EUROPEAN SOUTHERN OBSERVATORY

BULLETIN NO. 5

The Governments of Belgium, the Federal Republic of Germany, France, the Netherlands, and Sweden have signed a Convention[1] concerning the erection of a powerful astronomical observatory on October 5, 1962.

By this Convention a European organization for astronomical research in the Southern Hemisphere is created. Denmark became a member of the organization on June 1, 1967. The purpose of this organization is the construction, equipment, and operation of an astronomical observatory situated in the Southern Hemisphere. The initial program comprises the following subjects:

1. a 1.00 m photoelectric telescope,
2. a 1.50 m spectrographic telescope,
3. a 1.00 m Schmidt telescope,
4. a 3.60 m telescope,
5. auxiliary equipment necessary to carry out research programs,
6. the buildings for administration, laboratories, workshops, and accommodation of personnel.

The site of the observatory will be in the middle between the Pacific coast and the high chain of the Andes, 600 km north of Santiago de Chile, on La Silla, at an altitude of 2400 m.

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[1] The ESO Management will on request readily provide for copies of the Paris Convention of 5 October 1962.

Organisation Européenne pour des Recherches Astronomiques
dans l'Hémisphère Austral

EUROPEAN SOUTHERN OBSERVATORY

BULLETIN NO. 5

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ESO BULLETIN NO. 5

CONTENTS

Announcement of the ESO Directorate 5

Notification de la Direction de l'ESO 7

A. Behr: The Polarimeter of the 1 m Photometric Telescope 9

Th. Schmidt-Kaler and **J. Dachs:** The 61 cm Photometric Telescope of the Bochum University at La Silla 15

K. Bahner: Large and Very Large Telescopes: Projects and considerations 19

J. Stock: Astronomical observing conditions in Northern Chile 35

ANNOUNCEMENT OF THE ESO DIRECTORATE

Applications for the use of the ESO telescopes for the period September 1, 1969 — March 1, 1970

Applications may now be submitted for the above period for the use of

the 1 m Photometric Telescope

the 1.52 m Spectrographic Telescope

the Radial Velocity Objective Prism Astrograph

the small photometric telescope(s) (40 cm or 50 cm) which will be partly at the disposal of visiting astronomers.

Applications should be submitted to the

Directorate of the European Southern Observatory
131 Bergedorfer Straße, 205 Hamburg 80, Germany,

not later than March 1, 1969. Applicants may expect to be informed by May 1, 1969, whether, and how much, time will be granted.

The application should, apart from a general description of the objectives of the program, contain such particulars as:

(a) required auxiliary instrumentation,
(b) most desirable period(s) of observing,
(c) an indication of the number of stars and the distribution of their apparent magnitudes (particularly for photometric programs),
(d) required accuracy of the quantities to be determined (particularly for photometric programs),
(e) possible restrictions with regard to moon phase,
(f) the applicant's previous experience in observing,

etc., as are useful for judging the required observing time and instrumental facilities.

The 1 m telescope may be used in combination with the ESO photometer, a description of which has been published by M. de Vries in ESO Bulletin No. 1, 1966.

The 1.52 m spectrographic telescope can be used in combination with the coudé spectrograph and with a Cassegrain spectrograph on loan from the Marseilles Observatory. A description of the Marseilles spectrograph will be published in the ESO Bulletin. A description of the 1.52 m telescope and the coudé spectrograph has been published by Ch. Fehrenbach in ESO Bulletin Nr. 3, 1968. However, since the coudé spectrograph has not yet passed all tests, applicants are advised to consult with the ESO Directorate about the cameras which may be available.

Applicants considering projects for the Radial Velocity Astrograph are advised to make themselves familiar with its performance by means of the publications on the work done at the Zeekoegat site, by Ch. Fehrenbach and collaborators in Communications of the European Southern Observatory No. 1 to 7.

Applications should normally be endorsed by the Director of the applicant's Institute. They will be reviewed by the ESO Scientific Programs Committee.

The ESO Budget provides for travel funds and for fixed allowances for lodging and food to such an extent that, as a rule, it will not be necessary for the applicants to whom observing time is granted (or for their Institute) to contribute financially. Defrayal of travel expenses of accompanying wives is foreseen to a limited extent and only in case the observers will have to stay in Chile for a period of at least 6 months. Particulars are fixed in the ESO Rules for Visiting Astronomers. It is assumed that, generally, applicants have employment in their home countries and that this employment, with the applicant's salary, social securities and pension rights, will in principle continue during his stay at the ESO observatory. Applications by astronomers who do not have such employment will require special treatment by the ESO Directorate.

Observing periods granted may range from several weeks to several months, and observers may have to share the telescopes for alternating use depending on the nature of their observing program.

All visiting astronomers are subject to the internal rules for La Silla and the Santiago Headquarters adopted by the Management. The ESO Management will aim at the most efficient use of its facilities and counts on the collaboration of all visiting astronomers in pursuing this purpose. Visiting astronomers are supposed to write a brief report on their project for the ESO Directorate upon the termination of their stay.

Applications should be clearly typed so as to allow proper copying for internal use at the Directorate.

Hamburg-Bergedorf, November 1968

A. Blaauw
Scientific Director, ESO

NOTIFICATION DE LA DIRECTION DE L'ESO

Demandes de missions d'observation pendant la période du 1er septembre 1969 au 1er mars 1970

Dès à présent, des demandes pour l'utilisation des instruments ci-après mentionnés sont acceptées pour la période indiquée:

Télescope photométrique de 1 m
Télescope spectrographique de 1.52 m
Astrographe à Prisme Objectif
Petit(s) télescope(s) photométrique(s) (40 cm ou 50 cm) qui sera (seront) partiellement à la disposition des astronomes visiteurs.

Les demandes doivent être adressées à la:

Direction de European Southern Observatory
131 Bergedorfer Straße, 205 Hamburg 80, Allemagne,

au plus tard jusqu'au 1er mars 1969. Les candidats seront informés vers le 1er mai 1969 si leur demande a été acceptée et combien de temps leur sera accordé.

Les demandes, outre une description générale des objectifs du programme, devront contenir des détails tels que:

(a) l'instrumentation auxiliaire requise,
(b) période(s) préférée(s) pour l'observation,
(c) une indication sur le nombre des étoiles et la distribution de leurs magnitudes apparentes (particulièrement pour des programmes photométriques),
(d) l'exactitude nécessaire des quantités à déterminer (particulièrement pour des programmes photométriques),
(e) restrictions possibles en ce qui concerne la phase de la lune,
(f) expérience antérieure du candidat dans l'observation,

etc., qui sont utiles pour juger le temps d'observation requis ainsi que les facilités instrumentales à pourvoir.

Le télescope de 1 m peut être utilisé en combinaison avec le photomètre de l'ESO, sur lequel M. de Vries a publié une description dans le Bulletin ESO No. 1, 1966.

Notification

Le télescope spectrographique de 1.52 m peut être utilisé en combinaison avec le spectrographe coudé et avec un spectrographe Cassegrain prêté par l'Observatoire de Marseille. Une description du spectrographe de Marseille sera publiée dans le Bulletin ESO. Une description du télescope de 1.52 m et du spectrographe coudé a été publiée par Ch. Fehrenbach dans le Bulletin ESO Nr. 3, 1968. Cependant, le spectrographe coudé n'a pas encore passé tous les essais; par conséquent, nous conseillons aux candidats intéressés de se mettre en rapport avec la Direction de l'ESO pour savoir quelles caméras seront disponibles.

Nous recommandons aux candidats qui désirent travailler avec l'Astrographe à Prisme Objectif de se renseigner sur sa performance au moyen des publications sur le travail accompli à Zeekoegat par Ch. Fehrenbach et collaborateurs dans Communications of the European Southern Observatory, Nos. 1 à 7.

La demande normalement doit être visée par le Directeur de l'Institut auquel appartient le candidat. Elle sera examinée par le Comité des Programmes Scientifiques de l'ESO.

Le budget de l'ESO prévoit des moyens financiers pour les voyages et des sommes fixes pour le logement et les repas, de sorte que, en règle générale, il ne sera pas nécessaire que le candidat ayant obtenu du temps d'observation (ou son Institut) contribue aux frais. Il est prévu que les frais de voyage de l'épouse accompagnant l'astronome visiteur seront remboursés dans certaines limites, pourvu que l'observateur ait à travailler pour ESO au Chili pendant 6 mois au moins. Les détails y relatifs sont déterminés dans le Règlement de l'ESO pour Astronomes Visiteurs. Il est supposé que les candidats sont employés dans leurs pays d'origine et que cet emploi, avec le salaire du candidat, sa sécurité sociale et ses droits à la pension, continuera, en principe, pendant son stage à l'observatoire. Des candidatures par d'astronomes n'ayant pas un tel emploi, feront l'objet d'une étude spéciale par la Direction de l'ESO.

Les durées d'observation peuvent varier entre quelques semaines et quelques mois, et il est possible que les observateurs doivent utiliser le télescope par équipe, selon la nature de leur programme d'observation.

