have been very much guided by this excellent cooperation of the RT members to whom we extend our grateful thanks.

7. Present Status (2.5.79)

The design is near completion and the bids for optical and mechanical parts have been received. The contracts for manufacture are in the process of being signed.

8. Future Plans

After the definition of the test procedures we have now started with the design of the test facilities. One part comprises the tests in Geneva (stability of spectrograph, functional test of the detector and of the instrument), the other for tests on La Silla. Also in the near future the control and handling aspects will be finalized.

The present planning of the main activities for the subsequent development is shown in table 3.

Table 3. Present Schedule

Activity	Dates	
Manufacture mechanics	May–Sept.	1979
Assembly mechanics	Oct.	1979
Assembly controls	Nov.–Dec.	1979
Manufacture optics	May–Dec.	1979
Optics test Geneva	Jan.–Feb.	1980
Improvements	March–May	1980
Integral test	June–July	1980
Shipment	Aug.–Oct.	1980
Installation La Silla	Nov.–Dec.	1980

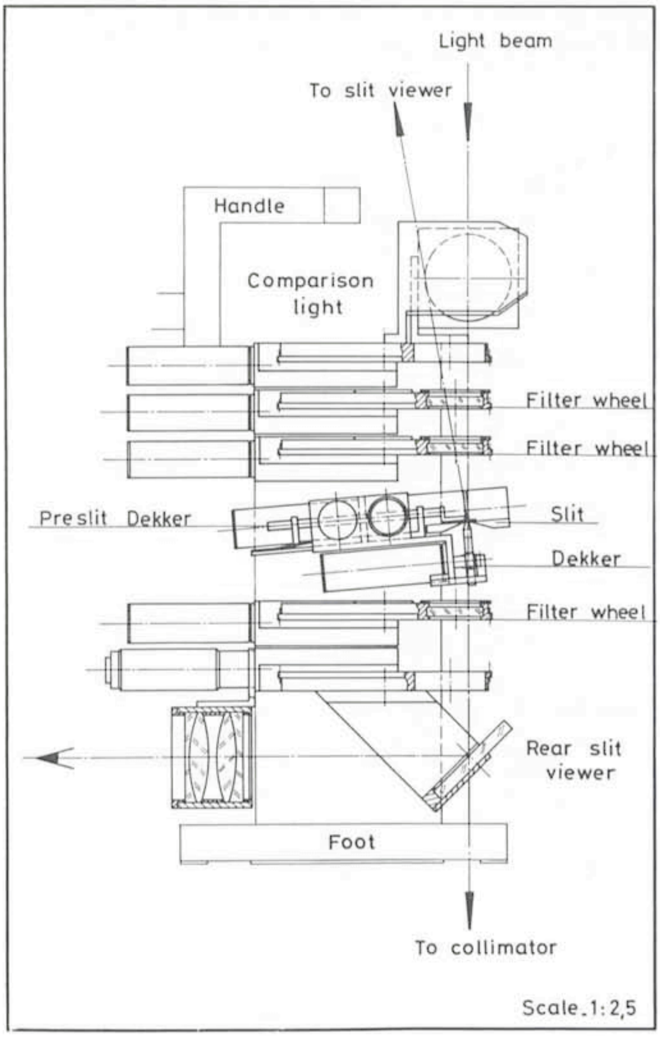

Fig. 2: *Slit area.* ▶

Relative Radial Velocities of Stars Determined from GPO Spectrograms

F. Gieseking

One of the first telescopes to be installed on La Silla was the GPO 40 cm astrograph. Although it is one of the "smallest" instruments at the ESO observatory, it is by no means less productive than the larger ones! On the contrary, the impressive results that have recently been obtained by Dr. Frank Gieseking of the Hoher List Observatory, near Bonn, proves the tremendous potential of this instrument. Thanks to the good accuracy of the measured radial velocities, large-scale investigations of stellar motions can now be carried out.

The General Problem

The *radial velocities* and the *proper motions* of stars (and their possible temporal variations) are fundamental parameters for the investigation of the kinematics and dynamics of stars and stellar systems like binary and multiple systems of stars, stellar associations, star clusters, the galaxy as a whole and clusters of galaxies. Proper motions, however, defined as the angular velocity of the tangential component of the space velocities, are important only in the solar neighbourhood. For example, a binary system, even with the large orbital period of 100 years, consisting of two solar-type stars, has a separation of less than 0.1 arcsecond if at a distance larger than 270 parsecs. With terrestrial telescopes such a system can only be resolved by application of laborious interferometric techniques like speckle interferometry. On the other hand, the error of the tangential motion of single stars as derived from proper motions is proportional to their distances. Typical values for the errors of average accurate proper motions indicate that already at distances larger than 800 parsecs the error of the tangential velocity is larger than ± 6 km s^{-1}.

