Session IV

Early- and Late-type Galaxies

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Dissecting the Formation Histories of Galaxies with Stellar Populations Models

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Abstract. How did galaxies evolve from primordial fluctuations to the well-ordered but diverse population of disk and elliptical galaxies that we observe today? Stellar populations synthesis models have become a crucial tool in addressing this question by helping us to interpret the spectral energy distributions of present-day galaxies and their high redshift progenitors in terms of fundamental characteristics such as stellar mass and age. I will review our current knowledge on the evolution of stellar populations in early- and late type galaxies at $z < 1$ and the tantalizing – but incomplete – view of the stellar populations in galaxies at $1 < z < 3$, during the global peak of star formation. Despite great progress, many fundamental questions remain: what processes trigger episodes of galaxy-scale star formation and what quenches them? To what degree does the star formation history of galaxies depend on the merger history, (halo) mass, or local environment? I will discuss some of the challenges posed in interpreting current data and what improved results might be expected from new observational facilities in the near- and more distant future.

Keywords. galaxies: evolution, galaxies: stellar content

1. Introduction

Our present understanding of how galaxies form is based upon the idea that the visible portions of galaxies correspond to only a small subset of the total mass of a galaxy, most of which is contained by its dark matter halo. While a successful and elegant theoretical framework for dark matter halos exists, describing their growth via mergers from the initial fluctuations visible in the cosmic microwave background, it has proven incapable in predicting the visible properties of the galaxies themselves: stars and gas.

Characterizing the stellar populations of galaxies – their stellar masses, ages, metallicities – and their relation to the morphology – structure, size – as a function of cosmic time is key to addressing the ultimate question: how did galaxies evolve from primordial seeds to the well ordered population of disk and elliptical galaxies that we observe today? The overarching question can be broken up in specific issues to be addressed:

- When did the first galaxies form?
- What triggers episodes of galaxy-scale star formation? What shuts them off?
- How do energetic feedback processes affect the galaxy formation process?
- What is the role of environment in the evolution of the stellar populations?
- Is star formation inherently different in the distant universe compared to locally?
- How do galaxies acquire their gas from and expel into the intergalactic medium?
- What drives the relation between galaxy properties and their central black holes?
- Connecting galaxy populations at different lookback times: what evolves into what?

Stellar population synthesis models (e.g. Fioc & Rocca-Volmerange 1997; Leitherer *et al.* 1999; Vazdekis 1999; Bruzual & Charlot 2003; Maraston 2005; Kotulla *et al.* 2009)

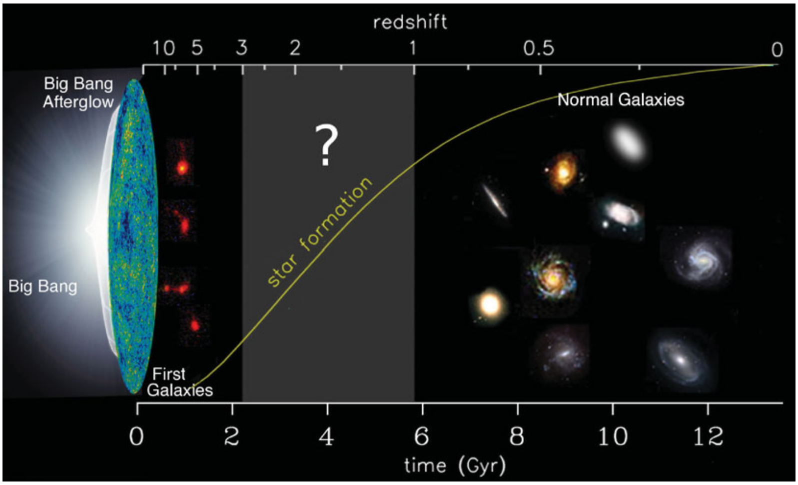

Figure 1. The importance of the $1 < z < 3$ redshift range for studies of galaxy formation. Here galaxies transformed from the small building blocks to the familiar spiral and elliptical galaxies that we see today. The line shows the cumulative fraction of star formation with time. During this crucial era in the history of the Universe, $\sim 60\%$ of all star formation in the history of the Universe took place and the number of luminous quasars peaked. Due to the current limitations of ground-based spectroscopy our knowledge of $\sim M^*$ galaxies beyond $z \sim 1$ is largely based on rather crude "photometric redshifts", derived from fitting stellar population synthesis models to multi-color photometry.

