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THE SERENDIPITOUS DISCOVERY OF A DEBRIS DISK AROUND THE A DWARF HD 46190

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ABSTRACT

The Infrared Spectrograph on the *Spitzer Space Telescope* has observed several A dwarfs as potential standards and cross-calibrators, and one of these stars, HD 46190, shows the spectroscopic signature of a debris disk. The disk produces a spectral excess that can be fitted with a cool blackbody of ∼81 K. If the emitting particles are spherical blackbodies, they would lie at a distance of ∼82 AU from the central star. The spectrum from the disk can also be fitted with a spectrum rising proportionally with wavelength, and this spectral behavior is consistent with material falling into the inner disk as a result of Poynting-Robertson drag.

Subject headings: circumstellar matter — infrared: stars — stars: individual (HD 46190)

1. INTRODUCTION

The Infrared Spectrograph (IRS; Houck et al. 2004)[7] on the *Spitzer Space Telescope* (Werner et al. 2004) has observed a series of A dwarfs and K giants as part of a spectrophotometric calibration campaign. In a separate campaign to cross-calibrate with the other instruments on *Spitzer*, several more objects have also been observed, including the A0 dwarf HD 46190. We have attempted to limit our sample of standard stars to sources with easily and accurately predicted spectra by imposing a number of constraints in the selection process. Sources to be avoided include variable stars, visual or spectroscopic binaries, stars with unusual MK spectral classifications or optical and near-infrared photometry inconsistent with their spectral classes, sources with mid-infrared excesses, and stars embedded in crowded regions or regions with bright backgrounds.

The sensitivity of the IRS complicates the selection of standards. Any naked star brighter than 1.3 Jy at 12 μm (color-corrected) would saturate the low-resolution mode at the shortest wavelengths, and this limit rules out the most well-known and best-studied infrared standards. As a result, our sample has been skewed to fainter sources about which much less is known. HD 46190 is the faintest source observed in our calibration program. We observed two other sources fainter than 150 mJy at 12 μm, HR 7018 and HR 5467, both also A dwarfs. Table 1 provides details about these sources and how they were observed.

Here we report on the discovery of an infrared excess in the spectrum of HD 46190 best explained as emission from a debris disk. We compare its spectral properties to the other two faint standards observed, neither of which have infrared excesses.

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2. OBSERVATIONS AND REDUCTIONS

Spitzer observed the cross-calibrators using the low-resolution spectrometers on the IRS, Short-Low (SL; 5.2–14 μm) and Long-Low (LL; 14–38 μm). Other standards were observed using both the low-resolution and high-resolution spectrometers, but we will concentrate here on SL and LL observations. Table 1 gives the total integration times for each of the three objects considered here. We observed HR 7018 five times from 2003 November to 2004 January, HR 5467 six times in 2004 February and March, and HD 46190 once in 2003 November.

The standard *Spitzer* Science Center (SSC) online data reduction pipeline (S9.1 and S9.5) produced flat-fielded images for all individual observations.[8] For SL observations, we performed a background subtraction by differencing images with the object in the two SL apertures. For LL, we differenced images with the source in the two nod positions in a given aperture. Spectra were then extracted from these difference images using the SSC offline pipeline. We flux-calibrated the extracted spectra using spectral corrections generated by comparing extracted spectra of the IRS standards to their expected spectra, as estimated using the spectral templating method described by Cohen et al. (2003). The current state of the flat fields for SL and LL requires separate spectral corrections for each nod position.

We then combined the four individual low-resolution segments: two from SL (SL first- and second-order) and two from LL (LL first- and second-order). The discontinuities between the spectral segments arise primarily from the loss of flux through the spectrographic slits when the source is not well centered. To correct for these discontinuities, we multiplied each segment by a scalar to force the segments into alignment in the region of overlap. The segment that suffered the least loss of flux served as the reference; other segments were normalized to it.

