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FN8-23-7179: A Low-temperature Circumstellar Shell?

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Abstract

In the course of a narrow-band imaging survey for dwarf emission-line galaxies in a nearby void, we serendipitously discovered a low-excitation nebula that fits the profile of a shell surrounding a low-temperature star. The star has a parallax of 0.47 ± 0.34 mas with a most likely distance of 1686 pc. It has apparent magnitudes in r' and g of 18.5 and 19.54, absolute magnitudes $M_{r'}$ and M_g of 7.4 and 8.41, and a redshift of 140 km^{-1}. The color and magnitude are consistent with a K6V dwarf. A lack of forbidden emission suggests that the nebular electron temperature is $< 3500°$ K.

Previous article in issue

Next article in issue

1. Introduction

As part of a survey for emission-line galaxies in nearby void centers (Draper et al. 2022), we discovered a point source with an emission-line spectrum. Designated FN2-23-7179 in accordance with our survey naming scheme, it has a position of R.A. = $03^{h}42^{m}56^{s}.20$, decl. = $17°17'39''.81$ (J2000.0) with an r' magnitude of 18.5 from our photometry. The object is in Gaia Data Release 3 (Gaia Collaboration et al. 2016, 2022) with source ID = 44171814494809344 and has a parallax of 0.47 ± 0.34 mas (Gaia Collaboration et al. 2018) with a most likely distance of 1686 pc (Bailer-Jones et al. 2021). It has a g magnitude of 19.54 (Gaia Collaboration et al. 2018).

2. Spectral Data

The object was discovered in a narrow-band imaging survey for Hα-emitting dwarf galaxies in a nearby galaxy void. A confirmation spectrum was obtained with the ARC 3.5 m telescope and DIS on 2021 January 11. The observation was four exposures of 200 s each at a dispersion of 1.83 Å pix^{-1} in blue and 2.31 Å pix^{-1} in red. A deeper spectrum was taken on 2021 December 31 with the ARC 3.5 m telescope and KOSMOS. This observation was eight exposures of 900 s each at a dispersion of 0.66 Å pix^{-1} in blue and 0.98 Å pix^{-1} in red. In both cases the slit width was 2". The blue and red spectra were obtained at the same time. In this research note we present only the higher S/N KOSMOS spectrum.

Wavelength calibration was done using night sky lines from Osterbrock et al. (1996) as tabulated by The Keele Astrophysics Group. [1] While arc lamps had been taken, the solution in the red was more precise when using night sky emission alone. Once the red spectrum was calibrated we fit a wavelength relation to the blue spectrum using the spectral Balmer series emission lines after allowing for the redshift found from the red spectrum.

The redshift solution was obtained from the red spectrum alone using the Hα emission line and four well-fitted He I emission lines between 5870 and 7230 Å. The resulting redshift was 140 ± 16 km^{-1}. This agrees well with the redshift of 98 ± 67 km^{-1} derived from the DIS data which was calibrated from HeNeAr arc lamps.

After the blue and red spectra were calibrated, we merged them together into one continuous spectrum for publication purposes. The resulting spectrum is presented in Figure 1. The detector spectral response has not been calibrated out leaving the intensity in the arbitrary unit of counts.

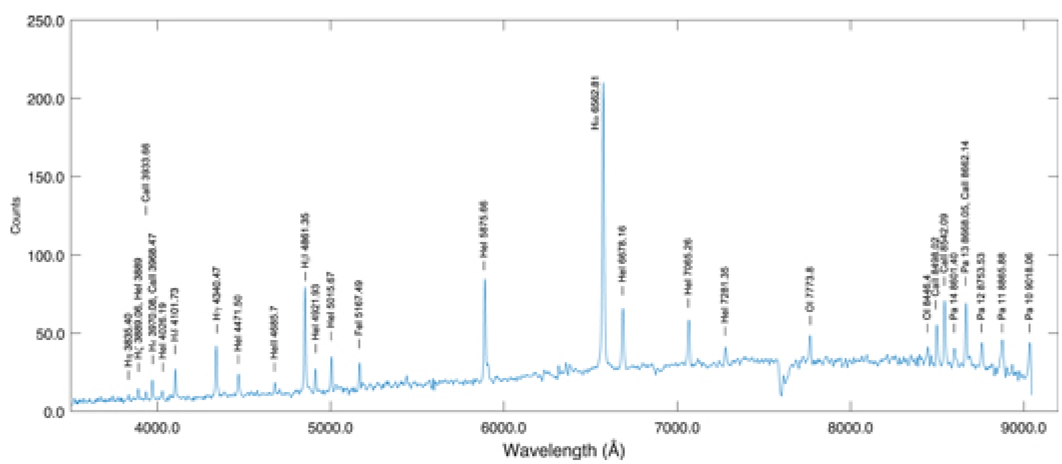

Figure 1. A full optical spectrum of FN8-23-7179 created by joining the blue and red scans from the KOSMOS spectrometer. Identified lines have the atomic specie and rest wavelength printed above the line.

The spectrum is consistent with a low-excitation nebula similar to those of cataclysmic variables (i.e., Sheets et al. 2007). The Balmer series is readily apparent, extending from Hα to Hη. Paschen series lines Pa 10 to Pa 14 are present, although Pa 13 is blended with Ca II λ8662.14. Nine He I lines were identified at wavelengths of 3889.06, 4026.19, 4471.50, 4921.93, 5015.67, 5875.66 (blend), 6678.16, 7065.26, and 7281.35 Å. One of them, He I λ3889.06, is blended with Hζ λ3889.06.

A He II emission blend is visible at 4685.7 Å. Five Ca II lines were identified at wavelengths 3933.66, 3968.47, 8498.02, 8542.09, and 8662.14 Å. Ca II λ3968.47 is blended with Hζ and Ca II λ8662.14 is blended with Pa 13 as previously noted. An Fe I line is present at 5167.49 Å. Two O I line blends appear to be at 7773.8 and 8446.4 Å. There is no detection of the [O II], [O III], [N II], and [S II] lines common to H II regions and planetary nebula. All line wavelengths are from the National Institute of Standards and Technology *Basic Atomic Spectroscopic Data Handbook* (Sansonetti & Martin 2005) with the exception of the Balmer and Paschen lines which were calculated from the Rydberg formula.

3. Discussion

The absolute magnitudes are consistent with a late-type main-sequence K dwarf. The $g - r'$ color places it as a K6V type star with or without allowing for the differences between r and r' magnitudes (Fukugita et al. 2011). So the temperature would be approximately 4200° K. We note that the absence of TiO absorption suggests that the star must be hotter than M0.

A nebular electron temperature cannot be derived using common emission-line techniques such as those in Osterbrock & Ferland (2006) or Izotov & Thuan (2007) since there are no forbidden emission lines present in the spectrum. The lack of optical forbidden emission requires either the electron density to be high or the mean temperature to be low. As pointed out by Osterbrock & Ferland (2006) electron densities in typical circumstellar shells is on the order of 10^2 which is far too low for collisional de-excitation to be important. For collisionally excited lines near 6000 Å a temperature of $T < 3500°$ K is required for the Boltzman factor $\exp(-\chi/kT)$ to be small enough to not generate forbidden emission. It therefore seems most likely that this is a circumstellar shell with a temperature < 3500° K surrounding a late-type star. There is no evidence of P Cygni line profiling and the line widths are relatively narrow so any outflow velocity would be low.

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Facility: ARC:3.5 m (DIS and KOSMOS) - .

Footnotes

1 https://www.astro.keele.ac.uk/jkt/GrSpInstructions/GrSpArcCalSky.html