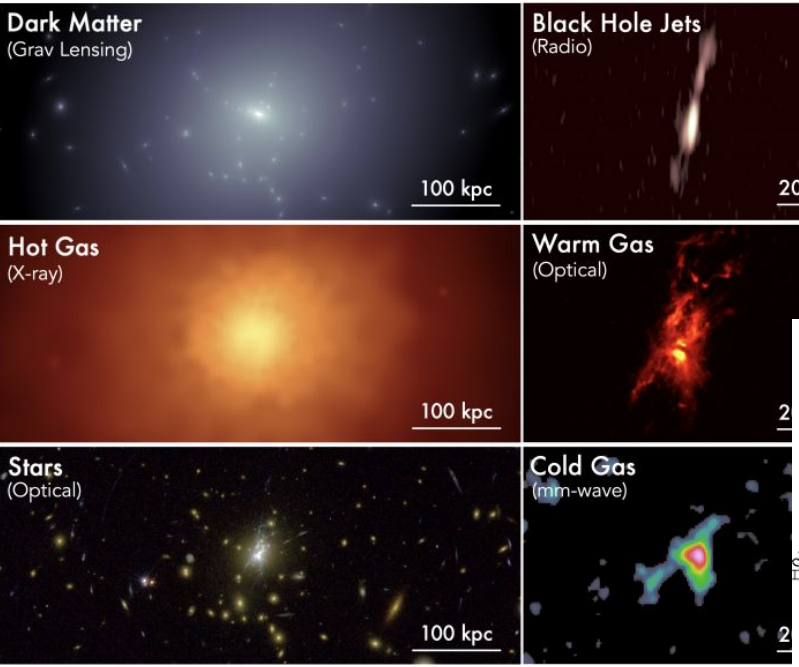
Open questions

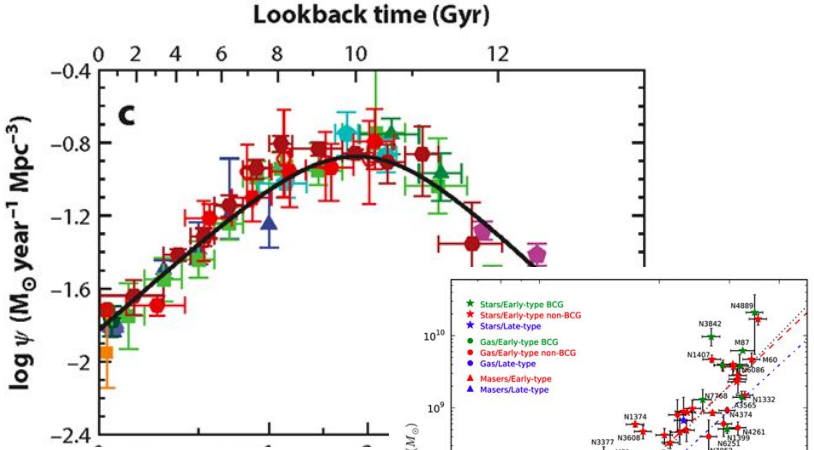
Formation and evolution of galaxies and AGN

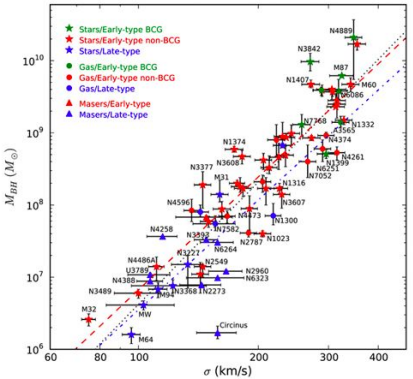
Laura Pentericci & Micol Bolzonella

Giornate INAF del RSN 1: Galassie e Cosmologia - Napoli, III ottobre 2022

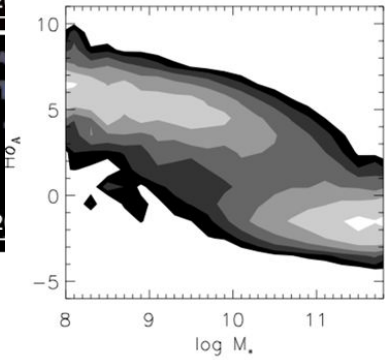
Galaxies are complex, multi-scale, evolving systems





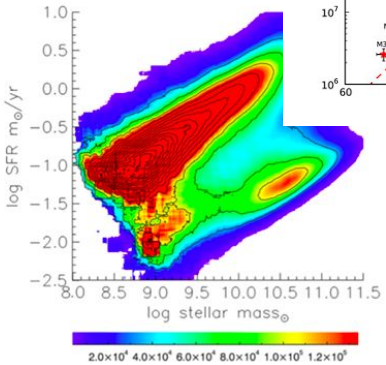


❖ Colour—Magnitude Relations



Bower, Lucey & Ellis 1992;
Kauffman et al. 2003, 122,808 galaxies

❖ Star Formation Ma Sequence



Renzini & Peng 2015, ~240,000

Galaxy formation: the accepted (?) framework

- Halos grow by gravitational amplification of fluctuations in an initially near-uniform distribution of pre-existing dark matter
- Galaxies are formed when gas cools and condenses at the centres of these massive halos. Black holes and galaxy formation and evolution are tightly linked
- The efficiency of galaxy formation is limited by feedback processes which must be very effective in low and high mass halos, and have various physical origins, with AGN as main (?) contributors
- The morphological transformations (growth in size and change of internal structure) are regulated primarily by angular momentum generation and transfer

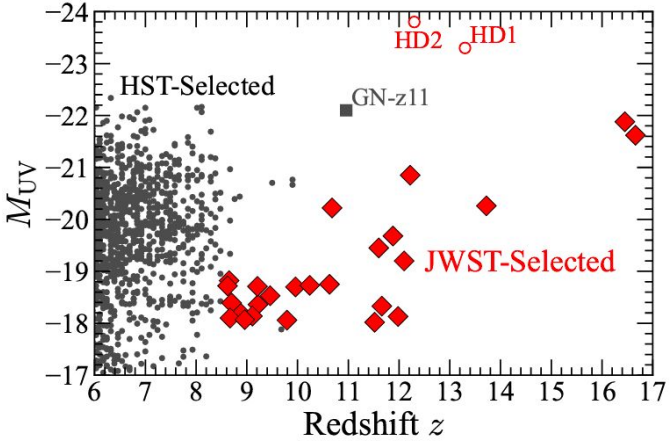
Fundamental aspects are still unknown

- When did the first galaxy form? what were their stellar populations properties?
- How and when did supermassive black holes form? Can they quickly assemble at high redshift?
- How do galaxies exchange matter and energy with their intergalactic environments?
- How are the heavy chemical elements produced and distributed through the galaxies? How do these processes scale with galaxy properties and epoch?
- How does environment influence the physical and morphological properties of galaxies?
- How are SMBHs they fed by their host galaxies? How do they affect the evolutionary trajectory of their host galaxies?
- And many more...

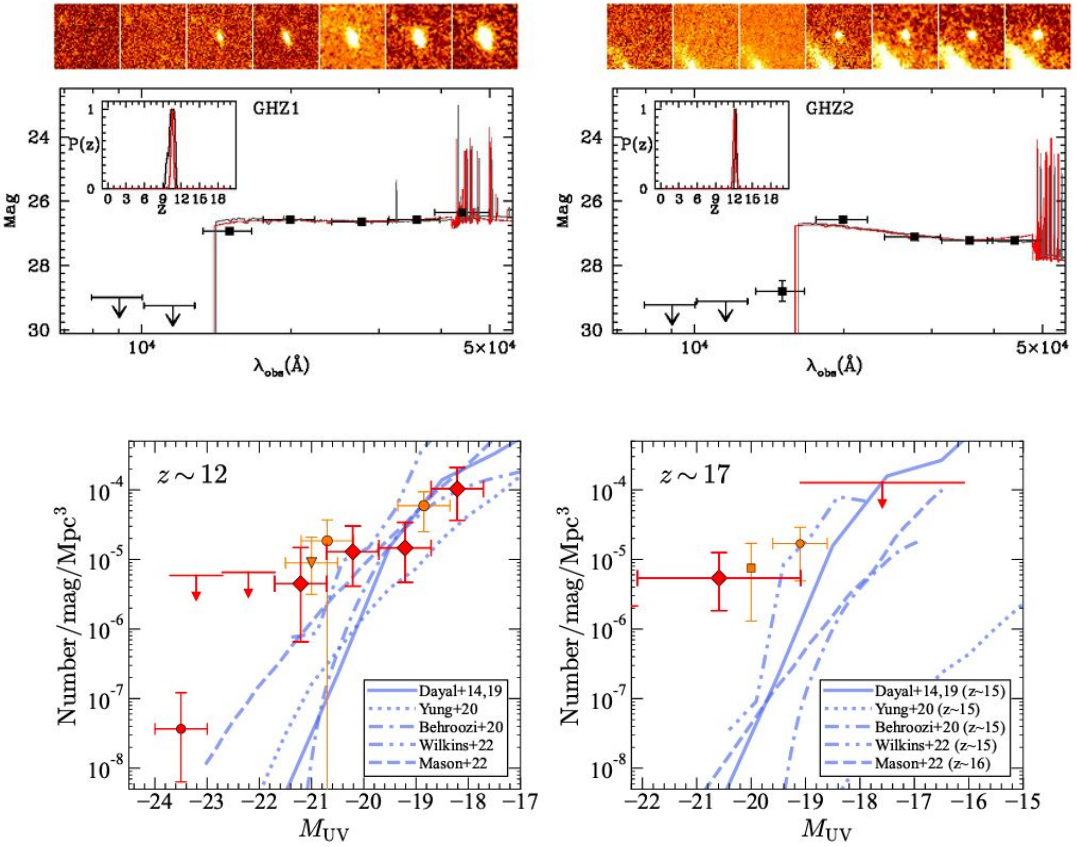
First galaxies

New stunning results from JWST

- z>10 galaxies **are far more numerous than expected(** Castellano+22, Harikane+22, Naidu+22 and many more)



Robust z=12 candidates from GLASS-ERS program (Castellano+22)



Results are in (partial) tension with most model predictions (Harikane+22)

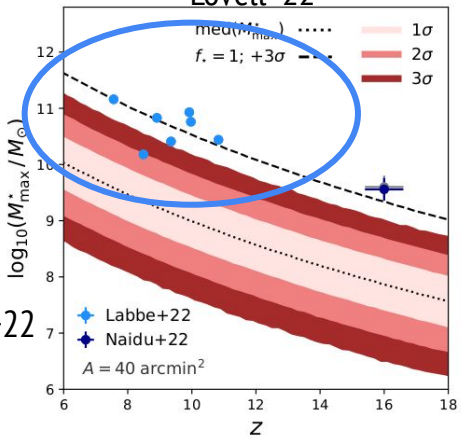
First galaxies

New stunning results from JWST

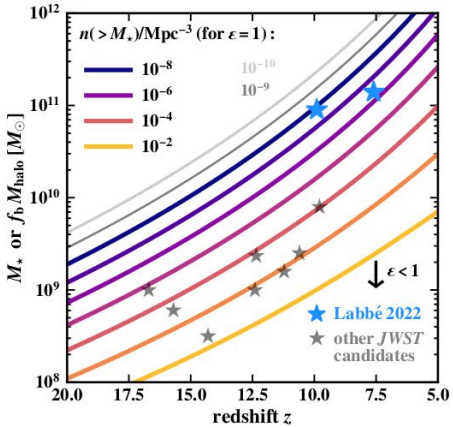
- z>10 galaxies are already rather massive systems (<u>modulo the uncertainties in the calibration</u>)
  Too massive for ΛCDM???

