



MAGIC

Max-Planck-Institut für Physik



The Galactic Center region imaged with MAGIC — & — variability during the G2 pericenter passage

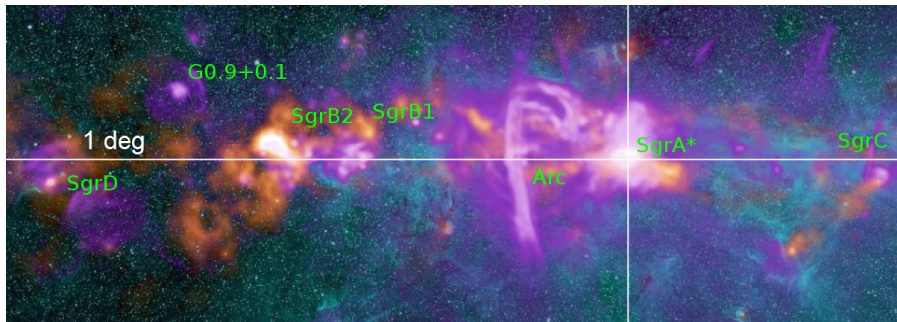
Christian Fruck, John E. Ward, Marcel Strzys, levgen Vovk
fruck@mpp.mpg.de
Tokyo - October 2015



- ▶ Imaging Air-shower Cherenkov Telescopes for observing γ -rays from 50 GeV to 50 TeV
- ▶ located on the Roque de los Muchachos (at 2200 m a.s.l.) on the Canary island La Palma
- ▶ two 17m diameter parabolic dish, $F/D = 1.03$, telescopes
- ▶ photomultiplier (PMT) cameras with 1039 pixels each
- ▶ support structure from carbon fiber, allowing for fast repositioning (180° in about 20 s)



image credit: Robert Wagner



- ▶ GC hosts **Super Massive Black Hole (SMBH)** ($4 \cdot 10^6 M_{\odot}$)
- ▶ very dense and active **astrophysical environment**
- ▶ considered good place to search for **DM** annihilation/decay

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

- ▶ report about a **gas cloud of three times the Earth mass** on its way to SgrA* (S. Gillessen et al. 2012)
 - ▶ pericenter passage 2013-2014, **≈ 2000 Schwarzschild radii** (S. Gillessen et al. 2013) (≈ 25 light hours or $20\times$ Saturns semi major axis)
 - ▶ possible that part of the cloud interacts with the SMBH
- ⇒ **monitoring** campaigns triggered in nearly all wavelengths (**radio to γ rays**)

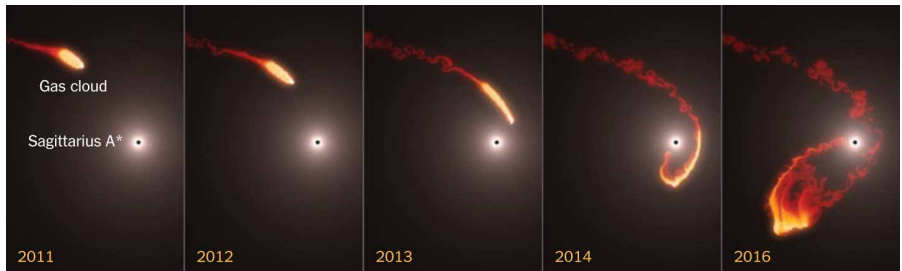


image source: ESO



Possible observable effects in an interaction scenario:

- ▶ Formation of a hot accretion disk
 - ⇒ Production of thermal X-rays (X-ray satellites)
- ▶ Production of energetic electrons (in shock/jet/magnetosphere)
 - ⇒ Synchrotron radiation from Radio to X-ray from energetic electrons (Radio telescopes, X-ray satellites)
 - ⇒ 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 (shock/jet/magnetosphere)
 - ⇒ π^0 production in interaction of hadronic cosmic rays (γ ray satellite observatories, ground based γ ray observatories)

