FORMATION & EVOLUTION of GALAXIES :
STRESSING the NEED for
WIDE-FIELD ULTRAVIOLET REST-FRAME PHOTOMETRY

by D. Burgarella[1], V. Buat[1], F. Hammer[2], M. Ward[3], P. O'Brien[3] & B. Milliard[1]

[1] LAS/IGRAP Marseille, France
[2] Observatoire de Paris, France
[3] University of Leicester, Leicester, UK

The NGST core instruments will be able to carry a deep photometric imaging survey aimed at understanding the formation and evolution of galaxies. The present proposal would like to stress the need for a UltraViolet (UV) rest-frame i.e. Visible (VIS) Camera (CAM) which would allow us to get a crucial information on those objects which could not be (or could not be adequately) studied with the Near InfraRed (NIR) Multi-Object Spectrograph (MOS). Moreover, the astrophysically very valuable information contained in the UV rest-frame by itself would have a strong impact on the study of the observed galaxies in complement or even independently to the NIR data.

Scientific Objectives :

The limiting magnitudes for the deepest visible exposures in the imaging surveys (ASWG DRM proposal "The formation and evolution of galaxies I: The deep imaging surveys") are $m_{AB} = 34.8$ for the DEEP FIELD and $m_{AB} = 33.3$ for the WIDE FIELDs. The visible database provided by these images would be a "gold mine" for studying the physics of galaxies.

A) Potential Targets :

1. forming galaxies at $3 < z < 7.3$. Using the information contained in the NIR (observed) only (continuum and emission lines) may lead to a limited view of the object. Indeed, as we will see below, the ultraviolet rest-frame observed with VISCAM would contain a wealth of information which sometimes provides a complement to other wavelength-based information but is also a source of a very valuable information not available elsewhere (Waller et al. 1997, "The Ultraviolet at Low and High redshift", AIP Conf. # 408).

2. Galaxies observable with NIRMOS : a deep spectroscopic survey will be carried out with the NIR spectrograph. It will reach a limiting magnitude $m_{AB} = 27$ with a spectral resolution R=1000 for about 5000 galaxies in the $1 < z < 5$ redshift range. In this case, the visible wavelength range (0.5μm - 1μm) will correspond to the UV rest-frame ($\lambda > 830A - 2500A$ depending on the redshift). In this ideal case where Balmer lines will be easily detected and their flux measured, we need to take this exceptional opportunity to carry out a multi-wavelength approach that will bring a wealth of astrophysical information (redundancy in the Star Formation Rate (SFR), abundances, extinction, hint on the Initial Mass Function (IMF)).

3. Galaxies not observable with NIRMOS with the adequate spectral resolution : the deepest spectroscopic exposures will reach $m_{AB} = 30-31$ at a resolution R=100. At this resolution (Kennicut 1998, Colloquium "The Next Generation Space Telescope", ESA Sp-429, p. 81), the amount of information that can be extracted from the Hα line is far from being optimal. The UV-based photometry would therefore provide us a better/other way of estimating the Star Formation Rate (SFR) of these galaxies in a more systematic way if we know the amount of extinction due to dust. The Hα/Hβ Balmer line ratio may be used to estimate the extinction but a more appropriate method would be to use the UV-slope to evaluate the amount of extinction and correct for it (Meurer et al. 1999, astro-ph/9903054; Calzetti et al. 1994, ApJ 429, 582).

4. Galaxies in the $6.6 < z < 7.3$ range for which Hα will move beyond the 5-micron redward limit : the UV rest-frame will be the best available tool for the above studies (SFR, extinction, etc.). But for this limited but potentially (who knows ?) redshift range, the Lyman break would provide a very powerful way of estimating the redshift, even for low Signal-to-Noise (S/N) galaxies.

B) Specific Scientific Objectives :

1. Redshift : for all the objects observed in UV rest-frame, the Lyman break will provide us a powerful way of estimating the redshift without any ambiguities even for low Signal-to-Noise galaxies. However, we must stress that due to the transmission of the Universe the effective break would not be at $\lambda_{Ly\alpha} = 912$ A but more likely around 1200 A (e.g. Madau 1995, ApJ 441, 18). Nevertheless, the strong break that should occur may be used to detect and identify high redshift galaxies from VISCAM images up to a redshift of about $z = 7.5$. This is crucial for the objects where no NIR spectroscopy will be available.