Tous les astronomes visiteurs sont soumis au règlement interne, adopté par la Direction, pour l'Observatoire de La Silla et l'Institut à Santiago. La Direction de l'ESO s'appliquera à faire servir ses installations de la façon la plus efficace et compte sur la collaboration de tous les astronomes visiteurs, afin d'atteindre ce but. Les astronomes visiteurs sont priés d'écrire un court rapport sur leur projet à la terminaison de leur stage et de le soumettre à la Direction.

Les demandes doivent être écrites à la machine, afin de permettre le tirage de copies pour usage interne à la Direction.

Hambourg-Bergedorf, novembre 1968

A. Blaauw
Directeur Scientifique, ESO

THE POLARIMETER OF THE 1 m PHOTOMETRIC TELESCOPE

A. Behr

During the ESO Colloquium on Photometry at Kapteyn Observatory, Roden, the Netherlands, in February 1966, the question was raised whether the 1 m telescope should not be equipped with a two channel polarimeter in addition to the already available photometer. Following up a decision of the Instrumentation Committee in May 1966, this question was studied, and at a conference at Groningen in September 1966 the general design of the planned polarimeter was outlined in a discussion between Borgman, de Vries, Kapteyn Observatory, Lodén, Stockholm Observatory, and Behr, then Göttingen Observatory. The instrument was constructed in the workshop of the Göttingen Observatory. A provisional form was tested in February and March 1968 at the 1 m telescope on La Silla. The definite instrument was installed late in October 1968.

The principle of the polarimeter rests on an idea of Hiltner, who proposed to split the light of the star by means of a Wollaston prism into two beams of light polarized in planes of vibration perpendicular to each other and being observed simultaneously. In this way the effects of atmospheric scintillation should be minimized, and changes in extinction during a set of measurements compensated.

An earlier form of such a polarimeter has been described by Behr (1956). A detailed description of the measuring technique and the possible error sources are given in that paper. Other authors in the meantime have constructed similar polarimeters. Numerous experiences have been made.

The ESO polarimeter is a modified and improved version of the original instrument allowing more than one way to measure the polarization.

The basic principle of the construction may be demonstrated with Fig. 1. The whole polarimeter consists of 3 main parts:

a) the guiding box A,
b) the unit B with the diaphragm D, a rotatable half wave plate $\lambda/2$, color filter F, and some auxiliary optical elements,
c) the rotatable unit C with Wollaston prism W, Fabry lens L, and the removable cell-box C_3 with the photomultiplier cells PM I and PM II.

The guiding box A, connected to the base plate of the telescope, contains a plane mirror with a central hole of 20 mm diameter, inclined under an angle of 45° to the optical axis. It can be shifted along the plane of its sur-

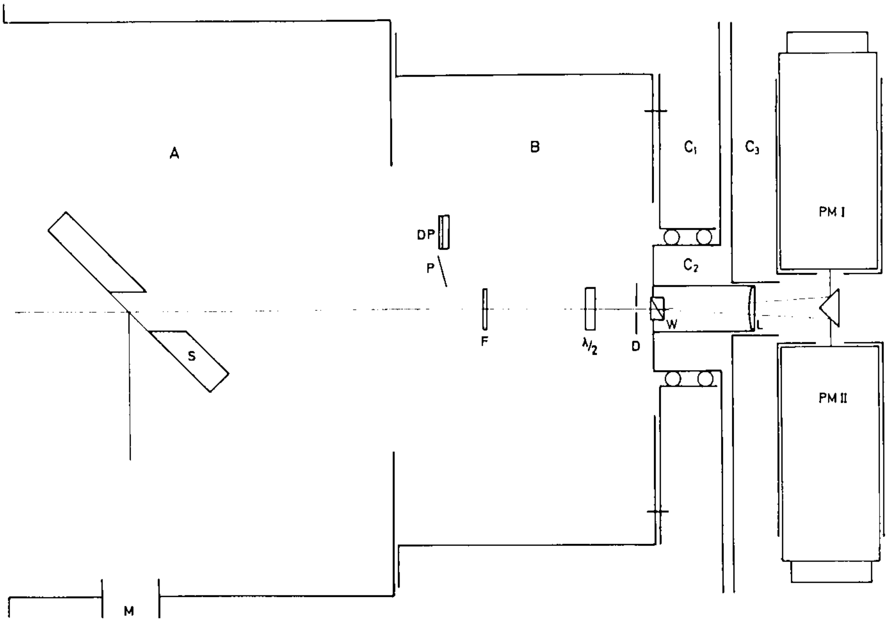

Fig. 1: Optical layout of the polarimeter.

face by a comfortable handle operated by the left hand of the observer, allowing the observation of the star before and after the measurement on a reticle in a wide angle eye-piece. However, offset guiding is possible by shifting the eye-piece by means of a two-coordinate micrometer M to any desired place in a square field of about 12′ × 12′. This guiding box, if separated from the adhering parts B and C, can be used independently as an offset guider in connection with other equipments. A single joy-stick, operated by the right hand of the observer, enables guiding in α and δ with two different speeds.

Unit B contains a set of three interchangeable diaphragms of 7″, 15″, and 35″ diameter in the focal plane of the telescope. The achromatic half wave plate can be rotated in 6 steps of 22°.5 through an angle of 360°, or removed if necessary. A filter disk F with 6 color filters for measurements in the UBV-system, or other selected spectral ranges, can be operated from outside the box. The diameter of the filters is 20 mm. A Lyot-depolarizer or an inclined glass plate can be inserted into the optical beam for calibration purposes.

The flange C_1 of unit C is connected to B by three push-and-pull screws for alignment of its axis of rotation to the optical axis of the telescope. C_2 connected to C_1 by a high precision ball bearing can be rotated in 8 steps of 45° through an angle of 360°. Filter disk, half wave plate, and unit C_2 are provided with mechanical encoders to indicate their respective position to the photometric measuring system.

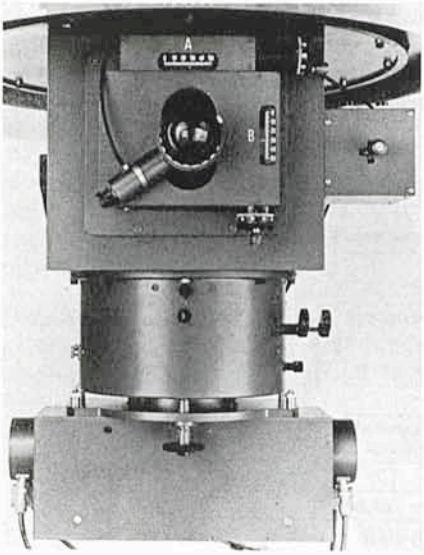

Fig. 2: Complete polarimeter on the telescope.

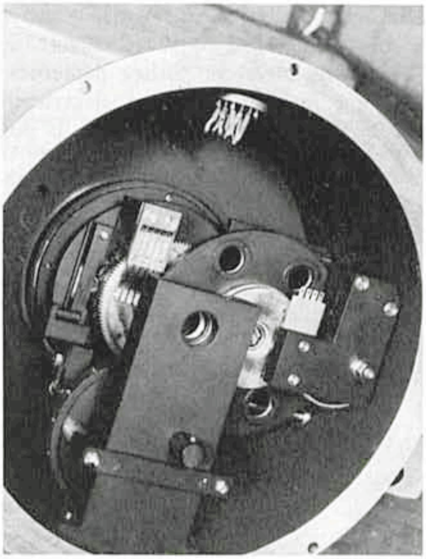

Fig. 3: Interior of unit A with motion of mirror S.

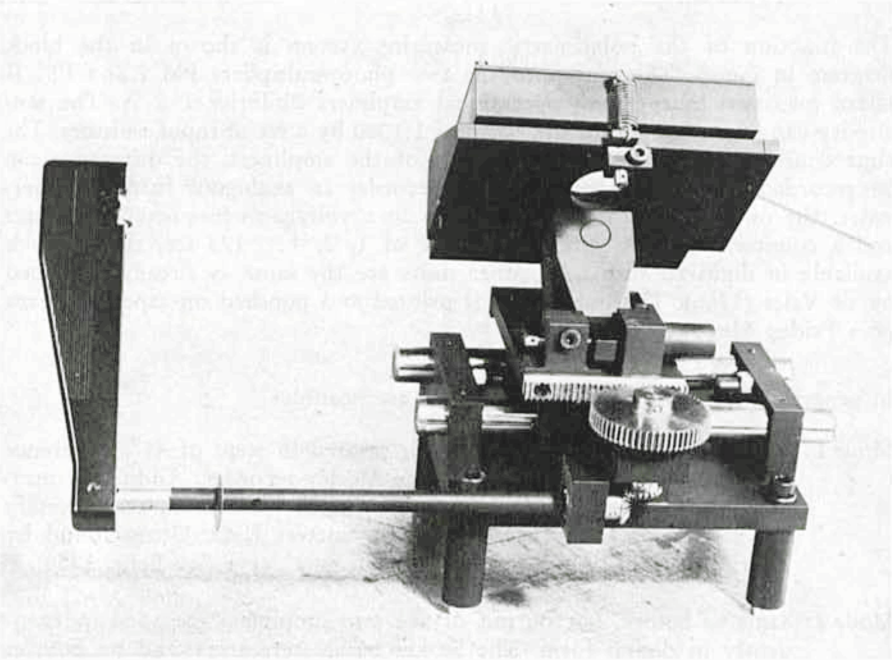

Fig. 4: Interior of unit B with filter disk, rotatable half wave plate and respective encoders.

