Report on the ESO workshop on

Wide-Field Spectroscopic Surveys

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Jorge Melnick[1]
Yannick Mellier[2]
Luca Pasquini[1]
Bruno Leibundgut[1]

[1] ESO
[2] Institut d'Astrophysique de Paris, France

The wide-field imaging surveys to be conducted with ESO VISTA and VST telescopes and with the ESA Gaia satellite demand spectroscopic follow-up. Presentations and discussions on the role of wide-field spectroscopic surveys with ESO telescopes at this dedicated workshop are summarised. The instrument requirements for spectroscopic surveys of large-scale galaxy structure, fundamental cosmology, and the structure of the Milky Way and its neighbourhood are presented.

Ever since the large surveys with the Schmidt telescopes in Chile and Australia, the European astronomical community has been very active in the execution and exploitation of wide-area imaging surveys. This has been reflected in the scientific policies within ESO and in particular has led to the advent of two specialised survey telescopes on Paranal: the 2.4-metre VLT Survey Telescope (VST) for optical surveys and the 4.1-metre Visible and Infrared Survey Telescope for Astronomy (VISTA) for wide-field near-infrared surveys. These telescopes have attracted a very strong interest from the community to propose public surveys with these facilities. A comprehensive set of three large surveys with VST and six public surveys with VISTA, supported by almost 500 astronomers in total, have been allocated more than 2000 nights with these telescopes over a period of five years[1]. To exploit these imaging surveys fully, several programmes will require follow-up spectroscopy, which in turn need proper facilities and policies to be implemented. Thus, the community has been asking ESO to enable wide-field spectroscopic surveys at either the La Silla or Paranal observatories. Besides the follow-up of ESO imaging surveys, the community also anticipates that wide-field spectroscopic survey capabilities at ESO will be needed for future major space missions, like Gaia.

ESO invited the community to present their ideas and requirements at the workshop "Science with the VLT in the ELT Era", where astronomers gathered in Garching in September 2007 to discuss plans for the second generation instruments on the VLT (Moorwood, 2009). Following that conference and the announcement of VIMOS and GIRAFFE upgrades, ESO's Scientific and Technical Committee (STC) issued the following recommendation:

A Short-term Path to Successful Implementation of Spectroscopic Surveys

With the upgrades of GIRAFFE and VIMOS, ESO will provide to the ESO community highly competitive facilities to run wide-field spectroscopic surveys as early as 2009. These instruments will be unique during the next 5 years and will put the ESO community in a strong leading position in the field. STC then requests that a joint STC-ESO workshop be organised as early as possible in order to review the scientific potential of these instruments for public wide-field spectroscopic surveys and to identify potential scientists in the ESO community who would lead these survey efforts. The workshop would also be an opportunity for the community to propose new concepts for the next generation wide field instruments on ESO telescopes consistent with the STC recommendations from STC-67 and STC-68. Depending on the outcome of the workshop, ESO could then call for Large Programmes or Public Surveys in order to begin wide field spectroscopic surveys as soon as the VIMOS upgrade is completed successfully.

Thus, the Wide-Field Spectroscopic Surveys Workshop was organised at very short notice so as to be able to report back to STC at its April 2009 meeting, and start the process to enable large spectroscopic surveys as early as possible. In spite of the short notice, more than 100 astronomers from all over Europe registered for the workshop, again attesting to the strong interest of the community in the subject. Each topic was treated in considerable depth, leading to an extremely pleasurable and informative scientific meeting in spite of its rather technical background.

The core scientific requirements for wide-field spectroscopic surveys were already anticipated by the scheduled ESO public surveys with VST and VISTA. In fact these core themes had been reviewed by the two ESA–ESO Working Groups that focused on optimising the ground/space synergies in these core themes: fundamental cosmology (Peacock et al., 2006) and populations, chemistry and dynamics of the Milky Way (Turon et al., 2008). They were also discussed by the ASTRONET Science Vision working groups (see Bode, Cruz & Molster, 2008) that envisioned an increasing demand for wide-field multiplex spectroscopic facilities over the next few decades.

