PROCEEDINGS OF SCIENCE

Constraining Dark Matter through CMB

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Self-Annihilating Dark Matter (DM) candidates can modify the recombination history of the Universe, injecting additional energy into the thermal gas, and modifying its ionization state. The electron fraction history affects the CMB temperature and polarization power spectra; observations of the modifications (or of the absence) of the latter can then be used to constrain the power injected by annihilating DM, and ultimately the DM parameters themselves. DM annihilations able to modify the CMB spectra are active at redshifts $100 \lesssim z \lesssim 1000$, thus involving only a smooth density field, and permitting to ignore structure formation. Current WMAP7 data on the TT, TE and EE angular power spectra already permit to rule out interesting regions in the $\langle \sigma v \rangle$-m_χ space; the forthcoming PLANCK ones will permit to explore the "thermal WIMP" region.

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Self-annihilating Dark Matter at the Recombination epoch

Before the formation of gravitationally bound structures, the DM density field can be approximated by a smooth, diffuse one[1], and the annihilation rate per unit volume, A(z) reads:

$$A(z) = \frac{1}{2}\rho_c^2\Omega_{DM}^2(1+z)^6\frac{\langle\sigma v\rangle(z)}{m_\chi^2} \tag{1}$$

with $n_{DM}(z)$ being the relic DM abundance at a given redshift z, m_χ the mass of the dark matter particle, Ω_{DM} the cold dark matter fraction, ρ_c the critical density of the Universe today, and $\langle\sigma v\rangle$(z) is the effective self-annihilation rate - which for the sake of generality here we assume to depend on the redshift z. The total energy $2m_\chi c^2$ produced in the annihilation will be only partially injected into the thermal gas -to which I will refer in the following as Inter Galactic Medium (IGM- although improperly as galaxies have not yet formed at the redshifts relevant for this process): part of the high energy shower produced in the annihilation will in fact not be deposited in the thermal gas and stream freely through the Universe. Under the approximation that the particles failing to interact with the IGM on–the–spot (namely within a short fraction of the Hubble time at the moment they are produced), do not interact with the thermal gas anymore, the energy deposited at any given time is only a fraction f(z) of the one produced, bearing an energy injection rate per unit volume:

$$\frac{dE}{dt}(z) = f(z)A(z) = f(z)\rho_c^2c^2\Omega_{DM}^2(1+z)^6\frac{\langle\sigma v\rangle(z)}{m_\chi}, \tag{2}$$

where $f(z)$ depends on the spectrum and characteristics of the primaries produced by the DM annihilation, and on very well known high energy astrophysics processes: in principle, that can be computed exactly for each DM candidate. The energy injection in the thermal gas, which ultimately determines the evolution of the IGM temperature and ionization fraction, is therefore regulated (in this formalism) by only one DM–related parameter:

$$p_{ann}(z) \equiv f(z)\frac{\langle\sigma v\rangle(z)}{m_\chi}. \tag{3}$$

The recombination history

In the previous formalism, f(z) more precisely represents the fraction of energy that is degraded down to the keV scale: what is brought below this scale is "locked" inside the gas and affects it through *(i)* ionization, *(ii)* heating and *(iii)* Ly–α excitation; the details and final ripartition of the three processes eventually depending only on the temperature and original ionization fraction of the gas. The equation for the ionization state of the gas can be exactly solved in presence of an "exotic" source of energy (in this case DM annihilation) -see e.g. [1]- and the ionized fraction of the Universe exactly recovered. Even for the right DM parameters (m_χ,$\langle\sigma v\rangle$), alterations of the "standard" recombination will take place as long as the energy absorbed by the gas is high enough. When the gas becomes transparent to the high energy radiation, annihilation of DM doesn't play

[1] The presence of inhomogeneities does not mine the validity of the argument, and only make the results more conservative.

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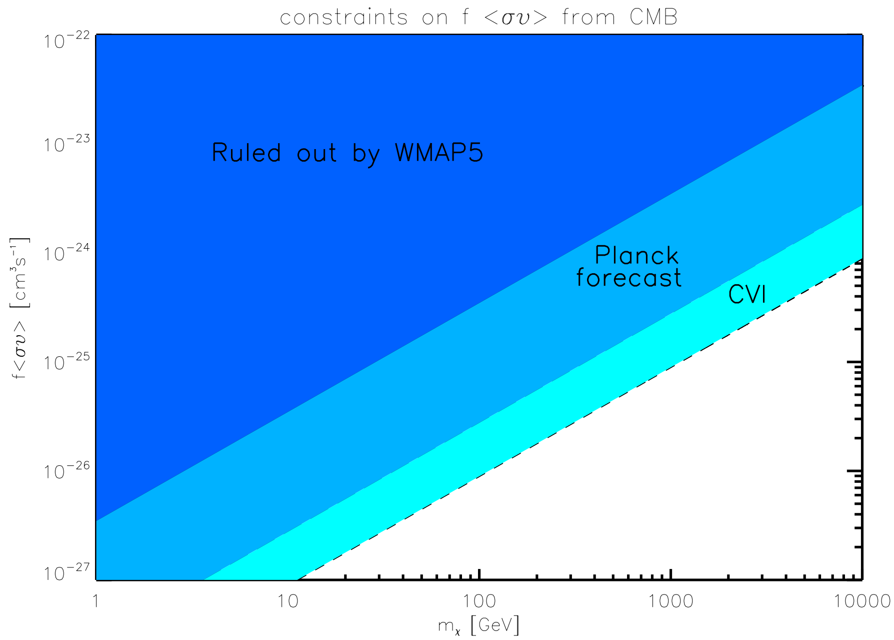

