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Searching for Dark Matter with (a) GECCO

ICRC 2021

Wednesday July 21, 2021

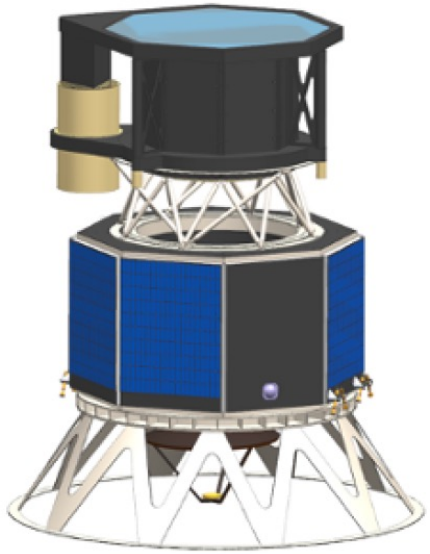
GECCO @ICRC21

- **Elena Orlando** (INFN/Univ. of Trieste & Stanford Univ.)
  "*The future look at the Galaxy with the Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO)*" 12. July 2021 - 18:00

- **Alex Moiseev** (UMCP and CRESST/NASA/GSFC)
  "*New Mission Concept: Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO)*" 20. July 2021 - 18:00

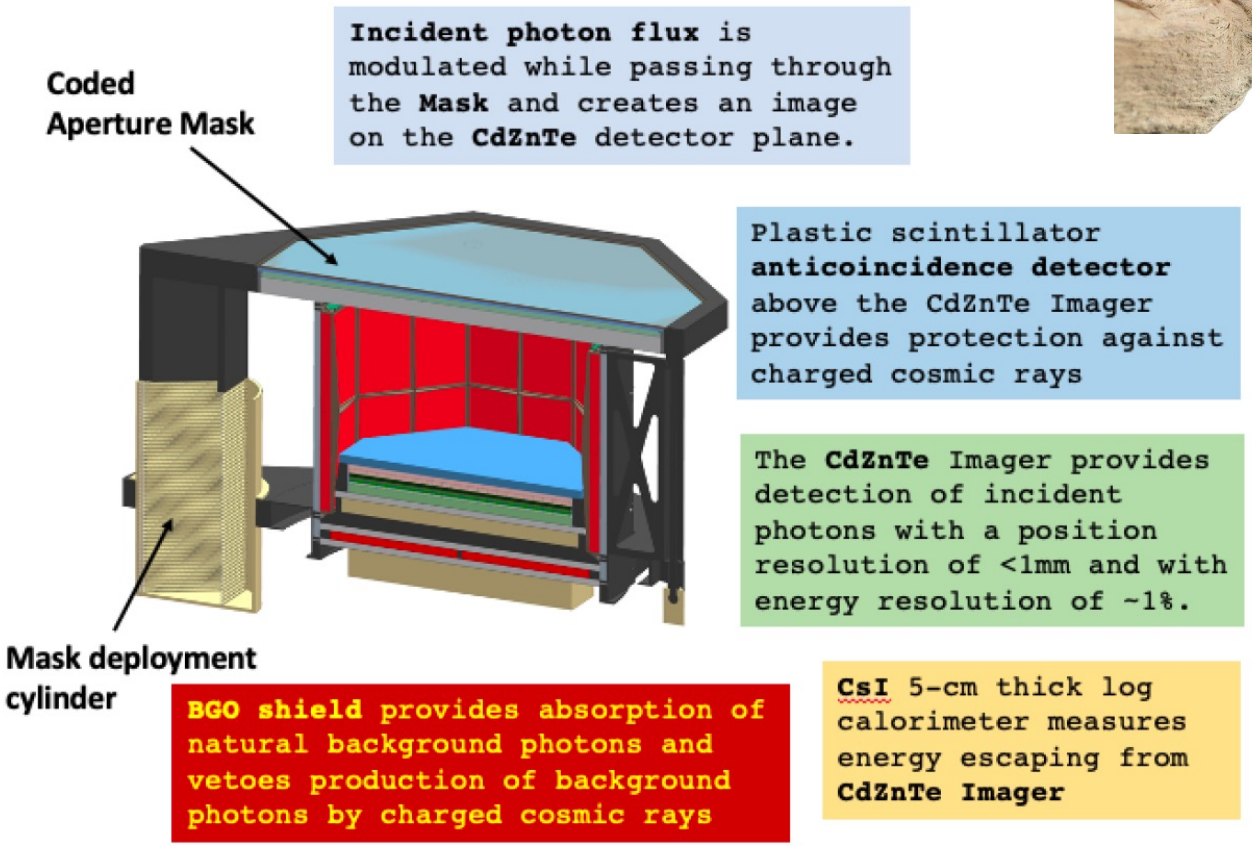
- **Aleksey Bolotnikov** (Brookhaven National Laboratory)
  "*High-resolution Imaging Calorimeter based on position-sensitive virtual Frisch-grid CdZnTe detectors for gamma-ray space instruments*" 16. July 2021 - 18:00

...for context: **Andreas Zoglauer** (University of California at Berkeley) "*Highlight: Future Missions for MeV Gamma-Ray Astrophysics*" 15. July 2021 - 16:00



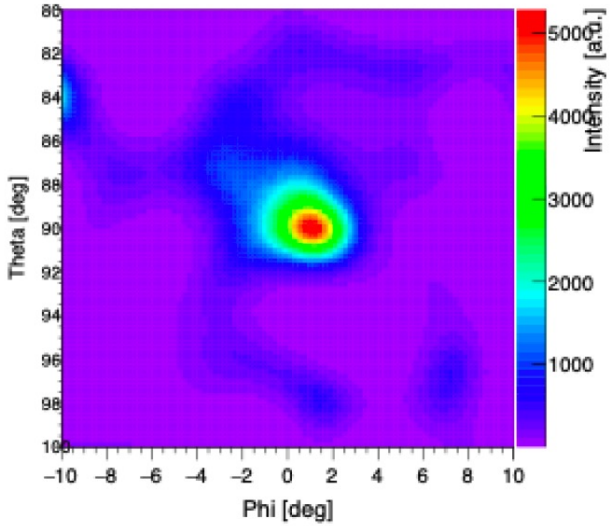
GECCO with Mask in stowed position

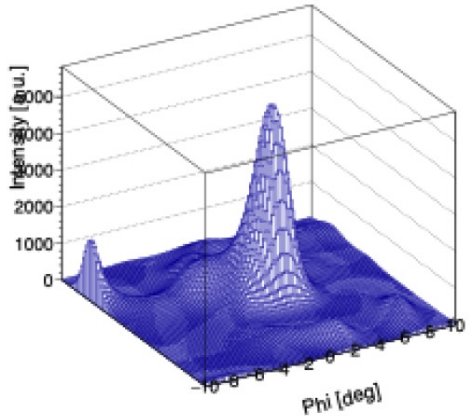
GECCO with Mask in deployed position



GECCO, cutaway

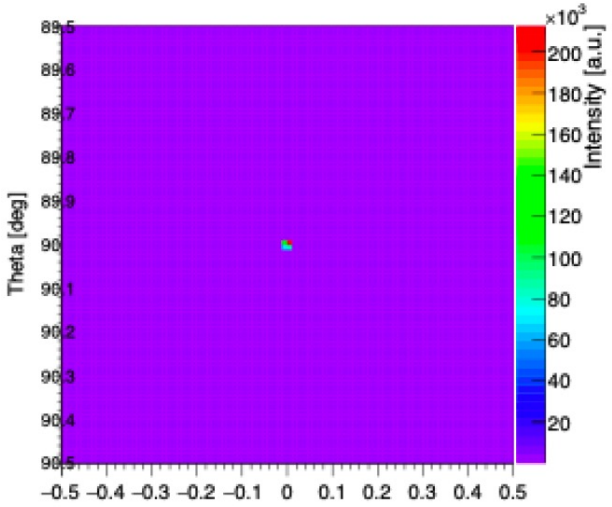
Compton analysis (FoV ~ 60º)

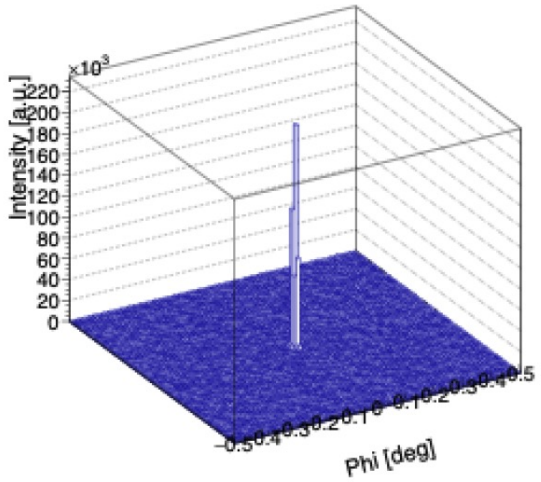




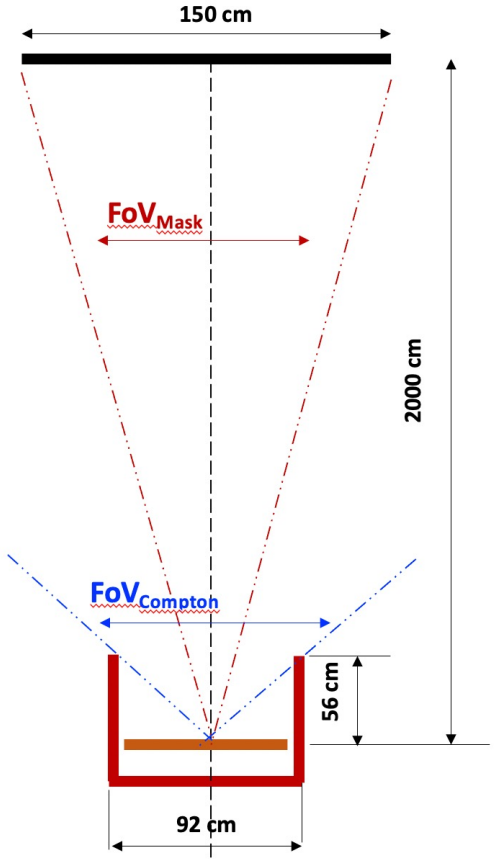
angular resolution: 4º-8º

Mask analysis (FoV ~ 4º)

