

Questions on Galaxies and Cosmology

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Presentation of some of the research of the future “Galaxies and Cosmology” team of the LUX, “Laboratoire d’étude de l’Univers et des phénomènes eXtrêmes”

Very general questions:

- How does the Universe evolve?
- How do galaxies evolve?

In particular:

- How can one test cosmological models?
- How does dark energy work?
- How did reionisation occur?
- How can one explain statistics in properties of galaxies?
- What controls star formation in galaxies?
- How do supermassive black-holes (SMBH) and galaxies co-evolve?
- ...

How do the Universe and galaxies evolve?

Current cosmological paradigm based on cosmological principle + General Relativity.

Expansion (responsible for redshift) and its acceleration deduced from observations.

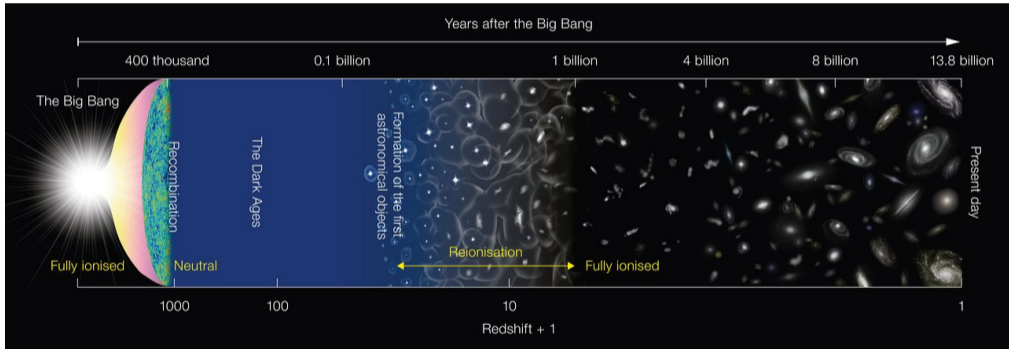


Figure: History of the Universe in the current cosmological paradigm. Credits: NAOJ.

How do the Universe and galaxies evolve?

Variety of galaxies in sizes, masses, morphologies, etc.

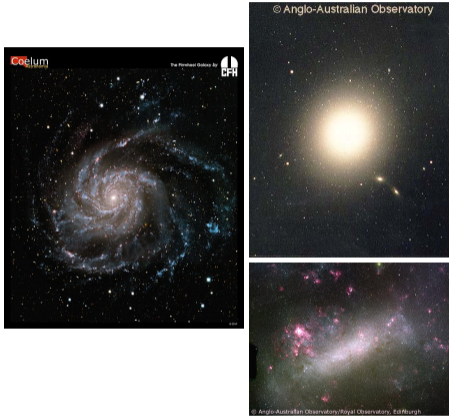


Figure: Left: a spiral galaxy (M101), top right: an elliptical galaxy, bottom right: an irregular galaxy (LMC).

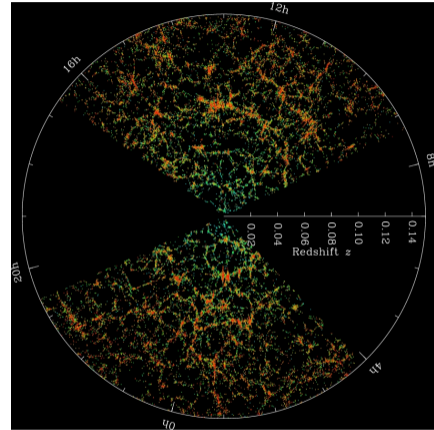


Figure: Galaxies (each point) in the SDSS survey, colored by stellar age.

Change in properties with environment, with redshift. New observations e.g. with **JWST**.

How do the Universe and galaxies evolve?

Observations point to contributions of **dark matter** (gravitational effect) and **dark energy** (acceleration of expansion).

What are these dark components? Is the standard Λ CDM the (only) solution?

