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Astronet ELT-SRC: Report status as of June 2015
European Large Telescope Strategic Review Committee

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The task of this Committee is to discuss the main scientific drivers to use the 8-10m class telescopes (including the VLT, GTC, LBT and Gemini, as well as interferometers, like the VLTI) in the era of ELTs (i.e. 2025-2035), and write a report to Astronet-2 and Opticon Executive Committee in order to prepare the coordination of existing facilities and the optimization of the operation of the European optical/IR 8-10m telescopes. The final document should be ready for December 2015, but a preliminary one is expected for December 2014.

Terms of reference:

1. Identify those goals of the updated ASTRONET Science Vision that are effectively delivered by 8-10m class optical/infrared telescopes

2. Identify which observational capabilities (site, field of view, instrumentation capabilities & operation modes) are foreseen to be required, analyzing the recommendations of the updated ASTRONET Roadmap and the instrumentation programs of each facility

3. Establish a proper share between scientific, technological and educational goals of 8-10m class telescopes, taking into account contributions from both EELT and the smaller facilities

4. Among the scientific tasks, consider the appropriate balance between regular observing programs and large-scale survey-type efforts, including complementary ground-based programs in support of European space missions

5. Develop a realistic set of recommendations, including technical developments and structural arrangements, which would enable European 8-10m class telescopes to deliver the best scientific output to European astronomy in a cost-effective manner in the era of Extremely Large Telescopes

6. Analyze major needs and opportunities for collaboration on the European stage, e.g. with countries interested in accessing to telescope time in the Northern Hemisphere or instrumental developments

7. Analyze major needs and opportunities for collaboration on the global stage, e.g. with the space missions or the US system

8. Propose arrangements for the open access to the data, where not already the case, e.g. through the Virtual Observatory

The first part of the document discusses in details the **science goals** from Science Vision, and extrapolates to the years 2025-35. After the main scientific points are prioritized, the present and **future instrumentation** will be commented in correspondence.

I- List of Science Vision goals, involving the 8-10m

A2 (and B3): Galaxy clusters. The goal is to obtain the mass function of clusters and proto-clusters as a function of redshift, not only for the cosmology probe (may be the equation of state of dark energy will be solved in 2025) but also the astrophysics. The very large spectroscopic survey described below could tie up at least one 8m for the entire decade. The 8-10m telescopes complement other ground and spaced-base extragalactic work (eg Euclid, LSST etc.) in supplying targets for the 30m+ telescopes.
(Malcolm Bremer)

For clusters to be used as (a) cosmological probes and (b) as laboratories to study galaxy evolution, it will be extremely beneficial to have large (complete, or at least with well-understood selection functions) samples of clusters with high spectroscopic completeness for membership over a wide range of redshift.

For cosmology, while simply knowing the cluster redshift is helpful, providing that an estimate of cluster mass is obtained from elsewhere (X-ray, lensing, SZ etc), as cosmological studies become more refined it will be necessary to understand the dynamical state of the clusters. A detailed understanding of this will only come from a high level of spectroscopic completeness down to a given mass/luminosity in each cluster (so tens of galaxies), necessary to identify substructures etc within each cluster. The resolution/sensitivity of lensing/xray maps etc is enough to crudely identify significant substructure, but interpretation and accounting for detailed substructure will require a well-sampled velocity distribution.

A clear picture of cluster and cluster galaxy evolution will emerge over the next decade. Now, most studies are focused on the red sequence as these cluster members can be identified clearly from photometry alone - the bluer cluster members fall in a similar area of color space as intervening/background sources unless a significant number of photometric bands are used. Even then the uncertainty on photometric redshifts will mean it’s not clear whether a galaxy is a cluster member, a nearby foreground/background galaxy, or a member of an infalling subcluster/group, the latter is important if we are to understand how environment affects galaxy properties in detail and the role of 'pre-processing'.

For both of the above highly complete spectroscopy of a large, well defined cluster sample with a fully understood selection function is required. The precise wavebands for spectroscopy (whether optical or IR) depends on the redshift of the cluster and the range of spectral diagnostics to be captured by the observations. To be complete to below L* at high redshift, the observations will have to be deeper than those typically carried out now. Clearly at the same time as obtaining redshifts for the fainter cluster members, higher fidelity spectra of the more massive systems can be obtained, allowing for detailed analysis of their stellar populations, although clearly such work is then ideal for 30m+ telescopes (identify with 8m, take apart with 30m+).

Where will these clusters come from? By the mid 2020s cluster samples will be drawn from X-ray surveys (e.g. XXL and similar and eROSITA), SZ surveys (e.g. SPT) and optical/IR surveys (e.g. the various Spitzer surveys to be mass-selected to high-ish -z~1.5-2 - redshift. It is becoming apparent that optical selection is imprecise:- X-ray and IR selection identify different high redshift populations with the IR selection seemingly identifying chance projections, line-of-sight filaments and un-virialized systems as well as the same kind of systems identified by X-ray and SZ surveys. After eROSITA there will be likely to be a gap until ~2030 in X-ray missions capable of identifying large samples of (z>1) clusters. Optical samples will come from LSST and Euclid. Presumably by this time JWST will give the rest-frame K-band that SPITZER currently provides, though clearly it cannot identify huge numbers of such clusters given the time pressure on that telescope.

Protoclusters:

Currently there is not a widely accepted definition of a protocluster, though I would argue that above z~2 pretty much any confirmed gravitationally bound (or soon-to-be bound) system can be regarded as a protocluster, such is the limited time available for the stellar populations and dynamics of the systems to mature. The majority of the systems identified thus far have been from targeted observations of the fields of known high redshift populations (QSOs, RG, SMGs, LABs). If we are to progress in our understanding of the formation & early evolution of clusters and they galaxy populations, we will have to carry out unbiased surveys for these objects. Starting from wide-area deep photometry (so by 2020s this means Euclid, LSST, Pan-Starrs etc) we need to carry out wide area, relatively complete spectroscopy of the same areas over hundreds or thousands of square degrees. The optical waveband will cover Ly-alpha and Lyman breaks between z~2 and z~6, though the sweet spot is likely to be z~3-4, at these redshifts sufficient clustering will have started to develop (though not developed too much) and confirming redshifts (LBGs, Lyman alpha) is comparatively straightforward - the regime covered by Steidel in the 90's with Keck.

Again, detailed follow-up is ideally-suited to 30+m telescopes given their field-of-view and sensitivity.

A5 Strong gravity. The topic includes the neighborhood of our Galactic black hole, which will be intensively studied with VLTI and GRAVITY, but also the study of other black holes and microquasars *(Petr Hadrava)*

Studies of strong gravity, i.e. the general relativity and its alternatives, are important first of all for fundamental physics. Besides their cosmological consequences, the only possibility to verify the corresponding theoretical conceptions in nature is provided by observations of astrophysical compact sources, i.e. mainly the black holes and neutron stars. Super-massive black holes (with masses of millions of solar masses) are found in centers of galaxies, while black holes of masses of an order of the mass of Sun arise as final stages of evolution of stars with a higher initial mass. Understanding of physics of these objects is thus also an important part of the theory of stellar evolution. The enrichment of interstellar medium with heavy elements and energy by these sources also influences the star formation and evolution of galaxies.

Both super-massive and stellar-mass black holes are observable thanks to the accretion processes in which the rest mass of the accreted matter is efficiently converted into an energy and its great part is radiated away. Similar is also phenomenology of these classes of black holes (e.g. the occurrence of accretion disks, jets or time variability) which differ in scale only. The stellar-mass black holes are thus also named microquasars and the investigation of both these kinds of objects is complementary. The accretion on the stellar-mass black holes or compact stars is mostly fed by mass loss from their companions in binary and multiple stellar systems which enable us to determine masses and other parameters of the compact components. At the same time, the interaction of the close binaries during their evolution causes a large variety of these objects. Mapping of this variety of sources in different stages of their evolution and revealing the boundaries between white dwarfs, neutron stars (and other possible compact objects) and black holes can also shed a light on the equation of state of matter in extreme conditions (especially at high densities) and thus to exceed the framework of physics of gravitation.

