White dwarfs in surveys

1. **Gaia DR2: White Dwarfs, Warnings and Caveats**

   Stefan Jordan (Heidelberg University)

   Gaia Data Release 2, published on April 25, 2018, contains 1.3 billion stars with positions, proper-motions, parallaxes, and photometry. Among them is huge number of white dwarfs for which the high-precision astrometry on a level down to 50 microarcseconds allows unprecedented view on the late phases of stellar evolution. The talk will also provide some advice how to use the Gaia data with care.

2. **Fundamental properties of white dwarf stars with Gaia DR2**

   Martin A. Barstow (University of Leicester), J.B. Holberg (University of Arizona)

   Accurate measurements of masses and radii have been crucial to understanding the population of white dwarfs and their evolution. However, although there are various techniques that can be applied, e.g. Balmer/Lyman line spectroscopy, gravitational redshift, dynamical analyses of binary systems, they each have some limitations. The results may be model-dependent or are only available for small samples. Recent work has been greatly facilitated by the availability of large samples of white dwarfs observed by various sky surveys, including SDSS, 2MASS, Pan-Starrs and LAMOST, bringing the total number of white dwarfs known to around 20,000 objects. However, the second data release of Gaia achieves a transformation of our knowledge of white dwarfs. DR2 includes $\sim 25,000$ white dwarfs, distributed over the whole sky, a major fraction being new discoveries. All of these have precise parallax measurements and accurate photometry, which will allow removal of some major sources of uncertainty in our studies of the properties of white dwarfs. This paper will outline the properties and limitations of DR2 from the white dwarf perspective and present some early results of studies carried out using the DR2 sample of white dwarfs.

3. **Revisiting the white dwarf local sample in the era of Gaia**

   Mark Hollands (University of Warwick), Pier-Emmanuel Tremblay (University of Warwick), Boris Gänsicke (University of Warwick), Nicola Gentile-Fusillo (University of Warwick), Silvia Toonen (Amsterdam)

   Volume-limited samples of stars are important for understanding the properties of stellar populations. Making use of the recently released Gaia DR2 data, we have revisited the 20 pc white dwarf sample. Here I will present the updated sample membership including new white dwarf identifications and atmospheric-parameter fits to their absolute photometry. I will discuss our search for companions and methodology in the presence of (almost) universally available 5-parameter astrometry. Finally I will discuss our updated estimate of the local-space density.

4. **A Virtually Complete Sample of White Dwarf Stars Within 25 pc**

Jay B. Holberg (University of Arizona), Martin A. Barstow (University of Leicester), Terry D. Oswalt (Embry-Riddle Aeronautical University), Edward M. Sion (Villanova University)

Gaia DR2 data has made possible a virtually complete determination of the population of white dwarfs within 25 pc of the sun. Among other things, this new sample results in a greatly improved determination of the local white dwarf space density. It also forms the basis for larger unbiased the studies of the local white dwarf population out to greater distances.

5. **White dwarfs in Gaia DR2**

Nicola Gentile Fusillo (University of Warwick), Pier-Emmanuel Tremblay (University of Warwick), Boris Gaensicke (University of Warwick)

Large, well-defined samples of white dwarfs are one of the fundamental requirements for any study of the global properties of these stars, as well as the necessary starting point in any search for specific types of rare sub-classes. Until now, all white dwarf samples were either limited in size, or heavily biased, or both. The second data release of the ESA mission Gaia marks the beginning of a new era in white dwarf science. Relying on Gaia DR2 parallax measurements we constructed the largest and most complete all-sky catalogue of white dwarfs, increasing the sample size by a factor ten. We describe in detail the selection methods used in our work, discuss the completeness and level of contamination of the final white dwarf sample, and provide some examples of first science applications.

