Population Studies of Galaxies in the Early Universe

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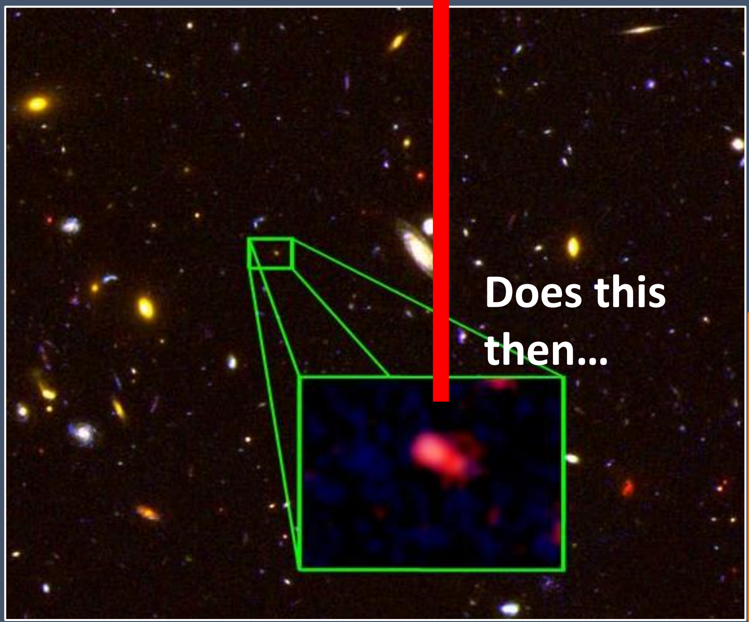
Introduction

Over the past **40 years**, advances in telescope surveys have revealed more and **more galaxies** located at **extreme distances** (so far that the light has travelled for >12 billion years!). We have gone from **single detections** in the 1980s to confirming **tens of thousands** of these objects today. This has allowed us to expand our studies of these galaxies from **individual cases** to examining the **population as a whole**.

A relatively local spiral galaxy NGC 1746. Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA), R. Thompson (University of Arizona)

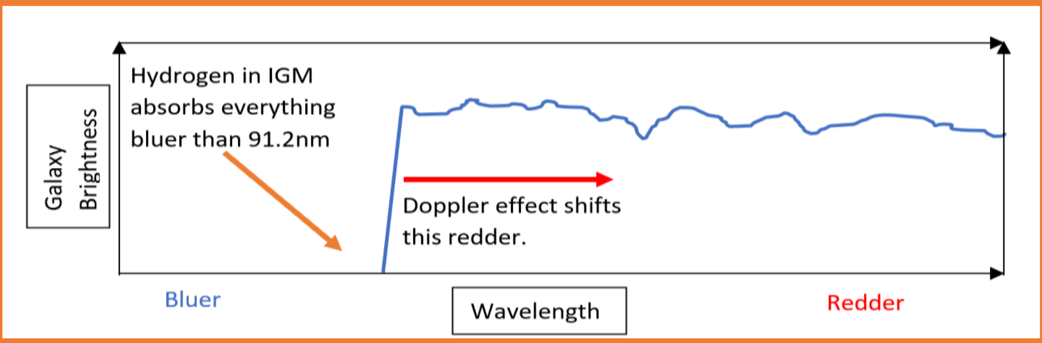


2013 record holder of most distant galaxy. Hubble Space Telescope CANDELS survey. Credit: V. Tilvi, Texas A&M University; S.L. Finkelstein, University of Texas at Austin; C. Papovich, Texas A&M University.

What are galaxies?

