Lectures

THE LARGE SCALE DISTRIBUTION OF GALAXIES

Observational facts
Lecture plan

Part 1: Deep large scale galaxy surveys
Part 2: The Universe on large scales
  - Large scale structures observations
  - Measuring clustering: the correlation function (and power spectrum)
Part 3: Baryon Acoustic Oscillations and Redshift space distortions
Part 4: The Euclid Surveys and galaxy clustering
The large-scale structure of the Universe evolves through the competing effects of cosmological expansion and structure growth.
Halo & galaxy bias

- Classical picture

- Large-scale density fluctuations modulate the number density of local density peaks, bringing the highest above the critical density for collapse ($\delta_c = 1.686$ in EdS model)

- Halo large-scale bias described as $b = 1 + (\nu^2 - 1)/\delta_c$: rare objects (most massive) exhibit a higher bias

  **But, halo ↔ galaxy?**

- Large-scale linear bias:
  - Valid only on large scales

  $b \equiv \delta_g/\delta$

*From de la Torre (Les Houches 2016)*

Kaiser 1984
Bardeen et al. 1986
Cole & Kaiser 1989
Mo & White 1996
Use galaxies as a tracer of the matter field.

Millennium Run
(Springel et al. 2005)

$z=0$
Part 1

DEEP LARGE SCALE GALAXY SURVEYS: METHODS
Outline

1. Designing a deep survey
2. Instruments for deep surveys
3. Observational methods
4. Data processing
5. Databases and information systems
6. Comparing surveys
Cosmological probes

- Measurements sensitive to the « cosmological parameters » of the world model
  - Geometry: standard rods
  - Content: mass of the different components
- Need to combine several cosmological probes to fully constrain the full set of parameters

Probes ➔ Surveys
(Euclid = a BIG survey)
What are “deep surveys”? 

**Deep galaxy surveys** are observations of a part of the sky, assembling representative samples of galaxies from well defined selection criteria.

Two types of complementary surveys:
- Deep photometric surveys
- Deep spectroscopic redshift surveys

Surveys rely on **large number statistics**

Surveys are used for:
- Galaxy formation and evolution
- Measuring cosmological parameters
Surveys = polls

- Ask the opinion of 1 person: always wrong
- Ask 10 persons: strong biases
- Ask 100 persons: some biases
- Ask 1000 persons: average is probably close to truth
- ...
- Votes from the whole population make the truth

Need large samples
Designing a survey

- Science goals & strategy
- Survey parameter space
- Instrumentation
- Survey examples
How are galaxy surveys designed?

The ‘Wedding cake’ approach

- Deep / small field
- Medium / large field
- Shallow / all-sky
Some Principles

- Surveys need to be unbiased
  - Volume, luminosity/mass, type, environment...
  - Proper photometric catalogs
- Statistically robust
- Complete census

- Selection function control
  - Apriori hypotheses
  - Large deep imaging surveys
- Large samples
- Multi-wavelength

2 types of surveys: photometric and spectroscopic
Science goals: the starting point

- What are the science questions addressed by the survey?
- What are the measurements to be performed?
- What is the desired accuracy?

Cosmology-clustering:
  - BAO
  - RSD

Cosmology: SNe, WL, Clusters...

Galaxy formation & evolution:
  - Merging, accretion, feedback, ...

As a function of z...
Survey parameter space

Survey

- Volume
- Depth
- Spectral resolution
- Spatial resolution
- z-range
- Nobj
Survey volume

- **Volume** $\propto Area \times dz$
- Area depends on telescope+instrument
  - Etendue $\mathcal{A}\Omega$
- Instantaneous volume and tiling
  - One instrument pointing necessarily limited in area
  - Need tiling to implement survey

Single pointing footprint: Megacam @CFHT

Whole sky tiling: Euclid
Etendue (some instrumentation stuff...)

- An instrument system is more efficient when the *Etendue* is larger.

