cover edit 18.10.31.22

Sloan Digital Sky Survey

v. 23 April 2017

Sloan Foundation
2.5-m Telescope
Apache Point, NM

Image credit: Drew Chojnowski

My work in cosmology is strongly dependent on the high-quality astrophysical data produced by the Sloan Digital Sky Survey (SDSS). Many people have devoted a good portion of their lives and made significant personal sacrifices to produce this data. I am privileged to have had the opportunity to benefit from their life's work and they share in the personal achievement of any scientific discovery that arises from it.

This slide presentation, designed for a general audience with an interest in astronomy and cosmology, both informs the reader about the SDSS in some detail and celebrates the individuals whose genius, combined with hard work, have made it a reality. The SDSS is arguably the most important contribution to physical science in our time.

– Alexander Franklin Mayer

“They’re beginning to build a road map to the universe that will take them farther and deeper back into time than anyone has gone before.

What they are actually building is an extraordinary camera, the size of a coffee table, and software so complex that it boggles the mind. These instruments, together with a wide-angle telescope in New Mexico and a pair of spectrographs, are going to produce a three-dimensional map of the universe over a thousand times more detailed than ever before created.”

Kathryn Watterson

– Kathryn Watterson, “Road map to the universe,” *Princeton Weekly Bulletin* (February 24, 1997).

IMPORTANT!

Images and *literature references* throughout are clickable relevant Internet links.
Search for ‘concealed’ hyperlinks with your pointer (cursor changes over links).
OS X

Tycho Brahe*
(1546 – 1601)

James Edward Gunn,

“Father” of the SDSS

“In 1987 Gunn proposed putting an array of CCDs on a 2.5m-telescope and using it for both images and spectra, scanning the entire visible sky in about five years and building an enormous data archive which could be used for far more than his main interest, determining the three-dimensional structure of the universe of galaxies. This ultimately became the Sloan Digital Sky Survey, and Gunn devoted a large portion of his career to building it and making it work.”

Source: http://www.phys-astro.sonoma.edu/brucemedalists/Gunn/index.html

- Recipient of the 2009 U.S. National Medal of Science
- Recipient of the Catherine Wolfe Bruce Medal Gold Award
- Recipient of the Gold Medal of the Royal Astronomical Society
- Eugene Higgins Professor of Astronomy at Princeton University

JAMES E. GUNN ET AL., “THE 2.5 m TELESCOPE OF THE SLOAN DIGITAL SKY SURVEY,”
THE ASTRONOMICAL JOURNAL, 131:2332-2359, 2006 April

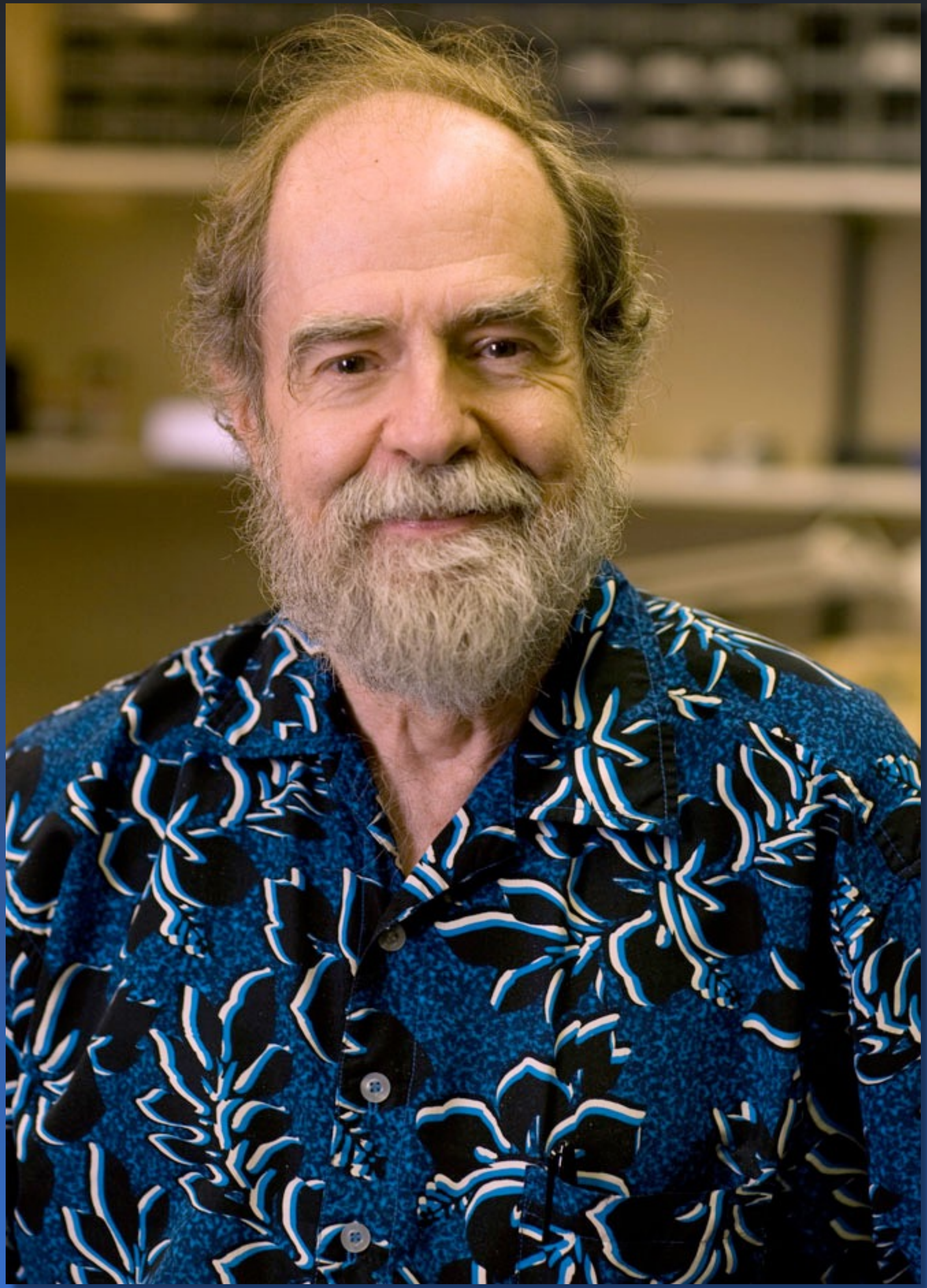
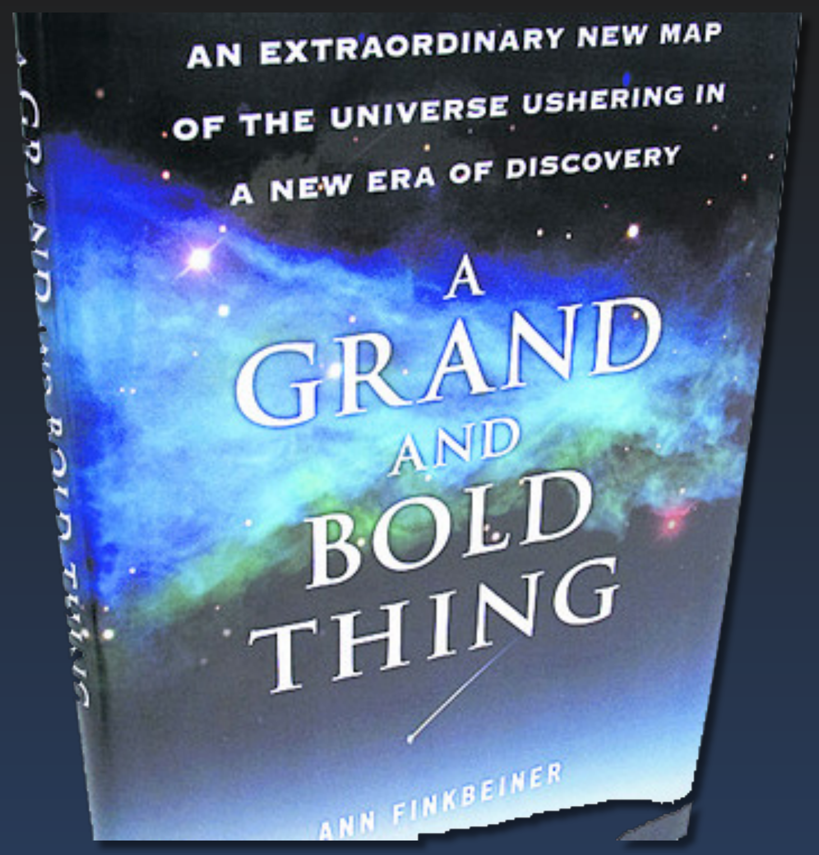


Photo 2009 by Brian Wilson • brianwilsonphotographer.com •

* Tycho Brahe’s accurate astronomical data allowed Johannes Kepler to discover that the planets moved in elliptical orbits, which led to Isaac Newton’s universal law of gravitation. James Gunn’s work proves to be of a similar nature.



Builders of the Sloan Digital Sky Survey

"The builders of the SDSS are those individuals whose contributions to project infrastructure make the exciting SDSS science possible. Specifically, these are the individuals who have contributed two years or more of effort to the infrastructure of the project writing pipeline software, building hardware, or through leadership and fundraising."

SciAm book excerpt

Click name for homepage or best reference.

John Anderson
Scott Anderson
Jim Annis
Neta Bahcall
Jon Bakken
Steve Bastian
Eileen Berman
William Boroski
Charlie Briegel
John Briggs
Jon Brinkman
Robert Brunner
Scott Burles
Larry Carey
Michael Carr
Francisco Castander
Pat Colestock
Andy Connolly
Jim Crocker
Istvan Csabai
Paul Czarapata
Jon Davis
Mamoru Doi
Tom Dombeck
Brian Elms
Michael Evans
Xiaohui Fan
Glenn Federwitz
Scott Friedman
Joshua Frieman
Masataka Fukugita
Bruce Gillespie
James Gunn
Vijay Gurbani
Fred Harris
Mike Harvanek
Tim Heckman
Greg Hennessy
Bob Hindsley
Don Holmgren
Chih-Hao Huang
Charlie Hull
Takashi Ichikawa
Zeljko Ivezic
Sebastian Jester
Stephen Kent
Mark Klaene
Scot Kleinman
Jill Knapp
John Korienek
Rich Kron
Jurek Krzesinski
Peter Kunszt
Donald Lamb
Brian Lee
Roger (French) Leger
Siri Limmongkol
Carl Lindenmeyer
Dan Long
Craig Loomis
Jonathan Loveday
Robert Lupton
Bryan Mackinnon
Edward Mannery
Paul Mantsch
Bruce Margon
Tim McKay
Jeff Munn
Tom Nash
Eric Neilsen
Heidi Newberg
Pete Newman
Robert Nichol
Tom Nicinski
Atsuko Nitta-Kleinman
Sadanori Okamura
Jeremiah Ostriker
Russell Owen
Georg Pauls
John Peoples
Don Petravick
Jeff Pier
Ruth Pordes
Angela Prosapio
Thomas Quinn
Ron Rechenmacher
Gordon Richards
Michael Richmond
Claudio Rivetta
Constance Rockosi
Kurt Ruthmansdorfer
Dale Sandford
David Schlegel
Kazu Shimasaku
Don Schneider
Maki Sekiguchi
Gary Sergey
Walter Siegmund
Stephen Smee
Allyn Smith
Stephanie Snedden
Chris Stoughton
Michael Strauss
Mark Subbarao
Alex Szalay
Gyula Szokoly
Ani Thakar
Doug Tucker
Michael Turner
Alan Uomoto
Dan Vanden Berk
Michael Vogeley
Patrick Waddell
Shu-i Wang
David Weinberg
Brian Yanny
Naoki Yasuda
Don York

(118 individuals)

Source: http://classic.sdss.org/members/builders.html (April 2014)

If you find that this list is incomplete, please contact the Help Desk and Cc: amayer@alum.mit.edu to initiate verification.

"This is one of the biggest bounties in the history of science. This data will be a legacy for the ages; we expect the SDSS data to have that sort of shelf life." [1]

– Professor Mike Blanton, New York University

Mike Blanton

The unprecedented number of high-quality measurements in the SDSS, which represents the first accurate consolidated "map of the Universe," allows for unprecedented objective investigation. This abundance of data promises the opportunity for many revolutionary scientific discoveries.

1. http://www.sdss3.org/press/20110111.largestimage.php

SDSS website reference

FOR RELEASE 10:30 AM PST (1:30 PM EDT), January 11, 2010

ASTRONOMERS RELEASE THE LARGEST COLOR IMAGE OF THE SKY EVER MADE

Today, the Sloan Digital Sky Survey-III (SDSS-III) is releasing the largest digital color image of the sky ever made, and it's free to all. The image has been put together over the last decade from millions of 2.8-megapixel images, thus creating a color image of more than a trillion pixels. This terapixel image is so big and detailed that one would need 500,000 high-definition TVs to view it at its full resolution. "This image [representing the breadth and detail of SDSS astrophysical data] provides opportunities for many new scientific discoveries in the years to come," exclaims Bob Nichol, a professor at the University of Portsmouth and Scientific Spokesperson for the SDSS-III collaboration.

Annotation to the original text in brackets.

(References the image on the next slide.)

Bob Nichol

Source: http://sdss3.files.wordpress.com/2011/01/aas-print-release.pdf

SDSS website reference

Every point in this image is a galaxy.

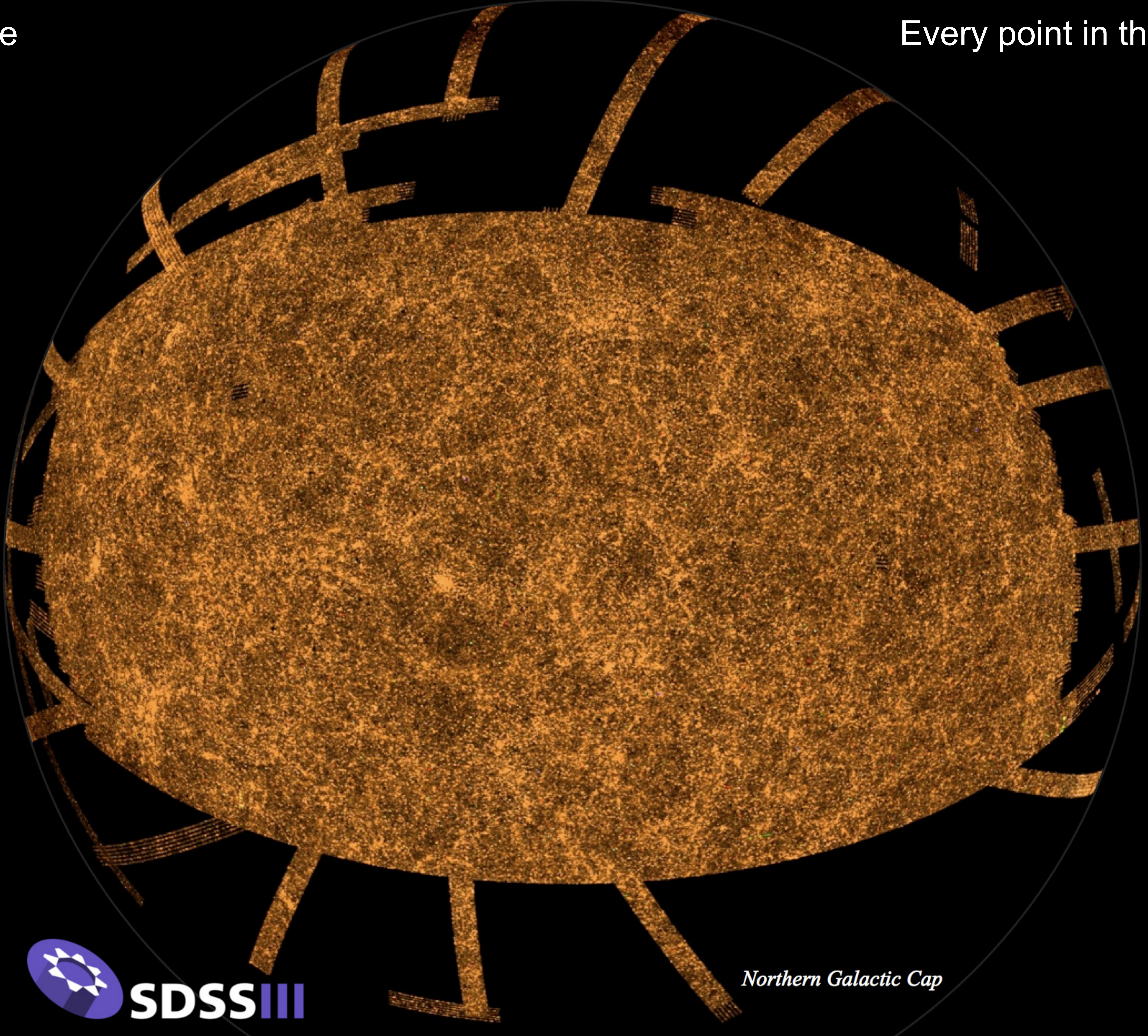


Image credit: M. Blanton and the SDSS-III

SDSS website reference

SDSS

The Sloan Digital Sky Survey. The survey has proceeded in three phases. SDSS-I was in operation from 2000 through 2005. SDSS-II continued for the following three years, and SDSS-III began in July 2008 and will continue through 2014.

SDSS-II

The second phase of the SDSS. It took place from July 2005 to July 2008 and included:

legacy, completing the science goals of SDSS-I.

SDSS-III

The third phase of the Sloan Digital Sky Survey. It started in September 2008, and will continue through Summer 2014. It includes:

BOSS, a spectroscopic survey of galaxies and quasars to study large-scale clustering.

current

SDSS-IV

"The latest generation of the SDSS (SDSS-IV, 2014 – 2020) is extending precision cosmological measurements to a critical early phase of cosmic history (eBOSS) …"

Source: http://www.sdss.org/dr13/help/glossary/#sdss

SDSS website reference

legacy

One of the three surveys that comprise the second phase (SDSS-II) of the Sloan Digital Sky Survey (SDSS). It completes the SDSS-I survey of the extragalactic universe. SDSS-I plus legacy obtained images and redshifts of a million galaxies and quasars over a contiguous 7500 deg^2 in the Northern Galactic Cap, and three stripes in the Southern Galactic Cap.

BOSS

The Baryon Oscillation Sky Survey, one of the four component surveys of SDSS-III. It is obtaining redshifts of 1.5 million galaxies, and spectra of 150,000 $z > 2.2$ quasars, to measure the baryon oscillation signal in the correlation function as a geometrical probe of cosmology. It also obtained imaging over roughly 3100 deg^2 of the Southern Galactic Cap beyond that in SDSS-I/II. It uses substantially improved spectrographs over those used in SDSS-I and SDSS-II, with more fibers per plate (1000 vs. 640), smaller fiber aperture (2", not 3"), improved throughput, and somewhat wider wavelength coverage.

Source: http://www.sdss.org/dr13/help/glossary/

SDSS website reference

Fiber

The SDSS spectrograph uses optical fibers to direct the light at the focal plane from individual objects to the slithead. Each object is assigned a corresponding `fiberID`. The fibers for SDSS-I/II were 3 arcsecs in diameter in the source plane; they are 2 arcsecs in diameter for BOSS. Each fiber is surrounded by a large sheath which prevents any pair of fibers from being placed closer than 55 arcsecs on the same plate (62 arcsecs for BOSS).

fiberMag

The magnitude measured by the frames pipeline to simulate the flux that would fall into a 3" fiber in typical seeing. Similarly, fiber2Mag simulates the 2" fiber magnitude.

Plate

Each spectroscopic exposure employs a large, thin, circular metal plate that positions optical fibers via holes drilled at the locations of the images in the telescope focal plane. These fibers then feed into the spectrographs. [Three images follow.]

