A SEARCH FOR WIDELY SEPARATED SUB-STELLAR MASS COMPANIONS TO NEARBY STARS WITH *SPITZER*/IRAC. Brian M. Patten[1,2], Kevin L. Luhman[3], Joseph L. Hora[1], Massimo Marengo[1], Michael T. Schuster[1,4], Sarah M. Sonnett[1], Richard G. Ellis[1], John R. Stauffer[5], and Giovanni G. Fazio[1], [1]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA, USA 02138, [2](bpatten@cfa.harvard.edu), [3]Pennsylvania State University, 525 Davey Lab, University Park, PA USA 16802, [4]University of Minnesota, 116 Church St., Minneapolis, MN USA 55455, [5]Spitzer Science Center, MS-220-6, Caltech, Pasadena, CA, USA 91125.

Introduction: The Spitzer/IRAC [1],[2] Nearby Stars Guaranteed Time Observer (GTO) program consists of some ~256 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 $M_{Jupiter}$. Ultimately, this survey, when combined with radial velocity, coronographic and other imaging surveys, 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. In this paper, we will present an overview of the Nearby Stars GTO program (targets, observing strategy, etc.) and describe a software suite for the post-pipeline processing of IRAC data and a statistical approach that we are using to identify candidate companion objects.

The Sample: The GTO program is broken into four sub-samples, each of which is selected via a common property that gives each sub-sample a particular characteristic:

5-parsec: The "*5-Parsec*" sample consists of 45 systems within five parsecs of the Sun. The data from this program, when combined with Spitzer/IRAC pointings from other GTO programs, will mean that each star known within five parsecs will have been observed with IRAC to search for low mass companions. Simply because of their proximity, these targets promise to provide one of the most sensitive experiments possible with IRAC – the detection of super-Jupiters around the nearest stars. Depending on distance and separation from the stars, companions with masses as low as 5-20 $M_{Jupiter}$ can be detected in this sample.

Nearby Young Stars: Seventy-three young dwarfs with types ranging from A0V to M4.5V comprise the "*Nearby Young Stars*" sample. The targets in this program have been selected from the literature using multiple indicators of youth (age ≤120 Myr) including high X-ray luminosity, high chromospheric activity levels, high Li abundance, rapid rotation, photometric colors consistent with youth (when combined with theoretical isochrones), and young disk kinematics. The advantage of observing targets which are relatively young is that sub-stellar mass companions will also be young and therefore much more luminous than their cooler counterparts found around older stars in the field.

Exoplanets: Forty-eight stars with extra-solar planet candidates (the "*Exoplanet sample*") will be observed to detect additional, wider companions. The primary question this sample will address is whether there are brown dwarf companions in these systems at larger radii. If a brown dwarf were discovered in addition to the planetary companions around one of these stars, it would have serious implications for the formation of solar systems.

MLT: The "*MLT sample*" consists of eighty nearby, low-mass dwarfs of type M5.0V and later. These targets are ideal for a companion search because they are nearby, yet relatively faint. This allows low-mass companions to be revealed close to the target object because the PSF of the (usually saturated) primary in the other Nearby Stars GTO programs is not as overwhelming. In addition to the companion search, this study will do double duty because the target objects themselves are the ideal calibrators for other IRAC brown dwarf search programs.

Observing Strategy: All observations in the Nearby Stars GTO program share a common Spitzer Astronomical Observation Request (AOR) design. Each AOR was set up as a five-position Gaussian dither pattern using the small scale factor. Dithering is necessary to mitigate the effects of cosmic rays and bad/hot pixels while the use of the small scale factor for the dither pattern keeps the target near the center of the arrays and maximizes the amount of surrounding sky that can be searched for companions. For some targets, high dynamic range mode was used to cover a wide range of brightness since the photometry of the targets themselves (i.e., the *MLT* sample) was also desired. The relative sensitivities of the four IRAC detectors preclude a single exposure time that will produce good signal-to-noise and unsaturated photometry in all four channels. Frame times of 30 and 2 seconds in the AOR yield effective exposure times for each dither position of 26.8 and 1.2 seconds, respectively.

