EMISSION LINES IN THE NEAR-INFRARED SPECTRA OF THE IR QUINTUPLET STARS IN THE GALACTIC CENTER

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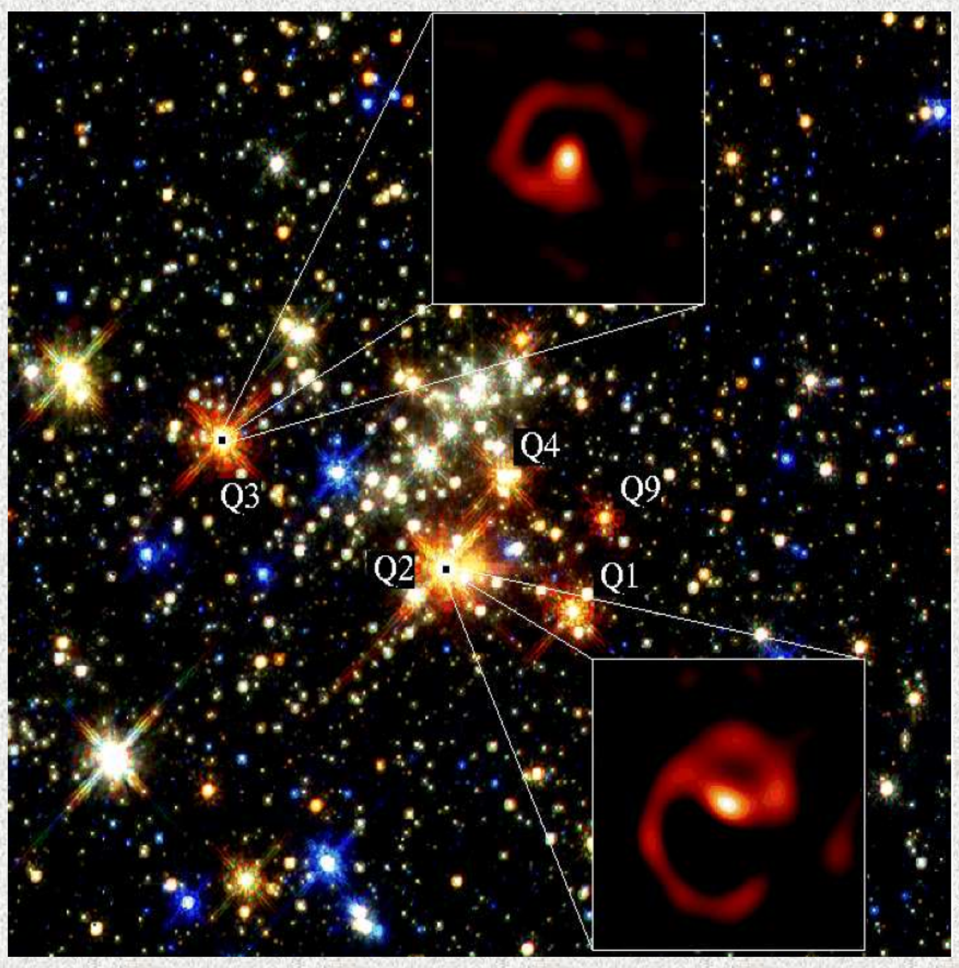
Abstract: The precise natures of the five infrared stars for which the Galactic center's "Quintuplet Cluster" was named have long been a mystery, although the pinwheel morphologies of two of them suggest that those two are Wolf-Rayet colliding wind binaries. Not only does each of the five IR stars suffer the same large interstellar extinction that obscures all objects in the Galactic center, but also each is embedded within a warm and dusty cocoon. Until now near-infrared spectra of them have revealed only dust continua steeply rising to long wavelengths. In the *J* and *H* bands the Quintuplet stars are very faint due to the high extinction, but the continuum emission from their warm cocoons is much less than at longer wavelengths and lines arising within their dust shells should be relatively more prominent. Here we report the detection of a number of emission lines characteristic of hot and massive stars in 1.0-1.8μm spectra of four of the IR Quintuplet. The lines that have been detected to date allow initial classifications of most of these stars.