2. Star Formation Rate : several tracers are used to study the large-scale recent (at least observed) star formation activity in galaxies :

   - Even if it would fall in the visible range for the considered redshifts, it seems hopeless to use the Lyα line to estimate the SFR due to the very strong extinction if even a small amount of dust is present (e.g. Charlot & Fall 1993, ApJ 415, 580). This line is not a quantitative estimator of the SFR.

   - The Hα recombination line of the atomic hydrogen ionized by massive stars is commonly used at low and moderate redshifts to study the SFR (Kennicut 1983, ApJ 254, 72; Gallego et al. 1996, ApJ 459, L43; Tresse & Maddox 1998, ApJ 495, 691; Glazebrook et al. 1999, astro-ph/9808276). The intensity of the hydrogen Balmer lines (e.g. Kennicut 1992, ApJ 338, 310; Gallagher et al. 1989, AJ 97, 700) is a direct and robust way of measuring the SFR. Indeed, the number of photons emitted by the ionized gas of an HII region is directly proportional to the number of ionizing photons emitted by massive stars which in turn is proportional to the number of young stars and to the SFR over timescales of 10^6 years. This is the lifetime of massive ($M > 10$ M_o) stars emitting the Lyman continuum photons.

   - Briefly considering other emission lines : Hβ is fainter than Hα (by a factor of 2.87 assuming a standard case-B recombination hypothesis but more likely a factor of $f_{H\alpha}/f_{H\beta} = 4.3$ (Meurer et al. 1999; Calzetti et al. 1994) and undergoes the effect of underlying stellar absorption. [OII] has also been used to estimate the SFR but the combined effect of the excitation and abundances play not to make it a good SFR tracer.

   - The hot and massive stars ($2 - 8$ M_o) quickly evolve off the main sequence, this means that the integrated UV light of a star-forming population quickly decreases after a single burst or reaches a plateau after a few 10^8 years for a constant SFR. Under this assumption which seems reasonable at the scale of a whole galaxy, the rest-frame UV directly traces the SFR in galaxies over about 100-Myr time-scales, i.e. independently of the previous star formation events. Compared to NIR imaging, a variation of the SFR (Fig. 1, models Starburst99, Leitherer 1999, http://www.stsci.edu/science/starburst99) would produce a SFR-related variation of the UV flux while the effect of an increase of the SFR would be hardly detectable in visible rest-frame (NIR for high redshift galaxies). Before NGST will be launched, the UV SMEX Galaxy Evolution Explorer (GALEX) will harvest a huge amount of UV data which will provide an accurate calibration of the UV-SFR relationship.
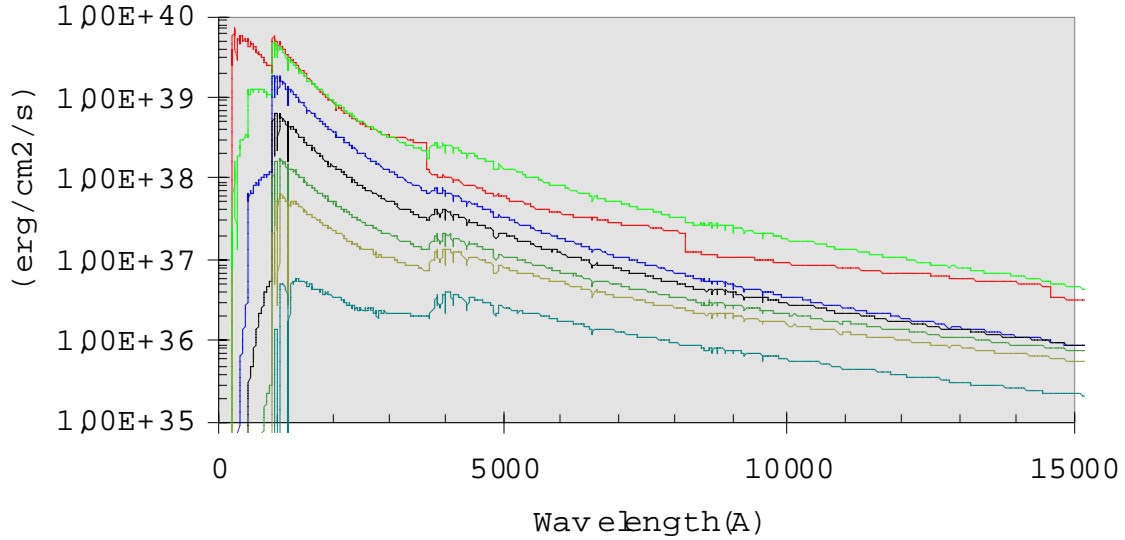
Fig. 1 : models STARBURST99 (Leitherer 1999) showing the SED of a stellar population 1, 5, 10, 20, 50, 100 and 500 Myrs after an instantaneous burst. While the range is huge in UV(corresponding to the visible for 3 < z < 7 objects) it is only a few tens in visible and NIR.

