White Dwarfs as Probes of Fundamental Physics: Tracers of Planetary, Stellar and Galactic Evolution
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Main conclusions from Symposium discussions

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Abstract. The programme of this IAU Symposium, number 357, consisted of sessions organized around a number of key themes, as detailed in the preceding text. Each session included one or two invited keynote talks plus a number of contributed papers. Time was set aside for extensive discussion following the sessions associated with each of them. These were moderated by members of the Science Organising Committee, posing a number of questions to the audience to stimulate the discussion. The nature of such discussions makes them hard to record in detail, but a number of key points have been extracted and incorporated into this short concluding paper.

Keywords. white dwarfs

1. Introduction

White dwarf stars are interesting in their own right, as the end stage of the evolution of most stars ($M >\approx 8M_\odot$). However, they are also very important players in other branches of astrophysics. White dwarfs are clearly implicated in the mechanism(s) of Type Ia Supernovae, although proven progenitors have yet to be identified. Measurement of the ages of the oldest white dwarfs provides a limit on the age of the galaxy and its components, while the white dwarf luminosity function can be used to trace episodes of historical star formation. Study of their cooling rates and pulsations can shed light on the behaviour of matter under the extreme physical conditions found in their envelopes and cores. Several decades of studies of their photospheric composition have concluded that many are accreting material from the debris of past planetary systems. Therefore, currently, they provide the **only** way of exploring the range of bulk compositions of extra-solar planetary material. The presence of large numbers of absorption lines of highly ionised elements such as iron and nickel provides an opportunity to search for tiny differences between laboratory and observed line wavelengths that might indicate variation in the fine structure constant α. Similar anomalies in the wavelengths of molecular H_2 lines could, if present, point to a gravitational dependence of the fundamental proton-electron mass ratio (μ). White dwarfs can also act as background sources for observation of absorption lines which can be used to probe the structure and state of interstellar and circumstellar gas across a wide range of temperatures and densities.

The aim of this symposium was to bring together scientists covering the wide range of topics outlined above, allow them to present their work and stimulate discussion across the disciplinary barriers. As conferences are generally narrower in scope than this particular meeting, thought was also given to how this dialogue could be continued in the future.

2. Scientific conclusions

It is clear that the "exotic" and interesting white dwarfs that might provide the strongest evidence for, or constraints on, a particular physical phenomenon are often small in number, even in the current samples (≈10,000 stars) that have been expanded by recent surveys such as SDSS, Pan-STARSS and LAMOST. For example, the potential channels for SN Ia may be more diverse and complicated than we thought. Although there is a regular stream of candidates, it is still the case that no clear progenitor system has so far been identified. We do need to find the progenitor systems. Similarly, in studying accretion of exotic-planetary material, we need to observe active systems with transiting debris to test the models and mechanisms proposed. However, we currently have only a single example where transiting orbiting debris is detected.

Over a period of more than 20 years, spectroscopic observations of several hundred white dwarfs have been carried out with a variety of ground- and space-based telescopes to understand their composition. However, these observations are trying to address many variables across the white dwarf temperature and mass range, besides the many elements detected. Therefore, the observational statistics often limit any strong conclusions from being drawn. The Gaia DR2 catalogue contains an estimated 200,000 white dwarfs, more than a factor 10 increase on current numbers. It is gratifying to see, as a member of the Gaia Data Processing and Analysis Consortium (DPAC), that Gaia data appears in almost every paper in these proceedings, from large scale surveys to studies of small groups and individual objects. However, to make use of this increase, a significant dedicated follow-up effort from both ground- and space-based telescopes is required. While this might be feasible on the ground with multi-object spectroscopy, the limited time available on space telescopes (currently only Hubble) is an insurmountable problem.

Photometry with space telescopes such as Kepler and Tess has dramatically increased the number of pulsating white dwarfs known. However, several presenters demonstrated that understanding the complexities of individual objects is very time-consuming. Therefore, there is a need to focus on the pulsators that are already known and well-studied to provide follow-up data and detailed analysis for these.

3. Organisational and programmatic conclusions

As indicated in the previous section, one of the greatest challenges for future studies of white dwarfs is access to telescope time for follow-up work. Astronomy is an ever expanding subject: 25 years ago, few telescopes were observing extra-solar planets; surveys increase in breadth and depth and produce ever larger catalogues of objects. Against this, as larger facilities are developed, smaller one come under increased financial pressure and may close or be repurposed into narrower scope, single-instrument activities. An important message in the discussion was to limit competition between members of the "white dwarf"community through more coordination and cooperation. The community needs to generate coordinated cases for future observing capabilities to observatories (or their funders), facility directors and oversight committees.

Attendees were encouraged to share the existing data that we have through the Montreal White Dwarf Database (MWWD, http://www.montrealwhitedwarfdatabase.org). More sharing of relevant astrophysical techniques was also encouraged, as some are already doing. However, at the moment there is not a clear forum that would simplify this. An important related topic is access to improved models across the board, including atmospheres, pulsations and structure/evolution. Some of these are already available, with a shining example being the Montreal evolutionary calculations made available through the MWWD, but more coordination and on-line publication is needed. The generation and use of improved models is placing increased demand on computational resources. A good example is the need to run many trials of pulsation models to find a match to the complex modes in real stars and understand the uniqueness of such a match. There is a need to discuss new approaches to computation and data storage to address these problems. Extending our discussions to include Informatics and AI experts may offer some solutions.

4. The community

While most of the discussion focussed on the scientific questions addressed by the symposium, some of the debate was drawn to the issues for the scientists working in the white dwarf community. These are not unique to white dwarf researchers, but, as a relatively compact group of scientists who are mostly well known to each other, it should be possible to identify common issues and work on them together. While the conference attendees work in many different academic systems, each one has a shortage of funding in varying degrees. Common to everyone is that the situation is driven by the political factors of government policy and economics and the programmatic tensions between project funding (building large new facilities) and exploitation (money for people to do research). Changing these things is very hard, but coordinated advocacy for our subject can help. We should also collaborate outside our discipline, seek new applications for our work and then try to access funding sources beyond those we usually approach. A good example is how the University of Texas, Austin group has branched out into simulating the physical conditions of white dwarf atmospheres using the Z machine at Sandia National Laboratory.

Cross-disciplinary working is seen to be increasingly important, but interdisciplinary meetings like this IAU Symposium are rare. The bi-annual European White Dwarf Workshop already has a very packed programme and bringing in new topics will inevitably force out others. More focused meetings on a single WD-related topic could be envisaged or WD researchers could attend the meetings of other subjects, but a proliferation of meetings is undesirable due to cost, time and the need to all lower our travel carbon footprint. It is essential that we develop solutions to holding large remote meetings that are able to recreate some of the positive advantages of a face-to-face conference.

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