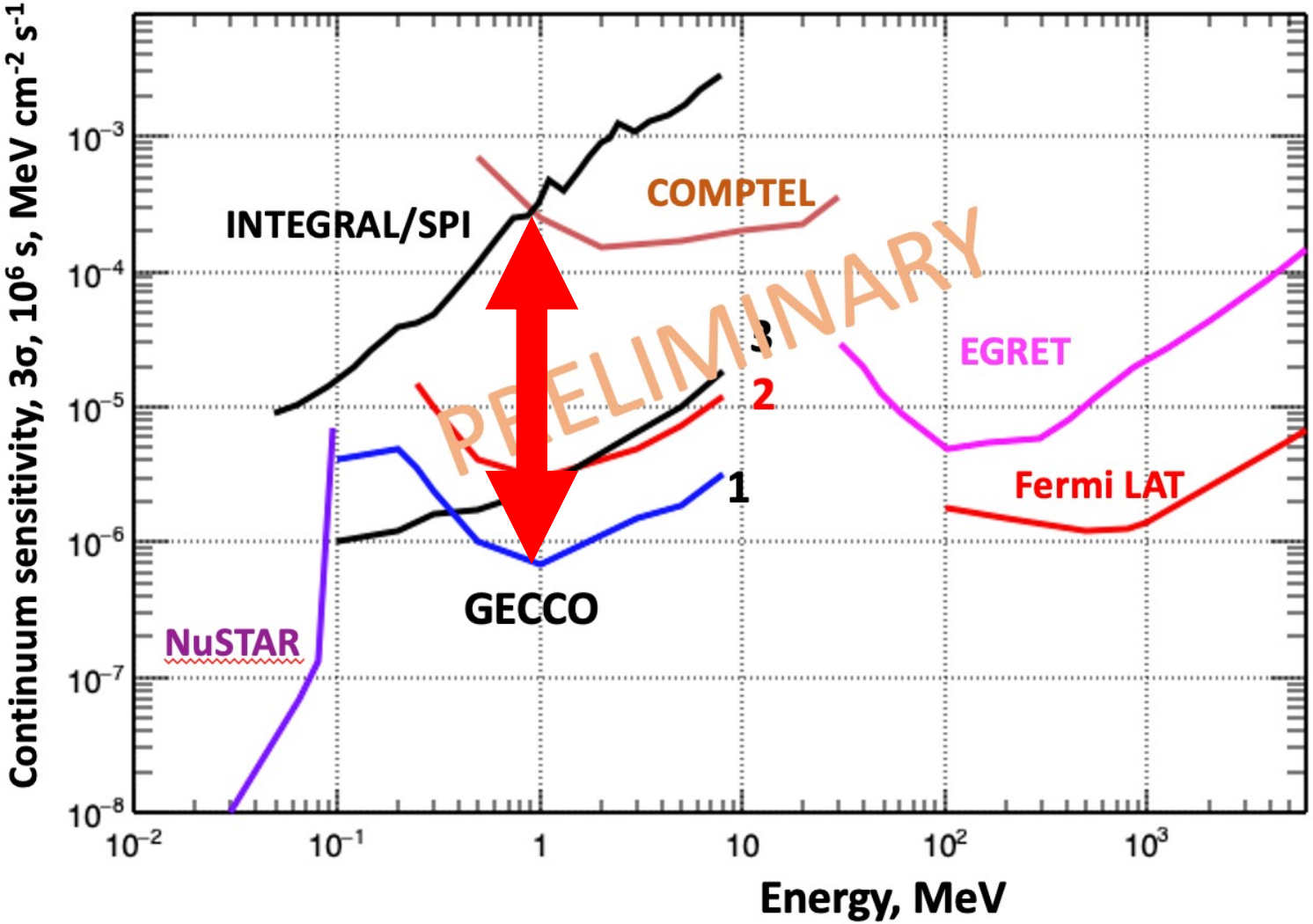




angular resolution: 0.5’



GECCO continuum sensitivity



1 - Mask data, deployed, total

2 - Compton data, deployed or stowed

3 - Mask data classical, stowed

~ 2.5 orders of magnitude improvement @ 1 MeV

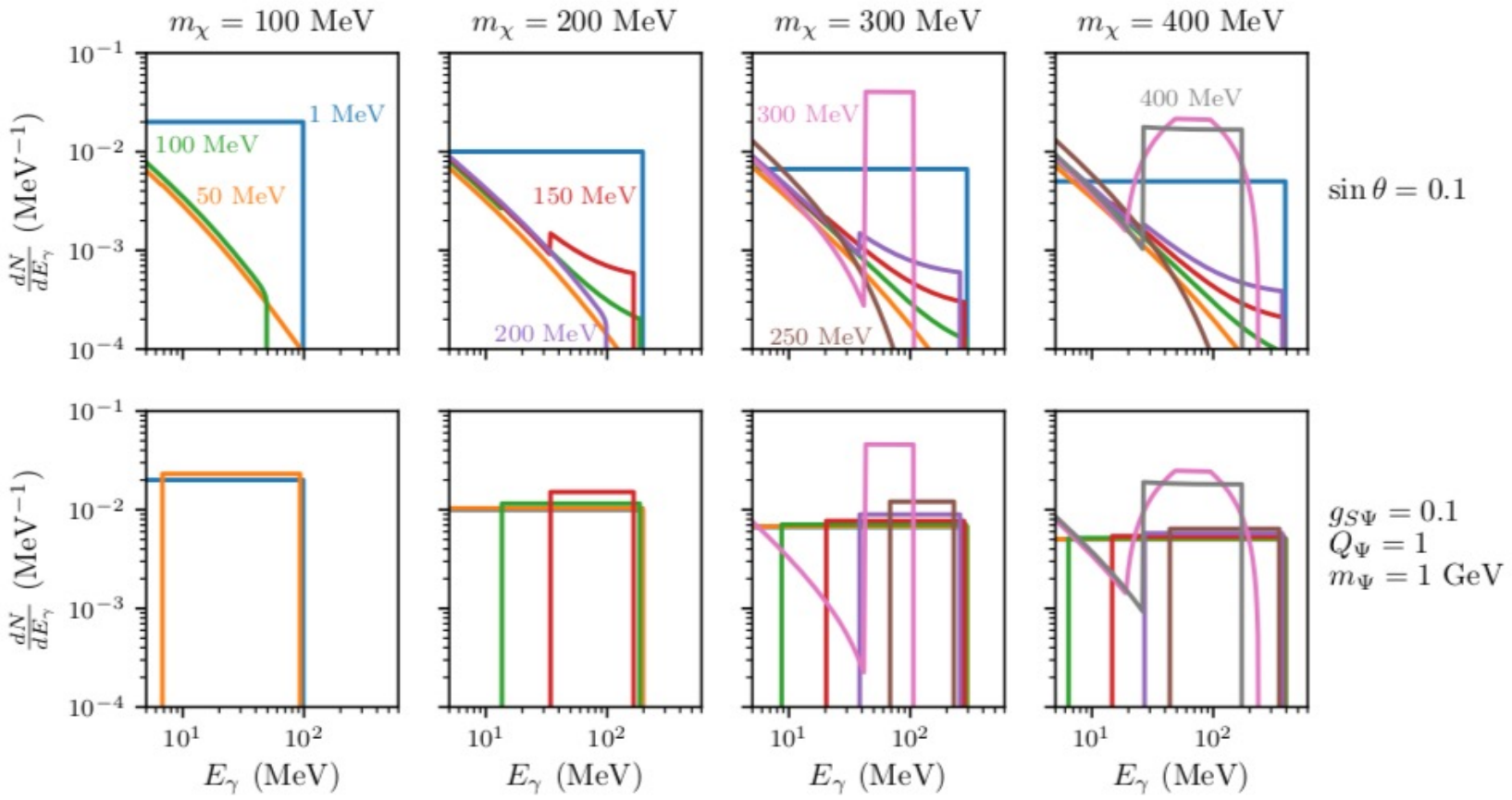
- For various reasons, the **sub-GeV** and **sub-MeV** range is getting increasing attention in the search for **particle Dark Matter**

- A broad range of **experimental approaches** have been proposed and are under investigation to target sub-GeV and sub-MeV dark matter particles with **direct detection**

- Indirect detection is, on the other hand, **very limited** in that energy range

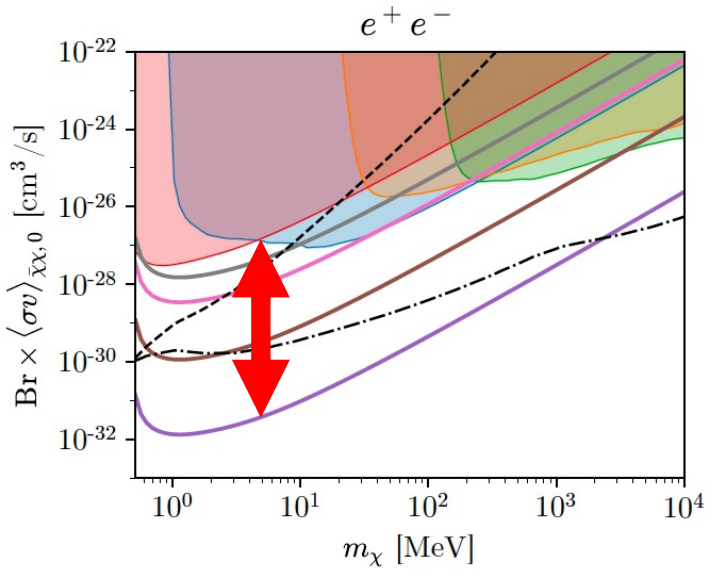
- The need for a **multipronged approach** in the search for dark matter and new physics warrants consideration of new observational capabilities in the sub-GeV and sub-MeV gamma-ray range

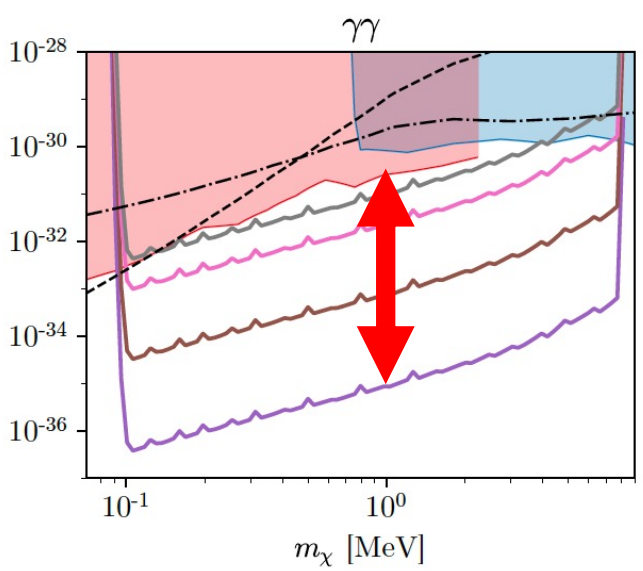
- In addition, that range is key for existing possible signals of new physics, such as the **511 keV line**

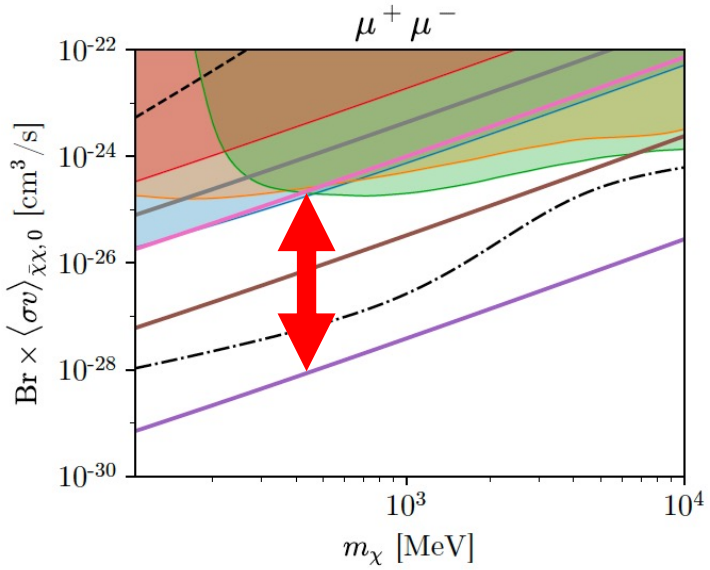


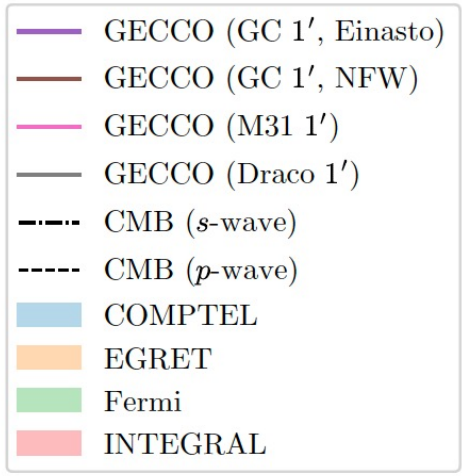
- Depending on the mediator and dark matter particle mass, a variety of possible **spectral signatures**, often **unmistakable from astrophysics**, are possible

