

Ongoing and Upcoming Breakthroughs in the Field of Galaxies and Cosmology

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INAF - OAS Bologna

on behalf of
Comitato Scientifico Nazionale n.1 (CSNI)

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Primary Questions RSN I aims to address*

1. What mechanisms regulate the formation and evolution of galaxies and active galactic nuclei? How do these processes depend on the environment and cosmic time? (**galaxy and SMBH evolution**)
2. What is the large scale structure of the Universe at different cosmic epochs? What are the physical mechanisms that govern the properties of matter within cosmic structures? (**cosmic structures**)
3. What is the nature of dark matter and dark energy? How does gravity behave on cosmological scales? (**cosmology**)

RSNI people and topics

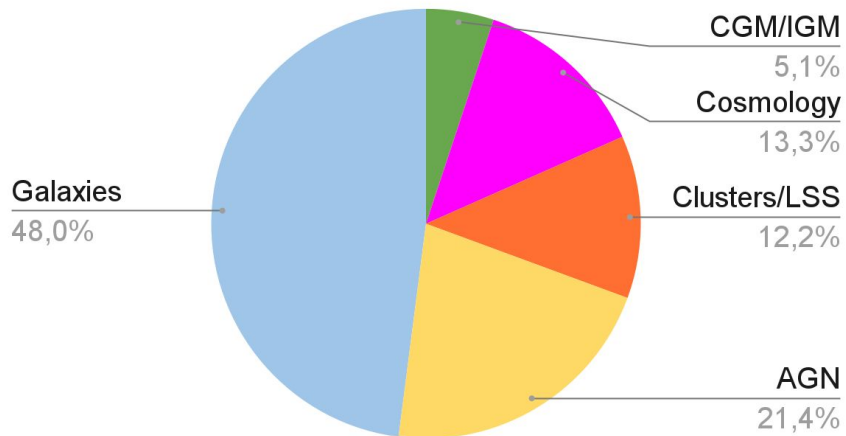
157/911 (17%) of INAF personnel has RSNI as primary (TI+TD+Ass.Inc.Ric)*

*source anagrafica INAF 2023

Schede 2023 - RSNI as primary

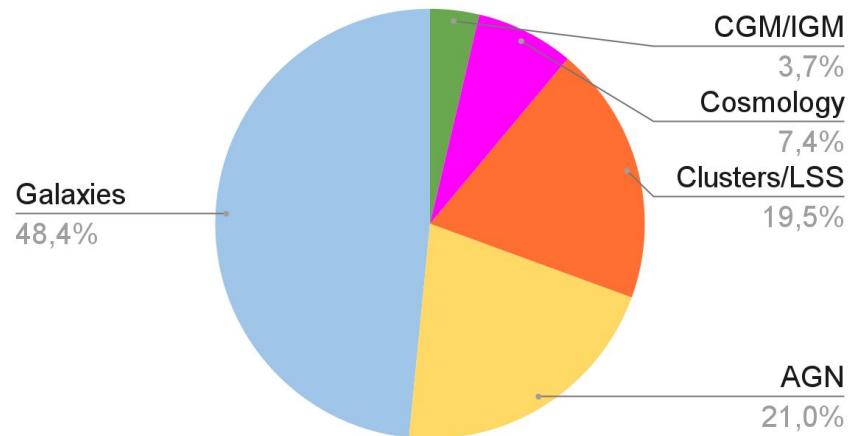
98 schede

N. Schede

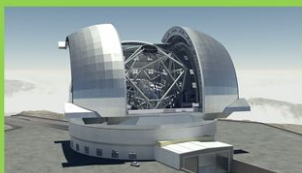


336 FTE (certe)

N. FTE

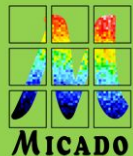


RSNI tools and facilities



VERA C. RUBIN
LSST
Legacy Survey of Space and Time

Euclid
consortium



MICADO



MIRFEO
Multi-conjugate Adaptive Optics Relay For
ELF Observations

MOSAIC



LBTO



James Webb Space Telescope
JWST
NASA • ESA • CSA



NASA | ESA
hubble



VST
INAF



athena

eROSITA



XRISM
X-Ray Imaging and Spectroscopy Mission



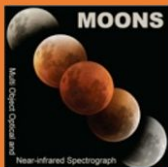
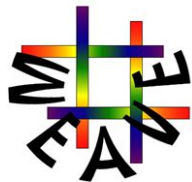
CHANDRA
X-RAY OBSERVATORY



xmm-newton



NLS1A



MOONS



Near-infrared Spectrograph



4
MOST

MAVIS
Deeper than HST, sharper than JWST

LEONARDO
CINECA



SOUTH
POLE
TELESCOPE

SPT



ALMA
ATACAMA LARGE MILLIMETER ARRAY



SKA
SQUARE KILOMETRE ARRAY



MeerKAT



iram
Institut de
Radioastronomie
Millimétrique



GMRT



SRT
SOUTH POLE TELESCOPE



ASKAP



LOFAR

RSNI highlights*

- Characterization of galaxies and supermassive black holes in the early Universe through multi-band observations and gravitational lensing;
- improved estimate of galaxy physical properties, including their ability to form stars and chemical abundances, at different cosmic epochs through deep spectroscopic campaigns;
- probe of the formation and evolution of galaxy (proto-)clusters and of how these environments modify the physical properties of their member galaxies;
- tests of cosmological models and growth of structure through the observations of diffuse matter in galaxy clusters and filaments and the demographics of low luminosity galaxies.

