ERASMUS MUNDUS JOINT MASTER DEGREE
MASTER IN ASTROPHYSICS AND SPACE SCIENCE

Introduction to Active Galctic Nuclei

Tutorial 1

SDSS database

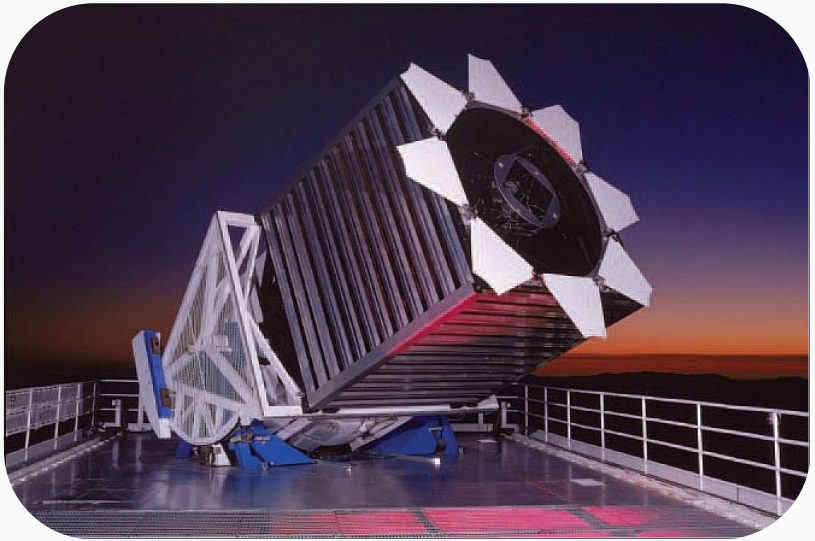
Isidora Jankov

March 2023

MATΦ
University of Belgrade
Faculty of Mathematics

Sloan Digital Sky Survey

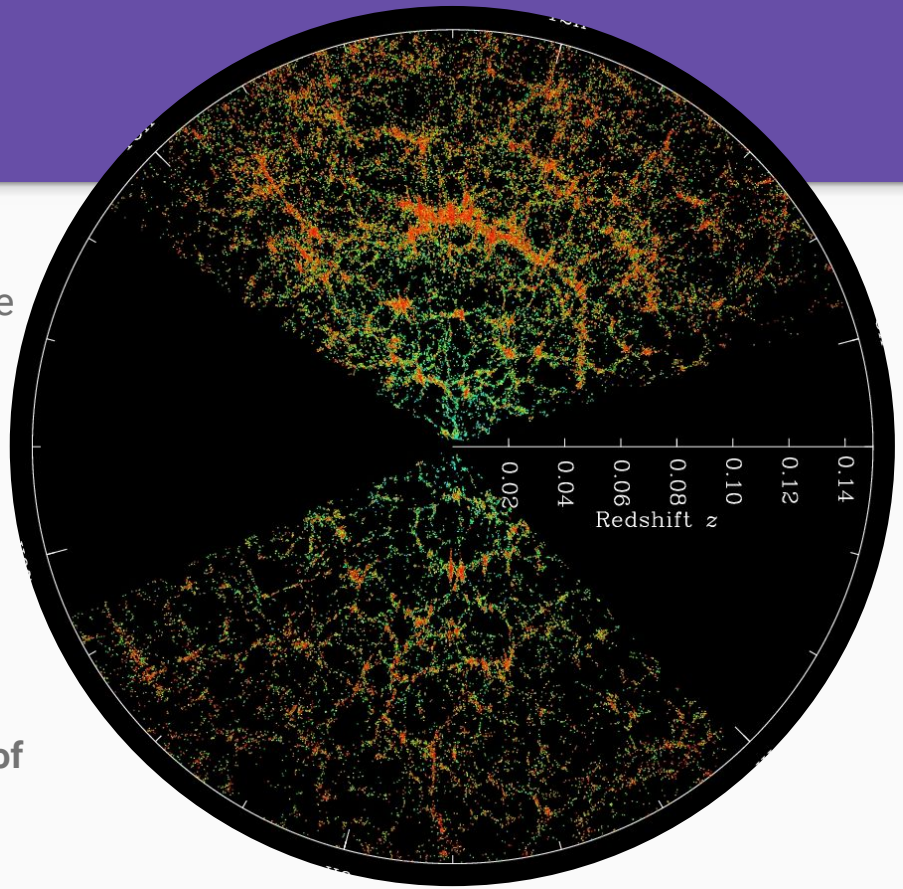
- One of the **largest**, most **detailed**, and most often **cited** astronomical surveys that has ever existed!
- 2.5m optical telescope at Apache Point Observatory, New Mexico, USA
- Data collection began in 2000, and the final imaging data release covers over 35% of the sky.



SDSS - science goals

Expand our understanding of:

- large-scale evolution and structure of the universe
- formation of stars and galaxies
- history of the Milky Way
- the nature of supermassive black holes
- science behind dark energy



Produced some of the most detailed 3D maps of the Universe ever made, with deep multi-color images of 1/3 of the sky and spectra for more than 3 million astronomical objects!

