Evidence for a warm ISM in the Fornax dEs FCC046 and FCC207

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Based on observations collected at the European Southern Observatory, Chile (ESO Large Programme Nr. 165.N-0115)

ABSTRACT
We present Hα+[NII] narrow-band imaging of FCC046 and FCC207, two dwarf ellipticals (dES) in the Fornax Cluster. B-R and B-I color-maps clearly show signs of dust-absorption in FCC207. FCC046 has a very bright blue nucleus, offset by about 1.1″ with respect to the outer isophotes. FCC046 was classified as a non-nucleated dE4 so the presence of its nucleus came as a surprise. Moreover, FCC046 shows a pronounced lopsided shape. Given that FCC046 is an isolated galaxy, it is unlikely that an encounter caused this asymmetry. The emitting regions differ considerably between the two galaxies. Whereas FCC207 has only one central emission region, FCC046 also contains fainter emission regions. Based on broad-band colours, its disturbed shape and its very bright nucleus, FCC046 is akin to the class of amorphous dwarfs. The central emission regions of both galaxies are barely resolved under seeing conditions of FWHM≈ 0.8″ and we estimate their diameters at about 60 pc. Their Hα luminosities can be explained as photo-ionisation by post-AGB stars in an old population. Some of the fainter extended emission regions in FCC046 are resolved and have diameters of the order of 50–150 pc and Hα luminosities of the order of 1030 W, comparable to supernova remnants or nebulae around Wolf-Rayet stars. Hence, FCC046 is clearly undergoing star-formation while for FCC207 the case is not as clearcut. We estimate the mass of the HII gas in FCC046 at \( M_{\text{HII}} = 40 - 150M_\odot \) (for \( T = 10^4 \text{ K}, N_e = 1000 \text{ cm}^{-3} \)). The ionised-gas content of FCC207 is somewhat higher : \( M_{\text{HII}} = 60 - 190M_\odot \).

Key words: galaxies:dwarf – galaxies:individual:FCC046, FCC207 – ISM:HII regions – ISM:supernova remnants

1 INTRODUCTION
Dwarf ellipticals as a rule are pressure-supported objects, characterized by very low rotation velocities compared to their velocity dispersions (fast-rotating dEs do exist but they are rare, see De Rijcke et al. (2001)). There is currently a number of models in vogue that attempt to explain this apparent lack of rotation as a result of significant mass-loss. According to the “wind-model”, proposed by Dekel & Silk (1986), dEs form from average-amplitude density fluctuations. Most, if not all, of the ISM is subsequently blown away after it has been heated to velocities that exceed the galaxy’s escape velocity by the first burst of supernova explosions. This dramatic mass-loss causes a more anisotropic orbital structure and makes the galaxy puff up. A more sophisticated version of this scenario can be found in Mori et al. (1997) who discuss the chemodynamical evolution of a \( 10^{10}M_\odot \) dwarf galaxy. The first supernovae expell a supersonic outflow of gas from the center of the galaxy. Stars form in this expanding shell and subsequent supernova explosions further accelerate the expansion of the shell and enrich it with metals. This model explains the outward reddening of dEs as a metallicity effect and reflects in the characteristic exponential surface-brightness profile.

Other scenarios take into account the fact that dEs are found predominantly in high-density environments such as groups and clusters. Mori & Burkert (2000) argue that ram-pressure stripping is able to completely remove the gas from a dE less massive than \( 10^9M_\odot \) within a few \( 10^8 \) years. More massive dEs might be able to retain some gas in the central region. Moore et al. (1998) examine the role of tidal interactions between small spirals and giant cluster-members to produce dE-like objects. On its orbit through the clus-
Marlowe are not irregular enough to be classified as Im. Marlowe due to recent star formation and the presence of dust but dwarfs" for dwarf galaxies that have a disturbed appearance (1999) argue that BCDs, Hα

-component. Their amorphous dwarfs show strong Hα emission in the form of a central extended emission region of 50 pc in diameter, probably a SNR. On the other hand, NGC205 is devoid of emitting regions. Hence, the presence of an ionised ISM in dEs should not be taken for granted. NGC205 and NGC185 also show a few dust patches. The dE A 0951+68, in the M81 group, possesses a high-excitation HII region (Johnson et al. (1997)). The observed extended blue light is regarded as evidence of a recent star formation event. NGC4486A, a relatively bright dE seen almost edge-on, contains a stellar and dust disk (Kormendy et al. (2001)), reminiscent of the nuclear disks of spiral galaxies.