1. Extinction : the main limitation to the SFR estimation is the correction to the dust extinction to be applied to UV fluxes to get a good any valuable and safe SFR estimate. During the past years, our knowledge of the dust extinction longwards 1200 A has been considerably improved by the analysis of IUE spectra complemented with optical data. This led to an empirical attenuation curve and the calibration of the relative light attenuation by the internal dust as a function of the wavelength. Indeed, Calzetti et al. (1994) have shown that the extinction (measured from the Balmer lines) is correlated to the UV spectral slope β ($F_\lambda \propto \lambda^\beta$; Fig. 2 from Calzetti et al. 1994).

2. Assuming the stationarity of the shape of the UV continuum in the range (1200-1600è), which is achieved as soon as the SFR has been constant over some 10^7 years, Calzetti (1997, AJ 113, 162) has derived a recipe for correcting from dust extinction using the color excess measured with the Balmer decrement.
If we know that a number of very dusty galaxies exist in the Universe (e.g. Trentham et al. 1999, astro-ph/9812081, Barger et al. 1999, astro-ph/9903142), we also have an indication that a good proportion of starbursting galaxies have low-to-moderate extinction (Meurer et al. 1995, AJ 110, 2665, Fig. 3 from Buat & Burgarella 1998, A&A 334, 772) at low redshift meaning an important relative UV flux.. At higher redshift the situation is less clear but the extinction seems to be not dramatic (a factor of ~5; Meurer et al. 1995, Steidel et al. 1999, astro-ph/9811399, Pettini et al. 1998, ApJ 508, 539).
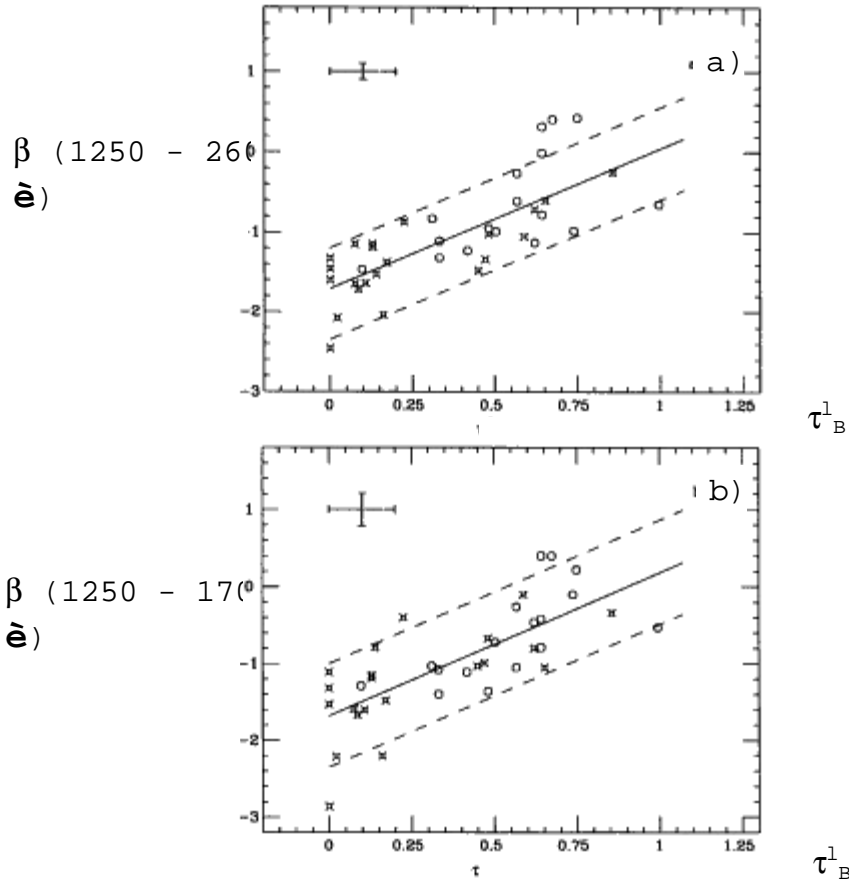
Fig. 2 : This figure extracted from Calzetti et al. (1994) shows that the parameter β (slope of the UV Spectral energy Distribution as defined in the in the Fig.) is strongly correlated to the Balmer optical depth τ^l_B. The bluer galaxies have β ~ -2 which can be interpreted as a low extinction while redder galaxies in the sample have larger β (β ~ 0) meaning a higher extinction. a) β is obtained from 1250 - 2600 A and b) β is from 1250 - 1700 A.
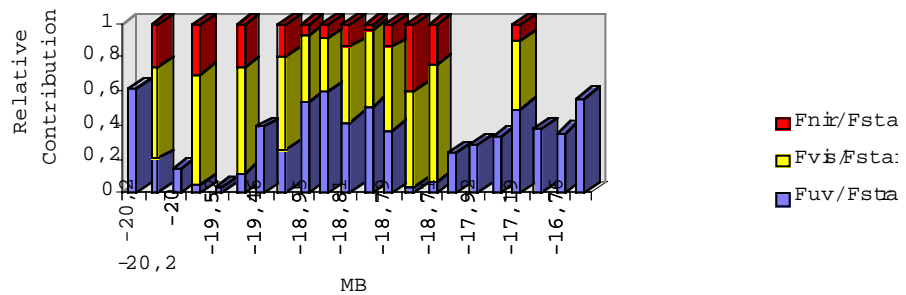

