The Galactic Center Region Imaged by VERITAS from 2010-2012

M.Beilicke[1] for the VERITAS Collaboration[2]

1: Washington University in St.Louis, Physics Department and
McDonnell Center for the Space Sciences, MO, USA
2: http://veritas.sao.arizona.edu/

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The Galactic Center (GC) – VHE interpretation?

- **Galactic center**

- SgrA* (radio source): ~4x10^6 solar mass BH

- **Cosmic rays, SNR & plerions**

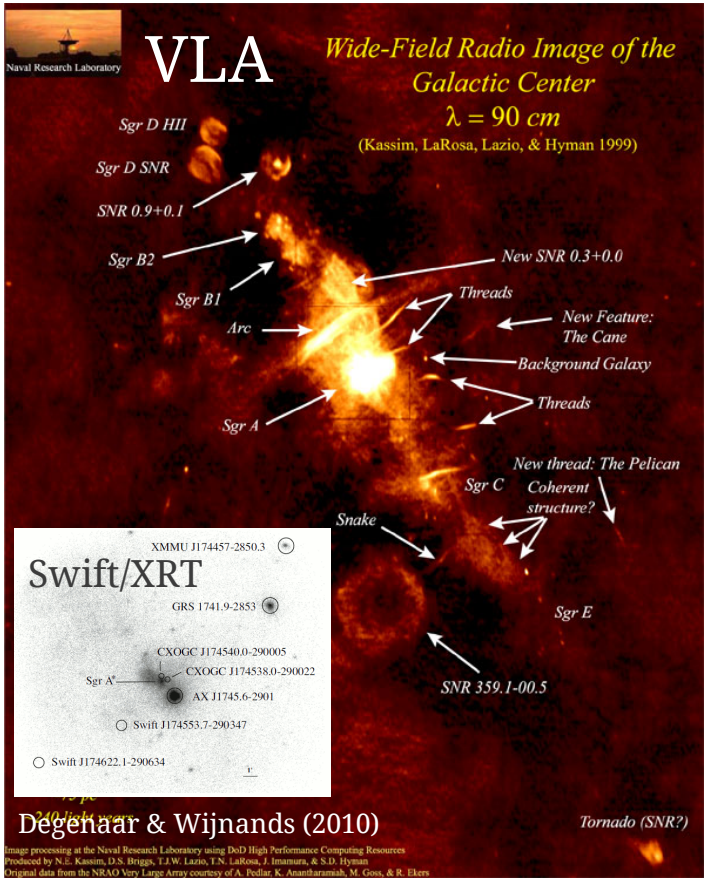
- Increased level of CR activity & MCs
  Aharonian et al., Nature, 439, 695 (2006)
- SNRs (e.g. Sgr A East) or plerions in GC
  Wang et al., MNRAS, 367, 937 (2006)

- **Transients**

- X-ray transients: 2-10 keV peak: ~10^{35} ergs/s
- Recent flares at X-ray/MeV/GeV:
  Swift/XRT, MAXI/GCS, Fermi/LAT, Integral
  ATels: 2690, 2770, 2770, 3123, 3162, 3163, 3183

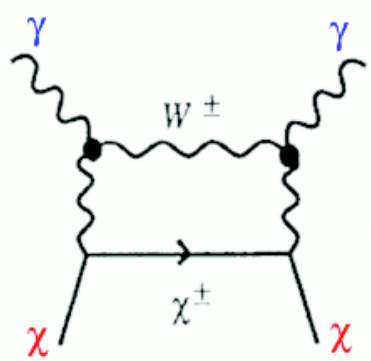
- **Dark matter?**

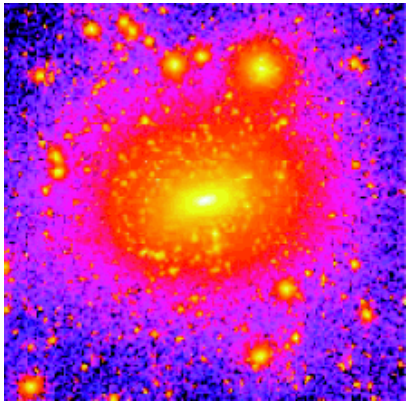
- Neutralino annihilation: γ-ray continuum+line
  Jungman et al., Phys.Rep., 267, 195 (1996)
- γ-ray flux calculations for NWF halo profile:
  Bergstrom et al, Aph,9,137(1998)



Degenaar & Wijnands (2010)

Kassim et al. (1999)

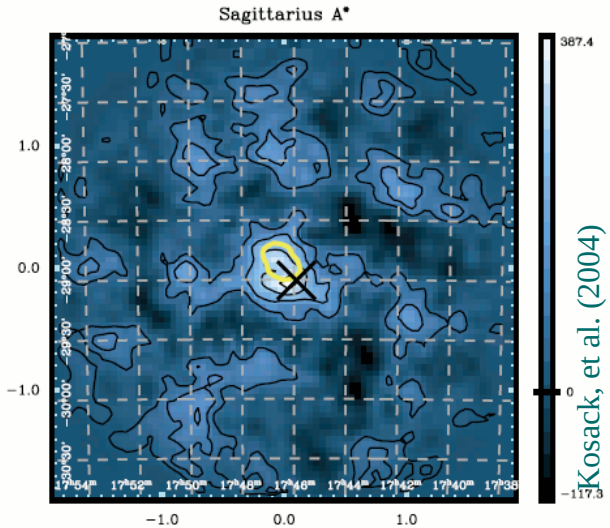




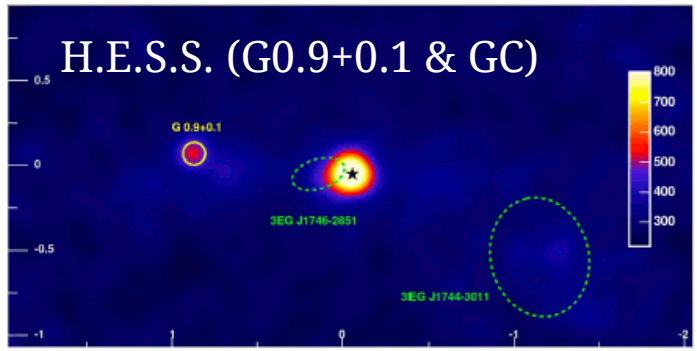
Previous GeV/TeV γ-ray observations of the GC

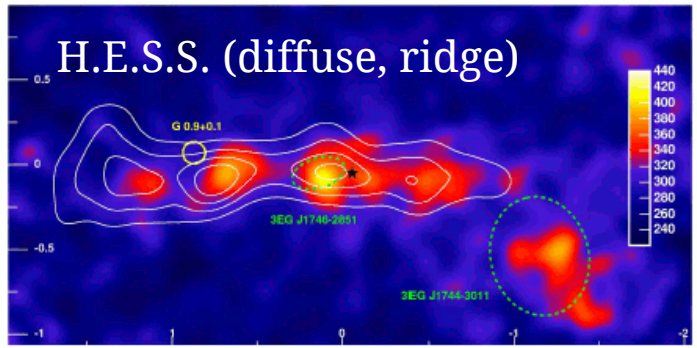
- **GeV:** EGRET: 3EGJ1746-2851 (Hartman et al. 1999)
  Fermi/LAT: 1FGL J1745.6 (Abdo et al. 2010)
- **CANGAROO-II (2001/02):**
  - Steep spectrum (dN/dE ~ $E^{-4.6}$), 10% Crab
  Tsuchiya et al., ApJ, 606, L115 (2004)
- **Whipple 10m (1995-2003, LZA):**
  - Evidence for GC emission: 3.7 std.dev.
  Kosack, et al., ApJ, 608, L97 (2004)
- **H.E.S.S (2004-2006):**
  - > 60 std.dev., dN/dE ~$E^{-2.1}$, cutoff ~15TeV,
  - no variability, Sgr A* (BH) - not Sgr A East
  - Diffuse emission: ~$E^{-2.3}$, CR/MC interaction?
  Aharonian et al.: A&A,425,L13 (2004) & Nature,439,695 (2006)
  Interpretation: Fatuzzo&Melia (2012), arxiV1202.4680 / Yusef-Zadeh et al (2012)
- **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



