Spitzer / IRAC Photometry of M, L, and T Dwarfs

Brian M. Patten[a], Todd J. Henry[b], Adam Burrows[c], John R. Stauffer[d], Deepak Raghavan[b], James Liebert[c], Kevin L. Luhman[a], Joseph L. Hora[a], Tom Megeath[a], Massimo Marengo[a], & Giovanni G. Fazio[a]

[a]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA, USA 02138
[b]Georgia State University, Department of Physics & Astronomy, PO Box 4106, Atlanta, GA 30302-4106
[c]University of Arizona, Steward Observatory, Department of Astronomy, 933 N. Cherry Ave., Tucson, AZ 85721
[d]Spitzer Science Center, MS-220-6, Caltech, Pasadena, CA, USA 91125

The *Spitzer Space Telescope* Infrared Array Camera (IRAC) is a four-channel camera that uses two pairs of 256x256 pixel InSb and Si:As IBC detectors to provide simultaneous images at 3.6, 4.5, 5.8, and 8 µm. Two adjacent 5.2x5.2 arcmin fields-of-view in the *Spitzer* focal plane are viewed by the 4 channels in pairs (3.6/5.8 µm and 4.5/8 µm).

The IRAC Nearby Stars guaranteed time observer (GTO) program consists of some ~255 stars and brown dwarfs located within ~30 pc of the Sun which will be imaged with IRAC in order to search for low-mass companions on distance scales of ~50 to 4000 AU from the primary to limiting mass of ~10–20 M_{Jup}. This survey will allow us to determine the frequency of planetary and sub-stellar mass companions over the full range of possible separations to very low masses.

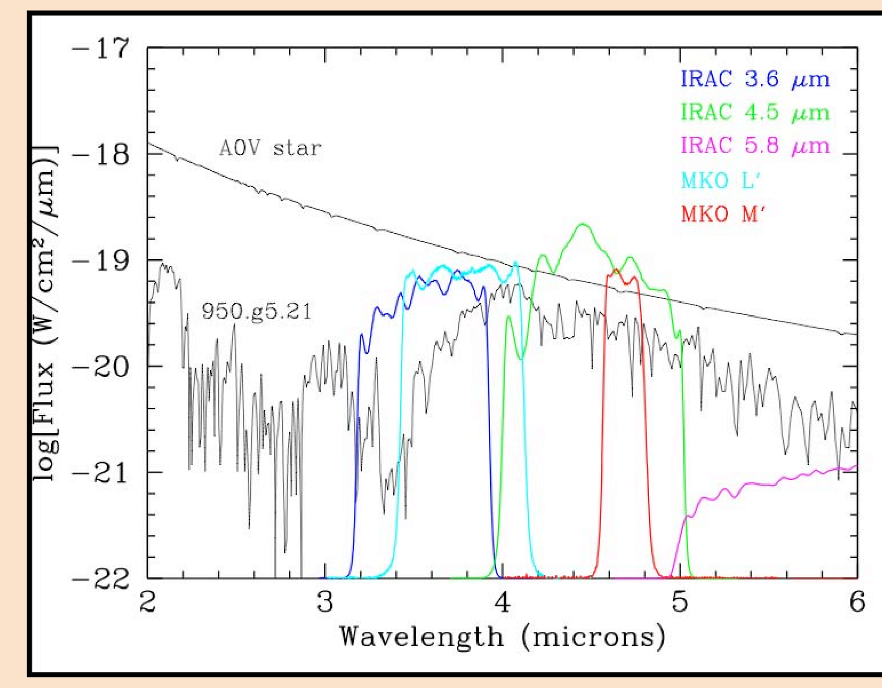
An important subset of the Nearby Stars GTO program are some ~88 late-M, L, and T dwarfs for which we have specifically acquired unsaturated IRAC photometry in order to define the IRAC colors over this spectral type range.

Observations, reduction, and analysis

Each target in the MLT GTO program was observed using with 30-second FRAMETIMEs in high dynamic range mode for each of a 5-position Gaussian dither pattern. This strategy insured that unsaturated photometry were acquired in all 4 IRAC channels for all targets as well to mitigate the effects of cosmic ray hits and bad pixels on the arrays. This resulted in an effective exposure time of 134 + 5 seconds per target for 3-σ limiting magnitudes of 20.3, 19.2, 16.7, and 15.9 for the 3.6–8.0 µm bands respectively for a medium background in the Vega-relative system.

