Introduction to SDSS-IV and DESI

Ho Seong HWANG (KIAS)

2015 January 27
The 4th Survey Science Group Workshops
➢ SDSS-I: 2000 - 2005
➢ SDSS-II: 2005 - 2008
➢ SDSS-III: 2008 - 2014
➢ SDSS-IV: 2014 - 2020

An introduction to SDSS data products and data access

Ho Seong Hwang¹, Yun-Young Choi², Taehyun Kim¹, Myung Gyoong Lee¹, and Changbom Park²

¹Astronomy Program, SEES, Seoul National University
²Korea Institute for Advanced Study

가을 전문학회 (2005/10/13)

고등과학원(KIAS) & SDSS 한국과학자 그룹(KSG)

SDSS-KSG 하계 워크숍

일시: 2005년 8월 22일 ~ 24일
장소: 안면도
SDSS-IV: Project Members

Full Institutional Members (24):
- Carnegie Institution for Science
- Carnegie Mellon University
- CU Boulder
- Kavli IPMU / U. Tokyo
- Instituto de Astrofísica de Canarias
- Johns Hopkins University
- Lawrence Berkeley National Labs
- Max-Planck-Institut fuer Astrophysik (MPA Garching)
- Max-Planck-Institut fuer Extraterrestrische Physik (MPE)
- Max-Planck-Institut fuer Astronomie (MPIA Heidelberg)
- National Astronomical Observatory of China
- New Mexico State University
- New York University
- The Ohio State University
- Observatório Nacional
- Penn State University
- Shanghai Astronomical Observatory
- Shanghai Jiao Tong University
- Universidad Nacional Autónoma de México
- University of Arizona
- University of Portsmouth
- University of Utah
- University of Wisconsin
- Yale University

Participation Groups (4, comprising 9 institutions):
- Harvard-Smithsonian Center for Astrophysics (AC)
- Israel Center Of Research Excellence (I-CORE)
  - Tel Aviv University
- Korean Participation Group
  - Korea Institute for Advanced Study
  - Korea Astronomy and Space Science Institute
- United Kingdom Participation Group (AC)
  - Liverpool John Moores University
  - University of Cambridge
  - University of Nottingham
  - University of Oxford

Associate Institutional Members (21):
- Academia Sinica Institute of Astronomy and Astrophysics (ASIAA)
- Brookhaven National Labs
- École Polytechnique Fédérale de Lausanne
- Leibniz Institut fur Astrophysik Potsdam (AIP) (AC)
- Nanjing University
- Princeton University
- Sejong University
- Texas Christian University
- Tsinghua Center for Astrophysics
- University of Alabama, Tuscaloosa
- University of California Irvine
- University of Edinburgh
- University of Iowa
- University of Kentucky
- University of Notre Dame (AC)
- University of Pennsylvania
- University of Pittsburgh
- University of Toronto
- University of Washington (AC)
- University of Wyoming
- Vanderbilt University (AC)
SDSS-IV: Programs

APOGEE-2
Exploring the Milky Way from both hemispheres
Explore

eBOSS
Surveying galaxies and quasars to measure the Universe
Explore

MaNGA
Mapping the inner workings of thousands of nearby galaxies
Explore
MaNGA (Mapping Nearby Galaxies at APO)

SDSS-IV Dissects 10,000 Galaxies in Nearby Universe

PI: Kevin Bundy (Kavli IPMU)
MaNGA: Technical Details

➢ Dark-time observations (half of SDSS-IV)
➢ Fall 2014 – Spring 2020
➢ 17 IFUs per 7 deg² plate
➢ Wavelength: 360-1000 nm, R~2000 (~64 km s⁻¹)
➢ 3-hour exposures with dithering (sub-fiber-diameter)
MaNGA: Sample Selection

- 10,000 galaxies at 0.01<z<0.15 across ~4000 deg$^2$
- Flat $M_{\text{star}}$ distribution with $M > 10^9\,M_{\odot}$
  - No size or inclination cuts
  - Only redshift and a color-based stellar mass estimate
- Primary sample: 67%, spatial coverage to 1.5 $R_e$
- Secondary sample: 33%, spatial coverage to 2.5 $R_e$
MaNGA: Instrumentation

- IFU complement per plate: 12″ - 32″ diameter

- 17 IFUs deployed to targets anywhere within the 3° diameter focal plane

- Fibers with 2″ diameters
MaNGA

MaNGA: 10,000

SAMI: 3,400

CALIFA: 600

wavelength (nm)
MaNGA: Science Goals

➢ How does gas accretion drive the growth of galaxies?

