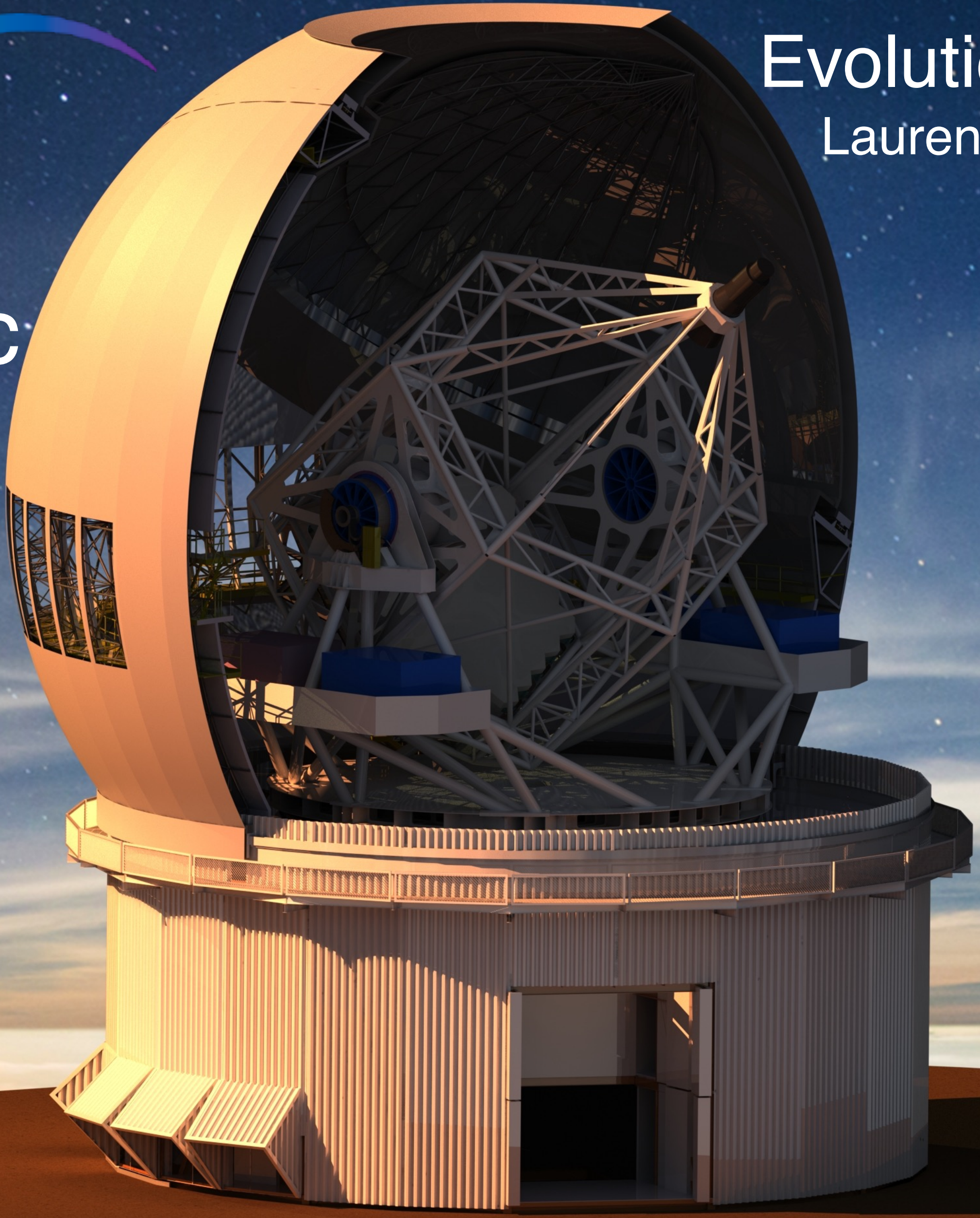
Evolution and formation of galaxies

Laurence Tresse (CRAL)

Maunakea
Spectroscopic
Explorer
(MSE)



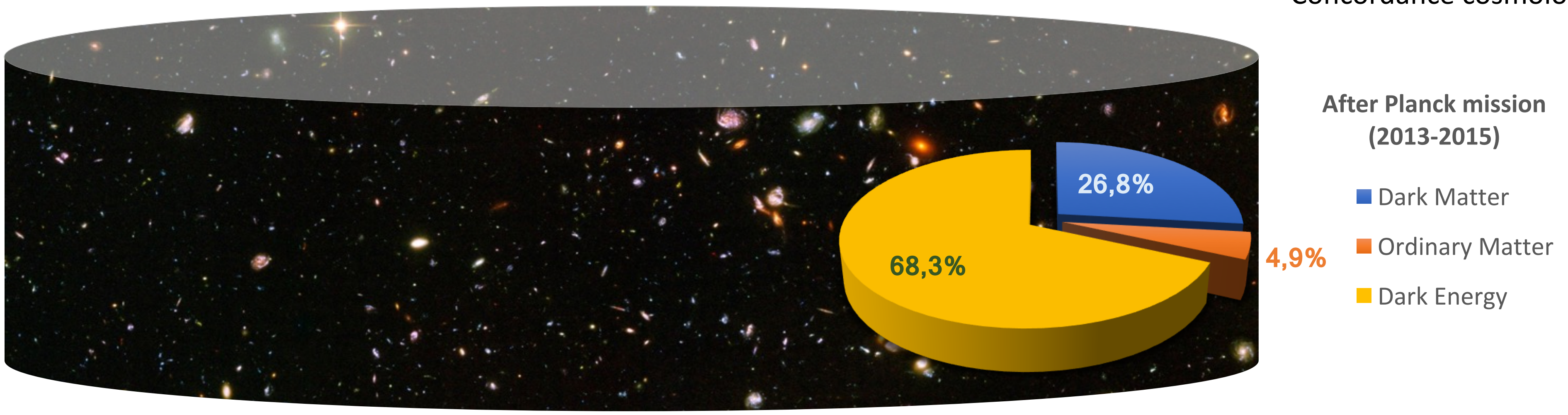
- Context
- What are the challenges
- What MSE will enable

http://mse.cfht.hawaii.edu

SF2A 14th May 2019, Nice

Galaxies

Cosmological model ΛCDM (*Lambda – Cold Dark Matter*)
Concordance cosmology - CMB fluctuations, SNIa, LSS



