

## NEW SUBMILLIMETER LIMITS ON DUST IN THE 55 CANCRI PLANETARY SYSTEM

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### ABSTRACT

We present new, high-sensitivity submillimeter observations toward 55 Cancri, a nearby G8 star with one, or possibly two, known planetary companion(s). Our 850  $\mu\text{m}$  map, obtained with the Submillimeter Common-User Bolometric Array on the James Clerk Maxwell Telescope, shows three peaks of emission at the 2.5 mJy level in the vicinity of the star's position. However, the observed peaks are 25"–40" away from the star, and a deep *R*-band optical image reveals faint point sources that coincide with two of the submillimeter peaks. Thus, we do not find evidence of dust emission spatially associated with 55 Cancri. The excess 60  $\mu\text{m}$  emission detected with the *Infrared Space Observatory* may originate from one or more of the 850  $\mu\text{m}$  peaks that we attribute to background sources. Our new results, together with the *Hubble Space Telescope* NICMOS coronagraphic images in the near-infrared, place stringent limits on the amount of dust in this planetary system and argue against the existence of a detectable circumstellar dust disk around 55 Cnc.

*Subject headings:* circumstellar matter — planetary systems — stars: individual (55 Cancri)

*On-line material:* color figure

### 1. INTRODUCTION

Dusty disks that are believed to be the debris of planetary formation have now been imaged at infrared and submillimeter wavelengths around several nearby main-sequence stars including  $\beta$  Pictoris, HR 4796A, Vega, Fomalhaut, and  $\epsilon$  Eridani (Smith & Terrile 1984; Holland et al. 1998; Jayawardhana et al. 1998; Greaves et al. 1998). These disks may be young analogs of the Kuiper belt in our solar system (Jewitt & Luu 2000). The  $\sim 5$  Gyr old (Gonzalez & Vanture 1998; Baliunas et al. 1997) G8 V star 55 Cancri (HR 3522; HD 75732), at a distance of 13 pc, has attracted much attention in recent years for having planet(s) as well as a possible dust disk. The only other example reported to date of a planet coexisting with a disk is  $\epsilon$  Eri, which has a well-resolved, prominent disk in the submillimeter images (Greaves et al. 1998). However, the presence of a giant planet around  $\epsilon$  Eri (Hatzes et al. 2000) is difficult to establish with radial velocity measurements because of the high level of stellar chromospheric activity and possible face-on orientation of the planet orbit. On the other hand, in the case of 55 Cnc, it is the putative disk that is in dispute.

The star 55 Cnc harbors an inner planet with  $M \sin i = 0.84 M_J$  in an orbit with a semimajor axis of 0.11 AU (Butler et al. 1997). There is evidence of a second planet at several AU in the form of a residual drift in the radial velocity over the past 10 years (Marcy & Butler 1998; Fischer et al. 2001). It has been noted that 55 Cnc—along with 14 Her, another planet-bearing star—is one of the two most metal-rich stars in the solar neighborhood, with  $[\text{Fe}/\text{H}] \geq +0.4$ , perhaps suggesting a causal link between planets and the metallicity of the parent star (Gonzalez & Vanture 1998; Gonzalez, Wallerstein, & Saar 1999).

Dominik et al. (1998) first presented evidence for a Vega-like disk around 55 Cnc based on *Infrared Space Observatory* (ISO) measurements between 25 and 180  $\mu\text{m}$ . They detected the stellar photosphere at 25  $\mu\text{m}$ , significant excess emission

at 60  $\mu\text{m}$ , and infrared cirrus at 135 and 180  $\mu\text{m}$ . Trilling & Brown (1998) and Trilling, Brown, & Rivkin (2000) confirmed the debris disk interpretation of the far-infrared data by reporting a resolved scattered-light disk out to a radius of 3".24 (40 AU) in ground-based, near-infrared, coronagraphic images. They estimated the disk position angle as  $50^\circ \pm 10^\circ$ , inclination  $27_{-11}^{+8}$  deg, and minimum dust mass  $0.4 M_\oplus$ . Our previous submillimeter observations detected 850  $\mu\text{m}$  flux of  $2.8 \pm 0.5$  mJy and 450  $\mu\text{m}$  flux of  $7.9 \pm 4.2$  mJy in the direction of 55 Cnc, which implied a dust mass at least 100 times lower than the Trilling & Brown (1998) estimate. Our mid-infrared observations at 10 and 18  $\mu\text{m}$  showed no excess emission above the stellar photospheric level (Jayawardhana et al. 2000). Using the NICMOS near-infrared camera on the *Hubble Space Telescope* (HST), Schneider et al. (2001) were not able to confirm the results of Trilling and coworkers down to a flux level that is 10 times lower.

