Astron. Astrophys. 347, 473–477 (1999)

ASTRONOMY AND ASTROPHYSICS

The peculiar M giant HD 154791

Optical counterpart of the X-ray source 4U1700+24*

S. Gaudenzi[1] **and V.F. Polcaro**[2]

[1] Istituto Astronomico dell'Università "La Sapienza", Via G.M. Lancisi 29, I-00161 Roma, Italy
[2] Istituto di Astrofisica Spaziale, CNR, Area della Ricerca di Roma Tor Vergata, V. Fosso del Cavaliere snc, I-00133 Roma, Italy

Received 15 January 1999 / Accepted 14 April 1999

Abstract. HD 154791 is the only optical counterpart of an hard X-ray source (4U1700+24) with an apparently normal M giant spectrum. We present here new high S/N spectroscopic observations of this interesting and poorly studied object, pointing out a number of peculiarities never noticed before; therefore we derive a possible scenario involving a wide binary system, where an old, slowly rotating, neutron star is weekly interacting with its late optical companion. We foresee that this system could evolve, in a short time, into a normal LMXB.

Key words: line: identification – stars: evolution – stars: individual: HD 154791 – stars: late-type – stars: neutron – X-rays: stars

1. Introduction

The X-ray source 4U1700+24 was firstly discovered by the Uhuru satellite (Forman et al., 1978) and reported as an X-ray emitter also in the 3A and 1H catalogs (Pye et al., 1983; Wood et al., 1984). Its optical counterpart was identified as the red giant HD 154791 by Garcia et al. (1983): these authors stressed that it was the first (and, to date, it remains the unique) case of hard X-rays detection for an M giant having a "completely normal" optical spectrum.

Until now, HD 154791/4U1700+24 has been observed in the X, UV, optical and infrared wavelength ranges. However, a definite classification of the system, based on both morphological and physical characteristics, is still controversial. This situation is caused by the very few and sparse data published to date and by the fact that the observations of this object available until now show a significant variability at all wavelengths.

Actually, Garcia et al. (1983), from data obtained by HEAO1 and Einstein Observatory, found a 2–11 keV X-ray luminosity of 4U1700+24 (for a distance of 830 pc -see later-) ranging from $\geq 10^{33}$ to 1.4×10^{34} erg s^{-1}; the column density value was $N_H=10^{22}$ cm^{-2} and the derived temperatures of 15 keV or more. On the other hand, the X-ray spectrum successively measured by Dal Fiume et al. (1990) using EXOSAT, in the framework of a multiwavelength campaign performed in 1985, was significantly softer and much more absorbed: the source intensity was lower by a factor ∼6 and the N_H value was much higher: $(2.1–3.8)\times10^{22}$ cm^{-2}. Moreover, a time variability with an average fractional variation in flux of ∼50% was always evident at this flux level. Finally, in a systematic search for long-term variability in a large sample of X-ray sources observed with Einstein Observatory, Maccacaro et al. (1987) evidenced a variation of a factor 2 in 203 days in the flux emitted by the system.

Strong variability is also evident in the UV range from the comparison of the Garcia et al.(1983) and Dal Fiume et al. (1990) results. Strong emission lines of C IV λ 1550 Å, N V λ 1238 Å, Mg II λ 2800 Å, very unusual among M giants, were observed by Garcia et al. (1983) and were present also in a previous archive observation, performed in February 1981. The C IV and N V lines later disappeared and the Mg II line intesity decreased of a factor 2 (Dal Fiume et al.,1990).

