Where Peculiars Turn Normal – IR Observations of CP Stars

R. KROLL, Universitäts-Sternwarte Göttingen

Upper Main Sequence Stars

If you make all possible simplifications in the theory of stellar atmospheres – LTE, no convection, gas pressure two times the electron pressure, plane parallel atmosphere with solar composition, etc. – and look, where such a concept could actually work, you arrive at the upper main sequence stars. And in fact, there has been much progress in understanding such atmospheres, the model atmosphere grid calculated with Kurucz's famous ATLAS programme as an outstanding example.

Yet there is a large fraction (~ 20 %) of upper main-sequence stars that refuse to obey such simple physics. They show large metal overabundance, photometric variability, magnetic fields, breathtaking spectra or curious flux distribution. Following the systematic of Preston (1974) we call these stars 'chemically peculiar' or shortly CP stars.

Two mainstreams are distinguished, one that exhibits no magnetic fields and consists of the metallic line (Am) stars – nowadays called CP1 stars – and the Mercury-Manganese (HgMn or CP3) stars, and one that displays magnetic fields up to some 10,000 Gauss on the other hand. This article will mainly deal with these magnetic Ap stars, and reference them, more up-to-date, as CP2 stars.

Here the physical situation is complicated a little, namely by the strong magnetic field. This field in turn tries to be kind to the astronomer and keeps the second simplest form possible in most cases, that of a dipole, but inclined by some angle against the rotational axis. This working model – the oblique rotator – can explain most of the observed characteristics of CP2 stars, e.g. the photometric and spectroscopic variability, or polarity changes in the magnetic field, but the question remains, what causes the variety of abundance patterns in CP2 stars, which peak in objects like the famous and infamous Przybylski's star HD 101 065, where from the 15 strongest metallic lines 11 belong to Rare Earth Elements, 6 of these to the element Holmium, which is rarely encountered in any other branch of astrophysics.

Analysing the atmospheres of these stars is not a time consuming, unproductive work in some astrophysical niche, but a necessity in understanding stellar evolution in the presence of magnetic fields, which is a commonly encountered configuration. The CP stars are not an accident in stellar evolution, but at least one possible branch, or maybe even a state that every upper-main-sequence star passes.

But the variety of phenomena is discouraging at the first glance; let us consider the most commonly observed phenomena. In most cases we find a flux deficiency in the ultraviolet spectrum and in turn a 'heating' of the visual part which is understood as a back-warming effect from the enhanced metal abundances found in CP2 stars. In other words, flux is redistributed from the UV to optical wavelengths. This process works according to the individual abundance pattern of the specific star, so all temperature estimates, photometric calibrations, curve-of-growth analysis, etc. tend to produce rather uncertain, scattering results. Do we have any spectral window which is unaffected from the chemical peculiarity of the star, where we can find a stand?

Infrared Observations of CP Stars

In 1983 the last hope, the infrared part of the spectrum, seemed to slip away. Large flux excesses at 5 microns were reported, measured at the ESO 1-m photometric telescope by Groote and Kaufmann. These observations pointed to the existence of considerable circumstellar matter around CP stars, with blackbody temperatures of 300 to 600 K, which must be connected to the CP phenomenon in one way, either being the cause of it, or an unavoidable result. Both could hardly be understood

