# Do we need an 8m wide-field spectroscopic survey telescope?

Malcolm Bremer

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# What do we mean by an 8m *wide-field* spectroscopic *survey telescope*?

- Wide field : Instantaneous field-of-view a good fraction of a square degree. Capable of surveying 100s or 1000s of square degree
- Survey telescope: High multiplex – 1000+ slits/fibres per pointing/configuration

# Existing (2020s) missions as drivers

Non-exhaustive list of existing/recent facilities that will have produced large area data sets that may/will benefit from detailed very wide area follow-up spectroscopy :

Optical/IR imaging:- galaxy photometry & morphology to $z>1$
**EUCLID**, **KIDS**, **VISTA**, **LSST**, **DES**

Radio:- star forming galaxies and AGN to high redshift $z>1$
**SKA and precursors**

X-ray:- Galaxy clusters to $z\sim1$-$1.5$ and AGN to $z>1$
**eROSITA**

The Galaxy: individual stars
**Gaia**

# Science Drivers

1. **COSMOLOGY**
   Dark Energy
   Structure Growth
   Dark Matter

2. **GALACTIC ARCHAEOLOGY**
   Assembly history of the MW and local group
   Chemistry
   Dynamics
   Formation of different components
   Dark Matter

3. **GALAXY EVOLUTION**
   Re-ionization
   Stellar mass growth
   Baryon processing/chemistry
   Structure growth
   Dark Matter

Obviously, some of these are also drivers for missions on the previous slide – Can do a lot with photometric redshifts in cosmology and galaxy evolution

# The limits of photometric redshifts

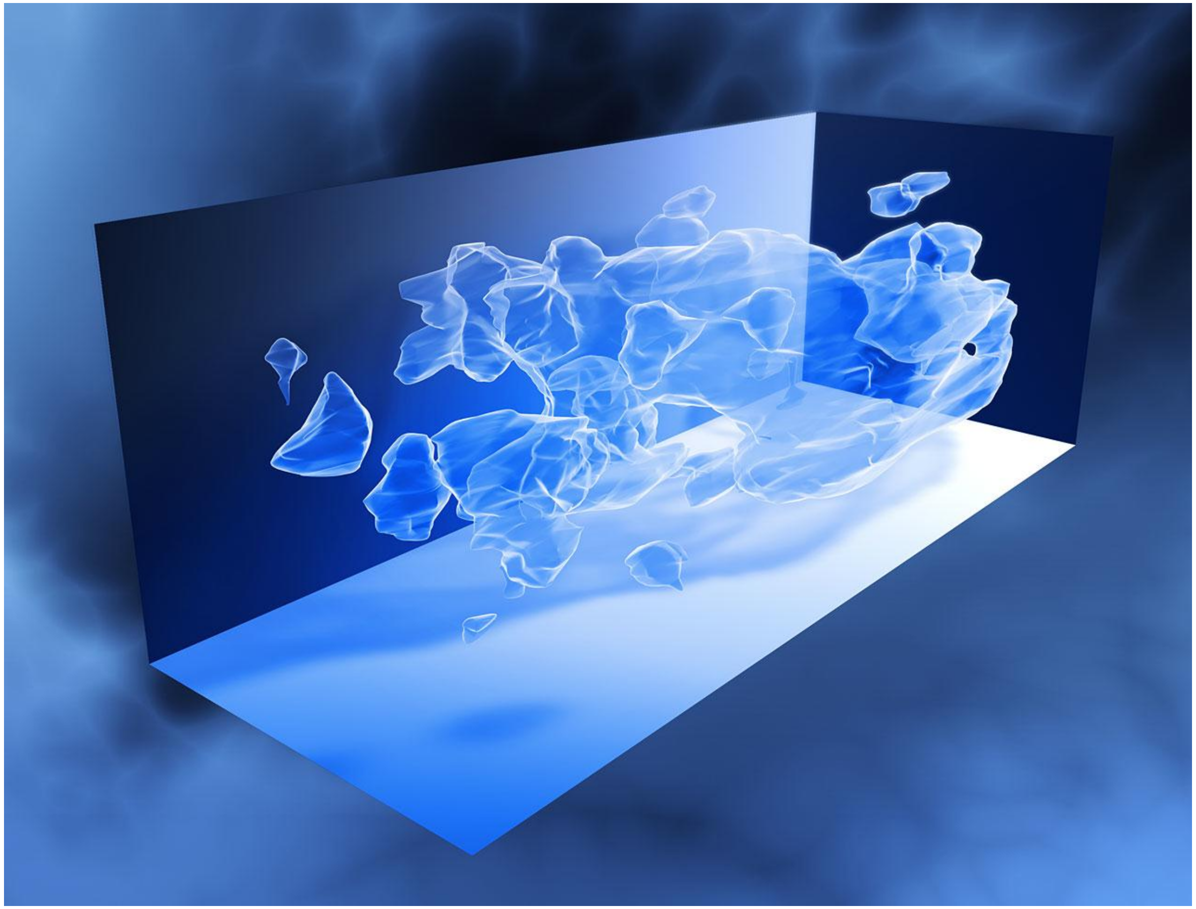
Precision in Distance, Time and Luminosity for a Redshift Uncertainty of $\sigma/(1+z) \sim 0.03$.