Sandage & Brucato (Sandage & Brucato (1979), see also e.g. Quill et al. (1995), Noreau & Kronberg (1986), Marlowe et al. (1997; 1999)) coined the name “amorphous dwarfs” for dwarf galaxies that have a disturbed appearance due to recent star formation and the presence of dust but are not irregular enough to be classified as Im. Marlowe et al. (1999) argue that BCDs, HII galaxies and amorphous galaxies are actually all members of the same class of star-forming dwarfs and owe their names mostly to the selection criteria involved. Most amorphous dwarfs in the sample of Marlowe et al. (1997) have a two-component surface brightness profile: an exponential envelope and a bluer core component. Their amorphous dwarfs show strong Hα emission (LHα ≈ 10³³ W). These authors argue that it is possible – at least in principle – that the cores and envelopes of BCDs and amorphous dwarfs will fade and reach an end-state similar to present-day nucleated dEs after they have used up their gas supply and star-formation has ended. However, star-formation in dwarf galaxies probably takes place in a series of mild star-bursts that deplete the gas rather slowly. Hence, dEs must have had ancestors that evolved more rapidly. The fact that dEs are found predominantly in clusters while BCDs are remarkably scarce in these high-density environments (Salzer (1989)) might hold a clue: repeated encounters with giant galaxies and ram-pressure stripping may have sped up the gas-depletion process. It is clear that the present-day star-formation rate (SFR) and ISM-content hold important clues to understand the origin of dEs.

FCC046 (Fig. 1) and FCC207 (Fig. 2) (Ferguson (1989)) were selected as targets for an ongoing ESO Large Programme to study the structure and dynamics of dEs. These were the only galaxies in our sample with published evidence of the presence of an ISM and recent star-formation. Ionised hydrogen was detected by Drinkwater et al. (2001) in both galaxies. These authors interpret this as photo-ionisation by young stars and use Kennicutt’s (1983; 1992) calibration between the total SFR and the Hα+[NII] equivalent width (EW)

\[
SFR \approx 2.7 \times 10^{-12} \frac{L_B}{L_{B,\odot}} \text{EW}(\text{Hα} + [\text{NII}]) \frac{M_\odot}{\text{yr}},
\]

with \(L_B\) and \(L_{B,\odot}\) the B band luminosity of the galaxy and the sun, respectively, to estimate the SFRs in these galaxies at \(1 - 2 \times 10^{-3} M_\odot/\text{yr}\). Held & Mould (1994) present UVB colors and metallicities of, amongst others, FCC207. They conclude that FCC207 is too blue in U−B (U−B= 0.15) and too metal-poor for its B−V (B−V= 0.78) and interpret this as a consequence of the presence of a young stellar population. This motivated us to investigate both objects more closely using BRI broad-band and Hα+[NII] narrow-band imaging. In section 2, we discuss the details of the observations and data reduction. The B−R color maps are presented in section 3 and the results of the Hα+[NII] narrow-band imaging are shown in section 4.

2 OBSERVATIONS AND DATA REDUCTION

The observations were carried out on 18 and 20 November 2001 with Yepun (VLT-UT4) using FORS2. We took 20 minute exposures of FCC046 and FCC207 with the Hα/Alpha/2500+60 filter centered on 6064 Å and with a FWZH= 64 Å. R band images obtained during a previous run (1-8 November 2000) served as off-band images. Two Hα-images of the spectrophotometric standard star LTT9239 were taken for flux-calibration. During these observations, the seeing (determined from the stars on the images) typically was 0.7′′−0.8′′ FWHM. The standard data reduction procedures (bias subtraction, flatfielding, cosmic removal, interpolation over bad pixels, sky subtraction) were performed with MIDAS*. All science images were corrected for atmospheric extinction (using the R band extinction coefficient: \(k_e = 0.13\)) and interstellar extinction (we used the Galactic extinction estimates from Schlegel et al. (1998): \(A_R = 0.050\) for FCC046 and \(A_R = 0.039\) for FCC207). The images were finally converted to units of electrons/second/pixel.

