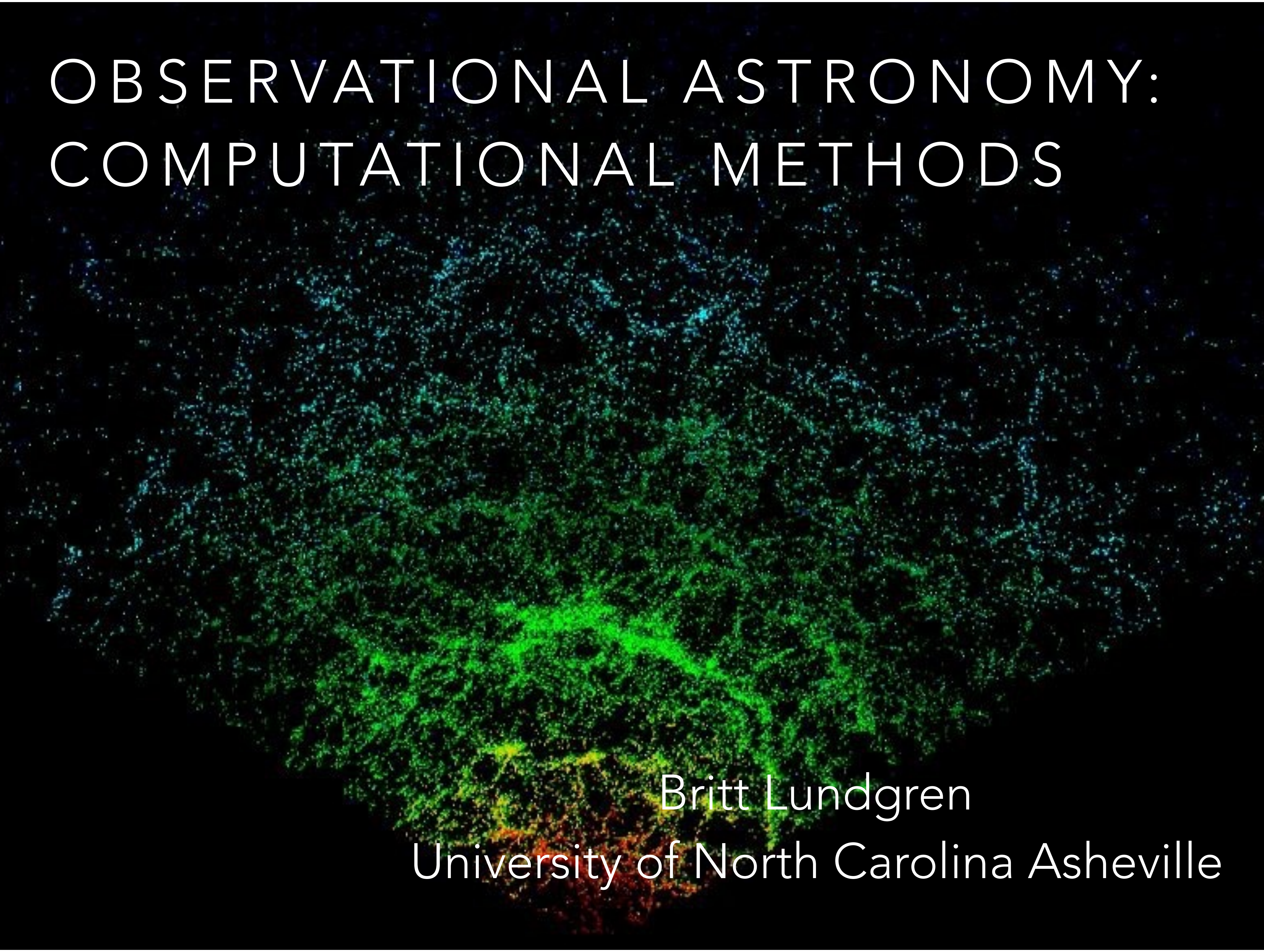
OBSERVATIONAL ASTRONOMY: COMPUTATIONAL METHODS



Britt Lundgren
University of North Carolina Asheville

Instructor: Dr. Britt Lundgren, blundgre@unca.edu, RRO 117, 828-255-7130
Office Hours: Mon/Wed/Fri. 3:30pm-4:30pm

Prerequisites:
Students are expected to have completed Observational Astronomy I (ASTR 320) and Introduction to Astronomy: Stars and Galaxies (ASTR 103). Although this course will rely heavily on computational methods, no previous programming experience is expected.

Suggested Materials:

This course will use the following free, online textbook:

Python for Astronomers: An Introduction to Scientific Computing by Imad Pasha & Christopher Agostino (https://prappleizer.github.io/textbook.pdf)

We will also extensively rely on the following resources and tutorials:

Sloan Digital Sky Survey: http://www.sdss.org/
SciServer collaborative research environment: http://www.sciserver.org/
Python3 programming language tutorial: https://docs.python.org/3/tutorial/
Zooniverse Project Builder: https://www.zooniverse.org/lab

General Information and Motivation

This course provides an introduction to computational methods in observational astronomy. The class will be structured as a project-based exploration of professional astronomy survey data. No previous computing experience is required, but the course content will rely heavily on computer-based projects. The course includes an introduction to basic programming (Unix, SQL, and Python3), statistical analysis, and data visualization, all placed within the context of astrophysical investigations.

This course builds on Observational Astronomy I by incorporating the fundamental computing skills required to undertake projects using data from modern professional astronomy surveys. The course will be particularly useful to research-oriented students, who may be considering graduate school in physics, astronomy, or computer science.

Modern observational astronomy requires a basic familiarity with coding in order to interface with digital datasets of ever-increasing scale. This course provides students with the opportunity to obtain these fundamental skills via open-ended explorations of authentic research-grade astrophysical data.

Course Structure and Requirements

Attendance is required at all class meetings. Absences due to university approved or unforeseeable circumstances must be supported with written documentation, and the time missed in class must be made up at another time.

Class meetings during the first 3 weeks of the semester will consist of guided activities on the following topics:

1. An Introduction to the Sloan Digital Sky Survey (SDSS)
2. Data analysis and visualization with Python3
3. Accessing and analyzing astronomy survey data using SciServer
4. Creating and sharing record of your research with Jupyter notebooks

Once comfortable with the aforementioned topics and skills, students will embark on a series of inquiry-based computing activities using SDSS data to explore a number of key astrophysical research topics, which may include: classifying galaxies and measuring their evolution, mapping structure in the Universe, differentiating stars and quasars, and exploring the properties of variable and moving objects.

Assignments

- **Short reading assignments** (~1/week) - 20% of grade
  - Due at the start of each class

- **Computational assignments** (~1 / week) - 40% of grade
  - begin in class, turn in the following Thursday by 3pm
  - Jupyter notebook file format (e.g., *name_homework1.ipynb*)

- **Team research project** (last month of the semester) - 40% of grade
  - Jupyter notebook file containing annotated analysis
  - Final Report
  - Final Presentation

Goals for Week 1

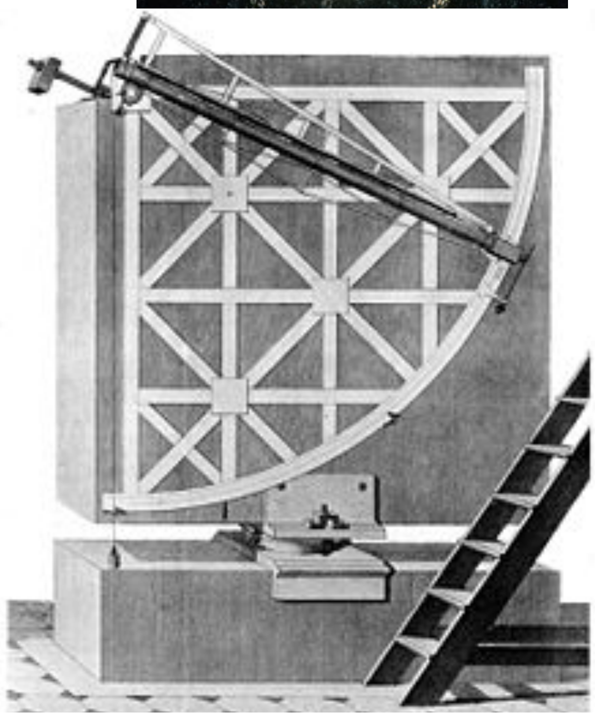
- Review the history of astronomical catalogs and surveys
- Collaboratively map the Sloan Digital Sky Survey science goals & data types
- Explore different ways of accessing the Sloan Digital Sky Survey

Astronomy: the original “Big Data" science

Tycho Brahe: Human Camera

- Danish nobleman and astronomer (1546-1601)
- Naked eye observations 5x more accurate than any to date!

- Accurately (<1 arcmin) measured ~1000 stars
- Noticed “new stars” appear (supernovae). This <u>challenged the Aristotelian belief of an unchanging cosmos.</u>



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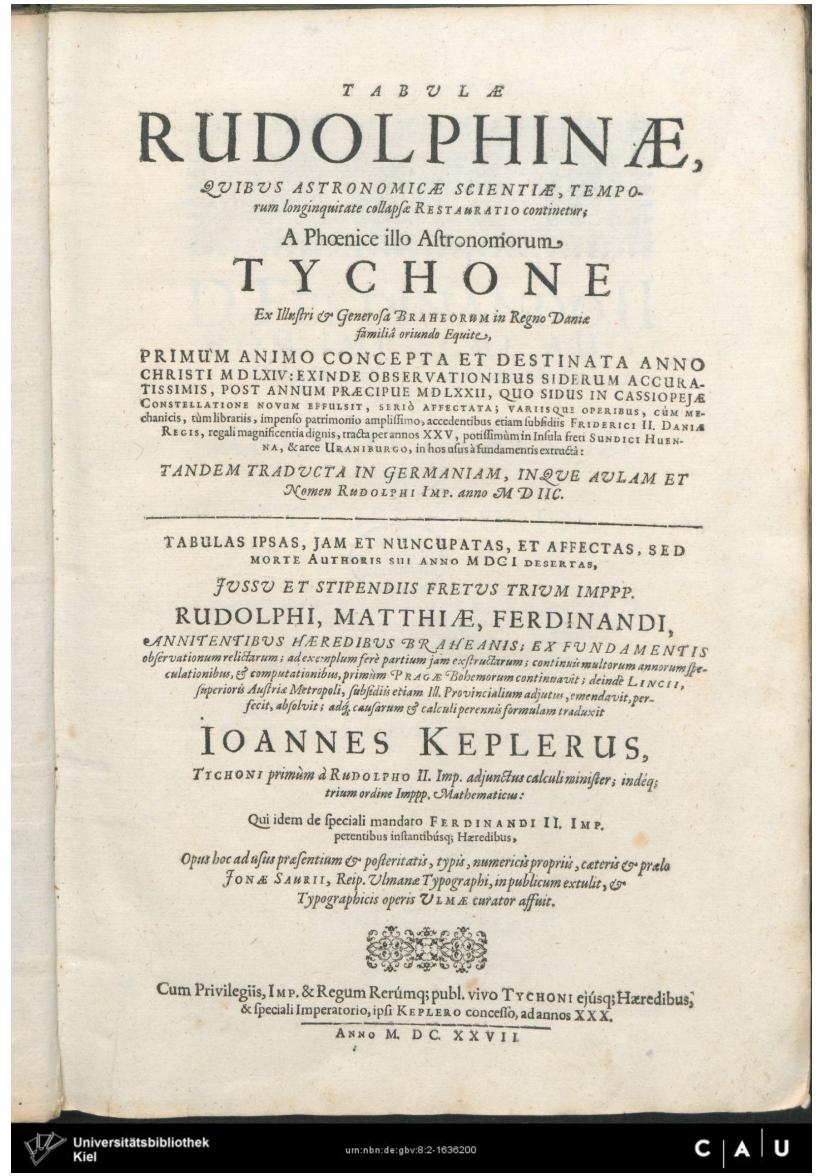


TABULÆ
RUDOLPHINÆ,
QUIBUS ASTRONOMICÆ SCIENTIÆ, TEMPORUM longinquitate collapsæ RESTAURATIO continetur;
A Phœnice illo Astronomorum
TYCHONE
Ex Illustri & Generosa BRAHEORUM in Regno Daniæ familiâ oriundo Equite,
PRIMUM ANIMO CONCEPTA ET DESTINATA ANNO CHRISTI MDLXIV: EXINDE OBSERVATIONIBUS SIDERUM ACCURATISSIMIS, POST ANNUM PRÆCIPUE MDLXXII, QUO SIDUS IN CASSIOPEJÆ CONSTELLATIONE NOVUM EFFULSIT, SERIÒ AFFECTATA; VARIISQUE OPERIBUS, CÙM MECHANICIS, TÙM LIBRARIIS, IMPENSO PATRIMONIO AMPLISSIMO, ACCEDENTIBUS ETIAM SUBSIDIIS FRIDERICI II. DANIÆ REGIS, regali magnificentia dignis, tracta per annos XXV, potissimùm in Insula freti SUNDICI HUENNA, & arce URANIBURGO, in hos usus à fundamentis extructâ:
TANDEM TRADUCTA IN GERMANIAM, INQUE AULAM ET Nomen RUDOLPHI IMP. anno MDIIC.

TABULAS IPSAS, JAM ET NUNCUPATAS, ET AFFECTAS, SED MORTE AUTHORIS SUI ANNO MDCI DESERTAS,
JUSSU ET STIPENDIIS FRETUS TRIUM IMPPP.
RUDOLPHI, MATTHIÆ, FERDINANDI,
ANNITENTIBUS HÆREDIBUS BRAHEANIS; EX FUNDAMENTIS observationum relictarum; ad exemplum ferè partium jam exstructarum; continuis multorum annorum speculationibus, & computationibus, primùm PRAGÆ Bohemorum continuavit; deindè LINCII, superioris Austriæ Metropoli, subsidiis etiam Ill. Provincialium adjutus, emendavit, perfecit, absolvit; adq; causarum & calculi perennis formulam traduxit
IOANNES KEPLERUS,
TYCHONI primùm à RUDOLPHO II. Imp. adjunctus calculi minister; indéq; trium ordine Imppp. Mathematicus:
Qui idem de speciali mandato FERDINANDI II. IMP. petentibus instantibúsq; Hæredibus,
Opus hoc ad usus præsentium & posteritatis, typis, numericis propriis, cæteris & prælo JONÆ SAURII, Reip. Ulmanæ Typographi, in publicum extulit, & Typographicis operis ULMÆ curator affuit.

Cum Privilegiis, IMP. & Regum Rerúmq; publ. vivo TYCHONI ejúsq; Hæredibus, & speciali Imperatorio, ipsi KEPLERO concesso, ad annos XXX.
ANNO M. DC. XXVII.

