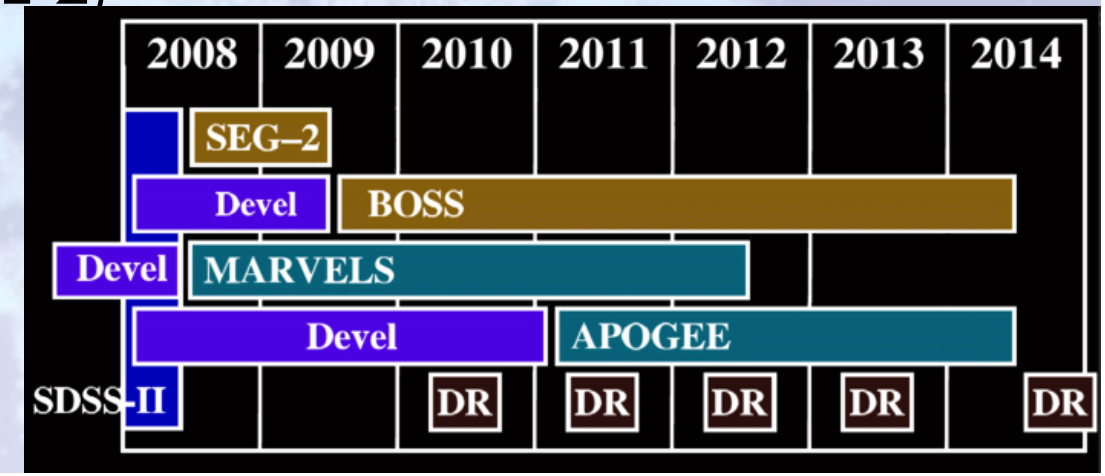
Sloan Digital Sky Survey III

Yun-Young Choi (KHU)

Contents

- SDSS-III (2008 July- 2014 July)
  - the Apache Point Observatory Galactic Evolution Experiment (**APOGEE**)
  - the Baryon Oscillation Spectroscopic Survey (**BOSS**)
  - the Multi-Object APO Radial Velocity Exoplanet Large-area Survey (MARVELS)
  - the Sloan Extension for Galactic Understanding and Exploration 2 (SEGUE-2)
- Science Organization

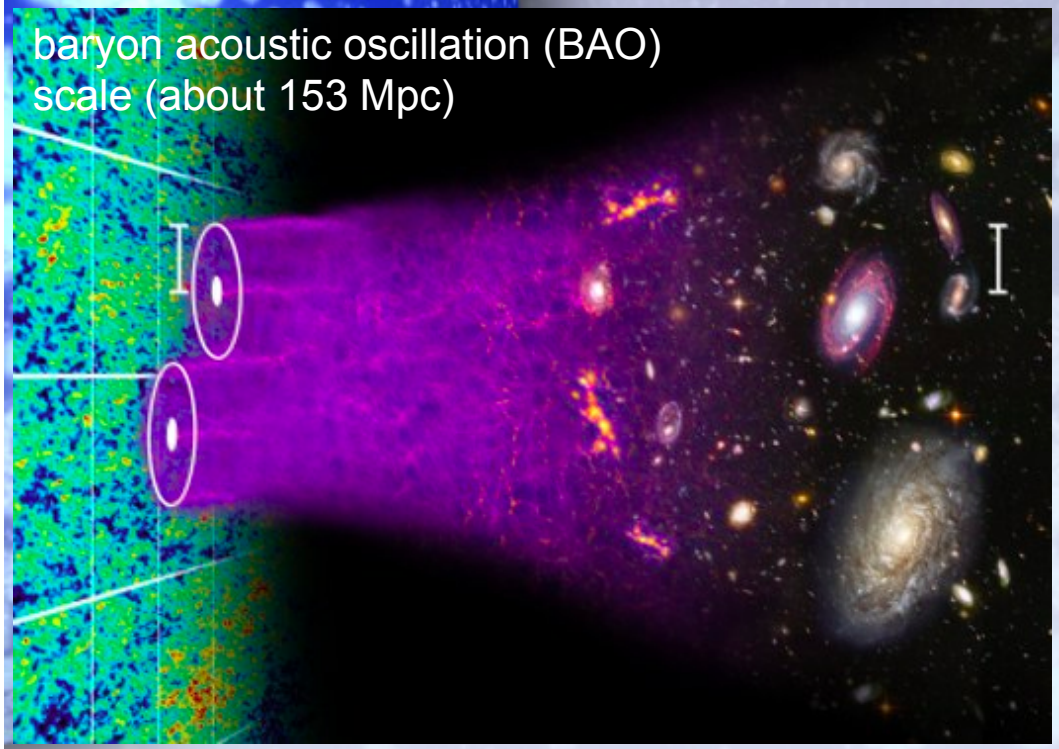


SDSS-II

- 2005-2008
- 8400 deg^2
- 9×10^5 galaxies, 10^5 quasars, 2×10^5 stars
- SN survey: >500 Type Ia SNs ($0.1<z<0.4$)
- SEGUE (the Sloan Extension for Galactic Understanding & Exploration): 3200 deg^2, 2.4×10^5 stars

BOSS

- What causes cosmic acceleration?
- If the acceleration is caused by "DE", is its energy density constant in space and time or does evolve?



→ To measure the history of cosmic expansion and the growth of DM clustering over a wide range of redshift

→ BAO feature measured in the 3-d clustering of matter tracers at z (BAO scale: angular diameter distance & Hubble parameter)

Summary of BOSS

Duration: Fall 2009–Summer 2014, dark time
Area: 10,000 deg^2
Spectra: 1000 fibers per plate
3600 Å $< \lambda <$ 10000 Å
$R = \lambda/\Delta\lambda = 1300$–$3000$
$(S/N)^2$
≈ 22 pixel^{-1} at $i_{fib} = 21$ (averaged over 7000–8500 Å)
≈ 10 pixel^{-1} at $g_{fib} = 22$ (averaged over 4000–5500 Å)
Targets: 1.5×10^6 massive galaxies, $z < 0.7$, $i < 19.9$
1.5×10^5 quasars, $z \geqslant 2.2$, $g < 22.0$ (20% of fiber)
selected from 4×10^5 candidates
75,000 ancillary science targets, many categories
Measurement goals:
galaxies: $d_A(z)$ to 1.2% at $z = 0.35$ and 1.2% at $z = 0.6$
$H(z)$ to 2.2% at $z = 0.35$ and 2.0% at $z = 0.6$
Lyα forest: $d_A(z)$ to 4.5% at $z = 2.5$
$H(z)$ to 2.6% at $z = 2.5$

65 km/s rms for LRG sample (from repeat observations)
1.8 km/s systematic limit for high signal-to-noise stars
Redshift accuracy

Magnitude limits for spectroscopy

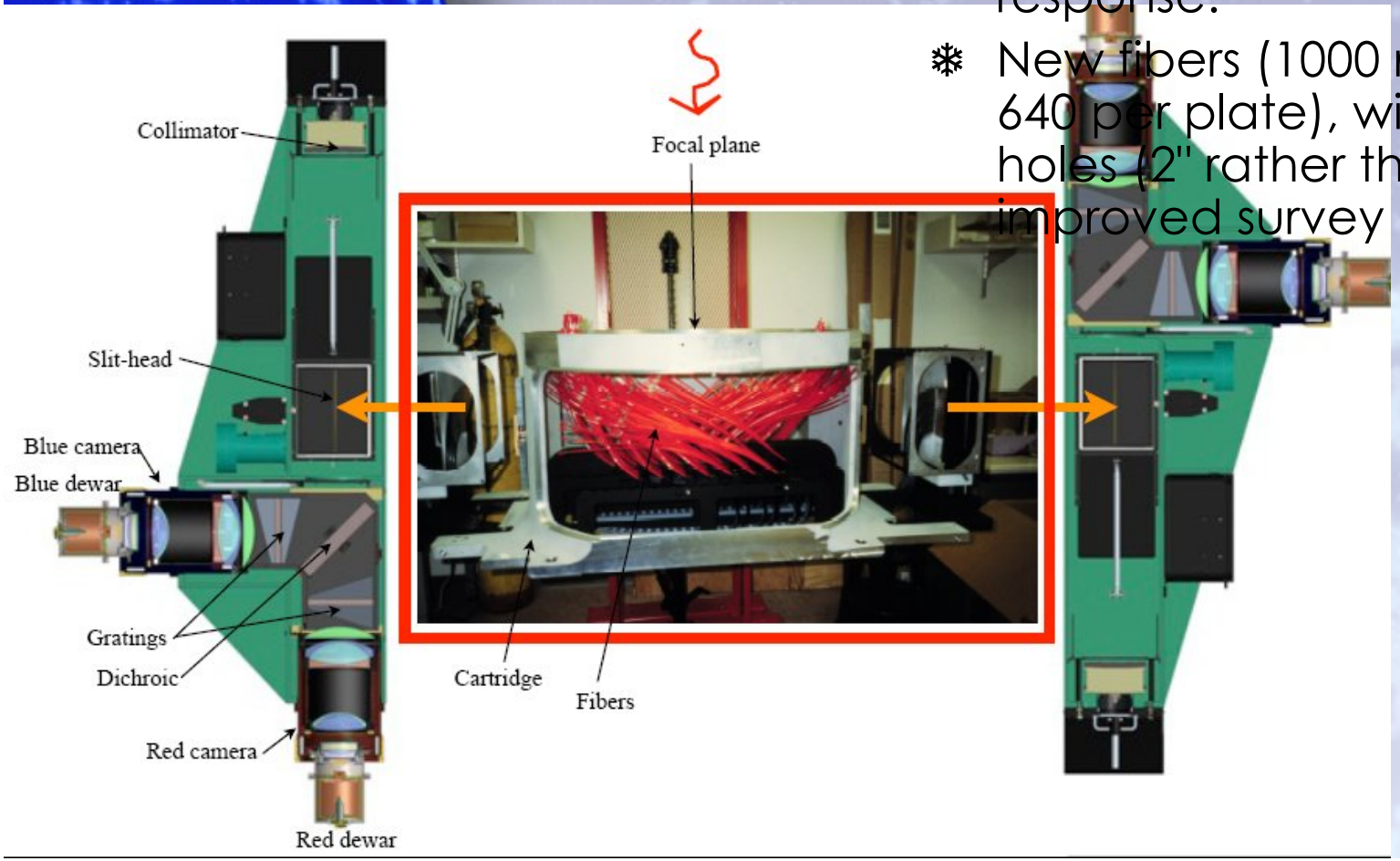
LRGs $i < 19.9$ White et al. (2011)

