THE GROUND BASED IDENTIFICATION AND CHARACTERIZATION OF IRAC CELESTIAL CALIBRATORS

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ABSTRACT

We describe an ongoing campaign to identify and characterize celestial standards for the Infrared Array Camera (IRAC) which will be deployed on the Space Infrared Telescope Facility (SIRTF). These standards must extend to much fainter magnitudes than calibrator sources used for previous IR space missions, and thus, need to be identified and characterized through ground based observations. The method we have chosen is to use a combination of empirical templates of cool stars and Kurucz models of hot stars to extrapolate BVRIJHK photometry of known K giants and A dwarfs to the IRAC bands. There will be two sets of calibrators: one set near the north ecliptic pole which can be observed continuously throughout the SIRTF mission, and a second set distributed along the ecliptic plane which will be used to monitor the calibration on a day to day basis.

We overview the entire selection, identification, and characterization process. The K giants and A dwarfs are being selected from existing catalogs of stars. To verify the spectral types of these stars, we have undertaken observations of the candidates with the FAST spectrometer on the 1.5 meter Tillinghast telescope at Mt. Hopkins. By comparing the spectra of these stars with MK standards, we are able to establish the spectral type with an uncertainty of one subclass, and in the case of K giants, identify K dwarfs contaminating our sample. We are now beginning CCD camera observations to obtain accurate BVRI photometry for the selected stars.

Key words: SIRTF, Infrared Calibration Stars, Optical Spectroscopy, Ground Based Observations, MK Classification, Optical Photometry, Infrared Photometry

1. INTRODUCTION

IRAC, the InfraRed Array Camera, is one of three instruments to be launched on NASA's SIRTF mission (also see Hora et al., these proceedings). IRAC is designed for wide field ($5' \times 5'$) imaging at 3-8 μm with an angular resolution of $2.3''$ and a sensitivity of a few micro-Jansky. Using two 256×256 InSb arrays and two 256×256 SiAs BIB arrays, IRAC will image simultaneously in four bands (Table 1). The instrument has only one moving part, a shutter, and contains no filter wheels or changeable optics. There are two main observing modes for IRAC: a full array imaging mode in which the entire 256x256 array is read out, and a sub-array mode capable of integration times less than 0.4 seconds, in which a 32x32 sub-section of each array is read out. Due to the simplicity of the instrument and its operation, IRAC can be calibrated frequently with a low overhead.

Among the science programs currently planned for IRAC are deep sky surveys to probe the early universe, observations of the spectral energy distributions of young stars to study the evolution of circumstellar disks, and searches for brown dwarfs. Accurate photometric calibration is critical to achieve the goals of each of these programs.

Table 1. The IRAC bands and the required flux densities and magnitudes for the IRAC calibrator stars

Channel	λ (μm)	$\Delta\lambda$ (μm)	Flux Density (mJy)	Magnitude
Channel 1	3.6	0.75	1.5 - 850	6.2 - 13.1
Channel 2	4.5	1.02	1.4 - 700	6.0 - 12.7
Channel 3	5.7	1.44	2.5 - 1250	4.9 - 11.6
Channel 4	7.9	2.91	1.2 - 850	4.6 - 11.7

2. THE IRAC FLUX CALIBRATION PLAN

The IRAC flux calibration requirements are 2% relative photometric accuracy and 10% absolute photometric accuracy. To achieve these goals, there are three main challenges. The first challenge is to preserve the calibration integrity over the entire mission. The SIRTF observations will be organized into instrument campaigns, in which a single instrument will be operated over several days to a week. During each campaign, the two unused instruments will be switched off. Consequently, IRAC must be re–calibrated during every campaign in a manner which will maintain a consistent calibration from campaign to campaign. The second challenge is to maintain the calibration throughout one campaign. Frequent calibrations during a campaign may be necessary to correct drifts in the calibration that occur day to day. The final challenge is to determine the conversion from engineering units to absolute flux units.

To solve all of these challenges, IRAC will rely on celestial calibrators with well understood properties. We will extend into the optical a method developed by Martin Cohen for the calibration of previous IR satellites (Cohen et al. 1999). The basic outline of this method is the following:

1. Select K III stars and A V stars using ground based observations and obtain optical and near-IR photometry for each star.
2. Fit empirically derived spectra of K III stars and model spectra of A V stars to ground based optical/near-IR photometry and extrapolate the stellar flux density into the 3-8 μm regime (Cohen, these proceedings).
3. Use laboratory measurements of the IRAC spectral response curves to integrate extrapolated flux densities over the four IRAC bands (Hora et al., these proceedings).

In the remainder of this contribution, we will focus on the selection and characterization of the IRAC calibration stars using ground based observations.

