HUBBLE SPACE TELESCOPE STIS SPECTROSCOPY OF THE \text{Ly} \alpha \ EMISSION LINE
IN THE CENTRAL DOMINANT GALAXIES IN A426, A1795, AND A2597:
CONSTRAINTS ON CLOUDS IN THE INTRACLUSTER MEDIUM$^1$

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ABSTRACT

We report on HST STIS spectra of the Ly$\alpha$ emission in the central dominant galaxies in three rich clusters of galaxies. We find evidence for a population of clouds in the intracluster medium. We detect 10 Ly$\alpha$ absorption systems toward the nucleus of NGC 1275 with columns of $N$(H\textsc{i}) $\sim 10^{12}$–$10^{14}$ cm$^{-2}$. These columns would not have been detected in the 21 cm line but are easily detected in the Ly$\alpha$ line. Most of the absorption features are located in the broad wings of the emission line. The detected absorption features are most consistent with associated nuclear absorption systems. There is very little nuclear absorption at the systemic velocity in NGC 1275 [feature 8 contains $N$(H\textsc{i}) $\sim 3 \times 10^{12}$ cm$^{-2}$]. This implies that the large columns detected in the 21 cm line toward the parsec-scale radio source avoid the line of sight to the nucleus. This gas may be located in a circumnuclear disk or torus. We detect at least one and possibly two absorption features toward the extended Ly$\alpha$ in A426. We do not detect Ly$\alpha$ absorption toward the extended Ly$\alpha$ emission in A1795 and A2597 with upper limits $N$(H\textsc{i}) $\sim 10^{13}$ cm$^{-2}$ for optically thin absorbers. Our data constrain the covering factor of any high column density gas [$N$(H\textsc{i}) $> 10^{15}$ cm$^{-2}$] in the ICM to be less than 25%. Our results suggest that the lack of observed intermediate-temperature gas is not explained by obscuration. In addition, the low columns of gas on $\sim 100$ kpc scales in the ICM suggest that (1) the rate at which cold gas accumulates in the ICM on these scales is very low and (2) the dense nebulae in the central $\sim 10$ kpc must have cooled or been deposited in situ.

Subject headings: cooling flows — galaxies: active — galaxies: clusters: individual (A426, A1795, A2597) — galaxies: ISM — ultraviolet: galaxies

1. INTRODUCTION

The hot $T \sim 10^7$–$10^8$ K X-ray–emitting gas is currently thought to constitute the bulk of the baryonic mass in rich clusters of galaxies. If substantial amounts of cold gas do exist in the intracluster medium (ICM), this would have important implications for our understanding of (1) cooling flows (how much mass do they deposit?), (2) the physics of the ICM (is it a multiphase medium like our ISM?), (3) the intracluster magnetic field (can it suppress conduction?), (4) galaxy formation and evolution (how important are winds and stripping?), and (5) Ly$\alpha$ forest systems (are they formed in clusters? e.g., Crawford et al. 1987).

There are several potential candidates for a population of cold clouds that might exist in the ICM of clusters of galaxies (e.g., Sarazin 1988): (1) Cold gas that has been removed from the individual galaxies, possibly by ram pressure stripping or by galaxy collisions (Soker et al. 1991; Sparks et al. 1989), (2) primordial clouds or protogalaxies that are currently falling into the cluster, and (3) clouds that condense from thermal instabilities in a cooling flow in the inner $\sim 100$ kpc of the cluster center (e.g., Cowie & Binney 1977; Fabian & Nulsen 1977; Mathews & Bregman 1978; Fabian 1994). Mass accretion rates in cooling flows have been estimated to be in the range $\dot{m} \sim 10$–$100 \, M_\odot$ yr$^{-1}$. If these accretion rates last for the lifetime of the cluster ($\sim 10^{10}$ yr), the accumulated mass in gas would be $10^{11}$–$10^{12} \, M_\odot$. On the other hand, potential sinks and destructive processes for cold gas include (1) star formation (e.g., Allen 1995) and (2) heating and evaporation via thermal conduction, mixing layers, etc. (e.g., Sparks 1992; Böhringer & Fabian 1989), and shredding (e.g., Loewenstein & Fabian 1990).

