Probing dark matter around black holes at the centers of galaxies

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Dark matters

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Introduction

- Indirect searches for dark matter (DM) using astrophysical observations: very promising + multiple probes

- Cores of galaxies extremely interesting: larger DM abundance expected

- Inner DM density profile critical for indirect searches but poorly constrained

- Significant clustering of DM around supermassive black holes (SMBHs) in galactic cores?

- Probing profile via electromagnetic signatures of DM annihilations + dynamics

Dark matter spikes at the centers of galaxies?

- DM 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)

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

  $\Rightarrow$ strong annihilation signals

- No direct evidence in favor or against adiabatic spikes yet

Dark matter spikes affected by competing dynamical processes

Disruptive dynamical effects

- Instantaneous BH growth (Ullio+ 2001)
- Off-centered BH formation (Nakano & Makino 1999; Ullio+ 2001)
- Halo mergers (Merritt+ 2002)
- Stellar dynamical heating (Gnedin & Primack 2004; Merritt 2004)

Processes with positive effect

- Triaxiality of DM halo $\Rightarrow$ enhanced DM accretion (Merritt & Poon 2004)
- Core-collapse from DM self-interactions (Ostriker 2000)
- Regeneration by accretion?

Stronger case for spikes in M87 and Cen A

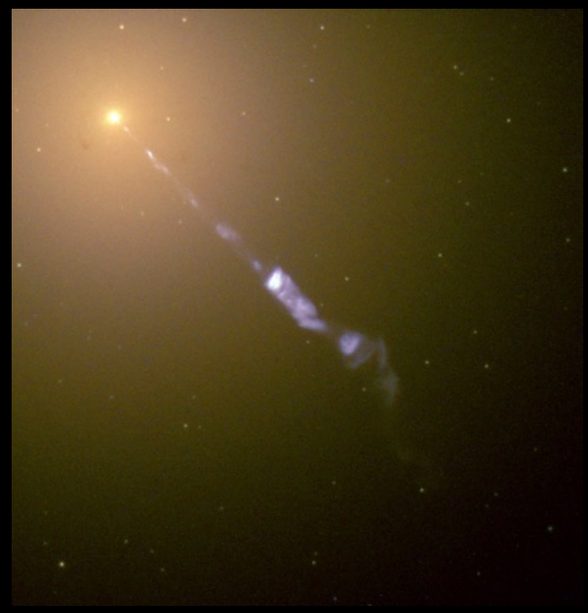
Negligible stellar heating in dynamically young galaxies

$$t_{\rm r} \sim 2 \times 10^9 \text{ yr} \left(\frac{M_{\rm BH}}{4.3 \times 10^6 \ M_\odot} \right)^{1.4}$$

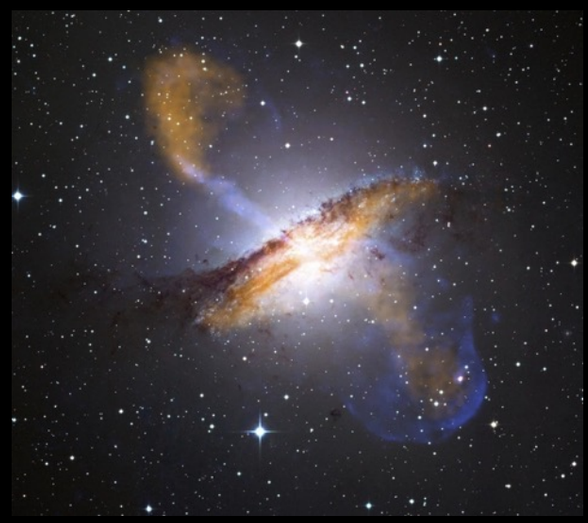
M87 ($M_{\rm BH} \approx 6.4 \times 10^9 \ M_\odot$, Gebhardt & Thomas 2009) and **Cen A** ($M_{\rm BH} \approx 5.5 \times 10^7 \ M_\odot$, Neumayer 2010) dynamically young

