Variable K-type Stars in the Pleiades Cluster

F. Van Leeuwen, Royal Greenwich Observatory, and P. Alphenaar, Leiden Observatory

As a result of an extensive astrometric and photometric study of the Pleiades cluster it was found that a high percentage of its K-type stars are variable. These variabilities may provide new insights in the problem of redistribution of angular momentum.

The first indications for this variability were obtained from a photometric survey of all known or suspected members of the cluster. This survey was carried out in November 1979 using the Dutch 91 cm telescope on La Silla equipped with the Walraven five-channel photometer (Lub, 1979: *The Messenger,* **19,** 1). Because variabilities can provide valuable information on the internal structure of stars, we applied for new observing time in 1980 and 1981.

The Photometric Observations

The photometric observations were again performed using the Dutch 91 cm telescope. During two seasons (October-November 1980 by Van Leeuwen and Alphenaar and October-November 1981 by Alphenaar and Meys), 3 late G- and 16 early K-type stars were investigated. At the start of the investigation only an indication for variability of these stars was available, but after completing our seond run, all 19 stars were known to be variable and for 11 of them we had established light-curves and periods. This was made possible by reducing all measurements within 24 hours after obtaining them and incorporating all available information in the planning for the coming night. In 1980 we used for this purpose an HP 41C pocket calculator but in 1981 the reduction programme for the Walraven photometry was finished and could be used at the computer centre on La Silla. The amount of extra work to be done by the astronomers is considerable, but only in this way can one be sure to get the best use of the telescope time, especially in studying periodic variability. In addition, the excitement of discovering variable stars, finding their periods, plotting their light-curves, and looking for clues to their behaviour makes up for a lot of the extra work.

The observations were performed in two periods of three weeks. During the first week the selected stars were measured several times per night each in order to check on their variability and the time scale on which this variability takes place. Using those results, the second week was spent obtaining fractions of the light curves and determining periods. The third week was used to fill in the uncovered parts of the light-curves.

The Photometric Interpretations

The light-curves we found, as shown in Figs. 1a-e, are similar to those of BY Draconis stars. These stars are supposed to be pre-main-sequence stars in their final contracting stage towards the main sequence. The main characteristics of BY Dra stars are: (a) spectral type dKe or dMe, (b) periodic variabilities with periods of a few days and amplitudes up to 0.4 magnitudes, (c) emission lines of Ca II and H. The source of the variation is usually sought in rotational modulation.

Except for the period, which is of the order of several hours, the characteristics of the 9 stars in Figs. 1a-c, which will be called 'v' type, are the same as observed for many BY Dra stars. The shape of the light-curves are similar: smooth, only one maximum and one minimum, and often asymmetric. Those shown in Fig. 1d which show broad minima and will be called 'u' type, and those of Fig. 1e, which show broad maxima and will be called 'n' type are less frequently observed. Like many BY Dra stars some of the Pleiades K-type stars are known as flare stars (Haro, 1976: *Ton. Obs. Bull.,* **2,** 3).

The light-curves shown in Fig. 1 are sorted on period, with different symbols for the 1980 and 1981 observations. When we examine Figs. 1a-c, over increasing periods, the first star encountered is Hz 1883. (The star numbers come from the Catalogue of the Pleiades by Hertzsprung [1947: *Leiden Annalen* XIX, 1 part A].) This star with its very stable and smooth light-curve has the shortest period and largest amplitude (0.20 magnitude in V) of all. It is followed by the possibly disturbed light-curve of Hz 686 (1980 observations) and the smooth light-curves of Hz 3163, 1531 and 882. These stars have amplitudes around 0.11 magnitude and periods from 10 to 14 hours. The third group consists of two light-curves, those of Hz 1124 (1981) and 879, both having amplitudes around 0.07 magnitudes and periods around 22 hours. Finally, there is Hz 34 with an amplitude of 0.03 magnitude and a period of 28 hours. A similar light-curve is possibly also shown by Hz 1039. Figure 1d shows a similar behaviour for the stars with a broad minimum, viz. Hz 25 and Hz 1332 and Fig. 1e for those with a broad maximum, viz. Hz 2034, Hz 686 and Hz 1124. The data presented in Fig. 1 show a relation between amplitude and period, as well as with the shape of the light-curves. Those shown in Fig. 1e all have smaller amplitudes than those of Figs. 1a-d for similar periods. This effect was especially notable for Hz 686, which showed a V-shaped light-curve with large amplitude in 1980 and an n-shaped one with smaller amplitude in 1981. The period-amplitude relation is shown in Fig. 2, in which the stars of Figs. 1a-c are indicated by 'v', those of Fig. 1d by 'u' and those of Fig. 1e by 'n', all according to the shape of the light-curve.

