SDSS Spectroscopic Survey of Stars

Željko Ivezić
University of Washington

D. Schlegel, A. Uomoto, N. Bond, T. Beers, M. Jurić, R. Lupton, C. Rockosi, G. Knapp, J. Gunn, B. Yanny, S. Jester, S. Kent, J. Pier, J. Munn, G. Richards, H. Newberg, M. Blanton, D. Eisenstein, M. Strauss, P. Szkody, S. Hawley, S. Anderson, B. Margon, H. Harris, F. Kiuchi, A. Chen, J. Bushong, H. Sohi, D. Haggard, A. Kimball, J. Barentine, H. Brewington, M. Harvanek, S. Kleinman, J. Krzesinski, D. Long, A. Nitta, S. Snedden,
for the SDSS Collaboration

Exploiting Large Surveys for Galactic Astronomy

Joint Discussion 13, IAU GA, Tuesday, Aug 22, 2006

Outline

1. Sloan Digital Sky Survey: an overview

2. SDSS Spectroscopic Survey of Stars

3. 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 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

Spectroscopic Targets:

- 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

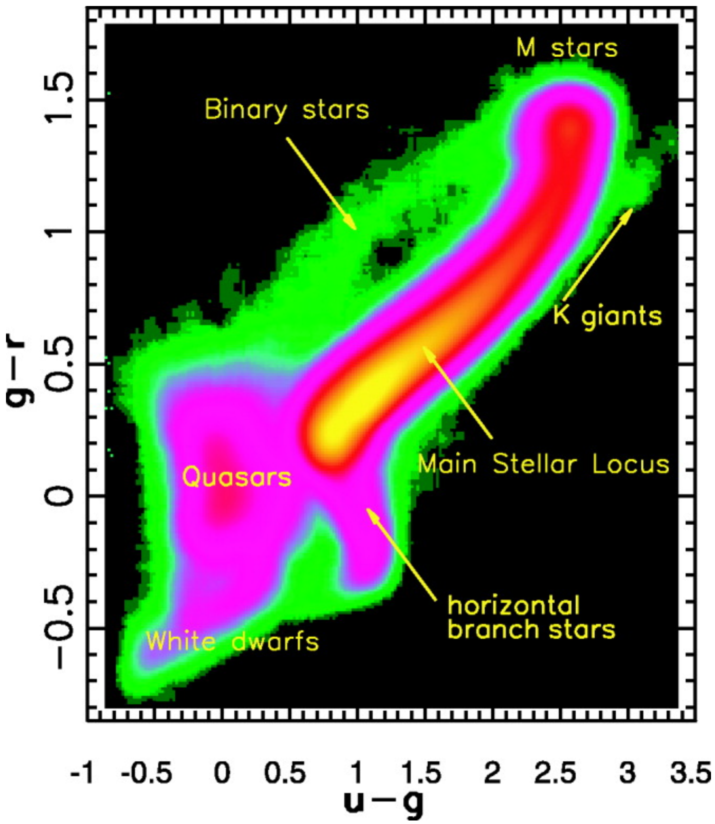
The Utility of SDSS Stellar Spectra

1. Calibration of observations (e.g. can synthesize photometry with an accuracy of $\sim$0.04 mag)

2. 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.

