Extended Ionized Gas Clouds in the Abell 1367 Cluster*

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Abstract

We surveyed a central 0.6 deg² region of the Abell 1367 cluster for extended ionized gas clouds (EIGs) using the Subaru prime-focus camera (Suprime-Cam) with a narrowband filter that covers Hα. We discovered six new EIGs in addition to five known EIGs. We also found that the Hα tail from the blue infalling group is extended to about 330 kpc in projected distance, which is about twice longer than previously reported. Candidates of star-forming blobs in the tail are detected. The properties of the EIG parent galaxies in Abell 1367 basically resemble those in the Coma cluster. A noticeable difference is that there are significantly fewer detached EIGs in Abell 1367, while the fraction of blue member galaxies is higher. The results suggest a difference in the evolutionary stage of the clusters; Abell 1367 is at an earlier stage than the Coma cluster.

Key words: galaxies: clusters: individual (Abell 1367) – galaxies: evolution – galaxies: structure

1. Introduction

Gas loss from star-forming (SF) galaxies is an important process in galaxy evolution. Quiescent galaxies outnumber SF galaxies in galaxy clusters, and some gas-loss mechanisms should have worked efficiently. Various physical mechanisms for the gas loss have been investigated: internal consumption by a star formation (Larson et al. 1980), ram-pressure stripping (Gunn & Gott 1972), viscous stripping (Nulsen 1982), tidal interaction (Toomre & Toomre 1972; Icke 1985; Moore et al. 1996, 1999), expulsion by a galactic wind caused by an active galactic nucleus (AGN) and/or starburst (Veilleux et al. 2005), etc. (see Boselli & Gavazzi 2006, for a review). If the interstellar gas was not consumed in a galaxy but was expelled, the gas could be found around the galaxy. Such gas around galaxies in a cluster has been found in X-ray (e.g., Fabian et al. 2003; Wang et al. 2004; Sun & Vikhlinin 2005; Sun et al. 2006, 2010; Randall et al. 2008; Ehler et al. 2013; Gu et al. 2013; Zhang et al. 2013; Schellenberger & Reiprich 2015), in the Hα line (e.g., Gavazzi et al. 1995, 2001a; Kenney et al. 1995, 2008, 2014; Kenney & Koopmann 1999; Conselice et al. 2001; Yoshida et al. 2002; Chemin et al. 2005; Cortese et al. 2006; Sun et al. 2007, 2010; Yagi et al. 2007, 2010, 2013a, 2015a; Arrigoni Battaia et al. 2012; Fossati et al. 2012; Boselli et al. 2016), radio continuum (e.g., Gavazzi 1978; Miley 1980; Kotanyi & Ekers 1983; Dickey & Salpeter 1984; Gavazzi et al. 1984; Hummel & Saikia 1991), in H I (e.g., Oosterloo & van Gorkom 2005; Chung et al. 2007; Hota et al. 2007; Scott et al. 2013), and in molecular lines (e.g., Boselli et al. 1994; Salomé et al. 2006, 2011; Scott et al. 2013, 2015; Jáchym et al. 2014). Different phases of the gas are observed at different wavelengths, while their spatial distributions often resemble each other (e.g., Sun et al. 2010).

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By imaging in the Hα narrowband, we can observe an ionized gas with high spatial resolution and high sensitivity. The Hα gas around a galaxy in a cluster suggests a recent or ongoing gas-loss event of the parent galaxy, since the gas is heated by the ambient hot plasma and will eventually be mixed with it. Such extended ionized gas (EIG) was reported in various nearby clusters; in Abell 1367 (e.g., Gavazzi et al. 2001a, 2003b; Iglesias-Páramo et al. 2002; Sakai et al. 2002, 2012; Cortese et al. 2006), in the Virgo cluster (e.g., Kenney & Koopmann 1999; Yoshida et al. 2002; Kenney et al. 2008, 2014; Arrigoni Battaia et al. 2012), in the Coma cluster (e.g., Yagi et al. 2007, 2010; Yoshida et al. 2008, 2012; Fossati et al. 2012), in Abell 3627 (e.g., Sun et al. 2007, 2010), and in some distant clusters (e.g., Abell 851 Yagi et al. 2015a). Yagi et al. (2010) found 14 EIGs in the central 1 Mpc of the Coma cluster, a nearby rich cluster. In addition, Yagi et al. (2015a) searched for EIGs in two clusters at z ~ 0.4. In one of them, nine EIGs were found, and eight of their parents are spectroscopically confirmed members of the cluster. In the other cluster, no EIG was found. These studies suggest that the relative EIG number normalized by the cluster richness is significantly different. It is therefore intriguing to investigate what characteristics of a cluster affect the number of EIGs, and a survey for EIGs in clusters with different characteristics from the Coma cluster is important.

The Abell 1367 cluster at z = 0.0217 (6494 km s⁻¹ Gavazzi et al. 2010) lies at the intersection of two filaments (West & Blakeslee 2000). Abell 1367 is thought to be a young cluster from its high fraction of spiral galaxies (Butcher & Oemler 1984), low central galaxy density (Butcher & Oemler 1984), and the irregular shape of the hot gas distribution (Jones et al. 1979; Bechtold et al. 1983; Grebenev et al. 1995). Moreover, Abell 1367 would have experienced a multiple merger of substructures. From the analysis of 273 redshift measurements, Cortese et al. (2004) confirmed that the cluster has two main density peaks associated with two substructures. The northwest subcluster is probably in the early phase of
merging into the southeast substructure. Donnelly et al. (1998) presented observations of a strong localized shock in the intracluster medium. Chandra observations (Sun & Murray 2002) indicate the presence of cool gas streaming into the cluster core, supporting a multiple merger scenario. The evidence for infall of galaxies at high velocity in the NW subcluster is provided by three further galaxies: CGCG 097-073, 097-079, and 097-087, which display extended cometary emission exceeding the galaxy length by approximately 50 kpc in the direction opposite to the cluster center. Gavazzi (1978) discovered extended radio continuum (1420 MHz) emission trailing behind them, which was analyzed in more detail by Gavazzi et al. (1984, 1995) and Gavazzi & Jaffe (1987). These three galaxies appear marginally H I deficient (Gavazzi 1987, 1989) and have normal CO content (Boselli et al. 1994).

Moreover, Abell 1367 is one of the best-studied nearby clusters in Hα. Gavazzi et al. (2001a) discovered Hα cometary trails coinciding in length and direction with the radio continuum ones. Iglesias-Páramo et al. (2002) compiled the Hα emitter catalog of Abell 1367 (including the Coma cluster) using four exposures of 0.5 degree², each obtained with the WFC camera attached to the 2.5 m William Herschel Telescope, with a sensitivity of approximately 10⁻¹⁵.5 erg s⁻¹ cm⁻² obtained with one-hour exposures per field. The total number of galaxies with Hα in this sensitivity was 41. Sakai et al. (2002) discovered a group of dwarf SF galaxies near the X-ray center of Abell 1367 from a deep Hα survey, and discussed their tidal origin. Gavazzi et al. (2003b) independently investigated this SF compact group and suggested that it is in fact infalling onto Abell 1367 (the group was dubbed BIG for blue infalling group). Cortese et al. (2006) provided deeper Hα imaging and multislit spectroscopy of BIG, providing further evidence for a high-velocity encounter between the compact group and the cluster as a whole.

Thus, many intensive studies in Hα have been performed on Abell 1367, including a uniform survey in Hα (e.g., Iglesias-Páramo et al. 2002). Meanwhile, no uniform survey of EIGs has been carried out yet because this requires a deep and wide-field Hα observation. In this paper, we present a catalog of EIGs in the Abell 1367 cluster found in our Hα narrowband imaging with the Subaru prime-focus camera (Suprime-Cam). We assume that the distance modulus to Abell 1367 is \((m-M)_0 = 35.00\) and \((h_0, \Omega_M, \Omega_L) = (0.697, 0.282, 0.718)\) (Hinshaw et al. 2013). Under these assumptions, 1 arcsec corresponds to 0.463 kpc. We use the AB-magnitude system of the instrument unless otherwise noted.