have become an unmissable and widely adopted tool to relate observables to fundamental parameters of stellar populations (e.g., stellar mass, age, metallicity) and provide the crucial bridge between the theoretical dark matter framework and the observations of luminous matter.

Modern stellar population models are rather complex, however – at least to the average user! – with a large number of significant uncertainties that may not be apparent to non-experts. A comprehensive overview is given by Jarle Brinchmann in these proceedings which I shall not repeat, but I will recall some of the widely acknowledged areas for improvement: uncertain aspects of stellar evolution (horizontal branch stars, thermally pulsing asymptotic giant branch stars, post-AGB stars, mass loss, binary evolution), non-solar abundance patterns, non-universal or even evolving IMF. We will return to accounting of the impact of these uncertainties at the end.

2. Stellar populations of early and late type galaxies across time

We now live in the waning days of cosmic star and galaxy formation. Galaxies at $z < 1$ show many of the basic properties they have today, such as the division into blue spiral galaxies and red ellipticals. The "heyday" of galaxy formation was at redshift $1 < z < 3$, when the cosmic SFR and the abundance of bright quasars peaked, and the majority of all star formation and black hole accretion in the history of the Universe took place. Figure 1 shows a graphical representation of the cosmic timeline: during the short 3.5 Gyr between $1 < z < 3$, galaxies transformed from small building blocks to the familiar families of elliptical and spiral galaxies we see at later times.

2.1. *The fossil record*

The slow growth since $z = 1$ makes it somewhat difficult to decipher what physical processes were responsible for the build-up of galaxies, their regularity, and for correlations

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between galaxy properties. Nevertheless, as has been shown by a long list researchers mining e.g., the Sloan Digital Sky Survey (York *et al.* 2000), a tremendous amount has been learned from very large homogeneous surveys at low redshift $z \sim 0.1$. The scaling laws and correlations between galaxy stellar populations and structural properties have been established in impressive detail (e.g., Kauffmann et al. 2003, Shen *et al.* 2003, Tremonti *et al.* 2004). Full optical spectrum fitting using stellar population synthesis models has even allowed a deconvolution of the fossil record to (roughly) infer the history of star formation and metal enrichment as function of time (e.g., Cid Fernandez *et al.* 2005, Blanton & Roweis 2007, Panter *et al.* 2008, Tojeiro *et al.* 2009; for a detailed overview, see the contribution of Mike Blanton in these proceedings and references therein).

The general well-established picture, is that the stellar populations of massive early types galaxies are old, quiescent, more metal enriched, formed in a relatively short time at high-redshift, have concentrated profiles, velocity distribution dominated by random motions, and tend to live in high density environments. Late type disk galaxies are generally lower mass, lower metallicity, experienced more extended and slower star formation, are less concentrated, dominated by rotation, and prefer lower density environments. However, the detailed formation history of galaxies, the relationship between disk galaxies and ellipticals, the triggers of star formation and quiescence, the relation to the underlying evolving dark matter halos, and the role of in-situ assembly (through star formation) versus hierarchical assembly by merging are not well known.

To tackle these questions we need to resort to lookback studies to trace the build-up of galaxies directly, providing an independent "differential" constraint on galaxy evolution: we can compare the detailed integrated properties of galaxies at each redshift with the differential change towards earlier times. The ultimate goal of these studies is to reconstruct the entire galaxy formation history by connecting representative and complete galaxy population snapshots, from the time when the first stars formed to the present. Clearly, stellar population models play a crucial role in these studies, as they are used to connect the observables at different redshifts to each other, and to simulations of the underlying dark matter.

