#### **SDSS Spectroscopic Survey of Stars**

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## Outline

- 1. Sloan Digital Sky Survey: an overview
- 2. SDSS Spectroscopic Survey of Stars
- The Utility of SDSS Stellar Spectra: Recent results on the Milky Way Kinematics and Metallicity Distribution

# Sloan Digital Sky Survey(s)

- Imaging Survey
  - $-10,000 \text{ deg}^2$  (1/4 of the full sky)
  - 5 bands (ugriz: UV-IR), 0.02 mag photometric accuracy
  - < 0.1 arcsec astrometric accuracy
  - 100,000,000 stars and 100,000,000 galaxies
- Spectroscopic Survey: two multi-object fiber spectrographs on the same telescope. Each plate (radius of 1.49 degrees) can accommodate 640 fibers. Targets selected from imaging data: 1,000,000 galaxies, 100,000 quasars, 100,000 stars

- Galaxies: simple flux limit for "main" galaxies, flux-color cut for luminous red galaxies (cD)
- Quasars: flux-color cut, matches to FIRST survey
- Non-tiled objects (color-selected): calibration stars (16/640), interesting stars (hot white dwarfs, brown dwarfs (tiled), red dwarfs, C stars, CV, BHB, PN stars), sky

SDSS Data Release 5: 675,000 galaxies, 90,000 quasars, 155,000 stars.

#### Spectroscopic Data and Processing

 Spectra: Wavelength coverage: 3800–9200 Ang, Resolution: 1800, Signal-to-noise: >4 per pixel at g=20.2: These spectra have much better quality than needed for a redshift survey of galaxies; they are publicly available in a user-friendly format through an exquisite web interface at www.sdss.org

#### • Pipelines:

- *spectro2d:* Extraction of spectra, sky subtraction, wavelength and flux calibration, combination of multiple exposures
- *spectro1d:* Object classification, redshifts determination, measurement of line strengths and line indices
- *target:* target selection and tiling

## The Utility of SDSS Stellar Spectra

- 1. Calibration of observations (e.g. can synthesize photometry with an accuracy of  $\sim$ 0.04 mag)
- More accurate and robust source identification than based on photometric data alone: e.g. confirmation of unresolved binaries, low-metallicity stars, cold white dwarfs, L and T dwarfs, C stars, CVs, etc.
- 3. Accurate stellar parameters estimation (Teff, log(g), metallicity, detailed chemical composition)
- 4. Radial velocity for kinematic studies of the Milky Way (especially useful when combined with proper motions)







#### Source Identification

- Stellar spectroscopic targets are colorselected, as illustrated in the **top left** figure
- A spectrum is required to secure a robust identification, as well as for a detailed measurement of the source properties
- Bottom left: an example of a C star: SDSS has discovered 95% of all known dwarf C stars (Margon et al. 2006)
- Bottom right: an example of an L dwarf (SDSS has discovered the first known field T dwarf, Strauss et al. 2000)

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RA=162.17848, DEC= 1.19958, MJD=51910, Plate= 275, Fiber=575







## Stellar Parameters Estimation

- SDSS stellar spectra are of sufficient quality to provide robust and accurate stellar parameters such as effective temperature, gravity, metallicity, and detailed chemical composition (c.f. poster by T. Beers)
- Stellar parameters estimated from spectra show a good correlation with colors measured from imaging data
- Top left: the median effective temperature as a function of the position in the g r vs. u g diagram (from 4000 K to 10,000 K, red to blue)
- Bottom left: zoomed-in version of the top left figure
- Photometric estimate of effective temperature:  $T_{eff}$  determines the g - r color, but has negligible impact on the u-g color





## Stellar Parameters Estimation

- Stellar parameters estimated from spectra show a good correlation with colors measured from imaging data
- Top left: the median metallicity as a function of the position in the g r vs. u-g diagram (from -0.5 to -2.5, red to blue)
- Bottom left: zoomed-in version of the top left figure
- Photometric estimate of metallicity: can be determined with an error of  $\sim 0.3$  dex (relative to spectroscopic estimate) from the position in the g - r vs. u - g colorcolor diagram using simple expressions
- This finding is important for studies based on photometric data alone, and also demonstrates the robustness of parameters estimated from spectroscopic data



The Milky Way Metallicity Distribution • SDSS has provided a large sample to interestingly large distances, with robust and accurate stellar parameters, and good photometric distance estimates

