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INFRARED SPECTROSCOPY, IMAGING, AND 10 MICRON PHOTOMETRY OF GICLAS 29-38

A. T. TOKUNAGA,[1] K.-W. HODAPP, E. E. BECKLIN,[2] D. P. CRUIKSHANK,[2,3] M. RIGLER, AND D. TOOMEY[2]
Institute for Astronomy, University of Hawaii

R. H. BROWN[2]
Jet Propulsion Laboratory

AND

B. ZUCKERMAN[2]
University of California, Los Angeles
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ABSTRACT

A near-infrared spectrum and several images of Giclas 29-38, a white dwarf suspected to have a brown dwarf in orbit around it, are presented. There is no absorption feature in the spectrum that is deeper than 5% in the wavelength range 1.95–2.45 μm, from which it is inferred that there is no feature deeper than 10% at 2.4 μm from any brown dwarf companion. The infrared spectrum does not yield any strong constraint on whether or not the thermal emission observed from G29-38 comes from a brown dwarf or dust. The 1.6 and 2.2 μm images of G29-38 appear indistinguishable from a point source with an upper limit of 0".4 for the separation of the white dwarf and the source of the excess IR emission. This corresponds to a projected linear separation of 5.6 AU. A 2 σ limit at 10 μm of 10 mJy constrains possible alternative models for the infrared excess by emission from dust grains. While the present results do not show evidence for the suspected brown dwarf companion around G29-38, we cannot rule out the presence of such an object.

Subject headings: infrared: spectra — photometry — stars: white dwarfs — stars: binaries

I. INTRODUCTION

Zuckerman and Becklin (1987) have recently reported that the white dwarf Giclas 29-38 shows an infrared excess at wavelengths longer than 1.6 μm. Considering a number of alternative explanations for this excess, they argued that the most likely source of the infrared radiation is a cool companion in orbit around the white dwarf. From their photometry, a temperature of 1200 K and a radius of 0.15 $R_{\odot}$ of the companion were derived. A subsequent analysis by Greenstein (1988) yields a range of temperatures of 1100–1500 K and a range of radius of 0.18–0.10 $R_{\odot}$ for the companion. Such an object should be below the hydrogen-burning main sequence and thus be classified as a brown dwarf.

At a wavelength of 2.2 μm the postulated brown dwarf contributes ~50% of the total flux of this double star system, thus making it possible to attempt confirmation of its presence by infrared spectroscopy or by direct imaging. This paper presents such studies of G29-38, and we find no direct evidence for a brown dwarf companion. Since our measurements do not rule out the presence of a brown dwarf, elucidation of the nature of the infrared excess in G29-38 requires other observational techniques.

II. THE OBSERVATIONS

a) Infrared Spectroscopy

The Cooled-Grating Array Spectrometer (CGAS) at the NASA Infrared Telescope Facility (IRTF) was used for the observations presented here, and it is described in detail by Tokunaga, Smith, and Irwin (1987). A 75 line mm^{-1} grating blazed at 2.5 μm provided a resolving power of 110 at 2.2 μm. Since the CGAS has 32 detectors, a 1.95–2.45 μm spectrum was obtained with a fixed grating position.

The data in Figure 1 were obtained on 1987 September 2 and 7 UT with a total of 2400 s and 3200 s of integration, respectively, on G29-38. The standard star ι Psc (BS 8969) was chosen because of its proximity to G29-38 and because its spectral type (F7 V) would not introduce spurious spectral features at 2 μm. The spectra of G29-38 were divided by BS 8969 without accounting for the small air mass difference (<0.09). The spectra were then averaged for each night, and the resulting two spectra were subsequently averaged and weighted by the standard deviation. The final spectrum is shown in Figure 1.

The bright white dwarf 40 Eri B, which has the same effective temperature as G29-38, was also observed on September 2 as a comparison object. The slight curvature in the spectrum of 40 Eri B, Figure 1, is an artifact arising from the fact that it was observed with an integration time of 100 s, while the integration time for BS 8969 was 0.6 s. In such a case, the dark current component is not properly removed in the sky subtraction, and this leads to curvature in the spectrum. Additional details of the data-taking procedure are given by Tokunaga, Smith, and Irwin (1987) and by Tokunaga, Nagata, and Smith (1987).

