SDSS Spectroscopic Surveys

Željko Ivezić
University of Washington
For the SDSS Collaboration

VI SCSLSA

Sremski Karlovci, Serbia, June 11-15, 2007

Outline

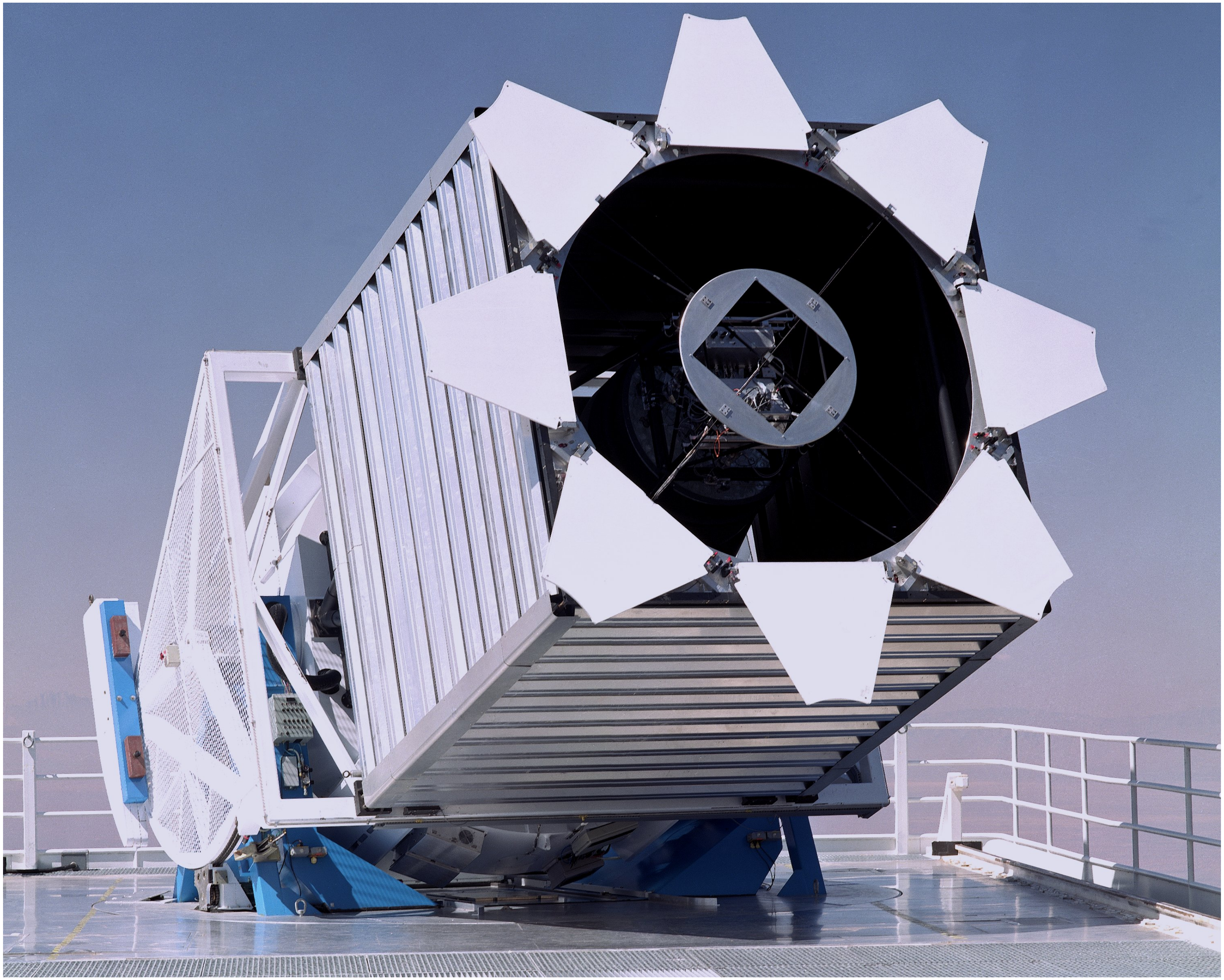
1. Sloan Digital Sky Survey: an overview
    - Imaging Survey
    - Spectroscopic Surveys: galaxies, quasars, stars

2. Brief Review of Results Based on SDSS Spectra:
    - Galaxies: large-scale structure, BAO
    - Quasars: luminosity function, composite spectra
    - Stars: unusual stars, Milky Way kinematics and metallicity distributions

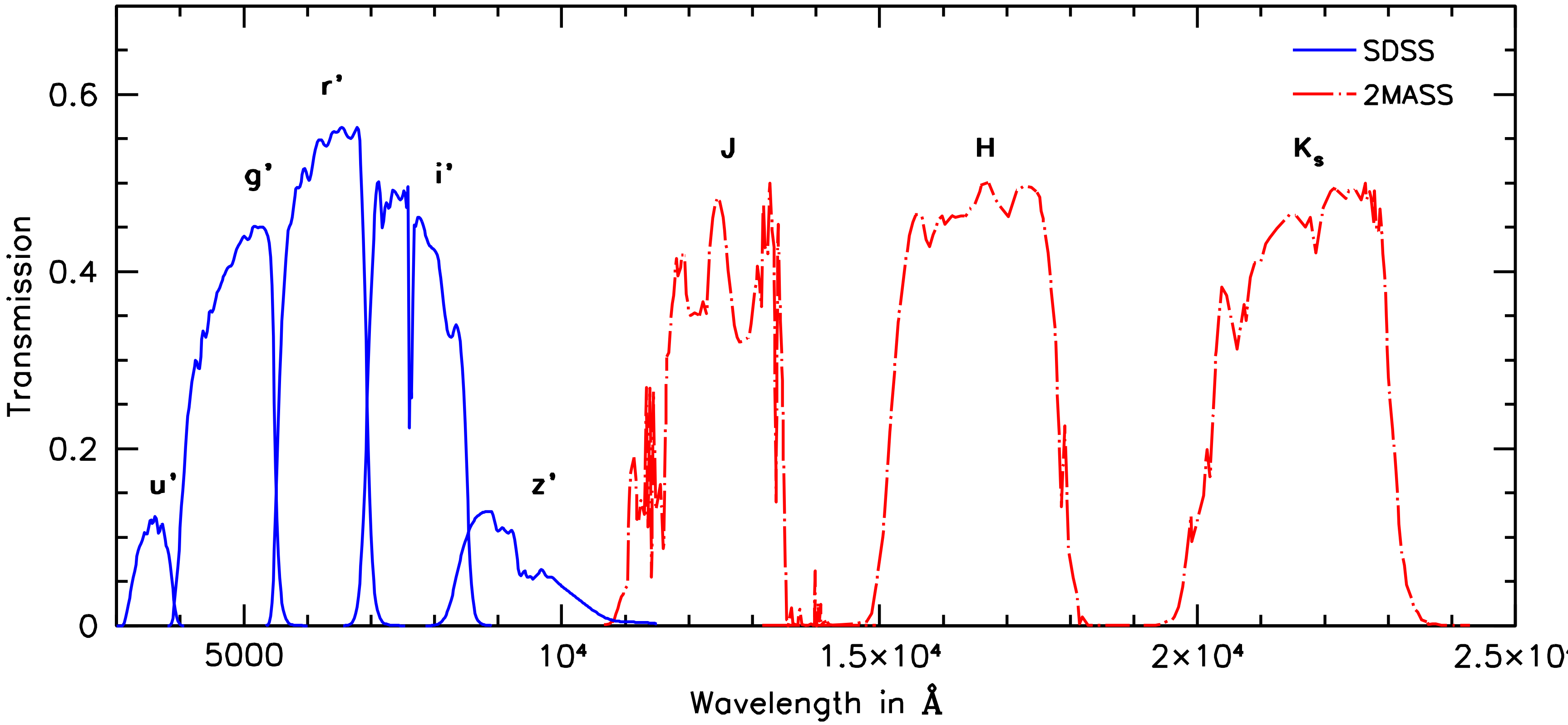
Sloan Digital Sky Survey(s)