6. **Gaia, White Dwarfs, and the Age of the Galaxy**

Elizabeth J. Jeffery (California Polytechnic State University), T. von Hippel (Embry-Riddle Aeronautical University), D.A. van Dyk (Imperial College London), D.C. Stenning (Imperial College London), E. Robinson (Argiope Technical Solutions), W.H. Jefferys (University of Texas, Austin; University of Vermont)

The Milky Way is composed of four major stellar populations: the thin disk, thick disk, bulge, and halo. At present, we do not know the age of any of these populations to better than one or two billion years. This lack of knowledge keeps us from answering fundamental questions about the Galaxy: When did the thin disk, thick disk, and halo form? Did they form over an extended period, and if so, how long? Was star formation continuous across these populations or instead occur in distinct episodes? The Gaia satellite is providing precise trigonometric parallaxes for a plethora of white dwarfs in each of these populations. We combine these parallaxes (and hence, distances) with photometry and analyze them using a modeling technique that relies on Bayesian statistics. This allows us to derive precise ages for individual white dwarfs and determine the age distribution and star formation history for each of the constituents of our Galaxy. We will present current progress in this endeavor.

7. **A homogeneous analysis of white dwarfs in MWDD and beyond**

Patrick Dufour (Université de Montréal), P. Bergeron (Université de Montréal), A. Bédard (Université de Montréal), S. Blouin (Université de Montréal), S. Coutu (Université de Montréal), C. Genest-Beaulieu (Université de Montréal), F. Hardy (Université de Montréal), E. Loranger (Université de Montréal)

At the time of this writing, the Montreal White Dwarf Database contains 34390 white dwarfs, 31846 of which have Gaia data available. We will present a comprehensive and homogeneous analysis of all these stars, as well as all the ones in the solar neighborhood newly identified by Gaia, and discuss the implication on our understanding of white dwarf evolution.

8. **The Gaia white Dwarf Population within 100 pc of the Sun**

Santiago Torres (Universitat Politècnica de Catalunya)

The recent Gaia Data Release 2 will provide an unprecedented sample of the local white dwarf population. The high astrometric resolution and the photometry provided by Gaia allows to build a clean magnitude-color diagram. However, this sample is not exempted from a mixture of the different subpopulation, for instance, thin and thick disk and halo white dwarfs. Consequently, a thorough analysis of the sample is needed in order to extract the maximum information available. With the aid of a state-of-the-art population synthesis based on Monte Carlo techniques we analyze the white Dwarf Population accessible by Gaia within 100 pc of the Sun. Our code incorporates the most recent and reliable white dwarf cooling sequences, an accurate description of the Galactic neighborhood along with a realistic treatment of all the known observational biases. Our estimates indicate a completeness of the sample near a 96%, while some strategies to disentangle the different subpopulations are pointed out and the corresponding preliminary luminosity functions are presented.

9. **The mass distribution of accreting white dwarfs from Gaia DR2**

Anna Francesca Pala (University of Warwick)

The mass retention efficiency is a key question in both the theoretical and observational study of accreting white dwarfs (WDs) in interacting binaries, with important implications for their potential as Type Ia Supernova progenitors. Zorotovic et al. (2011) showed that the average mass of accreting WDs in cataclysmic variables (CVs) is substantially higher ($\sim 0.83\,\mathrm{M}_\odot$) than that of single WDs ($\sim 0.64\,\mathrm{M}_\odot$), suggesting that CV WDs may grow in mass. Different models have been invoked to explain this mass difference, such as quasi-steady helium burning after several nova cycles (Hillman et al. 2016) or additional mechanisms of angular momentum loss driving binary evolution (Schreiber et al. 2016, Nelemans et al. 2016). At present, none of these hypotheses provide a definitive solution to the mass discrepancy between single and accreting WDs. However, the sample of accreting WDs with accurate masses is small, ~ 30 systems, and most of the measurements are based on the analysis of eclipse light curves. Increasing the size of this sample and diversifying the method used to measure the masses is important to improve the observational constraints on the mass distribution of CV WDs.

For this purpose, we have begun a systematic study of 73 CV WDs which have accurate Gaia DR2 parallaxes and for which archival ultraviolet spectroscopy is available. By combining the distance to the system with ultraviolet spectroscopy we can accurately measure the mass of the WD. We present here the preliminary results from this project which provides a critical test for the mass growth hypothesis.