| Redshift | $\Delta z$ | $\Delta D_L$ (Mpc) | $\Delta D_A$ (Mpc) | $\Delta t$ (Mpc) | $\Delta L/L$ |
|---|---|---|---|---|---|
| 0.1 | 0.033 | 162.7 | 111.38 | 399.4 | 0.705 |
| 0.5 | 0.045 | 306.3 | 60.29 | 320.0 | 0.216 |
| 1 | 0.06 | 489.4 | 23.12 | 237.9 | 0.148 |
| 2 | 0.09 | 854.6 | 8.57 | 141.1 | 0.110 |
| 3 | 0.12 | 1223.1 | 18.82 | 94.0 | 0.096 |

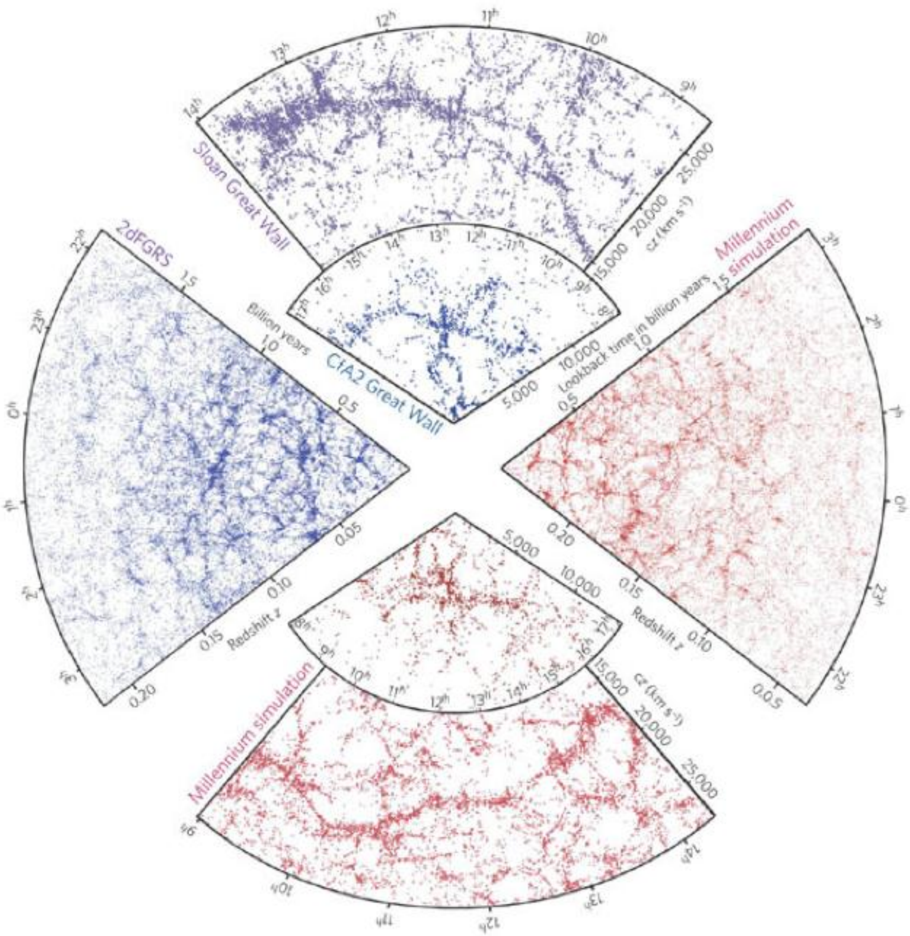
(From ngCFHT feasibility case)

Although spectroscopy obviously gives much better determinations of the above, still need to be concerned about radiative transfer effects for Lyα at high redshifts limiting studies on the  smallest scales (pairs, groups – mergers HOD, low mass LSS build-up).

# Don’t underestimate the ***wider*** impact of knowing the names addresses & telephone numbers of millions of galaxies



# Don’t underestimate the ***wider*** impact of knowing the names addresses & telephone numbers of millions of galaxies



# ESO MOS facilities in the 2020s

| FACILITY | WAVE-BAND | M-PLEX | Ω | AΩ | Density | "SPEED" | R |
|---|---|---|---|---|---|---|---|
| VIMOS | 0.4-1 | 600 | 0.06 | 3.3 | 9700 | 60 | 180-2500 |
| FLAMES | 0.4-1 | 8-130 | 0.136 | 7.2 | 955 | 10 | 5-25000 |
| MOONS | 0.6-1.8 | 1000 | 0.14 | 7.3 | 7150 | 100 | 4-6000, 9000, 20000 |
| 4MOST | 0.4-1 | 1500 300 | 3 | 40 | 500 | 37 | 5-7000 20000 |

SPEED– simply MULTIPLEX x A, normalised to 100 for MOONS. The higher the better.
A is a proxy for sensitivity, does not take into account throughput etc

# Other 8m WF MOS facilities in the 2020s

| FACILITY | BAND | M-PLEX | Ω | AΩ | DENSITY | "SPEED" | R |
|---|---|---|---|---|---|---|---|
| ngCFHT/ MSE | 0.4-1.3<br>0.4-1 | 3200<br>800 | 1.5 | 118 | 2130 | 470 | 2000<br>6500,20000 |
| Subaru/P FS | 0.8-1.3 | 2400 | 1.1 | 70 | 2180 | 240 | 5600-25000 |
| MOONS | 0.6-1.8 | 1000 | 0.14 | 7.3 | 7150 | 100 | 4-6000, 9000, 20000 |
| 4MOST | 0.4-1 | 1500<br>300 | 3 | 40 | 500 | 37 | 5-7000<br>20000 |

To simply generate spectra, regardless of area, Subaru is twice as fast, MSE three times as fast as MOONS (M-PLEX)
To generate the density of targets achievable by MOONS, MOONS is faster for areas up to ~ 0.5 degrees$^2$
Obviously, need to take into account throughput, efficiency, fibre placing efficiency, wavelength coverage.

