

FUSE Observations of Warm Gas in the Cooling Flow Clusters A1795 and A2597

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ABSTRACT

We present far-ultraviolet spectroscopy of the cores of the massive cooling flow clusters Abell 1795 and 2597 obtained with FUSE. As the intracluster gas cools through 3×10^5 K, it should emit strongly in the O VI $\lambda\lambda 1032, 1038$ resonance lines. We report the detection of O VI $\lambda 1032$ emission in A2597, with a line flux of $1.35 \pm 0.35 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$, as well as detection of emission from C III $\lambda 977$. A marginal detection of C III $\lambda 977$ emission is also reported for A1795. These observations provide evidence for a direct link between the hot (10^7 K) cooling flow gas and the cool (10^4 K) gas in the optical emission line filaments. Assuming simple cooling flow models, the O VI line flux in A2597 corresponds to a mass deposition rate of $\sim 40 M_{\odot}$ yr $^{-1}$ within the central 36 kpc. Emission from O VI $\lambda 1032$ was not detected in A1795, with an upper limit of 1.5×10^{-15} erg cm $^{-2}$ s $^{-1}$, corresponding to a limit on the mass cooling flow rate of $\dot{M}(28 \text{ kpc}) < 28 M_{\odot}$ yr $^{-1}$. We have considered several explanations for the lack of detection of O VI emission in A1795 and the weaker than expected flux in A2597, including extinction by dust in the outer cluster, and quenching of thermal conduction by magnetic fields. We conclude that a turbulent mixing model, with some dust extinction, could explain our O VI results while also accounting for the puzzling lack of emission by Fe XVII in cluster cooling flows.

Subject headings: cooling flows-galaxies: clusters: individual (A1795, A2597)
-galaxies: intergalactic medium-ultraviolet: galaxies

1. Introduction

X-ray observations have shown that a very hot ($\sim 10^7 - 10^8$ K) diffuse intracluster medium pervades the cores of clusters of galaxies (Forman & Jones 1982). Without continued heating, this gas will cool, and, if the density of the gas is high enough, the characteristic cooling time will be less than a Hubble time (Cowie & Binney 1977; Fabian & Nulsen 1977). This cooling gas should “flow” quasi-hydrostatically onto the cD/D galaxy at the bottom of the cluster potential well. Typical mass flows inferred from the x-ray data are $> 100 M_{\odot} \text{ yr}^{-1}$ within the central ~ 100 kpc of the cluster.

As the gas cools, it will emit strongly in various X-ray lines of highly ionized Fe and O for $T \lesssim 10^7$ K (Canizares, Markert, & Donahue 1988). Emission lines of O VIII Ly α and Fe XXIV arising in this hot gas have been detected in the cores of clusters (Peterson et al. 2000; Tamura et al. 2000). Spatially resolved x-ray spectroscopy has confirmed the presence of distributed cooling gas in clusters (Allen & Fabian 1997). As the gas cools rapidly through the $T \sim 3 \times 10^5$ K regime, it should emit strongly in certain UV resonance lines – particularly the O VI $\lambda\lambda 1032, 1038$ doublet (Edgar & Chevalier 1986; Voit, Donahue & Slavin 1994). Finally, as the gas cools to $T \sim 10^4$ K, it should emit strongly in the hydrogen lines (H α , Ly α). Optical H α emission from cooling flows has been detected toward several clusters (Heckman 1981; Cowie et al. 1983; Hu, Cowie & Wang 1985), Hu (1992) has also reported extended Ly α emission from a number of clusters having H α emission.

Emission lines from warm (3×10^5 K) gas in cooling flows have yet to be convincingly detected. Dixon et al. (1996) observed several clusters, including A1795, with the FUV spectrograph on the *Hopkins Ultraviolet Telescope* (HUT) in an attempt to detect emission from O VI. No detections were made, although in the case of the strongest X-ray cooling flow cluster observed, A1795, the HUT exposure time was only 2000 sec. In efforts to detect gas at temperatures of $10^{5.5} - 10^{6.5}$ K, a number of investigators have attempted to

detect the Fe X $\lambda 6374$ coronal line in cooling flow clusters (Anton, Wagner & Appenzeller 1991; Donahue & Stocke 1994; Yan & Cohen 1995). Yan & Cohen (1995) provided the the most sensitive search reported to date, and found no evidence for the line and set an upper limit for the surface brightness of 10^{-18} erg cm $^{-2}$ s $^{-1}$ arcsec $^{-2}$. Emission lines from Fe XVII arising in gas at $T \lesssim 5 \times 10^6$ K have also not been detected in a recent XMM observation of A1795 (Tamura et al. 2000).

Detection of emission from warm gas would provide the lynchpin to physically connect the previously detected hot and cool gas components in the cores of clusters. We have therefore begun a program with the *Far Ultraviolet Spectroscopic Explorer* (FUSE) to search for emission from O VI $\lambda\lambda 1032, 1038$ in the cores of the x-ray bright, cooling flow clusters A1795, A2199 and A2597. Results for A1795 and A2597 are presented in this paper. FUSE has twice the effective area of HUT at O VI $\lambda 1032$, which, when coupled with longer integration times and higher spectral resolution can provide a considerable increase in sensitivity over the HUT.

Throughout this paper, we have used a value of $H_0 = 50$ km s $^{-1}$ Mpc $^{-1}$. All distances scale as the inverse of H_0 , while observed line luminosities and derived cooling flow mass deposition rates scale as H_0^{-2} .

