Discovery of a new extragalactic population of energetic particles

Based on Brown et al. 2016 [arXiv:1603.05469]

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Introduction

Central regions of active galaxies extremely interesting

- Supermassive black holes (SMBHs), high-energy radiative processes, acceleration of cosmic rays, dark matter (DM) annihilation...
- Potentially unexplained observations
- DM phenomenology essentially unexplored

γ-rays extremely valuable source of information

- Information on sources of high-energy cosmic rays
- Very sensitive γ-ray telescopes like the *Fermi* Large Area Telescope (LAT)
- Focus on Centaurus A (Cen A)

Cen A

- Cen A radio galaxy: active galaxy with a misaligned jet
- Closest known γ-ray emitting radio galaxy
  $d_{\mathrm{Cen\ A}} \approx 4$ Mpc

[Credit: ESO/WFI (Optical); MPIfR/ESO/APEX/Weiss et al. (Submillimeter); NASA/CXC/CfA/Kraft et al. (X-ray)]

New analysis of the *Fermi* spectrum of the core of Cen A [Brown et al. 2016]

Data

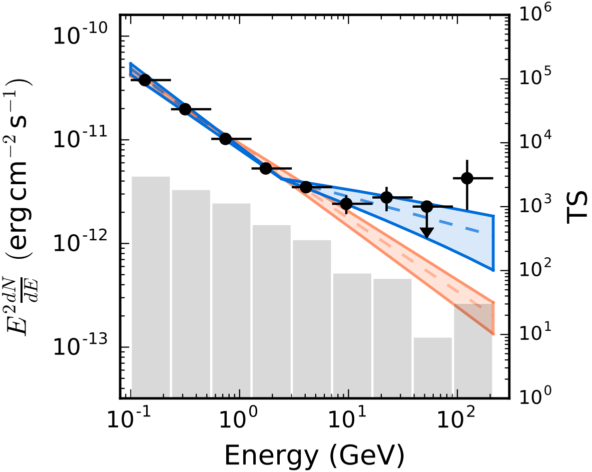
- 7.5 years of *Fermi*-LAT data between 0.1 GeV and 300 GeV
- PASS8 event characterisation

Model of the γ-ray emission

- Core (point source)
- Radio lobes (extended)
- 2 pulsar wind nebulae (extended)
- Known Galactic and extragalactic sources (point and extended)

New spectral feature in the γ-ray spectrum of the core of Cen A

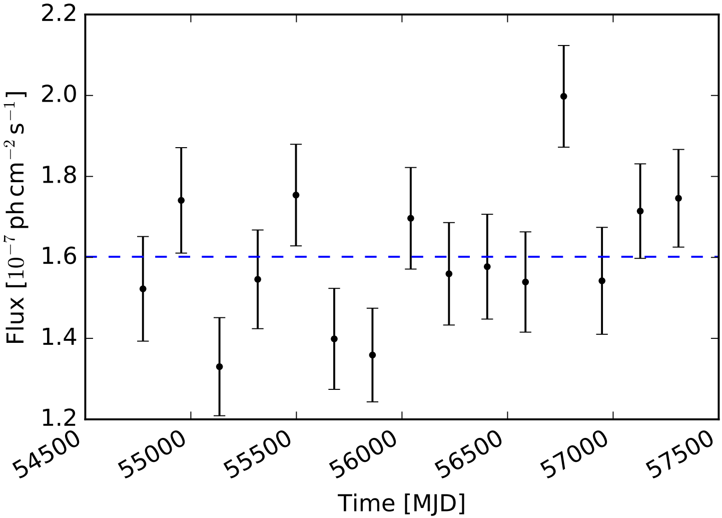
- Spectral hardening above $\sim$ 2.4 GeV at 5σ
- Much larger significance than previous result of 2σ [Sahakyan et al. 2013]



[Brown et al. 2016]

Variability below the break

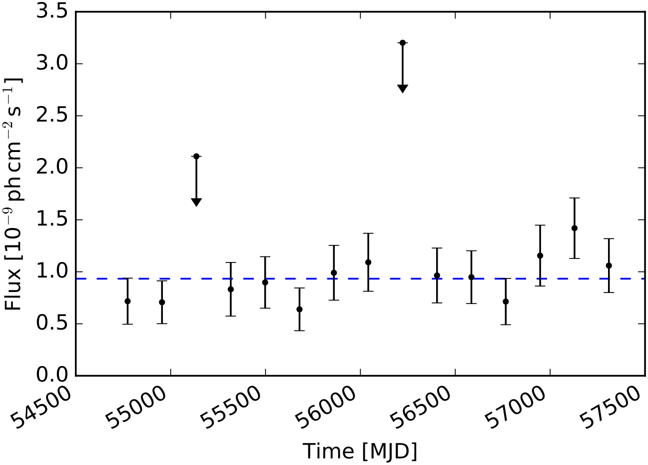
Low-energy flux variable at a 2σ confidence level



