THE QUASAR/GALAXY PAIR PKS 1327–206/ESO 1327–2041: ABSORPTION ASSOCIATED WITH A RECENT GALAXY MERGER

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ABSTRACT

We present HST/WFPC2 broadband and ground-based Hα images, H i 21 cm emission maps, and low-resolution optical spectra of the nearby galaxy ESO 1327–2041, which is located 38” (14 h−1 00 kpc in projection) west of the quasar PKS 1327–206. Our Hubble Space Telescope (HST) images reveal that ESO 1327–2041 has a complex optical morphology, including an extended spiral arm that was previously classified as a polar ring. Our optical spectra show Hα emission from several H ii regions in this arm located ∼5” from the quasar position (∼2 h−1 00 kpc in projection) and our ground-based Hα images reveal the presence of several additional H ii regions in an inclined disk near the galaxy’s center. Absorption associated with ESO 1327–2041 is found in H i 21 cm, optical, and near-UV spectra of PKS 1327–206. We find two absorption components at cz abs = 5255 and 5510 km s−1 in the H i 21 cm absorption spectrum, which match the velocities of previously discovered metal-line components. We attribute the 5510 km s−1 absorber to disk gas in the extended spiral arm and the 5255 km s−1 absorber to high-velocity gas that has been tidally stripped from the disk of ESO 1327–2041. The complexity of the galaxy/absorber relationships for these very nearby H i 21 cm absorbers suggests that the standard view of high-redshift damped Lyα absorbers is oversimplified in many cases.

Key words: galaxies: interactions – intergalactic medium – quasars: absorption lines

1. INTRODUCTION

H i absorption lines in the spectra of background quasars are one of the rare astrophysical phenomena to be discovered first at great distances, where the far-UV Lyα transition redshifts into the optical. Only with the advent of the Hubble Space Telescope (HST) and its UV spectrographs have we been able to study these absorption lines at low redshift and probe their associations with gas in and around nearby galaxies (e.g., Morris et al. 1993; Bowen et al. 2001, 2002; Penton et al. 2002; Jenkins et al. 2003; Tripp et al. 2005; Lehner et al. 2009).

Lyα produces a “forest” of highly ionized absorption at z > 1.8 in ground-based spectra, as well as the occasional (dN/dz ∼ 1) high column density (17 < log N H i < 20.3 cm−2) “Lyman-limit systems” (LLSs; Bergeron & Boissé 1991; Steidel & Sargent 1992; Prochaska 1999; Prochaska et al. 2010) and the rare (dN/dz ∼ 0.1) very high column density (log N H i ∼ 20.3 cm−2) “damped Lyα absorbers” (DLAs; Wolfe et al. 2005). Unlike the vast majority of lower column density absorbers, including the LLSs, the DLAs consist of primarily neutral gas and so are potentially more directly related to star formation. Indeed, DLAs represent the largest neutral gas reservoir at each redshift of observation, which has been extended to z ∼ 5 through the discovery of very high-z QSOs and to z < 1.8 using HST (Wolfe et al. 2005).

There is no strong evidence for cosmological evolution in Ω H i over that entire range (Prochaska & Herbert-Fort 2004), although there is a factor ∼2 discrepancy between the lowest redshift DLA Ω H i values and those derived from H i 21 cm emission surveys at z ∼ 0 (Zwaan et al. 2005). Further, there are very few DLAs known at z < 1.8 because observing time on HST is too restrictive to allow a blind survey for low-z DLAs. A hybrid method of surveying only those QSOs with strong Mg ii (and Fe ii) absorption has shown some success (Rao et al. 2006; Nestor et al. 2005, 2006), but the factor of two discrepancy remains.

High-z DLAs are often modeled as thick gas disks associated with the progenitors of massive spiral galaxies (e.g., Wolfe & Prochaska 2000), but this is largely out of a desire for simplicity since the optical/IR emitting galaxy associated with the DLA is rarely detected, or even detectable, using current ground-based or space-based telescopes. The galaxy population responsible for DLAs is spread over a large range of luminosities (0.001−1 L*; Zwaan et al. 2005; Rosenberg & Schneider 2003), so it is not surprising that it has been difficult to detect the galaxies responsible for high-z DLA absorption nor that the spread in DLA metallicities is ∼2 dex at any given redshift. The log N H i > 20.3 cm−2 limit makes good sense physically since above this limit the gas must be primarily neutral; however, systems with H i column densities just below this limit (sometimes called “sub-DLAs” or “super LLSs”) may share many of the same associated galaxy properties with the DLAs (Tripp et al. 2005; Péroux et al. 2010).

The absence of direct galaxy detection for many DLAs and sub-DLAs is in marked contrast to the situation for LLSs, which are found to be associated with nearby (impact parameter ≤50 kpc), luminous (L > 0.1 L*), gas-rich galaxies (Bergeron & Boissé 1991; Steidel & Sargent 1992; Barton & Cooke 2009; Chen et al. 2010a, 2010b). The high luminosity and proximity of LLS host galaxies to the quasar sight line have been critical to their successful identification (e.g., Steidel 1995; Churchill et al. 2007; Kacprzak et al. 2010). The current consensus model for LLSs is gas in the halo of luminous galaxies although the physical processes that give rise to this gas are unclear and can encompass outflowing, unbound winds (Martin 1999; Heckman et al. 2001; Adelberger et al. 2003; Kacprzak et al. 2010) as well as outflowing or infalling galactic “fountain” material (Keeney et al. 2005; Richter et al. 2009; Stocke et al. 2010; Chen et al. 2010b). Theoretical models also predict that QSO
imaging of this resolution, in addition to the aforementioned long-slit spectroscopy of various galaxy components, as well. 

H\textsubscript{i} in this system is not directly observable due to a high-
z absorber (Kere\'s \& Hernquist 2009)

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The importance of this system for interpreting high-
z DLAs and sub-DLAs. We assume \( h_{70} = H_0/(70 \text{ km s}^{-1} \text{ Mpc}^{-1}) \) and a distance to ESO 1327–2041 of \( 80 \pm 5 h_{70}^{-1} \) Mpc throughout this paper.

2. THE INTERACTING GALAXY PAIR ESO 1327–2041

Early CCD images of ESO 1327–2041 revealed its disturbed optical morphology, which includes an elongated nucleus (oriented roughly north–south) with a central bulge, an east–west “polar ring” that extends from the galaxy nucleus to the quasar position, and a bright plume that extends 45° northeast of the galaxy nucleus (Giraud 1986). Subsequent H\textsubscript{i} 21 cm emission maps of ESO 1327–2041 confirmed the presence of a regularly rotating gaseous ring extending in the direction of PKS 1327–206 (CvG92). This complex morphology suggests that ESO 1327–2041 is the result of a recent major merger and/or a significant tidal interaction and that any absorption lines probing this system will also be quite complex.

We have obtained high-resolution observations of ESO 1327–2041 at multiple wavelengths, allowing us to study this galaxy in unprecedented detail. These observations include: HST broadband (Section 2.1) and ground-based H\alpha images (Section 2.2) of ESO 1327–2041, H\textsubscript{i} 21 cm emission maps of ESO 1327–2041 and PKS 1327–206 (Section 2.3), and long-slit optical spectra of several regions of ESO 1327–2041 (Section 2.4).

2.1. Broadband HST Images

ESO 1327–2041 was observed with the Wide-Field Planetary Camera 2 (WFPC2) on board HST on 2007 Apr 16 for a total of 4200 s in the F675W (R-band) filter and 2400 s in each of the F450W (wide B-band) and F791W (wide I-band) filters as part of GO program 10925 (PI: J. Stocke). The images were reduced and co-added using the stsdas package of IRAF, as described in the WFPC2 Data Handbook.\(^5\) Our images were oriented such that ESO 1327–2041 and PKS 1327–206 fell only on WF2 and WF3, so we did not analyze the WF4 or PC chips of the detector. Our reduced images reach limiting 3 times Vega magnitudes of 26.9, 26.5, and 26.0 for point sources in the F450W, F675W, and F791W filters, respectively.

