Statistical properties of local & intermediate z galaxies

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Abstract

Galaxy evolution during the last 9 Gyr is discussed. It can be traced back from well known present-day galaxies or directly observed for galaxies at different look back times. This requires clear and consistently matched selection criteria for galaxy samples. There is a net decrease of rest-frame, UV luminosity density, at least since $z = 1$. It is interpreted as an important decline of the star formation since the last $\sim 9$ Gyr. A similar trend is found for the evolution of the IR luminosity density which accounts for heavily extincted starbursts. Interestingly the global star formation density, after including IR selected galaxies, is twice the value of estimates based on the UV luminosity density, and this holds from $z=0$ to $z=1$.

Large disks are not contributing much to the observed decrease, which is mainly related to significant changes with the epoch in the distribution of galaxy morphologies. A significant fraction of the global star formation occurs in luminous galaxies which are apparently small or in interacting galaxies detected in the deepest IR or radio surveys.

1 Introduction

Studies of distant galaxies are limited by spatial resolution (HST/WFPC2, 0.1 arcsec or $1h_{50}^{-1}$kpc at $z\geq 0.75$) and by object faintness. The interesting features in the visible at rest are also redshifted to the infrared window, where the OH atmospheric lines limit the observations. For a galaxy redshifted at $z=1.8-2.5$, the visible window virtually includes none of the strong emission lines. There are two important reasons for further studying $z \leq 1$ galaxies:
- a large fraction of the present day stellar mass has been formed since the last 9 Gyr ($z\sim 1$);
- they are bright enough for optical/near IR detailed studies aimed to understand their morphology (luminosity profiles), their chemistry & their dynamics.

The aim of this review is to summarize the most recent progresses in understanding galaxy evolution since $z=1$. Observational selection effects have to be carefully examined as they can easily mimic evolutionary trends. Distant galaxies are naturally selected by their observed fluxes, which lead to various selection biases in spectroscopic samples:
- imagery used for selecting sources should be at least 1-2 magnitude deeper than the spectroscopic limit in order to securely include galaxies with low surface brightness.
- high redshift galaxy samples, if selected in the visible -i.e. rest-frame UV-, are obviously biased against both the old stars and the obscured massive stars; this has motivated some selections in the I-band at 0.835$\mu$m (up to $z=1$) or K band at 2.2$\mu$m (up to $z=4$); also IR or radio selections is a prerequisite to a proper evaluation of the energy output reprocessed by dust.
- deep pencil beams based on too small areas (i.e. few square arcmin) are not ideal to sample
galaxy evolution; they include galaxies within a large redshift range and redshift dependent effects could become rather complex; in the lowest redshift bin they sample a too small volume, including only galaxies with much lower luminosities than at a higher redshift. The latter point emphasizes the need for fair comparison samples at very low-z, which represent the non-evolution reference. Selection at low z is far from being trivial, and can be also affected by large scale structures.

General properties of nearby galaxies will be presented, including local luminosity & star formation density, as well as the star formation processes in disk and in circumstellar nucleus regions. Evolution of quantities at various look-back times will be examined, including star formation density derived from UV, mid-IR & radio light density measurements. This leads to a general discussion on how extinctions can limit our view of galaxy evolution. Finally, star formation can be differentially traced for galaxies of various morphological types. Galaxies show a wide variety in size, mass, morphology, overall energy distribution, nuclear activity etc... Understanding the relative contribution of a galaxy class to the star formation density requires large samples (100 objects provide a Poisson uncertainty of 10%) selected with a reliable criterion within the available redshift range.

2 General properties in local galaxies

2.1 Luminosity densities and star formation density

The difficulty in establishing global properties of local galaxies is illustrated by the long debate about the exact shape luminosity function (see Efstathiou et al, 1988). There is now a general agreement that the blue luminosity function is rather steep ($\alpha = -1.2$) at its faint end (Zucca et al, 1997). Converted into blue luminosity density this provides: $(\phi L)_B = (3.9 \pm 0.5) \times 10^7 h_{50} L_\odot Mpc^{-3}$ (Loveday et al, 1992; Marzke et al, 1994). Integration of the K band luminosity function gives: $(\phi L)_K = (4 \pm 1) \times 10^8 h_{50} L_\odot Mpc^{-3}$ (Gardner et al, 1997). This leads to a stellar mass density of $(4 \pm 2) \times 10^8 M_\odot Mpc^{-3}$, assuming $0.6 h_{50} < M/L_K < 1.8 h_{50}$ and a Salpeter IMF.

The average color of the local stellar population taken as a whole is then $(B-K)_{AB} = 2.5$, a value typical for a Sab galaxy.

Gallego et al (1995) have selected $z \leq 0.045$ galaxies from H$\alpha$ emission in Schmidt objective-prism plates. According to their results, the H$\alpha$ luminosity density of local Universe is $10^{39.1 \pm 0.4} h_{50} erg s^{-1} Mpc^{-3}$. This leads to a SFR density of $0.008 \pm 0.0006 h_{50} M_\odot yr^{-1} Mpc^{-3}$. Using the same technics, Gronwall et al (1998, KISS project) suggest twice this value. Based on UV selected galaxies, Treyer et al (1998) have derived $9.3^{+0.75}_{-0.45} \times 10^{25} h_{50} erg s^{-1} Hz^{-1} Mpc^{-3}$ for the luminosity density at 2000Å of $z \sim 0.15$ galaxies. This corresponds to a SFR density of $0.012^{+0.005}_{-0.003} h_{50} M_\odot yr^{-1} Mpc^{-3}$, i.e. 50% higher than the Gallego et al value. All the above estimates are assuming a Salpeter IMF (0.1-125$M_\odot$), and without correction for dust extinction. One would expect the H$\alpha$ estimated SFR to be less affected by biases against dusty objects, hence higher than UV estimates. One can suspect overestimation of SFRs for a substantial fraction of Treyer et al galaxies, which are extremely blue and are probably young starbursts with low metallicities.

Tresse and Maddox (1998) have estimated the H$\alpha$ luminosity density of $z \sim 0.2$ galaxies, assuming an average 0.45 mag extinction correction at 6562Å. This is still an uncertain estimate. Applying this to the Gronwall et al (1998) value would provide a local density of star formation of $0.024 h_{50} M_\odot yr^{-1} Mpc^{-3}$. It is probably irrelevant to apply the same correction to FOCA
UV-selected galaxies, since they are likely to be less dusty than $H\alpha$ galaxies.

On the other hand, IRAS galaxies contribute only marginally to UV light density, while they individually produce large amounts of bolometric luminosity and/or star formation. Estimates of local SFR density based on IRAS measurements (Saunders et al., 1990), provide a SFR density of $\sim 0.012 \, h_{50} \, M_\odot yr^{-1} Mpc^{-3}$, i.e. close to the FOCA value. So the exact value of the local SFR density is probably slightly below twice the IRAS value ($0.024 \, h_{50} \, M_\odot yr^{-1} Mpc^{-3}$). Locally there is an apparent equipartition of the energy balance between UV and IR emissions from hot stars.