The integration time on-chip before readout of the array was 200 s for G29-38 and 100 s for 40 Eri B. This difference in integration time does not lead to a significant slope change between these two sources, and we expect comparable curvature in the spectrum of G29-38. Since we are looking for prominent spectral features, the above problem of uncorrected dark current would not affect our interpretation. Within the errors of the observation, we do not see any spectral features in

1 Staff Astronomer, NASA Infrared Telescope Facility, which is operated by the University of Hawaii under contract with the National Aeronautics and Space Administration.

2 Visiting Astronomer, NASA Infrared Telescope Facility, which is operated by the University of Hawaii under contract with the National Aeronautics and Space Administration.

3 Now at NASA Ames Research Center.

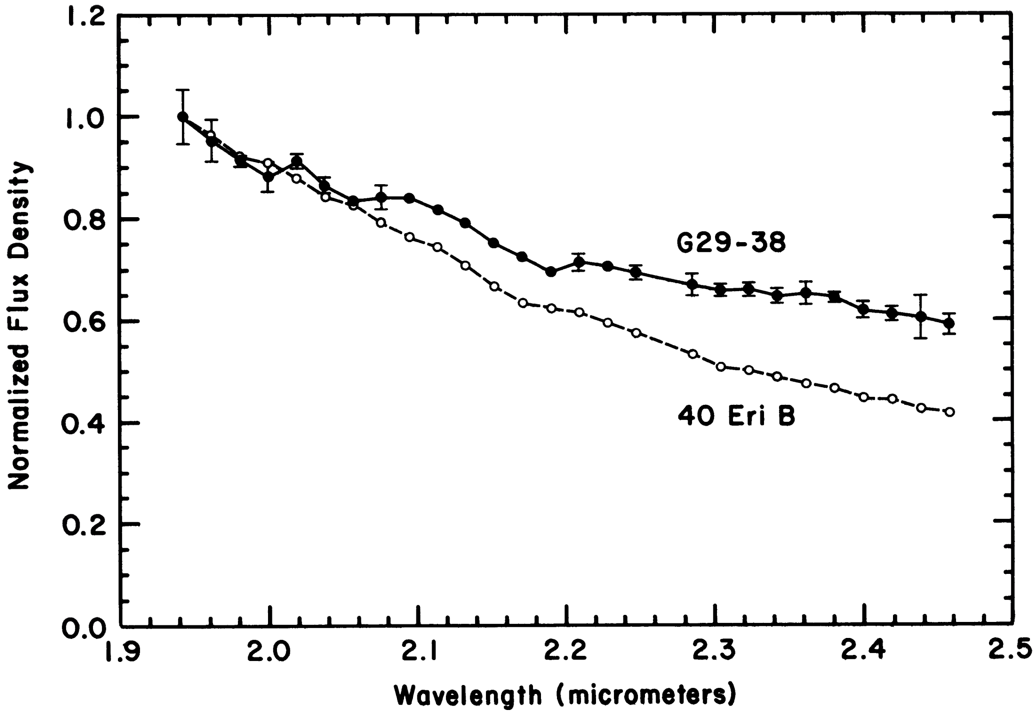

FIG. 1.—The spectrum of G29-38 (*solid line*) and of a comparison white dwarf with no infrared excess, 40 Eri B (*dashed line*) in units of $W\ m^{-2}\ \mu m^{-1}$. Note that the normalization shown is arbitrary; it does not show the true relative flux densities of these two sources.

the spectrum of G29-38. From Figure 1, it is seen that G29-38 shows a redder spectrum than 40 Eri, confirming the red excess found by Zuckerman and Becklin.

There is a further complication in that detector 13 has a high dark current that made it unusable. Also, detectors 1 and 2 are not usable because they are affected by the array readout electronics, and detector 32 is sometimes unreliable. The data from these detectors were removed in the final spectrum.

b) Infrared Imaging

The University of Hawaii Infrared Camera at the UH 2.2 m telescope on Mauna Kea was used on 1987 September 10 UT to obtain images of G29-38. It employed a JPL/SISEX array with 64 × 64 pixels and a cutoff wavelength of 2.5 μm. The image scale at the f/35 focus of the 2.2 m telescope was 0".142 pixel^{-1}, well suited for high-resolution imaging. The on-chip integration time was 500 s, and sky frames with the same integration time were subtracted from the object frame to cancel out the dark current of the detector and signal contributions from the telescope and the sky. Dome flats were used to correct for nonuniform pixel responsivity. Prior to further processing, the images were smoothed with a $\sigma = 1.5$ pixel Gaussian function to suppress noise without noticeably degrading the spatial resolution. The UH Infrared Camera and the observing procedure are described in detail by Capps *et al.* (1987).

