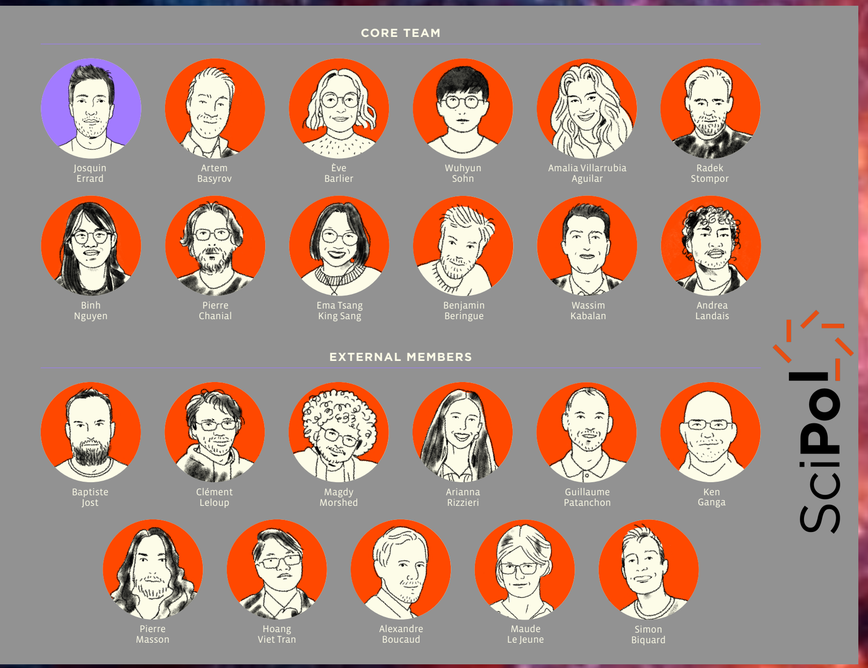


Cosmology Group @ APC

Josquin Errard
Head of the Cosmology Group

Cosmology Group @ APC



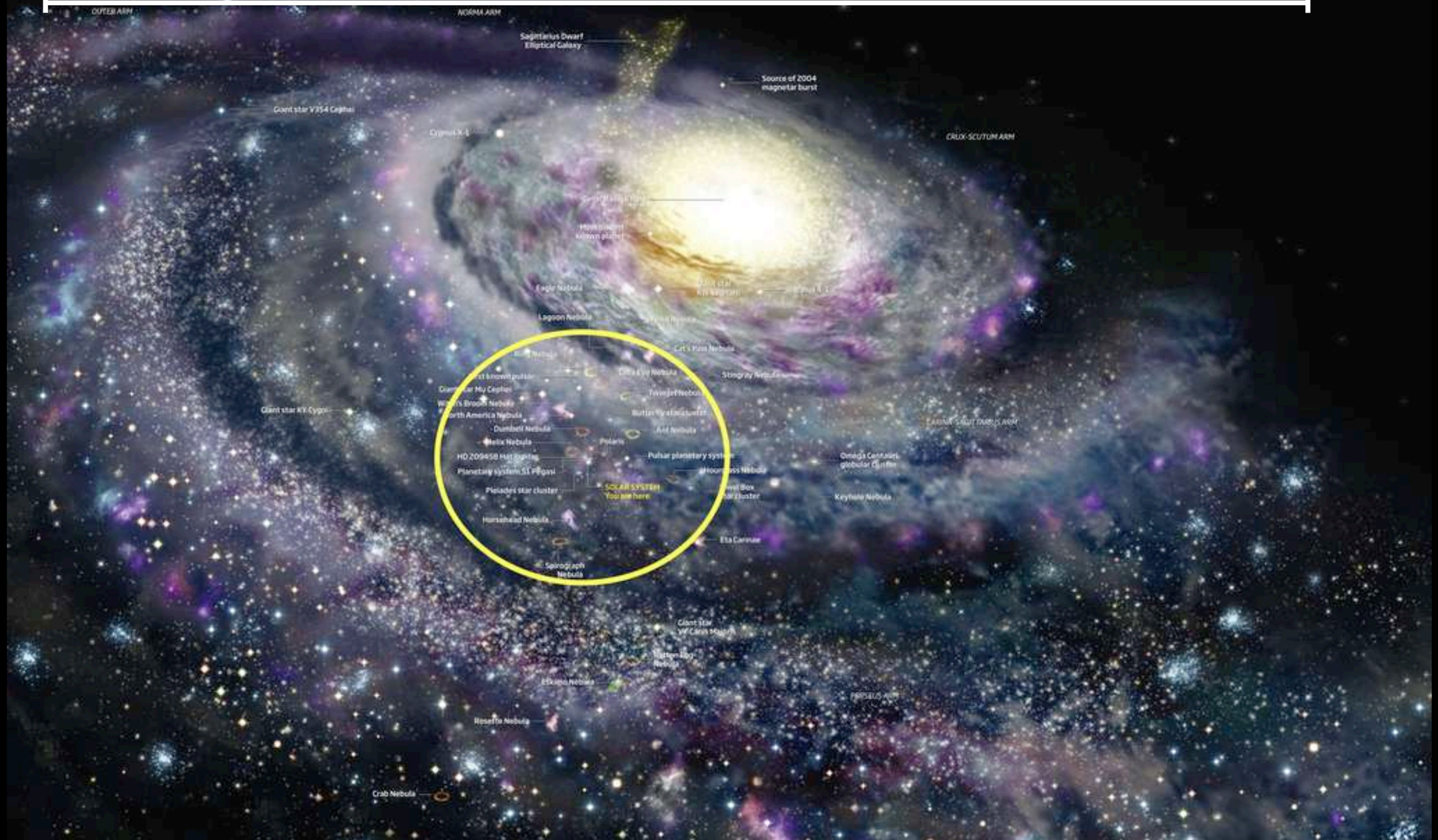


Projet ERC SciPol
Objectif ultime : lever de nouveaux voiles sur l'origine, l'évolution et les grandes énigmes de l'Univers.

Josquin Errard
Head of the Cosmology Group

3 to 400 billion stars in the Milky Way …

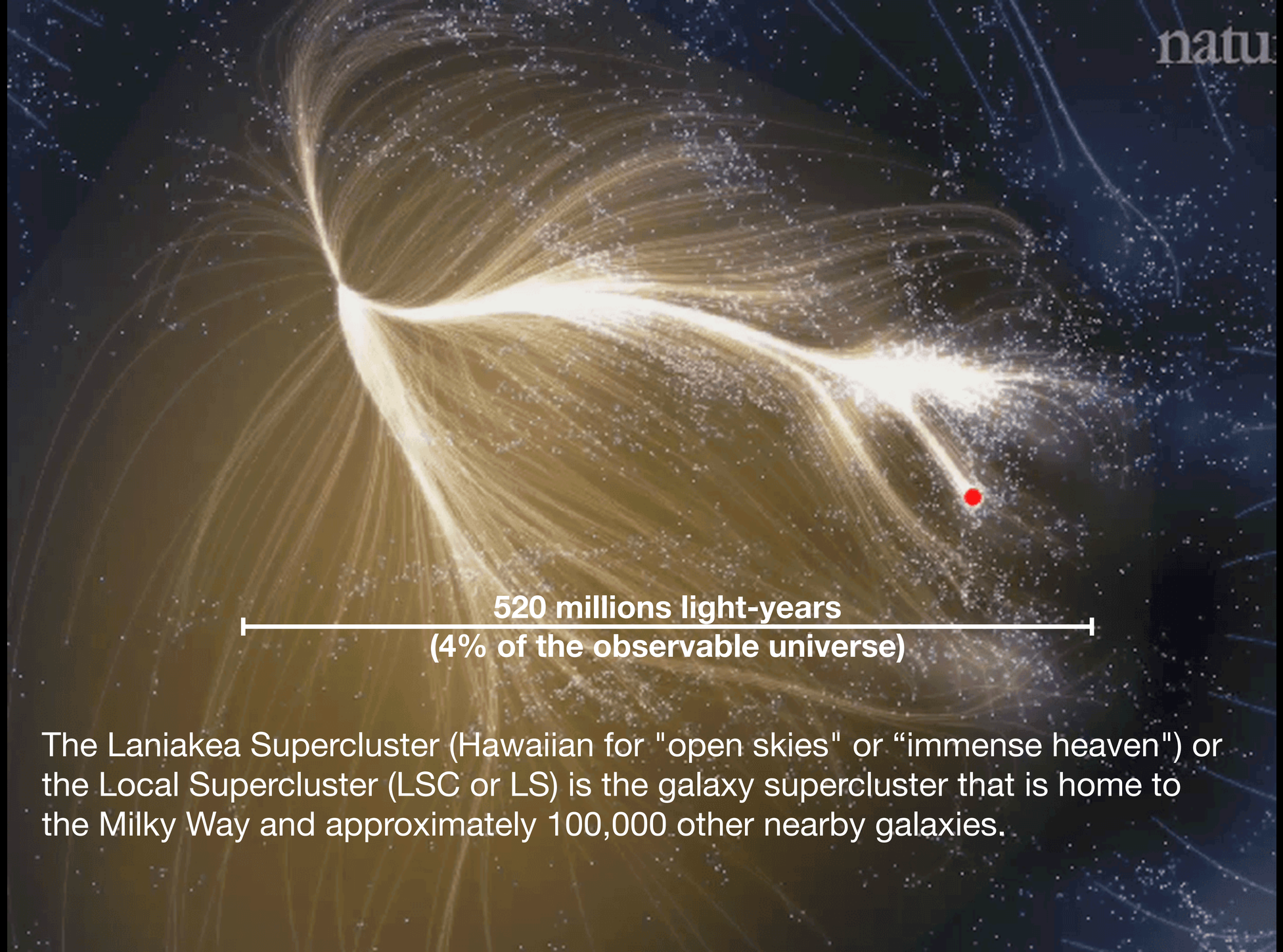
50 000 light-years ~ 5 x 10^{17} kilometers