Their baryonic content represent less than <1% of the observable Universe, the remaining being gas (H and HI)

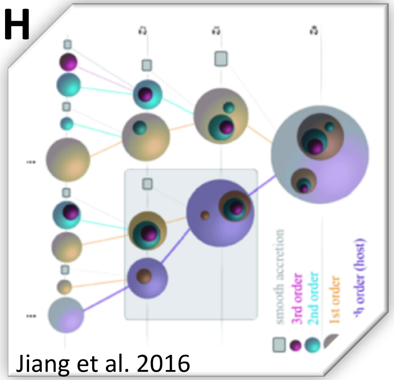
Represent little of the content of the Universe but brings us so much in surveying them

- ✓ Galaxies are the site of formation of billions of stars that make them visible through several Gyrs
- ✓ Galaxies are the visible blocks emerging from the dark matter halos
- ✓ Galaxies are the result of the physical processes at work of the mass-energy content of the Universe

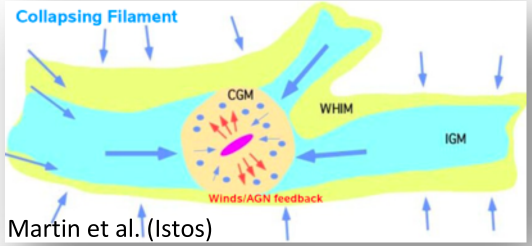
Galaxies evolve in and within the DM halo host

Dark Matter Halo evolution is admitted to be hierarchical – i.e. merge to form more massive halos

DMH

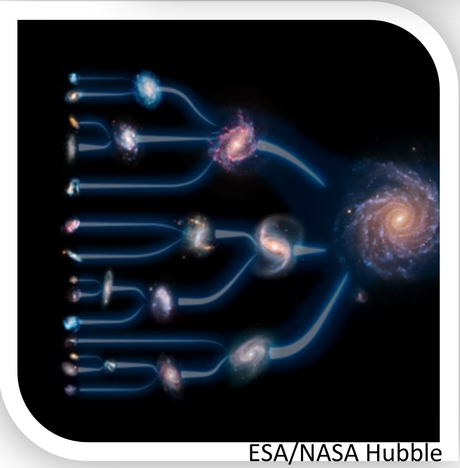


Jiang et al. 2016



Martin et al. (Istos)

Galaxies



ESA/NASA Hubble

The difficulty to decipher the galaxy evolution

starts as soon as baryons are considered in the DMH potential wheel

- Physical process in action are extremely complex
  in particular the connection with virialized DMH properties.

✓ Galaxies from baryonic gas condensed in halos, evolve in and within the halo host.

✓ Under gravity, gathering and mergers of galaxies (within mergers of DMH) is the mean to increase their mass and design the cosmic web.

✓ The intergalactic gas connects halos, pervades structures at large scales, gives a natural reservoir of baryons to increase the stellar mass of galaxies.

☞ Need to understand the consequences of feedback processes (stellar, AGN) on the galaxy evolution that affect the interstellar medium and the circum-galactic medium

These processes predict fundamental properties of galaxies like size, angular momentum, luminosity function

Galaxy populations

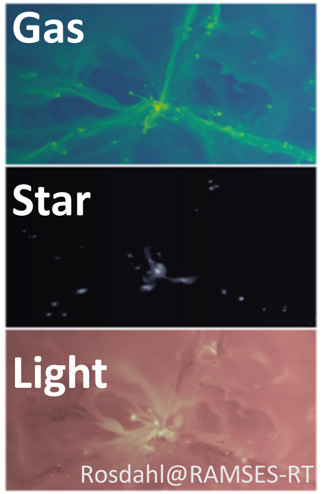
To unveil and quantify the evolution of galaxies one need a statistical approach

Detailed studies of stellar population (ages, kinematics, chemical abundances) enable to describe a galaxy and can help to determine backward the evolution

But galaxies experience stochastics growth rate (merger, accretion of sub-systems,…) with a continuous exchange of matter and energy between in and out

Difficulty to interpret measurements, e.g.

- at what time stars or gas from which they are formed are part of the studied galaxy?
- going back 2 Gyrs earlier, limitation due to the age-metallicity degeneracy (an old metal-poor stellar population appears the same as a young, metal-rich galaxy)
- what means the age of a galaxy? The one of its last major fusion?



Normal galaxies undergo larger star formation in the past.
If we extrapolate the mean Star Formation Rate of our Galaxy (1 solar mass/year) we cannot explain all stars accumulated today.

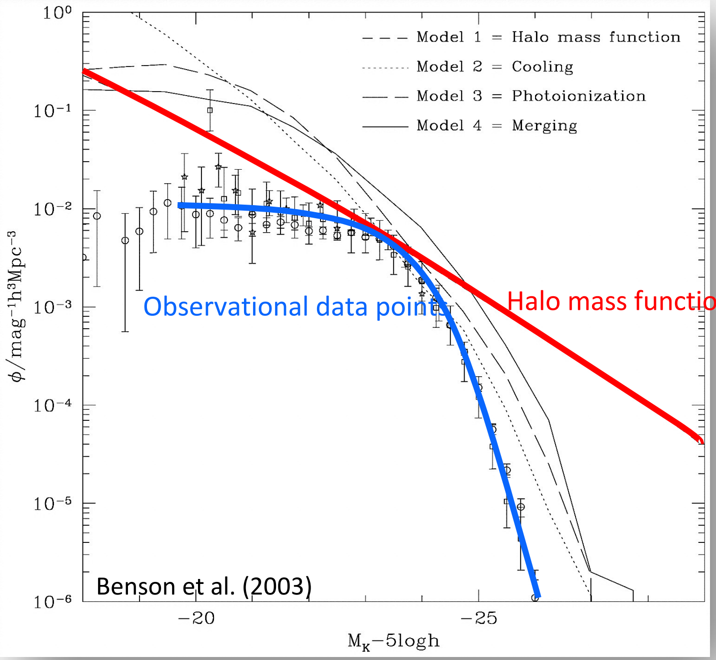
Deep surveys of galaxies enable to trace a coherent history of the galaxy populations

