HOT MASSIVE STARS IN LOCAL GROUP GALAXIES

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ABSTRACT. Massive stars play a fundamental role in the origins of the heavy elements, in the evolution of metal content, and star formation cycles in galaxies. Massive stars control the chemical and dynamical evolution of their parent galaxies through their strong stellar winds and extensive mass loss, supernova explosions, and their FUV ionizing radiation. We describe our program, aimed to characterize the hot massive star population of Local Group galaxies, to understand how metallicity and environmental factors influence massive stars formation and evolution. In particular, while most previous and current other UV studies are investigating Galactic and Magellanic Cloud objects in detail, we extended the comparison to the galaxies M31, M33 and NGC6822.Our program is articulated in different aspects, complementary to each other:

- Accurate measurement of photosperic and wind parameters (T_{eff}, log g, L, R, wind velocity, mass loss rate, abundances) of hot massive stars in the Galaxy, Magellanic Clouds (MC), M 31, M 33, NGC 6822 with a consistent analysis of optical, UV and FUV lines from ground based, HST and IUE data. FUSE (900−1200Å) data are scheduled from 1999. The stellar parameters are compared among stars of similar spectral type in different Local Group galaxies, to establish their observational correlations with global galaxy parameters, metallicity in particular, and star formation history. Such correlations will refine theories of radiation pressure winds, stellar evolution, galaxy chemical evolution, and will provide a key to interpret integrated properties of more distant galaxies.
- Global characterization of the hot massive star content, through HST UV - optical photometry of selected regions in nearby galaxies, and detailed studies of coeval populations. HST imaging allows a major step forward with respect to previous ground based surveys for two reasons: (*i*) the FUV photometry additional to U,B,V allowes us to identify the most massive stars, to whose hot temperatures the optical colors are rather insensitive and which are elusive in the optical images dominated by visually bright B-A supergiants, but easily stand out in the FUV. (*ii*) the HST spatial resolution allows to resolve a large number of individual objects at the distance of these galaxies.
- Study of the UV properties of the insterstellar dust as a function of metallicity and environment. Understanding the UV extinction by dust is important both to derive accurate UV fluxes and luminosities for hot stars, and to understand the fundamental role played by dust in regulating the star formation. This study, when carried beyond the Magellanic Clouds, encounters the observational limits of the current UV spectrographs on HST. Only the brightest UV stellar objects, with moderate extinction, are accessible. However some significant results are obtained.

1. Introduction.

Massive (30–120 $M_\odot$), hot stars – OB types and their evolved, supergiant, WR and LBV descendents – control the appearance and chemical and dynamical evolution of their parent galaxies through their strong stellar winds and extensive mass loss, supernova explosions, and their FUV ionizing radiation. Hot massive stars are bright, thus can be seen far away, and often dominate the appearance of their parent galaxies. They also evolve rapidly, thus trace star formation activity. Mass loss also plays a controlling role in determining the stars' evolutionary history, whereby the outer atmosphere is peeled down to reveal successive chemical products of interior nuclear processing. Nearby galaxies offer the ideal laboratory, spanning over a dex in metallicity, and a variety of morphology types, to learn how stellar evolution depends in detail on local and global parameters.

Detailed studies of hot massive stars in Local Group (LG) galaxies ultimately also provide a fundamental calibration to interpret UV properties of galaxies at moderate and large distance in terms of Star Formation Rate (SFR). UV luminosities of distant galaxies, as will be provided by GALEX (see Bianchi, this book) for redshift $0<z<2$, and by HST and NGST further back in time, will ultimately reveal the global picture of the evolution of the Universe. The interpretation of these data must rest on a solid understanding of hot massive stars properties and evolution as a function of environment and galaxy type. A basic step forward towards this local calibration is provided by the study of hot stars in nearby galaxies.

Fundamental parameters for individual hot massive stars in nearby galaxies (M 31, M 33, NGC 6822) are derived from UV and optical spectroscopy with HST and ground based telescopes, and HST imaging in UV and optical bands. Parameters of comparison stars in the Milky Way and the Magellanic Clouds are obtained analyzing IUE and HST archive spectra (Section 2). UV and optical HST imaging is used to characterize the massive star population globally (Section 3). Investigation of the interstellar extinction is described in Section 4. Another aspect of our program is the study of stellar clusters in nearby galaxies (described elsewhere in this book: Bianchi, Chandar & Ford), which provide further insight into the star formation history of these galaxies.

2. Parameters of Massive Stars in Different Galaxies

Hot stars' winds are best studied in the UV wavelength range, because most of the strongest transitions from the most abundant ionic species in the accelerated stellar envelopes fall shortwards of 1900Å (see Figure 1). Galactic and Magellanic Cloud (MC) hot stars were observed with IUE, in the past. In the last decade, with the launch of HST and the availability of large telescopes from the ground, we extended the study to the most luminous hot objects in other nearby galaxies: M 33, M 31, NGC 6822. Although at the limit of the current HST capabilities, and requiring long exposures and careful observation techniques, for a limited sample of stars in each of these galaxies we were able to determine stellar parameters with accuracy almost comparable to the information available for Galactic and Magellanic Could counterparts. UV spectroscopy of hot supergiant stars in M31, in M33, and NGC6822, and six WR stars (three in M33 and three in M31) was obtained with FOS and GHRS. Complementary optical observations were obtained at KPNO, CFHT, MMT and WHT. We give here a short overview of both the work in progress with HST and ground based telescopes (Sections 2.1 and 2.2) and of future observations planned with FUSE (Section 2.3).

