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The A-type stars: Normal or ... what?

R.E.M. Griffin

Dominion Astrophysical Observatory, Herzberg Institute for Astrophysics

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Abstract. This Introduction to the CP-Ap Workshop attempts to discuss some disadvantages of the traditional segregation of this region of the H-R Diagram into groups labelled "normal", "abnormal" or "peculiar", and suggests that the spectra of these objects could owe their appearances as much to chance combinations of certain properties as to specific causes.

Key words: stars: binaries – stars: chemically peculiar – stars: individual: λ Boo

1. Preamble

By way of introduction, I would like to disclaim any right to give a review of this nature, and even to address this meeting at all, since I have not worked significantly in the field of A-type stars. My total contribution to the literature, as a first author, is but one paper (on *o* Leo; Griffin, 2002).

However, I do have to deal with A-type stars in the analyses which are the main focus of my research for many years. That research tackles the separation of the components of composite-spectrum binaries in order to determine the physical properties of the component stars and to measure their mass ratios. A composite-spectrum binary is defined as one in which the two component stars are appreciably different but both spectra are visible in the blue spectral region – where they are merged and horribly intermingled. Such a binary contains a cool giant as the primary, and a warm or hot main-sequence star as the secondary. Some 50 systems have now been, or are being, analysed by a technique of spectral subtraction, and I depend nowadays upon high-resolution spectra from the DAO 1.2-m telescope, which yields about 140 Å per exposure with a resolving power of about 90 000; I routinely centre observations on the Ca II K line at 3933 Å, Hδ at 4101 Å and the Mg II line at 4481 Å. The cool primary stars range in luminosity from class III to class Ib, while observational constraints usually dictate that the secondary components span spectral types from early B to early F. Many of the secondaries therefore occupy the band collectively shared with the Ap stars or their close associates (Bp ... Fm), and it is that confrontation with those secondary stars which has involved dealing with (and trouble from) the same sets of objects which absorb expert attention from most of the other researchers at this meeting.

My insatiable fascination with A-type stars pre-dates the composite-spectrum project, and I have attended – mostly just as a listener – a number of meetings devoted to these categories of stars. If one thing has stood out from those meetings, it has been the obligation – almost a fixation – to consider the A-type stars *en bloc* as a group of "normal" stars plus a fraction of spectrum oddities whose classifications have earned the general description of "peculiar". The term "peculiar" can of course mean vastly different things to a stellar classifier; it was introduced into the Henry Draper classification system simply as a warning that a spectrum deviated in some significant way from the MK standard nearest to its type, and many of those early stamps of "peculiarity" have since been replaced by a semi-quantitative notation that contains an explanation (e.g. Fe−3), and thereby acknowledges a natural breadth to star types of all temperatures. Even so, the spectrum of Arcturus is still labelled by many as "peculiar" (K2 IIIp) because it shows weak CN for a cool giant, though since the star is a high-velocity object there is in fact nothing in that observation that merits such an outcast description.

2. Peculiarity among the A-type stars

"Peculiarity" among the A-type stars, on the other hand, encompasses a wide range of spectrum oddities which have already taken half a century to document and will probably take at least another half-century to explain with full satisfaction. But may we not have created difficulties for ourselves by insisting that the A-type stars should be as like the Sun in every respect except temperature, and then having to explain any spectrum differences with respect to that (artificial and almost hypothetical) norm?

Most A-type stars represent a turbulent period of stellar evolution where things physical are in a broad state of change. By simple analogy, many of us know humans in that state – our adolescents or teenagers. There never was a "normal" teenager, yet we are still flummoxed by some of the things they get up to; we expect them to undergo physical changes – they increase considerably in height and mass (and occasionally in radius too), and we consider that "normal" because it is what just about all of them do. But when one of your teenage offspring comes home with half his hair shaved off and the other half dyed orange, you suppose he is out of his mind and you want to consult a psychologist. In fact, such extremes are all part of normal development into adulthood and the discovery of one's own identity, and one's impact on those nearby are all part of that process; it just seems rather extreme peculiarity when judged against more mature standards.

