The Southern Sky Survey
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E1 Title: The Southern Sky Survey

E2 Project Description, Aims and Background

Project Description and Aims: We propose to use the robotic Great Melbourne Telescope (GMT) to carry out an optical survey of the entire southern sky. The survey will be:

- Multi-Colour. We will observe at six wavelengths, from the near-UV to the near-IR
  1. Photometric. We will measure the brightness of each object detected, at each wavelength, with systematic errors of less than 0.02 mag
  2. Astrometric. We will determine the absolute positions of the objects we detect with an accuracy of better than 0.05 arcsec.
  3. Sensitive to variability. Each part of the sky will be observed multiple times, to look for time variability and movement.

The RSAA director has guaranteed that at least 80% of the Great Melbourne Telescope observing time will be devoted to this project, over 5 years. We will generate 25 terabytes of data and will detect more than $10^9$ objects. All calibrated data will be made publicly available online via the ANU supercomputer facility.

We anticipate that the survey will be used for an enormous variety of scientific projects by astrophysicists worldwide for decades to come. The team members, however, are particularly interested in the following science goals:

- Mapping the distribution of dark matter in the outer regions of our own galaxy.
- Searching for high redshift QSOs to probe the reionisation of the universe.
The Southern Sky Survey

1 Jan 2003 - Our ARC DP grant starts.

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My own picture from 20th January 2003
What is SkyMapper?

- 1.35m telescope with a 5.7 sq. degree field of view
- Fully Autonomous observing
- To conduct the Southern Sky Survey:
  - Five year
  - Multi-colour (6 filters)
  - Multi-epoch (6 exposures, each filter)
  - \(2\pi\) steradians
  - Limiting mag. \(g \sim 23\)
- Aiming for regular operations this year
- Summary of program: Keller et al. 2007 PASA 24,1

Total Cost: Hardware US$11M software: ~$1.5M
Dedicated Science/Operations: ~0.6M/yr
Who is SkyMapper?
The SkyMapper Enclosure

- Rear Shutter
- Front Shutter
- Level 3 Observing Space
- 11.5m tall
- Vent Door
- 6m diameter
- Level 2 Service Level
- Level 1 Thermally Isolated Equipment Level

SkyMapper
Thursday, 29 July 2010
Telescope Optics

0.75m secondary

0.6m fused silica asphere

1.3m primary

2 x 0.45m fused silica spherics

Telescope – Focal length & f/ ratio.

<table>
<thead>
<tr>
<th></th>
<th>16224.75mm f/4.78</th>
</tr>
</thead>
</table>

Modified Cassegrain design
SkyMapper Cassegrain Imager

- Being built by RSAA
- 16384x16384 pixel array Cooled with Closed-Cycle He system
- Shack-Hartmann system for focus, collimation, etc.
- 6 Filters slots (~8 second exchange time)
- Bonn shutter (2ms accuracy)
The SkyMapper CCDs

- 32 E2V CCD44-82 devices:
  2048x4096 15 micron pixel CCDs
  - Broadband coated
  - 40 micron (thick) devices
  - Reduced fringing, inc. red response, without bad blue
- 16384x16384 0.5” pixels
- Using new Pan Starrs controllers (Onaka at IfA)
- Readout in ~14 seconds through 64 channels (300 kpix/s)
- Readnoise ~5-6e
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SkyMapper
Optimised for Stellar Astrophysics

• Encoded in the spectrum of each star
• Using filters we can isolate portions of the spectrum
• In designing our survey we sought to optimise our ability to determine the three important stellar parameters (T, log(g), Z)
• so SkyMapper not only compliments survey efforts in the northern hemisphere but enables us to tackle important astrophysics in an exciting new way.
SkyMapper Filter Set is sensitive to Stellar Parameters

- stellar parameters
- sensitivity to different wavelengths
- data points plotted in a graph
- wavelength range from 4000 to 8000 Ångströms
- logarithmic scale for flux
- example data set for M3 (7412 stars)
SkyMapper Filter Set

Normalised Throughput vs Wavelength (Å)