SDSS Phases & Data Releases

- **SDSS - I** 2000 - 2005

  Early Data Releases and Data Releases 1-5

- **SDSS - II** 2005 - 2008

  DR6 - DR7

- **SDSS - III** 2008 - 2014

  DR8 - DR12

- **SDSS - IV** 2014 - 2020

  DR13 - DR17

- **SDSS - V** 2020 - 2027

  Current: DR18 (since January 2023)

http://classic.sdss.org/

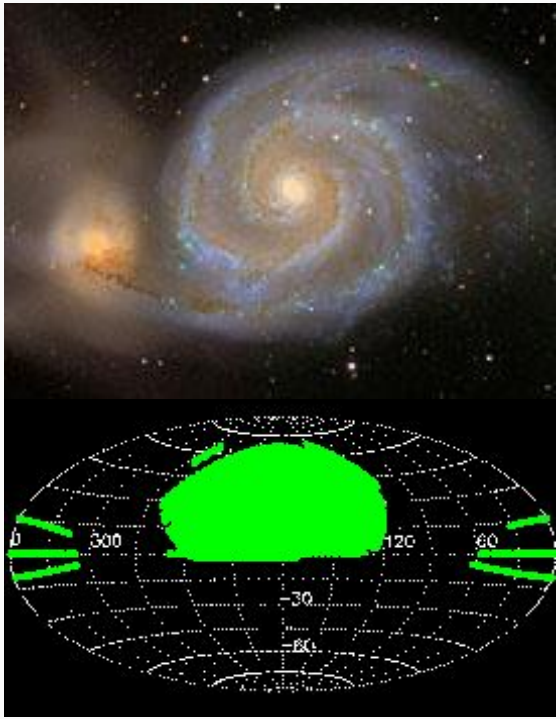
https://www.sdss3.org/

https://www.sdss4.org/

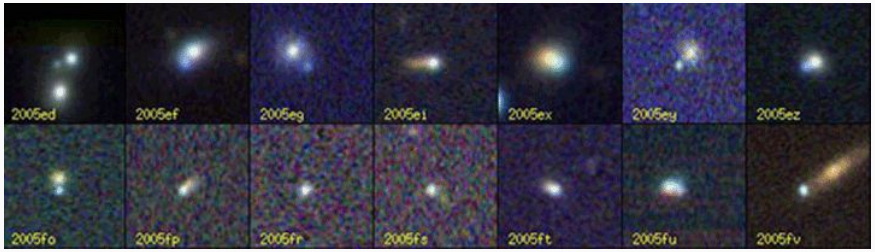
https://www.sdss.org/

SDSS - I/II 2000 - 2008 Early Data Releases & DR1-DR7

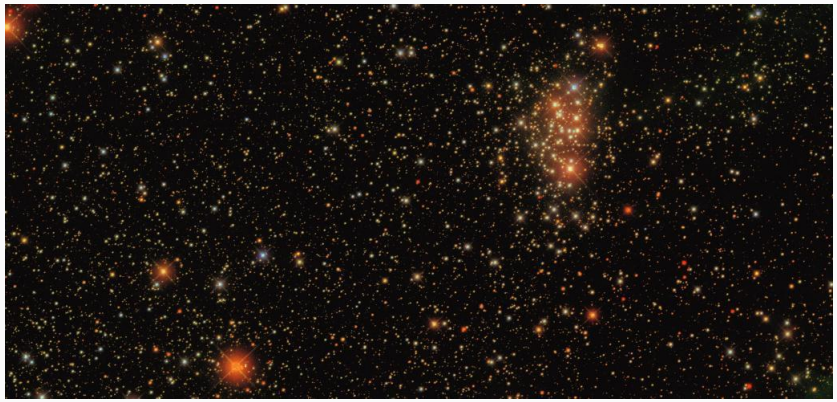
Legacy survey
ugriz images + spectra



Supernova survey: multiband light curves

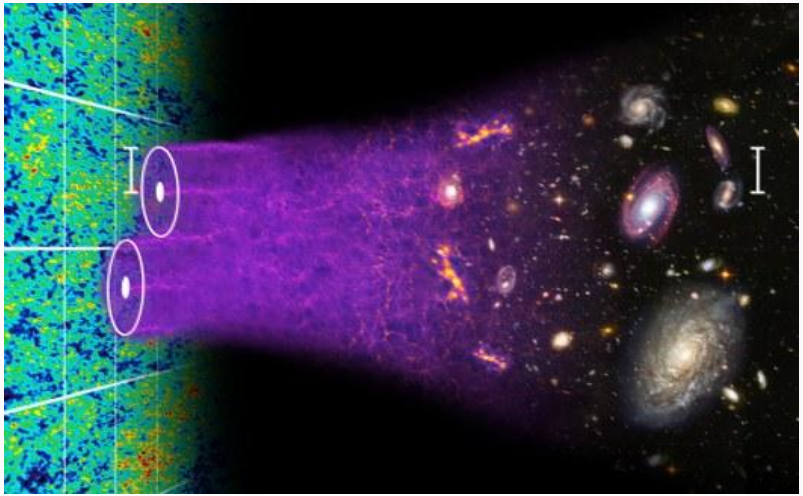


SEGUE-1: optical spectra of Milky Way stars

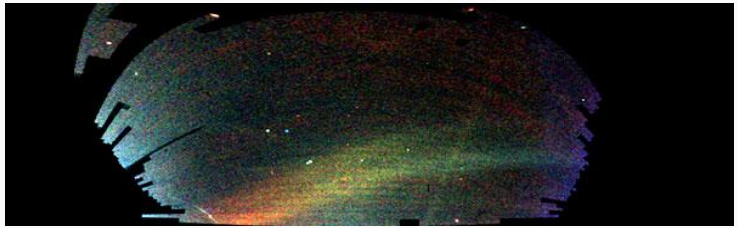


SDSS - III 2008 - 2014 DR8 - DR12

BOSS: optical spectra, largest volume 3D map of galaxies to date and measuring the scale of the Universe to 1%.