So with the A-type stars: since all stars above a small, defined mass must perforce pass through that rather unstable region of the main-sequence, could it not be that they *all* undergo some forms of change in condition that can be bizarre but never permanent? Many possible phenomena – diffusion, magnetism, convection, pulsations, accretion – can present themselves at precisely this temperature range. With the construction of ever better observing facilities we now know that most of those processes are present in parallel in most CP stars, but what are the forces that determine whether the dominant output of the convolved spectrum will be (say) roAp or Am? Could the actual situation be mathematically chaotic (as is the detailed development of local weather), and that the decision as to which process finally dominates becomes a matter of a chance balance of factors such as primordial abundance or binarity?

3. Normality versus abnormality

In her scholarly and fundamental treatise on the A-type stars, Sidney Wolff defined a normal A-type star as "one which exhibited none of the peculiarities common to Am or Ap types, and which showed solar abundances". Subsequent conferences or workshops focussing on this region of the H-R Diagram have continued the "normal–abnormal" theme; IAU Colloquium 138 in 1993 selected that concept for its title, and opened the meeting with a review of "the physics of normal A stars". IAU Symposium 224 (2004) in Poprad, "The A Star Puzzle", was nominally a little more forgiving, by apparently conceded that none of the A stars was that well understood. The Mons Workshop (2005) homed in on Diffusion for a reason that was obvious, and various meetings in Prague in 2006 studied other individual processes to a large degree in isolation. The principal idea which I would like to offer this Workshop is that if we select and apply just one of these processes in isolation we ought not to be surprised if the results fail to stand up to the rigours of comparison with actual observation, and that vital clues could be found in the very way that the different processes co-exist and compete.

4. Designing a comprehensive approach

From the privileged placing of this talk right at the start of a meeting such as this, I would like to suggest that a workshop is somewhere where I shop, and you work. But before I think seriously about purchasing any of your products, I want them to answer three fundamental questions: **WHAT** are the CP A-type stars, **HOW** are they as they are, and **WHY** are they as they are? On the matter of WHAT, we already have most of the oddities exhibited by these objects rather well covered – as Dr. Schnell has just summarized. We are also in command of some pretty powerful models which tell us HOW their spectrum oddities arise – as meetings such as the Mons Workshop could demonstrate very ably. It is the third question that has so far defied explanation, or may not yet have been the target of serious address – WHY do some stars show spectrum oddities while others with apparently similar properties such as age or binary membership do not? Is there one trigger mechanism, perhaps one that has not yet been considered as such, or is it (as suggested above) a matter

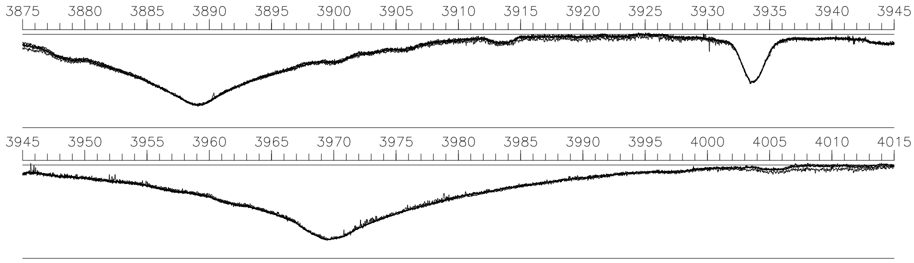

Figure 1. Five spectra of 15 And observed at intervals of 6, 107, 231 and 731 days.

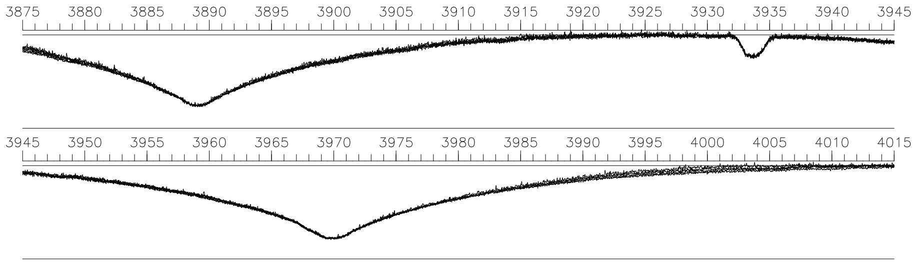

Figure 2. Five spectra of 35 Aql, observed at intervals of 1 day (twice), 59 and 1070 days.

closer to chance? I believe that some progress could be made in this direction by inverting the question: why do many stars *not* exhibit spectrum oddities?

