The AVES adaptive optics spectrograph for the VLT: status report

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ABSTRACT

We report on the status of AVES, the Adaptive-optics Visual Echelle Spectrograph proposed for the secondary port of the Nasmyth Adaptive Optics System (NAOS) recently installed at the VLT. AVES is an intermediate resolution (R∼16,000) high-efficiency fixed-format echelle spectrograph which operates in the spectral band 500 - 1,000 nm. In addition to a high intrinsic efficiency, comparable to that of ESI at Keck II, it takes advantage of the adaptive optics correction provided by NAOS to reduce the sky and detector contribution in background-limited observations of weak sources, thus allowing a further magnitude gain with respect to comparable non-adaptive optics spectrographs. Simulations show that the instrument will be capable of reaching a magnitude V=22.5 at S/N>10 in two hours, two magnitudes weaker than GIRAFFE at the same resolution and 3 magnitudes weaker than the higher resolution UVES spectrograph. Imaging and coronographic functions have also been implemented in the design. We present the results of the final design study and we discuss the technical and operational issues related to its implementation at the VLT as a visitor instrument. We also discuss the possibility of using a scaled-up non-adaptive optics version of the same design as an element of a double- or triple-arm intermediate-resolution spectrograph for the VLT. Such an option looks attractive in the context of a high-efficiency large-bandwith (320 - 1,500 nm) spectrograph ("fast-shooter") being considered by ESO as a 2nd-generation VLT instrument.

Keywords: Optical Instrumentation, Echelle Spectrographs, Adaptive Optics Instruments, VLT

1. INTRODUCTION

The AVES (Adaptive-optics Visual Echelle Spectrograph) concept was first proposed by Pasquini et al.[1] as a compact low-cost instrument for 8-10m class telescopes with adaptive optics (AO) correction. By taking advantage of the concentrating power of AO which allows narrowing the slit to match the image size, one can reduce the sky and detector background while retaining at the same time most of the light from the source. The gain which is typically obtained in this way is about one magnitude at visible wavelengths and depends on the performances of the adaptive optics system and the brightness and angular distance of the reference star to the scienc object. Added to an intrinsic high efficiency of the spectrograph design, this may easily result in a gain of 2 to 3 magnitudes with respect to conventional spectrographs such as UVES or GIRAFFE

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at the VLT, thus allowing much fainter sources to be reached at medium resolution than otherwise possible. Preliminary estimates[1] indicated that a S/N>10 could be reached for sources as weak as V=22.5 at spectral resolution of R$\sim$15,000. Main-sequence stars in distant parts of the halo, in the buldge, in the Magellanic Clouds and in dwarfs galaxies of the Local Group become thus accessible to spectroscopic determinations of elemental abundances and dynamics. The improved image quality also makes the instrument ideal for spectroscopy of crowded regions such as globular clusters and distant open clusters. Extragalactic objects may also become accessible provided a bright reference star sufficiently close to the target object is available.

Although Pasquini et al.[1] did not go beyond a conceptual design, they suggested the possibility of using AVES at one of the VLT foci for which adaptive optics was either forseeen or under development. They also suggested the possibility of porting AVES from one telescope focus to another, or using it at different telescopes, by simply changing the relay system to match the spectrograph F number. In practice, this is more difficult than expected since the adoption of different standards at different telescopes (for instance for control electronics and software) may limit the portability of the spectrograph if adoption of specific standards is indeed required. For NAOS at the VLT[2], whose main focus is used by the CONICA instrument, there are even stronger constraints since AVES must use a secondary port that requires the spectrograph to be fully integrated into the AVES+NAOS+CONICA system[3].

The early suggestion of Pasquini et al.[1] was taken-up by Pallavicini et al.[3] who developed the AVES concept for the specific case of NAOS at the VLT. They also considered the possibility of integrating in the same instrument both spectroscopic and imaging capabilities by using a few toggling mechanisms to switch between the imaging and spectroscopic functions. The two functions share a common fore-optics to reimage the NAOS F/15 focus to an intermediate F/20 focus where the slit (for spectroscopy) and masks (for imaging and coronography) are located. Two different optical paths located inside the NAOS structure produce an F/3.2 focus for the spectrograph and an F/45 focus (F/36 in the preliminary design reported in reference[3]) for direct imaging. The two functions share the same CCD detector which is located, as the whole spectrograph, outside of the NAOS structure. We refer to Pallavicini et al.[3] for a full description of the AVES spectrograph and imager/coronograph and its integration in the NAOS structure.

In this paper we focus on the spectroscopic function of the instrument and on the expected performances as derived from a study that we have carried out over the past two years. We also report on the results of the instrument reviews performed by ESO and its advisory bodies, also in the light of the measured performances of NAOS (which had first light at the VLT on 25 November 2001). The feasibility study of AVES was carried out by a Consortium of four Italian Institues working in collaboration with researchers at ESO. The Institutes involved include the Astronomical Observatories of Brera, Catania, Palermo and Trieste. The P.I. is R. Pallavicini (Palermo) and the Project Manager is F.M. Zerbi (Brera). Link with the NAOS team for the interface with NAOS and for the imaging part of AVES was provided by J-L. Beuzit and A.M. Lagrange of the Laboratoire d'Astrophysique - Observatoire de Grenoble.

