the resulting reproduction of the *lpv* of He I 4471 and Mg II 4481. In Fig. 4, results for additional lines of helium and other ions are shown, all computed with the same set of stellar and pulsational parameters.

4. Do all Be stars pulsate?

Since the periodic *lpv* of ω CMa is among the strongest known, the question needs to be addressed whether it is a typical Be star.

ω CMa is a B2 IV star. Since it is known that Be stars rotate almost critically, its low projected rotational velocity *v* sin *i* points to a pole-on orientation, which is also supported by the derived model parameters. If all (or most) other such Be stars would show this kind of periodic variability (possibly weaker, but in principle the same), the *lpv* could be explained by *nrp* in general.

Although most Be stars are of early B spectral type, there are not too many bright ones in the same range of *v* sin *i* as ω CMa. Searching archival data and securing additional observations with FEROS, we found most of them to show spikes like ω CMa, or a similar variability with lower amplitudes, i.e. no fully developed spikes, but global asymmetry variations, as is shown in Figure 5.

A complementary approach focuses on the observed *lpv* of equator-on (high *v* sin *i*) stars. The *lpv* of these stars looks different from the pole-on ω CMa. But if ω CMa is proto-typical, the differences should be just inclination effects. To address this expectation the model of ω CMa was computed for a set of inclinations, so that the resulting *v* sin *i* would be the same as for some typical Be stars. Then, the modelled variations were compared to the observed ones (Fig. 6). The similarity of model and observations shows that the model of ω CMa represents a typical early-type Be star.

5. Consequences and outlook

The main result of the modelling project is the confirmation that early-type Be stars pulsate nonradially in *g*-modes. Based on the detailed modelling of ω CMa, it could be shown that this star is proto-typical, and that the periodic *lpv* of early type Be stars in general is due to nonradial pulsation.

Several stars in the database, including ω CMa, were observed to replenish their disks via outburst events during our campaigns. Although plain *nrp* cannot account for mass and angular momentum transfer into the disk, there is observational evidence for a connection between *nrp* and the disk formation. Among other effects, the *lpv* pattern of ω CMa changes in several spectral lines during an outburst, which might provide the key to understand the mass transfer mechanism between Be stars and their disks.

Just as the pulsational parameters are determined by the best fit of the variability, the stellar parameters can be determined by the best fit of the mean absolute line profile. The modelling method described above offers the potential to combine these two steps in a single analysis, due to the good reproduction of both residual variability and absolute line profile (see Fig. 6). Since nonradial pulsation breaks the symmetry of the stellar surface w.r.t. rotation, one can even derive the stellar inclination angle from the modelling, while otherwise it is inseparably factored into the projected rotational velocity *v* sin *i*. Rotation is becoming increasingly important for understanding stellar structure and evolution. A method to derive *v* and *i* separately, utilizing the *nrp* pattern on the stellar surface, bears great potential not only for Be stars, but for a much wider range of objects, since nonradial pulsation is widespread in the Hertzsprung-Russell-Diagram.

The VLT and the most distant quasars

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1. Introduction: optical surveys for high-redshift quasars

Quasars are amongst the most luminous objects in the Universe, allowing us to study them and any intervening material out to very large distances, corresponding to look-back times when the Universe was very young. Finding and studying quasars at high redshifts is one of the best ways to constrain the physical conditions in the early Universe. The mere existence of luminous quasars at such early times, and the implied presence of black holes with $M \geq 10^9$ $M_\odot$ place stringent limits on the epoch at which massive condensed structures formed, thereby constraining structure formation models (e.g. Efstathiou and Rees 1988).

Most known high redshift quasars have been found as outliers in color space from the stellar locus in multicolor optical surveys (e.g. Warren et al. 1994, Kennefick et al. 1995). One prominent survey is the Sloan Digital Sky Survey (SDSS, York et al. 2000) which is systematically mapping one-quarter of the entire sky, producing a detailed multi-color image of it and determining the positions and absolute brightnesses of more than 100 million celestial objects. The SDSS will also measure the distance to a million of the nearest galaxies, producing a three-dimensional picture of the Universe through a volume one hundred times larger than that explored to date.

One of the principal aims of the SDSS is the construction of the largest sample of quasars ever, with more than 100,000 objects spanning a large range of redshift and luminosities, giving us an unprecedented hint at the distribution of matter to the edge of the visible Universe.

