A MAGIC picture of our Galactic Center

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MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

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Some of the most important reasons ...

- The GC hosts the by far closest Super Massive Black Hole (SMBH) to Earth
- Studying the GC might finally allow for testing new theories describing Gravity in a quantum-mechanical framework
- Spatial/angular resolution of sub Event Horizon scales of the GC BH in radio and optical are only few years away
- The DM concentrated at the GC , if annihilating/decaying should be the most luminous when observed from Earth
- Therefore the GC is one of the best candidates for indirect DM searches
- The GC is a very dense and active environment, from an astrophysical point of view
- It hosts star forming regions with plenty of molecular gas, heavy young stars, and many supernova remnants

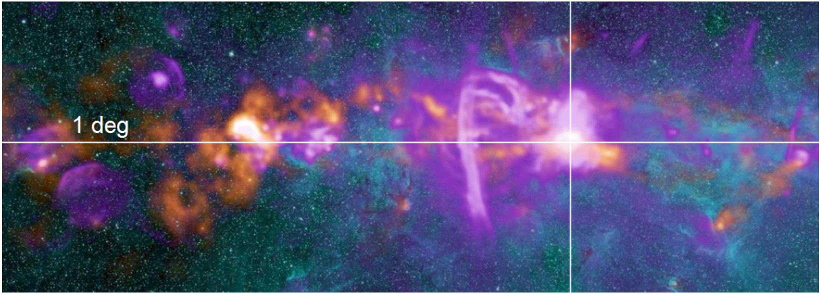
Putting the Galactic Center into context

Milky Way galaxy:

- disk (30 kpc x 0.3 kpc): young stars, gas, molecular clouds, dust
- bar (4.5 kpc) and bulge (1.5 kpc): old stars low star formation
- Galactic Center (250 pc): dense molecular clouds high star formation rate

image source: en.wikipedia.org

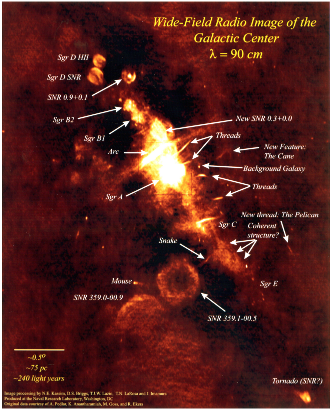
GC region in 20cm, 1.1mm, IR



- VLA (20cm): H II regions that are illuminated by hot, massive stars, supernova remnants, and synchrotron emission
- Caltech Submillimeter Observatory (1.1mm): cold (20-30 K) dust associated with molecular gas
- Spitzer (IR): primarily emission from stars and from polycyclic aromatic hydrocarbons

image source: http://images.nrao.edu

Radio sources SgrA and SgrA*



- bright point-like radio source
- at the center of SgrA-West (Mini-Spiral)
- at the edge of SNR SgrA-East
- thought to be SMBH
- from stelar motions: $\approx 4 \cdot 10^6\ M_\odot$

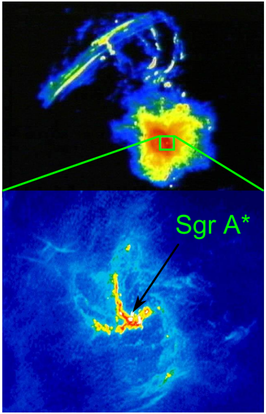
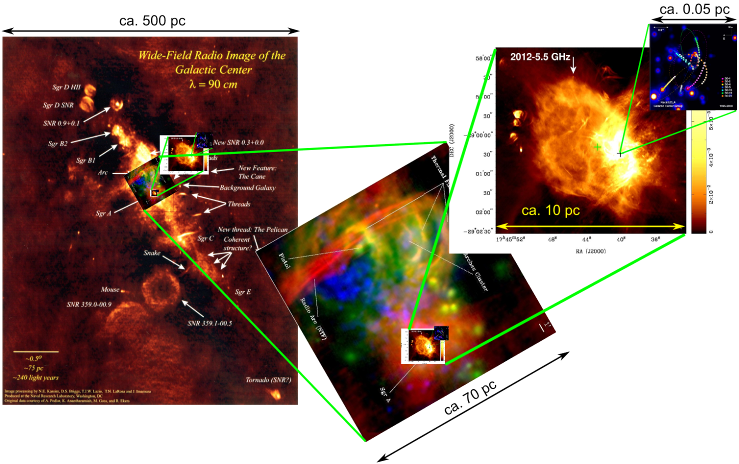


