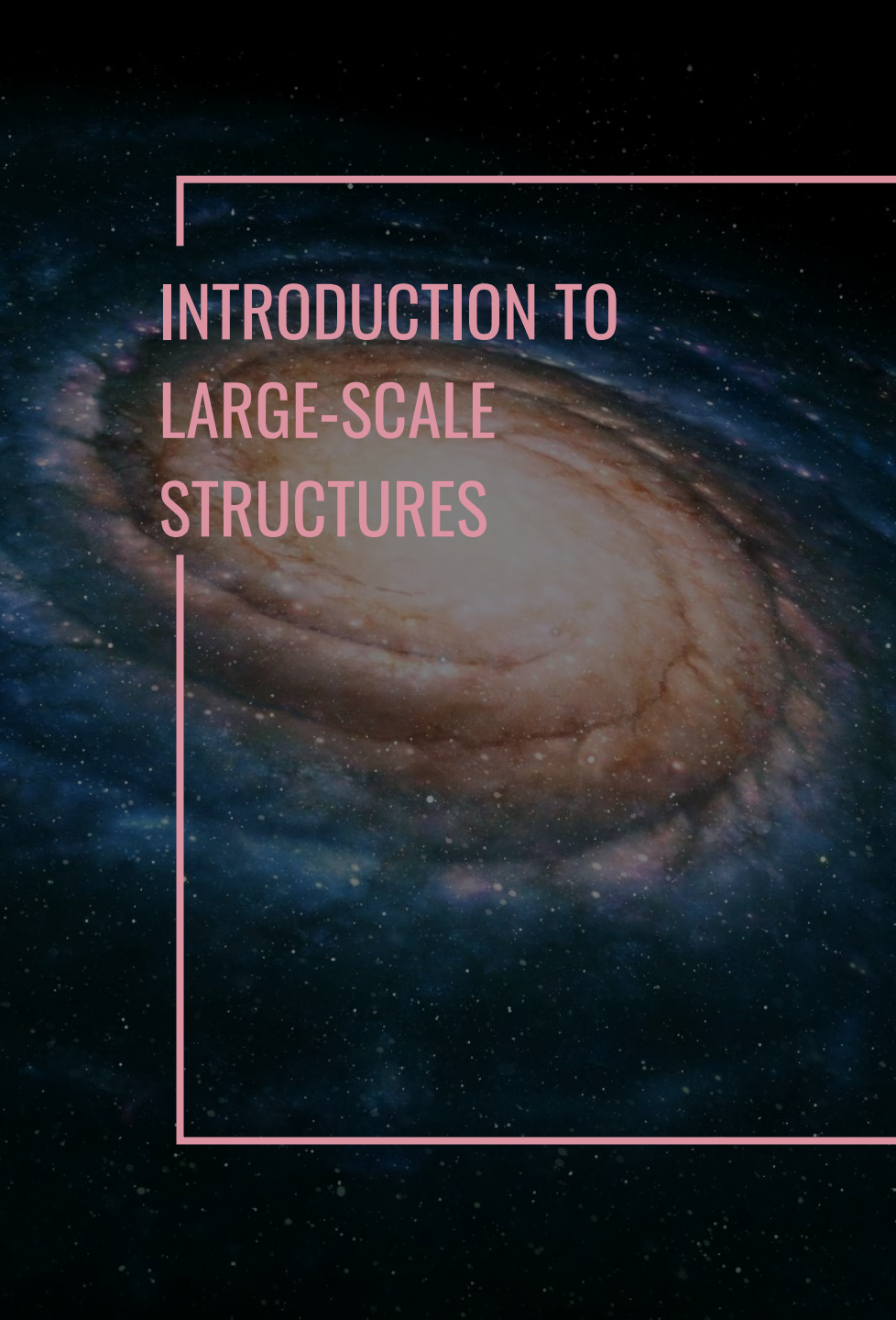


LARGE-SCALE VOIDS AND FILAMENTS IN THE UNIVERSE

Section 1.1 Overview



INTRODUCTION TO LARGE-SCALE STRUCTURES

The large-scale structure of the universe is composed of two dominant features: **voids** and **filaments**.

