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SKYMAPPER CRITICAL DESIGN REVIEW

SKYMAPPER SCIENCE REQUIREMENTS

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Revision History

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1	Schmidt 05 Sep 2004	Schmidt 05 Sep. 2004	Original document.
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Contents

1. Purpose

This document defines the scientific requirements of the SkyMapper system. It provides an overview of the basic science to be done with the telescope+imager, and the requirements that these science programs place on our system. It provides an estimation of relative importance of various important technical features in terms of the ability of SkyMapper to map the sky.

2. Applicable Documents

Document ID	Source	Title
CDR Document Pack	SkyMapper	SkyMapper CDR Document pack

3. The SkyMapper Telescope

The SkyMapper telescope is designed as a replacement for the Great Melbourne Telescope destroyed in the bushfires of 18 Jan. 2003. To be located at Siding Spring Observatory, this 1.3m telescope's primary scientific aim is to conduct the Southern Sky Survey: a multi-colour photometric survey of the southern sky, but will also serve as the primary imaging resource for the Australian Astronomical community.

The telescope + imager design presented here is baselined to have a 5-sq. degree FOV, to provide good sensitivity from the 340nm-1micron, to automatically acquire data, and to possess an automated data pipeline for many scientific applications. It will be accessible to the wider astronomical community for research that is beyond the scope of the Southern Sky Survey via a peer-judged time allocation process.

4. A Southern Sky Survey

4.1. Background

The whole sky has now been mapped at every wavelength from Gamma-ray (NASA's Compton Gamma Ray Observatory) to radio (the SUMSS, NVSS and FIRST surveys). Optical surveys detect substantially more objects than surveys at all other wavelengths (due to the maturity of the technology and the relative brightness of many astrophysical sources at optical wavelengths). The current best all-sky optical surveys were carried out with photographic plates, using Palomar and United Kingdom Schmidt Telescopes. These photographic surveys have several serious drawbacks:

- They are not photometric. It is not possible to determine the brightness of any of the millions of sources detected to better than 50% accuracy, without extensive follow-up calibrations.
- Only two wavelengths are available: the current surveys only map the whole sky at blue (460nm) and red (700nm) wavelengths.
- Due to their photographic nature, the current surveys have a limited dynamic range and provide all-sky astrometry accurate to at best 0.5 arcsec.
- Current all-sky surveys contain no information on variability.

Recent spectacular advances in astronomical detector technology now allow us to overcome these drawbacks. Modern Charge Coupled Devices (CCDs) are more than 50 times as sensitive as photographic plates. They are digital, astrometrically stable, intrinsically linear in their response and sensitive over a wide range of wavelengths. Until recently, they had too few pixels to rival photographic plates in mapping the whole sky but the recent development of cameras with tens of millions of pixels has solved this problem.

Several groups are now considering using CCD detectors to carry out digital, multi-colour surveys of the whole sky. The only study already in progress is the Sloan Digital Sky Survey (SDSS). Using a dedicated telescope in New Mexico, USA, this project has nearly finished mapping 8500 sq degrees of the northern hemisphere sky in five colours. The SDSS survey has been used to do everything from asteroid science to discovery of the most distant quasar at z=6.43[Fan et al. 2003, 125, 1649]. No comparable survey is currently in progress or planned to commence in the near future in the southern hemisphere.

There is thus a brief window of opportunity for us to do the definitive digital Southern Sky Survey. With a small and focussed team we can complete our survey before any rival gets started, and map the whole southern sky to a depth comparable to that reached by the SDSS in the northern hemisphere, but with significant improvements in near-IR sensitivity, sensitivity to stellar parameters, in areal coverage, and, finally, including the coverage of temporal variability.

4.2. *Scientific questions*

The science that can be done with a comprehensive survey of this type cannot be fully described or predicted. Previous southern sky surveys, such as the Parkes radio survey or the UK Schmidt photographic surveys, have been used in literally thousands of papers and important discoveries are still being made from them decades after their completion. We, instead, outline scientific questions that are of particular interest to members of RSAA staff and wider Australian astronomical community, working outward in distance:

4.2.1. *What is the distribution of Solar-system objects beyond Neptune?*

The existence of comet-like objects orbiting the Sun in a region beyond Neptune was first proposed around 1950. Known as the Kuiper Belt, the objects in this region remained undiscovered until 1992 when the first Trans-Neptunian Object (TNO) was discovered [Jewitt, D & Luu, J 1993, Nature, 362, 130]. Subsequent searches have uncovered more than 300 TNOs. TNOs are believed to be debris left over from the initial construction of the solar system. The distribution of their orbits and masses give us important clues on how the solar system formed and on the origin and nature of both comets and the outer planets.

