Zeitschrift: Orion : Zeitschrift der Schweizerischen Astronomischen Gesellschaft
Band: 63 (2005)
Heft: 331

Artikel: Aspects of Geneva photometry : part 7 : peculiar studies
Autor: Cramer, Noël
DOI: https://doi.org/10.5169/seals-897783

Aspects of Geneva Photometry[1]

Part 7 – Peculiar studies

NOËL CRAMER

In this seventh and final part of the series, we present a few examples of some more specific applications of Geneva Photometry.

Fig 79. A peculiar view of the Jungfraujoch Sphinx Observatory (3580 m) with the Jungfrau in the background. The Geneva Photometric System was defined by observations first made from that Observatory in 1960.

7. Photometry? - Spectroscopy?

Photometry in a well defined passband provides one of the fundamental forms of data used in astrophysics. Multicolour photometry goes a step further by measuring stellar spectral energy distributions via flux calibrations for the various bands, or through their relative comparison using colour indices. Multicolour photometry may be regarded as a very low resolution spectrophotometry. Spectroscopy goes much further in resolution by analysing the emitting source (the stellar atmosphere) at the basic level of the quantum states of its atomic constituents. These depend for the most part on chemical composition, temperature, gas pressure, local electromagnetic and corpuscular radiation and magnetic field intensity. The observation from afar, as is our predicament, of the associated spectral features (absorption or emission lines) is furthermore affected by local «dynamics» such as gas turbulence of the medium or, globally; by the star's rotation, or pulsation, or its ejection of large quantities of gas in the form of a «stellar wind», for example. On the whole, the types of information provided by photometry and spectroscopy are complementary.

As we have seen earlier, the multicolour photometric effect primarily reflects temperature. But, the more specifically spectroscopic effects of gas pressure (i.e. surface gravity) affecting the spectral line profiles, for example, are also perceived by photometry because of spectroscopic «redundancy» – i.e. the *collective* and similar influence of discrete spectral features which modify the spectral energy distribution on a larger scale. Some additional cases may occur:

- Other, still finer spectral features related to stellar physics can also produce specific multicolour effects, provided the photometry is sufficiently accurate and homogeneous, and thus allow correlations to be established.
- In some cases, spectroscopic and multicolour photometric effects can both be large – though not necessarily correlated – and provide complementary information.
- Single-colour photometry can sometimes be more directly informative than multicolour data or spectroscopy.
- Single-colour photometry may provide the only useful data - multicolour data and spectroscopy being superfluous.

Examples of these four circumstances are given below.

7.1 Peculiar stars

Early in the 20th century, it was recognized that the A-type stars had line spectra showing much more diversity than other types. W.W. MORGAN pointed out in 1935 that the large differences observed among A-type stars for the line strengths of singly ionised calcium (Ca), manganese (Mn), mercury (Hg), silicon (Si), strontium (Sr), chromium (Cr) and europium (Eu) could not be explained by differences of temperature and surface gravity alone. The term «peculiar A» or Ap began to be used around that time for those unusual stars that were so difficult to classify.

MORGAN, and other spectroscopists also noted a temperature dependency of the anomalous abundances: strong Mn lines were seen notably among B8 to A0 types whereas Eu lines were stronger for the cooler A0 to A3 types. The subclassification of the Ap stars became quite sophisticated, and a periodic relative variability of the line intensities was often detected.

In photometry, peculiar Ap stars are quite well detected as seen in the XZ diagram of Fig 80. The temperature dependence indicated by the X parameter is clear – decreasing from the «Si» stars (about B8) and «SiCr» (about B9) to the cooler «SrCrEu» category at A0 – A3. The latter are most numerous, but are not fully shown here because of the cutoff at Y < -0.08. This is even better seen in the XY diagram of Fig 81. For Si stars the temperature range is 18000°K > T_{eff} > 11000°K, for Si,Cr 14000°K > T_{eff} > 10000°K and for Sr,Cr,Eu 12000°K > T_{eff} > 8000°K.

---

[1] Based on data acquired at the La Silla (ESO, Chile), Jungfraujoch and Gornergrat (HFSJG International Foundation, Switzerland), and Haute-Provence (OHP, France) observatories.

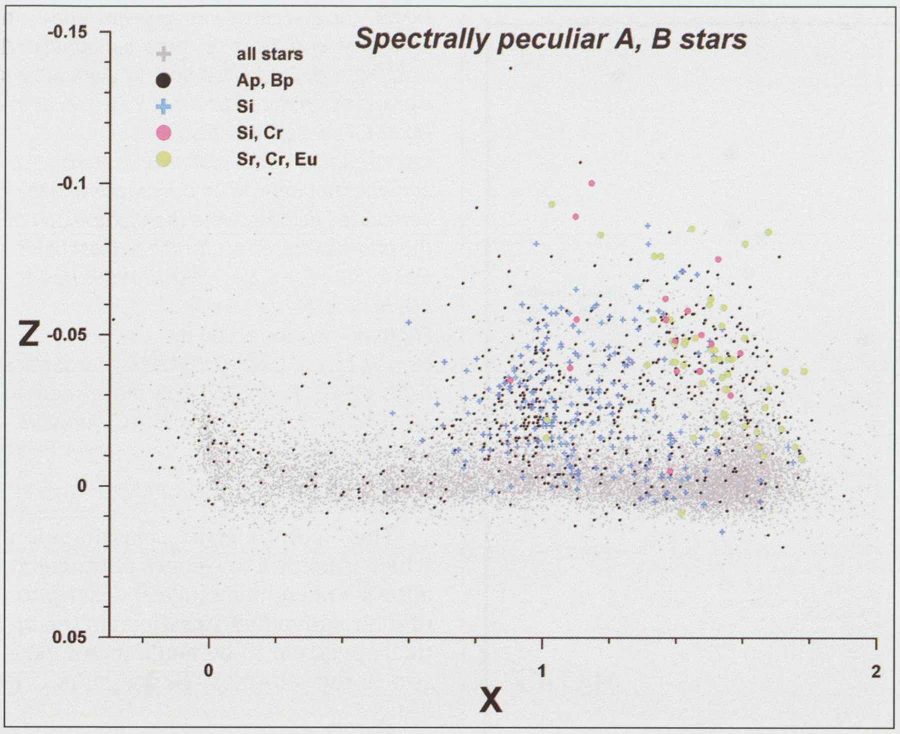


Fig 80. The locations of the various classes of Ap stars in the restricted (Y > -0.08) XZ diagram relatively to the normal sequence (shaded). The spectrally peculiar stars clearly stand out with negative Z values.

