Mem. S.A.It. Vol. 82, 577

Memorie della

The AGN outburst and merger in HCG 62

D. A. Rafferty[1], L. Bîrzan[1], B. R. McNamara[2,3], M. W. Wise[4], and P. E. J. Nulsen[5]

[1] Sterrewacht Leiden, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands
e-mail: rafferty@strw.leidenuniv.nl
[2] Department of Physics and Astronomy, University of Waterloo, Waterloo, N2L 2G1 Ontario, Canada
[3] Perimeter Institute for Theoretical Physics, 31 Caroline St. N., Waterloo, N2L 2Y5 Ontario, Canada
[4] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, U.S.A.
[5] ASTRON (Netherlands Institute for Radio Astronomy), P.O. Box 2, 7990 AA Dwingeloo, The Netherlands

Abstract. We report on an analysis of new *Chandra* data of the galaxy group HCG 62, well known for possessing cavities in its intragroup medium (IGM) inflated by the radio lobes of its central active galactic nucleus (AGN). With the new data, a factor of three deeper than previous *Chandra* data, we re-examine the energetics of the cavities and determine new constraints on their contents. We confirm that the ratio of radiative to mechanical power of the AGN outburst that created the cavities is less than 10^{-4}, among the lowest of any known cavity system, implying that the relativistic electrons in the lobes can supply only a tiny fraction of the pressure required to support the cavities. This finding implies additional pressure support in the lobes from heavy particles or thermal gas, and we place new constraints on the presence of thermal gas in the cavities. Lastly, we report additional evidence for a recent merger in the surface brightness, temperature, and metallicity structure of the ICM.

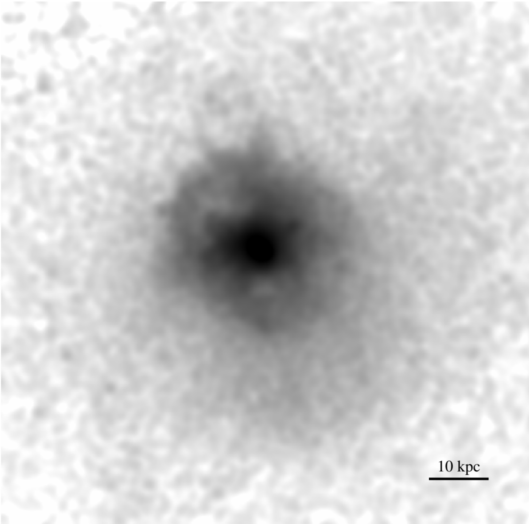
Key words. Galaxies: clusters: general – X-rays: galaxies: clusters

1. Introduction

HCG 62 is a nearby ($z = 0.0137$), compact group of $\sim$ 60 galaxies. Three large galaxies (NGC 4761, NGC 4776, and NGC 4778) dominate the core, with NGC 4778, an S0 galaxy, being the brightest cluster galaxy (BCG). The group is X-ray luminous, with an X-ray luminosity within the cooling radius Rafferty et. al ($\approx$ 33 kpc; 2006) of 1.8×10^{42} ergs s^{-1}. The temperature and cooling time profiles of the IGM show the classical cooling-flow behaviour, inwardly decreasing to a cool, high-density core. The cooling time in the core is $\approx 8 \times 10^7$ yr.

HCG 62 was previously observed by *Chandra* in 2000 for 50 ks. This observation revealed a set of large cavities in the IGM that were subsequently shown to be filled with radio emission from the lobes of the central AGN. Interpreting these cavities as buoyant bubbles, Bîrzan et. al (2004) found a total me-

Send offprint requests to: D.A. Rafferty



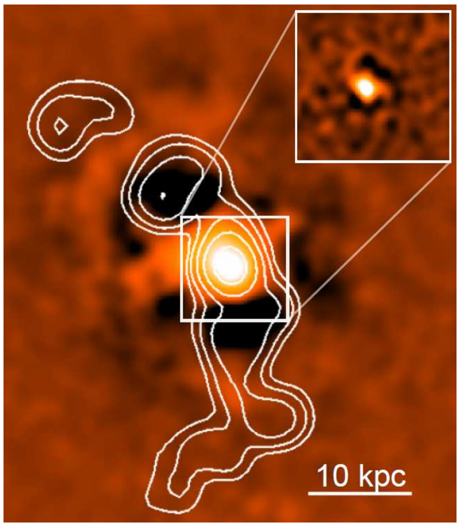


Fig. 1. *Left:* Exposure-corrected, 0.5–7 keV image of HCG 62, smoothed with a gaussian of $\sigma = 5''$. *Right:* Unsharp mask image of the core showing the two large outer cavities and two small inner cavities. Contours show the 235 MHz radio emission (Gitti et. al 2010).

