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NOTES FOR THE OBSERVER

by T. P. Prabhu

1. Two hundred years of Cepheid variables

From the beginning of the present century the classical Cepheids have been used as effective tools for a study of the distance scale of the universe. They have thus fully justified the title 'the most important stars' given to them by Harlow Shapley. As we shall see below, the Cepheids provide the best means of determining distances to the nearby galaxies, which is an important step towards estimating Hubble's constant. Cepheids are therefore of great help in solving puzzling problems of cosmology involving the past and the future of the universe.

Cepheids, like galactic clusters, have also been used in the studies concerning the distance scale, rotation and spiral structure of our own Galaxy. They also provide useful criteria for the observational verification of post-main-sequence evolutionary calculations for massive stars. By comparing the predictions of pulsation hypothesis with observations, our understanding about the internal structure of F and G supergiants can be improved.

Discovery

The story of variable stars dates back to the first half of the eighteenth century. After the two brilliant galactic supernovae of 1572 and 1604 which were studied by Tycho and Kepler respectively, the light variation of ο Ceti was discovered by Holwarda in 1638. This star, popularly called Mira, the Wonderful, was studied in detail by Bullialdus in 1667 who reported a period of 333 days for the variation of its brightness. Edmond Halley confirmed the novalike variability of three stars in Cygnus that were first noticed in 1600, 1670 and 1686. The variability of β Persei was discovered in 1667 by Montanari.

In 1781, at York in the northern part of England, an astronomical alliance between Edward Pigott & John Goodricke had commenced which resulted in a number of spectacular discoveries. Under the guidance and encouragement of Pigott, a deaf and mute teenager Goodricke began the observations of supposedly variable stars in the constellation of Cygnus. Pigott & Goodricke together also studied the light variation of β Persei. Not only did they calculate the period but also proposed the theory of an eclipsing body circulating around the star to explain the light variations. Goodricke, in late 1984, discovered the variability of β Lyrae and derived its light curve. Though the constellation Cepheus was not included in the program of observations, it seems that it was sheer familiarity with the sky that led Goodricke to suspect on 1784 October 20 some variation amongst the stars ζ, ι, δ, ε and ξ Cephei.

He continued observing these stars of Cepheus on the following two nights and was convinced by October 23 that δ Cephei was the one varying in brightness. However it was after eight months—in 1785 June—that he sent his results containing the light curve and period of variations to *Philosophical Transactions of the Royal Society of London*. Goodricke further observed this star for more than a hundred nights, but did not live to report the high asymmetry of the light curve which his observations indicated. On 1786 April 20, at a young age of twentyone, Goodricke died of pneumonia. Meanwhile in 1784 itself Pigott had discovered another short period variable η Aquilae (period of 7 days) which was the second Cepheid variable discovered.

The work of Goodricke and Pigott was followed by new discoveries of variable stars including several Cepheids. X Sagittarii and ζ Geminorum were discovered by Schmidt in 1847 and 1866 respectively, and T Monocerotis and *l* Carinae by Gould in 1871. Chandler (1886 : *Astr. J.* **7**, 159) discovered X Cygni. He also calculated more precise periods for the Cepheids discovered till then, by compiling and reanalysing the observations of different workers. The third catalogue of variable stars by Chandler (1896 : *A. J.* **17**, 145) contains period and epochs of maximum and minimum brightness for nearly thirty Cepehid variables.

E. C. Pickering (1895) at Harvard announced the discovery of some short-period variables by S. I. Baily in globular clusters. These variables displayed Cepheid characteristics but had much shorter periods of the order of a fraction of a day. Later studies of other brighter globular clusters revealed a high abundance of these stars in those clusters. Since these stars were discovered in globular clusters, they were called 'cluster variables'. At the beginning of the present century, a short-period Cepheid RR Lyrae was discovered by Ms W. P. Fleming at Harvard Observatory. While RR Lyrae did not belong to any globular cluster, it still had the light curve and period very similar to cluster variables. At first, RR Lyrae was thought to have escaped from a cluster; but more and more such variables with no possible connection with clusters were discovered which ruled out this idea. Subsequently, the entire group of such variables was named after the prototype RR Lyrae. These stars are also pulsating like the Cepheids, but are population II objects with spectral types ranging between A2 and F6, compared to classical Cepheids of population I which have spectral types between F5-K2. Long-period Cepheids of disc population are called classical Cepheids. Long-period Cepheids of halo population are named after their prototype W Virginis. In what follows, we will drop the word 'classical' for brevity. More than eight hundred Cepehids have been discovered in the Galaxy, their periods usually confined to the range 1–50 days. The longest known period for a Cepheid in the Galaxy is 125 days for V810 Centauri. A few Cepehids in the Large Magellanic Cloud have periods approaching 100 days, whereas in the Lmall Magellanic Cloud the periods extend upto 200 days. A large fraction of galactic Cepheids are found in the period range of 4–6 days.

