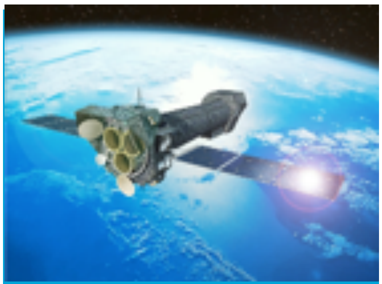
OBSERVATION OF A LIGHT DARK MATTER SIGNAL?

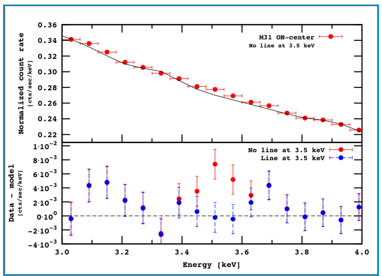
The fact: observation

In February 2014, the authors of [1] and [2] analyzed data of the European satellite XMM-Newton. These studies were based on the X-rays observation of the spectrum emitted by clusters of galaxies like Perseus or nearby dwarf galaxies as Andromeda (M31). These clusters are some of the more massive objects in the Universe and contain thousands of galaxies of the Milky Way type. Perseus is at a distance of 240 millions light years and is immersed in a giant cloud of gaz of millions degrees, emitting radiation of the order of keV[1] (kilo-electronVolt) corresponding to X-rays frequencies. This range of frequencies is precisely the one observed by satellites like Chandra (NASA) or XMM-Newton (ESA), both launched in 1999.



The satellite XMM Newton (X-ray Multi-Mirror) was launched by the European Space Agency in 1999. It gives a cartography of the sky between 0.1 and 12 keV.

The results of these analyses surprised the astrophysics and nuclear community. Indeed, the spectrum has some unexplained features, an excess under the form of a « peak » (at more than 99.9% of confidence level) for photons of energy around 3.5 keV (see figure on the right). This signal corresponds to a flux of one photon per meter square and per second. Several articles then appeared trying to find a coherent explanation to this phenomena. Until now, not a single astrophysical source can justify such an excess of photons at this energy.



Photon spectrum (number of photons as function of their energy in keV) emitted by Andromeda galaxy (M31) in the X-rays frequencies, and observed by XMM-Newton [2]. In the lower plot, the blue dots correspond to the values predicted by astrophysical model without dark matter component, the red ones are the values observed by XMM-Newton. We clearly see an excess of red points around 3.5 keV.

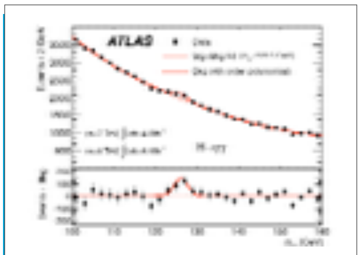
The interpretation: a dark matter candidate?

The galaxies and clusters of galaxies are very well studied objects in astrophysics, and more precisely in the field of astroparticle. Indeed, these massive objects are considered as being the main place to look for the dark matter in the Universe. The visible light that we observe, emitted by stars or interstellar gaz, represents only 10% of such structures. The dark

[1] The electronvolt is a typical unit of mass and energy in particle physics. One electronvolt corresponds to the energy acquired by an electron accelerated under a potential of one volt. A proton travelling at 300 km/s (typical velocity in our galaxies) possess a 1 keV kinetic energy.

matter (that we call χ of mass M_χ) interacts only very weakly with gaz or compact objects like stars or pulsars. Its detection is by observing indirect processes through its auto-annihilation where two particles collide, or its decay if it is unstable. The main effect of such interactions is the emission of photons with an energy of the order of the dark matter mass (energy conservation). Moreover, if the annihilation occurs directly without intermediate state, the energy E_γ of the photon is monochromatic and thus has a well defined energy $E_\gamma = M_\chi$. This produce a spectrum with a peak, of the same nature than the one observed by XMM-Newton.

Recently, researchers from the LPT Orsay and Ecole Polytechnique proposed a scenario [3] where a relatively light dark matter could be the source of such a signal. During their trajectories in the cluster of galaxies, there exists a non-null probability that two particles of dark matter collide (see the frame below). In this case, as a results, two mono-energetic photons of opposite directions are produced: one travelling toward our solar system and the satellite, whereas the other one escaped from the cluster. The researchers computed the probability for such an event to occur corresponding to the signal observed (a « cross section » σv). They obtained[2] $\sigma v = 10^{-37}$ cm^2 s^{-1}. They then showed that this interaction rate is quite natural in the framework of motivated theoretical buildings where the dark matter interacts via the exchange of a second Higgs boson (ϕ) much lighter than the one discovered at the LHC in July 2012 (h) : M_ϕ = 1 MeV (M_h=125 000 MeV). Moreover, this second Higgs boson is also predicted in order to explain large scale structures formation, solar anomalies, or the shape of the dark matter profiles near galactic centers. The decay of this intermediate boson in two photons : $\chi\,\chi \rightarrow \phi \rightarrow \gamma\,\gamma$ is by chance the same process which gave the opportunity to discover the standard Higgs boson at CERN through its decay $h \rightarrow \gamma\,\gamma$, generating a similar peak in the spectrum of LHC detectors (see figure on the right).



