Optical Detection of Star Formation in a Cold Dust Cloud in the Counterjet Direction of Centaurus A

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Abstract

We have identified a set of optical emission-line features 700\'' (12 kpc) to the southwest of the nucleus of Centaurus A, roughly opposite to the radio jet and well-known optical emission filaments associated with the northern radio structure. This location is roughly along the axis of the southwestern radio lobes, although there is no coherent jet at this radius. We use integral-field optical spectroscopy to trace the ratios of strong emission lines, showing changes in excitation across the region, and significant local reddening. The emission regions are spatially associated with far-infrared emission peaks in one of two cold dust clouds identified using Herschel and Spitzer data, and there may be a mismatch between the low temperature of the dust and the expected heating effect of young stars. The strong emission lines have ratios consistent with photoionization in normal H\textsc{ii} regions, requiring only modest numbers of OB stars; these stars and their cooler accompanying populations must be largely obscured along our line of sight. These data fit with a picture of fairly ordinary formation of clusters in a large giant molecular cloud, or network of such clouds. The location, projected near the radio-source axis and within the radius where a starburst wind has been inferred on the other side of the galaxy, raises the question of whether this star-forming episode was enhanced or indeed triggered by an outflow from the central parts of Centaurus A. However, the level of star formation is normal for the associated cold-gas mass and column density, and optical emission-line ratios and line widths limit the role of shocks on the gas, so any interaction with an outflow, associated either with the radio source or star formation in the gas-rich disk of Centaurus A, can at most have compressed the gas weakly. We speculate that the presence of similar star-forming regions on both sides of the galaxy, contrasted with the difference in the character of the emission-line clouds, reflects the presence of a collimated radio jet to the northeast and perhaps anisotropic escape of ionizing radiation from the AGN as well. In this view, the star formation on the southwestern side of Cen A could be enhanced indirectly via compression by a broad outflow (whether originated by a starburst or AGN), distinct from the radio jet and lobes.

Key words: galaxies: active – galaxies: individual (NGC 5128) – galaxies: star formation

1. Introduction

Centaurus A (NGC 5128), as the nearest galaxy hosting a large double radio source, has long played a special role in our understanding of similar objects. It displays a host of characteristic features observable in unique detail—a large-scale double radio source spanning 600 kpc (e.g., Cooper et al. 1965; Feain et al. 2011; McKinley et al. 2017), radio and X-ray jets on scales up to 3 kpc (Feigelson et al. 1981; Schreier et al. 1981), merger signatures in stars, gas, and dust (Baade & Minkowski 1954; Malin et al. 1983; Quillen et al. 2006; Struve et al. 2010), and optical emission-line features often attributed to interaction between the propagating jet and ambient interstellar medium, generating both shock ionization and star formation.

These emission regions, and possible young stars near the northeastern radio jet, were identified by Blanco et al. (1975); spectroscopy by Osmer (1978) confirmed that both normal H\textsc{ii} regions and bright supergiants were present. Graham & Price (1981) used higher-resolution spectra to show that large “turbulent” velocities in the range 400 km s\(^{-1}\) appear across few-arcsecond scales, well beyond what could be produced in star-forming regions. Data presented by Peterson et al. (1975) show that multiple ionizing mechanisms may be at work, with line ratios in some parts of the first-discovered emission regions having [O\textsc{i}] too strong for ordinary H\textsc{ii} regions ionized by stars. The ionization of the gas in these filaments is complex; Morganti et al. (1991) suggest a dominant role for photoionization by the beamed continuum of a small-scale jet. In contrast, Sutherland et al. (1993) present models showing that the small-scale velocity structure matches shock excitation of the spectral lines; Chandra X-ray data analyzed by Evans & Koratkar (2004) support this through showing very hot gas along one side of the most prominent filament. Rejkuba et al. (2002) used color–magnitude diagrams to local young supergiant stars; comparison of their locations to the ionized gas structure provides additional evidence for multiple ionizing mechanisms, while a deeper Hubble Space Telescope analysis by Crockett et al. (2012) makes this case more stringently in the brightest emission region.

