X-ray properties of z>4 Blazars

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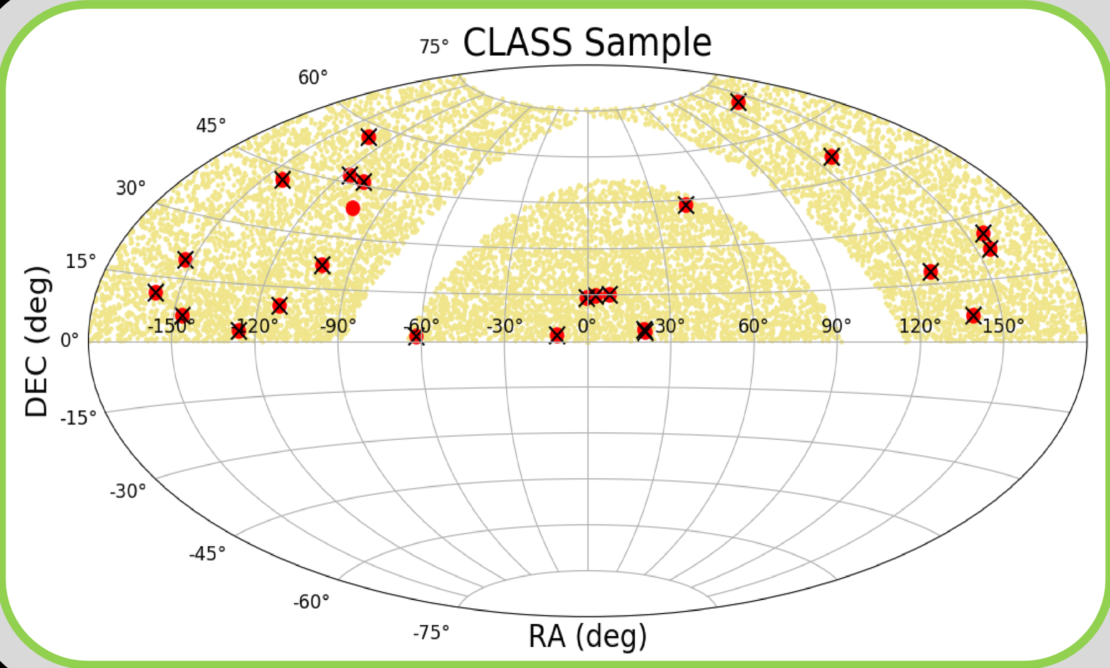
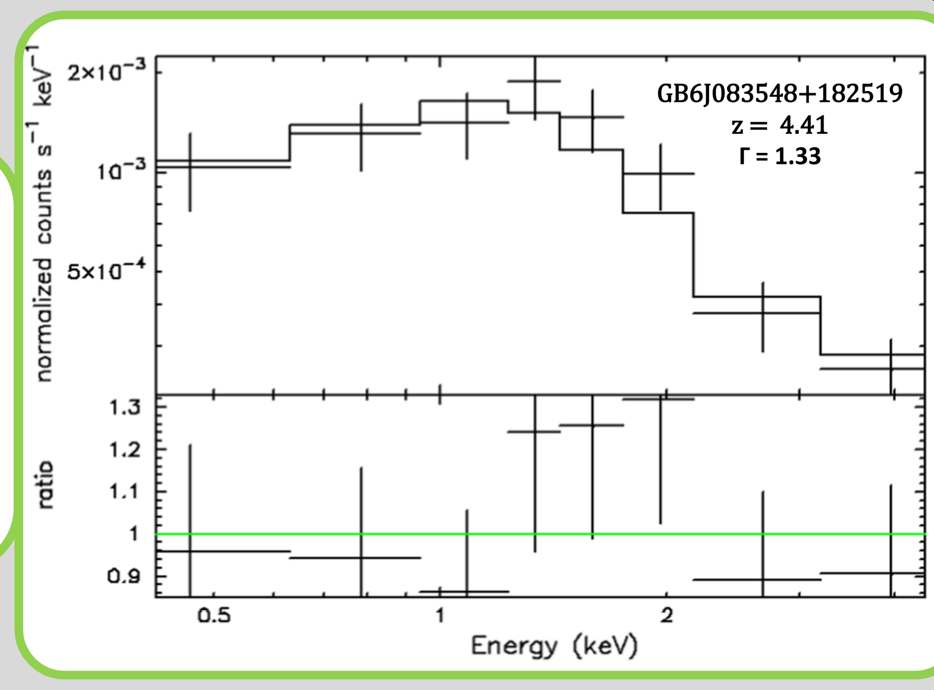
Abstract: We present the X-ray properties of a complete and well-defined sample of 24 high-z (z=4-5.5) blazar candidates selected from the CLASS radio survey. After completing the existing archival data (Swift-XRT, Chandra and XMM-*Newton*) with dedicated Swift-XRT observations, we identified the bona-fide blazars based on the X-ray luminosity (compared to the optical one) and flatness of the X-ray spectrum. We then compared their X-ray-to-radio luminosity ratios with those of a sample of confirmed blazars at lower redshifts ($\bar{z}$=1.1), finding a significant difference in the two populations. We interpret this redshift-dependant evolution of the X-ray-to-radio luminosity ratios due to the interaction of the electrons within an extended part of the jet with the Cosmic Microwave Background photons (see Ighina et al., 2019 for more details).