In the optical range too a variation of the system behaviour points out. Actually, Garcia et al. (1983) found that the measured colors were consistent with those from a normal M giant, except that the star is 0.3 magnitudes brighter than the normal in B. These authors also found, from low dispersion measurements, a normal M type giant spectrum (M3II) with none of the emission lines (Hα, Hβ, He II λ 4686 Å) characteristic of accretion driven X-ray sources. The Ca II K doublet was in emission and its flux level, measured from ten high dispersion echelle spectra, was found to be high, but not unusual for an M giant. From its width at the base, a luminosity class of II and a distance of 830±100 pc was deduced. The search for a secondary star gaves ambiguous conclusions and it was argued that any eventual companion must have photospheric lines in the optical region much weaker than those of the primary and must induce the M giant to have a radial velocity variation less than 3 Km s^{-1}. On the other hand, Dal Fiume et al. (1990) found optical results consistent with a spectral type (M5-M7) later than that proposed by Garcia et al. (1983) probably indicating a real change in the temperature of the star atmosphere. The Ca II λ 3933 Å emission was completely desappeared two years after the Garcia et al. (1983) observations. No variability on long time scale was found in V and B bands, with only some evidence in U

Send offprint requests to: V.F. Polcaro (polcaro@ saturn.ias.fra.cnr.it)
* Based on data collected at the Loiano Observatory

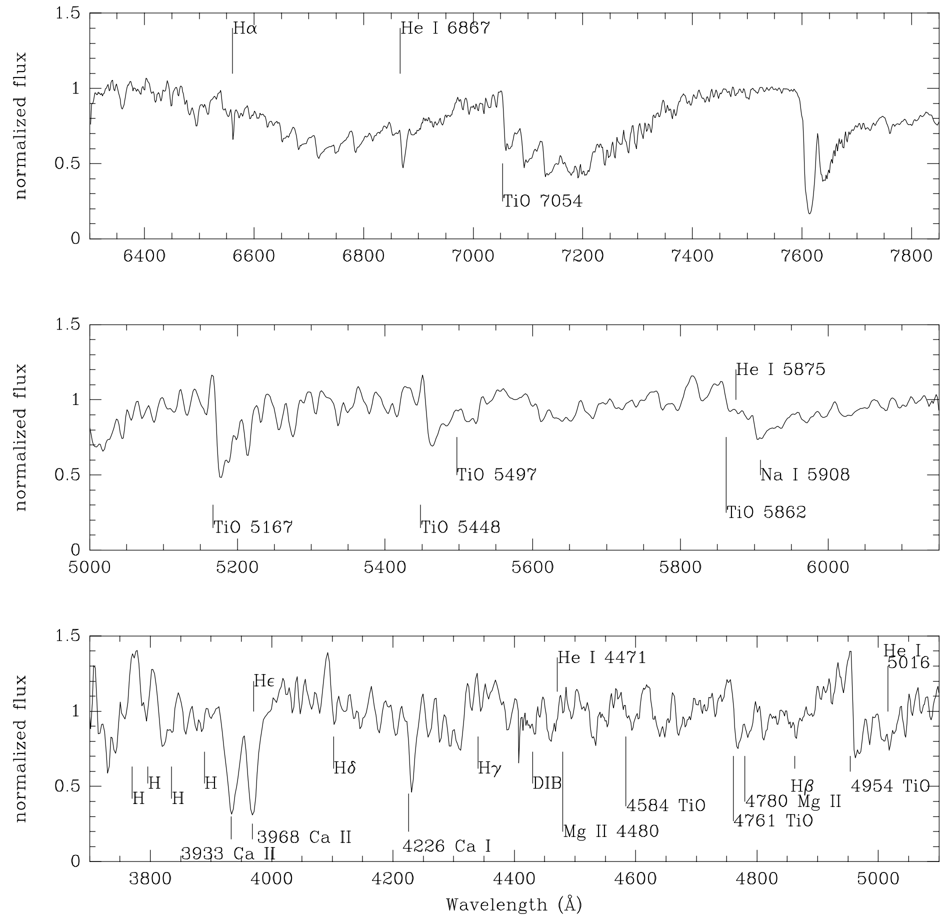

Fig. 1. The normalized spectrum of HD 154791 (23 July 1996) in the 3500–7800 Å range.

band. Only occasionally, small amplitude (0.15 mag) variations on short time scale (weeks) were detected.