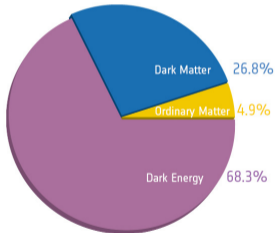


Figure: Matter-energy content of the Universe from Planck.

What controls observed **characteristics of galaxies** (colours, sizes, masses, morphologies, ...) across cosmic time? What controls **star formation**?

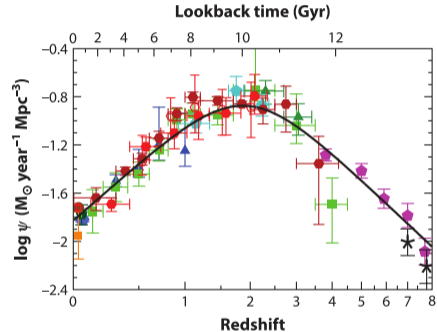


Figure: History of star-formation, Madau and Dickinson, 2014.

How to constrain cosmology?

Very large-scale and high-resolution simulations of dark matter evolving in universes with **different forms of dark energy**.

Study of **impact of cosmology** on structure growth, internal structure of dark matter haloes.

Computation of precise **relativistic effects**.

Aim: comparison of simulations and observations to constrain cosmology.

Foreseen input of **Euclid** : large-field optical+NIR space telescope which provides statistics on the matter distribution.

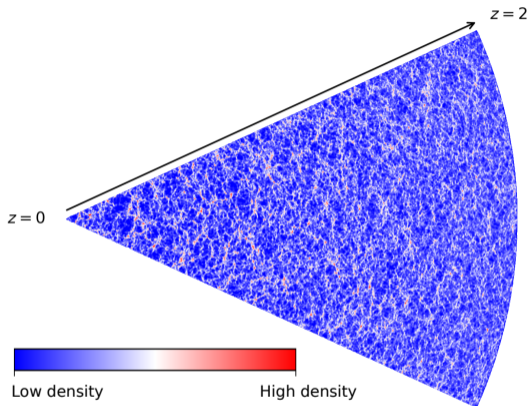


Figure: Light-cone from RayGal simulation, of $(2625 h^{-1} \text{ Mpc})^3$ volume with 4096³ particles, computed with inclusion of relativistic effects. Rasera et al 2022.

How to constrain cosmology?

Study of various **tools and diagnostics for cosmology**: e.g. use of “**sparsity**” of dark-matter haloes of galaxy clusters to probe the imprint of cosmology on DM haloes mass profiles and constrain cosmology with observations.

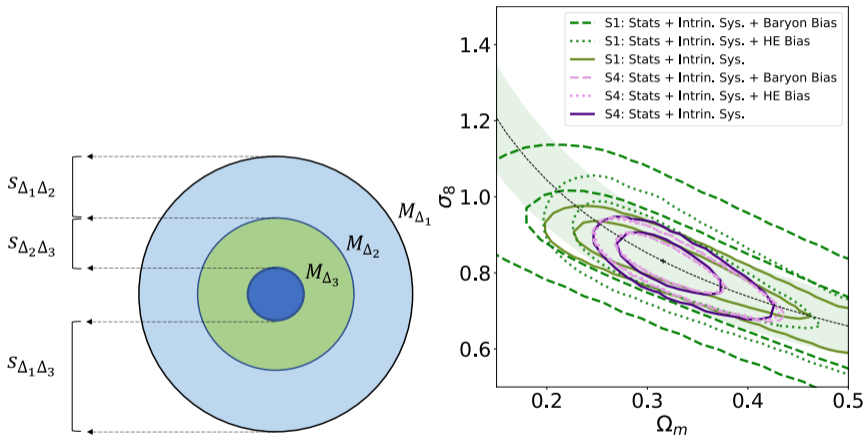


Figure: Use of sparsity s , with e.g. $s_{\Delta_1,\Delta_2} = M_{\Delta_1}/M_{\Delta_2}$ to constrain cosmological parameters. Corasaniti et al 2022.

How did reionisation occur?

