Near-Infrared Observations of IRAC M, L, and T Dwarfs with PAIRITEL

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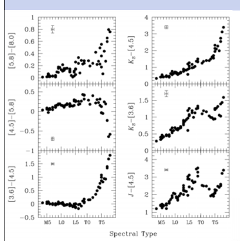
Abstract

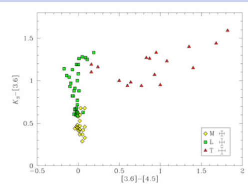
We have started a project to observe a subset of the sample of M, L, and T dwarfs observed in the IRAC GTO program (Patten et al. 2006) with the Peters Automated Infrared Imaging Telescope (PAIRITEL). PAIRITEL is based on the 2MASS instrument and telescope at the Whipple Observatory which has been upgraded to operate autonomously in a queue-based mode (Bloom et al. 2006). The purpose of the observations is to assist in the search for low mass companions by obtaining deeper J, H, K_s photometry of the fields to better match the depth of the IRAC images, and to be able to search for companions using similar proper motions. For a subset of the M, L, and T dwarfs, we are obtaining repeated measurements to monitor for photometric variations. We summarize the status and results of the project as of October 2006.

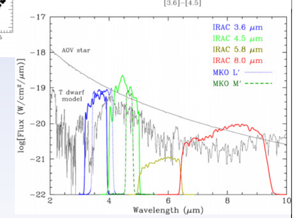
IRAC M, L, T dwarf program

We have completed a program to obtain photometry of a sample of late-M, L, and T dwarfs using IRAC at 3.6, 4.5, 5.8, and 8 µm (Patten et al. 2006). The sources in the sample were chosen before the Spitzer launch so were based on the current knowledge in 2002. The primary consideration for selection was whether the target had a measured trigonometric parallax. The secondary constraints were: (1) relatively bright in order to ensure good S/N photometry, (2) the targets needed to have well-determined spectral types to have representatives of all spectral sub-type bins from late-M through T types, (3) the targets needed to be located in relatively uncrowded fields, and (4) should not be known close binaries (separations of 6″ or less). Sources of the near-IR photometry were the 2MASS, DENIS, and SDSS surveys.

It was found that by combining the JHK_s and IRAC photometry, a clear progression with spectral type and colors is apparent, and in particular, the near-IR photometry breaks the degeneracy in the M and L dwarf IRAC-only colors. This can be seen in the plots below. In the plot at the left, the color in two bands is plotted against spectral type. For the IRAC-only colors, there is little trend in the M to mid-L types, but when the near-IR bands are used, for example the K_s-[4.5] plot, the color is a clear function of spectral type throughout the range.







Spectra of the M, L, and T dwarfs and IR photometry

Sample stellar spectra for a A0V star and a mid-T dwarf model (Burrows et al. 2002) along with the IRAC bandpasses are plotted in the figure above. IRAC channel 1 (3.6 µm) includes much of the CH_4 fundamental absorption band (~3.3 µm). Channel 2 (4.5 µm) includes the continuum peak present for all stars cooler than 3000 K, making this the most sensitive IRAC channel for the study of sub-stellar objects. Channel 2 also contains the broad but shallow CO fundamental absorption band (~4.7 µm), whose presence in the T dwarfs provides evidence for non-equilibrium chemistry models. Channel 3 (5.8 µm) includes H_2O absorption and, for low T_{eff}, NH_3 absorption. Channel 4 (8 µm) samples the molecular absorption due to CH_4.

The L dwarf spectra exhibit absorption from CO and H_2O. T dwarfs have broad absorption bands of CH_4 and H_2O, and H_2 absorption. In the near-IR photometry, M and L dwarfs become redder with decreasing T_{eff} in $J-H$ and $H-K_s$. The L to T dwarf transition occurs as the silicate and iron condensates (clouds) become buried at increasing depth in late-L dwarfs. H_2O absorption begins to dominate the near-IR spectrum, leading to a bluing of the near-IR colors through the early-T types. The colors then become even bluer from early-T to late-T with the onset and growth of CH_4 absorption and H_2 in K_s. The overall result is that the $J-H$ and $H-K_s$ colors for T dwarfs become bluer with increasing spectral subtype, becoming degenerate with the colors of higher mass K and M dwarfs.

References

Artigau, E., Nadeau, D., & Doyon, R. 2003, Proc. IAU Symp. #211, 451
Bloom, J. S. Starr, D. L., Blake, C. H., Skrutskie, M. F., Falco, E. E. 2006, in Astronomical Data Analysis Software & Systems XV, ed. C. Gabriel et al. (San Fransisco: ASP), 751.
Burrows, A., Burgasser, A. J., Kirkpatrick, J. D., Liebert, J., Milsom, J. A., Sudarsky, D., & Hubeny, I. 2002, ApJ, 573, 394
Patten, B. M. et al., 2006, ApJ, 651, 502