$\Rightarrow$ stellar heating negligible

$\Rightarrow$ **spike more likely to have survived**



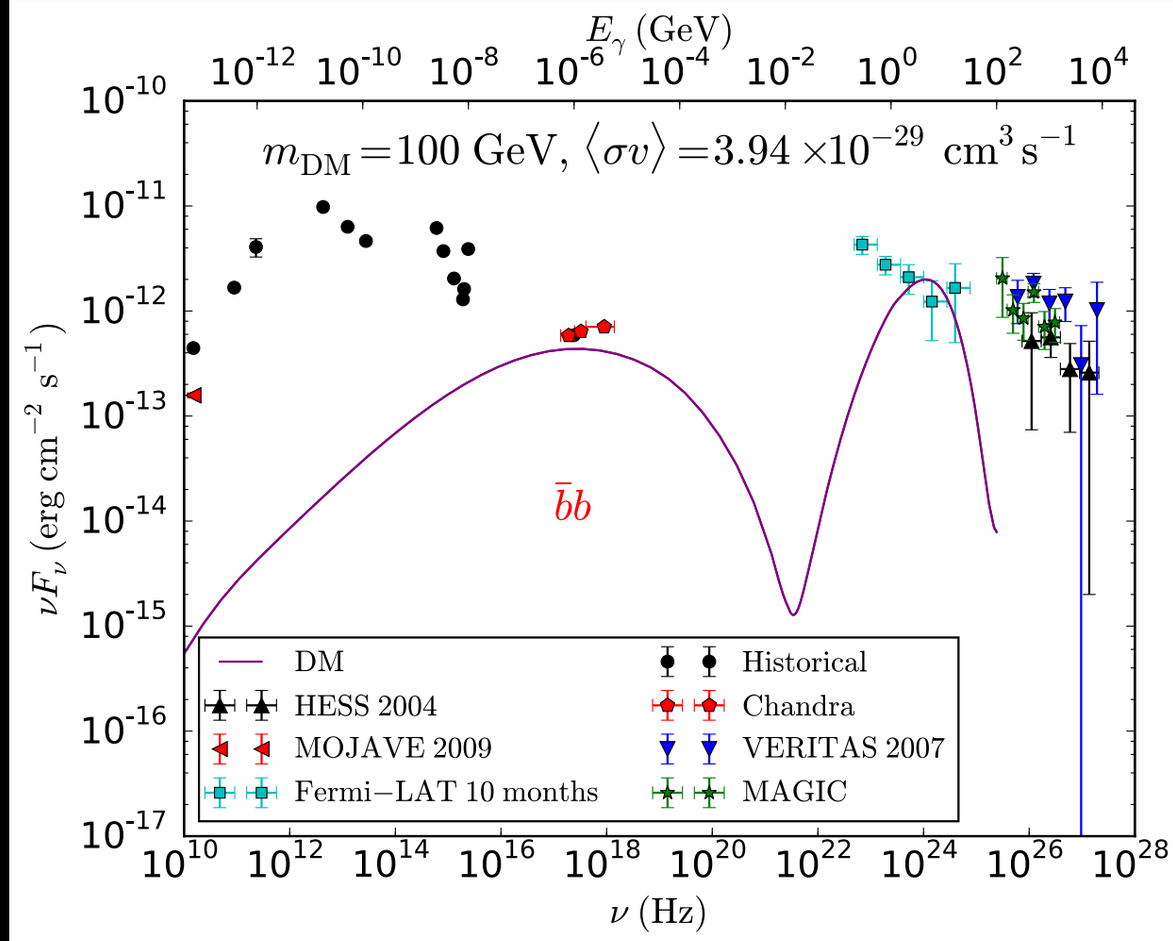
Credit: NASA and The Hubble Heritage Team (STScI/AURA)

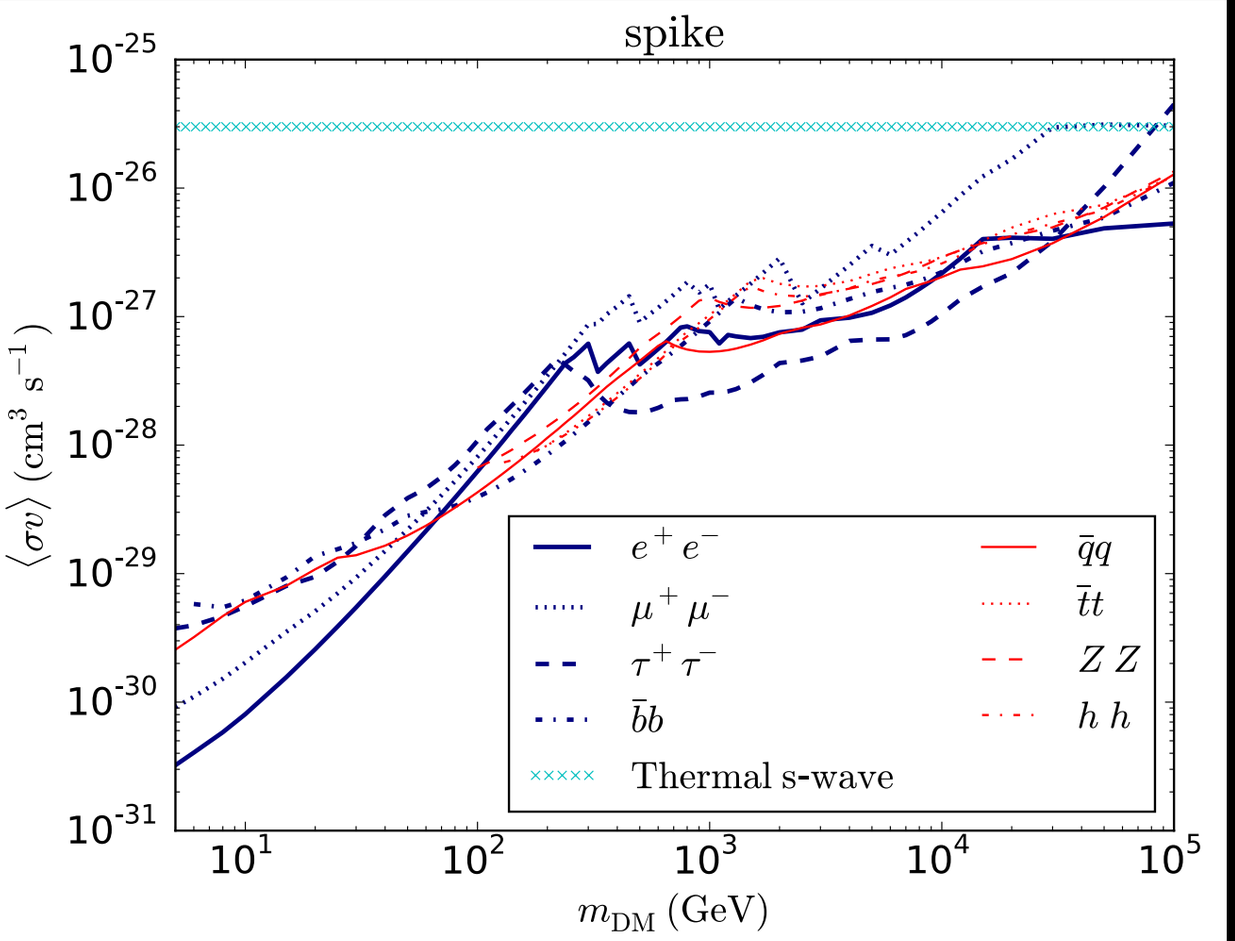


Credit: ESO/WFI (Optical); MPIfR/ESO/APEX/Weiss et al. (Submillimeter); NASA/CXC/CfA/Kraft et al. (X-ray)]