In order to find the correct scaling for the R-band images we adopted the following strategy. The pure emission “Em” can be recovered from a narrow-band image “Nb” and an R-band image “Rb” as

\[
Em = Nb - (c \times Rb + \delta)
\]

with \(c\) the proper scaling constant and \(\delta\) a correction for possible faulty sky-subtraction. To find the best values for \(c\) and \(\delta\), we first fitted the isophotes of the narrow-band and R-band images in an annulus between \(m_{R} = 24.5 \text{ mag}/\alpha''\) and \(m_{R} = 26.5 \text{ mag}/\alpha''\), which in retrospect did not contain any emission (hence Em= 0), using the standard MIDAS

* ESO-MIDAS is developed and maintained by the European Southern Observatory
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Figure 1. 450 sec. B-image of the dE4 FCC046. The nucleus is offset by 1.1″ to the south-west of the center of the outer isophotes.

Figure 2. 450 sec. B-image of the dE2 FCC207.

FIT/ELL3 command. Thus, a smooth version of this annulus could be constructed for both images. The optimal c and δ can be found by minimising the expression $|\text{Nb} - (c \times \text{Rb} + \delta)|$ with Nb and Rb the smoothed versions of the annulus. With these values in hand, the pure-emission image can be obtained using relation (2). δ was very small for both FCC046 and FCC207, which makes us confident that the sky was properly subtracted in all images. Since the Hα and R-band overlap, subtracting an R-band image in lieu of a continuum image entails a partial removal of some Hα+[NII] light. The error thus introduced is of the order of the ratio of the effective widths of the filters (R-band: $W = 165.0$ nm, Hα: $W = 6.4$ nm), i.e. less than 4%. Since this effect is negligible in comparison to the other possible sources of error, we did not correct for it.

A pixel-value in the pure-emission image (corrected for both atmospheric and interstellar extinction), denoted by $N_\alpha$, expressed in electrons/second, can be converted to flux units, $F^\alpha$, using the formula:

$$F^\alpha = N_\alpha \times \frac{\varphi_\alpha}{N_\alpha} \int_0^{\infty} F^\lambda_\alpha(\lambda) \varphi_\lambda(\lambda) \, d\lambda \; \text{W m}^{-2}. \quad (3)$$

Here, $F^\lambda_\alpha(\lambda)$ is the spectrum of a flux-calibration standard star and $N_\alpha$ is the measured flux of that star, expressed in electrons/second. $\varphi_\lambda(\lambda)$ is the transmission of the Hα filter and $\varphi_\alpha$, the transmission of the optics (which is basically constant for a narrow-band filter). The prime on $F^\alpha$ indicates that this is the flux incident on the CCD, after going through the telescope and instrument optics and the narrow-band filter. This can also be written as:

$$F^\alpha = \varphi_\alpha \left[ F_{\text{H} \alpha} \varphi_\lambda(\lambda_{\text{H} \alpha}) + F_{\text{[NII]}} \varphi_\lambda(\lambda_{\text{[NII]}}) \right] \quad (4)$$

with $F_{\text{H} \alpha}$, $F_{\text{[NII]}}$, and $F_{\text{[NII]}}$ the incoming fluxes – i.e. before going through the telescope and instrument optics and the narrow-band filter – of respectively the Hα 6563Å, the [NII] 6548Å and the [NII] 6583Å emission line (approximated as δ-functions). This allows one to obtain the true incoming flux of the Hα emission line as:

$$F_{\text{H} \alpha} = \frac{N_\alpha}{N_\alpha} \int_0^{\infty} F^\lambda_\alpha(\lambda) \varphi_\lambda(\lambda) \, d\lambda \quad (5)$$

The total incoming Hα+[NII] flux is simply:

$$F_{\text{em}} = F_{\text{H} \alpha} \left( 1 + \frac{F_{\text{[NII]}}}{F_{\text{H} \alpha}} \right). \quad (6)$$

Since the Hα filter is relatively flat-topped and the Hα and [NII] lines are well inside the filter transmission curve, the total flux is rather insensitive to the adopted relative line-strengths. In the following, we will assume the mean value $F_{\text{[NII]}}/F_{\text{H} \alpha} = 3$ for the ratio of the line-strengths of the two Nitrogen lines (Macchetto et al. (1996), Phillips et al. (1986)). The ratio $F_{\text{[NII]}}/F_{\text{H} \alpha}$ is not known and is treated as a free parameter, varying between 0 and 2. The rms scatter in the final pure-emission images is about 0.035 electrons/pixel/second (or $2 \times 10^{-20}$ W m$^{-2}$ for $F_{\text{[NII]}}/F_{\text{H} \alpha} = 1.38$, the average value found by Phillips et al. (1986) for a sample of normal ellipticals).