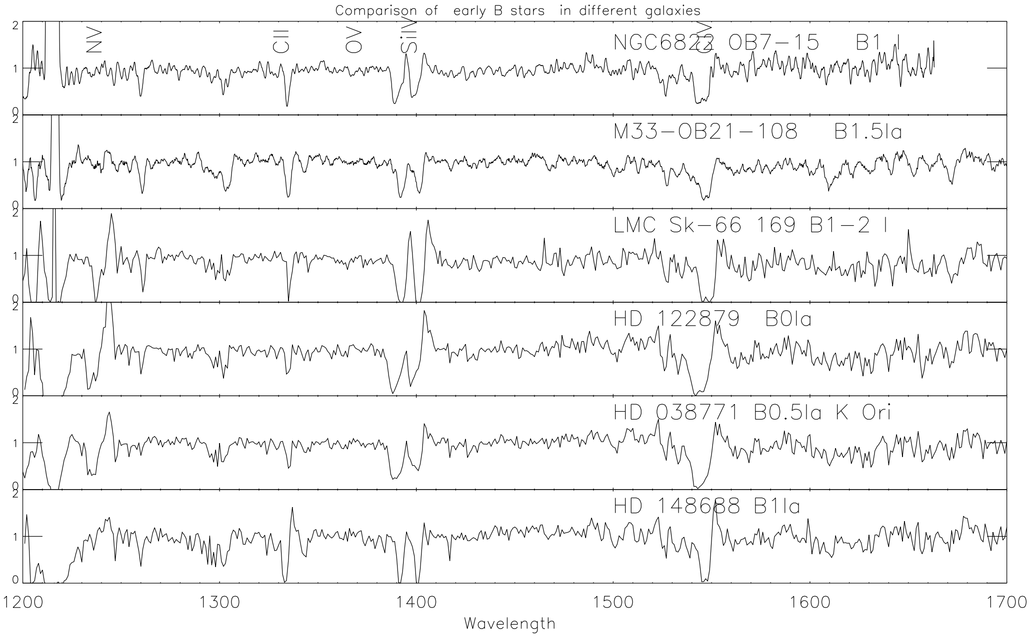

Fig. 1. Comparison of UV lines among early B stars in different galaxies. For more comparisons, including M 31 and M 33 stars, see Bianchi et al. (1996a).

2.1. Wind Features and Metallicity

Direct comparison of UV wind features among stars of the same spectral type in different galaxies reveals qualitatively but unambiguously metallicity effects, independently from *model analysis* of the stellar lines (see Bianchi et al 1996a, 1998a). Figures 1 to 3 show the strongest far-UV wind lines of similar stars in M31, M33, NGC6822, the Galaxy and the Magellanic Clouds (MC). Some of the results can be summarized as follows:

(i) metallicity signatures in the UV spectra confirm Galactic similarities for M31 stars
(ii) chemical peculiarities are revealed by the UV spectra of some M31 stars (e.g. C, or N, underabundant in stars having solar-like abundances of other elements)
(iii) wind velocities and UV line intensities in M 33 hot supergiants are comparable to LMC counterparts and weaker than in Galactic and M 31 counterparts (Bianchi et al 1996a, 1998a, Bianchi 1998)
(iv) narrow absorption components are detected in a M 33 object, confirming clumpiness of the mass outflow to be a ubiquitous phenomenon (Bianchi et al 1996a)
(v) hot stars in NGC 6822 reveal similarities to SMC objects in their UV lines, as expected for the extremely low metallicity. However one object shows Galactic-like metallicity and wind velocity. Further investigation in this region of the galaxy is under way, to determine whether a strong metallicity gradient exists (Bianchi et al. 1998b, Scuderi and Bianchi 1997).

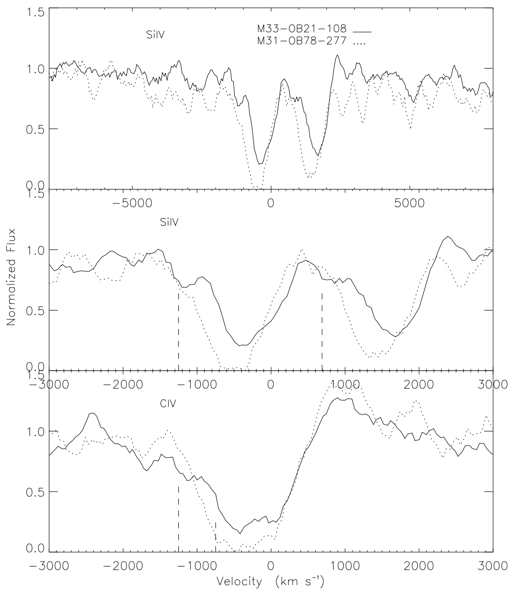

Fig. 2. The Si IV and C IV line profiles of an M31 and an M33 early B supergiant are compared. In the top panel, the broad depression (due to Fe transitions) around the Si IV doublet in the M31 star is an indication of the metallicity being higher in this object. In the middle panel, the continuum is normalized locally to the Si IV line: the absorption is weaker, and extends to lower velocities, in M33 than in M31. The same metallicity effect is evident in the CIV line (bottom panel). In the middle and bottom panel, narrow absorption components (NAC) in the wind of the M33 star are indicated with vertical dashed lines at a velocity of -1250 km s^{-1} (from Bianchi et al. 1996a).