5. The λ Boo stars

I do not mean to suggest that spectrum abnormalities, whatever they be, can be explained away as not really existing at all. An energetic attempt in that direction was made by Faraggiana and Gerbaldi (2003) in suggesting that the λ Boo phenomenon was the result of combining two "normal" A-type spectra as a composite one; the flux from one component would veil a fraction of the flux from the other component and cause the combined output to appear weak-lined. In the absence of eclipses, the only observable proof of their hypothesis would be changes in the widths of the combined line profiles due to radial-velocity shifts associated with binary motion. Several people have investigated those claims in detail, and of course it can take a long time and a lot of effort to prove that something does *not* vary.

I too have made occasional observations of a few of the stars which Faraggiana and Gerbaldi ranked as strong candidates for composite-spectrum binaries, and I show here my results for the K-line region in two of them; Fig. 1 is a superposition of five spectra of 15 And observed at intervals of 6, 107, 231 and 731 days, while Fig. 2 shows five plots of 35 Aql observed at intervals of 1 day (twice), 59 and 1070 days. If either object is really a pair of similar stars, its lines will appear weakened and broadened variously by the mutual radial-velocity displacements of the components from the systemic velocity. There are no indications yet of such line-profile changes in either 15 And or 35 Aql. Additional pairs of spectra of different wavelength regions, observed at intervals of 400 days in the case of 15 And and of 2 and 401 days in the case of 35 Aql, likewise show no suspicion of change. While the coverage is admittedly coarse, it is statistically unlikely that nodes of zero radial movement were encountered at *all* the phases which my observations happened to select, or that both objects are viewed pole-on. There is therefore no evidence so far that the λ-Boo characteristics of these particular two objects can be explained by the composite-spectrum hypothesis.

6. Critical input from composite-spectrum binaries

I now turn to analyses of traditional composite-spectrum binaries. Of nearly 40 systems for which the individual spectral types of both components are now known with reasonable confidence, 6 (possibly 7) secondaries can be classified as Am or Fm, and one as a λ Boo star. About 20% of the hot secondary stars therefore have "peculiar" spectra, which is very similar to the percentage quoted for A-type stars in general. However, the existence of these stars in composite-spectrum binaries means that we know both their masses and their ages rather well – or as well as we can fit evolutionary tracks to each A star and its cool-giant primary. We can also examine whether binary membership is a necessary or sufficient condition to explain certain spectrum peculiarities of the secondaries. This last premise is immediately questioned by the fact that about 80% of the secondaries do *not* show spectrum peculiarities. Three of the systems (o Leo, HD 88021 and τ Per) challenge directly some widely accepted explanations for spectrum oddities in A-type stars, and deserve detailed examination.

6.1. The special case of o Leo

o Leo has traditionally be classified as a composite-spectrum binary, and in most respects it satisfies the criteria of that category: it is a binary consisting of a cooler, rather evolved primary and a less bright, somewhat hotter, secondary. The system is 3rd magnitude, has a precise astrometric orbit and double-lined radial-velocity orbit and an accurately-measured inclination, so the individual masses are already known – though before 2002 the spectral types of the component stars had not been determined with any degree of confidence.

