Summary of the VLT in 2030 workshop

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1. **Introduction**

VLT and VLTI will move from the ESO optical/near-infrared flagship facility into a new role when the ELT arrives. In many ways, VLT/I, ELT and the ESO 4m telescopes, which will mostly cater to surveys, are complementary and while the ELT considerably expands the observational capabilities in terms of sensitivity and angular resolution, the VLT/I will keep unique strengths in many areas. VLT and the VLTI offer unique capabilities through their versatile instrumentation on four 8m telescopes, angular resolution at the diffraction limit of the equivalent of a 100m telescope through interferometry, UV/blue and optical wavelength coverage and the flexible operations model. These features empower the VLT and VLTI to achieve science that no other ESO facility offers.

Putting the VLT/I together with ALMA ESO is able to offer a comprehensive coverage of the electromagnetic spectrum accessible from the ground to the European astronomical community and its partners.

The development of the VLT and VLTI over the past years followed the prioritisation presented in STC-551 (April 2015). There were three phases envisaged: 2016-2020, 2021-2025 and after 2025. The LPO priorities (including the La Silla telescopes) were presented in the following table.

### LPO priorities and roadmap

**Epoch 1: 2016-2020**

a) Deliver GRAVITY by 2017 to observe the periapsis of S2, providing reliable, high-performance VLTI infrastructure and robust fringe tracking;
b) Deliver AOF, ESPRESSO and CRIRES+ by 2018;
c) Complete the ongoing public surveys;
d) Establish development plan for the VLTI (VLTI White Book, mid-2016);
e) Deliver MATISSE, ERIS and MOONS;
f) Deliver new instrument for the NTT;
g) Start second round of VISTA public surveys;
h) Revise operational model for a more flexible time allocation and execution process;
i) Expand VLTI user base by improving access to the facility to non-experts through dedicated expertise centre(s);
j) Develop upgrade and replacement plan (VLT and VLTI);
k) Select and design AO instrument.

**Epoch 2: 2021-2025**

a) Fully exploit the by-now existing VLTI infrastructure by expanding its instrumentation;
b) Upgrade and replace VLT science capabilities, as defined in the upgrade plan;
c) Deliver 4MOST to VISTA;
d) Design and deliver AO instrument to VLT;
e) Encourage visiting instruments for VLT and VLTI.

**Epoch 3: Beyond 2025**

Operate the ESO optical/NIR telescope system making best use of the synergies. With the E-ELT starting operations, the support role of the VLT, VLTI and the 4-m telescopes needs to be defined. Support capabilities for other ESO observatories, e.g. ALMA.

*Table 1: Priorities for the La Silla Paranal Observatory development as presented in STC-551. The individual items are discussed in the text.*