2.2 Star formation in disks

Star formation currently occurs in galactic disks, and is generally estimated from $H\alpha$ and UV flux measurements. It varies considerably from one galaxy to another, from virtually 0 in gas poor S0 to $1 \, M_\odot yr^{-1}$ in our Galaxy, and to $\sim 10 \, M_\odot yr^{-1}$ in gas rich disks. It is more convenient to compare the star formation rate per unit of red luminosity, because galaxies show a large range in mass/luminosity. This parameter -SFR/$<$$\text{SFR}>$, where $<$$\text{SFR}>$ is the past averaged SFR-, provides a good representation of the relative strength of star formation in a galaxy. It is generally estimated from the $H\alpha$ equivalent width (Kennicutt et al., 1994). The strength of star formation increases on average, from early type (Sa: $\sim 0.1$) to late type (Sc-Sd: $\sim 1$). The dispersion within a morphological class is however very large (factor $\sim 10$), reflecting the large spread of galaxy properties and histories.

Relating the star formation surface density to the gas content (Schmidt law), Buat (1992) and Kennicutt (1998) have derived low time scales (2-5 Gyr) for the gas consumptions. This is consistent with findings based on our own Galaxy (see Prantzos and Aubert, 1995).

2.3 Star formation in circumnuclear regions

Star formation also occurs in compact regions, generally in galaxy nuclei. Nuclear HII regions are found in 42% of bright spirals, with the fraction increasing from S0 to Sc-Im galaxies (Ho et al., 1997). They show modest SFRs, averaging from 0.1-0.2 $M_\odot yr^{-1}$. However SFRs can reach values in excess of $100 \, M_\odot yr^{-1}$ in the much less numerous population of luminous IRAS galaxies. It might be particularly difficult to disentangle star formation from AGN emission in the ultra-luminous IRAS galaxies (ULIRG). Lutz et al (1998) found 50% of AGN in ULIRGs with $L_{IR} > 2 \times 10^{12} L_\odot$.

SFRs in luminous IRAS galaxies are generally estimated from their FIR luminosity, assuming that most of the ionizing photons are re-processed by dust. In these dense regions, most of the gas is molecular (see Sanders and Mirabel, 1996). Kennicutt (1998) found that Schmidt law is followed more tightly by compact starburst galaxies than by disks, though sharing the same slope. The global star formation efficiencies are much higher than in normal disks, with a characteristic time scale for gas consumption of few tenths of Gyr.

3 Evolution of star formation from deep surveys of galaxies
Figure 1: \( M_{\text{star}}/L_{1\mu} \) versus galaxy age from Bruzual and Charlot (1999) stellar tracks with SFR \( \sim \exp(-t/\tau) \). An average present-day age of 11.25 Gyr has been assumed for luminous galaxies observed in the CFRS sample. At larger redshifts galaxies are younger on average, they are bluer ((\( U-V \)\(_{AB} \) color is displayed on the top) and produce more 1\( \mu \)m light per unit mass.

3.1 Evolution of global quantities at optical wavelengths

The most exhaustive study of the galaxy evolution up to \( z=1 \) is provided by the Canada France Redshift Survey (CFRS, Lilly et al, 1995) which includes 600 galaxies with \( 0.1 \leq z \leq 1 \). From its selection criterion (\( I_{AB} \leq 22.5 \)), all the \( M_B(AB) \leq -20 \) galaxies are included in the sample, and this up to \( z=0.9-1 \). Hammer et al (1997) found that the fraction of star forming galaxies increases with the redshift: more than 50% at \( z>0.5 \) have \( W_0(OII)>15 \)\( \AA \), which should be compared to 13% locally (see Vettolani et al, 1998). This observed trend for CFRS luminous galaxies (\( M_B \leq -20 \)) is followed by a shift in color: the average rest-frame (\( U-V \)\(_{AB} \) color varies from 1.6 (Sab color) at \( z\sim0 \), to 1.3 (Sbc color) at \( z=0.5 \) and 0.7 (Sdm-Irr color) at \( z=1 \).

The increase in star formation with redshift has been quantitatively estimated by Lilly et al (1996) from the rest frame 2800\( \AA \) luminosity, whose comoving density evolves as rapidly as \((1+z)^{3.9\pm0.75} \). This value is provided after assuming a constant slope of the luminosity function in the \([0,1]\) redshift range. A similar, even stronger trend is also observed for the [OII]3727 comoving luminosity density, which follows \((1+z)^{6.5\pm2.5} \) (Hammer et al, 1997). Differences between exponents could be due to errors in measuring [OII] fluxes in faint and distant galaxies, to extrapolation of 2800\( \AA \) luminosities at low redshift, and possibly to changes with the redshift in the average metal abundance in galaxies. These evolutionary changes have been interpreted as due to a large decrease of the star formation by a factor 10 from \( z=1 \) to \( z=0 \) (Madau et al, 1996). According to them and to Steidel et al (1996), this suggests a peak at \( z=1-2 \) in the comoving UV luminosity density.

Lilly et al (1996) also found a redshift increase of the comoving 1\( \mu \)m light density, following \((1+z)^{2.1\pm0.5} \). This could mainly explained by the expected shift in age and color of the bright galaxies (see Figure 1). At \( z=1 \), galaxies were on average younger by 8-9 Gyr, their (\( U-V \)\(_{AB} \) colors were bluer by \( \sim 1 \) mag, and their \( L_{1\mu}/M_{\text{star}} \) ratio were larger by a factor of \( \sim 4 \) at \( z=1 \) than today.

3.2 Evolution of spectral properties

Hammer et al (1997) found that 40% of the CFRS emission line galaxies show spectra with features typical of an important A star population (Balmer continuum or \( W(H\delta) \)). There is no trend with the redshift, and this is consistent with \( W(H\delta)=5 \)\( \AA \) found by Kennicutt (1992) in a sample of local galaxies. Population of A star is generally thought to be a reminiscence of a previous burst occurring few tenths of Gyr ago. At \( z\geq0.5 \), many galaxies simultaneously present current star formation and A star population. This suggests that most galaxies have experienced long periods of star formations (> 1Gyr) or, alternatively, numerous consecutive small bursts during long periods. In addition, only few galaxies (\( \sim 5\% \)) present an HII flat spectra.
Redshifted galaxies show a wide range of ionization properties (Hammer et al. 1997). Beyond $z=0.7$, 30% of the CFRS galaxies have continuum properties (namely their relation between 4000Å break intensity and UV continuum slope), not reproducible by population synthesis models with solar abundance. Their continua are similar to those of low abundance Magellanic star clusters, suggesting low metallicities for a significant fraction of star forming galaxies at $z\geq0.7$.