QSOs $g < 22$, $i < 22$ Ross et al. (2012)

1.7% BAO distance constraint at z=0.57 with DR9!

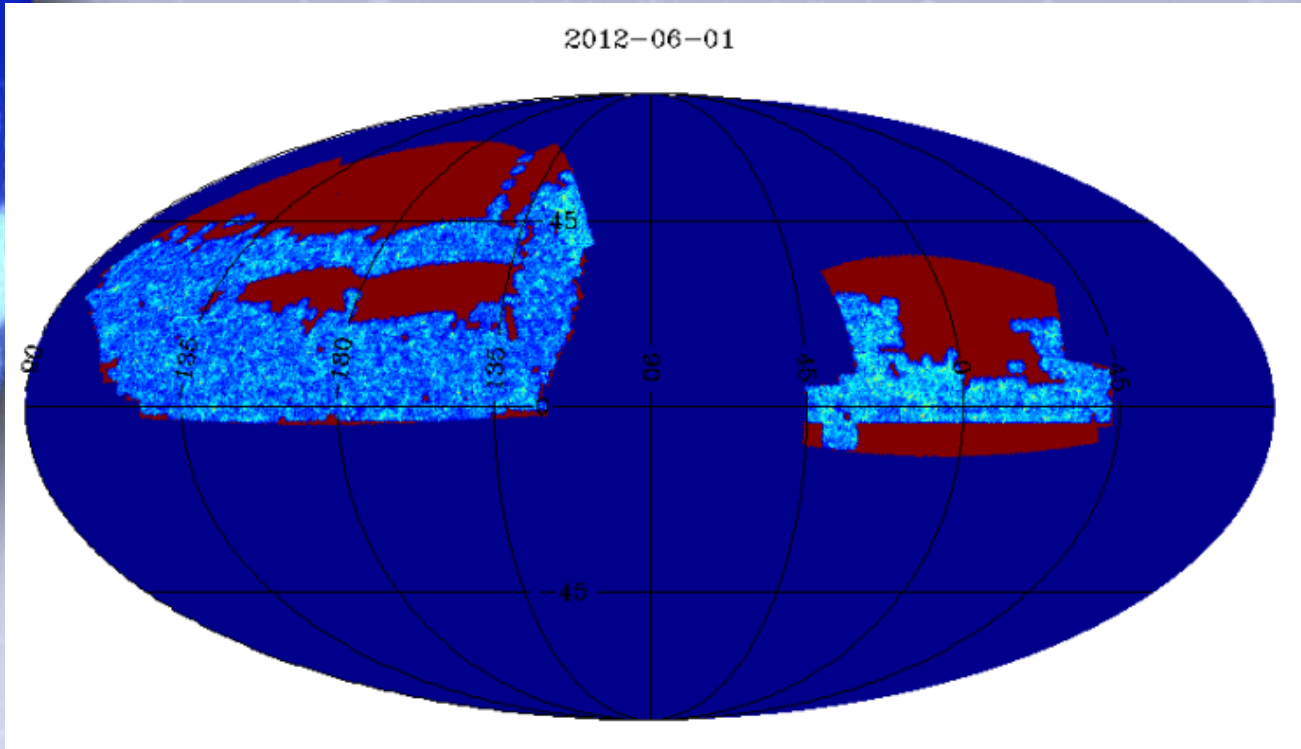
New BOSS Spectrograph

- New diffraction gratings (volume-phase holographic transmission gratings): spectral resolution 1300 at 3600Å to 3000 at 10000Å
- 4k×4kCCDs with improved response.
- New fibers (1000 rather than 640 per plate), with smaller holes (2" rather than 3"): **50%** improved survey efficiency



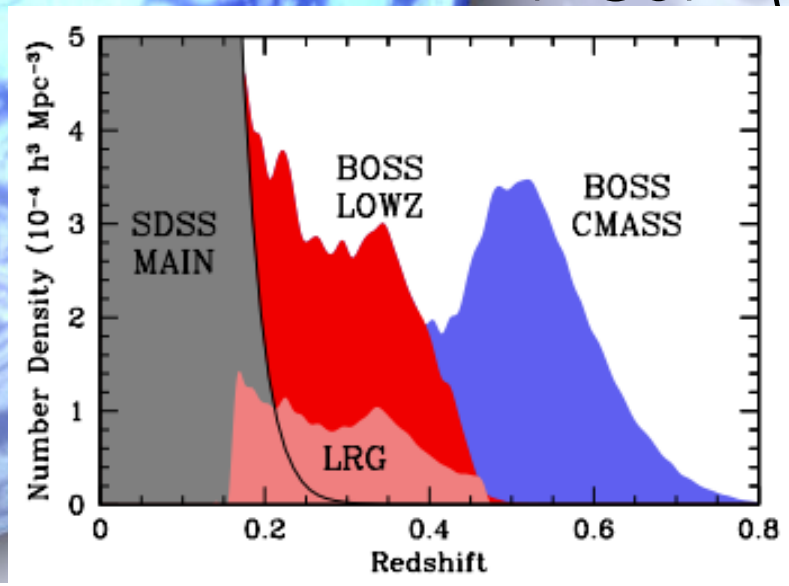
Current Status

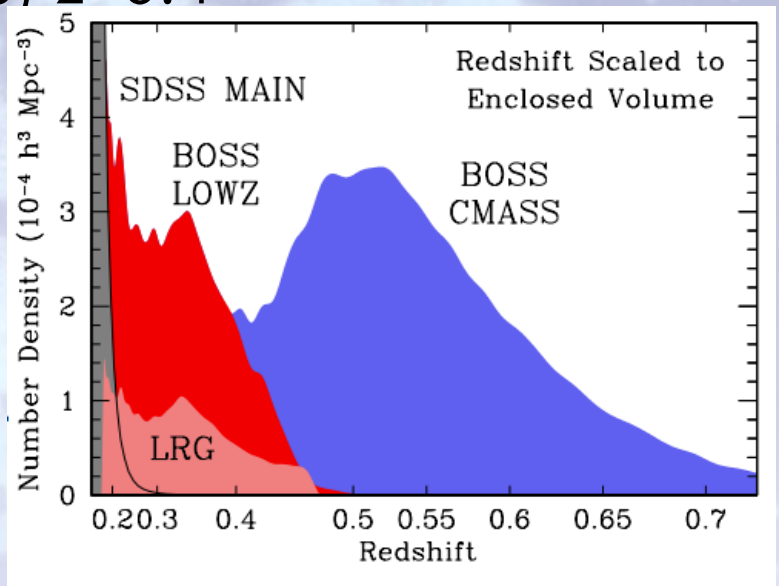
- >500,000 galaxy and >100,000 quasar redshifts, over a million spectra in total!

