NGC 1365: Formation, Evolution, and Cosmic Context

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Figure 1. NGC 1365: Majestic Island Universe (2010 August 20). Credit & Copyright: Martin Pugh. Courtesy of apod.nasa.gov/apod/ap100820.html (Public Domain).

1 Introduction

In a galaxy cluster located 60 million light-years away, there exists a unique supergiant spiral galaxy, spanning 200,000 light-years across from deep within the Formax cluster (Figure 2), NGC 1365. To reach this galaxy from Earth, we would need a rocket that can travel at the speed of light for 60 million years[1]. If this was a time machine that could go back 60 million years, it would've just missed the end of the Cretaceous period, or more notably the last dinosaurs on Earth[2]. Upon arriving at the tip of 1365's barred spiral structure shown in Figure 1, it would take this rocket an additional 200,000 years to traverse across its elongated bar-like cross-section. During this journey, we would behold the cosmic choreography of stellar genesis within 1365's galactic bar.

If you're finding the name hard to remember, you're not alone. NGC 1365 sacrifices a recognisable name in favour of a more systematic identity. Very few galaxies have names, most are just symbolised by a catalogue number. The Messier catalogue contains galaxies such as M31 (aka. Andromeda Galaxy) and the New General Catalog (NGC) contains our galaxy at number 1365, along with nearly 8000 other stellar objects[3]. There are roughly 2 trillion galaxies[4] in the known universe, that's 250 galaxies for every human on Earth. It'd get really awkward to find out galaxy names we got used twice.

Studying galaxies like NGC 1365 is an incredibly important task for astronomers as it helps them understand the universe's evolution, composition and structure. The astronomy community can then distil the most relevant discoveries to the rest of the world. This kind of work impacts us all in many ways. Have you ever wondered where everything came from, where did it all start? Why are we here? Are we alone? These are huge existential questions that can be answered by unlocking discoveries of other galaxies!

Figure 2. High-fidelity telescope imagery of the central part of the Formax cluster. At the lower right is the elegant barred-spiral galaxy NGC 1365. Acknowledgement: Acknowledgement: Aniello Grado and Luca Limatola. Courtesy of ESO `eso.org/public/images/eso1612a/` (Public Domain).

2 Observation

After being observed through the eyepiece of a 3.6 metre-long telescope at the European Southern Observatory (ESO) (Figure 3), it remained a standout galaxy because its unique characteristics (Lindblad 1999):

- It's spiral structure displays a variety of vibrant nuclear activity
- An absence of interacting neighbours
- Unusual X-ray emission emanating from its star forming regions

Figure 3. The 3.6-metre telescope at ESO's La Silla observatory (from the view of the road) is responsible for much of the observations on NGC 1365. Courtesy of ESO `eso.org/public/images/dsc_0063/` (Public Domain).

Amongst many of the surrounding galaxies to NGC 1365 illustrated in Figure 4 is NGC 1316, the brightest of them all. This lenticular galaxy[5] is the fourth-brightest radio source in the sky (Schweizer 1980). Unlike NGC 1365, it does appear to interact with the nearby northern system of NGC 1317. Distortions from neighbouring systems is a primary cause in galactic imperfections and asymmetry, none of which we can see in NGC 1365.

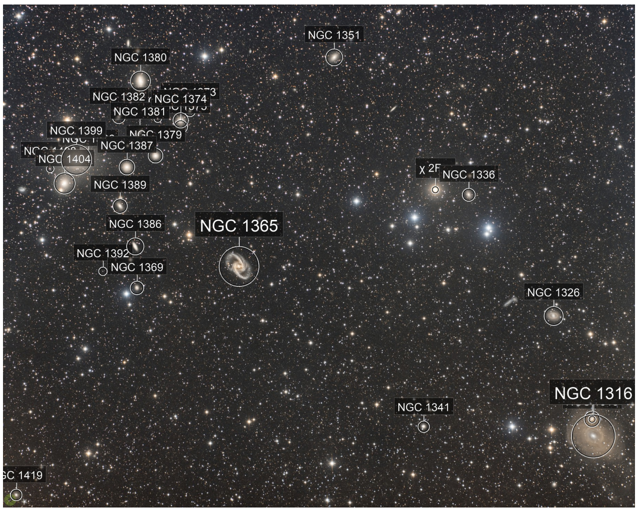

Figure 4. Annotated galaxies across the Formax cluster. Courtesy of `astrobin.com/gu154q/0/`.