Previous observations have constrained the properties of small TNOs close to the ecliptic. Only a little is currently known about any larger TNOs, especially those on scattered orbits that take them out of the ecliptic. Some models predict that many large TNOs may exist, some with masses larger than that of Pluto. Recent discoveries of Sedna, a highly scattered object with a mass 50% of Pluto, demonstrates the possibilities for future discovery.

Program requirements: Interesting science is finding moving objects at r<21. Motions are typically 1"-3"/hr. To disentangle nearby objects from distant objects, at least 3 observations are required over 24-96hr period within 20 degrees of opposition. Large sky coverage (whole sky) is essential to get significant numbers of objects.

Table 4.2.1 Scattered Large TNOs						
sensitivity	***u***	***v_s***	***g***	***r***	***i***	***z***
				7σ *r*<21 **3 epochs (2 day baseline)**		
systematic	**none**					
Astrometry	**200 mas (absolute)**					

4.2.2. What is the history of the youngest stars in the solar neighbourhood?

Perhaps the best way to learn how stars and solar systems form would be to study newborn stars. Unfortunately, star formation is known to take place deep inside molecular clouds and the earliest phases are invisible to all but far-infrared light. The nearest dark clouds are sufficiently distant from the Earth that current astronomical instrumentation does not provide the resolution necessary to image these stars to look for planet forming disks.

It has recently become clear that there are some very young unobscured stars moving through the solar neighbour. They have recently been ejected from molecular clouds, probably in the Sco-Cen association, a massive region of star formation in the southern sky [Zuchermann & Song 2004 ARAA, 42, 685]. Because these stars are unobscured, close to the Earth and young, they are ideal targets for high resolution imaging of protoplanetary disks. We also know the ages of these stars from their progenitor association – hence we can explore the evolution of the circumstellar material. These stars will be among the first targets of IR adaptive optics imagers that are planned for Gemini and other 8m-10m class telescopes.

While several comoving streams of such stars have been found from the Hipparcos and Tycho catalogues, these surveys do not go faint enough to find anything more than the brightest, most extreme examples. Our survey will allow us to greatly increase the number of such stars known, using a combination of proper motion and colour selection. As well as discovering more nearby candidates for planetary disk searches we will gain a better understanding of the creation of the population of "field stars" by evaporation, ejection or dissipation of cluster stars. We can also measure the mass function of these sibling stars using their intrinsic luminosities and ages.

Scientific requirements: Key is to have good proper motions of objects across entire sky, as well as accurate colour selection down to R=18, to select the few nearby candidates. Relative astrometry requirement is 50mas to derive proper motions over a 3 year baseline. This will allow us to find relevant objects within 120pc.

Table 4.2.2 Young Nearby Stars

sensitivity	***u***	***v_s***	***g***	***r***	***i***	***z***
			σ=0.02mag *g*<18.5 **3 epochs** **(3year baseline)**	**σ=0.02mag *r*<18** **3 epochs** **(3year baseline)**	**σ=0.02mag *i*<17.5** **3 epochs** **(3year baseline)**	
systematic	**0.03 mag**					
Astrometry	**50 mas (relative)**					

4.2.3. How far does the dark matter halo of our galaxy extend and what shape is it?

Dark matter is the dominant gravitational component in our universe but as yet we have almost no idea of its nature. One of the few possible clues is its distribution. It is now clear that dark matter in the cores of galaxies is not distributed in accordance with theories [Navarro, J.F., Steinmetz, M. 2000 ApJ, 528, 607]. Less is known about the distribution of dark matter in the outer regions of galaxies, even our own. How far out does it extend? Is its distribution spherical, flattened or triaxial? All these questions place constraints on both the nature of dark matter and the formation of our galaxy.

