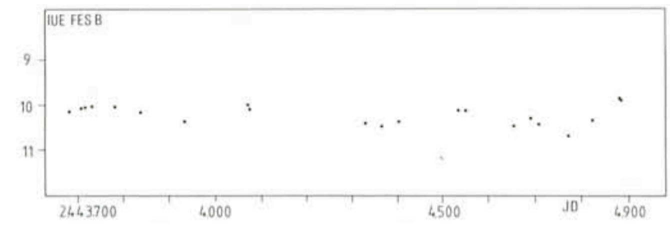

Fig. 4: *IUE FES B magnitudes from 1978 to 1981.*

of the maxima in time on the J and IUE FES B lightcurves agree very well.

Another interesting curve can be obtained from the records of the American Association of Variable Stars Observers. Fig. 5 displays the available visual estimates averaged by groups of 50 days for the years 1949 to 1963. Further monthly averages were also available to us for the epoch 1972–1977. Apart from a general decline after the outburst, a periodicity is also clearly visible.

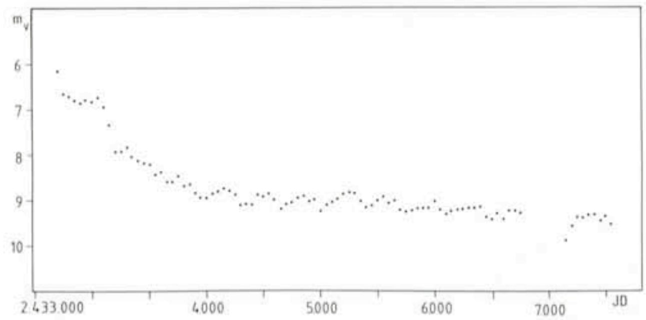

Fig. 5: *50-day averages from the AAVSO visual estimates for the years 1949–1963.*

Although visual estimates are less precise than photoelectric measurements, Fourier analyses of these data can provide quite reliable determinations of the period because of the large number of cycles covered by the time basis available. For the whole 1949–1963 range, a mean period of 355 days has been derived, but a more detailed analysis shows that this period decreased from about 377 days just after the outburst to about 345 days at JD 2,437,000 (1960). It is really a pity that no infrared data were available at that time to check whether this shorter period was also appearing in that range. From the visual averages between 1972 and 1977, it was impossible to determine clearly a period.

Conclusions and Comments

When they are overlapping, the observations of RR Tel in J and IUE FES B magnitudes are coherent, leading to a period of the order of 390 days, that is very close to the value of 387 days proposed by S. Gaposchkin in 1945 from forty pre-outburst observations. The V values for 1981 are also in agreement and those for 1978 and 1980 are too uncertain to be declared in definite disagreement. There are also strong suspicions on the occasional presence of short-time scale variations in V.

Moreover, it is certain that the period in the visible range did not remain constant from the pre-outburst phase until nowadays. It has been shorter immediately after the outburst and has been decreasing at least until 1960. No data are unfortunately available in the infrared range during this period. So the hypothesis by Feast et al. that a Mira has been present at all times with a constant period cannot be checked then. Nevertheless, the spectral evidence of H_2O and TiO bands supports the Mira presence, as well as the very pre-outburst behaviour.

The visible variations from the outburst until nowadays, however, cannot be accounted for directly by the Mira if this component remained constantly between 13^m and 17^m. It is easy to show that such variations would be completely masked by another component of radiation as soon as this would be brighter than about 11^m.

The variations of this blue component contributing to the visible light might have been related to the rate of mass loss. The interesting point is that it seems now to have returned to the Mira periodicity after a long time of different behaviour. This could indicate the end of a crisis.

A.R. Walker (1977, *MNRAS* **179,** 587) proposed that the outburst had been triggered by an increased mass accretion from the implied Mira because of the necessary rate of mass loss. A more sophisticated model has recently been proposed by G.T. Bath (*MNRAS* **182,** 1982, 35): RR Tel would be a case in which modulated bursts of mass transfer and associated accretion events were occurring within the underlying binary star prior to the major eruption in 1944. The outburst itself would have been caused by a sudden onset at a super-critical rate. In that picture, RR Tel could be the missing link between dwarf novae, classical novae and symbiotic stars.