2.2. *Lookback studies*

It should be stressed that lookback studies are very challenging. The cosmological surface brightness dimming and redshifting of the well-calibrated optical part of the spectrum into the near-IR at $z > 1$, make these surveys extremely expensive and cumbersome. In fact, I will argue that progress in this area has been largely limited by technology and lack of photons. Gustavo mentioned that we have collected more photons from distant galaxies than from nearby stars, but that is certainly not true for $z > 1$ galaxies (although more *hours* may have been spent on them!). Key for progress here is improved observations.

2.2.1. *The evolution early and late type galaxies at low redshift $z < 1$*

Deep optical galaxy evolution surveys (e.g., VVDS, Le Fevre et al. 2004; DEEP-2 survey, Davis *et al.* 2003; COMB0-17, Wolf *et al.* 2003; COSMOS, Scoville *et al.* 2007) have given us a fairly well established census of galaxy evolution since $z \sim 1$. Several key results of these surveys were:

- By $z \sim 1$ the galaxy bimodality of red quiescent spheroidal galaxies and blue disk galaxies was already in place
- The decline in cosmic average SFR of a factor of ~10 from z=1 to z=0 primarily reflects the decline of star formation in average disk galaxies; not the (slow) decline in merger rate.

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- the LF of red quiescent galaxies shows a factor of ~ 2 growth in number, while the blue star forming LF shows little growth
- the scaling relations of disk and red galaxies (color-magnitude, magnitude-size) appear to have evolved only modestly

The overall emerging picture is that significant numbers of disk galaxies are being transformed into non-star-forming spheroid-dominated galaxies by galaxy interactions, AGN feedback, environmental effects, and other physical processes (e.g., Faber *et al.* 2007, Bell *et al.* 2007). Furthermore, on average the population of galaxies grows inside-out: as individual galaxies grow in mass through the formation of stars, they grow in radius. Despite all this vigorous activity, most scaling relations of galaxies appear to evolve modestly (e.g., Gebhardt *et al.* 2003, Kobulnicky *et al.* 2003, Bell *et al.* 2004). Also the morphology-density relation (Dressler 1980), i.e., the increase in the fraction of early type galaxies in dense environments, is preserved to $z \sim 1$ (e.g., Cooper *et al.* 2007, van der Wel *et al.* 2007) and red galaxies are more clustered (reside in more massive dark matter halos) than blue galaxies (Coil *et al.* 2008).

Note that the technological drivers of progress of galaxy studies to $z = 1$ have been the availability of multi-object optical spectrographs on 8−m class telescopes (for redshifts and diagnostics) and relatively wide field imaging capability from space with ACS on HST (for sizes and morphologies; sizes of distant galaxies are typically ~ 1 arcsec or less).

2.2.2. *Galaxy populations at redshift $z > 1$*

The situation beyond redshift 1 has been much more challenging. Our knowledge of the "heyday" of galaxy formation, when processes such as star formation, merging, and AGN activity peaked, is much less accurate. Although efficient optical multi-object spectrographs have provided us with spectra of thousands of high redshift galaxies (e.g., Steidel *et al.* 2003), these observations did not sample the well-calibrated spectral diagnostics such as $H\alpha$ and the $4000\AA$ break. In addition, early surveys targeted the subset of $UV-$bright galaxies, which makes up only a small fraction of galaxies with typical stellar masses $\sim M^*$ at $z < 3$ (e.g., van Dokkum *et al.* 2006).

The arrival of large near-IR imagers on 4−m+ telescopes did give us a more complete census of $z > 1$ galaxies by detecting them in the rest-frame optical (e.g., Cimatti *et al.* 2002, Labbé *et al.* 2003). However, out of necessity studies of typical galaxies have relied almost completely on photometric redshifts. This technique derives distances from fitting stellar population models to the multi-color broadband photometry, yielding relatively crude and model-dependent redshift estimates, and allowing only a general characterization of the distant galaxy populations (e.g., Chen *et al.* 2003, Brammer *et al.* 2009).