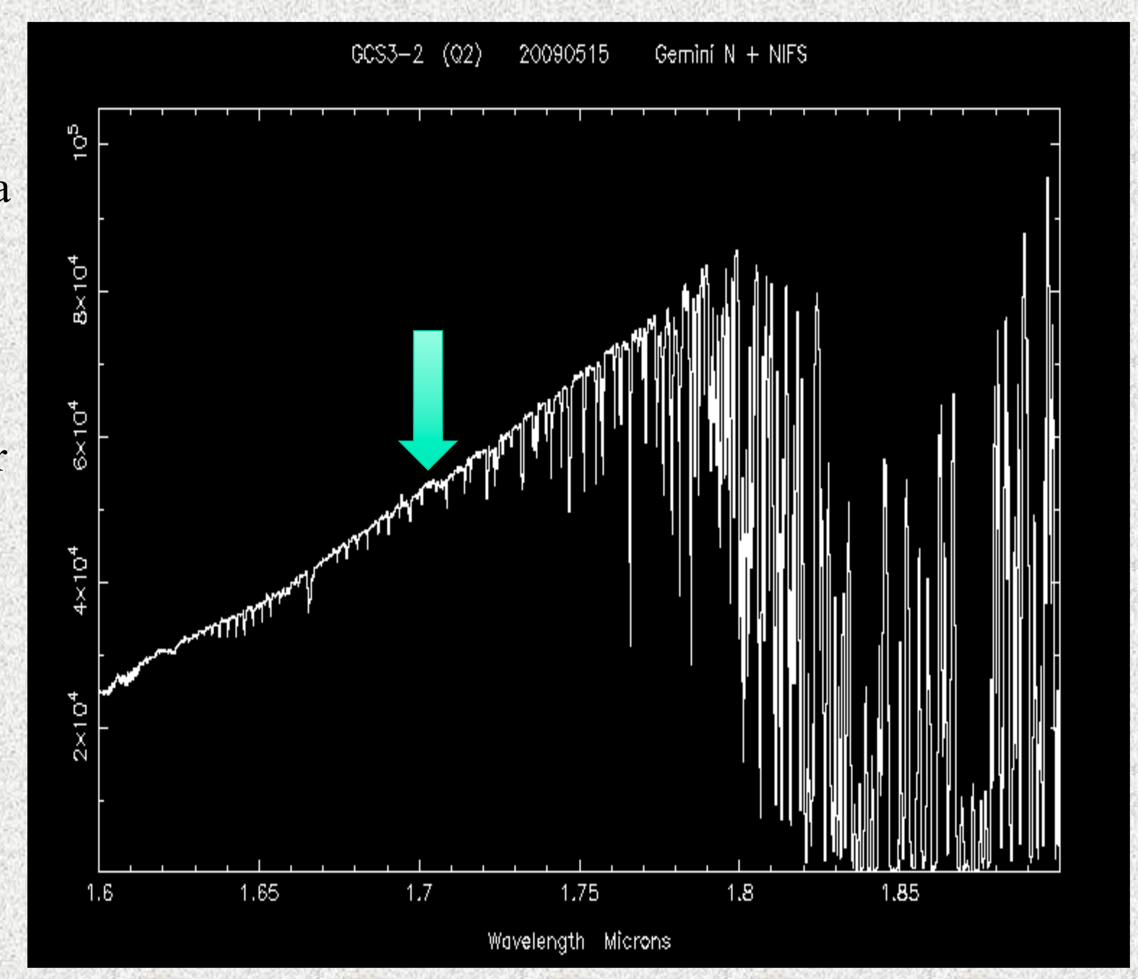
INTRODUCTION



IR multi-wavelength image of Quintuplet Cluster. Labeled objects are the five IR cocoon stars. Other red objects are red giants in the Galactic center. Most of the white objects are hot stars in the cluster. Blue objects are foreground stars. Insets are speckle imaging. Tuthill et al. (2006).

