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Aspects of Geneva Photometry[1]

Part 1, equipment and historical background

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The Geneva seven colour photometric system has been applied since 1960 in both hemispheres. It is the most homogeneous and one of the more accurate ground-based systems in use today and its data base has grown over the years to include some 380000 individual measurements of 50000 stars of all types. In the first part of this article we present a concise historical overview of the instrumentation and observational sites.

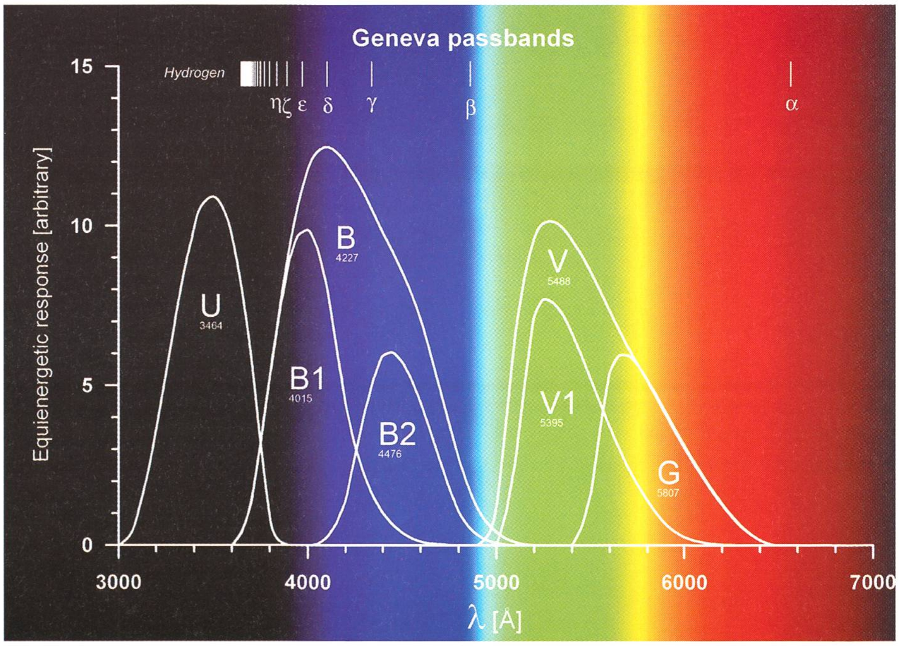
1. Introduction

Astronomy is the only natural science where the objects of research, if we overlook the handful of bodies orbiting within our solar system, are physically inaccessible. All data pertaining to the universe at large and down to our local stellar neighbourhood have to be gained by the passive analysis of incident electromagnetic and corpuscular radiation. Nevertheless, the amount of information conveyed by such radiation is vast and, as Fred Hoyle pointed out some 50 years ago in the prologue to his popular book Frontiers of Astronomy, *«The astronomer's problem is not a lack of information but an embarrassing excess of it. His is often a problem of disentanglement rather than one of synthesis»*.

Many techniques have been developed throughout the history of astronomy to assist that process of «disentanglement». They resort as a whole to the physical analysis of starlight and of electromagnetic emission and absorption by interstellar matter at all wavelengths, as also to the precise measurement of stellar positions over the course of time by astrometry. The latter provides fundamental data that establish the first rungs of the cosmic distance ladder and measures the tangential dynamical component of nearby stellar systems. The former enables us to spectrally analyse the *locally prevalent* conditions of the emitting (or absorbing) media and to derive the related physical quantities such as chemical composition, temperature, gas pressure, magnetic field intensity as also their radial dynamical components. One of the fundamental observational quantities relevant to the electromagnetic spectrum is the photometric – i.e. quantitative – estimation of radiation intensity in various well defined wavelength regions. Visual techniques, sometimes using coloured filters, have been attempted since antiquity and perfected up to the application of photography in the late nineteenth century. Truly accurate «multicolour photometry» had, however, to await the advent of highly sensitive and linear photoelectric detectors such as the photomultiplier tubes (PM) that were originally developed for nuclear physics in the middle of last century. Multicolour photometry thus truly gained its status as an essential tool of observational astrophysics in the nineteen fifties, and is still one of the basic methods applied by the astronomer.