# As an example: Subaru/PFS plans

EXTRAGALACTIC SCIENCE, COSMOLOGY AND GALACTIC ARCHAEOLOGY WITH THE SUBARU PRIME FOCUS SPECTROGRAPH (PFS)

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*Draft version August 1, 2013*

## ABSTRACT

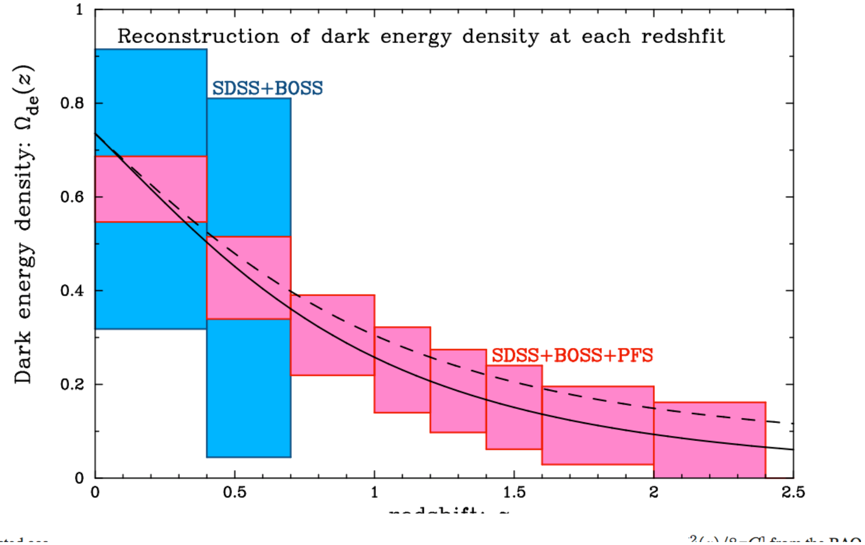
The Subaru Prime Focus Spectrograph (PFS) is a massively-multiplexed fiber-fed optical and near-infrared 3-arm spectrograph ($N_{\rm fiber}$=2400, 380$\leq \lambda \leq$ 1260nm, 1.3 degree diameter hexagonal field), offering unique opportunities in survey astronomy. Following a successful external design review the instrument is now under construction with first light anticipated in late 2017. Here we summarize the science case for this unique instrument in terms of provisional plans for a Subaru Strategic Program of $\simeq$300 nights. We describe plans to constrain the nature of dark energy via a survey of emission line galaxies spanning a comoving volume of $9.3h^{-3}$Gpc$^3$ in the redshift range $0.8 < z < 2.4$. In each of 6 independent redshift bins, the cosmological distances will be measured to 3% precision via the baryonic acoustic oscillation scale, and redshift-space distortion measures will be used to constrain structure growth to 6% precision. In the near-field cosmology program, radial velocities and chemical abundances of stars in the Milky Way and M31 will be used to infer the past assembly histories of spiral galaxies and the structure of their dark matter halos. Data will be secured for $10^6$ stars in the Galactic thick-disk, halo and tidal streams as faint as $V \sim 22$, including stars with $V < 20$ to complement the goals of the Gaia mission. A medium-resolution mode with $R = 5,000$ to be implemented in the red arm will allow the measurement of multiple $\alpha$-element abundances and more precise velocities for Galactic stars, elucidating the detailed chemo-dynamical structure and evolution of each of the main stellar components of the Milky Way Galaxy and of its dwarf spheroidal galaxies. The M31 campaign will target red giant branch stars with 21.5$< V <$22.5, obtaining radial velocities and metallicities over an unprecedented area of 65 deg$^2$. For the extragalactic program, our simulations suggest the wide wavelength range of PFS will be particularly powerful in probing the galaxy population and its clustering over a wide redshift range. We propose to conduct a color-selected survey of $1 < z < 2$ galaxies and AGN over 16 deg$^2$ to $J \simeq$23.4, yielding a fair sample of galaxies with stellar masses above $\sim 10^{10} M_\odot$ at $z \simeq 2$. A two-tiered survey of higher redshift Lyman break galaxies and Lyman alpha emitters will quantify the properties of early systems close to the reionization epoch. PFS will also provide unique spectroscopic opportunities beyond these currently-envisaged surveys, particularly in the era of Euclid, LSST and TMT.

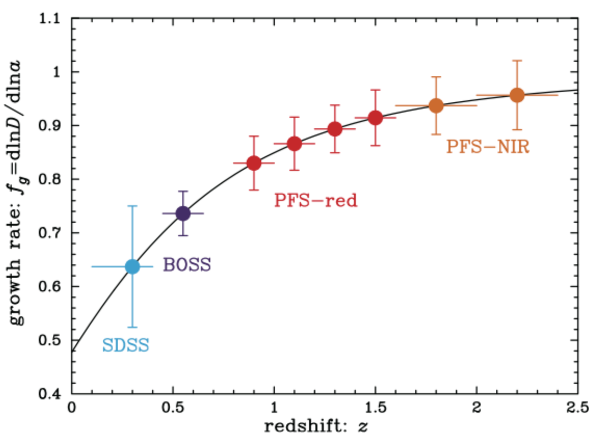
*Subject headings:* PFS — cosmology — galactic archaeology — galaxy evolution

