THE NEED FOR ULTRAVIOLET TO UNDERSTAND THE CHEMICAL EVOLUTION OF THE UNIVERSE, AND COSMOLOGY

Willem Wamsteker , *INTA-LAEFF, Madrid, Spain*
Jason X. Prochaska, *University of California, Santa Cruz, California, USA*
Luciana Bianchi, *GALEX, Space Research Lab, JHU, Baltimore, USA*
Dieter Reimers, *Remeis Sternwarte, Hamburg, Germany*
Nino Panagia, *STScI, ESA-RSSD, Baltimore, USA*
Andrew C. Fabian, IOA, *Cambridge University, Cambridge, UK*
Claes Fransson, *Stockholm University*
Boris M. Shustov, INASAN, *Russian Academy of Sciences, Moscow, Rusland*
Patrick Petitjean, *Institute D'Astrophysiques, Paris, France*
Phillipp Richter, *Sternwarte, University of Bonn, Bonn, Germany*
Eduardo Bataner, *Institute of Physics, University Granada, Granada, Spain*

Abstract: We identify an important set of key areas where an advanced observational Ultraviolet capability would have major impact on studies of cosmology and Galaxy formation in the young Universe. Most of these are associated with the Universe at $z < 3$-4. We address the issues associated with Dark matter evidence in the local Universe and the impact f the Warm-Hot Intergalactic Medium WHIM on the local Baryon count. The motivations to make ultraviolet (UV) studies of supernovae (SNe) are reviewed and discussed in the light of the results obtained so far by means of IUE and HST observations. It appears that UV studies of SNE can, and do lead to fundamental results not only for our understanding of the SN phenomenon, such as the kinematics and the metallicity of the ejecta, but also for exciting new findings in Cosmology, such as the tantalizing evidence for "dark energy" that seems to pervade the Universe and to dominate its energetic. The need for additional and more detailed UV observations is also considered and discussed.

Finally we show the enormous importance of the UV for abundance evolution in the Intergalactic Medium (IGM), and the importance of the He II studies to identify re-ionization epochs, which can only be done in the UV.

Key Words: Ultraviolet astronomy – Chemical evolution - Cosmology – Galaxy formation – Supernovae –Intergalactic Medium .

1. INTRODUCTION

Dramatic progress has been made during the past decade in the acquisition of observational evidence of the contents of our Universe at high redshift. Special mention can be made here of the coordinated efforts though the Hubble Deep Fields (HDF-N and HDF-S; Williams et al. 1996) and the associated Great Observatory Origins Deep Survey, GOODS (Giavalisco et al. 2004) multi-wavelength data collection effort. In addition to these, the results obtained from two major mapping efforts: the 2dF survey at the Anglo-Australian Telescope (Hawkins et al. 2003) and the Sloan Digital Sky Survey (SDSS; York et al. 2000), have supplied new insights in the stellar and galaxy content of the Universe, in a redshift range extending from 0 to z > 6 and higher. The results on the structure of the Cosmic Background (CMB) by the Wilkinson Microwave Anisotropy Probe (WMAP) mission (Bennet et l. 2004) have, at the same time, allowed a much more detailed evaluation of the formation of structure after the first inflationary phases of Big Bang Cosmologies (Tegmark et al. 2004). However all these efforts did not succeed to give a definite answer to the structure formation epoch, scale and evolution. These questions can not be answered from the high z side alone, because the consequences for the present state of the Universe are rather different for different cosmologies. Tegmark et al. (2004) have shown that the recent WMAP CMB studies appear to be best compatible with a

ΔCDM cosmology (i.e. “vanilla type models with 6 parameters). Further new data on the small scale fluctuations and the polarization characteristics of the CMB are expected to be found by ESA’s Planck mission and from the various studies made from Antarctica.

A complete new window on the high redshift Universe can be expected to be opened up though the James Webb Space Telescope mission (JWST; NASA/ESA foreseen to be launched in 2012) and its precursor mission the Wide-Field Infrared Survey Explorer (WISE; NASA; launch in 2008), which will perform a new high sensitivity IR sky survey. Some of the infrared veils appear to be lifted by the Spitzer Space Telescope Observatory from NASA. Quite interesting results have been obtained already (e.g. Eyles et al. 2005). Further progress in this area is expected from the Herschel mission of ESA expected to be launched in 2007.

All these surveys and future mission characterize the history of star formation, the evolution of galaxy morphology and distribution in space, and in combination with the CMB data, give information on large-scale structure. These results will have a major effect on our understanding of the part of the baryonic material which has passed through the process of Galaxy and star formation in the Universe at all redshifts. There remain however some fundamental issues which can not be addressed through any of the observatories foreseen for the future either on the ground , or in space.

One needs to evaluate how the Universe evolved over its lifetime, after the first ionization phase. This requires a proper understanding of the variation in time of a number of different observables, such as abundance evolution, star formation rate changes with time, identification of possible re-ionization phases etc. All of these can only addressed by observations of baryonic matter out to redshifts of $z \approx 3$-4.

The main questions can be summarized as follows:

1. All luminous material in the Universe has been formed from the gaseous matter in the Interstellar Matter and the Intergalactic matter, and little data are available to describe how this gas in cycled to feed star and galaxy formation.

2. Any self-consistent theory of Star formation and Galaxy formation will need an understanding of the Star Formation Rate (SFR) including UV data. This will allow us to incorporate the most massive and most rapidly evolving stars. The play a critical role in the recycling of matter in the Universe and are an important factor in the energy cycling in galaxies. An understanding of these processes is very important to clarify the nature and extent of “dark matter”. Similarly, the possible existence and effects of a major pressure associated with “dark energy” can be expected to be addressed through adequate observations in the UV. Due to cosmological redshift we can observe objects emitting or absorbing in FUV (at $z>\sim 2$) only with a space telescope.

3. The important task is to establish the connection between the nearby ($z>\sim 2$) Universe, covering 80% of the cosmic time and containing most of the baryonic matter, and the early Universe which is being studied in great detail at the redshifted UV wavelengths with the new generation of ground based telescopes.

From the results of observations related to the early phases (CMB and high z quasars and ultraluminous galaxies at $z > 3$) the following constituents of the Universe have been derived ($\Omega = \rho/\rho_{crit}$ with $\rho_{crit} = 3H_0/8pG = h^2 \times 1.88 \times 10^{-29}$ g/cm^3 and $H_0 = h \times 100$ km/s Mpc^{-1}):

Total density of matter-energy	$\Omega = 1.02 \pm 0.02$
Dark energy density	$\Omega_\Delta = 0.70 \pm 0.03$
Dark matter density	$\Omega_m = 0.27 \pm 0.07$
Baryonic matter density	$\Omega_b = 0.444 \pm 0.01$
Hubble constant	$h = 0.72 \pm 0.05$.

Most of these parameters are referred to, and obtained from observations related to the first 3 Gyr of the Universe and therefore are based on strong assumptions and priors. For example, a major assumption underlying the quoted errors above, is the adoption of the errors associated with each prior. In particular, primordial Gaussian adiabatic, scale-invariant density fluctuations are adopted. If, for example, an admixture of 30 percent isocurvature fluctuations is included, consistency with CMB data is still obtained, but the error bars are up to an order of magnitude larger. Thus, many of these assumptions have strong effects on the above indicated constituent distribution in the Universe.

The very information on the (re)cycling of the IGM and population evolution over 90% of the lifetime of the baryonic Universe is an essential requirement for the understanding of the physical transition from the early universe to the current epoch (14 Gyr) *in which we exist.*

One of the most direct tests of the standard big bang nucleosythesis (SBBN) is the determination of the primordial abundances of the different light elements, especially H, D, and ^{4}He. The astration (destruction) of deuterium as gas is cycled through stars will than give also a strong constraint on the history of star formation (see Epstein et al. 1976). Various high redshift D/H ratios have been established through ground-baed and HST observations of Lyman limit systems (and damped Ly-α systems) of QSO's with $z > 2.0$. Many attempts have been made in the recent years to establish the primordial D/H ratio. Unfortunately the values derived for D/H show a considerable spread for systems with $z_{abs}>2$ (e.g. Pettini and Bowen 2001). The prediction from SBBN for the ^{4}He abundance is $Y = 0.247\pm0.02$ and a present day baryon density of $\Omega_b h = 0.0193\pm0.0014$ (Burles and Tytler 1998), implying a surprisingly high baryon-to-photon ratio $\eta=5.3\pm0.04 \times 10^{-10.}$

The interesting problem remains that FUSE observations have shown for the Local Bubble a relatively constant value for $D/H \approx 1.5 \times 10^{-5}$ while for somewhat more distant stars values extending from 7 ppm to 25 ppm are derived for *D/H.* It remains therefore an important challenge to find the "exact" value of Ω_b, i.e. to obtain and independent estimate amount of ordinary (baryonic) matter. The required D/H values can only be established if enough objects are used in the redshift range between 0 an 2, as that will allow to establish the validity of the astration model in the context of SBBN. A large amount of work is done in the theoretical aspects of the outstanding cosmological questions, but without good observational evidence to guide the theories for the time interval between $0 < z < 3$ – which spans 80% of the age of the Universe- no real choice can be made between the different models. Independent of the different models for the early Universe the major baryonic component of the Universe at $z < 3$ must be associated with the Inter Galactic Medium (IGM).

In the following sections we will illustrate the critical role of the UV domain to clarify the questions raised by this theoretically exciting, but observationally very unsatisfactory situation. We will evaluate the new observational capabilities needed to address the physical properties of the Inter Galactic Medium (IGM) such as metallicity, dust content, ionization state, temperature. These will lead to a much improved determination of the total baryonic mass Ω_{bar} in the present day Universe and its state evolution during the expansion phase.

In this discussion we will not introduce different shades of baryonic matter such as concept of "dark baryonic matter" (Combes, 2003), but will confine ourselves to the distinction between baryonic matter and the generic term for non-baryonic matter, i.e. dark matter. The possibility for a non-zero cosmological constant is maintained conceptually as "dark energy", but a detailed discussion of the various models which can be invoked introducing non-standard physics , is beyond the scope of this paper. As most accessible diagnostics for the baryonic matter associated with the IGM lie in the UV for redshifts $z < 2$, new space missions will be required.