image source (left): N. E. Kassim, D. S. Briggs, T. J. W. Lazio, T. N. LaRosa, J. Imamura (NRL/RSD)

image source (right): astro.ucla.edu

The Galactic Center S-star cluster — stellar motion reveals the SMBH



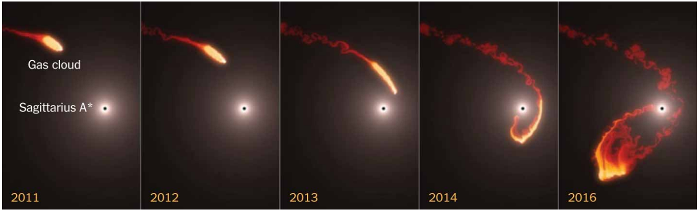
- few 10 OB stars confined inside the central arc-sec around SgrA*
- star S2 periastron: 120 AU, period: 15.6 y

refer to for example: Ghez, A. M., et al. The Astrophysical Journal 509.2 (1998): 678.

G2 gas cloud falling onto the Galactic Center

- Reports by ESO about a gas cloud of three times the Earth mass on its way to SgrA* (S. Gillessen et al. 2012)
- Pericenter passage 2013-2014, $\approx$ 2000 Schwarzschild radii (20 light hours) (S. Gillessen et al. 2013)
- Tidal disruption of the cloud has already begun 2011
- Likely that part of the cloud will be subjected to accretion in the upcoming years

$\Rightarrow$ Monitoring campaigns triggered in nearly all wavelengths



Possible scenarios

Rough summary of possible observable accretion scenarios:

- Formation of a hot accretion disk

$\Rightarrow$ Production of thermal X-rays (X-ray satellites)

- Production of energetic electrons

$\Rightarrow$ Synchrotron radiation from Radio to X-ray from energetic electrons (Radio telescopes, X-ray satellites)

$\Rightarrow$ Bremsstrahlung and/or Inverse Compton scattering of high energy e^- (γ ray satellite observatories, ground based γ ray observatories)

- Acceleration of protons and heavy nuclei

$\Rightarrow$ π^0 production in interaction of hadronic cosmic rays (γ ray satellite observatories, ground based γ ray observatories)

IACTs in context of other Instruments

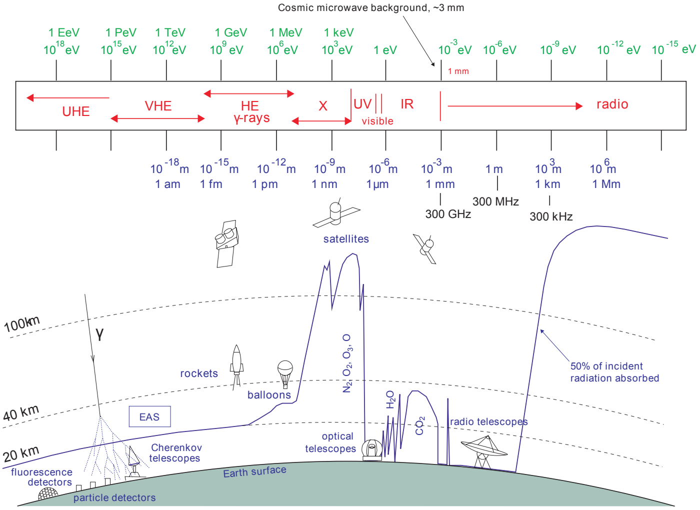


image credit: Robert Wagner

Extended air-showers

EM (left) and hadronic (right) shower and Atmospheric MC simulations (center)