3 B–R COLOR MAPS

The B, R and I images were used to extract surface brightness, position angle and ellipticity profiles (see Figure 3). The deviations of the isophotes from a pure elliptic shape were quantified by expanding the intensity variation along an isophotal ellipse in a fourth order Fourier series with coefficients $S_1$, $S_3$, $C_4$ and $C_5$:

$$I(\theta) = I_0 (1 + C_1 \cos(3(\theta - \text{PA})) + C_4 \cos(4(\theta - \text{PA})) + S_3 \sin(3(\theta - \text{PA})) + S_1 \sin(4(\theta - \text{PA}))) \quad (7)$$

with PA the position angle. All photometric parameters were fitted by cubic splines as functions of semi-major axis distance. The galaxy nucleus (i.e. the brightest pixel) was used.
Figure 3. Photometric properties of FCC207 (left) and FCC046 (right), derived from the I band image, versus the geometric mean of the semi-major and semi-minor distances $a$ and $b$. From top to bottom: the I-band surface brightness $\mu_I$ (the dotted line corresponds to a surface brightness equal to 1% of the sky level), the deviation in declination $\Delta \delta$ and right ascension $\Delta \alpha$ of the centers of the isophotes with respect to the brightest point, the position angle $PA$, the ellipticity $\epsilon = 10(1 - b/a)$, and the Fourier coefficients $S_4$, $S_3$, $C_4$ and $C_3$ that quantify the deviations of the isophotes from ellipses.
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Figure 4. B−R color map of FCC207. The nucleus is rather blue (B−R ≈ 0.9 mag) compared to the bulk of the galaxy (B−R ≈ 1.25 mag). The inset shows the central 5″ × 5″ region with a different greyscale. To the north of the nucleus, a signature of dust-absorption is visible (Δ(B−R) = 0.2 mag).

Figure 5. B−I, B−R and R−I profiles of FCC207 as a function of the geometric mean of semi-major axis a and semi-minor axis b distance. Outside the nucleus, the colors are essentially constant.

as zeropoint for both a and b, the semi-minor axis distance. This allowed to reconstruct the surface brightness at a given point on the sky and to construct color profiles (e.g. B−R as a function of radius).

3.1 FCC207

FCC207 has de-reddened magnitudes $m_I = 14.39$ mag, $m_R = 14.86$ mag and $m_B = 16.19$ mag (hence B−R = 1.33 mag, R−I = 0.47 mag). Its nucleus has a distorted shape: it is more elongated than the bulk of the galaxy (E3 versus E2) and is somewhat kidney-shaped. This is probably due to dust-absorption to the north of the nucleus, noticeable in the B−R color map (Figure 4) as a patch that is ≈ 0.2 mag redder than its surroundings. The nucleus (B−R = 0.90 mag) is significantly bluer than the bulk of the galaxy (B−R = 1.25 mag). This behavior is similar...
to what e.g. Bremnes et al. (1998) find in dwarf galaxies in nearby groups, A small, slightly east-west elongated blue object (B−R = 1.10 mag) can be seen to the west of the nucleus. It is also visible in the Hα image. Its elongation rules out the possibility that it is a faint foreground star. As can be seen in Figure 5, the B−R, B−I and R−I colors stay essentially constant outside the nucleus. If a young stellar population is present outside the nuclear region of FCC207 (the inner 2′′) then these stars are apparently well mixed with the older population.

3.2 FCC046

FCC046 is a rather blue object, with de-reddened magnitudes $m_I = 14.43$ mag, $m_R = 14.88$ mag and $m_B = 15.99$ mag (hence B−R = 1.11 mag, R−I = 0.45 mag). The nucleus, a round (E0) and blue (B−R = 0.10 mag) object (see Figure 6), is offset by 1.1′′ to the south-west of the center of the outer isophotes (see Figure 3). B−R, B−I and R−I color profiles are presented in Figure 7 and show a very different behavior than those of FCC207. The colors of the stellar population become redder towards larger radii. The nucleus of FCC046 is much bluer than those of nucleated dwarfs presented by Bremnes et al. (e.g. (1998)). These authors typically find B−R ≈ 0.5 for the nucleus. The nucleus is resolved in the B-band image. This implies that the nucleus is much larger than would be expected for a typical dE. Even with the superior resolving power of HST, Lauer et al. (1995) could not resolve the nuclei of 5 nucleated Virgo dEs. The diameter (FWHM) of the nucleus was estimated using the relation

$$\text{FWHM}_{\text{true}} = \sqrt{\text{FWHM}_{\text{obs}}^2 - \text{FWHM}_{\text{star}}^2}$$

