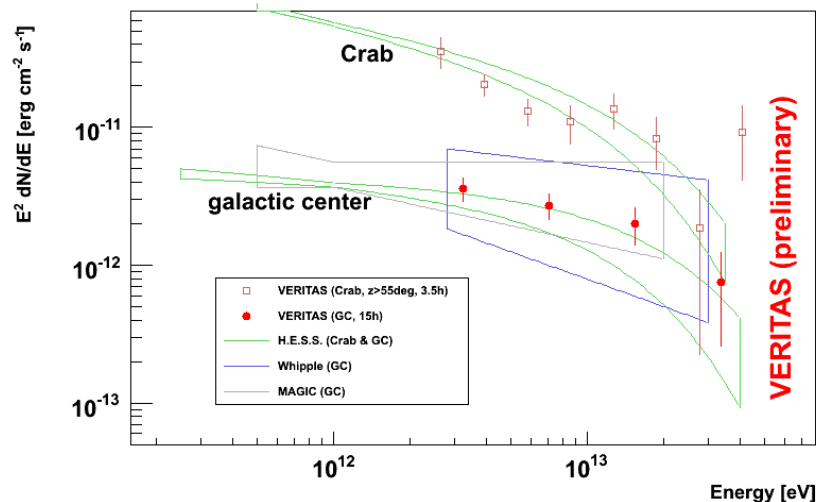
VERITAS observations of the galactic center

● VERITAS (2010, 15h), sky map:

- 12 std.dev. excess @ galactic center:
fit: longitude = -0.06 ± 0.02 , latitude = -0.06 ± 0.01
- No evidence for variability
- Overlay: HESS (GC+diffuse) & Fermi sources
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/

● Energy spectrum (preliminary):

- Flux systematic: ~40% (conservative est.)
(contemp. Crab LZA: estimate systematics)
- Compatible with H.E.S.S., Whipple & MAGIC



VERITAS: can detect GC (LZA) in ~3h

Comparison to astrophysical models

● Hadron accelerator around BH:

- (1) p's diffuse into ISM (2) pions (3) γ -rays
- @MeV/GeV: variability $\sim 10^4$ yr (old flares)
- @ >10 TeV: **variability ~ 10 yr** (recent flares)

Chernyakova et al., ApJ, 726, 60 (2011)

● Hadrons from BH vicinity (2):

- Protons accelerated within $\sim 20 R_s$
- Spectral variability for **$E > 10$ TeV**

(TeV Spectrum will soften after outburst)

Ballantyne et al., MNRAS, 410, 152 (2011)

● BH plerion (leptonic wind):

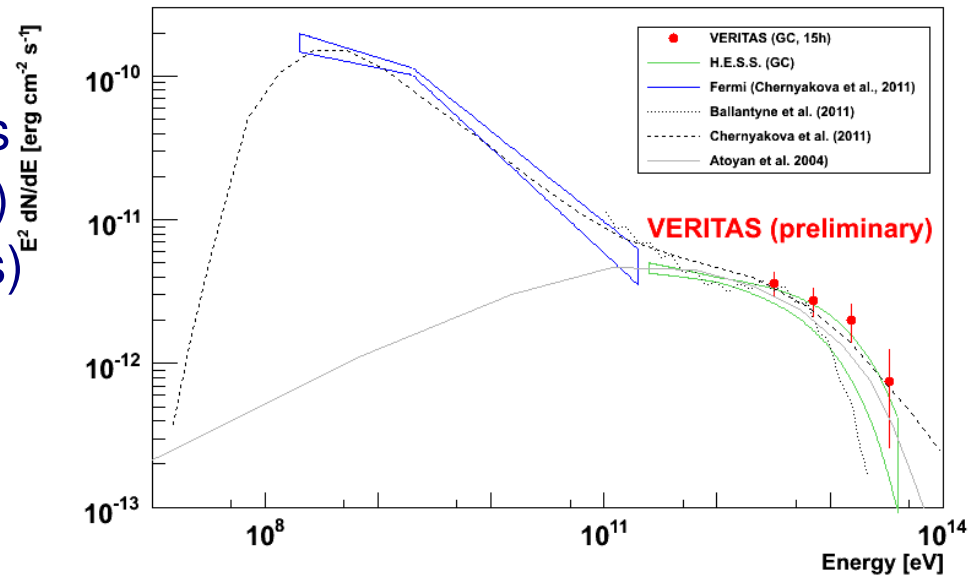
- terminat. shock, TeV γ 's via IC, $T_{\text{var}} \sim 100$ yr

