The Bright Pre-Main-Sequence Shell Star HR 5999

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It has been known for some time that stars are born by contraction in interstellar clouds. During most of this phase they remain invisible to us, because of the gas and dust shell in which they are imbedded. It is only towards the end of the birth process, when they approach the Zero-Age Main Sequence in the Hertzsprung-Russell diagram, that the newborn stars start to shine through their cocoon. At least that is what most astronomers thought until recently, when observations showed that the very young star HR 5999 is at least three *magnitudes above the Main Sequence. Drs. Pik Sin Thé and H.R.E. Tjin A Djie from the Astronomical Institute of the University of Amsterdam (the Netherlands) explain how HR 5999 was recently observed simultaneously from La Silla, South Africa and with the IUE satellite.*

The Herbig Ae-Be-type stars are generally thought to represent an early phase of stellar evolution, which preceeds the main sequence A- and B-type stars. They bridge the gap between the birth of stars of 3-5 $M_{\odot}$ from a nebula consisting of gas and dust and the main-sequence stage. The general idea is that in the beginning this nebula obscures the newly-born star. During the pre-main-sequence phase the nebula has almost disappeared and this situation offers unique possibilities to observe the star and its circumstellar matter in all spectral regions from the far ultraviolet up to the infrared.

The Pre-Main-Sequence Star HR 5999

HR 5999 (= HD 144668) is one of the brightest Herbig Ae-Be-type stars. It provides us with an excellent opportunity to make a detailed study of the pre-main-sequence stage. Since the brightness is variable in an irregular way ($V = 7^m - 8^m$), an international cooperation was organized in 1978 to observe the star simultaneously by means of different observational techniques.

