The ESO Echelle Spectrograph for the Cassegrain Focus of the 3.6 m Telescope

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In the first tests at La Silla, CASPEC, coupled with a CCD detector, proved to be a promising instrument for high dispersion work on faint objects.

A Brief History of CASPEC

The decision to build a cross dispersion Cassegrain echelle spectrograph for the 3.6 m telescope can be traced back to 1974. However, the load of work to complete the 3.6 m telescope was such that only in 1976 Maurice Le Luyer could present the first optical concept. With the collaboration of a review team composed of J. Andersen, L. Delbouille, E. Maurice, P. E. Nissen and several ESO astronomers (P. Crane, J. Danziger, J. Melnick and M. H. Ulrich) a final design was adopted in June 1978. Then the detailed engineering phase took off: M. Le Luyer was appointed project leader and in charge of the optics; W. Richter designed the mechanics and the structure, and W. Nees and P. Schabel took the responsibility of the instrument control and its detector. The latter was initially thought to be a SEC vidicon.

When, in the summer of 1980, ESO moved into its new headquarters in Munich, CASPEC's construction was well advanced, but many of the staff members who were involved in the project left ESO. This resulted in a delay of more than a year: only in October 1981 could J. F. Tanne, a new staff member at the time, be appointed technical project leader with the task of finally assembling and testing the mechanical and optical components. In this he was helped by J. L. Lizon, while G. Raffi coordinated the instrument software, and D. Ponz started to work on a data reduction package. S. D'Odorico took care of the astronomical requirements and the preparation of the test programme.

At the end of 1982 it was realized that the VIDICON was not performing as well as expected, due mainly to problems with the magnet coils. It was then decided to switch to a CCD, which had been routinely used in direct imaging at La Silla for some time, as the spectrograph detector.

In the tests at the 3.6 m telescope in June and July 1983, CASPEC performed exceptionally smoothly and without problems for a complex instrument used for the first time at the telescope. Some minor hardware and software problems were detected and will be solved before the instrument comes into routine operation. Resolution, stability and speed proved to be very close to the predicted values.

Although the reduction and detailed evaluation of the more than one hundred useful astronomical images has just started, we report preliminarily on the instrument, to give some guidelines to the astronomers who want to apply for the next observing period.

A detailed technical report and a user's manual will be available to the users by the beginning oft next year.

The Present Instrument Configuration and Mode of Operation

The Optical Layout

The optical design and the parameters of the main optical components of CASPEC have been presented in the *Messenger* No. 17 and will not be repeated here. The configuration in which the instrument will be offered initially to the users is determined mainly by the small size of the present CCD, which is a 512 × 320 pixels, 15.36 × 9.6 mm back illuminated RCA chip. The combination of a 31.6 lines/mm echelle (blaze angle = $63^{\circ}.4$) and a 300 lines/mm cross dispersion grating (actually a mosaic of two), and the short camera (achromatic and of the folded Schmidt type, F = 1.5) gives a compact format in which about 900 Å, split into several orders, are recorded in one frame.

At 5000 Å, the reciprocal dispersion is 5 Å/mm with a resolving power of 20000. At the Cassegrain focus of the 3.6 m telescope, 1.2 and 0.74 arcsec are projected on one pixel of the detector in the direction of the dispersion and perpendicular to it respectively.

CASPEC can be used in the range 3500–10000 Å; the different wavelength regions are centred on the CCD by moving the cross disperser. The echelle grating position is kept fixed. Spacing between the orders varies from more than 50 pixels in the extreme red to as little as 5 in the extreme blue. These values and the need for a free interorder spacing in the CCD to monitor the background define the limits of the two-dimensional capability of CASPEC. For example, at H_{α}, a 20 arcsec slit can be used while still keeping the orders well separated. A thorium lamp is used for the comparison spectrum and a built-in quartz lamp for the flat field. In both cases the exposure times are of a few seconds. The stability of the instrument, which represented a major problem in the first tests in Garching, is now better than 1 pixel over 90° of rotation.