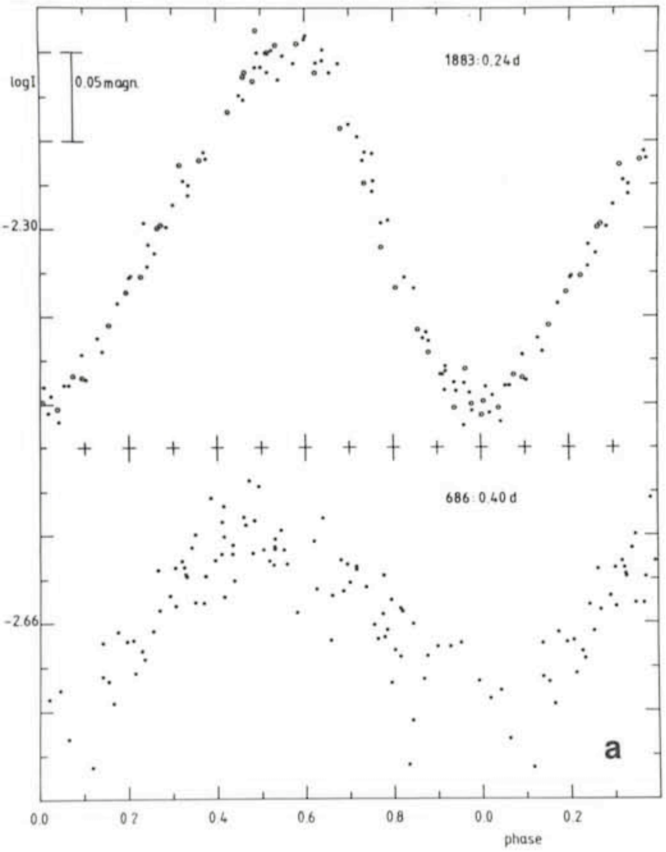
Fig. 3 shows the V-(V-B) relation for K-type members of the Pleiades cluster. For star Hz 1883 the direction and size of its variations are also indicated. This direction appears to be the same as the relation between V and (V-B) of all stars together, which is the relation for normal stellar atmospheres of stars on the main sequence. This could mean that the appearance of Hz 1883 changes as if we see a normal stellar atmosphere with the accompanying surface and mass. Its variations do not take place along lines of constant radius. A calculation showed that the effective surface of the star is about 6 ± 1.2 per cent larger at maximum than at minimum light.