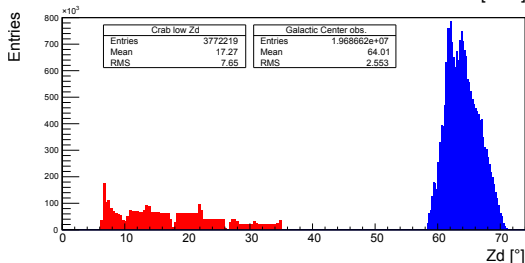
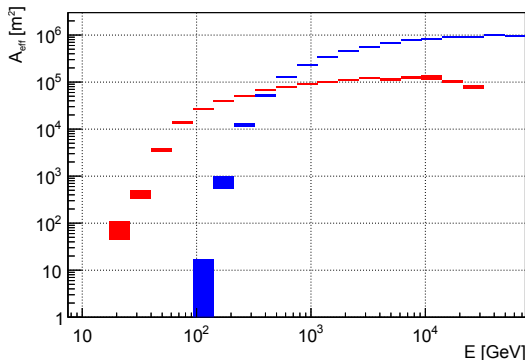
⇒ So far no enhanced variability in other wavelengths

⇒ Monitoring of SgrA* with MAGIC at high zenith angles

⇒ Observations in 2012, 2013, 2014 and 2015 (~ 65h very good quality)



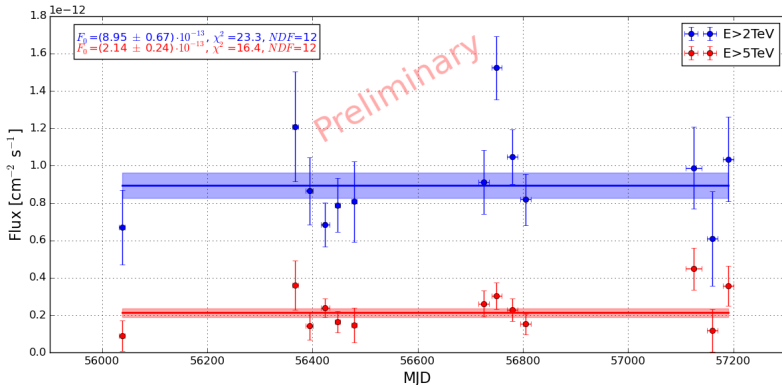
- ▶ Culmination at $\sim 58^\circ$ zenith distance
- ▶ Observation at large zenith distance ($58^\circ - 70^\circ$) with all advantages and disadvantages (light pool size vs. light dilution, enhanced absorption ...)
- ▶ Energy threshold increase by factor of the order 10
- ▶ Effective collection area increasing by about the same factor
- ▶ Good, because in case of hadronic acceleration/diffusion scenarios fastest reaction expected in multi TeV regime (D. R. Ballantyne, M. Schumann, B. Ford, 2011)





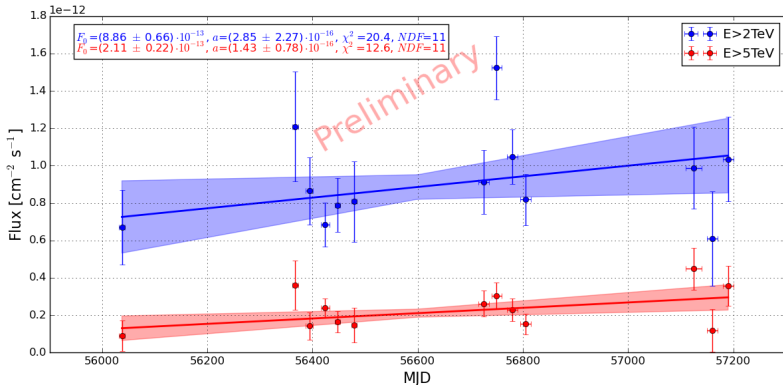
Light curve: any observable effect of the G2 flyby?