Function Control and Operating Software

All CASPEC functions, 15 in total, are remotely controlled from the console at the user station. A new modular design approach was conceived for the functions (like, e.g., collimator, slit, and cross disperser) which have to vary within a given range. They are performed by closed-loop positioning systems, all of which incorporate the following items: D. C. motor, tacho, absolute-position encoder, motor-drive amplifier, encoder position decoding module and a microprocessor controller. As a result most of the individual functions at the spectrograph are interchangeable among each other and the total number of spare components could be minimized. The microcontrollers are new ESO standard CAMAC modules especially developed for control applications.

The CASPEC on-line software, to control the instrument, acquires data from the CCD detector and to do on-line data reduction, consists of quite a number of programmes cooperating together. It runs under the RTE-4B operating system in an ESO standard HP 1000 configuration (256 Kw of memory, 50 Mbytes disk, CAMAC crate). The main programme (CASP) handles the user interface and the instrument logic. A software package sets up and monitors the CCD detector via a microprocessor controller. It executes exposures on demand and stores acquired data on disk and tape. The IHAP data processing system is used for on-line data reduction and now includes a command for extraction of an order from the two-dimensional echelle format.

The user input is via function keys and forms, which have to be filled in with the appropriate parameters. The format is such that a visiting astronomer should quickly learn how to set up a single exposure or a sequence of exposures.

The CASPEC programmes make use of a new data acquisition system (called DAQ) developed at ESO to easily transfer detector packages (like that of the CCD) to various instruments and instrument packages to different telescopes. CASPEC is the first instrument developed within this new frame but the software for the new B & C spectrograph for the 2.2 m telescope and for EFOCS, the faint object spectrograph for the 3.6 m are being implemented now along the same lines.

The Bright and Dark Sides of the CCD

The performance of the CCD chip which is currently used at CASPEC is in general quite satisfactory. The read-out noise is 40 e^-/pixel, the dark current 15 e^-/hour/pixel at T = 150°K. The quantum efficiency peaks at λ5000 with 60 % and is 15 % and 25 % at 3500 Å and 9000 Å respectively. These values were measured on the detector test bench in Garching. There the CCD was also found to be linear within 0.1 %.

On the dark side, this CCD shows a degraded horizontal charge transfer when a spectral image is formed on a dark background. This results, e.g., in a low amplitude tail at the right side of a comparison spectrum line. This effect can be eliminated by exposing the chip uniformly to a low level of light, at the price, however, of introducing additional noise to the image. In the present configuration the effect is perpendicular to the dispersion direction. Two hot areas, whose intensities increase linearly with time, are also observed on the border of the CCD. The charge spread which they produce is not severe for exposure times up to two hours. More annoying are the randomly distributed, non-reproducible spikes whose number rises with exposure time at a rate of about 2/minute. The only possible explanation are cosmic rays, but their frequency is about twice that quoted in the literature.

The most severe problem of the CCD remains however that of the "fringes" which are produced by light interference within the chip and result in a reduction of the sensitivity at a given wavelength and position. For this chip, they are as high as 30 % in the red. In the scarce literature on spectroscopic use of the CCDs which is available, it is stated that they can be accurately flat-fielded. In our case, the process is made more complicated by the existence of a background of bias and scattered light which has to be subtracted before the star spectrum is divided by the flat field image from the quartz lamp. When these problems are taken into account, our preliminary reductions indicate that an accuracy of at least 1 % can be achieved in the flat-field correction.

Tentative Time-table of Council Sessions and Committee Meetings Until December 1983

November 8	Scientific and Technical Committee
November 9–10	Finance Committee
November 11	Committee of Council
November 29–30	Observing Programmes Committee
December 1–2	Council

All meetings will take place at ESO in Garching.

The First Astronomical Results

The test observations indicate that the main goal of the CASPEC project, i.e. relatively high dispersion spectroscopy on faint objects, has been achieved. Fig. 1 can be used as a guideline for limiting magnitudes, and S/N ratios. Observations at good signal to noise of the continuum of objects as faint as m_v = 14 have easily been achieved with average seeing conditions. Emission lines have been observed in objects of fainter magnitudes. Fig. 2 shows one such observation. CASPEC definitely gives new possibilities to European astronomers and its capabilities appear rather good when compared with the performances of similar instruments, such as the Kitt Peak or MMT echelle spectrographs. The programmes which become feasible cover quite different topics in astrophysics. One can mention the study of interstellar lines in the Magellanic Clouds stars, the determination of abundances of stars in globular clusters and in the halo, the study of the velocity profiles in emission line galaxies, stars, quasars and supernova remnants, but this list is obviously incomplete.