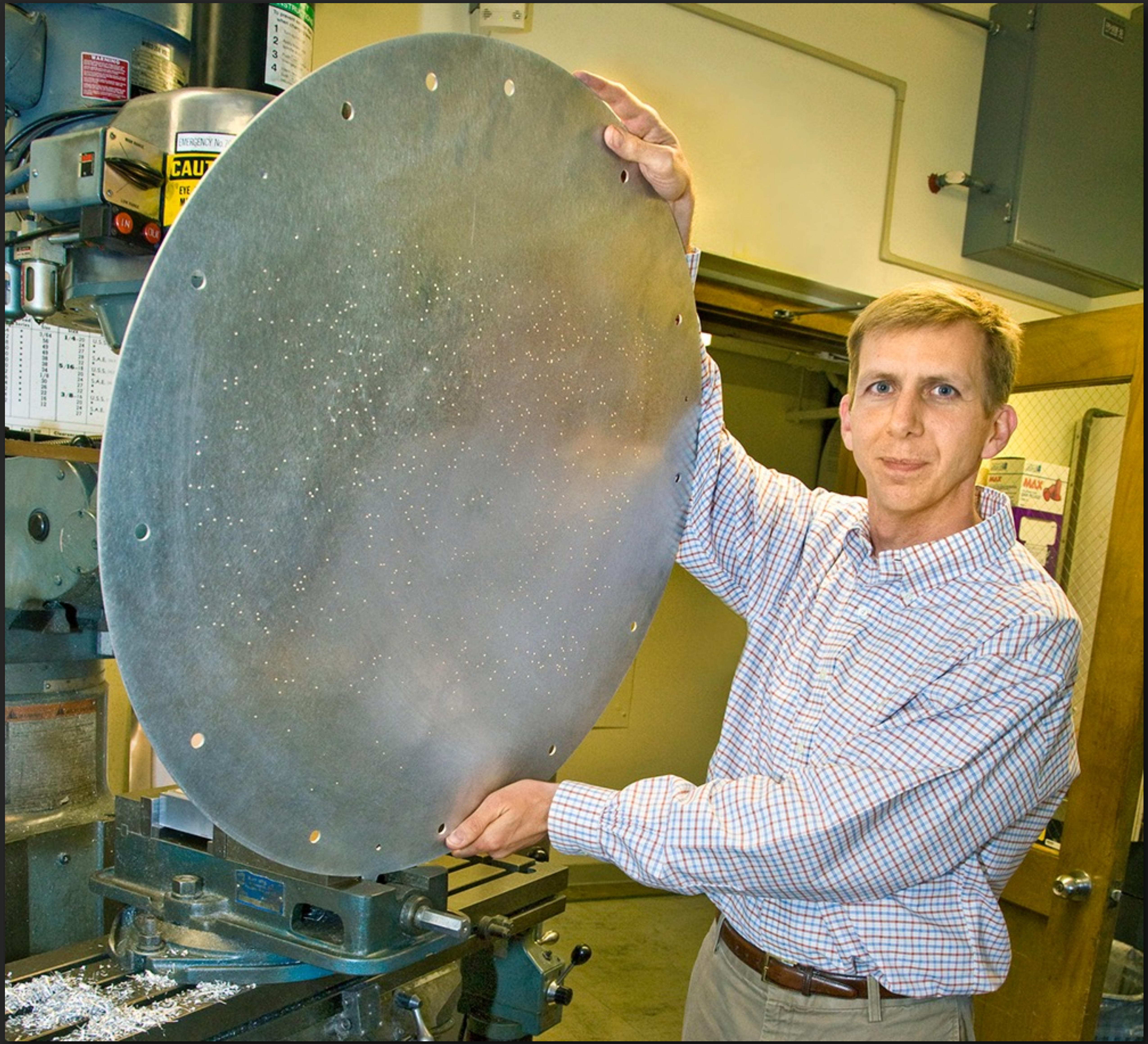
Source: http://www.sdss.org/dr13/help/glossary/#fiber

One of many precision-machined SDSS plug plates

Click on David's photo for his excellent 8-minute LBL* talk: "Mapping the Universe."

Caveat: In the introduction, when David says "discovery," this is accurate as concerns Neptune, but "*interpretation*" is the more accurate term for for 'dark matter' and also for 'dark energy.' Both obscure phenomena could be subject to revised interpretation.

* BERKELEY LAB
Lawrence Berkeley National Laboratory
Bringing Science Solutions to the World



BOSS Principal Investigator David Schlegel with one of numerous SDSS "plug plates."

☞ Important!

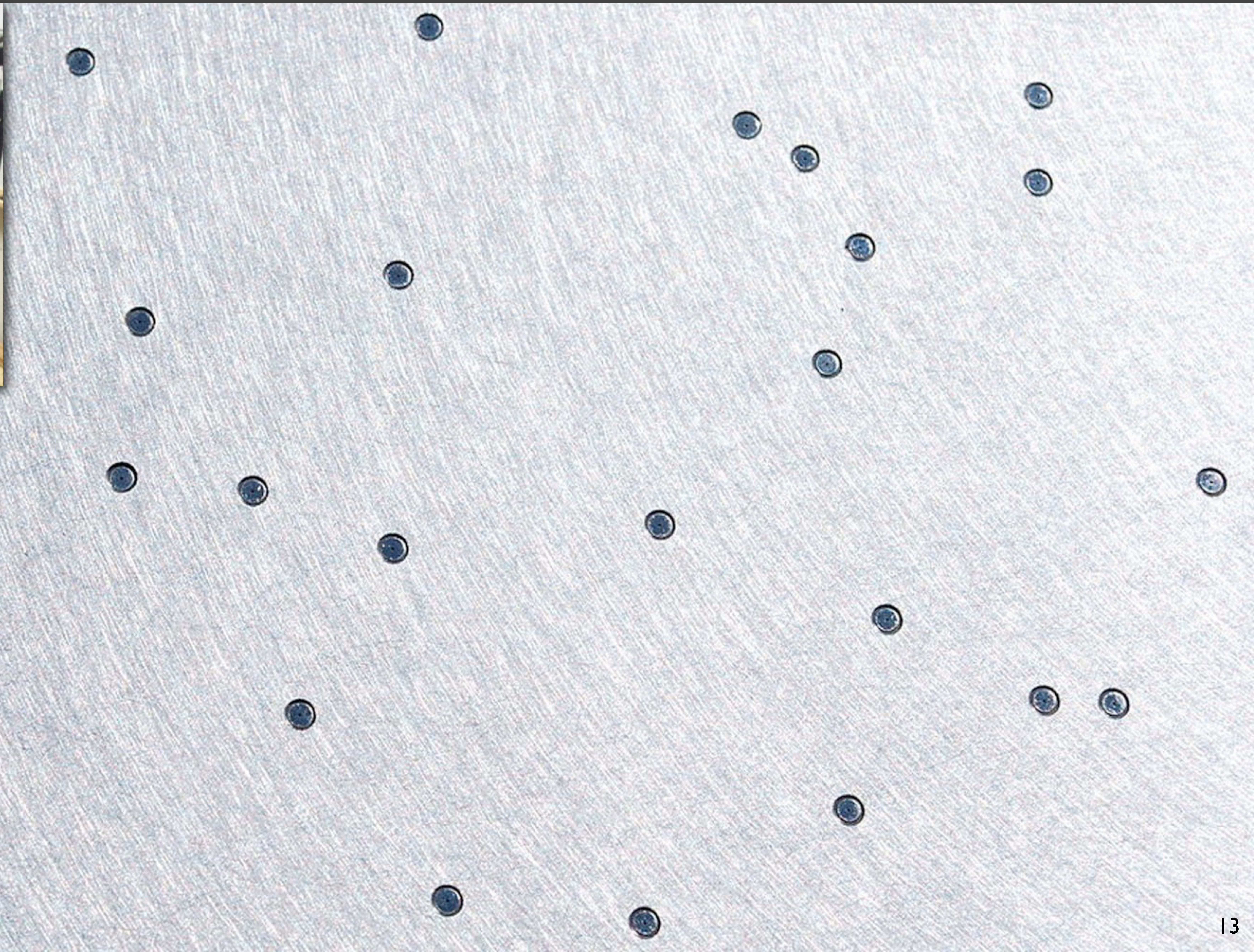
Do take a break and listen to David's talk about the SDSS.

Source: http://newscenter.lbl.gov/2008/09/15/boss/

Plugging fibers into the plate

Source: https://www.sdss3.org/dr8/spectro/spectro_basics.php

Closeup of SDSS spectrograph plug plate



Source: http://commons.wikimedia.org/wiki/File:SDSS_spectrograph_plate.JPG

An SDSS spectrograph plug plate (in situ)

Source: http://commons.wikimedia.org/wiki/File:SDSS_spectrograph_cartridge.JPG

The following slides demonstrate a *subset* of the astrophysical data measured by the SDSS and freely available to researchers worldwide from the online Catalog Archive Server (CAS) relational database and the collection of other scientific and educational tools on the SDSS SkyServer website, now a portal of the generalized SciServer.org website, as of April 2016.

I am in awe of the team of people who (A) dreamed up this idea and (B) made it a reality. They are my heroes; what they did with their lives is truly extraordinary and meaningful, both to present-day society and for posterity. The SDSS is a historic scientific achievement.

The most recent SDSS Data Release 13 became available on 31 July 2016 and contains data gathered between July 2014 and July 2015, added to data from all prior releases (DR 1 – 12).

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

SDSS J120003.16+081054.1

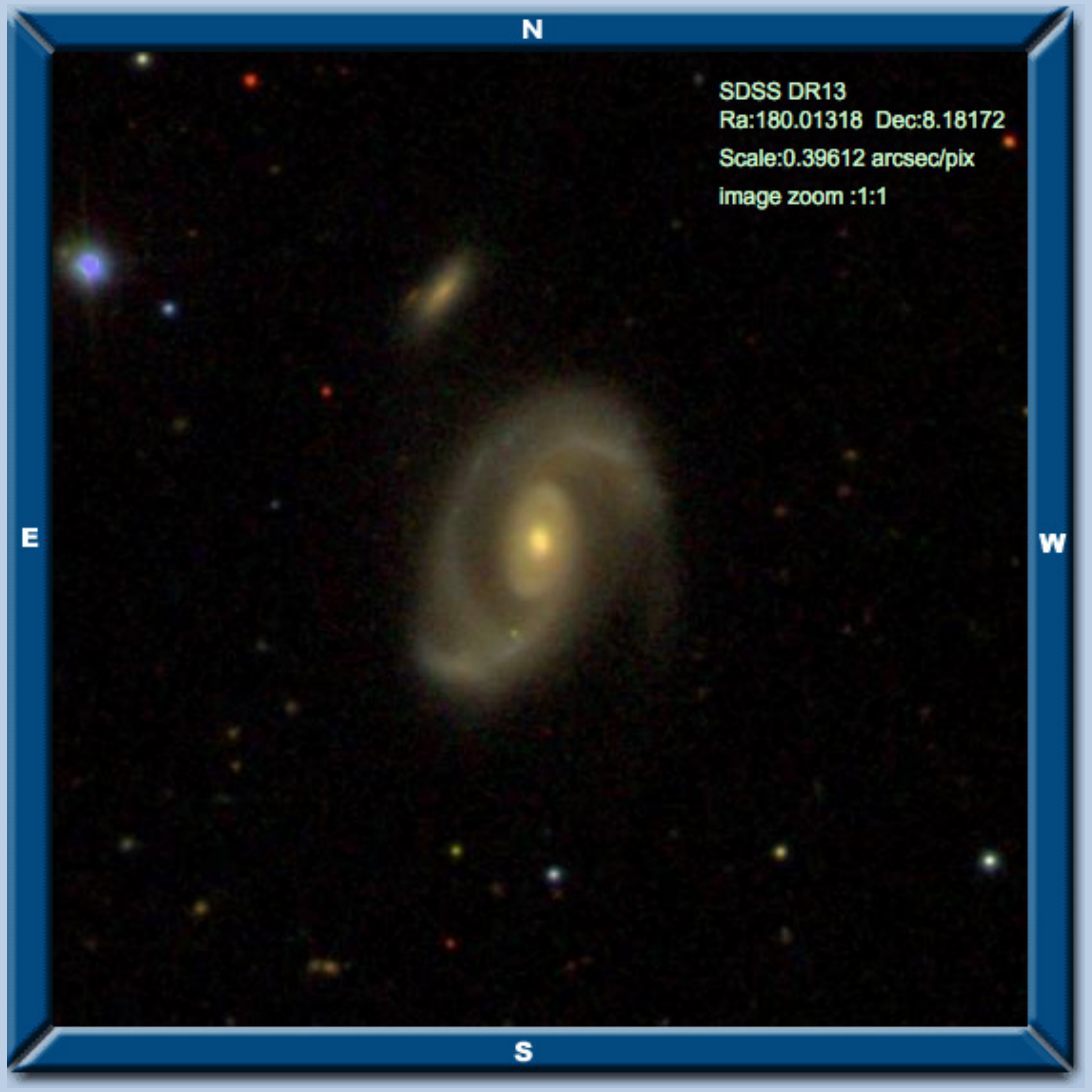
SDSS Object ID: 1237658424636276773

$z = 0.020\,429\,8 \pm 0.000\,008\,9$

Plain image

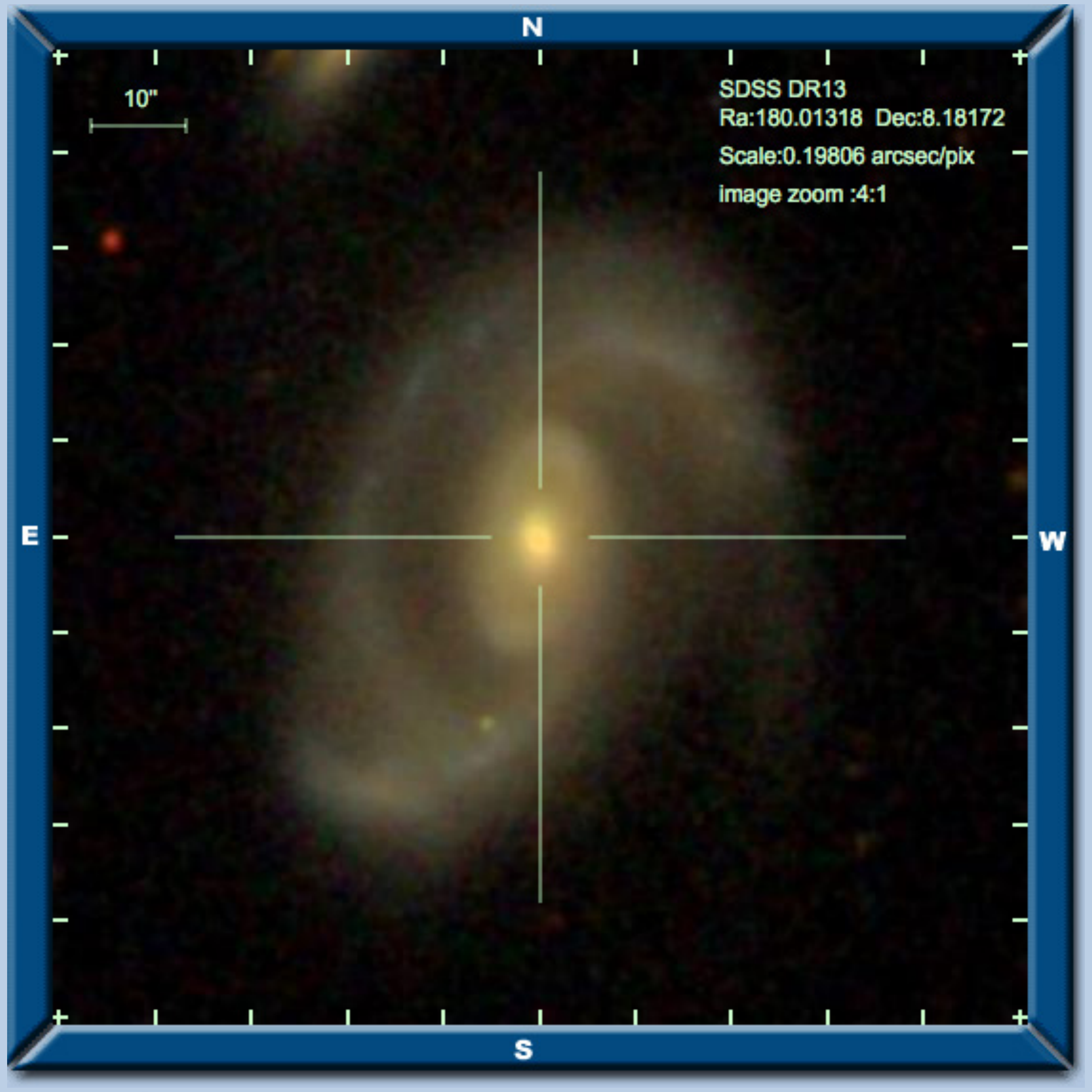
6'
(6 *arcminutes* = 0.1 degree)

Label added



3'
native pixel resolution (0.396 arcsecs/pix)

Scale grid added



1' 30"
(90 *arcseconds* = 1.5')

