Mid-Infrared T-Dwarf Mass Companion Limits for Nearby Planet-Host Stars

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Abstract

The sensitivity of Spitzer's IRAC at 4.5 µm provides the ability to use direct imaging (Luhman 2007) to capture light from Y and T dwarfs expected to have peak emission in this band (Patten 2006). Using PSF subtraction techniques, we can detect sources with better than 10^4 contrast at separations as close as 12 arcseconds. Potential substellar companions can be identified from their characteristically red colors between the 3.6 µm and 4.5 µm photometric bands. In a sample of 14 nearby stars already found to have planetary companions from radial velocity searches, we found no sources consistent with substellar-mass companion colors within 20 arc seconds of the stars. This corresponds to 4.5 µm upper limits for objects of 5 MJ at 1 Gyr age and 10 pc distance. We present a description of the point spread function and artifact subtraction process necessary to achieve this result.

Star sample

The set is comprised of 14 stars within 15 pc of the sun, with detected radial velocity planets, omitting the brightest sources. Eight of these stars have at least one detected planet with high eccentricity, which could indicate a perturbing outer body.

Target	Dist (pc)	Age (Gyr)	Type	Ks Magn.	Notes
SCR 1845-6357	3.9	>0.1	M8.5V	8.5	one close T dwarf companion
GL 876	4.7	9.9	M4V	5.0	3 planets, one with high e
GL 581	6.7	4.3	M3	5.8	
GJ 849	8.8	?	M3.5	5.6	star has radial velocity trend
GJ 436	10.2	10.5	M2.5	6.1	star has radial velocity trend one planet with high e
GL 86	11.0	2.3	K1V	4.1	1.7" binary system
HD 3651	11.0	5.3	K0V	4.0	known T dwarf companion one planet with high e
HD 69830	12.6	7.0	K0V	4.2	3 planets, one with high e, debris disk
HD 147513	12.9	0.7	G3/G5V	3.9	one planet with high e
47 UMa	13.3	6.0	G0V	3.8	2 planets
55 Cnc	13.4	5.5	G8V	4.0	4 planets, 3 with high e
ups And	13.5	2.4	F8V	2.9	3 planets, 2 with high e
51 Peg	14.7	6.6	G2IV	3.9	hot Jupiter
HD 160691	15.3	6.4	G3	3.7	4 planets, 2 with high e

Data Processing

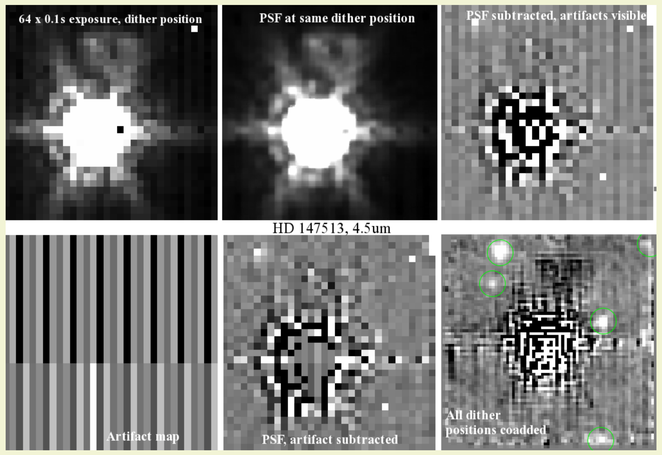


Figure 1, above, demonstrates the process of removing the point spread function and electronic artifacts for a star, in this case HD 147513. Marengo (2009) used a similar process with a single PSF, but the location on the detector of IRAC subarray images depends on the dither position, making the PSF in each position slightly different. The PSF for a given dither position is created from a subpixel-sampled, median image of the other stars in the set. Subtracting this PSF makes visible the electronic column and pulldown artifacts, which are then estimated and subtracted. The nine cleaned images are then coadded on a subpixel grid to produce the final image.

