The peculiar Of?p stars HD 108 and HD 191612[*]

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Abstract: The Of?p spectral category was introduced by Walborn in 1972 to describe peculiar stars which possess intense emission lines of C III λλ 4647,4650,4651. Recently, two of them, HD 108 and HD 191612, were found to display spectacular line profile variations in the visible domain: these stars apparently alternate between two different spectral states (O6-O8). To discover the origin of this intriguing behaviour, a multiwavelength campaign was undertaken. In this context, the analysis of the X-ray emission is especially important since it provides crucial information for constraining the nature of these peculiar objects and testing conflicting models. We are therefore carrying out high-quality XMM-*Newton* observations of these stars and we present the results of the data obtained up to now.

1 Introduction

The Of?p category was introduced by Nolan Walborn in 1972 to describe two stars, HD 108 and HD 148937, with spectra that were slightly different from those of normal Of supergiants. Notably, they present C III lines around 4650Å with an intensity comparable to that of the neighbouring N III lines. In addition, their spectra showed sharp emission lines and some P Cygni profiles. A third star was soon added to this new class, HD 191612.

Of all Of?p stars, HD 108 is the best studied, but its observation led to conflicting results in the past. Some authors found radial velocity (RV) variations reminiscent of a binary motion, usually with a relatively short period (Hutchings 1975) although Barannikov (1999) derived a much longer period. However, other papers (e.g. Vreux & Conti 1979, Underhill 1994) reported no sign of orbital motion and rather attributed the RV and line profile variations to wind instabilities. To settle the conflicting situation, a new campaign for observing the Of?p stars was undertaken.

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[*]Based on data collected at the Haute-Provence Observatory (France) and with the XMM-*Newton* satellite (ESA)

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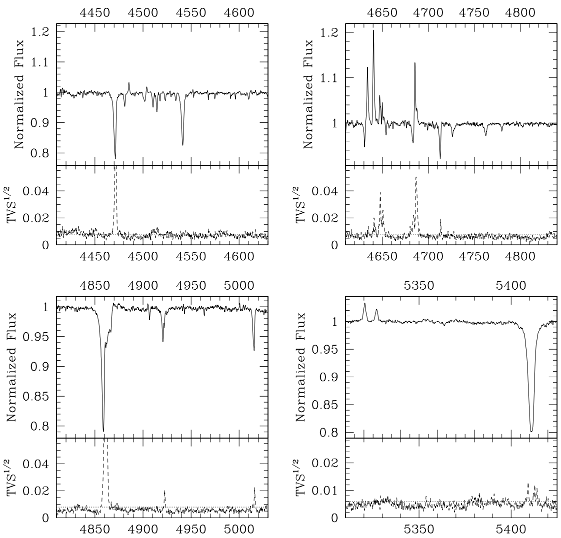

Figure 1: Mean visible spectrum of HD 191612 (top) and Time Variance Spectrum (TVS, bottom) around some key lines.

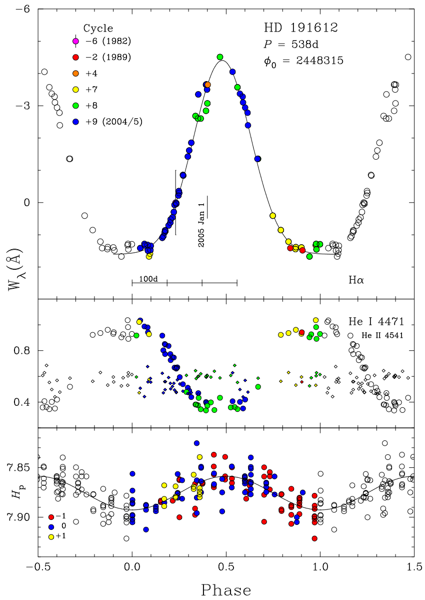

Figure 2: Variations of the EW of the Hα line (top), of the He I λ 4471 and He II λ 4542 lines (middle) and *Hipparcos* photometry of HD 191612 (bottom).

2 Observational results

2.1 Visible spectroscopy

Nazé et al. (2001) reported the first results of an ongoing monitoring of HD 108 at the Haute-Provence Observatory. The carefully measured RVs of the star were clearly incompatible with the proposed orbital solutions. In fact, they do not show any signature of orbital motion, be it on short or long term. However, when examining in detail the spectra, Nazé et al. discovered that the star underwent long-term line profile variations. The Balmer lines and the He I lines passed from emission or P Cygni profiles to absorptions. On the other hand, other emission and absorption lines were unchanged, like He II λ 4542. Since the ratio of the equivalent widths of He I λ 4471 and He II λ 4542 is used to determine the spectral type of the star, HD 108 is displaying apparent spectral type variations. After a thorough look into the literature, Nazé et al. (2001) discovered that such transitions in the H and He I line profiles had already happened in the past: the variations seem recurrent with a recurrence timescale of approximately 50-60 years. A few years later, Walborn et al. (2003) reported a very similar phenomenon in the spectrum of another Of?p star, HD 191612 (see Fig. 1), but the timescale appears much shorter, about $\sim$540 days.

Since two out of three Of?p stars are varying, Nazé (2004) tried to check the behaviour of the last member of the class, HD 148937. This star is poorly known, and only one high-resolution spectrum could be found in the literature. Compared to more recent data, no significant variations apparently occurred but if the timescale was much larger or much shorter than those of HD 108 and HD 191612, the changes would have been missed. MacConnell & Bidelman (1976) claimed that the Hβ line of HD 148937 was "filled in" while this line is now in absorption, but this does not constitute a certain clue of variation since the study relied on low-quality photographic data. On the other hand, this star is surrounded by a nebula, NGC6164-5, which is chemically enriched. It is supposed that the gas surrounding the star was ejected during a past eruption. Neither HD 108 nor HD 191612 are surrounded by such a nebula, but HD 148937 could simply be in a more advanced phase of evolution.