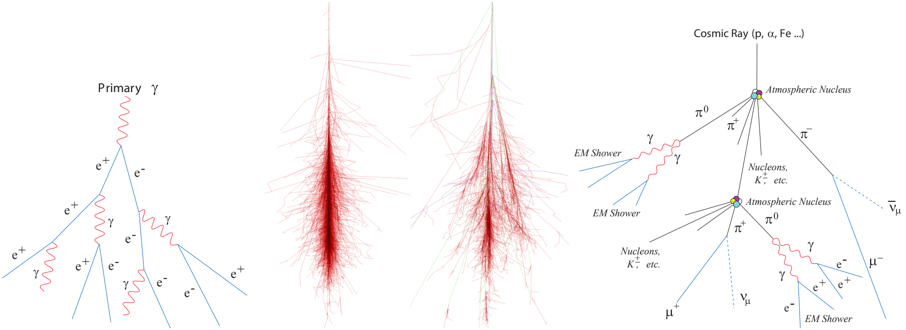
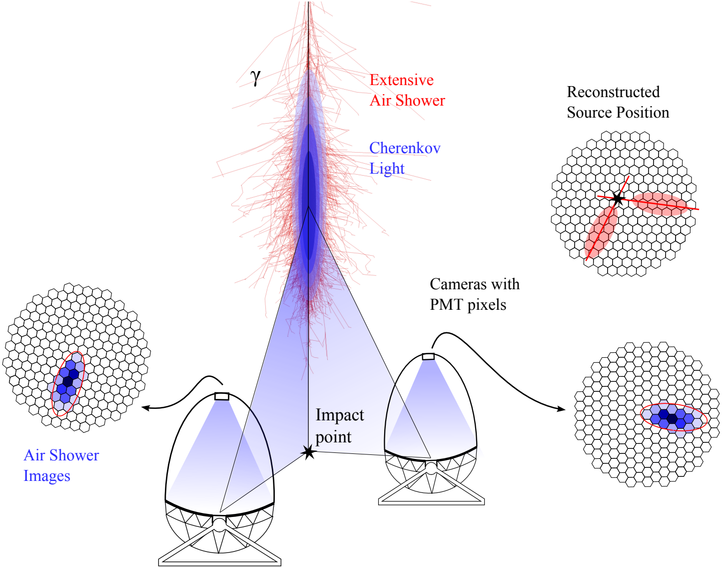


image credit: Robert Wagner / CORSIKA

Imaging Air Cherenkov Telescopes



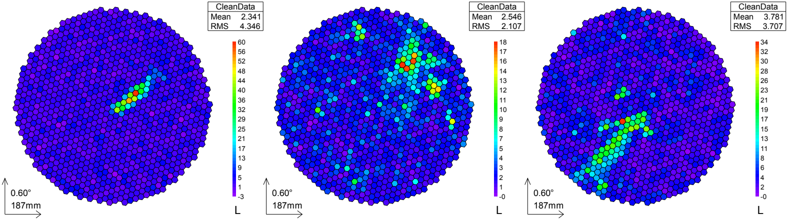
The MAGIC telescopes

- located on the Roque de los Muchachos (at 2200 m a.s.l.) on the Canary island La Palma
- Two 17m diameter parabolic single-mirror telescopes consisting of 239 1 m^2 mirror panels each
- Support structure from carbon fiber can rotate 180° in about 20 s

image credit: Robert Wagner

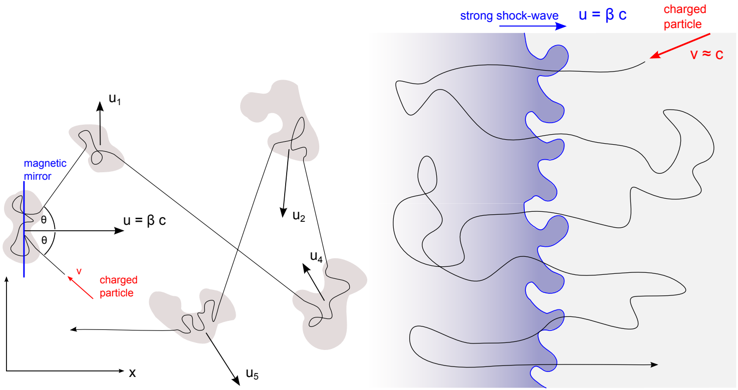
Images recorded by the cameras of the MAGIC telescopes

- The two cameras consist of 1039 photomultiplier pixels each (3.5° FoV)
- Events last only a few ns
- Different coincidence criteria (charge concentration in small region of camera in one and simultaneous such events in both telescopes) required for the events to be recorded
- Typical CR event rate 300 Hz
- Event classification offline via Random Forests



Short excursion: How are VHE γ-rays produced?