Fundamental cosmology and the high redshift Universe

This broad heading encompasses not only the quest for the fundamental cosmological constants and related mysteries, such as the nature of dark matter and the origin of cosmic acceleration, but also topics focused on the high-redshift Universe, the mass assembly of galaxies, and the star-formation history of the Universe.

The subject was reviewed by Jordi Miralda-Escude who described the rather large number of ongoing or planned surveys to address the current most fundamental problem in observational cosmology: the nature of dark energy. One of the best techniques to investigate the nature of dark-energy is the so-called Baryon Acoustic Oscillations (BAO — also known as baryon wiggles). These are fluctuations in the galaxy distribution at large spatial scales imprinted in the dark matter distribution by acoustic waves in the early Universe. This translates into a peak in the galaxy power-spectrum that defines a physical scale that can be used as a standard ruler to map the geometry of the Universe a function of redshift. The effect of BAOs is shown in Figure 1 from the Sloan Digital Sky Survey (SDSS) results at low redshift that clearly detect the BAO peak at a scale of about 100 Mpc (from Eisenstein et al., 2005). The challenge, of course, is to detect this peak at higher redshift.

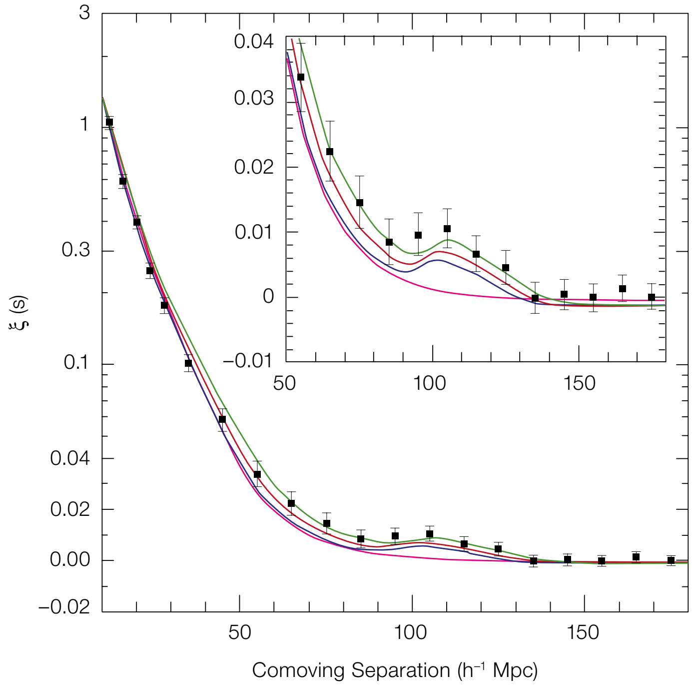

Figure 1. The large-scale redshift-space correlation function of the Sloan Digital Sky Survey Luminous Red Galaxy sample. The different line types show different models, including a pure Cold Dark Matter (CDM) model (i.e. with no dark energy) in magenta, which lacks the acoustic peak. (From Figure 2, Eisenstein et al., 2005).