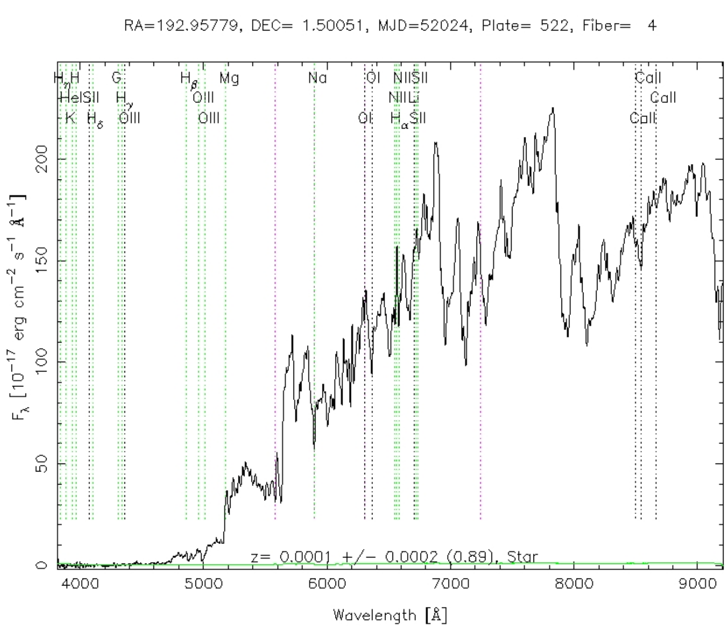
3. Accurate stellar parameters estimation (Teff, log(g), metallicity, detailed chemical composition)

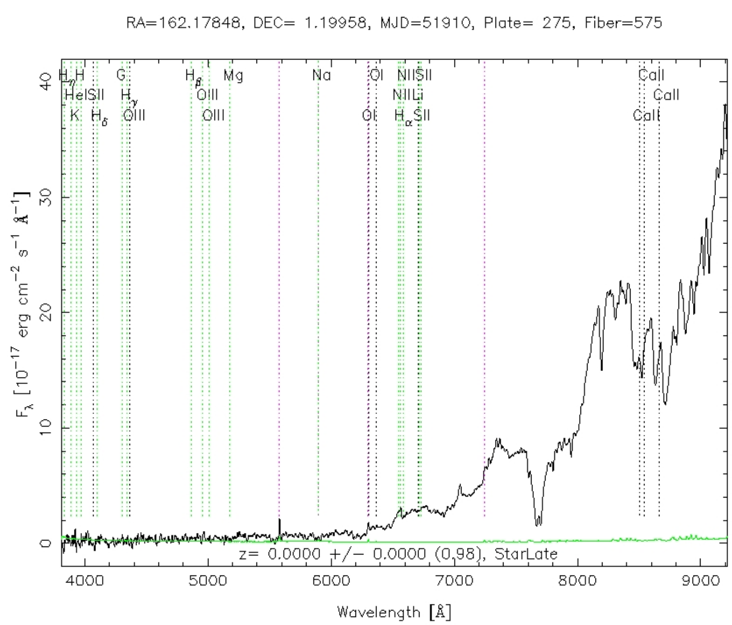
4. Radial velocity for kinematic studies of the Milky Way (especially useful when combined with proper motions)