(8)

with FWHM$_{\text{true}}$ the true dimension, FWHM$_{\text{obs}}$ its observed FWHM and FWHM$_{\text{star}}$ the average FWHM of the stars in the image. The seeing, estimated from 10 stars in the B-band image, was 0.82′′ ± 0.04′′. The measured FWHM of the nucleus is FWHM$_{\text{obs}} = 1.1′′$ or FWHM$_{\text{true}}$ ≈ 65 pc (for $H_0 = 75$ km/s/Mpc and a Fornax systemic velocity $v_{\text{sys}} = 1379$ km/s). We fitted a two-component model to the B-band surface brightness of FCC046: an axisymmetric component centered on the position of the nucleus. The results of this decomposition are presented in Figure 8. The nucleus has a blue magnitude $m_B = 18.55$ mag ($M_B = -12.77$) and comprises about 10% of the total B-band luminosity of the galaxy. It should be noted that the nucleus of FCC046 was apparently not visible on the photographic plates on which Ferguson’s catalog (1989) was based, since it is classified as a dE4 (i.e. as a non-nucleated dwarf). The underlying stellar envelope deviates from an axisymmetric mass model and shows a pronounced lopsidedness, visible in Figure 3 as the bump in Δα in the region $\sqrt{\sigma b} \approx 2′′ - 12′′$. This asymmetry may be due to an asymmetric distribution of few but bright young stars. This appears to be plausible since the dynamical time scale, estimated as

$$\Delta t = \frac{2\pi r}{v_{\text{circ}}} = \sqrt{\frac{16\pi^2 r^3}{GM(r)}} \approx 20 \text{ Myr}$$

(9)

for typical values $r \approx 0.5$ kpc and $M(r) \approx 10^9 M_\odot$, is of the order of the life-time of the youngest stars so these would not have had time to disperse all over the face of the galaxy. The cause of persistent $m = 1$ perturbations, that involve a sizable fraction of a galaxy’s mass, is still poorly understood.

4 Hα IMAGING

4.1 The Hα equivalent width

Drinkwater et al. (2001) have measured Hα EWs of 108 confirmed Fornax cluster members, including FCC046 and FCC207 with the FLAIR-II spectrograph on the UK Schmidt Telescope. The effective aperture diameter of this system is at least 6.7′′ (the fibre diameter) and could be as large as 15′′ (because of image movements due to tracking errors and differential atmospheric refraction). They find:

$$\text{EW}(\text{FCC046}) = 2.1 \, \text{Å},$$
$$\text{EW}(\text{FCC207}) = 2.2 \, \text{Å}.$$  

For comparison, we calculated the EW inside some aperture radius $r$ from our images as:

$$\text{EW} = \frac{F_{\text{em}}(r)}{F_{\text{cont}}(r)} \Delta \lambda$$

(10)

with $\Delta \lambda = 64$ Å the FWHM of the redshifted Hα filter and $F_{\text{em}}(r)$ and $F_{\text{cont}}(r)$ the total number of counts inside a circular aperture with radius $r$ respectively the Hα+[Nii] and the continuum image. We find:

$$\begin{align*}
F_{\text{em}} &= 54.1 \, \text{e}^-/\text{sec} \\
F_{\text{cont}}(8′′) &= 3745 \, \text{e}^-/\text{sec} \rightarrow \text{EW}(8′′) = 0.9 \, \text{Å} \\
F_{\text{cont}}(3.5′′) &= 1462 \, \text{e}^-/\text{sec} \rightarrow \text{EW}(3.5′′) = 2.4 \, \text{Å}, \\
F_{\text{em}} &= 78.0 \, \text{e}^-/\text{sec} \\
F_{\text{cont}}(8′′) &= 3300 \, \text{e}^-/\text{sec} \rightarrow \text{EW}(8′′) = 1.4 \, \text{Å} \\
F_{\text{cont}}(3.5′′) &= 1250 \, \text{e}^-/\text{sec} \rightarrow \text{EW}(3.5′′) = 3.7 \, \text{Å}.
\end{align*}$$

Given the possible sources of error (photon shot-noise, sky and continuum subtraction) that can affect our measurements, we consider these values in good agreement with the EWs measured by Drinkwater et al. (2001).