The most striking photometric feature is, however, the small but significant negative deviation in the Z parameter of the Ap stars. This effect was shown to be related to the stellar magnetic field intensity by P. NORTH and by CRAMER and MAEDER in 1980 (Fig 82).

Following the successful measurement of the magnetic fields of sunspots, as well as of the general solar field by ZEEMAN spectroscopy in the first years of the 20th century, the study of stellar magnetic fields had to await the advent of sensitive instrumentation used with large telescopes in the 1940s and the work of H. BABCOCK. A first catalogue of magnetic stars was published by him in 1958, where most of the detections turned out to be Ap stars. These showed very strong fields reaching several thousand kilogausses (kG) with often variable polarity. The variation of polarity was eventually interpreted as a dipolar field oriented obliquely to the star's rotation axis, and thus periodically presenting one pole, then the other, to the observer. It is now accepted that the oblique rotator model is largely correct, and that magnetic fields play an essential role in the Ap phenomenon. A strong magnetic field influences the diffusion of ionised heavy elements in the stellar atmosphere and concentrates them unevenly over the surface. Rotation then causes the observed spectral variability as different regions of the star face the line of sight.

The particularly slow rotation velocities observed for Ap stars are consistent with the atmospheric stability required by diffusion processes. Ap stars are, however, also seen to pulsate with periods that can be as small as a few minutes. If diffusion does really play an important role in the distribution of elements, then the pulsations have to be such that they do not cause much mixing of the stellar atmosphere.

The spectroscopic effects are subtle, and the theoretical treatment of diffusion in a strong magnetic field (not necessarily dipolar) is complex. The subject is still not resolved and much debated.

Photometry detects a broad absorption feature at 5200 Å within the range of the V1 band and to which the Z parameter is most sensitive (see sensitivity indicators in Fig 87). Its correlation with the stellar magnetic field intensity is unquestionable (Figs 80 and 82). The photometric effect breaks down for surface fields in excess of about 5 kG. This is presumably related to the decoupling of atomic spin-orbit interaction by very high fields (PASCHEN-BACK effect). The cause of the 5200 Å feature has, however, not yet been satisfactorily explained. Nevertheless, the ultimate treatment of

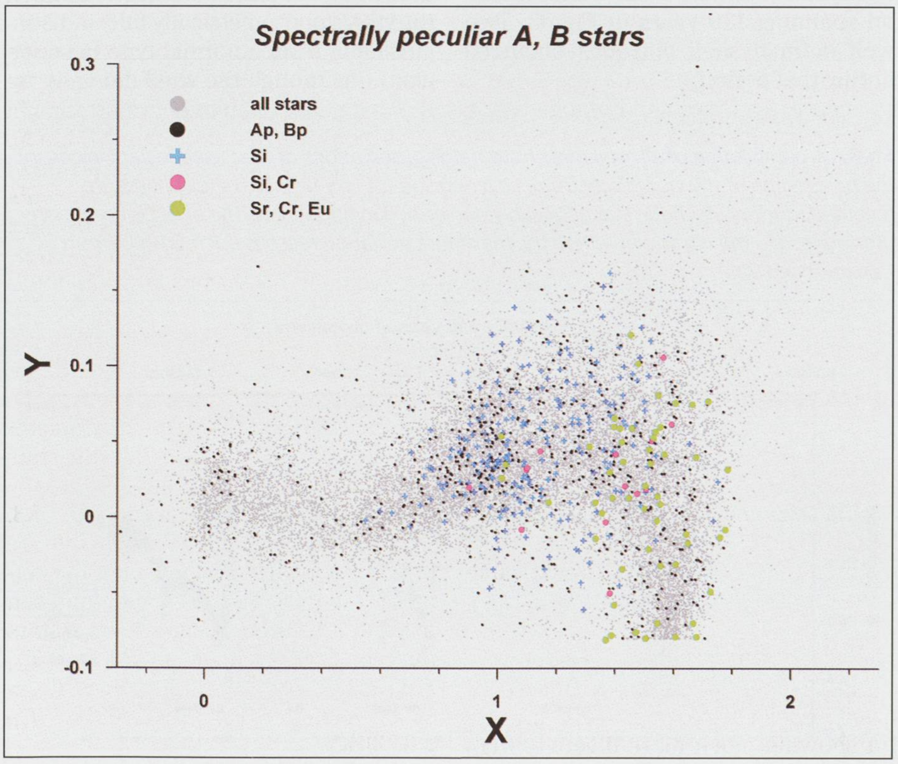


Fig 81. The locations of the various classes of Ap stars in the restricted XY diagram. The calibrations given in Part 3, Orion 326, give for Si stars the temperature range 18000°K > T_{eff} > 11000°K, for Si, Cr 14000°K > T_{eff} > 10000°K and for Sr, Cr, Eu 12000°K > T_{eff} > 8000°K. The black dots are stars simply classified as «peculiar» by spectroscopy. The various types of Ap stars are not restricted to the young class V sequence, but also occupy the location of more evolved class III stars.