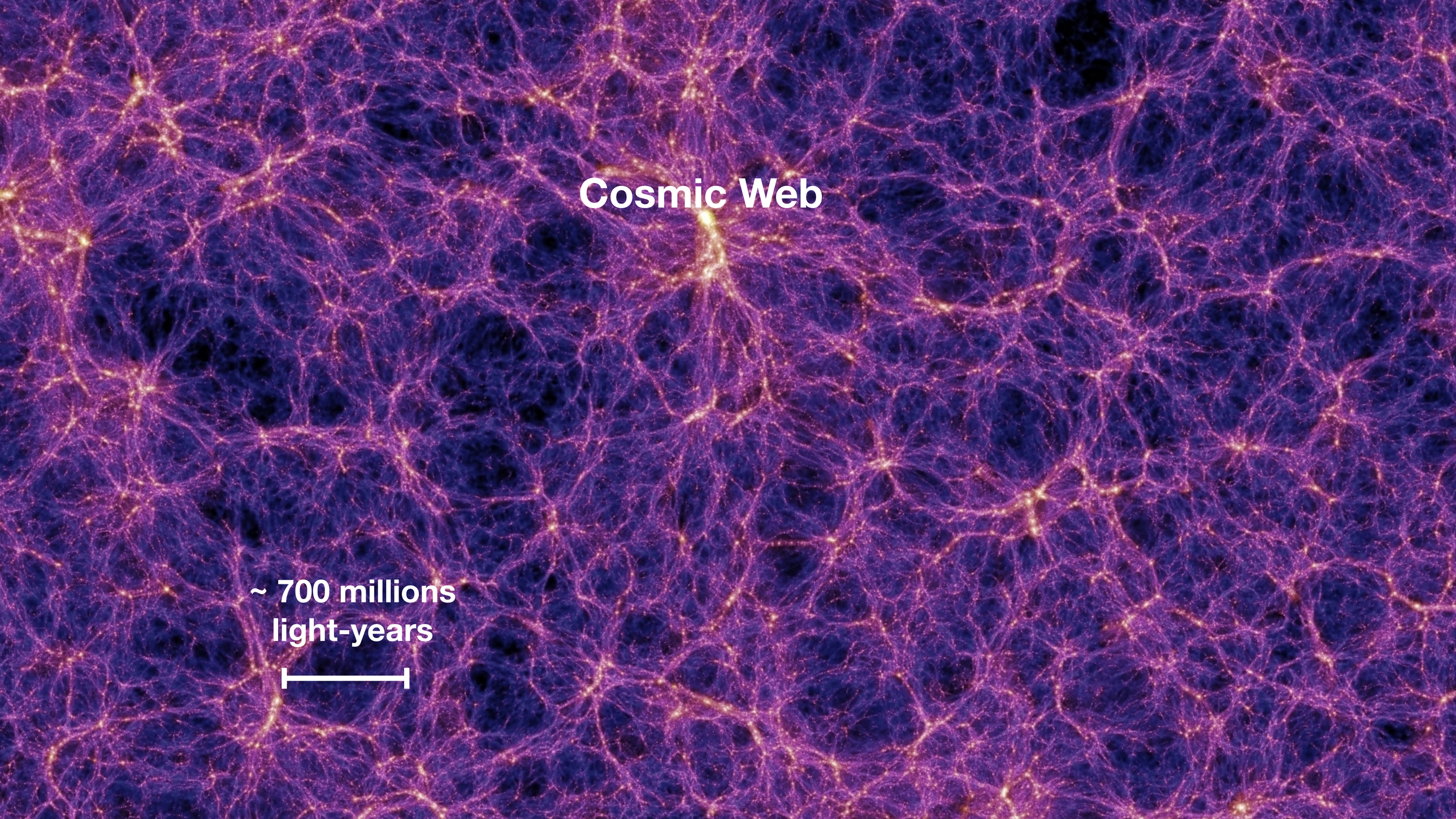
….. and hundreds billions of other galaxies in the Universe



collaboration DESI
observation de ~13 millions de galaxies

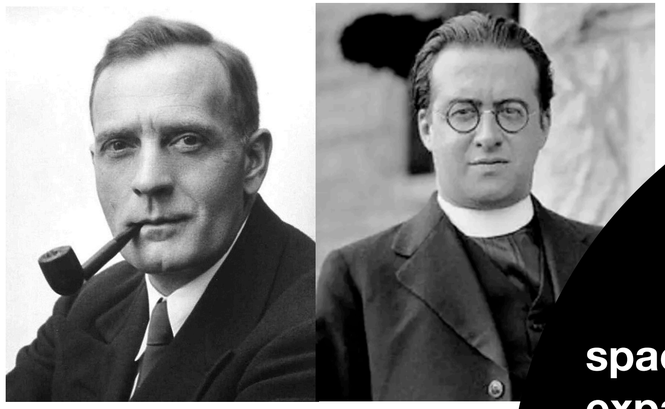


The Laniakea Supercluster (Hawaiian for "open skies" or “immense heaven") or the Local Supercluster (LSC or LS) is the galaxy supercluster that is home to the Milky Way and approximately 100,000 other nearby galaxies.

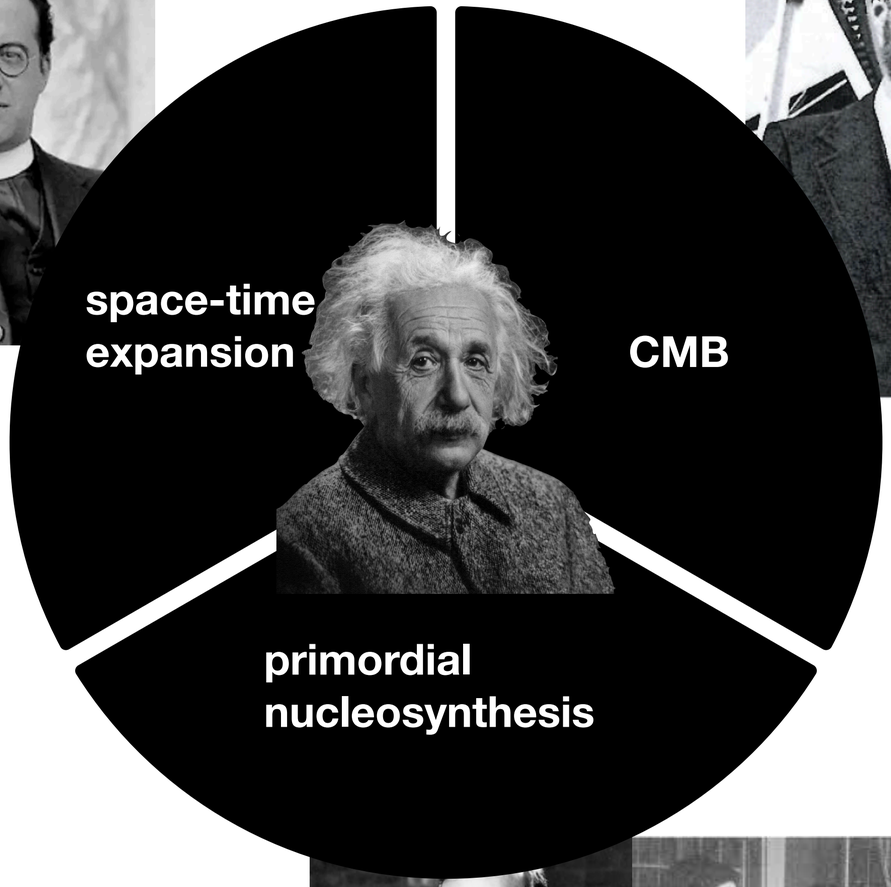

Cosmic Web
~ 700 millions
light-years

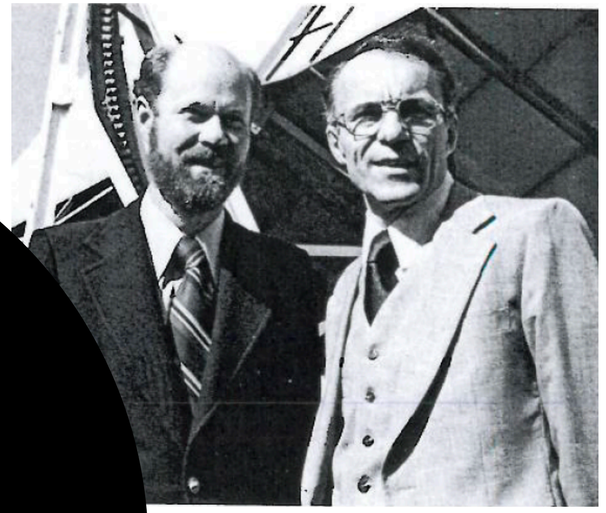

93 billion light years
The known universe, Now

(Hot) Big Bang theory



Hubble-Lemaître Law





Penzias et Wilson

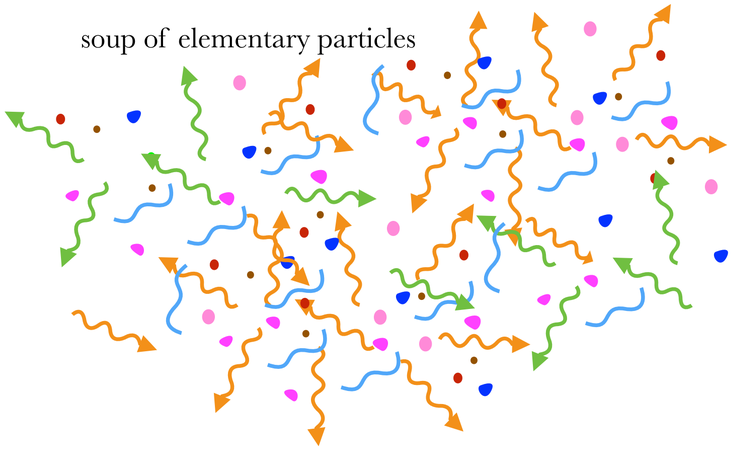
George Gamow proposed the hypothesis that most of the helium in the universe today was produced in the early Big Bang in ‘less time than it takes to cook a goose



Gamow, Alpher, Hermann

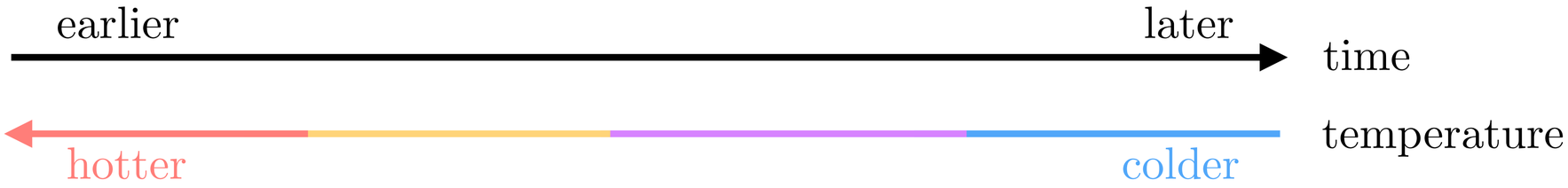
The Hot Big Bang

The Universe started in a hot and dense state:



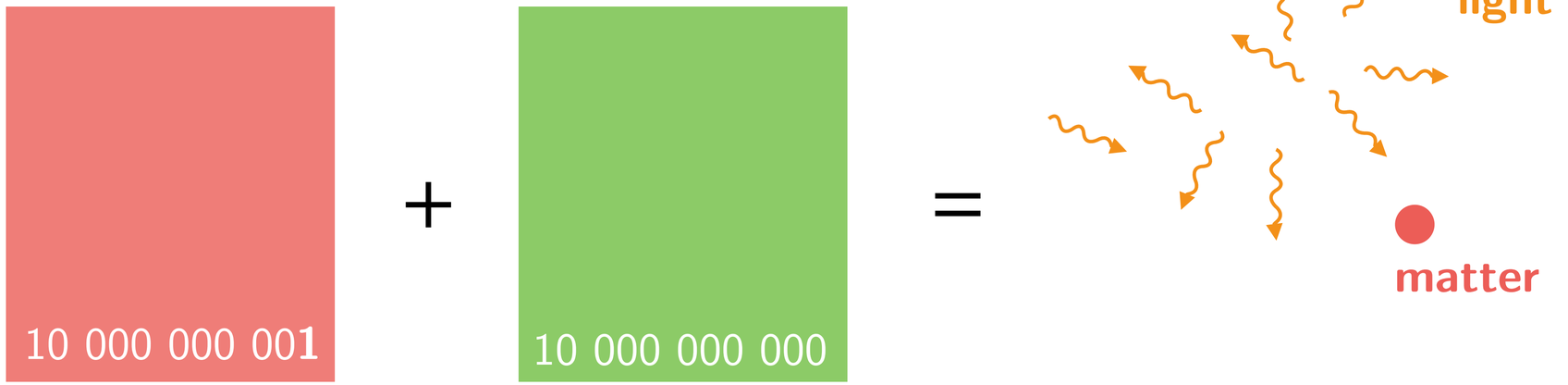
$$T(t) \propto a(t)^{-1}$$

As the Universe expands, it cools.
Many interesting things happened.