A. Coogan, L. Morrison and S. Profumo, ``*Hazma: A Python Toolkit for Studying Indirect Detection of Sub-GeV Dark Matter*'' arXiv:1907.11846 [hep-ph], JCAP 01 (2020) 056



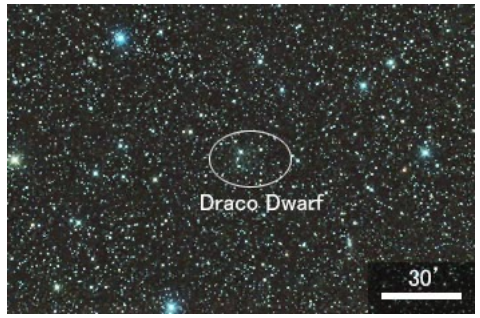






Galactic Center

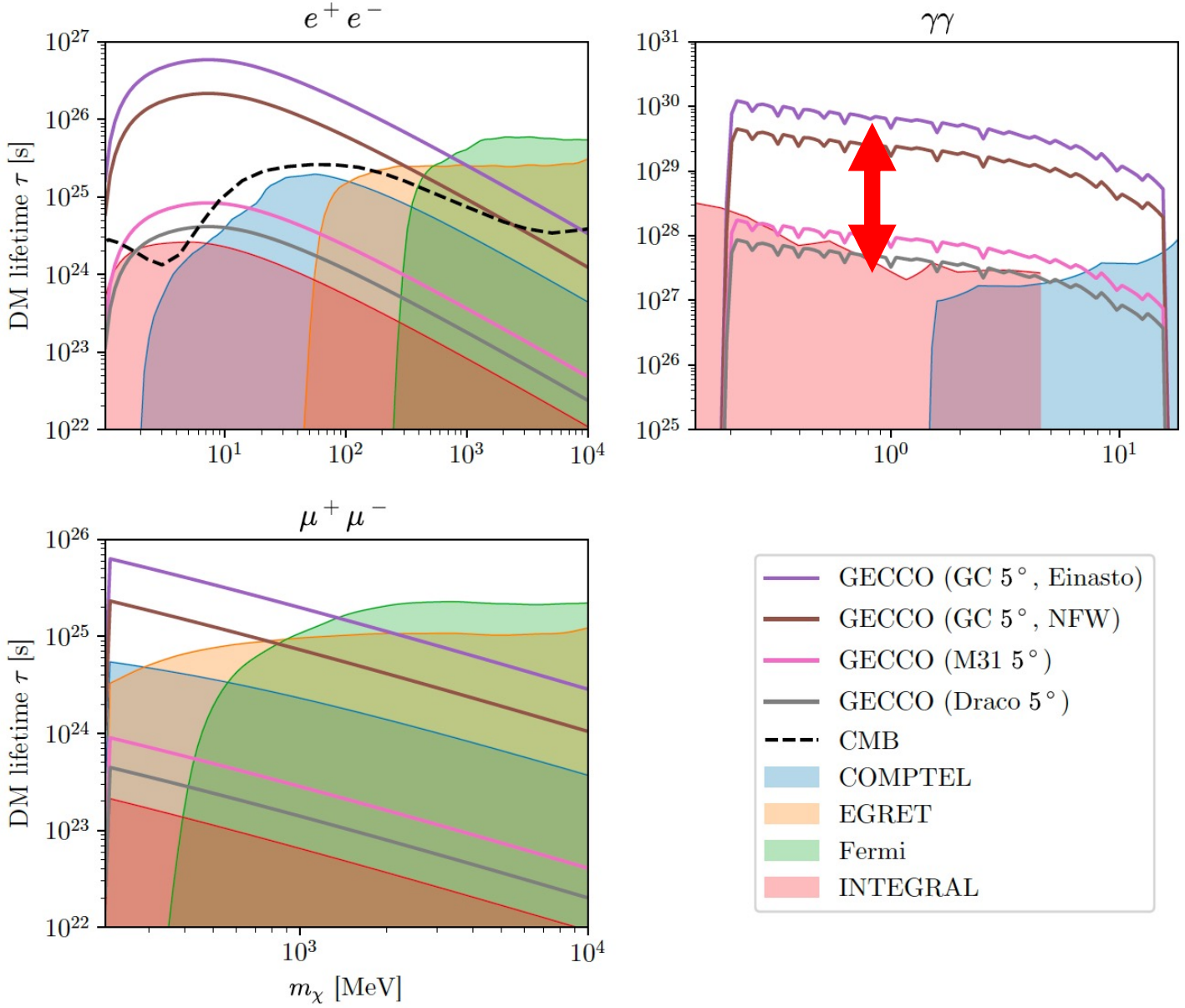
M31 (Andromeda)



Draco

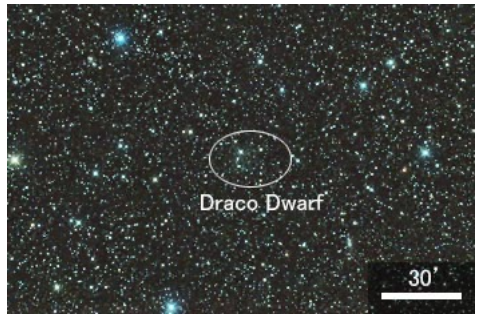
Predictions for Dark Matter **annihilation** into a **single** final state (Galactic Center, M31, Draco)

A. Coogan, A. Moiseev, L. Morrison and S. Profumo, ``Hunting for Dark Matter and New Physics with (a) GECCO'' arXiv:2101.10370



Galactic Center

M31 (Andromeda)

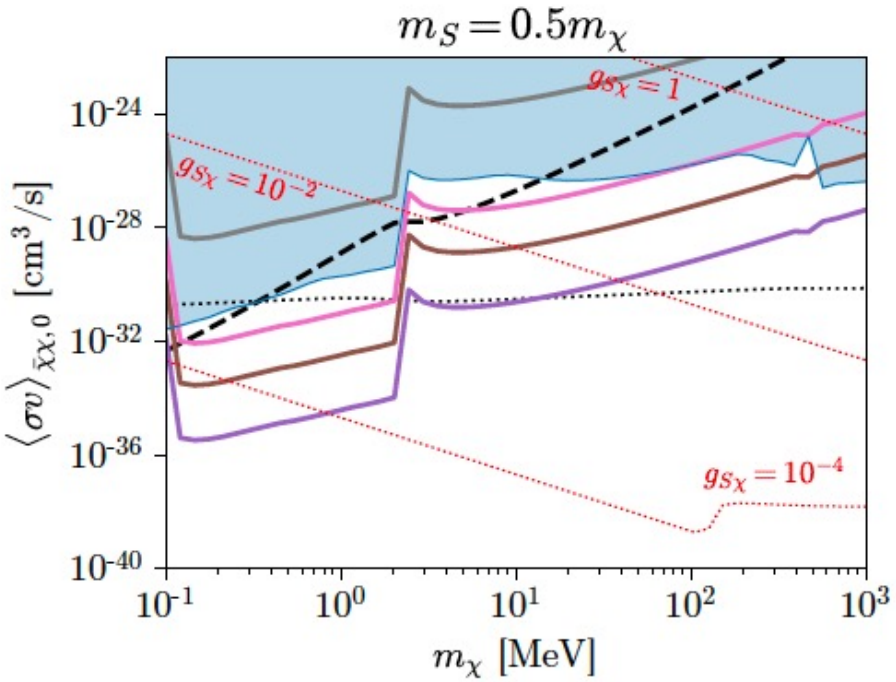


Draco

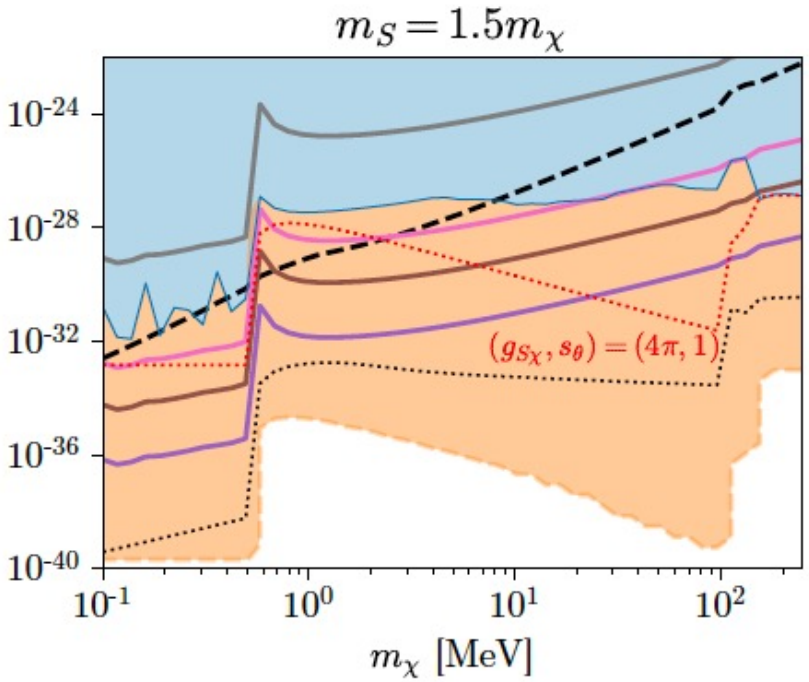
Predictions for Dark Matter **decay** into a single final state

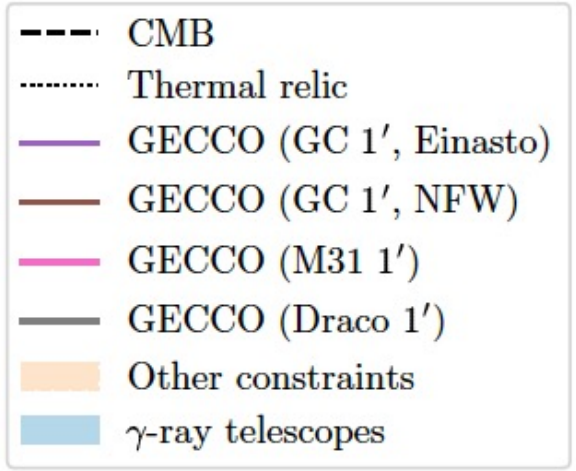
A. Coogan, A. Moiseev, L. Morrison and S. Profumo, ``Hunting for Dark Matter and New Physics with (a) GECCO'' arXiv:2101.10370