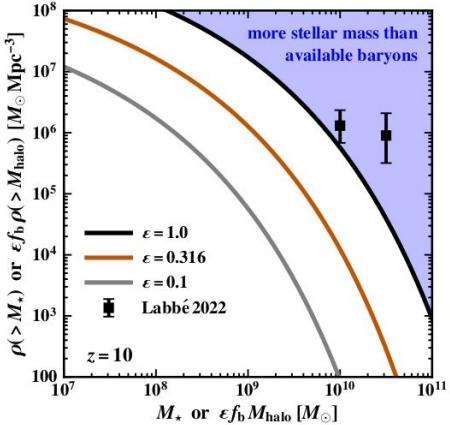
Stellar masses distribution fom Extreme Values statistics compared to recent estimates of stellar masses of JWST detected galaxies (Labbe+22, Naidu+22, Donnan+22,Harikane+22

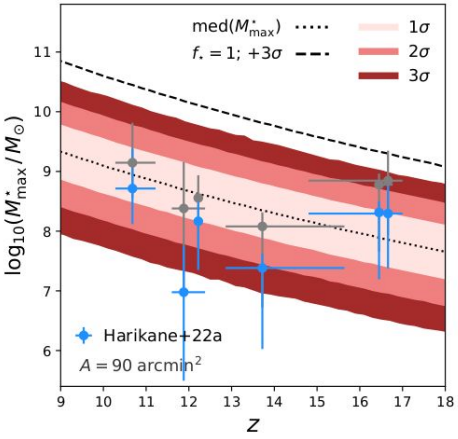
Lovell+22



Labbè+22 galaxies are found in a volume $V=10^5 Mpc^3$
Probability $=10^{-3}$







Boylan-Kolchin+22 see also Menci+22

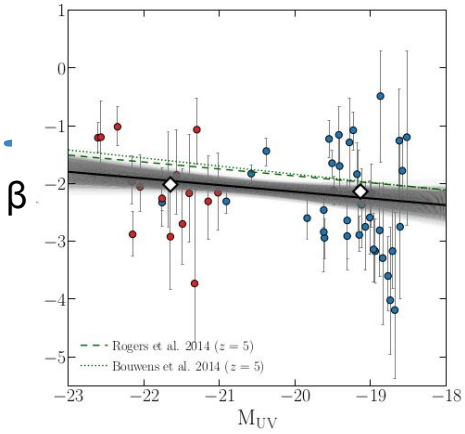
First galaxies

New stunning results from JWST

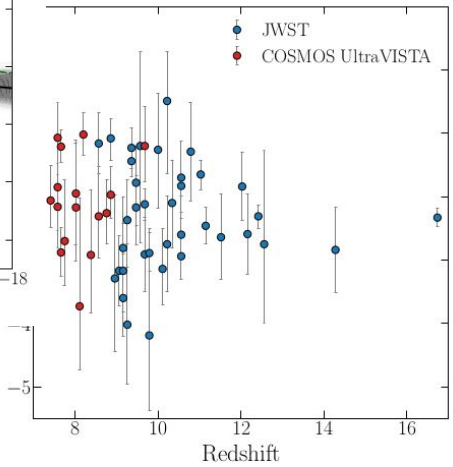
- z>10 galaxies are already rather massive systems (<u>modulo the uncertainties in the calibration</u>)

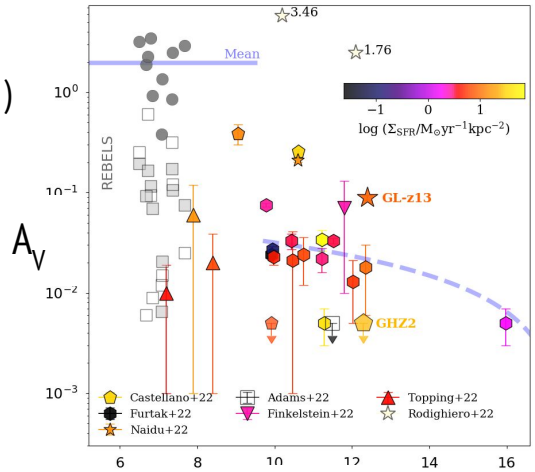
They also characterised by very blue UV slopes i.e. they are apparently dust free "**Blue monsters**"
Deep ALMA undetection of the 88μm dust continuum in GHZ2 (z≈12) (Bakx+22, Popping22) seem to reinforce this picture

→ **where has all the dust gone?**
(a) ejected by radiation pressure, or
(b) segregated with respect to UV-emitting regions.



Cullen+22

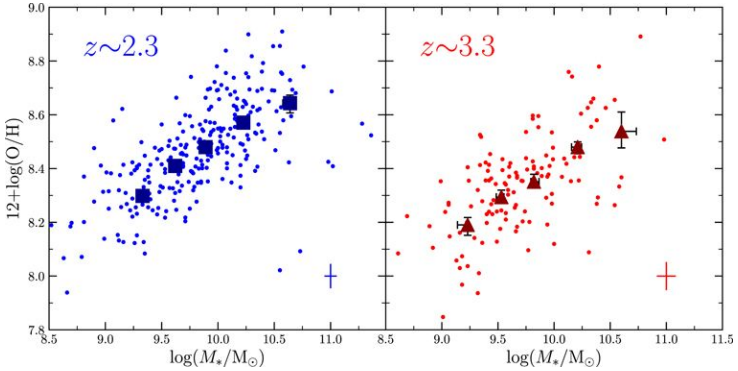




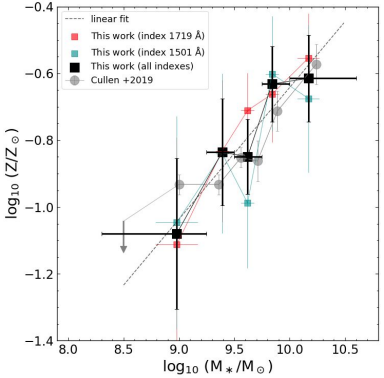
Ziparo+22

Gas and stellar metallicity over cosmic epochs

Gas-phase metallicity from MOSDEF survey



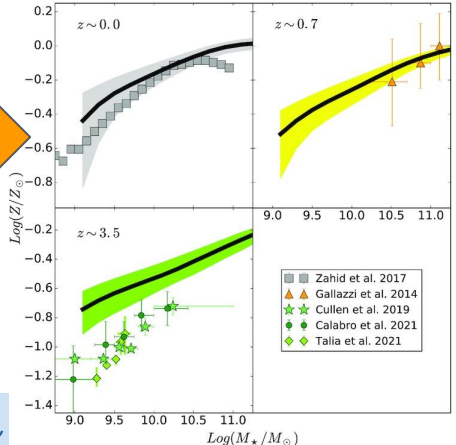
Sanders+21

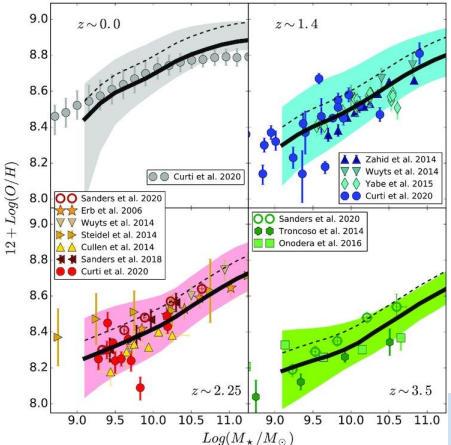


Stellar-metallicities at z=3.5 derived from UV spectral indices in ultra deep optical spectra (Calabrò+21)

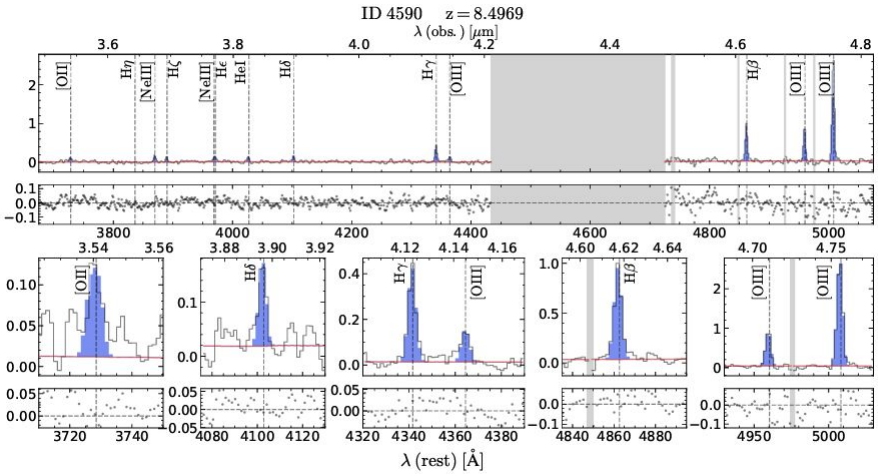
Redshift evolution of stellar (left) and gas phase metallicity (right) and comparison to GAEA predictions (Fontanot+21)

Stellar metallicity still hard to probe at intermediate to high redshift





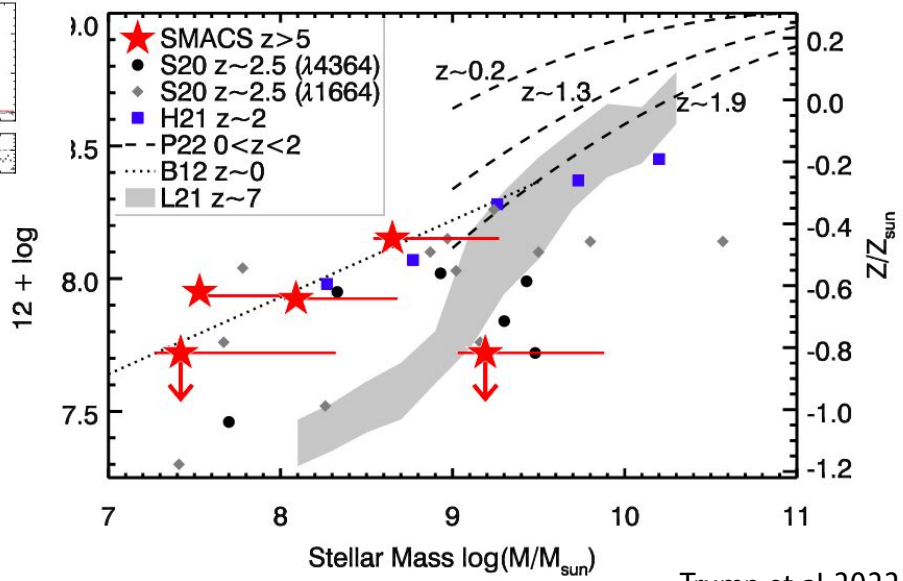
Gas and stellar metallicity over cosmic epochs



Curti+22

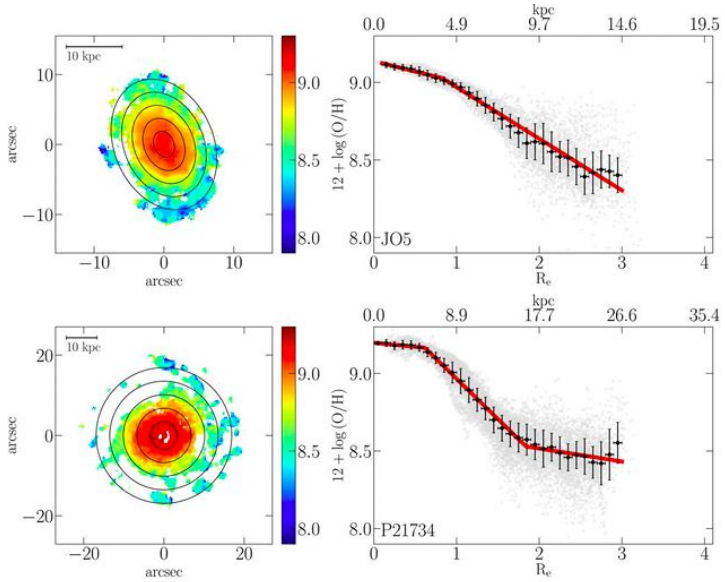
Data from SMACS 0723 Early Release Observations of z=5-8.5 galaxies showing [NeIII]λ3870/[OII]λ3728, [OIII]λ4364/Hγ, and [OIII]λ5008/Hβ. ...a lot more to come from ERS, GTO and GO programs!!!

