The A-Star Puzzle
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How are we doing so far? A summary of the Symposium

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Abstract.
Some highlights of Symposium 224 on "The A-Star Puzzle" are reviewed and transcribed from the author's *ad hoc* oral presentation on the final day of the meeting. Articles referred to are all contained in this volume, hence there are no figures or references. Topics include theory and observations of normal A stars, HgMn, Am, and Ap stars, λ Boo stars, magnetic fields, rotation, convection, pulsations, supergiant stars, and observational methods including polarimetry, spectroscopy, and photometry.

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1. Introduction

After listening to several days of talks on the latest ideas and achievements in research in this vast and vibrant field, I am somewhat overwhelmed by the power and detail in both the new observations and the theoretical advances being made. I feel rather like the commander of an English regiment at the battle of Waterloo, who found himself surrounded by French forces on all sides. He dispatched a messenger to the Duke of Wellington to request urgent reinforcements, but everything available had been committed elsewhere. Instead, a message was sent back, the rider dodging shot and shell, and when the dispatch was opened, it read: "Sir–you are in a devilish awkward predicament, and you must get out of it as best you can."

2. Normal and peculiar A stars

When in doubt, I always find that the direct approach often works, so let us start at the beginning. On our first day, we began with Adelman's review of what we mean by the terms "normal" and "peculiar" in the A-star business. Essentially anything not classed as peculiar is assumed to be normal, but there may be no bold line that can be drawn between normal and peculiar, as defined by low or intermediate dispersion classification. The A stars themselves range from radiative photospheres at A0 and hotter to mainly convective photospheres by A9 and cooler. So to account for all the anomalies seen, as well as many phenomena of normal stars, we need a very wide range of physical tools. And I will use "A star" to include phenomena of the later B stars like HgMn stars.

On the issue of "what resolution to use to distinguish normal from peculiar stars" let us recall what Adelman said about abundances in two stars, o Peg and θ Leo, that at classification dispersions are regarded as normal, but at higher dispersions clearly are not, but are definitely hot Am stars. Their abundance trends clearly show this. Over 30 years ago I borrowed a slide from George Preston that was used to demonstrate the spectral appearance of peculiar *vs.* normal stars. The "normal" star image was the spectrum of o Peg! Perhaps, as Bidelman suspected long ago, at high dispersion there are no normal A stars with both sharp enough lines to analyse and normal compositions. The boundary is around 80-120 $\mathrm{km s^{-1}}$ in v_e, though this is violated in some magnetic Ap stars.

Krtička and Kubát, and several others in poster papers, reminded us, not for the first time, that we are now well past the phase when LTE calculations can point the way to detailed truth about compositions of A stars, though such analyses still have their uses. Non-LTE methods are desirable in the case of stars close to the main sequence, and for supergiants NLTE and wind dynamics are needed. It is probably here that we A-star fanatics will make our direct contribution to extragalactic astronomy. Why? Because as we also heard later from Przybilla, the galactic composition gradients of elements not available from nebulae can, in principle, be obtained from luminous A supergiants, provided we thoroughly understand them first. The limits on knowledge gained will be set by light-gathering ability.

3. Rotation and evolution

The rotation of A stars is now better understood (Hill *et al*). Vega has been modelled and is a nearby pole-on rapid rotator with well-defined parameters of oblateness, brightness distribution, and equatorial speed. But interior modelling is still a source of controversy and needs more analysis. Reiners & Royer showed us that most A stars rotate as a "solid" body on the outside, with oblate spheroidal shapes, but a few stars also have differential rotation: their equators rotate faster than the high latitudes. Yıldız found from his investigation of apsidal motion of PV Cas that the inside must be rotating faster than the outside. Arlt discussed internal magnetic fields and rotation of evolving Ap stars and drew different conclusions: magnetic fields should damp out differential rotation. There is coupling between the core and the surface if fields are present. The question of how stars rotate as they evolve, and the role of magnetic fields, was a subject that sparked some hot exchanges. It remains to be understood how magnetic fields arise in A stars and to answer the question: Why don't they all look like Ap stars?

The papers by Noels *et al.* and Talon reviewed the internal structure of A stars and the crucial roles played by convection, diffusion and rotational meridional mixing. The link between mixing and internal differential rotation needs further exploration, but the subject is advancing.

Another result that caught my attention in that session was the study of pre-main-sequence evolution of A stars by Marconi & Palla. During their contraction phase, Herbig Ae stars pass through the instability strip where δ Scu stars lie. The PMS strip is narrower than the δ Scu strip. Sure enough, when they pass through, they pulsate as predicted for their PMS structure.

4. Diffusion and magnetic fields

Diffusion is thought to be the fundamental process giving us abundance anomalies in chemically peculiar stars. As Georges Michaud told us, it is no longer correct to consider it merely a surface effect. Instead, he showed us that the entire star may be affected: the observed spectra are connected to changes in the deep interior. Alecian followed this with a discussion of the way diffusive particle transport in magnetic Ap stars leads to element patches on time scales orders of magnitudes less than 10^7 yr. The keyword throughout the session was "stratification". Once only a theoretical notion, several papers at this Symposium presented direct evidence, of one form or another, that it was an observable.

