Mapping The Universe
The SDSS is Two Surveys

The Fuzzy Blob Survey

The Squiggly Line Survey
The telescope

- 2.5 m mirror
Digital Cameras

- 1.3 MegaPixels: $150
- 4.3 Megapixels: $850
- 100 GigaPixels: $10,000,000
CCDs
CCDs: Drift Scan Mode
HUBBLE's TUNING FORK DIAGRAM
NGC 1032
NGC 2967
UGC 01962
NGC 5334
Arp 240
Measuring Quantities From the Images: The Photo pipeline
How do you measure brightness?

Most People use Magnitudes
\[ m = -2.5 \log (\text{flux}) + C \]

We use Luptitudes
\[ m = \frac{-2.5}{\ln(10)} \left[ \text{asinh} \left( \frac{f/f_0}{2b} \right) + \ln(b) \right] \]
OK, but how do you measure flux?

Isophotal magnitudes:
What we don’t do
OK, but how do we measure flux?

Petrosian Radius: Surface brightness Ratio = 0.2

Petrosian flux: Flux within 2 Petrosian Radii
Some Other Measures

PSF magnitudes

Fiber magnitudes
Galaxy Models

de Vaucouleurs magnitudes:
assume profile associated with ellipticals

\[ I = I_0 \exp \left\{ -7.67 \left[ (r/r_e)^{1/4} \right] \right\} \]

Exponential magnitudes:
Assume profile associated with spirals

\[ I = I_0 \exp \left\{ -1.68(r/r_e) \right\} \]

Model magnitudes→pick best
### Which Magnitudes to Use?

<table>
<thead>
<tr>
<th>Photometry of Distant QSOs</th>
<th>PSF magnitudes</th>
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<tbody>
<tr>
<td>Colors of Stars</td>
<td>PSF magnitudes</td>
</tr>
<tr>
<td>Photometry of Nearby Galaxies</td>
<td>Petrosian magnitudes</td>
</tr>
<tr>
<td>Photometry of Distant Galaxies</td>
<td>Petrosian magnitudes</td>
</tr>
</tbody>
</table>
Other Image Parameters

- Size
- Type
  \[ \text{psfMag} - \text{expMag} > 0.145 \]
- Many hundreds of others
SPECTRA
An Astronomical Primer of Stellar Spectra
Stellar Spectra

RA=255.19030, DEC=60.71902, MJD=51695, Plate=351, Fiber=254

\[ F_{\lambda} \left[ 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1} \right] \]

Wavelength [Å]

\[ z = -0.0014 \pm 0.0002 \text{ (1.00), Star} \]
Stellar Spectra

RA = 7.51348, DEC = 15.44149, MJD = 51821, Plate = 417, Fiber = 428

$F_\lambda [10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1}]$

$z = 0.0002 \pm 0.0005 \ (1.00), \ Star$

Wavelength [Å]
Stellar Spectra

Counts

Wavelength

$z = 0.0006 \pm 0.0001 (1.00), \text{specStar: X-high}$
A graph showing stellar spectra with wavelengths ranging from 4000 to 9000 Å. The graph includes lines for various elements and their corresponding wavelengths. The inset image shows a close-up of the spectra with a prominent peak at the center. The text reads:

RA=353.12396, DEC=-1.17712, MJD=51821, Plate=384, Fiber=201

The figure also includes a note: "z=-0.0000 +/- 0.0003 (0.87), StarLate".
Stellar Spectra

RA=134.40525, DEC=-1.22670, MJD=51994, Plate= 293, Fiber=203

$F_{\lambda}$ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]

Wavelength [Å]

z=-0.0001 +/- 0.0005 (0.95), StarLate
Stellar Spectra

RA=117.26805, DEC=-42.40558, MJD=51885, Plate=434, Fiber=176

$F_x \left[ 10^{-17} \text{ erg cm}^2 \text{ s}^{-1} \text{ Å}^{-1} \right]$

$z = 0.0009 \pm 0.0005 \text{ (0.95), Star}$

Wavelength [Å]
Stellar Spectra

M star + White Dwarf

RA=118.09646, DEC=43.53673, MJD=51885, Plate= 434, Fiber=566

[Graph showing stellar spectra with various lines and labels such as HeII, K, He, OIII, Mg, Na, OI, H₂, SII, NII.