The light curve

The typical light curve of a Cepheid is characterized by a steep rise in brightness while approaching maximum brightness, followed by a much slower decline. For the Cepheids in the period range 3–40 days, it was pointed out by Hertzsprung

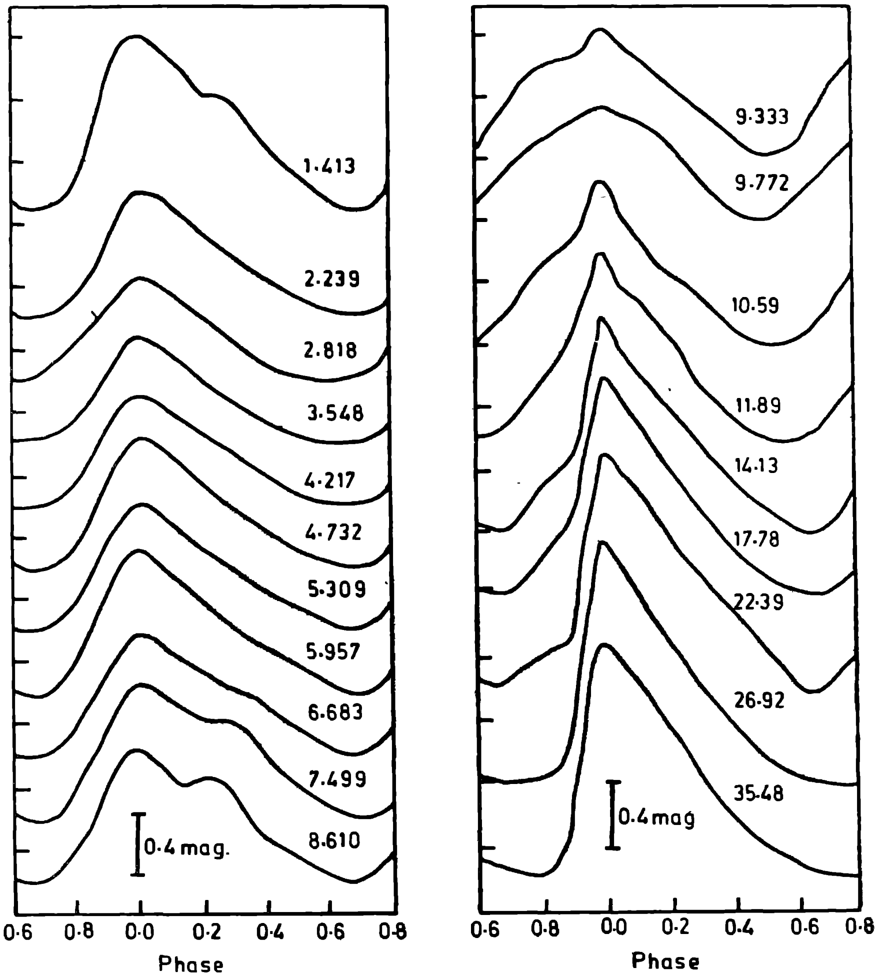

Figure 1. Hertzsprung sequence showing the variation of the shape of the light curve of Cepheids with different periods.

(1926 : *Bull. Astr. Inst. Netherl.* **3,** 115) that the light curves if arranged according to periods, exhibit a systematic variation of shape. The Hertzsprung relation is shown in figure 1. This relationship was studied carefully by Kukarkin & Parenago (1937: *Sov. A. J.* **14,** 181). Using normal curves for 168 stars, they found that although the individual light curves for a given period are not strictly identical, the average curve for a given period has a definite shape. The Hertzsprung relation was also observed for other stellar systems such as M31, M33 and NGC 6822. From figure 1, it is obvious that the light curves are smooth and asymmetric, upto a period of 6 days. At higher periods, the light curves have smooth rise with a hump on the descending branch. As the period increases, the hump becomes more pronounced and shifts towards the maximum of the curve. At the period of 9 days the hump is so prominent that the light curve sometimes has two nearly identical peaks. With further increase in period, at 12 days, there is a central peak superimposed upon a flat, broad maximum; i.e. the hump which made its appearance at the period of six days becomes the maximum of light curve, and the former principal maximum appears as a hump on the ascending branch.

The light curve of δ Cephei observed by Stebbins (1945 : *Ap. J.* **101,** 4) in *UVBGRI* bands is shown in figure 2. These broad bands are situated in ultraviolet, violet,