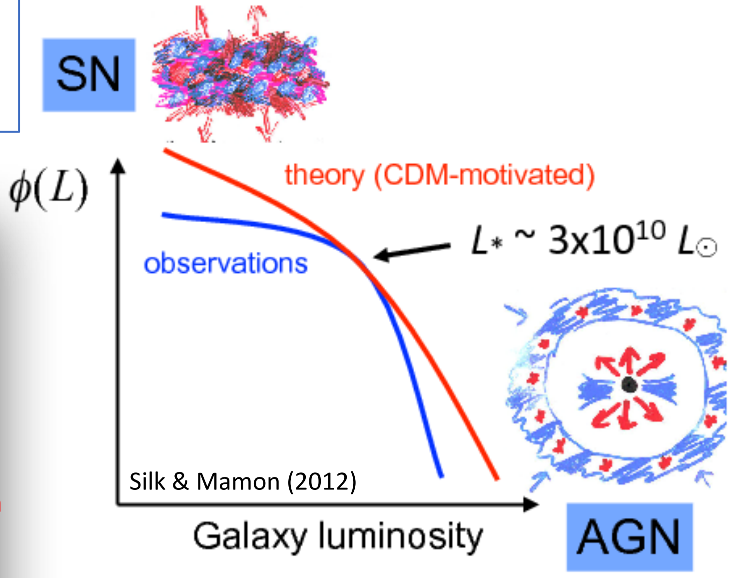
☞ The state-of-art and difficulty is to deduce evolution of galaxy population over several Gyrs

Volume densities of galaxies vs. luminosity or mass

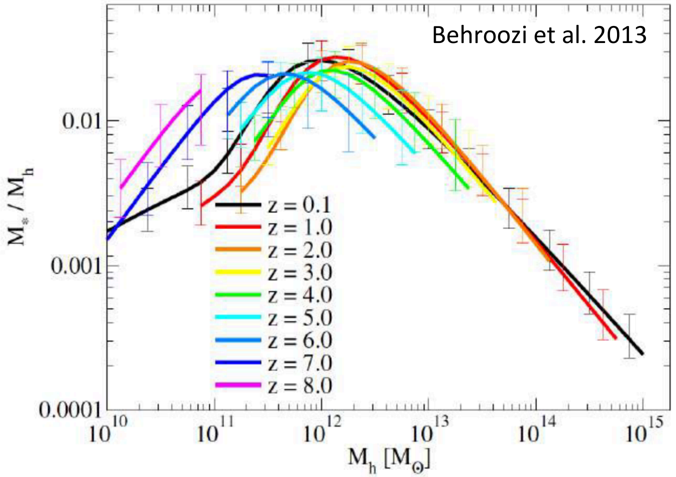
Balance between bright (exponential drop) and faint galaxy (power law) populations **at a given cosmic time**

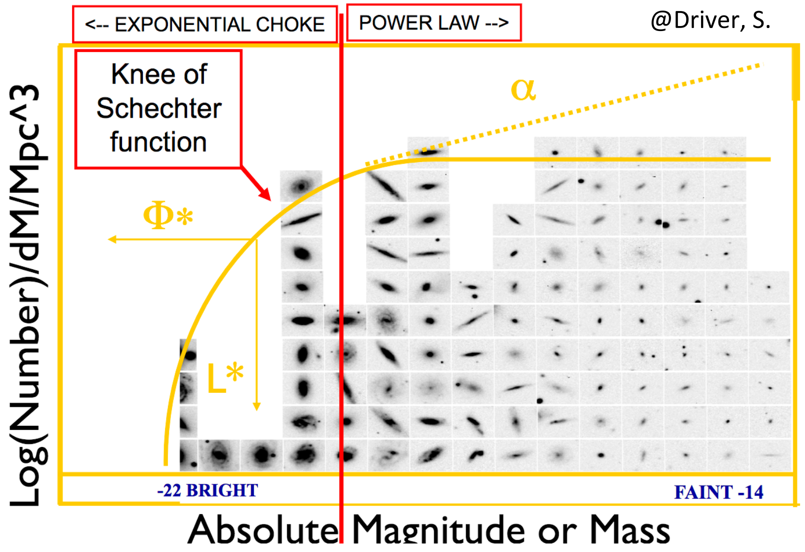
To relate theory and observations
☞ need of representative samples in mass, in environment, in type,… at any cosmic epoch





Stellar-to-halo mass ratio vs. halo mass
Non-linear growth of stellar mass, decoupled from DM growth



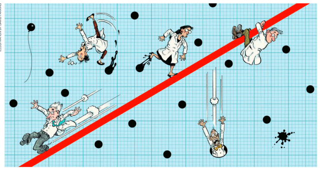


The exact distance of sources underlie all of the intrinsic physical parameters
☞ need of spectroscopic redshifts