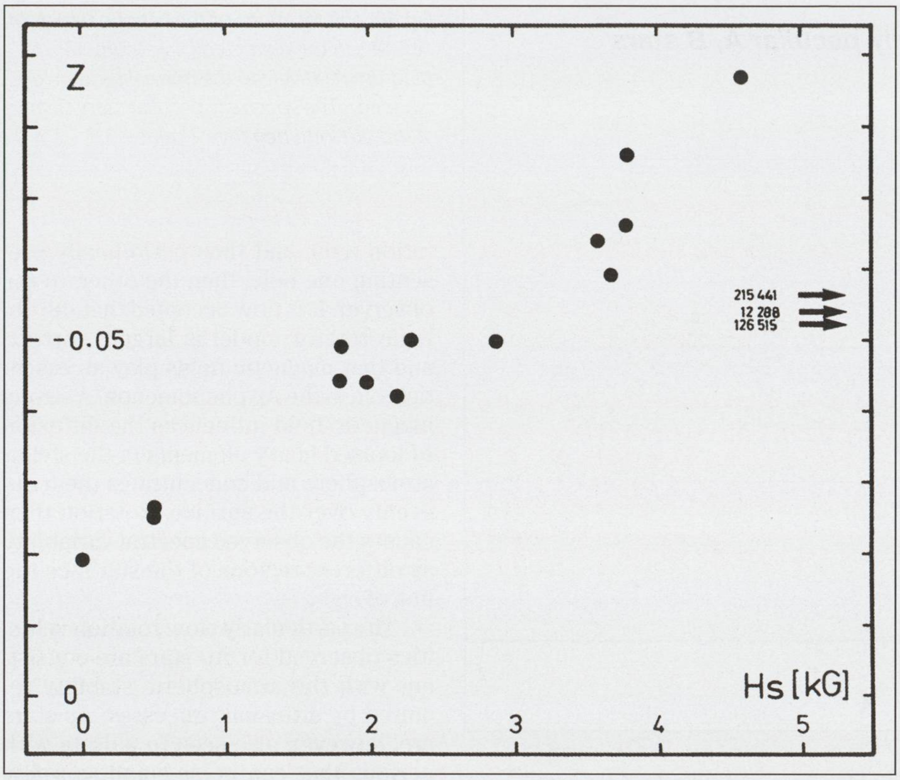


Fig 82. The first correlation between the Z parameter and the mean surface magnetic field intensity Hs derived by G.W. PRESTON for a group of Ap stars (cut-off at Y < -0.08 as in Fig 81). The «surface» field Hs is representative of the global field intensity, and does not depend on orientation like the «effective» field He. Note the «saturation» of the photometric effect for the highest fields (HD 12288: 6.1-8.8 kG, HD 126515: 16.1 kG, HD 215441: 33.9 kG).
Photometry is correlated by:
$Hs = -0.15 + (0.02Z - 0.0042)ZT_{eff}$ for surface fields < 5 kG. T_{eff} is defined by the relation given in Part 3, Orion 326 (from CRAMER and MAEDER, 1980).

the question lies in the hands of the spectroscopists and stellar atmosphere theoreticians. Indeed, a photometrist speaking up at a colloquium concerning magnetic Ap stars is sometimes looked upon as a vagabond turning up uninvited at a cocktail party.

7.2 Pleione's shell

B-type stars presenting emission in the hydrogen lines have been known since the mid-1860s. But, their notation as «Be» was first adopted in 1922 during the first General Assembly of the IAU in Rome. A subclass of Be stars are the «shell stars» which present hydrogen lines having narrow dark cores implying an extended atmospheric layer – or «shell» – above the photosphere. Be stars constantly emit strong and variable stellar winds. Some of these are more highly active and undergo «shell events».

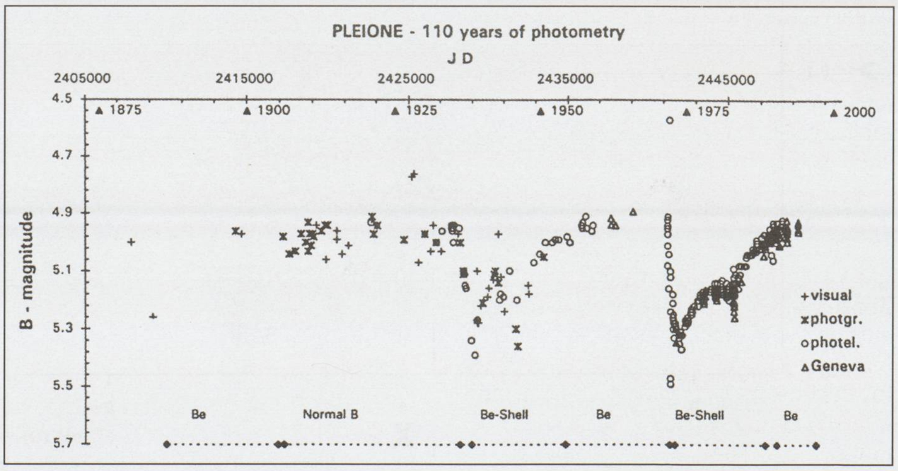
Phase transitions in Be stars, from Be to Be-Shell and/or «normal» B are known to exist since the beginning of the 20th century. But they have rarely been well observed because of their unpredictability. However, the existence of phase changes carries important implications. From the observational viewpoint, phase changes are particularly interesting because these changes show the largest amplitude of variability that a given Be star has the capacity to produce. The variations between a strong Be phase and a strong Be-shell phase of an individual Be star are incomparably larger - in line spectrum and in light, and in any observable wavelength - than any change occurring in a given phase, Be or shell. Quite generally, such phase changes are challenging from the theoretical modelling viewpoint.

One of the most notorious shell stars is the Pleiades cluster member Pleione (BU Tau, 28 Tau, HD 23862, B8Ve, a fast rotator with v sin i = 320 km s^{-1}). Its variability in the B band is shown for a period spanning 110 years in Fig 83. Two well defined shell episodes occurred during that period.

The colorimetric classification, which is natural to Geneva photometry, allows a phenomenological description of the relative flux variations in the optical spectrum to be made in comparison to the «normal» B-type stars (Fig 84).