The only way to map our galaxy's dark matter halo is by measuring the dynamics of tracer objects orbiting far from the centre of the Milky Way. RR-Lyrae stars are perhaps the best such tracers but such stars are rare: approximately 1 per 10 degrees beyond 50 kpc (the distance we wish to study) and one per 100 square degrees beyond 100 kpc [Mackey, D. 2000, thesis, ANU]. Other tracers, such as blue horizontal branch stars, are more common but harder to discriminate, or, in the case of bright giants (which can be seen to large distances), are hard to discriminate and are about as common as RR-Lyraes. Our planned survey will discover approximately a thousand giant stars and RR Lyrae stars beyond 50 kpc, and several thousand blue horizontal branch stars. This will allow us to extract the shape, extent and density of the outermost part of the Milky Way, especially if these data are married with a spectroscopic follow up program, and provide clues to how the galaxy was assembled, by looking at collection of objects in phase space.

These same objects should also provide a method to finally understand the basic physical nature of the HI high velocity clouds (HVCs). HVCs fill the radio sky in 21cm radiation but their mass, distance and origin are still unknown to an order of magnitude. A large sample of stars with clean spectra and specific distances - blue horizontal branch stars + Giants for very distant clouds – can be used to bracket the distance to the clouds: if the star lies behind the cloud, the cloud will project a narrow spectroscopic line onto the star's continuum when observed with an 8m-class telescope.

Program requirements: RR Lyraes can be discriminated on the basis of two colours plus variability over a 12hr period. Blue Horizontal stars (BHB) can be discriminated on the basis of colour information, with a gravity indicator (such as Stromgren *v* – referred to v_s) to differentiate between blue stragglers and BHB stars. RR Lyraes and BHB are the same brightness, and *r*=21 corresponds to an object at 120kpc. Giants are much brighter, and need to be discriminated on the basis of a gravity indicator alone. Five colour photometry + v_s will allow F+G giants to be discovered, and five colour photometry + *Mg51* filter discriminated K giants from other objects. 90% of RR Lyrae stars can be discovered with a *g-r* colour to 0.1mag precision and 6 epochs in *g* with a precision of 0.1 mag. BHBs and Giants require 0.03 mag photometry for complete discrimination.

Table 4.2.3 Distant Halo Stars						
sensitivity	***u***	***v_s***	***g***	***r***	***i***	***z***
	σ=0.03mag **u<19.5**	**σ=0.03mag** **v_s<20.0**	**σ=0.1mag** **g<21.2** **6 epochs**	**σ=0.1mag** **r<21.0** **6 epochs**		
systematic	**0.03 mag**					
Astrometry	**200 mas (absolute)**					

4.2.4. Selection for the RAVE and First Stars programs

The precision of the Southern Sky Survey allows the temperature, metallicity, and gravity to be estimated for all stars in the catalogue. The RAVE program seeks to obtain the spectra, and hence radial velocities of all Hipparcos/Tycho stars to *V*=16. The Southern Sky Survey will provide accurate temperatures, metallicity and gravity information to 0.5 dex, as shown in Figure A.6.1. When combined with RAVE spectra, these data will allow metallicity to be measured to much better precision. SkyMapper can also be used to preselect the stars for RAVE to observe, thereby increasing the efficiency of RAVE by a significant factor. This is an especially important contribution if the UKidna spectrograph is not funded.

The Southern Sky Survey will allow large numbers of very metal-poor stars – the stars that were first formed after the Big Bang – to be studied in detail. This will assist us to unravel the history of this particularly interesting time in our Universe, by choosing stars with correct temperatures, gravities, and metallicities for further study. Our metallicity sensitivity remains high at Z<-2 due to our v_s bandpass that includes the strong Ca K line.

Program requirements: RAVE is studying bright stars and requires accurate (0.03 mag) six colour photometry (*uv_sgriz*) for stars between 8-12th magnitude to obtain the requisite temperature gravity and metallicity discrimination. The First Stars program is targeting stars which are fainter - 15-18 magnitude - and requires a similar precision over this magnitude range.