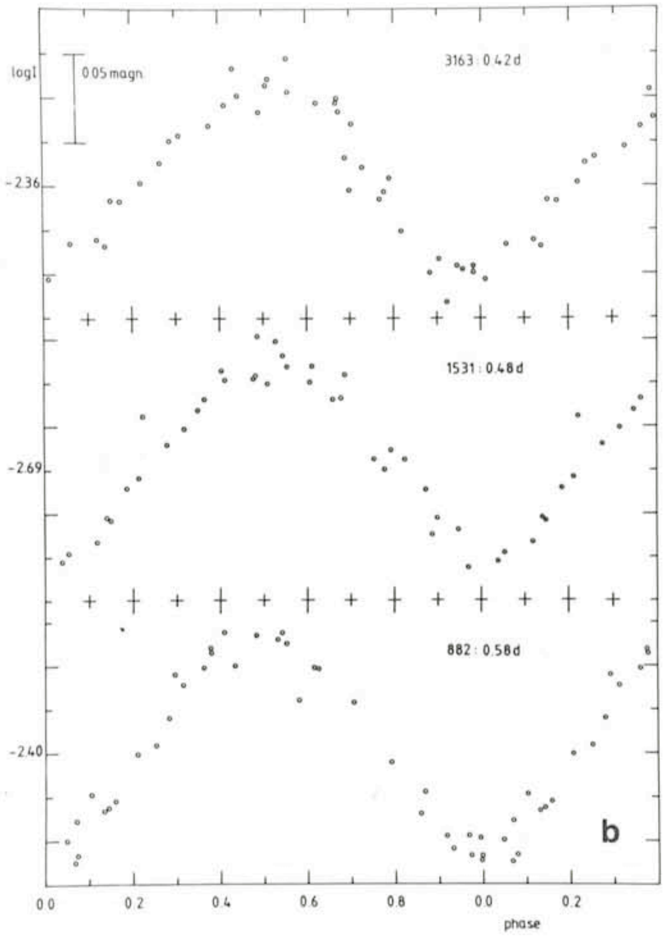
The Spectroscopic Observations

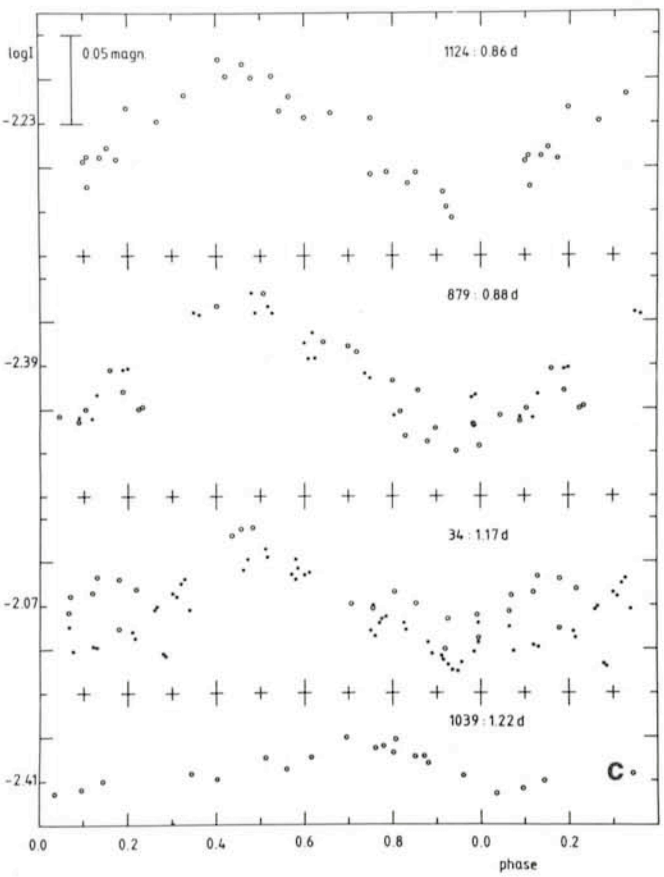
In addition to the photometric observations, spectroscopic data were obtained for two stars, viz. Hz 1883 and Hz 3163. These observations were performed at Lick Observatory by Dr. M. F. Walker, using the 120 inch reflector and coudé spectrograph.

In December 1980, four time-resolved spectra were taken of Hz 1883, using the resolution of 115 Å/mm. These spectra showed no double lines or significant changes in radial velocity, which means that this star is most probably single. The spectrum was determined as K3Ve. Line profile measurements obtained for the same star in October 1981 showed a rotational velocity of 150 km/sec, which is extremely high for a K-type star.

A similar result was found for star Hz 3163. Spectra taken in December 1981 showed a rotational velocity of 75 km/sec. The ratio between the rotational periods and the photometric periods for Hz 1883 and Hz 3163 are almost the same.







