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KECK SPECKLE IMAGING OF THE WHITE DWARF G29-38: NO BROWN DWARF COMPANION DETECTED

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ABSTRACT

The white dwarf Giclas 29-38 has attracted much attention on account of its large infrared excess and the suggestion that excess might be due to a companion brown dwarf. We observed this object using speckle interferometry at the Keck telescope, obtaining diffraction-limited resolution (55 mas) at the *K* band, and found it unresolved. Assuming that the entire *K*-band excess is attributable to a single pointlike companion, we place an upper limit on the binary separation of 30 mas, or 0.42 AU at the star's distance of 14.1 pc. This result, combined with astroseismological data and other images of G29-38, supports the hypothesis that the source of the near-infrared excess is not a cool companion but a dust cloud.

Subject headings: binaries: general — circumstellar matter — stars: individual (G29-38) — stars: low-mass, brown dwarfs — white dwarfs

1. INTRODUCTION

Zuckerman & Becklin (1987) discovered that the white dwarf Giclas 29-38 has a large infrared excess and proposed that the excess could be due to a brown dwarf companion. This suggestion inspired discussion of brown dwarfs as white dwarf companions (Stringfellow, Black, & Bodenheimer 1990), oscillating brown dwarfs (Marley, Lunine, & Hubbard 1990), and other possible cool companions that could explain the excess (Greenstein 1988). Later photometry by Tokunaga, Becklin, & Zuckerman (1990) and Telesco, Joy, & Sisk (1990) suggested that the 10 μm excess greatly exceeds that expected from a brown dwarf companion, leading to the interpretation that the mid-infrared excess originates from a cloud of circumstellar dust. However, new data from ISOCAM (Chary, Zuckerman, & Becklin 1998) show that the 7 and 15 μm excesses are in agreement with a 1000 K blackbody fit to the excess at other wavelengths. The source of the infrared excess of G29-38 remains uncertain.

Direct searches for a companion have produced mixed results. Tokunaga et al. (1988) imaged G29-38 at the *H* and *K* bands and limited the extent of the source to a diameter of 400 mas or 5.64 AU. Tokunaga et al. (1988) and Tokunaga et al. (1990) took near-infrared spectra of the object and found no evidence for absorption features due to a brown dwarf. Haas & Leinert (1990) took slit scans of G29-38 in 1988 and found a north-south extension at the *K* band that was well fit by a binary model with a flux ratio of 1:1 and a separation of 230 ± 40 mas (3.24 ± 0.56 AU). However, when Haas & Lienert repeated their observations the following year under better seeing conditions, the object appeared unextended. C. Shelton, E. E. Becklin, & B. Zuckerman (1998, private communication; hereafter SBZ) took slit scans of G29-38 in the *J* and *K* bands at the Lick 3 m telescope in 1989 October to look for the centroid shift that would arise if, as the photometry suggests, the hypothetical cool companion is brighter in *K* and the white dwarf is brighter in *J*. They did not see this effect. They place an upper limit of 40 mas (0.56 AU) on the north-south binary separation and an upper limit of 120 mas (1.69 AU) on the east-west separation.

Attempts to find the radial velocity signature of a companion to G29-38 have also proven frustrating. Barnbaum & Zuckerman (1992) combined their own spectroscopy with radial velocity data by Graham et al. (1990), Graham, Reid, & Rich (1991, private communication reported in Barnbaum & Zuckerman 1992), Liebert & Saffer (1989, private communication reported in Graham et al. 1990) and Liebert, Saffer, & Pilachowski (1989) and reported a probable radial velocity variation with a period of 11.2 months and an amplitude of 10 km s^{-1}. Kleinman et al. (1994), however, argued, based on extensive astroseismological observations, that the radial velocity variation due to a binary companion must be less than ± 0.65 km s^{-1} assuming a ~1 yr period.

Hoping to find another clue to the mystery of the infrared excess, we imaged G29-38 at the *K* band on the 10 m W. M. Keck telescope using speckle interferometry to search for a resolved companion at the diffraction limit.

