SDSS-III

Hyunmi Song (KIAS)

4th SSG workshop at High 1

Jan. 25-27, 2015

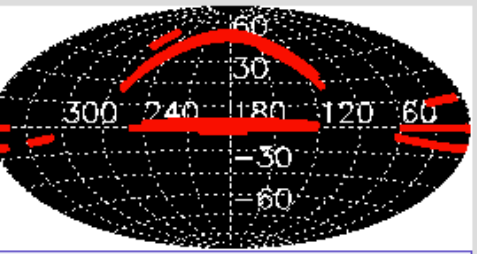
Sloan **D**igital **S**ky **S**urvey: Mapping the Universe

- Major multi-filter imaging and spectroscopic redshift survey using a dedicated 2.5m wide-angle optical telescope at Apache Point Observatory in New Mexico, US

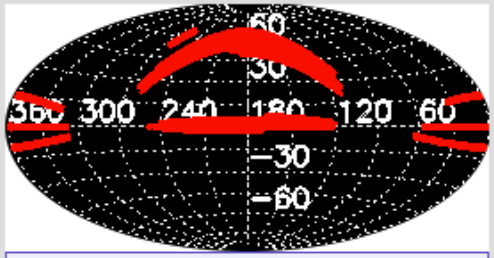
SDSS and SDSS-II

- SDSS (1999-2005) imaged 8,000deg^2 in 5 optical bands and took 849,920 objects' spectra over 5,700deg^2.
- SDSS-II (2005-2008) performed 3 projects – Legacy, SEGUE, Supernova – finishing the spectroscopy of the SDSS footprint with 1,640,960 objects at the end.
- Data release (DR) 1-7

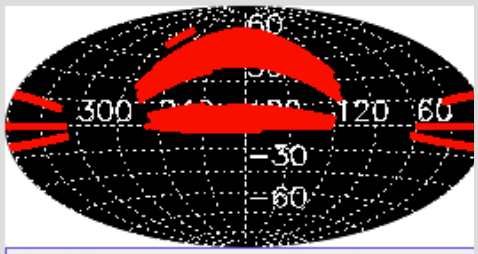
SDSS and SDSS-II



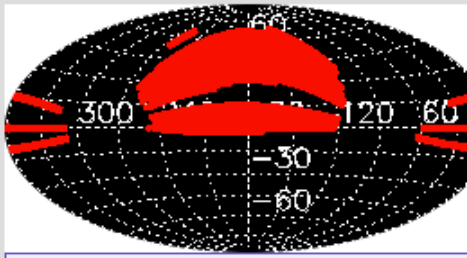
SDSS DR1 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



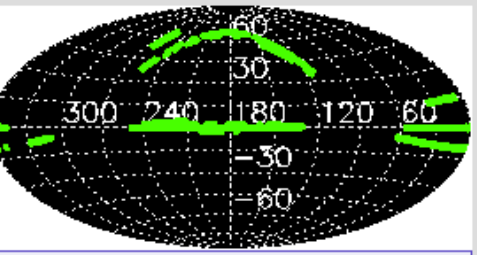
SDSS DR2 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



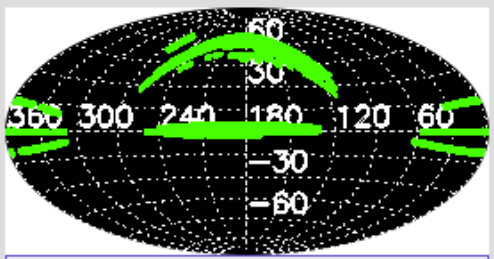
SDSS DR3 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



SDSS DR4 Imaging Sky Coverag (Aitoff projection of Equatorial coordinates)



SDSS DR1 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)



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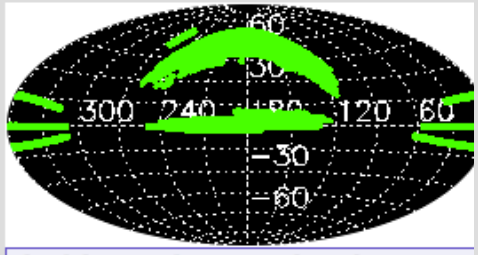
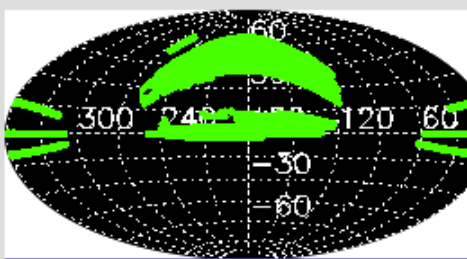


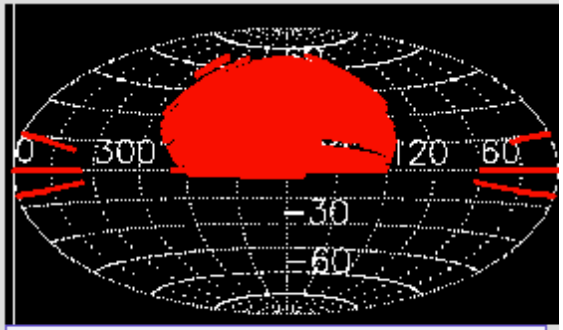
SDSS DR3 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)



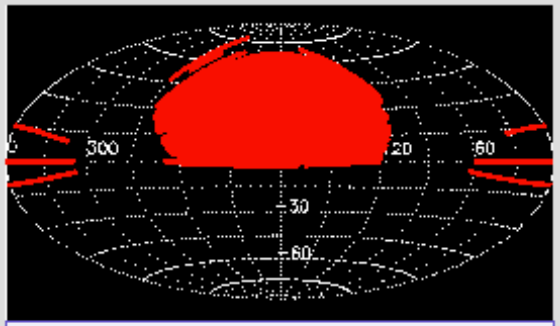
SDSS DR4 Spectral Sky Coverag (Aitoff projection of Equatorial coordinates)

http://classic.sdss.org/dr*/

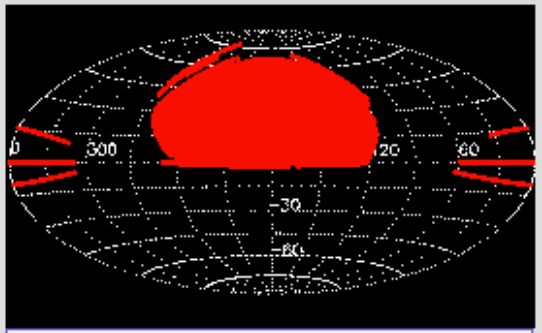
SDSS and SDSS-II



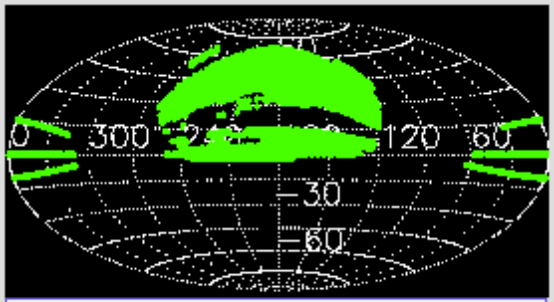
SDSS DR5 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



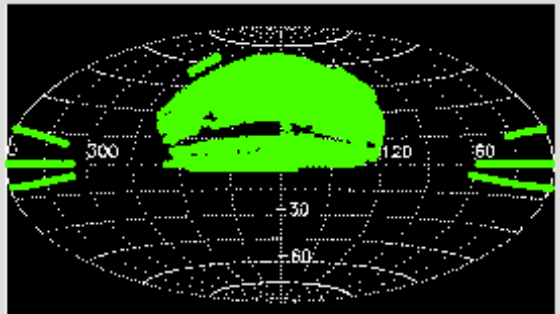
SDSS DR6 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



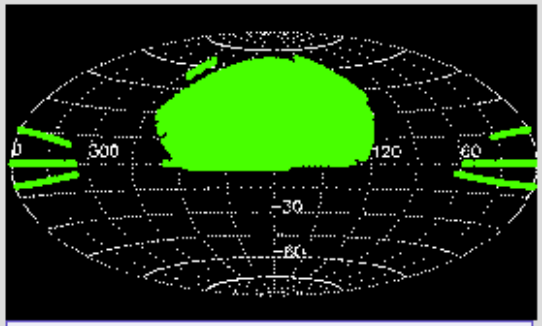
Legacy DR7 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)