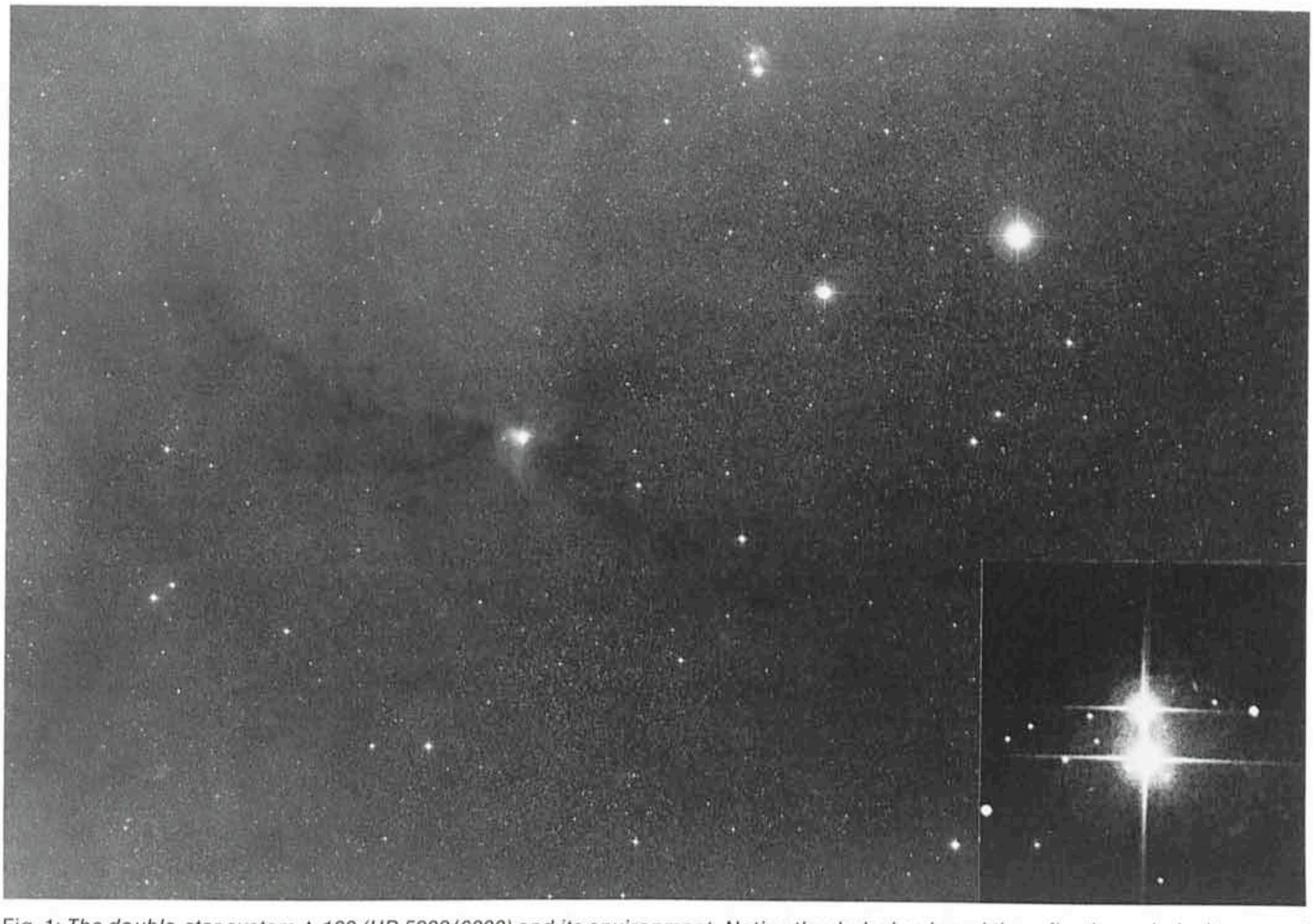

Fig. 1: *The double-star system Δ 199 (HR 5999/6000) and its environment. Notice the dark clouds and the reflection nebulosity around Δ 199. The system is shown enlarged in the insert. Reproduced from the ESO (B) Atlas. North is up and East to the left.*

HR 5999 does not appear in Herbig's 1960 list of probable pre-main-sequence stars with masses larger than those of T Tauri stars. The first detailed observations were made in 1970 by Bessell and Eggen at Mount Stromlo Observatory (Australia). According to them it has a proper motion in common with HR 6000 (= HD 144669) so that it is believed that these stars form a physical double star system (Δ 199), which is seen projected against a very dense dark butterfly-shaped cloud in the constellation Scorpius. A reflection nebulosity surrounding Δ 199 suggests that this binary is intimately associated with the cloud (fig. 1). In the immediate surroundings of Δ 199 more than 10 faint Hα emission objects, most probably very young T Tauri stars, have been found by one of us (P.S.T., 1962) in a survey of emission Hα objects in southern dark clouds, made with the Schmidt-type telescope of the Bosscha Observatory in Lembang (Indonesia). Subsequent photometric and spectroscopic observations by Bessell and Eggen show that HR 5999 is irregularly varying, that it exhibits circumstellar shell lines of H, Fe II, Ti II, Mg II, Na I and Ca II, and that the Hα and Hβ Balmer lines are in emission. From these facts one can already conclude that HR 5999 is very probably a Herbig-type pre-main-sequence object. It should be mentioned here that HR 6000 is, surprisingly, an Ap star located in the environment of a system of very young objects. So far no brightness variations of HR 6000 have been detected.

Photometric Observations

HR 5999 has recently been followed photometrically by Thé and his collaborators in April–May 1976 and in July–October 1977, in order to obtain a better knowledge of its light-curve in general, and in particular to study whether there are rapid smaller-scale variations or not. In 1976 the Walraven VBLUW photometer attached to the 90 cm light collector of the Leiden Southern Station Hartbeespoortdam (LSSH), South Africa, was used. In 1977 the same photometer and the Strömgren-type photometer were employed, the latter one attached to the Danish 50 cm telescope at ESO (La Silla). The combined light-curve of 1977 is shown in figure 2 (*Astronomy and Astrophysics, Suppl. Series,* Vol. 33, page 17). From this light-curve it is especially to be noted that at maximum the star varies rapidly.

From the photometric data the following results have also been derived. The 1976 Walraven photometry of the non-variable star HR 6000 can be used to determine that the foreground extinction $E(B-V)_J = 0^{m}.2$ (J stands for Johnson) and that the photometric distance of Δ 199 is 270 pc. By plotting the visual magnitude against colour index during the light-variation one can derive the ratio of total to selective absorption of the material in the circumstellar shell of HR 5999. Since the total extinction is known, it is then possible to derive the extinction-free brightness of the star, and with its distance also the absolute magnitude: $M_{V,J} = -0^{m}.9$. The spectral type estimated by Bessell and Eggen is A7 III-IV. The resulting position of the star in the HR diagram is about 3^{m} above the main sequence, in support of its pre-main-sequence character. A tentative comparison with Larson's evolutionary tracks shows that the star lies on a 3 $M_{\odot}$ track and could have an age of 7×10^{5} years. However, in the models of Larson the star should not be visible during this evolutionary stage, being still heavily covered by an opaque envolope. This is in contradiction with our observations. It is therefore important to make a more profound study of the physical properties of gas and dust in the shell, to obtain better input data for the theoretical calculations.

