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Diffuse Interstellar Bands in Emission

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Recent Fabry-Pérot observations towards the galaxy NGC 1325 with the Southern African Large Telescope (SALT) led to the serendipitous discovery of an emission feature centered at 661.3 nm arising from material in the interstellar medium (ISM) of our Galaxy; this emission feature lies at the wavelength of one of the sharper and stronger diffuse bands normally seen in absorption. The flux of the feature is $4.2 \pm 0.5 \times 10^{-18}$ e s^{-1} cm^{-2} arc-sec^{-2}. It appears that this is the first observation of emission from a diffuse band carrier in the ISM, excited in this case by the interstellar radiation field. We present the discovery spectra and describe follow-up measurements proposed for SALT.

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1.Introduction

The longest-standing problem in astronomical spectroscopy is the identification of the carriers of the diffuse interstellar absorption bands (DIBs), the first systematically studied examples of which were investigated by Merrill [1] on photographic plates over 80 years ago. Most researchers consider a population of large carbon-based molecules to be responsible for the DIBs (see for example Douglas [2], Léger & d'Hendecourt [3], Kroto et al. [4], and Campbell et al. [5]). Identification of the carriers would open a new probe of interstellar conditions and processes in interstellar clouds and could have implications far beyond - including the role of such molecules in star and planet formation and even for the origins of life. Only one clear-cut example exists where complementary emission (from a subset) of DIBs is seen – in the Red Rectangle nebula – where the emission is excited by radiation from the central star HD 44179 (see Sarre [6], Fossey [7], and Scarrott et al. [8], but questioned by Glinski & Anderson [9]).

2.Observations and Data Reductions

As part of the RINGS (RSS Imaging and spectroscopic Nearby Galaxy Survey) program (Mitchell et al. [10]), we observed the galaxy NGC 1325 (l = 212° b = -55°) on the nights of 01 November 2011 and 28 December 2011, using the Fabry-Pérot (FP) medium resolution mode of the Robert Stobie Spectrograph (RSS) on the Southern African Large Telescope (SALT). On each night we took 23 exposures, each of 60 second duration, covering the spectral range from 658.7 nm to 663.1 nm in equally spaced 0.2 nm steps, to measure the Hα emission from the galaxy. The spectral resolution of each image was 0.4 nm. The images cover the full 8 arc-minute field of view of the telescope. The seeing on the two nights was 1.8 and 2.0 arc-seconds FWHM, respectively. Twilight sky flats were obtained with the spectrograph configured as for the observations, but without the FP etalon. We also observed similar scans for the galaxy NGC 2280 (l = 237° b = -14°) on the same nights.

The RSS medium resolution FP system is designed to operate with two etalons in series, using a lower resolution etalon to block adjacent interference orders of the medium resolution etalon. Full details of the system are given in Rangwala et al. [11]. Mechanical flexures in the spectrograph have precluded this dual-etalon operation, and the data described here were taken with only the medium resolution etalon and an interference filter, admitting three successive orders of the etalon. Thus each point in the image receives light from three wavelengths, separated by the 7.5 nm free spectral range of the etalon. This wavelength ambiguity can lead to possible confusion in interpreting the data, and will be addressed in detail below.

Light that reaches different points in the image illuminates the FP etalon at different angles in the collimated beam, producing a radial wavelength gradient in each image. The wavelength varies quadratically with radius, with the outer edge of the image approximately 2.4 nm bluer than the center. Thus a uniform monochromatic illumination of the telescope focal plane produces a circular ring in the image, with the radius of the ring related to the wavelength of the illumination. Night sky OH emission features (see Osterbrock, et al. [12]) produce such rings in

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our images. These features are useful for calibrating the wavelengths of our spectra, but must then be subtracted from the images in order to properly analyze the galaxy spectrum. In order to better measure the night sky emission, we calculate the median of all the images in each galaxy scan and subtract this median image from each of the individual images. This removes the continuum and leaves the emission in each image. We then identify the OH emission features in the median-subtracted images and use them to calculate the wavelength calibration, achieving an accuracy of 0.01 nm RMS.

3.Results

When we inspected the median-subtracted images of NGC 1325, we found a weak emission feature at wavelength 661.3 nm. Figure 1 shows median-subtracted images for each of the two nights of observation, and the azimuthally averaged spectra extracted from them. The strong night sky OH line at 660.4 nm is readily apparent, and the weak feature at 661.3 nm, marked with the arrow, is clearly visible. The continuum gradients in the spectra are mainly due to incomplete subtraction of galaxy Hα emission. On both nights of observation the 661.3 nm emission feature is visible on each of the 9 images of NGC 1325 that include its wavelength. Figure 1 also shows a corresponding image from the scan of NGC 2280; the 660.4 nm OH line is apparent, but there is no feature at 661.3 nm. None of the images of NGC 2280 show any detectable emission at 661.3 nm.