- ▶ MAGIC light curve for the central point-like (SgrA*) source: $E > 2$ TeV, $E > 5$ TeV
- ▶ Integration radius 0.14° around SgrA*
- ▶ Only very good quality 2012/13/14/15 data (~ 65 h)
- ▶ Flux compatible with constant in all energy bands
- ▶ Linear fit does not show significant improvement of χ^2
- ▶ Also no reports about unusual flux variability in other wavebands





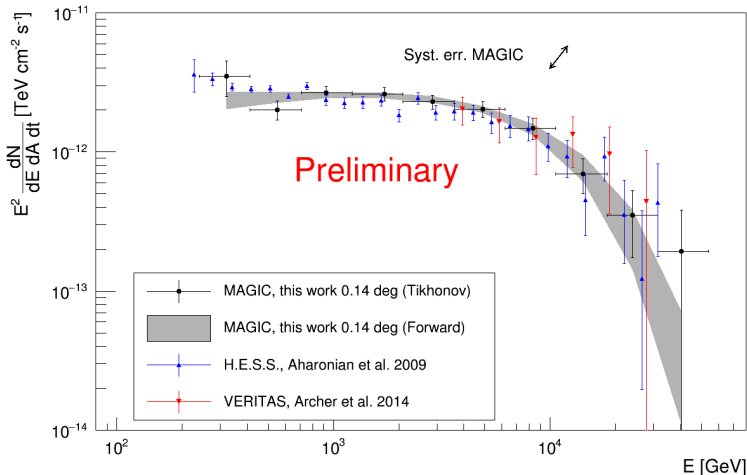
- ▶ MAGIC light curve for the central point-like (SgrA*) source: $E > 2 \text{ TeV}$, $E > 5 \text{ TeV}$
- ▶ Integration radius 0.14° around SgrA*
- ▶ Only very good quality 2012/13/14/15 data ($\sim 65\text{h}$)
- ▶ Flux compatible with constant in all energy bands
- ▶ Linear fit does not show significant improvement of χ^2
- ▶ Also no reports about unusual flux variability in other wavebands

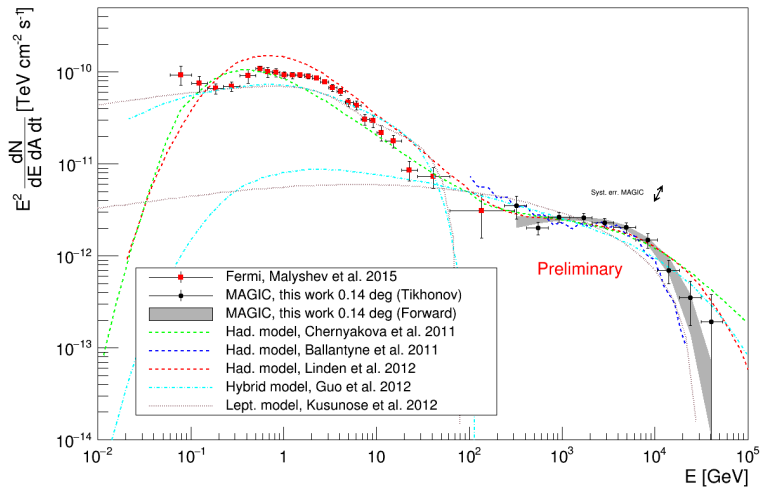




- ▶ MAGIC SED compared to other previous measurements
- ▶ Integration radius 0.14° around SgrA*, $\sim 65h$ of very good quality 2012/13/14/15 data
- ▶ Power law with exponential cutoff fit (forward folding):

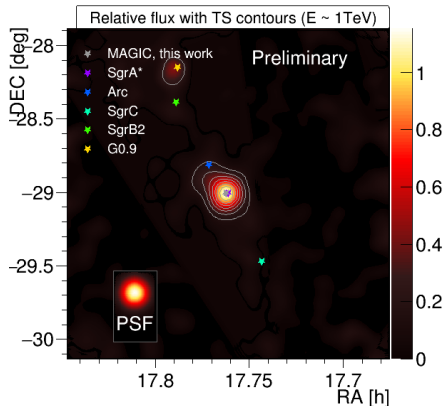
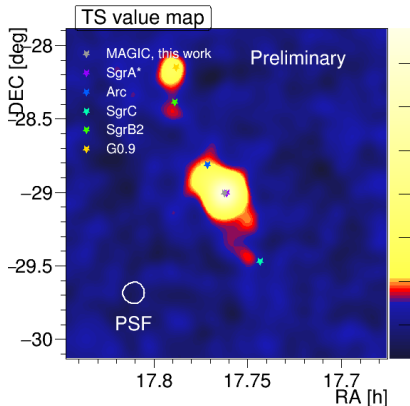
$$\frac{dF}{dE} = (7.92 \pm 0.98) \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1} \left(\frac{E}{2 \text{ TeV}} \right)^{(-1.86 \pm 0.13)} \exp - \frac{E}{(8.49 \pm 2.89) \text{ TeV}}$$



