Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY LETTERS

Mon. Not. R. Astron. Soc. **403,** L26–L30 (2010) doi:10.1111/j.1745-3933.2009.00808.x

Diffuse far-infrared and ultraviolet emission in the NGC 4435/4438 system: tidal stream or Galactic cirrus?

L. Cortese,[1★] G. J. Bendo,[2] K. G. Isaak,[1] J. I. Davies[1] and B. R. Kent[3]

[1]*School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA*
[2]*Astrophysics Group, Imperial College London, Blackett Laboratory, Prince Consort Road, London SW7 2AZ*
[3]*NRAO, 520 Edgemont Road, Charlottesville, VA 22903, USA*

Accepted 2009 December 23. Received 2009 December 16; in original form 2009 November 10

ABSTRACT

We report the discovery of diffuse far-infrared and far-ultraviolet emission projected near the interacting pair NGC 4435/4438, in the Virgo cluster. This feature spatially coincides with a well-known low surface-brightness optical plume, usually interpreted as tidal debris. If extragalactic, this stream would represent not only one of the clearest examples of intracluster dust, but also a rare case of intracluster molecular hydrogen and large-scale intracluster star formation. However, the ultraviolet, far-infrared, H I and CO emission as well as the dynamics of this feature are extremely unusual for tidal streams but are typical of Galactic cirrus clouds. In support to the cirrus scenario, we show that a strong spatial correlation between far-infrared and far-ultraviolet cirrus emission is observed across the centre of the Virgo cluster, over a scale of several degrees. This study demonstrates how dramatic Galactic cirrus contamination can be, even at optical and ultraviolet wavelengths and at high galactic latitudes. If ignored, the presence of diffuse light scattered by Galactic dust clouds could significantly bias our interpretation of low surface-brightness features and diffuse light observed around galaxies and in clusters of galaxies.

Key words: dust, extinction – galaxies: individual: NGC 4435/4438 – galaxies: interactions.

1 INTRODUCTION

The study of the diffuse low surface-brightness light around galaxies and within clusters represents a unique tool for understanding the assembly history of structure in the universe. The detection of faint stellar tails associated with apparently undisturbed systems (McConnachie et al. 2009) and the presence of diffuse light in galaxy clusters (Mihos et al. 2005) are among the clearest pieces of evidence supporting a hierarchical picture of galaxy formation. In the past, the long integration times (and accurate flat-fielding) required to detect faint features have hampered the search for diffuse extragalactic light. In the next few years, with the advent of dedicated deep optical photometric surveys such as Pan-Starrs and the Next Generation Virgo Cluster Survey will we eventually obtain an unprecedented view of the complex low surface-brightness universe, reaching very high sensitivities ($\mu \gtrsim 28$ mag arcsec^{-2}). The main challenge for future investigations will likely be discriminating between extragalactic emission and scattered light from Galactic cirrus. At low surface brightness ($\mu_B \gtrsim 27$ mag arcsec^{-2}), scattered light from cirrus dust clouds is clearly detected at optical wavelengths even at high galactic latitude (e.g. Guhathakurta & Tyson 1989). This might be erroneously interpreted as tidal debris or intracluster light. To show how difficult it is to discriminate between extragalactic and Galactic low surface-brightness features, here we present the properties of a plume projected near the NGC 4435/4438 pair in the Virgo cluster. This plume is usually interpreted as a tidal stream (Mihos et al. 2005).

NGC 4438 (Arp 120) is the most dramatic example of a tidally disturbed galaxy in the Virgo cluster. Dynamical models suggest that NGC 4438 has been perturbed by a high-velocity ($\sim$800 km s^{-1}) interaction with the companion S0 NGC 4435 (e.g. Vollmer et al. 2005). However, recent Hα observations favour a different scenario in which NGC 4438 has collided with the giant elliptical galaxy M86 (Kenney et al. 2008). Deep optical investigations (Mihos et al. 2005) also reveal the presence of a faint stellar plume apparently extending from NGC 4435. This feature has been interpreted in the past as a tidal debris, but it is not clear how it would fit into the NGC 4438–M86 interaction scenario. In this Letter, we show that the multiwavelength properties of the optical plume are more similar to Galactic cirrus clouds than to tidal debris and that this feature might not be associated with the NGC 4435/4438 system at all.