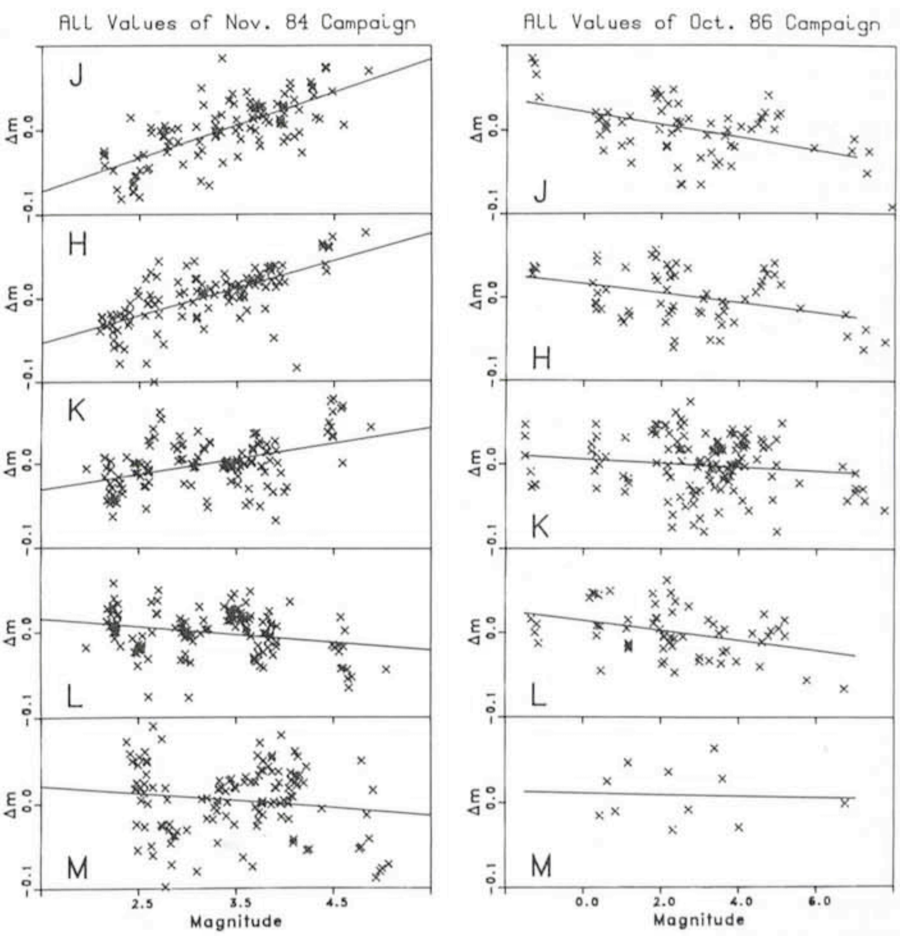

Figure 1a: *Catalogue minus observed brightness versus intrinsic magnitude for all standard star measurements during the November 1984 campaign. The nonlinearity effect changes its slope continuously from J to M filter.*

Figure 1b: *Same as 1a, but for the October 1986 period. Note that the abszissa spans a double range compared to Figure 1a. Nonlinearity effects have been greatly diminished.*

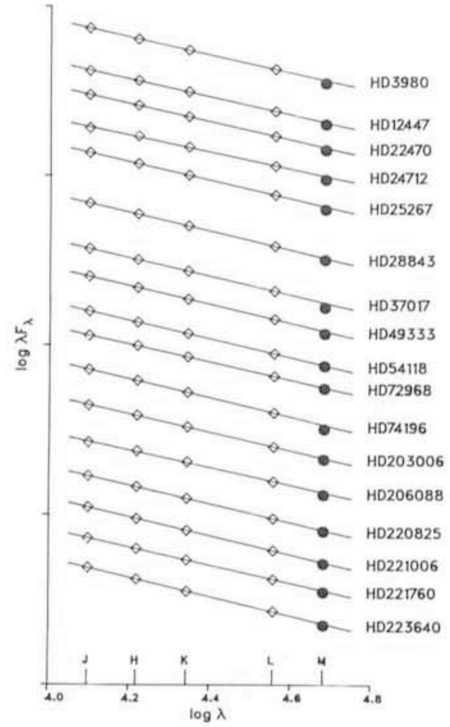

Figure 2: *Rayleigh-Jeans diagnosis. M values above line would indicate flux excesses. All observed stars are normal.*

with the most promising attempts to explain the forming up of chemical overabundances, like Michaud's diffusion theory.

But other researchers, like Bonsack and Dyck were unable to verify the claimed fluxes, so a careful reinvestigation of the subject was desirable. Franco Catalano from Catania/Sicily joined a group at Göttingen University Observatory in that attempt. Our first observing period dated November 19 (84 at the ESO 1-m telescope, equipped with its liquid nitrogen cooled IR photometer with InSb diode, which had undergone of course some minor changes since the time when Detlef Groote and Jens-Peter Kaufmann had made their exciting measurements.