Maunakea Spectroscopic Explorer

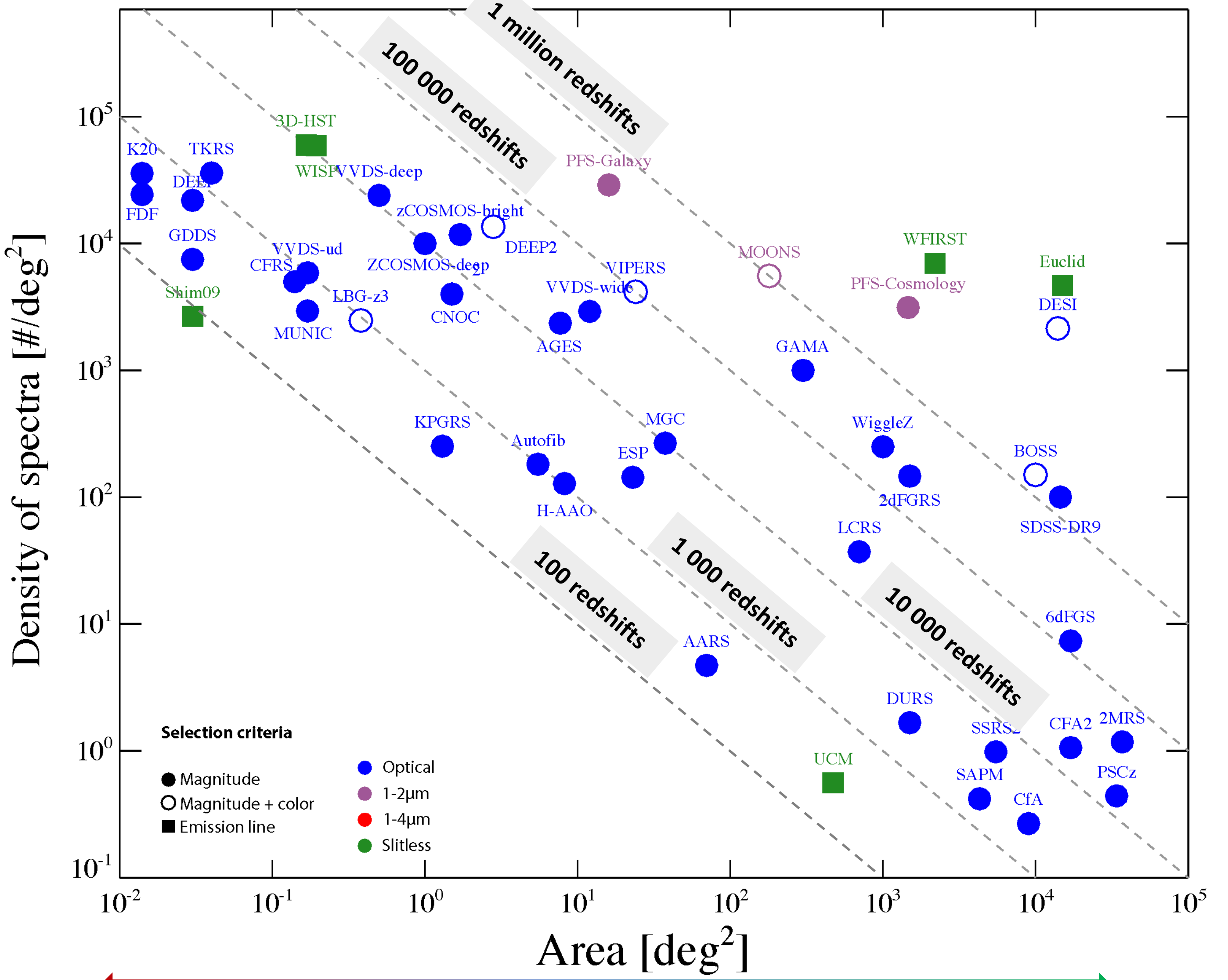
Massive redshift surveys

☞ well-defined samples



Nature, vol 551 (2017)

Need to sample representative volumes of the Universe, to compare similar populations at different redshifts



Gal. Evol, High-z **Environment** **LSS – BAO – Clusters**

The wedding cake observational strategy

UltraDeep – towards the early universe

Deep - Demographic knowledge of the sources

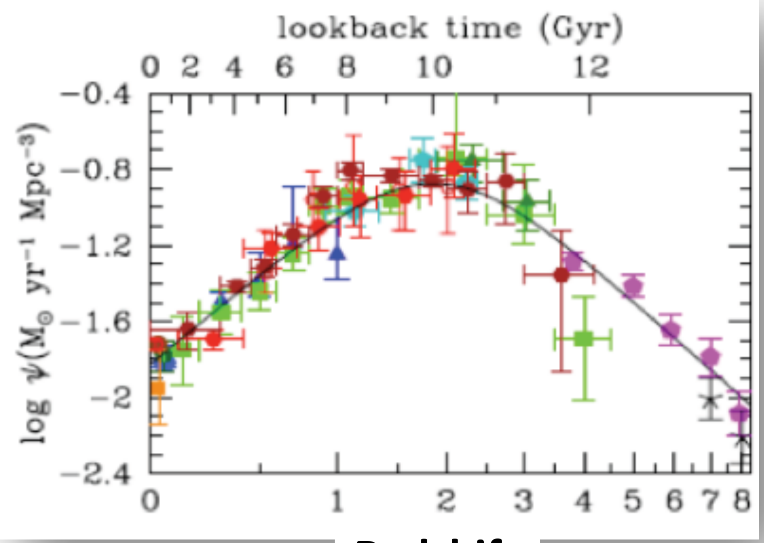
Wide - Large Scale Structures - Cosmology probe

