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Chapter 6

Future prospects

Really significant progress (that allows, for example, to cover the whole region of parameter space in Fig. 5.28) in searching for decaying dark matter cannot be achieved with the existing instruments by simply increasing the exposure of observations. Indeed, the width of the dark matter decay line, $\Delta E/E_\gamma$ is determined by the virial velocities of dark matter particles in halos and ranges from $\mathcal{O}(10^{-4})$ for dwarf spheroidal galaxies to $\mathcal{O}(10^{-3})$ for the Milky Way-size galaxies to 10^{-2} for galaxy clusters. If the spectral resolution is much bigger than the width of the line, one averages the photons from the line with the background photons over a large energy bin. This is the case for all existing X-ray missions, whose detectors are based on CCD technology (c.f. [410]) and where the spectral resolution is at the level $\Delta E/E \gtrsim 10^{-2}$, see Fig. 6.1. Therefore, *an X-ray spectrometer with the energy resolution at least $\Delta E/E \sim 10^{-3}$ is crucial for detection of a decaying dark matter line.*

The technology behind such spectrometers (known as *X-ray micro-calorimeters*, see e.g. [411, 412]) has been actively developed by the high-energy astrophysical community in the last decades. There is a strong interest for building such a spectrometer, and different versions of high resolution X-ray missions had been proposed in response to the ESA and NASA calls (including the ESA's call for Fundamental Physics Roadmap), see e.g. [75, 365, 413–415]. Astrophysical interest to X-ray spectrometer is motivated by a number of important applications to observational cosmology, providing crucial insight into the nature of dark matter by studying the structure of the "cosmic web". In particular, (i) search for *missing baryons* in the cosmic filaments;

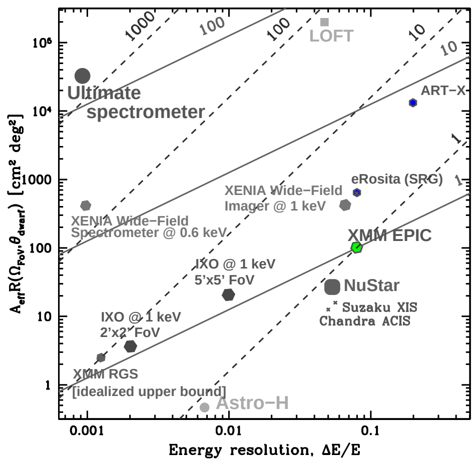

Figure 6.1: Comparison of sensitivities of existing and proposed/planned X-ray missions for the detection of the dark matter decay line in a nearby dwarf spheroidal galaxy of the angular size of 1°. The sensitivity of XMM-Newton EPIC camera is taken as a reference. Solid lines indicate improvement of the sensitivity by factors of 1, 10 and 100 (the top left is the most sensitive). The dashed lines show the improvement of the sensitivity towards the detection of a strong line (in an effectively background free regime). See also [75, 229]

through their emission and absorption ; (ii) trace the evolution and physics of clusters out to their formation epoch; (iii) use gamma-ray bursts as backlight to observe the warm-hot intergalactic media in absorption; (iv) study the evolution of massive star formation using Gamma Ray Bursts to trace their explosions back to the early epochs of the Universe ($z \sim 6$) (see e.g. [365, 414, 415]).

The first spectrometer based on this technology was flown (albeit unsuccessfully) on *Suzaku* mission [416] and another one is being planned for the Astro-H [413, 417] (to be launched in 2014). However, currently planned and proposed X-ray micro-calorimeter missions (Astro-H [413], Athena [415], ORIGIN [414], etc.) are not optimal for the purpose of decaying dark matter search. These missions are optimized for the astrophysical goals and have limited field-of-view (usually, much below $1\,\mathrm{deg}^2$), good angular resolution and narrow energy range.