4.2 The Hα+[Nii] and Hα luminosities

Pure Hα+[Nii] emission images of FCC046 and FCC207 are presented in Figures 9 and 10. For FCC046, we find $F_{\text{em}}(\text{FCC046}) = 1.53 - 1.57 \times 10^{-18} \, \text{W m}^{-2}$, corresponding to a total luminosity $L_{\alpha\nu}(\text{FCC046}) = 6.21 - 6.37 \times 10^{38} \, \text{W}$. The range of values is given for $F_{\text{em}}(\text{FCC046}) = 0 - 2$ (see Figure 11). The central emission peak comprises about half of the luminosity. It alone has a luminosity of about $3 \times 10^{38} \, \text{W}$. The total flux of FCC207 is somewhat higher: $F_{\text{em}}(\text{FCC207}) = 1.93 - 2.18 \times 10^{-18} \, \text{W m}^{-2}$, which
yields a total luminosity $L_{\text{em}}(\text{FCC207}) = 7.83 - 8.84 h_{75}^{-2} \times 10^{39} \text{ W}$. These numbers can be compared to those found by Buson et al. (1993), Kim (1989), Phillips et al. (1986) and Shields (1991) for normal elliptical and S0 galaxies. The luminosities of the central emission peaks in FCC046 and FCC207 are compared to those of ellipticals in Figure 12. Typical emission luminosities for these galaxies lie in the range $L_{\text{em}} = 10^{33} - 10^{35} \text{ W}$, i.e. more than a 1000 times brighter. The fact that the luminosity of the nuclear emission in these dEs agrees fairly well with the trend of normal Es – extrapolated over more than 2 magnitudes – suggests that the ionising mechanism, at least for the central emission, is the same and therefore somehow related to the stellar population.

The total Hα-flux of FCC046 is $F_{\text{H}\alpha} = 4.17 - 15.7 \times 10^{-19} \text{ W m}^{-2}$, depending on the value of $F_{\text{[Nii]}}/F_{\text{H}\alpha}$. This translates into a total Hα luminosity $L_{\text{H}\alpha} = 1.69 - 6.37 h_{75}^{-2} \times 10^{35} \text{ W}$, about half of which is emitted by the central peak corresponding to the galaxy’s nucleus. The total Hα-flux of FCC207 is somewhat higher: $F_{\text{H}\alpha} = 5.95 - 19.3 \times 10^{-19} \text{ W m}^{-2}$, corresponding to $L_{\text{H}\alpha} = 2.41 - 7.83 h_{75}^{-2} \times 10^{36} \text{ W}$. Binette et al. (1994) propose photo-ionisation by post-AGB stars as a source for the central emission in elliptical galaxies. Using their prescriptions, we derive central Hα luminosities of the order of $2 \times 10^{40} \text{ W}$, i.e. comparable to what is observed. Hence, blindly interpreting the central Hα emission as evidence for star-formation may be somewhat audacious. We can however check our results and use Kennicutt’s (1983) calibration between the total SFR and the Hα luminosity,

$$\text{SFR} \approx 8.93 \times 10^{-33} L_{\text{H}\alpha} E_{\text{H}\alpha}$$

with $E_{\text{H}\alpha} = 1 \text{ mag}$ the internal extinction factor. We obtain

$$\text{SFR(FC046)} = 0.4 - 1.4 \times 10^{-3} M_\odot/\text{yr}$$

$$\text{SFR(FC207)} = 0.5 - 1.8 \times 10^{-3} M_\odot/\text{yr},$$

Figure 9. The pure emission image (Hα+[NII]) of FCC046. The asterisk marks the center of the outer isophotes. The bright emission feature in the center coincides with the off-center nucleus. The six fainter emission “clouds” are labeled $\text{Cl}1$ up to $\text{Cl}6$.

in good agreement with the estimates based on the EWs given by Drinkwater et al. (2001).