$t = 10^{-19}\,\mathrm{s}$

The Universe is filled with almost equal amounts of **matter** and **antimatter**

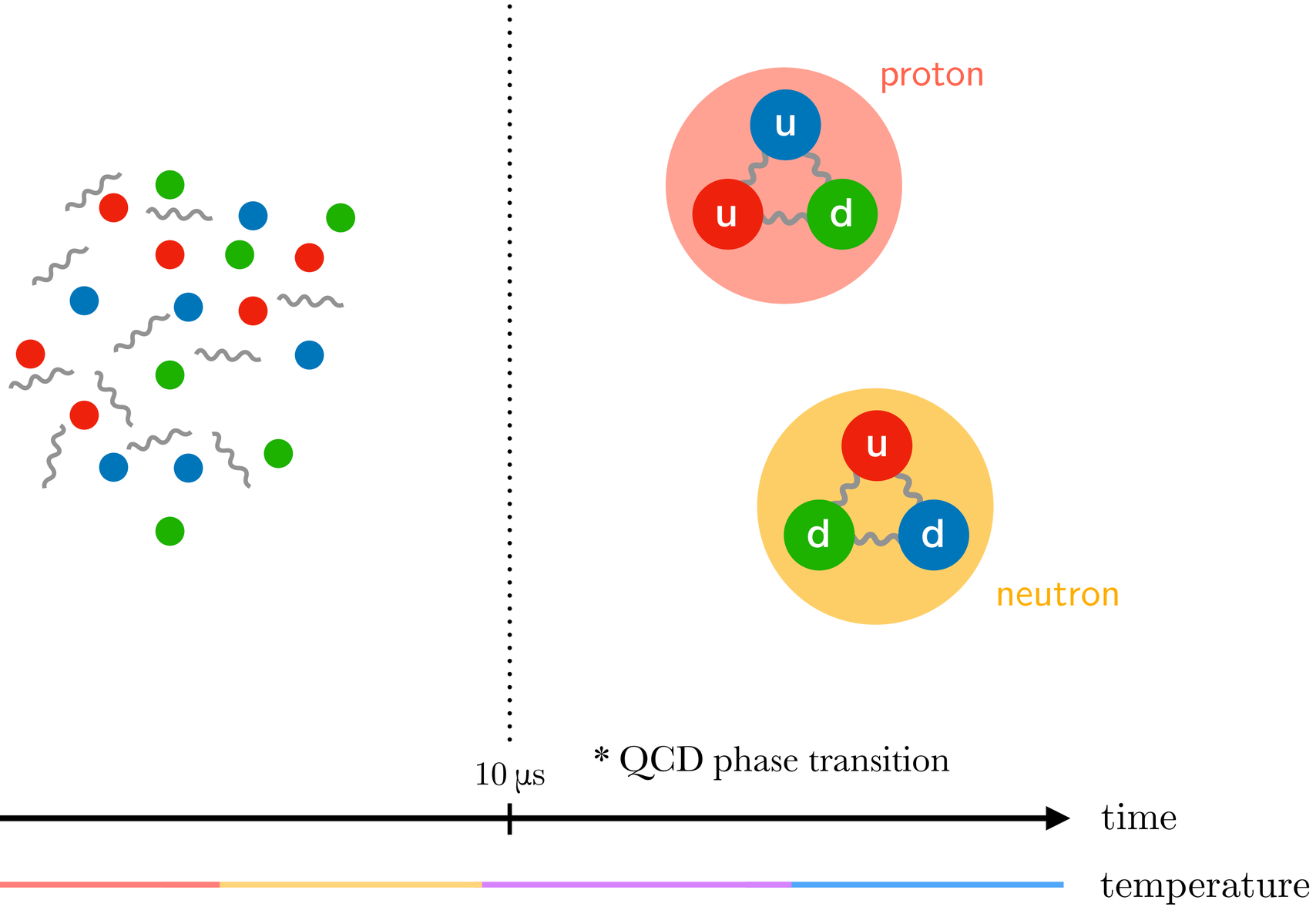


As the universe cools, matter and antimatter annihilate.

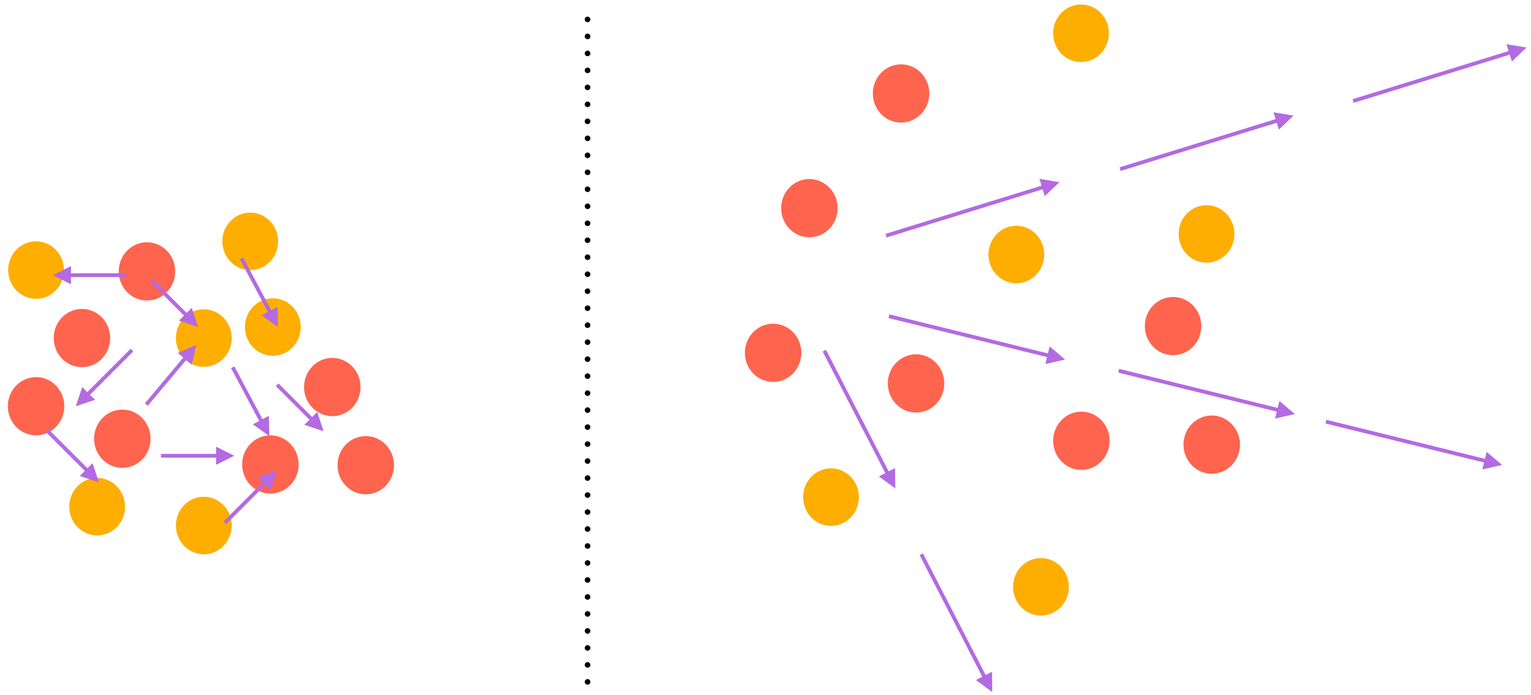
For some mysterious reason, there was initially a fraction more matter than antimatter. This matter survived the annihilation.

Without this **asymmetry** we wouldn't exist.

$t = 10^{-5}\,\mathrm{s}$ Quarks and gluons condense into nuclei:



$t = 1\,\mathrm{s}$ Neutrinos decouple and neutrons freeze out:



Free-streaming neutrinos

- 40% of the energy density
- Significant effect on the expansion

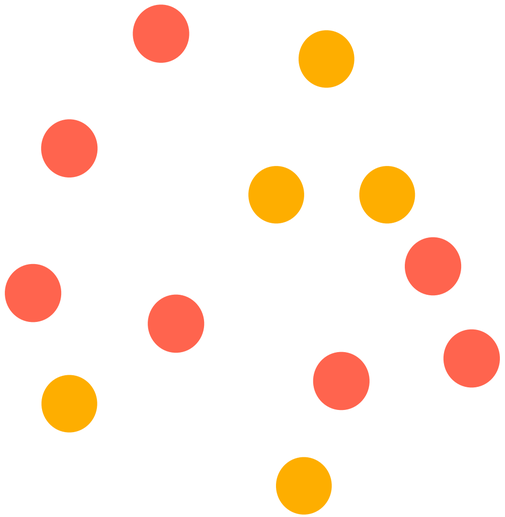
$$\rho_{\mathrm{rad}} = \rho_\gamma + \rho_\nu = \rho_\gamma \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\mathrm{eff}}\right]$$

