Diffuse γ-ray emission constraints on light WIMPs

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In these proceedings I report on a study of the contribution of light WIMPs to the isotropic gamma-ray diffuse emission. Specifically, I confront a singlet scalar candidate interacting through the Higgs portal to the Fermi-LAT data and the (unmodulated) signal from CoGeNT, a neat illustration of the complementarity between direct and indirect searches for dark matter.

We still have no clue of the nature of dark matter, but recently some interest has been taken in Light WIMPs, that is particles with picobarn scale annihilation cross-sections, but which are substantially lighter than the usual suspects, say the neutralino [1]. This is of course motivated by the DAMA/LIBRA [2] and CoGeNT [3] signals. Now, after Xenon100 [4] or CDMS-II [5], to speak of light WIMPs may sound like beating a dead horse – for sure this is what it felt like this Winter. However the current exclusion limits on light WIMPs are, apparently, not yet bullet proof.[6] Of course the new development is the modulation observed by CoGeNT.[7] Although of low statistical significance, the rough agreement with DAMA is more than intriguing.[8,9,10,11,12,13]

It is a very interesting coincidence that, while we are being puzzled by direct detection data, at the very same moment indirect searches experiments are reaching the sensitivity required to probe Light WIMP candidates. This is for sure well-known and appreciated but yet is not enough advocated in my humble opinion. Baring threshold effects, that indirect searches are relatively more sensitive to relatively lighter WIMPs is just because of the dark matter mass dependence of the flux of, say gamma-rays,

$$\phi_\gamma \propto \langle \sigma v \rangle \times \frac{dN_\gamma}{dE} \times \int_{los} dl \frac{\rho^2_{\rm dm}(l)}{M^2_{\rm dm}}. \tag{1}$$

For fixed annihilation cross-section, say $\langle \sigma v \rangle \approx 3 \cdot 10^{-26}$ cm^2·s^{-1}, there is a decrease of the number of gamma-rays produced by a lighter WIMPs, but this is more than compensated by their increasing number density. Interesting constraints on light WIMPs may be get based on solar neutrinos limits [14,15,16,17], anti-protons in cosmic rays [18,19], gamma-rays from the galactic centre [20] and from dwarf spheroidal galaxies [21,22,23] and synchrotron radiation [24,25].

Here I briefly report on an analysis [26] of the isotropic diffuse gamma-ray emission, based on the data released by the Fermi-LAT collaboration [27]. Our work is complementary (and concords) with the other works on the same topic[28,29], but our analysis extends to slightly lighter candidates, and as shown in the figure, conservatively obtained by requiring that the signal from a putative Light WIMPs does not exceed the signal inferred by the Fermi-LAT collaboration, puts interesting constraints on Light WIMPs candidates. Here this is illustrated by a scalar singlet interacting through the Higgs portal [22], but which also apply to other portals, like a Z' [30].

The basic quantity is the spectral flux,

$$\frac{d\Phi_\gamma}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2M_{DM}^2}\int_0^\infty dz' \frac{1}{H(z')(1+z')^4}\frac{dN_\gamma}{dE'}\mathcal{B}^2(z')\mathrm{e}^{-\tau(E',0,z')}\,. \tag{2}$$

which in general depends critically on two astrophysical factors, a boost factor $\mathcal{B}^2(z')$ which depends on the distribution of halos of dark matter of all size and at all redshift z, and an absorption factor which depends on the optical depth $\tau(E,z)$ of a photon of energy E emitted at redshift z. Absorption of a gamma-ray may be due to various processes (Compton scattering on background photons, etc) but interestingly the universe is optically thin for a light WIMP, say with $M_{\rm dm} \leq 20$ GeV.[26] Hence, at the end of the day, the largest uncertainty comes from the boost factor.