The Diffuse Interstellar Medium and the CES

R. Ferlet, LPSP, Verrière-le-Buisson

Introduction

Representing a few per cent of the mass of our Galaxy, but 30–40 % in the case of the Small Magellanic Cloud, it is well recognized that diffuse matter in space plays a decisive role in the evolution of galaxies. Primordial gas—together with material ejected in stellar winds, novae, supernovae, planetary nebulae and other types of evolved stars, and enriched in heavy elements through nucleosynthesis—has accumulated to form a complex and violent medium with an amazing variety of physical conditions, containing regions with densities ranging from 10^{-4} to 10^6 particles cm^{-3} and with temperatures from 10 to 10^6K. From time to time, part of this interstellar medium collapses to form further generations of stars. This simple picture of evolution is altered by possible accretion of intergalactic gas and by matter circulation between different parts of a given galaxy, including a gaseous halo; activity in the galactic nucleus may also play a role.

With the exception of the H II regions surrounding the massive, young stars, the planetary nebulae and the centers of dense molecular clouds, the interstellar atoms, ions and molecules are in their ground states (because densities and the

UV interstellar radiation field are low) and they are best observed through the resonance absorption lines they form in the spectra of target stars. These lines are extremely numerous and sensitive to low column densities, but most of them occur in the far UV range, especially below 1200 Å; their analysis provides unique clues for understanding the galactic history outlined above: kinematics, ionization and elemental abundances in the diffuse interstellar medium.

In 1904, Hartmann first noticed two steady absorption lines, due to Ca II, in the spectrum of the binary star δ Ori which were recognized as interstellar by Slipher in 1909. Until 1951 with the discovery of hydrogen through its 21 cm line, only Ca II, Na I and very few other ions and molecules (CN, CH, CH^+) were observable in the visible. Nevertheless, they allowed, with the increasing resolution of the spectrographs, the detection of multiple components toward many lines of sight; thus, the random radial velocities of the absorbing regions with respect to each other have been shown to be around 6 km s^{-1}. However, the revolution in our understanding of the interstellar medium came from the space era and in particular from the UV astronomy.

Astronomers seem now to agree—without anything better, this is a criterium!—on the broad lines of the Mc Kee and Ostriker's model (1977, *Ap.J.,* **218,** 148). Briefly speaking, let us say that most of the interstellar volume is filled with a one million degree, diluted ($\sim 10^{-3}$ atoms cm^{-3}) gas which was evidenced by the oxyen VI absorption lines near 1035 Å and recently by the OV II X-ray emission lines. This gas is produced in overlapping cavities by supernovae explosions and strong stellar winds. The residual space is essentially made of relatively cold (10 to 10^4K) denser (10 to 10^3 at. cm^{-3}) gas forming irregular clouds of the order of a few parsecs. These diffuse clouds (a few per cent of the total volume but a significant fraction of the total mass) are continually modified by their mutual collisions; they are swept up by shock waves and evaporating by thermal conduction.

A Difficult Problem

Apart its structure, the other fundamental advance in our knowledge of the interstellar medium refers to its chemical composition. To go from absorption line observations to the abundance of the corresponding elements is often a very complicated way which involves three steps: first to determine the column density for each observed line; then add the contribution from the different ionization states for a given element, and if one of them is not observed, try to calculate its contribution; finally, to normalize the total abundance to hydrogen which has to be observed in some way.

Introduced in 1948 by Strömgren, the usual method for partly resolving the first problem is to build a curve of growth (COG), which is the logarithmic relation between the measured equivalent width of absorption lines (normalized to the wavelength λ) and the product Nfλ where f is the oscillator strength and N the column density (cm^{-2}) of the corresponding ion on the observed line of sight. While this method can give rather accurate *integrated* column densities (within a few tens %) when the line is weak (linear part of the COG) or when it is completely saturated (damping part of the COG), the results are often up to several orders of magnitude in error either if the line shows saturation effects (flat part of the COG) when N depends strongly on the velocity dispersion b within the absorbing region, or/and if the line of sight intercepts several interstellar clouds. Unfortunately, these two cases represent the large majority of observations.