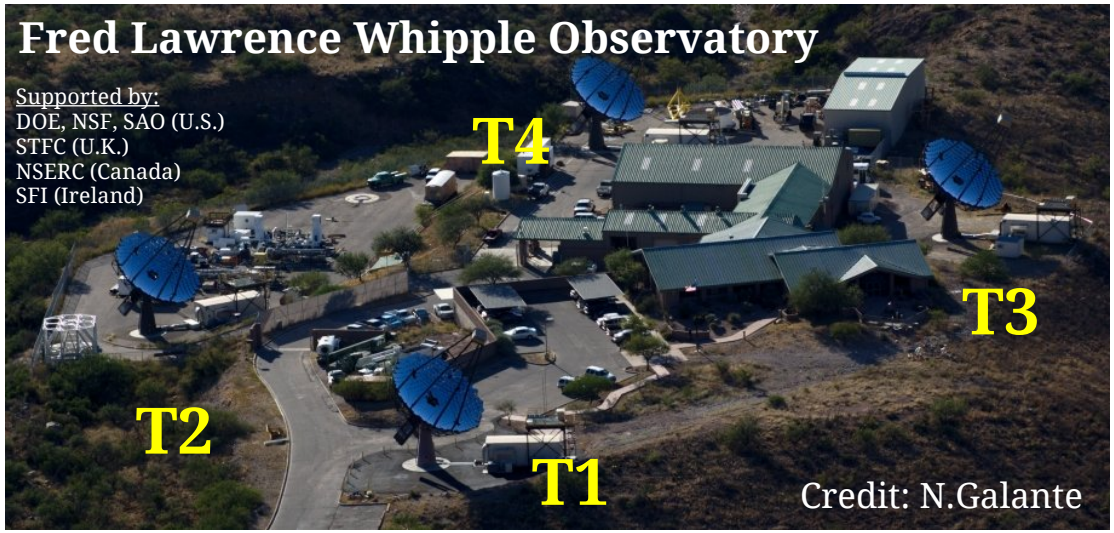
Kosack, et al. (2004)

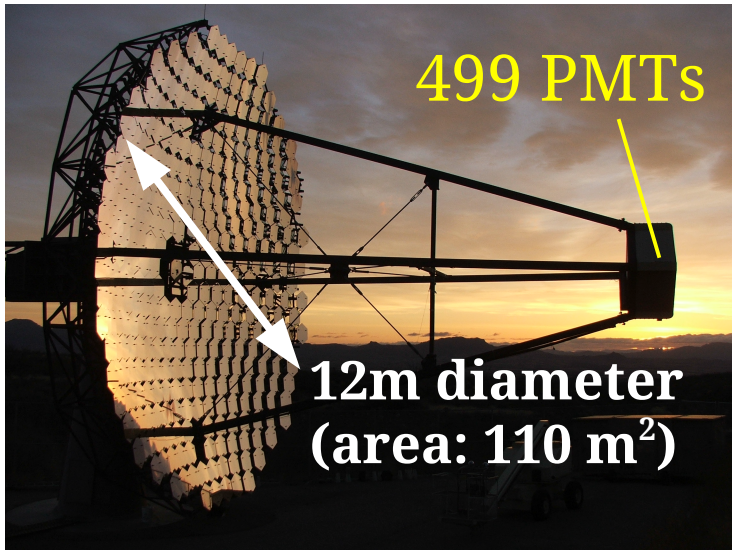




Aharonian, et al. (2006)

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

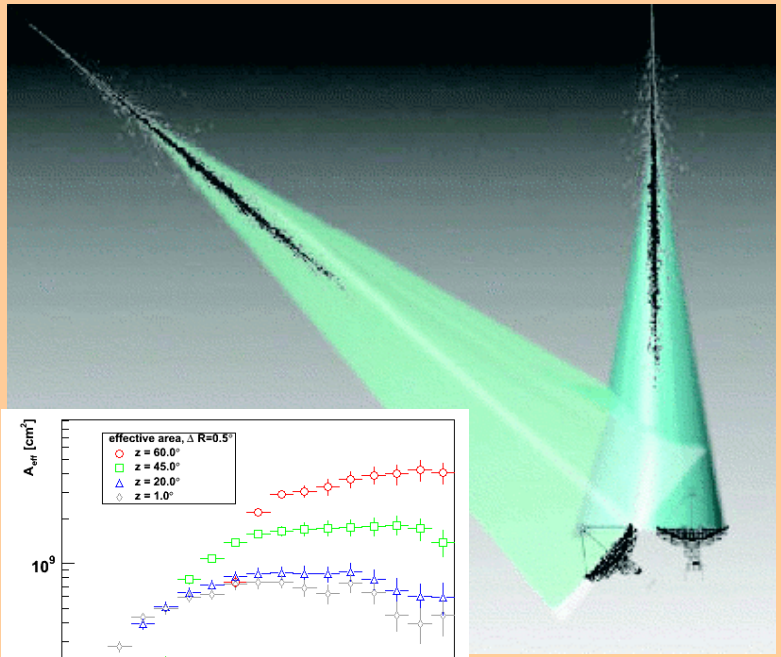




- Energy range: 0.1-30 TeV ($\Delta E/E$ <20%)
- Sensitivity: 0.1(0.01) Crab in 0.5h (26h)