2 THE DATA

Spitzer observations. We obtained *Spitzer* MIPS 24, 70 and 160 μm observations of the NGC 4435/4438 system from the Spitzer

★E-mail: luca.cortese@astro.cf.ac.uk

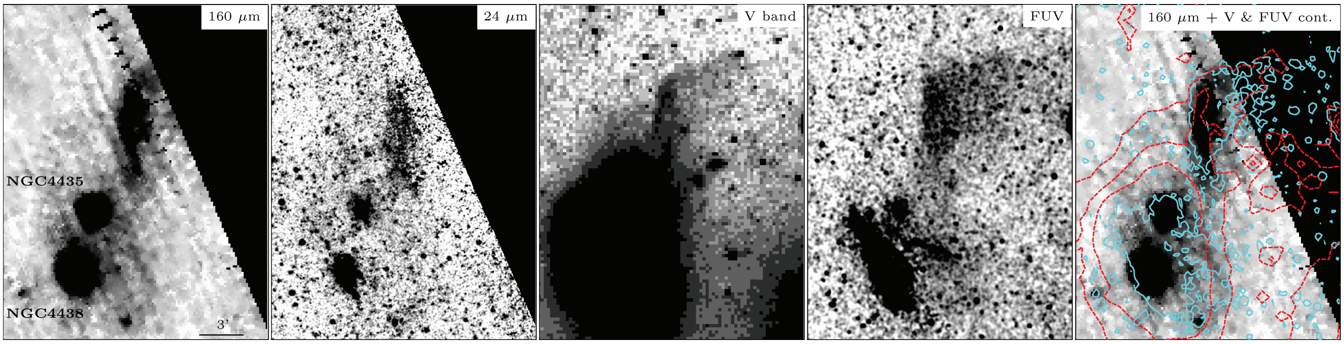

Figure 1. From left to right, the *Spitzer* MIPS 160 μm, 24 μm, *V*-band (Mihos et al. 2005) and *GALEX*-FUV images are shown. In the right-hand panel, the optical (dashed red) and FUV (solid cyan) contours are superposed to the 160 μm. The contour levels are 25.5, 26.5, 27.5 mag arcsec^{-2} and 29.8 AB mag arcsec^{-2} in *V* and FUV, respectively. The 24 μm and FUV images have been smoothed using a Gaussian filter with $\sigma = 3$ pixels in order to make the plume more visible.

Science Archive. These data are all scan maps taken as part of a single proposal (P30945). The image frames were created using the MIPS Data Analysis Tools (Gordon et al. 2005) version 3.10 and using the same technique described in Bendo et al. (2009). The rms in the final maps are 0.037, 0.38 and 0.39 MJy sr^{-1} at 24, 70 and 160 μm, respectively. The full widths at half-maximum (FWHM) of the point spread functions (PSFs) are 6, 18 and 38 arcsec at 24, 70 and 160 μm, respectively.

Ultraviolet imaging. The *Galaxy Evolution Explorer* (*GALEX*) has observed the NGC 4435/4438 system in both near-ultraviolet (NUV; $\lambda = 2316$ Å, $\Delta\lambda = 1069$ Å) and far-ultraviolet (FUV; $\lambda = 1539$ Å, $\Delta\lambda = 442$ Å) bands, as part of the Nearby Galaxy Survey. Two different tiles include the two galaxies and the stellar tail. We downloaded the final intensity maps from the MAST archive (GR4/5) and coadded them, reaching a total exposure time of 7628.35 and 2967.8 s in the NUV and FUV bands, respectively. The spatial resolution of the final images is ∼5 arcsec. Details about the *GALEX* pipeline can be found in Morrissey et al. (2007).

Single-dish 21 cm H I line data. Single-dish H I observations of the NGC 4435/4438 system were obtained as part of the Arecibo Legacy Fast ALFA (ALFALFA) survey (Giovanelli et al. 2005). The data set used here comes from the first ALFALFA data release (Giovanelli et al. 2007), covering the centre of the Virgo cluster. The total integration time is 48 s beam^{-1}, providing an rms of ∼2.2 mJy beam^{-1} at a velocity resolution of ∼10 km s^{-1}. The data are gridded into a data cube with 1 arcmin pixels and the spatial resolution is given by the size of the Arecibo beam, 3.3 × 3.8 arcmin^2.