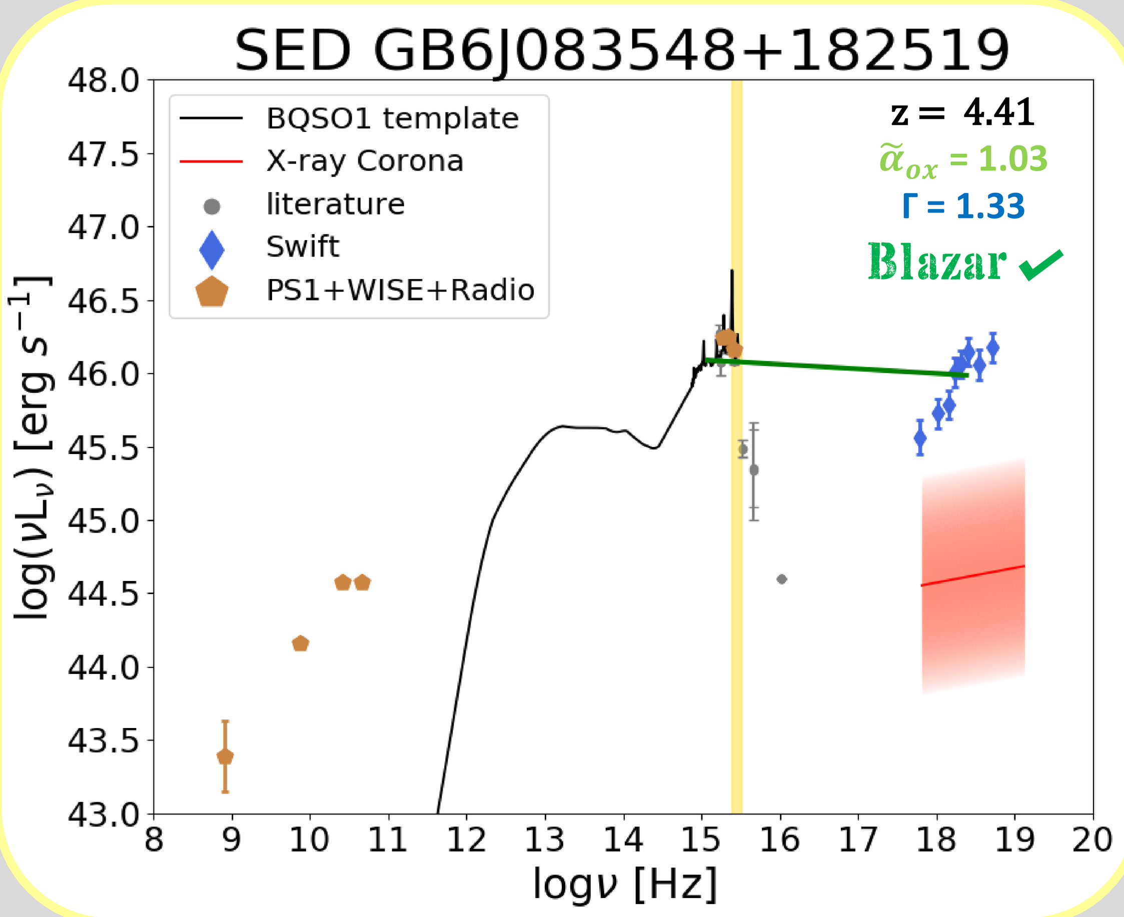
CLASS sample:



All the sources were selected from the CLASS radio survey (S_ν>30mJy at 1.4GHz, yellow points, left Fig). In Caccianiga et al. (2019) we have spectroscopically confirmed the AGNs with a redshift z > 4 (25, red points, left Fig).
We carried out Swift-XRT dedicated observations of 8 sources to complete the archival X-ray data (Swift-XRT, Chandra or XMM–Newton, black crosses, 24 objects in total). We then analysed the observations by fitting the data with a **power-law model filtered by Galactic absorption** (right Fig).



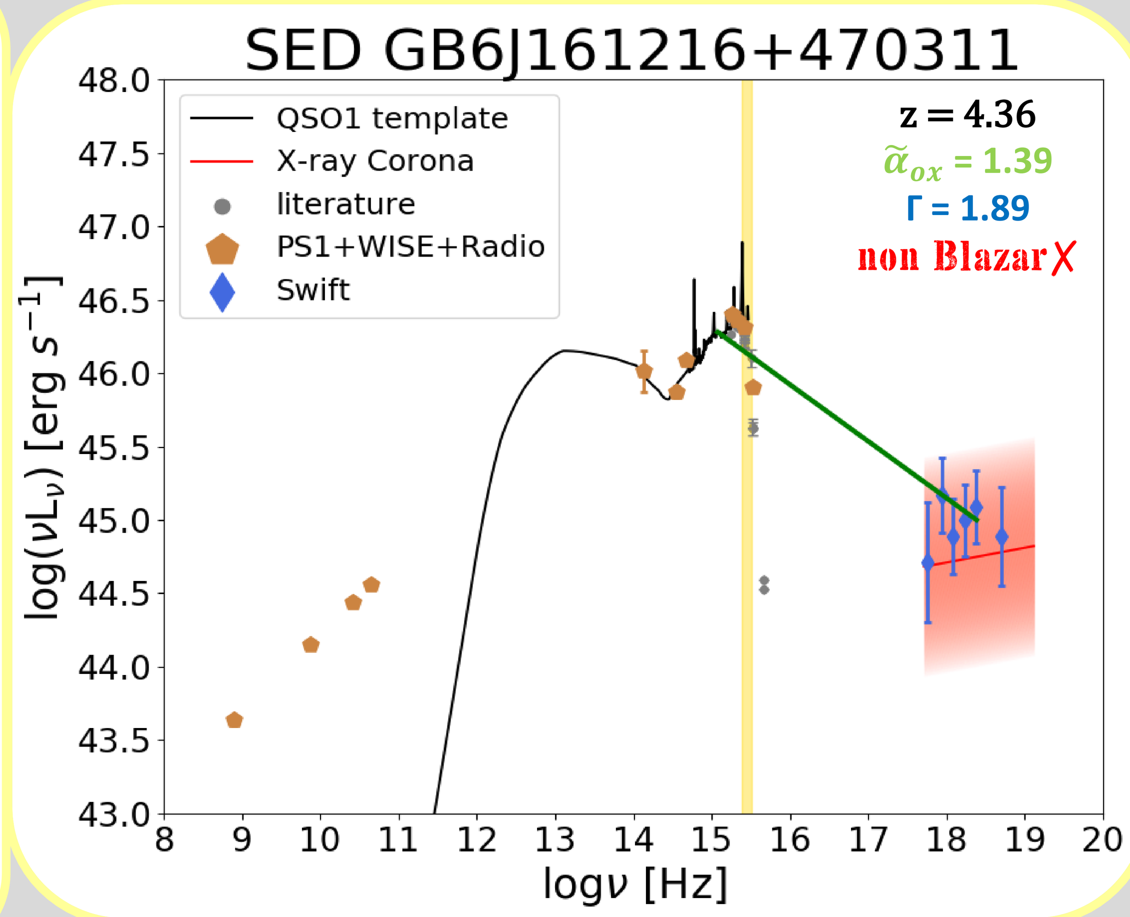
Classification: Blazars vs Non-blazars:

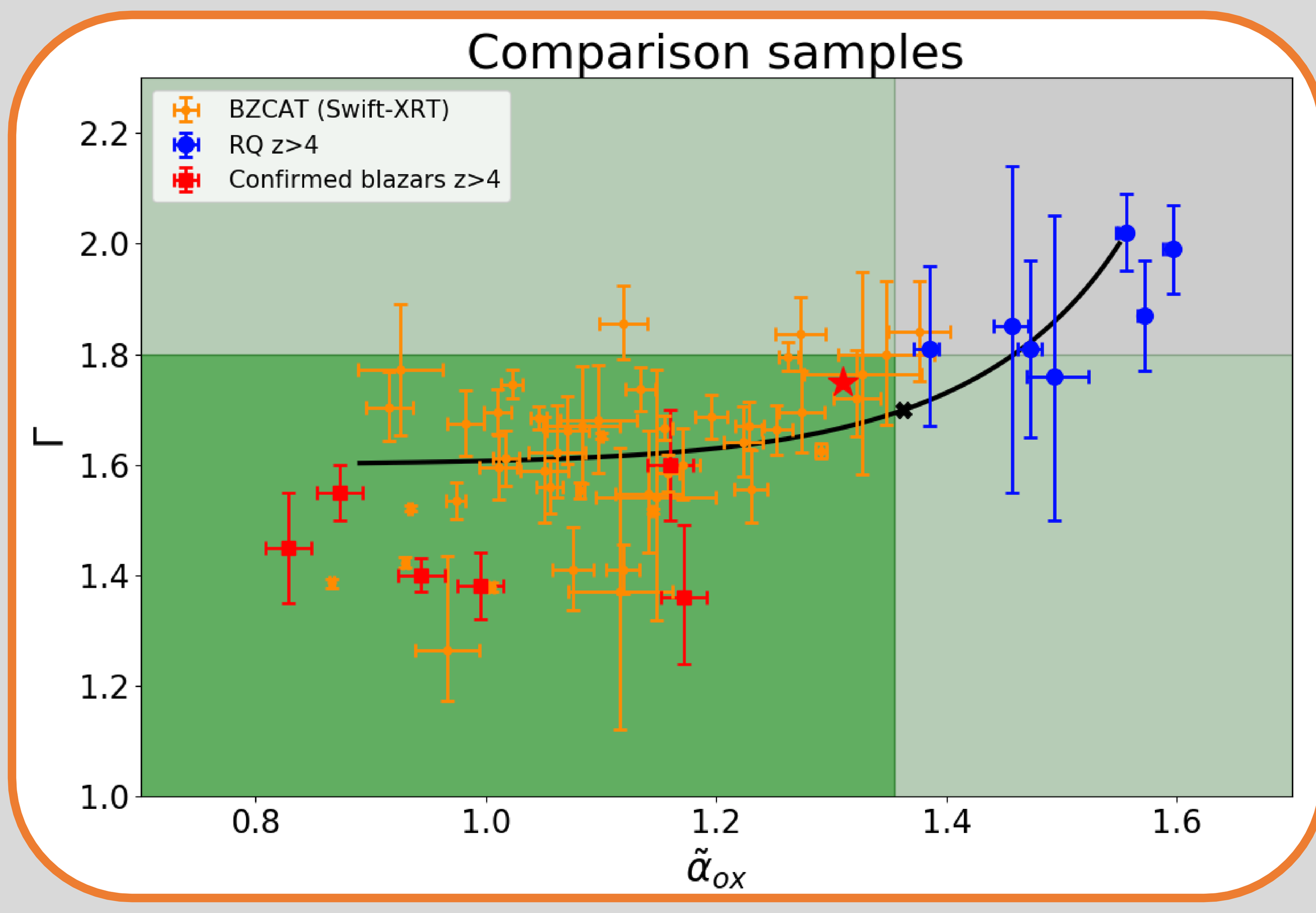


Blazars can be identified thanks to their Flat X-ray spectral indices and Intense X-ray emission (when compared to the optical ones, e.g. Giommi et al. 2019).
As examples, we report here the Spectral Energy Distribution (SED) of two sources in the CLASS sample.
The red region represents the expected X-ray emission from the X-ray corona for radio-quiet (RQ) AGNs with the same