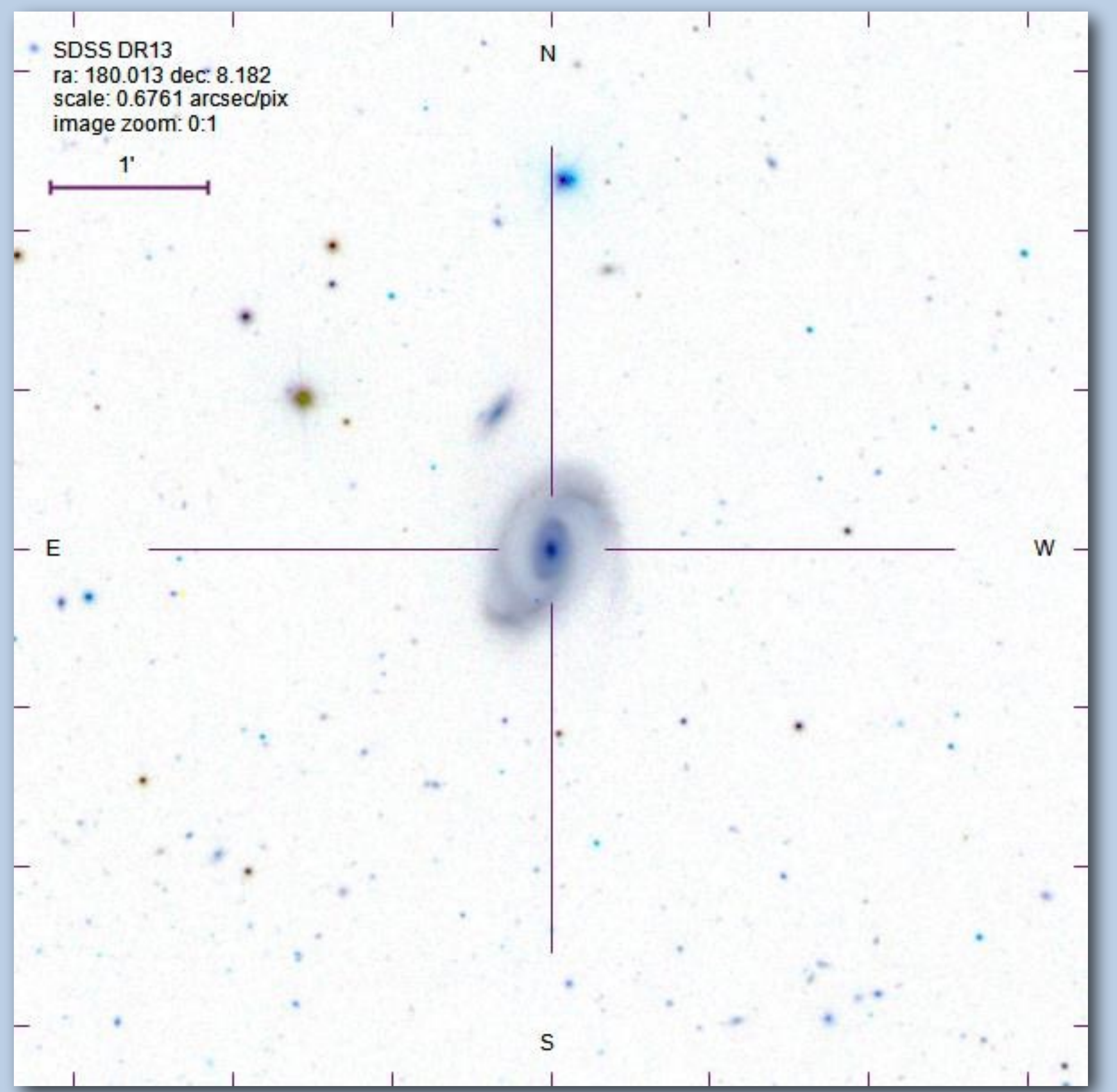
SDSS DR13 Navigate Tool

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

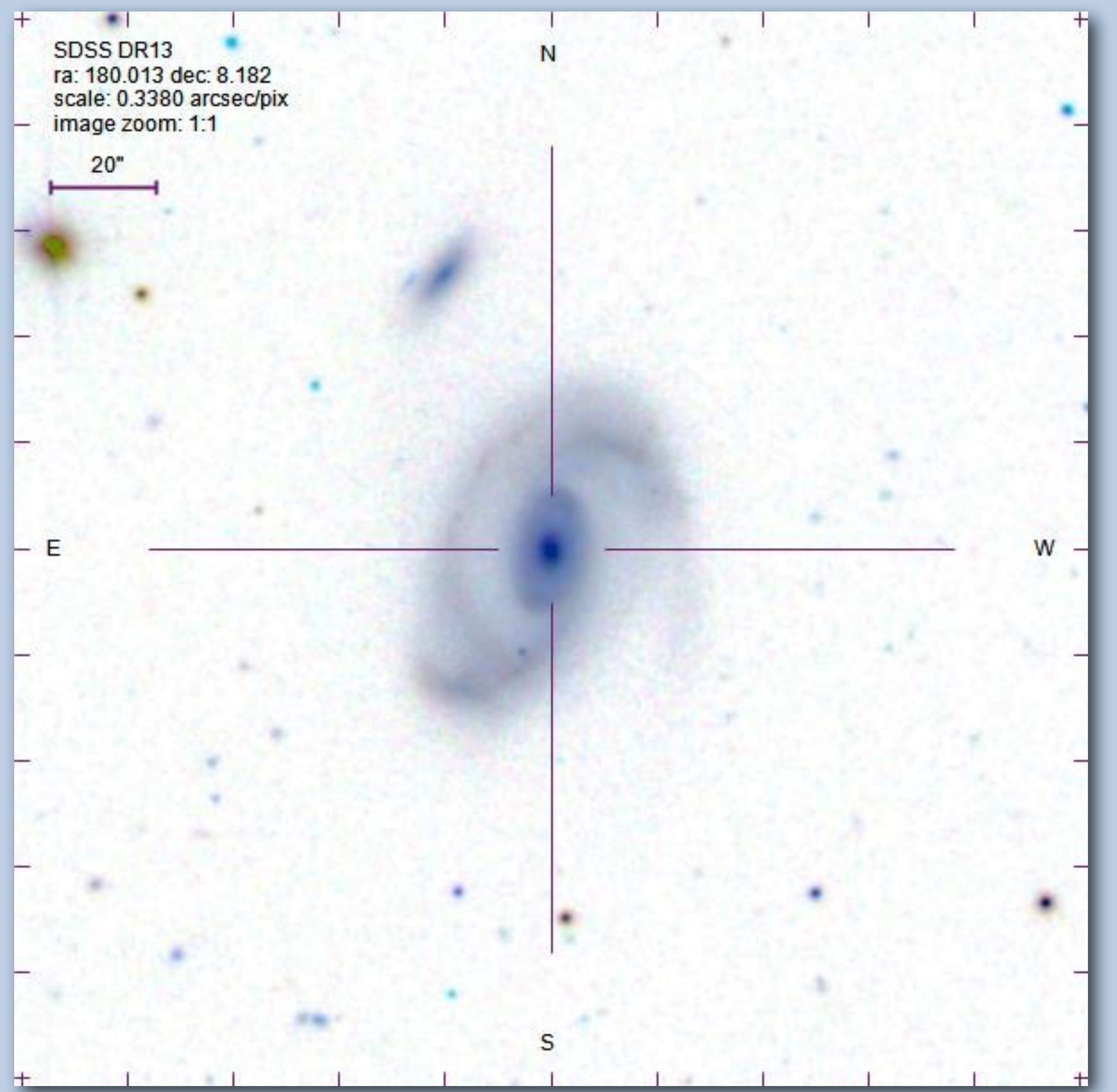
SDSS J120003.16+081054.1

SDSS Object ID: 1237658424636276773

$z = 0.020\,429\,8 \pm 0.000\,008\,9$

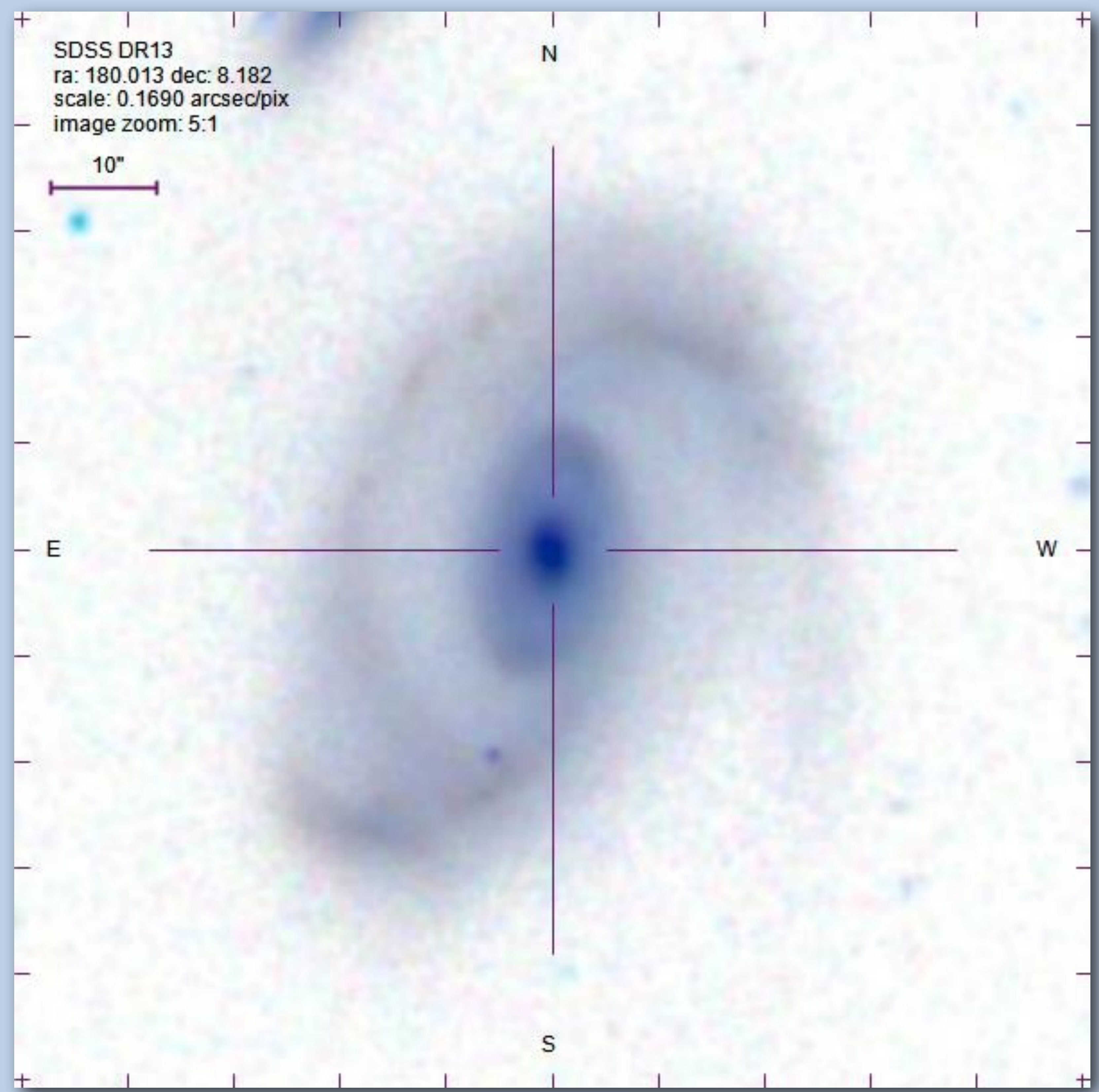


360"



200"

(200 *arcseconds*)



100"

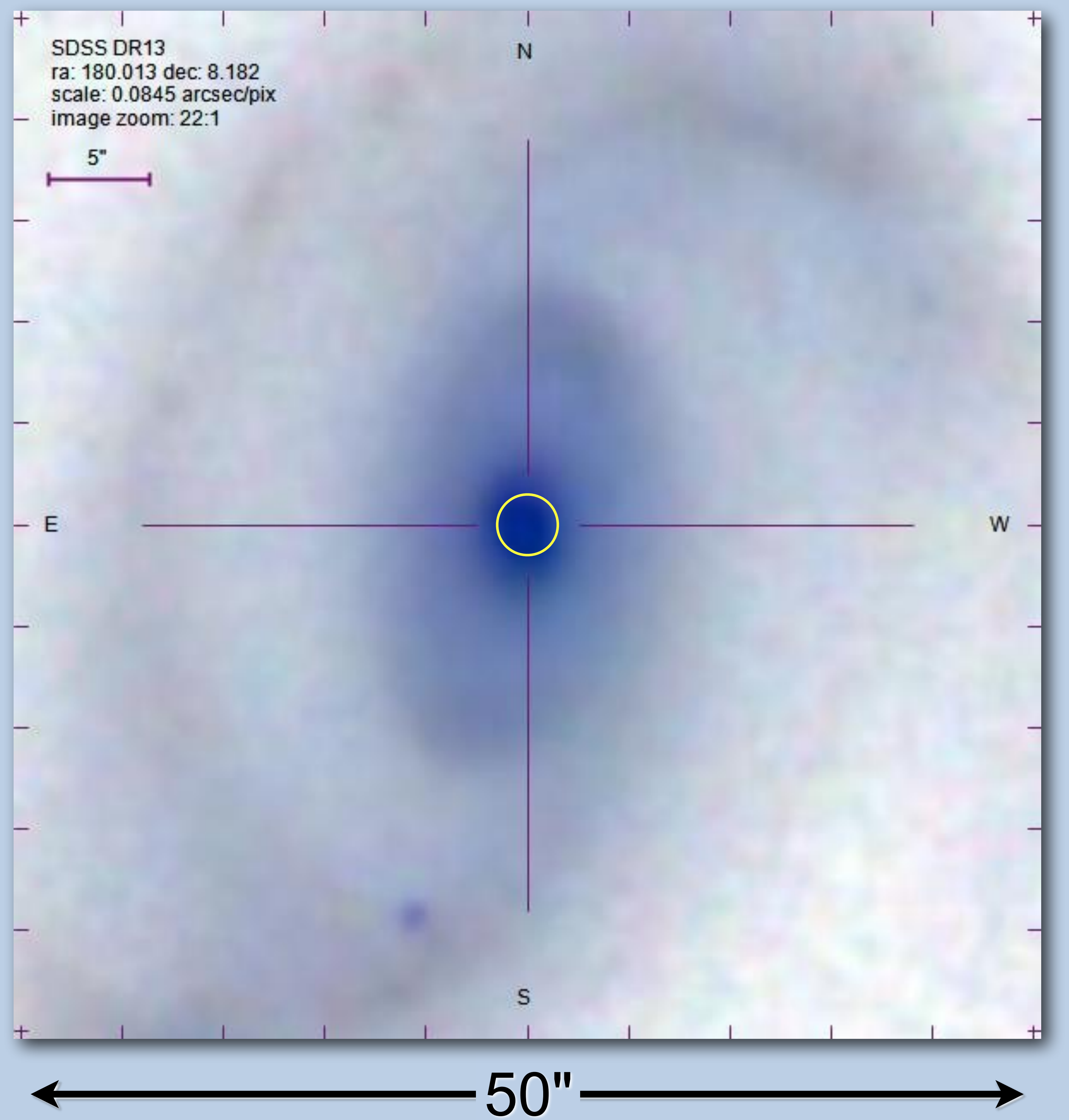
Negatives (print image feature)

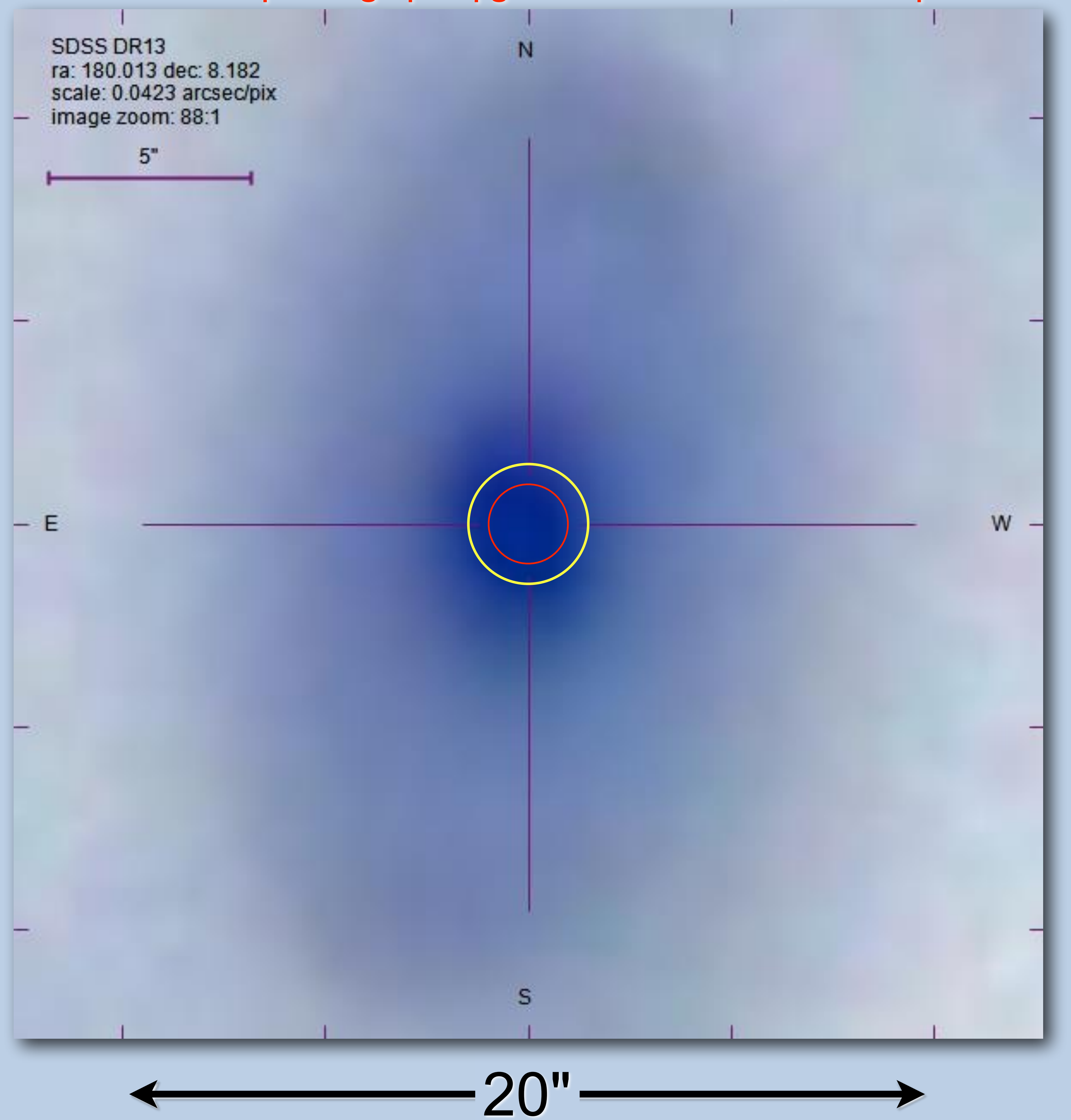
SDSS J120003.16+081054.1

SDSS Object ID: 1237658424636276773

$z = 0.020\,429\,8 \pm 0.000\,008\,9$

2″-fiber BOSS spectrograph upgrade shown in red, for comparison.





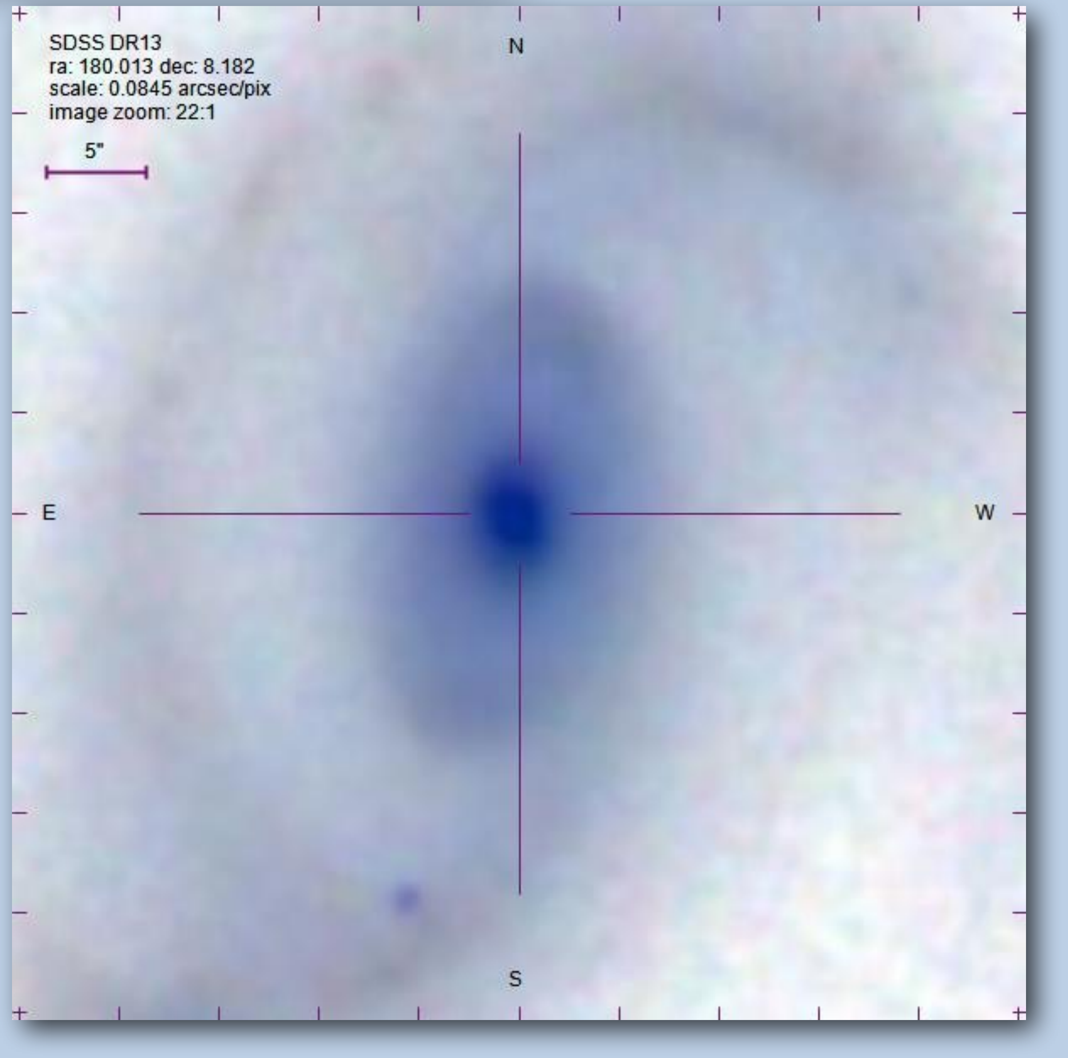
Size and placement of the 3-arcsecond-diameter optic fiber directing light to the SDSS *Legacy* spectrograph