X-ray spectroscopy with XMM-\textit{Newton} and \textit{Chandra} has failed to find evidence for gas at temperatures below about 1/3 of the cluster virial temperature (e.g., Kaarstra et al. 2001; Tamura et al. 2001; Peterson et al. 2001, 2003). The limits on the luminosity of the intermediate-temperature gas imply reductions in the inferred mass accretion rates by factors of 5–10. One possibility...
is that there is a source of heat in the ICM (radio galaxies e.g., Baum & O'Dea 1991; Tucker & David 1997; Soker et al. 2002; Böhringer et al. 2002) that halts the cooling of the gas. Alternately, it may be possible that the X-ray luminosity of the cooling gas is absorbed, with the luminosity finally emerging at another waveband (e.g., Fabian et al. 2001, 2002; Peterson et al. 2001). This raises the question of whether the required absorbing matter exists in these clusters.

Early X-ray observations indicated evidence for low-energy X-ray absorption in excess of what would be produced by the known Galactic column densities in the range \(10^{20} - 10^{21}\) cm\(^{-2}\). However, recent Laor et al. (2002) has used a high-resolution \((\text{Fe}^{2+}\) and \(\text{Mg}^{2+}\)) UV spectra of the quasar in the center of A1050 and placed limits on column densities in the range \(10^{11} - 10^{13}\) cm\(^{-2}\) for a wide range of molecular, atomic, and ionized species that may be associated with the ICM. Miller et al. (2002) obtained limits of \(10^{12} - 10^{13}\) cm\(^{-2}\) on column densities for several absorption lines (Fe \(\text{ii}\) and Mg \(\text{ii}\)) through lines of sight toward the outer parts of six clusters. Laor (1997) has used a low-resolution (\(<200\) km s\(^{-1}\)) HST FOS spectra of the Ly\(_\alpha\) line in the center of the Perseus Cluster (published by Johnstone & Fabian 1995) to set an upper limit of \(N_{\text{Ly}\alpha} < 4\times10^{17}\) cm\(^{-2}\). It was clear that an improvement of several orders of magnitude in the constraints on the atomic hydrogen columns could be achieved by obtaining higher resolution spectra of the Ly\(_\alpha\) line.

In this paper we present medium-dispersion (20 km s\(^{-1}\)) HST Space Telescope Imaging Spectrograph (STIS) long-slit spectroscopy of the Ly\(_\alpha\) line toward the central nebulae in three clusters, A426, A1795, and A2597. We report the discovery of Ly\(_\alpha\) absorption systems toward the nucleus and extended Ly\(_\alpha\) emission of NGC 1275. We discuss the nature and origin of these systems. We also place constraints on the properties of clouds in the ICM.

### 2. OBSERVATIONS AND RESULTS

The properties of the three central galaxies are summarized in Table 1. The HST STIS (Kimble et al. 1998) spectroscopic observations are summarized in Table 2. We observed with the far-UV Multianode Microchannel Array (MAMA) and the G140M gratings centered on the redshifted Ly\(_\alpha\) emission line. Spectral and spatial pixel scales are 0.05 A pixel\(^{-1}\) and 0.029 pixel\(^{-1}\), respectively. Spectral resolution is 1.6 pixels (0.08 Å) FWHM, which gives approximately 20 km s\(^{-1}\). We used the 0′′1 slits to preserve our spectral and spatial resolution. We observed in TIME-TAG mode to allow us to reject data with high sky background.

| Parameter |
|-----------|
| Second name | A426/NGC 1275 | A1795 | A2597 |
| V magnitude | 3C 84 | 4C 26.42 | PKS B2322—123 |
| Galactic E(B - V) | 0.171 | 0.013 | 0.030 |
| Observed H\(\alpha\)/H\(\beta\) | 4.77 | 3.2 | 4.2 ± 0.1 |
| Redshift | 0.017559 | 0.06326 | 0.08220 |
| Scale (kpc/arcsec) | 0.33 | 1.12 | 1.42 |
| 1.4 GHz flux density (Jy) | 21.2 | 1.0 | 2.0 |
| Radio power log \(P_{\text{14 GHz}}\) (W Hz\(^{-1}\)) | 25.51 | 25.31 | 25.84 |