2. OVERVIEW OF THE INSTRUMENT

The idea behind AVES is to use the light concentrating power of Adaptive Optics (AO) in the 500–1000 nm range to narrow the spectrograph slit without significant slit losses (at least 60% of the light in a 0.3" slit under average seeing conditions at Paranal). This drastically reduces the sky background and therefore enhances the instrument capabilities in the observation of faint sky-limited objects. Moreover, although the Strehl ratio will be lower in the optical than in the IR, AVES with NAOS should be able to provide diffraction limited images in the V, R, and I bands, thus complementing the near-IR imaging capabilities of CONICA. All this, coupled with a very high intrinsic efficiency of the spectrograph, will provide outstanding spectroscopic and imaging capabilities, not matched by any other instrument currently available at the VLT.

The small image size provided by NAOS will be a clear advantage in the observation of crowded fields (like globular clusters and distant open clusters) to reduce the contamination by nearby objects. Observations in crowded fields have the additional advantage of mitigating the intrinsic limitation of current NGS AO systems which require a bright (V<15-16) reference star sufficiently close (<10-15") to the target for optimum AO correction (and within $\sim$ 1 arcmin with degraded AO performances).

Table 1. Summary of AVES characteristics

Spectrograph F/ratio	F/3.2	average
Pupil size	5 cm	
Grating	echelle	R2, 79 gr/mm
Resolving power	15,600	with 0.3 arcsec slit
Sampling	2.5 pixels	0.12 arcsec/pixel
Crossdisperser	prism	double pass
Spectral coverage	500-1000 nm	in one exposure
Order separation	27 to 49 pixels	decreasing towards red
Detector	2K×2K, 15 μm pixel	frame transfer
Imaging F/ratio	F/45	also for object acquisition
FOV	5 arcseconds	
Image scale	9 mas/pixel	
ADC	yes	adjustable
Calibration lamps	two	ThAr and quartz
Spectro performances	S/N>10 for V=22.5	seeing 0.6" 2h int.
	S/N>4 for V=24.0	seeing 0.6" 2h int.

The AVES spectrograph will provide a sensitivity higher (by nearly 3 magnitudes) than presently available for UVES at the VLT and nearly 2 magnitudes more than for GIRAFFE, and will have higher resolution (by at least a factor 3) than FORS1/2. Performance estimates discussed later in this paper demonstrate that the AVES spectrograph will bring many investigations currently possible only at low resolution into the domain of intermediate/high resolution (R≈16,000). This will allow breakthroughs in several fields, both galactic and extragalactic.

We stress that AVES, independently of the additional improvement provided by the AO correction, is an intrinsically very efficient spectrograph, with an efficiency comparable to that of the ESI spectrograph at Keck (which has similar, although slightly lower, resolution). Figure 1 shows a comparison of the expected efficiency of the AVES spectrograph (including telescope, AO transmission, spectrograph optics and detector) with the measured efficiencies of ESI[4] and of UVES (ESO Web pages) as well as with the expected efficiency of GIRAFFE at the VLT (ESO Web pages). In addition to its high *intrinsic* efficiency, AVES will profit from the advantage of the AO correction, which is crucial in the observation of faint sky-limited objects.

Furthermore, AVES will provide imaging capabilities in the optical with diffraction limit (20 mas at 800 nm) when using bright reference objects. This translates into typical linear resolutions of 3 AU at 150 pc or 100 AU at 5 kpc. The angular resolution of AVES in its imaging mode will be higher than that of HST and CONICA. The advantage over HST is that AVES will be fed by an 8m telescope rather than the 2.4m mirror of HST. An advantage of optical over IR observations is the much lower sky level. Moreover the optical detectors have generally higher quantum efficiency and lower noise than the IR detectors. These factors amply balance the fact that the Strehl ratio provided by NAOS is lower in the optical than in the IR. For all the above reasons AVES will be a necessary complement of CONICA.

Finally, AVES will be the first instrument at the VLT to explore the potential of Adaptive Optics for spectroscopy and imaging *at visible wavelengths* thus paving the road to future generations of optical instruments at very large telescopes.

Table 1 summarizes the main characterists of the AVES spectrograph and its expected performances.