In Section 2 we will discuss the issues associated with the baryonic mass fraction Ω_{bar}. In Section 3 we will discuss the relevance of SN as probes of the Universe. In Section 4 we will discuss the IGM cycling aspects and abundance issues. In section 5 the ionization state and the re-ionization epoch(s). Finally in section 6 the instrumental requirements for future instruments will be outlined. All this should be seen in the context of the results from the Galactic Evolution Explorer (GALEX; launch April 2003) which makes the first sensitive UV Sky Survey ever (Martin et al. 2005). The complete results catalogue of GALEX is expected to be ready in 2007.

2. Baryonic content of the universe
(Weighing the universe)

2.1. What part of baryons do we observe?

The most direct way is to estimate relevant contributions from observations of all baryonic components. However this requires that we have identified all baryonic constituents. Even for those baryonic matter constituents we know, we can only observe part. From the ms-luminosity relation for galaxies the luminous matter density is estimated as $\Omega_{\mathrm{lum}}h$ = 0.002-0-006 i.e only up to 30% of Ω_b.

This implies that apart from the fact that a large fraction of the Universe is made up of Dark Matter and Dark Energy we do not even have a certainty about the baryons beyond 30%. The primary question to be addressed than is: where are missing baryons? (Carr, 1994). The known phases of baryonic matter are:

- **Condensed:** Stars and gas in or near galaxies; Easily observed
- **Very hot** ($10^{7\text{-}8}$K): intracluster and intragroup gas: X-ray observations
- **Diffuse** (Warm 10^4K) photoionized gas: Ly-alpha absorbers
- **Warm-hot:** intergalactic medium (WHIM) at $10^{5\text{-}7}$K: Difficult to observe-highly ionized low density gas.

(C)DM is required to trigger the formation of structure after the inflationary phase in BB cosmologies. Support for the existence of DM has been found in the consistency of the Ly-α forest results with the predictions from CDM cosmologies. It must however be kept in mind that most these results have been obtained from the ground and thus are related to the distribution at $z > 2$ (i.e. where redshifted Ly-α enter the optical passbands). Only very few sightlines have been studied in the range from $0 < z < 2$. This has been mainly caused by a lack of dedicated observing capabilities, but also by the lack of identified background UV sources. A new UV mission would, with the expected 10^5 QSO's in the GALEX catalogue, allow immediately sufficient statistics to determine both the distribution and evaluation of Ly-α forest with redshift.

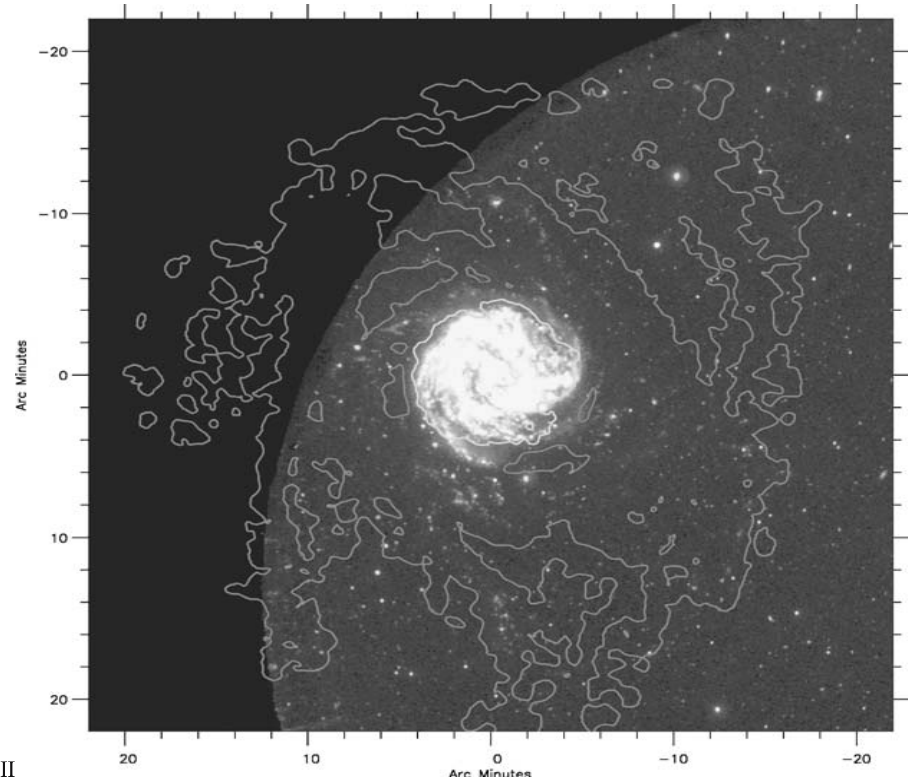
It has been well established that CDM is distributed in different ways throughout the Universe. While at high redshifts the DM appears to supply the separation between the individual Ly-α filamentary structures, in the massive clusters of galaxies strong gravitational lensing requires a distribution closely following the luminous matter. This would naturally lead to the idea that the DM distribution must show a strong evolution over the time from $z= 3$ to the current epoch. As the evidence in the last 10 Gyr for DM is all associated with observables in a semi-indirect way, it is clear that a firm understanding of the dominant component of the baryonic content of the Universe will have a direct and very important influence on the verification of DM evolution, and supply the, currently poorly understood, evolution of the Universe after structure formation.

We will here only comment on the low redshift evidence for non-baryonic DM and the damped Ly-α systems (DLA). As it is uncertain that observables can be defined to identify the DM associated with Gravitational Lensing and the virial masses of large clusters, we will not discuss those further here.

2.2 Damped Ly-α systems and their origin

We would like to comment on the conclusions derived from the observations of the damped Ly-α systems (DLA) and the Lyman forests. Especially the first are strongly influenced by the definitions of galaxy sizes, mainly on the basis of the very nearby galaxies as studied at optical and radio (21 cm) wavelengths. However, with the higher sensitivity supplied by the Ly-α absorption in the UV and the information on the ionization conditions supplied by the other strong UV lines (CIV, NIII, He, II, NII, etc.) a completely new view can be expected to be derived from the availability of a large number of background sources from the GALEX survey. Already early GALEX results on M83 (NGC 5236) have shown that the galaxy extent can be much larger than assumed in the normal DLA evaluations (Fig.1). Also star formation may take place in much more rarified surroundings than was considered feasible till now (Thilker et al. 2005). The fact that only a limited number of galaxies can be expected to be discovered could limit the statistical value of such studies. On the other hand even a few galaxies will allow us to study the equivalent of many sightlines.

Through objects like M83, we will be able to study the environment giving rise to the DLA system, not only through the absorption characteristics, be we will also be able to evaluate the nature of the stars formed in such rarified media, which is important for the interpretation of the DLA systems at higher redshifts. Finally it will be possible to extend the empirical mass function of the Lyman forest to much lower surface densities than is possible by any other means. This as a consequence of the high sensitivity to relatively low densities of the Ly-α line in the UV.



HII

Fig. 1 GALEX Color image of M83 (NGC 5236) showing starforming regions in the far outer disk extending to $R \sim 20$ Kpc from Thilker et al. (2005). This is nearly 4 times the radius where the majority of HII regions are detected. The normal size of galaxies is indicated by the contour just touching the outline of the galaxy body. The deep 21 cm contours are from Rogstadt et al. (1974) and extend to a limit of 10^{21} $n_{\rm HI}$/cm^2

2.3 Baryons in the warm-hot intergalactic medium

While the diffuse photoionized ionized intergalactic medium that gives rise to the Ly-α forest is expected to account for ~30 percent of the baryons at z=0, the so-called Warm-Hot Intergalactic Medium (WHIM) at temperatures $T = 10^5 - 10^7$ K most likely contributes at a similar level to the cosmological mass density of the baryons in the local Universe, as predicted by cosmological simulations (e.g., Cen and Ostriker 1999). The WHIM is believed to emerge from intergalactic gas that is shock-heated to high temperatures as the medium is collapsing under the action of gravity.

Directly observing this gas phase is a challenging task, as the WHIM represents a low density (n_H~10^{-4} – 10^{-6} cm^{-3}), high-temperature (T~10^5-10^7K) plasma, primarily made of protons and electrons together with traces of some highly ionized heavy elements. The most promising approach to study the WHIM is the search for absorption features from the WHIM in the FUV and in the X-ray regime. Five-times ionized oxygen (OVI) currently is the most important high ion to trace the WHIM at temperatures of T~3x10^5 K in the FUV regime. Recent measurements indeed imply that intervening OVI absorbers contribute with Ω_{bar} (OVI)~0.002 to the cosmological mass density at z=0 (e.g. Savage et al. 2002). Next to high-ion absorption from oxygen and other metals (e.g. NeVIII; Savage et al. 2005), observations with STIS (Richter et al. 2004) suggest that WHIM filaments can be detected in FUV Ly absorption of neutral hydrogen (Fig.2).

Although the vast majority of the hydrogen in the WHIM is ionized, a tiny fraction (typically < 10^{-6}) of neutral hydrogen should be present if the gas stays in collisional ionization equilibrium. Depending on the total gas column density of a WHIM absorber and its temperature, weak but broad HI Ly-α absorption at column densities $12.5 < \log N$ (HI) < 14.0 may arise from WHIM filaments and can be used to traced the ionized hydrogen component. Recent STIS observations imply a mass density of the broad Ly-α absorbers (BLAs) of Ω_{bar} (BLA) > 0.003. These absorbers therefore represent a significant baryon reservoir in the low-redshift Universe.

The STIS FUV measurements of the WHIM are encouraging, as they demonstrate that a large fraction of the baryons at z = 0 indeed is hidden in a highly-ionized, high-temperature intergalactic medium. However, to more precisely pinpoint the baryon budget of the WHIM and to explore its physical state, a FUV instrument more sensitive than STIS is required. Such a new FUV instrument would be of crucial importance

- To significantly improve the statistics of intervening OVI and broad Ly-α absorbers, and
- To achieve a higher S/N in QSO FUV absorption line data.

The latter point is particularly important to beat down the detection limit for FUV WHIM absorbers and to provide a more reliable estimate of the ionization conditions in the WHIM.

These considerations will lead to a dramatically improved determination of the baryonic content of the Universe in the range of 0 < z < 3, and will supply new and important constraints to which cosmological theories will have to match.