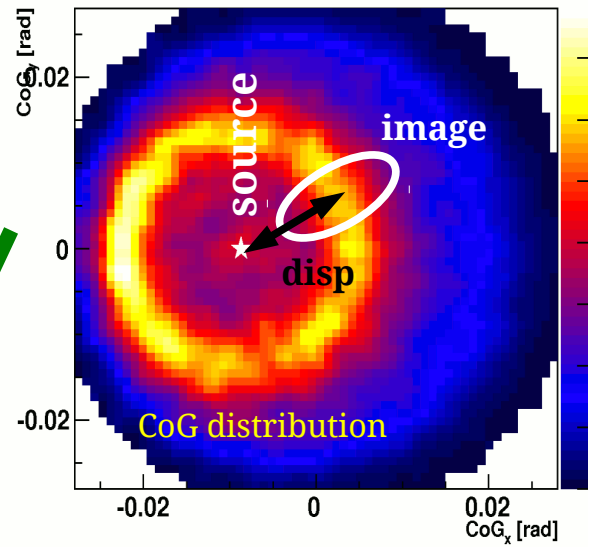
LZA observations

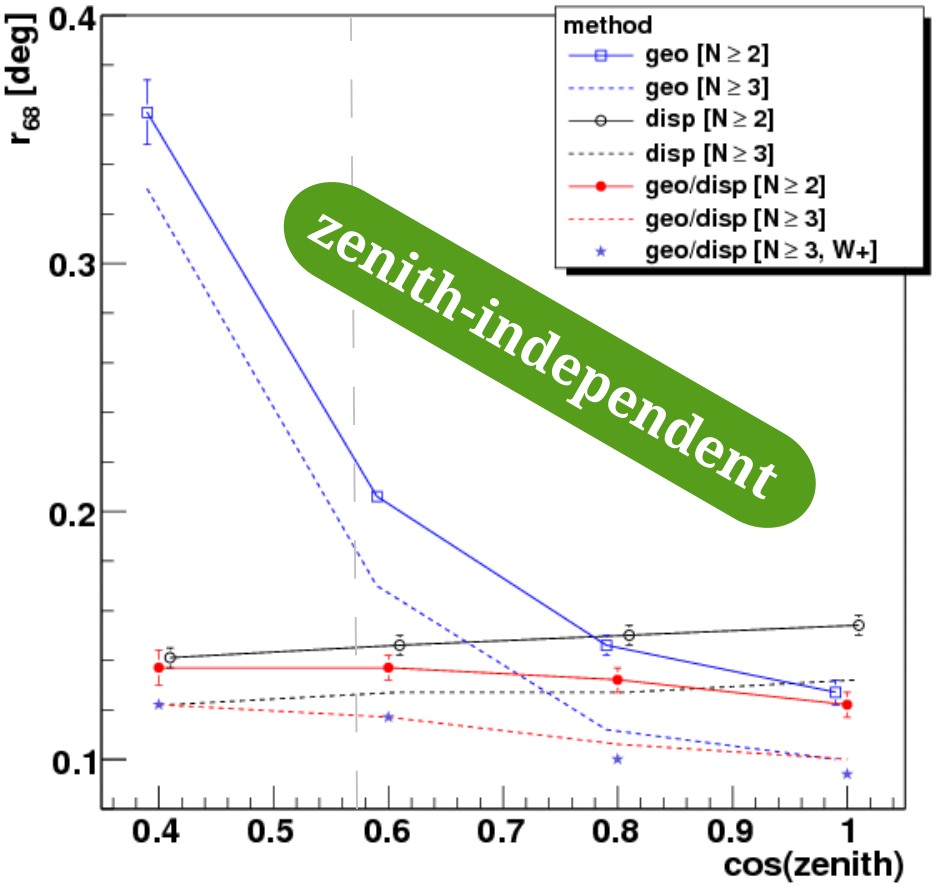
- **Good:** increased effective area @ high energies
  (larger shower foot print @ ground)
- **Bad 1:** increased threshold
  (light absorption & spread)
- **Bad 2:** decreased ang. res.
  (reduced telescope stereo angle)

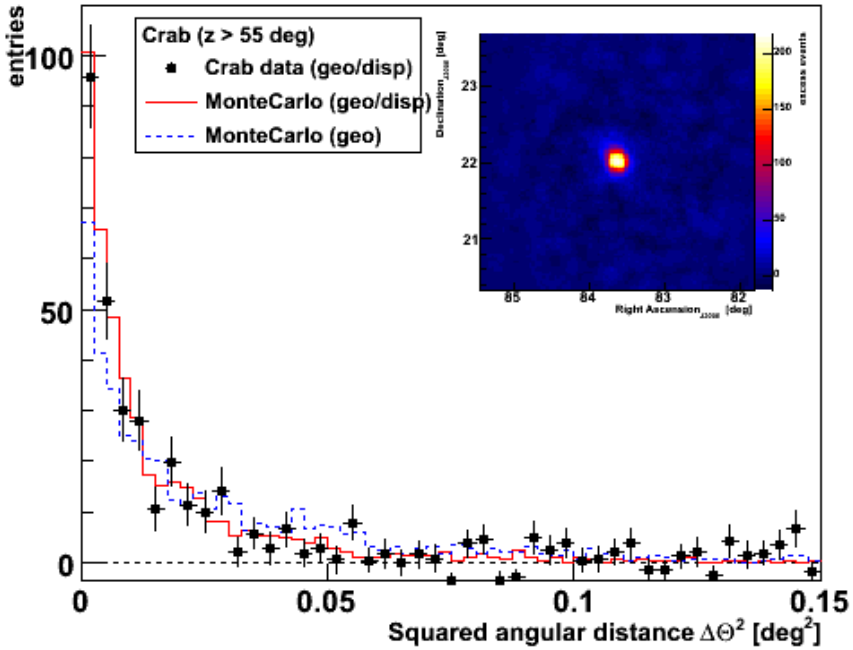


Improvement of large zenith-angle (LZA) sensitivity: Displacement method

- **Displacement method** Buckley et al, A&A, 329, 639 (1998)
  - disp parameter: Use 6-dim look-up table from MC
  - Combine with standard geometrical method
- **Use LZA Crab data to test:**
  - TeV angular resolution & sensitivity improved => works ✓