2. FUSE Observations

Far-ultraviolet spectra of the cores of A1795 and A2597 have been obtained with the FUSE observatory. A description of the FUSE instrument and its in-orbit performance is described in papers by Moos et al. (2000) and Sahnou et al. (2000). In brief, FUSE spectra cover the wavelength range 905 – 1185Å with a spectral resolution of $\sim 15 - 20$ km s $^{-1}$ (depending on wavelength) for point sources. FUSE spectra are recorded in four

separate optical channels, two of which employ LiF optics covering the wavelength range $\sim 1000 - 1185\text{\AA}$ and two which use SiC optics covering the $905 - 1090\text{\AA}$ range. Dispersed light is focused onto two photon-counting microchannel plate detectors.

All observations were carried out with the LWRS spectrograph entrance aperture ($30'' \times 30''$). For extended emission which fills the LWRS aperture, the instrumental line width is $\sim 100 \text{ km s}^{-1}$, which is narrower than the expected line width of cooling flow gas in the core of a cluster of galaxies.

The data were processed with the FUSE calibration software (*calfuse*, version 1.8.7). Since the signal from the source is expected to be weak, extra care was taken in subtraction of the detector background. Photons events with pulse heights less than 4 or greater than 15 were screened out of the data, since these events are predominately background in nature. Furthermore, the standard background subtraction employed by *calfuse*, which is adequate for bright objects, was not used. Instead, the background level on each detector was determined from a co-addition of all exposures for each cluster. The local background in the vicinity of the expected line positions was measured on the 2D spectral image at locations just above and below the spectra, and were then subtracted from the extracted spectra.

We have searched the extracted spectra for emission from O VI $\lambda 1032$ and C III $\lambda 977$. O VI $\lambda 1032$ is redshifted to 1097\AA and 1117\AA in A1795 and A2597 respectively. These wavelengths fall in the LiF channels for both detectors 1 and 2, and for the SiC channel in detector 2 (for A1795 only), and is outside the wavelength range of the SiC channel in detector 1. The combined effective area of the 2 LiF channels at $\sim 1100\text{\AA}$, based on in-flight calibrations, is about 52 cm^{-2} . The SiC2 channel at this wavelength has an effective area of only $\sim 3 \text{ cm}^{-2}$, and hence we have not used the SiC2 spectrum in our analysis. The C III $\lambda 977$ line is also redshifted to a wavelength covered by both LiF and SiC channels.

However, the combined effective areas of the LiF channels is much greater than the SiC channels, and given the fact that the signal is close to the detector background, we have used only the LiF spectra from channels 1 and 2.

Terrestrial airglow lines in the far-UV (Feldman et al. 2000) have also posed a special problem in our search for emission lines from cooling flows. For example, in A1795 the C III $\lambda 977$ line is redshifted to 1038.7\AA , which is adjacent to an O I airglow line. In A2597, the C III line is redshifted to 1057.4\AA , which is potentially contaminated by a terrestrial N₂ emission band. Finally, in A1795, the O VI $\lambda 1032$ line is redshifted to coincide with a band of N I airglow lines. We have thoroughly investigated all these possible contaminations and discuss the results below.

2.1. A1795

A1795 was observed on February 23, 2000 with an integration time of 37,189 seconds. The cluster has a redshift of 0.0631 (Oegerle & Hill 1994), hence the FUSE aperture subtends 50×50 kpc at the cluster. The spectrograph aperture was centered on the cD galaxy at the peak of the X-ray emission at coordinates: $\alpha(2000) = 13^{\text{h}}48^{\text{m}}52.5^{\text{s}}$, $\delta(2000) = +26^{\circ}35'35''$.

Any O VI $\lambda 1032$ emission from A1795 would be redshifted to an observed wavelength of 1097\AA , which is unfortunately at nearly the same wavelength as a complex of N I terrestrial airglow lines (Feldman et al. 2000). These lines are strong only when looking at the illuminated earth. However, they are also present in spectra taken near the earth limb, and are faintly visible throughout the daylit portion of the orbit. To avoid the effects of these airglow lines as much as possible, we have restricted our analysis of the O VI line to data obtained during spacecraft orbital night, limiting the integration time to 17 ksec.

The LiF1 and LiF2 spectra of A1795 were coadded and the resulting spectrum at the

expected wavelengths of the redshifted O VI lines is shown in Figure 1, where the data has been binned by 0.2\AA ($\sim 60 \text{ km s}^{-1}$). A faint continuum from the cD elliptical galaxy is detected at a level of $\sim 1.5 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$, in good agreement with the UV continuum flux reported by (Hu 1992) at wavelengths $\lambda > 1215\text{\AA}$ from an IUE large aperture observation. This relatively large far-UV flux from an old elliptical galaxy at a redshift of 0.0631 indicates the presence of substantial star formation activity. Hu (1988) has estimated an ongoing star formation rate of $\sim 1 M_{\odot} \text{ yr}^{-1}$ from the IUE data. Smith et al. (1997) and Mittaz et al. (2001) have reported broad-band UV emission from the center of A1795, and concluded that a population of early type stars is present, which presumably formed from the cooling flow.

In Figure 1, we note possible Galactic absorption lines of H_2 at 1094 and 1100 \AA , which makes the spectrum appear somewhat noisier than it truly is. These absorption features do not correspond to any metal absorption lines at the redshift of A1795. In any event, there is no obvious O VI emission. After subtracting a continuum fit to the galaxy spectrum, we compute a flux in the $\lambda 1032$ line of $6 \pm 6 \times 10^{-16} \text{ erg cm}^{-2} \text{ s}^{-1}$, where we have integrated from -300 to $+300 \text{ km s}^{-1}$ about the expected line center. The uncertainty quoted here is purely a random error. There is also a systematic uncertainty in the continuum placement, so we estimate a 2σ upper limit to the flux in $\lambda 1032$ line of $1.5 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$, or in terms of the average surface brightness within the FUSE LWRS aperture, $\mu(\text{O VI}) < 1.7 \times 10^{-18} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ arcsec}^{-2}$ or equivalently, $7 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. This then yields an upper limit to the luminosity in the O VI $\lambda 1032$ line of $L_{\text{obs}}(\text{O VI}) = 2.5 \times 10^{40} \text{ erg s}^{-1}$.

