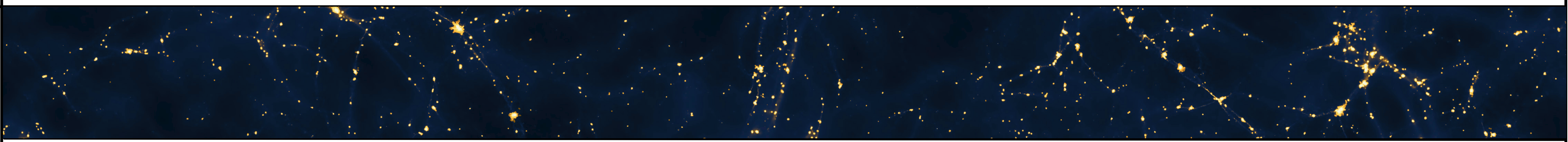
TRACING THE COSMIC WEB

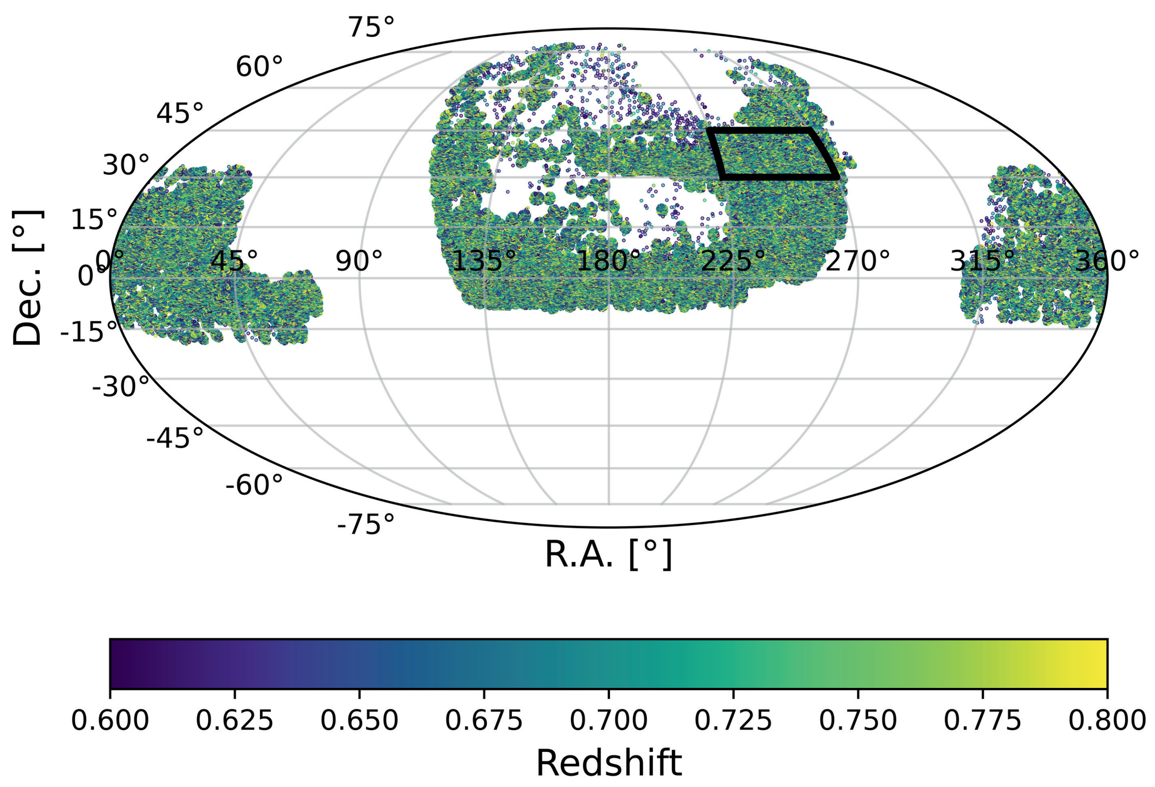
A percolation analysis of the Large-Scale structure of the Universe