Deep surveys are made in larger and larger collaborations

A real challenge for future Astronomy made in large collaborations

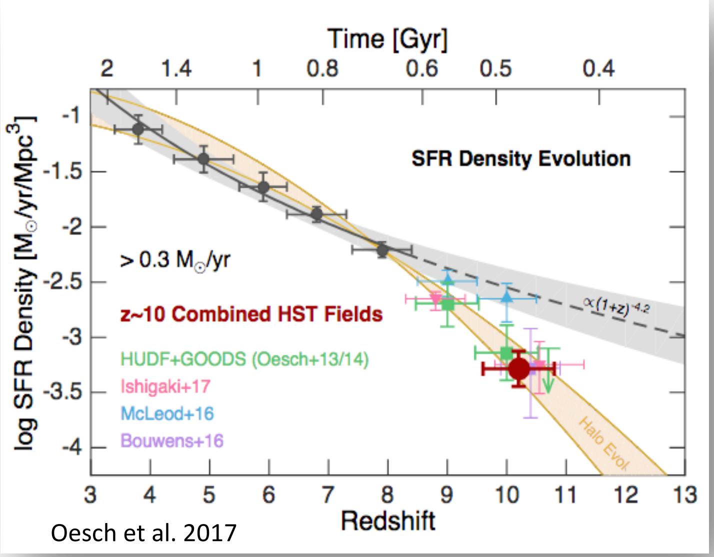
Galaxy population evolution

A very robust picture of the Cosmic Star-Formation History



Redshift

Madau & Dickinson 2014, ARA&A, 52, 415

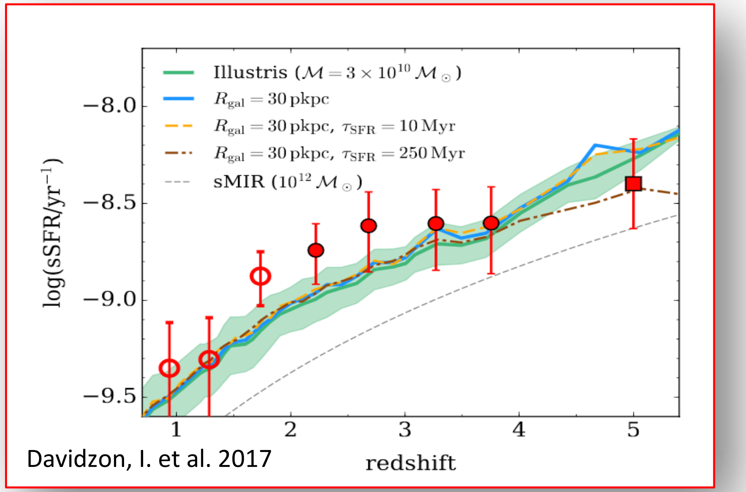


At z>8
accelerated evolution?

In less than 4 Gyr z=8 (EoR) → z=2 (Cosmic Noon)

- ✓ the Universe reached its maximum SF activity
- ✓ ½ local stellar mass content is assembled

sSFR - the efficiency of growing mass within a galaxy



at $z > 2$ $sSFR \propto (1+z)^{1.1\pm0.2}$

☞ very efficient gas cooling at z > 2 in DM halos

All culminate at z=2 – the cosmic noon in the redshift desert

Maunakea Spectroscopic Explorer

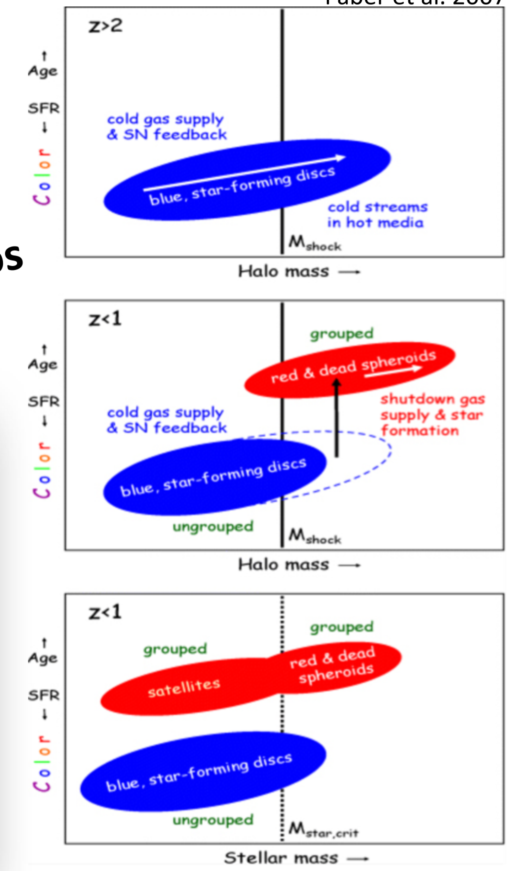
Cosmic SFR, AGN activity, galaxy growth, massive black hole accretion history, mass assembly, morphological differentiation, dust attenuation, …

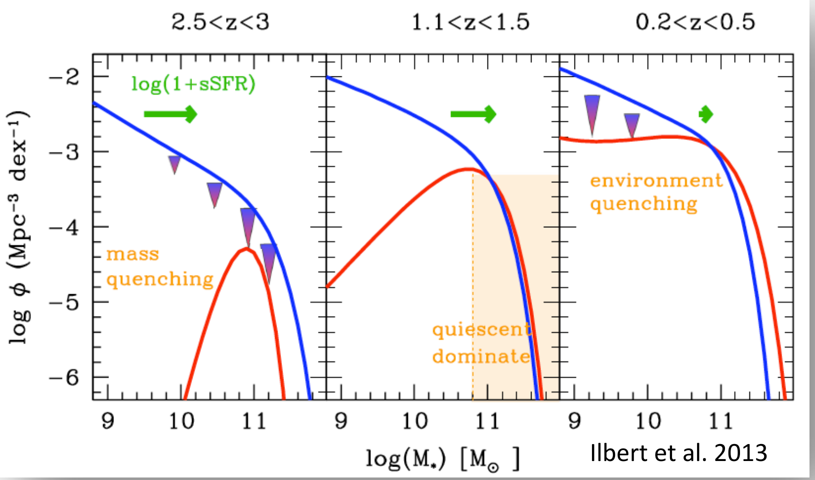
☞ Need Blue + NIR facilities to span the z desert – [OII] doublet out…Ly-alpha in

Galaxies above a certain mass must stop forming stars
need efficient quenching processes

Not solved yet
many proposed scenarios

Faber et al. 2007

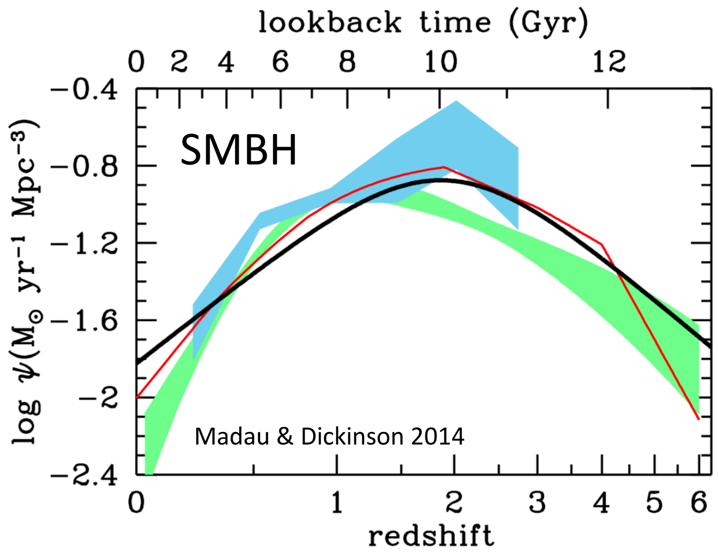




Environment quenching?