With the first data we had a glimpse of what JWST can mean in terms of determining the gas phase metallicity of galaxies at the highest redshifts accessible →NIRSPEC is going to open a completely new Observational window



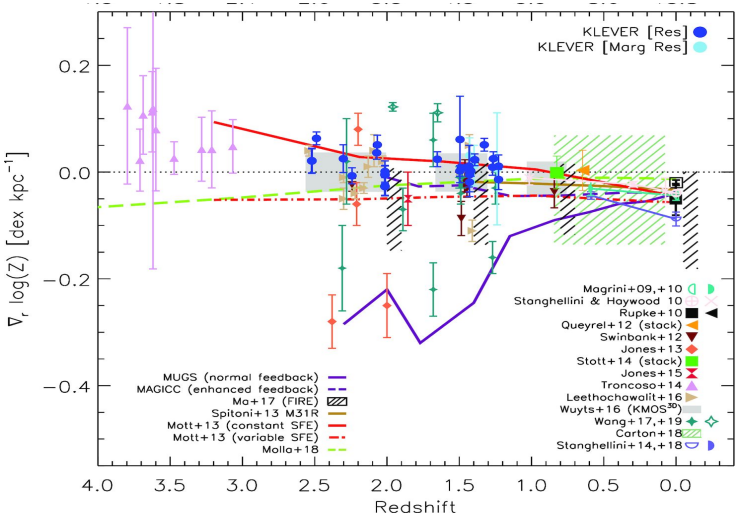
Trump et al 2022

Metallicity gradients



Gas Metallicity Gradients in Disk Galaxies : from GASP(MUSE) and MAnga: metallicity gradients anticorrelate with gas fractions. Also trend with environment (Franchetto+21)

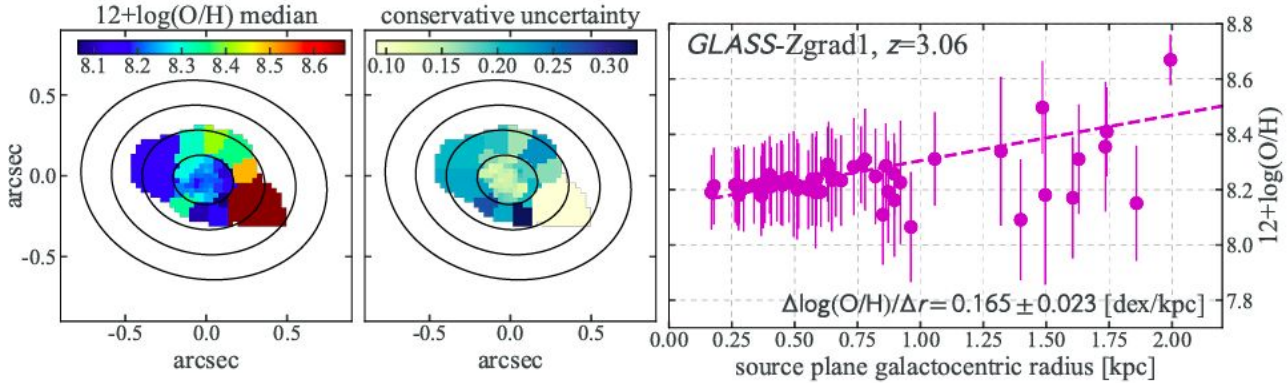
The distribution of metals within galaxies places strong constraints on galaxy formation with many different mechanisms able to shape them (radial motion, metal-poor and metal-rich gas accretion, turbulent transport, and outflows)



Evolution of metallicity gradients with redshift
From the KMOS program KLEVER (Curti+19)
Also CLEAR (Simons+21) from HST grism observations

Metallicity gradients

Early results from GLASS-JWST. IV: Spatially resolved metallicity in a low-mass z ~ 3 galaxy with NIRISS

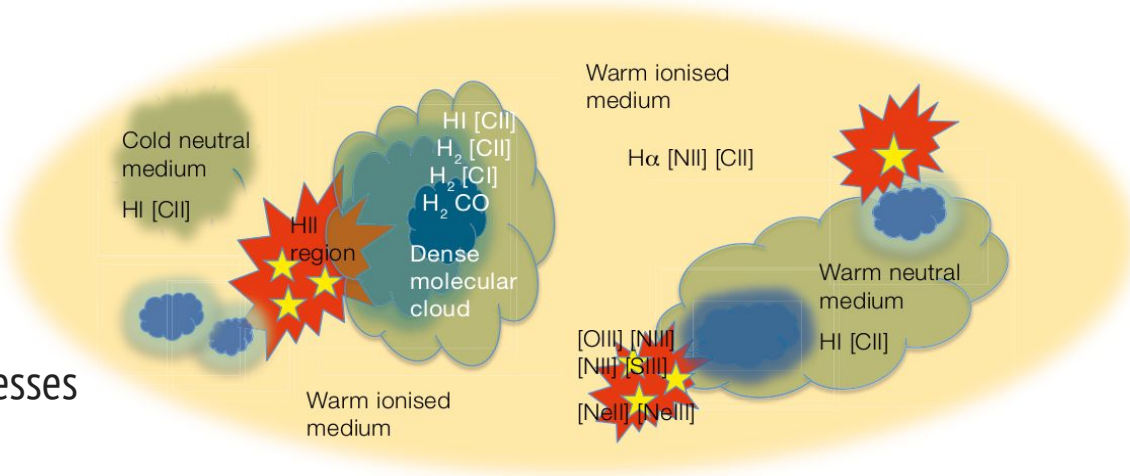


The great resolution and sensitivity of JWST/NIRISS, combined with lensing magnification, allows to resolve this z ~ 3 dwarf galaxy. The radial metallicity gradient of GLASS-Zgrad1 is strongly inverted (i.e. positive) possibly due to infall of metal poor gas (Wang+22 and GLASS team)

Exploring the universe with ALMA

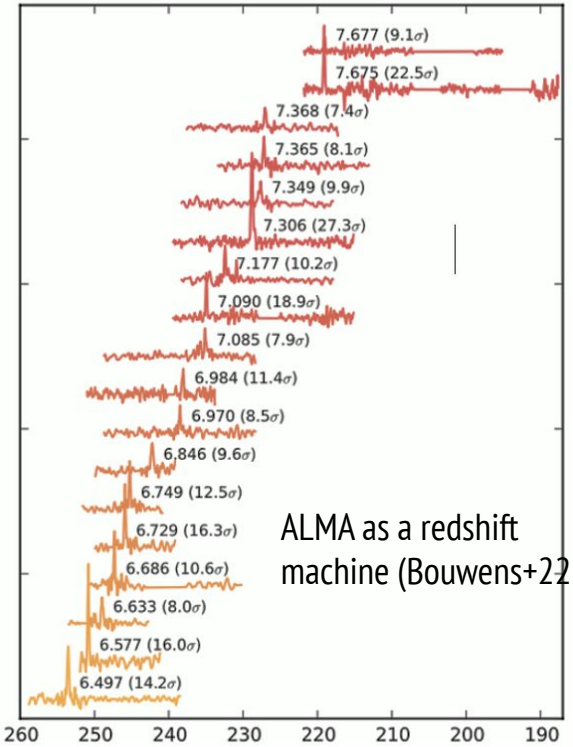
ALMA has had a groundbreaking role in the study of galaxies ISM at all redshifts, by observing dust, atomic lines and molecular lines and sheding light on:

- the interplay between the accretion of baryons onto galaxies
- the physics that drives the buildup of stars out of gas,
- chemical evolution and feedback processes
- the reionization of the Universe.

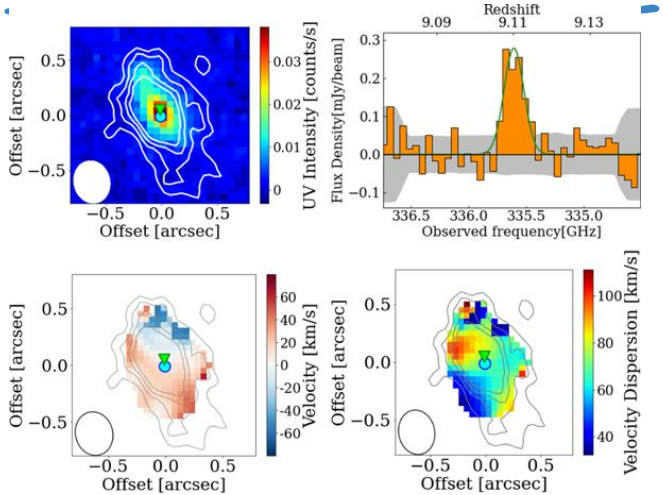


van der Tak et al. (2018)

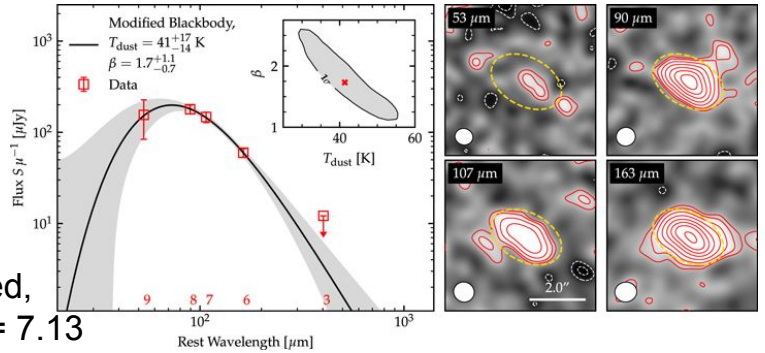
Exploring the high-z universe with ALMA



ALMA as a redshift machine (Bouwens+22)



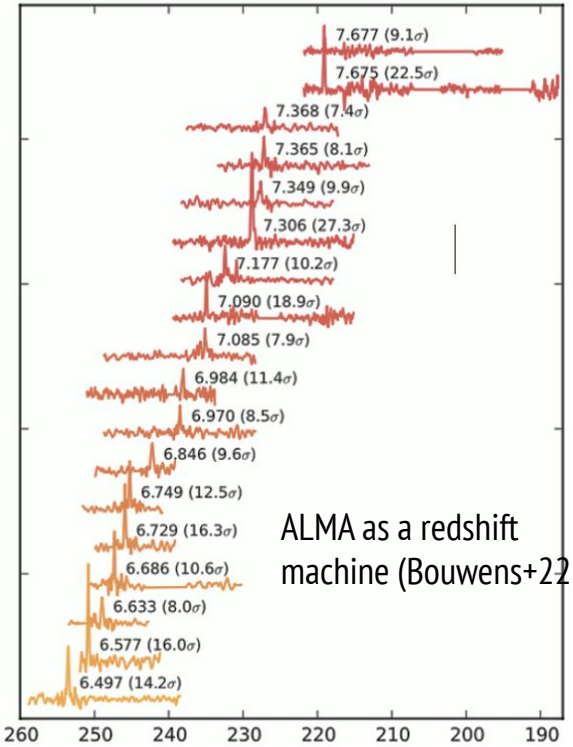
Possible systematic Rotation in the mature Stellar population of a z = 9.1 Galaxy (Tokuoka+22) from [OIII]88μm maps