RSNI contribution
to ongoing and upcoming breakthroughs
in the field of galaxies and cosmology
(within this decade)

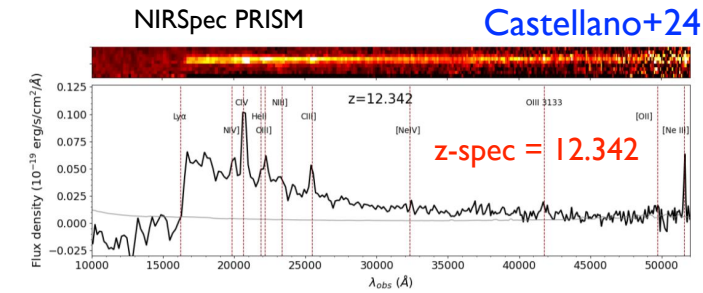
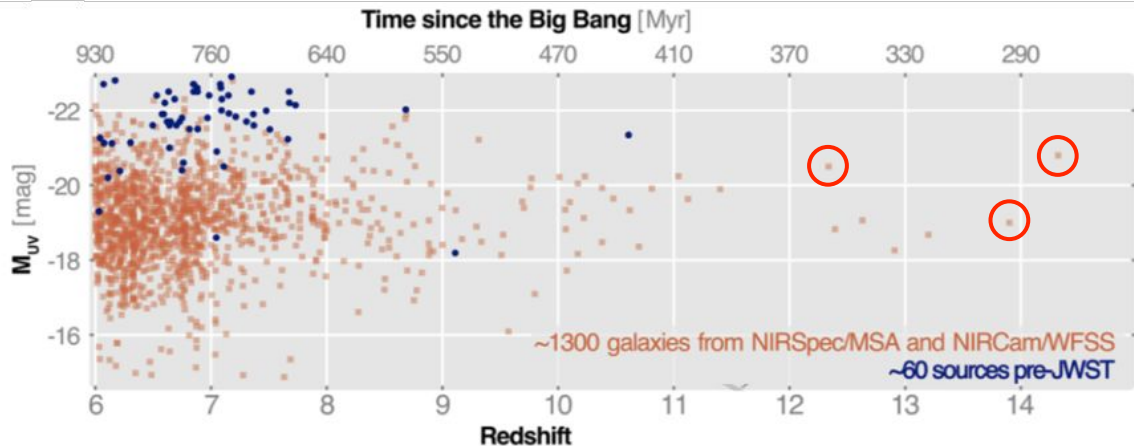
Question I (galaxy and SMBH evolution)

- I. What mechanisms regulate the formation and evolution of galaxies and active galactic nuclei? How do these processes depend on the environment and cosmic time?

High-z Universe : the ongoing JWST revolution



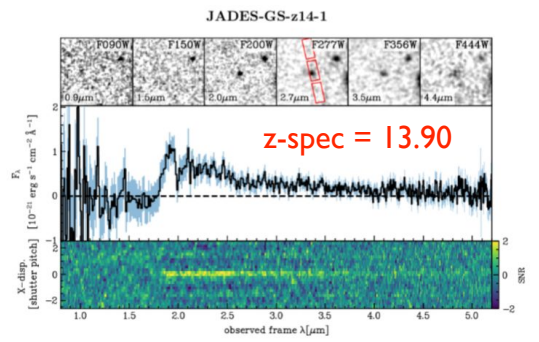
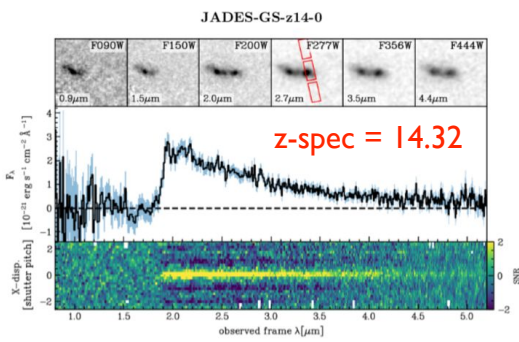
Galaxies



highly ionized species: strong UV field from young, massive stars

ISSI Breakthrough Workshop 2024 [arXiv:2405.21054](https://arxiv.org/abs/2405.21054)

the most distant galaxies discovered



Carniani+24

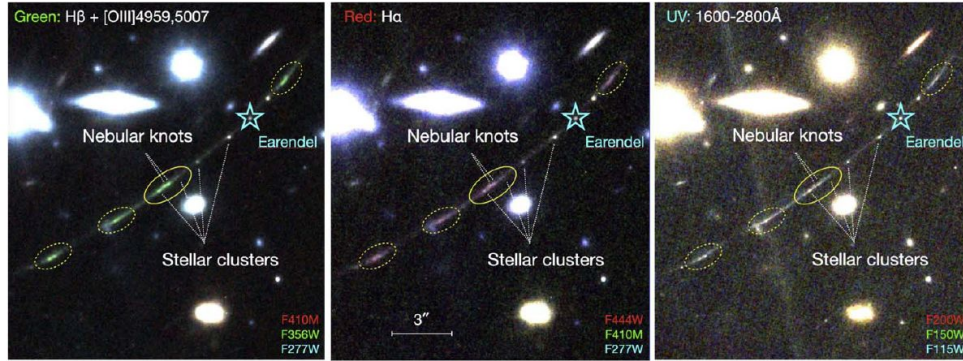


High-z Universe : the ongoing JWST revolution



Galaxies (star clusters) in lensed fields

Sunrise Arc (the most magnified galaxy at $z \sim 6$)

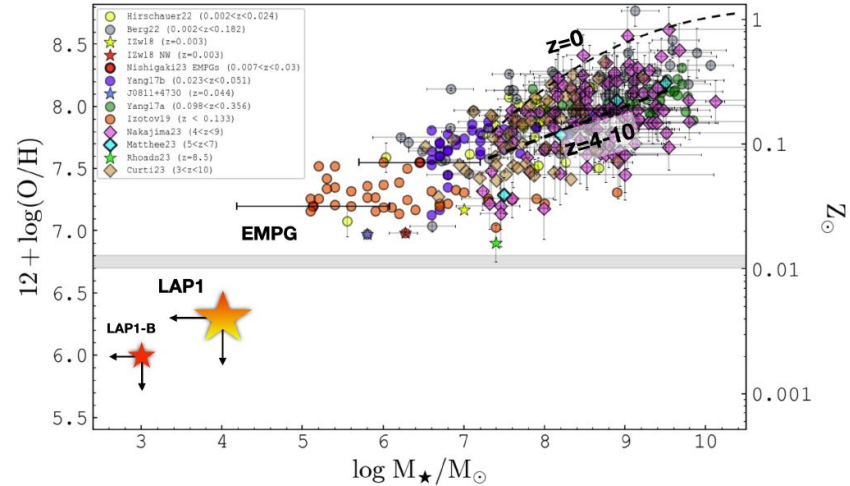


six Young Massive Clusters:

$$r \sim 1-20 \text{ pc}, M_* \sim 10^{6-7} M_{\text{sun}}, \Sigma_* \sim 1000 M_{\text{sun}}/\text{pc}^2$$

likely progenitors of local globular clusters

LAP1 at $z=6.64$



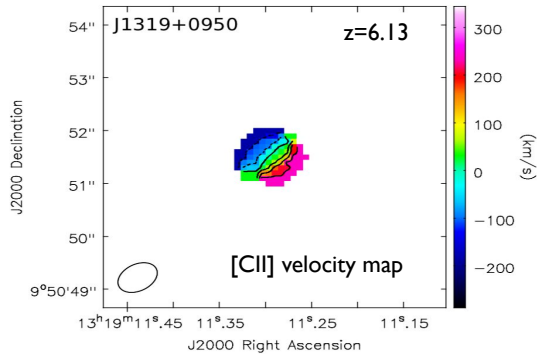
the most metal-poor star-forming region known in the reionization era:
PopIII site?