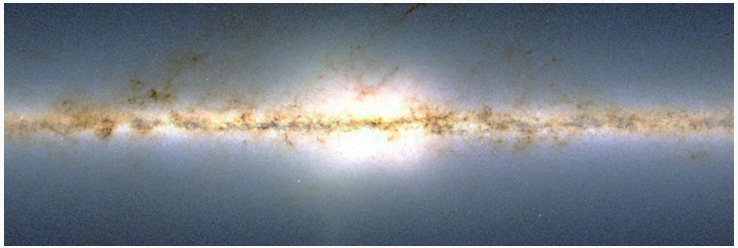


SEGUE-2: extension of SEGUE-1

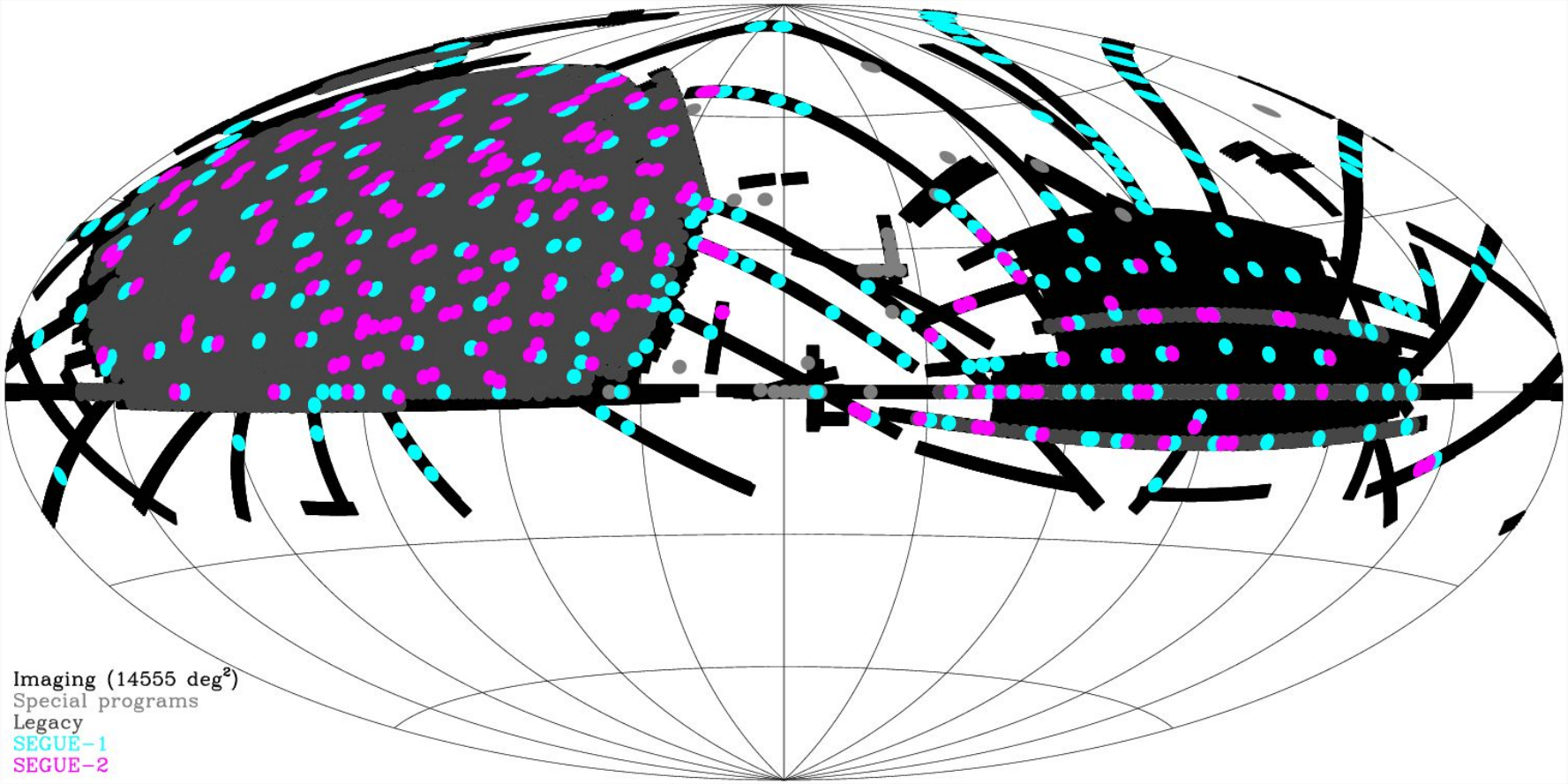


MARVELS: radial-velocity exoplanet survey

APOGEE: high-res. IR spectroscopy of stars

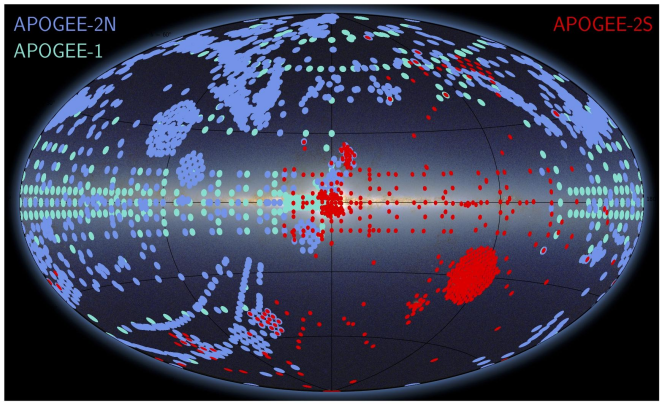


SEGUE and SDSS Legacy sky coverage

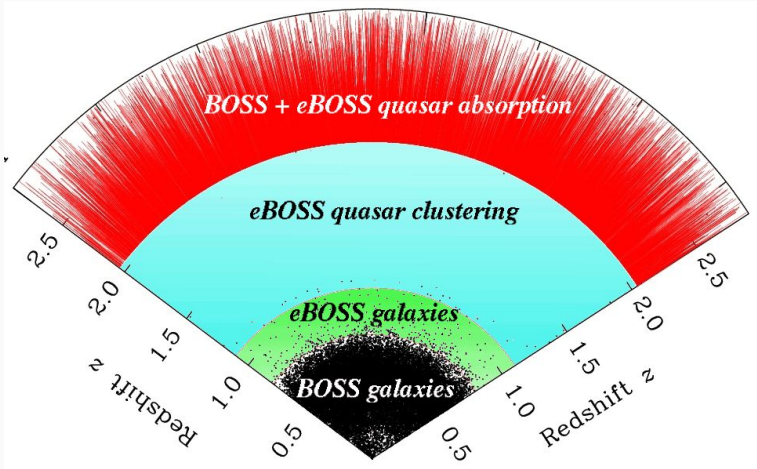


SDSS - IV 2014 - 2020 DR13 - DR17

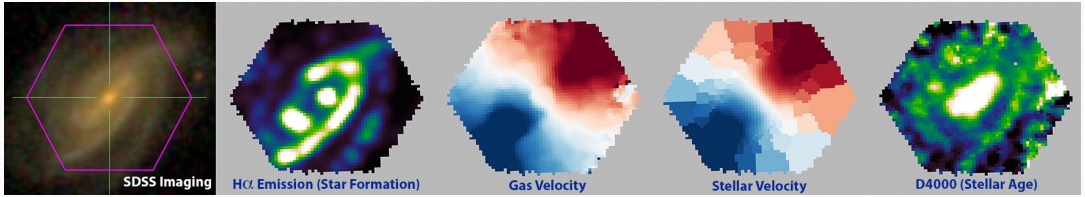
APOGEE-2: extension of APOGEE-1



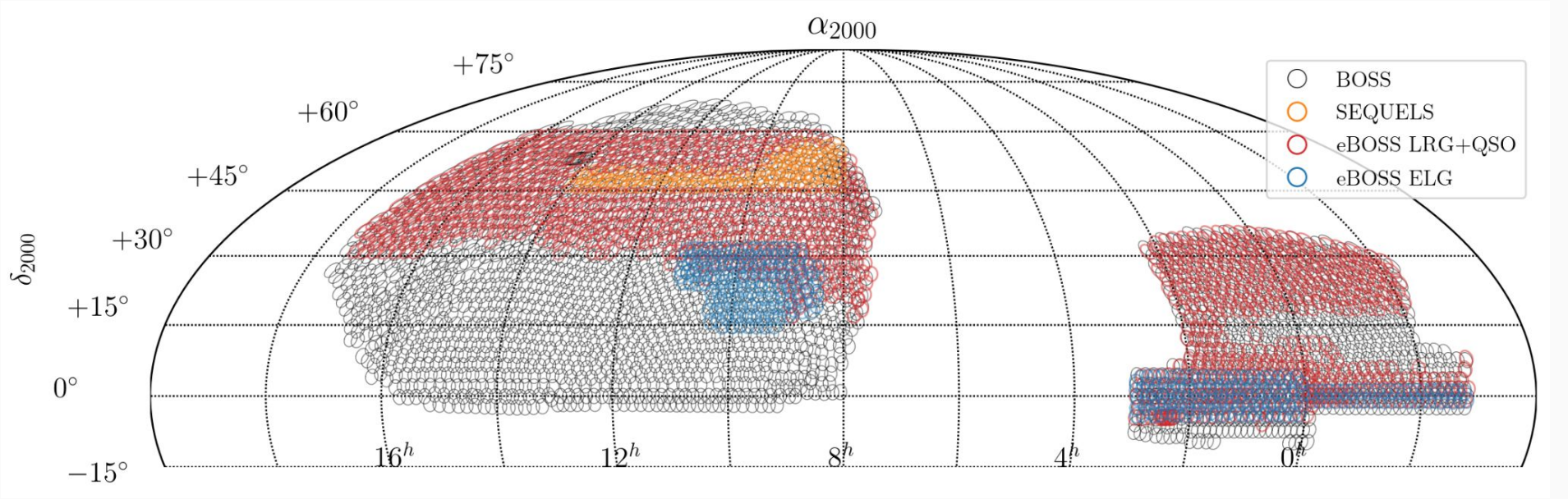
eBOSS: extended precision cosmological measurements to a critical early phase of cosmic history.



