KUEYEN: a unique machine for stellar studies

Luca Pasquini[1]

European Southern Observatory, Karl Schwarzschild Strasse 2, D-85748 Garching Bei München, Germany

Abstract. The VLT telescope KUEYEN (formerly UT2) will be a unique facility for stellar study thanks to the coupling of high resolution spectroscopy and multiplex capabilities with an 8 meter telescope.

FORS2, UVES and FLAMES will produce data which will in principle be able to solve several current outstanding problems in stellar astrophysics. On the other hand, when considering both the quantity and the quality of the data produced, the full exploitation of the facilities offered at this telescope requires a novel and well planned approach by the users.

1 Introduction

8 meter class telescopes and the VLT in particular represent a major step in the advancement of observational astrophysics. While emphasis is often given to the impact of these telescopes and their instrumentation on observational cosmology and extragalactic astronomy (cfr. the contributions to the plenary session of this meeting), little doubt exists that the VLT will have a tremendous impact also on stellar astrophysics. In particular the instrumentation of KUEYEN (formely UT2) will be especially suitable to stellar studies, thanks to the combination of 4 key characteristics:

1. High Resolution Spectroscopy
2. High Multiplex
3. High Performance
4. Fed by the VLT!

The scheme of the instrumentation on KUEYEN foresees three instruments. On Nasmyth B the UVES high resolution spectrograph will be offered from April 2000, at the same time as the Cassegrain instrument FORS2. The Nasmyth A platform will host the FLAMES facility, which will initially feed the GIRAFFE and UVES spectrographs and it will have the capability of being upgraded to feed a third (TBD) spectrograph. FLAMES will be offered in the second half of 2001.

2 Instruments summary

FORS2 is very similar to FORS1, the focal reducer and low resolution spectrograph successfully installed at ANTU (Appenzeller et al. 1999); the main differences between these two instruments being that FORS2 will be equipped with an echelle which will alllow to obtain a resolving power of 5000 and that it will have a multislit (MOS) capability to acquire up to $\sim$50 spectra simultaneously, compared to the maximum of 19 slits with FORS1.

UVES is a high resolution spectrograph, with two (Blue and Red) optimized arms and with a resolving power - aperture product $R\times\alpha = 40000$. A resolving power of up to 120000 can be obtained in the Red arm by using image slicers. Observations can be carried out in the Red or in the Blue arm, or simultaneously in both arms if the dichroic mode is chosen.

Thanks to the optimization of the components of the two arms (optics and detector), UVES is very efficient over the whole 300-1000 nm spectral range. This high efficiency will allow to gather a S/N of 10 on stars of V$\sim$20 or a S/N of 100 on stars of V$\sim$16 in a 2 hours long observation.

FLAMES is a fibre facility composed of a Nasmyth corrector, a fibre positioner and the fibre links to the GIRAFFE and UVES spectrographs. The main characteristics of FLAMES are summarized below:

- Field of View: 25 arcminutes diameter
- Capability of positioning 130 fibres for next observation in less than 20 minutes while simultaneously observing
- Minimum separation between objects: 10 Arcseconds
- 8 one arcsecond fibres feed the Red arm of UVES, with a R=40000
- 132 fibres feed GIRAFFE in Medusa mode, each with a 1.2 arcseconds aperture; with the two GIRAFFE gratings R=15000 and R=5000 can be obtained
- 15 deployable Integral Field Units feed GIRAFFE in IFU mode. Each IFU is composed of 20 microlenses, each of 0.5 arcseconds aperture for a total sky coverage of $\sim 2\times3$ arcseconds, and R=22000 and R=9000
- 1 GIRAFFE Integral field unit (ARGUS): 300 microlenses will provide a field of 7×11 arcseconds and R=22000 and R=9000 with a 0.5 arcsec sampling. A focal enlarger will also allow a 0.3 arcsecond sampling.
- Simultaneous GIRAFFE and UVES observations will be possible.
- FLAMES will be offered to users in Sept 2001 in UVES and GIRAFFE Medusa mode, two months later with the GIRAFFE Argus and IFUs modes.

Although it is not possible to easily summarize the capabilities of the three KUEYEN instruments, Table 1 gives an overview of the multiplex and highest resolution combination available.

3 Scientific applications

Thanks to the combination of the characteristics summarized in Table 1 a number of outstanding observational problems will not only be takled, but solved by KUEYEN.