Astronomy: the original “Big Data" science

Charles Messier

French Astronomer (1730 -1817)

- At 14, he saw an unusually spectacular six-tailed comet and took an interest in astronomy
- Began working for the astronomer of the French Navy at age 21
- A career comet-hunter, using a 4” refracting telescope
- Along with his friend and assistant Pierre Mechain, he cataloged 110 non-stellar objects **“Messier Catalog”** (1781, 1784) of potential comets (“white nebulae”: mostly galaxies & star clusters, and “green nebulae”: emission line regions)
- Objects denoted as “M#”

Charles Messier

Pierre Mechain

Comet C/1743 X1, The Great Comet of 1744, or "Comet de Cheseaux-Klinkenberg", at 4am on March 9, 1744, showing six tails rising above the horizon, *The World of Comets* (London, 1877)

The Messier Objects

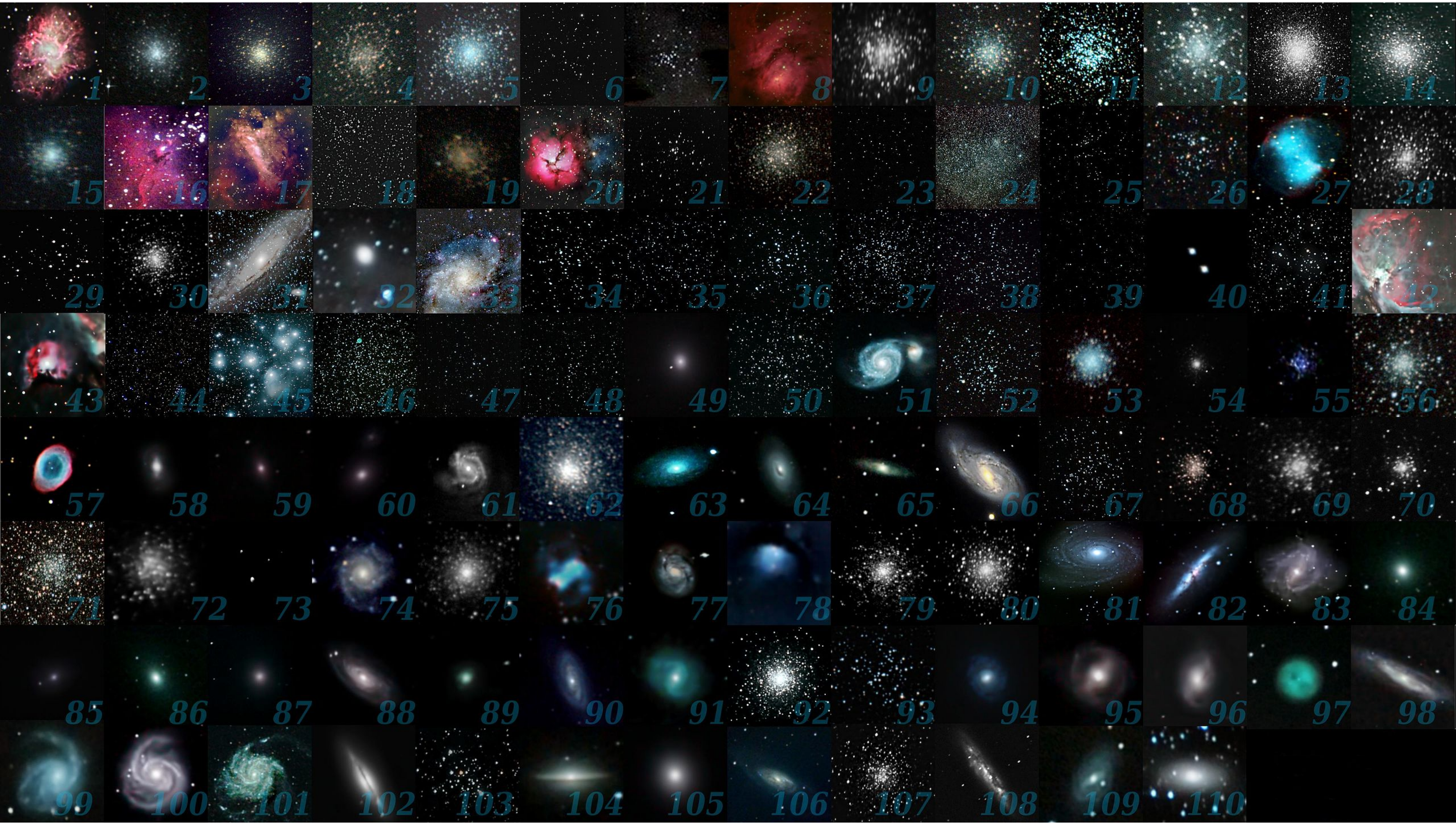
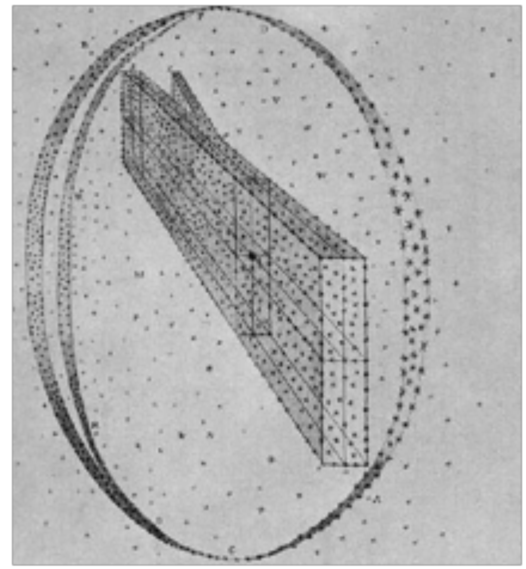


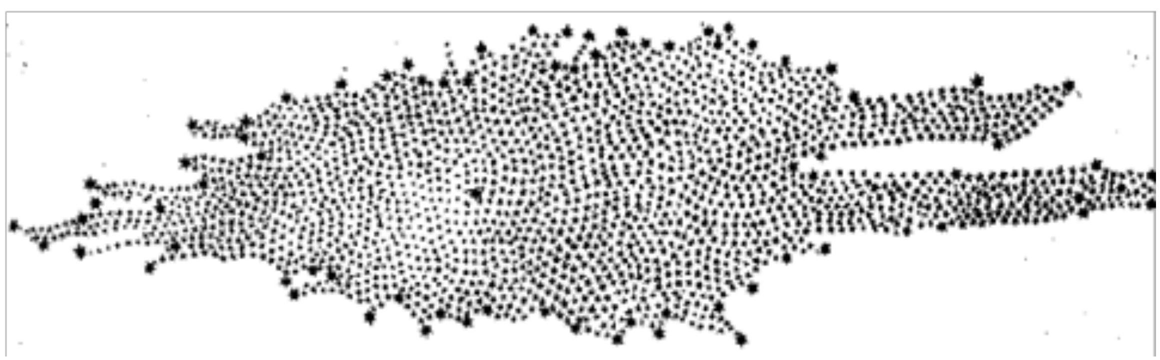
Image Credit: Michael A. Phillips

Britt Lundgren - UNC Asheville

Astronomy: the original “Big Data" science



The disk-like shape of the Milky Way, as drawn by German-British musician and astronomer **William Herschel (1738-1822).**

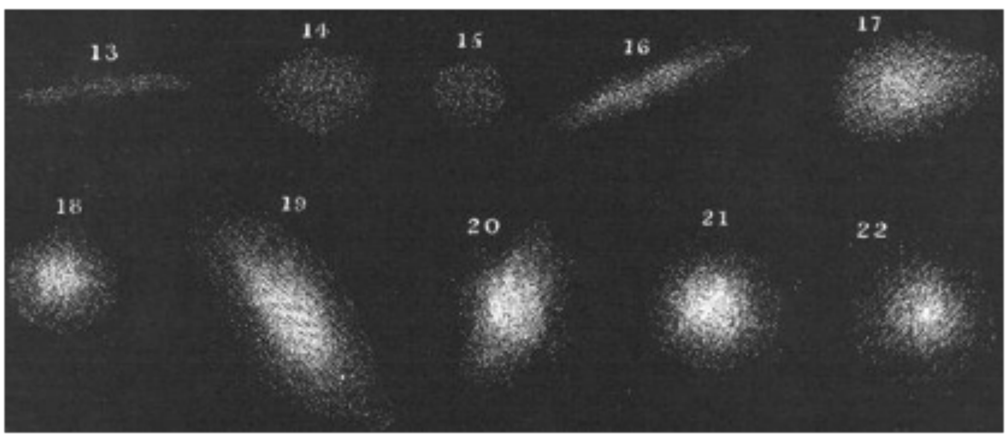


Astronomy:
the original "Big Data" science

An accomplished musician and composer, Herschel only started tinkering in astronomy in his late 30s (c. 1774).

He would go on to:

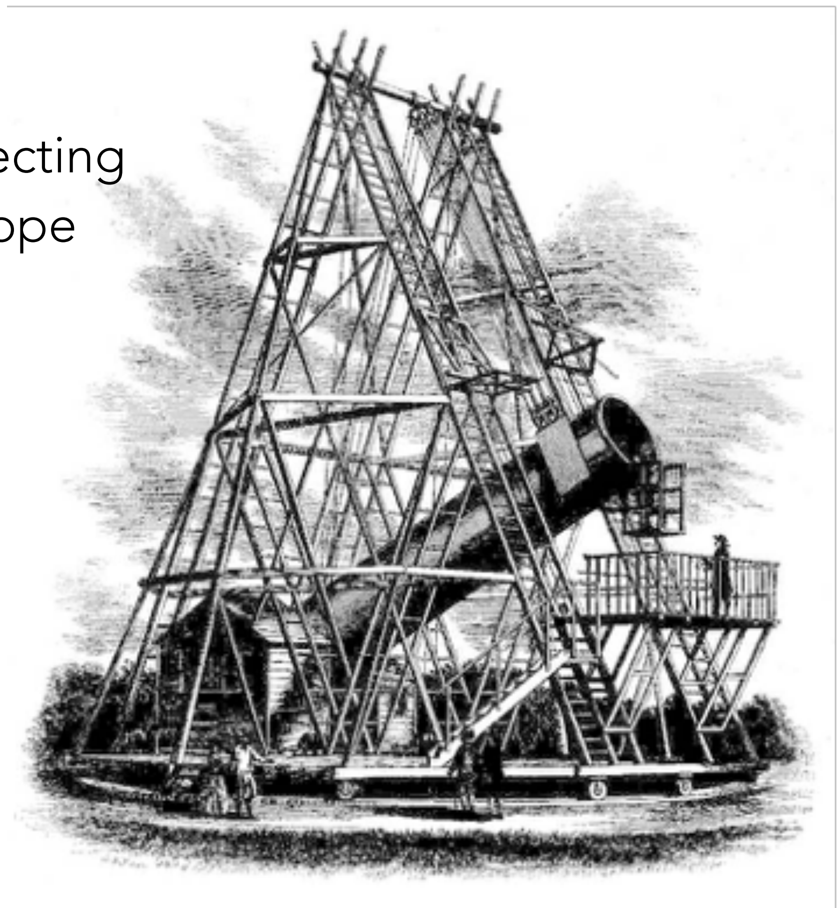
- Discover Uranus, four Jovian moons, AND infrared radiation
- Produce the survey of deep sky objects (nebulae)
- Become the first President of the Royal Astronomical Society



Astronomy: the original “Big Data" science

William Herschel and his sister Caroline built **reflecting** telescopes (the largest being 40 feet long) and the first large catalog of nebulae (galaxies).

48″ Reflecting telescope



Caroline Herschel

German-British Astronomer
(1750-1848)

NGC 7789:

”Caroline's Rose”

- The first woman to receive a salary for services to science (1787)
- The first woman to be awarded a Gold Medal of the Royal Astronomical Society (1828)
- The first woman to be named an Honorary Member of the Royal Astronomical Society (1835, with Mary Somerville).
- Named an honorary member of the Royal Irish Academy (1838).
- Presented with a Gold Medal for Science from the King of Prussia on the occasion of her 96th birthday (1846)

Astronomy: the original “Big Data" science

The Catalogue of Nebulae and Clusters of Stars (“CN”; 1786, 1802)

- Produced by William & Caroline Herschel
- 2500 objects, named “H#”

General Catalogue of Nebulae and Clusters of Stars (“GC”; 1864)

- John Herschel
- 5079 objects, named “GC#”

General Catalogue of Multiple and Double Stars (“hGC”)

- John Herschel (published after death)
- 10,300 entries (“h#”)

Astronomy:
the original “Big Data" science

New General Catalogue (“NGC”; 1888)

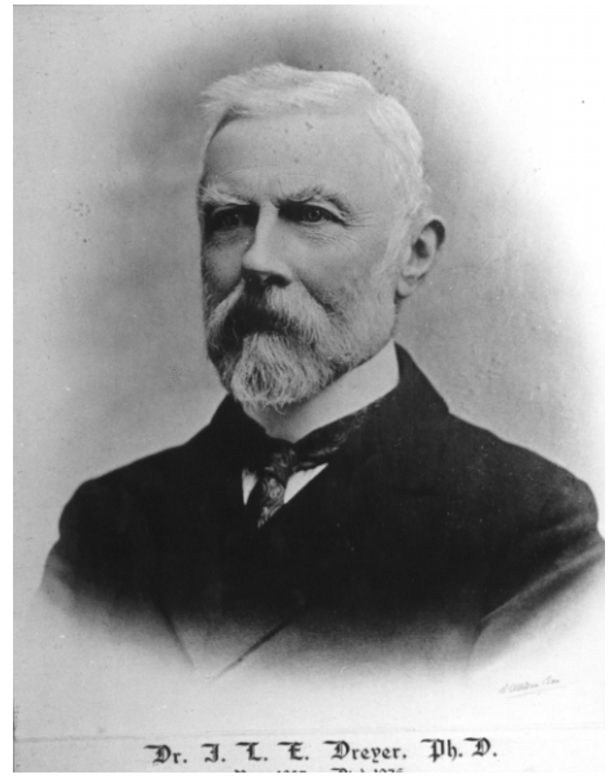
- John Louis Emil Dreyer
- expanded the GC
- 7,840 objects
- galaxies, star clusters, & nebulae

Index Catalogues (“IC”; 1895, 1908)

- John Louis Emil Dreyer
- 5,386 additional objects

Corrected & revised multiple times (most recently “NGC 2000.0”, 1988)

- Roger Sinnott



Danish-Irish Astronomer **John Louis Emil Dreyer**
(February 13, 1852 – September 14, 1926)

Astronomy:
the original “Big Data" science

Four planetary nebulas from the first systematic survey of such objects in the solar neighborhood made with NASA's Chandra X-ray Observatory.

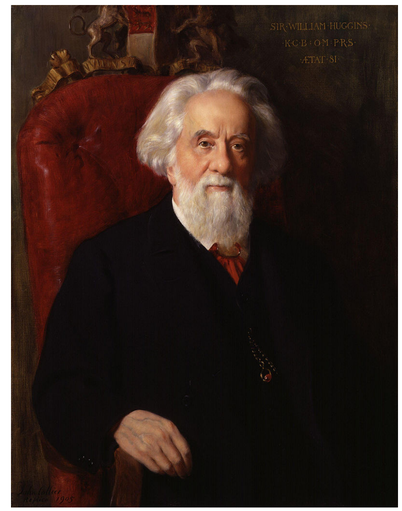
Shown on left: NGC 6543 (the Cat's Eye), NGC 7662, NGC 7009 and NGC 6826. In each case, X-ray emission from Chandra is colored purple and optical emission from the Hubble Space Telescope is colored red, green and blue.

Credit: NASA/CXC/STScI

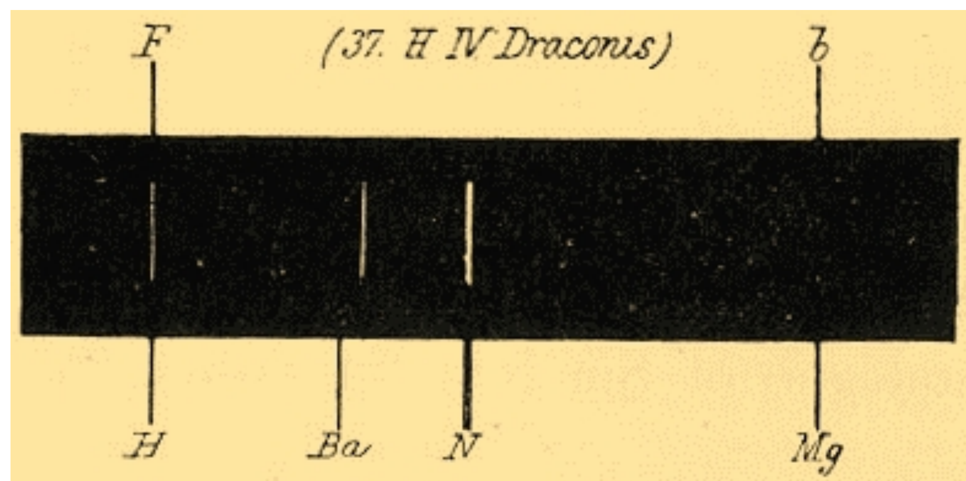
Pioneers of Photographic Spectroscopy

- Husband-wife team Huggins & Murray capture the first photographic spectra of planetary nebulae using an 8″ refracting telescope at their home observatory in London

- Published the **Atlas of Representative Stellar Spectra** (1899)



English and Irish Astronomers
Sir William Huggins (1824 – 1910) and **Margaret Lindsay Murray** (1848-1915)



Pioneers of Photographic Spectroscopy

"AN ATLAS OF REPRESENTATIVE STELLAR SPECTRA."*—A REVIEW.

By W. W. Campbell.

This is the title of "Publications of Sir William Huggins's Observatory, Vol. I.," by Sir William Huggins, K. C. B., and Lady Huggins, issued in March, 1900. Outwardly, the volume is a masterpiece of the bookmaker's art. It is doubtful if any other astronomical book of this century is so

*Published by Wm. Wesley & Son, London. £1 5s net.

truly an *édition de luxe*. In addition to thirteen half-sheet page of celestial spectrograms, there are splendid photographic illus trations of the observatory and its instruments; and the charm of the book is greatly enhanced by some fifteen headpieces anc initials exquisitely sketched by the pen of Lady Huggins. The pleasure of the reader is increased by these evidences that the beautiful in astronomy has not escaped the esthetic sense of the authors.

These external charms have their counterparts in the text. I is a record of pioneer work in stellar spectroscopy, written ir sufficient detail to interest the technical astrophysicist, but ir language so simple that the general reader can comprehenc equally well.

Sir William Huggins's observatory, founded in London in 1856, contained at first a five-inch Dolland telescope, which was replaced by an eight-inch Clark in 1858. His work was mainly in the line of physical observations of the planets. Kirchhoff's discovery of the significance of the Fraunhofer spectrum-lines in 1859 attracted Huggins's attention to the possibility of applying these newly discovered principles to the study of the stars. Inviting Dr. Miller, Professor of Chemistry in King's College, to join him in the work, these gentlemen constructed a small spectroscope and attached it to the eight-inch refractor; and their great work of laying the foundations of the spectroscopic astronomy began at once. "The observatory became a meeting-place where terrestrial chemistry was brought into direct touch with celestial chemistry. The characteristic light-rays from terrestrial hydrogen shone side by side with the corresponding radiations from starry hydrogen, or else fell upon the dark lines due to the absorption of hydrogen in *Sirius* or in *Vega*. Iron from our mines was matched, light for dark, with stellar iron from opposite parts of the celestial sphere. Sodium, which upon the Earth is always present with us, was found to be widely diffused through the celestial spaces.