- γ-rays in the TeV regime are exclusively of non-thermal origin.
- They are always produced as a by-product of the acceleration of charged particles to VHE
- The favored acceleration scenarios are: Diffusive shock acceleration and acceleration in rotating magnetic fields (Pulsars, BH plerions)



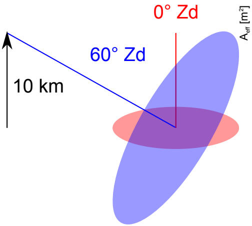
Short excursion: How are VHE γ-rays produced?

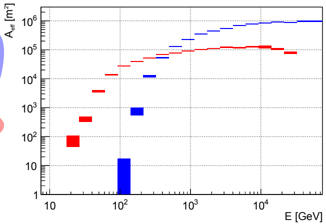
- γ-rays are then produced via:
- Leptonic: Bremsstrahlung, Curvature radiation, Inverse Compton scattering (IC) – mostly on synchrotron radiation produced by the same population (SSC)
- Hadronic: decay of π^0 form pp interaction

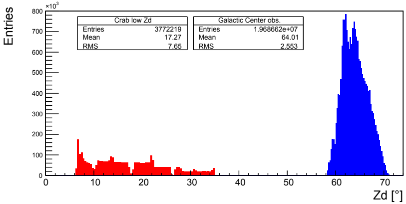
Observability of the GC

- Source declination of -29° ⇒ culminates at 58° zenith distance

⇒ Observation at large zenith (58° – 70°) distance with all advantages and disadvantages (light pool size vs. light dilution, enhanced absorption ...)

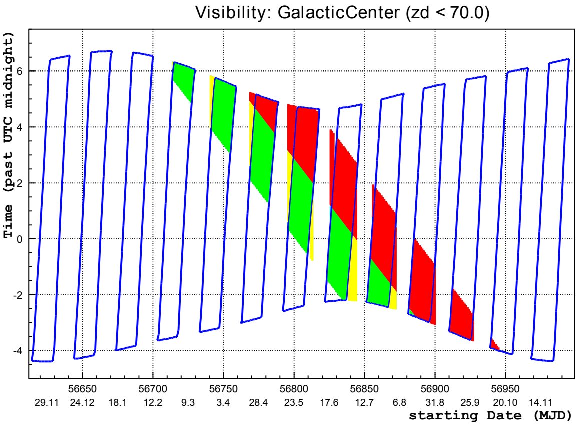






Observed about 60 h in total!

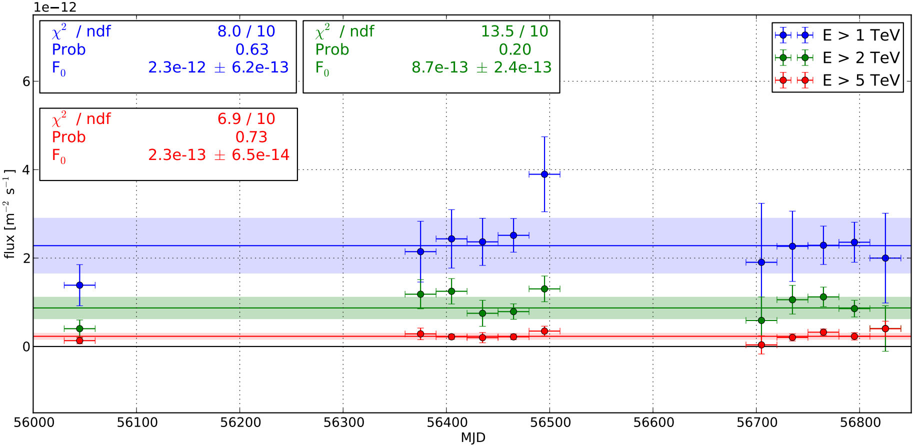
- Total observability throughout the year (only about 1/3 of the year available for monitoring)



- Due to limited trigger delay between both telescopes, part of the observable window is lost