A color composite image of the WFPC2 data (WF2 and WF3 chips only) is shown in the left panel of Figure 1, where the F450W data are displayed in blue, the F675W data in green, and the F791W data in red. The lower-resolution red areas in the center of ESO 1327–2041 are H\textsubscript{i} regions detected in our ground-based H\alpha images (Section 2.2). The field of view of Figure 1 is approximately \( 75'' \times 150'' \), which corresponds to a physical scale of \( 28 \times 56 h_{70}^{-1} \) kpc at the redshift of ESO 1327–2041.

All of the features identified by Giraud (1986) and CvG92 are present in the WFPC2 images, but the superior spatial resolution of HST reveals several new features that we have labeled in a schematic of the WFPC2 images in the right panel of Figure 1. In particular, the central region of ESO 1327–2041 is resolved into two components that are blended together at ground-based resolution: a lenticular component that corresponds to the “elongated nucleus” of Giraud (1986), and an inclined spiral galaxy collision now on-going. In Section 5, we summarize the results of our observational campaign on this system and discuss the importance of this system for interpreting high-
z DLAs and sub-DLAs. We assume \( h_{70} = H_0/(70 \text{ km s}^{-1} \text{ Mpc}^{-1}) \) and a distance to ESO 1327–2041 of \( 80 \pm 5 h_{70}^{-1} \) Mpc throughout this paper.

3 The WFPC2 Data Handbook can be found at http://www.stsci.edu/hst/wfpc2/.
that contains several H II regions. These components are clearly co-spatial since H II regions in the spiral disk are seen in front of the starlight from the lenticular component to the south of the galaxy nucleus but are occulted by the lenticular starlight to the north of the nucleus (i.e., the inclined disk is seen both in front of and behind the lenticular component). The “plume” of material extending NNE from the galaxy nucleus is resolved into a stellar stream with a compact embedded source that we speculate in Section 4 is the ejected nucleus of the inclined spiral. There is also a small companion galaxy located just north of the stellar stream, approximately halfway between the embedded source and the lenticular nucleus.

The previously identified “polar ring” is now resolved to be the outermost arm of the inclined spiral in the central regions of ESO 1327–2041. This arm may be in the process of being tidally stripped and passes quite close to the PKS 1327–206 sight line. We have detected several H II regions in this extended arm located ∼5″ (∼2 h⁻¹ 70 kpc) north of PKS 1327–206 (see Figure 1 and Section 2.4).

CvG92 found that the gas in the “polar ring” of ESO 1327–2041 is rotating regularly with lower velocities (∼5250 km s⁻¹) in the west and higher velocities (∼5500 km s⁻¹) in the east. This rotation is not surprising since we now identify this feature with an extended spiral arm. However, whether we call the gas that extends from the galaxy nucleus in the direction of PKS 1327–206 a “polar ring” or an “extended spiral arm” is largely a matter of semantics since the standard picture of polar-ring galaxies is that they are formed via galaxy mergers or the accretion of a companion galaxy or intergalactic medium (IGM) filament (Moiseev & Bizyaev 2009; Bournaud & Combes 2003).

2.2. Hα Images

Ideally, we would have obtained Hα images of ESO 1327–2041 with HST as well, but neither WFPC2 nor the Advanced Camera for Surveys had a narrowband filter suitable for observing Hα at the redshift of ESO 1327–2041. Instead the galaxy was observed at Apache Point Observatory.
(APO) on 2006 March 24 using the SPIcam imager of the ARC 3.5 m telescope. Redshifted Hα + [N II] images were obtained in 1′3 seeing for a total of 3000 s using a filter with a central wavelength of 6650 Å and FWHM = 80 Å. Additionally, ESO 1327−2041 was observed for 1800 s in 1′4 seeing through an off-band filter with FWHM = 100 Å and a central wavelength of 6450 Å in order to measure the strength of the stellar continuum. All images were reduced and co-added using standard IRAF procedures. The off-band image was then scaled so that its sky level matched that of the Hα on-band image before continuum subtraction. The resulting image should only contain flux from the Hα and [N II] emission lines, but there is some residual flux in the cores of bright stars due to the slight mismatch in seeing between the on-band and off-band images. Our final continuum-subtracted Hα image has been overlaid in red on the WFPC2 data in Figure 1. Only pixels with $F(H\alpha) > 10^{-17}$ erg s$^{-1}$ cm$^{-2}$ are shown, corresponding to areal star formation rates $> 0.005 h_{70}^{-3} M_\odot$ yr$^{-1}$ kpc$^{-2}$ at the distance of ESO 1327−2041 (Kennicutt 1998).

Figure 1 clearly highlights several H II regions in the inclined spiral disk of ESO 1327−2041. These H II regions have an integrated Hα flux of $F(H\alpha) = (7.2 \pm 1.4) \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ assuming a [N II]/Hα ratio of 0.3 ± 0.2 (derived as in Kennicutt et al. 2008). At our assumed distance to ESO 1327−2041 of 80 ± 5 $h_{70}^{-1}$ Mpc, this corresponds to a luminosity of $(5.5 \pm 1.3) \times 10^{40} h_{70}^{-2}$ erg s$^{-1}$ and a star formation rate of 0.44 ± 0.10 $h_{70}^{-2} M_\odot$ yr$^{-1}$ (Kennicutt 1998). So, despite the morphological evidence for a significant merger event in the recent past of ESO 1327−2041, this interaction is not currently driving a major starburst episode.

The semi-stellar knots just NNW of PKS 1327−206 (labeled as H II regions in the right panel of Figure 1) show no obvious Hα emission in our narrowband images. Nevertheless, a deep long-slit optical spectrum clearly detects very weak Hα emission associated with these knots (see Section 2.4), solidifying our earlier identification.

2.3. H I 21 cm Emission Maps

ESO 1327−2041 and PKS 1327−206 were observed by the VLA in the CnB configuration for 18.74 hr between 2005 June 18 and July 4. Data were obtained in L band (1.4 GHz) centered at a heliocentric velocity of 4 of 5370 km s$^{-1}$ (48.8 kHz) per channel. To improve sensitivity and resolution, these data were combined with the data of CvG92 after flagging and calibration. The CvG92 data were obtained with the VLA C-array on 1990 December 20 with the same channel configuration described above. The addition of the CvG92 data increases the total exposure time of our observations to 25.8 hr. All reductions for both data sets were performed with the Common Astronomy Software Applications (CASA) Beta Release, Version 2.0.

Figure 2 shows H I 21 cm (blue) and 1.4 GHz emission contours overlaid on the F675W WFPC2 data. The large red ellipse in the upper left corner of the image is the restoring beam for the H I contours and the smaller ellipse is the restoring beam of the uniform-weighted continuum contours. PKS 1327−206 has a double-lobed morphology and a peak continuum flux of 280 mJy beam$^{-1}$ at this resolution. There is also a weak continuum source (peak flux $\sim 5$ mJy beam$^{-1}$), first detected by CvG92, located $\sim 10''$ south of the embedded object in the stellar stream (see Figure 1) that Figure 2 reveals is associated with a background galaxy and not the embedded object itself.

Continuum sources were subtracted from the data cube before imaging the H I emission using the CASA task uvccontsub to perform a channel-by-channel linear fit to the continuum. We believe that the hole in the H I distribution toward PKS 1327−206 is due to the H I 21 cm absorption against the quasar background (see Section 3.1). The H I contours in Figure 2 show three peaks:

\[ \frac{v/c}{v} = (\nu_0 / \nu_0 - \nu) / (\lambda_0 / \lambda_0) = z, \]
one (labeled “A” in Figure 2) near the nucleus of the lenticular component of ESO 1327–2041 and two ("B" and “C”) that are likely associated with the extended spiral arm. There is also a region of more diffuse emission (“D”) that extends in the direction of the stellar stream but is offset approximately one beam width to the east and, finally, a large diffuse region (“E”) near the northern edge of the image.