The investigation of both microquasars and galactic nuclei requires multi-wavelength observations from gamma-ray to radio region and long-term monitoring. Typically, the microquasars are identified as X-ray binaries by satellite observations which need than a follow-up in optical and IR region. Generations of X-ray satellites discover new objects from 1970s (e.g. UHURU, ROSAT, RXTE, Swift, INTEGRAL, Chandra, XMM-Newton, Suzaku). The number of known or suspected targets thus permanently increases. For instance, the catalog by Ritter and Kolb (2003, A&A 404, 301) contains 105 low-mass X-ray binaries (LMXBs) and 500 related objects in its last version 7.21 from 2014 and their number increases exponentially with a mean rate 9% per year. Similarly the catalogue by Liu et al. (2007, A&A 469, 807) contains 187 LMXBs in the Galaxy, LMC and SMC, and other catalogues by these authors (2005, A&A 442, 1135) list 128 high-mass X-ray binaries (HMXBs) in Magellanic clouds and (2006, A&A 455, 1165) 114 Galactic HMXBs. Hundreds of discrete X-ray sources have been found in other galaxies (M31, M33, M51, M101 etc.) or globular clusters for which optical observations are needed to decide their classification.

While in X-rays the microquasars belong to the brightest sources on the sky, telescopes of the diameter about 8m are needed for optical spectroscopy of most of these objects in our Galaxy and/or the Local Group. For instance, between the above mentioned 114 Galactic HMXBs only 25 are brighter than 10th magnitude in V-band and thus accessible to efficient spectroscopic observations using smaller telescopes. Regarding the need to cover the orbital periods (ranging from hours to hundreds of days for different targets) the spectroscopy of X-ray binaries is highly time-consuming. Multi-object spectroscopy is helpful to satisfy the large demands for observations of the numerous objects. Construction of new spectrographs for these purposes may be desirable. A use of new generation of telescopes of the size 30-40m may enable to extend similar observations to more distant galaxies or to reach a better spectral and temporal resolution for a few objects of particular interest, but in view of the cost and the expected small field of view, it would be inefficient to use such telescopes for the needed routine follow-up of the plenty of objects.

In addition to the spectroscopy performed now using the 8m class telescopes, also a multi-color photometry is needed to determine, e.g., the periods or temperatures of the optical counterparts of X-ray binaries. This photometry is mostly obtained using telescopes of diameters around 1-2 m. In a case of spectroscopic observations in more distant galaxies using 40m telescopes, the 8m telescopes will be needed to add the necessary photometry.

A6: Supernovae physics. The LSST will make a revolution in the transient universe, and certainly will require a follow up with 10m telescopes. It could be considered to negotiate a participation of Europe in obtaining the data, if is offered in exchange some 10m time to follow up. *(Artemio Herrero)*

Some numbers
When the E-ELT, TMT and GMT telescopes arrive, astronomers will approximately enjoy a photon collecting area of pi*(20x20+15*15+12*12) = 2415 m2 from the 30-40m class telescopes. The one available at that time from 8-10m class telescopes will be: 4 VLTs, 2 Keck, 2 Gemini, 1 Subaru, 1 GTC, 2 LBTs, 1 HET, 1 SALT that can amount again approximately to pi*(10*(4*4)+1*(4.5*4.5)+3*(5*5))= 800 m2. Adding the LSST to this class would increase the number by pi*4*4= 50 m2, bringing the total to 850 m2. We see that the TMT alone has a collecting power close to that of all 8-10m class telescopes together, whereas the E-ELT and the GMT are clearly above and below that value.
However, we also see that there will be 15 8-10m class versus only 3 30-40m class telescopes. Thus, daily we will have about (15x9)= 135 observing hours available to the astronomical community on 8-10 telescopes for only 3x9= 27 hours available on 30-40 m telescopes. Moreover, the typical FoV of the instruments will be of some tens of arcmin in the 8-10 class to a few arcmin in the 30-40m class telescopes.
It is therefore clear that the 30-40m class telescopes will be best suited for the observation of a small number of faint objects, isolated or tightly clustered in a small region. 8-10m class telescopes will be advantageous for the following conditions: (a) brighter objects (as compared to those accessible with 30-40m); (b) clustering in wider fields; (c) needing follow-up repeatedly; (d) being observed as preparation for 30-40m telescopes.

Supernovae
There are still important open questions concerning Supernovae, whose answers may have a deep impact on our understanding of the Universe. We may cite the origin of type Ia Supernovae and their use as standard candles at different epochs. What's the origin of these SNe and how do their properties vary with metallicity and cosmic age? There are two basic scenarios for the production of type Ia SNe: the double degenerate (two white dwarfs) and the single degenerate scenario (white dwarf+ red giant). On the side of type II Sne, we still lack a clear idea of the relationship between initial stellar and final mass. In other words, we don't know which stars are progenitors of stellar black holes. And of course, even less the dependence of this relationship with metallicity.
These questions have to be answered by large statistical studies, including detailed spectroscopy. Although 30-40m telescopes will surpass 8-10m ones for individual objects, they will be available only for a few cases. About 250 SNe are discovered each year and this number can increase with the many present day surveys (searches are carried out with nearly all telescope sizes) or future surveys using the LSST. High S/N spectra of SNe in different environments are needed to understand the explosion mechanisms, put constraints in

evolutionary models and apply accurate distance corrections as a function of the SNe and host galaxy properties. Given the importance of SNe (not only of type Ia) for Cosmology, these are crucial points for Astrophysics. Presently, spectra of SNe can be secured with 8-10m telescope up to z □1 close to the peak (perhaps this could be extended using lensed SNe), but following-up of the spectra of most SNe is done with 4-6m class telescopes.

B2 First galaxies. They are related to the epoch of re-ionization of the universe. JWST will image them, and determine their SED, and ELTs will do their spectroscopy. SKA will explore the redshifted HI (21cm line) of the background statistically in emission or absorption in front of the CMB. They are therefore **Not a topic** for 8-10m in the era of ELTs.

B4 Metal content of the universe. Study the evolution with redshift, through ejection from galactic superwinds, combining emission and absorption observations.
(Malcolm Bremer)

The evolution of metallicity through time can be studied with 8m telescopes in at least two ways, both requiring spectroscopy. Firstly, individual galaxy spectra can be analysed comparing the strengths of various absorption and emission lines, for the weaker lines, and depending upon redshift, the exposure times can be long. Some lines will be inaccessible over various redshift ranges, but the overall trend can be determined. Both gas-phase and stellar metallicity can be probed. Secondly, absorption line systems can be observed in the spectra of QSO and then related to nearby (on the sky) galaxies, in this way tracing patterns of inflow and outflow around galaxies as a function of redshift.

The key to determining the evolution of metallicity in galaxies is to ensure the same, properly calibrated, line indices are used across the range in redshift - not doing this can lead to an apparently evolving signal which is more to do with the need to change the calibration with redshift or using an insufficient number of line indices and falling foul of the degeneracies that occur in these measurements (metallicity indicators can also be dependent on ionization and other environmental factors that are expected to vary with redshift and even object to object!). There are certain redshift ranges (e.g. $2.1<z<2.4$) that allow multiple indices to be observed in the same object (in this case in J/H/K). Metallicity is found to vary with mass at low redshift, it is still not clear what happens at high redshift. It is plausible the environmental will increase with redshift: at $z\sim1.5$-2 cluster galaxies appear "older" than field galaxies by a significant fraction of their overall age, so there could be significant differences in metallicity. This is not the case at low redshift as any fractional difference in age is less, so metallicity differences are minimized.

All of this work is starting to be done, with quite a lot already achieved with both 4 and 8m surveys of QSOs (and other bright background continuum sources). A deep and wide spectroscopic survey, again matched to photometry that will exist in the 2020s should enable the definitive work to be carried out on how the metallicity of the Universe evolves and in detail how galaxies recycle metals into the IGM (or how material flows into them). The key will be associating the gas and stellar-phase metallicities of a large number of galaxies with that of their surrounding IGM, requiring deep spectroscopy of the galaxies themselves (so much more than needed for redshift determination) and the association of these galaxies with QSO lines-of-sight.

Large-scale-structure (LSS)

Related to all of the above is the detailed study of the growth of LSS. Currently, most work on this at any appreciable redshift is statistical in nature, usually 2-D correlation functions, combined with Limber's approximation to obtain 3D results. At lower redshift (e.g. 2dFGRS) LSS is mapped spectroscopically, allowing both a full 3D representation of the positions of galaxies, but also the large-scale dynamics and underlying mass distributions through the use of redshift distortions etc. Similar work has been carried out using SDSS.

At higher redshift, the best known attempt at mapping the 3D distribution of matter is that carried out using the COSMOS survey (so only about 2 sq. degrees of sky) using a combination of redshift and lensing-derived information to determine a (crude) 3D map of the COSMOS field. In the 2020s, similar work will be carried out with, e.g. LSST, over a much larger area.