Annihilation to mediators

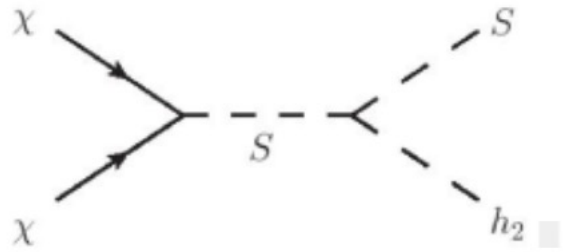


Annihilation to SM particles

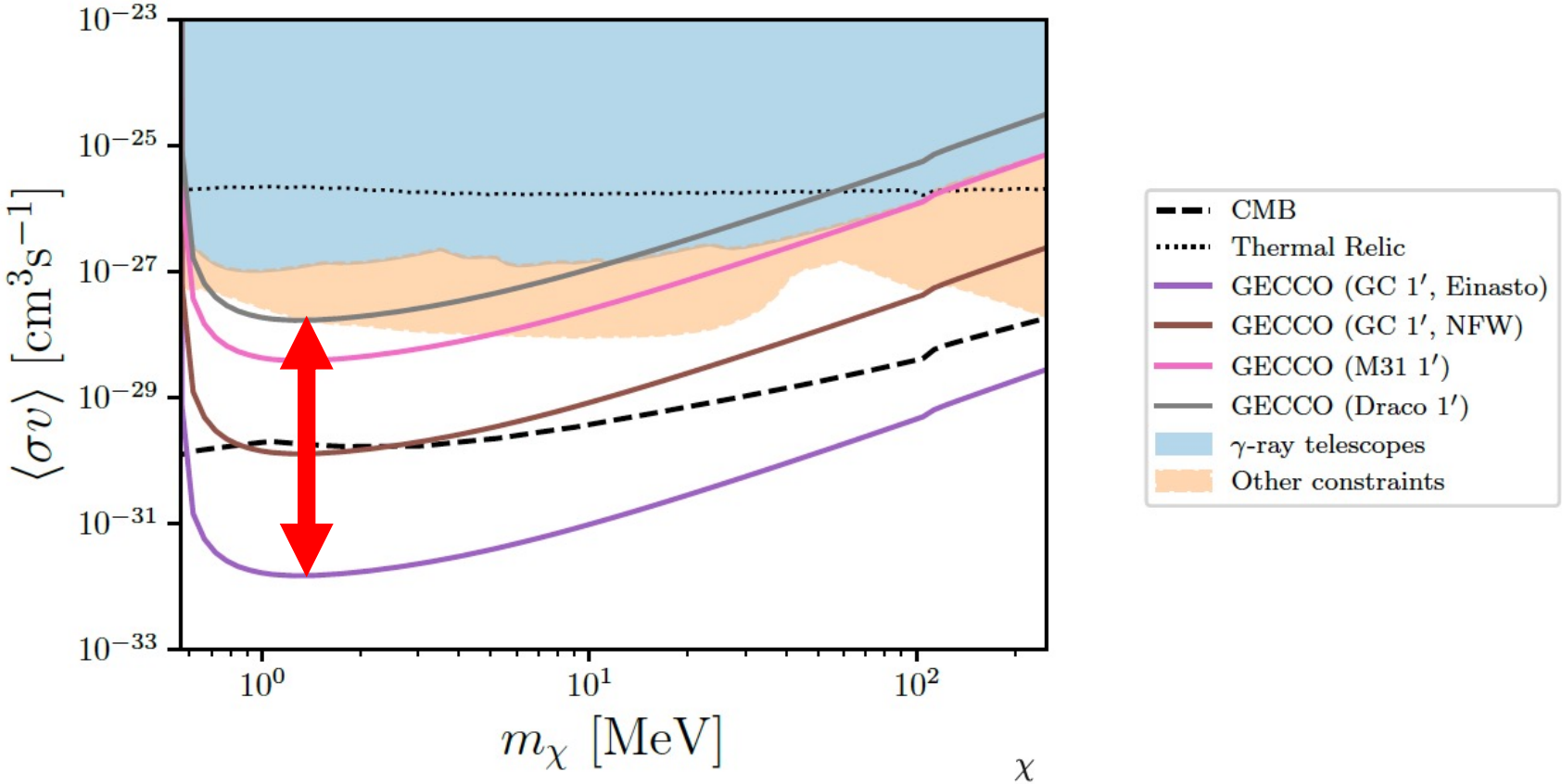




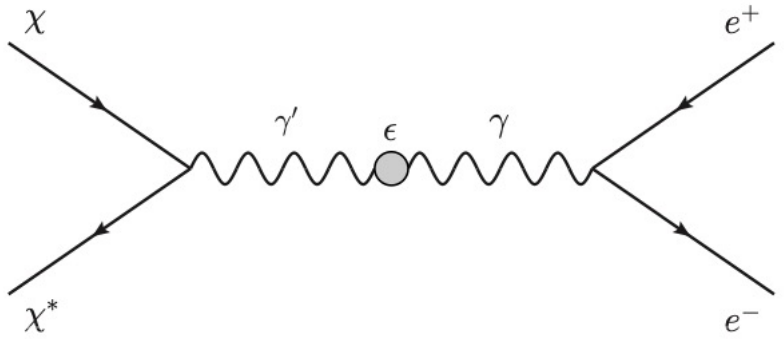
Scalar mediator simplified model



A. Coogan, A. Moiseev, L. Morrison and S. Profumo, ``Hunting for Dark Matter and New Physics with (a) GECCO'' arXiv:2101.10370



Vector mediator simplified model



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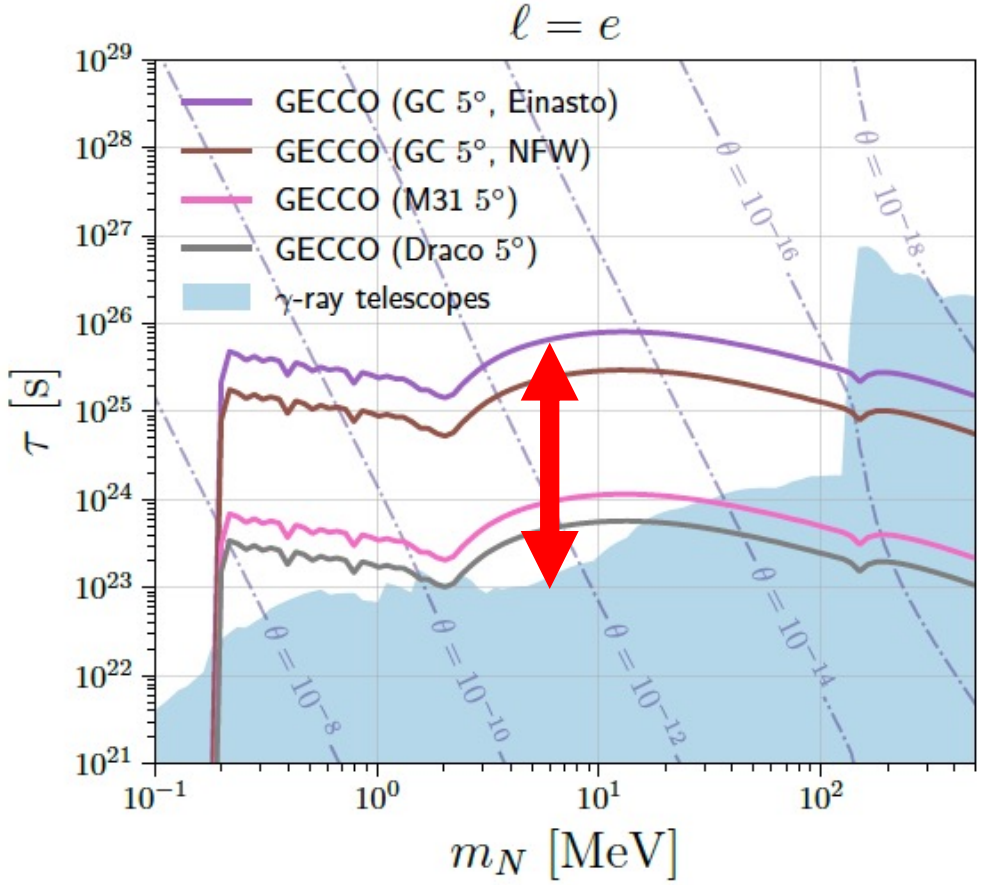
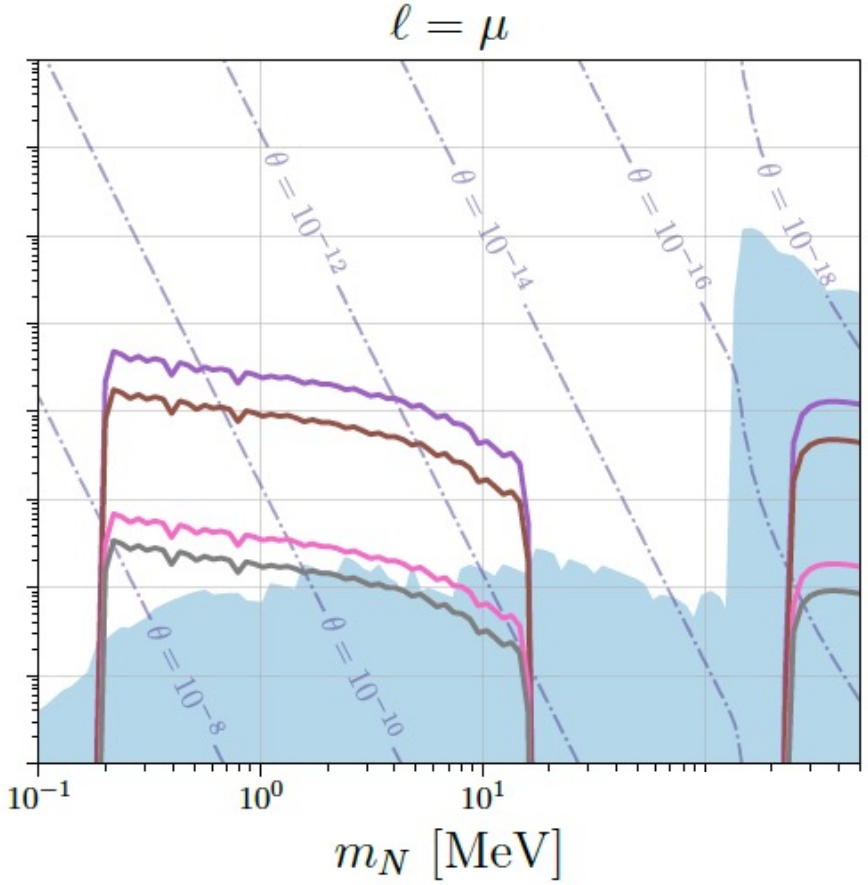
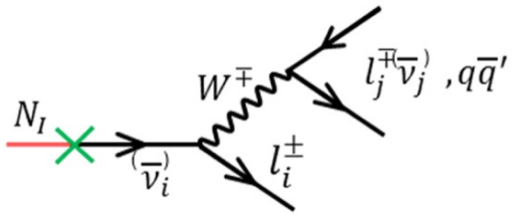
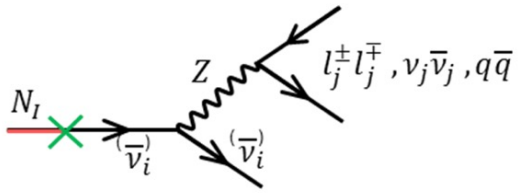


