CONFERENCE SUMMARY*

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Introduction

As we have heard in the course of this Symposium, there have been major advances in the last few years, especially on the observational side, thanks to HST, Keck, ASCA and also the humble 4m telescopes, among others. As Jim Truran pointed out in his opening review, we can now begin to connect local observations with phenomena at high red-shift, giving a time axis for cosmic, as opposed to merely local, chemical evolution.

Primordial Nucleosynthesis

Dave Schramm brought us up to date on the current situation with primordial abundances. The best baryometer is $(D/H)_P$ (despite some reservations expressed by Jean Audouze) and the most widely accepted current value is 3.2×10^{-5}, by Scott Burles and David Tytler from two 'clean' Lyman-limit systems, although a much higher value is reported for one similarly clean object with $z \simeq 0.7$ observed by K. Lanzetta and his colleagues with HST. Jeff Linsky showed some beautiful Ly-α observations of nearby stars showing the influence of the dynamics of the local interstellar medium. As discussed by Nikos Prantzos, his current value 10^5 D/H $= 1.5 \pm 0.1$ is compatible with Burles & Tytler's primordial value on the basis of reasonable galactic chemical evolution models, but the evolution of ^{3}He is not understood.

The observation of ^{6}Li in the low-metallicity star HD 84937 suggests that the ^{7}Li plateau does not underestimate primordial lithium by more than a factor 2 when uncertainties in the effective temperature scale are taken into account. It would be reassuring to have a similar plateau for D/H. Given Tytler & Burles's upper limit of 4×10^{-5}, the primordial helium abundance Y_P has to exceed 0.243, close to the upper limit estimated by Pagel *et al.* (1992), but in better agreement with the more recent determination by Izotov, Thuan and Lipovetsky (1997). The baryon density parameter $\Omega_{b0}h_{50}^2$ is

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Table I
Inventory of baryonic matter

	gm cm^{-3}	$M_{\odot}$ Mpc^{-3}	Ω_0
$\rho_{\rm crit}$	$4.7 \times 10^{-30}\, h_{50}^2$	$7.7 \times 10^{10}\, h_{50}^2$	
$\rho_b(\frac{\rm D}{\rm H} = 3 \times 10^{-5})$	3.8×10^{-31}	6.2×10^9	$.08\, h_{50}^{-2}$
E/S0$_{\rm lum}$	$7.4 \times 10^{-33}\, h_{50}^2$	$1.2 \times 10^8\, h_{50}^2$	.0015
S$_{\rm lum}$	$3.5 \times 10^{-33}\, h_{50}^2$	$5.7 \times 10^7\, h_{50}^2$	.0007
Cluster gas	$4.4 \times 10^{-33}\, h_{50}^{0.7}$	$7.4 \times 10^7\, h_{50}^{0.7}$	$.001\, h_{50}^{-1.3}$
Group gas	$3.2 \times 10^{-33}\, h_{50}^{0.7}$	$5.2 \times 10^7\, h_{50}^{0.7}$	$.0006\, h_{50}^{-1.3}$
Total lum + gas	$1.8 \times 10^{-32}\, h_{50}^{1.6}$	$3.0 \times 10^8\, h_{50}^{1.6}$	$.0037\, h_{50}^{-0.4}$
$\rho_Z(\langle Z \rangle = .02)$		$6.0 \times 10^6\, h_{50}^{1.6}$	$7.4 \times 10^{-5}\, h_{50}^{-0.4}$
Damped Ly-α			$.004\, h_{50}^{-1}$
Gals + DM halos ($\frac{M}{L} = 150\, h_{50}$)			.25
All matter ($f_b = .009 + .14\, h_{50}^{-1.5}$)			$.54\, h_{50}^{-0.7}$
Time-averaged $\dot{\rho}_*$		$1.5 \times 10^{-2}\, h_{50}^3$ yr^{-1}	
Time-averaged $\dot{\rho}_Z$ ($\langle Z \rangle = .02$)		$4.5 \times 10^{-4}\, h_{50}^{2.6}$ yr^{-1}	

thus between 0.06 and 0.10, requiring substantial amounts of both baryonic and non-baryonic dark matter (see Table I).