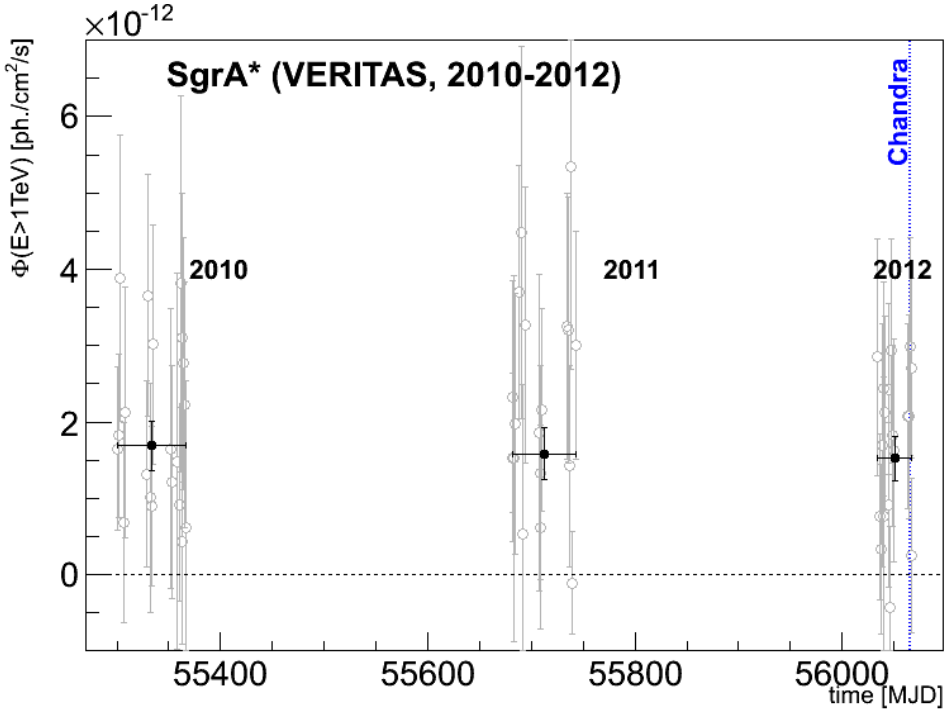


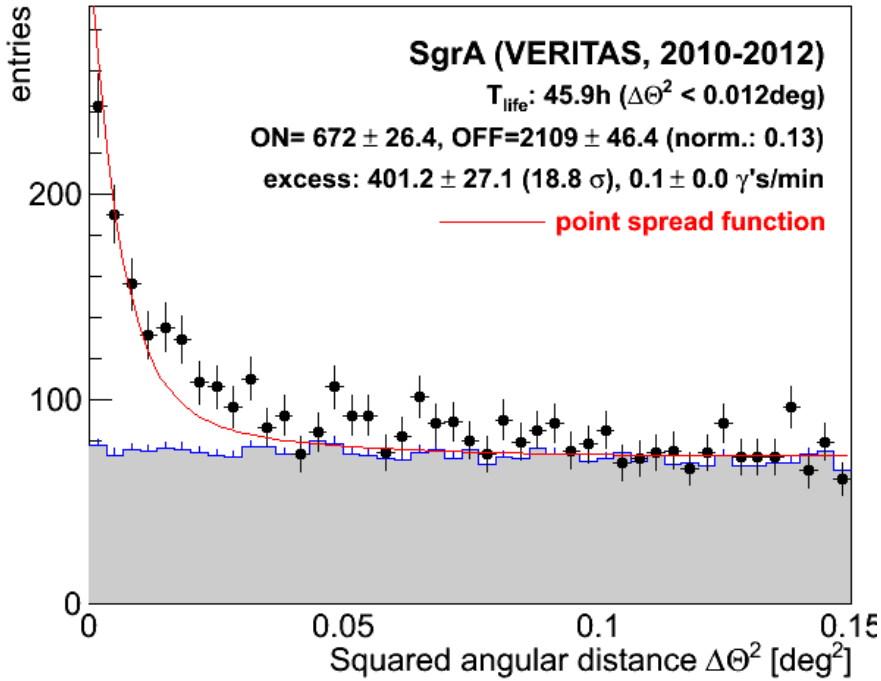


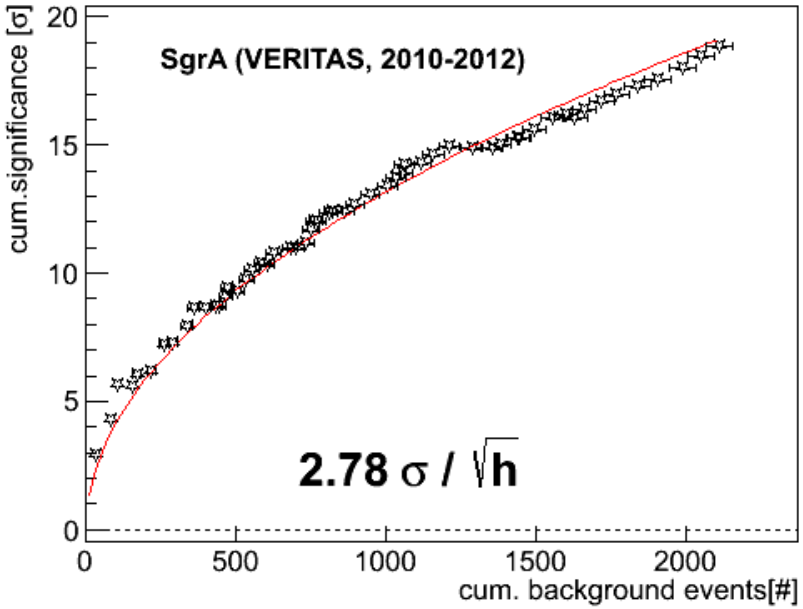


VERITAS: the galactic center 2010-2012

- **VERITAS observations 2010-2012:**
  - Good data: ~46 hrs (life time, wobble)
  - Zenith angle: 60-66 deg, threshold: ~2 TeV
- **Results (2010-2012):**
  - Constant signal growths
  - no evidence for variability





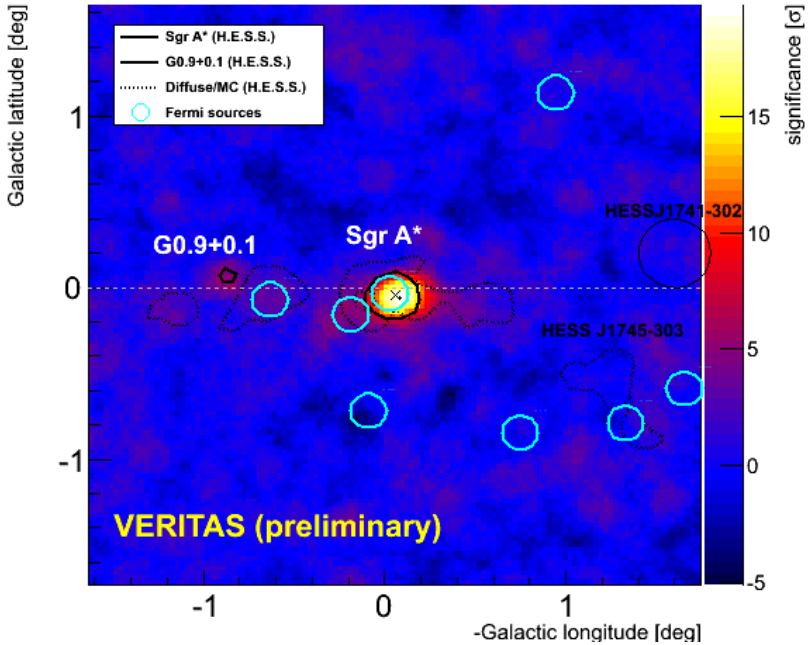


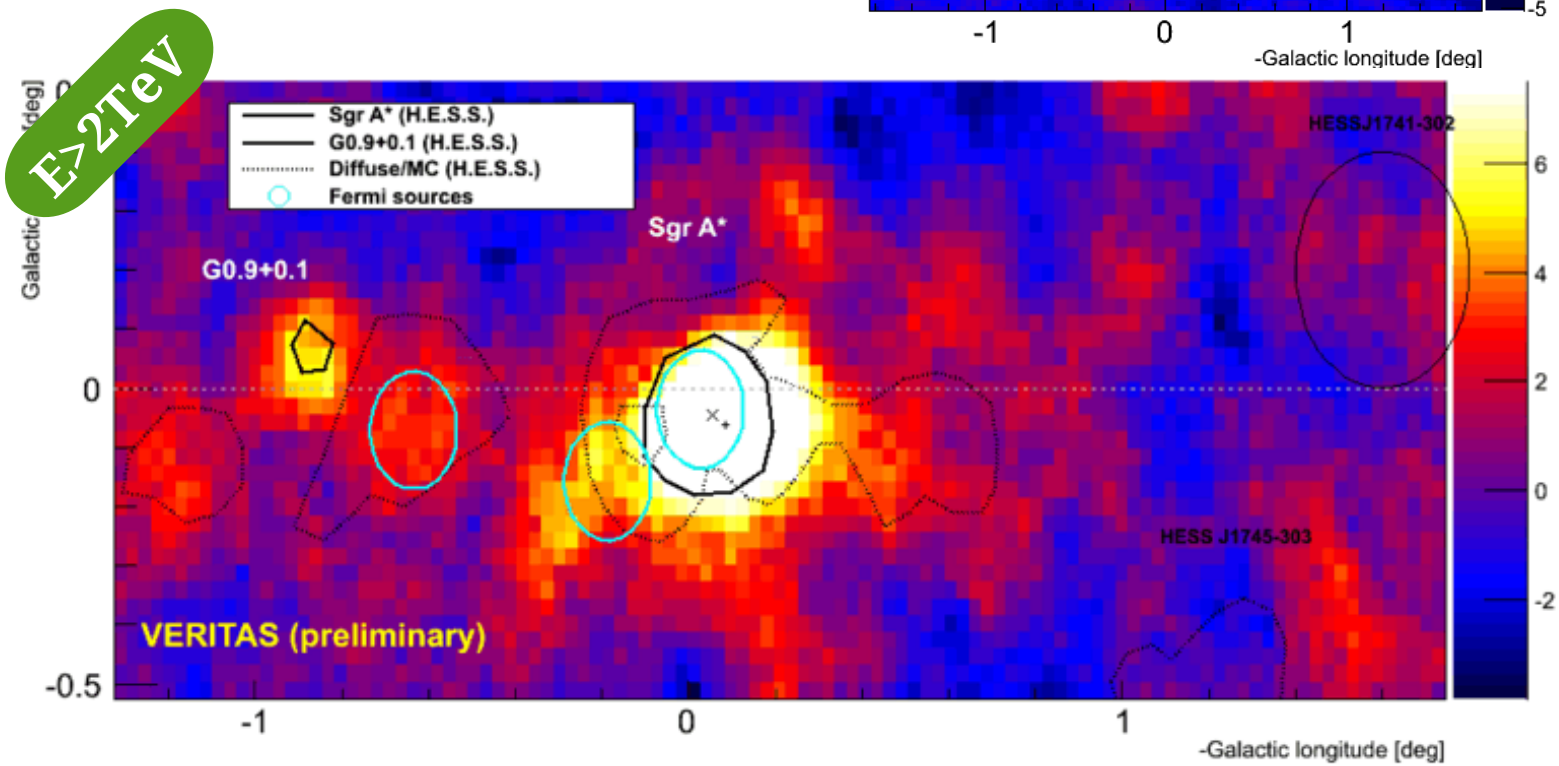
VERITAS detects GC @ LZA in ~3h

VERITAS: galactic center sky map (2010-2012)

