Stars and their variability observed from space
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PUTTING STARS INTO BOXES

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Abstract.
The approaches which researchers follow can be subdivided into two simple but quite distinct categories: (A) "broad sweepers", and (B) "ultimate refiners". The first look at the wide picture and extract the kind of statistics upon which stellar physics was founded. The second look at the outliers – the ones that don't fit that wide picture, and spend a lifetime showing that the wide picture doesn't fit.

In researching a sample of nearly 50 northern composite-spectrum binaries I have succeeded in identifying some norms, but some of those systems "just can't be like that". Two will be summarized: (1) a triple system containing a pair of similar early-A stars in a 3.8-day orbit which are both traveling at over 100 km/s and yet show no rotation at all, and (2) an SB2 system that shows no evidence of a third body or of mass loss, and yet the SB2 orbit finds that the mass of the secondary is more than twice that of the primary. These two alone challenge theories of stellar evolution, or need to be re-observed thoroughly and sorted out - but who will do high-dispersion spectroscopy on 6th-mag systems when the rest of the world is after 23rd mag? I have presented these cases to conferences, but I not been able to frighten any theoretician sufficiently into investigating closely. The only one who was at all interested claimed that the observational data were wrong, and proceeded to alter them.

Other systems cry out for more attention too. Epsilon Aurigae ($V = 2.9$, $P = 27$ years) was centre stage while it was in eclipse in 2010; it still baffled everyone, and it was left unsolved. It is obscured by something opaque – we know not what, and during egress (and only then) it emits a thin stream of gas that is rich in rare-earths. Then those Am stars – a significant fraction – seem to have low rotation and to be in binary systems, often with Am companions and quite possibly tidally locked in synchronous rotation, but the more cautious see room for doubt as to whether the slow rotation is the cause of the Am characteristics, since not all Am stars are members of short-period binaries, and several are known to fall outside that particular box. Surveys like *LSST* and *Gaia* predict the volumes of their discoveries by extrapolation. We can extrapolate too; the four brightest stars in the northern sky (Arcturus, Vega, Sirius and Capella) are all curiously odd in some way. What does that say, then, for the rest of the stars in our Galaxy? Have the ultimate refiners been in the shadow of the broad sweepers for too long?

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1 Two Distinct Boxes

Researchers in astrophysics can be divided broadly into two types: *broad sweepers* and *ultimate refiners*. The phrases were invented by the late Bernard Pagel, of stellar abundance fame, and aptly describe participants at this conference: those whose work requires them to assign stars to specific boxes and to attribute to each box a generic set of parameters, and those who find such an approach anathema, are deeply disturbed by the oddballs that do not fit, and spend a lifetime working out why they don't fit.

1.1 Avoiding Bias

At the outset, it is important to identify one's own natural tendency in terms of broad sweeper or ultimate refiner, because one's natural leaning can colour, influence or bias the approaches one adopts in research, and how much weight or credence one gives to solutions, whether from one's own work or from that published by others. Identifying one's own specific position also helps discussions between those of the two opposite camps to flow more productively.

Modelling stars – whether to simulate spectra, pulsations, rotation, velocities or whatever – commences with the assumption of some particular set of parameters, and if those parameters were merely derived as

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average representatives of objects within some 'box' then the purity of the output will be compromised and the significance of any deviations by members of that set will not be recognized, or not correctly. Some of these problems are already being faced in early efforts to characterize large volumes of spectra recorded in surveys, where it is tempting to dismiss oddballs as glitches in the data.

2 Oddities from the Start

Because these two different approaches are fully complementary, even orthogonal, they are essential to any scientific field, not least astrophysics (where direct experiment is of course not possible). Broad sweepers generated the statistics which laid the foundations of stellar science as we know it today, beginning with the classification of some 10,000 stars in the HD Catalogue 100+ years ago, while ultimate refiners find there are many more exceptions to the rule than conformers, and have largely been responsible for designing ingenious space experiments, questioning every definition of so-called normality, and challenging theories of stellar evolution. From the very beginnings of astrophysics it has therefore been felt necessary (and very important) to put stars into boxes, each with a well-defined label, though – thanks to the insistence of the ultimate refiners – also allowing one box to be labelled "odd". But even while the Harvard classifiers were busily putting stars into boxes, Antonia Maury was equally busy taking some of them out again. She noticed that some cool stars had unusually narrow spectral lines, and that their Balmer lines had distinct, narrow, cores (Maury & Pickering 1897): she had discovered the signatures of the low pressure that prevails in the atmospheres of giants and supergiants. Nancy Roman was later to point out that the dominant molecular bands of CN and CH in the mid-blue were stronger in some stars than 'normal' in the same 'box' (Roman 1965), a characteristic that could be explained as a consequence of stellar evolution.