3.3 Calibration of star formation for redshifted galaxies

The choice of star formation tracers in the visible, is limited when looking at a population of redshifted galaxies. $H\alpha$ line is observable up to $z=0.5$, and [OII]3727 up to $z=1.5$. On the other hand, visible observations of redshifted galaxies are measuring rest-frame UV fluxes of galaxies which could be a direct measure of the star formation. However, both [OII]3727 and 2800Å luminosities appear to be poor tracers of the star formation, because they are not well correlated with $H\alpha$ luminosity (Hammer and Flores, 1998). Since [OII]3727 and 2800Å luminosities correlate well together, this suggests that extinction is the major source of uncertainties when these luminosities are used for tracing star formation. This is illustrated in Figure 2, which shows the relation between $W(H\beta)$ and $W(H\alpha)$. This relation is much more dispersed than the one of Kennicutt (1992) for local galaxies. This is not necessarily related to an evolutionary effect, and could be simply a selection effect. For example, Jansen et al. (1999) provided spectrophotometric measurements of $\sim200$ local galaxies representative of the local luminosity function and found a relation between $W(OII)$ and $W(H\alpha)$ with a dispersion similar to our result at higher redshift.

Most of the galaxies which lie above the Kennicutt (1992) fiducial relation have colors bluer than a Sbc ($(U-V)_{AB}\leq1.3$). A crude interpretation of Figure 2 would be that these galaxies suffer from extinctions similar to those of local irregular galaxies (i.e. $A_V\sim0.6$, Gallagher et al. 1989), or two times less than as derived for Kennicutt galaxies ($A_V=1.2$). This value is consistent with findings at $z\sim0.2$ by Tresse and Maddox (1998), at $z\sim1$ and at $z\sim3$ (Pettini et al., 1998). One should however notice (see Figure 2) the presence of galaxies with non negligible $H\alpha$ lines and with virtually no $H\beta$, [OIII]5007 and [OII]3727 lines. These could be very extincted galaxies which might affect estimates of SFRs based on $H\alpha$ lines (Gruel et al., 1999, in preparation).

3.4 Star formation evolution seen in infrared and at radio wavelengths

Observations in the visible of redshifted galaxies are likely biased against star forming, dust enshrouded galaxies. Recent ISOCAM deep surveys show that 15μm counts below 1mJy present a significant excess in galaxy numbers relatively to no-evolution models (Elbaz et al., 1999). Strong starbursts forming 50 $M_\odot yr^{-1}$ at $z\sim1$ can be easily detected by ISOCAM deep exposures and also by VLA deep surveys (Flores et al., 1999).
Figure 3: Metal production and star formation history. SFR estimates are assuming a Salpeter IMF from $0.1 \, M_\odot$ to $100 \, M_\odot$. Flores et al points (filled circles, labeled ISO-VLA-CFRS) are 1.9 times higher in SFR density or in metal production than those (open circles) previously derived from the UV flux density at 2800Å. The same situation is found locally with an equal contribution from IRAS galaxies and UV selected galaxies (FOCA, Treyer et al, 1998) to the star formation density. At higher $z$, estimates are derived from UV rest frame wavelengths and come from Connolly et al (1997) and Madau et al (1996) (HDF) (open squares). No UV estimate has been corrected for extinction. Other estimates (stars) from $H\alpha$ are given for comparison and are from Gallego et al (1995, UCM) and Gronwall et al (1998, KISS), as well as at higher $z$ from few galaxies at $z \sim 1.25$ by Yan (1999).

From a CFRS follow-up study with ISOCAM, Flores et al (1999) have provided a first estimate of the fraction of star formation density which is hidden by dust. Classification of $\sim 30$ sources with $0.2 \leq z \leq 1$ has been done from the spectral energy distribution based on rest-frame UV, visible, near and mid-IR and radio photometric points, from line diagnostic diagrams and from radio slopes and sizes. It results that 60% of the $S_{15\mu} \geq 250\mu$Jy sources are starbursts, 25% are Seyfert2 or Liners, and 15% are broad-line emission objects. ISOCAM galaxies at $0.5 \leq z \leq 1$ have IR luminosities lower than $2 \times 10^{12} \, L_\odot$, and the fraction of AGN is significantly higher than what Lutz et al (1998) found locally ($\sim 15\%$). At least a part of the discrepancy could be a selection effect, because Lutz et al (1998) selected galaxies from their fluxes at 60µm, a wavelength which is much more sensitive to starburst galaxies than the Flores et al $15\mu m/(1+z)$ limit.

Flores et al (1999) conclude that 4% of the field galaxies are strong and heavily extincted starbursts with SFR from 40 to $200 \, M_\odot \, yr^{-1}$, and produce a third of the global star formation density at $z \sim 1$. To provide the corresponding star formation density, one could assume no evolution for the low-end slope of the IR luminosity function as it was done by Lilly et al (1996) for UV estimates. It results in a global star formation density $1.9\pm0.7$ times higher than that derived from UV measurements (Figure 3). Error bars are still large and are related to small statistics as well as to the ambiguity about the source of IR emission in some luminous galaxies (Seyfert2). The amplitude of the SFR density evolution at IR wavelengths is apparently similar to that estimated at UV wavelengths. Most of the ISOCAM sources at $0.5 \leq z \leq 1$, appear to be strong mergers, or at least they show signs of interactions.

4 Morphology evolution

Morphological studies of redshifted galaxies are complicated by redshift dependent effects. For example, the commonly used I broad band filter ($I_{814W}$ HST/WFPC2) is sampling the rest-frame B band at $z=0.9$, a color which is more sensitive to star forming regions than in the redder ones. This effect has been extensively studied by Brinchman et al (1998). They quote that 24% of the spirals at $z=0.9$ would be mis-classified as irregular because of that redshift effect. This is likely to become predominant at higher redshift and could severely affect the conclusions on morphological evolution studies. Another expected bias in selecting galaxies in optical could be related to a deficiency in edge-on galaxies, which are more affected by extinctions. Several
Figure 4: Rest frame $(U - V)_{AB}$ color versus HST morphological class for $M_B \leq -20$ CFRS, in three redshift bins. Brinchman et al classification is supported by the comparison with local values (large crosses; Coleman et al, 1980). Most galaxies have an earlier type than Sbc in the lower redshift bin, while the reverse is found at high redshift.

distant galaxies are so compact that they are merely resolved with HST/WFPC2. This probably provides the most severe limitation to the morphological studies of distant galaxies.

Brinchman et al (1998) have presented the HST imagery of $\sim 340$ galaxies up to $z=1$, using the CFRS selection criterion. Figure 4 shows the morphology-color evolution of the field galaxies from $z=0.25$ to $z=1$. The color evolution discussed in section 3.1 is well adjusted to a general shift towards later types at higher redshifts. Brinchman et al (1998) quoted that 9% of galaxies at $0.2<z<0.5$ are irregular, a fraction which reaches 32% at $0.75<z<1$. Indeed, extended star forming galaxies ($W_0(OII) \geq 15\AA$) generally show irregularities, companions or circumstellar regions not always located at the galaxy centers.

