Astronomy

# A sharper gaze on galaxy clusters

**Stefano Borgani**

Data from the XRISM X-ray satellite provide unprecedented detail on how ionized plasma moves in massive galaxy clusters — a question with huge cosmological and astrophysical implications. **See p.365**

Galaxy clusters are collections of hundreds to thousands of galaxies bound together by gravity. Elucidating the internal dynamics of these exceptional structures is key to understanding how they formed, and thus to gaining insights into the matter and energy content of the wider Universe. On page 365, Audard *et al.*[1] take a crucial step forwards with the most detailed observations yet of internal motions in the Centaurus cluster of galaxies, which lies approximately 36.8 megaparsecs (120 million light years) from Earth.

Observations of galaxy clusters have a long history of revealing cosmic surprises. The Swiss astronomer Fritz Zwicky[2] was the first to recognize that the rapid motions of galaxies — of around 2,000 kilometres per second — in the Coma cluster could be explained only by hypothesizing that these galaxies are held together by the gravitational pull of a large quantity of "*dunkle Materie*". The mass of this unseen 'dark matter' far exceeds the mass associated with a galaxy's stars.

Today, clusters of galaxies are the largest gravitationally bound structures known to exist in the Universe, with masses ranging from several tens of thousands of billions ($10^{13}$) to millions of billions ($10^{15}$) of solar masses. According to the standard cosmological model, in which the Universe's matter content is dominated by an unknown form of dark matter and its expansion is accelerated by an even more mysterious 'dark energy', galaxy clusters are the most recent structures to form.

In addition to their dominant dark matter and the mass of their visible stars, around 10–15% of the total mass of galaxy clusters consists of a diffuse and extremely hot plasma, mainly composed of hydrogen and helium ions, that reaches temperatures of several tens of millions of kelvin. At such high temperatures, the plasma is fully ionized and emits intense X-ray radiation. This occurs predominantly through the process known as bremsstrahlung, in which plasma electrons scatter off ions, emitting photons.

This plasma also contains a small fraction of elements heavier than helium, which astrophysicists refer to as metals. These metals are the by-products of nucleosynthesis in stars and are expelled into the plasma through energetic processes such as those associated with active galactic nuclei (AGNs). In these AGNs, energy is liberated by the accumulation of gas at supermassive black holes, which lie at the centre of galaxies and have masses up to billions of times that of the Sun.

Astronomers can identify the presence of these metals by studying emission lines — peaks of light emission that occur at frequencies corresponding to specific atomic energy transitions. These lines, which are superimposed on the bremsstrahlung spectrum, provide invaluable information about the physical properties of the plasma. Their strength indicates the abundance of metals contaminating the plasma, serving as a fossil record of the history of star formation in the cluster's galaxies. Moreover, the motions of the plasma can be gleaned by measuring the width and Doppler shift (change in frequency) of the lines relative to that expected from a static object. Such motions are fingerprints of both the gravity-dominated formation of clusters (Fig. 1a,b) and the immense energy generated by the powerful AGNs in the massive galaxies at the cluster's centre. Quantifying and characterizing these motions is crucial for the cosmological and astrophysical applications of galaxy clusters.

In their study, Audard *et al.*[1] used the advanced technological capabilities of the XRISM (X-Ray Imaging and Spectroscopy Mission) satellite — a joint mission by NASA and the Japan Aerospace Exploration Agency, with participation from the European Space Agency (ESA) — which launched in 2023. They conducted a detailed investigation of the velocity fields of the plasma in the core regions