Santoro et al. (2015) show that the dynamics of ionized gas in the prominent filaments are consistent with the ambient H\textsc{i} clouds, including components in regular rotation about the galaxy as well as being entrained by the radio jet. Additional MUSE observations by Santoro et al. (2016) show that even on small scales in these filaments, there is a changing mix of ionization mechanisms, with embedded star formation and
photoionization by the distant AGN both indicated by emission-line ratios. McKinley et al.
(2017) suggest that a newly identified northeastern emission-line filament, oriented
perpendicular to the jet axis, may result from interaction with a wind rather than a collimated jet, and speculate that the southwestern jet may not intersect suitable cold gas to produce
similar effects in the “counterjet” direction. Neff et al. (2015) reach similar conclusions for the ionization of yet fainter and more distant emission features detected both in Hα and in a far-UV band, another part of what Neff et al. (2015) and McKinley et al. (2017) refer to as a “weather system” due to the complex
multiphase behavior of the ISM.

As part of a study of these emission features, we have found an emission-line feature along the southwestern “counterjet” direction, which seems to have been previously unremarked.7

We present here morphological and spectroscopic observations of this southwestern emission-line region, abbreviated SWELR, which appears to consist of (possibly multiple) H II regions powered by young stars. The Hα emission is spatially
coincident with the peaks of the cold dust feature found by Auld et al. (2012) from Herschel observations and accompanying cold-gas tracers, furnishing an interesting puzzle as to how a star-forming region coexists with the dust without generating a higher temperature than observed.

Figure 1 presents a schematic overview of some relevant components of Centaurus A: the inner radio structure, Hα disk, H I and FIR-detected dust clouds outside the inner disk, and optical emission features associated with the northern jet.

The radio structure does not have a distinct counterpart to the
northern jet (or the “Northern Middle Lobe”) on the southern side at this distance. The regions we observe fall in a minimum in radio flux between inner and outer lobes (Junkes et al. 1993) and well away from where an interpolated jet axis would lie, making direct interaction with a jet unlikely.

In computing sizes and luminosities, we adopt a distance 3.7 Mpc (scale 17.9 pc arcsec−1), following the Cepheid results of Tully et al. (2013) and the red-giant studies from, e.g., Crnojević et al. (2013) and Tully et al. (2015).

2. Observations

2.1. Identification and Optical Imaging

The southwest emission-line region (SWELR) was identified in 2014 May using an Hα filter of FWHM 75 Å on the remotely operated SARA 0.6 m telescope at Cerro Tololo, Chile (Keel et al. 2017). A CCD system supplied by ARC of San Diego operated at −110 C; the pixel scale was 0″/38. We coadded images totaling 7 hr integration in this filter, and 70 minutes of continuum imaging in the R band, obtained between 2014 May and August. Flux calibration used Landolt (2009) standard stars, carried to the narrow filter using the ratio of filter widths. The narrowband image (Figure 2) shows a set of diffuse Hα emission regions, and two starlike objects with strong residual Hα flux after continuum subtraction using the R image. Color terms in this subtraction will be modest, because Hα is near the center of the R band. The image gives a total Hα

Figure 1. Schematic comparison of relevant structures in the inner part of Centaurus A. Radio continuum features (inner lobes and northern middle lobe) follow the data from McKinley et al. (2017), with the jet track between the northern lobes following Feain et al. (2011); there is no southern counterpart to the northern middle lobe. Cold dust features are taken from Auld et al.; emission-line features are shown from the data in this work; the newly identified southwest emission region is denoted SWELR. H I cloud locations are taken from the ATCA data of Struve et al. (2010). The scale of the optical galaxy is indicated by the dashed circle showing its effective radius (Dufour et al. 1979).

7 As this study was in progress, we found that the emission feature appears in the long-exposure, very deep composite image presented by Rolf Olsen at http://www.rolfolseanstrophotography.com/Astrophotography/Centaurus-A-Extreme-Deep-Field/ (also described by McKinley et al. 2017) and is mentioned in his text as possibly related to the jet: “A corresponding faint trace of nebulosity, likely related to the otherwise invisible Southern jet, is also noticeable as a small red smudge on the opposite side of the galaxy core.”

2.2. Optical Spectroscopy

Data cubes in both blue and red grating settings were obtained using the WiFeS integral-field spectrograph (Dopita et al. 2007) at the 2.3 m ANU Advanced Technology Telescope at Siding Spring. The field of view spans 25 × 38″, with 1″ sampling. Simultaneous exposures in the blue (3500–5700 Å)
and red (5400–7000 Å) ranges were obtained on 2016 March 4, for 900 s. The field covered the three southern discrete components, as well as more diffuse emission to their northeast, and the southern edge of the northern component.