While statistical and lensing-based studies give the crucial information for cosmological studies, to understand the detail of LSS formation and how it manifests through the galaxy and baryon distribution, we obviously need to take into account and understand the impact of the baryon physics delivered through galaxy evolution. This can only be achieved through a deep and wide-area galaxy survey out to redshifts where it is clear we can see the beginnings of large-scale structure evolution in the galaxy distribution (so z~5-6 based on current work). Unlike current efforts, these need to sufficiently densely sample galaxies to L* or below out to all relevant redshifts over wide areas (100s of sq. degrees). Such surveys can be seen as crucial counterparts to those carried out by LSST and Euclid etc., delivering the spectroscopic redshifts for the broader photometric surveys that they will carry out.

How large an area is required? Presumably at least 3 patches of sky will be needed to cover all hour angles. Each should be large enough to contain several massive clusters, or their progenitors, at each redshift to be explored. I estimate this means each redshift bin should have a volume of ~10^8 Mpc^3. So for z=1-1.5, this means about 25 sq degrees, and the same for z~3-3.5 and z~4-4.5. This is ~250 pointings of VIMOS, so about 3 dark years of good weather if 1 night per pointing is allowed. For 3 patches, this means committing VIMOS for ~ a decade and a similar amount for MOONS for bright time (comparable to the length of time of the LSST and Euclid operations).

B6 Assembly of galaxies

(Bianca Garilli)

One of the most challenging goals of Observational Cosmology is to understand the formation and evolution of galaxies. Despite the enormous progress made in the last twenty years, the overall picture is still fuzzy and many questions remain unresolved: What drives galaxy formation? How do red evolved galaxies stop their activity and, conversely, what fuels star formation in the still active galaxies? What is the role and incidence of merging? Do AGNs quench star formation, or instead do they trigger burst like episodes?

The current theoretical paradigm foresees hierarchical formation of dark matter halos. Galaxies form within these halos following a downsizing scheme, by which more massive objects form first and evolve faster. Starting from these basic ingredients, numerical simulations and semi-analytical models try to predict the main galaxy properties and their evolution in time, but firm observational evidence at all redshift is required to constrain the models and the many parameters entering simulations.

This is why all major phases of galaxy evolution, from the early formation and galaxy assembly to today, must be covered by observations. In order to study the correlations between the different properties in a as much as possible unbiased way, large samples are needed, samples which should cover all galaxy types, a wide range of luminosities and masses, different environmental conditions.

In the local Universe, first 2dFGRS, and then SDSS have set a firm reference point for galaxy properties nowadays. At redshift ~1 increasingly larger samples are being collected in different surveys (from VVDS to VIPERS, from DEEP2 to COSMOS), especially in the optical domain. We can imagine that in ten years-time samples will have grown to a point were the main observational galaxy properties and their relationships will be firmly established at least for the galaxies populating the bright end of the luminosity function. While 30m class telescopes, like E-ELT, or space based telescopes, as JWST, can easily reach the very faintest objects, their small field of view does not favor large surveys like the ones mentioned above. On the other hand, and likewise has been done in the past with 2m class telescopes first, and now with 4 m telescopes, the 8m telescopes can still be extremely useful for large surveys: they would allow to explore the faint end of the luminosity function, if enough telescope time is invested to reach fainter magnitudes (I~24.5)

In the intermediate redshift domain, 2<z<4, where also galaxies brighter than M* become fainter than I~24, collecting vast statistics becomes increasingly costly in terms of telescope time. Furthermore, the optical rest-frame band moves into the Near Infrared, where current facilities do not yet allow a high observational efficiency, due to either the relatively small field of view (for photometric studies) or to the relatively low multiplexing capabilities of Near Infrared spectrographs. For these reasons, current studies are still limited to few thousands of objects, a number which cannot be compared with the wealth of data available at lower redshift, and which does not allow a full exploration of the parameter space on firm statistical grounds. The star formation rate density peaks exactly in this range, which therefore is crucial to understand the galaxy formation mechanisms. The few spectrographs operating in the Near Infrared do not have the same large Field of View as their analogous operating in the optical domain, nor the same multiplexing capabilities. The most modern spectrographs being planned, like MOONS at the VLT and new WFMOS at SUBARU, will become in the ‘20ies the survey ‘work horses’ so widely used in the optical, and are bound to give a wealth of unprecedented information in the following 10 or 15 years

Large photometric surveys which make use either of ground based 8m class telescopes facilities or of space based smaller telescopes are already planned:

> LSST will cover 30.000 deg^2 in the equatorial zone and the southern hemisphere down to r_{AB}=24.5, providing a full optical photometric *ugrizy* coverage. Co-adding images will allow to reach the depth of r_{AB}=27.5 over 18000 deg. LSST will be carried out in the 2020-2030 decade using a dedicated automated 8 m class telescope.
>
> From space, EUCLID will cover 15000 deg^2 in the optical band, thus providing excellent photometry. It will also provide NIR photometry over the same area in the YJH band. These data, combined with ground based optical photometry, will allow the derivation photometric redshifts with an accuracy of the order of 0.005. This wealth of data will allow to study in detail photometric and morphological properties of galaxies, in all environmental conditions (from clusters to isolated objects) up to

redshift 2, over enormous areas. Still ground based optical photometry will be required, like the one which can be provided by LSST, both in the southern and in the northern hemisphere. Furthermore, a robust spectroscopic campaign is required to calibrate photometric redshifts.

Both LSST and EUCLID will provide huge databases from which to draw a wealth of spectroscopic follow-up programs. On the contrary, there is currently not much effort being dedicated on survey spectrographs. In the optical domain, the existing facilities, like DEIMOS on Keck, VIMOS on VLT, FMOS on SUBARU, MODS on LBT are already 10 or more years old, and it is not evident that they will still be operational in 10 years-time. The small field of view foreseen at ELT and JWST makes these two future facilities not ideal for large surveys. Other instruments with large FOV and high multiplexing, working at a medium-high resolution (R~1000-4000), in the optical and in the near Infrared domain will certainly be required to exploit the scientific outcome of the large planned surveys mentioned above, up to redshift 4. In the very high redshift domain, z > 4, objects become so faint that it becomes a real challenge also for the large existing telescopes. Furthermore, the surface density of very high redshift objects is low, so that also the (relatively) small field of view of E-ELT and JWST become again competitive: what is lost in terms of multiplexing is gained back in terms of exposure time.

Metallicity and gas content

ALMA will play a crucial role on this subject, allowing the tracing of cold gas and molecular content up to the medium redshift range. However the connection between gas, dust and stellar content is subject of debate, with observational evidences pointing one way or the other. The MUSE instrument @VLT will provide excellent resolved spectroscopy at intermediate redshifts. An E-ELT MOS operating in the Near Infrared will further exploit this domain. Unfortunately, both MUSE and ELT have a relatively small Field of View.

A spatially resolved, large field of view (of the order of some tens of arcminutes) spatially resolved spectrograph operating at medium resolution (R~4000) would allow studying the dynamics of high redshift galaxies in a statistical way.

B7 Stars in resolved galaxies

Nearby objects, in parallel to the follow up of GAIA for the Milky Way

(Eline Tolstoy)

The study of resolved stars in and around the Milky Way will undergo a transformation as a result of the GAIA mission, so much so that it is hard to predict what will be the implications. Follow up studies of resolved stars in the thin (and some of the thick) disc of Milky Way have already begun with the GAIA-ESO survey, a multi-fibre wide field spectroscopic survey to provide additional information (primarily abundances) in addition to the proper motions that are expected from GAIA. This is undoubtedly the first of many such surveys. They require wide field multi-object spectrographs that are sensitive across the optical range, and as one probes into more dense and dusty regions like the bulge and regions within the plane of the disc of the Milky Way infrared spectroscopy is also useful. It is often the only way to see through the depth of extinction. However FLAMES really has too small a field of view to be able to make a good census of the halo. The GAIA-ESO survey can really only provide a few pencil beams that is very unsatisfactory for a component that is predicted to be highly inhomogeneous. This has motivated the WEAVE and 4MOST spectrographs, but they are only on 4m class telescopes, so only extremely bright samples will be accessible to abundance analysis, which can afford only a relatively local view of the halo. So to complement the

GAIA study the Milky Way halo an optical very wide-field multi-object spectrograph on an 8m class telescope is required. Blue sensitivity is useful for detailed abundance studies, especially of extremely metal poor stars. Also very high spectral resolution is preferred (at least R~20000, ideally going up as high as R~40-60k) to ensure that a range of abundances of different chemical elements can be accurately measured.

