The X-ray Binary 4U 1700-37/HD 153919

G. Hammerschlag-Hensberge and E. van den Heuvel

New satellite data have provided ground-based optical astronomers with a large amount of extremely interesting work in connection with X-ray binary stars. Spectroscopic and photometric observations are urgently needed to further unravel the nature of these strange objects. The present report by Drs. Godelieve Hammerschlag-Hensberge and Edward P.J. van den Heuvel of the Astronomical Institute of the University of Amsterdam, the Netherlands, summarizes four years of painstaking observations of one of the brightest stars identified with an X-ray source. Their thorough study has already revealed some very interesting details about this binary system.

Since the discovery of the first X-ray binaries by the Uhuru satellite, our group in Amsterdam, in collaboration with the Astrophysical Institute of the Vrije Universiteit of Brussels, has put much effort in analysing the optical behaviour of these systems. For our observations we made primarily use of the ESO telescopes and of the 92 cm light collector of the Leiden Southern Station in South Africa.

In this note we will describe some recent results for HD 153919, the optical component of the 3.41 day period X-ray binary 4U 1700–37. HD 153919 is one of the brightest stars identified with an X-ray source (only the supergiant binary V 861 Sco, recently identified with the X-ray source OAO 1653-40, is brighter). Its spectral type is O 6.5f. The X-rays are eclipsed during 0.9 day of the 3.41 day orbital cycle.

Spectroscopy

Between 1973 and 1977 we collected 75 blue spectrograms of this star with the coudé spectrograph of the 1.5 m ESO telescope. The spectra were taken by van den Heuvel, De Loore (Brussels) and Hammerschlag-Hensberge. The spectral lines in this Of star are very broad, which makes measurements of radial velocities difficult. But thanks to our large number of excellent plates, we were able to determine a rather accurate radial velocity orbit. Figure 1 shows the result of these radial velocity measurements. We put a lot of effort in correcting the measurements for different kinds of systematic errors. One of the most important corrections is the following one: Due to the steady outflow of the atmosphere of the Of star, lines which are formed at different levels in the stellar atmosphere, show different velocities. Before calculating the mean velocity of all observed lines on a plate, corrections for this systematic deviation therefore had to be made. If the outflow of the atmosphere is spherically symmetric, one would expect that this radial velocity deviation of a spectral line remains constant through the binary cycle. But figure 2 shows that this is not the case! The radial velocity deviation of Hγ, for instance, shows two peaks per orbital cycle, of which the largest coincides with the phase where we see the side of the star which is turned toward the X-ray companion. At this phase (0.5) the velocity is more negative than average.

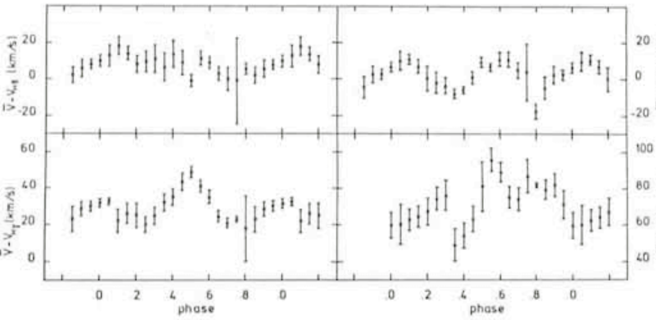

Figure 2: *The radial-velocity deviations from the mean for some of the Balmer lines, plotted against X-ray phase.*

This is also clearly demonstrated in figure 3: the radial velocity of Hγ deviates strongly from the mean velocity curve near binary phase 0.5 and becomes more negative, which is indicative for a stronger outflow of material. This asymmetry in the stellar wind influences the radial velocities of most stellar lines and hence the derived masses of both components.

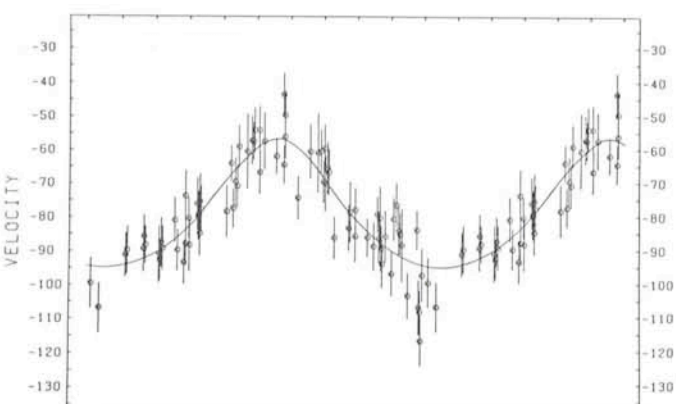

Figure 1: *Variation of the average radial velocity for all lines of HD 153919 with X-ray phase. Phase zero corresponds to mid X-ray eclipse time. Each point represents the average radial velocity for one ESO coudé plate. The curve drawn through the points represents the best-fit solution to the data.*