Multi-wavelength constraints on dark matter with a spike in M87

DM spike $\Rightarrow$ strong upper limits $\Rightarrow$ exclude DM candidates with thermal velocity-independent annihilation cross section over entire WIMP range



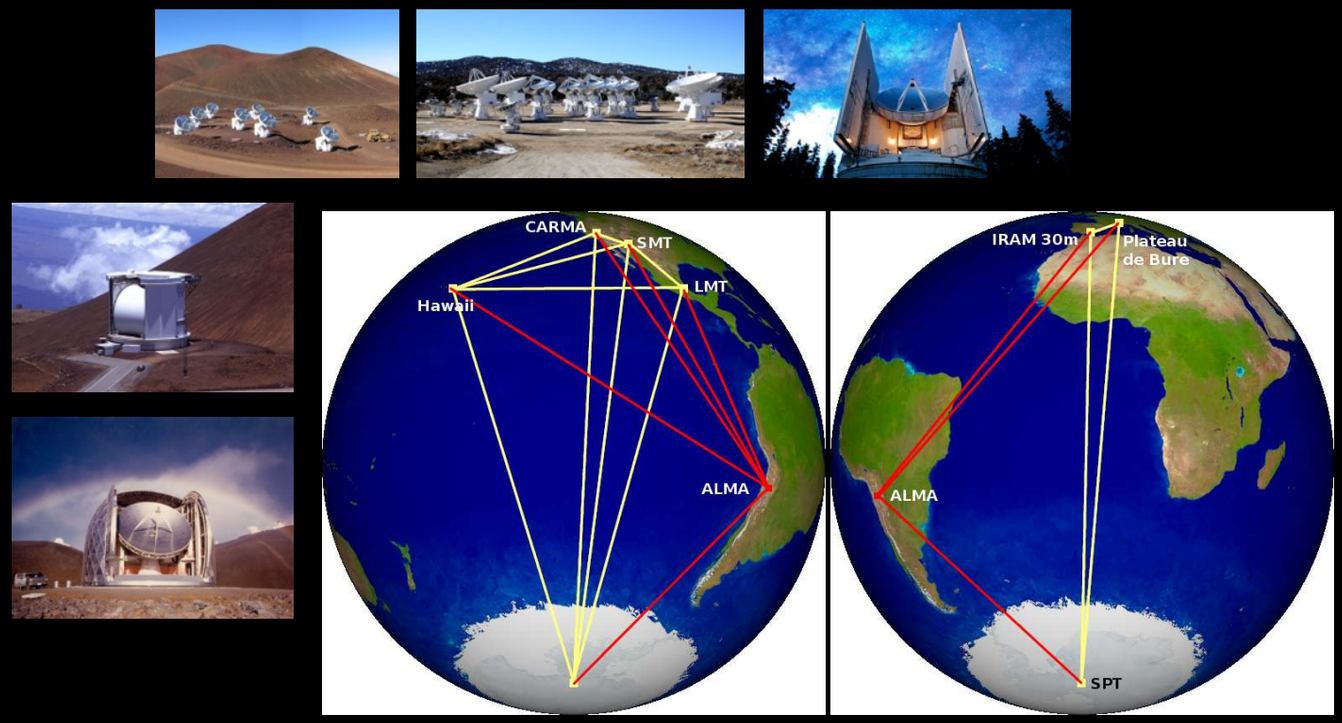


Lacroix+ 2015

Probing dark matter at the center of M87 with the Event Horizon Telescope

- Idea: exploit the morphology of the DM-induced synchrotron signal in the vicinity of the central SMBH
- Previously lack of angular resolution of existing facilities
- Very long baseline interferometry $\Rightarrow$ Earth-sized telescope

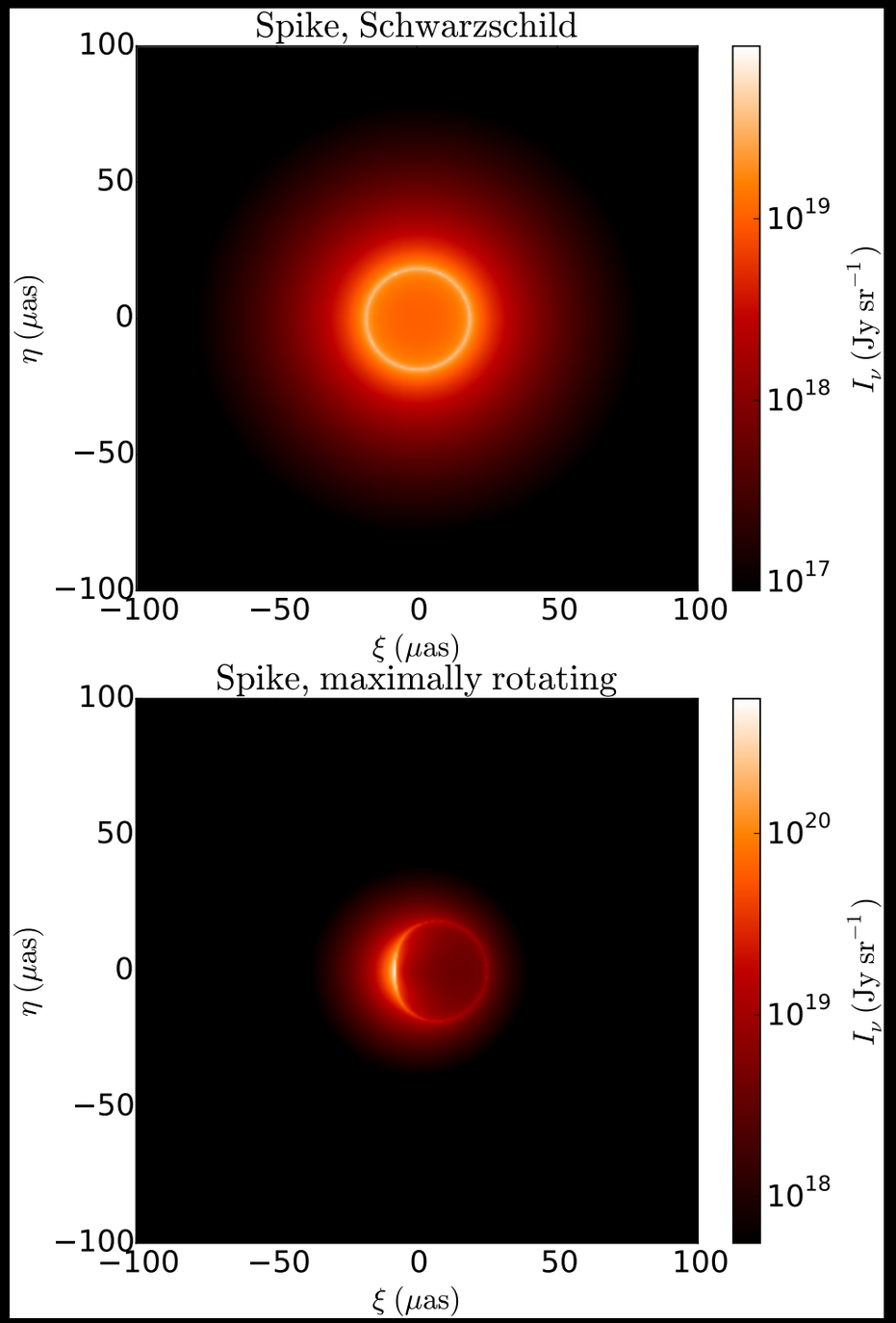
$\Rightarrow$ *micro-arcsecond-scale* angular resolution