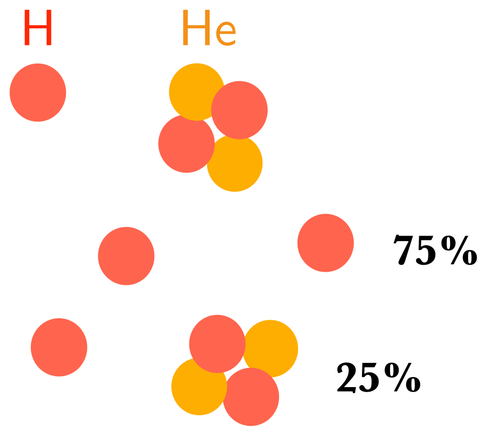
1 s

time

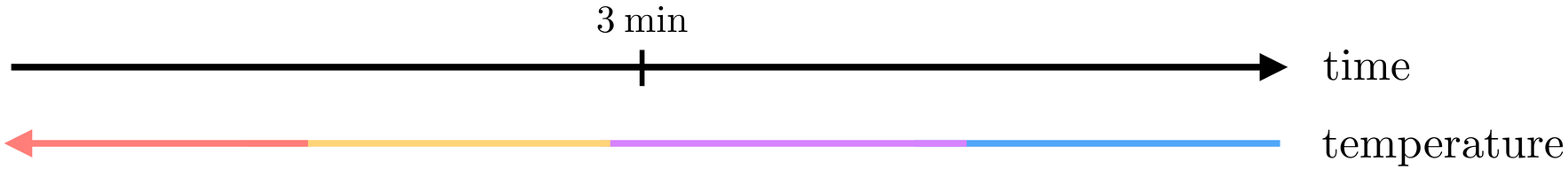
temperature

$t = 3\,\text{min}$ Light elements (H, He, and Li) form:

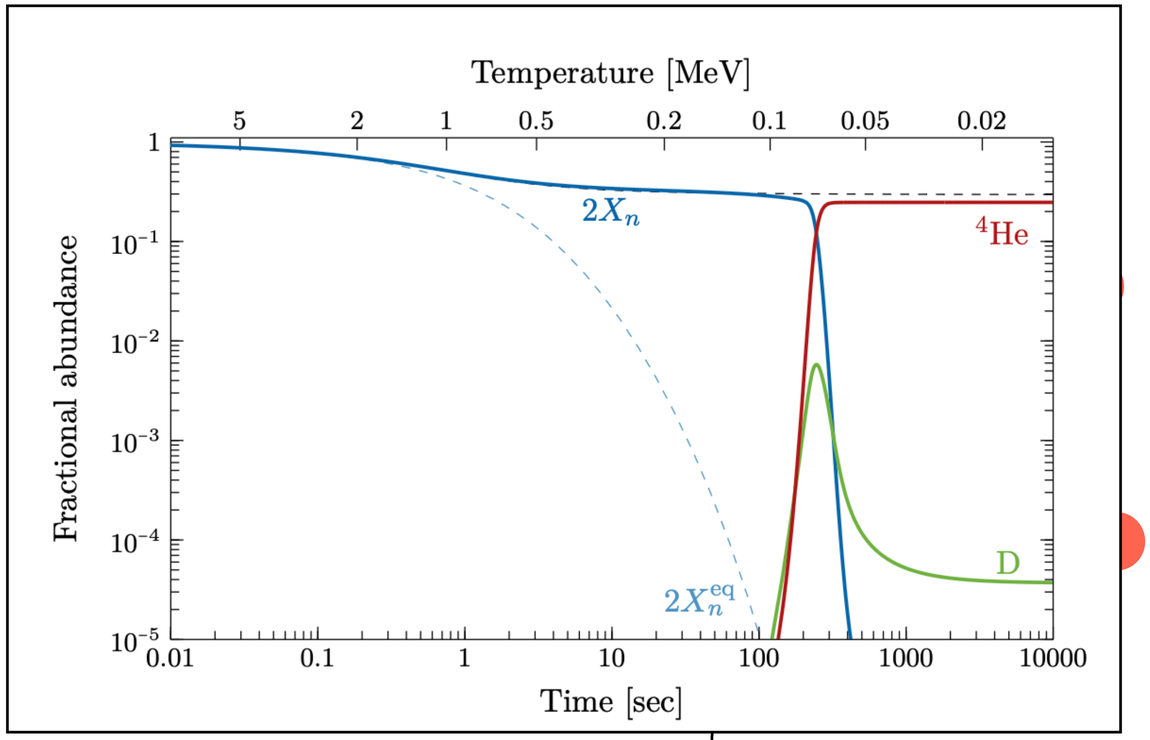


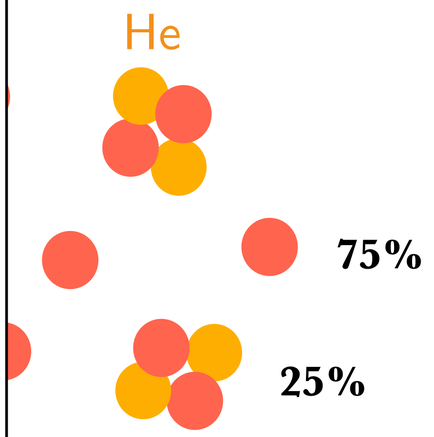


- Big Bang nucleosynthesis (BBN) predicts the correct abundances of the light elements.
- Heavier nuclei were fused inside stars.

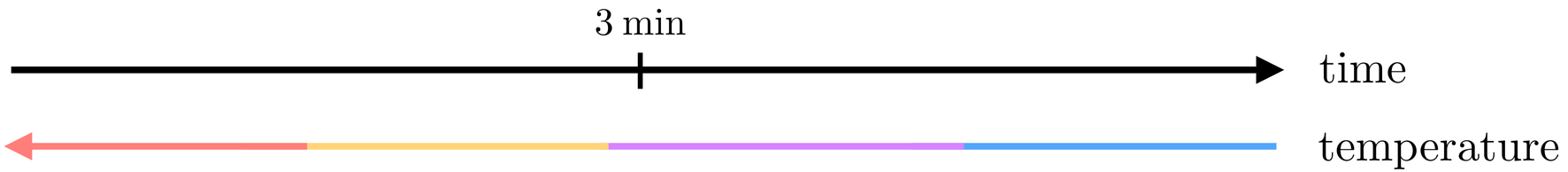


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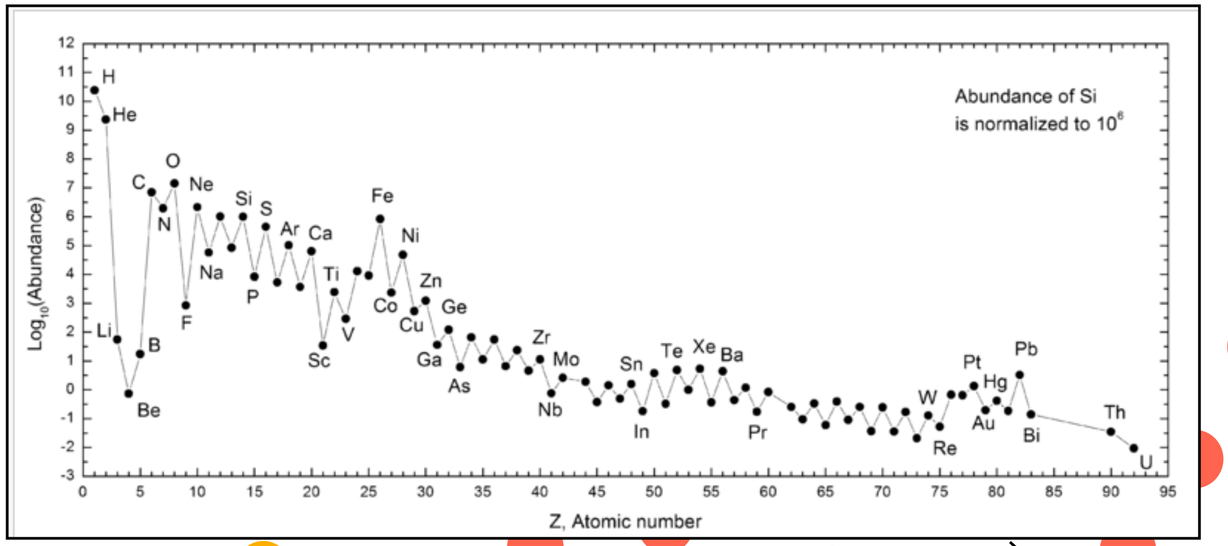