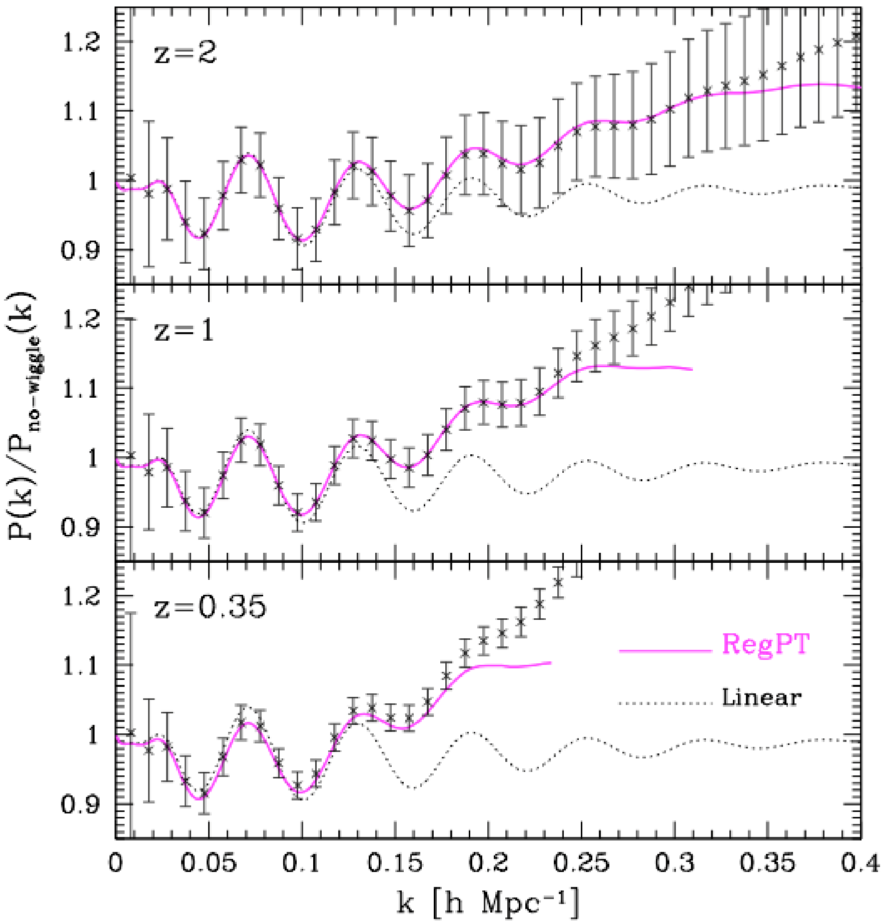
# Subaru/PFS Plans

**Dark Energy**: 100 nights through 0.6<z<2.4 [OII]

BAO survey (BAO scale >1 degree), <3% $D_A(z)$, $H(z)$, <7% $\Omega de(z)$, <0.3% $\Omega_k$ in 6 bins between 0.8<z<2.4. Growth rate of structure to <6% in 6 bins using RSD



# Subaru Plans

Galactic archaeology 100 nights (includes MW, M31, dIrr, dSph)

Radial velocities and elemental abundances for ~ a million stars
*Medium* resolution spectroscopy allows measurement of multiple α element abundances across all galactic components.