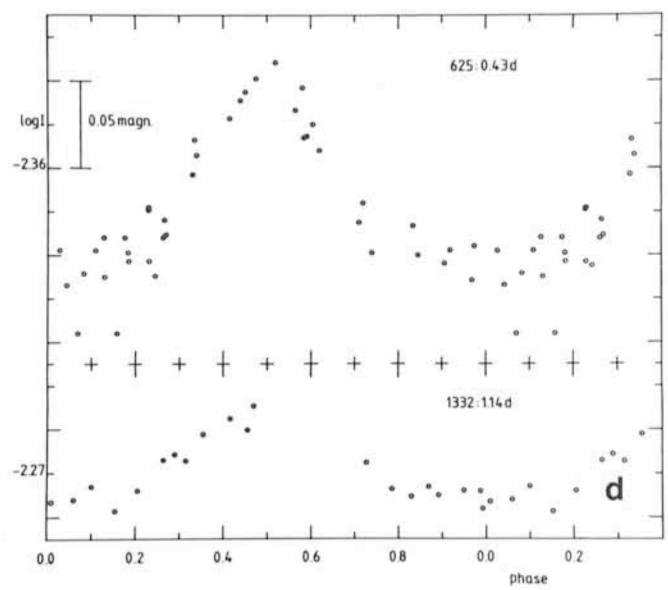
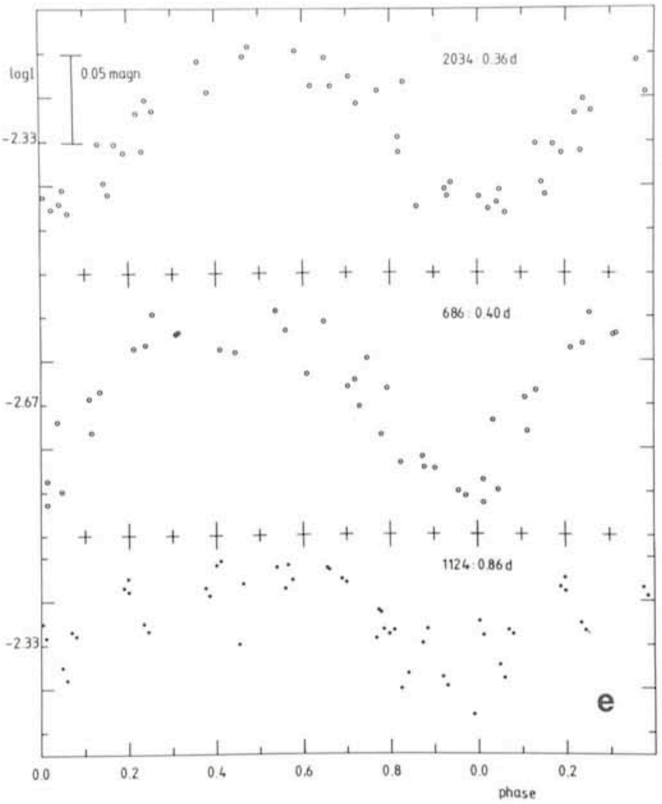


Fig. 1a-1e: *The light-curves for the stars measured so far, sorted on type (1a-1c: 'v' type, 1d 'u' type and 1e 'n' type) and on period.*

Moreover, the rotational period would be close to the photometric period for such high rotational velocities, an effect which is also observed for other BY Dra stars. It will therefore be assumed that the photometric and rotational periods are proportional for the Pleiades K-type stars, and that the photometric variations are probably due to rotational modulation.