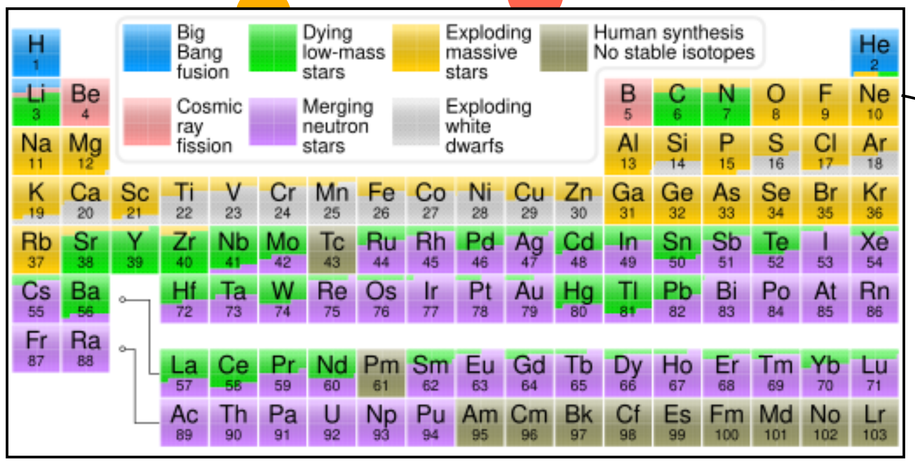


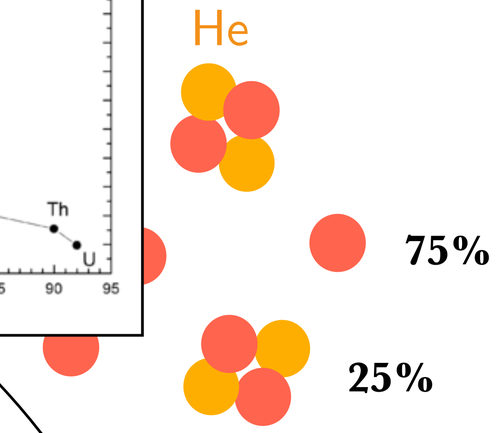
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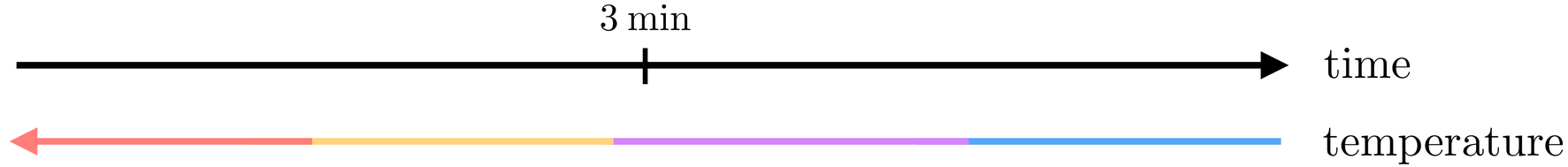
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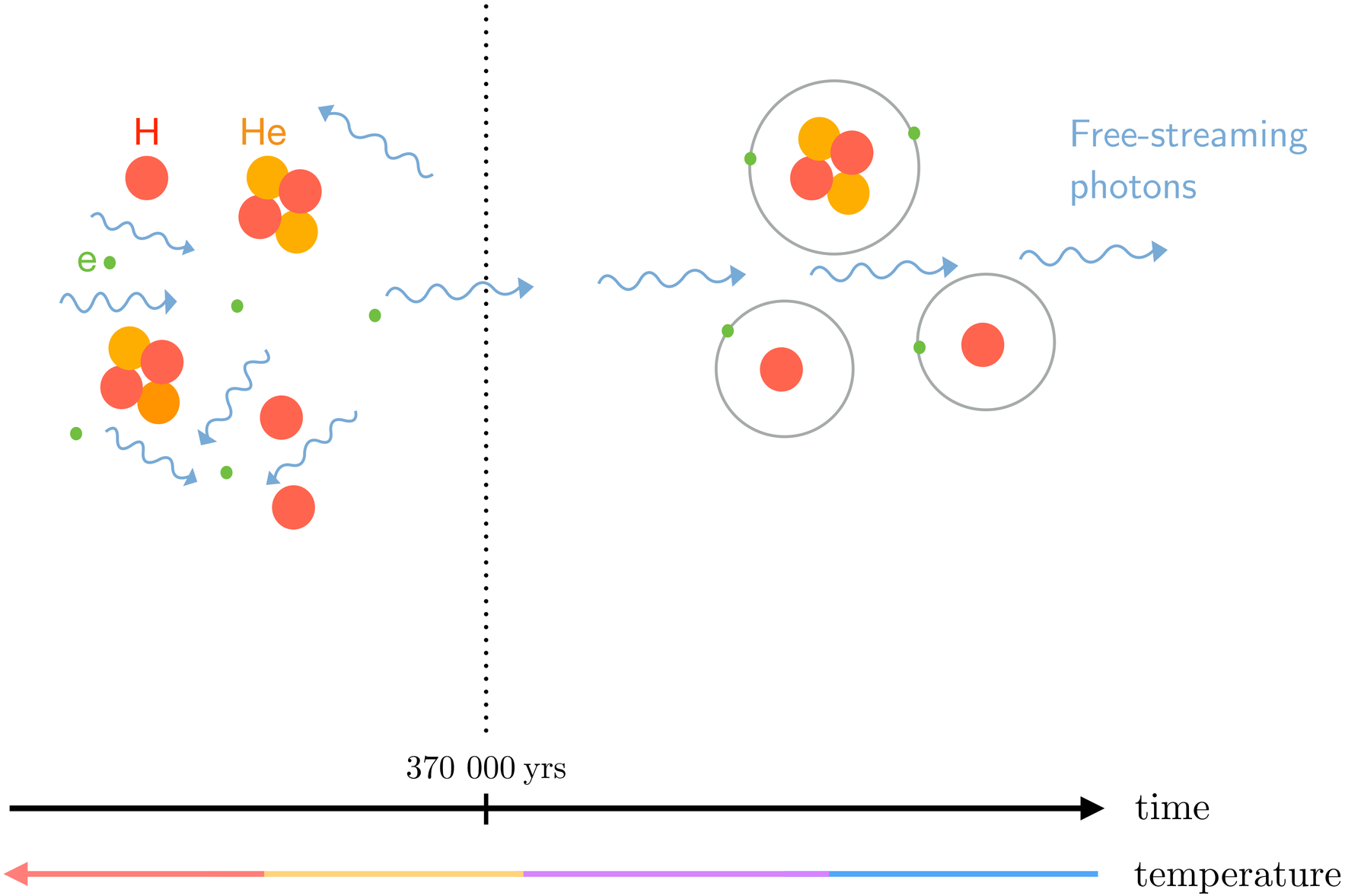




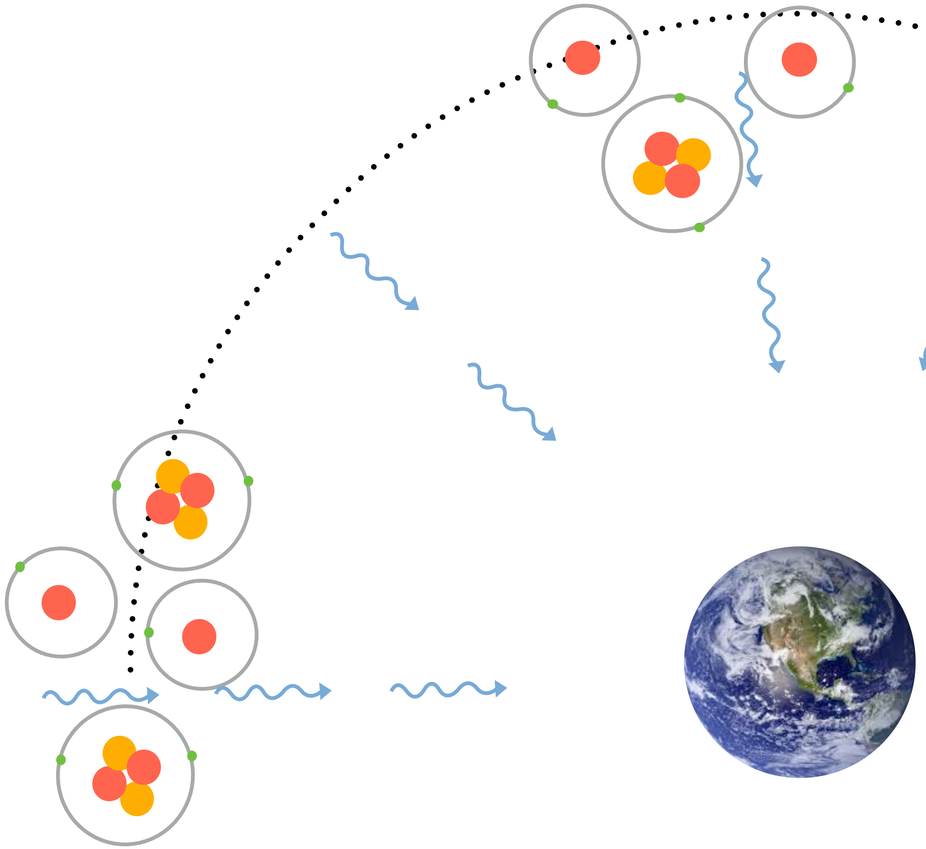
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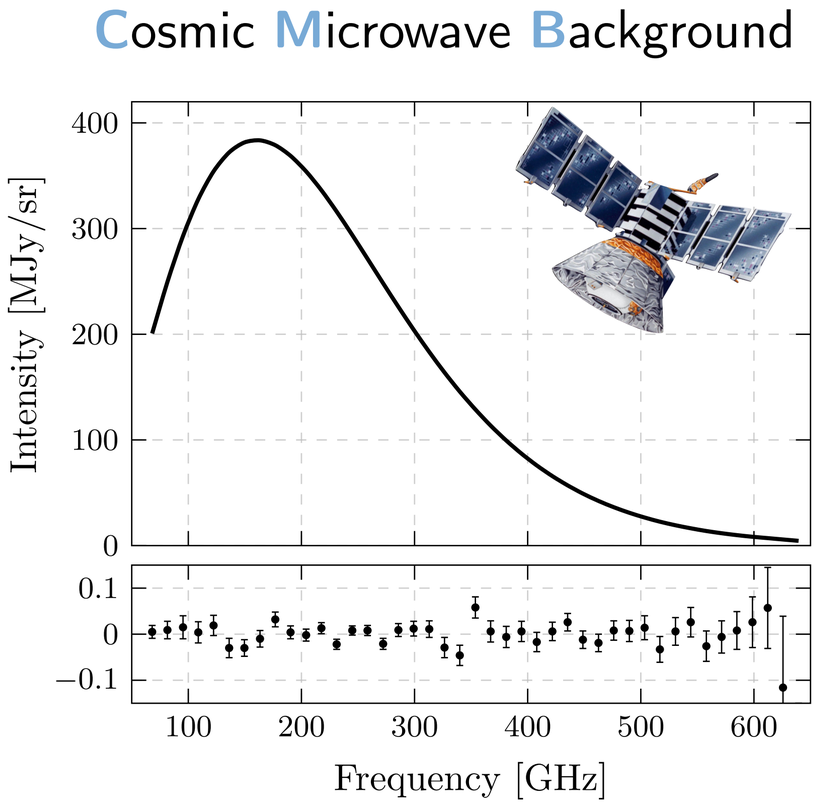


$t = 370\,000\,\text{yrs}$ Atoms form and the first light is released:



This afterglow of the Big Bang is still seen today:



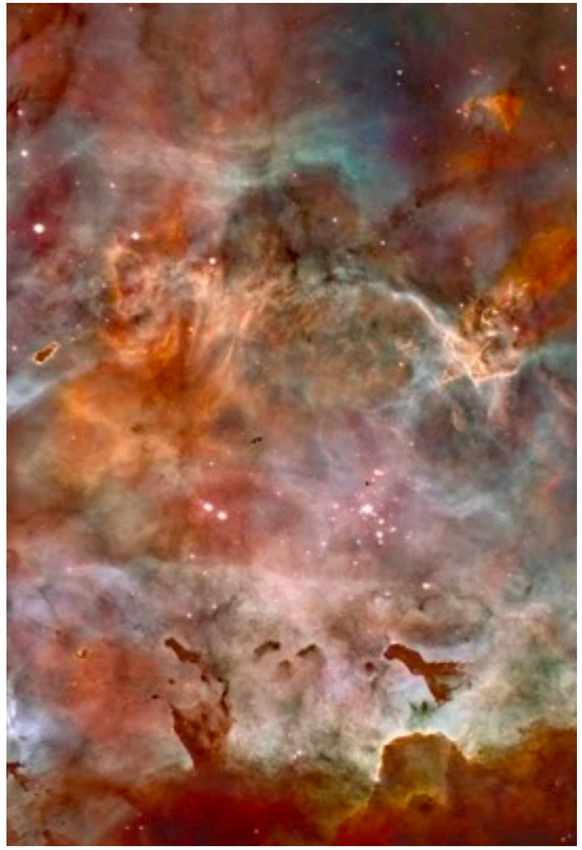


- 410 photons per cubic centimeter
- cooled by the expansion: 2.7 K
- faint microwave radiation: CMB

Measurement of the CMB blackbody spectrum by the COBE satellite. The error bars are too small to be seen in the top panel. In the bottom panel, we therefore also show the residuals relative to a blackbody spectrum with temperature $T_0 = 2.725$ K. Notice the change in scale between the two panels.

