Opening Session

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Monique and François Spite, enjoying the first day of the conference outside the conference building.

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From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
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A Tribute to Monique and François Spite

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Abstract. This contribution retraces the scientific careers of Monique and François. It highlights the impressive contributions that they have brought to astrophysics, from the discovery of the lithium plateau in subdwarfs the second year of operation of the Canada-France-Hawaii telescope, to the exceptional contribution of Monique to the ESO VLT Large Programme "First Stars", passing by several other findings which have marked our knowledge of the nuclear evolution of our Galaxy and of the Magellanic Clouds.

Keywords. Stars: abundances, supernovae: general, early universe, nuclear reactions, nucleosynthesis, abundances

1. The beginning

Monique was born in Lille, a city of northern France, and François in Lunéville, in the north-east of the country. They had all their higher education at the university of Lille. Fig. 1 is a nice picture of them, before they had seriously considered to be astronomers. However, if you believe Dr. Sigmund Freud, you see them here at the most critical age of their lives. Indeed, looking carefully, you may discover in the face of Monique the emergence of her highly developed sense of responsability, and in the eyes of François a vibrant curiosity, with the touch of humor, that he still has.

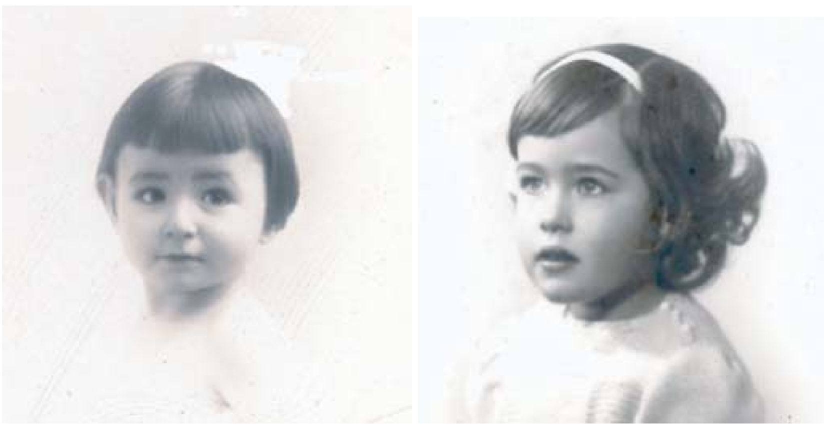

Figure 1. The early Spites.

2. Their theses

Monique and François started their research work with Vladimir Kourganoff in Lille, who was university professor there at that time. You see in Fig. 2 V. Kourganoff teaching

Figure 2. Vladimir Kourganoff teaching piano to his grandson.

piano to his grandson. V. Kourganoff played an important role in orienting the Spites and myself into the field of stellar atmospheres. His book *Basic Methods in Transfer Problems* was a bedside book for them and me in the 1960 s. But when Vladimir Kourganoff moved to Paris with a new position, he asked me if I could assume the direction of their theses. His first offer was asking me to come to Lille, but at the same time Jean-Claude Pecker was taking the direction of the Observatory of Nice, and asked me to replace him at the observatoire de Paris, where he had assembled an excellent team working on departures to local thermodynamical equilibrium. So it ended up that the Spite came to Paris in 1963, instead of me going to Lille. It was the time when the initial assumption that all the stars had the same chemical composition started to be seriously shaked. If the idea of Gamov that all the elements could be formed in the Big Bang nucleosynthesis had worked out, it would have been acceptable to adhere to such a view. But primordial nucleosynthesis did not pass ^{7}Li, and with the visionary paper B^{2}FH 1957 it became clear that the bulk of the elements were formed differently. Also the paper by Chamberlain & Aller 1951 presented the first evidence of stars with a metallicity widely departing from the solar value. So the theses of Monique and François were naturally oriented towards the third parameter of stellar classification: the chemical composition of the stellar matter. The titles of the theses of Monique and François were "Abundances of metals in stars of solar type" (June 1968) and "Quantitative method of three-dimensional classification of cool stars. Applications" (June 1966), respectively. Monique confirmed, via very careful differential detailed analyses, the trend found by Wallerstein in 1962 that the Ca/Fe and Ti/Fe ratios were increasing when metallicity was decreasing. François showed that measurements of pseudo-line-strength in low resolution spectra (about 0.2 nm) could lead to the determination of the three parameters T_{eff}, log(g), and [Fe/H], with the advantage that fluxes being compared only at very nearby wavelengths, the classification was unaffected by interstellar reddening. However, the CCDs were not yet invented, at that time, and photometry from photographic spectra was a serious practical difficulty.