In the first moment the observations made by Franco Catalano looked puzzling to us, when they were reduced in Göttingen. The calibration with standard stars from Koornneef's list was not satisfactory, because it showed a large scatter. During our attempts to localize the reason for that scatter, we plotted the difference between the expected and the measured brightness against the star's intrinsic magnitude in the specific filter. And here's the surprise (Fig. 1 a)!

Instead of showing the expected scatter around a horizontal line, a clear correlation was seen, which – even worse – reversed its trend with increasing wavelength, from the J- to the M-filter. This effect may be called by definition a nonlinearity, whatever caused it. After carefully correcting for that effect, none of our programme stars showed any sign of flux excess in the M-band, though many had been found to be excessive in the Groote and Kaufmann survey. Figure 2 shows this in a Rayleigh-Jeans diagnosis. We fitted a straight line through the logarithmic fluxes in the J, H, K and L filter and plotted it against the logarithm of the wavelength. Now the M value is excessive against a blackbody flux distribution in the Rayleigh-Jeans approximation, if it lays above this line. But this is not the case for any of the programme stars.

The IRAS View

Though the 5 μ flux excess was disproven this way, we were sensitized for the possible existence of circumstellar matter and looked for it in the IRAS point sources catalogue. We found 40 CP stars of various types, for which good near IR data were present. From the CP 2 group none showed fluxes at the IRAS wavelengths – which are 12, 25, 60 and 100 μ – that would not fit to a blackbody flux distribution. Two objects were found where in fact circumstellar dust was indicated, but they belong to the He peculiar stars, or CP4 group, where we also find stars with Be characteristics. Dust shells are not uncommon for these objects. Positively spoken, our result from the IRAS data is that CP stars show normal main-sequence characteristics in the infrared as far as we can observe them. Figure 3 shows some examples for various CP types.

We may now savely conclude that all flux redistribution, caused by the curious chemistry of the CP stars has come to an end at infrared wavelengths, and hence the infrared fluces are a superb indicator for the thermal properties of the atmospheres and a solid stand for further analysis.

IR Light Curves

The next logical step is to get precise light curves in the infrared, which tell us what thermal changes take place, as the stellar rotation brings different parts of the atmosphere into the line of sight of the observer. For this project Franco Catalano and I got ten nights of observing time at the 1-m in October 1986. Unfortunately the delayed spring made this time shrink to merely four nights effectively.

Another handicap was that in the beginning we did not know which stars would show pronounced variability. Our compromise in having many data points per star as well as many stars checked, resulted in sufficient data for about eight CP stars. Of course we had to restrict ourselves to objects with short periods.

First of all we checked whether the awful nonlinearity effect was still present – and were pleased to see that it had been nearly totally removed. Note that in Figure 1 b the abszissa spans now eight magnitudes instead of four in Figure 1 a.

Differently to the observations one year ago we performed differential photometry, taking comparison stars in the vicinity of the programme stars. This allows a much higher accuracy, be-