2. Data

2.1. Observation

Three fields of Abell 1367 were observed with Suprime-Cam (Miyazaki et al. 2002) at the Subaru Telescope (Iye et al. 2004) in 2014 April–May in UTC. The field position and orientation are shown in Figure 1, and the observations are summarized in Table 1. The pixel scale of the data is 0.′′0202 pixel⁻¹. The total survey area is 2207 arcmin², which corresponds to 1.7 Mpc². We dithered to fill the gap between CCDs by 1.1 arcmin, typically by five exposures.

We used three broadband filters (\(B, R, i\), and a narrowband filter (N-A-L671, hereafter NB). The NB filter was originally designed for observing Hα emitting objects in the Coma cluster at \(z = 0.0225\), and has a bell-shaped transmittance with a central wavelength of 6712 Å and a FWHM of 120 Å (Yagi et al. 2007; Yoshida et al. 2008). Since the redshift of Abell 1367 (\(z = 0.0217\)) is comparable to the redshift of the Coma cluster, the filter is also capable of observing Hα in Abell 1367.

2.2. Data Reduction

The data reduction was mostly the same as Yagi et al. (2010): overscan subtraction, flat-fielding, distortion correction, background subtraction, and mosaicking were performed. The sky background was subtracted with a mesh size of 512 pixels (1.7 arcmin) square. We also applied several improved processing steps. Crosstalk was corrected by the method by Yagi (2012), blooming was masked automatically, and some optical ghosts were corrected by new algorithms (Yagi et al. 2015b).

For the reference of the bright stars in the field, the PPM-Extended (PPMX) catalog (Röser et al. 2008) was used to obtain the position at the epoch of the observation, after world coordinate system calibration using astrometry.net (Lang et al. 2010). The star positions were used for the ghost correction.

2.3. Photometric Calibration

The flux zero-point was calibrated using the Sloan Digital Sky Survey III (SDSS-III) Ninth Data Release (DR9) photometric catalog (Ahn et al. 2012). The color conversion procedure was the same as in Yagi et al. (2013b), and the color conversion coefficients are given in Yoshida et al. (2016). About 300–900 stars were used for the calibration, and the root mean square (rms) was 0.04–0.05 mag.

We measured the flux in 2″ apertures at 10⁶ random positions in the combined images and estimated the rms from the median of the absolute deviation (MAD) as \(\text{rms} = 1.4826 \times \text{MAD}\). In the combined images, northeast and southwest regions have no data, and we discarded the apertures in the regions. As a result, valid aperture positions were \(\sim 7 \times 10^5\). The calculated rms is given in Table 1 as a limiting surface brightness (SB).

We adopted the Galactic extinction values of 0.084, 0.050, 0.050, and 0.039, for \(B, R, NB\), and \(i\) bands, respectively, from the NASA/IPAC Extragalactic Database (NED)\(^7\), which uses the Schlafly & Finkbeiner (2011) recalibration of Schlegel et al. (1998) data. The same extinction correction was applied to the whole field.

2.4. Search for EIGs

To detect Hα clouds, we subtracted the \(R\)-band image from the \(NB\) image. Here, we refer to the \(R\)-band subtracted \(NB\)-band image as \(NB-R\) image, or simply Hα image when it is not confusing. Note that this \(NB-R\) image includes [N II] emission and possible residual flux of the continuum. Following Yagi et al. (2010), we adopted \(R-NB = 0.065\) for the \(R\)-band subtraction from the \(NB\) image. The color determined the relative flux scaling between \(R\) and \(NB\) for a typical continuum spectrum of objects without Hα emission/absorption at \(z \sim 0.02\).

If the underlying continuum is bluer, the \(R-NB\) is smaller (Figure 3 of Yagi et al. 2010). An excess recognized in \(NB-R\) image is thus not always an emission, but could also be a

\(^7\) http://ned.ipac.caltech.edu/
residual of a red continuum. The Hα flux estimation is largely affected by the continuum subtraction. In this study, we therefore focused on the excess in the NB–R image where continuum is negligible. Such an excess would be the ionized gas out of galaxies, EIG. Meanwhile, a quantitative discussion about star formation in the galactic disk, for example, is beyond the scope of this paper. Later we investigate possible star formations in EIGs, but we caution that a future spectroscopic confirmation is necessary (e.g., Yagi et al. 2013a).

The seeing sizes were estimated using SExtractor (Bertin & Arnouts 1996) version 2.19.5. The NB image has a seeing size variation among the field: 0″.7 at NW and 0″.9 at SE. The seeing size of most NB data is smaller than that of the R-band images. To detect extended Hα clouds out of galaxies, the difference of the seeing size is little affected. The over-subtraction of R-band is small around pure Hα emissions, while it is large around objects with continuum (e.g., foreground stars).

In the Hα (NB–R) image, extended Hα clouds were searched for by visual inspection. Then B-, R-, and i-band images were used to reject possible residuals of the bright continuum. In Table 2 we list the newly detected Hα emitting clouds extending beyond galaxies. Previously known EIGs (CGCG 097-073, CGCG 097-079, CGCG 097-087, CGCG 097-087N, and BIG) are also shown as a reference.

In the first inspection, we did not match the point-spread function (PSF) because the NB images have a better resolution than the R-band images and PSF matching would blur the fine Hα structures. A slight debris of background subtraction sometimes mimics an Hα emitting object, but the high spatial resolution of the Hα image enables us to distinguish artifacts from EIGs. Moreover, a blur of R-band images due to the PSF mismatch does not affect the visual inspection since we focused on objects with a weak continuum flux. In our previous study of the Coma cluster (Yagi et al. 2010), all the EIGs detected with the same procedure as in this study are spectroscopically confirmed to be real EIGs in the Coma cluster (M. Yoshida et al. 2017, in preparation).

As the exposure time and the transparency of the atmosphere were not uniform in our data, the signal-to-noise ratio (S/N) should vary among the positions by ~10%. In this study, however, the detection of extended Hα clouds was not affected by the S/N variation. As a test, we made a low S/N image, half of the original, by adding artificial noise, and searched for EIGs again. We can find the same set of the EIGs in the lower S/N image, although the detail structures of EIGs were buried in the noise in the by-eye inspection. Because we adopted a threshold of a constant SB in the net Hα and focused on extended features, the measurement of the EIGs is not expected to be greatly affected by the change in S/N, either. For another test, we performed a visual inspection in PSF-matched images and

Figure 1. Abell 1367 cluster. The background image is taken in the R band of the Palomar Digitized Sky Survey 2 (DSS2). The size of the image is 75 arcmin square. The solid boxes represent the observed regions in this study.

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confirmed that the detected objects were unchanged. In the following analyses and figures, the PSF-matched images were used unless otherwise noted.

### 2.5. Conversion of NB–R into Hα

Pixel values (renormalized counts) in NB–R image are proportional to the Hα SB. We calculated a pixel value that corresponds to Hα SB of $10^{-16}$ erg s$^{-1}$ cm$^{-2}$ pixel$^{-1}$ and converted the NB–R counts into the Hα SB. As the NB filter has a bell-shaped transmittance curve, the response to Hα emission is dependent on the redshift. In order to take the redshift effect into account, we construct a simple model spectral energy distribution (SED) for each cloud assuming its redshift and measure the model magnitude with the NB- and R-band filters. The filter model includes CCD quantum efficiency, transmittance of the optics, and the atmospheric transmittance (Yagi et al. 2013b).