SDSS DR5 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)



SDSS DR6 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)

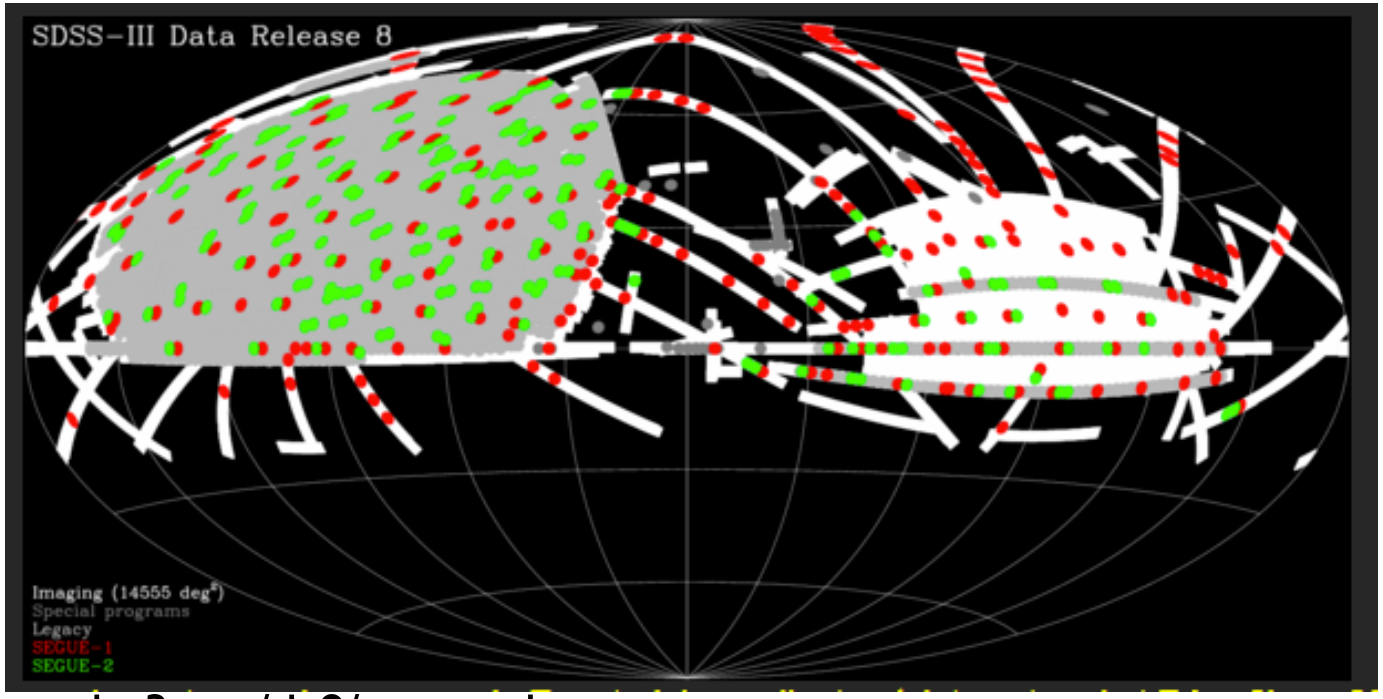


Legacy DR7 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)

http://classic.sdss.org/dr*/

SDSS-III

- SDSS-III goes deeper and wider than the previous.
  - 2,395deg^2 additional imaging to give contiguous coverage of the Southern galactic cap and 14,055deg^2 imaging in total (1/3 whole sky)

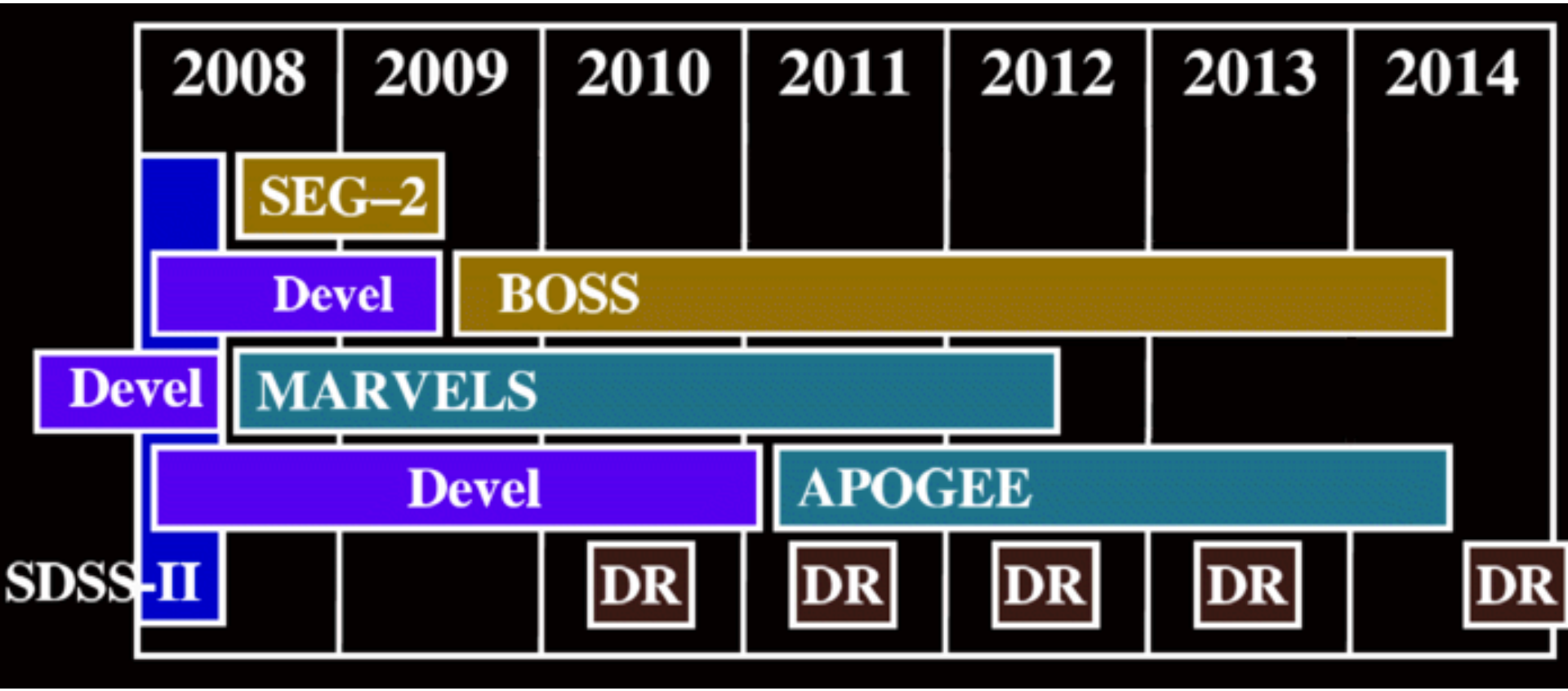


http://www.sdss3.org/dr8/scope.php

SDSS-III

- 6-years project (2008-2014)
- It consists of 4 surveys to explore 3 different topics in astrophysics regarding dark energy, the Milky Way, and exoplanets – BOSS, SEGUE-2, APOGEE, MARVELS.
- DR 8-12
- DR12, the final data release of SDSS-III, was released publicly in 2014 December.