We have also searched the A1795 spectrum for C III $\lambda 977$ emission using the full 37 ksec integration taken during both orbital night and day. In Figure 2, we display the 1020 – 1060 \AA spectral region from that dataset. The background subtraction appears to be quite good, since the C II $\lambda 1036$ absorption line from the Galactic interstellar medium

is black at line center, as expected. A faint emission line appears to be present adjacent to the O I $\lambda 1039.2$ terrestrial airglow line, and we suggest that this is emission from C III $\lambda 977$ in the cooling flow of A1795, redshifted to 1038.7\AA . The line flux is uncertain due to the airglow contamination, but we estimate a flux of $1.5 \pm 0.7 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$; ie. only a $\sim 2\sigma$ detection. We also note broad absorption extending from $\sim 1032\text{\AA}$ to 1037\AA in the observed frame. Absorption at the two ends of this range are due to O VI $\lambda 1032$ and C II $\lambda 1036$ from the Galactic ISM. The absorption at 1034\AA corresponds in wavelength to redshifted Ly γ in A1795. Absorption by neutral hydrogen in A1795 could, in principle, be confirmed by detecting Ly β absorption. However, Ly β is redshifted to 1090\AA , which is very near the edge of segment B of detector 1, where calibration is problematical. This wavelength is not recorded on detector 2, since it lies in the gap between segments A and B.

2.2. A2597

A2597 was observed on June 26, 2000 for a total integration time of 43,032 seconds. The spectrograph aperture was centered on the cD galaxy at coordinates: $\alpha(2000) = 23^{\text{h}}25^{\text{m}}19.7^{\text{s}}$, $\delta(2000) = -12^{\circ}07'27''$. The redshift of the A2597 cD galaxy is 0.0823 (Heckman et al. 1989; Taylor et al. 1999), thereby shifting the O VI $\lambda 1032$ line to 1116.86\AA in the observed frame. This is in a region of the spectrum where there is no observed or expected airglow emission (Feldman et al. 2000). We have therefore used spectra obtained during both orbital day and night in our analysis of A2597. The co-added spectrum from the LiF1 and LiF2 channels is shown in Figure 3, binned to 0.2\AA . A weak, but clearly detected emission line is evident at the expected position of redshifted O VI $\lambda 1032$. The emission line is clearly visible in both the individual LiF1 and LiF2 spectra, so it is very unlikely to be due to a detector artifact. Indeed, no such emission feature is observed at 1117\AA in the combined day and night (34 ksec) observation of A1795. We

therefore conclude that this weak emission line is redshifted O VI $\lambda 1032$ from the cooling flow nebula of A2597.

We measure a flux in the $\lambda 1032$ line of $1.3 \pm 0.35 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$, where we have integrated from -300 to $+300$ km s $^{-1}$ about the expected line center. The FUSE aperture subtends 65×65 kpc at the cluster, resulting in an average surface brightness within the FUSE LWRS aperture of $\mu(\text{O VI}) = 1.4 \times 10^{-18}$ erg cm $^{-2}$ s $^{-1}$ arcsec $^{-2}$ or equivalently, 6×10^{-8} erg cm $^{-2}$ s $^{-1}$ sr $^{-1}$. The luminosity in the O VI $\lambda 1032$ line is then $L_{\text{obs}}(\text{O VI}) = 3.6 \times 10^{40}$ erg s $^{-1}$.

An examination of the spectrum has also revealed an emission line at 1057.4\AA , the expected position of redshifted C III $\lambda 977$ (see Figure 4). Feldman et al. (2000) have observed emission from terrestrial N $_2$ at this wavelength when pointed at the bright earth. In order to determine if the observed line in our data is terrestrial in origin, we have also extracted spectra of A2597 obtained during orbital night. Although the night-only data was restricted to 14 ksec, the emission line at 1057\AA is detected quite easily. Furthermore, the flux in the line is the same during the night and daylit portions of the orbit. Finally, we note that there is no emission line at this wavelength present in the A1795 spectra. We conclude that the evidence is strong that the emission line at 1057\AA is not of terrestrial origin, and is in fact redshifted C III $\lambda 977$ from A2597. The measured line flux is $4.9 \pm 0.7(\text{random}) \pm 1.0(\text{systematic}) \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$ measured within ± 300 km s $^{-1}$ of the expected line center.

3. Discussion

The flux in the O VI line is a function of the temperature of the gas, its distribution in the cluster, and the mass flow rate in the cooling flow. Edgar & Chevalier (1986) and Voit,

Donahue & Slavin (1994) have computed the expected luminosities of ultraviolet emission lines from a gas cooling from a temperature $> 10^6\text{K}$ to 10^4K . The luminosity in the O VI line is given by

$$L(\text{OVI}) = \frac{k\dot{M}}{\mu m_H} A_O \int_{T_{\min}}^{T_{\max}} \left(\frac{3}{2} + s \right) \chi \frac{f_i j(\text{OVI})}{\Lambda} dT$$