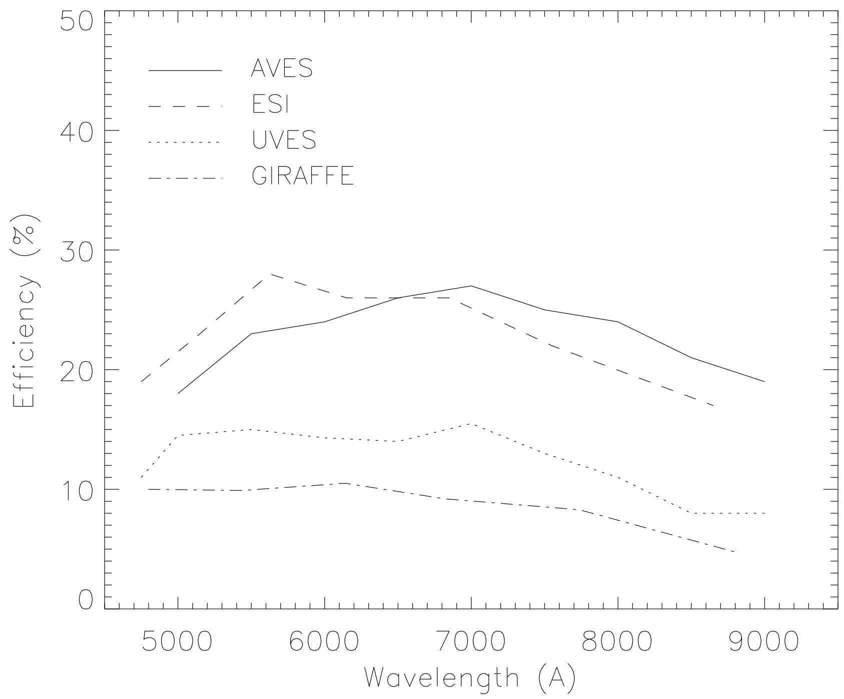

Figure 1. Comparison of the total efficiency of the AVES spectrograph with those of ESI at Keck and of UVES and GIRAFFE at the VLT.

3. SCIENTIFIC OBJECTIVES

An intermediate resolution optical spectrograph capable of observing objects as faint as V=22.5 at S/N>10, and as faint as V=24 for radial velocities, opens to spectroscopic investigations a large number of astrophysical problems, ranging from distant galaxies to solar-system objects, which can only partially be addressed, if at all, with the instruments available at present at the VLT. Moreover, the implementation of imaging and coronographic functions in the same instrument further enlarges the range of science topics that can be tackled effectively, and sometimes uniquely, with the proposed instrument. The scientific objectives of AVES *in its spectroscopic mode* will include, among others:

- Absorption lines of intervening objects in QSOs, Lyman-break galaxies and Damped Lyα systems
- Chemical abundances of main-sequence stars in the galactic bulge, in the halo and in the cores of globular clusters
- Chemical abundances of turn-off stars in the Magellanic Clouds and other galaxies of the Local Group (e.g. Sagittarius)
- Radial velocities of eclipsing and pulsating variables down to V=24 (e.g. eclipsing binaries and Chepheids in the Magellanic Clouds and bright Cepheids up to the distance of the Virgo cluster)
- Imaging and spectroscopy of faint galactic objects like very-low mass stars, brown dwarfs, magnetically active stars in young open clusters, young stellar objects in star forming regions, and optical counterparts of X-ray sources
- Spectroscopy of solar-system bodies including planets, asteroids and Kuiper belt objects

In the following we will focus on one science topics that we believe is ideally suited to spectroscopic observations with AVES, i.e. the study of the chemical evolution of the Galaxy and of Local Group galaxies[5]. AVES will allow us to reach for the first time *main sequence* stars in the magnitude range V=21−22 for abundance determinations. The dense environments of open and globular clusters, of the Magellanic Clouds and of dwarfs galaxies of the Local Group ensure that sufficiently bright stars are available close to the target stars for optimal image correction.

It has long been recognized that element synthesis is an on-going process and that the chemical composition of cosmic matter may change from place to place and with time. The challenge to observe and understand the chemical composition of stars in different environments is topical in modern astrophysics. The spectra of stars contain a wealth of lines from atoms and molecules which are apt to provide accurate abundances for many elements through state-of-the-art modeling of stellar atmospheres. Elemental abundances, and in particular abundance ratios, provide fundamental insights into galaxy evolution and important constraints for any theoretical interpretation.

Because low-mass stars are extremely long lived, in fact their main sequence lifetimes are of the order of the age of the Universe, their chemical composition may be considered as the fossil record of the composition of the interstellar medium at the time the star was formed. Observations of main-sequence stars of different ages allow tracing the chemical evolution of the stellar system (galaxy or galaxy component) to which they belong. It is important to stress that for this purpose it is crucial to observe main-sequence and turn-off stars, which are much fainter than the giants of the same colour but have a chemical composition which has not been altered by mixing episodes as is generally the case for giants.

Among the elements observable in stars, lithium plays a special role: it is one of the few elements produced in the Big Bang and knowledge of its "primordial" abundance allows the determination of the baryon to photon ratio at the time of nucleosynthesis, and therefore the baryonic density of the Universe. Furthermore lithium is a sensitive probe of stellar structure and mixing episodes, by virtue of its fragility. Only main-sequence stars of spectral type F and early G retain their pristine lithium abundance while lithium is generally depleted (diluted) in giants, due to their extensive convective zones, with the exception of the very rare Li-rich giants in which Li is produced; therefore any investigation aimed at the determination of the "primordial" lithium abundance should concentrate on observations of the main-sequence stars and turn-off stars.

From the above considerations it is clear that accurate measurements of chemical abundances of *late-type main sequence* stars in different environments such as: i) the galactic disk, ii) the galactic bulge, iii) the galactic halo, iv) external galaxies, represent a key to our understanding of the chemical evolution of the Galaxy and of Local Group galaxies. It is also clear that observations of *clusters*, both open and globular, are crucial in this respect, since they provide natural homogeneous samples of stars with a well-defined age and chemical composition. Although AVES is a single-object spectrograph, its large simultaneous wavelength coverage provides an important advantage with respect to multi-object spectrographs (like GIRAFFE) that generally allow only the observation of a narrow wavelength range in a single exposure. Accurate abundance determinations of main-sequence stars in various astrophysical environments will provide crucial information on problems such as the origin of the bulge and of the halo, the chemical gradients in the halo, the star formation history, chemical evolution and distance of the Magellanic Clouds, the nucleosynthetic history of Local Group galaxies, and the lithium abundance in distant open and globular clusters, in the Magellanic Clouds and in dwarfs galaxies like Sagittarius.