Photon spectrum of the Higgs boson discovery in 2012 at CERN. Notice the similarities with the spectrum observed by XMM-Newton (figure in the preceding page) justifying naturally the presence of a second lighter Higgs boson.

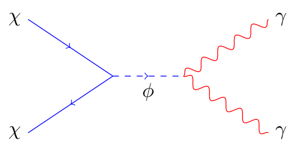
Alternatives

The signal has not yet any pure astrophysical explanation. On the other hand, other candidates have been proposed by Japanese [4] and American [5] team. In the first case, the authors proposed an unstable dark matter candidate, coupling very weakly to the neutrino, a standard model particle almost massless. If the coupling is sufficiently weak, the dark matter can have a lifetime of the order of 10^{28} seconds, much more than the age of the Universe, but decaying slowly into photon and neutrino (see frame). The other possibility developed in [5], is the presence of an excited state of the dark matter, as it exists in nuclear physics. During the process of desexcitation, there would be emission of a mono-energetic photon of 3.5 keV, the one observed by XMM-Newton.

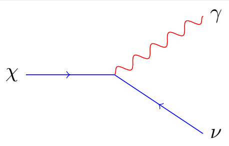
[2] This corresponds to a collision every 10^{28} seconds, largely compensated by the huge number of dark matter particles in the clusters of galaxies.

It is also interesting to notice that all the candidates proposed belong to a family of dark matter called « warm dark matter », by opposition to « cold dark matter » or « hot dark matter ». Indeed, keV particles are relatively light[3] and their ratio kinetic energy / mass is quite high. They are thus « warm ». This characteristic can explain the small number of satellite galaxies around the Milky Way, because the kinetic energy of the dark matter would forbid the formation of too large structures; this is the « free-streaming » mechanism: a too hot dark matter candidate would inferred the formation of our own galaxy, whereas a too cold dark matter would have allowed the creation of hundreds of galaxies around us that have not been observed[4]. In any case, this signal open a new way of research and gives interest to light dark matter models which will be very promising in the next few years.

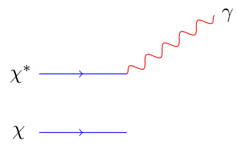
Annihilating, decaying or exciting dark matter?



Annihilation [3]



Désintégration [4]



Désexcitation [5]

Following the discovery of the anormal signal emitted by clusters of galaxies, several dark matter scenarios has been proposed by the authors of [4,5,6]. The dark matter χ could annihilate in the clusters of galaxies after several collisions. They would produce a light Higgs boson ϕ which would decay into two photons γ (left). Another possibility is that the dark matter is not completely stable but possesses a lifetime longer than the age of the Universe, giving us an illusion of stability. Its decay into photon γ and neutrino ν would be the source of the signal observed by XMM-Newton (middle). A third possibility would be that the dark matter exist under two states: one stable, χ and the other excited χ^*, as it exists in the radioactive element families on earth (right). The photon emitted during the desexcitation of the dark matter would be the one precisely observed by the satellite.

[1] « Detection of An Unidentified Emission Line in the Stacked X-ray spectrum of Galaxy Clusters » by E. Bulbul, M. Markevitch, A. Foster, R. K. Smith, M. Loewenstein, S. W. Randall; http://arxiv.org/abs/1402.2301

[2] « An unidentified line in X-ray spectra of the Andromeda galaxy and Perseus galaxy cluster » by A. Boyarsky, O. Ruchayskiy, D. Iakubovskyi, J. Franse; http://arxiv.org/abs/1402.4119

[3] « Generating X-ray lines from annihilating dark matter » by E. Dudas, L. Heurtier and Y. Mambrini

[4] « 7 keV sterile neutrino dark matter from split flavor mechanism » by H. Ishida, K.S. Jeong, F. Takahashi; http://arxiv.org/abs/arXiv:1402.5837

[5] « An X-Ray Line from eXciting Dark Matter » by D. P. Finkbeiner and N. Weiner; http://arxiv.org/abs/1402.6671

[3] Compared to the Higgs boson, 100 000 times heavier.

[4] The Milky Way is surrounded by only 20 nearby galaxies.