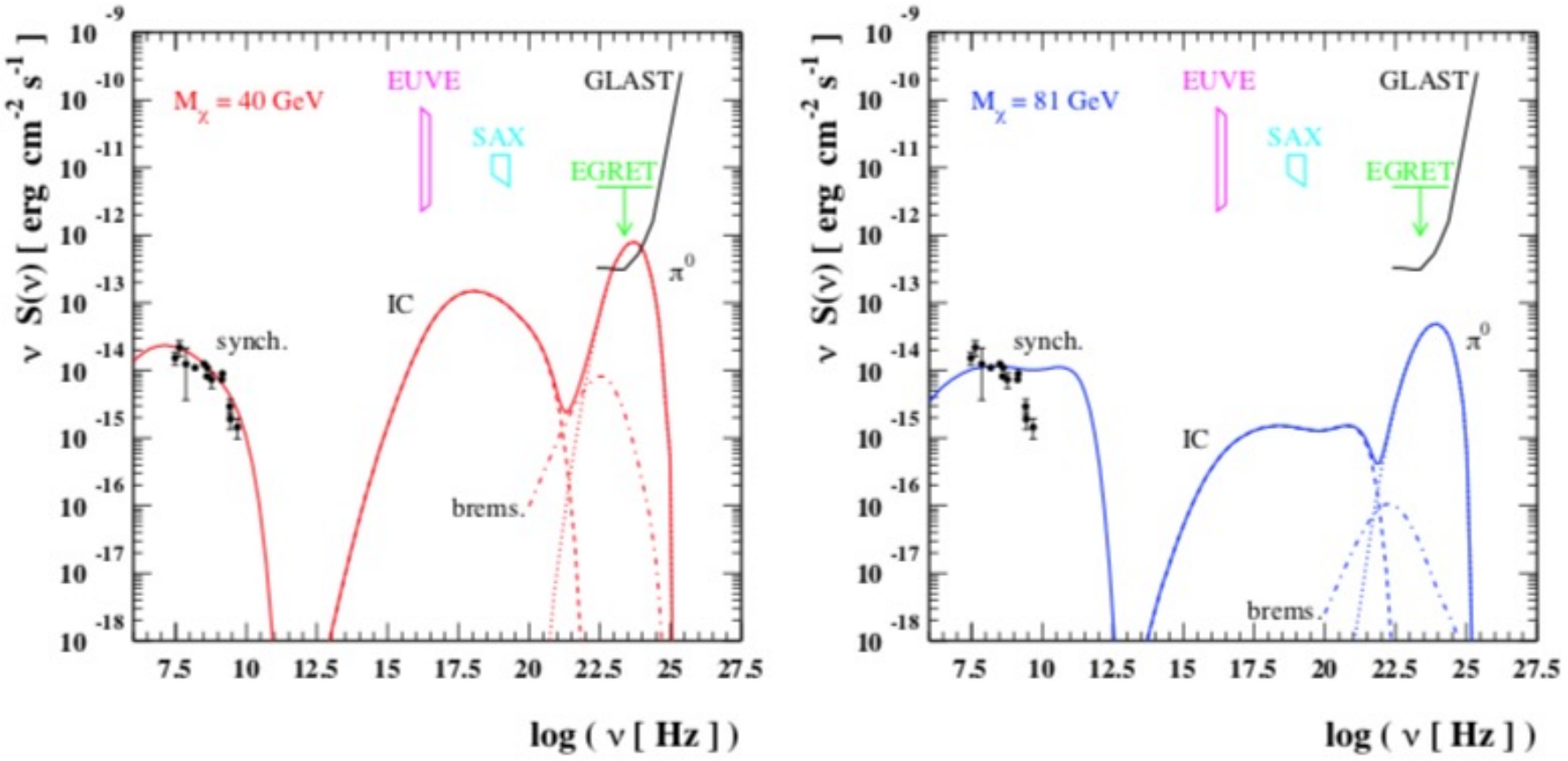






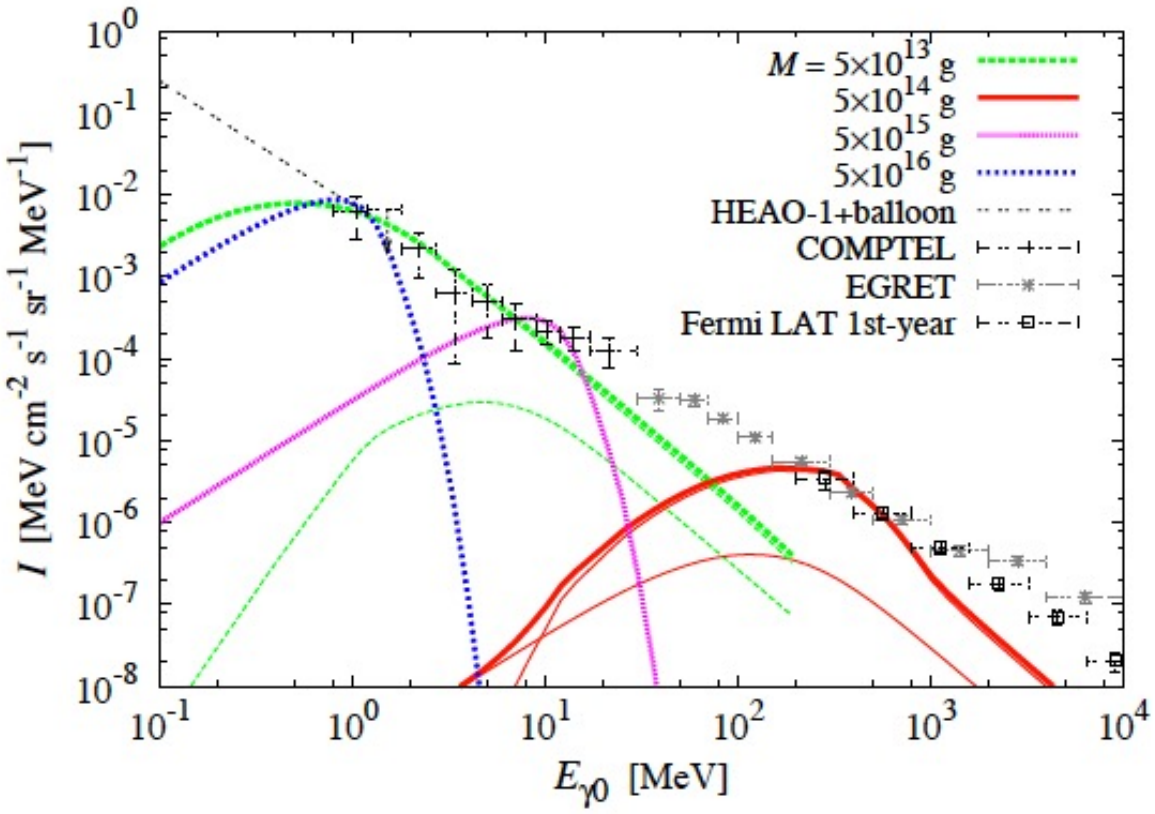
Right-handed **neutrino** decay

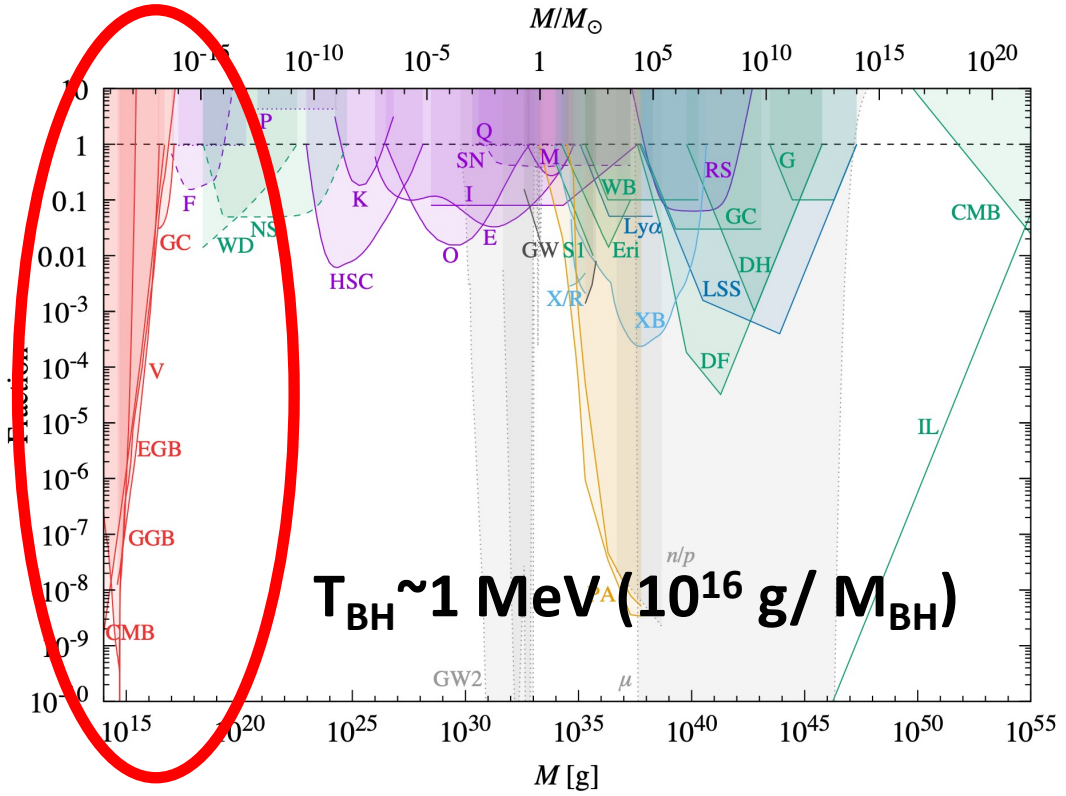
A. Coogan, A. Moiseev, L. Morrison and S. Profumo, ``Hunting for Dark Matter and New Physics with (a) GECCO'' arXiv:2101.10370



- Even for **heavier** candidates (e.g. WIMPs), the secondary emission from inverse Compton and/or synchrotron makes the MeV and sub-MeV range critical to disentangle a particle dark matter signal!