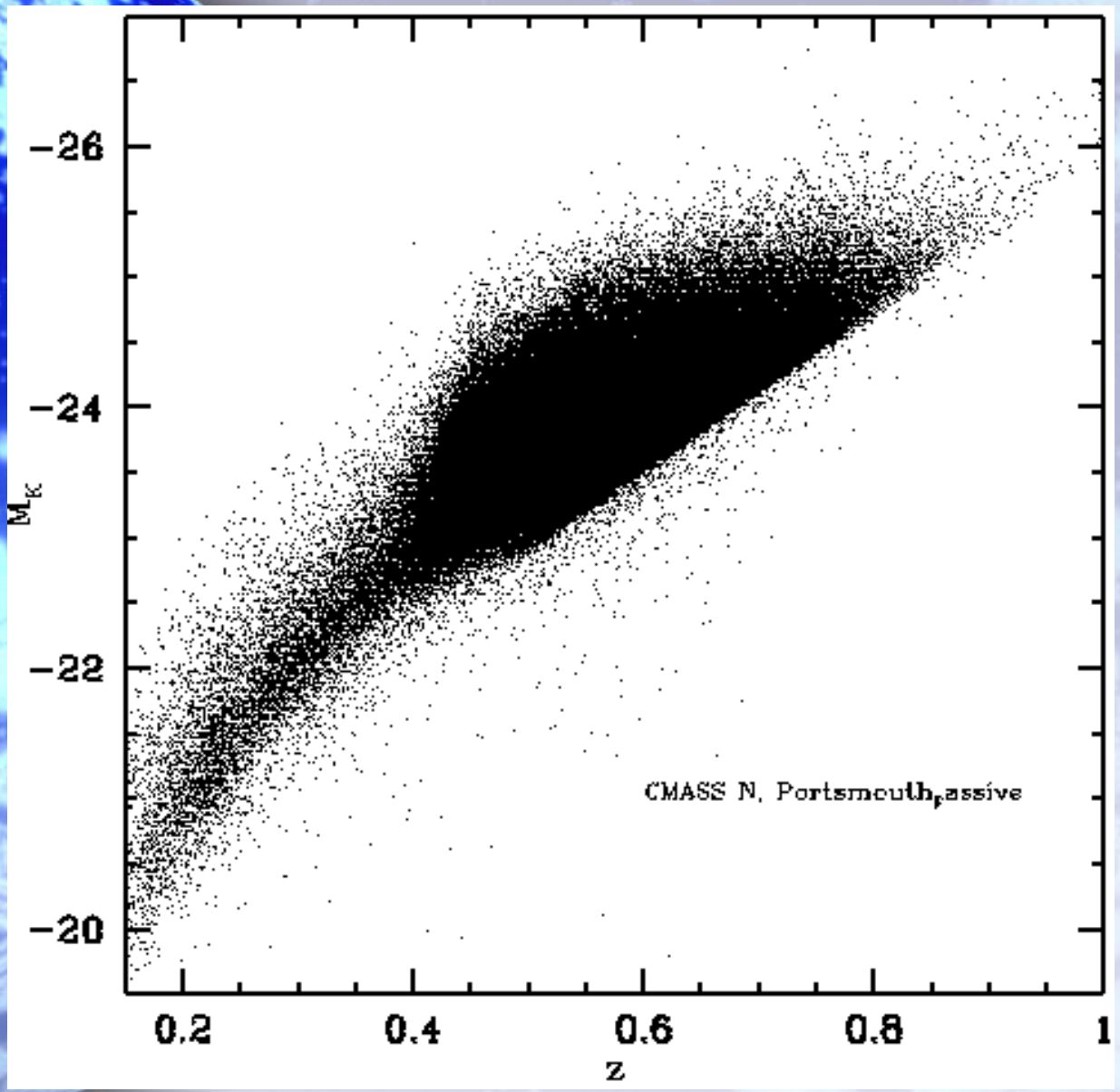


BOSS Target Selection

- Color-magnitude cuts to select massive luminous galaxies with an approximately uniform distribution of stellar masses from z=0.2 to z-0.6.
- Cut I (LOWZ) 0.2<z<0.4
- Cut II (CMASS) z>0.4

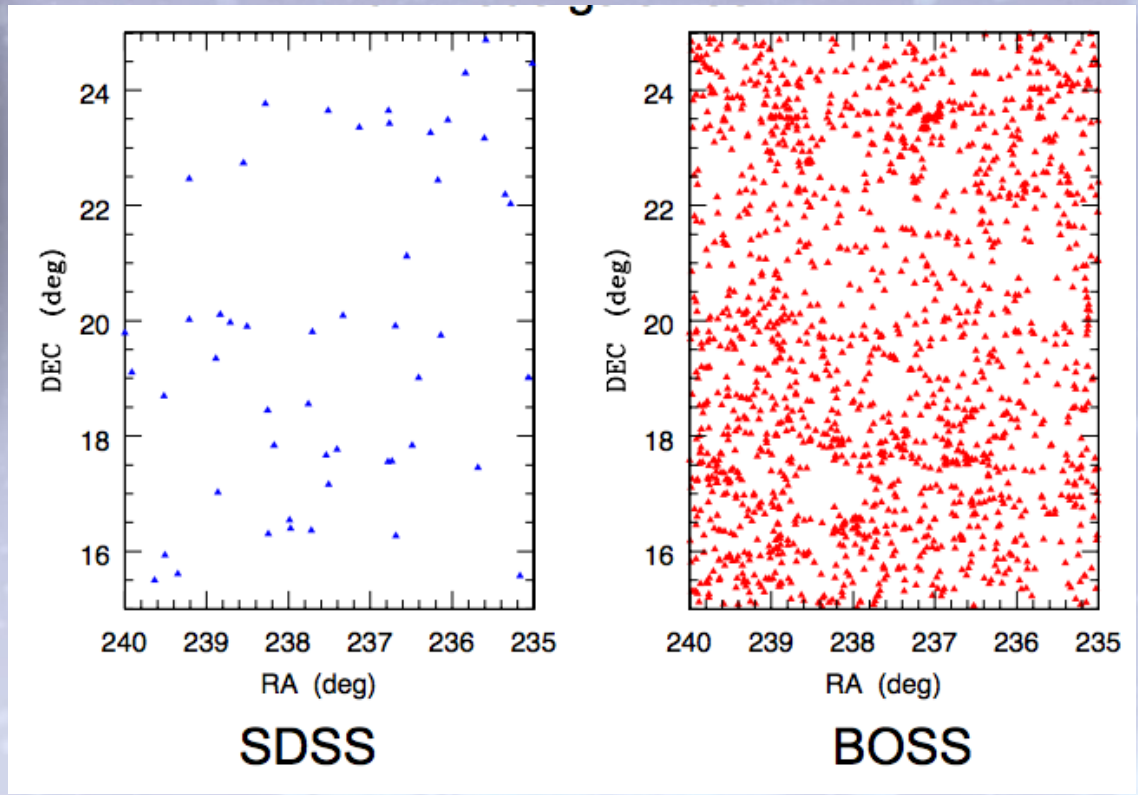




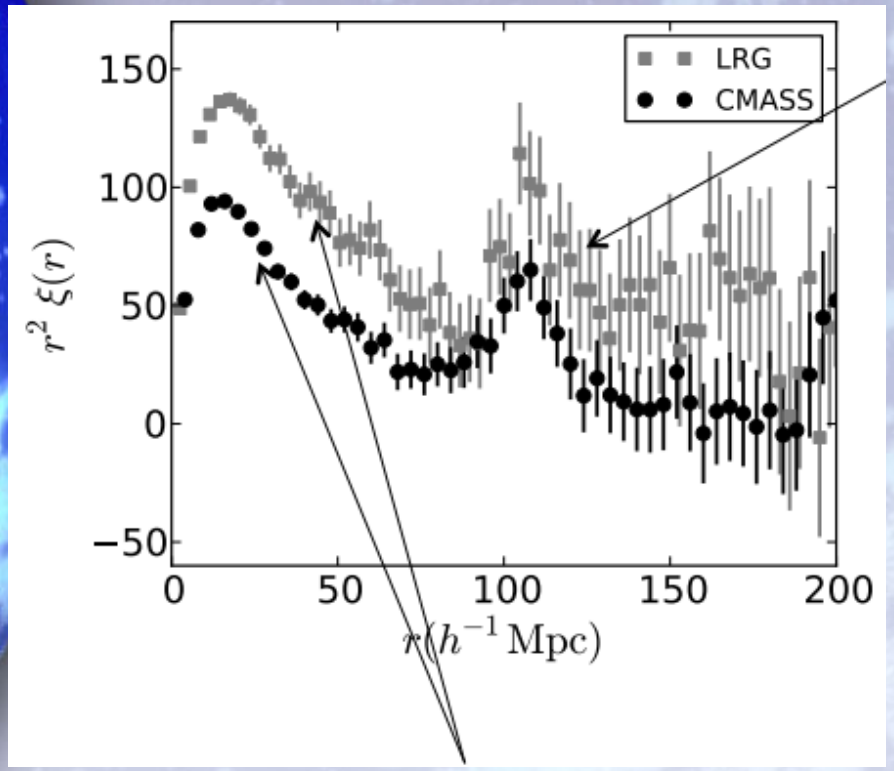

−26
−24
−22
−20
$M_{^{0.1}K}$
0.2
0.4
0.6
0.8
1
z
CMASS N, Portsmouth$_{passive}$