Single-dish CO(2–1) observations. To detect CO(2–1) associated with the stellar tail, we have carried out a pilot observation using the single-pixel A3 receiver (beam width of ∼22 arcsec) at the James Clerk Maxwell Telescope (JCMT[1]). We used the full bandwidth of ∼1.9 GHz ($-500 \lesssim V_\odot \lesssim 1900$ km s^{-1}), thus covering the entire velocity range between NGC 4435 and NGC 4438 (∼800 km s^{-1}), with a velocity resolution of ∼1.3 km s^{-1}. A simple ON-OFF observing technique was adopted. The ON position roughly corresponds to the peak of 160 μm emission in the stream (α_{J2000} = 12:27:30.2, δ_{J2000} = +13:12:29), while the OFF position was accurately chosen in order to avoid any possible contamination from Galactic emission. Data were reduced using the Starlink data reduction packages (KAPPA and SMURF). Individual spectra were inspected and then coadded to produce a final spectrum with a total on-source integration time of 1347 s. The rms on the final baseline-subtracted spectrum is ∼0.018°K (expressed in antenna temperature).

[1]The James Clerk Maxwell Telescope is operated by The Joint Astronomy Centre on behalf of the Science and Technology Facilities Council of the United Kingdom, the Netherlands Organization for Scientific Research and the National Research Council of Canada.

3 RESULTS

In Fig. 1, we compare the *Spitzer* 24 and 160 μm images, the *GALEX* FUV image and the deep *V*-band image obtained by Mihos et al. (2005) for the NGC 4435/4438 system. They clearly reveal the presence of FIR and FUV diffuse emission associated with the low surface-brightness ($\mu_V \sim 26.5$–28 mag arcsec^{-2}) optical plume to the north/northwest of NGC 4435 originally discovered by Malin (1994). While the MIPS field of view only includes the brightest part of this feature (close to NGC 4435), the larger area covered by *GALEX* allows us to trace the whole extent of the stream out to a distance of ∼13 arcmin from NGC 4435. The plume has an unusual L-shaped (or triangular) morphology, with abrupt and well-defined edges to the east and north. No resolved sources (e.g. star-forming knots) are visible in the plume.

Interestingly, we first noticed the presence of diffuse emission in the *Spitzer* images, where the intensity of this feature is particularly high: ∼1.5–5 and ∼0.05–0.08 MJy sr^{-1} at 160 and 24 μm, respectively. A detailed inspection of *IRAS* images reveals that the plume is marginally visible in the 100 μm image, although the lower spatial resolution of *IRAS* made it impossible to clearly associate the plume with the NGC 4435/4438 system. No emission is detected at 70 μm, implying a 3σ upper limit of ∼1.14 MJy sr^{-1}. The *GALEX* data reveal that the plume is really evident in FUV ($\mu_{FUV} \sim 29$ AB mag arcsec^{-2}), whereas in NUV it is only very marginally detected at a surface-brightness level of $\mu_{NUV} \sim 29.2$ AB mag arcsec^{-2}.

In addition to dust and stars, this feature also appears to contain a significant amount of atomic hydrogen and CO. Using the Very Large Array (VLA), Hota et al. (2007) detected H I emission associated with the brightest part of the plume. Intriguingly, the H I has a low recessional velocity (∼ −9.5 km s^{-1}, for a velocity resolution of 20.7 km s^{-1}) and a narrow velocity width (<40 km s^{-1}). Unfortunately, the northern and eastern edges of the tail were too close to the half-power of the VLA primary beam to be detected. Thanks to the higher sensitivity, velocity resolution and larger field of view of ALFALFA observations, we are now able to fill this gap and to characterize in more detail the H I properties of this plume. By inspecting the cube through a velocity range