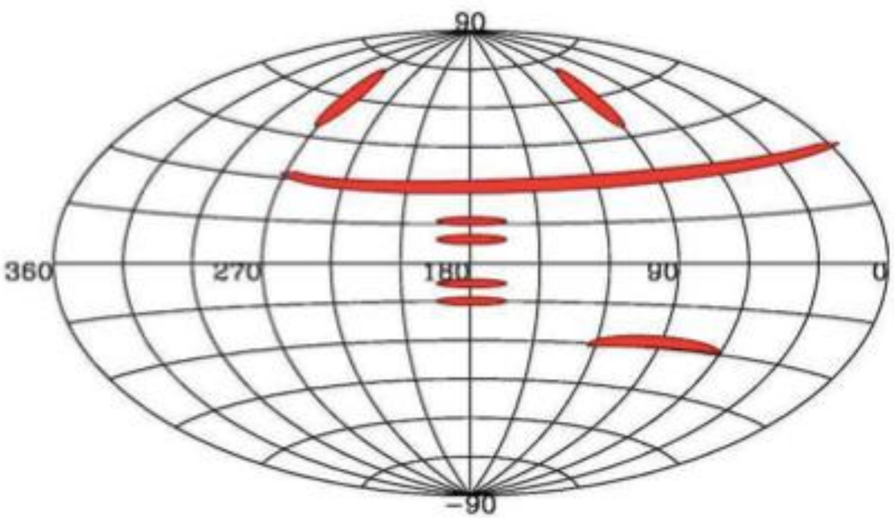
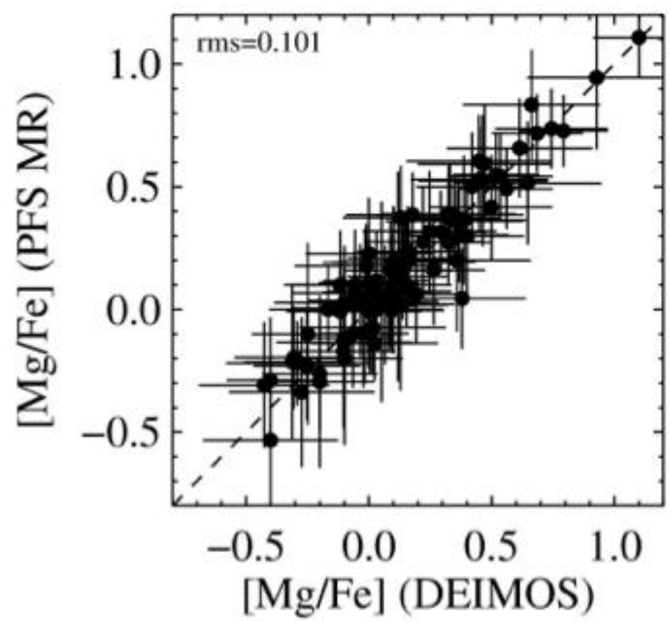
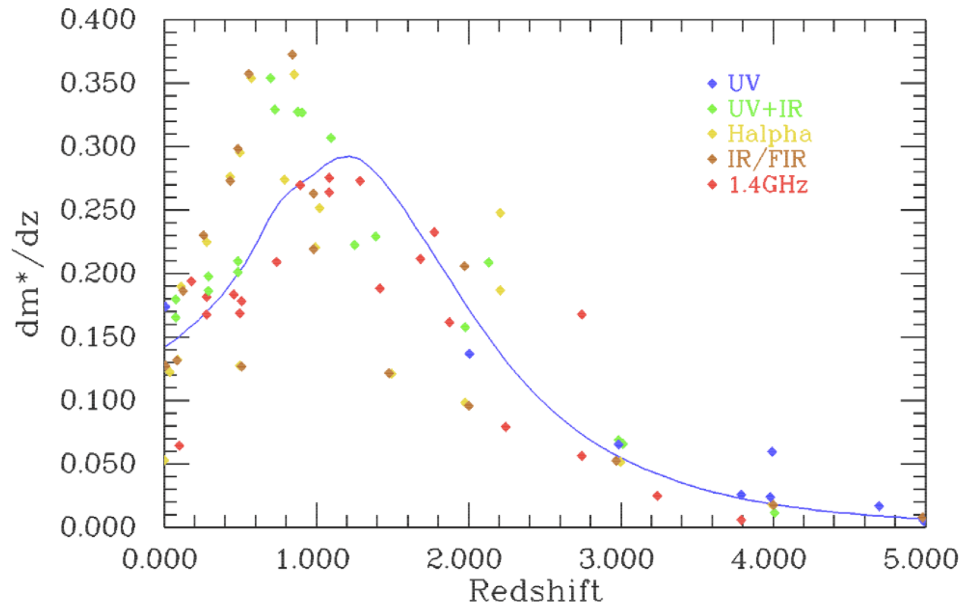



FIG. 18.— Proposed survey fields in the thick disk, stellar halo, and outer disk regions of the Milky Way in the galactic coordinate system.



# Subaru Plans

GALAXIES: 100 Nights 16 $deg^2$

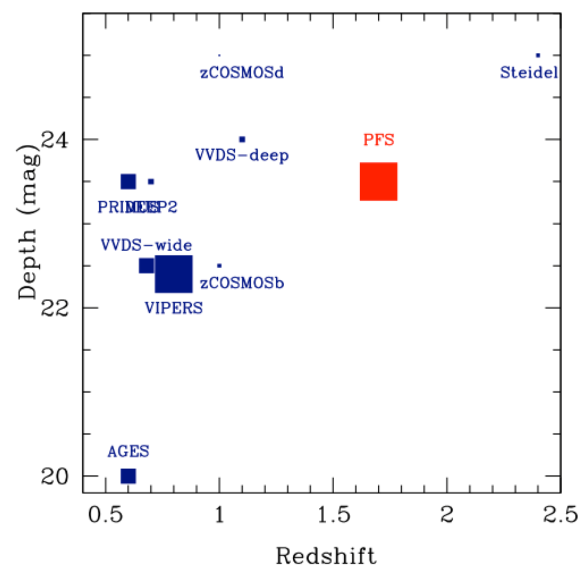



500,000 galaxies at 1<z<2

140,000 bright drop-outs and
LAEs at 2<z<7

50,000 3<z<7 colour-selected galaxies

- •The build up of stellar mass density (*SSFR*)
- •The growth of structure (*Correlation function, halo occupation, down to small groups*)
- •Gas inflow & outflow (*mass-metallicity, abs lines, stacking, cold accretion*)
- •The build-up of supermassive black holes (*QSO LF, clustering, environment, $M_{BH}$*)
- •EoR, ionized bubbles (*10K LAE line profiles*)
- •EoR, neutral fraction (*LAE LF*)



# MSE (ngCFHT) Plans

From Côté et al., feasibility study

1. *Galactic Archaeology.* ngCFHT would provide the ultimate spectroscopic complement to the Gaia mission, with a multi-year, bright/grey-time survey that would map a quarter of the volume of the Milky Way and yield medium-resolution spectra for a sample of 20 million stars, 5 million of which would also have high-resolution data. No planned or proposed survey could rival this programme in its ability to characterize the halo metallicity distribution function, perform chemical tagging of Galactic stars, or explore the three-dimensional, phase-space structure of our Galaxy.