3. CELESTIAL CALIBRATOR REQUIREMENTS

The operation of the satellite and the instrument sets a number of constraints on the selection of IRAC calibrator stars. We discuss here these constraints and the resulting requirements on the location of the calibrator stars in the sky and their magnitudes.

To maintain the calibration integrity of IRAC over the entire SIRTF mission, a set of the IRAC calibration stars must be observable throughout the mission. SIRTF will be in an Earth trailing heliocentric orbit, and consequently, the telescope pointing is constrained primarily by the position of the Sun in the sky (Figure 1). The two main constraints are that the telescope cannot be tipped more than 120° away from the sun, or the solar panel will not receive enough sunlight to power the telescope, and that the telescope cannot be pointed within 80° towards the sun, to ensure that the instruments are not damaged by sunlight scattered into the optical path. The latter constraint is the most stringent and results in only two constant viewing zones: the regions within 10° of the north and south ecliptic poles.

The primary calibrators stars for IRAC will be located in the constant viewing zone toward the north ecliptic pole. The north ecliptic pole was chosen due to our excellent access to the Mt. Hopkins observatory in the northern hemisphere; however, calibration stars may be selected at the south ecliptic pole at a later date. The primary calibrators stars are required to have a range of magnitudes so that there is at least one star which can be observed at each of the instrument integration times, which range from 0.02 seconds to 200 seconds. To obtain a sample of stars which can be observed at high signal to noise at every integration time without saturating requires a range of almost 1000 in flux density. The required ranges in magnitudes and flux densities are given in Table 1.

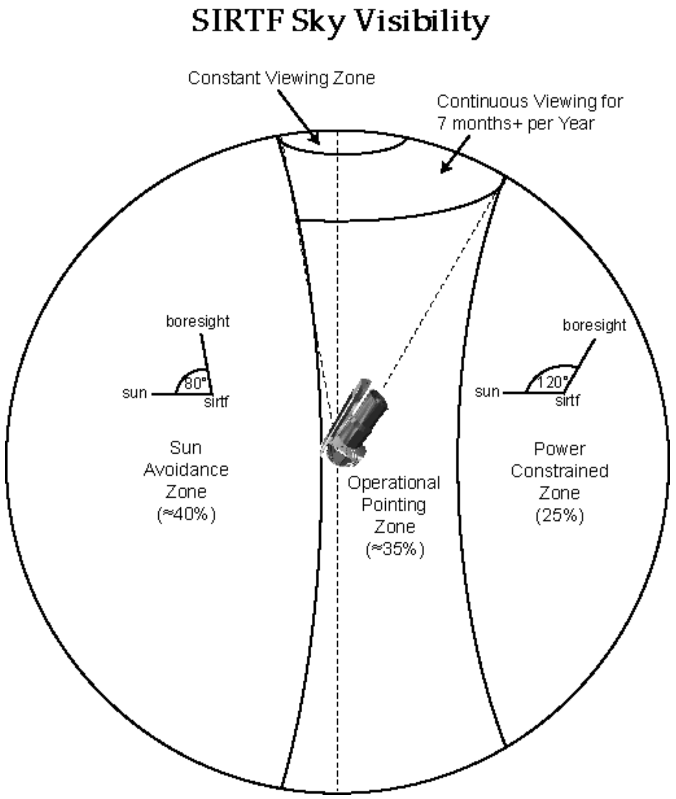

Figure 1. The SIRTF sky visibility. In the diagram, the primary constraint on the visibility, the Sun, is to the left. The north ecliptic pole is at the top of the diagram. Source: SIRTF Science Center.

Frequent observations of calibrators at the north ecliptic pole will be impractical due to the time required to slew to the ecliptic pole. Accordingly, a second set of calibrators stars will be selected along the ecliptic plane. The rational for this selection comes from the downlinking procedure for SIRTF. Every twelve hours, the high gain antenna on the satellite will be pointed at the earth to transmit data stored in memory. The antenna points directly opposite the telescope boresight. During this time, the telescope is pointed towards the ecliptic plane, and a calibrator in the ecliptic plane can be observed immediately before or after downlink with a minimal overhead for slewing. Since 40° of the ecliptic plane is visible at any one time, the ecliptic plane calibrators will span the ecliptic plane with a spacing of approximately 20°. They are required to be within 10° of the plane. These calibrators will be used to track drifts in the instrument gain during a single instrument campaign.