Tracing large-scale structure

- Cosmic web at z=0.5

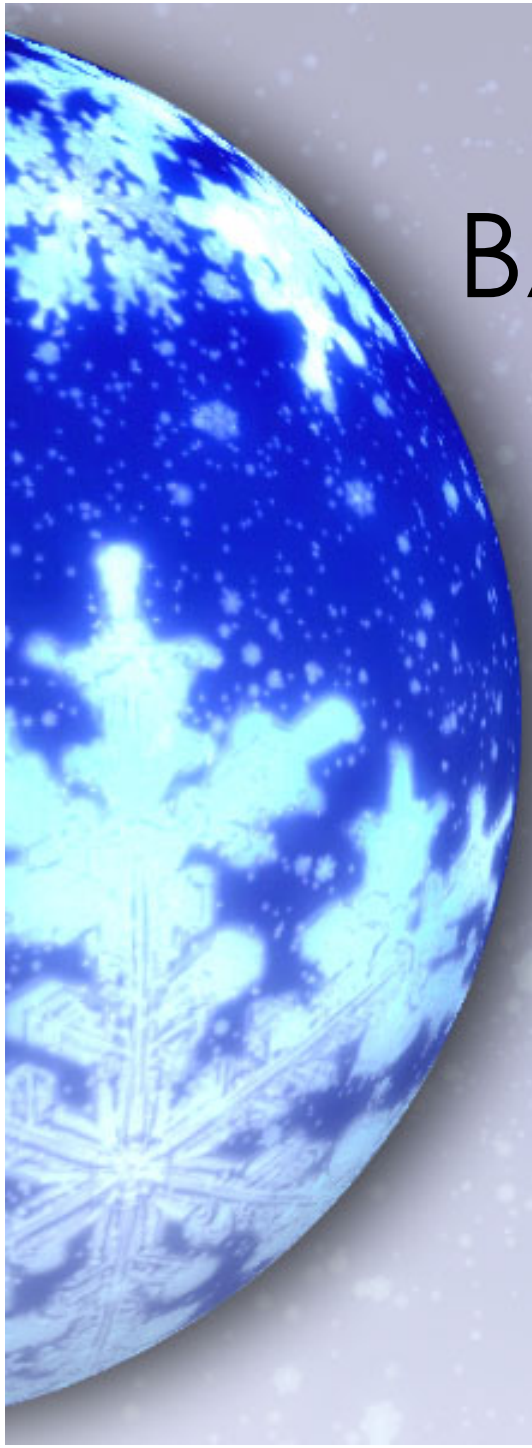


BAO detection



Anderson et al. 2012

The bias of SDSS LRG and BOSS CMASS differ.



BAO and the IGM

- Distance constraints become tighter as one moves to higher z
  - More volume per sky area.
  - Less non-linearity.
- Expensive if use galaxies as tracers - Any tracer will do.
  - 21cm from HI in galaxies: SKA
  - Lyα from IGM as probed by QSOs: First detection of large-scale clustering of the IGM using cross correlations between QSO lines of sight.

BOSS ancillary science

- 25 different programs: 3.5% of all DR9 spectra

Ancillary Science Programs in Stripe 82

The following ancillary target programs are now complete. Complete data for these ancillary targets is being released as part of Data Release 9.

- The Transient Universe through Stripe 82
- SDSS-II Supernovae
- Brightest Cluster Galaxies in Stripe 82
- High-Quality LRG Spectra
- Reddened Quasars
- No Quasar Left Behind
- Variability-Selected Quasars
- K-band Limited Sample of Quasars

Ancillary Science Programs in the Full BOSS Survey Area

Spectroscopic observations in the following ancillary target programs have not yet been completed. In each of these ancillary target programs, data for a subset of targets is part of DR9. Future data releases will include more targets from these ancillary target programs.

- Very Low-Mass Stars and Brown Dwarfs
- Low-Mass Binary Stars
- White Dwarfs and Hot Subdwarfs
- Distant Halo Giants
- Bright Galaxies
- High-Energy Blazars and Optical Counterparts to Gamma-Ray Sources
- An X-Ray View of Star Formation and Accretion in Normal Galaxies
- Remarkable X-Ray Source Populations
- Star-Forming Radio Galaxies
- Galaxies Near SDSS Quasar Sight Lines
- Luminous Blue Galaxies
- Broad Absorption Line (BAL) Quasar Variability Survey
- Variable Quasar Absorption
- Double-Lobed Radio Quasars
- High-Redshift Quasars
- High-Redshift Quasars from SDSS and UKIDSS

APOGEE at a Glance

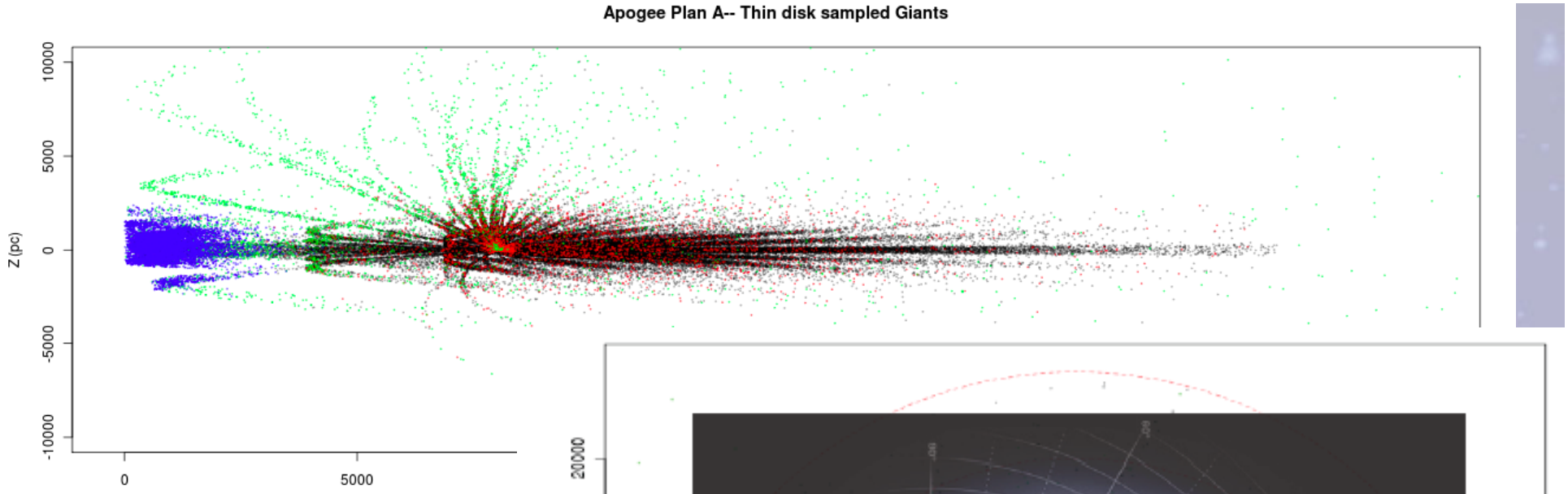
- A high-resolution, high signal-to-noise spectroscopic survey
- Operates in the near-infrared (H band): 1.51-1.68 μm
- Target-10^5 2MASS-selected, evolved stars, RGB, AGB, red supergiant stars sampling the bulge, disk(s), and halo(es)
- Stellar parameters and abundances for ~15 elements per star

More numbers!