HR 6348 (K0 III) was the initial standard for SL. For LL, we initially used a combination of HR 6348, HD 173511 (K4 III), and HD 166780 (K4.5 III). All calibration observations were obtained in 2003 November. Figure 1 plots the spectra of HR 5467, HR 7018, and HD 46190 as calibrated with the K giants.

Figure 2 compares the observed spectra with their spectral templates in units of $\lambda^2 F_\nu$, which for a Rayleigh-Jeans tail allows a much closer look at the detailed behavior of the spectrum. In Figure 2*a*, all of the apparent spectral structure beyond 10 μm in HR 5467 and HR 7018 can be attributed to residual calibration

[8] See the *Spitzer* Observer's Manual at http://ssc.spitzer.caltech.edu/documents/SOM for more details.

TABLE 1
OBSERVING INFORMATION

Target	Spectral Type	Magnitude[a] V	Magnitude[a] K	Flux Density[b] (mJy) 12 μm	Flux Density[b] (mJy) 25 μm	Total Integration Time (s) SL2 (5–7 μm)	SL1 (7–14 μm)	LL2 (14–21 μm)	LL1 (21–36 μm)
HR 7018	A0 V[c]	5.73	5.75	126 ± 10	34 ± 9	140	140	1200	2400
HR 5467	A1 V[d]	5.83	5.76	108 ± 11	36 ± 9	168	158	1440	2880
HD 46190	A0 V[e]	6.63	6.36	72 ± 11	<38	28	112	480	480

[a] *V* magnitudes from the Tycho Catalogue (Egret et al. 1992) and *Hipparcos* Catalogue (Perryman et al. 1997); *K* magnitudes from 2MASS (Cutri et al. 2003).
[b] From the *IRAS* Faint Source Catalog (Moshir et al. 1990), color-corrected.
[c] From Cowley et al. (1969), but Abt & Morrell (1995) give A0 IIIp, which is consistent with its slow rotation rate ($v \sin i = 30$ km s^{-1}).
[d] From Cowley et al. (1969).
[e] From Houk & Cowley (1975).

artifacts, most notably the apparent cusp at 20 μm and the concave-up shape to the first-order LL data (21–36 μm). The maximum difference between the spectrum of HR 5467 and its template is 8% at 28 μm. The spectra of both HR 5467 and HR 7018 are fully consistent with spectra from naked stars with no dust excesses.

To remove the artifacts in HD 46190 that are noticeable in the spectra of HR 5467 and HR 7018, we generated a new spectral correction assuming the templates of HR 5467 and HR 7018 are correct and applied that correction to HD 46190. The individual spectra of HR 5467 showed good internal consistency, but some of the HR 7018 spectra showed variations consistent with loss of light through the slit due to less accurate pointing. When generating the spectral correction, we estimated the pointing-induced loss of light in each individual spectrum and corrected it by scalar multiplication.

Figure 2*b* shows how the modified calibration has changed the spectra of our three sources. We also used the calibration to generate new spectra of HR 5467 and HR 7018 as a check for consistency. While we corrected for the pointing-induced throughput when generating the spectral corrections, we did not correct for it when recalibrating the data. As a result, the ~5% pointing-induced photometric discrepancy between the observed spectrum of HR 7018 and its template can be seen in Figure 2*b*.