- **Top left:** the median metallicity as a function of the height above the Galactic plane (a sample with 0.25 < g - r < 0.35)
- Middle left: metallicity distribution between 1 kpc and 2 kpc above the plane
- Bottom left: the median metallicity for a subsample with  $[Z/Z_{\odot}] > -1.3$  as a function of the cylindrical galactic coordinates R and Z (for the low-metallicity subsample, there is no discernible dependence)
- The metallicity distribution is bimodal. The median metallicity for the  $[Z/Z_{\odot}] < -1.3$  subsample is nearly independent of R and Z, while it decreases with Z for the  $[Z/Z_{\odot}] > -1.3$  subsample



## The Kinematics vs. Metallicity Distribution

- Top left: the radial velocity vs. metallicity for stars with 1 kpc < Z < 2 kpc
- **Middle left:** the radial velocity vs. metallicity for stars with 160 < l < 200 (towards anticenter, corresponds to  $v_R$  velocity component)
- **Bottom left:** the radial velocity distribution for the low- and high-metallicity subsamples
- The kinematics depend on metallicity: the lowmetallicity subsample has 2.5 times larger velocity distribution.
- This has been known for over half a century since the ELS paper (Eggen, Lynden-Bell and Sandage, 1962), but here it is reproduced with a 100 times larger sample!
- With SDSS samples, we can study the ELS conclusions as a function of the position in the Galaxy! (i.e. not only in the solar neighborhood)



# The Spatial Variation of Kinematics

- Top left: the median radial velocity in Lambert projection (b>0) for stars from the  $[Z/Z_{\odot}] >$ -1.3 subsample which have 1 kpc < Z < 2 kpc, color-coded from -100 km/s to 100 km/s (blue to red)
- Middle left: same as the top panel, except for the low-metallicity sample, color-coded from -220 km/s to 220 km/s
- Bottom left: the middle panel corrected for the solar motion, the green shade corresponds to 0 km/s
- The kinematics depend on metallicity: the lowmetallicity subsample does not rotate, and the high-metallicity sample rotates slower than the LSR.







High-metallicity, velocity dispersion, 40-160 km/s

#### The Spatial Variation of Kinematics

- Top left: the radial velocity dispersion in Lambert projection (b>0) for stars from the  $[Z/Z_{\odot}] > -1.3$  subsample which have 1 kpc < Z < 2 kpc, color-coded from 40 km/s to 160 km/s (blue to red)
- Middle left: the radial velocity distributions for low-metallicity stars with  $l \sim 90$  and  $l \sim 180$ .
- Bottom left: the same as the top panel, except for the high-metallicity sample
- Low-metallicity stars observed at high galactic latitudes towards anticenter have anomalously large velocity dispersion (~130 km/s, instead of 100 km/s)
- This effect is not observed for the highmetallicity sample using the same data set. The same region shows anomalous rotational component for the low-metallicity sample (determined from proper motion measurements)





#### "6D" Kinematics

- Top left: longitudinal proper motion in the Y=0 plane (l ~ 0 and l ~ 180) for low-metallicity stars; color-coded linearly from blue (small) to red (large)
- **Top right:** rotational velocity corresponding to the top left
- Middle panels: same as the top two panels, except for the highmetallicity sample
- Bottom panels: the median rotational velocity (left) and its dispersion (right) vs. height Z for low- (blue) and high-metallicity (red) samples
- Differential disk rotation: smoothly decreasing from 220 km/s in the plane to 0 at ~4 kpc (Bond et al. 2006)<sub>14</sub>

# Summary

- SDSS has already obtained high-quality spectra for over 150,000 stars that are publicly available and can be used for source identification, stellar parameter estimation, and kinematic studies
- Stellar parameter estimates by Beers et al. show a good correlation with the position of a star in the g r vs. u g color-color diagram
- The metallicity distribution is bimodal. The median metallicity for the  $[Z/Z_{\odot}] < -1.3$  subsample is nearly independent of R and Z, while it decreases with Z for the  $[Z/Z_{\odot}] > -1.3$
- The kinematics depend on metallicity: the low-metallicity subsample has 2.5 times larger velocity dispersion.

- Halo (low-metallicity stars) doesn't rotate (at the ~10 km/s level); the rotational velocity of disk stars decreases smoothly (as well as the dispersion for all three components) with the height above the Galactic plane
- The sample size is sufficiently large to constrain the global behavior and look for anomalies. E.g. low-metallicity stars observed at high galactic latitudes towards anticenter have anomalously large velocity dispersion and non-zero rotational component in a well-defined (*l*, *b*) region (due to streams?)
- SDSS stellar spectra will remain a valuable resource for a long time: e.g. RAVE doesn't go as deep, GAIA will not have such a large wavelength coverage, Pan-STARRS and LSST will only have imaging
- SDSS-II (SEGUE) will further advance this dataset by optimizing spectroscopic targeting to study the Galaxy