$t > 1$ billion yrs

Matter collapses into stars and galaxies:





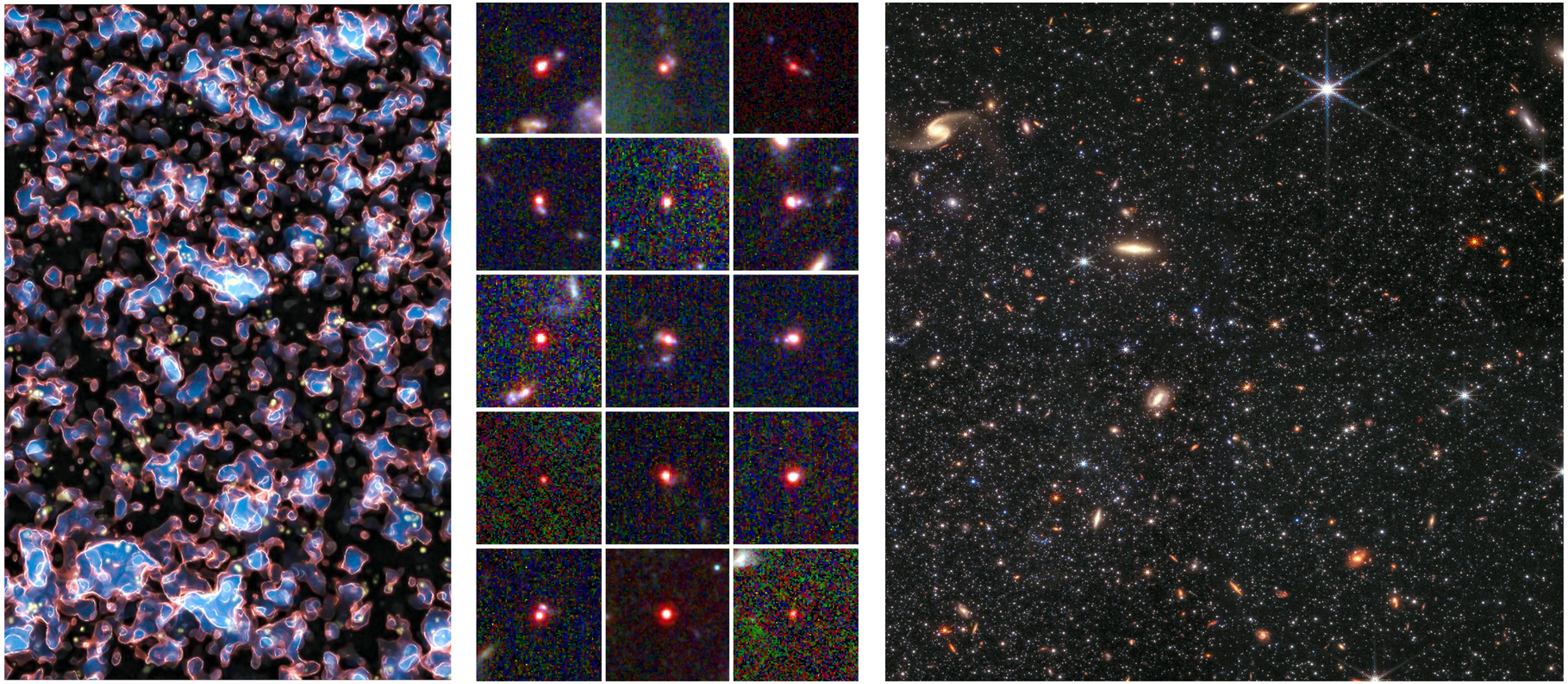
1 billion yrs

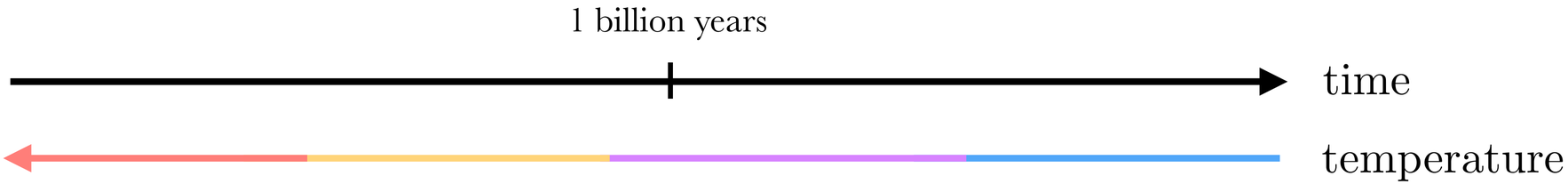
time

temperature

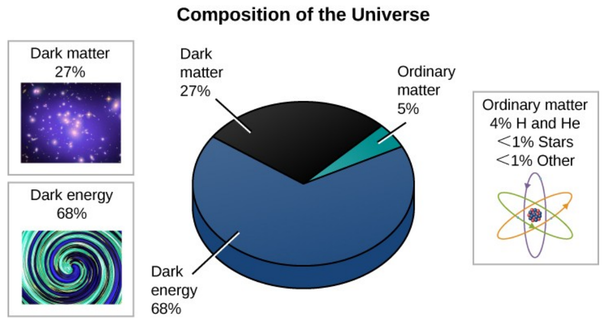
$t > 1$ billion yrs

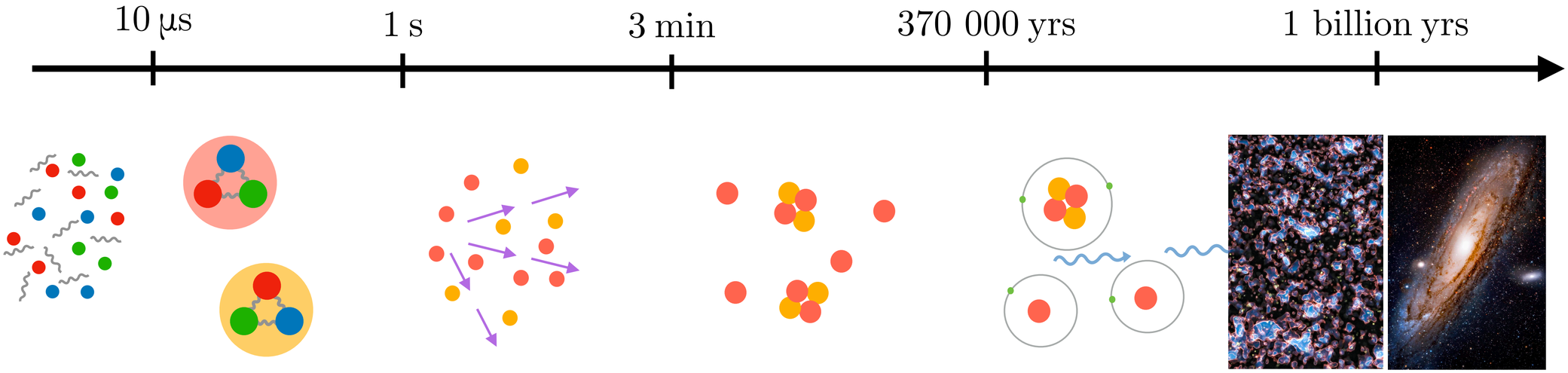
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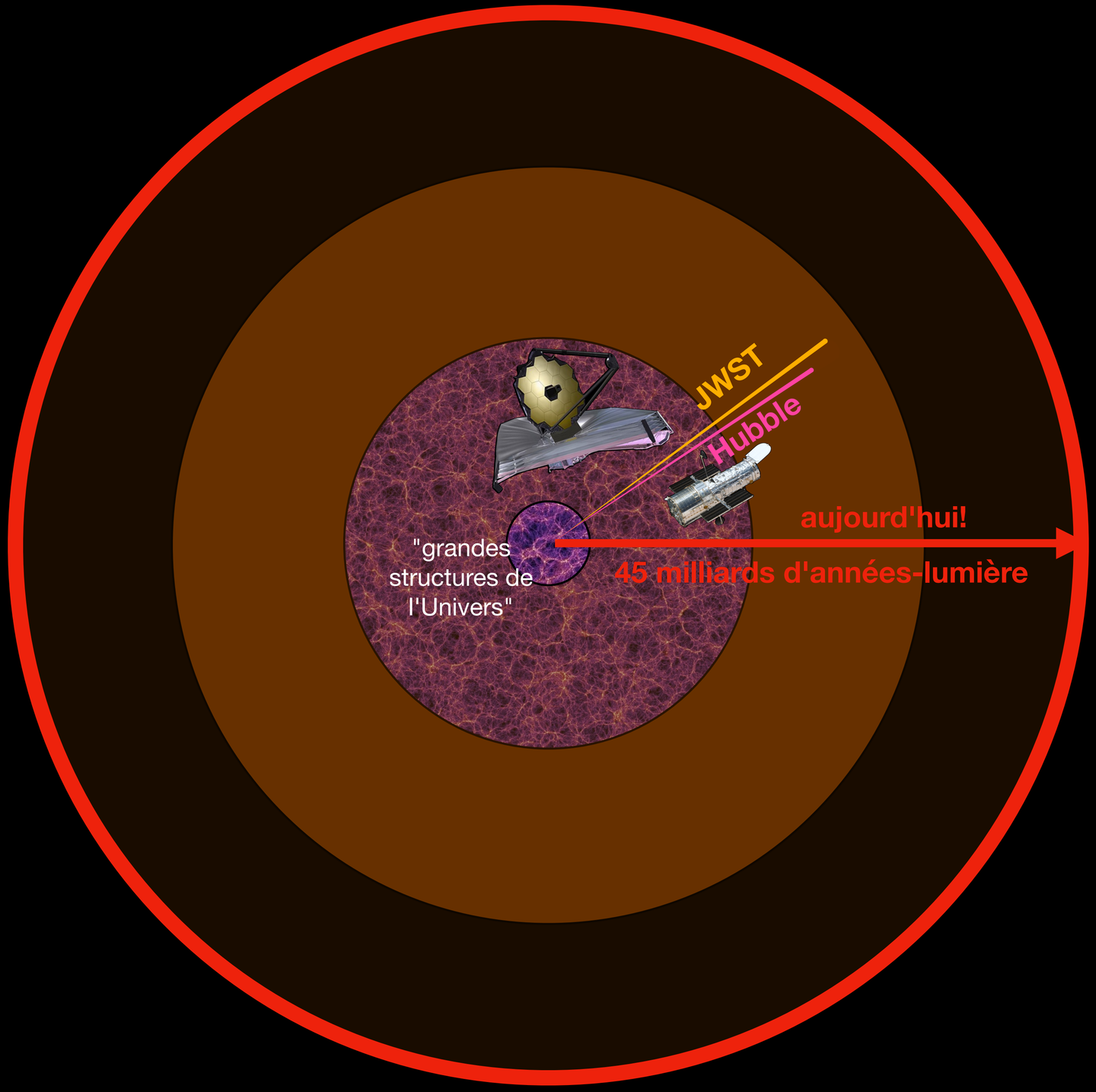


This history of the Universe is an observational fact:





- The basic picture has been confirmed by many independent observations.
- Many precise details are probed by measurements of the CMB.