However, even with (mostly) photometric redshifts and groundbased imaging much progress has been made, including estimates of evolution of the integrated mass density (e.g., Rudnick *et al.* 2003, Dickinson *et al.* 2003, Fontana *et al.* 2004; Drory *et al.* 2004; Bundy *et al.* 2005; Marchesini *et al.* 2009), the first detection of red quiescent galaxies at $z > 1.5$ (e.g., Daddi *et al.* 2005, Labbé *et al.* 2005), and characterizations of the stellar populations and sizes. A recent example is shown in Fig. 1, which presents the relation between rest-frame colors, specific star formation rates (SFR per unit mass), stellar mass, and sizes at $z = 1.5 - 2$ (Williams *et al.* 2009). Clearly, the galaxy population at early times was as diverse as it is today, and many of the well-known correlations with color and size appear to have emerged by at least $z \sim 2$.

In contrast, detailed studies including spectra and high resolution imaging in the near-IR are still very scarce. The grand total of $z > 1.5$ galaxies with deep near-IR spectra

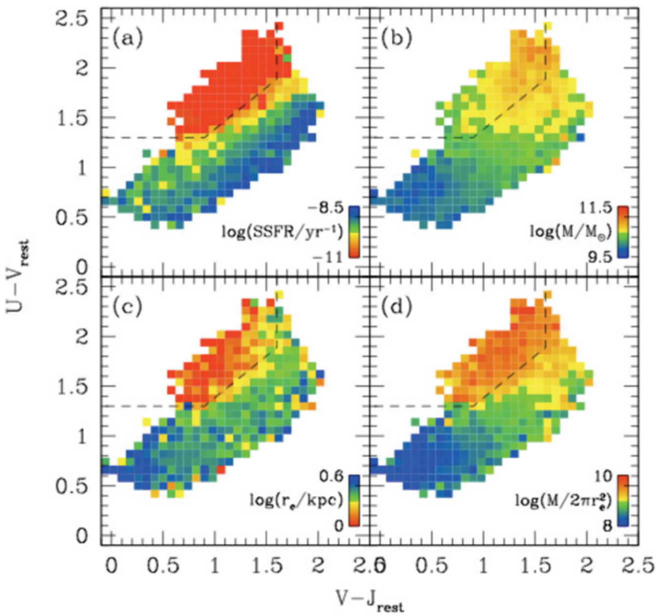

Figure 2. Rest-frame $U - V$ color versus $V - J$ color plot for galaxies at $1 < z < 2$ in the UKIDSS UDS, binned and color-coded by (a) log specific star-formation rate derived through SED fitting, (b) log(mass), (c) log(effective radius), and (d) log surface density (from Williams *et al.* 2009). The dashed line denotes the color space occupied by red galaxies with quiescent stellar populations. Below the diagonal glaxies are star-forming. Even with relatively crude photometric redshifts, there is clear evidence for the existence of correlations between galaxy structure and stellar populations at $z > 1$, and for evolution with redshift.

stands at a paltry ∼200 galaxies (e.g., Erb *et al.* 2006, Kriek *et al.* 2008, Förster Schreiber *et al.* 2009), compared with the ∼1 million or so spectra from the SDSS DR7. Of these high-redshift galaxies only a small subset have space based near-IR imaging or can even be considered a reasonably representative "snapshot" at $z \sim 2$. Nevertheless, tantalizing results have come from these few observations (see Fig. 3), including the discovery that the red quiescent galaxies at $z = 2$ were much more compact than today's ellipticals of the same mass (e.g., Trujillo *et al.* 2006, van Dokkum *et al.* 2008). This suggests that must grow in size, likely through ("hierarchical") merging with other (smaller) galaxies (e.g., Bezanson *et al.* 2009, Naab *et al.* 2009) and that today's ellipticals did not form in a single ("monolithic") burst of star formation at high redshift. Measurements of velocity dispersions provide direct tests of this scenario, and constraints on other uncertain aspects of the stellar populations, including the validity of the inferred "photometric" stellar mass and the IMF (e.g., van Dokkum *et al.* 2009, Cappellari *et al.* 2009).