The Basic Calibrated Data (BCD) used for this analysis were produced by the *version 10** pipeline at the SSC. The individual BCD frames in the dither pattern were coadded and the photometry for both the coadd and the individual frames were extracted using aperture photometry routines in IRAF.

**In the version 11 pipeline, the SSC will be introducing an update to the calibration for IRAC. This will be reflected in Patten et al. (2005).*

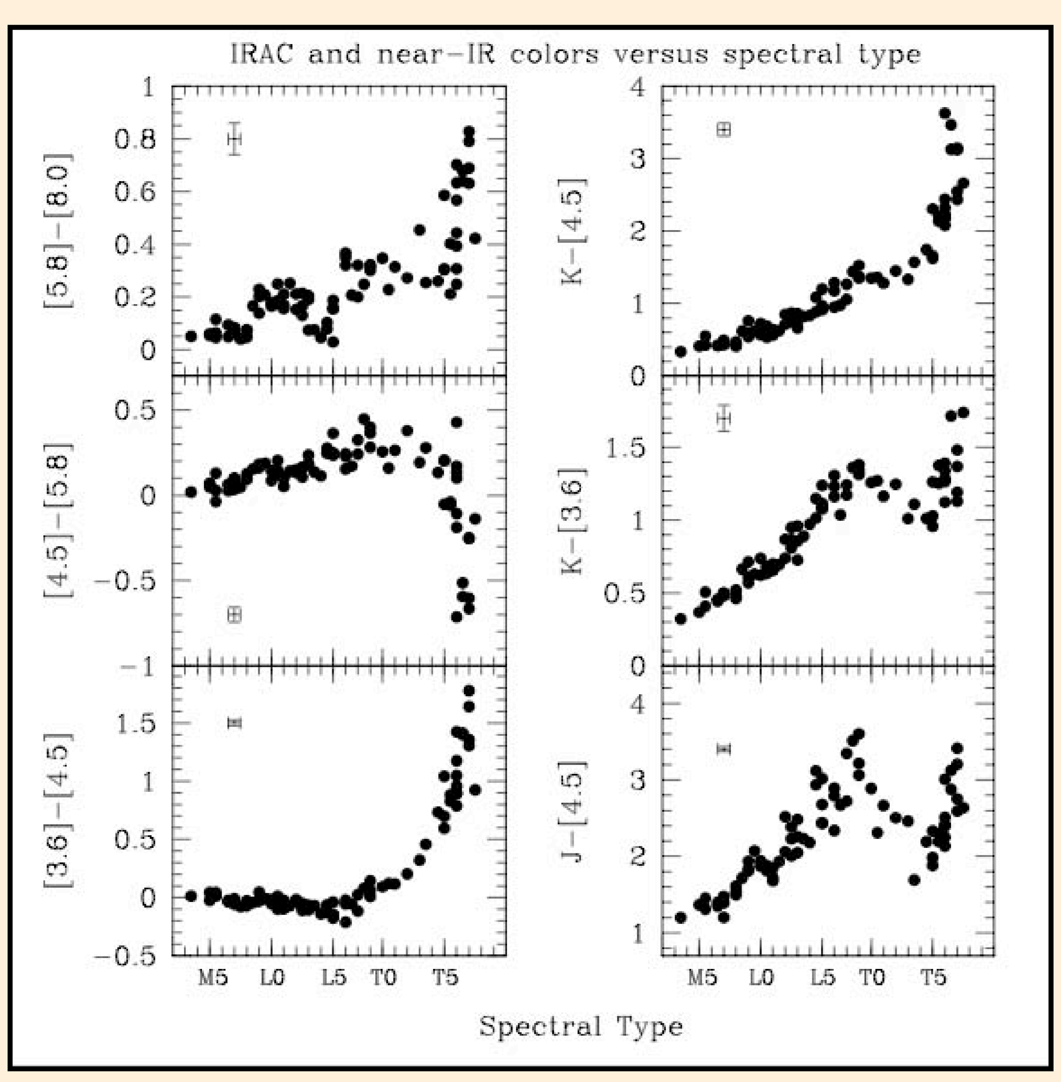


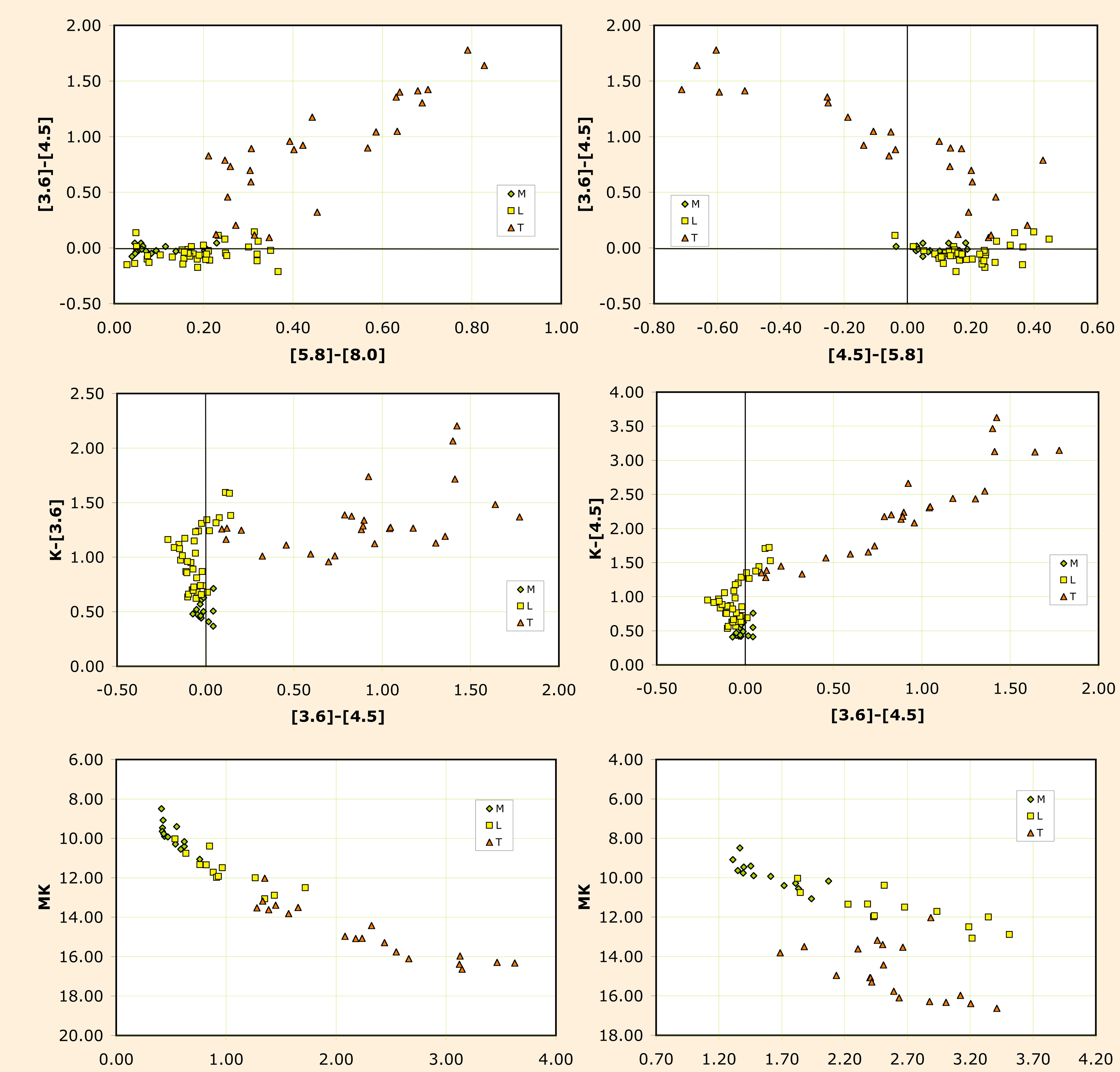
A comparison of IRAC bandpasses with the MKO *L'* and *M'* in recent use for ground-based studies of M, L, and T dwarfs. Also shown are a sample spectrum for a ~mid-T dwarf (Burrows et al. 1999) and that for an A0 V star.

The IRAC and near-IR colors of M, L, and T dwarfs

We find that it is the T dwarfs which stand out in the IRAC bandpasses, with colors virtually unique when compared to other stellar and sub-stellar types. It is clear that in the study of T dwarfs and in the detection of T dwarf companions to nearby stars is where IRAC will excel. On the other hand, for the late-M and L dwarfs, the IRAC colors are essentially degenerate, especially for ([3.6]-[4.5]), the two most sensitive of the four IRAC bandpasses. However, the addition of near-IR data to the IRAC photometry provides a useful discriminant between the M and L types.