While main sequence stars in the galactic disk and in nearby open clusters can be observed with existing VLT instruments (UVES and GIRAFFE), most *main sequence* stars in globular clusters, in distant open clusters, in the galactic bulge, in the halo and in external galaxies are out of reach for medium/high resolution spectroscopic observations. All these stars shall become accessible with AVES, which, in addition, is ideally suited for spectroscopic observations in crowded regions where the AO correction allows reducing the contamination by nearby objects. For instance, the Sagittarius dwarf galaxy is contaminated by a rich population of foreground disk and bulge stars which in fact provide useful relatively bright (V<16) stars sufficiently close (<10 arcsec) to the target stars for a good AO correction. Close inspection of the Sagittarius fields shows that the surface density of these objects is indeed sufficient to access turn-off stars in the Sagittarius galaxy. AVES has the

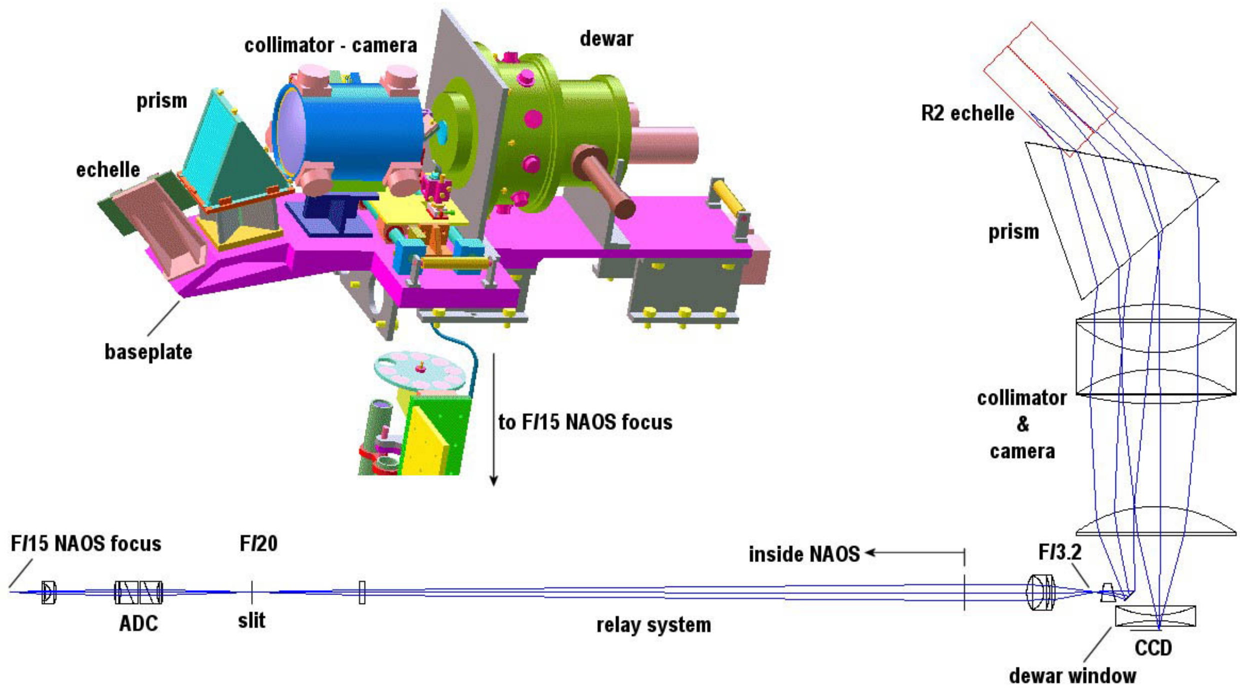

Figure 2. Optical design of the AVES spectrograph (to the right) and of the associated fore-optics (bottom of the figure). The mechanical structure of the spectrograph is also shown in the inset. The imaging/object aquisition system inside NAOS is not shown.

capability of obtaining medium resolution spectra for these faint stars, which will allow a detailed abundance analysis.

4. INSTRUMENT DESCRIPTION

AVES is a compact cross-dispersed echelle spectrograph designed to operate at magnification one with a slit of 0.3 arcsec and AO correction, providing a spectral resolution R$\sim$16,000. A schematic view of the optical design of the spectrograph and of the front optics for the spectrographic mode is given in Figure 2. The same optical component acts as collimator and camera. A front optics adapts the F/15 output beam of NAOS to the F/3.2 required by the AVES spectrograph. The fore optics include also a parallel beam (not shown in the figure) for the imaging function and for target acquisition in the spectrographic mode. The spectrograph is accomodated on the exterior of the NAOS structure, while most of the fore-optics is attached to a plate inside NAOS (Figure 3).

