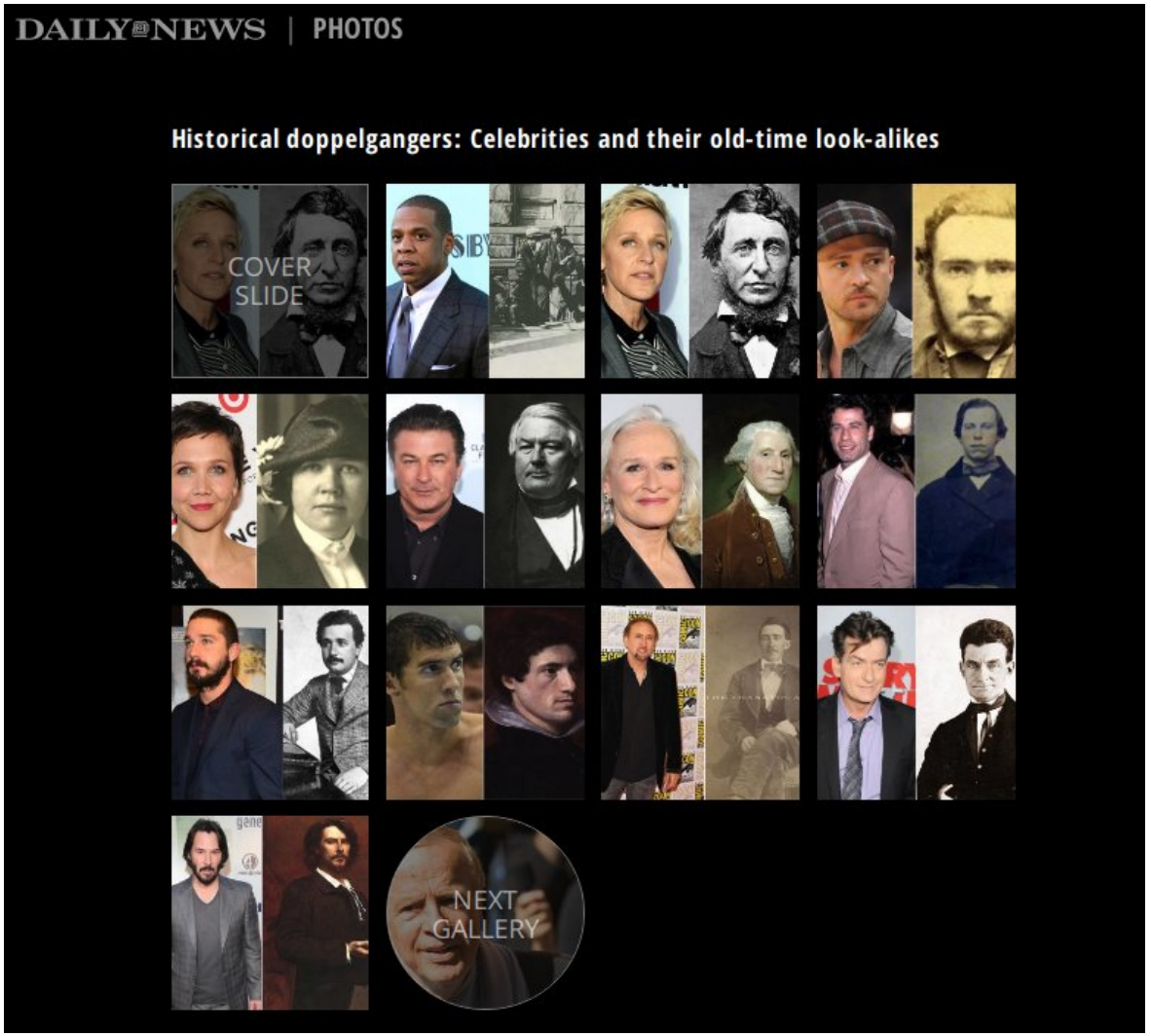
# Look-alikes and the expanding Universe

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Hubble: variable stars as standard candles in nearby galaxies.

measured period → luminosity → distance

plot distance vs recession velocity → Universe is expanding

velocity

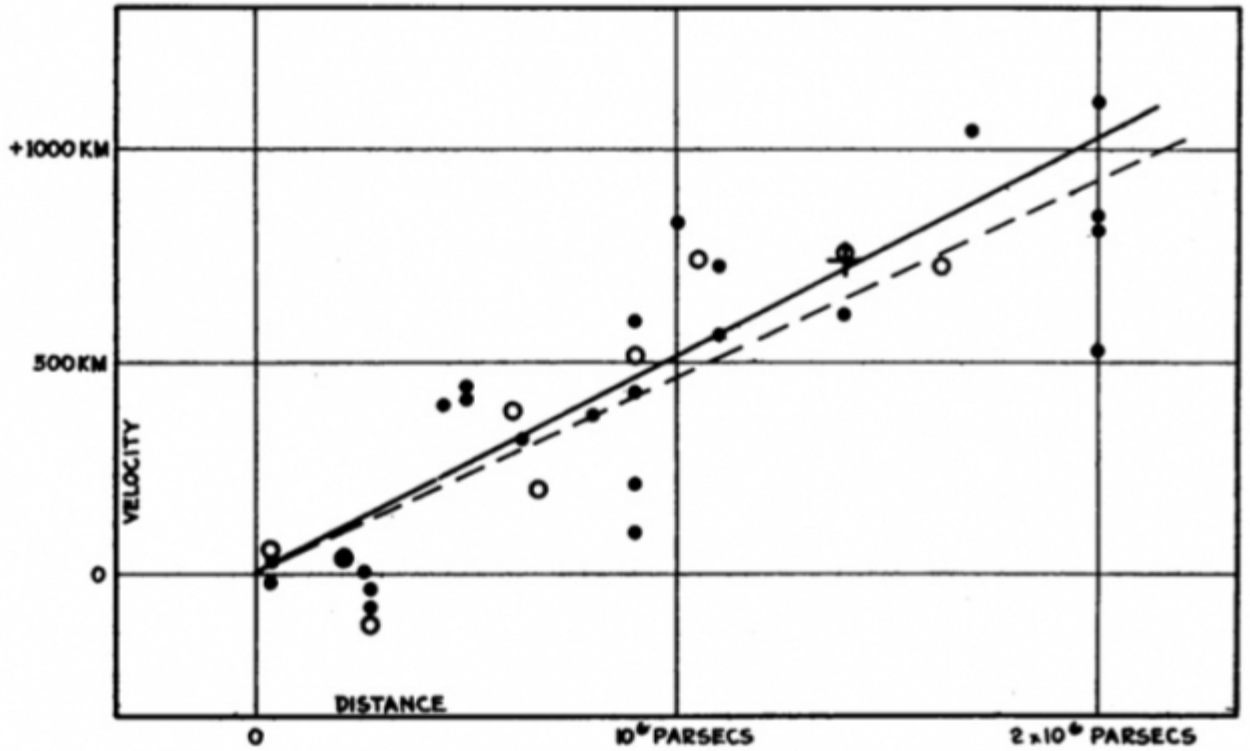
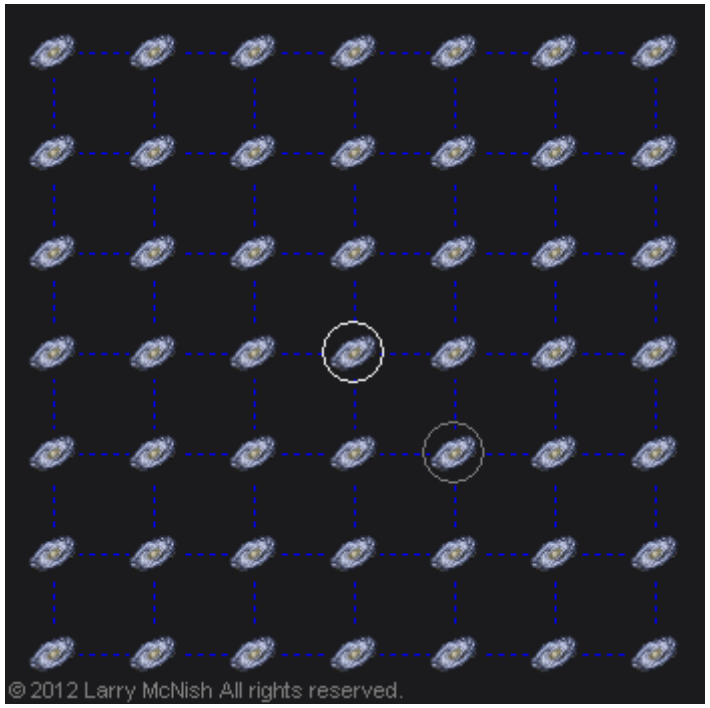



FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

distance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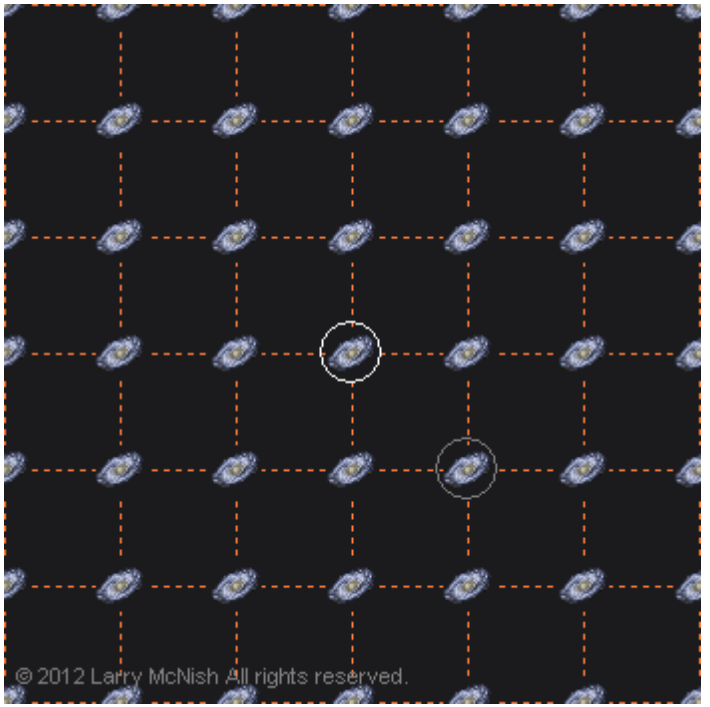
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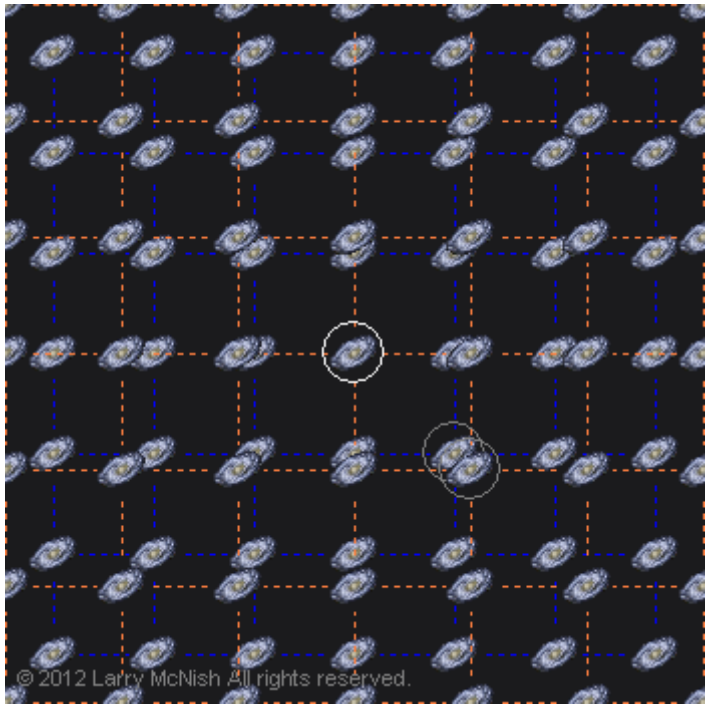
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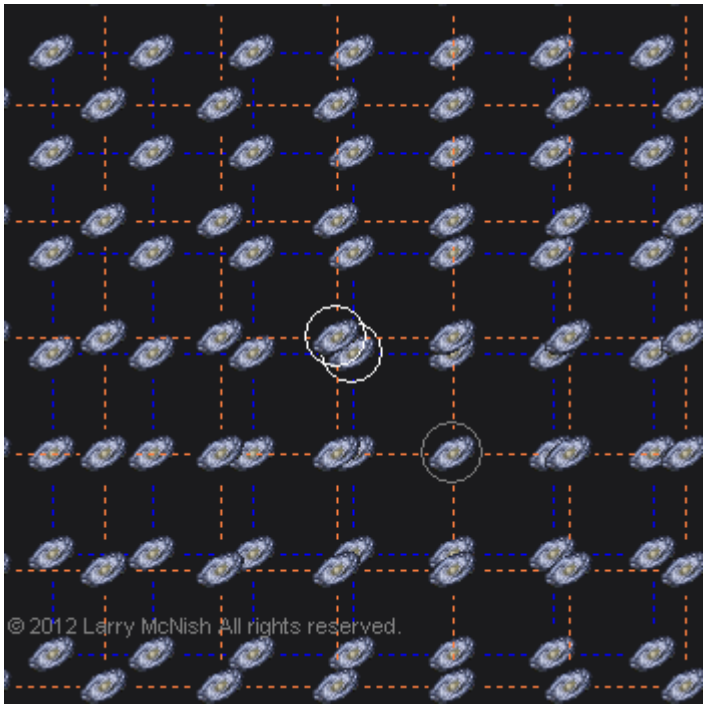