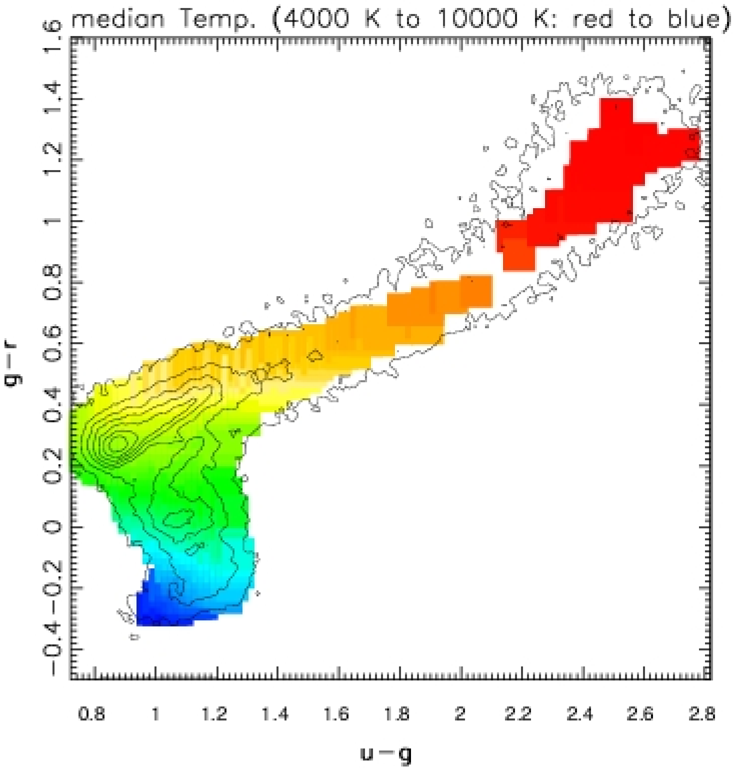


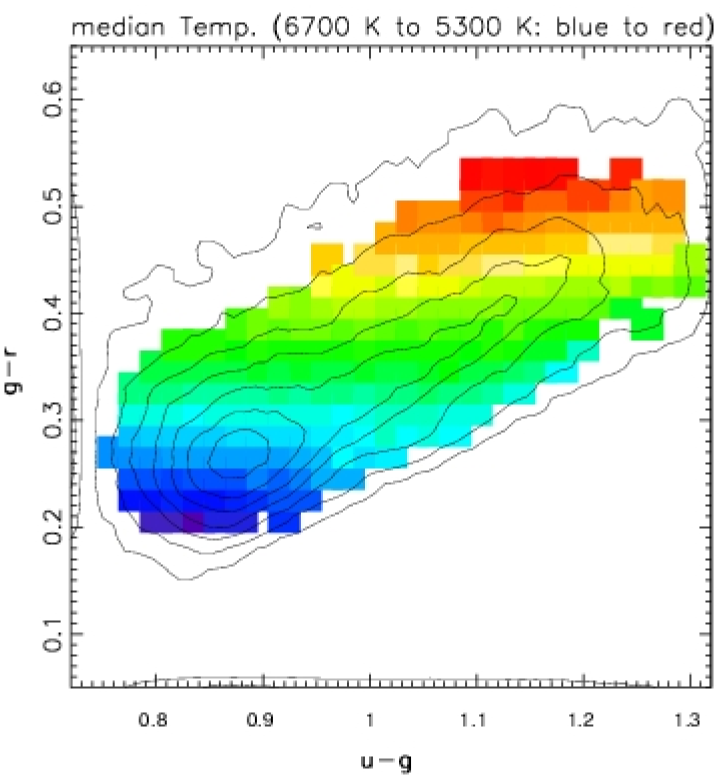
Source Identification

- Stellar spectroscopic targets are color-selected, 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)