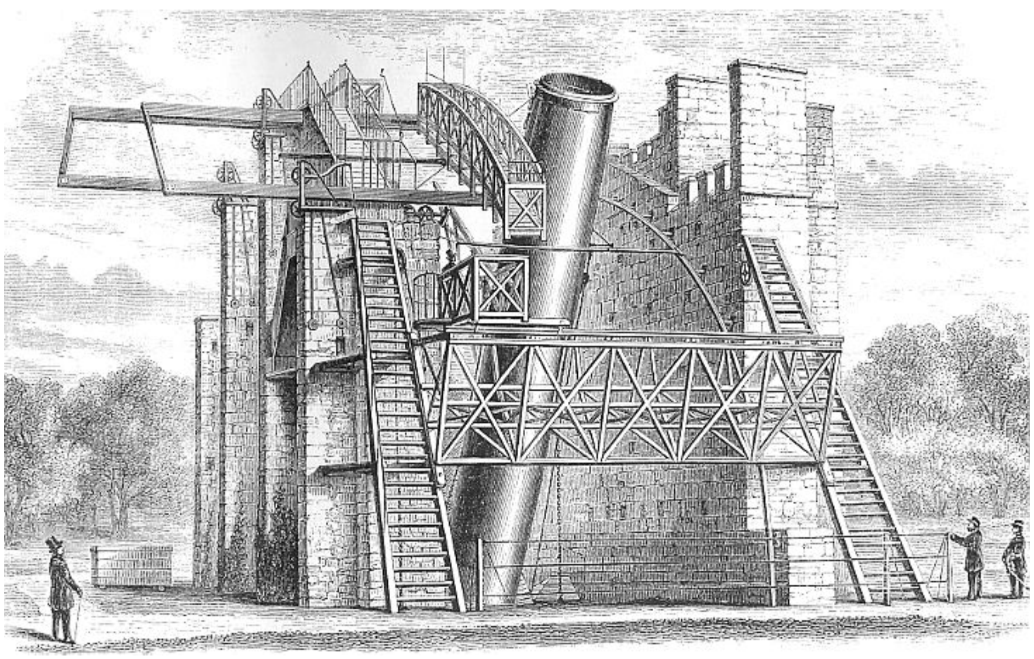
"The time was, indeed, one of strained expectation and of scientific exaltation for the astronomer, almost without parallel; for nearly every observation revealed a new fact, and almost every night's work was red-lettered by some discovery."

Publications of the Astronomical Society of the Pacific, Vol. 12, No. 76, p.246 - December 1900

Astronomy:
the original “Big Data" science

- Resolved the spiral structure of some “nebulae”
- **Observations of Nebulae and Clusters of Stars Made With the Six-foot and Three-foot Reflectors at Birr Castle From the Year 1848 up to the Year 1878** (Published 1878)

Anglo-Irish Astronomer **William, 3rd Earl of Rosse**
(1880 – 1867)



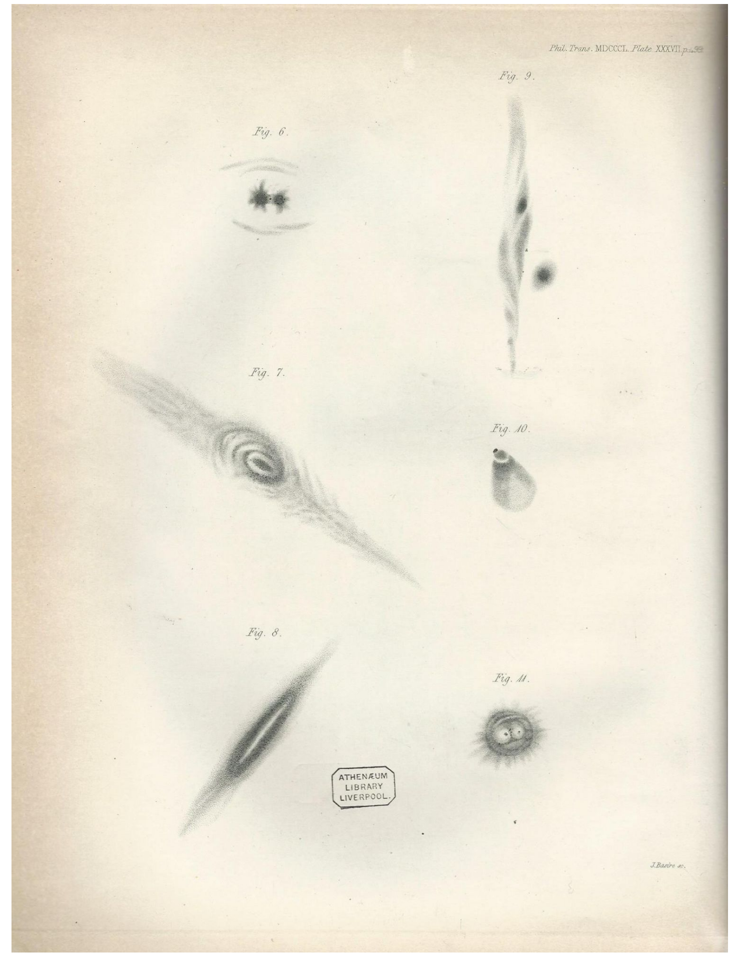
The largest telescope of the 19th century, the 72” reflector
known as the “Leviathan of Parsonstown”

Astronomy: the original “Big Data" science

William & Caroline Herschel had cataloged thousands of nebulae by the 1800s.

William Parsons, Edwin Hubble, and others had made detailed observations with more powerful telescopes by the early 1920s.

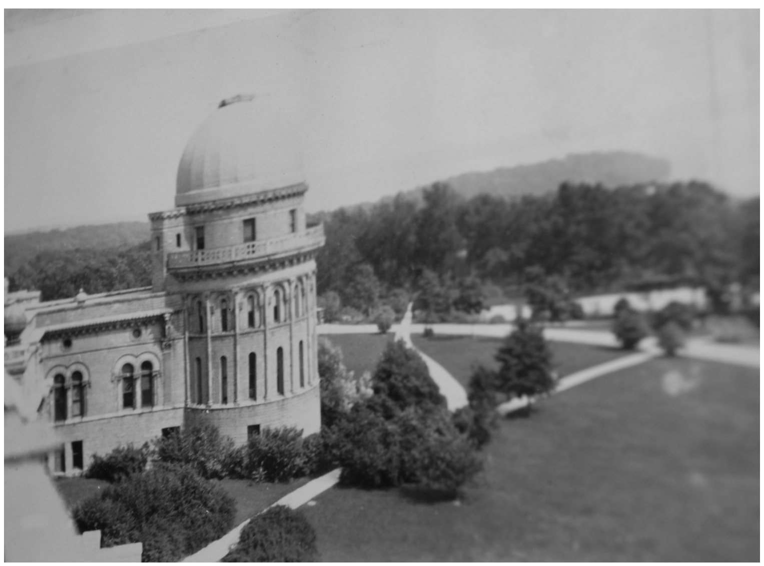
Still, the origin of the spiral ”nebulae” remained a mystery.



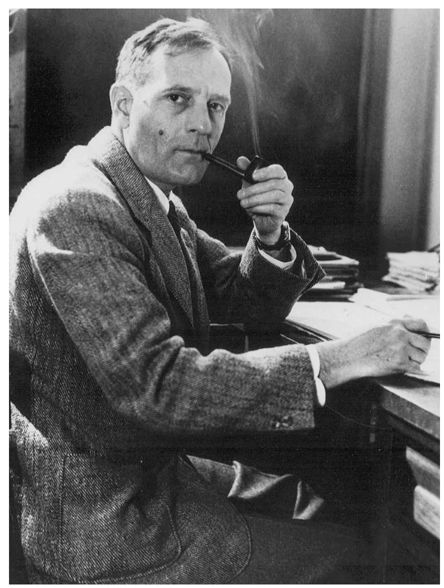
FIRST SPIRAL NEBULAE OBSERVATION: "Observations on the Nebulae" (Philosophical Transactions of the Royal Society of London, Vol. 140 for the Year 1850 Part II, pp. 499-514). William Parsons, Earl of Rosse.

Astronomy:
the original “Big Data" science

- Edwin Hubble completes graduate research at Yerkes Observatory - 1912
- **“Photographic Investigations of Faint Nebulae”** (1920)
- A statistical study of some of the ~17,000 known nebulae



Yerkes Observatory, Williams Bay, WI
(Photo Credit: Ethel Fisher)



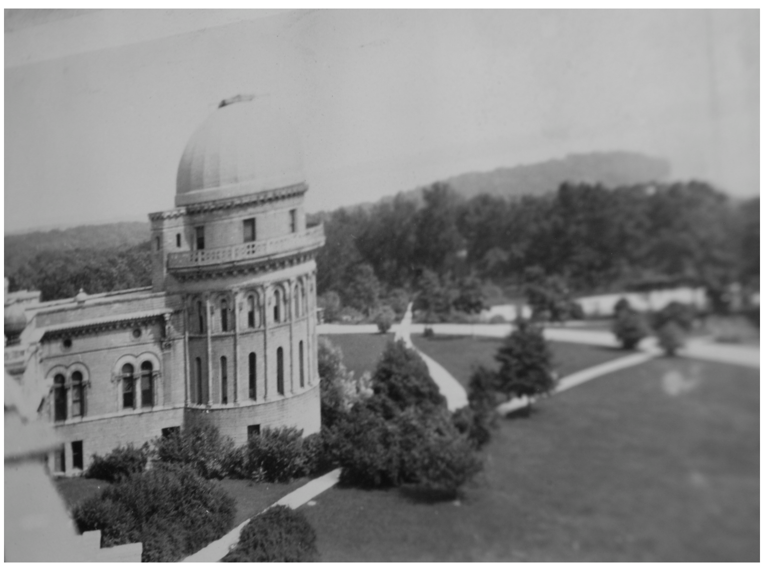
Edwin Hubble

24” Reflector

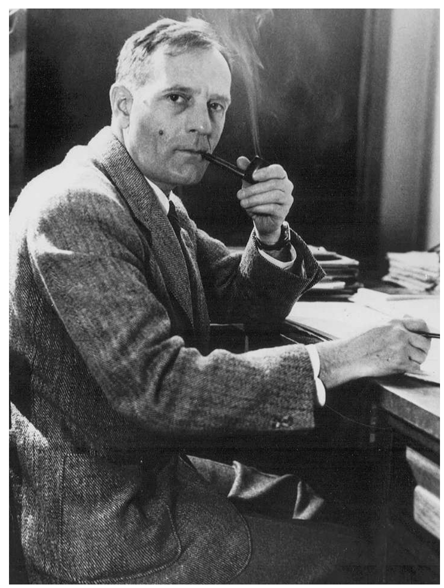
Astronomy:
the original “Big Data" science

“Since 1907 the numbers of nebulae recorded on photographs have increased so rapidly that the compilation of general catalogues is neither practical nor important. Many lists have been made for special purposes, but only one that covers the entire sky in a homogeneous manner (The Harvard Survey - 1932)… Individual, uncatalogued nebulae are designated by their positions in the sky, or with reference to some object whose coordinates are generally known. “

Edwin Hubble, *The Realm of the Nebulae* (1936)



Yerkes Observatory, Williams Bay, WI
(Photo Credit: Ethel Fisher)



Edwin Hubble

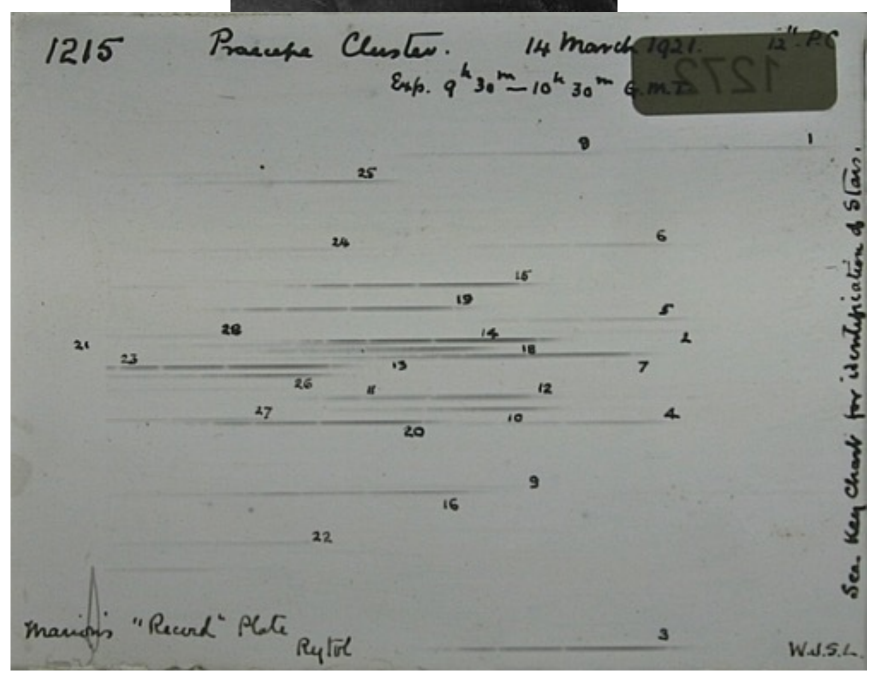
24” Reflector

Astronomy:
the original “Big Data" science

Edward Charles Pickering

American Astronomer, Harvard University
(1846-1919)

- Graduated from Harvard in 1865
- Director of Harvard College Observatory (1877-1919)
- Developed a method for photographing the spectra of multiple stars simultaneously on glass plates using a prism
- The new method gathered data so quickly he needed to hire a team of analysts.



Willamina Fleming

Scottish-American Astronomer, Harvard University (1857-1911)

- Harvard astronomer Edward Pickering was often frustrated with the performance of the (all-male) "computers" at the observatory and, reportedly, would complain loudly: "My Scottish maid could do better!"

- Fleming became Pickering's first female computer. She oversaw the first system for classifying stars based on the strength of their Hydrogen lines.

- The first American woman to be made an honorary member of the Royal Astronomical Society of London

Edward Pickering and the Harvard Observatory “Computers” in 1913

Image Credit: Harvard College Observatory

The Harvard Observatory “Computers” (~1890)

Image Credit: Harvard College Observatory

Astronomy: the original “Big Data" science

Henry Draper Catalogue (“HD”; 1918, 1924)

- Compiled by Pickering + Harvard “Computers”
- spectroscopic classifications for 225,300 stars
- funded by Henry Draper’s widow and astronomy collaborator, Mary Anna Palmer

American Doctor & Amateur Astronomer
Henry Draper
(1837-1882)

American Philanthropist & Amateur Astronomer
Mary Anna Palmer Draper
(1839-1914)

Astronomy:
the original “Big Data" science

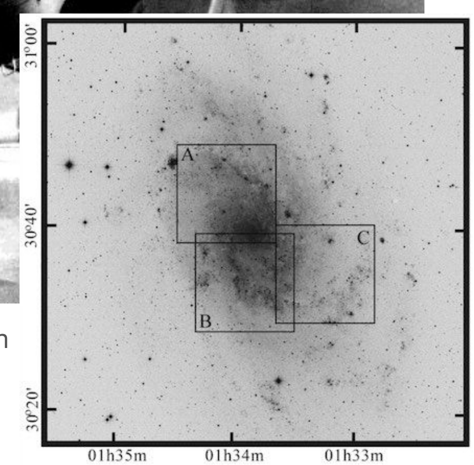
National Geographic Society - Palomar Observatory Sky Survey (“NGS-POSS”; 1949 - 1958)

- 1,872 14”x14” Photographic plates mapping the sky
- Obtained by the 48” Samuel Oschin telescope at Palomar Observatory
- Designed by Hubble, Humason, Baade, Bowen, & Minkowski

Digitalized Sky Survey (“DSS”, 1986 - 1994)

- Scanning & digitalization of the NGS-POSS
- 89 million objects identified
- 102 CD-ROMs

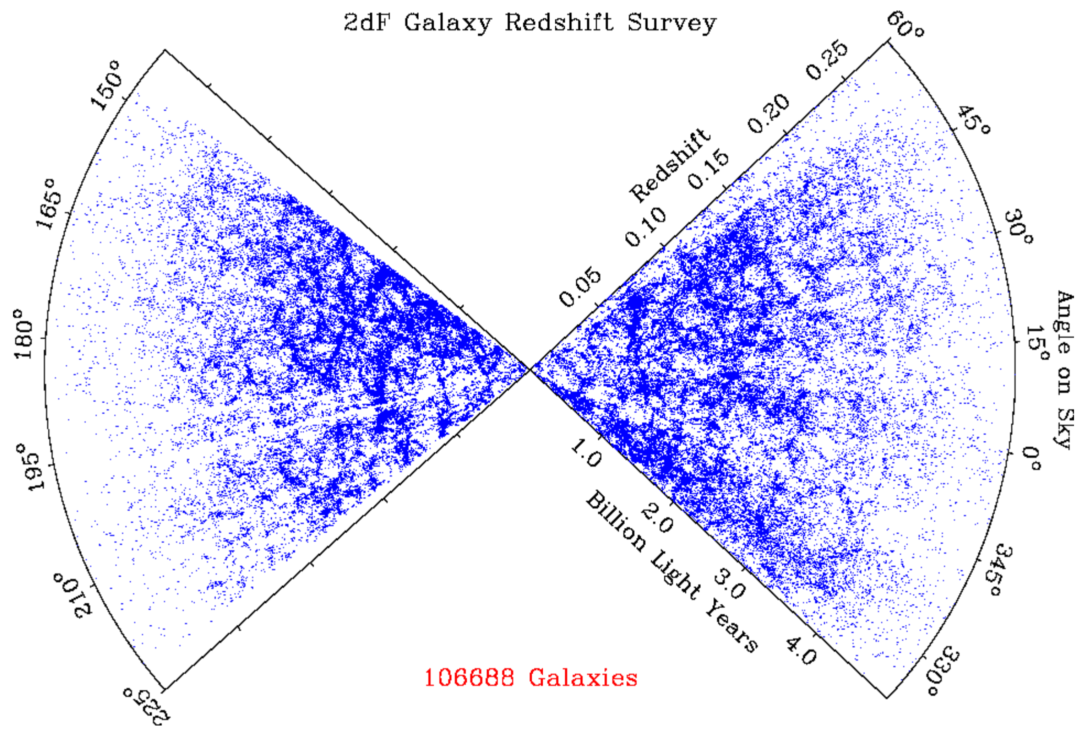
Edwin Hubble at Caltech Palomar Samuel Oschin 48 inch Telescope, (credit: Emilio Segre Visual Archives/AIP/SPL)