Almost the entire stellar community in Europe was mobilized to support the GAIA-ESO survey, and this suggests the acceptance of the growing trend for survey science. Also SEGUE and APOGEE stellar surveys that are an extension of Sloan surveys are proving very useful. However all these surveys usually required the possibility for more detailed follow up studies. The usual trade off seems to be to observe extremely large samples, in survey mode, at relatively low spectral resolution, and we are getting better and better at extracting rough information from these type of spectra which can then be used to create accurate follow-up sub-samples to observe at higher spectral resolution (e.g., extremely metal poor stars; carbon rich stars, r-process rich stars etc.). This suggests that the stellar community will always need a mix of survey and individual programmes. It seems likely that surveys are most useful low spectral resolution and follow up will be at higher spectral resolution. You could argue that a complete survey at low and high resolution would be useful but this would be a hugely ambitious goal.

A wide field multi-object spectrograph on 8m class telescopes, can also be used to study the resolved stellar population of Ultra-faint and dwarf spheroidal galaxies within ~200kpc of the Milky Way. These objects are the best chance we have to make a complete study of an entire stellar population in a well-constrained system.

It is recommended that large spectroscopic surveys, of universal use to the community, should be carried out. This would probably be best achieved at around R~8000, and if carried out around the Ca II triplet lines in the red (as was done by RAVE), provide a reliable metallicity indicator down to very low metallicities.

C2: Stellar structure and evolution, High resolution spectra will be required and ensured in the Southern Hemisphere by the 8-10m. High resolution would also be needed in the north (for example Andromeda is a unique target). A good idea would be that ESO proposes a copy of UVES, which can do high res (R=10^5) with 8 objects (with fibers)

(Artemio Herrero)

Again, the advantage of 8-10m telescopes versus the 30-40m ones (or the JWST) will be their availability. Programs dedicated to time series of mid- and high-resolution spectra, spectroscopic and photometric surveys and multi-object spectroscopy in wide fields will be the primary areas where the 8-10m telescopes will remain competitive in problems related to stellar structure and evolution (and in other areas).

Stellar astero-seismology is getting a lot of attention presently thanks to photometric surveys (some of them involving telescopes networks around the world) and the observations of satellites like COROT and Kepler. The next steps in this research are high resolution time series spectra that correlate photometric and spectroscopic changes and try to explain them in terms of the stellar structure. This may open new access to the stellar interior and reveal the behavior of the outer atmospheric layers. At some point, this will be done with entire clusters populations. While a few particularly interesting objects can be studied with larger telescopes and the brightest ones can be observed with smaller ones, 8-10m telescopes with suitable instrumentation will be able to access a large number of objects in a larger range of environments. This represents access to all mass ranges in all different positions in the Galaxy (and even in nearby galaxies for the brightest objects).

Cluster studies following Gaia will be required in the same way as the present Gaia-ESO Survey. This effort will begin before the 30-40m telescopes are ready, but will not be finished when they enter operation (except if they are delayed!). These spectroscopic surveys will be needed to further trace the structure and chemical history of the Milky Way. While Gaia will start an incredible epoch in our knowledge of our Galaxy, this effort will require intense follow-up spectroscopy, and the 8-10m telescopes will be the tool because of their combination of collecting power, field of view and accessibility. (NOTE: the FoV and the ability to place many targets at once in multi-object spectrographs, and the existence of large IFUs and adequate pipelines will be key in the role played by the different 8-10m telescopes. Remain competitive implies an effort in these areas).

A particularly important role will be played by the low-Z stars in the halo of our Galaxy. The routine identification of low-Z stars started with SDSS will continue with Gaia and large statistical samples will be needed to trace the chemical history of the Milky Way back to its origins and disentangle the role played by the different populations formed at different epochs. Particularly important will also be to identify the products of early Supernovae. They will be the object of 4-6m telescope surveys with wide FoV multi-object spectrographs, but the low-Z (and therefore faint lines) combined with the request for high S/N and very high resolution (well beyond 20,000, to derive accurate abundances) will again offer a niche for the 8-10m where they will be the best option.

Stars hosting planets will also be a field where 8-10m class telescopes furnished with high resolution spectrographs may play a key role. Surveys trying to establish the correlation between planet presence and host star properties will be carried out with these instruments.

All these studies that concentrate in the stellar Galactic population, would profit from strong spectro-polarimetric capabilities in the 8-10m telescopes, which would allow access to studies of magnetic fields. In massive stars the field is very active presently and it is difficult to predict whether it will continue like this in a decade (results indicate that large global fields are present in no more than 10% of massive stars). Low-mass stars are more numerous and close enough to study large samples with 4-6m telescopes. However, the in-depth study of solar analogs (and solar system analogs searches) will also profit from 8-10m telescopes with adequate instrumentation.

High energy binaries (HEB; X-ray binaries with neutron stars or black holes, gamma.ray binaries) in the MW and nearby galaxies are key objects to interpret the evolutionary paths of massive stars, to reveal the nature of Be stars and the equation of state of neutron stars through the determination of a large number of accurate masses of the compact objects or to clarify the mechanisms for the formation of gamma-rays. Many of these objects are quite faint, and they cannot be accessed with enough spectral resolution and S/N with 4-6m telescopes. Again, although some unique objects will be observed with 30-40m telescopes (for which, because of the large collecting power time series spectroscopy will be possible) the large number statistics will have to be provided by the 8-10m telescopes. Of course, there will also be a large number of binary systems (in the Milky Way, but also in other galaxies) with properties such that they can only be studied with large telescopes, and for which it will be difficult to get time in 30-40m telescopes.

Spectroscopic studies of resolved stellar populations in nearby galaxies with 8-10m telescopes, following present extensive photometric surveys, will continue in the era of the 30-40m telescopes. Although the large telescopes will be unbeatable for larger distances or for small files, the Local Group with its rich variety of environmental conditions will be open

to the 8-10m telescopes and the statistical samples required to correlate the properties of host galaxies, stellar clusters and stars will only be possible with 8-10m telescopes. Again, as in the case of HEB and differently to studies in our Galaxy, 4-6m telescopes have a frontier here that they cannot cross.
As a first conclusion, we may say that 8-10m telescopes will keep scientifically competitive in stellar research in the era of 30-40m telescopes, because they will provide the required statistically meaningful evidence through relatively wide field multi-object spectrographs (possibly with time resolved, polarimetric and very high resolution capabilities)

C4-C5-C6: Planetary systems

Espresso will continue what Harps does on the 4m class, but with the four 8m-VLT.
(Artie Hatzes)

The field of exoplanets is arguably one of the most vibrant and exciting fields in astrophysics and one that was created by observations made on 2-4m class telescopes. In particular, medium and large telescopes continue to make significant contributions to the field, and will do so for the foreseeable future.

Transiting exoplanets are an area of research ideal for large telescopes. These objects are the “Crown Jewels” of exoplanet studies as they enable us to characterize exoplanet systems. For example, photometric transit light curves tell us the radius of the planet, while Doppler measurements yield the planet mass and thus bulk density. From this bulk density we have the first clues about the internal structure of the planet. Photometric measurements of the planet occultation (often called the “secondary transit”) yield information about the planet brightness temperature and its albedo. Spectroscopic measurements taken during the transit are one of the few ways we can currently study the atmospheric composition of exoplanets.

At the forefront of these transit studies is the Kepler Space Mission. Kepler discoveries have demonstrated that planetary systems are even more diverse than initially thought. Important Kepler discoveries include: 1) There is a larger population of Neptune-size planets, than Jupiter-sized planets. 2) Compact, densely packed planetary systems with 5 or more Neptune and Super-Earth planets all with orbital radii less than about 0.5 AU are common. 3) Planets can have very diverse densities. Super-Earths can have bulk densities that are consistent with a rocky structure or ones that indicate the presence of a large amount of volatiles. 4) Earth-sized planets can exist with ultra-short orbital periods (8.5 hrs for Kepler-78b) 5) The discovery of the first circumbinary exoplanets.