Table 4.2.4 First Stars and RAVE program						
sensitivity	***u***	v_s	***g***	***r***	***i***	***z***
	σ=0.03mag **u<18**	**σ=0.03mag** **v_s<18**	**σ=0.03mag** **8<g<18**	**σ=0.03mag** **8<r<18**	**σ=0.03mag** **8<i<18**	
systematic	**0.03 mag**					
Astrometry	**200 mas (absolute)**					

4.2.5. Calibrating the 2dF and 6dF redshift surveys

In 2002 the 2dF redshift survey finished their analysis of 220,000 galaxies and the 6dF survey will complete measuring the distances and motions to 100,000 nearby galaxies by the end of 2005. These surveys will constrain the primordial fluctuations in our universe, pin down cosmological parameters and probe the distribution of dark matter. The Southern Sky Survey will provide accurate optical magnitudes, colours and morphologies for all the galaxies in these surveys, and provide insights into the selection biases against low (and high) surface brightness galaxies. This should enhance the usefulness of these surveys. It will also allow them to be calibrated in an almost identical way to the northern Sloan redshift survey. These three large surveys can then be analysed as one and any differences between the surveys sorted out using data, rather than rhetoric.

Program requirements: All-sky multicolour photometry of all galaxies over the 2dF (2000 sq degrees) and 6dF (all-sky) survey regions to an accuracy of 0.1 mag (we are limited here mainly by the vagaries of galaxy photometry) with systematic variations as a function of position < 0.03 mag.

Table 4.2.5 Galaxy Photometry						
sensitivity	***u***	v_s	***g***	***r***	***i***	***z***
	σ=0.1mag **u<20**		**σ=0.1mag** **12<g<20**	**σ=0.1mag** **12<r<20**	**σ=0.1mag** **11.5<i<19.5**	**σ=0.1mag** **11<z<19**
systematic	**0.03 mag**					
Astrometry	**200 mas (absolute)**					

4.2.6. When did the first stars in the Universe form?

We know that within 1.5 billion years of the Big Bang, some galaxies had formed; this is evidenced by galaxies observed to z~6. Curiously, even at this early epoch, the inter-galactic gas seems to be ionised. We can tell this due to the lack of continuous Lyman-alpha absorption in the spectra of these objects (the Gunn-Peterson effect). Some objects must have existed earlier still and pumped out enough UV photons to ionise nearly all the baryons in the Universe.

The SDSS recently broke the record for the most distant object ever found by identifying a quasar at redshift 6.42. This QSO does seem to show continuous Lyman-alpha absorption [Becker, R et al. 2001 AJ 122, 2850]. We appear at last be looking back in time to the era when the first galaxies and quasars formed, ionising the intergalactic gas. This observation is still not well understood with only three quasars showing the effect. Any definitive study of the ionisation of the universe thus needs observations of many QSO sight lines. QSOs at these redshifts are very rare. QSOs bright enough for the necessary follow-up observations are rarer still. There are only a handful (~20 using SDSS as a guide) in the whole sky. In addition to covering 2.5 times more of the sky than SDSS, our proposed survey is more red sensitive, and is therefore more able to find distant quasars. Consequently the survey should turn a dozen or more of comparable, or even more distant objects. Wyithe et. al. [Wyithe & Loeb 2004, Nature, 427, 815] have also shown how measurements of the blue side of these objects can probe the physical conditions around these first quasars. Follow-up spectra (8 metre telescopes required) will test this first glimpse of reionisation and provide information through several lines of sight of the Universe, showing when and how fast the first stars turned on.

Program requirements: All-sky multicolour photometry with *z* sensitivity to 20.5 and *i* sensitivity to 22.5. Good cosmic-ray rejection in subsequent reduction is a must.

Table 4.2.6 Distant Quasars

sensitivity	***u***	v_s	***g***	***r***	***i***	***z***
					3σ i**=22.5**	**7σ** z**<20.5**
systematic	**0.1mag**					
Astrometry	**200 mas (absolute)**					

4.2.7. Virtual observatory:

Nearly every observation made on any of the world's major telescopes is archived. The combined database of archived observations is potentially an extremely valuable resource. There is currently a major push in the USA, Europe, and now Australia to use modern high bandwidth communications to make this vast combined archive seamlessly available worldwide on-line: a so-called Virtual Observatory. For many astronomers, a decade from now, this virtual observatory will make telescopes unnecessary. Any type of data they require, for any part of the sky, will probably already exist within the virtual observatory. It will also allow astronomers to carry out vast multiwavelength statistical surveys involving far more data than any individual or team could ever hope to gather.