3. The period in Chili

After their theses Monique and François left Paris and spent three years at ESO in Chili (1972–1975). They extended their study of the chemical composition of metal-poor stars to southern objects with the 1.52m spectrographic telescope. At the end they could

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benefit from the installation of an electronographic camera of Lallemand at the coudé focus of the telescope.They made a detailed analysis of HD 128279 and of several binaries.

4. The first important discovery: the Eu/Ba variation in metal-poor stars

In a widely cited paper Spite M. & F. (1978) (over 130 citations), the Spites have shown that the ratio Ba/Eu was declining by a factor of ten, when the metallicity declines from its solar value to [Fe/H] ≈ -1.5. Truran (1981) interpreted this variation as the loss of the *s*-fraction of barium present in the solar system, when the interstellar matter was only enriched by ejectas of SNe II.

5. C,N,O in metal-poor stars: the thesis of Beatriz Barbuy

From 1978 to 1982, Monique directed the thesis of Beatriz Barbuy on the abundances of C,N,O in thick disk and halo stars. Beatriz had a good expertise in molecular spectra, and was able to study the abundances of C and N from spectral synthesis of the bands of CH and CN. Oxygen must be studied together, because of the formation of the CO molecule. B. Barbuy showed that [C/Fe] has practically no evolution with [Fe/H] in unevolved stars, but that C is depleted in luminous giants, as an effect of dredge up by stellar evolution, effect well known in globular cluster giants. Also [N/Fe] presented little variation with metallicity. Standard nucleosynthesis does not account for nitrogen production in SNe II, without extra-mixing. This point shall be discussed later in the Symposium. One battle horse of Beatriz Barbuy and the Spites has been the variation of [O/Fe] with [Fe/H]. Deriving the oxygen abundance from the forbidden [O I] line near 300 nm, they found an increase of [O/Fe] from 0 to about 0.4 dex when [Fe/H] decreases from 0 to −0.7 dex, and then stays at 0.4 dex at lower values of [Fe/H]. This results finds a natural explanation in the supply of O and Fe only from yields of SNe II on the flat portion, whereas O/Fe decreases when SNe Ia supply more Fe after some delay due to their slower formation mechanism. A few years later this behaviour was fought by Abia & Rebolo (1989) from a study of the oxygen abundance derived from the IR triplet. The authors found no plateau but a continuous increase of [O/Fe] up to 1.0–1.2 with decreasing metallicity. This initiated a long debate, fed by abundances derived from other lines, OH UV lines Israelian *et al.* (1998), or IR OH lines Meléndez *et al.* (2001) and by the emergence of 3D hydrodynamical models Asplund *et al.* (2004). Beatriz and the Spites have always supported the presence of the plateau, but possibly reaching [O/Fe] = 0.7 in 1D models, but likely less in 3D models.

6. The Big Bang in the scientific life of the Spites: the lithium plateau

The Spite were among the first users of the coudé spectrograph available at the Canada-France-Hawaii telescope. I was the head of the project office of the CFHT from 1973 to August 1980, i.e. during the conception and construction phase. There was a coudé spectrograph planned by the Scientific Council for CFHT, but that one was completed only ten years later (GECKO). The coudé spectrograph used by the Spite for their major discovery was made almost from parts taken out of the shelf, to accomodate a request of Gordon Walker, G. Herzberg and Bruce Campbell to start a program of search of planets around stars, by measuring the tiny periodic radial velocity change induced by the motion of the star with respect to the center of mass of the system star-planet. Actually the method which allowed to detect the first exo-planet in 1995 (Mayor & Queloz 1995). So