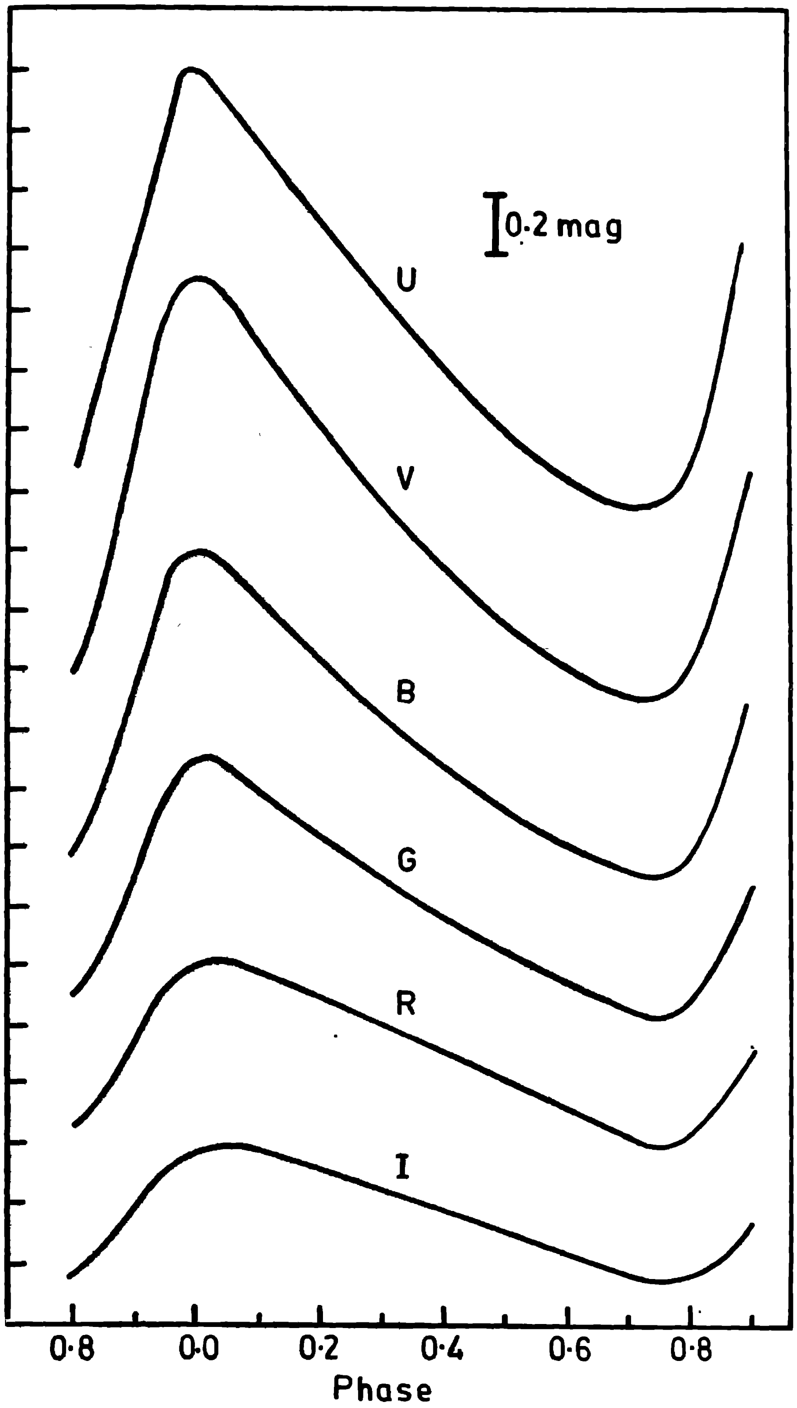

Figure 2. The light curve of δ Cephei in six colours observed by Stebbins.

blue, green, red and (near) infrared regions of the spectrum. A comparison of the magnitudes measured in different parts of the spectrum reveals the approximate shape of the stellar energy distribution. The difference between the magnitude in two bands, defined as the colour index, gives the first-degree shape, or the slope of the energy distribution curve. In the case of Cepheids, the surface temperature and the shape of energy distribution varies during its pulsation period. The effective temperature of Cepheids varies in the range of 7000–5500 K between maximum and minimum of the light curve. As a result, the maximum of the energy distribution shifts from blue spectral region at light maximum to yellow spectral region at the minimum. Thus amplitude of light variation is larger in *UBV* colours than in red and infrared colours, since the shape of energy distribution in red and infrared regions does not change significantly.

Period-luminosity relation

The period-luminosity relation is the most important known law relating to Cepheids. A first step towards the discovery of the period-luminosity relation was taken by Henrietta Leavitt in 1908 (*Harvard Ann.* **60**, No. 4) while studying the variables she had discovered in the Magellanic Clouds. She derived the period for 16 of the Small Magellanic Cloud (SMC) variables and noted that the brightness of the stars increased with their periods. E. C. Pickering (1912 : *Harvard Circ. No. 173*) made an announcement of the remarkable relationship between the brightness of these variables and length of their period. Since all these variables belonged to a single stellar system (SMC), their distances from the sun could be considered constant and one could conclude that the dependence of luminosity on the period is an intrinsic behaviour. Hertzsprung (1913 : *Astr. Nach.* **196**, 201), drew attention to the significance of this relationship which enabled a determination of the relative distances to the Cepheids and consequently to the stellar systems to which they belong. Using the proper motion data for 13 Cepheids, Hertzsprung derived the statistical parallaxes for them and ultimately calculated the distance to SMC. Shapley realized the potential of this relationship in the study of the distance scale of the universe. He revised the data on Cepheid parallaxes and also discarded two Cepheids (*l* Carinae and κ Pavonis from Hertzsprung's list because they showed slight variation in periods—a phenomenon not noticed in typical Cepheids. Then he combined the data on Cepheids in Magellanic Clouds, globular clusters and the solar neighbourhood to obtain a unified period-luminosity (P-L) relation. As we shall see later, such a unification of the variables, whose similarity lies only in the appearances of their light curve, is not justified. At the time when Shapley (1914 : *Ap. J.* **40**, 459) published his P-L relation, the concepts of different populations in stars had not emerged and hence the unified P-L relation was used for more than thirty years to determine the distances