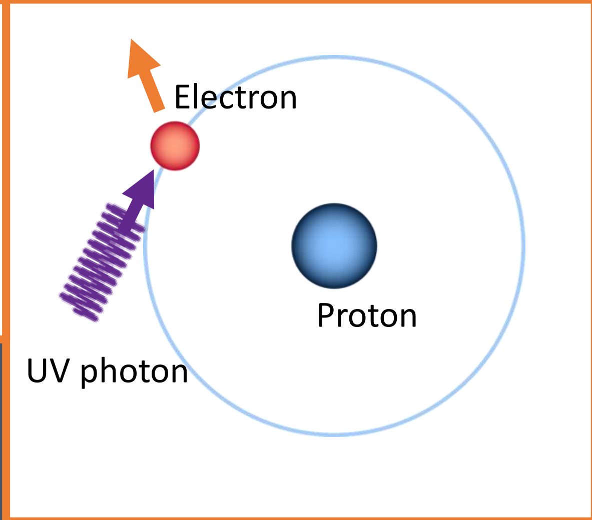
Collections of millions to trillions of **stars, loose gas and dust**. Galaxies are the **largest structures** that are luminous in **ultraviolet and optical light**. The **physical processes** that govern **how they grew** in the early universe are still **not well understood**.

Identifying The Most Distant Galaxies



The effect of the Lyman Break removing blue light in a galaxy spectrum.

The cause of the Lyman Break: A Hydrogen atom absorbs ultraviolet light causing the ejection of the electron.



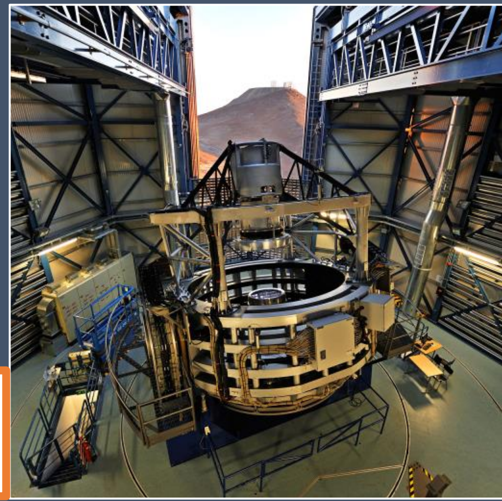
The Lyman Break

Around **74%** of the **mass** of atoms in the Universe is in the form of **Hydrogen**. This element can be found both **inside galaxies** and occupying the space **between galaxies** (often called the Inter-galactic Medium/IGM). Light with a wavelength of **91.2nm or smaller** is capable of **ionising** Hydrogen gas. This is where the **electron** of the atom **absorbs** the photon of light and the resultant **energy** gain is enough to knock it out of its orbit, leaving behind a naked proton. This results in a large **absorption** feature in the **galaxy spectrum** that can be detected by telescopes.

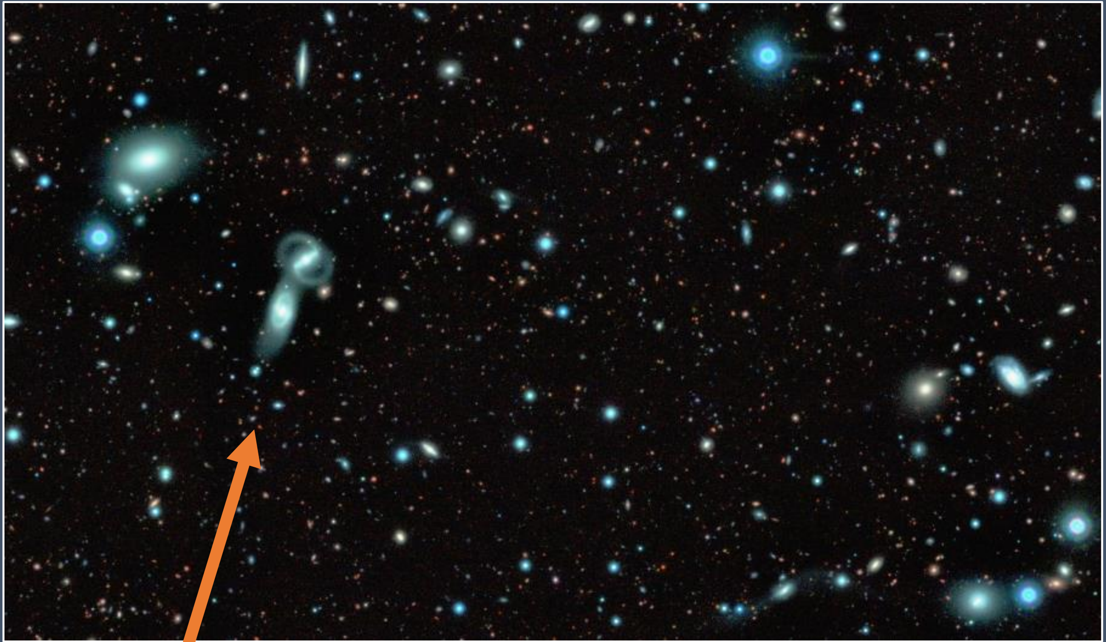
In addition to this, the **expanding Universe** causes galaxies more **distant** from us to move **increasingly faster** away from us. The **Doppler effect** then causes the light from these galaxies to be stretched to **redder wavelengths**. This results in distant galaxies appearing redder in colour. We can use the shifting of the Lyman Break as a proxy measurement of **speed** and thus **distance**.