UV Spectroscopic observation will be able to put strong constraints on the interpretation of the cosmological observations made of the CMB. Therefore less reliance on priors is needed for the analysis of structure formation, as derived from the data on the cosmic background.

With an improved baryonic mass content, we can expect to be able to make the connections needed for a Universe in which the CMB and other data on the early Universe can be understood in a coherent framework of physics *in which we can also exist.*

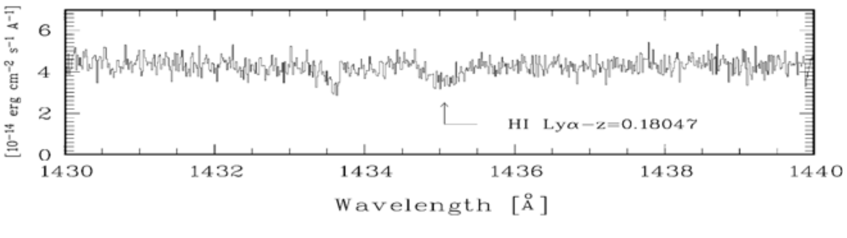


Fig. 2 The broad Ly-α absorber (BLA) at $z = 0.18047$ in the STIS spectrum of H1821+643is shown (Richter et al., 2005). As clearly visible, the shape of this BLA differs significantly from the shape of the narrow $z = 0.17924$ Ly-α forest absorption near 1433.5 °

3. Ultraviolet studies of supernovae

3.1. Introduction

Supernovae (SNe) are the explosive death of massive stars and moderate mass stars in binary systems. They enrich the interstellar medium of galaxies with most heavy elements (only C and N can efficiently be produced and ejected into the ISM by red giants winds and by planetary nebulae, as well as pre-SN massive star winds). The nuclear detonation supernovae, i.e. Type Ia SNe (SNIa; see Section 3.2.1 below) provide mostly Fe and iron-peak elements, while core collapse supernovae, i.e., Type II (SNII) and Type Ib/c (SNIb/c), mostly O and alpha-elements (see section 3.2.2 below). Through the interstellar medium (ISM) enrichment they are the primary drivers of the chemical evolution of the Universe. Additionally, SN ejecta deposit approximately 10^{51} ergs in the form of kinetic energy into the ISM of a galaxy. This compares with the total mechanical energy of a Milky Way class galaxy, which is approximately given by the product (galaxy mass) x (rotation velocity)^2 ~ 10^{43} x 4 x 10^{14} = 4 x10^{57} erg, approximately equivalent to 4 million SN events. At a SN rate of 4 SNe/century, these explosions double the energy of a galaxy in about 100 Myrs (if there were no losses and dissipation phenomena). It is quite obvious that one can not ignore this energy input for the evolution of the entire galaxy, both dynamically and, through cloud compression/energetic, for star formation.

SNe are bright events that can be detected and studied up to very large distances. Therefore they can be used for many different approaches to trace the evolution of the Universe. The general feasibility of these different techniques has been amply and very successfully demonstrated (e.g. Blades et al. 1998; Sonneborn et al. 1997; Gilmozzi et al. 1987) by the extensive UV observations of SN1987A with the International Ultraviolet Explorer (IUE). Ultraviolet spectroscopy is crucially important in order to:

(1) Study the metallicity of individual SNe.
(2) Study the metallicity of the intervening ISM/IGM
(3) Study the kinematics of the fast moving (i.e. the outermost layers) of the ejecta through the analysis of strong UV lines with P Cyg profiles
(4) Study the overall energetic of the S explosion at early phases (from shock breakout to optical maximum for types of SNe, but most importantly for SNII).
(5) Study the strong emission lines produced in the interaction of the ejecta with pre-SN circumstellar material, e.g. NV1240 Å and collisionally excited VIV1550 Å, NIV] 1470 Å,OIII] 1665 Å, NIII] 1750 Å, CIII] 1909 Å , etc.

3.2 Types of supernovae

3.2.1. Nuclear Detonation Supernovae: Type Ia

Type Ia supernovae are characterized by a lack of hydrogen in their spectra at all epochs and their optical spectra are characterized by a number of broad, deep absorption bands, most notably the Si II 6355 Å feature (actually the blue-shifted absorption of the 6347-6371 Å Si II doublet; see e.g. Filippenko, 1997), which dominate their spectra at early epochs. SNIa are found in all types of galaxies, from giant elliptical to dwarf irregulars. However, the SNIa explosion rate, normalized relative to the galaxy mass, is much higher – up to a factor of 16 for the extreme cases of irregulars and ellipticals-in late type galaxies than in early type galaxies (Panagia, 2000; Mannucci et al. 2005). This suggests that, contrary to the common belief, a considerable fraction of SNIa belong to a relatively young (age «1 Gyr), moderately massive stellar population of 3.5 $M_\circ$<M(SNIa progenitor)<$8M_\circ$, and that in present day elliptical, SNIa are most likely the explosion in stars resulting from the capture of dwarf galaxies by massive ellipticals.

Classical Type Ia supernovae are important objects throughout many fields of astrophysics. They are believed to result from the explosion of accreting white dwarf (WD) in a binary system. They can be used to probe the physics of thermonuclear burning in degenerate or partially degenerate matter, under conditions not achievable in the chemical evolution of galaxies, and details of the burning front influence the elemental relative abundances. SNIa are especially important because of their possible use as cosmological candles: one uses their observed live curve shape and color to standardize their luminosities.

3.2.2. Core Collapse Supernovae: Types II and Ib/c

Massive stars($M_* > 8M$) end their evolution by collapsing onto their inner Fe core and producing an explosion by a gigantic bounce that launches a shock wave which propagates through the star and eventually erupts through the photosphere. In this ejection several solar masses of material are thrown into the surroundings at velocities of thousands of km/s. The current view is that single stars explode as type II supernovae, while the supernovae of types Ib and Ic originate from massive stars in interacting binary systems. Although the explosion mechanism is essentially the same in both types, the spectrum and light curve evolution are markedly different for each.

3.3 Ultraviolet observations

The launch of the International Ultraviolet Explorer (IUE) satellite in early 1978 marked the beginning of a new era for SN studies because of its capability to measure the ultraviolet emission of objects as faint as m_B=15. Moreover, just around that time, other powerful astronomical instruments became available, such as the Einstein Observatory for X-rays, the VLA in the radio domain, and a number of telescopes with new and highly efficient IR instrumentation, e.g. UKIRT, IRTF; AAT and ESO). As a result a wealth of new multi-wavelength information became available in the early 1980's. The coordinating efforts of astronomers operating at widely different wavelengths, have provided us with fresh insights in the properties and the nature of supernovae of all types. Eventually, the successful launch of the Hubble Space Telescope (HST) could have opened new possibilities for the study of considerably fainter supernovae, allowing us to study SN spectra with a high accuracy and to reach beyond the local supercluster.

From 1979 through 1996 all bright supernovae, and a number of fainter ones have been observed with IUE. A total of 25, out of which 8 are of Type II, 12 Type Ia and 5 Type Ib/c.

Of these 25 only 7 SNe (1979C, 1980K, 1981B, 1983N, 1987A, 1990N, and 1992A) were bright enough to obtain fair quality ultraviolet spectra and/or to follow their time evolution (Capellaro, Turatto and Fernley, 1995). However even after 18 years of IUE observations and 14 years of HST observations , the number of SN events that have been studied in detail with UV spectroscopy remains quite small (no more than two objects per SN type with high quality spectra form more than three epochs). As a consequence, we still know very little about the properties and the evolution of the ultraviolet emission of SNe. On the other hand, the Ultraviolet observations of SN1987 (Pun et al. 1995) have shown that it is just the UV spectrum of a SN, especially at early epochs, that contains a wealth information that cannot be obtained at other wavelengths. A full review on the Ultraviolet observations f Supernovae can be found in Panagia (2003).

3.3.1. What we Know and Can Learn from UV Spectra of SNIa

The UV spectra of type Ia SNe decline rapidly with frequency, making them hard to detect at short wavelengths ($\lambda < 2500$ Å). This aspect is illustrated in Fig. 3, which displays the $\lambda <$ 2000 Å spectra of a sample f 10 type Ia SNe observed with IUE. In all cases, the observing epoch is within three days of the optical maximum. The spectra do not have a smooth continuum but rather consist of a number of "bands" with somewhat different strengths. The most prominent feature is the apparent emission at $\lambda \sim 2950$ Å with a half power width of ~100 Å, i.e. $\Delta v \sim 10^4$ km/s. This band is likely to be the result an opacity minimum between strong absorptions on both sides i.e. Mg II centered at ~2800 Å and De II ~3060 Å, each with half-power widths corresponding to the expansion velocity of $\sim 10^4$ km/s. Several other absorption features can be recognized, which are present at all epochs of observation. Some of them are most likely associated with multiplets of FeI, Fe II and Mg II, but the majority of these absorptions have not been unambiguously identified. The very fact that the spectra are so similar for the first three SNe in Fig.3 and also at all epochs, is an important result. This supports the concept of homogeneity in the properties of all type Ia SNe.

On the other hand, some clear deviations from "normal" can be recognized in Fig. 3. While the UV spectra of most SNIa shown in Fig. 3 are quite similar, and virtually indistinguishable from the spectrum of SN1992A near maximum light, one notices that both SN1983G and SN1986G display excess flux around 2850 Å, and a flux deficiency around 2950 Å. This suggests that the Mg II resonance line is consistently weaker and may indicate a lower abundance of Mg in these two SNIa. They were characterized by a fast-decline and some under luminosity. Contrary, SN 1990N, SN1991T, and possibly, SN1989M show excess flux around ~2750 Å and ~2950 Å and a clear deficit around ~3100 Å, possibly due to enhanced Mg II and Fe II features and showed a slow-decline and over-luminosity.