The cell box C_3 can be easily removed from C_2 if necessary for adjustments or to be replaced by another one. EMI photomultipliers of type 6094 S and 6097 S are foreseen. Other detectors of similar types may also be used. The cells are magnetically and electrically shielded by μ-metal tubes on cathode potential. Cooling with dry ice is possible.

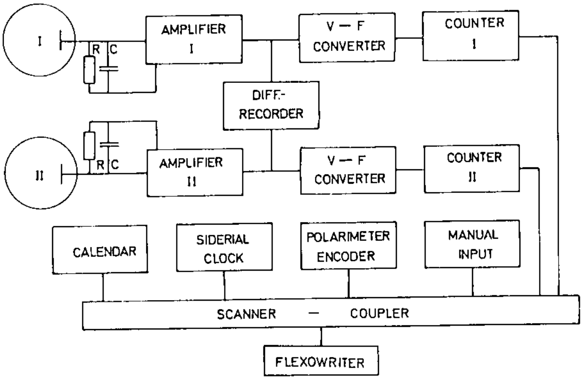

Fig. 5: Block diagram of the polarimetric measuring system.

The function of the polarimetric measuring system is shown in the block diagram in Fig. 5. The output of the two photomultipliers PM I and PM II is fed into two independent operational amplifiers Philbrick P 2 A. The sensitivity can be varied within the range of 1:1000 by a set of input resistors. The time constant RC is $0^{\mathrm{s}}3$. At the output of the amplifiers, the difference can be recorded immediately on a Mosley-recorder in analogous form. Furthermore, the output in each branch is given to a voltage-to-frequency converter and a counter. After an integration time of 1, 2, 4 . . . 128 sec, the result is available in digitized form. All other units are the same as already described by de Vries (1966). The final result is printed and punched on tape by means of a Friden Flexowriter.

In general, 3 different modes of operation are possible:

Mode 1: Half wave plate removed, unit C_2 rotated in steps of 45°, difference recorded in analogous form on the Mosley-recorder. Additional measurements with inclined glass plate P in the main beam are necessary for calibration. The three Stokes parameters I, Q, U are found by Fourier analysis of the recorded double sine curve (see Behr, 1956).

Mode 2: Same as before, but output of the two amplifiers recorded independently in digital form. The Stokes parameters are found by Fourier analysis of the ratio of two beams. No calibration necessary. This mode is highly independent of changes in atmospheric transparency.

Mode 3: Half wave plate inserted into the beam and rotated in steps of 22°5. Unit C_2 in zero position. The result is again found by Fourier analysis of the 4-sine wave of the ratio as function of the rotation angle.

Mode 1 should be used in case of a break-down of the digitizing unit. Mode 2 may be regarded as standard method allowing the highest grade of accuracy. Mode 3 avoids the sometimes dangerous and time-consuming rotation of the cell box and some inconveniences. It is the most economic way; it needs, however, a careful study of the color dependence of the "achromatic" half wave plate.

Detailed descriptions of the measuring techniques, standard formats of the print-out scheme, and complete programs for the reduction of the results by a commercially available computer in Fortran IV are being prepared.

REFERENCES

A. Behr	1956, Veröff. Univ. Sternwarte Göttingen Nr. 114.
M. de Vries	1966, ESO Bulletin No. 1, 35.

Prof. Dr. A. Behr
Hamburger Sternwarte
Gojenbergsweg 112
205 Hamburg 80
Federal Republic of Germany

THE 61 cm PHOTOMETRIC TELESCOPE OF THE BOCHUM UNIVERSITY AT LA SILLA

Th. Schmidt-Kaler and J. Dachs

During the first week of September 1968, a new Cassegrain reflecting telescope of 24 inch (61 cm) aperture, focal ratio 1/15, has been installed at the site of the European Southern Observatory at Cerro La Silla, Chile, for the Astronomical Institute of the Ruhr-Universität Bochum, Germany. According to an agreement which has been set up between the Deutsche Forschungsgemeinschaft (D. F. G., German Research Foundation) who is the owner of the telescope and ESO, a building has been constructed by ESO for the Bochum telescope.

In exchange, ESO is granted 30 % of the observing time at the new telescope, and the D. F. G. will leave the telescope at its present site for at least twenty years. The telescope is equipped with a versatile photoelectric photometer and will serve various research programs of the Astronomical Institute of Bochum University on Milky Way Structure. The dome for the building has been provided by the D. F. G., the installation of the Bochum building has been taken over by ESO, and the furniture in the building is the property of the University of Bochum.

1. The building for the 61 cm Telescope

The building for the Bochum telescope has been erected by ESO in 1967, under the supervision of Dr. Muller, near the northwestern sloping edge of the lower flat part of Cerro La Silla, about 80 m to the north-west of the ESO 152 cm spectrographic telescope.

The Bochum telescope is mounted in a dome of 5.63 m outer diameter made by Ash-Dome Comp., Plainfield, Illinois. The dome is mounted 4.50 m above ground level on a circular wall. The telescope is standing on a concrete pier and is operated from a fixed platform in the first floor of the building. The room below the platform contains the staircase to the telescope platform and a small kitchen, and gives access to a rectangular extension of the dome building which includes two living rooms for observers of 17 resp. 14 square meters, and a bathroom with shower. The building is equipped with an electric water boiler, gas stoves, refrigerator, and a small electric cooking-stove.

2. The 61 cm Telescope

One of the main reasons for the actual choice of the size, the type and the focal ratio of the telescope was to supplement in an optimal way the instrumental plans of ESO.

The 61 cm telescope is a standard instrument made by the Boller & Chivens Division of Perkin-Elmer Corporation in South Pasadena, California, U.S.A.

It is supported by a heavy welded steel base. A stationary inner polar axle bolts to the sloping south face of the base, carrying a stationary right ascension worm gear of 30 inches diameter and two large bearings. The cone-shaped rotating outer polar axle housing has a 48 inch diameter skirt that contains the right ascension drive, dials for reading right ascension, declination, and hour angle, and the polar axle counterweight system. The declination axle mounts through the upper end of the conical polar axle housing and terminates in a flange, to which the telescope tube is attached.

The telescope tube, a solid aluminium weldment, carries the tubular support for the secondary mirror on the upper end and the primary mirror cell at the lower end. The primary mirror cell gives dual-pad back support to the mirror at three points as well as radial support through a metal sleeve in the mirror central hole. Instruments up to 50 kg in weight and 90 cm long can be attached to the mounting flange at the back side of the primary mirror cell. For focussing, the secondary mirror is moved along its axis by an electric servo motor. The focal plane of the telescope which in its mean position is situated 30 cm behind the mounting flange at the primary mirror cell, can so be shifted in either direction by 17 cm. Both mirrors are made of fused quartz.

The synchronous tracking motor is driven from a quartz controlled 50 Hz oscillator. Declination and right ascension drives have three speeds each, a slew drive of 3 degrees/sec, a set drive of 3 minutes of arc/sec, and a guide drive of 3 seconds of arc per second of time to be selected on two control paddles. The telescope position is indicated on the illuminated dials on the polar axle housing and can be read to 10 seconds of time in right ascension, 2 minutes of arc in declination, and better than 1 minute of time in hour angle.

Both primary worms of the right ascension and declination drives can be partially disconnected from their gears to give enough backlash for sensing balance. When the telescope is operated, d. c. motors provide about 3 mkp of preload on both primary worm gears to prevent backlash.

The finder attached to the main telescope has 10 cm aperture, 86 cm focal length, and an eyepiece of 26.6 mm focal length giving a field of view of $1\overset{\circ}{.}5$ diameter.

3. The stellar photometer

The photoelectric stellar photometer for the 61 cm Bochum telescope has been built by the Zentralwerkstatt Göttingen GmbH., Göttingen, Germany, based on the design of one of us (D.). Filter wheel, diaphragm slide, Fabry lens, and photomultiplier tube cold box are constructed as plug-in units which can be easily inserted and exchanged. Two filter wheels are available for 12 filters of 1 inch (25.5 mm) diameter and 15 mm maximum thickness each, as well as two diaphragm slides with six diaphragms each. The diameters are

first set	second set
0.3 mm = 7″	2.0 mm = 0′.75
0.5 mm = 11″	3.2 mm = 1′.2
0.8 mm = 18″	5.0 mm = 1′.9
1.25 mm = 28″	8.0 mm = 3′.0
2.0 mm = 45″	12.6 mm = 4′.75
20.0 mm = 7′.5	20.0 mm = 7′.5

Furthermore the photometer contains two Fabry lenses of fused silica with 80 and 100 mm focal length respectively, and two photomultiplier tube chambers for dry-ice cooling of EMI photomultipliers type 9502 and 9558 respectively (model TE-200 chamber made by Products for Research, Inc., Danvers, Mass., U.S.A.).

The star is centered to the diaphragm by means of two eyepieces into which the light beam of the telescope may be deflected by shifting diagonal mirrors into the photometer axis. The first eye-piece in front of the diaphragm has a field of view of 56 mm diameter corresponding to 21′ at the sky. The second eye-piece behind the diaphragm gives a 15 × magnification of the diaphragm and the star image in it.

