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Constraining Dark Matter annihilation with the Cosmic Microwave Background

S. Galli(1)(2), G. Bertone(3)(4), F. Iocco(3)(5) and A. Melchiorri(2)

(1) *APC - Laboratoire de Astroparticule et Cosmologie, Université Paris Diderot - 75205 Paris France*
(2) *Dipartimento di Fisica and INFN, Università di Roma "La Sapienza" - P.le Aldo Moro 2 00185, Rome, Italy*
(3) *Institut d'Astrophysique de Paris, UMR 7095-CNRS Paris, Université Pierre et Marie Curie Boulevard Arago 98bis, 75014, Paris, France*
(4) *Institute for Theoretical Physics, University of Zurich - Winterthurerst. 190, 8057 Zurich Switzerland*
(5) *Institut de Physique Théorique, CNRS, URA 2306 & CEA/Saclay - F-91191 Gif-sur-Yvette France*

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Summary. — I review one of the numerous physical processes that might change the standard model of recombination, *i.e.* the annihilation of Dark Matter particles. The high precision of current and future CMB data may allow the detection of these processes, that leave recognizable imprints on the angular power spectra. I review some of the results obtained in constraining this phenomenon using current WMAP5 data and forecasted data for future experiments such as the Planck satellite mission.

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1. – Introduction

The recent measurements of the Cosmic Microwave Background (CMB) flux provided by the Wilkinson Microwave Anisotropy Probe (WMAP) mission [1] and the ACBAR Collaboration [2] have confirmed several aspects of the cosmological standard model and improved the constraints on several cosmological parameters. A key ingredient in the CMB precision cosmology is the accurate computation of the recombination process, *i.e.* the epoch around redshift $z_r \sim 1000$ when the CMB forms, as photons decouple from baryons because of the recombination of electrons and protons in neutral hydrogen. Since the seminal papers by Peebles and Z'eldovich (see [3,4]) detailing the recombination process, further refinements to the standard scheme were developed [5] allowing predictions at the accuracy level found in data from the WMAP satellite and predicted for the future Planck [6] satellite mission [7,8].

While the attained accuracy on the recombination process is impressive, it should be noticed that these computations rely on the assumption of standard physics. Non-standard mechanisms could produce extra sources of radiation or determine a variation

Table I. – *Upper limit on* p_{ann} *from current WMAP data and future upper limits achievable by the Planck satellite mission and by a cosmic-variance–limited experiment. Taken from* [9].

Experiment	p_{ann} 95% c.l.
WMAP	$< 2.4 \times 10^{-6}\,\mathrm{m^3/s/kg}$
Planck	$< 1.7 \times 10^{-7}\,\mathrm{m^3/s/kg}$
CVl	$< 5.9 \times 10^{-8}\,\mathrm{m^3/s/kg}$

of fundamental constants, therefore yielding a modification of the recombination process. With the WMAP results and the future Planck data, it therefore becomes conceivable that deviations from standard recombination may be detected.

Here I want to focus on one of the extremely vast possible non-standard scenarios that might affect the physics of recombination, *i.e.* the annihilation of Dark Matter particles. I will show how much current and future CMB data can constrain these models. The work presented here is taken from [9]. I refer the reader to this paper for further details.

2. – Annihilating Dark Matter

Dark Matter (DM) annihilation is one of the mechanisms that could produce extra-Lyman-α and ionizing photons during the epoch of recombination. This kind of processes have received particular attention as they could provide one of the possible explanations [10] for the excess of positrons and electrons in cosmic rays measured by different experiments, such as PAMELA [11], ATIC [12] and FERMI [13]. The attempt to explain these features in terms of Dark Matter annihilation has prompted the proliferation of new DM candidates with very large annihilation cross-section. In particular, models that include the so-called "Sommerfeld enhancement" [14] of the annihilation cross-section (σv) have been proposed. In these models, the efficent exchange of force carriers at low relative particle velocities leads to a velocity-dependent (σv), which behaves roughly as $\propto 1/v$ and saturates below a critical v_s. When recombination occurs, the velocity of the particles is small, roughly $v(z_r)/c \sim 10^{-8}$, for a $O(100\,\mathrm{GeV}/c^2)$ mass WIMP. We therefore expect that for large enough cross-sections, DM annihilation will significantly modify the recombination history, thus leaving a clear imprint on the angular power spectra of CMB anisotropy and polarization. In particular, the interaction of the shower produced by the annihilation of these particles with the thermal gas has three main effects: i) it ionizes the gas, ii) it induces Ly-α excitation of the hydrogen and iii) it heats the plasma. The first two modify the evolution of the free electron fraction x_e, the third affects the temperature of baryons.