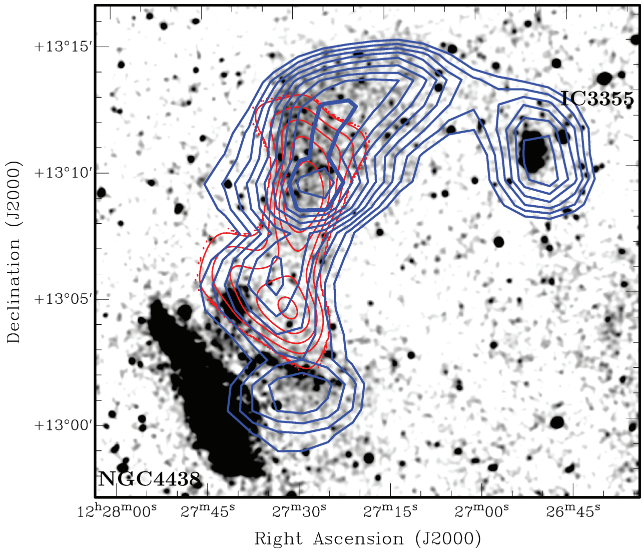

Figure 2. The H I contours of the plume superposed on the FUV image. The blue contours show the H I emission detected by ALFALFA (including diffuse Galactic H I) across the heliocentric velocity range $-9.2 < V_\odot < -19.5\,\mathrm{km\,s^{-1}}$. Contours levels are 7.2–8.2 Jy km s^{-1} beam^{-1}, in steps of 0.1 Jy km s^{-1} beam^{-1}. As discussed in Section 3, the net H I intensity of the plume has been obtained by performing a median subtraction of the Galactic emission around the feature. For comparison, the VLA contours of the tail published by Hota et al. (2007) are shown in red. We note that part of the H I associated with NGC 4438 and IC 3355 is not visible given the narrow velocity range investigated here.

$-200 < V < 1000\,\mathrm{km\,s^{-1}}$ (i.e. the typical interval expected if the plume is related to the NGC 4435/4438 system), we confirm that the only H I emission clearly associated with the optical plume has a heliocentric velocity $V_\odot = -15 \pm 4\,\mathrm{km\,s^{-1}}$ and a width $W_{50} = 5 \pm 7\,\mathrm{km\,s^{-1}}$. In Fig. 2, the ALFALFA and Hota et al. (2007) H I contours are superposed to the FUV image of the NGC 4435/4438 system. While the two data sets fairly agree in the overlapping region, the ALFALFA observations are able to trace the H I along the whole extent of the plume, showing a good match between the H I and FUV morphology of this feature. To estimate its net H I intensity, we performed a median subtraction of the Galactic emission around the plume. The net flux density varies in the range of 0.6–1.2 Jy km s^{-1} beam^{-1}. Assuming that the H I fills the Arecibo beam, this can be translated into a column density of ~1.5–3 × 10^{19} cm^{-2} (see also Hota et al. 2007). The integrated H I spectrum of the plume[2] is shown in Fig. 3. The peak and absorption features on either side of the detection are residual artefacts of the sky subtraction based on the median values in the selected channels. The recessional and velocity widths of the plume are confirmed, and even better constrained, by our CO(2–1) observations, as shown in Fig. 3. CO(2–1) emission is clearly detected (peak signal-to-noise ratio of ~20) at a heliocentric velocity $V_\odot = -13.9 \pm 0.1\,\mathrm{km\,s^{-1}}$ and with an FWHM = $1.5 \pm 0.2\,\mathrm{km\,s^{-1}}$.

In summary, the plume shows emission coming not only from stars and atomic hydrogen but also from dust and CO, emerging as an almost unique feature in the panorama of low surface-brightness streams and tails discovered so far in the Virgo cluster.

[2]We only considered the main H I feature visible in Fig. 2, i.e. the one clearly associated with the optical, UV and FIR plume.

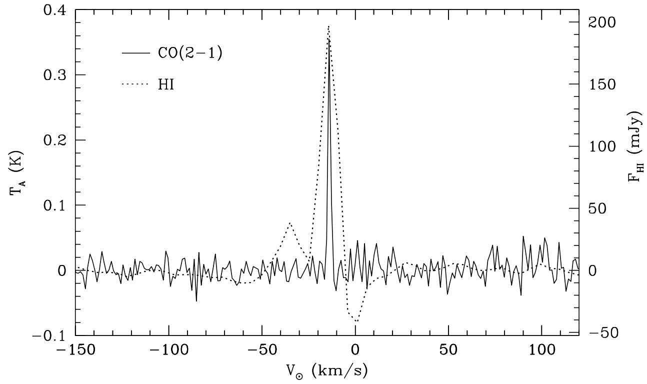

Figure 3. The single-pointing CO(2–1) (solid line) and integrated H I (dotted line) spectrum of the plume.