High-z Universe : the ongoing JWST revolution



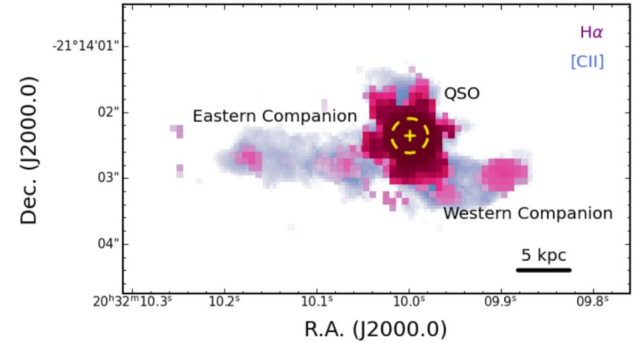
Black Holes

ALMA 2013

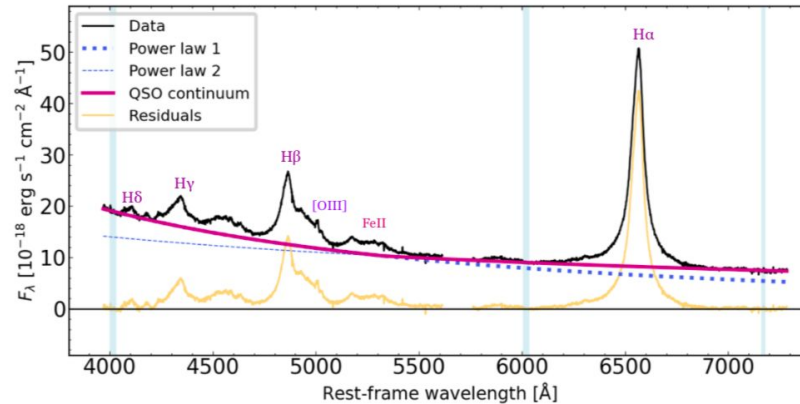


quasar-galaxy merger
PJ308-21 at $z=6.23$

JWST (+ALMA) 2024



Wang+13

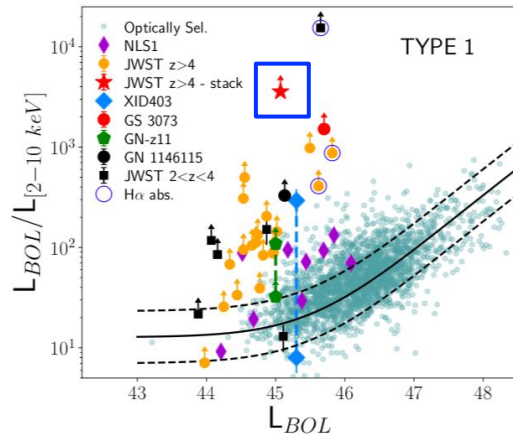
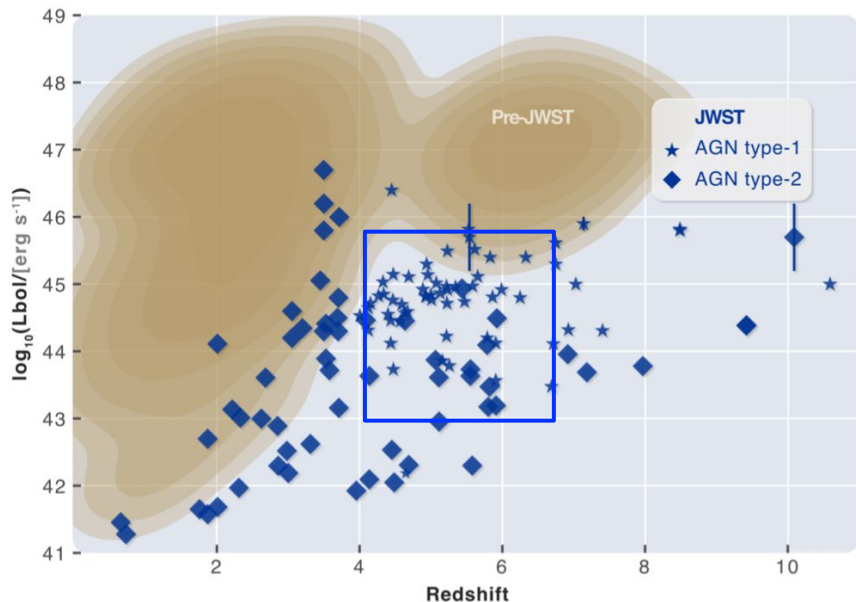


Loiacono+24

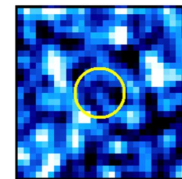
High-z Universe : the ongoing JWST revolution



Black Holes

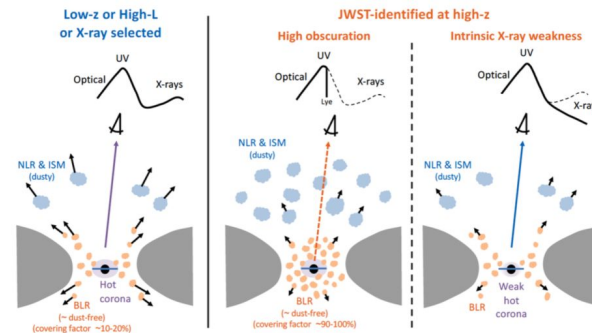


Type I X-ray stack



large, new population of X-ray undetected BLAGN: new obscuration pattern? weak corona?