4.3 HII masses

The total mass in ionised hydrogen can be written as

$$M_{\text{HII}} = \frac{L_{\text{H}\alpha}}{4\pi j_{\text{H}\alpha}} m_{\text{H}} N_e$$

with $L_{\text{H}\alpha}$ the total Hα luminosity, $m_{\text{H}}$ the mass of the hydrogen atom and $N_e$ the electron density in the gas. The hydrogen Hα emissivity $j_{\text{H}\alpha}$ is given by

$$4\pi j_{\text{H}\alpha} = N_e^2 \alpha_{\text{H}\alpha} h\nu_{\text{H}\alpha} = 3.544 \times 10^{-32} N_e^2 \text{ W cm}^{-3}$$

in “case B” recombination, i.e. complete re-absorption of all Lyman photons in an optically thick nebula (Osterbrock 1989, Spitzer 1978, Macchetto et al. 1990). Each Lyman photon emitted from a level with $n \geq 3$ is later on converted to (a) Balmer photon(s) plus one Lyman α photon, thus raising the flux in the Balmer lines. The production coefficient $\alpha_{\text{H}\alpha}$ (calculated for $T = 10^4$ K) is insensitive to the electron density (it changes by only 4% if $N_e$ is raised from 1 cm$^{-3}$ to 10$^6$ cm$^{-3}$) and varies as $T^{-0.8}$ as a function of temperature. Using equations (13) and (14), the ionised hydrogen mass

$$M_{\text{HII}} = 23.72 \left( \frac{1000 \text{ cm}^{-3}}{N_e} \right) \left( \frac{F_{\text{H}\alpha}}{10^{35} \text{ W}} \right) M_\odot$$

$$= 2.85 \left( \frac{1000 \text{ cm}^{-3}}{N_e} \right) \left( \frac{F_{\text{H}\alpha}}{10^{-23} \text{ W cm}^{-2}} \right) \left( \frac{r}{10 \text{ Mpc}} \right)^2 M_\odot,$$

Figure 10. The pure emission image (Hα+[NII]) of FCC207. The asterisk marks the center of the outer isophotes. A small emission feature can be discerned 2′′ to the west of the nucleus.

can be written concisely as:

cf. Kim (1989). In the following, we will assume the value $N_e = 1000 \text{ cm}^{-3}$ for the electron density to be in accord
with most other authors and to be able to directly compare
our ionised hydrogen masses with the literature (however,
Spitzer (1978) advocates $N_e = 100$ cm$^{-3}$ as a typical value
for both Galactic H\textsc{ii} regions with diameters of the order of
100 pc and for supernova remnants). Using equation (15),
the mass of the ionised hydrogen gas in FCC046 can be esti-
mated at $M_{\text{H} \text{ii}} \approx 40 - 150 M_\odot$ and at $M_{\text{H} \text{ii}} \approx 60 - 190 h_{75}^{-2} M_\odot$
in FCC207.

4.4 FCC046: a starforming dE?

The H\textsc{ii} emission of FCC046 is distributed over a bright
central region and six fainter clouds, labeled C1 to C6 in
Figure 9. C11, C12, C15, and C16 are identifiable in the B−R
color map. C11 and C16 are part of the bluish nebulosity
to the north of the nucleus whereas C12 and C15 show up
as individual blue spots, about 0.1 mag bluer than their
immediate surroundings. The diameters (FWHM) of these
clouds were estimated using equation (8). We fitted gaussian
profiles to 11 stars in the pure-emission image of FCC046
and found $\text{FWHM}_{\text{star}} = 0.78'' \pm 0.06''$. Hence, clouds with an
observed FWHM smaller than 0.84'' (or a diameter smaller
than $\approx 30$ pc) cannot be regarded as resolved. Clouds C1, C13, and C16 are resolved under the given seeing conditions.
In Table 1, the diameters and luminosities of the clouds
are listed. In the fourth column, we give the emission rate
of hydrogen ionising photons $Q_{\text{max}}$ needed to produce the
luminosity $L_{\text{em}}$ if the clouds would be H\textsc{ii} regions (i.e. we
assume that all the light is in the H\textsc{a} line to obtain an upper
limit for $Q$):

$$Q_{\text{max}} = L_{\text{em}} \frac{\alpha_B}{h_{\text{Planck}} \alpha_{\text{H\alpha}}} \quad (16)$$

with $\alpha_B = 2.59 \times 10^{-13}$ cm$^3$s$^{-1}$ the “case B” recombination
coefficient for $T = 10^4$ K (Osterbrock (1989)). An upper
limit for the diameter of a H\textsc{ii} region, $D_{\text{max}}$, is then given
by

$$D_{\text{max}} = \left( \frac{6Q_{\text{max}}}{\pi N_e^2 \alpha_B} \right)^{1/3} \quad (17)$$

The values in Table 1 are calculated for $N_e = 100$ cm$^{-3}$.
In Figure 13, the diameters ($D = \sqrt{ab}$ with $a$ and $b$ re-
spectively the long and short axes FWHM) and H\textsc{a}+[N\text{ii}]
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Figure 11. The logarithm of the total Hα+[Nii] flux ($F_{\text{em}}$) and the Hα flux ($F_{\text{H}\alpha}$) versus the ratio of the strengths of the [Nii] 8584 Å and the Hα line. The total flux is virtually independent of this line-ratio.