On the other hand, extended, star-forming galaxies at $z = 2$ do somewhat resemble today's spiral galaxies, but their specific star formation rates are $1 - 2$ orders of magnitude higher (comparable to the dynamical time) and their velocity structure is quite different compared to the present-day cold rotating disks, with larger (or even dominant) contributions from random motions (e.g., Law *et al.* 2008, Forster Schreiber *et al.* 2009). These early disk analogs are thus thicker and more turbulent, possible indicating large inflows of gas, star formation feedback, or dynamical stirring (e.g., Genzel *et al.* 2008, Khochfar & Silk 2009). A word of caution: the samples underlying all these results do not constitute complete representative samples of the early universe: we still have long

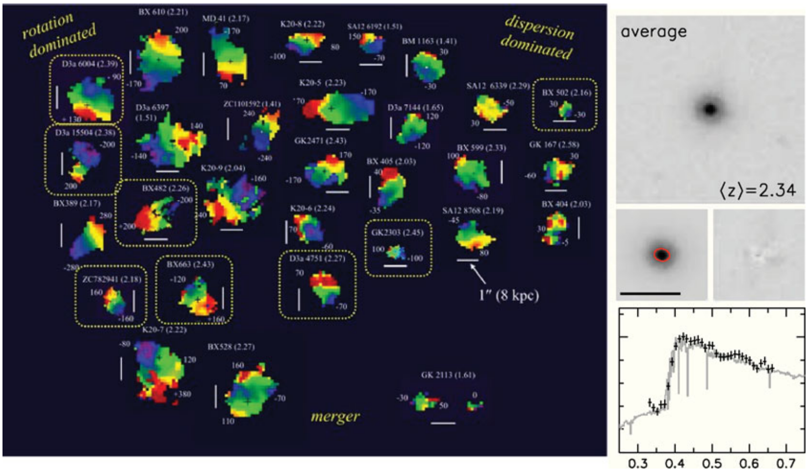

Figure 3. Detailed studies have been performed on only a small number of objects. (*left panel*) VLT/SINFONI maps of nebular emission line flux density of several luminous UV−selected star forming galaxies at $z = 1.5 - 2.5$ (Förster Schreiber *et al.* 2009). Although large scale velocity gradients (rotation) are visible for most objects, many galaxies have internal random motions of similar magnitude, quite unlike the dynamically cold disks of today's spiral galaxies. (*right panels)* the average NICMOS H_{160}−band image and the average near-IR (rest-frame optical) spectrum from Gemini/GNIRS of massive galaxies at $<z>= 2.34$ (van Dokkum *et al.* 2008). The galaxies have old stellar populations, with very little star formation. However, they are a $\sim 5\times$ more compact than local ellipticals of the same stellar mass: i.e., the galaxies would have to grow in size, likely through merging, to resemble elliptical galaxies at $z = 0$.

ways to go before we have complete population snapshots with high quality spectra over the entire redshift range $1 < z < 3$.

In summary, observations of the important vigorous epoch $1 < z < 3$ show that here the galaxy population evolved from subgalactic clumps to regular families of ellipticals and spirals, and recognizable correlations between galaxy properties first emerged. Yet, the detailed properties of high-redshift "red and blue sequence analogs" are quite dissimilar, implying strong structural evolution towards $z < 1$.

3. The Future: Near

The room for improvement is staggering. The most crippling limitations in interpreting the current observations at $z > 1$ are the the *lack of near-IR spectra* of complete samples, which provide the indispensable redshift, as well as physical diagnostics, and *scarcity of high spatial resolution imaging in the near-IR*, which traces the rest-frame optical morphology of galaxies to $z \sim 3.5$. In addition: certain measurements are photon starved with present 8-m class visible/near-IR telescopes (e.g., velocity dispersion from absorption lines at $z > 1.5$ and detailed integral field $3D$ spectroscopic maps at high spatial resolution < 0.1 arcsec).

It is important to realize that the future is really now: some of the limitations that have plagued earlier studies are about to be resolved. We will discuss three facilities that stand to make a great impact.