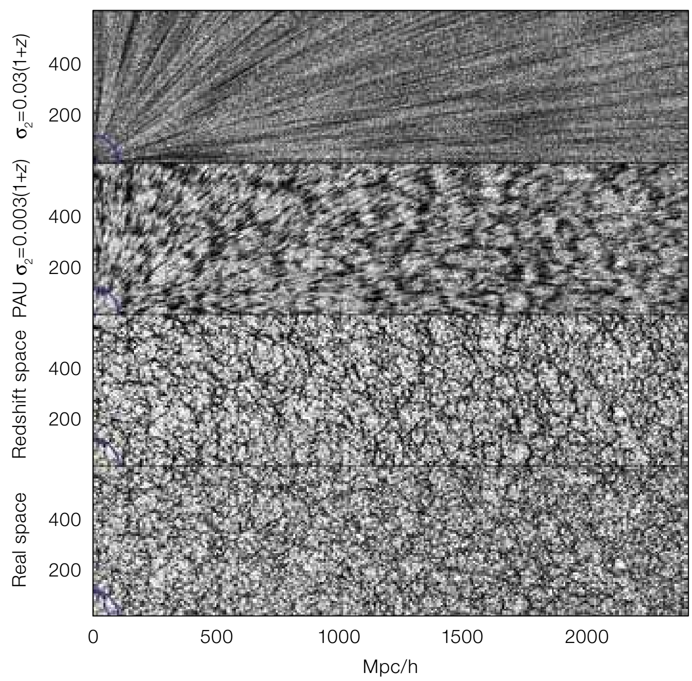

Figure 2. The effect of redshift errors on the observation of large-scale structure. All signal is erased if the error is as little as 0.03(1 + z). (From Figure 2, Benitez et al., 2009).

In his presentation, Tom Shanks proposed focusing on wide-field spectroscopic surveys of Lyman-break galaxies selected from current deep imaging surveys to explore the properties of the BAO peak at $z \sim 3$. Several presenters showed beautiful simulations that clearly illustrate the effect of redshift errors in the observation of the large-scale structure. One example, shown in Figure 2, taken from the presentation of Enrique Gaztañaga, shows that if the errors are larger than about 0.03(1 + z) the structure is completely washed out; to measure the structure, therefore, the redshift accuracy must be better than 0.003(1 + z). While the required accuracy can comfortably (but not trivially) be achieved with spectrographs, Gaztañaga claimed that it could also be achieved photometrically by using about 40 intermediate-band interference filters, as the Physics of the Accelerating Universe (PAU) project is planning to do. But of course a very large number of spectroscopic redshifts will still be required to calibrate the photometric estimates.

Konrad Kuijken reviewed the imaging cosmological surveys that are planned with the VST and VISTA. He showed that the fundamental properties of the Universe outlined above could be investigated using photometric redshifts of 60 million galaxies studied through weak lensing. This requires an accuracy of 3% in the photometric redshifts. Again this requires a large number of spectroscopic redshifts to calibrate the photometric estimates. Figure 3 from Kuijken's presentation shows that with 60 million galaxies and 3% redshifts it will be possible to extract the BAO signal from the weak-lensing potential spectrum illustrating the power of large multicolour broadband imaging surveys.

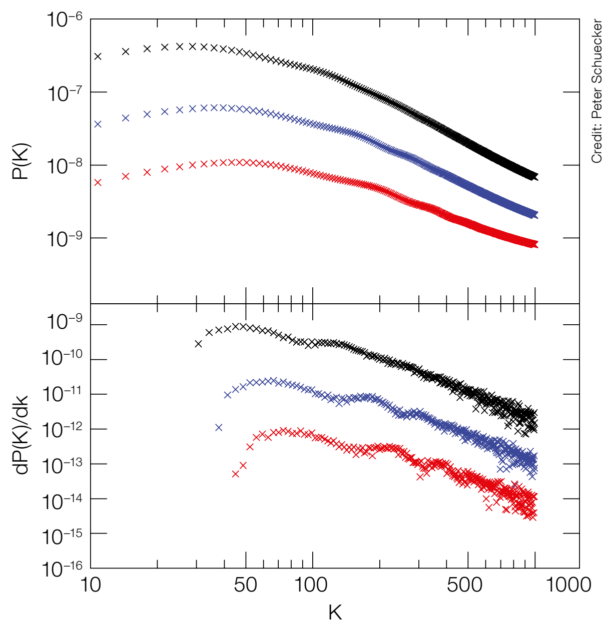

Figure 3. Estimated power spectrum in the galaxy distribution for the KIDS/VIKING surveys for z = 0.6 (black); z = 1.0 (blue); and z = 1.4 (red) based on photometric redshifts accurate to 3% for 60 million galaxies. The bottom panel shows that with this sample it should be possible to detect BAO in the weak-lensing signals.