Rotational Modulation

Rotational modulation is caused by inhomogeneous luminosity distribution over the stellar surface, which can be due to spots or to non-axial symmetry. The first possibility is observed for some A-type stars and is generally also applied to



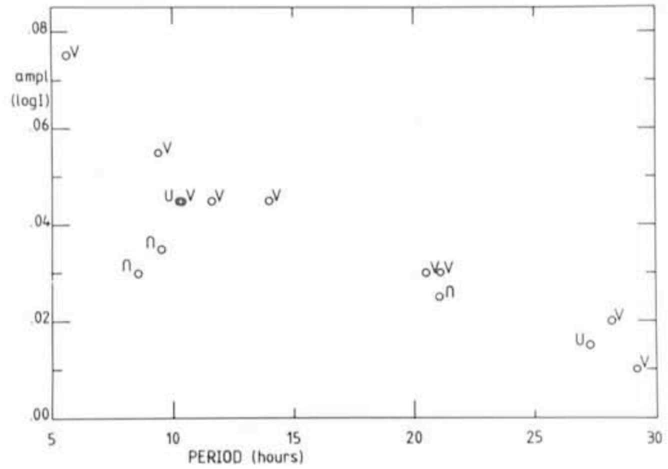


Fig. 2: *The period-amplitude relation for the Pleiades K-type stars.*

BY Draconis stars. In this case the source of variation is sought in an analogue of sunspots, situated on the stellar surface. The second model is supported by theories that predict deformation for contracting stars that rotate very fast (see Lebovitz, 1974: *Astrophysical Journal* **190,** 121). In that case the observed intensity variations would be mainly due to temperature variations over the stellar surface.

By looking at the light-curves we can draw some general conclusions about the nature of the source of the variations. The smoothness of the light-curves and the absence of flat maxima and minima imply that the source itself is smooth and always present. The almost straight rising and descending slopes and the presence of always only one maximum and one minimum indicate that there is only one source for the variations. More sources would give rise to changing slopes and the occurrence of secondary minima or maxima. In addition, we observed that the amplitude of the light-curve can remain constant up to 1 per cent for over a year, some 500 to 1,500 revolutions. Therefore the source of the variations must be very stable. And finally, the observed relation between period and amplitude, as plotted in Fig. 2, indicates that there is a clear relation between the strength of the source and the rotational velocity of the star.

Explaining the observed variations by means of the spot-model will lead to the following unsatisfactory conclusions. There can be only one spot, of which parts must be visible at all times. This spot must be distributed smoothly over the stellar surface in such a way that it is more prominent on one side of the star. For an amplitude of 0.2 magnitudes (as in the case of Hz 1883) and the observed V-(V-B) relation we can calculate the surface covered by this "spot". It should cover 30 per cent more of the visible surface at minimum light than at maximum light. Because of the stability of the light-curve of Hz 1883 we conclude that the spot is not at all influenced by differential rotation. This is not in agreement with our knowledge of the sun with respect to sunspots and differential rotation on the surface. We therefore conclude that an explanation in terms of spots is very unsatisfactory.

The other possible explanation, deformation, leads to a much simpler picture. The star could be deformed to a tri-axial ellipsoid due to its fast rotation, which would give rise to a smooth light-curve with two maxima and minima. The rotational periods of the stars would in that case be twice the photometric periods. The maximum radii of the stars would be around 1.5 solar radii but, as such a star is considerably flattened, this would not give rise to unacceptably high luminosities. When the period of the star decreases, the rotational velocity and hence the deformation will increase, which can be recognized in the light-curve, showing a larger amplitude, exactly as observed. Variability caused this way is much more stable than a large star spot, which can explain the stability of the light-curves. The differences in the shapes of the light-curves, the 'v', 'u' and 'n' shapes, could be due to different inclination angles, in which case the change in light-curve observed for Hz 686 and Hz 1124 would be the result of precession of the rotational axis.

The model of non-axial symmetry for fast rotating stars is not far enough developed yet to say whether it is a plausible explanation or not. However, as the theory developed by Lebovitz also predicts the formation for double stars it is very interesting to have a look at the angular momentum distribution over stars with different masses.