However, there are two compelling aspects which distinguish o Leo as unusual among classical composite-spectrum binaries: its short period of only 16 days, and the very considerable strengths of the lines in the cool component. Those line-strengths immediately presented a challenge to the spectrum-subtraction technique, because no standard late-type giant could be identified with lines that were *deeper* than those of composite spectrum, and it was therefore not possible to uncover the secondary's spectrum by simple subtraction. The fact that both components had many spectral features in common added to the general confusion of the spectra as observed. The system was eventually analysed (Griffin, 2002) by applying spectrum disentangling, and it was shown that both stars are metallic-lined, with types near F8m and A7m. Comparisons with evolutionary tracks (reproduced here in Fig. 3) demonstrate that the primary is presently in a very rapid state of evolution.

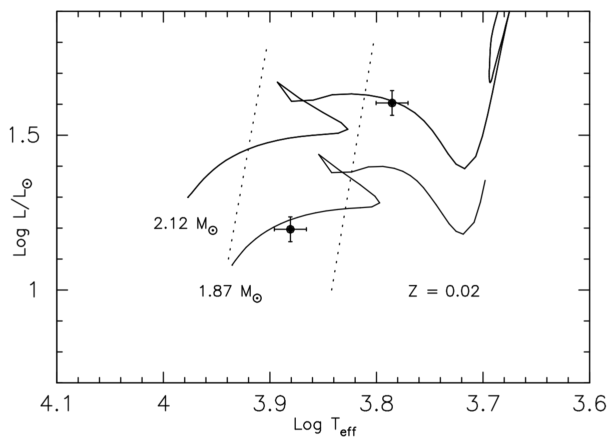

Figure 3. The component stars in the *o* Leo binary are compared with appropriate evolutionary tracks. The dotted lines indicate the instability strip.

Selective diffusion – the interplay between radiative levitation and gravitational settling – has for 40 years been a very strong contender to explain the abundance anomalies which are collectively described as "metallicism". But despite its popularity, diffusion theory has frequently faced the criticism that the associated time-scales can be comparable with the evolutionary age of the star itself, the more so the lower the effective temperature. That aspect of diffusion theory was directly challenged by *o* Leo, whose evolving primary (with a $T_{\rm eff}$ only a few hundred degrees hotter than the Sun) was cooler than the minimum temperature at which it was credible for diffusion to become established. The impasse was successfully resolved (Michaud, Richer 2005) by increasing the mass fraction, i.e. the depth, in the models across which diffusion operates. It was not necessary to modify the theory in any substance; in fact, the smaller depth parameter had been chosen previously simply because – prior to the analysis of *o* Leo – there was no observational evidence to require anything larger.

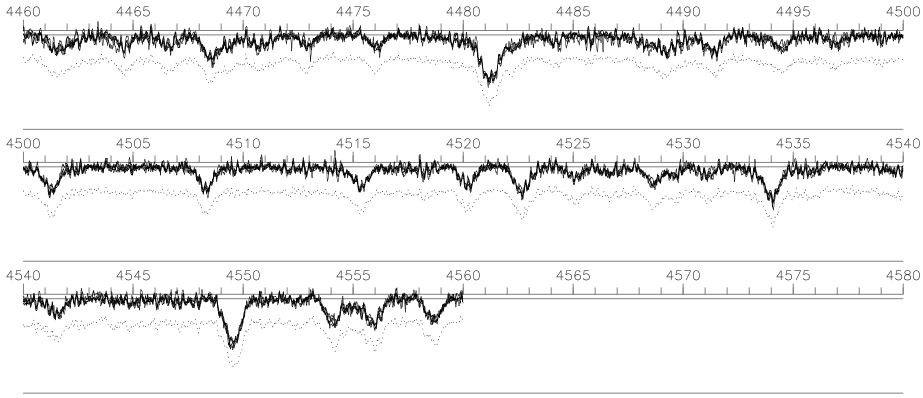

Figure 4. Five spectra of HD 88021 B observed at dates separated by 6 days, 7 weeks, 3 months and 4.5 years, and superimposed (thick line). For comparison, one of the spectra has been re-drawn (dotted) and displaced vertically by 25%.

It seems probable that the system was until relatively recently a double-Am binary, and that the diffusion in the primary which gave rise to its Am characteristics has not been broken down yet by convection because that phase of its evolution has not been operating long enough. *o* Leo is therefore a rare object simply because the time-scale of its present evolutionary status is so short that it is very unusual to catch a binary – in this case an Am binary – in that precise state. Nevertheless, since the object is so bright, it is a little surprising that its interesting properties had hitherto escaped notice.

