EPFL

Laboratory of Astrophysics

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https://www.epfl.ch/labs/lastro/

TP IV @ LASTRO

In **two** steps over the two semesters

1. Learn the specific tools of astrophysics on a set of prepared exercises
2. Apply this knowledge to real research projects

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Register to IS-Academia NOW
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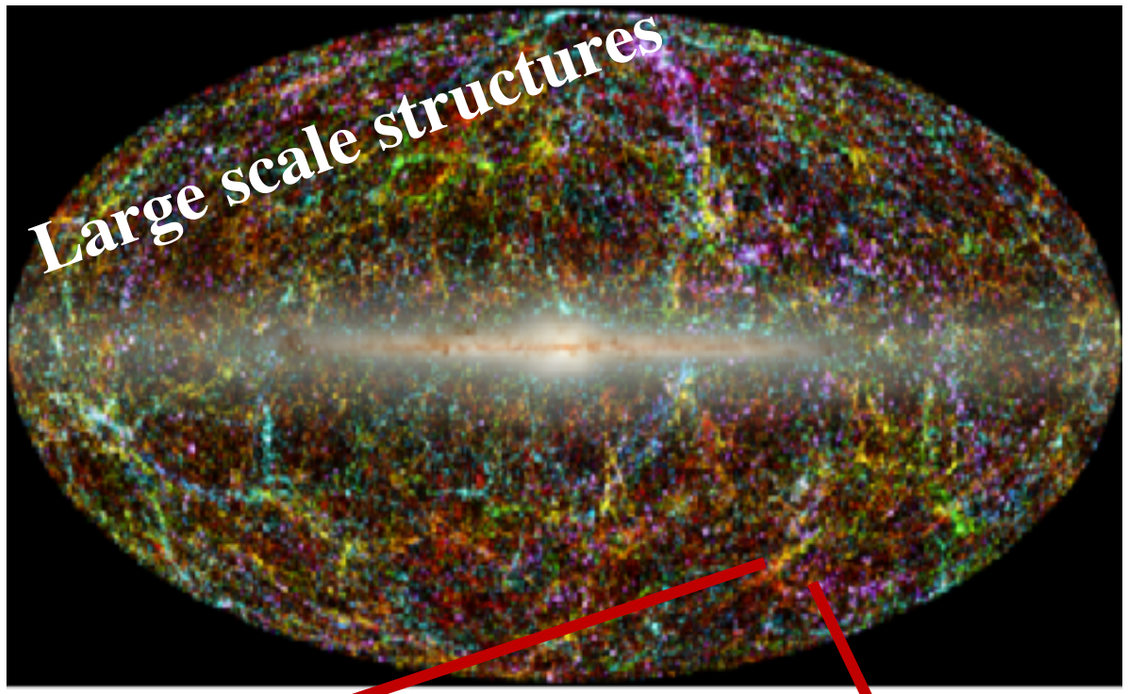
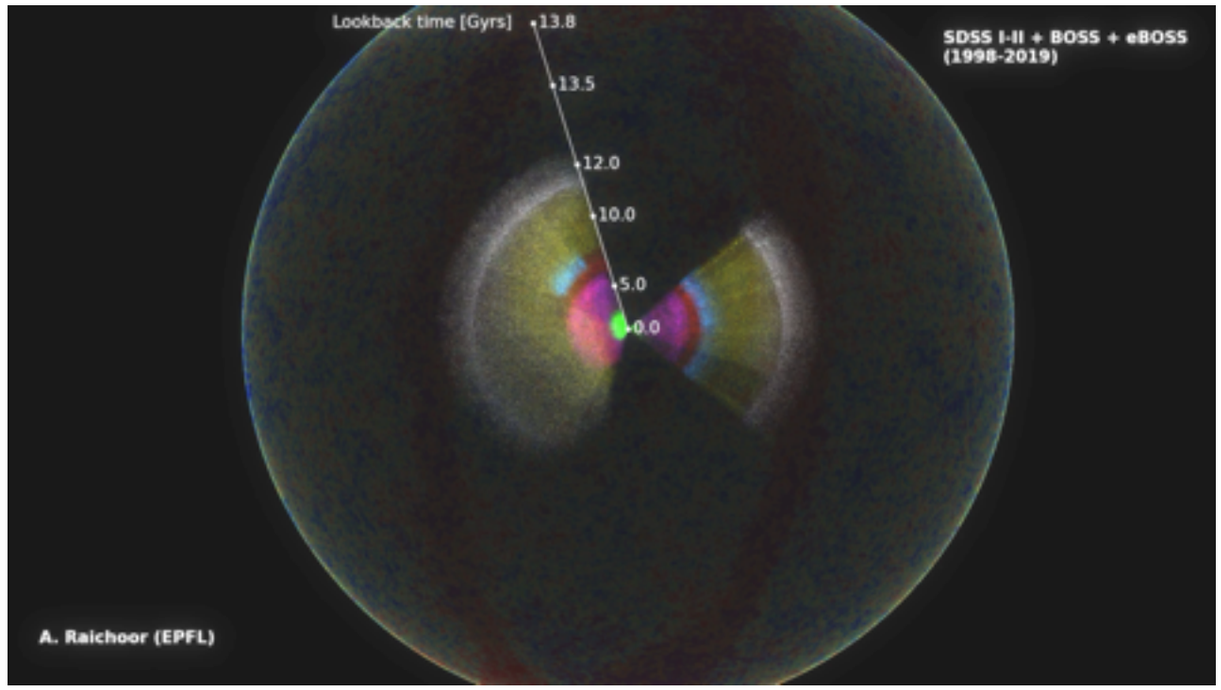
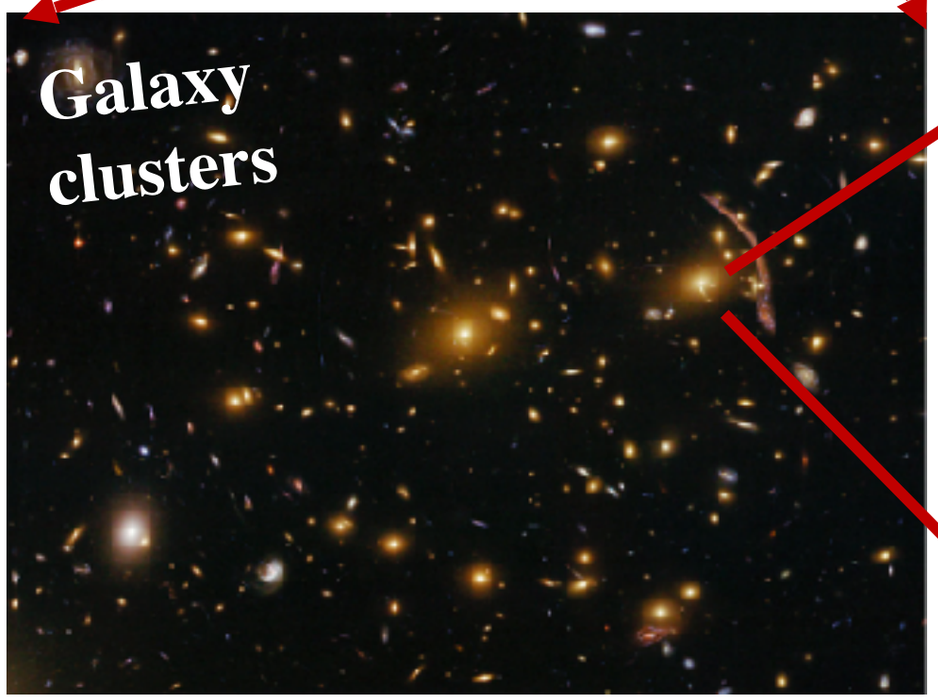
Astrophysics is the study of our Universe as a whole and its components at all scales



