



Il Colle di
Galileo

A deep study of the most massive galaxy cluster at $z>1.5$

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Abstract. The X-ray satellite Chandra is the only telescope able to provide high-resolution (~ 1 arcsec) images in the X-ray band (0.5-10 keV). An international collaboration met in January 2014 at the Villa Il Gioiello to discuss the Chandra Large Program on the high redshift ($z=1.58$) galaxy cluster XDCP J0044.0-2033, constituting the deepest X-ray observation currently achieved on a massive, high redshift cluster. Thanks to this unprecedented observation, coupled to a wealth of optical and IR data, we are able to investigate the properties of the Intra Cluster Medium, star formation and nuclear activity in the cluster galaxies, and to measure the total mass of the cluster, for the first time at such a high redshift.

Keywords. Galaxies: clusters: intracluster medium - X-ray: galaxies: clusters - cosmology: large-scale structure of universe

Scientific motivations

The search and characterization of distant (redshift $z>1$) clusters of galaxies has been a major field of research in extragalactic astronomy over the last ten years. A systematic investigation of galaxy clusters at high redshift can at once provide both strong constraints on cosmological parameters, on the physics of the Intra Cluster Medium (ICM) and of the interaction of the ICM with cluster galaxies, and on the evolution of the cluster galaxy population. Over the last five years, the number of known clusters at $z>1$ has dramatically increased from a few to several dozen, while their characterization still remains very challenging.

X-ray observations play a key role in this context. Thanks to the X-ray thermal emission from the ICM, which is the largest baryonic component of galaxy clusters, it is possible to identify galaxy clusters as X-ray extended sources up to $z>1$. Moreover, the X-ray band presently provides the best diagnostic of the dynamical state of the clusters, of the thermo- and chemo-dynamical properties of the ICM and a robust measurement of cluster masses.

At present, if we focus on the most distant cluster candidates, we find that only nine clusters have been spectroscopically confirmed at $z>1.5$ to date and only

a few have estimated masses in excess of $10^{14} M_{\odot}$. Clearly, the characterization of massive clusters at $z > 1.5$, corresponding to a lookback time greater than 9 Gyr, would be extremely valuable for deriving strong constraints on the evolution of the ICM and of the cluster galaxies. In fact, recent observations indicate that this cosmic epoch is key for the assembly of cluster mass and the inversion of the star formation-density relation in cluster galaxies. The workshop held at the Villa Il Gioiello in January 2014 focused on the Chandra Large Program (a deep pointing of the Chandra X-ray telescope for a total of 380 ks) on XDCP J0044.0-2033 at $z=1.58$, which is the cluster with the largest estimated mass at such a high redshift.

