AVES

AN ADAPTIVE OPTICS VISUAL ECHELLE SPECTROGRAPH FOR THE VLT AND THE LBT

A proposal to CNAA in response to AO 1/98
Research projects on novel technologies of astrophysical interest
Research area: instrumentation for large telescopes

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presented by

Dr. R. Pallavicini
Osservatorio Astronomico di Palermo, Italy

with the participation of:

Osservatorio Astronomico di Trieste (OATs)
Osservatorio Astronomico di Brera (OABr)
Osservatorio Astronomico di Palermo (OAPa)
Osservatorio Astrofisico di Catania (OACt)
European Southern Observatory (ESO)

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EXECUTIVE SUMMARY

We propose to develop a novel high-performance echelle spectrograph optimized for the use with adaptive optics (AO) systems of new generation large telescopes (like the VLT and the LBT). This spectrograph is meant for intermediate (R=16000) resolution spectroscopy of faint (sky and/or detector limited) sources, like stars belonging to distant (or highly reddened) galactic clusters, to the halo and to the nearest galaxies, or like high-redshift star forming galaxies and absorption line QSOs. There is no such instrument planned for either the VLT or the LBT.

AVES will outperform comparable non adaptive optics instruments by more than one magnitude for sky and/or detector limited observations, and will be very suitable for observations in crowded fields. It will operate in the red part of the spectrum ($\lambda = 560 - 1100$ nm) to obtain, e.g., chemical abundances of absorption line objects as faint as R=22 and radial velocities for objects as faint as R=24. Adaptive Optics coupled with large telescopes allow the full exploitation of their capabilities, providing diffraction limited images in the near IR and at least partial correction in the V and R bands. In addition to the obvious advantages for imaging, the use of AO systems will have a tremendous impact also on spectroscopy, if new spectrographs like AVES are properly designed.

We propose to carry out a 2 year study of this instrument leading to a final design review for use at the AO foci of the VLT or of any other large telescope with AO capabilities (such as the LBT or the Spanish 10m GTC). If approved for use at one of these telescope, AVES could be built on a very short timescale (less than 2 years) with no further costs for development studies. The cost of building such an instrument is estimated to be around 700 ML (Million Lire), including procurement, construction, integration and testing, but excluding development costs. The cost of the present study, which will cover all development costs for AVES, is estimated to be 270 ML in 2 years. This is the amount requested in this proposal, including the contribution of the proposing institutions (up to 30% of the total cost).

This study will be carried out by a consortium of Italian institutes working in close collaboration with researchers at ESO, where the first concept, and need, of an instrument such as AVES first arose. While ESO will be responsible for the optics, the division of responsibilities among the other partecipating institutions is as follows: mechanics and integration (OABr), control software (OATs), electronics and management (OAPa), detectors (OACt). Science requirements and data analysis will be addressed by all participating institutions.

Although initially studied for use at one of the AO foci of the VLT (either the Cassegrain or the Nasmyth), AVES, thanks to its conception, compactness and low weight, will be a highly portable instrument that could easily be mounted on other telescopes by simply changing the focal reducer at the spectrograph entrance. The procurement of several low-cost similar systems could also be envisaged. **AVES will be a unique instrument in its capabilities of obtaining intermediate resolution observations of extremely faint objects.**

RESEARCH PROJECT

Several programs of astrophysical interest, both galactic and extragalactic, require high or intermediate spectral resolution observations of faint objects, which at present are beyond the capabilities of instruments fed by, or planned for, the largest telescopes. In addition, to properly observe selected objects in very crowded regions, like the core of globular clusters, a very narrow slit coupled with excellent image quality is needed, in order to avoid contamination from nearby objects.

In the following, a few science cases are presented which require both these characteristics. We shall show how these problems can be satisfactorily tackled by building AVES, a spectrograph connected at the foci of Adaptive Optic (AO) systems, like the Cassegrain (MACAO) or the Nasmyth (NAOS) foci of the VLT, or the foci presently considered for the LBT.