In order to overcome these difficulties, we have pointed out, in collaboration with C. Laurent and A. Vidal-Madjar of the LPSP and D. York of Princeton University, a new method for analysing interstellar absorption lines. Contrary to the equivalent width which is an absorption measurement integrated over the whole line of sight and independent of the instrumental resolution, our method makes use of the information contained in the line profiles. It is based on fitting observed lines with theoretical Voigt profiles calculated by varying the parameters of the different clouds on the line of sight (number of clouds, their radial velocities, b-values and column densities) and convolved with the instrumental function (see Ferlet et al., 1980, *Ap.J.,* **235,** 478, for the first application to a wide range in f-values of atomic nitrogen lines observed with the Copernicus satellite towards γ Cas). Thus, for the first time, it is possible not only to determine the velocity structure of a line of sight observed with a spectral resolution insufficient to fully resolve the true line profile, but also to evaluate more accurate parameters for *each* detected cloud.

The second step on the way to true abundances is to add the contributions from different ions of a given element. It is sometimes easy: elements like N, O, Ar should exist in diffuse clouds only in atomic form; this has been demonstrated for nitrogen (Ferlet, 1981, *AA,* **98,** L1). However, in some cases one cannot observe the dominant ionization state: for instance, only Na I, K I, Li I are observable and one must compute through ionization equilibrium the contribution of the second ion from observations of another similar element such as Ca I/Ca II, Mg I/Mg II. But this increases a lot the uncertainties.

The last step is to normalize abundances to hydrogen which in general is present in atomic and molecular forms. As H I and H_2 give some heavily saturated lines with damping wings, their integrated column densities can be well known, but it is almost impossible to distinguish the different clouds unless by using the profile fitting method described above. By performing such an analysis toward γ Cas, we have for instance pointed out a striking variation of the argon abundance from cloud to cloud (Ferlet et al., 1980, *Ap.J.,* **242,** 576).

Abundance Variations

Generally speaking, from extensive studies of cold clouds within 1–2 kpc of the Sun, it appears that heavy elements are selectively depleted when compared to solar values, sometimes by a factor of more than 1,000, this depletion being more pronounced for refractory elements like calcium, iron, aluminium, titanium. . . . The question is then where are the missing atoms? The more probable, and the simplest, explana-

Preliminary Announcement

The 1st ESO-CERN Symposium will be held in the week of November 21st, 1983 at CERN (Geneva) on the subject:

Large Scale Structure of the Universe, Cosmology and Fundamental Physics

The Scientific Organizing Committee is composed of G. Setti (ESO) and L. Van Hove (CERN), co-chairmen, J. Audouze, J. Ehlers, E. Fiorini, H. van der Laan, D. Nanopoulos, M.J. Rees, D.N. Schramm, D.W. Sciama and G. Tammann.

The attendance to the Symposium will be limited to approximately 150 participants.

tion is that these atoms are contained in a solid phase of more or less small grains well mixed in the gas. In fact, this dust has been known since the thirties by its effects on the background stellar light, namely absorption, reddening and polarization. Studies of these phenomena provide an estimation of the dust mass—nearly 1 % of the mass of the interstellar medium, which is roughly equal to the mass of the missing species measured in the gas phase, within the COG uncertainties. This is quite satisfactory for mind! More specifically, dust grains should consist of oxydes and/or silicates, others of graphite, with almost no nitrogen compounds, this important and abundant volatile element being nearly undepleted (Ferlet, 1981, *AA,* **98,** L1).

Also, it is worthwhile to notice that depletion can vary considerably from one line of sight to another. In few cases, UV instruments could resolve high velocity clouds and find almost no depletion, a fact already known as the Routly-Spitzer effect in the visible: a very much lower ratio of Na I/Ca II column densities in high velocity clouds. This suggests a mechanism to destroy grains (for returning Ca to the gas) related to the cloud velocity, perhaps the passage of a shock wave.

Further advances in this area will come from precise knowledge of *individual* properties of the interstellar clouds in order to study what are the formation and destruction processes of dust grains, to understand the interstellar chemistry, to establish possible abundance fluctuations which will give accurate insights on the history of local nucleosynthesis. In that respect, the variable abundance of the rare gas argon that we outlined toward γ Cas could be very promising.