chanical power of $\sim 3 \times 10^{42}$ erg s^{-1}, more than enough to offset cooling losses of the IGM in the core. We report here on new, deep *Chandra* observations of HCG 62 that reveal further cavities and strong evidence of a recent merger.

2. Data reduction

HCG 62 was observed by *Chandra* for 50 ks (ObsID 921) and 120 ks in two observations of 60 ks each (ObsID 10462 and 10874), all using the ACIS-S detector. The full 170 ks of data were used in all subsequent analysis. Standard data reduction (e.g., Rafferty et. al 2006) was followed. For spectral fitting, spectra and responses were extracted from each observation separately and were then fit simultaneously using Sherpa in CIAO 4.2.

3. Results

The 170 ks, exposure-corrected 0.5–7 keV image is shown in Fig. 1. A number of features noted by other authors in analyses of the original data are apparent, including the large cavities in the core and the surface-brightness edge some 40–50 kpc to the south of the core. Additionally, there are two small cavities visible in the unsharp mask image on either side of the core.

3.1. AGN cavities

Measurements of X-ray cavities have for the first time allowed a strong lower limit to be placed on the total jet power of AGNs. Fig. 1 shows an unsharp mask of the central region of HCG 62, showing the radio lobes of the AGN filling the large cavities. There is also evidence of small inner cavities, oriented roughly N-S. The jet power of the outburst may be estimated from the enthalpy of the cavities.

To this end, we used simulated images to recover the cavity sizes and locations. The large-scale cluster emission was modelled with a 2-D double Beta model, the cavities as empty spheres, and the rims as uniform rings of emission made up of the gas removed from the cavities (see Fig. 2). The best-fit values give a total cavity enthalpy ($H = 4pV$, assuming a relativistic plasma) for the outer cavities of 1.1×10^{57} erg. For the small, inner cavities, we find a total enthalpy of 3×10^{55} erg. Using the buoyant rise times as the ages of the cavities

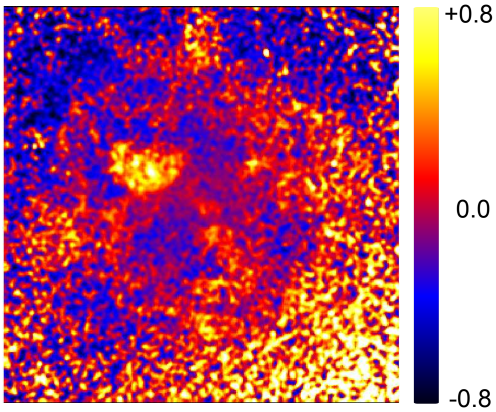


Fig. 2. Residual image (in the sense of [image - model]/image) of the core, made using the 0.5–3 keV image and smoothed by a 2.5 arcsec Gaussian. The model is a 2-dimensional Beta model with empty spherical cavities, whose rims are spherical shells composed of the material displaced from the cavities.

(e.g., Bîrzan et. al 2004), we find a total jet power (H/t) of $\sim 3 \times 10^{42}$ erg s^{-1}, a factor of several above the cooling luminosity (Rafferty et. al 2006). Given the total radio luminosity of 3×10^{38} erg s^{-1} (Gitti et. al 2010), the implied radiative efficiency is $\sim 10^{-4}$. Under the assumption of equipartition, the requirement of pressure support constrains the content of the lobes. For the observed radio luminosity, the relativistic electrons in the lobes can provide only a tiny fraction ($< 0.2\%$) of the particle pressure required (Morita et. al 2006; Bîrzan et. al 2008; Gitti et. al 2010).

This result implies a large population of heavy particles (such as cosmic rays) or hot thermal gas in the lobes. Geometrical arguments can be used to place limits on any thermal gas in the cavities. Using the new data, we can improve on the constraints of Morita et. al (2006), and we find that thermal gas cooler than $\sim$ 5 keV is excluded if the cavities are spherical. With the new data, we also hope to place spectral constraints on the presence of this gas.