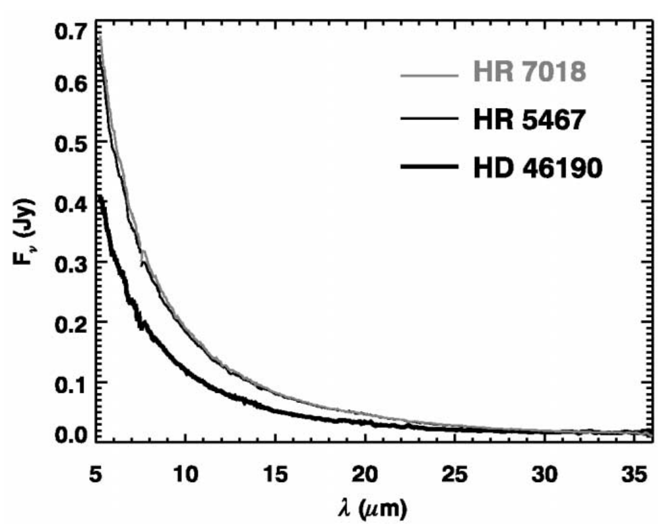

FIG. 1.—*From top to bottom*: Spectra of HR 7018 (*gray line*), HR 5467 (*thin black line*), and HD 46190 (*thick black line*) from the IRS on the *Spitzer Space Telescope*.

3. ANALYSIS

The two independent calibrations also provide a means of testing the robustness of the spectrum of HD 46190. As Figure 2 shows, the long-wavelength excess does not result from a particular calibration. While the two calibrations produce qualitatively similar results, there are some detailed differences, most notably the reduction in the size of the 20 μm cusp in the calibration using the A dwarfs. Since the calibration using the A dwarfs reduces the apparent artifacts, we rely on it in the analysis below.

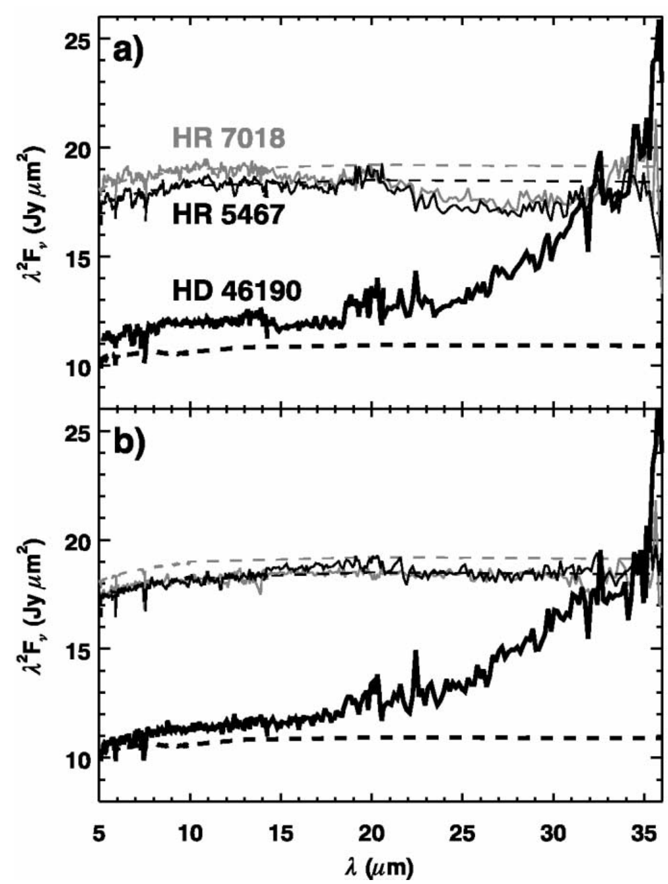

FIG. 2.—Spectra of HR 7018 (*gray line*), HR 5467 (*thin black line*), and HD 46190 (*thick black line*) calibrated and compared to their spectral templates (*dashed lines*). Panel *a* shows the spectra as calibrated with the K giants, while panel *b* shows the recalibration using HR 7018 and HR 5467. The recalibration has removed much of the detailed structure apparent in (*a*), but the excess in HD 46190 remains.