The discovery of the P-L relation resulted in a remarkable improvement in our understanding of the universe. Using the photometric data on Cepheids in M31, M33 and NGC 6822, and applying the P-L relation, Hubble (1926 : *Ap. J.* **63**, 236) derived the distances for them and established once for all that they were extra-galactic objects. By this time, Shapley had used the RR Lyrae stars and globular clusters to show that the Milky Way is a gigantic system of stars and the sun resides towards its edge rather than in its centre.

While calibrating the P-L relation, early workers had not taken into account the correction due to the absorption of light by interstellar medium, which was yet to be discovered. Trumpler demonstrated in 1928 that the interstellar extinction was an important factor and neglecting this correction would lead to an overestimate of the distances. The correction to interstellar extinction was derived by Wilson

(1939: *Ap. J.* **89**, 219) using the proper-motion and radial-velocity data for nearly hundred stars. The resultant correction to zero point of Shapley's P-L relation is −0.14 mag. Nevertheless there were some disturbing observations. First, there was a discrepancy between the luminosities of globular clusters in our Galaxy and in M31 (the Andromeda galaxy). The upper limit for the luminosity of the globular clusters belonging to our Galaxy is around −9.0 mag whereas it was barely −7.5 mag in M31. This difference was well established by a number of observers. Secondly a similar difference in the mean brightness of novae observed in the two systems was also noticed. In our Galaxy the accurate estimate of the mean brightness for the novae was −7.2 mag whereas for the novae of M31 it was found to be −5.7 mag.

Many attempts were made to resolve this discrepancy. Baade proposed in 1940s the idea of two population groups of stars. Population I stars were young, massive and confined to dusty areas of the Galaxy. Population II stars were old, less massive and confined to the halo. Baade investigated the possibility of two kinds of Cepheids belonging to each population. Also if there were Cepheids belonging to the two populations then it was quite possible that they had different luminosities. Baade was beginning to doubt the validity of the unified P-L relation of Shapley. He believed that a decision could be reached by the study of Cepheids of M31 because objects of both populations were discovered in them. The distance modulus of M31 determined by Hubble using Shapley's P-L curve was 22.75 mag. In M31, the brightest of the population II Cepheids (W Virginis type) were already detected on the photograph obtained using the 100-inch telescope. Using the 100-inch telescope, Baade was hoping to detect short-period cluster variables (RR Lyrae variables). The absolute magnitude for these cluster variables is known to be 0.0 mag and therefore considering the distance modulus 22.7 mag for M31, they were well within the plate limit. However the repeated exposures of M31 by Baade failed to detect these stars. Close to the plate limit were only the brighter stars of Population II, which were 1.5 mag brighter than the cluster variables. Since the absolute magnitudes of cluster variables were well established, Baade suspected the distance modulus of M31 to be 22.7 − (−1.5) = 24.2 mag. In 1952, when Baade presented his results at the Rome Congress of the International Astronomical Union, Thackeray promptly supported his view. While studying the cluster variables in SMC, Thackeray found that they were only as bright as 18.9 mag instead of the expected brightness of 17.4 mag. It became clear that Shapley's zero point needed a correction of −1.5 mag. Baade's discovery (see Baade 1963 : *Evolution of Stars and Galaxies*, Harvard University Press) naturally explained the discrepancy between the luminosities of Novae and globular clusters in M31 and in our Galaxy. This correction of −1.5 mag in distance modulus doubled the distance estimates for M31 and other galaxies for which the distances were estimated using Shapley's relation.

Next attempt to calibrate the P-L relationship for Population I Cepheids was made by Blaauw & Morgan (1954 : *Bull. Astr. Inst. Netherl.* **12**, 95) using the proper motions of high accuracy for 18 Cepheids. To account for the correction due to interstellar extinction, colour excesses derived by Eggen (1951 : *Ap. J.* **111**, 367) were used. Their calculations indicated a correction of −1.4 ± 0.4 mag to the zero point of Shapley. However, the systematic errors in the measurement of proper motions of distant stars, and the effects of the peculiar motions of the stars themselves, greatly affects the accuracy of this approach.

