No. 89 – September 1997

TELESCOPES AND INSTRUMENTATION

FEROS, the Fiber-fed Extended Range Optical Spectrograph for the ESO 1.52-m Telescope

A. KAUFER, B. WOLF; Landessternwarte Heidelberg-Königstuhl, Germany
J. ANDERSEN, Astronomical Observatory Copenhagen, Denmark
L. PASQUINI, ESO

Overview

FEROS is a fiber-fed bench-mounted prism-crossdispersed echelle spectrograph for the ESO 1.52-m telescope at La Silla. It works in quasi Littrow mode and in white pupil configuration. For the object and the nearby sky, the complete optical spectrum from 370–860 nm is recorded in one exposure with a resolving power of R = 48,000 by the use of a two-beam, two-slice image slicer.

A first concept of FEROS, which is supposed to replace ECHELEC at the 1.52-m telescope, was presented by Pasquini et al., 1992, "FEROS for the ESO 1.52-m Telescope", 32nd Scientific Technical Committee Meeting, Garching. Designed as a fiber-linked spectrograph connected to the permanently mounted Boller & Chivens spectrograph it has the advantage of being always available. The fibre entrance of FEROS is mounted on the slit unit of the Boller & Chivens spectrograph, and it will be possible to change from one spectrograph to the other by a simple translation of the slit unit. Because FEROS provides high-dispersion spectroscopy with a wide, simultaneous wavelength coverage, this instrument mounted on an intermediate-size telescope fills a gap in the present and future ESO instrumentation park. It will allow to realise many important scientific programmes (a few of which are described below) of objects down to about 16th magnitude with high efficiency, little constraints on operations and will relieve the pressure on larger telescopes.

FEROS is built for ESO by a consortium of four astronomical institutes under the leadership of the Landessternwarte Heidelberg (LSW). The Principal Investigator (PI) of the FEROS project is Prof. Dr. Bernhard Wolf at the LSW. Further members of the consortium are the Astronomical Observatory Copenhagen (AOC), the Institut d'Astrophysique de Paris (IAP), and the Observatoire de Paris/Meudon (OPM). The contract between ESO and the FEROS Consortium was signed in September 1996. It is planned that the instrument will be available to the community in early 1999.

Scientific Objectives

The need for instruments for high-resolution spectroscopy has increased considerably in the last years. With the advent of fiber-linked echelle spectrographs, the former domain of the largest telescopes became accessible for small- to medium-size telescopes with their advantage of higher availability for long-term programmes. Furthermore, the high long-term spectral stability of bench-mounted and fiber-fed spectrographs turns out to be crucial for high-precision spectroscopic work. Therefore, it is expected that FEROS will be an important work-horse instrument for the ESO community, e.g., for the search for extrasolar planets with high-precision radial-velocity measurements on long time bases, for investigations in the growing field of asteroseismology, and for spectroscopic investigations of time-dependent phenomena in stellar atmospheres and envelopes in general.