Since AVES will not be a general purpose instrument, but mostly dedicated to special observing programs, we aimed at a very contained price, easy maintenance and simple operations. The optical design of the spectrograph and its compactness will in addition allow AVES to be transported easily from one telescope to another (or from one VLT focus to another) with minor modifications.

1 Scientific case for AVES

Performance estimates for the AVES spectrograph at the adaptive optics foci of one VLT unit (see below) open to the domain of high resolution many investigations that are currently reserved to much lower resolution work. This possibility is attractive for a number of galactic and extragalactic researches. In the following we present a few representative scientific cases which we regard as important scientific drivers for the AVES spectrograph. The list is by no means exaustive but it shows that a step further with respect to the sensitivity and resolution presently foreseen for UVES and FORS1/2 is scientifically fully justified for the second generation of VLT instruments.

1.1 Observational Cosmology

1.1.1 High redshift star forming galaxies

In the last two years various techniques have revealed a population of high redshift, i.e z$>$ 3, *normal* galaxies (Steidel et al 1996, ApJ 462, L17). At z$>$ 3 there is a rapid decline in the space density of quasars suggesting that structured objects able to trigger intense star formation with associate nucleosynthesis has just begun. Stellar integrated spectra of Lyman break galaxies are currently observed at low resolution with the 10m Keck telescope yielding SFR at these very early epochs. The AVES resolution is higher than FORS1 and FORS2 and would enable to disentangle the interstellar from the stellar components. The information content with respect to the composite stellar features would be enormously improved and would allow a tight comparison with high resolution spectral synthesis yielding chemical composition and ages for these protogalaxies, which are essential for reconstructing the cosmic evolution at these very early epochs. Such a primeval stellar generation may be also an important source of photons able to rival the AGN background radiation at very early epochs.

1.1.2 Quasar absorption systems

Narrow absorption line systems are frequently detected in quasar spectra and about 10% of the QSOs have absorption systems. The narrow absorption systems are formed in intervening objects along the quasar line of sight, and they arise from disks and halos of galaxies, debrids of galactic mergers and, particularly at large redshifts, from protogalaxies of various kinds. They are detected from zero up to the highest observed redshifts and hold the potential of tracing the Universe physical evolution on cosmological scales. As it is for the Lyman break galaxies, they allow direct observations of chemical abundances and projected structure of protogalaxies at the greatest lookback time. The kind of information that can be extracted from the analysis of the absorption lines in quasar spectra is illustrated in the proceedings of the *QSO absorption lines* ESO meeting (1995, G. Meylan editor). It

has been a major achievement to realize that intervening systems already at z$\geq$ 4 show considerable amounts of metals which require previous stellar synthesis.

The damped Lyα systems are a subclass of absorbers characterized by a large neutral hydrogen column density ($\log N(HI) \geq 20.3$), which is optically thick to the background radiation. It is generally, but not universally, believed that Damped systems are already formed rotating disks with rotational velocities of the order of $V_{rot} \approx$ 200 km/s and sizes of 5-10 Kpc. Line asymmetries or structures for the cool gas component of the damped systems are potentially capable of revealing the true nature of these objects. Damped systems allow a determination of the absolute abundances of various elements with great precision. Most of the currently collected data for DLA comes from the 10m Keck telescope, which has standardized the study of elemental abundances in systems up to a redshift of 4.4 (Lu et al. 1996, ApJ 457, L1). By now about 80 damped systems are known (Wolfe et al. 1995, ApJ 454, 698) with only a minority towards QSOs brighter than V = 19.0 This sample represents a solid base on which spectroscopy can be successfully performed with AVES. Absolute abundances will allow reconstructuring the so called cosmic chemical evolution while relative elemental abundances are a valuable diagnostics of the first elemental built-up since the elements form by different processes and on different time scales. This information is an important complement to the present knowledge of galactic chemical evolution which is mainly obtained from studies of stellar populations and interstellar medium in the Milky Way and in nearby galaxies.