3.2. Temperature and abundance structure

An arc of high metallicity gas was discovered in the original Chandra data by Gu et. al (2007), and is confirmed in the new data (see Fig. 3). In the new data, this arc is seen to correspond to a region of excess surface brightness near the southern edge (relative to a model of the large- scale emission made using the Multi-Gaussian Expansion of Cappellari et. al 2006). Although a weak shock model fits the edge (Gitti et. al 2010), the surface brightness and temperature structure of the gas matches well with that seen in simulations of mergers in cooling flows (e.g., Ascasibar & Markevitch 2006). In this scenario, the merger induces sloshing in the cool core, creating a low-temperature, high-abundance spiral-like feature and associated cold fronts (the edge). The merger scenario is also supported by the kinematic study of Spavone et. al (2006), who found evidence that NGC 4778 has undergone a recent merger, possibly with NGC 4761. Such a merger could have a significant heating effect on the cool core, as cool gas is mixed with hotter gas and turbulence increases (e.g., Sharma et. al 2009; ZuHone et. al 2010).

4. Discussion

We present preliminary results of an analysis of new Chandra data of HCG 62. We refine previous measurements of the AGN cavities and confirm the extremely low radiative efficiency of the outburst. This low efficiency constrains the pressure support from electrons in the cavities to be very small, implying that either a large population of cosmic rays, possibly entrained by the lobes, or thermal gas is needed in the lobes (which we constrain to be $\gtrsim$ 5 keV). Additionally, we find evidence for a recent merger in the surface brightness, temperature, and metallicity structure of the hot gas. Such a merger may have contributed to the heating of the cool gas in the core, although the AGN cavities alone represent more than enough power to offset cooling.

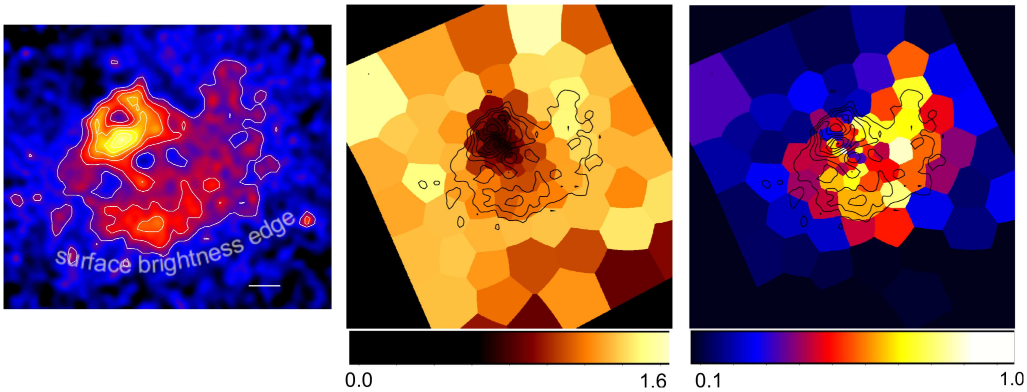


Fig. 3. *Left:* Residual 0.5–3.0 keV image of the core after subtracting the best-fit Multi-Gaussian Expansion model with contours overlaid. *Center* Temperature map with contours from the residual image overlaid. Note the presence of cooler gas to the inside of the surface-brightness edge and warmer gas to the outside, a classic signiture of a cold front. *Right:* Metallicity map (relative to solar) with contours from the residual image overlaid.

References

Ascasibar & Markevitch, 2006, ApJ, 650, 102
Bîrzan et. al, 2004, ApJ, 607, 800
Bîrzan et. al, 2008, ApJ, 686, 859
Cappellari et. al, 2006, MNRAS, 366, 1126
Gitti et. al, 2010, ApJ, 714, 758
Gu et. al, 2007, ApJ, 659, 275
Morita et. al, 2006, PASJ, 58, 719
Rafferty et. al, 2006, ApJ, 652, 216
Sharma et. al, 2009, ApJ, 699, 348
Spavone et. al, 2006, A&A, 457, 493
ZuHone et. al, 2010, ApJ, 717, 908