3.1. *High spatial resolution near-IR imaging*

Our limited ability to spatially resolve the extent of high redshift galaxies in the rest-frame optical has precluded us to study the morphology of the long-lived stars that dominate the stellar mass. Some important progress has been made from the ground with

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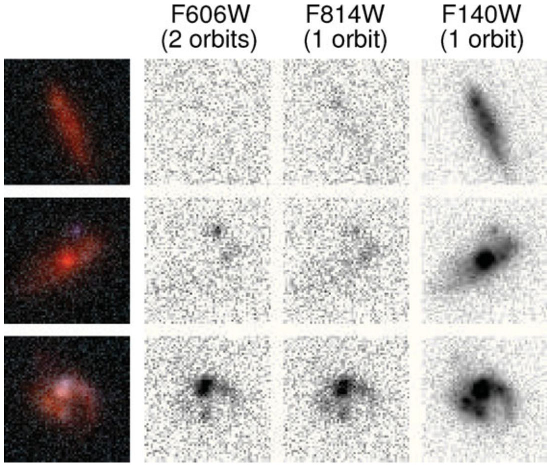

Figure 4. Measuring sizes and morphologies of distant galaxies requires spacebased or AO-assisted imaging in the near-IR. The recent installation of WFC3/IR aboard HST in particular, will soon create an unparalleled imaging legacy in the near-IR. The panels show ACS optical (V_{606} and I_{814}; rest-frame UV) and WFC3/IR near-IR (H_{140}; rest-frame optical) data of $z \sim 2$ galaxies in the HUDF. High spacial resolution ($\sim$ 1kpc scale) near-IR data of large numbers of distant galaxies permit us to study the stellar populations of sub-components (star forming regions, spheroids, and bars, etc) in high-redshift galaxies. Such observations are key to characterizing the build-up of the Hubble Sequence from $z \sim 3$ to $z \sim 1$.

AO and with the small area HST/NICMOS camera, but the recent arrival of WFC3/IR aboard HST promises to change the game by providing deep, relatively wide-field near-IR imaging at exquisite spatial resolution. Large samples at high-resolution will tie down the overall profiles and the internal $\sim$kpc scale color variations, enabling us to study the stellar populations of the sub-components (star forming regions, central spheroid, bars, etc). Figure 2 shows examples of some of the first WFC3/IR data taken in September 2009. These data will provide a rich harvest for investigation the structural evolution, triggers of star formation and quiescence, and the relation between galaxy structure and black hole growth.

3.2. *Multi-object near-IR spectrographs*

A slew of multiplexed near-IR spectrographs are about to arrive on large $6 - 10$m class telescopes (e.g. MMIRS on Magellan, FLAMINGOS-2 on Gemini, MOSFIRE on Keck, and X-SHOOTER on VLT). Observations will still be challenging, especially for absorption studies of passive galaxies, but will open the door at least an order of magnitude increase of distant galaxies with quality near-IR spectra, nebular lines fluxes and ratios, providing estimates of SFRs, metallicity, attenuation, and AGN activity.

3.3. *Long wavelength imaging and spectroscopy*

It has become clear that much of the vigorous activity of galaxies at $z > 1$ is obscured by dust, and re-emitted at long (far-IR, sub-mm) wavelengths (e.g., Le Floc'h *et al.* 2005). The estimation of the total infrared output (which dominates the bolometric luminosities of galaxies) and of the associated obscured star formation and AGN activity, has been hampered by spotty and relatively shallow sampling of the full IR SED. Much of our information on typical galaxies at $z = 1 - 3$ comes from single band Spitzer 24μm observations, which requires large corrections to estimate the total infrared light (e.g., Papovich *et al.* 2006, Wuyts *et al.* 2008). To explain the origin of the dust reprocessed