Figure 2 shows the redshift distribution of galaxies taken from the SDSS DR12 spectroscopic catalog (Alam et al. 2015). Galaxies brighter than $r = 17.8$ mag and within 1.5 from the cluster center are counted. We adopted R.A.(J2000) = $11^h44^m36^s5.0$, decl.(J2000) = $+19^d45^m32^s$ for the cluster center (Piffaretti et al. 2011). Based on Figure 2, we defined the galaxies with $0.014 < z < 0.030$ as the member galaxies of Abell 1367. From the distribution, the standard deviation of the recession velocity is estimated as 815 km s$^{-1}$. The maximum change of the transmittance of the NB filter for the Hα line is about 0.6 mag (factor ~0.6) in 0.014 < z < 0.030. The result of the Hα SB and flux in the following analyses may suffer ~40% error if the redshift of the emission is uncertain.

Spectra of EIGs in previous studies (Yoshida et al. 2004, 2012; Yagi et al. 2007) show a wide variety in [N II]/Hα.
The vertical broken lines show the redshift range of Abell SDSS DR9 within 0.15 from (R.A., decl.)(J2000) = (11:44:36.5, +19:45:32). The redshift histogram around Abell 1367 is shown in Figure 2.

The systematic error by this NB–R count could be ∼10% of the rescaled R-band count. In the regions where the rescaled R-band count is comparable to or larger than the NB–R counts, this error is the dominant one. We summed the rescaled R-band count where the count is larger than NB–R counts, and used 10% of the sum as the estimated error of the NB–R counts. The errors given in Table 2 include the errors described above; the background variation, the zero-point uncertainty, and the possible continuum error, assuming that the three errors are independent.

In the conversion of the NB–R count to the Hα flux, various uncertainties exist, since we do not have spectroscopic information of EIGs. As shown in Figure 3, the redshift should change the observed count in NB band. Thus the error of the redshift can introduce an error in Hα flux. As mentioned in Section 2.5, the error is ∼40% if no parent galaxy is identified. Even if the redshift of the parent galaxy is known, the EIG may have a recession velocity different by several hundred km s⁻¹ from the parent, as in the Coma EIGs (Yoshida et al. 2012). If the offset is 300 km s⁻¹, for example, it may introduce ≥10% error. In the conversion from NB–R to the Hα flux, we adopted a model SED with several assumptions in emission line ratios; [N II]/Hα, [S II]/Hα, and [O I]/Hα. The uncertainty in [N II]/Hα directly affects the conversion, which may introduce an error of ∼40%. The uncertainty in [S II]/Hα and [O I]/Hα only affects the correction of the oversubtraction, which would be ∼10% at most.

3. Newly Detected Extended Ionized Gas Clouds (EIGs)

In Abell 1367, several EIGs were reported in the literature. CGCG 097-073 and CGCG 097-079 are well known with their prominent tails (e.g., Gavazzi & Jaffe 1987; Gavazzi 1989; Boselli et al. 1994; Gavazzi et al. 1995, 1998, 2001a; Scott et al. 2010). Boselli & Gavazzi (2014) showed a preliminary image from the data in this study. The prominent tails of the EIGs were well recognized in Gavazzi et al. (2001a) as a whole. CGCG 097-087 (UGC 6697) is also the best-studied galaxies in Abell 1367 (e.g., Gavazzi & Jaffe 1987; Gavazzi 1989; Boselli et al. 1994; Gavazzi et al. 1995, 1998, 2001b; Scott et al. 2010). Gavazzi et al. (2001b) presented an Hα image and spectra of the galaxy and a part of the tail with a detailed investigation. The Hα distribution around BIG shows a quite complex morphology, and has been studied intensively (e.g., Iglesias-Páramo et al. 2002; Sakai et al. 2002; Gavazzi et al. 2003b). Cortese et al. (2006) investigated the detailed Hα structure around BIG.

In addition to the well-studied EIGs, we found several new EIGs in Abell 1367, as given in Table 2. The distribution of the EIGs is shown in Figure 5. As most of the EIGs in this study are clearly related to a galaxy (parent galaxy) that would be

![Figure 2](image-url) 

**Figure 2.** Redshift histogram around Abell 1367. The data are taken from SDSS DR9 within 1.5° from (R.A., decl.)(J2000) = (11:44:36.5, +19:45:32). The vertical broken lines show the redshift range of Abell 1367 membership we adopted.

(-1.1 < log([N II]/Hα) < 0.0). The [N II]/Hα around BIG given by Cortese et al. (2006) also varies within 0.09 < [N II]/Hα < 0.42. In this study, we adopted log([N II]/Hα) = −0.4, i.e., [N II]/Hα = 0.4, for model SED for the conversion. The systematic error by this [N II]/Hα uncertainty is ≤60%. Other emission lines in R band, [S II], and [O I] are added in the R-band model magnitude assuming log([S II]/Hα) = −0.4 and log([O I]/Hα) = −1.0, according to Yoshida et al. (2012). Possible contamination of [S II] in the NB band in lower redshift is also taken into account. The transmittance and the model SEDs at different redshifts are shown in Figure 3.

We also estimated the oversubtraction of the Hα flux in the R band using the model SED at each redshift. Because our continuum subtraction is not performed in magnitude but in the renormalized counts, the oversubtracted flux is proportional to the NB–R pixel value regardless of the Hα equivalent width. In the redshift range, the oversubtraction is 18%–30%. It is comparable to the estimation in a z = 0.023 galaxy by Yoshida et al. (2016) (23%). The redshift dependence is shown as Figure 4. As expected from Figure 3, the pixel count in R band is almost constant, while that in NB band changes according to the redshift. The oversubtraction is corrected when converting NB–R counts into the Hα SB.

2.6. Error of the Hα Flux

We estimated the error of the Hα flux of EIGs in two steps. One is the uncertainty in NB–R count with a calibrated zeropoint, and the other is the uncertainty in the conversion of the NB–R count to the Hαflux.

The limiting SB is shown in Table 1, which is a 1σ fluctuation of the SB measured in an aperture of 2 arcsec diameter. The value includes the photon noise of the background sky, the readout noise, and errors in the data reduction. The effect of a possible remnant of an optical ghost is also included as an average value. As the adopted isophote in this study was comparable to or larger than the 1-σ fluctuation and the area of the object is much larger than that of a 2 arcsec circle, the S/N of the isophotal flux is high. Even for the faintest object, the estimated relative error of the count is three percent.

The absolute calibration of NB and R bands relies on the SDSS photometry and the color conversion models. The conversion may have ∼0.04 mag error in each band (Yagi et al. 2013b). The residual of the continuum of overlapping objects (e.g., the disk of the parent galaxy) may remain in the NB–R counts. Yagi et al. (2010) reported a change in R–NB magnitude of the continuum of about 0.15 mag peak-to-peak. This means that the error in the NB–R count could be ∼10% of the rescaled R-band count. In the regions where the rescaled R-band count is comparable to or larger than the NB–R counts, this error is the dominant one. We summed the rescaled R-band count where the count is larger than NB–R counts, and used 10% of the sum as the estimated error of the NB–R counts. The errors given in Table 2 include the errors described above; the background variation, the zero-point uncertainty, and the possible continuum error, assuming that the three errors are independent.
the origin of the gas, the EIGs are named after their parent galaxy. The exceptions are the orphan clouds and the clouds tail around BIG. The total mass of the ionized clouds is roughly estimated and given in Table 2. The detail of the mass estimation is given in the appendix.

In the following subsections, the new EIGs are shown from the north to the south. For each EIG, we present a B, i, and Hα composite before PSF matching, and an Hα image after PSF matching. In the Hα image, the green contour represents Hα isophote of $2.5 \times 10^{-18}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$. The depth is adopted from the previous study in the Coma cluster (Yagi et al. 2010). To suppress the fluctuation around the isophote, we smoothed the image by a Gaussian with $\sigma = 2.5$ pixels before measuring the isophote. When the redshift of the parent galaxy was available, the redshift was used to calculate the isophote level. When it was not available, the cluster redshift, $z = 0.0217$, was used. In order to remove false detections of a clump of noises, we used SExtractor and only sampled large clumps of Hα excess. We adopted DETECT_MINAREA = 500 pixels. Then the remnant of noise clumps and debris of bright star subtraction are carefully removed by visual inspection of the $B$, $R$, $i$, and $NB$ images. The flux and the mean Hα SB are measured inside the contour, and the extension and the bounding rectangle are measured based on the contour.