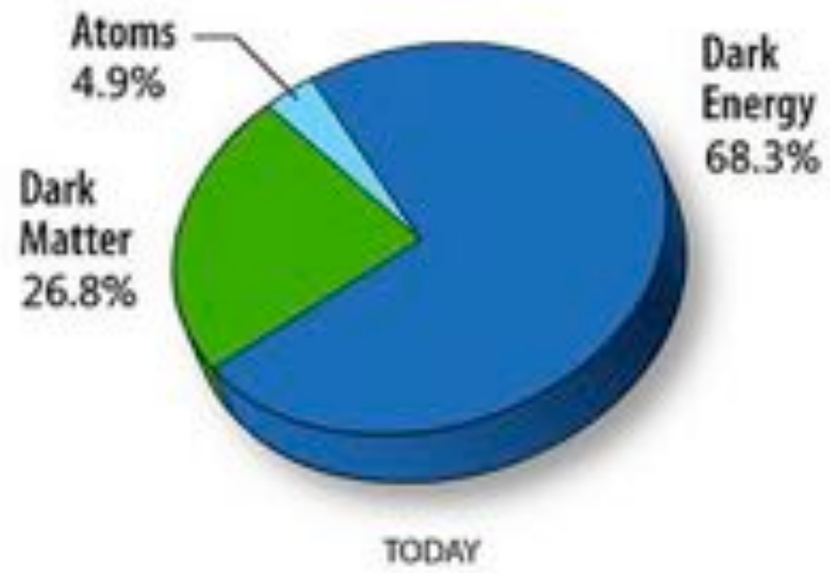


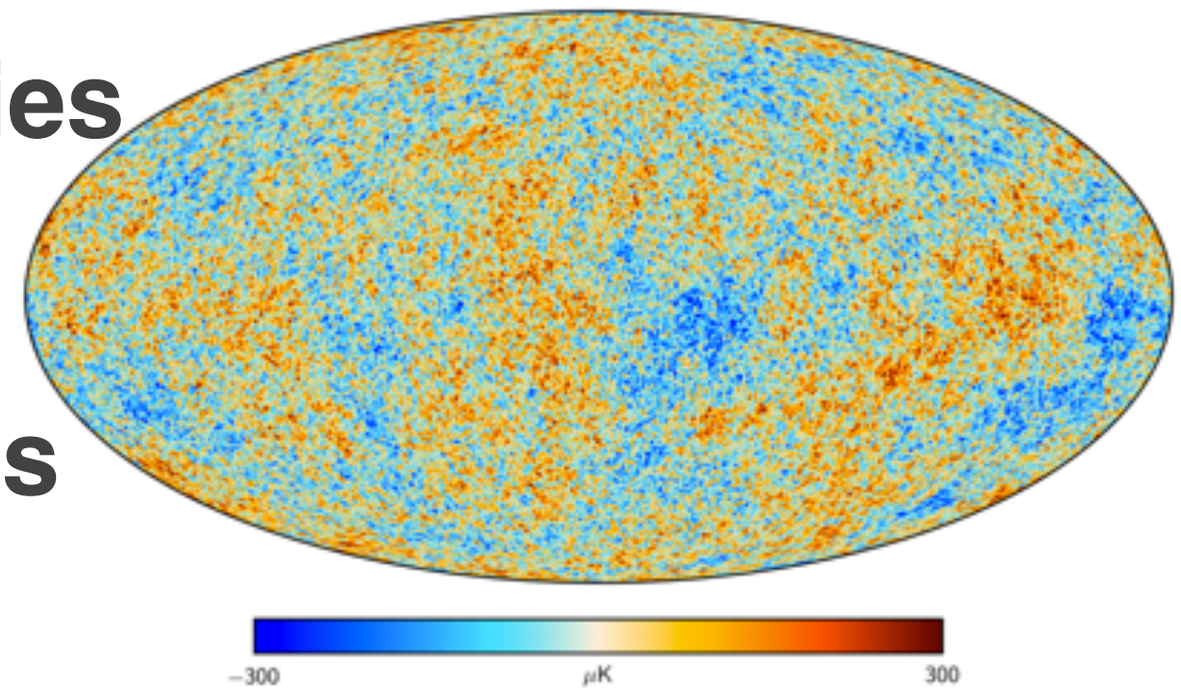


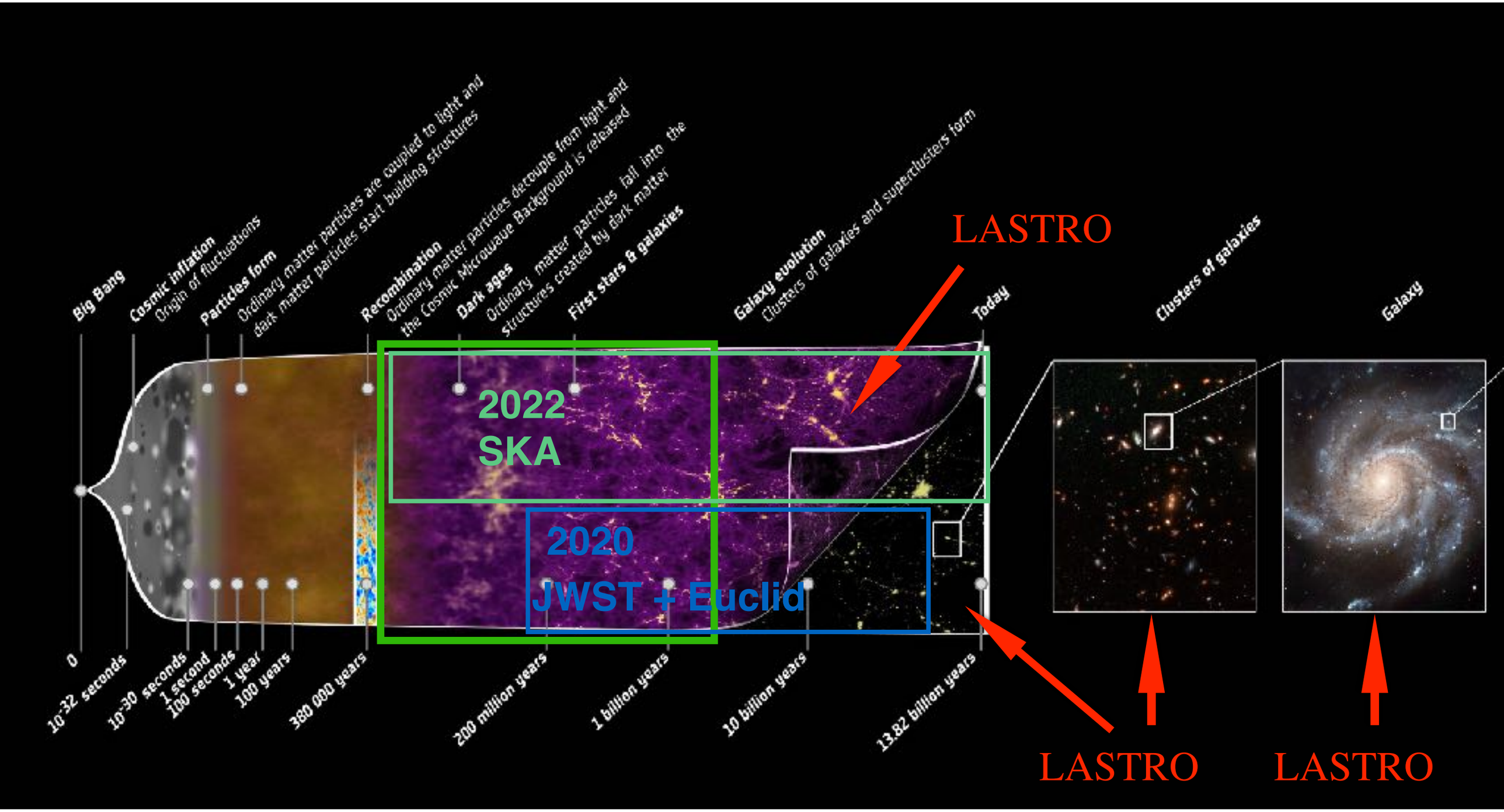
but also … planets, dust, gas, etc …

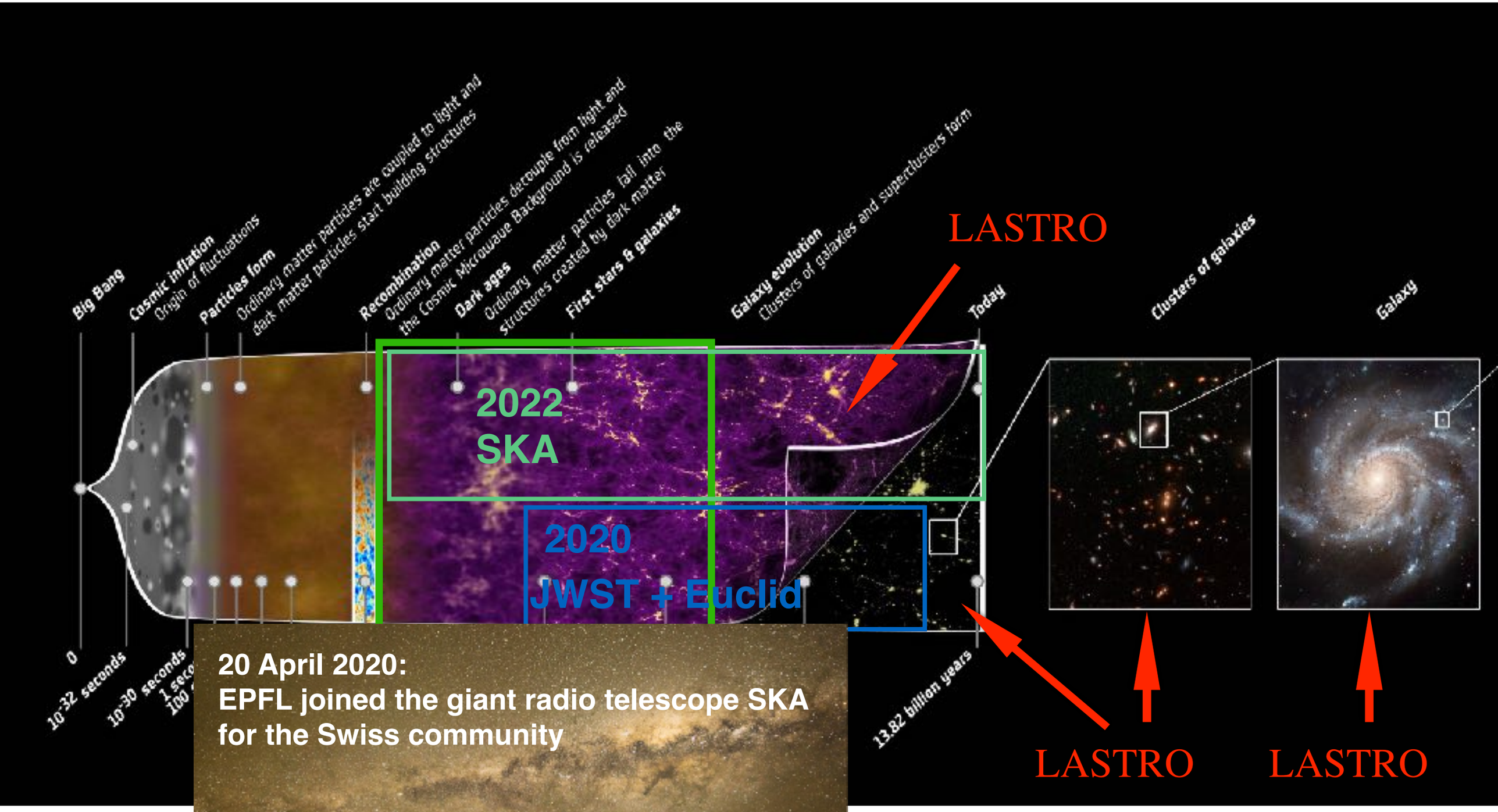
Open Questions

- **Expansion rate of the Universe**
- **Dark Energy**
- **Dark Matter**
- **First Stars, First Galaxies**
- **Coevolution of Large Structures and Galaxies**