SDSS-III schedule



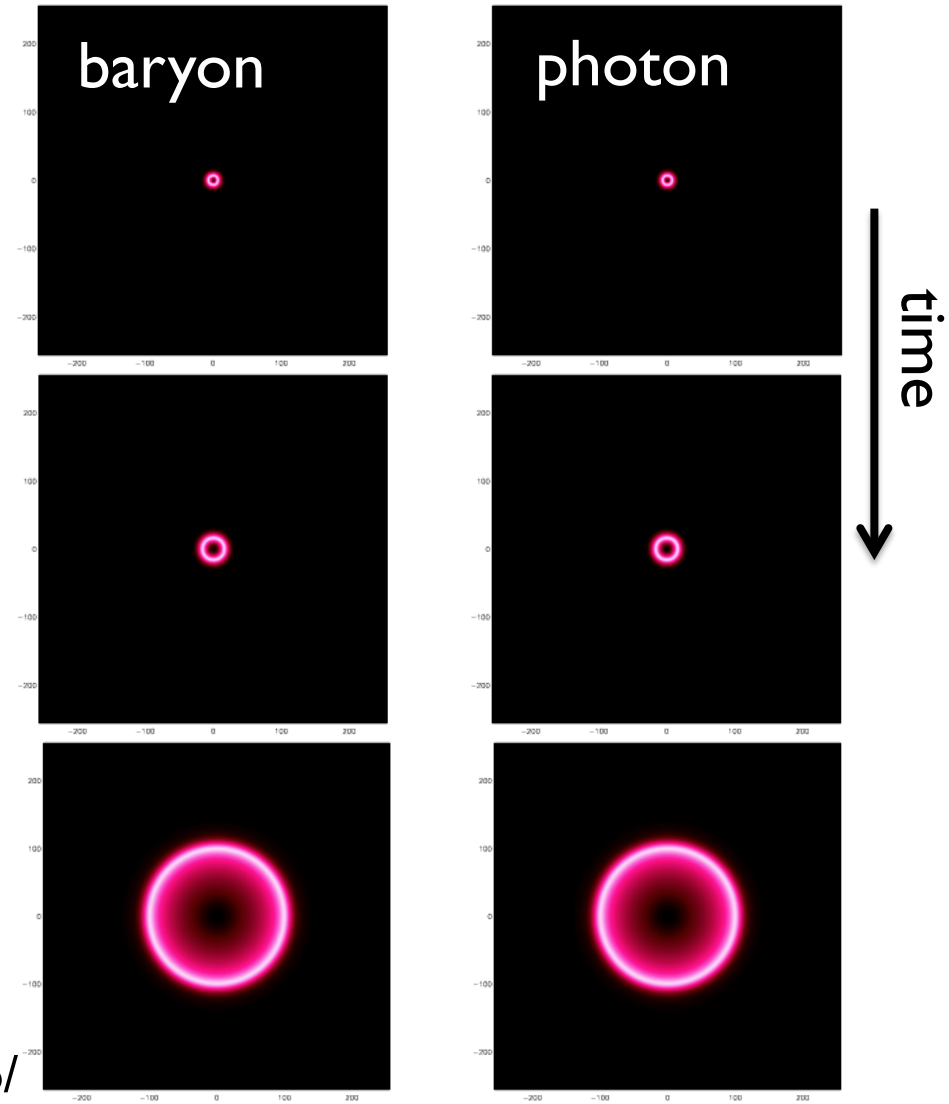
BOSS

Dark energy

- The expansion of the universe is accelerated.
- Tries to explain the accelerating expansion
  - Cosmological constant?
  - Dark energy?
  - Modified gravity?
  - Extra dimensions?
- To discriminate between different theories, precise distance measurements are needed with either standard candle or standard ruler.

Baryonic Acoustic Oscillation, Standard ruler

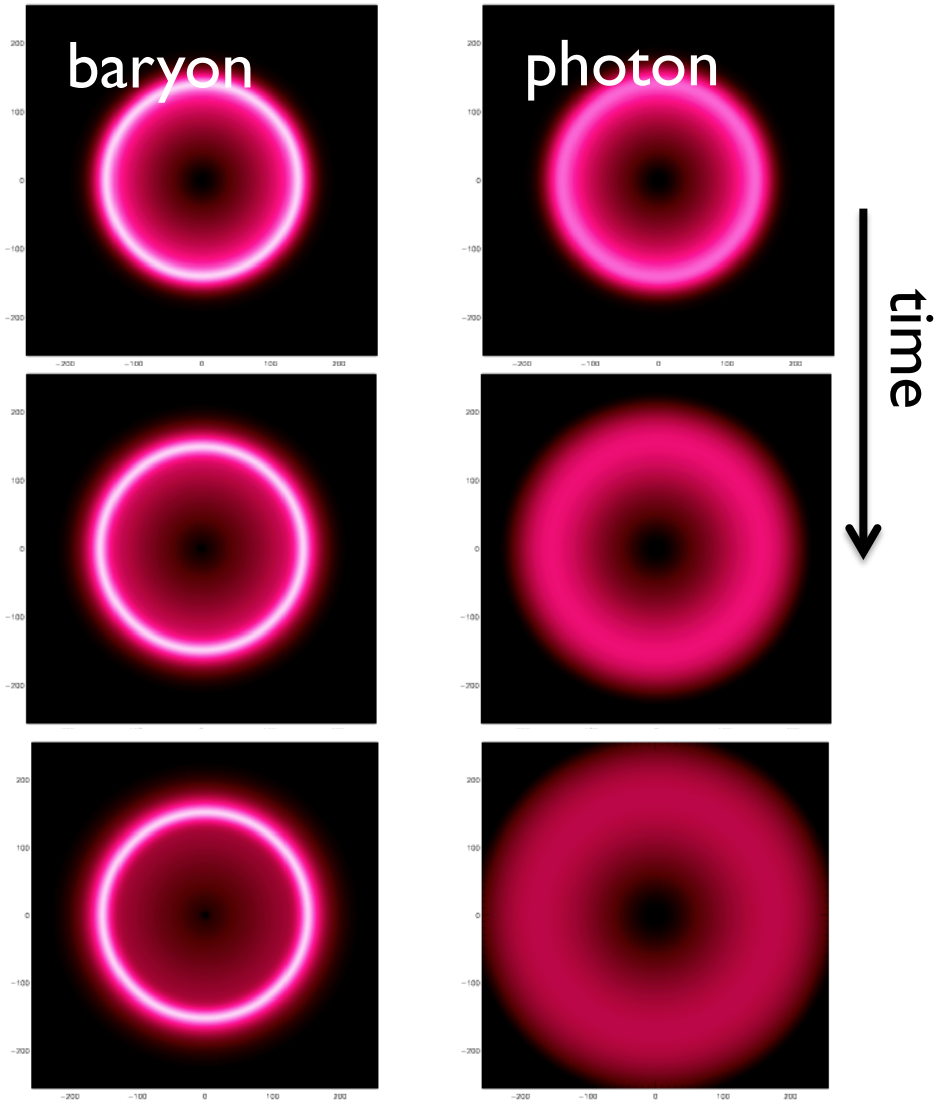
- In early universe, overdensities of matter (baryon+photon) launched spherical sound waves traveling outwards at 57% of the speed of light because of high pressure in the overdensities.



Credit: Martin White
http://astro.berkeley.edu/~mwhite/bao/

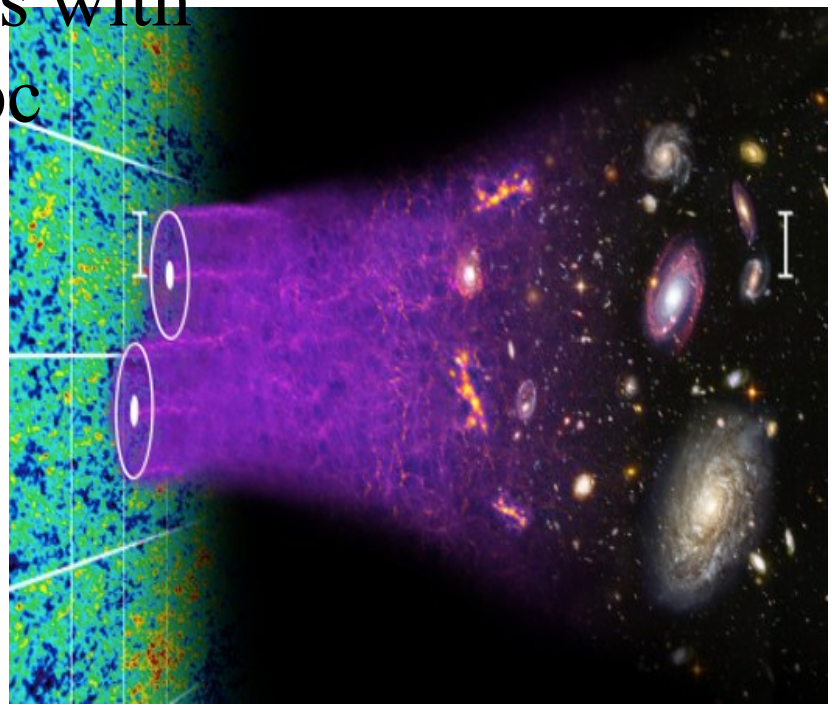
Baryonic Acoustic Oscillation, Standard ruler

- At recombination, pressure-providing photons were decoupled and sound waves stalled at a radius of 150Mpc.