FEROS at the ESO 1.52-m telescope will meet the requirements posed by

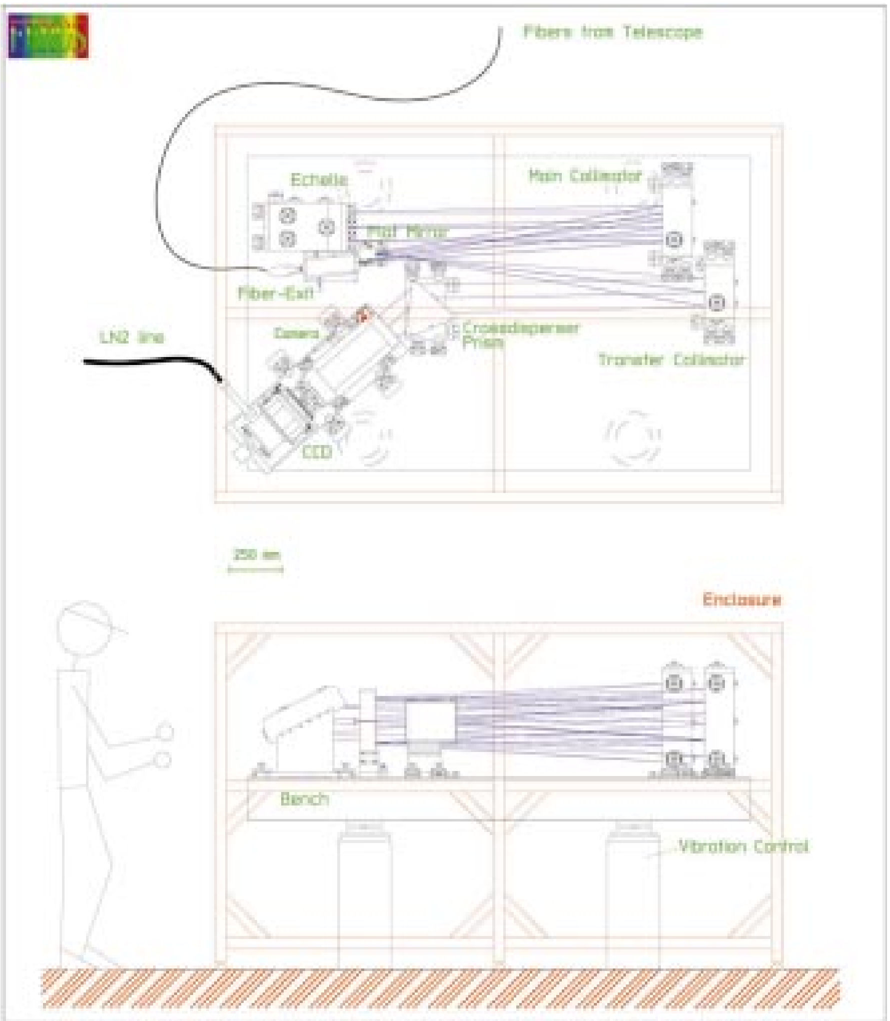

Figure 1: Top and side view of the opto-mechanical layout of FEROS.

these scientific objectives. Due to its high efficiency, many of the observing programmes which to date can only be conducted with CASPEC at the 3.6-m telescope or EMMI at the NTT are within reach of FEROS with a comparable spectral resolution and even superior spectral coverage. The same holds for the CES at the CAT if the highest-resolution mode is not imperative for an observing programme. It is worth to note that FEROS will not touch the domain of programmes which can only be carried out effectively with UVES at the VLT, i.e., low to medium *S/N* observations of the faintest objects and high *S/N* observations with resolutions of the order 10^5 of brighter objects [Dekker & D'Odorico, 1992, *The Messenger* 70].

Instrument Description

Opto-mechanical layout

The bench-mounted part of the opto-mechanical layout of FEROS is shown in Figure 1. The Boller & Chivens spectrograph in the Cassegrain focus of the ESO 1.52-m telescope will be modified to carry the additional fibre-entrance unit and the extended calibration unit for both spectrographs.

The light of the object and the nearby sky is coupled via micro-lenses into two 100 μm fibres in the Cassegrain focus of the telescope. The micro-lenses convert the F/15 telescope beam into a F/4.6 beam which is optimal for the fibres. In the coudé room, where the bench-mounted spectrograph will be located in a temperature- and humidity-controlled room, the fibre exit is converted to the F/11 focal ratio accepted by the spectrograph via a lens system. A two-beam, two-slice image slicer in the F/11 focal plane halves the width of the images of the two fibres in the direction of dispersion (cf. Fig. 3). The fibres are re-imaged on the R2 echelle grating through the main off-axis collimator. Then, the light goes back to the main collimator and is reflected by the flat folding mirror to the transfer off-axis collimator. The entrance surface of the large LF5 prism cross-disperser is located near the white pupil image and the light is finally imaged by the dioptric camera onto the detector. The detector foreseen is a monolithic thinned 2048 × 4096 15 μm pixel CCD.

The mechanical design of FEROS follows in many parts the design of the UVES instrument and consequently uses standard techniques for bench-mounted instrumentation. The echelle grating and the off-axis collimators are mounted in kinematic mounts; if feasible, standard industrial mechanical elements are used.