Dust temperature determination for a strongly lensed, sub-L* galaxy at z = 7.13

Akins+22

Exploring the high-z universe with ALMA



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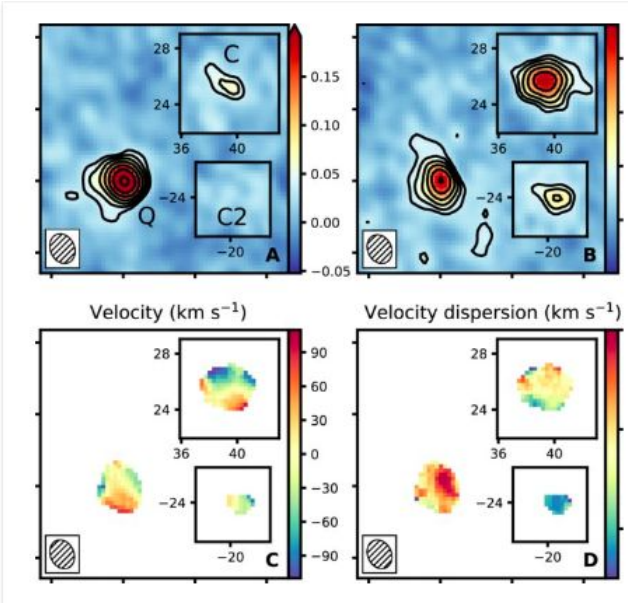
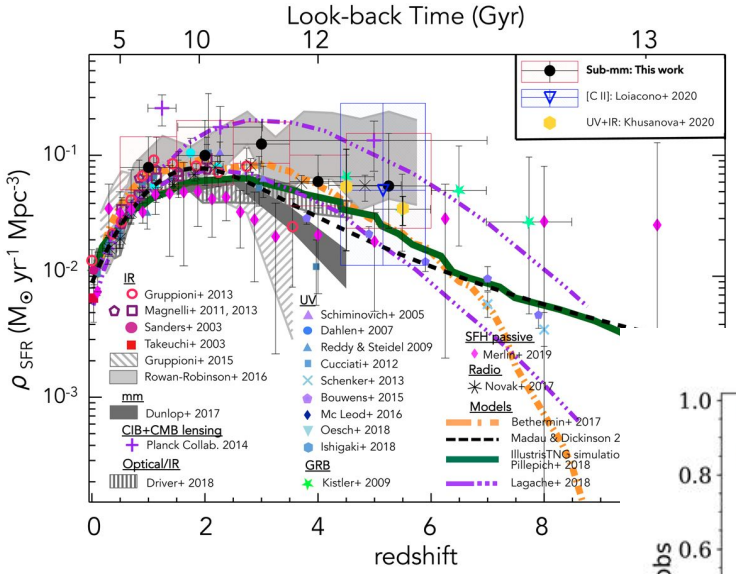


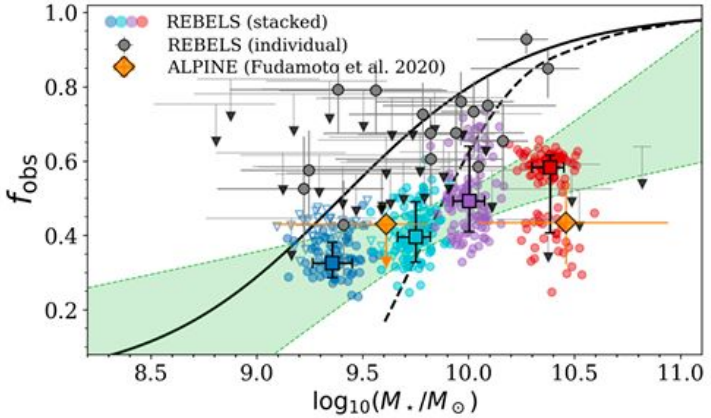
ALMA reveals close companion galaxies around high redshift QSOs (Neeleman+20,Garcia-Vergara+22 and many more)

ALMA probes the obscured SF at high z

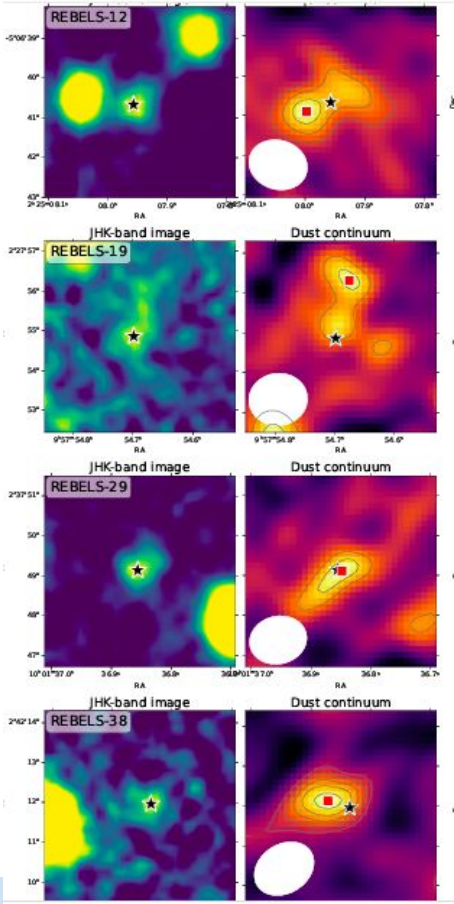


Gruppioni+20, also Kuhsanova+21
Casey+22 and many more

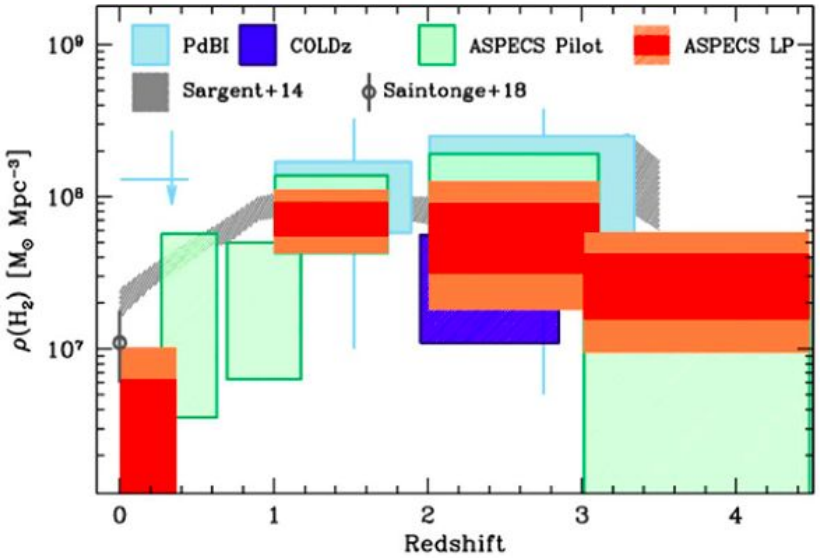
ALMA large programs such as ASPECS, ALPINE, REBELS and other are revolutionizing the way we cosmic star formation and the assembly of normal dusty galaxies



Algera+22

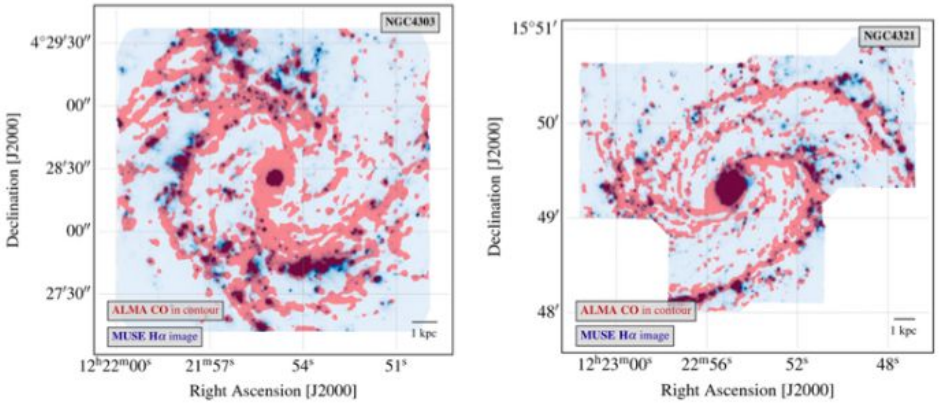


ALMA reveals molecular gas in galaxies



Redshift evolution of the cosmic molecular gas density, ρ (H2),as constrained by ASPECS and other programs (DeCarli+19 and others)

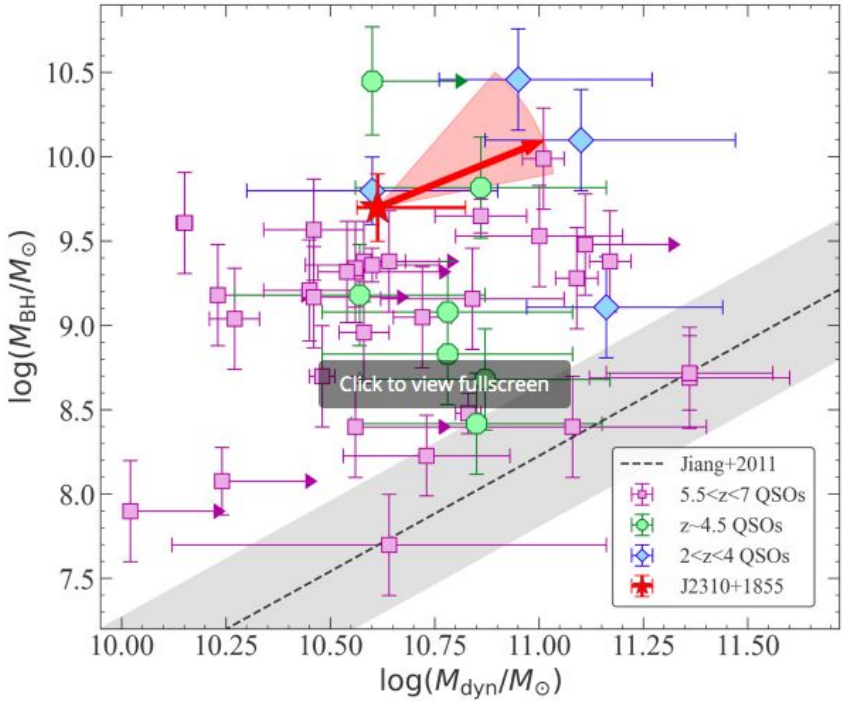
PHANGS–ALMA, a high resolution (100pc i.e. cloud scale) survey to map CO $J = 2 \longrightarrow 1$ line emission in nearby galaxies



Maps of CO (ALMA) and Halpha (MUSE) Leroy+22

Supermassive BH at high redshift

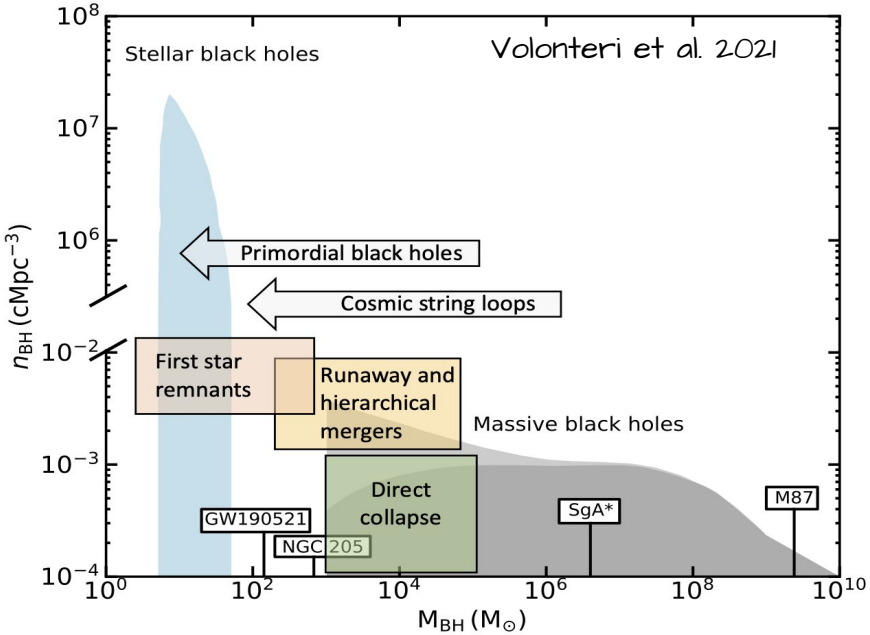
ALMA can probe, dynamical, molecular and dust masses in SMBH hosts up to z=6-7

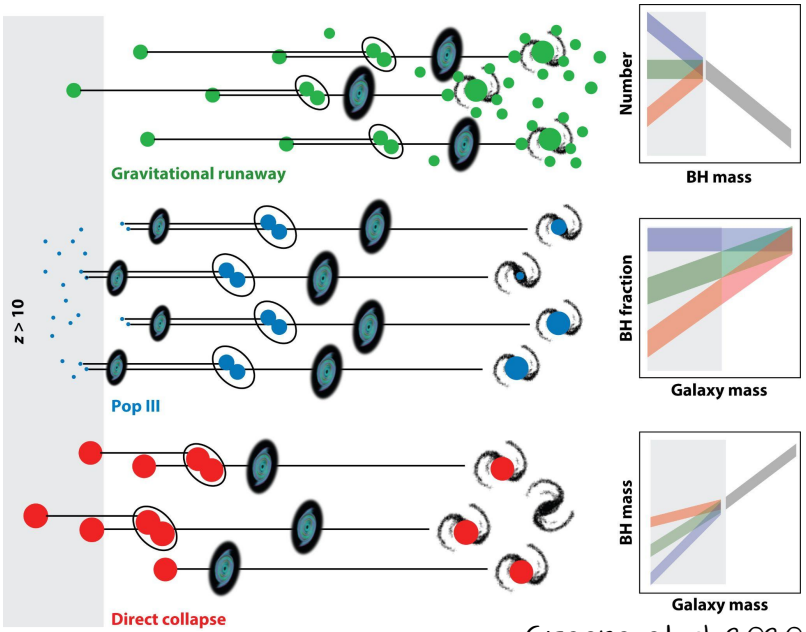


BH mass as a function of the dynamical mass for J2310+1855 at z=6 (red star - Tripodi+22), compared with WISSH QSOs at $z \sim 2-4$ (Bischetti+21) and luminous $z \sim 4-7$ QSOs (green dots and violet squares, from Venemans+17 and others)

The seeds of SMBH

In the local Universe SMBHs are tightly connected to the properties of the host galaxy: how and when did the seeds of massive BH formed in the early Universe?