The density of large disks with $r_{disk} \geq 3.2h_{50}^{-1}$kpc is found to be the same at $z=0.75$ than locally (Lilly et al, 1998). Only a density decrease by less than 30% at $z=1$ is consistent with the data. Lilly et al (1998) also find that star formation in large disks present only a modest increase with the redshift. From long-slit spectroscopy studies, Vogt et al (1997, see also Koo et al, in this volume) show an almost unevolved Tully Fischer relation for disks at $z \sim 1$. Redshift changes in large disks appear not to be the main contributors to star formation evolution as detected in that redshift range. At large distance most of the disks are of a late type.

The most rapidly evolving population of galaxies is made of small and compact galaxies (Lilly et al, 1998, see also Guzman, in this volume). This confirms the Guzman et al (1997) claim, based on a HDF sample in the same redshift range. Their UV luminosity density was 10 times higher at $z=0.875$ than at $z=0.375$, and they correspond to $\sim 30\%$ of the rest-frame UV luminosity density in the higher redshift bin (Hammer and Flores, 1998b). These objects are somewhat enigmatic: their sizes $-r_{disk} \leq 2.5h_{50}^{-1}$kpc- and their velocity widths -35 to 150 km/s (Phillips et al, 1997)- are apparently similar to those of local dwarves, while they are up to 100 times more luminous than a $M_B=-17.5$ dwarf.

5 Conclusion

There is a general decrease of star formation in galaxies since at least the last 9 Gyr ($z\sim 1$). This is supported by:

- a general decrease of the rest-frame UV & IR luminosity density, since $z=1$
- average properties of $z\sim 1$ luminous galaxies are broadly consistent with those of blue, starbursting and irregular galaxies.

A large fraction of galaxies in the past show an important population of A stars, and very few galaxies show a HII-like spectrum. So star formation in most field galaxies appears to be a continuous process during long periods of times, or alternatively to be the result of numerous
and successive bursts. Large disks present a modest evolution since the last 9 Gyr. Star formation in these systems is sustained over time scale \( \leq 5 \) Gyr. These results are solid because they are independently obtained from analysis of nearby and distant galaxies. Most of the reported star formation evolution found in the UV seems to be related to a population of star forming, compact galaxies. At a high redshift they have sizes and velocities apparently comparable to those of local dwarves, while they are overluminous by factors reaching 100.

Uncertainties on dust extinctions appear to be a major problem in estimating the evolution of star formation. Accounting for the population of obscured, strong starbursts detected at IR and radio wavelengths would increase the SFR density by a factor 1.9+0.7, when compared to estimation based on UV luminosity density. From the ratio of IR to UV luminosity density, one can derive a moderate global extinction at 0\( \leq z \leq 1 \), corresponding to \( A_V=0.45^{+0.3}_{-0.2} \). From \( z=0 \) to \( z=1 \), the global energy output from hot stars seen directly at UV wavelengths is similar to that reprocessed by dust. This result is consistent with the bolometric measurements from UV to sub-millimeter wavelengths which integrate all the energy emitted by extragalactic sources (see Pozetti et al, 1998). Integrating global star formation from \( z=1 \) to \( z=0 \) provides a value from 50% to 100% of present day stellar mass. This might prevent from a scenario in which star formation density is still increasing beyond \( z=1-2 \). However, a large fraction of the stellar mass and metal lie in metal rich bulges, and the next important challenge is to know when most of these objects have been formed.

References

[1] Brinchman, J., Abraham, R., Schade, D., Tresse, L. et al, 1998, Astrophys. J. 499, 112
[2] Bruzual, G., Charlot, S., 1999, in preparation
[3] Buat, V., 1992, Astr. Astrophys. 264 444
[4] Coleman, G., Wu, C., Weedman, D. 1980, Astrophys. J. Suppl. Ser. 43, 393
[5] Connolly, A.J., Szalay, A.S., Dickinson, M. et al, 1997, Astrophys. J. 486, L11
[6] Efstathiou, G., Ellis, R., Peterson, B., 1988, MNRAS 232 431
[7] Elbaz, D. Aussel, H., Cesarsky, C. et al, 1999 (astro-ph/9902229)
[8] Flores, H., Hammer, F. Thuan, T.X., Cesarsky, C. et al.,1999, Astrophys. J. 517, 148
[9] Gallagher J., Bushouse, H., Hunter, 1989, Astron. J. 97, 700
[10] Gallego, J., Zamorano, J., Aragon-Salamanca, A., Rego, 1995, Astrophys. J. 455, L1
[11] Gardner, J., Shaeples, R., Frenk, C., Carrasco, B., 1997, Astrophys. J. 480, 99
[12] Gronwall, C., 1998, in Proceedings of the XVIIIth Moriond Conference on ”Dwarfs Galaxies and Cosmology”, eds Thuan et al, Ed. Frontières (astro-ph/9806241)
[13] Guzman, R., Gallego, J., Koo, D.C., Phillips, A.C. et al, 1997, Astrophys. J. 489, 559
[14] Hammer F., Flores H., Lilly S., Crampton D. et al, 1997, Astrophys. J. 480, 59.
[15] Hammer F., Flores H, 1998, in Proceedings of the XVIIIth Moriond Conference on ”Dwarfs Galaxies and Cosmology”, eds Thuan et al, Ed. Frontières (astro-ph/9806184)
[16] Jansen, R., Fabricant, D., Franx, M., Caldwell, N., 1999 (astro-ph/9910093)
[17] Kennicutt, R. 1992, Astrophys. J. 388, 310
[18] Kennicutt, R., Tamblyn, P., Congdon, C. 1994 Astrophys. J. 435, 22
[19] Kennicutt, R., 1998 Astrophys. J. 498, 541
[20] Lilly S., Tresse, L., Hammer, F. et al, 1995, Astrophys. J. 455, 108
[21] Lilly S., Le Fèvre O., Hammer F., Crampton, D., 1996 , Astrophys. J. 460, L1
[22] Lilly, S.J., Schade, D., Ellis, R.S. et al, 1998, Astrophys. J. 500, 75
[23] Loveday, J., Peterson, B., Efstathiou, G., Maddox, S., 1992 Astrophys. J. 390, 338
[24] Lutz, D., Spoon, H., Rigopoulou, D., et al 1998, Astrophys. J. 505, L103
[25] Madau P., Pozzetti L. and Dickinson M., 1998, Astrophys. J. 498, 106
[26] Marzke, R., Huchra, J.P., Geller, M., 1994, Astrophys. J. 428, 43
[27] Pettini, M., Kellog, M., Steidel, C. et al 1998, Astrophys. J. 508, 539
[28] Phillips, A., Guzman, R., Gallego, J., Koo, D. et al, 1997, Astrophys. J. 489, 543
[29] Prantzos, N., Aubert, O., 1995, Astr. Astrophys. 302, 69
[30] Pozzetti, L., Madau, P., Zamorani, G., Ferguson, H.C., Bruzual, G., 1998, MNRAS 298, 1133
[31] Sanders, D., Mirabel, F., 1996 in Annual Review of Astronomy & Astrophysics 34 749
[32] Saunders, W., Rowan-Robinson, M., Lawrence, A. et al, 1990, MNRAS 242, 318
[33] Steidel, C., Giavalisco, Pettini et al, 1996, Astrophys. J. 462, L17
[34] Treyer, M., Ellis, R., Milliard, B. et al 1998 MNRAS , 300 303
[35] Tresse L. and Maddox, 1998, Astrophys. J. 495, 691
[36] Vogt, N., Phillips, A., Faber, S., et al, 1997, Astrophys. J. 479, 121
[37] Yan, L., 1999, [astro-ph/9906461]
[38] Zucca, E., Zamorani, G., Vettolani, G., et al, 1997, Astr. Astrophys. 326, 477
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- high redshift galaxy samples, if selected in the visible -i.e. rest-frame UV-, are obviously biased against both the old stars and the obscured massive stars; this has motivated some selections in the I-band at 0.835μm (up to z=1) or K band at 2.2μm (up to z=4); also IR or radio selections is a prerequisite to a proper evaluation of the energy output reprocessed by dust.
- deep pencil beams based on too small areas (i.e. few square arcmin) are not ideal to sample
galaxy evolution; they include galaxies within a large redshift range and redshift dependent effects could become rather complex: in the lowest redshift bin they sample a too small volume, including only galaxies with much lower luminosities than at a higher redshift.