- Imaging Survey: the first large multi-color digital map of optical sky
  - 10,000 $\deg^2$ (1/4 of the full sky; 20 TB of data)
  - 5 bands (ugriz: UV-IR), 0.02 mag photometric accuracy
  - <0.1 arcsec astrometric accuracy
  - $>$100,000,000 stars and $>$100,000,000 galaxies

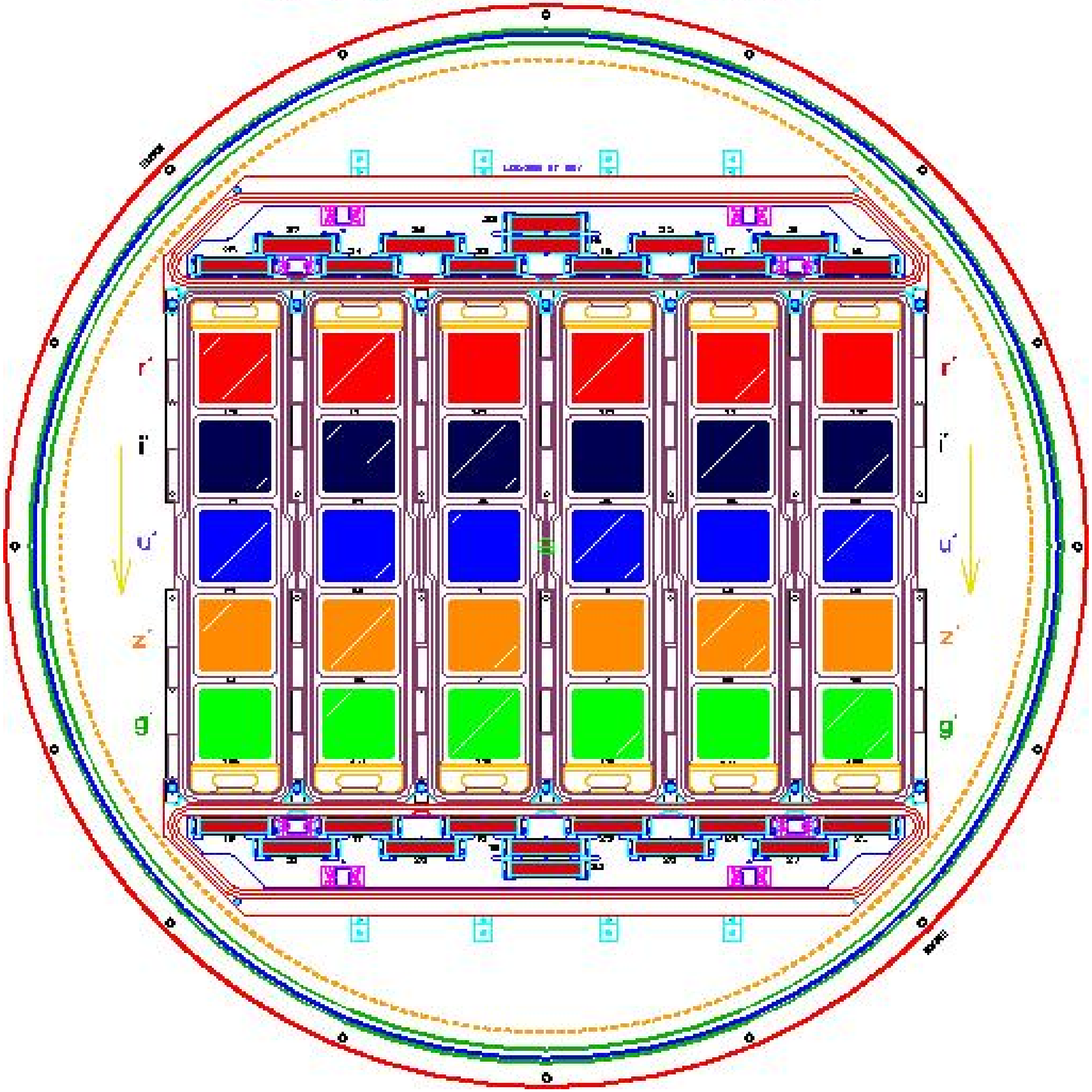
- Spectroscopic Survey: two multi-object fiber spectrographs on the same telescope. Each plate (radius of 1.49 degrees) can accommodate 640 fibers. Targets selected from imaging data: 1,000,000 galaxies, 100,000 quasars, 100,000 stars



SDSS Telescope


SDSS
2MASS
u'
g'
r'
i'
z'
J
H
K_s
0.6
0.4
0.2
0
Transmission
5000
10⁴
1.5×10⁴
2×10⁴
2.5×10⁴
Wavelength in Å

SDSS CAMERA



Sloan Digital Sky Survey(s)

- The first large multi-color digital map of optical sky

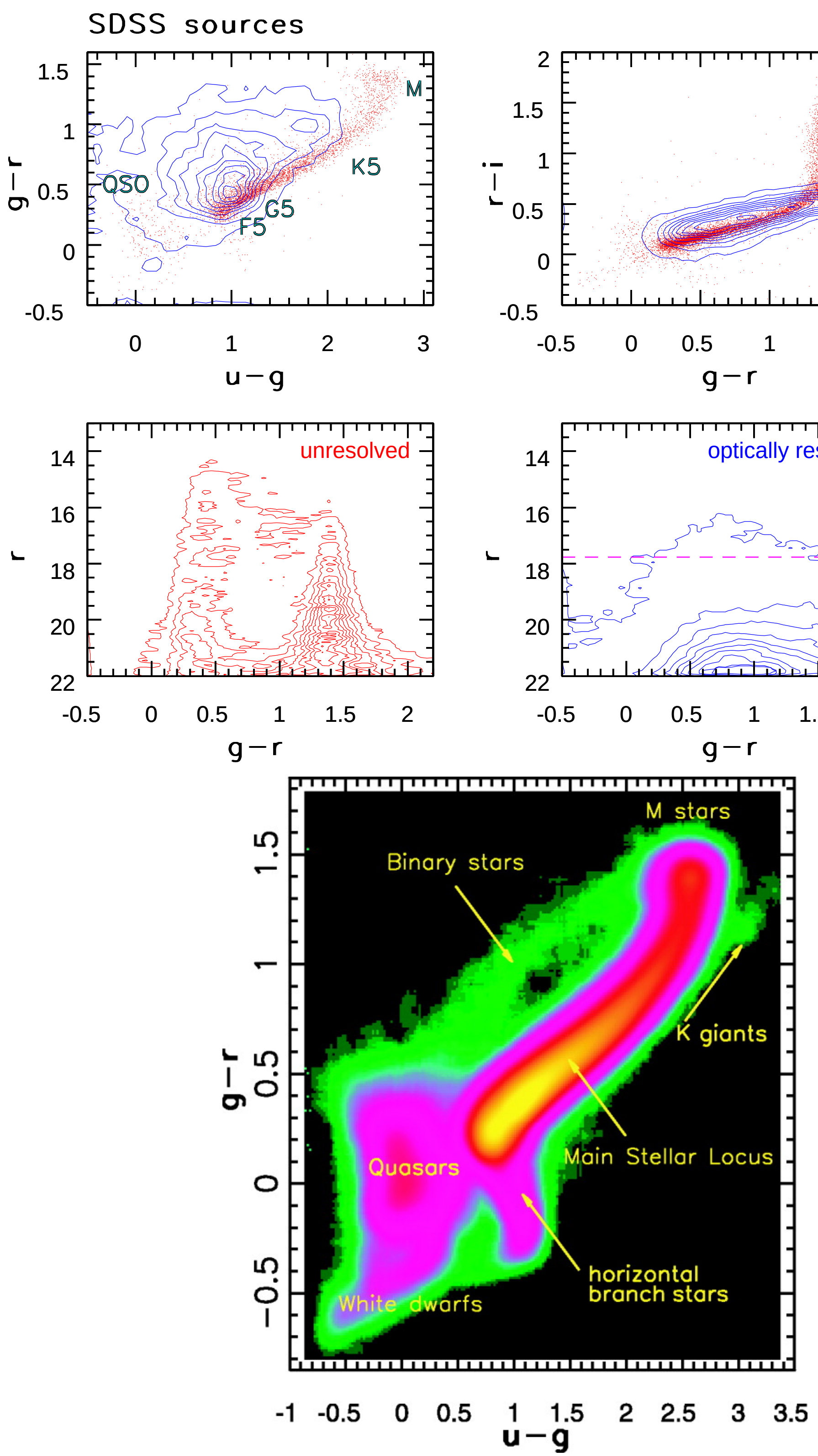
- Several dozen institutions from USA, EU, Japan, Korea