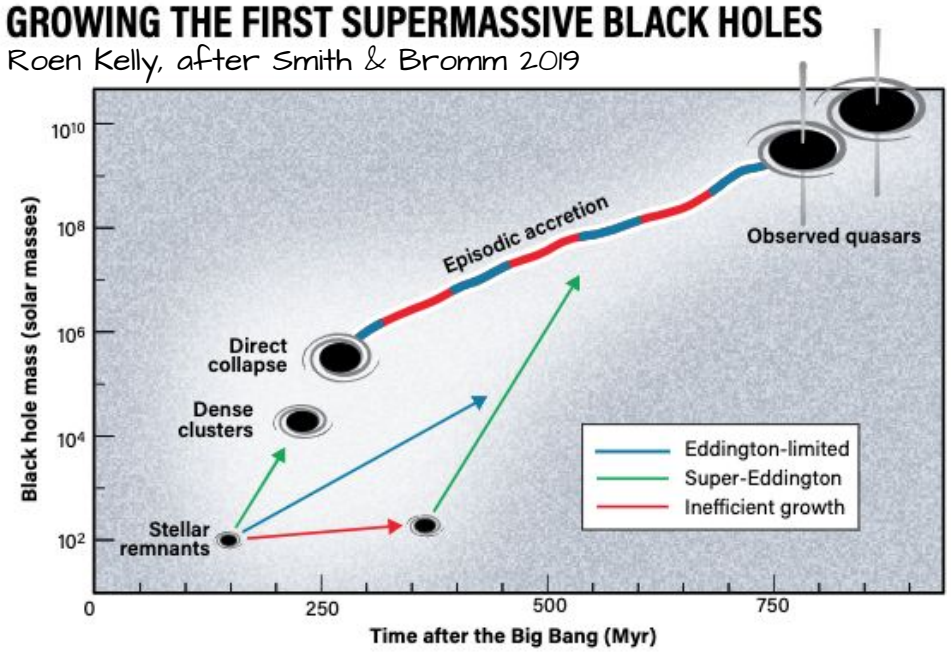


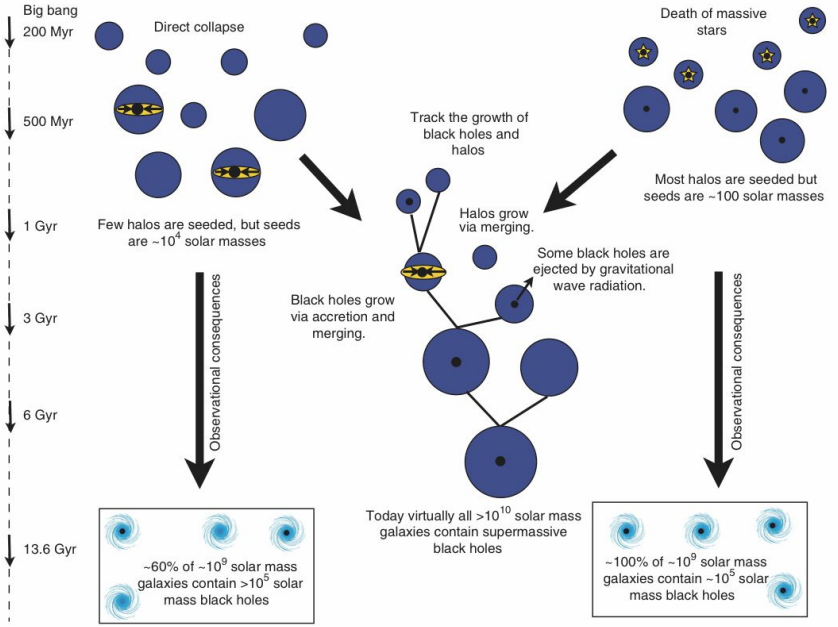


Greene et al. 2020

The growth of SMBH

How SMBHs grew at high redshift? What's the connection between the growth of BHs and their host galaxies?

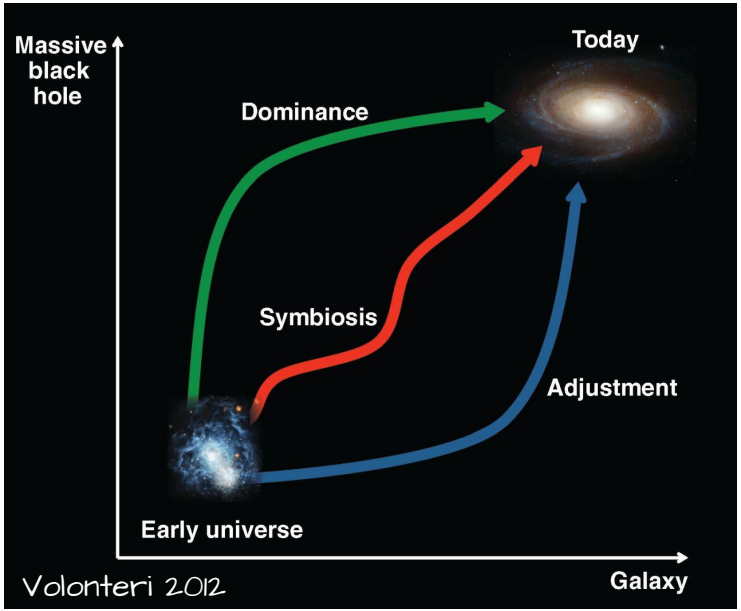


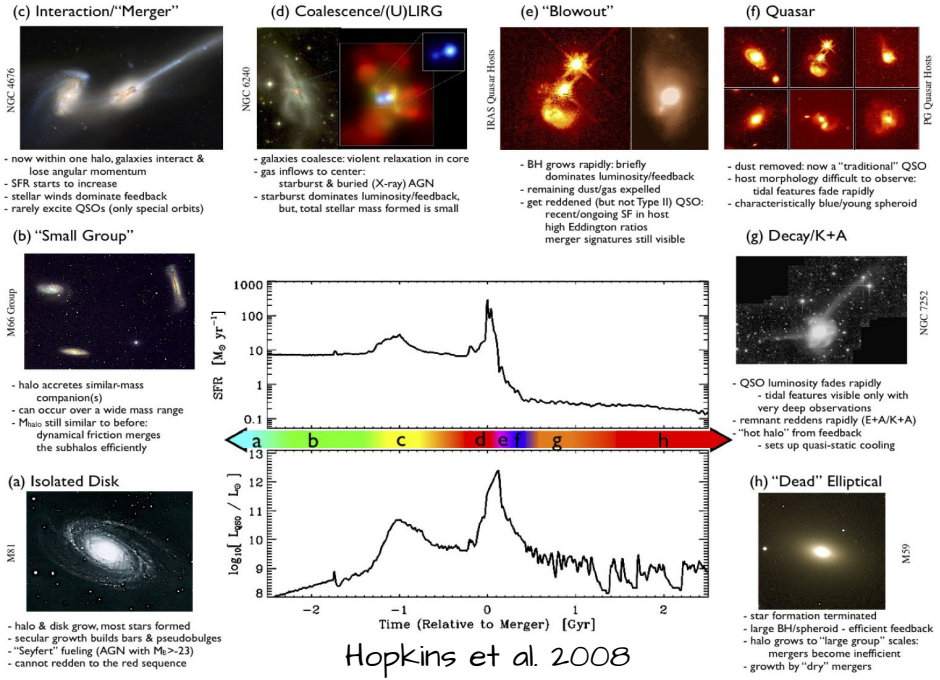


Greene et al. 2012

MBH and galaxy coevolution

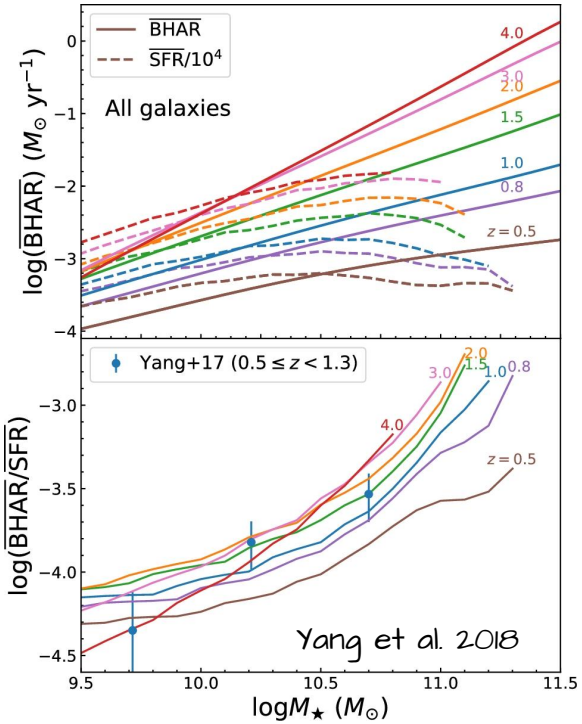
How are SMBHs fed by their host galaxies? Is galaxy-AGN coevolution regulated by the MBH or by the galaxy? How AGN (and dual AGN) affect the evolutionary trajectory of their host galaxies?



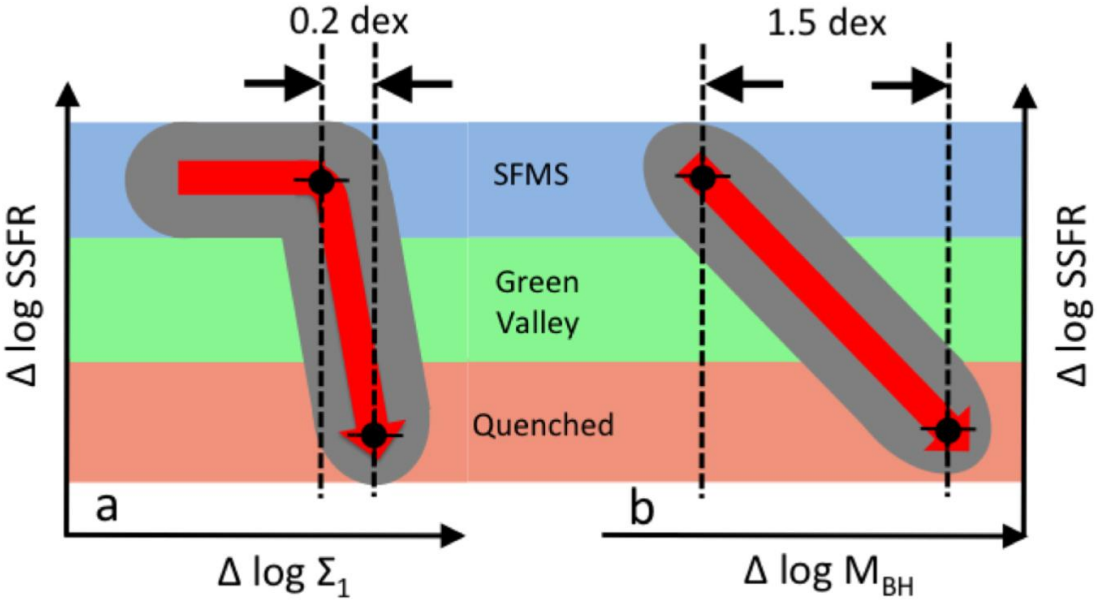


AGN feedback on their host galaxies

How the BH is connected to SFR and quenching?