The quality of a ground-based photometric system depends, however, on a number of conditions that are not always self evident. The measurements are done through the earth's atmosphere and not always from the same altitude. For a given site, measurements are made at different elevations above the horizon, i.e. through different thicknesses of atmosphere – or «air masses». The overall atmospheric transparency varies continually. All these variable factors have to be accounted for to reduce the measurements to their values outside the atmosphere – which is the necessary condition for a photometric measurement to be of any astrophysical value. Drifts in instrumental sensitivity have to be under control. These can arise from the electronics, the transmission of the telescope optics as well as from variations affecting the optical response functions of the filters and detectors. A «standard» consisting of a sufficient number (> 100) of well measured and non-variable stars of all types and for which the values outside the atmosphere are perfectly determined has to be initially set up. These standards are then measured jointly with new «program stars» and serve to reduce their measurements by correlation to the «standard system». Moreover, conditions of atmospheric transparency and dark sky background have to be optimised by the selection of isolated high altitude sites in meteorologically stable locations. The «homogeneity» of a system – its long term stability and general consistency – depends on how well all of these constraints are fulfilled.

Fig. 1: The spectral sensitivity profiles of the Geneva photometric system's passbands. The response functions are given as they would appear under an equi-energetic flux (E(λ) = Const) and in arbitrary units. The mean wavelength of each band is also given. The hydrogen Balmer spectrum is shown in the upper part of the figure to aid with the discussion of the system's application to stellar fluxes.



[1] Adapted from *Archs Sci. Genève, Vol. 56, Fasc. 1, pp. 11-38, Juillet 2003*. Based on data acquired at the La Silla (ESO, Chile), Jungfraujoch and Gornergrat (HFSJG International Foundation, Switzerland), and Haute-Provence (OHP, France) observatories.

Of several well standardised photoelectric multicolour systems in the visible (3000 to 6000 Å) which differ by the shapes and spectral domains of their passbands, the most important currently in use for ground-based observations are the «international» – or JOHNSON - UBV system, the STRÖMGREN uvby-β system and the Geneva system. Of these, the latter is the most homogeneous and in most applications also the most precise. Here, we will first present a brief historical overview of the instruments and observation sites used by the Geneva group as well as a summary of the system's colorimetric properties. As a practical example, we will then proceed with a synopsis of its applications to the analysis of the more massive ($M > 2.5\ M_\odot$, $T_{eff} > 10000$ K) and luminous stars using methods that are specific to the Geneva system.

2. The Geneva system

2.1. Historical background

The definition of the Geneva seven-colour photoelectric photometric system by MARCEL GOLAY dates back to the late fifties. The purpose at the time was to take advantage of the newly available photomultiplier tubes and their photometric accuracy. The passbands (Fig 1, RUFENER and NICOLET, 1988) were produced by coloured glass (Schott) filters of high chromatic stability. The V and G bands are limited red-ward by the chromatic response of the PM's photocathode.

The passbands were chosen with the object of reproducing the general properties of JOHNSON's U,B,V system with a practically identical V band but with slightly different U and B bands presenting less overlap at the locus of the Balmer jump (see end of BALMER series in Fig. 1, and Fig.2). The identical V band was important since the universally accepted visual magnitude scale is defined with that band. Four more bands of intermediate width, B1,B2, V1 and G, were added in view of approximating the colorimetric properties of the BARBIER - CHALONGE - DIVAN system (Observatoire de Paris BCD system, see EGGER, WILD, GOLAY, 1995) using low resolution photographic spectrophotometry and which was one of the most sensitive stellar classification tools of its time. It relied on a measurement of the BALMER jump, an estimate of the hydrogen line strengths via the mean position of the

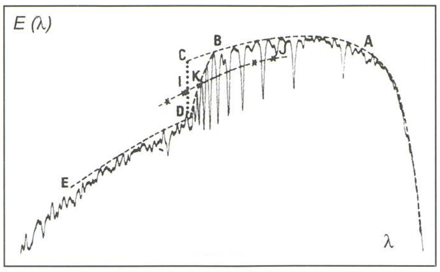


Fig 2: The parameters of the BCD system illustrated by the spectrum of a B-type star. The ultraviolet (or BALMER) continuum is defined by the line ED. The visible (or PASCHEN) continuum by ABC. The BALMER jump is measured at 3700 Å and defines the parameter D = log [E(λ,C) / E(λ,D)]. The wavelength λ_1 is that at the point K, equidistant to ED and ABC. The actual parameter that measures the hydrogen line strengths is the difference 3700 - λ_1 (IK). The third parameter Φ_b is the absolute gradient (comparable to fitting a PLANCK function) over the PASCHEN continuum between 3800 and 4800 Å (AB).