Contrary to this, the error of radial-velocity measurements is in principle, *independent*, of the distance of the stars. Since the accuracy of radial-velocity determinations from spectra of medium dispersion (60 Å mm^{-1}) is of the order of $\pm$ 6 km s^{-1} (for early-type stars), we arrive at the conclusion that at distances larger than 800 parsecs the radial component of the space velocity can be determined more precisely than the tangential component. (At still larger distances the radial velocity soon becomes the only relevant kinematical parameter of stars and stellar systems.)

Unfortunately, however, at distances larger than 800 parsecs even the intrinsically brighter stars (B1V) are fainter than 8.5 mag in V. Since the measurement of radial velocities with conventional slit spectrographs is very laborious (requiring long observing times at large telescopes for the exposure of only one spectrum at a time), our data for stars fainter than 6 mag are still rather incomplete. We therefore come to the general conclusion that a more efficient method for radial-velocity determinations is urgently needed for a further progress in the investigation of the kinematics and dynamics of the stars.

The Fehrenbach Prism

The search for more efficient methods to determine stellar radial velocities is the search for more efficient methods to obtain stellar spectra. The most efficient astronomical spectrograph is the objective prism-telescope combination, because:

(1) The light losses are reduced to a minimum: In detail, the light losses of an objective prism by reflection and absorption are expected to be of the order of 30%, whereas in the case of the conventional grating slit spectrograph light losses by reflection of about 60% and transmission losses of about 85% are typical (Fehrenbach, Ch.: 1966, *Adv. Astron. Astrophys.* **4,** 1). (For slit spectrographs without image slicer the sometimes drastic light losses at the slit must be added.) This means that an objective prism has at least a tenfold greater transparency as compared with a conventional slit spectrograph.

(2) The objective prism allows the exposure of numerous stellar spectra at the same time: In detail, in a 4-square-degree field of a telescope of 4 meter focal length, well-exposed 100 Å mm^{-1} spectra of typically up to 100 stars can be expected.

From this example we see that an objective prism should be a thousand times more efficient than a conventional slit spectrograph. (For a realistic comparison for the case of the GPO astrograph, see below.)

Unfortunately, there are two serious drawbacks of the objective prism:

(1) Due to the absence of any comparison spectral lines, the wavelengths of the objective-prism spectra are a priori not calibrated.

(2) Since we have to do with a slitless spectrograph, the spectral resolution depends on the seeing.

Whereas the second problem cannot be overcome by terrestrial telescopes, there have been many attempts to calibrate the wavelengths of objective-prism spectra. After numerous failures, Pickering's (*Astron. Nachr.* **142,** 105, 1896) "reversion method" proved to be most attractive. Its principle is as follows: First, an exposure of the star field is made through the objective prism adjusted with the direction of dispersion parallel to declination. Then, the exposure of the same star field is repeated on the same plate after "reversion" of the prism by rotating it through 180° around the optical axis of the telescope. If the telescope has been slightly shifted in right ascension between the exposures, the plate contains two side-by-side spectra of each star, with the red end of one next to the violet end of the other. It should now in principle be possible to measure Doppler shifts of the spectral lines by comparing the positions of lines in one spectrum with those of the corresponding lines in the reversed spectrum.

But unfortunately, the relative positions of the lines in both spectra are not determined by the Doppler shift alone, because:

(1) They are partly determined by the performance of the reversion (the declinations of the plate centres of the normal and the reversed exposure cannot be made exactly the same [an accuracy of typically better than 0.05 arcsecond would be necessary]) and by instrumental influences like temperature effects, mechanical stability, etc.