Fish+ 2013

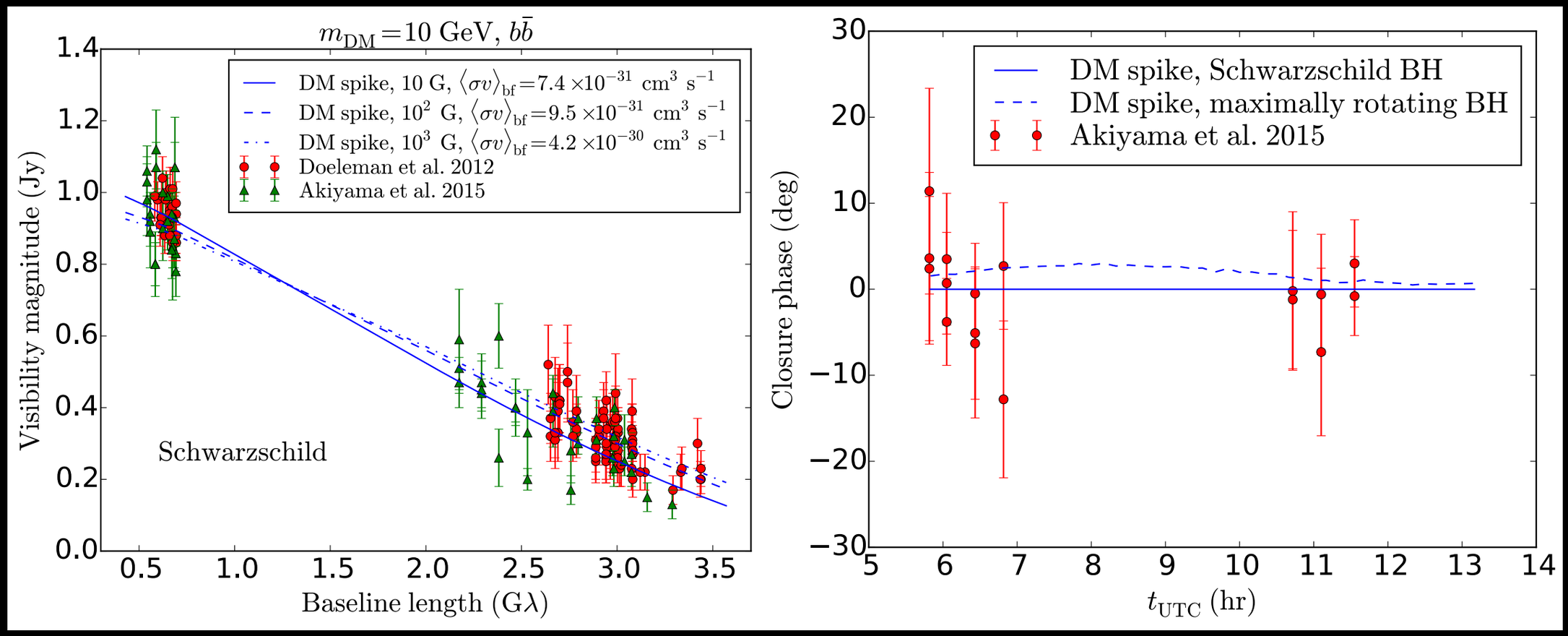
Black hole shadow and dark matter annihilation

- EHT can probe the vicinity of the BH at the center of M87
- Observe shadow of the SMBH in the DM annihilation-induced synchrotron signal at 230 GHz
- Ray-tracing scheme to model radiative transfer in the vicinity of the BH (Broderick 2006; Broderick & Loeb 2006)