Figure 3. Redshift dependence of the model SED of the emission line object and the transmittance of $NB$ and $R$ bands. The black solid lines show $NB$- and $R$-band total transmission with telescope, optics, and atmospheric transmittance. The red solid line is our model SED of an EIG after continuum subtraction. The flux scale is arbitrary. The three panels show $z = 0.014$, 0.022, and 0.030 from top to bottom.

Figure 4. Redshift dependence of the pixel values of a model emission line object in $NB$- and $R$-band data. The count scale is arbitrary, since the flux zero-point of the data is changeable. Meanwhile, the $R$ band is scaled to the $NB$ band so that the flux zero-points of the data satisfy $R-NB = 0.065$. The Astrophysical Journal, 839:65 (23pp), 2017 April 10 Yagi et al.
3.1. Orphan Clouds

The “orphan clouds” appear to be floating in intergalactic space (Figure 6). If the clouds are in Abell 1367, the size of the north clump (orphan 1) is $33 \times 20 \text{kpc}$, and the southeast clump (orphan 2) is $12 \times 3 \text{kpc}$. Although the isophote of $2.5 \times 10^{-18} \text{erg s}^{-1} \text{cm}^{-2} \text{arcsec}^{-2}$ at $z = 0.0217$ separates the two clouds, a faint filamentary cloud is connecting the clouds and possible SF blobs are found between the two, as seen in the left panel. It is uncertain whether they are physically related to each other.

At least within $80 \text{kpc}$, there are no possible parent galaxy candidates. The nearest giant ($M_r < -17$) galaxy is CGCG 097-102S, whose projected distance is $\sim 80 \text{kpc}$ (Figure 7). No such parent-less clouds were found in the Coma cluster (Yagi et al. 2010) or in Abell 851 (Yagi et al. 2015a). In Abell 1367, the tip of the EIG of CGCG 097-083 is $\sim 170 \text{kpc}$ in the projected distance from the center of the parent galaxy. The tip seems connected to the parent galaxy as a long tail, however.

Several questions arise about the orphan clouds: what is the ionizing source, and what is the origin of the gas. The ionizing source is a great problem for all EIGs. Possible mechanisms are a star formation in situ, illumination of the young stars in the parent galaxy, illumination of an AGN, inside shock heating, UV from ambient hot gas, etc. Since the orphan clouds are at least $80 \text{kpc}$ away from the giant galaxies, a UV from a parent galaxy disk is unlikely. A possible star formation around the cloud is seen in some of the clouds. In Figure 6, H$\alpha$ emission and a blue continuum is recognized near orphan 2, which are marked as SF blobs.

The region is also visible in a Galaxy Evolution Explorer (GALEX) near-ultraviolet (NUV) image in the archive. If the SF blobs are the ionizing source of the whole clouds, however, a gradient of H$\alpha$ SB is expected. The SB should be bright near the region and fainter in distant regions. No such gradient is seen in the data, and thus ionization by the SF blobs is unlikely. More details of the SF blobs are discussed in Section 5.2.

http://galex.stsci.edu/GR6/
Figure 6. (Top left) $B$, $i$, and $NB-R$ ($H\alpha$) three-color composite around the orphan clouds. North is up and east is to the left. The PSF is not matched to obtain higher spatial resolution. The contrast of each color is arbitrary. The yellow bar at the bottom left shows 10 kpc. (Top right) $H\alpha$ ($NB-R$) image of the same region after PSF matching. White indicates $NB$ flux excess and black indicates $NB$ flux deficiency. Typical $z \sim 0.022$ galaxies without $H\alpha$ emission have the same color as the sky background. As discussed in the text, redder and bluer underlying stellar components cause $NB$ excess and $NB$ deficiency, respectively. The green contour represents the isophote of $2.5 \times 10^{-18} \text{erg s}^{-1} \text{cm}^{-2} \text{arcsec}^{-2}$ assuming $z = 0.0217$. The PSF matching decreased the spatial resolution, and the detailed faint feature seen in the top left panel is below the threshold. (Bottom left) PSF-matched $B$, $R$, and $NB$ composite. The relative $B$, $R$, and $NB$ scales are set so that typical galaxies at $z = 0.022$ without $H\alpha$ emission ($B-R = 1.0$, and $R - NB = 0.065$) are gray. The magenta objects would be SF blobs. (Bottom right) Schematic figure around the orphan clouds.
To examine the possibility of AGN illumination, we compared them with an example of a known AGN-illuminated cloud, Hanny’s Voorwerp (Lintott et al. 2009; Keel et al. 2012) at z = 0.050. Hanny’s Voorwerp is a famous extended ionizing cloud in a less crowded environment found in SDSS imaging data by the Galaxy Zoo project (Lintott et al. 2008). The ionizing source of Hanny’s Voorwerp was revealed to be the AGN of the parent galaxy (IC 2497) 50 kpc away. The size of Hanny’s Voorwerp (18 × 33 kpc) is comparable to that of orphan 1 (~20 × 33 kpc), but Hanny’s Voorwerp is much brighter than the orphan clouds. According to Table 2 of Lintott et al. (2009), the mean SB of Hα+[N II] is 5 × 10^{-16} erg s^{-1} cm^{-2} arcsec^{-2}, which corresponds to 21.7 mag arcsec^{-2} in our NB–R image. The mean SB of the orphan clouds is 26.6 mag arcsec^{-2}, about 1/90 in flux. The nearest AGN from the orphan clouds is CGCG 097-121 at ~180 kpc in Gavazzi et al. (2011), which is classified as a LINER. If the orphan clouds are also ionized by the AGN, the ionizing flux from the AGN would be weaker by an order of magnitude or more than that at Hanny’s Voorwerp because of the distance. Added to that, if the ionizing flux of CGCG 097-121 is an order of magnitude weaker than the source AGN of Hanny’s Voorwerp, the mean SB of ~27 mag arcsec^{-2} of the orphan clouds could be reproduced. Thus the AGN illumination is one promising scenario. Shock heating and UV from the hot gas are also promising ionizing mechanisms.

The origin of the gas is another question. They would have been ejected from a galaxy, but the mechanism is unclear. It can be a ram-pressure stripping, a jet, a wind, a tidal interaction, etc. The clouds are at least at a distance of 80 kpc from their parent if their parent is a giant galaxy. Assuming that their speed to the parent galaxy is ≲1000 km s^{-1}, they should have survived in the cluster environment for ≳70 Myr. As no counterpart is found near the clouds in the H1 survey of Abell 1367 (Scott et al. 2010), it is rather unlikely that the orphan clouds are reionized portions of a long tail, such as the long tail of NGC 4388 in the Virgo cluster (Yoshida et al. 2002; Oosterloo & van Gorkom 2005).

Another possibility is that the parent galaxy is a very faint dwarf. A possible ultra-diffuse galaxy (UDG; e.g., Koda et al. 2015; van Dokkum et al. 2015a, 2015b; Yagi et al. 2016) is detected near the possible SF region, and the elongation of the SF blobs seems to be aligned to the galaxy. The galaxy is visible in the bottom left panel of Figure 6, but it shows no Hα emission. At the distance of Abell 1367, the R-band absolute magnitude of the galaxy is M_R ~ −14.5 mag and its effective radius is ~4 kpc, measured by GALFIT (Peng et al. 2002, 2010).