10. **Atmospheric parameters of white dwarfs from Gaia DR2**

Pier-Emmanuel Tremblay (University of Warwick), E. Cukanovaite (U. of Warwick), N.-P. Gentile Fusillo (U. of Warwick), T. Cunningham (U. of Warwick), M. Hollands (U. of Warwick), B. Gaensicke (U. of Warwick)

The cornerstone European Space Agency Gaia mission is completely transforming stellar and white dwarf research. The satellite is now allowing the cataloguing of hundreds of thousands of new white dwarfs down to Gaia G magnitude 21, providing a list of targets for future spectroscopic surveys such as 4MOST, WEAVE, SDSS-V, and DESI. In the meantime, I will discuss the interpretation of the white dwarf parameters derived from Gaia photometric and astrometric data alone.

11. **GALEX Absolute Calibration and Extinction Coefficients Based on White Dwarfs**

Renae E. Wall (University of Oklahoma), Mukremin Kilic (University of Oklahoma), Benoit Rolland (Universite de Montreal), Cynthia Genest-Beaulieu (Universite de Montreal), A. Gianninas (University of Oklahoma), P. Bergeron (Universite de Montreal)

We use 3257 DA white dwarfs form the Sloan Digital Sky Survey to verify the absolute calibration and extinction coefficients for the Galaxy Evolution Explorer (GALEX). We use white dwarfs within 100 pc combined with the sample from Camarota & Holberg to determine an improved linearity correction to the GALEX data for magnitudes brighter than 17.2 and 17.7 for the Far Ultraviolet (FUV) and Near Ultraviolet (NUV) bands, respectively. We also use DA white dwarfs beyond 250 pc to calculate new extinction coefficients in the FUV and NUV bands; $\mathrm{R_{FUV}} = 9.53 \pm 0.03$ and $\mathrm{R_{NUV}} = 8.08 \pm 0.03$. These are consistent with the predicted extinction coefficients for Milky Way type dust. With well understood optical spectra and state-of-the-art model atmosphere analysis, these white dwarfs currently provide the best constraints on the extinction coefficients for the GALEX data.

12. **White dwarfs in LAMOST DR5**

Jincheng Guo (Peking University), Jingkun Zhao (NAOC), Huawei Zhang (Peking University), Jifeng Liu (NAOC)

We report the DAWDs and DBWDs identified from the LAMOST DR5. Together with our previous report, there are $\sim$ 2000 DAWDs, $\sim$ 200 DBWDs in total in the end of the first phase of LAMOST regular survey. Among those sources, about a few hundreds of DAWDs

and dozens of DBWDs are new identifications in this work after cross-match with literature. In selecting DAWD candidates, we believe the classification of LAMOST pipeline is sufficient enough. However, for DBWDs, since there is no template for DBWD in the pipeline model, we adopt a machine learning method called random forest to select the candidates. All the candidates have been visually checked individually. The estimation of effective temperature, surface gravity, mass, cooling age and distance has been done for DAWDs and DBWDs of relatively high signal-to-noise ratio. At last, the data and method we used to select WD candidates for the next phase of LAMOST survey is also presented.

13. **White dwarf and subdwarf stars in the Sloan Digital Sky Survey Data Release 14**

S.O. Kepler (UFRGS, Brazil), Detlev Koester (Universitat Kiel), Nicole Reindl (University of Leicester), Stephan Geier (University of Potsdam), Ingrid Pelisoli (UFRGS), Alejandra D. Romero (UFRGS)

Examining the spectra of all stars with 3 sigma proper motion in the Sloan Digital Sky Survey Data Release 14, we report the classification and atmospheric parameters for 34,321 spectroscopically confirmed white dwarf, subdwarf, cataclysmic variable and dC stars. We obtain $T_{\rm eff}$, $\log g$ and mass for hydrogen atmosphere white dwarf stars (DAs) and helium atmosphere white dwarf stars (DBs), sdB and sdO subdwarfs, and estimate the photometric effective temperatures for the white dwarf stars with metallic lines (DZs) and carbon dominated spectra DQs. We find a significant fraction of objects between the white dwarf cooling sequence and the main sequence, especially below $T_{\rm eff} \sim 10\,000\,{\rm K}$, possibly due to interacting star binary evolution.