Lacroix+ 2017

Current EHT data



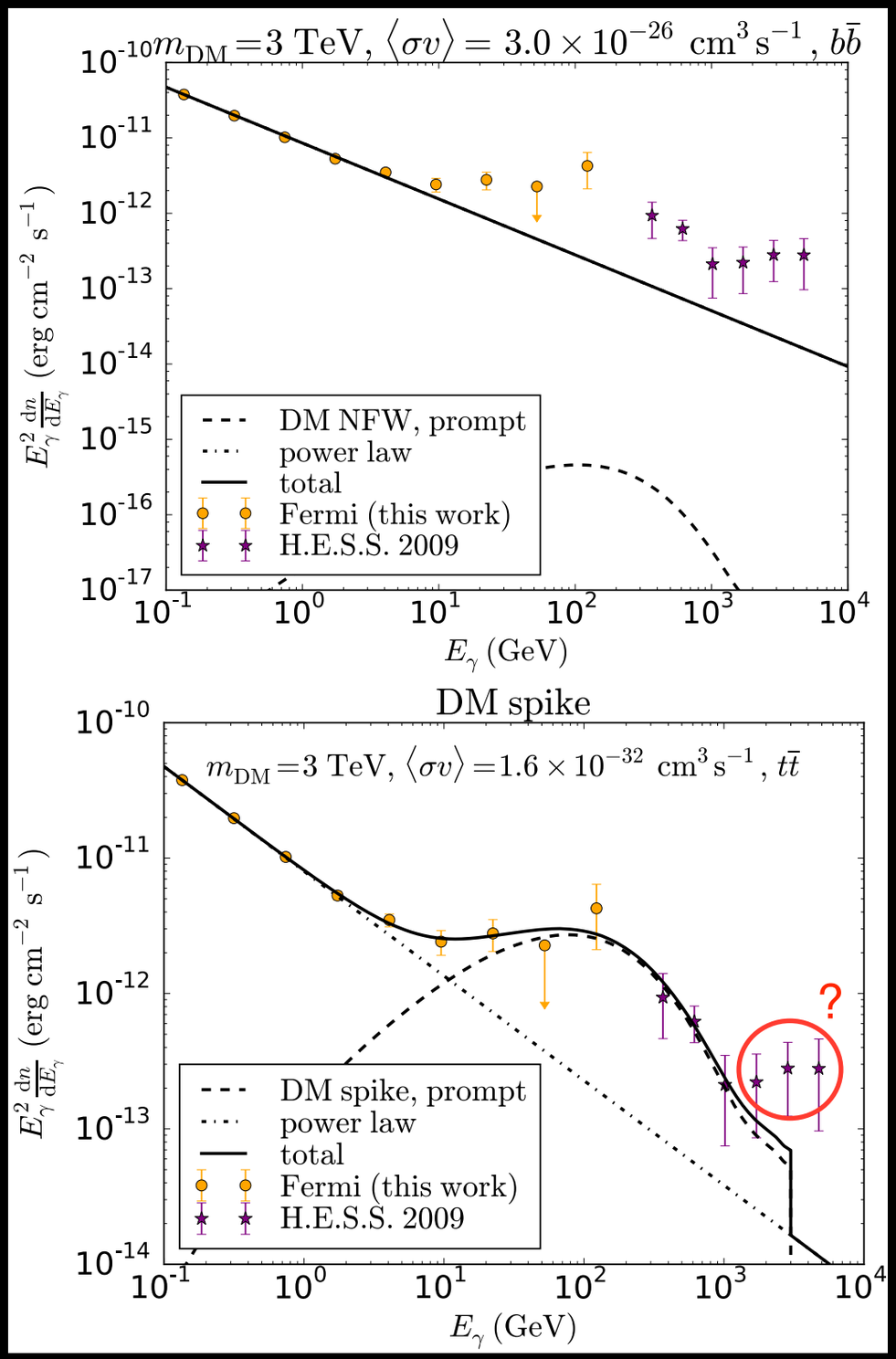
Lacroix+ 2017

- Interferometric observables: complex visibilities (amplitude + phase)
- Photon ring around BH shadow enhanced by DM spike
- Adequate fit to current EHT data with spike of annihilating DM
- Very stringent constraints on annihilation cross-section:
  a few $10^{-31}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$ at 10 GeV
- Degeneracy with astrophysical components