MaNGA: spatially resolved spectroscopy of 10,000 nearby galaxies



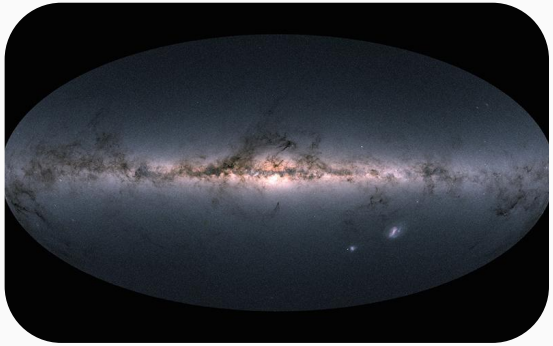
DR14 BOSS/eBOSS spectroscopic footprint



SDSS - V 2020 - 2027 DR18

Milky Way Mapper

- 4-5 million stars
- IR and/or optical spectra
- Time-domain
- Evolution of Milky Way
- Physics of stars and ISM
- Multiple-star and planetary systems



Black Hole Mapper

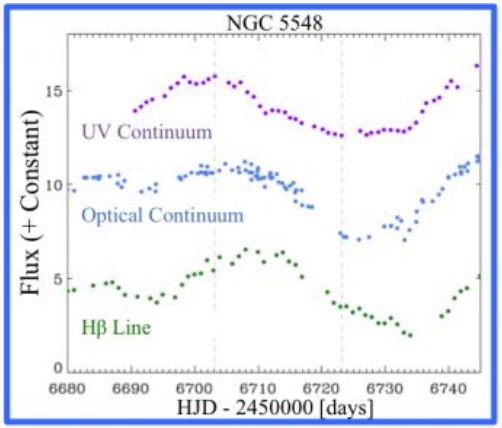
- 400,000 quasars
- Optical spectra (BOSS)
- Time-domain
- Measure BH masses
- Probing BH growth over cosmic time
- Characterizing X-ray sky