Schaefer (1986) included this system in its IRAS observations of binaries with compact objects obtaining IR fluxes lower than most of the X-ray binaries. He thus argued that it is not clear if a compact object is present in this system. On the other hand, Brown et al. (1990) found the presence of the HeI 10830 Å spectral line, both in absorption and emission; they thus considered HD 154791 as a red giant with a probable hot companion.

Two possible scenarios can explain the just described observational data: an M giant star with an X-ray emitting corona or an M giant with a compact accreting companion.

Temperatures of 15 kev or more are typical of those found in X-ray binaries and much higher than that expected from an hot corona; also the X-ray flux is greather than the one given by coronal emission at a distance of $\sim$800 pc; the erratic time variability is a very common feature in accreting compact objects of very different classes (LMXBs, HMXBs, low luminosity HMXBs); modulations with orbit could explain the observed variations in the neutral hydrogen column density (N_H). On the other hand, a spectral evidence of any companion or a clear variation of the radial velocity are not observed until now and no periodicities have been found to date in the X-ray flux of this source.

Furthermore, Tomasella et al. (1997) have recently reported optical observations of HD 154791 during an outburst of 4U1700+24 occurred in November 1997 (Remillard, 1997, electronic announcement reported by Tomasella et al., 1997), when its 2–10 KeV flux reached the historical maximum of 35 mCrab. They found that no change in high resolution spectra were visible and no emission lines appeared in the Hδ-Hα region. This fact rules out the possibility that part of the optical flux of HD 154791 comes from an accretion disk.

2. Observations and results

A low resolution spectrogram of HD 154791, in the 3450–5800 Å range with $\Delta\lambda$ = 5.5 Å was taken by us in May 1995 at the Loiano 1.52 m Telescope with the Bologna Faint Objects Spectrometer and Camera (*BFOSC*, Merighi et al., 1994). The signal-to-noise ratio (S/N) of this spectrum is 200 at its bluer end and over 5000 at the redder end.

Two higher resolution spectra taken in the same run covered the optical emission of the star from 4500 to 6300 Å ($\Delta\lambda$=4 Å) and from 6300 to 7800 Å($\Delta\lambda$=3.0 Å), both with S/N higher than 1000 in the whole range. Spectra of the standard stars BD+33 2642 and Wolf 485A were taken with the same instrumental setup and were used for absolute flux calibration of HD 154791. Data were then reduced and analyzed using standard *IRAF* procedures. The cross calibration of the fluxes of the two standard stars (a B star and a white dwarf) gaves results perfectly compatible with that reported in the ESO Standards data base.

Table 1. Observations log of HD 154791

date	object	exp. (min)	UT beg (hh:mm)	sp. range (Å)	res. (Å)
1995 May 26	BD+33 2642	10	23:09	6300–7800	3
1995 May 26	HD 154791	3	23:50	6300–7800	3
1995 May 26	HD 154791	5	23:58	6300–7800	3
1995 May 27	BD+33 2642	15	00:29	6300–7800	3
1995 May 27	Wolf 485A	15	01:35	6300–7800	3
1995 May 27	BD+33 2642	15	20:52	6300–7800	3
1995 May 27	BD+33 2642	10	23:23	4500–6300	4
1995 May 28	HD 154791	10	00:08	4500–6300	4
1995 May 28	Wolf 485A	15	00:32	4500–6300	4
1995 May 28	BD+33 2642	30	23:03	3450–5800	5.5
1995 May 29	HD 154791	20	00:08	3450–5800	5.5
1995 May 29	Wolf 485A	45	01:05	3450–5800	5.5
1996 July 23	BD+33 2642	10	20:15	6300–7800	3
1996 July 23	HD 154791	1	20:34	6300–7800	3
1996 July 23	HD 154791	5	20:37	6300–7800	3
1996 July 23	HD 154791	5	20:45	4500–6300	4
1996 July 23	HD 154791	15	20:45	4500–6300	4
1996 July 23	HD 154791	30	21:16	3450–5800	5.5
1996 July 24	BD+28 4211	5	01:06	3450–5800	5.5
1996 July 24	BD+28 4211	5	01:22	4500–6300	4
1996 July 24	BD+28 4211	5	01:36	6300–7800	3
1996 July 25	K star in the HD 154791 field	60	20:34	4000–7200	6