The right are color-color and color-magnitude diagrams for all MLT program targets observed to date using IRAC and (mostly) 2MASS photometry. Below are spectral type versus color diagrams in same spirit as those presented in Leggett et al. (2002), Golimowski et al. (2004), and Knapp et al. (2004).



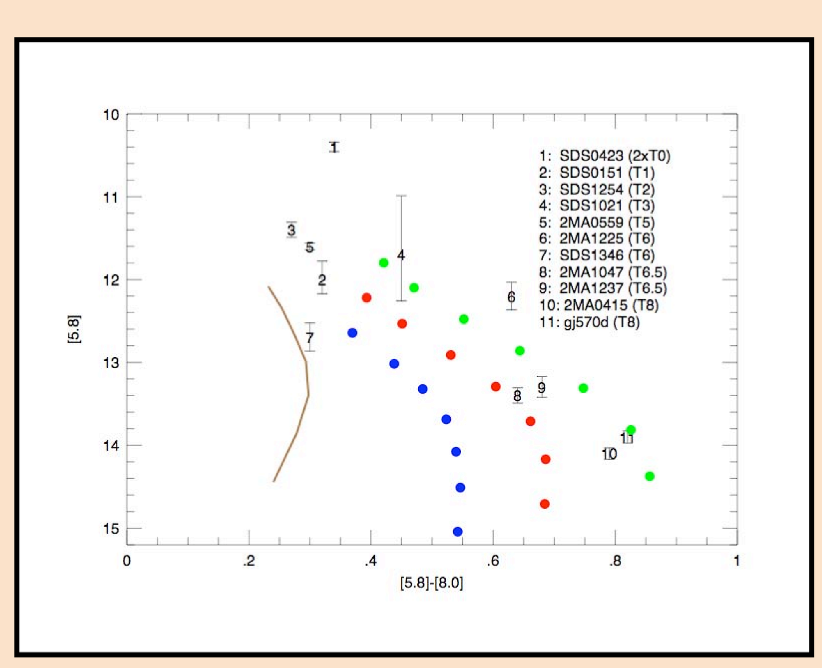


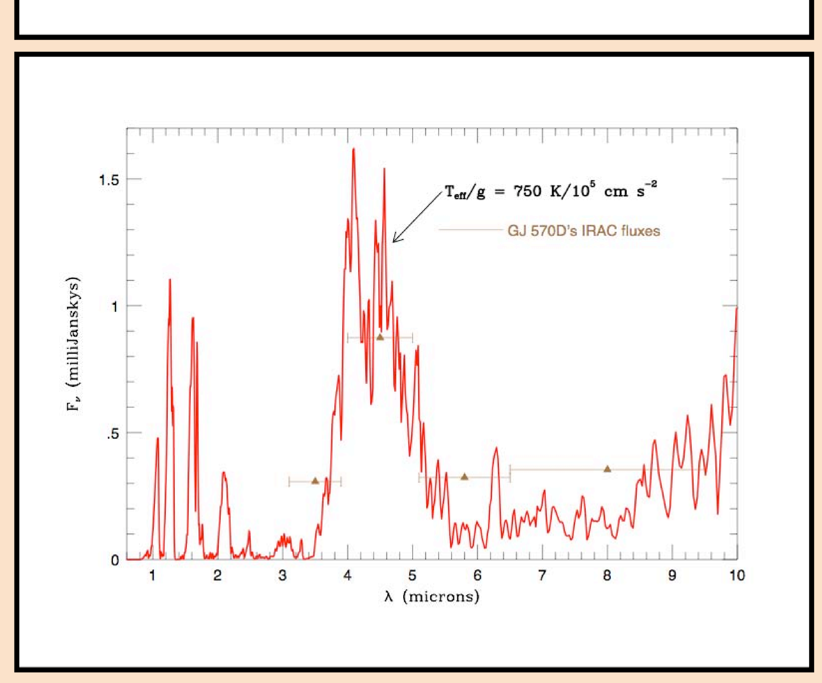
Observation compared to theory

For the T dwarfs we find that for [5.8] versus ([5.8]-[8.0]) (*top right*) the IRAC data are not monotonic in either magnitude or color, giving the clearest indication yet that that the T dwarfs are not a one parameter family in T_{eff}. Since metallicity does not vary enough in the solar neighborhood to act as the second parameter, the most likely candidate then is *gravity*, which in turn translates to *mass*.