Even though 2020 has not been completely reached one can see that the priorities of the first five years have been followed and achieved. GRAVITY has obtained unique data and has established new stringent measurements on the supermassive black hole at the centre of the Milky Way. The passage of S2 has been fully covered and can be considered a major
observational achievement of the VLTI. GRAVITY is making new and exciting discoveries in many other areas, like material around AGNs, exoplanet atmospheres and binary stars. The AOF has been delivered and is fully operational. Exciting results from the MUSE narrow-field mode are emerging, e.g. the discovery of a second young planet in the PDS70 system complementing ALMA and SPHERE observations. ESPRESSO has now been fully commissioned and an upgraded CRIRES is returning to Paranal at the end of this year. These two instruments were delayed due to technical difficulties. The ESO public surveys are completed and a PSP review in May 2019 has attested to the scientific success of many of the past surveys and the survey concept. The synergetic effects in the community have been stressed by several survey collaborations. The second round of VISTA surveys is in full swing and will be completed by 2020, in time to make space for the new instrument 4MOST. The VLTI Roadmap has been completed (STC-599; Messenger 171, 14) and established the development plans for interferometry. MATISSE has been commissioned and is observing. ERIS is planned to be delivered to Paranal in 2020 and MOONS should follow in 2021. The new instruments for the ESO 3.6m telescope, NIRPS, will be coming to La Silla in 2020 and the NTT instrument SOXS should start operations in late 2021. These instruments are almost entirely financed by the community and the consortia receive large fractions of guaranteed observing time. These instruments employ a new operational model with the consortia providing most of the operational support. The upgrade plan for the existing VLT instrumentation was presented to the STC in April 2017 (STC-588; Messenger 169, 11) and resulted in the proposal to update FORS for another two decades of operations. The future of the existing instruments needs to be seen together with the new proposals for VLT/I instrument in 2030. MAVIS has been selected as an optical multi-conjugate adaptive optics instrument for the VLT and is in a Phase A study. All Epoch 1 items (a through k in Table 1) for the timeline between 2016 and 2020 have been addressed and, with the exception of the operations model, have been either completed or are under way. Items for the following 5 years (Epoch 2) are on track and the decisions leading to the completion of those items have been prepared and/or taken. Epoch 3, which covers the time when the ELT will be operational, has been largely undefined in STC-551. The aim of the ESO workshop on “The Very Large Telescope in the 2030” (Garching, 18-20 June 2019) was to prepare the planning for this period. A summary of the workshop and the scientific presentations can be found in the Messenger (176, 51). This document presents a summary of the workshop, the various community (instrument) proposals and a first assessment.

2. **Scientific landscape**

It can be expected that several astronomical fields will make exciting new discoveries and continue to change our view of the world. Until a few years ago electromagnetic radiation was the primary source of information on celestial objects. This has now changed with the addition of gravitational wave and neutrino observations. These provide additional physical insight into the (mostly) violent processes in the Universe. A strong move towards statistical astrophysics has taken place over the past two decades and will continue with many new survey facilities coming online. Exoplanet research has moved from discovery to characterization of individual planets and planetary systems. The combination with the investigations of disks, enabled through the access to cold dust by ALMA and the increased angular resolution with, e.g., SPHERE and VLTI, provides astronomers with a comprehensive view of critical phases of star and planet formation. The structure of the Milky Way is emerging in ever more detail through Gaia and the associated spectroscopic surveys. The dynamics of the Local Group galaxies has also been opened. Ever more
detailed observations, both in angular and spectral resolution, have mapped galaxy evolution and the roles of central massive black holes. The various galaxy components (cold and hot gas, dust, stars) are accessible at different wavelengths and the many facilities start to provide a complete picture on the evolution and interplays of the various galaxy parts. Cosmology is exploring the current Λ cold dark matter model and tries to tie down the parameters of the model. All fields have clear paths into the future and observational programmes leading to new insights.

A decade from now astronomers will use new flagship facilities and immense archival resources. It will be the era of the 30m and 40m optical/near-infrared telescopes, radio networks around the globe and a powerful radio observatory, the Square Kilometer Array with two southern sites, and very high energy observatories, the Cerenkov Telescope Array, from the ground. Space observatories will continue to explore the X-ray and gamma-ray sky (XMM/Newton, Chandra, eROSITA, ATHENA), the infrared universe (JWST) and provide large surveys (EUCLID, WFIRST for cosmology and PLATO for exoplanets). The HST will most likely have terminated its mission, Gaia produced a catalogue of the dynamic Milky Way, CHEOPS leave a detailed characterization of many exoplanet systems and TESS a long list of new exoplanet candidates. Future satellites will aim at characterization of the planet atmospheres (ARIEL). Several surveys will be well underway (LSST, DESI/4MOST/WEAVE, TESS) and their analyses will continue for years after they have finished taking data. At the same time, astronomers will have access to essentially all observations taken over the past 2 decades through data archives (ESO, ESA, NASA), which provide references across the electromagnetic spectrum. Additional ‘messengers’ will routinely yield information on astrophysical processes which are not accessible through electromagnetic radiation. Gravitational wave and neutrino observatories are already operational but will continuously enhance their sensitivity and capabilities throughout the decade.