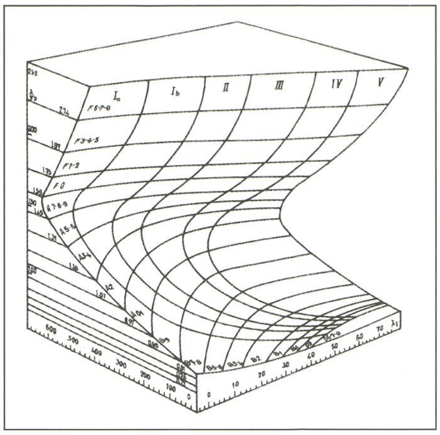


Fig. 3: The three dimensional BCD empirical spectral classification using the D, Φ_b and 3700 - λ_1 parameters.

Fig. 4: The Jungfraujoch Sphinx Observatory (3585 m), looking South-East. The Aletsch glacier is to the right and the southern foot of the Mönch can be seen to the left.

Fig. 5: Panoramic view over the Aletsch glacier and the Jungfrau massif from the upper terrace of the Sphinx Observatory.

Balmer jump and on gradients fitted over the Balmer and Paschen continua (Figs 2 and 3).

The instrumentation of the new photometric system was designed by M. Golay and F. Rufener and systematic observations were initiated by them in 1960 at the Sphinx Observatory (3585 m) of the Jungfraujoch High Altitude Research Station (Figs. 4 and 5) with the aid of a first photometer named « P2 » (Figs 6 to 8). A prototype made by Golay and called P1 had formerly been tested in Geneva but not used for future observations.

Together with that instrumentation, Rufener also introduced a new measurement and reduction technique based on a twin Bouguer method that makes use of two contra-varying extinction stars, and called by him the « M and D » technique (see Rufener, 1964, 1985). That technique allows the determination of « instantaneous » extinction lines at given moments (usually 4 to 6 times) during the night, and allows by interpolation an accurate determination of atmospheric extinction and of its evolution during the observations.

Five other photometers have been constructed since then. The first four, P3 to P6 (Figs. 9 and 10) were of an improved design, but were still one-channel instruments that measured through the 7 filters consecutively. Only two of these were equipped with Geneva filters (P5 was sold to the Observatoire de Paris in 1969, and P6 has been kept as a reserve of spare parts).

A double-channel instrument called P7 (see Fig 11, and Burnet 1976, 1979), that ensures the quasi-simultaneous measurement through the 7 filters of star and star plus sky background by