Most stars in the Galactic center are obscured from view by ~30 visual magnitudes of. The five IR stars of the Quintuplet Cluster (Nagata et al. 1990), labeled in the image at left, not only suffer that extinction, but are additionally obscured by warm dusty cocoons, which also superimpose bright IR continua on whatever spectral features might faintly leak out from within the cocoons. Spectra of them in the *K* and longer infrared bands are featureless apart from interstellar gas and solid phase absorptions (e.g., due to CO, H_3^+, and the 3.4-micron and silicate features); because of this they have on occasion been used as telluric standards for Galactic center sources with more "interesting" spectra. Only photometry of these stars has been reported at shorter infrared wavelengths (Figer et al. 1999). Thus little has been known as to the natures of the embedded stars. Figer et al. and Moneti et al. (2001) proposed that they are dusty WC stars. More recently, using speckle imaging techniques in the *K*-band Tuthill et al. (2006) resolved all five objects finding that two of the sources (Q2 and Q3, aka GCS3-2 and GCS4, respectively) have pinwheel-like morphologies (insets in Fig. 1), seen previously only in binary systems in which one component is a Wolf-Rayet star. Those authors argued that all five of the cocoon stars contain Wolf-Rayet stars.

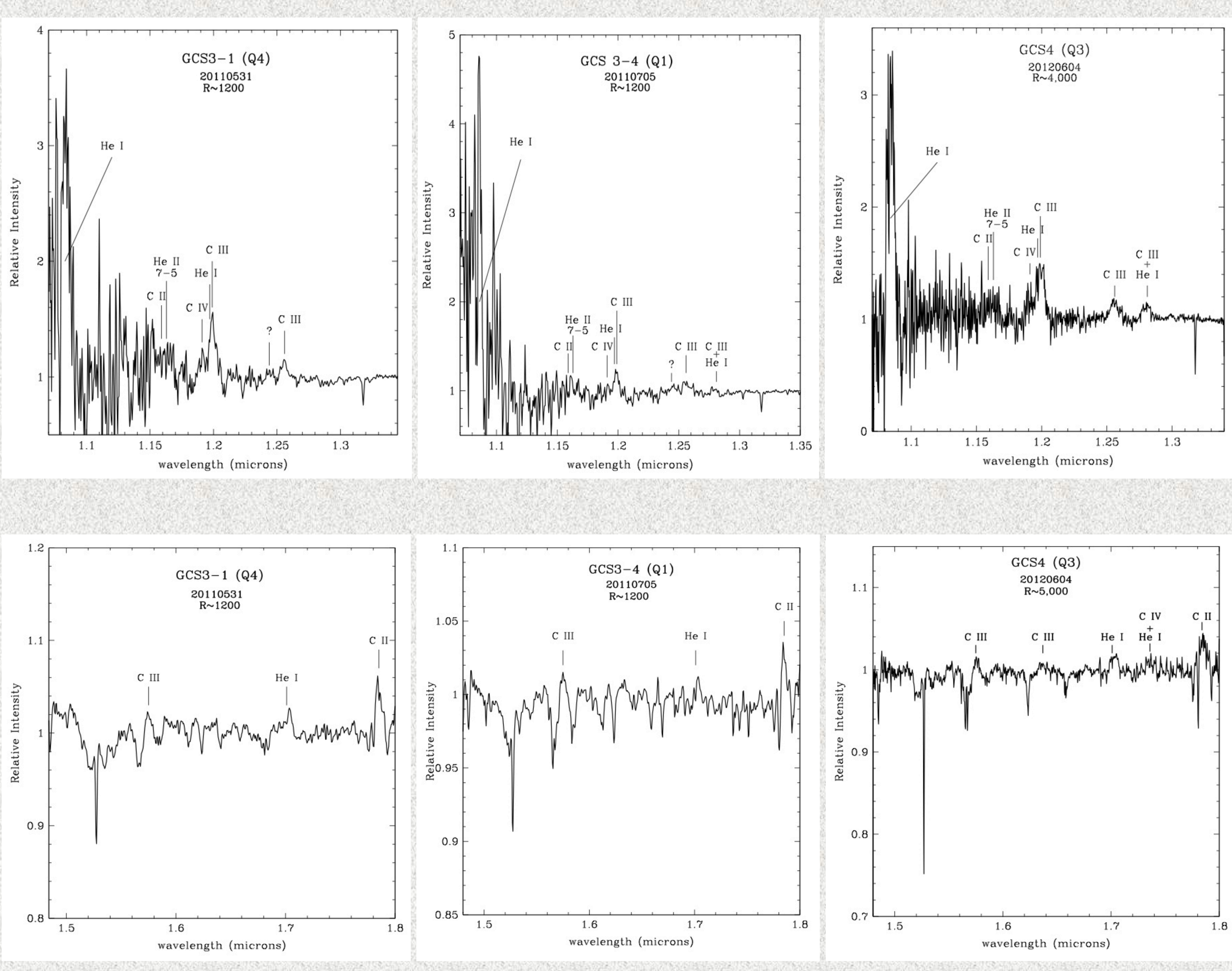
On UT May 15, 2009, the course of a progam to obtain an *H*-band spectrum of the Galactic center source GC IRS8 we observed GCS3-2 as a telluric standard and, to our surprise, detected a weak and broad emission line centered near 1.70 microns (see spectrum at right), presumably leaking out through the cocoon. The detection led us to obtain spectra of the other cocoon stars in the H-band and to push to even shorter wavelengths, approaching 1.0 microns. Although extinction decreases the signal rapidly toward shorter wavelengths, the dust continua from the cocoons weaken rapidly also. Since equivalent width is the principal impediment to detecting lines from the embedded stars at longer infrared wavelengths, it might be possible to detect lines more easily at shorter infrared wavelengths, despite the much weaker signal.