Astrophysicists will draw on many more and more diverse resources than they do today. Individual observatories will complement many of the flagship facilities and the data archives. They need to define their strengths to remain relevant.

Futures lie in increased angular resolution, higher sensitivity, wavelength coverage, statistical samples, detailed investigations of singular objects or small samples, time aspects (including flexible scheduling), and complementarity with other messengers from the universe.

The role of the VLT and VLTI in this future will be manifold. VLTI, the most sensitive of the handful of optical interferometers, will continue its successful investigation at the smallest angular scales. The spectacular successes with the observations of the Galactic Centre and the environments of active black holes in distant galaxies demonstrate the power of extension to smaller scales. Detailed structures of proto-planetary and debris disks have become accessible as is the characterization of exoplanet atmospheres through the improved separation of planet from host star. The above measurements are not simply improvements of spatial information, but breakthroughs that are impossible at lower resolution. As one of the most efficiently run 8m class observatory, the VLT remains second only to the 30 to 40m telescopes of the next generation. At optical and particularly at UV and blue wavelengths the VLT remains among the largest ground-based telescopes. The versatility of beam combinations (single telescope, interferometry through coherent beam combination, ‘16m-light bucket’ by incoherent beam combination), its instrumentation, and the existing adaptive optics support on UT4 places the telescopes of the La Silla Paranal
observatory in a unique position for follow-up studies of individual targets. The operational model also provides unique advantages to explore the capabilities of the VLT and VLTI. The VLT will remain the ESO’s ‘volume’ observatory serving about 1200 nights per year to the entire ESO community. The VLT will also be the central connection in ESO’s collection of telescopes from 4m to 40m diameter.

3. Strengths and weaknesses of the VLT/I

The various presentations and follow up discussions brought up interesting points regarding VLT/I. VLT has contributed to various fields, but not to others: even though VLT/I is a very versatile machine, it is not a universal one. Over the years, the VLT/I has been serving a wide community.

3.1 Uniqueness of VLT/I

Arguably, the most unique aspect of VLT/I is the ability to combine 8m telescopes, either coherently or incoherently. The interferometric mode, VLTI, is unique in the world by the size of telescopes combined: the second largest optical interferometer employs 1m telescopes. GRAVITY is providing outstanding and high impact results which cannot be obtained by any other facilities in the world. The incoherent combination is being used only recently with ESPRESSO: the possibility to have virtual continuous observations with an ultra-stable spectrograph is a great advantage to characterize exoplanets. These unique features will remain in the coming decades, since no other facilities (running or planned) will match the VLT. Finally, an often-overlooked uniqueness of VLT is the many foci (and associated instruments) which are continuously available for single telescope use by the 4 UTs.

3.2 Leadership of VLT/I, ESO and its community

VLT/I and its community have recognized leadership in several domains: IFU imaging; high-resolution spectroscopy; AO imaging, including high contrast studies of exoplanets; interferometry. Maintaining / reinforcing these leadership positions is the best way for the VLT to stay at the forefront of astronomical research. Of course, science cases should be compelling and competitive in the upcoming landscape of facilities. Conversely, one could argue that VLT and ESO’s community could attempt to take on new leaderships, but it is unlikely that ESO could dedicate proper resources while building the ELT at the same time: the traditional domains of leadership of VLT/I and its community are already found within ESO staff. Supporting new VLT/I projects within the historical leadership is less likely for ESO to require taking on new competences or hire new staff.

3.3 Instrumentation

A strength of the VLT/I lies in its large suite of instruments (16) which cover a wide spectral range, spectral and angular resolutions, combined with an operation model which allows to handle small to large programmes, including surveys running several years or fast reaction to ongoing events. Operations can be switched from one to another instrument mounted on the same telescope in minutes. VLT/I instruments fall into two categories: workhorses and specialized. Workhorses are instruments which can cover a wide range of science cases, whereas specialized instruments address specific science cases requiring specific characteristics.