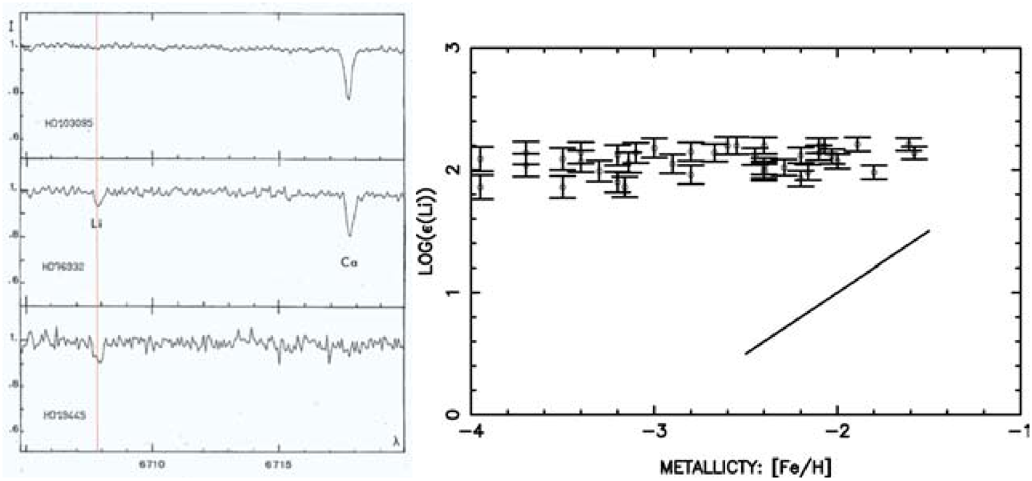

Figure 3. Left:the first observations of Li by the Spites in metal-poor stars (see text). Right: The Spite plateau with the observations availabe in year 2000.

we asked to Harvey Richardson, optical engineer at DAO, to install a simple coudé f/8 Schmidt camera spectrograph using an available RETICON as detector. For the planet search programme an HF cell was inserted in the beam to supply an accurate reference spectrum. But outside the few weeks per year used for the planetary search programme, the spectrograph was available for abundance work.

In March 1981 the Spite saw the resonance line of Li I at 6707.8 Å, in the metal-poor star HD 76932, when nobody was expecting to see such a line in a star twice older than the Sun, in which lithium was already depleted by a factor of 100. Fig. 3 shows the first observation of Li by the Spite in the metal-poor subgiant HD 76932. The figure also shows that in the cool nearest subdwarf HD 103095 (also known as Groombridge 1830) lithium has been strongly depleted, and that in the extreme subdwarf HD 19445 the Ca I line at 6718 Å becomes weaker than the Li line. The Spite re-applied immediately for observing time, to a have results on a larger set of stars, including old disk stars of intermediate metallicity. Their main paper Spite M. & F. (1982) is remarkably exhaustive, presenting both the explanation of the survival of ^{7}Li in metal-poor stars with $T_{eff} > 5500$ K because of the shrinking of the convective zone at low metallicities, and a discussion of their Li abundance in the frame of the primordial nuleosythesis computations for ^{7}Li, but also for ^{4}He, ^{3}He and D, available in 1982. This paper has 397 citations today.

Fig. 3 also shows the large extension of the plateau with observations up to year 2000 (Cayrel, Spite and Spite 2001). A lot of papers will be devoted to the Spite plateau in this symposium. Important issues are the existence or not of a significant scatter along the plateau, and the existence or not of a significant depletion of the plateau by atomic diffusion or a combination of atomic diffusion and mixing with deeper zones where Li can be burnt, producing an offset of the plateau with the BBN primordial abundance. The scatter is not anymore an issue, all recent work find it rather small, in any case below 0.1 dex. The offset with the BBN + WMAP value remains an issue, which will be addressed during the symposium.

The Spite have also contributed to our knowledge of the abundance of ^{6}Li, observing the subgiant HD 87937 at CFHT, with a S/N ratio of 1000 per resolved element, and a spectral resolution of 100 000. A ^{6}Li/^{7}Li ratio of 0.052 ± 0.020 was found, more accurate than former determinations. Very new and interesting results on ^{6}Li from Asplund and al. will be presented during the symposium.

7. The thesis of Patrick François 1986 and the first attempt to derive the age of the halo from the radioactive decay of thorium

Patrick François has studied the abundances of Na, Al, Mg and Si in a sample of 36 disc stars. Whereas the two even elements Mg and Si show a well behaved trend of continuous increase from solar metallicity to [FeH] = −1.0, Na and Al are more scattered, but clearly have a milder increase, or no increase with declining metallicity. Somewhat later, P. François and the Spites studied the abundance of sulphur as a function of metallicity in disc and halo stars, and showed that sulfur behaves as the other α-elements, a useful result for the comparison with abundances in Lyman-α damped systems, because sulphur is not partially trapped in grains, as oxygen. The Spites and P. François tried to use the ratio Th/Eu to estimate the age of the halo, from the radioactive decay of Th. However, the decay was hardly above the scatter of the abundance determinations, preventing to reach a valid conclusion.