We use the R magnitudes of several of the stars in the field of view to calibrate the flux of the emission detected at 661.3 nm. Table 1 lists the average flux measured on the 9 images of each night, the mean wavelength of the feature, both observed and corrected to the heliocentric frame, and the uncertainties calculated from the variance of the individual measurements. The fluxes measured here are about 50 times fainter than those measured for the 661.3 feature observed in the Red Rectangle (Glinski & Anderson [9]). This sensitivity is due to both the large aperture of SALT and to the ability of FP imaging spectroscopy to collect light from a large area on the sky.

Date	Flux (e s^{-1} cm^{-2} $arc\text{-}sec^{-2}$)	Observed Wavelength (nm)	Heliocentric Wavelength (nm)
01 Nov	$4.03 \pm 0.62 \times 10^{-18}$	661.33 ± 0.01	661.33 ± 0.01
28 Dec	$4.29 \pm 0.17 \times 10^{-18}$	661.38 ± 0.02	661.34 ± 0.02

Table 1 Emission feature in field of NGC 1325

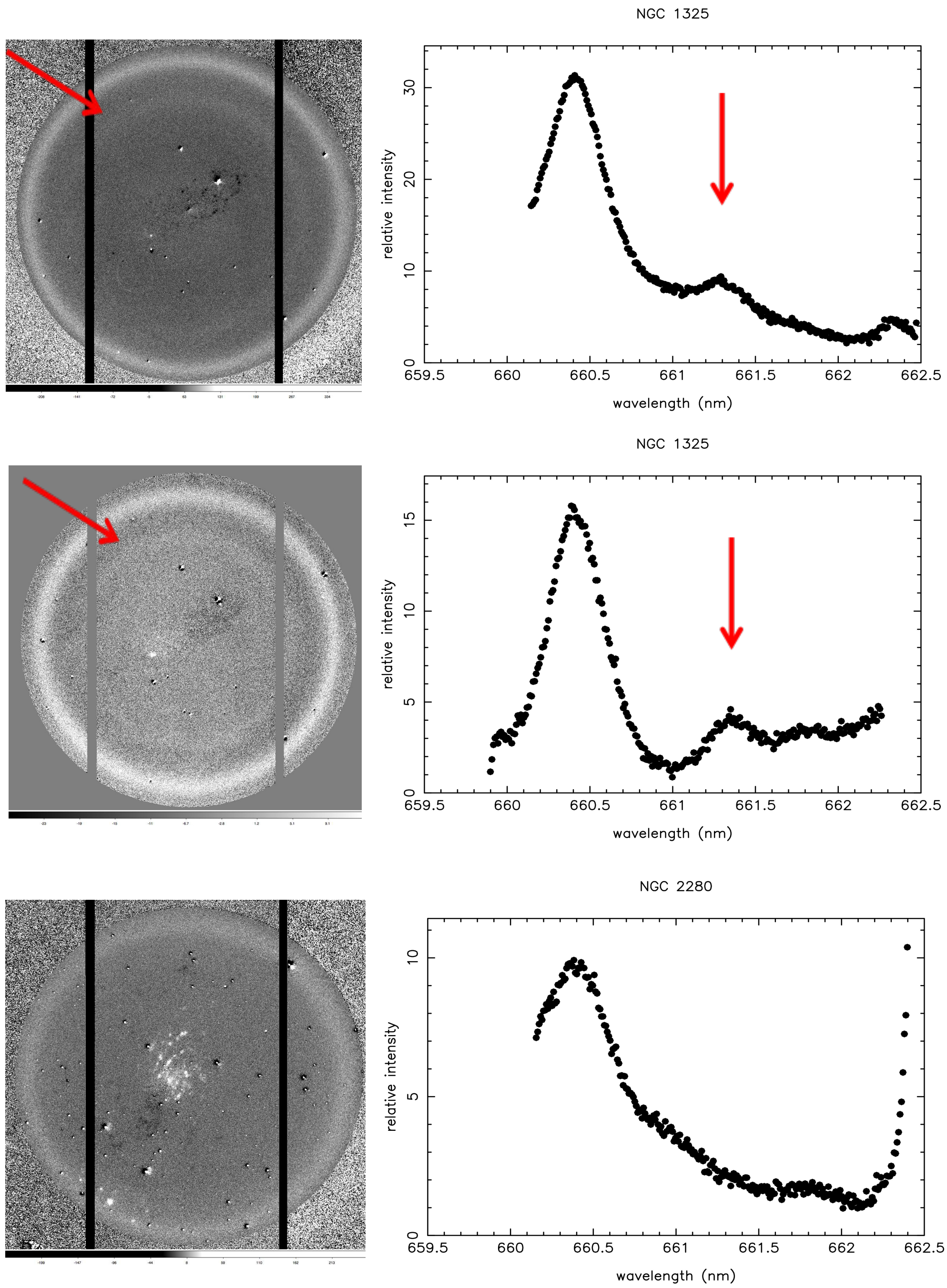

Figure 1. Sample FP images and spectra. Top row: NGC 1325 on 01 Nov. 2011; middle row: NGC 1325 on 28 Dec. 2011; bottom row: NGC 2280 on 01 Nov. 2011. Left column: median-subtracted images; right column: azimuthally-averaged spectra. Red arrow indicates 661.3 nm emission. Emission is present in all NGC 1325 images that contain that wavelength, absent in all NGC 2280 images.