A virtual observatory needs a base structure around which it can be woven. Our survey can provide this structure for optical/IR observations, providing a positional grid on which to map all other observations, and providing precise colour information that will allow optical observations, regardless of the wavelength band in which they were observed, to be calibrated and mapped onto the virtual observatory structure.

Program requirements: Complete sky coverage with photometry accurate globally to 0.03 mag and astrometry accurate, globally to 50mas. Should extend to as faint as possible, but a depth similar to SDSS is essential to be competitive.

Table 4.2.7 Virtual Observatory Optical Survey

sensitivity	***u***	v_s	***g***	***r***	***i***	***z***
	5σ ***u*=22**		**5σ** ***g*=22.2**	**5σ** ***r*=22.2**	**5σ** ***i*=21.3**	**5σ** ***z*=20.5**
Systematic	**0.03mag**					
Astrometry	**50 mas**					

5. Non-survey SkyMapper science

The instrumentation that enables the Southern Sky Survey also enables other science not covered by the survey. An email solicitation to astronomers in Australia indicates that the Southern Sky Survey covers most people's needs, but one area highlighted for special attention is planetary transits:

- SkyMapper's 268 Million pixel array over 5 sq degrees will allow tens of thousands of stars to be monitored simultaneously to a relative flux measurement of better than 0.01 mag, making it a highly competitive telescope in this field.

In addition, it is likely that SkyMapper can undertake a supernova survey in conditions that do not meet the survey's requirements because of poor seeing conditions, or excessive sky background. Such a survey should be able to find approximately 10 Supernovae per night observing to r<20 magnitude. These data allow the following:

- a systematic exploration of the statistical properties of Type Ia supernovae in order to better use them as cosmological distance indicators;
- discovery of Type II supernovae and exploring their properties to understand the energetics and nucleosynthetic production of the explosions; and

- discovery of hypernovae providing a set of objects to explore the relationship between these objects and Gamma Ray Bursts.

6. Analysis of Scientific Requirements

6.1. Defining scientific requirements:

To achieve our scientific goals, we require filters which provide both inter-operability with existing systems (such as SDSS), and key information for specific science objectives. A cleanly separated i and z filter is required for discovery of distant quasars. High throughput bands with some color discrimination are particularly useful for discovering RR-lyrae stars and TNOs, with the stellar work requiring a long baseline over several bands, and two filters in the UV/Blue portion of the spectrum. These two filters are constructed to break the degeneracy between metallicity and gravity. Our filter set choice is discussed in SDN02.02.

Using this filter set, table 6.1 provides the defining (most difficult to achieve) constraints to achieve the above scientific goals.

Table 6.1 Southern Sky Survey – Defining Constraints						
sensitivity	***u***	v_s	***g***	***r***	***i***	***z***
	σ=0.03 u**<20**	**σ=0.03** v_s**<20**	**σ=0.1** g**=21.2** **(each of 6 epochs – baseline hours to years)**	**σ=0.1** r**=21.0** **(each of 6 epochs - baseline hours to years)**	**3σ** i**=22.5**	**7σ** z**=20.5**
Systematic	**0.03mag**					
Astrometry	**50 mas over 3 year baseline**					

Finally, the Southern Sky Survey needs to be completed within 5 years to realise its full potential. A quicker release of data to the astronomical community would be beneficial.

6.2. The Main Survey Design

To meet our scientific requirements we need to undertake a Southern Sky Survey with a series of relatively short exposures on each patch of sky. The combination of short exposures will provide a relatively uniform survey (dithers fill in the gaps between chips and bad pixels and allow cosmic rays to be removed), and a time series to meet our variability requirements.

To calibrate this survey to the requisite 0.03 mag, we need a shallow survey on photometric nights to calibrate the sky. This network of standards will enable the survey to be calibrated even on non-photometric nights. This calibrating survey is discussed in Section 6.3.

The top level science goals emphasize variability on short (RR-Lyraes, Asteroids) and long time (proper motions of stars) scales. For VO work it would be advantageous to cover as much parameter space as possible.