The latter point emphasizes the need for fair comparison samples at very low-z, which represent the non-evolution reference. Selection at low z is far from being trivial, and can be also affected by large scale structures.

General properties of nearby galaxies will be presented, including local luminosity & star formation density, as well as the star formation processes in disk and in circumstellar nucleus regions. Evolution of quantities at various look-back times will be examined, including star formation density derived from UV, mid-IR & radio light density measurements. This leads to a general discussion on how extinctions can limit our view of galaxy evolution. Finally, star formation can be differentially traced for galaxies of various morphological types. Galaxies show a wide variety in size, mass, morphology, overall energy distribution, nuclear activity etc... Understanding the relative contribution of a galaxy class to the star formation density requires large samples (100 objects provide a Poisson uncertainty of 10%) selected with a reliable criterion within the available redshift range.

2 General properties in local galaxies

2.1 Luminosity densities and star formation density

The difficulty in establishing global properties of local galaxies is illustrated by the long debate about the exact shape luminosity function (see Efstathiou et al, 1988). There is now a general agreement that the blue luminosity function is rather steep (α = -1.2) at its faint end (Zucca et al, 1997). Converted into blue luminosity density this provides: \( \phi(L)_B = (3.9 \pm 0.5) \times 10^7 \, h_{50} \, L_\odot \, Mpc^{-3} \) \( \) at its faint end (Zucca et al, 1997). Integration of the K band luminosity function gives: \( \phi(L)_K = (4 \pm 1) \times 10^8 \, h_{50} \, L_\odot \, Mpc^{-3} \) (Gardner et al, 1997). This leads to a stellar mass density of \( (4 \pm 2) \times 10^8 \, h_{50}^2 \, M_\odot \, Mpc^{-3} \), assuming \( 0.6 h_{50} < M/L_K < 1.8 h_{50} \) and a Salpeter IMF. The average color of the local stellar population taken as a whole is then \( (B - K)_{AB} = 2.5 \), a value typical for a SAB galaxy.

Gallego et al (1995) have selected \( z \leq 0.045 \) galaxies from Hα emission in Schmidt objective-prism plates. According to their results, the Hα luminosity density of local Universe is \( 10^{39.1+0.04} h_{50} \, ergs^{-1} \, Mpc^{-3} \). This leads to a SFR density of \( 0.008 \pm 0.0006 \, h_{50} \, M_\odot yr^{-1} Mpc^{-3} \). Using the same technique, Gronwall et al (1998, KISS project) suggest twice this value. Based on UV selected galaxies, Treyer et al (1998) have derived \( 9.3^{+0.76}_{-0.45} \, 10^{25} \, h_{50} \, erg \, s^{-1} \, Hz^{-1} Mpc^{-3} \) for the luminosity density at 2000 Å of \( z \approx 0.15 \) galaxies. This corresponds to a SFR density of \( 0.012^{+0.005}_{-0.003} \, h_{50} \, M_\odot \, yr^{-1} \, Mpc^{-3} \), i.e. 50% higher than the Gallego et al value. All the above estimates are assuming a Salpeter IMF (0.1-125 \( M_\odot \)), and without correction for dust extinction. One would expect the Hα estimated SFR to be less affected by biases against dusty objects, hence higher than UV estimates. One can suspect overestimation of SFRs for a substantial fraction of Treyer et al galaxies, which are extremely blue and are probably young starbursts with low metallicities.

Tresse and Maddox (1998) have estimated the Hα luminosity density of \( z \approx 0.2 \) galaxies, assuming an average 0.45 mag extinction correction at 6562 Å. This is still an uncertain estimate. Applying this to the Gronwall et al (1998) value would provide a local density of star formation of \( 0.024 \, h_{50} \, M_\odot \, yr^{-1} \, Mpc^{-3} \). It is probably irrelevant to apply the same correction to FOCA
UV-selected galaxies, since they are likely to be less dusty than \( H\alpha \) galaxies.

On the other hand, IRAS galaxies contribute only marginally to UV light density, while they individually produce large amounts of bolometric luminosity and/or star formation. Estimates of local SFR density based on IRAS measurements (Saunders et al., 1990), provide a SFR density of \( \sim 0.012 \ h_{50} \ M_\odot yr^{-1} Mpc^{-3} \), i.e. close to the FOCA value. So the exact value of the local SFR density is probably slightly below twice the IRAS value (0.024 \( h_{50} \ M_\odot yr^{-1} Mpc^{-3} \)). Locally there is an apparent equipartition of the energy balance between UV and IR emissions from hot stars.

2.2 Star formation in disks

Star formation currently occurs in galactic disks, and is generally estimated from \( H\alpha \) and UV flux measurements. It varies considerably from one galaxy to another, from virtually 0 in gas poor S0 to 1 \( M_\odot yr^{-1} \) in our Galaxy, and to \( \sim 10 \ M_\odot yr^{-1} \) in gas rich disks. It is more convenient to compare the star formation rate per unit of red luminosity, because galaxies show a large range in mass/luminosity. This parameter \( \text{SFR}/<\text{SFR}> \), where \( <\text{SFR}> \) is the past averaged SFR-, provides a good representation of the relative strength of star formation in a galaxy. It is generally estimated from the \( H\alpha \) equivalent width (Kennicutt et al., 1994). The strength of star formation increases on average, from early type (Sa: \( \sim 0.1 \)) to late type (Sc-Sd: \( \sim 1 \)). The dispersion within a morphological class is however very large (factor \( \sim 10 \)), reflecting the large spread of galaxy properties and histories.