Table 1 lists the positions, velocities, and H\(_i\) masses of these regions. We find that gas in the extended spiral arm is rotating regularly with lower velocities in the south and west (regions A and C) and higher velocities in the north and east (region B). The more diffuse extended regions of H\(_i\) 21 cm emission (regions D and E) have velocities that are \(\sim\)150 km s\(^{-1}\) lower than the closest disk gas in region B.

Figure 2 can be used to determine how the recent merger history of ESO 1327–2041 has affected its 21 cm emission properties compared to more isolated galaxies. The H\(_i\) emitting regions of typical spiral galaxies extend about twice as far as the regions of optical emission (e.g., Broeils & Rhee 1997; Noordermeer et al. 2005), which suggests that the “pre-merger” H\(_i\) extent of ESO 1327–2041 was \(\sim\)60" (\(\sim\)23 \(h_7\)\(^{-1}\) kpc). The measured angular extent of regions A–C in Figure 2 is \(\sim\)60", but increases to \(\sim\)80" (\(\sim\)31 \(h_7\)\(^{-1}\) kpc) if region D is included. Thus, the size of the H\(_i\) emitting region of ESO 1327–2041 has increased only modestly as a result of its recent interaction.

However, the galaxy interaction has caused ESO 1327–2041 to become noticeably H\(_i\)-deficient as compared to more isolated galaxies. The total H\(_i\) mass of regions A–E of ESO 1327–2041 is \(M_{\text{Hi}} = (9.6\pm0.6) \times 10^9 M_\odot\) (see Table 1), but late-type spirals with the same luminosity and optical size as ESO 1327–2041 tend to have H\(_i\) masses of \(M_{\text{Hi}} \sim 4 \times 10^9 M_\odot\) (Haynes & Giovanelli 1984). This deficiency can easily be explained if most of the H\(_i\) in ESO 1327–2041 was ionized during the interaction. Ionization considerations may also explain why the interaction failed to dramatically increase the H\(_i\) extent of ESO 1327–2041.

2.4. Optical Spectra

ESO 1327–2041 was observed with the DIS spectrograph of the ARC 3.5 m telescope at APO on 2008 May 1 and 2009 February 27–28 using a 1" slit and the B400+R300 gratings. These gratings cover the wavelength range 3600–9000 Å at 6–7 Å resolution except for a gap from \(\sim\)5300 to 5700 Å caused by a dichroic in the spectrograph. Data were obtained at three different slit positions: the first slit position was oriented along the major axis of the lenticular component of ESO 1327–2041, the second position was along the stellar stream with the slit passing through the embedded compact object, and the third position connected the compact object embedded in the stellar stream and PKS 1327–206 with the slit also passing through the

| Region | R.A. (J2000.0) | Decl. (J2000.0) | \(v_{\text{peak}}\) (km s\(^{-1}\)) | \(M_{\text{Hi}}\) (10\(^8 \, h_7^2\) \(M_\odot\)) |
|--------|----------------|----------------|-----------------|---------------------|
| A      | 13 30 05.2     | −20 55 56      | 5338            | 2.61 ± 0.33        |
| B      | 13 30 06.7     | −20 55 49      | 5402            | 1.81 ± 0.23        |
| C      | 13 30 06.4     | −20 56 18      | 5306            | 1.91 ± 0.25        |
| D      | 13 30 07.7     | −20 55 55      | 5263            | 1.01 ± 0.13        |
| E      | 13 30 07.6     | −20 54 38      | 5253            | 2.22 ± 0.28        |

Notes. a Region of interest as indicated in Figure 2. b The channel velocity of the H\(_i\) 21 cm emission peak for this region.

Table 2 Absorption Lines Detected in the Embedded Source

| ID   | \(\lambda_{\text{rest}}\) (Å) | \(\lambda_{\text{obs}}\) (Å) | \(v_{\text{helio}}\) (km s\(^{-1}\)) | \(W_{\lambda}\) (Å) |
|------|-----------------|----------------|-----------------|----------------|
| H\(_\gamma\) | 3835.38 | 3900.2 ± 2.4 | 5090 ± 190 | 13.7 ± 9.7 |
| H\(_\delta\) | 3899.05 | 3957.4 ± 3.7 | 5290 ± 200 | 7.8 ± 6.7 |
| Ca\(_{\text{II}}\) | 3933.66 | 4005.2 ± 1.4 | 5480 ± 110 | 3.5 ± 2.3 |
| Ca\(_{\text{II}}\) | 3970.07 | 4040.1 ± 3.9 | 5310 ± 300 | 15.4 ± 8.9 |
| H\(_\delta\)| 4101.73 | 4172.5 ± 2.6 | 5190 ± 190 | 9.0 ± 2.7 |
| H\(_\gamma\)| 4340.46 | 4416.7 ± 2.9 | 5290 ± 200 | 9.3 ± 3.5 |
| H\(_\beta\)| 4861.32 | 4946.4 ± 2.2 | 5270 ± 140 | 7.4 ± 2.4 |
| Na\(_i\) D | 5891.94 | 5995.6 ± 4.8 | 5300 ± 250 | 3.2 ± 1.5 |
| H\(_\alpha\)| 6562.80 | 6683.2 ± 2.3 | 5520 ± 110 | 3.7 ± 1.0 |

Notes. The average absorption-line velocity for this source is 5370 ± 50 km s\(^{-1}\).

Table 3 Absorption Lines Detected in the Stellar Stream

| ID   | \(\lambda_{\text{rest}}\) (Å) | \(\lambda_{\text{obs}}\) (Å) | \(v_{\text{helio}}\) (km s\(^{-1}\)) | \(W_{\lambda}\) (Å) |
|------|-----------------|----------------|-----------------|----------------|
| Ca\(_{\text{II}}\) | 3933.66 | 4006.8 ± 3.9 | 5600 ± 300 | 3.8 ± 2.4 |
| Ca\(_{\text{II}}\) | 3968.47 | 4036.7 ± 2.6 | 5180 ± 190 | 3.3 ± 1.7 |
| H\(_\gamma\)| 4340.40 | 4428.2 ± 2.2 | 5460 ± 160 | 4.7 ± 3.6 |
| H\(_\beta\)| 4340.46 | 4425.7 ± 1.9 | 5910 ± 130 | 5.9 ± 3.7 |
| H\(_\beta\)| 4861.32 | 4945.9 ± 5.2 | 5240 ± 320 | 4.8 ± 2.4 |

Notes. The average absorption-line velocity for this source is 5590 ± 80 km s\(^{-1}\).

H\(_\alpha\) regions in the extended spiral arm. Observations of Feige 34 taken each night were used for flux calibration, and all data were reduced with a combination of standard IRAF tasks and custom IDL routines.

The DIS spectrograph has a spatial scale of 0.4 pixel\(^{-1}\), and extraction apertures of 10", 40", and 5" were used for the lenticular component of ESO 1327–2041, the stellar stream, and the source embedded in the stream, respectively. The spectra of these galaxy components are shown in Figure 3. Only the blue portion of the spectra is shown, and the flux levels have been arbitrarily scaled for ease of display. The vertical dashed lines indicate the positions of the H\(_\beta\)–H\(_\gamma\) absorption lines detected in the spectrum of the embedded source. There are indications of even higher-order Balmer absorption from H\(_\delta\), H\(_\epsilon\), and H\(_\zeta\) in the spectrum of the embedded source, but declining signal-to-noise blueward of 3800 Å precludes us from making positive identifications.