To ensure a maximum long-term stability of the spectrograph, *no* movable or remotely-controlled parts besides the CCD shutter are foreseen on the bench-mounted part of the instrument. Further, the CCD detector will be equipped with a continuous-flow cryostat supplied with liquid nitrogen from a nearby vessel with a capacity for about two weeks. The cooling by a continuous flow of liquid nitrogen is important to keep the weight of the CCD dewar constant over longer periods. The evaporation of the LN_2 from a standard dewar during the night would cause considerable shifts of the spectrum in main dispersion direction on the detector. In addition, the spectrograph is built on a vibration-controlled optical bench and will be housed in a separate light-tight room, which is temperature and humidity controlled.

The main parameters and the ex-

Table 1: Main parameters of FEROS.

Wavelength range in one exposure (object+sky)	3700–8600 Å (40 orders, 2 fibres)
Resolving Power (with 2-slice image slicer)	$\lambda/\Delta\lambda$ = 48,000
Entrance Aperture	2.7 arcsec
Fiber input/output Focal Ratio	F/4.6
Spectrograph Beam Size	136 mm diameter
Off-axis Collimators	F/11, cut from one parent paraboloid
Echelle	R2, 79 lines/mm, 154 mm by 306 mm
Crossdisperser Prism	LF5 glass, 55¡ apex angle
Dioptric Camera	
Wavelength Range	350–900 nm
Focal Length; F ratio	410 mm; F/3.0
Field Diameter	69 mm
Image quality (E_{80})	< 25 μm
Efficiency	> 85%
CCD	2048 × 4096, 15 μm, thinned
Expected Detection Efficiency (without telescope)	6% (3700 Å), 21% (5000 Å), 9% (9000 Å)
Expected Limiting Magnitudes at the ESO 1.52-m	16 mag in V (S/N = 10, 2 h)
	12 mag in V (S/N = 100, 2 h)
Expected Radial-Velocity Accuracy	< 25 m/s, < 5 m/s with iodine cell (contract: < 50 m/s)

Figure 2: Spectral format of FEROS showing a simulated flatfield exposure. Red is to the left with the extreme order 32 with λ_c = 9850 Å; blue is to the right with the extreme order 63 with λ_c = 3600 Å. Each spectral order is double due to the illuminated object and sky fibre. The whole echelle spectrum is rotated counter-clockwise by 2.4° to align the slit image with the CCD rows.

pected performance for FEROS are summarised in Table 1.

Observing Modes

For the observations with FEROS, only three observing modes will be provided:

1. Calibration (Flatfield and Thorium-Argon)
2. Object + Sky
3. Object + Calibration

For the latter mode, the spectrum of an adequately attenuated Thorium-Argon lamp will be recorded through the sky fiber during the object exposure. The Object + Calibration mode allows to record the residual motions of the spectrograph during the object exposure and to considerably improve the radial-velocity accuracy. This technique in combination with software cross-correlation has successfully been used in the ELODIE instrument at the Observatoire de Haute-Provence and achieves a long-term accuracy of $<$ 15 m/s for a sharp-lined G dwarf [Baranne et al., 1996, *A&AS* 119, 373]. For even higher accuracy of the order of $<$ 5 m/s, the use of an iodine absorption cell placed in the telescope beam is evaluated at the moment [cf. Butler et al., 1996, *PASP* 108, 500].

For flatfield and wavelength calibrations, the B&C calibration unit will be equipped with a blue-enhanced flatfield source and a Thorium-Argon hollow-cathode lamp, respectively.

All observing modes will be supported by the DAISY instrument control software foreseen at the ESO 1.52-m telescope for the operation of the B&C and the FEROS instruments. This will allow a change between the two instruments within a few minutes – an interesting option for spectroscopic programmes which require a pre-examination of the targets with low resolution or spectrophotometric observing programmes.

Further, full on-line data reduction will be available at the telescope to enable the observer to fully exploit the capabilities of the instrument already during the observations.