The «evolution» of Pleione in the X,Y diagram is quite striking. If one compares its successive locations in that diagram with those of the various spectral types, one notes that it starts out from the vicinity of the main sequence B7V-B8V stars (Be phase, 1962-72), «evolves» up to the luminous supergiants branch among the A5Ia to F0Ia stars (maximum of shell phase) and finally returns to its initial place among the main sequence late type B's as the shell spectrum vanishes, leaving the star in a well-developed Be phase (1988-1993). It is interesting to point out here that, at the maximum of the shell phase, the star is photometrically fully indistinguishable from a normal type Ia supergiant - as though the shell did truly re-

Fig 83. A compilation of all available photometric observations of the Pleiades star Pleione in the blue region of the visible spectrum, covering some 110 years. Two shell phases are recorded, during which the star noticeably diminished in brightness. The effect is even more pronounced in the ultraviolet where the maximum deviation reaches 0.8 mag in U (from CRAMER et al, 1995).



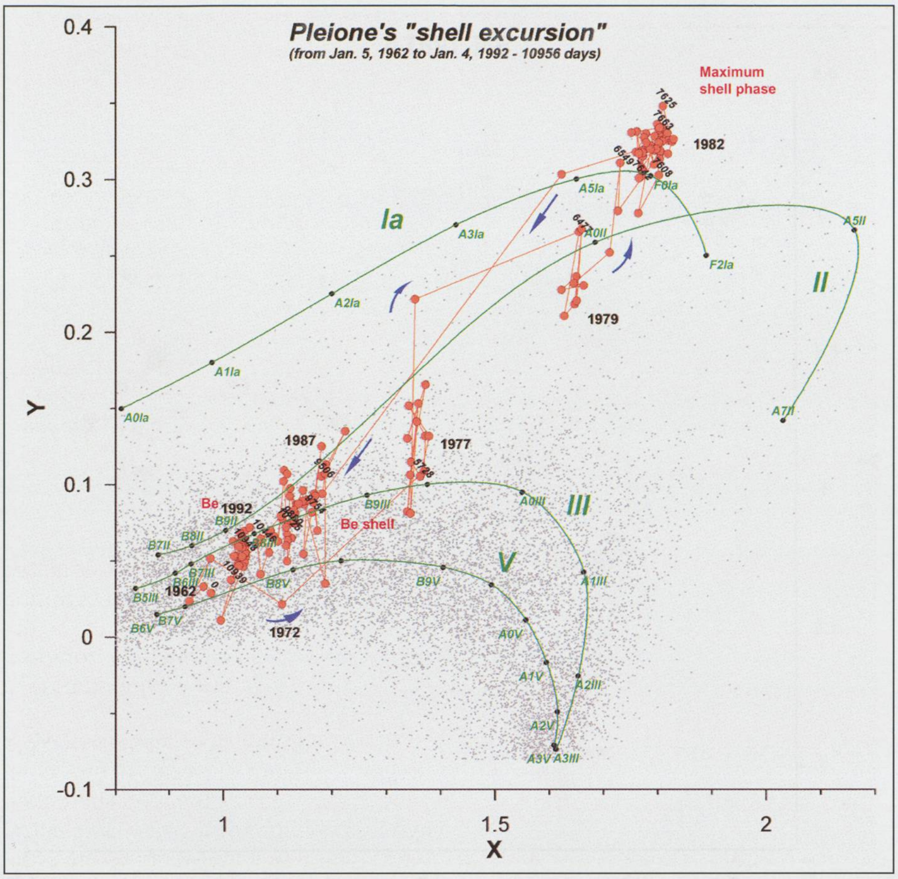


Fig 84. The «shell excursion» of the Pleiades star Pleione as seen in the XY plane with Geneva photometry done between January 5, 1962 and January 4, 1992. Starting out as a B7.5Ve it photometrically mimics a more evolved star, reaching the photometric supergiant sequence as a late A-type before gradually returning to its original location as a Be star on the class V sequence. During its «supergiant» phase, it became colorimetrically indistinguishable from a real supergiant with an extended atmosphere – as one would expect in the case of a shell that could also take the form of a «thick disk». Paradoxically, Pleione's brightness was least at that phase (see Fig 83).

Fig 85. The optical light curve of SN 1987A during the 869 days following its outburst. It is interesting to recall that the radiated light energy (~10^{49} ergs) represents only 1% of the kinetic energy which, likewise, equals 1% of the energy dispersed by neutrinos (~10^{53} ergs). A Supernova is in fact a «neutrino event»! The green curve corresponds here to the actual measurements made with a 21" diaphragm. However, the field also contained two faint companion stars located at 2.9" and 1.6" from SK -69°202 with V magnitudes 14.96 and 15.82, respectively. Their relative contribution is insignificant until day 600 when the corrected light curve (in red) visibly detaches itself from the composite one. The behaviour of the light curve is explained in the text.

produce the properties of the extended atmosphere of such a luminous and massive star. This also means that, seen from a «photometrical» viewpoint, a single measurement of a Be star spuriously made during a shell phase will grossly misclassify it, overestimate its intrinsic luminosity and, consequently, its distance.

The underlying mechanism of a Be star's shell event is still poorly understood. The study of the phenomenon requires photometric and spectroscopic data gathered over the whole electromagnetic spectrum during the shell episode. Photometric observations in the optical range alone, such as those shown above, are necessary but do not provide enough constraints to definitely serve the theoretical solution of the problem. The astronomer's observational armoury is presently very powerful and quite fit for the task. What is still missing regarding Pleione is the next shell event.

7.3 Supernova!

The supernova 1987A appeared in the Large Magellanic Cloud (LMC) on February 23, 1987, a few days after the author (who had been observing the LMC) had left the La Silla Observatory for the blissful isolation of Easter Island – far from any worldly (or heavenly…) news.

