

Mapping the Molecular Hydrogen Emission in the Cooling Flow Cluster Abell 1795

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We present near-infrared imaging data of the $v = 1-0$ S(1) emission line of molecular hydrogen (H_2) in the cooling flow cluster Abell 1795. A symmetric extended H_2 emission (~ 3 kpc in diameter) is found in the central dominant galaxy. We measure a H_2 line emission flux for this central component of $1.93 \pm 0.79 \times 10^{-18}$ W/m². This result is consistent with recent spectroscopic measurements of Jaffe et al. (2001). The H_2 emission is aligned with the $H\alpha$ and excess UV emission but does not share the tail-like extended morphology. Comparison with X-ray data reveals an offset for the central emission peaks as well as the absence of a corresponding H_2 extended tail. The $H\alpha/H_2$ ratio is consistent with heating by hot stars. However, our H_2 image does not reveal any diffuse spatial structure usually associated with heating due to stellar UV sources. Rather, its condensed nature is more consistent with heating by an AGN. We also report on the first detection of H_2 emission in other cooling flow cluster members.

1. Introduction

X-ray observations of nearby clusters of galaxies show sharp emission peaks as dense gas in the center of the clusters cool. This cool gas, unable to support the outer part of the intracluster medium, flows towards the center of the cluster. The result is a long-lived stable “cooling flow”. In the very central regions of these flows, the gas is expected to become molecular. We expect H_2 emission, which is characteristic of molecular gas at temperatures of order 1000 K.

Molecular gas has been observed spectroscopically in the central dominant galaxies (CDGs) of many cooling flow clusters (CFCs) (Jaffe & Bremer 1997; Jaffe et al. 2001; Edge 2001; Edge et al. 2002). Molecular hydrogen (H_2) is detected in many CDGs of cooling flow clusters, but not all (Edge et al. 2002). A handful of CDGs have also been imaged in $H\alpha$ (Donahue et al. 2000; Baker et al. 2003) and in H_2 (Donahue et al. 2000) and a remarkable correspondence of the bright emission features is found. Some CDGs that contain radio sources have been observed to show structure in X-ray that is similar to the $H\alpha$. On large scales (~ 10 kpc), at the center of these clusters, the X-ray morphology seems to be anti-correlated with the position of the radio lobes.

Jaffe & Bremer (1997) find in their sample of CFCs that the inferred mass cooling rate from the X-ray data is lower than the one inferred from H_2 emission at 1000 K. One explanation for this discrepancy is that the cool (~ 1000 K) molecular gas at the center of the cooling flow is being excited by an external source. Possible scenarios include reheating by an active galactic nucleus (AGN), shocks, and ultra-violet (UV) radiation from hot stars (Wilman et al. 2002). Of the three cooling flow clusters whose molecular hydrogen emission has been imaged, NGC 1275 shows condensed emission whereas Abell 2597

and PKS 0745-191 display filamentary emission (Donahue et al. 2000). Donahue et al. (2000) find a correlation between morphology of the H_2 emission and the reheating mechanism. They suggest that an H_2 emission with condensed morphology is associated with nuclear activity (AGN) whereas filamentary emission is mostly seen if the heating is due to stellar UV sources.

Abell 1795 was first classified as a cooling flow cluster by Stewart et al. (1984). Its X-ray emission implies a mass deposition rate of $\sim 100 M_\odot$ /year (Ettori et al. 2002). Abell 1795 has a large centrally located cD galaxy (Bautz-Morgan type I) and is at a redshift of 0.0627. The Chandra observations of this cluster reveal an X-ray peak five arcseconds north of the cD galaxy and a tail which extends ~ 80 kpc to the south-southeast (Fabian et al. 2001a). The misaligned peaks and tail may be the result of the oscillation of the cD galaxy around the cluster potential which creates a wake (Fabian et al. 2001a). Abell 1795 has been imaged in the optical, radio and X-ray (Pinkney et al. 1996; Ge & Owen 1993; Fabian et al. 2001a). $H\alpha$ emission and UV excess has been detected in its CDG (Baker et al. 2003; McNamara et al. 1996), suggesting a recent star formation episode. These emissions also appear to exhibit the same tail-like spatial structure as seen in the X-ray. Spectroscopy of the CDG has been done in the near-IR, optical and UV. The $v = 1-0$ S(1) emission line of H_2 is detected with a flux of $1.58 \pm 0.1 \times 10^{-18}$ W/m² (Jaffe et al. 2001) and $5.9 \pm 2.1 \times 10^{-19}$ W/m² (Edge et al. 2002). The line emission flux for $H\alpha$ is measured to be 2.50×10^{-17} W/m² (Baker et al. 2003). Finally, the UV spectroscopy reveals the presence of ionized O and C emitted as the intracluster gas cools through the 3×10^5 K regime (Oegerle et al. 2001).

