Searching for X-ray emission from an e⁻/e⁺ pair halo with X-ray telescopes

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Electron/positron (e±) pair halo [1,2] is a physical phenomenon in which the very high energy gamma rays (γ_0) emitted from a blazar interact with cosmic infrared background (CIB) so that produce the e± pairs; the produced e± pairs could up-scatter the cosmic microwave background (CMB) reproducing the gamma-rays (γ), thus these form the cascade process of producing the e± pairs appearing as a halo around the blazar. In case that the halo presents in the strong ambient magnetic field, the e± pairs could emit X-ray light via synchrotron process providing another opportunity to detect the halo [3]. Here, we search for the X-ray emission from the halos using X-ray telescopes: i.e. *XMM-Newton* and *Athena*.

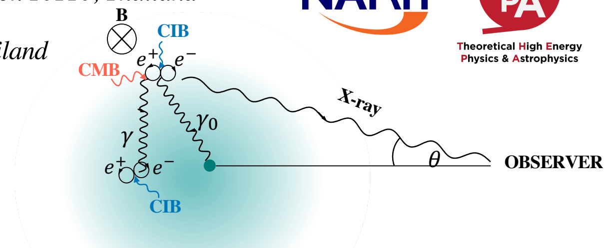

Figure 1. *The diagram shows X-ray emission from a pair halo.*

MODEL AND THEORETICAL PREDICTION

We simulated the electromagnetic cascades generated by intrinsic VHE gamma-rays as shown in Fig. 1. The e± pairs radiate synchrotron radiation during their gyrations. The synchrotron emission time distributions were computed during the simulations and used for calculating the spectral energy (SED) and surface brightness distributions (SBD). The SEDs and SBDs of X-ray that θ is < 0.1° in different conditions of pair halos from H1426-428 assuming that its gamma luminosity is 10^{45} erg s^{-1} were shown in Fig. 2. We observed that the SEDs are very sensitive to the seed gamma-ray energies between 10 to 100 TeV. The SBDs are more compact and centrally peaked when the energies of seed gamma-ray are higher, but this does not occur when magnetic fields increase.

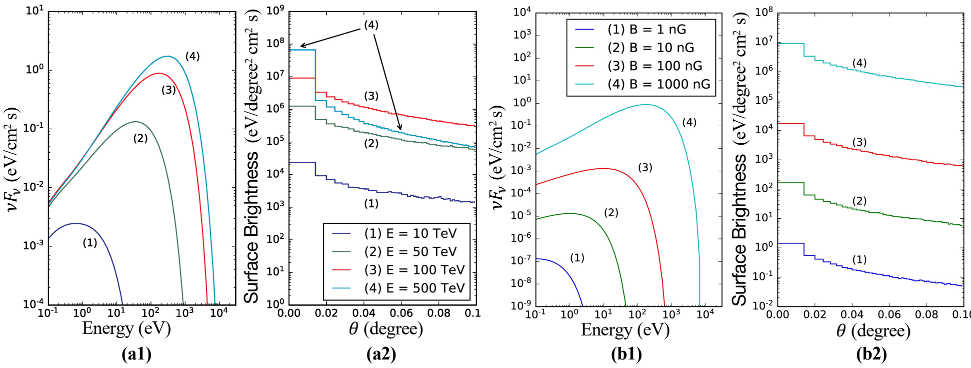

Figure 2. *The simulation results from Eungwanichayapant et al. (2019) [4] showed the spectral energy and surface brightness distributions of X-ray pair halos in different seed gamma-ray energies* (**a1-2**; B=1000 nG) *and magnetic fields* (**b1-2**; E=100 TeV)

OBSERVATIONAL FEASIBILITY

Here, we test whether the pair halo X-ray emission purposed above would be detected by current and near future X-ray instruments: *XMM-Newton* pn and *Athena* Wide Field Imager (WFI)? The observed count rates of the halos for each instrument were simulated by XSPEC using the RMFs and ARFs available in the official web pages of the observatories. During the simulation, we considered the halos emission as an extended source with the angular radius of 0.1°, having a constant surface brightness. The halo count rates obtained from the different levels of magnetic field (30-1000 nG) and seed gamma-ray energy (10– 500 TeV) were calculated and plotted in Fig. 3. It is clear that we would get more count rate at higher level of magnetic field and/or seed gamma-ray energy; this implies that some halos with appropriate physical conditions could be detected.