**Notes:** We adopt a Hubble constant of \(H_0 = 75\) km s\(^{-1}\) Mpc\(^{-1}\) and a deceleration parameter of \(q_0 = 0.0\). Balmer decrements are from Kent & Sargent (1979), Hu et al. (1985), and Voit & Donahue (1997), respectively.
We obtained "early acquisition" images of the Ly$\alpha$/C$\text{IV}$ emission line and the nearby far-UV continuum. These data are discussed by O'Dea et al. (2004). We used these images to select a position angle for the slit that maximized the amount of bright Ly$\alpha$/C$\text{IV}$ and/or far-ultraviolet (FUV) continuum in the slit. The locations of the slits are shown in Figures 1, 2, and 3. The data were reduced with the STIS pipeline using the best updated reference files.

The two-dimensional spectra are shown in Figures 4, 5, 6. We detect spatially extended Ly$\alpha$ emission in our spectra of all three sources. The fluxes for the extended emission are consistent with those derived from those locations in the UV images (O’Dea et al. 2004). In the A2597 spectrum, we also detect the geocoronal O i lines at 1302, 1305, and 1306 Å (Table 3).

In A426 we detect a bright Ly$\alpha$ emission line with broad wings from the active nucleus. We do not see evidence for pointlike nuclear emission in A1795 or A2597.

### 3. Absorption Lines Toward the Nucleus of NGC 1275

We detect 10 Ly$\alpha$ absorption systems toward the nucleus of NGC 1275 (3C 84; Fig. 7; Table 4). In order to determine the properties of each absorption system, we multiplied the observed spectrum by $e^{\tau_\lambda}$, where $\tau_\lambda$ is the wavelength dependence of the optical depth of each system. The value of $\tau_\lambda$ is set by the center of the line, $\lambda_0$, the velocity dispersion parameter, and the H$\text{I}$ column, through the standard Voigt profile calculations (e.g., Rybicki & Lightman 1979). We iterate over the values of these three parameters until the corrected spectrum appears featureless. We estimate the uncertainty in the column density and velocity dispersion to be at a level of 10%–30%. The wavelength uncertainty is generally set by the spectral resolution. This absorption correction procedure assumes absorption by a uniform screen. The implied column could be larger in case of partial obscuration (i.e., absorbing filaments that are smaller than the continuum source). The requirement that the Ly$\alpha$ damping wings are not broader than the observed absorption width provides a strict upper limit to the possible column. The two strongly damped systems correspond to Galactic absorption and to absorption by the infalling foreground system at 8200 km s$^{-1}$, also detected in H$\text{I}$. The column densities in the detected absorption lines are in the range $N$(H$\text{I}) \sim 10^{12}$–$10^{14}$ cm$^{-2}$, and Doppler parameters are in the range $b \sim 25$–70 km s$^{-1}$.

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**Table 2**

| Source   | Date     | Position Angle | Exposure Time | Central $\lambda$ |
|----------|----------|----------------|---------------|--------------------|
| A426     | 2000 Dec 5 | 100            | 4900          | 1222               |
| A1795    | 2001 Mar 17 | -158           | 4500          | 1272               |
| A2597    | 2000 Nov 18 | 19             | 4300          | 1321               |

Notes.—Observations were obtained with the STIS FUV-MAMA and the G140M grating through the 52" x 0.1 slit under program 8107. TIME-TAG mode was used. Col. (1): Cluster name; col. (2): date of the observation; col. (3): slit position angle on the sky; col. (4): total exposure time; col. (5): central wavelength of the G140M grating.
Fig. 2.—A1795: STIS FUV-MAMA Ly$\alpha$ image (O’Dea et al. 2004), showing location of the slit position angle (−158$^\circ$). Positions are epoch J2000.0.

Fig. 3.—A2597: STIS FUV-MAMA Ly$\alpha$ image (O’Dea et al. 2004), showing the location of the slit position angle (19$^\circ$). Positions are epoch J2000.0.
Fig. 4.—A426: Gray-scale image of the STIS FUV-MAMA two-dimensional spectrum. Geocoronal Ly\textalpha{} is visible at 1216 Å. Extended Ly\textalpha{} emission is seen at 1237 Å.
Fig. 5.—A1795: Gray-scale image of the STIS FUV-MAMA two-dimensional spectrum. The background is dominated by a nonuniform glow from the detector window. Faint extended Ly$\alpha$ emission in A1795 is seen at 1292 Å.
The Lyα in NGC 1275 is viewed through two damped Lyα absorption systems, one in our Galaxy at $v = 0$ and one in the infalling high-velocity system ($v = 8200 \text{ km s}^{-1}$). The data corrected for the effects of these two systems are shown in Figure 8. We estimate column densities of $\sim 1 \times 10^{21} \text{ cm}^{-2}$ in the damped systems, which is in agreement with the observed 21 cm columns, providing a consistency check on our analysis.