Strong, narrow emission lines appear; the mean heliocentric radial velocity is $cz = 773 \pm 6 \text{ km s}^{-1}$ (internal error) for the brightest region, and $759 \pm 21 \text{ km s}^{-1}$ for the fainter one just to its north. These compare to the consensus systemic velocity $547 \text{ km s}^{-1}$ from NED, and more closely the value $\approx 735 \text{ km s}^{-1}$ derived for H I in this region by Schiminovich et al. (1994). We examined the radial-velocity behavior summed along east–west lines, which would most nearly show the H I velocity gradient; within the errors for each summed spectrum, we do not detect any gradient within the SWELR, while noting that the errors likewise allow the ionized gas to share the gradient $\approx 0.6 \text{ km s}^{-1} \text{ arcsec}^{-1}$, increasing to the SW, seen in H I. The beam sizes for both CO and H I are larger than the extent of the SWELR (44″ for CO and 48 × 70″ in H I), so there could well be unresolved velocity structure in the cold gas. While the internal error on the optical velocity of the brightest “main” component formally distinguishes it from the H I value, it is not clear whether this is within the range of potential systematics in the WiFeS reduction.

These observations used the B3000/R7000 grating combination, with nominal resolutions 1.6 Å in the blue and 0.9 Å at Hα. All the emission lines are narrow, close to the instrumental resolution, which is well-measured at 0.96 Å near Hα by Dopita et al. (2017). Correcting for the spectrograph resolution with simple Gaussian quadrature, Hα FWHM values range from 0.87 to 1.52 Å, or 40 to 69 km s$^{-1}$.

The associated continuum is quite faint; even summed over all spatial pixels in the brightest knot, the continuum S/N is only 0.9 per 0.77-Å pixel at 5000 Å and 1.2 per 0.44-Å pixel near Hα. This limits what we can learn about associated starlight. In measuring the Balmer emission lines, we therefore consider the full range of plausible corrections for absorption in young stellar populations. While Hα absorption in old populations is weak, with equivalent with near 2 Å it can be as strong as 12 Å in type A stars (Jacoby et al. 1984). Corresponding value for Hβ are 4–16 Å. Since the line emission has large equivalent widths, we include the ranges in these corrections in our uncertainties on Balmer decrement, other ratios involving these Balmer lines, and reddening. Error contributions from noise were evaluated from empty continuum regions near various emission lines. We follow Santoro et al. (2016) in converting from Balmer decrements to reddening values and Hα extinction, which include both foreground Milky Way and internal contributions. The effect of Milky Way dust is significant in this direction, with $A(H\alpha) = 0.25 \text{ mag}$ from the results of Schlafly & Finkbeiner (2011); Hα fluxes in each region are listed both as observed ($F$) and including this correction ($F_0$) in Table 2. Emission-line ratios and luminosities listed there include this correction for foreground reddening. Internal attenuation is dominant in each of the three regions where we can measure the Balmer decrement, with $E(B–V)$ ranging from 0.45 to 1.16, and Hα

| Component | α (J2000) | δ (J2000) |
|-----------|-----------|-----------|
| Main      | 13 24 35.224 | −43 09 09.5 |
| Main N    | 13 24 35.186 | −43 09 06.5 |
| Duffuse   | 13 24 35.636 | −43 09 06.9 |
| North     | 13 24 36.192 | −43 08 52.2 |
| Starlike Emission Objects: | | |
|           | 13 24 41.371 | −43 07 29.8 |
|           | 13 24 44.032 | −43 07 03.7 |

**Figure 2.** SARA Hα+[N II] (left) and R (center) images of the southwestern field in Centaurus A. The third panel shows a continuum-subtracted version, smoothed with a 3-pixel (1.72) Gaussian; approximate PSF matching was done by convolving the R images with a Gaussian of 1.6 FWHM, but residuals appear in the cores of bright stars. The boxed features are essentially pure line emission. Two starlike objects to their northeast have significant residual flux in Hα, but may be foreground stars. Each panel spans 178 × 266”, with north at the top. The nucleus of Centaurus A lies about 700″ to the upper left. Faint diffuse streaks to the north in the Hα and difference images are scattered light from a 9th mag star.
extinction from 1.1 to 1.9 mag. The tabulated Hα luminosities are corrected for both foreground Milky Way and internal extinction, based on the Balmer decrement.