Since most variable astronomical objects have scales of variability ranging over hours (e.g. RR-Lyrae stars, distant asteroids), months (Supernovae, Mira Variables) and years (QSOs, stellar parallax and proper motion), we believe each patch of the sky should be observed on 6 different occasions, with a separation of observations being approximately 4 hours, 1 day, 1 week, 1 month, 1 year.

For observing efficiency and quick turn around of a preliminary catalog of the entire sky, this sequence will be separated into two observing blocks, separated by one year. For example a patch might have observations made at 0,+1day,+1 week,+1 year, +1year+4hrs, +1year+1month. A dither pattern will be used to ensure that chip gaps and chip defects are not always placed on the same part of the array. To get the survey out as fast as possible, two passes will be made through the data, one when the first 3 observations have been obtained (plus5-Second survey data), and a final pass after all 6 observations have been made. We want, in the the 3-pass data, 99% coverage of the sky with at least 1 epoch, and 80% with 3epochs. For the final survey, we desire 100% of sky to be covered at least 3-epochs, and 90% of the survey to have 5 or more epochs.

For the sake of uniformity and software convenience, it is desirable to integrate on each piece of the sky with 6 epochs in all filters. Because the overhead between exposures is large, this maybe a less than optimal solution, depending on the final overhead time achieved by our system. As a first cut, the u and v_s exposures could be lowered from 6 to 3. Variability in these filters is not particularly useful, and this strategy provides almost 100% coverage of the sky. A disadvantage is that there is significant non-uniformity across the survey in these filters (a factor of 3 in integration time at worst), and approximately 20% of the imaged area will be subject to cosmic rays in the final combined images. This could be extended to the i band as well, but the g, r, and z bands need to have more than 3 epochs – this is for both cosmic ray rejection (critical for z-band, important in g and r since these bands will drive the catalog selection) and time series information (g,r).

Another compromise would be to reduce the number of epochs from 6 to 5. While not as good as 6 epochs (few baselines for measuring variability – less uniformity in final composite images), it would not significantly impact on any of the science goals.

6.3. The 5-Second Survey Design

To calibrate the southern survey to the requisite 0.03 mag, on photometric nights the sky will be imaged with an exposure time of 5 seconds, allowing stars from 8-15th magnitudes to be photometered. This survey will provide a calibrating anchor over the entire sky, thereby providing a photometric and astrometric catalog onto which deeper survey images will be attached. Each piece of the sky needs to be observed at least 3 times in each band, with an approximate exposure time of 5 seconds to be chosen once the efficiency and saturation levels of the instrument are measured in a real-world situation.

Table 6.3 5-Second Survey						
sensitivity	**u**	**v_s**	**g**	**r**	**i**	**z**
	σ=0.03 u=14	**σ=0.03 v_s<14**	**σ=0.03 g=14**	**σ=0.03 r=14**	**σ=0.03 i=14**	**σ=0.03 z=14**
Systematic	**0.03mag**					
Astrometry	**50 mas**					

6.4. Time to complete the Southern Sky Survey

To achieve the Southern Sky Survey, it is imperative to have a stable instrument with sufficient capability to finish the survey of the southern sky within 5 years.
The Southern Sky Survey will be allocated a minimum of 75% of the telescope time (the remainder will be competed against other proposals), and we now calculate the time to achieve the Southern Sky Survey given a variety of trade-offs.

The SSO weather pattern shows little seasonal variation, with approximately 60% of the time useable throughout the year, with significant year to year variations. Using DIMM measurements (Wood et al, 1995, PASP), the median free-seeing at SSO is approximately 1.1”, but this assumes turbulence is not near the ground, and therefore actual seeing maybe somewhat worse. Experience with the 2.3m indicates 30% of clear nights have seeing worse than 2.5”, 50% worse than 2”, 75% worse than 1.5”, and 90% worse than 1”. The claimed median seeing value of the AAT is 1.5”, (C Tinney, personal communication), which indicates that we should be able to achieve numbers that are significiantly better than the 2.3m sky conditions.