2. *Galaxy Evolution and Cosmology.* A suite of dark-time surveys covering many thousands of square degrees would yield spectra for more than 10 million galaxies, allowing a study of galaxy evolution at seven distinct epochs between $0.5 < z < 1.5$ (each with the same statistical power as the SDSS) while providing BAO distances (accurate to better than 1%) to be used in a precise measurement of dark energy and its possible evolution with redshift. No planned or proposed spectroscopic survey would provide comparable constraints on the growth factor, the law of gravitation on large scales, or the shape of the power spectrum.

“Unrivalled” but still just a plan – 100% dedicated to surveys.

# What about MOONS?

- Key drivers are GAIA follow-up for Galactic studies and detailed studies of galaxy evolution at z>1.
- Optimised for these drivers
- As currently envisaged supports cosmology studies (particularly with EUCLID) rather than leads them.

# MOONS for Galactic studies

MOONS will be able to observe all the main components of our Galaxy

**Gaia + VISTA imaging**

- Position
- Transverse velocities
- Photometry

→

**MOONS Spectra**

- Radial velocities
- Global metallicity
- Detailed chemistry

→

**MOONS + Gaia + VISTA**

- Positions & velocities
- Dynamics
- Abundances
- iron-peak, alpha, CNO
- Astrophysics (ages, histories, etc)

- Formation and evolution of the Bulge.
- Origin of the thick Disc.
- Structure and evolution of the thin Disc.

- Quantitative studies of Halo sub-structure, dark matter, and rare stars.
- Kinematic multi-element distribution function in the Solar Neighbourhood.

Slide stolen from Hector Flores/ Michele Cirasuolo,

# MOONS for Galactic studies

MOONS will be able to observe all the main components of our Galaxy

**Medium resolution mode**

Radial velocities via
CaT @R=8,000 for I<21
+
[M/H] (via Fe,Si,Ti,Mg)
@R=4000-6000 (J+H)

**High resolution mode**

Detailed chemical abundances
(Si, Ca, Ti, Mg, Fe, Cr, Mn, CNO ...)
@R=20,000 for H<15.5
+
CaT @R=8,000

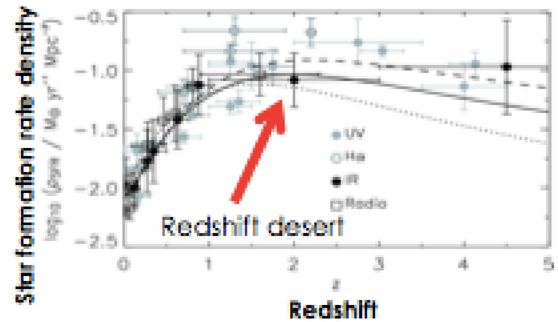
**Gaia:** MOONS will be the only instrument to provide the necessary radial velocities and especially chemical abundances for faint stars and the inner Bulge and Disc.

- Formation and evolution of the Bulge.
- Origin of the thick Disc.
- Structure and evolution of the thin Disc.

- Quantitative studies of Halo sub-structure, dark matter, and rare stars.
- Kinematic multi-element distribution function in the Solar Neighbourhood.

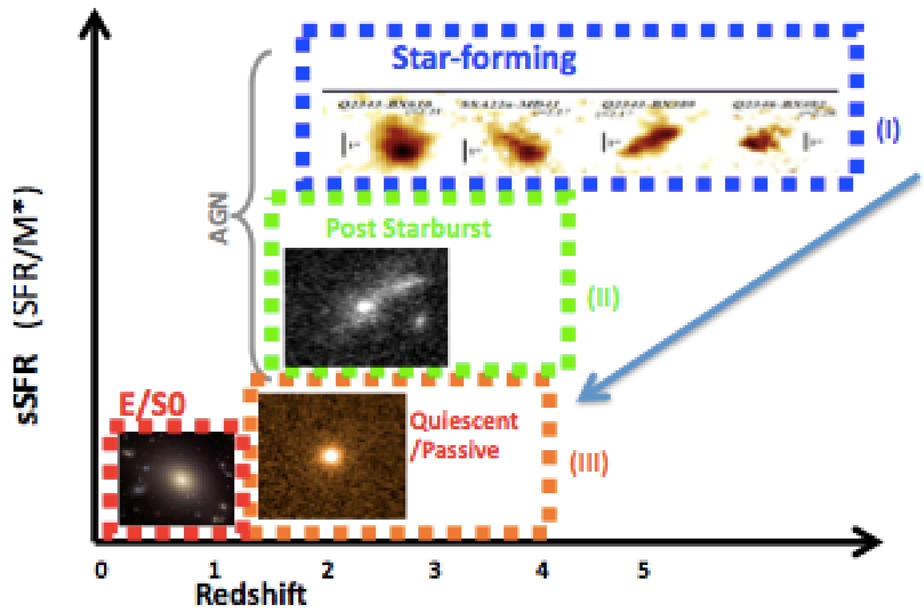
# Extra Galactic Science Case

**1M galaxies at z>1 across the peak of star-formation and black hole accretion, up to the very first galaxies at z>7-8**