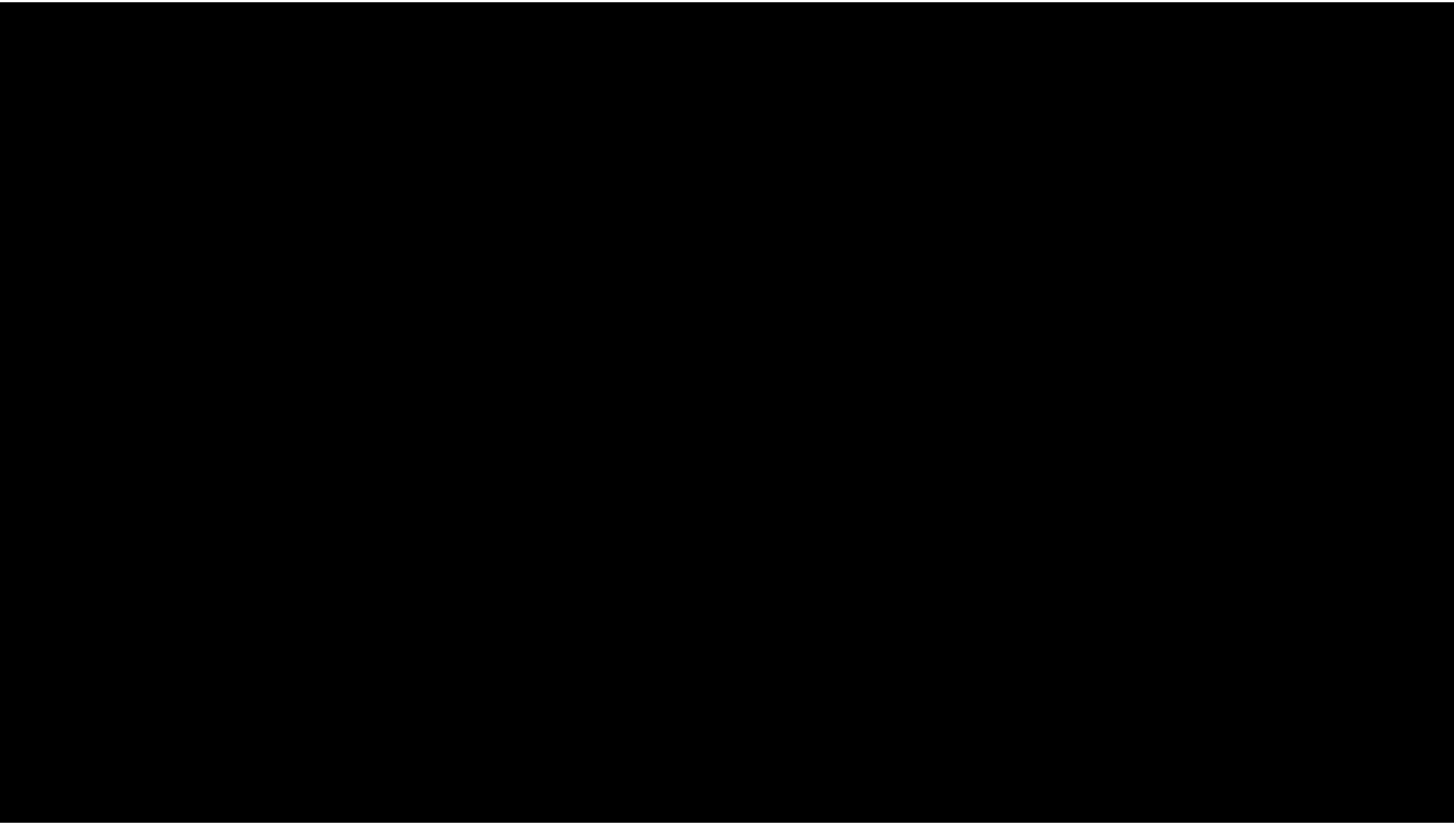


Astronomy:
the original “Big Data" science

2 Degree Field Redshift Survey
(“2dF”; 1997 - 2002)

- 3.9m Anglo-Australian Telescope (272 nights over 5 years)
- 1500 square degrees
- photometry for 382,323 objects
- spectra for 245,591 objects
    - 232,155 galaxies
    - 12,311 stars
    - 125 quasars
- Measured large scale structure out to redshift 0.2 (2.5 Billion light years)





https://youtu.be/ItgCiRrpZ2M

The Sloan Digital Sky Survey

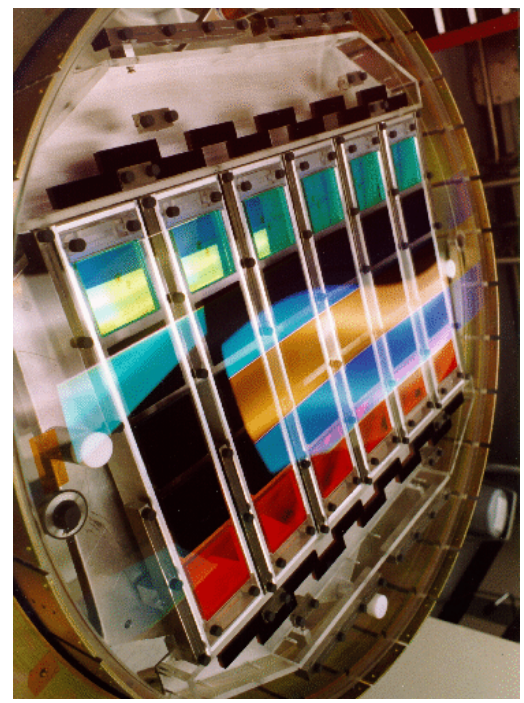
An international collaboration of hundreds of scientists and technicians, working together to **map in 3D & study**:

- the compositions of stars in the Milky Way Galaxy,
- the compositions and kinematics of other nearby galaxies, and
- the large-scale structure and expansion history of the Universe.

SDSS-IV Collaboration Meeting - Santiago, Chile - 2017

The Sloan Digital Sky Survey I/II 2000-2008

- Dedicated 2.5m Sloan Telescope at Apache Point Observatory, New Mexico, USA
- 120 megapixel camera with 5 filters: u,g,r,i,z
- Multi-object spectrograph (640 fibers)
- 8-year survey to map 1/4 of the night sky
  - **Imaging** for 10,000 square degrees of sky
  - **Spectra** of 930,000 galaxies, 106,000 quasars

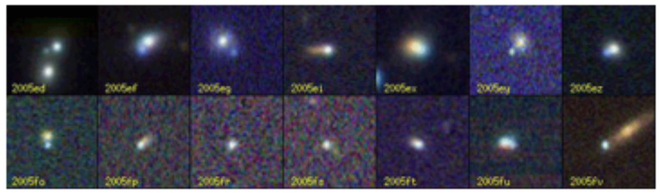


The Sloan Digital Sky Survey I/II 2000-2008

Legacy

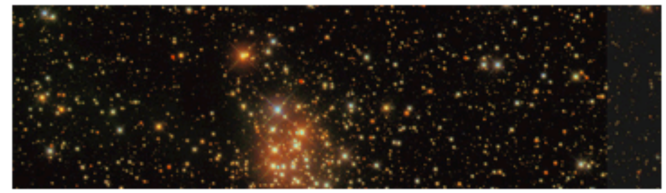
The original SDSS observing plan, which ran from 2000 to 2008, is now known as the SDSS Legacy Survey. It resulted in a uniform, well-calibrated map of the Universe that will be used for decades to scientific studies ranging from asteroids to the large-scale structure of the Universe.

Supernova



The SDSS Supernova Survey, which ran from 2005 to 2008, performed repeat imaging of one stripe of sky along the celestial equator. The project discovered more than 500 type Ia supernovae, which have led to a deeper understanding of the history of the Universe.

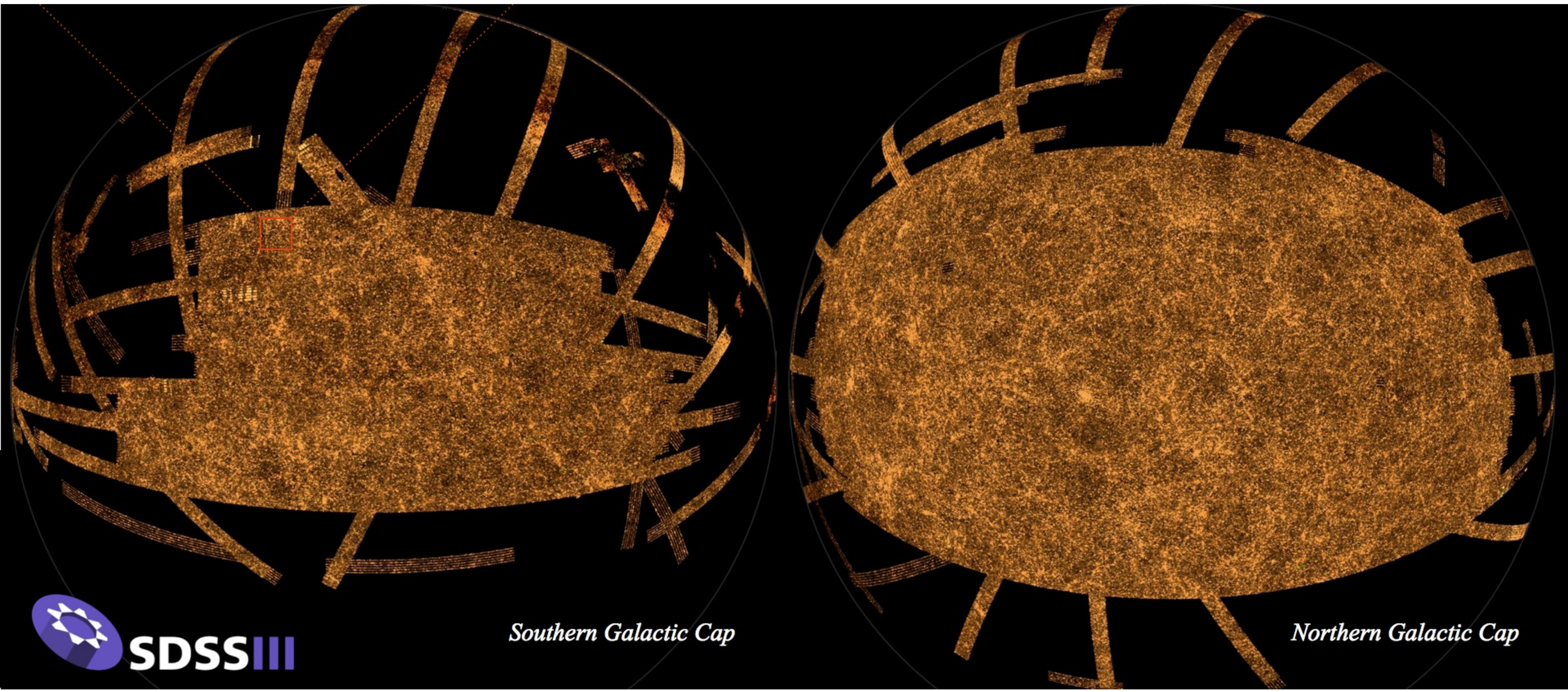
SEGUE-1



The primary goal of SEGUE-1 was the kinematic and stellar population study of the high-latitude thick disk and halo of the Milky Way.

The Sloan Digital Sky Survey I/II
2000-2008

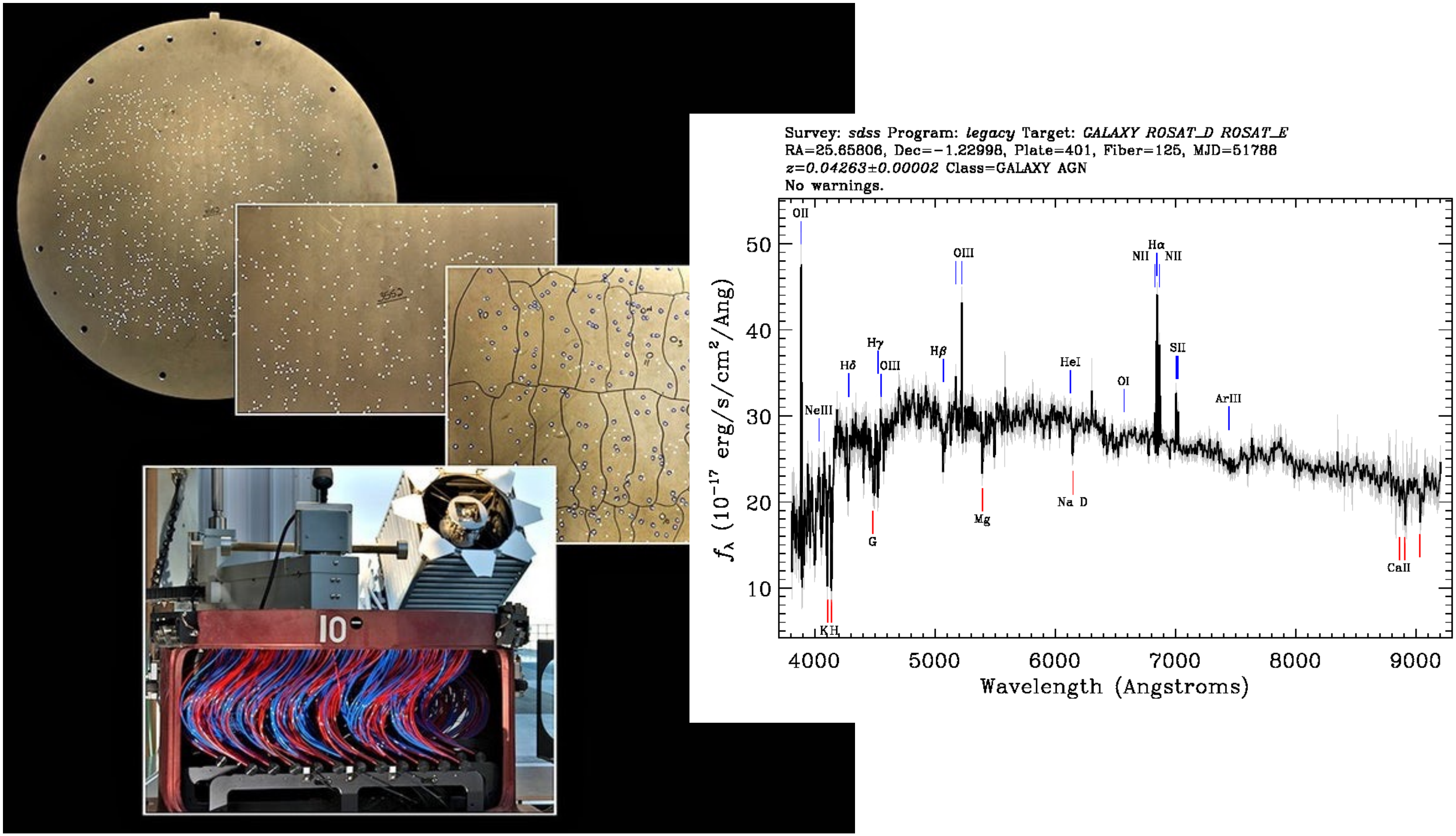
The largest color image of the night sky ever made!
(>30% of the entire sky visible from Earth)



The SDSS camera in its current home: a basement of the Smithsonian Museum in Washington, D.C.