3 Examples from Composite-Spectrum Binaries . . .

In researching a sample of some 45 northern composite-spectrum binaries I have met interesting examples of these problems. A composite-spectrum binary is a detached system containing a G-K-M giant and a B-A dwarf, clearly of unequal masses and of correspondingly different luminosities. Their SEDs are of course also quite different, but in such a way that both spectra are easily visible in the blue-UV region, though superimposed and thus somewhat tangled, making it difficult to measure one spectrum faithfully in the presence of the other. In this situation it is necessary to separate the component spectra digitally so that the individual spectra can be handled uncontaminated by the features of the other star, and measured as though they were single stars. One can thus obtain accurate SB2 orbits, and thence the mass ratios of the component stars, yielding some of the most precise results possible for any binary system. Ten members of this class also undergo eclipses, so in those cases the masses of both components can be derived absolutely.

Many of my sample of composite-spectrum binaries appear to conform to familiar norms, but some simply do not. One is a hierarchical triple system (HR 6497), whose inner orbit consists of a pair of similar early-A stars in a 3.8-day orbit; the pair are both traveling at over 100 km/s *and yet show no rotation at all* (Griffin & Griffin 2012). Another is an SB2 system that shows no evidence of a third body or of mass loss, and yet Griffin & Griffin (2018) find that the SB2 orbit gives a mass for the secondary that is more than twice that of the primary. If a merger has taken place, there is no spectroscopic evidence for such an event in the blue-visible spectral region. These two cases alone challenge theories of stellar evolution, or need to be re-observed thoroughly and sorted out - but who will do high-dispersion spectroscopy on 6th-mag systems when the rest of the world is after 23rd mag? I have presented these cases to conferences, but I have not been able to frighten any theoretician sufficiently into investigating closely. The only one who was at all interested claimed that the observational data were wrong, and proceeded to alter them.

4 . . . and Throughout Astrophysics

Other systems cry out, too, for more attention. Epsilon Aurigae ($V = 2.9$, $P = 27$ years) was centre stage while it was in eclipse in 2010, yet it still baffled everyone, *and it was left unsolved.* Its bright F-supergiant primary is nearly completely obscured by something opaque – we still know not what – and during egress (and only then) it emits a thin stream of gas that is rich in rare-earths. Perfectly fascinating, yet where in stellar evolution does it fit in, and if not, why not?

Then those Am stars, confidently postulated by someone once as being so formed because they are members of fairly close but detached binaries, a hypothesis that has become adopted as theory by being repeated so frequently. But can we really be so sure that they are all members of short-period binaries when that 75-year system HD 88021 has a secondary that is clearly Am but is also quite clearly *single*, as Griffin & Griffin (1988) demonstrated? What about Sirius, too, an Am star whose only companion (Sirius B) is a white dwarf, and whose orbit has $P = 50$ years? And why are those two scarcely-rotating, early-A dwarfs that comprise the double secondary of HR 6497 (Griffin & Griffin 2012) *not* Am stars? Indeed, the detailed study by the ultimate refiners Carquillat & Prieur (2007) shows that there is no simple correlation between binarity and aspects of the Am phenomenon. Moreover, if not all Am stars have been formed by the same process as once so confidently asserted, how is that being explained where astrophysics is taught, and where does it leave stellar evolution theory?

One final note: Broad-sweeping surveys like LSST and Gaia predict the volumes of their discoveries by extrapolation. Ultimate refiners can extrapolate too. The four brightest stars in the northern sky (Arcturus, Vega, Sirius and Capella) are all curiously odd in some way; what does that say, then, for the rest of the stars in our Galaxy?

Have the ultimate refiners been in the shadow of the broad sweepers for too long?

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