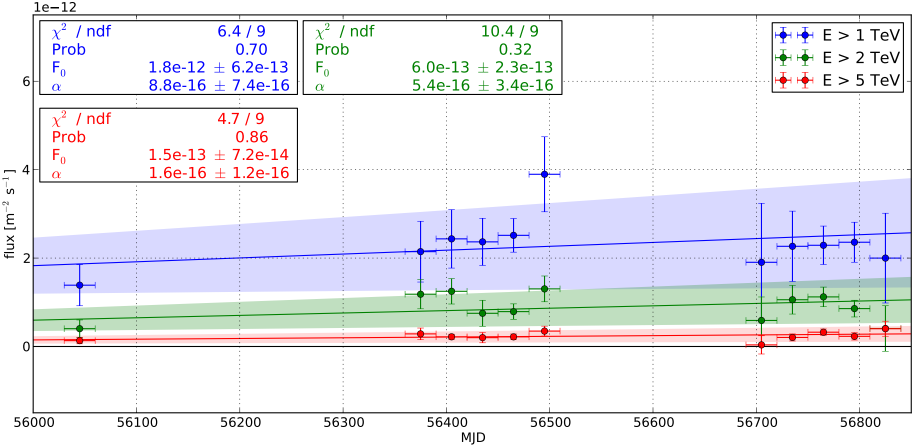
Lightcurve (Is the flux variable?) – constant flux (correlated fit)

$$F(t) = F_0$$



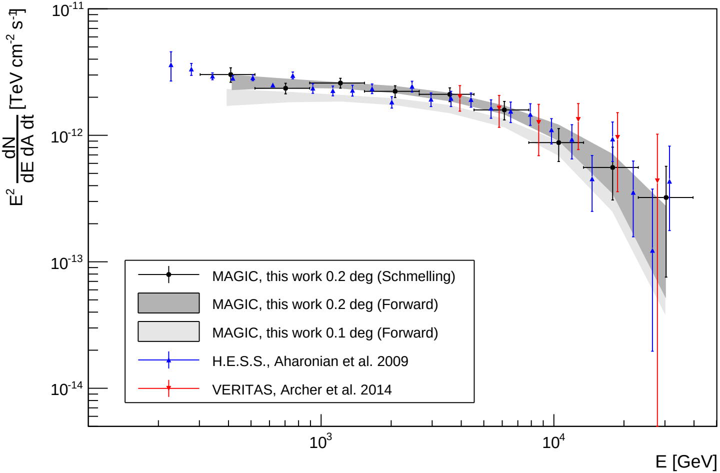
Lightcurve (Is the flux variable?) – linearly increasing flux (correlated fit)

$$F(t) = F_0 + \alpha(t[\mathrm{MJD}] - 56000)$$



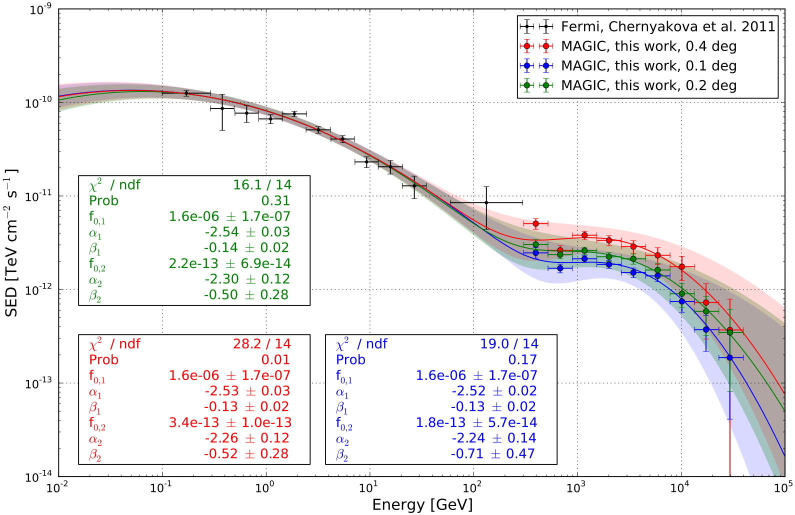
Spectral Energy Density (SED)

- MAGIC SED (flux per relative bandwidth) compared to other measurements
- Power-law with exponential cutoff fit: $\frac{\mathrm{d}F}{\mathrm{d}E} = f_0 \left(\frac{E}{1\,\mathrm{TeV}}\right)^{-2.0} \exp - \frac{E}{10\,\mathrm{TeV}}$



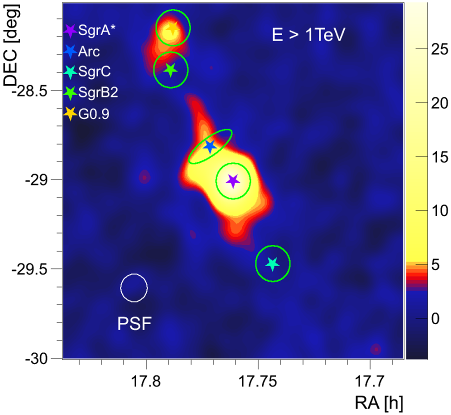
Spectral Energy Density (SED) – MAGIC and Fermi (same source?)