The switching between the two modes of operation (imaging and spectroscopy) is obtained by means of two mechanisms, one internal and one external to NAOS. Both modes of operation share the same atmospheric dispersion compensator (ADC) and pre-slit optics. The ADC is made of 2 counter-rotating prisms. In order to save surface losses the same ADC prisms are used as lenses. A first doublet in combination with the first ADC prism provides a real image of the telescope pupil, suitable for ADC location. The second prism, located just after such pupil, provides an F/20 real image where the coronographic masks and the slit for spectroscopy will be inserted.

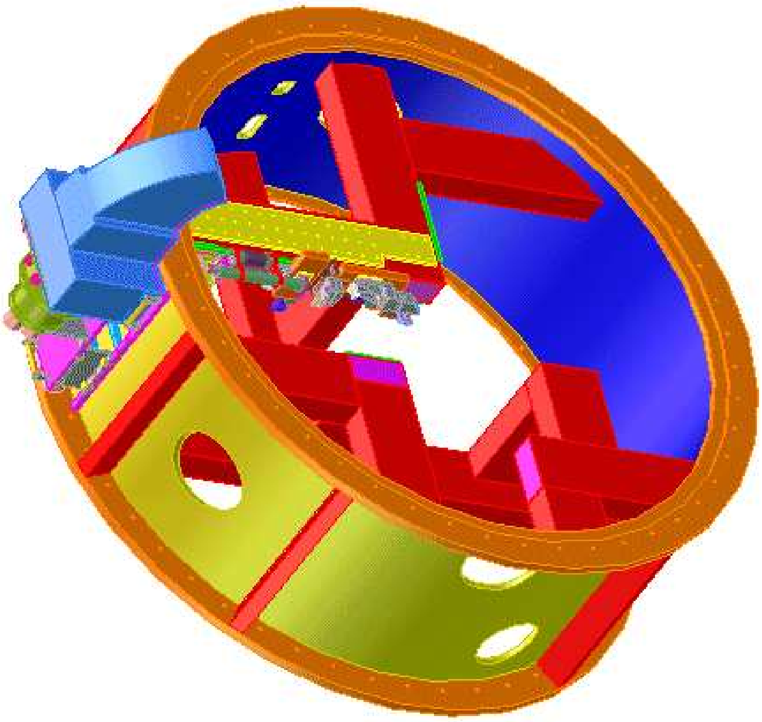

Figure 3. 3D view of the AVES instrument mounted on NAOS

After the intermediate F/20 focus a toggling mechanism inserts either the direct imaging or the spectroscopic lenses. The direct imaging lens consists of 2 doublets and a folding mirror, which provides an image of sky on the AVES CCD. These doublets change the F/20 into F/45 providing a plate scale of 9 mas per pixel. A filter wheel accomodates several narrow and broad band filters for imaging. The spectroscopy fore-optics consists instead of a pupil relay lens and an imaging triplet. The entrance slit (F/15) is re-imaged on the focal plane of the spectrograph with the adequate F/ratio (F/3.2).

Dispersion and cross-dispersion are obtained via an echelle grating 79 gr/mm blazed at 63 deg (R2) and a Schott SF4 prism with 52 deg apex angle. The spectrograph will be operated between order 22 and order 44 providing a full coverage of the 504 – 1045 nm wavelength range.

Some features need to be emphasized. Since high efficiency is a primary requirement, the wavelength coverage is limited to above 500 nm to ensure that optimal coatings are used (and the AO correction would not be good anyway at shorter wavelengths). The selected echelle grating (R2 79 gr/mm, silver coated) is probably one of the most efficient echelle ever produced. Another key feature is that the full spectral range is covered in one exposure. There are no movable parts inside the spectrograph (except for alignement and focussing and for switching between the operating modes) and the whole instrument is less than 60 cm in length (w/o cryostat) to be easily accomodated on the external side of the NAOS structure.

Mechanically, AVES consists of two principal subsystems, one internal and one external to NAOS. The inset in Figure 2 shows the mechanical structure of the external part which supports the spectrograph components. The internal subsystem (not shown in the figure except for the latter part attached to the external subsystem) supports the pre-focal plane functions for both imaging and spectroscopy such as the atmospheric dispersion compensator (ADC), the slit, the coronographic masks and the filters. We refer to Pallavicini et al.[3] for detailed figures of the internal subsystem.

The external subsystem consists of a carbon-fiber base-plate which acts as an optical bench lodging all the opto-mechanical components of AVES that are located outside the NAOS structure. The high stiffness (the Young modulus of carbon-fiber material is commonly higher then 300 Gpa, to be compared to the aluminum alloy Young modulus which is about 70 Gpa) and the low weight (1.8 g cm^{-3}) make carbon-fiber a very good material for the base-plate. The base-plate is fixed to NAOS by means of 3 supports made of aluminium and screwed on the fixation points.

The main components fixed on the base-plate are the spectrograph mechanics, the External Exchange Mechanism (EEM) and the cryostat. The spectrograph mechanics consists of the supports for the grating and the prism with related adjustment system for alignment. The camera/collimator optics will be mounted in an internal tube suspended through retaining spheres to an external tube attached to the base-plate. Such a support system is provided with a translation adjustment that allows a focal correction by sliding the lenses inside the external tube. The adjustment is made by means of a micrometer screw connected to a pivot.