Tables 2–4 list the line identification, rest wavelength, observed wavelength, heliocentric velocity, and rest-frame equivalent width of all lines detected in the DIS spectra, including lines detected at wavelengths not displayed in Figure 3. For the emission lines detected in the lenticular nucleus, Table 4 lists integrated line fluxes instead of rest-frame equivalent widths. These fluxes have not been corrected for Galactic or intrinsic reddening. Rest wavelengths for these and all other tables were taken from the Atomic Line List.3

Examination of these tables shows that Ca\(_{\text{II}}\) H and K absorption lines are detected in all three spectra, that the embedded source is detected primarily in Balmer absorption lines, and that the lenticular component is detected mostly in

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3 The Atomic Line List is hosted by the Department of Physics and Astronomy at the University of Kentucky (see [http://www.pa.uky.edu/~peter/newpage/](http://www.pa.uky.edu/~peter/newpage/)).
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Figure 3. Blue portion of our optical spectra of the lenticular region of ESO 1327–2041 (bottom), the stellar stream of material (middle), and the compact object embedded within the stream (top). The vertical axis is displayed in arbitrarily scaled $F_\lambda$ units. The dashed vertical lines indicate the positions of the Hβ–Hγ absorption lines detected in the embedded source at $cz = 5370 \pm 50$ km s$^{-1}$. The lenticular spectrum also contains [O ii] $\lambda$3717 and [O iii] $\lambda$5007 emission from a foreground H ii region in the slit (see Table 4).

Table 4

| Emission Lines | Absorption Lines |
|----------------|------------------|
| ID             | $\lambda_{\text{rest}}$ ($\AA$) | $\lambda_{\text{abs}}$ ($\AA$) | $v_{\text{helio}}$ (km s$^{-1}$) | $\lambda_{\text{helio}}$ (Å) | Integ. Flux | $W_v$ (Å) |
| [O ii]         | 3727.42          | 3794.7 ± 0.5 | 5400 ± 40 | 9.4 ± 3.6 | Ca ii K 3933.66 | 4005.9 ± 0.6 | 5500 ± 50 | 10.3 ± 3.1 |
| [O iii]        | 5007.84          | 5096.9 ± 0.4 | 5330 ± 30 | 10.4 ± 2.4 | Ca ii H 3968.47 | 4041.1 ± 0.7 | 5480 ± 50 | 10.8 ± 3.0 |
| [N ii]         | 6548.04          | 6613.0 ± 0.2 | 5310 ± 60 | 3.3 ± 0.8 | G band 4304.40 | 4382.4 ± 1.0 | 5430 ± 70 | 6.6 ± 2.4 |
| Hα             | 6562.80          | 6608.6 ± 0.3 | 5380 ± 20 | 15.1 ± 1.6 | Na i D 5891.94 | 5999.0 ± 0.6 | 5450 ± 30 | 4.9 ± 0.7 |
| [S ii]         | 6716.44          | 6837.3 ± 1.0 | 5390 ± 40 | 5.7 ± 1.0 | Hα 6562.80 | 6608.6 ± 0.3 | 5380 ± 20 | 15.1 ± 1.6 |
| [S iii]        | 6730.82          | 6852.0 ± 0.8 | 5390 ± 40 | 6.1 ± 1.0 |

Notes. The average emission-line velocity for this source is 5380 ± 10 km s$^{-1}$ and the average absorption-line velocity is 5460 ± 20 km s$^{-1}$.

We have detected very weak Hα emission from the H ii regions in the extended spiral arm at our third slit position. These H ii regions, which are heavily blended at ground-based resolution, are located $\sim$5′ ($\sim$2 $h_{70}$ kpc) north of PKS 1327–206 (see Figure 1) and have a heliocentric velocity of 5440 ± 20 km s$^{-1}$. Examination of their two-dimensional spectrum reveals a velocity gradient across the Hα blend that we have extrapolated to the position of PKS 1327–206 to estimate the disk velocity at the quasar position to be 5500 ± 30 km s$^{-1}$. This estimate is close to the H1 21 cm emission velocity near the quasar position, which ranges from $\sim$5400 to 5490 km s$^{-1}$ (CvG92).

3. ABSORPTION LINES ASSOCIATED WITH ESO 1327–2041 IN THE SPECTRUM OF PKS 1327–206

Past studies of the optical and radio spectra of PKS 1327–206 have found absorption associated with the nearby galaxy ESO 1327–2041 ($cz_{\text{gal}} = 5380 ± 10$ km s$^{-1}$). A high-resolution ($v_{\text{res}} \approx 30$ km s$^{-1}$) optical spectrum obtained by Bergeron et al. (1987) revealed two velocity components in the Na i D doublet at 5250 ± 10 and 5490 ± 10 km s$^{-1}$. A lower resolution ($v_{\text{res}} \approx 225$ km s$^{-1}$) optical spectrum, also from Bergeron et al. (1987), showed Ca ii H and K absorption at 5340 ± 90 km s$^{-1}$. CvG92 also found two velocity components in the H1 21 cm absorption spectrum of PKS 1327–206, although their detection of the 5490 km s$^{-1}$ component was tentative due to potential confusion from emission in the beam.

We have acquired more sensitive H1 21 cm and optical spectra of PKS 1327–206, which we present in Sections 3.1 and 3.2, respectively. We have also analyzed an archival HST near-UV (NUV) spectrum of PKS 1327–206, which is presented in Section 3.3 and the Appendix. These spectra allow us to confirm the presence of two H1 21 cm absorbers, search for evidence
overlaid. The dashed vertical lines show the velocities of the Na\textsc{i} D absorption components found by Bergeron et al. (1987). The dotted vertical line indicates the disk velocity at the position of PKS 1327–206, extrapolated from H\textsc{ii} regions in the extended spiral arm of ESO 1327–2041 (see Section 2.4).

![Figure 4. H\textsc{i} 21 cm absorption spectrum of PKS 1327–206 at 20′′ × 13″ resolution and 10.4 km s\(^{-1}\) channel\(^{-1}\) with best-fit absorption line profiles (see Table 5) overlaid. The dashed vertical lines show the velocities of the Na\textsc{i} D absorption components found by Bergeron et al. (1987). The dotted vertical line indicates the disk velocity at the position of PKS 1327–206, extrapolated from H\textsc{ii} regions in the extended spiral arm of ESO 1327–2041 (see Section 2.4).](image)

| $\theta_{helio}$ (km s\(^{-1}\)) | FWHM (km s\(^{-1}\)) | $T_0$ | $N_{H_1}/T_{spin}/f$ (10\(^3\)cm\(^{-2}\) K\(^{-1}\)) |
|-----------------|-----------------|-------|------------------|
| 5255 ± 5 | 17 ± 7 | 0.0068 ± 0.0006 | 2.3 ± 1.0 |
| 5510 ± 10 | 54 ± 18 | 0.0042 ± 0.0006 | 4.3 ± 1.6 |

3.1. H\textsc{i} 21 cm Spectrum

Our VLA observations (Section 2.3) allow us to search for H\textsc{i} 21 cm absorption against the quasar continuum in addition to studying the H\textsc{i} 21 cm emission properties of ESO 1327–2041. The H\textsc{i} 21 cm absorption spectrum of PKS 1327–206 is shown in Figure 4 with Gaussian fits to the absorption lines overlaid with thick black lines. The dashed vertical lines show the velocities of the Na\textsc{i} D absorption components found by Bergeron et al. (1987), which clearly match the observed 21 cm absorption velocities. Table 5 lists best-fit physical parameters derived from the Gaussian fits to the H\textsc{i} absorption components in Figure 4.

The H\textsc{ii} regions just NNW of PKS 1327–206 (see Figure 1) have heliocentric velocities comparable to the 5510 km s\(^{-1}\) H\textsc{i} absorption complex. An extrapolation of the H\textsc{a} emission line velocities toward PKS 1327–206 (see Section 2.4) arrives at the velocity indicated by the dotted vertical line in Figure 4. From this extrapolation we identify the 5510 km s\(^{-1}\) H\textsc{i} 21 cm absorber with the extended spiral arm of ESO 1327–2041, and thus as galactic disk absorption. The velocity of the H\textsc{i} 21 cm emission near the position of PKS 1327–206 is present in the NUV spectrum of PKS 1327–206.

at velocities between 5190 and 5296 km s\(^{-1}\) (CvG92). CvG92 suggests that the H\textsc{i} 21 cm absorber at 5255 km s\(^{-1}\) arises in the low surface brightness gas. Given the complex optical and H\textsc{i} 21 cm morphology of ESO 1327–2041, we hypothesize that the 5255 km s\(^{-1}\) absorber represents gas that has been tidally stripped from the disk of ESO 1327–2041.