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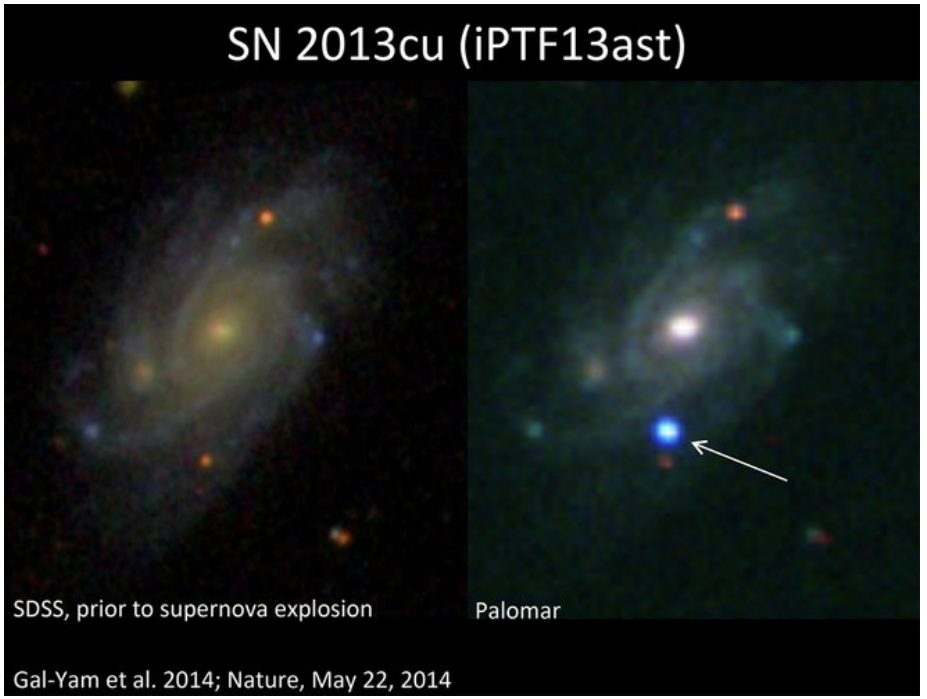
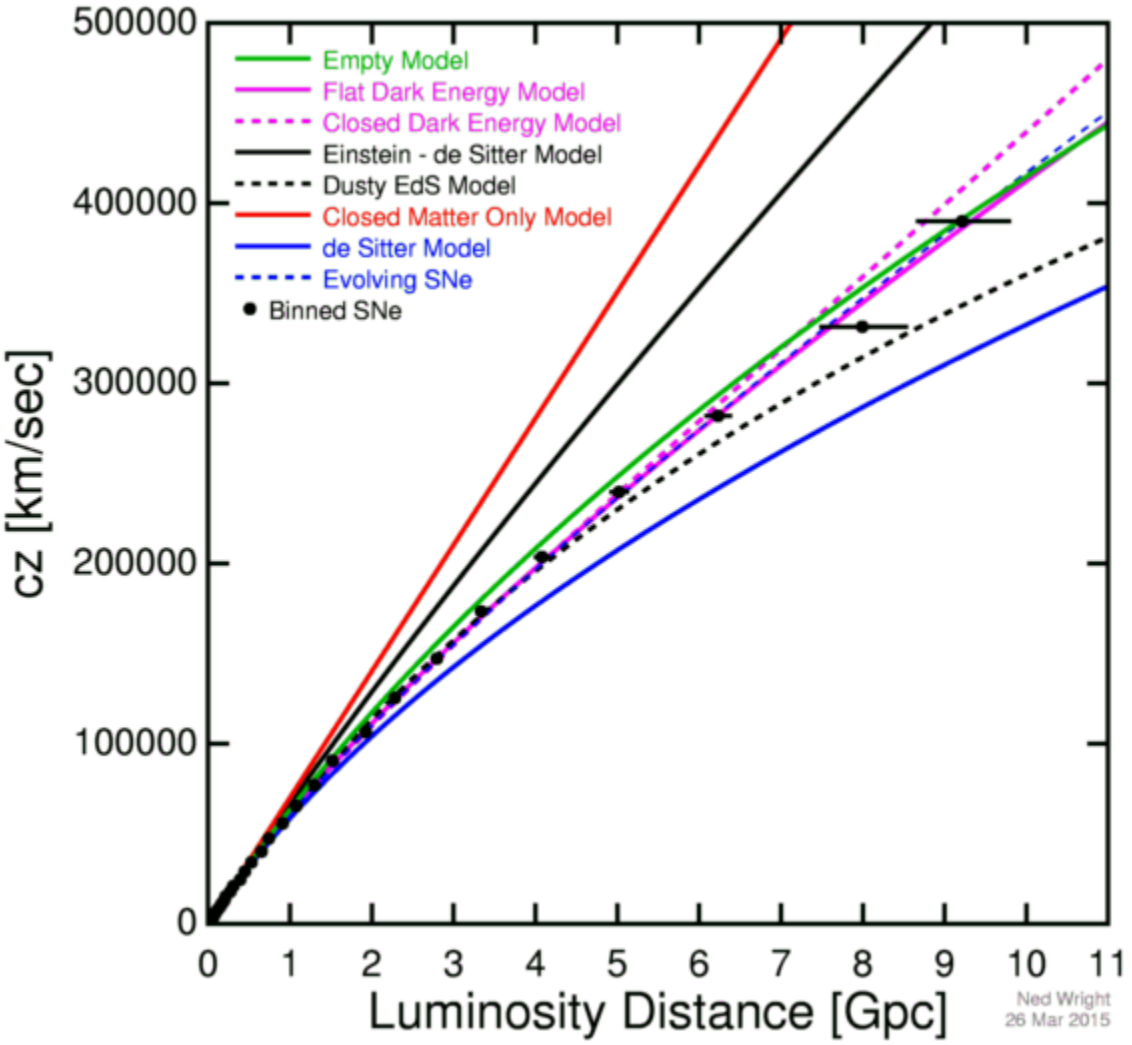
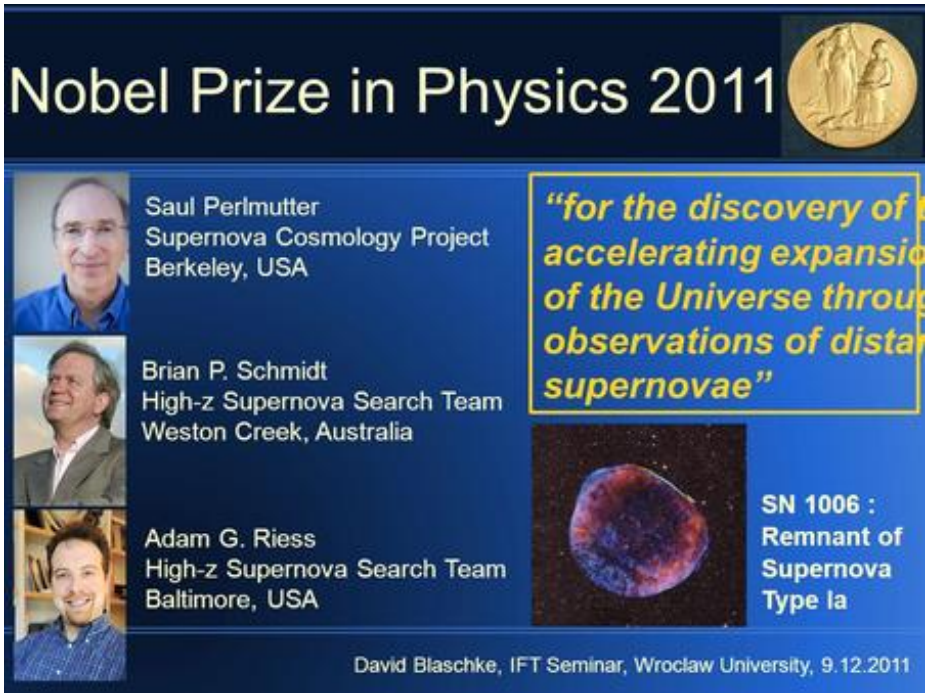
- Supernova cosmology
- bright exploding stars as standard candles
- can extend Hubble's curve to much greater distances
- can see whether expansion of Universe is slowing down or speeding up