We detect Lyα absorption (feature 8) at the systemic velocity of NGC 1275. However, it is the weakest of our detections. The other absorption features are seen mainly in the wings of the Lyα emission line. Seven of nine features are blueshifted with respect to the systemic velocity of NGC 1275. The absorption systems extend out to $-3500 \text{ km s}^{-1}$ with respect to systemic.

### 3.1. Where Are the Nuclear 21 cm Absorbers?

The 21 cm line has been detected in absorption toward the nucleus of NGC 1275 (Crane et al. 1982; Jaffe 1990; Sijbring 1993) with an optical depth $\tau \approx 0.0024$ and FWHM $\sim 440 \text{ km s}^{-1}$, which gives a column density of $N(\text{H}i) \approx 2 \times 10^{20} \text{ cm}^{-2}$ for “warm” clouds ($T = 100 \text{ K}$). However, the column measured in the Lyα absorption line (system 8) is only $N(\text{H}i) \approx 3 \times 10^{12} \text{ cm}^{-2}$. This difference suggests that the atomic hydrogen detected in the 21 cm line avoids the line of sight to the nucleus.

NGC 1275 exhibits a two-sided (but asymmetric) parsec-scale radio source (e.g., Walker et al. 1994; Vermeulen et al. 1994). Our results imply that the 21 cm absorption is seen against the parsec-scale radio source, but not directly against the Lyα-emitting region in the nucleus.

Multifrequency VLBI observations have shown that there is free-free absorption toward the northern radio jet (e.g., Walker et al. 1994, 2000; Vermeulen et al. 1994). The free-free absorbing medium seems likely to be located in a disk or torus (e.g., Levinson et al. 1995; Walker et al. 2000). We suggest that the...
atomic hydrogen responsible for the 21 cm absorption may also be located in that putative disk or torus.

3.2. Comparison of the STIS and FOS Spectra at Similar Resolution

Johnstone & Fabian (1995) presented an HST FOS spectrum of the nucleus of NGC 1275 taken 1993 February 3 through the G130H grating with a spectral resolution of ~1 Å. They found an apparent dip in the spectrum at 1237 Å, which they attributed to the presence of a blueshifted component of Lyα produced by Fermi-accelerated Lyα emission (Neufeld & McKee 1988; Binette et al. 1998). For NGC 1275, this model requires that the Lyα photons be scattered back and forth across a shock with velocity $v_s \sim 100$ km s$^{-1}$ and atomic hydrogen column density $1.1 \times 10^{20}$ cm$^{-2} < N < 1.3 \times 10^{21}$ cm$^{-2}$ (Johnstone & Fabian 1995). The Lyα photons must also be generated in or near the shock to avoid destruction by dust associated with these high columns.

In Figure 9 we present a comparison of the FOS 130H data with our STIS G140M spectrum scaled to similar spectral resolution. The FOS spectrum has too low resolution and too low signal-to-noise ratio to have detected the 10 Lyα absorption features that we detect in our STIS G140M spectrum. However, we should have seen the feature in the FOS spectrum at 1237 Å. The discrepancy could be due to bad data in the FOS spectrum. However, it is also possible that the 1237 Å feature is variable. This would imply that it is an “intrinsic absorption feature” (see § 3.3.1). If the variability of the feature is due to the motion of clouds near the nucleus, at a velocity of 0.01 c perpendicular to our line of sight, they could move only 0.07 lt-yr in the ~7 yr between the two observations. Thus, the clouds should be less than 0.025 pc across. Alternately, the difference in the STIS and FOS spectra could be at least partially due to aperture affects. The larger FOS aperture contains a contribution from extended Lyα emission that exhibits a Lyα absorption feature at the systemic velocity (see below). This could be the source of the feature seen in the FOS spectrum.