One of the current drawbacks of current transit surveys, both from ground and space, is that target stars are relatively faint with V = 11-15 mag. This makes a Doppler measurement of the mass difficult, and the characterization of the exoplanet atmosphere exceedingly challenging. There are a number of upcoming transit surveys that seek to remedy this and thus build on the discoveries by Kepler. From the ground the Next Generation Transit Survey (NGTS) will use an array of small robotic telescopes to search for Neptune-sized objects around stars with V = 9-12 mag.

From space NASA’s Transiting Exoplanet Survey Satellite (TESS) will survey 500,000 stars that will be 30-100 times brighter than Kepler targets. Stellar fields will be observed for about 30 days. The more ambitious Planets Transits and Oscillations of Stars (PLATO) mission of

ESA will monitor up to a million stars in the magnitude range V = 4-16 mag for up to 3 years in several fields. The goal of PLATO is to find transiting planets in the habitable zone of sun-like stars. A key component of PLATO is that it will also perform astero-seismology on the targets in order to derive accurate stellar parameters – the limiting factor in determining the planetary parameters. PLATO should yield planet radii to within an error of 2%, the planet mass to within 10%, and the planet age to within 10%.

The lesson learned from such space transit surveys such as Kepler and CoRoT is that ground-based follow-up observations are needed for the success of the mission. In particular, large (8-10 m class) telescopes are essential for the follow-up of the smallest planets that will be found by PLATO and TESS. Although these missions are targeting relatively bright stars, the stellar reflex motion of small rocky planets with be only several tens of cm/s. Doppler measurements for the mass determination will require spectra of superb signal-to-noise and spectrographs with exquisite stability. In this respect ESPRESSO on the VLT will play a key role in PLATO follow-up. ESPRESSO is a HARPS-like instrument being built for the VLT. It will be able to use any of the unit telescopes individually, or all four in a combined focus. A state-of-the-art calibration unit provided by a frequency laser comb holds the promise of achieving a radial velocity precision of several cm/s. ESPRESSO may be the only instrument that can confirm and characterize the small transiting planets detected by PLATO and TESS.

Large telescopes like the VLT can also continue to play a prominent role in the atmospheric studies of exoplanets. The spectroscopic signature of a planet is less than 10 □4 that of th stellar flux so large aperture telescopes are needed. Certainly, extremely large telescopes will be more efficient, but it may be more difficult to get sufficient time given the expected over subscription rate on these larger facilities. By simply taking more observations (e.g. observe more transits), 8-m class telescopes can also be effective at atmospheric studies. The near IR is an ideal spectral region to study exoplanet atmospheres since many molecular features can be found there.

The Cryogenic Infrared Echelle Spectrograph (CRIRES) of the VLT has already made significant contributions to the characterization of exoplanet atmospheres. The first ground-based detection of CO in the atmosphere of a hot Jupiter was made using the CRIRES (Snellen et al. 2010). For the first time to rotational velocity of an exoplanet was measured by CRIRES, a value of 25 km/s for the companion of Beta Pic. This value is larger than for solar system planets, but consistent with the expected spin velocity of a planet with mass. These measurements were made with the current CRIRES which has a limited wavelength coverage (~0.1 nm) and uses old, cosmetically poor detectors. The upgrade to the current spectrograph, CRIRES+, will increase the wavelength coverage by a factor of 10-15 and use modern, efficient IR detectors. CRIRES+ will enable atmospheric studies to be expanded to more stars, particularly if they are bright candidates from TESS and PLATO. Radial velocity measurements made in the near IR will be also able to detect low mass planets in the habitable zone of very cool objects (M and brown dwarfs) and whose atmospheres can be characterized.

One of the more surprising results to come from exoplanet atmospheric studies is the featureless spectra of Neptune-mass planets. The transmission spectra of the transiting super-Earth GJ 1214b and GH 436b in the wavelength range 1-1.7 microns taken with the Wide Field Camera of HST were found to be flat and without obvious spectral features. These spectra are consistent with atmospheres having a significant amount of clouds. The HST observations were taken at low resolution so it is not known if spectral features will become apparent at higher spectral resolution. IR observations taken at higher spectral resolution may be able to answer this. In short, high resolution IR spectrographs on 8-10 m telescopes can have an important impact in the characterization of planetary systems.

D Solar system Trans Neptunian Objects (TNO)

(Thérèse Encrenaz)

The discovery of extrasolar planets, over the two past decades, has led us to reconsider our understanding of our own solar system in a new perspective, as a peculiar planetary system, which is by no way representative of the others, but is reachable by in situ exploration. New questions have emerged from this new perspective: Why are the giant planets so different and how did migration affect their early evolution? Did the terrestrial planets also migrate and what kind of super-Earths can we expect in other planetary systems? How does the Kuiper belt compare with the debris disks of other planetary systems? What can its structure tell us about planetary migration in the solar system? What is the origin of comets, and do similar families exist in other planetary systems? In addition to the on-going space planetary exploration devoted to the in-situ analysis of a few solar system bodies, statistical studies of small bodies (asteroids, comets and TNOs) are more and more necessary. They will continue to require ground-based campaigns for exploring their dynamical and physical properties. In this context, 8-m telescopes will be essential for pursuing long-term campaigns, while ELTs will be more specifically devoted to the study of fainter small bodies, presently beyond the VLT capabilities.

ELT instruments (CAM, IFU, HIRES, MIDIR) will be used for imaging and characterizing small bodies not observable with the VLT. In particular, ELT-CAM will be able to image weak TNOs to search for binaries (expected to be common) and determine their masses and densities; ELT-IFU and HIRES will perform the spectroscopy of these weak objects up to the K band, and MIDIR will extend the spectral range into the thermal regime.

In the ELT era, our knowledge of the various small bodies of the solar system will have changed considerably, thanks to the availability of deep ground-based and space surveys. Within ten years from now, the ESO VLT Survey Telescope, located at Cerro Paranal in Chile, will have significantly extended the population of known TNOs (presently 1600 discovered objects, while over 105 objects are suspected). The PanSTARRS survey in Hawaii will have provided a complete coverage of weak objects up to a visual magnitude of 24, in particular near-Earth asteroids but also distant asteroids and comets. In particular, the population of Trojan asteroids, in Jupiter’s orbit, presumably as numerous as the Asteroid Main Belt, will be fully sampled; most likely, similar populations in the orbits of Saturn, Uranus and Neptune will be also discovered. The GAIA astrometry space mission, launched in 2013, is expected to discover several thousands of asteroids located within 6 AU, including a large number of Trojans. GAIA is also expected to discover several thousands of near-Earth asteroids.

Within ten years from now, we will have discovered new families of small bodies, close or distant, and we will have significantly enlarged our knowledge of distant populations, in the Kuiper belt and beyond. Many objects discovered by the new surveys will be bright enough to be studied with 8-m telescopes, both for imaging and spectroscopy. Light curves will provide information of their orbital properties (rotation period, spin), needed to constrain their dynamical history. Masses and densities will be inferred from binary systems. Near-infrared spectroscopy at moderate resolution will be used to characterize the composition of these bodies. High-resolution spectroscopy in the near infrared will be also necessary for characterizing the parent molecules of bright comets from different origins (Oort-cloud comets and Kuiper-belt comets) and for monitoring their transient activity.

Planets and outer satellites will also benefit from the continuous use of 8-m class telescopes. Long slit spectroscopy with visible and infrared high-resolution spectrographs has led to the measurement of wind fields on planetary disks, as illustrated by UVES in the case of Venus, and the characterization of gaseous atmospheres around small bodies, as illustrated by CRIRES in the case of Triton and Pluto. Such observations are not optimized on the ELT because of its very high spatial resolution, but may be successfully performed on 8-m telescopes on all planets and outer satellites.

Finally, one could consider implementing new instruments on 8-m telescopes to obtain a better coverage of the near and far infrared spectral ranges. For example, an instrument combining high spatial and spectral resolution (R = 100000) in the 5 – 25 micron range, like TEXES at IRTF and EXES aboard SOFIA, would be excellent for mapping gaseous atmospheric species on planetary disks, and ideal for monitoring transient phenomena or day/night variations. In addition, an infrared camera in the 10, 20 and possibly 300-micron windows would allow to measure the thermal emission of asteroids, Centaurs and TNOs, and thus, by coupling with visible measurements, to derive their albedos and sizes.