Observation Goals

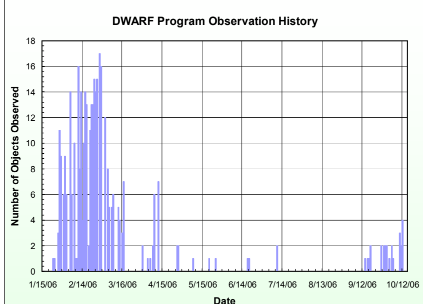
There are two primary goals for the PAIRITEL DWARF program. The first is improved photometry for the sample. Some of the targets were close to the sensitivity limits of the original 2MASS, or SDSS or DENIS surveys. Therefore more accurate photometry can be obtained by using a slightly longer integration time. For some of the stars, the photometry was affected by nearby sources in field. Due to the relatively high proper motion, in some cases the stars are now better separated and can be measured more accurately. Also, the observations are with the former 2MASS telescope and instrument, so they can easily be put in the 2MASS photometric system.

The second goal of the program is variability monitoring. Variations could occur in the flux of the dwarf for example due to uneven coverage of the surface in CH_4 or other types of weather which could cause changes in flux over periods of hours to days. Rotation periods 1-10 hr have been detected in dwarfs. Presence of other intrinsic variations in T dwarfs is not well established. Flux variations in T dwarfs of 2–17% have been observed by Artigau et al. (2003) in J & H. However, others have reported the results of monitoring programs that have detected no variations. IRAC continuous monitoring for hours saw no variability in the dwarfs observed.

The PAIRITEL observations were designed to sample long-term variations of periods from days to months. This was designed to be consistent with the expected duty cycle possible on PAIRITEL, which is queue-scheduled and based on the priority of the program. The highest priority programs on PAIRITEL include following up gamma ray burst detections from *Swift* and obtaining light curves of supernovae. In addition, there are a number of other

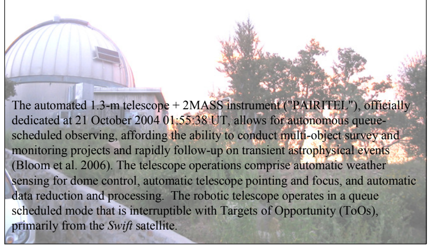
We also have a Cycle 3 IRAC GTO program to monitor a set of T dwarfs on timescales of hours, weeks, months, and years to detect and characterize their variability. The observations will be sensitive to rotational modulations as well as longer term changes in the atmospheres of the dwarfs. We have just begun to receive the first Spitzer data from the program this fall.

Observation Status



There are 68 dwarfs in our observing program, 34 scheduled for a single observation, and the remainder are monitored as the telescope schedule permits. Since the start of the program in January 2006, a total of 366 observations have been made. The figure above shows the number of observations per night, each observation lasting from 10 to 30 minutes. As of the end of October 2006, 33 of the 35 objects scheduled for single observations have been completed (see box at right). In addition, there have been repeated observations of the 34 targets to be monitored, with each target observed between 5 to 28 times (see figures at far right).

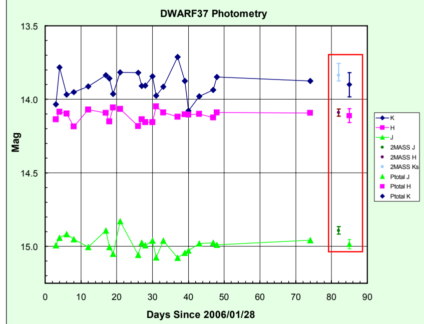
The PAIRITEL Telescope

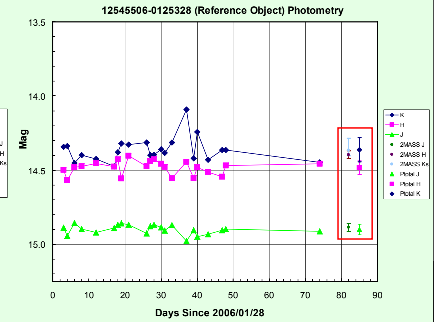


The automated 1.3-m telescope + 2MASS instrument ("PAIRITEL"), officially dedicated at 21 October 2004 01:55:38 UT, allows for autonomous queue-scheduled observing, affording the ability to conduct multi-object survey and monitoring projects and rapidly follow-up on transient astrophysical events (Bloom et al. 2006). The telescope operations comprise automatic weather sensing for dome control, automatic telescope pointing and focus, and automatic data reduction and processing. The robotic telescope operates in a queue scheduled mode that is interruptible with Targets of Opportunity (ToOs), primarily from the *Swift* satellite.