The strength of H\textsc{i} 21 cm absorption depends on the column density ($N_{H_1}$), covering fraction ($f$), and spin temperature ($T_{spin}$) of the absorbing gas (see Table 5). Assuming $T_{spin} \sim 20$ K (Kobulnicky & Dickey 1999) found $T_{spin} = 20–40$ K in tidally disrupted gas in the Magellanic Bridge and $f = 1$, the column density of the 5255 km s\(^{-1}\) absorber is $N_{H_1} \sim 5 \times 10^{18}$ cm\(^{-2}\) and the column density of the 5510 km s\(^{-1}\) absorber is $N_{H_1} \sim 9 \times 10^{18}$ cm\(^{-2}\). These column densities are clearly uncertain due to ambiguities in both the spin temperature and covering factor of the absorbing gas; however, a higher spin temperature indicative of disk gas or halo gas and/or a smaller covering factor would tend to increase the derived column density, so we treat the above estimates as lower limits to the true H\textsc{i} column. Thus, the two 21 cm absorbers may combine to form a DLA ($N_{H_1} \geq 2 \times 10^{20}$ cm\(^{-2}\) as has been found in several other QSO sight lines that pass within $15 h_70$ kpc of a low-z foreground galaxy (see, e.g., Table 2 of Zwaan et al. 2005).

The large velocity width of the 5510 km s\(^{-1}\) absorber could be caused by either thermal broadening or velocity structure along the line of sight. The Gaussian shape of the line profile suggests that the broadening is thermal, but the associated kinetic temperature of the absorber is $\sim 60,000$ K in that case. The kinetic and spin temperatures should be coupled due to particle collisions; however, our kinetic temperature estimate for the 5510 km s\(^{-1}\) absorber is $T_{kin} \sim 5 \times 10^4$ K which is much lower than the largest spin temperatures reported in the literature ($\sim 5000$ K; see, e.g., Kanekar et al. 2009). If we allow the kinetic and spin temperatures to be coupled at $60,000$ K then the 5510 km s\(^{-1}\) absorber would have a neutral fraction of $N_{H_1} \approx 10^{-4}$ (Sutherland & Dopita 1993) and an H\textsc{i} column density of $N_{H_1} \geq 10^{22}$ cm\(^{-2}\).

$\text{CvG92}$ identified very weak H\textsc{i} 21 cm emission aligned with the stellar stream of ESO 1327–2041 and extending much further to the north (see their Figures 3 and 4), but at significantly lower spatial resolution ($50′$) than we show in Figure 2. Regions D and E in Figure 2 are the densest regions of this very diffuse emission, which extends into the vicinity of PKS 1327–206.

\footnote{The cold neutral medium of spiral galaxies typically has $T_{spin} \sim 100$ K (e.g., Roy et al. 2006).}$^7$

\footnote{Keeney et al. (2005) found $T_{spin} \sim 500$ K in the halo of the nearby spiral NGC 3067.}
or a total hydrogen column of $N_H \sim 10^{26}$ cm$^{-2}$. This situation is clearly unphysical, since gas at these densities would be molecular and quickly cool to more modest temperatures (e.g., Krumholz et al. 2009). Therefore, we attribute the width of the 5510 km s$^{-1}$ 21 cm absorber to velocity structure along the line of sight, which implies that the extended spiral arm of ESO 1327–2041 has a velocity dispersion of $\sim 25$ km s$^{-1}$ at the quasar position.

3.2. Optical Quasar Spectrum

Bergeron et al. (1987) argued that the observed Ca$\text{ii}$/Na$\text{i}$ ratio ($\lambda V_\lambda$(Ca$\text{ii}$)/$\lambda V_\lambda$(Na$\text{i}$) = 0.34 for the 5255 and 5510 km s$^{-1}$ absorbers combined) points toward a galactic disk origin for the absorbing gas. However, since their Ca$\text{ii}$ spectrum does not resolve both of the velocity components that they detected in Na$\text{i}$, they cannot assess the origin of the individual absorbers directly. Therefore, we obtained high-resolution optical spectra of PKS 1327–206 near the Ca$\text{ii}$ H and K ($v_{\text{res}} \approx 150$ km s$^{-1}$) and Na$\text{i}$ D ($v_{\text{res}} \approx 75$ km s$^{-1}$) absorption lines associated with ESO 1327–2041 to study the Ca$\text{ii}$/Na$\text{i}$ ratio of the individual velocity components.

ESO 1327–2041 was observed with the DIS spectrograph of the ARC 3.5 m telescope at APO on 2010 February 10, 2010 April 4, and 2010 May 6 using a 1″5 slit and the B1200+R1200 gratings. At central wavelengths of 4500 and 6400 Å, these gratings cover the wavelength ranges from 3900 to 5100 Å and 5800 to 7000 Å at 2 Å resolution. Observations of Feige 34 taken each night were used for flux calibration, and all data were reduced with a combination of standard IRAF tasks and custom IDL routines.

The regions surrounding the Ca$\text{ii}$ H and K and Na$\text{i}$ D absorption lines associated with ESO 1327–2041 are shown in Figure 5. Two velocity components are clearly detected in the Na$\text{i}$ D doublet, with the Na$\text{i}$ D1 line of the bluer component blended with the Na$\text{i}$ D2 line of the redder component. Best-fit velocities and deconvolved equivalent widths of these components were determined by simultaneous Voigt profile fits to the Na$\text{i}$ D doublets. The velocity structure of the Ca$\text{ii}$ profiles is less clear, but an apparent optical depth analysis of the Ca$\text{ii}$ K profile shows two significant peaks, which we use to measure the velocities and calculate the apparent column densities of both components (Sembach & Savage 1992). Deconvolved equivalent widths were then calculated.
from the apparent column densities assuming optically thin absorption.

Table 6 lists the line identification, rest wavelength, observed wavelength, heliocentric velocity, and rest-frame equivalent widths derived from these profiles. The Ca\textsc{ii} and Na\textsc{i} velocities clearly agree with each other, as well as with the velocities of the H\textsc{i} 21 cm components. However, while the velocity of the apparent column density peak associated with the bluer Ca\textsc{ii} component clearly matches that of the bluer Na\textsc{i} component, its equivalent width is not significant and is hereafter treated as an upper limit.

The 5255 and 5510 km s\textsuperscript{-1} velocity components have $W_\lambda$(Ca\textsc{ii})/$W_\lambda$(Na\textsc{i}) ratios of <0.26 and 0.63 ± 0.15, respectively, and a combined ratio of <0.48. Ratios this low require a weak ionizing radiation field and are typically associated with disk gas in our Galaxy (Morton & Blades 1986), whereas larger values ($W_\lambda$(Ca\textsc{ii})/$W_\lambda$(Na\textsc{i}) > 1) indicate a stronger radiation field associated with a galactic halo environment (e.g., Morton & Blades 1986; Stocke et al. 1991). A disk gas origin for both velocity components suggests that the 5255 km s\textsuperscript{-1} absorber represents gas that has been tidally stripped from the disk of ESO 1327–2041 rather than an HVC in the halo of the galaxy.