- **VERITAS (2010-2012), sky map:**

- ring background (size > 1000 dc)
- Overlay: HESS (GC+diffuse) & Fermi sources
  http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/
- excess @ galactic center: 18 sigma
- excess @ position of SNR G0.9+0.1

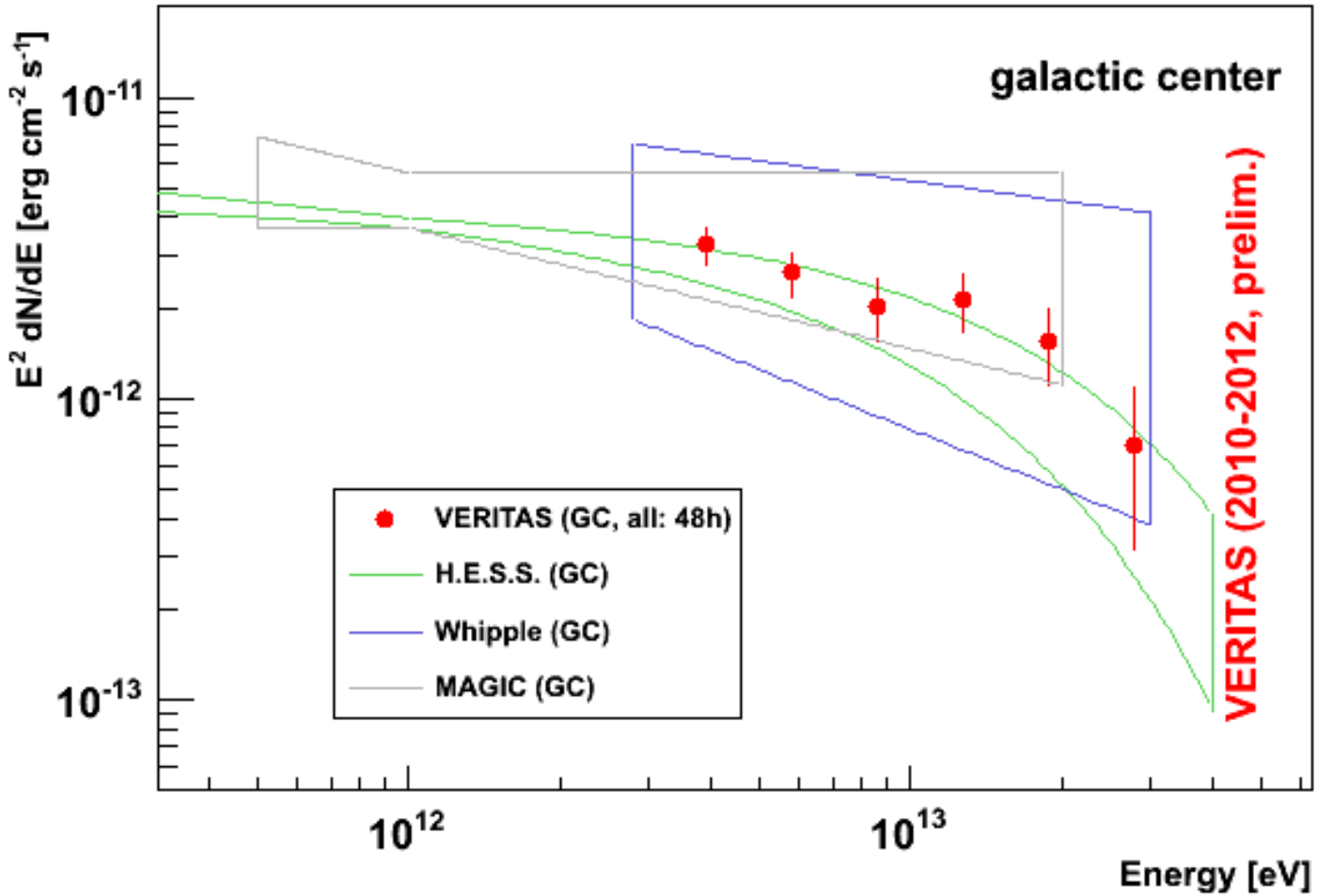




VERITAS: SgrA* spectrum (2010-2012)

Energy spectrum (preliminary):

- Flux systematic: ~40% (conservative est.)
  (contemporaneous Crab LZA: confirm spectral reconstruction)
- VERITAS: 2010 vs 2011 vs 2012 compatible
  Confirms H.E.S.S./Whipple/MAGIC



Comparison to astrophysical models

- **Hadron accelerator around BH:**

- (1) protons diffuse into ISM (2) pion creation (3) decay into γ-rays
- time scales: @MeV/GeV: ~10^4 yr (old flares), @>10 TeV: ~10 yr (recent flares)

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

- **Hadrons from BH vicinity (2):**

- Protons accelerated: <20R_s, spectral variability @E>10TeV (softer after outburst)

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

- **Hadrons hitting gas morph.(3):**

- Gas morphology (as proton target) defines TeV morphology

Linden et al., arXiV1203.3539 (2012)