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

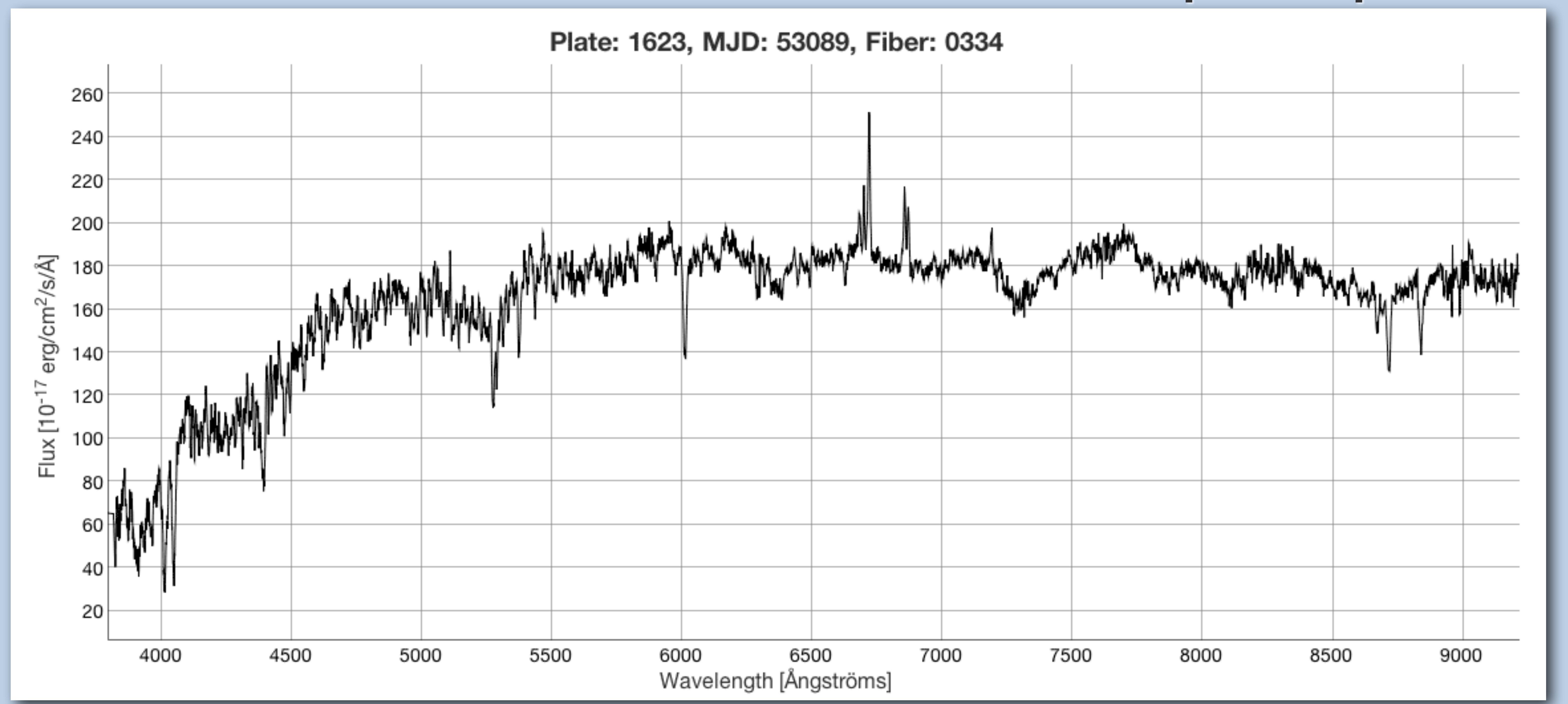
SDSS J120003.16+081054.1

SDSS Object ID: 1237658424636276773

$z = 0.020\,429\,8 \pm 0.000\,008\,9$



Optical Spectrum



Line Measurement Information

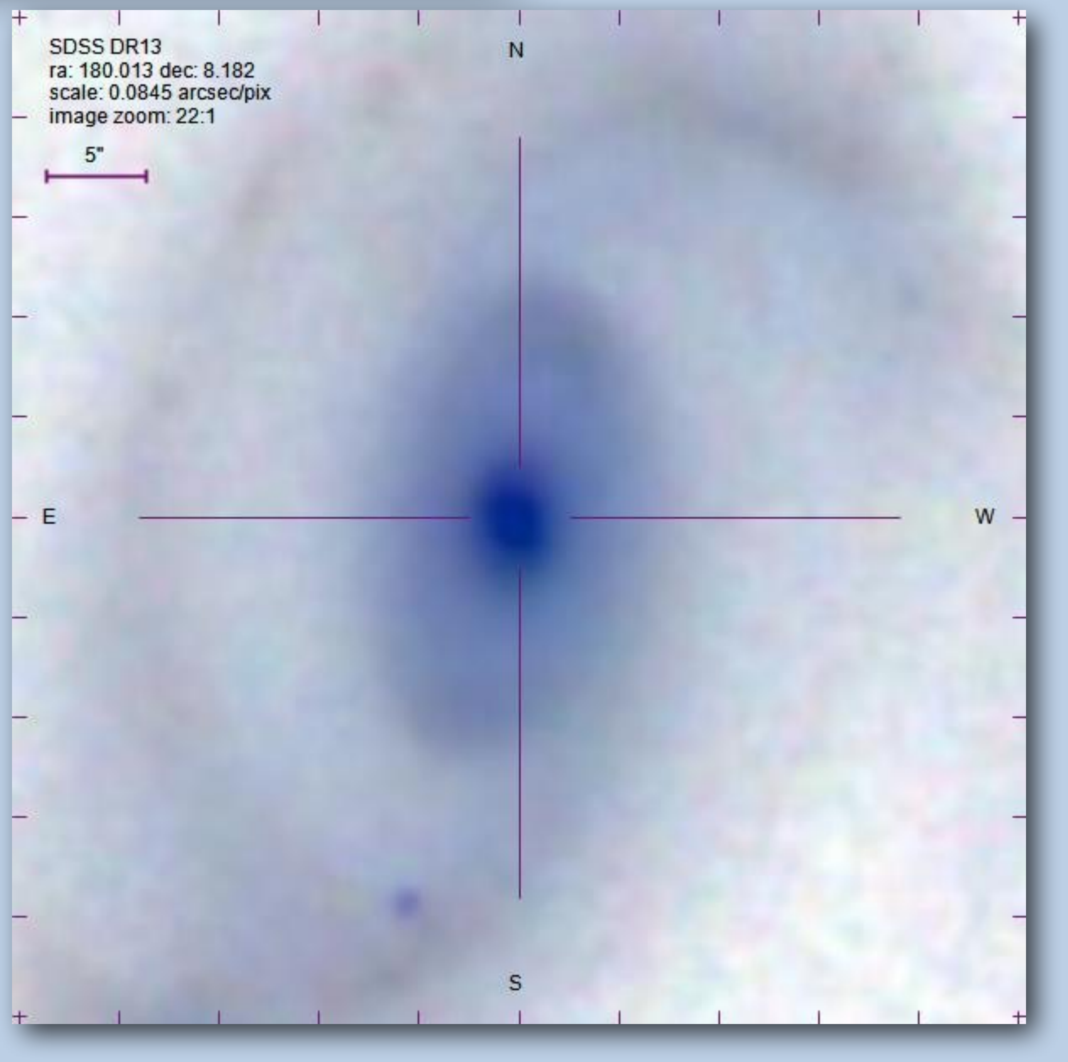
Line Name	Rest Wavelength [Å]	Line z	Line σ [km s^{-1}]	Line Flux [10^{-17}erg/cm^2/s]	Continuum [10^{-17}erg/cm^2/s/Å]
[O_II]	3727.1	0.0202296	365.2	0.0	30.1543
[O_II]	3729.9	0.0202296	365.2	120781.0	31.8086
[Ne_III]	3869.9	0.0202296	365.2	70.5768	59.4613
H_epsilon	3890.2	0.0202297	258.097	-84.8788	68.0559
[Ne_III]	3971.1	0.0202297	365.2	-671.774	88.5972
H_delta	4102.9	0.0202297	258.097	-165.906	110.116
H_gamma	4341.7	0.0202297	365.2	-36.9513	116.558
[O_III]	4364.4	0.0202297	365.2	-25.3075	138.277
He_II	4687.0	0.0202297	365.2	9.64026	153.924
H_beta	4862.7	0.0202299	258.097	36.4644	145.173
[O_III]	4960.3	0.0202287	365.2	86.8648	160.899
[O_III]	5008.2	0.0202296	365.2	263.113	150.71
He_II	5413.0	0.0202299	365.2	-0.881848	166.799
[O_I]	5578.9	0.0202307	365.2	-15.3327	179.374
[O_I]	6302.0	0.0202308	365.2	132.722	175.628
[S_III]	6313.8	0.0202293	365.2	-40.6494	180.38
[O_I]	6365.5	0.02023	365.2	-12.7465	173.176
[N_II]	6549.9	0.02023	365.2	225.009	183.758
H_alpha	6564.6	0.0202294	258.097	422.349	164.383
[N_II]	6585.3	0.0202287	365.2	778.841	185.167
[S_II]	6718.3	0.0202298	365.2	331.525	174.341
[S_II]	6732.7	0.0202302	365.2	381.41	179.828
[Ar_III]	7137.8	0.0202304	365.2	-114.164	167.051

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

SDSS J120003.16+081054.1

SDSS Object ID: 1237658424636276773

$z = 0.020\,429\,8 \pm 0.000\,008\,9$



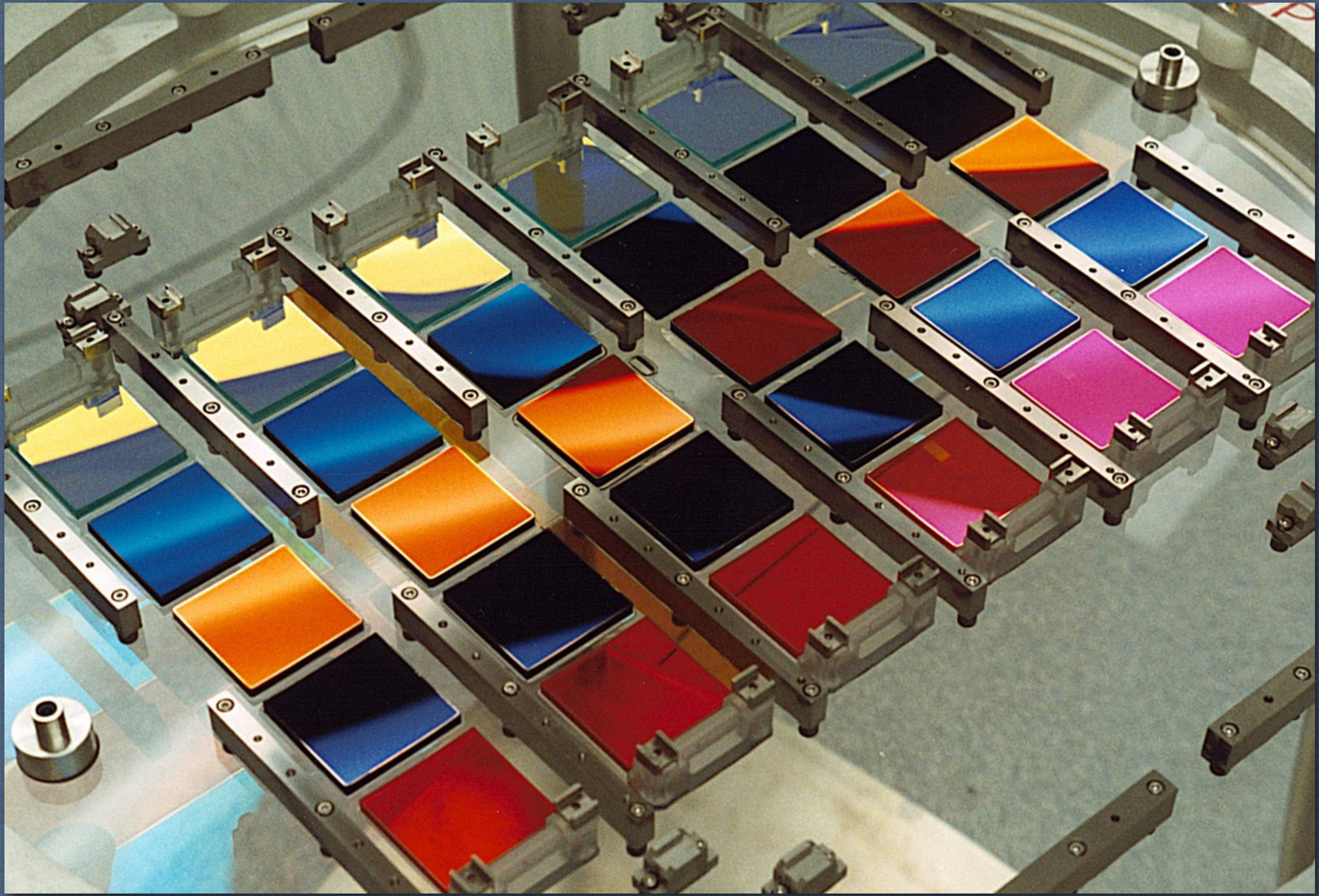
Survey	SDSS
Programname	legacy
firstRelease	DR7
Right Ascension	180.0132°
Declination	8.1817218°
Redshift	$0.020\,429\,8 \pm 0.000\,008\,9$
Class	GALAXY
Subclass	BROADLINE
PRIMTARGET	Bit: 5 - GALAXY_RED Bit: 6 - GALAXY

Luminosity (measured & derived)

Median S/N 42.9488

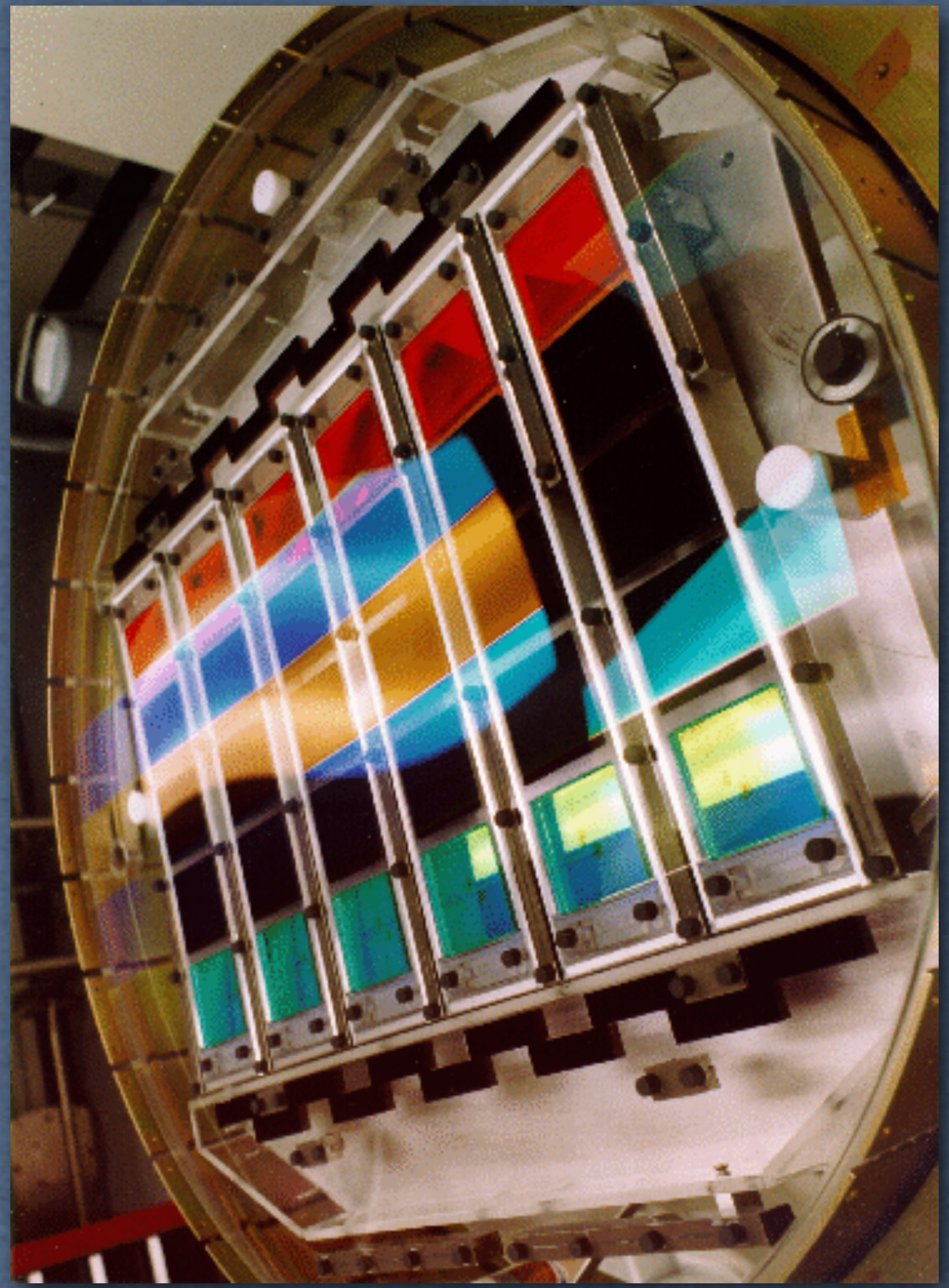
	u	g	r	i	z
PSF Magnitude	18.32	16.51	15.91	15.66	15.02
cModel Magnitude	15.91	14.20	13.48	13.07	12.86
Fiber Magnitude	18.46	16.66	15.81	15.40	15.09
Fiber2 Magnitude	19.15	17.35	16.50	16.09	15.77
Model Magnitude	16.06	14.28	13.48	13.08	12.81
Petrosian Magnitude	15.76	14.14	13.36	12.95	12.79
de Vaucouleurs Magnitude	15.89	14.20	13.48	13.07	12.86
Exponential Magnitude	16.57	14.53	13.75	13.38	13.42

SDSS astronomical filters



Ultraviolet (u)	Green (g)	Red (r)	Near Infrared(i)	Infrared (z)
3531	4627	6140	7467	8887

Central wavelengths λ_{eff} (Å) from Doi et al. (2010), Table 2.



Conventional Johnson-Cousins UBVRI system, for comparison

Ultraviolet (U)	Blue (B)	Visual (V)	Red (R)	Infrared (I)
3663	4361	5448	6407	7980

Central wavelengths λ_{eff} (Å) from Bessell (2005), Table 1.

Image source: http://www.lastwordonnothing.com/2011/01/17/jims-camera-2/

Try to find all 9 hyperlinks on this page.

SDSS telescope image of M31 (the Andromeda galaxy)

There are 3 different links below:

NASA/IPAC **E**xtragalactic **D**atabase data:

Blueshift: 0.001001 ± 0.000013 (−300 ± 4 km/s)

Effective redshift distance: $z << 0.001$

Summary Statistics computed by NED from 199 Distance(s) in the literature:

Mean Metric Distance:	**0.788 Mpc**
Standard Deviation:	**0.163 Mpc**
Minimum Distance:	**0.440 Mpc**
Maximum Distance:	**2.800 Mpc**

M31 image credit: The Sloan Digital Sky Survey Collaboration

Detailed perspective of M31 image

M31 image credit: The Sloan Digital Sky Survey Collaboration

Image credit: *NASA/JPL-Caltech/K. Gordon (University of Arizona)*

GALEX satellite UV image of M31

FUV: (1344 – 1786), $\lambda_{\rm eff}$ = 1528 (Å); white/blue

NUV: (1771 – 2831), $\lambda_{\rm eff}$ = 2271 (Å); orange

Source: http://www.galex.caltech.edu/researcher/techdoc-ch1.html

Image credit: *NASA/JPL-Caltech*

SWIFT satellite UV image of M31

λ : 1700 – 6000 Å

0.25 degrees (15′)

Per 0.4036° M31–M32 angular separation.

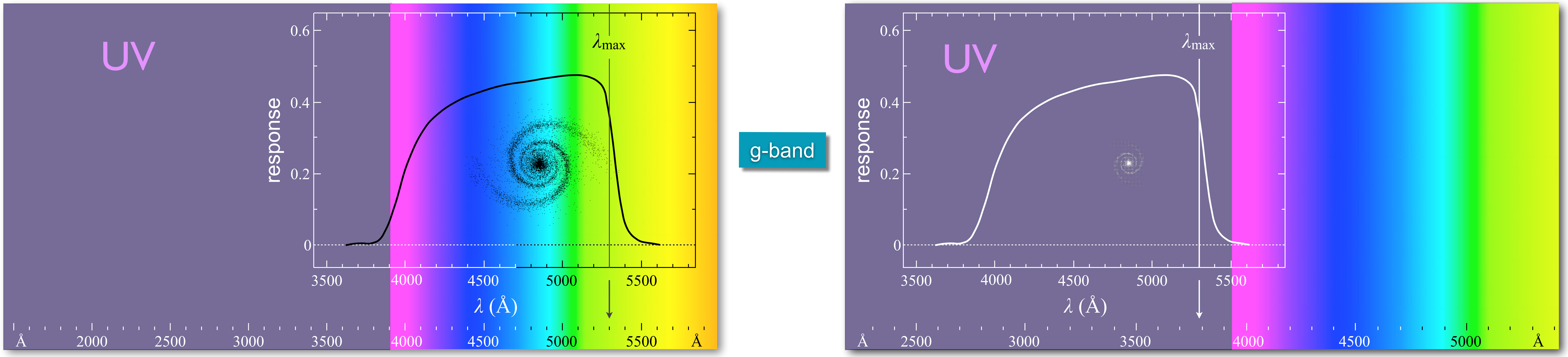
Source: http://swift.gsfc.nasa.gov/about_swift/

Image credit: NASA/Swift/Stefan Immler (GSFC) and Erin Grand (UMCP)

The colored backgrounds represent galaxy emission wavelength. The foreground graphs represent the SDSS g-band filter observing this emission at natural (left) and redshifted (right) wavelengths.

One observes emitted wavelengths of nearby galaxies.

One observes redshifted wavelengths of distant galaxies.