In this paper, we present near-infrared imaging data of

the $v = 1-0$ S(1) emission line of H_2 in the cooling flow cluster Abell 1795. Our observations and data reduction steps are described in detail in Section 2 and 3. Section 4 and 5 contains the results of our data analysis and the comparison with previous data on Abell 1795. A discussion and summary of our findings follows in Section 6.

2. Observations

We obtained images on the night of 2003 April 14 U.T. using CFHT-IR at the F/8 Cassegrain focus of the 3.6-m Canada-France-Hawaii Telescope (CFHT). The CFHT-IR detector is a HgCdTe CCD with 18.5 microns pixels and an angular scale of 0.211 arcsec per pixel. At a redshift of 0.0627, the $v = 1-0$ S(1) H_2 2.12 μm emission line is observed in the K continuum (KC) filter. The observations were therefore taken in the KC filter (central wavelength 2.26 μm , $\Delta\lambda=0.06$ μm) to detect the line emission and in the CO filter (central wavelength 2.296 μm , $\Delta\lambda=0.02$ μm) to measure the continuum. A total of 5116 s of on-source integration was obtained in the KC filter and 14040 s in the CO filter. The exposures were broken into five dither positions of duration 246 s for the KC filter and 360 s for the CO filter. The photometric standard FS18 was observed at an airmass similar to our target for flux calibration.

3. Data Reduction

The initial stages of the data reduction followed standard procedures and were accomplished using IRAF¹. First the flat field frames were combined and the “light-off” combined frame was subtracted from the “light-on” combined frame. All our images were divided by the normalized resulting flat field image in order to remove pixel to pixel sensitivity variations. The resulting flat was also used to create a bad pixel mask for images in each filter. Sky subtraction was done using the IRAF package DIMSUM (Deep Infrared Mosaicing Software, UM..., Stanford et al. 1995). Our final KC and CO mosaics each cover an area of $4'.5$ by $4'.5$. The pixels in the final mosaics have half the size of the original pixels. Flux calibration was done using our standard star.

We subtracted the CO mosaic from the KC mosaic to obtain our final H_2 image. First, the images were aligned using the IRAF task IMSHIFT with an accuracy of half a pixel. Second, we matched the point spread functions (PSF) of the images in the two filters. This was done with the IRAF task PSFMATCH which smeared out the smaller PSF of the KC filter in order to match the PSF of the CO filter. Third, we corrected for the different filter transmission functions. Our resulting H_2 image is shown in Figure 1.

4. H_2 Flux Measurement

The central H_2 emission is aligned with the CDG (see Figure 1) and measures 2.88 kpc in extent. We calculate

¹ The Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

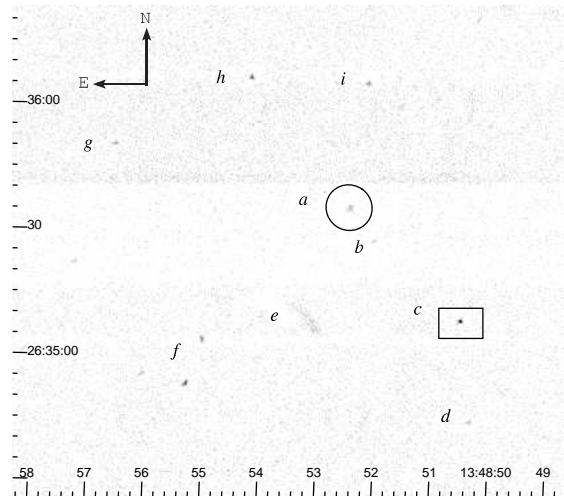


FIG. 1.— Image of H_2 emission a central $2'.0 \times 2'.0$ region of the cooling flow cluster Abell 1795. This image shows Feature $a-i$ (as discussed in the text). A circle is placed around the CDG and a rectangle around Feature c . In this image dark features represent emission.