Local Volume Mapper

- 25 million contiguous optical spectra over 2,500 square degrees on the sky
- ISM, stellar populations in Milky Way and several other local galaxies
- Physics of star formation
- ISM-stars interaction

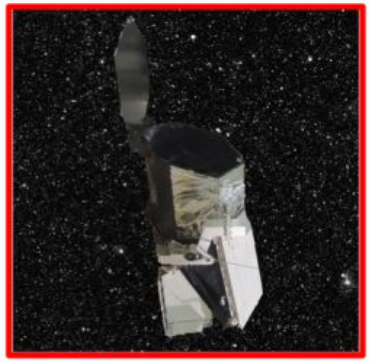
Black Hole Mapper

- RM of 1000 quasars, in more than 100 epochs
- 22,000 quasars spectra in <10 epochs
- 300,000 optical spectra of eROSITA X-ray counterparts.



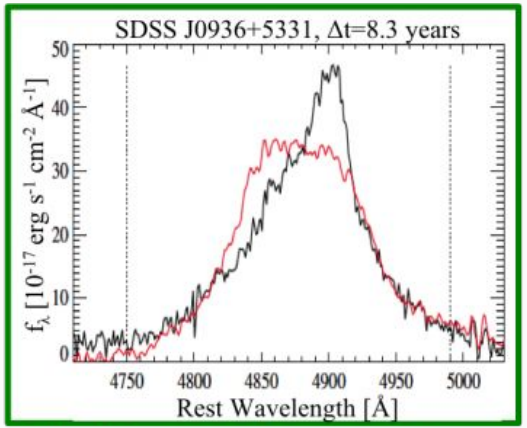
Reverberation Mapping

Measuring BLR sizes and BH masses