Spectral Format

A simulation of the two-dimensional echelle spectrum on the 2k × 4k 15 µm detector is shown in Figure 2. This simulation includes the wavelength-dependent intensity distribution of the blue-enhanced flatfield source, the wavelength dependent transmission of FEROS itself, the two-beam two-slice image slicer, models for the blaze function, for the straylight distribution, and for the photon and detector noise. This simulation runs in the MIDAS environment and is primarily used for the development of the on-line data-reduction and instrument-simulation software.

A special complication of the spectral format is introduced by the permanently mounted Bowen-Walraven image slicer which is needed to achieve the spectral resolution of R = 48,000. Figure 3 shows the output of a scaled prototype of this device built from Acrylic in the mechanical workshop at the LSW. The circular outputs of the two object and sky fibres (top) are simultaneously sliced into two 'half moons' (bottom) which effectively halves the equivalent slit width in the main dispersion direction. The equivalent slit height was chosen to be 4.5 times the slit width which leaves a quite small gap between the two half moons. The individual slit images will be sampled on 2 by 10 pixels on the CCD detector. Therefore, a double-peaked cross-dispersion slit profile has to be handled by the data-reduction software, which requires special care for the order definition and the optimum extraction.

Table 2: Time schedule for FEROS.

Contract Signature	September 1996
Final Design Review	June 1997
Preliminary Acceptance (@LSW, HD)	June 1998
Provisional Acceptance (@ESO, La Silla)	December 1998
Availability to the Community	early 1999

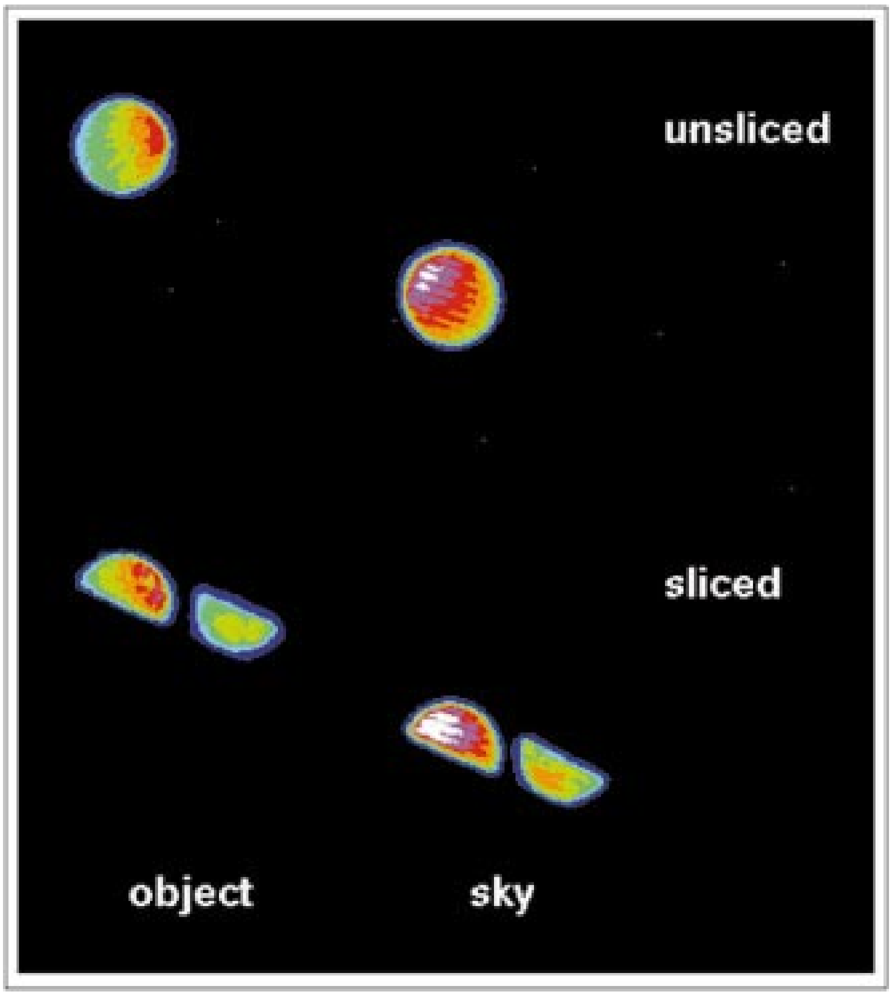

Figure 3: CCD images of the unsliced and sliced outputs of the scaled image-slicer prototype. The inhomogeneous intensity distributions within the images is due to the low polishing quality and inhomogeneity of the Acrylic's surfaces.