### Table 4

| Feature | EW (Å) | λ (Å) | $v$ (km s$^{-1}$) | $N$(H) ($10^{14}$ cm$^{-2}$) | b (km s$^{-1}$) |
|---------|--------|-------|----------------|----------------------------|-----------------|
| 1...    | 0.5383 | 1223  | 1718           | 1.70                       | 70              |
| 2...    | 0.1715 | 1225  | 2270           | 0.50                       | 25              |
| 3...    | 0.6398 | 1226  | 2458           | 2.40                       | 70              |
| 4...    | 0.1331 | 1231  | 3857           | 0.30                       | 35              |
| 5...    | 0.3093 | 1232  | 4037           | 1.10                       | 35              |
| 6...    | 0.3232 | 1233  | 4205           | 1.05                       | 35              |
| 7...    | 0.2666 | 1233  | 4331           | 0.75                       | 40              |
| 8...    | 0.1567E-01 | 1237 | 5264 | 0.63 | 70 |
| 8*      | ...    | 1237  | 5264           | 0.63                       | 70              |
| 9...    | 0.2817 | 1238  | 5585           | 0.67                       | 60              |
| 10...   | 0.5348 | 1239  | 5794           | 1.90                       | 60              |
| 11*     | ...    | 1237  | 5259           | ...                        | ...             |

**Notes.—** Properties of the detected absorption lines. Col. (1): Assigned number; col. (2): equivalent width; col. (3): observed central wavelength of the line; col. (4): heliocentric velocity of the line; col. (5): estimated column density of atomic hydrogen, assuming a covering factor of unity; col. (6): Doppler b factor (where $b = \sigma \sqrt{2}$ and $\sigma$ is the Gaussian dispersion).

*a* Detected toward the extended emission.

*b* Uncertain detection.

3.3. What Are the Absorption Features toward NGC 1275?

#### 3.3.1. Intrinsic Nuclear Absorption Features

Seven of nine features seen toward the nucleus of NGC 1275 are blueshifted with respect to the systemic velocity of NGC 1275. The absorption systems extend out to ~3500 km s$^{-1}$ with respect to systemic. One possibility that applies to these systems is that they are associated with outflowing nuclear gas. We note that “intrinsic” absorption features are found in about half of Seyfert 1 AGNs (e.g., Crenshaw et al. 1999), which have optical and X-ray luminosity similar to NGC 1275. The intrinsic absorption features in AGNs tend to be blueshifted, variable, have a range of line widths of ~20–400 km s$^{-1}$, and exhibit high-ionization metal lines (e.g., Weymann et al. 1997; Crenshaw et al. 1999; Kriss et al. 2000). The intrinsic features are thought to be produced by clouds in an outflowing wind.

The column densities, widths, and velocity offsets of the absorption features in NGC 1275 are roughly consistent with those of intrinsic absorption features. In addition, the possibility that the 1237 Å feature (if real) is variable is also consistent with that
Fig. 8.—A426: Same as Fig. 7, but including corrections for damped Ly$\alpha$ absorption by the Galaxy (at $v = 0$) and by the foreground infalling galaxy (at $v = 8200$ km s$^{-1}$). The Ly$\alpha$ absorption profile of both systems suggests a column of about $1 \times 10^{21}$ cm$^{-2}$, consistent with the 21 cm absorption by these systems.

Fig. 9.—A426: Comparison of the 1993 FOS G130H spectrum (Johnstone & Fabian 1995) with our 2000 STIS G140M spectrum. The FOS spectrum was scaled by a factor of 1.55 to match the STIS spectrum. The STIS G140M spectrum has been rebinned by a factor of 8 (pixel size 0.85 Å) so that it has resolution similar to that of the FOS G130H spectrum.
origin. Additional observations to search for variability and determine the metallicity of the systems would test this scenario.

3.3.2. Emission-Line Filaments

We have compared the velocities of the absorption features with those of the line-emitting filaments given by Conselice et al. (2001). The emission-line filaments cover a velocity range of roughly 5000–5500 km s\(^{-1}\). We find that only one absorption feature (system 8) agrees with the velocity of any of the filaments. In fact, most of the absorption features lie at velocities well beyond the range of velocities of the line-emitting filaments. Thus, the emission-line filaments do not produce the majority of the absorption features.