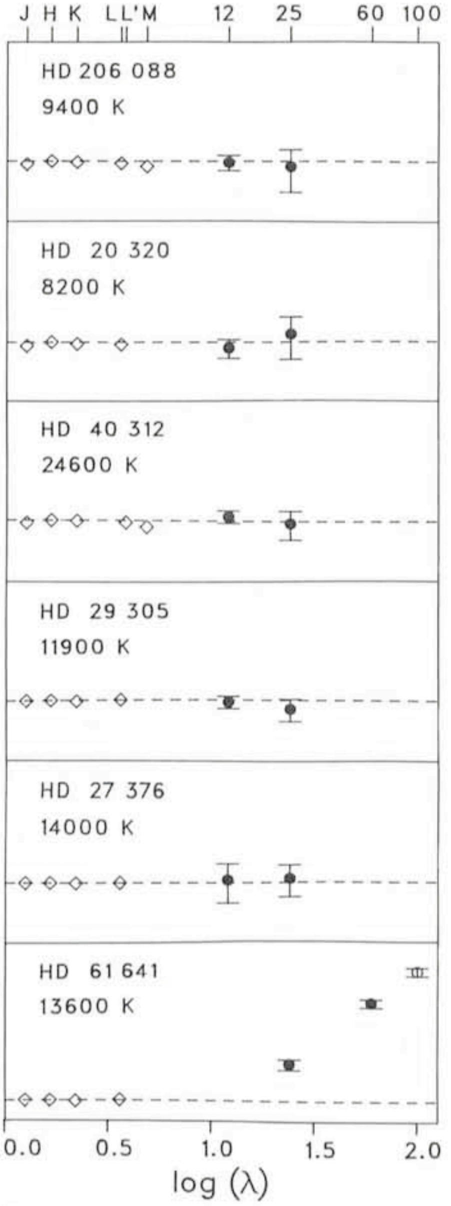

Figure 3: *IRAS observations. Fluxes above dashed line are excessive against a blackbody with the indicated temperature, deduced from the near IR colours. The CP4 star HD 61 641 shows indications of a dust shell, which gives it Be type characteristics. All other stars show blackbody flux distribution (HD 206088 and 20320 are cool CP2 stars, HD 40312 and 29305 hot Si type CP2 stars, HD 27374 is a CP3 star). Error bars indicate 3 σ.*

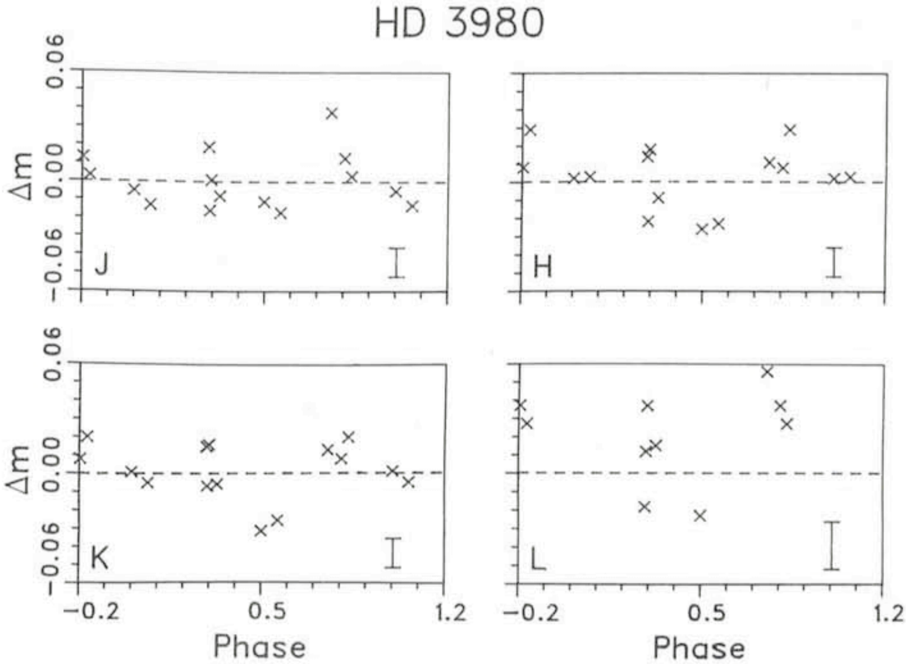

Figure 4: *IR light curve of HD 3980 in four filters. No sign of periodic variability could be found. Mean errors are indicated by the error bars in the lower right corners.*

cause the infrared sky is much more inhomogenous than the visual. We knew that high precision was needed, since our previous data showed that the expected amplitudes would be lower than about 0.03 magnitude.

The first results looked disappointing, one star after the other showed no clear sign of variability, like in the case of the well-known cool CP2 star HD 3980 (Fig. 4). So we reached the final star on our list, α Doradi or HD 29305. Though we had only seven data points per filter, we observed in all filters a clear variation with a mean amplitude of 0.028 magnitude (Fig. 5). The phase shifts and amplitudes are very similar in every filter but, because of the few data, the light curve must be confirmed by subsequent observations.

HD 29305 is a bright silicon type CP2 star, with an effective temperature of about 12,000 K. It has a high projected rotational velocity (v * sin i = 130 km/s, but this value may be overestimated). Together with its rotational period of 2.95 days, this tells us that the rotational axis is tilted close to a right angle to the line of sight. So we have a total exchange of the visible surface after half a period.

In the Rayleigh-Jeans regime, flux and temperature are linearly related, a 3 % variation in flux corresponds to a 3 % temperature change, which in the case of α Dor gives 350 K. That means, the light minimum phase corresponds to an average temperature, which is 700 K lower than in the maximum phase. Remember, this value is an average over one hemisphere, so actual temperature differences may be much higher.

