

Black Holes as Dark Matter Annihilation “Boosters”

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Abstract. The presence and growth of Intermediate and Supermassive Black Holes modify the surrounding distribution of stars and Dark Matter, and inevitably affect the prospects for indirectly detecting Dark Matter through its annihilation products. We show here that under specific circumstances, Black Holes can act as Dark Matter annihilation “boosters”. In particular, we show that mini-spikes, i.e. Dark Matter overdensities around Intermediate-Mass Black Holes, would be bright sources of gamma-rays, well within the reach of the space telescope GLAST, that can be discriminated from ordinary astrophysical sources thanks to their peculiar energy spectrum and spatial distribution.

1. Introduction

Although many astrophysical and cosmological observations provide convincing evidence for the existence of a “dark” component in the matter density of the Universe, the nature of this *dark matter* (DM) remains unknown. It is commonly assumed that DM is made of new, as yet undiscovered, particles, associated with theories beyond the Standard Model of Particle Physics. Among the most widely studied DM candidates are the supersymmetric neutralino and candidates arising in theories with extra-dimensions, which appear difficult to constrain with direct searches (i.e. by looking for nuclear recoils due to DM particles scattering off nuclei) and whose prospects of discovery at future accelerators strongly depend on the details of the particle physics setup (for recent reviews see e.g. Refs. [?, ?, ?]). Indirect searches via the detection of annihilation radiation provide an interesting alternative, although they are usually affected by large astrophysical and cosmological uncertainties. Here we discuss how the distribution of DM, thus the prospects of indirect detection, are affected by the presence and the growth of massive black holes, and show that massive black holes can act as *Dark Matter annihilation boosters*. The results presented here are based on Refs. [?, ?, ?, ?].

The effect of the formation of a central object on the surrounding distribution of matter has been investigated in Refs. [?, ?, ?, ?] and, in the framework of DM annihilations, in Ref. [?]. It was shown that the *adiabatic* growth of a massive object at the center of a power-law distribution of DM with index γ , induces a redistribution of matter into a new, steeper, power-law, dubbed “spike” (see below for further details). In particular, the authors of Ref. [?] have proposed that a DM spike could be present around the Supermassive Black Hole harbored at the center of our Galaxy [?]. It was subsequently shown that not only its existence would be at odds with gamma-rays and synchrotron observation of the inner Galaxy in a large region of the DM parameter space [?, ?, ?, ?], but the formation of such a DM spike would have required significantly fine-tuned initial conditions [?], and in any case it would have been destroyed by major mergers [?] and by gravitational scattering off stars [?, ?].

Recently, it was shown that the very same process that tend to destroy high density spikes,

i.e. gravitational scattering off stars, can also regenerate large DM overdensities called *crests* (Collisionally REgenerated Structures) [?]. We refer the interested reader to Ref. [?] and references therein, for a detailed discussion on DM spikes and crests at the Galactic center, and the consequences for indirect DM detection.

A gamma-ray source spatially coincident within $1'$ with the Galactic center, has been actually observed [?] by the Air Cherenkov telescope HESS [?], and its spectrum has been confirmed by MAGIC [?]. However, the spectrum appears consistent with a power-law of index -2.2 ± 0.1 over the range 160 GeV – 30 TeV, and it is thus incompatible with a DM interpretation [?, ?, ?, ?]. However, it may still possible to find the signature of DM annihilations at energies lower than 160 GeV [?]with GLAST [?].

It is thus important to study alternative detection strategies, and to focus in particular on those allowing the discrimination against ordinary astrophysical sources, and potentially leading to an unambiguous identification of a DM origin. Here we describe a scenario that may provide smoking-gun evidence for the annihilation of DM particles. If intermediate-mass black holes (IMBHs), with a mass ranging between 10^2 and $10^6 M_\odot$ (e.g. [?]), exist in the Galaxy (as may well be the case, see the discussion below), their adiabatic growth would have modified the DM distribution around them, leading to the formation of “mini-spikes”, that is, large, local enhancements of the DM density. The DM annihilation rate being proportional to the square of the number density of DM particles, these mini-spikes would be bright gamma-ray sources, distributed in a roughly spherically-symmetric way about the galactic center, and well within the observational reach of the next-generation gamma-ray experiments. Their brightness and isotropy make them ideal targets of large field-of-view gamma-ray experiments such as GLAST [?]. In case of a positive detection, Air Cherenkov Telescopes such as CANGAROO [?], HESS [?], MAGIC [?] and VERITAS [?] could extend the observations to higher energies and improve the angular resolution. Mini-spikes could also be detectable with neutrino experiments such as Antares and IceCube. Furthermore they may also lead to strong enhancements of anti-matter fluxes, within the reach of experiments such as PAMELA. The observation of numerous (up to ~ 100) point-like gamma-ray sources with identical cut-offs in their energy spectra, at an energy equal to the mass of the DM particle, would provide smoking-gun evidence for DM particles.

