The Galactic Center region imaged with MAGIC

variability during the G2 pericenter passage

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The MAGIC telescopes

- Imaging Air-shower Cherenkov Telescopes for observing $\gamma$-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
The Galactic Center: in 20cm, 1.1mm, IR

- 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
G2 gas cloud falling onto the Galactic Center

- 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, \( \approx 2000 \) Schwarzschild radii (S. Gillessen et al. 2013) (\( \approx 25 \) light hours or \( 20 \times \) Saturns semi major axis)

- possible that part of the cloud interacts with the SMBH

\( \Rightarrow \) **monitoring** campaigns triggered in nearly all wavelengths (**radio to \( \gamma \) rays**)

![Image source: ESO](image.jpg)

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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)
  - $\pi^0$ 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 ($\sim 65h$ 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: $E > 2 \text{ TeV}, E > 5 \text{ TeV}$
- Integration radius $0.14^\circ$ around SgrA*
- Only very good quality 2012/13/14/15 data ($\sim 65h$)
- Flux compatible with constant in all energy bands
- Linear fit does not show significant improvement of $\chi^2$
- Also no reports about unusual flux variability in other wavebands

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Light curve: any observable effect of the G2 flyby?

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![Graph showing MAGIC light curve for the central point-like (SgrA*) source.](image)

- Preliminary
Spectral Energy Density (SED) of SgrA*

- MAGIC SED compared to other previous measurements
- Integration radius $0.14^\circ$ around SgrA*, $\sim65h$ of very good quality 2012/13/14/15 data
- Power law with exponential cutoff fit (forward folding):
  \[
  \frac{dF}{dE} = (7.92 \pm 0.98) \text{cm}^{-2} \text{s}^{-1} \text{TeV}^{-1} \left(\frac{E}{2 \text{TeV}}\right)^{-1.86 \pm 0.13} \exp\left(-\frac{E}{8.49 \pm 2.89} \text{TeV}\right)
  \]

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Preliminary
Adding 2015 Fermi data and comparing to models

- 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
Sky map (∼65h) 2012/13/14/15 (E ≥ 1 TeV)

- 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
Sky map (~65h) 2012/13/14/15 ($E \gtrsim 1\,\text{TeV}$)

- point source model fitted and subtracted from SgrA* location
- $2.25 \times 2.25\,\text{deg FoV}$, Galactic Plane from bottom right to top left
- TS value map (left)
- excess in units of background $\frac{N_{\text{on}}-N_{\text{off}}}{N_{\text{off}}}$ with sign. contours starting from $3\sigma$ (right)
- New source MAGIC J1746.4-2853
- possible coincidence with HESS J1746-285 and VER J1746-289
Sky map (~65h) 2012/13/14/15 ($E \gtrsim 1$ TeV)

- point source model fitted and subtracted from SgrA* location
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Origin of the extended emission

- 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)

Conclusions

- Large Zd $\sim 60-70^\circ$ observation technique with MAGIC very successful!
- SED over more than 2 orders of magnitude with only 65h of data.
- **No 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 (e.g. star with stellar wind)?
  - Seems to be the case, because the cloud is still intact after passing the pericentre arXiv: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
PSF Model subtracted from Crab Nebula sky map

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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 stellar motions: \( \approx 4 \cdot 10^6 \, M_\odot \)

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

For a Crab-like spectral index!