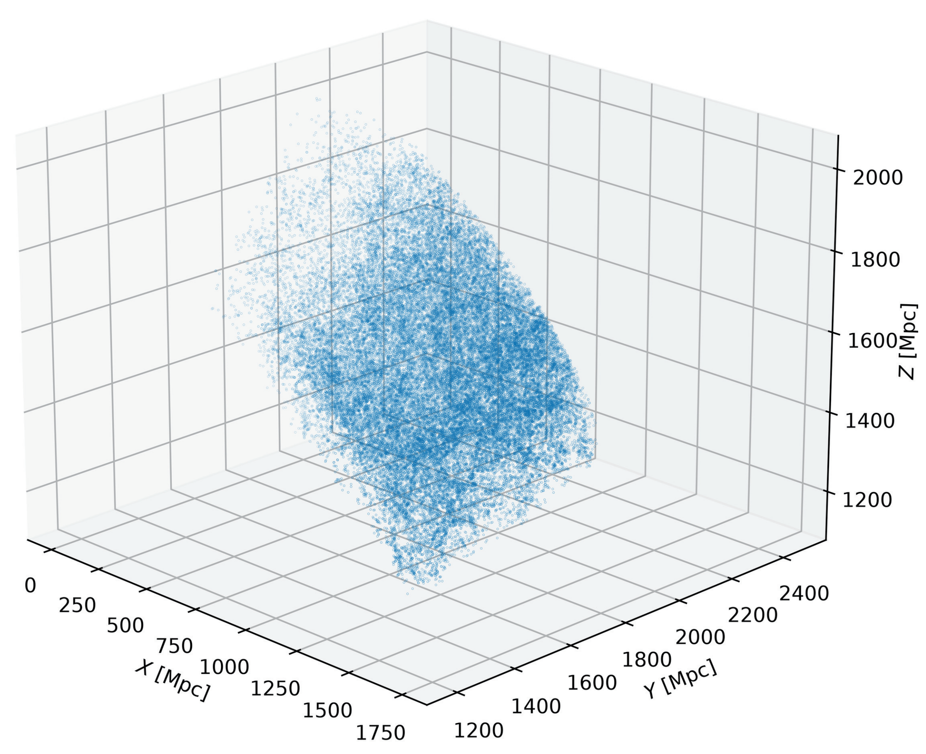
On large scales, the **distribution of matter** in the Universe exhibits a local **non-uniform organization**, resulting in the formation of galaxy aggregations across various scales. These galaxies tend to align into a **cosmic network** of **filaments** and **dense nodes**. This pattern primarily originates from initial density fluctuations following the Big Bang, which led overdense regions to gravitationally attract surrounding matter. This is what we call the cosmic web, or **Large-Scale structure** of the universe.