1.2 Stellar spectroscopy throughout the Milky Way

1.2.1 Main-sequence stars in the galactic Bulge

The galactic bulge contains the most chemically evolved old stellar population in the Galaxy. In this region of the Galaxy there is a strong extinction (A$\approx$ 2.7) and main sequence stars are out of reach. At a distance of 8 Kpc the magnitude of a G0V star is m=19.1+A and it is 17.6 +A for an F0V. The confusion limit towards the galactic center in the V band is at 23.6 mag and therefore there is a large range of magnitudes for AVES observations. The study of main sequence stars at the turnoff will allow age estimates which are not accurate with giant stars and therefore it will make possible the study of the abundances of those elements which are affected by stellar evolution processes. Very recently, Minniti et al. (1998, ApJL, in press) have observed, with the Keck 10 m telescope, the main sequence star responsible for the MACHO microlensing event 97 BLG 45. The star is in the Bulge and has V=19.8 but was magnified by about 1 mag due to the microlensing event. AVES will open new prospects for the study of the chemical composition and enrichment history of the Galactic Bulge and it may then be possible to establish if the Bulge formed from gas previously enriched in the halo.

1.2.2 Galactic Halo

It will be possible to observe main sequence stars in the Galactic halo to a distance of 30 kpc i.e throughout the whole halo. At this distance an F5VI star with absolute magnitude of M=4.8 has an apparent magnitude of m=22.2. High-quality abundance determinations of various elements would allow the study of chemical gradients in the halo to a distance significantly larger than possible with others VLT spectrographs. In addition AVES will allow us to measure radial velocities with an accuracy of 3-4 km/sec for the most distant stars and will provide fundamental insights into the dynamics of the outermost halo and therefore into the Galaxy formation.

AVES will allow measuring relative abundances of elements such as Fe, C, N, O for main sequence stars in Globular Clusters with a gain of a few magnitudes with respect to those that will be obtained with UVES. Turnoff stars will be into reach for all the globular clusters within a distance modulus less than 15.4, i.e within a distance of about 9 Kpc. If we consider 47 Tuc which at a distance of 5.1 Kpc is one of the closest GCs it will be possible to observe at high resolution main sequence stars down to K0 and study those elements which are not present in the hottest stars. Globular clusters as Terzan 7, Terzan 8, Arp 2 and M54 which might have originated from the Sagittarius galaxy have turnoff magnitudes around m=21 (Marconi et al. 1997, A&A 330, 453) and are within AVES possibilities.

1.2.3 Faint local objects

Some objects in the solar neighbourhood are very faint. These are late-type M dwarfs, brown dwarfs and cool white dwarfs. Very-low mass stars of M$\approx$ 0.1 $M_\odot$ have M_v=15.5 and are reachable within 100 pc distance, brown dwarfs with M<0.08 $M_\odot$ have fainter magnitudes (V about 25) and are probably out of reach even for AVES unless very close-by. The lithium test used to discriminate between very low mass stars and brown dwarfs requires both the high resolution and sensitivity provided by AVES (cf. Basri 1997, in *Cool Stars in Clusters and Associations*, p. 917).

High resolution spectroscopy will be possible for hot (A0) white dwarfs within 500 pc and for cool (M0) white dwarfs within 100 pc. In young galactic clusters, white dwarf candidates are identified as faint blue objects in the field and spectroscopy is then used to identify them as white dwarfs and confirm the cluster membership. The critical mass for white dwarf formation is of great importance for stellar evolution and this can be obtained from observations of young clusters. It will be interesting to study rich clusters like NGC6067, NGC6664, NGC3766, and M25 with turnoff masses between 4.7 and 6. The expected V magnitudes of white dwarfs in these clusters range from 21 to 24 (Koester 1996, in *Science with the VLT*, p. 145).