Here we report new, extremely sensitive submillimeter observations in the vicinity of 55 Cnc using the Submillimeter Common-User Bolometric Array (SCUBA) on the James Clerk Maxwell Telescope (JCMT). We find three faint sources of emission, none of which are centered exactly on 55 Cnc. Our results, combined with the NICMOS observations, place strong limits on the amount of dust emission associated with the 55 Cnc planetary system.

### 2. OBSERVATIONS AND RESULTS

The 850  $\mu\text{m}$  observations of 55 Cnc presented here were carried out with the SCUBA instrument (Holland et al. 1999) on the JCMT on Mauna Kea, Hawaii. The data were obtained over several observing runs in 1999–2000 using the SCUBA photometry mode. In total, there were 31 separate photometric observations at two different pointings in the vicinity of 55 Cnc for a total on-source integration time of 7.1 hr. Zenith atmospheric opacities at 850  $\mu\text{m}$  ranged from 0.10 to 0.35. When co-added together, the maps were noise-weighted to account for the range of conditions. Observations of Uranus were used for calibrations. Pointing accuracy was 2", which is small compared with the beam size of 15" at 850  $\mu\text{m}$  (FWHM). The data were

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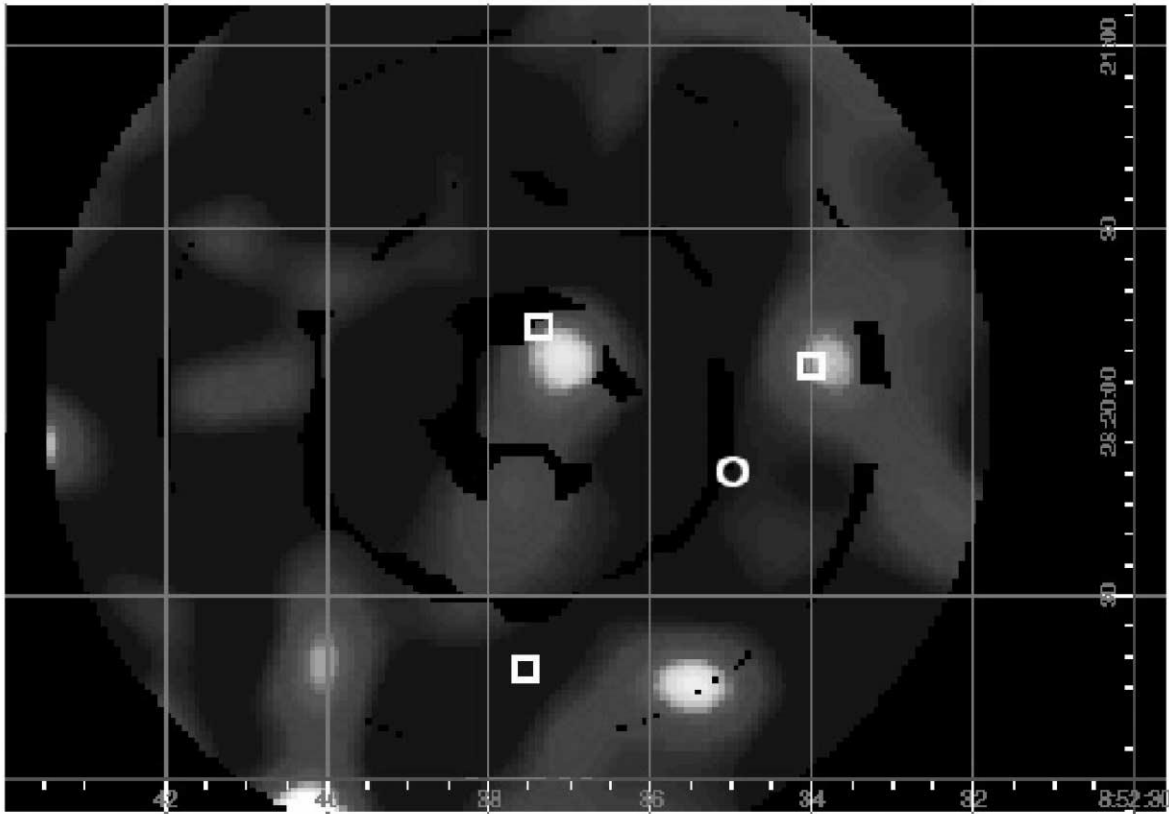