Purpose of the EEM is to alternatively deviate the beam directly to the CCD in the imaging mode or to the spectrograph in the spectroscopic mode. A movable trail is mounted on steel rectified rods fixed by means of 4 aluminum supports to the base-plate. The movement of the EEM is ensured by a system made of motor, toothed belt and a pulley. The toothed belt is connected to the movable plate. During operation the trail is maintained in place by means of permanent magnets that are over-written by electromagnets when the trail has to be moved, just as in the IEM. Two limit switches are used to control the activation of the electromagnets that release the trail.

The continuous flow cryostat (similar to the one adopted in many VLT instruments) is fixed on the base-plate by means of an aluminum flange. The calibration lamps and the shutter are instead mounted on the lower side of the base-plate.

The stability of the mechanical design has been tested by means of a Finite Element Analysis code. The most critical element is the base-plate which supports the heavier loads. The results of the analysis performed on the upgraded model guarantee the stability required.

AVES needs to be equipped with its own calibration system both for imaging and spectroscopy. Since NAOS is very sensitive to thermal contamination, the lamps for calibration have to be positioned outside the NAOS structure. Two types of lamps are foreseen for the AVES instrument. A ThAr lamp and a low voltage halogen quartz lamp. We plan to position the lamps in the lower side of the base-plate outside NAOS and transfer via fibers the light inside NAOS up to before the original F/15 focus, i.e. onto the mirror (governed by NAOS) that toggles the beam between CONICA and the parallel instrument.

AVES motorized functions, calibration system and data acquisition for telemetry will be driven by a suitable control electronics (ICE). Such electronics is fully VLT compliant and is implemented with VME-based LCU connected via Local Area Network (LAN) to the Instrument Workstation (WS). The WS is used for instrument control and user interface while the LCU is used for real time control. The ICE consists of two main sections, namely the electronic boards controlling all the functions, located on board the instrument itself, and the Instrument Cabinet, hosting the LCUs, the power supplies and the rest of the controllers (lamps, sensors). The connecting cables, attached with proper connections located on the instrument, will reach the Instrument Cabinet via the cable-rotator.

The detector that will be used in the AVES spectrograph is a 2K x 2K (13.5-15 μm pixel) CCD. Performance evaluation has been made of available CCDs to select the best suitable for our purposes. In this evaluation emphasis has been put on the red-oriented spectral range, the Q(E) and the uniformity of the response (fringing-free device). The most promising results of the search concern High Resistivity Deep Depleted CCDs. With respect to ordinary CCDs these devices provide enhanced sensitivity between 500 and 1000 nm, i.e. the AVES working wavelength range. A viable solution is represented by the MARCONI A.T. 2048x4608 50 μm thick back-illuminated deep-depleted CCD which provides QE as high as 60% at 900 nm and 30% at 1000 nm. The Deep depletion technique together with the consolidated “fringe suppression” technique can easily be applied by

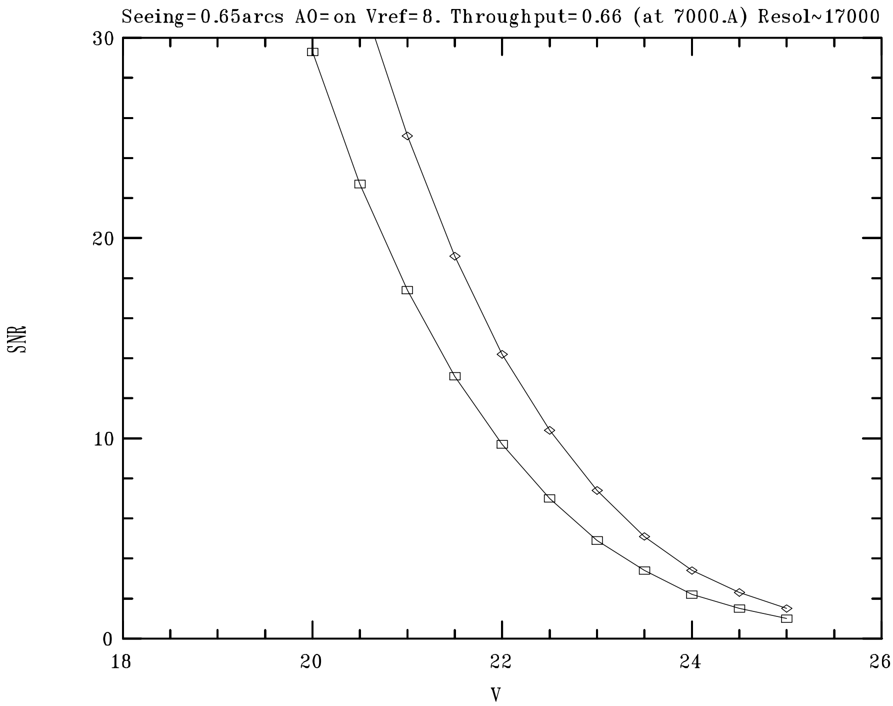

Figure 4. S/R ratio per resolution element expected from AVES (at λ=700 nm for G2V star) as a function of V mag for 1h exposure (squares) and 2h exposure (diamonds).