- Galaxy formation and evolution is govern both on small scales and large cosmological scales

☞ Need of a high spatial density sampling of targets



SMBH growth broadly traces evolution of SFR in galaxies

Mass quenching? AGN, supernova and stellar feedbacks

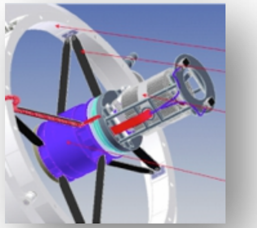
- One in 100-1000 galaxies host an active nucleus at any time, AGN play a major role for galaxy formation theory (cooling flow, scaling relations, massive galaxies,…)

☞ Need larger samples because of stochasticity of AGN phenomenon

Maunakea Spectroscopic Explorer

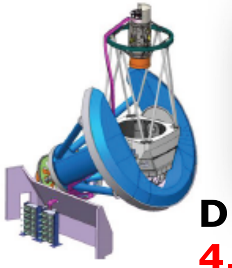
Many anticipated wide-field MOS facilities

brought together with imaging survey synergies

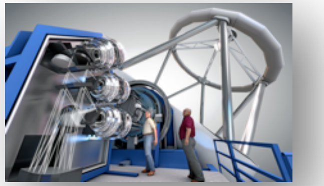


WEAVE@WHT
4.2m, 2 deg. dia, 1000 fibers
0.37-1 R<5000/20,000
Dedicated facility

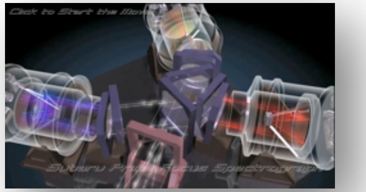
4MOST@VISTA-ESO
4.1m, 2.5 deg. dia, 2400 fibers
0.39-0.93 R<5000/18,000
Dedicated facility



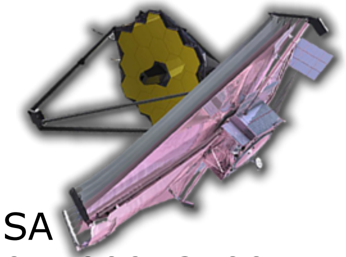
DESI@Mayall
4.0m, 3 deg. dia, 5000 fibers
0.36-0.98 R<5000
Dedicated facility



MOONS@VLT-ESO
8.2m, 0.4 deg. dia, 1000 fibers
0.64-**1.8** R~5000/8000/20,000
~~Dedicated facility~~

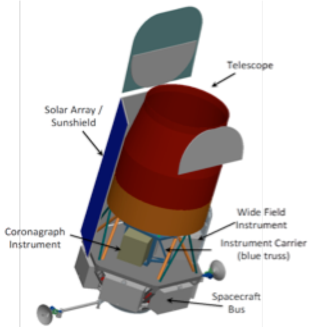


PFS@Subaru
8.2m, 1.5 deg. dia, 2400 fibers
0.38-**1.26** R~3000/5000
~~Dedicated facility~~



JWST
6.0m, ~100 MSA
0.6-5.3, R=100, 1000, 2700
~~Dedicated facility~~

Euclid
1.2m, 0.7 deg. dia
0.9-2.0 R~250 slitless
Dedicated facility



WFIRST-AFTA
2.4m, 2.5 deg. dia
1.35-1.95 R~460 slitless
Dedicated facility

Do we need more wide-field MOS facilities?

Galaxy Assembly and Cosmic Web (Ellis et al. 2016 - ESO report)

- Low resolution spectroscopy with modest SNR, often one emission line - PFS, DESI, Euclid

Need to resolve emission line doublets, measure internal stellar velocity dispersion that encode crucial physical information

- Deeper spectroscopy will probe too small volumes to probe the cosmic web at high z or to probe rare/extreme populations

- Spatial density low and biased towards brighter galaxies – limit the study of close environment around galaxies, and clustering measurements on small scales for modelling galaxy-halo properties

- Optimised for cosmological studies, and not for the physics of galaxy formation on a statistical basis

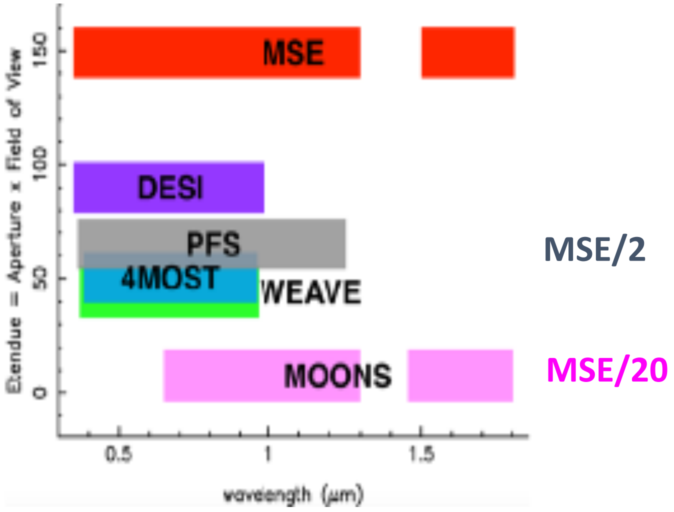
Deep multi-band imaging over large areas will permit efficient and reliable target selection
(until now, possible in small areas, eg VANDELS)