an H_2 line flux of $1.93 \pm 0.79 \times 10^{-18}$ W/m^2 . Our error estimate is derived from the flux residual in a star in our field (feature d in Figure 1) and is primarily due to PSF matching and alignment errors. Our flux measurement agrees well with the Jaffe et al. (2001) spectroscopic measurement of $1.58 \pm 0.1 \times 10^{-18}$ W/m^2 . As the inferred mass cooling rate from the H_2 flux is larger than the one inferred from the X-ray emission (Jaffe & Bremer 1997), we expect that reheating is occurring and we can use our observation to constrain the possible reheating mechanisms.

We use our measurement of the H_2 flux, in combination with the $H\alpha$ flux determined by Baker et al. (2003) to estimate the $H\alpha/H_2$ flux ratio. We expect this ratio to be greater than 30 for shock heating and a factor of ten lower for stellar UV excitation (Donahue et al. 2000). Previous observations of the $H\alpha/H_2$ flux ratio in other CFCs find numbers of 1–10 which are too low for shock heating. The $H\alpha$ flux determined by Baker et al. (2003) was measured in an aperture ~ 7 times larger the one used to determine the H_2 flux. We therefore calculate an upper limit for the $H\alpha/H_2$ flux ratio of 13, ruling out shocks as the main source of heating.

We examine the morphology of our H_2 emission to put an extra constraint on the dominant excitation mechanism. Figure 2 shows a close-up of the central region of the H_2 image and one can clearly see the condensed morphology of the H_2 emission. If the heating is due to hot stars, we expect the H_2 emission to be filamentary and diffuse in morphology (Donahue et al. 2000). However, the H_2 emission associated with the CDG does not show any filamentary structure and there is no hint of an H_2 tail, such as the one seen in the $H\alpha$ and the UV excess images. Rather, the morphology of the H_2 is condensed which is more in agreement with what is expected if the heating source is an AGN. If a faint H_2 tail exists, a higher signal-to-noise image is needed to reveal it.

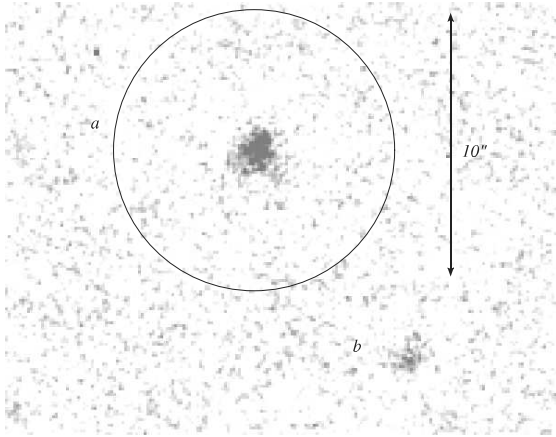


FIG. 2.— Image of H_2 emission a central $15'' \times 15''$ region of the cooling flow cluster Abell 1795. This close-up of the central H_2 emission shows its condensed nature. Dark features represent emission.

5. Non-CDG H_2 Detection

As the field of view for CFHT-IR is large ($3'6$ on a side) and our mosaic covers an even larger area ($4'5$ by $4'5$), we are able to capture the H_2 emission, if present, coming from not only the CDG but surrounding galaxies as well. Although most other galaxies in the field do not show any H_2 emission, it is interesting to find 6 other sources of emission in our image, identified as Features *b*, *c* and *f-i* in Figure 1 (note that Feature *e* is an instrumental artifact and should be ignored). This is quite surprising as the brightest H_2 emission is expected to be seen in the central cluster galaxy and there exist only attempts to search for H_2 emission from cooling flow clusters in the CDG itself.

Features *c* and *h* have a near-infrared counterpart as seen in the Two Micron All Sky Survey (2MASS). We extracted the images from the 2MASS Extended Source Image Server but their small size made it impossible to identify their morphological type. As we do not have spectra for these galaxies, we cannot rule out the possibility that their continuum emission differs from the CDG and other members of the cluster and that the flux we detect is not from H_2 . Also, without redshift information, we cannot be certain that the H_2 line we are trying to detect falls as expected in the KC filter. However, we do have a redshift for Feature *h* of 0.0612. Moreover, Figure 3b of Cowie et al. (1983) shows $H\alpha$ emission at the location of Feature *c* and Figure 2 of McNamara et

al. (1996) shows a UV excess at the location of Feature *h*. Therefore, in the particular case of Feature *h*, we are confident that we are seeing H_2 emission. Feature *h* is located at a distance of ~ 40 arcsec or 46 kpc from the CDG, which puts it inside the cooling radius (~ 2.6 arcmin or 181 kpc for Abell 1795, Grenatcher et al. 1999). However, it is unlikely that this H_2 emission is associated with the cooling flow process.