Observation of nearby galaxy at $z \rightarrow 0$

redshift

$\lambda_{obs} \approx \lambda_0$

Observation of distant galaxy at $z = 0.4$

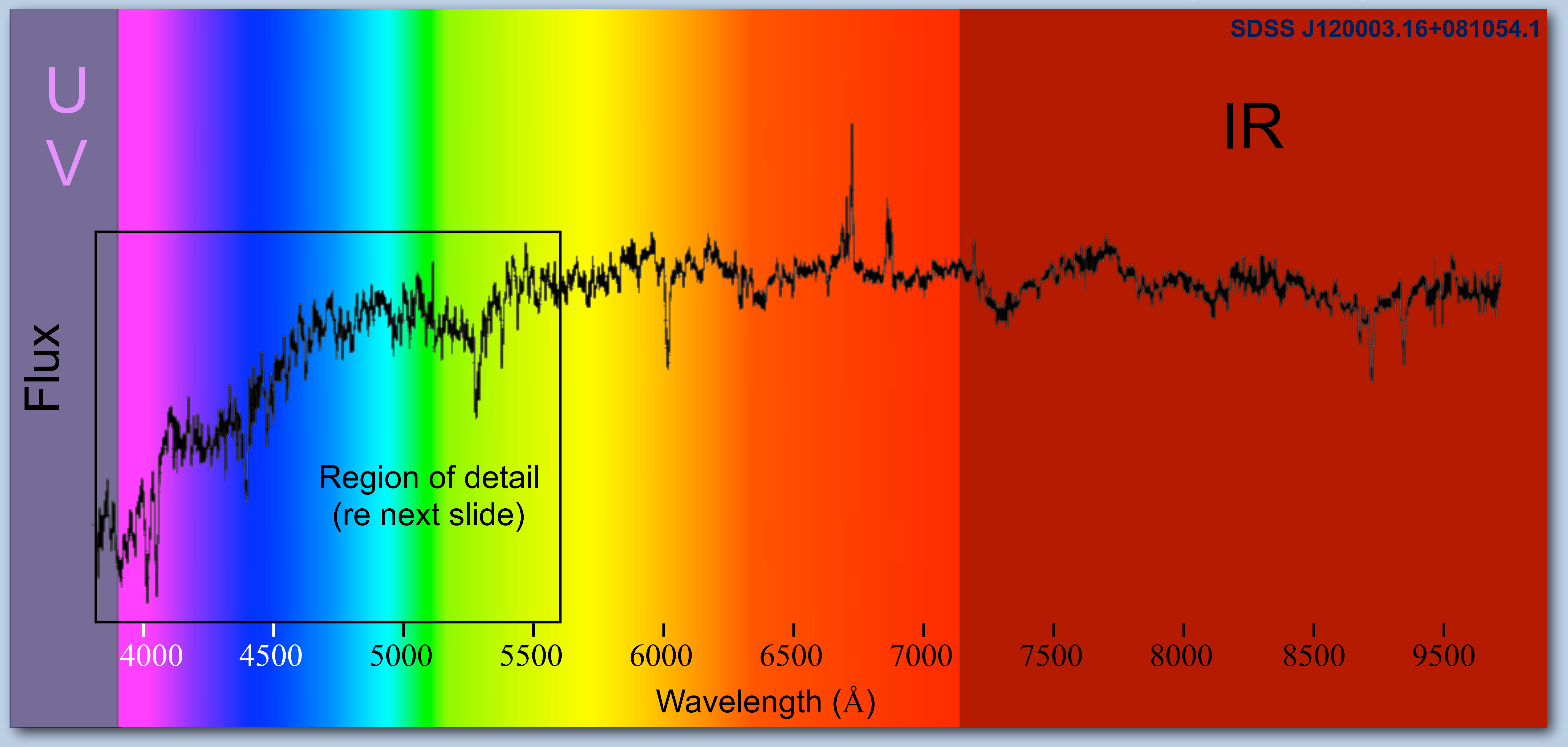
$\lambda_{obs} = \lambda_0(z+1) \longrightarrow \underset{\textbf{observed}}{5300\text{Å}} \approx \underset{\textbf{emission}}{3786\text{Å}}(1.4)$

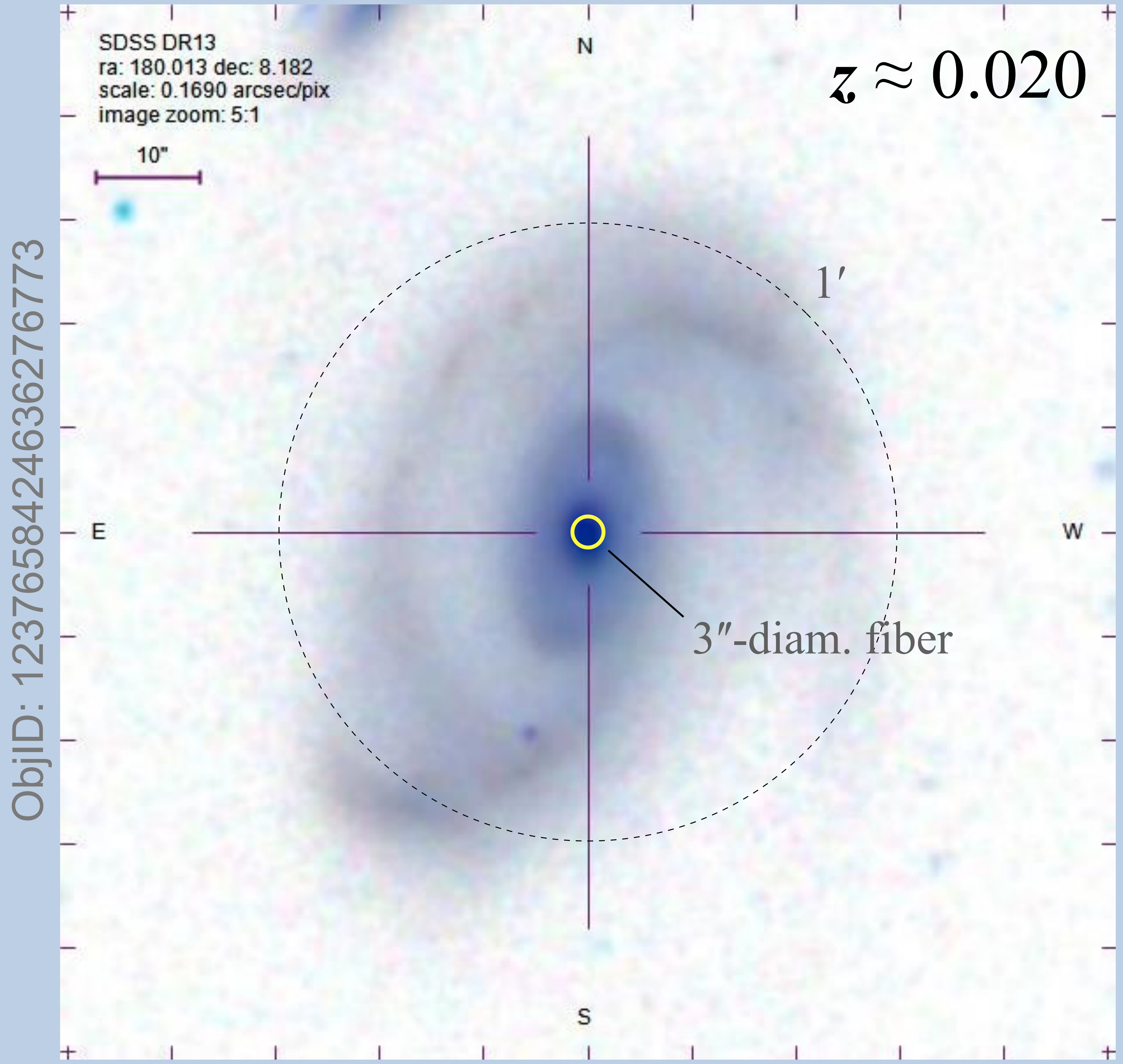
In practice, magnitudes (m_λ) are measured at a particular wavelength (λ) using bandpass filters (e.g., SDSS g), which restrict observation to a limited range of the electromagnetic spectrum. Due to the cosmological redshift, a visible-spectrum bandpass filter observes photons emitted in the ultraviolet for sufficiently-distant galaxies. As compared to the emission wavelength (λ_0), the observed wavelength (λ_{obs}) is dilated by a factor of $(z+1)$.

As demonstrated in this empirical graph of flux as a function of emission wavelength for a single nearby galaxy, the intrinsic luminosity of a galaxy is a function of emission wavelength: $M = f'(\lambda_0)$. Accordingly, apparent luminosity is a function of both distance (i.e., redshift) and the observed emission wavelength of a galaxy: $m = f(z, \lambda_0)$.

The rapid decline in galaxy luminosity with decreasing observed wavelength seen in the 4000-Å break region (also called the "Ca II break" for singly-ionized calcium) is created primarily by accumulation of absorption lines in galaxies with metal-rich stellar populations.

Optical Spectrum





This quantitative detail of flux measurement shows the dimming effect of decreasing λ.

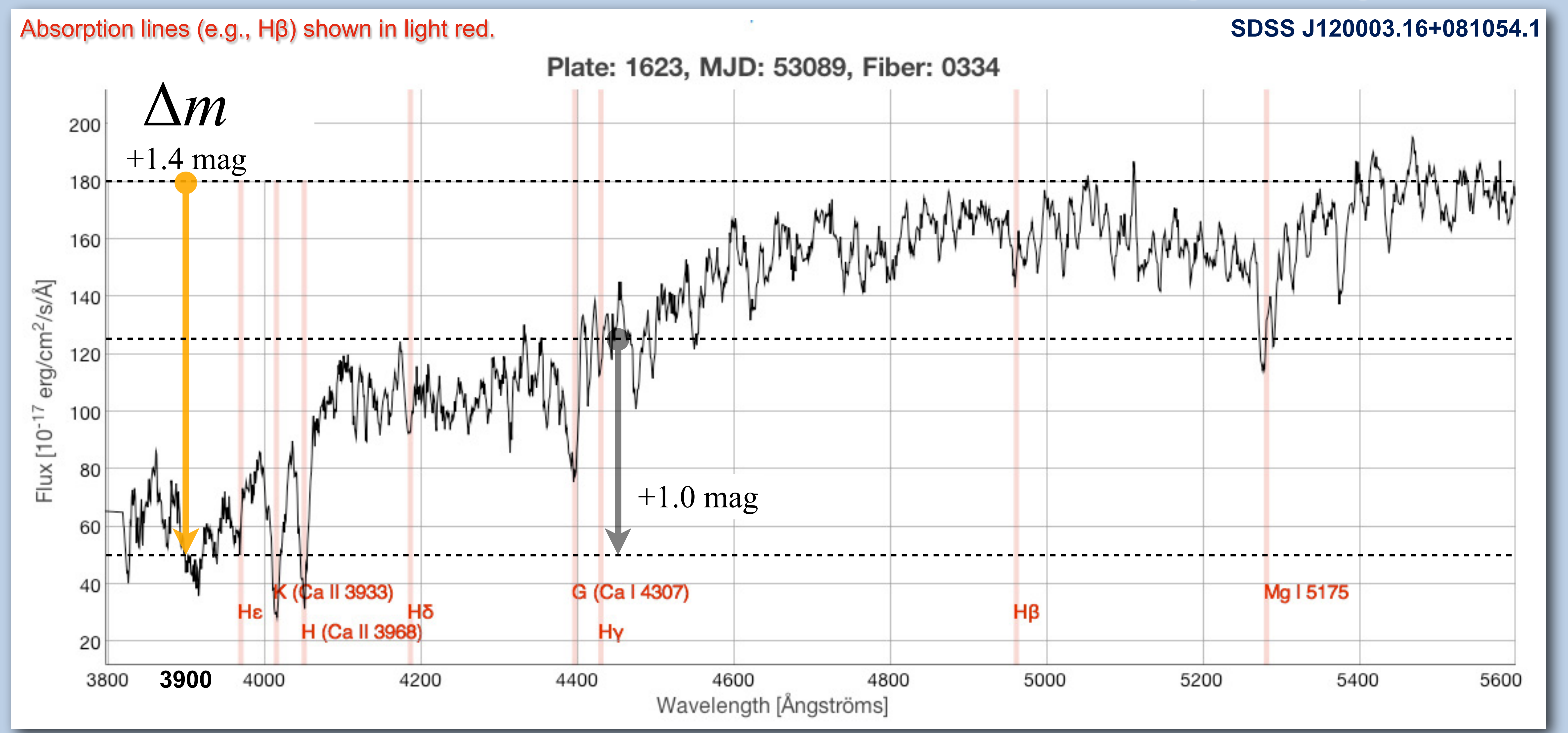
If no "K correction" is applied to observations within a bandpass filter to account for the changes in apparent magnitude incurred due to redshift of λ_0, then Δm will be evident.

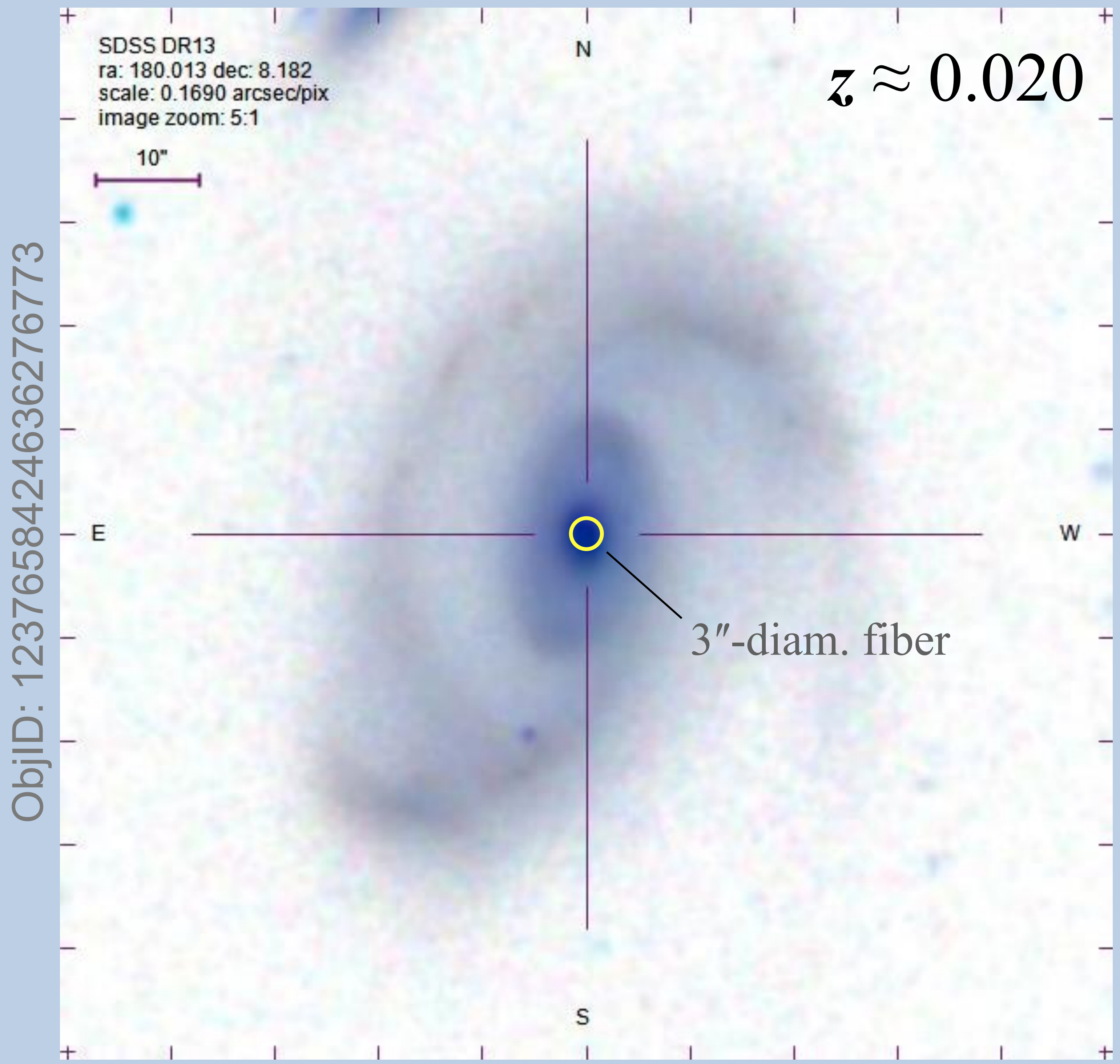
$$\Delta m \approx -2.5 \cdot \log_{10}\left(\frac{50}{180}\right) = +1.4$$

Less bright means *higher* magnitude (m); this dates back to Hipparchus of Nicaea.

A *reduction* in flux (i.e., less bright) corresponds to an *increase* in measurement of astronomical "magnitude."

Optical Spectrum





SDSS website reference

petroRad

The Petrosian radius. A measure of the angular size of an image, most meaningful for galaxies. Units are seconds of arc. The Petrosian radius (and related measures of size called petroR50 and petroR90) are derived from the surface brightness profile of the galaxy, as described in Algorithms.

Surface Brightness & Concentration Index

The `frames` pipeline also reports the radii containing 50% and 90% of the Petrosian flux for each band, `petroR50` and `petroR90` respectively. The usual characterization of surface-brightness in the target selection pipeline of the SDSS is the mean surface brightness within `petroR50`. It turns out that the ratio of `petroR50` to `petroR90`, the so-called "inverse concentration index", is correlated with morphology (Shimasaku et al. 2001, Strateva et al. 2001). Galaxies with a de Vaucouleurs profile have an inverse concentration index of around 0.3; exponential galaxies have an inverse concentration index of around 0.43. Thus, this parameter can be used as a simple morphological classifier.

An important caveat when using these quantities is that they are *not* corrected for seeing. This causes the surface brightness to be underestimated, and the inverse concentration index to be overestimated, for objects of size comparable to the PSF. The amplitudes of these effects, however, are not yet well characterized.

Source: http://www.sdss.org/dr13/help/glossary/#P

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

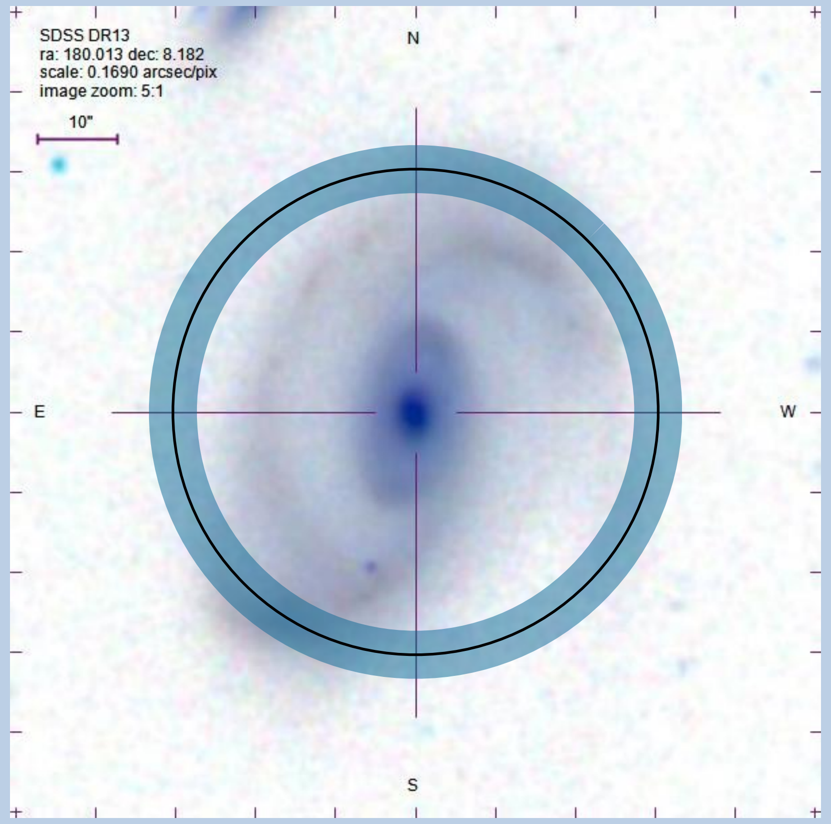
SDSS J120003.16+081054.1

SDSS Object ID: 1237658424636276773

$z = 0.020\,429\,8 \pm 0.000\,008\,9$

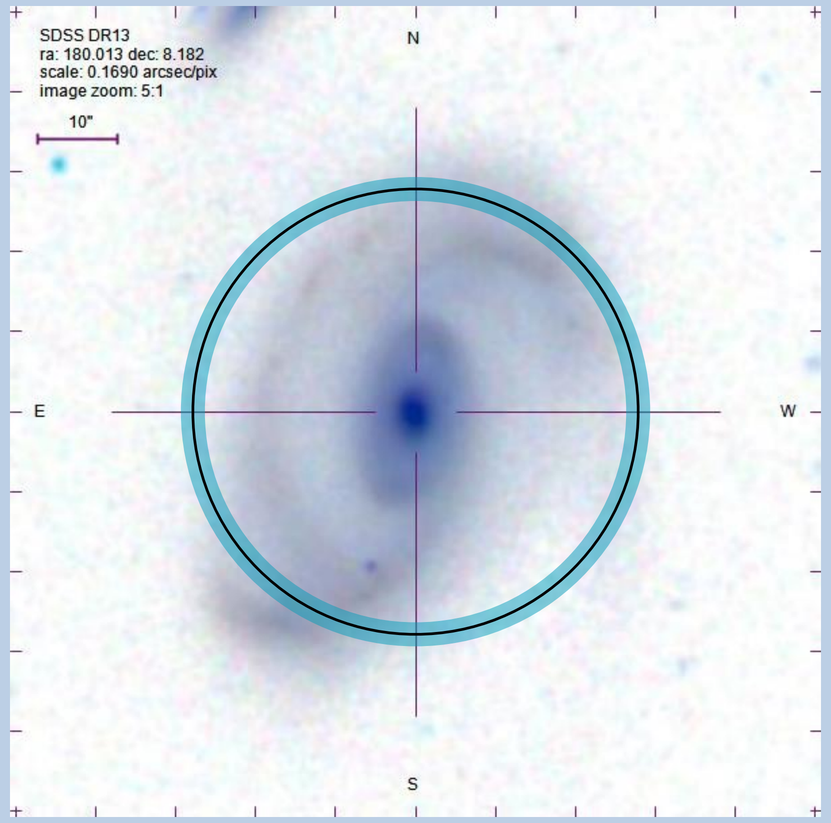
Backgrounds are identical negative optical images.