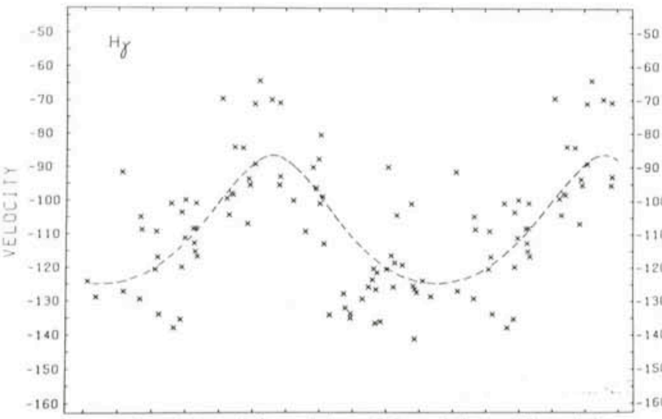

Figure 3: *Radial velocity variation of Hγ, plotted against X-ray phase. The dashed curve drawn through the points represents the best-fit orbital solution for the mean velocities of all lines together.*

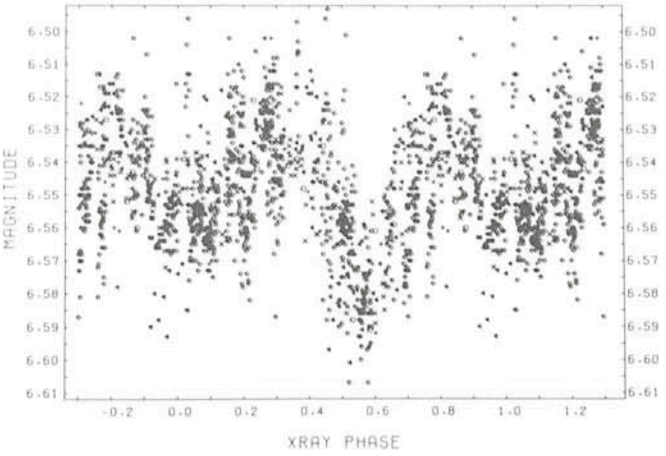

Figure 4: *V-light curve of HD 153919. The symbols denote observations by the different observers, viz.:*
◁ *Penny, Olowin, Penfold and Warren, 1973*
○ *de Freitas Pacheco, Steiner and Quast, 1974*
+ *van Genderen, 1976*
◇ *van Paradijs, Hammerschlag-Hensberge and Zuiderwijk, 1978*
× *Hammerschlag-Hensberge and Zuiderwijk, 1976.*

Photometry: A Possible 97-Minute Periodicity

At the same time we also studied this star photometrically. Together with Ed Zuiderwijk (Amsterdam), one of us (G.H.–H.) observed it in the uvby system with the Danish 50 cm telescope at ESO in 1975. One year later, van Paradijs (Amsterdam) observed the star during one month with the Walraven 5-colour photometer in South Africa. At that time, we collected all existing photometry of this star and plotted it in the 3.41-day orbital period. The result is shown in figure 4. The double wave variation typical for massive X-ray binaries is clearly visible although there is much intrinsic scatter in the points.

