

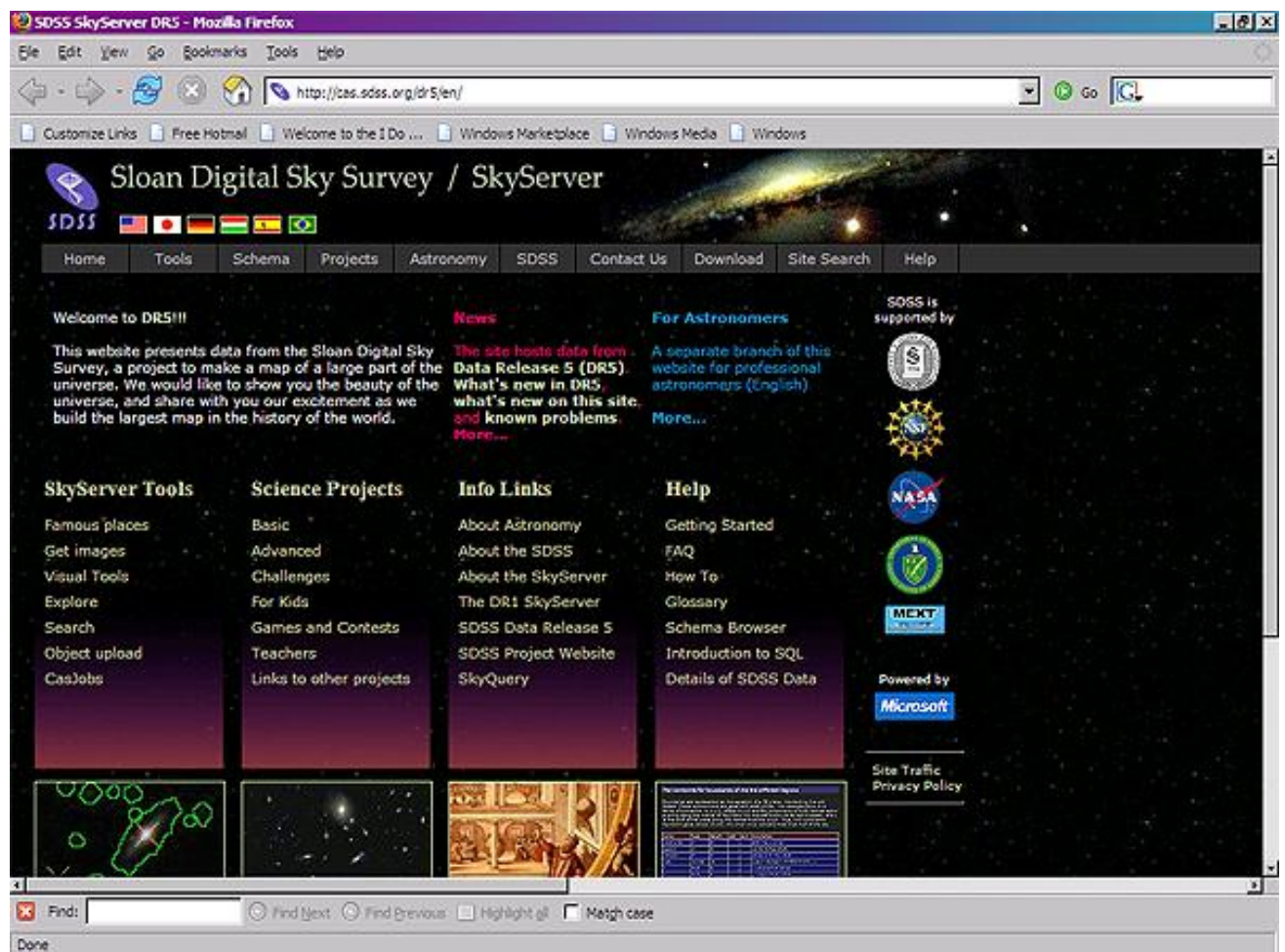
How Do I...

Create a Hubble Diagram to show the expanding universe?

An extremely important topic in astronomy is the expansion of the universe. Although the expanding universe is nearly always discussed in lecture during astronomy survey courses, it can be difficult to address in lab because data can be so difficult to obtain. But the SDSS has photometric data on more than 130 million galaxies – so labs are limited only by the imaginations of students and instructors.

This guide will show you how to create a Hubble Diagram in two different ways.