2.2. Quantitative Determination of Stellar Parameters

Detailed modeling of UV (HST) wind lines and complementary optical photospheric line profiles is used to precisely measure T_{eff}, L_{bol}, log g, Radius, Mass, wind velocity, mass loss rate and abundances. Different codes are used for the modeling.

The UV lines of O-B stars have been modeled so far with the SEI method (Lamers et al. 1987) and its modifications (Bianchi et al 1994), which yields an accurate measurement of the wind terminal velocity V_∞ and the optical depth of each ion. The SEI method is based on the calculation of the source function with the escape probability method (Sobolev approximation) and an exact solution of the transfer equation (see e.g. Bianchi et al. 1997 for the parametrization adopted). An example of UV P Cygni profile model fit for an M 31 star is shown in Figure 4. Because of the uncertainties in the ionization of wind highly ionized species, for an accurate measurement of the mass-loss rate and photospheric parameters, we additionally model the Balmer lines ($H\alpha$ to $H\gamma$) with SEIBALMER (Bianchi et al. 1994) and SSBAL (Scuderi et al 1994) - see Figure 4.

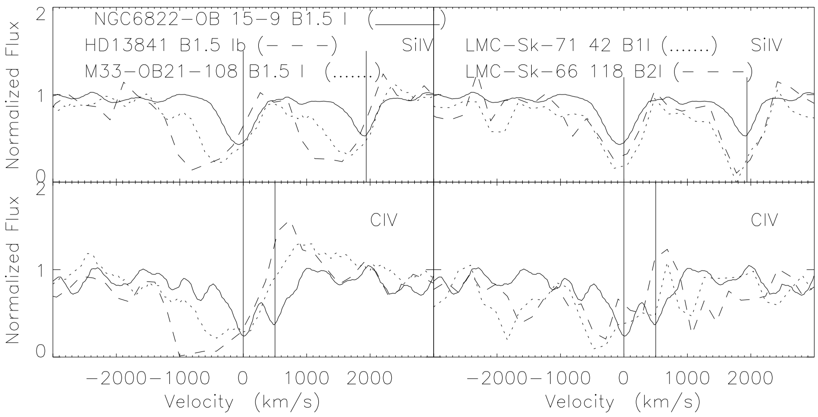

Fig. 3. Comparison of the most conspicuous winds lines in the HST range: the Si IV λ1400 and C IV λ 1550 doublets, among early B stars in the Galaxy, LMC, M 33 and NGC 6822. Wavelengths are transformed to wind velocity (regression velocities of individual galaxies have been removed). Vertical lines indicate zero points in the rest frame of the stars. Intensity of the wind lines, and extension of the blue absorption wing of the P Cygni profile, strongly reflect metallicity differences.

The wind emission decreases progressively from Hα to Hγ, which is mostly photospheric absorption. By iteratively fitting all the lines with a model that includes photospheric absorptions and mass-loss emission, all wind and photospheric parameters are derived consistently. Model fit of the Balmer-line profiles, additional to the UV line fit, yields mass-loss rate determinations more accurate than those based on the Hα Equivalent Width (EW) of the line only (e.g.Lamers & Leitherer 1993) that neglect important information contained in the line *profile* and may result in some systematic errors (see Puls et al 1996 for a discussion, Scuderi et al 1994). Another important advantage of our method is to determine the photospheric contribution to the Hα wind profile by fitting other photospheric lines of the same stars, rather than applying a correction to the Hα EW with an estimated photosperic contribution. Fig. 4 shows that the photospheric correction is quite significant, even for a star with high mass loss rate and luminosity, thus the gain in accuracy is considerable. As a future development, we plan to reanalyse the data with EMISSEI - a code which calculates the wind lines, the photospheric spectrum, and also the absolute continuum flux consistently. EMISSEI was developed by Jeroen van Gent as a thesis project (Univ. of Utrecht) directed by Prof. Lamers and in collaboration with L. Bianchi (J. van Gent has been visiting student of L. Bianchi).