- Goal S/N = 100/pixel
- R ~ 22,500
- 300 fibers at a time, 7 deg^2 FOV

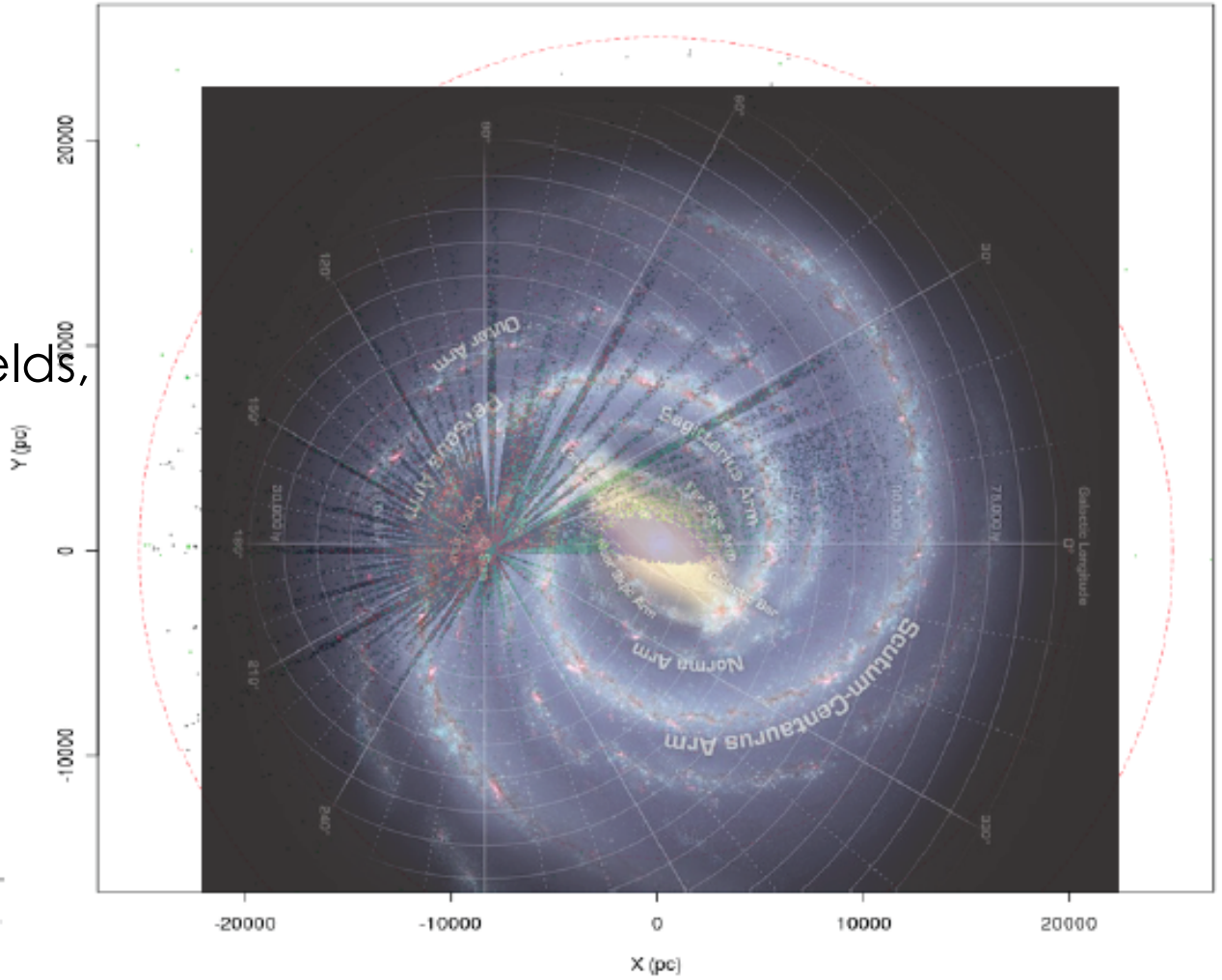
(MARVELS shares the focal plane)

- RV precision: <0.1 - 0.5 km/s
- Abundance precision: <0.1 dex
- Area: ~1575 deg^2 ,~230 fields

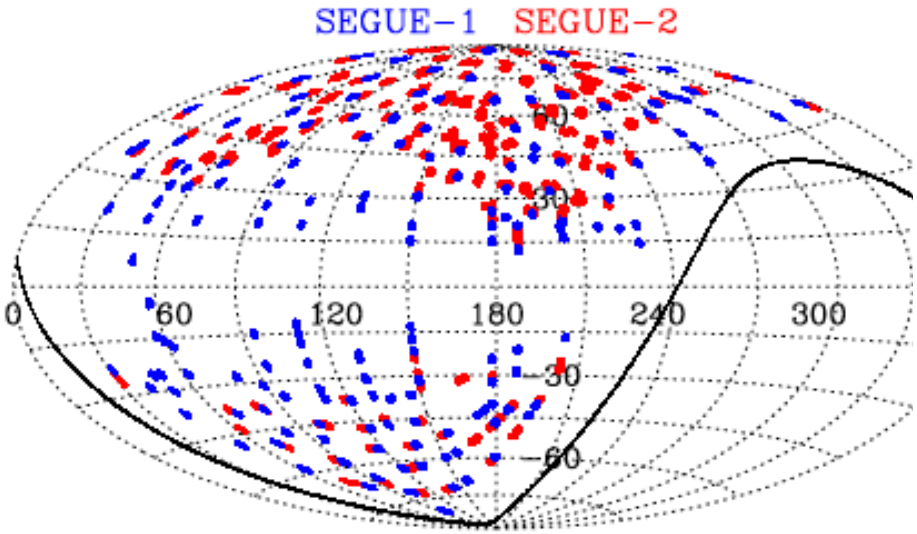


For currently selected fields,
Bulge 8000 stars
Thin disk 84100 stars
Thick disk 4300 stars
Halo 4500 stars!

79% giants



SEGUE-2



SEGUE-2: deep pointing "outer halo"

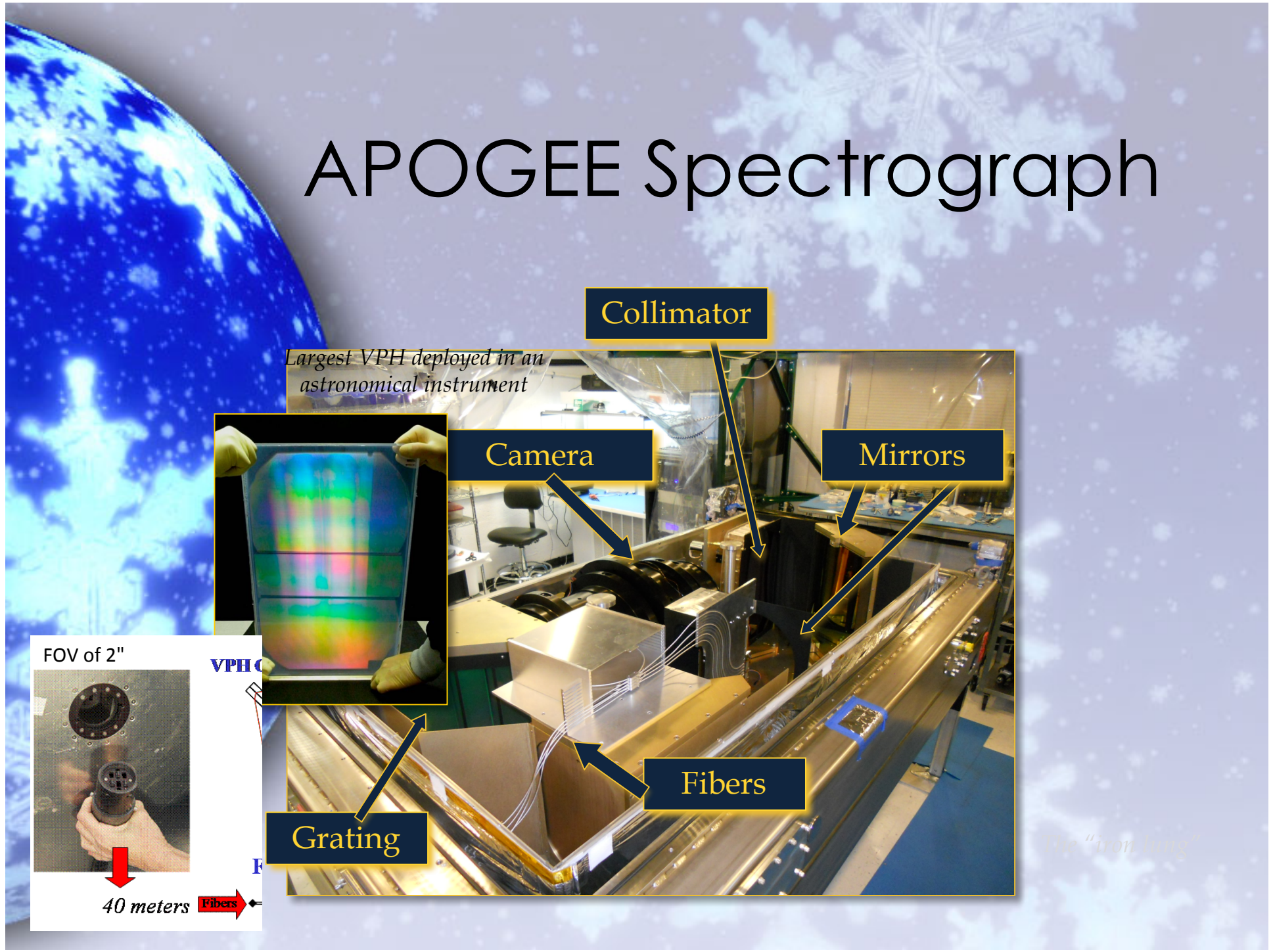
Summary of SEGUE-2

Duration: Fall 2008–Summer 2009, dark+gray time
Area: 1317 deg^2, 118,151 targets
Spectra: 640 fibers per plate
- 3800 Å $< \lambda <$ 9200 Å
- $R = \lambda/\Delta\lambda = 1800$
- S/N $\approx$ 10 per pixel at $r_{psf} = 19.5$