CCD Detector

The thinned 2k × 4k CCD and the standard ESO-VLT continuous-flow cryostat will be provided by ESO (cf. Lizon, 1997, *The Messenger* 88, p. 6, Fig. 1).

The CCD controller electronics will be built by the AOC; also the integration and testing of the complete CCD system will be carried out at the AOC. For the beginning, an engineering grade 13.5 µm EEV CCD was already delivered by ESO at the end of March 1997. The first devices of this type have been tested at the Royal Greenwich Observatory. They show a good performance with an on-chip noise of 4 e^- rms and a peak quantum efficiency of 85% at 550 nm and 27% (goal 50%) at 350 nm. The delivery of the science grade 15 µm EEV CCD to the FEROS consortium is planned for November 1997.

On-line Software

The FEROS data reduction software (DRS) is currently developed in the MIDAS environment at the LSW. The DRS will provide full on-line data reduction of the standard observing modes at the telescope workstation during the observation. In addition, the observer will be supported by a graphical user interface (GUI) for the on-line reduction and an instrument simulation for the preparation of the observations.

A dedicated DRS is particularly suitable for the FEROS instrument because of its fixed configuration. But it is also crucial because of the complex spectral format on the CCD and the large size of the raw frames (16 Mb for a 16-bit ADC). As was seen in Figure 2, the DRS has to cope with the strong curvature of the orders, the doubling of the orders due to the object and sky/calibration fibres, and the double-peaked slit profile in cross-dispersion direction.

Basically, the DRS will follow the standard echelle reduction scheme with order definition, wavelength calibration, background subtraction, flatfield correction, optimal order extraction to optimise the *S/N* of the spectra, rebinning to constant wavelength steps in linear and logarithmic scale, and if required, order merging, correction for the instrument response function, and sky subtraction. It is worth to note that because of the very stable spectral format of the bench-mounted and fiber-fed spectrograph, the correction for the blaze function, that is needed to allow precise order merging, can be carried out with the internal flatfields alone. Further, cross-correlation facilities will be supplied for high-precision radial velocity work and time-series analysis facilities for variable-star research which probably will be the main fields of work for FEROS.

Time Schedule

The time schedule for the FEROS project is given in Table 2. It is planned to make the instrument available to the community in early 1999. The present status of the project is that after the final optical design review was passed in October 1996, the procurement of the optical components was started immediately. The final mechanical design was completed in June 1997 and the manufacturing of the mechanical components started afterwards. The FEROS final design was presented at the design review at the end of June 1997 and was approved by ESO. Up-to-date information on the status of the project is available in the WWW on the FEROS homepage (URL http://www.lsw.uni-heidelberg.de/~akaufer/Feros.html).

Project Teams

The project teams of the consortium and ESO consist of the people listed in Table 3. The project is further supported by the technical advice of G. Avila, B. Delabre, H. Dekker, W. Eckert, A. Gilliotte, J.-L. Lizon, and R. Olivares at ESO.

Table 3: FEROS project teams.

LSW	B. Wolf (PI), I. Appenzeller (Advisor)
	A. Kaufer (Instrument Responsible)
	W. Seifert (Optic Design), H. Mandel (Adjustment)
	O. Stahl, A. Malina (Data-Reduction Software)
	C. Hartlieb, L. Schäffner (Mechanics)
AOC	J. Andersen, P. Nørregaard, J. Klougart (CCD controller)
IAP	M. Dennefeld
OPM	R. Cayrel
ESO	L. Pasquini (Instrument Scientist)

A. Kaufer
E-mail: A.Kaufer@lsw.uni-heidelberg.de