2. OBSERVATIONS

We imaged G29-38 at the *K* band with the near-infrared camera (NIRC) (Matthews & Soifer 1994) on the W. M. Keck telescope on 1997 December 15. The seeing was extraordinary; we used 0.5 s integrations and saw about five speckles and a diffraction-limited core. We took 12 sets of 100 frames of G29-38. Among observations of G29-38 we interspersed observations of two nearby, presumably unresolved calibrator stars (S23291+0515 and S23292+0521), which we observed in the same manner as G29-38, for a total of six sets of calibrator frames. We used a version of the speckle reduction software described in Koresko et al. (1991) adapted for use with NIRC. We chose a 128 × 128 pixel subframe centered on the object and constructed 128 × 128 pixel sky frames from the corners of the 256 × 256 pixel NIRC images. From each set of object and sky frames, we computed a power spectrum and a bispectrum and reconstructed Fourier phases and amplitudes. We divided the Fourier components from each target set by the Fourier components from a few different calibrator sets to correct for the telescope-aperture transfer function and in this way assembled 18 calibrated images and 18 calibrated power spectra.

Figure 1 shows the mean of the images, compared to a simulated image of a point source—the Fourier transform of the apodizing function (a Gaussian times a Hanning function)

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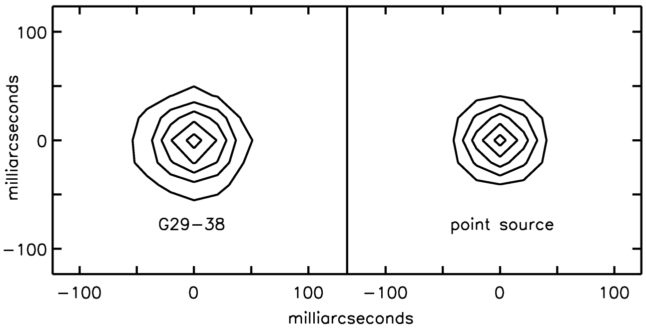

FIG. 1.—Reconstructed *K*-band speckle image of G29-38 compared to a synthesized image of a point source. Both are normalized so that their intensities range from 0 to 1 and have contour levels of 0.1, 0.3, 0.5, 0.7, and 0.9. G29-38 is unresolved.

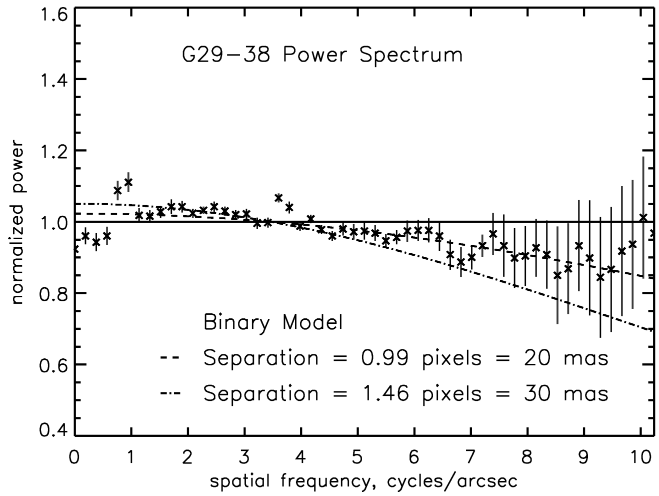

FIG. 2.—Azimuthally averaged spatial power spectrum of G29-38 compared to simulated azimuthally averaged power spectra of a binary with a flux ratio equal to G29-38's *K*-band excess. The error bars represent 1 σ variations among the 18 object-calibrator pairs. If G29-38 were a binary with this *K*-band flux ratio and the separation were larger than 30 mas, we would have detected the companion.

used to synthesize the speckle images. The plate scale is 20.57 mas pixel^{-1}. Figure 2 shows the azimuthal average of the arithmetic mean of the calibrated power spectra, where we normalized each power spectrum by dividing it by the geometric mean of the first 15 data points after the zero-frequency component. The error bars represent the 1 σ variations among the 18 power spectra. The λ/D diffraction limit of Keck at the *K* band is 55 mas. The noise increases at high frequencies because the power in the images decreases near the diffraction limit. The low-frequency spike probably occurs because of seeing noise, the change in seeing between observations of G29-38 and observations of the calibrators. Because the final image closely resembles a point source and the power spectrum is consistent with a constant—the power spectrum of a δ-function—we conclude that we did not resolve G29-38.