The radio source 3C 84 appears to have evacuated “bubbles” in the ICM (e.g., Böhringer et al. 1993; McNamara et al. 1996; Fabian et al. 2000). A. C. Fabian (2003, private communication) has noted that we may be viewing the nucleus of NGC 1275 through the northern bubble and has suggested that the bubble has displaced the emission-line filaments from our line of sight to the nucleus. An alternate possibility is that any dense line-emitting clouds that have been engulfed by the expanding bubble have been destroyed by shredding (e.g., Loewenstein & Fabian 1990; Klein et al. 1994; O’Dea et al. 2003, 2004).

3.3.3. Galaxies in the Perseus Cluster

We have searched in NED for galaxies close to NGC 1275 in projection and in velocity that might be candidates for some of the absorption features (Table 5). We searched a box-shaped region 8′ across centered on NGC 1275 and within a heliocentric velocity range 1000–6000 km s\(^{-1}\). We find that four of the absorption systems have potential associations with cluster galaxies 30–80 kpc in projection to the line of sight and 27–106 km s\(^{-1}\) offset in velocity. At this point it is not clear which if any of these candidate associations are real.

3.3.4. Ly\(_\alpha\) Forest Systems

The column densities and Doppler \(b\) parameters of the absorption features toward NGC 1275 are similar to those of typical Ly\(_\alpha\) forest systems (e.g., Rauch 1998). However, according to Bahcall et al. (1996), the density of the Ly\(_\alpha\) forest at \(z \sim 0\) is \(dN/dz = 24.5 \pm 6.6\) for systems with \(EW > 0.25\) Å. Now, the 10 absorption systems we see cover \(\Delta v = 4076\) km s\(^{-1}\), or \(dz = \Delta v/c = 0.0136\). Thus, we would have expected 0.0136 × 24.5 = 0.33 Ly\(_\alpha\) forest systems to fall at the velocity interval we observed, while there are 7 (out of the 10) systems with \(EW > 0.25\) Å. So, this suggests that the systems we have detected are most likely not part of the general Ly\(_\alpha\) forest in the direction of A426. Since the velocity range of the Ly\(_\alpha\) absorption systems is so much larger than the velocity range of the \(\mathrm{H}\alpha\) emission filaments (Conselice et al. 2001), it seems that the best bet is that most of these absorption systems are associated with the active nucleus.

4. CONSTRAINTS ON EXTENDED ABSORPTION IN A426, A1795, AND A2597

Figure 10 shows a comparison of the nuclear spectrum with the sum of two off-nuclear emission regions. We detect the absorption system seen against the nucleus at the systemic velocity of 5264 km s\(^{-1}\) and possibly also a system at 5259 km s\(^{-1}\), which is not formally detected against the nucleus. The column density in the extended 5264 km s\(^{-1}\) system is about a factor of 30 times larger than that seen toward the nucleus. This suggests that the extended absorbing system is possibly associated with the plane of the galaxy. If the extended system is damped and is seen with an absorption depth of 0.5 because of scattering or partial covering, then the upper limit to the estimated column becomes \(N(\mathrm{H}\alpha) < 2 \times 10^{18}\) cm\(^{-2}\).

Extracted spectra showing Gaussian fits to the extended Ly\(_\alpha\) emission lines in A1795 and A2597 are shown in Figures 11 and 12. The results of the Gaussian fits are presented in Table 6. A fairly conservative upper limit on the absorption EW in these spectra is 0.1 Å, or 25 km s\(^{-1}\). We use the curve of growth analysis in Laor (1997) to convert the EW to a column density. Laor gives convenient analytic approximations for the three regimes in the curve of growth (linear, saturated, and damped). When the absorption becomes optically thick, the absorption EW \(\sim 1.66\) Å, so the optically thin case applies for \(EW = 0.1\) Å when \(b > 15\) km s\(^{-1}\), and in that regime \(N(\mathrm{H}\alpha) \approx 1.8 \times 10^{13}\) cm\(^{-2}\). The transition to damped absorption occurs when \(b < 4\) km s\(^{-1}\), which happens when \(T < 10^3\) K, and in that case \(N(\mathrm{H}\alpha) \approx 5.9 \times 10^{10}\) cm\(^{-2}\). We suspect that such cold and kinematically quiet H \(\upalpha\) inside clusters is quite unlikely, so the \(b > 15\) km s\(^{-1}\) H \(\upalpha\) column estimate is probably much more realistic. Thus, we find an implied column density of \(\leq 10^{13}\) cm\(^{-2}\) if the Doppler parameter \(b > 13\) km s\(^{-1}\).