u-band



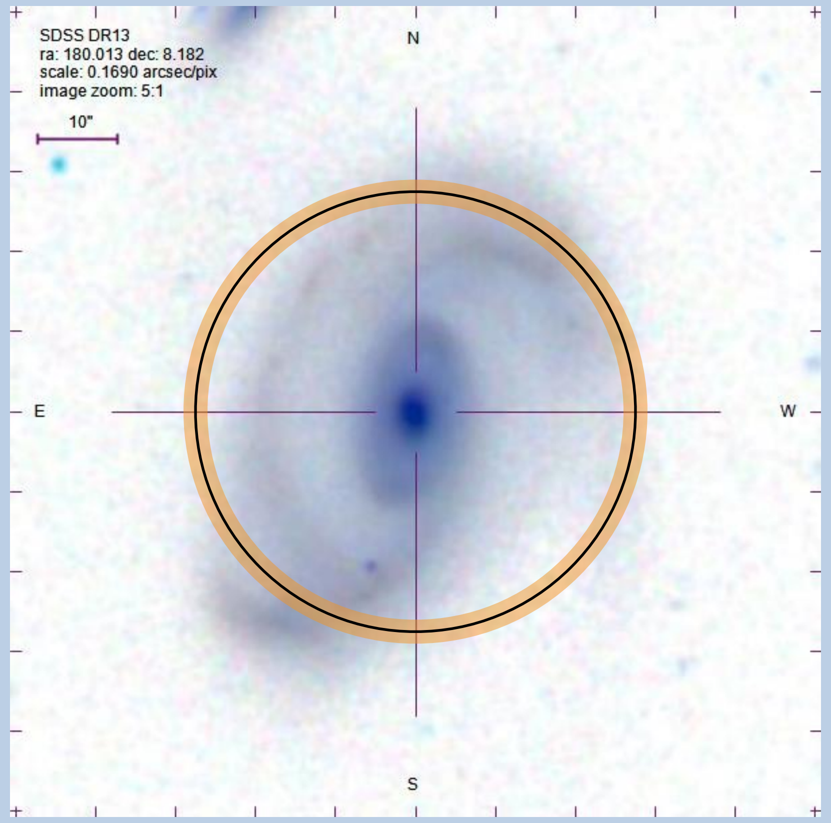
petroRad_u: 30.4"
petroRadErr_u: ±3.0”
(lower signal-to-noise)

g-band



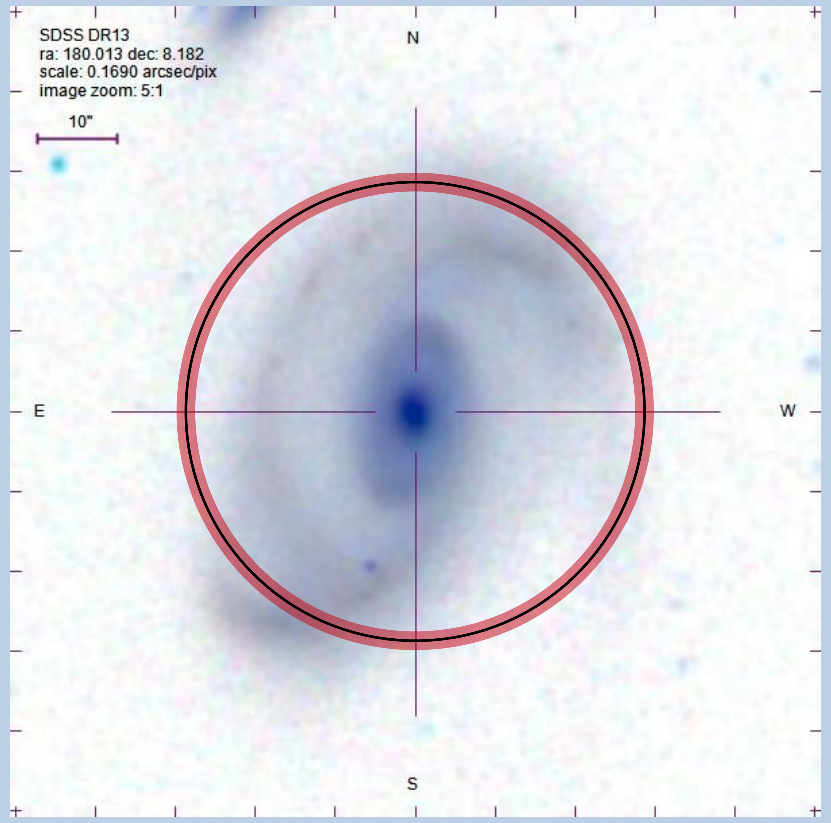
petroRad_g: 27.8"
petroRadErr_g: ±1.5"

r-band



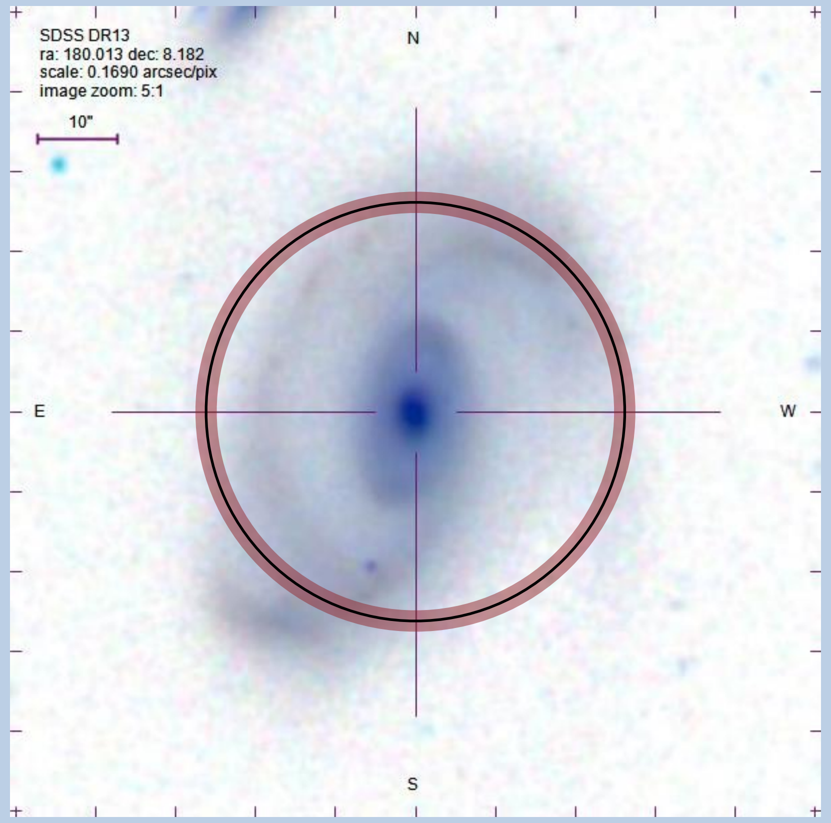
petroRad_r: 27.5"
petroRadErr_r: ±1.5"

i-band



petroRad_i: 28.6"
petroRadErr_i: ±1.2"

z-band



petroRad_z: 26.2"
petroRadErr_z: ±1.4"

The colored rings are error bars.

Petrosian radius measurements
(named after Professor Vahe Petrosian)

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

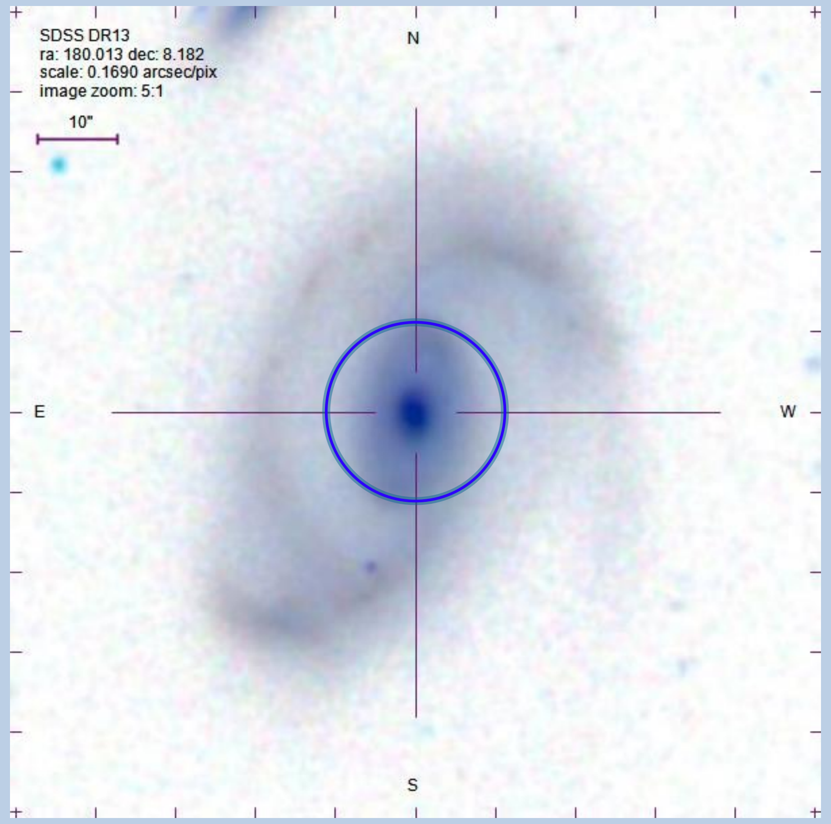
SDSS J120003.16+081054.1

SDSS Object ID: 1237658424636276773

$$z = 0.020\,429\,8 \pm 0.000\,008\,9$$

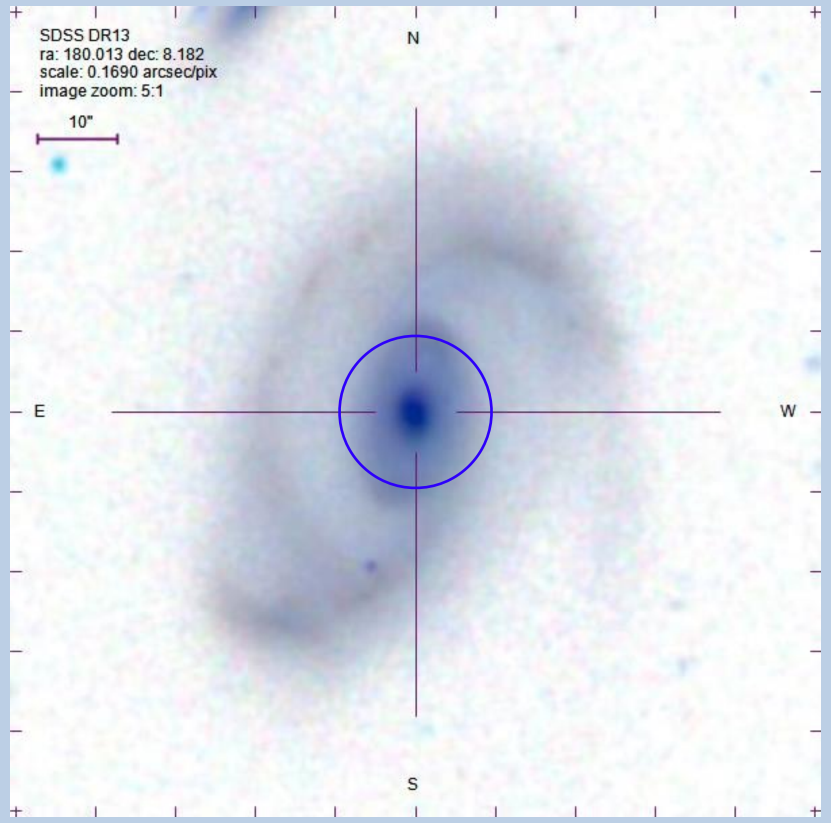
Backgrounds are identical negative optical images.

u-band



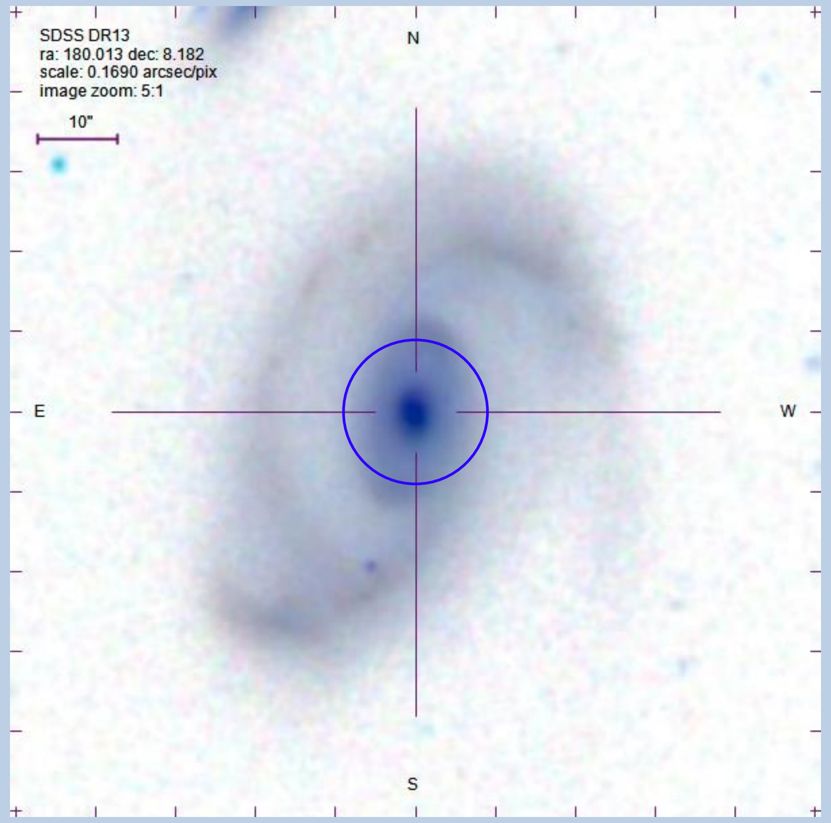
petroR50_u: 11.2"
petroR50Err_u: ±0.5"

g-band



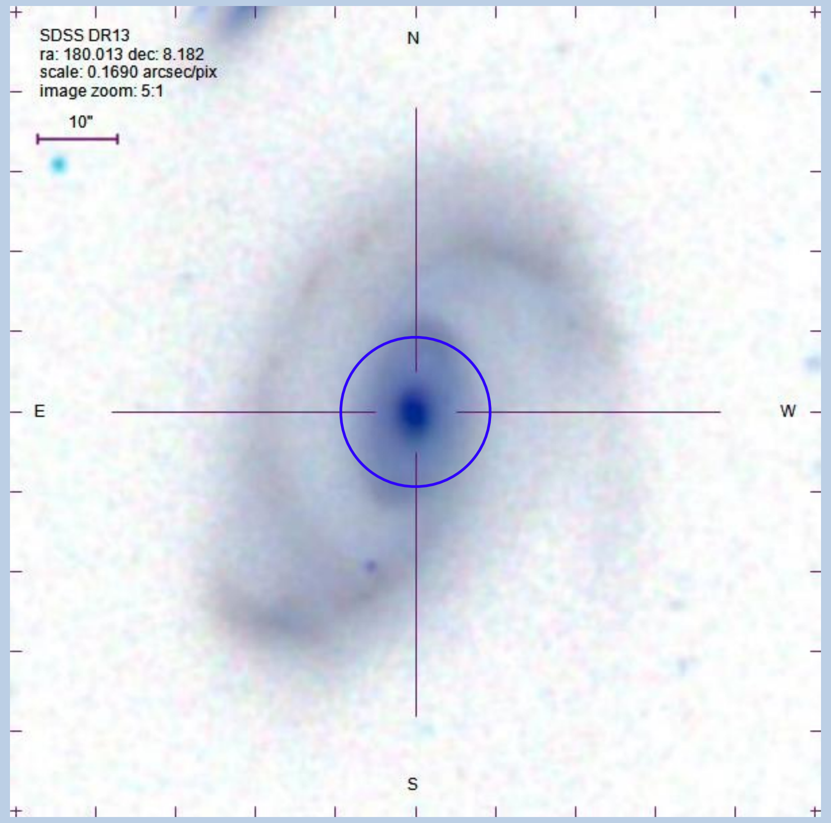
petroR50_g: 9.5"
petroR50Err_g: ±0.1"

r-band



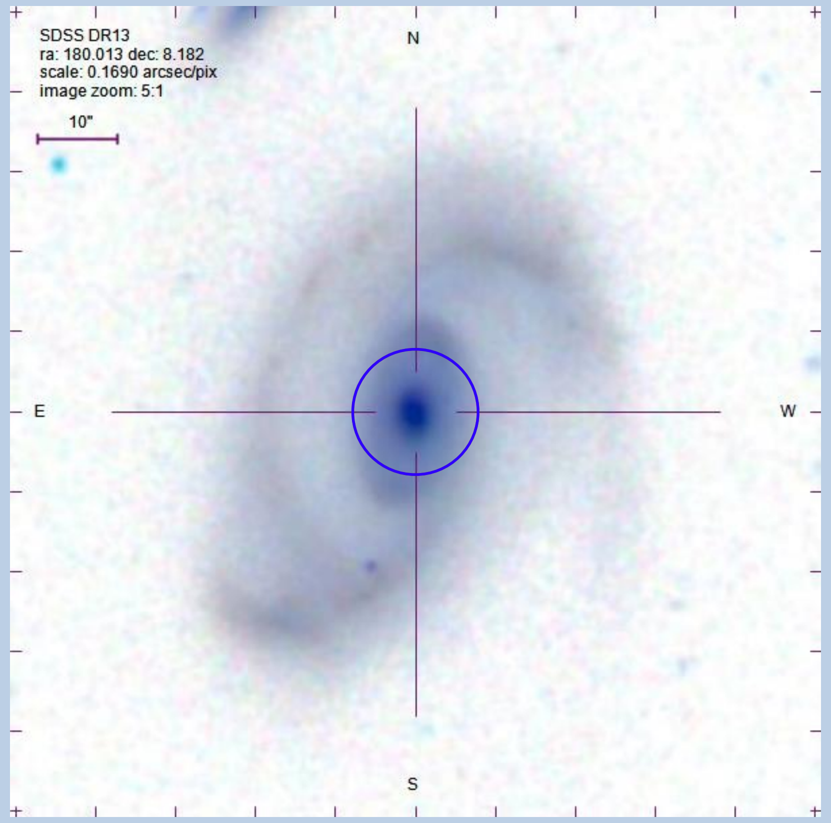
petroR50_r: 9.0"
petroR50Err_r: ±0.0"

i-band



petroR50_i: 9.3"
petroR50Err_i: ±0.0"

z-band



petroR50_z: 7.8"
petroR50Err_z: ±0.1"

Reported measurement error is close to zero.

Half-light radius measurements (50% of Petrosian flux*)

* See slide 35.

