Snowmass2021 - Letter of Interest

Searching for Dark Matter and New Physics with GECCO

Thematic Areas:

■ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics

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Abstract: We outline the potential science opportunities offered by a future MeV gamma-ray telescope. We point out that such an instrument would play a critical role in opening up a discovery window for particle dark matter with mass in the MeV or sub-MeV range, in disentangling the origin of the mysterious 511 keV line emission in the Galactic center region, and in potentially discovering Hawking evaporation from light primordial black holes. We refer to a new, proposed MeV gamma-ray telescope, the Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO) that could deliver on all of those science objectives in the search for new physics and specifically for the nature of dark matter.

1 Brief overview of GECCO's anticipated performance

The Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO) is a novel concept for a next-generation γ-ray telescope that will cover the hard X-ray–soft γ-ray region, and is currently being considered for a future NASA Explorer mission.

GECCO will conduct high-sensitivity measurements of the cosmic γ-radiation in the energy range from $100\,\mathrm{keV}$ to $\sim 10\,\mathrm{MeV}$ and create intensity maps with high spectral and spatial resolution, with a focus on the separation of diffuse and point-source components. These observations can help disentangle astrophysical and dark matter explanations of emission from the Galactic Center, and potentially provide a key to discovering as-of-yet unexplored dark matter candidates.

The instrument is based on a novel CdZnTe Imaging calorimeter and a deployable coded aperture mask. It utilizes a heavy-scintillator shield and plastic scintillator anti-coincidence detectors. The unique feature of GECCO is that it combines the advantages of two techniques – the high-angular resolution possible with coded mask imaging, and a Compton telescope mode providing high sensitivity measurements of diffuse radiation. With this combined "Mask+Compton" operation GECCO will separate diffuse and point-sources components in the GC radiation with high sensitivity. GECCO will be operating mainly in pointing mode, focusing on the Galactic Center and other regions of interest. It can be quickly re-pointed to any other region, when alarmed.

The expected GECCO performance is as follows: energy resolution $< 1\%$ at $0.5 - 5\,\mathrm{MeV}$, angular resolution $\sim 1\,\mathrm{arcmin}$ in Mask mode ($5 - 6°$ field-of-view, $\sim 2000\,\mathrm{cm}^2$ effective area), and $3 - 5°$ in the Compton mode ($15 - 20°$ field-of-view, $\sim 500\,\mathrm{cm}^2$ effective area). The sensitivity is expected to be better than $10^{-6}\,\mathrm{MeV/cm^2/s}$ at $1\,\mathrm{MeV}$. These parameters are particularly promising for searching for dark matter particles with MeV-scale masses and primordial black holes with $10^{17}\,\mathrm{MeV}$ masses, as explained below.

2 Searches for MeV dark matter annihilation or decay

GECCO will significantly improve the performance of past sub-GeV telescopes such as INTEGRAL-SPI[2], and enable the discovery of dark matter particle candidates with masses at or below the MeV. While strong constraints on MeV dark matter candidates arise from CMB distortions[4], it has been shown that a signal from dark matter annihilation is possible for a variety of particle models[1]. A notable general class of models that readily evade CMB constraints are those where the pair-annihilation cross section has a strong dependence on temperature, so that the low-temperature cross section is dominated by the p-wave[3]. Additionally, dark matter decay with a sufficiently long life-time is unconstrained by CMB observations.

We anticipate that GECCO will have a discovery potential over 2 orders of magnitude larger in life-time/annihilation cross section than previous telescopes, although the precise improvement will depend on assumptions on the dark matter density profile and on the annihilation final state (see fig. 1 and 2). The ideal targets are somewhat model dependent, and will also depend on the astrophysical background in the MeV from the Galactic center: for dark matter annihilation, nearby dwarf spheroidal (dSph) galaxies are highly promising targets, while for decaying dark matter nearby massive clusters or the Andromeda Galaxy (M31) usually offer comparable signal to noise. Finally, the Galactic Center might be the best target in either case, depending on the inner profile of the dark matter density distribution and on the MeV astrophysical background.

3 Unraveling the origin of the 511 keV signal in the Galactic center

GECCO's extraordinary angular resolution in Mask mode will potentially enable the disentanglement of a genuinely diffuse emission versus an emission from a complex of faint sources for the 511 keV line. Additionally, given a class of source candidates, such as for instance Wolf-Rayet stars or millisecond pulsars, GECCO will be able to search for 511 keV emission from nearby sources. Finally, we calculate that if the 511 keV emission has an exotic origin such as from dark matter decay or up-scattering, then GECCO will be able to detect a signal from other systems, such as M31 and nearby dSph galaxies.