Other routes to Ω_{b0} are the baryon fraction in clusters of galaxies, consistent with $\Omega_{b0} = 0.05$, $\Omega_{M0} = 0.25$ (no baryonic catastrophe, but $\Omega_M < 1$ if distributed like galaxies; cf. Bahcall *et al.* 1995), large-scale streaming motions and the spectrum of microwave background fluctuations.

I present some numbers relevant to BBNS limits and cosmic chemical evolution in Table I.

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The table shows that Ω_{b0} now seems to exceed the contribution from visible stars and gas (Persic & Salucci 1992) by a factor of about $20h_{50}^{-1.6}$ — a vast amount of baryonic dark matter that may be accounted for by ionized gas associated with the Ly-α forest clouds (e.g. Weinberg *et al.* 1997), but has no well-known counterpart today (intergalactic gas? Machos? LSB galaxies?). The total Ω_{M0} from galaxy halos and cluster dynamics is about 0.2 to 0.3 according to Bahcall *et al.* (1995) and from the baryon fraction in clusters of galaxies according to White *et al.* (1993) it is $\leq 0.54h_{50}^{-0.7}$. The other entries in the table will be commented on later.

Population III

Population III was postulated 30 years ago by Doroshkevich, Zeldovich and Novikov to explain the re-ionization of the intergalactic medium and quite widely discussed for some years, but then widely neglected. Jerry Ostriker has now brought the idea back in force by showing that pre-galactic stars can indeed be formed at red-shifts up to 15 and produce a wide range of initial metallicities in different places according to density and other factors.

Observed galaxies including Lyman forest clouds are found with metallicities down to about 10^{-3} solar (Tytler) whereas in our own Galaxy stars have been found down to 10^{-4}. Are these latter a genuine Population III, possibly associated with the mini-halos suggested by Mesashi Chiba, or can we expect to find Lyman clouds of still lower metallicity at still higher red-shifts than observed to date?

Ostriker mentioned an interesting test: if the most metal-poor stars in our Galaxy are pregalactic, they may be expected to have a dark-matter like density distribution $\sim R^{-2}$ in contrast to the steeper fall-off of the conventional stellar halo.

Galaxy formation and evolution

This is a huge topic, to which one can hardly do justice in a short summary. As was explained to us by Simon White and Richard Ellis, it is currently driven by observations, notably the AAT-LDSS and Canada-France red-shift surveys to $z \simeq 1$ and the discovery of star-forming galaxies up to $z \simeq 4.5$ using the multi-colour drop-out technique, especially in the Hubble Deep Field, with red-shifts confirmed using Keck.

At the lower red-shifts, it appears that regular large galaxies like our own were already established by $z = 1$ at which time they were about 1^{m} brighter than now; ellipticals are consistent with passive evolution although on-going mergers are not excluded. On the other hand, there is a dramatic rise in the number of blue irregular star-forming galaxies with [O II] emission.

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At higher red-shifts, Madau *et al.* (1996) have estimated the luminosity and hence the star-formation-rate density as a function of z from the HDF, and there are signs of a decrease beyond $z = 2$, corresponding to a peak near $z = 1$ as predicted by Pei & Fall on the basis of the decline in $\Omega_{\mathrm{H\,I}}$ with decreasing z. According to the models and according to the analysis by Storrie-Lombardi *et al.* (1996), $\Omega_{\mathrm{H\,I}}$ is more or less constant (or at least not increasing with z) for $z > 2$, so disk galaxies would have been forming few stars earlier than that. Madau *et al.* found fair agreement with an average 'fiducial' star formation rate giving a solar average metallicity to visible matter at the present time (see $\rho_Z(\langle Z\rangle = .02)$, time-averaged $\dot{\rho}_*$ and time-averaged $\dot{\rho}_Z(\langle Z\rangle = .02)$ in Table I), but there are problems with incompleteness and absorption so that all the star formation rate estimates are probably too low (e.g. Pettini *et al.* 1997). That this is so is also suggested by the ISO survey of HDF galaxies by Rowan-Robinson *et al.* (1997), who find larger star formation rates by a factor of about 3 and suggest that the extra metals are hidden in baryonic dark matter. Thus we may have a dark metal problem as well as a dark matter problem!