MARCONI A.T. to a 2048x2048 device suitable for AVES, which in fact has been already quoted by MARCONI for the AVES Consortium. The dark current of this device (at -110^o) is 2-3 e$^-$/h and the max read-out noise is 3-4 e$^-$ r.m.s. These numbers as well as those regarding PSF, non-uniformity, full well and charge transfer efficiency are almost identical to standard grade 1 thinned back-illuminated CCDs like the MARCONI A.T. 42-40-904; the only appreciable difference is the QE versus wavelength curve that privileges longer wavelengths. As a base-line for the CCD controller we plan to use a modified version of the standard ESO FIERA controller, the modification consisting in the weight distribution to meet the stringent requirements imposed by ESO on the weight of the NAOS parallel instrument.

The AVES software has necessarily to be fully VLT-compliant. This because it will have to be integrated in the complex environment governing VLT, NAOS and CONICA.

5. EXPECTED PERFORMANCES

A study of the AVES spectroscopic performances (in terms of S/N ratio) has been made using an Exposure Time Calculator (ETC) developed for AVES in the IRAF environement.

Figure 4 shows the S/N ratio for stellar continuum (at 700 nm) as a function of visual magnitude V of a G2V type star and airmass=1 for 1h and 2h exposure times for a slit width of 0.3". A V sky magnitude of 21.8 mag/arcsec^2 has been assumed, RON of 3 e/pix (rms) and a dark current of 1e/pix/hour. A reference star of magnitude V=8 has been assumed but the results in terms of S/N ratio and magnitude limit are only slightly dependent on the magnitude of the reference star down to V=16. In typical seeing conditions of 0.65", a S/N=8 is reached in 2 hour exposure with V=23; very low S/N (S/N=3.5 for 2h) can be reached for V=24 for G main-sequence stars. Sky brightness can be an important noise source for very faint targets. When AO is operating, an improvement in S/N can be obtained because the AO will concentrate most of the light in

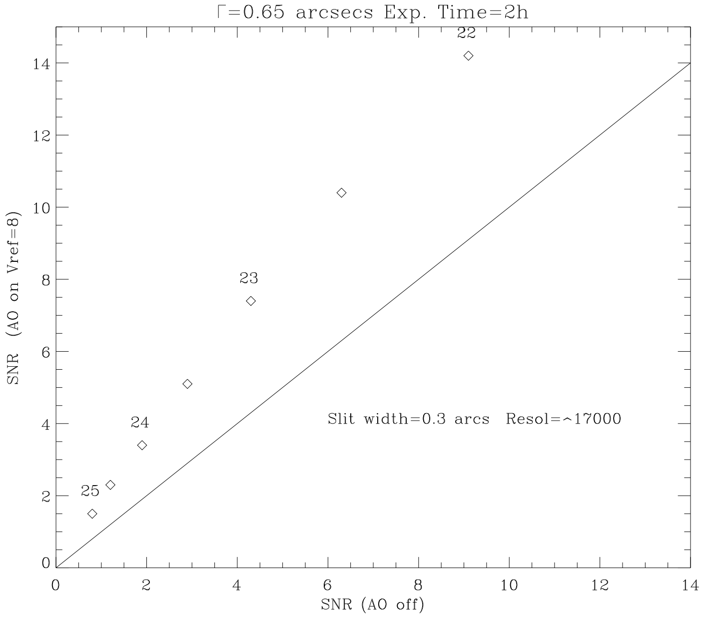

Figure 5. S/R ratio per resolution element expected from AVES (at λ=700 nm for G2V star) in 2h exposure in the case of AO-on and AO-off for stars of different magnitudes

a very small region (<0.3") reducing drastically the background contribution of the sky. Figure 5 shows the improvement due to the use of AO under the same conditions for stars of different magnitudes and an exposure time of 2 hours.

To conclude, since a seeing of 0.65" is a median seeing at Paranal, the high efficiency of a spectrograph like AVES (not lower than 20% not including slit losses but including telescope reflectivity, AO module transmission, and spectrograph and detector efficiencies) guarantees a competitive instrument with respect to conventional spectrographs. All these considerations are strongly dependent on the assumptions used for the monochromatic PSFs when AVES works with the AO module. Anyway, also taking into account these limits, the preliminary results indicate that the nominal specification of achieving S/N>10 for V=22.5 at R$\sim$16,000 in 2 hours can be fulfilled. The gain introduced by the use of adaptive optics is about a factor of 2, but the higher intrinsic efficiency of the spectrograph in comparison to GIRAFFE and UVES ensures a gain of nearly 2 and 3 magnitudes, respectively, with respect to these other ESO instruments. With respect to ESI, which has an efficiency comparable to that of AVES, there should still be an advantage (due to the use of AO) in the observation of background-limited objects.