1. Go to the SDSS SkyServer website (<http://cas.sdss.org/>). The web site is shown below:



2. Click on the **Projects** link in the menu bar:

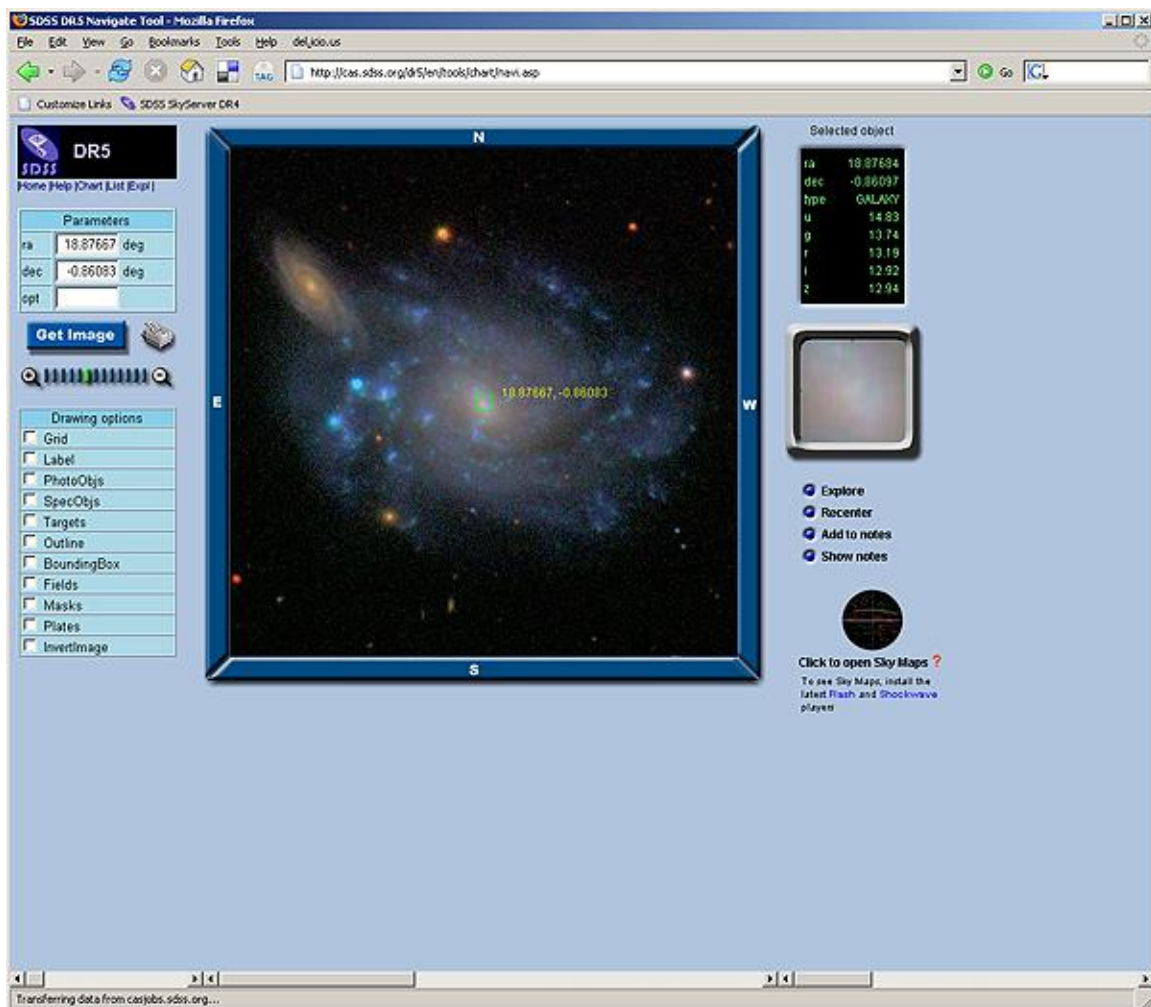


3. SkyServer **Projects** are a series of lesson plans and labs that teach astronomy and other sciences at various levels. The projects are divided into different levels. The levels that are most important for two- and four-year colleges are the *Basic* and *Advanced* levels. *Basic* projects are intended for non-science majors; *Advanced* projects are intended for science majors.
4. There is a project on SkyServer in which students create a Hubble Diagram and learn how to interpret it. It is listed as *The Universe* in the Basic projects and *Hubble Diagram* in the Advanced projects. However, the rest of this guide will talk about how to create the Hubble Diagram yourself, allowing you to adapt the activity to suit your students' needs. You are welcome to use and adapt any materials from the Projects. Credit should go to "The Sloan Digital Sky Survey."