4 DISCUSSION

What is the nature of this plume? Is it really a tidal stream associated with the NGC 4435/4438 system? If extragalactic, it would represent an extremely rare example of intracluster dust and molecular hydrogen stripped by gravitational interactions. However, the multiwavelength properties of this feature demand a little bit of attention before one can interpret it as a tidal feature. This is particularly true since the plume is detected in FIR, where the contamination from foreground Galactic cirrus emission might be significant, if not dominant. In the following, we investigate the two possible scenarios (tidal stream and Galactic cirrus) in order to unveil the most likely origin of this feature.

4.1 The tidal scenario

If at the distance of the Virgo cluster (16.5 Mpc; Mei et al. 2007), the plume would have a physical size of ~33 kpc (in both right ascension and declination), extending up to ~70 kpc from NGC 4438. Its H I and CO recessional velocities (~ −14 km s^{-1}) are roughly consistent with the H I velocity of NGC 4438 ($V_\odot = 104 \pm 2$ and $W_{50} = 244 \pm 5\,\mathrm{km\,s^{-1}}$; Giovanelli et al. 2007) but significantly different from the redshift of NGC 4435 ($V \sim 801\,\mathrm{km\,s^{-1}}$). This apparently rules out a gravitational interaction between NGC 4438 and NGC 4435: given their large velocity difference, we should expect the stripping material to lie at a velocity intermediate between the two systems.

The plume apparently connects NGC 4438 to the dwarf irregular galaxy IC 3355 ($V \sim -17\,\mathrm{km\,s^{-1}}$; Gavazzi et al. 2003), perhaps suggesting a recent interaction between the two systems. This seems supported by the presence of a H I tail associated with IC 3355 (Chung et al. 2009). However, contrary to what is expected in the case of a fly-by encounter with NGC 4438, IC 3355's tail points to the west, thus in the opposite direction with respect to NGC 4438. Moreover, it is still unclear whether or not IC 3355 is really a member of the M86 cloud (Chung et al. 2009). Thus, although we cannot exclude that IC 3355 is playing a role, the current data do not allow us to further investigate this hypothesis.

A more plausible scenario is that the plume has been created during the collision between NGC 4438 and M86 ($V \sim -244\,\mathrm{km\,s^{-1}}$) as recently unveiled by Kenney et al. (2008). A complex structure of Hα filaments connects the two galaxies and spans a velocity range ($-240 < V < +70\,\mathrm{km\,s^{-1}}$) consistent with the value observed in the plume. Moreover, the morphology of our feature (i.e. well-defined edges on the east with less clear boundaries on the west side) would be consistent with the direction of motion of NGC 4438, from west to east. The time-scale of the interaction is ∼100 Myr (Kenney et al. 2008), significantly shorter than the dust sputtering time-scale expected at the position of NGC 4438 (∼10^8 yr; Popescu et al. 2000). Thus, although extremely unusual, the presence of dust in the tail does not rule out the tidal scenario.

However, not all the properties of the plume are entirely consistent with a gravitation interaction. Above all, its velocity width (∼2–5 km s^{-1}) is significantly smaller than the typical values (≥20 km s^{-1}) observed in tidal tails, candidate tidal-dwarf galaxies, isolated H I clouds and ram-pressure-stripped material (e.g. Hibbard et al. 2001; Oosterloo & van Gorkom 2005; Kent et al. 2007). Although we cannot exclude that the cloud is seen 'face-on', we consider this to be unlikely. The presence of a clear velocity gradient in the Hα filaments between M86 and NGC 4438 (Kenney et al. 2008) suggests in fact that the tidal acceleration is not parallel to the plane of sky. Moreover, it is difficult to imagine how a violent process such as a tidal interaction would be able to strip material along a well-defined direction and to keep the velocity dispersion of the H I cloud so small. It is therefore unclear how tidal debris can maintain such small velocity spread on a scale of a few tens of kpc.