### 3. Discussion

#### 3.1. Relation to Cold Dust Cloud and Neutral Gas

Figure 3 overlays the Hα on-band image with contours of a Spitzer 24 μm MIPS observation described by Brookes et al. (2006), Auld et al. (2012) showed that the cloud was clearly detected at this wavelength, where angular resolution is better than the longer-wavelength data from either Spitzer or Herschel. The two emission-line peaks are closely associated with the 24 μm peak locations. There are no similar Hα or 24 μm features within ≈30″, leaving little doubt that these are associated physically rather than only along the line of sight. As noted by Auld et al. (2012), the cold dust coincides closely with the highest column-density parts of H I clouds detected far from the central disk of Centaurus A; the lower panel of Figure 3 compared the Hα image to contours of N(H I) from Struve et al. (2010) to show that the SWELR H II regions likewise occur near the H I peak, with N (H I) ≈1.6 × 10^{21} cm⁻² as smoothed over a 15″ beam.

As well as angular coincidence, the radial velocities are closely matched between H II and H I at this location. From Figure 3 of Schiminovich et al. (1994), the peak H I column density occurs at about 735 km s⁻¹, within 40 km s⁻¹ of the optical velocity in the brightest, best-measured part of the SWELR. The ionized gas therefore shares most of the internal motions of the H I (offset 200 km s⁻¹ from systemic).

#### 3.2. Ionizing Sources and Star Formation

To evaluate likely ionization mechanisms, we measured emission-line ratios in four spatial regions (Figure 4), fitting Gaussian profiles and linear baselines, with results given in Table 2. These regions, selected by position and surface brightness, differ significantly in Balmer decrement Hα/Hβ.

All the [Si II] line-ratio values cluster near the low-density limit of $I(λ6717)/I(λ6731)$ = 1.43 (mean of all values 1.49 ± 0.06).

The location of the regions in the BPT line-ratio diagrams (Baldwin et al. 1981), using the revised dividing curves from Kewley et al. (2006), classifies all of them as photoionized by hot stars. This fits with the narrow line widths measure from the WiFeS data, ≤50 km s⁻¹, indicating that shocks fast enough to add significantly to the ionization levels are not important.

These emission regions coincide spatially with the cold dust cloud seen in Herschel data by Auld et al. (2012), who consider limits on the star formation set from the dust temperature and (lack of) associated UV sources. Their highest allowed star formation rate (SFR) is set from the 24 μm flux, 0.00012 $M_\odot$ yr⁻¹. The Galaxy Evolution Explorer near- and far-UV limits are <2 × 10⁻⁴ and <5 × 10⁻⁵ $M_\odot$ yr⁻¹ respectively, indicating that any associated population of young stars must be largely obscured from our point of view.

As a star-forming region, after correction for reddening based on the Balmer decrement, the line emission we detect gives an overall Hα luminosity close to 2 × 10^{38} erg s⁻¹. This is a few times greater than that of the Orion Nebula M42, requiring only a few ionizing stars (<10). To compare with

