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The SkyMapper Southern Sky Survey

S. Keller, M. Bessell, B. Schmidt and P. Francis

RSAA, The Australian National University, Mount Stromlo, Cotter Rd, Weston, ACT 2611, Australia

Abstract. SkyMapper is an automated 1.3-m telescope with an 5.7-square degree field of view being built at Siding Spring Observatory. It will have 16K×$16K$ 0.5-arcsec pixels and conduct a multi-color (u, v_s, g, r, i, z), multi-epoch (4hr, 1 day, 1 week, 1 month, 1 yr sampling) survey of the southerly 2π steradian to below 22 magnitude. It will provide star and galaxy photometry to better than 3% global accuracy and astrometry to better than 50 mas. Data will be supplied without proprietary period as part of Virtual Observatory work. The survey will take 5 years to complete.

1. Introduction

There is no existing deep digital map of the southern sky. Many digital sky surveys are underway or being planned for the future (Table 1), but most of these are in the northern hemisphere. Apart from SkyMapper, no instrument is planned in the near future that can map the entire southern sky in multiple colors and at multiple epochs.

Beyond 2010 it is likely that the Dark Energy and LSST projects will include the southern hemisphere but over the next 5 years there is a window of opportunity for SkyMapper to do the definitive digital southern sky survey, similar to SDSS, but with significant improvements due to enhanced blue/violet and far-red sensitivity, wider area and temporal coverage, and most significantly,

Table 1. Other Large Imaging Surveys.

Name	Aperture (m)	FOV (sq deg)	Photom. Bands	Areal Coverage	Hemi sphere	First Light
SDSS	2.5	Drift scan	*ugriz*	$\pi(2/3)$	N	Now
CFHT MegaCam	3.6	1	*ugriz*	<1000	N	Now
VST	2.6	1	*ugriz*	1000	S	2006
PanStarrs	1.8(+3x)	7	*grizY*	3π	N	2007
SkyMapper	1.3	6	uv_sgriz	2π	S	2007
VISTA	4	1	$zJHK$	π	S	2008?
Discovery Channel	4	2	?	?	N	2009
Dark Energy	4	2	?	5000	S	2009?
LSST	6.5	7	*griz*	3π	S	2012+

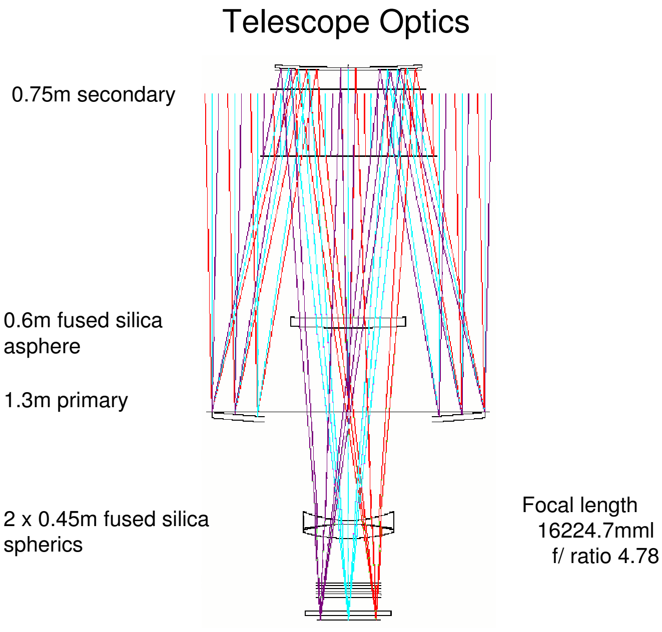

Figure 1. The SkyMapper lightpath: telescope, camera, filters and focal plane.

better sensitivity to stellar parameters through the use of carefully selected u and v_s bands.

2. Telescope Optics

The 1.3-m telescope is a completely automated telescope built by EOS-tech[1]. The telescope optics are shown in Fig. 1.The focal-plane is paved with 32 2K×4K deep-depletion CCD44-82 devices from E2V[2]. This provides reduced fringing and greatly enhanced far-red response. The AR coating is designed to provide excellent UV response. The dewar is cooled with a closed cycle He system. PanStarrs[3] controllers will be used providing full readout in less than 15 secs.

A Shack-Hartman system will be used for collimation and focus. An off-axis guider is also available. There are 6 slots for filters with dimension $309 \times 309 \times 15$ mm. The filters can be exchanged in 10–20 secs. A Bonn shutter[4] with 2 ms accuracy will be used. The dewar, focal-plane and the filter exchange mechanism has been designed and assembled at the RSAA.