4.Discussion

Inspection of the Osterbrock [12] night-sky atlas reveals no emission feature at a wavelength of 661.3 nm. There are also no night sky features at the adjacent orders of the FP etalon that are transmitted at 653.8 nm, 668.8 nm and 676.3 nm. The feature is detected with the same flux, within the uncertainties, on both nights of observation in the NGC 1325 field, while there is no emission detected at this wavelength in the observations of NGC 2280 taken on the same nights. Finally, the observed wavelength of the feature is significantly different on the two nights, but after correction for the Earth's motion, the heliocentric wavelengths agree within the measurement uncertainties. All of these considerations argue strongly that the feature is not of terrestrial origin, but arises along the observed line of sight towards NGC 1325.

The emission feature is uniformly distributed across the field of view, and its wavelength is constant over the image. Thus the feature is certainly not associated with NGC 1325 itself, which is highly structured, fits well within the field of view, and has a strong rotational pattern.

We thus speculate that this emission arises in the interstellar medium of our Galaxy along the line of sight toward NGC 1325. Because the interference filter transmits several adjacent orders of the FP etalon, the wavelength of the feature could be either 661.3 nm or 668.8 nm, where the filter transmission is 83% and 85%, respectively, or possibly 653.8 nm or 676.3 nm, where the filter transmission is 5% and 8%, respectively. The coincidence of one of these possible wavelengths with one of the strong DIBs suggests that this emission may be produced by the same (unknown) carrier that produces the DIB absorption seen along reddened lines-of-sight. This would be the second detection of DIB emission known in the Galaxy, after the Red Rectangle (and possibly V 854 Cen at minimum light). Unlike the Red Rectangle emission, there is no obvious stellar source of excitation, so the source of excitation is presumed to be the interstellar radiation field. The lack of emission towards NGC 2280 suggests that the distribution of the carrier in the ISM is not uniform, but clumped. The scale and distribution of the clumping remains to be determined.

We have been awarded additional observation time on SALT to use the RSS FP system to search for emission from other strong DIB features in the direction of NGC 1325, at wavelengths of 514.8 nm, 579.7 nm, and 585.0 nm. If these features are also detected, it will greatly strengthen the argument that we are detecting DIB emission from clouds in the ISM. We will also search for emission in the extended environment around the Red Rectangle and in other likely targets. If this association with the DIBs is confirmed, these sorts of measurements will provide additional information with which to address the long standing problem of the source of the DIBs.

References

[1] P.W. Merrill, *Unidentified Interstellar Lines*, *PASP* **46** 206 (1934).

[2] A.E. Douglas, *Origin of Diffuse Interstellar Lines*, *Nature* **269** 130 (1977).

[3] A. Léger, L. d'Hendecourt, *Are polycyclic aromatic hydrocarbons the carriers of the diffuse interstellar bands in the visible?, A&A* **146** 81 (1985).

[4] H.W. Kroto, J.R. Heath, S.C. O'Brian, S.C.Curl, R.E. Smalley, *C(60): Buckminsterfullerene, Nature* **318** 162 (1985).

[5] E.K. Campbell, M. Holz, D. Gerlich, J.P. Maier, *Laboratory confirmation of C_{60}^{+} as the carrier of two diffuse interstellar bands*, *Nature* **523**, 322 (2015).

[6] P.J. Sarre, *Diffuse Bands in Emission, Nature* **351** 356 (1991).

[7] S.J. Fossey, *Red Rectangle Emission, Nature* **353** 393 (1991).

[8] S.M. Scarrott, S. Watkin, J.R. Miles, P.J. Sarre, *Evidence for a link between the more prominent optical emission bands in the Red Rectangle and some of the diffuse interstellar absorption bands, MNRAS* **255** 11 (1992).

[9] R.J. Glinski, C.M. Anderson, *On the Red Rectangle optical emission bands, MNRAS* **332** L17 (2002).

[10] C.J. Mitchell, T.B. Williams, K. Spekkens, K. Lee-Waddell, R. Kuzio de Naray, J.S. Sellwood, *The RINGS Survey I: Hα and HI Velocity Maps of Galaxy NGC 2280, AJ* **149** 116 (2015).

[11] N. Rangwala, T.B. Williams, C. Pietraszewski, C.L. Joseph, *An Imaging Fabry-Perot System for the Robert Stobie Spectrograph on the Southern African Large Telescope, AJ* **135** 1825 (2008)

[12] D.E. Osterbrock, J.P. Fulbright, A.R. Martel, M.J. Keane, S.C. Trager, *Night-Sky High-Resolution Spectral Atlas of OH and O_2 Emission Lines for Echelle Spectrograph Wavelength Calibration, PASP* **108** 277 (1996).

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