- **Workhorse:** FORS, UVES, XSHOOTER, HAWK-I, MUSE, ESPRESSO, PIONIER, ERIS, MAVIS
- **Specialized**: KMOS, FLAMES, SPHERE, VISIR (NEAR), SINFONI, GRAVITY, MATISSE, 4MOST, MOONS

Workhorses tend to be more requested and have a wider user base than specialized instruments. Specialized instruments have the potential to yield high impact results or remain instruments serving niche science cases (see STC-588 for the assessment of the current VLT instrumentation).

Smaller projects can be implemented as visitor instruments. Visitor instruments do not follow all requirements of facility instruments: they have minimal interface with the telescope and are operated by the instrument’s consortium. The access to the instrument is not offered to the community, except if the consortium supports it.

The VLT with its 16 focal stations is uniquely placed here. A good mix of workhorse and specialized instruments can be accommodated, which is not possible at facilities with fewer foci.

### 3.4 Weakness of VLT/I

There are some fields where VLT/I is not competitive. VLT/I is not operated as a dedicated facility and some science cases cannot be addressed as a consequence. For instance, large scale surveys (at the level of hundreds of nights a year) have never been carried out. The largest survey is the Gaia-ESO survey using FLAMES which used about 300 nights of UT2 over more than 6 years. During the VLT2030 workshop, it was recognized that ESO uses only a fraction of its observing time to large scale programmes (so called “large programmes” and surveys), and execution time is often spread over several semesters, without necessity.

The VLT is not a universal machine, it lacks for instance a wide field, highly multiplexed low-resolution spectroscopic capabilities for competitive redshift surveys of galaxies. The coming decades will see large investments into the cosmological measurements of the baryon acoustic oscillations with several facilities (most prominently DESI and PFS). The VLT optical concept does not provide a competitive field of view for such surveys and the investment into modifying a UT cannot be justified on a competitive timescale. Such a modification would also severely impact the interferometric capabilities of the VLT. Although such a concept was presented at the workshop, if is not pursued further here: the preliminary cost estimates goes several times beyond what is foreseen for the next decade Paranal Instrumentation Programme (PIP) developments. A separate ESO study by Ellis et al 2018[^1] showed the interest for wide field spectroscopy as implemented in a dedicated telescope.

4. **Summary of instrument presentations**

New instrumentation ideas were presented at the workshop over two days. The list of proposals can be found at [http://www.eso.org/sci/meetings/2019/VLT2030/program.html](http://www.eso.org/sci/meetings/2019/VLT2030/program.html) with links to the individual presentations. Table 2 gives a list of the presented instruments concepts.