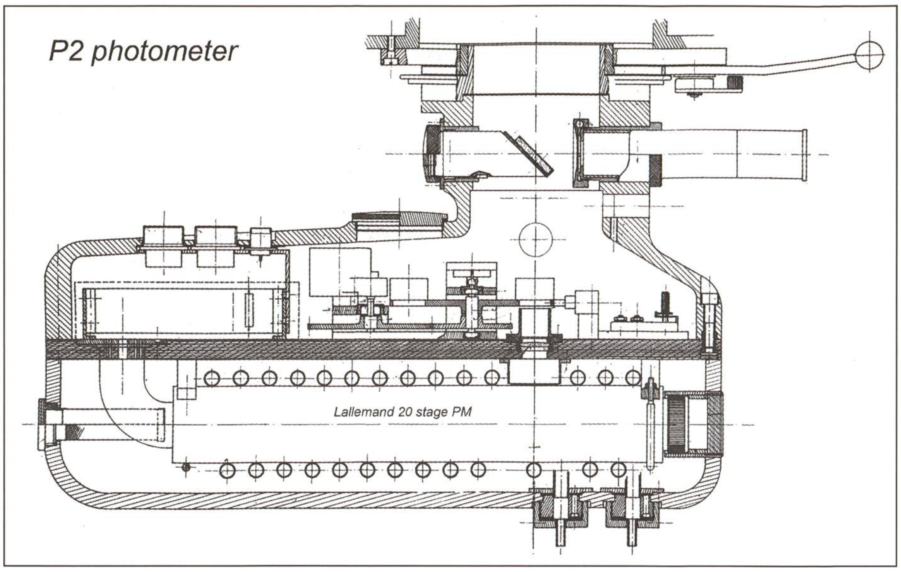
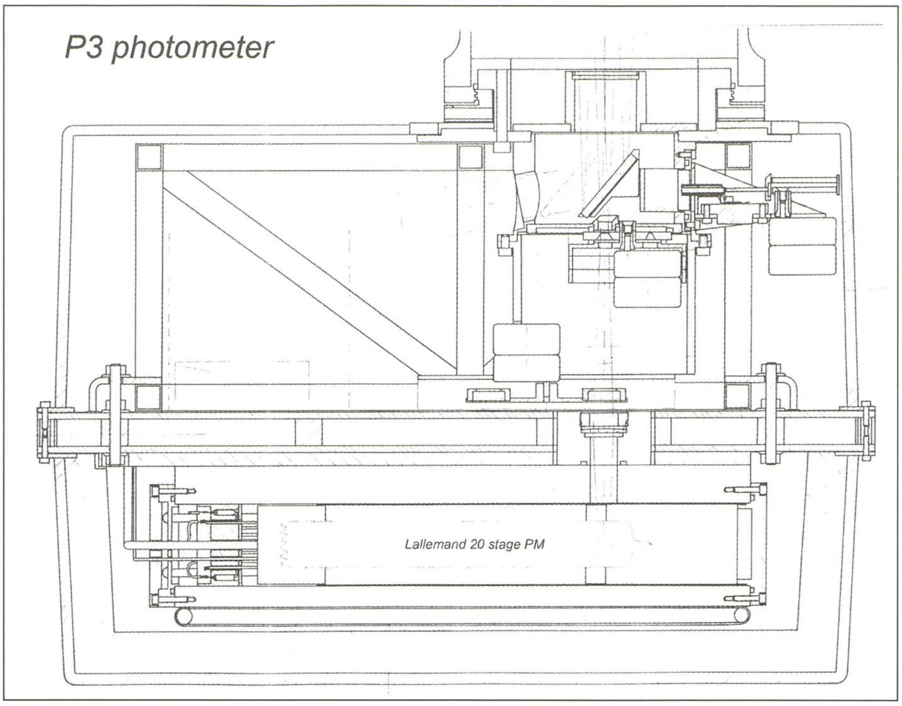


Fig 6: Schematic view of the P2 photometer. After passing the level of a retractable field eyepiece, the starlight goes through a selectable diaphragm before being intercepted by the chosen filter on the filter wheel. It then enters the refrigerated compartment (typically -20°C) containing the magnetically shielded PM through a Fabry lens. The function of the latter is to focus an image of the primary mirror onto the photocathode, thus rendering the measurement less sensitive to the position of the star in the field of the diaphragm. Both compartments are sealed to prevent dust and water vapour from entering.

Fig 7: The P2 photometer mounted on the Gornergrat 40 cm telescope in 1969. Actually, the same equipment (dome, telescope and photometer) was used at the Jungfraujoch Sphinx Observatory until 1968, before it was transported to Gornergrat. It is interesting to note here that in 1974, prior to the installation of the 1 m Lyon telescope at Gornergrat, the mounting and dome were taken over by the Société Astronomique du Haut Léman (René Durussel). The mounting was replaced in 2004, but the dome is still used intensively for public observations at their observatory at La Tour de Peilz.

Fig 8: The Gornergrat Observatory (3130 m) in 1969. The Geneva 40 cm telescope occupied the South Dome at the left. The dome to the right housed a solar spectrometer belonging to Oxford University. The hotel on which the two observatories were set up had been built in 1909, and was in its original condition and derelict at that time. The astronomers lived a monastic life in an environment akin to the scene setting of a ghost movie: broken windows, snow banks in the corridors and creaky precarious floorboards. The only animation was a small cafeteria that opened for the tourists a few hours in daytime.

Fig. 9: Schematic diagram of the P3 – P6 photometers. The principle is essentially the same as for P2, but all operations are motorised. The construction is also more robust.



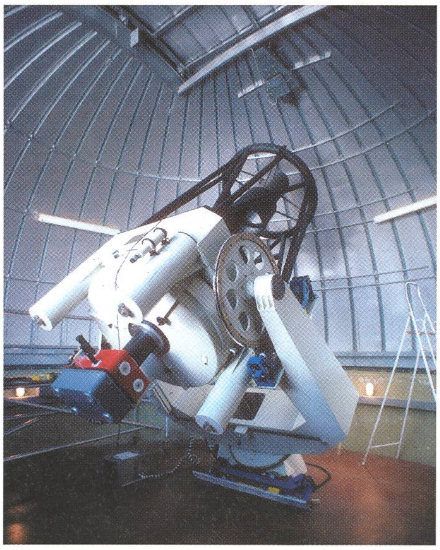
means of a single photomultiplier, revolving filter wheel and beam selecting chopper, became operational in 1975. Since 1977 and up to 2000, P7 was attached to the Swiss telescope at the ESO La Silla observatory and most of the Geneva photometry carried out in the southern hemisphere, indeed most of the entire Geneva catalogue, has been acquired with this last instrument. Since 2001, and up to now, the refurbished P7 photometer has been attached to the 1.2 m Belgian telescope at the IAC (Instituto Astrofísico de Canarias) Cerro de los Muchachos observatory on the island of La Palma. Beginning in 2004, it has been supplemented by a CCD camera using the Geneva system.