While a large amount of original work can certainly be done with the present instrument configuration, one has also to be aware of its limitations. Fig. 3 shows that the higher resolution of the CAT + CES combination is worth being used when one

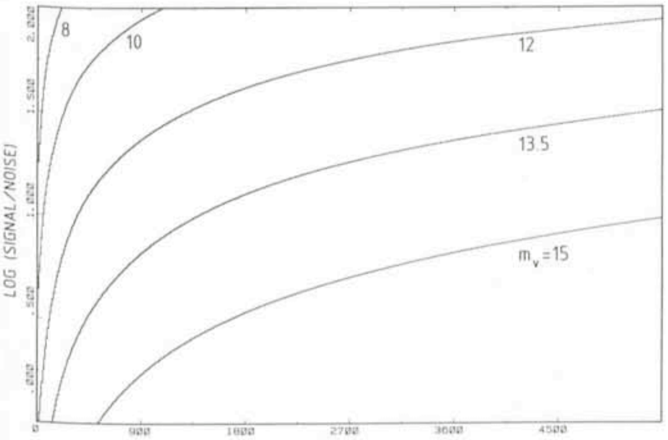

Fig. 1: *The predictions for signal/noise ratios as a function of exposure time for stars of different magnitudes at λ5000 Å. Photon statistics and the read-out noise of the CCD (50 electrons) were considered as sources of noise. These predictions were made a few months before the test observations. They were found to provide useful guidelines for the actual observations under very good seeing conditions (FWHI ≤ 1 arcsec). With larger images, both the loss of light and the spread over more pixels perpendicular to the dispersion partially degrade the S/N of the observations.*

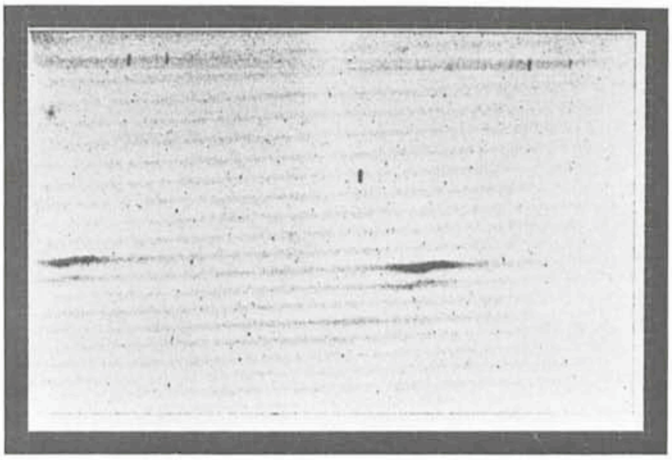

Fig. 2: *A 130-minute CASPEC exposure of the approximately 14th magnitude quasar MR 2251–178. The entrance aperture measured 2.1 × 5 arcsec on the sky. The H_β and [OIII] λλ 4959, 5007 lines (well visible in two different orders) as well as the narrow λ 5577, λ 5890–96 Å sky lines are present in the spectrum.*

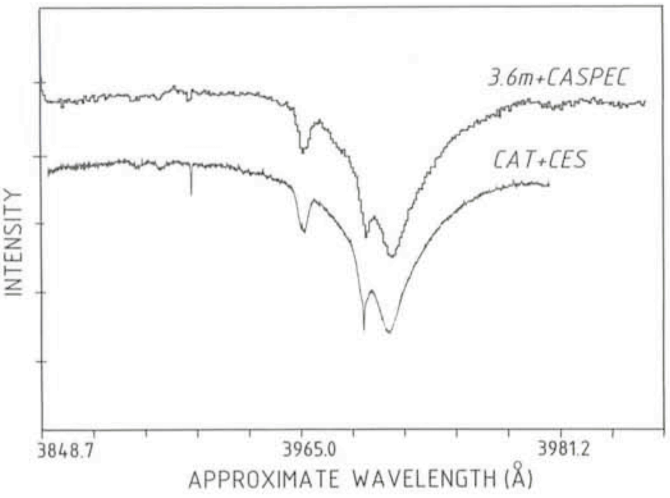

Fig. 3: *This figure, which shows the interstellar H line of CA II in the star HR 5358 (m_B = 4.4) as observed on the same night with the CAT + CES and with the 3.6 m + CASPEC, permits an interesting comparison. Parameters of the first observation are as follows: R = 100000, slit width = 1.1 arcsec, exposure time 20 min., spectral coverage = 33 Å. For CASPEC: R = 20000, slit width = 1.2 arcsec, exposure time = 1 min., spectral coverage = 1000 Å. The CES observation is a courtesy of Dr. I. K. Furenlid.*