Atoyan et al., ApJ, 617, L123 (2004)

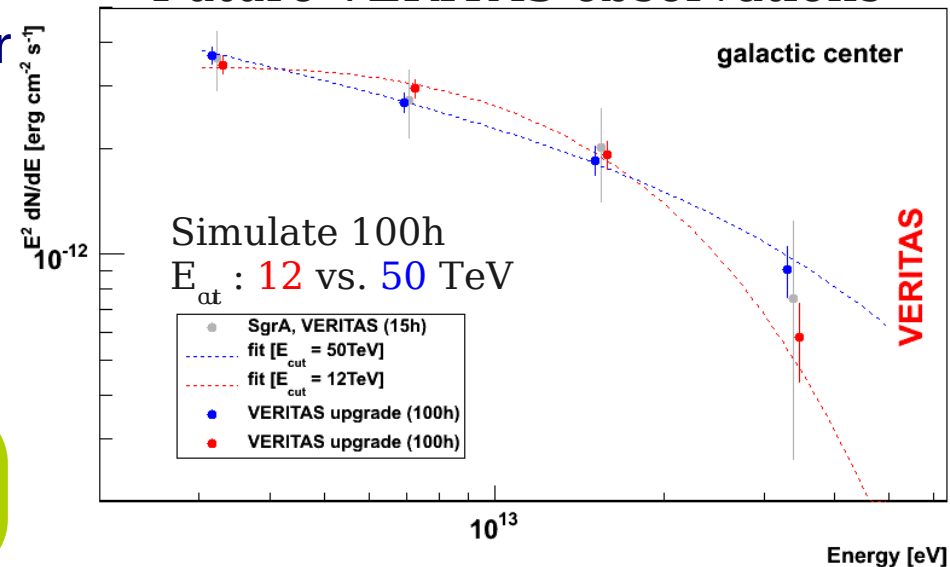
● Future: Constrain cutoff energy:

- Assume sensitivity $\times 1.3$ (upgrade) & 100h
- => **Can constrain cutoff energy**