II- The 8-10m, necessary complement to the new facilities

(Malcolm Bremer)

As well as being the first decade that 30+m telescopes will be available, the 2020s will also be one where observational astronomy will be driven by multiple other new ground-breaking facilities and missions. These will strongly influence the use of 8m telescopes during this time, both through the need to follow up samples derived from them and also for using 8m-derived data to calibrate the results from these new facilities. Their impact will be felt across all subfields of astronomy from Galactic archaeology (following up **Gaia**) all the way to galaxy evolution and large-scale structure (observational cosmology) studies. The following discusses the extragalactic drivers connecting these new facilities and missions to 8m-class telescopes.

By the beginning of the decade, a wide range of large-area optical and near-IR imaging will be available (or will become available) including that from **Euclid, VISTA, LSST, DES, HSC** etc. Most of these data sets will be motivated by exploring one or two key issues, e.g. the nature of dark energy, the history of star formation in the Milky Way. All of them will also have extensive legacy value. While individually each data set will allow a wide-range of studies in observational cosmology, when combined these will be extremely powerful, providing deep samples of galaxies drawn from many thousands of square degrees with detailed UV-IR spectral energy distributions (and therefore reasonably accurate photometric redshifts) from multiple broad-bands and near-HST resolution morphology (mainly from Euclid). A fraction of these will have spectroscopic redshifts of sufficient quality to carry out BAO work (largely from Euclid).

In the **radio SKA1** will come on-line with data from its precursor surveys already available, identifying mainly star forming galaxies (through continuum observations) to the highest redshifts and (neutral) gas-rich galaxies to z~1. In the **X-ray eRosita** will provide a near all-sky sample of tens of thousands of virialised groups and clusters to $z>1$ and millions of AGN out to the highest redshifts.

Follow-up of the samples produced by these instruments and missions will become a key task for ground-based 8m telescopes during the decade. Largely, this will be spectroscopic follow-up, determining accurate redshifts for individual objects, exploring both their internal dynamics and that of the structures and environments that they are embedded in, determining their chemical enrichment history and exploring their relationship to the cosmic web, delineated both by galaxy and gas (the latter through tomography).

The key type of instrumentation required for many of these follow-up observations is massively multiplexed large-area spectroscopy. The ideal instrument would cover U-band through to H or K-band with a multiplex of a thousand or more, an instantaneous areal grasp of 1 or more square degrees and low and medium resolution. The spectral range allows for observations of galaxies over the widest range in redshifts and tomography of the IGM from $z\sim2$ to 3 and possibly higher (the upper redshift limit for tomography set by the surface density of background sources - AGN or LBGs at higher redshifts).

Two instruments with capabilities similar to the above will be available before the end of the current decade. In the northern hemisphere Subaru will commission the Prime Focus Spectrograph (PFS) in 2017-2018. This has a multiplex of over 2000 with an instantaneous field of view of ~1.3 degree diameter, a wavelength range from U to J band at medium resolution. It will carry out several large projects in its initial years including a BAO survey using galaxies at redshifts $0.8<z<2.4$, extending SDSS and BOSS-style measurements to higher redshift. At the same time It will obtain spectra for several hundred thousand galaxies at $1<z<7$ in order to carry out studies of the build up of stellar mass, the growth of structure, gas inflow and outflow, super-massive black hole build up. It will also explore the epoch of reionization through searches for ionized bubbles at $z\sim7$ and determining the neutral fraction of the IGM at the same redshift. While these studies will take several hundred nights, they no doubt will not be that last word on each topic, with significant further studies being required using PFS itself and other similar instruments.

In the southern hemisphere, the MOONS instrument will be commissioned on the VLT at the end of the current decade. It has a multiplex of 1000, a field of view of approximately 1/7 of a square degree and a wavelength range spanning G to H bands at medium resolution. In observational cosmology, its initial science case is driven by Euclid follow up, and a putative 5-year survey obtaining spectra for up to 1 million galaxies at $1<z<8$ enabling multiple studies of galaxy evolution (metallicity, star formation, AGN activity, dust content, mass and super-massive black hole build up) similar to that envisaged with PFS. The same survey would allow studies of the evolution of structure through the measurement of the growth rate of fluctuations in the density field and can be seen as a “high redshift SDSS equivalent”.

The differences in the details of these two instruments give them different strengths. MOONS appears better optimized for high target densities, so is faster on sub degree scales if high completeness is required. It has wider IR coverage, so potentially allows a more complete sampling of distant galaxy populations. The significantly larger PFS field of view makes it faster at covering large areas/volumes so long as its target density is sufficient for the given science. Its wavelength reach down into the U-band allows it to carry out tomography of the

IGM at z~2.5-3 which should provide significantly stronger constraint as to the nature and distribution of neutral gas and how it traces the matter field than similar observations at higher redshifts, due to the lower surface density of sufficient bright background sources.

Both could provide crucial support for the large area photometric surveys. For example, both Euclid and LSST photometric redshifts need large, uniformly selected and wide-area spectroscopic calibration samples, potentially of very high completeness. Different galaxy populations vary in how easy they are to obtain redshifts for and may have different redshift distributions/different systematics when translating from photometric to spectroscopic redshifts. Missing a fraction of any one population may compromise the use of photometric redshifts for particular tasks (e.g. BAO or weak lensing using photometric redshifts), hence the need for high completeness.

The highly multiplexed spectroscopy carried out by these instruments will be transformative, primarily because of the high surface density of targets that can be observed combined with the very large areas (volumes) that can be probed. Consequently, key to the transformative nature of the science is the on-sky availability of the instrument - exactly how much each of these instruments can achieve, and over what time-scale depends on their scheduling. PFS shares a single telescope with multiple instruments, limiting its time on sky, while MOONS could conceivably be the main or even sole instrument on one of the UTs of the VLT.

In addition to these two instruments there are other similar facilities in the planning stage. At least some of these are dedicated 100% to high multiplex spectroscopy. Perhaps foremost of these is the Canadian-led **Mauna-kea Spectroscopic Explorer (MSE**, formerly ngCFHT). The MSE project envisages upgrading the 3.6m CFHT to a 10m dedicated wide-field spectroscopic telescope, with a~1.5 degree field of view, a multiplex of 3000 or more and a low-medium resolution U to J bands. Its science drivers are similar to those of PFS and MOONS, in the extragalactic field carrying out surveys to obtain spectra of 10 million galaxies or more and to explore BAO to z~1.5 with the same sensitivity as that of SDSS at lower redshifts. If anything this is an even more capable version of PFS, albeit currently at the design stage with several feasibility studies already completed and start of operations. Obviously this would be another northern hemisphere instrument.

A significant fraction of the facilities that drive these uses of 8m telescopes are in the south **(LSST, SKA)** or cover both hemispheres (Euclid, eROSITA). MOONS is currently the only instrument that can cover the whole of the southern hemisphere. Given its capabilities, and particularly its comparatively small field of view and lack of blue sensitivity, it may be worth exploring whether it is sufficient. The answer will obviously depend on specific usage cases and potentially on the detail of scheduling its availability. Any increase in surveying speed would require a different design of 8m telescope to the VLT (where the telescope design limits the MOONS field-of-view), or indeed a more sensitive (and therefore larger) telescope than the current southern 8m facilities

One final driver for wide field highly multiplexed spectroscopy that has not been considered above is one that could have a cultural and societal impact. Many of the cases for the photometric wide field survey instruments are motivated at least in part by understanding the large-scale-structure of the universe and its evolution. However, on their own these instruments will not be able to demonstrate this in the simplest way possible - through a map.

The use of photometric redshifts will necessarily smear any 3-dimensional representation of structure in the z (redshift) direction, losing any detail on the scales of individual structures. The maps produced will not look like the large-scale computer simulations of structure that are used to capture the public's imagination, interest in and support for the exploration of the universe on large scales. Compare the impact of the blobby 3-D map generated in the COSMOS field through gravitational lensing or the two-dimensional map of the dark matter distribution produced recently by the DES project to the precise and exquisite 3-D maps of the (comparatively nearby) universe from the 2dF-GRS and SDSS projects. Along with a detailed 3-D map of our galaxy (from Gaia and its follow-up), a precise map of the matter distribution reaching over billions of parsecs and reaching back to the first few billion years of the history of the universe could well be defining cultural artefacts produced by astronomy in the coming decade (and longer) with a legacy value beyond that of the immediate science return.

III- Instrumentation on the 8-10m

Several specificities have been identified:

High-resolution spectroscopy: It has been noticed that high resolution (R> 10^5) can be done for the moment only in the South with multi-objects spectrographs. The committee recommends to explore the possibility of building a copy of UVES from ESO at GTC, with collaborations.