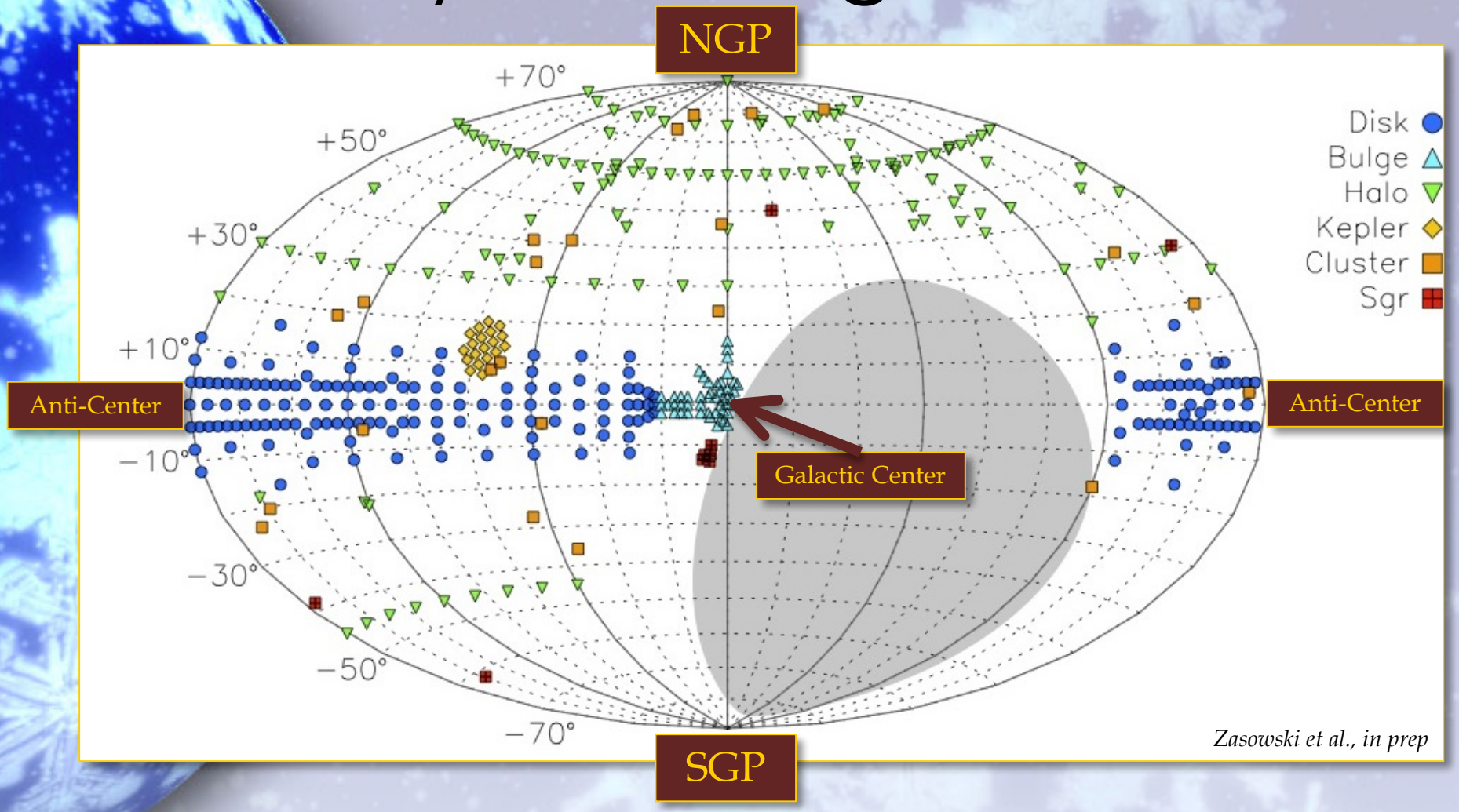
Target categories:
- halo main-sequence turnoff stars (37,222)
- blue horizontal branch stars (9983)
- K-giants and M-giants (43,604)
- high-velocity stars (4133)
- hypervelocity stars (561)
- cool extreme subdwarfs (10,587)
- low metallicity candidates (16,383)

Precision: dependent on stellar type and S/N, but typically
- 150 K in T_{eff}, 0.23 dex in log g
- 0.21 dex in [Fe/H], 0.1 dex in [α/Fe]