In April 1978 Dr. T. Matilsky of Rutgers University and Dr. J. Jessen of the Massachusetts Institute of Technology reported the discovery of X-ray pulsations in 4U 1700-37 with a 97-minute periodicity from observations with the SAS-C satellite. This is the longest reported period for any X-ray pulsar. Most other X-ray pulsars have periods between 0.7 sec. and 12 minutes. Although such long periods may also be produced by rotating white dwarfs, there is a variety of reasons why these pulsars—including 4U 1700-37—are most likely to be neutron stars. The main reason is the X-ray spectrum: all the pulsating sources, including 4U 1700–37, appear to have very hard X-ray spectra, strongly suggesting that we are dealing with accreting neutron stars. Some of the previously reported X-ray pulsars in binaries showed optical pulses with the same period as the X-ray pulses. For 4U 1700–37 our optical photometry comprised the largest available material, so that it was natural to use our data to search for possible optical variability. Dr. A. Kruszewski from Warsaw University Observatory searched for 97-min optical pulsations in the yellow-filter photometry obtained by van Paradijs and reported evidence for the presence of this 97-minute variability. According to him, the variability appears strongest around orbital phases 0.4 – 0.6 and it disappears at X-ray eclipse time. We studied the variability not only in the V channel but in all the five available spectral regions of the Walraven system. The 97-minute variability is probably present in all these channels and becomes stronger towards the ultraviolet as is shown in figure 5. Similar plots for other periods did not produce positive results. More observations in the Walraven 5-colour system (by A. van Genderen) and in Hβ-photometry (by H. Henrichs at ESO) are being analysed at this moment to try to examine whether this variability remains present over longer time intervals than one month. Although the present data seem very suggestive, we feel that still more data are required to definitely confirm the presence of this periodicity.

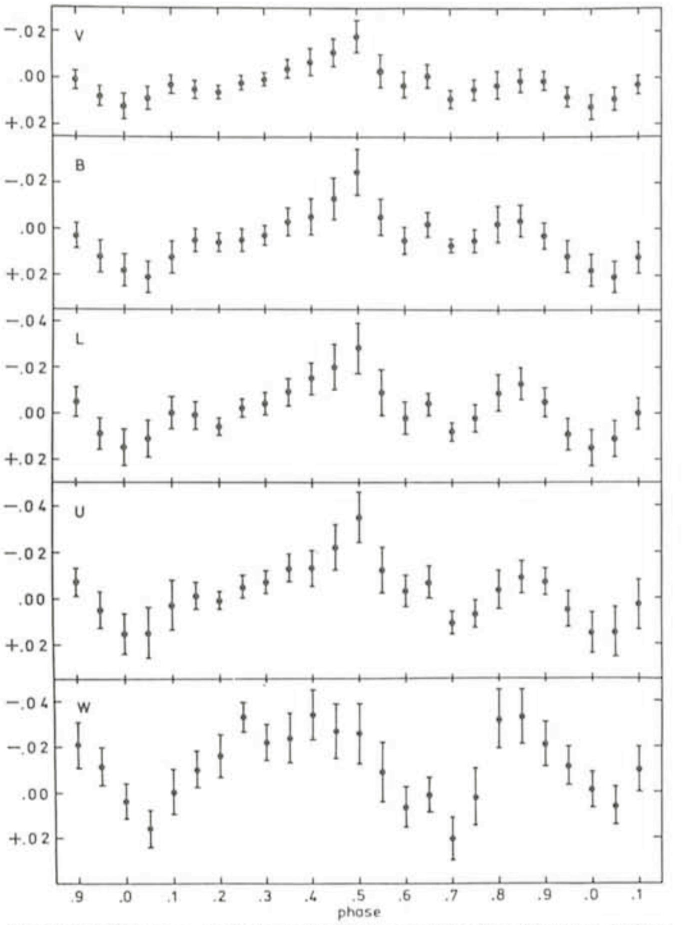

Figure 5: *The average light curve of a possible 97-minute variation of HD 153919 in the five channels of the Walraven system. The results were obtained from observations between orbital phases 0.44 and 0.59 when the X-ray source is in front of the Of star.*

What is very mysterious about this pulsar is why its pulse period is so long. No theoretician has so far come up with a satisfactory answer to this question.

About the "Messenger"

We regret that this issue is somewhat delayed due to summer holidays. The next issue will appear as planned on December 1, 1978.

The *Messenger* is printed in approximately 2,200 copies and distributed to all major observatories in the world. It is also sent to the IAU members in the ESO countries and to many other friends of astronomy, including science journalists and amateurs. We shall always be happy to review the application for a free copy from others who are interested in ESO and in European astronomy.

Most of the authors are professional astronomers who work in Europe and many of them describe their observations at the ESO La Silla observatory. We try to bring the latests news and to inform the readers about what is going on in astronomy *now*. It is therefore unavoidable that some of the articles have a "preliminary" look and that statements therein are often expressed with some caution. We certainly do not attempt to compete with the professional journals.

Readers, who have suggestions or would like to propose changes and improvements over the present form are welcome to write to us—the address is on the last page.

The editors