4 Direct detection of light primordial black holes

GECCO will offer the unique opportunity to discover Hawking radiation from the evaporation of light ($M \sim 10^{17}$ g). Notice that the corresponding Hawking temperature, $T_H \sim (10^{10}\ \mathrm{g}/M)\mathrm{TeV} \simeq 0.1$ MeV would force evaporation at low redshift to only consist of neutrino and photon emission (barring evaporation to new exotic light particles). The detectable emission would thus primarily consist of a grey-body radiation with a very specific temperature, and with a readily calculable intensity, simply depending on the mass over distance squared of the system under scrutiny. Preliminary estimates indicate that current limits from electron-positron emission and prompt photon at all redshifts would generally be weaker than those GECCO could obtain from observation of nearby dSph, clusters, or even galaxies such as M31 or the Milky Way center.

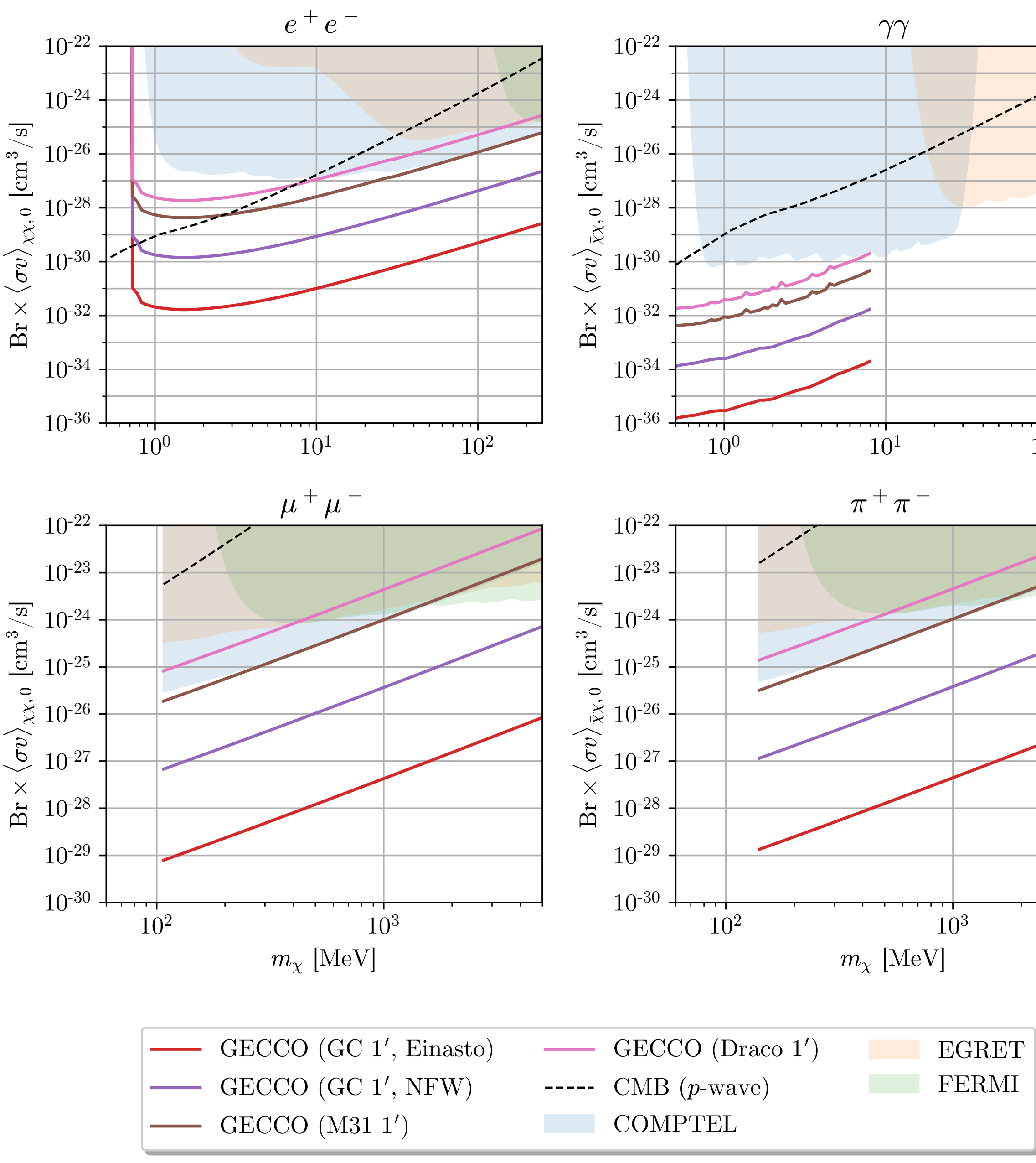

Figure 1: **Constraints on annihilation into different final states.** The shaded regions show constraints from existing gamma ray data, assuming an NFW profile. The dashed black line shows the CMB constraint assuming the DM annihilation are p-wave ($\langle \sigma v \rangle_{\bar{\chi}\chi} \propto v_\chi^2$.