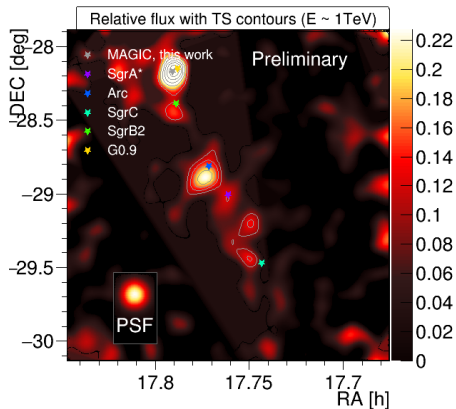
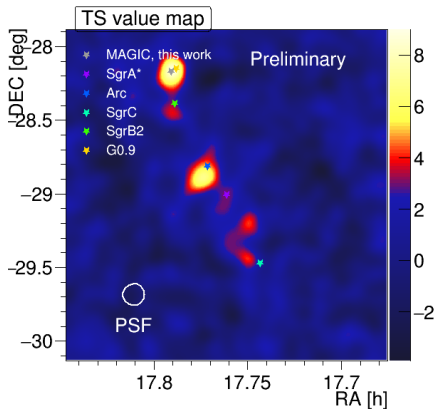


- ▶ peculiar 2-bump structure – none-trivial for modeling
- ▶ hadronic scenarios are exploiting **morphology** (**target**) and **time variability** (**source**)
- ▶ leptonic models have problems explaining the spectral shape with single source
- ▶ the available data does not yet allow discrimination of models

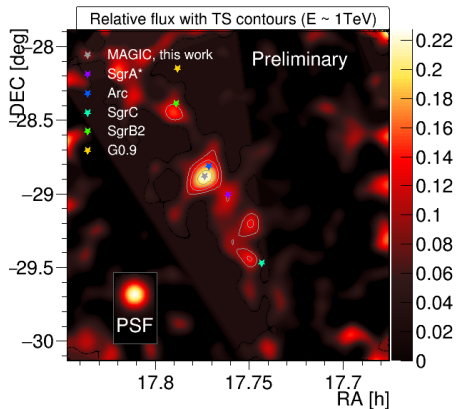
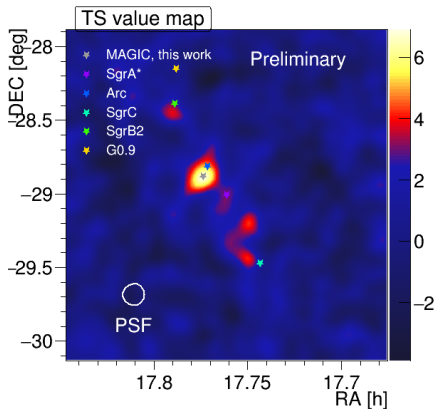
- ▶ 2.25×2.25 deg FoV, Galactic Plane from bottom right to top left
- ▶ TS value map (**left**)
- ▶ excess in units of background $(N_{on} - N_{off})/N_{off}$ with significance contours starting from 5σ (**right**)
- ▶ strong point-like contributions from the locations of SgrA* and G0.9+0.1



- ▶ point source model fitted and subtracted from SgrA* location
- ▶ 2.25×2.25 deg FoV, Galactic Plane from bottom right to top left
- ▶ TS value map (left)
- ▶ excess in units of background $\frac{(N_{on}-N_{off})}{N_{off}}$ with sign. contours starting from 3σ (right)
- ▶ New source [MAGIC J1746.4-2853](#)
- ▶ possible coincidence with [HESS J1746-285](#) and [VER J1746-289](#)