Cepheids in open clusters

It was first suggested by Doig in 1925 (*J. Br. Astr. Assoc.* **35,** 202) that certain Cepheids were possibly members of open clusters. He derived the distance to M25 assuming the Cepheid U Sagittarii to be a member of the cluster. At that time, Doig's suggestion did not make any impact possibly due to the fact that the distances to the clusters were still rather unreliable and therefore the Cepheids belonging to them could not have been used to standardize the P-L relation.

After thirty years, when Irwin (1955 : *Mon. Not. Astr. Soc. South Africa* **14,** 38) suggested the possible membership of U Sagittarii in M25 and of S Normae in NGC 6087, the circumstances were much more favourable. The nagging problem of interstellar correction could be dealt with more reliably using the three-colour photometry. Also, reliable colour-magnitude diagrams had been constructed, and the methods worked out to derive accurate distances to the clusters. Inspired by Irwin's finding, Kraft and van den Bergh carried out extensive search for the Cepheids belonging to open clusters. Kraft began his search by comparing the coordinates of the clusters and the Cepheids, while van den Bergh looked for clusters around the Cepheids on the Palomar Observatory Sky Survey plates. The following two criteria were used to confirm the reality of the Cepheids in the clusters : (i) closeness of the proper motions of Cepheids and cluster members, and (ii) closeness of radial velocities. Also, from evolutionary considerations, it is obvious that Cepheids belonging to a cluster are not likely to be fainter or brighter by over 3 mag than the brightest main-sequence star of the cluster.

Cepheids belonging to open clusters are of great importance and deserve a careful study. They can be used to determine the zero point of P-L relation. Also, it is easy to find their colour excesses using the neighbouring early-type stars belonging to clusters. The combined effort of Sandage. Arp, Kraft and Irwin resulted in the discovery of several Cepheids that were members of open clusters. Using the *UBV* photometric data on such Cepheids, Kraft (1961 : *Ap. J.* **134,** 616) derived the following P-L relations for visual and blue colour bands :

$$\langle M_V \rangle = -1.67 - 2.54 \log P,$$

$$\langle M_B \rangle = -1.33 - 2.25 \log P.$$

The relationship was used for a long time both in the study of the Galaxy and to construct the extragalactic distance scale. The P-L relation of Kraft also yields a correction of -1.4 mag to Shapley's zero point. Thus the studies of Cepheids in open clusters confirmed the zero point of Baade.

The importance of the colour term

The intrinsic scatter in the P-L relation was a source of discontent for all workers who used it for the determination of distances. Sandage (1958 : *Ap. J.* **127,** 513) suggested that the scatter in the P-L relation was caused by a scatter in a period-colour relation and by the slope of constant-period lines in the colour-magnitude diagram, so that the bluer Cepheids were brighter and the redder ones fainter compared to an average Cepheid of a given period. Using the *UBV* photometric data for 13 Cepheids belonging to open clusters, Sandage & Tammann (1969 : *Ap. J.* **157,** 683) derived a period-luminosity colour relationship which is given by $\langle M_V \rangle = -3.425 \log P + 2.52 (\langle B^0 \rangle - \langle V^0 \rangle) - 2.459$. Here $\langle B^0 \rangle$ and $\langle V^0 \rangle$ are the mean B and V magnitudes corrected for interstellar extinction. This P-L-C relation reproduces the observed absolute magnitudes of the calibrating Cepheids to within ±0.064 mag. Martin *et al.* (1979; *M.N.R.A.S.* **188,** 139) derived the following P-L-C relation for large Magellanic Cloud (LMC) Cepheids :

$$\langle M_V \rangle = -3.80 \log P + 2.7 (\langle B^0 \rangle - \langle V^0 \rangle) - 2.39.$$

For a given period, Cepheids belonging to LMC tend to be bluer than the galactic Cepheids which fact is believed to be due to the difference in the metal content of the two systems, our Galaxy being richer in metals compared to LMC.

(*S. Giridhar*)

2. Morphological classification of galaxies

While each galaxy has its own individuality which sets it apart from others, a vast majority of galaxies can be classified into families and varieties. Such a taxonomic approach helps in understanding better the structure, dynamics, formation and evolution of galaxies. Edwin Hubble (1936 : *The Realm of the Nebulae*, Yale University Press) placed together the elliptical (E) and spiral (S) galaxies in a single morphological sequence which has since formed the basic classification scheme of galaxies. G. de Vaucouleurs (1959 : *Handbuch der Physik* **53,** 275) later extended this sequence to include the Magellanic-type irregular (Im) galaxies as well. This sequence has the gas-poor (E) stellar systems at one end and gas-rich (Im) ones at the other, with the composite (S) systems of stellar bulge and gas-rich disc in the middle.