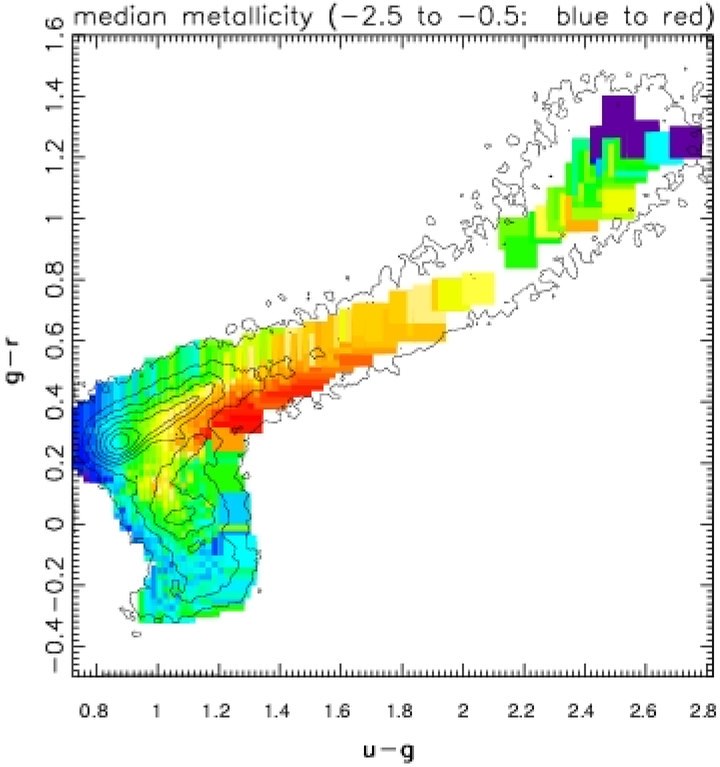


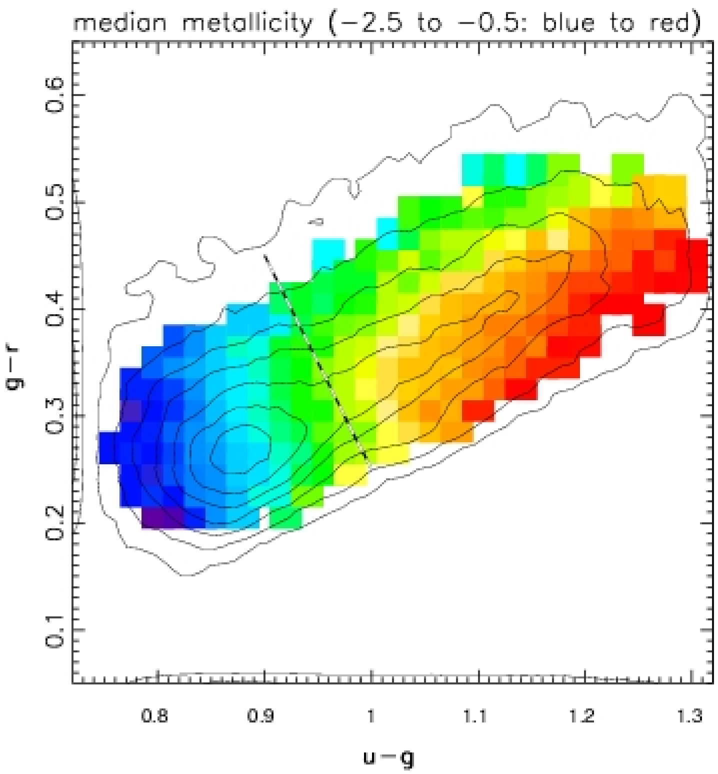




Stellar Parameters Estimation

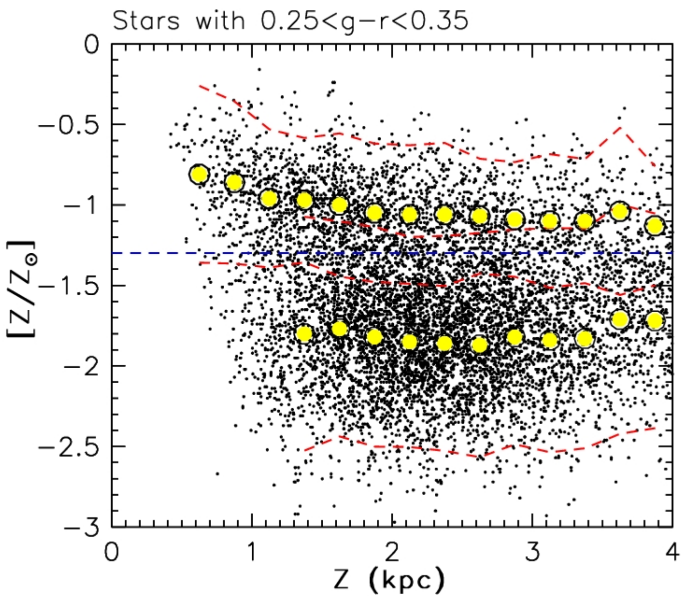
- SDSS stellar spectra are of sufficient quality to provide robust and accurate stellar parameters such as effective temperature, gravity, metallicity, and detailed chemical composition (c.f. talk by T. Beers)
- Stellar parameters estimated from spectra show a good correlation with colors measured from 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: $T_{\rm eff}$ determines the $g - r$ color, but has negligible impact on the $u - g$ color