1.2.4 Neutron stars, black holes

Neutron stars and black holes are generally discovered via the X-rays emitted in the mass accretion process from a companion star. The mass donors are either massive O and B stars or low-mass stars with M<1$M_\odot$. In low-mass X-ray binaries the donor is detectable in a few wider systems or in transients during their quiescent phases. In these systems the donor star is typically rather faint with magnitudes in the range 18-20. In the LMC the optical counterparts are around 20-23. For instance for Nova Muscae 1991 the magnitude of the K4V companion is 20.3 and the radial velocity variation is 830 km/s in a period of a few hours (9.6 hours). Incidently the spectral observations of the cool companion revealed the presence of freshly synthesized lithium (Martin et al. 1996, New Astronomy 1, 197). The case of Nova Muscae 1991 illustrates that a very efficient spectrograph is required to observe faint objects when exposures have to be short to avoid orbital velocity smearing. Orbital periods for X-ray binary systems are important to understand the evolution of the system and the mass of the compact object.

A neutron star at the distance of 10 pc emitting as a blackbody of 5x10^5 K would have a magnitude of 21. Obtaining spectra of the atmosphere of a neutron star will provide gravitational redshift and therefore the mass-radius relation for neutron stars. The γ-ray source Geminga is a single neutron star at a distance of possibly 38 pc (Bertsch et al. 1992, Nature 357, 306).

1.3 Stellar Spectroscopy in the Local Group galaxies

1.3.1 Stars in the Local Group

HST is providing stars in the outer regions of the Local Group galaxies. Main sequence stars in these galaxies will be observed for the first time with AVES at a resolution which is adequate for chemical analysis. In the LMC (d=52 Kpc) a F0 star on the ZAMS (M=3.1) has an apparent magnitude of 21.6 and of 22 at the distance of the SMC and other closeby members of the local group such as Draco, UMi and Sculptor. The Sagittarius dwarf galaxy recently discovered shows a turnoff at V$\approx$ 21 (Marconi et al. 1997, A&A 330, 453). Radial velocities of these objects allow galaxy dynamics to be probed at large radii as it has been mapped by means of radio observations of neutral gas. In M31 (d=670 Kpc) probably only bright giants (G, F II m$\approx$ 22) will be reachable with the AVES sensitivity.

1.3.2 Lithium in the Magellanic Clouds

The possibility to observe Li in mean sequence stars of the LMC is chosen to illustrate in more detail the great potentials of AVES for stellar spectroscopy in nearby galaxies.

Lithium is a very interesting element, whose abundance can be determined by observing the Li I 6708 resonance doublet in late type stars. The interest in deriving Li abundance stems mostly from the fact that Li is the heaviest element expected to be produced in Big Bang nucleosynthesis. Li is depleted in stellar interiors at temperatures above $\sim 2.5 \times 10^6$ K but it is also produced during galactic evolution by several processes. The primordial Li is currently taken to be that observed in Pop II stars (the so-called Li *plateau*, Spite and Spite 1982, A&A 115, 357; Bonifacio and Molaro 1997, MNRAS 285, 847) providing an independent measure of the baryonic density ($\Omega \times h^{-2}$). This value has been afterwards enriched in the Galaxy up to the $\sim$ twenty times higher value observed in young Pop I stars and in meteorites. However, this interpretation suffers of some uncertainties since no stellar model is so far able to reproduce the whole body of Li observations in Pop I and II stars. In addition, recent observations of the metal poor cluster M92 with Keck (Boesgaard et al. 1998, ApJ 493, 206) revealed that one star belonging to this cluster may have a Li abundance higher than the Li *plateau*.

To fully address the Li problem it is important to observe stars in open and globular clusters, where the stellar parameters can be rather well constrained (Pasquini and Molaro 1996, A&A 307, 761; Pasquini and Molaro 1997, A&A 322, 109; Pasquini et al. 1997, A&A 325, 535), and to extend the observations to some fundamental groups of stars which are not easily accessible in our own Galaxy, namely young metal poor stars and old metal rich objects. A group of metal poor, but relatively young globular clusters exist in our Galaxy (Fusi-Pecci et al. 1995, AJ 110, 1664) and much younger metal poor clusters are present in the Magellanic Clouds. As far as old, metal rich stars are concerned, they can be found in clusters in the Galactic Bulge (Guarnieri et al. 1998, A&A 331, 70). All these extremely interesting objects are located at very large distances from the Sun and/or in very reddened regions; their F-G type dwarfs have magnitudes around V=20.5 or fainter for the galactic globulars and $\sim$ two magnitudes fainter if belonging to the LMC. Also, Li analysis requires main-sequence stars and these have been accessible so far only in own Galaxy so that we have no clues on Li abundance in other environments. The Sagittarius dwarf galaxy recently discovered has turnoff stars with magnitudes $\sim$ 21 and can offer for the first time such a possibility.