Analysis: Starting with the Basic Calibrated Data (BCD) product from the IRAC data pipeline as delivered by the *Spitzer* Science Center [3], we further process the data using a software suite "IRAC_proc" developed by three of us (MS, MM, & BMP) at SAO in support of the Nearby Stars GTO program. IRAC_proc facilitates the co-addition of dithered or mapped IRAC data to make them ready for photometric analysis. In addition to mosaicing the data, IRAC_proc also performs cosmic ray and other transient rejection as well as (optional) PSF-fitting and subtraction of saturated stars near the center of the fields.

For the PSF subtraction, we used a set of High Dynamic Range PSFs obtained by combining an unsaturated core, derived from the observation of standard stars in the IRAC PSF calibration project, with the image of bright stars from the "Fabulous Four Debris Disks" GTO program, which, in turn, provide a good characterization of the faint extended tails and diffraction spikes of the IRAC PSF near the center of the arrays. PSF-fitting and subtraction allows us to drastically reduce the light of the central star outside the saturated region, revealing fainter sources that would be otherwise lost in the bright source glare. Using this technique (described in detail in [4]) it is possible to extend the companion search as close as 20-arcseconds (on average) from the central star.

IRAC_proc makes use of MOPEX, IRAF, Perl, and PDL. Outlier rejection with IRAC_proc is significantly improved from what is available using the standard MOPEX package alone. Currently, IRAC_proc can be run on any Linux system and can be applied to any IRAC dataset for which an observer would like to produce cleaned mosaics, not just data from the Nearby Stars GTO program.

Once the cleaned mosaic for a target field has been created, we use a combination of Perl and IRAF scripts to identify sources in each IRAC channel. Aperture photometry for each source is then extracted using routines from the IRAF *digiphot* package. Magnitudes in each channel are then calculated on the Vega-relative system. The sources are then cross-correlated across the four IRAC channels by sky position to produce a single source list with all available photometry.

The IRAC colors of late-M, L, and T-type dwarfs have been well established with the survey of ~80 objects of these types from the MLT sample [5],[6]. We make use of these photometric data to conduct the search for candidate companions in both color-color and color-magnitude space.

For the color-color searches, the existing database of late-M, L, and T calibrators establish two dimensional regions where similar type objects should lie. The use of multiple color-color combinations helps to filter other astronomical sources (i.e., distant background galaxies and heavily reddened stars in our own galaxy) from the sample. T dwarfs in particular have been established to have almost unique colors in the IRAC bandpasses when compared to other astronomical objects.

The use of color-magnitude combinations for the companion search requires an additional assumption to be made – that any companion to the primary should be located at approximately the same distance as the primary. The distance estimate for the primary is then used to apply a distance modulus to the photometry of all objects in the field. Using absolute magnitude in this way in the color-magnitude diagram acts as a filter to eliminate more distant, background objects in the field with interesting colors, since they will appear too faint to be considered as a candidate companion to the primary.

While this kind of multi-dimensional approach is potentially very powerful in this kind of search, such an analysis would be tedious given the number of color-magnitude and color-color combinations available to us. To address this problem, one of us (MM) has implemented a statistical analysis technique based on the "k Nearest Neighbor" method [7]. This method is used to examine the desired color and magnitude combinations of interest and computes a "score" for each object in the field. This score reflects the proximity of the object to the hyper-volume in the colors and magnitude space defined by template objects representing the sub-stellar dwarf type of interest.

While IRAC photometry alone is not sufficient to conclusively identify a sub-stellar mass companion to any of the objects in our program, this software suite will allow us to efficiently sort through the photometry of tens of thousands of objects to identify candidate companions and assign them a level of priority for follow-up ground-based photometry, spectroscopy, and proper-motion measurements. As a part of this paper, we will present preliminary results of our search efforts to date for each of the sub-samples in the program.

References: [1] Fazio, G. G., et al. (2004), ApJS, *154*, 10. [2] Werner, M. W. et al. (2004), ApJS, *154*, 1. [3] Spitzer Science Center, IRAC Data Handbook, http://ssc.spitzer.caltech.edu/irac/dh/. [4] Marengo, M., et al. (2005), in preparation. [5] Patten, B. M., et al. (2004), AAS, *205*, 1110. [6] Patten, B. M., et al. (2005), in preparation. [7] Fix, E. & Hodges, J. L. (1951), USAF School Aviation Medical Report 4.