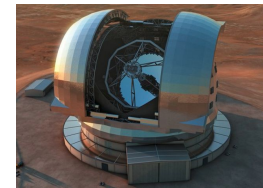
ISSI Breakthrough Workshop 2024 [arXiv:2405.21054](https://arxiv.org/abs/2405.21054)



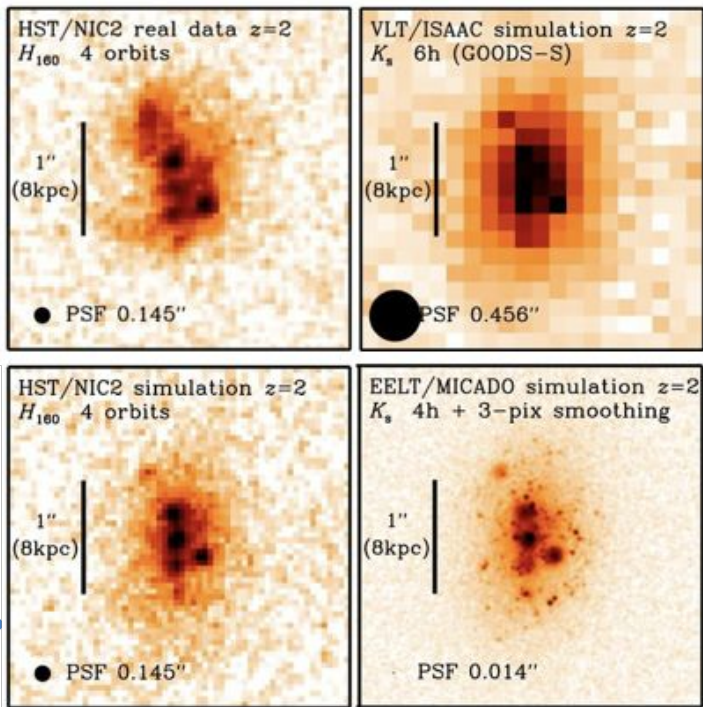
Maiolino+24

High-z galaxies : forthcoming revolutions

ELT follow-up of high-z systems

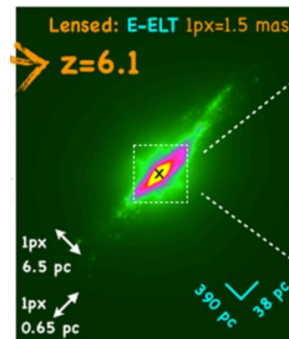
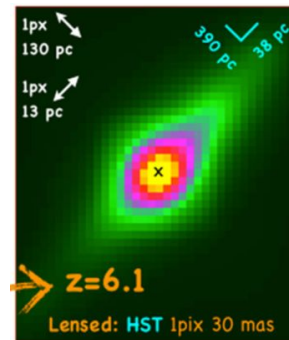


massive galaxy at $z=2$



ESO ELT website

lensed dwarf galaxy at $z=6.1$

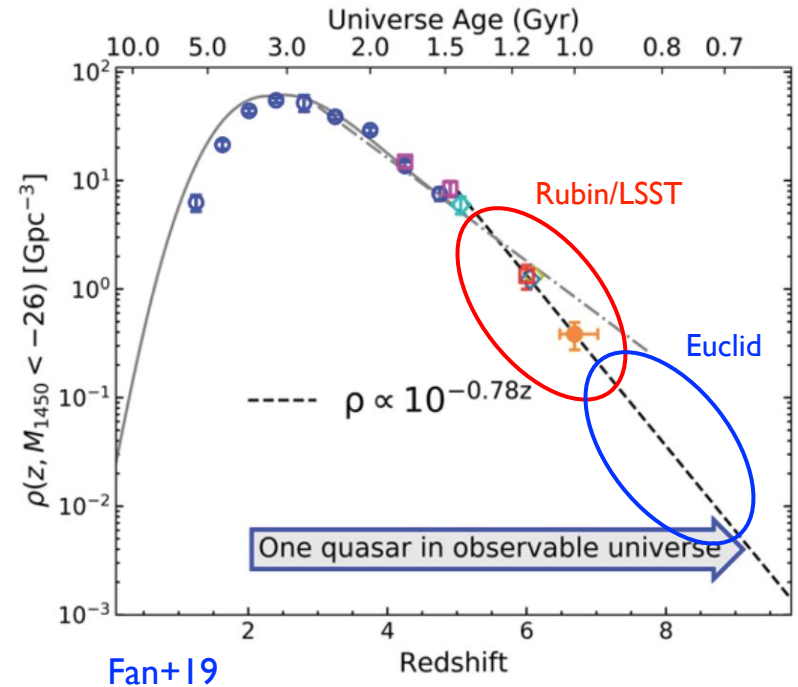


MORFEO+
MICADO simu.

Vanzella+19

>10x luminous quasars from deep-and-wide (>10⁴ deg²) surveys

	Rubin/LSST	Before Rubin
High-redshift quasars, z>6	~8,000	~200
	Euclid	Before Euclid
High-redshift quasars, z>7	~100	~10
High-redshift quasars, z>8	~10	0

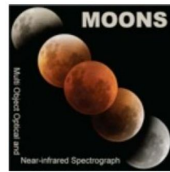


Nominal LSST Start Date: August 2025

First Data Release in 2026

<https://rtn-01.lsst.io/>

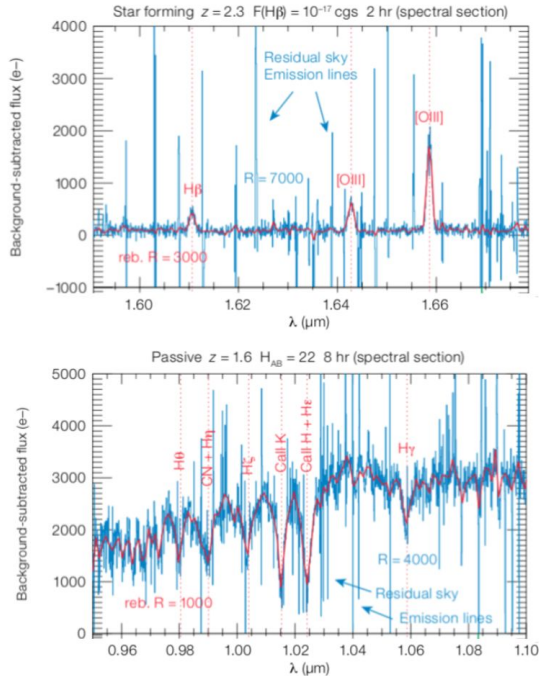
Galaxy evolution: revolutions from spectroscopic surveys