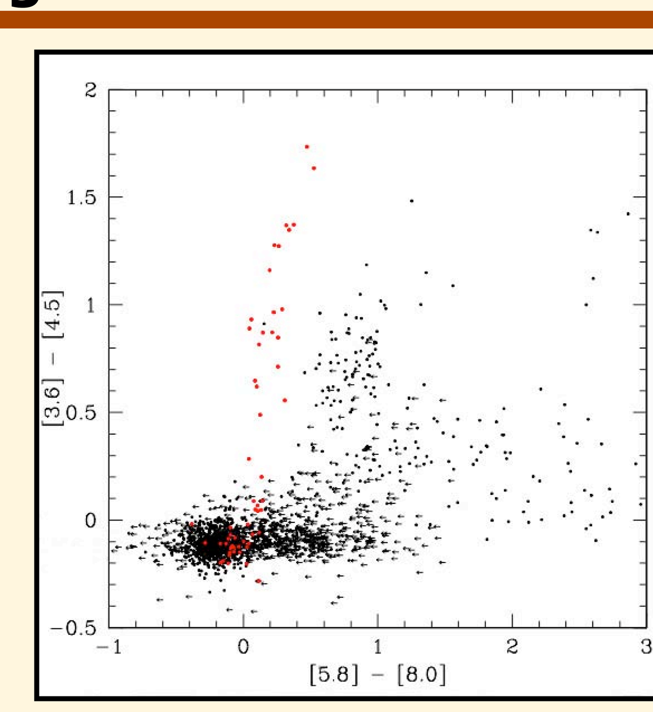
To quantify the spread in mass, we have compared the IRAC photometry with previous theoretical models (e.g. Burrows et al. 1997) as well as new spectrum and atmosphere calculations performed by one of us (AB) for this project. The triangles are the T dwarf data. The blue dots are models 700 to 1300 K at $g=10^{5.5}$cm s^{-2}. The red and green dots are models at $g=10^{5}$ cm s^{-2} and $g=10^{4.5}$ cm s^{-2} respectively. Among objects with similar spectral type, the range of mass suggested by our sample is about an order of magnitude (~70 – ~15 M_{Jup}). These models were calculated using the new solar and carbon abundances of Allende-Prieto et al. (2001,2002) and Asplunde et al. (2004). The gold line is where the red dot sequence would be if the older Anders & Grevesse (1989) oxygen abundances were used. We also find the 4.5 µm fluxes to be lower than expected, from which we infer a stronger CO fundamental band at ~4.67 µm. This suggests that equilibrium CH_4/CO chemistry underestimates the abundance of CO in T dwarf atmospheres, confirming a conclusion reached by Golimowski et al. (2004) using *M*-band observations from the ground.

On the other hand, the bottom right figure shows a comparison of a theoretical T dwarf spectral model (Geballe et al. 2001: Burrows et al. 2002) (*red line*) with the four IRAC fluxes measured for the T8 dwarf GJ 570D (*gold lines*). This model was generated in 2002 for GJ 570D to fit its optical spectrum *shortward* 1.0 µm (Burrows et al. 2002). A slight (~40%) discrepancy in the 4.5 µm band, attributable to a CO abundance excess in its atmosphere, is visible. Despite this, the model represents an acceptable fit from 0.6 to ~8.0 µm and indicates that the IRAC data were successfully anticipated.





Searching for brown dwarfs using IRAC



While the T dwarfs are clearly set apart from the M and L dwarfs in the IRAC bandpasses, particularly for the ([3.6]-[4.5]) color index, IRAC's two most sensitive channels, it is important to note that a single IRAC color index alone is not effective for low-mass object searches since there is substantial degeneracy with the colors of *extragalactic* objects. The figure above shows the IRAC photometry for all objects in the MLT program fields. Red points show the M, L, T dwarf sequence for this calibration. Black points represent all other point sources detected in the images of the MLT dwarfs, which encompass a total of 0.8 square degree. The objects with the red colors are distinct from the T dwarf sequence and presumably are extragalactic.

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