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[1] `http://www.eostech.com`

[2] `http://www.e2v.com`

[3] `http://pan-starrs.ifa.hawaii.edu`

[4] `http://www.astro.uni-bonn.de/ ccd/shutters/`

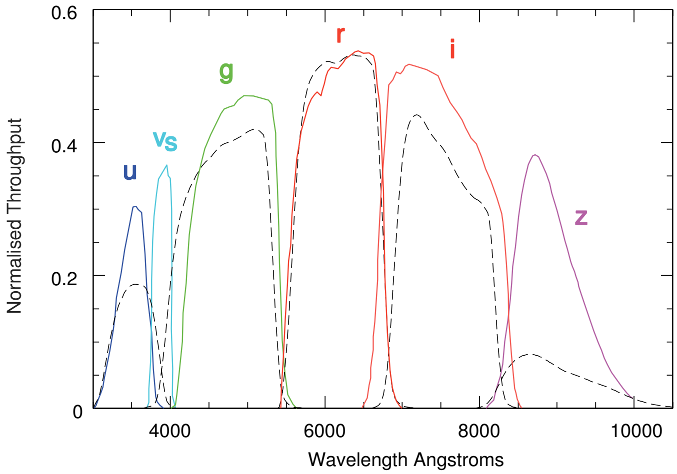

Figure 2. The computed SkyMapper and SDSS passbands.

3. Photometric Filters

It was decided to base the passbands on the SDSS system *griz* bands and to incorporate the ultra-violet u band of the Strömgren system and add the violet band of the DDO system. The choice of the u and v_s bands will enable better temperatures and luminosities to be derived for hot OBA stars and better luminosities and metallicities for cooler FGK stars. The expected SkyMapper passbands are shown in Fig. 2 in comparison with the SDSS passbands. The limiting magnitudes of SkyMapper and SDSS are listed in Table 2.

3.1. Changing Prospects for Large Filters

Because of difficulties and expense in achieving uniform and high transmission across large interference filters, especially in the violet and UV, we wished to explore using colored glass filters. Initial responses from Schott and Hoya were that large colored glass filters could no longer be made because of production-line restrictions. Vytautas Straizys kindly provided the names of some glass filter manufacturers in the former USSR. We followed these up and found that MacroOptica could source and polish large colored Russian glass filters. However, recently we have had positive discussions with Thorsten Doehring from Schott AG Mainz, who has agreed to make us a large z filter using RG850.

Table 2. Expected SkyMapper Survey limiting magnitudes.

	u	v_s	g	r	i	z
1 epoch	21.9	21.9	21.8	21.8	20.8	20.2
exp secs	55	35	25	25	15	15
6 epochs	22.9	22.9	22.8	22.8	21.9	21.2
SDSS	22.0	n/a	22.2	22.2	21.3	20.5

Table 3. 309 × 309 mm filter components.

Passband	Component glasses
u	8 yΦC2 + 6.3 BC4
v	3 yΦC1 + 6.5 C3C23 + 5 BC7
g	4 ZhC11 + 5 C3C21 + 5.7 BC4
r	6.5 OC12 + 8 Schott B270 + SWP coating
i	6 KC19 + 8.5 Schott B270 + SWP coating
z	4.5 RG850 + 10.1 Schott B270

There are also prospects that he may soon be able to produce all Schott filters in even larger sizes.

In Table 3 we list the design components of our glass filters. The u, v_s and g filters are entirely glass combinations. The r and i filters have short-wave-pass (SWP) coatings to define the red edges. The red edge of the z filter is defined by the long wave cutoff of the CCDs. All filters have broad-band anti-reflection (BBAR) coatings from Optical Surface Technologies, Albuquerque[5]. We are currently experimenting with glueing the component glasses together prior to final polishing and coating.

4. Image Processing

4.1. Initial CCD Reduction

The raw data will be bias subtracted and corrected for non-linearities. It will then be flatfielded and any scattered light and fringes removed. Initially we planned to generate median twilight flat-fields in all colors, however, for PanStarrs, Chris Stubbs (these Proceedings) proposes to use a custom-made internally illuminated collimated flatfield screen that will be mounted over the telescope aperture and has offered such a device to us. This will avoid problems associated with using twilight skyflats that are believed to be the limiting factor in current wide-field photometric accuracy (e.g. Magnier & Cuillandre 2004). Superflats will be generated from median filtering only night-sky pixels, and the scaled screen flat will be subtracted from the superflat to give fringe flats in i and z which will be scaled and subtracted from the observations.