One method to create a Hubble Diagram:

1. The first step to create a Hubble Diagram is to find distances to galaxies. This is by far the hardest step. One simple way to do it is to use magnitudes and assume that a brighter galaxy is closer. However, this is not a safe assumption, because galaxies have different intrinsic properties – a brighter galaxy might be intrinsically brighter, but farther away.
2. One way to get around the difficulty mentioned in step 5 is to look at galaxy clusters. All the galaxies in a cluster can be assumed to be the same distance from Earth, so differences among the cluster galaxies should arise only from intrinsic differences. This means that, for example, the 5th brightest galaxy in a cluster should be just as intrinsically bright as the 5th brightest galaxy in another cluster. Therefore, observed differences in magnitudes between the 5th brightest galaxies should be due entirely to the differing distances between the clusters. This is only an approximation, but it should be enough to demonstrate the expansion of the universe.
3. The first step, then, is to find galaxy clusters. SkyServer has a list of Abell clusters that overlap with the SDSS survey region. To download the list, click on **Tools** on the menu bar, then on **Famous Places**.

4. Scroll to the bottom of the page and click on the **Abell** link. You will see images of six Abell clusters, as seen by the SDSS. Scroll to the bottom of the page and click on the **Abell Data** link to download a CSV (comma-separated value) file containing numbers and positions of Abell clusters. Save this file to your computer.
5. Open the file with a graphing program. The SkyServer Projects use Excel because it is a tool that many students are already familiar with, but similar instructions will apply for other graphing programs.
6. Open the file in Excel or another graphing program. Highlight and copy all the data.
7. Return to the *Tools* menu and click on **Navigate** to go to the Navigate tool. The tool looks like this:



8. Look at the *ra* and *dec* input boxes near the top left of the tool. Enter the coordinates of one of the Abell clusters. (Note that you may enter coordinates either as decimal degrees or as HMS/DMS. If you enter them as HMS/DMS, use the format “hh:mm:ss ±dd:mm:ss”.) Click **Get Image**.
9. The image in the center panel will reset to an image of the area that includes your cluster. Click the directional buttons (NWSE) to pan the image, and click on the + or – magnifying glasses to zoom in or out.
10. Click on one or more of the *Drawing Options* checkboxes in the left-hand panel to redraw the image with various features selected. Of particular interest is the **SpecObjs** checkbox. When it is selected, the tool displays a red square around all objects for which the SDSS has obtained a spectrum.
11. Decide which galaxies are genuinely part of the cluster and which are not, using whatever method you like.
12. Click the **SpecObjs** checkbox to mark objects that have spectra measured by the SDSS. These objects will be marked with red squares.
13. Decide on some property of a galaxy that you want to measure across clusters. For example, you might want to measure the magnitude of the 5th brightest galaxy in each cluster, or the apparent size in arcminutes of the 3rd brightest spiral galaxy. Measure that property.
 - a. To measure magnitudes, click on the galaxy to see its data. You will see its magnitudes (u, g, r, i, z) displayed in the right-hand frame.
 - b. To measure apparent sizes, turn on the **Grid** checkbox to put up tickmarks around the edges of the main frame. Count the number of tickmarks the galaxy takes up and multiply by the grid scale shown in the top left of the image.
 - c. For whatever galaxy you choose to measure, be sure to record its objID, ra, and dec too.
14. Return to studying the cluster, and turn on the **SpecObj** checkbox if you haven't already. Look for a galaxy in the cluster with a red square around it – the SDSS has measured its spectrum. Click **Explore** to learn more about the object. A new window will open containing the Explore tool:


SkyServer Object Explorer - Mozilla Firefox

http://cas.sdss.org/astro/en/tools/explore/obj.asp?id=587731186203951236

SDSS J000007.81-000226.0

GALAXY ra=0.03258, dec=-0.040575, ObjId = 587731186203951236

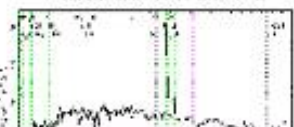
mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	BINNED1 INTERP COSMIC_RAY CHILD
PrimTarget	TARGET_GALAXY
SecTarget	



run	rerun	camcol	field	obj	rowc	colc
2662	40	3	283	132	242.4	1607.9
u	g	r	i	z		
16.87	15.67	15.13	14.87	14.60		
fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r	
17.41	15.06	14.79	15.13	17.87	15.13	
extinction_r	petroRad_r	parentId	nChild			
0.09	8.768	587731186203951235	0			

SpecObjID = 109153257443557376

plate	mjd	fiberid	z	zErr	zConf	specClass	ra	dec	fiberMag_r	objId
387	51791	192	0.024	0.00019	0.994	GALAXY	0.03260	-0.04057	17.37	587731186203951236



zStatus	XCORR_EMLINE
zWarning	
PrimTarget	TARGET_GALAXY
SecTarget	
eClass	0.029

NED search
SIMBAD search
ADS search

15. You will see the object's identifier, ra and dec, and SDSS 18-digit object ID at the top of the page. Below that is a close-up images of the object with its photometric data, and below that is its spectrum and spectroscopic data.

