Herschel observations of the Centaurus cluster, the dynamics of cold gas in a cool core

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Abstract
Brightest cluster galaxies (BCGs) in the cores of galaxy clusters have distinctly different properties from other low redshift massive ellipticals. The majority of the BCGs in cool-core clusters show signs of active star formation. We present observations of NGC 4696, the BCG of the Centaurus galaxy cluster, at far-infrared (FIR) wavelengths with the Herschel space telescope.

Introduction
Recent high-resolution XMM-Newton and Chandra observations have shown that the cooling rates at the center of galaxy clusters are below the simple cooling-flow models by an order of magnitude (e.g. McNamara & Nulsen 2007). Despite AGN and other sources of heating which stop the intracluster-medium (ICM) from cooling catastrophically, observations of many (~20) BCGs show that the intracluster medium gas is cooling but at a much suppressed level. They appear to have substantial amount of cold gas, of which a small fraction is forming stars (e.g., Johnstone et al. 1987; McNamara et al. 1989; Edge & Fryer 2003).

A significant number of cool-core clusters show the Hα optical line-emission. In addition, detections of the [O II] optical line-emissions are also seen in several cool-core clusters (e.g., Canning et al. 2010). Of the lines observed, we detected [O I], which stop the intracluster-medium (ICM) from cooling catastrophically, observations of many (~20) BCGs show that the intracluster medium gas is cooling but at a much suppressed level. They appear to have substantial amount of cold gas, of which a small fraction is forming stars (e.g., Johnstone et al. 1987; McNamara et al. 1989; Edge & Fryer 2003).

The basic photodissociation region (PDR) model parameters. The geometry is assumed to be plane-parallel. Columns: (1) parameter; (2) symbol; (3) the input range and (4) the most likely parameter values.
Table 1: The basic photodissociation region (PDR) model parameters. The geometry is assumed to be plane-parallel. Columns: (1) parameter; (2) symbol; (3) the input range and (4) the most likely parameter values.

We used the ESA Herschel space observatory (Pilbratt et al. 2010) using PACS (Poglitsch et al. 2010) and SPIRE (Griffin et al. 2010) to study the cold phase (< 10 K) of the interstellar and intracluster medium. The aim of these observations was to understand the details of mass and energy transfer between the different phases of gas. We observed the two primary coolants of the neutral ISM, the [C II] line at 157.74 µm and the [O I] line at 63.18 µm, along with [O II] at 145.52 µm, [Si II] at 66.70 µm, [N II] at 121.96 µm and [O III] at 88.36 µm with the PACS spectrometer. We also conducted PACS and SPIRE photometry at 70 µm, 100 µm, 160 µm, 250 µm, 350 µm and 500 µm.

Results
Of the lines observed, we detected [O I], [N II] and [N I] in NGC 4696 (Fig. 1). We did not detect [Si I], [Si II] and [O II]. Also detected dust emission at all six PACS and SPIRE wavebands.

Figure 2: Photometry images of NGC 4696. Left: PACS colour images at 70 µm (blue), 100 µm (green) and 160 µm (red) combined with the same smoothing gaussian of FWHM 0.25″. Middle: SPIRE colour images at 250 µm (blue), 350 µm (green) and 500 µm (red) with a resolution of 6″, 8″ and 10″ respectively. The image units are Jy/beam and each side measures 2″. Right: The FIR spectral energy distribution obtained from a modified two-component blackbody fit to the Herschel and Spitzer data.

X-ray, optical and far-infrared correlations

The morphological and kinematical correlation between the far-infrared forbidden line coolant, [O I], and the optical line filaments is a key result of this work (see Fig. 3). This correlation has a profound implication, namely that the optical hydrogen recombination line, Hα, the optical forbidden lines, [N II], and [O II] line all have the same energy source.

Figure 3: Soft Chandra X-ray image (left), Gemini optical Hα emission (middle) Crawford et al. (2005) and Herschel far-infrared [O II] 157.74 µm emission (right).

Modelling of the ISM of NGC 4696
To understand the complete picture giving rise to emission in NGC 4696 at different wavebands, we performed simulations to investigate the physical parameters of its ISM using the spectral synthesis code, CLOUDY (Ferland et al. 1998).

We performed a detailed spectral energy distribution fitting using a two-component modified blackbody model and found a cold 19 K dust component with mass 1.7 × 10^8 M_☉ and a warm 46 K dust component with mass 4.0 × 10^9 M_☉. The total FIR luminosity between 8 µm and 1000 µm is 7.5 × 10^9 L_☉, which using Kennicutt relation yields a low star formation rate of 0.13 M_☉ yr^-1. This value is consistent with values derived from other tracers, such as ultraviolet emission. Combining the spectroscopic and photometric results together with optical Hα, we modeled emitting clouds consisting of photodissociation regions (PDRs) adjacent to ionized regions. We showed that in addition to old and young stellar populations, there is another source of energy, such as cosmic rays, shocks or reconnection diffusion, required to excite the Hα and [O II] filaments.

Conclusions
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 References


Figure 1: The forbidden FIR line detections in the center of NGC 4696.