4.2. Generating Photometric Flatfields

We will generate the photometric flatfield by observing the same standard field in all CCDs, then determine the relative magnitude of each star in each chip and compare them to the mean magnitudes from all CCDs. A smoothed map of the average deviations will be made for each CCD to correct the nominal flat to get the true photometric flat that will be applied to all images.

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[5] `http://www.opticalsurfacestech.com`

5. The Five Second Survey

As a first step in providing global precision of better than $0\overset{\mathrm{m}}{.}03$ to 22 mag we will first conduct a quick survey of the southern sky. This Five Second Survey will comprise 3 × 5 sec exposures and be carried out only in photometric conditions. (This also has the virtue of enabling the main survey to proceed in non-photometric conditions.) The resulting Five Second Catalog will have photometry from 8 to 15th mag and provide a calibrating anchor over the entire sky onto which the deeper SkyMapper Southern Sky Survey (S4) will be attached.

5.1. Photometric Reference Fields

During commissioning, a series of photometric reference fields in uv_sgriz will be established around the sky. These fields will be centered on existing Stetson/Landolt[6] (Stetson 2000) fields and on SDSS equatorial[7] and Seque[8] southern extension fields. After 6 and 9 months, additional fields will be established until they connect E–W around the sky. All these fields will provide calibrated photometry over the entire SkyMapper field of view. During establishment, each Stetson and SDSS standard star sequences will be placed in each CCD of the array. Images will also be taken with 4 × 90 degree rotator positions for astrometric corrections for World Coordinate System (WCS) determinations.

5.2. Five Second Survey Calibration Technique

The photometric status of each frame will be assessed by performing aperture photometry of all point sources and comparing their u, v_s, g, r, i or z magnitudes with 2MASS color-magnitude relations and TYCHO-2MASS color-magnitude relations of stars in common. The seeing, photometric zeropoint and sky-background will also be monitored on each frame.

Two different standard reference fields will be observed every hour to provide zero-points for each chip and flat-field illumination corrections. The extinction and photometric zeropoints will also be derived from these standard reference fields. We will endeavour to observe different passbands consecutively.

The photometric package Source-Extractor[9] will be used with an aperture set to twice the FWHM with additional growth curve correction to infinite aperture to generate the standard magnitudes.

5.3. The SkyMapper Natural and Standard Photometric Systems

The SkyMapper uv_sgriz system will initially be established as a natural photometric system. When the Five Second Survey is complete we will investigate whether to define the standard system by linear interpolating onto the SDSS $griz$ system and the Strömgren u system.

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[6] `http://cadcwwww.dao.nrc.ca/standards`

[7] `http://www.sdss.org/dr5/`

[8] `http://home.fnal.gov/~yanny/fut/layout.html`

[9] `http://terapix.iap.fr/`

6. SkyMapper Survey Photometric Catalog

Stars brighter than 15 mag from the Five Second Survey will be used to put the S4 instrumental photometry onto the standard uv_sgriz system. The images will be combined and an object catalog created. At high galactic latitude this will be done for all bands. At low galactic latitudes only the i band will be used. Transients will be extracted by comparing individual frames with the combined frame, masking out all cataloged objects and locating objects with the appropriate PSF. The PSF shape for each object in each image will be determined using a software filter. The PSF will be used as the basis for galaxy/star separation. The galaxy shape parameter (PA and ellipse isophot) will be determined and the magnitude measured using Source-Extractor.

A unique aspect of the SkyMapper survey is the provision of the u and v_s bands which greatly enhances our ability to describe the fundamental stellar parameters, $T_{\rm eff}$, $\log g$ and metallicity, over that provided by the $griz$ bands.

6.1. The SkyMapper *u* Band

The reason we chose to match the Strömgren u band for SkyMapper is that placing the u band essentially below the Balmer Jump greatly improves the delineation of temperature and effective gravity in AF stars, compared to Johnson-Cousins u and SDSS u bands both of which straddle the Balmer Jump. In Fig. 3 is shown the predicted $u - v_s$ color difference with gravity against $g - i$ color. The Population II blue Horizontal-Branch stars are cleanly separated from main-sequence stars enabling SkyMapper to photometrically select BHB stars to distances up to 130 kpc from the galactic plane, which will be extremely valuable for galactic structure studies and probing the distances of High Velocity HI Clouds. RR Lyrae stars will also be able to be identified at similar large distances from the time series observations.