3 Importance

In the grand cosmic odyssey of galactic exploration, we embark on a journey that unravels the mysteries of celestial evolution. Galaxy formation, evolution, and clusters represent the celestial trifecta, where each strand intertwines to compose the rich mosaic of the universe. From the celestial nurseries nurturing newborn stars within the vibrant spirals of NGC 1365 to the gravitational choreography of galaxy clusters, we unveil the cosmic saga that sculpts the cosmos. Delving into the depths of celestial birthplaces and the dynamics of supermassive black holes[6], we peer into the cosmic symphony of creation. By scrutinizing these celestial phenomena, we embark on a voyage of discovery, deciphering the enigmas of the universe and revealing the interplay of cosmic forces on scales both cosmic and minute.

3.1 Galaxy Formation

Galaxy formation has been, for a long time, an area of study we thought we know a lot about. Now with the power of the James Webb Telescope (JWST) as seen in Figure 5 and its unique lens[7], we can take a peak behind the curtain of the universe's history to look even further back[8]. This has revealed that giant galaxies like NGC 1365 have supermassive blackholes at their centres[9] (Magorrian et al. 1998). Whilst this is still an area of active research it's believed that the presence of central supermassive blackholes can be attributed to the early merger events of smaller blackholes along with accretion of surrounding matter.

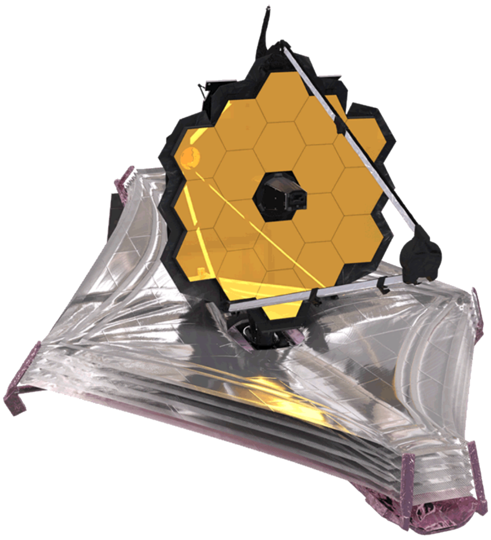

Figure 5. Rendering of the fully deployed James Webb Telescope. Unlocking cosmic secrets: The James Webb Telescope peers into the depths of space, revealing the birthplaces of galaxies and the enigmatic dance of celestial evolution. Courtesy of `https://commons.wikimedia.org/wiki/File:JWST_spacecraft_model_3.png` (Public Domain).

The formation of spiral-like shapes in galaxies is influenced by various factors, including density waves[10] and tidal interactions. Tidal interactions are gravitational *tugs* from nearby galaxies that stretch the galaxy's body towards and away from the centre of mass of another body. Forces of these magnitudes are bound to influence a galaxy's shape.

The spiral arms are essentially stellar factories. These are regions where stellar dust accretes to form stars. When enough particles are pressed together with the force of gravity[11], that pressure creates temperatures high enough to fuse hydrogen atoms together[12], forming a star. The hot massive blue stars don't live long enough in the spiral arms to make it to orbit around the galaxy, unlike the cooler red stars. Because blue stars are hotter they burn through more fuel and go supernova faster than red stars. If you scan Figure 1, the tail-end of the spiral arms contains all hot blue stars whilst the cooler red stars can be seen ordinarily orbiting the galaxy closer to its centre.

Other galaxy types are shown in great detail in Figure 6 and include elliptical galaxies, which are characterised by their lack of significant structure and appear as ellipses in shape. They are believed to form from the merger of smaller galaxies. There are also irregular galaxies, which lack a distinct shape and are often influenced by gravitational interactions with other nearby galaxies. Understanding the formation of different galaxy types provides valuable insights into the diverse mechanisms that shape the universe's large-scale structures.

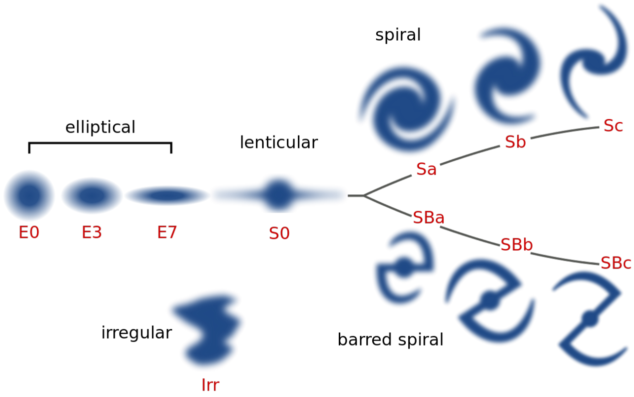

Figure 6. Diagram of the Hubble system of classifying galactic morphology. Courtesy of Wikimedia Commons `https://en.wikipedia.org/wiki/File:Hubble_classification_scheme.svg` (Public Domain).