### 3.3. HST Near-UV Spectrum

PKS 1327–206 was observed with the Faint Object Spectrograph (FOS) on board HST on 1997 January 13 for a total of 6540 s with the G270H grating as part of GO program 5654. These data were taken in the 1.0 aperture\textsuperscript{8} and cover a wavelength range of 2222–3277 Å at 2 Å (∼200 km s\textsuperscript{-1}) resolution. The FOS spectrum of PKS 1327–206 is filled with absorption lines from many redshifts, including Galactic ISM lines, lines associated with ESO 1327–2041, lines associated with the LLS at $z = 0.85238$ (Bergeron et al. 1987), and intergalactic Ly\textalpha forest absorbers. We discuss the lines associated with ESO 1327–2041 here and defer discussion of the other absorption lines in the PKS 1327–206 spectrum to the Appendix since this spectrum has not been discussed previously in the literature.

Table 7 lists the line identification, rest wavelength, observed wavelength, heliocentric velocity, and rest-frame equivalent width of all absorption lines associated with ESO 1327–2041 that were detected at >4σ confidence (observed $W_\lambda$ > 200 mÅ).

### Notes.
1. The average velocity of this absorption-line system is 5360 ± 10 km s\textsuperscript{-1}.
2. This line is blended with Mg\textsc{i} λ2853 absorption from the Galactic ISM.

\[8\] The actual size of the aperture is 0’/86 since these observations were obtained after the installation of COSTAR on HST.

\[9\] To ensure that Galactic ISM lines were centered at $\theta_{\text{helio}} \sim 0$ we applied a zero-point offset of 145 ± 8 km s\textsuperscript{-1} to the FOS wavelength scale (see the Appendix for more details).
position of PKS 1327–206 (CvG92). This origin simultaneously explains the disk gas signatures and HVC kinematics of this velocity component.

One drawback to our H\textsc{i} 21 cm, optical, and NUV spectra of PKS 1327–206 is that we are only sensitive to neutral or singly ionized species at the redshift of ESO 1327–2041. We are therefore unable to speculate on the multi-phase nature of the absorbing gas, which may be crucial for understanding the radiation field incident on the 5255 and 5510 km s\(^{-1}\) absorbers and thus their locations with respect to ESO 1327–2041. Detailed study of the ionization state of the absorbing gas requires searching for Lyman series H\textsc{i} lines or abundant metals of varying ionization states (e.g., C\textsc{ii}, C\textsc{iii}, C\textsc{iv}, Si\textsc{ii}, Si\textsc{iii}, Si\textsc{iv}, N\textsc{v}, O\textsc{vi}) in the far-UV (FUV) spectrum of PKS 1327–206 as has been done for other close QSO/galaxy pairs (see, e.g., Bowen et al. 2001, 2005; Jenkins et al. 2005; Stocke et al. 2004; Keeney et al. 2005, 2006; Chen & Mulchaey 2009).

Unfortunately, there is an LLS at \(z = 0.85238\) that makes PKS 1327–206 too faint for FUV spectroscopy (see the Appendix and Bergeron et al. 1987). PKS 1327–206 was observed by the Galaxy Evolution Explorer (GALEX) as part of its All-Sky Imaging Survey and found to have an FUV magnitude of 21.2 (\(F_{\lambda} \approx 1.5 \times 10^{-16} \text{erg s}^{-1} \text{cm}^{-2} \text{Å}^{-1}\)). However, even with the exquisite FUV sensitivity of the recently installed Cosmic Origins Spectrograph on HST (J. C. Green et al. 2011, in preparation; Osterman et al. 2011) it would still take \(\sim 60\) orbits to reach S/N = 10 per resolution element (\(R \approx 18,000\)) with the G160M grating (\(\lambda \approx 1400–1800\) Å), which covers the Si\textsc{iv} and C\textsc{iv} transitions.

Two recent papers (Gupta et al. 2010; Borthakur et al. 2010) have searched for H\textsc{i} 21 cm absorption in quasar–galaxy pairs culled from the Sloan Digital Sky Survey. Both papers highlight the difficulty of detecting galaxies via H\textsc{i} 21 cm absorption: only 1 of 5 galaxies were detected by Gupta et al. (2010) and 1 of 12 by Borthakur et al. (2010), and both of these galaxies had impact parameters of \(< 11 h_{70}^{-1} \text{kpc}\) to the quasar sight line. As for the PKS 1327–206 absorbers, Gupta et al. (2010) and Borthakur et al. (2010) found that their absorbers had DLA/sub-DLA column densities and were most likely associated with disk gas in the foreground galaxies. The Gupta et al. (2010) absorber has a significantly larger \(V_{\lambda}(\text{Ca} \text{ii})/V_{\lambda}(\text{Na} \text{i})\) ratio (1.19 \(\pm 0.19\)) than our PKS 1327–206 absorbers, however, which suggests that it is embedded in a stronger radiation field.

4. DETECTION OF AN EJECTED GALAXY NUCLEUS?

There are several potential identifications for the compact object embedded in the stellar stream of ESO 1327–2041. The simplest explanation would be that it is a background elliptical galaxy projected in the middle of the stream by chance. However, our optical spectrum of this source (Figure 3) shows that its radial velocity is 5370 \(\pm 50\) km s\(^{-1}\), 90 \(\pm 55\) km s\(^{-1}\) less than the absorption-line velocity of the lenticular nucleus to the south (see Tables 2 and 4), so it is clearly not a background object.

Another explanation would be that the compact object is a globular cluster. Close examination of the embedded source in Figure 1 shows that it has a relatively bright core surrounded by a more extended spheroid of lower surface brightness material. The core is marginally resolved with an FWHM of \(-0.2^\prime\) (70 \(h_{70}^{-1}\) pc) in our HST images, which is 3 times larger than \(\omega\) Cen, the largest globular cluster in the Milky Way (Tolstoy et al. 2009). Furthermore, the core of the embedded object has an absolute \(B\)-band magnitude of \(M_{B} \approx -11.9\), corresponding to a luminosity of \(L_{B} \approx 10^7 L_{\odot}\), which is \(\sim 5\) times larger than typical globular cluster values (\(M_{B} \gtrsim -10\); Tolstoy et al. 2009).

The more extended emission has an FWHM of \(\sim 2^\prime\) (70 \(h_{70}^{-1}\) pc) and is \(\sim 3.5\) times brighter than the core of the embedded source. This measurement is somewhat uncertain, however, due to the presence of the stellar stream in which it is embedded.

Tidal streams created by tidal disruption of a dwarf companion galaxy have been identified in the halo of our Galaxy (Mathewson et al. 1974; Majewski et al. 2003; Newberg et al. 2003; Yanny et al. 2003; Rocha-Pinto et al. 2003) and in a few other nearby galaxies (e.g., M 31; Ibata et al. 2001; Ferguson et al. 2002; Guhathakurta et al. 2006; Brown et al. 2006). If both the compact source and the stellar stream of ESO 1327–2041 were originally parts of a dwarf companion, it would have had \(M_{B} \lesssim -16.0\) (\(L_{B} \gtrsim 4 \times 10^8 L_{\odot}\)). Grant et al. (2005) found that \(\gtrsim 80\%\) of dwarf ellipticals in the Virgo cluster with \(M_{B} \lesssim -16\) had central nuclei. Further, the two closest examples of nucleated dwarfs, the M 31 satellites M 32 and NGC 205, both show strong Balmer absorption in their nuclei (Ho et al. 1995) similar to the Balmer absorption seen in the compact object (see Figure 3). Recent ground-based spectroscopy of dwarf ellipticals in the Fornax cluster and nearby galaxy groups (Koleva et al. 2009) have also found evidence for gradients in age (increasing) and metallicity (decreasing) with increasing galaxy radius, which would explain the age differences between the compact object and the stellar stream (see Section 2.4). Given these compelling similarities we cannot be conclusive about ruling out a tidally disrupted dwarf galaxy producing this stream and nucleus, but arguments against this hypothesis include: (1) this scenario requires a collision between three galaxies, not two, a much rarer occurrence and (2) this explanation does not account for the absence of a second nucleus in the two galaxies to the south.