8. Jumping out of the Galaxy

The Spite always felt cramped in the Galaxy and took the opportunity of the ESO key programme on the Magellanic Clouds (1988–1991) to get abundances elsewhere. Not surprisingly, they measured the first abundance of lithium outside the Galaxy. In these years, only supergiants were observable at this large distance, so the game was to compare magellanic supergiants with galactic supergiants, and with H II regions, which were supposed to have the same chemical composition as young stars. The Spite have nine refereed papers on the subject. This work was continued by the thesis of Vanessa Hill directed by Monique.

9. The thesis of Vanessa Hill 1997 and its VLT extension

The thesis of Vanessa showed a great homogeneity of abundances in the LMC at a metallicity about half solar, and a somewhat less uniformity in the LMC, with a mean metallicity one fifth solar. There was also a hint that [O/Fe] did not present the same behaviour in the MCs and in the Galaxy. But old stars have been well observed only at the completion of the VLT. Fig. 9 shows a very neat result derived from Hill *et al.* (2000). The [O/Fe] ratio, measured in giants of old and young globular clusters, datable via their isochrones, does not show the variation known to exist in our Galaxy. Clearly the stellar formation rates of SNe II and SNe Ia have been different in the two systems. The fast evolution present in the early days of our Galaxy (many SNe II before the first SN Ia), seems to be missing in the LMC.

10. The role of Monique in the VLT-ESO large programme "First Stars"

Another major accomplishment of the Spites, is the central part that Monique has played in the VLT-UVES large programme "Galaxy formation, Early Nucleosynthesis and the First Stars". This programme has collected spectrosopic data with S/N per pixel usually 200, spectral resolution 40 000, on stars of the Beers,Preston, Schectman H & K survey having a metalicity less than [Fe/H] = −2.8. It spanned four 6-month periods,

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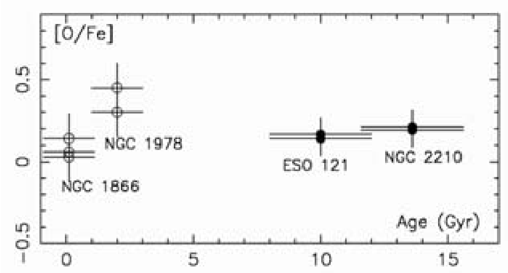

Figure 4. [O/Fe] as a function of age in the Large Magellanic Cloud.

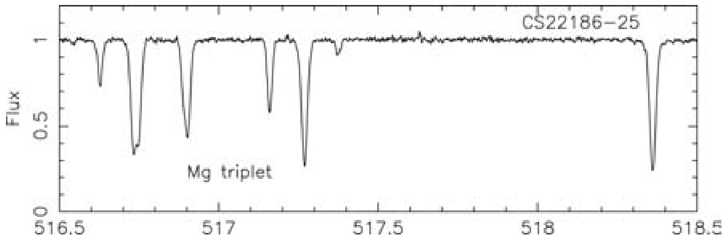

Figure 5. Sample of a spectrum taken with the VLT-UVES of a star of V-magnitude 14.2.

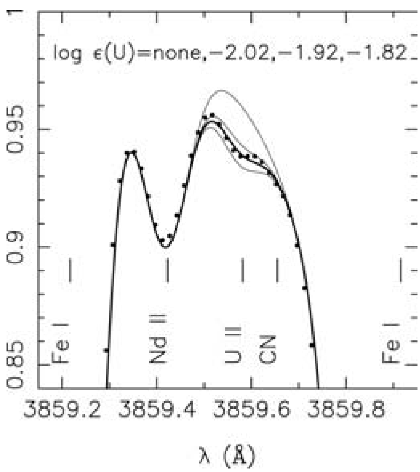

Figure 6. The U II line at 3859.57 Å in CS 31082-001.

and represents 38 night of visitor observing time. The dichroic mode was used to cover a maximum range of wavelengths. Monique had the responsability of the reduction of the observations for all giant stars of the programme, of the archiving of the full sample, and of the application of a standardized procedure for determining the atmospheric parameters of the target stars.She directed the thesis of Eric Depagne on the results derived for the giants of the sample. As Monique will speak in the symposium only on a very focussed part of the programme, I shall summarize here a few of the results which are of course to be credited to the whole team, but with a “lion share” for Monique.

The first shock is to see the incredible gain in signal/noise ratio obtained with VLT-UVES. Fig. 10 shows the region of the Mg I green triplet on a very metal-poor giant CS 22186-025 of V= 14.2!