Baryonic Acoustic Oscillation, Standard ruler

- Original overdensity centers and propagated overdensity shells became seeds of galaxy formation, and galaxy distribution appears with preferred separation of 150Mpc (BAO signature).



Credit: Cris Blake and Sam Moorfield

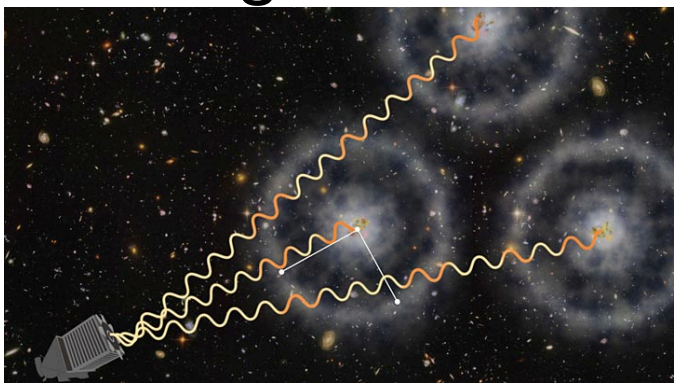
BAO, robust distance measure

- It was created at recombination when perturbations remained in linear regime
  – we can use linear perturbation theory.
- It is imprinted at a very large scale even today
  – non-linear effects are mild, so we can simulate accurately.

BAO and cosmology

- d_A – function of H(z)

angular diameter distance
BAO signature



Hubble parameter
cosmological parameters
(Ω_m, Ω_{DE}, ω, …)

BOSS instrumentation

- BOSS has upgraded the old SDSS spectrograph.
  - Increase to 1000 fibers, decrease to 2” aperture.
  - Better CCDs & gratings to improve throughput.

BOSS (2009-2014)

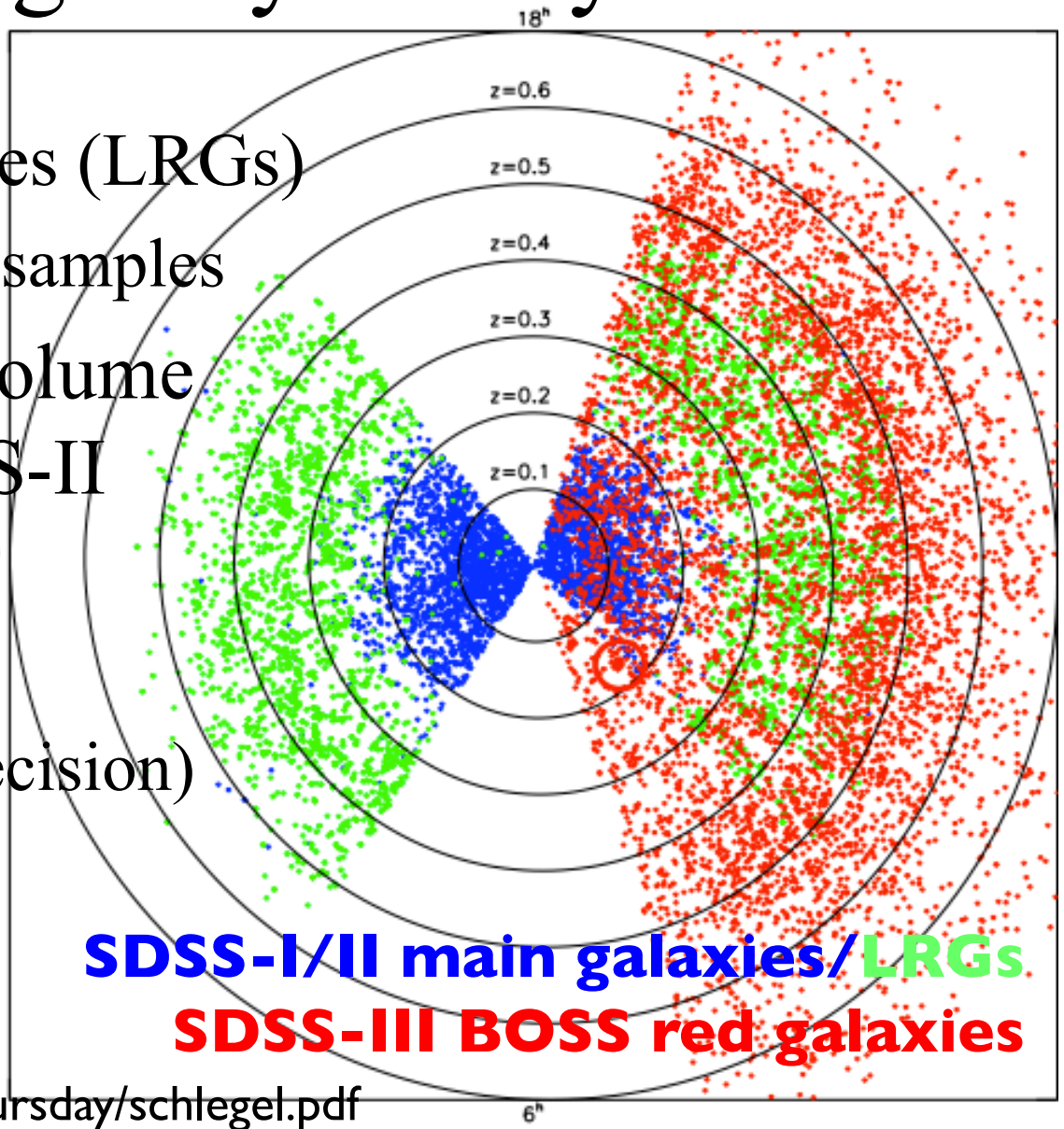
Credit:i Karen Kinemuchi

Baryonic **O**scillation **S**pectroscopic **S**urvey

- BOSS measured the BAO signature from large-scale clustering of galaxies and intergalactic medium (IGM).

BOSS galaxy survey

- Luminous red galaxies (LRGs)
  - LOWZ & CMASS samples
- 7-fold increase in volume above the full SDSS-II
- d_A with precision of 1% to z=0.6
  (cf. SDSS-I/II: 4% precision)