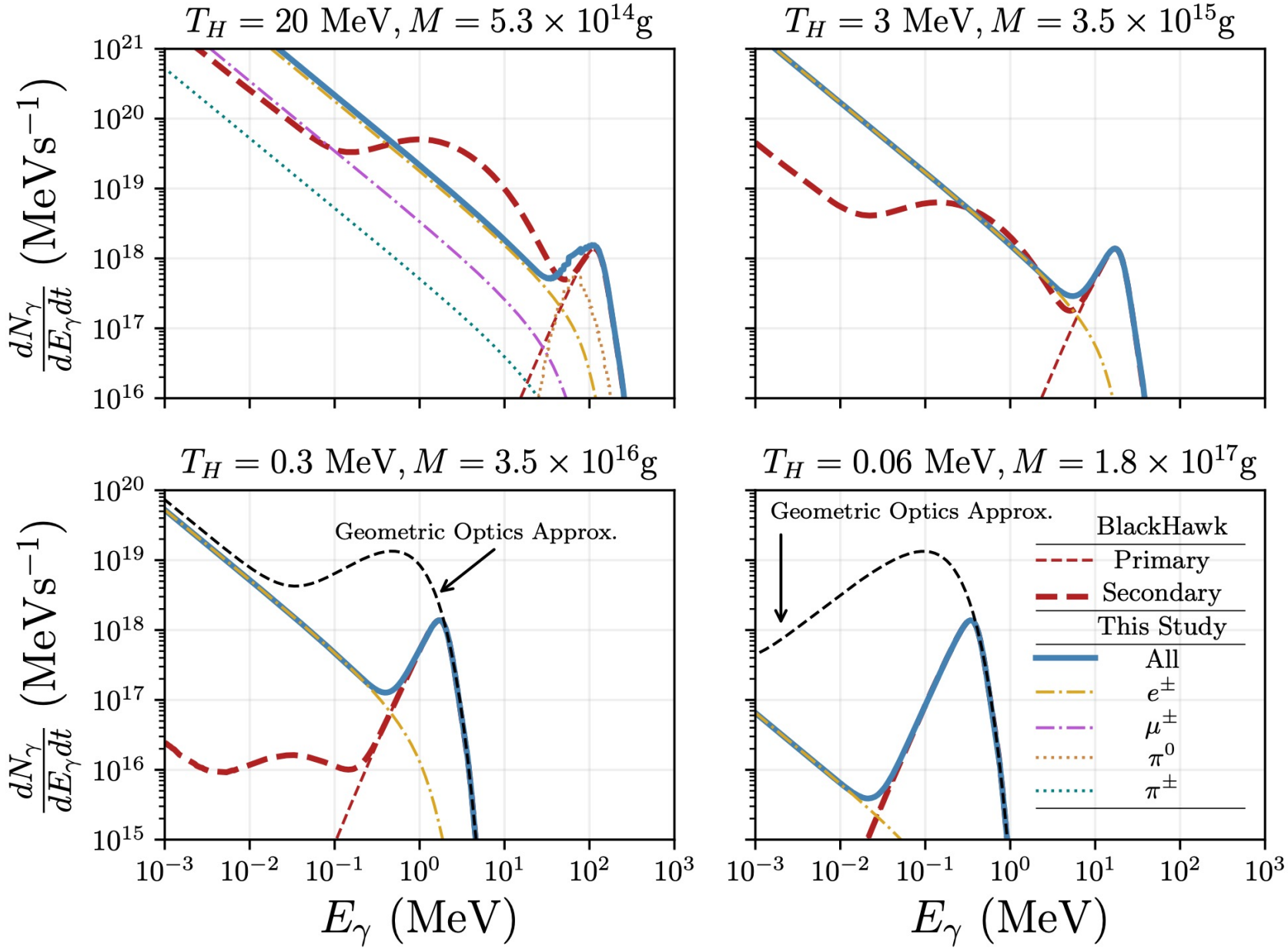
S. Colafrancesco, S. Profumo and P. Ullio, ``*Multi-frequency analysis of neutralino dark matter annihilations in the Coma cluster*'' Astron. Astrophys. **455**, 21 (2006)



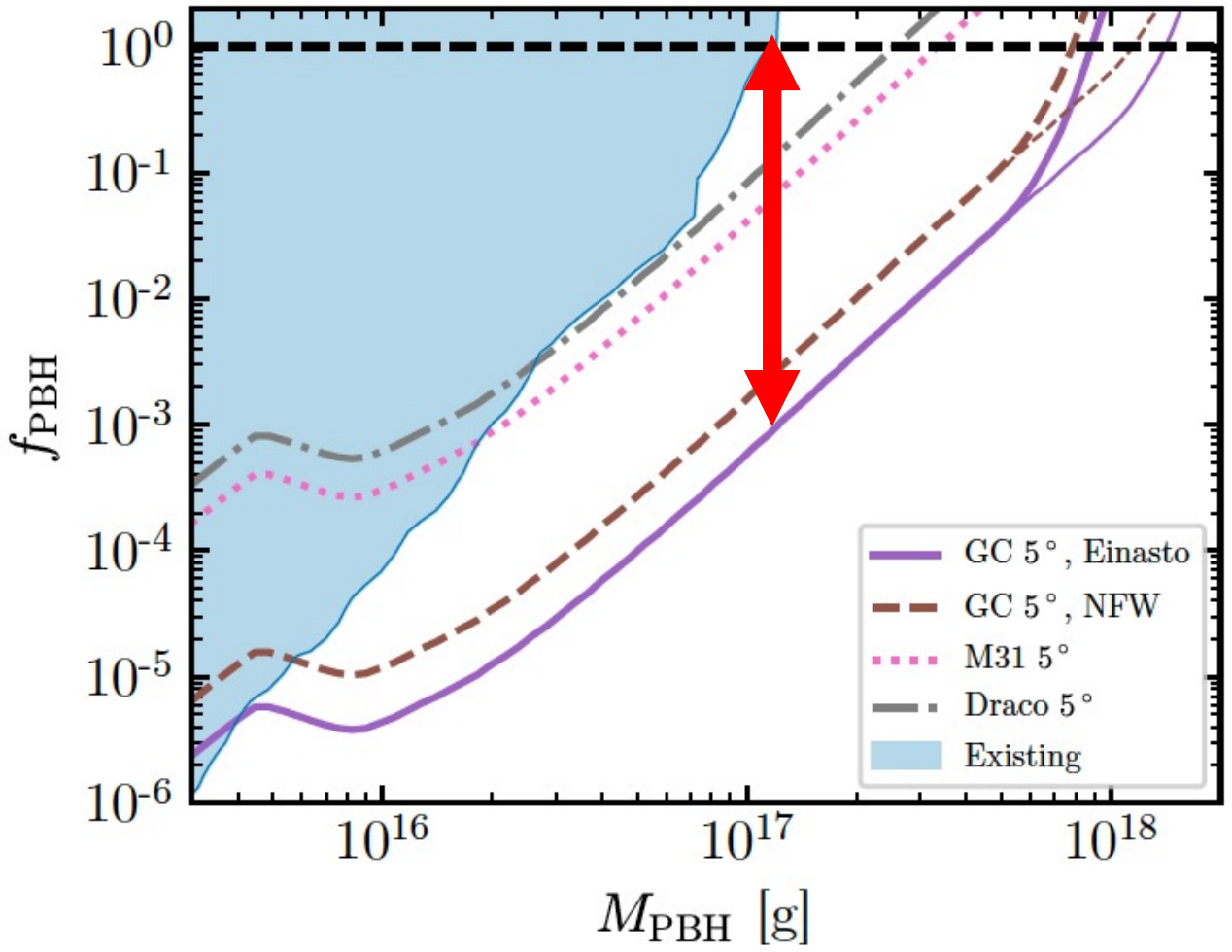


- Light Primordial Black Holes, on which much attention has been growing after the LIGO detections, can only be directly constrained with **new capabilities in the MeV**
- Currently studying targeted observations of nearby dSph or galaxy clusters that would offer **GECCO** a PBH decay **discovery potential**!

N. Prantzos, ``*Nucleosynthesis and gamma-ray lines*'' PoS INTEGRAL **2010**, 018 (2010)



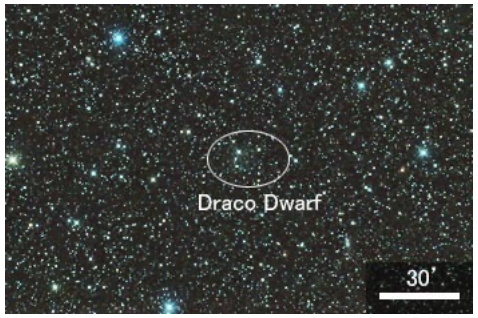
A. Coogan, L. Morrison and S. Profumo, ``Direct Detection of Hawking Radiation from Asteroid-Mass Primordial Black Holes'' arXiv: 2010.04797 [astro-ph.CO], *Phys.Rev.Lett.* 126 (2021) 17, 171101



GECCO potential to discover decaying Primordial Black Hole Dark Matter

Galactic Center

M31 (Andromeda)



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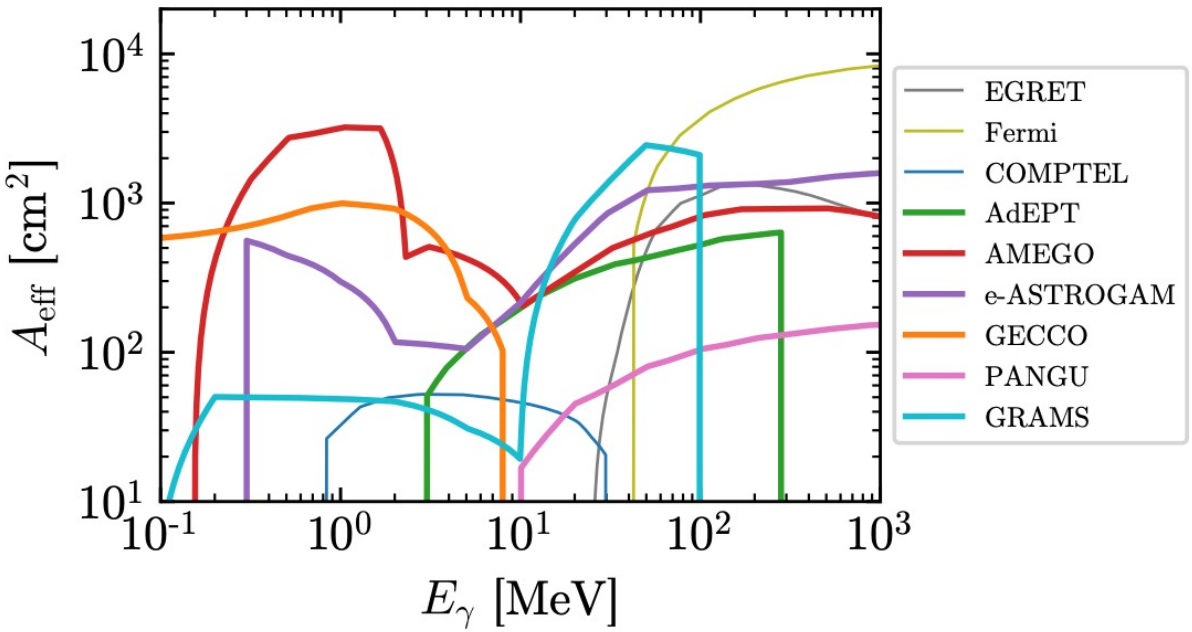