FIG. 1.—JCMT/SCUBA  $850\ \mu\text{m}$  map of the region surrounding 55 Cnc. The star's position is marked by the white circle. Positions of optical  $R$ -band sources are marked by white boxes. The map is produced from photometry observations at two different pointings. Each individual pointing produces a map with concentric rings. Even with two separate pointings, combined with the effects of sky rotation, a fully sampled map is not produced, and hence residual holes are evident. [See the electronic edition of the *Journal* for a color version of this figure.]

reduced using the SCUBA User Reduction Facility (Jenness & Lightfoot 1998). The co-added map is shown in Figure 1.

The  $850\ \mu\text{m}$  map shows three obvious peaks of emission at the  $\sim 2.5\ \text{mJy}$  level. Their fluxes and positions are given in Table 1. The rest of the field is rather flat, with an rms noise of about  $0.4\ \text{mJy}$ . Each of the peaks is  $25''$ – $40''$  ( $325$ – $500\ \text{AU}$ ) away from 55 Cnc. There is no emission exactly coincident with the position of 55 Cnc.

We also obtained optical  $R$ -band CCD images at the University of Hawaii 2.2 m telescope on Mauna Kea on 2000 January 31. An optical coronagraph (Kalas & Jewitt 1996) blocked the stellar point-spread function (PSF) at the focal plane using a hard-edged occulting spot  $6''.5$  in diameter. A Lyot stop at a reimaged pupil plane suppressed diffracted light from the telescope mirrors and support structures. The imaging camera was a Tek  $2048 \times 2048$  CCD with a plate scale of  $0''.407\ \text{pixel}^{-1}$  and with a circular field of view  $5''.5$  in diameter.

Thirty-two frames with 20 s integration times each were obtained for 55 Cnc. Immediately after these observations, we imaged a nearby bright star (HR 3521) with the same instrumental configuration. These data serve as a reference for subtracting the 55 Cnc PSF.

After bias subtraction and flat-fielding, we selected 20 frames from the 55 Cnc data that were well centered behind the occulting spot and that had field star PSFs with FWHMs in the range of  $1''.0$ – $1''.2$ . These frames were median-combined to produce an image of 55 Cnc with a 400 s cumulative integration time. The HR 3521 data were for the most part unsuitable for subtracting the 55 Cnc PSF because of the poor centering of HR 3521 behind the occulting spot. However, one HR 3521 frame (15 s integration) was well centered and adopted as the PSF reference source. We azimuthally smoothed this PSF by rotating the image in  $20^\circ$  increments and median-combining the resulting frames. The azimuthally smoothed PSF was sub-

TABLE 1  
POSITIONS AND FLUXES OF SUBMILLIMETER AND OPTICAL SOURCES

SOURCE	SUBMILLIMETER			OPTICAL			DIFFERENCE (arcsec)	
	R.A. (2000)	Decl. (2000)	$850\ \mu\text{m}$ Flux (mJy)	R.A. (2000)	Decl. (2000)	$R$ Magnitude	R.A.	Decl.
1 .....	08 52 37.1	28 20 09.0	2.7	08 52 37.4	+28 20 14.6	19.0	4.0	5.6
2 .....	08 52 33.8	28 20 09.0	2.4	08 52 34.0	+28 20 06.3	21.1	4.0	2.7
3 .....	08 52 35.4	28 19 16.0	2.8	08 52 37.5	+28 19 18.2	21.5	29.1	2.4

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

tracted from the original HR 3521 frame, revealing residual light along a southeast-northwest axis. The residual halo of the self-subtracted PSF is probably due to a combination of instrumental and atmospheric aberrations.

The azimuthally smoothed HR 3521 PSF was registered, scaled, and subtracted from 55 Cnc (Fig. 2). The subtracted 55 Cnc PSF also appears to have residual light symmetrically distributed about the occulting spot along a southeast-northwest axis. This axis is perpendicular to the position angle of the disk reported by Trilling & Brown (1998). The residual PSF halo extends from approximately  $4''$  to  $16''$  radius, decreasing approximately with the fourth power of radius, and with a surface brightness in the range of  $17.5$ – $23.0$  mag arcsec $^{-2}$ . Trilling & Brown (1998) report an  $H$ -band disk surface brightness that falls below  $24$  mag arcsec $^{-2}$  beyond a  $4''$  radius. Our data do not have the sensitivity to detect extended nebulosity fainter than  $23.0$  mag arcsec $^{-2}$ .