The chronology of the four photometers that « made » Geneva photometry may be summarised, up to the present, as follows:

1960-1968 : Photometer P2 attached to a 40 cm telescope at the Jungfraujoch Sphinx Observatory (3585m) in the Bernese Alps. Definition of the standard photometric system by F. RUFENER. In 1968, installation of the present 76 cm telescope at Jungfraujoch. Transfer of the 40 cm telescope and P2 to Gornergrat (3130m) in the Valais Alps. Between 1966 and 1968, photometer P3 mounted on the 1 m Swiss telescope at the Observatoire de Haute Provence (OHP) in France (Fig. 12).

1969-1977 : P2 for the first two years at Gornergrat (Fig. 8), then P3 and P4 operating alternatively at Gornergrat, Jungfraujoch and OHP (in 1974, P2 was purchased by Mons University and sent to

Fig. 10: The P3 photometer installed on the 1 m Lyon Ritchey-Chrétien telescope at Gornergrat.



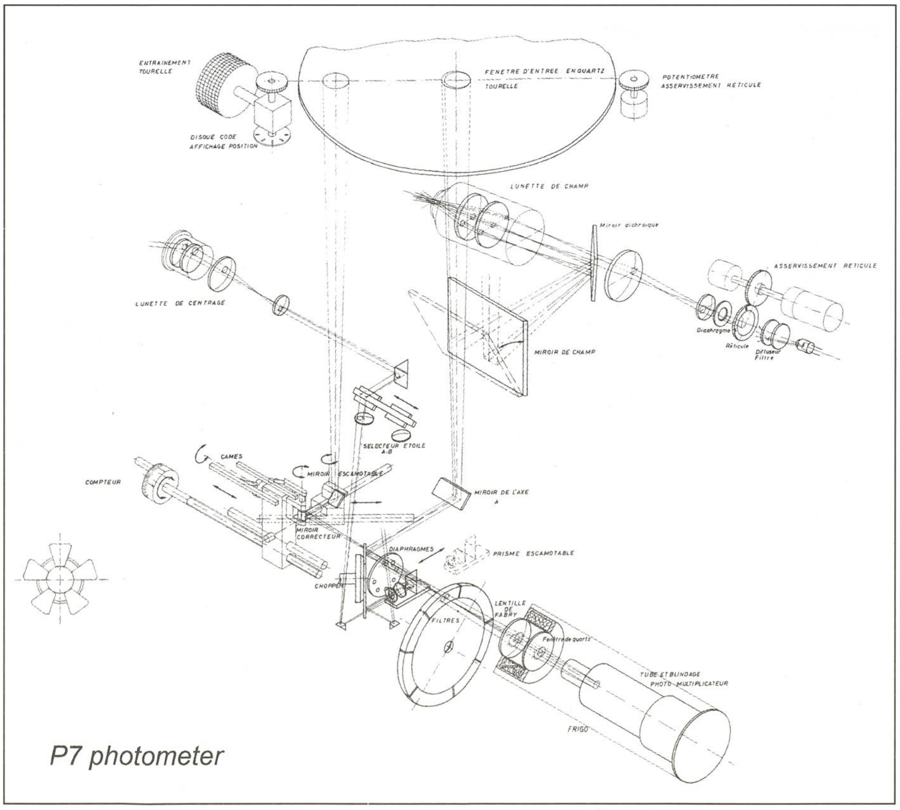


Fig. 11: Schematic presentation of the principle of the P7 photometer. Two nearby fields (typically about 1' apart), the one containing the star plus background, the other just the sky background, are sent as alternating channels to the PM via a system of mirrors and a rotating chopper mirror. After passing through a selected diaphragm, the alternating channels pass consecutively, and repeatedly, through the 7 filters on a rotating wheel (typically at about 240 rpm) before reaching the photocathode. The system effectively functions as a quasi-simultaneous 14 channel instrument (7 star and sky + 7 sky). The colorimetric accuracy is greatly enhanced by this rapid sampling technique.