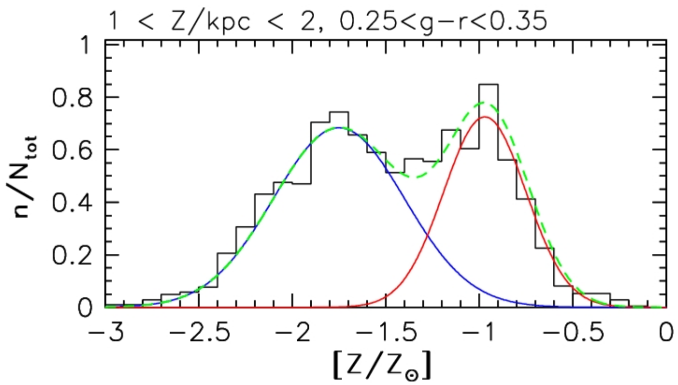


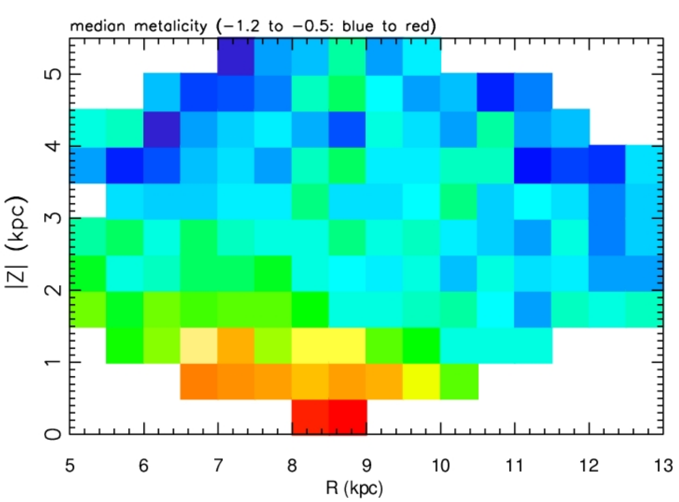


Stellar Parameters Estimation

- 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. $u-g$ color-color 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