optical luminosity of the blazar candidate (Steffen et al. 2006), the slope is assumed to be Γ=1.97 (α_x=0.97, Shemmer et al. 2005). The slope of the continuous green line is given by 1-$\tilde{\alpha}_{ox}$, where the $\tilde{\alpha}_{ox}$ index measure the relative intensity of the X-ray/optical emission:

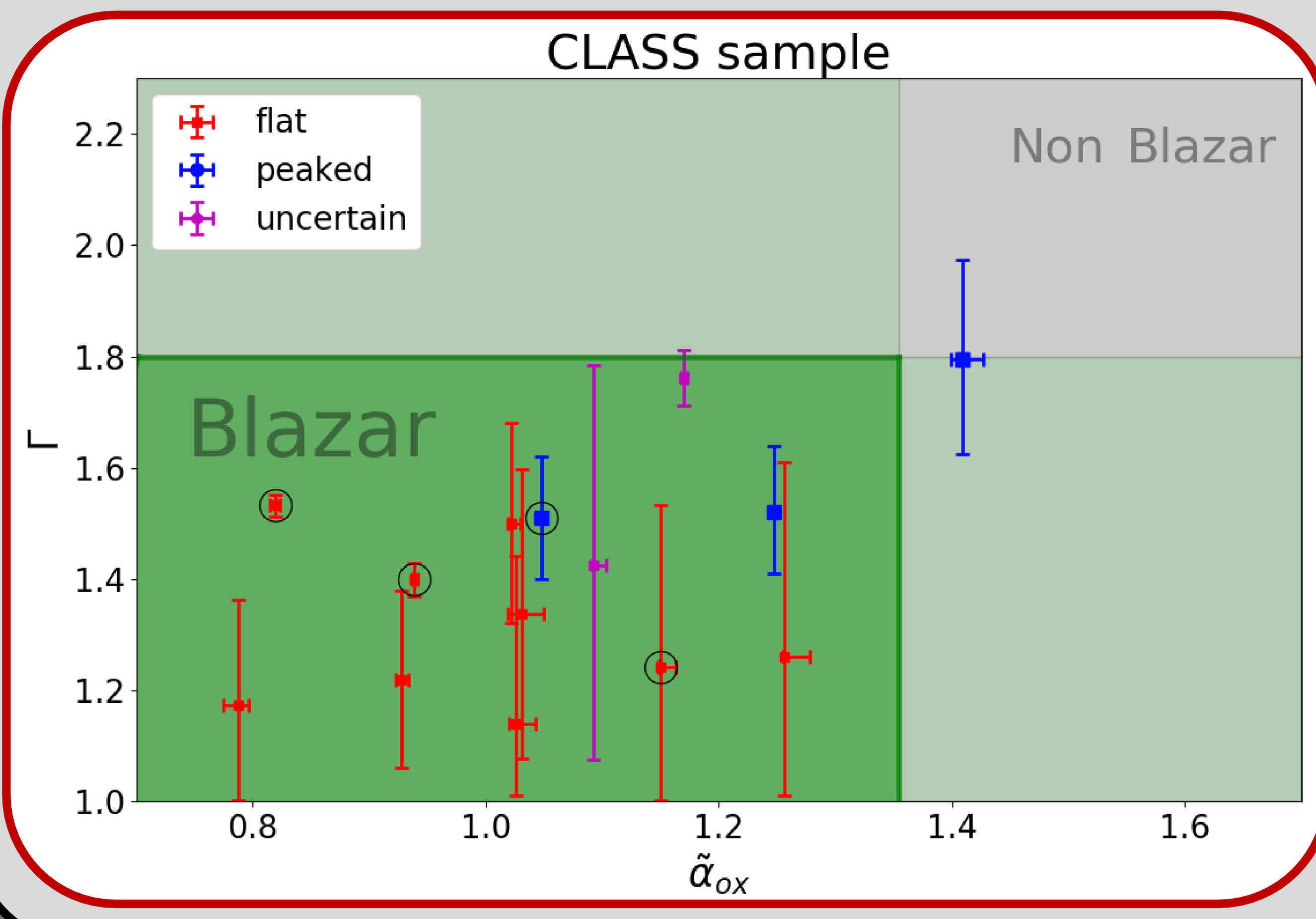
$$\tilde{\alpha}_{ox} = -0.3026 \log(\frac{L_{10keV}}{L_{2500Å}})$$