In Hubble's classic 'tuning-fork diagram', the elliptical galaxies from E0 to E7 form the handle of the tuning fork. The number following the letter E denoted the ellipticity class $= 10(1 - b/a)$ where b and a are the apparent semiminor and semimajor axes of the image of the galaxy seen projected against the sky. There are no clues available yet to the intrinsic shape of elliptical galaxies and one has to be satisfied with what one sees in projection. Thus the E0 would not only contain the intrinsically round galaxies, but also the flatter galaxies seen face-on. Similarly all the classification bins will be contaminated by favourably-inclined galaxies that are intrinsically flatter than what the apparent axial ratio suggests. Yet, no elliptical appears more elongated than E7. Hence one concludes that there are no galaxies intrinsically flatter than $b/a = 0.3$ and that all the galaxies in class E7 are intrinsically as flat as they appear on the sky.

If one assumes that the elliptical galaxies are flattened because they rotate about their intrinsic minor axis, one may reasonably well assume that they are oblate spheroids of revolution. In such an event, one can derive a unique model distribution of intrinsic axial ratios from the observed (apparent) ones. Several such analyses have been made. In particular, J. Binney & G. de Vaucouleurs (1981 : *M.N.R.A.S.* **194,** 679) find that the most common intrinsic shape is E3.5—E3.8, with a significant number of spherical objects, and none flatter than E6.5.

On the other hand, ever since F. Bertola & M. Capaccioli (1975 : *Ap. J.* **200,** 439) measured the first rotation curve of an elliptical galaxy (NGC 4697) it has become increasingly apparent that the ellipticals do not rotate fast enough to account for their flattening. If so, it is not unlikely that E galaxies are intrinsically triaxial, with all the three axes different. The introduction of an additional unknown axial ratio renders difficult any inference on the distribution of intrinsic axial ratios.

Spiral galaxies form the two branches of Hubble's 'tuning fork'. The 'barred' galaxies form one branch and the 'normal' ones the other. In barred galaxies the spirals emerge from the ends of an apparently-stellar bar. Such bars are not seen in the normal ones. A look at the spiral galaxies illustrated in the *Hubble Atlas of Galaxies* (A. Sandage 1961 : Carnegie Institute of Washington) for example, shows that the bars come in all degrees of prominence. The classical examples of normal and barred galaxies are extremes of a continuum that is uniformly populated. Hence de Vaucouleurs introduced an intermediate class of galaxies between the two classes. The observed galaxies are equally distributed between all these three 'families' and thus there is nothing 'abnormal' about the barred galaxies. The preferred name for the unbarred spirals is now simply 'ordinary' spirals denoted by a letter A against B for barred and AB for intermediate.

The major distinction between S and E galaxies is that the spirals contain a prominent disc of gas, dust and young stars, in which the spiral arms unfold. Hubble arranged spirals in a sequence from Sa to Sc along which the prominence of stellar bulge decreases and that of the disc increases. The other criteria of classification along this sequence are the decreasing degree of tightness of the winding of the arms and an increasing resolution in terms of HII regions and associations of young, blue stars. The above three classification parameters are apparently correlated. This fact constitutes an important astrophysical problem, namely the physical interpretation of the Hubble sequence. The presence of a disc of gas implies that the spirals have a high specific angular momentum, for, as a rotating pregalactic cloud dissipates its energy, the gas would settle down in a disc perpendicular to the axis of rotation. Further, the absence of gas in E galaxies implies that most of the gas was converted into stars in the early phase of galaxy formation. Thus a simple explanation of the Hubble sequence would be that it is a sequence of the relative importance of dissipation in gas clouds compared with the efficiency of star formation. In this picture, which was generally believed until recently, the sequence of ellipticals is also a sequence of increasing specific angular momentum, their flattening being a result of rotation. While the rate of star formation in ellipticals decreased exponentially from a very high initial value to a negligible amount at the present epoch, it has always remained at a nearly constant low value in late-type spirals. Recent evidence for the low rotation of E galaxies undermines this hypothesis.

Some inference on the axial ratios of bars can be obtained since their inclination to the line of sight can be estimated from the apparent shape of the disc. The bars of spirals appear to be highly triaxial, tumbling end over end about a shorter axis. An axial ratio of 1 : 2 : 10 appears rather common. Since the rotation studies of E galaxies suggest that they could as well be triaxial, there appears some hope that they may be understood as low-angular momentum equivalents of the spiral families—ordinary to barred. However, the unknown inclination of the elliptical galaxies and the consequent ignorance about their three dimensional shapes render any such physical classification scheme well-nigh impossible.

Hubble had predicted a transition type of galaxies between the spirals and ellipticals at the point where all the three branches join (E, SA and SB). Eventually such 'S0' galaxies were discovered (*cf.* Sandage 1961), as the ones containing stellar spheroids and stellar discs with low amount of young stars and gas. The subsequent discovery of such galaxies increased the credibility of the Hubble squence to a very large degree. However, it now appears that there is a great spread in the bulge-to-disc ratios of 'lenticular' (S0 or L) galaxies. Thus, van den Bergh (1976 : *Ap. J.* **206**, 883) suggests that the S0 galaxies should form a sequence parallel to the spirals, as S0a—S0b—S0c, the only difference being lack of gas. He even identifies a family of 'anemic' spirals Aa—Ab—Ac which have an intermediate amount of gas and young stars between the classical spirals and lenticulars.