Table 1. In this table some characteristics of the KEUYEN instruments are summarized. In column 2 the multiplexity degree is indicated, in Column 3 the aperture on the sky corresponding to the maximum resolving power (given in Column 4). Note that the highest resolving power on UVES Red is obtained through the use of an image slicer. In the last column the approximative wavelength coverage per setting is given.

Inst/Conf	Mult.	Slit (Arcsec)	R_{Max}	Coverage (nm)
UVES Blue	1	0.5	80000	80
UVES Red	1	0.3*	120000	200 or 400
UVES Dichr	1	0.5	80000	280 or 480
FORS2 Slits	19	0.5	5000	
FORS2 MOS	50	0.5	5000	
GIRAFFE Medusa	132	1.2	15000-5000	$\lambda/19$ - $\lambda/7$
GIRAFFE IFUs	15	0.52	22000-9000	$\lambda/19$ - $\lambda/7$
'3D'	20 each	2×3		
GIRAFFE Argus	1	0.52/0.3	22000-9000	$\lambda/19$- $\lambda/7$
'3D'	300	$7\times11/4\times6.3$		
FLAMES+UVES Red	8	1	40000	200-400

By 'solved' in this context is meant that the observational data will be of sufficiently good quality and quantity that no further data should be required to answer the astrophysical questions as they are presently formulated; surely more questions will arise as a result of these observations.

A non-exhaustive list of these astrophysical topics is given below, and, since most of them are discussed by other authors in this volume, the reader may refer to these contributions for a detailed discussion.

- Bulge Chemical Composition
- Light Element Abundances (Be, Li, Li^6/Li^7)
- Abundances of the most metal poor stars
- Chemical composition and dynamics of galactic Globular and Open Clusters
- Magellanic Clouds: Age and chemical composition of Field and Clusters, Star Formation History (SFH), Metallicity dependence of RR Lyr P-M relationship.
- Metallicity, SFH of the Sagittarius dwarf galaxy
- Local Group galaxies: Chemical composition and dynamics
- Accurate distances of clusters and MCs with Eclipsing Binaries
- Evolution of O-A stars in Local Group galaxies; abundances and mass losses along the tracks
- Stellar parameters, mass losses of central stars of planetary nebulae
- Evolution of massive stars as function of metallicity, dating starbust at high Z
- Rotation of white dwarfs from narrow NLTE core of Balmer lines

- Physics of Cepheids, calibration of Baade-Wesselink method.
- Hot stars beyond the local group: chemical composition, distances

3.1 Science case: 47 Tuc

In order to illustrate the possible observational strategies and the potentiality of KUEYEN, it is instructive to briefly analyze a well established science case.

47 Tuc is one of the best studied Globular Clusters and it has very interesting characteristics: for instance it probably belongs to the old cluster generation, even if it has a quite metal rich (Fe/H $\sim$-0.7) population (see i.e. Hesser et al. 1987). The turnoff is located at V$\sim$17.5, which implies that main sequence stars are well reachable with UVES and GIRAFFE.

By studing a large number of stars with high resolution and high S/N ratio observations, it will be possible to resolve many outstanding problems which affect this cluster and have deep implications in many branches of modern astrophysiscs. For instance, in 47 Tuc evidence exists of chemical differences (CH and CN) among giants *and* among main sequence stars (see i.e. Cannon et al. 1998). What is producing the observed spread? Do other chemical elements show these differences? Does the chemical composition correlate with the spatial distribution of the stars ?

Also, thanks to its combination of old age and high metallicity, 47 Tuc is a very ineteresting object for the study of the Li evolution and big bang nucleosynthesis (Pasquini and Molaro 1997); what is the Li abundance in turnoff stars? Is that higher than the Li plateau (Spite and Spite 1982) indicating Li production in the early galaxy? Does a dispersion in Li abundance exist among main sequence stars of 47 Tuc with similar temperatures?

Also, after Hipparcos, several authors have investigated the ages of globular clusters calibrating them with nearby subdwarfs (Gratton et al. 1997, Pont et al. 1998). This analysis is based on the assumption that the derived chemical abundances do not suffer from systematic effects when derived for main sequence and giant stars (cfr. i.e. Pont these proceedings). Do systematic effects exist in deriving metal abundances in dwarfs and giants ? An homogeneous data set covering from the RGB to the TO of a Globular Cluster will provide the ideal test.

In order to answer these questions a set of high resolution, high S/N ratio spectra for a large number of stars belonging to the cluster and spatially distributed is required. In the following I assume that 450 stars, divided in several magnitude bins from the tip of the RGB to 0.5 magnitudes below the TO are observed. I also assume that 3 GIRAFFE settings are enough to derive the most relevant elemental abundances (Li, Fe, Ca, C, N, Mg, Na).