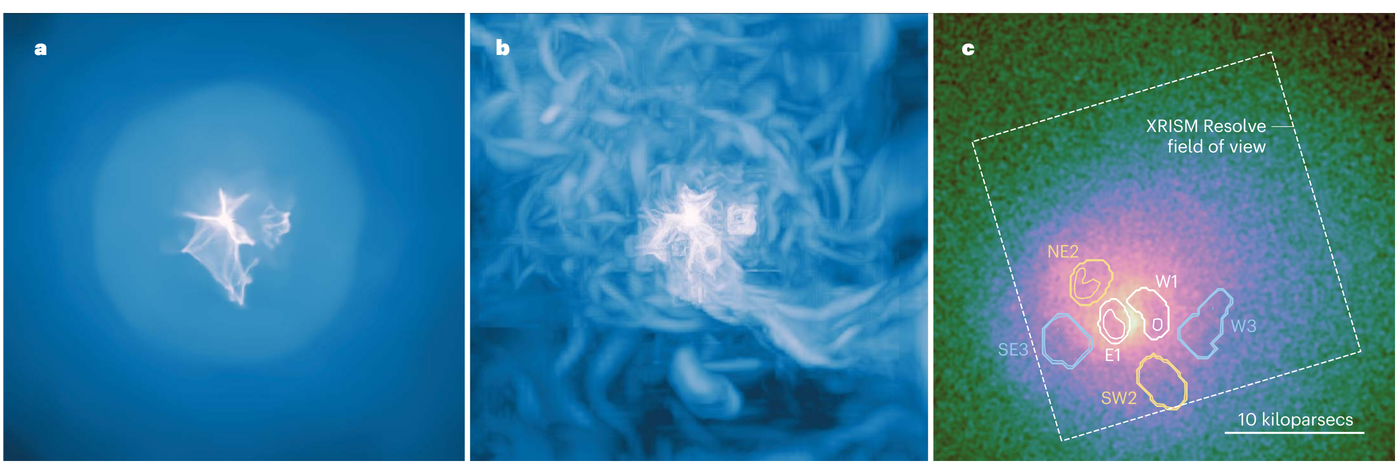


**Figure 1 | Insights into galactic plasma motions.** **a**, A map of gas density in a cosmological hydrodynamical simulation of a galaxy cluster. **b**, The same map as in panel a, but showing the degree of rotation of the velocity field (courtesy of David Vallés-Pérez; from ref. 3). These images demonstrate how gas flows in galaxy clusters propagate from larger, cosmological scales — at which gas density is too low for X-ray emissions to be detected — to smaller scales, at which higher gas density means emissions can be detected by instruments such as the XRISM (X-Ray Imaging and Spectroscopy Mission) satellite. **c**, An X-ray image of the Centaurus cluster from NASA's Chandra X-ray Observatory. The regions that have been covered by observations of the XRISM satellite are superimposed on the image (adapted from Fig. 1 of ref. 1).

of the Centaurus cluster (Fig. 1c).

The distinguishing feature of the XRISM satellite is its Resolve instrument, an X-ray spectrometer equipped with detectors offering an unprecedented energy resolution. Remarkably, this instrument can discern differences of just a few parts per thousand in the energy of incoming X-ray photons. Thanks to this exceptional energy resolution, Audard *et al.* were able to perform a careful analysis of the widths of emission lines from various metals, and so deduce the velocity of the plasma containing these metals in a central region roughly 60,000 parsecs across.

Their key finding is that a total plasma mass of approximately 10 billion solar masses is moving coherently in this region at a velocity of about 200 km $s^{-1}$ relative to the central galaxy. In seeking to uncover the physical origins of this motion, Audard *et al.* also determine that the gas near the central galaxy exhibits only a low variation in its velocity. This suggests that the energy released by the AGN hosted in the central galaxy has a limited impact on driving the observed plasma motion.

The outstanding quality of the data and the meticulous analysis presented in this work unequivocally demonstrate that high-resolution X-ray spectroscopy can provide transformative insights into the physics of intracluster plasma. It brings closer a full understanding of the interplay between processes on scales of a few parsecs on which AGNs release energy, and processes on cosmological scales of millions of parsecs.

The XRISM satellite's remarkable energy resolution comes, however, with a compromise: reduced angular resolution in its imaging. At the distance of the Centaurus cluster, XRISM cannot resolve features in the plasma's distribution smaller than approximately 15,000 parsecs across. This coarse-grained perspective prevents researchers from drawing firm conclusions about the details of the plasma velocities and, therefore, what ultimately causes them.

By contrast, two older X-ray telescopes, ESA's XMM-Newton and, especially, NASA's Chandra X-ray Observatory, both launched in 1999, can produce much higher-resolution images of the intra-cluster plasma. However, this comes at the cost of much poorer energy resolution, making it impossible to conduct meaningful studies of plasma velocities.