APOGEE Spectrograph

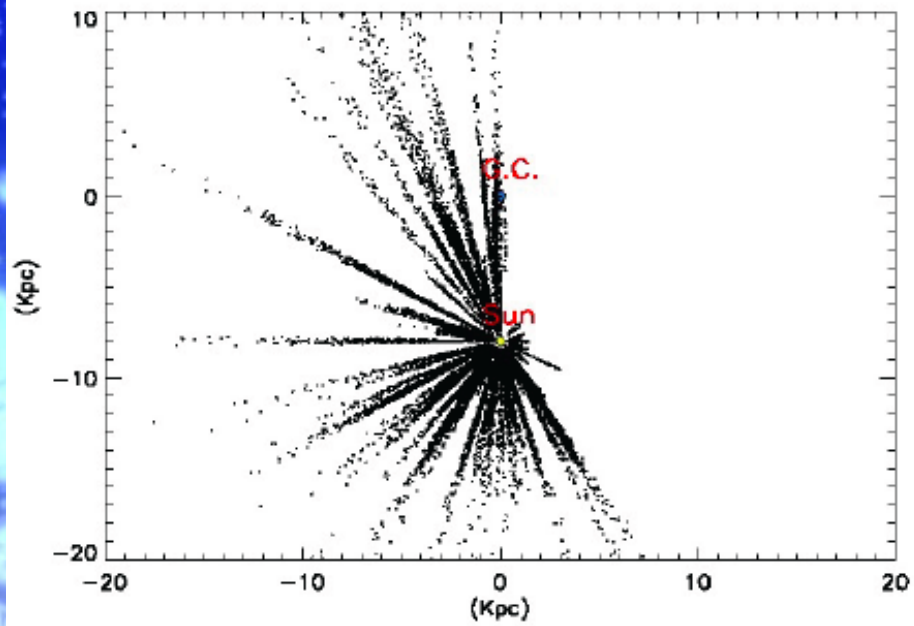


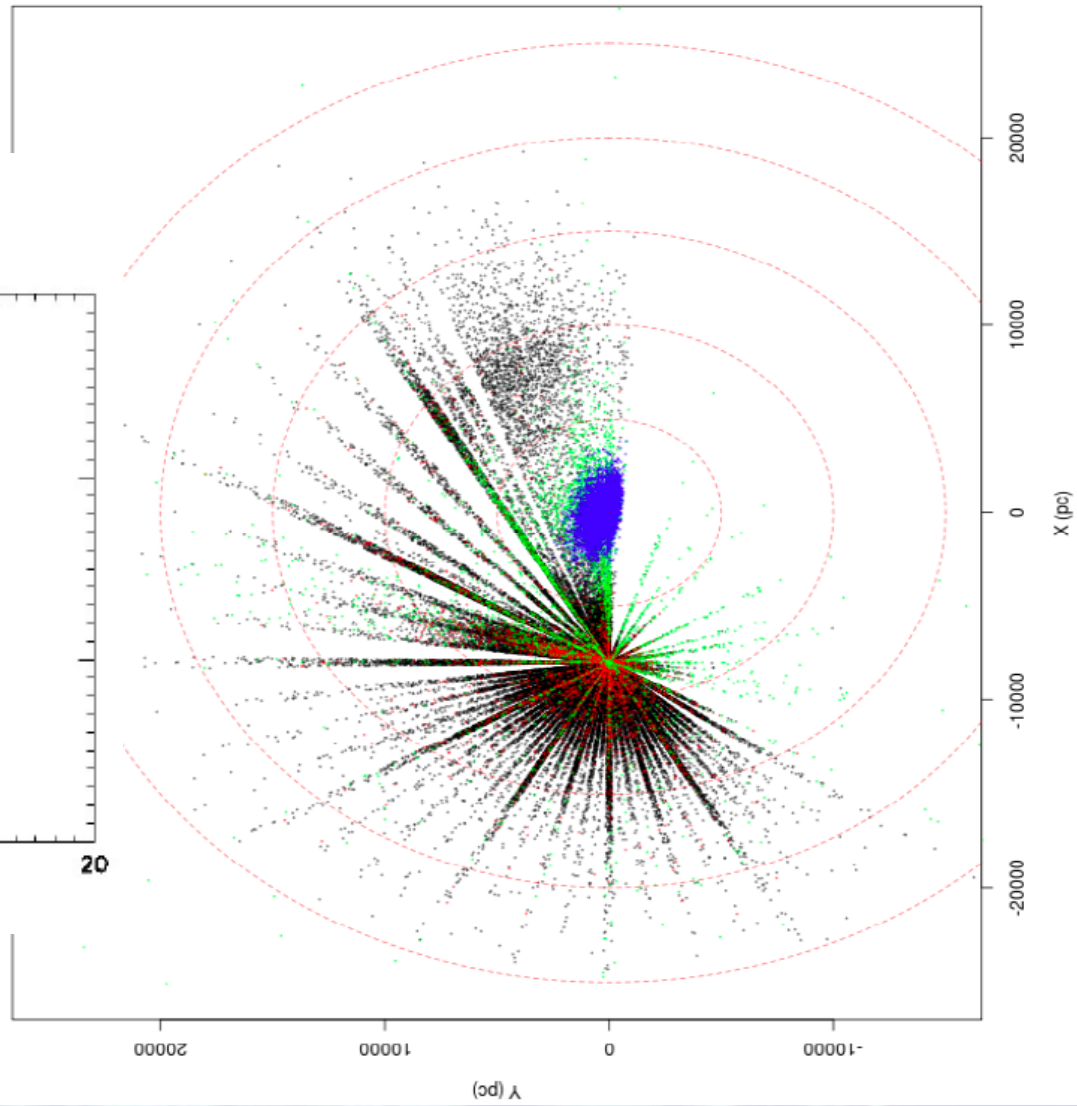
Sky Coverage



Fields chosen to sample all major Galactic components.

Data used

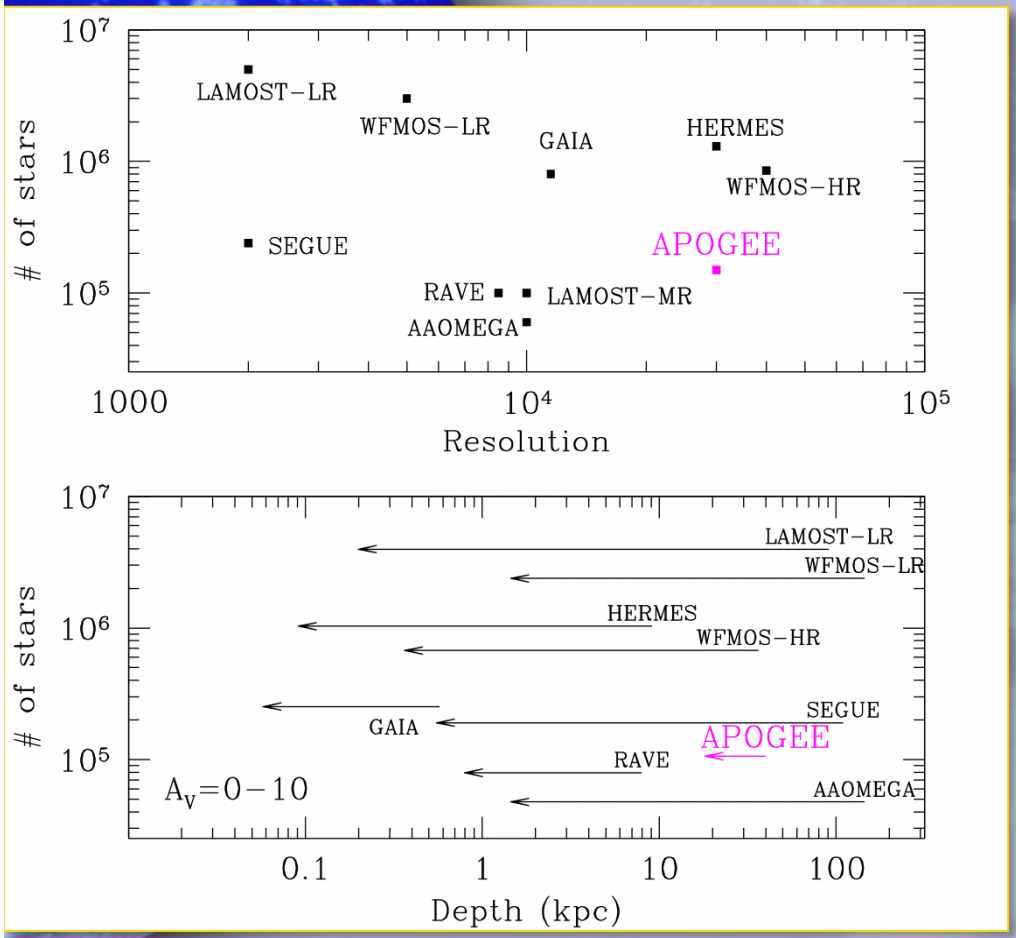

G.C.
Sun
(Kpc)
(Kpc)
10
0
−10
−20
−20
−10
0
10
20


X (pc)
Y (pc)
20000
10000
0
-10000
-20000
20000
10000
0
-10000

APOGEE Sciences

- To derive tight constraints on models for the history of star formation, chemical evolution (processes of chemical mixing and feedback in the interstellar medium), and mass assembly of the Galaxy - High-precision abundances for many types of elements: Fe, CNO, a-elements, odd-Z, iron peak, possibly even neutron capture…
- To constrain the stellar IMF in each of the main Galactic components.
- First large-scale, systematic, uniform Galactic stellar survey
- Access to regions highly obscured by dust (thus typically avoided!)
- Precise RVs to map kinematics for constraining dynamical models of the disk, the bulge, the bar, and the halo and to to provide insights into the Galaxy's dynamical history.
- A dataset 2-3 orders of magnitude larger than any other high-resolution Galactic chemistry survey!