3.2 Galaxy Evolution

One key aspect of NGC 1365's evolution is its metallicity gradient, as revealed by the work of Chen et al. 2022. Metallicity refers to the abundance of elements heavier than hydrogen and helium in a galaxy's stars, providing clues about its star formation history and chemical enrichment. By analysing the distribution of metals across NGC 1365, astronomers can trace the past interactions and mergers that have shaped its stellar population.

The knots observed along the central parts of NGC 1365's bar, as depicted in Figure 1, represent regions of intense star formation. The gravitational forces exerted by the bar funnel gas and dust towards its centre, triggering the formation of new stars in dense molecular clouds. This concentration of star formation activity highlights the dynamic nature of barred spiral galaxies and the role of internal structures in regulating stellar birth.

Moreover, the alignment of dust lanes with the bright spiral arms in NGC 1365 provides further insights into its evolutionary trajectory. Dust lanes consist of interstellar dust grains that absorb and scatter light, often appearing as dark streaks against the background of luminous stars. The proximity of dust lanes to spiral arms indicates regions of enhanced gas and dust density, where gravitational instabilities promote the formation of young, massive stars. Additionally, the presence of magnetic fields in NGC 1365, particularly near the dust lanes, suggests a complex interplay between magnetohydrodynamic processes and galactic dynamics.

3.3 Galaxy Clusters

NGC 1365, a celestial luminary within the Formax cluster, serves as a cosmic Rosetta Stone, unlocking the mysteries of the broader Formax supercluster. Its mesmerising barred spiral design and bustling star-forming regions offer astronomers a window into the intricate dance of galactic evolution within this bustling cosmic metropolis. Through meticulous analysis of NGC 1365's interactions with its galactic neighbours, we glean profound insights into the gravitational ballet and environmental symphony that orchestrate the dynamics of supercluster formation. Indeed, NGC 1365 emerges as a linchpin in our quest to decipher the cosmic narrative, illuminating the pathways of formation and evolution within the vast expanse of the Formax supercluster and beyond.

Comparative studies between the Formax cluster and our local galaxy cluster, the Laniakea cluster[13] (Figure 7), offers valuable insights into the diversity of cluster environments and their influence on galaxy evolution. While the Laniakea cluster exhibits a higher galaxy density and a greater prevalence of elliptical galaxies, the Formax cluster displays a more diverse population of galaxies, including both spiral and elliptical types.