The same sequence of measurements on HD 154791 was repeated on July 1996 (see Table 1) and was flux-calibrated using the standard stars BD+33 2642 and BD+28 4211.

During the same run, a deep low-resolution spectrum of the only other object marginally compatible with the 4U1700+24 error box was also taken. It resulted a foreground K0V star (V$\simeq$17), without any peculiarity.

No X-ray activity of the system is reported in literature at the epochs of our measurements.

On the base of the identified spectral features (see Fig. 1), HD 154791 can be classified as M3III, following Jaschek & Jaschek (1987). However, the star spectrum has a number of strong peculiarities that were not noticed to date. Actually, both in 1995 and 1996 the Hα, Hβ, He I 5016 Å, 5875 Å and 6867 Å lines are in emission, with a very peculiar shape, the same for all lines: these lines are characterized by a wide emission profile, with a narrow central absorption, at the laboratory wavelength (see Fig. 2). Hγ and Hδ looks in reemission and the Balmer lines of higher order are clearly visible in absorption. The Ca II 3933–68 Å doublet was in absorption but it was deeper than the Ca I 4226 line, as it is in the K stars (see Fig. 2).

The continuum too shows some peculiarities: the measured flux does not fit a 3500 K black body, in contradiction with the derived spectral type. Actually, the ratio between our flux calibrated spectrum of HD 154791 and that of the standard M3 star GL49, obtained from the GKM data-base and normalized to the same V flux, is equal to 1 at wavelengths longer than 4200 Å, but it raise up smoothly at shorter wavelengths. The dereddening, with any E(B-V), of our flux-calibrated spectra of HD 154791 produces only an unphysical distorsion. We thus argue that an anomalous reddening is present.

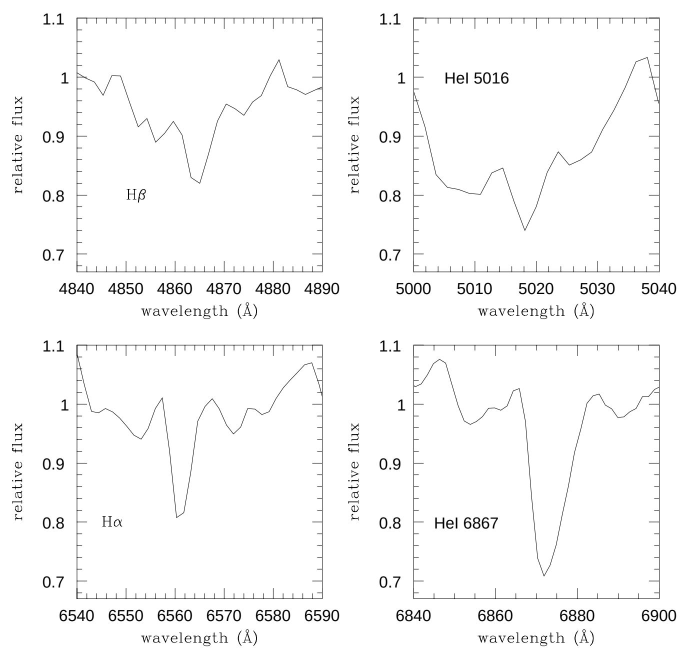

Fig. 2. The Hβ, He I 5016 Å, Hα and He I 6867 Å line profile of HD 154791

We can thus conclude that our spectra are in some way intermediate between those of Garcia et al. (1983) and Dal Fiume et al. (1990), while a comparison with those of Tomasella et al.