- A new paradigm for astronomy: a large collaboration (>100 people) reminiscent of high-energy physics

- Extraordinary range of science themes and huge scientific legacy

  - In less than a decade 1400 SDSS papers with >40,000 citations

  - In 2003, 2004, and 2006 the most productive astronomical observatory (in 2005 second after WMAP), as measured by the citation rate



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 (public): 675,000 galaxies, 90,000 quasars, 155,000 stars.

Spectroscopic Data and Processing

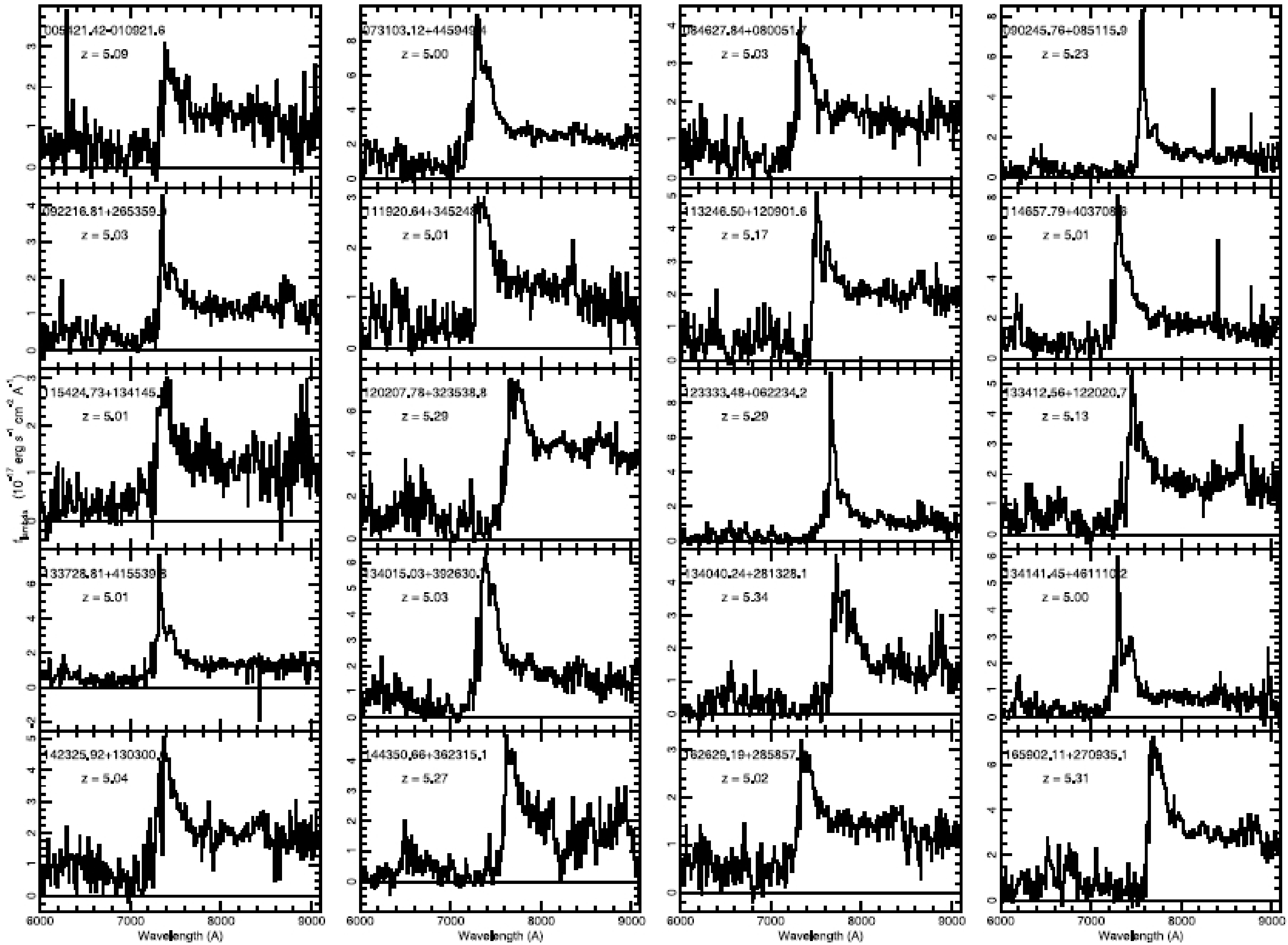
- Spectra: Wavelength coverage: 3800–9200 Ang, Resolution: 1800, Signal-to-noise: $>$4 per pixel at g=20.2: *These spectra have much better quality than needed for a redshift survey of galaxies;* they are publicly available in a user-friendly format through an exquisite web interface at www.sdss.org

- Automated 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

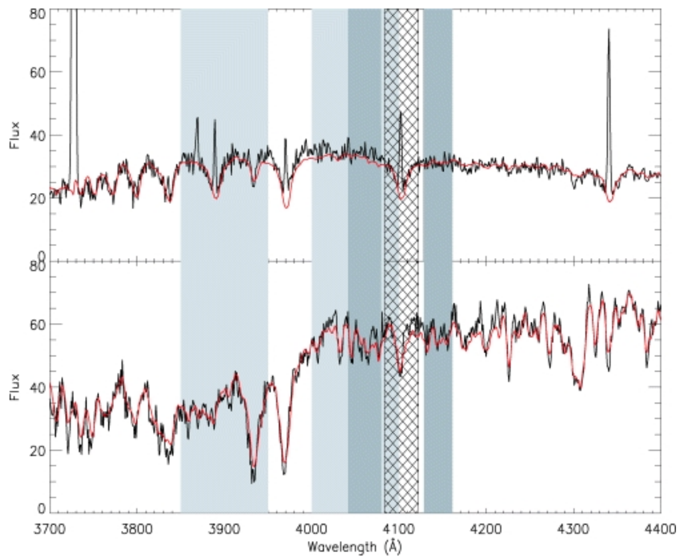
  – *target:* target selection and tiling