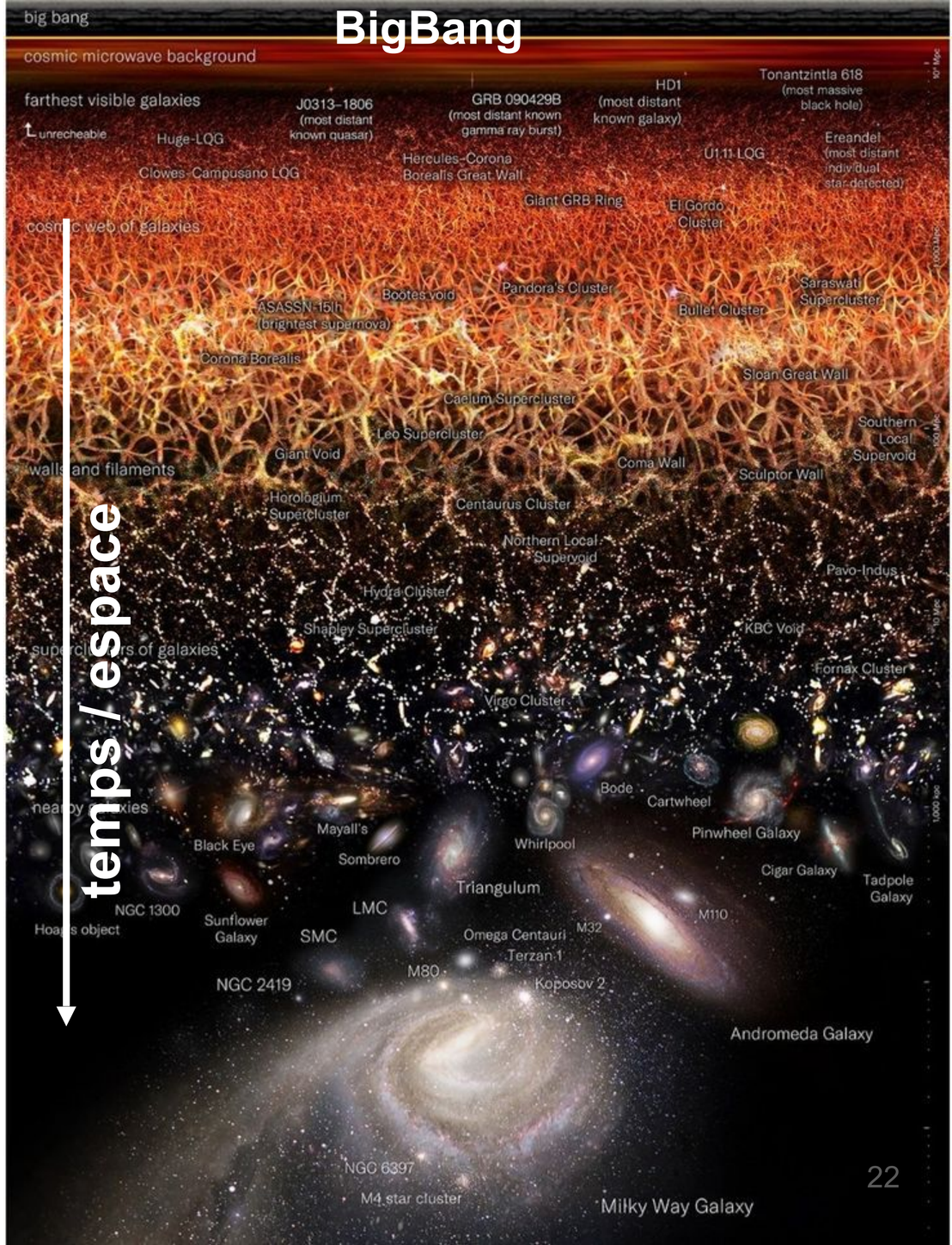

JWST
Hubble
aujourd'hui!
45 milliards d'années-lumière
"grandes
structures de
l'Univers"

Positionnement du groupe cosmologie dans les grandes questions du laboratoire

👉 **Expliquer l’origine, la composition et l'évolution de l’Univers**

👉 **Tester le modèle standard de la cosmologie (ΛCDM) jusqu’à une précision <1%**

👉 **Trouver des signes de nouvelles physiques**



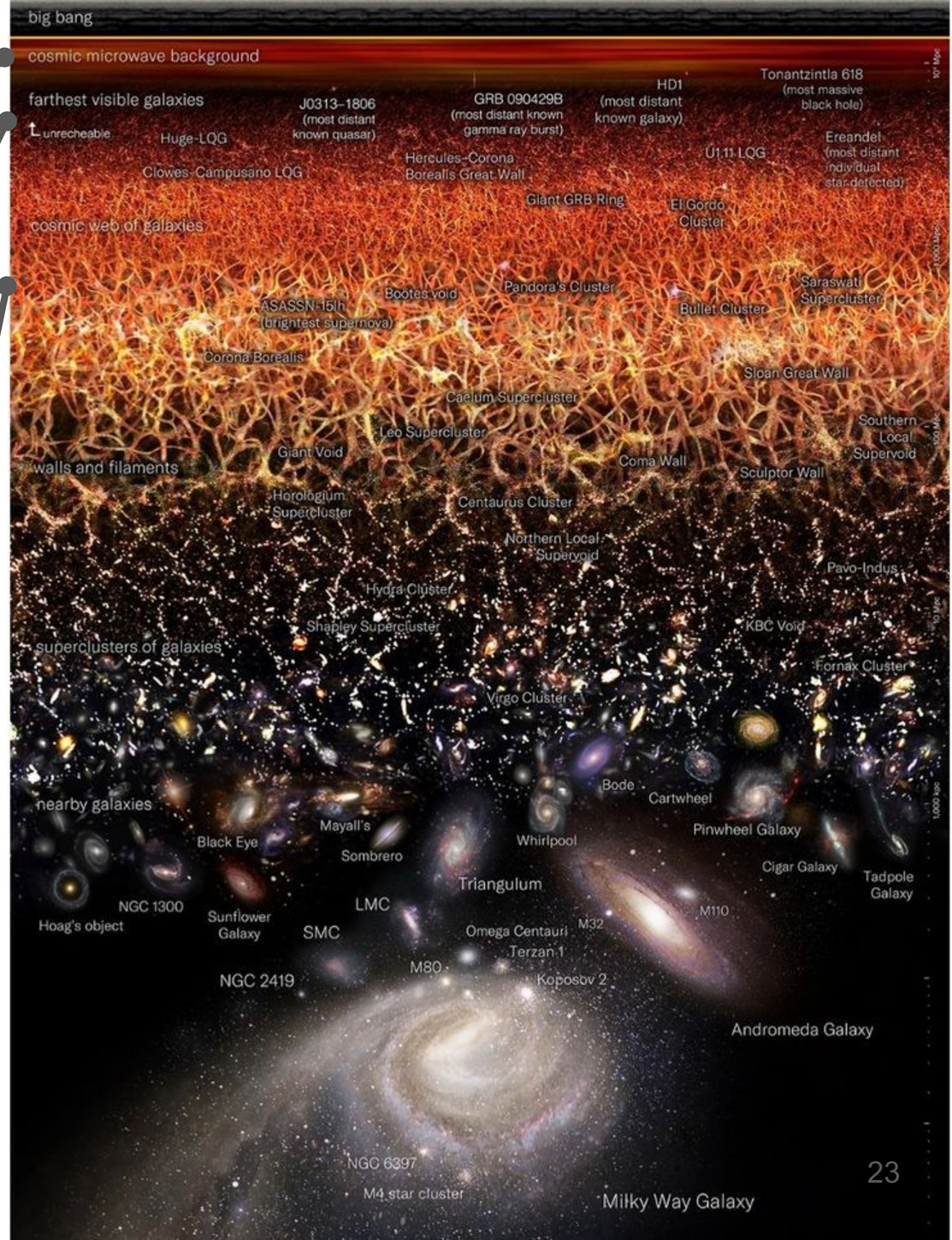
Objectifs scientifiques du groupe

CMB

21cm

Large Scale Structure (LSS)

+ **corrélations croisées entre sondes !**



A Vision for the Next decade

Preparing the French cosmology community for the era of precision, multi-probe cosmology.

DESI
(on-going)

Euclid
(on-going)

Rubin/LSST
(2026-2036)

+other LSS!

Roman Space Telescope
(2027)

Simons Observatory
(on-going)

+21cm

combination of probes

Lazuli
(2028-2030)

SKAO
(2030s)

South Pole Observatory
(on-going)

Gravitational Waves (Einstein Telescope, LISA)
(2035)

+other CMB!

QUBIC TD
(on-going)