If the redshift of the UDG is comparable to the SF blobs, the SF blobs may be associated with the galaxy, and it will be an indication that may help to understand the formation of UDGs. Meanwhile, the shape of the whole orphan clouds is unlikely to have been stripped from the possible UDG. There are many other faint dwarfs whose redshift is unknown. Current data are insufficient to investigate the parent galaxy of the clouds in more detail.

3.2. CGCG 097-092

CGCG 097-092 (Figure 8) shows an EIG with a cone-like appearance extended to ~30 kpc. The parent galaxy does not show signs of an AGN (Gavazzi et al. 2011), while the spectrum of the center of the parent galaxy shows a starburst feature. The UV light from the starburst would be the source of the ionization. In Table 2 we also show the property of the tail, without the core region. The origin of the EIG could be ram-pressure stripping or a superwind by the central starburst (Veilleux et al. 2005). We will be able to distinguish the two when the recession velocity profile will become available in the future. The velocity of EIG should be
Figure 8. Same as the top panels of Figure 6, but around CGCG 097-092. In the right panel, the redshift in Table 3 is used to convert the Hα surface brightness to the isophote. The red contour represents the isophote of the R-band image, which corresponds to the SDSS r-band petroR50 (the radius containing 50% of the Petrosian flux).

Figure 9. Same as Figure 8, but around 2MASX J11443212+2006238.
comparable to the parent near the galaxy if the ram-pressure is the mechanism, while a difference should be seen if a wind is the origin.

The direction of the tail is somehow “toward” the cluster center; the angle is about 30°. The recession velocity of the parent galaxy shows a small difference from that of the cluster (∼−40 km s⁻¹). If ram-pressure stripping is the origin, this suggests that the parent galaxy moves away from the cluster center in the projected plane.

3.3. 2MASX J11443212+2006238

The EIG of 2MASX J11443212+2006238 was detected at the very edge of our field Figure 5. The EIG may have a much longer extension. In Figure 9, residuals of CCD chip edge pattern remain. The sharp cutoff on the left would be an artifact. Thus the size and total Hα flux are unreliable. Meanwhile, the S/N of the EIG is high enough, and the mean SB is reliable.
SDSS spectrum of the parent galaxy shows clear H$_\alpha$ emission from the core, and Gavazzi et al. (2011) classified it as HII. Kriwattanawong et al. (2011) also reported H$_\alpha$ from the galaxy. Interestingly, the parent galaxy is red, as shown in Section 4.2. We checked the $g - i$ color in Consolandi et al. (2016) and confirmed that $g - i$ is also red ($g - i = 1.03$). In the $NB-R$ image, the central $\sim15''$ region shows an excess.
which may be the remaining star formation, although the $NB-R$ color is unreliable for an H$\alpha$ estimator in the galactic disk. In the disk, no obvious spiral pattern is recognized in H$\alpha$. In the H$\alpha$ image, the southern half of the galaxy shows a sign of negative $NB-R$, while it is positive in the northern half. This morphology resembles IC 4040 in the Coma cluster (Yoshida et al. 2008) and implies that 2MASX J11443212+2006238 suffers strong ram-pressure stripping from the south direction. The red color and negative $NB-R$ may be implying that this galaxy is partly in a transition phase from an SF galaxy to a post-SF galaxy.

3.4. H$\alpha$ Tail from BIG

We found that the H$\alpha$ tail from BIG continued about twice longer than reported by Cortese et al. (2006) and reaches a projected distance of $\sim$330 kpc (Figure 10). The tail was called “NW” in Cortese et al. (2006).

In Table 2 we list two measurements. We first measured the whole H$\alpha$ including BIG regions, Then, we set the northwest boundary of BIG as the knot named K1 in Gavazzi et al. (2003b) and Cortese et al. (2006), and measured the tail out of the boundary. The total H$\alpha$ gas mass of BIG+tail is calculated to be $(8 \pm 5) \times 10^{10} f_v M_\odot$, where $f_v$ is the volume-filling factor. Without the H$\alpha$ around BIG, the tail mass would be $\sim(3 \pm 2) \times 10^9 f_v M_\odot$. The long tail implies that the group would have suffered ram-pressure from the intracluster gas of Abell 1367 for several hundred Myr, while the group has moved roughly straight toward the southeast.

The ionizing source of the long H$\alpha$ tail is a great mystery in EIGs (e.g., Yoshida et al. 2004; Cortese et al. 2006; Yagi et al. 2007; Kenney et al. 2008). Boselli et al. (2016) speculated that the ionizing mechanism of 80 kpc long tail of NGC 4569 in the Virgo cluster could be shocks, magnetohydrodynamic (MHD) waves, or heat conduction. The discovery of the 330 kpc long H$\alpha$ tail of BIG sets constraints on possible models. In $B$, $R$, and NB composite images, we detected several SF blob candidates. The zoomed-in images are shown in Figure 11. All of them have counterparts in GALEX NUV data. Although they may ionize some gas in the vicinity, they are insufficient to ionize the distant part of the tail. The details of the SF blobs are investigated later in Section 5.2.

As seen in Figure 10, the tail of BIG shows a sign of winding with a width of $\sim$40 kpc. The morphology might be explained as the winding results from the internal motion of the galaxy in the group. Although a merger and interactions among the members of BIG has been suggested (Cortese et al. 2006), here we calculate a simple model. Assuming that the typical velocity of group member galaxies around the center of the group is $\sim$200 km s$^{-1}$ (Gavazzi et al. 2003b), the crossing time of 40 kpc would be $\sim$200 Myr. In the H$\alpha$ image, one or two possible periods are barely recognized in the tail. The projected length of 330 kpc tail might have been formed in 400–800 Myr, and the tangential velocity of BIG would be 400–800 km s$^{-1}$. As a result, the H$\alpha$ tails form helices, and we see them as winding shapes by projection. This speculation can be examined by measuring the velocity profile of the tail along the winding by future spectroscopic observations.

3.5. CGCG 097-093

CGCG 097-093 (Figure 12) shows a morphology like jellyfish galaxies (e.g., Cortese et al. 2007; Smith et al. 2010; Ebeling et al. 2014; Poggianti et al. 2016). Enhancement of faint blue stars and H$\alpha$ emission are seen to the northeast. Inside of the disk, an asymmetry of the spiral arms is recognized, which may be the sign of a recent tidal interaction. The recession velocity of CGCG 097-093 is 7298 km s$^{-1}$. Its southwest neighbor, CGCG 097-088 is at 5616 km s$^{-1}$, and the north neighbor CGCG 097-094 is at 7998 km s$^{-1}$. If the


Hα ejection is affected by interaction with the neighbor, it would be with CGCG 097-094. Meanwhile, the morphology in Hα suggests a ram-pressure origin, as the galaxy-wide gas flow would be difficult to be caused by tidal interaction alone. Although the asymmetric stellar distribution suggests a tidal interaction, some ram-pressure stripped galaxies also show an asymmetry (Abramson & Kenney 2014; Jáchym et al. 2014). Vollmer (2003) suggested a mixture of tidal interaction and ram pressure for NGC 4656 in the Virgo cluster, which shows an extended gas tail and an asymmetric stellar distribution.

3.6. CGCG 097-122

CGCG 097-122 (NGC 3859) looks like a spiral galaxy seen edge-on with a distorted faint halo that was revealed by our deep imaging (Figures 13). The halo is elongated toward the northeast almost along the major axis of the galaxy. At the southwest side of the galaxy, the halo is extended to a projected distance of ∼10 kpc above the galaxy disk. North of the galaxy,
We found that EIGs in Abell 1367 are typically longer than those in the Coma. In Figure 14 we plot the cluster-centric projected distance versus the long side of the bounding box of EIGs in both clusters. This does not mean that the EIG is continuously extended to this length. The length rather approximates the distance of the tip of the EIG from the parent. As the virial radius of the Coma is larger than that of Abell 1367, the difference increases when we normalize it by the cluster virial radius. In Figure 14 the longest one is the tail of BIG. The parents of other long (>50 kpc) EIGs are three bright spirals, CGCG 097-073, 097-079, and 097-087 in Abell 1367, and GMP2559(IC4040), GMP4060(RB199), and GMP2910(D100) in the Coma. All of them are thought to be caused by ram-pressure stripping (Gavazzi et al. 2001a, 2001b; Yagi et al. 2007; Yoshida et al. 2008, 2012). Of these spirals, two in the Coma, GMP4060 and GMP2910, show a post-starburst signature.