is not limited by the number of photons or when one does not require a wide spectral coverage. Another point worth noting is that the compactness of the present format limits the use of the two-dimensional capabilities and makes the data reduction problems harder below λ4500 Å. It is hoped that these problems will be solved in the future by the introduction of a large detector. In the meantime, a limited amount of compromise is possible between different requirements. As an example, if the echelle grating with 79 lines/mm is used, the spacing between the orders is doubled but the merged spectrum presents gaps in its wavelength coverage above 4000 Å. We envisage that the possible modifications of the present set-up will depend on the desiderata of the users and on the experience gathered in the first months of operation.

There are a few points of the present mode of operation which are worth mentioning to help the planning of the observations. One is the upper limit for the exposure time. The spread of the hot areas and the spatial frequency of spikes in the CCD suggests limiting the exposures to something like 2 hours. Since these cosmetic defects can be removed at least partially in the data processing phase, the decision depends somewhat on the scientific goals of the observer.

In the test observations the sky was visible on the spectra only in long exposures within 90 degrees of the full moon. In any case it is a sensible procedure to monitor the background by using a long slit wherever this is permitted by the spacing

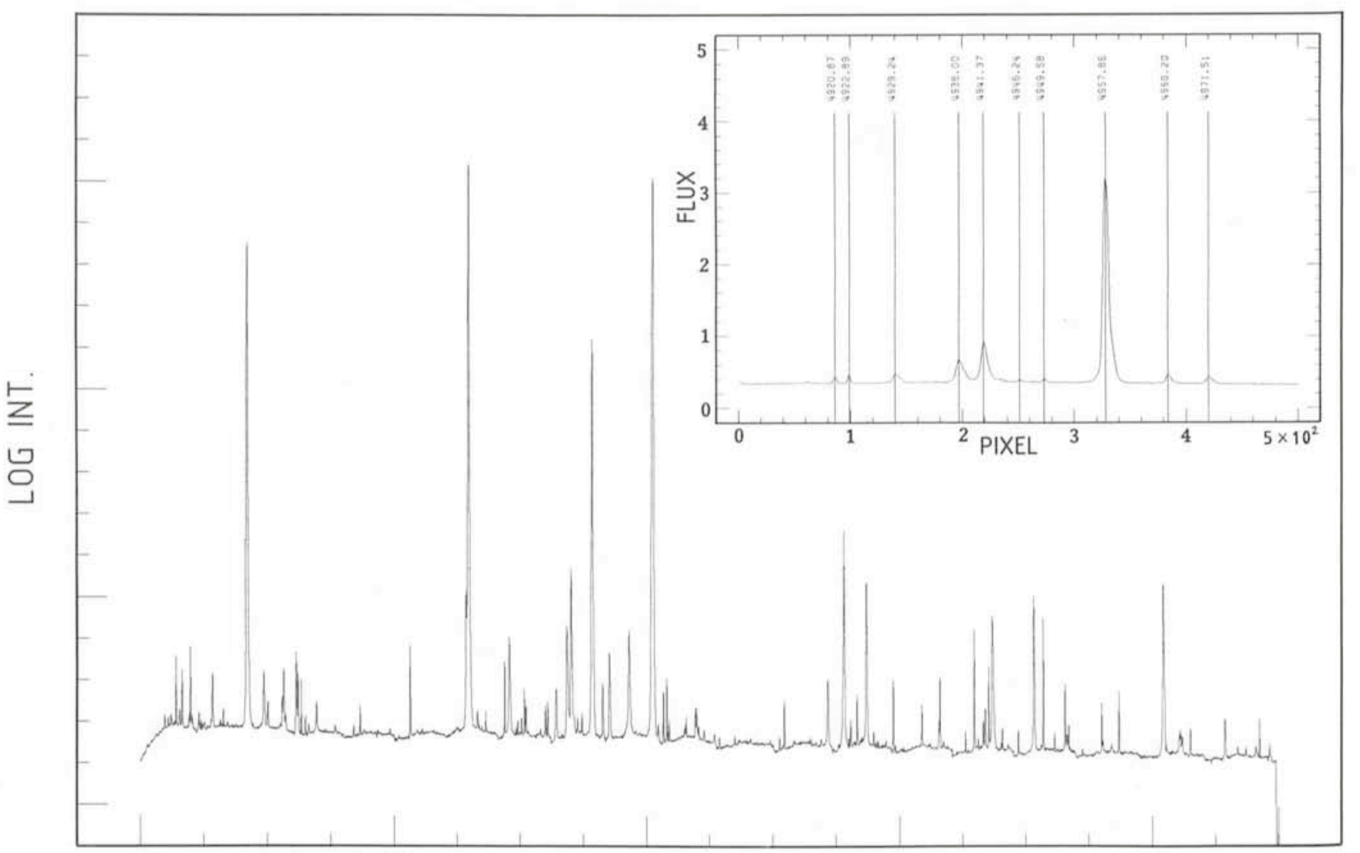

Fig. 4: *23 wavelength-calibrated and merged orders from a CASPEC CCD frame of the slow nova RR Tel centred at λ = 5000 Å. The exposure time was 8 minutes. The positions of the orders were automatically identified using the corresponding flat-field image. The wavelength calibration was obtained again automatically upon entering the screen position of a few lines of the comparison lamp image. The standard deviation, based on the position of 115 lines, was 0.05 Å. The line intensities have not been corrected for the instrumental response. The inset shows the automatically measured wavelengths of emission lines in one of the orders of the RR Tel image.*