Figure 1: Constraints on the parameter p_{ann}, shown in the $f\langle\sigma v\rangle$-m_χ plane, from [4].

a role anymore in contributing to the ionization of the medium. This is typically the case at redshifts lower than $z\sim$100, as it can be seen e.g. in Fig. 2 of [2]; this bears the extremely relevant consequence that whichever alteration of the CMB signal induced by DM annihilation, that will be caused by the density field at $z\gtrsim$100, and therefore in absence of structure formation. The modified recombination history shows up in the CMB angular power spectra: as it has been shown e.g. in [3], additional electrons dump the temperature angular power spectra on all scales, and show up in the TE and EE mode on small scales (700$\lesssim l \lesssim$1000), corresponding to the quadrupole scale at the redshifts (100$\lesssim$z$\lesssim$1000) at which DM power is injected; see e.g. Figure 2 in [4]. Information about the parameter regulating the extra ionization source can be extracted with a thorough analysis, and degeneracies with other cosmological parameters (for instance the running of n_s) can be resolved by using all of the TT,TE, EE angular power spectra information.

Current approximations and DM constraints

Under the assumption that the annihililation cross-section $\langle\sigma v\rangle$, and the fraction of energy absorbed by the gas stay constant during 100$\lesssim$z$\lesssim$1000, the DM-induced alterations are regulated by a single, time and model-independent parameter

$$p_{ann} = f\frac{\langle\sigma v\rangle}{m_\chi} \tag{4}$$

CMB observations can constrain this only parameter, and this in turn can be transformed in information about DM models. In particular, the fraction f must be computed for each DM model, and that can be done in a straightforward way, once the nature of the DM particle (and its composition in terms os standard model particles) is known. An example is drawn in [2], see their Fig. 4, where it is shown how f is a slowly varing function of redshift, and its value strongly depends on the nature of primaries produced by DM annihilation. As it can be seen from Fig 1, taken from [4], the absence of an alteration in WMAP5 data can already constrain p_ann very tightly. If an absence of additional signal will be seen in PLANCK, its constraining power on p_ann will be of the order of the so called “thermal WIMP miracle”. For 10$\lesssim m_\chi \lesssim$100 and $f \sim$0.5 (a good approximation for leptonic channels, see [2]), the values of the cross sections probed by the PLANCK observations will reach $\langle\sigma v\rangle_r \sim 10^{-26}$cm^3/s.

Few remarks are in order: *i)* whereas the on-the-spot approximation is good for the redshifts of interest, f is not constant. Such approximation has been acceptable so far in order to rule out some extreme models (e.g. leptophilic with extremely high $\langle\sigma v\rangle$, apt to explain the PAMELA positron excess in terms of DM annihilation); if one wants to perform a thorough DM analysis, $f(z)$ must be computed in a model-dependent way, and implemented properly. *ii)* The constraint that one obtains by CMB observations is caused by a signal produced at redshift 100$\lesssim$z$\lesssim$1000 (in the following, z$_r$): strictly speaking, as $f(z)$ is univocally determined at given DM model, and m_χ does not change with redshift, the constraints apply to $\langle\sigma v\rangle$(z$_r$), namely the self-annihilation rate at the epoch of recombination $\langle\sigma v\rangle_r$. In simple s-wave models, $\langle\sigma v\rangle$ is not a function of z (or the relative velocity of DM particles) and $\langle\sigma v\rangle_r$=$\langle\sigma v\rangle$(z=0); this equality does however fail in models where $\langle\sigma v\rangle$ depends on β=(v/c). Care must be applied in model-dependent analysis when recovering $\langle\sigma v\rangle_0$ with respect to $\langle\sigma v\rangle_r$. *iii)* The “DM signal” which one observes in the CMB is produced before structure formation, therefore any constraint obtained through this method is free of any dependence on related parameters such as the halo shape, concentration parameter, minimal halo mass.

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