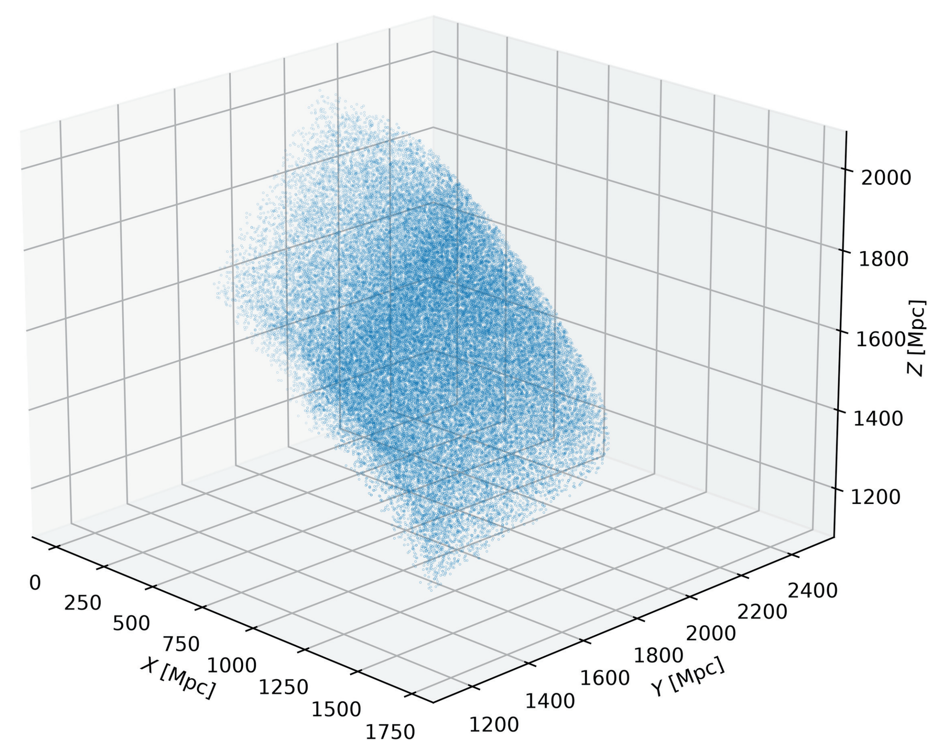
TARGET SELECTION

We utilise data from the **Dark Energy Spectroscopic Instrument** (DESI) Data Release 1 - a spectroscopic survey designed to map the expansion history of the Universe. From this catalog, we extract a sample of **53,592 Luminous Red Galaxies** spanning a specific footprint on the sky within the redshift range *0.6 < z < 0.8*. A synthetic **control sample** with an identical volume, geometry, and number density is generated using a **uniform distribution**.