Instead, we propose that the hyper-compact object in the stellar stream is the spiral’s nucleus, ejected during the collision. Given that the nucleus has an early-to-mid A star spectrum, as evidenced by strong Balmer absorption with no associated emission, an age for these stars is estimated to be \(\sim 1\) Gyr (Hansen & Kawaler 1994; Bruzual & Charlot 2003). If this age indicates the time of a starburst created by the collision, then there is plenty of time for the nucleus to reach its current location 14 \(h_{70}^{-1}\) kpc in projection from the center of the spiral arms to the south and consistent with the (poorly constrained) radial velocity difference of 90 \(\pm 55\) km s\(^{-1}\) between the ejected nucleus and the lenticular nucleus. The somewhat older stars in the stellar stream would constitute a small bulge of pre-existing stars also ejected during the collision, some with larger and some with smaller ejection velocities than the ejected nucleus. However, the spiral would also have had time to move a comparable or larger distance on the sky since this putative merger-triggered starburst. So, by the ejected nucleus hypothesis, it appears likely that the current collision is not the first close passage of these two galaxies and we are seeing these galaxies during their second or third close passage.

Alternatively, the age of the nuclear star cluster may not be related to the galaxy–galaxy collision, in which case the nucleus could have been ejected at a significantly higher velocity given the lack of proper motion between the lenticular and the spiral structure superposed on it; i.e., the collision which ejected the nucleus is very much still on-going. The poor constraint on the velocity difference mentioned above and the unknown inclination angle of the ejected nucleus’ path
allow for a consistent picture but do not constrain this picture significantly. So, the required scenario for an ejected nucleus is somewhat complicated. This unresolved discussion invites a numerical simulation to determine how easily these observables can be reproduced (e.g., Barnes & Hibbard 2009) and would lend considerable credence to the ejected nucleus hypothesis if they are reproducible.

Current simulations predict that there are two scenarios which can lead to the ejection of a galaxy nucleus as a result of the interaction of two galaxies: grazing-incidence tidal interactions and mergers (e.g., Moore et al. 1996; Komossa & Merritt 2008a, 2008b). In both scenarios, the ejected nucleus is expected to consist of a supermassive black hole surrounded by a compact stellar system with a radius of a few tens of parsecs. In the case of galaxy mergers, one of the nuclei can receive a kick of up to $\sim 1000 \, \text{km s}^{-1}$ from asymmetric gravitational wave emission associated with the merger, causing the displaced black hole and any stars within its gravitational sphere of influence to be ejected from the host galaxy (Komossa & Merritt 2008a, 2008b). Usually the so-called hyper-compact galaxy nucleus that is ejected remains bound to the new system and eventually sinks via dynamical friction to its center where it will merge with the undisplaced nucleus. The predictions of these simulations agree very well with what we observe in ESO 1327–2041.

While we do not know of a completely conclusive test of the ejected nucleus hypothesis, the detection of a weak AGN in this hyper-compact object would argue strongly in favor of that hypothesis. Our VLA $L$-band continuum images set a $3\sigma$ flux limit of $\lesssim 1 \, \text{mJy}$ (corresponding to $L \lesssim 10^{31} \, \text{W Hz}^{-1}$) at the position of this knot. Since many elliptical galaxies have weak radio sources less luminous than this (Nagar et al. 2002) this limit is not conclusive, especially in the context of an ejected spiral nucleus, which would normally be radio-quiet.

Loeb (2007) has assessed the circumstances by which a supermassive black hole and at least a portion of its accretion disk could be ejected from a galaxy merger in progress. He finds that the disk accretion could survive for a few million years allowing the black hole to move $\sim 10 \, \text{kpc}$ away from the galaxy nucleus. Since this is the approximate distance that the candidate ejected nucleus identified here is from its putative nuclear location, there is some chance that it may be still accreting. A moderately deep $Chandra$ image might detect an X-ray source associated with a weak AGN in this nucleus and is likely the best observational test; i.e., an $\sim 10^6 \, \text{M}_\odot$ black hole accreting at $\sim 1\%$ of the Eddington rate would be detectable with $Chandra$ in a few tens of kiloseconds.

Recently, Comerford et al. (2009a, 2009b) have proposed other candidate ejected nuclei based upon a large radial velocity difference between two emission line components in a distant AGN (see also Boroson & Lauer 2009). However, given the large cosmological distance to these ejected nuclei candidates, little detail can be discerned to confirm their hypothesis.

5. CONCLUSIONS

In this paper, we have presented new $HST$ imaging and supporting ground-based imaging and spectroscopy of the complex galaxy system ESO 1327–2041, which is located near on the sky to the background quasar PKS 1327–206, whose optical, UV, and radio spectra contain absorption lines due to the foreground galaxy. The $HST$ images reveal that a spiral galaxy is in the process of colliding with a lenticular galaxy since different nebular regions in the spiral arms are seen in front of or behind the lenticular’s bulge. Ground-based imaging and spectroscopy confirms that these nebular regions are H$\text{ii}$ regions with velocities close to that of the lenticular’s nucleus. Thus, there is no doubt that these two systems are co-spatial (see Figure 1). The rather diffuse H$\text{ii}$ 21 cm emission associated with this system confirms this conclusion since, while some H$\text{ii}$ is associated with the spiral arms in the late-type galaxy disk, much of it has been ejected from the spiral and is detected far to the north and east of the optical galaxy. There may also be some diffuse H$\text{ii}$ to the south of these galaxies. However, the size of the H$\text{ii}$ emitting area of ESO 1327–2041 is not appreciably larger than our estimates of the pre-merger size of the galaxy (see Figure 2).

The $HST$ and ground-based images also detect a “stellar stream” extending parallel to the H$\alpha$ stream to the north, which we identify as a tidal feature also created in the collision. Unique to this tidal feature (to our knowledge) the $HST$ images have discovered a marginally resolved source centered in the stream with an intermediate age ($\sim 1 \, \text{Gyr}$) stellar population. This knot is too luminous ($\sim 10^9 \, \text{L}_\odot$) and too large to be a globular cluster and is unlikely to be the nucleus of a tidally disrupted dwarf companion to these galaxies. We suggest that this knot is the hyper-compact galaxy nucleus of the inclined spiral component of ESO 1327–2041, which was ejected from the system as a result of its recent interaction with the lenticular component and is itself being shredded by tides to produce the observed stellar stream. This assertion can be supported by detecting a non-thermal X-ray point source associated with the putative ejected nucleus and by numerical modeling of an early-type/late-type galaxy merger that results in the formation of a polar ring galaxy (Whitmore et al. 1990; Barnes & Hibbard 2009).

The PKS 1327–206/ESO 1327–2041 system provides us with a very detailed, and far from simple, view of a DLA/sub-DLA system. Rather than an isolated gaseous disk of H$\alpha$, this DLA/sub-DLA is a mixture of two components, only one of which appears related to the spiral disk. However, both have Ca$\text{ii}$/Na$\text{ii}$ ratios typical of the disk of the Milky Way and not of halo gas. In fact, the narrow high-velocity component has a smaller Ca$\text{ii}$/Na$\text{ii}$ ratio than the broad H$\alpha$ component we have identified as due to the outer spiral arm and so we also identify this as disk, not halo or HVC, material. Following CvG92, the best identification of the $\sim 5250 \, \text{km s}^{-1}$ component appears to be with the diffuse tidally disrupted H$\alpha$ found by those authors to the northeast of ESO 1327–2041 at similar velocities.

Using a spin temperature of 100 K, appropriate for galactic disk material, the column density associated with the outer spiral arm at $\sim 5500 \, \text{km s}^{-1}$ and the column density associated with the high-velocity component at $\sim 5250 \, \text{km s}^{-1}$ are nearly equal and, if added together, yield a total log $N_{\text{H}\alpha} \approx 19.8 \, \text{cm}^{-2}$, a sub-DLA. However, using these estimated column densities and the velocity separation for the two components, we have simulated the Ly$\alpha$ profile of this entire system and find it to be best-fit by a sub-DLA with a single velocity component having log $N_{\text{H}\alpha} = 20.0$ when the signal-to-noise of the spectrum is modest ($\lesssim 15$). This experiment suggests that using a single-component Ly$\alpha$ profile to determine $N_{\text{H}\alpha}$ for DLAs and sub-DLAs with multiple metal-line components can overpredict the total H$\alpha$ column density of the system, particularly for closely spaced components with comparable $N_{\text{H}\alpha}$.