We performed a second PSF subtraction using an azimuthally smoothed version of the 55 Cnc image as described above for HR 3521. This self-subtraction of 55 Cnc also resulted in residual light along a southeast-northwest axis. Because the residual light appears in both the 55 Cnc and HR 3521 self-subtractions, we attribute it purely to instrumental and atmospheric aberrations. The dominant source is most likely a static aberration such as focus error. Finally, as a third PSF subtraction, we selected the best 55 Cnc frame and registered, scaled, and subtracted the unsmoothed HR 3521 frame. Although the result contains significantly greater noise than the image in Figure 2, the residual light does not contain significant azimuthal asymmetry.

Three point sources are detected in the  $R$ -band image within a  $40''$  radius surrounding 55 Cnc (Fig. 2). Their positions are indicated by white boxes in Figure 1 to show their relation to the  $850\ \mu\text{m}$  emission. Table 1 lists the magnitudes of the  $R$ -band sources and their offsets in units of arcseconds from the centroids of  $850\ \mu\text{m}$  emission. The two point sources north of 55 Cnc may be optical counterparts of the  $850\ \mu\text{m}$  sources. No object was detected in the optical data that corresponds to the position of the submillimeter peak south of 55 Cnc. The  $3\ \sigma$  point-source sensitivity of the optical data is  $m_R = 22.2$  mag, as determined by injecting artificial point sources near the positions of the optically detected sources and the  $850\ \mu\text{m}$  peaks.

### 3. DISCUSSION

Our submillimeter observations of the field around 55 Cnc reveal three faint sources of emission at the  $\sim 2.5$  mJy level. The separation between 55 Cnc and each of the  $850\ \mu\text{m}$  peaks is approximately two beamwidths and thus unambiguously noncoincident with the star. The spatial association of two of the submillimeter peaks with optically detected point sources (Fig. 2) makes it unlikely that the  $850\ \mu\text{m}$  peaks are components of an extended dust ring around 55 Cnc.

According to the galaxy counts derived by Blain et al. (1999) from their deep submillimeter survey, one would expect  $3 \pm 1$  galaxies brighter than 1 mJy at  $850\ \mu\text{m}$  in a patch of the sky with a  $40''$  radius. Thus, all of the peaks in our  $850\ \mu\text{m}$  map could be background galaxies. In that case, the optical point sources could be either bright compact nuclei of the galaxies or stars whose positional coincidence with the submillimeter peaks is simply due to chance alignments in the line of sight. Without additional color information or spectra, we are not able to comment further on the nature of these sources.

If the submillimeter peaks are due to unrelated sources, which appears likely, then we can place an upper limit of

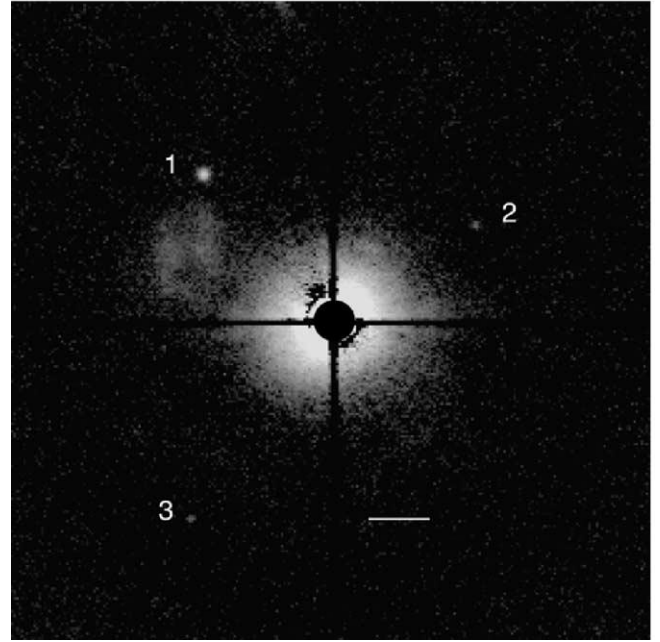


FIG. 2.— $R$ -band coronagraphic image of 55 Cnc after PSF subtraction. North is up, east is left, and the bar represents  $10''$ . A  $6''.5$  diameter, hard-edged occulting spot is supported by four wires at the telescope focal plane. Spurious instrumental scattered light is evident as an extended feature northeast of 55 Cnc and south of source 1.