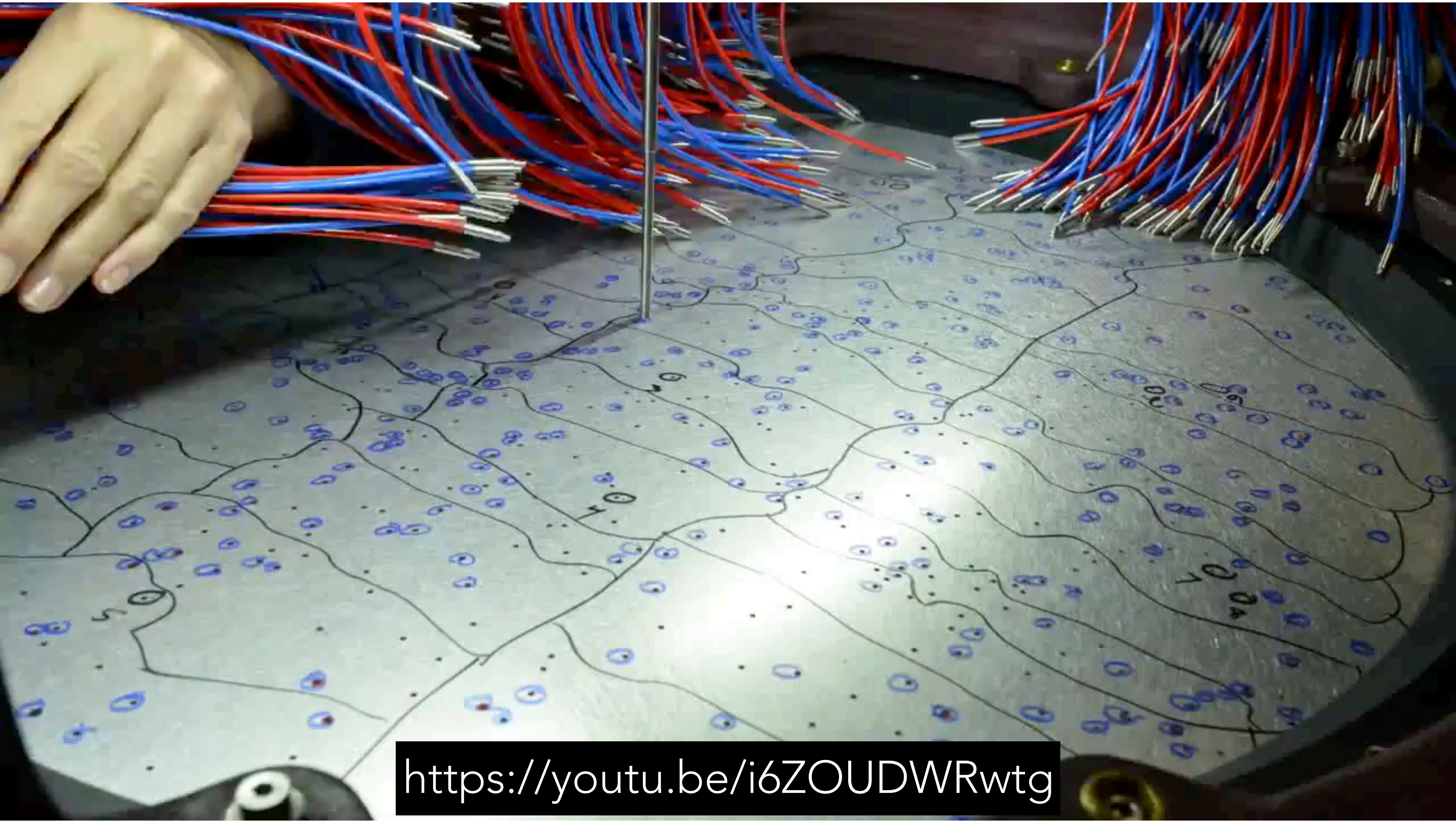
Image Credit: Xavier Poultney, SDSS.

The SDSS multi-object spectrograph is the key to making these maps 3D, and <u>fast</u>!



A visualization of the 3D structure behind BOSS plate 6640 based on redshifts measured by SDSS. Image credit: David Kirkby.

The SDSS multi-object spectrograph is the key to making these maps 3D, and fast!



The SDSS multi-object spectrograph is the key to making these maps 3D, and <u>fast</u>!

In good weather months, SDSS-IV observers need to plug more than 100 plates (>100,000 fibers!)

https://youtu.be/iYyO7pGaJNw

https://youtu.be/AHsS57NMQjE

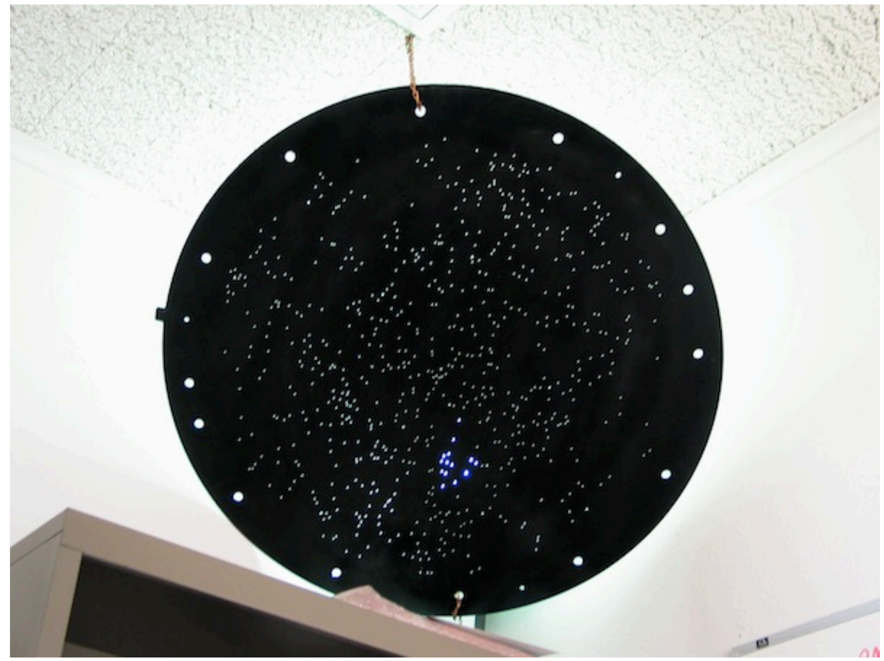
https://youtu.be/08LBltePDZw

Plates for Education:

where SDSS plates go to retire!

Britt Lundgren - UNC Asheville

Coffee table with under lighting by Brian Lee from SDSS-II.

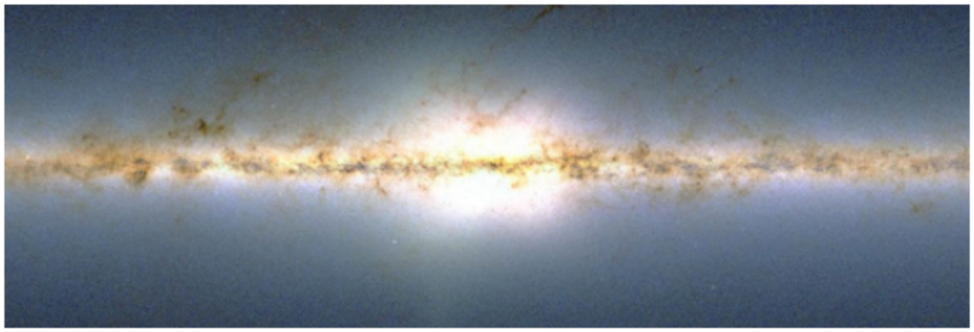


Mounted in the corner of Mark Klaene's office at APO. It is spray painted black with a fluorescent desk lamp back light.

Sculpture by Josiah McElheny using SDSS plug plate. Image provided by David Weinberg.

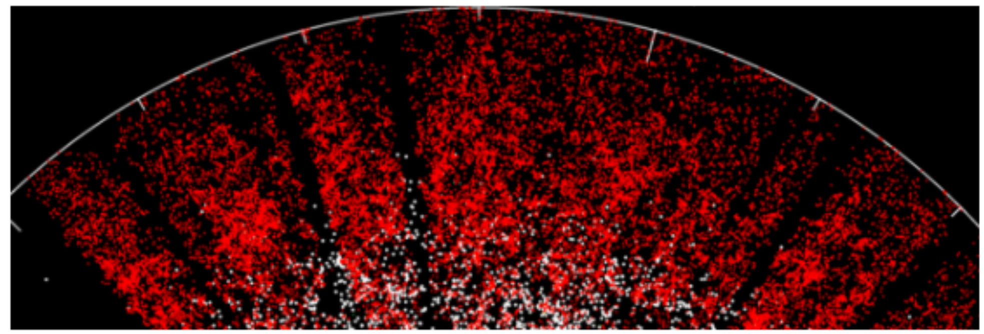
The Sloan Digital Sky Survey III 2008-2014

APOGEE



The Apache Point Observatory Galactic Evolution Experiment (APOGEE) focuses on the structure and evolution of our own Milky Way galaxy using high-resolution infrared spectroscopy.

BOSS

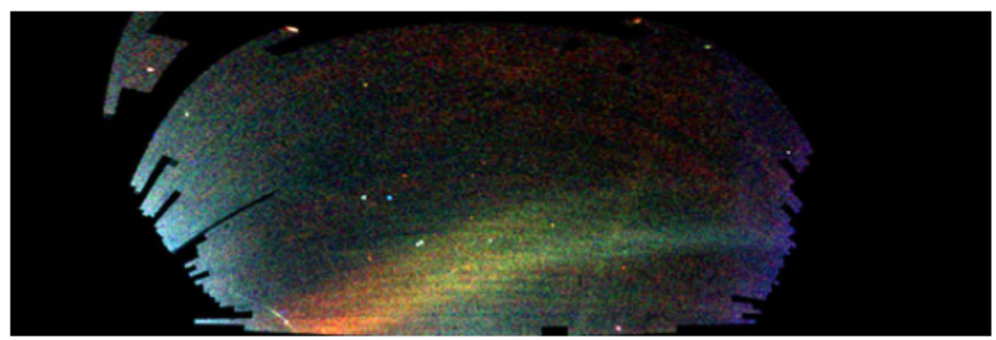


The Baryon Oscillation Spectroscopic Survey (BOSS) focused on mapping the Universe on the largest scales, creating the largest volume three-dimensional map of galaxies to date and measuring the scale of the Universe to one percent.

MARVELS

The Multi-Object APO Radial Velocity Exoplanet Large-area Survey (MARVELS) searches very nearby stars for evidence of "exoplanets" surrounding them.

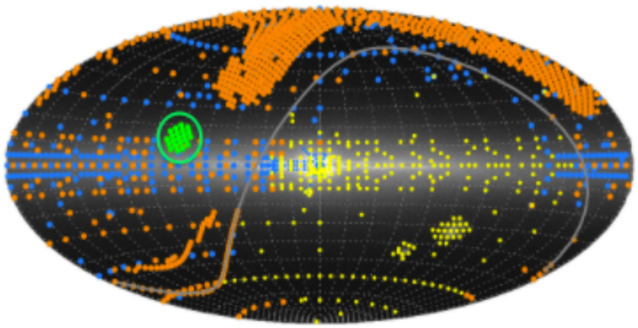
SEGUE-2



The Sloan Extension for Galactic Understanding and Exploration (SEGUE) focuses on the structure and evolution of our own Milky Way galaxy. The SEGUE-2 survey builds off of the work of SEGUE-1.

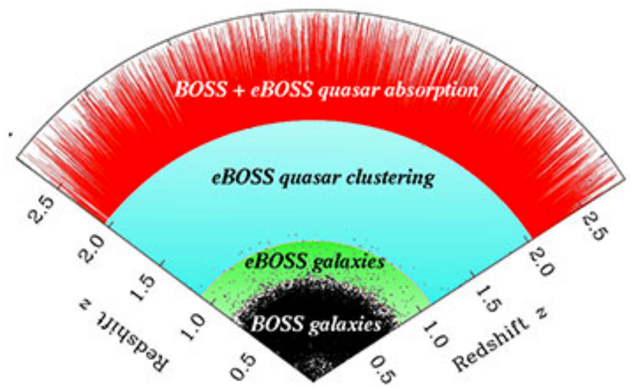
The Sloan Digital Sky Survey IV
2014-2019

APOGEE-2



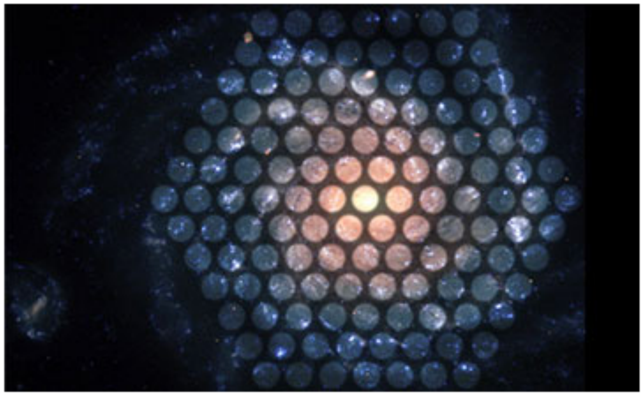
A stellar spectroscopic survey of the Milky Way, with two major components: a northern survey using the bright time at APO, and a southern survey using the 2.5m du Pont Telescope at Las Campanas.

eBOSS



A cosmological survey of quasars and galaxies, also encompassing subprograms to survey variable objects (TDSS) and X-Ray sources (SPIDERS).

MaNGA

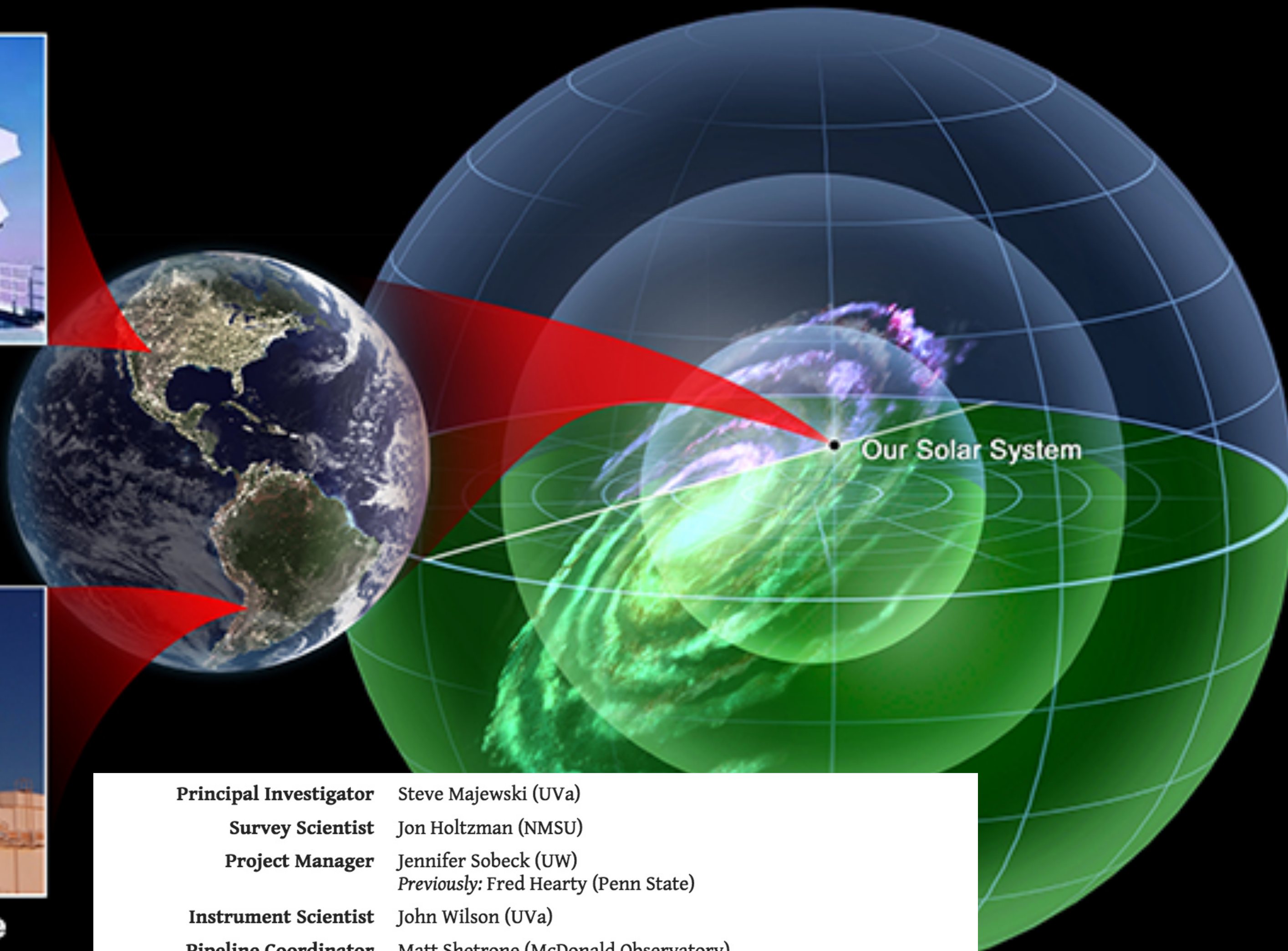


The galaxy survey for people who love galaxies! MaNGA (Mapping Nearby Galaxies at Apache Point Observatory) will explore the detailed internal structure of nearly 10,000 nearby galaxies using spatially resolved spectroscopy.