The situation is expected to improve in the second half of the 2030s with the launch of ESA's NewAthena (New Advanced Telescope for High-Energy Astrophysics) mission. NewAthena will offer energy resolution that is superior even to that of XRISM, coupled with much greater X-ray photon collection capabilities, all while maintaining imaging quality that is at least comparable to that of XMM-Newton. NewAthena should finally uncover the mechanisms driving the powerful AGNs at the centres of galaxy clusters, simultaneously shedding light on the evolution of the Universe's most massive galaxies and the hot plasma that surrounds them.

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## Medical research

# A way to disperse clusters of circulating tumour cells

**Daniel J. Smit & Klaus Pantel**

A drug that limits the clustering of malignant breast-cancer cells that are moving through the bloodstream to distant organs might open avenues to block the lethal spread of a tumour.

Malignant tumours such as breast, lung or prostate cancer can spread from the initial site of tumour growth to other parts of the body through the bloodstream. Such cells are called circulating tumour cells (CTCs), and the spreading process, called metastasis, is the leading cause of cancer-related death. Writing in *Nature Medicine*, Kurzeder *et al.*[1] present an approach to target CTCs.

CTCs can travel through the bloodstream either individually or as clusters, and ultrasensitive technologies can detect them among millions of blood cells. CTC clusters occur more frequently in people who have reached an advanced stage of the disease than in those at earlier stages (before metastasis results in cancer growth at a distant site), and having CTC clusters indicates an increased metastatic potential, compared with just having individual CTCs[2]. Thus, any intervention that can prevent cluster formation or break up existing CTC clusters might open a fresh therapeutic avenue. Kurzeder and colleagues provide proof-of-concept data demonstrating that CTC clusters can be separated in people who have breast cancer.

Previous preclinical animal studies[3] have paved the way for this work by showing that

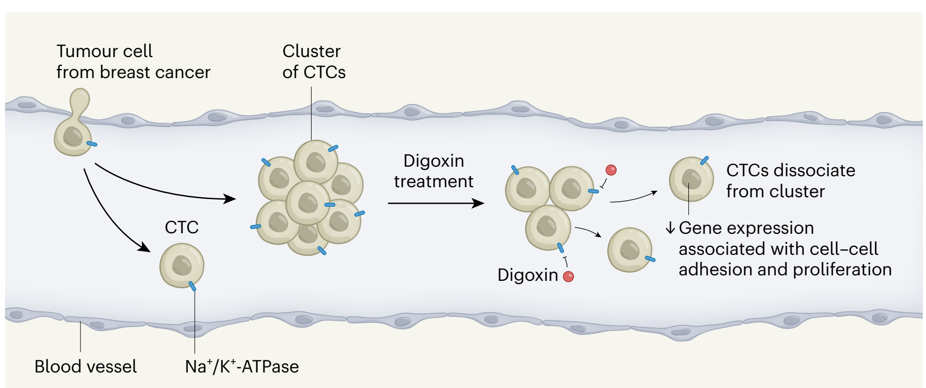


**Figure 1 | A way to dissociate cells from clusters of circulating tumour cells.** Breast-cancer cells can detach from the initial site of tumour growth and move into blood vessels. These tumour cells in the circulation are called circulating tumour cells (CTCs) and are thought to have a key role in the spread (metastasis) of a tumour to distant organs, which is associated with lethality. CTCs can move through the bloodstream as individual cells or as clusters of cells. CTC clusters are a sign of a high potential for tumour spread by metastasis[2]. Kurzeder *et al.*[1] report clinical data indicating that the number of cells in CTC clusters can be reduced by treatment with the drug digoxin, which inhibits the $Na^+/K^+$-ATPase ion pump. The $Na^+/K^+$-ATPase actively exports sodium ions out of the cell in exchange for potassium ions (not shown), affecting the electrical charge of the cell and also contributing to cellular signalling[4,5]. On digoxin treatment, the dissociated CTCs had gene-expression changes that included lower expression of genes involved in cell division and adhesion between cells.