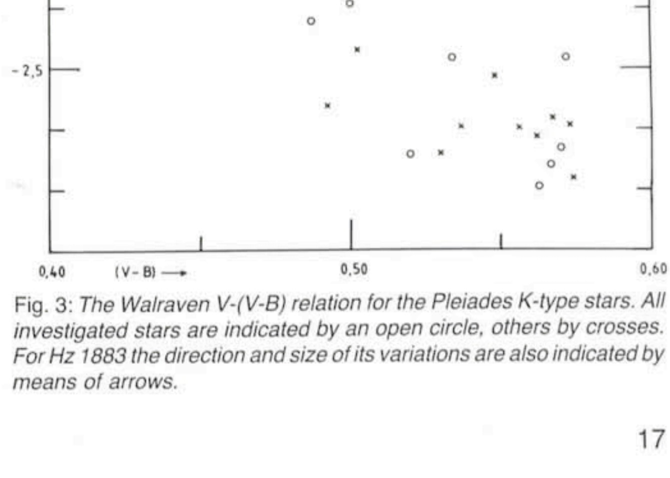


Fig. 3: *The Walraven V-(V-B) relation for the Pleiades K-type stars. All investigated stars are indicated by an open circle, others by crosses. For Hz 1883 the direction and size of its variations are also indicated by means of arrows.*

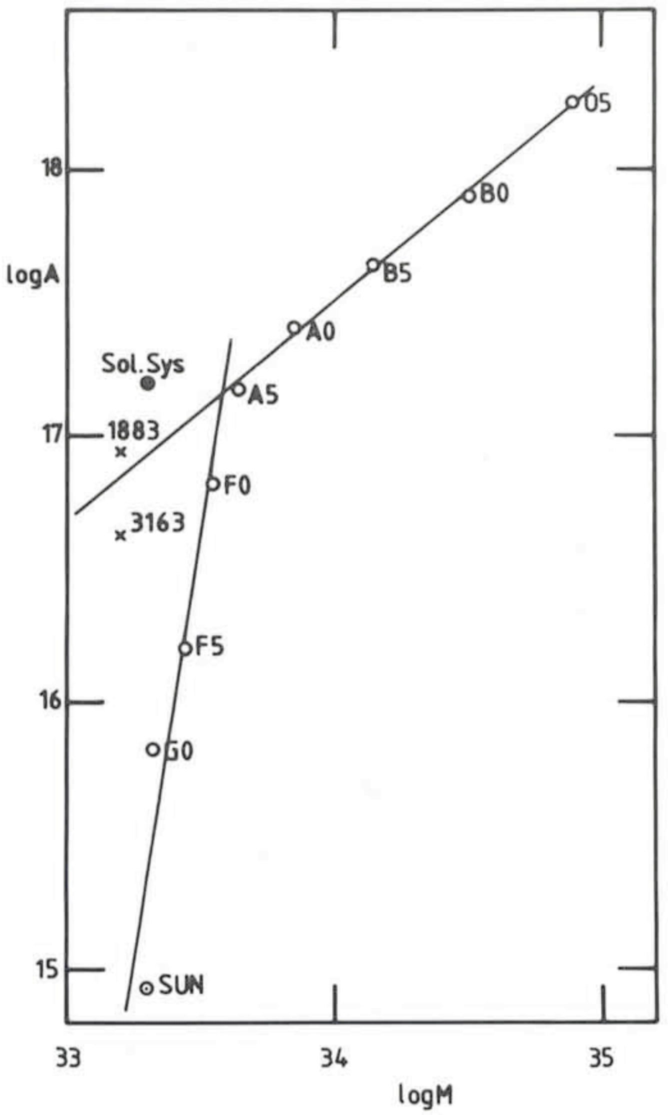


Fig. 4: *The relation between the angular momentum per unit mass (A) and the total mass (M) for average field stars, the solar system, the sun and two of the investigated K-type stars of the Pleiades.*

The Angular Momentum Distribution

In Fig. 4 we compare for average field stars their angular momentum per unit mass A and their mass M, following McNally (1964: *The Observatory* **85,** 166) who pointed out that there are two distinct relations with strongly different slopes, one for the O, B and A-type stars and one for the F and G-type stars. McNally also showed that the position of the solar system in this diagram seems to coincide with the O, B and A star relation while the sun itself follows the F, G star relation.