- Sample: 450 stars with $14 < V < 18$: 100 stars $14<V<15$; 100 stars $15<V<16$; 100 stars $16<V<17$, and 150 with $17<V<18$.
- 110 stars in GIRAFFE MEDUSA mode are observed simultaneously (leaving 22 fibres for sky recording), with a minimum of S/N=60 per resolution element.

This translates into approximately:
6×0.5 Hour for the V<16 200 stars
3×1 Hours for the 100 16< V <17 stars
6×3 Hours for the 150 17< V <18 stars
for a total of 24 observing hours, or less than 4 VLT UT2 nights and a total of more than 2000 spectra.

- In addition, simultaneously $\sim$ 120 UVES Red Spectra at higher resolution can be obtained. These spectra can be used to determine a more detailed and thorough analysis and/or to validate the results obtained from the GIRAFFE lower resolution spectra.
- By distributing in time the observations, at least 3 spectra at different epochs are obtained, thus providing a good statistics on binary stars and dynamics of this globular cluster as an additional bonus. If, finally, information on the dynamics of the core is required, this could be obtained with one frame of GIRAFFE in Argus mode, or an additional 0.5 hour of observing time.

What clearly emerges from the previous discussion is that with a reasonable number of KUEYEN nights it will be possible to observationally solve a number of outstdanding unsolved questions.

What is also relevant, is that when combining the number of targets, the S/N ratio and resolution required, this research seems impossible with any telescope other than KUEYEN.

4 Implications for Astronomers

The example in the previous section has shown how in a few nights KUEYEN will be able to produce thousands of spectra.

Since in typical stellar high resolution work, on the other hand, a detailed analysis is required in order to retrieve the astrophysical information, this large amount of spectra calls for an effort towards the automatization not only of the data reduction (which will be provided by ESO), but also of the data analysis.

In Table 2 the amount of STELLAR spectra produced by KUEYEN in the typical 10 years lifetime of the instruments is estimated. It is assumed that the KUEYEN nights dedicated to stellar work are of the order of 160/year and that a mean of 6 science exposures per night are acquired.

Even if this simple prediction may be off by a factor 2, it clearly shows that it will be possible to obtain with KUEYEN $\sim$ 0.5 million stellar spectra in 10 years.

In addition FLAMES will require accurate relative astrometry (0.2 arcseconds) for targets, guide and fiducial stars, and this has to be provided by the observers. One very positive note in this sense is that the 2.2m WFI recently installed (Baade et al. 1999) at the ESO-MPA 2.2m telescope at the

Table 2. Number of stellar spectra produced by KUEYEN instruments in 10 years of use; for assumptions see text. The UVES spectra in FLAMES mode are considered to be acquired simultaneously to the GIRAFFE spectra.

Inst/Conf	Mult.	Nspectra/Night	Nights/Yr	NYr	Total
UVES	1	6	80	10	4800
FORS2 SLIT	19	6	10	10	11400
FORS2 MOS	50	6	10	10	30000
GIRAFFE Medusa	120	6	50	10	360000
GIRAFFE IFUs	15	6	10	10	9000
FLAMES+UVES Red	8	6	60	10	28800
			160	10	444000

La Silla observatory has a field of view well matching the one FLAMES, and a request for a survey of FLAMES stellar field has been recently submitted to the Working Group for Public Surveys (The Messenger **94**, 31).

Nevertheless, it is clear that both the observation preparation and analysis of such an amount of high quality data will require an unprecedented effort by the ESO stellar community;

while KUEYEN will represent a quantum leap in our capability of understanding many stellar astrophysical problems, we need to adjust ourselves to KUEYEN.

5 Figures

References

1. Appenzeller, I., Fricke, K. et al. (1998) The Messenger **94**, 1
2. Baade, D., Meisenheimer, K. et al. (1998) The Messenger **93**, 13
3. Cannon, R.D., Crocke, B.F.W, Bell, R.A., Hesser, J.E., Stathakis, R.A. (1998) MNRAS **298**, 601
4. Gratton, R.G., Fusi Pecci, F. et al. (1997) ApJ **491**, 749
5. Hesser, J.E., Harris, W.E. et al. (1987) PASP **99**, 739
6. Pasquini, L., Molaro, P. (1997) A&A **322** , 109
7. Pont, F., Mayor, M., Turon, C., Vandenberg, D.A. (1998) A&A **329**, 87
8. Spite, F., Spite, M. (1982) A&A **115**, 357