Relating the star formation surface density to the gas content (Schmidt law), Buat (1992) and Kennicutt (1998) have derived low time scales (2-5 Gyr) for the gas consumptions. This is consistent with findings based on our own Galaxy (see Prantzos and Aubert, 1995).

2.3 Star formation in circumnuclear regions

Star formation also occurs in compact regions, generally in galaxy nuclei. Nuclear HII regions are found in 42% of bright spirals, with the fraction increasing from S0 to Sc-Im galaxies (Ho et al, 1997). They show modest SFRs, averaging from 0.1-0.2 \( M_\odot yr^{-1} \). However SFRs can reach values in excess of 100 \( M_\odot yr^{-1} \) in the much less numerous population of luminous IRAS galaxies. It might be particularly difficult to disentangle star formation from AGN emission in the ultra-luminous IRAS galaxies (ULIRG). Lutz et al (1998) found 50% of AGN in ULIRGs with \( L_{IR} > 2 \times 10^{12} L_\odot \).

SFRs in luminous IRAS galaxies are generally estimated from their FIR luminosity, assuming that most of the ionizing photons are re-processed by dust. In these dense regions, most of the gas is molecular (see Sanders and Mirabel, 1996). Kennicutt (1998) found that Schmidt law is followed more tightly by compact starburst galaxies than by disks, though sharing the same slope. The global star formation efficiencies are much higher than in normal disks, with a characteristic time scale for gas consumption of few tenths of Gyr.
Figure 1: $M_{\text{star}}/L_{1\mu}$ versus galaxy age from Bruzual and Charlot (1999) stellar tracks with SFR $\sim \exp(-t/\tau)$. An average present-day age of 11.25 Gyr has been assumed for luminous galaxies observed in the CFRS sample. At larger redshifts galaxies are younger on average, they are bluer ($(U - V)_{AB}$ color is displayed on the top) and produce more $1\mu$m light per unit mass.

3 Evolution of star formation from deep surveys of galaxies

3.1 Evolution of global quantities at optical wavelengths

The most exhaustive study of the galaxy evolution up to $z=1$ is provided by the Canada France Redshift Survey (CFRS, Lilly et al, 1995) which includes 600 galaxies with $0.1 \leq z \leq 1$. From its selection criterion ($I_{AB} \leq 22.5$), all the $M_B(AB) \leq -20$ galaxies are included in the sample, and this up to $z=0.9-1$. Hammer et al (1997) found that the fraction of star forming galaxies increases with the redshift: more than 50% at $z>0.5$ have $W_0(OII) > 15$A, which should be compared to 13% locally (see Vettolani et al, 1998). This observed trend for CFRS luminous galaxies ($M_B \leq -20$) is followed by a shift in color: the average rest-frame $(U - V)_{AB}$ color varies from 1.6 (Sab color) at $z\sim 0$, to 1.3 (Sbc color) at $z=0.5$ and 0.7 (Sdm-Irr color) at $z=1$.

The increase in star formation with redshift has been quantitatively estimated by Lilly et al (1996) from the rest frame 2800Å luminosity, whose comoving density evolves as rapidly as $(1 + z)^{3.9\pm0.75}$. This value is provided after assuming a constant slope of the luminosity function in the [0,1] redshift range. A similar, even stronger trend is also observed for the [OII]3727 comoving luminosity density, which follows $(1 + z)^{6.5\pm2.5}$ (Hammer et al, 1997). Differences between exponents could be due to errors in measuring [OII] fluxes in faint and distant galaxies, to extrapolation of 2800Å luminosities at low redshift, and possibly to changes with the redshift in the average metal abundance in galaxies. These evolutionary changes have been interpreted as due to a large decrease of the star formation by a factor 10 from $z=1$ to $z=0$ (Madau et al, 1996). According to them and to Steidel et al (1996), this suggests a peak at $z=1-2$ in the comoving UV luminosity density.

Lilly et al (1996) also found a redshift increase of the comoving $1\mu$m light density, following $(1 + z)^{2.1\pm0.5}$. This could mainly explained by the expected shift in age and color of the bright galaxies (see Figure 1). At $z=1$, galaxies were on average younger by 8-9 Gyr, their $(U - V)_{AB}$
colors were bluer by $\sim 1$ mag, and their $L_{1\mu}/M_{\star}$ ratio were larger by a factor of $\sim 4$ at $z=1$ than today.

3.2 Evolution of spectral properties

Hammer et al (1997) found that 40% of the CFRS emission line galaxies show spectra with features typical of an important A star population (Balmer continuum or $W(H\delta)$). There is no trend with the redshift, and this is consistent with $W(H\delta)=5\AA$ found by Kennicutt (1992) in a sample of local galaxies. Population of A star is generally thought to be a reminiscence of a previous burst occurring few tenths of Gyr ago. At $z\geq0.5$, many galaxies simultaneously present current star formation and A star population. This suggests that most galaxies have experienced long periods of star formations ($>1$Gyr) or, alternatively, numerous consecutive small bursts during long periods. In addition, only few galaxies ($\sim 5\%$) present an HII flat spectra.

Redshifted galaxies show a wide range of ionization properties (Hammer et al 1997). Beyond $z=0.7$, 30% of the CFRS galaxies have continuum properties (namely their relation between 4000Å break intensity and UV continuum slope), not reproducible by population synthesis models with solar abundance. Their continua are similar to those of low abundance Magellanic star clusters, suggesting low metallicities for a significant fraction of star forming galaxies at $z\geq0.7$.

3.3 Calibration of star formation for redshifted galaxies

The choice of star formation tracers in the visible, is limited when looking at a population of redshifted galaxies. $H\alpha$ line is observable up to $z=0.5$, and [OII]3727 up to $z=1.5$. On the other hand, visible observations of redshifted galaxies are measuring rest-frame UV fluxes of galaxies which could be a direct measure of the star formation. However, both [OII]3727 and 2800Å luminosities appear to be poor tracers of the star formation, because they are not well correlated with $H\alpha$ luminosity (Hammer and Flores, 1998). Since [OII]3727 and 2800Å luminosities correlate well together, this suggests that extinction is the major source of uncertainties when these luminosities are used for tracing star formation. This is illustrated in Figure 2, which shows the relation between $W(H\beta)$ and $W(H\alpha)$. This relation is much more dispersed than the one of Kennicutt (1992) for local galaxies. This is not necessarily related to an evolutionary effect, and could be simply a selection effect. For example, Jansen et al (1999) provided spectrophotometric measurements of $\sim 200$ local galaxies representative of the local luminosity function and found a relation between $W(OII)$ and $W(H\alpha)$ with a dispersion similar to our result at higher redshift.