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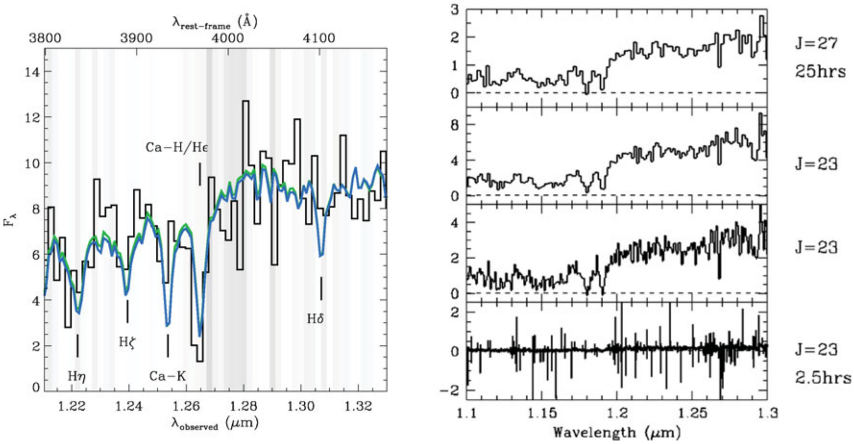

Figure 5. (*left*) State of the art (29 hour) near-IR spectrum (rest-frame optical) of a massive $\sim 10^{11} M_\odot$ red galaxy at $z = 2.18$ with GNIRS on Gemini (Kriek *et al.* 2009), representing the best we can currently do from the ground. Familiar absorption features are detected, and the best-fit stellar population age is ≈ 2.1Gyr. Future multi-object spectrographs in the near-IR will allow similar quality spectra for larger number of objects. The real breakthroughs will come from JWST and groundbased ELTs (*right*) Simulated spectra as would be observed with the 25-m GMT and its proposed near-IR multi-object spectrograph. The panels show (from bottom to top) the raw sky subtracted spectrum, a binned spectrum, a spectrum obtained with OH suppressing Bragg fibers and, last, a spectrum obtained with a noiseless photon counting detector and OH suppression.

emission in the far-IR (discriminate between star formation and black hole accretion processes) it is necessary to sample the full far-IR SED. The recent launch of the Herschel Telescope will help to do that by sampling the infrared SED from $\sim 70-500$ micron where the dust emission of high-redshift galaxies peaks, allowing us to start integrating the far-IR emission into stellar population modeling in a self-consistent way (e.g., da Cunha *et al.* 2008). ALMA, which is expected to start operations in 2010, will enable very deep (sub-)mm observations at exquisite spatial resolution, mapping the obscured star formation to $z = 10$, and spatially resolve it to ascertain if the IR emission is nuclear or extended (possibly ruling out an AGN origin). The brightest sources high redshift sources can be followed up spectroscopically with ALMA to measure CO, HCN, and CII emission lines, yielding gas masses, dust masses, and dust temperatures for some.

4. The Future: Far

The new generation of wide field near-IR imagers being developed for 8-m class telescopes will be sensitive enough to detect small stellar mass building blocks of galaxies up to $z = 4$ over a wide range of environments. Eight-meter telescopes, however, do not have the sensitivity, resolution, or both, to carry out the spectroscopy needed to understand the nature of the objects. The superior capabilities of the planned James Webb Telescope (JWST) and next-generation Extremely Large Telescopes (ELTs; e.g., the European ELT, and the North-American GMT and TMT) do allow us to address the most urgent questions, several of which we will mention here.

• Abundances and stellar populations: Gas phase metallicities have been measured for the brightest star-forming galaxies at $z \sim 2$ with current 8-m telescopes (e.g., Erb *et al.* 2006), but stellar abundances, a fundamental measure of the history of galaxy assembly,

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Science Question	Ground-based 8-m	JWST	ALMA	GSMTs
Global Mass Evolution	Large area imaging surveys	Low mass end of distribution	-	Spectroscopy of large samples
Internal Dynamics	-	Large samples of line widths	Dynamics of cold gas	IFU studies at diffraction limit
Stellar Populations	Photometric samples	Low dispersion spectra	Obscured star formation	High resolution line indices
Abundances	Rare, bright objects	Nebular diagnostics	Molecular gas	Photospheric abundances

Figure 6. The coming decade will bring revolutionary facilities, e.g., JWST, ALMA, and GSMTs, whose capabilities are strongly complementary in wavelength coverage, spatial and spectral resolution, and survey efficiency. This table summarizes how these facilities can work together to address the key questions.

are far more difficult to determine. The JWST and ELTs will revolutionize the study of absorption and emission line indices sensitive to stellar populations and star-formation histories (see Fig. 5).