6.2. The case of HD 88021

HD 88021 is an astrometric binary with a period of about 75 years; its primary is K0 III and its secondary (HD 88021 B) is early Am – about A2m. This system challenges a different aspect of the diffusion theory, namely why diffusion becomes established in the first place. The cause most often cited is tidal forces in a binary system, an hypothesis which largely owes its popularity to statistics which demonstrate the high percentage of Am stars that are in binary systems (though the presence of possible observational bias has not to my mind been conclusively refuted). Therefore, if the metallic-lined nature of HD 88021 B is due to tidal forces, that component must itself be a fairly close binary since its cool-giant primary is too distant to have noticeable tidal influence. Since that hypothetical third body is likely to have sufficient mass to cause discernible radial-velocity changes in the Am star, its existence can be verified through that route.

In fact, spectra of HD 88021 B have to date revealed no evidence of a third body in the system. In Fig. 4 are superimposed five spectra of the secondary star observed at intervals varying between a few days to a few years; no velocity change is detected. Similar comparisons of the H-δ and the K-line regions, at random intervals between 1 day and 2 years, likewise reveal no radial-velocity shift of the secondary star. It should be noted that the original composite spectra were all reduced in the rest-frame of the cool-giant primary star; the spectrum of the primary component was removed as completely as possible by subtracting the spectrum of a well-matching cool-giant standard, so the residual spectrum (i.e. that of HD 88021 B) is in the rest-frame of the primary. Any orbital motion of the secondary is therefore revealed simply as a relative displacement within that rest-frame. In the present case, it was to be expected that no orbital motion of HD 88021 B due to the 75-year orbit would be detected during the span of the spectroscopic observations because the time-base was too short. However, the lack of any *shorter*-period radial-velocity changes in HD 88021 B demonstrate that there is also no evidence that the secondary is itself in a (closer) binary system. We must therefore find a different reason as to why the secondary of HD 88021 happens to be an Am star.

6.3. The case of τ Per

τ Per is another composite-spectrum binary whose A-type secondary (τ Per B) displays some inconvenient truth that won't go away. The primary star is a slightly bright G-type giant, classified as G8 IIIa. It was noted a number of years ago (Griffin *et al.*, 1993) that the spectrum of the secondary could not be matched with a "normal" A-type star and that its broad, shallow H lines and weak metal lines resembled more nearly a λ Boo star than any standard mid-A spectrum. New, higher S/N spectra have not caused that conclusion to be modified. Fig. 5 compares the spectrum of τ Per B with (a) a synthetic standard, solar-abundance spectrum (smooth line) calculated with a $T_{\rm eff}$ chosen to fit the profile of Hδ, and (b) the λ Boo star HR 4875 (dotted line). The metallic lines, especially the Ca II H & K lines, are weak in τ Per B relative to the synthetic spectrum but correspond quite closely with those in the λ Boo star. Reducing the $T_{\rm eff}$ of the synthetic spectrum in order to improve the match to the two Balmer lines only accentuates the disagreement with the metal lines.

The impression gained is that the surface of τ Per B is veiled by general absorption, and one might postulate that the evolving primary star has deposited circumbinary material in the system. Indeed, flux measurements by *IRAS* show a significant surplus of 100-μ flux in τ Per, indicating the presence of warm ($\sim$30 K) dust associated with the binary. The model of τ Per which Griffin *et al.* derived in 1993 from eclipse photometry and spectroscopy suggests modest absorption in the system of about $0^m.2$ when compared to the luminosity corresponding to its *Hipparcos* parallax (which was of course not then available). Such "dust", if it can be established, could be evidence of an *external* explanation for the spectrum peculiarities of τ Per B.

