

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

ABSTRACT

With today's improved telescopes, such as the Hubble Space Telescope, we are collecting more astronomical data than ever. The amount of data has increased exponentially and is doubling every 1.5 years. The NASA data archive alone has reached 200 terabytes. Sharing of data and images poses a significant challenge. On the current publicly accessible systems, navigation of these data sets is cumbersome even for the more skilled scientist.

The goal of this project is to enhance access to astronomical survey data through a web service that uses the Google Maps navigation models. Space telescope images and information about the galaxies are presented simultaneously, thus, **creating a virtual observatory to navigate deep fields**. The web interface developed is online and publicly available for the benefit of the entire astronomical community and citizen scientists.

EXECUTIVE SUMMARY

The night sky has captured the imagination of man ever since the first human tilted his head back and looked up to the stars. With the advent of powerful orbiting telescopes such as the Hubble Space Telescope, we can gaze into the distant corners of the universe in areas known as deep fields. Deep fields refer to small regions of the sky, selected because they are devoid of nearby stars that can interfere with our view of distant galaxies. By observing galaxies at different distances and therefore different ages, we can infer the origin and evolution of our galaxy.

Sharing of data and images that are being generated by telescopes around the world poses a significant challenge, especially since the size is growing exponentially each year. The NASA data archive alone has reached 200 terabytes. Currently, there is no publicly available resource that seamlessly joins in an interactive fashion the deep field images with the associated data sets that can contain up to a thousand data values for each galaxy. Astronomers and citizen scientists must face the time-consuming, daunting task of retrieving the data of interest and merging together before being able to study the properties of stars and galaxies.

My goal was to address this issue by building a web-based, graphical interface that enabled the end user to explore the deep field galaxies as easily as using Google Maps on earth. Once a galaxy of interest is found, the user can click through to retrieve additional information. Through the integration of the visual map interface with the extensive extragalactic database, a virtual observatory was created that grants access to expensive, remote, time constrained telescopes to anyone, anytime, anywhere.

The end result is a functioning “Google Deep Field” that has never been accomplished before. This advanced web interface backed with complete compilations of deep fields will revolutionize access to information by the astronomical community.

1 INTRODUCTION

Our fascination with the stars dates back to antiquity. As one of the oldest natural sciences, astronomy, the study of matter in outer space and the universe as a whole, is considered purely observational. Unlike experimental sciences, which follow the scientific method, it is not currently possible to design and conduct direct, controlled experiments on distant galaxies. For instance, how would a scientist study the collision of galaxies in a controlled experiment? Drop each galaxy into a universal solvent and observe the reaction? An astronomer cannot yet travel to a distant galaxy and must rely only on the light emitted by stars and galaxies to study their properties.

Since the 1900s, telescopes have become bigger and more efficient allowing us to study fainter galaxies. With the advent of space-based telescopes, astronomers can gaze even farther and deeper into the cosmos and measure the light emitted at multiple wavelengths for instance. The data collected from NASA's Hubble Space telescope, consisting of over one million exposures, served as the basis for more than 10,000 scientific publications.¹

1.1 Galaxies

Whereas it is impossible to directly study the origins of a specific galaxy, such as the Milky Way, observing the evolution of other galaxies at various points in time over their lifetimes is equally helpful and can produce insights. Because light travels at a finite speed, light emanating from distant galaxies originated sometime in the past. The farther away the celestial object is, the longer the light takes to reach the telescope, and hence, the farther back in time the observation reflects. For example, light reaching earth from the nearest galaxy, Andromeda, was emitted over 2.5 million years ago.² But given that Andromeda was formed 5-9 billions years ago, that represents only 0.03% of its existence.³ In terms of an average human lifespan, this is equivalent

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

to observing a human subject only a week earlier. So to find a galaxy further back in time requires looking at a more distant one. To travel into the past, observers must peer deep into space. By viewing galaxies at different distances and therefore different ages, astronomers can infer the formation and evolution of the galaxies in the universe.

1.2 Deep Fields

Deep field surveys are the crown of such observations. Focused on just a small portion of the sky, these observations are conducted from several space and ground-based observatories at

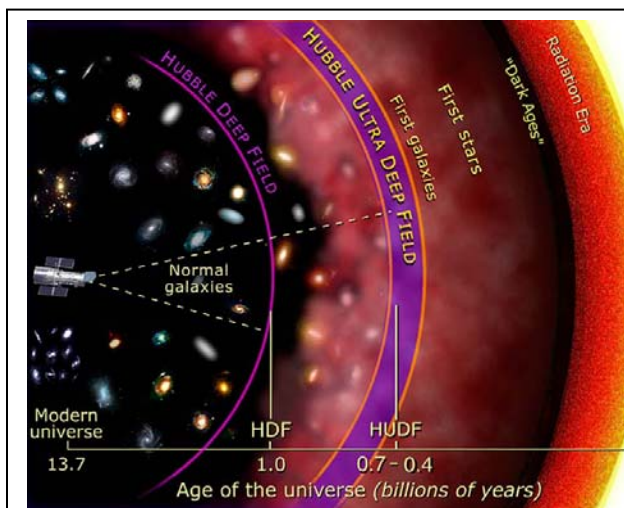


Figure 1. The Hubble Space Telescope surveys deep fields

different wavelengths ranging from the X-rays to the far-IR. The Hubble Space Telescope in Figure 1,⁴ Chandra, and Spitzer among others are focused into these deep fields. The most powerful ground-based telescopes, including the European Southern Observatory (ESO), the Kitt Peak National Observatory (KPNO), and the National Astronomical Observatory of Japan (NAOJ), also generate thousands of observations into deep fields. As more

observatories are upgraded and more advanced instruments are developed, we can probe the spectral range in more detail and with much finer sensitivity. The amount of astronomical data being collected has increased exponentially and is doubling approximately every 1.5 years.⁵