between the orders. The CCD package allows binning of the pixels in the read-out process. This option finds useful application in an observation where the read-out of the CCD is the dominant noise source. Binning perpendicular to the dispersion can be advantageous in poor seeing conditions. In the present set-up however, it can be applied only at wavelengths above 5000 Å, to avoid an excessive crowding of the spectral orders. Binning in the direction of the dispersion, with the resulting loss of resolution, may also be an attractive solution in the observation of very faint sources or to follow with higher temporal frequency the spectral behaviour of brighter objects.

The Status of the Data Reduction Software

Astronomers who have used other ground-based echelle spectrographs or, e.g., the high dispersion mode of IUE, are familiar with the difficulties in the data reduction and calibration of spectra in echelle format. To these must be added, in the case of CASPEC, the problems specific to the CCD data reduction. ESO plans to have a full reduction package working by the end of 1983 on the VAX 11/780 computer within the framework of the data processing system MIDAS. The programme will run partly automatically, partly in interactive mode from a de Anza display station. It will flat-field the images, find and extract the spectral orders, set a wavelength calibration from the comparison lamp spectrum, merge and flux-calibrate the spectral orders. The user will then have the option to analyse further the one-dimensional files within MIDAS, to switch to IHAP or to perform the final steps of the data reduction at his home institution. The same package will be installed on the VAX computer at La Silla, to be used by the La Silla staff and off the telescope by visiting astronomers.

A large part of this package is already operational. Fig. 4 illustrates what can be achieved today as regards extraction, wavelength calibration and merging of the spectral orders in one CCD frame. At present we are using the test observations to optimize the procedure to flat-field and flux-calibrate the spectra.

A Word of Thanks

It is largely thanks to the excellent assistance of the La Silla staff that CASPEC's installation at the telescope was such a smooth and successful operation. We would also like to thank the other people who have contributed with their work or their advice in the different phases of this project, among them P. Biereichel for the CCD package, R. Gustafsson for the control modules, F. Middelburg for the updating of IHAP, J. Melnick for the data reduction, and the European astronomers who have provided useful suggestions for the programme of test observations. A particular acknowledgement goes to Prof. I. Appenzeller, who was actually present during part of the test period and was of great help in evaluating the instrument performances.