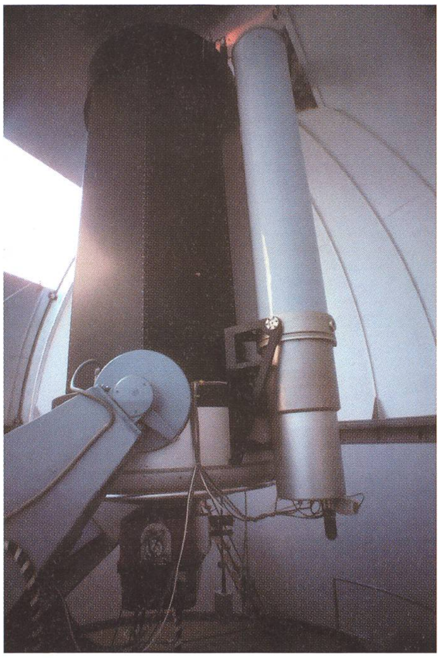


Fig. 12: The P4 photometer on the 1 m Swiss telescope at the Observatoire de Haute Provence, before it was sent to Chile in 1975.

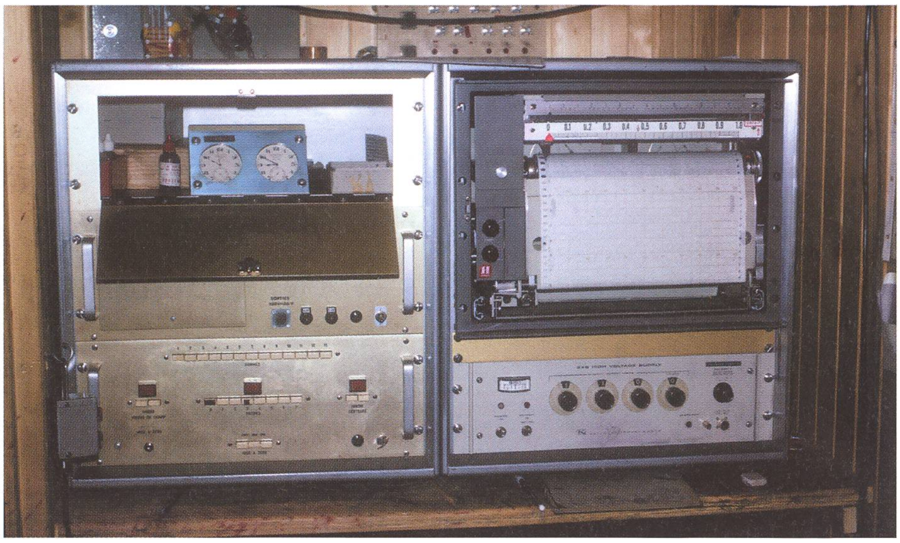


Fig. 13: The chart recorder used with the P3 and P4 photometers. The current from the PM was measured by an electrometric tube and a WHEATSTONE bridge. The left part of the rack contains the commands for the filter selection and the ramp of buttons choosing among a set of 13 resistors determining the sensitivity of the bridge with a step of about 2.15 per level. The observer chose the sensitivity giving a maximum deviation on the recorder for each filter.

their Izaña station on the Canary island of Tenerife). Two short campaigns in 1971 and 1974 at La Silla with P5 temporarily equipped with a set of Geneva filters and attached to ESO telescopes. In 1975, transfer of the 40 cm telescope and P4 to La Silla and beginning of an uninterrupted measurement campaign in November (Fig. 14). Installation of a 1 m telescope at Gornergrat by the Observatoire de Lyon, France (Fig. 10). Sharing of the telescope with the Lyon group; Geneva photometry being done with P3.

1977- 2004 : Installation of the P7 photometer at La Silla. In 1980, replacement of the 40 cm telescope by a 70 cm instrument (Fig. 16). In 1985, removal of the 1 m telescope from Gornergrat. The South Tower is taken over by Köln University who install a new dome and a small millimetre wave radio telescope. Until 2001, all subsequent northern photometry was done at Jungfraujoch with P3 and P4. In 1979, one of these photometers was used for 4 months on the Spanish 1.5 m telescope at Calar Alto (Fig. 15). In 1986, the 70 cm telescope at La Silla was displaced to make room for the construction of the ESO NTT 3.5 m telescope (Fig. 18) and P7 was used at the new site until 2000. In 2001, P7 was refurbished and installed on the Belgian «Mercator» 1.2 m telescope at the IAC Cerro de los Muchachos Observatory on the island of La Palma (Figs. 19 and 20), where it is still in use. Some years earlier, a new photometer P8 based on the rapid sampling technique of P7 but presenting several improvements was designed, but the project was subsequently abandoned.