For the Wolf Rayet stars observed in our sample, the modeling is performed in collaboration with Lars Koesterke and W.-R. Hamann (Potsdam). We are using their models that fully account for the complex physics in the winds of WR stars (Hamann & Koesterke 1998, Graefner et al. 1998). The radiation transfer is calculated in the comoving frame under non-LTE conditions, accounting for large model atoms with up to 200 levels. Consistent solution of the radiation transfer and the statistical equilibrium is

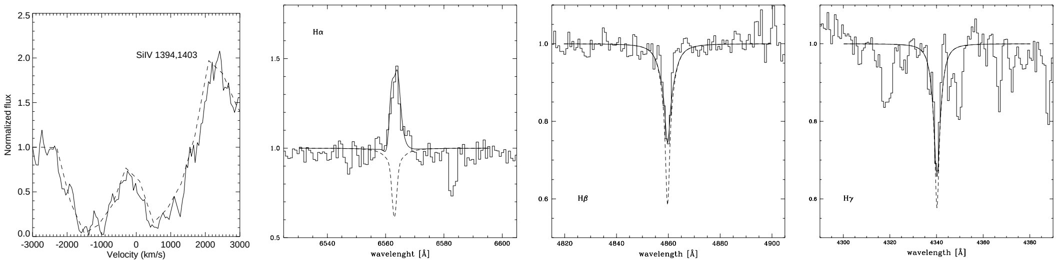

Fig. 4. From left to right: fits of the SiIV1400Å, Hα, Hβ & Hγ line profiles, observed with HST-FOS and the 4.2m WHT, respectively, of an O supergiant in M31. In the Balmer lines, the solid line is the best fit total profile (wind and photospheric) the dotted line is the underlying photospheric profile (from Bianchi et al, 1998b).

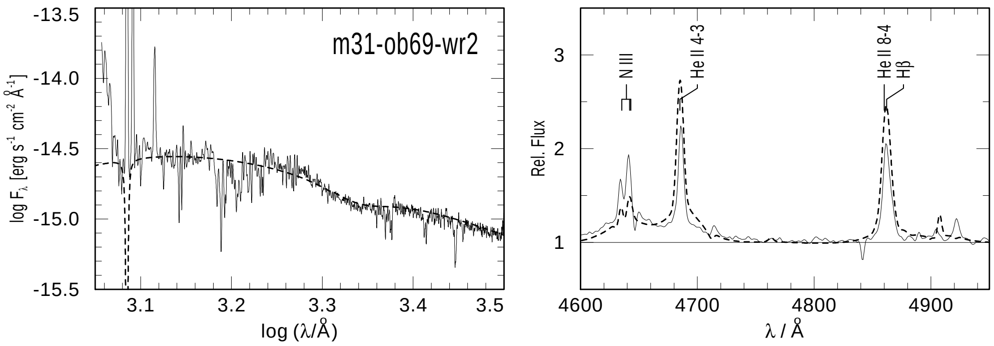

Fig. 5. HST UV and ground-based optical spectra of a WNL star in M 33 and best fit model (from Koesterke, Bianchi and Hamann 1998, in preparation). The left panel shows the overall continuum fit, in the right panel a small portion of line fits is shown in detail.

achieved by the Approximate Lambda Iterations method. Fit of the lines and the absolute spectral energy distribution yields reliable luminosities, temperatures, radii, mass loss rates and abundances. An example is shown in Figure 5. Results so far include:
(i) wind velocities and mass loss rates of M 31 stars are comparable to Galactic values, as expected given the similar metallicity (Bianchi 1995, 1997, –– et al. 1996a, 1998)
(ii) the wind momentum rate in the three galaxies agree with theoretical models (Bianchi 1998a, c)
(iii) hot, *evolved*, low luminosity objects in the LMC do not reveal conspicuous differences in wind velocity and UV line intensity with respect to Galactic counterparts as is instead observed in hot luminous (young) LMC stars (Bianchi et al 1997).

2.3. The Future: FUSE far UV observations of Hot Stars Winds

A further expansion of our program will be provided by the launch of FUSE *(the Far Ultraviolet Spectroscopic Explorer)* in February 1999. FUSE will allow us to extend the study of hot stars' winds to the range $\lambda\lambda$900–1200, where different ions abundant in the hottest, outer layers of the stellar winds are observable. A large science team program (coordinated by J. Hutchings, Canada) is planned to cover with FUSE a significant range of stellar parameters for Galactic and Magellanic Clouds (MC) hot objects, and an exploratory sample of hot stars in M 31 and M 33. We will obtain FUV ($\lambda\lambda$900–1200) spectra of a representative sample of O-B and WR stars in the Galaxy, the LMC, and SMC. The sample (over 200 stars) will cover systematically spectral types from O3 to B1 from main sequence to supergiants, and WR, matched in the 3 galaxies. All stars selected for the FUSE reserved list already have HST and/or IUE spectra ($\lambda\lambda$1200–3200) of comparable resolution. The FUSE data will contain line features of a wide range of ionization, not available at any other wavelengths, which will enable a full determination of the ionization balance in stellar winds for the first time. Our present, incomplete knowledge of the ionization balance in the stellar winds leads to large uncertainties in mass loss rates, since, from P-Cygni profile modelling, one must convert measurement of trace ions to the total mass loss rate. IUE and HST data give only partial, and often conflicting information, since they can only observe the (often saturated) resonance lines of CIV, SiIV and NV. With FUSE we can observe wind lines in a greater spread of species and ionization states: NII, NIII, N IV,CII , CIII, PIII, PIV, PV, SIII, SIV, SVI, OVI. From the FUSE data the degree of ionization can be determined accurately. This systematic analysis covering a range of metallicity, will: (a) refine and use the theory of radiation pressure-driven winds, (b) refine massive stellar evolution theory with mass loss, (c) determine the chemical and dynamical evolution in different galaxy environments, and thereby (d) provide a template for spectral and evolutionary synthesis studies of more distant galaxies, of cosmological interest, where it is only possible to study the integrated properties of stellar aggregates.