Another technique that also allows to test the effects of non-standard gravity (e.g., braneworlds) was presented by Luigi Guzzo in his discussion of the VIMOS Public Extragalactic Redshift Survey (VIPERS). The idea is to look for distortions in the two-dimensional galaxy correlation function (in the radial and spatial directions). This so-called Kaiser effect is illustrated in Figure 4 where the distortions from the VIMOS–VLT Deep Survey (VVDS), at a redshift range between 0.6 and 1, are shown (Guzzo et al., 2008). While the distortions are clearly detected, the error bars are much too large to discriminate models and, in particular, to say anything about alternative theories of gravity. Many more galaxies at even higher redshifts are required for this crucial distinction.

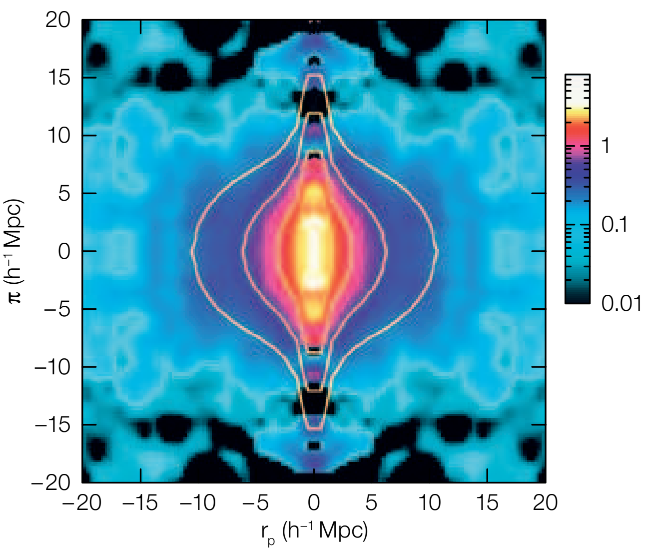

Figure 4. Colour-coded representation of the galaxy correlation function measured using ~6000 galaxy redshifts with $0.6 < z < 1$. The intensity describes the measured degree of correlation as a function of the transverse (r_p) and radial (π) separation of galaxy pairs. The actual measurement is replicated over four quadrants to show the deviations from circular symmetry. Galaxy peculiar velocities combine with the cosmological expansion producing the distorted pattern when the redshift is used as a distance measure. From Guzzo et al. (2008).

Spectral resolution	$300 < R < 3000$
Wavelength coverage:	350 nm –2.2 microns
Number of objects	$>10^5$ –10^6
Multiplex	200–1000
Depth (continuum S/N 10–30)	$22.5 < I_{AB} < 25.0$
Sky coverage	100–5000 deg^2
Typical number of nights	> 300
Targets	Faint galaxies; QSOs

Table 1. Technical requirements for wide-field cosmological surveys.

The nature of star formation, its evolution with redshift, the role of environment and the intergalactic medium, and the cosmic history of galaxies and haloes are the most pressing issues that were presented by O. Le Fèvre, S. Lilly, A. Renzini and L. Tresse. All present-day spectroscopic samples suffer from incompleteness, poor spatial sampling, or insufficient uniformity, and are still not deep enough to probe with enough statistics large volumes of the very high redshift Universe and the faintest galaxy populations. Beyond redshift ~1.5 the need for near infrared spectra is essential. The presenters were insistent on the increasing demand for large subsamples (~10^5 spectra) in order to unravel biases, selection effects, and the different physical processes at work. There was a consensus that it is of primary importance that new surveys move towards very well-defined spectroscopic subselections per magnitude, colour, and redshift bins, as well as towards extremely faint galaxy and quasar samples ($I_{AB} \geq 25$), all of which are within the reach of an upgraded VIMOS.