1.3 Redshift

Redshift occurs when the wavelength of light emitted from a celestial object (e.g. galaxy) that is moving away from the observer becomes elongated or shifted toward the red end (lower

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

frequency) of the spectrum. Redshift is defined as the relative difference between the observed and emitted wavelengths of light from the source object. Astronomers prefer a dimensionless quantity z , where

$$z = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}}$$

For extragalactic galaxies, redshift is approximately proportional to the galaxy's distance from earth as described in Hubble's law.⁶

1.4 Problem Statement

With today's space and ground-based telescopes, a substantial amount of deep field data has been accumulated to this point. The NASA data repository alone contains about 200 terabytes of data.⁷ Berriman of NASA's Exoplanet Science Institute estimates there is 1 petabytes of astronomical data available to the public and refers to the situation as the "data tsunami."⁸ Unfortunately, navigation of such data sets is cumbersome even for the more skilled scientist.

2 PROJECT DESCRIPTION

The design statement for this project is straightforward: create an interactive galaxy map of the deep fields on a web browser where the individual galaxies can be identified and linked to their corresponding photometric and spectroscopic data stored in the RAINBOW Cosmological Surveys Database⁹, thus helping astronomers around the world to access the information quickly and efficiently.

2.1 Goal

My main goal is to unify the accessibility to deep field surveys through a web mapping service that uses a Google Maps to graphically reference, retrieve and present the observed images and underlying galactic measurements for the benefit of the entire astronomical community and

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

citizen scientists. In effect, I am **building a virtual observatory for deep fields**. As new galaxies are discovered, this virtual observatory will absorb the new data, facilitating the accessibility for the users. This map is highly useful for any astronomer working on deep fields because they can visualize their work in the map, quickly maneuver to their galaxy, and view it in relation to those around it. The interface is already available among academicians within the university setting, but will soon be released for use by the entire astronomy community.

2.2 Importance

By creating an interactive map interface of deep field, giving astronomers a common, intuitive view from which to retrieve information in a more intuitive way, I transform the RAINBOW into a much more efficient virtual observatory for deep fields. In the same tradition of naming Google Earth, Google Moon, Google Mars, Google Sky, this project can be thought of as Google Deep Field Galaxies, the *de facto* standard for deep field surveys. The creation of such a visualized deep-field galaxy navigator has never been accomplished before on such an extensive database with an interactive web service.^{10 11 12} Similarly, thirty years ago, a particle physicist had a similar vision for sharing experimental data being generated throughout the world and inadvertently spawned the World Wide Web.¹³

2.3 Premise

2.3.1 Deep Field Database

Each deep field survey comes with its own set of photometric and spectroscopic measurements. Regions of these deep fields have been surveyed more than once at different wavelengths. For instance, the Great Observatories Origins Deep Survey (GOODS) region has been surveyed numerous times: first in great detail with Hubble Ultra Deep Field (HUDF) in 2004¹⁴, and in even greater detail with Hubble eXtreme Deep Field (HXDF) more recently in 2012.¹⁵ Thus,

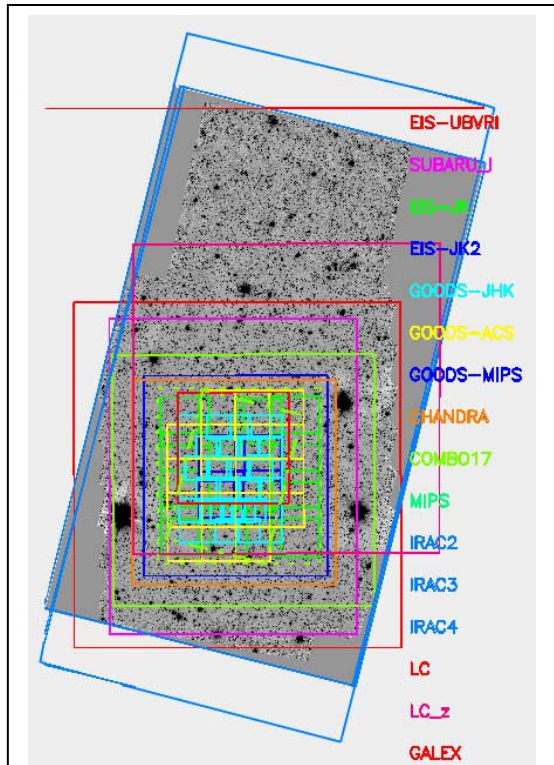


Figure 3. The RAINBOW deep field surveys include many other surveys from different observatories at various wavelengths.