velocity




distance



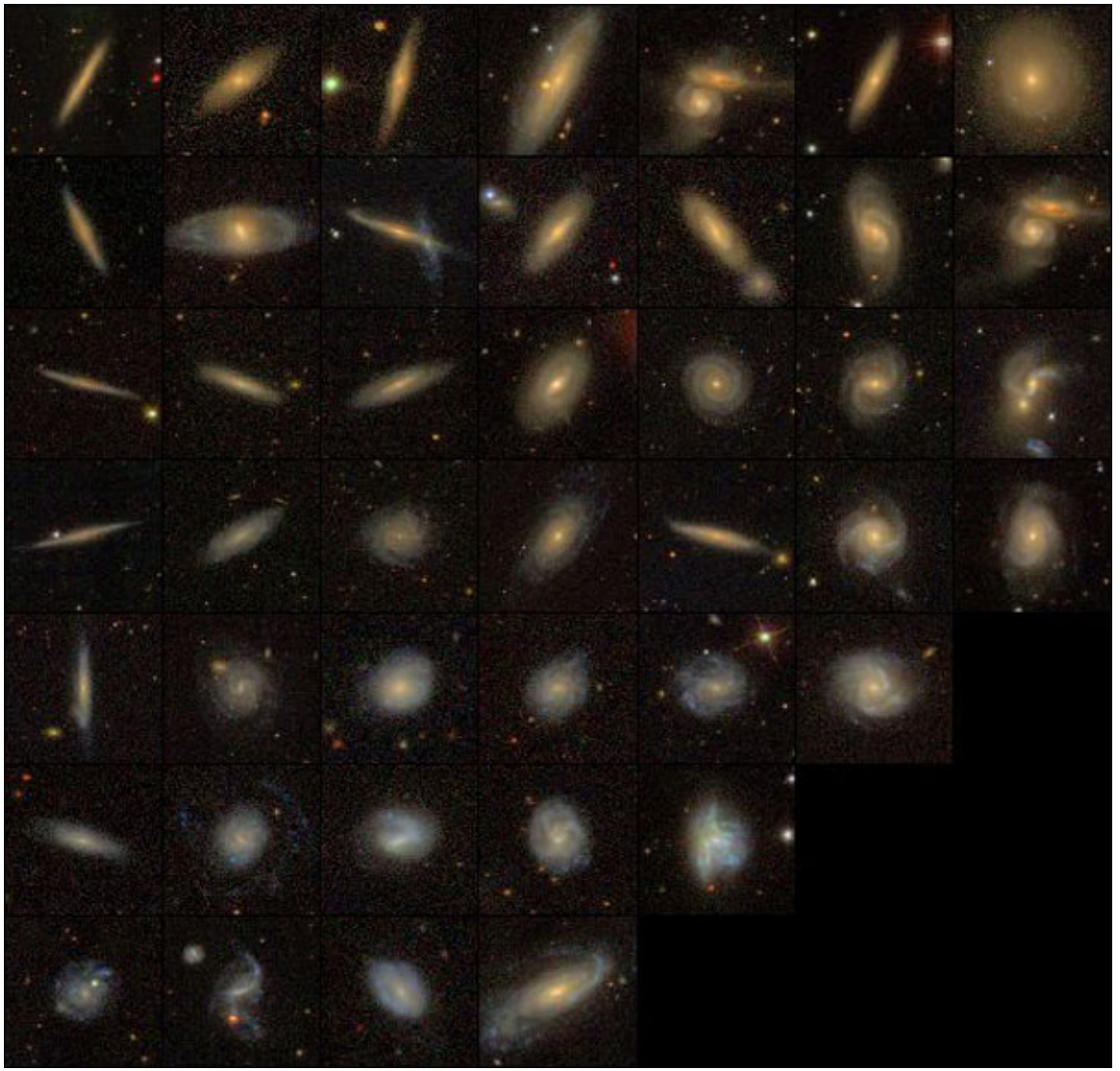

Universe is accelerating
but still not clear why

"dark energy"?
"cosmological constant"?
modified law of gravity?

need more observations to
pin down reason why.

Supernovae are difficult to find (2011 Nobel was based on < 100 SN)

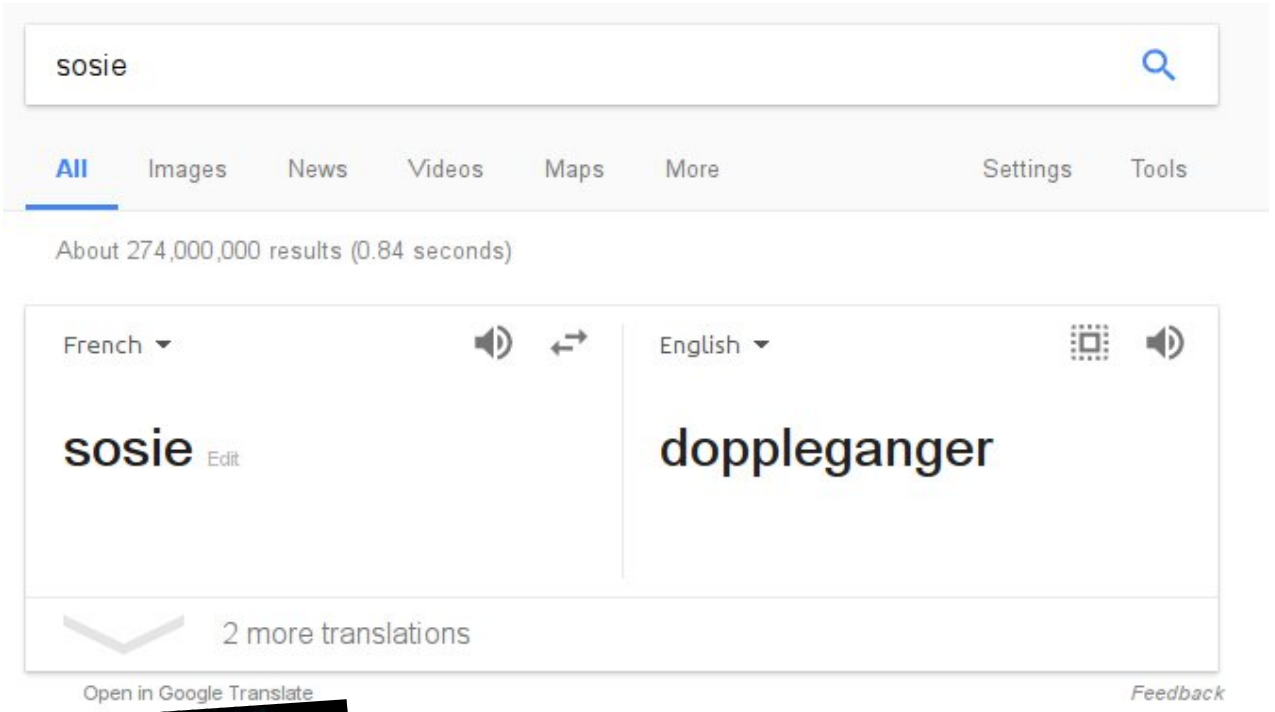
We have many (> 100 million) observations of galaxies- how can we use them as standard candles?



Method of “sosies” (Paturel 1983)

Assume that two galaxies that look identical actually have the same size and luminosity

→ can get the ratio of their distances




THE ASTROPHYSICAL JOURNAL, 308:487–492, 1986 September 15


# THE HUBBLE RATIO FROM SOSIES OF M31 IN THE VIRGO S CLOUD AND IN THE HERCULES SUPERCLUSTER

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*Received 1985 December 20; accepted 1986 March 4*

## ABSTRACT

The method of "sosie" (or look-alike) is applied to the Virgo cluster S cloud and to the Hercules supercluster in which spirals closely matching M31 in all their observable distance-independent parameters have been found.

Three galaxies in the Virgo S cloud and two in the Hercules supercluster are "sosies" of M31 with respect to Hubble stage, luminosity class, and luminosity index, H I line width, color, surface brightness, and inclination. If, as may be reasonably expected, they have also closely similar linear diameters and absolute magnitudes, the differential moduli can be derived directly from the apparent diameters and magnitudes.

For Virgo, the differential modulus is in the range 6.50–6.68 (from magnitudes) or 6.80–7.12 (from diameters), with a weighted mean of 6.72. For Hercules, it is 11.29 (from magnitudes) or 10.95 (from diameters), with a weighted mean $\langle \Delta\mu_0 \rangle = 11.18$.

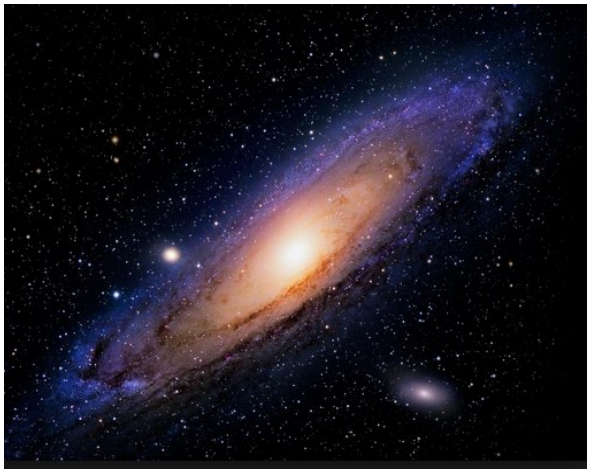
If the M31 modulus is $\mu_0 = 24.07 \pm 0.16$, the resulting distance moduli are $\langle \mu_0 \rangle = 30.8 \pm 0.3$ for the Virgo S cloud and $\langle \mu_0 \rangle = 35.25 \pm 0.3$ for the Hercules supercluster. Both are in close agreement with values previously derived from a variety of indicators.