The point-spread function of the telescope, measured on frames of nearby SAO stars, was used to deconvolve the object frames in an attempt to increase the effective resolution of the images. Figure 2 shows one frame at 1.6 μm (*H* band) and one at 2.2 μm (*K* band) and the deconvolved versions of these frames after 8, 16, 32, and 64 iterations of the Lucy-Richardson algorithm (Richardson 1972; Lucy 1974).

As can be seen from Figure 2, the algorithm converges toward a point source. Some artifacts caused by slight instabilities of the point-spread function of the telescope with time are visible in Figure 2 and limit the effective resolution. Three frames of G29-38 in the *H* band and five frames in the *K* band have been obtained, and the residual structure in the deconvolved images does not show any systematic deviation from a point source. To test the deconvolution algorithm and to derive an upper limit for the spatial separation of the two components of the hypothetical white dwarf/brown dwarf pair, we numerically simulated pairs of equally bright point images separated by 1, 2, 3, and 4 pixels using the original frames of Figure 2 as "point-source images." As can be seen from Figure 3, such a pair with 3 pixel (0".42) separation would have appeared clearly elongated using the same deconvolution algorithm that was applied for the images of G29-38 in Figure 2. An image separation of 2 pixels would, on the other hand, be hard to detect, although indications for elongation of the image can be seen in Figure 3.

This leads to an upper limit of 0".4 for the angular separation of the hypothetical white dwarf/brown dwarf pair, corresponding to an upper limit of 5.6 AU for the projected linear separation at a distance of 14.1 pc to G29-38. Figure 3 also does not show any indication for emission around the stellar image that extends beyond a radius of 0".2 (2.8 AU). This poses a constraint on the extent of any hypothetical cloud of small dust particles that might explain the infrared excess observed by Zuckerman and Becklin (1987).

The images presented in Figure 2 were obtained under cirrus conditions. The photometric values derived from the images are of such poor quality that they can confirm the infrared excess found by Zuckerman and Becklin (1987) only qualitatively and with large errors.

c) 10 µm Photometry

The bolometer system on the IRTF was used to measure the 10 μm flux from the G29-38 system. The observations were made with a standard *N* filter and a 5".5 focal plane aperture on