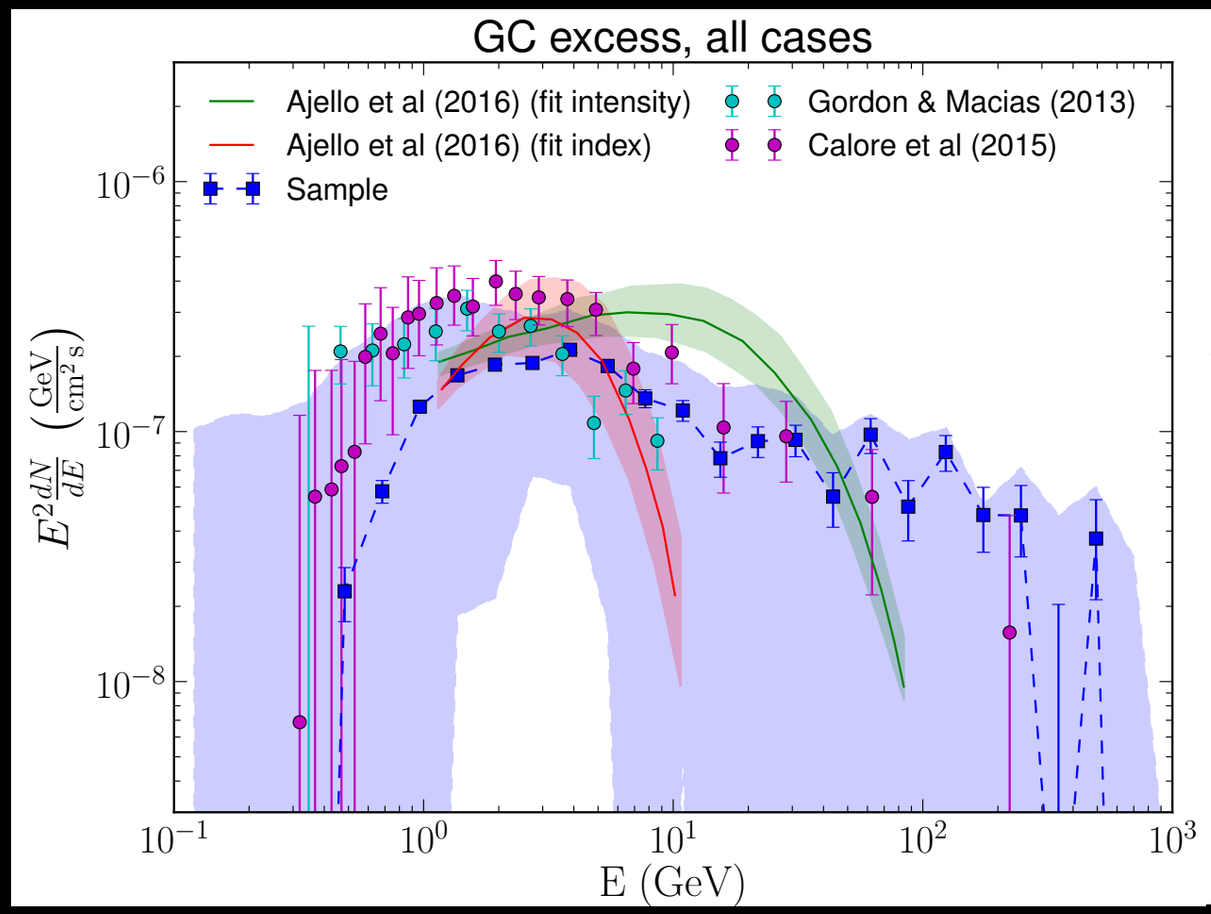
Origin of the spectral break in the gamma-ray emission from Cen A's core?

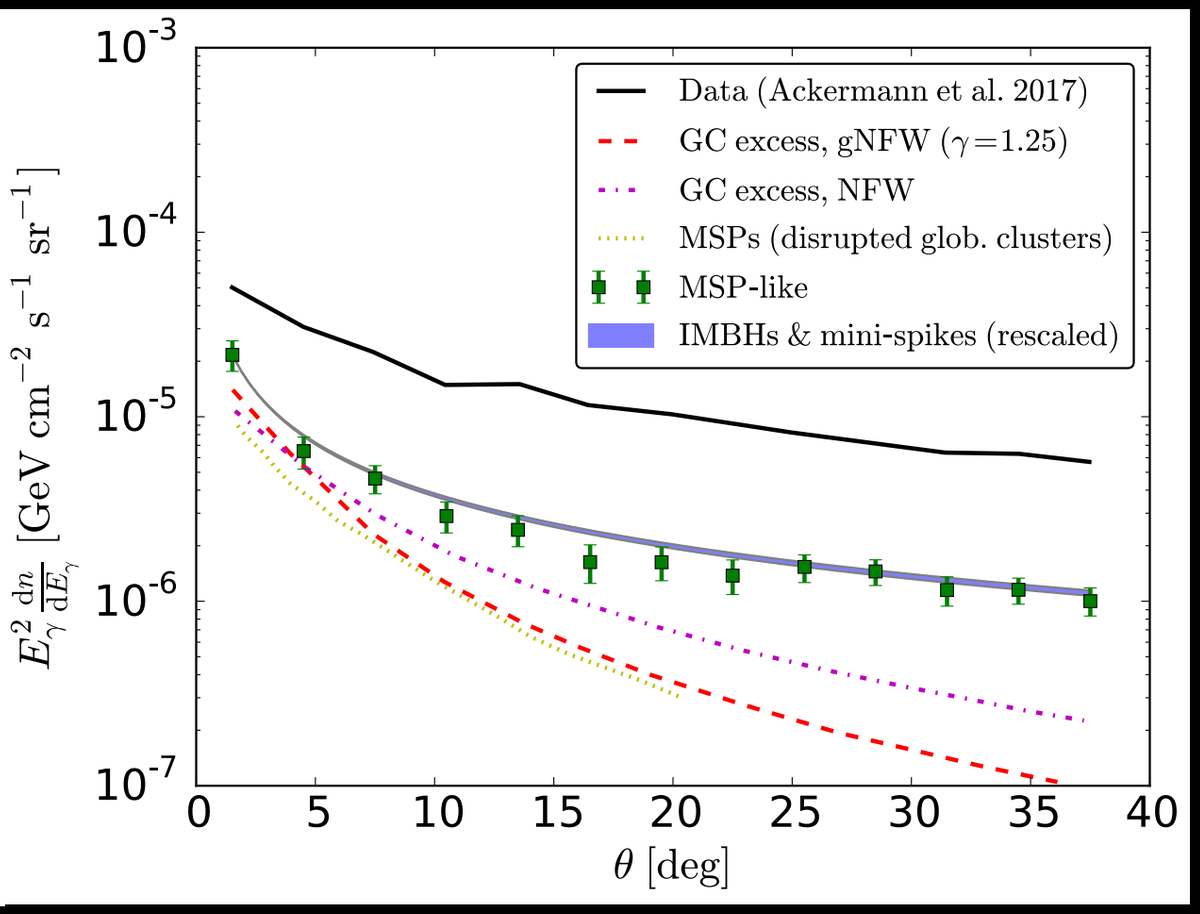
- Cen A closest known gamma-ray emitting radio galaxy
- Spectral hardening above ~ 2.6 GeV at 5σ (Brown+ 2017)
- No variability above the break
- Prompt emission from spike of TeV DM?