• Dynamical mass functions: velocity measurement with JWST and ELTs will go a long way to calibrate the mass scales of galaxies, elucidating the relations between galaxy populations at different redshifts, and provide constraints on the IMF.

• Advanced probes of internal properties: spatially resolved kinematics at the diffraction limit of ELTs will allow us to dissect galaxies on scales of ∼100 pc (∼0.01 arcsec at $z = 2$) and deconstruct the velocity fields of galaxies into their sub-galactic components, placing constraints on models for the inflow of gas and mergers (e.g., Naab *et al.* 2007).

In conclusion, the next decade promises a spectacular increase in the number, depth, resolution, and wavelength coverage of high redshift galaxies. An overview of the capabilities and relative strengths of the new facilities is given is Fig. 6.

5. Stellar population models: accessibility to uncertainties

There is no doubt that the expected massive increase in knowledge at high redshift will go a long way to addressing the primary questions of galaxy formation and evolution as mentioned in the introduction, but it is still true that stellar population synthesis models remain a fundamental tool (and limitation) for the interpretation of galaxy spectra.

Several challenges stand out, including the role of dust (spatial distribution, effective reddening "law"), details of the stellar evolution models (such as the contribution of the TP-AGB phase to the rest-frame near-IR), and the IMF (which complicates relating star formation at early times with the stellar mass seen at later times).

Obviously, the stellar population models will (hopefully!) continue to improve, reflecting our deepening understanding of star formation processes. However, the next step from the perspective of the *non-expert users* of the codex is to have improved access to the more uncertain aspects of the models pending that progress: i.e. allowing observers to evaluate the impact of uncertain ingredients on the interpretation of data. Not only will it make confidence intervals on the inferred stellar population parameters more realistic (e.g., Conroy *et al.* 2009) but it may be that transparent access by observers to components of the models (e.g., phases of stellar evolution, IMF, non-solar abundances) yield better tests for galaxy evolution models... or help to identify further observations that will help reduce the model uncertainties.

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6. Summary

The past decade has seen enormous progress in our knowledge of galaxy formation and evolution. Stellar population synthesis models have proved a key tool, not only for the detailed examination of vast array of observations of low redshift galaxies, but also for determining the general properties of galaxies during the active phase of galaxy formation at $1 < z < 3$, and relating populations of galaxies at different redshifts.

Some domains of galaxy evolution studies are already limited by uncertainties in the ingredients of the stellar population models. Aside from improving the models, it would help (observers and theorists alike) to improve access to the uncertain model ingredients. This will allow observers to obtain more realistic confidence intervals of inferred galaxy population parameters, and perhaps even tests the uncertain aspects of the models.

But as it stands now, galaxy observations beyond $z \sim 1$ appear to be firmly observationally limited. That is good news, meaning that we are poised to gain tremendously from the new and upcoming facilities. Obviously, JWST and 30-m class groundbased ELTs with adaptive optics will revolutionize studies of the stellar populations of galaxies at $1 < z < 3$ by providing access to same well-calibrated diagnostics that we have used at low redshift. But even in the near-term we will see dramatic improvement: WFC3 on HST will soon provide rest-frame optical morphologies and spatially resolved ($\sim$ 1kpc scale) stellar populations of tens of thousands of galaxies beyond $z = 1$ and multi-object near-IR spectrographs on 8-m class telescopes will determine redshifts for many of them, allowing us to study large, representative, volume limited samples to track the emergence of the Hubble sequence. At long wavelengths, Herschel and ALMA will open up obscured universe to massively increased depths and resolutions, providing better insight in obscured star formation and AGN activity. There is no doubt that exciting times are ahead!

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