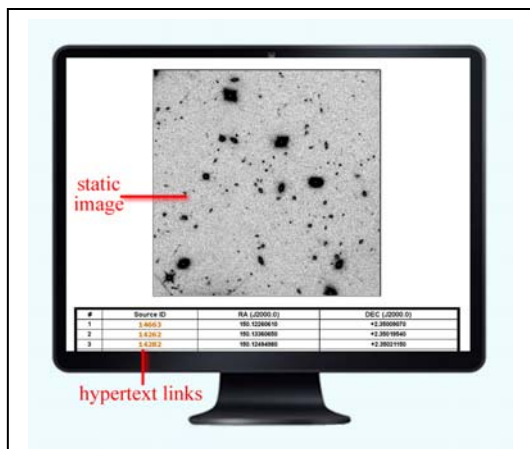


Figure 2. The RAINBOW navigator supports only text queries and static image maps.

keeping up with recent observations in a systematic, detail oriented manner is critical to getting the maximum information for each galaxy. For example, Figure 2¹⁶ depicts the GOODS-S deep field, an area in space. The colored boxes are the different surveys done on this field at varying wavelengths.

The RAINBOW database depicted represents a vast compilation of photometric and spectroscopic data for galaxies from several of the deepest fields such as GOODS North and South, COSMOS and the Extended Groth Strip.

The database contains over two million galaxies selected in X-ray to radio.¹⁷

Unfortunately, until now, the RAINBOW navigator supported only a text-based query-by-example access method and static HTML maps of galaxies with small illustrative markers. The maps are not interactive with no click-through, no scrolling or zooming capability.

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

2.3.2 Technology

Like most modern web applications, the web browser manages synchronous and asynchronous interactions with the user and renders screens while the majority of the logic and computing occurs on the server side. To develop this project, I used the following:

- LAMP open source architecture: Linux operating system and includes the Apache web server, connected to a MySQL relational database management system, using Python CGI server side scripting language.
- Google Maps API to support Google Maps look and feel
- 3DHST library to convert FITS image files into JPEG format

2.4 Features

The web mapping service executes on a web browser to reach the broadest possible audience and follows the user friendly Google maps navigation model. In addition, it supports all the convenient and familiar features of Google maps such as drag scrollable images, zoom levels, zoom in and out, point-of-interest markers and pop-ups, direct input of coordinates (not latitude and longitude but their astronomical analogues: right ascension (RA) and declination (DEC)), and different graphical views (based on different wavelengths). In addition a specific map location can be positioned based on RA and DEC coordinates or on a unique galaxy ID number in the database. As a key performance feature, asynchronous page loading allows the user to scroll the image without waiting for all the galaxy markers to completely update. Also, filtering galaxies based on user-defined *redshift range*, a surrogate for relative distance from earth, allows astronomers to view neighboring galaxies instead of seeing apparent juxtaposed galaxies that are actually billions of years apart. This filter modifies the map markers for an interactive viewing of the galaxies matching the selection criteria. Similar to a map and satellite view on Google Maps,

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

the image view optional displays different graphical and wavelength views of the map to assist the astronomer in better viewing of the map.

2.5 Implementation

In the following, I describe the major milestones in the development of this project as two separate efforts: the image processing of the deep field image tiles to be displayed and the web programming required to modify and enhance its behavior.

2.5.1 Image Processing

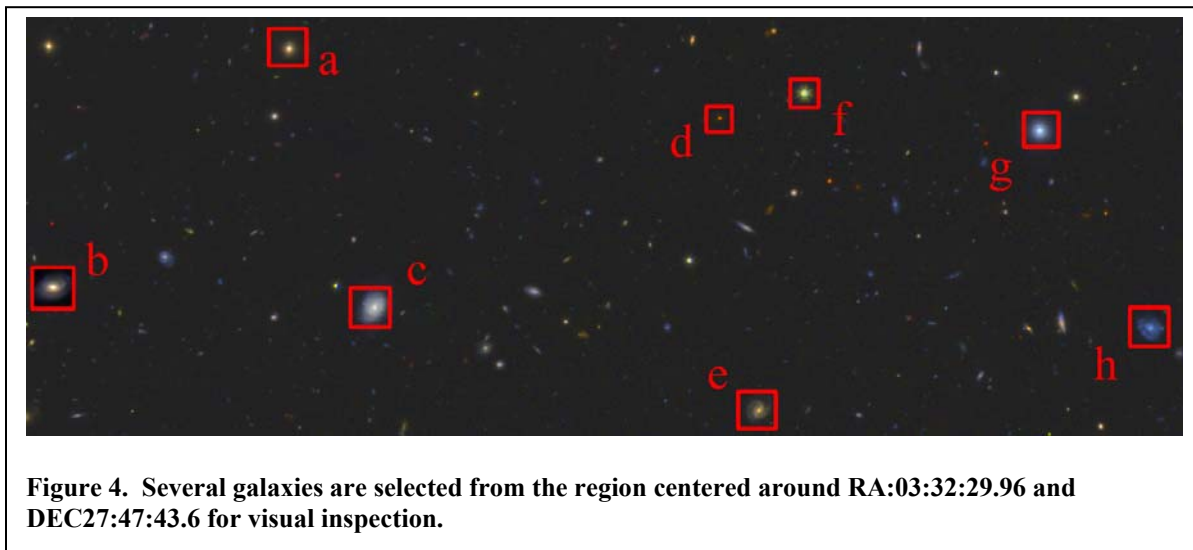
The Google Maps API required a specific set of calibrated images. A calibration algorithm was developed to determine the optimal parameters for consistent Google Maps tiled images. Then, FITS-formatted deep field images were rescanned using these adjusted parameters to produce JPEG-formatted images compatible with Google Maps API using the 3DHST utility. Several sets of image maps (3 color maps created by combining the corresponding three separate RGB maps and 2 near-infrared maps) at several different zoom levels per deep field were generated to support the desired Google Maps functionality.