In [9] we searched for an imprint of self-annihilating Dark Matter in current CMB angular power spectra, introducing the annihilation parameter $p_{ann} = f\langle\sigma v\rangle/m_\chi$ where $\langle\sigma v\rangle$ is the effective self-annihilation rate, m_χ the mass of our Dark Matter particle and f indicates the fraction of energy which is absorbed *overall* by the gas, under the approximation that the energy absorption takes place locally.

Table I shows the constraints on p_{ann} obtained using the five-year data of the WMAP experiment and using simulated data for the Planck experiment and for a hypotetical cosmic-variance–limited experiment.

The results are visualized in fig. 1, where we show the region excluded by our analysis in the (σv) *vs.* m_χ plane, adopting a fiducial value $f = 0.5$ for the coupling between

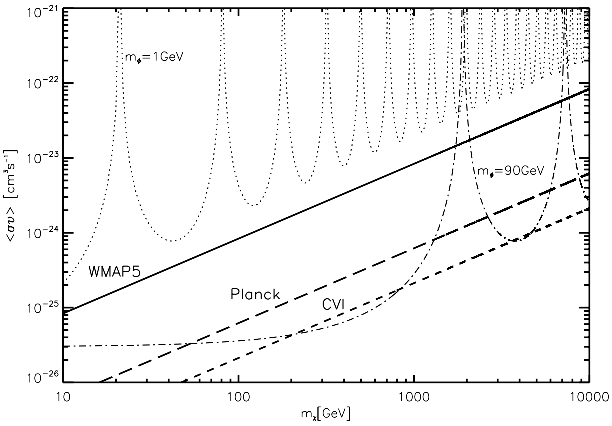

Fig. 1. – Constraints on the self-annihilation cross-section at recombination $(\sigma v)_{z_r}$, assuming the gas-shower coupling parameter $f = 0.5$. Regions above the solid (/long dashed/short dashed) thick lines are ruled out by WMAP5 (/Planck forecast/Cosmic Variance limited); the thin dotted and dash-dotted lines are the predictions of the "Sommerfeld" enhanced self-annihilation cross-sections with force-carrying bosons of $m_\phi = 1\,\text{GeV}/c^2$ and $m_\phi = 90\,\text{GeV}/c^2$, respectively. Taken from [9].

the annihilation products and the gas, following the detailed calculation of DM-induced shower propagation and energy release performed by [15].

We find that the most extreme enhancements are already ruled out by existing CMB data, while enhancements of order 10^3–10^4 with respect to thermal value $\sigma_v = 3 \times 10^{-26}\,\text{cm}^3/\text{s}$, required to explain the PAMELA and ATIC data, will be probed over a larger WIMP mass range by Planck. We also note that for small enough m_χ, a CMB experiment allows us to probe the region of thermal cross-sections, and that Planck sensitivity will reach it, making it possible perhaps to find hints of particle DM in CMB data.

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REFERENCES

[1] Hinshaw G. *et al.*, *Astrophys. J. Suppl.*, **180** (2009) 225 (arXiv:0803.0732).
[2] Reichardt C. L. *et al.*, *Astrophys. J.*, **694** (2009) 1200 (arXiv:0801.1491).
[3] Peebles P. J. E., *Astrophys. J.*, **153** (1968) 1.
[4] Zel'dovich Ya. B., Kurt V. G. and Sunyaev R. A., *Sov. Phys. JETP.*, **28** (1969) 146.
[5] Seager S., Sasselov D. D. and Scott D., *Astrophys. J.*, **523** (1999) 1, astro-ph/9909275.
[6] Planck Collaboration, arXiv:astro-ph/0604069.
[7] Hu W., Scott D., Sugiyama N. and White M., *Phys. Rev. D*, **52** (1998) 5498.
[8] Rubiño-Martín J. A., Chluba J., Fendt W. A. and Wandelt B. D., *Mon. Not. R. Astron. Soc.*, **403** (2010) 439.
[9] Galli S., Iocco F., Bertone G. and Melchiorri A., *Phys. Rev. D*, **80** (2009) 2 (arXiv:0905.0003).
[10] Malyshev D., Cholis I. and Gelfand J., *Phys. Rev. D*, **80** (2009) 063005.

[11] ADRIANI O. *et al.* (PAMELA COLLABORATION), *Nature*, **458** (2009) 607 (arXiv: 0810.4995).
[12] CHANG J. *et al.*, *Nature*, **456** (2008) 362.
[13] ABDO A. A. *et al.*, *Phys. Rev. Lett.*, **102** (2009) 181101.
[14] LATTANZI M. and SILK J., *Phys. Rev. D*, **79** (2009) 083523 (arXiv:0812.0360).
[15] SLATYER T. R., PADMANABHAN N. and FINKBEINER D. P., *Phys. Rev. D*, **80** (2009) 043526.