4. CELESTIAL CALIBRATOR SELECTION

The calibrator star candidates were selected from existing sky surveys, source catalogs and compilations of optical and near–IR standards. The primary sources of candidates

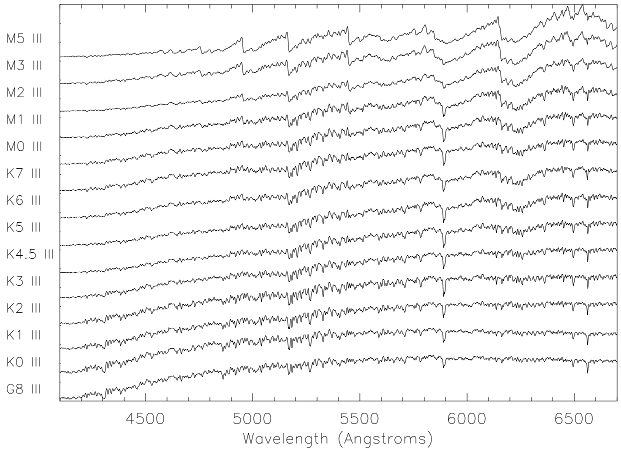

Figure 2. FAST spectra of MK standards: K and M giants sorted by spectral class.

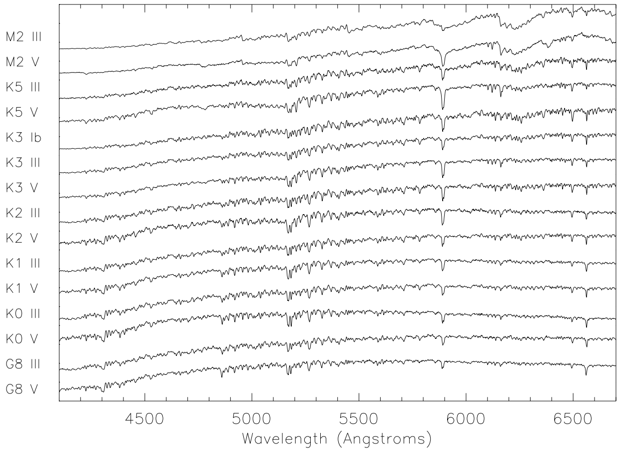

Figure 3. FAST MK standards: K and M stars sorted by spectral and luminosity class.

were the 13^{th} General Catalog of MK spectral classifications (Buscombe 1998), the Lick Proper Motion Program: NPM1 Catalog (Klemola et al. 1987), the Michigan Catalog of two dimensional spectral types (Houk & Swift 1999) and the Second Incremental Release Point Source Catalog of the 2MASS survey. Fainter stars were selected from the recently published Calar Alto $BRIK$-band survey of the NEP (Kuemmel & Wagner 2000). Additional stars near the ecliptic plane were found in tabulations of optical and near–IR standards. These tabulations contain high quality photometry which are invaluable for extrapolating the optical and near–IR magnitudes into the IRAC bands. Candidates were chosen from Landolt (1973, 1983, 1992), Carter & Meadows (1995), and Hunt et al. (1998).

The selection of candidates from such a diverse set of data requires several methods. Since the optical colors (such as $B-V$) depend on the spectral class, candidate K and A stars can be identified using optical photometry, although there is some ambiguity due to extinction. However, the optical colors do not discriminate between luminosity classes. This is a particularly significant problem for the selection of K III stars since 70% of the K type stars toward the north ecliptic pole are dwarfs. Without a technique for distinguishing between giants and dwarfs, the selection of K III stars by their optical colors would result in a 30% success rate. A combination of optical and near–IR photometry can be used to distinguish between K dwarfs and giants (Epchtein 1997), and the application of this technique to the Kuemmel & Wagner (2000) survey resulted in a 63% success rate in locating giants (Cohen & Kümmel, private communication). A more successful technique is to combine V–band magnitudes with proper motion measurements to generate a reduced proper motion,

$$H_V = m_V + 5log(\mu) + 5 \tag{1}$$

where μ is the total proper motion in arcsec year^{-1}. Since more distant stars will show a lower proper motion (and thus, will have a lower H_V), the reduced proper motion method can be used to distinguish nearby dwarfs from distant giants (Chiu 1980). Using the proper motion data from the NPM1 Catalog (Klemola et al. 1987), a 90% success rate has been achieved in selecting K III stars in the northern constant viewing zone.

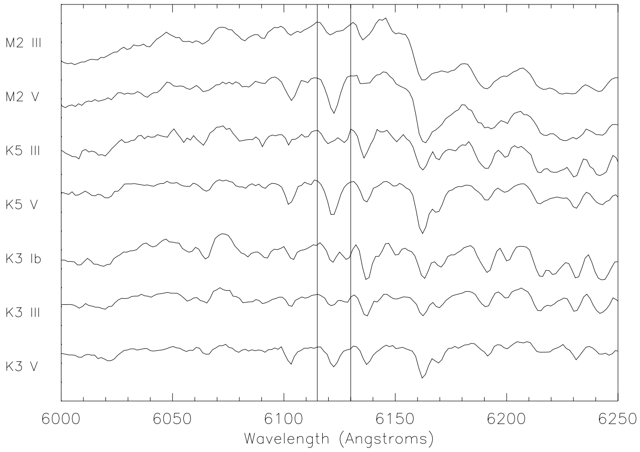

Figure 4. FAST MK standards: the variation of the Ca I 6122 Å feature with luminosity class for several K and M type stars.