The whole photometer is mounted into a rigid aluminium body. Its weight is about 35 kg.

The filter wheels are at present equipped with standard filters for UBV photometry with photomultiplier EMI 9502

U: 2 mm Schott UG2
B: 1 mm Schott BG12 + 2 mm GG385
(new designation for GG 13)
V: 2 mm Schott GG495 (new designation for GG11),

for BVr photometry in the system of Sandage and Smith (1963) with photomultiplier EMI 9558

B: 0.7 mm BG12 + 2 mm GG385 + 2.5 mm 80 % $Cu_2 SO_4$
V: 2 mm GG495 + 1.5 mm BG18
r: 2 mm RG610,

for uvby photometry in the Strömgren system with photomultiplier EMI 9558

u: 4 mm Schott UG11
v: Baird Atomic interference filter B-3 for 4118 Å,
half width 160 Å
b: interference filter B-3 for 4670 Å, HW 170 Å
y: interference filter B-3 for 5465 Å, HW 230 Å

Hα: B-11 for 6561 Å, HW 13 Å
B-1 for 6566 Å, HW 157 Å
Hβ: B-10 for 4857 Å, HW 27 Å
B-2 for 4848 Å, HW 98 Å
Hγ: B-10 for 4333 Å, HW 33 Å
B-2 for 4329 Å, HW 82 Å.

Two d.c. amplifiers are available for the photometer, a Keithley Instruments model 416 Picoammeter and a Rakos type electrometer amplifier built by J. Schumann at the Observatorium Hoher List of the University of Bonn. The range is 1.10^{-13} to 3.10^{-5} A in steps 1:3:10 for full deflection, the time constant may be chosen between 0.01 and 3 sec resp. 1.10^{-9} to 1.10^{-4} A in steps of $0^{m}5$ with 1 sec time constant.

The output of either amplifier is recorded on a Philips model PM 8000 potentiometric recorder.

A more detailed description of the Bochum-DFG station and observing programs is forthcoming in "Sterne und Weltraum" 9 (1969).

Applications for observing time are to be directed, as usual, to the Directorate of the European Southern Observatory, one copy for reference to the Direktor des Astronomischen Institutes der Ruhr-Universität Bochum, 463 Bochum, Postfach 2148, Germany.

Acknowledgments

The 61 cm telescope, the dome, and the photometer have been provided by a grant from the Deutsche Forschungsgemeinschaft. Special thanks are due to the Director of ESO, Professor Heckmann, and the ESO Council for their willingness to accept the Bochum station at La Silla and to build a housing for the 61 cm telescope, and to Dr. Muller and the ESO staff at La Silla who undertook to supervise the construction of the building, the erection of the dome, and gave every assistance needed in the installation and operation of the telescope.

Prof. Dr. Th. Schmidt-Kaler,
Astronomisches Institut der Ruhr-
Universität Bochum, Buscheystraße,
463 Bochum-Querenburg, West Germany

Dr. J. Dachs (same address)

LARGE AND VERY LARGE TELESCOPES

PROJECTS AND CONSIDERATIONS

K. Bahner

The instruments mentioned in the ESO Convention are by now either operating, or well advanced in the construction or design phase. This fact has led the ESO Council to considerations of a possible further instrumental development of ESO. The author was asked by the ESO Council to collect information about large telescopes now being built or planned, and to survey the literature for papers bearing on the design of very large telescopes.

I. Large Telescopes: Data for existing and planned instruments

The engineering study concerning the construction of the largest feasible telescope (mentioned in the "Whitford Report") does not seem to have been started.

Kitt Peak National Observatory has long-range hopes for an "x-inch" telescope ($D \approx 7.5$ m), but has not yet advanced far into this field.

The 610 cm telescope for the Zelinchuk Observatory (USSR) is now being assembled on site. A description from first-hand knowledge is given by Ingrao (1968). My attempts to get more information from colleagues in the Soviet Union have been unsuccessful. The telescope has an f/4 paraboloid mirror made of low expansion glass and uses the prime and the Nasmyth (f/30) focus. It has a symmetrical altazimuth mounting; the coudé installation takes part in the rotation about the vertical axis.

The Palomar 200 inch is too well known to need a description here [1]). There are plans for more telescopes of similar size: The CARSO project (Babcock 1967) will more or less duplicate the 200 inch at a mountain site in north-central Chile, with modifications in the optics (Ritchey-Chrétien system, Wynne prime focus corrector) and in the mirror support system. A fused silica mirror is considered. Negotiations to get the necessary funds (estimated at $ 19.000.000 for the complete installation including a 60 inch) are under way.

A Saudi Arabian project, which will possibly result in a 5 m telescope with the help of British astronomers, is in a very early stage of development.

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[1]) Condensed data for the older instruments are given by Bahner (1965).

There are quite a number of telescopes in the 3.5 to 4 meter range in the design or construction phase now. They all are to have symmetrical parallactic mountings of the horseshoe- or disk/fork-type, pure or modified Ritchey-Chrétien optics, and modern prime focus correctors. These instruments are similar enough to permit presentation in Table 1. Cost estimates are mostly 10 to 12 megadollars.

Next in size is the Lick 120 inch, to be followed by the new McDonald 270 cm reflector which is interesting because it extends considerably the range of the English cross axis mounting with the well-known coudé advantages.

The fork-mounted Crimea 2.6 m is in operation for several years now (no adequate description has yet come to my notice). The Isaac Newton Telescope at Herstmonceux (Brown 1967) of 2.5 m aperture has just been commissioned; its "polar disk" mounting and the mirror support system are noteworthy. The Swiss astronomers have plans to erect a 2.5 m telescope at the Gornergrat near Zermatt. Steward Observatory's 90 inch reflector (Hilliard 1967), similar to the KPNO 84 inch but with an interesting dome design, is nearing completion on Kitt Peak.

II. Very Large Telescopes: Design topics

a) General

The design of a large telescope, though not possible without the help of astronomers, is essentially an engineering problem. It may well be that the organization of a close co-operation between engineers and astronomers is one of the really important steps towards a modern large telescope. Possibly even a survey of the literature can be done only by engineers and astronomers working together. I had to restrict myself to publications usually found in an observatory library, which may not refer to all aspects of the problem.

One should not, however, expect too much from the study of old papers. There has been tremendous technological progress in the past decade or two; the full impact of this progress on telescope design is still before us. In some fields it may lead to rather drastic changes in design philosophy. I am sure that thinking along these lines is going on in several places, but next to nothing has been published.

An example of what I have in mind is the availability of small cheap electronic computers. In future telescopes, one has to consider such a computer not as an additional piece of equipment simplifying telescope operations, but as an integral part of the system. This means a definite farewell to the idea that a telescope is a passive apparatus which can be operated by hand if something fails. Up to now one tried to make the essential parts as rigid as possible, resorting to (mechanical) compensating devices if forced to. With a computer, one will have digital control instead; freedom from hysteresis and high frequency noise may become more important than built-in stiffness. In this way we can hope to keep the weight down, which is essential for very large structures.

Table 1
Instruments in the 3.5 to 4 m range under design or construction (state: Dec. 1967)

Observatory or Project	KPNO	CTIO	Canada Queen Elizabeth II Tel.	ESO	Anglo-Austral. SRC	France CNRS	Germany Max-Planck Inst.	Italy Oss. Astr. Nazionale
Aperture (cm)	400	400	380 (... 395)	360	380	366	350	350
Primary f-no. field	2.6 1°	2.6 1°	2.8	3.0 1°	3.3			~ 3
Secondary f-no. field	8 30′	8 30′	8 45′	8 42′	8			~ 9
Mirror	Silica (blank existing)	Cer-Vit	Silica	Silica (worked on)	Cer-Vit	Cer-Vit		Pyrex?
Design	finished	finished	under way	under way	under way (similar to KPNO design)			considerations
Construction	started	started						
Site	Kitt Peak	Cerro Tololo	Mt. Kobau	La Silla	Coonabarabran	Mediterranean?		Sicily
Completion expected	1972	1973	1975	1972	1973—75			
Cost estimate (10^6 U.S. \$)	10	10	11.76		11			5
Ref.:	Crawford 1965, 1968		Odgers 1967 Odgers and Secord 1968	Baranne 1966 Köhler 1968	E. G. Bowen et al 1968			

If the purpose of a telescope is to produce a high-quality image of the selected object and keep it fixed on a radiation detector, the obvious problem areas are mirror figure, collimation of optical system, focus position, and direction of optical axis. For all of these, programmed control or servo control has been considered (e. g., Fellgett 1956, 1959), and will certainly be used in future large telescopes.

Combinations of the two control principles are possible: for guiding, in the routine operation of to-day the basic term (sidereal rate, refraction, flexure) is programmed, and small corrections are done by servo; on the other hand: collimation and focus may be set by servo operation at the beginning of an observation, and changes fed in by computer program, depending on telescope position, temperature, etc. It is by no means necessary that the system derives all the required information from photons of the object under observation, which may be faint. If we make use of all possibilities, there is no good reason any more to keep the astronomer at (or in) the telescope during observations.