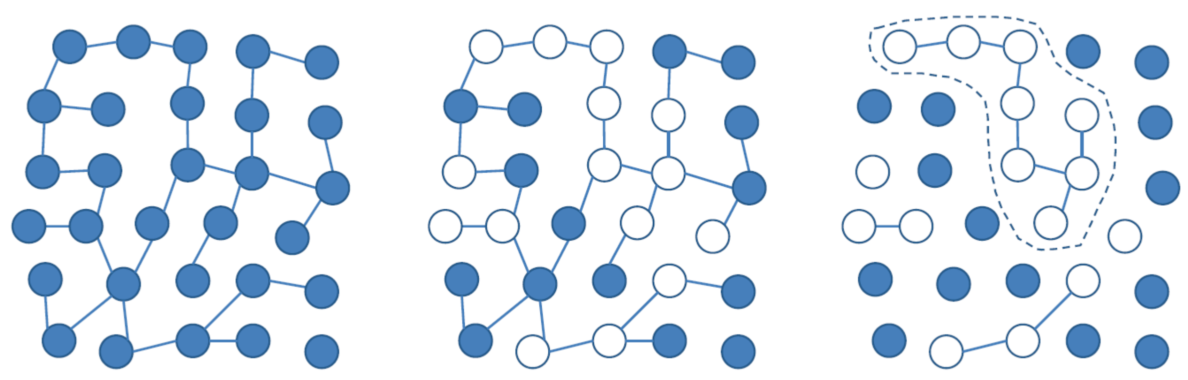
DESI Catalog



Random Uniform

PERCOLATION ANALYSIS

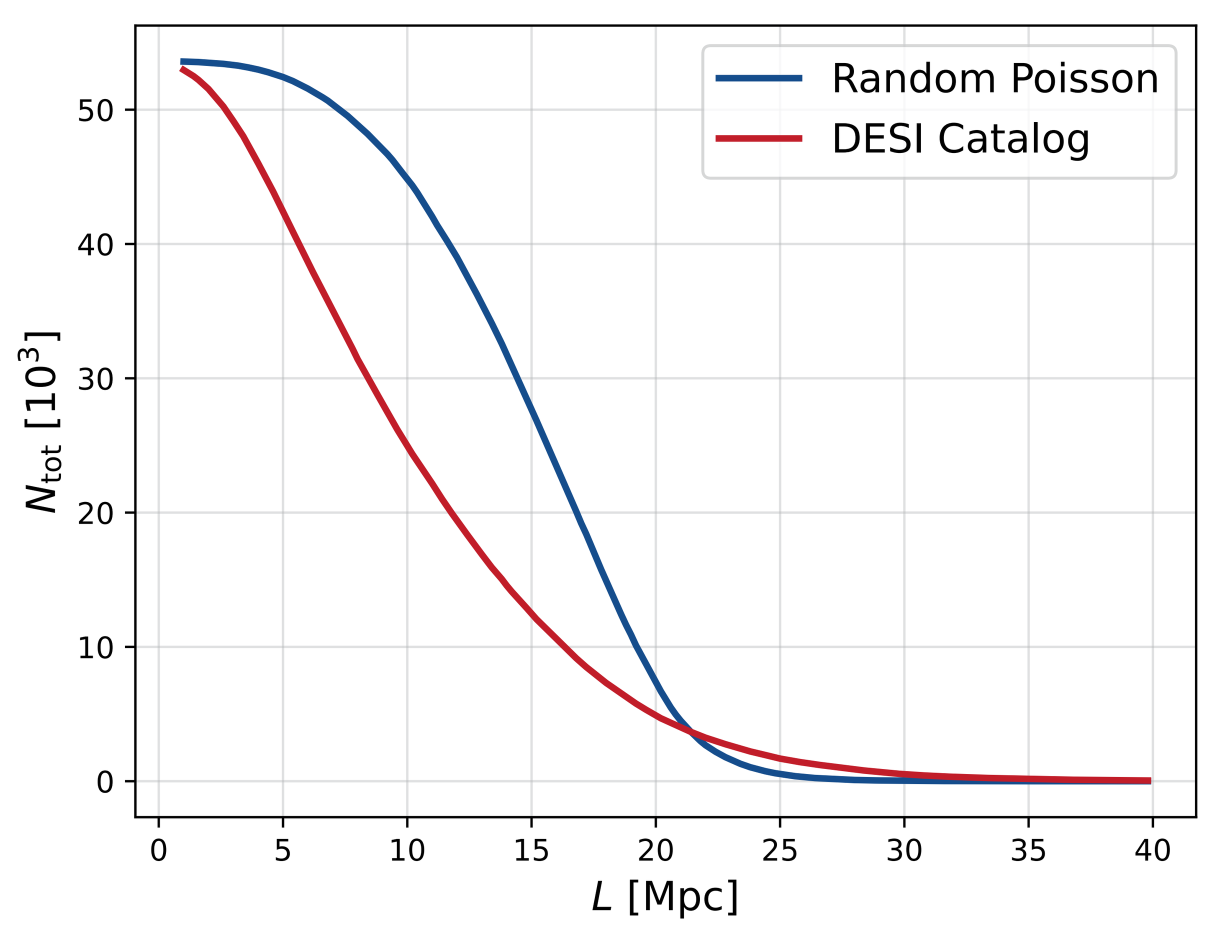
A **cluster** is defined as a **connected network** of galaxies where every member is linked to at least one other by a distance $d \leqslant L$, ensuring a continuous path exists between any two galaxies in the group.