2. Mini-Spikes

Mini-spikes result from the reaction of DM mini-halos to the formation or growth of IMBHs. In fact, the *adiabatic* growth of a massive object at the center of a power-law distribution of DM with index γ , induces a redistribution of matter into a new power-law with index $\gamma_{sp} = (9 - 2\gamma)/(4 - \gamma)$ [?]. This formula is valid over a region of size $R_s \approx 0.2r_{BH}$, where r_{BH} is the radius of gravitational influence of the black hole, defined implicitly as $M(< r_{BH}) = M_{BH}$, with $M(< r)$ mass of the DM distribution within a sphere of radius r , and M_{BH} mass of the Black Hole [?].

To make quantitative predictions, we focus on a specific IMBHs formation scenario [?], representative of a class of models where these objects form directly out of cold gas in early-forming DM halos, and are characterized by a large mass scale, of order $10^5 M_\odot$ (see also Ref. [?] and references therein). The distribution of these IMBHs was obtained in Ref. [?], which is based on the Monte Carlo halo evolution procedure given in Ref. [?]. The method for populating black holes at high-redshift are described in detail in Refs. [?, ?].

In Fig. ??, we show the (average) integrated luminosity function of IMBHs in scenario B. We define the integrated luminosity function as the number of black holes producing a gamma-ray flux larger than Φ , as a function of Φ . The upper (lower) line corresponds to $m_\chi = 100$ GeV, $\sigma v = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1}$ ($m_\chi = 1$ TeV, $\sigma v = 10^{-29} \text{ cm}^3\text{s}^{-1}$). In a practical sense, the plot shows the number of IMBHs that can be detected with experiments with point source sensitivity Φ above 1 GeV. We show for comparison the point source sensitivity above 1 GeV for EGRET and

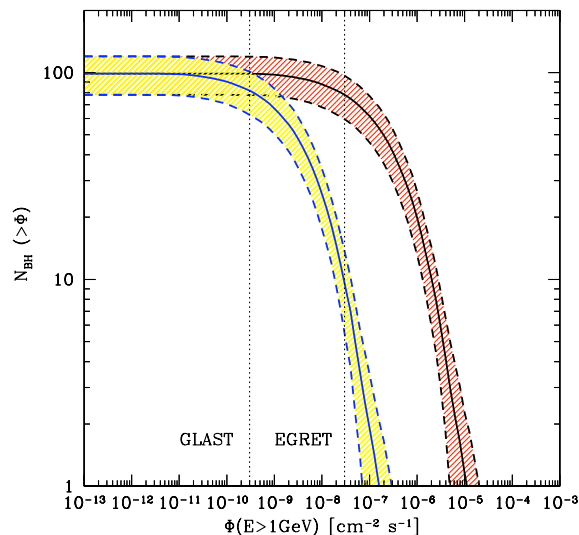


Figure 1. IMBHs integrated luminosity function, or number of IMBHs that can be detected from experiments with point source sensitivity Φ (above 1 GeV). The upper (lower) line corresponds to $m_\chi = 100$ GeV, $\sigma v = 3 \times 10^{-26}$ cm³ s⁻¹ ($m_\chi = 1$ TeV, $\sigma v = 10^{-29}$ cm³ s⁻¹). For each curve we also show the 1σ scatter among different realizations of Milky Way-sized host DM halos. We show for comparison the 5σ point source sensitivity above 1 GeV of EGRET and GLAST (1 year). From Ref. [?].

GLAST, corresponding roughly to the flux for a 5σ detection of a high-latitude point-source in an observation time of 1 year [?]. The dashed region corresponds to the 1σ scatter between different realizations of Milky Way-sized halos. This band includes the variation in spatial distributions of IMBHs from one halo to the next as well as the variation in the individual properties of each IMBH in each realization.

The number of detectable sources is very high, even in the pessimistic case, and either strong constraints on a combination of the astrophysics and particle physics of this scenario, or an actual detection, should be possible within the first year of operation of GLAST, which is expected to be launched in 2007. Depending on the specific scenario, EGRET may have observed some of these IMBH mini-spikes, which would still account only for a small fraction of the unidentified sources. The prospects for detecting high energy neutrinos from mini-spikes are also interesting [?].

3. Conclusions

Black Holes can significantly modify the distribution of DM around them. Their adiabatic growth can deepen the gravitational well felt by DM particles; put another way, BHs can “pull closer” DM particles as they grow, and therefore boost the annihilation signal. This process would be effective for BHs of any size, but in galactic Nuclei the dense stellar cusps that develop around the same objects, would rapidly destroy spikes via gravitational scattering of DM particles off of stars. Smaller spikes, or mini-spikes, would instead evolve more or less unperturbed around Intermediate Mass BHs, which may exist in large numbers in galactic halos. If this scenario is correct, a large number of gamma-ray sources may be discovered with the space telescope GLAST, thus providing smoking-gun evidence for DM annihilations.

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