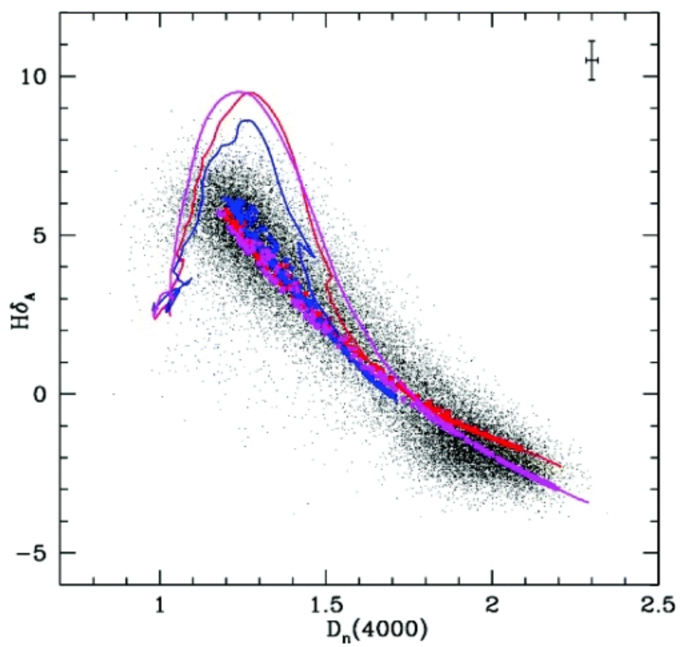


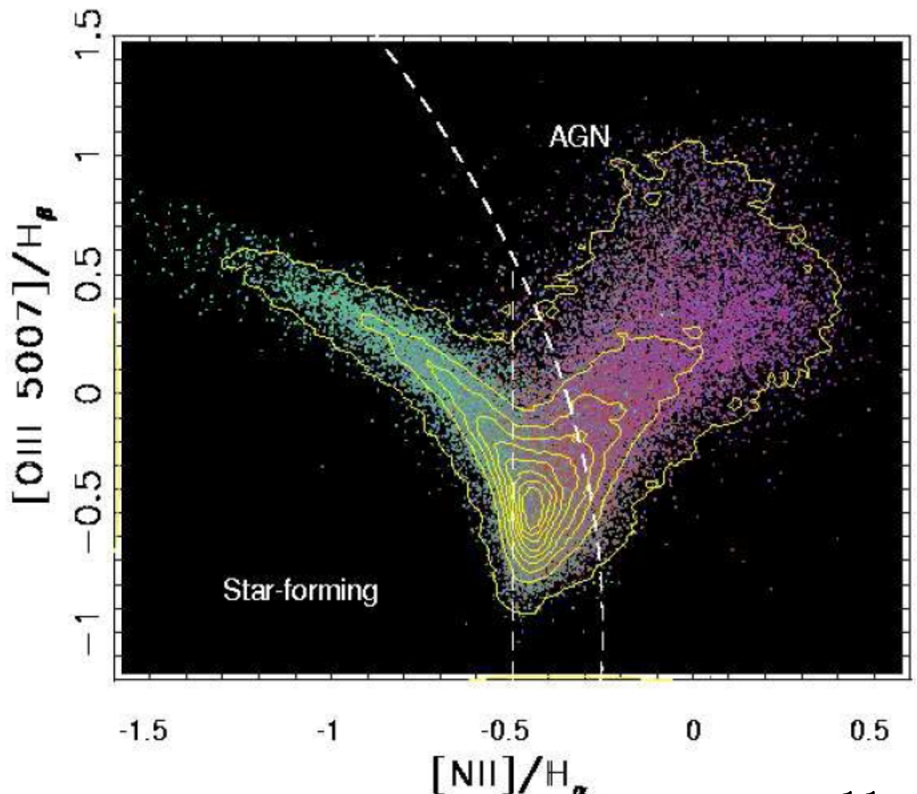
SDSS DR5: $z > 5$ quasars

The Utility of SDSS Galaxy Spectra

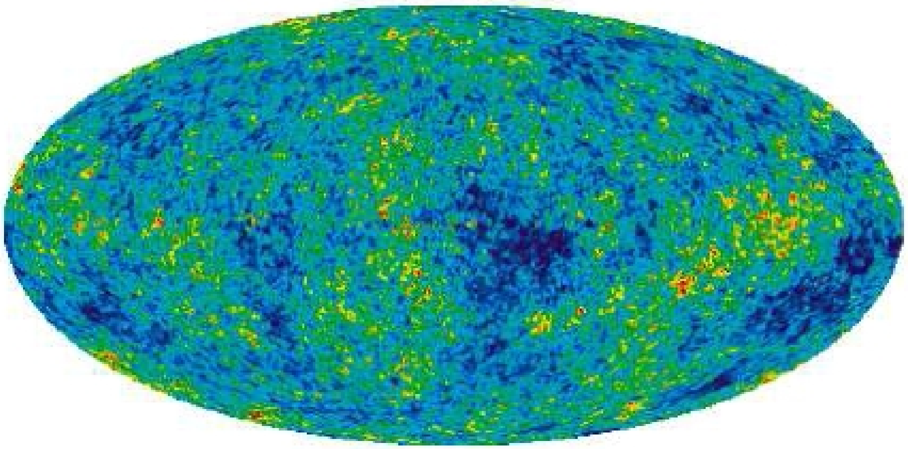
- Kauffmann et al. (2003, 2004): model-dependent estimates of stellar mass and dust content using H_δ, D_{4000} and broad-band colors
- Star-forming galaxies vs. AGNs from the emission-line based Baldwin-Phillips-Terlevich diagram