- u
- v
- g
- r
- i
- z

Thursday, 29 July 2010
SkyMapper Filter Set

Normalised Throughput

Wavelength (Å)

0 0.2 0.4 0.6

4000 6000 8000 10000

Thursday, 29 July 2010
## Expected Survey Limits

<table>
<thead>
<tr>
<th></th>
<th>u</th>
<th>v</th>
<th>g</th>
<th>r</th>
<th>i</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 epoch</td>
<td>21.5</td>
<td>21.3</td>
<td>21.9</td>
<td>21.6</td>
<td>21.0</td>
<td>20.6</td>
</tr>
<tr>
<td>6 epochs</td>
<td>22.9</td>
<td>22.7</td>
<td>22.9</td>
<td>22.6</td>
<td>22.0</td>
<td>21.5</td>
</tr>
<tr>
<td>Sloan Digital Sky Survey comparison</td>
<td>22.0</td>
<td>n/a</td>
<td>22.2</td>
<td>22.2</td>
<td>21.3</td>
<td>20.5</td>
</tr>
</tbody>
</table>

AB mag. for signal-to-noise = 5 from 110s exposures
Cadence

- 1st epoch: all filters consecutively (colour + short term variability in UV)
- 3 first epochs in (g,r) in less than 7 days: for Astrometric and photometric short term variation (TNO + RRlyrae/Cepheids+young SN):
- (i,z) spread out to measure parallax over the year.
  - in total, 160,000 sq-degrees observed per year to g~22
- Use a “Score” algorithm for field priority - weighted by amount of time field is observable in survey’s remaining time.
- Deal with “Quick Data Quality Check” + DataBase Quality to validate each field meets criteria to be in main survey.
- Take care: distance of the Moon, Planets, Sky conditions, Satellites...
Cadence

- 1<sup>st</sup> epoch: all filters consecutively (colour + short term variability in uv)
- 3 first epochs in (g,r) in less than 7 days: for Astrometric and photometric short term variation (TNO + RRlyrae/Cepheids+young SN):
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Sky conditions, Satellites...
Cadence

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Some Science Themes
Extremely Metal-poor Stars in the Halo

- Goal: find the first stars to have formed in the Universe: tell us about the assembly and chemical enrichment of the Galaxy
- \( v-g \) is dependent on the level of metal line blanketing in the blue continuum
- ✓ not perturbed dramatically by C-enhancement, chromospheric emission as affects objective-prism surveys
High-redshift QSOs

- High-redshift QSOs are among the most distant optical objects in the Universe, probing the Universe and host galaxies at 6% of its current age.
- Key objects for studying reionisation - Murchison Widefield Array targets.
- 50 objects are expected in the southern hemisphere
- Exercise in data mining - these are faint, very red objects
High-z QSOs

- Detection is simple: i-band dropouts.
- Contaminants: L+T dwarfs
- SDSS tells us we can expect of order 50 objects $z<20.5$ in the SSSS
  - Detection limited by our i sensitivity (not $z$!)
  - Proper motions can help remove most L+T dwarfs
  - as will J,H,K photometry
  - initial follow-up with WiFES+2.3m and IRIS2+AAT
What will MWA see?
Search for extreme LSB MW satellites

Jerjen, Willman, Mateo ...

- Chemical abundance measurements of individual stars to learn about SN yields, Pop-III stars?, and how smallest galaxies form.

SkyMapper will cover an uncharted 20000 sq-degrees 0.7 mag deeper than SDSS.

UMa, 100kpc, -6.8?

Discovered by Willman et al. 2005 from SDSS data
And a whole lot more

- All Sky Tully-Fisher peculiar velocity survey when combined with ASKAP (250000 galaxies)
- Input catalog for HERMES (+$T_{\text{eff}}$ and $g$)
- QSOs (Bright QSOs for $dz/dt$, $d\alpha/dz$, TPE) and input to Ly$\alpha$-BAO experiment
- Large sample of hyper-velocity stars in halo based on gravity+metallicity
- Structure of outer Halo of galaxy with giants, BHBs and RR-Lyrae
- Transiting planet discrimination (HAT-South based at RSAA)
up to 25% of time for other things