The reality of stratification can lead to large effects on the $T - \tau$ structure, as shown by LeBlanc & Monier. In the absence of mixing, the effects on the line-forming region can be huge, depending on the assumptions about stratification and the strength of mixing processes. A self-consistent approach is required.

5. Chemically peculiar or CP stars

Cowley introduced us to a classification tool that may be able to suggest new, previously unsuspected, relationships between individual chemically peculiar stars. These tools are normally used by psychologists and sociologists, but perhaps we have something to learn from them.

Ryabchikova reviewed observations of magnetic CP stars. There is much new evidence for stratification in the photospheres. Again, as in the work of LeBlanc & Monier, the results are non-trivial. There are serious discrepancies in Balmer line profiles in some stars, indicating large variations in $T - \tau$ relationships.

Wahlgren reviewed the non-magnetic HgMn stars and Am stars. Among new results that are explicable by stratification are isotopic anomalies of Hg and Pt that appear to vary from line to line, and the weak emission lines of several elements, such as Mn in stars like 46 Aql and 3 Cen A. These results imply strong stratification (and also NLTE effects).

A remarkable new result was unveiled by Pyper & Adelman. Out of about 100 magnetic Ap stars monitored photometrically for several years, several show clear evidence for period changes. This monitoring will continue and a rich harvest of results can be expected. At this time the period change of CU Vir cannot be distinguished between a sudden change or a gradual slowing of rotation.

6. Highly evolved A stars

Möhler gave an excellent historical and physical review of Horizontal Branch Stars on Saturday morning. There are many phenomena observed that require better theory and observation, such as a sudden increase in Fe abundance with effective temperature, accompanied by decreasing He abundance.

Preston told us of recent discoveries among the blue metal-poor stars, including the "blue-stragglers" in globular clusters. There are several hot analogues of Pop I carbon stars as well as stars that contain high abundances of Pb! these objects are among the clearest indicators of nuclear s-processing in evolved metal-poor stars, or rather, in their defunct companion stars before mass transfer.

7. Advances in modelling convection

Kupka and Smalley told us about progress in modelling convection and how it looks to the obsever trying to compare theory and observation. As to the merits of parameterizing convection, and its effect on stellar atmosphere observables using the mixing length l/H, did Barry Smalley only joke, or was he serious, when he asked, "Could we observers be allowed to use $l/H < 0$ if it fits the data better?"

The discussions of new simulations of convection in A stars began with the paper by Freytag. The cells are expected to be much larger on A stars than on the Sun. Convective motions, up and down, can be modelled and may produce something that looks like microturbulence. This was nicely demonstrated by Trampedach. And Browning *et al.* used new simulations to show how magnetic dynamo action in convecting A star cores can greatly amplify small seed magnetic fields. As John Landstreet said of all this work, "These numerical simulations are very impressive."

8. Magnetic fields

Monday morning we heard about magnetic fields. Mathys summarized the history of magnetic measurement and some recent studies as well. It remains inconclusive whether there are disordered fields on Am stars or HgMn stars. Recent observations give upper limits to averaged magnetic fields of 40 Gauss for HgMn stars and less for Am and normal stars. The fields in magnetic Ap stars are much stronger, of course, up to several kG. The distribution seems to follow a negative exponential relation of numbers *vs.* $< H >$, with very few stars having more than 8 kG. There have been a few attempts to look for depth dependence of fields by inspecting spectra on both sides of the Balmer Jump, with mixed results. No one would be surprised to find some effect; there may not be a general rule for the results obtained.

Wade gave us an excellent summary of recent magnetic field measurements using Stokes parameter polarimetry on large telescopes. Instruments like FORS1 and MuSiCoS are leading a revolution in these studies–Babcock would surely be envious and congratulate astronomers for these fine data. If we are giving a prize for best spoken and visual presentation this talk would be a finalist, in my view.

Moss reverted to "steam technology" (overhead projector sheets) to present a fine discussion of the basic theoretical problems associated with explaining the existence of Ap magnetic fields. A dynamo model needs a field to rise to the surface where it can be seen, but the physics says it is difficult for this to happen. Fossil fields, on the other hand, are hard to create because pre-main-sequence convection tends to kill the field. At least there is no problem finding enough magnetic flux in the interstellar medium before a cloud contracts into a star.

Braithwaite then told us about new calculations that show a poloidal-toroidal field is a naturally stable configuration. And we also heard from the Vienna-Potsdam collaboration that a new analysis of spectra leads them to conclude that there is substantial stratification in at least one rapidly oscillating Ap (roAp) star.

9. Pulsating variable stars

I turn now to the session on pulsating variable stars. The groups discussed by Balona, Breger and Kurtz included new results on δ Scuti and γ Doradus stars, and on roAp stars. Some weird and wonderful cases have emerged, including γ Equ's pulsations seen in line profiles despite its extremely long (many years) rotation period. Although better known for its protoplanetary infrared disk and infalling comets, β Pic has been found to have δ Scu pulsations.