Wide field: The competition is harsh. The Japanese are building now for SUBARU a spectro for surveys with 1.3 degree field in diameter, which will cost about 50 million euros, and this instrument will be unsurpassed. The Prime Field Spectrograph (PFS) on Subaru will include installation of 2400 fibers at the telescope's prime focus, with a wavelength coverage extending from 3800Å to 1.3 µm, in three components. The resolution in the optical will be around 2000 (twice as high in the near-IR). A partnership with the Japanese involving a small number of institutes in the US and Europe is currently falling into place and operations might begin at the end of the decade.

Could there be some equivalent on one of the 8m of VLT? It would mean a transformation to have a wide field. This will break the symmetry between all the 4 VLT, and may be penalize VLTI.

Future of VLTI, after GRAVITY and MATISSE
The VLTI group at ESO have been integrated in the Instruments team and a position of VLTI Project Scientist has been opened in 2012 A roadmap for the VLTI will be released in 2016. What will be the **requirements for VLTI for 2022-2035?** The current main objects of VLTI are the nearby stars, and some AGN, but only the brighter ones. GRAVITY in the coming years is devoted to the Galactic Center black hole and will offer an increased sensitivity.

GRAVITY: specialized for the Galactic Center, requires 4 UT. This is a K-band instrument, needs a guiding star of 10mag. The integration time is limited to 1-2 minutes, to reach 17-18mag. Longer integration times are not possible to maintain the astrometric precision. Possible targets: stars essentially, and some AGN (e.g. NGC1068).

For the moment, the FOV is 2 arcsec, so you need a bright star very nearby, this limits highly the number of possible targets. In the future, it is possible that the FOV reaches up to one arcmin, and then the number of objects will increase significantly.

MATISSE thermal infrared > 10micron, L, M, N. The observations require 4 UT.
Will have 10mas resolution, could see the planets around the stars, the dust emitted by the disk, the gaps. These observations are very complementary to those of ALMA, which will operate at 300 microns. With 3 UT, there is only one phase closure relation, with 4 UT, 4 closure relations. Thus 4 UT are indispensable. Then for AT, 2 more would be welcome, since the optimum is to observe with 4-6 telescopes. After that, since the light beam must be shared and cut in the N-telescopes, this would be impossible. There is no need of a large number of telescopes, as in radio astronomy.

A possible specialization of one of the VLT for the wide field spectroscopy might generate troubles for the VLTI, in 4 UT modes. The specialized telescope will break the symmetry, generating difference of transmission and polarization.

Other interferometers in the world

CHARA will remain competitive and is continued. It might be developed with the Charles Townes 1.65m 3 telescopes, ISI, interferometer at Berkeley (Mount Wilson). Baselines could aim to reach 1km.
CHARA is operated by a consortium: Georgia State, Michigan, Lovell, Arizona NOAO, and now Cote d'Azur which installed a visible instrument. Paris Observatory provided the FLUOR instrument. Telescopes: 6x 1m, 30-330 m baselines.
Magdalena Ridge Observatory is in a standby position with funding issues.

Goals, and long-term prospective for VLTI:
1- Going towards the visible
2- Imaging planets, with UT/AT
3- specialized niche complementary to space missions

Future use of instrumentation on 8-10m *(Malcom Bremer)*

Looking at all of the above, it all points in a single direction: The need to carry out significant wide area and deep extragalactic spectroscopic surveys and medium (R~1-5000) resolution and the will to commit significant amount of time (years over multiple telescopes) to do this, possibly through dedicated telescopes. Looking at what suitable instrumentation exists, or is expected to exist in the 2020-30 time-frame, we have PFS on Subaru in the north (1.3 deg field, 2400 fibers, U to J at R=1400 to 4800 (latter for skyline removal in IR).DEIMOS on Keck gives a 5x16 arcmin field in the optical at R ~ few thousand. MOSFIRE gives IR spectroscopy over ~36 sq. arcmin (so both Keck instruments are not particularly suited to these huge surveys). EMIR on GTC In the south the VLT has VIMOS (1/10 sq. degree per pointing, 4000-9000 Angstrom at medium resolution) and will have MOONS (500 sq. arcmin, 0.8-1.8 micron R=5000) that complements VIMOS. KMOS probably has too little in the way of multiplex to be useful here. Given that LSST will be a southern hemisphere survey, backed up by VISTA, it appears to me that significant southern spectroscopic instrumentation is required. The combination of VIMOS and MOONS may be feasible for such work, though ideally having something with the capability of PFS in the south would be ideal. Given the required unobscured field-of-view, this probably rules out the VLTs (and Gemini) without significant top end changes.

Clearly, all of the individual fields (or individual objects) are perfect targets for a 30m+ telescope. Clusters & protoclusters are matched to 5-10 arcmin fields of view and the expected typical offset between absorbers and their host galaxies are likely to be ~1 arcmin at most.

Relative fraction of time which should be spent on surveys, with respect to small individual programs.

The committee recommends that large surveys, with universal use in the community, will be carried out in priority. In any case, there will be in the future a large telescope time devoted to huge follow up from Euclid and GAIA.

A specific operation of data reduction, like HDF, HUDF or SDSS should be recommended.

This requires detailed quantification, to know how much time on VLT/GTC is spent in GTO, LP and follow up. The committee will come back with precise numbers to recommend.

APPENDICES

Appendix A. List of the main Large Programs carried out now and foreseen for the 8-10m

- Exoplanets: HARPS-4m class

After CoRoT and Kepler, TESS (NASA, 2017)

- Protoplanetary disks (VISIR)
- Stars in the Milky Way, Spectroscopy, GAIA follow up
- First stars: metal poor stars
- Magnetism in stars
- Interferometry on stars
- Local group dwarfs, dark matter probes
- Black hole in the Galactic Center (GRAVITY)
- Black hole masses, surveys of nearby AGN galaxies
- Absorption lines in front of Quasars
- Starbursts, flows and outflows, abundance cycle
- Cluster survey, Dark energy probe
- High-z galaxies, high-res (GOODS, CANDELS)
- Follow up of satellites in spectro (Euclid, JWST…)

Appendix B. Projects not possible with the 2-4m, identified by the previous Astronet 2-4m ET-SRC Committee

- MOS at NIR wavelengths
- Spectro-polarimetry of stars and AGN
- Optical high-res R>20 000 of objects fainter than 14
- High-order High-strehl AO

Appendix C. Current European Instrumentation and Competitors

Optical Instruments

ESO

FORS: General purpose Spectrograph (LS & MOS10)/ Camera/Polarimeter
FOV 6.8 x 6.8 (0.25”/px)/ 330-1100nm/R= 260-2600
FLAMES: MOS intermediate/high-res spectrograph
GIRAFFE MEDUSA(x132), IFU(x15),ARGUS(11.5x7.3arcsec)
FOV 25 arcmin diameter/370-950nm/ R=5600-46000
UVES echelle 300-1100/ R= 40000-110000
VIMOS: MOS (150-750 slits/quadrant) & IFU (45”x45”) intermediate spectrograph
4 quadrants with FOV 7´ x 8´ with gap of 2´/360-1000/R= 180-2500

GTC

OSIRIS: Multipurpose spectrograph and camera (LS, MOS x40, TF)
FOV 7.8´x7.8´ /0.365-1.01 nm/ R=300-2500

LBT

MODS: Optical Double Spectrograph
FOV 6´x6´/ 330-1000nm/ R= 2000
LBC: Prime focus optical camera
FOV 23´x 23´ 0.23”/px/UBVRIz
PEPSI: fiber-feed high-resolution Echelle spectrograph/ 383-907 nm/ R=32000-320000

SALT

SALTICAM: Imaging and acquisition camera
FOV 10´diameter (0.14”/px)
RSS: General purpose Spectrograph LS, MOS (x 50), Fabry-Perot and TF
FOV 8´diameter/ 370-900 nm/R= 250-5000
HRS: Echelle Spectrograph
FOV 2”/ 300-1000 nm/ R= 16000-65000