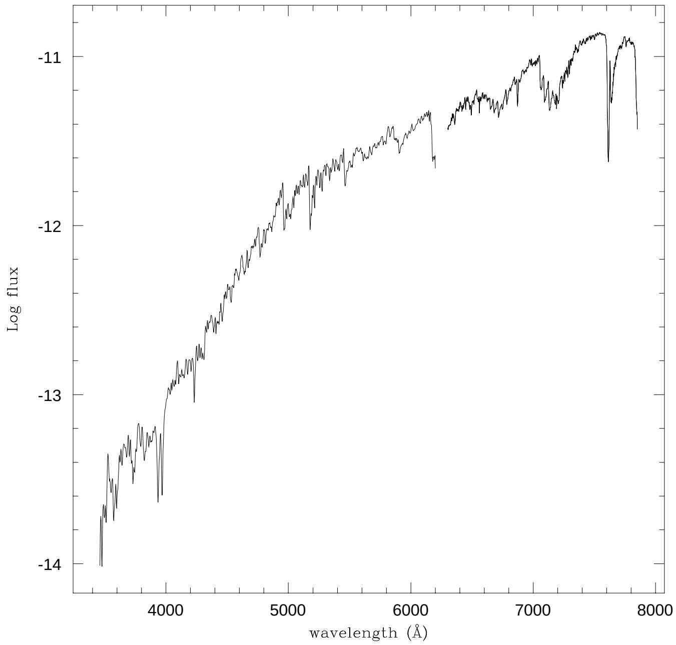

Fig. 3. The 1995 flux calibrated spectrum of HD 154791; flux is in erg cm^{-2} $Å^{-1}$ s^{-1}

(1997) is difficult because of the different resolution. However, the very high resolution spectra of the Hα region of Tomasella et al. (1997) clearly demonstrate that no emission was present at this epoch.

The V (=7.96) magnitude computed by our flux calibrated spectrum is compatible with that reported in literature (V=7.79, Garcia et al., 1983; V=7.64, Tomasella et al., 1997), while the B (=10.5) and U (=12.64) magnitudes are fainter (B=9.1, U=11.26 Garcia et al., 1983; B=9.36, U=11.0, Tomasella et al., 1997).

3. Discussion and conclusions

The peculiarities that we have described in the previous section show that HD 154791 has not a “standard M spectrum”, as it was reported in literature.

All data indicate that we are dealing with an evolved M giant but the comparison of the spectra taken in different epochs suggests that a number of features used for detailed spectral and luminosity classification are variable and are thus useless for this purpose. Lines emission at an energy level higher than in usual Me stars is evident in our spectra. We cannot say if these emissions were absent at the epochs of the other measurements or if they were firstly noticed by us because of our instrumental set-up and S/N ratio.

In any case, the spectral variability, the unusual ratio between Ca II and Ca I lines, as well as the clear presence of the Balmer lines, that are usually barely visible in the M stars, can be the effect of a strong coronal activity. On the other hand, the emission line profile that we found in HD 154791 is different from that of a typical Me star and strongly reminds that of many Be stars (see, e.g., Hanuschik, 1996). The HeI emissions, detected by us in optical range and by Brown et al. (1990) in the near IR, are also difficult to explain in a coronal activity framework. At the same time, this object cannot be classified as a symbiotic star due to the lack of strong and narrow emission features and of forbidden lines.

These facts, as well as the high kT of the X-ray emission during the outbursts, strongly support the presence of a compact companion; on the other hand, the lack of detectable dynamical effects on the optical star suggests that its orbit must be quite wide.