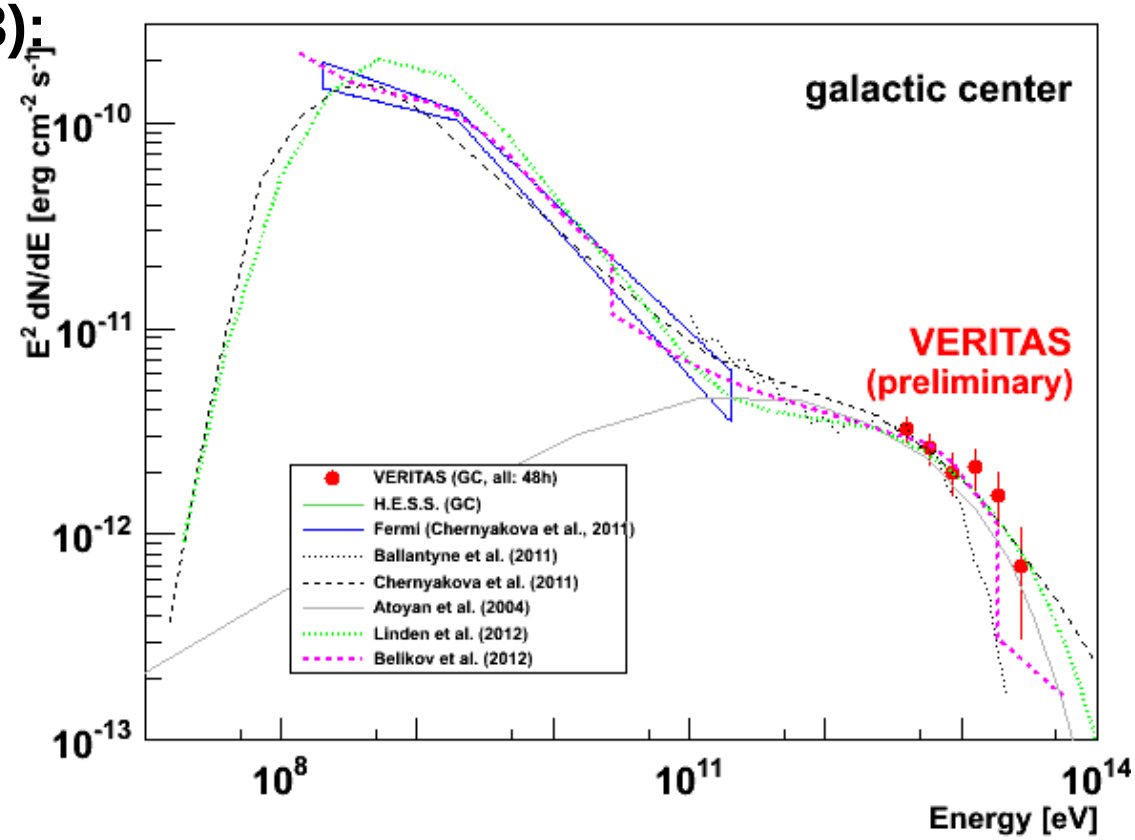
- **BH plerion (leptonic wind):**

- termination shock, TeV γ's via IC, T_{var}~100 yr

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

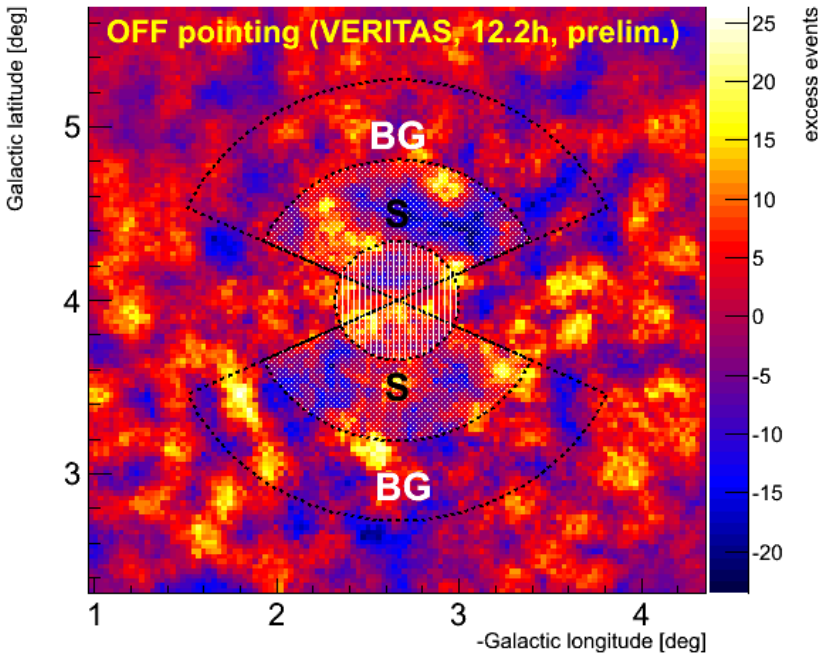
- **Log parabola + DM contrib.:**

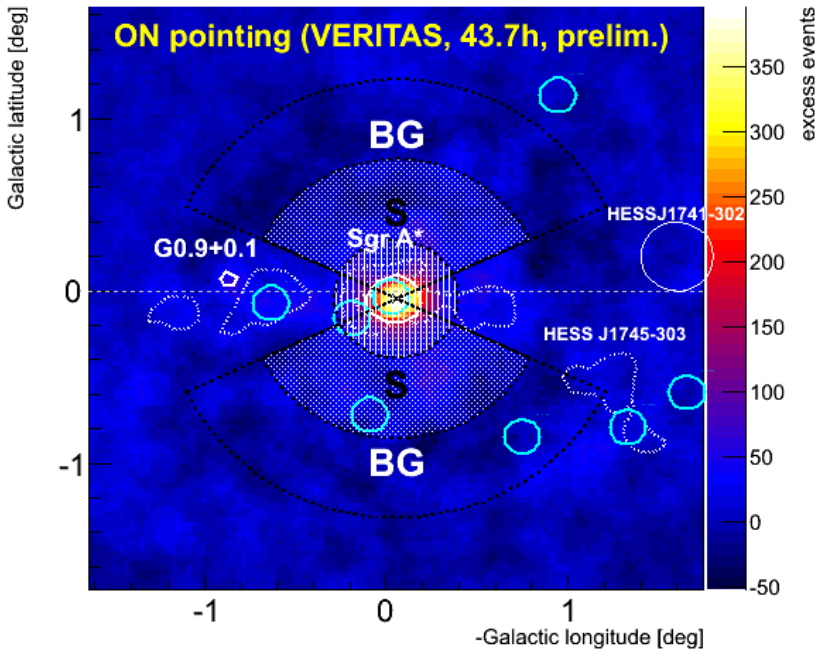
Belikov et al., arXiV1207.2412 (2012)



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

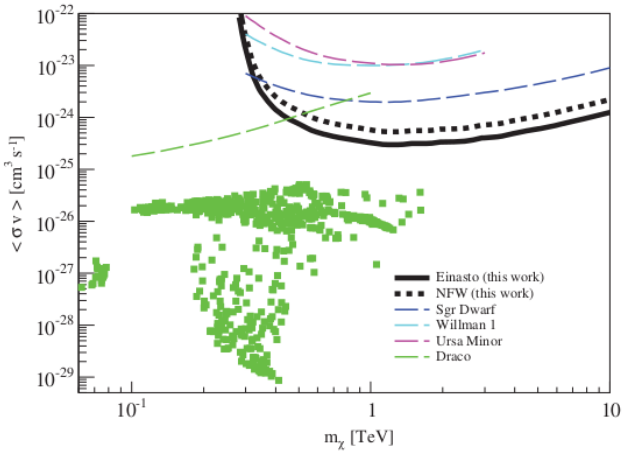
Estimate of an diffuse upper limit spectrum
(dark matter annihilation limits)





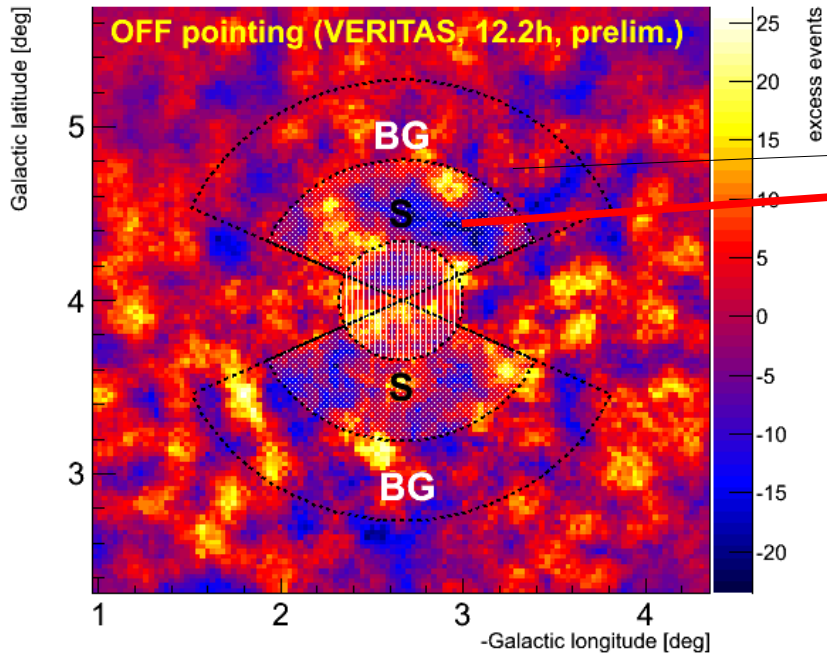
- **Extended emission (ON/OFF):**
  - Define signal (**S**) and backgr. (**BG**) regions
    (cut out galactic plane, inner radius: 0.34deg)
  - **Method**:
    => OFF data: determine energy dependent acceptance between r='S'/'BG'
    => ON data: apply ratios and determine differential spectrum: 'S' – r*'BG'
    (slight caveat: accept. may differ ON vs OFF)