The expanding Universe causes more distant galaxies to move away from us at ever greater speeds. This Doppler shifts the Lyman Break, making the galaxy redder.

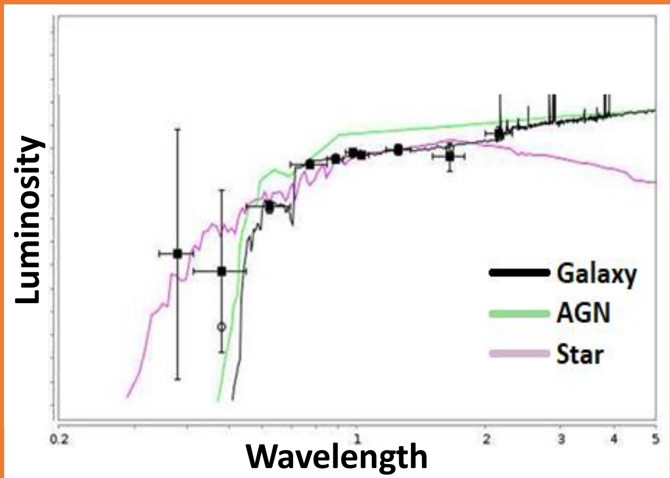
Applying these Techniques to Modern Surveys



The 4.1 metre VISTA telescope at Paranal Observatory, Chile.
Credit: European Southern Observatory



A ≈1% slice of the area of sky used in our study. We are interested in the many miniscule red/orange objects. Credit: VISTA/VIDEO survey.

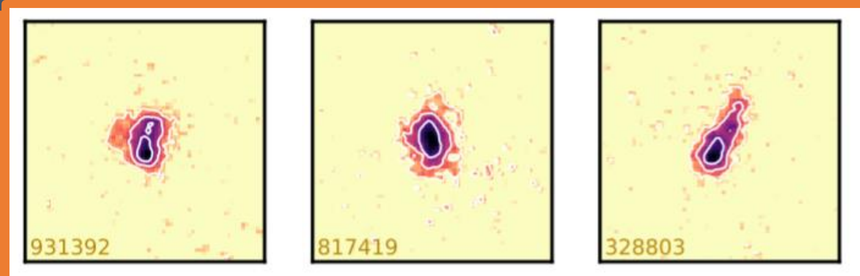


Example of a galaxy from our data. A Lyman Break at 500nm causes this galaxy to be undetected in the two “bluest” (leftmost) bands.

Finding our galaxies

We make use of observations of **2 large patches of sky** with **3 telescopes** to search for early Universe galaxies: VISTA (above), Subaru and the Canada-France-Hawaii Telescope. Within an area the size of **30 full moons**, we have over **1.8 million detected objects**. We measure the **near-ultraviolet, optical and near-infrared** light of these objects in **10 coloured filters** to search for **Lyman Breaks** around “blue/green” wavelengths of 400-500nm. Such objects have been **redshifted** by a **factor of ≈5**. Using the current **model of cosmology**, converting this **redshift** into a **distance** shows these galaxies emitted the observed light when the Universe was **10% of its current age**. Conducting this search in our data reveals **47,700 galaxies** located at this epoch.