14. **Calibrating the Dark Energy Survey: The Role of DA White Dwarfs**

J.Allyn Smith (Austin Peay State University), D.J. Gulledge (Austin Peay State University), J.M. Robertson (COMPASS Science Communication), M.B. Fix (STScI), S. Charbonnier (Ecole Polytechnique), D.L. Tucker (Fermilab), W. Wester (Fermilab), S.S. Allam (Fermilab), P-E. Tremblay (U. Warwick), G. Narayan (STScI), J. Marriner (Fermilab)

We have been searching the southern hemisphere for hot DAs which can be used as part of the Dark Energy Survey (DES) calibration process. This involves photometric and spectroscopic efforts. We will describe the program and results to date; the overall DES calibration effort; and future plans to finalize our project.

15. **The systematic search for compact white dwarf binaries using large scale time domain surveys**

Kevin Burdge (Caltech), Tom Prince (Caltech), Thomas Kupfer (UC Santa Barbara)

White dwarf binaries serve as a useful probe of a rich range of physics including common envelope evolution, tidal interactions, accretion physics, and general relativity. Here, we will

discuss techniques for finding compact white dwarf binaries based purely on their time domain behavior, and present results from the Palomar Transient Factory (including a new detached LISA verification source). After concluding the discussion of results from the Palomar Transient Factory, we will highlight the upcoming Zwicky Transient Factory galactic plane survey. Using the same 48 inch Schmidt telescope as PTF, ZTF expands on PTF by increasing the field of view from 7.8 square degrees to 47 square degrees, while also reducing the total exposure plus readout time from 96 to 45 seconds while reaching a similar limiting magnitude. Additionally, the survey will cover the galactic plane with a nightly cadence for three years, ultimately obtaining hundreds of epochs in both g and r band down to a limiting magnitude of about 20.3 in r band. We will discuss why we expect heavily sampled surveys such as ZTF to be particularly useful probes of the shortest period systems ($<$ 30 minutes).

White dwarfs as SN Ia progenitors

16. **Progenitors and ejected companions of thermonuclear supernovae in the Gaia era**

    Stephan Geier (University of Potsdam), et al.

    Close sdB binaries with massive white dwarf (WD) companions are potential progenitors of thermonuclear supernovae type Ia (SN Ia). We discovered such a progenitor candidate as well as a candidate for a surviving companion star, which escapes from the Galaxy. Several more candidates for both types of objects have been found by crossmatching known sdB stars with ground-based proper motion and light curve catalogues. Here we present most recent results of this project making use of data from Gaia DR2.

17. **Confirming the D^6 Type Ia Supernova Scenario with Hypervelocity White Dwarfs in Gaia DR2**

    Ken Shen (UC Berkeley)

    The binary companion and mechanism responsible for triggering the explosion of a white dwarf (WD) as a Type Ia supernova (SN Ia) have been the subject of intense research for decades. In the "dynamically driven double-degenerate double-detonation" (D^6) scenario, the binary companion is another WD that begins to undergo unstable mass transfer. The violence of this dynamical accretion leads to a helium detonation on the primary WD's surface that then triggers a carbon core detonation and subsequent SN Ia. One possible outcome of the D^6 model is that the secondary WD survives the explosion and flies away from the SN Ia site with its pre-explosion orbital velocity of $> 1000\,\mathrm{km/s}$. We performed a search for such hypervelocity runaway WDs in Gaia's second data release and found three very intriguing stars whose characteristics, derived from follow-up observations, match many of the predictions of the D^6 model. These potential D^6 survivors are the strongest evidence to date of a successful SN Ia progenitor scenario, and future work may confirm the hypothesis that the D^6 model is responsible for the majority of all SNe Ia.