APOGEE-2
Mapping the Milky Way from both Hemispheres

Sloan Foundation Telescope
New Mexico, U.S.A.

du Pont Telescope
Chile

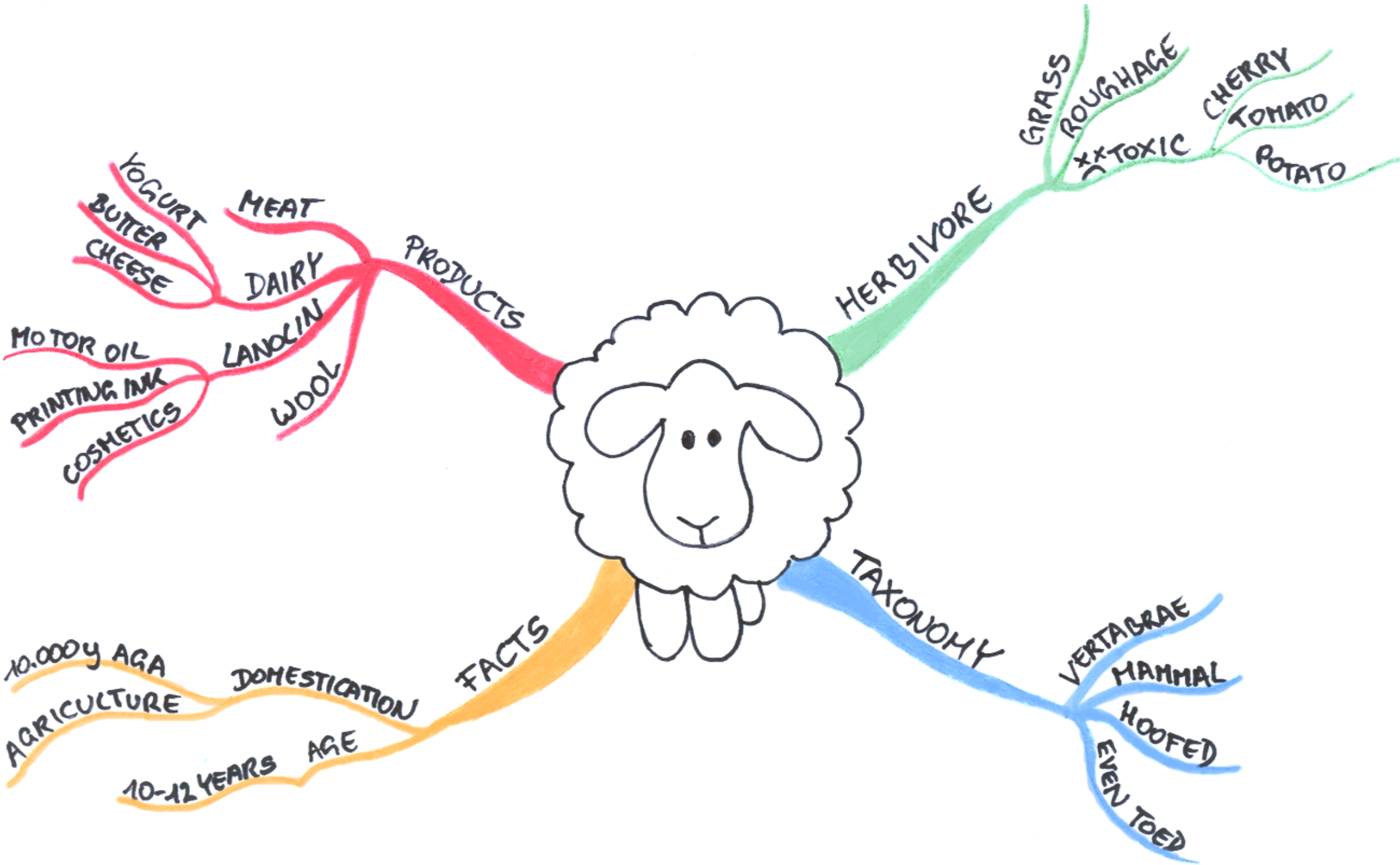


Principal Investigator	Steve Majewski (UVa)
Survey Scientist	Jon Holtzman (NMSU)
Project Manager	Jennifer Sobeck (UW) *Previously:* Fred Hearty (Penn State)
Instrument Scientist	John Wilson (UVa)
Pipeline Coordinator	Matt Shetrone (McDonald Observatory)
Target Selection Coordinators	*North:* Ryan J. Oelkers (Vanderbilt); *South:* José Fernández Trincado (Universidad de Concepción); *Special Targets & External Programs:* Kevin Covey (WWU)
Survey Operations Scientists	*North:* Nathan De Lee (Northern Kentucky University); *South:* Penélope Longa-Peña (Universidad de Antofagasta)
LCO Operations Manager	Christian Nitschelm (Universidad de Antofagasta)

MILLIONS OF OBJECTS… MULTIPLE PROJECTS AND INSTRUMENTS…

WHERE TO START?

Mind Maps



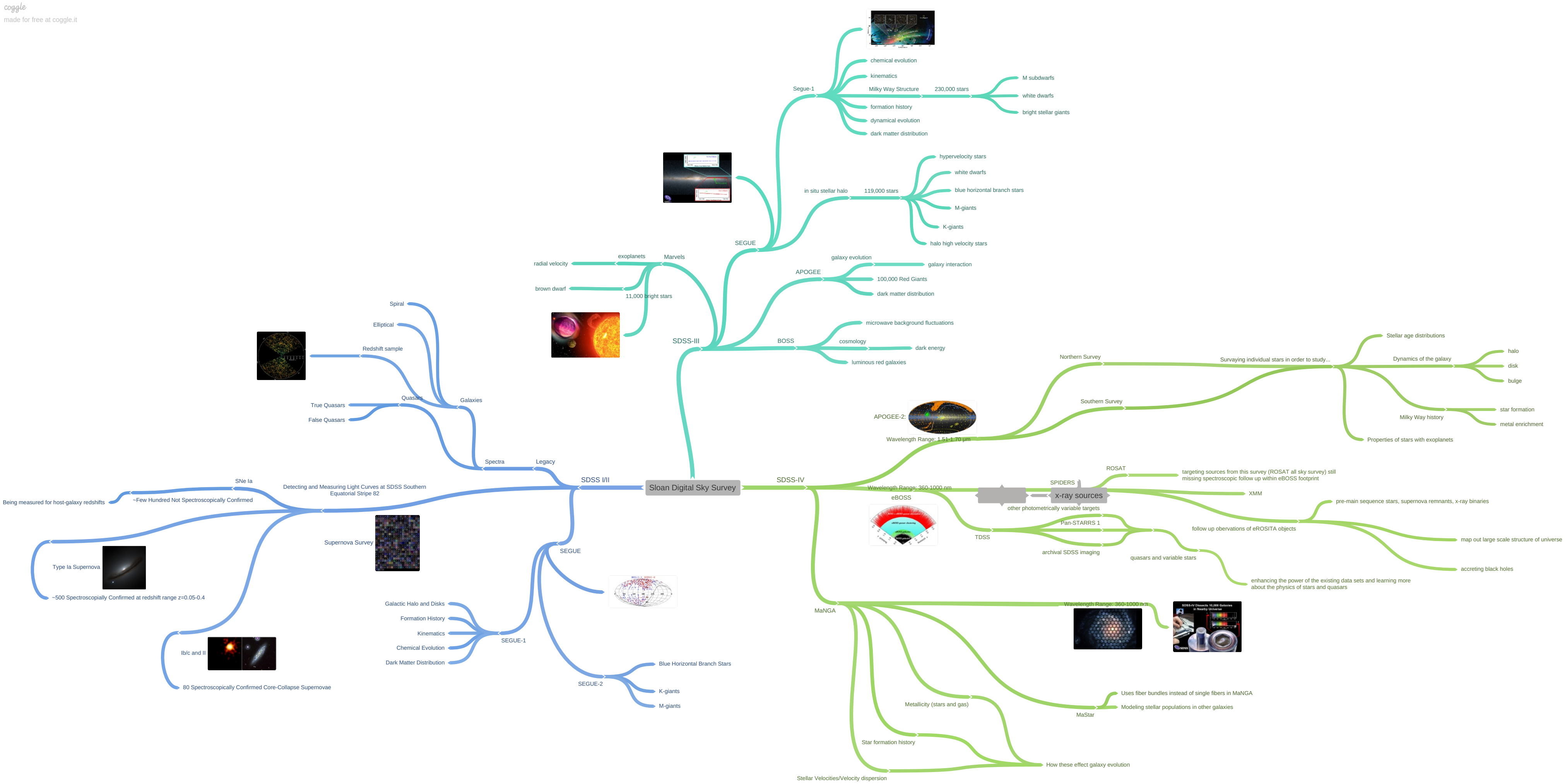
PRODUCTS
MEAT
DAIRY
YOGURT
BUTTER
CHEESE
LANOLIN
MOTOR OIL
PRINTING INK
COSMETICS
WOOL
HERBIVORE
GRASS
ROUGHAGE
TOXIC
CHERRY
TOMATO
POTATO
FACTS
DOMESTICATION
10.000 y AGA
AGRICULTURE
AGE
10-12 YEARS
TAXONOMY
VERTABRAE
MAMMAL
HOOFED
EVEN TOED

MIND-MAPPING: SURVEY PROJECTS & TIMELINE

Make & share, using:

https://coggle.it/

MIND-MAPPING:
SURVEY INSTRUMENTS & DATA



Britt Lundgren - UNC Asheville

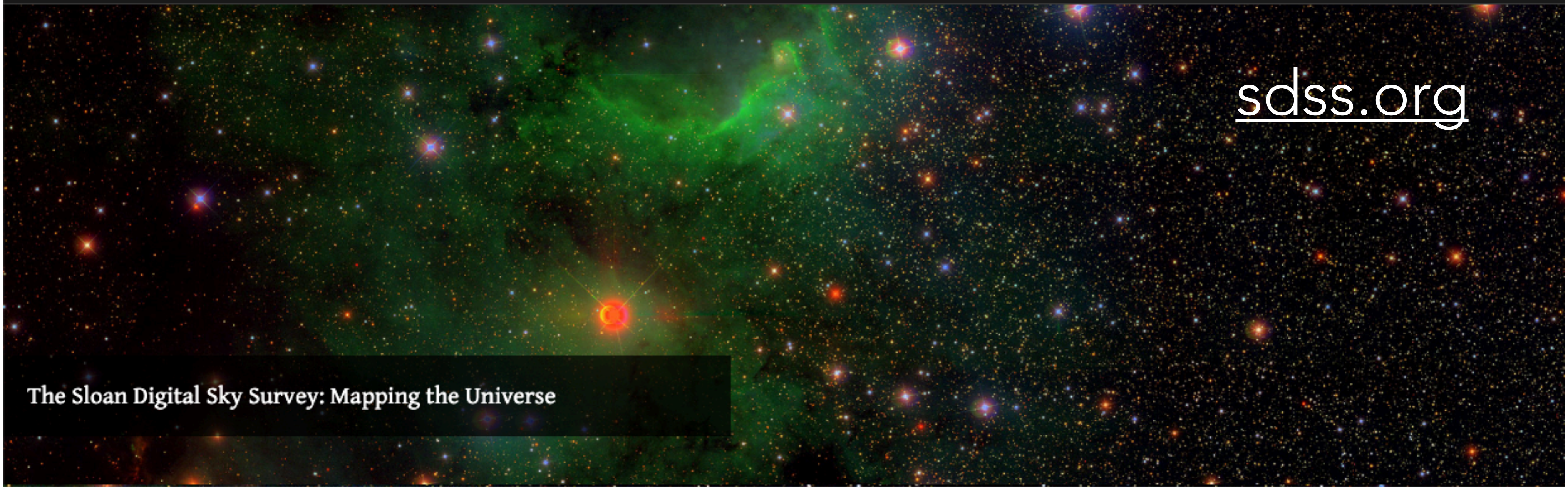
MIND-MAPPING: WEBSITE & DATA ACCESS

SDSS

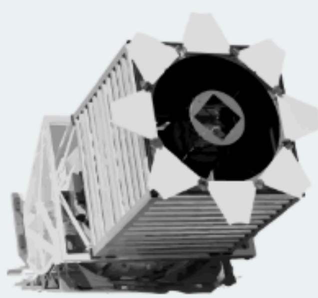
This is Data Release 16.

Data | Surveys | Instruments | Collaboration | Results | Education | The Future | Contact

Search www.sdss.org Search



The Sloan Digital Sky Survey has created the most detailed three-dimensional maps of the Universe ever made, with deep multi-color images of one third of the sky, and spectra for more than three million astronomical objects. Learn and explore all phases and surveys—past, present, and future—of the SDSS.



EXPLORE OUR DATA

Go to Data Access

Current data: Data Release 16

News

SDSS Press Releases

Don't judge a galaxy by its cover: Astronomers develop new tool to find merging galaxies

SDSS

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Datasets | Imaging Data | Optical Spectra | APOGEE IR Spectra | MaStar Library | MaNGA IFU Spectra | Algorithms | Help | Tutorials

Data Release 16

Data Release 16 (DR16) is the fourth data release of the fourth phase of the Sloan Digital Sky Survey (SDSS-IV). DR16 contains SDSS observations through August 2018.

DR16 includes the following:

- ✩ The latest and final data release of optical spectra from the SDSS component extended Baryon Oscillation Spectroscopic Survey (eBOSS), including the spectra of the SPectroscopic IDentfication of ERosita Sources (SPIDERS) survey and Time Domain Spectroscopic Survey (TDSS).
- ✩ The latest infrared spectra of the SDSS component Apache Point Observatory Galaxy Evolution Experiment 2 (APOGEE-2), including the first public release of spectra taken at Las Campanas Observatory (APOGEE-2 South) as well as newly improved data tutorials
- ✩ The most current data cubes from integral field unit (IFU) spectroscopic observations of nearby galaxies from the SDSS component Mapping Nearby Galaxies at APO (MaNGA), as well as the first data products and maps from the MaNGA Data Analysis Pipeline (DAP)
- ✩ The most current optical stellar spectra of the MaNGA Stellar Library program (MaStar)
- ✩ Marvin: a new tool to visualise and analyse MaNGA datacubes and maps
- ✩ Value Added Catalogs (VACs) for all three SDSS components (eBOSS, APOGEE-2 and MaNGA), including targeting catalogs
- ✩ The most current reprocessed imaging and spectra from the SDSS legacy survey

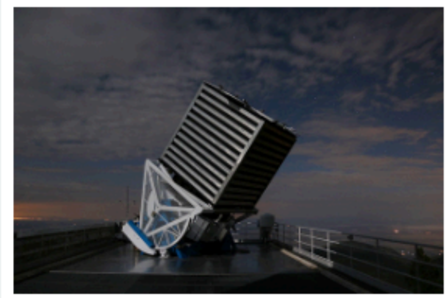
DR16 directly follows DR15. As always, SDSS data releases are cumulative, so DR16 includes all the sky coverage of prior releases. Data Release 12, Data Release 13, Data Release 14, and Data Relase 15 are still available on this website, and prior data releases are available from www.sdss3.org (for DR8 through DR10) or classic.sdss.org (for DR1 through DR7).

DR16 Highlights

Data Access

What's New in DR16

Scope of DR16



The SDSS telescope at night

Image Credit: Patrick Gaulme

Working with SDSS Data

If you use public SDSS data in your paper, please see our guide on how to cite the SDSS. We hope you find our resources useful!

If you have questions about working with SDSS data, please email our helpdesk.

Tutorials Overview

Table of Contents

Welcome to the SDSS tutorials. If you are unsure about what type of SDSS data or which survey is best for your science, see the first section with links to the various SDSS data and surveys.

The sections following provide tutorials for these different data types and surveys.

If you have any problems accessing or using SDSS data products, please consult the DR16 Help pages.

Which SDSS data should I use?

The Sloan Digital Sky Survey is currently observing in its fourth phase (SDSS-IV). SDSS-IV, like previous phases, is organized into component surveys, each of which has its own unique science goals and techniques for observing and data processing. Because SDSS data releases are cumulative, data from all prior component surveys are available as part of DR16.

The tables below describe each component survey whose data are included in DR16. Use them to decide which dataset will best meet your needs. Once you know which dataset(s) to use, see the survey-specific tutorials in the next sections.

General information about how use SDSS data access tools to access any dataset is available in the DR16 Data

Overview
Get an image
Get a spectrum
BOSS Quick Look
Find image quality
Create a finding chart
Find data
Find images and spectra
Find supernovae
Find SDSS matches (Cross-ID)
Get random subset
Find close pairs
Find by color constraints
Find proper motions
Get redshift catalogs
Stripe 82 Images
FITS Images
SEGUE file data

MILLIONS OF OBJECTS... WHERE TO START?

I want to:

Access an image or spectrum for a single object.

Download an image or spectrum for a list of objects.

Find all (or the first N) objects with specific observable properties.

Find all objects near to a point in the sky with detections in the SDSS.

...