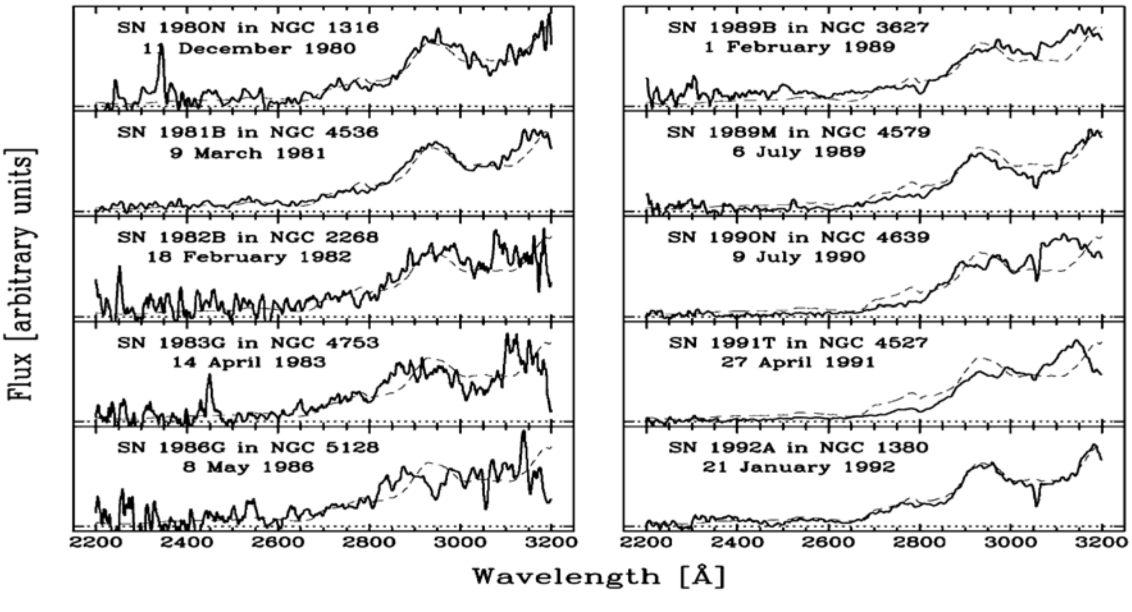


Fig. 3 Ultraviolet spectra of a sample of Type Ia supernovae observed with IUE around maximum light. For comparison (see text) we show the spectrum of SN1992A at maximum as a dotted line

The best studied SNIa is the “normal” type Ia supernova SN1992A in the S0 galaxy NGC1380, that was observed both with IUE and HST (Kirshner et al. 1993). The FS spectra of HST from 5 to 45 days past maximum light, are the best UV spectra available for any SNIa and reveal, with good signal to nose ratio also the spectral region at below λ≈2650 Å. The UV photometry taken with the FOC of HST in the F175W, F275W, and F342W bands shows light curves that resemble the SNIa template U-band light curve (Leibundgut, 1988). Using data from SN1992A and SN1990N, Kirshner et al. (1993) constructed a SNIa template light curve for the flux region near 2750Å (Fig.4) that is quite detailed from 14 days before maximum light to 77 days after maximum light. This light curve resembles the template U-band light curve although it drops off a bit faster.

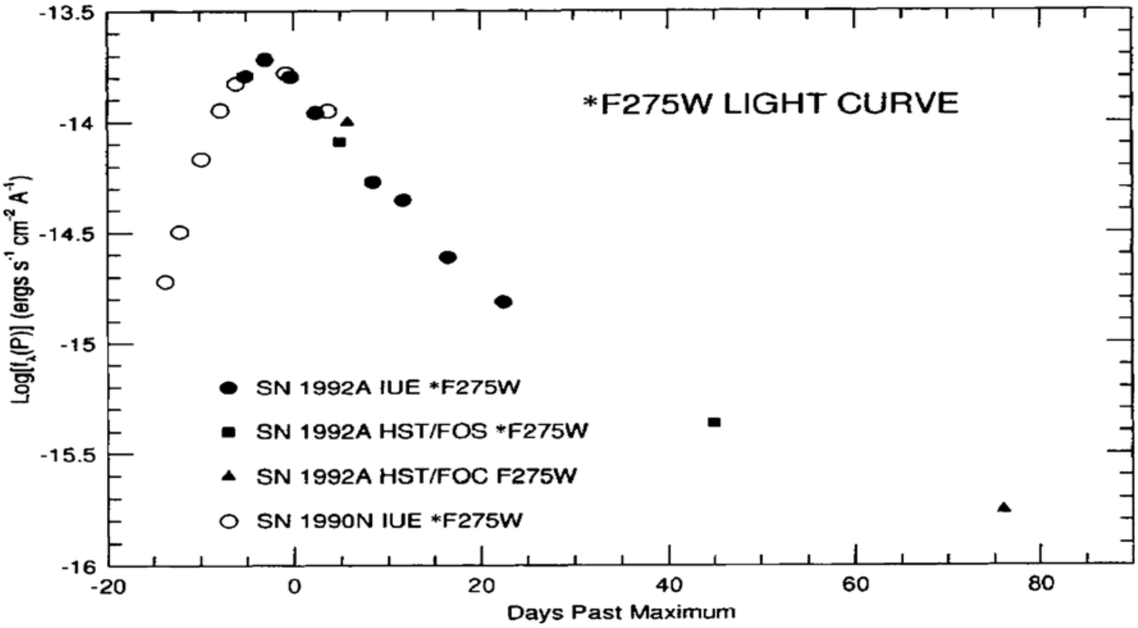


Fig. 4 The light curve of SN1992A in the near ultraviolet

It is thus clear that type Ia supernovae are consistently weak UV emitters, and even at maximum light their UV spectra fall well below a blackbody extrapolation of their optical spectra. Broad features due to P Cygni absorption of Mg II and Fe II are present in all SNIa spectra, with remarkable similarity for normal SNIa and systematic deviations for slow-decline, over-luminous SNIAa (enhanced Mg II and Fe II absorptions) and fast-decline, under luminous SNIa (weaker Mg II lines).

Despite the fact that SNIa are relatively weak UV emitters, obtaining UV spectroscopy of them is of fundamental importance for at least three reasons:

a) *Definition of the UV Luminosity/Light Curve Shape/Color Relations for Cosmological Applications:* At optical wavelengths SNIa are remarkably uniform in luminosity (0:16 mag), once corrected for the light curve shape and color. Recent work suggests the existence of a general correlation between the U-band light curve width and luminosity. Almost nothing is known, however, about SNIa behavior at space-UV wavelengths.

b) *The Nature of the Progenitors and Explosion Mechanisms of SNIa*: We have no idea how a white dwarf (WD) reaches the Chandra limit (e.g. mass accretion from a main-sequence star, a subgiant, a red giant, or a merger with another WS), or whether it even reaches the Chandra limit, and how it explodes (off-center detonation, deflagration, or pulsed delayed detonation). Establishing the SNIa progenitor systems and explosion mechanisms are essential to a reliable use of SNIa as cosmological probes, and will allow to determine evolutionary trends from the progenitor age and its initial composition.

c) *Determination of the Metallicity and Other Effects in SNIa*: Given that the main dust extinction related issues surrounding high-z SNIa appear to be largely resolved possible evolutionary effects such as metallicity are now the major unresolved aspect of using SNIa as cosmological distance indicators.

For cosmological studies the apparent brightness of high-z SNIa must be compared to those of low-z SNIa in order to measure accurate relative distances. Moreover, the physical understanding of SNIa, as well as techniques for standardizing SNIa and correcting for host galaxy dust extinction come from detailed observations of low-z SNIa.

Even more importantly, modern observations of high-redshift SNIa have provided evidence for a recent (past several billion years) acceleration of the expansion of the Universe, pushed by “dark energy”. If confirmed, this exciting result may require new physics (Panagia, 2005 and references therein; see also Section 1).

Thus, an efficient strategy to elucidate all relevant aspects about SNIa is:

a) To study the brightest, closest SNIa to make maximum progress in advancing our understanding of the physics of SNIa,

b) To utilize Hubble flow SNIa, where accurate relative luminosities can be determined, to search for, and constrain subtle effects that can affect precision cosmology measurements, and

c) To compare high-z SNIa to local Universe SNIa to determine cosmological parameter accurately and confidently.

As the UV spectra of type Ia SNe decline rapidly with frequency and time prompt, early UV observations are of paramount importance.

3.3.2. Type Ib/c Supernovae

Type Ib/c supernovae (SNIb/c) are similar to SNIa in not displaying any hydrogen lines in their spectra. They are also dominated by broad P Cygni-like metal absorptions, but they lack the characteristic 6150A trough of SNIa. The finer distinctions between SNIb and SNIc were introduced by Wheeler and Harkness (1986) and are based on the strength of He I absorption lines: the spectra of SNIb display strong He I absorptions and those of SNIc do not. SNIb/c have been found only in spiral galaxies associated with spiral arms and/or H II regions and seem associated with the evolution of massive stars in close binary systems.

The best observed SNIc is SN1994 both with IUE and with HST-FOS. The high quality UV spectra were remarkably similar to those obtained for SN1983N and were taken only at two epochs well past maximum light (10 days and 35 days). Synthetic spectra matching inferred a photospheric velocity decrease from 17, 500 to 7,000 km/s (Millard et al 1999). The kinetic energy carried by the ejected mass is near the canonical supernova energy of 10^{51} erg. Such velocities and kinetic energies for SN1994I are “normal” for SNe and are much lower than those found for the peculiar type Ic SN1997ef and SN1998bw (see, e.g. Branch, 2000)which appear to have been hyper-energetic. Type Ib/c supernovae are, like type Ia, weak UV emitters with the UV much weaker than blackbody extrapolations of the optical and NIR spectra. Their typical luminosity is about a factor of 4 lower than that of SNIa, and thus the mass of ^{56}N synthesized in a typical SNIb/c is only ~0.15 M$_{\circ}$

3.3.3. Type II Supernovae

Type II supernovae display prominent hydrogen lines (Blamer series in the optical) with a strong continuum and broad P Cygni lines superimposed. SNII are considered to be the result of a core collapse of massive stars exploding at the end of their RSG phase. SN1987A was both a confirmation and a exception to this model (see Arnett et al. 1989; Panagia, 2003; Pun et al. 1995 for details on SN1987A). There are two types of SNII, the so-called “linear” type (SNIIL), which are characterized by an almost straight-line decay of the B and V-band light curves, and the more common “plateau” type (SNIIP) which display a flattening in their light curves a few weeks after maximum light.

