Synergy between the Large Synoptic Survey Telescope and the Square Kilometre Array

David Bacon (ICG Portsmouth)
Sarah Bridle (Manchester)
on behalf of LSST-SKA chapter team
SKA-LSST Chapter
Authors

Sarah Bridle, Rob Fender, Željko Ivezic, Matt Jarvis, Michael Brown, Stefano Camera, Philip Bull, Filipe Abdalla, John McKean, Jeffrey Newman, David Bacon, Chris Blake, Chris Fassnacht, Neal Jackson, Bob Mann, Phil Marshall, Carole Mundell, Ue-Li Pen, Alvise Raccanelli, Martin Sahlen, Mario Santos, Michael Schneider, Stephen Smart and Tony Tyson

1 Jodrell Bank Center for Astrophysics, School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester, M13 9PL, UK
2 University of Oxford, Department of Physics, Astrophysics, Keble Road, Oxford, OX1 3RH, UK
3 Astronomy Department, University of Washington, Box 351580, Seattle WA 98195-1580
4 Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, N-0315 Oslo, Norway
5 Department of Physics & Astronomy, University College London, Gower Place, London WC1E 6BT, UK
6 Astronomy Group, ASTRON, Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands
7 University of Pittsburgh, Department of Physics and Astronomy, 310 Allen Hall, 3941 O’ Hara St. Pittsburgh, PA 15260, USA
8 Institute of Cosmology and Gravitation, University of Portsmouth, Burnaby Road, Portsmouth PO1 3FX, UK
9 Centre for Astrophysics and Supercomputing, Swinburne University of Technology, PO Box 218, Hawthorn, Victoria 3122, Australia
10 Department of Physics, University of California, One Shields Avenue, Davis, CA 95616, USA
11 Royal Observatory Edinburgh, Blackford Hill, Edinburgh EH9 3HJ, UK
12 Kavli Institute for Particle Astrophysics and Cosmology, P.O. Box 20450, MS29, Stanford, CA 94309, USA
13 Astrophysics Research Institute, Liverpool John Moores University, 146 Brownlow Hill, Liverpool L3 5RF, UK
14 Canadian Institute for Theoretical Astrophysics, McLennan Laboratories, 60 St. George Street, Toronto, Ontario, Canada
15 NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
16 Department of Physics, University of Western Cape, Cape Town 7535, South Africa
17 Lawrence Livermore National Laboratory, P.O. Box 808 L-211, Livermore, CA 94551, USA
18 Astrophysics Research Centre, School of Mathematics and Physics, Queen’s University Belfast, Belfast BT7 1NN, Northern Ireland UK
* Presenter
The LSST

Taking an Inventory of the Solar System
Mapping the Milky Way
Exploring the Transient Optical Sky
Probing Dark Energy and Dark Matter

Cerro Pachón in northern Chile

First light around 2021
First public data releases around 2023
The LSST

Contiguous overlapping imaging of over half the sky
6 bands (ugrizy, 320–1050 nm)

50 PB imaging data
15 PB catalog database

~15 TB of raw imaging / nt

Effective diameter of 6.5m
3.2 Gigapixels

Large field of view (9.6 deg$^2$)
0.2×0.2 arcsec$^2$ pixels
Large footprint

10,000 deg$^2$ of sky in 2 photometric bands every 3 nights
5σ depth for point sources of $r \sim 24.5$

30,000 deg$^2$ with $\delta < +34.5^\circ$
18,000 deg$^2$ visited over 800 times during 10 years.

Coadded data 5 mag deeper than SDSS ($r \sim 27.5$).  
20 billion galaxies and a similar number of stars
Cosmological Probes with SKA and/or LSST

- e.g. Source clustering
- including Baryon Acoustic Oscillations and Redshift Space Distortions (SKA)
- Cosmic shear, shear-galaxy, cosmic magnification, strong lensing.
Mutual help with Redshifts

LSST will provide photometric redshifts for SKA, about 50 galaxies per square arcminute.

SKA HI redshifts will calibrate LSST photo-zs, using cross-correlation of clustering (e.g. Newman 08, McQuinn & White 13); also train photo-zs for some objects.

SKA redshifts allow McDonald & Seljak(2009) removal of cosmic variance and bias.
SKA+LSST Cosmology

e.g. PCA approach (c.f. Hojjati et al 12): LSST lensing + SKA HI clustering

Dark energy equation of state

\[ w(z) + 1 = \sum_i \alpha_i e_i(z) \]

Gongbo Zhao; Provisional
Large-scale Gravity tests

- LSST lensing + SKA HI clustering

Hojjati et al. 12

Zhao; provisional

RSD sensitive to upper, lensing to both plots - synergy
Large scale physics

Non-Gaussianity of density fluctuations on large scales informs about inflation

Raccanelli et al. 14 LSST+SKA significantly improves constraints
**Systematic Effects**

- With heroic efforts, future surveys will reduce *statistical* error bars on cosmological parameters.
- Even so, we are likely to enter a *systematics* dominated regime, for all probes.
Using two surveys improves matters

- Cross correlation of clustering picks out fluctuations which are not due to instrumental effects or e.g. stars.

- Cross correlation of lensing shear picks out signal which is not due to telescope systematics.
Novel Shear Information

Polarization and rotational velocity (SKA) provides info on unlensed orientation (see Brown’s talk)

Spatial variation of galaxy colour biases shape measurements

SKA keeps the spectral information - so we can calibrate and remove this systematic for LSST
**Strong lensing**

SKA will preferentially find **sources**

LSST will preferentially find **lens** galaxies

**Redshifts** from LSST

$10^4$-$10^5$ lenses - examine sources at high magnification, cosmology (see McKean’s talk)
Galaxy Evolution

SKA will probe e.g. AGN and SF history over cosmic time and wide area

Redshifts and stellar masses from LSST

Pathway from neutral (SKA HI) to molecular gas (ALMA) to star formation (SKA continuum, LSST).

NB deep drilling fields (9 sq deg) - will see objects at z>6 (match with CO redshifts from SKA band 5)
**Time Domain**

**LSST nightly pipelines** rapidly detect interesting **transient** events.

2 billion objects routinely monitored
10,000 events per night

Send out alerts to the community within **60 seconds**.
Exploring Transients

Can immediately identify stellar-scale sources throughout the galaxy, separate out pulsars, GRBs, stars, TDEs

Stewart, Munoz-Darias & Fender (in prep)
Using both surveys gives:

- **Complementary** physical constraints.
- Removal of **systematics**
- **Cross checks** of results
- **Mutual support** (e.g. redshifts)
- A **more complete picture** (e.g. galaxy evolution)
- Exploitation of the **time domain**.