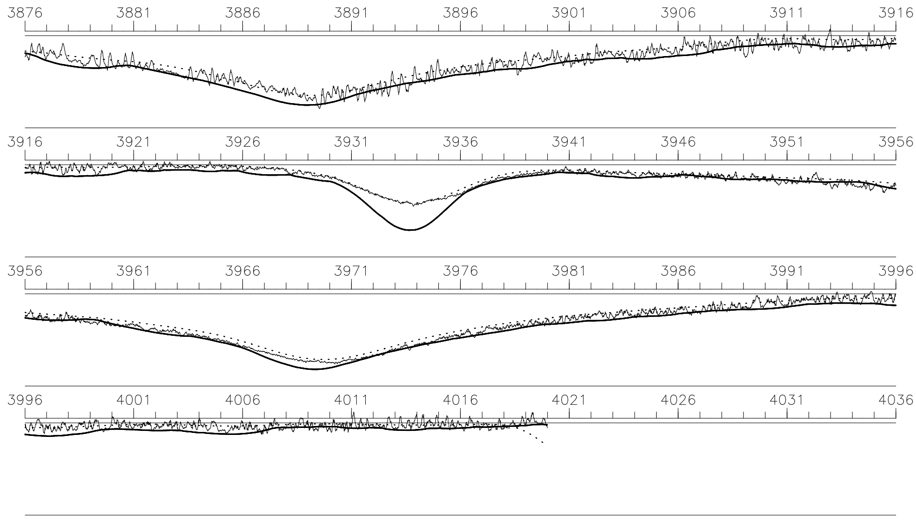

Figure 5. The spectrum of τ Per B, compared to a synthetic spectrum (solid line) and to the λ Boo star HR 4875 (dotted line).

These last two examples test quite severely the hypotheses that (a) binarity is the root cause of metallicism and that (b) λ Boo stars are young, possibly pre-main-sequence objects. By studying CP-related phenomena as they happen to occur in a sub-class of astrophysics which is not related to pre-selection into the CP classes, one may gain an improved insight into **WHY** the CP attributes of those few have come about. In such exercises, the stars which share properties in common with the CP stars but do **not** manifest chemical peculiarities can have as much useful evidence to offer as those that do.

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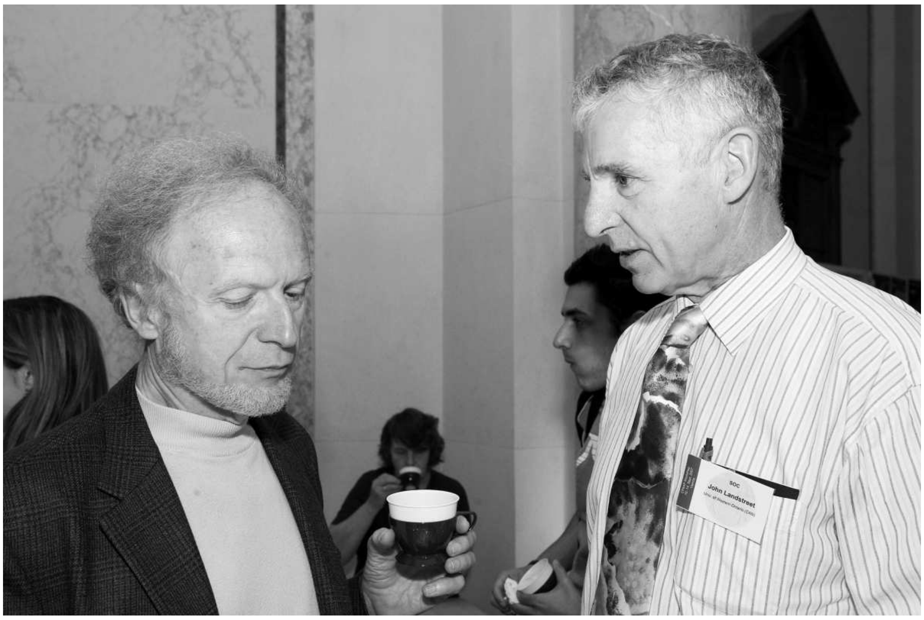
Elizabeth Griffin and Chuck Cowley



Georges Michaud and John Landstreet