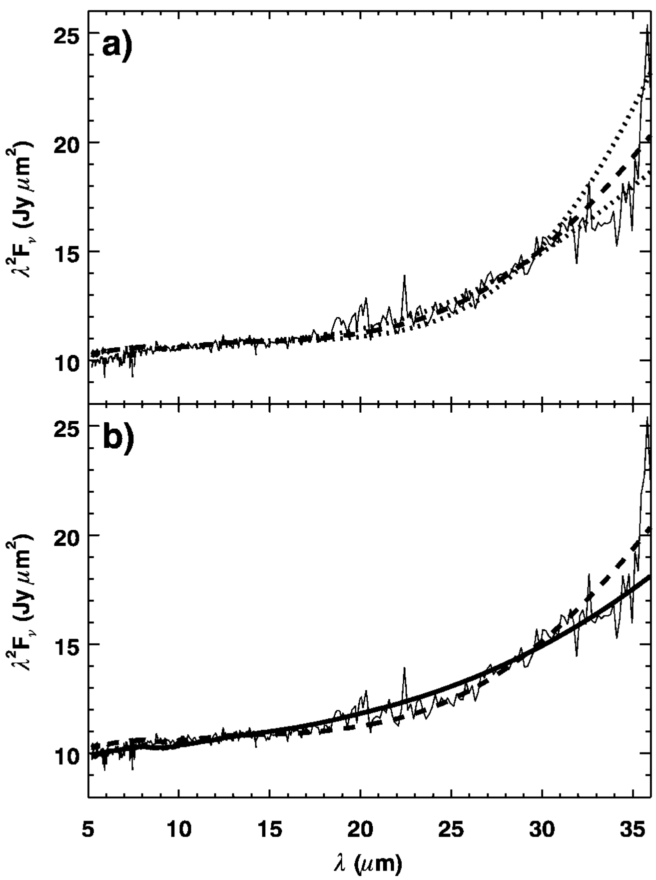

FIG. 3.—Comparison of models fitted to the spectrum of HD 46190. (*a*) Combinations of the spectral template (fitted to the spectrum from 10 to 18 μm) and a single blackbody. The central dashed line is for an 81 K blackbody, and the dotted lines above and below it correspond to temperatures of 65 and 97 K. (*b*) Model with a star and an excess proportional to wavelength (*thick black line*). The dashed line is the 81 K blackbody excess for comparison. Both models fit the data equally well.

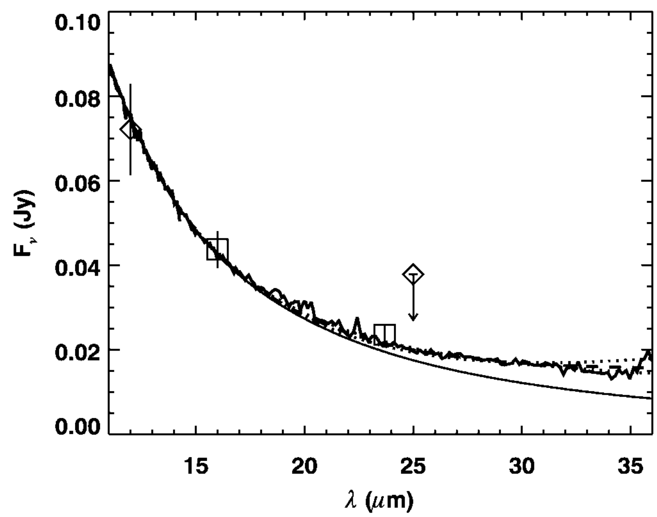

FIG. 4.—Spectrum of HD 46190 compared to the photometry from *IRAS* (*diamonds*) and *Spitzer* (*rectangles*). The 16 μm photometry is from the IRS peak-up array; the 24 μm photometry is from MIPS. Both have 10% error bars. The stellar continuum (*thin solid line*) and the models shown in Fig. 3*a* (*dashed and dotted lines*) are shown for comparison.