Brown+ 2017



Dark matter mini-spikes around intermediate mass black holes at the Galactic center?



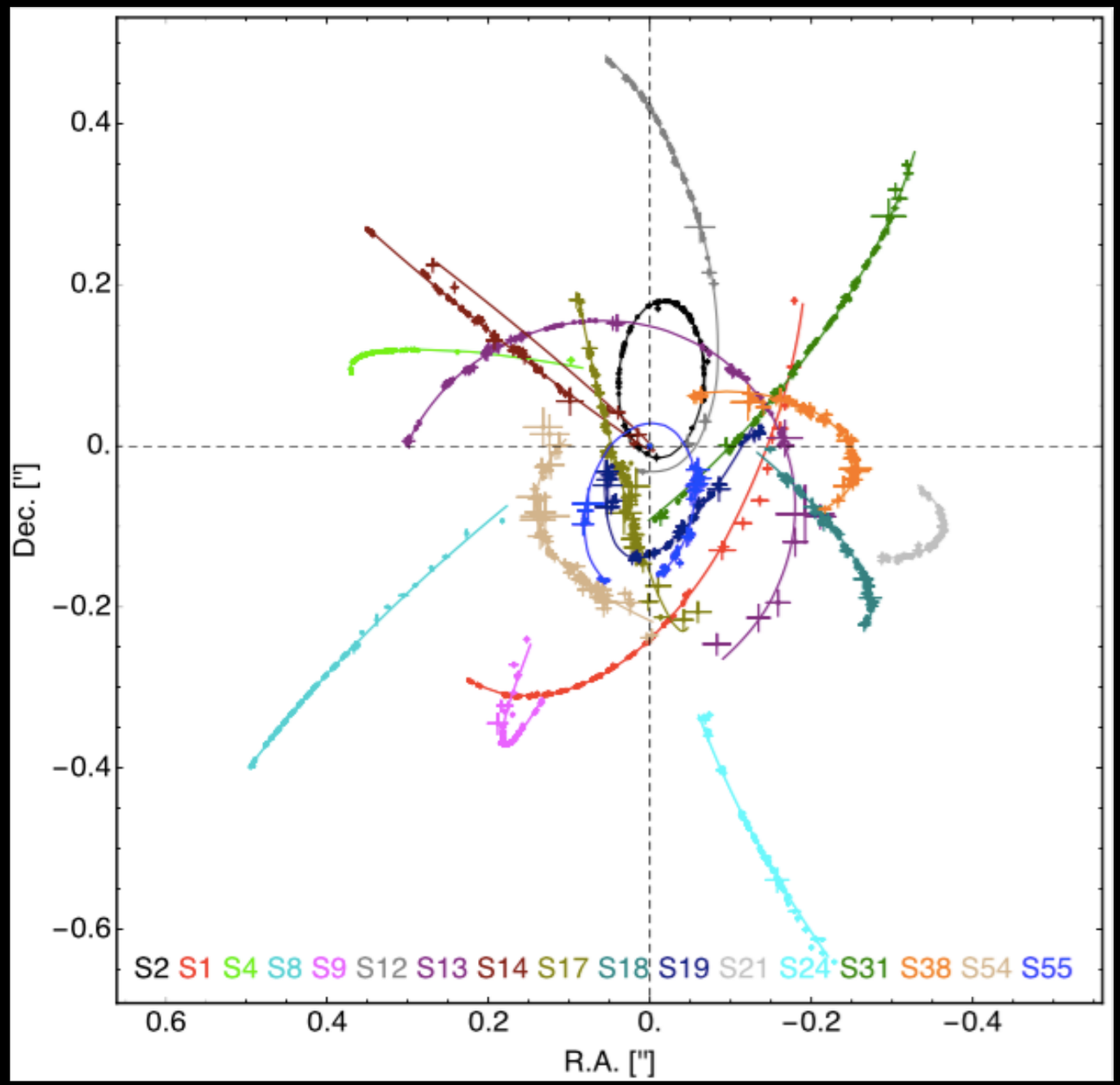


Ackermann+ 2017 Lacroix & Silk 2017

- Relic population of IMBHs (primordial or Pop III) at the GC from merging dwarfs?
- Favored by observation of IMBHs in dwarfs (Baldassare+ 2017) and massive globular clusters (e.g., Kiziltan+ 2017)
- Mini-spikes of annihilating DM around IMBHs can account for GC ''excess'': spectrum + spatial morphology (Lacroix & Silk 2017)

Constraining a dark matter spike at the Galactic center with stellar orbits

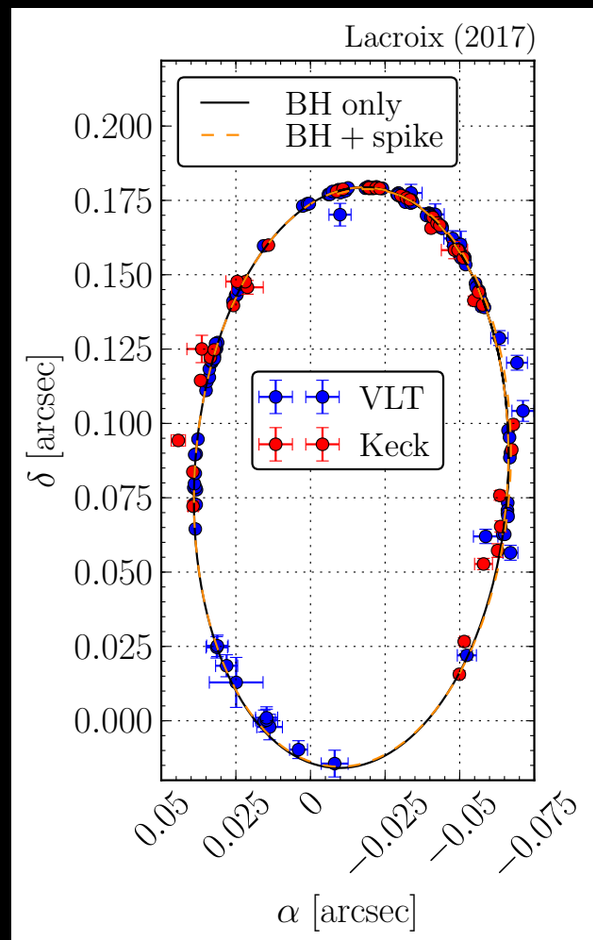
- No direct evidence in favor or against DM spike at the GC
- Direct dynamical probes needed but small scales
- Quantify precession of the orbits of S stars from DM spike
- S2 star: ~1.5 orbits
- 25 years of data (Gillessen+ 2017, Boehle+ 2016)