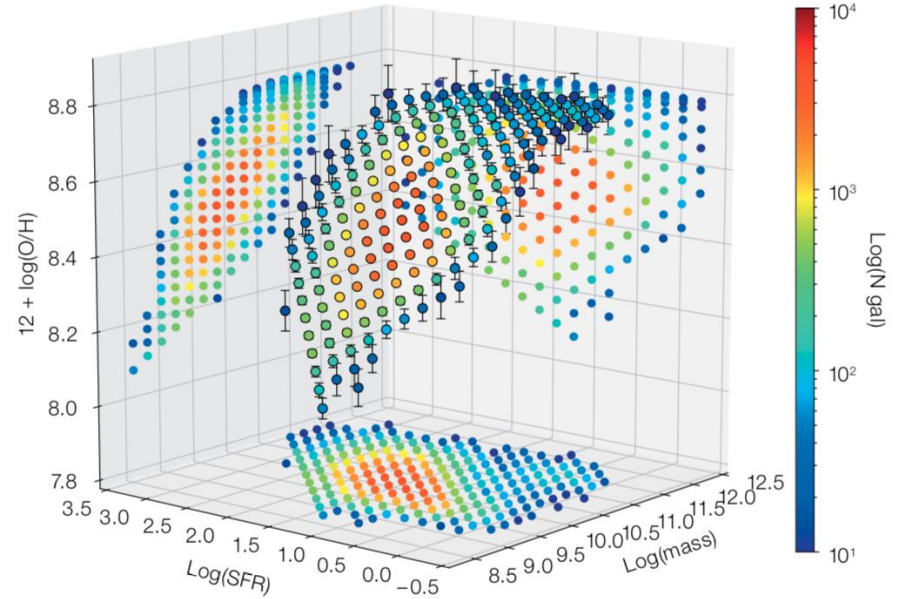
MOONRISE

190 nights GTO:
key diagnostics
for $>10^5$ gals
at $z=0.9-2.6$

strong italian
participation



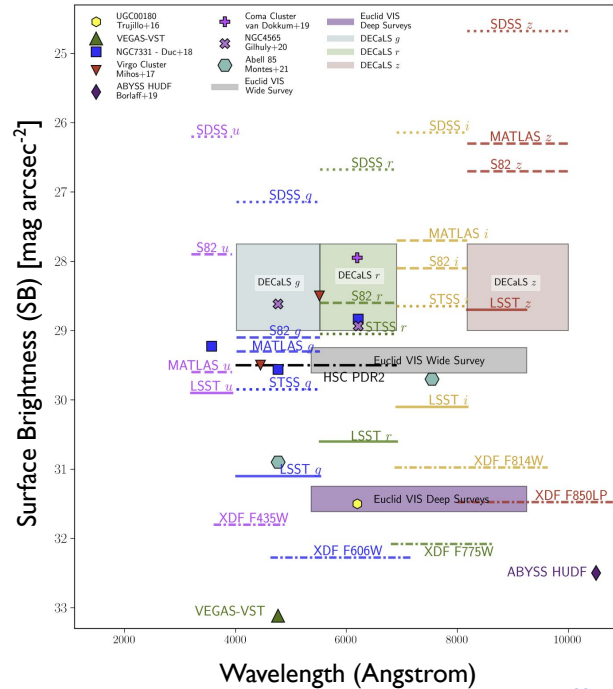
metallicity scaling relations and their evolution at $z > 1$



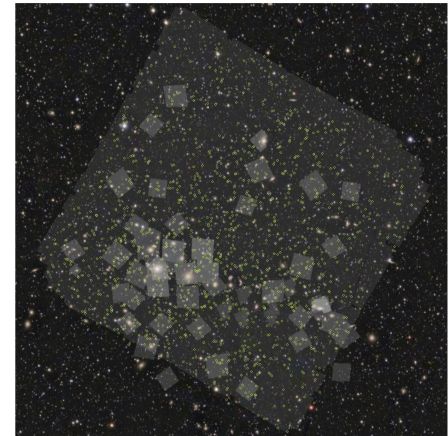
Galaxy evolution: revolutions from imaging and spectroscopic surveys

Euclid as a dwarf-galaxy machine:
same SB sensitivity as HST on 1000x larger area

What	Euclid (EWS, EDS)
Galaxies at $1 < z < 3$ with good mass and morph.	$\sim 2 \times 10^8$
Massive galaxies ($1 < z < 3$) w/spectra	$\sim \text{few} \times 10^3$
H α emitters/metal abundance in $z \sim 2-3$	$\sim 4 \times 10^7 / 10^4$
[OIII] λ 5007 emitters $1.5 < z < 2.3$	$\sim 6 \times 10^6$
Clusters at $0.1 < z < 2$ (30% at $z > 1$)	$\sim 10^6$
AGN (70% Type 2)	$\sim 4 \times 10^7$
Galaxy mergers	$\sim 10^5 - \text{few} \times 10^6$
Strongly lensed galaxy-scale lenses	$\sim 100,000$
$z > 8$ QSOs	~ 10
Globular clusters	$\sim 350,000$
Deepest images of galaxies at $D < 100$ Mpc	$\sim 25,000$



Marleau+24



Perseus field: 600 new
dwarf galaxies discovered
in the cluster

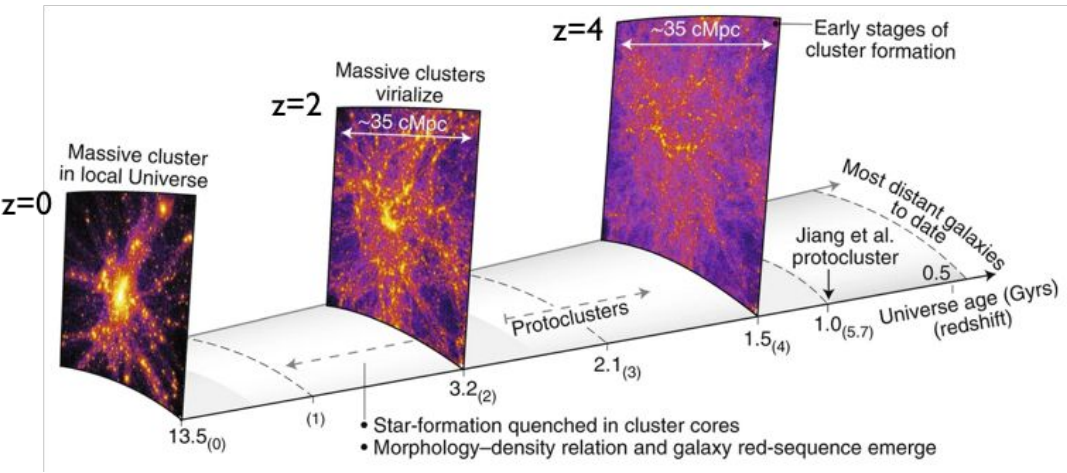
Mellier+24; Voggel+24;
Pozzetti (priv. comm.)