18. **The Evolution of Accreting Oxygen-Neon White Dwarfs**

    Josiah Schwab (UC Santa Cruz), Eliot Quataert (UC Berkeley), Lars Bildsten (UC Santa Barbara), Kyle Rocha (UC Santa Cruz)

    White dwarfs with oxygen-neon core compositions that grow to near the Chandrasekhar mass are thought to collapse to form neutron stars. However, recent multidimensional hydrodynamics simulations of the collapse have raised the possibility that these objects instead explode, potentially leaving behind a low-mass bound remnant. The details of the collapse process are known to be sensitive to quantities such as the location of oxygen ignition. In turn, the evolution up to the point of oxygen ignition depends on the detailed composition of the white dwarf and requires careful treatment of the nuclear reactions and mixing processes that occur in the deep interior. I will discuss a series of calculations that use MESA (Modules for Experiments in Stellar Astrophysics) to follow this evolution. These calculations demonstrate the important effects of Urca-process cooling and the role played by trace amounts of carbon remaining from the white dwarf formation process. These calculations provide important initial conditions for further studies of the collapse process itself and will be a key ingredient in understanding whether the collapse of an oxygen-neon white dwarf leaves behind a neutron star or a partially-burnt peculiar white dwarf.

19. **Where are the double-degenerate progenitors of type Ia supernovae?**

Alberto Rebassa-Mansergas (Universitat Politècnica de Catalunya), S. Toonen (University of Amsterdam), S. Torres (Universitat Politècnica de Catalunya)

The double-degenerate channel for type Ia supernoavae (SNIa) involves the merger of two white dwarfs with a total mass near the Chandrasekhar mass limit. No direct SNIa progenitor has been robustly idenfitied among the observed double white dwarf binary population. In this contribution we study whether or not this is a sufficient condition for disregarding the double-degenerate channel, a commonly adopted assumption. To that end we simulate the population of double white dwarfs in the Galaxy and we obtain synthetic spectra for the resulting direct SNIa progenitors. Taking into account all possible observational biases, we show that the probability of identifying direct double-degenerate SNIa progenitors is negligible with the available current optical telescopes and instrumentation.

20. **High mass white dwarfs as progenitors for double-detonation supernovae Ia**

Thomas Kupfer (KITP/UCSB), Kevin Burdge (Caltech), Tom Prince (Caltech)

A recently proposed SN Ia channel is via the so-called sub-Chandrasekhar double-detonation scenario. In this scenario a white dwarf (WD) is orbited by a core Helium(He)-burning compact hot subdwarf star (sdB/sdO) in an ultra-compact orbit ($P_{\rm orb} < 80\,{\rm min}$). Due to the emission of gravitational waves, the binary is predicted to shrink until the hot subdwarf star fills its Roche lobe and starts mass transfer. He-rich material is then transferred to the C/O-WD companion which will lead to the accumulation of a He-layer on top of the WD. After accreting a small amount He-burning is predicted to be ignited in this shell. This in turn triggers the ignition of carbon in the core even if the WD-mass is significantly lower than the Chandrasekhar limit. However, the number of known systems is still limited. In this talk I will present the discovery of several ultracompact white dwarf binaries with hot subdwarf companions as part of a search for hot (ultra)compact post-common envelope systems with the Palomar Transient Factory data based on a color selected sample from PanSTARRS. I will present properties for each system and discuss the characteristics of the known population of high mass white dwarfs with hot subdwarf companions in tight orbits which are potential progenitors of the SN Ia double-detonation scenario.

21. **Detonation Initiation in Turbulent Electron-Degenerate White Dwarf Matter**

Robert Fisher (UMass Dartmouth), Pritom Mozumdar (UMass Dartmouth), Gabriel Casabona (UMass Dartmouth)

Type Ia supernovae (SNe Ia) are known to be the product of explosive burning of carbon-oxygen white dwarfs, and are of interest as standardizable cosmological candles. However, the SNe Ia stellar progenitors are still poorly understood. A key piece of the SN Ia puzzle is the detonation initiation mechanism itself. In particular, a long-standing problem in modeling SNe Ia is the fact that 3D simulations leave the length scales crucial for a possible detonation unresolved. In this talk, we will present recent results of highly-resolved three-dimensional simulations of turbulent electron-degenerate white dwarf material, which demonstrate that these unresolved scales play a key role in giving rise to hot spots which subsequently detonate. The results imply a much broader range of carbon detonation than previously thought possible, and have implications for all major channels of SNe Ia.