- Etendue: the area of the entrance pupil (telescope collecting area) times the solid angle the source

\[ E = A \Omega \]
**AΩ: a key element in instrument systems**

- **A** = telescope collecting area
- **Ω** = telescope + instrument field of view
- The larger the **AΩ**, the more information can be accessed

These instrument systems have the same efficiency

<table>
<thead>
<tr>
<th>Telescope φ</th>
<th>1m</th>
<th>4m CFHT</th>
<th>8m VLT</th>
<th>40m ELT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>1 deg²</td>
<td>0.08 deg²</td>
<td>0.02 deg²</td>
<td>0.0008 deg²</td>
</tr>
<tr>
<td>ΑΩ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Survey depth

- Depends on
  - Telescope diameter
  - Instrument throughput (optical efficiency)
  - Exposure time
  - Detector noise
  - Background

- Signal to noise S/N

\[
S/N = \frac{R_* \times t}{\left[ (R_* \times t) + (R_{sky} \times t \times n_{pix}) + (R N^2 + (G/2)^2 \times n_{pix}) + (D \times n_{pix} \times t) \right]^{1/2}}
\]
Survey redshift range

The redshift range will determine the wavelength range (and vice-versa)
Survey spectral resolution

- Ability to separate spectral features
- $R = \lambda / d\lambda$
- The higher $R$, the better is the velocity resolution, or velocity accuracy
- Choice depends on the spectral features you are interested into
  - Broad features (e.g. because of velocity dispersion) or narrow
- Directly linked to wavelength coverage in instrument design
Survey number of objects

- A key number: $10^5$ objects

Why?
Nobj ??

~$10^5$ !!

- Study evolution vs. Luminosity, color (type), environnement
- Minimise cosmic variance effects: survey several independant fields
- Several time intervals to follow evolution
- 50 galaxies per measurement bin
- **Total number of galaxies:** $50 \times 10 \times 3 \times 3 \times 4 \times 7 > 100000$

per bin, mag.bin, colors, env., fields, time steps
### Science vs. parameter space: matrix

<table>
<thead>
<tr>
<th>Science Goals</th>
<th>Survey parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
</tr>
<tr>
<td>Goal 1</td>
<td>1 deg$^2$</td>
</tr>
<tr>
<td>Goal 2</td>
<td>0.5 deg$^2$</td>
</tr>
<tr>
<td>Goal 3</td>
<td>3 deg$^2$</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

Compile all science goals into one single survey observing strategy
Examples of spectroscopic survey design

<table>
<thead>
<tr>
<th>Survey</th>
<th>Survey Design Parameters</th>
<th>Area</th>
<th>λ-range (microns)</th>
<th>z-range</th>
<th>Spectral R</th>
<th>Mag. Lim.</th>
<th>Nobj</th>
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<tr>
<td>SDSS-III</td>
<td></td>
<td>10000 deg²</td>
<td>0.36-0.9</td>
<td>0-0.5</td>
<td>2000</td>
<td>18</td>
<td>10⁶</td>
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<tr>
<td>VVDS-Wide</td>
<td></td>
<td>8 deg²</td>
<td>0.55-1</td>
<td>0-1.5</td>
<td>250</td>
<td>22.5</td>
<td>22500</td>
</tr>
<tr>
<td>VVDS-Deep</td>
<td></td>
<td>1 deg²</td>
<td>0.55-1</td>
<td>0-5</td>
<td>250</td>
<td>24</td>
<td>12500</td>
</tr>
<tr>
<td>VIPERS</td>
<td></td>
<td>25 deg²</td>
<td>0.5-1</td>
<td>0.5-1.5</td>
<td>250</td>
<td>24</td>
<td>10⁵</td>
</tr>
<tr>
<td>VUDS</td>
<td></td>
<td>1 deg²</td>
<td>0.36-1</td>
<td>2-6+</td>
<td>250</td>
<td>25</td>
<td>10⁴</td>
</tr>
<tr>
<td>PFS</td>
<td></td>
<td>1400 deg²</td>
<td>0.4-1.3</td>
<td>0.5-7</td>
<td>3500</td>
<td>25</td>
<td>3×10⁶</td>
</tr>
<tr>
<td>DESI</td>
<td></td>
<td>14000 deg²</td>
<td>0.4-1</td>
<td>0-1.6</td>
<td>4000</td>
<td>19.5</td>
<td>25×10⁶</td>
</tr>
<tr>
<td>Euclid</td>
<td></td>
<td>15000 deg²</td>
<td>0.95-1.8</td>
<td>0.8-2</td>
<td>300</td>
<td>(22)</td>
<td>50×10⁶</td>
</tr>
<tr>
<td>WFIRST</td>
<td></td>
<td>2200 deg²</td>
<td>1.35-1.9</td>
<td>1.1-2.7</td>
<td>500</td>
<td>(23)</td>
<td>20×10⁶</td>
</tr>
</tbody>
</table>
Which instrument for my survey?