The SNII studied best in the UV, is SN1998S, a type II with relatively narrow emission lines. SN1998S was discovered several days before maximum. The UV spectral evolution of SN1998S (Fig.5) showed the spectrum to become gradually steeper in the UV, from near maximum light on 16 March 1998 to about two weeks past maximum on 30 March, and the blue absorptions weaken or disappear completely. About two months after maximum (13 May 1998) the continuum was much weaker, although its UV slope had not changed appreciably, and it had developed broad emission lines, the most noticeable being the Mg II doublet at about 2800 Å. This type of evolution is quite similar to that of SN1979C (Panagia et al. 1980).

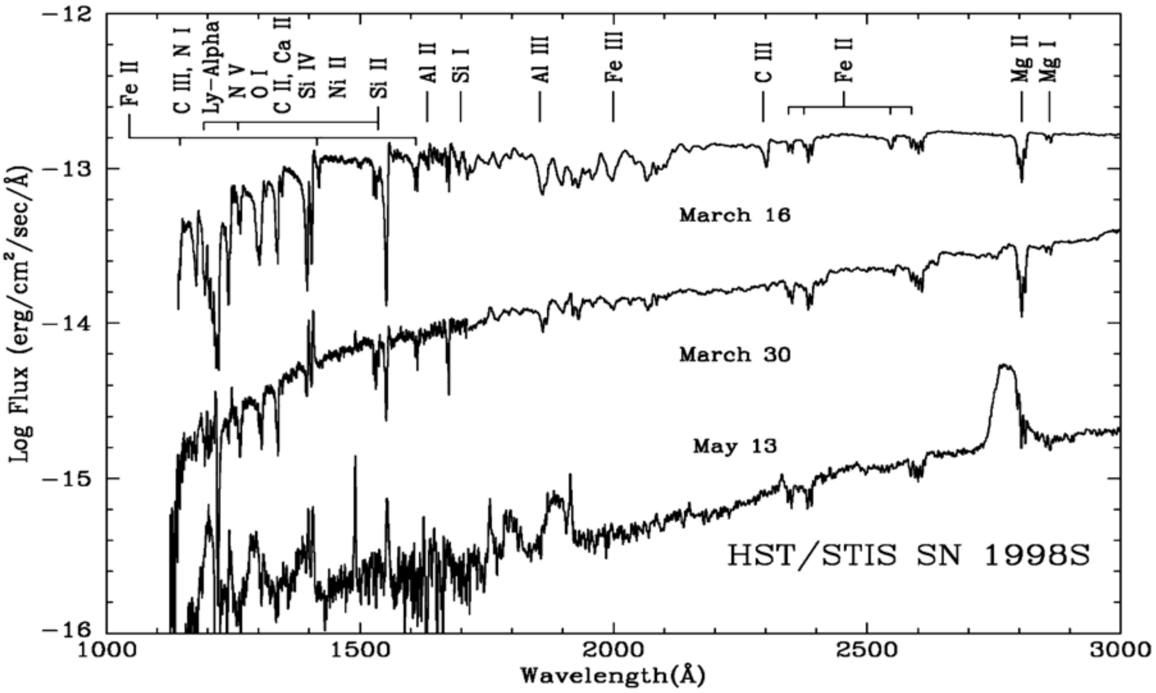


Fig. 5 UV spectral evolution of SN1998S (SINS project, unpublished). Shown are spectra obtained near maximum light (March 16, 1998), about two weeks past maximum (March 30, 1998), and about two months after maximum (May 13, 1998)

Type II plateau (SNIIP) supernovae account for a large fraction of all SNII. However, the only SNIIP that has been studied in some detail in the ultraviolet is SN1999em. An analysis of the early optical and UV spectra (Baron et al. 2000) indicates that, spectroscopically, this is a normal type II. Very early spectra combined with sophisticated spectral modeling can supply an independent estimate of the total reddening of the supernova. When the spectrum is very blue, derredening leads to changes in the blue flux that cannot be reproduced by altering the "temperature" of the emitted radiations. Thus, detailed modeling of the early spectra allow us to determine both the abundance and total extinction of SNII.

Another sub-type of the SNII family is the so-called type IIb SNe, which display strong Balmer lines early on, but later the Balmer lines weaken significantly or disappear altogether (e.g. Filippenko et al. 1997). At this point their spectra become more similar to type Ib SNe. The prototype this class is SN1993J. An HST-FOS UV spectrum of SN1993J was obtained about 18 days after explosion and close to maximum light. This spectrum (Jeffery et al. 1994) shows that the region between ~λλ1650-2900 Å is smoother than observed for SN1987A and SN1992A and lacks strong P Cygni lines absorptions from iron peak element lines. The UV spectrum of SN1993J is appreciably fainter than observed in most SNII, thus revealing its "hybrid" nature and some resemblance to a SNIb. Synthetic spectra calculated using a parameterized LT procedure and a simple model atmosphere do not fit the UV observations. Radio observations suggest that SN1993J is embedded in a thick circumstellar medium envelope (Van Dyk et al. 1994). The UV spectra of other supernovae that are believed to have thick circumstellar envelopes also have the λλ1650-2900 Å regions lacking strong P Cygni absorptions. Interaction of supernova ejecta with circumstellar matter may be the origin of the smooth UV spectrum. UV observations of such supernovae provides insight in the circumstellar environment of the supernova progenitors.

Thus, despite their different characteristics in the details of the UV spectra, all type II supernovae of the various subtypes appear to provide clear evidence for the presence of a dense circumstellar medium and enhanced nitrogen abundance. They are important as background UV sources at early phases with the strong UV excess relative to a blackbody extrapolation of their optical spectra.

3.4. Cosmological applications

As mentioned before, SNIa are very good standard candles (e.g. Macchetto and Panaggia, 1999) to measure distances of distant galaxies, currently up to redshift $z \approx 1$ and, considerably more in the foreseeable future. HST observations of Cepheids in the parent galaxies of SNIa have lead to very accurate determinations of their distances and the absolute magnitudes of normal SNIa at maximum light (e.g. Sandage et al. 1996; Saha et al. 2001). With these calibrations it is possible to determine the distances of much more distant SNIa. The Hubble diagram of distant SNIa (30,000 km/s > v > 3,000 km/s) gives a Hubble constant of H_0= 59±6 km/s/Mpc (Saha et al. 2001) while the independent HST calibration for SNIa absolute magnitudes at maximum light from Freedman, Kenicutt, Mould and collaborators (Freedman et al. 2001) gave a Hubble constant of H_0=71±8 km/s/Mpc.

Studying the more distant SNIa (i.e. $z > 0.1$) it has been possible to extend our knowledge to other cosmological parameters. These results (Perlmutter et al. 1998, 1999; Riess et al. 1998; Knop et al. 2003; Tonry et al. 2003; Riess et al. 2004) suggest a non-empty inflationary Universe, which is characterized by $\Omega_M \approx 0.3$ and $\Omega_\Lambda \approx 0.7$. Correspondingly, the age of the Universe can be bracketed within the interval 12.3-15.3 Gyrs to a 99.7% confidence level (Perlmutter et al. 1999).

However systematic uncertainties are uncomfortably large and observations of more high-z SNIa are absolutely needed. This is a challenging proposition, both for technical reasons, in that searching for SNe at high redshifts one has to make observations in the near IR (because of redshift) of increasingly faint objects (because of distance) and for more subtle scientific reasons, i.e. one has to verify that the discovered SNe are indeed SNIa and that these share the same properties as their local Universe relatives. One can only discern Type I from Type II SNe on the basis of the overall properties of their UV spectral distributions (Panagia, 2003, 2005), because Type II SNe are strong UV emitters, whereas all Type I SNe, irrespective of whether they are Ia or Ib/c, have spectra steeply declining at high frequencies, as illustrated in Fig. 6 for SNIa 1992A and SNIIn 1998S. Figure 6 also shows the same spectra that have been degraded to a resolution of *R* = 50 (low resolution spectroscopy), and to *R* = 3 (broad-band photometry, expressed in magnitude difference relative to the V-band; bottom panel). We see that while the characteristic spectral features are still easily recognized in the *R*=50 spectra, the only property that in the *R*=3 spectra distinguish a SNIa from SNII is the UV slope. This technique of recognizing SNIa from their steep UV spectral slope was first suggested by Panagia (2003), and has been successfully applied by Riess et al. (2004a,b).

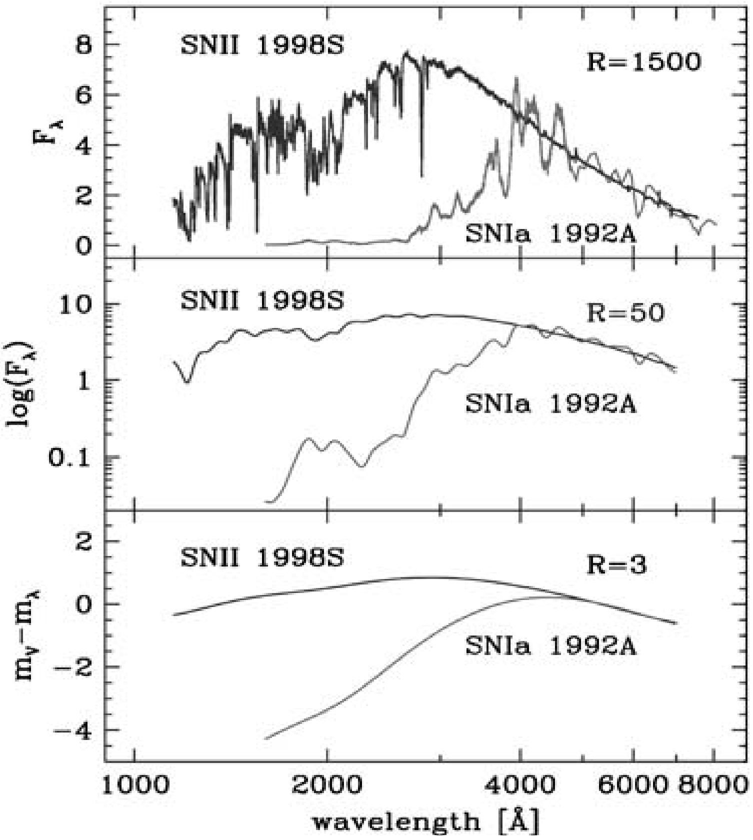


Fig. 6 Spectra of Type Ia SN1992A and Type IIn SN1998S near maximum light, normalized so as to have the same average flux in the rest-frame V band. Upper panel: Linear flux scale, original spectral resolution R∼1500. Middle panel: Resolution degraded to *R* = 50 (low resolution spectroscopy). Lower panel: Magnitude scale ($m_\lambda = -2.5\log(F_\lambda) + \text{const}$), resolution *R* = 3 (broad-band photometry)