6.2. The SkyMapper v_s Band

Most important is the SkyMapper v_s band that we have inserted between u and g and which resembles the DDO38 band (McClure 1975). The very well known Strömgren v band is a narrower band centered on the Hδ line at 4100 Å. Although it has been used very successfully in studies of stellar metallicities (Schuster et al. 2004; Nordström et al. 2004), it has two disadvantages compared to our v_s band. Firstly, it is situated in a part of the spectrum where the density of metal lines is less than at shorter wavelength and secondly, the standardization of the Strömgren v band is uncertain (see below). Figure 4 shows the distribution of metal-line blanketing with wavelength as seen by comparing model fluxes with solar and 1/10 solar metallicity.

The SkyMapper v_s band being situated further to the ultra-violet will measure larger differences in line blanketing than the Strömgren v band and be able to discriminate metallicities below -3 dex solar and work at higher temperatures than the Strömgren system is able to do. Figure 5 shows the computed $v_s - g$ variation with metallicity and $g - i$ color. Some stars from the Cayrel et al. (2004) sample of EMP stars are shown together with the Frebel et al. (2005) -5.4 star.

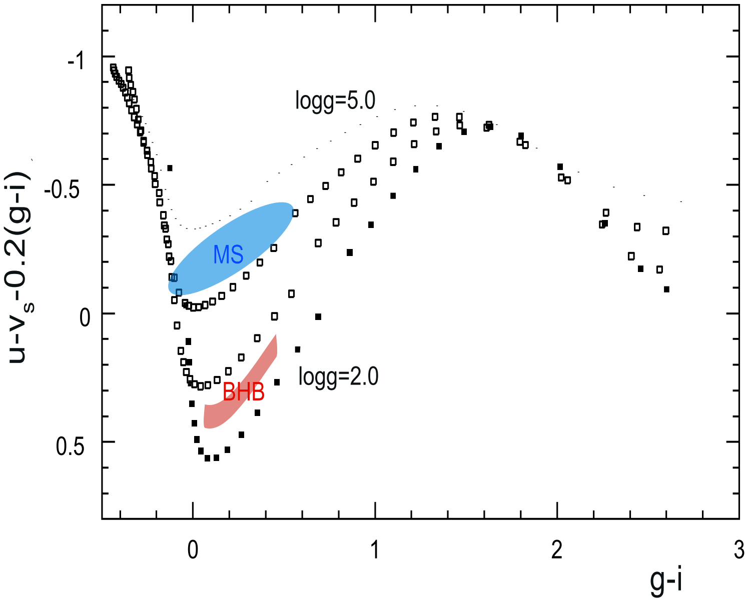
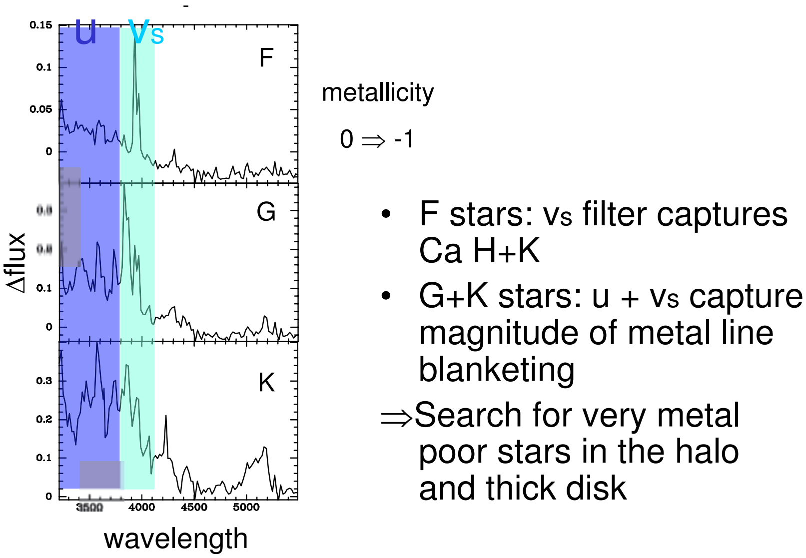


Figure 3. The variation of $u - v_s$ with gravity from $\log g = 5.0$ to $\log g = 2.0$. The separation between blue-horizontal-branch (BHB) stars and their contaminants is $\sim 0^{\mathrm{m}}.5$ for A-type stars.



- F stars: vs filter captures Ca H+K
- G+K stars: u + vs capture magnitude of metal line blanketing

⇒Search for very metal poor stars in the halo and thick disk

Figure 4. The variation of line blanketing with wavelength.