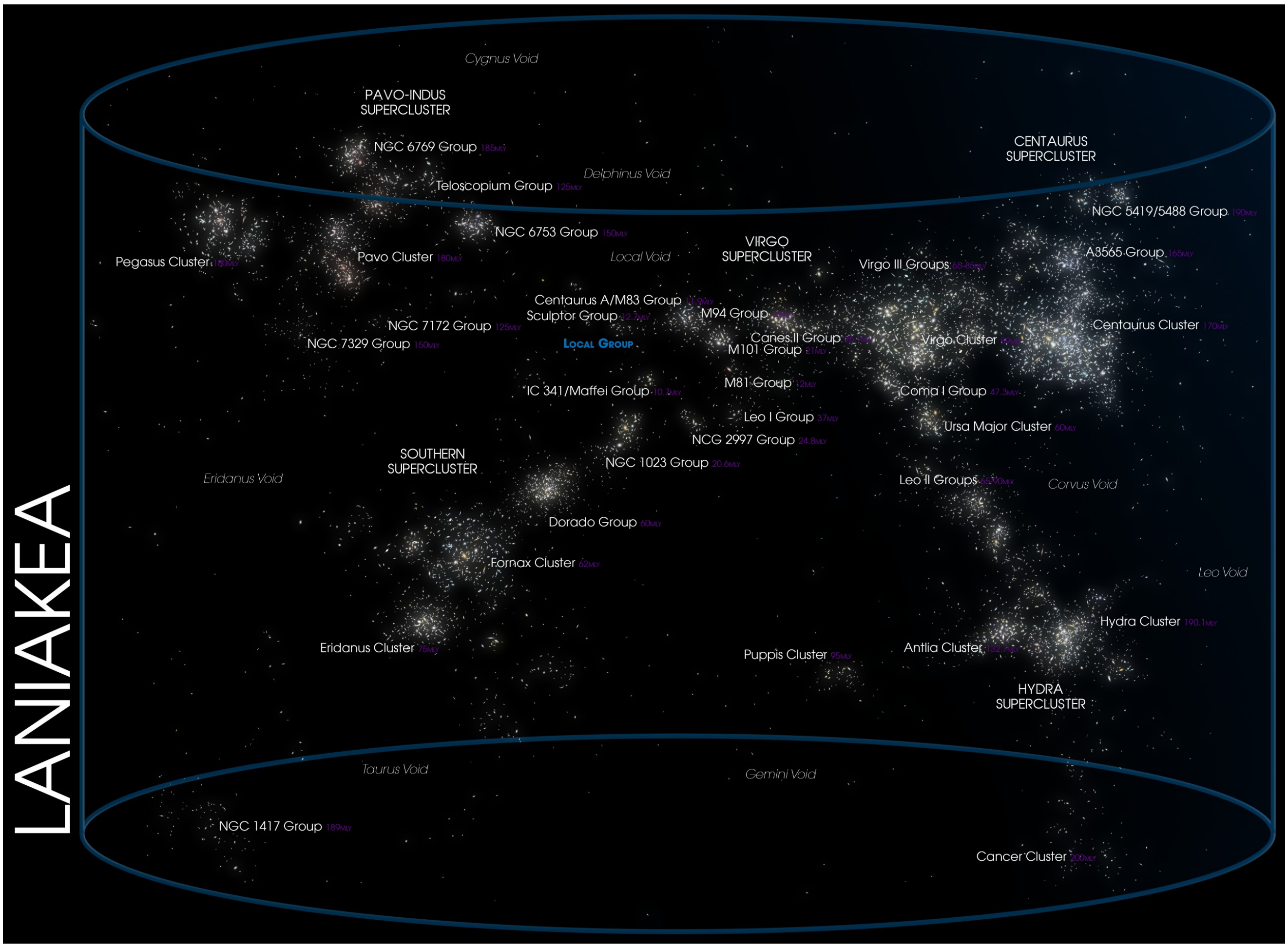

Figure 7. The Laniakea supercluster with many galaxy clusters. Acknowledgment: Andrew Z. Colvin. Courtesy of Wikipedia `https://en.wikipedia.org/wiki/Galaxy_cluster#/media/File:07-Laniakea_(LofE07240).png`.

The dominance of elliptical galaxies over spirals in the Laniakea supercluster stems from its dense environment, where frequent galaxy interactions and mergers occur. These interactions strip spiral galaxies of gas and dust, hindering their ability to form new stars through processes like ram pressure stripping. Additionally, galactic cannibalism leads to the growth of massive elliptical galaxies through the absorption of smaller companions. As a result, the Laniakea supercluster hosts a higher proportion of older elliptical galaxies compared to spirals, reflecting its advanced evolutionary stage and mature age within the cosmic landscape.

4 Closing Thoughts

In our cosmic voyage, we've navigated the celestial seas to behold the splendour of NGC 1365, a cosmic masterpiece within the Formax cluster. Its barred spiral grace and stellar nurseries evoke a sense of wonder, inviting us to ponder the mysteries of the universe. As we traverse the cosmic landscape, we've glimpsed the intricate dance of galaxy formation and evolution, unravelling the tapestry of cosmic history.

But our journey doesn't end here. The cosmos beckons us to continue our quest for knowledge, to embrace curiosity, and to engage in the wonders that await us. Let us not merely observe from afar, but actively seek out opportunities for exploration and discovery. Through conversations, online resources, and citizen science projects, we can delve deeper into the cosmos and uncover its hidden treasures.

As we bid farewell to NGC 1365, let us carry with us the spirit of curiosity and awe that it has ignited. For in the vast expanse of the cosmos, endless mysteries are waiting to be unveiled, and it is our privilege and duty to seek them out. So let us embark on this cosmic journey with fervour and enthusiasm, inspired by the wonders of NGC 1365 and fueled by our insatiable thirst for knowledge.

Notes

[1]One light-year (ly) is the unit of length that light travels in a Julian calendar at a speed of $c \approx 3 \times 10^8$ ms^{-1}.

[2]To be exact the Cretaceous period ended 66 million years ago, so the rocket wouldn't quite get there (Renne et al. 2013).

[3]Other objects include star clusters and nebulae. Dreyer 1888 contains the full catalogue when it was first published in 1888.

[4]2 trillion is the most recent estimate (Conselice et al. 2016) and evolving technology will possibly unlock more accurate approximations.

[5]A lenticular galaxy is a type of galaxy intermediate between an elliptical and a spiral galaxy.