The evolving galaxies at high red-shift tend to be compact and may be merging to form more conventional galaxies as was described very nicely by Simon White and Guinevere Kauffmann, but this is still uncertain.

Evolution in our own Galaxy has been milder, as shown by Nikos Prantzos; this is entirely consistent with the evolution of spirals described by Richard Ellis. Elliptical galaxies can arise from mergers of disk-like systems, as Guinevere described, but these were not the spirals that we see today. Another type of merger is on-going, at least in the Milky Way halo, as described by S. Majewski, and leads to an uneven distribution of the stars in phase space.

After all this, it is not clear to me how the classical ELS model of formation of our Galaxy, still supported by the properties of the inner halo and thick disk if not by those of the outer halo, ties in with current models of hierarchical clustering.

Abundance patterns

These have been very nicely reviewed for us by Chris Sneden for the halo and metal-poor thick disk, by Mike Rich for the Bulge and by Limin Lu for the damped Lyman-α systems, which (as Jim Truran pointed out) can now provide a time-scale for metal enrichment, although (as shown by Lanzetta) the age-metallicity relation derived for the latter demands caution because the geometry favours high impact parameters (cf. Phillipps and Edmunds 1996). The apparent lack of increase in mean metallicity from $z = 2$ to $z = 1$ could be due to this effect.

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The basic pattern of α-element enrichment at low metallicities, first noticed by Aller & Greenstein nearly 40 years ago, persists among Galactic stars and apparently also shows up in Lyman forest clouds (Si/C observed by Tytler and by Boksenberg); whether it does so in damped Lyman-α systems is controversial. Don York explained that corrections from observed to total abundance are tricky owing to the presence of a multi-phase medium with different ionization and dust properties.

The explanation of the α/Fe effect in terms of a time delay of the order of 1 Gyr or more for SN Ia which provide about 60 per cent of the iron in the Solar System still seems to hold good (although possibly challenged by Takuji Tsujimoto's report of a high Fe/Mg ratio in a quasar), but among Galactic halo stars there are exceptions as noted recently by Nissen & Schuster (1997) and by King (1997) and as can also be retrieved from earlier data. The exceptional stars were presumably captured from merging dwarf galaxies for which Majewski provided ample evidence; in these systems, e.g. the LMC as reported by Beatriz Barbuy, the effect is mitigated by slower star formation and possibly effects of bursts separated by quiescent intervals (Gilmore & Wyse 1991). The main difference observed between damped Lyman-α systems on the one hand and both Galactic halo stars and dwarf irregular galaxies on the other is the low N/Si ratio, accompanied by a large scatter, in the DLA systems. This favours a scenario in which the stars in the DLA systems are very young and primary nitrogen comes from intermediate-mass stars with a significant time delay, rather than from primary nitrogen production by mixing processes in massive Population III stars.

The behaviour of heavy metals in Galactic halo stars is intriguing. For $[\mathrm{Fe/H}] \leq -3$, there is a strange pattern among iron-group elements (which may or may not be explicable by supernova nucleosynthesis models) and a large scatter in the abundances of neutron-capture elements relative to iron. However, the neutron capture elements themselves often show an excellent match to the r-process contributions in the Solar System, notably in the case of CS 22892–092, which is a sort of Rosetta stone for the r-process and has been used as a thorium chronometer.

Above $[\mathrm{Fe/H}] = -3$, the r-process continues to dominate for a while (as Jim Truran predicted 15 years ago), notably for barium in HD 140283 and 122563, and this is now confirmed by hyperfine structure broadening as shown in the very nice new work by Walter Gacquer. By the time [Fe/H] reaches -2, however, the s-process takes over for barium and other conventional s-process elements, which is not exactly what is expected from current models of low-mass AGB stars. Pagel & Tautvaišiene (1997) have modelled the Galactic chemical evolution of these elements assuming two distinct s-processes with different time delays; only the second one, with a time-delay exceeding that of SN Ia, corresponds to the classical AGB model.