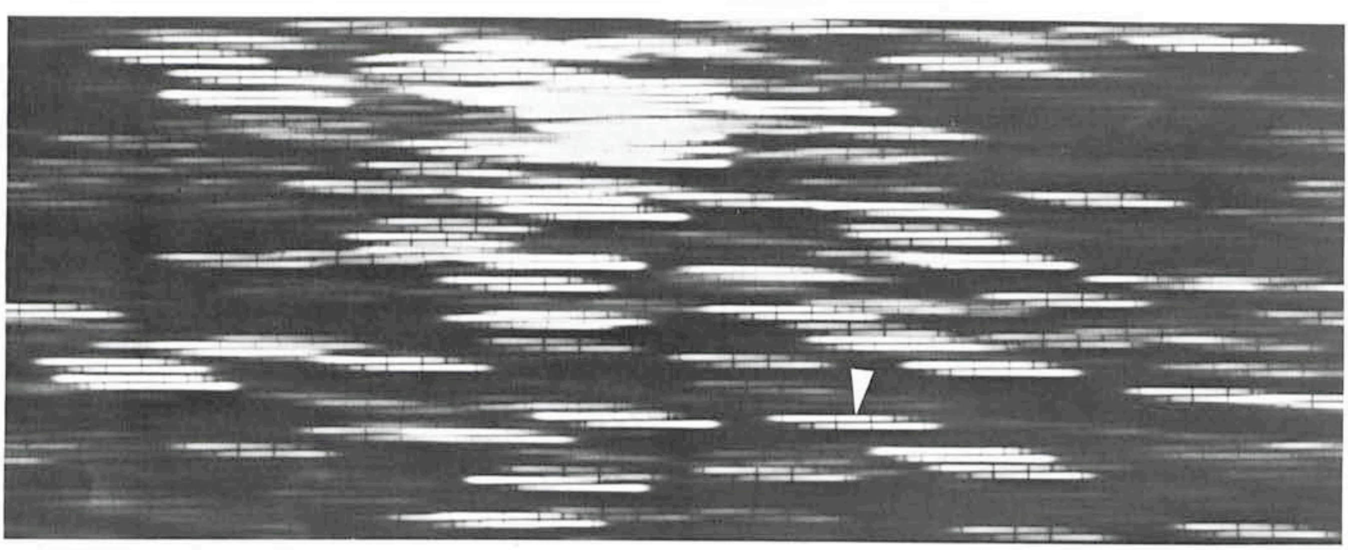

Fig. 1: *An enlarged 1.2 by 0.46 square-degree section of plate GPO 2557, which is approximately only 1/10 of the original plate. At top is the western part of the rich open star cluster NGC 3532. The total plate, exposed for 2 times 30 minutes, shows approximately 500 pairs of spectra. The spectra of more than 100 stars down to the 10th magnitude are exposed to sufficient density to be measured with high precision. The marked star is HD 95878 (see fig. 2). North is to the right, west is down.*

(2) The distorsion of a normal prism produces an apparent shift of the spectral lines, which in a 2-degree field is of the order of ± several thousand km s^{-1}!

The first problem, which cannot be overcome in practice, limits us to the determination of only *relative* radial velocities. Because of the second problem, the application of objective prisms for the determination of radial velocities was forgotten for several decades, until Charles Fehrenbach invented the distorsion-free, direct vision Fehrenbach prism. In simplest form, it is a compound prism, shaped like a plane-parallel plate, which consists of two prisms made of different kinds of glass. The components have different dispersive powers, but equal refractive indices for a certain wavelength in an accessible wavelength region. (For details the reader is referred to Fehrenbach [*Ann. d'Astrophys.* **10**, 257, 1947] or to the popular representation by Gieseking [*Sky & Tel.* **57**, 142, 1979]).

The radial-velocity astrograph of the European Southern Observatory is equipped with one of the six Fehrenbach prisms existing today. This "Grand Prism Objectif" (GPO) has a diameter of 40 cm and produces at 4 meter focal length spectra with a linear reciprocal dispersion of 110 Å mm^{-1}. With this instrument, the reversion method can now be applied successfully. The latest refinement of this method was supplied by the author, who introduced a modified reduction method for Fehrenbach-prisms spectrograms, which yields a considerable improvement of the measuring accuracy (*Astron. Astrophys.* **47**, 43, 1976 and *Sky & Tel.* **57**, 142, 1979).

Present Results

With this new reduction method, until now a total of about 8,000 relative radial velocities of more than 500 stars in 10 star fields (mostly in the region of selected open star clusters) have been determined. The investigated stars have photographic magnitudes fainter than 6 mag and brighter than 10.5 mag. Their spectral types are mostly between late B and early A. As expected, the measuring accuracy depends on the density of the spectra and therefore (with the exposure time as an additional parameter) on the brightness of the stars. With an exposure time of 2 times 30 minutes the observation errors of the radial velocities of stars brighter than 9.7 mag lie between 4 km s^{-1} and 9 km s^{-1}. This is approximately half the error to be expected for radial-velocity measurements of early-type stars from slit spectra with a comparable dispersion of 110 Å mm^{-1}. Since the strictly *relative* measuring principle of the reversion method with a Fehrenbach prism is affected mainly by *statistical* observation errors, the accuracy can be significantly improved by accumulation of observations. This is contrary to the slit-spectrum technique, which is also affected by systematic errors. (This is demonstrated by the fact that the external error of the measurements is expected to be twice the internal error.) Since for each star on the average 15 observations are available, the observation error for about 300 stars with (assumed) constant radial velocities can be brought down to the region of ± 2 km s^{-1}. Herewith the quality of the relative GPO velocities of stars fainter than 6 mag becomes comparable to that of most published "conventional" radial-velocity data of stars brighter than 6 mag.