To examine the nature of the long-wavelength excess, we assume that the observed spectrum can be modeled as the sum of a stellar continuum and an excess. We also assume that the difference between the template and the spectrum of HD 46190 at shorter wavelengths is simply the result of photometric uncertainty in the observed spectrum, so we shift the observed spectrum to fit the template over the wavelength range 10–18 μm. The spectrum immediately to the red and blue of this range appears to be more poorly calibrated. Fitting from 10 to 18 μm requires that we multiply the observed spectrum by 0.933.

Subtracting the stellar contribution from the spectrum reveals an excess that increases with wavelength and shows no significant spectral structure beyond what might be expected with the current state of the calibration. Fitting a Planck function to the excess from 24 to 32 μm gives a blackbody temperature of 88 K. Expanding the fitting range to 35 μm forces the Planck function to the shoulder in the 31–35 μm range, which drives the temperature up to 100 K. The difference between these two temperatures depends on how closely one should fit the spectrum of HD 46190 beyond 32 μm, which is the least reliable wavelength range. The same fit to the spectrum as calibrated with the K giants gives lower temperatures, 67 and 69 K, respectively. Averaging these four temperatures gives a mean of 81 ± 16 K. Figure 3*a* shows the spectrum of HD 46190 as fitted with a combination of the spectral template and a cool blackbody.

4. DISCUSSION

Figure 4 compares the spectrum of HD 46190, the template, and our models, and photometry from the *Infrared Astronomical Satellite* (*IRAS*) and *Spitzer* in more familiar F_ν units. The *IRAS* photometry is from the *IRAS* Faint Source Catalog (Moshir et al. 1990), and it has been color-corrected. The photometry at 16 μm is from IRS peak-up images obtained while centering on HD 46190 before moving it to a spectroscopic aperture. HR 5467 served as the calibrator for the peak-up photometry. The photometry at 24 μm is from the Multiband Imaging Photometer for *Spitzer* (MIPS; Rieke et al. 2004). Both the IRS photometry and MIPS photometry are plotted with 10% error bars and are color-corrected.

The IRS peak-up photometry at 16 μm agrees closely with the template and the corrected spectrum. The photometry from MIPS at 24 μm is at 23.5 ± 2.4 mJy. The 24.0 μm flux from the spectrum is 21.1 ± 0.4 mJy (after normalization), and the flux from the template is 19.0 mJy. Thus, the spectroscopic excess at 24 μm is 11%, compared to 24% (±13%) as measured by MIPS. While the IRS peak-up and MIPS photometry confirm the presence of an excess in the spectrum at 24 μm, some disagreement about the strength of the excess remains at the 1 σ level. Longer wavelength photometry from *Spitzer* would not only help to strengthen the evidence for an excess, but it would also better constrain the temperature of the dust.

The photometry from the *IRAS* Faint Source Catalog (Moshir et al. 1990) only gives an upper limit for HD 46190 at 25 μm. As Table 1 shows, the uncertainty of the 25 μm photometry for HR 7018 and HR 5467 was too large to help discriminate the presence of long-wavelength excesses in these objects before the launch of *Spitzer*. The other A dwarfs observed as standards were bright enough for reliable photometry at 25 μm, so out of a total of 13 A dwarfs observed as standards by the IRS through campaign 5, only the three sources considered here had a significant chance of showing an excess at longer wavelengths. Of these three sources, one shows an excess and the other two are naked stars.

Since the discovery of a debris disk around α Lyr (Aumann et al. 1984), attempts to determine the fraction of main-sequence stars associated with long-wavelength excesses using data from *IRAS* and the *Infrared Space Observatory* have produced results varying from only a few percent (e.g., Fajardo-Acosta et al. 2000; Laureijs et al. 2002) to ∼14% (Fajardo-Acosta et al. 1999), but the fraction of A dwarfs with excesses is more like 40%–50%. In the sample of Laureijs et al. (2002), all five of the sources with Vega-like excesses are A dwarfs, out of a total of 11 A dwarfs. Aumann (1985) used *IRAS* photometry at 12 and 60 μm to identify excesses in three out of eight or six out of 12 A dwarfs, depending on how he defined his sample. Our finding of one A dwarf with an excess out of three sources is consistent with these previous results. The MIPS team is currently working to extend this method to a much larger and fainter sample of main-sequence stars.