$z = -0.0002 \pm 0.0002$ (0.70), Star

Wavelength [Å]

$F_\lambda \times 10^{17}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$ ]

0, 5, 10, 15]
Galaxy Spectra

Galaxies = Star+gas
QSO spectra

Z = 0.1
QSO spectra

Z=1
QSO spectra

$Z=2$
QSO spectra

Z=3
QSO spectra

Z=4
QSO spectra

$Z=5$
Types of Maps

- Main Galaxy Sample
- LRG sample
- Photo-z sample
- QSO sample
- QSO absorption systems
- Galactic Halo
- Ly-\_ systems
- Asteroids
- Space Junk
EDR PhotoZ

Tamás Budavári
The Johns Hopkins University

István Csabai – Eötvös University, Budapest
Alex Szalay – The Johns Hopkins University
Andy Connolly – University of Pittsburgh
### Pros and Cons

<table>
<thead>
<tr>
<th>Empirical method</th>
<th>Template fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redshifts from calibrators with similar colors</td>
<td>Comparing known spectra to photometry</td>
</tr>
<tr>
<td>+ quick processing time</td>
<td>+ no need for calibrators, physics in templates</td>
</tr>
<tr>
<td>– new calibrator set and fit required for new data</td>
<td>+ more physical outcome, spectral type, luminosity</td>
</tr>
<tr>
<td>– cannot extrapolate, yields dubious results</td>
<td>– template spectra are not perfect, e.g. CWW</td>
</tr>
</tbody>
</table>
Empirical Methods

- Nearest neighbor
  - Assign redshift of closest calibrator
- Polynomial fitting function
  - Quadratic fit, systematic errors
- Kd-tree
  - Quadratic fit in cells

$\Delta z = 0.033$

$\Delta z = 0.027$

$\Delta z = 0.023$
Template Fitting

• Physical inversion
  – More than just redshift
  – Yield consistent spectral type, luminosity & redshift
  – Estimated covariances

• SED Reconstruction
  – Spectral templates that match the photometry better
  – ASQ algorithm dynamically creates and trains SEDs
Trained LRG Template

- Great calibrator set up to $z = 0.5 - 0.6$!
- Reconstructed SED redder than CWW
Photometric Redshifts

- 4 discrete templates
  - Red sample $\Delta z = 0.028$
    - $z > 0.2 \Rightarrow \Delta z = 0.026$
  - Blue sample $\Delta z = 0.05$

- Continuous type
  - Red sample $\Delta z = 0.029$
    - $z > 0.2 \Rightarrow \Delta z = 0.035$
  - Blue sample $\Delta z = 0.04$

- Outliers
  - Excluded 2% of galaxies

- Sacrifice?
  - Ell type galaxies have better estimates with only 1 SED
  - Maybe a decision tree?
PhotoZ Plates

- The Goal
  - Deeper spectroscopic sample of blue SDSS galaxies
    - Blind test
    - New calibrator set

- Selection
  - Based on photoz results
  - Color cuts to get
    - High-z objects
    - Not red galaxies
Plate 672

- The first results
  - Galaxies are indeed blue and higher redshift!
- Scatter is big but…
  - … that’s why needed the photoz plates

\[ \Delta z = 0.085 \]
- Redshift distributions compare OK# of $g = 519$
  - Photometric redshifts (Run 752 & 756)
  - Spectroscopic redshifts (Histogram scaled)
Measures of the Clustering

- The two point correlation function \( r \)
- The power Spectrum
- N-point Statistics
- Counts in Cells
- Topological measures
- Maximum Likelihood parameter estimation
Constraining Cosmological Parameters from Apparent Redshift-space Clusterings

Taka Matsubara
Alex Szalay
Constraining Cosmological Parameters

(Traditional) Quadratic Methods

Redshift Survey Data $\rightarrow P(k)$ or $\xi(r)$

$\rightarrow \Omega_M, \Omega_\Lambda, \Omega_B, h, \sigma_8, b, n,...$

- Effective for spatially homogeneous, isotropic samples.
- However, evaluation of $P(k)$ in real (comoving) space is not straightforward. (z-evolution, redshift-space distortion)
Example:

\[ z << 1, \text{ real-space: } \xi(1,2) = \xi(r) \]

\[ \text{Redshift-space: } \xi(1,2) = \xi(z_1, z_2, \theta_{12}) \]
Anisotropy of the clustering