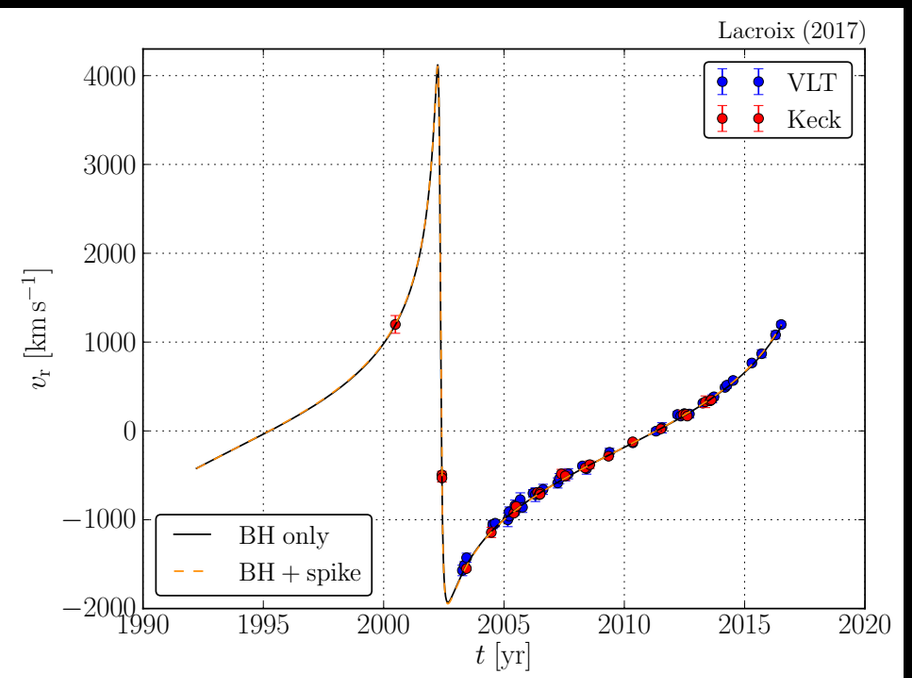


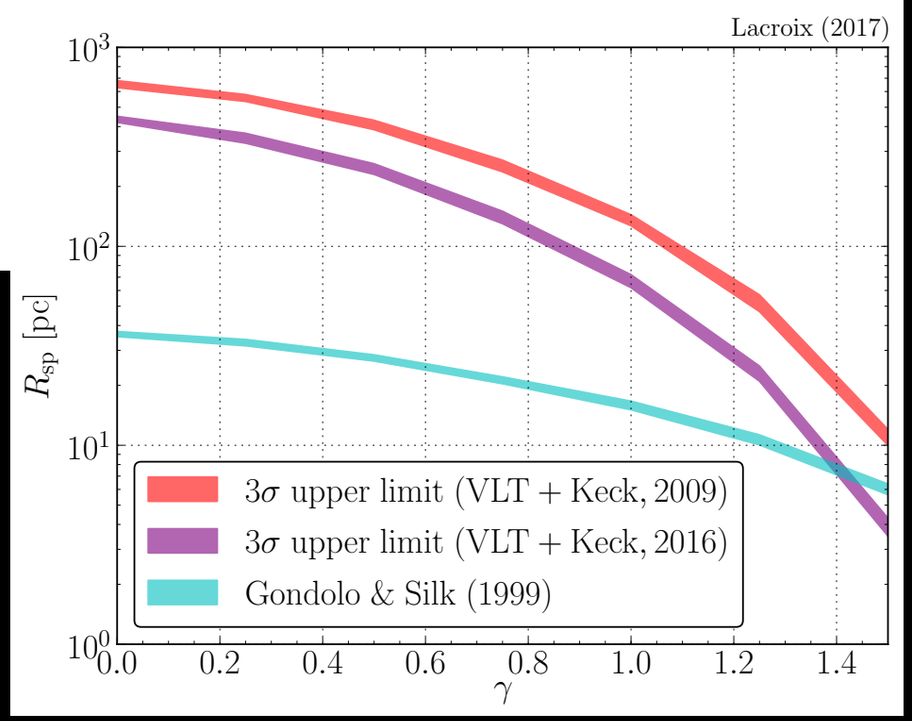
Gillessen+ 2017

Direct dynamical constraints from orbit of S2

- Measure sensitivity of current data to deviation from BH-only orbit
- Upper limit on extended mass ~1% central BH mass (Gillessen+ 2009, 2016)
- First direct constraints on spike radius at pc scales (Lacroix 2017, in prep)







Conclusion

- Very strong signatures of the clustering of annihilating DM particles around SMBHs or IMBHs
- DM spikes probe very weakly annihilating DM
- Dedicated probes can break the degeneracy between annihilation cross section and inner DM profile
- Event Horizon Telescope: very strong new independent constraints (spatial morphology at very small scales)
- Direct constraints on parsec-scale DM profile at the GC from stellar orbits

Thank you for your attention!