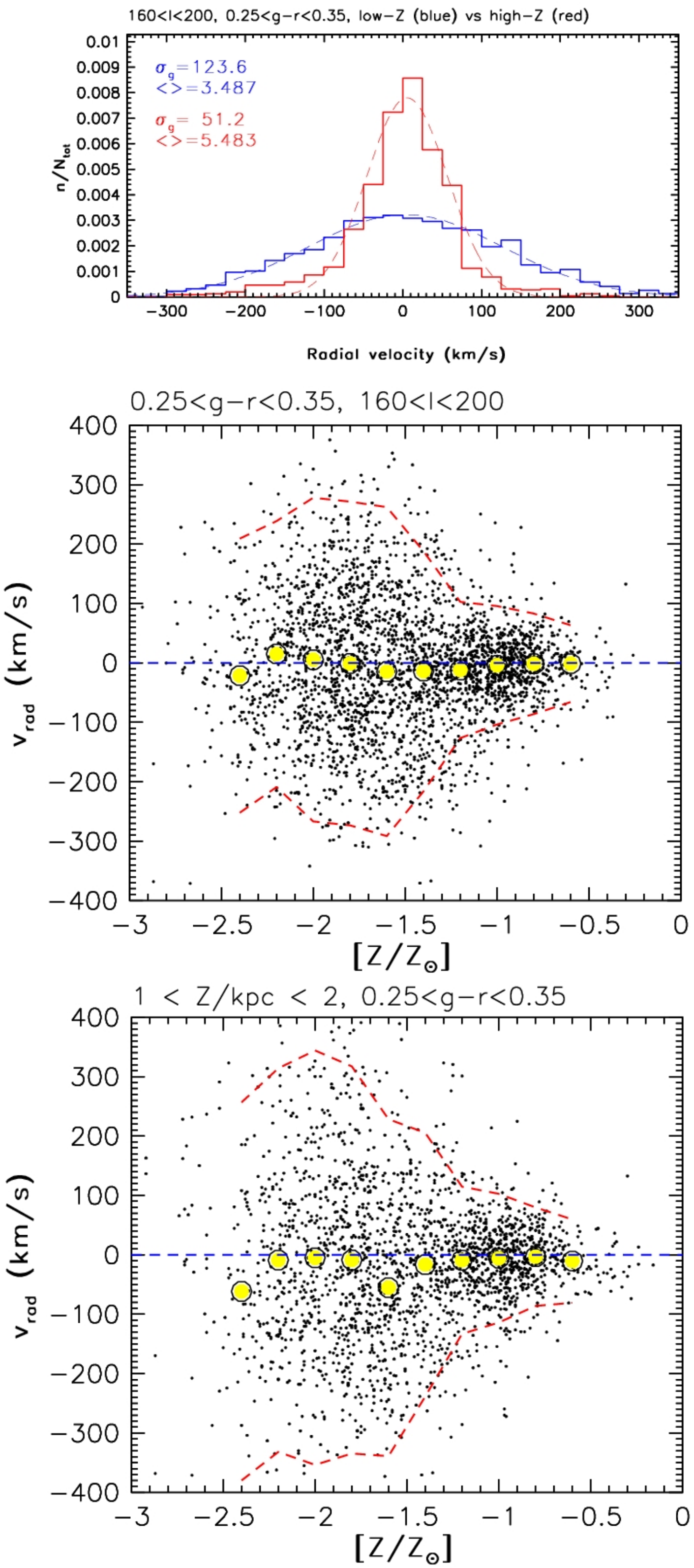






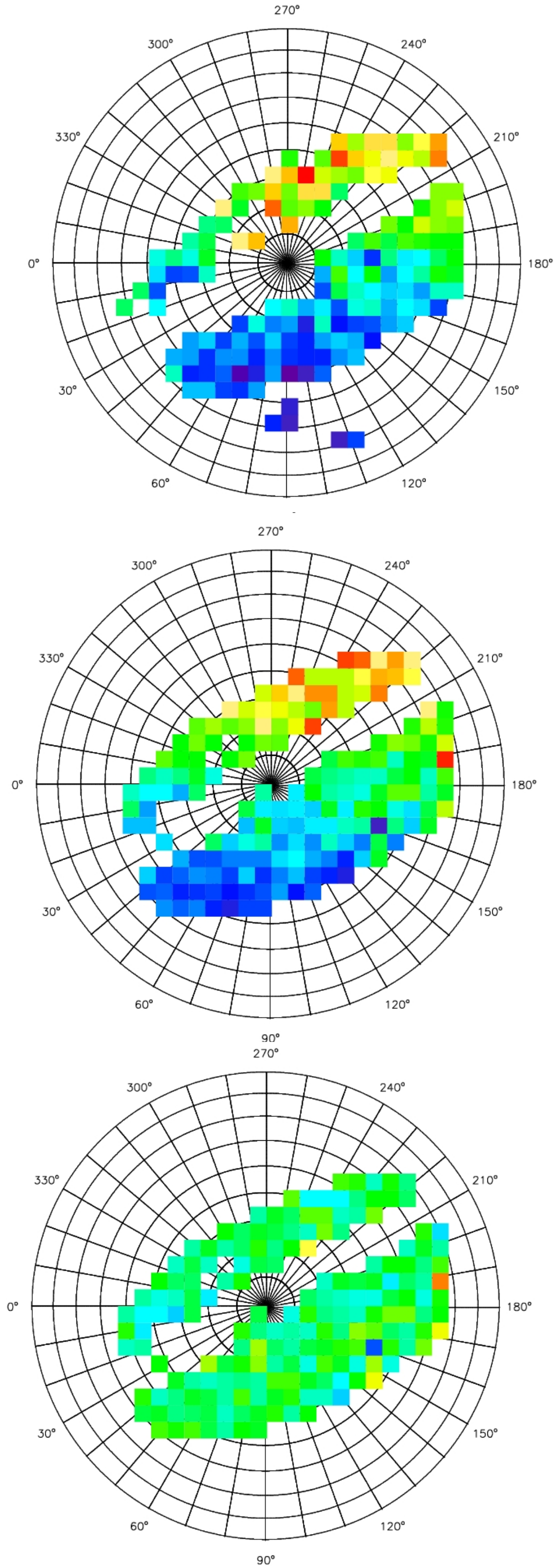
The Milky Way Metallicity Distribution

- 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



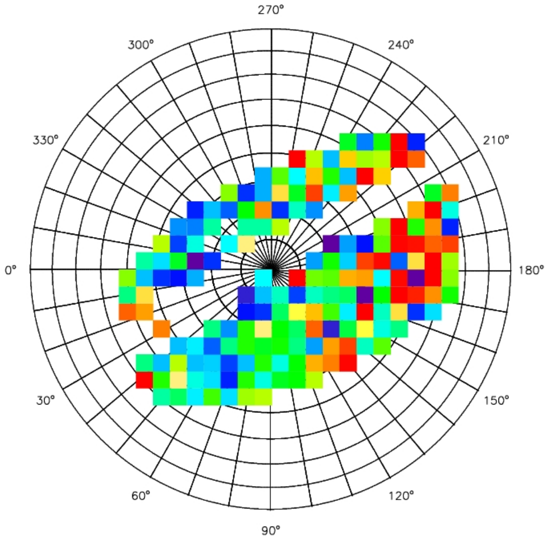
The Kinematics vs. Metallicity Distribution

- **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 low-metallicity 