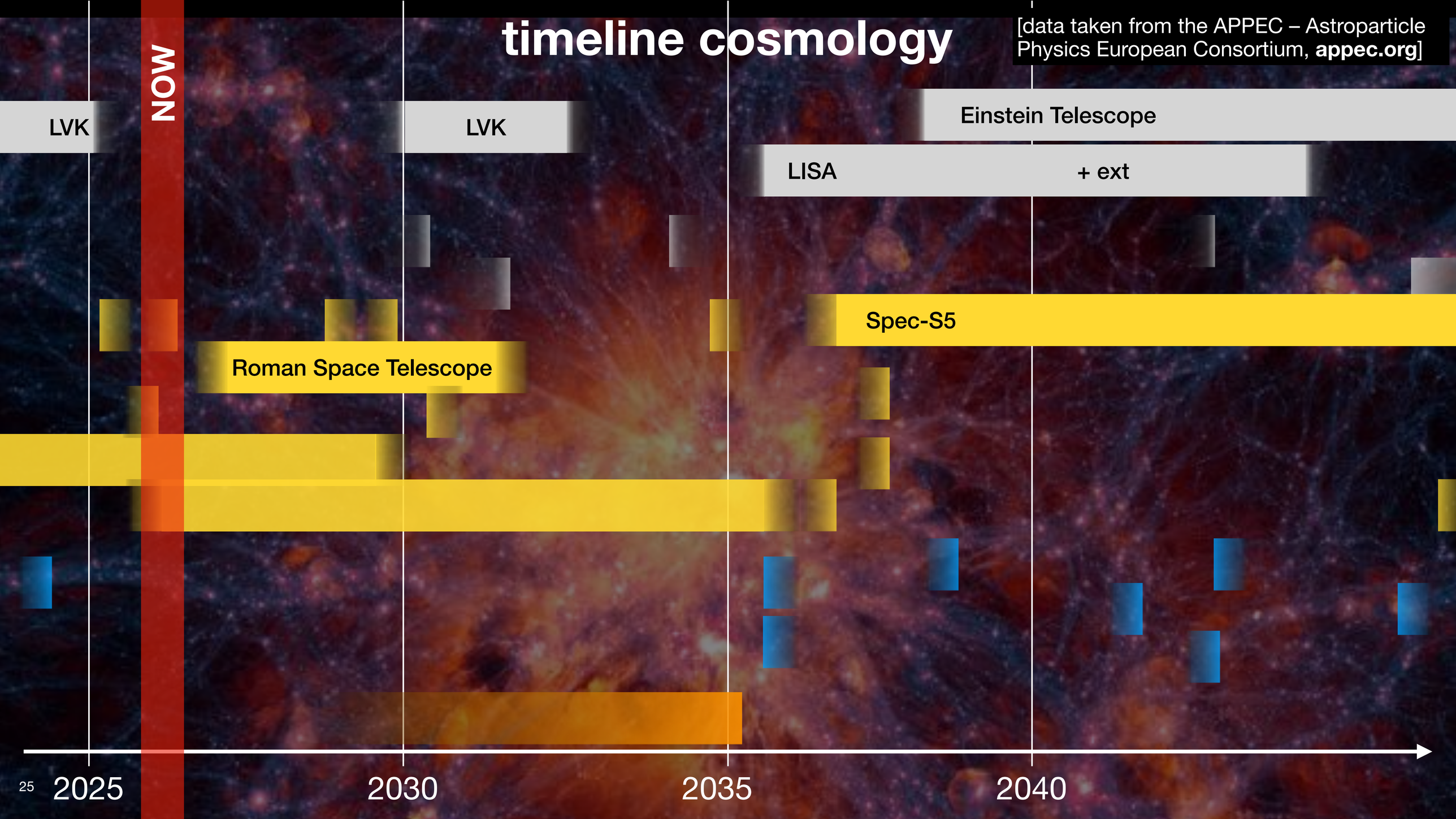
LiteBIRD
(late 2030s)

FOSSIL
(2040?)

+ several other past, current and future projects

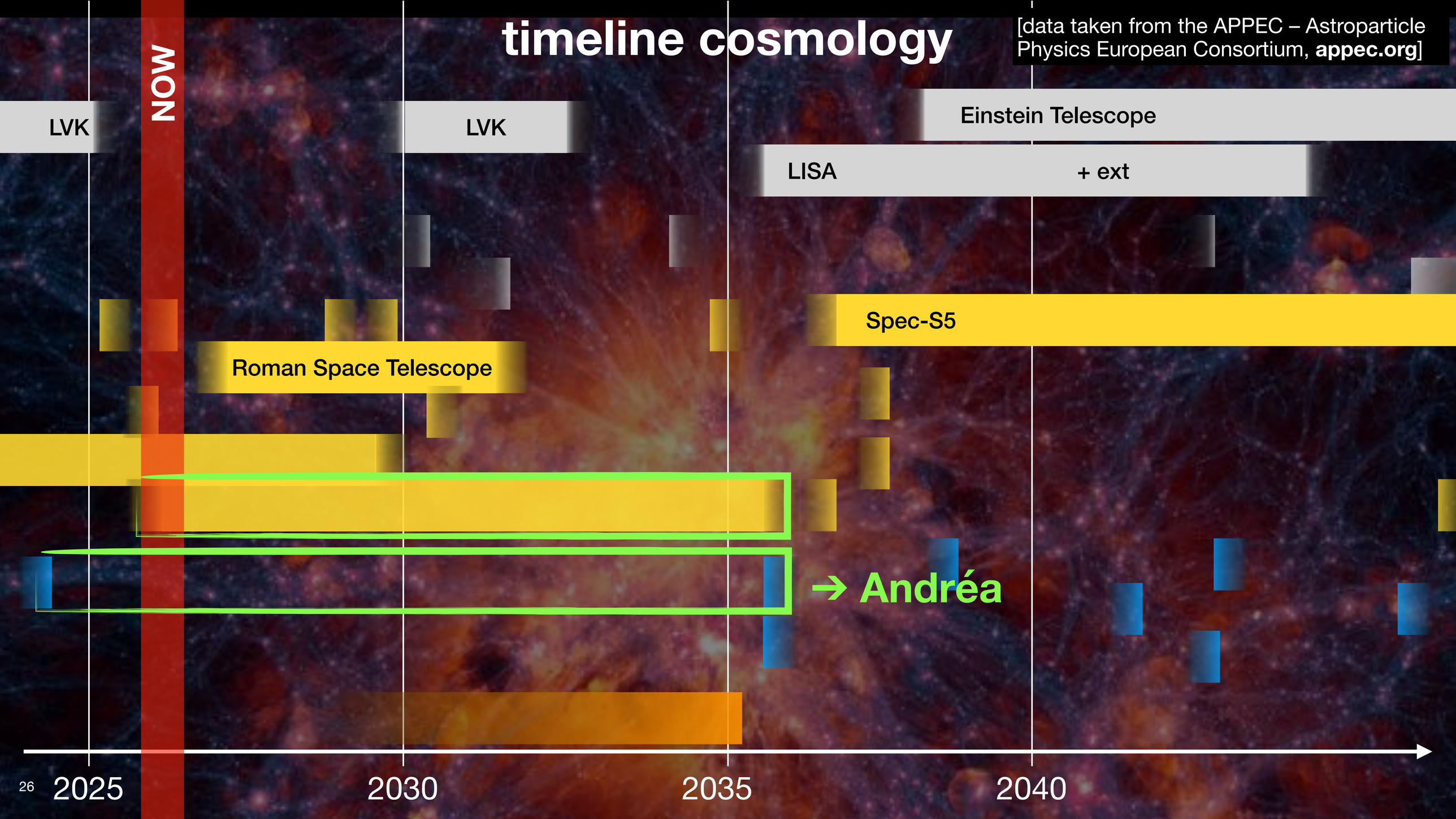
timeline cosmology

[data taken from the APPEC – Astroparticle Physics European Consortium, **appec.org**]



timeline cosmology

[data taken from the APPEC – Astroparticle Physics European Consortium, **appec.org**]

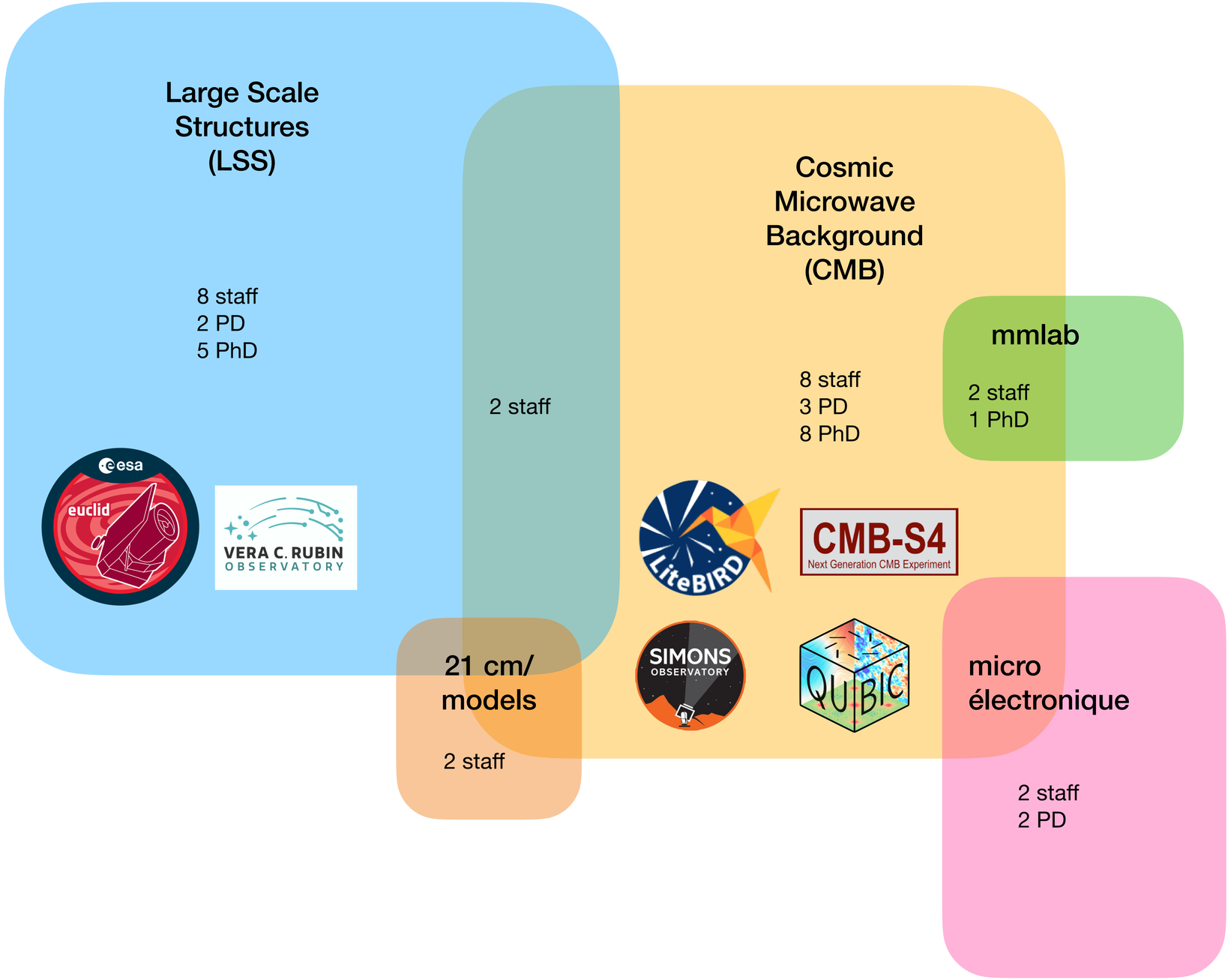




A small section of the Vera C. Rubin Observatory's total view of the Virgo Cluster shows two prominent spiral galaxies (lower right), three merging galaxies (upper right), several groups of distant galaxies, many stars in the Milky Way galaxy, and more.


SDSS


VERA C. RUBIN
OBSERVATORY


Large Scale Structures (LSS)
8 staff
2 PD
5 PhD
2 staff
Cosmic Microwave Background (CMB)
8 staff
3 PD
8 PhD
mmlab
2 staff
1 PhD
21 cm/ models
2 staff
micro électronique
2 staff
2 PD
esa
euclid
VERA C. RUBIN OBSERVATORY
LiteBIRD
CMB-S4
Next Generation CMB Experiment
SIMONS OBSERVATORY
QUBIC

(exemples de) synergies au sein du laboratoire