where \dot{M} is the mass flow rate, μm_H is the mean mass per atom, A_O is the abundance of oxygen, f_i is the fraction of oxygen in the O^{+5} ionization stage, χ is the number of particles per H atom, $j(\text{O VI})$ is the volume emissivity in the O VI line, and Λ is the radiative cooling function (Cowie 1981; Edgar & Chevalier 1986). The gas cools from T_{\max} down to T_{\min} with an evolution that could be isobaric, isochoric or some combination of the two; s is 1 for isobaric cooling and 0 for isochoric. The intracluster medium (ICM) has abundances that are typically 0.1 – 1 times solar (Mushotzky 1992; Allen & Fabian 1998) which can be understood in terms of the ICM being composed of galactic ejecta mixed with primordial gas. Note in the above equation that lower metallicity (of oxygen in the present case) is offset by a similar decrease in the cooling function, assuming that the abundance of oxygen is not dissimilar to other metals providing the bulk of the cooling. Hence, the line luminosity is rather insensitive to metallicity, as first pointed out by Cowie81. We also note that the assumption made here is that this is the luminosity of an optically thin, extended region, with no self-absorption. Edgar & Chevalier (1986) have calculated UV line luminosities for solar abundances, with $T_{\min} = 10^4$ K and $T_{\max} = 10^6$ K. Voit, Donahue & Slavin (1994) arrive at very similar results. Adopting an intermediate case between isobaric and isochoric cooling, the predicted luminosity in the O VI $\lambda 1032$ line is $\sim 9 \times 10^{38} \dot{M}_{\odot}$ erg s^{-1} , where \dot{M}_{\odot} is the mass cooling flow rate in solar masses per year. For an optically thin plasma, the luminosity of the 1038\AA line is half of that of the 1032\AA line.

3.1. A1795

Based on model prediction above, our upper limit to the observed luminosity of A1795 in the O VI $\lambda 1032$ line implies an upper limit to the mass cooling flow rate of only $\sim 28 M_{\odot} \text{ yr}^{-1}$.

Edge, Stewart & Fabian (1992) determined the mass flow rates in a large sample of clusters observed with the *Einstein Observatory* and EXOSAT, using a deprojection analysis of the x-ray images. For A1795, they found a mass deposition rate of $\dot{M} = 478 M_{\odot} \text{ yr}^{-1}$ within a radius of 230 kpc. Allen (2000) computed mass flow rates for a sample of 30 of the most luminous X-ray clusters, by applying a similar deprojection technique to ROSAT HRI images, and analyzing spatially resolved spectra of the clusters obtained with ASCA. Within a cooling radius of $r_{cool} = 188$ kpc, (Allen 2000) finds a spectroscopic mass flow rate of $\dot{M}_S = 300 M_{\odot} \text{ yr}^{-1}$. However, deprojection of the ROSAT images yielded $\dot{M}_I = 449 M_{\odot} \text{ yr}^{-1}$. A deprojection analysis including intrinsic absorption using the same column densities determined from the spectral analysis of the ASCA data yielded a corrected value of $\dot{M}_C = 1038 M_{\odot} \text{ yr}^{-1}$.

In the generally adopted cooling flow picture, gas begins cooling from a temperature of $\sim 5 \times 10^7 \text{ K}$ at several hundred kpc from the cluster center, and cools as it flows inwards with $\dot{M}(r) \propto r$, where $\dot{M}(r)$ is the integrated mass deposition rate interior to r . For A1795, the FUSE aperture has an effective radius of 28 kpc, or $0.15 r_{cool}$ as determined by Allen (2000). Assuming a mass deposition rate proportional to radius, then the x-ray mass cooling rate within the FUSE aperture is $\dot{M}_X = 45 - 155 M_{\odot} \text{ yr}^{-1}$ depending on whether one adopts \dot{M}_S , \dot{M}_I or \dot{M}_C from (Allen 2000). Our upper limit to the mass cooling flow rate of $28 M_{\odot} \text{ yr}^{-1}$ from the non-detection of O VI $\lambda 1032$ emission is about half of that derived from the ASCA x-ray spectra, assuming no absorption of the O VI line.

3.2. A2597

The observed O VI $\lambda 1032$ luminosity in A2597 implies a cooling flow rate of $\sim 40 M_{\odot} \text{ yr}^{-1}$, based on the model described above.

Sarazin et al. (1995) has derived a cooling rate for the ambient hot gas of $\dot{M} = 327 M_{\odot} \text{ yr}^{-1}$ within a radius of $r_{cool} = 130 \text{ kpc}$ from ROSAT HRI x-ray images. The effective radius of the FUSE aperture at the redshift of A2597 corresponds to 46 kpc, or $0.35 r_{cool}$. Scaling the mass deposition rate with radius, we then find an x-ray mass cooling rate within the FUSE aperture of $\dot{M}_X = 115 M_{\odot} \text{ yr}^{-1}$, which is almost 3 times the cooling rate of $40 M_{\odot} \text{ yr}^{-1}$ inferred from the the luminosity of the O VI line.

3.3. Dust Scattering

One possible way to destroy O VI emission is through scattering by dust. Edge et al. (1999) have reported the existence of significant amounts of dust in the cores of some cooling flow clusters, based on submillimeter observations. Hu (1992) has investigated the Ly α /H α emission line ratios in cooling flow clusters, and found an average excess reddening, above the foreground extinction, of E_{B-V} in the range 0.09 – 0.25. Hu (1992) discusses the location of the dust in the cluster, and favors the idea that the bulk of the dust is in the extended cluster component, instead of embedded in the localized cooling flow region. An extended dust component was found to be in rough agreement with estimates of cluster extinction based on background galaxy counts (Karachentsev & Lipovetskii 1969), and is supported by the lack of a correlation between E_{B-V} with \dot{M} in cooling flow systems. If this is the case, then regardless of the geometry of the cooling flow region, O VI emission from the core of the cluster will have to pass through the dust in the outer cluster on its way to the observer. Hu (1992) derived a value of $E_{B-V} = 0.14^{+0.08}_{-0.10}$ for A1795 (although