SN 1987A was the first supernova with a formerly known progenitor. The massive blue OB giant SK -69°202 nicely confirmed stellar evolution models with strong mass loss by stellar wind com-

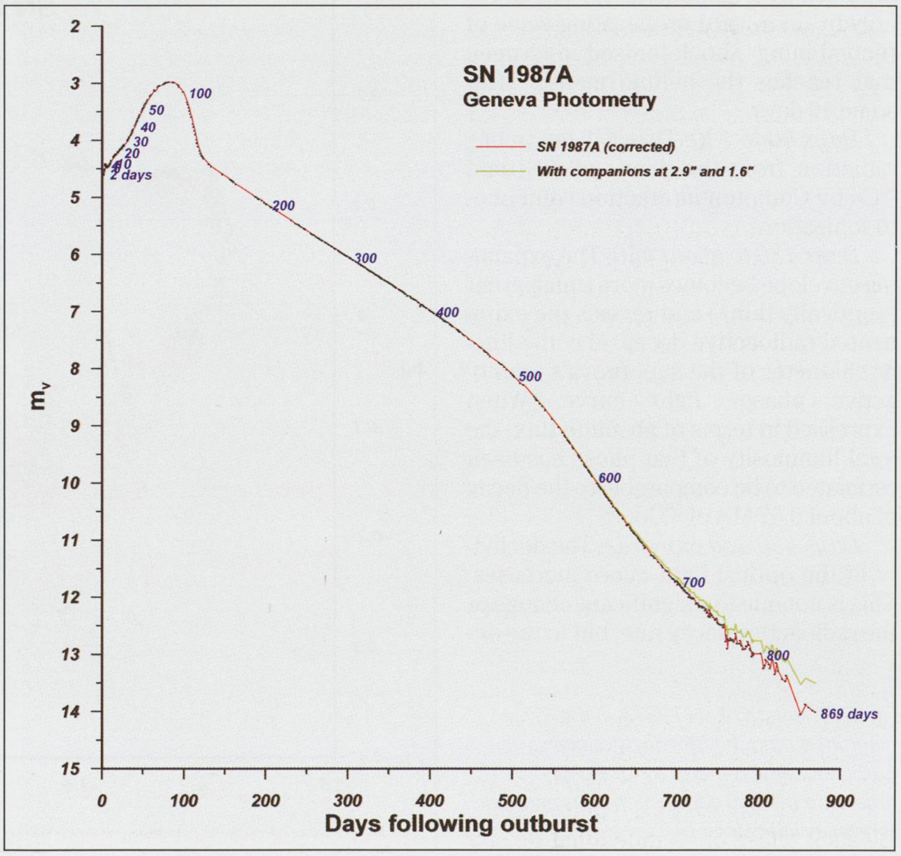
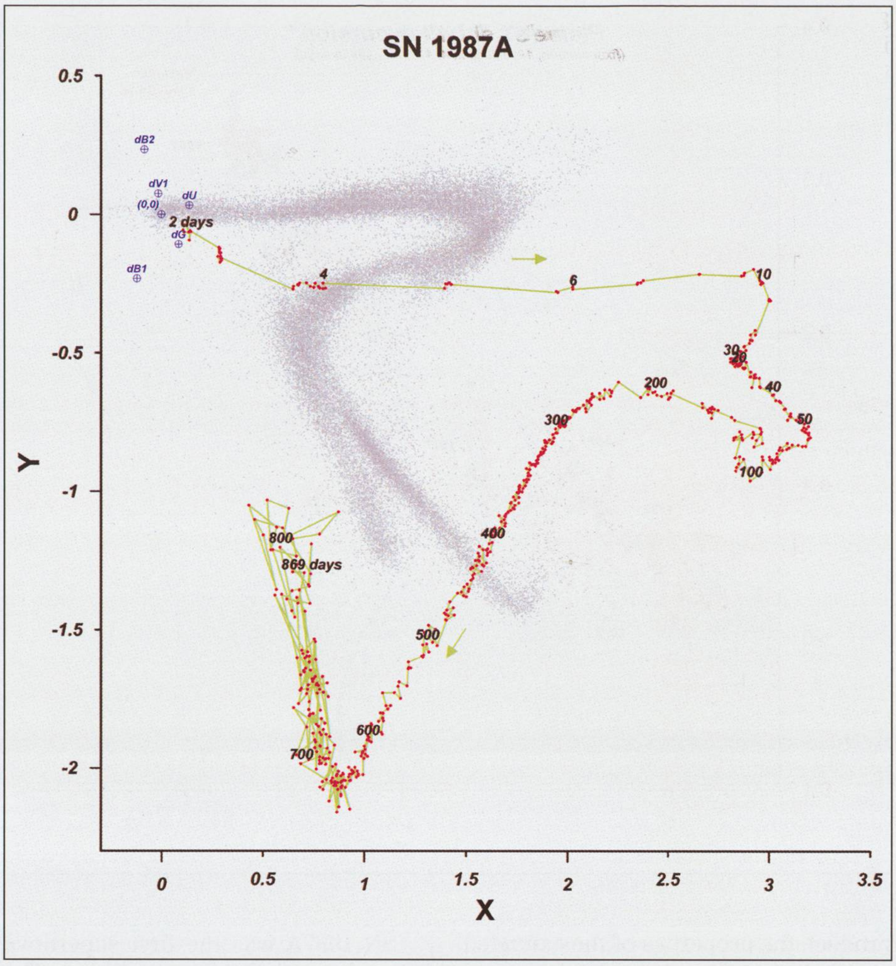


Fig 86. The path of SN 1987A in the XY diagram during the 869 days following its outburst. The parameters were not corrected here for the two companion stars, and their colours bias the path toward higher temperatures after day 700. The sequence of normal stars is shown for comparison. The sensitivity of the diagram to variations of 0.1 mag in each colour is indicated by the blue symbols relatively to the zero-point. Because of the use of magnitudes, the directions correspond to a decrease in relative flux.



puted by André Maeder (see Orion 230, Feb. 1989, p 7), which predicted possible blue progenitors. At that time, it was still widely held that a supernova explosion directly followed the red supergiant phase.