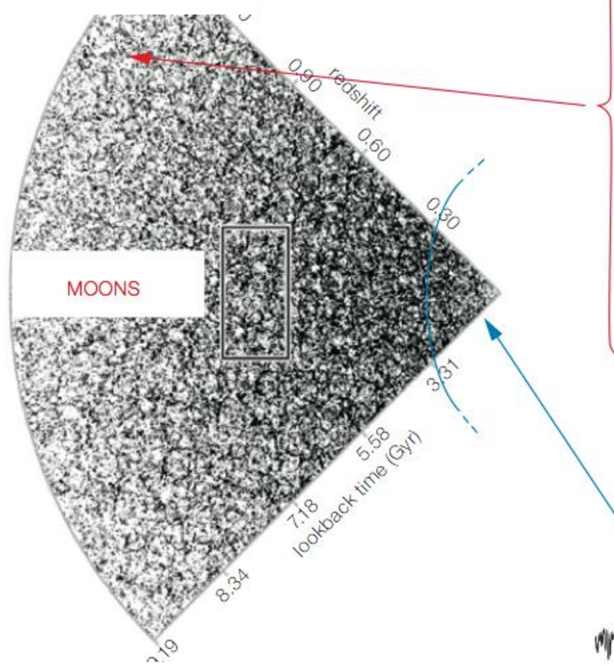

Galaxy Evolution: Diagnostics for passive and star-forming galaxies

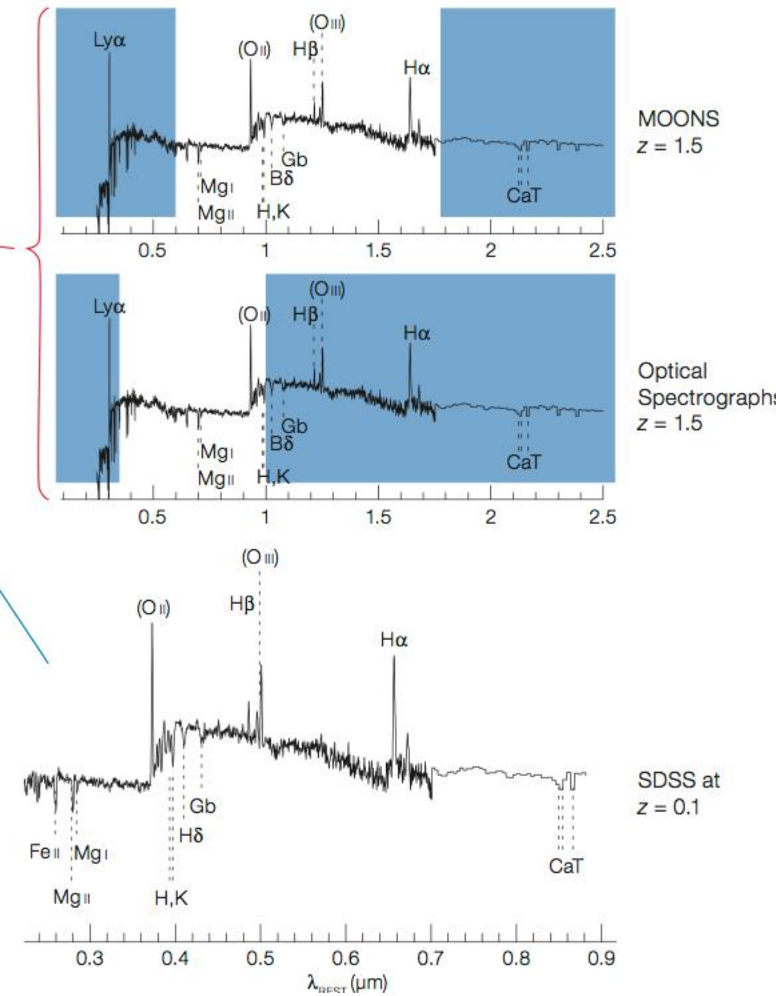
- *Metallicity ($R_{23}$,$N_2$)*
- *SFR (Hα, Hβ, [OII])*
- *AGN power (BPT)*
- *Dust extinction (Hα/Hβ)*
- *Galaxy mass ($\sigma_v$)*
- *BH mass (BLR)*