### Table 2

| Quantity                  | Main            | Main N          | Diffuse         | North           |
|---------------------------|-----------------|-----------------|-----------------|-----------------|
| $F$(Hα) (erg cm⁻² s⁻¹)    | 9.3 × 10⁻¹⁵     | 1.3 × 10⁻¹⁵     | 1.1 × 10⁻¹⁵     | 1.0 × 10⁻¹⁵     |
| $F$(αHα) (erg cm⁻² s⁻¹)   | 1.17 × 10⁻¹⁴    | 1.6 × 10⁻¹⁵     | 1.4 × 10⁻¹⁵     | 1.3 × 10⁻¹⁵     |
| Hα EW (Å)                 | 156 ± 6         | 319 ± 10        | 58 ± 9          | 780 ± 300       |
| [N II] 3658/3658          | 0.28 ± 0.04     | 0.36 ± 0.06     | 0.40 ± 0.13     | 0.44 ± 0.18     |
| [S II] 6717/6731          | 1.53 ± 0.13     | 1.52 ± 0.28     | 1.52 ± 0.18     | 2.0 ± 0.3       |
| [S II] 6717 + 6731/Hα     | 0.18 ± 0.02     | 0.27 ± 0.07     | 0.49 ± 0.10     | 0.25 ± 0.07     |
| [O I] 5354+5375/Hβ       | 0.025 ± 0.006   | 0.018 ± 0.002   | ...             | ...             |
| [O II] 5500/5500          | 0.69 ± 0.10     | 0.60 ± 0.30     | 0.47 ± 0.14     | ...             |
| [O II] 3727 + 3729/[O III] 5007 | 1.8 ± 0.5 | <1.1          | 4.8 ± 1.4       | ...             |
| $E_{B-V}$                 | 6.4 ± 0.7       | 9.8 ± 2.5       | 4.6 ± 0.8       | ...             |
| A(Hα)                     | 1.88 ± 0.18     | 2.91 ± 0.51     | 1.13 ± 0.40     | ...             |
| L(Hα) (erg s⁻¹)           | 1.4 × 10³⁸       | 4.8 × 10³⁷       | 7.2 × 10³⁶       | >2.5 × 10³⁶      |
SFRs in other environments, we follow Kennicutt et al. (2007), comparing luminosities in Hα and at 24 μm to assess the effects of obscuration. Auld et al. (2012) give a total 24 μm luminosity $1.36 \times 10^{39}$ erg s$^{-1}$ for the whole FIR cloud, so if this is all heated by the young population associated with the Hα emission, the IR is energetically dominant. The Kennicutt et al. (2007) prescription gives an effective Hα luminosity for SFR calculations (based on a weighted sum of Hα and 24 μm values and calibrated for disk H II regions in M51) modestly increased to $2.5 \times 10^{39}$ erg s$^{-1}$. This implies a total SFR $2.0 \times 10^{-3}$ $M_\odot$ yr$^{-1}$ (using the calibration from Kennicutt 1998) and a Salpeter initial-mass function. This is an order of magnitude greater than the 24 μm and near-UV limits from Auld et al. (2012), and correspondingly larger than their far-UV limit. This makes sense if the ionizing stars (presumably in clusters) are largely obscured along our line of sight, but the 24 μm flux is still interestingly low to be associated with even a few ionizing stars. One can, for example, picture a geometry in which the dust blocks optical and UV light over only a small solid angle about the stars, but still hides them from our direction.

For individual star-forming regions, the relation between long-term SFR and tracers of massive stars, such as Hα, has a strong stochastic element. For example, using the stellar-atmosphere results from Vacca et al. (1996) and Sterberg et al. (2003) as in Gil de Paz et al. (2005) shows that the expected Hα luminosities from nebulae completely encompassing the star range from $2 \times 10^{38}$ erg s$^{-1}$ at spectral type B0 to $10^{38}$ erg s$^{-1}$ at O3. The entire ionizing flux in this complex could be provided by the equivalent of 9 O7 stars, so small number statistics would change the emission-line output strongly as individual stars are formed and evolve. Even so, there may be more to learn; the levels of IR emission from Auld et al. (2012) are quite low in comparison to the SFR inferred from Hα emission, a mismatch which may have the kind of geometric solution noted above.

The associated dust cloud matches one of the two regions in the H I “shells” of Centaurus A where Charmandaris et al. (2000) detected CO emission, implying a typical H2/H1 ratio near unity and consistent with conditions for star formation in the inner regions of spirals. With an estimated H2 mass $2 \times 10^7 M_\odot$, and linear scale ≈0.5 kpc, this would be either an exceptionally large giant molecular cloud or a collection of more usual clouds (noting that geometrically it may not be easy to distinguish these cases). Under these conditions, it would be common for parts of a “blister” H II regions to be highly obscured in the optical unless viewed face-on, which fits with the low UV limits on radiation from young stars.

In Hα luminosity and Balmer decrement, these star-forming regions are similar to those found embedded in the northeastern filaments (in what is sometimes known as the “necklace” structure) by Santoro et al. (2016). In comparison with the Santoro et al. (2016) regions, these are comparable in scale and observed luminosity, although perhaps more luminous when dereddened (Figure 5). We might speculate that in both cases, interaction with a central outflow has compressed ambient H I to trigger star formation, but that the southwestern structure lacks the additional ingredients of a direct view of the AGN and a collimated radio jet which enhance both effects in the gas kinematics and ionization on the “jet” side.