*Table 2: Instrument proposals presented at the VLT in 2030 workshop*

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Telescope</th>
<th>Description</th>
<th>Project size</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV spectrograph</td>
<td>single UT</td>
<td>300 to 400 nm high-resolution spectrograph</td>
<td>medium</td>
<td>facility instrument</td>
</tr>
<tr>
<td>BlueMUSE</td>
<td>single UT</td>
<td>integral-field spectrograph in the blue</td>
<td>large</td>
<td>facility instrument</td>
</tr>
<tr>
<td>Polarization for UVES</td>
<td>single UT</td>
<td>bonnet from Cassegrain focus to UVES (fibre)</td>
<td>small</td>
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</tr>
<tr>
<td>SOXS concept for VLT</td>
<td>single UT</td>
<td>single-object wide-spectral range intermediate resolution spectrograph</td>
<td>medium</td>
<td>facility instrument</td>
</tr>
<tr>
<td>Spectropolarimetry</td>
<td>single UT</td>
<td></td>
<td>medium</td>
<td>facility instrument</td>
</tr>
<tr>
<td>GRAVITY+</td>
<td>VLTI</td>
<td>new AO for UTs / LGS / off-axis FT / improved instrument for better sensitivity</td>
<td>large</td>
<td>facility instrument</td>
</tr>
<tr>
<td>Visible VLTI</td>
<td>VLTI</td>
<td>Halpha enabled combiner</td>
<td>medium</td>
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</tr>
<tr>
<td>VLTI/Asgard</td>
<td>VLTI</td>
<td>fringe tracker / high contrast in L band / J band spectrograph</td>
<td>large</td>
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</tr>
<tr>
<td>New Generation fringe tracker</td>
<td>VLTI</td>
<td>possibly for MATISSE, GRAVITY+, Asgard</td>
<td>medium</td>
<td>facility upgrade</td>
</tr>
<tr>
<td>SPHERE+</td>
<td>single UT</td>
<td>upgrade of SPHERE extreme AO module</td>
<td>medium</td>
<td>instrument upgrade</td>
</tr>
<tr>
<td>HIRISE</td>
<td>single UT</td>
<td>fibre link from SPHERE to CRIRES</td>
<td>small</td>
<td>visitor instrument</td>
</tr>
<tr>
<td>RISTRETTO</td>
<td>single UT</td>
<td>fibre link from SPHERE to an optical high-resolution spectrograph</td>
<td>small</td>
<td>visitor instrument</td>
</tr>
<tr>
<td>ESPRESSO-ATOM</td>
<td>single UT</td>
<td>adaptive optics for ESPRESSO</td>
<td>medium</td>
<td>facility upgrade</td>
</tr>
<tr>
<td>OH suppression</td>
<td>single UT</td>
<td>for infrared spectroscopy</td>
<td>medium</td>
<td>visitor instrument</td>
</tr>
<tr>
<td>moderate-resolution optical facility spectrograph</td>
<td>single UT</td>
<td></td>
<td>medium</td>
<td>visitor instrument?</td>
</tr>
<tr>
<td>multi-IFU AO visible instrument</td>
<td>single UT</td>
<td></td>
<td>large</td>
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</tr>
<tr>
<td>Broadband Q-band VLTI Heterodyne instrument</td>
<td>single UT</td>
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<tr>
<td>UV instrumentation</td>
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<tr>
<td>GravityCam</td>
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<td>lucky imaging camera</td>
<td>medium</td>
<td>proposal for NTT</td>
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<tr>
<td>Surface imaging of evolved stars</td>
<td>VLTI</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Multi-object high-resolution spectrograph</td>
<td>single UT</td>
<td>Abundances for Gaia stars</td>
<td>large</td>
<td>facility instrument</td>
</tr>
</tbody>
</table>

4.1 **Science**

The proposed science for the new instruments covers many interesting topics. The most often mentioned science case were exoplanets and their characterization, a better understanding of the role of circumstellar disks in star and planet formation, the abundance determinations of stars to map the structure of the Milky Way, the evolution of black holes through cosmic time and their influence on the shaping of galaxies, the transient sky and the access to additional information of violent astrophysical processes. For some of these cases the VLT can play a crucial role or even offer unique capabilities that cannot be matched anywhere else and in others it is an important contributor providing complementary data. In both roles, it represents a backbone of the astronomical community in the ESO Member States.
The new instrument concepts have to be evaluated in the context of the existing instrumentation. In some cases, they complement and extend current instrumentation, but some very specific singular ‘experiments’ were proposed. One proposal considers a substantial extension of the UTs, which could be regarded as a facility upgrade. The following tries to categorize the proposals into new facility instruments, facility upgrades, instrument upgrades and visitor instruments (see also Table 2).