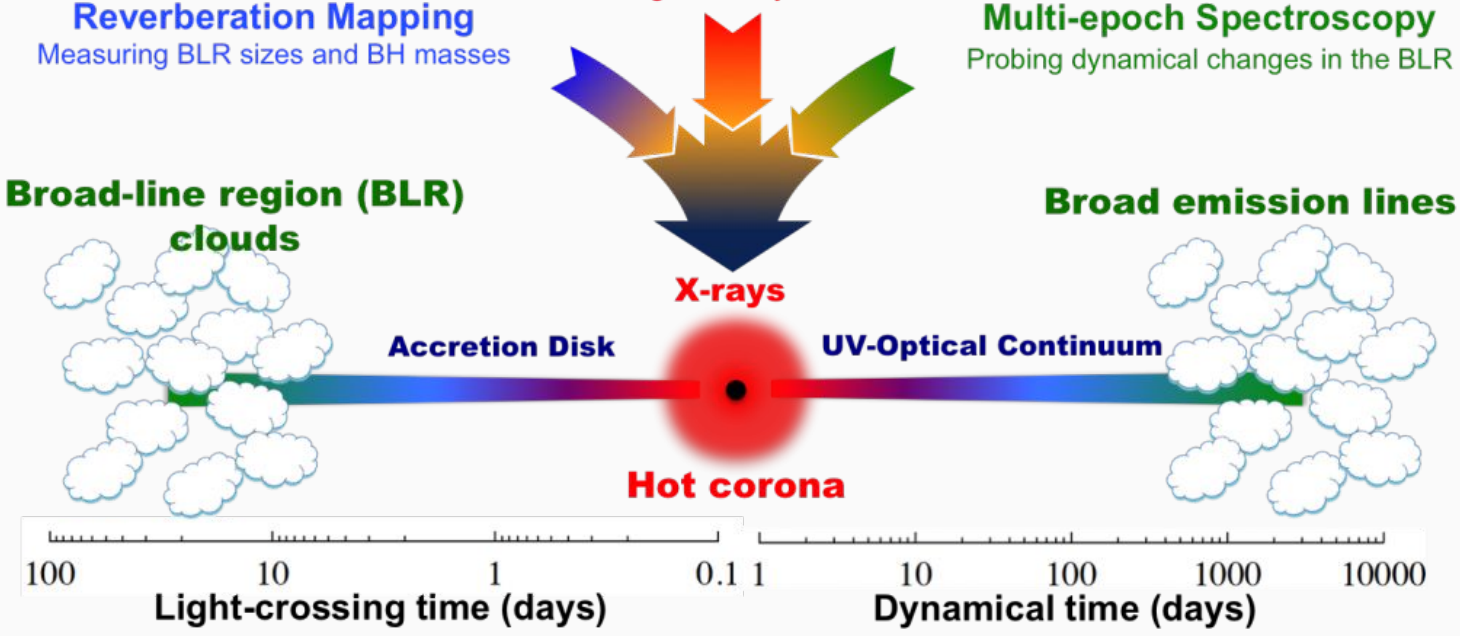
***eROSITA* Follow-up**

Probing hot X-ray coronae

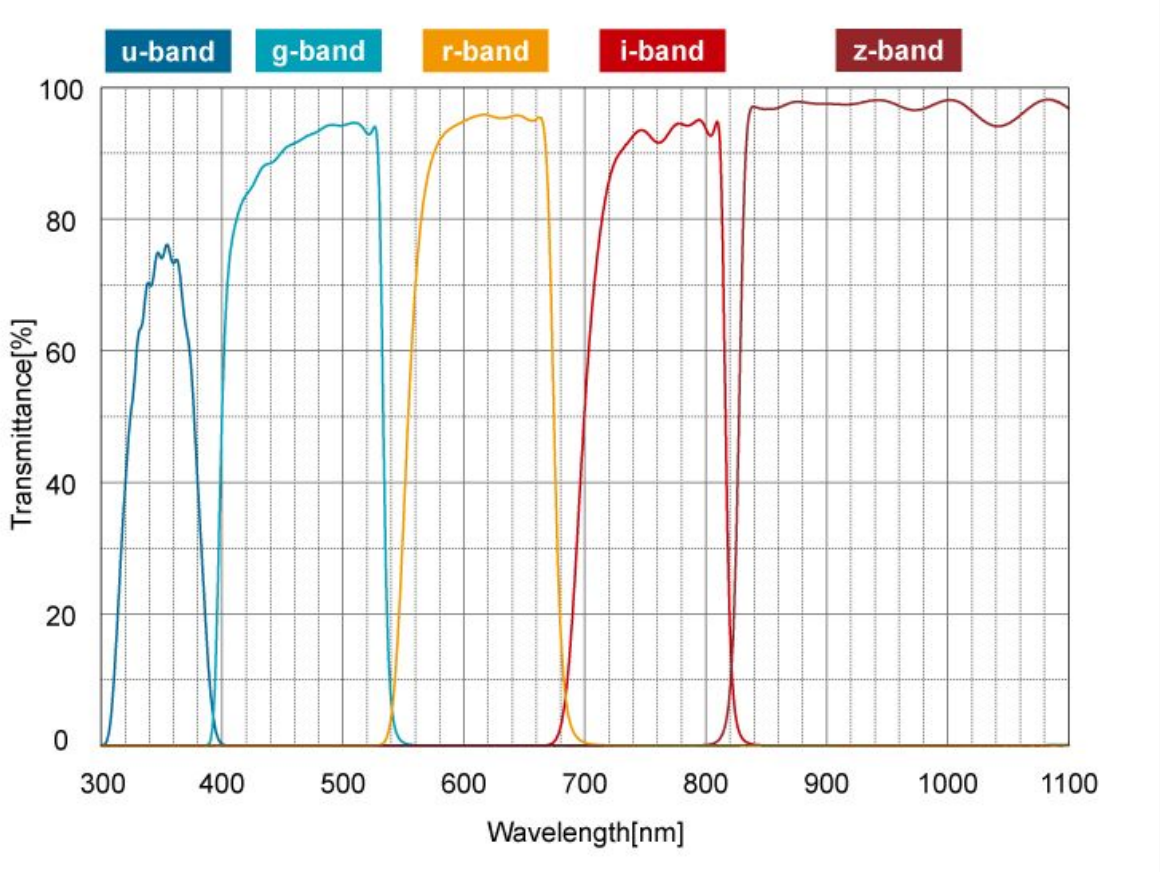


Multi-epoch Spectroscopy

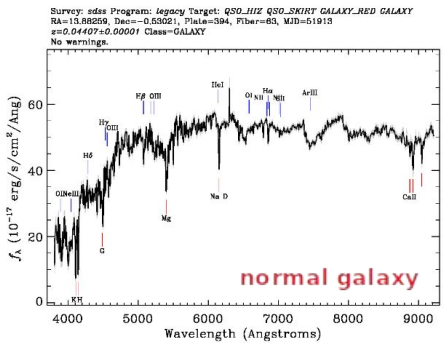
Probing dynamical changes in the BLR

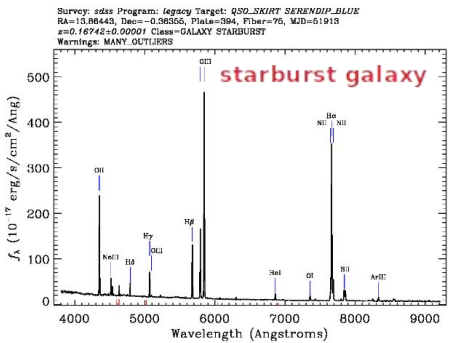


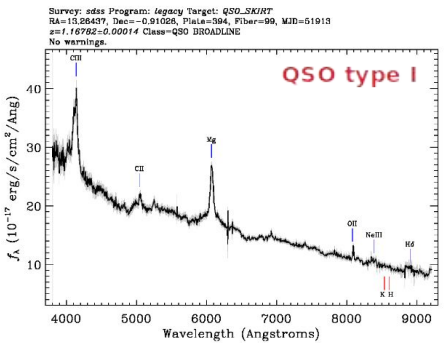
SDSS ugriz

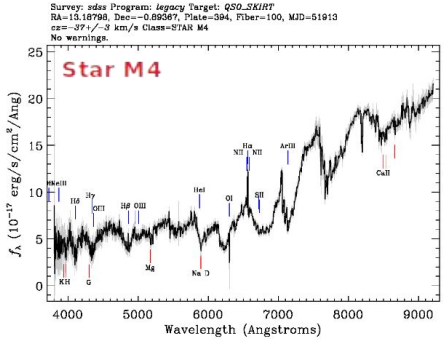

u-band
g-band
r-band
i-band
z-band
100
80
60
40
20
0
Transmittance[%]
300
400
500
600
700
800
900
1000
1100
Wavelength[nm]

