SpiKeS: The Spitzer Kepler Survey

Michael Werner (JPL), Varoujan Gorjian (JPL), Charles Beichman (NExScI), David Ciardi (NExScI), Grant Kennedy (Cambridge University)
John Livingston (JPL), Patrick Lowrance (Spitzer Science Center), Peter Plavchan (NExScI), Christopher Stark (Carnegie Institution)
Mark Wyatt (Cambridge University)

Abstract

We have obtained Cycle 10 Warm Spitzer observing time to survey the entire Kepler field to provide precision 3.6 and 4.5 micron photometry of the more than 180,000 Kepler Observed Objects (KOBs) for which light curves have been obtained by Kepler. We base this survey on a successful Cycle 9 pilot project which studied one 2.4x2.4 degree Kepler tile. These data from the pilot project have been expeditiously and thoroughly analyzed and show that our observing strategy will allow us to achieve a photometric precision of 2% or better for half the KOBs and 3% or better for more than 90% of the KOBs. The principal science thrusts of this survey are to:

1.Facilitate searches for infrared excesses above the stellar photosphere attributable either to warm circumstellar dust or to cool companions. Either could be of great significance in understanding the properties of planets or planetary systems detected around those stars.

2.Provide fundamental data on the KOBs, already the best characterized group of stars in the sky, which can be used to test stellar models and to support the all−important determination of stellar effective temperatures and radii, and thus exoplanet radii and densities.

3.Augment the Kepler archive with precision infrared photometry which will be a vital ingredient in research using this archive to study both exoplanetary and astrophysical questions over the coming decades

The Spitzer data will thus greatly enhance both the exoplanet and the astrophysical power of the Kepler data. Once completed, this survey will become a very important part of the scientific legacy of both Spitzer and Kepler.

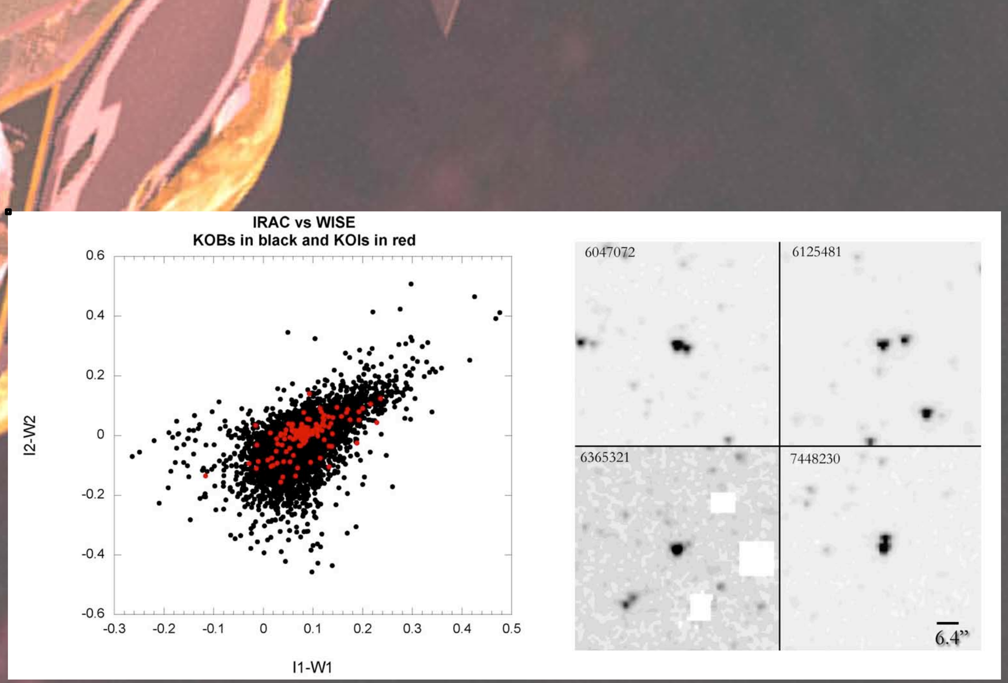
The Pilot Project

In Cycle 9 of Spitzer we proposed and were approved for a 21 hour pilot project to survey one of the 21 tiles which comprise the Kepler field of view. We have carefully reduced and analyzed the data and find that it demonstrates both the immediacy and the archival value of the larger project now being undertaken. Our sample tile, number 14, is 2.4 x 2.4 degrees in extent and contains over 150 KOIs and ~10,000 KOBs. The results of the pilot project are summarized here.

Sensitivity. In analyzing the data from our pilot project we had to deal with the fact that for our observing strategy of three widely-spaced dithers and 12 sec integration times, the photometric precision for the KOBs, which are bright for Spitzer, is totally determined or strongly influenced by uncertainties in systematic corrections to the data, and not by source or background photon noise or by detector noise. Careful treatment of these effects led to the result that for at least 50% of the KOBs the measurement uncertainty will be comparable to or smaller than the overall calibration uncertainty of Warm Spitzer, which is estimated to be ~2%.