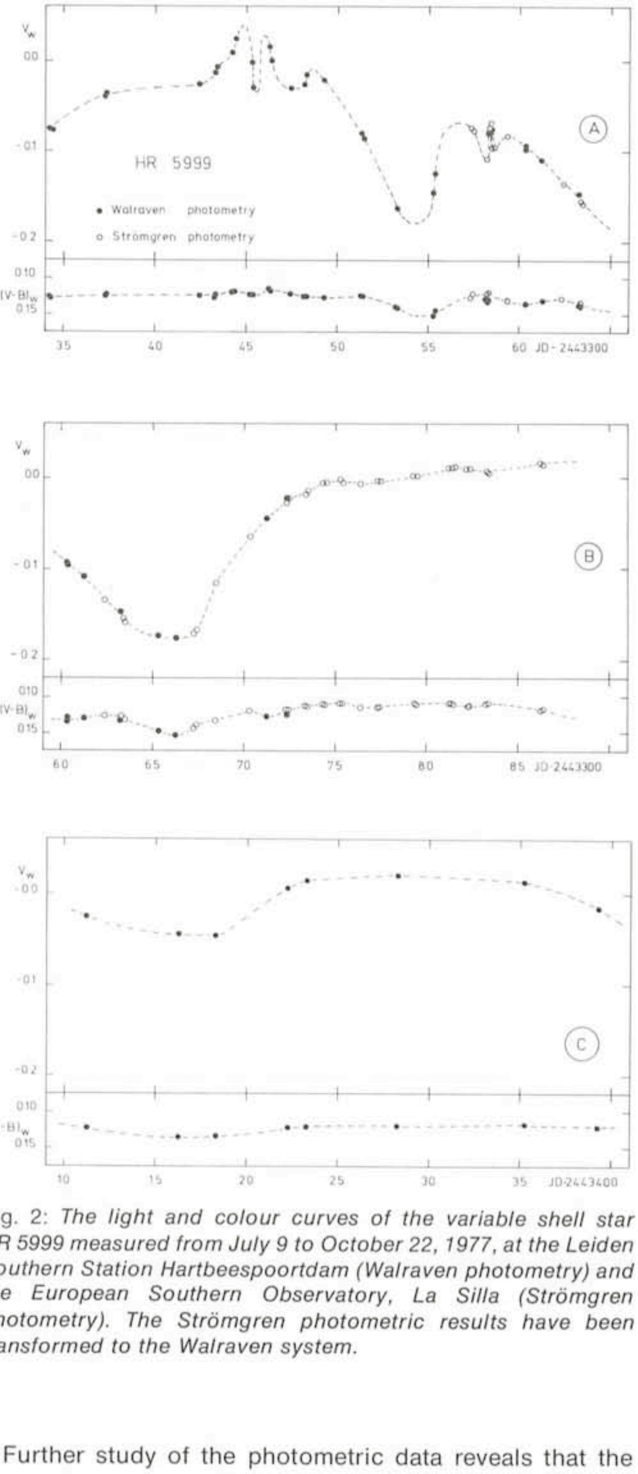

Fig. 2: *The light and colour curves of the variable shell star HR 5999 measured from July 9 to October 22, 1977, at the Leiden Southern Station Hartbeespoortdam (Walraven photometry) and the European Southern Observatory, La Silla (Strömgren photometry). The Strömgren photometric results have been transformed to the Walraven system.*

Further study of the photometric data reveals that the Balmer jump remains constant during the brightness variation of the star. It can thus be concluded that these variations are not caused by intrinsic changes in the photospheric temperature, but rather by variations in the column density of the circumstellar dust. Dust column density and grain size can be estimated from the extinction variation if the composition of the dust grains is known. If we assume that the grains consist of an iron core surrounded by a mantle of $MgSiO_3$, we find a grain radius of 0.16 μm and a column density variation between 1.8×10^{9} and 6.1×10^{8} cm^{-2}. The rate of change is about 1.4×10^{8} cm^{-2} per day. Additional information concerning the grain composition may be obtained from infrared and ultraviolet observations.

A very important result has been obtained by Smyth, Dean and Robertson in 1977 at the South African Astronomical Observatory (SAAO). Their observations show that the star exhibits a large infrared excess radiation which could be attributed to either graphite or iron grains with a temperature of 1,100 °K or 900 °K, respectively.