A second development with far-reaching consequences is the production of mirror materials (Monnier 1967, Rathmann et al 1968) with very small thermal expansion (coefficients smaller by a factor 30 . . . 50, compared with Pyrex). This practically eliminates the thermal deformation of the largest mirrors (not, by the way, the influence of the mirror as a heat source!). Avoiding thermal gradients within the disk is no longer of primary importance. The question of the optimum rib structure for large mirrors could be taken up again, since the restriction that all members have the same thickness can be dropped.

b) Optical systems

Most astronomers agree that a large telescope — since it is so expensive — must be usable as a field imaging system, in addition to its flux collecting mode. The development of optical systems for this purpose (prime focus correctors, the Ritchey-Chrétien and its modifications) up to 1966 is reviewed by Bahner (1967) and I. S. Bowen (1967) ²); later papers not included there are by Wynne (1967, 1968), Köhler (1968), Wilson (1968).

The general opinion that a large telescope has to be "universal" is challenged, however, especially by Fellgett (e. g. 1964) for the following reasons:

1.

For field imaging systems, an appropriate figure of merit is $D^2\Phi^2$, where D — diameter of the entrance pupil, and Φ — angular diameter of the field (it is supposed that the focal length is large enough for the image to be seeing limited). Obviously a Schmidt telescope cannot be surpassed here even by very large conventional reflectors.

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²) See also Gascoigne (1968).

To give an example: We want to study the region between the Magellanic clouds. The ESO Schmidt ($D = 100$ cm, $\Phi = 5^\circ 5$) on fine grain plates gives "seeing limited" images with a limiting magnitude of 22 in one hour; an effective combination of 5 such plates reaches a limit of 22.9 magnitude. With the ESO 3.6 m reflector, a 20 minute prime focus exposure goes down to 22.8 magnitude covering a 1° field. For the same area as above, 30 plates are necessary requiring 10 hours of much more expensive instrument time, compared to 5 hours with the Schmidt. The effect is, of course, less spectacular for objects not filling the large field of the Schmidt.

2.

For many studies of not too faint objects, on the other hand, a very high image quality is not necessary. If the observation is "signal noise limited", D^2 $\sim$ collecting area) is an appropriate figure of merit. We can do without extreme angular resolution and tracking accuracy, and make our observations with large, but inexpensive telescopes. Fortunately, interferometric spectroscopes with very high intrinsic dispersion permit good spectral resolution even with bad images. These flux collectors are equally well adapted to present-day infra-red receivers. Larger instruments of this type are operating at Bellevue and in the planning stage at Reading University (cf. Connes et al 1967) and Heidelberg Observatory (Elsässer 1967).

The argumentation does not take into account that large diameter-high precision telescopes are still necessary for observations of faint objects where the background noise must be discriminated against.

For direct photography, the limiting magnitude depends on D and the useful exposure time; if the "speed" of the emulsion is chosen correctly, the limiting magnitude is not a function of the focal length or f-ratio (Marchant and Millikan 1965, Bahner 1967).

This means that photography of medium-sized fields with large telescopes should be done at the prime focus, where the same image content can be obtained as at the R.—C. without handling plates in the 1 m^2 range. In consequence, the question of the prime focus corrector, but now with the deformation of the mirror as a free parameter, should be taken up once more. In this way we may end up with a "Rosin-system" (cf. Schulte 1966). At the secondary focus, the correction of a field large enough for offset guiding does not seem to present unsolvable problems (Gascoigne 1966).

Except for photography, the prime focus will probably not be used much. The light efficiency of one mirror plus corrector is hardly better than that of two mirrors. Even for a paraboloid primary, the advantage of the single reflecting surface is offset, in many cases, by an additional surface needed to feed the f/3-pencil into a spectrograph or photometer. If the photographic work is shifted to the prime focus, the secondary f-ratio is open for discussion again.

The "coudé laboratory" will be used more and more for complex apparatus, not just for a high dispersion spectrograph. In this connection, it is well to remember that each additional mirror costs about 15 % of the energy (equivalent to something like 20 % in telescope expenses!), and it does not matter much whether additional mirrors are large or small, before the focus or within the auxiliary apparatus. One can predict that before long observers will want offset guiding facilities for the coudé focus; if the sensors are to operate in the (rotating) coudé image, a larger unvignetted field than is usual now would be necessary.

c) Mirror support

After the thermal deformation of telescope mirrors is no longer important, the mirror support (during figuring and in the telescope) will be the limiting factor for optical precision. Obviously, there is some interdependence with the structure of the disk. If the number of the supporting points is large enough for the sag to be unimportant, the inaccuracies of the supporting forces become predominant in large mirrors.

In the discussion by Jones (1966), it is stated that for conventional lever systems (with coefficients of friction 0.001 . . . 0.003) the flexibility of the disk must be

$$\frac{D^2}{h} \lesssim 2.500 \text{ cm}$$

(h — thickness). For the Palomar 200 inch disk, one has

$$\frac{D^2}{h_{\text{eff}}} \approx 7.000 \text{ cm}$$

which seems to be the limit for a lever system taken to its extreme. In gas pressure supporting systems (Sisson 1960, Hoag et al 1967), the friction is so low that one can hope to have a coefficient of only 1/100 of that of a lever system, giving

$$\frac{D^2}{h} \lesssim 25.000 \text{ cm}$$

(it is assumed here that friction is the only source of error). With such a system, one could get adequate support for a 5 meter disk of only 10 cm thickness; clearly, the flexibility during figuring and the lack of strength in handling would present problems. A more conservative view (Rule 1966) supposes a coefficient of friction of 10^{-4} for the pneumatic system, still making possible a 3:1 reduction in thickness. Since the mass of the mirror is the starting point of the weight-escalation experienced in large mountings, one would expect a closer look at the minimum necessary thickness in future large instruments.

For very thin disks the additional loading by wind forces may become more important than the support errors. Closing the dome by a thin window would help (Herbig 1967).

The possibility of servoing the mirror figure is brought up time and again in discussions of mirror support systems (e. g., Rule 1966), but no detailed analysis has come to the writer's notice. From an O. S. A. abstract (Robertson 1968), one may infer that a closed-loop control system for a segmented composite mirror has been built.

d) Accuracy of optics

Closely connected with the support problem is the question what precision in mirror figure we should strive for. Results in the papers of Scheffler (1962, 1964) have been interpreted (e. g. Serkowski 1967) in this way: even with an amplitude of image motion (seeing) of 0,5 arcsec the (much smaller) diffraction image of a large mirror can be obtained, if only its surface accuracy is extremely high. By the strong concentration of light, considerable gains in limiting magnitude or spectroscopic speed should be possible.

One can say at once that the short period image shifts and tracking errors must be smaller than the image radius to make the image quality usable.

With regard to the optics, it is known that the (irregular, statistical) wavefront aberrations in the exit pupil must be $V_{rms} < \frac{\lambda}{14}$ for a Strehl definition $Z > 80\,\%$, which means a diffraction limited system. With slightly different criteria Scheffler arrives at a slightly different number; he shows that for $V_{rms} = 0.1\,\lambda$, the diffraction "spike" is still prominent in the "halo". It does not matter whether the aberrations are of atmospheric or of instrumental origin.

Two remarks should be made in this context:

a) The Strehl criterion is not essentially different from or more stringent than the "quarter wavelength rule" which is valid for a one-sided, symmetrical, monotone wave aberration (such as primary spherical).

b) Scheffler's quality standard (mirror surface true to $0.03\,\lambda_{rms} \sim V_{rms} = 0.06\,\lambda$) is close to the Rayleigh-Strehl-value of $0.07\,\lambda$.

If the "seeing" is measured by the rms image excursion as observed in a small telescope, we need a length to connect it with the wave aberration. Rather crudely, we may take the typical diameter of a quasi-plane wave front element as such a length. Only if this is of the order of 5 . . . 10 cm, the Rayleigh-Strehl condition can be met at 0.″3 seeing; if many larger elements are present, even a perfect mirror will not help. For his calculations, Scheffler has assumed a spectrum of the Fourier components for the disturbed wave surface which has the form

$$P\,(k) \sim \exp\,(-\pi^2 \ell_0^2 k^2),$$

where k is the wave number and ℓ_0 a parameter giving approximately the smallest wave-length present. This spectrum reaches its maximum power

$P\left(\frac{1}{k}\right) d\,\frac{1}{k}$ at $\frac{1}{k} \approx 3\,\ell_0$ and decreases towards longer waves. If α is the image excursion observed with a small telescope, we have

$$V_{rms} = \tfrac{1}{2}\,\ell_0\,\alpha_{rms}\,,$$

and with $\ell_0 = 5$ cm, $\alpha = 0\overset{''}{.}5$ diffraction limited imaging is just possible. If $\ell_0 = 20$ cm, even $\alpha_{rms} = 0\overset{''}{.}3$ is not sufficient.

Whereas this spectrum seems to represent atmospheric conditions close to the ground, for the higher levels a different law might be expected. Scheffler mentions the possibility of a Kolmogoroff spectrum:

$$P\,(k) \sim k^{-5/3}\,;$$

here,

$$V_{rms} \sim \frac{D}{4} \cdot \alpha_{rms}\,,$$

and the departure from diffraction limited imaging increases with telescope aperture. With our present knowledge of atmospheric turbulence, it is hardly possible to fix a limit in α_{rms} below which the atmosphere does not influence the image.

e) Mounting

The field of equatorial mountings to be considered for large instruments seems to be well covered by the designs for the Palomar 200 inch, Kitt Peak 150 inch, ESO 3.6 m, and Isaac Newton telescopes.