Putting all these science cases together results in the set of instrument requirements summarised in Table 1.

The Galaxy and its neighbourhood

The second day of the workshop started with a review by Amina Helmi of the recommendations of the ESA–ESO Working Group No. 4 on Galactic Populations, Chemistry, and Dynamics. The focus of the report was on the synergy between the Gaia mission and ground-based observations of the Milky Way, since the quality and the sheer volume of the Gaia data will revolutionise the study of the Galaxy. Gaia will provide astrometric information of a complete sample of stars out to distances of 10 kpc and will therefore allow investigating the properties of the major components: thin disc, thick disc, Bulge, spiral structure and halo with unprecedented depth and accuracy. Gaia will thus allow questions such as the initial mass function (IMF) of clusters and associations, the chemical enrichment history, the dynamics of the central region and the influence of the central black hole, among others, to be addressed. The Gaia data will also expand so-called near-field cosmology as it will be possible to map the history of mass assembly of the Galaxy and in particular to address the problem of the missing satellite galaxies predicted by the CDM galaxy-formation scenarios.

A serious problem with the exploitation of the Gaia data will be the incompleteness of the radial velocities. Gaia was conceived from the beginning as an astrometric instrument with the inclusion of a multi-colour photometer and an onboard low dispersion slitless spectrograph. The 1.45 × 0.5 m telescopes onboard Gaia allow radial velocities to be measured for stars brighter than V = 17 mag. At that limit the radial velocity accuracy will be degraded to about 14 km/s, to be compared to the astrometric precision on the transverse velocity which will be about ten times better at that magnitude. In her talk Alejandra Recio-Blanco summarised the situation as shown in Figure 5 that shows that the full exploitation of the Gaia astrometric data for V > 15.5 mag requires deep, high resolution spectroscopic surveys from the ground. In particular, these ground-based complementary observations are required for the Galactic Halo and the Bulge. As several participants pointed out, the HERMES survey on the AAT planned for 2011+ will likely skim some of the cream of the Gaia targets unless something is started at the VLT or La Silla.