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10.1. *The uranium star CS 31082-001*

A few months after the beginning of our ESO large programme, a run for which Vanessa Hill was the observer, revealed a giant star with [Fe/H] = −2.9, which turned out to be one of our most interesting target. It had an overabundance of neutron-capture elements by a factor of 50 with respect to iron, quite similar to that found in the extensively studied star CS 22892-052, but wit a much less blending by CN lines (see Fig. 10. This, with the additional help of a still larger overabundance of the actinides (Th and U), allowed a good determination of the U/Th ratio, used for the first time as a radioactive cosmochronometer in a very old star (Hill *et al.* 2002).

This has triggered new theoretical work on the production ratio U/Th, and also shown that U/Th is much more reliable than Th/Eu. Lead has also been measured in CS 31082-001, with the interesting result that most of the lead results from the decay of the three actinides ^{232}Th, ^{235}U and ^{238}U (Plez *et al.* 2004).

10.2. *The thesis of Eric Depagne 2003*

The most unexpected result of the analysis of the 35 giants of the sample is the fact that, in spite of the enormous gain in S/N ratio, abundance ratios remain in general with an intrinsic scatter not emerging from the observational S/N ratio, C and Na excepted. This applies from O to Zn, the neutron-capture elements showing a clear intrinsic spread (P. François *et al.* 2003). Another interesting result is the mesurement of the oxygen abundance from the forbidden line [O I] in a star of metallicity -4, CS 22949-037, showing that this carbon-star is also oxygen rich with [O/Fe] = 2.0, a very unusual value. So the underdeficiency is really in C,N,O, and to a milder extent in Na, Mg and Si. The star clearly shows evidence of C,N,O processing with a ^{12}C/^{13}C = 4.0, and probably a large fraction of the initial carbon has been processed into nitrogen. The abundance ratios in objects with [Fe/H] < −3.0 do not show any metallicity dependence, so can be identified with the yields of zero or quasi zero metal supernovae. A table of these yields is in a Messenger article (No. 118). In Fig 11 these yields are compared to the theoretical yields of supernovae of masses between 15 and 35 $M_{\odot}$ from Woosley & Weaver (1995), and of pair-instability supernovae (140–260 $M_{\odot}$) Heger & Woosley (2002). Clearly, the yields of low mass SNe fit better the observations than those of PISNs.

10.3. *The good giants and the bad giants*

Monique has shown in paper VI of the "First Stars" (M. Spite *et al.* 2005) series in A&A that the "First Stars" giant sample, can be subdivided in two subgroups. One, corresponding to stars not chemically affected by internal evolution, still has the initial abundances of C and N. The stars have absolute magnitudes below that of the "bump" of the red giand branch, a moderate dilution of lithium, [N/Fe] < 0.5 and [C/N] > −0.4. Giants brigther than the bump, have C and N abundances altered, C down and N up, but C+N unchanged. The dilution of Li is so strong that the Li resonance line is no more detectable, and the ^{12}C/^{13}C is much lower than in the first group, not far from the so called equilibrium value ≈ 3. Speaking of primeval abundances, it is of course highly desirable to select the giants of the first group.

11. Wishes to Monique and François

After this partial view of the work of the Spites (I have skipped their important contribution to the study of the globular clusters, the search of deuterium in stars, and many other things), I suppose that I am interpreting the general feeling of the audience

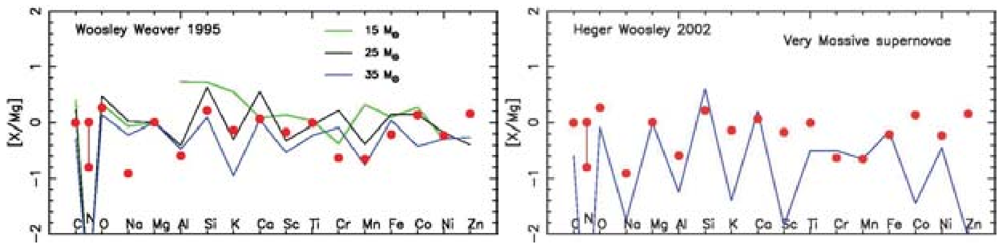

Figure 7. Observed abundances in the most metal-poor stars compared with theoretical yields. Left:yields from Woosley and Weaver 1995 of SNe II of moderate masses. Right: yields from Heger & Woosley 2002 for pair instability SNe.

in thanking them, and congratuling them for their outstanding contribution to astrophysics. On behalf of all of us, I am wishing to them an happy continuation of their scientific life at the Observatoire de Paris, with new exciting discoveries.

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