- **On the left**, a good example of bona-fide **blazar**, with an X-ray emission flatter (i.e. smaller value of photon index) and stronger than the one expected from a RQ AGN;
- **On the right**, the X-ray emission consistent with the one expected from the corona, indicating a **non-blazar** nature.



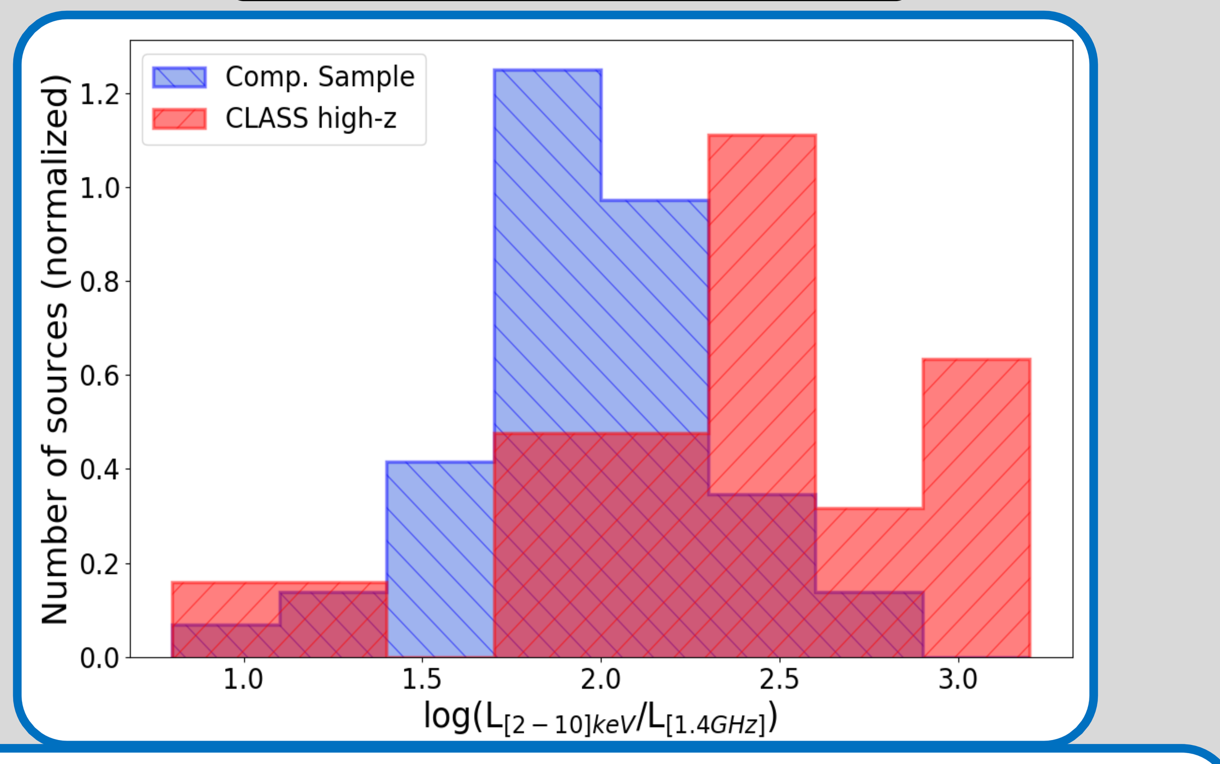


In order to **calibrate the classification** based on these two parameters, we used **three comparison samples and a simple model**:
Orange => **confirmed blazars at $\bar{z}$=1.1** selected from the BZCAT (5th edition, Massaro et al. 2015);
Blue => **RQ AGNs at z>4** (Shemmer et al. 2005);
Red => few **confirmed blazars at z>4** (red star X-ray-weakest one discovered so far, Belladitta et al. 2019);
Black line => predicted dependence of the **photon index with the** $\tilde{\alpha}_{ox}$ according to the beaming model. The black cross indicates the critical angle that discriminates blazars from non-blazars (ϑ=1/Γ_{Lor} , where Γ_{Lor} is the bulk Lorentz factor of the jet), under the assumption that at 10 keV the ratio between the pure jet (ϑ=0) and the corona emissions is 50.



Photon index as a function of the $\tilde{\alpha}_{ox}$ for the sources in the CLASS sample with a reasonable estimate of the photon index (uncertainty <0.4). The different colours represent the classification proposed in Caccianiga et al. (2019) based on their radio properties (flat=blazar, peaked= non-blazar, purple=uncertain). The black circles highlight the confirmed blazars at z>4 in the literature.
The sources with large errors on the Γ (>0.4), not reported in this figure, have been classified according to their $\tilde{\alpha}_{ox}$ only.

X-ray Enhancement:



Comparison of the X-ray-Radio luminosity ratio of the confirmed blazars in the CLASS sample with a well-defined radio selected sample of blazars at lower redshift ($\bar{z}$=1.1) with an almost complete X-ray data (see Ighina et al. 2019 for more details on the selection).
CLASS sources have an average X-ray-to-radio ratio 2.4 (±0.5) higher than blazars at lower redshift. The difference can be tentatively interpreted as due to the **interaction of the electrons in an extended region of the jet through Inverse Compton with the photon of the Cosmic Microwave Background** (**CMB**), see e.g. Wu et al 2013 and Zhu et al. 2019. We expect the X-ray emission produced by this process to increase with redshift as the energy density of the CMB:

$$\frac{L_X}{L_R}(z) = \frac{L_X}{L_R}(z=0)\,[1 + A(1+z)^4]$$

References:

Belladitta S. et al., 2019, arXiv:1908.08552; Caccianiga A., et al., 2019, MNRAS, 484,204; Giommi P., et al., 2019, arXiv:190406043; Ighina L., et al., 2019, arxiv:190808084; Massaro E., et al., 2015, Ap&SS, 357; Shemmer O., et al., 2005, ApJ, 630, 729; Steffen A. T., et al., 2006, AJ, 131, 2826; Wu J., et al., 2013, ApJ, 763, 109; Zhu S. F., et al., 2019, MNRAS, 482,2016;

Conclusions:

- **From our X-ray analysis we confirmed the blazar nature of 21 CLASS sources, whereas the remaining 3 are too faint to be blazars (VLBI observations are under way in order to strengthen this classification);**
- **Comparing the CLASS sample with blazars at lower redshift we found a dependence of the X-ray-to-radio luminosity ratio on z;**
- **A redshift-dependent evolution of the X-ray emission could be interpreted as the interaction of the relativistic jet with the photons of the CMB. We are now evaluating whether this model can explain the discrepancy recently observed between the Cosmological properties of X-ray and radio selected samples of blazars (see Caccianiga et al. 2019).**

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