[Brown et al. 2016]

But no significant variability above

Steady flux very good description of high-energy component



[Brown et al. 2016]

⇒ Strong support for additional steady source of high-energy particles above 2.4 GeV

Possible interpretations

Single zone leptonic jet model

Standard leptonic synchrotron self-Compton model
$\Rightarrow$ Variability

Lepto-hadronic model [Petropolou et al. 2013]

Synchrotron from leptonic byproducts of hadronic interactions
$\Rightarrow$ Variability

Dark matter annihilation

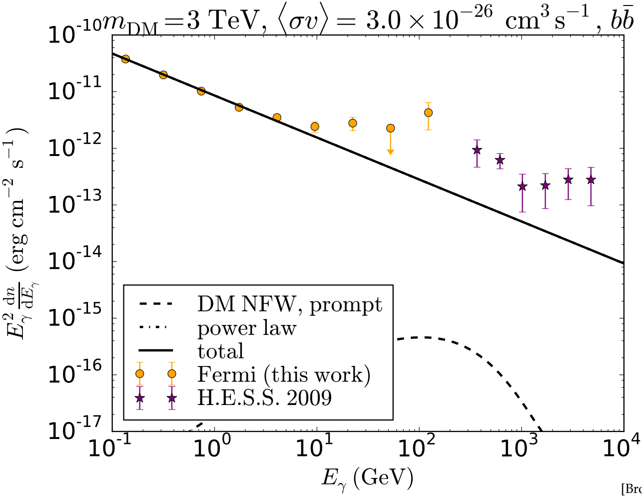
Prompt γ-ray emission
$\Rightarrow$ No variability expected

Population of millisecond pulsars (MSPs)

$e^{\pm}$ wind $\rightarrow$ acceleration in shocks up to tens of TeV [Bednarek & Sobczak 2013]
$\rightarrow$ high-energy γ-rays via inverse Compton scattering
$\Rightarrow$ No variability expected

Dark matter annihilation?

Standard NFW profile insufficient to account for observed emission



[Brown et al. 2016]

Dark matter spikes at the centers of galaxies?

- Density profile very uncertain below parsec scales
- Can be significantly affected by supermassive black holes (SMBH)
- Adiabatic (slow) growth of SMBH at the center of DM halo $\Rightarrow$ **spike**: strong enhancement of the DM density in the inner region [Gondolo & Silk 1999]

$$\rho_{\rm sp}(r) \propto r^{-\gamma_{\rm sp}}, \quad \gamma_{\rm sp} \sim 7/3 \tag{1}$$

  $\Rightarrow$ strong annihilation signals
- But adiabatic spikes are debated...

Dark matter spikes affected by competing dynamical processes

Disruptive dynamical effects

- Instantaneous BH growth [Ullio et al. 2001]
- Off-centered BH formation [Nakano & Makino 1999; Ullio et al. 2001]
- Halo mergers [Merritt et al. 2002]
- Stellar dynamical heating [Gnedin & Primack 2004; Merritt 2004]

Dynamical effects strengthening the case for DM spikes

- Core-collapse from DM self-interactions [Ostriker 2000]
- Efficient replenishment of the loss cone from steep stellar cusp [Zhao et al. 2002]
- Triaxiality of DM halo $\Rightarrow$ enhanced DM accretion [Merritt & Poon 2004]

Motivation for spike in Cen A

Dynamical relaxation time in the core of a galaxy

$$t_r \sim 2 \times 10^9 \text{ yr} \left(\frac{M_{BH}}{4.3 \times 10^6 \, M_\odot} \right)^{1.4} \tag{2}$$