Infrared Instruments

ESO

HAWK-I*: WFI
FOV 4 x (7.5´x7.5´)/ Y,J,H,K
CRIRES: high-resolution echelle
Slit 0.2, 0.4 x 40 arcsec/ 0.95-5.38µm/ R= 100.000
KMOS: IFU MOS (x 24) NIR spectrograph
IFU-FOV 2.8 x 2.8 arcsec/ FOV 7.2 arcmin/ 0.8-2.5µm/R= 2000-4000
ISAAC: General purpose camera and spectrograph/polarimetry
FOV imaging 152 x 152 arcsec (0.148”/px) 73x73v(0.07”/px)/1-5µm/ R= 500-3000
SINFONI: IFU NIR spectrograph
FOV 0.8”x0.8”, 3”x3”,8”x8”/1.1-2.45µm/ R= 1500-4000
NACO: Adaptive Optics imaging/polarimetry/coronography/spectroscopy
Extended objects < 4”/J (32mas),H(32mas),K(56mas),L(98mas),M(123)
FOV for 54.3mas/px 56”x56”/0.9-4.2µm/R = 400-1500
X-Shooter: medium resolution optical-NIR Long-slit &IFU(1.8”x4”) spectrograph
FOV 1.5´x1.5´/300-2500nm/ R= 3000-10.000 (UV), 5400-18200(VIS), 3890-10500(NIR)

MIR Instruments

ESO

VISIR*: General purpose MIR spectrograph/imager
FOV 62”x62”(0.076”/px) &40”x40”(0.045”/px)
7.5-25µm (N,Q)
R=350,3200,25000(N) /

GTC

CANARICAM: General purpose MIR spectrograph/imager/corono/polarim
FOV 26” x 19” (0.16” FWHM imaging)
7.5-25µm (N,Q)
R=185-1300

Interferometric Instruments

VLTI

MIDI: MIR spectrograph
8-13µm
R=30, 230

AMBER: Interferometric beam combiner in JHK
JHK
Limit resolution 2mas in K
R=30, 1500, 12000

Future Instruments

ESO 2nd GENERATION 2013+

MUSE: Panoramic IFU
FOV ~1´x1´ (0.2”/px) / 7.5”x7.5” (0.025”)
400-1000nm
R= 2000@460, 4000@930

SPHERE: Spectro Polarimetric High contrast Exoplanet Research
FOV = >11” (12.25mas),>1.35”(12.25mas), >3” (<7.8mas)
0.9 - 2.5 µm
R= 30

GRAVITY: Second generation VLTI for astrometry in the galactic center

MATISSE: Multi Aperture MIR Spectroscopic Experiment for VLTI
3- 13 µm
R= (20-1000@L, 20-550@M, 20-250@N)

ERIS**: NACO/SINFONI+

GTC 2015+

CIRCE: NIR Camera
FOV ~3.4´x3.4´ (0.1”/px)

EMIR: wide field camera and a NIR MOS medium resolution spectrograph
FOV = 6' x 6'

0.9 - 2.5 µm
R= 4000
MEGARA: an optical IFU and MOS(x94)
FOV MOS 3.5´X3.5´ IFU 14”x12”
350-1100 nm
R=5000-20000
HORUS: High Resolution Spectrograph LS
370-900 nm
R=50000
FRIDA: AO Integral Field Spectrograph at NIR
FOV 40” x 40”
0.9 - 2.5 µm
R= 1500-30000
MIRADAS: NIR MOS (x20) high resolution spectrograph
FOV 5´/0.9 - 2.5 µm/ R=20000

GEMINI

Optical

GMOS(N/S): General purpose Imaging & Spectrograh with LS, IFU (5”x7”),MOS(x60 (0.2”))
FOV Imaging 5.5 arcmin / 360-940nm/ R=630-4400

NIR

NIRI(N): General purpose Imaging & Spectrograh
FOV 22”x22”(0.02), 51”x51”(0.05), 120”x120”(0.117)/ 1-5 µm/ R= 400-1000
NIFI(N): NIR IFU
FOV 3”x3”/ 0.95-2.4 µm/ R=5000
GNIRS(N): Camera & Spectrograph
FOV 99”x 0.15 45” x 0.05/ 1-5.4 µm/ R= 1800-18000
GSAOI(S): AO Imager
FOV 85”x85” (0.02”/px)/ 0.95-2.4 µm
FLAMINGOS2(S): WFI & MOS(x80 slits)
Imaging FOV 6.1´ diameter/ MOS FOV 2.2´x 6.1´/0.95-2.4 µm/R=1200-3000

MIR

TEXES(N): Echelle Spectrograph
FOV 0.52” 0.75”/ 5-25 µm/ R=4000-80000(10 µm), 11000-60000(20µm)

SUBARU

Optical

Suprime-CAM: Primary focus WFI camera
FOV 34´x27´(0.20”/px)/400-1000nm
Hyper- Suprime-CAM: WFI
FOV 1.5 degree (0.17”/px)/400-1000nm
FOCAS: General purpose Camera and Spectrograph LS MOS (30 slit 2”)
FOV 6´ diameter/ 370-1000nm/ R= 200-5000
HDS: High Dispersion Spectrograph
FOV 2-60” x 0.2-4”/ 300-1000 nm/R= 160000

NIR

FMOS: MOS Spectrograph (x400)
FOV 30´diameter/ 0.9-1.8 µm/ R= 600-2200
IRCS: NIR Camera and Spectrograph
FOV 54”x54”(0.05) 20”x20”(0.02) 12” x 12”(0.01)/1-5 µm/ R=100-2000
MOIRCS: Spectrograph NIR MOS (x40 slit)
FOV 4´x7´ (0.117”/px)/ 0.9-2.5/ R=500-1300

MIR

COMICS: MIR Camera and Spetrograph
FOV 42” x 32”/ 7.5-25 µm/ R= 2500-8500

KECK I,II

Optical

DEIMOS: Deep Imaging Multoibject Spectrograph (x130slit)
FOV 16.7´x 5´ (0.12”/px)/400-1050nm/R=200-6000
ESI: Echelle Spectrograph and Camera
FOV 2´x 8´/390-1100 nm/R= 1000-20000
HIRES: Echelle Spectrograph
FOV 43” x 2”/ 300-1000 nm/ R= 25000-80000
LRIS: Low Resolution Imaging Spectroscopy
FOV 6´x 7.8´ (0.135”/px)/ 320-1000 nm/R= 200-5000

NIR

MOSFIRE: NIR MOS(x46) Spectrograph
FOV 6.1´x 6.1´/ 0.97-2.45µm/R= 3600
OSIRIS: NIR IFU
FOV 3.2” x 6.4” (0.10) 1.6”x3.2 (0.05) 1.12”x2.24(0.03)/ 1.1-2.4 µm/ R= 3800
NIRC2: NIR imager
FOV 10”x10”(0.01) 20”x20”(0.02) 40”x40”(0.04)/ 0.9-5.34 µm/R=2500
NIRSPEC: High-res NIR Spectrograph
FOV 46”x46” (0.18”)/ 0.9-5.34 µm/ R= 2000, 25000

Appendix D: Sections of Science Vision mentioning explicitly the need of 8-10m

SV A5 Make direct studies of regions near the event horizon of super-massive black holes in galactic nuclei, to test strong gravity and to understand how large-scale relativistic jets are launched;

SV B3. Determine the evolution of the galaxy cluster mass function and constrain the equation of state of the dark energy;
SV B4. Make an inventory of the metal content of the Universe over cosmic time, and connect its evolution to detailed models of star formation, and the subsequent metal production and ejection from galaxies by super-winds;
SV B6. Measure the built up of gas, dust, stars, metals, magnetic fields, masses of galaxies and thus the evolution of the Hubble sequence with cosmic time and the connection between black hole and galaxy growth;

SV C1. Determine the initial physical conditions of star formation, including the evolution of molecular clouds, and the subsequent development of structures in general, and the formation and mass distributions of single, binary or multiple stellar systems and stellar clusters;

SV C2. Unveil the mysteries of stellar structure and evolution, also probing stellar interiors;
SV C3. Understand the life cycle of matter from the interstellar medium to the processing in stars and back into the diffuse medium during the last stages of stellar evolution;
SV C4. Determine the process of planet formation, aiming for a full understanding of the timeline for the formation of planets and the chemical evolution of the material that will eventually end up in exo-planets;
SV C5. Explore the diversity of exo-planets in a wide mass range from giants to Earth-like, to characterize the population of planetary systems in relation with the characteristics of their host stars;
SV C6. Determine the frequency of Earth-like planets in habitable zones and push towards their direct imaging with the long-term goal of spectroscopic characterization including the detection of biomarkers in their atmospheres.

SV D1. Utilize the vicinity of Solar System plasmas, in (i) the Sun, (ii) the heliosphere and (iii) planetary environments, to develop a detailed understanding of physical processes which apply to astrophysical phenomena;