The abundance variations of the interstellar deuterium are another unexpected discovery due to the Copernicus observations. Unlike all elements heavier than 12, deuterium has a non-stellar origin and is supposed to be ashes of the very early phases of the Universe. Its production is strongly dependent on the baryonic number, and the evaluation of a primordial D/H ratio provides one of the very few crucial tests on the geometry of the Universe, in the frame of the Big Bang. As deuterium is very easily destroyed in stellar interiors, one expects that its interstellar abundance is about constant, at least on a small scale. On the contrary, profile fitting analysis (see e.g. Laurent, Vidal-Madjar and York, 1979, *Ap.J.,* **229,** 923) have evidenced real variations of at least a factor of two and even more in the very nearby interstellar medium. Also, York and Jura (1982, *Ap.J.,* **254,** 88) pointed out a possible correlation between D/H and Zn/H, — zinc being observed only slightly depleted (within the COG uncertainties) and thus taken as an approximate measure of the gas metallicity — as might occur if deuterium is manufactured in stars rather than only in the Big Bang. Obviously, all these results open the question of the cosmological interpretation of the observed deuterium abundance. Various models have been put forward to explain them (Bruston et al., 1981, *Ap.J.,* **243,** 161), including deuterium depletion onto grains, but none is especially convincing.

The Galactic Halo

Although the far-UV Copernicus data were at the origin of the bulk of our knowledge on the interstellar medium, they were restricted to space within 1 kpc of the Sun. Also, 1 kpc is characteristic of the extent of the epicyclic orbits around the Galaxy, and we might expect important abundance gradients beyond this distance. With the IUE satellite, some observations of other interstellar media have been made possible but only in the strongest lines above 1200 Å and at the cost of a lower spectral resolution. Therefore, all the related problems we mentioned in the data analysis are still more severe. Nevertheless, here are some exciting results concerning the Galactic halo.

Pettini and West (1982, *Ap.J.,* **260,** 561) have demonstrated the ubiquity of C IV and Si IV in the near halo (below ~3 kpc from the galactic plane), while C IV is generally not observed in the Galactic disk (Laurent, Paul and Pettini, 1982, *Ap.J.,* **260,** 163). Suggesting a temperature of 8×10^4 K if in collisional equilibrium, this halo component corotating with the disk appears qualitatively similar to the hot Galactic corona originally postulated by Spitzer in 1956 to explain the high velocity clouds observed in H I 21 cm; it could be very much relevant to the origin of the narrow QSO absorption lines.

Observations of sight-lines penetrating the entire halo (unfortunately, they are still very few within the present instrumental capability, except OB stars in the Magellanic Clouds), are clearly consistent with a corotating halo. There is also growing evidence that the Magellanic Cloud sight-lines may not be typical of halo gas: in these directions, the occurrence of high velocity interstellar components seems much more frequent. Last, a portion of the famous Magellanic Stream has been detected in the visible by York and Songaila (1980, *Ap.J.,* **242,** 976) in absorption in the spectrum of the Seyfert 1 galaxy ESO 113–IG 45 (Fairall 9), and further IUE studies show that abundances are broadly consistent with those in the Magellanic Clouds, ruling out a primordial composition.

Use of the Coudé Echelle Spectrograph (CES)

Although the UV range provides a great wealth of interstellar absorption lines, its use has suffered up to now from the lack of spectral resolution and of efficiency of space instruments. The High Resolution Spectrograph onboard the Space Telescope will open a new step but will be limited to wavelengths above 1150 Å and also by the expected little time devoted to this particular field. On the contrary, the European project Magellan, if selected by ESA, will give access to the wavelength range 300–1500 Å with a resolution of 0.03 Å down to magnitudes as faint as 16 for an unreddened O9 star at 1000 Å. In any case, both projects must be prepared by ground-based observations. The great advantage now given by ground-based instrumentation is the possibility of obtaining very high resolution, and we have largely demonstrated before how great this need is in particular to interpret the currently available UV data. Even the profile fitting method is more efficient if one can get a priori an idea of the velocity structure of a given line of sight. Unfortunately, only very few ions and molecules show interstellar absorption lines in the visible.