- Imaging or spectroscopy?
- Need both!
14 Instruments at the VLT (and VLTI, VISTA, VST)

- UT1 (Antu)
  - CRIRES
  - FORS2
  - KMOS (2013)

- UT2 (Kueyen)
  - FLAMES
  - X-SHOOTER
  - UVES

- UT3 (Melipal)
  - ISAAC
  - VISIR
  - VIMOS
  - SPHERE (2013)

- UT4 (Yepun)
  - AOF (2015)
  - HAWK-I
  - SINFONI
  - NACO
  - MUSE (2014)

- VST
  - OmegaCAM

- VISTA
  - VIRCAM

- VLTI
  - MIDI
  - AMBER
  - PRIMA
  - Visitor Instrument
  - GRAVITY (2016)
  - MATISSE (2016)

- LGS
  - VLT incoherent focus
  - ESPRESSO (2016)
Imaging cameras

- Based on CCDs for the visible domain
- Based on HgCdTe arrays for 1-5 microns
- Other hybrid detectors in UV and to ~25 microns
- Radio and sub-mm receivers
- X-ray cameras
- ....

Key elements

- Field of view
- Wavelength domain
- Spatial resolution
- Throughput / Quantum efficiency
Visible cameras: CFHT 3.6m+Megacam

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>1 deg²</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.33-1 microns</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.2 arcsec</td>
</tr>
<tr>
<td>Filters</td>
<td>ugriz</td>
</tr>
</tbody>
</table>
IR cameras: on 4m VISTA at ESO

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>0.6 deg²</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.8-2.5 microns</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.34 arcsec</td>
</tr>
<tr>
<td>Filters</td>
<td>YJHK</td>
</tr>
</tbody>
</table>
HST imaging

**ACS**

<table>
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<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>11 arcmin²</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.35-1 microns</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.05 arcsec</td>
</tr>
<tr>
<td>Filters</td>
<td>Ubvriz-like</td>
</tr>
</tbody>
</table>

- The best resolution
- The best sensitivity
- The smallest field

**WFC3**

<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Field of view</td>
<td>4.6 arcmin²</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.8-1.7 microns</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.13 arcsec</td>
</tr>
<tr>
<td>Filters</td>
<td>zYJH</td>
</tr>
</tbody>
</table>
Optical filters, are interference filters, selectively transmit light in a given bandpass, while blocking the remainder.

Imaging systems have a high throughput (efficiency in catching photons)
Limiting magnitudes in imaging

- Depend a lot on the wavelength
  - Optics throughput and detector quantum efficiency
  - Background

Example of the COSMOS survey
MOS: multi-object spectrographs

- A key invention for Cosmology!
- Principle: observe more than one object at once
  - Multiplex $N_{\text{obj}}$
- The multiplex is like having $N_{\text{obj}}$ telescopes each observing 1 object
- Different types of MOS
  - Multi-slit: better sky subtraction
  - Multi-fiber: wide field
  - Multi-IFU: velocity fields

Key elements
- Field of view
- Wavelength domain
- Spectral resolution
- Multiplex
- Throughput
Spectra, one by one