FUSE measurements of O VI and S VI will provide unique probes of the hottest, most ionized portions of the winds, hitherto inaccessible.

3. Charaterizing the Massive Star Population of Local Group galaxies

3.1. UIT and HST UV Photometry of M33

One of our goals is also to contribute to a detailed, quantitative characterization of the young massive stellar population in Local Group galaxies.

Massey, Bianchi, Hutchings and Stecher (1996) published near- and far-UV (1500Å) and optical photometry of the 400 UV-brightest objects revealed in images of M33 taken with the Ultraviolet Imaging Telescope (UIT, Stecher et al 1992) on ASTRO-1 on board the Space Shuttle. Follow-up classification spectra of the UV-brightest objects revealed their nature and allowed interpretation. The UV-brightest sources are found to follow the spiral arm pattern, and confirmed recent star formation in the central region of the galaxy. The sample is dominated by B-type supergiants, although we found stars as early as O6. New WN stars, and Ofpw/WN9 were detected. The "superluminous" Wolf-Rayet stars detected earlier by Conti and Massey are detected in the UIT images, but the fainter WR stars are below the UIT detection limit of $F_{1500}=2.5 \times 10^{-15}$ ergs cm^{-2} s^{-1} Å^{-1}. Our HST imaging of seven fields in M33 however showed that about half of the UIT UV sources are multiple objects.

HST imaging offered a tremendous improvement with respect to our previous ground based and UIT studies in two ways. The superior HST resolution is crucial, given the distance of these galaxies, allowing us to resolve most of the luminous stellar objects. The additional far-UV bands are crucial for the detection of the hottest stars (O, early B, WR), to whose high temperatures the optical U,B,V bands are not sensitive, and thus essential for an unbiased study of the hot star population in these galaxies. For instance, B-V varies from 0.32 to 0.30 from O5 to B0 for luminosity classes III and V, and from 0.31 to 0.24 for supergiants (Massey 1998), and the bolometric correction for O3 supergiants is two mag. higher than for B0 supergiants. Interesting locations in M31, M33, and NGC6822 were imaged with WFPC2 (U,B,V and UV filters). M33 was sampled from the nucleus (bulge population) to bright star formation regions in the spiral arms, to obscure regions between the arms and outside. Different galactocentric distances were covered, to check for both a possible metallicity gradient and a global "galaxian heritage". Several thousand stars were measured in U,B,V and a few hundreds also in the far UV (see Figure 6 for a sample result). From the sample we selected the hottest massive star candidates and obtained follow-up classification spectroscopy at CFHT (Hawaii). More follow-up spectra are planned at KPNO in Oct. 1998.

3.2. Discovery of Young Coeval Populations in NGC6822

Another powerful way of learning about the massive star content of a galaxy and about star formation in different environments is the study of coeval populations. To resolve star forming regions into their stellar and nebular constituents helps understanding starburst activities in galaxies in many ways, by measuring how the ionizing stellar populations are structured, and the balance between radiative and mechanical processes powering the starburst. With detailed studies of stellar "nurseries" in different galaxies, we learn how the initial mass function (IMF) depends on environment, especially metallicity and starburst intensity.

Massey et al (1995) found no evidence for a significant dependence of the IMF power-law slope on metallicity, from photometry and spectroscopy of Galactic and Magellanic Clouds ionizing clusters. Multiband HST photometry of three Giant HII Regions in M 33 with different metallicities have been carried out by Malumuth et al (1996) and Hunter et al (1995). These studies again did not find a significant relation between metallicity and IMF slope, but follow-up spectroscopy has not been performed yet to our knowledge. We extend detailed studies of the stellar content and global parameters of starburst regions to different galaxies and environments, as a definite calibration for integrated studies of composite spectral indices of unresolved starburst regions in distant galaxies. In fact, results from composite diagnostics (emission line ratios, Hα equivalent widths, etc.) differ from resolved studies, and give contradicting indications of IMF being richer in massive stars at low metallicities (Shields 1990), or being dependent on dynamical factors (Waller and Hodge 1991), or on the intensity of starburst activity (Gehrz, Sramek and Weedman 1983). However resolved studies are to date only a handful, and the only way to clarify the picture is to extend the quantitative characterization of stellar populations with spectroscopic and photometric studies of coeval young populations in