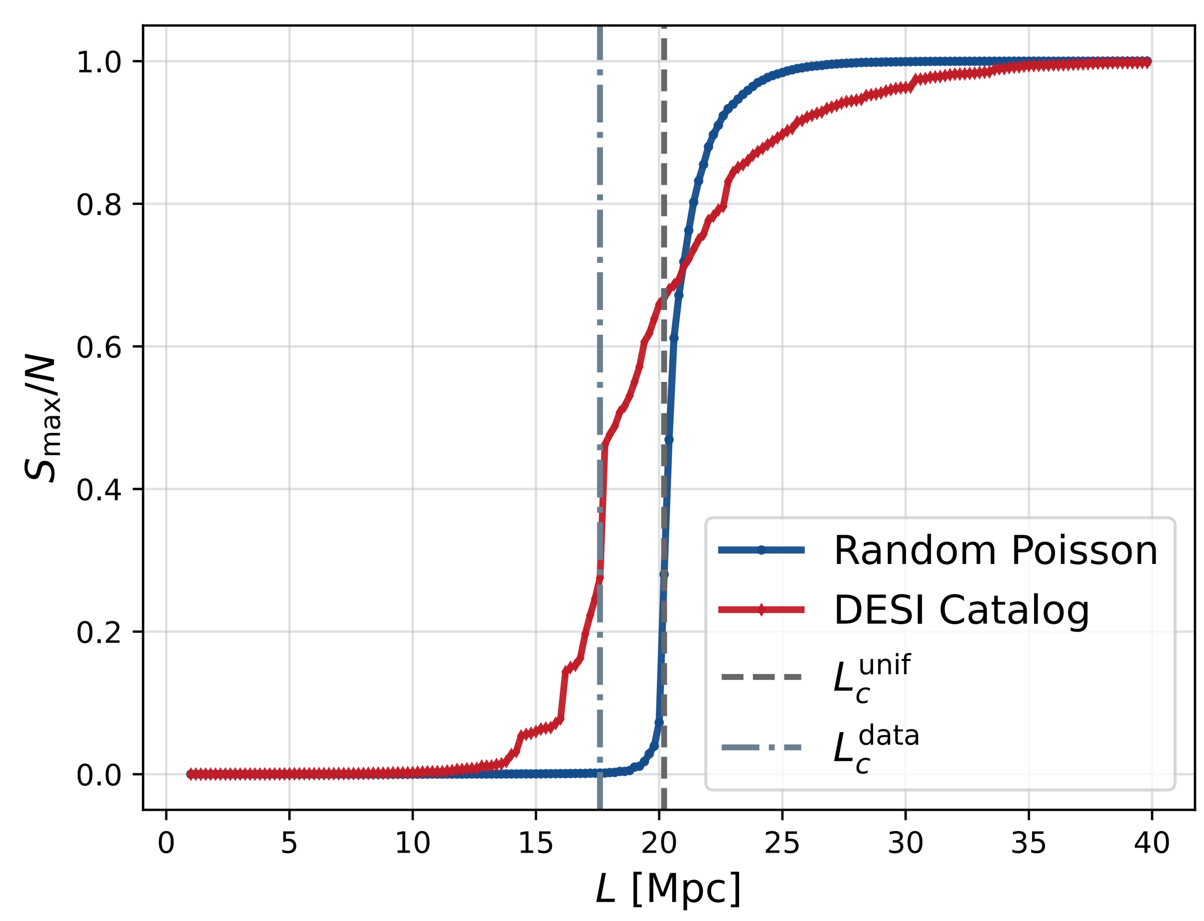
As the linking length L increases, smaller isolated clusters **merge** into larger structures until reaching a **critical threshold**, where a single, space-spanning network forms across the volume.

