Hot X-ray Coronae: A Unique Probe of Galaxy Formation

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Understanding the formation and evolution of galaxies is one of the major challenges of modern astrophysics. To gain a deep insight into the processes that generated the observed structures in the Universe, the following fundamental questions must be answered.

- How do galaxies get their gas and transform it into stars?
- How do supermassive black holes alter the evolution of galaxies?
- How are galaxies and their surroundings enriched by metals?

Studying the characteristics and the evolution of luminous hot gaseous coronae in massive galaxy-sized dark matter halos offers a powerful method to address these crucial questions. The presence of hot coronae in the dark matter halos of massive galaxies is a fundamental prediction of structure formation models (White & Rees, 1978). In a simple picture, primordial gas is accreted onto the dark matter halos, which gets shock heated to the virial temperature of the halo. Since the virial temperature of massive halos is in the $kT \approx 0.2 - 0.8$ keV (about $(2.3 - 9.3) \times 10^6$ K) range, **hot gaseous coronae can only be explored with advanced X-ray satellites.**

Although this gas collapse scenario has been established more than thirty years ago, the first X-ray coronae around massive spiral galaxies has only been detected very recently (Bogdán et al. 2012). The major complication in detecting and characterizing such coronae arises from their very extended nature and their low surface brightness. Indeed, with present-day X-ray telescopes highly demanding observations are needed, which, however, can only study the most luminous X-ray coronae within about 100 Mpc ($z \sim 0.024$). To fully explore the properties and the evolution of hot gaseous coronae from high resdhifts to the local Universe, an X-ray mission is required that (i) offers large collecting area, thereby probing faint and/or distant X-ray coronae; (ii) provides high-resolution, high-throughput spectroscopy to precisely measure temperatures and abundances; and (iii) has sub-arcsecond angular resolution, allowing the separation of X-ray halos from discrete sources and compact star-forming regions even at high redshifts (100 kpc = 12″ at $z = 2$).

In the upcoming decades, the study of hot X-ray coronae will face two major challenges. First, a complete census of coronae must be obtained in the local Universe. Second, the evolution of X-ray coronae must be explored out to $z = 2$, near the peak in the cosmic star formation, at which redshift the first hot coronae emerged. These long term goals can be achieved with a future X-ray mission, which will take years to develop.

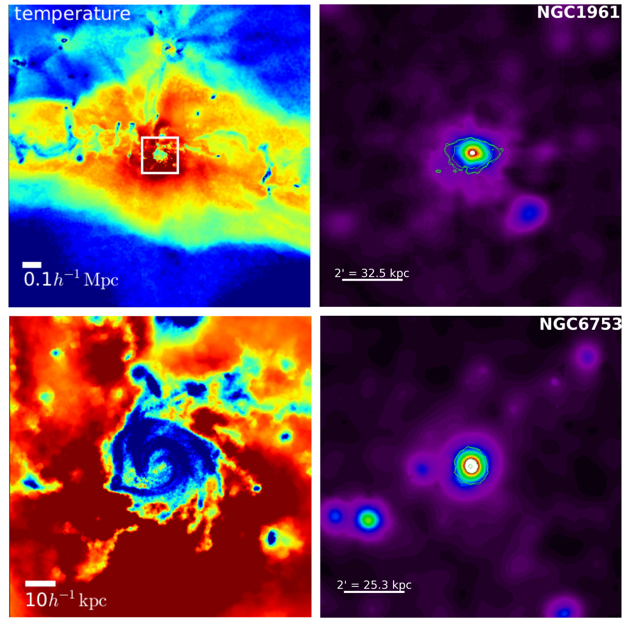

Figure 1: Left: Simulated gas temperature maps at $z = 2$ (Vogelsberger et al. 2012), showing the rise of hot X-ray coronae with sub-keV temperatures (yellow–red colors). The upper panel shows the large-scale surroundings of a disk galaxy, whereas the lower panel shows a zoomed region indicated by the white square. Right: Extended hot X-ray coronae with $kT \approx 0.6$ keV detected around two massive spiral galaxies at $D \approx 50$ Mpc ($z \approx 0.012$). The X-ray luminosity of the hot coronae is $\sim 6 \times 10^{40}$ erg s^{-1} (Bogdán et al. 2012). With present-day X-ray telescopes, demanding observations are required to detect the most luminous and nearby coronae.

Exploring the evolution of hot coronae as a function of redshift offers tremendous possibilities in understanding how different processes (for example supermassive black holes or starburst-driven winds) alter the evolution of galaxies. According to structure formation models, at $z > 2$ galaxies get $\gtrsim 80\%$ of their gas from cold-mode accretion (Crain et al., 2010). The hot-mode accretion starts to play a notable role from $z \lesssim 2$, which also defines the first manisfestations of hot X-ray coronae. In fact, between redshifts $1 < z < 2$ the hot-mode accretion becomes the dominant source of the gas in galaxies, from which epoch **~60% of the total gas is in the form of hot halos.** Hence, most of the stars observed in massive halos at $z = 0$ arise from gas accreted in the hot-mode. **Thus, to understand galaxy formation in detail, it is essential to observationally probe the hot-mode accretion and the evolution of X-ray coronae from z ≈ 2 to the present Universe.**

Bogdán, Á., et al., arXiv:1212.0541; Crain, R., et al., 2010, MNRAS, 407, 1403; Vogelsberger, M. et al., 2012, MNRAS, 425, 3024; White, S. D. M. & Rees, 1978, MNRAS, 183, 341