1.4 Stellar spectroscopy beyond the Local Group up to 3 Mpc

Bright galaxies at 3 Mpc have a distance modulus of 27.4 and therefore cool supergiants (Mv= -7.5) are into reach once resolved. Spectroscopy of red supergiant stars yields abundances of CNO, α-process, Fe-group and s/r-process elements which help tracing the galaxy evolution. It will be possible to study abundance gradients and chemical patterns in spirals, barred spirals and dwarf irregular star forming galaxies, possibly also nearby blue compact dwarfs with low metallicity.

Investigation of Hα emission properties of OBA supergiants in galaxies of differing metallicities will provide insights into mass loss as a function of metallicity, which is rather important for understanding massive star evolution as a function of metallicity and hence for high redshift galaxies.

2 Instrument requirements

Once the astrophysical goals have been established, we are able to outline the Level 1 instrument requirements:

- Resolving power: to allow a proper chemical analysis of F-G stars a resolving power of at least R=15000 is required.
- High efficiency: at R=15000 a V=20.5 star will give in reasonable integration times only a limited number of photons per pixel, even with an 8m-class telescope. Efficiency is therefore of primary concern. To obtain the highest efficiency the spectral range of the spectrograph has to be limited to a selected region (for instance the red only). Working in a limited wavelength range it will be possible to optimize the optical transmission of the spectrograph through a proper choice of coatings and glasses and of the best detector.

- Low noise: when considering that the spectrograph should observe objects beyond magnitude R$\sim$20.5, sky becomes the predominant source of noise. In addition, even if low read-out-noise is nowdays achievable with state-of-the-art CCDs and controllers, to maintain a small number of pixels per resolution element will help in minimize this noise source. These requirements drive that the sky aperture and its projection on the detector should be minimal, while preserving high efficiency.
- Crowding: Since often the targets will be embedded in very crowded fields, excellent telescope image quality and small spectrograph aperture are required to limit the contamination by nearby objects.
- Costs: Since the instrument proposed will not be a multi purpose general facility, costs should be contained. This implies that a compact instrument should be built.

All these requirements naturally drive to one conclusion: the instrument should be fed by an adaptive optics system.

The VLT will be equipped with two AO systems: one at the Cassegrain focus (MACAO) and one at the Nasmyth focus (NAOS). Both systems are equipped with a secondary port where an auxiliary spectrograph can be hosted. At the LBT, all foci will probably benefit from an AO system, and AO systems are being considered at present for a large number of telescopes, both of the 4m and of the 8m class. There will be no shortage of new generation telescopes where a spectrograph like AVES could profitably be used.

3 Proposed instrument

The proposed instrument is based on a prism crossdispersed, double pass echelle spectrograph concept. The light from the AO system is converted to F/3 by a focal reducer. *Note that simply by changing the focal reducer AVES can easily be mounted on other telescopes or moved to another focus.*

The main characteristics of the spectrograph are given below:

- Classical Design, prism cross-dispersed, Littrow
- Fixed format (no movable parts)
- Entrance slit 0.3 arcsec
- Collimator and camera aperture: F/3.2
- Beam: 5cm
- Echelle: R2, 79lines/mm. R$\sim$16700 with a 5cm beam. $\lambda/\delta\lambda = 41500$ per pixel.
- CCD: 1K by 2K with 15 micron pixels. 2K by 2K preferred for frame transfer and very slow readout.
- Sampling: 2.5 pixels (F/3.2 Camera for 15 μm pixel, 0.12 arcsec/pixel)
- Wavelength coverage: full coverage from order 39 (5600 Å) to order 21 (11000 Å).
- Order separation: with SF4 prism and an apex angle of 50 degrees: $\sim$27 pixels (3.2 arcseconds) between the reddest order, $\sim$49 pixels (5.9 arcseconds) between the bluest.
- Length: Less than 60 cm (w/o cryostat)

4 Expected performances

High efficiency is a key parameter. The echelle grating (R2 79 lines/mm) is probably the most efficient R2 echelle ever produced. Limiting the wavelength range above 500 nm will ensure that optimal coatings can be used.