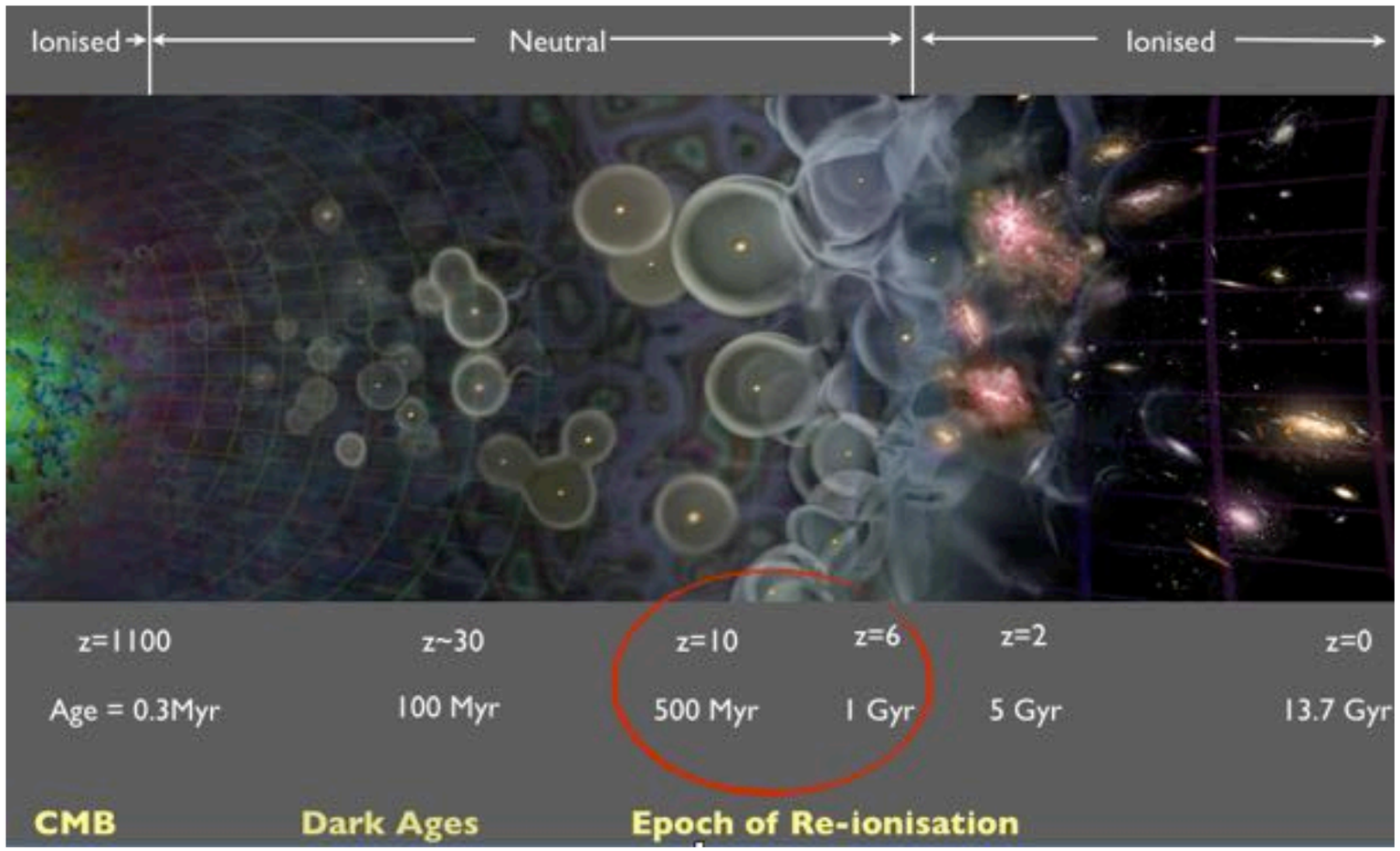


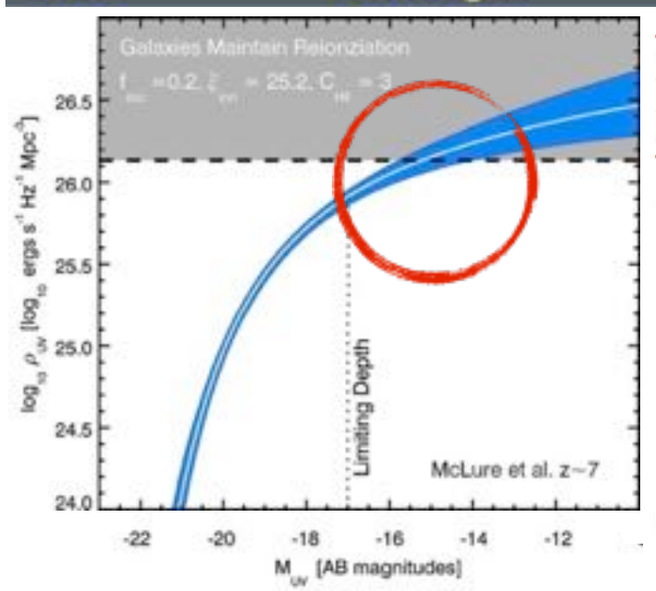

LASTRO
Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
Clusters of galaxies
Galaxy
2022
SKA
2020
JWST + Euclid
0
10^-32 seconds
10^-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years
LASTRO
LASTRO



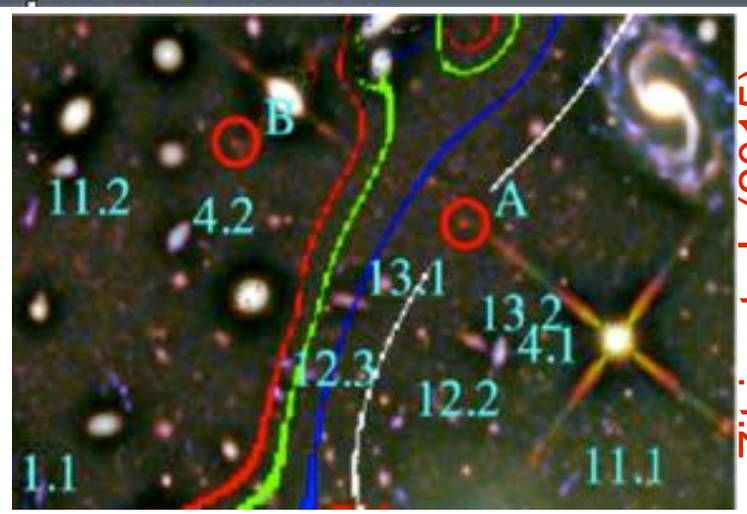
20 April 2020:
EPFL joined the giant radio telescope SKA for the Swiss community

First Stars , First Galaxies ?





Robertson et al. (2013)

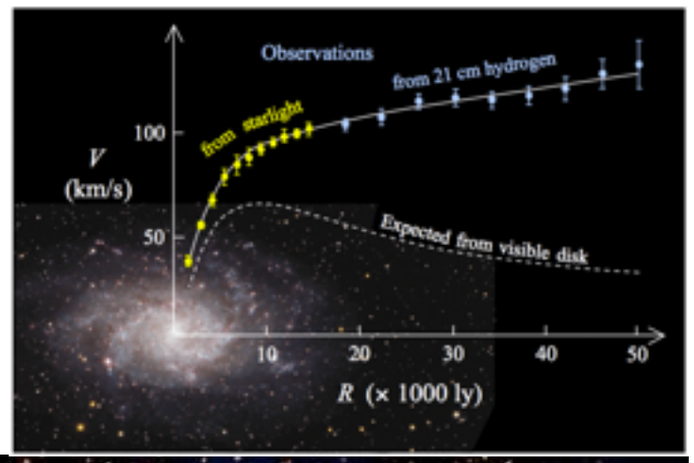


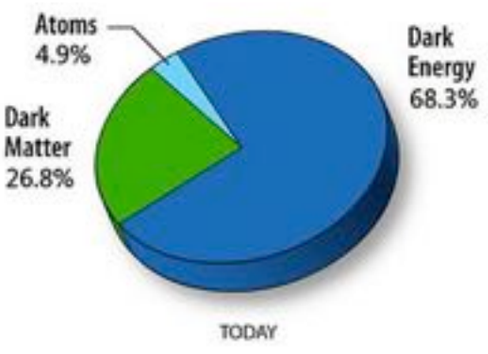
Zitrin et al. (2015)

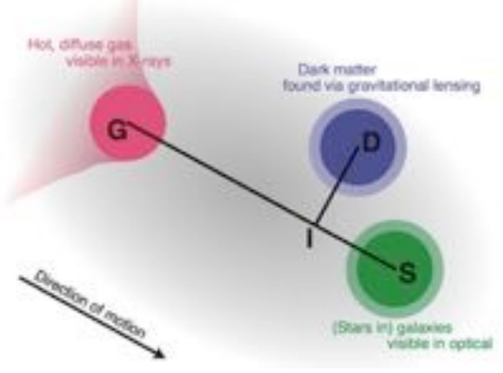
z~9.8 lensed pair

- Universe was dark & neutral = **Dark Ages.**
- Universe is now bright and ionized.
- **When re-ionization started?**
- **What are the sources of re-ionization?**
- **How different are the properties of the first systems from what we know?**
- *Strong UV radiation from the first galaxies and quasars are likely responsible.*
- **Future powerful radio observation (SKA) will also help probing re-ionization epoch by mapping the Hydrogen 21 cm line at z~7**

Dark Matter ?

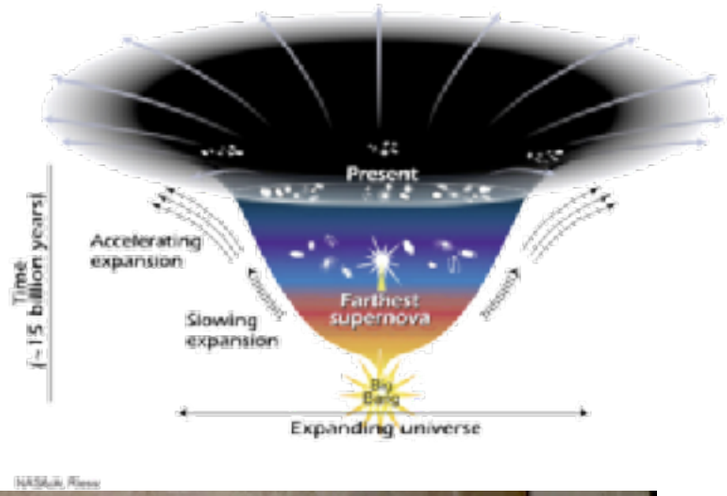






- **~1930**: First evidence by Zwicky studying galaxy velocities in the Coma cluster.
- **~1970**: Velocity curves of Spiral Galaxies => **Missing/Dark Matter**.
- **1987:** Discovery of giant arcs: cluster lensing requires dark matter.
- **1996:** Bullet cluster: **Separating Dark Matter and Baryons** => Limit on the interaction cross-section.
- **Probe nature of DM? Self Interacting?**
  - **use galaxy clusters as DM laboratories!**
  - **use dwarf galaxies as testbed**

Dark Energy ?



2011: Physics Nobel Prize

- **1930:** E. Hubble first measure the Universe expansion.

$$\frac{H^2}{H_0^2} = \Omega_R a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda$$

- **1990:** Key project of the *Hubble Space Telescope:* measuring H_0 with high precision (today known at ~1-2%).
- **1998-2003:** CMB favor a flat Universe.
- **1999:** Supernovae Type Ia confirmed accelerated expansion => Nobel Prize (2011).
- **2000: Dark Energy** (DE) concept put forward to explain Accelerated expansion.
- **What is the nature of DE? new component? or is Gravitation different on large scale? Fractal Geometry???**

Open Questions

Addressed by new observations,
new techniques of analysis,
and new technologies.