In all cases, spectroscopic observations are needed to produce a final MK classification of each star. Furthermore, the classification should be done with a uniform methodology, preferably with the same instrument and instrument settings. Literature searches for spectral types are inadequate: many of the IRAC celestial candidates do not have existing spectral types, and the existing spectral types are from a variety of sources, making it difficult to assess their accuracy.

For these reasons, a spectroscopy campaign was undertaken at the 1.5 meter Tillinghast telescope on Mt. Hopkins in the southwestern USA. This telescope, which is dedicated to spectroscopy, is equipped with FAST (Fabricant et al. 1998), a moderate resolution, high throughput, CCD spectrometer. Observations of the IRAC calibrator candidates were taken with a 5 Å resolution and a 4000 Å wavelength coverage. In addition to the IRAC calibrators candidates, a set of MK standards from the Keenan & McNeil (1989) catalog of cool stars were observed with FAST. These MK standards consisted of a mixture of G, K, and M stars of all luminosity classes. The spectra of the calibrator candidates were then visually compared to the grid of MK standards to obtain a type for each candidate. Figure 2 shows the MK standards of luminosity class III sorted by spectral class. Numerous features are seen to vary with spectral class. We estimate the typical uncertainty of this technique to be one spectral subclass. There are also several spectral features which are a function of luminosity class (Figure 3). A particularly useful feature is the Ca I line at 6122 Å which is prominent only in dwarfs (Figure 4). In addition to the FAST observations, spectra were obtained of stars selected from the Kümmel & Wagner (2000) survey using the 2 meter telescope on Calar Alto (Cohen & Kümmel, private communication).

5. CURRENT STATUS AND FUTURE GOALS

Currently, the list of K III stars confirmed with FAST or Calar Alto spectroscopy contains 81 stars. A scheme for spectral typing A stars is currently being developed. The A dwarfs are particularly important for establishing a set of faint calibrators, with magnitudes of 11-13 in the IRAC bands, for two reasons. First, there is a distinct lack of faint K III star candidates in the existing catalogs. Furthermore, due to their red colors, faint K III star with the required IRAC magnitudes would have $m_V = 14 - 16$ and would be difficult to accurately spectral type with the FAST spectrometer. The A dwarfs do not share this difficulty. In total a sample of 47 potential A stars have been located toward the northern constant viewing zone using the Second Incremental Release Catalog of 2MASS (Figure 5). FAST spectra of these sources will be obtained in the spring and summer of 2001.

In addition to the ongoing spectroscopic observations, a campaign of optical photometry has been started to provide accurate $BVRI$ photometry for the chosen candidates. Combined with 2MASS JHK photometry, these data will provide well sampled, accurate photometry of the calibrators stars, and will be be crucial for extrapolating the flux densities of the calibrator stars into the IRAC bands.

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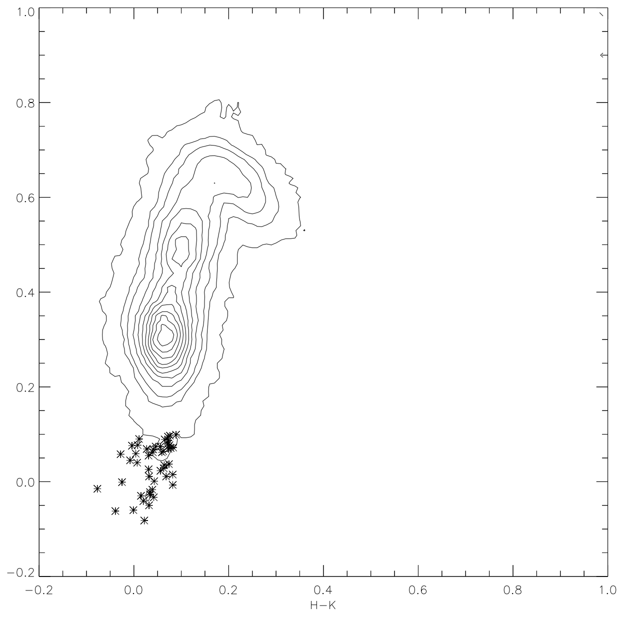

Figure 5. The color-color diagram of 2MASS point sources toward the northern constant viewing zone. In total, 28800 source with $m_K < 13$ *were found. The A star candidates were selected on the basis of their* $J-H$ *and* $H-K$ *colors. Forty seven A star candidates were found with magnitudes of* $11 < m_K < 13$.

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