The advantages of an altazimuth mounting for large telescopes are obvious, likewise the disadvantages in use, resulting from the position of the instrumental pole. An instructional graph for the speed in Az is given by Vasilevskis (1966, see also Mikhelson 1966). There can be little doubt that — with computer, digitized drive, and/or consequent use of photoelectric guiding — these difficulties are not too serious for the major part of the sky; the interaction between tracking and field rotation does present problems, however. The largest existing telescope (now completed at the Leningrad works) has an altazimuth mounting.

A certain lack of enthusiasm for the altazimuth among astronomers is probably due to the fact that one encounters the same coudé problems as with a fork mount, at least in the symmetrical case. In a very large instrument there is, of course, space enough for a conventional coudé spectrograph within the mounting, with very smooth motions, but with accelerations and varying orientation nevertheless. One might hesitate to restrict oneself definitely to this space for the next 50 years.

The horizontal frame (cf. Fellgett 1956), called alt-alt by some, with the instrumental pole in the east point of the horizon, permits a good coudé arrangement (with a slotted tube) and has much smaller accelerations for tracking. The principal advantage of the altazimuth — gravitational forces fixed or restricted to a plane — is lost, however. In this connection it should be mentioned that the variable driving speeds required by these types of mountings do not present serious problems, since digitally-controlled drive systems with high precision and flexibility are now available (Trumbo 1966; stepping motor).

For very large instruments, more radical deviations from conventional mountings have been proposed. In the designs of the Department of Applied Physical Sciences at Reading University, the primary mirror is carried in a space frame which is supported by servo-controlled hydraulic rams. This mounting has no axes; a fixed focus position is obtainable (cf. Connes et al 1967).

Even fixed or semi-fixed primary mirrors are a possibility, if we agree to partial mirror illumination and sky coverage. A spherical primary is obviously necessary and would require a correcting system (e. g. of two aspheric mirrors). The radiation detector would have to move about the centre of curvature; coudé operation with 4 reflecting surfaces is possible (Meinel 1966).

f) Importance of Very Large Telescopes

The above discussion shows that engineers who are asked to produce conventional telescopes of very large size have now more and better technical means at their disposal than the people who built the 200 inch. The maximum telescope size would possibly be set today by the necessity of safely transporting and handling the mirror disk. At the same time, however, our methods of data acquisition and evaluation have improved and are still developing. Basically, photons are collected in proportion to the collecting surface and the integration time; one might ask, therefore, whether the very large telescope is the only answer to the needs of observational astronomy.

Historically, in a time which is not so far back and which has left a still vivid impression in our minds, there was the one and only 200 inch in a class by itself, above the time-honoured 100 inch and a handful of 2 meter instruments. Progress in several fields of research could be expected only from the largest telescope. But this situation has changed already; the Lick 120 inch is working at more or less the same problems — with, after all, only one third of the light collecting area — and even the Kitt Peak 84 inch is producing radial velocities of quasars down to 19th magnitude. The 3.5 to 4 meter instruments now being built will without doubt belong to the same class as the 200 inch, with only quantitative differences.

Since the time scale for the realization of a very large telescope is of the order of 10 years, nobody can say today for which scientific questions such an instrument will be used. It can be safely predicted, however, that our methods of data acquisition will develop in the direction of preserving the quantized structure of information. This will enable us to approach the physical limits set by signal or background noise in more and more fields.

Following discussions by Baum, I. S. Bowen, Fehrenbach and others, graphs relating the performance of telescopes to their size are given, for different observational methods. The increase in photographic limiting magnitude with

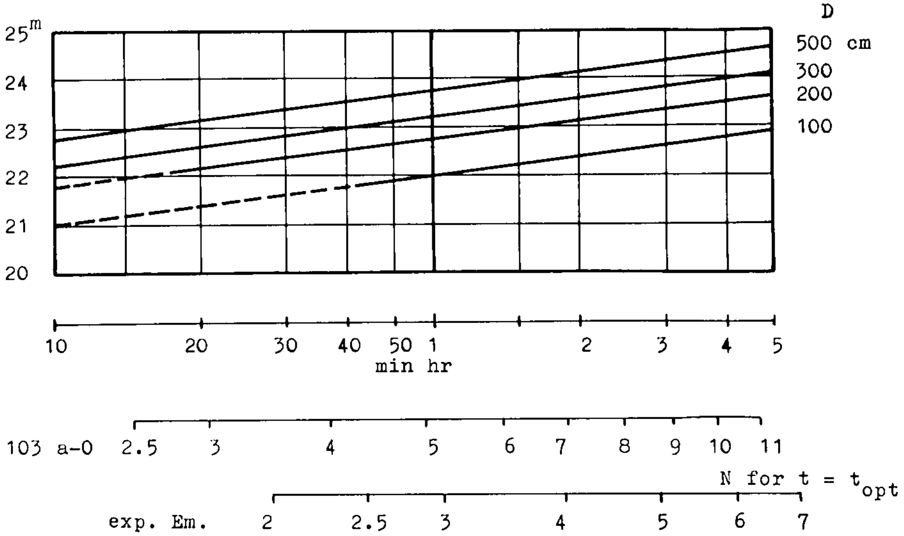

Fig. 1: Photographic limiting magnitude vs. telescope aperture D and exposure time t, resulting from discrimination against sky background for "seeing limited" images of 1″. For single plate, t is to be not larger than t_{opt} which leads to optimum background density. For two emulsions of different "speed" (but equal quantum efficiency) corresponding f-numbers $N = \frac{f}{D}$ are given (exp. Em. = experimental emulsion mentioned by Marchant and Millikan 1965).

telescope aperture may be taken from Fig. 1, the gain for photoelectric wide-band and narrow-band photometry from Fig. 2. In Fig. 3, the relation between telescope size, angular resolution, and spectral purity is illustrated. If we want to avoid "geometrical" losses at an entrance opening of the spectrograph, the minimum spectral bandwidth is

$$\Delta\lambda \quad \frac{D}{d} \cdot \frac{1}{\frac{d\Theta}{d\lambda}} \cdot \beta ,$$

where D diameter of the entrance pupil,

d used diameter of dispersing element,

$\frac{d\Theta}{d\lambda}$ angular dispersion of dispersing element

β angle at the sky.

This relation is obvious for a conventional spectrograph, where d is the diameter of the exit pupil, and angles are magnified by $\frac{D}{d}$ from object- to image-space. It holds for other cases too, e. g., dispersion of the pupil. The expression for the angular dispersion is somewhat complicated in the case of an interferometer, giving

$$\left(\frac{d\Theta}{d\lambda}\right)_{\text{eff}} \approx \frac{5}{\lambda} \cdot \frac{d}{D} \cdot \frac{1}{\beta}$$

for the Pérot-Fabry spectrometer, whereas

$$\frac{d\Theta}{d\lambda} = \frac{\sin\Theta}{\lambda}$$

for a normal incidence grating, and

$$\frac{d\Theta}{d\lambda} = \frac{2\tan\Theta}{\lambda}$$

for a grating in Littrow arrangement, e. g. an échelle.

It follows that the spectral resolution is

$R = \frac{\lambda}{\triangle\lambda} \approx 0.5\,\frac{d}{D} \cdot \frac{1}{\beta}$ for a conventional spectrograph,

$R \approx 4\,\frac{d}{D} \cdot \frac{1}{\beta}$ for the échelle, and

$R \approx 5\,\frac{d^2}{D^2} \cdot \frac{1}{\beta^2}$ for the interferometer.

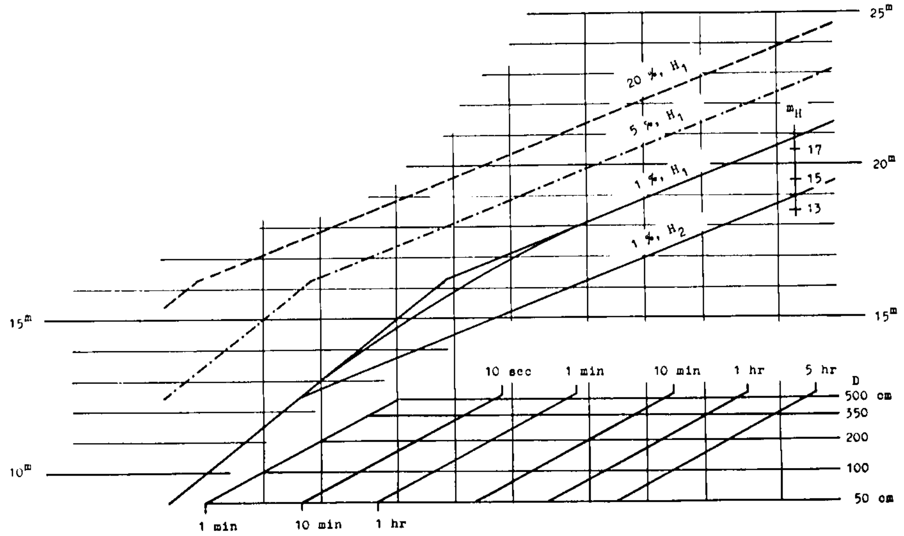

Fig. 2: Limiting magnitude for photoelectric photometry can be found by entering grid at lower right with telescope aperture D and time of integration t, and going upwards to line of statistical accuracy (% rms) selected. The upper time scale applies for B magnitudes, where a counting rate of 1/sec at a telescope of D = 1 cm for an 11.5 magnitude star is assumed. The lower time scale is valid for narrow-band photometry ($\Delta\lambda$ = 50 Å) with an over-all efficiency (atmosphere, telescope, spectrometer, photomultiplier) of 2 %. H_1 refers to a sky background of 22 mag/arcsec^2 and an 8 arcsec diaphragm, whereas H_2 has a 30 arcsec field and 21 mag/arcsec^2 sky. For differing background conditions, 1 % accuracy lines are to be drawn through the total sky signal indicated by m_H.