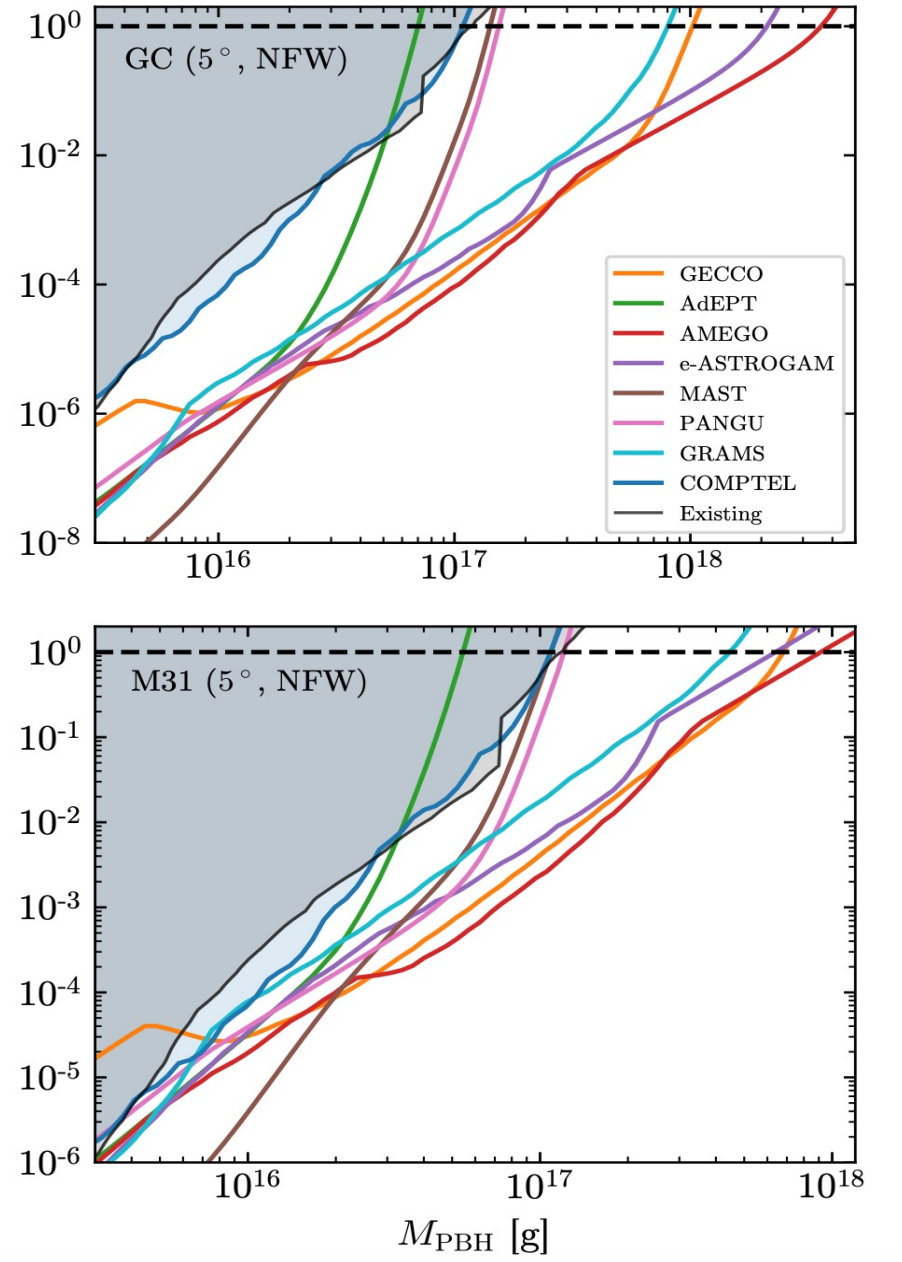

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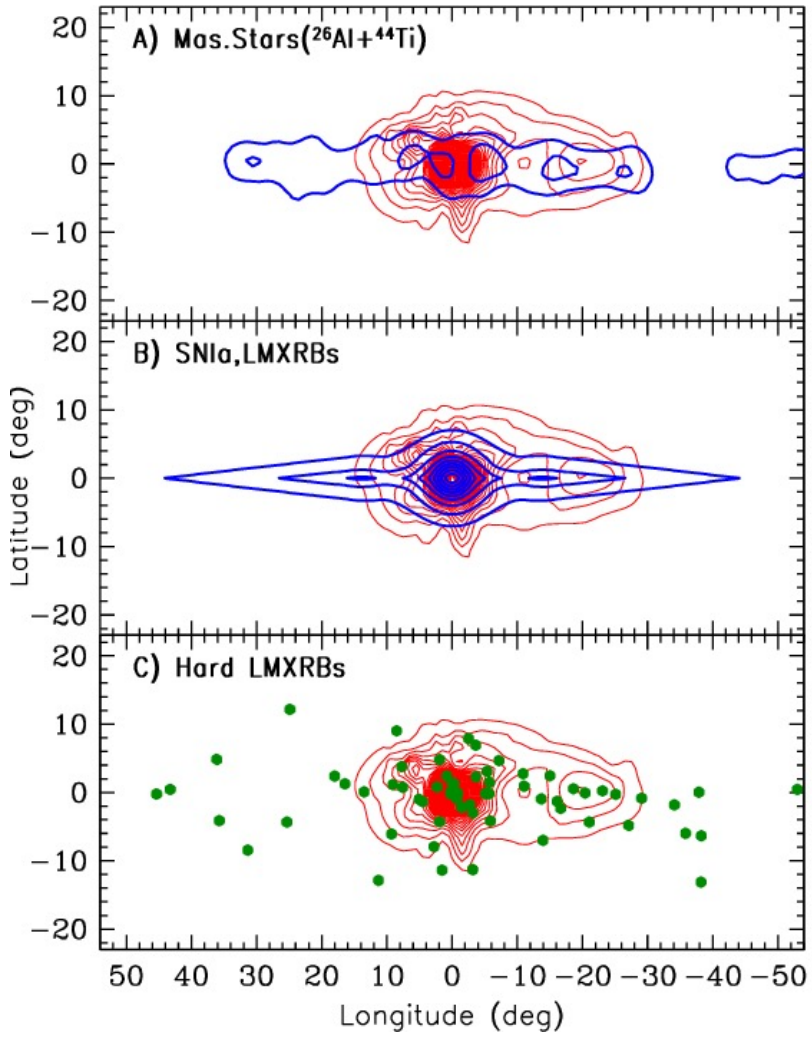
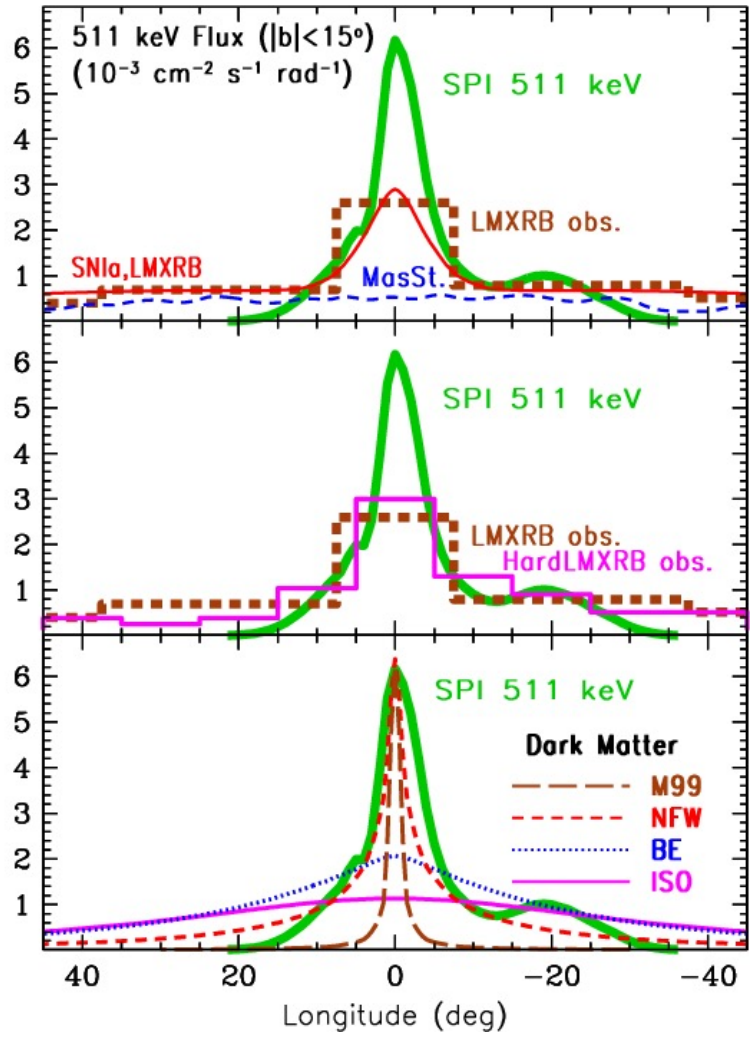




- Disentangling astrophysical sources and a possible dark matter induced signal in the production of low-energy positrons generating the **511 keV line** will only be possible with adequate observational capabilities

N. Prantzos, ``*Nucleosynthesis and gamma-ray lines*'' PoS INTEGRAL **2010**, 018 (2010)

- Depending on the distribution and number of point-sources, GECCO should be able to identify a **truly diffuse** from a "**clustered**" 511 keV line emission

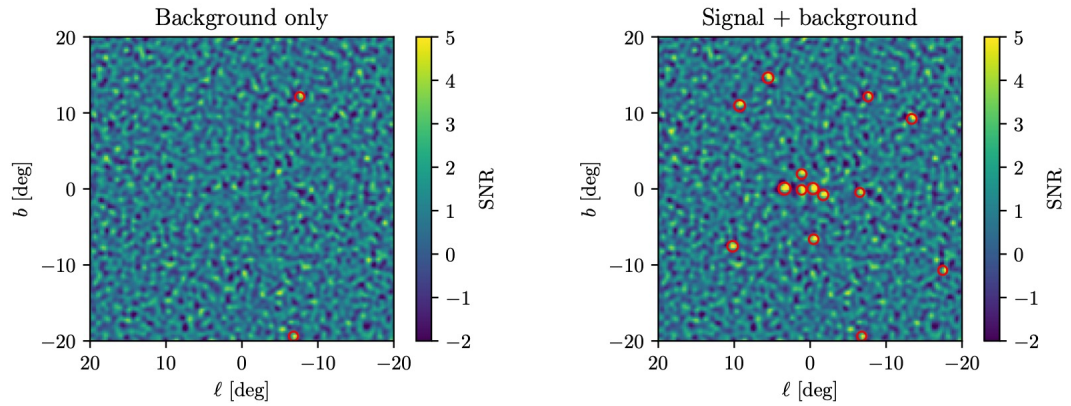


Figure B3. Wavelet transformed map of a background only image (left panel) and an image containing a dim point source population (right image). Red circles indicate sources with a signal-to-noise ratio above 5.

- DM annihilation or "de-excitation" remains an open possibility!!

Galactic Binaries Can Explain the Fermi Galactic Center Excess and 511 keV Emission

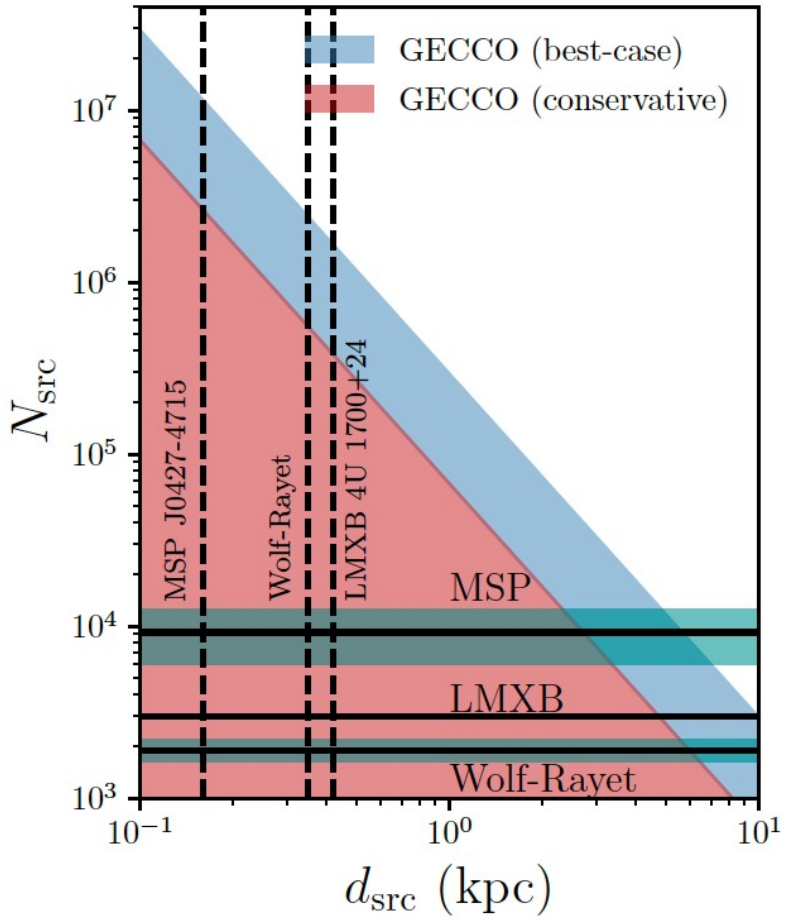
R. Bartels,[1]★ F. Calore[2], E. Storm[1], and C. Weniger[1]
[1] *GRAPPA, Institute for Theoretical Physics and Delta Institute for Theoretical Physics, University of Amsterdam, Science Park 904, 1098XH Amsterdam, The Netherlands*
[2] *LAPTh, CNRS, 9 Chemin de Bellevue, 74941 Annecy-le-Vieux, France*