☞ MSE

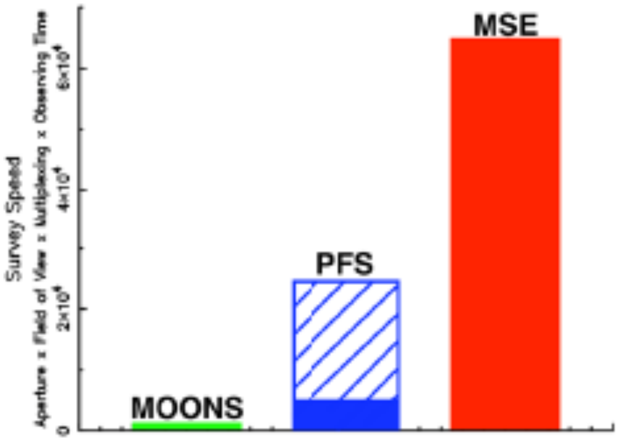
MSE and other anticipated **wide-field** MOS facilities

MSE is the largest of these facilities and the only dedicated facility on a large aperture telescope that could be operational in the 2020s, to overlap with facilities such as LSST, Euclid, and WFIRST.

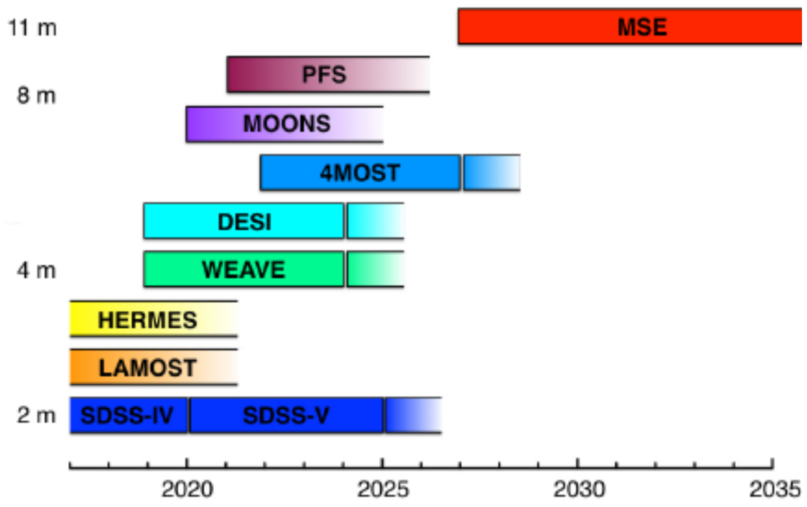
Etendue
FOV x π (M1/2)^2



Survey speed
Etendue x Multiplexing x Observing time

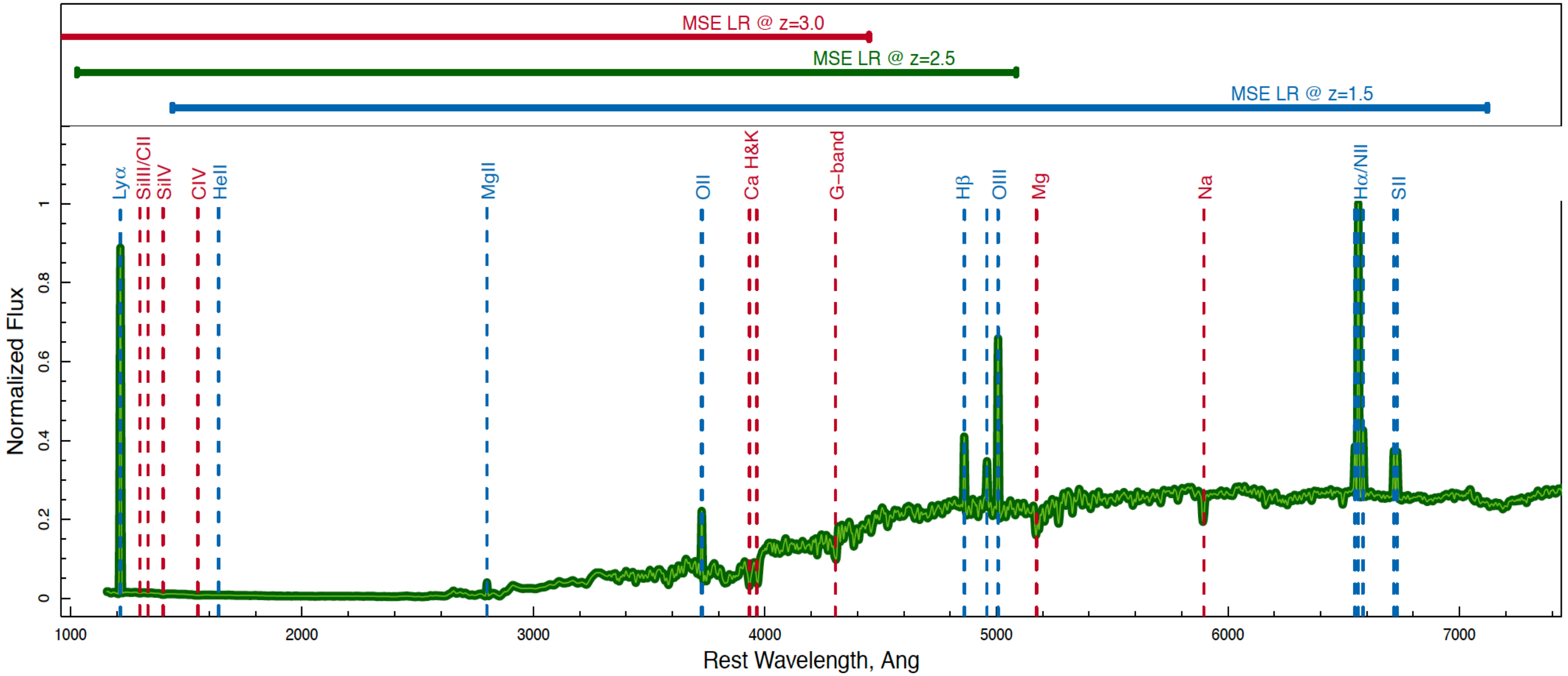


Wide-field MOSE timelines



MSE is designed to enable efficient massive spectroscopic surveys by 2030 and to remain productive for several decades
It will surpass its original rationale as proved with most astronomical facilities.