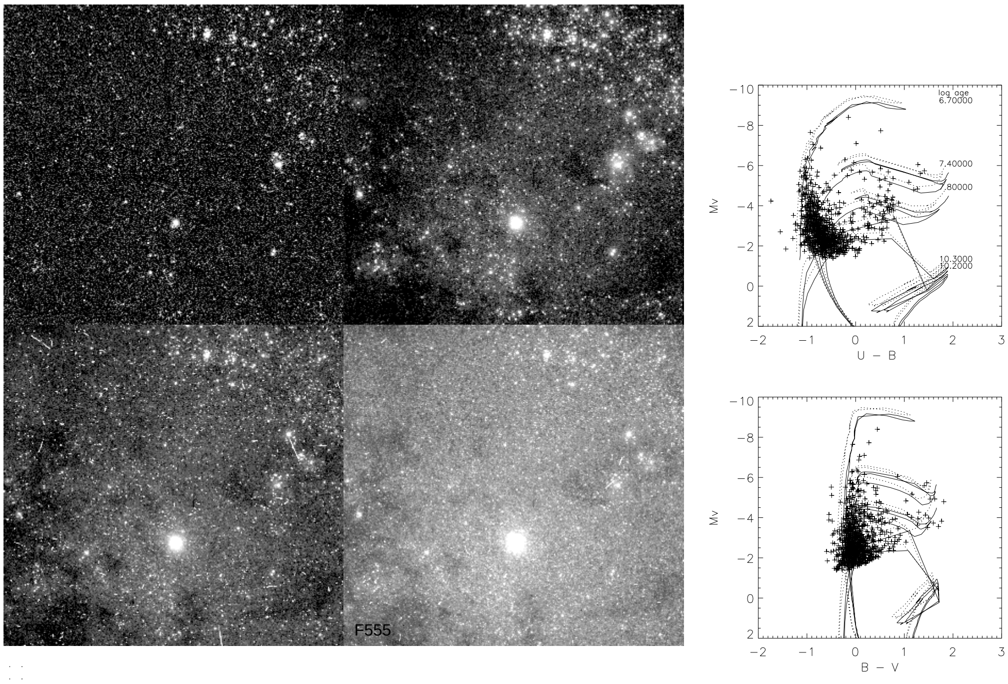

Fig. 6. Left: HST imaging of the central region of M33 (about 70″). The filters, clockwise from top left, are F170W (1700Å), U, V, B. The figure shows the dramatic advantage of using UV filters to detect the very hot stars, where the B-A type population dominating the V-band desappears. The bright hot objects in the F170W panel are fainter than the brightest objects at optical colors. Right: Isochrones (models of Bertelli et al. 1994, LMC metallicity, ages in log years) are superimposed onto the measured color - magnitude diagrams for the massive stars in field shown at the left. Different populations (young massive stars from OB association, and older field stars) are contained in this WFPC2 chip. No dereddening is applied to the data points, and no transformation to T_{eff} - L_{bol}, because for very massive stars the U-B, B-V colors are **not** sensitive enough to their high temperatures, so the transformation would introduce significant errors. Isochrones and evolutionary tracks are instead plotted in U,B,V colors. To show the reddening effect, each isochrone is plotted unreddened (dotted curve) and reddened with E(B-V)=0.1 (solid line) which is a typical value for this field. (from Bianchi et al. 1998a,d).

different environments. Other authors (Hunter, Waller, Massey, Malumuth) studied the most outstanding star forming regions in M33. We present here our results for one of two spectacular star forming regions in NGC6822 that we studied with HST.

NGC 6822 is an irregular galaxy in the Local Group, with a metallicity intermediate between that of the SMC and LMC (Pagel, Edmunds, & Smith 1980). Its old and intermediate age stellar population has been studied in some detail recently (Gallart et al. 1996a,b,c), but its massive star content has been harder to study. Ground-based *UBV* photometry (Wilson 1992, Massey et al. 1995a) made it possible to select stars for follow-up spectroscopy, which confirmed the presence of massive O-type stars in several of its OB associations (Massey et al. 1995a). We used ground-based data on