This observation implies that in this particular star the atmospheric variations may not be explained exclusively by the line blanketing mechanism, since this would leave the effective temperature unchanged.

Since any attempt to map the distribution of chemical elements on the surface of CP stars – and to relate that to the magnetic field configuration – needs a map of the physical parameters first, the infrared light curves may be of great value for such work. Till now, for such work the stellar atmosphere was always assumed to be homogenous in their physical parameters.

We will continue this work in July at La Silla.

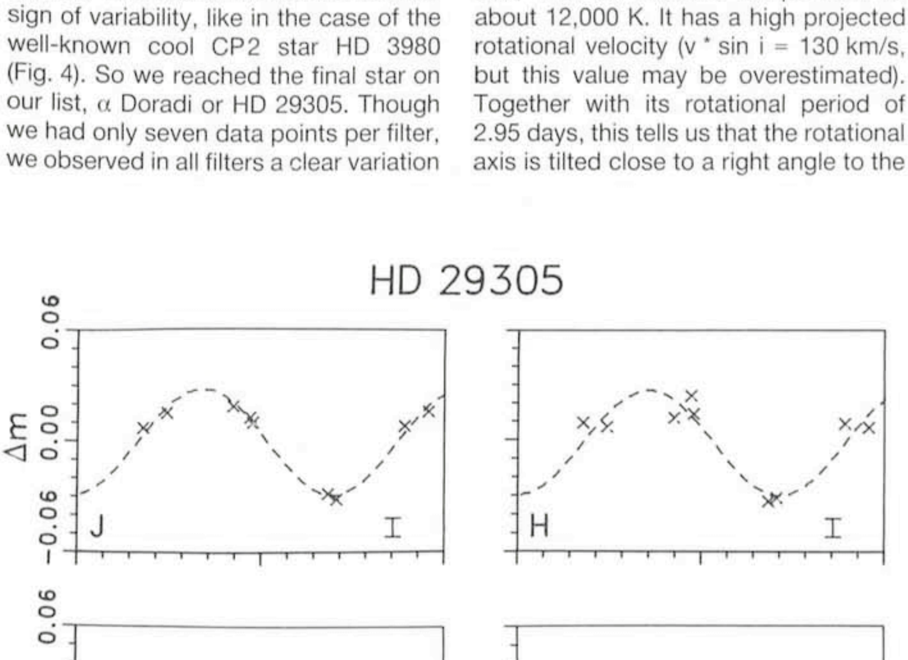

Figure 5: *IR light curve of HD 29305 in four filters. The mean amplitude is 0.028 mag. Mean errors are indicated in the lower right corners.*

References

Bonsack, W.K., Dyck, H.M., 1983: *Astron. Astrophys.* **125,** 29.

Groote, D., Kaufmann, J.P., 1983: *Astron. Astrophys. Suppl. Ser.* **53,** 91.

Koornneef, J., 1983: *Astron. Astrophys. Suppl. Ser.* **51,** 489.

Kroll, R., Schneider, H., Catalano, F.A., Voigt, H.H., 1987: *Astron. Astrophys. Suppl. Ser.* **67,** 195.

Kurucz, R.L., 1979: *Astron. J. Suppl. Ser.* **40,** 1.

Michaud, G., 1980: *Astron. J.* **85,** 589.

Preston, G.W., 1974: *Ann. Rev. Astr. Astrophys.* **12,** 257.

ESO Press Releases

The following Press Releases have been published since the last issue of the *Messenger*.

PR 01/87: Possible Planetary System Photographed Around Nearby Star (31 December 1986; with B/W photo on request).

PR 02/87: Quasar-like Activity in the Outskirts of an Elliptical Galaxy (29 January 1987; with B/W photo and Colour photo on request).

PR 03/87: Bubbles From A Dying Star (20 February 1987; with B/W photo).

PR 04/87: Brightest Supernova Since Four Hundred Years Explodes in Large Magellanic Cloud (25 February 1987).

PR 05/87: Supernova in Large Magellanic Cloud: Overview of First Results (3 March 1987).