Equally unusual are the UV properties of the tail. The FUV emission is in fact diffuse and not patchy with star-forming knots as observed in star-forming discs, tidal tails and extended UV discs (e.g. Thilker et al. 2007). Extraplanar diffuse UV emission is often interpreted as being due to light scattered by diffuse dust, in particular when associated with the haloes of starburst galaxies (such as M82; Hoopes et al. 2005). Although the *Spitzer* images reveal that dust is surely present in the plume, the lack of a powerful central starburst and the large distance of the tail from any strong radiation source apparently exclude the scattering scenario. Thus, if extragalactic, the FUV emission must come from young stars in the plume. The absence of star-forming knots and Hα emission (Kenney et al. 2008) implies an age between ∼10 Myr (i.e. the lifetime of OB associations emitting in Hα) and ∼25 Myr (i.e. the lifetime of B stars, supposed to be responsible for the diffuse UV light in galactic discs; Pellerin et al. 2007), significantly shorter than the time-scale of the interaction but consistent with the age of the UV tidal tail to the west of NGC 4438 discovered by Boselli et al. (2005). This might suggest that the plume has just entered a post-starburst phase, consistent with the fact that its colour is significantly bluer than the observed colour of NGC 4438 ($FUV - V \sim 5.2$ mag; Gil de Paz et al. 2007). However, if this is really the case, it remains unclear to us why the plume stopped forming stars. The very low-velocity dispersion, the large amount of H I and the presence of molecular hydrogen should allow the cloud to continue forming stars. Moreover, the fact that CO is usually associated with dense star-forming regions, even in tidal tails and stripped clouds (Lisenfeld et al. 2004), makes the post-starburst scenario unlikely.

4.2 The Galactic cirrus hypothesis

A completely different possibility is that the plume is in reality a Galactic cirrus cloud of gas and dust just superposed by chance near NGC 4435. In this case, the diffuse FUV and optical emission would come from light scattered by the dust grains in the cloud.

Before testing the cirrus hypothesis in detail, it is worthwhile to examine the probability of a cirrus cloud appearing superimposed in front of the Virgo cluster. Despite its high Galactic latitude ($b \sim 75°$), the centre of Virgo lies in a region that is significantly contaminated by cirrus emission. A ring-like cirrus structure centred near M87 and extending over several degrees (Brosch et al. 1999) is clearly visible in the *IRAS* 100 μm images (see Fig. 4, right). Since scattered light is often associated with cirrus clouds (e.g. Guhathakurta & Tyson 1989), we should expect to see the same ring at both UV and optical wavelengths, though only at very low surface brightness ($\mu_B \sim$ 27–28 mag arcsec^{-2}). While deep optical data of the whole Virgo region are not available, the deep and wide *GALEX* coverage of the Virgo cluster makes it possible to test this hypothesis. We thus combined all the available *GALEX* pointings near the centre of Virgo having FUV exposure time longer than 800 s. The mosaic is shown in the left-hand panel of Fig. 4, and it likely represents the