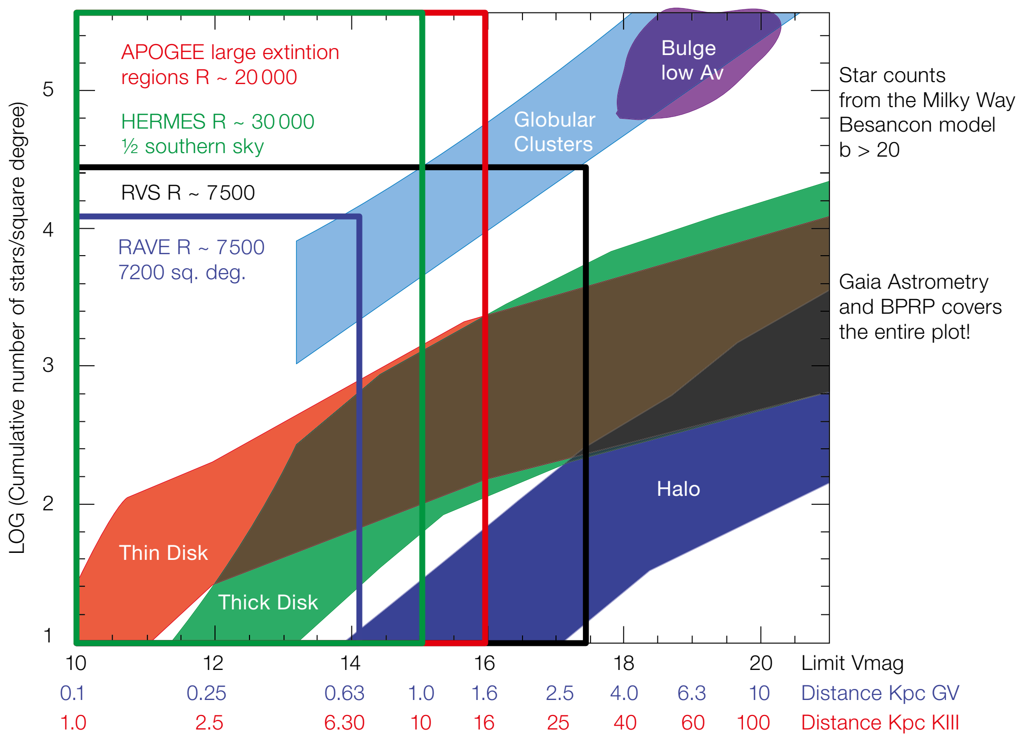

Figure 5. Plot of the number density and locus of different components of the Milky Way *v.* V magnitude and equivalent distance for two spectral types as relevant to the follow-up of stars from Gaia. (From the presentation by Recio-Blanco.) The locus of some other spectroscopic surveys are indicated.

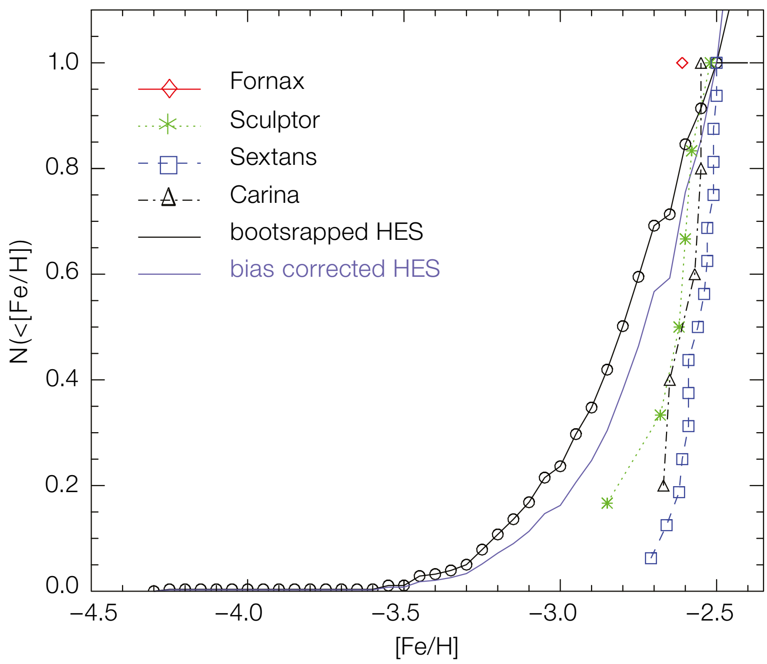

Figure 6. The cumulative metallicity distribution function in the metal-poor satellites of our Galaxy is shown as individual points for different galaxies. The solid black line shows the distribution of metallicities of stars in the Milky Way from the Hamburg–ESO survey and the blue line for the Galactic halo (Figure 10 from Tolstoy et al., 2009).

Similar problems to those investigated by the ESA–ESO Working Group for the Galaxy can also be studied in the nearby dwarf satellites of the Milky Way, and the spectroscopy case was presented by Maria Rosa Cioni and Giuseppina Battaglia at the workshop. For example, Figure 6 shows that the distribution of metallicities in the dwarf satellites of the Milky Way seem to be radically different from the distribution of metallicities in the halo of the Milky Way itself (when suitably scaled). The recently discovered nearby dwarf galaxies with extremely low surface brightness have a metallicity distribution that is substantially lower again.

Janet Drew reviewed the current imaging surveys of the plane of the Galaxy, in particular with UKIRT, and the plans for Galactic surveys with VST and VISTA. She showed that the wide wavelength coverage afforded by the addition of the near IR bands to the optical wavelengths, plus the use of narrowband Hα filters, significantly narrow the gap between photometric and spectroscopic surveys. However, imaging surveys can never replace spectroscopy for kinematics or abundances.