Focus on the **Epoch of Reionisation (EoR)** and **cosmic dawn** (before EoR) in the context of study/preparation of observations by **SKA** and other radio-telescopes of the **21 cm signal of neutral hydrogen**.

- **Processing of radio observations:** deconvolution, foreground removal, ...
- Large-volume numerical simulations with **Licorice** code + machine learning to **constrain astrophysical parameters** of the EoR.

Study of **high-redshift galaxies** (esp. at the EoR) in high-resolution simulations.

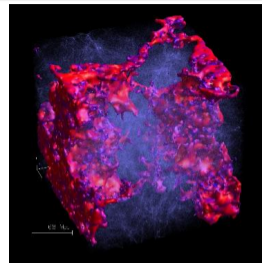


Figure: Simulated box with ionized parts in blue, Semelin.

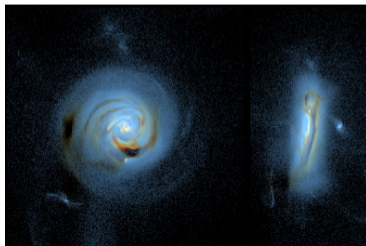


Figure: Mock image of a galaxy at $z = 6$ (with dust in brown), Trebitsch et al 2021

What affects the evolution of galaxies until low redshift?

Study of **physics of galaxies**.

Respective influence of **secular evolution**,
mergers, **environment**, **AGN** on galaxy properties?

Physics of groups and **(proto-)clusters**?

Models, **simulations**, sometimes with alternative
DM or gravity.

Observations at various wavelengths. **Molecular
gas** studied with IRAM telescopes and ALMA: SF
efficiency, galactic dynamics.

Identification of galaxies by **machine-learning**.

Future input in study of galaxies from VLT and ELT
instruments **MOONS** and **MOSAIC**.

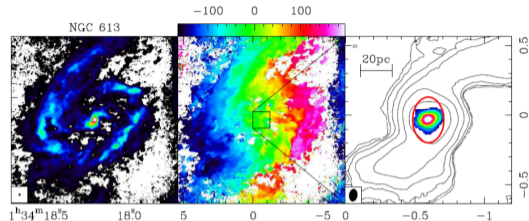


Figure: Molecular gas around SMBH: density, velocity and zoom (density). Combes et al 2019.

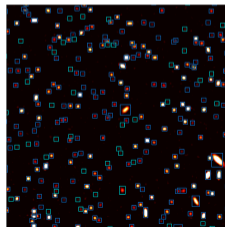


Figure: Sources (in boxes) detected by machine-learning, Cornu et al 2024.

Questions on Galaxies and Cosmology

The LUX “Galaxies and Cosmology” team has expertise to answer lots of questions on the evolution of the Universe and galaxies.

Context of increasing amount of data from telescopes (SKA, Euclid, JWST, ...) and numerical simulations.

Various methodologies to approach problems: theory, simulations, machine-learning.

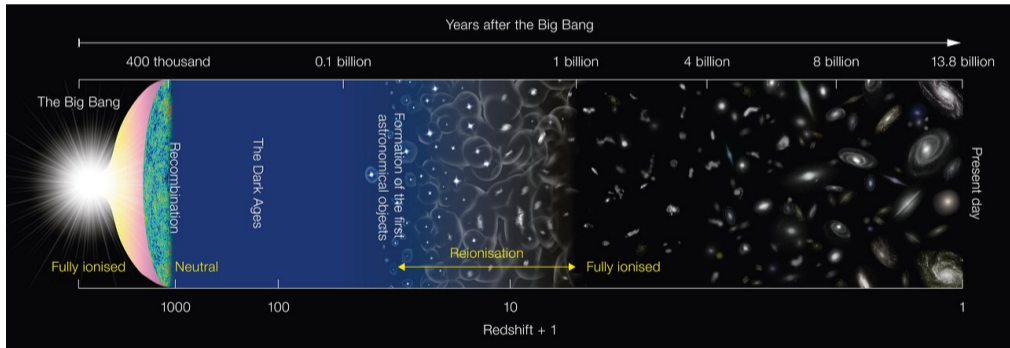


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