E. Hubble
Multi-object spectroscopy

- Deep multi-color imaging
- Target selection
- Multi-object spectroscopy

Today MOS have $N_{\text{obj}} \gg 100$
Multiplies the efficiency of your telescope by $N_{\text{obj}}$!
Multi-Object Spectrograph have become the work-horse of many observatories

- In all major observatories: SDSS survey, CFHT-MOS/SIS, Keck-LRIS, VLT-FORS, GMOS, Keck-DEIMOS, VLT-VIMOS, IMACS ...
- Now going to the IR: MOSFIRE, VLT-KMOS
**VIMOS on the VLT**

Most efficient MOS
Produced high-z cosmology surveys

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>220 arcmin²</td>
</tr>
<tr>
<td>Apertures</td>
<td>Slit mask</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.36-1 microns</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.2 arcsec</td>
</tr>
<tr>
<td>Filters</td>
<td>Ugriz</td>
</tr>
<tr>
<td>Spectral R</td>
<td>250-2500</td>
</tr>
<tr>
<td>Number of slits</td>
<td>~600</td>
</tr>
</tbody>
</table>
VIMOS: 1000 spectra in one shot

- Vertical trace: one galaxy spectrum
- Horizontal lines: night sky emission
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>80 arcmin²</td>
</tr>
<tr>
<td>Apertures</td>
<td>Slit mask</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.42-1 microns</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.1 arcsec</td>
</tr>
<tr>
<td>Filters</td>
<td>BVRIZ</td>
</tr>
<tr>
<td>Spectral R</td>
<td>1500-5000</td>
</tr>
<tr>
<td>Number of slits</td>
<td>~120</td>
</tr>
</tbody>
</table>
### SDSS spectrograph

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of view</td>
<td>7 deg²</td>
</tr>
<tr>
<td>Apertures</td>
<td>Fibers</td>
</tr>
<tr>
<td>λ-range</td>
<td>0.38-92 microns</td>
</tr>
<tr>
<td>Fiber size</td>
<td>3 arcsec</td>
</tr>
<tr>
<td>Spectral R</td>
<td>2000</td>
</tr>
<tr>
<td>Number of fibers</td>
<td>~600</td>
</tr>
</tbody>
</table>
MOS in the IR: MOSFIRE on Keck

**Parameter** | **Value**
--- | ---
Field of view | 45 arcmin²
Apertures | Moveable slits
λ-range | 0.8-2.5 microns
Pixel scale | 0.1 arcsec
Filters | YJHK
Spectral R | 2000-5000
Number of slits | 45

Note stars in alignment boxes and in 0.7" slits!

Difference of two 120 s J-band exposures, positions +/- 1.5" along slit direction from fiducial
Integral field spectroscopy: velocity fields

MASSIV survey at $z \sim 1.5$
MUSE on VLT: largest IFS

Large Field (for an IFS): 1x1 arcmin²

Finds faint emission line galaxies (not seen by Hubble)
Slitless spectrographs

- Insert a prism (grism) in the beam: all objects produce a dispersed spectrum
- Pros: all objects get a spectrum
- Cons:
  - Geometric superimposition
  - Higher background
- Recent example: 3D-HST survey with the WFC3 camera on HST (600 arcmin²)

EUCLID NISP will do a slitless survey of 15000 deg²
Instrument design and development

- Instrument making is fundamental to astrophysics
- Relies on new & improved technology
  - Optics, detectors, mechanics, control (active)
  - Space technology
  - Software: data processing, databases
- Professional project development
  - Skilled instrument scientists and specialty engineers
  - Project management
- Expensive telescopes (~1G€) and instruments (~15-80M€ ground-based / ~150M€ space-based)
**Instrument development cycle**

- Define science goals: science requirements
  - Survey volume, number of objects, redshift
- Derive technical requirements
  - Field of view, wavelength, resolution, throughput
  - Global performances
- Produce strawman opto-mechanical design
- Identify new technology developments: grating, detectors,…
  - Produce prototypes
- Manufacture all parts
- Assembly, integration and tests
  - Measure performances, calibrate
- First light