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)

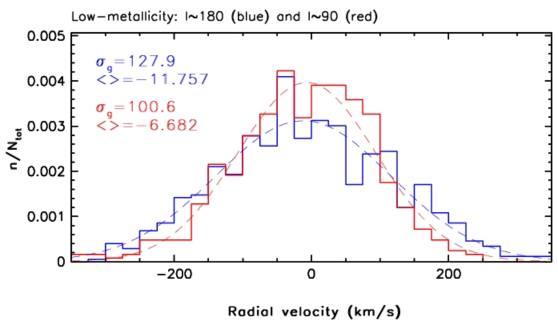


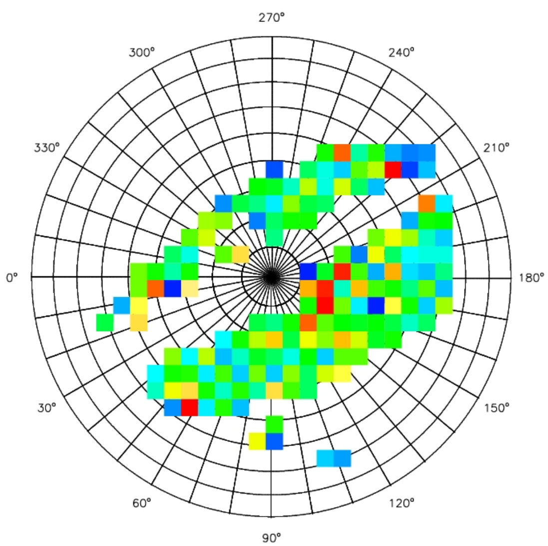
The Spatial Variation of Kinematics

- **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 low-metallicity subsample does not rotate, and the high-metallicity sample rotates slower than the LSR.