SDSS website reference

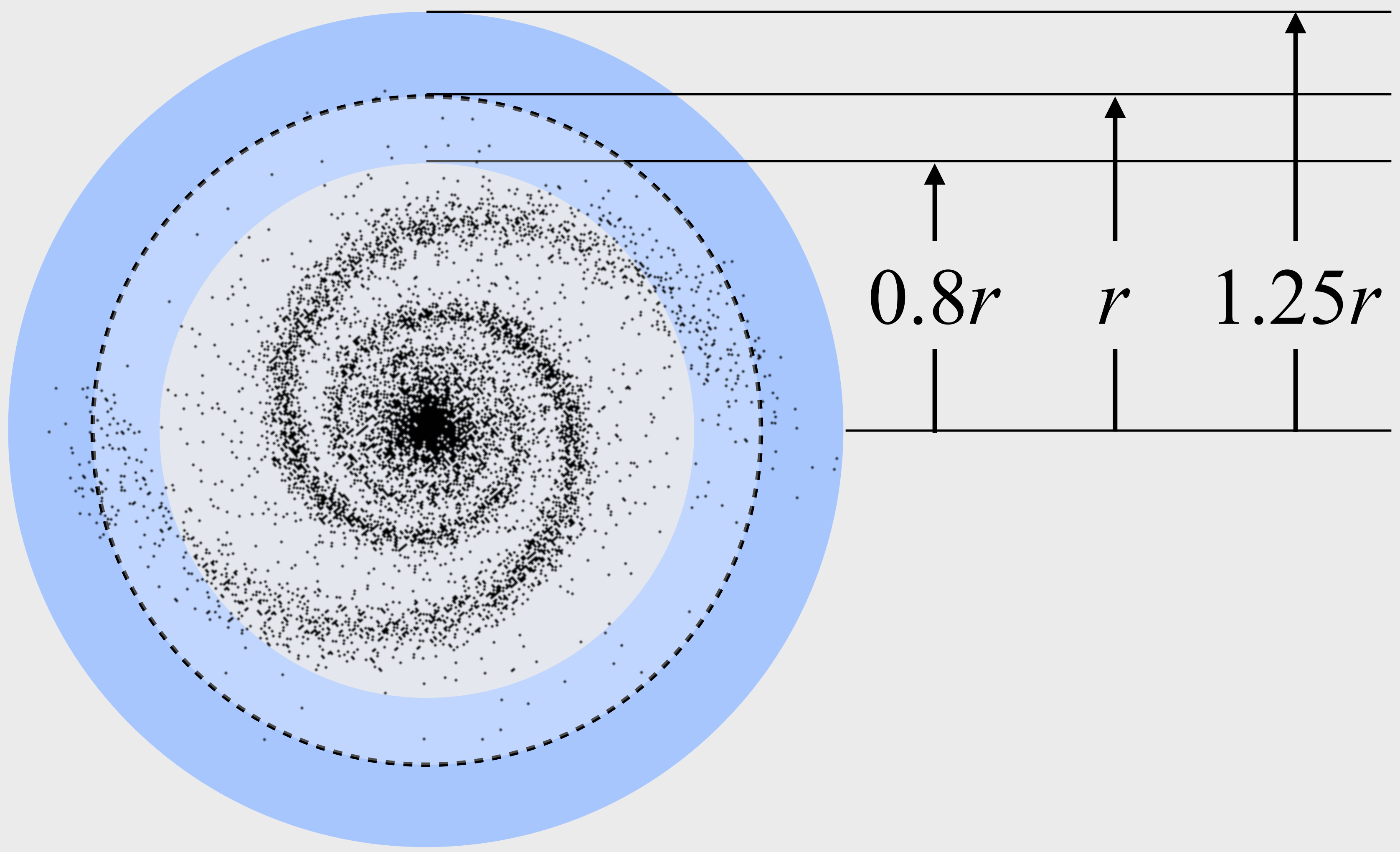
Magnitude, Petrosian

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. Model magnitudes share most of the advantages of Petrosian magnitudes, and have higher S/N; they are therefore used instead of Petrosian magnitudes for target selection in BOSS.

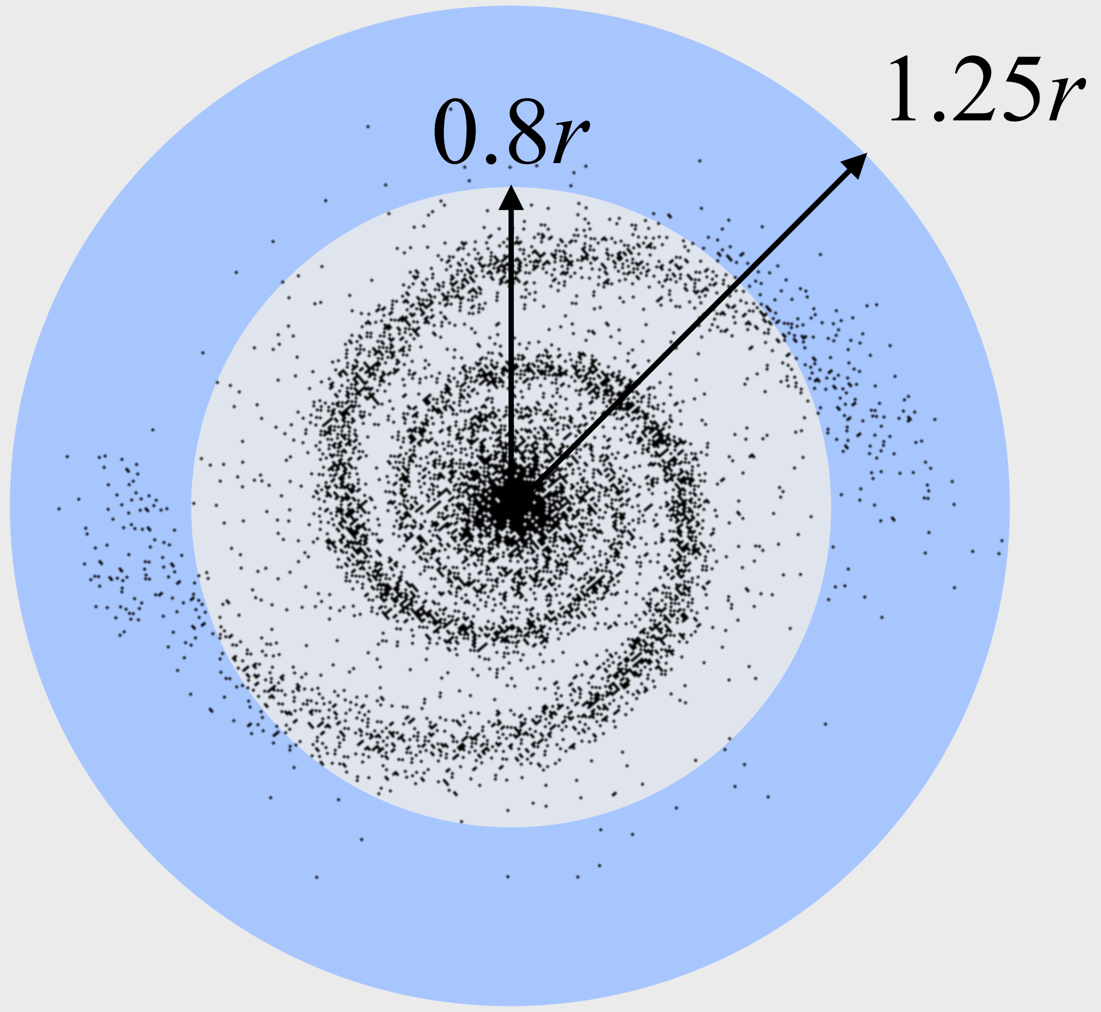
The somewhat cryptic mathematical description of SDSS Petrosian magnitudes is simply described schematically in the next two slides.

Source: http://www.sdss.org/dr13/help/glossary/#M

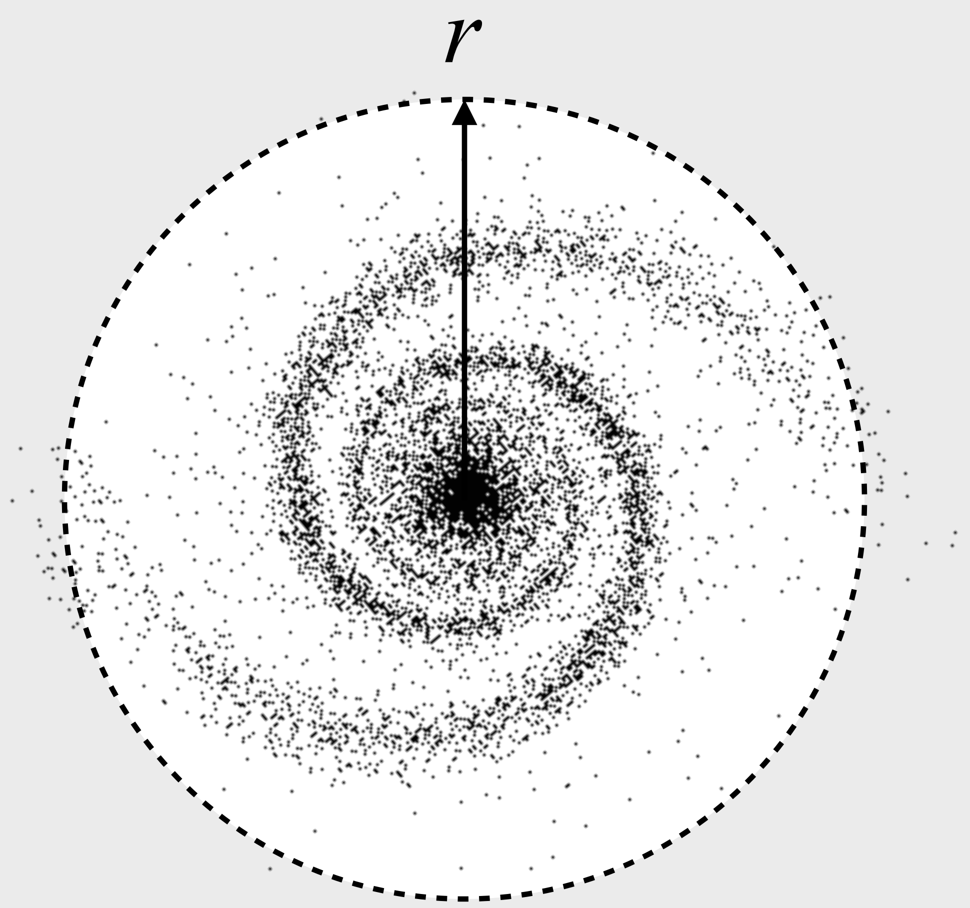
DEFINITION: "Petrosian ratio," $\mathscr{R}_{\mathrm{P}}(r)$ =



Here, r is a variable measurement;
it is not a recorded measurement.



local surface brightness in annulus (blue region) ÷



mean surface brightness measured inside radius r

Define $\mathscr{R}_{\mathrm{P,lim}}$ as $\mathscr{R}_{\mathrm{P}}(r_{\mathrm{P}}) = \mathscr{R}_{\mathrm{P,lim}}$ where r_{P} is the measured and recorded Petrosian radius. $\mathscr{R}_{\mathrm{P,lim}} = 0.2$ for the SDSS:

Varying r, when $\mathscr{R}_{\mathrm{P}}(r) = 0.2$, then $r_{\mathrm{P}} = r$.

$$\mathscr{R}_{\mathrm{P}}(r) \equiv \frac{\int_{0.8r}^{1.25r} dr' 2\pi r' I(r') / [\pi(1.25^2 - 0.8^2) r^2]}{\int_0^r dr' 2\pi r' I(r') / (\pi r^2)}$$

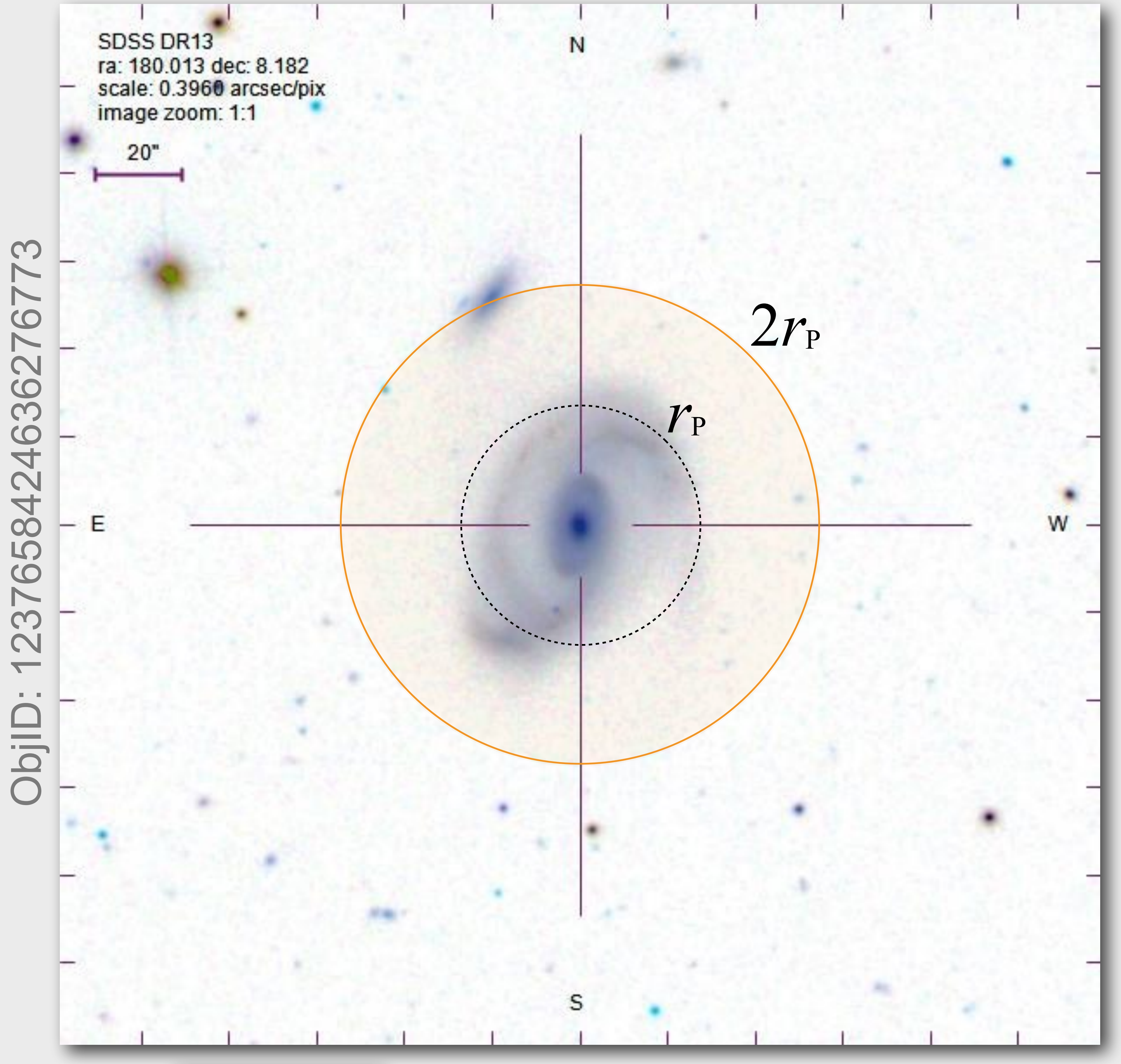
The observed radial galaxy brightness profile [$I(r')$] is "azimuthally averaged" (i.e., averaged over 2π radians).

Reference: http://www.sdss.org/dr13/algorithms/magnitudes/#mag_petro

DEFINITION: "Petrosian flux"

$$F_{\mathrm{P}} \equiv \int_0^{N_{\mathrm{P}} r_{\mathrm{P}}} dr' 2\pi r' I(r') \quad [N_{\mathrm{P}} = 2.0]$$

The SDSS Petrosian flux in any band is defined as the flux within two Petrosian radii ($2r_{\mathrm{P}}$).



r-band petroRad_r: $r_{\mathrm{P}} = 27.5''$

"In the SDSS five-band photometry, the aperture in all bands is set by the profile of the galaxy in the *r* band alone. This procedure ensures that the color measured by comparing the Petrosian flux F_{P} in different bands is measured through a consistent aperture."

Note: SDSS imager native resolution is 0.396 arcsec/pixel.

Click the galaxy image to view in the SDSS **Explore** Tool.

Reference: http://www.sdss.org/dr13/algorithms/magnitudes/#mag_petro

SDSS Catalog Archive Server (CAS)

This slide deck now references SDSS Data Release 13, which was issued on 31 July 2016 (see *blog post*).
DR13 is the first release of the fourth epoch of the Sloan Digital Sky Survey, which initiated in July 2014.

Click image for webpage.

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

Catalog Archive Server (CAS) Database Tables (1 of 2)

	name	description
1	apogeeDesign	Contains the plate design information for APOGEE plates.
2	apogeeField	Contains the basic information for an APOGEE field.
3	apogeeObject	Contains the targeting information for an APOGEE object.
4	apogeePlate	Contains all the information associated with an APOGEE plate.
5	apogeeStar	Contains data for an APOGEE star combined spectrum.
6	apogeeStarAllVisit	Links an APOGEE combined star spectrum with all visits for that star.
7	apogeeStarVisit	Links an APOGEE combined star spectrum with the visits used to create it.
8	apogeeVisit	Contains data for a particular APOGEE spectrum visit.
9	aspcapStar	Contains data for an APOGEE star ASPCAP entry.
10	aspcapStarCovar	Contains the covariance information for an APOGEE star ASPCAP entry.
11	AtlasOutline	Contains a record describing each AtlasOutline object
12	DataConstants	The table stores the values of various enumerated and bitmask columns.
13	DBColumns	Every column of every table has a description in this table
14	DBObjects	Every SkyServer database object has a one line description in this table
15	DBViewCols	The columns of each view are stored for the auto-documentation
16	Dependency	Contains the detailed inventory of database objects
17	detectionIndex	Full list of all detections, with associated 'thing' assignment.
18	emissionLinesPort	Emission line kinematics results for SDSS and BOSS galaxies using GANDALF
19	Field	All the measured parameters and calibrations of a photometric field
20	FieldProfile	The mean PSF profile for the field as determined from bright stars.
21	FIRST	SDSS objects that match to FIRST objects have their match parameters stored here
22	Frame	Contains JPEG images of fields at various zoom factors, and their astrometry.
23	galSpecExtra	Estimated physical parameters for all galaxies in the MPA-JHU spectroscopic catalogue.
24	galSpecIndx	Index measurements of spectra from the MPA-JHU spectroscopic catalogue.
25	galSpecInfo	General information for the MPA-JHU spectroscopic re-analysis
26	galSpecLine	Emission line measurements from MPA-JHU spectroscopic reanalysis
27	HalfSpace	The constraints for boundaries of the the different regions
28	History	Contains the detailed history of schema changes
29	Inventory	Contains the detailed inventory of database objects
30	apogeeDesign	Contains the plate design information for APOGEE plates.
31	LoadHistory	Tracks the loading history of the database
32	mangaDrpAll	Final summary file of the MaNGA Data Reduction Pipeline (DRP).

	name	description
33	mangatarget	MaNGA Target Catalog
34	marvelsStar	Contains data for a MARVELS star.
35	marvelsVelocityCurveUF1D	Contains data for a particular MARVELS velocity curve using UF1D technique.
36	Mask	Contains a record describing the each mask object
37	MaskedObject	Contains the objects inside a specific mask
38	Neighbors	All PhotoObj pairs within 0.5 arcmins
39	nsatlas	NASA-Sloan Atlas catalog
40	PhotoObjAll	The full photometric catalog quantities for SDSS imaging.
41	PhotoObjDR7	Contains the spatial cross-match between DR8 photoobj and DR7 photoobj.
42	PhotoPrimaryDR7	Contains the spatial cross-match between DR8 primaries and DR7 primaries.
43	PhotoProfile	The annulus-averaged flux profiles of SDSS photo objects
44	Photoz	The photometrically estimated redshifts for all objects in the GalaxyTag view.
45	PhotozErrorMap	The error map of the photometric redshift estimation
46	Plate2Target	Which objects are in the coverage area of which plates?
47	PlateX	Contains data from a given plate used for spectroscopic observations.
48	ProfileDefs	This table contains the radii for the Profiles table
49	ProperMotions	Proper motions combining SDSS and recalibrated USNO-B astrometry.
50	qsoVarPTF	Variability information on eBOSS quasar targets using PTF lightcurves.
51	qsoVarStripe	Variability information on eBOSS quasar targets using SDSS stripe 82 data.
52	QueryResults	Store the results of performance tests here
53	RC3	RC3 information for matches to SDSS photometry
54	RecentQueries	Record the ipAddr and timestamps of the last n queries
55	Region	Definition of the different regions
56	Region2Box	Tracks the parentage which regions contribute to which boxes
57	RegionArcs	Contains the arcs of a Region with their endpoints
58	RegionPatch	Defines the attributes of the patches of a given region
59	RegionTypes	
60	Rmatrix	Contains various rotation matrices between spherical coordinate systems
61	ROSAT	ROSAT All-Sky Survey information for matches to SDSS photometry
62	Run	Contains the basic parameters associated with a run
63	RunShift	The table contains values of the various manual nu shifts for runs
64	sdssBestTarget2Sector	Map PhotoObj which are potential targets to sectors

It takes a lot of work to design and administer such a complex database and its associated hardware and software…

SLOAN DIGITAL SKY SURVEY
SkyServer DR13

Catalog Archive Server (CAS) Database Tables (2 of 2)