Chen et al. 2020

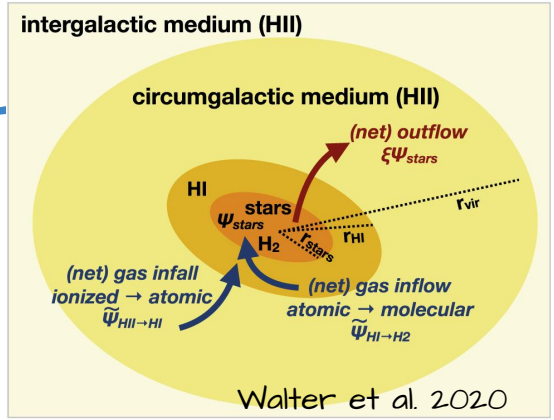


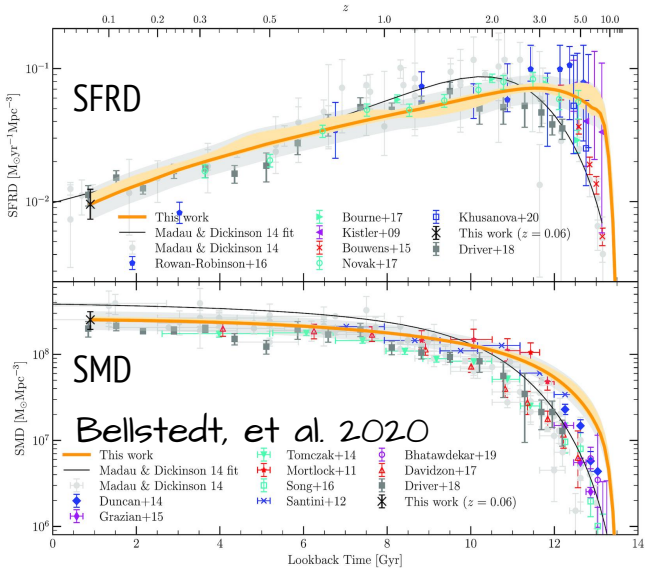
Σ_1: "Elbow"

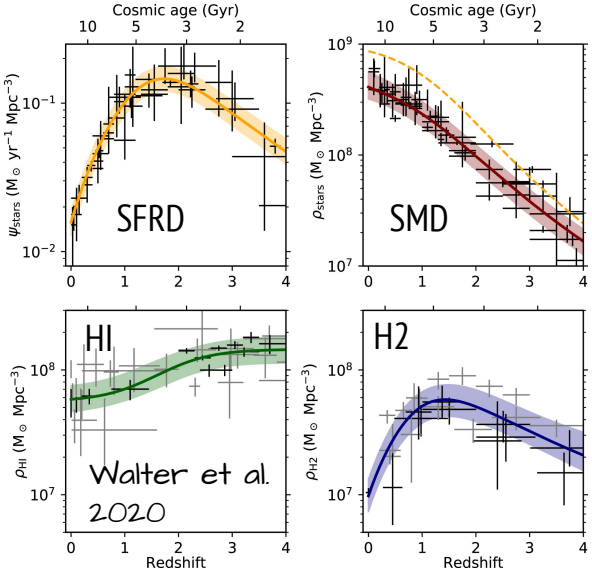
M_{BH}: Straight

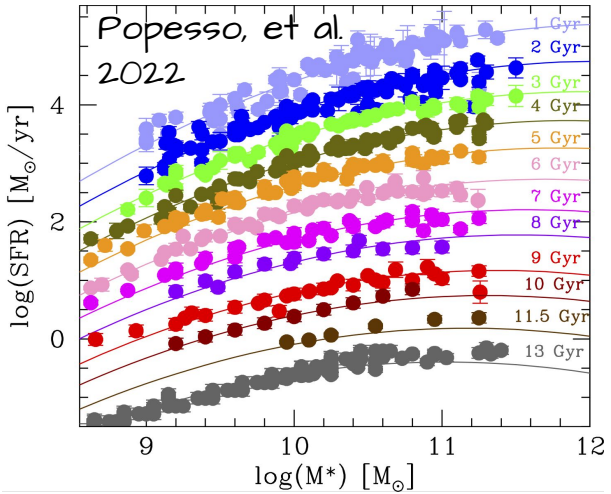
The drivers of galaxy growth

- Are the star formation rate density and the cosmic stellar mass density in agreement? What drives the SFRD?
- Is the gas supply evolving and how efficient is the formation of stars?
- What is the origin of the scaling relations?





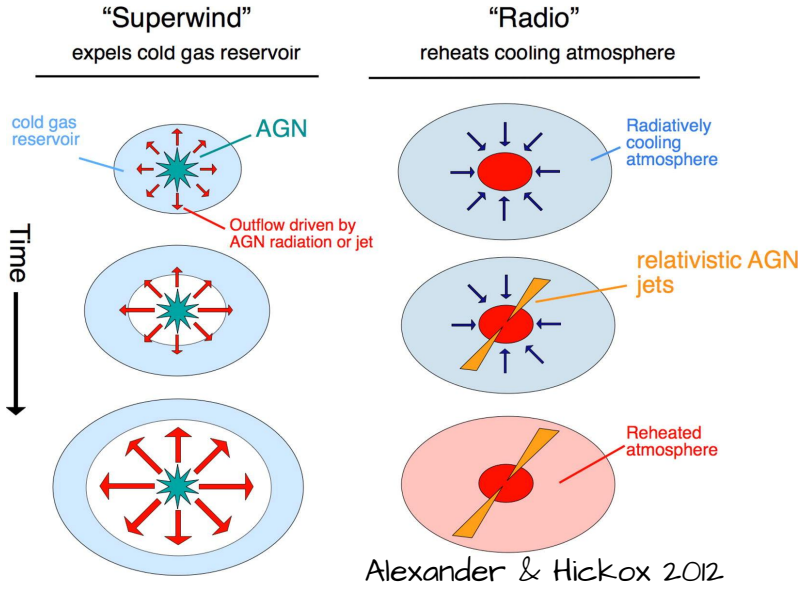




Quenching

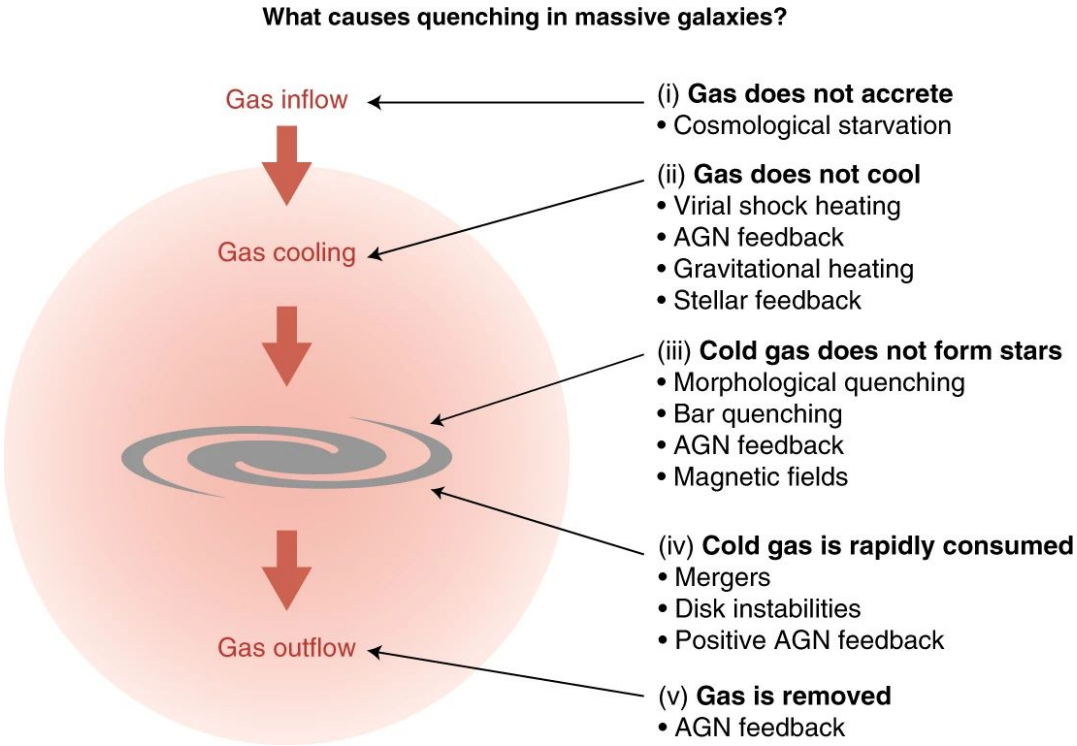
What is the relative weight of quenching mechanisms?

- merger/interactions
- internal dynamics/secular evolution
- AGN feedback



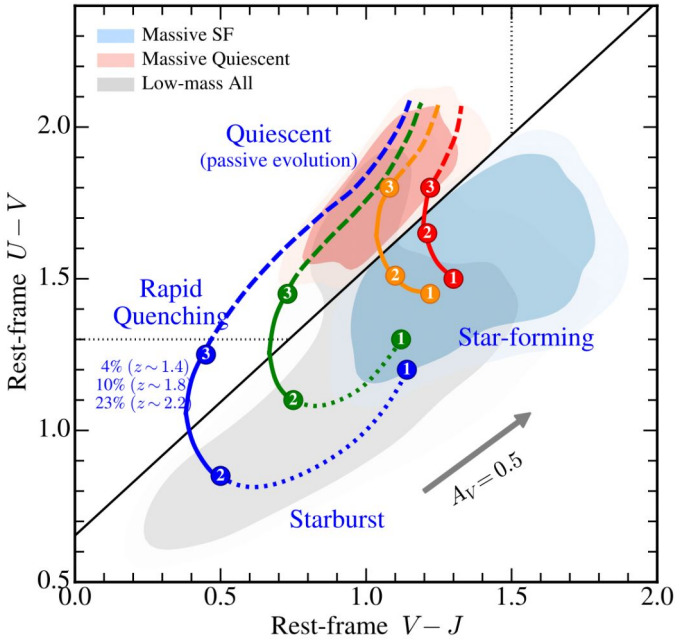
Alexander & Hickox 2012

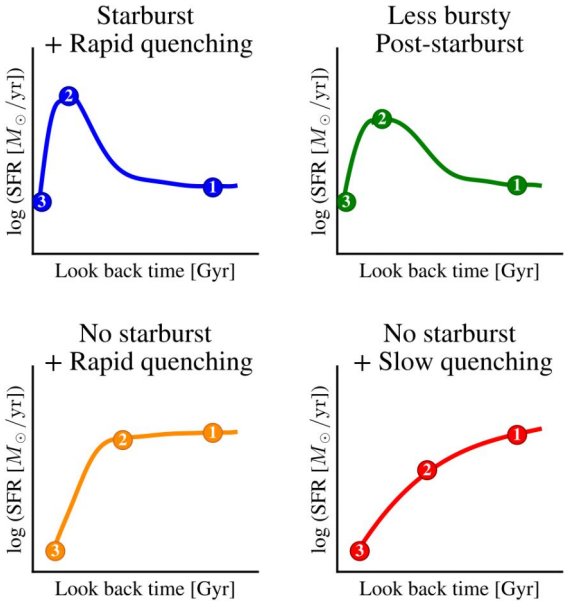
Man & Belli 2018



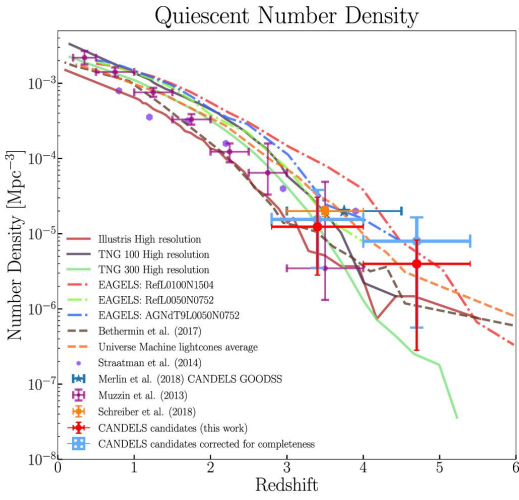
How did star formation quench?