16. Click on the picture of the spectrum to see a larger view. Spectral lines are marked on the spectrum by green and pink dotted lines, as well as labels. The redshift and error are shown at the bottom of the spectrum. Record the redshift. Don't worry if the redshift you are recording is for a different galaxy than the galaxy whose properties you recorded in step 13 – the cluster is far enough away that you can assume that all the galaxies are at the same redshift, so you can measure one redshift for the entire cluster.

17. You now have magnitude and redshift data for a galaxy in a galaxy cluster. Repeat the measurements for a number of other clusters.

18. Make a graph of redshift against the quantity you measured in step 13, with a point on the graph for each cluster. You should see a roughly straight line. The straight line is a powerful piece of evidence that the universe is expanding, although discussing how the line indicates the expanding universe is beyond the

scope of this guide. There are many good activities for teaching more about the Hubble Diagram, including the activities in the **SkyServer Projects**.

Another method to create a Hubble Diagram:

1. Another way to overcome the problem of intrinsic differences between galaxy magnitudes is to look at a large sample of galaxies. With a large enough sample, intrinsic differences of galaxy brightness should average out, meaning that the trend of the Hubble Diagram should truly reflect the expansion of the universe.
2. Go to the Search tools by going back to the **Tools** menu, then clicking **Search**. Click **Search Form** to go to the Search Form tool. Click **Launch the Search Form tool**. (Note that this Search Form is different from the Imaging Query Form; it is designed for public and student use.) The Search Form tool looks like this:

The screenshot shows the SkyServer Search Form interface. The browser window title is "SkyServer DR5 Search Form - Mozilla Firefox" and the address bar shows "http://cas.sdss.org/dr5/en/tools/search/form/form.asp". The page header includes the Sloan Digital Sky Survey logo and navigation links: Home, Tools, Schema, Projects, Astronomy, SDSS, Contact Us, Download, Site Search, Help. The main content area is titled "SkyServer Search Form" and contains a search interface. It includes a "DR5 Tools" sidebar with links like "Getting Started", "Famous places", "Get images", "Scrolling sky", "Visual Tools", "Search", and "Object Crossid". The search form itself has a "Show me" dropdown set to "any objects", an "in the region" dropdown set to "anywhere", and two columns of magnitude and color filters. The "with magnitudes" column has filters for u, g, r, i, z. The "and colors" column has filters for u-g, g-r, r-i, i-z, u-r. Below these are checkboxes for "for" (set to "all objects"), "Please return:" (with options for "Num. of Objects" and "Image Data"), and an "SQL Query" section with "Generate Query", "Edit Query", and "Syntax" buttons. At the bottom, there are buttons for "Submit Query to SkyServer", "Output Format" (HTML selected, CSV unselected), "Submit Query to Image List", and "Reset Form".

3. The principle of the Search Form tool is that you choose from menus and put values in textboxes to write a sentence in English. Then you click a button to generate an SQL query that represents your English sentence. Make the selections on the Search Form tool that are appropriate for making a Hubble diagram,

forming this sentence (the bold items are the selections you make from the menus):

Show me **galaxies** in the region **anywhere** with magnitudes (**unspecified**) and colors (**unspecified**) for **only objects with spectra**, with redshifts (**unspecified**). Please return **1,000** objects with **object IDs, RA and Dec, magnitudes, and redshift**.

4. Click **Generate Query** to translate this sentence into SQL. The SQL statement that the tool generates looks like this:

```
select top 1000 p.objid, p.ra, p.dec, p.u, p.g, p.r, p.i, p.z, s.z as redshift
from galaxy p, specobj s
where p.objid=s.bestobjid
```

5. Change the **Output Format** to *CSV* (comma-separated value).
6. Click **Submit Query to SkyServer**. A new window will open where you can save your query results to your computer.
7. Make a graph of redshift (or log of redshift) against magnitude. Here is what a sample graph looks like:

