The search for X-ray emission from electron/positron pair halos using the *XMM-Newton* observatory

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Abstract. An electron/positron pair halo is formed by electromagnetic cascades that initiate when high energy gamma-rays from extragalactic sources – i.e. Blazar AGN – interact with the cosmic infrared background (CIB), and are then absorbed via the electron/positron pair production process. The high energy electron/positron pairs produced could up-scatter the cosmic microwave background (CMB) and become gamma rays which can interact with CIB again. Thus, the process could happen continuously until the produced gamma-rays have insufficient energy to interact with the CIB. Indeed, given the presence of intergalactic magnetic field, the produced electron/positron pairs could gyrate before scattered with the CMB photons so that they emit X-ray photons via the synchrotron radiation process. In this work, we determine whether the predicted X-ray photons emitted from the halo can be detected by the current generation X-ray observatory: *XMM-Newton*. The Spectral Energy Distributions (SEDs) of the synchrotron radiation of the pair halo predicted to be obtained from the AGN H1426+428 are simulated by the Monte Carlo simulations method; these are used as a source model for simulating observed spectra. The spectra of the halo virtually observed by *XMM-Newton* are generated in three different regions: the inner region, outer region and the region out of the *XMM-Newton's* field of view. The resulting spectra suggest that the outer region spectra could provide the best opportunity to detect and confirm the existence of electron/positron pair halos.

1. Introduction

An electron/positron pair halo was first proposed in 1994 by Aharonian [1]; it is formed by electromagnetic cascades that initiate when high energy gamma-rays from an AGN are absorbed by the cosmic infrared background (CIB) via the electron/positron pair production process. The produced high energy electron/positron pairs could up-scatter the cosmic microwave background (CMB) and become gamma rays which can interact with the CIB again. Thus, the process can occur continuously until the produced gamma-rays have insufficient energy to interact with the CIB. According to the model, the calculated size of electron/positron pair halos is in the order of $\sim$ 10 Mpc and appear to enclose the central AGN [2]; the gamma rays which have energy in the range of 0.1 - 10 TeV are predicted to be emitted from the halo [1]. Indeed, given the presence of the intergalactic magnetic field (IGMF), the produced electron/positron pairs could gyrate before being scattered with the CMB photons so that the halo also emits X-ray photons via the synchrotron radiation process [3]. Importantly, the discovery of pair halo emission would provide a new tool to probe the CIB and the IGMF around AGNs. The first attempt to observe the pair halo was in 2001. The High-Energy Gamma Ray Astronomy (HEGRA) team [4] attempted to detect gamma rays from the halo using the its gamma-ray telescope; however, no detection was claimed. Later, in 2009, Eungwanichayapant and Aharonian [5] further calculated the angular distribution of the gamma ray emission; the detectable distance of the AGN has been proposed. A year later, Ando and Kusendo [6], reported the detection of the electron/positron pair halo from the AGN which has a magnetics field of ∼1 fG. However, it was argued by Neronov [7] that the detection is artificial due to systematic errors of the telescope instruments. Nevertheless, the SEDs and angular distribution of the halo in the X-ray waveband were proposed in 2011 [3]. Until now, there has still not yet been an attempt to search for such an emission in this regime. Among the current generation of X-ray observatories, *XMM-Newton* cameras – EPIC pn, MOS1 and MOS2[1] – are the best instruments for hunting the halo X-ray emission, given that they have the largest effective areas [8]. In this research, we will demonstrate whether the current generation of X-ray telescope – *XMM-Newton* –will be able to detect such an emission. The paper is laid out as follows. In Section 2, we explain how the SEDs in the X-ray waveband are generated; then the method used to simulate *XMM-Newton* spectra is shown in Section 3. We then discuss and conclude these in light of the obtained results in Section 4.

2. Simulation of SEDs

In this work, we simulated the X-ray SEDs expected to be obtained from the AGN H1426+428 which is a BL Lacertae object with a luminosity in the order of 10^{45} erg s^{-1} [9] and located at $z = 0.129$. This object has been observed the absorption feature in the gamma-ray spectra [10] and is expected to have a gamma pair halo [11]. Given the source properties, we simulated the X-ray SEDs using parameters similar to that of the AGN: the monoenergetics, intrinsic gamma ray photon energy of 100 TeV, source luminosity of 10^{45} erg s^{-1} and a magnetics field of 1 μG. The SEDs were calculated using Monte Carlo simulations following the model of Eungwanichayapant et al. 2011 [3]. All electromagnetic cascades from the AGN were simulated to get the energy and spatial distributions of the electrons/positrons to compute the energy and angular distributions of the X-ray photons from the pair halo. However, to search for the X-ray emission from the halo using the *XMM-Newton* observatory, we should consider the X-ray flux from the central AGN. Therefore, in this work we separated the observed radiation regions of the AGN H1426+428 into three regions: region A, B and C. Region A covers the angular distance from 0 – 0.133 degrees. This is the area that the contamination of X-ray emission from the AGN could dominate the X-ray emission from the pair halo. Region B covers the angular distance from 0.133 – 0.200 degrees. This part is still in the field of view of *XMM-Newton* but sufficiently far away that we can ignore the AGN X-ray emission. Region C covers the angular distance from 0.200 to infinite degree which is an area outside the telescope's field of view.

The simulated SED of the X-ray emission from each region is shown in figure 1.