take note of the large uncertainties, which are primarily systematic). Assuming an upper limit to E_{B-V} of 0.22, this translates into < 2.9 magnitudes of extinction in the ultraviolet, computed assuming a standard Galactic dust extinction curve with $R_V = 3.1$. If we assume that all of this extinction arises in the outer cluster and scatters the O VI emission, then our observed, extinction-corrected line luminosity is $L_{corr}(\text{O VI}) < 3.6 \times 10^{41} \text{ erg s}^{-1}$. This then raises the limit to the mass cooling rate to $\dot{M}_{\text{OVI}} < 400 M_{\odot} \text{ yr}^{-1}$, which does not constrain the x-ray models. For A2597, Hu (1992) quotes $E_{B-V} < 0.11^{+0.08}_{-0.09}$ which would result in an extinction corrected mass flow rate derived from the O VI observation of $\dot{M}_{\text{OVI}} \sim 150^{+140}_{-100} M_{\odot} \text{ yr}^{-1}$, which is in reasonable agreement with the x-ray derived mass flow rate within the FUSE aperture, given the uncertainties in the actual extinction value.

However, let us consider an alternative model in which dust is confined principally to the cool, optical emission line filaments. In a study of the galaxy colors in nearby clusters, Ferguson (1993) found that $E_{B-V} < 0.06 \text{ mag}$, implying that on cluster-wide scales extinction by dust is limited (however, Voit & Donahue (1995) have pointed out that dust in the ICM may be unlike Galactic dust and may have different extinction properties). In the core of A1795, Pinkney et al. (1996) have resolved a 7 kpc long dust lane, whose morphology matches that of the $\text{H}\alpha$ emission. Koekemoer et al. (1999) have also resolved an elongated dust lane southeast of the nucleus of A2597, together with patches of dust near the cluster core. In this scenario, the observed $\text{Ly}\alpha/\text{H}\alpha$ emission line ratio is altered by dust in the emission line filaments. The O VI emission arises in regions exterior to the cool filaments, and in regions hot enough that dust would be destroyed by thermal sputtering. If the filaments have a low filling factor, then the O VI line photons may suffer less extinction than implied by the hydrogen recombination line ratios.

3.4. Conduction and Mixing

The existence of magnetic fields in intracluster gas with strengths of order $1 \mu\text{G}$ have been inferred from observations of Faraday rotation of radio sources seen through the ICM (Kim, Kronberg & Tribble 1991). Tangled magnetic fields, or field lines that run perpendicular to the temperature gradient, can prevent thermal conduction in an ionized gas. Recent x-ray observations of two clusters, A2142 (Markevitch et al. 2000) and A3667 (Vikhlinin, Markevitch & Murray 2000), by *Chandra* have revealed what appears to be central, cooler intracluster gas separated from the outer, hot gas by a very sharp density discontinuity. Etorri & Fabian (2000) have pointed out that this sharp temperature discontinuity could not be maintained without a significant suppression of heat conduction.

Recent *Chandra* x-ray images of the core of A1795 reveal an 80 kpc long filament of x-ray emission extending to the SSE of the cD galaxy (Fabian et al. 2000). There is a remarkable morphological similarity between this x-ray emission and the $\text{H}\alpha$ emission. Although the nature of the filament is unclear (ie. a cooling wake, or ram pressure stripped gas from a moving galaxy, etc; see Fabian et al. (2000)) there appears to be a direct physical relationship between the x-ray cooling gas and the optical emission. Although not all of this filamentary structure is within the FUSE aperture, the brightest parts of the filament near the cD galaxy are within the aperture. If the cool clouds in the filament are small enough, they will be destroyed by thermal evaporation in the hot, ambient gas, unless conduction is quenched by tangled magnetic fields. The existence of the filament may then indicate that conduction is ineffective in cooling the hot x-ray emitting gas.

The absence of O VI emission in A1795, the rather weak O VI emission in A2597, and the absence of observed Fe XVII lines in cooling flows (Fabian et al. 2001) could then be explained by the suppression of conduction. Nevertheless, we do observe O VI emission in A2597 at a level consistent with expectations from x-ray observations if we correct the O VI

flux for a reasonable amount of scattering by dust. We are then left to ponder why no x-ray emission has been detected by XMM from gas with temperatures less than $\lesssim 4 \times 10^6 \text{K}$. A possible explanation is turbulent mixing (Begelman & Fabian 1990) of hot and cool gas, as proposed by (Fabian et al. 2001). Note that this model presumes that cool gas clouds or filaments have somehow managed to form. If the cool gas, at temperature $T_c \sim 10^4 \text{K}$, and the hot gas at temperature $T_h \sim 10^7 \text{K}$ are mixed in some turbulent manner (possibly caused by energy input from the radio source), then the gas temperature will homogenize with a final temperature of $\sim \sqrt{T_c T_h} \sim 3 \times 10^5 \text{K}$. This gas is at the peak of the cooling curve, and would rapidly cool and emit O VI $\lambda 1032$, while being too cool to emit the Fe XVII x-ray lines.