In summary, of the three low-$z$ QSO/galaxy pairs with likely DLA or sub-DLA absorbers that we have imaged using $HST$, neither 3C 232/NGC 3067 nor PKS 1327–206/ESO 1327–2041 appear to have absorbers that are associated with quiescent thick disk gas. This is in keeping with a recent suggestion by Zwaan.
et al. (2008) that the widths of low-ionization metal lines are too broad by a factor of two to be consistent with the canonical model of DLAs arising due to ordered rotation in cold disks (Wolfe et al. 1986, 1995; Lanzetta et al. 1991). Zwaan et al. (2008) conclude that superwind outflows or galaxy interactions are most likely the cause of the broader velocity widths. The current observational work supports this conclusion, particularly the case presented here.

However, we do note that the third QSO/galaxy pair in our study, PKS 2020–370/Klemola 31A does appear consistent with rotating disk gas. CvG92 shows that the observed H I 21 cm emission contour at the quasar location is $\sim 2 \times 10^{20}$ cm$^{-2}$ with velocities consistent with disk rotation. Our HST images show no H$\alpha$ emission beyond the spiral arms in Klemola 31A and neither line nor continuum emission is observed at the quasar location. If we imagine that our small sample of H I 21 cm absorption-selected DLA/sub-DLAs are representative, then we expect that other DLA samples are a rather uniform mixture of disk gas, halo gas, and gas whose cross-section on the sky has been modestly increased by tidal interactions during galaxy collisions and mergers.

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**Figure 6.** Full HST/FOS spectrum of PKS 1327–206. Quasar emission lines at $z = 1.169$ are labeled and the positions of absorption lines associated with ESO 1327–2041 (see Section 3.3 and Table 7) are indicated by the dashed vertical lines.

| Table 8 | Galactic ISM Lines in the HST/FOS Spectrum of PKS 1327–206 |
| --- | --- |
| ID | $\lambda_{	ext{rest}}$ | $\lambda_{\text{obs}}$ | $v_{\text{helio}}$ | $W_{i}$ |
| --- | (Å) | (Å) | (km s$^{-1}$) | (mÅ) |
| Fe II | 2344.21 | 2344.6 ± 0.2 | 50 ± 30 | 1040 ± 330 |
| Fe II | 2374.46 | 2374.4 ± 0.2 | 0 ± 30 | 570 ± 130 |
| Fe II | 2382.77 | 2382.7 ± 0.2 | −10 ± 30 | 1310 ± 150 |
| Mn II | 2576.88 | 2577.3 ± 0.3 | 50 ± 30 | 1100 ± 340 |
| Fe II | 2586.65 | 2586.7 ± 0.2 | 10 ± 20 | 840 ± 270 |
| Mn II | 2594.50 | 2595.9 ± 0.2 | 160 ± 20 | 2460 ± 180 |
| Mg II | 2796.35 | 2795.6 ± 0.2 | −80 ± 20 | 1500 ± 170 |
| Mg II | 2803.53 | 2803.2 ± 0.2 | −30 ± 20 | 1170 ± 150 |
| Mg II | 2852.96 | 2853.4 ± 0.2 | 50 ± 20 | 3350 ± 150 |

**Notes.** a This line is blended with an IGM Ly$\alpha$ absorber at $z = 1.1353$. b This line is blended with Mg II $\lambda 2804$ absorption from ESO 1327–2041.

**APPENDIX**

**OTHER ABSORBERS IN THE NEAR-UV SPECTRUM OF PKS 1327–206**

The HST/FOS spectrum of PKS 1327–206 is filled with absorption lines from a variety of redshifts, including lines associated with ESO 1327–2041 at $z = 0.0178$ (cz $\approx 5500$ km s$^{-1}$; see Section 3.3), lines associated with the LLS at $z = 0.85238$ (Bergeron et al. 1987), intergalactic Ly$\alpha$ forest absorbers, and Galactic ISM absorbers. Here, we present measurements of the absorption-line parameters of these systems. Figure 6 displays the full FOS spectrum of PKS 1327–206 with quasar emission lines at $z = 1.169$ labeled. The dashed vertical lines indicate the positions of absorption lines associated with ESO 1327–2041 (see Section 3.3, Figure 5, and Table 7).

Table 8 lists the line identification, rest wavelength, observed wavelength, heliocentric velocity, and rest-frame equivalent width of all Galactic ISM absorbers detected at $>4\sigma$ confidence. We detect ISM absorption from four Fe II transitions, two Mn II lines, the Mg II $\lambda\lambda 2796, 2804$ doublet, and Mg I $\lambda 2853$. We have added a zero-point offset of $145 \pm 8$ km s$^{-1}$ to the FOS wavelength scale so that the interstellar absorption lines have an average velocity (excluding Mn II $\lambda 2594$) of $v_{\text{helio}} =$
The species and rest wavelength of the line are labeled in the lower left corner of each panel. The vertical dashed line indicates an LLS rest-frame velocity of zero.

Table 9
Lines Associated with the LLS in the HST/FOS Spectrum of PKS 1327–206

| ID | \(\lambda_{\text{rest}}\) (Å) | \(\lambda_{\text{obs}}\) (Å) | \(z\) | \(W_{\text{obs}}\) (mÅ) |
|----|-----------------|-----------------|-----|-----------------|
| Si ii | 1206.50 | 2233.3 ± 0.1 | 0.85104 ± 0.00004 | 1960 ± 190 |
| Ly\(\alpha\) | 1215.67 | 2251.5 ± 0.1 | 0.85203 ± 0.00004 | 3270 ± 400 |
| Si ii | 1260.42 | 2334.2 ± 0.1 | 0.85193 ± 0.00004 | 1400 ± 320 |
| O i | 1302.17 | 2412.8 ± 0.1 | 0.85292 ± 0.00005 | 580 ± 50 |
| Si ii | 1304.37 | 2416.8 ± 0.1 | 0.85826 ± 0.00004 | 1060 ± 50 |
| C ii | 1334.53 | 2471.4 ± 0.1 | 0.85187 ± 0.00004 | 1610 ± 90 |
| Si iv | 1393.75 | 2581.9 ± 0.2 | 0.85249 ± 0.00006 | 320 ± 140 |
| Si iv | 1402.77 | 2599.7 ± 0.1 | 0.85323 ± 0.00004 | 390 ± 70 |
| Si iii | 1526.71 | 2827.7 ± 0.1 | 0.85216 ± 0.00005 | 380 ± 90 |
| C iv | 1548.20 | 2868.5 ± 0.1 | 0.85281 ± 0.00004 | 910 ± 80 |
| C iv | 1550.78 | 2873.5 ± 0.1 | 0.85293 ± 0.00004 | 550 ± 80 |
| Al ii | 1670.79 | 3094.9 ± 0.1 | 0.85236 ± 0.00004 | 630 ± 70 |

Notes. The average redshift of this absorption-line system is 0.85238 ± 0.00001. This line is blended with Fe \(\alpha\) \(\lambda\)2374 absorption from ESO 1327–2041 but we attribute most of the absorption to Si ii at \(z\) = 0.85286.

0 ± 10 km s\(^{-1}\). This same zero-point offset has been added to all wavelengths, velocities, and redshifts in Tables 7–10.

The LLS is clearly detected in a number of neutral to moderately ionized species. Table 9 lists the line identification, rest wavelength, observed wavelength, redshift, and rest-frame equivalent width of all lines detected at >4σ confidence (observed \(W_{\lambda,\text{obs}} > 200\) mÅ) that are associated with the LLS. The average redshift of these absorption lines is