Velocity distortions

\[ cz = H_0 r + v_{\text{pec}} \]

real space \hspace{1cm} redshift space

Finger-of-God (non-linear scales)

Squashing by infall (linear scales)

\[ \Omega^{0.6} / b \]
Geometric distortions (non-small $z$)

real space \hspace{2cm} \text{redshift space}

\[
H(z) = H_0 \sqrt{(1+z)^3 \Omega_M + (1+z)^2 (1-\Omega_M - \Omega_\Lambda) + \Omega_\Lambda}
\]

\[
d_A(z) = \frac{1}{H_0 \sqrt{1-\Omega_M - \Omega_\Lambda}} \sinh \left( H_0 \sqrt{1-\Omega_M - \Omega_\Lambda} \int_0^z \frac{dz'}{H(z')} \right)
\]
Likelihood analysis of cosmological parameters without direct determination of $P(b \mid r)$ or $\xi(r)$

$L(\theta_\alpha \mid \delta_i) \propto L(\delta_i \mid \theta_\alpha)L(\theta_\alpha)$  \hspace{1cm} (Bayesian)

$\delta_i = \frac{\delta \rho}{\rho}(x_i), \quad (\theta_\alpha) = (\Omega_M, \Omega_\Lambda, \Omega_b, h, \sigma_8, b, n, \ldots)$

Linear regime $\rightarrow$ $L(\delta_i \mid \theta_\alpha)$ Gaussian, fully determined by a correlation matrix

$C_{ij}(\theta_\alpha) = \langle \delta_i \delta_j \rangle_{\text{model}(\theta_\alpha)}$

Huge matrix $\leftarrow$ a novel, fast algorithm to calculate $C_{ij}$ for arbitrary $z$ : under development
## Results

### single determination

<table>
<thead>
<tr>
<th></th>
<th>$\Omega_M$</th>
<th>$\Omega_\Lambda$</th>
<th>$\Omega_B/\Omega_M$</th>
<th>$h$</th>
<th>$n$</th>
<th>$\sigma_8$</th>
<th>$b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>±3%</td>
<td>±19%</td>
<td>±16%</td>
<td>±4%</td>
<td>±2%</td>
<td>±0.5%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Red</td>
<td>±2%</td>
<td>±4%</td>
<td>±9%</td>
<td>±2%</td>
<td>±1%</td>
<td>±0.3%</td>
<td>±0.4%</td>
</tr>
<tr>
<td>QSO</td>
<td>±14%</td>
<td>±15%</td>
<td>±76%</td>
<td>±20%</td>
<td>±14%</td>
<td>±5%</td>
<td>±6%</td>
</tr>
</tbody>
</table>

### simultaneous determination (marginalized)

<table>
<thead>
<tr>
<th></th>
<th>$\Omega_M$</th>
<th>$\Omega_\Lambda$</th>
<th>$\Omega_B/\Omega_M$</th>
<th>$b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>±14%</td>
<td>±57%</td>
<td>±51%</td>
<td>±2%</td>
</tr>
<tr>
<td>Red</td>
<td>±9%</td>
<td>±10%</td>
<td>±33%</td>
<td>±0.9%</td>
</tr>
<tr>
<td>QSO</td>
<td>±170%</td>
<td>±75%</td>
<td>±360%</td>
<td>±69%</td>
</tr>
</tbody>
</table>
Summary

- Direct determinations of cosmological parameters
- A novel, fast algorithm to calculate correlation matrix in redshift space
- Normal galaxies: dense, low-z, small sample volume
- QSOs: sparse, high-z, large sample volume
- Red galaxies: intermediate
  → best constraints on cosmological parameters
Visualization

- CAVE VR system at Argonne National Laboratory
- SDSS VS v. 1.0 Windows based visualization system
- Tool directly tied to the skyserver for general visualization of multi-dimensional data
Accessing the Data

• Two databases
  • Skyserver (MS SQL)
    – Skyserver.fnal.gov
  • SDSSQT
    – Download from www.sdss.org
• Lab
  astro.uchicago.edu/~subbarao/chautauqua.html