Fig. 14: The first Swiss Dome at the ESO La Silla Observatory (2400 m) in Chile with the other telescopes in the background (photo: 1983).The 3.6 m telescope lies behind and outside the field of the image. The site is now occupied by the ESO NTT 3.5 m telescope.

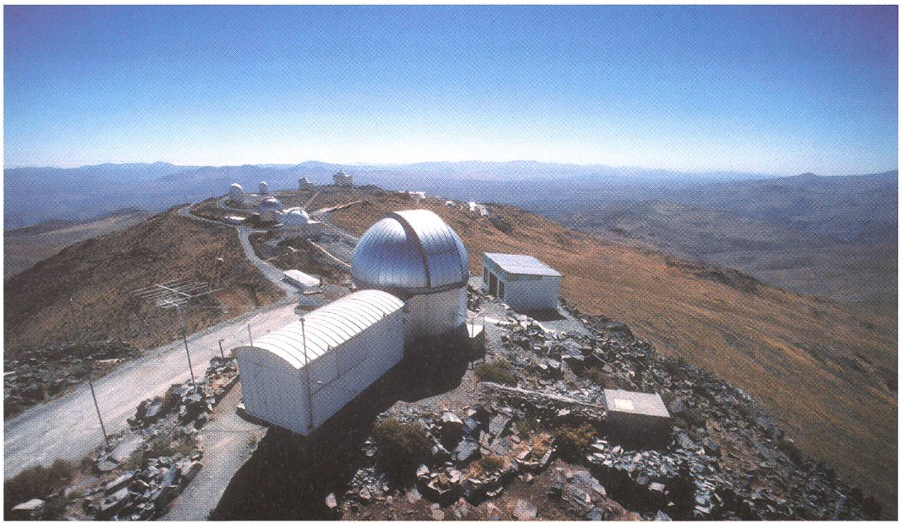


Fig. 15: P3 photometer attached to the Spanish 1.5 m telescope at the Calar Alto Observatory of the MAX PLANCK Gesellschaft, in Spain (photo: 1979).

Fig. 16: The 70 cm Swiss Telescope at La Silla equipped with the P7 photometer.

made their application impractical. The detectors of the early photometers are LALLEMAND 20-stage photomultipliers, used in current-measuring mode and equipped with S-11 photocathodes. The detectors are thermostatically cooled and magnetically shielded. The temperature of the filters is also thermostatically controlled so as to limit drifts of their colour transmissions. FABRY lenses are mounted so as to minimise the effects of imperfect centring in the field limited by the diaphragm, and the photometers are sealed so as to prevent dust and the condensation of water vapour from altering the instrumental response.

P7 is equipped with the same filters and shares the same general features of the earlier photometers, but is equipped with an EMI 9502B photomultiplier which is better suited for pulse counting. The accuracy of the measurement is also significantly enhanced by the rapid sampling technique which simulates a simultaneous acquisition of data in the 7 channels (see BURNET, 1976 ; BARTHOLDI et al, 1984). In all cases, stability was increased by the long term dedication of the telescopes to each photometer.

The instrumental stability is supplemented by the constancy of the reduction techniques (RUFENER, 1964, 1985). The whole data bank is also periodically recalculated, and mean values of colours and magnitudes incorporating the new measurements are computed. At

2.2. Homogeneity of the system

As mentioned above, homogeneity is important in photometry, and the conservation of the system has always been the prime concern of the Geneva photometrists. The limited number of photometers and observing sites has contributed to materialise the conditions necessary to attain that goal.