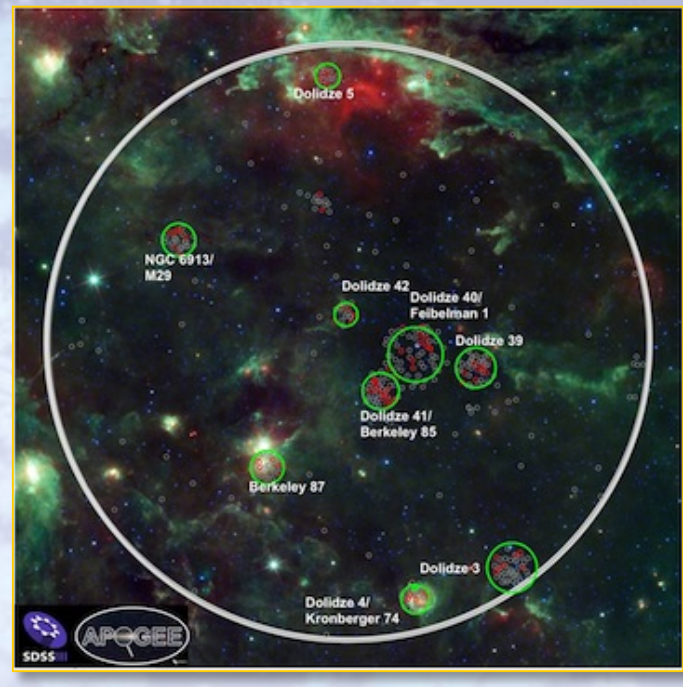
APOGEE



- Complements many recent and imminent surveys

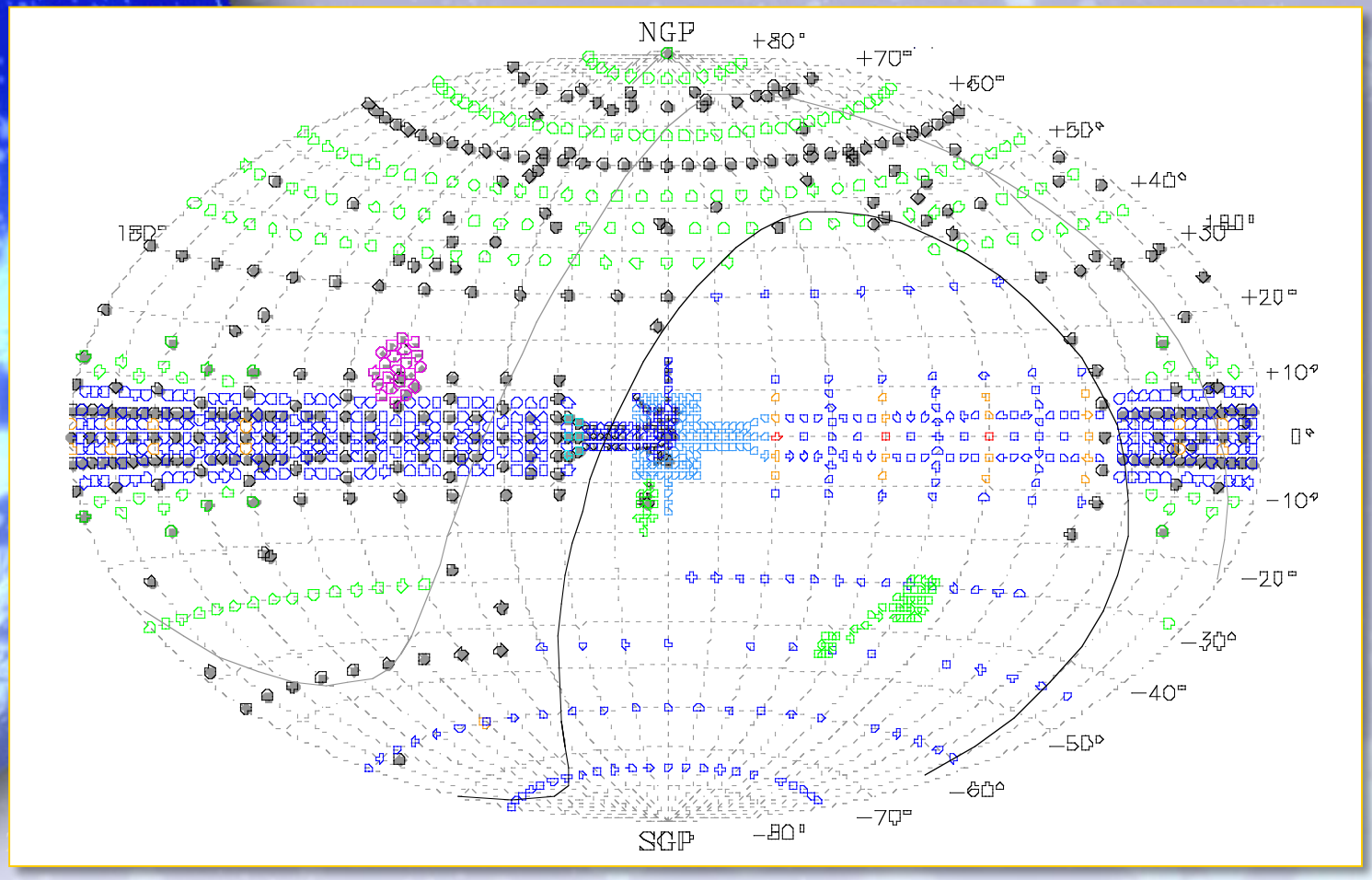
Additional Target Sample

- Open and globular clusters
- Overlap with other surveys: BRAVA, SEGUE-II, *Kepler*, GAIA-ESO
- 15 ancillary programs:
  - M dwarfs & companions
  - Eclipsing Binaries
  - Embedded YSOs
  - M31 Globular Clusters
  - B[e] (Emission Line) Stars
  - Massive MW Stars
  - And more!



Looking Ahead…

- Potentially nearing 500,000 stars in APOGEE-II N & S!



Data Release

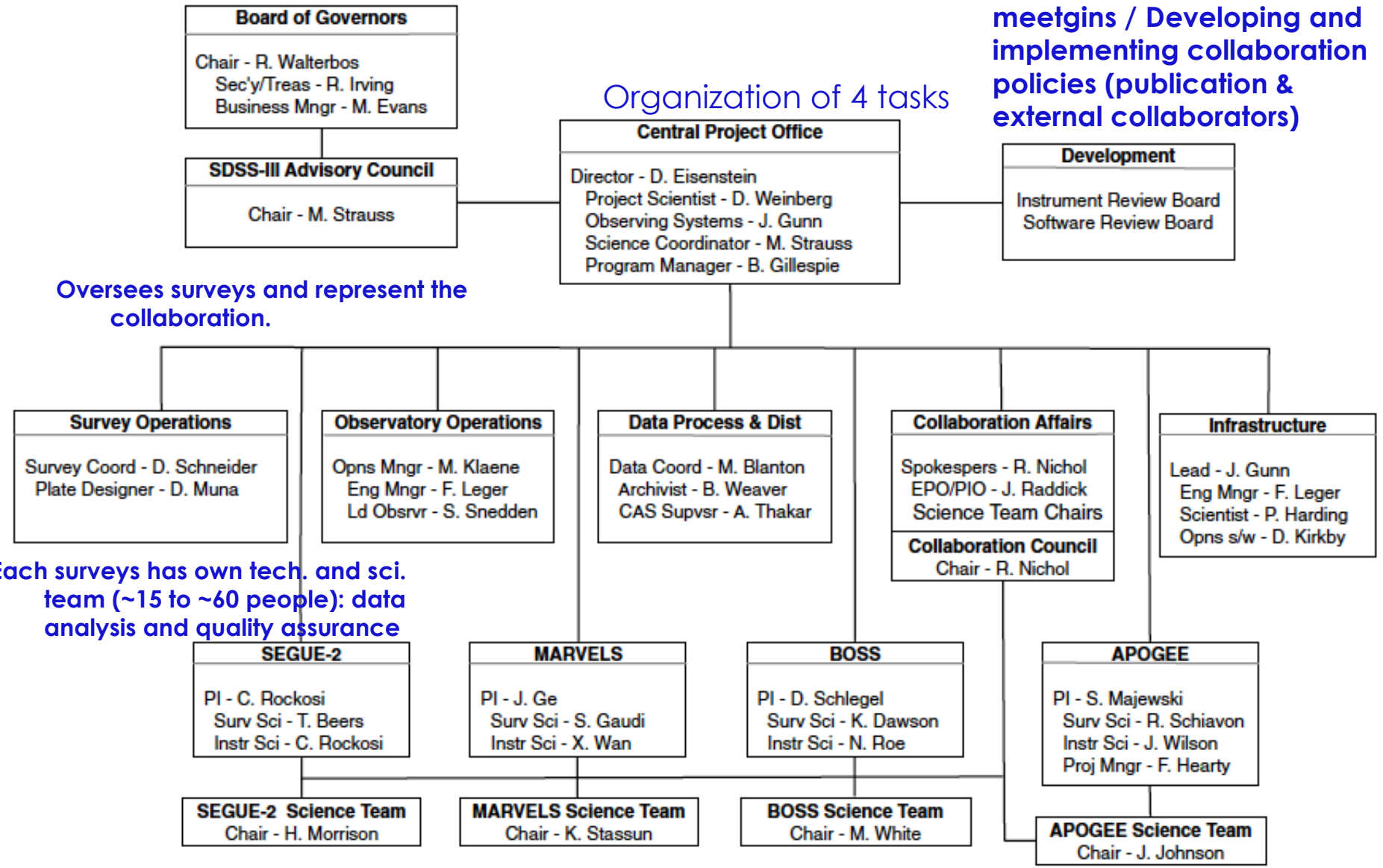
Date	Data Release	APOGEE	BOSS	MARVELS	SEGUE-2
Jan. 2011	DR8		Final imaging		Final spectra
Jul. 2012	DR9		Spectra (up to Jul. 2011)		
Jul. 2013	DR10	Spectra (up to Jul. 2012)	Spectra (up to Jul. 2012)		
Dec. 2014	DR12	Final spectra	Final spectra	Final radial velocities	

Science Organization

- Successful execution of SDSS-I/II: Effective collaboration culture
- Large & Diverse international collaboration: Principles of Operation
  - Institution - financial or equivalent in-kind contribution
  - Full member, Associate member, Participation group, External Participants
  - Advisory council: voting members

Eisenstein et al. 2011

SDSS-III Organization Chart



Organization of 4 tasks

Co-Co: Organizing collaboration meetgins / Developing and implementing collaboration policies (publication & external collaborators)

Oversees surveys and represent the collaboration.

Each surveys has own tech. and sci. team (~15 to ~60 people): data analysis and quality assurance

Each SST: working groups eg. For BOSS, Galaxy evolution, Galaxy clustering, Lyman Alpha Forest survey, Quasar science, Lensing science, Spectroscopic Pipeline, Emission Line Galaxy Ancillary Program