The distance, $\Delta = 112 \pm 17$ Mpc, and the mean redshift of the Hercules supercluster in the cosmic background reference frame, $\langle V_c \rangle = 11{,}078 \pm 108$ km s$^{-1}$, give a Hubble *ratio* $H^* = 99 \pm 15$ km s$^{-1}$ Mpc$^{-1}$. The Hubble *constant* may differ by a few percent depending on cosmological model.

*Subject headings:* cosmology — galaxies: clustering

Application by De Vaucouleurs in 1985 used
5 galaxies which were “sosies” of M31 (Andromeda)

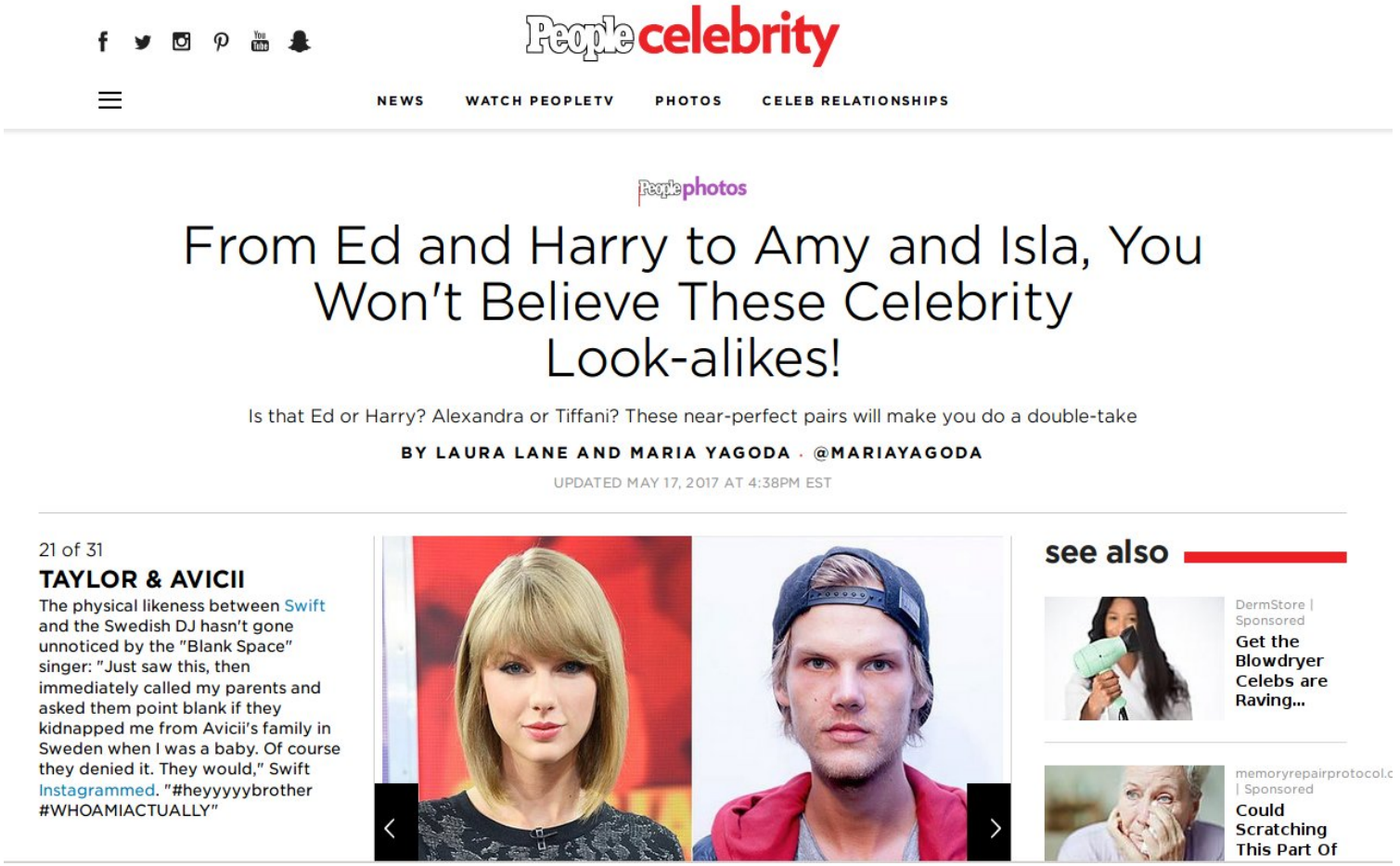
This method has not been used since – now we have
millions of times more galaxies from digital sky surveys.



With sosies don't have to model/understand face-on vs edge-on

The problem:

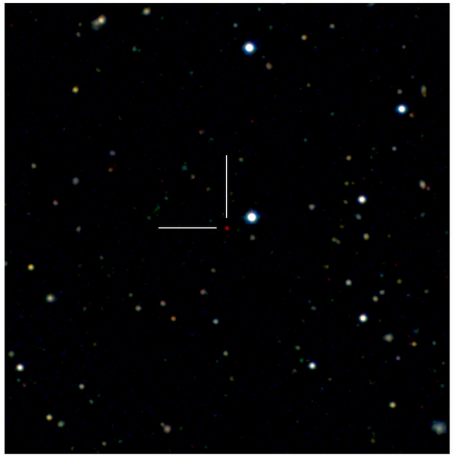
How to decide if two objects are identical.



Objects we can use as standard candles (luminosity) or standard rulers (size):

Spiral galaxies

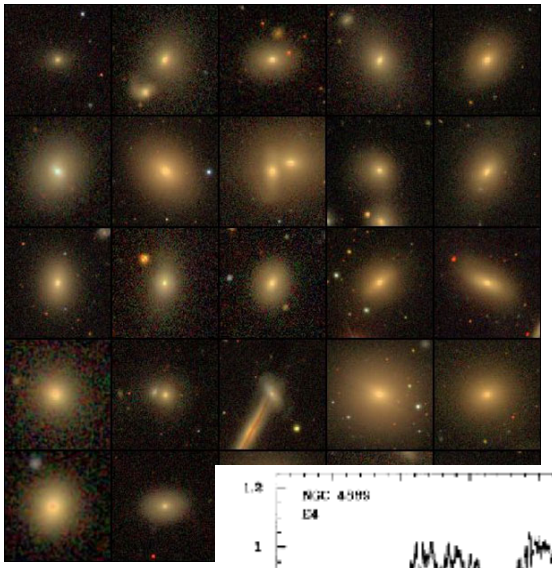
Elliptical galaxies



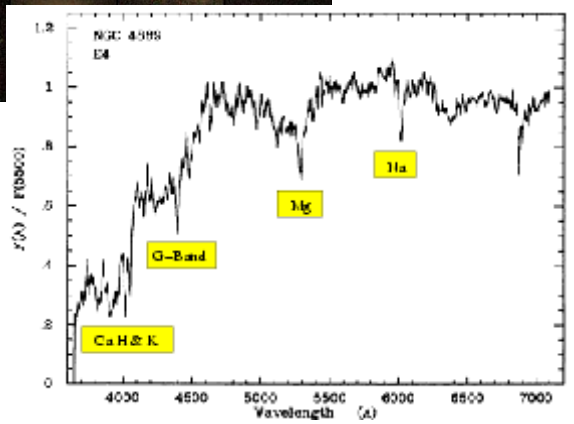
quasars (candles only - they are point sources)

Data available:

- Images



- Spectra




- Measured parameters from images
- e.g., color, luminosity gradient, ellipticity,...
-

- Measured parameters from spectra
- line widths, line flux ratios, ...

General idea:

(1) Use data (parameters or images or spectra, or a combination) to find pairs of sosies:

(2) Predict their distance ratios from their observed fluxes or observed angular sizes.