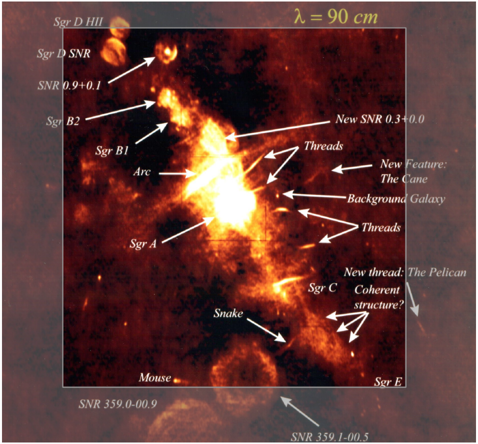
- Correlated fit: $\frac{dF}{dE} = f_{0,1}\left(\frac{E}{5\,\mathrm{GeV}}\right)^{\alpha_1+\beta_1\log\left(\frac{E}{5\,\mathrm{GeV}}\right)} + f_{0,2}\left(\frac{E}{3\,\mathrm{TeV}}\right)^{\alpha_2+\beta_2\log\left(\frac{E}{3\,\mathrm{TeV}}\right)}$



Skymaps: MAGIC and 90cm radio

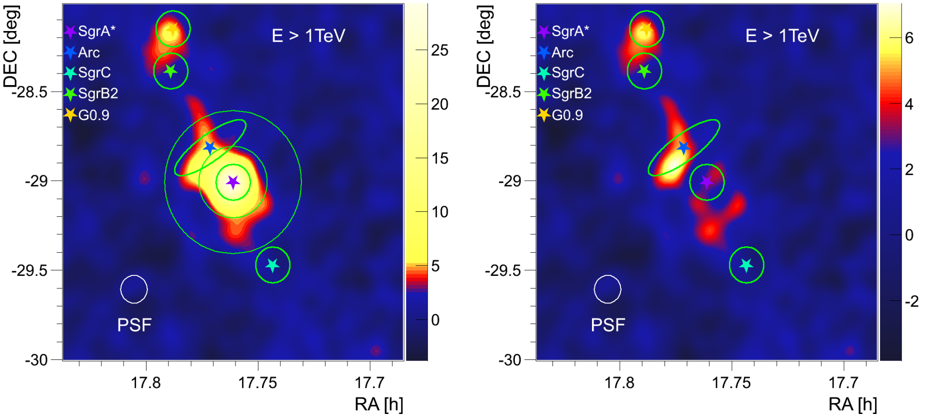
- Morphology can definitely not be explained by point source
- Resembles quite much the 90 cm radio image – but what causes the TeV radiation?





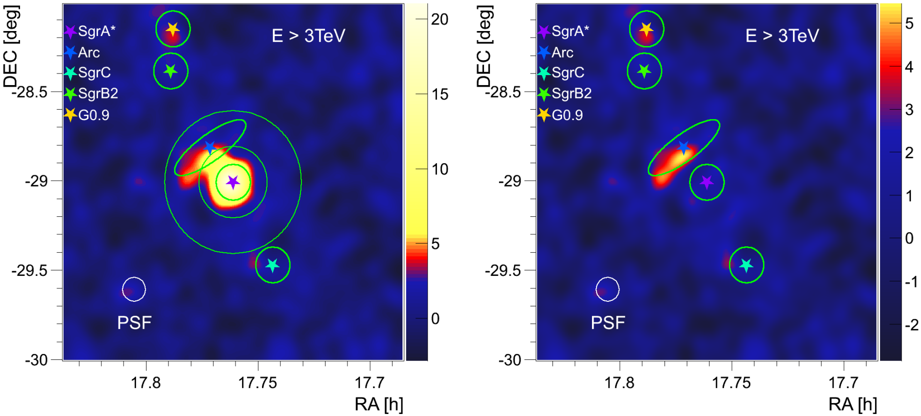
GC skymaps MAGIC, E > 1Tev (~60h)