The instrumental stability was basically achieved for P2 to P7 by using filters coming from the same batch of Schott glass. Interferential multilayer filters were tested initially, but the presence of extensive wings and secondary bands as well as their potential fragility

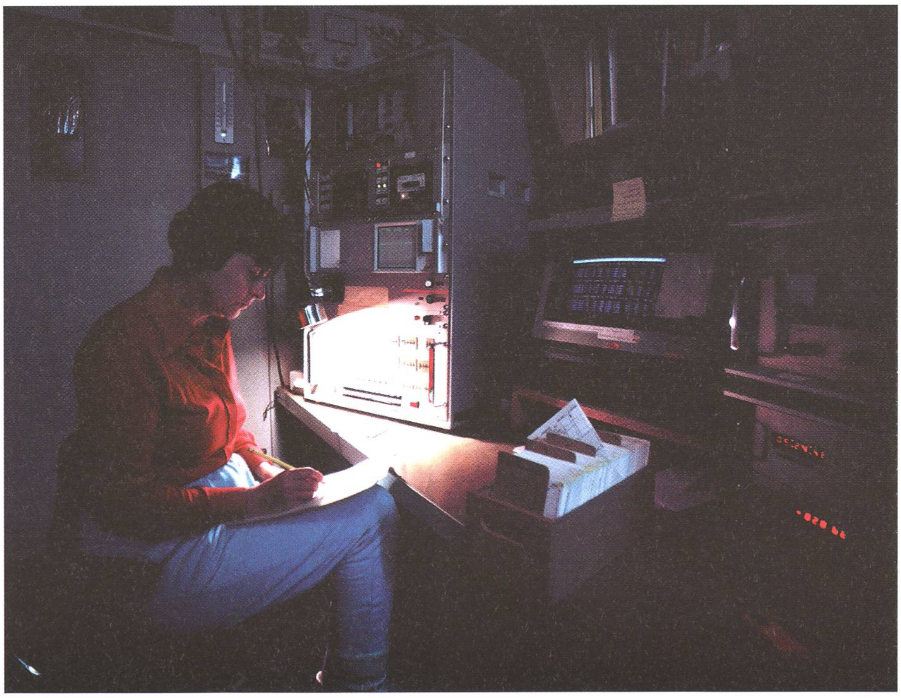


Fig. 17: Working at La Silla with P7 (photo: 1986). Data acquisition is now in digital form and telescope pointing and dome rotation are also automatic.

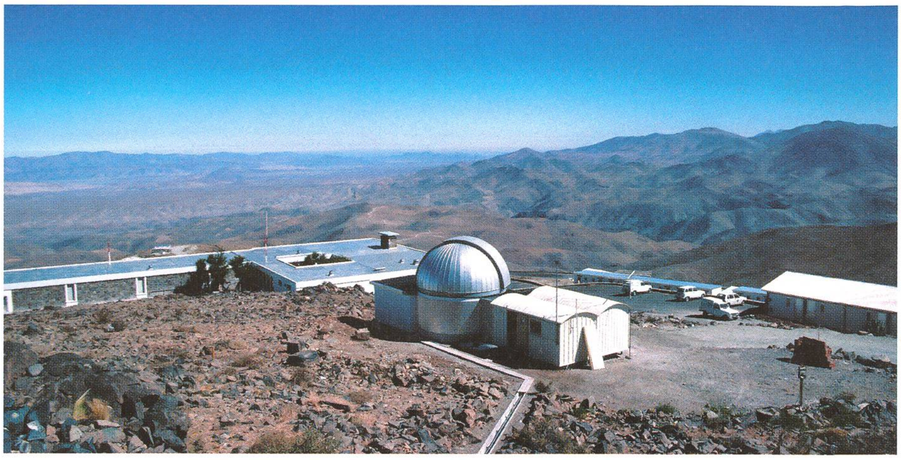


Fig. 18: The second Swiss Dome at La Silla in December 1986, after having been «chased away» by the NTT. One important advantage: the cafeteria is much closer!

the same time, a variety of stability tests based on the inter-comparison of batches of old and new measurements are carried out to ascertain the conservation of the system (see RUFENER, 1981, 1988). These tests have consistently shown that the homogeneity of the colours exceeds the 10^{-3} magnitude level over the whole extent of the catalogue.

The important implication – *exclusive to the Geneva system* – is that calibrations, or any other procedures set up to extract information from the measurements, are unique. They can be applied equally well to all the available reduced data, even to those acquired several decades ago, without any particular adjustments being necessary.

The next section of this article will describe the photometric data and initiate the discussion of their use in astrophysical applications.

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Fig. 19: The Belgian dome at La Palma (2333 m) housing the 1.2 m «Mercator» telescope which was designed by the Geneva Observatory.

Fig. 20: The 1.2 «Mercator» telescope with the refurbished P7 photometer mounted at its Nasmyth focus (right).

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