(3) Compare to the distance ratios predicted given their redshifts and a model of the expanding Universe.

(4) Decide whether the model and data are consistent.

**Where and how to get data.**


CMU has been part of the Sloan Digital Sky Survey since it's beginning in 2000

The survey is currently on its 4th iteration (SDSS IV). There have been 14 public data releases- the most recent, DR14 was in June 2017.

We will use the public data, which can be obtained from:

http://www.sdss.org/

There are many tutorials and much documentation on the site.

SLOAN DIGITAL SKY SURVEY

# SkyServer DR14

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

SDSS is supported by

## Data Release 14

**NEW:** SkyServer now contains data from the new SDSS Data Release 14! For more information, see the **DR14 documentation on the SDSS website.**

Welcome to the **DR14 site**!!!

This website presents data from the Sloan Digital Sky Survey, a project to make a map of a large part of the universe. We would like to show you the beauty of the universe, and share with you our excitement as we build the largest map in the history of the world.

**News**

The site hosts data from **Data Release 14 (DR14)**. **What's new in DR14**, and **known problems**. **More...**

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## Data Access

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Quick Look | Explore
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Search
IQS | SQS | IRSQS
SQL Search
Cross-ID
SkyQuery CrossMatch NEW!
CasJobs

## Education

For Educators
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College Lab Activities
Instructor Guides
Student/Public Research
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Zooniverse
Voyages

## Links

sdss.org
Data Release 14
Surveys | Instruments
SDSS Science
Science Archive Server
About Astronomy
About SkyServer
Credits

## Help

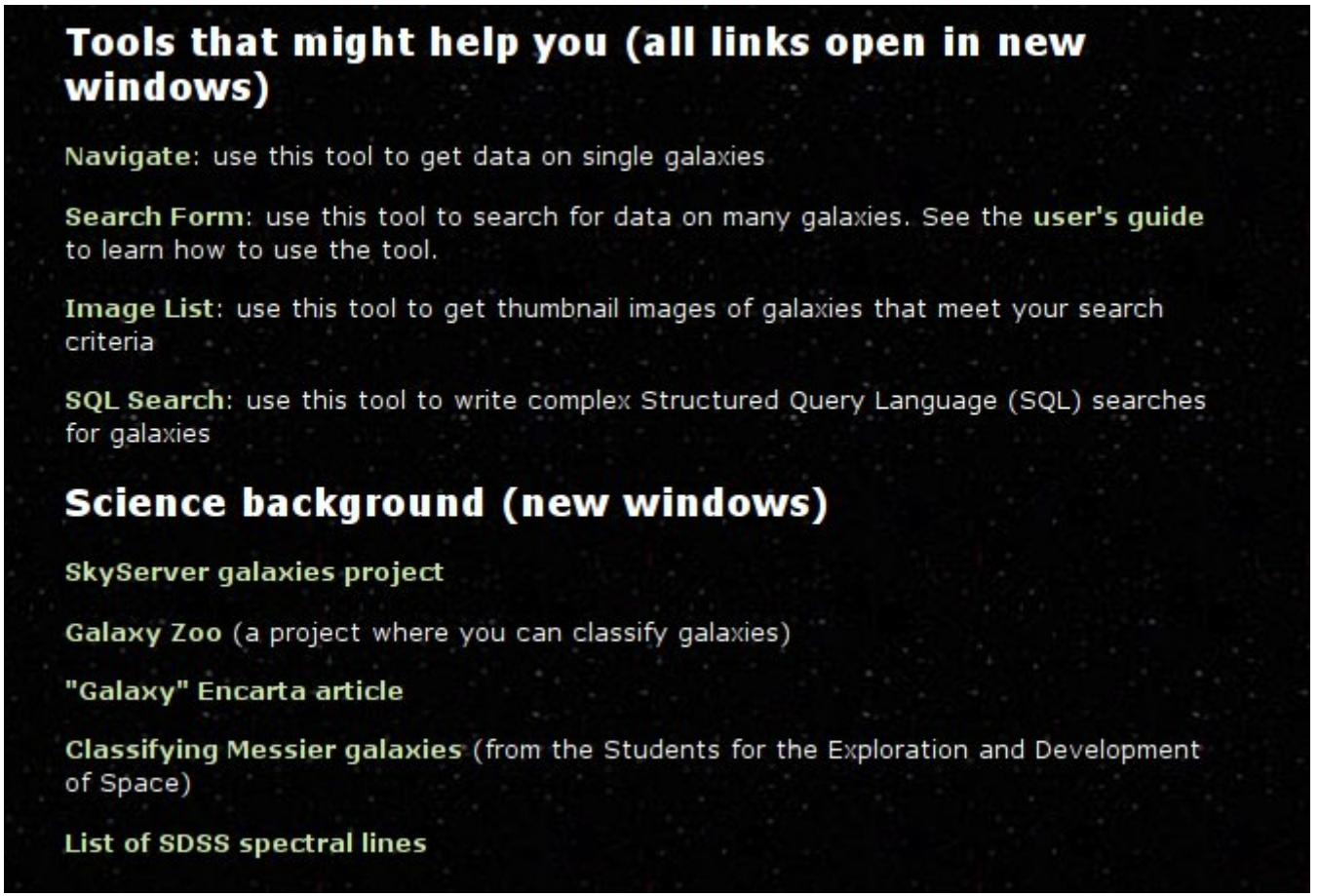
Start Here | FAQ
Glossary
Algorithms
Cooking with Sloan
SQL Tutorial
About the Database
Schema Browser
Sample SQL Queries