Hubble had discarded a minority of galaxies of irregular structure as not fitting into his scheme of things. But it was later learnt that only a part of irregular galaxies is morphologically peculiar as a consequence of interaction or possible violent events. Rudimentary spiral arms could be seen in irregulars like the Magellanic Clouds and hence de Vaucouleurs extended the Hubble sequence to include them. Under de Vaucouleurs' scheme, one has E^+ galaxies between the classical ellipticals and lenticulars: the latter are themselves subclassified into early ($S0^-$), intermediate ($S0^0$) and late ($S0^+$) types. From the lenticulars one goes over to the Sa—Sb—Sc scheme and continues through Sd and Sm to the Magellanic-type irregulars (Im). The difficulty with fitting the lenticulars in such a scheme has already been discussed above. The problems of the late-type spirals and irregulars will be apparent below.

A new dimension was added to the classical morphological sequence by Sidney van den Bergh (1960 : *Ap. J.* **131**, 215, 558). This is the DD0 luminosity classification scheme for spirals. Van den Bergh showed that high-luminosity Sb-c galaxies have long well-developed ('massive') spiral arms compared to the low-luminosity galaxies of the same Hubble type. Thus galaxies could be classified from supergiant (class I) galaxies to the dwarf (class V) ones with adjacent luminosity classes differing in intrinsic brightness by $\sim$ 1 mag. This classification scheme, after due calibration, could yield a method of determining the intrinsic luminosity of a galaxy simply by looking at its appearance on the photographs and has been exploited in the estimation of extragalactic distance scale. It is worth noting, however, that there are no Sb galaxies of luminosity lower than class III. Furthermore, van den Bergh points out that the Hubble sequence is defined by supergiant galaxies, and as one moves lower down the luminosity sequence, it becomes increasingly difficult to distinguish between the Hubble classes, all spirals showing a patchy irregular appearance. Finally, the galaxies of the lowest luminosity, observable only in the nearest metagalactic space, can be classified only as dwarf ellipticals or dwarf irregulars. Again, the brightest irregulars are intrinsically much fainter than the brightest spirals. Viewing the galaxies under this new dispersion axis of luminosity leads one naturally to the revelation that morphological sophistication is a previlege of the most luminous galaxies [J. Kormendy 1982 : in *Morphology and Dynamics of Galaxies* (eds : L. Martinet & M. Mayor), Geneva Observatory, p. 113].

Some examples of the sophistications alluded to above are the varieties in de Vaucouleurs system. The spiral arms in 'r' varieties emerge from an inner ring while they emerge directly from the nucleus in varieties 's'. An outer low-brightness ring (R) or ringlike structure (R′) surrounding the entire galaxy also finds place in de Vaucouleurs system. While this scheme describes the galaxy morphology very well, it is not very commonly used because of such complicated descriptions as (R)SAB (rs) bc ! Yet, there is one thing that may be learnt from de Vaucouleurs' scheme—that it is possible to understand galaxies as assemblages of different structural units like the spiral arms, bars, inner rings, outer rings *etc.* One can build a galaxy by assembling all these units in different strengths. The first exposition of such an idea constitutes V.A. Ambartsumian's principle of superposition of quasi-independent subsystems in a galaxy (1961 : *Trans. I.A.U.* **11B,** 145). In more recent years, Kormendy—among others—has pursued the idea that it is profitable to study the individual building blocks rather than the galaxies themselves. The meaning of the Hubble sequence may become clearer only after such studies progress.

3. Occultations

Lunar Occultations

Table 1 lists the lunar occultations of stars brighter than the sixth magnitude observable from Kavalur between 1984 July–December. Predictions of reappearances are given only when the disappearances are also observable. Additional information on some of the stars being occulted is given in table 2.

Occultations by asteroids, planets and comets

Table 3 lists several probable occultations of stars by solar-system objects.

David Dunham reports that the occultation of star ZC 2173 by Mars on 1984 May 12 will be difficult to observe since Mars will be at opposition with essentially no defect of illumination (dark crescent). Taylor predicts immersion at $15^h\ 36^m.2$ and emersion at $15^h\ 54^m.4$ in p.a. 103° for Naini Tal.

The periodic comet Halley will be occulting a 12.9-mag star on 1984 November 20 and a 12.4 mag star on 1984 December 27. The diameter of the comet's nucleus is about 100 km, but there may be some material in about 50 km from the nucleus (*Occultation Newsletter* **3**, No. 6, January 1984). E. Bowell & L. H. Wasserman have predicted occultations of stars by the periodic comet Crommelin, assuming a coma radius of 22500 km (approximately 1 arcmin diameter at 1 A. U.). The details of events which are observable from India are included in table 3. As there are large uncertainties in cometary ephemerides, the stellar occultation predictions may not be trustworthy far into the future. Bowell & Wasserman expect to update the stellar occultations whenever more accurate cometary orbital elements become available. (*International Halley Watch Newsletter*, No. 4, Jan 1, 1984).