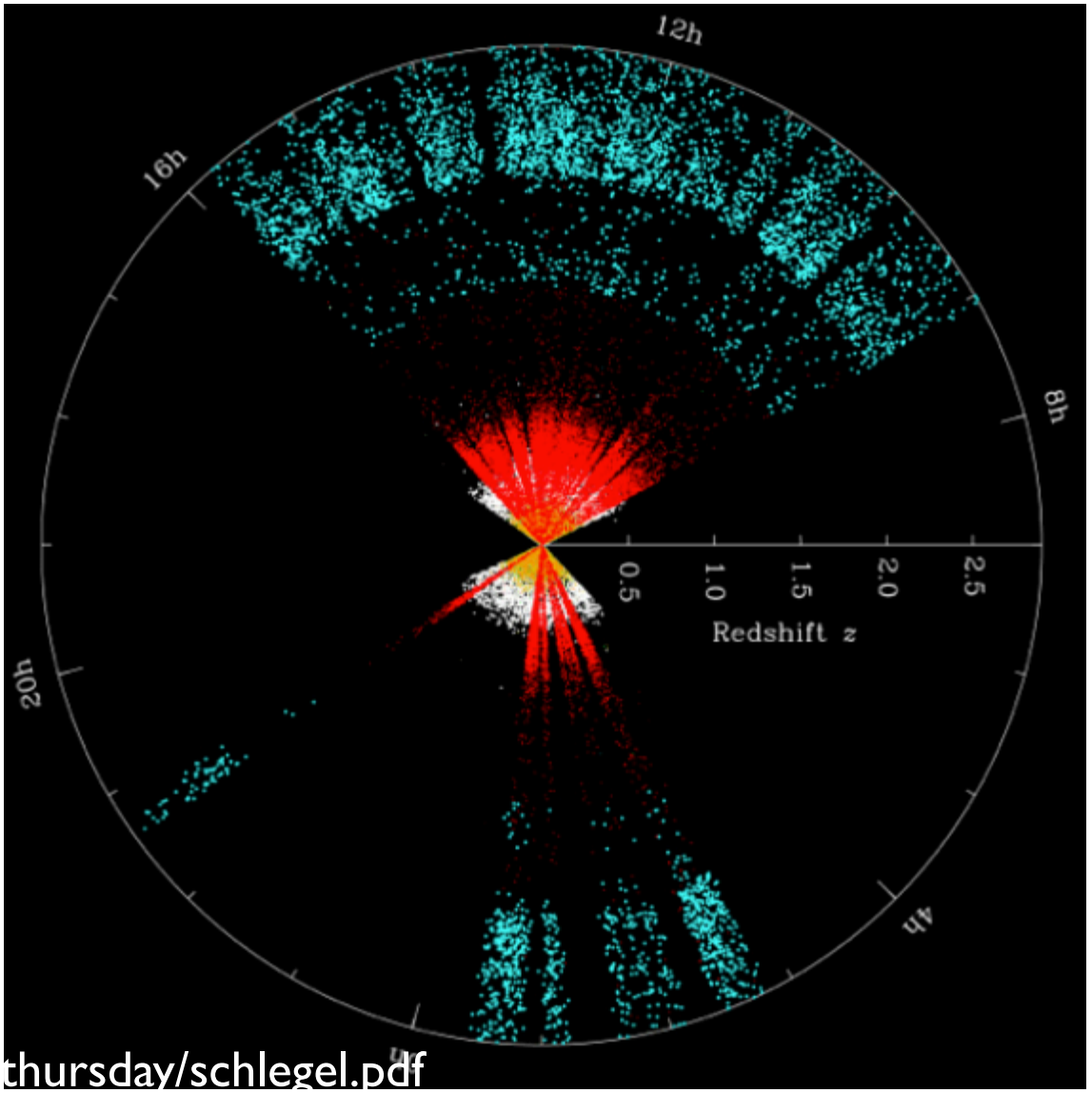
Credit: David Schlegel
http://moriond.in2p3.fr/J08/trans/thursday/schlegel.pdf

BAO with BOSS

- BAO has now been detected
  with different probes of the matter density field
  at different redshifts.
  - LRGs (z=0.35, 0.44, 0.57)
  - Lyman-α forest (z=2.34)
- eBOSS (SDSS-IV) will soon fill the gap
  between z=0.57 and 2.34 with ELGs and quasars.

BOSS quasar survey

- Large-scale distribution of IGM using Lyman-α forest
- Cheapest way to do z>2 BAO
- d_A with precision of 5% at z=2.34



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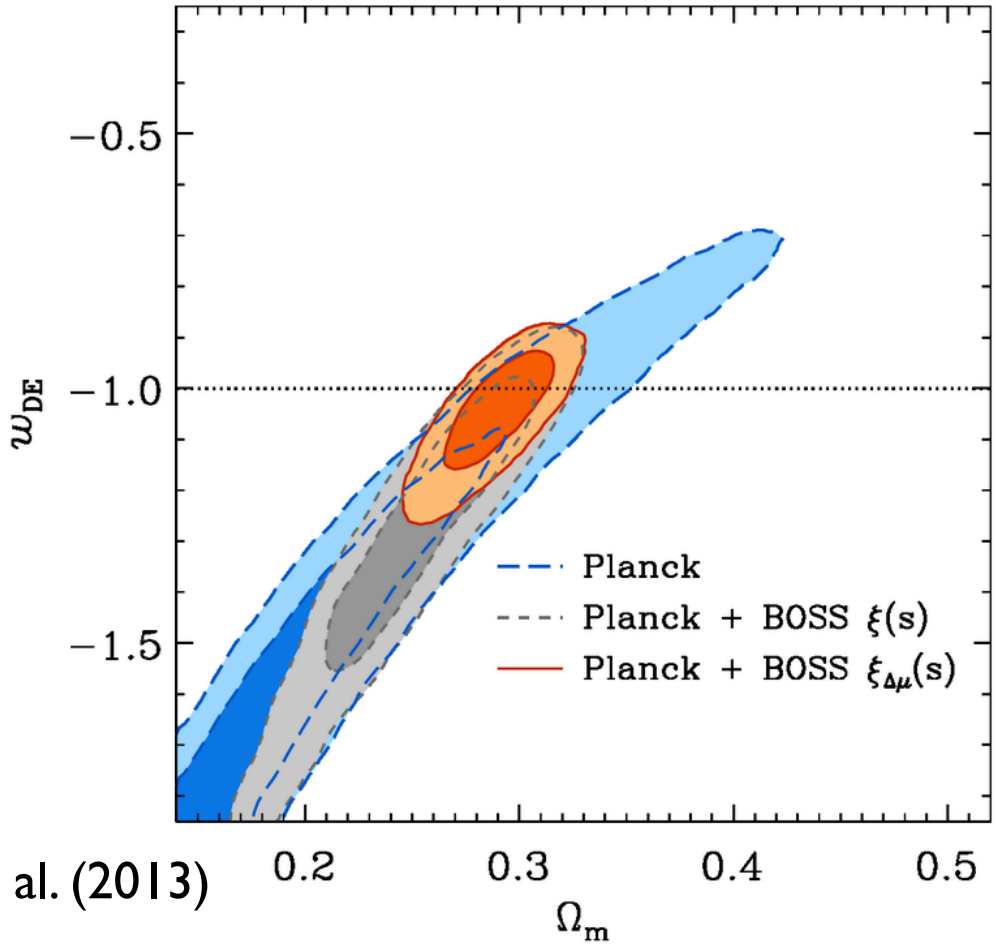
Cosmology with BOSS

- BOSS combined with Planck CMB gives powerful cosmological constraints.



Sanchez et al. (2013)

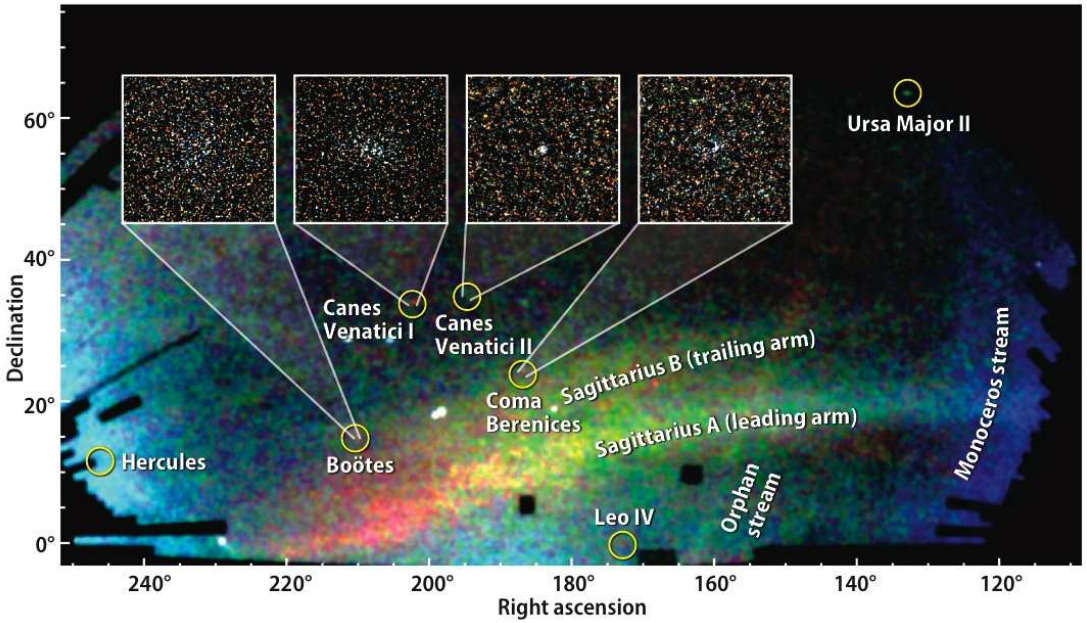
BOSS at a glance

- Redshifts of 1,500,000 red galaxies to $z=0.7$
- Lyman-α forest spectra of 160,000 quasars at redshift $2.2<z<3$
- With BOSS objects, we can do more than BAO.
  - Statistical studies on properties of galaxies and quasars
  - Searching galaxy groups, clusters, and supersclusters

SEGUE-2

Sloan **E**xtension for **G**alactic **U**nderstanding and **E**xploration **2**

- SEGUE-2 aimed to map dynamical and chemical history of the outer regions of the Milky Way by probing the kinematics, spatial distribution and chemical abundances of the stars (tidal streams).