7. Synthetic Photometry and Calibration of Stellar Parameters

An unfortunate disadvantage of the existing Strömgren v band is the fact that standardization has been difficult to achieve because passbands of different width and shape have been used by various observers over the years (Olsen 1995; Bessell

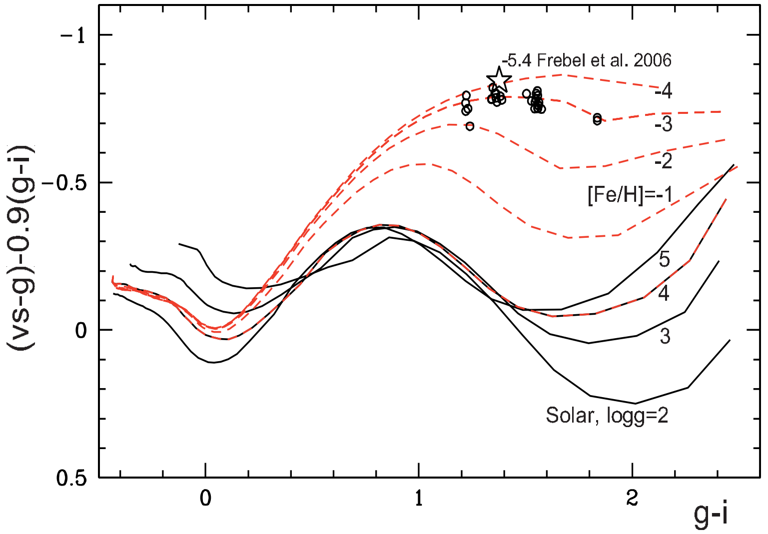


Figure 5. The computed variation of $v_s - g$ with metallicity and $g - i$ color.

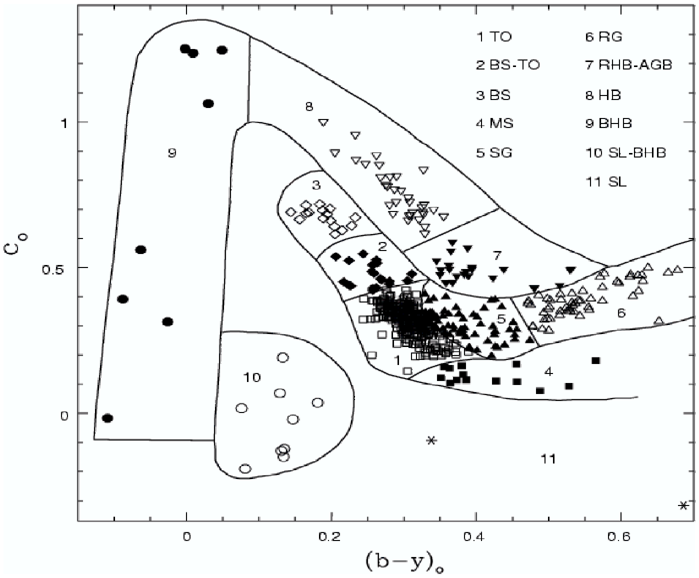


Figure 6. The Schuster et al. (2004) classification of Pop II stars from *uvby*.

2006). This has introduced systematic differences in m_1 and c_1 due to non-unique transformations for different kinds of stars, and makes it a complicated and uncertain process to synthesize Strömgren m_1 and c_1 indices from model atmosphere fluxes.

The SkyMapper uv_sgriz system, like the SDSS system, will be a closed photometric system (Bessell 2005) ensuring that its passbands are uniquely defined and maintained and the various colors can be precisely synthesized. We are working with Kurucz/Castelli fluxes (Munari et al. 2005; Castelli 2006) and with NMARCS fluxes (Gustafsson et al. 2002, 2006) to compute synthetic colors so that astrophysically precise parameters can be derived for all stars in our catalog. Theoretical isochrones from Pietrinferni et al. (2006); Cassisi (2006) will be used for interpreting the color-color and color-magnitude diagrams of halo stars.

8. Photometric Classification of Halo Stars

As well as using $v_s - g$ to determine more precise metallicity indices for halo stars, we aim to provide diagrams from our broad-band uv_sgi photometry similar to the well defined narrow-band photometric classification diagram for halo stars of Schuster (Schuster et al. 2004) shown in Fig. 6. Such schemes are invaluable tools to use in understanding the structure and evolution of our galaxy.

9. Conclusions

SkyMapper will undertake a deep digital survey of the southern sky in uv_sgriz from Siding Spring Observatory. The $griz$ bands are similar to the SDSS bands, the u band is close to the Strömgren u and the v_s band is similar to the DDO38 band. The catalog will contain accurate magnitudes and positions for all stars and galaxies, between 8 and 22 mag. The data will be available through the Virtual Observatory and the project is expected to take 5 years to complete.

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