4. The State, abundances and distribution of the IGM at $0 < z < 3$

4.1. HI and metal enrichment

Damped Ly-α systems derive their name from the observed quantum mechanical damping of the Ly-α transition relating to their very large HI column density N(HI). Because the Ly-α profile is dominated by this damping, a standard fit to the observed profile has two free parameters. (i) the centroid or z_{abs}; and (II) N(HI). Therefore, accurate measures of N(HI) can be acquired with modest resolution and S/N data. and his collaborators initiated surveys for these galaxies 20 years ago (e.g. Wolfe et al. 1986; Storrie-Lombardi and Wolfe, 2000) and the majority of research has been performed on 4 m-class telescopes. The principal results from these HI surveys are: the cosmic evolution of Ω_{DLA}, the universal mass density of neutral gas in units of the critical density. The uncertainties in the each of the data sets obtained with IUE and HST are very large and there exists a stark disagreement between the central values of the two surveys. The uncertainties emphasize the current challenge of studying HI gas at $z < 2$ with existing UV spectrographs. While HST/COS would enable a modest survey of DLA at $z>0.6$, the parameter space $z=0.6-1.7$ will require a next generation space telescope simply to survey Ly-α.

Aside from the HI content, the most basic measure of the DLA is metallicity. Because of the large HI surface density of DLA, ionization corrections are generally small (e.g. Vladilo et al. 2001) and measurements of low-ions like Fe^+, Si^+ and Zn^+ yield accurate measures of the metallicity, i.e.[Zn/H] ~ [Zn^+/H^0]. The only serious systematic error is dust depletion; refractory elements like Fe and Si might be depleted from the gas-phase such that Si^+/H^0 and Fe^+/H^0 are lower limits to the true metallicity. In general, the depletion levels of the DLA are small (Pettini et al. 1997; Prochaska and Wolfe, 2002) and the basic picture is well revealed by any of these elements at high z. Metallicity observations of a large sample of DLA present two main results: (1) an N(HI)-weighted mean ‹Z›, which is the cosmic mean metallicity of neutral gas; and (2) metallicities for a set of galaxies which presumably span a large range of mass, morphology and luminosity.

Figure 7 presents over 50 metallicity measurements from z~2-4.5 (Prochaska and Wolfe, 2002). The principal results are: (1) the mean metallicity (weighted or unweighted) is significantly sub-solar; (2) there is little evolution in the mean metallicity over this redshift range with the possible exception of a modest decrease at $z>3.5$; (3) no galaxy exhibits a metallicity lower than 1/1000 solar. These optical observations constrain models of chemical evolution at these epochs (e.g. Pei et al. 1999) and give the first glimpse into metal production in the early universe. It is crucial, however, to press to lower redshift. The time encompassed by the redshift interval $2<z<4.5$ pales in comparison with $z<2$. Of immediate concern is to determine how the mean metallicity rises to the enrichment level observed today.

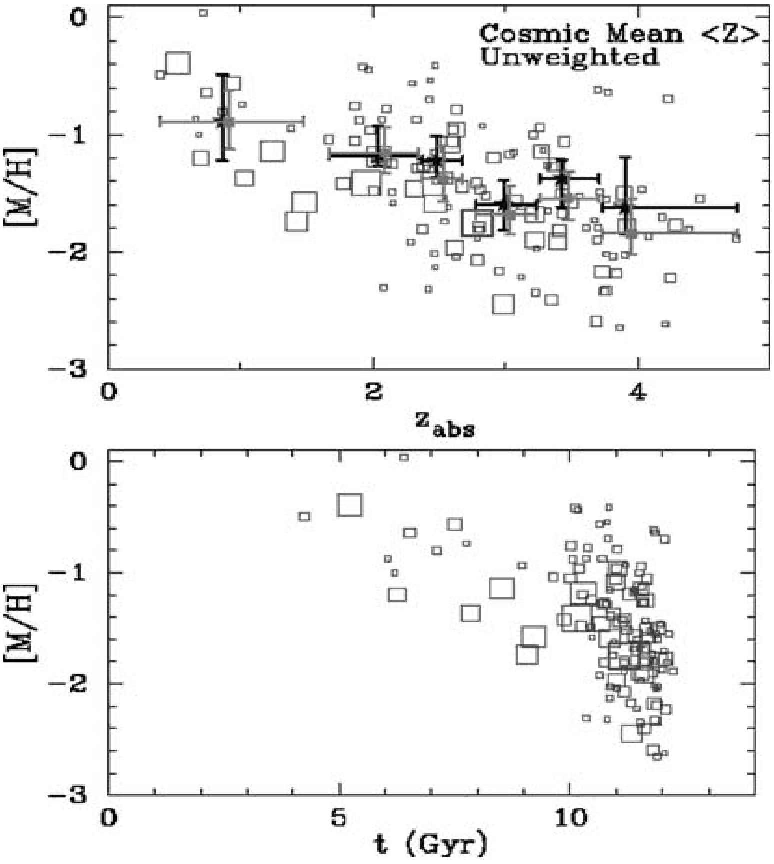


Fig. 7 The upper panel shows metallicity measurements versus redshift for some 100 DLA. Overplotted are the HI-weighted and unweighted means in several redshift bins. The lower panel presents the same measurements against cosmic time. It is clear that the cosmic enrichment history of the universe is severely undersampled over the past 10 Gyr

4.2 Relative abundances: Dust and nucleosynthesis

High resolution (*R* > 30000), high S/N (>30 per resolution element), observation of the damped LYα systems enable detailed studies of nucleosynthetic enrichment and dust properties in the early universe. This level of data quality is crucial to achieving the better than 10% precision required by relative abundance studies. Currently, there is an entire “cottage industry” focused on this area (Lu et al. 1996; Prochaska and Wolfe, 1999; Molaro et al. 2000; Pettini et al. 2000; Ledoux et al. 2002). Figure 8 presents two of the principal results from these efforts: (a) [Si/Fe] and (b) [N/α] measurements against [Si/H] metallicity.

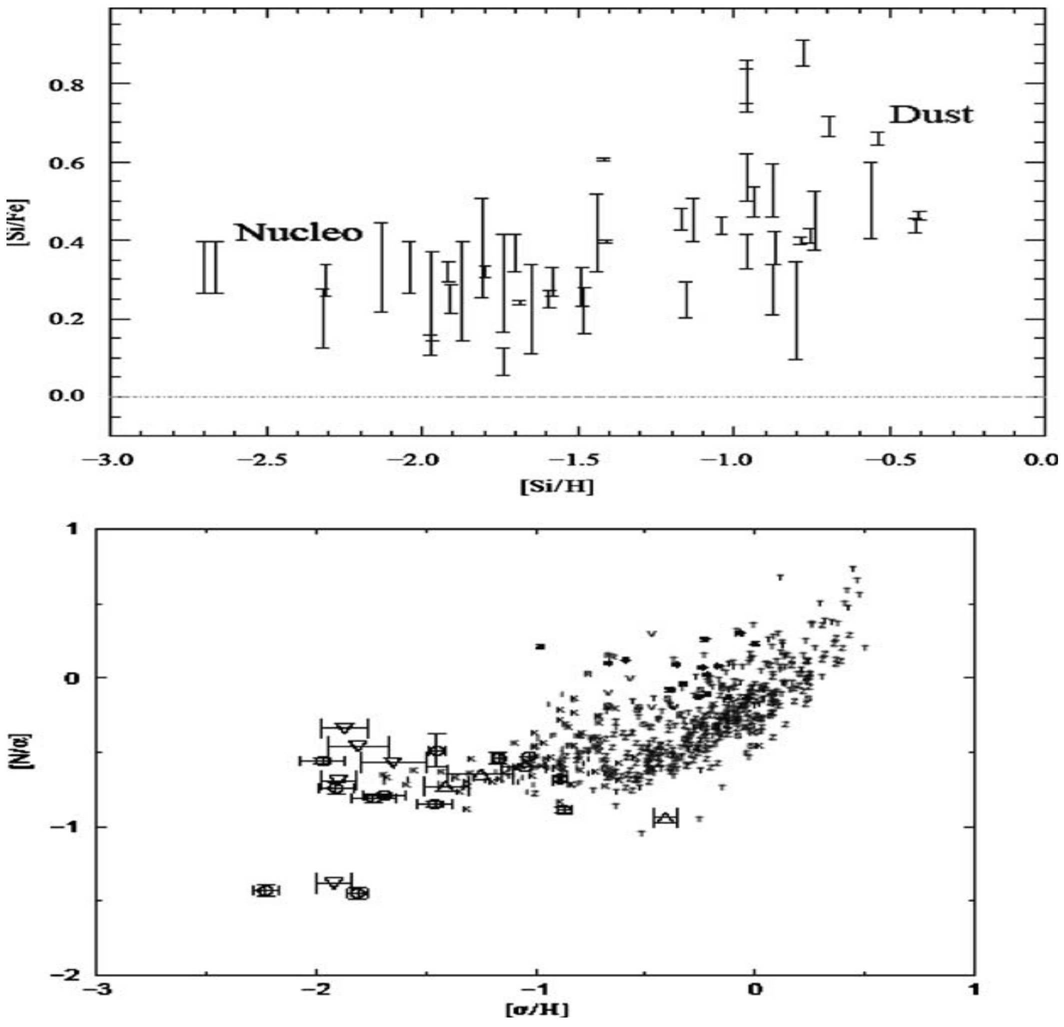


Fig. 8 Relative abundances of(a) Si/Fe and (b) N/*α* versus Si/H and *α*/H where *α* refers to either Si or S For the DLA. The upper panes highlights the competing effect of nucleosynthesis and dust depletion in interpreting the gas-phase abundances. We interpret the plateau of [Si/Fe] at [Si/H] < -1.5 as the result of nucleosythesis in Type II Supernovae. The rise in Si/Fe at [Si/H] > -1 is associated with differential depletion (Prochaska and Wolfe, 2002). UV observations would allow one to trace these two processes at $z < 2$. The lower panel compares DLA (circles and triangles; the latter are upper/lower limits) against N/*α* measurements for HII regions and stars at $z \approx 0$ (Prochaska et al., 2002; Henry et al., 2000). Although the majority of the DLA lie on a N/*α* plateau associated with metal-poor HII regions, a significant sub-sample is identified at $N/\alpha < -1$. This sub-sample could present evidence for a truncated or top-heavy IMF (Prochaska et al., 2002). Observations of N/*α* at $z < 2$ would be able to confirm this result .