We can thus suggest the following scenario: the SN explosion of the 4U1700+24 precursor happened in a wide, intermediate mass, binary system and left HD 154791 substantially unaffected. This star then followed its natural evolutionary track, without strong interaction with its compact companion, and is now in the red giant phase. But the dense, slow wind typical of this phase is now generating a nebula around the optical star. This nebula can explain the anomalous reddening found by us and the faint IR excess discussed by Schaefer (1986). The neutron star is thus now orbiting in a relatively denser medium, and a continuous, low level accretion is now present. The related X-ray emission is probably well below the detectability threshold of the present day instrumentation, but it is high enough to warm the external layers of the M star, generating a pseudo-coronal effect, as we see in the optical spectra of HD 154791. Inhomogeneities, quite common in M stars wind bubbles, and/or orbital eccentricity give origin to a variable energy output from the neutron star and are detected as spectral variability of the optical star. Time to time, a denser wind blob cross the orbit of the neutron star and a transient high level X-ray outburst rise up, without any periodicity and with random intensity and N_H, depending from the blob density.

In this hypothesis, the neutron star is very old and no momentum transfer from the optical star was present until recent times: thus, its rotation can be very slow, the X-ray pulsed fraction quite small and therefore very difficult to detect during the outbursts. However, the neutron star is now loosing potential energy, due to the interaction with the HD 154791 wind: we can thus foreseen that its orbit is lowering and that this process will increase the X-ray luminosity of the system and the neutron star angular velocity. The higher energy input will encrease the mass loss of the primary star and, after some time, the system will probably look similar to GX 1+4 (M6III–M3III, symbiotic, see, e.g. Chakrabarty & Roche, 1997). During this phase, HD 154791 will loose part of its external layers and will then appear smaller and hotter, as a late dwarf G or K. Thus this process could generate a normal low mass X-ray binary in a time that is difficult to evaluate but that must not be too long. Actually, the uniqueness of the HD 154791/4U1700+24 system strongly suggests that this evolutionary phase should not be too long.

Our scenario explains also the lack of spectral activity during the outburst pointed out by Tomasella et al. (1997): in our hypothesis, this activity is not due to an accretion disk but to the X-Rays reprocessing in the external layers of the

HD 154791 photosphere. Since we believe that the neutron star is still quite far from its optical companion, such activity will appear some time after the outburst. Unfortunately, no continuous monitoring following the end of the X-ray outbursts are reported to date in literature: if they will be performed in future, they will prove or discard our scenario and, in case of positive detection, will allow the direct measurement of the orbital radius.

Acknowledgements. We thank Drs A. Bazzano (CNR-IAS), A. Tornambe' (OAT) and R.K.Manchanda (TIFR) for usefull discussion about 4U1700+24. We also thank F. Bucciarelli for its assistance in the spectra catalogs research. This work has made use of the SIMBAD database at the CDS (Strasbourg). The reduced spectrograms of HD 154791 listed in Table 1 are available as computer ASCII files on request to the authors at the address: polcaro@saturn.ias.rm.cnr.it

References

Brown J.A., Smith V.V., Lambert D.L., et al., 1990, AJ 99, 1930
Chakrabarty D., Roche P., 1997, ApJ 489, 254
Dal Fiume D., Poulsen J.M., Frontera F., et al., 1990, Nuovo Cimento 13C, 481
Garcia M., Baliunas S.L., Doxsey R., et al., 1983, ApJ 267, 291
Hanuschik R.W., 1996, A&A 308, 170
Jaschek C., Jaschek M., 1987, The classification of stars. Cambridge Univ. Press
Forman W., Jones C., Cominsky L., et al., 1978, ApJS 38, 357
Merighi R., Mignoli M., Ciattaglia C., et al., 1994, BFOSC User's Manual. RT 09-1994-05, Bologna Astronomical Observatory
Maccacaro T., Garilli B., Mereghetti S., 1987, AJ 93, 1484
Pye J.P., McHardy I.M., 1983, MNRAS 205, 875
Schaefer B.E., 1986 PASP 98, 556
Tomasella L., Munari U., Tomov T., et al., 1997, IAU Inform. Bull. Var. Stars 4537, 1-3
Wood K.S., Meekins J.F., Yentis D.J., et al., 1984, ApJS 56, 507