### 3.3. Star Formation and Cold Gas—Triggering or Happenstance?

The widely used Schmidt–Kennicutt relation between surface densities of cold gas and of star formation (e.g., Kennicutt 1998) provides a reference prescription to estimate the “expected” level of star formation associated with cold gas (typically H1 +H2). However, it will break down on sub-kiloparsec scales, due to the stochastic nature of star formation (Feldmann et al. 2012), finite scales of molecular clouds (Calzetti et al. 2012), and physical differences in location of dense gas and young stars as the stars exercise feedback on...
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Figure 6. SARA Hα+[N II ] image mosaic showing the newly described H II regions (SWELR) in a wider context including the core of Centaurus A. The continuum has been subtracted using an R-band image, leaving some residuals around bright stars. The prominent disk of emission around the nucleus extends to a radius 212", while the southwest knots are 700" away. Additional emission-line regions outside the central disk are circled to distinguish the from stellar residuals; no others are found near the SWELR within these fields.

their surroundings. With these limitations in mind in examining a region less than 500 pc in size, we can ask how the SFR in the SWELR compares to the gas density and thus whether the star formation or gas density has been externally influenced. Near the SWELR, column densities of both CO and H I are available averaged over large beams; following Charmandaris et al. (2000), updated with the ATCA H I data from Struve et al. (2010), their combined surface mass density is about 40 \( M_\odot \) pc\(^{-2}\). If, for example, the SFR is considered over a 250 \( \times \) 500 pc region encompassing the emission features, the Kennicutt (1998) relation suggests a total SFR 0.004 \( M_\odot \) yr\(^{-1}\) using a Salpeter initial-mass function. While this is about twice the SFR estimated from H\(\alpha\) and 24 \( \mu \)m luminosities, given the substantial uncertainties introduced by (at least) the differing resolutions at which gas densities and ionization are measured, it is notable that the values are close. The comparison therefore furnishes no evidence that star formation was triggered given the presence of the cold gas to begin with.

On the other hand, the greatest densities of H I outside the central disk are roughly along the jet axis, even to the southwest where there is no collimated radio jet at the relevant radius. Available CO data were targeted at these same regions, so the presence of gas at similar column densities is not an independent tracer. These properties together could suggest that compression of the gas, associated with the radio plasma or more widely with a starburst wind, influences the gas properties and indirectly the location (if not rate) of star formation far from the core.

4. Summary

We have described a set of optical emission-line regions found 12 kpc to the southwest of the nucleus of Centaurus A, closely coincident with dust and gas structures previously reported. The emission-line ratios as well as UV and FIR properties are well accommodated as a set of normal H II regions, photoionized by only a few OB stars.

Even in a system as disturbed as Centaurus A, this is a distant place to find apparently normal H II regions. Figure 6 shows the location superimposed on an H\(\alpha\) image of the inner regions, where the rich distribution of star-forming regions is strongly confined to the warped remnant disk, within a radius of 212" (3.8 kpc). Charmandaris et al. (2000) suggest that an outflow from the central regions of the system has played a role in compressing gas (possibly concentrated dynamically in a way similar to the stellar shells) so as to trigger such distant star formation. On this basis, we might speculate that star formation can be triggered by a broad outflow (driven either by the AGN or strong star formation in the inner disk), but the southwest region lacks the additional factors producing the rich optical emission along the north jet. Since the level of star formation in the SWELR is not unusual for its cold-gas mass, such triggering must be indirect—for example, in compressing gas already present, which in turn could be amplified by increasingly effective collisional cooling as compression proceeds.

The striking asymmetry between emission-line and star-forming complexes on the two sides of Centaurus A could result from the absence of a collimated radio jet on the southwestern side, misalignment of the southwestern complex of gas and dust with the implied cone of escape for ionizing AGN radiation, or indeed inability of ionizing radiation from the AGN to escape effectively on this whole side. A contribution from mechanical interaction with the radio jet (or surrounding cocoon) may be suggested by the contrast in kinematics between the SWELR, with relatively small internal Doppler motions, and the chain of emission-line filaments on the northeastern side, where large “turbulent” line widths
≈400 km s\(^{-1}\) are present on small linear scales (Morganti et al. 1999; Santoro et al. 2016). Morganti et al. (1999) argue that these line widths, plus the distance between the radio jet and emission filaments, indicate that the connection is indirect, perhaps via disruption of a cocoon or bubble around the jet as the interstellar medium responds to its passage.

Further study that could improve our understanding of these aspects of the Centaurus A system would include high-resolution mapping of the structure and kinematics of cold gas on both sides of the galaxy, and a census of young stars in the southwestern region that could reveal the history of star formation.

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