For a realistic estimate of the efficiency of the GPO method we have the opportunity to compare for a number of stars in NGC 6475 the GPO radial velocities with (by chance) almost equally accurate slit-spectrum measurements. Though the slit spectrograms were obtained with a fast grating spectrograph at a 90 cm reflector, the GPO was faster by a factor 5 per star, after reduction to equal telescope aperture. After inspection of the whole GPO material, on the average 35 stars per field were found, which could be measured with the accuracy in question. Therefore, the total gain in efficiency is of the order of 150 to 200 (which in rich fields could further increase by a factor of 2).

We therefore come to the conclusion that the GPO method offers the first really promising, efficient method for the determination of the radial velocities of the fainter stars.

The present GPO material has so far been analysed with two kinds of study in mind: The first aspect is the investigation of spectroscopic binaries. If the dependence of the measuring error on the density of the spectra is considered carefully, the GPO data establish the most homogeneous, large set of relatively accurate radial velocities published so far. Therefore, the identification of variable radial velocities is possible with very high statistical significance. A careful statistical analysis of the observed overall error distribution yielded the first reasonable estimate of the frequency of spectroscopic binaries. This number may provide an important contribution to the complex problem of the overall binary frequency and the frequency distribution of the semi-major axes of binaries, which in turn is a measure of the frequency distribution of angular momentum. Besides the possibility of a *statistical* identification of spectroscopic binaries with even extremely small amplitudes, an *individual* identification of spectroscopic binaries proved to be reliable down to radial-velocity amplitudes of K = 12 km s^{-1}. The observations of one of the numerous spectroscopic binaries discovered in this way on GPO plates are illustrated in the figures with this article.

The second aspect is the investigation of the kinematics and dynamics of open star clusters. So far only the study of the most extensively observed cluster NGC 3532 (see fig. 1) has been completed. Here, relative radial velocities of a total of 82 field and cluster stars could be determined with a mean error of only ± 1.77 km s^{-1}. With these GPO measurements, NGC 3532 becomes the second open star cluster (besides the Pleiades), for which accurate radial velocities of a larger number of stars are known. Moreover, NGC 3532 is the first open cluster for which reliable membership probabilities were calculated on the basis of a statistical analysis of the observed radial-velocity distribution of the stars. Besides this essential contribution to the separation of field and cluster stars—which is especially important in the halo of the cluster—the GPO radial velocities proved to be accurate enough to estimate even the true internal motion of the cluster, as far as the investigated cluster stars are concerned. This, however, is the key to the dynamical properties of the aggregate, like its dynamical mass, the mass distribution or the structure of the cluster halo and the evaporation of cluster stars. These results will be published in a series of forthcoming papers.

Future Programmes

First of all the investigation of NGC 3532 should be extended to fainter stars. Furthermore, similar studies should be carried out also for several other open star clusters and additional observations in all fields investigated so far, and an extension of the observing programme to other open clusters and stellar associations are therefore highly desirable. One of the principal aims would be to

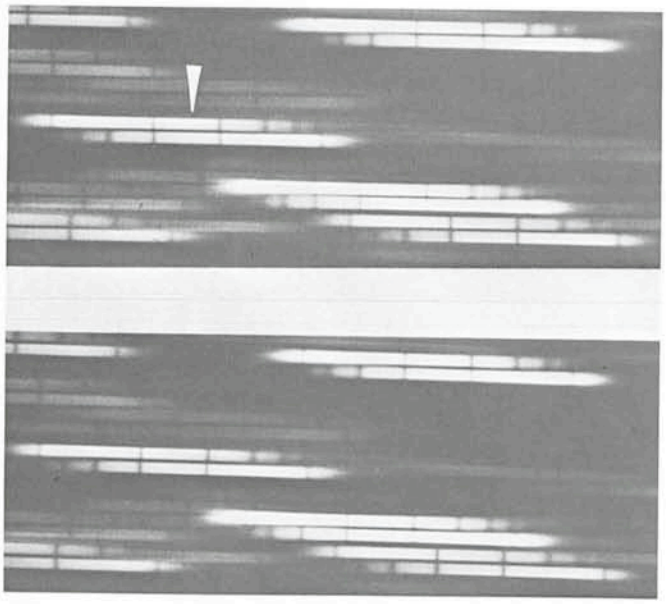

Fig. 2: *The figure at top represents a further enlargement of plate GPO 2557, taken on March 16, 1977, showing the region around HD 95878 (see fig. 1). The figure below shows the same section on plate GPO 2564, taken in the next night on March 17, 1977. Note the large relative Doppler shift of spectral lines of HD 95878 between the two observations (as compared with the line positions of surrounding reference stars). Measurement yields a difference in radial velocity of 165 km s^{-1} with an expected error of a single observation of $\pm$ 7 km s^{-1}. This star is one of the numerous spectroscopic binaries, discovered by the author on GPO plates.*