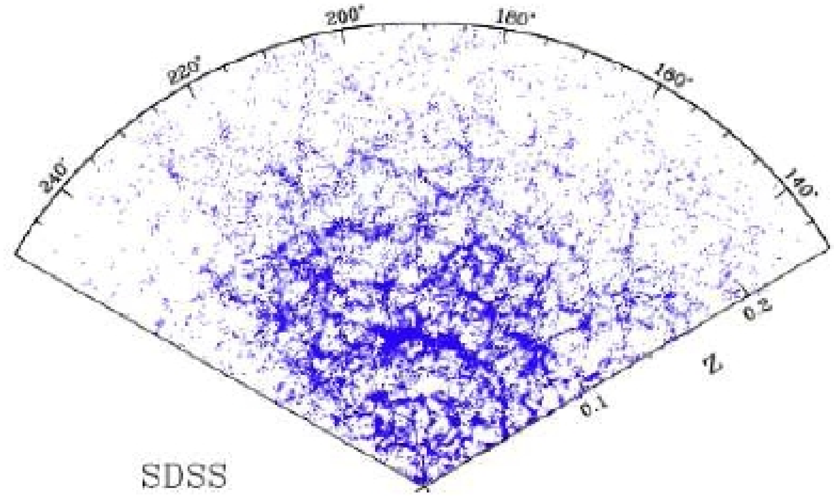


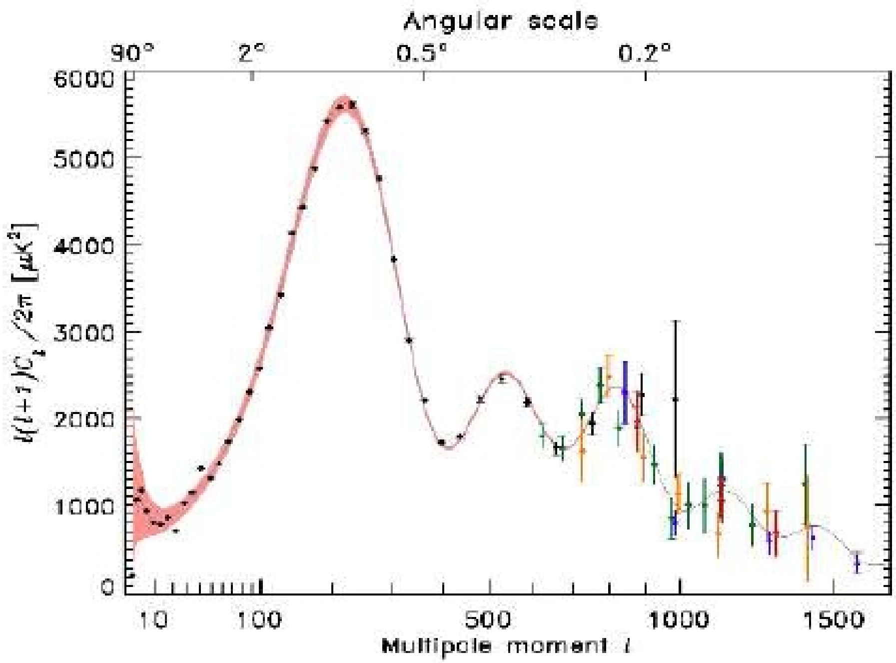


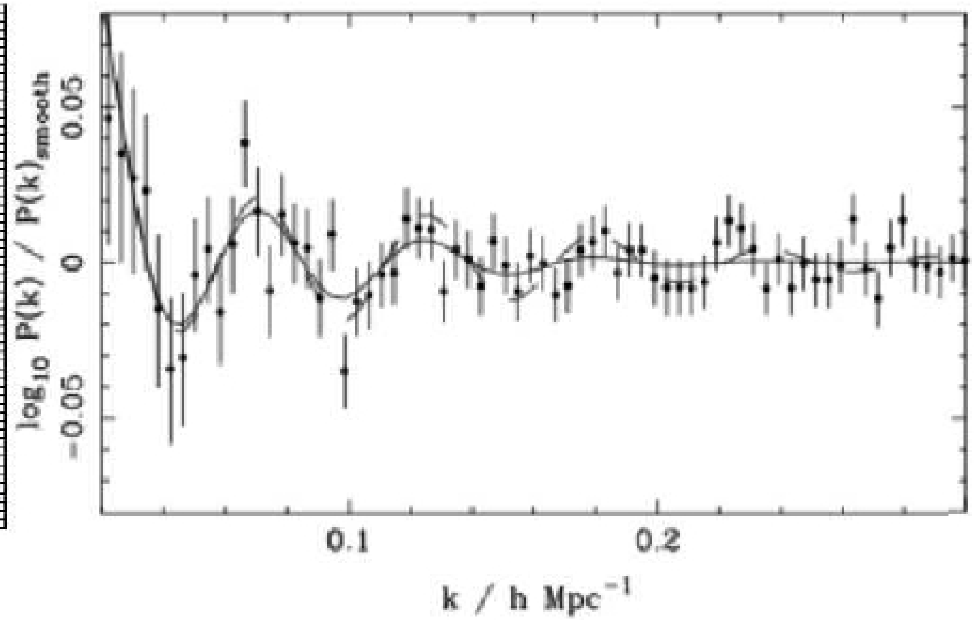
CMB



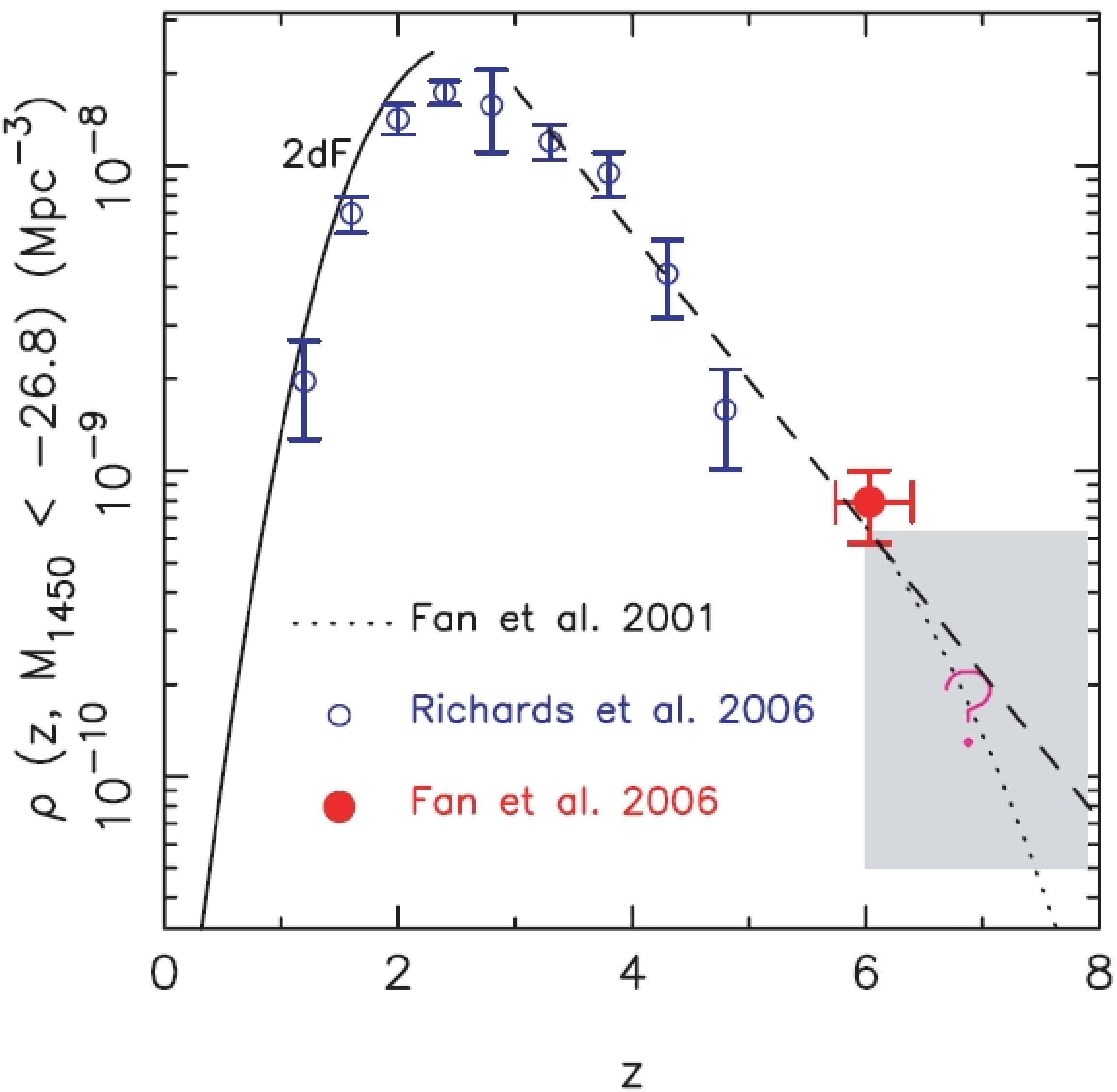
Galaxies





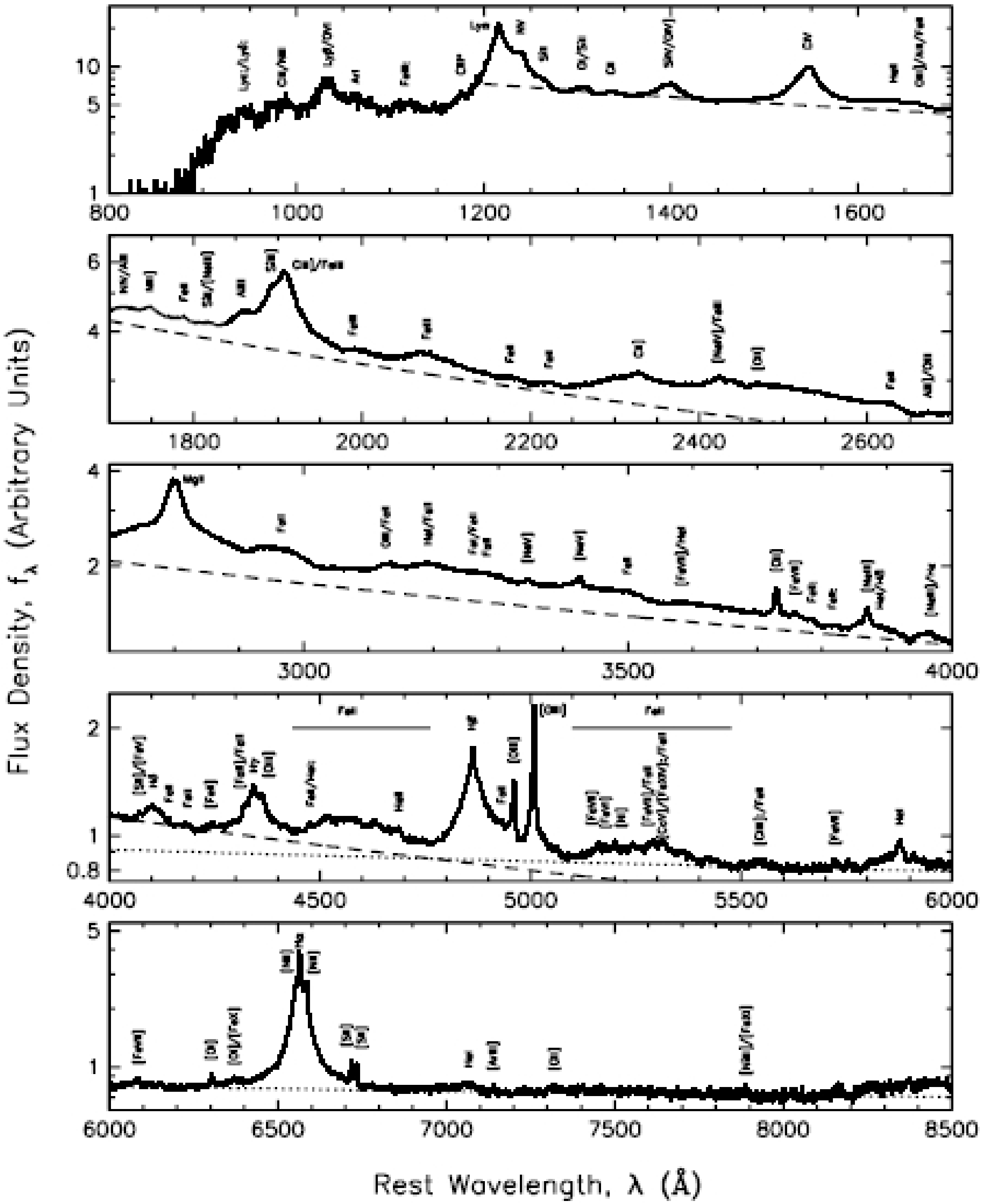


Baryon acoustic oscillations: standard ruler – new cosmological tool



The Utility of SDSS Quasar Spectra

- Quasar catalog with ~100,000 quasars, listing SDSS **and other data**, is public (Schneider et al. 2007)
- Precision measurement of the luminosity function: the rise and fall of quasars



The Utility of SDSS Quasar Spectra

- Quasar catalog with ~100,000 quasars, listing SDSS **and other data** is public (Schneider et al. 2007)