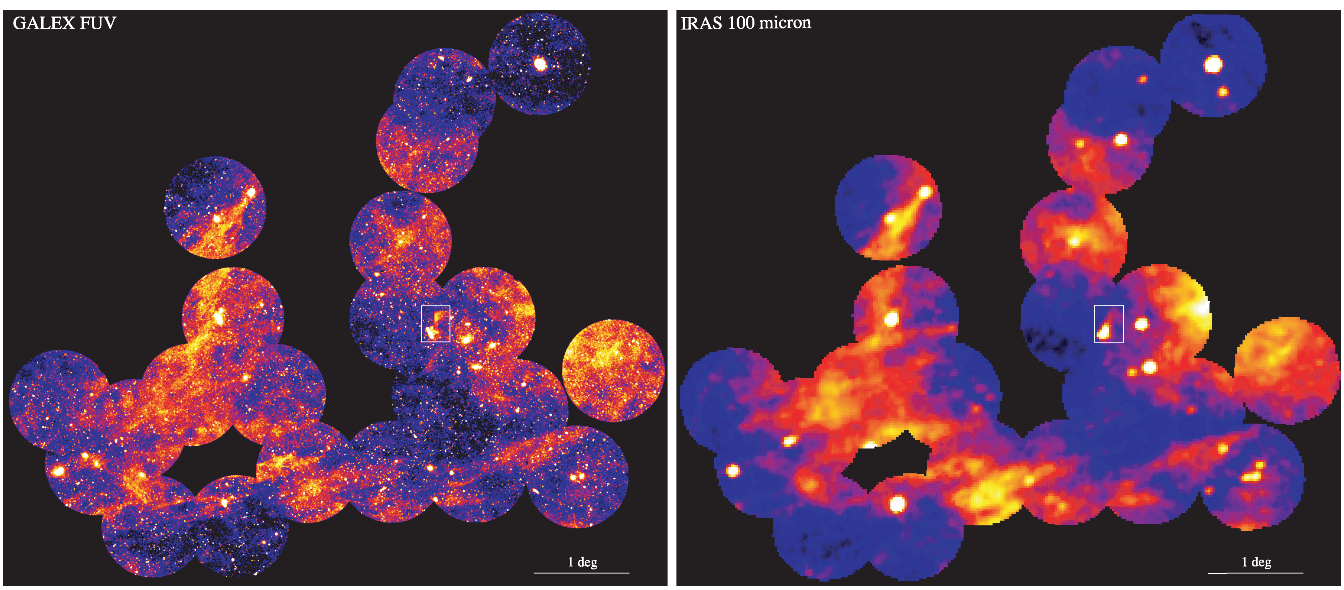

Figure 4. The Virgo cluster region as seen in FUV (left) and 100 μm (right). The region shown in Fig. 1 is indicated by the white rectangle. The FUV mosaic has been smoothed using a Gaussian filter with $\sigma = 9$ pixels in order to highlight the diffuse cirrus emission.

highest resolution large-scale map of FUV cirrus emission made to date. It clearly illustrates the presence of diffuse FUV emission tracing the distribution of FIR Galactic cirrus emission. In addition, the high spatial resolution of *GALEX* allow us to see for the first time the detailed structure of the cirrus clouds. In order to quantify the correlation between FUV and FIR diffuse emission, we first removed all sources detected by SExtractor (Bertin & Arnouts 1996) and then smoothed the UV images to the resolution of the 'point-source free' Schlegel, Finkbeiner & Davis (1998) *IRAS* map (∼6 arcmin) by applying a Gaussian filter. The Pearson correlation coefficient between the FIR and UV intensity in each pixel ($142 \times 142\,\mathrm{arcsec}^2$) is ∼0.82, consistent with the range of values obtained by previous analysis of cirrus clouds (e.g. Haikala et al. 1995; Sasseen & Deharveng 1996). Thus, there is a reasonably high probability of detecting diffuse scattered FUV (and perhaps also optical) light associated with cirrus emission in the direction of the Virgo cluster.

More direct support to the cirrus hypothesis is provided by the properties of the plume. Its negative recessional velocity, narrow velocity width and H I column density are completely consistent with what is observed in Galactic low-velocity clouds (e.g. Stanimirović et al. 2006). In addition, the presence of CO emission (and thus of molecular hydrogen) is commonly observed in cirrus clouds (Reach, Wall & Odegard 1998).

Several studies have shown that there is a good correlation between the 100 μm FIR intensity and the H I column density of cirrus clouds, e.g. $I(100\,\mu\mathrm{m})/N(\mathrm{H\,I}) \sim 0.5\text{–}3\,\mathrm{MJy\,sr^{-1}}/10^{20}\,\mathrm{cm}^2$ (Boulanger et al. 1996). At 160 μm, the FIR-to-H I ratio of the plume is $\sim 10\,\mathrm{MJy\,sr^{-1}}/10^{20}\,\mathrm{cm}^2$. Assuming a typical 160-to-100 μm flux ratio of ∼1.5–3 for cirrus clouds (Bot et al. 2009), our feature appears to have a significant FIR excess. This is however not inconsistent with the cirrus hypothesis since Galactic 'FIR excess clouds' are not rare at high Galactic latitudes and, as observed in this case, they are usually associated with significant CO emission (Reach et al. 1998). Thus, the FIR-to-H I ratio does not allow us to conclusively discriminate between the two proposed scenarios. This is also because our knowledge of the gas and dust content of cirrus is mainly based on studies of physical scales of tens of arcminutes, and it is not yet clear whether we can extrapolate them to the physical scale of the plume.

5 CONCLUSION

In this Letter, we have investigated the multiwavelength properties of the optical plume projected near the NGC 4435/4438 system. It is very tempting to interpret this feature as tidal debris in the Virgo cluster, as this would represent an extraordinary case of intracluster dust and molecular hydrogen as well as large-scale intracluster star formation. However, our analysis reveals that the dynamics, morphology, gas and dust content of this stream are more consistent with what is observed in Galactic cirrus clouds than in tidal features associated with cluster galaxies. Whatever its real origin, this stream is a fascinating object and it clearly highlights how difficult it is to discriminate between Galactic clouds and extragalactic diffuse light. This will be a great challenge for both FIR Herschel surveys and deep optical investigations of the extragalactic sky. Only a detailed characterization of the FUV-to-FIR properties of cirrus at all physical scales might eventually allow us to disentangle between the two different scenarios.