The foreseen efficiency in the R band is given in Table 1, where, as an example, we have considered AVES at one of the AO foci of the VLT. Since some of the components of the whole train have not yet been fixed, in Table 1 a range of possible values is given for some of the transmissions. The result is summarized in the last two rows, where a "best" and "worse" value are indicated. The "best" value considers the optimal solutions (i.e. Cassegrain focus, best echelle) while the "worse" case considers all the transmissions at minimum. Note that the "best" values given in Table 1 are nowdays realistic, and can be obtained with present technology.

The overall efficiency (including telescope mirrors and adaptive optics modulus) can easily reach $\sim$ 15%, which compares well with that of the best conventional spectrographs. It is worth noticing that there is some room for improvements, mostly in the transmission of the AO system, which has been taken at conservative values. It is also worth noticing that with a 0.65 arcsecond seeing (i.e. the median seeing at Paranal), even if MACAO and NAOS will not provide diffraction limited images in the R band, they still concentrate 60% of the light in a 0.3 arcsecond wide slit, and this is the crucial point for spectroscopy. At 560 nm (the shorter wavelength end of the AVES spectral range), the AO performances will only be slightly worse (10% less light in a 0.3 arcsec slit). **AVES therefore will have a photon source collecting capability similar to the best conventional spectrographs, but with only $\sim$ 1/10 of their sky contamination.**

Table 1: Estimated AVES efficiency if used at the VLT with the AO system

Component	Efficiency	Options
Mirrors(2)	0.77	0.66 Nasm.
Red Filter	0.98	1.00 No filter
AO Transmission	0.70	
Slit Transmission	0.60	
F/N reducer	0.98	
Echelle	0.65	0.77 (Silver Coated)
Spectr. Optics	0.83	0.85
CCD	0.85	0.9
TOTAL "Worse"	0.12	
TOTAL "Best"	0.19	

The expected signal to noise ratio of AVES per wavelength pixel in the R band has been estimated for the case of the VLT (Pasquini et al. 1998, Proceedings SPIE, in press). For this estimate (based on photon and noise statistics) a sky magnitude of R=20.9 per square arcsecond has been assumed, and an overall transmission of 17 %. A S/N ratio better than 10 per pixel (i.e. S/N=16 per resolution element) can be reached in 2 hours for stars of R magnitudes brighter than 22, which corresponds for instance to a late F star in the LMC or to a G star in the Sagittarius dwarf. To the best of our knowledge, we will be able to outperform for these faint objects existing or planned spectrographs by almost 2 magnitudes. For stars brighter than R=20, the S/N ratio is greater than 20 in 1 hour exposure. By adding several two hours exposures, it will thus be possible to derive chemical abundances for stars of magnitudes up to R=22 (V$\sim$ 22.4 for G main sequence stars).

Also, it is worth noticing that very low S/N observations can be obtained for objects up to magnitude R$\sim$24, which implies that 1 Km/sec radial velocities could be obtained for these stars (see Queloz et al. 1995, A&A 300, 31).