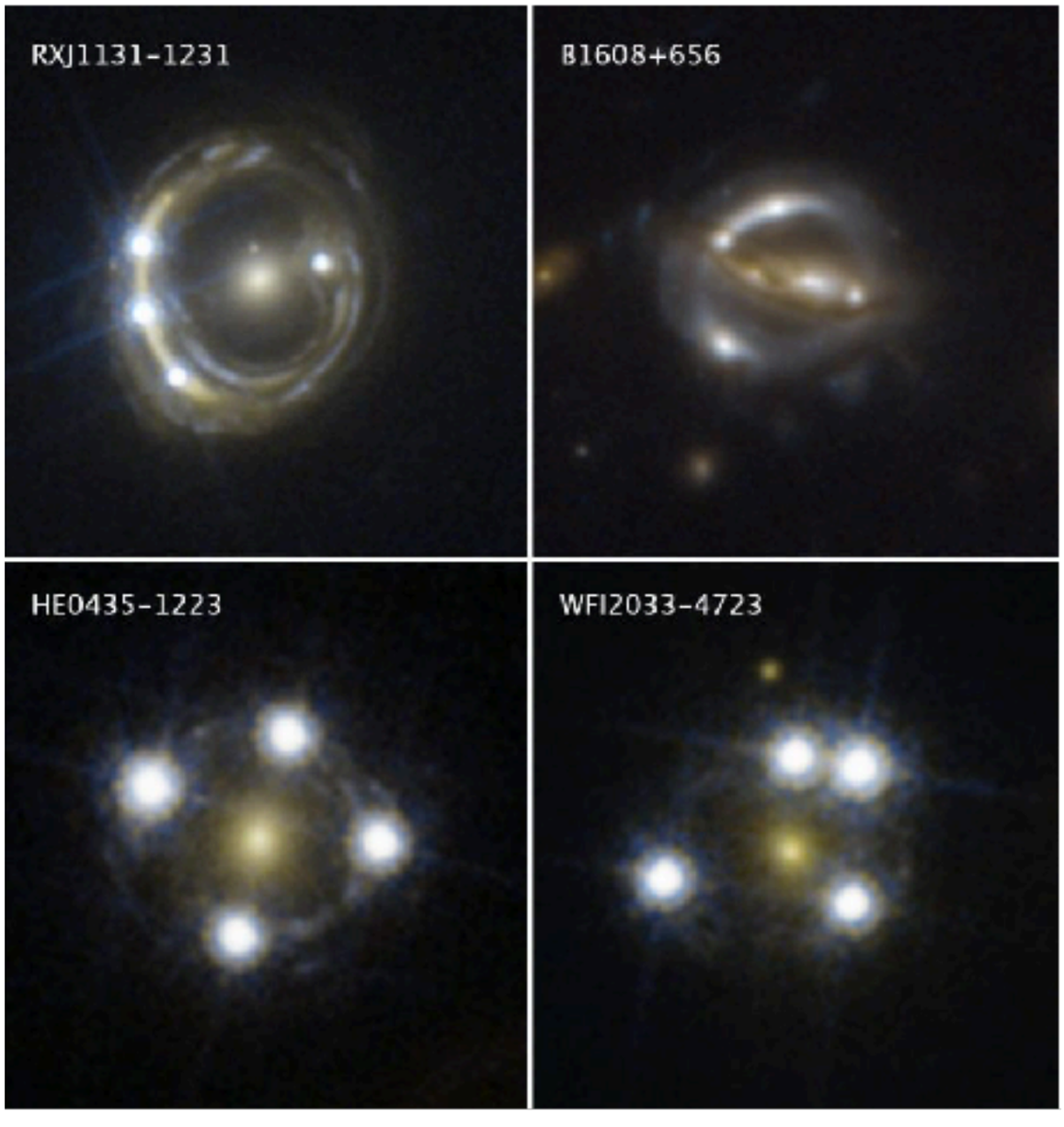
Involve:

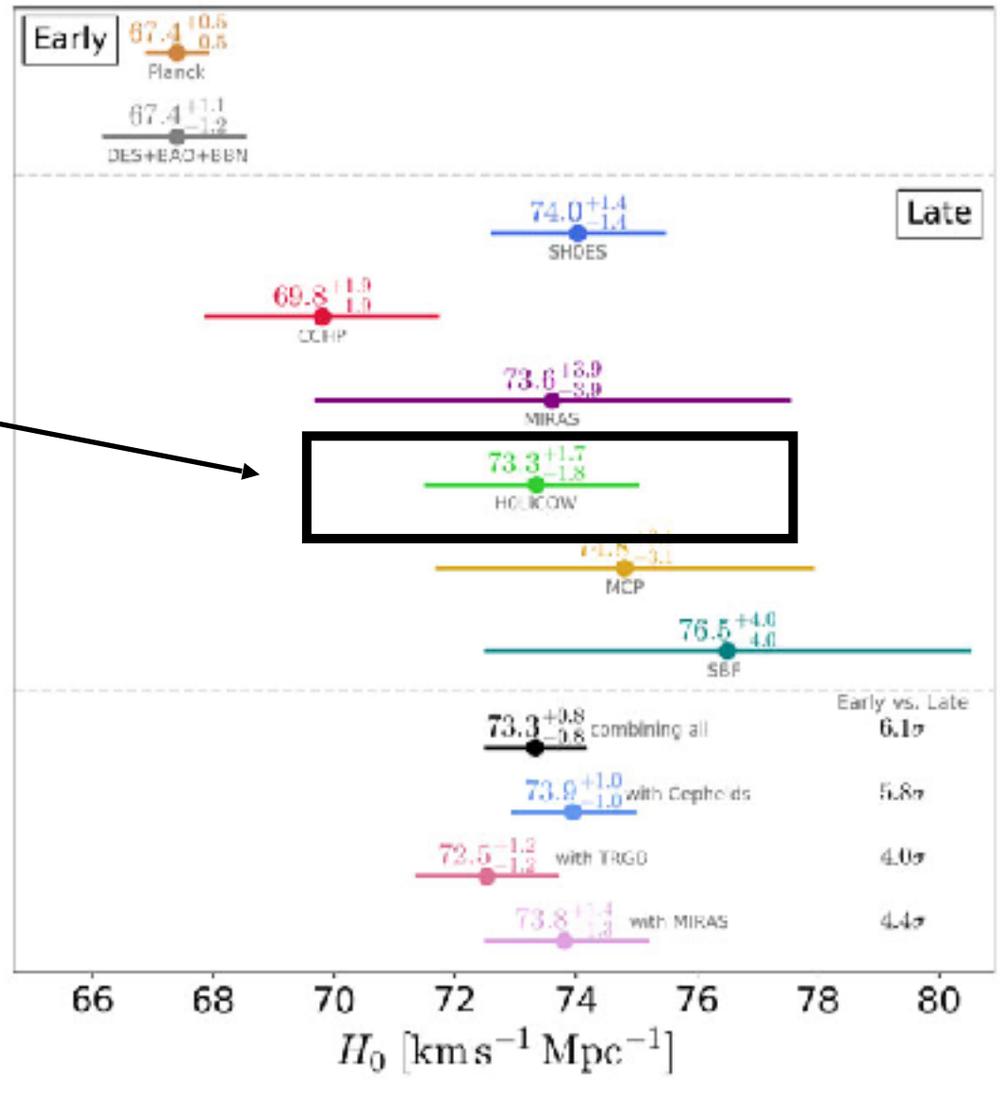
- Instrumentation (ground-based observatory or with space missions)
- Observational strategy (ground- and space-based telescopes)
- (Big) Data flow and processing
- (Big) data analysis (imaging, photometry and spectroscopy)
- Modelling (theory, analytical calculations to numerical simulations)

Research is conducted in a very international context
LASTRO is connected worldwide.

Universe expansion

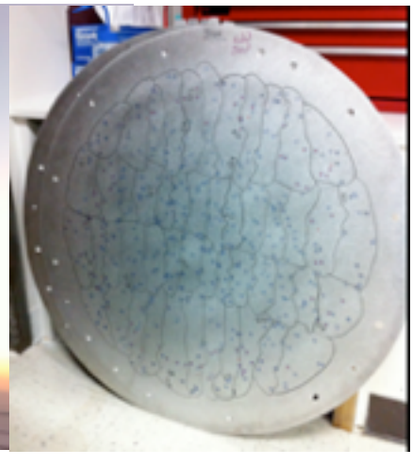
Monitor gravitational lenses to find how fast the Universe grow