$\sim 0.4$  mJy to the  $850\ \mu\text{m}$  emission from within  $\sim 100$  AU of 55 Cnc itself. Since the submillimeter flux is relatively insensitive to the temperature of dust grains, we can use it to derive a limit on the dust mass associated with 55 Cnc. Following Jura et al. (1995), the dust mass  $M_d$  is given by

$$M_d = F_\nu R^2 \lambda^2 / [2kT_{\text{gr}} K_{\text{abs}}(\lambda)], \quad (1)$$

if  $R$  denotes the distance from the Sun to 55 Cnc. Assuming a dust absorption coefficient  $K_{\text{abs}}(\lambda)$  between  $1.7$  and  $0.4$  cm $^2$  g $^{-1}$  at  $850\ \mu\text{m}$  (Greaves et al. 1998), we obtain an upper limit to the dust mass of  $(1-7) \times 10^{-4} M_\oplus$ , assuming a disk temperature range of  $T = 100$ – $130$  K. The lower value of  $K_{\text{abs}}(\lambda)$  is suggested by models of large, icy grains (Pollack et al. 1994), while the higher estimate has been used for previous observations of debris disks (Holland et al. 1998). It is important to point out that submillimeter observations are not sensitive to very large grains or planetesimals, which could dominate the total mass while adding little submillimeter emission. Therefore, our dust mass estimate is only a lower limit to the total mass and does not rule out a Kuiper belt analog around 55 Cnc comprised of larger particles.

The  $HST/NICMOS$  coronagraphic observations by Schneider et al. (2001) at  $1.1\ \mu\text{m}$  did not detect a dust disk around 55 Cnc down to a flux level 10 times below that reported by Trilling and coworkers. Schneider et al. also searched for and failed to find a suggested flux-excess anisotropy in the ratio of  $1.7 : 1$  in the circumstellar background along and orthogonal to the plane of the putative disk. They concluded that if such a disk does exist, its surface brightness in the near-infrared (and thus its dust mass) would have to be an order of magnitude lower than the Trilling et al. estimate.

Our new limit on the dust mass in the 55 Cnc planetary system is a factor of  $\sim 7$  lower than that reported by Jayawardhana et al. (2000), which was already a factor of  $\sim 100$  below

the value reported by Trilling & Brown (1998) based on near-infrared scattered-light observations. We have now established that our previous submillimeter “detection” was not exactly coincident with 55 Cnc but was close to one of the peaks (source 1) in Figure 1. The pointing center used by Jayawardhana et al. (2000) was fortuitously close to this source because of a coordinate transcription error. Given the large *ISO* beam size of  $45'' \times 45''$  per detector element, it is plausible that the Dominik et al. (1998) *ISO* detection at  $60 \mu\text{m}$  also originates from one or more of these nearby, likely unrelated sources and is not due to a dust disk around 55 Cnc.

In light of our results, those of Schneider et al. (2001), and the possibility of an unrelated source accounting for the *ISO* detection, there is little evidence of a dust disk around 55 Cnc other than the scattered-light coronagraphic images of Trilling & Brown (1998). The limits on the amount of small dust particles in the 55 Cnc planetary system from submillimeter and *HST/NICMOS* measurements are inconsistent with the Trilling & Brown (1998) estimate by a factor of 10 at best and 700 at worst. As Schneider et al. suggest, the most likely explanation for this significant discrepancy is that the detection reported by Trilling & Brown (1998) is spurious.

#### 4. SUMMARY

We have obtained sensitive submillimeter observations toward (and around) the 55 Cnc planetary system. We detect

three peaks at the 2.5 mJy level in our  $850 \mu\text{m}$  map that are offset from 55 Cnc by  $25''$ – $40''$ . Optical coronagraphic observations show three point sources over the same region, with two sources north of 55 Cnc approximately aligned with two  $850 \mu\text{m}$  peaks. These peaks are likely unrelated background sources. Our results, together with the *HST/NICMOS* observations of Schneider et al. (2001), place stringent limits on the amount of dust in the 55 Cnc system and are inconsistent with the existence of a circumstellar dust disk as reported by Dominik et al. (1998) and Trilling & Brown (1998).

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