MANAGEMENT AND PLANNING

The Institutes involved in the AVES project are:

- Osservatorio Astronomico di Trieste (OATs)
- Osservatorio Astronomico di Milano (OABr)
- Osservatorio Astronomico di Palermo (OAPa)
- Osservatorio Astrofisico di Catania (OACt)
- European Southern Observatory (ESO)

The project will be managed by OAPa (PI R. Pallavicini) in close collaboration with ESO (co-PI L. Pasquini). Responsibilities will be equally shared among all partecipating institutions. The key personnel involved and the division of responsibilities between the consortium members will be briefly described below. **The strategy adopted for the development of the project aims at arriving at a Final Design Review (FDR) within a 2-year timeframe (middle 1998 to middle 2000).** Once the instrument design is completed, it will be proposed for use at the adaptive optics foci of 8-m class telescopes (VLT, LBT, GTC). If use of AVES on one (or more) of these telescopes is approved, procurement, manifacturing and integration of the subcomponents can start immediately, with the aim of arriving at a complete working instrument within 2 years (middle 2000 to middle 2002 or later depending on approval by the telescope host institution and the funding agency). The baseline option, and the one that will become possible on the shorter timescale, is to use AVES at the VLT, adopting ESO standards and using the experience gained in other ESO programs (UVES, VIRMOS) by some of the partecipating institutions.

5 Responsibilities

The main areas of responsibilities are divided among the consortium members as follows.

5.1 Management

Management of the project, including development and upgrade of planning and schedule, management of the budget, recruiting of manpower, issuing contracts with subcontractors, and coordination of activities, is under the responsibility of OAPa (R. Pallavicini). He will also be responsible for establishing and maintaining an efficient reporting system within the consortium. He will be assisted by L. Pasquini (ESO) for the contacts with ESO for the optical design and the adaptive optics interface.

5.2 Science support

Identification of the science requirements and definition of the key instrument specifications will be carried out by all partecipating institutions under the coordination of an AVES Science Team chaired by P. Molaro (OATs). The Science Team will operate in close contact with the various Instrument Teams (optics, mechanics, electronics) and with the Software Team. Operation and calibration plans are also part of this unit, as well as the development of the requirements for the data reduction SW.

5.3 Optics

Design of the complete optical system is the responsibility of researchers at ESO (B. Delabre and coworkers) which will provide the initial conceptual design and will supervise the development of the final optical design by industry. This unit also includes design of the calibration system and of different focal reducers. The optical Preliminary Design Review (PDR) will be used to prepare the PDRs of mechanics and electronics, which will run in parallel to the Final Design Review (FDR) for the optics.

Researchers at ESO (F. Rigaut, G. Avila) will also be responsible for the adaptive optics interface and AO constraints for the baseline option of using AVES at the VLT.

5.4 Mechanics

Design of the complete mechanical system is the responsibility of OABr (P. Conconi and coworkers) which will provide the initial conceptual design and specifications and will supervise the development of the final optical design (including thermal control, finite element analysis, etc.) by industry. OABr will also have responsibility of instrument integration, to ensure that all HW parts (including optics and electronics), developed by different institutions, integrate one with the other in the proper way.

5.5 Electronics

Design of the control electronics and of CCD controllers will be carried out jointly by OAPa (R. Pallavicini and coworkers) and OACt (G. Bonanno and coworkers) which will provide the design of control electronics (OAPa) and the specifications for CCD detectors and controllers (OACt). The standards ESO will be assumed as a baseline for control electronics and detectors, but other options will be explored for possible use of AVES at telescopes other than the VLT. The same institutions will also be responsible for supervising the final design of control electronics by industry.

5.6 Software

The design of the instrument control SW and observing SW will be the responsibilitiy of OATs (P. Santin and coworkers) and will be mostly carried out in-house using existing facilities and the large experience acquired in other ESO programs (e.g. UVES for the VLT). The data reduction SW will be based on the standard MIDAS echelle package and will be implemented for AVES by the AVES Science Team.

6 Key personnel

The following scientists and technicians will play a key role in the AVES project at the indicated institutions. The time devoted by each of them to the project is also indicated (in months per year).