Optimized to give a resolving power of 10^5 or 3 km s^{-1} in its multichannel mode, and more in its scanner mode (one can note for instance that a resolution below 1 km s^{-1} is required to be able to observe the hyperfine structure of Na I), the Coudé Echelle Spectrograph (CES) offers another important characteristic for absorption spectroscopy, namely a very clean instrumental function. Indeed, the stray-light level in the classical coudé ruled gratings degrades spectra, giving rise to more than 20 % error in measured equivalent widths. The third advantage of the multichannel mode is provided by the actual detector, a Reticon silicon photodiode array cooled to 136 K, which has a responsive quantum efficiency near 70 % at 6000 Å. This, together with a possible immediate reduction of the data, makes it a very fast and friendly system for the detection of very weak features in strong continuum signals (Enard, 1981, *The Messenger,* No. 26, 22).

For one year now, we have used the CES + Reticon, fed by the 1.4 m Coudé Auxiliary Telescope. In the following, we illustrate some specific interstellar questions. One of the best suited laboratory for studying the violent interstellar medium is the Carina Nebula region. Several high-velocity clouds are seen, some also in the UV, and abundance determinations show that one of them has been contaminated by freshly

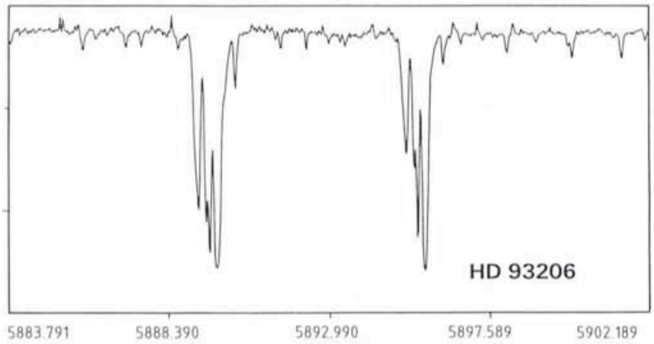

Fig. 1: *The interstellar Na I D lines toward HD 93206 in the Carina region, taken with the CES + Reticon at 10^5 resolving power in one hour. The wavelength calibration is based as usual on neon and thorium lines and/or on a standard star. Clearly 5 components are detected; all very weak lines spread over the spectrum are due to atmospheric water absorptions.*

processed material ejected by a recent supernova explosion (Laurent, Paul and Pettini, 1982, *Ap.J.,* **260,** 163). As an example of the information that CES data bring about the velocity structure, Fig. 1 shows the Na I D-lines toward HD 93206: five components are clearly detected.

Deuterium abundance variations have been recognized in the local interstellar medium, along with fluctuations in the H I densities. In order to explain these, Vidal-Madjar, Audouze, Bruston and Laurent have first postulated in 1977 (*La Recherche,* No. 80, p. 616) the presence of a very nearby interstellar cloud, coming roughly from the Sco-Oph direction toward the solar system with a velocity around 22 km s^{-1}. Further UV and X-ray data are currently interpreted as the evidence of the location of the Sun at the edge of such a cloud, and we have undertaken IUE observations since, thus, a unique opportunity is offered to study an interstellar cloud from inside. However, it is obvious that high resolution, high signal-to-noise ratio data are absolutely essential. Such a programme is also under way through observations in selected directions of several co-aligned stars at various distances. It is in course of interpretation; but within a few parsecs, no OB stars are available and only white dwarfs can be used to probe the very local medium. This requires a lot of time.

Still about deuterium, but now in more remote places, a recent profile fitting analysis of Copernicus data toward ε Persei (Vidal-Madjar, Ferlet, Laurent and York, 1982, *Ap.J.,* **260,** 128) revealed a surprising behaviour of the deuterium absorption features which led us to reanalyse all the published values of interstellar deuterium abundances. A strikingly clear trend has been discovered between these values and the luminosity class of the target stars, suggesting that for main sequence stars, D/H seems to be overestimated (due to some stellar wind H I material producing blended features with the D lines). Thus a probable D/H ratio of the order of 5×10^{-6} is derived, implying a more open Universe than previously thought (except if neutrinos are massive enough to close the Universe). On the other hand, it has been shown that stars more massive than 6–7 $M_\odot$ should retain their initial deuterium, although surface deuterium depletion may occur during and after the main-sequence stage. Therefore, search for deuterium in stellar atmospheres could provide valuable information on the initial D/H ratio as modified by stellar evolution. Fig. 2 shows the enlarged Dα region in the CES spectrum of the supergiant massive star Canopus (Ferlet, Dennefeld, Laurent and Vidal-Madjar, 1982, AA, submitted). No deuterium feature is seen at a detection level of 0.07 mÅ. Our derived D/H upper limit of 5.5×10^{-7} could mean that the initial D/H has been depleted by a factor of at least 9 through mass loss and/or mixing. The next step which will be performed soon is to look for deuterium in massive main-sequence stars. In the future (the Magellan project), a much expected observation for cosmology will be to determine the deuterium abundance in less evolved galaxies like the Magellanic Clouds.