Alternatively, the covering factor of any high column density gas must be less than \(\sim 25\%\). We note that in PKS 2322–123, the extended 21 cm absorption is consistent with a covering factor as low as \(6 \times 10^{-2}\) (O’Dea et al. 1994).

5. IMPLICATIONS

Many mechanisms have been proposed to explain the lack of cooling gas below temperatures of about 1 keV in “cooling

| Feature (1) | Galaxy (2) | Type (3) | Magnitude (4) | \(V_{\text{line}} - V_{\text{ID}}\) (km s\(^{-1}\)) | Offset (arcsec) | Offset (kpc) |
|------------|------------|---------|---------------|-----------------|----------------|-------------|
| 4          | Per 152    | E       | 15            | -80             | 203            | 67          |
| 5          | PGC 012423 | E       | 17            | -106            | 238            | 79          |
| 9          | PGC 012441 | E       | 16            | 99              | 94             | 31          |
| 10         | PGC 012433 | E?      | 18            | -27             | 92             | 31          |

Notes.—Results from a NED search using \(F = 1000–6000\) km s\(^{-1}\) within a box 8′ across, centered on NGC 1275. There are two candidate identifications for feature 4. Col. (1): Number of the absorption feature (see Table 4); col. (2): name of the galaxy that is a candidate for identification with the absorption line; col. (3): Hubble type of the galaxy; col. (4): magnitude of the candidate galaxy; col. (5): offset in velocity between the absorption line and the candidate galaxy; col. (6): angular separation between the candidate galaxy and the nucleus of NGC 1275; col. (7): offset in kpc, assuming the system is at the distance of the Perseus Cluster.
Fig. 10.—A426: G140 spectra. Top, Nucleus of NGC 1275; middle, sum of extended emission between 0''87 and 2''1 from the nucleus; bottom, sum of extended emission between 2''1 and 7''1 from the nucleus.
Fig. 11.—A1795: G140 spectra vs. rest wavelength. Each panel shows a spectrum integrated along 1/3 of the slit, corresponding to 11’6 (row numbers are indicated in parentheses, where row 1 corresponds to the bottom of the image in Fig. 5, south). Significant Lyα emission is detected near the core. The peak of the emission from the upper half of the core (rows 600–800) is blueshifted by ∼200 km s⁻¹ compared to the emission from the lower half (rows 400–600). Some extended emission may be present south of the nucleus region, but none is detected to the north. The apparent rise in the spectrum in the south results from a nonuniform instrumental background. No clear Lyα absorption is present toward the nucleus.
Our results are relevant to models that invoke differential absorption by cold gas to hide the missing low-temperature X-ray gas. Fabian et al. estimate that the required atomic hydrogen column densities are in the range of a few times $10^{21} - 10^{22}$ cm$^{-2}$. Such high columns would have been easily seen in Ly$\alpha$ absorption, since our upper limits are of the order of $10^{13}$ cm$^{-2}$. The covering factors would need to be fairly high in order to reduce the emission from the cooling gas by the observed factors of 5–10 (e.g., Peterson et al. 2003). Fabian et al. note that the cold gas need not have a uniform distribution in the ICM, but must preferentially cover the regions where gas is cooling. Since our observations sample the lines of sight to the emission-line nebula (which are presumably the locations of the cooling gas), we directly constrain this reduced covering factor model. Thus, we find that the “missing” cooling gas in cooling core clusters is unlikely to be hidden by absorption.