Probably the best ground-based sequence of photometric observations of the first year and a half of the light curve was carried out in the Geneva system due to the permanent dedication of the 70 cm «Swiss Telescope» at La Silla to the P7 photometer. The observations were facilitated by the fact that the LMC is circumpolar at the La Silla site (G. Burki et al). The visual light curve of SN 1987A is shown in Fig 85, and can be interpreted in terms of a type II core-collapse supernova as follows:

First few days: A short, transient increase in luminosity due to the shock-provoked expansion of the stellar surface is first observed. This is then followed by a continuous release of energy by an inward propagating wave of recombining shock-ionised hydrogen that reaches the helium mantle after some 40 days.

Days 40 to 130: Thermalization of γ radiation from the decay of ^{56}Ni and ^{56}Co by Compton interactions and photo-ionization.

Days 130 to about 450: The expanding envelope becomes more transparent («optically thin») and reveals the exponential radioactive decay – i.e. the linear character of the supernova's «radioactive phase» light curve. When expressed in terms of absolute flux, the total luminosity of that phase has been estimated to be comparable to the decay of about 0.07 $M_\odot$ of ^{56}Co.

Days 450 and onwards: The declivity of the optical light curve increases. This is not due to a significant change of the radioactive decay rate, but to the on-

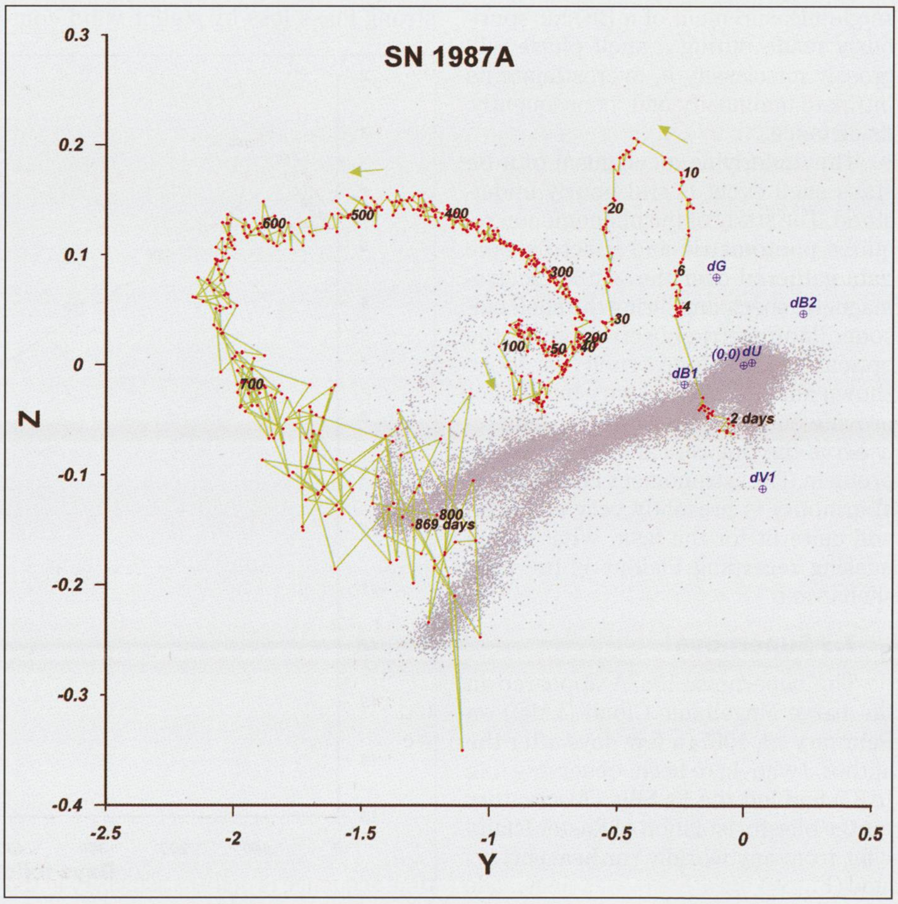


Fig 87. The path of SN 1987A in the YZ diagram during the 869 days following its outburst. Same remarks as for Fig 86 regarding the two companion stars and the sensitivity indicators.

going formation of dust in the expanding shell. The radiated energy is increasingly released in the infrared at the expense of shorter wavelengths.

The evolution of the supernova's colours is shown in Figs 86 and 87. The latter bear little in common with the sequence of «normal» stars rendered in the background in these figures. The parameter diagrams are more difficult to interpret, and their sensitivities to variations in each colour are given by the blue symbols surrounding the diagram's zero point. The deviations correspond to an increase of 0.1 mag in each colour – which reflects a relative *decrease* in flux in the spectral range covered by the band (because of the use of «magnitudes»).

Initially, spectroscopy played an important complementary role; notably by measuring the velocity of the expanding shell of gas. The maximum expansion rate was estimated to be 40000 km s^{-1} at the time of the shock breakout at the stellar surface. The first measurements by the IUE satellite made some hours after detection gave 35000 km s^{-1}. The expansion has presently stabilised at about 2600 km s^{-1}.

The outburst subsequently revealed the three puzzling ring-like structures caused by earlier activity of the progenitor. No evidence of a remnant neutron star or black hole has yet been observed. We may however recall that, some weeks after the outburst, astronomers at the Cerro Tololo Inter-american Observatory in Chile reported electromagnetic pulses in the millisecond range. However, these were soon identified as electronic interference from a nearby monitoring camera.

7.4 Trapped by Penelope!

Stars are not the only objects that are liable to be studied by multicolour photometry. In October 1980, the M class asteroid 210 Penelope having a diameter of roughly 70 km was favourably positioned at opposition. That minor planet has a very short synodic rotation period of $3^h44^m52^s$ and, at the time of its 1980 opposition, showed a large total visual light variation of 0.52 mag with two distinct maxima and minima (Fig 88).