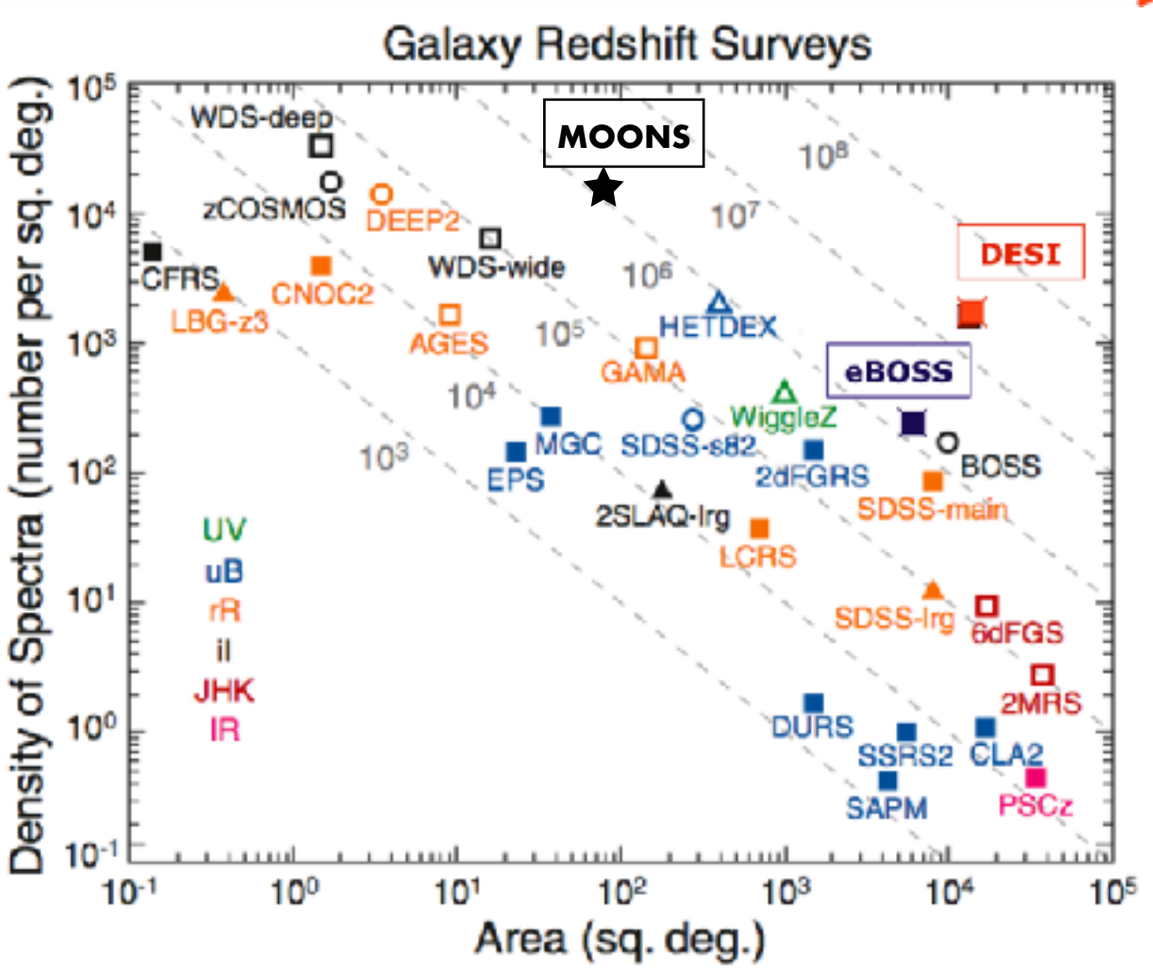




Massive Redshift Surveys





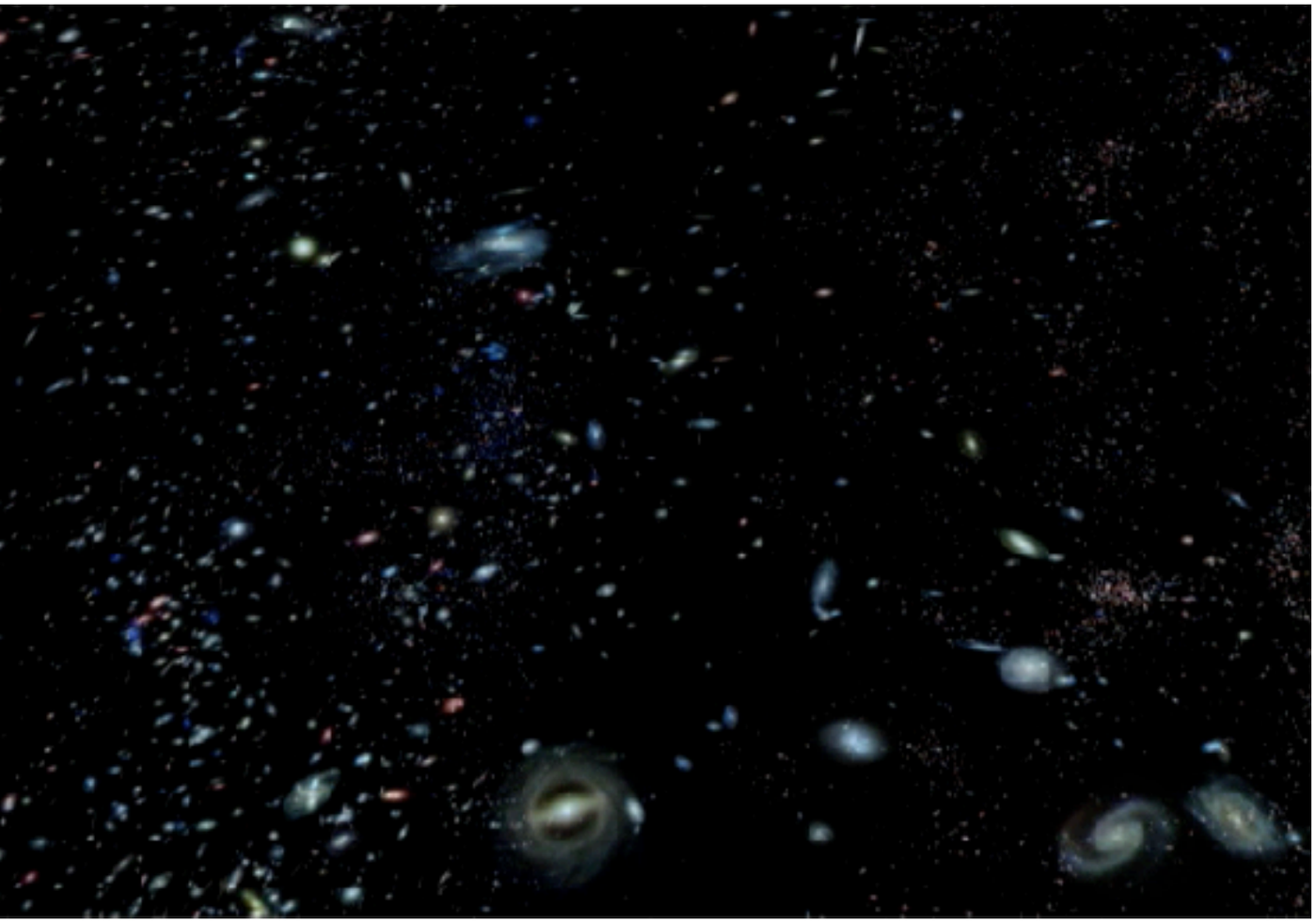


- **Hubble (1930):** expanding Universe
- **CfA Redshift Survey (1985):** first large scale structures
- **2dF (2000-6):** 1500 deg²
- **SDSS (2002-9):** 5700 deg²
- **VVDS/DEEP2 (2004):** deep Universe ~1 deg²
- **zCOSMOS (2005-10):** 2 deg²
- **WiggleZ (2011)**: 800 deg² (BAO)
- **SDSS-III/BOSS (2014)**: 10,000 deg² BAO/LSS (BAO)

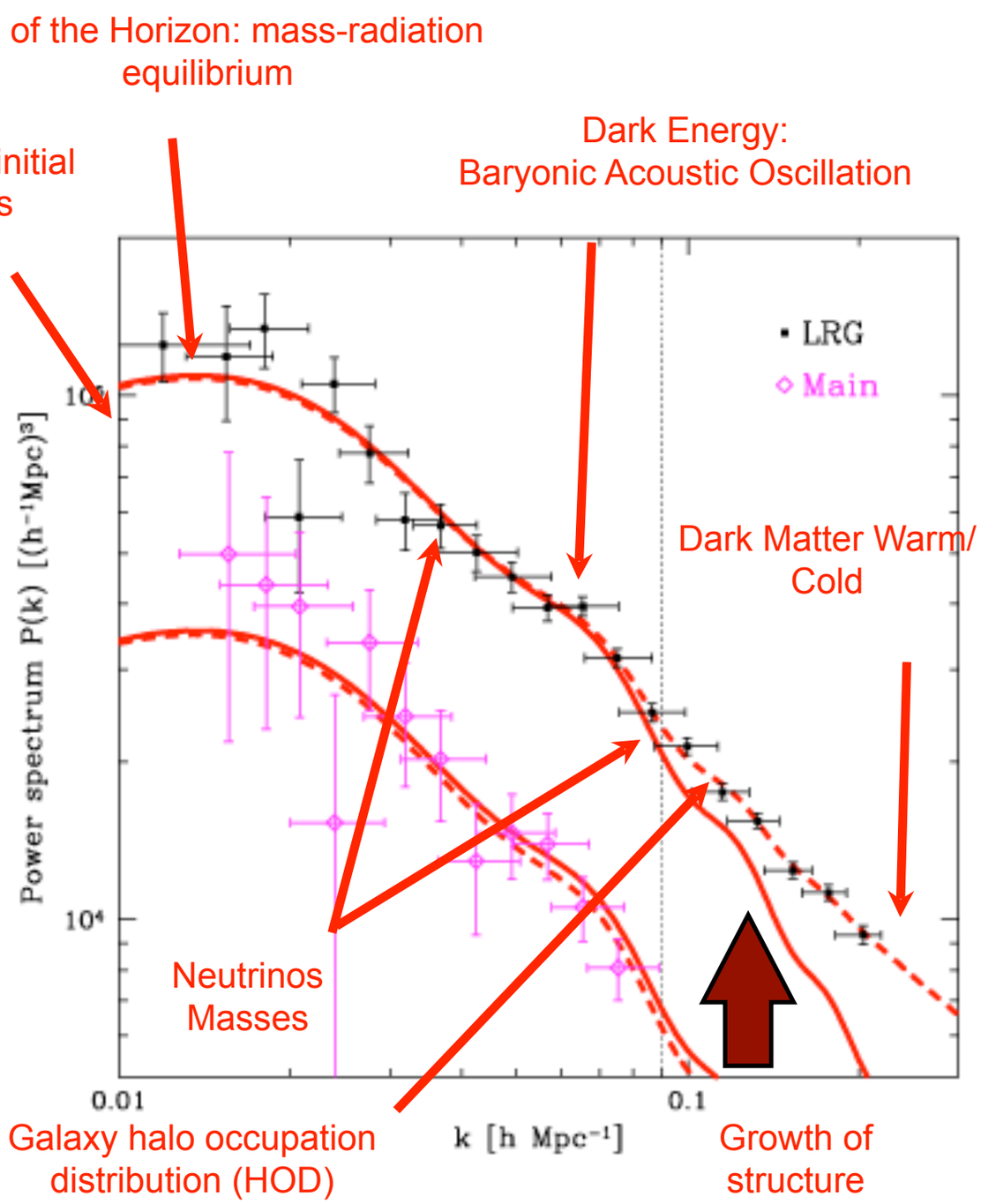
- **e-BOSS (2014-2020):** BAO/LSS: 7,500deg² w/ LRG+QSO & 1,500deg² of ELGs
- **DESI** (2019), **4MOST** (2021) Optical
- **MOONS** (2020) Infrared
- **Euclid** (2020) Space mission
- **SKA** (2025) Radio Telescope

Galaxy Power Spectrum

3D mapping of the position of galaxies



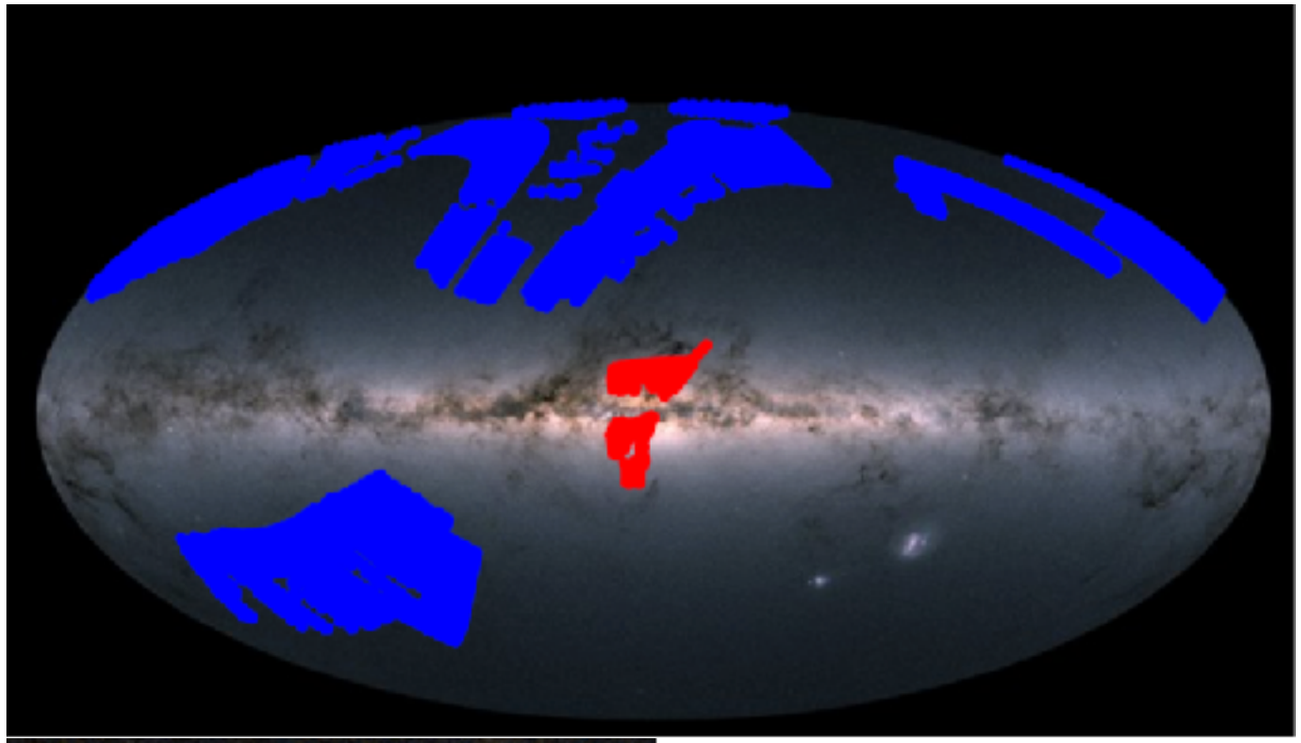
Distribution of galaxies (SDSS)