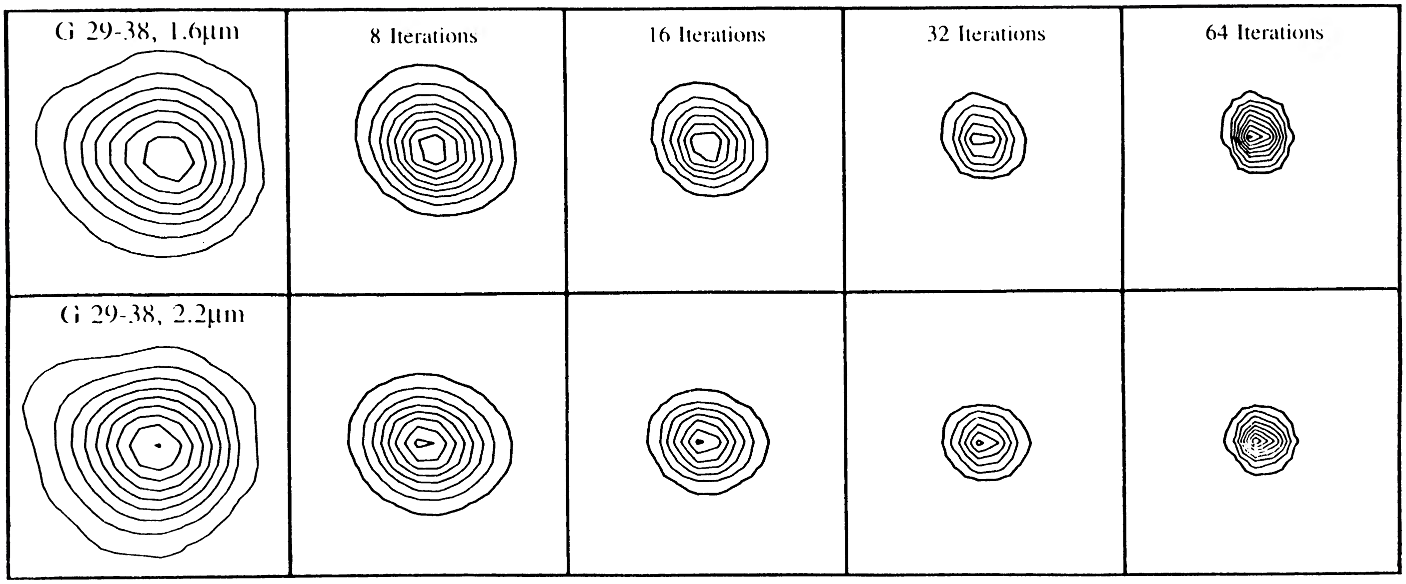

FIG. 2.—Images of G29-38 at a wavelength of 1.6 μm and 2.2 μm. The leftmost image is an original frame smoothed with a Gaussian function, and the other images are the results of application of the Lucy-Richardson deconvolution algorithm. A 2″ × 2″ region around G29-38 is shown in each square.

1987 October 6 and 7 and 1988 January 21 and 22 UT. A total of 2 hr integration was obtained under photometric conditions. The fluxes were calibrated using the standard magnitudes and fluxes given in the *IRTF Photometry Manual* (Tokunaga 1986). The sum of all nights of observations gives a flux of 3.9 ± 3.3 mJy. This can be interpreted as a 2 σ upper limit of 10 mJy. We note, in addition, that due to a printer's error, the J magnitude for G29-38 appears in Zuckerman and Becklin (1987) as 13.03, whereas the measured value was actually 13.09.

III. DISCUSSION

There is no indication of H_2 absorption at 2.12 μm, the CO overtone bands at 2.3–2.5 μm, or Bγ at 2.166 μm in the spectrum of G29-38. However, the dominant absorber at 1.9–2.4 μm in the atmosphere of a very cool star is H_2O, as can be seen in the infrared spectra of M dwarfs (Berriman and Reid 1987). Their Figure 2 contains a spectrum of GL 406 that shows that deep absorption by H_2O is present shortward and longward of 2.2 μm. This is one of the coolest M dwarfs they measured, with an estimated $T_{\rm eff} = 2600$ K, and $R = 0.16\ R_\odot$. The bottom of the H_2O absorption band at 2.4 μm is ~0.6 of the expected continuum at 2.4 μm, assuming that the continuum is a blackbody extrapolated from 2.2 μm.

We can now estimate the depth of the expected absorption band *for a similar degree of* H_2O *absorption* as in GL 406 for the case where all of the excess flux in G29-38 arises from a very cool object. In Figure 3 of Greenstein (1988), the total flux at 2.4 μm is 2 times that of the white dwarf continuum. If the absorption by H_2O were as high as that in GL 406, then the expected band would show as an absorption that was 20% of the continuum at 2.4 μm.

In Figure 1*a*, there does not seem to be any absorption band

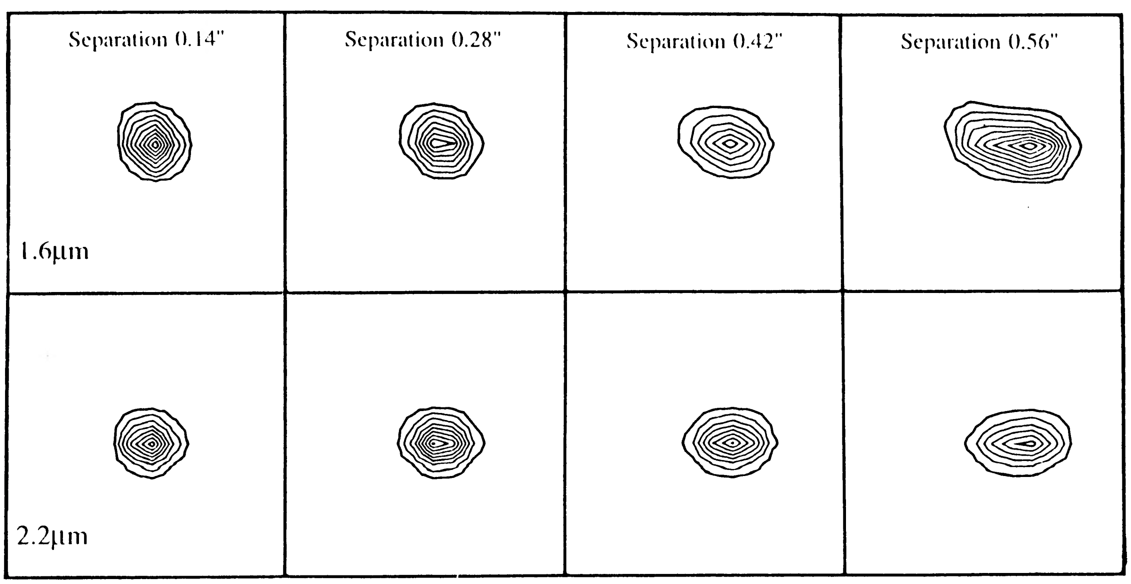

FIG. 3.—Simulations of two equally bright point sources separated by 0″.14, 0″.28, 0″.42, and 0″.56, deconvolved with 64 iterations of the Lucy-Richardson algorithm in the same manner as the images in Fig. 2.