- Precision measurement of the luminosity function: the rise and fall of quasars
- Extremely high signal-to-noise composite quasar spectrum (as well as studies of various subsamples)
- Large-scale structure with quasars (the cosmic growth of black holes)

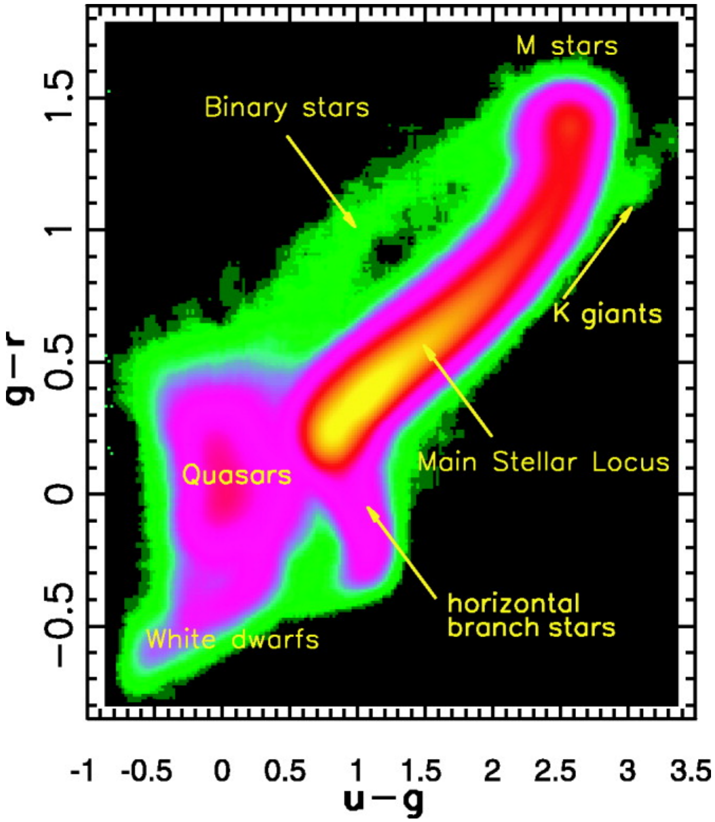
The Utility of SDSS Stellar Spectra

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.

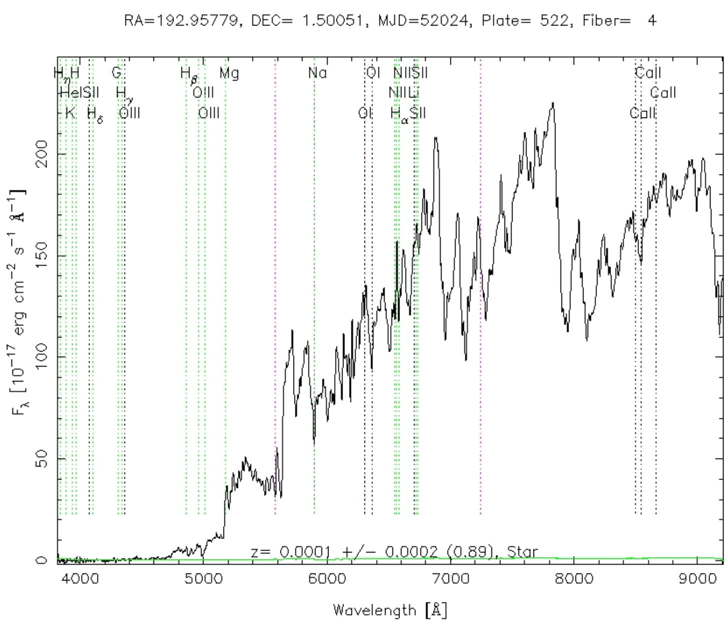
3. Accurate stellar parameters estimation (Teff, log(g), metallicity, detailed chemical composition)

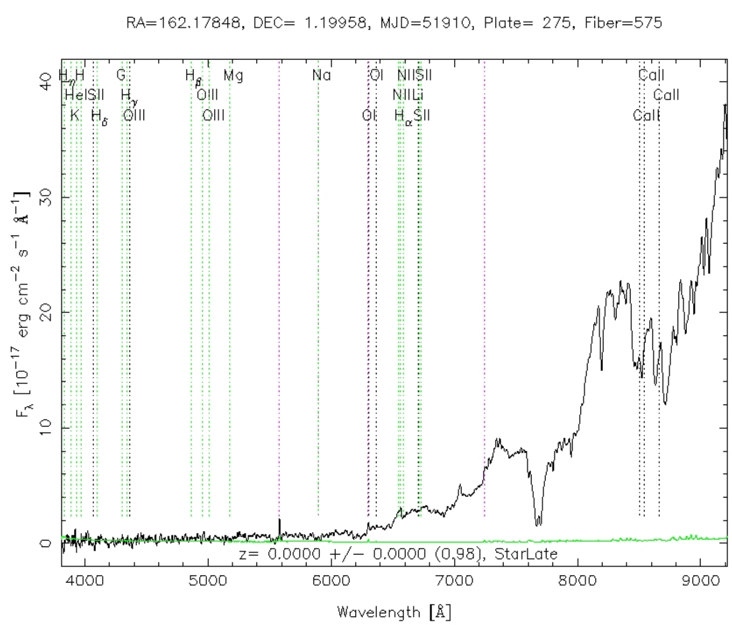
4. Radial velocity for kinematic studies of the Milky Way (especially useful when combined with proper motions)