2.2 Photometry

Regarding HD 108, Barannikov (1999) found some magnitude and color variations in recent years: the star is becoming fainter at the same time as the emissions are decreasing. On the other hand, *Hipparcos* has observed all three Of?p stars: variability for HD 108 and HD 148937 cannot be totally excluded but the photometry of HD 191612 shows a clear modulation (Nazé 2004). The magnitude of the stars is varying with a period of approximately 540 days. Comparing with the spectroscopic results, it appears that the spectral variations and photometric changes are indeed correlated (see Fig. 2): when the star is fainter, its emission lines are minimum and the star presents a spectral type O8 (Walborn et al. 2004). This changing broad-band luminosity is not an effect of the varying emission lines themselves, since the lines are too weak to induce the large variations that are seen in the photometry.

2.3 X-ray data

To better understand these stars, we have obtained some XMM-*Newton* data. For HD 108, they were taken during Rev. 0494 and were presented in Nazé et al. (2004). To summarize, the high-resolution RGS data revealed a thermal X-ray spectrum, well fitted by a two temperature optically thin plasma (with kT_1 ~0.2 keV and kT_2 ~ 1 keV). Note that the iron line is present at 6.7 keV, and the star is slightly overluminous compared to the classical $L_X - L_{BOL}$ relation. Comparing to the previous detections of HD 108, by *Einstein* and *ROSAT*, we found no significant changes but these data have very large error bars and we can not exclude a small decrease in flux (less than a factor of 2).

More recently, we have undertaken a campaign to observe HD 191612 with XMM-*Newton* throughout its 540d cycle. Up to now, three datasets were taken, during Revs 0975, 0981, and 1004 - a last one will be taken at the end of this year. The observations sample the descending branch of the EW variations (see Fig. 2). A preliminary analysis shows that the X-ray spectrum of HD 191612 is very comparable to that of HD 108, with similar absorbing columns and temperatures. If we compare these new, sensitive XMM-*Newton* data with older *Einstein* observations and *ROSAT* data, we find no significant variations of the star (i.e. larger than a factor of 2). However, if we compare the XMM-*Newton* observations between one another, a small decrease of the X-ray flux, of the order of 15%, is detected although no significant changes of the other spectral parameters were found. The star thus appears slightly fainter in the visible and in the X-ray domain when the emission lines are minimum.

Finally, for HD 148937, there exist only *ROSAT* data. Taking into account the different bandpasses of *ROSAT* and XMM-*Newton*, no large differences can be found in the spectral parameters compared to HD 108 and HD 191612 (Nazé 2004).

3 Discussion and conclusions

Our ongoing observational campaign revealed many new aspects of the Of?p stars HD 108 and HD 191612. First, we have uncovered spectacular long-term variations of their visible spectra. These changes are actually recurrent, with a timescale of ~540 days for HD 191612 and ~50-60 years for HD 108. They are correlated with the photometric variations. In X-rays, both stars present thermal spectra with a slight overluminosity and a small decrease of the flux in phase with the visible variability. This periodicity might be linked to binarity, but since we saw no changes in the RVs, the systems would have to be seen face-on.

Several models could explain the peculiar behaviour of the Of?p stars. A first idea is that these stars are eccentric binaries containing a compact object. This compact companion would accrete matter near periastron, emitting then X-rays that are capable of altering the wind ionization structure, preventing the formation of emission lines. Unfortunately, this model has to face two important objections: first, the recent X-ray data of HD 108 and HD 191612 showed that the star is not very bright in X-rays when at or near the minimum of the emission lines; secondly, the X-rays observations further suggest a simultaneous decrease of the X-ray flux and the emission lines, whereas they should be anticorrelated in this model.

In massive stars, variations in emission lines are often related to changes of the stellar wind. Such wind variability can result from several causes, like a variable magnetic field or stellar pulsations. It can also appear when the star undergoes a peculiar evolutionary phase. Such a possibility is consistent with the fact that HD 148937 is surrounded by an enriched nebula: Of?p stars would then be precursors of the LBV state. This wind interpretation faces one major problem: the strict (and rather long-term) recurrence of the phenomenon.

Finally, we may come back to the eccentric binary interpretation, this time considering two 'normal' stars. If we compare the X-ray emission from the Of?p stars with that of other massive stars in the NGC6231 cluster (Sana et al. 2005), all Of?p stars seem overluminous (although not enough to be considered as X-ray binaries). For comparison, Sana et al. found that only colliding wind binaries deviate significantly from the $L_X - L_{BOL}$ relation. Moreover, the colliding wind interpretation is also supported by the rather high value of the second temperature fitted to the X-ray spectra. However, the exact behaviour of the Of?p stars (notably the symmetric equivalent width changes) certainly requires a rather peculiar orientation of the system.

Obviously, there are still many unanswered questions regarding the nature of the Of?p stars, but the recent data have already enabled to discard some models and to put some tight constraints on the actual nature of the stars. It is hoped that future observations will help to solve completely this mystery. However, as we have focused up to now on HD 108 and HD 191612, a last challenge merits some attention: does HD 148937 present the same behaviour as the other Of?p stars, and if yes, with what timescale?

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