4. Summary

We have obtained far ultraviolet spectroscopy of the cores of the galaxy clusters A1795 and A2597, in order to detect emission lines from warm ($1 - 3 \times 10^5 \text{K}$) gas in the central cooling flows. We do not detect O VI $\lambda 1032$ in A1795, with a 2σ upper limit of $\sim 1.5 \times 10^{-15} \text{erg cm}^{-2} \text{s}^{-1}$. This corresponds to an upper limit to the mass deposition rate of $28 M_\odot \text{yr}^{-1}$ within the central 28 kpc, assuming cooling models of Edgar & Chevalier (1986) and Voit, Donahue & Slavin (1994). We report a marginal ($\sim 2\sigma$) detection of emission from C III $\lambda 977$ in A1795. We have detected O VI $\lambda 1032$ and C III $\lambda 977$ emission in A2597 providing direct evidence linking the cool gas at 10^4K with the ambient hot, 10^7K gas. In collisional ionization equilibrium, O^{+5} and C^{+2} are formed at temperatures of $3 \times 10^5 \text{K}$ and $8 \times 10^4 \text{K}$, respectively. The observed O VI $\lambda 1032$ line flux in A2597 is $\sim 1.3 \pm 0.35 \times 10^{-15} \text{erg cm}^{-2} \text{s}^{-1}$ and corresponds to mass deposition rate of $\dot{M}(< 36 \text{kpc}) \sim 40 M_\odot \text{yr}^{-1}$. The non-detection of O VI $\lambda 1032$ in A1795 could be due to scattering by dust, or to quenching of thermal conduction by intracluster magnetic fields, which prevents the gas from cooling

below $\sim 5 \times 10^6$ K. A turbulent mixing model, together with some dust extinction, appears to adequately describe our detection of O VI $\lambda 1032$ emission in A2597, while also accounting for recent XMM spectroscopic results, which indicate a lack of Fe XVII emission, and hence a lack of cooling flow gas at temperatures of $\sim 4 \times 10^6$ K.

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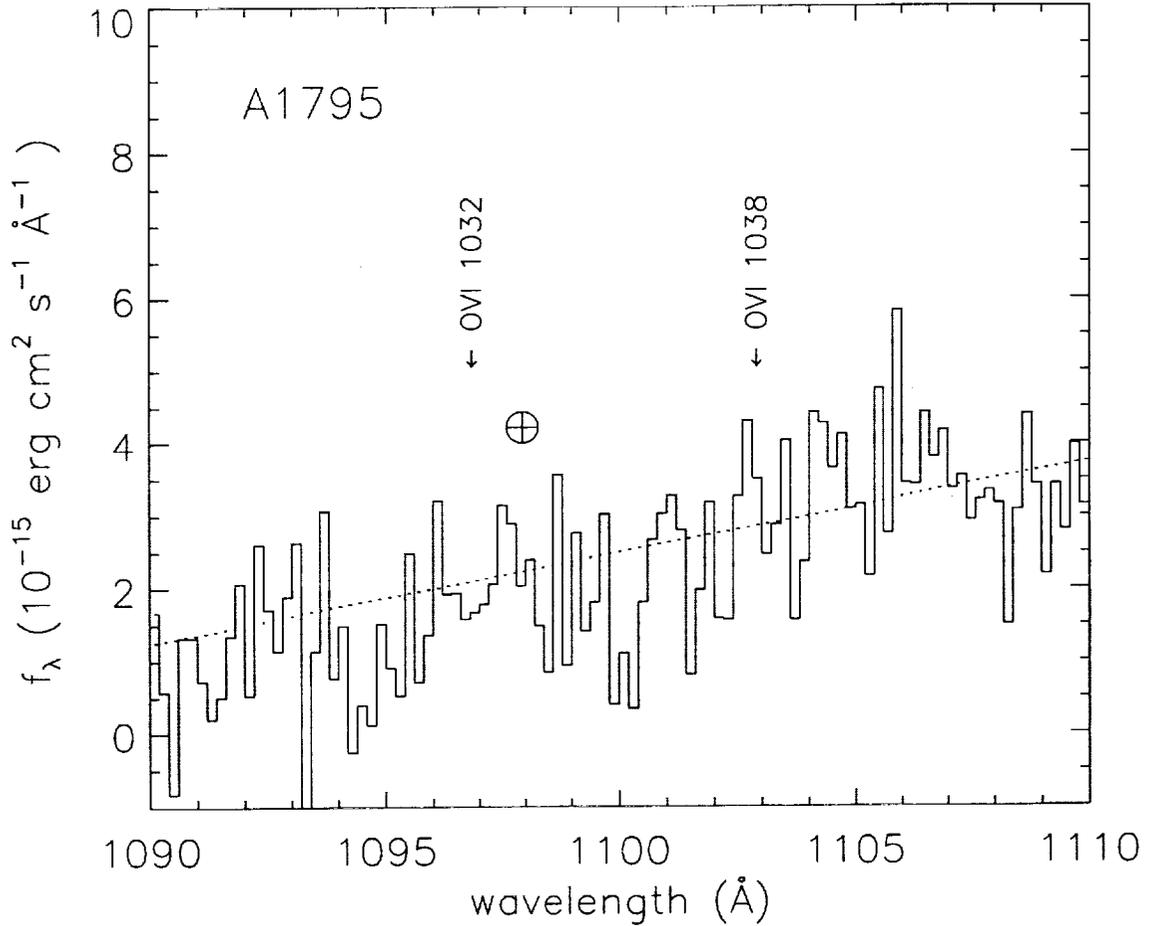


Fig. 1.— A portion of the FUSE spectrum of A1795 taken during orbital night (17 ksec) binned by 0.2\AA ($\sim 60\text{ km s}^{-1}$). The spectral resolution for an extended source is $\sim 0.3\text{\AA}$. The expected positions of the redshifted O VI $\lambda\lambda 1032, 1038$ lines are indicated. A faint continuum from the cD galaxy is detected. Terrestrial airglow lines are indicated with an Earth (\oplus) symbol. The dashed line in this figure, and subsequent figures, is the assumed continuum.