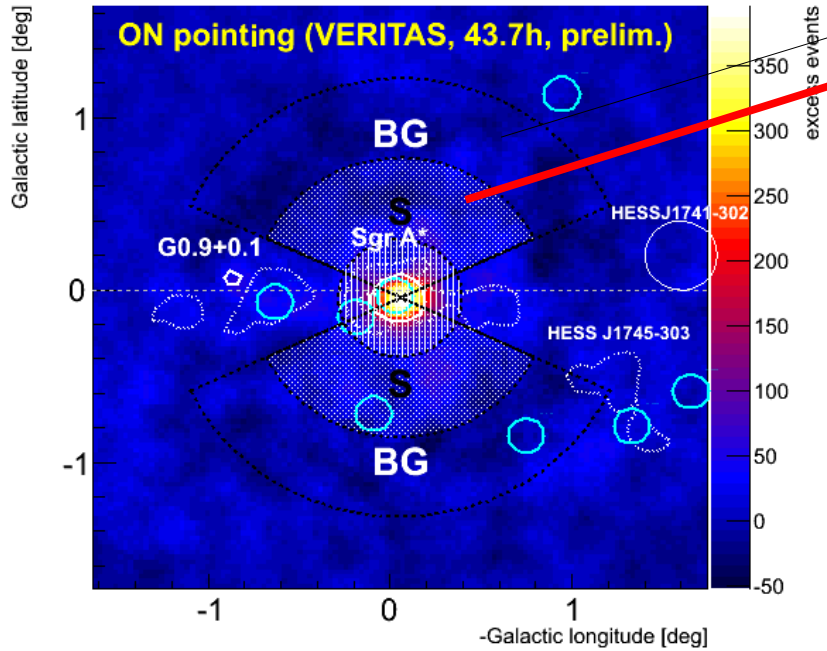
- **Use γ-ray UL to obtain DM limit:**
  - Model input: T_{obs}, E_{thr}, PSF(E), pointing uncertainty, SgrA* signal leaking into **S**
  - Compare with integral over annulus $\int \rho^2 \, dl$

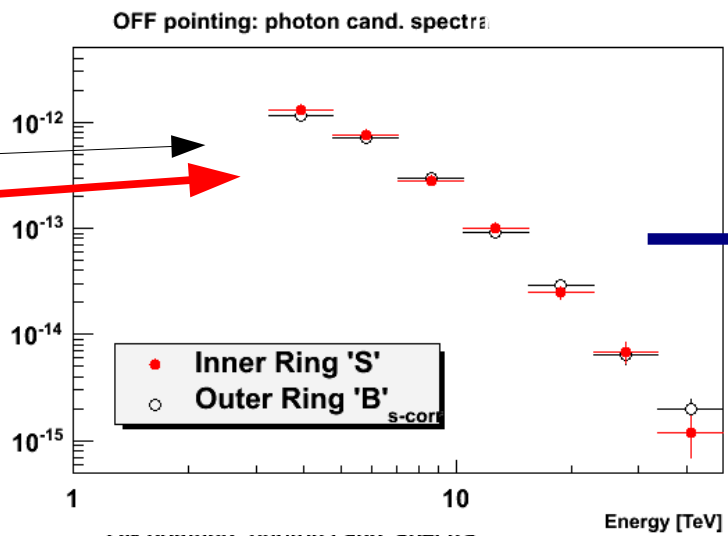


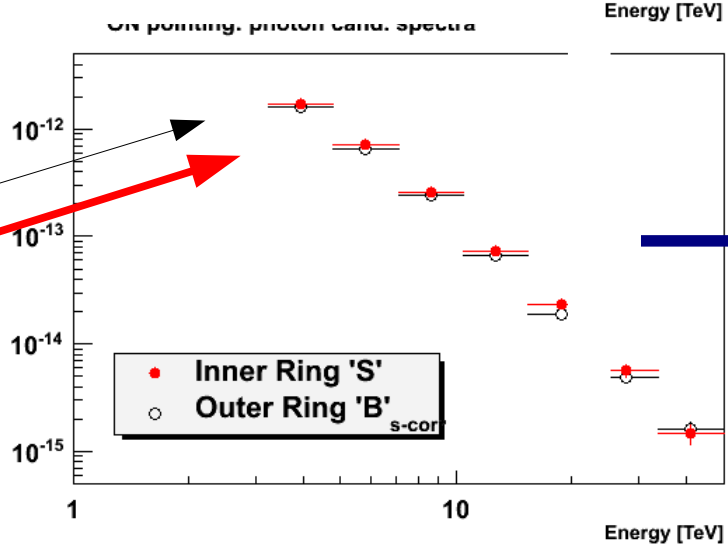
Abramowski, et al (2011), PRL, 106, 161301

Estimate of an upper limit spectrum









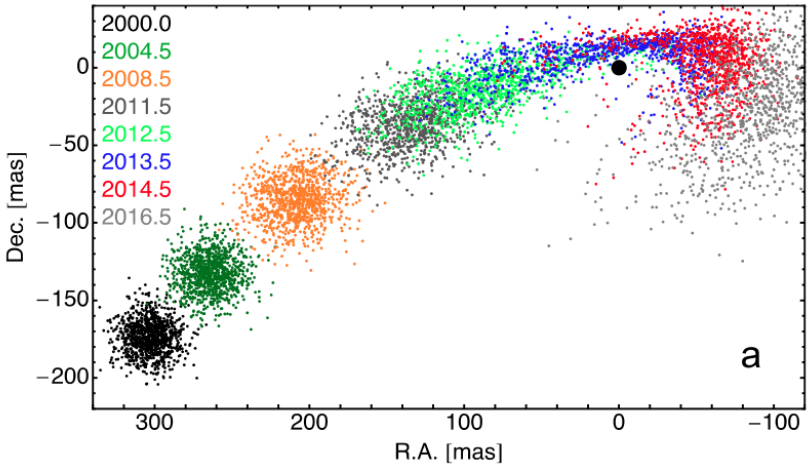
E-dependent ratio

UL spectrum

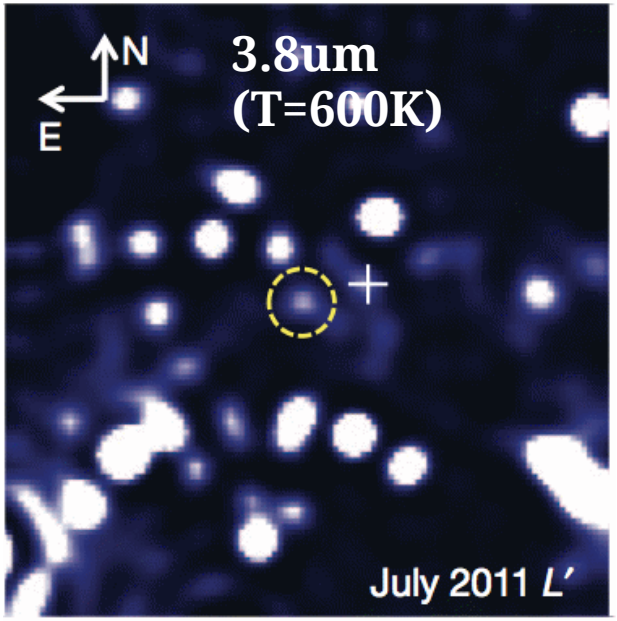
No excess in extended region 'S'