To create tiled maps from astronomical images in FITS format, a python-based 3DHST library was downloaded and installed. Multiple maps based on deep field mosaics at different wavelengths were generated via a 3DHST *MakeImageMap* function call using interactive python from a Linux command prompt in Ubuntu virtual machine.

An intelligible image map is essential for the interactive database so the user can correctly visualize the size and shape of a galaxy in relation to those surrounding it. Although a “best” image is highly subjective based on each individual user, the optimal image was defined as roughly equal distributions of red, green, and blue within the map through comparison of the means and standard deviations of the RGB histograms.

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

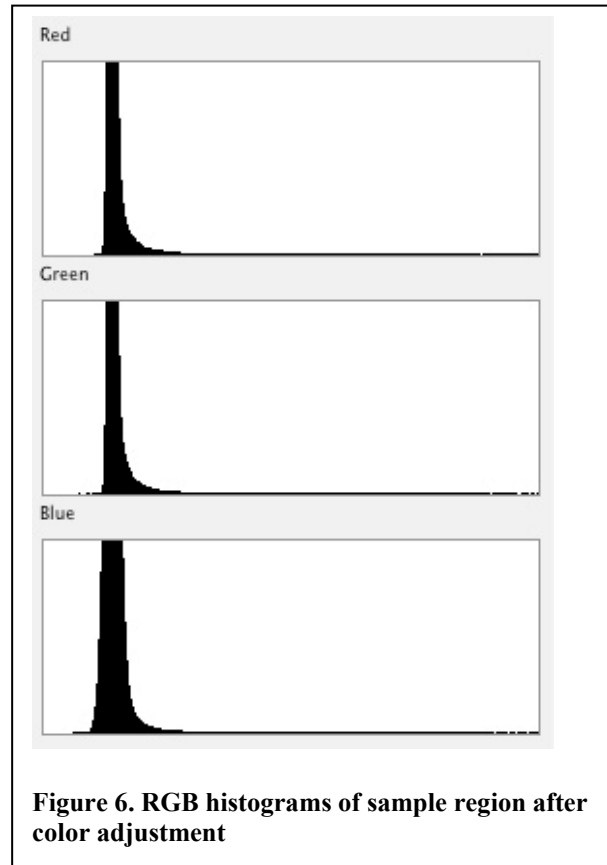
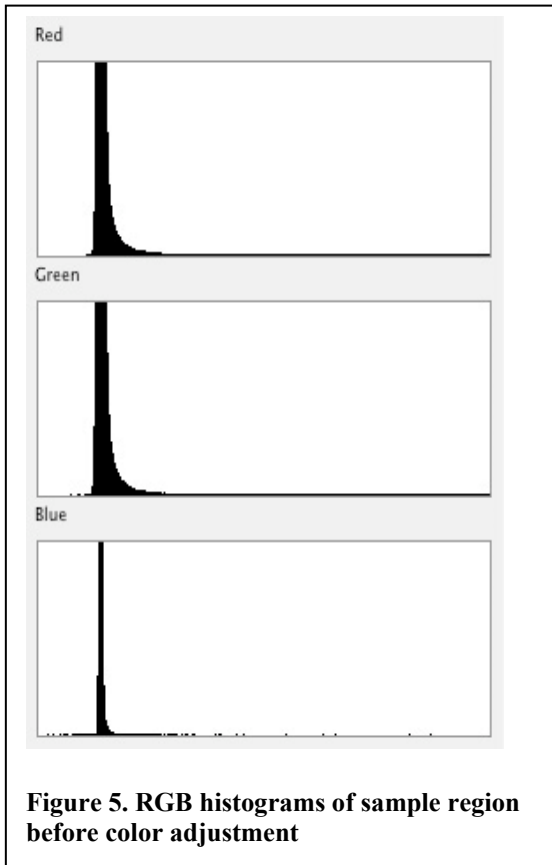
To ensure a consistent color sampling through the trial, a 1700x620 pixel map from GOODS-S centered at RA: 03:32:29.96 and DEC: -27:47:43.6 taken on zoom level 15 served as



the sample region. Several sample galaxies were selected arbitrarily for later visual inspection as indicated in Figure 4. When the final image was produced, RGB color distribution histograms were created where each pixel's color magnitude was decomposed into red, green, and blue; these magnitudes were then slotted into a value within the three color histograms as shown in Figure 5.

Just from viewing the unadjusted galaxy samples in Figure 7, the user can see the highly biased yellow film over the entire survey, implying the red and green values heavily outweigh the blue. Although the original color levels of the three wavelengths f160w, f125w, and f850l were all at their base magnitude when extracted from the FITS files, a yellow film was cast over the entire survey and needed to be corrected.

Upon examination of the original histograms (Figure 5), this yellow film becomes quantifiable by comparing the blue histogram to the red and green histograms. The mean of blue mean at 34.99 is drastically different from the red mean at 35.94 and green mean at 36.02.



The standard deviations emphasize this disparity with a blue standard deviation of 1.08 while red and green had standard deviations of 7.77 and 8.29 respectively.