Most of the galaxies which lie above the Kennicutt (1992) fiducial relation have colors bluer than a Sbc ($(U-V)_{AB} \leq 1.3$). A crude interpretation of Figure 2 would be that these galaxies suffer from extinctions similar to those of local irregular galaxies (i.e. $A_V \sim 0.6$, Gallagher et al 1989) , or two times less than as derived for Kennicutt galaxies ($A_V=1.2$). This value is consistent with findings at $z\sim 0.2$ by Tresse and Maddox (1998), at $z\sim 1$ and at $z\sim 3$ (Pettini et al, 1998). One should however notice (see Figure 2) the presence of galaxies with non negligible $H\alpha$ lines and with virtually no $H\beta$, [OIII]5007 and [OII]3727 lines. These could be very extincted galaxies which might affect estimates of SFRs based on $H\alpha$ lines (Gruel et al, 1999, in preparation).
Figure 2: $W(H\beta)$ versus $W(H\alpha + NII)$ for 100 CFRS galaxies with $0.15 \leq z \leq 0.5$. Solid line shows the tight correlation found by Kennicutt (1992) in his local sample. Full and open dots represent $M_B \leq -20$ and $M_B > -20$, respectively.

3.4 Star formation evolution seen in infrared and at radio wavelengths

Observations in the visible of redshifted galaxies are likely biased against star forming, dust enshrouded galaxies. Recent ISOCAM deep surveys show that 15$\mu$m counts below 1mJy present a significant excess in galaxy numbers relatively to no-evolution models (Elbaz et al, 1999). Strong starbursts forming 50 $M_\odot yr^{-1}$ at $z \sim 1$ can be easily detected by ISOCAM deep exposures and also by VLA deep surveys (Flores et al, 1999).

From a CFRS follow-up study with ISOCAM, Flores et al (1999) have provided a first estimate of the fraction of star formation density which is hidden by dust. Classification of $\sim 30$ sources with $0.2 \leq z \leq 1$ has been done from the spectral energy distribution based on rest-frame UV, visible, near and mid-IR and radio photometric points, from line diagnostic diagrams and from radio slopes and sizes. It results that 60% of the $S_{15\mu} \geq 250\mu$Jy sources are starbursts, 25% are Seyfert2 or Liners, and 15% are broad-line emission objects. ISOCAM galaxies at $0.5 \leq z \leq 1$ have IR luminosities lower than $2 \times 10^{12} L_\odot$, and the fraction of AGN is significantly higher than what Lutz et al (1998) found locally ($\sim 15\%$). At least a part of the discrepancy could be a selection effect, because Lutz et al (1998) selected galaxies from their fluxes at 60$\mu$m, a wavelength which is much more sensitive to starburst galaxies than the Flores et al 15$\mu$m/(1+z) limit.

Flores et al (1999) conclude that 4% of the field galaxies are strong and heavily extincted starbursts with SFR from 40 to 200 $M_\odot yr^{-1}$, and produce a third of the global star formation density at $z \sim 1$. To provide the corresponding star formation density, one could assume no evolution for the low-end slope of the IR luminosity function as it was done by Lilly et al (1996) for UV estimates. It results in a global star formation density $1.9\pm0.7$ times higher than that derived from UV measurements (Figure 3). Error bars are still large and are related to small statistics as well as to the ambiguity about the source of IR emission in some luminous galaxies.
Figure 3: Metal production and star formation history. SFR estimates are assuming a Salpeter IMF from 0.1 $M_\odot$ to 100 $M_\odot$. Flores et al points (filled circles, labeled ISO-VLA-CFRS) are 1.9 times higher in SFR density or in metal production than those (open circles) previously derived from the UV flux density at 2800\AA. The same situation is found locally with an equal contribution from IRAS galaxies and UV selected galaxies (FOCA, Treyer et al, 1998) to the star formation density. At higher z, estimates are derived from UV rest frame wavelengths and come from Connolly et al (1997) and Madau et al (1996) (HDF) (open squares). No UV estimate has been corrected for extinction. Other estimates (stars) from H$\alpha$ are given for comparison and are from Gallego et al (1995, UCM) and Gronwall et al (1998, KISS), as well as at higher z from few galaxies at z\sim 1.25 by Yan (1999).
Figure 4: Rest frame $(U - V)_{AB}$ color versus HST morphological class for $M_B \leq -20$ CFRS, in three redshift bins. Brinchman et al classification is supported by the comparison with local values (large crosses; Coleman et al, 1980). Most galaxies have an earlier type than Sbc in the lower redshift bin, while the reverse is found at high redshift.

(Seyfert2). The amplitude of the SFR density evolution at IR wavelengths is apparently similar to that estimated at UV wavelengths. Most of the ISOCAM sources at $0.5 \leq z \leq 1$, appear to be strong mergers, or at least they show signs of interactions.

4 Morphology evolution

Morphological studies of redshifted galaxies are complicated by redshift dependent effects. For example, the commonly used I broad band filter ($I_{814W}$ HST/WFPC2) is sampling the rest-frame B band at $z=0.9$, a color which is more sensitive to star forming regions than in the redder ones. This effect has been extensively studied by Brinchman et al (1998). They quote that 24% of the spirals at $z=0.9$ would be mis-classified as irregular because of that redshift effect. This is likely to become predominant at higher redshift and could severely affect the conclusions on morphological evolution studies. Another expected bias in selecting galaxies in optical could be related to a deficiency in edge-on galaxies, which are more affected by extinctions. Several distant galaxies are so compact that they are merely resolved with HST/WFPC2. This probably provides the most severe limitation to the morphological studies of distant galaxies.

Brinchman et al (1998) have presented the HST imagery of $\sim 340$ galaxies up to $z=1$, using the CFRS selection criterion. Figure 4 shows the morphology-color evolution of the field galaxies from $z=0.25$ to $z=1$. The color evolution discussed in section 3.1 is well adjusted to a general shift towards later types at higher redshifts. Brinchman et al (1998) quoted that 9% of galaxies at $0.2 < z < 0.5$ are irregular, a fraction which reaches 32% at $0.75 < z < 1$. Indeed, extended star forming galaxies ($W_0(OI) \geq 15\AA$) generally show irregularities, companions or circumstellar regions not always located at the galaxy centers.

The density of large disks with $r_{disk} \geq 3.2h_{50}^{-1}\text{kpc}$ is found to be the same at $z=0.75$ than
locally (Lilly et al., 1998). Only a density decrease by less than 30% at z=1 is consistent with the data. Lilly et al. (1998) also find that star formation in large disks present only a modest increase with the redshift. From long-slit spectroscopy studies, Vogt et al. (1997, see also Koo et al., in this volume) show an almost unevolved Tully Fischer relation for disks at z ~ 1. Redshift changes in large disks appear not to be the main contributors to star formation evolution as detected in that redshift range. At large distance most of the disks are of a late type.