Slide stolen from Flores/Cirasuolo,

**4h integration per pointing**
**5 years survey**
**0.5 – 1 Million galaxies at z>1**

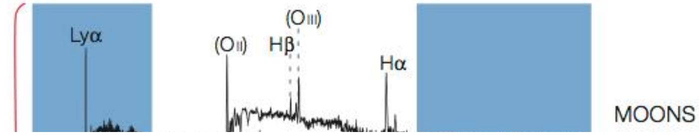


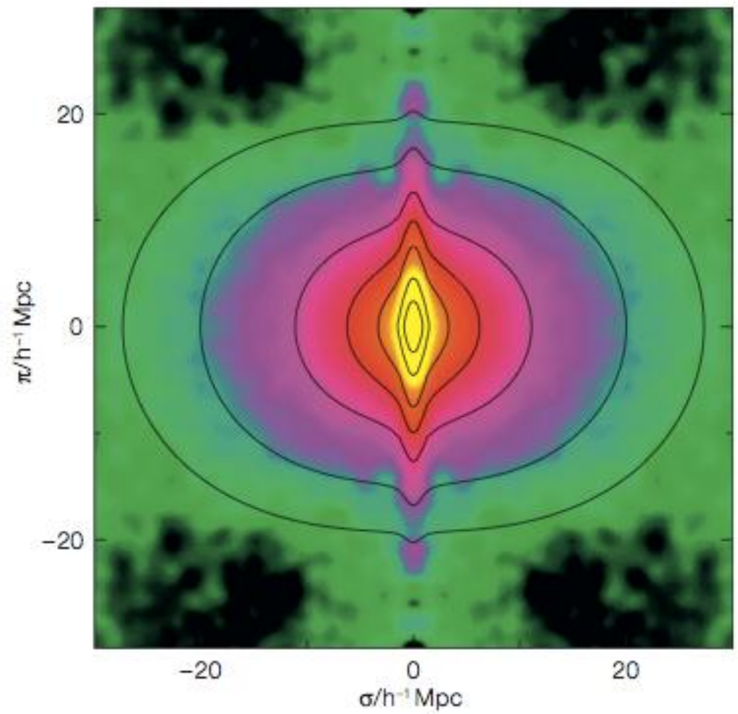



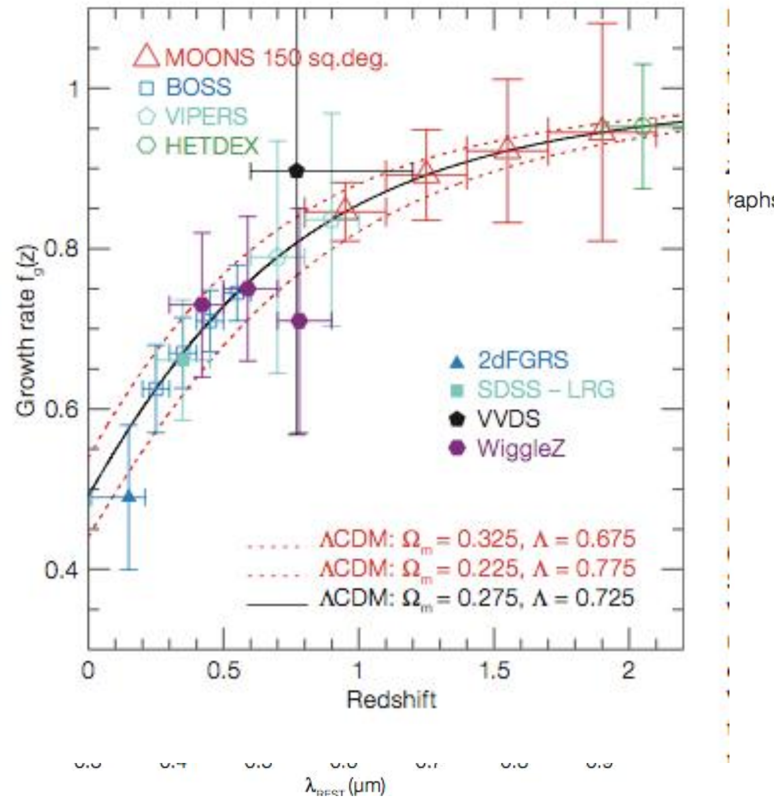

| Survey | Redshift | Volume ($h^{-3}$ $Mpc^3$) | #Objects |
|---|---|---|---|
| SDSS | $0 < z < 0.2$ | $1 \times 10^8$ | $10^6$ |
| MOONS | $0.8 < z < 1.8$ | $5 \times 10^7$ | $2.5 \times 10^6$ |

From Messenger article

**4h integration per pointing**
**5 years survey**
**0.5 – 1 Million galaxies at z>1**




From Messenger article

# Crucial input into photometric surveys eg EUCLID, LSST

The photometry-based extragalactic studies depend on accurate photometric redshifts.

To minimise systematics across surveys, spectroscopic training sets are required to be drawn from across a survey area (10s k-spectra).

To properly calibrate the redshifts, training sets must be of very high completeness. Different galaxy populations vary in how easy they are to obtain redshifts for and may have different redshift distributions/different systematics when translating from photometric to spectroscopic redshifts.

Missing a fraction of any one population may compromise the use of photometric redshifts for particular tasks (esp WL/BAO by photometric redshifts). Currently typical completeness levels are 50-75%, but compare GAMA and SDSS for nearby work. (~100k spectra) -> may require creative scheduling to get this completeness.

# PFS as a “straw” wide field spectrograph and MOONS

MOONS has smaller F.O.V, less fibres, so “slower” to achieve raw numbers of objects and area -> Issue for BAO studies. But Europe has Euclid for BAO.

MOONS has a higher target density per shot -> better completeness

MOONS has significantly better IR coverage -> better redshift range for many studies -> more complete in terms of range of galaxy population-> fewer systematic biases. Far less affected by obscuration for Galactic studies.

MOONS has better sensitivity over all IR bands

MOONS has better fibre positioning strategy (completeness, interactions, pairs).

Subaru is only one telescope – PFS has to share, more potential for MOONS to dominate if it can have significant share of one UT.

# So, do we need an 8m wide-field spectroscopic survey telescope?

- To answer this we need to define exactly what we want it to do in terms of the big questions and consider the context it will operate within (competition/timeliness/complementarity).
- We need to tension this with what we might lose/trade.
  - Cost of a new telescope with different top-end to VLT??
  - Can MOONS (+4MOST?) achieve all we want? If so, do we
    - Dedicate all or most of a UT to MOONS surveys, effectively losing a UT to other GO and large programmes?
    - Build VLT5 to accommodate it? Again, where does the money & resources come from?
    - Schedule MOONS not to dominate a single UT and don’t worry about the competition?
    - Or can we add some “cheap” complementary technology that fills in any supposed gap in capability?

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Deep Waves
100deg2 R<22 1.2Mgal
5k filaments and 50k halos

Wide Waves
750 deg2 R<22, z<0.25,
0.9Mgals
Halo occupancy for 10^11-12, to
a stellar mass limit of 10^7

->Dark Matter

Part of 5 year, 25Mspec,
15000deg2 survey
Gaia
eROSITA
Cosmology – Euclid,SKA,LSST
complementarity