4.2 Instrument concepts

4.2.1 UV high-resolution spectrograph

This instrument concept has been discussed for several years and was originally proposed as the CUBES spectrograph. The science case has been evaluated at an ESO workshop on “Challenges in UV Astronomy” (October 2013, Garching) and the instrument requirements in an SPIE paper in 2018 (arXiv:1806.11173). The main science goals are the measurement of heavy (r- and s-process) element abundances, light element abundances, in particular Beryllium, and a measurement of the escape fraction of UV photons to lower redshifts. The instrument concept has been updated recently and includes an image slicer, an atmospheric dispersion corrector and a three-arm spectrograph to optimize the throughput. With a resolution of more than 20000 the wavelengths from 300 to 430nm should be covered. The overall throughput (including telescope reflections) should reach more than 40%. The UV spectrograph extends the current UVES UV coverage at a much-improved throughput. It should be seen in connection with UVES, ESPRESSO and (at lower resolutions) Xshooter and BlueMUSE, which would cover the UV/optical high-resolution spectroscopy at the VLT.

4.2.2 BlueMUSE

This concept proposes to build an integral-field spectrograph comparable to the existing MUSE instrument, but without adaptive optics support and optimized for blue wavelengths (350 to 600nm) at a spectral resolution from 3000(@350nm)<R/ΔR<5000(@600nm). The field of view would be 1.4x1.4, slightly larger than the MUSE field of view. The most prominent science cases are spectroscopy in crowded fields, e.g. resolved stellar populations in nearby galaxies and a blue extension to observe rest frame UV lines at lower redshifts and hence map the intergalactic medium over a wider range (in combination with e.g. MUSE) in deep fields. A white book on BlueMUSE is available (arXiv:1906.01657) detailing the science case and some instrumental concepts. BlueMUSE clearly would be a facility instrument.

BlueMUSE would fill the gap of integral-field capabilities at bluer wavelength. Some of the capabilities, although for single targets, are already present through Xshooter, UVES and ESPRESSO, however the field of view is unique for BlueMUSE.

BlueMUSE is a large instrument and comparable in complexity and hardware to MUSE. Its costs would be of the same scale as MUSE.

4.2.3 SOXS concept for VLT

SOXS is a new spectrograph for the NTT to provide a large wavelength coverage for single targets. Many of the Xshooter concepts are transferred to SOXS. The optical spectrograph of SOXS uses a novel design, which keeps the spectra in first order and avoids the need of
cross-dispersing the spectrum. This new design promises increased throughput and stability of the spectrograph. One could imagine to pursue such a concept to duplicate the Xshooter capability or for an eventual replacement of Xshooter. This would be a facility instrument.

4.2.4 SPHERE+ and HIRISE

SPHERE has shown to be a fantastic planets and disks imager. The upgrade proposal (SPHERE+, presented by A. Boccaletti), led by the original consortium, would improve key performances of SPHERE: faster AO; improved sensitivity; higher spectral resolution, better coronagraph. HIRISE (presented by A. Vigan) is a separate and complementary proposal to link SPHERE (or SPHERE+) to the CRIRES spectrograph. The goal of HIRISE is to obtain spectra of exoplanets (as presented by G. Otten) with higher signal-to-noise ratio than with CRIRES alone (by a factor of 2, based on simulations).

While an upgrade of the SPHERE adaptive optics is probably a natural evolution with improvements of AO systems and should be considered an instrument upgrade, the HIRISE proposal deals with a rather special, albeit very interesting and topical, science case. Its implementation would be more suitable for a visitor instrument. Introducing a fibre from one instrument to another one has implication on the telescope and would have to most probably be coordinated by ESO.

4.2.5 GRAVITY+

This proposal is built on the undeniable successes of the GRAVITY instrument at VLTI. Not only GRAVITY monitored the peri-passage of the star S2 around the Galactic Center, it has also provided a wealth of “first” observations: BLR kinematics of a quasar, microlensing event, exoplanet astrometry and spectroscopy; microquasar etc. GRAVITY+ offers to improve the sensitivity and sky coverage of GRAVITY by upgrading key components of the spectrograph (detector and grism); improving the current visible AOs (MACAOs); adding LGS to UT1, UT2 and UT3; and adding true off-axis capabilities (up to 30° separation, re-using PRIMA hardware). The improved sensitivity by up to 5 magnitudes and extended sky coverage promise to bring the angular resolution of VLTI to much larger number of targets. For instance, black hole masses of hundreds of quasars, up to z~2.5, could be measured. The science case for exoplanets, covered separately (S. Lacour), argued that the gained contrast would fill the gap between planets found by astrometry (Gaia) and radial velocity. The team behind the proposal is led by the GRAVITY consortium and is accreting new collaborators and have already requested large sums of money to funding agencies.