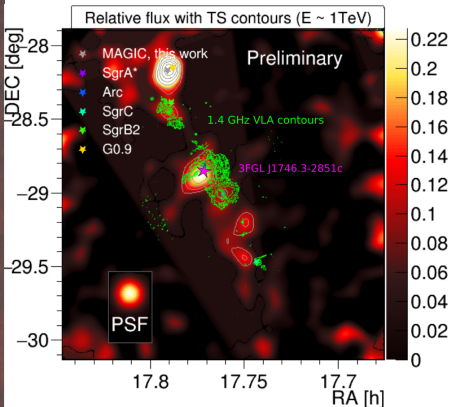
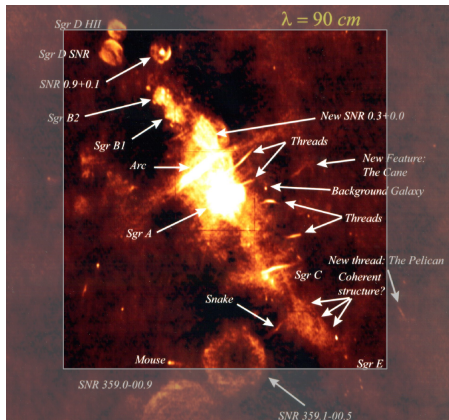


- ▶ point source model fitted and subtracted from SgrA* location
- ▶ 2.25×2.25 deg FoV, Galactic Plane from bottom right to top left
- ▶ TS value map (left)
- ▶ excess in units of background $\frac{(N_{on}-N_{off})}{N_{off}}$ with sign. contours starting from 3σ (right)
- ▶ New source [MAGIC J1746.4-2853](#)
- ▶ possible coincidence with [HESS J1746-285](#) and [VER J1746-289](#)





- ▶ good correlation between 90 cm radio image and TeV skymap ($E \gtrsim 1$ TeV)
- ▶ G0.9 is known TeV source (Aharonian et al., 2005)
- ▶ detected significant TeV gamma-ray excess apparently coincident with the radio Arc
- ▶ MAGIC source is coincident with the Fermi source 3FGL J1746.3-2851c
- ▶ Bremsstrahlung from cosmic electrons interacting with MCs? (Yusef-Zadeh et al., 2013)




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

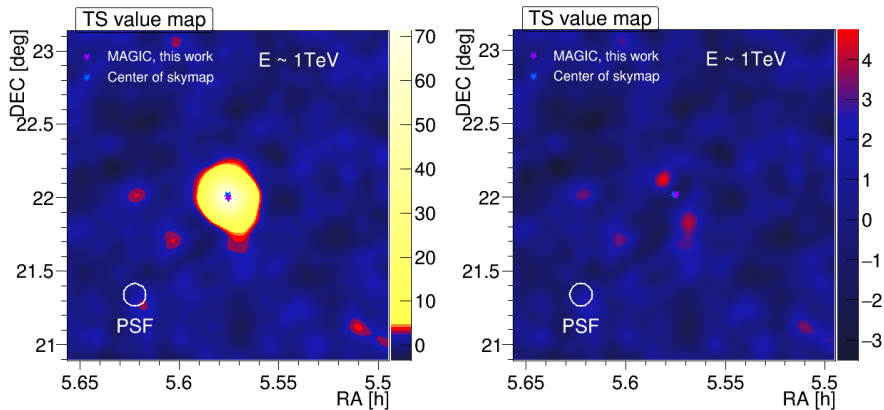


- ▶ Large $Z_d \sim 60-70^\circ$ observation technique with MAGIC very successful!
- ▶ SED over more than 2 orders of magnitude with only 65h of data.
- ▶ **Blue variability** in the TeV regime during the closest encounter of the GC with the **G2 gas cloud**
 - ⇒ Maybe the gas did not reach the accretion zone yet?
 - ⇒ Or the accretion is radiation inefficient?
 - ⇒ Or the gas cloud is very compact (eg. star with stellar wind)?
 - ▶ Seems to be the case, because the cloud is still intact after passing the pericentre [arXiv:1410.8731](https://arxiv.org/abs/1410.8731)).
- ▶ **New TeV source**: the GC **radio Arc** – source type still unknown, could be PWN, CR-MC interaction or SNR shell interacting with magnetic structure of the Arc
- ▶ Very complex and interesting region now being actively studied by MAGIC, H.E.S.S. and VERITAS
- ▶ **Stay tuned!**

Thanks for your attention!