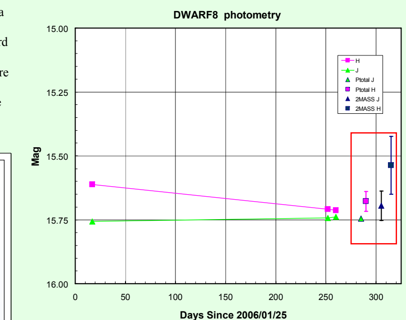
PAIRITEL site: http://www.pairitel.org
IRAC web site: http://www.cfa.harvard.edu/irac

Monitoring Observations





The plot above shows photometry for DWARF37, and the plot above right shows a reference object in the same field with comparable brightness. The 2MASS photometry is shown in the red box at the right, along with the average and standard deviation of the PAIRITEL measurements. The PAIRITEL photometry of the reference object is consistent with 2MASS, but the measurements of DWARF37 are slightly fainter in the three bands compared to 2MASS. There is no conclusive evidence for variations over the ~70 days that the source was monitored during the first part of this year. Further observations will take place in the coming months.



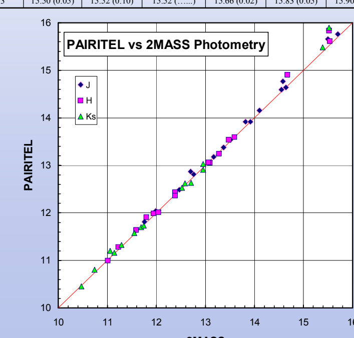
The plot above shows the longest monitoring period obtained thus far in our PAIRITEL program (points with lines). The 2MASS photometry are shown on the red box at right for comparison (blue points with error bars), as well as the result obtained from averaging the PAIRITEL points. More objects will soon begin to have measurements of one year separation as they begin to become visible again this winter.

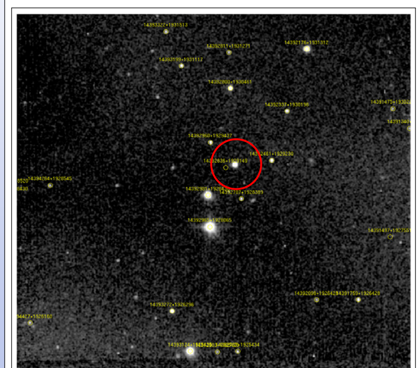
Single measurements

The table and plot below shows the results of PAIRITEL single measurement photometry where 2MASS data was also available. For these objects, the PAIRITEL photometry was performed on the mosaics which are constructed from a number of individual short exposures to obtain total integration times of 10-20 minutes.

Table 1. PAIRITEL Photometry

DWARF	2MASS J	2MASS H	2MASS K_s	PAIRITEL J	PAIRITEL H	PAIRITEL K_s
2	12.47 (0.03)	11.59 (0.03)	11.06 (0.02)	12.49 (0.01)	11.64 (0.01)	11.20 (0.01)
8	15.70 (0.06)	15.54 (0.11)	15.43 (0.20)	15.76 (0.02)	15.61 (0.04)	…
13	13.51 (0.02)	12.38 (0.02)	11.69 (0.02)	13.54 (0.01)	12.43 (0.01)	11.70 (0.01)
14	14.64 (0.03)	13.59 (0.03)	12.95 (0.03)	14.64 (0.01)	13.59 (0.01)	12.91 (0.01)
16	11.76 (0.02)	11.01 (0.02)	10.47 (0.02)	11.81 (0.01)	10.99 (0.01)	10.45 (0.01)
19	13.17 (0.02)	11.94 (0.02)	11.14 (0.02)	13.18 (0.01)	11.99 (0.01)	11.16 (0.01)
22	14.55 (0.02)	13.48 (0.03)	12.95 (0.03)	14.59 (0.01)	13.54 (0.01)	13.03 (0.01)
25	14.58 (0.04)	14.67 (0.03)	15.39 (0.06)	14.77 (0.01)	14.90 (0.02)	15.48 (0.06)
26	14.10 (0.02)	13.28 (0.03)	12.71 (0.02)	14.16 (0.01)	13.24 (0.01)	12.63 (0.01)
31	13.82 (0.04)	13.09 (0.04)	12.52 (0.03)	13.92 (0.01)	13.05 (0.01)	12.53 (0.01)
42	11.99 (0.02)	11.23 (0.02)	10.74 (0.02)	12.04 (0.01)	11.28 (0.02)	10.80 (0.01)
43	12.76 (0.02)	12.04 (0.02)	11.55 (0.02)	12.81 (0.01)	12.01 (0.01)	11.57 (0.01)
46	13.37 (0.02)	12.38 (0.02)	11.74 (0.02)	13.38 (0.01)	12.36 (0.01)	11.73 (0.01)
47	12.70 (0.03)	11.80 (0.03)	11.29 (0.03)	12.87 (0.01)	11.91 (0.01)	11.33 (0.01)
50	13.92 (0.03)	13.060 (0.02)	12.58 (0.03)	13.92 (0.03)	13.06 (0.04)	12.62 (0.04)
53	15.50 (0.05)	15.52 (0.10)	15.52 (…...)	15.66 (0.02)	15.83 (0.05)	15.90 (0.11)





The above image is a sample mosaic of the DWARF43 field taken with PAIRITEL with approximately 10 minutes total integration time. The 2MASS catalog sources are overlayed on the image. The location of the dwarf is circled in red. One can see the relatively high proper motion of this star which has moved from its previously cataloged position.

Acknowledgments

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