Raw NIFS spectrum of GCS 3-2 (Q2) in the H band and beyond, at R~5,000. Absorption features are due to telluric species. The arrow denotes the helium emission line. The steeply rising continuum (a factor of four from 1.60 to 1.80 microns) is due both to decreasing extinction from interstellar dust and dust in the cocoon, and increasing thermal emission from dust in the cocoon.

OBSERVATIONS AND INITIAL ANALYSIS

J-, *H*-, and K-band spectra of the Quintuplet's IR stars have been obtained at the Frederick C. Gillett Gemini North Telescope at various times between May 2009 and June 2012, using the facility instruments NIFS and GNIRS at resolving powers ranging from 1,000 to 6,000, and using standard stare/nod techniques. Early A-type dwarfs were observed at similar airmasses and served as telluric standards; the strong hydrogen recombination absorption lines in their spectra were removed using line-fiitting techniques, prior to ratioing. As the continua of the ratioed spectra increase rapidly with wavelength, for ease of viewing we plot continuum-normalized spectra below. Emission line identifications are mainly from Eenens et al. (1991) and Crowther et al. (2006). Spectra of GCS3-3 (Q9), obtained on 20110703 contained no emission lines and are not shown. Absorption features and complexes at 1.318, 1.485, 1.520,1.527, 1.56-1.57, 1.623, 1.657-1.660, and 1.77-1.80 microns are diffuse interstellar bands, most of them recently discovered (Geballe et al. 2011).