The most rapidly evolving population of galaxies is made of small and compact galaxies (Lilly et al., 1998, see also Guzman, in this volume). This confirms the Guzman et al. (1997) claim, based on a HDF sample in the same redshift range. Their UV luminosity density was 10 times higher at z=0.875 than at z=0.375, and they correspond to ~ 30% of the rest-frame UV luminosity density in the higher redshift bin (Hammer and Flores, 1998b). These objects are somewhat enigmatic: their sizes $r_{\text{disk}} \leq 2.5h^{-1}\text{kpc}$- and their velocity widths -35 to 150 km/s (Phillips et al., 1997)- are apparently similar to those of local dwarves, while they are up to 100 times more luminous than a $M_B=-17.5$ dwarf.

5 Conclusion

There is a general decrease of star formation in galaxies since at least the last 9 Gyr ($z\sim 1$). This is supported by:

- a general decrease of the rest-frame UV & IR luminosity density, since $z=1$

- average properties of $z\sim 1$ luminous galaxies are broadly consistent with those of blue, starbursting and irregular galaxies.

A large fraction of galaxies in the past show an important population of A stars, and very few galaxies show a HII-like spectrum. So star formation in most field galaxies appears to be a continuous process during long periods of times, or alternatively to be the result of numerous and successive bursts.

Large disks present a modest evolution since the last 9 Gyr. Star formation in these systems is sustained over time scale $\leq 5$ Gyr. These results are solid because they are independently obtained from analysis of nearby and distant galaxies. Most of the reported star formation evolution found in the UV seems to be related to a population of star forming, compact galaxies. At a high redshift they have sizes and velocities apparently comparable to those of local dwarves, while they are overluminous by factors reaching 100.

Uncertainties on dust extinctions appear to be a major problem in estimating the evolution of star formation. Accounting for the population of obscured, strong starbursts detected at IR and radio wavelengths would increase the SFR density by a factor $1.9\pm0.7$, when compared to estimation based on UV luminosity density. From the ratio of IR to UV luminosity density, one can derive a moderate global extinction at $0 \leq z \leq 1$, corresponding to $A_V=0.45^{+0.3}_{-0.2}$.

From $z=0$ to $z=1$, the global energy output from hot stars seen directly at UV wavelengths is similar to that reprocessed by dust. This result is consistent with the bolometric measurements from UV to sub-millimeter wavelengths which integrate all the energy emitted by extragalactic sources (see Pozzetti et al., 1998). Integrating global star formation from $z=1$ to $z=0$ provides a value from 50% to 100% of present day stellar mass. This might prevent from a scenario in which star formation density is still increasing beyond $z=1-2$. However, a large fraction of the stellar mass and metal lie in metal rich bulges, and the next important challenge is to know when most of these objects have been formed.
References

[1] Brinchman, J., Abraham, R., Schade, D., Tresse, L. et al, 1998, Astrophys. J. 499, 112
[2] Bruzual, G., Charlot, S., 1999, in preparation
[3] Buat, V., 1992, Astr. Astrophys., 264 444
[4] Coleman, G., Wu, C., Weedman, D. 1980, Astrophys. J. Suppl. Ser. 43, 393
[5] Connolly, A.J., Szalay, A.S., Dickinson, M. et al, 1997, Astrophys. J. 486, L11
[6] Efstathiou, G., Ellis, R., Peterson, B., 1988, MNRAS, 232 431
[7] Elbaz, D., Aussel, H., Cesarsky, C. et al., 1999 (astro-ph/9902229)
[8] Flores, H., Hammer, F., Thuan, T.X., Cesarsky, C. et al., 1999, Astrophys. J. 517, 148
[9] Gallagher J., Bushouse, H., Hunter, 1989, Astron. J. 97, 700
[10] Gallego, J., Zamorano, J., Aragon-Salamanca, A., Rego, 1995, Astrophys. J. 455, L1
[11] Gardner, J., Shaeples, R., Frenk, C., Carrasco, B., 1997, Astrophys. J. 480, 99
[12] Gronwall, C., 1998, in Proceedings of the XVIIIth Moriond Conference on "Dwarfs Galaxies and Cosmology", eds Thuan et al, Ed. Frontieres (astro-ph/9806240)
[13] Guzman, R., Gallego, J., Koo, D.C., Phillips, A.C. et al, 1997, Astrophys. J. 489, 559
[14] Hammer, F., Flores, H., Lilly, S., Crampton D. et al, 1997, Astrophys. J. 480, 59.
[15] Hammer, F., Flores H, 1998, in Proceedings of the XVIIIth Moriond Conference on "Dwarfs Galaxies and Cosmology", eds Thuan et al, Ed. Frontieres (astro-ph/9806184)
[16] Jansen, R., Fabricant, D., Franx, M., Caldwell, N., 1999 (astro-ph/9910095)
[17] Kennicutt, R. 1992, Astrophys. J. 388, 310
[18] Kennicutt, R., Tamblyn, P., Congdon, C. 1994 Astrophys. J. 435, 22
[19] Kennicutt, R., 1998 Astrophys. J. 498, 541
[20] Lilly S., Tresse, L., Hammer, F. et al, 1995, Astrophys. J. 455, 108
[21] Lilly S., Le Fèvre O., Hammer F., Crampton, D., 1996, Astrophys. J. 460, L1
[22] Lilly, S.J., Schade, D., Ellis, R.S. et al, 1998, Astrophys. J. 500, 75
[23] Loveday, J., Peterson, B., Efstathiou, G., Maddox, S., 1992 Astrophys. J. 390, 338
[24] Lutz, D., Spoon, H., Rigopoulou, D., et al 1998, Astrophys. J. 505, L103
[25] Madau P., Pozzetti L and Dickinson M., 1998, Astrophys. J. 498, 106
[26] Marzke, R., Huchra, J.P., Geller, M., 1994, Astrophys. J. 428, 43
[27] Pettini, M., Kellog, M., Steidel, C. et al 1998, Astrophys. J. 508, 539
[28] Phillips, A., Guzman, R., Gallego, J., Koo, D. et al, 1997, Astrophys. J. 489, 543
[29] Prantzos, N., Aubert, O., 1995, Astr. Astrophys. 302, 69
[30] Pozzetti, L., Madau, P., Zamorani, G., Ferguson, H.C., Bruzual, G., 1998, MNRAS 298, 1133
[31] Sanders, D., Mirabel, F., 1996 in Annual Review of Astronomy & Astrophysics 34 749
[32] Sanders, W., Rowan-Robinson, M., Lawrence, A. et al, 1990, MNRAS 242, 318
[33] Steidel, C., Giavalisco, Pettini et al, 1996, Astrophys. J. 462, L17
[34] Treyer, M., Ellis, R., Milliard, B. et al 1998 MNRAS, 300 303
[35] Tresse L. and Maddox, 1998, Astrophys. J. 495, 691
[36] Vogt, N., Phillips, A., Faber, S., et al, 1997, Astrophys. J. 479, 121
[37] Yan, L., 1999, (astro-ph/9906461)
[38] Zucca, E., Zamorani, G., Vettolani, G., et al, 1997, Astr. Astrophys. 326, 477