Thanks to the accurate 5 band photometry of SDSS, high redshift quasars can be efficiently selected by their distinctive position in color-color diagrams, with characteristic colors due to the main feature of the quasar spectra, viz., the strong Lyα emission line, the Lyα forest and the Lyman limit. During its first year of operation, the SDSS has already found a large number of extremely distant quasars, including more than 200 new quasars at redshift greater than 4 and the most distant quasar known, SDSS J1030 + 0524 at $z = 6.28$ (Fan et al. 2001). Until a few months ago this was also the most distant object known but it has been surpassed by a galaxy at $z = 6.56$ recently discovered by Hu et al. (2002).

2. VLT observations of the most distant quasars: revealing the conditions of the early Universe

The spectra of very high redshift quasars can tell us a great deal about the conditions in the early Universe. In particular, we can use them as probes of the intergalactic medium (IGM) to determine the state of any intervening material along the line of sight.

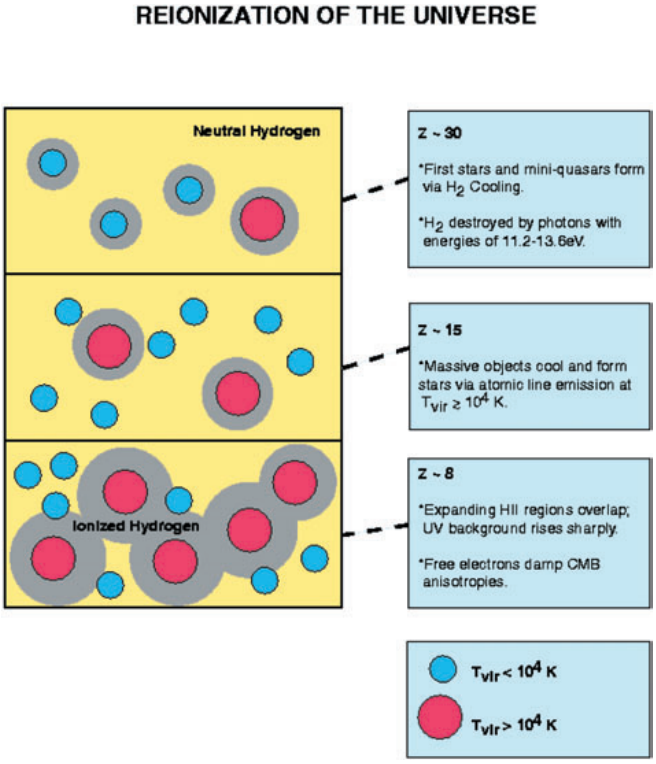
One of the fundamental questions of modern cosmology is how and when the Universe became ionized (for a complete review see Loeb & Barkana 2001). When the Universe was very young, after the recombination epoch at z ~ 1000, the hydrogen was mostly neutral and homogeneously distributed. As the first luminous sources formed, i.e. quasars and the first generation of stars, they started to ionize the surrounding hydrogen. In the very early stages only small regions around each source became partially or totally ionized, but as time passed and more sources turned on, these "bubbles" of ionized gas expanded until they finally overlapped. The time at which the hydrogen becomes completely ionized throughout most of the space, is called the "reionization epoch" and marks in turn the end of the so-called "dark ages". The transition from a totally neutral IGM to a completely ionized state that we just described is nicely illustrated in Figure 1 (from Loeb & Barkana 2001).

We can study the process of reionization through the spectra of luminous sources such as quasars: if a quasar is still surrounded by neutral (or partially neutral) hydrogen, its emission shortward of the Lyα line will be completely absorbed. As a consequence we will observe a sudden drop of flux in the spectrum: this is called a Gunn-Peterson trough.

We have recently started several VLT observing programs of follow up observations of SDSS quasars, including the most distant ones, using both ISAAC and FORS. In particular we have obtained optical and near-IR VLT spectroscopy of the most distant quasar SDSS 1030+0524 at $z = 6.28$ and near-IR spectroscopy of the second most distant quasar, SDSS J1306+0356 at $z = 5.99$ (Fan et al. 2001). The data were obtained with ISAAC and FORS2 through a director discretionary time proposal, in service mode. Figure 2 presents the VLT optical spectrum of SDSS 1030+0524: in the upper panel we show the 1-dimensional spectrum and in the lower panel the 2-dimensional spectrum.