deeper than 5% of the continuum at 2.4 μm, which in turn leads to an upper limit of 10% absorption in the continuum from the putative brown dwarf. At first sight, this may seem to conflict with the proposition that the infrared excess arises from a cool companion. However, model spectra of brown dwarfs by Lunine, Hubbard, and Marley (1986) show a great variation depending on whether large amounts of refractory particulates, such as silicates, are present in the atmosphere, or whether the C/O ratio is greater than or less than 1. The hot refractory particulates would provide an infrared continuum that would dilute, but not totally eliminate, the H_2O absorption band (see their Fig. 17). If the C/O ratio were greater than 1, then it may be possible for the H_2O band to be nearly eliminated, with all of the oxygen locked up in CO. Thus, it is not possible to draw any strong conclusions about the presence or absence of a brown dwarf from a featureless G29-38 spectrum to the extent that these theoretical models are correct.

The expected 10 μm flux density from G29-38, if the excess infrared radiation is from a 1200 K object with a diameter of 0.15 $R_\odot$, is $\sim$4 mJy, consistent with the 10 mJy upper limit discussed in § II*c*. The limit is not good enough to place a meaningful upper boundary on the temperature of a brown dwarf. The measurement can be used to place constraints on dust models that might be used to explain the infrared excess in G29-38. For example, most stars that show evidence of an infrared excess resulting from heated dust have a flux density distribution that increases from 3.5 to 10 μm (Neugebauer *et al.* 1971). This appears to be the case whether the dust is due to mass loss, accretion, or is in orbit around the star.

Small hot grains, such as those that provide the infrared continuum from reflection nebulae (Sellgren 1984), might provide an infrared excess like that observed in G29-38. In this process the observed continuum temperature, $\sim$1000 K, is *independent* of the distance from the star since the heating of the grains is produced by nonequilibrium single UV photon events. The small grains could be much further away from the white dwarf and the depletion time due to the Poynting-Robertson effect could be greatly increased compared with that estimated by Zuckerman and Becklin (1987) for 0.5 μm radius grains in thermal equilibrium ($\sim$10 yr). For 10 Å radius particles with a density of 2.5 g cm^{-3}, the depletion time is $\sim 10^4$ yr for a distance of 1 AU from the star. But the minimum mass of the dust would increase by the same factor ($\sim 10^3$) above that estimated by Zuckerman and Becklin so that the rate of deposition of dust onto the white dwarf would be unchanged.

IV. SUMMARY

We have obtained a high signal-to-noise 2 μm spectrum of G29-38 that is featureless and 1.6 and 2.2 μm images that do not show any companion or extension. We conclude the following: (1) If the infrared excess arises from a brown dwarf, then its spectrum, which does not have strong H_2O absorption band, is unlike that of the coolest M dwarf observed thus far. This might arise if the atmosphere of the brown dwarf is dusty or if the C/O ratio is greater than unity. (2) If the infrared excess arises from a brown dwarf, then the lack of an observable companion indicates that the projected separation of the white and brown dwarfs must be $\lesssim 0\farcs4$, or 5.6 AU. If the physical separation is larger, the brown dwarf companion may be detectable in the future in a different part of its orbit. (3) If the infrared excess is produced by hot dust grains, it could arise from very small grains similar to those that have been observed in reflection nebulae. (4) If the excess is caused by heated grains (both small and large), then the 10 μm flux limit of 10 mJy makes G29-38 unlike most galactic stellar sources that have infrared excesses.

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E. E. Becklin, K.-W. Hodapp, M. Rigler, A. T. Tokunaga, and D. Toomey: Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822

R. H. Brown: Jet Propulsion Laboratory, MS 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109

D. P. Cruikshank: MS 245-6, NASA Ames Research Center, Moffett Field, CA 94035

B. Zuckerman: Astronomy Department, University of California, Los Angeles, CA 90024