Stellar occultations by comets can give information on the distribution of dust in the coma. This method provides high spatial resolution. Combined with surface photometry, the occultation observation allows determination of both the optical depth and albedo of the dust. Spectroscopic study of starlight passing through the coma of the comet can give valuable information on the composition of the cometary material.

(*R. Vasundhara*)

Table 1. Predictions of lunar occultations of bright stars observable from Kavalur during 1984 July–December

Date	Event	Time (UT)			Max Mag	Spectral type	Percentage sunlight	Altitude	Star	Apparent DEC			Apparent RA		
		h	m	s						°	′	″	h	m	s
July. 6	D	12	13	09	4.8	M0	58+	65	74 Virginis	−6	10	30	13	31	8.8
	R	13	19	29				71							
Aug. 8	G	16	17	05	2.1	B3	91+	51	34 Sagittarii	−26	19	55	18	54	18.9
17	D	00	17	13	5.1	K2	76−	63	BD +5 0194	6	03	55	12	9	22.4
20	D	22	32	07	4.3	B5	38−	47	94 Tauri	22	55	43	4	41	17.9
	R	23	48	21				64							
Sept. 7	D	16	28	37	5.5	K0	94+	56	33 Capricorni	−20	55	7	21	23	18.0
16	D	19	17	30	5.3	A0P	65−	32	56 Tauri	21	44	17	4	18	41.6
17	D	00	39	11	4.4	A5	64−	70	69 Tauri	22	46	50	4	25	22.8
Oct. 1	D	11	52	00	4.7	K5	46+	50	CD −27 12684	−27	3	4	18	17	4.6
	R	13	24	29				47							
Nov. 3	D	18	18	33	5.2	A0	79+	38	95 Aquarii	−9	41	41	23	18	10.3
6	D	19	14	36	5.1	K2	96+	58	BD +05 0194	6	04	01	12	9	23.6
28	D	14	29	27	5.5	K0	33+	36	33 Capricorni	−20	55	12	21	23	17.0
Dec. 7	D	19	20	57	4.4	A5	100+	69	69 Tauri	22	46	54	4	25	24.6
	R	20	47	29				50							
	D	20	07	15	5.4	B5	100+	59	72 Tauri	22	57	53	4	26	23.7

Table 2. Additional information on the brighter stars in table 1

HR	Other name	Companion		Remarks
		Δm (mag)	Sep. (arcsec)	
1341	56 Tauri			Var. .07 V, 2.7098 d; cpm with HR 1339; Pleiades group
1392	69 ν Tauri	1.9	0.02	OB; another companion 12.5 V at 110 arcsec
1497	94 τ Tauri	0.7	0.1	OB
7121	34 σ Sagittarii	7.4	309.0	Lyman lines observed from *Copernicus*; Interferometry indicates multiplicity of the primary
8183	33 Capricorni			Wolf 630 group
8865	95 ψ^3 Aquarii	3.9	1.4	Hyades group

Abbreviations : cpm : common proper motion; var. : variable; OB : occultation binary.

Table 3. Occultations of stars by Planets, asteroids or comets during 1984 April–December

Date 1984	Time (UT)		Occulting body	Magnitude		RA(1950.0)		DEC(1950.0)			Apparent RA		Apparent DEC		Duration	Remarks
	h	m		Occulting body	Star	h	m	°	′	″	h	m	°	′		
April 22	15	1.5	P/Crommelin		8.80	7	21.49	−19	27	36.34						SAO 152814
April 28	13	44.5	P/Crommelin		9.20	7	50.95	−19	27	33.09						SAO 153544
May 12	15	18–52	Mars	−1.9	7.0 G5	15	09.6	−17	54		15	11.6	−18	02	19^m	
May 29	17	48–49	Diotima	13 1	14.0	9	08.8	26	55		9	10.8	26	47	7^s	NW India
Sept. 14	21	22–24	Hebe	9.8	12.0	6	00.8	8	01		6	02.7	8	01	8^s	
Nov. 4	0	04–27	Winchester	10.8	10.7	6	50.6	1	26		6	52.4	1	24	43^s	
Nov. 24	23	57–62	P/Halley	21.3	12.9	6	23.5	11	58		6	25.8	11	57	3^s	India
Dec. 1	15	24–50	Iris	7.3	11.5	5	39.1	23	50		5	41.2	23	51	34^s	
Dec. 7	13	48–75	Iris	7.1	11.1	5	33.2	23	18		5	35.3	23	20	31^s	E India
Dec. 10	23	15–18	Berbericia	13.5	9 3 F8	12	46.8	14	03		12	48.5	13	51	8^s	
Dec. 16	22	29–44	Dejopeja	13.1	10.0	5	31.4	24	49		5	33.5	24	51	10^s	S India
Dec. 27	14	30–35	P/Halley	20.9	12.4	5	50.4	12	00		5	52.3	12	00	3^s	Asia