The $z = 6.28$ quasar is indeed the first object to show a complete Gunn-Peterson trough: the flux is consistent with zero, within the noise, over a large wavelength region, 8400 Å to 8710 Å; below 8400 Å, there is detected flux. However, we cannot infer from this that *all* of the hydrogen in the IGM was neutral at this epoch: in fact only a small fraction of neutral hydrogen is sufficient to completely absorb the flux from the ionizing source. What is definitely true is that if we observe increasingly distant sources (e.g. Fan et al. 2001) the amount of flux suppression is rising steeply so we can conclude that we are getting closer and closer to the epoch of reionization. What we are probably observing at $z = 6.28$ is the end of the reionization process, i.e. the stage in which the ionized bubbles are overlapping.

Figure 1: A representation of the various stages in the reionization of hydrogen in the intergalactic medium. Initially the IGM is completely neutral. The first stars and quasars (here in blue and red) form at the center of the most massive halos, and start to ionize the surrounding hydrogen. These ionized bubbles grow and then overlap: eventually all the IGM becomes completely ionized (Figure from Loeb & Barkana 2001).



The VLT spectrum of SDSS 1030+0524 also clearly shows the presence of the ionized hydrogen bubble in the immediate surrounding of the quasar, the so-called "proximity effect". As we mentioned earlier, even if the quasar starts shining in a completely neutral medium it will ionize its surrounding very quickly. From the VLT spectrum we can measure the size of the bubble which is about 1.5 Mpc (physical size at $z = 6.28$). If we assume that all the hydrogen atoms in a sphere of such radius have been ionized by the quasar photons and estimate the ionization rate from the quasar UV continuum, we can then infer a minimum time that the quasar must have been "on", in order to produce a bubble of the observed size. This time is about 10 to 13 million years depending on the exact shape of the quasar continuum.

There are a number of uncertainties, such as the exact density of the gas in the quasar environment, the fraction of gas that was actually neutral when the quasar switched on and the clumpiness of the gas, i.e. whether it was distributed more or less homogeneously around the quasar. All these factors could modify the estimate of the quasar age, so the above result must be taken with some caution.

3. Metallicity of high redshift quasar environment: when did the first star form?

Remarkably, the optical and near infrared spectra of these high redshift quasars show strong NV and CIV emission lines. These lines give us the possibility to measure the presence of heavy elements (metals) in the quasars' broad line region. These metals are synthesized by the local stellar population and their abundance is related to the age of the stars and to the history of star formation. From measure-

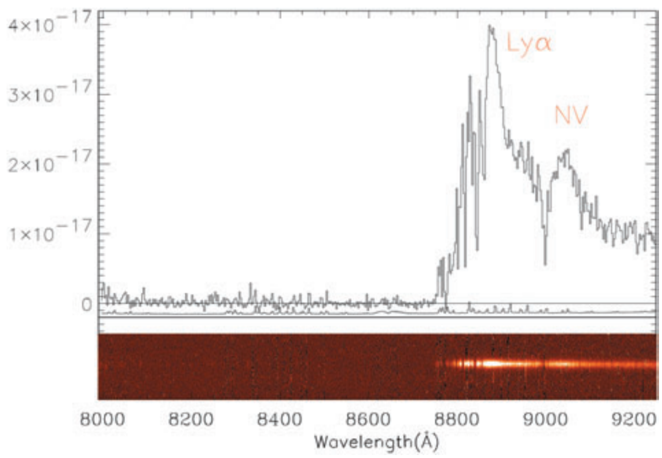


Figure 2: The VLT/ FORS2 one dimensional optical spectrum of the quasar SDSS 1030+0524 showing the lack of flux to the blue of the Lα emission line. The bottom line shows the error array derived from the sky spectrum and offset by -0.2×10^{-17}. Below is a color representation of the sky-subtracted spectrum on the same wavelength scale. The spatial (vertical) extent of the spectrum shown is 20″.

ment of C IV, Lyα and N V and from limits on HeII derived from the FORS and ISAAC spectra we were able to set constraints on the metallicity in SDSS 1030+0524 and SDSS 1306+0356. The metallicity turns out to be much higher than the solar value. Comparison with models for the formation of metals (e.g. Hamann & Ferland 1999) indicates that stars must have been forming for several hundred million years to produce all the metals observed. Therefore the firs stars must have formed around the active nucleus at redshift ~8.5 or higher. Note also that the inferred age of the stars is much longer than the age of the quasar derived in the previous section, even considering the uncertainty of both estimates.