On the contrary, the *key parameters* that determine the sensitivity of the proposed instrument for decaying dark matter search are (see Fig. 6.1):

– a spectral resolution $\Delta E/E \lesssim 10^{-3}$ over the range of energies $0.5 - 25\,\mathrm{keV}$ (this is the minimal energy range, that would allow to probe the parameter space of our baseline model, the νMSM);
– large '*grasp*' $\sim 10^3 - 10^4\,\mathrm{cm}^2 \times \deg^2$. There are essentially two possibilities to achieve such a grasp. One can either launch a non-imaging spectrometer (with a 'collimator' having a field-of-view as large as $\sim 10^2\,\deg^2$)[1]; or install mirrors (thus increasing the effective area beyond the geometric size of the detectors, probably to as much as $10^3\,\mathrm{cm}^2$). The latter option allows to have also imaging capabilities, however, it is usually extremely costly to cover the required energy range and to have sufficiently large (at least $1^\circ \times 1^\circ$) field of view.

Fig. 6.1 summarizes sensitivity of existing and proposed missions and demonstrates that none of them would provide a sufficient improvement with respect to the existing constraints (see [75, 229] for discussion).

Currently, there exists a project (the *X-ray quantum calorimeter*, XQC [418]) that can be considered a prototype of the proposed mission. It has the field of view of about $1\,\mathrm{sr}$ ($3.5 \times 10^3\,\deg^2$), an effective area of $\sim 1\,\mathrm{cm}^2$ and the energy resolution of 10 eV over the energy range $0.1 - 4\,\mathrm{keV}$ [418].[2] This calorimeter has been flown several times on sounding rockets [418]. Although each flight had been very short (about 100 seconds), it allowed to demonstrate that the Milky Way emission in the energy range $0.1 - 1\,\mathrm{keV}$ (which looks as a continuum in the spectra obtained with X-ray imaging instruments, see e.g. [327, 419] is actually a "forest" of thin lines (see Fig. 6.2). Because of its superior spectral resolution, decaying dark matter bounds based on the ~ 100 sec exposure of the flight of this spectrometer [418] are comparable with 10^4 sec of the *XMM-Newton* exposure [229].

To detect a dark matter decay line, that is much weaker than the lines resolved with the XQC spectrometer, a significantly longer exposure ($\sim 1\,\mathrm{year}$)

[1]Making field-of-view significantly large than about $10^\circ \times 10^\circ$ would of course further increase the sensitivity towards the line detection. However, in this case it would become challenging to identify the nature of the candidate line (if found), as in this case none of the nearby dark matter dominated objects with large angular size (Andromeda galaxy, Large and Small Magellanic clouds, Virgo cluster) will look like 'hot spots' of dark matter decays. Moreover, in this case it will not be possible to build a dark matter surface brightness profile as one varies the directions off the Galactic Center and investigate whether it is consistent with dark matter distribution in the Milky Way.

[2]A similar calorimeter used in Suzaku was capable of delivering a similar resolution up to the maximal energy range of 12 keV [416].

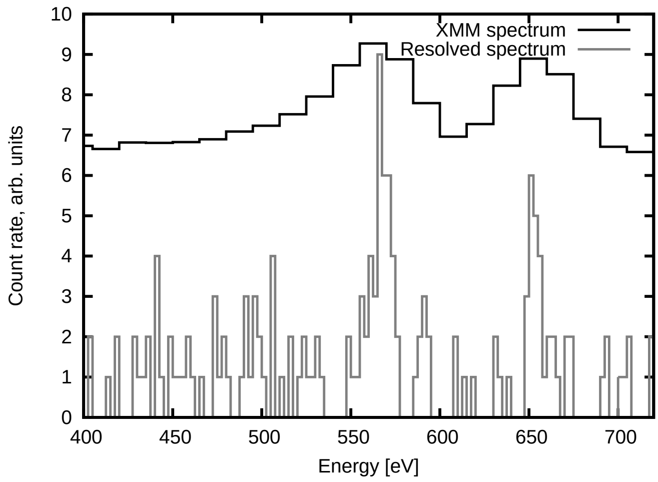

Figure 6.2: Galactic diffuse background (observed with *XMM-Newton* (black) and the same data, observed with the X-ray spectrometer (XQC project [418]).

would be required. The requirement to keep the cryostat of such a spectrometer in the stable regime, means that one cannot use the sounding rockets, but rather needs to use a satellite (probably, staying in Low Earth Orbit, unlike *XMM-Newton* or *Chandra*). The project therefore becomes a small-to-medium scale cosmic mission.