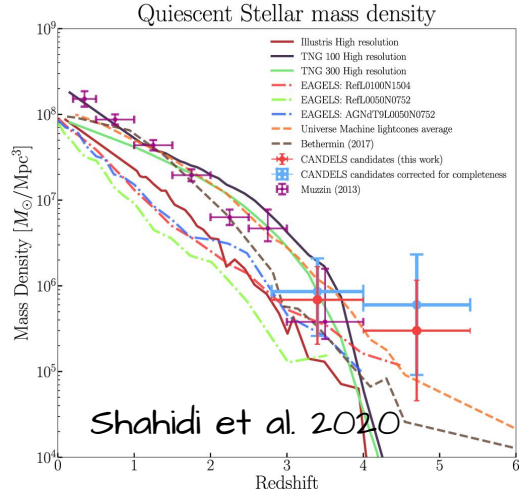
- How massive passive galaxies assembled their mass at high redshift?
- Did massive galaxies assemble their mass earlier and faster?





Park et al. 2022



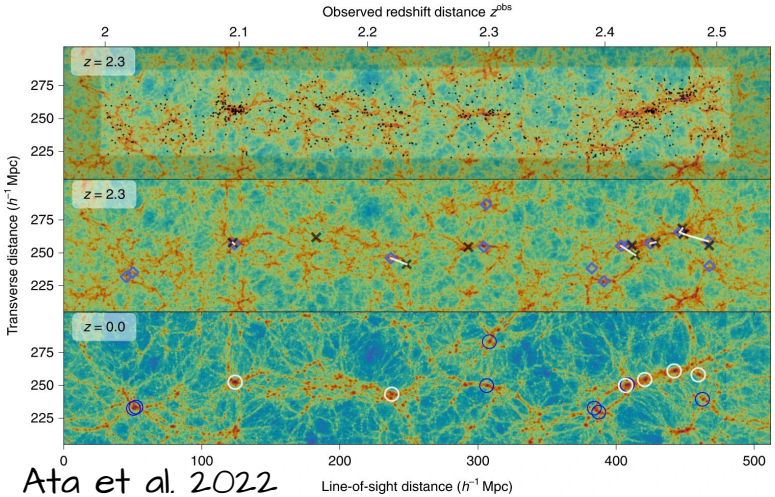


Shahidi et al. 2020

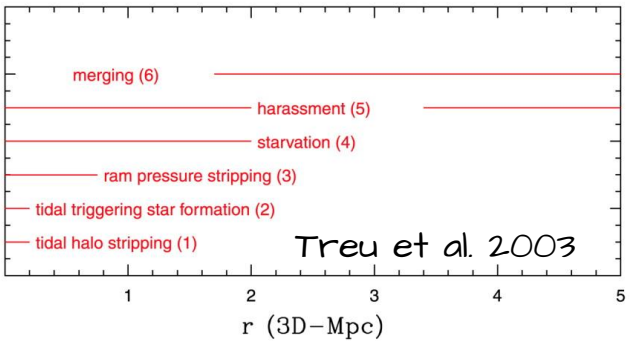
Environment as laboratory of galaxy evolution

Most galaxy evolution likely occurs in proto-clusters, groups, and high density environments at high redshifts:

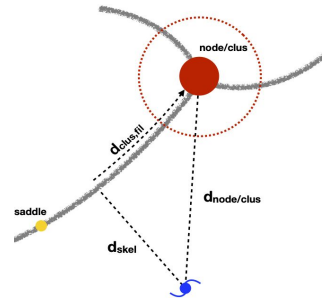
- environmental quenching
- morphological transformation
- AGN feedback

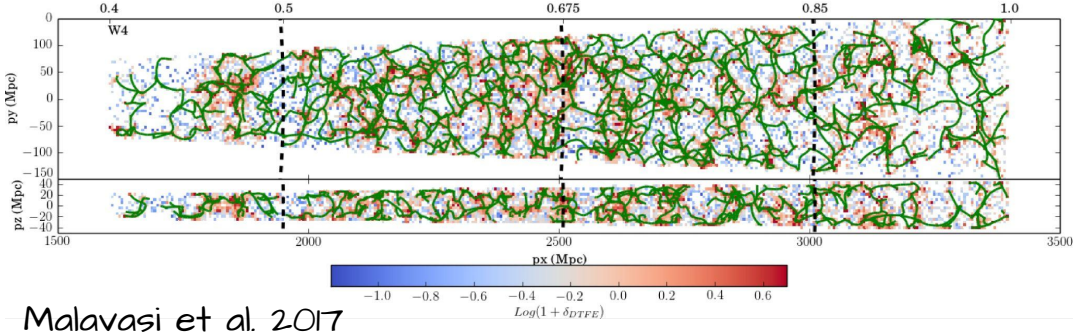


Ata et al. 2022



Sarron et al. 2019





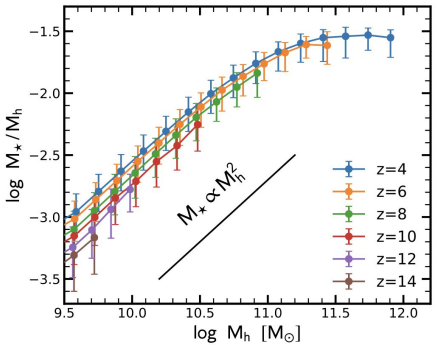
Malavasi et al. 2017

The link with dark matter

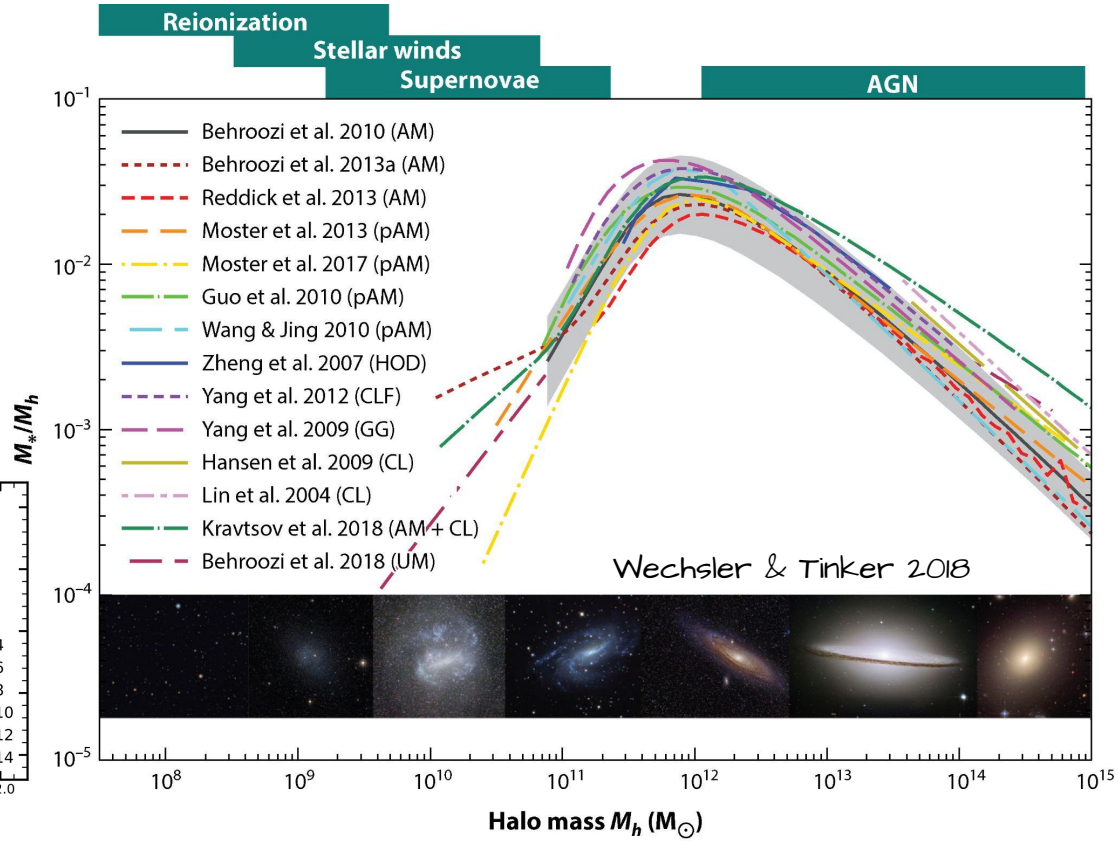
- How the visible properties of galaxies are connected to dark matter distribution?

- What is the role of halo formation epoch, concentration, angular momentum, merger history and large-scale environment?

- How the SHMR evolves at high redshift?



Tacchella et al. 2018



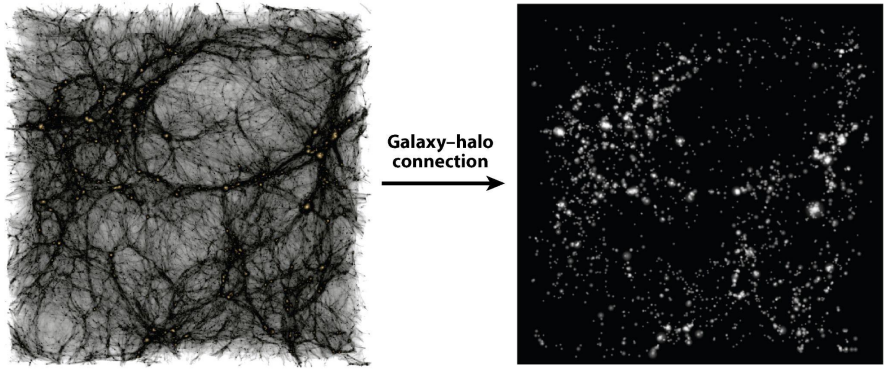
Wechsler & Tinker 2018

Simulations and mock catalogues

The development of "synthetic data" should be considered as integral part of the design and development of a mission, instrument and/or facility

Simulated data are needed to:

- study the connection between the formation of stars and galaxies and their dark matter halo
- define mission strategy and study of systematics
- develop models, e.g. train supervised ML methods
- test pipeline that will be used on data
- calibrate analysis
- validate the inference with a known Universe