4. Results

We compared the EIGs and their parents with those in the Coma cluster (Yagi et al. 2010). The redshifts of Abell 1367 and the Coma cluster are almost the same, z = 0.0217 and 0.0225, and the two data were obtained with the same filter sets, instrument, and telescope, and analyzed in the same way. Regarding the data quality, the 1σ of the SB in a 2 arcsec aperture in NB and R bands in our previous study in the Coma were 27.5(NB) and 28.1(R) mag arcsec$^{-2}$ (Yagi et al. 2010), while they were 27.7(NB) and 27.9(R) mag arcsec$^{-2}$ in Abell 1367 in this study. The difference of the S/N in the NB–R image is about six percent. This small difference is negligible compared with other factors. The projected survey area was 1.2 Mpc$^2$(Coma) and 1.7 Mpc$^2$(Abell 1367), respectively.

In this section, we give several results from the comparison of EIGs and their parents in Abell 1367 and in the Coma. An interpretation of the result is given later in Section 5.1.

4.1. EIG Length

We found that EIGs in Abell 1367 are typically longer than those in the Coma. Figure 14 shows the cluster-centric projected distance versus the long side of the bounding box of EIGs in both clusters. This does not mean that the EIG is continuously extended to this length. The length rather approximates the distance of the tip of the EIG from the parent. As the virial radius of the Coma is larger than that of Abell 1367, the difference increases when we normalize it by the cluster virial radius. In Figure 14 the longest one is the tail of BIG. The parents of other long (>50 kpc) EIGs are three bright spirals, CGCG 097-073, 097-079, and 097-087 in Abell 1367, and GMP2559(IC4040), GMP4060(RB199), and GMP2910(D100) in the Coma. All of them are thought to be caused by ram-pressure stripping (Gavazzi et al. 2001a, 2001b; Yagi et al. 2007; Yoshida et al. 2008, 2012). Of these spirals, two in the Coma, GMP4060 and GMP2910, show a post-starburst signature.

Figure 16. Distance from the cluster center vs. recession velocity. The data are taken from SDSS DR12. The symbols are the same as in Figure 15. Horizontal broken lines show the recession velocity of Abell 1367 ($v = 6494 \text{ km s}^{-1}$) and BIG ($v = 8244.3 \text{ km s}^{-1}$).
4.2. Color of the Parent Galaxies and EIG Parent Fraction

To investigate the color of the parent galaxies, we first used the SDSS DR12 spectroscopic catalog for the member selection of Abell 1367. Selection criteria were $0.014 < z < 0.030$, $r < 17.7$ mag, and in the region covered by our observation. We refer to the list as an “unbiased member list.” Although the spectroscopic target selection of SDSS is not complete, it is expected to be unbiased. Next, the galaxies in SDSS DR12 photometric catalog whose spectroscopic information is not available in SDSS DR12 were cross-identified with other spectroscopic catalogs (Iglesias-Páramo et al. 2002; Cortese et al. 2003, 2004, 2008; Gavazzi et al. 2003b; Smith et al. 2004; Kriwattanawong et al. 2011), and added if their redshift satisfied $0.014 < z < 0.030$ and $r < 17.7$ mag. We used our Suprime-Cam data for visual inspection of the cross-identification, and thus only the galaxies in our observed field are added. Although the completeness is higher in the list, the sampling is heterogeneous. We refer to the sample as an “extended member list.” The color-magnitude diagram (CMD) of the member galaxies is shown as Figure 15 using the extended member list. We applied the AB magnitude offset adopted by K-correct (Blanton & Roweis 2007) $v_A = m_{AB} - m_{SDSS} = 0.012(g)$ and 0.010(r), and the Galactic extinction correction ($A_v = 0.076$ and $A_r = 0.053$). The color-magnitude relation (CMR) of early-type members of Abell 1367 is

$$g - r = 1.210 - 0.0304r,$$  \(1\)

which is obtained from fitting to the data. When we classify the galaxies into red/blue at 0.2 mag redder than the CMR (broken line in Figure 15), six parents are blue and two are red (2MASX J1443212+2006238 and CGCG 097-122). Regarding the BIG members, CGCG 097-114 is blue, while CGCG 097-120 and CGCG 097-125 are red. SDSS J114501.81+194549.4 is marginally red (by 0.01 mag).

The number of members and EIGs are given in Table 5. For the statistical test, we did not count CGCG 097-087N, as it is not included in the unbiased member list. The CMR and color threshold of the Coma is taken from Yagi et al. (2010), and the unbiased member list of the Coma is constructed from SDSS DR12 by applying the criteria that $0.015 < z < 0.035$, $r < 17.7$ mag, and in the region covered by the observation.

Because the population size is very small, most of the differences are within the statistical error. Only the blue member fraction of Abell 1367 is significantly higher than that of Coma. The whole EIG parent fraction is six percent in the Coma and nine percent in Abell 1367. The difference is marginal ($p = 0.06$, upper).

4.3. Distribution in Velocity-distance Plane

Figure 16 shows the distribution of galaxies in the projected distance from the cluster center versus the recession velocity plane. Galaxies with a spectroscopic redshift by SDSS are plotted. Many of the parents have a large difference from the cluster recession velocity. This trend is similar to that in the Coma cluster (Yagi et al. 2010).

The two parents near the cluster velocity are CGCG 097-087 and CGCG 097-092. As the tail of CGCG 097-087 points away from the cluster center (Figure 5), it is natural to think that CGCG 097-087 would be entering the cluster directly to the center on the tangential plane. Meanwhile, the tail of 097-092 shows no alignment toward the cluster center (Figure 5).
and three BIG galaxies (classifies GMP3779 and GMP3896 in Yagi et al. +097-087, CGCG B1 11 h44m45

Notes.

B6 11 h44m32
B5c 11 h44m40
B2c 11 h44m44

4.4. Morphology of the Cloud-parent Connection

As in Yagi et al. (2010), the EIGs of Abell 1367 are classified into three types: (1) connected Hα clouds with a disk-wide star formation in the parent, (2) connected Hα clouds without a disk-wide star formation in the parent, and (3) detached Hα clouds. Type 1 includes CGCG 097-073, CGCG 097-079, CGCG 097-087, CGCG 097-087N, CGCG 097-093, CGCG 097-122, and three BIG galaxies (CGCG 097-120, CGCG 097-114, and CGCG 097-125). Type 2 includes 2MASX J11443212 +2006238. Although star formation partly remains in the galaxy, it resembles GMP3779 and GMP3896 in Yagi et al. (2010), which were classified as type 2. Type 3 includes CGCG 097-092, SDSS J114501.81 +194549.4, and the orphan clouds. The type classification is given in Tables 2 and 3.

In the Coma cluster, the number of each type was 4 (Type 1), 4 (Type 2), and 6 (Type 3). In Abell 1367, the fraction of Type 1 is larger and Types 2 and 3 are smaller. In the Coma cluster, four faint blue parents with detached clouds (Type 3) are found, and they show a post-starburst spectrum. In Abell 1367, there are fewer post-starburst parents. Only SDSS J114501.81 +194549.4 in BIG shows signs of post-starburst signature, whose color is barely red (0.01 mag redder than the demarcation line).