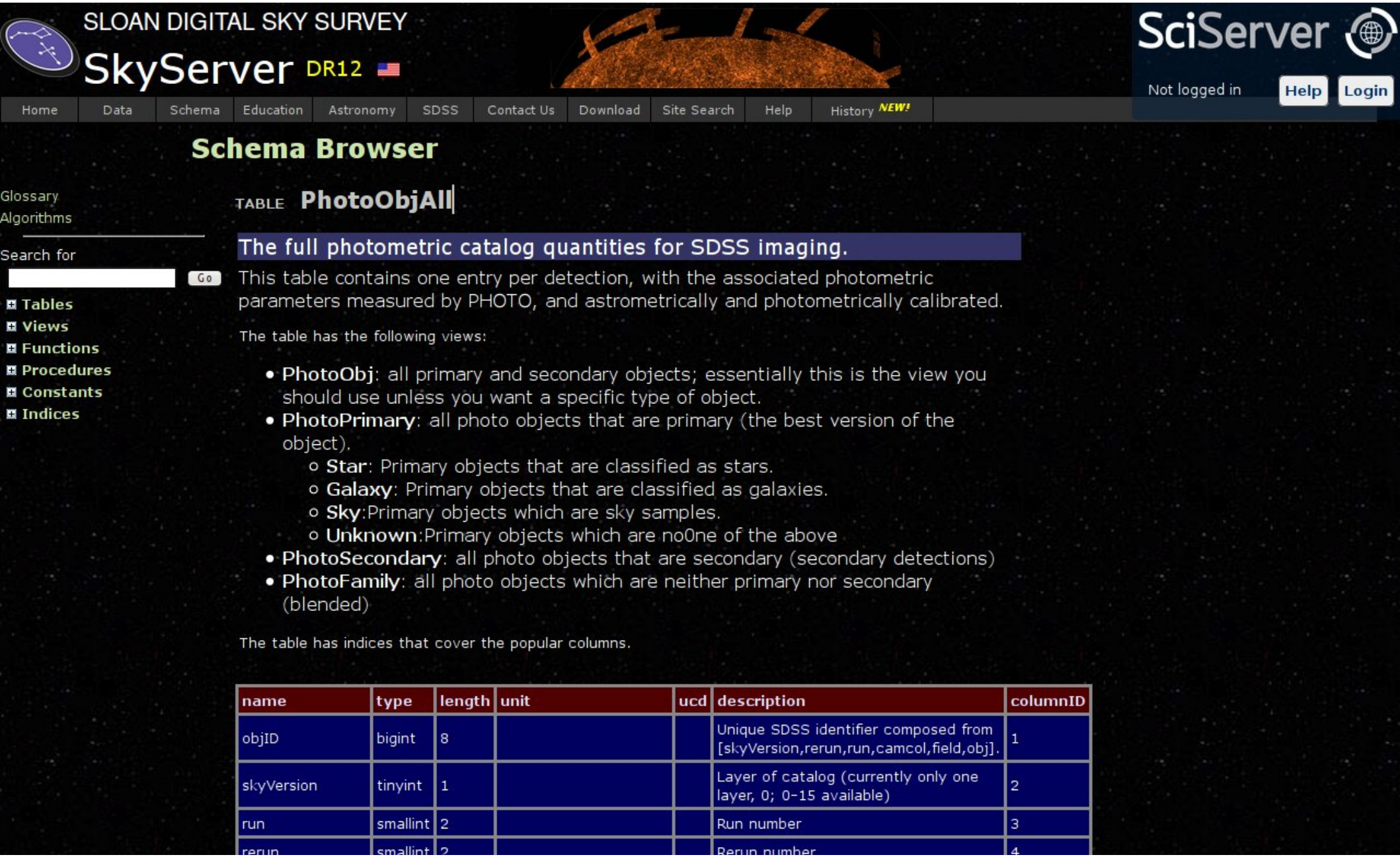

Some resources include mini projects to help get you familiar with the data. For example:

http://skyserver.sdss.org/dr14/en/proj/challenges/galaxies/galaxieshome.aspx

The above  page includes the following links to software tools:



Example: photometric parameters (quantities measured from images) are in Table: PhotoObjAll



http://www.sdss.org/dr12/spectro/

SDSS

This is Data Release 12.

Go to the latest Data Release.

DR12 Data | Surveys | Instruments | Collaboration | Results | Education | Futur

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Datasets | Imaging Data | Optical Spectra | APOGEE Spectra | MARVELS Spectra | Algorithms | Software | Help

# Optical Spectra Overview

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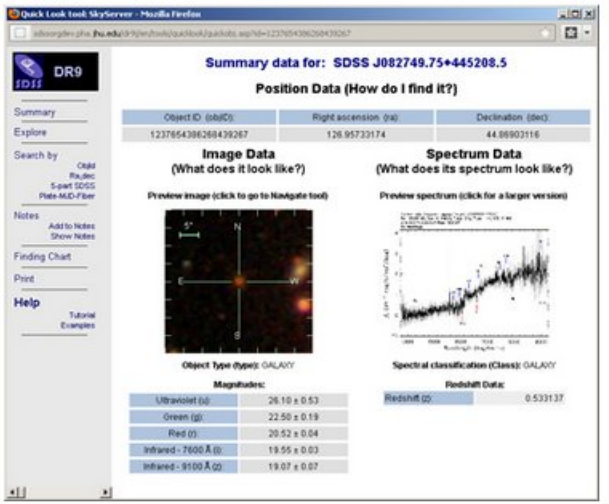
## SDSS-I/BOSS/SEGUE Optical Spectra

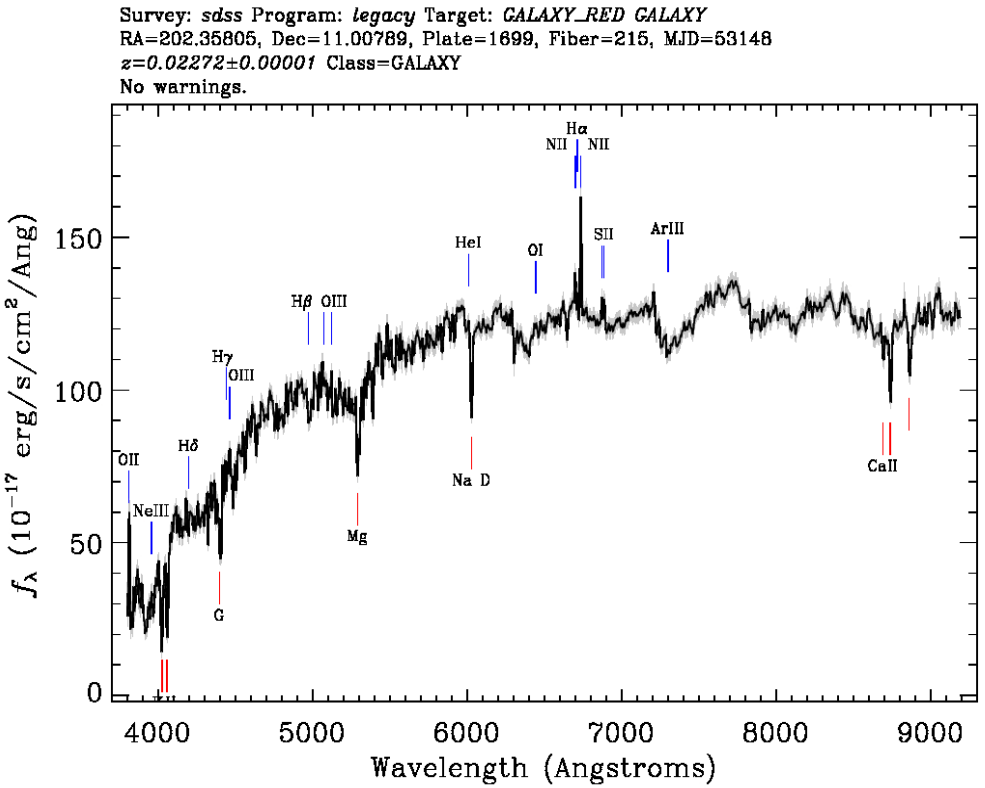
Data Release 12 includes the complete dataset of optical spectroscopy of the Sloan Digital Sky Survey through July 2014 – more than four million spectra. These spectra include all the galaxy, quasar, and stellar spectra collected by the Baryon Oscillation Spectroscopic Survey (BOSS), along with catalogs of galaxy parameters estimated in various ways.

DR12 also includes all spectra and derived stellar parameters measured by the Sloan Extension for Galactic Understanding and Exploration (SEGUE), as well as all the spectra of the original Sloan Digital Sky Survey.

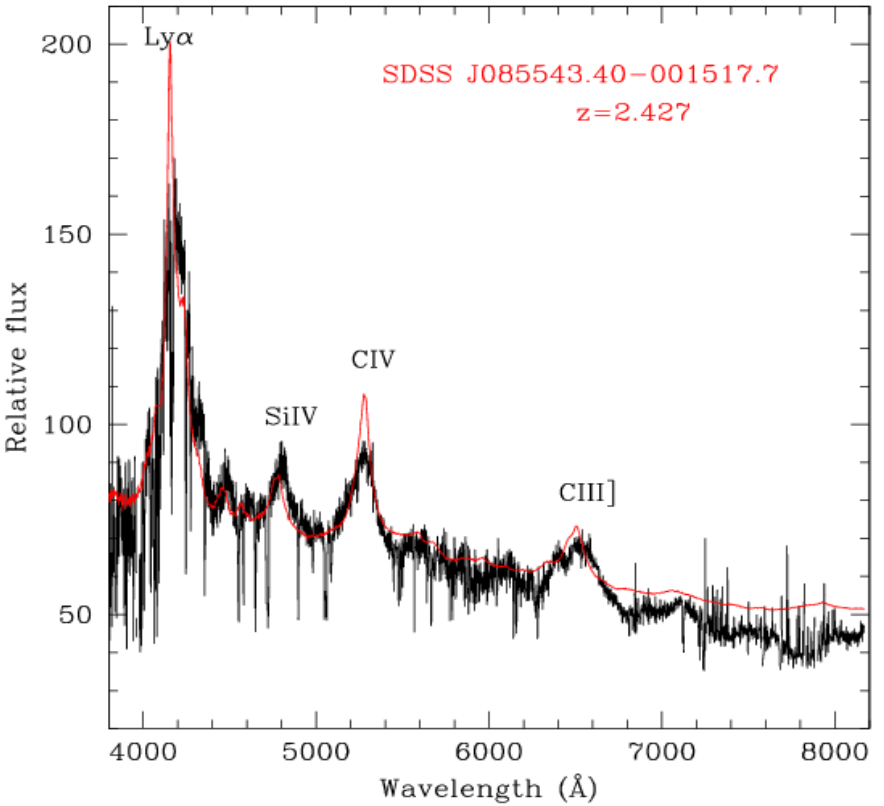



Quick Look view of the host galaxy of supernova 2011V (Hakobyan et al. 2012). Click on the image to go to the Quick Look tool.