Examples of what these “high-redshift” galaxies look like with high resolution Hubble data.



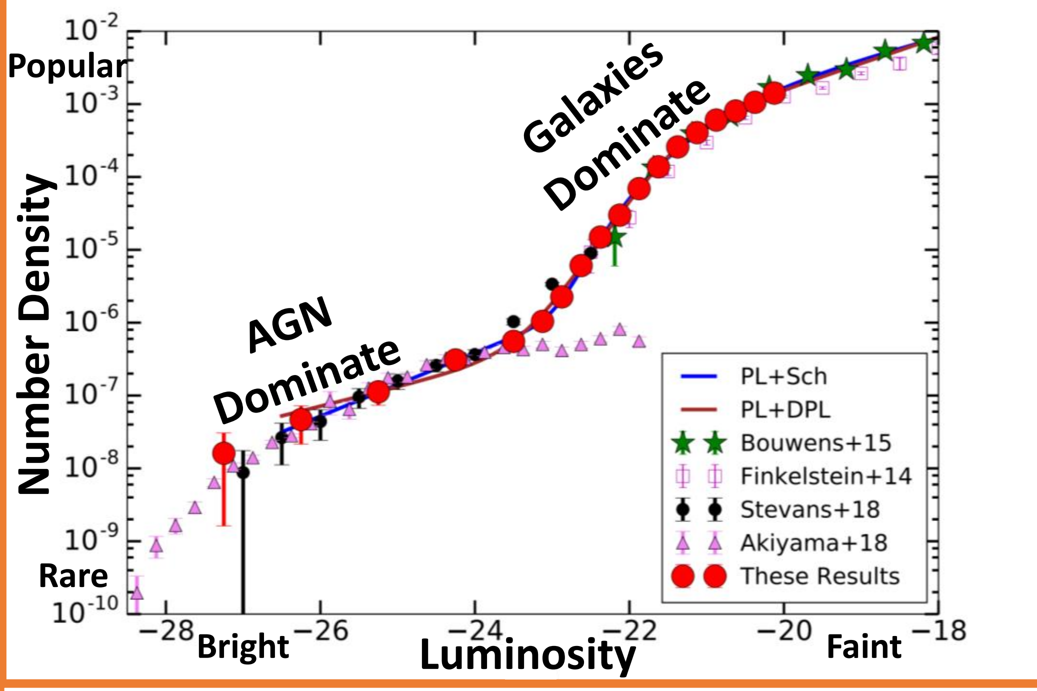
Early Scientific Findings: Measuring the Luminosity Function

The Luminosity Function

For **our sample** of galaxies, we can use our measurements of **how bright** they are and **how redshifted** they are to calculate their **total power** output at **ultraviolet wavelengths** just before the Lyman Break.

We then measure **how common** galaxies are of various power outputs (a **Luminosity Function**).

Our dataset is the first one to be capable of probing such a **large dynamical range** of the Luminosity Function. We find some **very rare**, ultra-luminous objects known as **Active Galactic Nuclei (AGN)** and a **large number** of more **typical galaxies**.



Results from measuring the ultraviolet Luminosity Function of our galaxies. Left is bright, right is faint and the higher the data point, the more numerous galaxies of that brightness are. We show examples of other studies over the past 5 years [1,2,3,4] and the two lines (blue/brown) are examples of models fit to the curve.

Conclusions

We introduce the methods and physical concepts used to robustly identify the most distant galaxies. Applying this to modern datasets has allowed us to measure the Luminosity Function of galaxies, when the Universe was 10% its current age, on a scale not previously possible. Our measurements find a sharp transition from AGN dominance to galaxy dominance in number counts and indicate that there could be more "faint" AGN than predicted from past measurements.

Acknowledgements

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References

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