Spatial Resolution Improvement. Our proposal was partially inspired by the work of co-Investigators Kennedy and Wyatt (2012, hereafter KW), who studied the Kepler field using the WISE data, including bands W1 and W2 at 3.4 and 4.6μm which closely parallel IRAC1 (I1) and IRAC2 (I2) at 3.6 and 4.5μm, respectively Although KW detected about 95% of the 190,000 stars for which Kepler obtained light curves during its first six quarters of observation, they discarded thousands of detected KOBs from further consideration due to possible contamination from nearby sources. Spitzer's ~2" beam has one-tenth the area of WISE's 6" beam, so we hoped to recover many of these confused sources. The pilot project demonstrated this benefit. In Figure 1, we show a plot of (I1-W1) vs. (I2-W2) for the KOBs in our observed tile. The points cluster near the origin – showing good agreement between the data sets – with a tail to the upper right showing some sources to be brighter in both WISE bands. This tail is the signature of confused sources, and, as shown in Figure 2, many of these sources are double or extended as observed by Spitzer. We estimate that over the entire field of our survey Spitzer will recover over 3000 sources which are clearly confused or unresolved as seen by WISE, enhancing the archival value of the Spitzer data. Moreover, we note that a number of KOIs appear to be multiple at Spitzer resolution; our higher resolution photometry will allow the precise determination of the properties of an exoplanet host star required for determination of the size of the transiting planet. The Spitzer data will be particularly important for studying exoplanet host stars cooler than ~4500K, which constitute ~10% of both the KOIs and the KOBs. Additionally the Spitzer photometry is both more precise and more reliable than that available from WISE for sources fainter than ~13th magnitude in W1.

Figure 1 (Near Right) compares IRAC and WISE photometry (I1-W1) vs. (I2-W2) for all KOBs in the pilot project. The spur of sources to the upper right suggests that many of the sources contain several stars as seen by WISE, but are resolved as seen by Spitzer. KOIs are in red, KOBs in black. The thumbnails shown in Figure 2 (Far Right) show Spitzer IRAC1 images of KOIs drawn from the spur, which are seen to be multiple and confused in WISE's 6.4" beam. White boxes are due to latent flags.



Science Themes

1. Searching For Infrared Excesses.

There are two potentially interesting mechanisms that could produce excesses, a red stellar or substellar companion, or thermal emission from hot circumstellar dust. In Figure 3, we show one example of each, drawn from the pilot project data.

<u>A faint red companion</u> – either physical or a line of sight coincidence - to a KOB would have interesting consequences. Firstly, an M dwarf could masquerade as a large transiting exoplanet, and such systems may remain to be discovered in the multiyear Kepler light curves, particularly if they orbit at great distances from their parent stars. Secondly the presence of an M dwarf companion in a system already shown to have one or more transiting exoplanets could pose interesting dynamical questions. Finally, the possibility of an M star – even a distant background M giant – in the Kepler measuring aperture would be a flag that any transiting planet candidate found around the star in question could be a false positive due to dilution of an eclipsing binary signal by the M star itself or, perhaps, by its [unseen] hotter companion. Using data from the pilot project we have identified a handful of excess sources, showing that our approach can identify companions; an example is shown in Figure 3. This system is unresolved by Kepler and Spitzer, but the Spitzer photometry clearly shows the presence of a companion. Spitzer is uniquely sensitive to very cool companions which might be difficult to find –via imaging or photometry – at shorter wavelengths.

<u>Circumstellar dust around main sequence stars warm enough to radiate at 3.6 or 4.5μm</u> is uncommon but interesting. A few photometric detections of dust in the 3-5μm range exist in the literature, which might be archetypes for the sources we hope to detect in our survey: most notably BD+20307 (Weinberger et al. 2011), which shows an excess over the photosphere of ~9% at 3.6μm and ~25% at 4.5μm. The origin of hot dust in these systems remains unknown, yet understanding this population is vitally important, both as an astrophysical phenomenon, and for its proximity to potentially habitable planets. Dust masses less than 1e-6 Moons, equivalent to what would be generated by the demolition of an asteroid less than 50 km in size, could be detected by Spitzer around stars in the Kepler field

2. Determining Stellar Properties

We are confident that our data set, when completed, will contain the largest and highest precision available body of self-consistent Spitzer data on the 3.6 and 4.5μm properties of bright field stars, particularly on stars which are exceedingly well-characterized at other wavelengths. We base this assertion on the painstaking analysis required to produce the data for the pilot project, which has the added benefit of associating well-determined uncertainties with the stellar data. The combined data base – containing ~180,000 stars, will be a unique resource for testing and refining stellar models, particularly when the GAIA observations provide distances to many of the stars. In addition to this global applicability, the precise 3.6 and 4.5μm magnitudes determined here will fit in well with the efforts underway to determine the radii of exoplanet host stars, which lead directly to the planetary radii through the transit depth.

Figure 3. Model SED for two KOBs from the pilot project showing evidence of infrared excess. KIC6954726 [Top] is a previously known Be star fit with a Kurucz stellar mdoel. The fit shows an excess with a temperature of ~1220K which could be due either to thermal emission from dust or to free-free emission. KIC6522824 [Bottom] is a K star with 10-to-20% excess in both I1 and I2, fit with a PHOENIX stellar model. The fit of the stellar models to the SED suggest that the excess is due to a 3000K companion