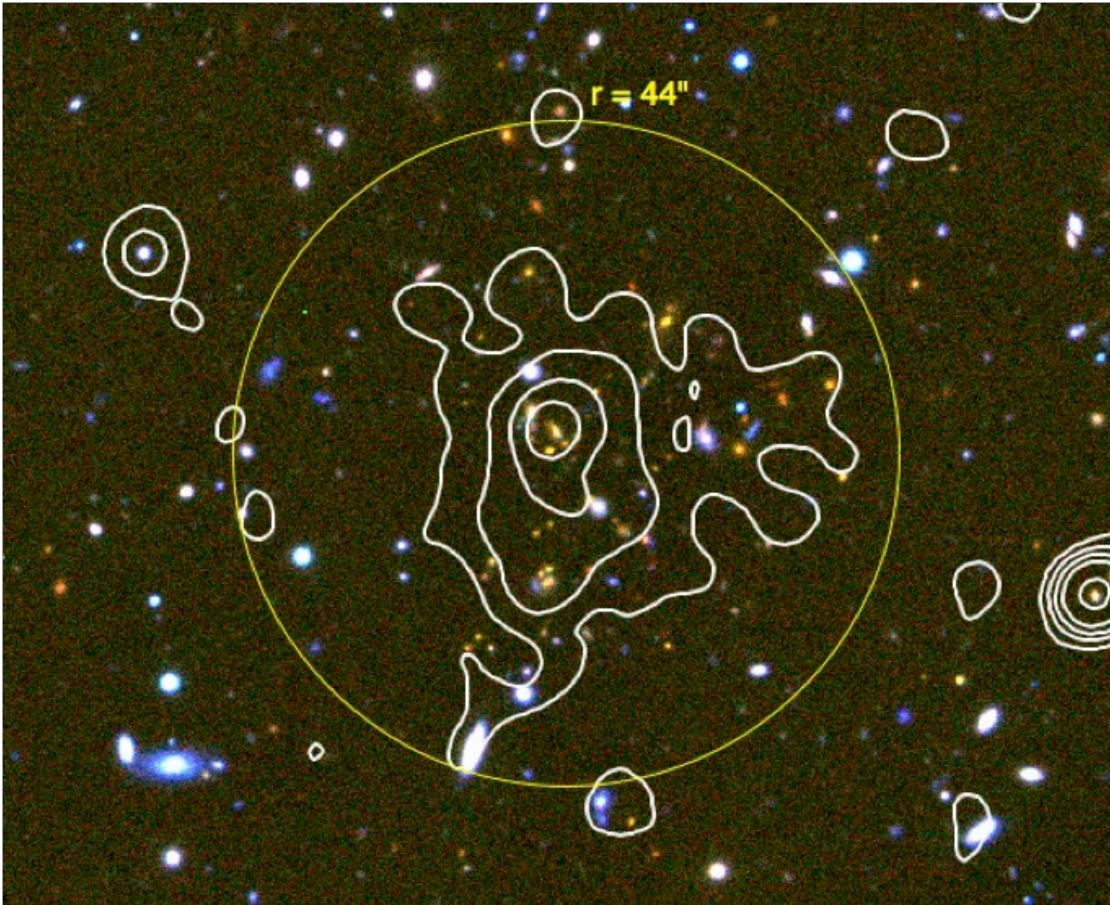
The workshop

The researchers involved in this workshop came from the USA, Germany, France and Italy. The three days dedicated to the review of the results and the discussion of the many predicted papers expected from this rich data set, were very intense and engaging. The optical and IR data confirmed the unusual activity in the central member galaxies, and this triggered many interesting discussions about the fact that we may start to witness the epoch of formation of the first, massive galaxy clusters, when most of the member galaxies are still forming stars, as opposed to the old and dead elliptical galaxies dominating clusters at lower redshift. The workshop allowed us to discuss in detail the many original results emerging from our data, setting the stage for future works.

Scientific results and highlights

During the workshop, we finalized the X-ray analysis of the data on XDCP J0044.0-2033, and compared the X-ray to the optical and IR data already in our hands to gather information on the member galaxies and on their relation with the dynamical and thermodynamical state of the cluster. We measured a very high temperature of the ICM $kT=7.1^{+1.5}_{-1.0}$ keV and also confirmed that the ICM is already polluted by the products of SNaE explosions at these redshifts to about 1/3 of the solar value. We are also able to measure a total mass of $M_{500}=3.5^{+1.1}_{-0.6} \times 10^{14} M_{\odot}$. This value can be used to compute the probability of finding such a massive cluster in the survey for a Λ CDM universe. Despite its mass, XDCP J0044.0-2033 appears to be a typical cluster at $z \sim 1.6$ for a standard set of cosmological parameters, as measured by CMB experiments. However, studies like this one, on the continuously increasing number of high- z massive clusters, can at some point force a substantial revision of the standard cosmological model, by including, for example, significant non-Gaussianity in the primordial density perturbation field, or modifications of general relativity, or considering coupled dark energy

models. Finally, the comparison of the ICM properties and of the galaxy population in this cluster will cast new light on the formation epoch of massive clusters, when processes like chemical enrichment, feedback from AGN, induced starburst in the member galaxies and merger events combine together in a short but hectic epoch. In the future, a systematic study of the distant cluster population, which is currently at the edge of the capability of present-day X-ray facilities, may reveal a wealth of complex processes whose comprehension is mandatory for a complete picture of cosmic structure formation.



Optical IJKs color image of XDCP J0044.0-2033 with Chandra smoothed soft-band contours overlaid. The image is obtained from Subaru (V and i bands) and Hawk-I at VLT (J and Ks band) and has a size of $2.5' \times 2'$. The solid circle has a radius of $44''$ (corresponding to 375 kpc at $z=1.58$), and encloses the bulk of the X-ray emission.