Borlaff+21

Question 2 (cosmic structures)

2. What is the large scale structure of the Universe at different cosmic epochs? What are the physical mechanisms that govern the properties of matter within cosmic structures?

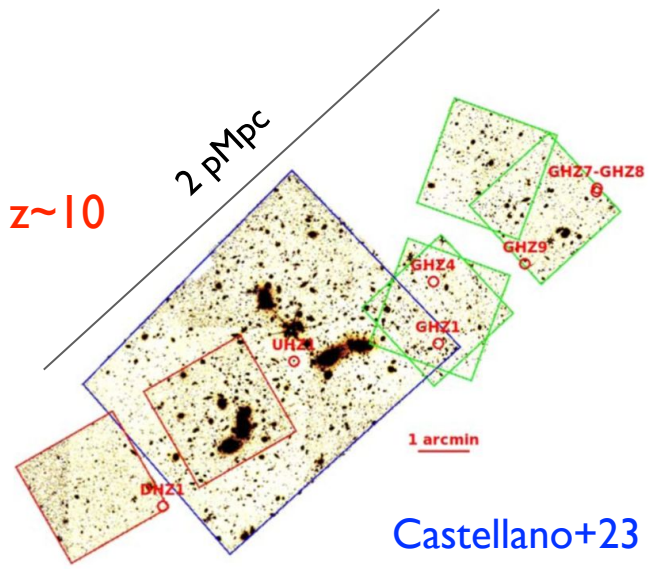
Large scale structures in the early Universe



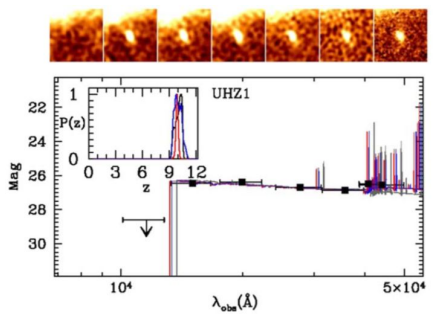
JWST LSS/protoclusters at $z > 5$:
 Helton+23, Morishita+23,
 Kashino+23, Eilers+24,
 Wang+23

Rosati+18

LSS at $z \sim 10$



Castellano+23

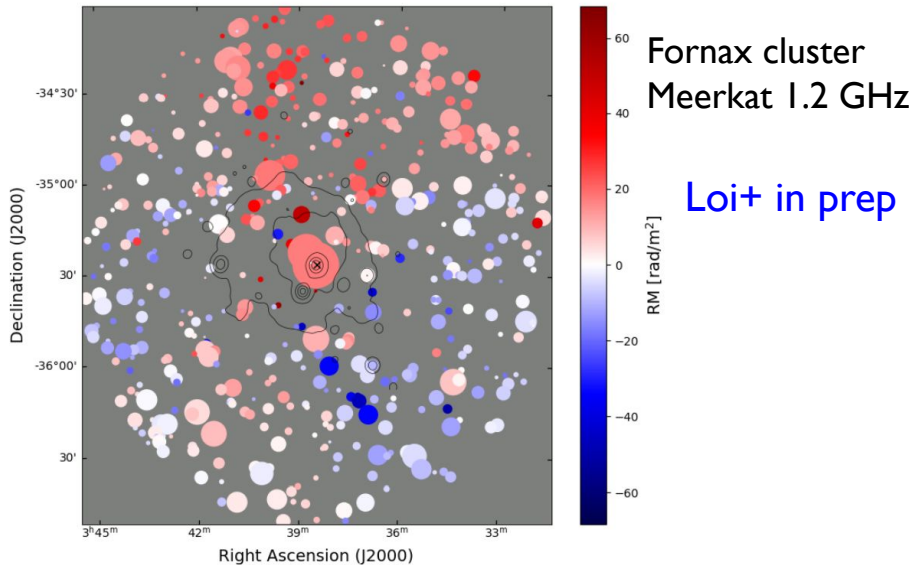




Large scale structure: cosmic magnetism

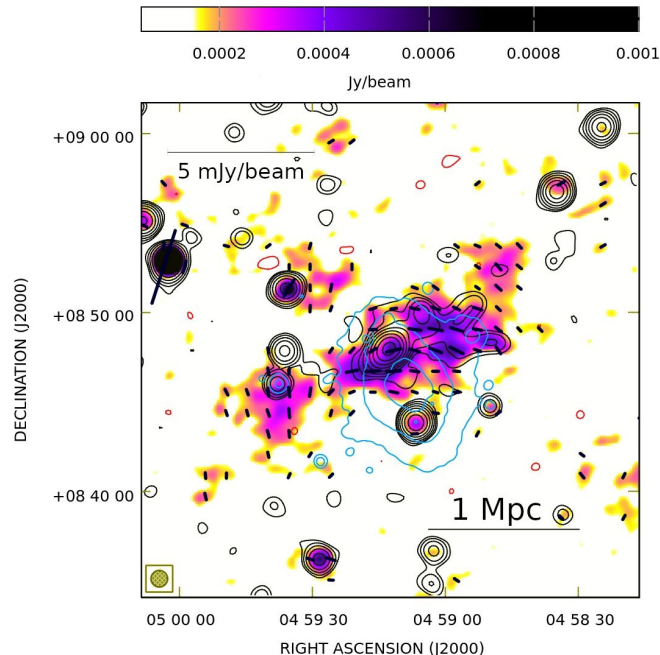
Faraday rotation

GALACTIC SUBTRACTED RM



densest rotation measure grid ever built
(80 polarized sources/deg²)