Visiting Astronomers

(October 1, 1983–April 1, 1984)

Observing time has now been allocated for period 32 (October 1, 1983–April 1, 1984). As usual, the demand for telescope time was much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6 m Telescope

Oct. 1983: Dennefeld, Bergeron/Kunth, Bergeron/Boissé, Zuiderwijk/de Ruiter, Shaver/Robertson, Moorwood/Oliva, Oliva/Moorwood/Panagia, Moorwood/Glass, Lequeux/Prévot, L&ML/Maurice/Rocca, Perrier/Léna/Chelli/Sibille, Alcaíno/Liller, Materne/Hopp, Azzopardi.

Nov. 1983: Azzopardi, Azzopardi/Breysacher/Lequeux/Maeder/Westerlund, Surdej/Henry/Swings/Arp, Materne/Hopp, Azzopardi/Breysacher/Lequeux/Maeder/Westerlund, Westerlund/Azzopardi/Breysacher, Westerlund/Lundgren, Westerlund/Gustafsson/Graae Jörgensen, Pakull/Beuermann/Motch/Ilovaisky/Henrichs/van Paradijs, Koornneef/Israel, Israel/Koornneef, Rouan/Leger, van Paradijs/Motch/Beuermann/Zuiderwijk, Lindblad/Jörsäter.

Dec. 1983: Lindblad/Jörsäter, Bertola/Zeilinger, Capaccioli, Olofsson/Bergvall/Ekman, Sherwood/Moffat, Epchtein/Braz, Durret/Boisson/Lawrence, Caplan/Deharveng/Comte/Viallefond, Marano/Braccesi/Zitelli/Zamorani.

Jan. 1984: Marano/Braccesi/Zitelli/Zamorani, de Vries, Barbieri/Cristiani/Nardon, Jörgensen/Hansen/Nörgaard-Nielsen, Danziger/de Ruiter/Kunth/Lub/Maccacaro/Gioia, Kunth.

Feb. 1984: Kunth, Mouchet/Motch/Beuermann/van Paradijs, Motch/Ilovaisky/Pakull, Courvoisier, Schoembs/Barwig/Vogt/Koester/Kudritzki, Reimers/Koester, Koester/Weidemann, Weigelt/Drechsler, Véron.

March 1984: Véron, Bettoni/Galletta, Galletta/Bettoni, Chincarini/Manousoyannaki, de Jong/Miley, de Loore/Burger/v. Dessel/v. Paradijs, de Jong/Miley, Thé/Lamers, Krautter, Engels/Perrier, Motch/Mouchet, Rodono/Catalano/Blanco/Marilli/Pazzani/Russo/Vittone/Butler/Scaltriti/Linsky/Foing.

1.4 m CAT

Oct. 1983: Kollatschny/Yorke/Fricke, Cayrel de Strobel, Gondoin/Mangeney/Praderie, Burkhart/Lunel/Van't Veer/Coupry.

Nov. 1983: Burkhart/Lunel/Van't Veer/Coupry, Barbuy, Grewin/Kappelmann/Bianchi, Seitter/Duerbeck, Kohoutek/Wehmeyer, Gustafsson/Andersen/Nissen.

Dec. 1983: Gustafsson/Andersen/Nissen, Eriksen, Ardeberg/Lindgren/Maurice, Danks/Lambert, Kudritzki/Gehren/Simon, Noci/Ortolani.

Jan. 1984: Noci/Ortolani, Westerlund/Krelowski, Drechsel/Rahe/Wargau, Reimers/Hempe, Gillet/Faurobert.

Feb. 1984: Gillet/Faurobert, Viotti/Altamore/Rossi, Gry/Ferlet/Vidal-Madjar, Ferlet/Roueff, Kudritzki/Nissen/Gehren/Simon, Baade.

March 1984: Baade, Felenbok/Roueff/Praderie/Catala/Czarny, Grewin/Krämer/Gutekunst/Bianchi, Foing/Bonnet/Linsky/Walter, Foing/Bonnet/Linsky/Bornmann/Haisch/Rodono.

1.5 m Spectrographic Telescope

Oct. 1983: Rafanelli/Bonoli, Pelat/Nottale, Schiffer, Prévot, L./Lequeux/Prévot, M. L./Maurice/Rocca, Richter/Sadler, Chincarini.

Nov. 1983: Chincarini, Crane/Chincarini/Tarenghi, Ardeberg/Lindgren, Bues/Rupprecht, Danziger/Maraschi/Tan-