- Hα of Southern Sky
- Mg 5100 filter for K Giants (maybe not needed)
- GRB, Gravity Wave, Radio Transient TOOs
- SN Search override
- High Cadence Variability surveys
Figure 3: Seeing at Siding Spring derived from logs of the Anglo-Australian Telescope.
SN Ia Simulated Discoveries - 2001

Number

Detected
Spec. Identified
Final Selection

redshift (z)

0.02 0.04 0.06 0.08 0.10 0.12

Nicolas Regnault & Julien Guy

Slide 27
Equation of State of Dark Energy in a Flat Universe

<table>
<thead>
<tr>
<th></th>
<th>$\Omega_m$</th>
<th>$w$</th>
<th>$\Omega_m$</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNLS 5yr + Current Nearby SN</td>
<td>0.021</td>
<td>0.214</td>
<td>0.016</td>
<td>0.071</td>
</tr>
<tr>
<td>SNLS 5yr + 300 SkyMapper SN</td>
<td>0.012</td>
<td>0.076</td>
<td>0.011</td>
<td>0.055</td>
</tr>
</tbody>
</table>

Including BAO
Calibration Plans

• Conduct Five-Second Survey
  • in photometric conditions cover the southern sky w. 3x5 exposures: 8-15th mag
  • During 5-s observe the highest two reference fields every 90 minutes
  • primary standards: Stars in Walraven system with STIS spectrophotometry

• Anchor the deeper Main Survey to the Five-Second photometry and astrometry
  • Enables the Main Survey to proceed under non-photometric conditions.
• Self Calibration via overlaps and the Main sequence (in low dust areas)
Data Release

Deliverables to the Outside User:

– Data (epoch, RA, DEC, mags, galaxy shape info,…) to be available through a web-served interface which provides catalogs over a user defined area

– Images to be available through a web-served interface which provides images over a user defined area (1 degree max, cut out of a 2-degree TAN projection across the sky), or individual frames.

Data release will occur after extensive data validation:

– Five-Second data after closure in RA and trial application to concurrently obtained main-survey data

– FDR Main Survey 3 epochs all filters

– SDR Main Survey 6 epochs all filters
Non-ANU parties can gain access to data during data characterisation period:

• Request is forwarded to Project Scientist for SkyMapper. Project Scientist will ensure Project does not overlap/interfere with existing projects.

• Establish a memorandum of understanding (MOU) between the external investigators and the School regarding the usage of data for specific purposes and authorship policy (inclusion of SkyMapper Development Group). External groups will be expected to visit Stromlo (we will try to support) as part of the MOU.
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We want to work with you!
Preliminary data has enabled us to
1. demonstrate the low read-noise, fast readout of the PanStarrs controllers (4 chips are at 8e-)
2. quantify the photometric zeropoints of the system - i.e. the throughput of SkyMapper
3. Initial alignment of the telescope and its operations

u filter 10% area defective

<table>
<thead>
<tr>
<th>Filter</th>
<th>ZP obs</th>
<th>ZP expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td>24.20</td>
<td>24.24</td>
</tr>
<tr>
<td>r</td>
<td>24.31</td>
<td>24.32</td>
</tr>
<tr>
<td>i</td>
<td>23.96</td>
<td>24.03</td>
</tr>
<tr>
<td>z</td>
<td>22.76</td>
<td>22.82</td>
</tr>
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Looks scary, but seems to be a very small ripple on the primary from milling which does not affect overall imaging of telescope. (pattern goes away at different focus values)
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Lady Bugs!
Observation Scheduler

- The scheduler must respond to photometric/seeing conditions during a night.

<table>
<thead>
<tr>
<th>Photometric?</th>
<th>Seeing &gt; limit?</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td>5 SecSurvey/Main</td>
</tr>
<tr>
<td>Yes</td>
<td>&lt;2.5&quot;</td>
<td>5 SecSurvey</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Poor Seeing</td>
</tr>
</tbody>
</table>

- Maximize the science output
  - 1st epoch: all filters consecutively u,v,g,r,u,v,i,z,u,v (colour + short term variability in uv).
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