6. Discussion

We present imaging of H_2 emission in the central ~ 300 kpc in diameter region of the cooling flow cluster Abell 1795. The central H_2 emission, associated with the CDG and 2.88 kpc in extent, has a flux of $1.93 \pm 0.79 \times 10^{-18}$ W/m². We find that this value is in agreement with the spectroscopic result of Jaffe et al. (2001).

The H_2 flux measured in the CDG is larger than what is predicted for a cooling flow from the X-ray data. It appears that the H_2 gas is being reheated by an external source. We are able to calculate an upper limit for the $H\alpha/H_2$ ratio of 13, ruling out reheating due to fast shocks. The $H\alpha/H_2$ ratio is consistent with heating by hot stars. However, our H_2 image does not reveal any diffuse spatial structure usually associated with heating due to stellar UV sources. Rather, its condensed nature is more consistent with heating by an AGN. It is possible that a faint H_2 tail or faint filaments may be revealed in a deeper exposure.

An unexpected result is the detection of H_2 in galaxies surrounding the CDG. Although most other galaxies in the field do not show any H_2 emission, we detect H_2 emission in 6 other sources. This is quite surprising as the brightest H_2 emission is expected in the central cluster galaxy and there exist only attempts to search for H_2 emission in the CDG itself. In the particular case of Feature *h*, we are confident that we are seeing H_2 emission as we detect as well a UV excess at the same location and the redshift of the galaxy confirms that H_2 falls in our KC filter. Although this emission is located inside the cooling flow radius, it is unlikely that it is associated with the cooling flow process.

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References

- Baker, K., et al., The Riddle of Cooling Flows in Galaxies and Clusters of Galaxies, Charlottesville, VA May 31- June 4, 2003
 Cowie, L. L., Hu, E., Jenkins, E., & York, D. 1983, ApJ, 272, 29
 Donahue, M., Mack, J., Voit, G. M. & Sparks, W. 2000, ApJ, 545, 670
 Edge, A. C. MNRAS, 328, 762
 Edge, A. C., Wilman, R. J., Johnstone, R. M. & Crawford, C. S. 2002, MNRAS, 324, 443
 Etti, S., Fabian, A. C., Allen, W. & Johnstone, R. 2002, MNRAS, 331, 635
 Fabian, A. C., Saunders, J. S., Etti, S., Taylor, G. B., Allen, S. W., Crawford, C. S., Iwasawa, K. & Johnstone, R. M. 2001a, MNRAS, 321, L33
 Fabian, A. C., Mushotzky, R. F., Nulsen, P. E. J. & Peterson, J. R. 2001b, MNRAS, 321, L20
 Ge, J. P., Owen, F. N. 1993, AJ, 105, 778
 Grenacher, L., Jetzer, Ph., Puy, D. 1999, astro-ph 9911438
 Jaffe, W. & Bremer, M. N. 1997, MNRAS, 284, L1
 Jaffe, W., Bremer, M. N. & van der Werf, P. P. 2001, MNRAS, 324, 443
 McNamara, B. R., Wise, M., Sarazin, C. L. & Jannuzi, B. T. 1996, ApJ, 466L, 9M
 Oegerle, W. R., Cowie, L., Davidson, A., Hu, E., Hutchings, J., Murphy, E., Sembach, K., Woodgate, B. 2001, ApJ, 560, 187
 Pinkney, J., et al. (1996), ApJ, 468, L13

Stanford, S. A., Eisenhardt, P. R., & Dickinson, M. 1995, ApJ, 450, 512
Stewart, G. C., Fabian, A. C., Jones, C., & Forman, W. 1984, ApJ, 285, 1S

Wilman, R. J., Edge, A. C., Johnstone, R. M., Fabian, A. C., Allen, S. W., Crawford, C. S. 2002, MNRAS, 337, 63