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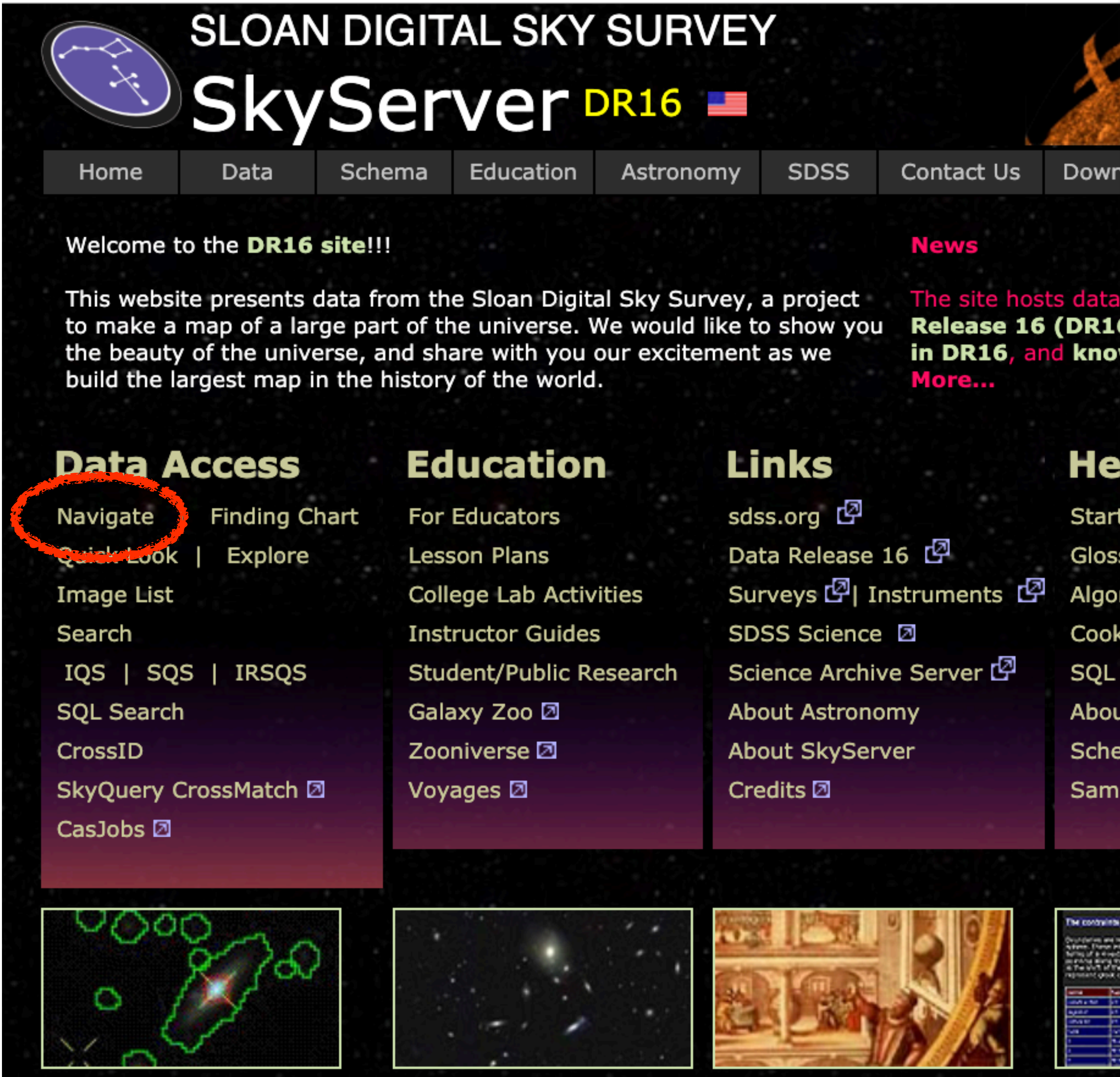
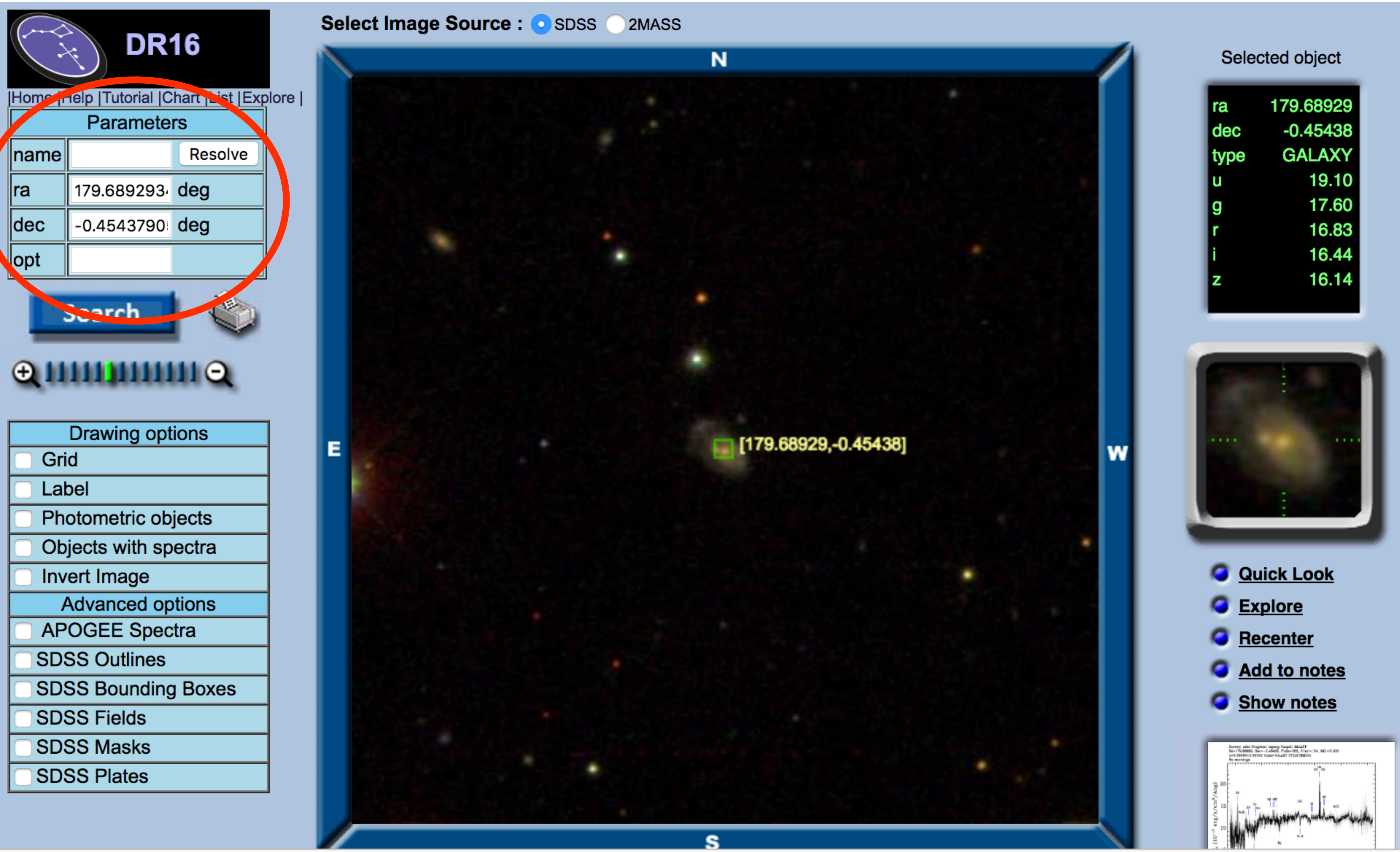
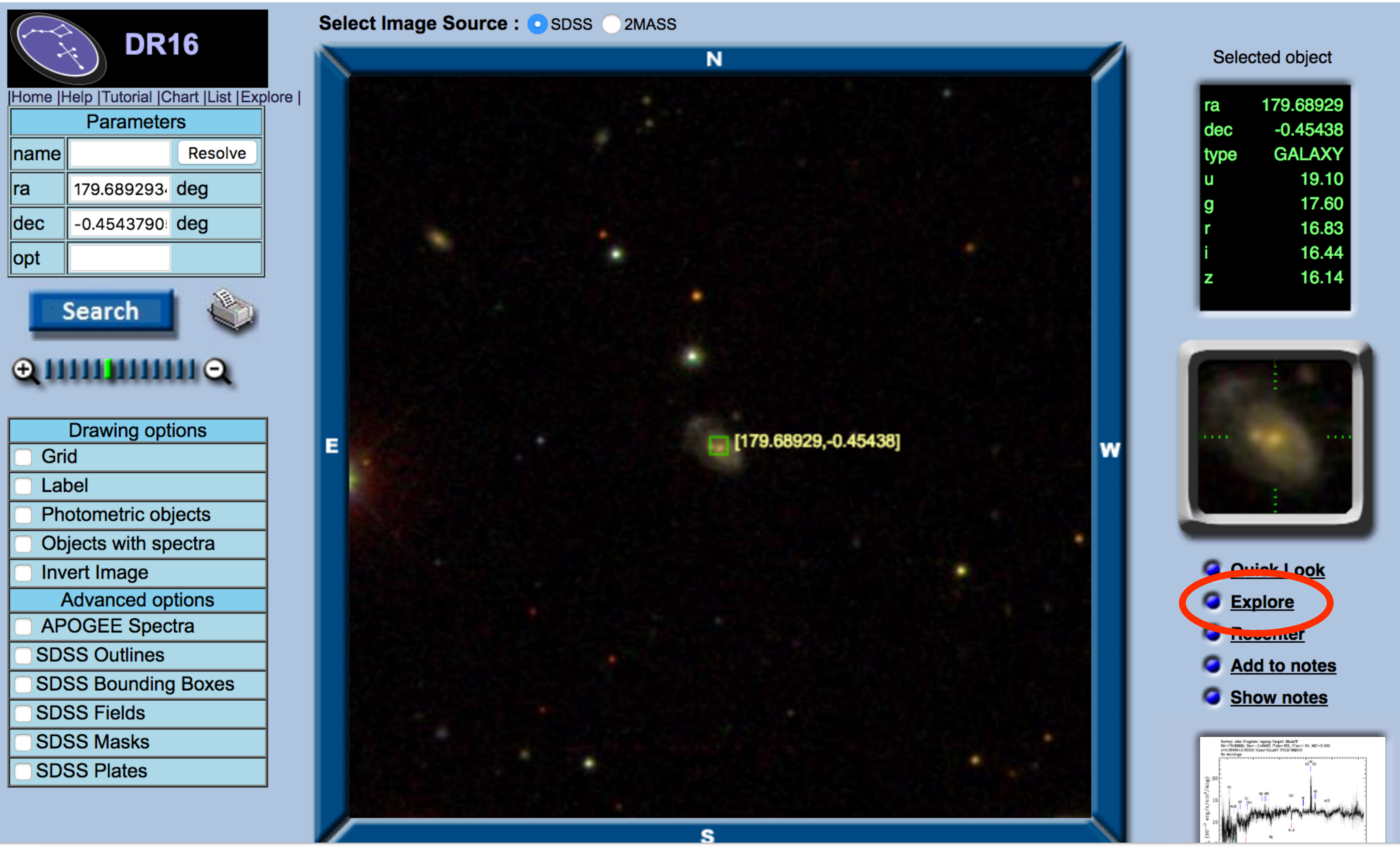
skyserver.sdss.org




DR16
|Home |Help |Tutorial |Chart |List |Explore |
Parameters
name
Resolve
ra
179.689293
deg
dec
-0.4543790
deg
opt
Search
Drawing options
Grid
Label
Photometric objects
Objects with spectra
Invert Image
Advanced options
APOGEE Spectra
SDSS Outlines
SDSS Bounding Boxes
SDSS Fields
SDSS Masks
SDSS Plates
Select Image Source : SDSS 2MASS
N
E
W
S
[179.68929,-0.45438]
Selected object
ra 179.68929
dec -0.45438
type GALAXY
u 19.10
g 17.60
r 16.83
i 16.44
z 16.14
Quick Look
Explore
Recenter
Add to notes
Show notes


DR16
|Home |Help |Tutorial |Chart |List |Explore |
Parameters
name
Resolve
ra
179.689293
deg
dec
-0.4543790
deg
opt
Search
Drawing options
Grid
Label
Photometric objects
Objects with spectra
Invert Image
Advanced options
APOGEE Spectra
SDSS Outlines
SDSS Bounding Boxes
SDSS Fields
SDSS Masks
SDSS Plates
Select Image Source :
SDSS
2MASS
N
E
W
S
[179.68929,-0.45438]
Selected object
ra 179.68929
dec -0.45438
type GALAXY
u 19.10
g 17.60
r 16.83
i 16.44
z 16.14
Quick Look
Explore
Add to notes
Show notes

DR16

- Explore Home
- Search
- Imaging Summary
  - FITS
  - Finding chart
  - Other Observations
  - Neighbors
  - Galaxy Zoo
  - PhotoTag
  - Field
  - Frame
  - PhotoObj
  - PhotoZ
- Cross-ID
- Spec Summary
  - All Spectra
  - FITS
  - Plate
  - SpecObj
  - sppLines
  - galSpecLine
  - galSpecIndx
  - galSpecInfo
- Fit Parameters
  - sppParams
  - StarformingPort
  - PassivePort
  - emissionLinesPort
  - PCAWiscBC03
  - PCAWiscM11
  - FSPSGranEarlyDust
  - FSPSGranEarlyNoDust
  - FSPSGranWideDust
  - FSPSGranWideNoDust
- NED search
- SIMBAD search
- ADS search
- Notes
  - Save in Notes
  - Show Notes

SDSS J115845.43-002715.7

Look up common name

SciServer

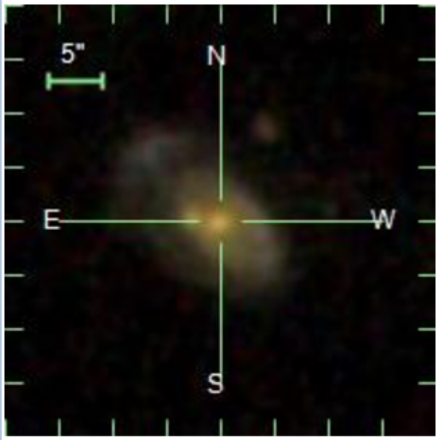
blundgre Help Logout

Type	run	rerun	camcol	field	obj	SDSS Object ID
GALAXY	756	301	2	427	14	1237648720693755918

RA, Dec		Galactic Coordinates (*l*, *b*)	
Decimal	Sexagesimal	*l*	*b*
179.689293428, -0.454379058	11:58:45.43, -00:27:15.76	276.131682383	59.647753983

Imaging

Flags	DEBLEND_DEGENERATE DEBLENDED_AT_EDGE STATIONARY BINNED1 INTERP COSMIC_RAY CHILD



Magnitudes				
u	g	r	i	z
19.10	17.60	16.83	16.44	16.14

Magnitude uncertainties				
err_u	err_g	err_r	err_i	err_z
0.04	0.01	0.01	0.01	0.01

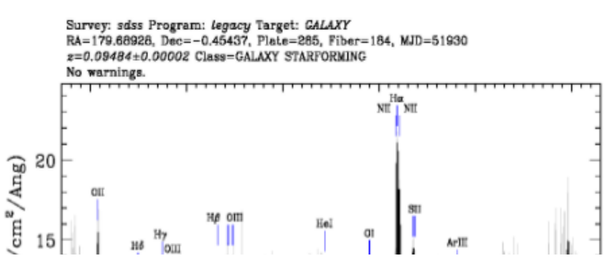
Image MJD	mode	Other observations	parentID	nChild	extinction_r	PetroRad_r (arcsec)
51259	PRIMARY	2	1237648720693755916	0	0.06	7.43 ± 0.418

Mjd-Date	photoZ (KD-tree method)	Galaxy Zoo 1 morphology
03/22/1999	0.090 ± 0.0211	Uncertain

Cross-identifications Show

Optical Spectra **SpecObjID = 3209320833650790400**

Interactive spectrum Coming Soon



Spectrograph	SDSS
class	GALAXY
Redshift (z)	0.095
Redshift error	0.00002
Redshift flags	OK
survey	sdss
programname	legacy