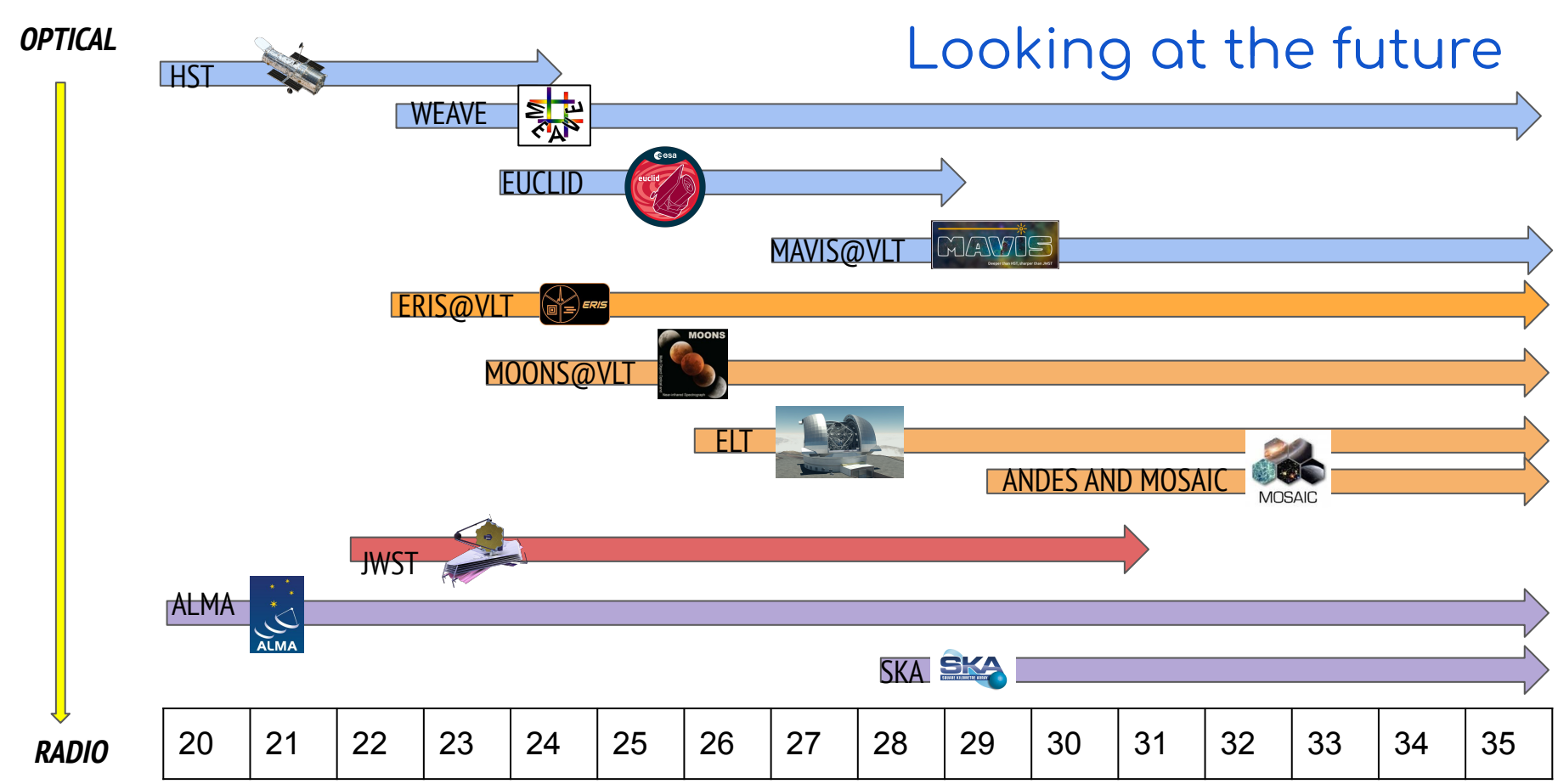


Approaches to modeling the galaxy–halo connection

← Physical models				Empirical models →
Hydrodynamical simulations	**Semianalytic models**	**Empirical forward modeling**	**Subhalo abundance modeling**	**Halo occupation models**
Simulate halos and gas; star formation and feedback recipes	Evolution of density peaks plus recipes for gas cooling, star formation, feedback	Evolution of density peaks plus parameterized star formation rates	Density peaks (halos and subhalos) plus assumptions about galaxy–(sub)halo connection	Collapsed objects (halos) plus model for distribution of galaxy number given host halo properties

Wechsler & Tinker 2018

Looking at the future



approximate expected date of operations

Adapted from McDermid+

GTO

near-future

Italian researchers are or will be involved into several GTO programs, most notably:

ERIS: - 60 nights GTO

- Growth of bulges & disks
- Inflows in disks
- Imprint of clumps &(minor)mergers in kinematics
- Star formation (in clumps vs interclump)
- Feedback & quenching (outflows from star formation & AGN)

MOONS: extragalactic survey MOONRISE

- First galaxies, Lyalpha emitters
- Clustering of high-z galaxies and constrain to reionization
- Large scale structure and role of environment
- Galaxy evolution diagnostics (metallicity, AGN outflows,)
- Galaxy fundamental relations
- Massive passive galaxies and their evolution

JWST-NIRSpec - JADES and WIDE programs

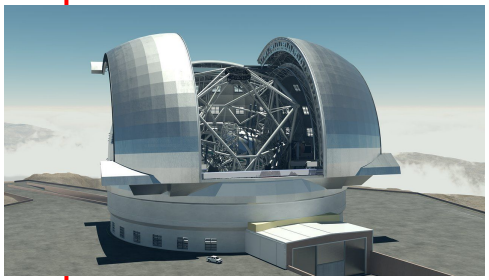
WEAVE@WHT:

- WEAVE-StePS (Stellar populations at intermediate Redshift survey)
- WEAVE-Clusters

distant-future

ANDES (formerly HIRES) : high resolution spectrograph for ELT
Italian PI-ship
Phase B started in ....

MOSAIC : the multi object and multi-IFU spectrograph for ELT
Large interest of italian community
Phase B to be started by end of year
(Italian participation to be consolidated before Phase B starts ?)



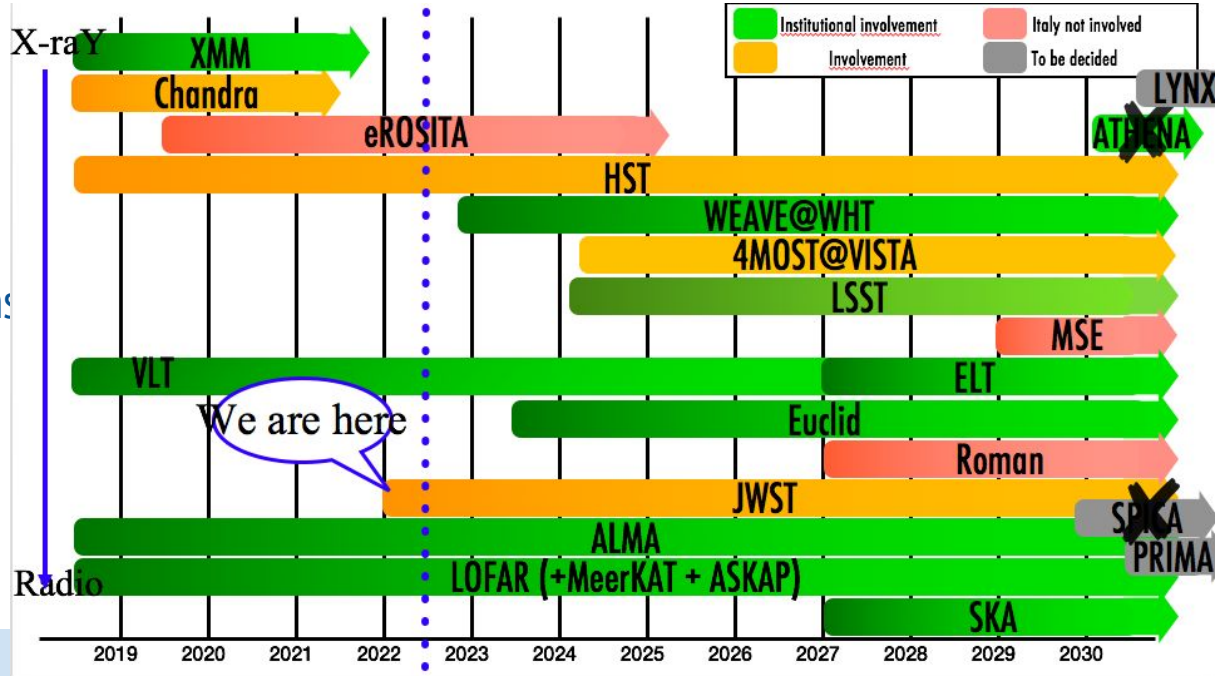
WST: Wide field Spectroscopic Telescope: community gathered for HORIZON-INFRA proposal
White Paper foreseen for 2023

MSE - MaunaKea- Spectroscopic Explorer→ 11.25m 4000x multiplexing
Could INAF join?

Galaxy evolution & environment community could greatly benefit for participation to (one of) these projects

Italian vs world community

- All the major hot scientific topics recognised by the international community are well represented in INAF, from theoretical and observational points of view
- Almost all new facilities see a participation from the italian community, with either an institutional involvement or involvement of some groups
- Exceptions are eROSITA, ROMAN &MSE (but WST could replace)
- IR and X-ray communities are orphans of ATHENA and SPICA



Criticalities

- Somewhat limited synergies between different groups: the community seems a bit fragmented with people working on similar topics but in a disjoint way
- AGN community is well organised with meetings: Active Galactic Nuclei reached the 14th edition https://indico.ict.inaf.it/event/949/
- Partially true also for cluster community
  Clusters3 https://sites.google.com/view/cluster3bo/home
- and Galaxy Evolution and Environment 6 https://www.oats.inaf.it/gee6/index.html (in 2019, to be restarted)

Some possible suggestions include:

→ Propose focused meeting for Galaxy formation & evolution

→ Propose "synergy grants" as an additional channel to large grants
These should be "real" synergy projects aimed at effective collaboration and support between groups
Not necessarily focussed on science only but also on instrumental driven etc

Criticalities

New instrumentation:

- We need to build expertise on current instruments (e.g. JWST, LOFAR) and in view of future ones (SKA)
- Lesson learnt from ALMA, where at the beginning the Italian community was limited by lack of expertise in the ability to both obtain and exploit data
- Criticalities LOFAR SKA

GTO:

We need to

- allow the people who are directly involved to exploit at best the data
- allow dissemination of expertise also to the rest of the community

Criticalities

- PhDs are usually formed at universities where the interests are only partially overlapping with those of INAF researchers (especially in some institutes)
- In some institutes there is a very limited access to PhD/Master students

This implies also that it is often difficult to find suitable people even for AdR positions since the PhD students have not gained any expertise on specific areas of interest for the INAF community (Is this problem limited to the galaxies&AGN community?? No idea...)

→ Potentiate the current programs with universities for more specific INAF PhD scholarships to be given to researchers with no direct connections to universities

Build foundations and optimise return

A balanced portfolio must support not just big projects, but the activities that support and enable the scientific return

- Programs that ensure the research community returns excellent science should be adequately supported
- Need to capitalise the era of big data and making sure the community is prepared to meet the upcoming data and computational challenges, supporting data archives and enhance dedicated human resources
- Supporting the basic theoretical underpinnings is crucial for motivating observations and interpreting the data
- Basic, early-stage technology development should be adequately supported, as the fuel of future innovation and technological competitiveness

[from astro2020]

Big Science Big Data

Infrastructure to process, manage and make available the vast amounts of data by telescopes (such as Euclid, the Square Kilometre Array (SKA) and the Vera Rubin Observatory), theoretical models, numerical simulations ⟶ urgent to include computing and data requirements at the core of our strategic planning.

- Production of science-ready data products and analysis tools
- Data Infrastructure for all types of data including models, simulations and mocks; connect with similar frameworks developed for other disciplines of science
- Develop fully collaborative, open and synergistic view of the Astronomy-computing ecosystem, including data, software, analysis, simulations and modelling ⟶ funding data and software storage/sharing facilities, archives, and cloud computing platforms
- Invest in professional software engineering / computational skills; career development to be promoted and considered as an integral part of our science/research portfolio, traditional metrics for academic performance are often inappropriate for measuring the impact and usefulness of computationally focussed outputs

[from ASTRONET Roadmap]

Recent meetings/courses co-organized by INAF:
Deep learning meeting (Pula 2019) https://indico.ict.inaf.it/event/815/

ML for astrophysics (Catania 2022) https://indico.ict.inaf.it/event/1692/
Introduction to ML and DL (2022) https://indico.ict.inaf.it/event/1879/
Astrostatistics school (2022) http://iaa.mi.oa-brera.inaf.it/IAA/thirdAstroStatisticsSchool.html