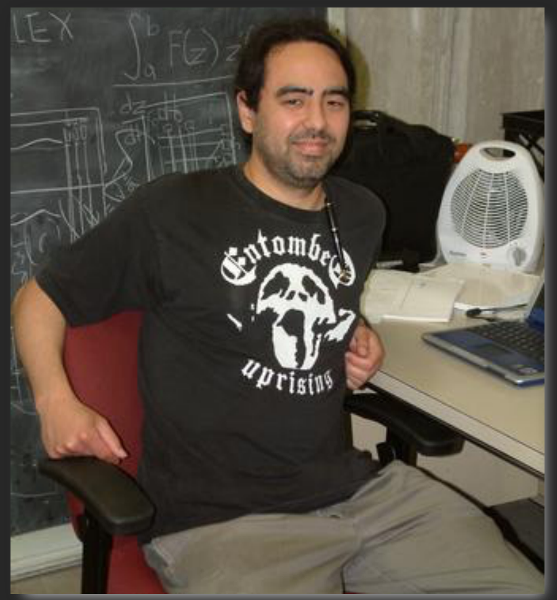
	name	description
65	SDSSConstants	This table contains most relevant survey constants and their physical units
66	sdssImagingHalfSpaces	Half-spaces (caps) describing the SDSS imaging geometry
67	sdssPolygon2Field	Matched list of polygons and fields
68	sdssPolygons	Polygons describing SDSS imaging data window function
69	sdssSector	Stores the information about set of unique Sector regions
70	sdssSector2Tile	Match tiles to sectors, wedges adn sectorlets, and vice versa.
71	sdssTargetParam	Contains the parameters used for a version of the target selection code
72	sdssTileAll	Contains information about each individual tile on the sky.
73	sdssTiledTargetAll	Information on all targets run through tiling for SDSS-I and SDSS-II
74	sdssTilingGeometry	Information about boundary and mask regions in SDSS-I and SDSS-II
75	sdssTilingInfo	Results of individual tiling runs for each tiled target
76	sdssTilingRun	Contains basic information for a run of tiling Contains basic information for a run of tiling
77	segueTargetAll	SEGUE-1 and SEGUE-2 target selection run on all imaging data
78	SiteConstants	Table holding site specific constants
79	SiteDBs	Table containing the list of DBs at this CAS site.
80	SiteDiagnostics	This table stores the full diagnostic snapshot after the last revision
81	SpecDR7	Contains the spatial cross-match between DR8 SpecObjAll and DR7 primaries.
82	SpecObjAll	Contains the measured parameters for a spectrum.
83	SpecPhotoAll	The combined spectro and photo parameters of an object in SpecObjAll
84	sppLines	Contains outputs from the SEGUE Stellar Parameter Pipeline (SSPP).
85	sppParams	Contains outputs from the SEGUE Stellar Parameter Pipeline (SSPP).
86	sppTargets	Derived quantities calculated by the SEGUE-2 target selection pipeline.
87	stellarMassFSPSGranEarlyDust	Estimated stellar masses for SDSS and BOSS galaxies (Granada method, early-star-formation with dust)
88	stellarMassFSPSGranEarlyNoDust	Estimated stellar masses for SDSS and BOSS galaxies (Granada method, early-star-formation with dust)
89	stellarMassFSPSGranWideDust	Estimated stellar masses for SDSS and BOSS galaxies (Granada method, early-star-formation with dust)
90	stellarMassFSPSGranWideNoDust	Estimated stellar masses for SDSS and BOSS galaxies (Granada method, early-star-formation with dust)
91	stellarMassPassivePort	Estimated stellar masses for SDSS and BOSS galaxies (Portsmouth method, passive model)
92	stellarMassPCAWiscBC03	Estimated stellar masses for SDSS and BOSS galaxies (Wisconsin method, Bruzual-Charlot models)
93	stellarMassPCAWiscM11	Estimated stellar masses for SDSS and BOSS galaxies (Wisconsin method, Maraston models)
94	stellarMassStarformingPort	Estimated stellar masses for SDSS and BOSS galaxies (Portsmouth method, star-forming model).
95	StripeDefs	This table contains the definitions of the survey layout as planned
96	Target	Keeps track of objects chosen by target selection and need to be tiled.

	name	description
97	TargetInfo	Unique information for an object every time it is targeted
98	thingIndex	Full list of all 'things': unique objects in the SDSS imaging
99	TwoMass	2MASS point-source catalog quantities for matches to SDSS photometry
100	TwoMassXSC	2MASS extended-source catalog quantities for matches to SDSS photometry
101	USNO	SDSS objects that match to USNO-B objects have their match parameters stored here
102	Versions	Tracks the versioning history of the database
103	WISE_allsky	WISE All-Sky Data Release catalog
104	WISE_xmatch	Astrometric cross-matches between SDSS and WISE objects.
105	wiseForcedTarget	WISE forced-photometry of SDSS primary sources.
106	Zone	Table to organize objects into declination zones
107	zoo2MainPhotoz	Description: Morphological classifications of main-sample galaxies with photometric redshifts only from Galaxy Zoo 2
108	zoo2MainSpecz	Morphological classifications of main-sample spectroscopic galaxies from Galaxy Zoo 2.
109	zoo2Stripe82Coadd1	Morphological classifications of Stripe 82, coadded (sample 1) spectroscopic galaxies from Galaxy Zoo 2
110	zoo2Stripe82Coadd2	Morphological classifications of Stripe 82, coadded (sample 2) spectroscopic galaxies from Galaxy Zoo 2
111	zoo2Stripe82Normal	Morphological classifications of Stripe 82 normal-depth, spectroscopic galaxies from Galaxy Zoo 2
112	zooConfidence	Measures of classification confidence from Galaxy Zoo.
113	zooMirrorBias	Results from the bias study using mirrored images from Galaxy Zoo
114	zooMonochromeBias	Results from the bias study that introduced monochrome images in Galaxy Zoo.
115	zooNoSpec	Morphology classifications of galaxies without spectra from Galaxy Zoo
116	zooSpec	Morphological classifications of spectroscopic galaxies from Galaxy Zoo
117	zooVotes	Vote breakdown in Galaxy Zoo results.

It takes a lot of work to design and administer such a complex database and its associated hardware and software…

SDSS SkyServer Team

Tamás Budavári



Samuel Carliles

Tanu Malik

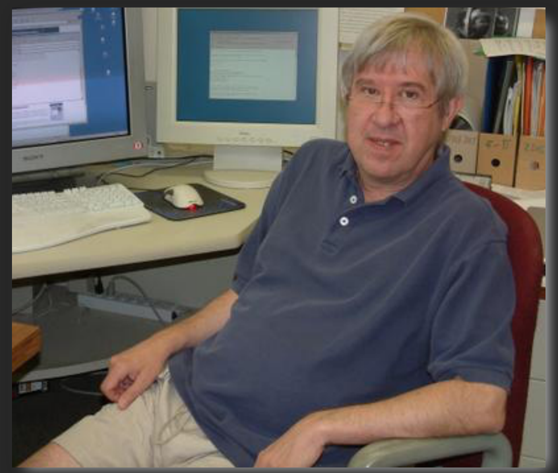
Jordan Raddick

Ani Thakar

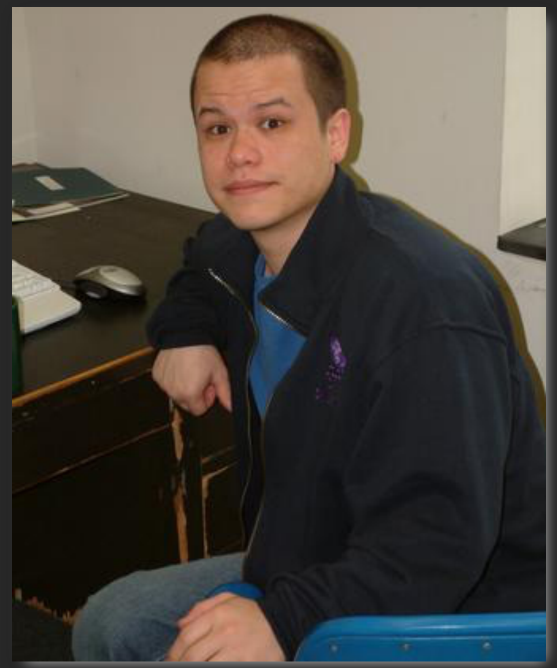
William O'Mullane

A few people (of many others) who I wish to thank for all their hard work, especially “back in the day” (photos circa 2004).

Click images for online details.



Alex Szalay



Nolan Li

George Fekete

Maria Nieto-Santisteban

Adrian Pope

Jan Vandenberg

Source: http://skyserver.org/team/

Apache Point Observatory, New Mexico USA

Home of the Sloan Digital Sky Survey 2.5 m Telescope

Click image for webpage.

I

II

About SDSS

Funding for the Sloan Digital Sky Survey (SDSS) has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/.

The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, University of Pittsburgh, Princeton University, the United States Naval Observatory, and the University of Washington.

Theoretical physics and cosmology, which is the work that I do, is not meaningful without reference to the physical world; it is not an endeavor where one is permitted to be arbitrarily creative and have one's work judged by subjective standards. If the objective empirical evidence does not support a scientific idea, which in physics, astrophysics and cosmology generally manifests as a predictive mathematical model in reference to first principles, the idea is incorrect and one must either abandon it or attempt to successfully correct it. What anybody *feels* or *believes*, in particular the author of any scientific work, has no bearing on the matter.

The remaining slides concern the theme of my work.

– Alex

"If it disagrees with experiment, it's wrong; in that simple statement, is the key to science." – Richard Feynman[1]

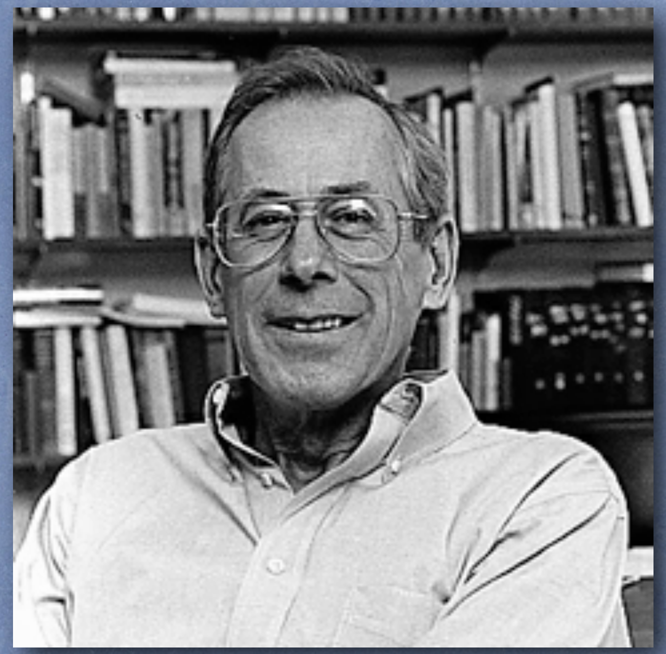
1. Pomeroy, S. R., The Key to Science (and Life) Is Being Wrong, (*SciAm Blog*, 2012).

Physical cosmology is the attempt to make sense of the large-scale nature of the material world around us, by the methods of the natural sciences. It is to be hoped that those who love physical science will take pleasure in cosmology as an example of the art. ...

Behind physics is the more ancient and honorable tradition of attempts to understand where the world came from, where it is going and why.[1]

– P. J. E. Peebles,

Albert Einstein Professor of Science, Emeritus, Princeton University



James Peebles

1. Peebles, P. J. E., *Principles of Physical Cosmology*. Princeton: Princeton University Press, 1993, p. 3.

"The consequences of overclaiming the significance of certain theories are profound — the scientific method is at stake (see go.nature.com/hh7mm6). To state that a theory is so good that its existence supplants the need for data and testing in our opinion risks misleading students and the public as to how science should be done and could open the door for pseudoscientists to claim that their ideas meet similar requirements.

What to do about it? Physicists, philosophers and other scientists should hammer out a new narrative for the scientific method that can deal with the scope of modern physics. In our view, the issue boils down to clarifying one question: what potential observational or experimental evidence is there that would persuade you that the theory is wrong and lead you to abandoning it? If there is none, it is not a scientific theory.

Such a case must be made in formal philosophical terms. A conference should be convened next year [2015] to take the first steps. People from both sides of the testability debate must be involved.

In the meantime, journal editors and publishers could assign speculative work to other research categories — such as mathematical rather than physical cosmology — according to its potential testability. And the domination of some physics departments and institutes by such activities could be rethought[1,2].

The imprimatur of science should be awarded only to a theory that is testable. Only then can we defend science from attack."

– George Ellis & Joe Silk, "Scientific Method: Defend the integrity of physics," *Nature* **516**, 331 (16 December 2014).

Click the reference to read the full open-access *Nature* article. ⬆


George Ellis


Joe Silk

1. Woit, Peter. *Not Even Wrong*. New York: Basic Books, 2006.
2. Smolin, Lee. *The Trouble with Physics*. Boston: Houghton Mifflin, 2006

A SIMPLE idea underpins science: “trust, but verify”. Results should always be subject to challenge from experiment. That simple but powerful idea has generated a vast body of knowledge. Since its birth in the 17th century, modern science has changed the world beyond recognition, and overwhelmingly for the better.

But success can breed complacency. Modern scientists are doing too much trusting and not enough verifying—to the detriment of the whole of science, and of humanity.

Too many of the findings that fill the academic ether are the result of shoddy experiments or poor analysis (see article*).

(san serif font, as in the source)

–Eds., “How Science goes wrong,” *The Economist* (19 October 2013)

* The quoted article and this referenced article are different.

“Theoretical physics is a developing subject and new physics may offer a variety of new cosmological applications. Finally, observations and theoretical understanding are always limited, hence even a quite credible world model has its limitations, too (in current cosmology 99.5% of the needed mass has unknown nature). These emphasize the importance of crucial observational tests as the only safe way to decide between alternative cosmological ideas.”

– Yurij Baryshev, “Paradoxes of cosmological physics in the beginning of the 21st century,” 30th Int’l Workshop on High Energy Physics, Protvino; arXiv:1501.01919 [physics.gen-ph] (4 January 2015).

"And where science gets *tough*, tough in the sense that you can be mistaken, even if you passionately believe something, is that a good scientific theory makes predictions and those predictions can be tested."[1]

– Lee Smolin, *Perimeter Institute for Theoretical Physics*

Lee Smolin

The pursuit of science requires sophisticated intellectual *and* emotional thinking; curiosity and inspiration in response to scientific criticism are the hallmark of a professional scientist. Fear, anger and other inappropriate defensive behavior may occur as instinctive responses to *tough* scientific challenges that have been emotionally misinterpreted as a personal attack. Intellectual discipline and professional ethics ought to override any such irrational responses, which include the choice to ignore or suppress criticism at the expense of scientific integrity.

1. Online Lecture: *The Nature of Space and Time* (1:05:50 / 1:28:25)

Note: The word "wrong" (verbatim) has been changed to "mistaken"; ideas are *wrong* — to avoid pejorative connotation, people are *mistaken*.

The tool implementing the mediation between theory and practice, between thought and observation, is mathematics. Mathematics builds the connecting bridges and is constantly enhancing their capabilities. Therefore it happens that our entire contemporary culture, in so far as it rests on intellectual penetration and utilization of nature, finds its foundations in mathematics.

…

For us there is no ignorance, especially not, in my opinion, for the natural sciences.

Instead of this silly ignorance, on the contrary let our fate be:

"We must know, we will know."

– David Hilbert, *Preeminent 20th-century mathematician (1862–1943)*

David Hilbert

Source: *Translation of an address given by David Hilbert in Königsberg*, Fall 1930; translation by Amelia and Joe Ball.

Young Men and Fire

For a scientist, this is a good way to live and die, maybe the ideal way for any of us — excitedly finding we were wrong and excitedly waiting for tomorrow to come so we can start over, get our new dope [old American slang for "information"] together, and find a Hypothesis Number One all over again.[1]

A River Runs Through It

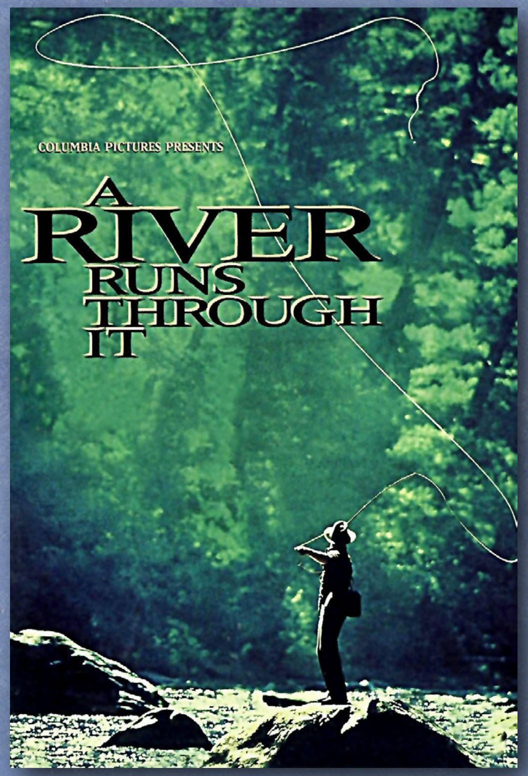
As for my father, I never knew whether he believed God was a mathematician but he certainly believed God could count and that only by picking up God's rhythms were we able to regain power and beauty. Unlike many Presbyterians, he often used the word "beautiful."

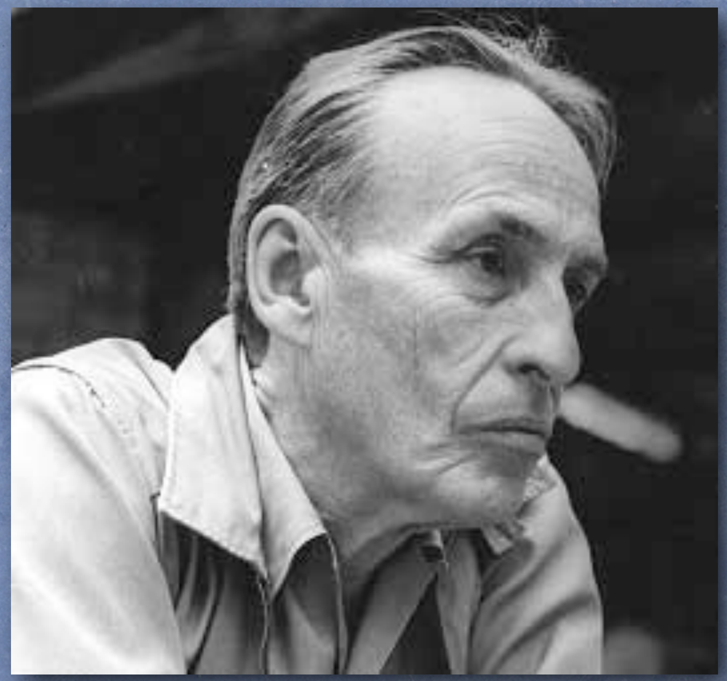
…

My father was very sure about certain matters pertaining to the universe. To him, all good things—trout as well as eternal salvation—come by grace and grace comes by art and art does not come easy.[2]

– Norman Fitzroy Maclean (1902 – 1990)

Professor of English Literature, The University of Chicago



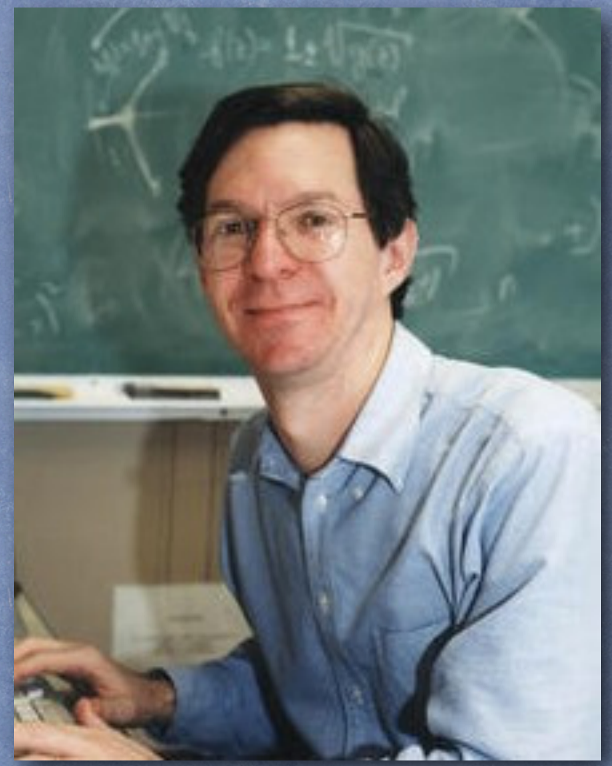


Norman Maclean

1. Norman Maclean, *Young Men and Fire*. Chicago: University of Chicago Press, 1993, p. 139.
2. Norman Maclean, *A River Runs Through It*. Chicago: University of Chicago Press, 1976, pp. 2–3.

I want to argue that clear thinking, combined with a respect for evidence — especially inconvenient and unwanted evidence, evidence that challenges our preconceptions — are of the utmost importance to the survival of the human race in the twenty-first century, and especially so in any polity that professes to be a democracy.[1]

– Alan Sokal,
Professor of physics at New York University
Professor of mathematics at University College London



Alan Sokal

1. Sokal, Alan, "What is science and why should we care? — Part I." Scientia Salon (26 March 2014).

The role of the scientist is to look towards the future with the purpose of improving the human condition.

…on ne voit que ce qui reste à faire.

"…one sees only what remains to be done."

– Marie Skłodowska-Curie