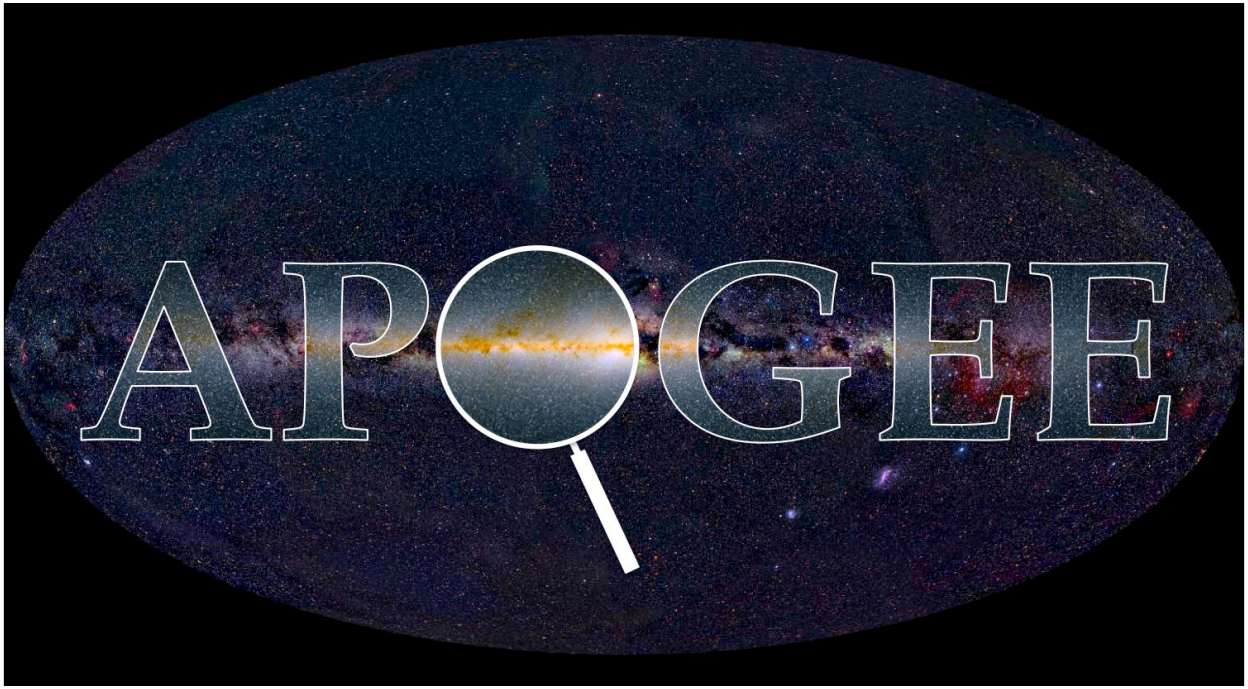
Sloan **E**xtension for **G**alactic **U**nderstanding and **E**xploration **2**

- SEGUE-2 aimed to map dynamical and chemical history of the outer regions of the Milky Way by probing the kinematics, spatial distribution and chemical abundances of the stars (tidal streams).
- SEGUE-2 searched for rarest, least enriched stars for clues about the earliest supernovae.
- SEGUE-2 observed 118,151 stars.

APOGEE

APO Galactic **E**volution **E**xperiment

- APOGEE unveils the inner Milky Way with a new high-resolution infrared spectrograph.
  - IR permits us to see the thin disk and inner bulge obscured by dust. Targets are prepared from 2MASS.



APO Galactic **E**volution **E**xperiment

- APOGEE unveils the inner Milky Way with a new high-resolution infrared spectrograph.
  - IR permits us to see the thin disk and inner bulge obscured by dust. Targets are prepared from 2MASS.
  - Abundances of over 10 elements including C, N, O
- APOGEE made ground-breaking sample of 100,000 stars, mostly giants.
- APOGEE together with SEGUE-2 will play a central role in near-field cosmology tests of galaxy formation and small-scale distribution of dark matter.

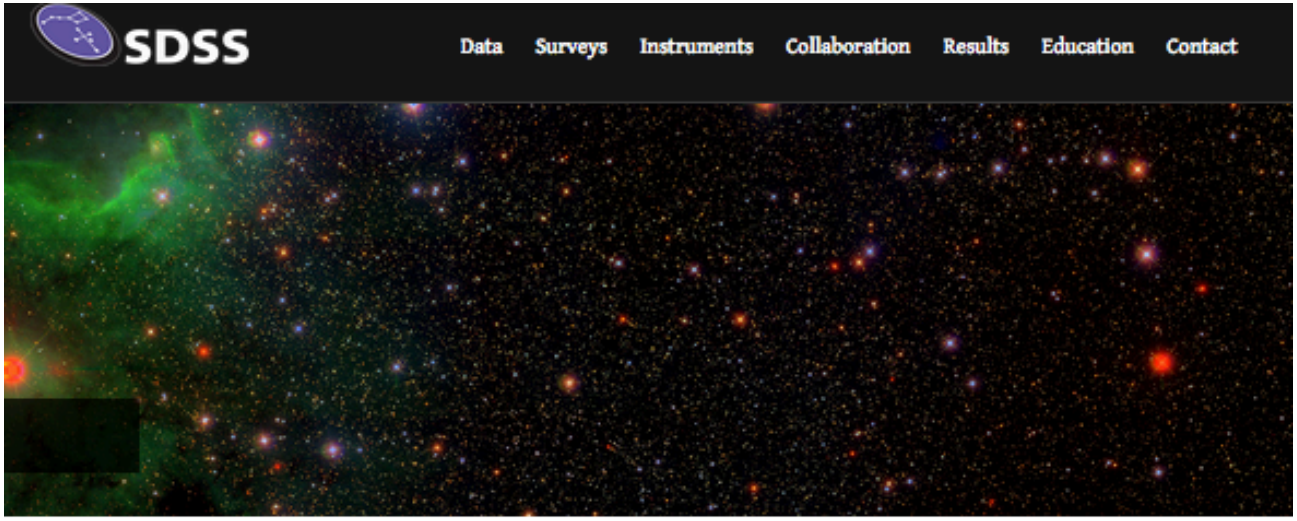
MARVELS

Multi-object **A**PO **R**adial **V**elocity **E**xoplanet **L**arge-area **S**urvey

- 15 years of study of exoplanets has revealed the large population of hot Jupiters.
- Currently available data is statistically small and heterogeneous – it is difficult to test planet formation scenarios.
- MARVELS observed 60 bright stars' reflex motion simultaneously with high precision – it provides us a large and statistically robust sample with 10,000 main sequence targets and 1,000 giant targets.

How to access to data

www.SDSS.org



The Sloan Digital Sky Survey has created the most detailed three-dimensional maps of the Universe ever made, with deep multi-color images of one third of the sky, and spectra for more than three million astronomical objects. Learn and explore all phases and surveys—past, present, and future—of the SDSS.

EXPLORE OUR DATA

Go to Data Access

Current data: Data Release 12

News

SDSS Press Releases

SDSS Science Blog

APOGEE's Infrared View of the Stellar Temperature Sequence
January 12, 2015

SDSS at #AAS225 – Tweets by SDSS-IV Spokesperson, Jennifer Johnson
January 5, 2015

www.SDSS.org

Accessing the Data

Each Data Release includes four types of data: **images**, **optical spectra**, **infrared spectra**, and **catalog data** (parameters measured from images and spectra, such as magnitudes and redshifts).