The super-solar Si/Fe ratios presented in panel (a) high-light the greatest obstacle to interpreting relative abundance measurements from gas-phase abundances: the competing effects of nucleosynthetic enrichment and differential depletion. In terms of dust depletion, one observes Si/Fe enhancements in depleted gas owing to the differential depletion of these two refractory elements. Regarding nucleosynthesis, Si/Fe enhancements suggest Type II SN nucleosynthesis(e.g. Woosley and Weaver 1995), whereas solarratios would imply Type Ia SN enrichment patterns. Currently, we interpret the plateau of Si/Fe values at low metallicity as the primary result of nucleosynthesis. The mean enhancement matches the Galactic halo-star observations at the same metallicity (e.g. McWilliam 1997) and it would be difficult to understand why differential depletion would imply such an uniform enhancement. In contrast, the rise in Si/Fe at [Si/H]>-1 is highly suggestive of differential depletion. One expects a decrease in Si/Fe from nucleosynthesis at higher metallicity due to the increasing contribution from Type Ia SN. Furthermore, larger depletion levels are expected at higher metallicity.

Investigating evolution in abundance ratios like these at $z<2$ would reveal the detailed enrichment history of galaxies and the evolution of dust formation.

Overcoming this dust/nucleosynthesis degeneracy is among the most active areas of DLA research. One avenue is to focus on special pairs of elements which are largely non-refractory. Panel (b) is an excellent example of this; plotted are N/α pairs from recent compilations by Prochaska et al. (2002), Pettini et al. (2002) and Centurion et al. (1998). For N, S, and Si (the latter are two α-elements), depletion effects are small and the results show the nucleosynthetic history of N in the DLA. For comparison, we also plot [N/α], [α/H] pairs for $z \sim 0$ HII regions and stars (see Henry et al. 2000). The majority of DLA observations fall along the locus of local measurements, in particular the plateau of N/α values at [Si/H] < -1. In contrast, a sub-sample of low metallicity DLA exhibit much lower N/α values which Prochaska et al. (2002) interpret these in terms of a truncated or top-heavy initial mass function (IMF). These observations have important implications for the processes of star formation in the early universe and measurements at $z < 2$ would assess the timescale of star formation in these galaxies and further elucidate the nucleosynthesis of nitrogen.

Finally, we wish to emphasize that a subset of DLA (<15%) exhibit very strong metal absorption (Prochaska et al. 2003). These metal-strong DLA allow the measurement of over 20 elements in a single galaxy including B, Fe, Ge, Pb, and Sn. At low redshift, the incidence of metal-strong DLA is presumably higher as the mean metallicity approaches the solar value. Furthermore, confusion with the Ly-α forest is minimized and high precision measurements of transitions with λ_{rest} <1200 Å are possible. This analysis would require high S/N, high resolution observations, yet the impact on studies of nucleosynthesis is extremely impressive.

5. HEII in the intergalactic medium

When the first generation of massive stars had been formed, the up to then cold and dark universe was ionized and heated (epoch of reionization). This happened at redshifts $z > 6$. After the reionization epoch, completely ionized intergalactic Hydrogen gives rise to the so-called Ly-α forest. Spectroscopic observations of the Ly-α forest confirm the general theoretical picture of an intergalactic medium as a fluctuating distribution of baryons organized by the cosmic web of dark matter and photoionized by high-redshift starburst galaxies and later also by QSOs.

Observations of the HeII 304 Å Lyman α line in the line of sight of a handful of bright QSOs have added to this picture that HeII is reionized much later at redshift $z= 2.9$ (Reimers et al. 1997, 2005). This delayed reionization of HeII compared to HI had been predicted by theoreticians as caused by the later appearance of AGN (only their hard, nonthermal radiation can ionize HeII) compared to stars and by the 5-6 times higher HeIII recombination rate. The apparent 1.4 Gyr lag between HI and HeII reionization carries information on the relative beginning of galaxy (stars) and AGN formation. Its quantitative understanding will pin down the first epoch of star formation, independent of direct detection methods.

The HeII Ly-α forest has been observed and spectroscopically resolved in the line of sight of two bright QSOs with FUSE (Kriss et al. 2001; Reimers et al. 2004). The earlier finding of a transition from continuous optically thick HeII 304 Å absorption for $z > 2.9$ (HeII Gunn-Peterson trough) to a resolved HeII Ly α forest at $z < 2.9$ has been confirmed, i.e. the epoch of HeII reionization is in fact around z=3. For $z < 2.9$, the resolved HeII 304 Å forest lines are observed to be generally much stronger than the HI Ly α forest by the factor η = N(HeII) (N(HI). The factor η depends mainly on the ratio of the intensities of the ionizing radiation at the Lyman edge to the HeII 228 Å edge J(911 Å)/J(228 Å) and is roughly 80. However, its value and correspondingly the shape of the ionizing radiation field appears to vary strongly between $\eta\sim 1$ and 400 on the scale of 1.3 Mpc h^{-1}_{70}, much smaller than the typical mean distances between AGN at z=3 of roughly 30 Mpc (Shull et al. 2004). If this fluctuations are real, this would have considerable implications for elemental abundances in the diffuse IGM. Part of the fluctuations can possibly be explained by a combination of the large range of EUV spectral shapes of AGN with additional filtering (softening) by absorption through the IGM.

Future observations of the HeII 304 Å forest at high spectral resolution and S/N have the potential to map both the Intergalactic Matter and Radiation Field in very much detail. A first, since the Ly-α forest "clouds" have kinetic temperatures of ~10^4 K, the lines are largely thermally broadened (with an additional turbulent/expansion component). This means that from a comparison of line widths of HI with HeII (the thermal widths of HeII lines are 2 times smaller) the kinetic temperature of the Ly-α forest gas can be measured directly with high spatial resolution. From theoretical modeling of the IFM we know that after reionization, the IGM cools by expansion, is reheated by the delayed HeII reionization at z=3 and continues to cool with decreasing redshift z. Observations of the HeII Ly-α forest over the redshift range $2.1 \leq z \leq 2.9$ will test this in the most direct way. Besides observing the evolution of the mean IGM temperature, density and the ionizing background radiation field can be measured at a spatial resolution of less than 1 Mpc (co-moving).

Having measured these quantities, the existing theoretical models of the IGM can be tested with much more detail than possible today, when basically only the statistical properties of theoretical Ly-α forest are compared with observations.

Due to the possibility to observe simultaneously HI and HeII spectroscopically, the redshift range $2.1 \leq z \leq 2.9$ covers the only cosmic epoch where the IGM and its evolution can be studied in detail. As such, this is a test bed for theoretical modeling of the IGM. If successful, it can be applied to the epoch $1 \leq z \leq 2$ where the major star formation takes place. By-products will be improved determinations of the cosmic baryon density (at z=3 more than 95% of the baryons are not in stars). Studies of the distribution of galaxies close to the lines of sight of QSO's with HeII forest observations will allow to study the influence of galactic winds, SN explosions as well as UV radiation of starburst galaxies and AGN on the temperature and density of the IGM.

For $z < 2.1$ information on the shape of the ionizing background will never be available from HeII/HI due to absorption by interstellar HI in our galaxy. This means that the composition of most of the baryonic matter in the universe for $z < 2.1$ will be difficult to measure. On one hand, DLAs where abundance studies are easy contain only of the order of 5% of the baryonic component. On the other hand, the determination of the composition of the remaining 95%, the diffuse highly ionized component, requires knowledge of the shape of the ionizing background. Therefore, the only way to study heavy element abundances and the physical state of this component is to observe simultaneously several ionization stages of abundant elements, e.g. OIII-OVI, CIII, CIV, SIII-SVI, NeIII-NeVII, with the aim to model the ionizing UV background radiation field and the physical status in absorption systems. Except a few single ions like SiIV, CIV and OVI observable from the ground and which are not sufficient to determine the state of ionization, all relevant lines are in the intrinsic EUV at rest wavelengths between 300 and 900 Ansgtroms. Consequently, quantitative information on the bulk of baryons in the diffuse IGM for $z < 2$ is only available by UV spectroscopy of QSO's in the satellite UV. In fact most of the mentioned ions have been observed in the UV I a few bright QSO's like HS 1700+6416 with the Hubble Space Telescope (Reimers et al. 1992).

6. Instrumentation roadmap for the cosmological questions

We will here try to give first approach to the instrumental requirements needed to address the questions which have been raised in Sections 2-5. As the roadmap concept pursued under NUVA is solely related to the UV, we will only address globally the needs and requirements. As the most developed technique for UV *astrophysics* are spectroscopy and quantitative imaging (i.e. photometry), we will confine ourselves to these two. And since the only way to make UV observations is from space, the options are limited to those associated with a *telescope in space.*

Independently of the technique – photometry or spectroscopy- the requirements space can essentially be split into two different groups distinguished by some very primary technical constraints and a major difference in cost. The fundamental difference of the two approaches is in the size of the associated telescopes. One can essentially separate this in two major classes:

1. The 2-m class and
2. The 6-m class.

One can try to establish the reachable goals for each of these and evaluate the importance of each of these through the net effect of being able to go to fainter flux levels. Although the possibility exists with the larger telescopes to obtain higher resolution this will require a major technology development programme.