- **Voids:** These are vast, empty regions of space that contain very few or no galaxies. They are essential in the study of the universe because they provide insights into the distribution of matter and energy on cosmic scales.
- **Filaments:** Filaments are elongated chains of galaxies that form the “backbone” of the universe’s structure. These galaxies are gravitationally bound and form intricate web-like patterns that span the universe, known as the **cosmic web**.

The interaction between voids and filaments defines how matter is distributed in the universe and how cosmic structures evolve over time.

This presentation will explore both structures, their properties, and how they help us understand the formation and evolution of the universe.



WHAT ARE VOIDS?

- Voids are the largest empty spaces in the universe, characterized by a lack of galaxies and other forms of matter. These regions typically span tens of h^{-1} Mpc, which translates to about 30 to 100 million light-years.
- **Formation of Voids:** Voids form in regions where matter is sparse due to the gravitational pull of denser regions. As galaxies and matter are pulled toward denser filaments, voids become increasingly empty over time.
- **Cosmological Importance:** Voids are important because they allow us to study areas of the universe where gravitational interactions are minimal. This lack of interaction provides a clearer picture of galaxy formation and evolution in isolated environments. Additionally, the properties of voids, such as their size and distribution, are closely linked to cosmological parameters like dark matter, dark energy, and the universe's expansion rate.
- **Planck's Constant and Void Sizes:** The size of voids is often measured in h^{-1} Mpc, where h refers to the Hubble constant, a parameter related to the rate of expansion of the universe. This allows astronomers to relate the size of voids to the large-scale behavior of the universe.



PROPERTIES OF VOID GALAXIES

- Galaxies that reside within voids are typically isolated, meaning they experience very little gravitational influence from neighboring galaxies. This isolation affects their formation and evolution in significant ways.
- **Blue and Faint Galaxies:** Void galaxies tend to be blue in color, which indicates ongoing star formation. They are often faint and less massive than galaxies found in denser regions (such as galaxy clusters).
- **Late-Type Galaxies:** Most void galaxies belong to the late-type classification, including spiral galaxies and irregular galaxies. These galaxies often show signs of recent star formation due to the abundance of gas and lack of significant interactions with neighboring galaxies, which would otherwise disrupt this process.
- The properties of void galaxies allow astronomers to study how galaxies evolve in the absence of strong gravitational interactions. In contrast to galaxies in denser regions, which are subject to frequent mergers and interactions, void galaxies evolve more independently.



RED VS. BLUE GALAXIES IN VOIDS

- **Blue Galaxies in Voids:** Blue galaxies are dominant in voids and are characterized by active star formation. These galaxies are still in the process of creating new stars, which gives them their blue color, as young stars emit more blue light. The low-density environment in voids allows gas within these galaxies to remain available for star formation, as there are fewer interactions to strip this gas away.
- **Red Galaxies in Voids:** While blue galaxies are the majority, red quiescent galaxies also exist in voids, albeit in much lower densities. These galaxies have ceased or significantly slowed their star formation processes. Red galaxies in voids are often found within massive dark matter halos, which means they reside in relatively denser pockets within the otherwise empty voids.
- The process of star formation quenching in red galaxies involves the loss or exhaustion of cold gas, which is necessary for forming new stars. In voids, this quenching is thought to occur in massive dark matter halos, which prevent gas from cooling and condensing into stars. These red galaxies are older and no longer producing new stars, which is why they appear red.



VOID FINDER ALGORITHM

- **What is the Void Finder Algorithm?** The Void Finder Algorithm, developed by El-Ad & Piran (1997), is a widely-used tool in cosmology for identifying voids in the large-scale structure of the universe.
- **How It Works:** The algorithm classifies galaxies as either “void” galaxies or “wall” galaxies based on the number of neighboring galaxies they have within a defined radius. If a galaxy has three or fewer neighbors within this radius, it is classified as a void galaxy. This helps researchers pinpoint galaxies that exist in low-density regions, away from the dense walls of galaxies that form filaments.
- **Defining Voids:** Once void galaxies are identified, the algorithm defines an individual void as the largest sphere that contains only void galaxies. This allows astronomers to map out the size and shape of voids in the cosmic web.