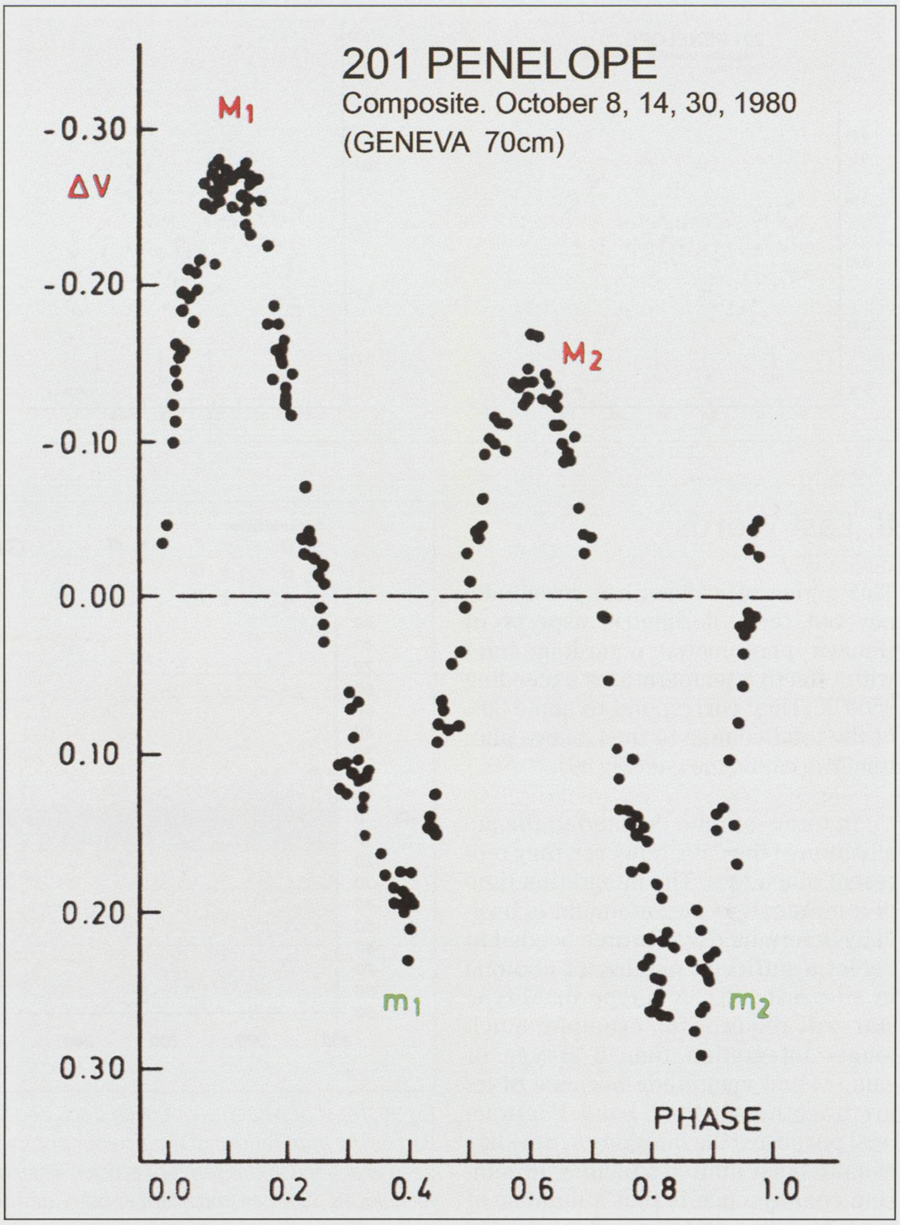


Fig 88. The optical light curve of 201 Penelope (from Surdej et al, 1983). The short synodic rotation period of $3^h44^m52^s$ and the relatively large amplitude of Penelope's light variation mean that extra precautions have to be taken when doing multicolour photometry with non-simultaneous exposures.

It was interesting at that time to explore the possibility of detecting slight colour variations over a rotation period. Such variations had previously been reported by some observers for other asteroids, but without any conclusive evidence.

Measurements of 210 Penelope done in UBV by Jean Surdej with the ESO 50 cm telescope did seem to show a significant colour variation over a rotation period (Fig 89). An attempt was then made to confirm these variations with the 70 cm Geneva telescope at La Silla. But, since the photometric reductions in the Geneva system were not done in real-time as is presently the case, a rough estimate made on the spot did not rule out colour variations and, indeed, tended to suggest them – though with a different periodicity.

The final reductions of the Geneva measurements done a few weeks later did not show any significant colour variations (Surdej et al, 1983). So, what went wrong?

The ESO UBV measurements were made with a single-channel photometer that measured the three colours sequentially with 40 second exposures. That time sequence is quite satisfactory in the case of most stellar observations where variations are much slower (except for some eclipsing variables or dwarf Cepheids, for example). But, in the case of the particularly steep light curve of 210 Penelope, separations of almost one minute in time to measure the two components of a colour index become significant. The asteroid's light intensity has had time to vary sufficiently between two exposures and to bias the true index by the light curve's gradient! The Geneva P7 photometer which measures the 7 colours quasi-simultaneously was not affected by that problem and no colour variation was seen.

So, resist the temptation to seduce data of heavenly bodies bearing incorruptible names.