International Cooperation

In 1978 several astronomers agreed to join efforts to study HR 5999 simultaneously with various techniques. In April simultaneous infrared and optical photometry of the star was carried out by Smyth (Edinburgh) in cooperation with Andrews of SAAO. A shallow minimum ($\Delta V = 0\overset{m}{.}25$) was observed. During this period a few coudé spectra were obtained by de Loore and Marijke van Dessel (Brussels) with the 1.5 m telescope at ESO (La Silla). A second period of simultaneous observations was carried out during the last 12 nights of May. The first 5 nights were devoted to infrared photometry between 1.25 and 4.8 μm by Thé and Wamsteker (ESO) with the 1 m photometric telescope. Hereafter Thé took coudé spectra of the blue and red spectral regions with the 1.5 m telescope. During the whole period of observations the star was followed photometrically at La Silla with the 50 cm Danish and the 60 cm Bochum telescopes by Bakker (Amsterdam) and Zeuge (Hamburg), respectively. These data show again a shallow minimum with $\Delta V = 0\overset{m}{.}2$. Polarization was observed during April and May by Bastiaansen (Leiden) with a polarimeter attached to the light collector of the LSSH. Meanwhile at four nights in May the star was observed spectroscopically with the IUE satellite (cf. *Messenger* No. 15, p. 27) in the far ultraviolet by Viotti and Cassatella (Frascati, ESTEC), and by Gahm and Fredga (Stockholm). Besides these data at shallow minimum, a few spectra were taken at ESO at the times of deep photometric minima ($\Delta V = 1^m$), in April 1976 by Andersen (Copenhagen) and in July 1978 by de Loore and van Dessel (Brussels). Another deep minimum was measured by Thé during August 1978 with the Walraven photometer at LSSH. All these data are now being reduced and analysed.

The infrared, ultraviolet and polarization data are expected to give limitations as to the possible *composition* and *temperature* of the grains, and hopefully to impose some constraints on the parameters of the dust shell. The spectra in the visible and the ultraviolet contain information on the emission and absorption regions of the gas shell. The time variations of the gas and dust components of the shell seem somehow to be correlated and a detailed study of this phenomenon should throw some light on the question of the origin of the dust variations, and on the more general problem of the evolution of the circumstellar dust shell.

The ESA Astrometry Satellite

E. Høg

Recent advances in methods and instruments for astrometry (i.e. the accurate determination of positions in the sky of astronomical objects) have resulted in a proposal for an astrometrical satellite by a group of European astronomers. Dr. Erik Høg of the Brorfelde Observatory (Copenhagen University, Denmark) outlines the project and explains how it would make possible an incredible number of accurate, positional observations of the brighter stars.

A technological study has demonstrated the feasibility of an Astrometry Satellite which will be able to obtain an accuracy of $\pm 0\overset{''}{.}002$ for parallaxes, yearly proper motions and positions of 100,000 stars, mostly brighter than $m_B = 11$.

It is emphasized that the scientific impact of these orders of magnitude improvements over present data will be multiplied if astrophysical data are also obtained for the selected stars by ground-based techniques.

Why Do Astrometry From Space?

Astrometric observations obtained from an instrument outside the earth's atmosphere should be more accurate than ground-based observations for a number of reasons. There is no refraction and no instrumental flexure due to gravity: The optical resolution of the telescope is not deteriorated and variable due to atmospheric turbulence. In return for these advantages, a number of technological problems must, however, be solved in connection with the optical system, the thermal control and the attitude stabilization of an Astrometry Satellite (AS or HIPPARCOS).

The European Space Agency (ESA) has carried out a feasibility study of such a satellite in a collaboration between a team of scientists and a number of industrial firms from ESA countries. The study has demonstrated that an AS is feasible. It employs the optical principle of a two-axis telescope for scanning of great circles as proposed by P. Lacroute many years ago. It has now been imbedded in the framework of a professional spacecraft design, as required for the judgement of feasibility, and incorporates new ideas for optical system, scheme of scanning the sky, orbit, photoelectric detection, data analysis, etc. The AS will be launched into a geosynchronous orbit.

What will be Observed?

About 100,000 preselected stars, most of them brighter than $m_B = 11$, will be observed. The predicted accuracy of the observed parallaxes, proper motions per year, and positions is $\varepsilon = 0\overset{''}{.}002$ for stars of $m_B < 11$, degrading to $\varepsilon = 0\overset{''}{.}010$ at $m = 14$. This includes all sources of error: photon statistics, attitude instability, optical aberrations, thermal disturbances, etc.

The 100,000 stars will be selected in advance by astronomers according to the astrometric and astrophysical criteria they may wish. A rather uniform distribution of the stars on the sky is required for technical reasons. All 60,000