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Among Galactic disk stars, as described by Bengt Edvardsson, the old discrepancy between abundance gradients derived from B stars and from other sources (H II regions, F stars) seems to be going away (Smartt and Rolleston 1997). The dispersion in metallicity at a given age is ±0.1 to ±0.15 dex, a bit less than some of the values in the classic Edvardsson *et al.* (1993) paper where they already pointed out that the scatter was slightly enhanced by selection effects. The solar oxygen abundance is about 1.5 times higher than the concordant determinations in the Orion nebula (Esteban *et al.* 1997), in B-type stars (e.g. Gies and Lambert 1992) and in the diffuse interstellar medium (Meyer, Jura and Cardelli 1997). The scatter could arise from orbital diffusion or gas inflow episodes; similarity of scatter between Fe and α-elements rules out a dominant contribution from self-enrichment in stellar associations. Recent results by B. Nordström *et al.* give a mild increase in C/Fe with decreasing Fe/H, indicating a major source of carbon in relatively massive stars.

Coming to the Bulge, as described by Mike Rich, things are quite confusing. Because star formation there was presumably more rapid than in our neighbourhood, we expect the α-rich effect to persist to higher metallicities. Mg and Ti seem to behave as expected, but Ca and Si do not, while oxygen is too difficult to measure. The abundance distribution function in terms of Mg roughly fits a Simple model with a large effective yield, which could arise from a dissipative collapse of the halo-bulge system setting up an abundance gradient. There is an intriguing connection with a bunch of super metal-rich field stars discovered by Michel Grenon and the SMR old open cluster (NGC 6791) with a blue horizontal branch reported by Ruth Peterson; this can now be used to calibrate SMR giant luminosities in external galaxies.

Hot gas in ellipticals and in groups and clusters of galaxies

The ASCA satellite has led to major developments in the study of hot X-ray gas. Possibly the most dramatic is the discovery reported by Mikato Hattori of a dark, massive gravitationally lensing cluster emitting X-rays with the usual iron line at $z \simeq 1$ and little optical light from a sole cD galaxy. The baryon fraction f_b is only half of the value quoted in Table I. Where did the iron come from if there are so few stars? There may also be a massive but cold cluster (no X-rays) at $z = 0.75$.

Gas phase abundances in more conventional clusters and individual elliptical galaxies were discussed from the observational point of view by Takaya Ohashi and M. Loewenstein and from the theoretical point of view in a beautiful presentation by Ms Yuhri Ishimaru. In some cases, the distribution of iron with radius tends to match that of the galaxies, which is steeper than that of the gas, and in general the Fe/O or Fe/α pattern is more or less solar, implying some contribution from SN Ia. In any case, while the iron

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abundance in the hot gas of rich clusters is around 1/3 solar, the total mass of iron, relative to stellar luminosity and presumably mass, is very large, indicating larger stellar yields than we think we have in the solar neighbourhood, although the mean metallicity of the stars themselves is not above solar. Ishimaru and Arimoto have developed theoretical models involving galactic winds and group winds, assuming high stellar yields (top-heavy IMF), with only the rich clusters managing to retain most of their gas.

Stellar yields

This leads on to the stellar yields themselves. Dave Arnett discussed SN II, including those associated with Population III, and emphasized the crucial role played by mixing in shell O-burning zones, which can now be treated in direct hydrodynamical simulations. The old onion-skin picture is challenged by the SN 1987A light curve and by isotopic anomalies (^{26}Al, ^{44}Ti) in pre-solar grains. Yields of primary elements like oxygen are not greatly affected, but those of secondary elements like nitrogen are very sensitive to mixing details. Dave was kind enough to quote me as having called for a primary nitrogen source for low-metallicity objects, but in view of the DLA behaviour I would rather favour intermediate-mass stars as the source.

Ken Nomoto and Xiangdong Li discussed SN Ia, which are now thought to come in two versions, both favouring a single-degenerate model with carbon deflagration at the Chandrasekhar limiting mass. The new type involves rapid mass transfer in systems identified with ultra-soft X-ray binaries.