**Important model input:
cut off & variability @ $E > 10$ TeV**



Future VERITAS observations



Estimate of an UL on Dark Matter Annihilation

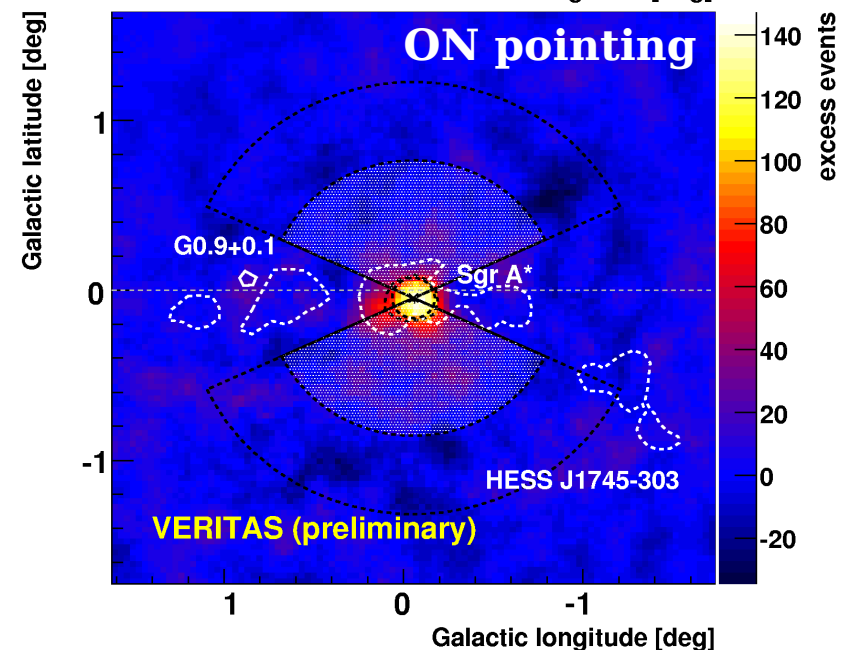
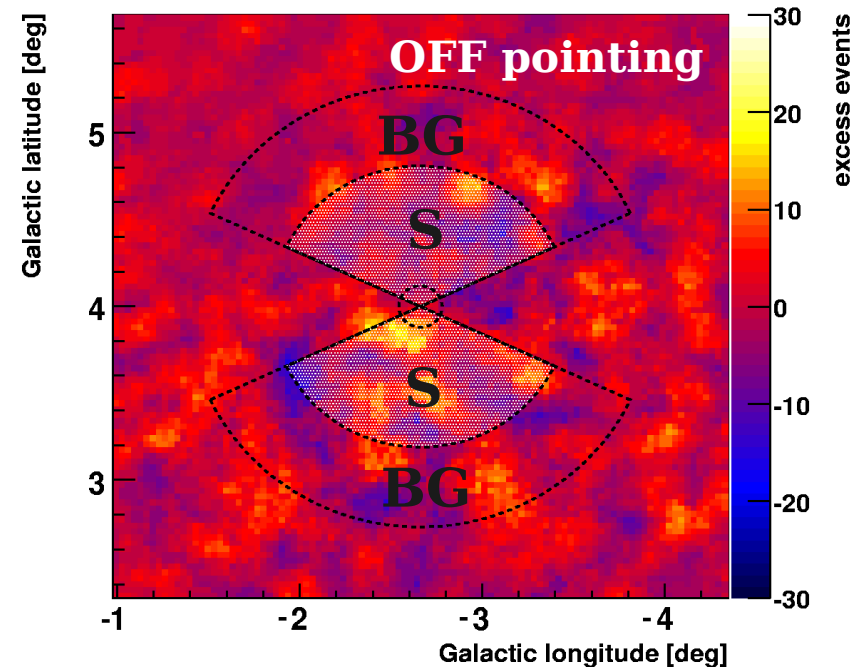
- **Extended emission (ON/OFF):**

- Define signal (**S**) and backgr. (**BG**) regions (cut out galactic plane, inner radius: r_{eff} of TeV PSF)
- OFF data: determine normalization
- Signal = $S_{\text{on}} - Bg_{\text{on}} \times S_{\text{off}} / BG_{\text{off}}$

- **Use γ -ray UL to obtain DM limit:**

- Model input: T_{obs} , E_{thr} , PSF(E), pointing uncertainty, SgrA* signal leaking into **S**
- Compare with integral over annulus $\int \rho^2 dl$

- **Work in progress...**



Summary and Conclusion

● VERITAS detected GC:

- 12 std.dev. (15 hrs)
- Spectrum compatible with H.E.S.S./MAGIC

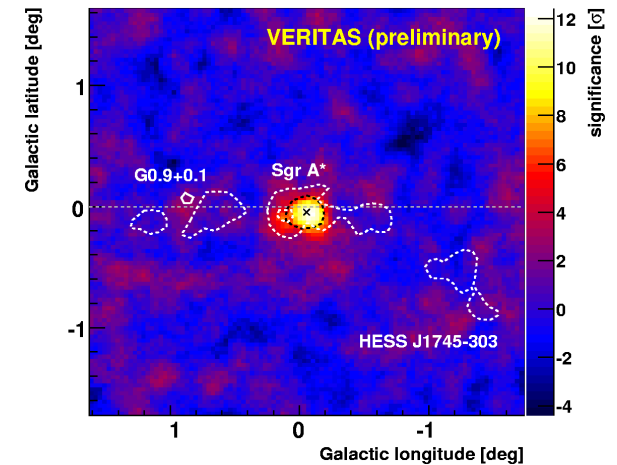
● Future observations:

- Constrain energy cut off
- Search for $E > 10$ TeV variability

● Prospects:

- Understand astrophysics of GC region
- Obtain UL on DM annihilation ($E > \sim$ few TeV)

Poster (M. Vivier): Indirect searches for DM annihilation towards spherical galaxies with VERITAS'



+++ telegram +++ telegram +++

- Another galactic center: Onset of rapid accretion by dormant massive BH?
Burrows et al., arXiv 1104.4787 (2011)
- 25h of VERITAS observations: upper limits (during Swift outburst & decline)
- Fermi/VERITAS: constrain emission models