The SDSS offers several different online data access tools, each suited to a particular need:

Website	Purpose
Science Archive Server	Interactive spectra and image mosaics
SkyServer	Browser-based access to the Catalog Archive Server (CAS) database, with resources for learning SQL and projects to teach science
CasJobs	Flexible advanced SQL-based interface to the CAS, for all data releases (quick registration required)
DR12 FITS	Direct download access to DR12 FITS data files for experts
Data Model	Details of the SAS directory structure, file formats, and the contents of each file

Past Data Releases

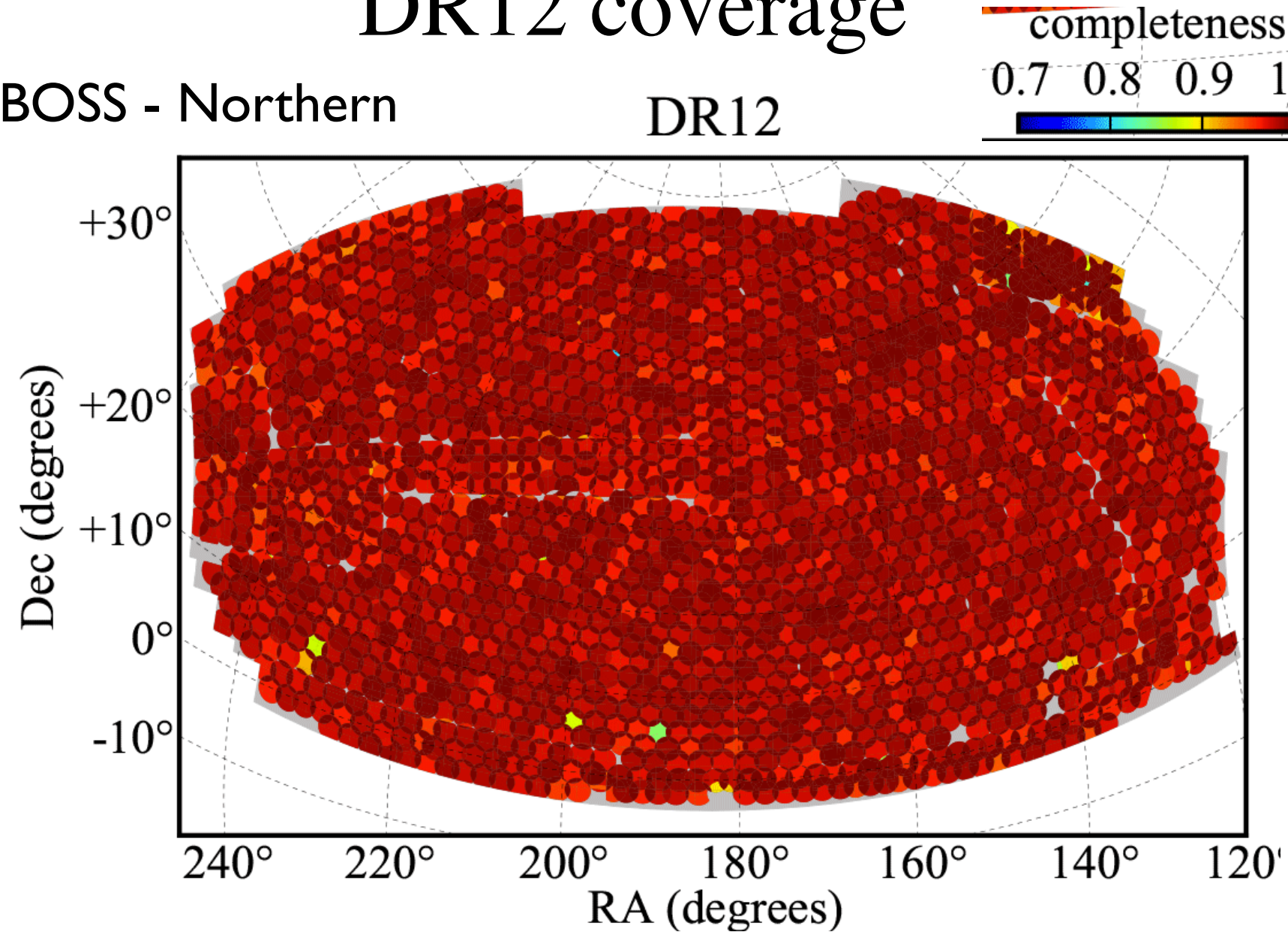
- Data Release 11
- Data Release 10
- Data Release 9
- Data Release 8
- Data Release 1-7

Working with SDSS Data

If you use public SDSS data in your paper, please see our guide on how to cite the