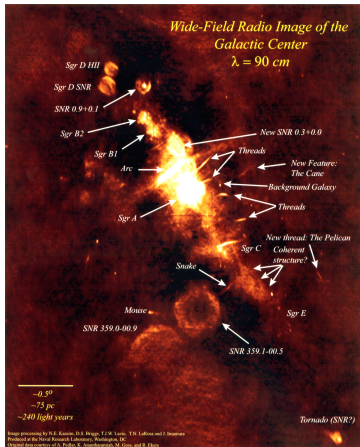
Backup





- ▶ 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>



- ▶ 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 stellar motions:
 $\approx 4 \cdot 10^6 M_{\odot}$

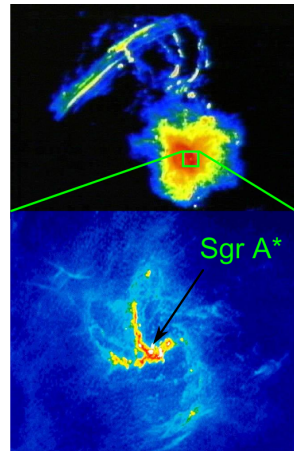
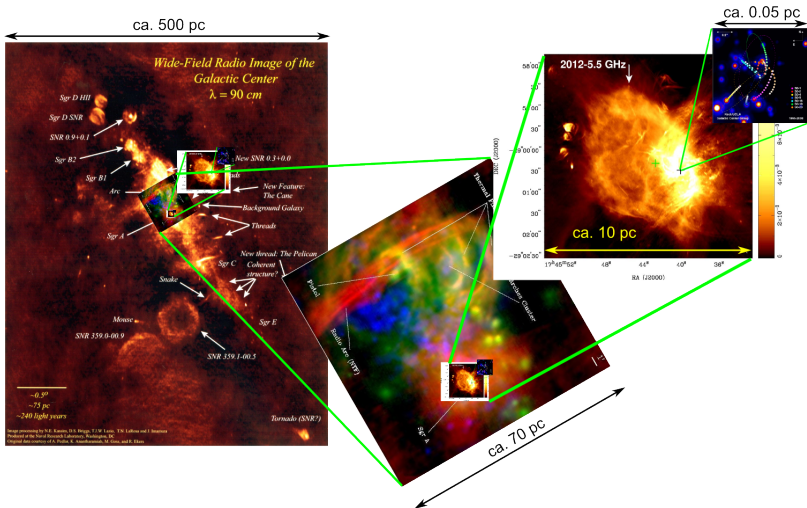


image source (left): N. E. Kassim, D. S. Briggs, T. J. W. Lazio, T. N. LaRosa, J. Imamura (NRL/RSD)
image source (right): astro.ucla.edu

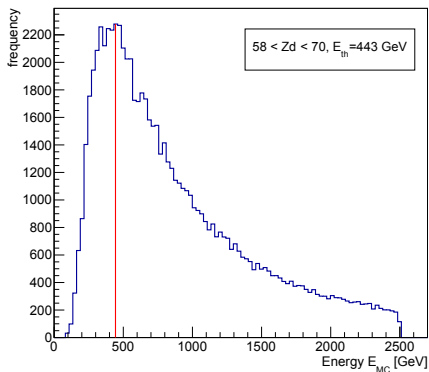


- ▶ few 10 OB stars confined inside the central arc-sec around SgrA*
- ▶ star S2 periastron: 120 AU, period: 15.6 y

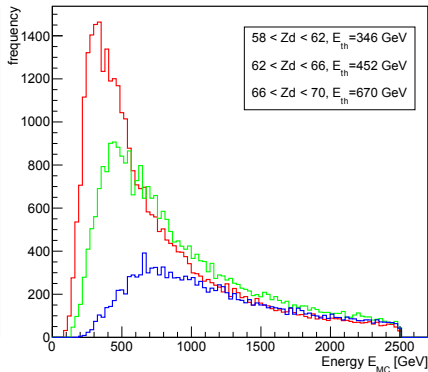
refer to for example: Ghez, A. M., et al. The Astrophysical Journal 509.2 (1998): 678.



Energy Threshold



Energy Threshold



For a Crab-like spectral index!