- OAPa: R. Pallavicini (5 months/year), F. Bocchino (3), R. Candia (3), S. Varisco (2), one CNAA fellow (11)
- OATs: P. Molaro (3), P. Santin (3), P. Di Marcantonio (3), P. Bonifacio (2)
- OABr: P. Conconi (2), L. Mantegazza (3), E. Molinari (2), F. Zerbi (2)
- OACt: G. Bonanno (3), R. Cosentino (3), M. Rodonò (1), S. Catalano (2)
- ESO: L. Pasquini (3), B. Delabre (3), G. Avila (2), F. Rigaut (2)

7 Time schedule

The proposed project aims at arriving at a final instrument design for implementation at the adaptive optics focus of an existing 8m-class telescope (albeit it could also be used on a 4m-class telescope like the TNG for less fainter objects). **Completion of this study will require 2 years, the first one devoted to in-house development of the conceptual design (for optics, mechanics, electronics and software) and the second one for the development of the final instrument design through industrial subcontracts.** As a baseline, it will be assumed that AVES will be used at one of the adaptive optics foci of the VLT (which will become available from 2001 onwards). However, AVES could also be used at one of the foci of the LBT or on any other large telescope with

adaptive optics. Several options will be considered depending on the potential host telescope (VLT, LBT, GTC, etc.). The procurement of several similar systems could also be envisaged, depending on the nature of the agreement with the different observatories.

The project will develop according to the following milestones:

- September 1998 : Project kickoff
- December 1998 : Project detailed definition. At the end of this phase the science cases will be fully developed and on their basis the final technical specifications and Statement of Work will be issued. In this phase the HW and SW standards to be used will also be established.
- September 1999: Preliminary Design Review including Final Design of the Optics.
- September 2000: Final Design Review. Large part of this phase will be subcontracted externally.

At each milestone the proper documentation shall be presented as defined in the Statement of Work.

8 Cost estimates

As detailed below, the total cost of this study is estimated to be 270 ML in 2 years. Procurement, manifacturing, assembling and testing of the various components of the instrument (once approved), including detector system and controllers, are **not** part of this study and are estimated to be around 700 ML (excluding the development costs that are all included in the present proposal).

Estimated costs for first year (1998)

- durable equipments (WS) : 30 ML
- travel costs : 40 ML
- fellowships (1 year) : 25 ML
- external contracts : 0 ML
- overheads : 5 ML

Total cost for first year : 100 ML

Estimated costs for second year (1999)

- durable equipments : 0 ML
- travel costs : 40 ML
- fellowships (1 year) : 25 ML
- external contracts : 100 ML
- overheads : 5 ML

Total cost for second year : 170 ML

Total cost of the project: 270 ML in 2 years

Funds available from partecipating institutions: up to 30% of the total cost

Funds requested from CNAA (for 2 years) : 180 ML

Funds assigned by (or requested to) other sources: none

PROPOSING INSTITUTION

Principal Investigator: **Dr. R. Pallavicini**
Institution: **Osservatorio Astronomico di Palermo**
Director of Institution: **Prof. S. Serio**

Partecipating Institutions:

- **Osservatorio Astronomico di Trieste (OATs)**
- **Osservatorio Astronomico di Milano (OABr)**
- **Osservatorio Astronomico di Palermo (OAPa)**
- **Osservatorio Astrofisico di Catania (OACt)**
- **European Southern Observatory (ESO)**

Principal contact points at partecipating institutions:

- **Dr. P. Molaro (OATs)** molaro@oat.ts.astro.it
- **Dr. P. Conconi (OABr)** conconi@merate.mi.astro.it
- **Dr. R. Pallavicini (OAPa)** pallavic@oapa.astropa.unipa.it
- **Dr. G. Bonanno (OACt)** gbo@sunct.ct.astro.it
- **Dr. L. Pasquini (ESO)** lpasquin@eso.org

The project PI (Dr. R. Pallavicini) and the Director of Osservatorio Astronomico di Palermo (Prof. S. Serio) agree to carry out the proposed research by using the expertises and facilities available at their institution and to manage the whole program also on behalf of the other partecipating institutions. The Directors of the partecipating Observatories have agreed to contribute to the cost of this program up to a maximum of 30% of the total cost (i.e. up to a maximum of 90 ML in 2 years to be shared among the 4 participating Italian Institutes).

Palermo, 28 May 1998 R. Pallavicini S. Serio