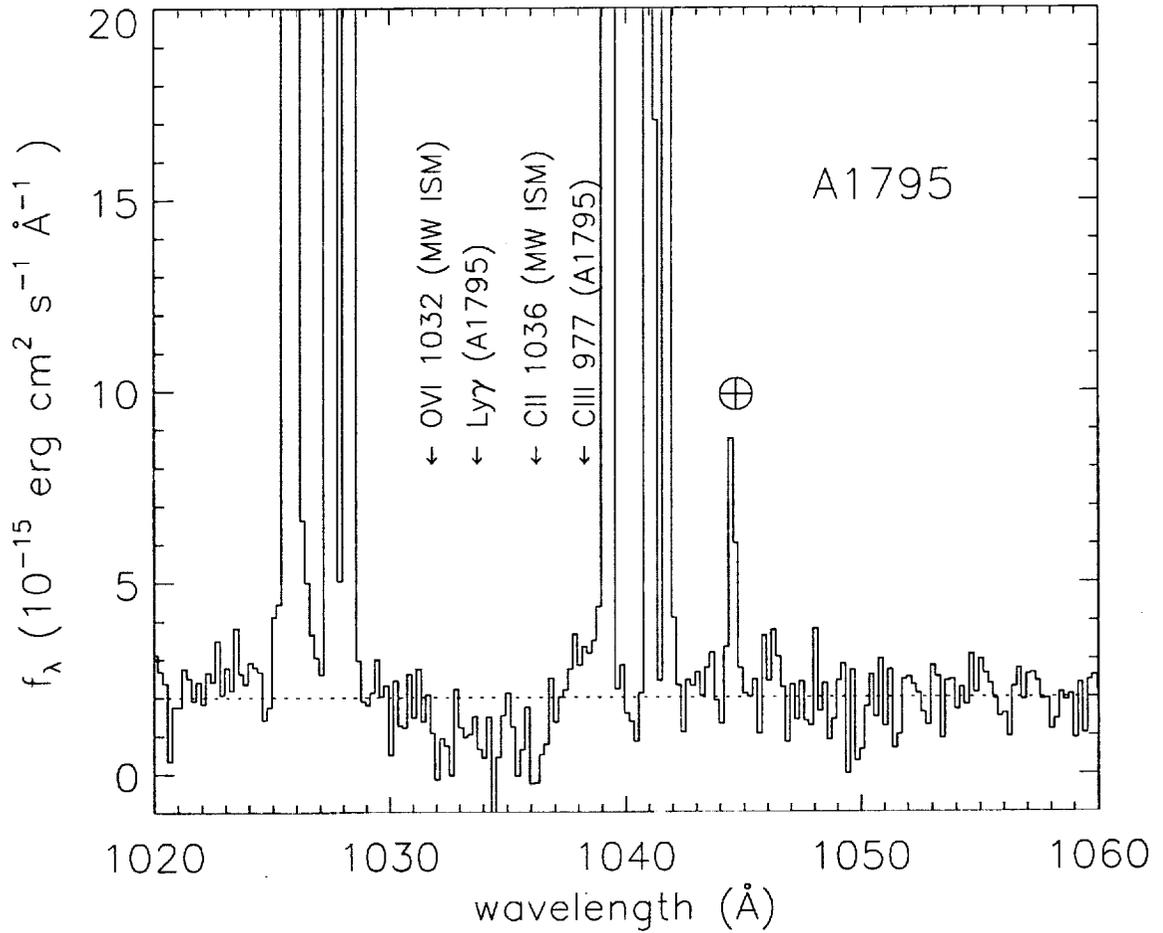


Fig. 2.— A portion of the spectrum of A1795, roughly centered on redshifted C III $\lambda 977$ (expected at 1038.67 \AA). This spectrum was obtained during orbital day and night (37 ksec). The data are binned by 0.2 \AA . The strong emission line at 1025 \AA is terrestrial Ly β , and all the other strong emission lines at $\sim 1027 \text{ \AA}$ and $1039 - 1041 \text{ \AA}$ are airglow lines of O I. C II $\lambda 1036$ and O VI $\lambda 1032$ absorption from the ISM in our Galaxy are indicated. The expected position of redshifted C III $\lambda 977$ in A1795 is indicated.