The VLT will soon give us more precise and reliable estimates of the age of the quasar environment. Emission lines from other elements, such as Fe and Mg can provide a better constraint to the age of the stars since their abundance depends more strongly on time. Fe is generated by supernovae type Ia on timescales of about 1 Gyr after the initial starburst (Greggio & Renzini 1983), whereas the production of Mg is dominated by supernovae types II, Ib and Ic. So the ratio of Fe to Mg should change dramatically after the first Supernovae Ia explode, i.e. 1 Gyr after the initial starburst.

We are presently carrying out a program to detect such lines in a sample of quasars at redshift between 5 and 6. By measuring the metal abundances we will then be able to set limits on the age of the stars and hence to the age of the Universe at redshifts as high as 6. From this age, constraints can then be put on H_0, $\Omega_0 = \Lambda = 0$: for $H_0 = 65$, $\Omega_0 = 0.3$ and $\Lambda = 0.7$, the age of the Universe is ~ 1.2 Gyr at $z = 5$, while a model with $\Omega_0 = \Lambda = 0$ has an age exceeding 2 Gyr and a model of $\Omega = 1$ has an age of 0.7 Gyr.

4. Future developments and VLT contribution

The VLT will certainly give further contributions to our understanding of quasar formation and the reionization process. Future targets for VLT observations will be provided by the SDSS in the next few years. From the space density of luminous quasars at $z \sim 6$ we estimate that the SDSS will find a further ~ 10 luminous quasars in the redshift range $6 < z < 6.6$ over the 10,000 deg^2 of the total survey area (Fan et al. 2001). At even higher redshift ($z > 6.6$) the Lyα emission line moves out of the optical window and into the infrared. Thus the objects become very faint at optical wavelengths due to the absorption by neutral hydrogen gas in the foreground at lower redshifts. SDSS optical photometry alone is not sufficient to find such objects but needs to be combined with near infrared colors. The next generation near-infrared sky survey, and in particular the UKIRT Infrared Deep Sky Survey (see the article by Stephen Warren in this issue of the Messenger) will provide the ideal complement to SDSS for the search of more distant sources. Indeed UKIDSS has amongst its aims the breaking of the redshift 7 barrier for quasars in order to determine the epoch of reionization.

Follow-up observations with 8-m-class telescopes giving high-resolution, high signal-to-noise ratio spectra of these luminous quasars in the Lyman series absorption regions will provide valuable probes of the reionization epoch (and beyond) and, in particular, measure the spatial inhomogeneity of the reionization process.

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Evidence for external enrichment processes in the globular cluster 47 Tuc?

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1. Abundance spreads in globular clusters

Globular clusters (GCs) have long had an appeal to astronomers as laboratories for studying stellar evolution. Part of their attraction arises not only from the vast number of stars that they contain, but also from the common properties that stars within a cluster are often thought to share. For example, in one standard text book (Carrol & Ostlie 1996) we find: "Every member of a given (star) cluster is formed from the same cloud, at the same time, and all with essentially identical compositions." Despite this paradigm, it has been known for 30 years that the element abundances among stars in a given GC can vary significantly. Globular clusters are the oldest star clusters known with ages on the order of the age of the universe. The chemical abundance pattern among their stars is therefore an important clue to the first substantial production of heavy elements by massive stars in the early universe. Understanding the origin of the chemical inhomogeneity of GCs is therefore of interest for cosmology as well as stellar evolution.

The abundance of the elements carbon, nitrogen, and oxygen (C, N, and O) in particular show large variations among the red giants in many GCs (for a review see, e.g., Kraft 1994). These elements are of particular interest since they are the catalysts in the CNO cycle of nuclear fusion, in which hydrogen is converted into helium. The abundances of individual elements such as C and O can be measured directly by high-resolution spectroscopy, but this is very time-consuming even with large telescopes. An efficient alternative to probing the star-to-star scatter in the CNO elements, especially for larger samples of stars, is to measure absorption band strengths of the CN molecule using low-resolution spectroscopy. The behaviour of this molecule can serve as a useful tracer of inhomogeneities in the individual CNO elements.

Absorption bands of CN occur at a number of places in the visible spectrum. As an example we show an integrated drift-scan spectrum of the moderate metallicity GC 47 Tuc in Figure 1, which was obtained in 2001 at the ESO 1.5m telescope with the B&C spectrograph. The CN absorption band at 3883 Å is clearly visible and is marked in the spectrum. Since the integrated light of 47 Tuc is emitted by a mix of stars, the existence of this strong 3883 Å feature indicates that stars with strong CN bands must be an important component of this cluster. The integrated spectrum, however, cannot tell us