From this diagram McNally developed the following idea: The O, B and A stars are, because of their large masses, able to hold a high amount of angular momentum while the amount possible to hold for less massive stars rapidly decreases. The O, B and A star relation may therefore indicate the average amount of angular momentum present at the time of star formation. This would mean that the stars with a later spectral type than that of the turnoff point, at about spectral type A5, will not be able to hold all of their initial angular momentum and will somehow get rid of it. The fact that the solar system as a whole lies, in this diagram, very close to the O, B and A star relation suggests formation of planetary systems or double stars as mechanisms for losing excess angular momentum.

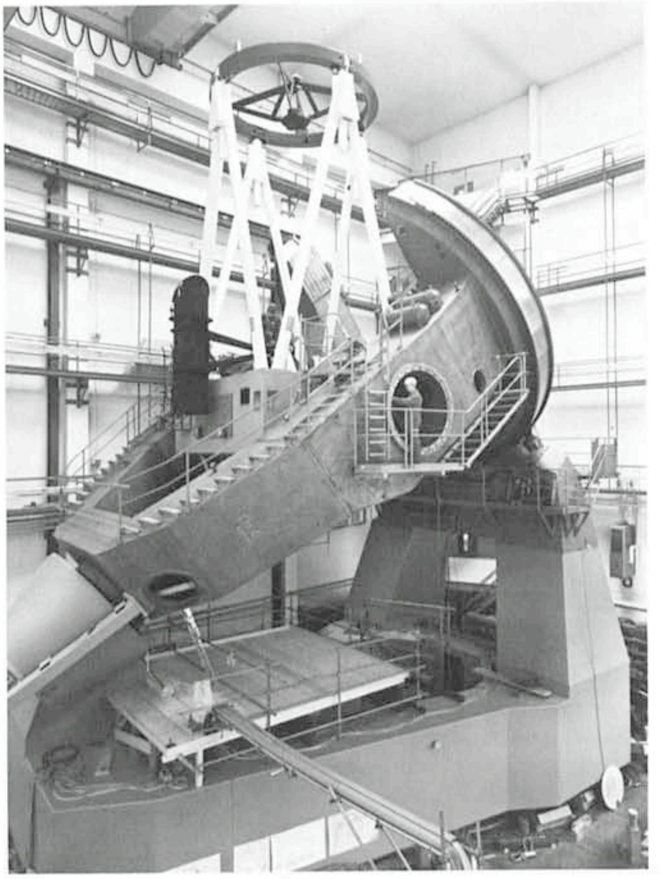
Looking at Fig. 4, we see that both Hz 1883 and 3163 follow the relation set by the O, B and A stars, which was assumed to be the initial distribution of angular momentum. This means that in this stage of the evolution, just before reaching the main sequence, the redistribution of angular momentum had not yet taken place. Our observations, together with the theory of deformation and breaking into two stars under fast rotation, may indicate that we observe this process for the K-type stars in the Pleiades.

We can conclude then that the redistribution takes place, for the K-type stars, on reaching the main sequence by forming double stars or possibly even planetary systems. These conclusions may also explain why so many field stars of the BY Dra type are known as close double stars. Finally, the disturbances as observed for the slower rotators like Hz 34 may be caused by material lost in the breaking-up process and which is still rotating close to the star.

A New Large Telescope for German Astronomers

On 9 March 1982 the largest telescope hitherto built in Germany was presented by Carl Zeiss to the public. It is the 3.5 m telescope of the Max-Planck Institute for Astronomy, which will be the center piece of the German-Spanish Observatory at Calar Alto in Southern Spain.

The 3.5 m telescope was built by Carl Zeiss in Oberkochen and its development and construction lasted about ten years.



The MPIA 3.5 m telescope in the assembley hall of Carl Zeiss, Oberkochen.