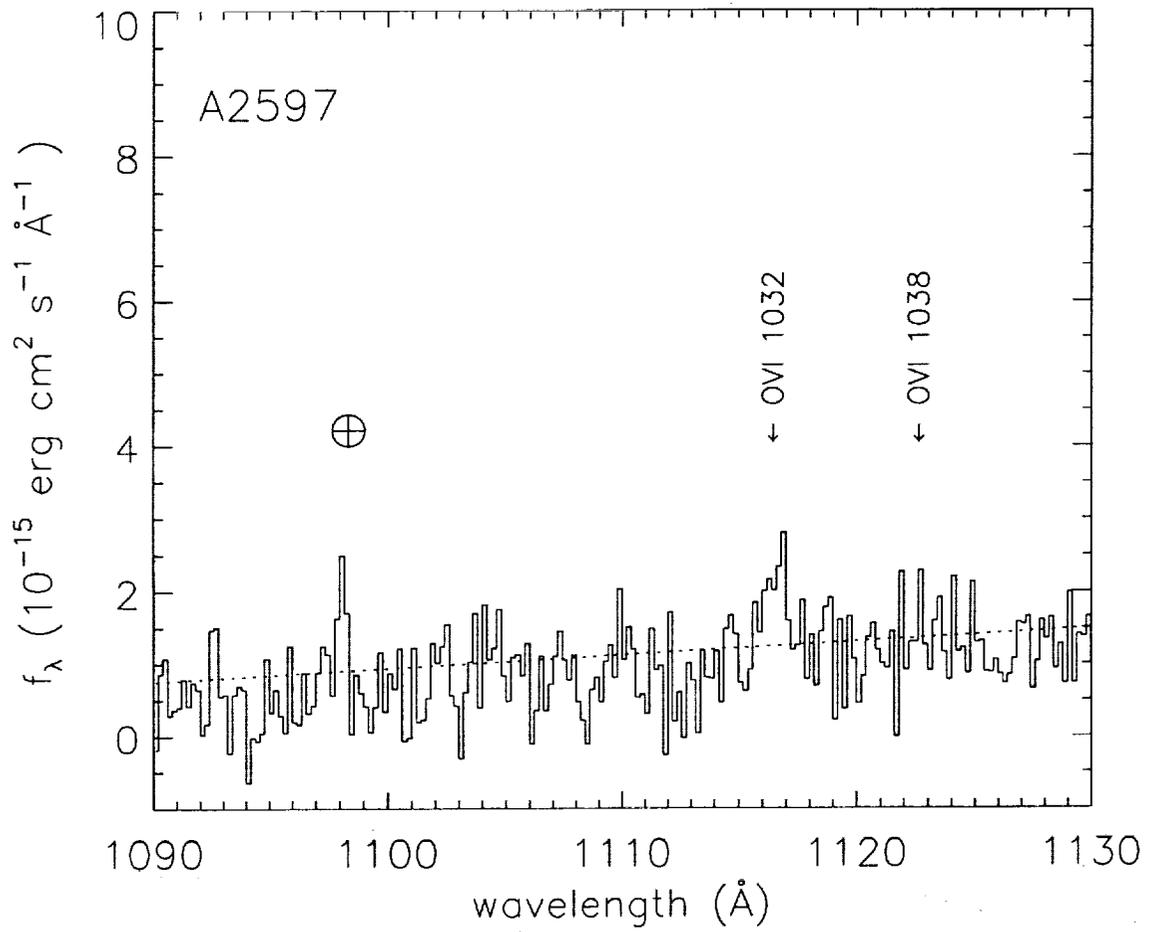


Fig. 3.— A portion of the FUSE spectrum of A2597 binned by 0.2\AA . The expected positions of the redshifted O VI $\lambda\lambda 1032, 1038$ lines are indicated.

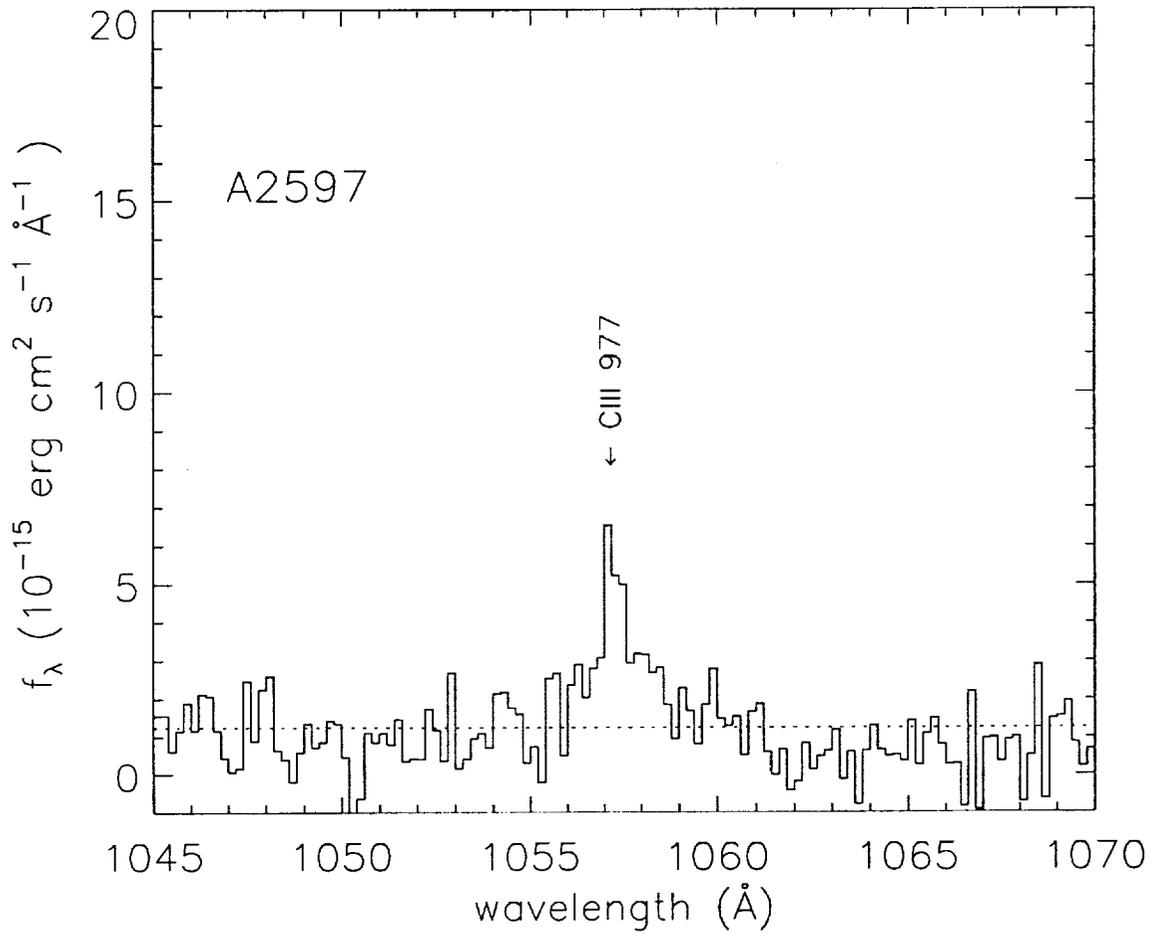


Fig. 4.— A portion of the FUSE spectrum of A2597 binned by 0.2\AA . The expected position of the redshifted C III $\lambda 977$ line is indicated.