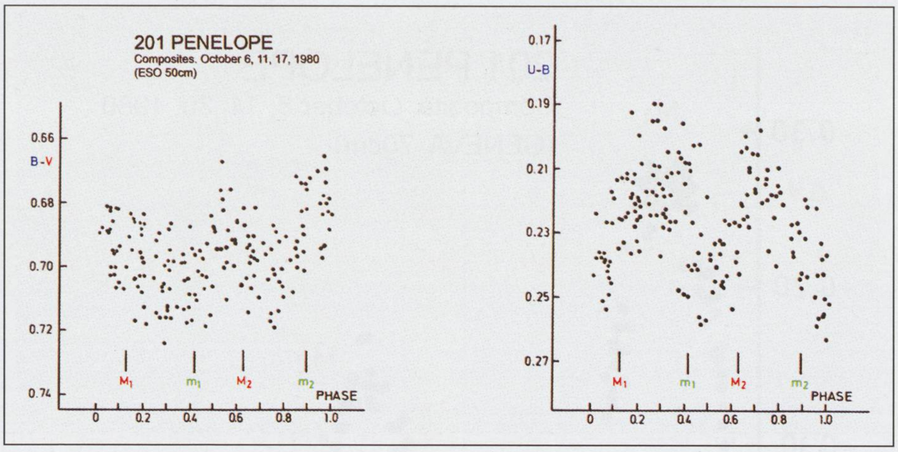


Fig 89. The «colour variations» detected with the ESO 50 cm telescope (from SURDEJ *et al, 1983). The variations were in fact due to the consecutive nature of the 40 sec U, B, V exposures. The asteroid's light variability was fast enough to bias the indices by the light curve's declivity.*

8. Last words

This series of articles has essentially covered the colorimetric aspects of Geneva photometry regarding stars with effective temperatures exceeding 9500°K. They correspond to some 30% of the total volume of the Geneva photometric catalogue (see Fig 90).

In terms of time devoted to the acquisition of the data, however, they represent much less. The integration time of a multicolour measurement is basically determined by the time needed to detect a sufficient number of photons in all passbands. A K-type or M-type star will require, for example, much longer integration than a B-type of same visual magnitude because of its low brightness in the U band. For practical purposes, the integration time has usually been limited to about 10 min. One consequence is that a number of the K-M stars tend to be under-sampled regarding the U measurement. The other consequence is that the time devoted to the measurement of the hottest stars mentioned above is not that of their proportional presence in the catalogue. All things considered, we may estimate it as amounting to ~15% of the total observational effort in the Geneva catalogue.

The colorimetric analysis of the cooler stars requires different strategies and techniques. Effects due to differences of chemical composition are more important because of greater photometric sensitivity – but also due to the greater variety of compositions encountered in those stars which are of very different ages and origins. Moreover, interstellar extinction effects tend to be confused with those of chemical composition and render a reddening-free representation, such as we have been using, much less straightforward.

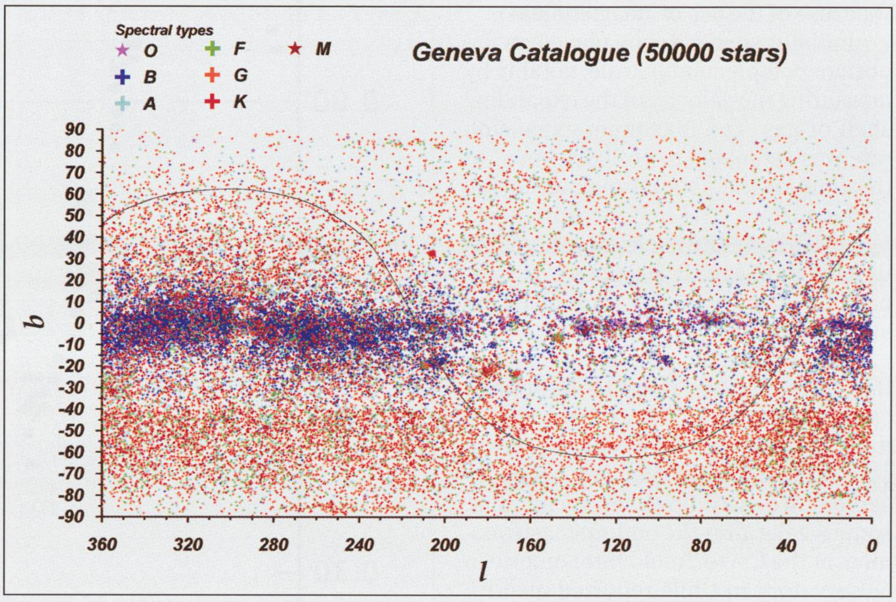


Fig 90. Most of what has not been discussed in this series of articles. Compare with Fig 74, Part 6. The applications of multicolour photometry to the stars of types later than A have not been examined in this series of articles. Their analysis has to be carried out using different techniques. Note an important «observational bias» of the data: the band of F, G, K, M stars at b < -40° corresponds to an extensive survey surrounding the south galactic pole.

Geneva photometry has also been extensively used – and is still being used – in the study of stellar variability due to various forms of pulsation. Here, the colorimetric information is less important than the measurement of periodic variability. Some studies involve light curve amplitudes of only a few millimagnitudes.

A number of eclipsing variables have also been thoroughly studied in the system. As for pulsating variables, eclipses provide important clues to stellar constitution and furthermore give direct access to stellar radii and masses.

Each of these further aspects – without mentioning the photometry of open clusters acquired in the Geneva system – is worthy of a whole new series of «Aspects» articles.

But – written by other authors!

NOËL CRAMER
Observatoire de Genève
Chemin des Maillettes 51, CH-1290 Sauverny

Bibliographie 7

BURKI, G., CRAMER, N., NICOLET, B.: 1991, *The optical light curve of SN 1987A in Geneva photometry*, A&A Sup. 87, 163

CRAMER, N., DOAZAN, V., NICOLET, B., DE LA FUENTE, A., BARYLAK, M.: 1995, *Colour and light variations of Pleione between the Be and shell phases*, A&A 301, 811

CRAMER, N., MAEDER, A.: 1980, *Relation between Surface Magnetic Field Intensities and Geneva Photometry*, A&A 88, 135

NORTH, P.: 1980, *A Photometric Way to the Surface Magnetic Field of Ap Stars*, A&A 82, 230

SURDEJ, J., LOUIS, B., CRAMER, N., RUFENER, F., WAELKENS, C., BARBIER, R., BIRCH, P.V.: 1983, *Photoelectric lightcurves and rotation period of the minor planet 201 Penelope*, A&A Sup. 54, 371