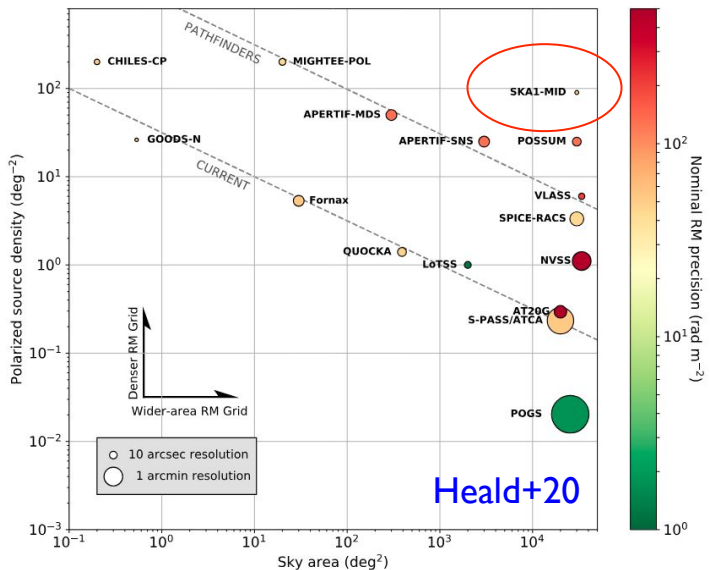
Radio (polarized) emission from ICM



JVLA 1.4 GHz polarized emission on > 1 Mpc scales

Prospects for SKA

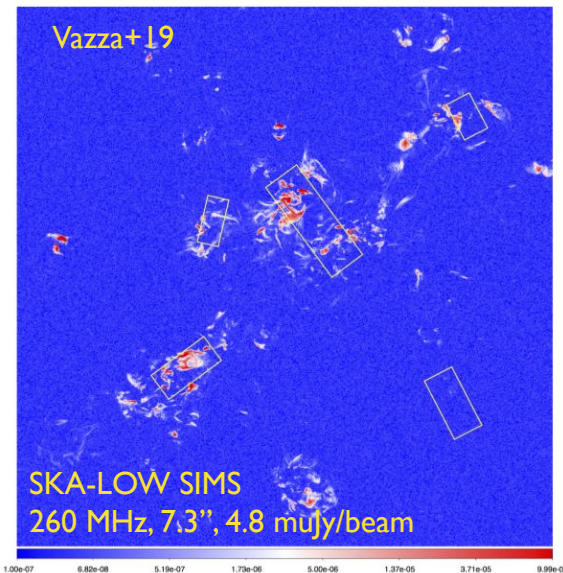
Faraday rotation



SKA-MID will deliver a rotation measure for a few millions sources: **trace cosmic web magnetization and infer their origin**

Carretti+23

Radio emission from ICM



SKA-LOW: emission from ICM, bridges of galaxy clusters pairs (Govoni+19), and cosmic filaments probing low-T and -n_e matter missed by X-ray observations.

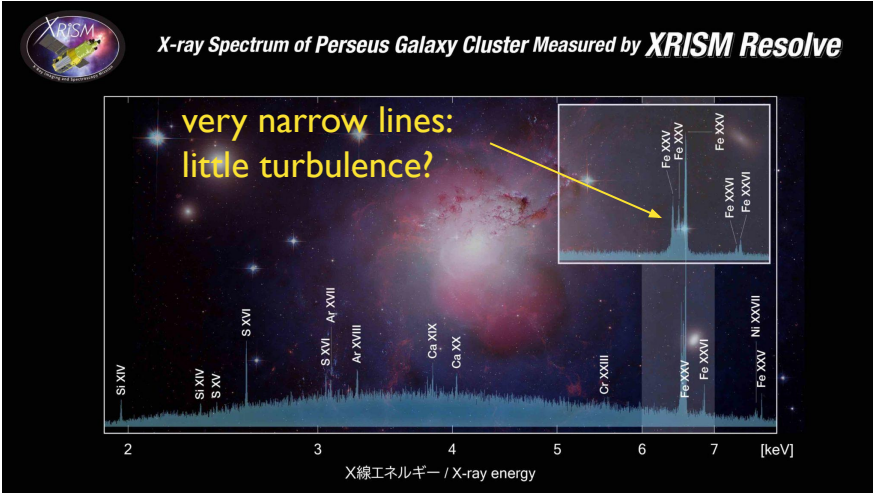


Dense environments, clusters / proto-clusters



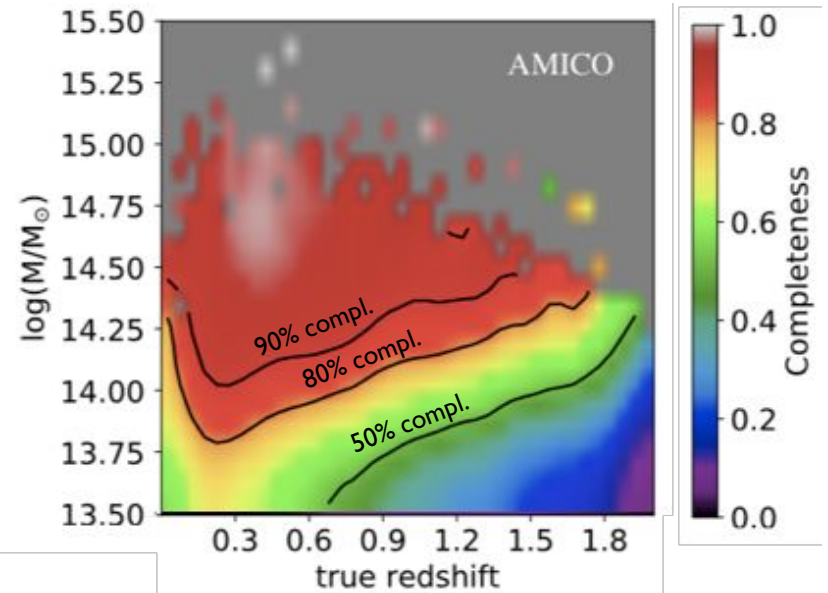
z=0

z=2



RSN1 strong in cluster / proto-cluster field. New parameter space opened by high-res (5eV) X-ray spectra from XRISM