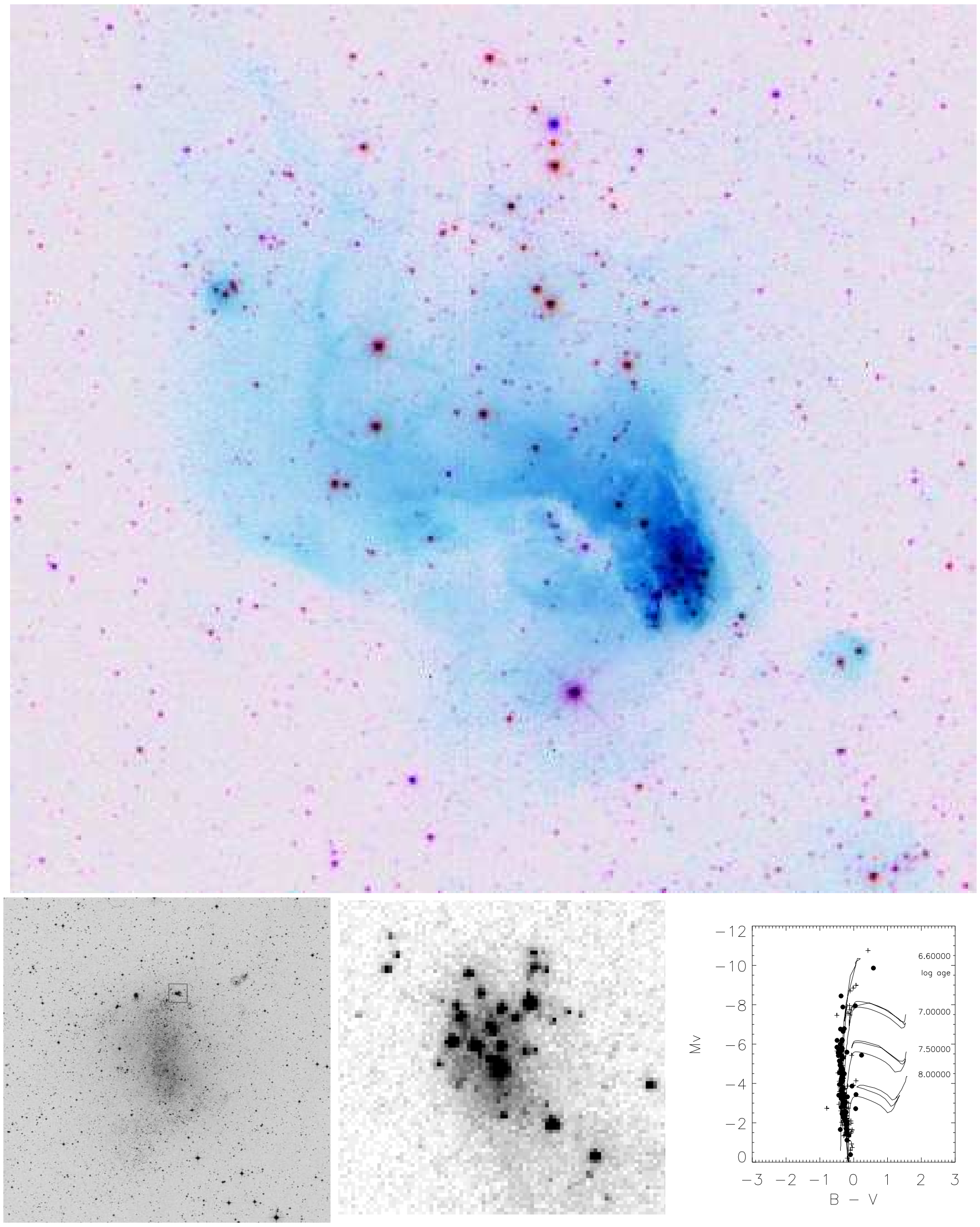

Fig. 7. Upper panel: HST image of the star forming region in NGC6822 ($\approx 30''$, extracted from our WFPC2 images). Lower panel: *Left*: the POSS image of the entire NGC6822 galaxy with the H-V region circled, *Middle:* an zoom-up of the upper image shows the stars resolved in the darker part of the cloud, which is obscured in the upper panel display. *Right:* One dereddened color-mag diagram for this field. Isochrones (log ages in years labelled) from Chiosi et al. (1997). Scatter of the points for the bright stars reflects difficulties in determination of the extinction for the hot objects.

NGC 6822 from Massey et al. (1995) to select two fields containing the richest massive star population for detailed photometry with WFPC2 during Cycle 6, with U,B,V and the F255W filters. Photometric measurements from these data show populations with a range of ages across the two WFPC2 fields (Scuderi & Bianchi, 1997; Bianchi et al. 1998d). Two particularly interesting star formation regions revealed young coeval populations that could not be resolved from ground based surveys. One of these two regions, Hubble V (Hubble 1925, Hodge et al 1988), is the richest in young massive stars candidates. Figure 7 shows the Hubble V region from our WFPC2 image, and a de-reddened color-magnitude diagram for its population. The diagram contains a handful of evolved stars and a few Galactic foreground contaminants, but basically reveals a strong, coeval population of massive stars with a cluster age of a few million years. This age is surprisingly much younger than the youngest OB associations previously known in this galaxy ($\approx 5\ 10^7$ yrs, Hodge 1977). When combining HR diagrams from all available filters, we have also an indication that the reddening might be anomalous within this region, while a Galactic-type E(U-B)/E(B-V) ratio of 0.72 is found in other areas of NGC6822 (Massey et al. 1995a). UV HST and optical spectroscopy is planned to derive optical spectral types, effective temperatures, bolometric corrections, accurate reddening corrections, wind velocities and mass loss from these stars.

4. The UV Interstellar Extinction in different galaxies

4.1. The importance of dust properties in the UV

Virtually all observations of astrophysical objects are affected by the presence of dust either within the system or along its line of sight. This is particularly true for extragalactic objects. A sample of four Local Group galaxies now exists for which UV extinction has been studied, to different extents. The result of these studies is that dust properties in the LMC, SMC and M31 are different from each other and more importantly different from our Galaxy.