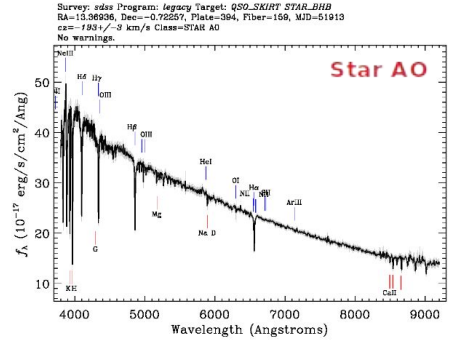
SDSS spectra

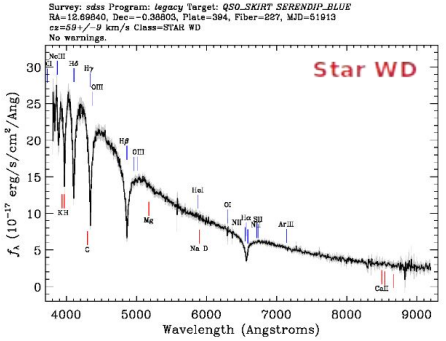


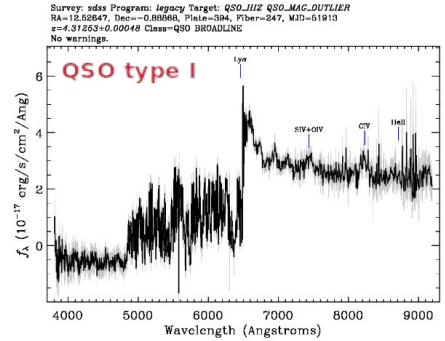


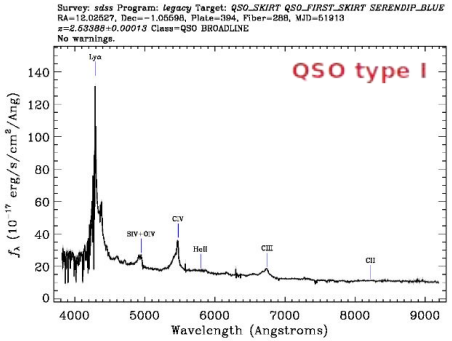


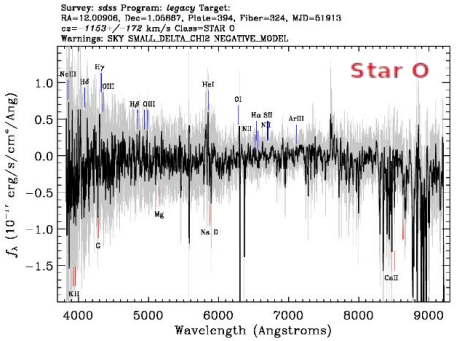












How to access data?

1. **SkyServer** - interface for accessing catalogs and derived parameters

   https://skyserver.sdss.org/dr18/

   - Visual tools
   - Search tools (focus on SQL Search)
   - CrossMatch tools

2. **Science Archive Server (SAS)** - interface for downloading original images and spectra

   - Images → https://dr12.sdss.org/fields
   - Optical spectra → https://dr18.sdss.org/optical/plate/search
   - And more → https://dr18.sdss.org/home

SQL Search

```
1  -- This query does a table JOIN between the imaging (PhotoObj) and spectra
2  --(SpecObj) tables and includes the necessary columns in the SELECT to upload
3  --the results to the SAS(Science Archive Server) for FITS file retrieval.
4  SELECT TOP 10
5  p.objid,p.ra,p.dec,p.u,p.g,p.r,p.i,p.z,
6  p.run, p.rerun, p.camcol, p.field,
7  s.specobjid, s.class, s.z as redshift,
8  s.plate, s.mjd, s.fiberid
9  FROM PhotoObj AS p
10 JOIN SpecObj AS s ON s.bestobjid = p.objid
11 WHERE
12   p.u BETWEEN 0 AND 19.6
13   AND g BETWEEN 0 AND 20
14
```

SDSS SkyServer SQL Search:
https://skyserver.sdss.org/dr18/SearchTools/sql

Structured **Q**uery **L**anguage - standard means of asking for data from databases

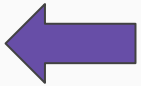
Sample Queries

- Basic SQL
- SQL Jujitsu
- Black Hole Mapper
- Milky Way Mapper
- Miscellaneous
- Variability Queries
- General Astronomy
- Galaxies
- Stars

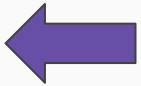
Simple SQL query

```
SELECT
SpecObj.plate, SpecObj.mjd,
SpecObj.fiberID, SpecObj.z

FROM SpecObj
```



What parameters you want to get for each found object



Which SDSS tables you use?

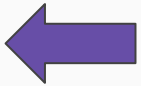
https://skyserver.sdss.org/dr18/MoreTools/browser

More complex SQL query

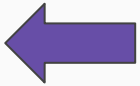
```
SELECT
SpecObj.plate, SpecObj.mjd,
SpecObj.fiberID, SpecObj.z

FROM SpecObj
JOIN GalSpecLine ON
SpecObj.specobjid =
GalSpecLine.specobjid

WHERE
 GalSpecLine.h_alpha_flux >
3*GalSpecLine.h_beta_flux
 AND SpecObj.class = 'QSO'
 AND SpecObj.z between 0.3 and 0.35
 AND SpecObj.sn1_g >30
```



What parameters you want to get for each found object



Which SDSS tables you use?

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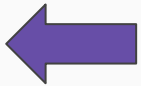


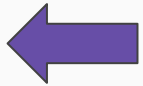
Narrow your search using constraints

SQL query with aliases

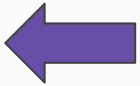
```
SELECT
s.plate, s.mjd,
s.fiberID, s.z

FROM SpecObj AS s
JOIN GalSpecLine AS g ON
s.specobjid = g.specobjid

WHERE
 g.h_alpha_flux > 3*g.h_beta_flux
 AND s.class = 'QSO'
 AND s.z between 0.3 and 0.35
 AND s.sn1_g >30
```



What parameters you want to get for each found object



Which SDSS tables you use?

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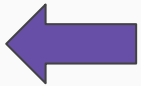

Narrow your search using constraints

Problem 1

In the redshift range $0.28 < z < 0.30$, check how many objects are:

(a) QSO with S/N>35 (S/N in optical band, near Hβ)

(b) galaxies or QSO with S/N>25. Display the number of objects in each category separately using one query.