Table 6.4 Available Astronomical Time at Siding Spring Observatory		
SSO Astronomical Hours per year		3285
SSO useable hours per year		1971
	Hours available any seeing	Hours available for main survey
Dark	991	660
Grey	490	330
Bright	490	330

In order to achieve a relatively uniform survey, we will only use data that has a fwhm < 1.5 median (fwhm). Experience and DIMM measurements at SSO indicates that this includes 2/3 of all workable nights – or approximately .67*0.6 = 40% of all available time. We will assume that we will only work in Dark and Grey time, although bright time could be used for low galactic latitude work, some i and z band work, and the 5 second survey. Experience indicate roughly 15% all workable nights are photometric – this equates to 9% of the total time available to the survey, or roughly 220 hours per year (some of this time is in bright and in poor seeing conditions).

We will model the seeing on three cases.

1. Median seeing input into telescope is 1.1" as indicated by the DIMM

Table 6.4 A Integration Time to Reach Southern Sky Survey goals (per epoch – 6 epochs total – 20 second overhead)							**Total Southern Sky Survey time (hours obs/years to complete)**
	u	**v_s**	**g**	**r**	**i**	**z**	
Zeropoint (AB Mag for 1 e- per sec)	22.0	22.6	24.2	24.3	24.0	22.8	
1.1" median	50s	30s	20s	20s	10s	10s	1775/2.4
1.5" median	55s	35s	25s	25s	15s	15s	1980/2.7
2.2" median	70s	45s	40s	40s	30s	25s	2530/3.4

2. Median seeing input into telescope is 1.5" as indicated by the AAT.
3. Median seeing input into telescope is 2.2" as indicated by the 2.3m

Using the performance of the telescope included in SDN02.03, we have calculated the exposure time in seconds (1 of 6 epochs for each filter) to meet each goal of the survey. These figures are provided in Table 6.4, along with the calculated zeropoint (throughput) of the telescope including all telescope, instrument, and atmospheric losses. The zeropoint of the telescope is similar (but slightly less) than the throughput measured by CFHT, scaled by the relative apertures of the two telescopes. We would like to go deeper than the baseline goals, and we would plan to integrate for as long as possible to complete the survey within its 5 year timeline.

We do not include these calculations for the 5-Second survey – it is defined by integration time alone, but is sensitive to overheads (see section 6.3) . These calculations indicate that we can meet our survey requirements for most conceivable situations.

6.5. Telescope/Instrument Performance impact on the Southern Sky Survey

6.5.1. Field of View.

The field of view of the nominal 32 2kx4k CCD system is 5 sq degrees. There exists the potential for descoping the Telescope from 32 to 24 CCDs in our E2V contract. For the scientific justification, this descope option directly reduces the overall sky coverage of SkyMapper by 25% resulting in 33% more time to achieve the same science goals with the descoped field of view. This still enables SkyMapper to deliver the Southern Sky Survey in 4.5 years – a marginally acceptable position, if the sensitivity is as expected. Because of the impact on the software pipeline and scheduling constraints of the survey, a delayed upgrade to 32 CCDs would be expensive and inefficient to implement.

6.5.2. Image Quality

The effect of instrument image quality is challenging to quantify due to the uncertainty in our free-seeing conditions at the site. If we assume SkyMapper will experience an average free-seeing of 1.5”, then table 5.5.2 gives the required percentage increase in exposure time to reach a magnitude limit (sky-limited) relative to a perfect telescope.

To best meet our science goals, we need to exploit the conditions to their fullest and not degrade the free-seeing with our telescope and instrument.
Since the median free seeing is around 1.1”, the fundamental requirement of our system is that it not significantly degrade free-seeing images of this level due to all sources over exposure times of 90 seconds. This implies the quadrature some of all image aberrations (FWHM) due to optics and guiding should not exceed 0.6”, with 1.0” seen as the absolute tolerable limit. Excursions beyond these numbers (due to wind, temperature variations, etc.) should not exceed 10% of the useable hours.

Table 6.5.2 Affect of Image quality on Surveying Speed

Telescope Degradation (arcseconds)	Increased Exposure time to reach a sky-limited value
0.2	1%
0.4	5%
0.6	11%
0.8	19%
1.0	30%
1.2	42%
1.4	57%

6.5.3. Total throughput

Total throughput of the telescope directly impacts on the magnitude limits achieved in a given amount of time. Most systems are able to achieve expected efficiencies in the range 450-750nm, but it is very easy to lose sensitivity in the UV (CCDs, mirrors, optics, coatings) and the infrared (CCDs and coatings). The most likely problem would be poor UV sensitivity - this would directly impact on most of the stellar science. Very poor sensitivity below 375nm implies an inability to measure gravity and metallicity of stars, and in this way would make SkyMapper ineffective for this crucial piece of science.