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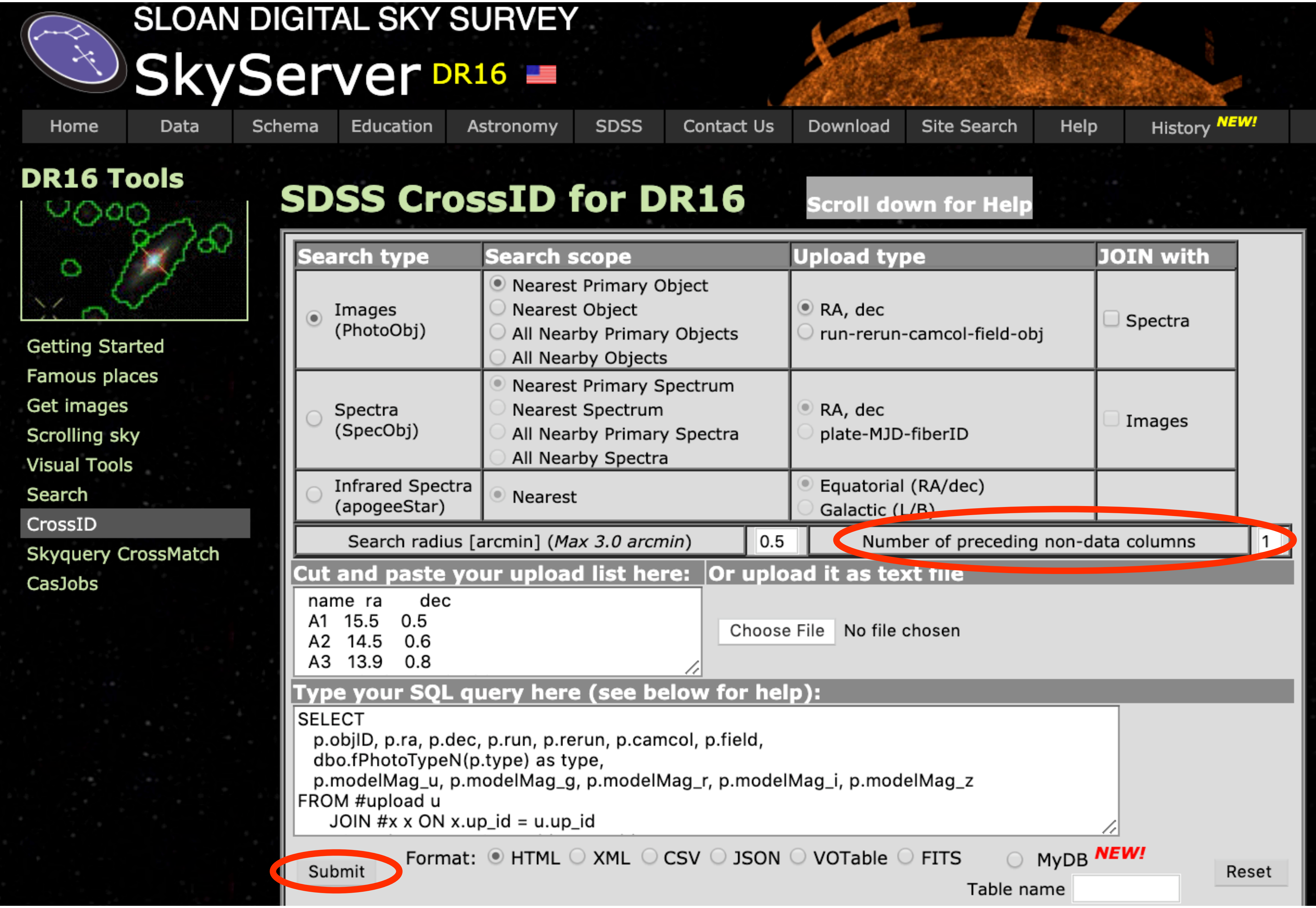
skyserver.sdss.org

http://skyserver.sdss.org/dr16/en/tools/crossid/crossid.aspx



Your SQL command was:

```
CREATE TABLE #upload ( up_id int, up_name varchar(32), up_ra float, up_dec float )
INSERT INTO #upload values ( 1, 'A1', 15.5, 0.5),( 2, 'A2', 14.5, 0.6),( 3, 'A3', 13.9, 0.8),( 4, 'A4', 197.614, 18.438)
create table #x (up_id int,objID bigint)
INSERT INTO #x
SELECT up_id, dbo.fGetNearestObjIdEq(up_ra,up_dec,0.5) as objId
     FROM #upload WHERE dbo.fGetNearestObjIdEq(up_ra,up_dec,0.5) IS NOT NULL
SELECT u.up_name as [name],
   p.objID, p.ra, p.dec, p.run, p.rerun, p.camcol, p.field,
   dbo.fPhotoTypeN(p.type) as type,
   p.modelMag_u, p.modelMag_g, p.modelMag_r, p.modelMag_i, p.modelMag_z
FROM #upload u
      JOIN #x x ON x.up_id = u.up_id
      JOIN PhotoTag p ON p.objID = x.objID
ORDER BY x.up_id
```

Your query output (max 500,000 rows):

name	objID	ra	dec	run	rerun	camcol	field	type	modelMag_u	modelMag_g	modelMag_r	modelMag_i	modelMag_z
A1	1237663784741045437	15.5022412183639	0.493596074914063	4263	301	5	219	GALAXY	22.92439	23.19065	22.51986	21.62165	21.1054
A2	1237663784740586925	14.4988099940347	0.601315790471128	4263	301	5	212	GALAXY	24.90403	24.89659	22.37838	22.48927	20.94322
A3	1237663204920263075	13.8964276004192	0.799057884274859	4128	301	5	216	STAR	24.38976	22.77014	21.32578	20.29712	19.78329
A4	1237668296598749280	197.614455634642	18.438168849489	5314	301	1	136	GALAXY	16.51686	14.95543	14.0022	13.32461	13.13738

Use the button below to upload the results of the above query to the SAS and retrieve the corresponding FITS files:

Submit Upload list of fields to SAS

DR12 Science Archive Server (SAS)

SDSS-III | Home | Imaging | Optical Spectra | IR Spectra | Documentation

Bulk Imaging Search — Imaging

Names

m42
NGC 5866
arcturus

Submit

RA, Dec

228.66942|27.13082
228.75516   27.54503
228.60244,27.51250

Submit

Run, Camcol, Field

4263,5,219
4263,5,212
4128,5,216
5314,1,136

Submit

Names File Upload

Choose File No file chosen

Submit

RA, Dec File Upload

Choose File No file chosen

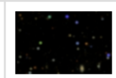
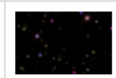
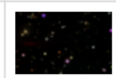
Submit

Run, Camcol, Field File Upload

Choose File No file chosen

Submit

Clear Filters | Table as Comma-Delimited Text (CSV) | Filters to Download: u g r i z | Download FITS

Run	Camcol	Field	RA (degrees)	Dec (degrees)	All None Inverse	Open in CAS	Thumbnail
5314	1	136	197.68359	18.39144		CAS	
4263	5	212	14.44656	0.52313		CAS	
4128	5	216	13.92449	0.73438		CAS	
4263	5	219	15.49444	0.52314		CAS	

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http://skyserver.sdss.org/dr16/en/tools/search/sql.aspx

SLOAN DIGITAL SKY SURVEY

SkyServer DR16

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SQL Tutorial

Back to Help

1. Introduction
2. A Simple Query

Practice

3. Common Searches
4. More Samples

Practice

5. Multiple Tables

Practice

6. Aggregate Fcns.
7. Group By
8. Order By

Practice

9. Views
10. Functions

Practice

11. Conclusion

SQL Tutorial

NOTE: This is a step-by-step tutorial for those new to SQL. If you already know some SQL and want a more in-depth introduction to how SQL applies to SkyServer, see **Using SQL with SkyServer**.

Another great way to learn SQL is to modify and submit queries that other people have already written. To jump right in to modifying queries written by scientists, see the **Sample SQL Queries.**

Searching for Data: A Tutorial

Did you know that you can search through SkyServer's database for only the objects you are interested in? For example, you might want to find all the bright blue galaxies for which we have obtained spectra. Looking through all the hundreds of millions of SDSS objects with the Navigation tool could take years. But using **the right search**, you could find 10 bright blue galaxies with spectra in seconds!

If you know how to retrieve the right data, you can ask millions of different questions. Searching SkyServer is an incredibly powerful tool for conducting astronomy research; in fact, many professional astronomers search the data in the same way you can.

In this tutorial, you will learn how to search SkyServer to answer many useful astronomical questions. Do the tutorial at your own pace, and use the links to the right to return to points later in the tutorial. As you work, you may also want to look at the **Sample Queries**, which are examples of real queries that other people have written to search the database.

Click Next to start learning.

SLOAN DIGITAL SKY SURVEY

SkyServer DR16

Home | Data | Schema | Education | Astronomy | SDSS | Contact Us | Download | Site Search | Help | History NEW!

DR16 Help

Start Here
- FAQ
- Cooking with Sloan
- Contact Help Desk

Searching SDSS
- SQL Tutorial
- SQL in SkyServer
- Sample SQL Queries
- Query Limits
- Searching Advice

- About the Database
- Table Descriptions
- Schema Browser
- Glossary
- Algorithms
- API/Tools

Sample SQL Queries

This page contains sample queries designed to serve as templates for writing your own SQL (Structured Query Language) queries. The first section, ***Basic SQL***, serves as an introduction to the syntax of the SQL database access language. The sections that follow feature queries written to solve real scientific problems submitted by astronomers. Those queries are grouped by scientific topic.

Click on the name of the query in the list below to go directly to that sample query. You can load the query into SkyServer's **SQL Query tool** by clicking on the Load Query button above each query. You can then modify the query to suit your needs before actually running it. Alternatively, you can send each query immediately to the database and see the results by clicking on the Run Query button. (In cases where there is more than one query in an example, only one of the queries gets loaded and run by the buttons, you have to copy and paste the other one manually.)

NOTE: Please read the **query hints** below before you try any queries, especially if you are new to SQL or the SkyServer.

Basic SQL:
- **Basic SELECT-FROM-WHERE**
- **Basic position search**
- **Using PhotoTag**
- **Search for a Range of Values**
- **Rectangular position search**
- **More than one table: JOIN...ON**
- **Photometry & spectroscopy**
- **Counting by type or category**
- **Using flags**

SQL Jujitsu:
- **Data subsample**
- **Objects in close pairs**
- **Selected neighbors in run**
- **Object counts and logic**
- **Repeated high-*z* objects**
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- **MaNGA Data Cubes of Good Quality**

A MAGNITUDE BY ANY OTHER NAME...

www.sdss.org/DR7/glossary/index.html#M

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M

maggie

A *maggie* is a linear measure of flux; one maggie has an AB magnitude of 0 (thus a surface brightness of 20 mag/square arcsec corresponds to 10^{-8} maggies per square arcsec). This unit is used for object radial profiles, where we provide the azimuthally averaged object surface brightness in a series of annuli.

magnitude, cmodel

Composite model magnitude. The magnitude obtained from the best-fitting linear combination of the best-fitting de Vaucouleurs and exponential model for an object's light profile (cf. magnitude, model). See cmodel magnitude description in Photometry section of the Algorithms pages.

magnitude, fiber

The flux contained within the aperture of a spectroscopic fiber (3" in diameter) is calculated by the frames pipeline in each band and stored in **fiberMag**. Details can be found in the Photometry section of the Algorithms pages.

magnitude, model

Just as the PSF magnitudes are optimal measures of the fluxes of stars, the optimal measure of the flux of a galaxy would use a matched galaxy model. With this in mind, the code fits two models to the two-dimensional image of each object in each band:
1. a pure deVaucouleurs profile, and
2. a pure exponential profile.

The best-fit model in the r-band is fit to the other four bands; the results are stored as the model magnitudes. Details, including a very important warning, can be found in the Photometry section of the Algorithms pages.

magnitude, Petrosian

Stored as **petroMag**. For galaxy photometry, measuring flux is more difficult than for stars, because galaxies do not all have the same radial surface brightness profile, and have no sharp edges. In order to avoid biases, we wish to measure a constant fraction of the total light, independent of the position and distance of the object. To satisfy these requirements, the SDSS has adopted a modified form of the Petrosian (1976) system, measuring galaxy fluxes within a circular aperture whose radius is defined by the shape of the azimuthally averaged light profile. Details can be found in the Photometry section of the Algorithms pages and the Strauss et al. 2002 AJ paper on galaxy target selection.

magnitude, Pogson

The Pogson magnitude is the standard astronomical magnitude system, where one increment in magnitude is an increase in brightness by the fifth root of 100. A star of 1st magnitude is therefore 100 times as bright as a star of 6th magnitude. That is, for two objects

```
M1 - M2 = -2.5log(F1/F2)
```

where M1 and M2 are the magnitudes of two objects, and F1 and F2 are their luminous fluxes.

magnitude, PSF

Stored as **psfMag**. For isolated stars, which are well-described by the point spread function (PSF), the optimal measure of the total flux is determined by fitting a PSF model to the object. Details can be found in the Photometry section of the Algorithms pages.

MILLIONS OF OBJECTS… WHERE TO START?

I want to:

Access an image or spectrum for a single object.

Access an image or spectrum for a list of objects.

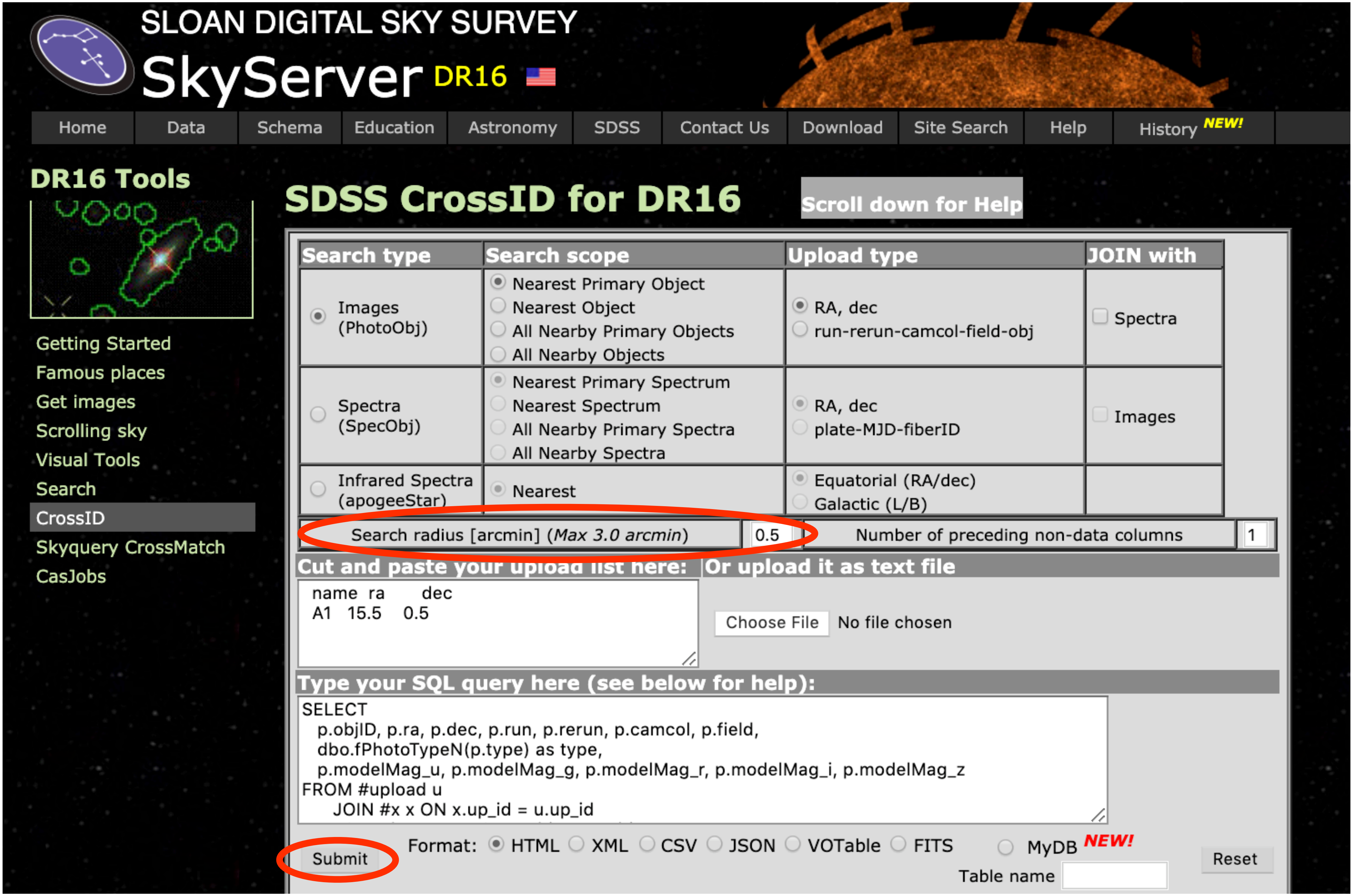
Find all (or the first N) objects with specific observable properties.

Find all objects near to a point in the sky with detections in the SDSS.

…

skyserver.sdss.org

http://skyserver.sdss.org/dr16/en/tools/crossid/crossid.aspx



https://www.sdss.org/dr16/data_access/bulk/

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This is Data Release 16.

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Bulk Data Downloads

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All data can be downloaded directly from data.sdss.org using the rsync or wget commands. Access is also available via Globus Online. The Data Model page has a description of the directory structure and file formats. Note that the total SDSS data volume is > 125 TB; see the data volume table. If you need a substantial fraction of that data (>1 TB), please contact the helpdesk to arrange a custom data transfer. This will be faster for you and easier on our servers.

To learn how to download MaNGA data cubes, see the MaNGA data access page.

NOTE: all rsync commands on this page have `--dry-run` added to them, and all wget commands have `--spider` added to them. You have to **remove those command line arguments** for these commands **to actually download data**. Also, wget commands use the same URL as you would in a web browser, *e.g.*,

```
wget --spider https://data.sdss.org/sas/dr16/eboss/spectro/r
```

yet, for rsync, drop the "sas" from the URL, *e.g.*,

```
rsync --dry-run -lv rsync://data.sdss.org/dr16/eboss/spectro
```

If you are having any difficulty with rsync URLs, check the notes below. The number of rsync connections is throttled but the number of wget connections is not. Thus it is recommended to use wget to initially fetch the data, and use rsync only to confirm that the data you have is correct and complete. The SAS website data.sdss.org/sas (US Mountain) is completely mirrored at mirror.sdss.org/sas (US Pacific). If you have difficulty connecting to data.sdss.org, try mirror.sdss.org instead by using an analogous command, *e.g.*,

```
wget --spider https://mirror.sdss.org/sas/dr16/eboss/spectro/redux/v5_13_0/platelist.fits
```

or

```
rsync --dry-run -lv rsync://mirror.sdss.org/dr16/eboss/spectro/redux/v5_13_0/platelist.fits .
```

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