(c) Select top 5 objects with S/N>25, and see their SDSS spectra (using *Explore* tool: https://skyserver.sdss.org/dr18/VisualTools/explore/summary) and images (using *Get Fields* tool: https://skyserver.sdss.org/dr18/MoreTools/fields)

Solution

In the redshift range 0.28 < z < 0.30, check how many objects are:

(a) quasars with S/N>35 (S/N in optical band, near Hβ)

```
SELECT count(*)

FROM SpecObj AS s

WHERE
 s.class = 'QSO'
 AND s.z BETWEEN 0.28 AND 0.3
 AND s.snmedian_g > 35
```

Solution

In the redshift range 0.28 < z < 0.30, check how many objects are:

(b) galaxies and quasars with S/N>25. Display the number of objects in each category separately using one query.

```
SELECT s.class, count(*)

FROM SpecObj AS s

WHERE
 (s.class = 'QSO' OR
  s.class = 'GALAXY')
 AND s.z BETWEEN 0.28 AND 0.3
 AND s.snmedian_g > 25

GROUP BY s.class
```

Solution

In the redshift range 0.28 < z < 0.30:

(c) Select top 5 objects with S/N>25, and see their SDSS spectra and images using *Explore* and *Get Fields* tool.

```
SELECT TOP 5

p.objid, p.ra, p.dec,
p.u, p.g, p.r, p.i, p.z,
p.run, p.camcol, p.field,
s.specobjid, s.class,
s.z AS redshift,
s.plate, s.mjd, s.fiberid

FROM PhotoObjAll AS p
JOIN SpecObj AS s ON
 s.bestobjid = p.objid

WHERE
 (s.class = 'QSO' OR s.class = 'GALAXY')
 AND s.z BETWEEN 0.28 AND 0.3
 AND s.snmedian_g > 25
```

unique id of specific observation of an object in SA

unique id of spectra in SAS

Problem 2

Select all galaxies and QSOs in SDSS with redshift $0.45<z<0.47$, S/N>35 (near Hβ) and magnitude in g band $m_g<25$. For selected objects, find their coordinates, redshift, S/N and all SDSS magnitudes (ugriz). Use only the magnitudes corrected for extinction.

Solution

Select all galaxies and QSOs in SDSS with redshift 0.45<z<0.47, S/N>35 (near Hβ) and magnitude in g band m_g<25. For selected objects, find their coordinates, redshift, S/N and all SDSS magnitudes (ugriz). Use only the magnitudes corrected for extinction.

```
SELECT
p.ra, p.dec,s.z, s.snmedian_g,
p.dered_u, p.dered_g, p.dered_r,
p.dered_i, p.dered_z,
s.plate, s.mjd, s.fiberid

FROM PhotoObjAll AS p
JOIN SpecObj AS s ON
 s.bestobjid = p.objid

WHERE
(s.class = 'QSO' OR
 s.class = 'GALAXY')
AND s.z BETWEEN 0.45 AND 0.47
AND s.snmedian_g > 35
AND p.dered_g < 25
```

Problem 3

Find all QSOs with 0.3<z<0.5, S/N>30 (near Hβ), which have [O III] 5007 and Hβ 4863 lines in emission. Put EW Hbeta to be larger than 10 Å and EW [O III] larger than 1 Å. Find EWs, flux for these lines and the flux of continuum under them. Check the spectra of first 5 found objects (this time, try https://dr18.sdss.org/optical/spectrum/search).

Solution

Find all QSOs with 0.3<z<0.5, S/N>30 (near Hβ), which have [O III] 5007 and Hβ 4863 lines in emission. Put EW Hbeta to be larger than 10 Å and EW [O III] larger than 1 Å. Find EWs, flux for these lines and the flux of continuum under them. Check the spectra of found objects.

```
SELECT
s.plate,s.mjd, s.fiberid,
g.oiii_5007_flux, g.h_beta_flux,
g.oiii_5007_cont, g.h_beta_cont,
g.oiii_5007_eqw, g.h_beta_eqw

FROM SpecObj AS s
JOIN GalSpecLine AS g ON
 s.specobjid = g.specobjid

WHERE
g.h_beta_eqw < -10
AND g.oiii_5007_eqw < -1
AND s.class = 'QSO'
AND s.z BETWEEN 0.3 AND 0.5
AND s.snmedian_g >30
```

How to download single spectrum from SDSS?

You can use basic search for optical spectra on Science Archive Server:

https://dr18.sdss.org/optical/spectrum/search

How to download many spectra from SDSS?

You can start from either:

https://skyserver.sdss.org/dr18/CrossMatchTools/ObjectCrossID

https://dr18.sdss.org/optical/spectrum/search (bulk search)

Homework 1 due: **Thursday 24.03, 23:59h**

Send your reports on

ijankov@proton.me

How should a report look like?

- Short, 2-5 pages
- Include SQL queries you used to obtain the results
- Attach output from SDSS in the form of csv

Useful links

CrossMatchID tool: https://skyserver.sdss.org/dr18/CrossMatchTools/ObjectCrossID

Schema (SDSS-V): https://skyserver.sdss.org/dr18/MoreTools/browser

Schema (SDSS-IV): https://skyserver.sdss.org/dr16/en/help/browser/browser.aspx

SQL Tutorial: https://skyserver.sdss.org/dr16/en/help/howto/search/searchhowtohome.aspx

SAS: https://dr18.sdss.org/home

SkyServer: https://skyserver.sdss.org/dr18/

Next tutorial on **Friday 24.03.** (prof. Dragana, zoom)

10h - 11h: Numerical simulations. CLOUDY code tutorial

13h - 15h: AGN spectral fittings and measuring line parameters with FANTASY