Figure 12. The total Hα+[Nii] emission-line luminosity of FCC046 and FCC207 versus absolute blue magnitude. The dark-grey lines indicate the linear relation and its 1 − $\sigma$ deviation observed by Phillips et al. (1986). The Es and S0s observed by Buson et al. (1993) fill the light-grey area. All observations have been converted to the distance scale adopted in this paper.

Table 1. Second and third column: the logarithm of the measured diameters $D$ (pc) and Hα+[Nii] luminosities $L_{\text{em}}$ (W) of the six emission clouds in FCC046. Fourth and fifth column: upper limits for the logarithm of the ionising photon emission rates $Q_{\text{max}}$ (s$^{-1}$) and diameters $D_{\text{max}}$ (pc) if the clouds would be HII regions with $N_e = 100$ cm$^{-3}$.

| name | log($D$) | log($L_{\text{em}}$) | log($Q_{\text{max}}$) | log($D_{\text{max}}$) |
|------|----------|----------------------|-----------------------|-----------------------|
| C1   | 1.87     | 30.36                | 49.62                 | 1.01                  |
| C12  | <1.49    | 28.52                | 47.78                 | 0.39                  |
| C13  | 1.91     | 29.72                | 48.98                 | 0.79                  |
| C14  | <1.49    | 29.50                | 48.76                 | 0.72                  |
| C15  | <1.49    | 29.42                | 48.68                 | 0.69                  |
| C16  | 1.64     | 29.13                | 48.39                 | 0.60                  |

5 CONCLUSIONS

The similarities of the broad-band colours of FCC046 to those of star-forming or amorphous dwarfs, its relatively strong core and the presence of emission clouds support the conclusion that FCC046 is actively forming stars, albeit at a very leisurely pace when compared to BCDs and amor-
phous dwarfs who are about a factor 1000 more luminous in Hα. The nuclear emission of FCC046 and FCC207 can be adequately accounted for by photo-ionisation by post-AGB stars although a contribution of Hα emission from star-formation cannot be excluded. Only the emission from the six clouds observed in FCC046 (supernova remnants, Wolf-Rayet nebulae) can be interpreted as unambiguous evidence for recent or ongoing star-formation. The presence of physically different emission regions makes the interpretation of this emission in terms of a star-formation rate cumbersome.

High-resolution spectroscopy of a broad wavelength region is required to measure the strengths of Hα, Hβ and of tell-tale O, N and S emission lines in the visible part of the spectrum. These can be used as diagnostics to probe the physical nature of the different emission clouds.

Drinkwater et al (2001) find no distinct class of star-forming BCD galaxies but instead observe Hα emission in dwarf galaxies of all sizes and types. Among these, star-forming dEs like FCC046 may prove to be the descendants of more fiercely star-forming dwarfs like BCDs which are not (or no longer) present in Fornax. As a check, we fitted exponentials to the surface brightness profiles of FCC046 and FCC207 and compared the extrapolated B-band central surface brightnesses and the scale-lengths with those of the Virgo dEs, BCDs, and dIrrs presented in Drinkwater & Hardy (1991). Both galaxies have scale-lengths in between those of BCDs and dEs, and quite high B-band central surface brightnesses compared to the dEs in the Drinkwater & Hardy sample. These results support our conjecture that dEs that contain ionised gas and possibly ongoing low-powered star-formation can be considered as amissable link between BCDs and traditional dEs.

ACKNOWLEDGMENTS

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We thank the anonymous referee for helpful comments. SDR wishes to thank Dr. Victor Debattista for useful comments on the causes of lopsidedness. WWZ acknowledges the support of the Austrian Science Fund (project P14783) and of the Bundesministerium für Bildung, Wissenschaft und Kultur.

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Figure 14. Extrapolated central B-band magnitude, $B_0$, versus scale-length derived by fitting an exponential to the surface brightness profile. Black dots : FCC046 and FCC207, asterisks : BCDs, triangles : dEs, and diamonds : dIrrs.
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