6. STATUS OF THE PROJECT

The feasibility study of AVES reported here was carried out over the period 1999-2001 with funds from Consorzio Nazionale per l'Astronomia e l'Astrofisica (CNAA, Italy) which also partially funded the construction of the instrument, if approved by ESO. AVES was proposed to ESO in September 2001 in response to an Announcement of Opportunity for Visitor Instruments for the secondary port of NAOS. Although we had to comply to this requirement, which also implies use of the instrument at the VLT for only a limited number of nights depending on the approved science programme, we stress that AVES barely satisfies the criteria for being a "visitor instrument" given its strong integration within the NAOS system. As a matter of fact, the whole development of the AVES design was carried out in close collaboration with the NAOS team and the imaging/coronograph function of the instrument was indeed developed upon request of NAOS people with the aim of being complementary in the visible to the IR observations carried out by CONICA. For the same reason, the whole AVES concept was conceived from the very beginning as fully VLT compliant with regard to control software, CCD controllers and operating modes. Although AVES can in principle be duplicated to accomodate it at other 8m telescopes with adaptive optics (or for use at 4m class telescopes without adaptive optics), it is out of question that it can be used as it is at other telescopes. Thus, although AVES is currently supposed to be used at the VLT for a limited amount of time and exclusively to carry out the research programme proposed by our Consortium, the high level of integration within the VLT+NAOS system suggests that it could be better used as a facility instrument open to the whole ESO community.

Another point that is worth mentioning are the stringent requirements on size and weight. While the first one can easily be accomodated (the AVES spectrograph is very compact and the beam size is only 50 mm), it is much more difficult to comply to the weight limitation (70 Kg in total) if the ESO standard detector controller FIERA has to be adopted. This constraint applies to any instrument proposed for the secondary port of NAOS if that instrument has to use the FIERA controller for VLT compatibility. In our study we have proposed a reengineering of the FIERA controller for the specific case of AVES and a redistribution of the weight among the various electronic components. This has drastically reduced the total weight of AVES which however is still slightly larger (by $\sim$30 Kg) than the nominally acceptable figure. Although the excess weight amounts to just 1% of the total weight limit for the VLT Nasmyth rotator/adaptor, this is an uncomfortable situation for a "visitor instrument" and needs to be clarified before proceeding to the construction phase.

The AVES proposal was reviewed by ESO advisory bodies (STC, OPC, Instrument Division) and the results were communicated to us in May 2002. The STC recognized "the strategic interest of ESO to implement a visual instrument coupled to AO in competition with ESI at Keck" and suggested the possibility of opening AVES to the full community of ESO users. With an expected construction phase of 2 years after final approval, AVES was evaluated positively by both the STC and the OPC as a "1.5 generation instrument" half-way between the currently available VLT instruments and 2nd generation instruments still to be defined[6]. At the same time, the review process also pointed out some potential problems in the use of AVES with NAOS due to the measured NAOS transmission (which is estimated at $\sim$50% rather than the 80% assumed above), the need to use the IR WFS and the fact that the instrument shall be used only under very good seeing conditions (which is a problem for an instrument operated in "visitor mode").

In the light of these considerations, while we believe that the AVES spectrograph is a highly valuable instrument for its innovative use of AO in the visible and for the high efficiency and compact design, it is still unclear whether its implementation as a "visitor instrument" at the VLT in conjunction with NAOS is the best way to reach the scientific goals. An alternative possibility which relies on a similar optical design but does not use adaptive optics is briefly discussed in the next section.

7. A NON-ADAPTIVE AVES-LIKE SPECTROGRAPH ?

In November 2001 ESO issued a Call for Preliminary Proposals for potential 2nd generation VLT instruments. One of the requested instruments called for a medium-resolution wide-band (0.32 to 2.4 μm) high-throughput spectrometer (dubbed "fast-shooter" or "X-shooter"). Emphasis was put on maximum efficiency, simultaneous spectral coverage as large as possible, and fast time response to transient events. Several proposals were submitted in response to this call (see ESO Web pages), among which one which included also our Consortium. The stated requirements clearly indicated the need of a multiple-arm system to cover the extremely large wavelegth range at high efficiency. Preliminary evaluation of the proposals and subsequent discussions have further narrowed the instrument requirements to a Cassegrain-focus single-object instrument with a resolution-slit product of $\sim$10,000 and a wavelenth range 0.32 to 1.5 μm, to be covered simultaneously with three highly efficient spectrograph arms. At the time at this writing, discussions are still going on, which should eventually lead to the kick-off of a feasibility study in early September of this year.

The "X-shooter" offers an interesting non-adaptive alternative to the AVES concept. Parts of the science objectives are clearly similar and the instrument should be capable, as AVES, to go two to three magnitudes deeper than current medium to high-resolution spectrographs at the VLT. The disadvantage of not using the concentrating power of AO to reach fainter objects could be compensated in large part by the increased efficiency of putting the instrument at the Cassegrain focus (instead of the Nasmyth) and by recovering the loss that would otherwise occur in the AO system. What is of importance is to have a high efficient spectrograph design with a throughput in the visible at least comparable to that of AVES and ESI (cf. Figure 1) but with sensitivity also at shorter ($\leq$400 nm) and longer ($\geq$1μm) wavelengths.

A scaled-up version of AVES could be an important element of such an instrument. A preliminary study shows that an optical design similar to that of AVES could be used for the visible arm of the "X-shooter" (and possibly also for the other arms) provided we double the beam size (to 100 mm) and thus the resolution-slit product (giving R$\sim$10,000 for a 1" slit). A detailed trade-off between this solution and that of AVES in terms of performances, complexity and cost should be carried out before deciding which instrument will be able to fullfill more effectively our science goals for both galactic and extragalactic astronomy.

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