More generally, we place limits on the column density of cool gas along our line of sight to the bright central emission-line nebulae. Thus, our results constrain the amount of cool gas embedded in the hot ICM, i.e., outside the dense nebulae in the central $\sim 10–20$ kpc of the cluster (e.g., Edge 2001; Jaffe et al. 2005). If we assume that absorption feature 10 is one such system in the ICM, the column density of $2 \times 10^{14}$ cm$^{-2}$ implies a total mass of $\sim 40,000 M_\odot$ of cold gas in the hot ICM within a shell of radius $\sim 20–100$ kpc. If dense cold gas is injected into the ICM, e.g., by ram pressure stripping from galaxies (e.g., Soker et al. 1991) or cooling on the $\sim 100$ kpc scale, it can sink to the center of the cluster on a timescale no shorter than $\sim (100$ kpc)/$(1000$ km s$^{-1}) \sim 10^8$ yr. This limits the rate at

### Table 6

| Galaxy  | Slit Length (arcsec) | Flux (ergs s$^{-1}$ cm$^{-2}$) | Central $\lambda$ (Å) | FWHM (Å) | FWHM (km s$^{-1}$) |
|---------|----------------------|-------------------------------|----------------------|---------|-------------------|
| A426..... | 5.8                  | $2.4 \times 10^{-12}$         | 1236.67              | 3.2     | 780               |
| A1795..... | 12.9                 | $4.9 \times 10^{-12}$         | 1291.80              | 2.7     | 630               |
| A2597..... | 18.7                 | $6.8 \times 10^{-12}$         | 1315.79              | 3.7     | 844               |

**Notes.**—The results of Gaussian fits to the spectra. The slit length is the distance along the slit that was summed to produce the spectrum.
which cold gas can accumulate in the ICM on 100 kpc scales. The accumulation rate (i.e., the difference between the sources and sinks of cold gas) is constrained to be no more than about $4 \times 10^{-4} M_\odot \, \text{yr}^{-1}$. This suggests that (1) if cold clouds are not efficiently destroyed, injection of cold gas into the hot ICM (by any mechanism, including cooling) on 100 kpc scales is very low, $\sim 10^{-4} M_\odot \, \text{yr}^{-1}$, or (2) any cold clouds on 100 kpc scales are efficiently reheated or destroyed (e.g., Loewenstein & Fabian 1999), and (3) the dense nebulae in the cluster center are produced by gas that is deposited or that cools in situ.

6. SUMMARY

We present HST STIS long-slit spectroscopy of the Ly\textalpha line in A426, A1795, and A2597. We detect 10 Ly\textalpha absorption systems toward the nucleus of NGC 1275 with estimated column densities in the range $N(\text{H}\alpha) \sim 10^{12} - 10^{14} \, \text{cm}^{-2}$. These systems could not have been detected in the 21 cm line, but are easily detected in Ly\textalpha absorption. Most of the detected features are located in the broad wings of the emission line and are beyond the velocity range of the emission-line filaments. The detected absorption systems are most consistent with associated nuclear absorption systems. Further observations of variability and/or the metal lines are necessary to confirm this hypothesis.

We do not detect the feature at 1237 Å reported by Johnstone & Fabian (1995) and interpreted as being due to Fermi-accelerated Ly\textalpha. If real, this feature is variable and would be consistent with an intrinsic absorbing system.

There is very little absorption at the systemic velocity of NGC 1275 [feature 8 contains $N(\text{H}\alpha) \sim 3 \times 10^{12} \, \text{cm}^{-2}$]. This implies that the very large column densities detected in the 21 cm line avoid the line of sight to the nuclear Ly\textalpha-emitting region and are likely detected against the parsec-scale radio jet. This atomic gas may be located in a circumnuclear disk or torus.

We detect two absorption systems (one at the systemic velocity) toward the extended Ly\textalpha emission in A426. We do not detect Ly\textalpha absorption toward the extended diffuse Ly\textalpha emission in A1795 and A2597, with upper limits $N(\text{H}\alpha) \lesssim 10^{13} \, \text{cm}^{-2}$ for optically thin absorbers with unity covering factor. Alternately, our data constrain the covering factor of any high column density gas [$N(\text{H}\alpha) \gtrsim 10^{15} \, \text{cm}^{-2}$] to be less than 25%.

Our results suggest that it is unlikely that the “missing” gas at temperatures below 1 keV in the cooling cores is due to absorption by large columns of absorbing gas with a covering factor of order unity. In addition, the low columns of gas on ~100 kpc scales in the ICM suggests that (1) the rate at which cold gas accumulates in the ICM on these scales is very low and (2) the dense nebulae in the central ~10 kpc must have cooled or been deposited in situ.

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