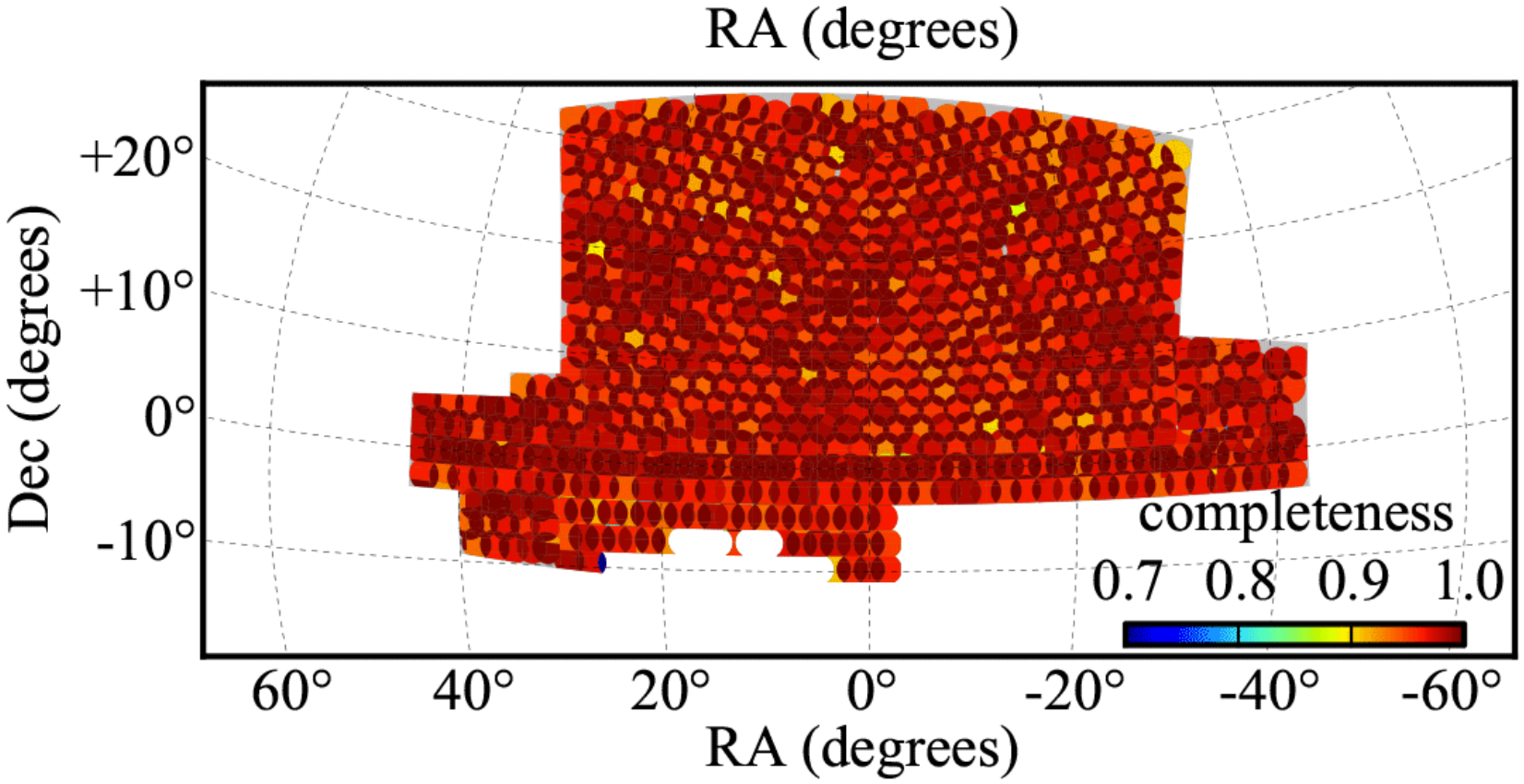
DR12 coverage

BOSS - Northern



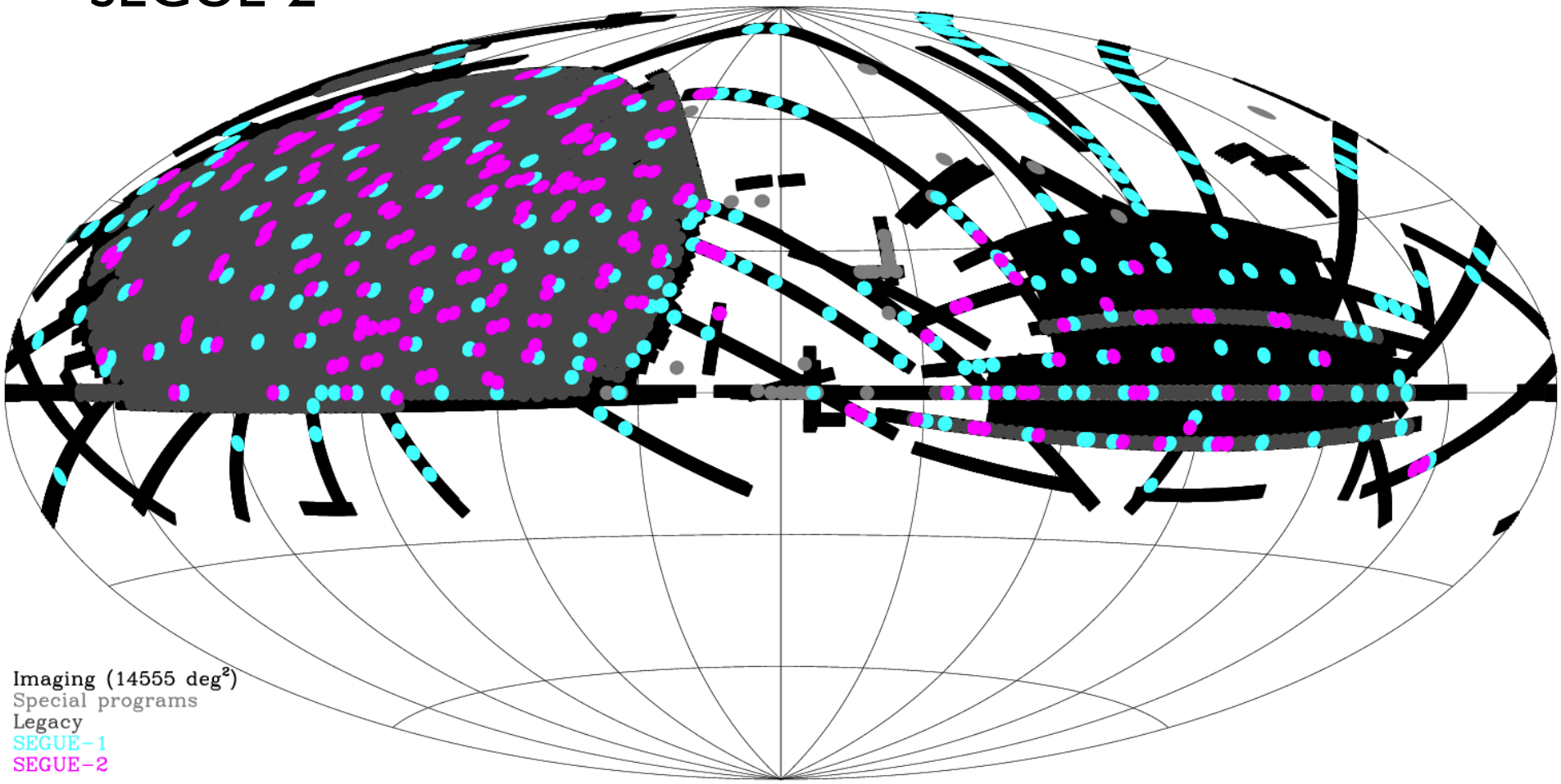
DR12 coverage

BOSS - Southern

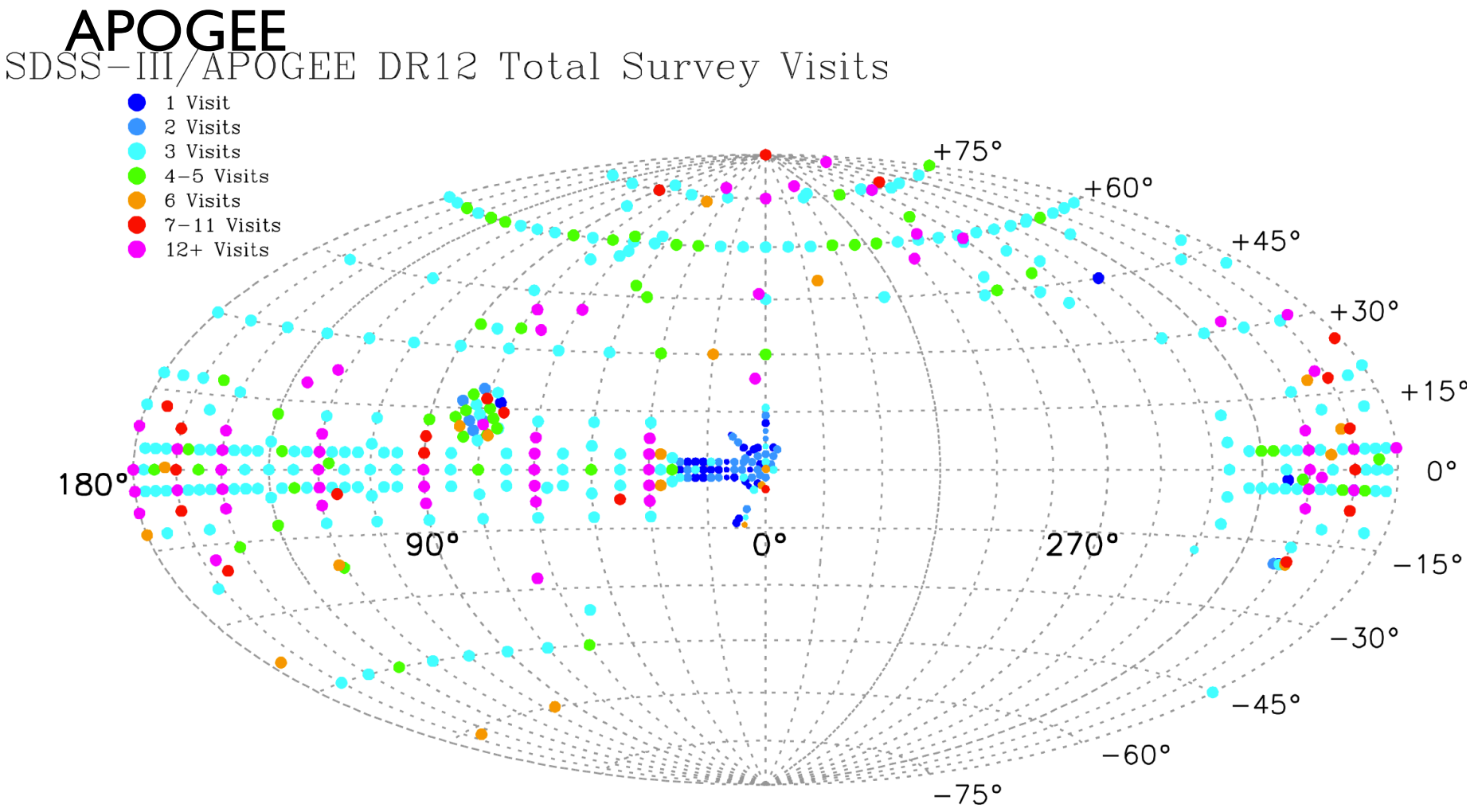


DR12 coverage

SEGUE-2



DR12 coverage



DR12 Coverage

MARVELS