A visualization of the cosmic web, showing a complex network of yellow and orange filaments and clusters of galaxies against a dark background. A pink rectangular frame is overlaid on the left side of the image, with the word 'FILAMENTS' in pink capital letters at the bottom left corner.

FILAMENTS

- Filaments are vast, elongated structures made up of galaxies, gas, and dark matter that connect galaxy clusters across the universe. They form the “cosmic web” and are the largest visible structures in the universe.
- **Size of Filaments:** Filaments typically span between 50 and 80 h^{-1} Mpc, making them hundreds of millions of light-years long. They stretch across the universe, forming interconnected pathways that link galaxy clusters and superclusters.
- **Role in Structure Formation:** Filaments play a key role in the formation and evolution of galaxies and galaxy clusters. Gravity causes matter to clump together along these filaments, leading to the formation of galaxies at their intersections, known as “nodes.”
- **Cosmic Web:** Filaments form the backbone of the cosmic web, with voids occupying the spaces between them. The interaction between these structures creates the large-scale pattern of the universe, influencing galaxy formation and the distribution of matter on cosmic scales.

A visualization of the cosmic web, showing a dense network of dark matter filaments in blue and purple, with bright orange and yellow spots representing galaxy clusters and individual galaxies.

FILAMENT PROPERTIES AND EVOLUTION

- **Length and Stability:** Research has shown that the lengths of filaments have remained relatively stable over time, with little change in the overall size and density of these structures over the last 7 billion years. This suggests that filaments are a long-lasting feature of the universe's large-scale structure.
- **Narrowing Width:** While filament lengths have stayed constant, their widths have narrowed. This narrowing is a result of the non-linear growth of cosmic structures, where matter continues to accumulate in denser regions (filaments) while voids expand. This compression leads to tighter, more defined filamentary structures over time.
- **Cosmic Evolution:** The evolution of filament widths and their stability over time offers important clues about the universe's expansion and the behavior of dark matter. As voids grow larger, filaments become more compressed, which influences the overall structure and distribution of galaxies.

A visualization of the cosmic web, showing a dense network of filaments and voids. The filaments are depicted as thin, interconnected lines of yellow and orange, while the voids are the large, dark purple spaces between them. The overall structure is complex and fractal-like, representing the large-scale distribution of matter in the universe.

VOIDS AND FILAMENTS TOGETHER

- **Dynamic Relationship:** Voids and filaments exist in a dynamic relationship, where the growth of one influences the behavior of the other. As voids expand due to the gravitational pull of matter into filaments, the filaments themselves become denser and narrower.
- **Voids Push Filaments Closer:** The expansion of voids pushes galaxies and matter into the filaments, causing the filaments to grow denser over time. This relationship is key to understanding the large-scale structure of the universe, as voids define the empty spaces between the cosmic web's dense filaments.
- **Cosmic Web as a Whole:** Together, voids and filaments form the cosmic web, the large-scale pattern of matter in the universe. The interplay between these two structures helps astronomers understand how galaxies are distributed and how the universe has evolved since the Big Bang.



CONCLUSION

- **Summary of Key Points:**
 - **Voids:** Vast empty regions in the universe that allow for the study of galaxy evolution in low-density environments.
 - **Filaments:** The largest structures in the universe, connecting galaxies and forming the cosmic web.
 - **Interdependence:** Voids and filaments shape the distribution of matter on cosmic scales, with voids expanding and pushing matter into filaments, leading to the formation of galaxies and galaxy clusters.
- **Importance of Studying Voids and Filaments:** Studying these structures provides important insights into the universe's large-scale behavior, the influence of dark matter, and the evolution of galaxies in different environments.
- **Looking Forward:** Future research into voids and filaments will continue to deepen our understanding of the universe, particularly regarding dark matter, cosmic expansion, and the processes that govern galaxy formation on the largest scales.
- Kahoot:
<https://create.kahoot.it/details/211d17f8-0458-4897-9b2a-2647209531bd>