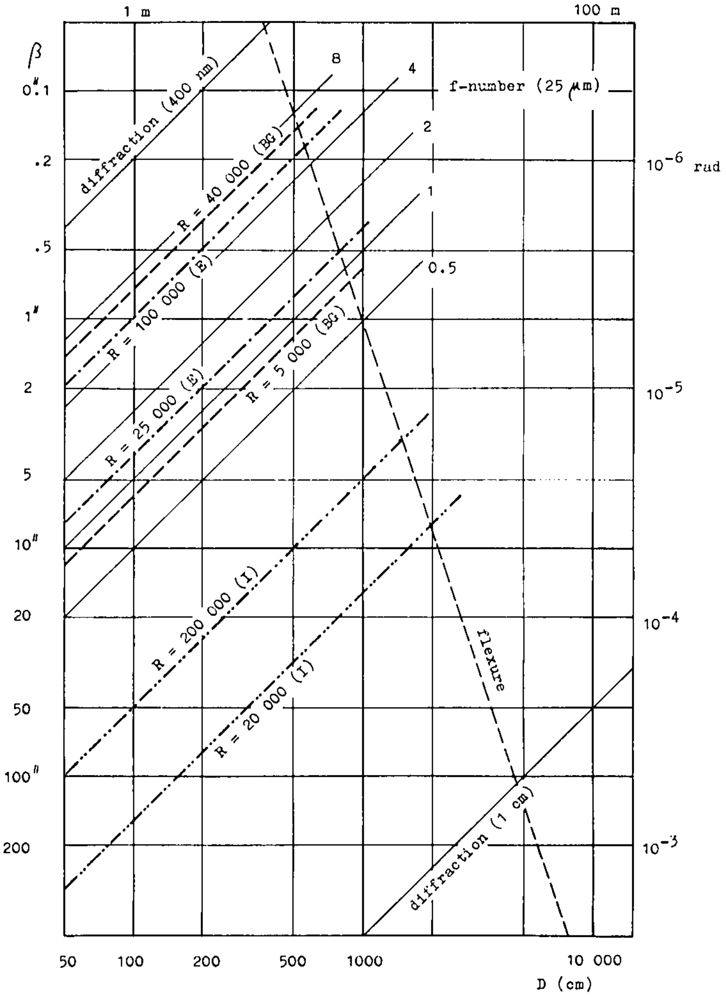

Fig. 3: Lines of constant spectroscopic resolution (R = $\frac{\lambda}{\Delta\lambda}$) in D, β-field (D: telescope aperture; β: angle at sky corresponding to spectrograph slit width or interferometer entrance aperture). ---- conventional spectrograph with plane grating of 30 cm illuminated width and 600 grooves/mm used in second order. -.-.-.- échelle spectrograph with 12.8 cm grating and 63° blaze angle. -..-..-..- Pérot-Fabry-interferometer of 5 cm diameter. Thin lines give f-number (N = $\frac{f}{D}$) of final pencil for 25μm image of β. (Adapted from Connes et al 1967; the "flexure" line is the one given in this reference.)

In Fig. 3, the well-known difficulties in the spectroscopic use of large telescopes are apparent. It is only the multichannel operation of conventional spectrographs that makes the light loss in high-resolution spectroscopy bearable.

The increase in performance of the larger telescope must be weighed against the increase in expense. A telescope of aperture D collects during the observing time t information in proportion to D^2 t (or $Dt^{1/2}$, if the background is predominant). The cost of one unit of observing time may be assumed to be a certain percentage of the initial investment. Clearly, if the cost of the telescope increases as D^m and $m > 2$, the larger telescope will produce the unit of information at higher cost. If the information adds up only as Dt (e. g., in a typical coudé spectrograph where the conditions of Fig. 3 cannot be met), this increase in cost of information is rather pronounced. Thus it would seem that a battery of large telescopes (which can work in parallel if high resolution in time is essential) is a more economic way to observational data than a single very large instrument.

This argumentation has, of course, its limitations: the telescopes must be large enough so that the cost of instrumentation is only a small fraction of the total investment; the increase of expenses, for telescope and observing time, as a power of the diameter is an oversimplification; detector noise has not been taken into account; etc. The argumentation is sound enough, however, to set us thinking — not about the "largest feasible", but the "optimum size" telescope, with instrument cost as an important weighing factor.

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ASTRONOMICAL OBSERVING CONDITIONS IN NORTHERN CHILE

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The astronomical observing conditions in Central and Northern Central Chile, comprising the latitude range from roughly 27° S to 34° S, have been studied extensively by the author. These studies formed the basis of the selection of Cerro Tololo by AURA, Inc. as the site for the Inter-American Observatory, and contributed to the choice of Cerro La Silla by the European Southern Observatory organization. The experiences gathered at these two sites as well as in the Santiago area in the years following the site surveys confirm the general conclusions and results of the surveys.

The northern latitude limit of the site surveys was derived from considerations concerning principally the Magellanic Clouds which are certainly among the most important objects to be studied in the southern hemisphere. Cloud occurrence in the Coquimbo Province, in which both Cerro Tololo and Cerro La Silla are located, shows a maximum during the winter months. On the average one may not expect more than fifty percent of the nights to be clear during the month of June in this region. It is well known that the number of clear nights per year increases northward in Chile up to a not yet well determined latitude which, however, is certainly far north of the Province of Coquimbo. In the extreme north, particularly in the mountain regions bordering Bolivia, the seasons are even inverted in the sense that maximum cloud frequency and also maximum precipitation occurs during the month of February.

In view of the above it seems justified to have a critical look at the latitude limitation. In deriving a latitude limit for a new observatory, if its principal purpose shall be the investigation of one single celestial object, one must keep in mind that this limit depends on the seeing conditions, extinction, scintillation, etc. for the object at the time of its meridian passage. Thus, at the site considered, the Small Magellanic Cloud, located at —73° declination, should not pass the meridian too far from the zenith.

In order to be able to compare different sites with respect to their suitability for the observation of one single celestial object, one should adopt a maximum tolerable seeing disk diameter, extinction, etc. and then investigate how many hours each site offers for the object of interest with conditions better than the adopted upper limits. Such a procedure automatically incorporates the inconvenience of low latitude and the frequency of cloud occurrence. Even the choice of a limiting value for the seeing seems arbitrary, at least as long as one does not know what values of the seeing one can count upon. As a start it seems more realistic to determine for each site the number of available observing hours for the object of interest as a function of the limiting value of the seeing disk diameter.

For the determination of such a distribution function for a given site and a given celestial object we need the following information:

(1) the latitude of the site,
(2) the declination of the object,
(3) the average cloud distribution throughout the year,
(4) the distribution of the seeing diameter at the zenith throughout the year,
(5) the zenith extinction and its variation during the year,
(6) the scintillation at the zenith and its variation during the year,
(7) knowledge of the airmass dependence of seeing, extinction, and scintillation.

Standard site survey equipment can provide all the information just listed.

The only limitation which has to be decided on before a site survey with the above objective is started is that of the elevation of the site. This is derived from human reasons rather than from astronomical considerations.

The zenith distance dependence, or more precisely the airmass dependence, of the seeing is fairly well known. It was shown by Stock (1), by Irwin (2), and by others that the relation

$$(1) \qquad D(\zeta) = D_0 \zeta^{1/2}$$

describes well the average variation of the seeing diameter $D(\zeta)$ as a function of the airmass ζ. The coefficient D_0 is the seeing disk diameter at the zenith. The average value of D_0 for a given site depends on many factors, including some of purely local character. Therefore, it cannot be predicted from parameters such as elevation, latitude, etc., not even for a limited period of the year. It has to be derived from measurements on the spot carried out over a long period of time.

The airmass dependence of the extinction is known. Its dependence on the elevation of a site can be predicted quite well as long as regions of industrial smoke, dust, etc. are avoided.

With regard to the scintillation we are concerned only with the rather slow intensity fluctuations (with frequencies < 1 c / s), since the rapid fluctuations are insignificant for large aperture telescopes. Observations made by the author at different sites with different telescopes show that

$$(2) \qquad A(\zeta) = A_0 \zeta^2$$

is a good description of the zenith distance dependence of the fluctuation amplitude $A(\zeta)$. Here A_0 is the amplitude observed at the zenith. Recently it was pointed out by Young (3) that the power of ζ might depend on the azimuth and fluctuate between 3/2 and 2, depending on the angle between the azimuth of the star observed and the wind direction at high altitude. This has not yet been verified by observation.