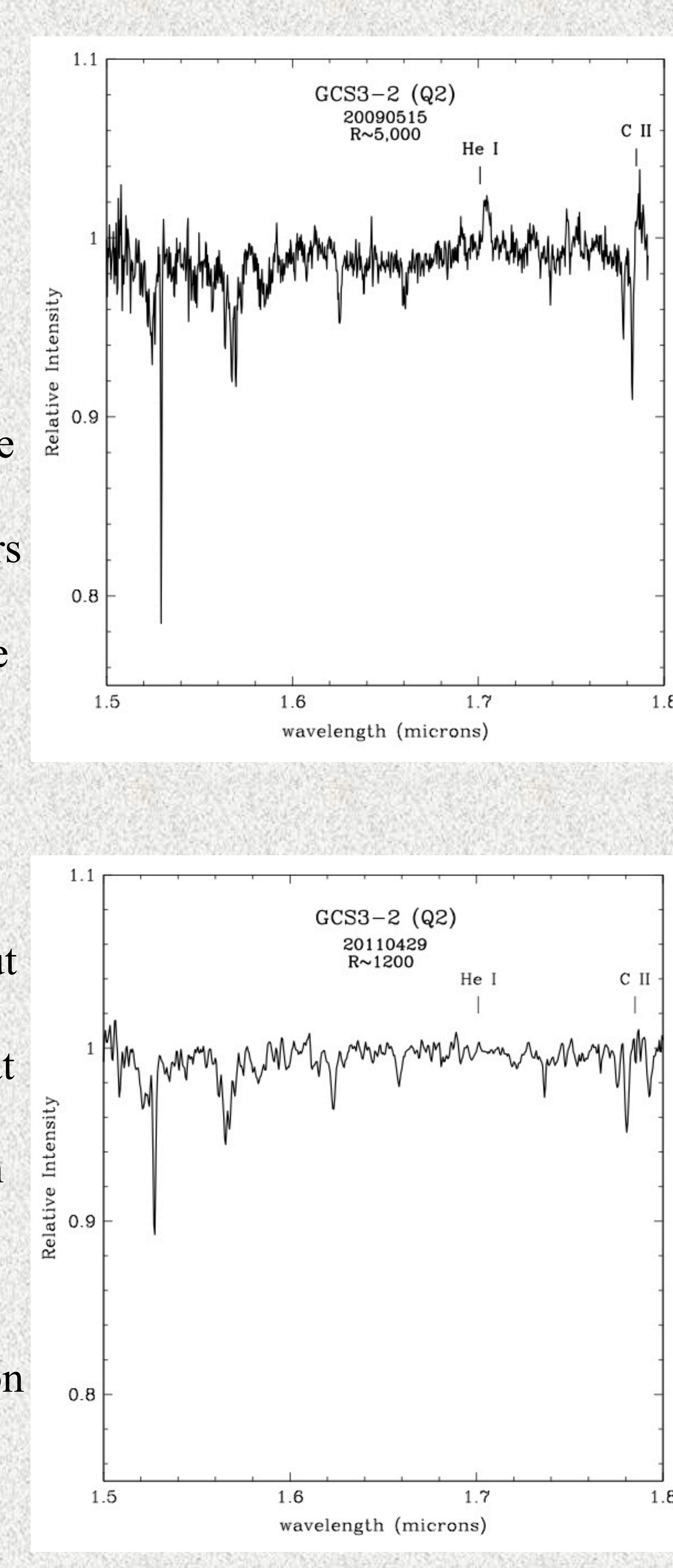


At left: *J*- and *H*-band spectra of GCS3-1, GCS3-4, and GCS4

These spectra resemble those of very late-type WC stars observed by Eenens et al. (1991), Varricatt & Ashok (2002), and Crowther et al. (2006). The dominant carbon species are C II and C III. He II lines are either weak or absent. The relative weakness or complete absence of C IV at 1.191 and 1.736 microns in these three stars and in GCS3-2 at right suggests that the spectral types of each is WC9 or later. Line widths are 2,000-3,000 km/s.

At right: *H*-band spectra of GCS3-2 at two epochs

Lines of He I and C II are present in the spectrum from May 2009 (upper panel), but are absent in the 2011 spectrum (lower panel). Tuthill et al. (2006) have shown that GCS3-2 and GCS4 are dust-producing colliding wind binaries. As dust production varies with orbital phase, it is possible that the time of the 2011 observations of GCS3-2 coincided with increased dust production, leading to increased obscuration of the line-emitting region and stronger continuum emission. Both changes would decrease line equivalent widths.



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REFERENCES

Crowther, P. A., Hadfield, L. J., Clark, J. S., Neguerela, I., & Vacca, W. D. 2006, MNRAS, 372, 1407
Eenens, P. R. J., Williams, P. M, & Wade, R. 1991, MNRAS, 252, 300
Figer, D. F., McLean, I. S., & Morris, M. 1999, ApJ, 514, 202.
Geballe, T. R., Najarro, F., Figer, D. F., Schlegelmilch, B. W., & de la Fuente, D. 2011, Nature, 479, 200
Moneti, A., Stolovy, S., Blommaert, J. A. D. L., Figer, D. F., & Najarro, F. 2001, A&A, 366, 106
Nagata, T., Woodward, C. E., Shure, M., Pipher, J. L., & Okuda, H. 1990, ApJ, 351, 83
Tuthill, P., Monnier, J., Tanner, A., Figer, D., Ghez, A., & Danchi, W. 2006, Science, 313, 935
Varricatt, W. P. & Ashok, N. M. 2002, in *Interacting Winds from Massive Stars*, ASP Conf. Ser., 260, 213