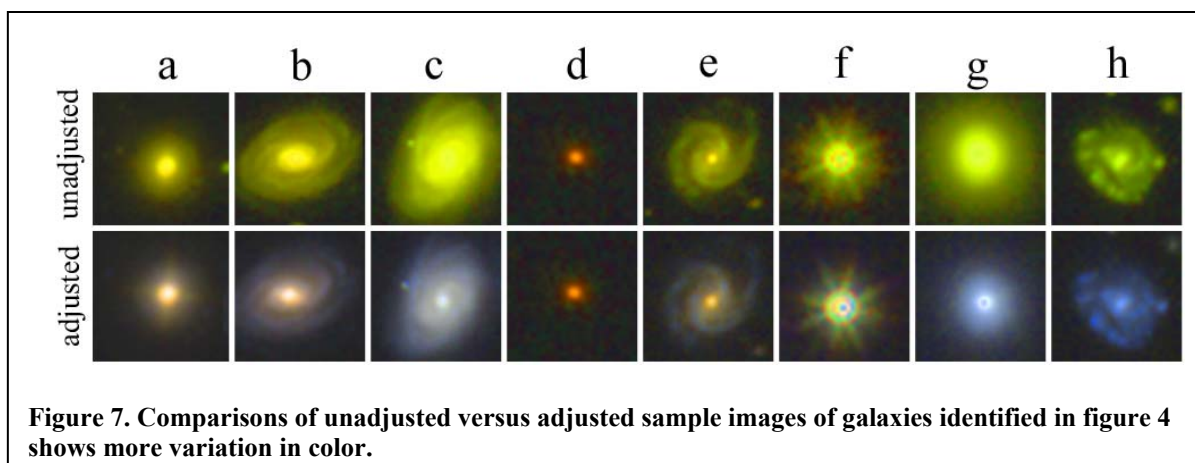
Table 1. Summary of Unadjusted/Adjusted RGB Histograms

	Unadjusted		Adjusted	
	Mean	Std. Dev.	Mean	Std. Dev.
Red	35.94	7.77	35.87	7.12
Green	36.02	8.29		6.95
Blue	34.99	1.08		6.90

In the final version of the map, the blue channel was adjusted to approximate mean and standard deviation of the red and green histogram curves. This theoretically creates a balanced image between the three red, green, and blue values.

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

Upon analysis of the adjusted histograms shown in Figure 6, they approximate the same curves with the same mean of 35.87 and nearly equivalent standard deviations of 7.12, 6.95, and 6.90 as seen in Figure 6. Visually inspecting the histograms revealed the distributions had roughly equivalent distributions, meaning the outputs were balanced. The comparison of the results in Figure 7 provided visual affirmation.



2.5.2 Web Programming

When using the standard Google Maps scrolling, the overlay (i.e., galaxy markers) on the newly exposed portion of the map requires a subsequent synchronous refresh to be displayed. I wanted the galaxy markers to be updated automatically while scrolling. But because galaxy markers require server-side database retrieval to position and draw new markers, scrolling performance would suffer. To eliminate the need to manually refresh and maintain reasonable scrolling speed, I modified the listener event *dragend* within the Google Maps API and used the AJAX (Asynchronous Javascript and XML) engine that asynchronously calls the refresh function to retrieve the new data into an XML document, and a Javascript function to update and create the new markers on the page all while the page is being scrolled.

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

Several MySQL select queries were developed to query the backend database for galaxy information including the galaxy catalogue along with individual redshift, marker locations, marker data, and distance.

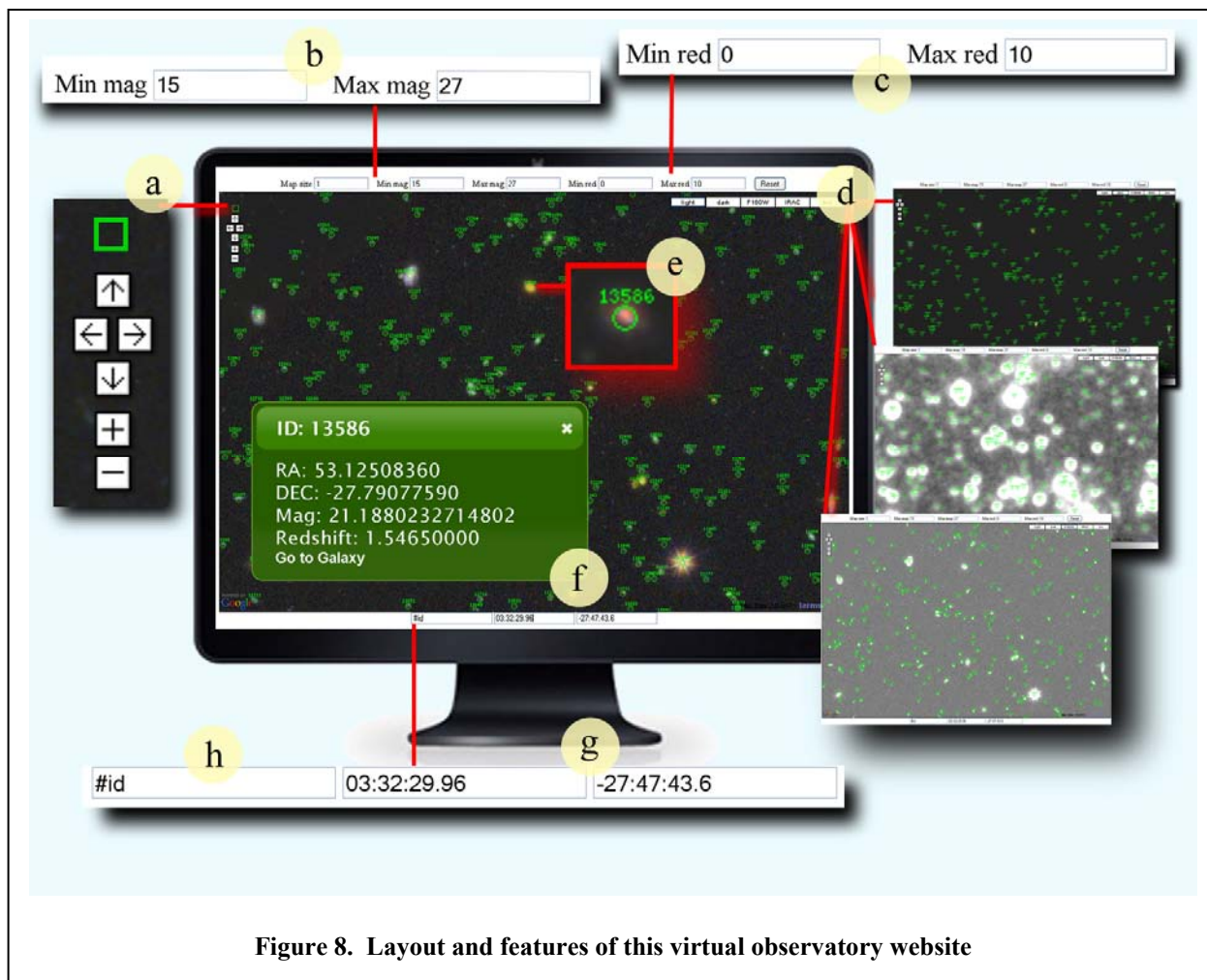
2.6 Roles

This project was completed during a summer internship under the direction of a mentor. Initially, my mentor provided extensive guidance on the architecture of the pre-existing services and the database. As the internship progressed, I worked nearly independently, resolving implementation issues and suggesting improvements to my mentor. To accomplish this, each night, I would return home to learn a new web development aspect and apply it the next day. In total, I learned to use ten different components and languages of web programming. My mentor and other summer interns provided feedback to the working version of the website as they used the new features and functionalities to access data of interest.

3 RESULTS

Through the integration of the visual map interface with the extensive RAINBOW database, a virtual observatory was built that grants access to expensive, remote, time constrained telescopes to anyone, anytime, anywhere. Figure 8 illustrates the features of the deep field virtual observatory website. In the following, I describe the key features highlighted by the semi-transparent yellow bubbles.

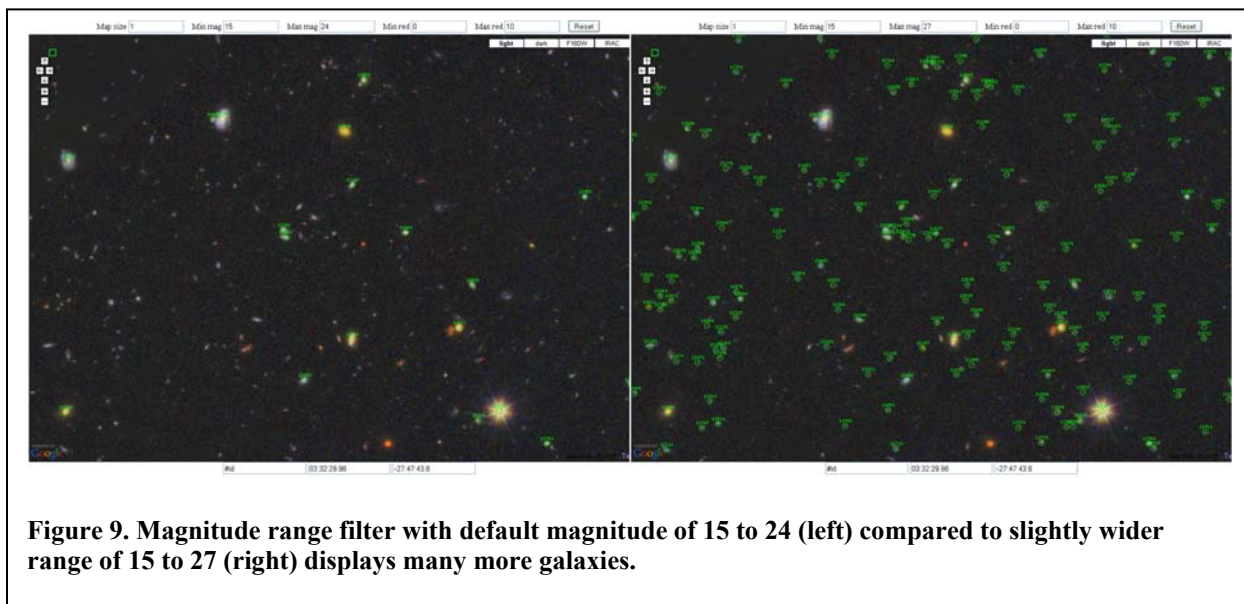
Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services



- a. Intuitive Google Maps style navigation. The navigation control in the upper left hand corner of the map gives the user intuitive scrolling and zooming functionality to allow easy exploration of the database using the arrow buttons and zoom in (+)/zoom out (-) buttons respectively. In addition, the deep field map supports a drag-to-scroll that automatically updates the galaxy markers. The green box above the navigation control lets the user toggle (display or hide) the galaxy markers to annotate or simplify the view of the map on demand.
- b. Magnitude range filtering. Minimum and maximum magnitude entries allows the user to filter out galaxies based a range of magnitudes, the negative logarithmic measure of brightness,

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

thereby narrowing the query and displaying only those galaxies an astronomer would be currently researching. Changing these will automatically update the queried galaxies. Figure 9 shows a deep field region where magnitude range is widened and additional galaxies are recognized.



c. Redshift range filtering. Minimum and maximum redshift entries allow the user to filter out galaxies based on a range of redshift thereby narrowing the query and displaying only those galaxies an astronomer would be currently researching.

d. Popular Views. Similar to the Google map view options (e.g. hybrid and satellite views) that provide a user with different perspectives of the same region, a user may choose to view the same region of the galaxy at different wavelengths along the spectrum. The map accommodates this by providing selected popular near infrared wavelengths with filters (e.g. F160W) and map styles to gain a different perspective of the galaxies or just gather more information.

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

e. Clickable Galaxy Markers. Like points-of-interest on satellite view maps, galaxy markers show the user all of the identified galaxies within the selected field. These markers are interactive and can be clicked to pop up a window with quick facts for that particular galaxy.

f. Quick Facts Popup Window.

When the user needs more information about a certain galaxy, the clickable marker opens a quick facts window, displaying only the essential information for that galaxy while preserving the user's position on the map. This gives

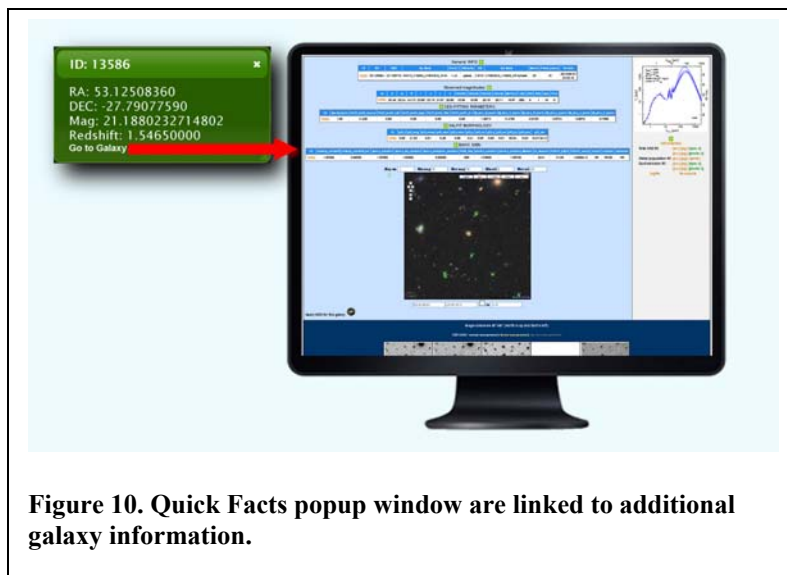


Figure 10. Quick Facts popup window are linked to additional galaxy information.

the user to confirm interest in that galaxy before clicking the “Go To Galaxy” link and retrieving extensive astronomical data with over one hundred separate values.

g. Position by ID. Similar to entering a point-of interest on Google Maps (on earth), the user can position the map over a galaxy by just specifying the galaxy ID. This feature is especially valuable if the galaxy was previously identified as a point of interest in a prior session and the user wants to quickly return to that region of the deep field without having to navigate back. The galaxy in question will be positioned at the center of the region and highlighted in blue.

h. Position by RA and D. Similar to finding a location by entering the latitude and longitude in Google Maps (on earth), the user can position the map by specifying the right ascension and declination within the field. Not only will these fields reflect the current position within the map, new coordinates may be entered to quickly jump to the next desired location. If the position of

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

the galaxy in question is unknown, the left box provides functionality to go to the galaxy by entering its ID number. The specific galaxy will highlight in blue for the user and the galaxies around it and their markers will be automatically queried.

In addition to the main navigation map, I also created individual maps for each galaxy and added special redshift functionality. Those galaxies with similar redshift values (z) to the specified galaxy at the center (highlighted in blue) are actually galactic neighbors signified by red markers as opposed to other galaxies (green markers) that only seem close on a 3D projection onto a 2D image. This selective coloring essentially allows the user to take a slice in time. This flexible tool can filter out the surrounding galaxies by modulating the tolerance of the redshift.

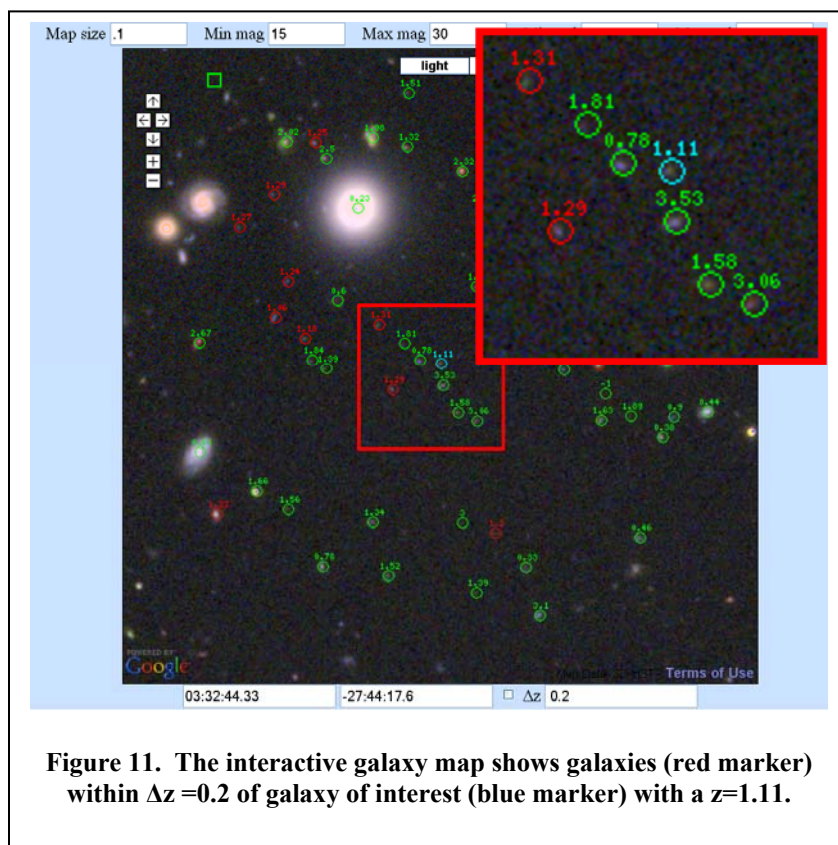


Figure 11 illustrates the interactive map for the specified galaxy with a redshift value of $z = 1.11$. By specifying $\Delta z = 0.2$ (in the lower right hand field), all galaxies with redshift values within $z =$

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

1.11 ± 0.2 have their marker color changed to red (from green). Although several galaxies (highlighted in green) seem closer to the specified galaxy, the galaxies highlighted in red have redshift values $z = 1.29$ and $z = 1.31$ and are actually closer compared to galaxies in green with values $z < 0.78$ or $z \geq 1.81$.

4 SUMMARY

I have developed a flexible web-interface to improve the RAINBOW database that allows for improved exploration within the vast amounts of data presented by utilizing the tools and data of 3DHST, Google Maps API, RAINBOW database, and LAMP architecture. The presentation was visually enhanced by optimized color maps created via the analysis of their color histogram levels as well as certain wavelength maps to assist the user in viewing the galaxies. On top of the visual aspect of the map, the interactive side included effective functionalities. An adaptive mechanism for navigation around the map allowed for several methods of navigation from scrolling to entering in galaxy ID or coordinates. A filtering method provided users with a way to selectively choose and see the galaxies in question, instead of being bombarded with thousands of galaxies. The implementation of clickable markers and quick facts popup boxes permitted users to preview a galaxy's profile before delving into the hundreds of data points on the galaxy's page. In the galaxy's page, a special redshift capability displayed a highly advantageous ability to view only the closest galaxies around the central one.

This virtual observatory will revolutionize the astronomical community's method of analyzing galaxies contained within deep fields. Instead of only sifting through hundreds of thousands of data points, an astronomer now has a tool to visually see their galaxy in relation to those around it. Because it will be free and publicly available online, both astronomers and citizen scientists worldwide have access to this resource. Since such an interactive map of such

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

magnitude and depth has never been accomplished before, this advanced web interface backed with complete compilations of deep fields will change the face of astronomy.

5 FUTURE WORK

The main advantage of the web-based implementation (software in general) is the flexibility to improve, enhance and deploy it. The future work can go in four directions: deeper content, richer functionality, better performance and easier maintenance.

Currently, my virtual observatory encompasses GOODS-S as a proof of concept; however, it is straightforward to extend it to include other deep fields in RAINBOW as well especially if conversion utilities are created to automate tedious and time consuming tasks. For the sake of symmetry, I would choose the GOODS-N as my next deep field addition. Eventually, I would like to host all the available deep fields within RAINBOW.

Although the virtual observatory has many initial features, two new features come to the top of the list for future additions: Exporting specific datasets to an external file and extending the filtering functionality to include other parameters and to mask out galaxies that are excluded.

When I presented this project to my colleagues, they conveyed that it could have saved them substantial time with exploration and frustration with data extraction. Although the navigational aspect has been addressed, data extraction still requires direct database querying to access details related to sets of galaxies. Adding such functionality would be invaluable to astronomers without the requisite database background and free up those with database knowledge to work on astronomy.

Instead of just toggling the marker colors of the galaxies based on magnitude, Δz or some other filtering parameter, the system could mask the galaxies that were filtered out from the

Graphically Navigating the Ever Expanding Observed Universe Through Web Mapping Services

image. This would require designing and incorporating algorithms to detect galaxy boundaries and another to apply the mask.

Although the web mapping service does function properly, better server-side data and webpage caching policies could obviate unnecessary roundtrips and improve navigation performance for the mapping service. I will consider caching strategies for HTML and XML fragments, as well as creating temporary “data warehouses” within the database specifically used for the mapping service navigation. But perhaps, I should review the overall caching strategy for the existing web and database server first to determine the true performance bottlenecks.

Much of the early work must be repeated when new deep field databases are to be brought online. These tasks should be streamlined into utilities that require minimum user interaction. The calibration and conversion process of FITS images to JPEG format is a perfect candidate.

Finally, the web mapping service is already available among academicians within the university setting, but will soon be released for use by the entire astronomy community. My mentor has recently presented the site at an astronomy conference, but I will need to work with my mentor to advertise its availability to the wider public audience.

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