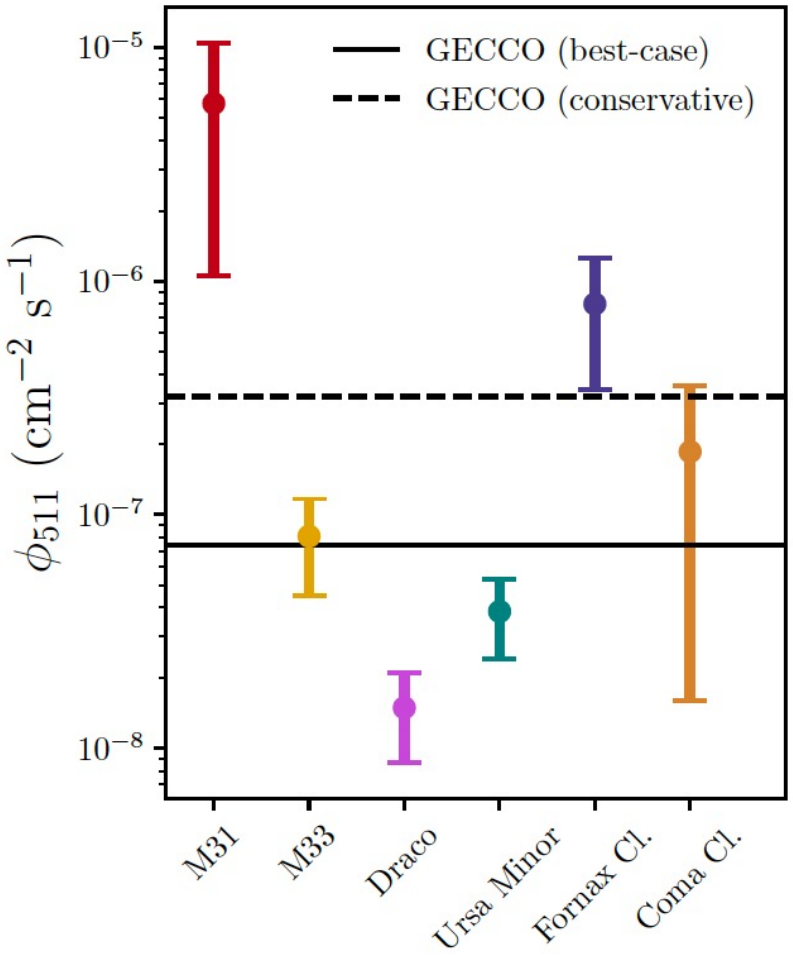
Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT
The *Fermi*-LAT Galactic Center excess and the 511 keV positron-annihilation signal from the inner Galaxy bare a striking morphological similarity. We propose that both can be explained through a scenario in which millisecond pulsars produce the Galactic Center excess and their progenitors, low-mass X-ray binaries, the 511 keV signal. As a proof-of-principle we study a specific population synthesis scenario from the literature involving so-called ultracompact X-ray binaries. Moreover, for the first time, we quantitatively show that neutron star, rather than black hole, low-mass X-ray binaries can be responsible for the majority of the positrons. In this particular scenario binary millisecond pulsars can be both the source of the *Fermi*-LAT γ-ray excess and the bulge positrons. Future avenues to test this scenario are discussed.

Key words: binaries – stars:pulsars – stars:jets – gamma-rays:general – Galaxy:bulge

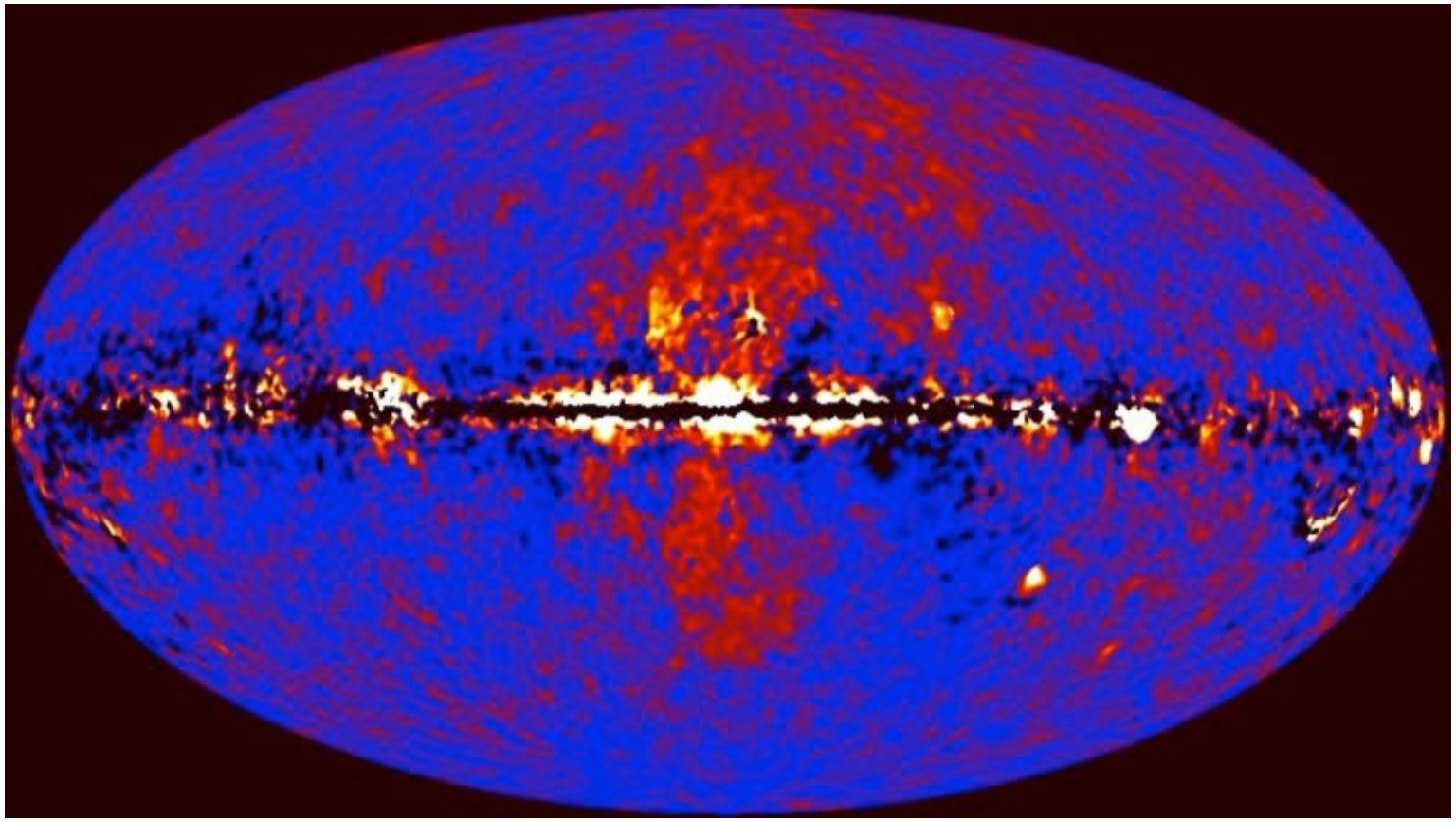
- In addition, one of the most promising candidate source class for the 511 keV emission, millisecond pulsars, could be tested by targeted observations of nearby objects such as **J1023+0038** (e.g. Deller et al. 2015) and XSS **J12270-4859** (Bassa et al. 2014; Roy et al. 2015)





GECCO's potential to observe a single, **nearby 511 keV line source** (left)
and the 511 keV **line from an outer system** (right)

A. Coogan, A. Moiseev, L. Morrison and S. Profumo, ``Hunting for Dark Matter and New Physics with (a) GECCO'' arXiv:2101.10370



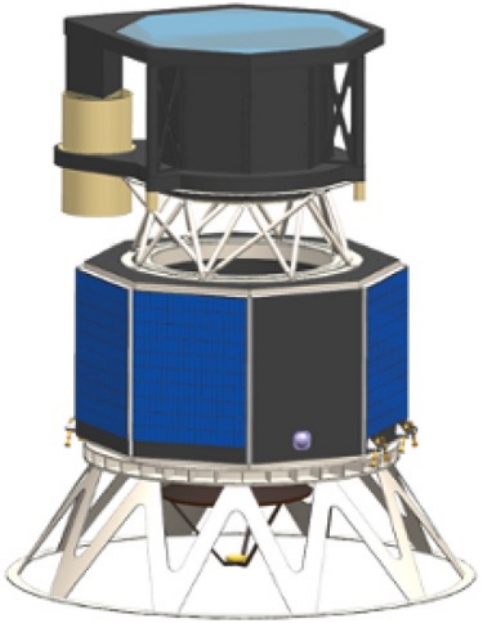
- The nature of the **Galactic center excess** and the origin of the **Fermi bubbles** will also tremendously benefit from multiwavelength information in the MeV and sub-MeV

- GECCO is ideally suited to **explore MeV dark matter candidates** as long as they decay and/or pair-annihilate. The new instrument would unveil dark matter signals up to **four orders of magnitude fainter** than the current observational sensitivity, and would make it possible to detect a dark matter signal from **multiple astrophysical targets**, reducing the intrinsic background and systematic effects that could otherwise obscure a **conclusive discovery**

- GECCO would enable the exciting possible **direct detection of Hawking evaporation** from primordial black holes with masses in the 10^{16} - 10^{18} grams range, if they constitute a sizable fraction of the cosmological dark matter. Under favorable circumstances, GECCO might detect Hawking evaporation from more than one astrophysical target as well

- Finally, we showed the potential of GECCO to **elucidate the nature of the 511 keV line**, by virtue of its unprecedented **line sensitivity** and **point-source angular resolution**: We found that GECCO should be able to observe a 511 keV line from a variety of **extra-Galactic targets**, such as nearby clusters and massive galaxies and, potentially, even from nearby dwarf galaxies; in addition, GECCO should be able to detect **single sources of the 511 keV emission**, as long as they are reasonably close

Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO)



GECCO would push the **observational frontier of MeV gamma rays** in ways that would enormously benefit the quest for **fundamental questions in cosmology and particle physics**, chiefly the nature and particle properties of the cosmological dark matter, and the origin of the mysterious 511 keV line emission from the center of the Galaxy.