➢ What are the roles of stellar accretion, major mergers, and instabilities in forming galactic bulges and ellipticals?

➢ What quenches star formation?

➢ How was angular momentum distributed among baryonic and non-baryonic components as the galaxy formed?
MaNGA: Star Formation History of Galaxies

Galaxy A (star-forming)

z=0.034
log M* = 10.3
Re=3.16"

Galaxy B (quenched)

z=0.024
log M*=9.7
Re=2.88"
MaNGA: Dynamical & Stellar Population Constraints

Observed galaxy

\[ \log M_\star = 10.1 \]
eBOSS (Extended Baryon Oscillation Spectroscopic Survey)

SDSS-IV Catches the Rise of Dark Energy

PI: Jean-Paul Kneib (EPFL)
eBOSS: Technical Details

- Dark-time observations
- Fall 2014 – Spring 2020
- 1000 fibers per 7 deg$^2$ plate
- Wavelength: 360-1000 nm, R~2000
eBOSS: Technical Details

- 375,000 luminous red galaxies over 7500 deg\(^2\), 0.6 < z < 0.8
- 260,000 emission line galaxies over 1500 deg\(^2\), 0.6 < z < 1.0
- 740,000 quasars over 7500 deg\(^2\), 0.9 < z < 3.5
eBOSS: Science Goals

➢ BAO: Baryon Acoustic Oscillations

Eisenstein+05
eBOSS: Science Goals

➢ BAO: the effects of dark energy on the expansion history
eBOSS: Science Goals

➢ Redshift-Space Distortion (RSD): Growth of Structure
→ Test of General Relativity

2D correlation function of DR9 CMASS
(Reid+12)
eBOSS: Science Goals

➢ RSD: Growth of Structure → Test of General Relativity
eBOSS: Science Goals

➢ Cosmology Beyond Dark Energy
  ➢ Test of non-Gaussianity in the primordial density field
  ➢ Test of inflation
  ➢ Measure of the sum of the neutrino masses

➢ More info: SDSS-IV White Paper
eBOSS: Sub-Programs (~5% each)

- TDSS (Time-Domain Spectroscopic Survey)
  - ~$10^5$ PanSTARRS-1 photometric variables at $i \leq 21$
  - No preselection based on colors or light curves
  - PI: Paul Green (SAO) & Scott Anderson (UW)

- SPIDERS (Spectroscopic Identification of eROSITA Sources)
  - ~$10^5$ eROSITA sources (AGN & Galaxy Clusters)
  - eROSITA (extended ROentgen Survey with an Imaging Telescope Array)
    - all-sky survey at 0.2 - 8 keV
    - to be launched early 2016
  - PI: Andrea Merloni & Kirpal Nandra (MPE)
APOGEE-2: APO Galactic Evolution Experiment 2

SDSS-IV Can View
the Whole Milky Way

Sloan Foundation Telescope
New Mexico, U.S.A.

du Pont Telescope
Chile

PI: Steve Majewski (EPFL)
➢ Bright-time observations at APO and LCO

➢ 300 fibers per 7 deg$^2$ plate (APO), 3.5 deg$^2$ plate (LCO)

➢ Fall 2014 – Fall 2020

➢ Wavelength: 1.51-1.70 µm (H-band), R~22,500

➢ 300,000 stars with signal-to-noise S/N > 100

➢ Radial velocity precision ~ 100 m/s
APOGEE-2: Technical Details

APOGEE-1, APOGEE-2 (orange and green (Kepler) for APO, yellow for LCO) (SDSS WP)
APOGEE-2: Science Goals

➢ What is the history of star-formation and chemical enrichment of the Milky Way?

➢ What are the dynamics of the disk, bulge and halo of the Milky Way?

➢ What is the age distribution of stars in the Milky Way?