ACKNOWLEDGMENTS

We thank the anonymous referee for useful comments which improved the clarity of this manuscript. We thank Ananda Hota and Chris Mihos for providing us with an electronic version of their data, Iain Coulson for his help in the preparation of the JCMT observations and David Hogg for useful discussions. LC is supported by the UK Science and Technology Facilities Council and KGI by the Research Councils UK. BRK is a Jansky Fellow at the NRAO.

NOTE ADDED IN PROOF

After the acceptance of this paper, we obtained three additional CO(2–1) pointings across the FIR plume. We clearly detected emission in at least two positions. The recessional velocity and velocity width of the CO(2–1) line are perfectly consistent with the values presented in this paper, suggesting that no velocity gradient is present over a scale of ∼1 arcmin. These data will be presented in a future paper.

REFERENCES

Bendo G. J., Wilson C. D., Warren B. E. et al., 2009, MNRAS, in press (arXiv:0911.3369)
Bertin E., Arnouts S., 1996, A&AS, 117, 393
Boselli A., Boissier S., Cortese L. et al., 2005, ApJ, 623, L13
Bot C., Helou G., Boulanger F. et al., 2009, ApJ, 695, 469
Boulanger F., Abergel A., Bernard J.-P. et al., 1996, A&A, 312, 256
Brosch N., Almoznino E., Wszolek B., Rudnicki K., 1999, MNRAS, 308, 651
Chung A. et al., 2009, AJ, 138, 1741
Gavazzi G. et al., 2003, A&A, 400, 451
Gil de Paz A., Boissier S., Madore B. F. et al., 2007, ApJS, 173, 185
Giovanelli R., Haynes M. P., Kent B. R. et al., 2005, AJ, 130, 2598
Giovanelli R., Haynes M. P., Kent B. R. et al., 2007, AJ, 133, 2569
Gordon K. D., Rieke G. H., Engelbracht C. W. et al., 2005, PASP, 117, 503
Guhathakurta P., Tyson J. A., 1989, ApJ, 346, 773
Haikala L. K., Mattila K., Bowyer S. et al., 1995, ApJ, 443, L33
Hibbard J. E., van der Hulst J. M., Barnes J. E., Rich R. M., 2001, AJ, 122, 2969
Hoopes C. G., Heckman T. M., Strickland D. K. et al., 2005, ApJ, 619, L99
Hota A., Saikia D. J., Irwin J. A., 2007, MNRAS, 380, 1009
Kenney J. D. P. et al., 2008, ApJ, 687, L69
Kent B. R., Giovanelli R., Haynes M. P. et al., 2007, ApJ, 665, L15
Lisenfeld U., Braine J., Duc P.-A. et al., 2004, A&A, 426, 471
McConnachie A. W., Irwin M. J., Ibata R. A. et al., 2009, Nat, 461, 66
Malin D., 1994, in MacGillivray H. T., ed., Proc. IAU Symp. 161, Astronomy from Wide-Field Imaging. Kluwer, Dordrecht, p. 567
Mei S., Blakeslee J. P., Côté P. et al., 2007, ApJ, 655, 144
Mihos J. C., Harding P., Feldmeier J., Morrison H., 2005, ApJ, 631, L41
Morrissey P., Conrow T., Barlow T. A. et al., 2007, ApJS, 173, 682
Oosterloo T., van Gorkom J., 2005, A&A, 437, L19
Pellerin A., Meyer M., Harris J., Calzetti D., 2007, ApJ, 658, L87
Popescu C. C., Tuffs R. J., Fischera J., Völk H., 2000, A&A, 354, 480
Reach W. T., Wall W. F., Odegard N., 1998, ApJ, 507, 507
Sasseen T. P., Deharveng J.-M., 1996, ApJ, 469, 691
Schlegel D. J., Finkbeiner D. P., Davis M., 1998, ApJ, 500, 525
Stanimirović S., Putman M., Heiles C. et al., 2006, ApJ, 653, 1210
Thilker D. A., Bianchi L., Meurer G. et al., 2007, ApJS, 173, 538
Vollmer B., Braine J., Combes F., Sofue Y., 2005, A&A, 441, 473

This paper has been typeset from a TEX/LATEX file prepared by the author.