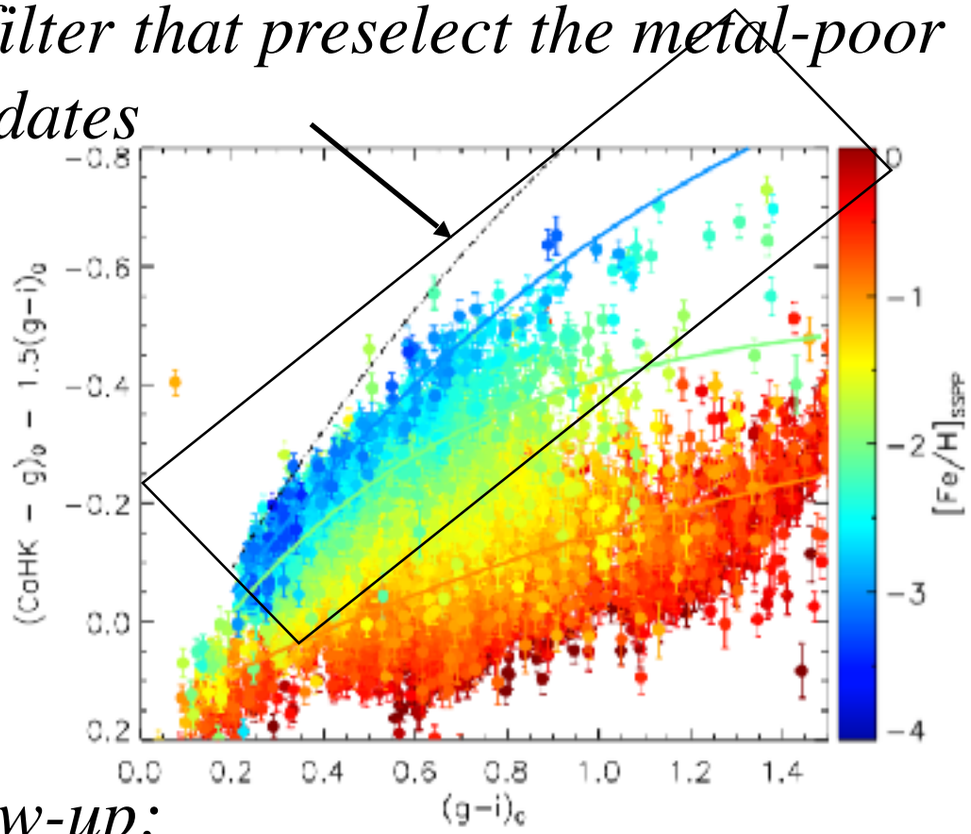
First Stars in the MW: Pristine

Looking for the imprint of the very first stars by looking deep in the Milky Way !

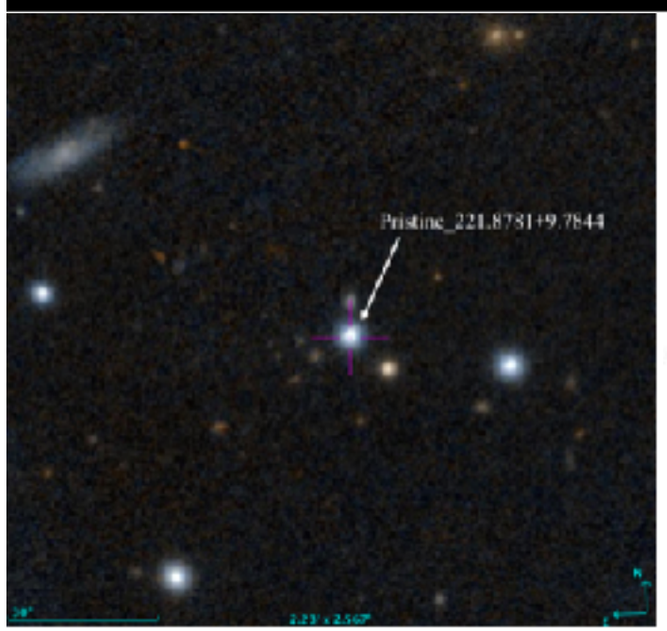
New observational strategy !

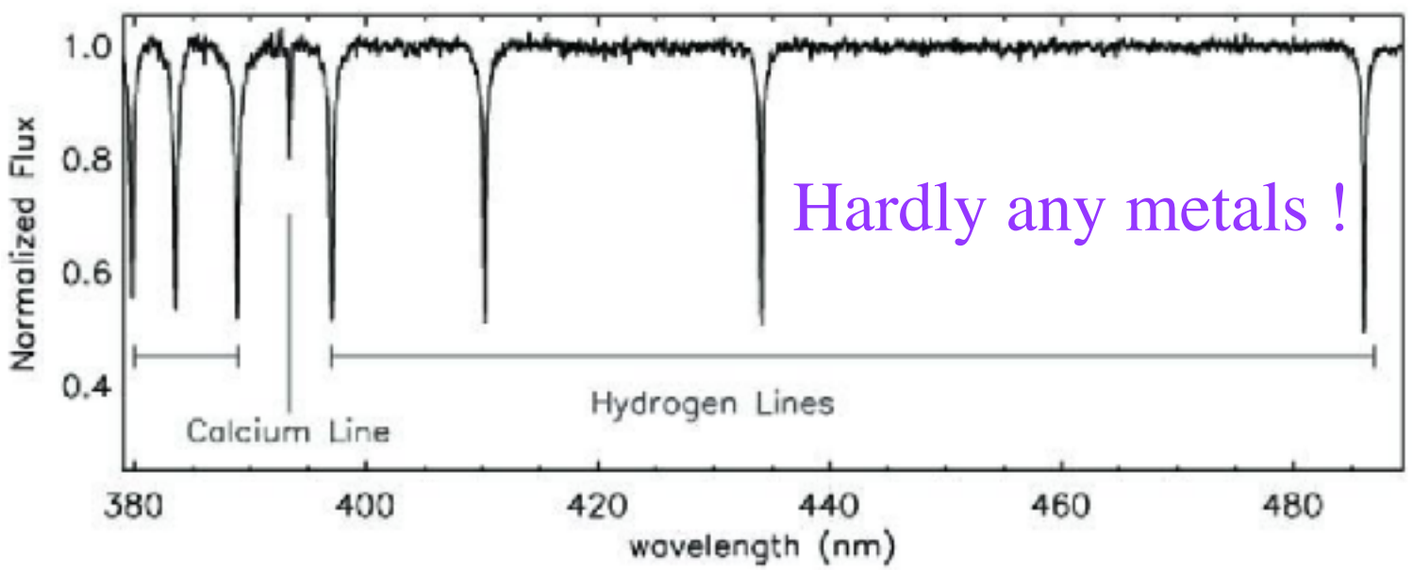


New filter that preselect the metal-poor candidates



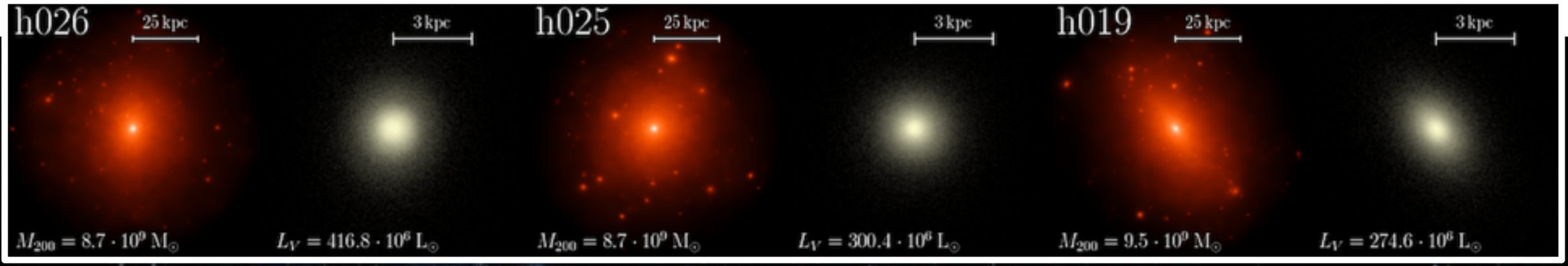
2 – Spectroscopic follow-up:





WEAVE
4MOST

Numerical simulations

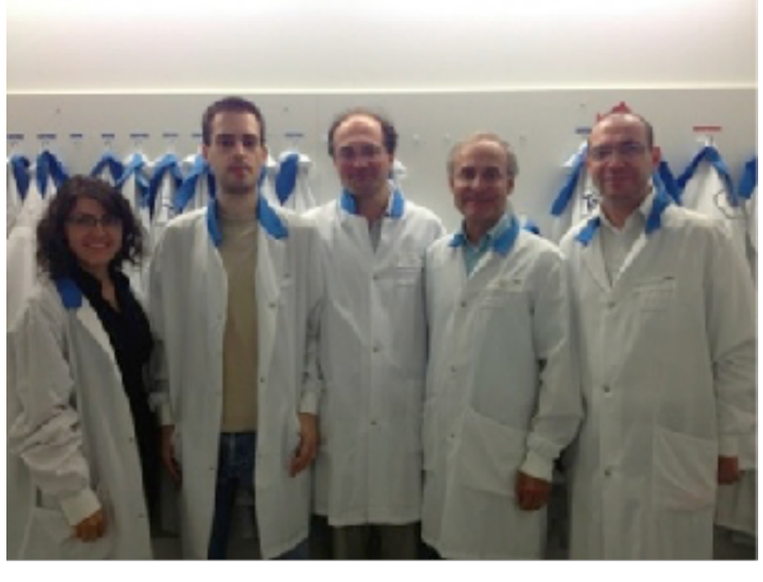


Unveling how galaxies form and evolve

- ➢ Nature of the dark matter?
- ➢ Initial conditions?
- ➢ Physics of baryons?
- ➢ Nature of the first galaxies?

- ★gravity
- ★hydrodynamics
- ★gas cooling
- ★star formation
- ★SNe explosions (stellar feedback)
- ★chemical evolution

Instrumentation:Astrobots



Aims:

- contribute to the building of the next generation instruments worldwide
- Contribute to the observational strategy
- Get primary access to the new datasets.