➢ Are certain properties of stars associated with whether or not they have planets?
APOGEE-2: Richness & Power of H-band Spectra
APOGEE-2: Fundamental Stellar Parameters

![Graph showing the relationship between metallicity ([Fe/H]), effective temperature (K), and surface gravity (log g) for 35,000 stars from APOGEE-1 (SDSS WP).]
DESI (Dark Energy Spectroscopic Instrument)

➢ Formally BigBOSS (Talk by Prof. Juhan Kim in 2013)
➢ (Imaging &) Spectroscopic Survey with 4m Mayall telescope
➢ 2018 - 2022
DESI: Project Members

Interim Institutional Board

- University of the Andes, Columbia - Jaime Forero-Romero
- University of Arizona and Steward Observatory - Buell Jannuzi
- Anglo-Australian Observatory - Andrew Sheinis
- Argonne National Lab - Salman Habib
- University of Barcelona - Francisco Castander
- University of California, Berkeley - Jerry Edelstein
- Observatorio Nacional, Brazil - Luiz Nicolaci da Costa
- Brookhaven National Lab - Anze Slosar
- CEA-Saclay - Christophe Yseke
- Carnegie Mellon University - Shirley Ho
- Laboratoire d’Astrophysique de Marseille - Jean-Gabriel Cuby
- Le Centre de Physique des Particules de Marseille - Anne Ealet
- Cornell University - Rachel Bean
- Durham University - Jeremy Allington-Smith
- University of Edinburgh - John Peacock
- Ecole Polytechnique Federale de Lausanne EPFL - Jean-Paul Kneib
- ETH Zurich - Alexandre Refregier
- Fermi National Accelerator Laboratory - Brenna Flaugher
- Harvard University - Daniel Eisenstein
- University of California, Irvine - David Kirkby
- University of Kansas - Gregory Rudnick
- Kansas State University - Bharat Ratna

- Korea Astronomy and Space Science Institute - Yong-Seon Song
- Korea Institute for Advanced Study - Changbom Park

- Lawrence Berkeley National Lab - David Schlegel
- Universidad Nacional Autonoma de Mexico - Axel de la Macorra

DESI Working Groups

Introduction

Our Working Groups and Committees are some of the most important organizational structures for the DESI Science Collaboration. Any DESI Collaboration member can join any working group. You do not need to apply; simply sign up for the relevant mailing list, identify yourself to the chair(s) of the Working Group, and get involved in WG activities!

- Galaxy & Qasar Clustering, focused on cosmological science from large-scale structure. Chaired by Shirley Ho & Nikhil Padmanabhan. Mailing list: desiclustering
- Lyman-alpha Forest, focused on cosmological science from the Lyman-alpha forest, other IGM absorption, and correlations with other $z > 2$ tracers. Chaired by David Kirkby & Mat Pieri. Mailing list: desilya
- Small-scale Clustering, Clusters, and Cross-correlation ($C^2$), focused on cosmological science from small-scale structure. Chaired by Rachel Bean & Eduardo Roza. Mailing list: desicc
- Imaging, focused on the proposal, observing, reduction, and testing of imaging data sets required by DESI. Chaired by Xiaohui Fan & Peter Nugent. Mailing list: desiming
- Target Selection, focused on the algorithms for selection of DESI targets. Chaired by Jeff Newman & Nathalie Palanque-Delabrouil. Mailing list: desitargets
- Survey Design, focused on the DESI observational strategy and fiber assignment. Chaired by Kyle Dawson & Jeremy Tinker. Mailing list: desisurvey
- Cosmological Simulations, focused on the design and generation of cosmological simulations and mock catalogs required by DESI. Chaired by Peder Norberg and Salman Habib. Mailing list: desicosim
- Spectroscopic Pipeline and Data Simulations, focused on development of the spectroscopic data reduction package and data simulations. Chaired by Stephen Bailey & Adam Bolton. Mailing list: desidata
- Bright Galaxy Survey, focused on the development of the Bright Galaxy Survey. Chaired by David Weinberg & Maria Geha. Mailing list: desibgs
- Milky Way Survey, focused on the development of the Milky Way Survey. Chaired by Connie Rockosi & Carlos Allende-Prieto. Mailing list: desimilkyway
- Data Distribution Committee, focused on developing concepts for distribution of DESI data to the collaboration and the public. Chaired by Ben Weaver and Chris Miller. Mailing list: desidata
- Galaxy & Qasar Physics, focused on developing the galaxy and quasar physics science case. This working group has not yet been founded, but we are beginning to organize activities in this area. Mailing list: desigalaxies
- Time Domain?, focused on developing the science case for the time domain, including supernovae. This working group has not yet been founded, but we are beginning to organize activities in this area. Mailing list: desitime
DESI: Instrument