If the assumption is correct that the slow fluctuations like those of higher frequencies originate mainly high above the ground, then their average amplitude for a given site is independent of its elevation but could well be a function of the latitude, since the "jet stream" seems to play a major rôle in the formation of the intensity fluctuations. The jet stream is restricted to a certain latitude belt, and within this belt it favours different latitudes during different seasons. Scintillation has lately become an important factor in certain astronomical observations because it limits the frequency and amplitude resolution that can be obtained for fast flickering objects such as pulsars.

Considering large telescopes, and excepting a few very special techniques, astronomical observations are more seriously affected by the seeing than by either the extinction or the scintillation, particularly when dealing with faint stars. Thus it appears justified to judge the astronomical quality of a site principally by the cloud frequency and the seeing conditions. In first approximation one compares two sites by comparing their average seeing disk diameters and their total number of clear nights. This procedure is not always satisfactory, particularly if the numbers to be compared do not differ very much. A more significant comparison can be made on the basis of the distribution of the seeing disk diameters.

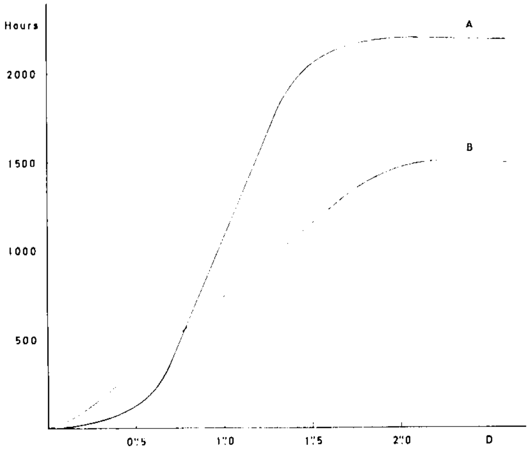

Fig. 1: Accumulative distribution of the seeing diameter D for two hypothetical sites A and B. The ordinates give the total number of clear night hours per year with the seeing better than D or equal to it. Note that both sites have about the same average seeing value. The total number of clear hours at site A is larger than at B, while at the same time more hours with exceptionally good seeing are available at B.

For every type of astronomical observation there is a maximum tolerable seeing disk diameter D_M. Given a value of D_M, one would like to know how many clear hours per year are available with $D_0 < D_M$. This number of hours, $T(D_M)$, is obviously a monotonous function of D_M. Fig. 1 shows two hypothetical curves for $T(D_M)$. Both hypothetical sites have about the same average seeing $<D_0>$, while site A has a larger number of clear hours. Even so, if seeing requirements are very strict, site B is the superior site.

If one wants to be so specific as to compare observing conditions for one single celestial object one can construct curves similar to those in Fig. 1. Using the zenith distance distribution of the object during the period it can be observed and the average seeing disk diameter for that same period, one can calculate the seeing distribution for the object of interest, obviously making use of equation (1).

As was already stated above, along the Andes mountains the cloud frequency diminishes with decreasing latitude, at least down to a not yet determined latitude. Thus, the optimum site for a southern observatory in Chile can be determined only by considering both cloudiness and seeing in the form outlined above. If one thinks only in terms of the Magellanic clouds, then Northern Chile — north of approximately 24° S — must be excluded because in the extreme north the period of maximum cloudiness coincides with the observing season for the objects mentioned. For the Galactic Center, however, all of Northern Chile can be considered. The same is, of course, true for observations of members of the solar system.

The site surveys conducted by AURA, ESO, and CARSO have accumulated a considerable amount of data for a number of sites located roughly between 30° S and 27°.5 S latitude. The data show that only small and often insignificant differences exist between the conditions at the various sites as long as in their selection certain requirements concerning the topography and the surface cover are observed. Thus it appears unlikely that a site with significantly superior conditions exists in this zone or close to it to the north or south. However, the fact remains that during the winter season, particularly during the month of June, cloud frequency is high in the zone where presently several major observatories are being built. As was already pointed out, the month of June is one of the clearest in Northern Chile. It is the author's opinion that this fact alone justifies a closer investigation of the astronomical observing conditions in Northern Chile.

In 1966 the Astronomy Department of the University of Chile began a closer study of Northern Chile, generally known as the "Norte Grande". There exists a permanent inversion layer with an elevation from 1200 m to 2000 m depending on the season and on the distance from the coast and frequently marked by fog development. This made it evident that only sites with elevations well over 2000 m could be considered.

There are a number of mountains of sufficient elevation south of the town of Antofagasta and very close to the coast. The abrupt rise from the Pacific Ocean on one side, and a large flat plain, more than 1000 m lower, on the other side give these mountains rather special conditions. High stability, that is, good seeing, is expected for night time conditions. Furthermore, the extremely low humidity makes this area very suitable for astronomical work in the infra-red. Since this area is absolutely arid, water supply for an observatory will be difficult and costly. Underground currents may exist, but most likely at a prohibitive distance and depth.

A considerable amount of precipitation, however, occurs over the main ridge of the Andes during most of the southern summer, giving origin to a number of small rivers. Most of them disappear in salt lakes or salt pans, but some penetrate far into the 100 kilometer wide desert belt which separates the mountains from the coast. Thus another possible choice would be sites in the interior of the country near one of these streams.

From experience one knows that an elevation of at least 1000 m above the surrounding desert floor is needed in order to avoid seeing effects of local origin. The rivers that reach the desert are, of course, located in its lowest parts, and have often carved themselves spectacular cañons. Thus it is difficult to find a site fulfilling the above condition and still being located near a water supply, except in the foothills of the Andes themselves. If one adds to that the requirement of an existing road leading into the area, as one would do at least for a preliminary survey, then only few choices are left.

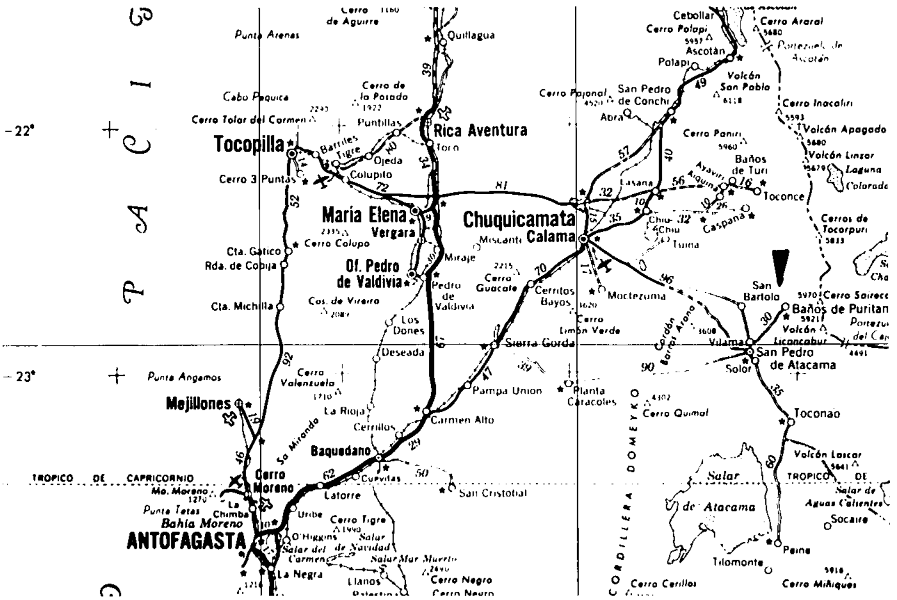

Fig. 2: Area Antofagasta/Chuquicamata/San Pedro de Atacama (copied from ESSO map).

A rather fortunate combination was found near the small town of San Pedro de Atacama (elevation 2240 m) at the northern extreme of the Atacama Salt Lake. San Pedro itself is a small agricultural center with a resort hotel and a number of tourist attractions. It can be reached from Calama by a mostly paved road in less than two hours. Calama has daily air service to and from

Santiago and Antofagasta. From San Pedro de Atacama several dirt roads lead right into the high Andes mountains. One of them follows the Guatin river. At a distance of about 20 km from San Pedro, road and river reach an elevation of about 3000 m. A number of flat hilltops in the area can readily be made accessible by road. They have extensive surfaces, suitable for the construction of an astronomical observatory.

Fig. 3: Double-beam telescope on Cerro Chaupiloma. In the background the volcano Licancabur.

The mountain chosen for study is named "Chaupiloma". Its elevation is 3300 m. Its summit has a flat area of approximately 300 m by 500 m. The road passes within a few hundred meters from the summit, and about 80 m below it. The river is almost as close, and about 120 m lower than the summit of Chaupiloma. The river has a minimum flow of 10.000 m^3 per day, an ample amount for a hydroelectric power station.

The topography of Cerro Chaupiloma may not be ideal for an observatory site. The possibility exists that some local seeing effects occur. On the other hand the convenience of nearby road and water are strong arguments in its favour. Therefore, it was decided to investigate it more closely.

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