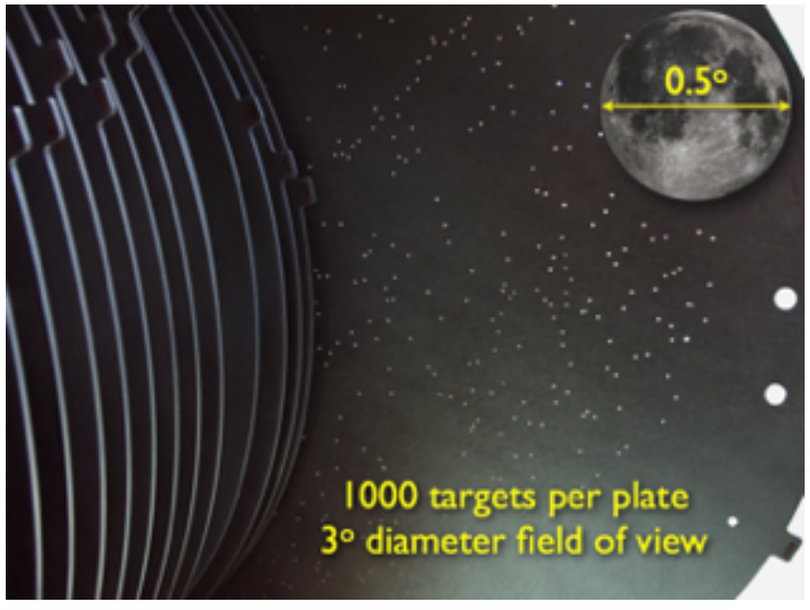
http://astrobots.epfl.ch/

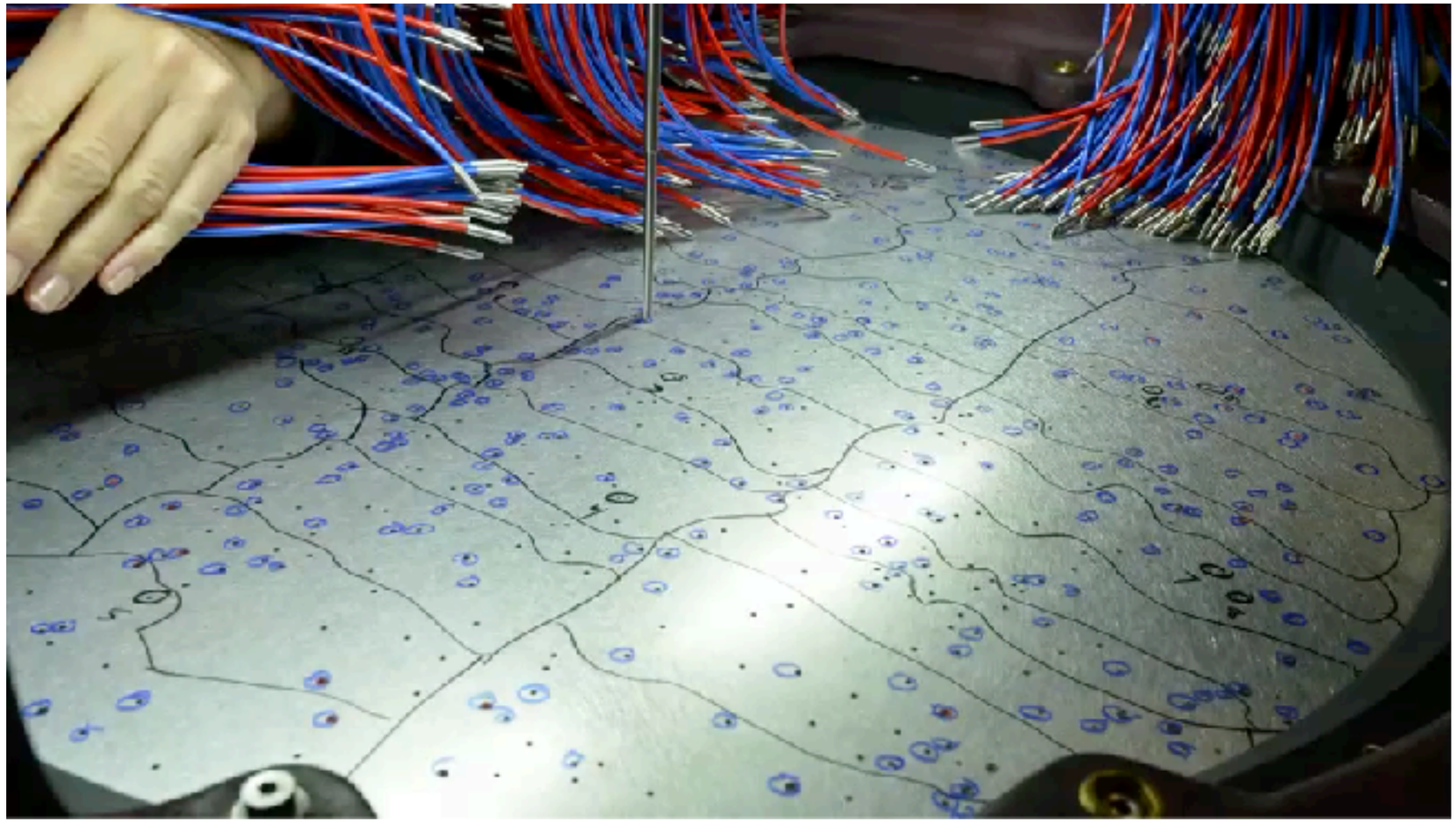
- **Interdisciplinary Group** formed in 2013, with members of LSRO, REACT and LASTRO.
- **Goal:** develop high-precision fiber positioner robotic system for massive spectroscopic surveys
- **Projects:** *DESI & VLT/MOONS & SDSS-V, Megamapper?*
- **Group and Equipement funded by:** SNF+Innosuisse+EPFL+*Sloan Foundation*

The Sloan Telescope & Spectrograph

- 90 cm aluminium plate with 1000 holes for fibers,
- 45 min to plug for typical 1 hour observation on sky
- up to 9 plates observed per (good) night
- 1.5 millions redshifts in ~4 years
- The best multiplexing spectroscopic facility still