3. DISCUSSION

The *K*-band flux of G29-38 is 5.46 ± 0.15 mJy; 2.05 mJy of this is in excess of Greenstein's (1988) white dwarf model (Tokunaga, Becklin, & Zuckerman 1990). We computed the power spectrum of a binary system consisting of a Greenstein white dwarf and a pointlike companion that supplies all of the excess flux. The only free parameter for this binary model is the angular separation of the components. We fit the model to the observed power spectrum and derive a best-fit binary separation of 20 mas. The maximum deviation of the power spectrum from a straight line, however, is consistent with typical deviations due to time variations of the atmosphere-telescope point-spread function. In Figure 2, we compare the 20 mas model with the observed power spectrum and a model with the same flux ratio but a 30 mas separation. The latter model is marginally inconsistent with our observations, so we report 30 mas as an upper limit to the binary separation.

At G29-38's distance of 14.1 pc (Tokunaga et al. 1990), 30 mas corresponds to a transverse separation of 0.42 AU. Assuming that G29-38 is 0.61 $M_\odot$ (Bergeron et al. 1995), a 0.06 $M_\odot$ brown dwarf orbiting the star at 0.42 AU would have a period of about 0.33 yr and would create a reflex motion in G29-38 that would have been detectable to Kleinman et al. (1994) if the orbit were inclined more than 10° from face-on. The statistical likelihood of an inclination ≤10° is 1.5%. Closer orbits would be easier to detect from reflex motion.

Perhaps a brown dwarf orbits G29-38 with a long period that would be hard to identify in reflex motion, and the brown dwarf happened to pass in front of the star or behind it when we observed it on 1997 December 15. For instance, Kleinman et al. (1994) saw a long-term trend in their radial velocity data that could be interpreted as a companion with an ~8 yr period causing radial velocity variations on the order of 0.8 km s^{-1}. Such a companion would have a semimajor axis of ~3.4 AU. If the orbit had a semimajor axis *a* and were edge-on, the fraction of the time the that brown dwarf would spend in the region in which we could not resolve it is $\sim(2/\pi)\sin^{-1}(0.42\ \mathrm{AU}/a)$; for $a = 3.4$ AU, there is a less than 8% chance that the brown dwarf would have been hidden from us. Since SBZ also missed the hypothetical edge-on brown dwarf in 1989 as it passed close to the star, we find this scenario unlikely.

A companion in an eccentric orbit is easier to detect from reflex motion than a companion in a circular orbit with the same semimajor axis. Therefore, such a companion would have to be farther away from the star on average for Kleinman et al. (1994) to have missed it, making it even more unlikely that it would have been hidden from us, Haas & Lienert (1990), and SBZ. A companion in an eccentric, face-on orbit would spend relatively little time close to the star and probably would not have been missed by both us and SBZ.

The infrared excess may represent thermal radiation from a cloud of dust rather than a cool companion (Zuckerman & Becklin 1987). We can place no constraints on the concentration or geometry of such a cloud. Dust radiating thermally at 1–15 μm heated by radiation from the white dwarf alone would be far too close to the star (less than 10^{-3} AU) for us to resolve.

4. CONCLUSIONS

We conclude that the infrared excess of G29-38 is not due to a single orbiting companion. If there were a single companion producing the excess, it would have to orbit almost face-on and closer than 0.4 AU; or it could orbit roughly edge on, with a period of several years, in such a way that it happened to appear at a minimum angular separation from the star in 1997 December when we observed it and in the fall of 1989 when Haas & Lienert (1990) and SBZ observed it. Either case is highly improbable. This result supports the hypothesis that source of the near-infrared excess is not a cool companion but a dust cloud (Zuckerman & Becklin 1987; Wickramasinghe, Hoyle, & Al-Mufti 1987; Graham et al. 1990; Koester, Provencal, & Shipman 1997).

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