Poor IR sensitivity limits the ability to discovery distant Quasars. Since this is a crucial piece of science, it would be necessary to increase exposure times in the *i*,*z* bands to make up for any shortfall.

The instrument must have adequate throughput to complete survey to levels indicated in table 6.4 in less than 5 years.

6.5.4. Overheads between exposures

Since the SkyMapper telescope is being constructed as a point and shoot system with short integration times (to cope with the largely non-photometric conditions of Siding Spring Observatory), the efficiency of the telescope is very dependent on the overheads between exposures. These include, in order of importance, CCD readout time, telescope settling time, and filter exchange time. Increased readout time affects the total time that the Southern Sky Survey takes to complete. It is especially hard on the 5-Second survey, which must be conducted in photometric conditions, but also impacts the main survey. Table 6.5.4 shows the amount of time to complete the 5-Second survey as a function of readout time, and the total integration time allocated to each filter in the deep survey, assuming the total time of the Southern Sky Survey plus 5-Second survey is 5 years. A readout time of 30 seconds is barely acceptable, with times longer than this having a large impact on the performance of the telescope. Times approaching 10 seconds are beneficial, but eventually likely filter exchange times and telescope settling times for the telescope will negate any benefit of faster readout times.

Table 6.5.4 Impact of Overheads on Southern Sky Survey

Overhead time (seconds)	Hours to complete 5 second survey (3 epochs)	Total combined integration time for deep survey in a 5 year survey per filter (seconds)
10	307	440
20	512	350
30	717	260

Telescope slew and settling time need to be less than the readout time. The slews required of SkyMapper will typically be small (< 5 degrees), but if the slew and settle time exceeds the readout time, then this effect will negate any benefit of a fast readout time. If this were to be a large problem, and the filter exchange time were relatively fast (compared to settling time), then the scheduler could change filters at each position, rather than changing position and keeping filters fixed.

Since filter exchanges can be scheduled to occur infrequently, they are less important. Ideally, the exchange time should be less than the readout time, but the overall impact to the project of not meeting this goal is less important than the readout time by an order of magnitude.

6.6. Instrument Calibration Constraints

6.6.1. Instument Stability

An unstable instrument, or one with significant scattered light, or other non-uniformity will be difficult to calibrate accurately. VO and stellar work demand calibration to 0.03 mags. If this is not achievable, these aspects of the Southern Sky Survey will be severely compromised, thereby critically impacting on the science case for the SkyMapper telescope.
To make the instrument stable, we require the following:

- filters to lock into accurate position (so variations across the focal plane are fixed with respect to ±a pixel on the focal plane);
- the telescope to be baffled so that scattered light is < 3% (and ideally less than that);
- The instrument to be able to be left in its cooled down state untampered with for at least 3 months at a time, and preferably a year at a time. For example the instrument should not be allowed to warm up more than 20 degrees C during power failures;

- Filters to be kept in dry-air/N2 enviroment at all time, protected from dust, bugs, and humidity. There throughput should not change over time; and
- Individual CCDs temperatures need to be stable to +/- 5 degrees, and it would be essential to monitor the array's temperature at least 1 point, with 5 points being desirable (z throughput depends critically on temperature).

6.6.2. Shutter Accuracy

To achieve the 5-Second Survey goals, it is imperative to have a shutter which is reproducible to 1% in a 5 second exposure - e.g. each part of the array should have a consistently reproducible exposure time to the sky to 0.05 seconds in a relative sense. It is preferable for the shutter to be consistent to this level in a absolute sense – but this is not mandatory, as a consistent, but variable exposure time across the array can be corrected for in software.

6.6.3. Uniformity of transmission

In order to calibrate onto a single system, we need to be able to accurately transform each part of the array to the average system. Each CCD will have its own QE curve, and this is easily dealt with in software. It will be difficult to correct varying wavelength transmission across individual CCDs due to non-uniformities in the filter or optics transmission (although it might be possible to do it after the survey is done). The linear color terms across the scale of individual CCDs should not vary by more than 0.015 mags per magnitude of (*B*-*V*) from all sources.