Preliminary tests have shown that the brightest Magellanic Cloud OB stars are already within the capabilities of the CES, although close to the practical limit. The use of extragalactic sources as probes of the Galactic interstellar medium presents three clear advantages. Firstly, there is in general a sufficient velocity separation between the sources and the local gas to avoid confusion. Secondly, they provide unconfined lines of sight over long pathlengths through the Galaxy and the halo. Thirdly, all kinds of effects related to the target object—as the one discovered in deuterium observations toward ε Per and described above—are eliminated for the local gas. Furthermore, in the case of Magellanic Cloud stars, one can also probe the interstellar medium of less evolved galaxies, closer to primordial matter, and attack directly the problem of the deepness of the Small Cloud. Such a programme is going to be undertaken in collaboration with M. Dennefeld, E. Maurice and a group of Marseille's Observatory, partly as a complement of IUE results already obtained by L. Prévot et al. As a feasibility test, Fig. 3 shows the Na I spectrum toward the high latitude B1 star HD 119608. At least 4 components are well resolved, one having a velocity > 50 km s^{-1}, which would be completely blended in present UV data. Another preliminary observation of R 136 in 30 Doradus is also very promising: for instance, some high velocity components are revealed at intermediate velocities between local gas (near 0 km s^{-1}) and Large Cloud gas (around +280 km s^{-1}). For this kind of observations, the improvement

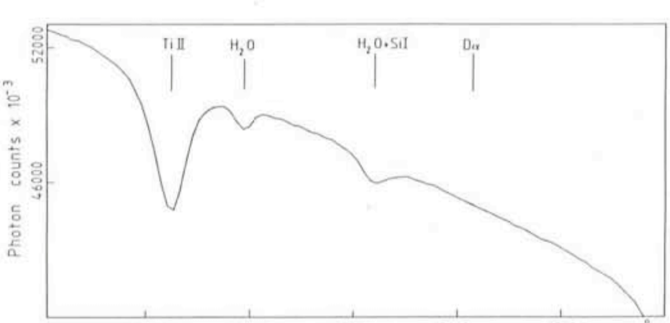

Fig. 2: *Enlarged portion of the Hα blue wing in the CES spectrum of Canopus, with some relevant stellar and atmospheric water lines marked. 29 exposures have been added and the actual signal-to-noise ratio is around 3700.*

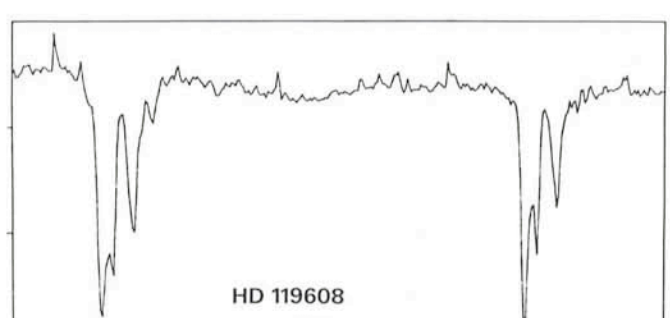

Fig. 3: *The Na I spectrum toward the high latitude B1 star (z~3 kpc) HD 119608, recorded in two hours at a resolving power of 10^5.*