UV extinction gives information on the properties of dust, which is an important tracer of global heavy element abundances. The steepness of the FUV extinction affects the ionisation and molecular chemistry of a galaxy. Knowledge of the extinction curve also allows accurate corrections of observed fluxes. Ultimately, relating dust properties to global galaxy parameters may enable better extinction corrections in distant galaxies and AGN.

The outstanding signatures of the UV extinction are the rise to shorter wavelengths and the broad maximum at 2175Å. It is known that the UV extinction curves in the Magellanic Clouds differ significantly from the average Galactic one, having a weaker 2175Å bump and a much steeper rise shortwards of 2000Å (Hutchings, 1982; Clayton and Martin,1985; Fitzpatrick 1985; Clayton *et al* 1996; Gordon & Clayton 1998), in the SMC even steeper than in the LMC. Strong deviations from the average Galactic curve are seen also in some Galactic lines of sight (e.g. Carnochan 1986; Seab, Snow and Joseph 1981; Witt, Bohlin and Stecher 1984; Bohlin and Savage 1981). Different extinction curves within the LMC are found, e.g. in and outside the 30 Dor region, stressing the relevant role of massive star presence and local factors.

Advances in the understanding of dust properties have come about by linking variations in observed extinction curves to variations in environments. In our Galaxy, the extinction has been studied in a wide range of interstellar dust environments, including diffuse dust, dark cloud dust, and dust associated with star formation (bright nebulae). Cardelli, Clayton and Mathis (1989, CCM), Cardelli and Clayton (1991) suggested that an average Galactic law A(λ)/A(V), depending on only one parameter R(V)=A(V)/E(B-V), is applicable to most interstellar dust environments, and can account for most observed extinction curves. However, the CCM law does not reproduce some Galactic observed curves, associated with dark clouds and star-forming regions, and can not account for the different properties shown by the MC's dust, which may arise from the known abundance difference between the MCs and the Galaxy. In a more general context, it is important to establish a dependence of the ISM properties on galaxy type or characteristics, as a basis for much extragalactic work (e.g. Lyα luminosity of distant objects).

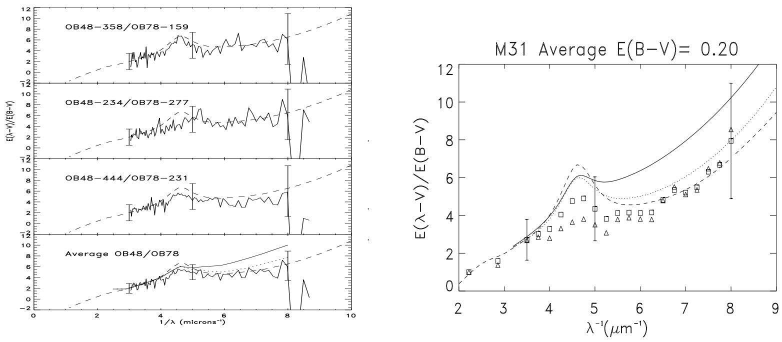

Fig.8. **LEFT**: Extinction curves from pairs of stars in M31. (dashed line: Galactic curve, dotted line: LMC non- 30 Dor, solid line: LMC 30 Dor). The bottom panel is the average from three pairs. **RIGHT**: Average extinction curves for M31 from comparison of M31 stars with Galactic standards (squares: total M31 + foreground extinction; triangles: extinction with Galactic foreground subtracted). Also plotted are the average extinction curves for LMC 30 Dor (solid line), the LMC outside of 30 Dor (dotted line), and the CCM curve for $R_v = 3.2$ (dashed line). $2-\sigma$ error bars are plotted for points at 3.5, 5, and 8 μm^{-1} (from Bianchi et al. 1996b).

4.2. The UV extinction curve in M31

From eight stars observed in M31 with the HST FOS at low resolution, we derived the UV extinction curve using three methods. First, we compared pairs of stars in M31 with the same spectral type, but different extinction. This approach largely eliminates the foreground Galactic extinction, and avoids possible intrinsic spectral differences that stars in another galaxy may have with respect to Galactic standard stars. However, due to the limited choice of targets accessible to the FOS capabilities, the maximum extinction in our sample was E(B-V)=0.24, of which E(B-V)=0.08 is due to the foreground Galactic halo. Thus photometric errors are significant. Due to the small E(B-V) differences among the M31 stars, we also derived extinction curves by comparing each M31 object with model atmospheres, and with Galactic standards. This yields extinction curves with formally smaller error bars, but the foreground Galactic extinction is then included, amounting to about half of the total. We also observed some bright foreground halo stars to obtain insight of the halo extinction in the direction of M31: these results are also limited by the amount of Galactic foreground reddening being very low in the M31 line of sight, but are suggestive of a possibly steeper Galactic curve than the average Galactic one. We find that the overall slope of the intrinsic M31 extinction curve (Fig. 8) is similar to the Galactic average curve, as expected from the similar properties of the two galaxies, however the 2175Å feature in M31 appears possibly smaller than that of the mean Galactic curve (Bianchi et al. 1996b).

We are extending the study to M33, where preliminary results indicate resemblance of the UV dust properties to the LMC (Bianchi et al 1991, 1998b, Hutchings et al. 1987).

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