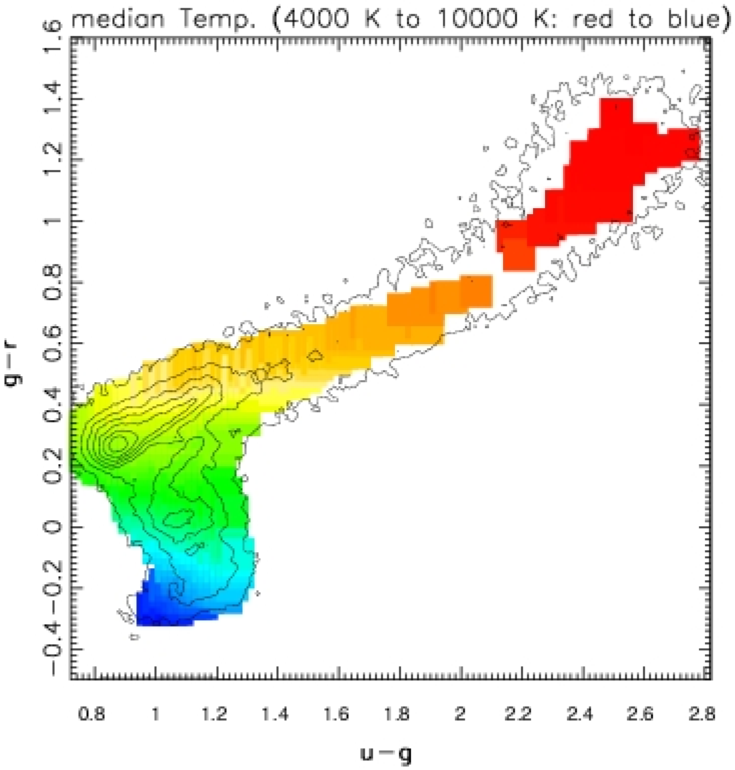


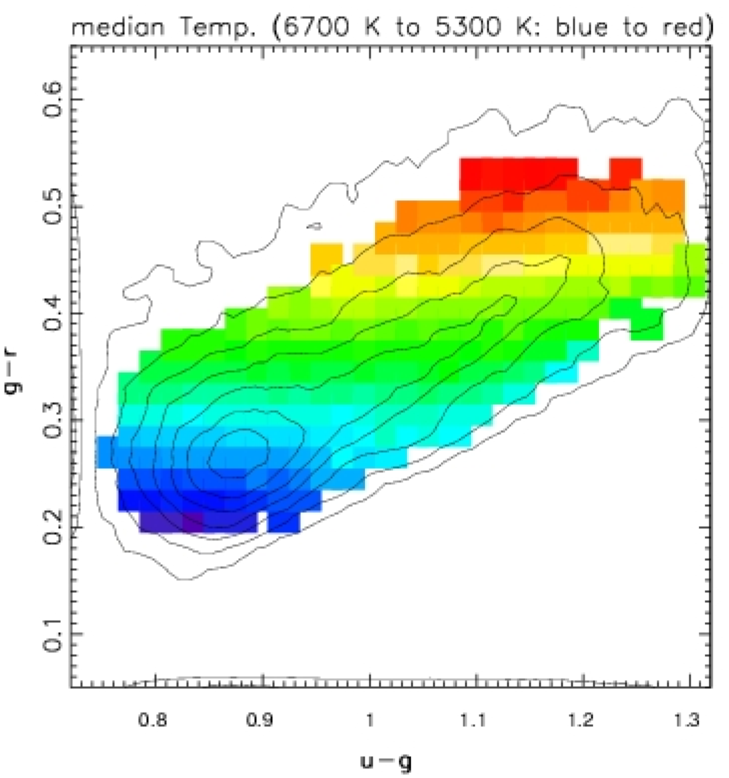
Source Identification

- 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)