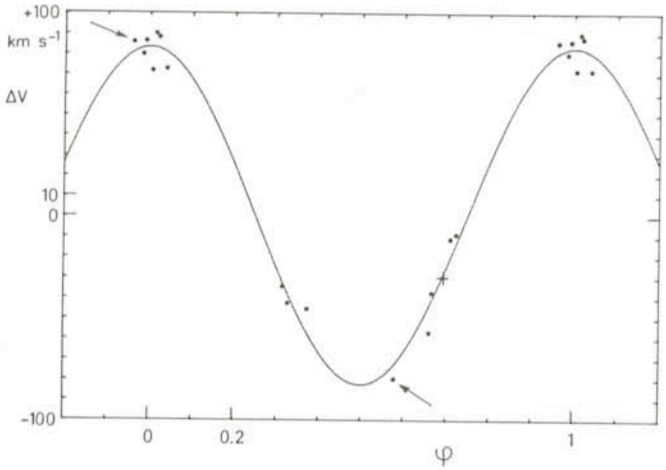

Fig. 3: *The relative radial velocity curve of HD 95878 as derived from the measurement of 17 GPO plates of the field around the open star cluster NGC 3532. The relative radial velocities determined from the spectra shown in figure 2 are identified by arrows. The zero point is arbitrary, but can be calibrated easily by one accurately known radial velocity in the field. The cross marks two independent measurements.*

compare the results for different clusters and eventually to correlate them with other physical parameters of these aggregates. In this context a comparison of the kinematical properties of stellar associations and open star clusters would be of special interest, because it may provide new insight into the dynamical evolution of these stellar systems. Beyond this, the discussion of the velocity distribution of the field stars and its dependence on spectral type and distance of the stars may provide important contributions to our knowledge of the kinematics and dynamics of our galaxy. For all kinematical investigations just mentioned, radial velocities are of special significance, if they can be combined with reasonably accurate proper motions to yield the space velocities of the stars.

Concerning the investigation of spectroscopic binaries, additional observations are also desirable: If for example membership probabilities for a larger number of open clusters are determined, the interesting question on possible differences of the binary frequencies in open clusters, stellar associations and the general star field can probably be answered. Furthermore, on the basis of a sufficiently extensive observation material, the correlation between binary frequency and spectral type and eventually other physical parameters of the stars can be investigated. Finally, continued observation of all star fields is desirable as well for improvement of the orbital elements of known and newly discovered spectroscopic binaries as for detection and investigation of long-period spectroscopic binaries (periods larger than about 200 days). For the latter a good detection probability can be predicted, since after construction of normal points, the individual identification of long-period variability of the radial velocity may be reliable down to radial velocity amplitudes of only K = 4 km s^{-1}.

The application of the objective prism for the determination of the radial velocities of the stars has opened new frontiers. The future will show how successful this instrument will be to contribute to the answers of numerous questions, a few of which have been outlined above.

Since 1977 all observations have been obtained by ESO night assistant Gorki Roman. I herewith gratefully acknowledge his very careful conduction of my observing programmes at the GPO.

Assembly of the Coudé Echelle Spectrograph (CES)

D. Enard, ESO Optics Section, Geneva

The coudé echelle spectrometer has already been described in the *Messenger* No. 11 of December 1977. It is a very high resolution spectrograph with a resolving power up to 100,000 fed by either the 3.6 m or the Coudé Auxiliary Telescope (CAT). Henceforth it will be complemented by the CASPEC which will provide a resolving power of 20 to 60,000 (cf. page 27).

After considerable delay in the delivery of several components, the assembly of the CES started early in April. The instrument is being assembled and tested in the ESO Optics Laboratory in Geneva, which, as a matter of fact, has become rather congested, as shown by the photographs.

Because no equipment has yet been installed at the 3.6 m coudé focus, the whole instrument including the computer, is assembled in Geneva for a complete test before it will be shipped to Chile. However, the temperature stability of the laboratory is not very good and may somewhat limit the measured performance level.