Examples for each of these two classes have been discussed on various occasions in the scientific literature and at various workshops (e.g. Wamsteker and Shustov, 2004 for the 2-m class and Shull, 2003 for the >4-m class). In practice there are not very many differences in the type requirements for the instrumentation. The main difference in capabilities between the two classes is given by the about 10-fold increase in sensitivity between group 1 and group 2. A second also important difference is the cost. A rough estimate of the cost ratio of the two classes is a factor of 5, in the sense that the cost for a 6-m class mission is at least 5 times the cost of a 2-m class mission. This is mainly associated with technology developments which are required before a high quality UV telescope with a diameter larger than 4 mc can be expected to be successfully launched. Therefore there is a clear need for a roadmap in the UV since otherwise no coherent planning and technology development will be implemented in the expectation that at some stage the results of this are sufficient that a major (6-m class) UV mission can be realistically considered.

Taking the position that a, in the UV, diffraction limited 6-m telescope will allow the range over which objects can be studied to be some ten times more distant, the science questions to be addressed with a 2-m class are very similar at the current stage of knowledge.

Although the requirements for the various subject areas considered in this paper are not completely identical the restraining properties of the instrumentation on a UV space telescope can be summarized as follows:

- A resolution R ~1000 is recommended for spectroscopic studies of SN ejecta.
- For ISM studies, a resolution R > 50,000, and possibly as high as R ~ 100,000 is recommendable.

Wavelength coverage. For the majority of QAL research, coverage from Ly-α (1215 Å) to 2000 Å rest-frame is essential. One of the problems associated with the wavelength coverage in the UV is that in the FUV (i.e. $\lambda < 1200$ Å) completely different technology is required than for the longer wavelengths. Many projects (e.g. D/H measurements, photoionization assessment, H_2 observations) need coverage down to 900 Å rest-frame. Therefore we are not only considering a single instrument but the full package of science described here would need an instrument which covers both the far UV and the near UV domain with associated increase in complexity and cost.

Resolution to examine the DLA or perform QAL studies in general is dependent on the specific research area. Nevertheless, we can learn on our extensive experience with high z QAL studies with optical spectrographs from the ground. For the majority of scientific applications R=30,000 is a *bare minimum.* Only at this resolutions can one confidently distinguish Ly-α clouds from metal lines in the Ly-α forest, obtain abundance measurements to greater than 0.1 dex precisions, resolve velocity fields, and investigate a multi-phase medium.

S/N, a good lower limit is 30 per resolution element (i.e. S/N = 15 pix^{-1} for 4 pixel sampling). At such level, one can carefully address systematic effects like continuum placement and analyze the absorption line diagnostics with a large dynamic range (e.g. Si II1808, C IV 1550, O VI 1030). As is obvious, higher S/N is desirable and many applications would depend on higher sensitivity.

Observing power. To allow observations of a large enough sample for QSO's at $Z < 2$, a UV telescope must achieve the above resolution, S/N, and wavelength coverage for a QSO at V

≈ 18 in a reasonable exposure time (< 10 h = 36 Ksec). This would provide enough targets to examine the physical conditions at similar levels as achieved at $z > 2$.

References

Arnett, W.D., Bahcall, J.N., Kirshner, R.P., Woosley, S.E. : ARA&Ap **27**, 629 (1989)

Baron, E. et al: ApJ 545, **444** (2000)

Bennet, C.L. et al..: ApJ Suppl.Ser.**148**, 1 (2003)

Branch, D.: in Livio, M., Panagia, N., Sahu, K. (eds). The largest explosions since the big bang: Supernova and gamma ray bursts, Cambridge University Press, Cambridge, p. 96 (2000)

Burles, S., Tyler, D: ApJ **499**, 699 (1998)

Cappellaro, E., Turatto, M., Fernley, J: ESA SP-1189, IUE-ULDA Guide no. 6, Supernova, Ed. W. Wamsteker (1995)

Carr, B: ARA & A **32**, 531 (1994)

Cen, R., Ostriker, J.: ApJ **514**, 1 (1999)

Centurión M., Bonifacio P., Molaro, P., Vladilo, G.: ApJ **509**, 620 (1998)

Combes, F.: New Astr. Review **46**, 755 (2003)

Epstein, R.I., Lattimer, J.M., Schramm, D.N.: Nature **268**, 198 (1976)

Eyles, L.P. et al.: MNRAS, Mon.Not.Roy.Astron.Soc. **364**, 443-454 (2005)

Filippenko, A.: ARA & A **35**, 309 (1997)

Freedman, W.L. et al.: ApJ **553**, 47 (2001)

Giavalisco, M., et al.: ApJ **600**, L93 (2004)

Gilmozzi, R. et al.: Nature **328**, 318 (1987)

Hawkins, E., et al. MNRAS **346**, 78 (2003)

Henry, R.B.C., Edmunds, M.G., Köppen, J.: ApJ **541,** 660 (2000)

Jeffery, D.J.et al.: ApJ **421**, L27 (1994)

Kirshner, R.P. et al.: ApJ **415**, 589 (1993)

Knop, R.D., et al.: ApJ **598**, 102 (2003)

Kriss, G.A., Shull, J.M., Oegerle, W. et al.: Science **293**, 1112 (2001)

Ledoux, C., Bergeron, J., Petitjean, P.: A&A **396**, 429 (2002)

Leinbundgut, B.: PhD Thesis, University of Basel (1988)

Lu, L.-M., et al. : ApJ Suppl.Ser.**107**, 475 (1996)

Manucci F. et al.: A&A in press [astro-ph/0411450] (2005)

Martin, D. et al.: ApJ **619**, L1 (2005)

Millard, J. et al.: ApJ **527**, 746 (1999)

Blades, J.C., Wheatley, J.M., Panagia. N, Grewing, M., Pettini, M., Wansteker, W.: ApJ **332,** L75 (1988)

McWilliam, A.: ARAAp **35**, 503 (1997)

Molaro, P. et al.: ApJ **541**, 54 (2000)

Panagia, N.: in Weiler, K.W. (ed), Supernovae and Gamma-Ray Bursters, Springer-Verlag, Berlin, pp. 113-144 (2003)

Panagia, n.: in Calamai, G., Mazzoni, M., Stanga, R., Vetranos, F. (eds.), Experimental Physics of Gravitational Waves, World Scientific, Singapore, p. 107 (2000)

Panagia, N.: in Giovanelli, F., Mannocchi, G. (eds), Frontier Objects in Astrophysics and Particle Physics, It. Phys. Soc., in press[astro-ph/0502247] (2005)

Panagia N. et al.: MNRAS **192**, 861 (1980)

Pei, Y.C., Fall, S.M., Hauser, M.G.: Apj **522,** 604 (1999)

Perlmutter S. et al.: Nature **391**, 51 (1998)

Perlmutter S. et al.: ApJ **517**, 565 (1999)

Pettini M., Bowen D.V.: ApJ **560**, 41 (2001)

Pettini, M. Ellison, S.L., Bergeron, J., Petitjean, P.: A&A **391**, 21 (2002)

Pettini, M., Ellison, S.L., Steidel C.C., Shapely A.L., Bowen D.V.: ApJ **532**, 65 (2000)

Prochaska, J.X., Wolfe A.M.: ApJS **121**, 369 (1999)

Prochaska,J.X., Wolfe A.M.: ApJ **566**, 68 (2002)

Prochaska, J.X., Henry R.B.C., O'Meara J.M., Tytler D.,Wolfe A.M., Kirkman D., Lubin D., Suzuki N.; PASP **114,** 933 (2002)

Prochaska, J.X., Howk J.C., Wolfe A.M.: Nature **423**, 57 (2003)

Pun, C.S.J., et al.: ApJ Supp.Ser. **99**. 223 (1995)

Reimers, D., Fechner C., Kriss G.A., Shull J.M. et al.: Proceed. FUSE Conf.Victoria [astro-ph0410588v1] (2004)

Reimers, D., Vogel, S., Hagen, H.J. et al.: Nature **360,** 561 (1992)

Reimers, D., Fechner C., Hagen H.J., Jakobsen P., Tytler D. and Kirkman, D.: A&A in press [astro-ph/0507178] (2005)

Richter, P., Savage B.D., Tripp T.M. Sembach K.R.: ApJS **153**, 165 (2004)

Riess A.G. et al.: AJ **166**, 1009 (1998)

Riess A.G. et al.: ApJ **600**, L163 (2004a)

Riess A.G. et al.: ApJ **607**, 665 (2004b)

Rogstad, D.H., Lockart, I.A., Wright M.C.H.: ApJ **193**, 309 (174)

Saha, A., Sandage A., Tammann G.A., Dolphin A.E., Christensen J., Panagia N., Macchetto F.D.: ApJ 562, 314 (2001)

Sandage, A., Saha G.SA., Tammann L., Labhardt N., Panagia N, Macchetto F.D.: ApJ **460**, L15 (1996)

Savage, B.D., Sembach K.R., Tripp T.M., Richter P: ApJ **564**, 631 (2002)

Savage, B.D., Lehner N., Wakker B.P., Sembach K.R., Tripp T.M.: astro-ph 0503051 (2005)

Shull, J.M.: in Sembach K.R., Blades J.C., Illingworth G.D., KenniutR.C. (eds),

Hubble's Science Legacy: Future optical-Ultraviolet Astronomy from Space, ASP Conf.series Vol. 291, p. 17 (2003)

Sonneborn, G. et al.: ApJ **477**, 848 (1997)

Storrie-Lombardi, L.J., Wolfe A.M.: ApJ **543**, 552 (2000)

Tegmark, M. et al.: ApJ **606,** 702 (2004)

Thilker et al. ApJ **619**, L79 (2005)

Tonry, J.L.: ApJ **594**, 1 (2003)

Van Dyk, S. et al.: Apj **432**, L115 (1994)

Vladilo, G., Centurion M., Bonifacio P.,. Howk J.C.: ApJ **557**, 1007 (2001)

Wheeler, J.C., Harkness R.P.: in Galaxy Distances and Deviations from Universal Expansion (1986)

Wamsteker, W. Shustov, B.M., in: Wamsteker, W., Albrecht R., Haubold H.J. (eds.), Developing Basic Space World-Wide, Kluwer Acad.Publ., p.373 (2004)

Williams, R.E. et al.: AJ **112,** 1335 (1996)

Wolfe, A.M. et al: ApJs **61**,249 (1986)

Woosley, S.E., Weaver, T.A.: ApJS **101**, 181 (1995)

York, D. et al.: AJ **120**, 1579 (2000)