[6]A type of black hole with a mass millions to billions of times that of the Sun, found at the centres of most galaxies. Supermassive black holes play a crucial role in galaxy formation and evolution and are believed to regulate the growth of galaxies through their gravitational influence.

[7]The JWST is equipped with a high-sensitivity camera and spectrograph on board the Mid-Infrared Instrument (MIRI) module. Its power far exceeds its predecessor, the Hubble Space Telescope. Infrared sensors cut through cosmic debris and allow JWST to capture the primordial light that has been redshifted to infrared wavelengths due to the Doppler Effect (Lemaitre 1979) that was undetectable by previous telescopes.

[8]JWST acquired pictures of galaxies at redshifts of $z \sim 9 - 15$ (Castellano et al. 2022). These represent the highest redshifts ever observed. The higher the redshift, the further back we look into the universe's history.

[9]The presence of supermassive black holes at the centre of nearly all galaxies can be only be explained by theories. This is still an active area of research. One of the more prominent theories credits central blackholes to the accretion of mass and the coalescence of smaller black holes during the galaxy's formation. As galaxies evolve, the central black hole grows in mass through more accretion of gas and stars, eventually becoming a supermassive black hole.

[10]Density wave theory suggests that the observed spiral structure is the manifestation of a density wave rather than a material configuration. According to Lin and Lau 1979 this theory proposes that the gravitational forces of the spiral arms cause matter to circulate between the arms, creating a self-supporting quasi-permanent spiral structure.

The spheroidal mass distribution of a galaxy makes it natural to describe in cylindrical coordinates (r, θ, z) where the z-axis holds rotational symmetry. Gravitational potential can thus be defined as

$$\psi(r, \theta, z, t) = \psi_0(r) + \psi_1(r) e^{i(\omega t - m\theta)}$$

and be calculated using

$$\psi_1(r) = -4G \int_0^\infty \frac{r'}{r + r'} \left(\int_0^{\pi/2} \frac{\cos 2mx}{\sqrt{1 - \zeta \cos^2 x}} \, dx \right) \times \sigma_1(r') \, dr',$$

where surface density is governed by $\sigma(r, \theta, t) = \sigma_0(r) + \sigma_1(r) e^{i(\omega t - m\theta)}$ and $\zeta = \frac{4rr'}{(r+r')^2}$.

[11]Newton's law of universal gravitation states that any two objects exert a gravitational force that attracts one another. This law is governed by

$$F = G \frac{m_1 m_2}{r^2}.$$

The most important relationship is that $F_g \propto 1/r^2$ where gravitational force becomes weaker the further two objects are from another.

[12]This process is known as thermonuclear fusion. Inside the hydrogen atom, past the outer electron shell, there exists the nucleus which contains a single proton. To break into this nuclear envelope and access that proton one needs to overcome the strong nuclear force, which is the strongest force in the universe. This is why it takes surface temperatures of 100 million Kelvin (15 million degrees Celsius) to achieve such a phenomenon.

[13]Earth's address recently changed from being in the Virgo supercluster to the newly established Laniakea supercluster (Gibney 2014) which is 100 times bigger than previously thought. Laniakea is Hawaiian for "immeasurable heaven".

Glossary

Doppler Effect The change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source. In astronomy, the Doppler Effect is used to determine the velocity of objects in space, such as stars and galaxies, based on the shift in their spectral lines.. 5

galaxy cluster A large, gravitationally bound system containing hundreds to thousands of galaxies, as well as dark matter and hot intergalactic gas. Galaxy clusters are the largest known structures in the universe and provide valuable insights into the formation and evolution of cosmic structures.. 1

lenticular galaxy A type of galaxy that exhibits characteristics of both spiral and elliptical galaxies, with a disc-like structure similar to spirals and a bulging central region like ellipticals. Lenticular galaxies are often found in galaxy clusters and are thought to form from the transformation of spiral galaxies through interactions and mergers.. 2

ram pressure stripping A process in which the interstellar gas of a galaxy is stripped away by the pressure exerted by a high-speed passage through a diffuse medium, such as the gas between galaxies in a cluster. Ram pressure stripping can remove gas from galaxies, inhibiting star formation and affecting their evolution.. 4

redshift An increase in the wavelength of light emitted by an object observed from Earth, caused by the object moving away from the observer. Redshift is commonly used to measure the distance to galaxies and the rate of expansion of the universe.. 5

thermonuclear fusion A nuclear reaction in which atomic nuclei combine to form heavier nuclei, releasing energy in the process. Thermonuclear fusion is the process by which stars, including the Sun, generate energy and heat, and is responsible for the synthesis of elements in the universe.. 5

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