4.2.6 ASGARD

ASGARD is a proposal for VLTI, composed of 3 sub-systems: HEIMDALLR (a H+K bands fringe tracker), BIFORST (a Y- and J-bands spectrograph) and VICKING/Hi5 (a L-band high contrast beam combiner). HEIMDALLR aims at improving sensitivity of the current fringe tracker of VLTI (GRAVITY). BIFROST science cases (presented by S. Kraus) revolve around stellar physics, galactic archeology, binary star evolutions and YSO disks. VICKING (presented by F. Martinache) aims at directly detecting and characterizing hot exoplanets in formation, at very small inner-working angle (better than ELTs). An alternate design to VICKING is Hi5 (presented by D. Defrère). The challenge is to remove the star light using a nulling beam combination. L band is the obvious choice due to the high relative brightness of
the young planets compared to the star. The science case of exoplanets in the context of ASGARD was also addressed by M. Ireland and D. Defrère.

Proposers of the ASGARD project aim at a visiting instrument approach for many reasons. The instrument is modular and would be built in stages: BIFROST is a relatively simple instrument to build (comparable to PIONIER); the beam combination for VICKING would likely be experimental, but with high scientific gains if the performances can be achieved.

4.2.7 Interferometry in the Visible

The presentation (by F. Millour) concentrated on technical developments and sky demonstrators of the past decade in visible instrumentation for interferometry, arguing that the field has reached maturity so a simple instrument can easily and robustly be built for VLTI. Science cases are mostly extension to current bread-and-butter cases for VLTI, in particular stellar surfaces images and stellar diameter/binarity surveys, but with higher angular resolution (thanks to the shorter wavelength). It is yet to be seen if the science case justifies the substantial upgrades to the VLTI, as currently only wavelengths in near and thermal infrared are propagated to the VLTI combination laboratory. A NAOMI upgrade would be also desirable, to extend the AO performances in the visible.

4.2.8 Smaller proposals

Polarization carries important information on magnetic fields and non-uniform scattering mechanisms. The science case here is to be able to observe variable sources, which require shorter exposures. Low spectral resolution polarimetry is available at the VLT through FORS2. This is the only polarimeter on an 8m telescope. High spectral resolution polarimetry could be implemented by a special bonnet to bring fibres from the Cassegrain focus to UVES. This requires some systems analysis and the construction of a fibre entrance at the Cassegrain. The science is currently mostly restricted to only few applications.

Light reflected of a planetary surface can provide signatures of life. This requires high spatial resolution to isolate the planet from the star (a contrast of about $2 \times 10^{-4}$) and high spectral resolution ($R>150000$) for the detection of the telltale lines. The RISTRETTO concept has taken as its goal to detect biosignatures of Proxima B. The concept requires a spectrograph like ESPRESSO behind a 2-stage adaptive optics system. There is only a very limited number of planets that could be investigated with this instrument and it was suggested as a visiting instrument to be implemented on the Nasmyth focus of UT4 between HAWK-I decommissioning and commissioning of MAVIS.

ESPRESSO-ATOM is the proposal to implement wavefront sensing for the single-UT observations with UT4 of ESPRESSO. In this case a significant improvement in efficiency could be gained for ESPRESSO using UT4. This is considered an instrument upgrade.