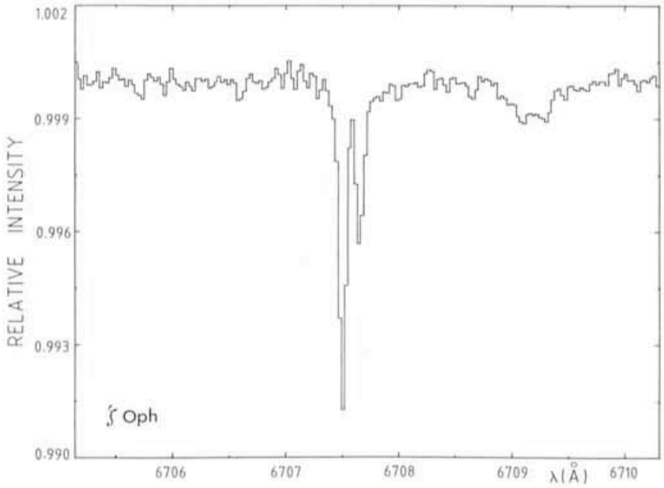

Fig. 4: *The interstellar lithium absorption line toward ζ Ophiucci, E(B-V) = 0.32. This spectrum is the sum of 34 exposures representing a total of 17 hours integration time. The signal-to-noise ratio (RMS) is ~3950. The intensities have been normalized to the continuum.*

expected soon will be to feed the CES directly from the 3.6 m prime focus through fiber optics and/or to implement a CCD detector instead of the Reticon.

Among other interstellar investigations, the last (but not least) we will speak about concerns the lithium abundance. As deuterium, the two isotopes of lithium are not of stellar origin. The existence of ^{6}Li is rather well explained by spallation reactions between galactic cosmic rays and interstellar gas. For the larger abundance of ^{7}Li, additional sources must be found. The main one is production during the primeval Big Bang, but complementary sites of creation have been proposed like red giants and nova outbursts. The interstellar lithium abundance and ^{7}Li/^{6}Li ratio are therefore key parameters to evaluate the relative weight of production and destruction processes, to check models of nucleosynthesis and of chemical evolution of galaxies, finally to provide a further test (beside deuterium and helium abundances) on the geometry of the Universe. The only accessible resonance line of lithium is the doublet of Li I at 6708 Å (151 mÅ of separation, the ^{6}Li I doublet being redshifted by 160 mÅ). The best result was obtained in collaboration with M. Dennefeld toward the 09.5 star ζ Oph which is known to shine behind a well studied interstellar cloud (Fig. 4). In order to derive the ^{7}Li/^{6}Li ratio for the first time outside the solar system, we have conducted a

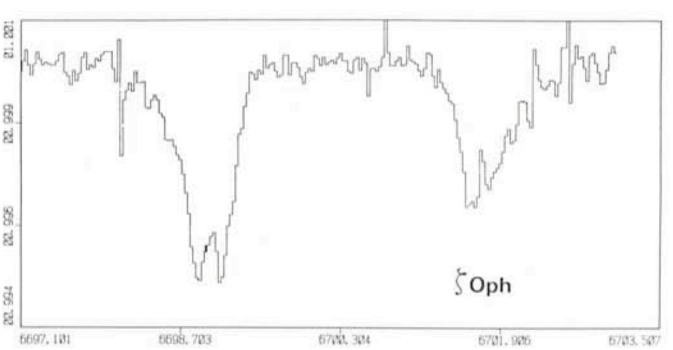

Fig. 5: *Possible new interstellar absorption lines due to the molecule CS^+ toward ζ Oph. Same spectrum as in Fig. 4. The equivalent widths of the two features are of the order of 3 and 2 mÅ.*

profile fitting analysis. In the best determined cloud, we find a temperature of less than 50 K. In this particular component, the solar ^{7}Li/^{6}Li (12.5) does not fit the data and must be replaced by a value between 25 and 180 (most probably 38). After correcting for the unobserved dominant ionization state Li II, the interstellar ^{7}Li/H ratio is found to be 1.2×10^{-10} (Ferlet and Dennefeld, 1982, *Ap.J.* submitted).

Finally, in the vicinity of the lithium lines, we have detected in several lines of sight faint absorption lines which could be due to the molecular ion CS^+ (Fig. 5). If the identification is confirmed—this requires accurate theoretical computations of laboratory wavelengths—the interstellar chemistry will have to thank the CES + Reticon for discovering an important new molecule.

Acknowledgement

It is a real pleasure to remind the most valuable help received from the ESO staff on La Silla. Special thanks are due to José Veliz and Robbie Spruit.

List of Preprints Published at ESO Scientific Group

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207. M.P. Véron-Cetty, P. Véron and M. Tarenghi: The Composite UV Emission Spectrum of Seyfert 1 Galaxies. *Astronomy and Astrophysics.* September 1982.
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