Euclid coll. 2019, 2024



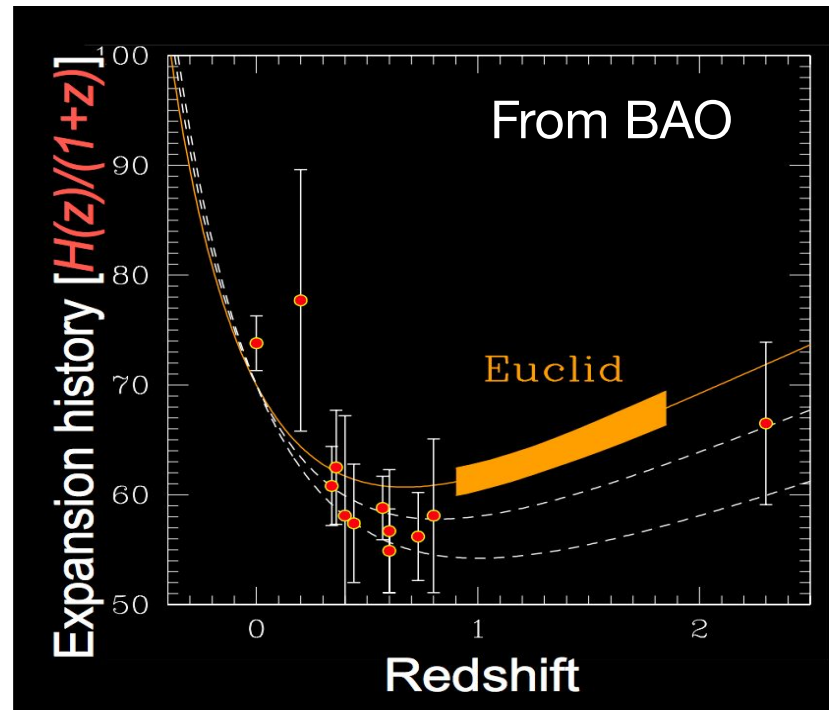
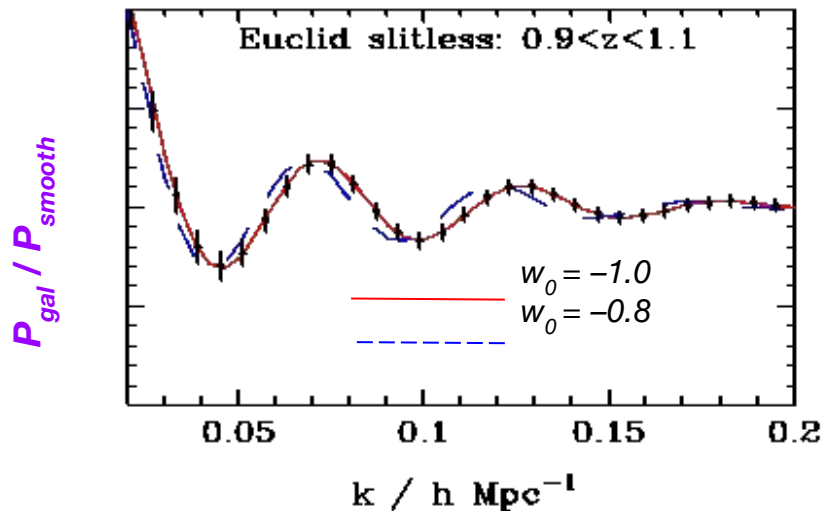
~10⁶ clusters at z<2 expected from Euclid surveys (30% at 1<z<2)

Question 3 (cosmology)

3. What is the nature of dark matter and dark energy? How does gravity behave on cosmological scales?

Cosmology and growth of structure: the forthcoming Euclid revolution

The Baryon Acoustic Oscillations (BAO) in the galaxy correlation function provide a standard ruler to measure the expansion history



(Forecasts from Euclid Collaboration, 2020)

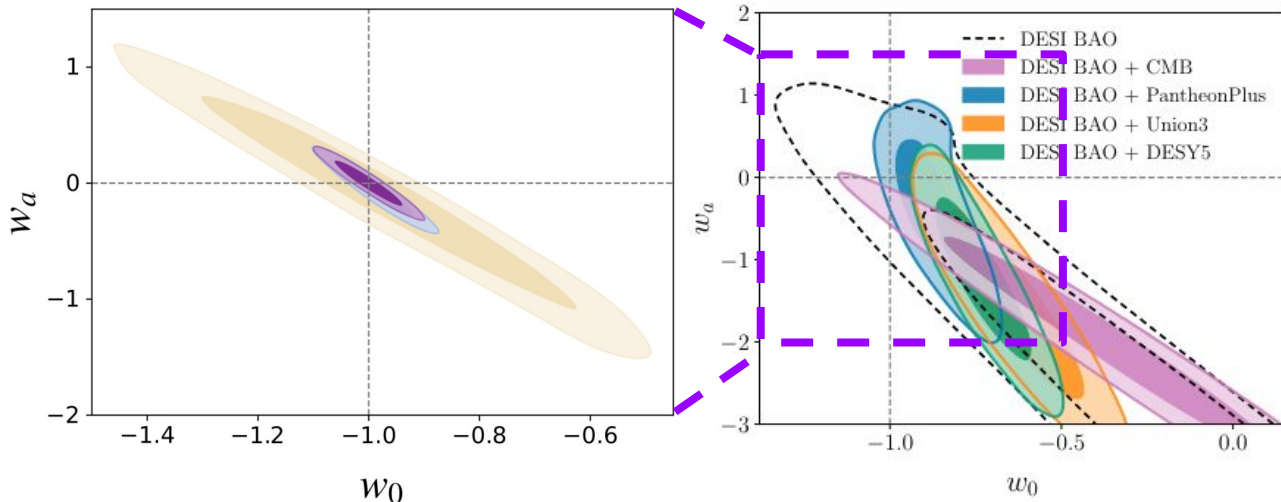
Cosmology and growth of structure: the forthcoming Euclid revolution

The dark energy equation of state $w \neq -1$ indicates a departure from the cosmological constant, and requires a new physical model of dynamical dark energy.

Parametrized evolution of the dark energy equation of state:

$$w(z) = w_0 + w_a \frac{z}{1+z}$$

- $w_0 w_a$ CDM (GCsp)
- $w_0 w_a$ CDM (3x2pt)
- $w_0 w_a$ CDM (3x2pt + GCsp)



Euclid Forecast (Mellier et al 2024)

DESI Collaboration 2024

Final remarks

This is truly a transformational era for our understanding of cosmic structures and of how galaxy and SMBH evolve.

Further transformations - including updates to the cosmological model - are expected by the end of this decade.