- 5000 fiber actuators
- 3.2° field-of-view corrector
- Spectrographs 360-980 nm
  Resolution 2000-5000
The largest spectroscopic survey for dark energy

SDSS $\sim 2h^{-3}\text{Gpc}^3$ $\rightarrow$ BOSS $\sim 6h^{-3}\text{Gpc}^3$ $\rightarrow$ DESI $50h^{-3}\text{Gpc}^3$

3 million QSOs

23 million ELGs

2 million LRGs

$r=5.0$ Gpc/h

$r=4.0$ Gpc/h

$r=3.0$ Gpc/h

$r=2.0$ Gpc/h

$r=1.0$ Gpc/h

$r=0.5$ Gpc/h

$r=0.2$ Gpc/h

$z=4$

$z=3$

$z=2$

$z=1.5$

$z=1$

$z=0.7$

$z=0.5$

$z=0.2$
DESI: Sample Selection

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Bands</th>
<th>Area deg²</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blanco DECam</td>
<td>$g, r, z$</td>
<td>9k</td>
<td>NGC+SGC equatorial (Dec&lt; +30 deg)</td>
</tr>
<tr>
<td>Bok 90Prime</td>
<td>$g, r$</td>
<td>5k</td>
<td>NGC (Dec&gt; +30 deg)</td>
</tr>
<tr>
<td>Bok $z$-band dewar</td>
<td>$z$</td>
<td>5k</td>
<td>NGC (Dec&gt; +30 deg)</td>
</tr>
<tr>
<td>WISE-W1</td>
<td>3.4 $\mu$m</td>
<td>all sky</td>
<td>all-sky</td>
</tr>
<tr>
<td>WISE-W2</td>
<td>4.6 $\mu$m</td>
<td>all sky</td>
<td>all-sky</td>
</tr>
</tbody>
</table>

- $g=24.0$
- $r=23.6$
- $z=23.0$
**DESI: Science Goals**

- **BAO:** the effects of dark energy on the expansion history
DESI: Science Goals

➢ RSD: Growth of Structure → Test of General Relativity

Samushia+14

Huterer+13
DESI: Science Goals

➢ Cosmology Beyond Dark Energy
  ➢ Test of non-Gaussianity in the primordial density field
  ➢ Test of inflation
  ➢ Measure of the sum of the neutrino masses

Current/Planned BAO capable Spectroscopic Surveys

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Telescope</th>
<th>Nights/ year</th>
<th>No. Galaxies</th>
<th>sq deg</th>
<th>Ops Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDSS I+II</td>
<td>APO 2.5m</td>
<td>dedicated</td>
<td>85K LRG</td>
<td>7600</td>
<td>2000</td>
</tr>
<tr>
<td>Wiggle-Z</td>
<td>AAT 3.9m</td>
<td>60</td>
<td>239K</td>
<td>1000</td>
<td>2007</td>
</tr>
<tr>
<td>BOSS</td>
<td>APO 2.5m</td>
<td>dedicated</td>
<td>1.4M LRG +160K Ly-α</td>
<td>10000</td>
<td>2009</td>
</tr>
<tr>
<td>HETDEX</td>
<td>HET 9.2m</td>
<td>60</td>
<td>1M</td>
<td>420</td>
<td>2014</td>
</tr>
<tr>
<td>eBOSS</td>
<td>APO 2.5m</td>
<td>180</td>
<td>600K LRG + 70K Ly-α</td>
<td>7000</td>
<td>2014</td>
</tr>
<tr>
<td>DESI</td>
<td>NOAO 4m</td>
<td>dedicated</td>
<td>+20M + 800k Ly-α</td>
<td>14000</td>
<td>2018</td>
</tr>
<tr>
<td>SUMIRE PFS</td>
<td>Subaru 8.2m</td>
<td>20</td>
<td>4M</td>
<td>1400</td>
<td>2018</td>
</tr>
<tr>
<td>4MOST</td>
<td>VISTA 4.1m</td>
<td>shared facility</td>
<td>6-20M bright objects</td>
<td>15000</td>
<td>2019</td>
</tr>
<tr>
<td>EUCLID</td>
<td>1.2m space</td>
<td>dedicated</td>
<td>52M</td>
<td>14700</td>
<td>2021</td>
</tr>
</tbody>
</table>
Conclusion

➢ SDSS4 started! (2014-2020)

➢ DESI will start soon (2018-2022)