- Overview
- Understanding
- The Pipeline
- Available Data
- Target Flags
- Catalogs
- Quality Flags
- Galaxy Properties
- Special Plates
- Stars
- Caveats




An SDSS galaxy spectrum




An SDSS quasar spectrum

## Distance measures in cosmology

A useful pedagogical article is Hogg (1998):

https://arxiv.org/abs/astro-ph/9905116

The *luminosity distance* $D_{\rm L}$ is defined by the relationship between bolometric (ie, integrated over all frequencies) flux $S$ and bolometric luminosity $L$:

$$D_{\rm L} \equiv \sqrt{\frac{L}{4\pi\, S}} \tag{20}$$

The *angular diameter distance* $D_{\rm A}$ is defined as the ratio of an object's physical transverse size to its angular size (in radians). It is used to convert angular separations in telescope images into proper separations at the source. It is famous for not increasing indefinitely as $z \to \infty$; it turns over at $z \sim 1$ and thereafter more distant objects actually appear larger in angular size. Angular diameter distance is related to the transverse comoving distance by

$$D_{\rm A} = \frac{D_{\rm M}}{1+z} \tag{18}$$

Also $$D_{\rm L} = (1+z)\, D_{\rm M} = (1+z)^2\, D_{\rm A}$$

Can compute luminosity distance using an analytical approximation due to Adachi & Kasai (2011):

https://arxiv.org/abs/1111.6396

In this paper, we present yet another analytical approximation to calculate the luminosity distance as follows:

$$d_{\rm L}(z,\Omega_{\rm m}) = \frac{2c}{H_0}\frac{1+z}{\sqrt{\Omega_{\rm m}}}\left\{\Phi\big(x(0,\Omega_{\rm m})\big) - \frac{1}{\sqrt{1+z}}\Phi(x(z,\Omega_{\rm m}))\right\}, \tag{1·1}$$

$$\Phi(x) = \frac{1+1.320x+0.4415x^2+0.02656x^3}{1+1.392x+0.5121x^2+0.03944x^3}, \tag{1·2}$$

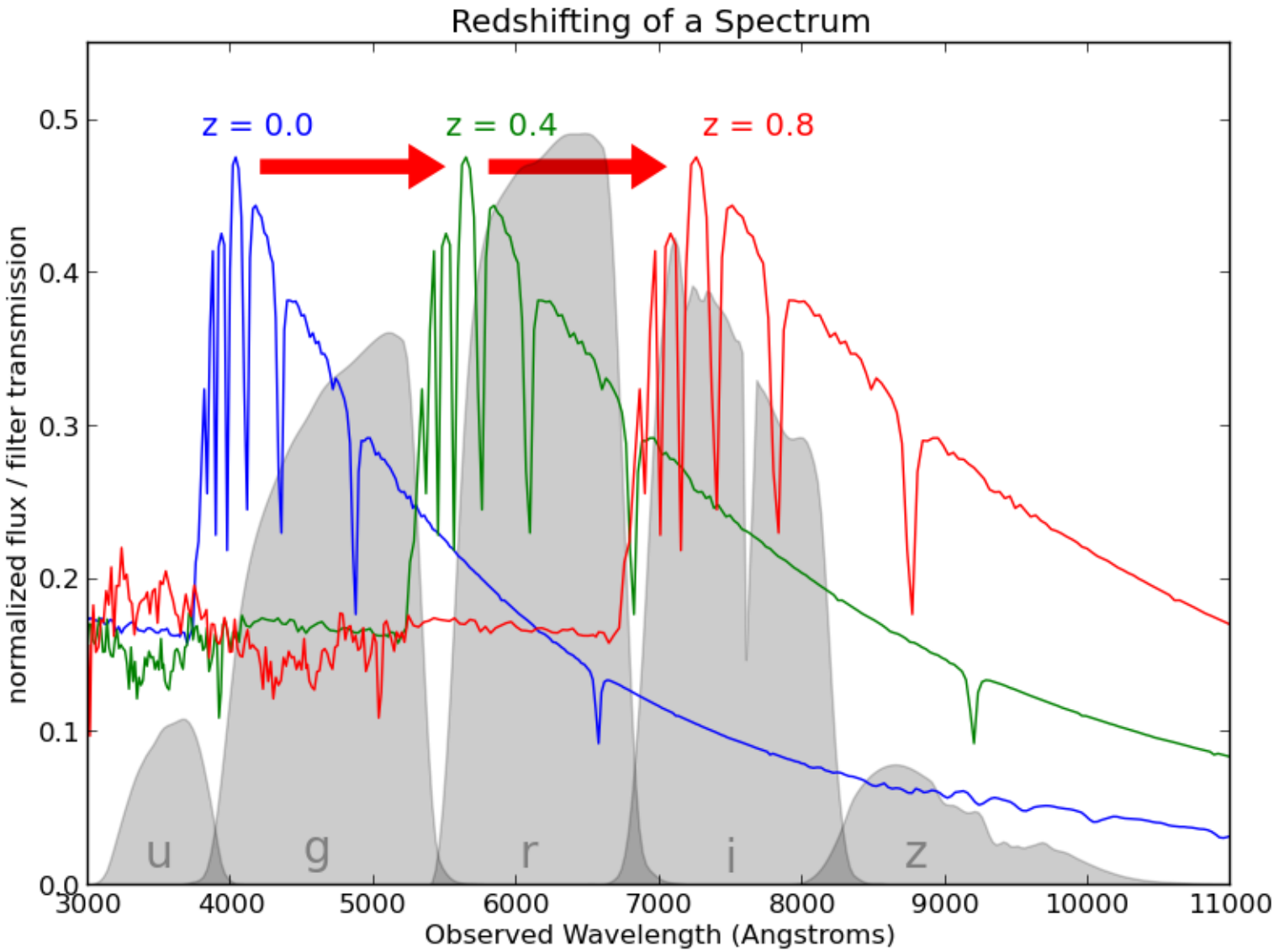
where $c$ is the speed of light, $H_0$ is the Hubble constant, $\Omega_{\rm m}$ is the density parameter of dust matter, related to the density parameter of vacuum energy $\Omega_\Lambda$ by $\Omega_{\rm m}+\Omega_\Lambda = 1$, and

$$x(z,\Omega_{\rm m}) = \frac{1-\Omega_{\rm m}}{\Omega_{\rm m}}\frac{1}{(1+z)^3}. \tag{1·3}$$

Apart from the overall factor $1/\sqrt{\Omega_{\rm m}}$, the effect of non-zero cosmological constant in our distance formula is written simply in terms of a rational function $\Phi(x)$.

(works only for a flat universe, but we can make that assumption for simplicity if we want)

A complication that you can deal with for better accuracy: the “K-correction”




Galaxies at different redshifts will have different parts of their spectra falling in each filter. The K-correction corrects the galaxy apparent luminosity in a filter to what it would be in the rest frame (z=0.0)

## Conclusions

What will we discover?

-new way to constrain cosmological model and how Universe is expanding.

-or if things are not consistent this shows that galaxy/quasar luminosities and/or sizes evolve even when everything else seems identical → a new window on galaxy evolution.