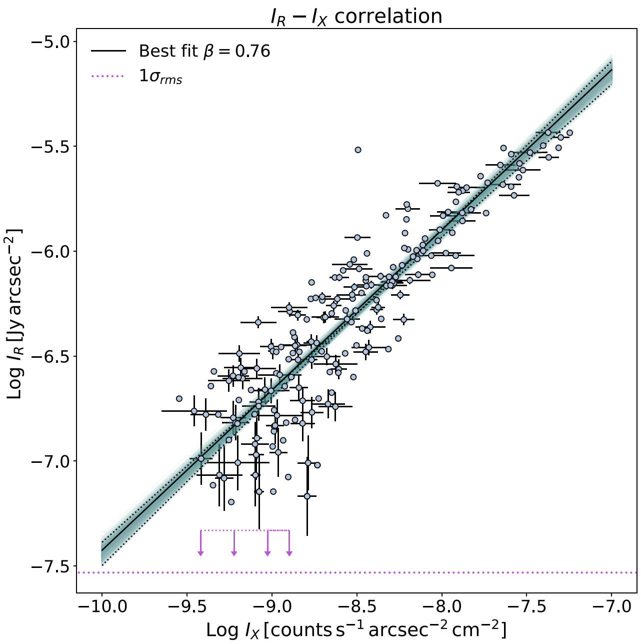

Figure 10. I_R–I_X correlation computed from the 6′ image using cells equally spaced by 6′. Arrows mark the $2\sigma_{\rm rms}$ upper limits, the black solid line shows the best-fit line, and dotted lines show the 10% and 90% slopes for the posterior distribution of β. The magenta dotted horizontal line marks the $1\sigma_{\rm rms}$. All data are computed within 2400″ from the cluster center. Here and in the following correlation plots, error bars are plotted every second point for clarity reasons.

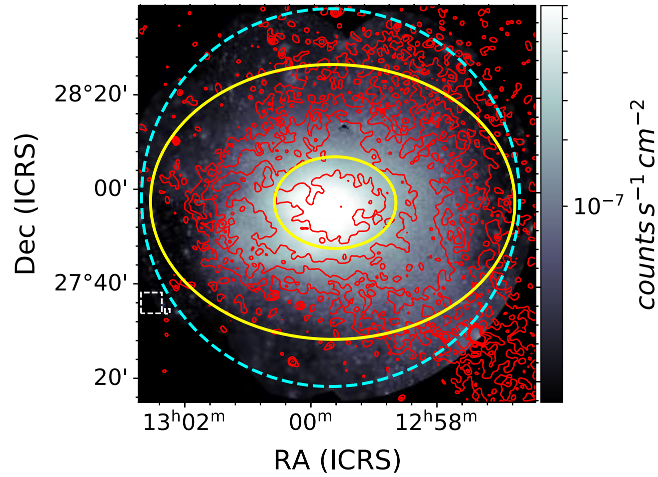

Figure 11. Left panel: colors are the X-ray emission from the Coma field from XMM-Newton observations. Contours show the radio emission at 1′ resolution, starting at $3\sigma_{\rm rms}$ and increasing by a factor 2. The major axes of the ellipses are r_1 and r_2 (inner ellipse) and $3r_1$ and 3 r_2 (outer ellipse). r_1 and r_2 are listed in Table 4. The inner ellipse is the region considered for the "halo core." The cyan dotted circle marks the region that is not contaminated by soft X-ray protons.

Govoni et al. (2001). The slope increases as we gain sensitivity to the low surface brightness emission that characterizes the outermost regions of the radio halo. This is suggesting that the slope of the correlation is not constant throughout the radio halo, with the slope β increasing when low surface brightness emission is added.

6.2. Correlations in the Halo Core and Outer Halo

Our analysis suggests that the point-to-point I_R–I_X correlation may be different in the halo central regions and in their outskirts.

Recent low-frequency observations have found radio emission in galaxy clusters that can be interpreted as the coexistence of a mini halo in the cluster core and a giant halo on larger scales (Savini et al. 2019; Biava et al. 2021). A different I_R–I_X trend is found in the core and in the outer part of the halo of these clusters, with a superlinear scaling in the mini halo region and a sublinear scaling in the outer part (Biava et al. 2021; G. Lusetti et al. 2022, in preparation).

Although those clusters have a cool-core and a radio halo with a steep spectrum, we note that a change in the I_R–I_X correlation slope for radio halos has never been explicitly investigated in the literature. In the cluster A2142, a radio halo with two components has been found (Venturi et al. 2017), yet no analysis of the radio and X-ray correlation has been performed so far. In addition, in the cluster A2744, a multicomponent halo has been discovered with a different radio–X-ray correlation slope for the northern and southern components (Rajpurohit et al. 2021b).

Since a point-to-point analysis of radio and X-ray surface brightness has been so far presented only for a few clusters, we investigate whether or not the different trends observed in the core and in the outer part of the Coma halo can be a common property of radio halos. We have repeated the analysis described in Section 6 considering the "halo core" and the "outer halo" separately (see Figure 11). For the halo core, we have used the finest grid of 1′ cell size, while for the outer halo we have used the 6′ grid, to recover the faintest emission.

We find that the slope of the "halo core" is $\beta = 0.41^{+0.04}$, while for the "outer halo" we find $\beta = 0.76 \pm +0.05$.

Hence, we can conclude that in the "halo core" we find a flatter slope for the I_R–I_X correlation, with respect to the outer part, which is the opposite trend found in cool-core clusters that host a mini halo and a halo-type component (e.g., RXC J1720.1+2638, Biava et al. 2021; A1413, G. Lusetti et al. 2022, in preparation). We note that this is the first time that a change in the I_R–I_X correlation has been investigated; hence, it could be a common property of radio halos. This result indicates that the inner part of the Coma radio halo has different properties than mini halos observed in more relaxed clusters, likely indicating different local plasma conditions. In particular, the detection of a sublinear trend in the brightest part of the halo hints at a negligible contribution to the halo central emission from the hadronic mechanism.

6.3. Radial Analysis

The point-to-point analysis above is important to understand the local connection between thermal and non-thermal plasma, and allows one to understand whether regions with higher non-thermal energy are traced by high X-ray brightness. The point-to-point analysis has also been used to probe the radial scaling of the radio and X-ray brightness (e.g., Govoni et al. 2001; Botteon et al. 2020a). To better analyze the radial trend of I_X and I_R and to investigate a possible change with radius, we have performed an additional analysis by comparing the X-ray and radio brightness in elliptical annuli and dividing the radio halo into sectors. Specifically, we have excluded from the analysis the SW sector, where the bridge is, and we have considered separately the NW, NE, and SE sectors. The profiles are computed in elliptical annuli with progressively increasing width to gain sensitivity toward low surface brightness emission in the halo outermost regions. X-ray profiles have