- Image before (left) after (right) the subtraction of a point source

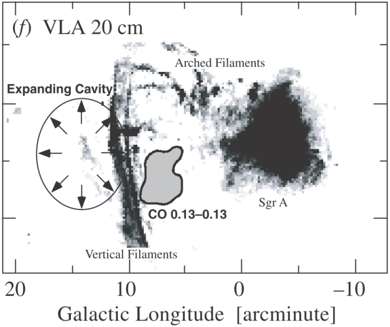


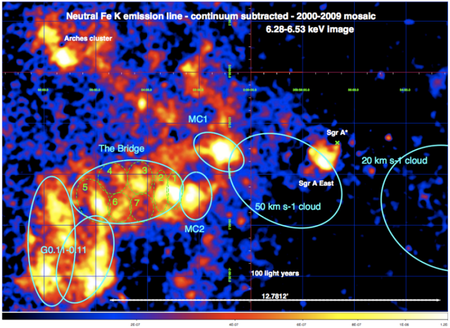
GC skymaps MAGIC, E > 3Tev (~60h)

- Image before (left) after (right) the subtraction of a point source



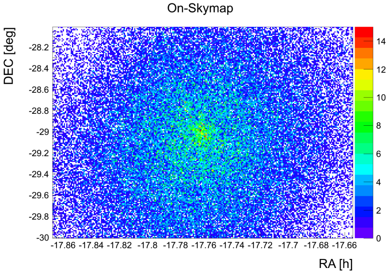
Source candidates for extended emission

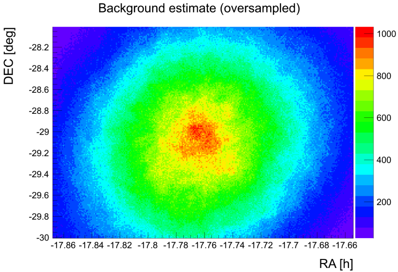


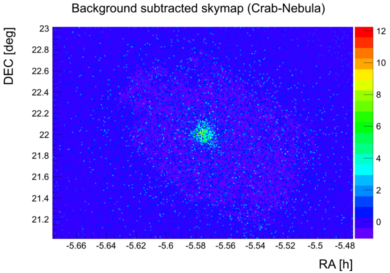


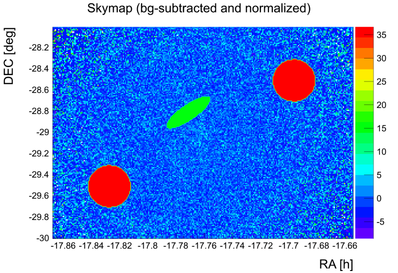
- Expanding giant molecular cloud G0.11-0.11 exactly matching the coordinates of MAGIC excess (M. Tsuboi et al. 1997) — possible origin: 10 - 100 SNE
- Possible origin of Arc γ-radiation from GMC G0.11-0.11 - maybe interaction of linear filaments and expanding GMC?
- Fe K_α emission either X-ray echo of SgrA* (M. Clavel et al. 2013) flare or excited by CRs (F. Yusef-Zadeh et al. 2013)
- Are same CRs also producing the TeV emission?

Attempting to calculate spectrum of the Arc

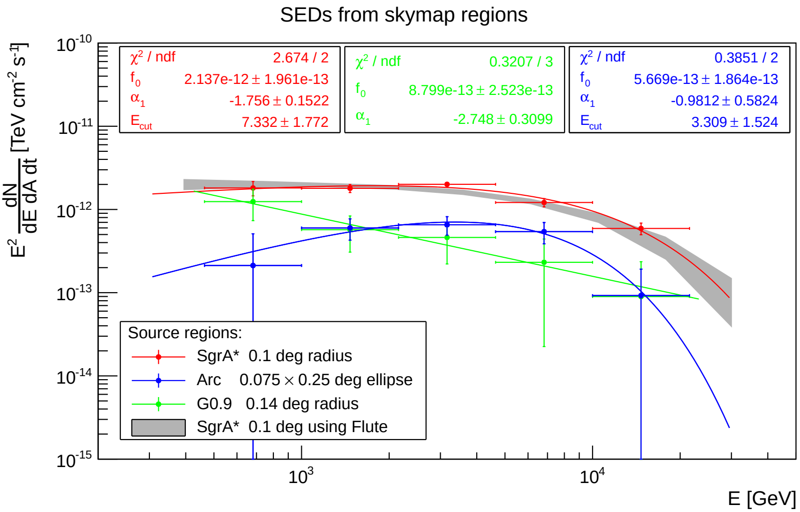








Preliminary Results:



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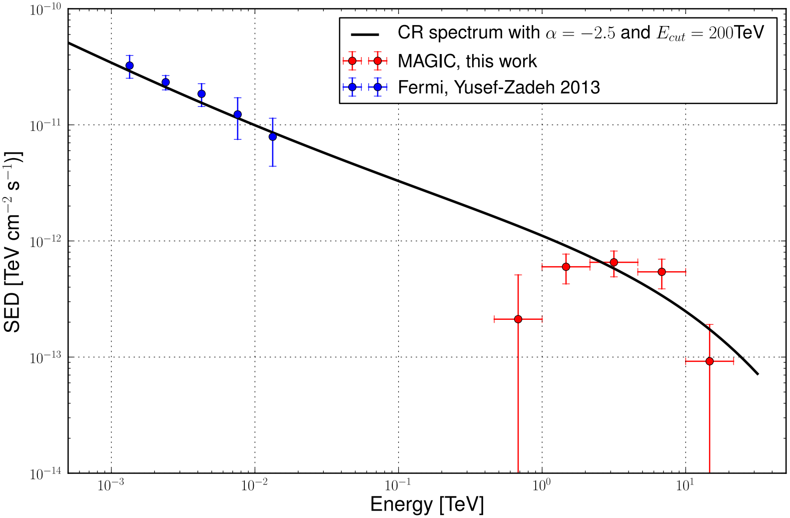
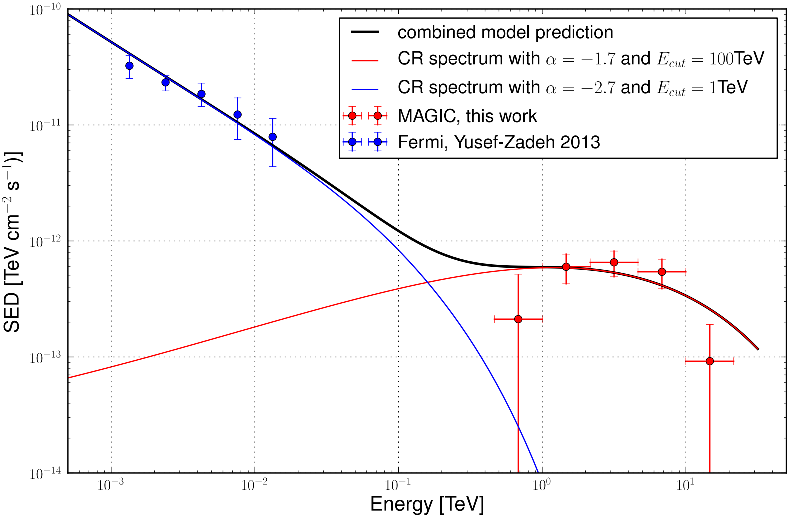


Preliminary Results:



Remarks

- Flux for the central object (GC/SgrA*):
  $F_{E>1\,\mathrm{TeV}} \approx 2 \cdot 10^{-12}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$,
  $F_{E>2\,\mathrm{TeV}} \approx 1 \cdot 10^{-12}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$,
  $F_{E>5\,\mathrm{TeV}} \approx 2 \cdot 10^{-13}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- This corresponds to ≈20 evts/h, ≈15 evts/h, ≈7 evts/h in case of MAGIC taking into account the average effective collection areas
- The observations are of course not background free

⇒ We are quite statistics limited, especially at high energies

- Also, because of the detection technique the angular resolution is always worse than 0.05°

Conclusions

- GC is a very interesting target for astronomical observations – also in VHE-γ
- We are coming closer and closer to revealing the origin of the high energy radiation from the GC
- Each observation at each wavelength serves as a piece in the puzzle

Thanks for your attention!