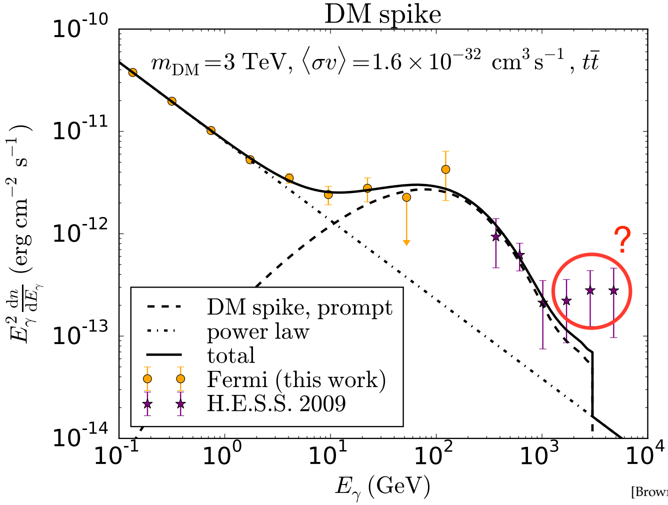
- To be compared with the age of the Universe ($\sim 10^{10}$ yr)
- Stellar dynamical heating potentially relevant for the Milky Way
- Negligible for galaxies with sufficiently massive central BHs

Negligible effect of stellar heating in dynamically young galaxies

Cen A ($M_{BH} \approx 5.5 \times 10^7 \, M_\odot$) dynamically young
$\Rightarrow$ stellar heating negligible
$\Rightarrow$ **spike more likely to have survived**

Dark matter annihilation?

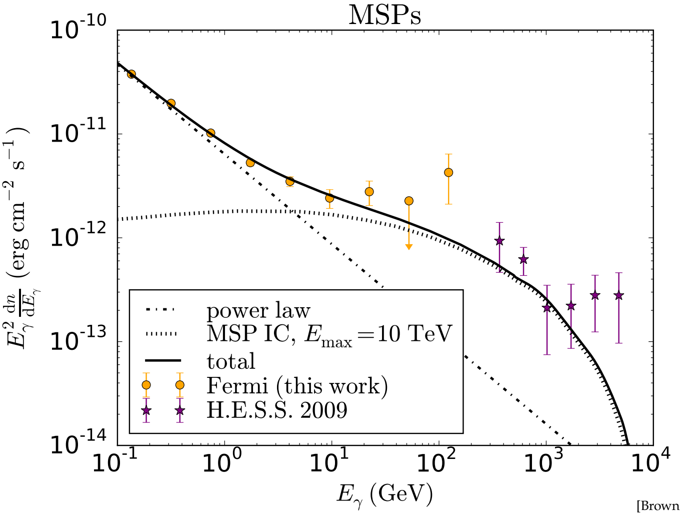
Prompt emission from a SMBH-induced spike of TeV DM



[Brown et al. 2016]

Millisecond pulsars?

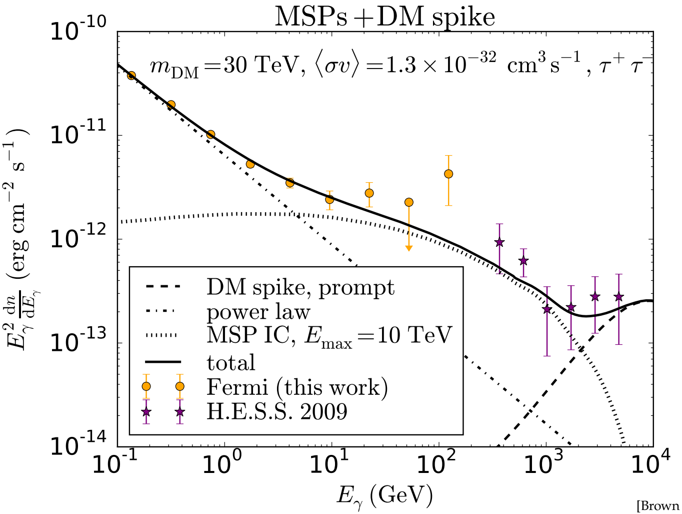
Inverse Compton emission of $e^{\pm}$ injected by a population of MSPs



[Brown et al. 2016]

Both?

Combination of prompt emission from DM spike and inverse Compton from MSPs



[Brown et al. 2016]

Some other possible explanations to investigate

Proton diffusion

Protons accelerated by the jet can travel away from the center via spatial diffusion and produce high-energy γ-rays [Chernyakova et al. 2011]

Backward emission from the jet

Possible emission from backward shock created at the interface of the jet with the interstellar medium

Conclusion

- Spectral break in the core of Cen A at 5σ
- Steady flux above the break
- Not consistent with standard leptonic jet model
- Points to a new population of high-energy particles
- Hint of DM annihilation + DM spikes?
- Opens up a new window into the central regions of active galaxies

Thank you for your attention!