MSE Deep Surveys – in the critical cosmic noon epoch 1.5 < z < 3

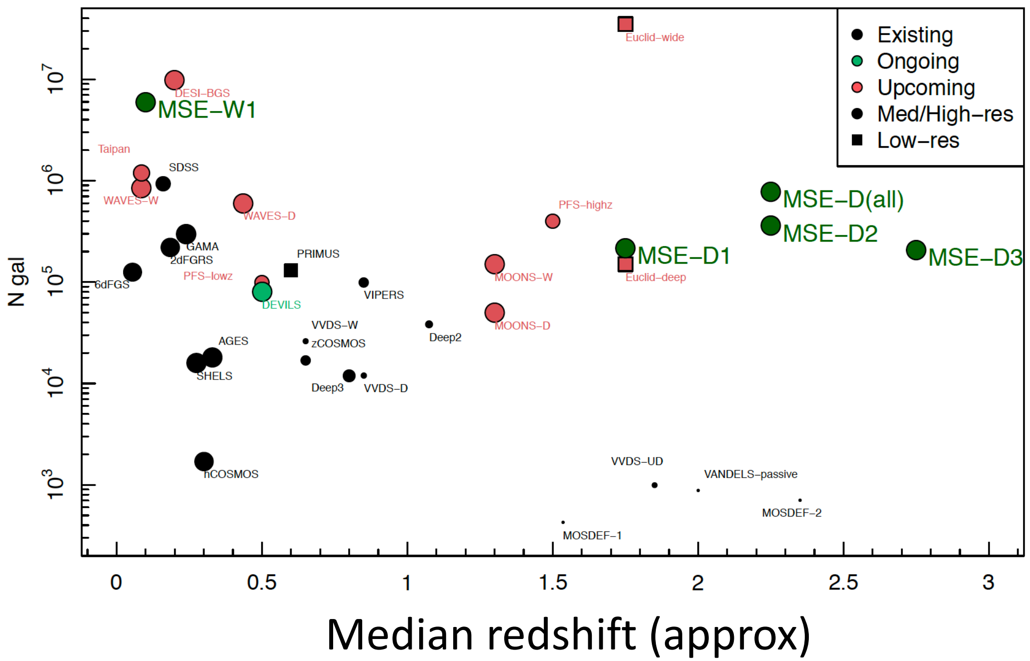


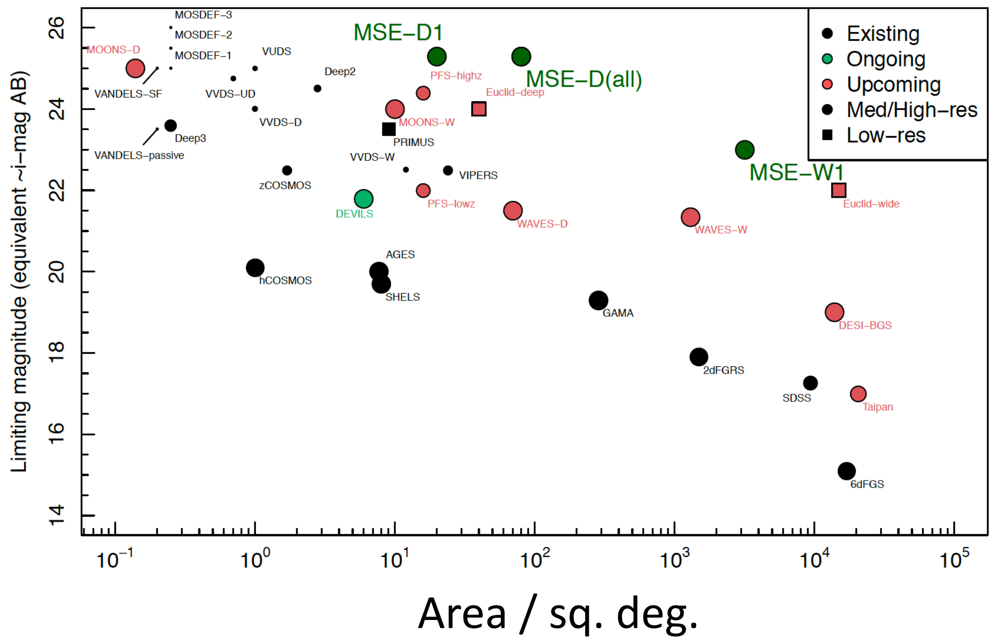
MSE Low Resolution: R =3000
Need of Blue + NIR

- at z ~ 1.5, MSE will observe all key optical features;
- at z ~ 2.5, it simultaneously links Lyman-α and UV-absorption lines with optical emission lines;
- MSE retains the ability to observe OII and Ca H&K features to z ~ 3.

MSE Deep Surveys – in the critical cosmic noon epoch 1.5 < z < 3

☞ See Science Cases astro-ph/1904.04907





To cover the range of environments explored by local surveys requires that we probe samples

(i) to similar stellar masses,

(ii) to similar completeness

(iii) over similar cosmological volumes.

Area (sq.deg)	z_{lo}	z_{hi}	Vol / Gpc^3	Selection	N (10^3)	Density (10^3/sq.deg)	Texp (m.hrs)
20	1.5	2.0	0.04	$i < 25.3$	220	11.0	1.8
80	2.0	2.5	0.16	$i < 25.3$	360	4.5	3.2
80	2.5	3.0	0.16	$i < 25.3$	200	2.6	2.0

D1 - designed to explore galaxies and their environments at 1.5 < z < 2.0, **90% completeness** at i=25.3 eg. 3 million fiber hours

Studies will be enabled about galaxy close pairs, groups/clusters, halo distributions, massive galaxies, environment, AGN, IGM tomography, etc.

Maunakea Spectroscopic Explorer

A **powerful**, **efficient** and **reliable** survey machine

Will unveil the fundamental quenching processes in the galaxy population