It has long been a mystery why all A and F stars in the instability strip do not vary, but as Breger informed us, this turns out to be more an observational problem than a theoretical one. As he explained, new results using photometric satellite techniques showed that a high percentage of such stars have δ Scu or γ Dor pulsations which can have extremely small amplitudes. Even Altair pulsates! These results from WIRE and MOST are providing precisions and quantities of photometry impossible before orbiting laboratories. Given the distribution of amplitudes, it is reasonable to extrapolate that all or nearly all stars in the instability strip are variable at some level.

Kurtz told us how spectroscopy is now teaching us more about roAp stars than photometry. A new data set reveals running waves in some spectral lines. In HD137949 the motions of Nd III and Nd II are out of phase by 180 degrees. Among the excellent invited talks was one describing the Blazhko Project, a new collaboration to combine spectroscopy and photometry to understand this "beat" phenomenon in RR Lyr stars.

10. The A Star as a physics laboratory

Landstreet, Kochukhov and Shibahashi presented three different views of the use of A and B stars (normal or peculiar) as physics laboratories; or, in some cases, views of the exploration of specific phenomena. Landstreet pointed out that the strong He stars around B2 are examples of the use of diffusion as a probe, where stars go to He I/He II ionization due to a stellar wind. In other domains, high-resolution line profiles carry information on the velocity field and might allow investigations of depth-dependent microturbulence. And there is still the need to investigate exactly how magnetic fields can lead to the loss of angular momentum during pre-main-sequence phases.

Kochukhov discussed progress in modelling diffusion and the effects of magnetic fields on stellar surfaces. We previously heard in Sec. 8 about Stokes parameter modelling and magnetic Doppler imaging. The mathematical method of inverting the observations to discern the surface structure is a tricky business. Stars like 53 Cam have much more complicated field geometries than previously thought, although α^2 CVn seems to be simpler. We were also shown new models of the roAp star HR3831 and of the mysterious Hg II spots on the HgMn star α And.

Shibahashi discussed some theoretical aspects of the magnetic polar regions of magnetic stars and asteroseismology prospects. Intense magnetic regions should be cooler if the density is unchanged, and such regions may actually expand slightly, leading to raised plateaus around the poles. Convection is supressed in such regions. There may be temperature differences $\Delta T \sim 500^\circ$ K between magnetic pole and equator. There are problems using asteroseismology to probe interior structures, because unlike the Sun we can only observe integrated light. But error simulations suggest that, "Inversion has still some hope."

11. Lambda Boo stars

Paunzen presented a thorough review of the status of the λ Boo stars. For more than a decade, these rare weak-lined A and early F stars have been known to have an abundance pattern that matches closely the atomic abundance pattern of the interstellar gas. The CNO abundances are normal yet they have underabundances of Fe and Ca, with a wide spread of Na abundances. Unlike other chemically peculiar stars in this range, their evolutionary stages are the same as normal stars and their rotational velocities are also indistinguishable from normal stars, and they are never found in clusters. When they occur in double-lined spectroscopic binaries, both components are λ Boo types. Diffusion and mass loss cannot account for the anomalies because rotational mixing would prevent them. A few of these stars have IR excesses and the anomaly may arise from their surrounding disks, but this cannot explain the older λ Boo stars. However, an A star passing through a small, dense region of the interstellar medium can accrete gas which can remain on the surface for a short period of time. As long as the accretion phase lasts, the surface will show anomalies, but as soon as it leaves the gas cloud, meridional circulation will quickly (*c.* 10^4 yr) re-establish a normal abundance pattern. This model accounts for all the features seen and for the fact that binaries always have both stars with λ Boo patterns, and it explains why they are never seen in open clusters: there is no dense gas to accrete. Most of them pulsate in the δ Scu instability strip. There is also evidence that they are shifted slightly to the blue side of the strip, and that the accretion may affect the pulsation mode.

12. Observational prospects

The final session of the Symposium was on present and future aspects of observations of A stars. Stefano Bagnulo discussed recent advances in interferometry (stellar diameters), photometry, and parallax (see the poster by Fraga & Kanaan at this Symposium). New instruments such as FLAMES at the ESO VLT for fiber optic multi-element spectroscopy down to 15th magnitude, or the UVES, provide new opportunities for spectroscopy of fainter stars, while FORS1 permits polarimetry and spectroscopy of several sources at once in a field about 7 arcmin square, so it is ideal for searching for magnetic stars in clusters. Polarimetry with instruments like MuSiCoS at Pic du Midi or ESPaDOnS at the CFHT will expand the scope of such investigations greatly. These aspects were explored further by Piskunov.

Finally, Padovani discussed the use of the Virtual Observatory allowing the user to interrogate vast data bases of spectra, photometry, parallaxes, and other measurements to address specific problems. The use of large telescopes for queued observations of spectra is to be seriously considered; bright stars do not usually need sub-arcsecond seeing with photometric conditions, and telescope operators can interweave requested observations when conditions are not ideal for the most demanding work on faint objects. In this way, many traditional A star observers can gain access to the new 8-m class of telescopes.

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