Suppressing the many OH radical lines in the infrared would benefit most spectroscopy. A new concept with fibre Bragg gratings has been demonstrated at the AAT and could be adapted for a VLT spectrograph. It could be implemented as fore-optics to an existing instrument. This has been proposed as a visiting instrument.

OASIS is a proposal to build a visiting instrument combining an improved fringe tracker and a simple J band spectrograph to measure Broad Line Regions of AGNs. The presentation showed possible new concepts for beam combination (so called hierarchical fringe tracking) and ongoing attempts to demonstrate the outstanding performance gains (7 magnitudes) using a bench experiment. The AGN science case was extensively presented, as well as
possible improvements to MATISSE if it uses a much more sensitive fringe tracker than GRAVITY. This proposal has obvious overlaps with GRAVITY+ and ASGARD and the small team is reportedly having discussions with these two larger projects.

4.2.9 Early concepts

A strong science case for high spectral resolution multi-object spectroscopy was presented for the study of the Galactic structure as follow-up of GAIA. 4MOST and MOONS will already provide the complementary radial velocity and abundance information to separate further substructures in the Milky Way. A spectral resolution of more than 50000 and blue sensitivity to complement MOONS should be considered. The target density needs to be evaluated to understand what the UT Nasmyth field of view can provide. This is clearly a field with leadership in the ESO community.

Resolving the area of influence of a supermassive black hole in an AGN should help in assessing the effect they have on the evolution of galaxies. Tracing the winds and the broad-line regions as well as the gas outflows will provide clues on the physics around the black hole. The high spatial resolution (<40mas) coupled with a spectral resolution of R=5000 requires an AO-supported multi-IFU at optical wavelengths. While the multiplex is still moderate (5), the requirements on the adaptive optics in the optical over a rather wide field of view are substantial and would require significant R&D efforts.

Transient follow-up spectroscopy will be needed for many objects found in the time domain surveys of the coming decade. A flexible instrument suite provides the basis. Placing a moderate resolution spectrograph in the incoherent combined focus would enable an operational flexibility by using any UT for the observations. For fainter object the combination of several UTs could be envisaged. There are some losses in efficiency due to the fibres as compared to FORS2, but this would be compensated by the increased flexibility.

A broadband Q-Band VLTI Heterodyne Instruments was presented as a technical development. The experiments are currently happening at a small scale, with key components yet to be developed.

5. Summary

The existing and planned VLT/I instrumentation probably offers the most versatile capabilities of any 8m observatory. The VLT/I appears well placed to adapt to the future changes in ground-based observations. The synergies with space observatories and new observatories of non-electromagnetic messengers are manifold and can be explored successfully. The VLT/I will be a central facility amongst the ESO telescopes.

The balance between workhorses and specialized facility instruments should be maintained in the future, in order to continue serving a wide community while enabling special science cases at the same time. Future workhorse instruments should complement upcoming astronomical facilities (e.g. an obvious case to be made is the blue part of the visible spectrum). Specialized facility instruments should make use of the uniqueness of VLT and maintain/reinforce the leadership of ESO and its community, based on strong science cases with possible use for an extended community. Visitor instruments should be considered for simple niche experiments.
The new concepts presented at the VLT2030 workshops were in many cases extensions of the existing facilities. The main changes are the move towards milli-arcsecond astrophysics with interferometric methods. The next step here is to provide access to fainter targets and larger sky coverage. Improving the contrast between host star and exo-planet coupled with higher resolution spectroscopy to characterize the planetary atmosphere or surface is a topic that leads to instrument upgrades (SPHERE) and the linking of AO with either existing or new spectrographs. The concentration of the VLT instrumentation towards the UV and blue wavelengths where it is fully complementary to the ELT requires an overall assessment of the spectroscopic resources offered at the VLT. The need for the full 6-dimensional mapping of GAIA stars to obtain space velocities and stellar abundances will strengthen a field were the ESO community is in the lead. Several upgrade paths for existing instruments were presented and it needs to be decided, which of these should be pursued in the future.