**SPACE instruments: 2× longer!**
Preparing future instrumentation for surveys

- **Ground**
  - PFS
  - DESI
  - LSST
  - ELTs

- **Space**
  - JWST
  - Euclid
  - WFIRST
Observational methods

- Sample selection
- Observations preparation and follow-up
- Measuring the sample selection function
Sample selection

- Magnitude or flux selection
- Color selection
- Color-color selection
- Photometric redshift selection
- Line flux selection ($H\alpha, Ly\alpha,...$)
Magnitude / flux selection

Observe all galaxies brighter than a limit

Here: $I_{AB} \leq 24$
Color selection

- Apply a color cut
- Color = difference between two photometric bands
- Here (magenta) select the red galaxies with $M_u - M_r > 1.4$
- Can add a magnitude selection on top (green): select all red and bright galaxies
Color-color selection

- Select objects in a part of a color-color diagram
- Most known: Lyman-break galaxy selection (LBG)
- Here is shown a gzK diagram to select galaxies at z~2
Lyman-break galaxy selection

- Use predicted galaxy tracks vs. Redshift to isolate galaxies in color-color space

Different types of galaxies
Photometric redshifts

- Photo-z is a redshift derived from photometric data
- Uses the SED (Spectral Energy Distribution)
- Correlate against a set of templates
- Same process gives *-mass, SFR, age, etc.
- Accuracy $\delta z \sim 3-5\%$
  - Probability distribution function
- Pb of catastrophic redshifts
**Hα selection**

- Hydrogen Hα transition 6562Å: the strongest emission at optical wavelengths
- Direct tracer of star formation rate
- Hα Flux selected survey: equivalent to a selection of star-forming galaxies
- Pros: strong emission easy to detect
- Cons:
  - Traces star-forming galaxies only
  - Degeneracies with other (single) line emitters: OII-3727, Lyα-1215

EUCLID-NISP survey will be Hα-selected
Survey observations preparation and follow-up

- Produce a reference photometric catalog based on your selection
  - The “parent catalog”
- Produce a list of objects to be observed
  - Satisfying your selection criteria
- Anticipate the geometric constraints of the instrument
- Produce a survey plan
  - Tilling to cover survey area
  - Exposure time, dithering
- Execute observations
- Follow with database
Observing blocks at VLT

<table>
<thead>
<tr>
<th>Name</th>
<th>MOS SN1987A</th>
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<tbody>
<tr>
<td>Status</td>
<td>(P)artiallyDefined</td>
</tr>
<tr>
<td>Execution Time</td>
<td>00:56:10.000</td>
</tr>
<tr>
<td>User Priority</td>
<td>1</td>
</tr>
<tr>
<td>OD Name</td>
<td>LR_blue 3offsets</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Template Type</th>
<th>VIMOS_1fu_obs_Offset</th>
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<tbody>
<tr>
<td>1</td>
<td>VIMOS_img_obs_Offset</td>
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<tr>
<td>1</td>
<td>VIMOS_mos_obs_Offset</td>
</tr>
</tbody>
</table>

### Table: Exposure and offsets

- **VIMOS_mos_acq_Mask**
  - Exposure time (seconds): 60
  - Additional Velocity RA: 0
  - Additional Velocity DEC: 0
  - ADP File 1: vm_SN1987A_LR_Blue_M1Q1.adp
  - ADP File 2: vm_SN1987A_LR_Blue_M1Q2.adp
  - ADP File 3: vm_SN1987A_LR_Blue_M1Q3.adp
  - ADP File 4: vm_SN1987A_LR_Blue_M1Q4.adp
  - Filter: R
  - Grism: OS-blue

- **VIMOS_mos_obs_Offset**
  - Exposure time (seconds): 600
  - Number of Exposures per Telescope Offset: 1
  - Number of Telescope Offsets: 3
  - List of offsets (arcsec) along the slit: 0 -2 3
  - List of offsets (arcsec) perpendicular to slit: 0 0 0
  - Return to Origin? (T/F): True
Resulting observations
4. Data processing