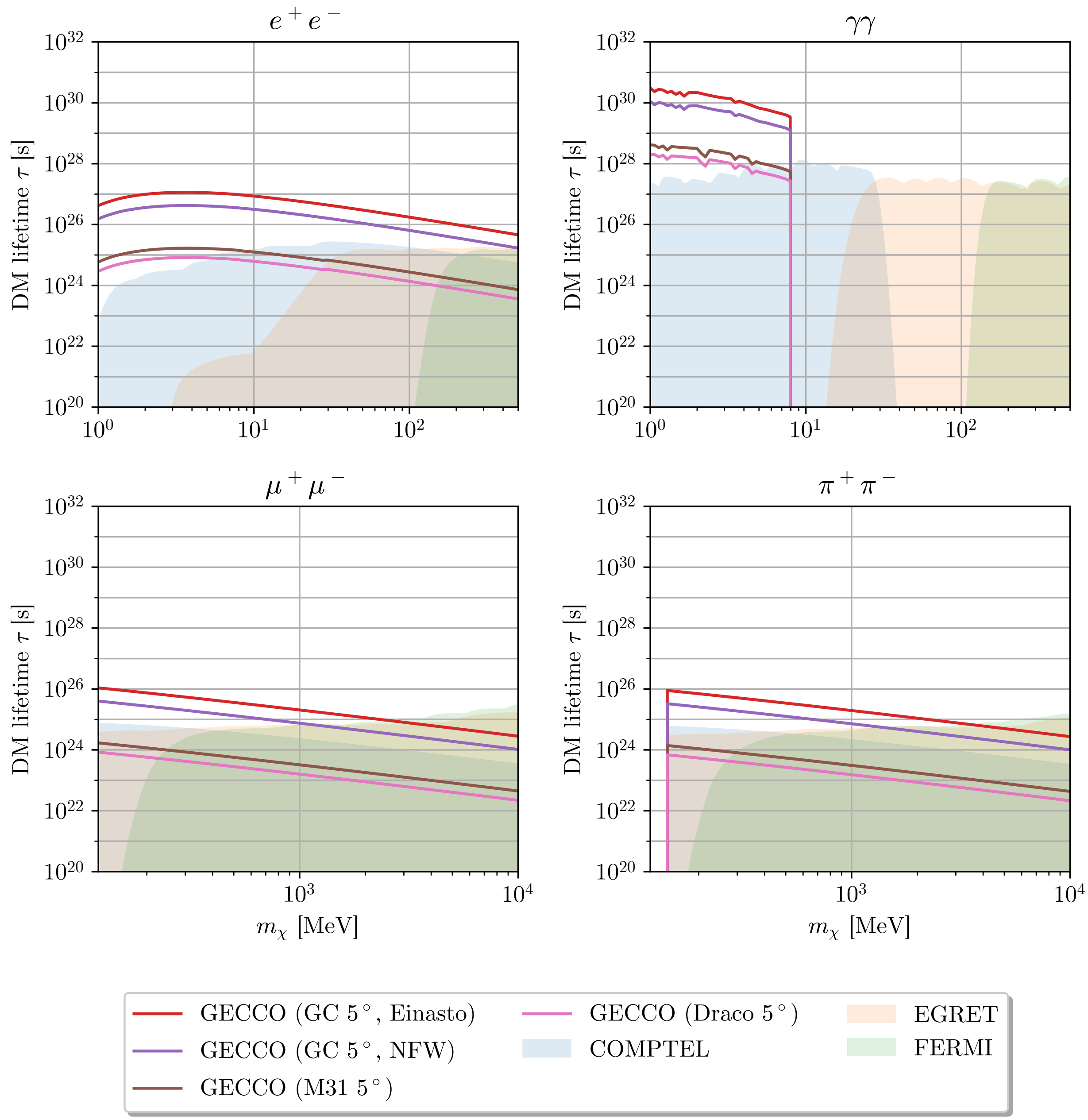

Figure 2: **Constraints on the DM particle's lifetime for decays into different final states.**

References

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