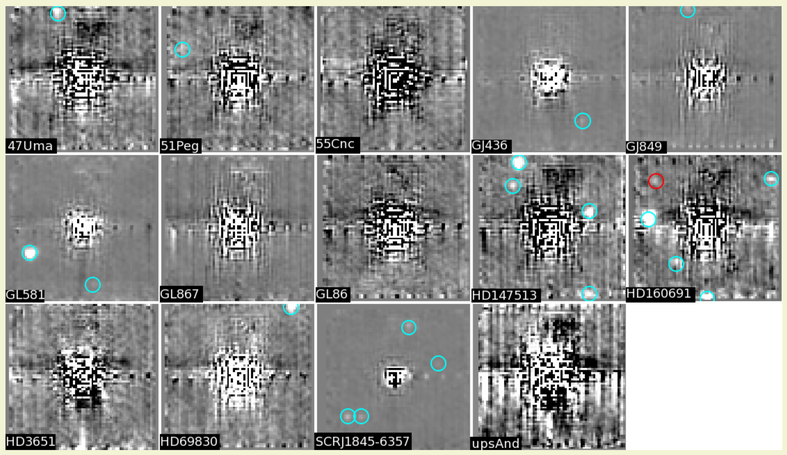


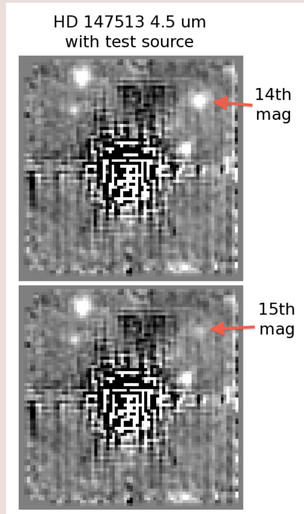
Figure 2, above, shows the final image for each star. Circled in cyan are objects detected (3-sigma) in 3.6 and 4.5 µm; all have colors consistent with background sources. Circled in red is an object only visible in 4.5 µm.

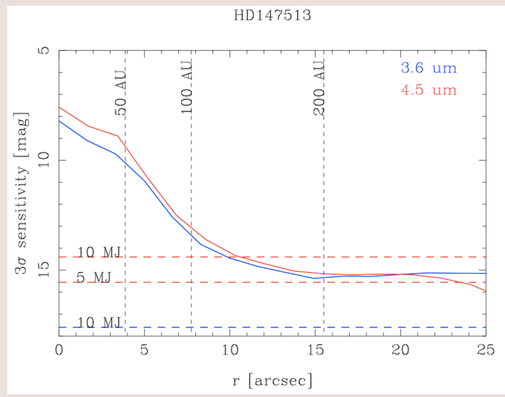
Results

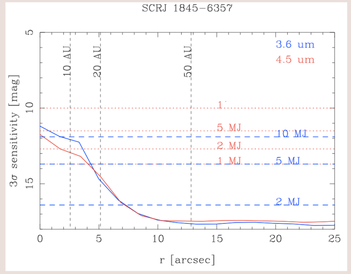
Sensitivity

For each object, the sensitivity is limited by the noise level; an aperture placed on an area of only noise represents the limit of detectable sources. This noise-equivalent flux density is calculated as the product of the area of the full-width half maximum of the stellar point spread function and the average (RMS) noise of the image, for a given radial distance from the star. Sample sensitivity curves for the median case (HD 147513) and our best case (SCRJ1845-6357) are below (**Figure 4**).

We visually verified the sensitivity by planting an artificial source at a given distance from the parent star (**Figure 3**) and determining the magnitude at which it becomes indistinguishable from background noise.







Predicted 4.5 µm Planet Magnitudes (10 pc)			
Mass	0.1 Gyr	0.3 Gyr	1.0 Gyr
1 MJ	15.7	17.9	20.7
2 MJ	14.7	16.1	18.2
5 MJ	13.5	14.6	15.3
10 MJ	12.0	13.0	14.1
based on models by Burrows et al. 2003			

Conclusions

We found no objects within 25 arcseconds of sample stars with [3.6]-[4.5] colors consistent with a Y- or T-dwarf companion. We calculated limits for sizes and orbital distances of non-detected companion objects for each star. One object in the frame of HD 160691 was only detected in 4.5 µm with a magnitude of 14.4; our 3.6 µm sensitivity at that distance is 15th magnitude, which puts this object in the range of being a possible T5 or later companion. Further observation will be necessary to place better constraints on this object's color.

References

Marengo et al. 2009, ApJ 700.1647M
Burrows et al. 2003, ApJ 596.587
Luhman et al, 2007, ApJ 654 L570
Patten et al, 2006, ApJ 651.502

This work is based [in part] on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. Support for this work was provided by NASA through an award issued by JPL/Caltech. Poster presented at Exploring Strange New Worlds, May 2011.