RESULTS

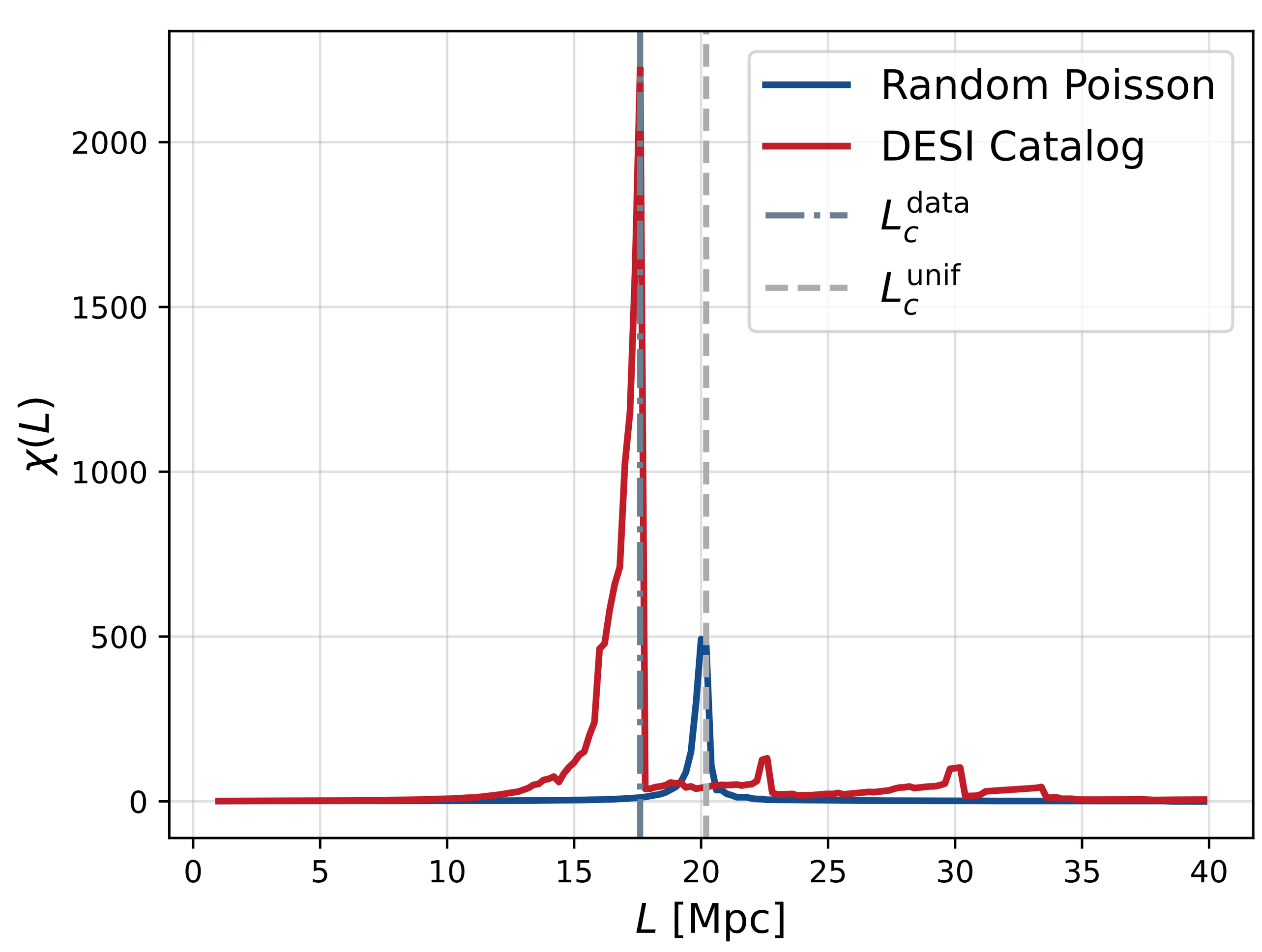
The **fraction of galaxies** in the biggest cluster is the quantitative tracker we use to determine when the phase transition happens. The **critical length** at which the phase transition happens is **bigger** for the **simulated dataset** than for the DESI data. This indicates **real Universe** is much **more clustered** than a purely random distribution.



Total number of clusters



Fraction of galaxies in the bigger cluster



Susceptibility can be seen as a **measure** of the **fluctuations** of the average cluster size within all existing clusters, excepted the largest one.

The average size is one order of magnitude **greater** for the **DESI catalog** at **critical lenght**.

Furthermore, the DESI catalog exhibits secondary susceptibility peaks at higher connection lengths, representing the merging of distinct sub-networks.

CONCLUSION

This research demonstrates how tools borrowed from statistical physics can help treat **galaxies** as a **complex**, interconnected **sub-system** of the Universe. The percolation metrics reveal that DESI galaxies reach global **connectivity** at a significantly **smaller linking scale** than a random field, while the distinct susceptibility features suggest a galaxy distribution consistent with a structured and **clustered network**. Extending this framework to denser galaxy populations will be vital for capturing the fainter, low-density filaments of the cosmic web.

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