However, detecting the halos is not an easy task since X-ray photons detected by the instruments will be dominated by that of the central blazars; in this work, we assume the blazar luminosity of 10^{45} erg s^{-1} located at a distance of 529 Mpc. In addition, we also have to account for the instrument background carefully as the halo count rates in most cases are relatively low. Therefore, we took the instrument and central blazar photons as the background contamination and proceeded to calculate the exposure time required for marginal detection of the halo at the confidence level of 3σ; we overlay the iso-exposure time lines of 100 ks, 1000 ks and 10,000 ks on the plots in Fig. 3.

Using the 100 ks and 10,000 ks exposure time lines, the contour plots in Fig. 3 can be divided into three regions: (i) below instrument sensitivity region (exp. time > 10,000 ks), (ii) challenge-to-detect region (observable window; 100 ks < exp. time < 10,000 ks) and (iii) ready-to-detect region (exp. time < 100 ks). Thus, it is obvious that the halo conditions lie in the region (i) could not be detected since the count rates are much lower than the capability of the instruments to detect the halo. In contrast, for the region (iii), the halos occur from these physical conditions should have been already detected if they exist. However, since there has been no observational evidence reporting the detection of the halo emission in any blazars, these could result in an observational constraint that halos in the real universe might have physical conditions outside this region (albeit the highly careful analysis might be required to search for the halo emission in this region as the halo signal comparing with that of blazars might be low statistically significant). Therefore, in this work, we define the region (ii) as the *observable window* for detecting the halos using the X-ray instruments. Indeed, the required exposure time for detecting the halos at some conditions in this region could match to large and very large programmes of the X-ray observatories (i.e. exposure time ≤ 1000 ks), while the others might need extremely long exposure time (up to 10,000 ks); in the latter case, the detection is possible by stacking the observational data together to meet the required S/N ratio.

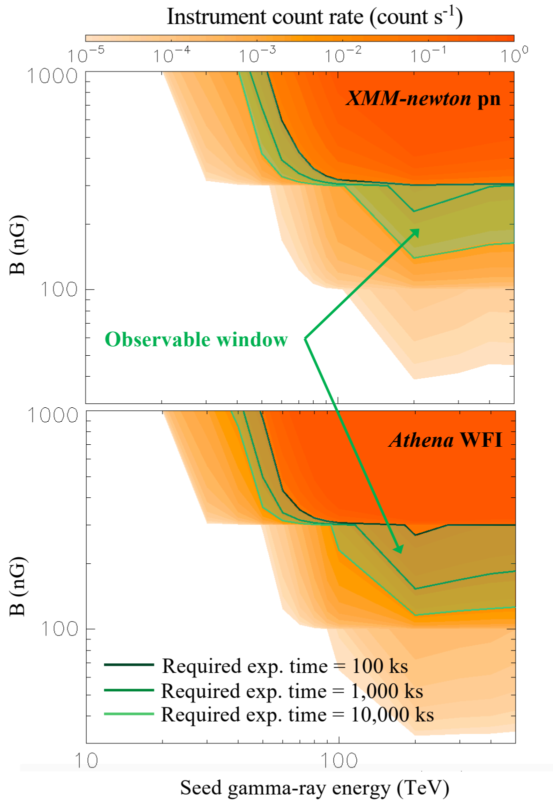

Figure 3. *The instrument count rates of the pair halos.*

Finally, we also compare the capability of *XMM-Newton* pn and *Athena* WFI to detect the halos. While the lowest detectable level of the halo seed gamma-ray energy is about the same (~40 TeV), the weakest magnetic field detectable are quite different. In fact, it is reduced from ~150 nG for *XMM-Newton* pn to 100 nG for *Athena* WFI. Furthermore, the advantage of *Athena* WFI over *XMM-Newton* pn can be seen obviously when the seed gamma-ray energy is >100 TeV; it is found that the required exposure time for the same level of magnetic field could be reduced by a factor of 10 by using *Athena* WFI.

CONCLUSION

In this work, we propose an idea to confirm the existence of pair halos using X-ray instruments. The halo SED were simulated and used as the models for calculating the obtained X-ray instrument count rates. By accounting for the contamination from the central blazars and instrument background carefully, we approximated the required exposure time to detect the halos at different physical conditions. We then identify the observable window - i.e. a range of halo physical parameters – which can be detected by *XMM-Newton* pn and *Athena* WFI.

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