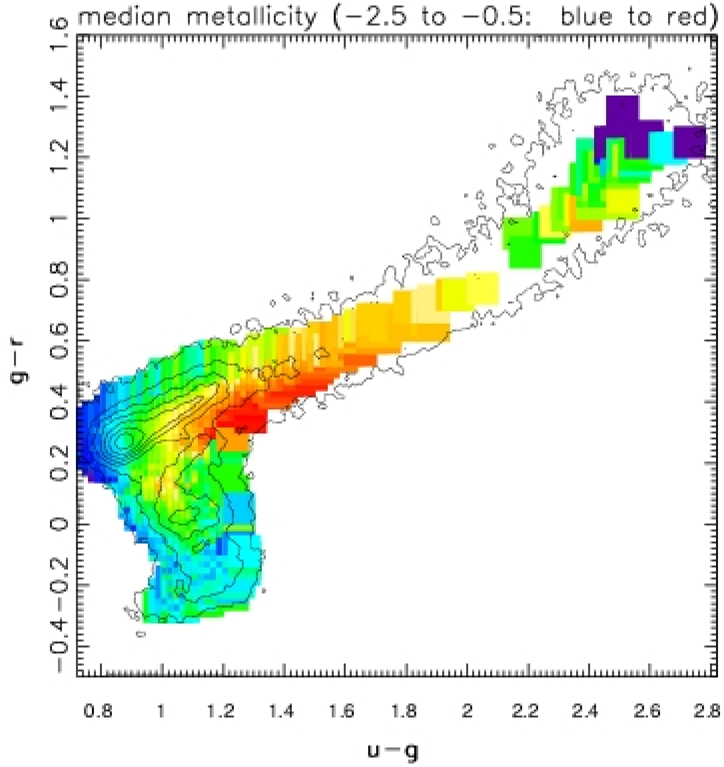


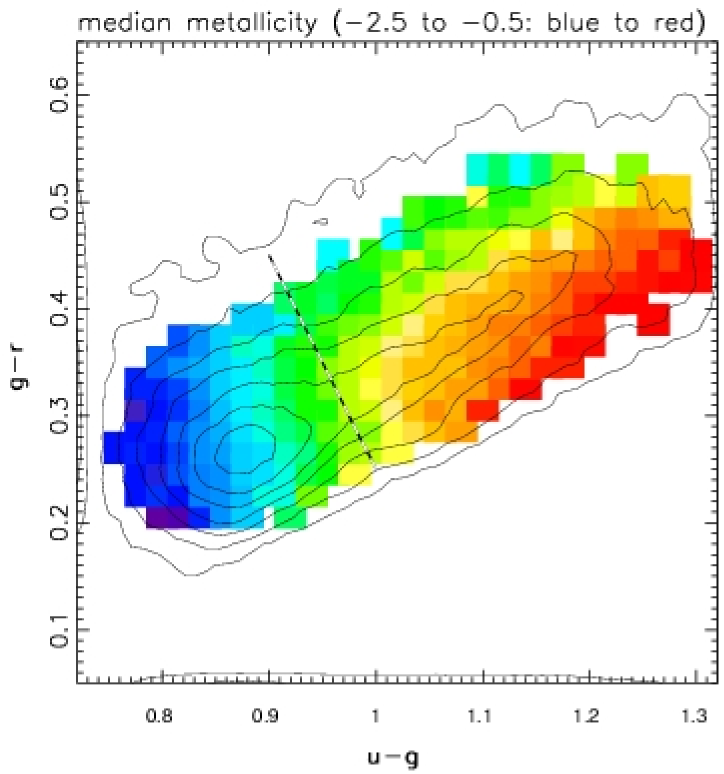




Stellar Parameters Estimation

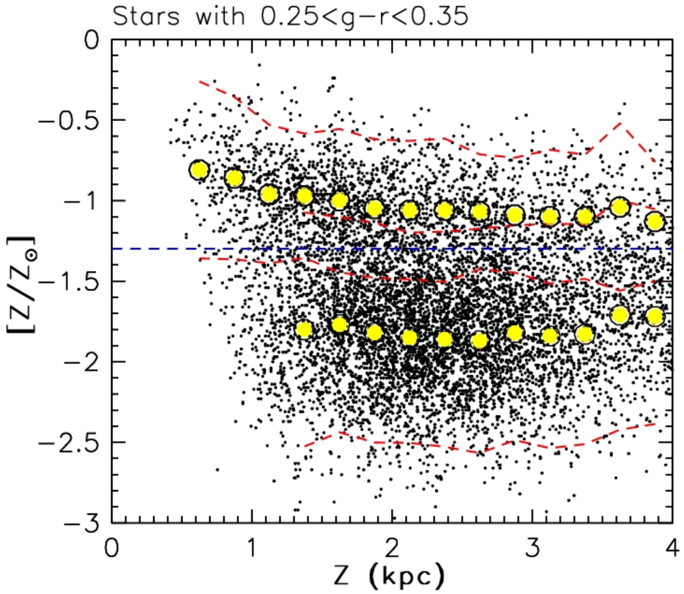
- SDSS stellar spectra are of sufficient quality to provide robust and accurate stellar parameters such as effective temperature, gravity, metallicity, and detailed chemical composition (c.f. poster by T. Beers)
- Stellar parameters estimated from spectra show a good correlation with colors measured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

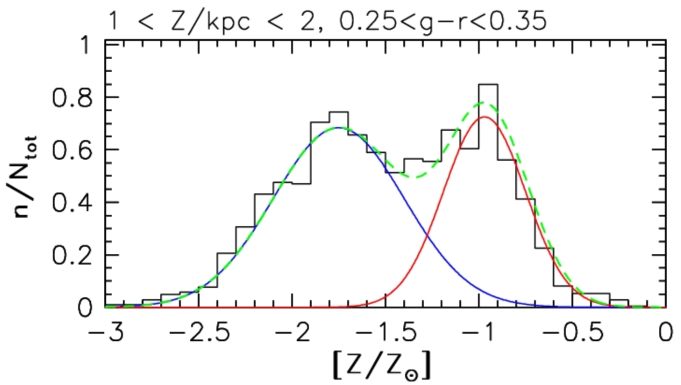


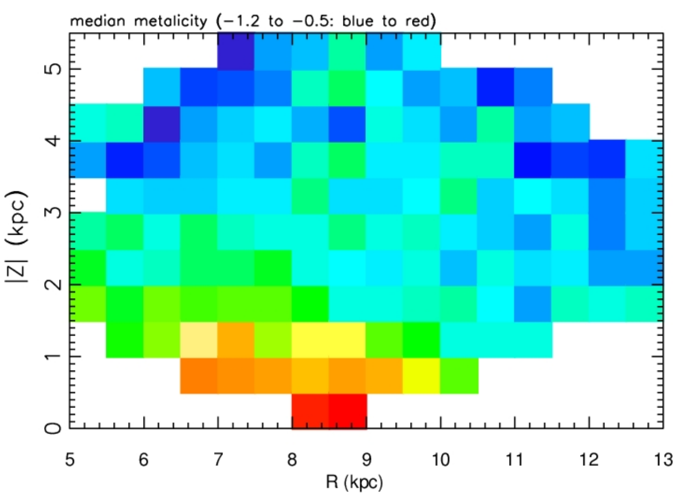


Stellar Parameters Estimation

- 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

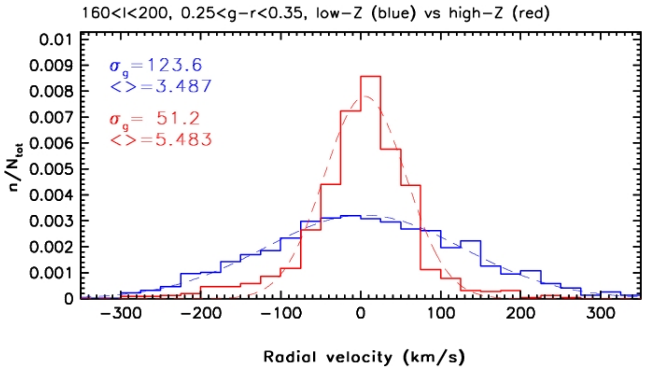


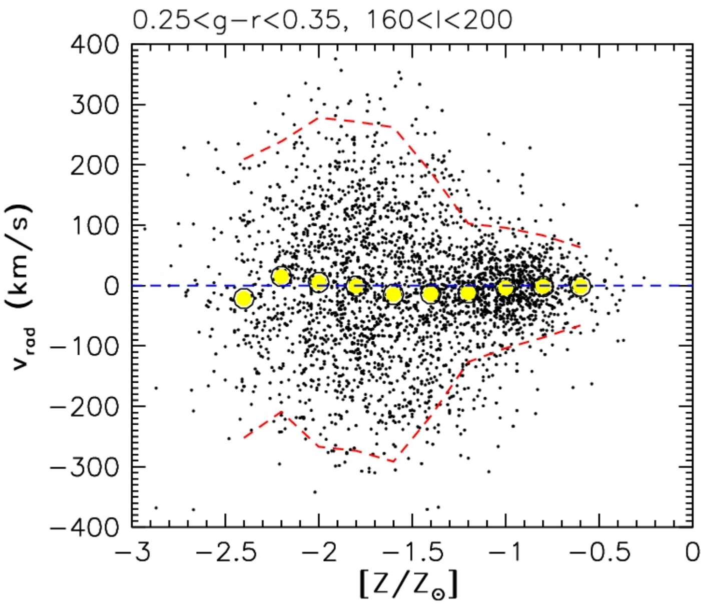


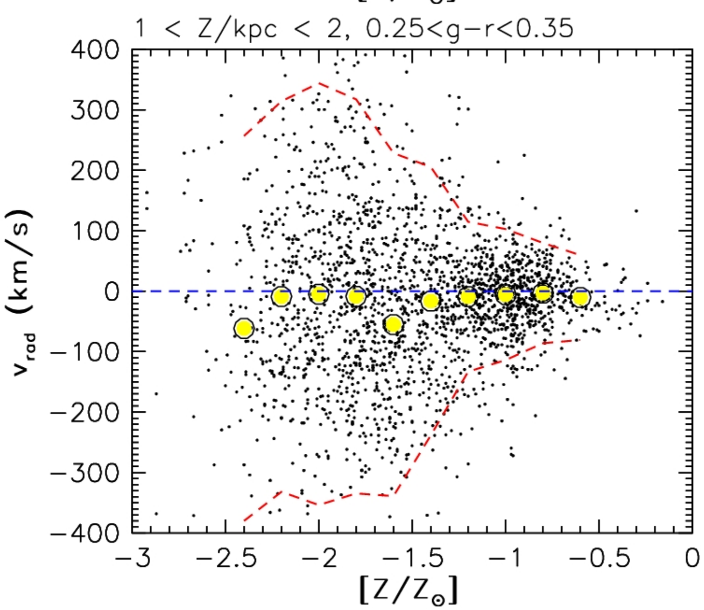


The Milky Way Metallicity Distribution

- 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)

Summary

- SDSS has obtained over a million high-quality spectra of galaxies, quasars and stars, and made them publicly available: www.sdss.org

- SDSS helped usher a new era of digital astronomy, and the large collaboration paradigm: the birth of a new breed of astronomers: data miners!