- Imaging and spectroscopy generate hundreds of Gb of data per night
- Process from raw uncalibrated data to instrument-corrected and calibrated data
- A very important step
- Data processing packages available for each instrument
  - Need to invest time before using them to the best
Measure spectroscopic redshifts

Identify observed spectral features to rest-frame known features
- Identify emission / absorption features
- Take continuum into account

Cross-correlation to galaxy templates (Tonry & Davis, 1979, AJ, 84, 1511)
EZ engine: Garilli et al., 2010, PASP, 122, 827

Euclid development in progress: AMAZED
5. Information system, Databases

- Data volume from surveys is huge, many Tb
- Information system: the management of all survey data
  - Data flow
- Includes all steps: from design to observations, to data processing, to final measurements
- Easy access to data
  - Query oriented
- Long term access, and reference
- Virtual observatory compatible
Follow the observations and data processing.
Search by general criteria

FIELD

- VVDS2H
- COSMOS
- ECDFS

Spectroscopic Redshift

z
min: 3, max: 3.3

z Flag pre-defined range
all primary objects with very reliable redshifts (z/ag~3-4)

Magnitude IAB
min: 17.5, max: 25

Submit the request  Reset

View your results

Search by criteria:
- MagI between 17.5 and 25
- Redshift Spectroscopic between 3 and 3.3
- Redshift Spectroscopic quality flag in (3,4)

23 objects selected

Objects: 1 to 23 / 23 - Page 1/1
PREV  NEXT
### Photometric Data

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<tr>
<th>Field</th>
<th>Magnitude</th>
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<tbody>
<tr>
<td>MagU_CFR98</td>
<td>26.652 ± 0.167</td>
</tr>
<tr>
<td>MagG_CFR98</td>
<td>24.645 ± 0.018</td>
</tr>
<tr>
<td>MagR_CFR98</td>
<td>23.906 ± 0.013</td>
</tr>
<tr>
<td>MagI_CFR98</td>
<td>23.749 ± 0.015</td>
</tr>
<tr>
<td>MagZ_CFR98</td>
<td>23.739 ± 0.037</td>
</tr>
<tr>
<td>MagJ_WIRES</td>
<td>23.712 ± 0.125</td>
</tr>
<tr>
<td>MagH_WIRES</td>
<td>22.806 ± 0.08</td>
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<tr>
<td>MagK_WIRES</td>
<td>22.672 ± 0.074</td>
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</tbody>
</table>

### Spectroscopic Data

<table>
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<tr>
<th>Identifier</th>
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<th>Redshift Quality Flag</th>
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<td>520441696</td>
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</table>

![Spectroscopic Data Graph](image)
6. Measuring the selection function

- Estimate the ability of the survey to detect galaxies satisfying the selection criteria
- Target Sampling rate
  - Which fraction of the galaxy population satisfying the criteria is observed
  - Masking bad regions
- Limiting magnitude
  - Limiting magnitude (at 5\(\sigma\) or at 90\% completeness)
Measuring the selection function

- Spectroscopic success rate
  - Fraction of targeted objects that deliver a measurement (redshift, line,...)
  - As a function of magnitude
  - As a function of redshift
  - ...

- Selection function can be complex
  \( \text{Sel}(\text{mag}, z, \text{type}, \alpha, \delta) \)
6. Comparing surveys

- Not so easy because the selection functions can be very different
- Look at the parameter space
  - Nobj vs. Area and vs. Magnitude
  - Area vs. Magnitude
  - Nobj and Area vs. Redshift
  - ...
Past and present deep spectroscopic surveys

<table>
<thead>
<tr>
<th>Survey</th>
<th>Instrument</th>
<th>redshift</th>
<th># galaxies</th>
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<tr>
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<td>SDSS/Apache Point</td>
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<td>CFHT-MOS</td>
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<td>KECK-LRIS</td>
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And more!