The long-wavelength excess in the spectrum of HD 46190 may arise from material associated with the star, such as a debris disk, or it might arise from nearby interstellar material, as seen in the Pleiades, for example. The Pleiades lie somewhere between 118 and 136 pc from the Sun (Stello & Nissen 2001), and the exciting stars are late B giants. The *Hipparcos* Catalogue (Perryman et al. 1997) gives a trigonometric parallax for HD 46190 of 12.7 ± 0.5 mas, or a distance of 79 ± 3 pc. On this basis, one would expect that scattered emission would be apparent in the vicinity of HD 46190, as it is around the Pleiades. The Palomar Sky Survey and the Two Micron All Sky Survey (2MASS) show no evidence for any scattered emission near HD 46190. Furthermore, HD 46190 lies along the axis of greatest elongation of the Local Bubble as measured by spectroscopy of the Na D line in a sample of stars within 300 pc of the Sun (Sfeir et al. 1999). Kalas et al. (2002) have identified reflection nebulosities around several stars with Vega-like spectral excesses, but all of these sources lie beyond the walls of the Local Bubble, while HD 46190 lies well within it. Thus, we conclude that the spectral excess in HD 46190 arises from a debris disk and not the Pleaides phenomenon.

If we assume that spherical blackbody radiators produce the excess, then the temperature of the particles scales as $T = T_*(R_*/2d)^{0.5}$, where T_* is the effective temperature of the star, and R_* and d are the radius of and distance to the star. HD 46190 has a spectral type of A0 V, which implies that $T_* = 9790$ K and $R_* = 2.4\,R_\odot$. Dust at a temperature of 81 K would be 82 AU from the central star. Our uncertainty in temperature is large, though, and a range from 65 to 97 K is reasonably consistent with the data. The corresponding range in distances from the central star for spherical blackbodies is 127–57 AU.

The range of temperatures and locations of the emitting material suggests a region analogous to the Kuiper Belt in the solar system. The lack of any obvious spectral structure suggests that the particles are larger than ∼10 μm in diameter.

The spectrum of HD 46190 closely resembles the spectrum of HR 1570, an A0 dwarf found by Jura et al. (2004) to have a dust excess that can be modeled with a single blackbody temperature of 88 K. As Jura et al. (2004) describe, the dust spectrum of this source can also be modeled as $F_\nu \propto \lambda$, and this second model is consistent with a disk where Poynting-Robertson drag is feeding material from the outer disk into the inner regions (e.g., Buitrago & Mediavilla 1985; Waters et al. 1988).

Figure 3*b* compares the best fits to the spectrum of HD 46190 for models combining a star with (1) an 81 K blackbody and (2) an excess proportional to wavelength. Both models fit the spectrum equally well, possibly for the simple reason that the dust excess does not have sufficient contrast to the stellar photosphere at these wavelengths to distinguish between them. Photometry at longer wavelengths would remove this degeneracy.

5. SUMMARY

We have serendipitously discovered a long-wavelength excess in the infrared spectrum of HD 46190, an A0 dwarf in our sample of calibrators and cross-calibrators for the IRS on the *Spitzer Space Telescope*. Of the A dwarfs observed as standards by the IRS, only three were faint enough to preclude the use of reliable infrared photometry to diagnose potential disk excesses prior to launch. The other two, HR 7018 and HR 5467, are clearly naked stars.

A debris disk of large and cool dust grains explains the excess in the spectrum of HD 46190 well. The best fit for a single blackbody temperature is 81 K, which would place the material 82 AU from the central star. However, the excess spectrum can also be fitted with excess emission that is proportional to wavelength, raising the possibility that some dust may be in the inner disk.

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