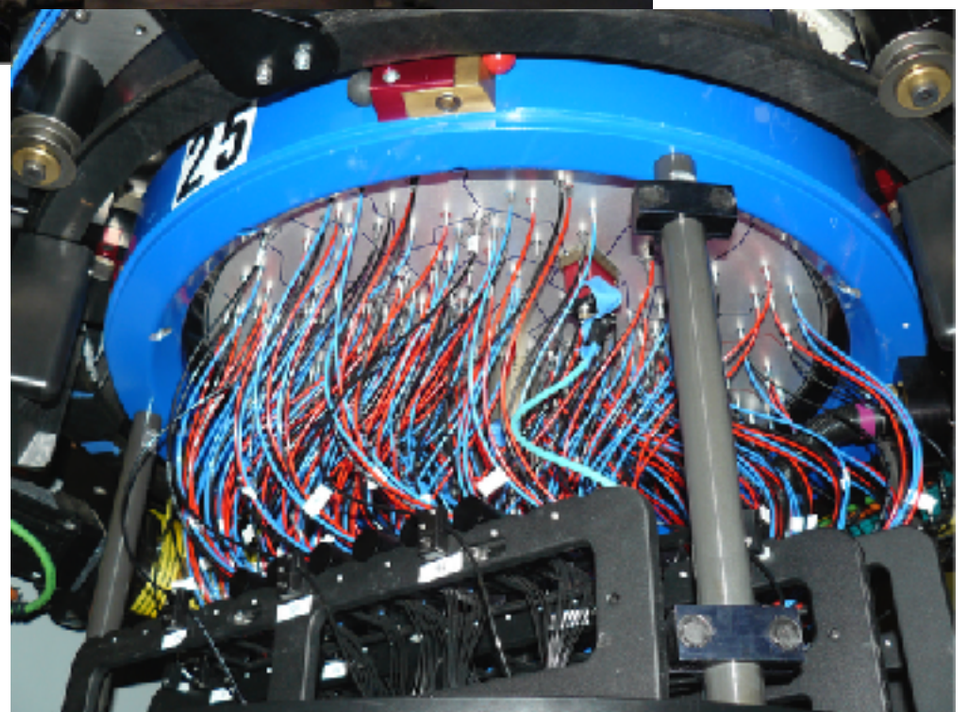
sdss.org

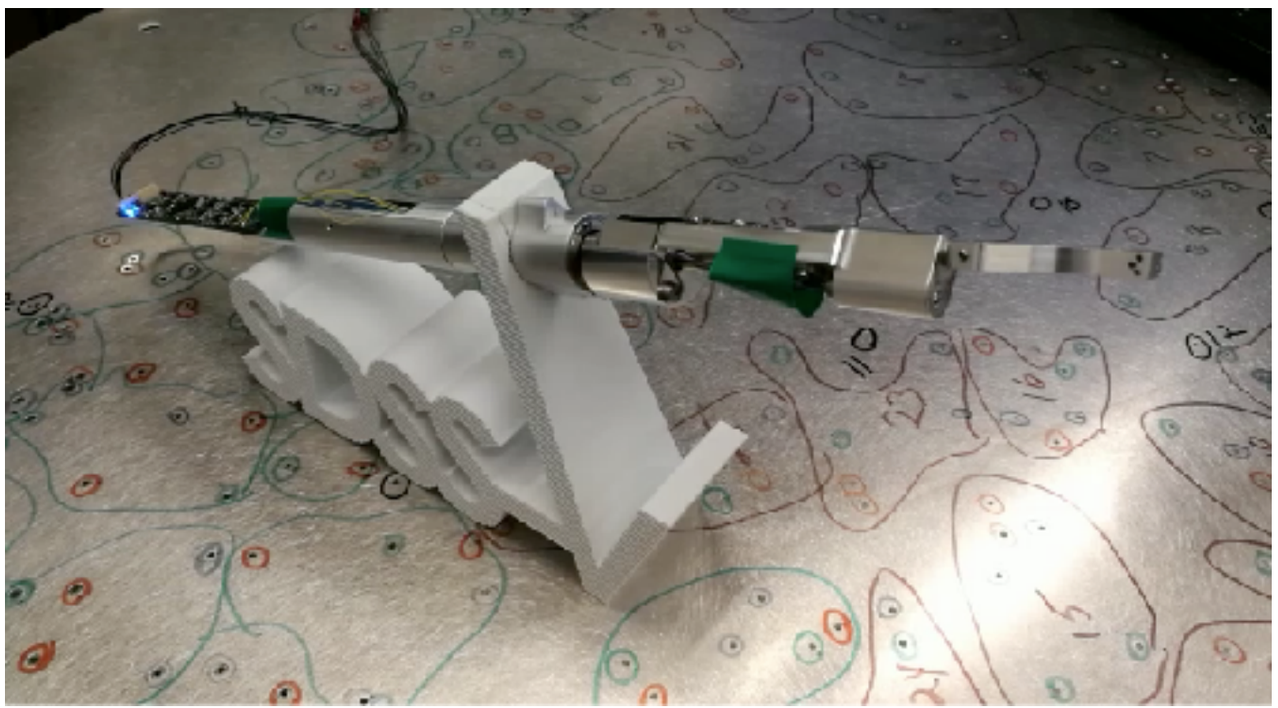




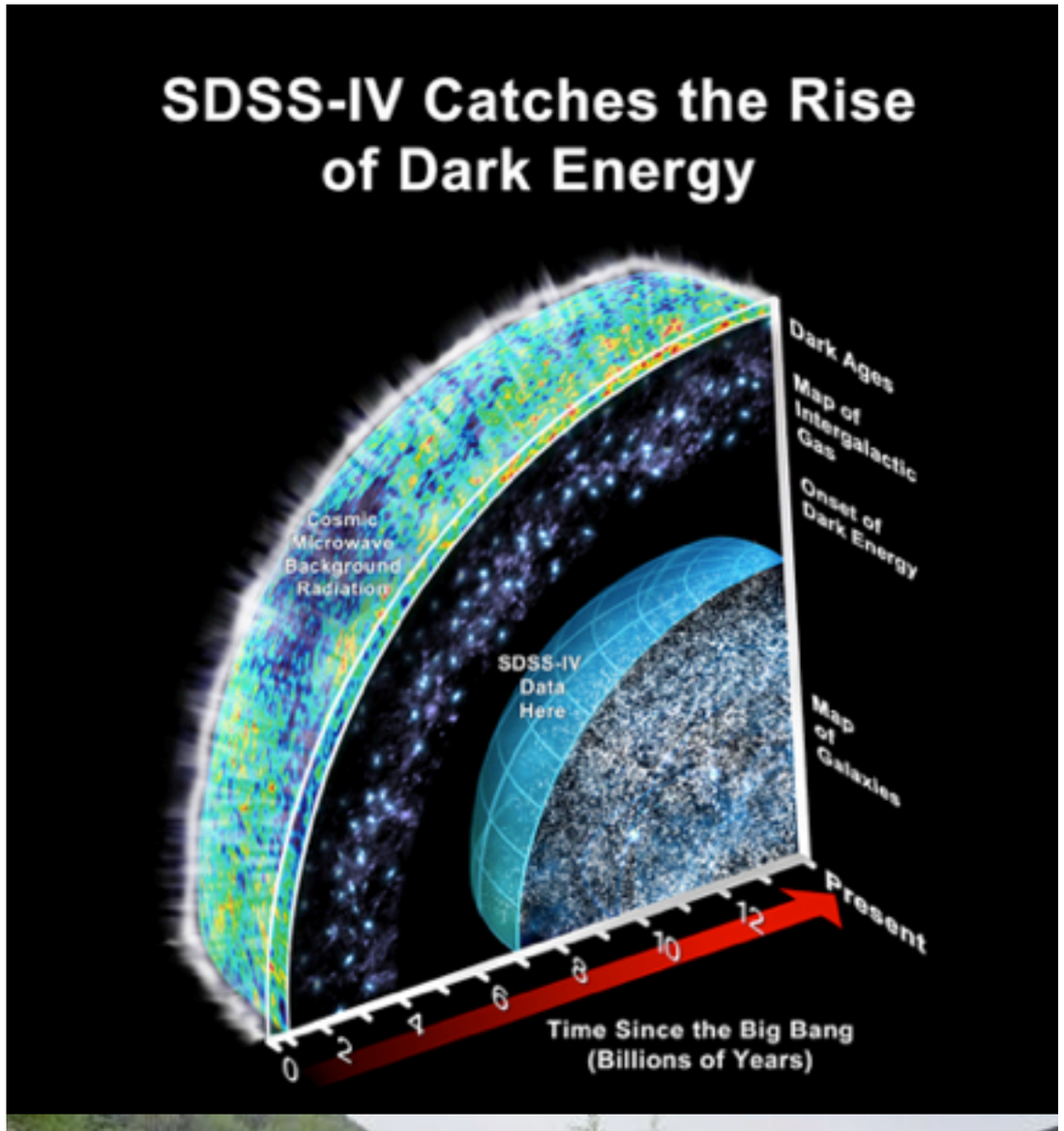
SDSS-V (2020-2025)

- Project started fall 2017
- 2 telescopes (New-Mexico+Chile)
- Fast development, for on-sky in 2020.
- EPFL responsible of the robotic fiber positioner systems, contract with industry
- Production this year by a Swiss company, validation done at EPFL



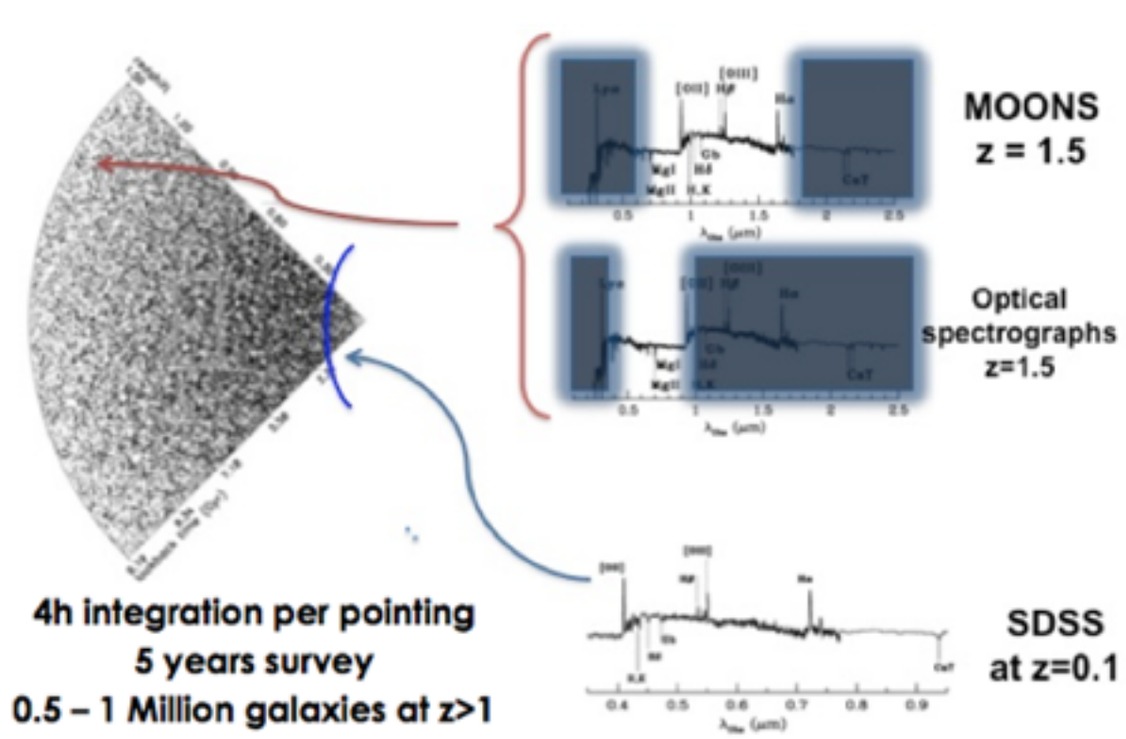


DESI (2020-2024) 4MOST (2022-2027)



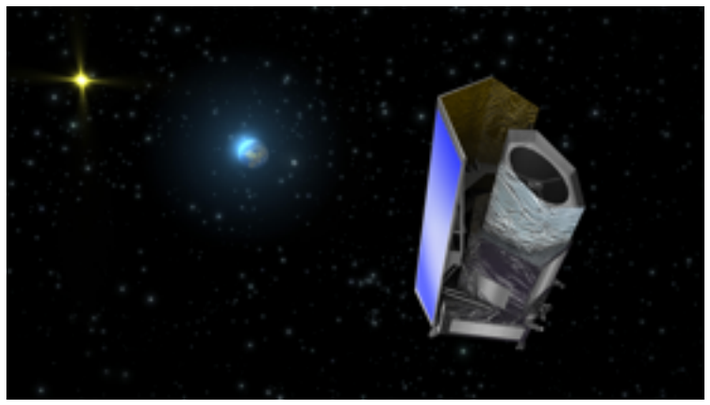
- *(eBOSS), DESI, 4MOST*
  - ★ Spectroscopic survey
  - ★ From 4 millions to 35 millions
- explore redshift window $0.2<z<3.5$
- Use 4 tracers: LRG, ELG, QSO & Ly-alpha forest
- Perform observations on telescopes (USA+Chili)

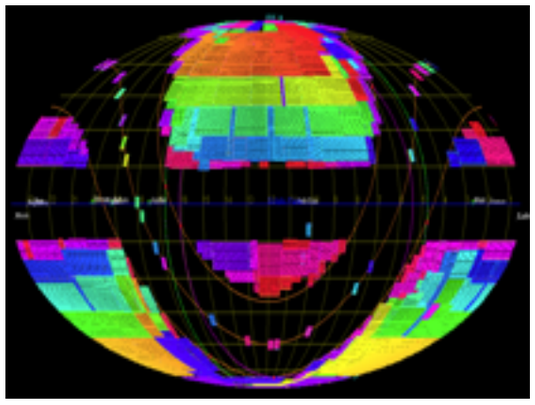
MOONS (2022-2027)



- Approved by ESO in 2014: 1000 fiber NIR spectrograph at VLT (3rd generation of instruments) to start observing in 2019.
- Study of galaxy evolution and formation at $1<z<5$
- Measure ~1 million galaxies over 50-100 deg^2. Much higher density than *DESI*, and *Euclid*.
- Will also probe the $z>7$ Universe and will constrain **Dark Ages**

Euclid (2022-2025)





- *Euclid* is a **major** wide-field imaging and spectroscopy space mission, lead by ESA with NASA participation (1 B$).

  ★ **J.P. Kneib** Cluster Lensing.

  ★ **F. Courbin** Galaxy Lensing.

- Machine Learning on Strong Lensing finder (tensorflow)
- modeling with GPU for fast computing (CUDA)
- **Ultimately contribute to the science of *Euclid*.**

Square Kilometer Array

- Participate in the SKA at Swiss level (EPFL leading the Swiss effort) http://ska.epfl.ch/
  - ★ Interest in the Astrophysics (Reionization, Dark Energy)
  - ★ Algorithm (Raw reduction - Data Analysis)
  - ★ Big-data (Data server - Machine Learning) - IBM DOME project
- Connections with South-Africa & Australia (**Possibility to go there for a master projects/internships**)

Conclusion

- Lot's to do in Astrophysics & Cosmology ! (Strong links with STI, IC possible)
- TP-IVa (learning) - b (practise)
- If you are interested, please contact us: jean-paul.kneib@epfl.ch, frederic.courbin@epfl.ch, pascale.jablonka@epfl.ch
- For TP-IV please register to IS-Academia NOW. Responsible: frederic.courbin@epfl.ch