AGB stars were discussed by Nami Mowlavi with special reference to ^{3}He, ^{26}Al, Tc, F and ^{7}Li, among others. Here again, extra mixing is required, in particular to produce the third dredge-up at low enough luminosities, to generate neutrons by $^{13}\mathrm{C}(\alpha, n)$ and to account for the destruction of ^{18}O. AGB stars may account for ^{3}He destruction and formation of ^{19}F and ^{26}Al, although Wolf-Rayet stars could be a better source for fluorine.

Brad Gibson gave an enlightening account of the wide range in stellar yields calculated by different authors, confirming my prejudice that one can to a large extent just as well take the yields *ad hoc* by fitting abundances with galactic chemical evolution models (cf. Pagel and Tautvaišiene 1995). M. Samland presented a highly sophisticated model in which he did just that.

New galactic chemical evolution models

Apart from the empirical determination of yields by Samland and the work on elliptical galaxies and hot gas, we had a fine presentation of the chemical

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evolution of the Galaxy by Nikos Prantzos and we heard briefly from Beatriz Barbuy about the LMC. Cosmic chemical evolution models are the Holy Grail as far as this meeting is concerned, tying together the information that we have, ranging from local galaxies to the universe at high red-shift. The two we have heard about are from Uta Fritze and Mike Fall who look at the question from quite different viewpoints. Uta uses basically the stellar population synthesis approach, tying the scattered metallicities in DLA and C IV systems respectively to disks and halos in different morphological types of galaxies seen today, whereas Mike Fall deals with a global average, tying star formation to the declining density of H I. The effects of varying ionization, and the status of elliptical galaxies, are not clear in these models, although such complications are given some recognition in Mike's inflow and outflow parameters.

Globular clusters

Globular clusters were discussed from the theoretical point of view by Doug Lin and from the observational point of view by Jean Brodie. Doug reached the interesting conclusion that globular clusters are already born with mass segregation, the most massive stars lying at the centre. It was not clear to me whether the predicted dependence of minimum stellar mass on metallicity could have some observational consequences.

Jean Brodie presented observations of the abundance distribution functions (ADFs) in extragalactic globular cluster systems (NGC 1275 and 1399) designed to test the hypothesis that globular clusters in elliptical galaxies are formed in mergers. Cluster ADFs in ellipticals are bimodal, with the more metal-rich clusters resembling the field stars; with other evidence, this suggests a two-phase model rather than a merger model, although Richard Larson contributed a percipient suggestion that the bimodal distribution could come from mergers with a galaxy like our own. Three clusters in NGC 1275 have A-type spectra and seem to demand a peculiar truncated IMF; these are not expected to survive long enough to develop into conventional old globular clusters, although here again there are caveats.

Light elements

Abundances of ^{6}Li, ^{9}Be and ^{10}B in the Solar System are readily explained by cosmic-ray spallation on CNO nuclei in the interstellar medium, but there are problems with the ^{10}B/^{11}B ratio and with the constant abundances of Be and B relative to iron or oxygen in low-metallicity stars. The solution currently proposed by Cassé, Vangioni-Flam, Ramaty *et al.* is based on

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energetic C and O nuclei in supernova ejecta impacting protons in the local interstellar medium.

There is still a problem, in that the SN ejecta need to be hydrogen-poor, coming from WC star progenitors, and Nikos Prantzos pointed out that these become rare in metal-poor systems, so the problem is not completely solved after all. Francesca Primas drew attention to another mystery: why do some stars have normal lithium but reduced beryllium and boron?

Conclusion

We have heard many interesting things at this very successful symposium. No problem has been solved in a conclusive sense, but there has been dramatic progress in the past three years and we now have some insights into the deep universe from the chemical evolution point of view. No doubt there will be yet another sea-change in knowledge and viewpoints by the time of the next IAU.

Finally, let us express our thanks to Jim Truran for the excellent work he has done to make this symposium a success and to our colleagues on the LOC for outstanding efficiency and hospitality which has made this IAU assembly such an enjoyable occasion.

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