3. Simulation of *XMM-Newton* spectra

In order to simulate the halo spectra of the AGN H1426+428, assuming that the source is observed by the *XMM-Newton* telescope, the three SEDs generated in Section 2 were used as the emission models of the H1426+428 halo. The simulation was performed by the X-ray spectral fitting package (XSPEC) version 12.9.[2] Firstly, the SED data obtained from Section 2 was converted into the FIT file format (i.e. XSPEC table models) to make them readable by XSPEC.

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[1] https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/epic.html

[2] https://heasarc.gsfc.nasa.gov/xanadu/xspec/

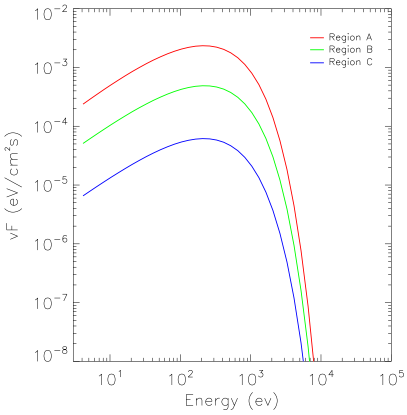

Figure 1. The pair halo X-ray SEDs simulated by assuming the monoenergetics, intrinsic gamma ray photon energy of 100 TeV, source luminosity of 10^{45} erg s^{-1} and the magnetics field of 1 μG.

In addition, we also added the absorption column (N_{H}) of 1.11×10^{20} atoms cm^{-2} into all the SED models to account for galactic absorption along the direction to the AGN H1426+428 [12]. Thus, the multiplicative models of N_{H} absorption and SED were used as a basis for the observed spectral simulations. After the models were well defined in XSPEC, the *XMM-Newton* spectra were simulated using the XSPEC command FAKEIT for all three *XMM-Newton* detectors: pn, MOS1 and MOS2; while the Response Matrix File (RMF) and Ancillary Response File (ARF) of each instrument at the current telescope cycle used in the simulation were obtained from the observatory's official webpage.[3] The spectra were generated using counting statistic, assuming the source exposure time of 500 ks.

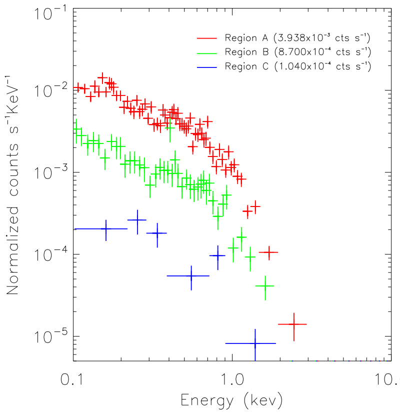

Figure 2. The simulated pn spectra of the pair halo obtained from the AGN H1426+428. The observed count rates are also shown in the plot legend.

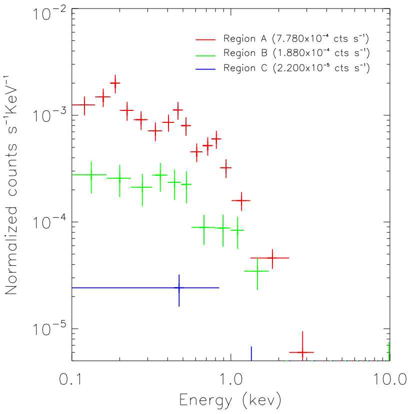

Figure 3. As for figure 2., the simulated MOS spectra.

The simulated spectra as well as the corresponding observed count rate of the AGN H1426+428 that is virtually observed by *XMM-Newton* are shown in figure 2 (for pn spectra) and figure 3 (for MOS1 and MOS2 spectra). As expected, the observed halo flux from region A is highest while regions B and C are relatively in the middle and lowest respectively, since

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[3] https://heasarc.gsfc.nasa.gov/docs/xmm/xmmhp_prop_tools.html

the halo flux should be reduced as a function of the distance from the central AGN. Assuming that the AGN H1426+428 is simultaneously observed by *XMM-Newton* pn, MOS1 and MOS2 detectors for 500 ks, a total photon counts of 2700, 580 and 70 should be expected to be obtained from regions A, B and C, respectively.

4. Discussion and Conclusion

In this work, the X-ray SEDs expected to be emitted from the AGN H1426+428 halo were calculated by Monte Carlo simulations following the proposed model [3]. Then, the observed spectra of the halo from the three different regions – region A, B and C – were simulated. Obviously, most of the halo X-ray photons (2700 counts, ∼80%) could be detected in region A, whilst only 580 counts (∼17%) and 70 counts (∼3%) were detected in regions B and C, respectively. In other words, up to ∼97% of the halo photons would fall into the *XMM-Newton* detectors. In fact, given that up to 2700 photon counts would be detected in region A, this might be a region with good potential to search for the halo X-ray emission. However, since the AGN is also located in this region, the halo photons could be much diluted by the AGN photons; indeed, more than ten million counts could be obtained from the AGN so that it is difficult to resolve the halo photons from that of the AGN. Although it is not impossible to perform an analysis in this region, the analytical methods that might be used to distinguish the halo X-ray photons from the AGN emission are outside the scope of this work and are not discussed here.

Given the complication of the analysis in region A, another chance to detect the halo emission could lie in region B. Although only 580 halo photons were detected in this region, we could be confident that the spectra will not be contaminated by the AGN emission. Thus, by carefully subtracting the instrument background from the observed spectra of the AGN H1426+428 in region B, the resulting spectra should provide the opportunity to detect and confirm the existence of electron/positron pair halos.

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