The boost factor may be evaluated using different approaches, and our analysis is based on the standard Press-Schechter formalism [31], like many works in the field.[32,33] The Press-Schechter formula depends in turn on various cosmological and astrophysical parameters. For instance we have adopted a NFW profile for early DM halos, clearly a more shallow profile would give less stringent constraints, but all in all the most critical parameter is the mass of the lightest halo that may form in the Early Universe. This depends on the temperature of kinetic decoupling of the DM candidate (see *e.g.* [34]). The kinetic decoupling temperature is generically much lower than the freeze-out temperature. The latter is typically $\mathcal{O}(100$ MeV$)$ for a Light WIMP, hence around the temperature of the QCD phase transition, while the former depends on the coupling to the thermal bath, which is composed of Standard Model particles. For the case of a Light WIMP interacting through the Higgs portal, and thus through Yukawa couplings, the couplings to the lighest Standard e^+e^- and neutrinos is completely negligible, and kinetic decoupling occurs close to the chemical freeze-out, $T \sim 150$ MeV. For the sake of comparison, typical neutralino candidates decouple close to $T \sim 1$ MeV. This in turn implies that quite light (and thus dense) dark matter halos may form in the early universe, so that the constraints are comparatively stronger.[26] To conclude we should emphasize that, as time goes by, the Fermi-LAT will resolve more extra-galactic astrophysical sources, and that the foreseen improvement in the analysis of the isotropic diffuse gamma-ray emission is likely to give stronger constraints on Light WIMPs, possibly by a factor of a few on the annihilation cross section, and thus, as emphasized here, on the spin independent cross section.[35]

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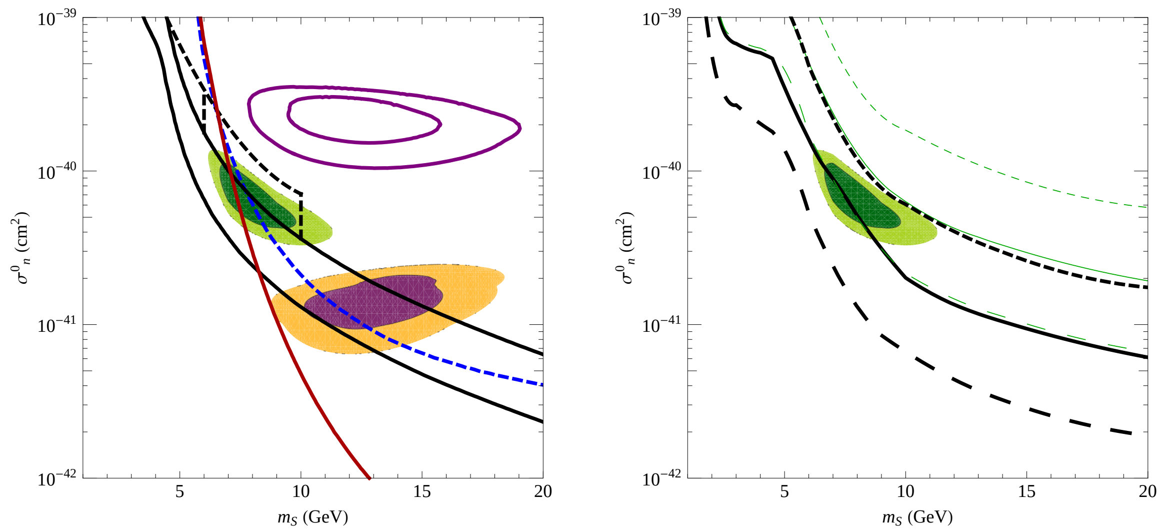

Figure 1: Left panel: SI cross-section (σ_n^0) *vs* scalar singlet mass (M_S) with the CoGeNT umodulated (middle, in green), and DAMA (in purple, above without channelling, below with channelling). The contours are given for 90 and 99.9 % C.L. The single continuous line (red) is the exclusion limit from Xenon10 (95 % C.L.). The dashed (blue) line corresponds to the CDMS-Si limit. The region between the two continuous black line correspond to S candidates with WMAP relic abundance. Right panel: only the CoGeNT region, together with 95 % C.L. exclusion limits from isotropic diffuse gamma-ray emission observation by *Fermi*-LAT. The lines correspond to distinct astrophysical assumptions. The region between the two continuous (black and green) lines may be considered to give conservative (range of) exclusions limits.

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