5. Discussion

5.1. The Difference in EIGs and Parents in Abell 1367 and in Coma

Although many statistical properties of EIGs and their parents are similar in Abell 1367 and the Coma, there are several differences. In Abell 1367 the EIGs are longer and tend to be connected to parents. The EIG parents in Abell 1367 have more star formation in the disk, and post-starburst EIGs are fewer. The fraction of EIG parents and blue galaxies is higher in Abell 1367.

Under the assumption that the EIG-parents connection would evolve from Type 1 to Type 3, the larger number of Type 1 in Abell 1367 and fewer Type 3 suggest that the EIGs and parents in Abell 1367 are in an earlier stage of the evolution on average. Most of the EIG parents are thought to be galaxies that infell into the clusters. The gas in the galaxy will be lost due to certain processes, while part of the gas may form an EIG. After some time, the star formation in the galaxy will cease, and the color of the galaxy will eventually become redder. The larger fraction of blue galaxies in Abell 1367 suggests that not only the EIG parents, but also other galaxies are still unprocessed. As the dominant mechanism of the gas removal in cluster environment is thought to be ram-pressure stripping (e.g., Boselli et al. 2016), it is natural that the evolution is slower in Abell 1367. From the X-ray observation by ASCA (Fukazawa et al. 2004), the central gas density of Abell 1367 is about 1/5 of that of the Coma, the mass is about 1/4, and the core radius is 30% larger. Thus the ram pressure, which is proportional to the density and the square of the velocity, should be weaker in Abell 1367. The smaller number of parents with post-starburst signature in Abell 1367 is also explained by the lower efficiency of the ram-pressure stripping.

The longer length of EIGs in Abell 1367 requires another explanation. The length of EIGs shows the distribution of the ejected gas from the parents and/or the reach of the ionization photons. If the ionization mechanism is spatially restricted, such as an UV from the young stars of the parent galaxy or inside the EIG, or AGN, the EIG length would be determined by the range of the flux. If it is the case, however, a gradient of SB by ASCA (Fukazawa et al. 2004), the central gas density of Abell 1367 is about 1/5 of that of the Coma, the mass is about 1/4, and the core radius is 30% larger. Thus the ram pressure, which is proportional to the density and the square of the velocity, should be weaker in Abell 1367. The smaller number of parents with post-starburst signature in Abell 1367 is also explained by the lower efficiency of the ram-pressure stripping.

The original gas before stripping would have been comparable as well. We present two possible explanations of the longer distribution of the ionized gas in Abell 1367. One is that the removal of the gas is relatively slower and longer lasting in Abell 1367, because of the low efficiency of the ram-pressure stripping. Another possibility is that the short length of EIGs in the Coma does not mean a short duration of the gas removal, but that the distant part of the gas was heated up and became invisible in Hα (Tonnesen & Bryan 2010; Tonnesen et al. 2011). The length reflects the survival timescale of the ionized gas in the cluster. Although the uncertainty is large, the estimated masses of the ionized gas of EIGs in Abell 1367 are higher than those in the Coma by about an order, while the difference in the length of EIGs is about twice as large. The mean SB in Hα is also brighter in EIGs in Abell 1367. These results suggest that the slow heating scenario would be more likely.

5.2. Star-forming Blobs in or near EIGs

There are several studies on star formation in a stripped tail: inside BIG (Gavazzi et al. 2003b), and galaxies in other clusters (e.g., Cortese et al. 2007; Sun et al. 2007, 2010; Yoshida et al. 2008, 2012; Hester et al. 2010; Yagi et al. 2013a;
Kenney et al. 2014). Results from simulations are also reported (e.g., Kapferer et al. 2008, 2009; Kronberger et al. 2008; Tonnesen & Bryan 2010; Tonnesen et al. 2011; Tonnesen & Bryan 2012). Regarding the tail of BIG, Cortese et al. (2006) predicted that star formation may occur since the mean column density is high enough to start star formation. In the B, R, and NB composite image in this study, we detected possible SF blobs in the tail of BIG and near the orphan clouds (Figures 6, 11, and Table 4.) We checked the GALEX image from the archive, and found that they are also detected in UV. We refer to the candidates as SF blobs for simplicity hereafter, although spectroscopic confirmation is needed to verify that they are genuine SF blobs in Abell 1367. We named the SF blobs in the tail of BIG B1–B6, according to the distance from BIG, and the one near the orphan clouds (orphan 2) we call O1. Their properties are shown in Table 4, and cutouts are shown as Figures 17 and 18. In this section, we mainly used images before PSF matching to make use of higher spatial resolution in NB band. Meanwhile, the magnitude shown in Table 4 was measured in PSF-matched images for consistency. The magnitude and Hα flux were measured within the isophote of 2.5 × 10^{-18} erg s^{-1} cm^{-2} arcsec^{-2}. We assumed z = 0.0275 for B1–B6 and z = 0.0217 for O1. In the B, R, and NB composite of B2, B4, and B5, possible blended fore- and background objects are recognized as yellow objects. Thus their magnitudes are contaminated by the blend. It should also be noted that since the PSF and deblending is different, the magnitude in optical and UV is not directly comparable.

The regions are very blue in the UV (FUV–NUV) and in the optical (B–R and R–i); −1.4 < FUV–NUV < 0.6, −0.3 < B–R < 0.6, and −0.5 < R–i < 0.3, before internal extinction correction. The color implies that they are SF blobs and do not suffer heavy dust extinction. The Hα luminosity of SF blobs is estimated to be (2–7) × 10^{36} erg s^{-1}, although the value has quite a large uncertainty, as discussed in Section 2.6.

5.2.1. SF Blobs in the Tail of BIG

The tangential distance of the SF blobs from galaxies in BIG is 63–150 kpc from CGCG 097-120, 120–190 kpc from CGCG 097-114, and 110–200 kpc from CGCG 097-125. The most distant SF blob, B6, is >150 kpc away. Even if the tangential motion of the blob relative to BIG is as high as 1000 km s^{-1}, B6 requires ≳1.5 × 10^8 years to reach the distance. Thus it would not be a stripped SF region from the parent, but in situ star formation.

In B4, a possible offset between B and Hα is recognized; the B-band emission is stronger near BIG. In the top panel of Figure 17, the blue component is extended to the bottom left corner. They resemble the “fireball” features found in EIG of RB199 in the Coma cluster (Yoshida et al. 2008); the ram pressure works in the regions, and Hα emitting clouds were swept downstream, while formed young stars were not. The offset is roughly aligned to the tail and points in the direction
of CGCG 097-120 and CGCG 097-125. This supports the assumption that B4 is a part of the tail.

### 5.2.2. SF Blobs near Orphan 2

The SF blobs near orphan 2 are almost perpendicularly aligned to the Hα filament from orphan 2 (Figure 19). Although the SF blobs are resolved into several compact sources in B and NB images before smoothing, they are merged in PSF-matched images, and we measured the magnitude as a whole in Table 4.

In the right panel of Figure 18, several residuals remain in the Hα image. The center panel of Figure 18 shows a B, R, and i composite as a reference; the objects that are orange-yellow in the B, R, and i composite are not SF blobs, and the Hα excess are fake because of a PSF mismatch, and they disappear in the PSF-matched Hα image.

In broadband images, a faint stream is seen near the SF blobs. The B-band image is shown in the bottom left panel of Figure 19. Because Hα is weak along the stream (Figure 18), the stream would be stars and might be a tidal tail. The stream seems to connect two galaxies, SDSS J114425.39+200923.2, and SDSS J114426.00+201001.8 across the orphan 2 filament. Their projected distance is 18.3 kpc if they are at the distance of Abell 1367. At the opposite side of SDSS J114426.00+201001.8, the stream is vague but possibly reaches the UDG, which is about 34 kpc away from the south galaxy (SDSS J114425.39+200923.2). As the three galaxies, SDSS J114425.39+200923.2, SDSS J114426.00+201001.8, and the UDG does not have spectroscopic information, the galaxies may not be a member of Abell 1367. Meanwhile, as the SF blobs show strong excess in Hα, they would be in Abell 1367.
As the SF blobs are aligned to the blue stream perpendicular to the Hα filament of orphan 2, and they are 4–8 kpc away from the Hα filament, they would be an accidental overlap on the orphan clouds. In Table 2 the flux of orphan 2 therefore does not include the SF blobs.