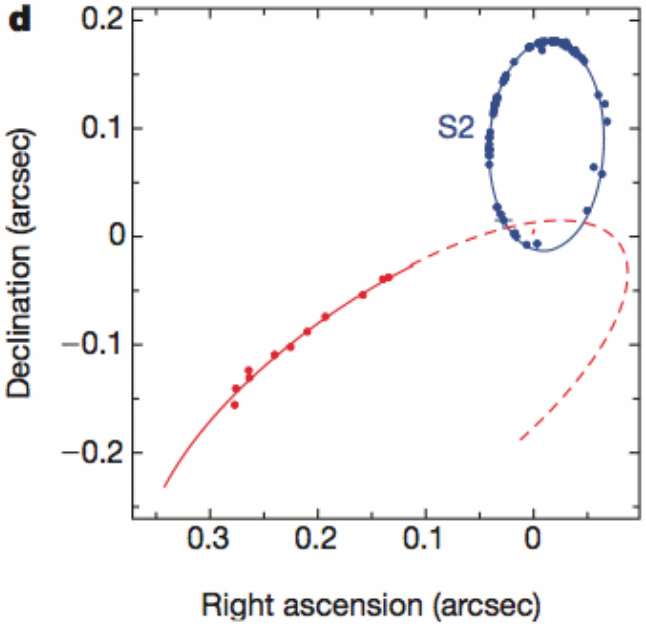
NIR data: Molecular cloud eaten by GC BH (2013)

- **Cold cloud discovered**
- **Orbit well-constrained**
- **Has no chance to escape BH!**



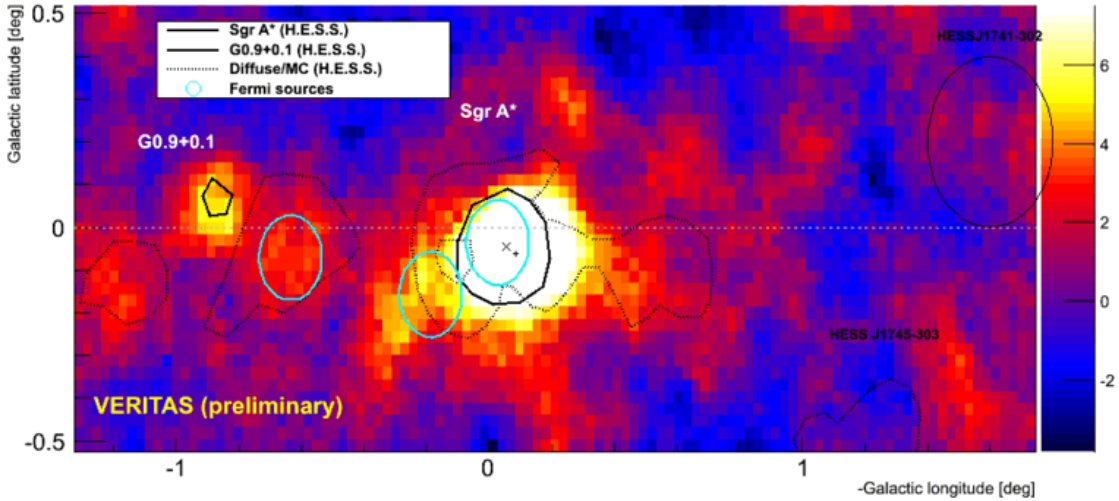
Unique chance:
Probe accretion flow in an almost controlled experiment





Summary and Conclusion

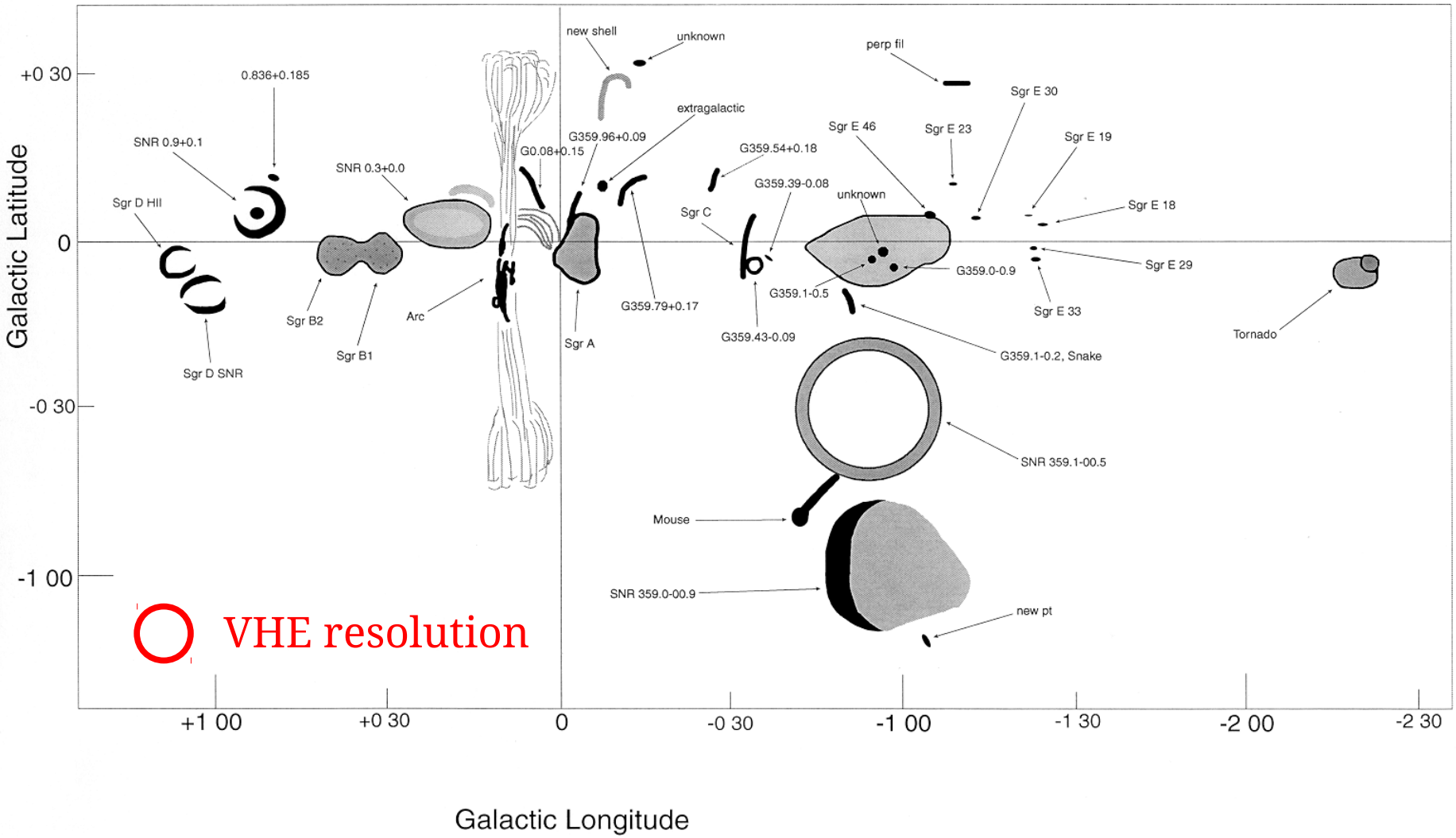
- **VERITAS detected GC:**
  - 18 std.dev. (46 hrs)
  - Spectrum compatible with H.E.S.S./MAGIC
- **Future observations:**
  - Constrain energy cut off
  - Constrain E>10 TeV variability
- **Prospects:**
  - Understand astrophysics of GC region
  - Obtain UL on DM annihilation (E > ~few TeV)



Backup slides

The Galactic Center: Schematic View

VLA (Kassim et al., 1999)



NIR data: Molecular cloud eaten by GC BH (2013)

slides borrowed by S.Gillessen (EHT meeting, Tucson, AZ)

tidal shear develop between 2008 and 2011