Table 2 summarises the instrument requirements demanded by the follow-up of the surveys by the VST, VISTA and Gaia.

Spectral resolution	5000 < R < 40000
Wavelength coverage:	370 nm –1.2 microns
Number of objects	$>10^5 – 10^6$
Multiplex	200–1000
Depth (continuum S/N 20–100)	$14.0 < I_{AB} < 20.0$
Sky coverage	100–5000 deg^2
Typical number of nights	> 300
Targets	Galaxy: Bulge, bar, spiral structure, clusters, halo streams. Magellanic Clouds. Dwarf satellites.

Table 2. Requirements for Galactic spectroscopic surveys.

Proposals for new instruments

In addition to talks concentrating on the science cases for advanced wide-angle spectroscopic surveys, several talks presented actual proposals for instruments to equip the VLT telescopes with wide-field high-multiplex spectrographs. Tom Shanks presented a very interesting concept of a 3 deg^2 field, 12 000-slit spectrograph for VISTA, which could survey more than 80 000 $z = 0.7$ galaxies per night. Adriano Fontana discussed a concept for a 5 deg^2 fibre-spectrograph with a multiplex factor of 5000, which is being studied for one of the prime foci of the Large Binocular Telescope (LBT). This instrument could also be suitable for other 8-metre-class telescopes such as the VLT, but it would demand changes of the UT top end. Joss Bland-Hawthorn presented FIREBALL, that would use the OzPoz positioner of FLAMES to feed five spectrographs with hexabundle fibres from 50 deployable Integral Field Units (IFUs). Francoise Roques proposed an instrument called ULTRAPHOT that would investigate the time-variability of different types of sources using the FLAMES positioner to feed up to 100 objects to a very fast CCD camera. Finally, Matt Lehnert presented super-GIRAFFE, a third possible upgrade of FLAMES/GIRAFFE, aimed at expanding the overall multiplex and throughput.

Summary

The primary outcome of the workshop was that there are two instruments at the VLT — VIMOS and FLAMES — that can be immediately used to address some of the most pressing scientific topics discussed at the meeting. The current ESO wide-field multi-object spectrographs can then keep the ESO community at the forefront of the field until 2015, when the next generation worldwide facilities come on line. However, while FLAMES has been recently upgraded (Melo et al., 2008) with the addition of a new detector, VIMOS needs some urgent repairs to reach the survey efficiency required to meet the scientific goals. An upgrade of VIMOS is planned for the coming year and hopefully will result in an enhanced reliability of the instrument. Thus, the workshop participants applaud ESO's plan to upgrade the red-sensitivity of VIMOS (i.e. replace the CCDs) and to solve some of the mechanical problems that have bedevilled operations in the past.

A call for large public surveys to address some of the astrophysics problems described above could place the European community in a favourable situation before instruments with massive multiplexing go into operation at other observatories. This discussion point was brought to the STC for recommendation and advice. A call for large cosmological redshift surveys is timely and would put European astronomy at the forefront of the relevant fields, if these surveys can be completed before 2014. Similarly, ground-based Gaia preparatory surveys would go a long way towards generating the data required to complement Gaia if the surveys begin soon.

Concerning the proposals for new instruments, the outcome of the workshop is to recommend that ESO make a call for wide-field instrument concepts that could either be entirely new instruments, or upgrades of existing instruments, in line with the ideas that were presented at the workshop. To be consistent with a previous recommendation by STC, these concepts must not include modifications to the VLT telescopes that could in any way compromise the VLT interferometric mode. Thus, at the VLT such an instrument could have a maximum field of view of 30 arcminutes, but must still have a large multiplex of 500 or more. The scientific cases require resolutions between R = 1000 and R = 40 000, and a very wide wavelength coverage between 350 nm and 2.2 microns.

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Links

[1] http://www.eso.org/sci/observing/policies/PublicSurveys/