Fig. 3 : Relative contributions of a sample of local starburst galaxies showing that the UV represents an average of ~ 30 - 50 % of the flux in NGST wavelength range (Buat, Burgarella 1998).

One major limitation to the above studies is that they are based on small samples of galaxies which do not represent the entire galaxy population. The templates used by Calzetti and Meurer are starburst galaxies observed by IUE but the sample is not

complete in any sense. In particular faint galaxies which are known to dominate the UV luminosity function are missing (Treyer et al. 1998, MNRAS 300, 303, Buat & Burgarella 1998).

It must again be stressed that a UV photometric and spectroscopic survey of the sky (GALEX to be launched around 2001) complemented by the Sloan survey will be carried out, this will greatly improve our knowledge of dust extinction and rest-frame UV properties of galaxies. Moreover in the same timescales, NIR spectroscopic observations from large ground-based (VLTs, Geminis, Kecks) will provide a wealth of data ($H\alpha$ / $H\beta$ Balmer decrements complemented by visible spectroscopy) to start doing the same job at $z > 1$. In conclusion, the UV rest-frame would be a powerful tool (by itself or in complement to emission lines) to decipher the effect of the dust extinction on high redshift galaxies and correct for it to get the intrinsic fluxes. This is crucial to get safe SFRs.

3. IMF: The distribution of stellar masses at birth (IMF) is a basic function of the process of star formation. It is a strong constraint on theories of star formation an an input parameter to evolution models of galaxies (Leitherer et al. 1999). Establishing whether the IMF is uniform in space and as a function of the redshift and if not what are the parameters at play would be of prime importance. The $H\alpha$ flux related to the Lyman continuum photons production rate (N_{Lyc}) is essentially due to very massive short-lived stars ($M > 10\ M_o$) while the UV flux (L_{UV}) dominated by intermediate stars ($2 - 8\ M_o$). Consequently, studying both the UV-based and the $H\alpha$-based SFRs (i.e. the ratio N_{lyc} / $L_{UV)}$ would give us a hint on the mass distribution in high redshift galaxies and therefore on the IMF (Buat et al. 1987, A&A 185, 33, Glazebrook 1999, astro-ph/9808276).

Need for NGST :

The NGST will provide the deepest visible exposures ever (ASWG DRM proposal "The formation and evolution of galaxies I: The deep imaging surveys") are $m_{AB} = 34.8$ for the DEEP FIELD and $m_{AB} = 33.3$ for the WIDE FIELDs. More currently, NGST will provide a number of fields with limiting magnitudes around $m_{AB} \geq 31$. Ground-based 8-m would need about 100-h exposures (with resolution of ~ 0.5 arcsec) to reach this limiting magnitudes. On the other hand, adaptive optics will only provide few-arcsec FOV (say 24 arcsec) in the visible and a single NGST NIRCAM 4'x4' image would need about 100 ground-based images. The most powerful instruments on HST (ACS and WF3) would have the adequate resolution/deepness but . at m_{AB} = 31 they will still need more than 10-h exposure times. Moreover, HST will no longer be available by this time. A number of pre-planned Deep-Field observations may be carried by then but not having a VISCAM on-board NGST would mean closing the door to the opportunity to add any new fields.