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

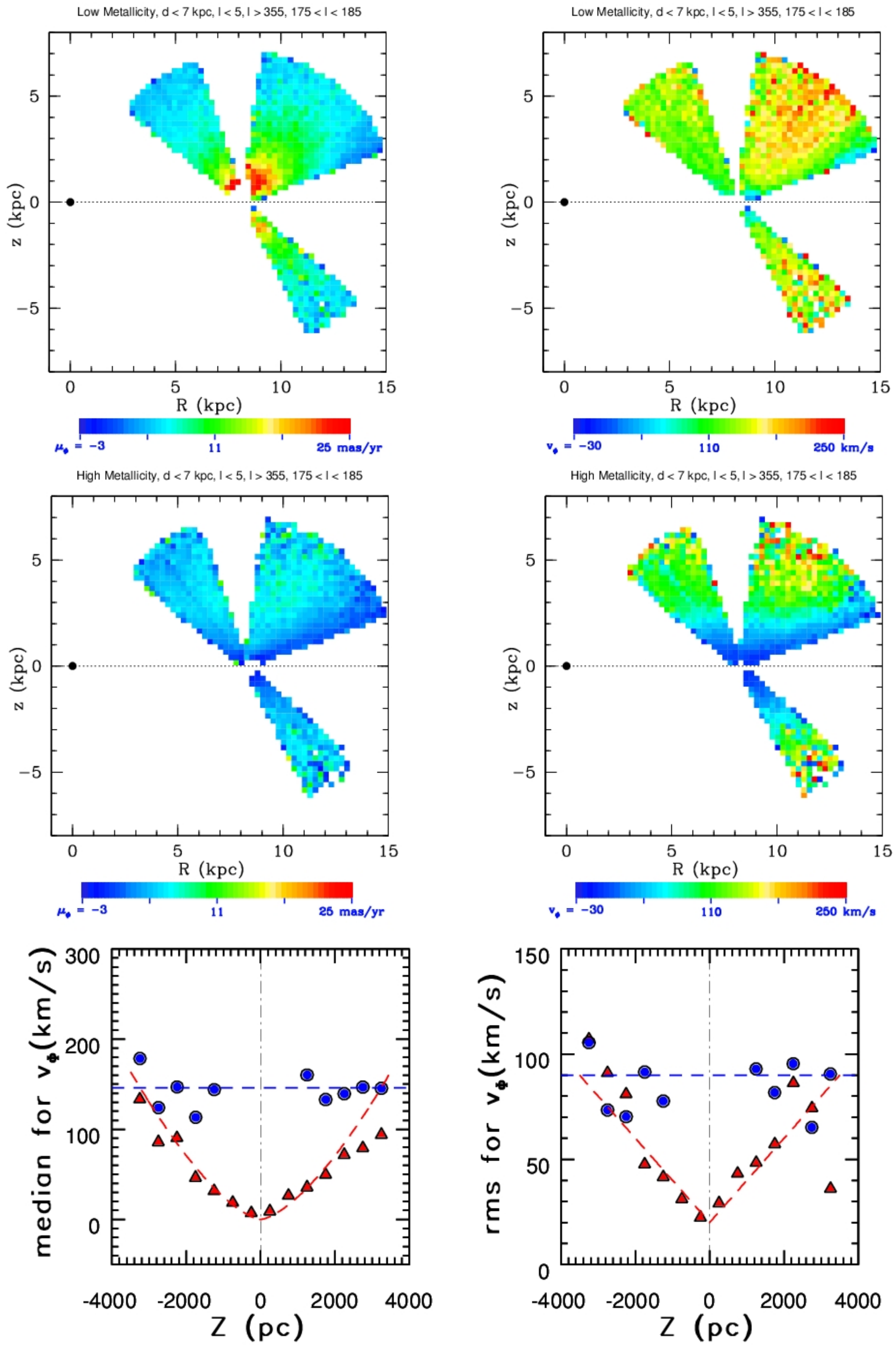




High-metallicity, velocity dispersion, 40-160 km/s

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 high-metallicity 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 ($l \sim 0$ and $l \sim 180$) 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 high-metallicity 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)

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