6. Summary

We investigated Hα images of Abell 1367 taken with Suprime-Cam, and made a catalog of extended ionized gas clouds (EIGs) and their parents. Although Abell 1367 is one of the best-studied clusters, we added six new EIGs to enable a statistical discussion and a comparison with EIGs in the Coma cluster. The deep Hα image also revealed that the Hα tails are extended in fainter SB much longer than previously known. The tail of BIG shows a sign of winding, which could be a result of motion of galaxies inside the group. We also found several candidates of SF blobs far from parent galaxies. The comparison of the parent galaxies of EIGs in Abell 1367 and in the Coma cluster showed that the properties of the parents are basically similar. Meanwhile, the length of EIGs is longer and more often connected to SF parents in Abell 1367. The difference suggests that the EIGs and parents in Abell 1367 are, on average, younger than those in the Coma cluster, and the length of EIGs is slower. This would reflect a different evolutionary stage of the clusters.

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Appendix A

Mass Estimation of the Ionized Gas Clouds

Using the photometric properties of the clouds given in Table 2, we estimated their masses as follows. We assume that the cloud is optically thin, and the volume of the cloud is calculated as \( V = S \times L \), where \( S \) is the projected area given in Table 2, and \( L \) is the mean length along the line of sight. Assuming a roughly cylindrical morphology, \( L \) is approximated by \( L = B \times \sqrt{S/(A \times B)} \), where \( A \) and \( B \) are the length and width of the bounding rectangle, respectively. The volume is thus calculated as \( V = S^{3/2} \sqrt{B/A} \). The case B recombination coefficient of Hα at \( T_e = 10^4 \) K is \( \alpha_\text{B} \sim 8.7 \times 10^{-14} \text{ cm}^3 \text{ s}^{-1} \) (Osterbrock & Ferland 2006). The Hα flux given in Table 2 \( (f_{\text{Hα}}) \) is then calculated as

\[
 f_{\text{Hα}} = \frac{h \nu_{\text{Hα}} \alpha_\text{B} n_e^2 V}{4 \pi d_L^2},
\]

where \( n_e \) is the mean electron density, \( h \) is the Planck constant, \( \nu_{\text{Hα}} \) is the frequency of Hα, and \( d_L \) is the luminosity distance to the gas, 100 Mpc. The mass \( (m) \) is calculated as

\[
 m \sim 9.7 \times 10^7 M_\odot \times \sqrt{f_{\text{Hα}}} \sqrt{10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2} \left( \frac{S}{100 \text{ kpc}^2} \right)^{3/2} \sqrt{B/A}}.
\]

where \( f_{\text{Hα}} \) is the volume-filling factor of the ionized gas, and \( m_p \) is the proton mass. The calculated mass of the clouds is given in Table 2. If the cloud distribution has inclination \( i \) against the tangential plane, the derived mass should be divided by \( \cos i \), but this effect is smaller than other uncertainties.

Appendix B

Notes on Known EIGs

B.1. CGCG 097-073 and 097-079

The two are well known for their prominent tails (e.g., Gavazzi & Jaffe 1987; Gavazzi 1989; Boselli et al. 1994; Gavazzi et al. 1995, 1998, 2001a; Scott et al. 2010). The Subaru images as Figure 8 is shown as Figure 20. Boselli & Gavazzi (2014) showed a preliminary result from the same data as this paper.

B.2. CGCG 097-087 and 097-087N

CGCG 097-087 (UGC 6697) is also the best-studied galaxy in Abell 1367 (e.g., Gavazzi & Jaffe 1987; Gavazzi 1989; Boselli et al. 1994; Gavazzi et al. 1995, 1998, 2001b; Scott et al. 2010). Gavazzi et al. (2001b) presented an Hα image and spectra of the galaxy and a part of the tail with a detailed investigation.

In the Subaru Hα data (Figure 21), we found that the tail of CGCG 097-087N extends more than 150 kpc from the core, more than twice as long as previously known in Hα (Gavazzi et al. 1995) and in other wavelengths (Sun & Vikhlinin 2005; Scott et al. 2010).

In the Subaru Hα data, CGCG 097-087N shows clear twin tails without a stellar counterpart toward CGCG 097-087 (Figure 21). Zoomed-in images before PSF matching are shown as Figure 22. The tails that overlap the CGCG 097-087 disk may be an indication that helps to understand the complex velocity field of the CGCG 097-087 disk (Gavazzi et al. 1984, 2001b).

CGCG 097-087 shows a quite red color \( (g - r = 1.81) \) in the DR12 catalog. We checked the SDSS database to find that the center of the galaxy suffers heavy dust extinction and SDSS extracted the region. The color therefore does not reflect its stellar population. We therefore used the color from the GOLDMine Database (Gavazzi et al. 2003a) for the galaxy, which measured SDSS images with the method by Consolandi et al. (2016). The adopted color of CGCG 097-087 is \( g - r = 0.61 \).
For a statistical discussion of EIG parents, the assignment of the parent galaxy of the complex Hα clouds around BIG is needed. From previous studies, it is known that CGCG 097-125 and CGCG 097-114 show a clear Hα tail and were identified as the parents. CGCG 097-120 (v_r = 5609 km s^{-1}; from SDSS DR12) has been thought to be an accidental overlap, since the measured recession velocity of the Hα clouds around BIG is as high as 8000–8800 km s^{-1} (Cortese et al. 2006). However, a recent spectroscopic observation by MUSE/VLT revealed that CGCG 097-120 is interacting with surrounding Hα gas and shows a smoothly connected distribution of the Hα velocity (G. Consolandi et al. 2017, in preparation). At least these three are therefore parent galaxies of EIGs.

Another possible parent of EIGs around BIG is SDSS J114501.81+194549.4, which shows a clear post-starburst...
feature from the SDSS DR12 spectrum at $v_r = 8220 \text{ km} \text{s}^{-1}$. The EIG just south of the galaxy may be connected with the galaxy. The galaxy is thus counted as an EIG parent in Table 5.

Yet another possible parent of EIG around BIG is SDSS J114513.76+194522.1 ($v_r = 8256 \text{ km} \text{s}^{-1}$), about 150 kpc east of the BIG complex. The galaxy shows a sign of stripping toward the west, although no extended H$\alpha$ feature is seen around it. Moreover, the south clouds of BIG (Cortese et al. 2006) show a sign that they come from far east of BIG. However, this is currently weak evidence. Thus we did not count the galaxy in Table 5 and did not plot it in Figures 15 and 16, but showed it in Table 3 with parentheses as a reference.

Other spectroscopically confirmed dwarfs and knots by Sakai et al. (2002) and Cortese et al. (2006) are fainter than the magnitude limit of the catalog ($r < 17.7$) used in the statistical analysis of this study. Previous studies (Sakai et al. 2002; Gavazzi et al. 2003b; Cortese et al. 2006) discussed the possibility that the dwarfs could have been formed in the stripped gas from giant galaxies. The dwarfs would not be parent galaxies of EIGs, but rather children. We therefore do not count them as parent galaxies of EIGs.

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Table 5

| Name   | Survey Area (Mpc$^2$) | Member | Blue Member | EIG Parent$^a$ | Blue Parent$^a$ |
|--------|----------------------|--------|-------------|----------------|----------------|
| Coma   | 1.2                  | 202    | 15          | 12             | 8              |
| A1367  | 1.7                  | 120    | 19          | 11             | 6              |

Note.
$^a$ Only $r < 17.7$ mag counts are observed.
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