22. **Supernova Survivors - Featuring GD 492 (aka LP40-365), a peculiar hypervelocity white dwarf**

Roberto Raddi (Dr Remeis-Sternwarte)

Type Ia supernova are spectacular transients, which are explained as the thermonuclear explosions of white dwarfs. The recently discovered hypervelocity white dwarf, GD 492, could be the evolutionary "missing link", if confirmed as the surviving remnant of a subluminous Type Iax supernova. We present optical spectroscopy of GD 492, displaying a cool, likely helium-dominated, atmosphere that is rich in neon (33%) and oxygen (2%). We confirm the detection of eleven additional atomic species from magnesium up to nickel, i.e. the nucleosynthesis products of carbon and silicon burning. We measure a manganese-to-iron ratio that is seven times larger than Solar, strongly suggesting a connection with single-degenerate Type Ia supernovae. We also present preliminary work on new, near-UV spectroscopy. Finally, we discuss the physical properties of GD 492 inferred from the Gaia parallax, and what we can learn about the progenitor system.

23. **Thermonuclear explosions of sub-Chandrasekhar mass white dwarfs**

Sabrina Gronow (Heidelberger Institut für Theoretische Studien, Zentrum für Astronomie der Universität Heidelberg)

Supernovae are the main contributers of iron in our galaxy and influence the galactic chemical evolution. The moving mesh code AREPO (Springel 2010) is used to simulate the double detonation of a sub-Chandrasekhar mass white dwarf as a possible progenitor of a type Ia supernova. It allows a parallel treatment of the occurring hydrodynamics and a nuclear network. The white dwarf is set up to consist of a carbon and oxygen core with a helium shell. The explosion mechanism is investigated considering different resolutions in the Helium shell. The results allow a comparison to previous work (for example Fink et al., 2010, and Sim et al., 2012).

24. **The long-term evolution of sub-Chandrasekhar white dwarf mergers**

Alina Istrate (University of Wisconsin-Milwaukee), P. Marchant (Northwestern University), P. Chang (University of Wisconsin-Milwaukee)

Although type Ia supernovae have been used as standard candles and played an essential role in the discovery of cosmic acceleration, their progenitors are still a subject of intense debate. One of the proposed models for type Ia progenitors in the double degenerate scenario is the sub-Chandrasekhar white dwarf mergers (van Kerkwijk et al., 2010). In this framework, the merger remnant does not explode during the merger phase but after a certain delay in which the remnant is possibly heated up by a combination of processes such as spin-down and heating from dissipating the energy of differential rotation. Using new state-of-the-art smoothed-particle hydrodynamics (SPH) simulations of carbon-oxygen white dwarfs, we aim to investigate the long-term evolution of the merger remnant and the feasibility of such mergers to lead to a type Ia-like event. The new SPH simulations feature among others, high resolution, composition profiles resulting from detailed stellar evolution calculations as well as nuclear burning during the merger process. We map the results from the 3D SPH simulations into 1D and import the models into the stellar evolution code MESA in order to study their long-term evolution. In this talk, we present our first preliminary results.

25. **Characterizing the local double white dwarf population**

Na'ama Hallakoun (Tel-Aviv University), Dan Maoz (Tel-Aviv University)

The characterization of the local double white dwarf (DWD) population is crucial to our understanding of multiple questions, from stellar evolution, through the progenitors of Type-Ia supernovae (SNe Ia), to gravitational wave sources. From a spectroscopic sample of 439 WDs from the SPY survey, we measure the maximal changes in radial-velocity (DRVmax) between epochs, and model the observed DRVmax statistics via Monte-Carlo simulations, to constrain the population characteristics of DWDs. We then combine the results with those of a complementary sample from the SDSS to obtain new and precise information on the DWD population and on its gravitational-wave-driven merger rate. We find that $\sim 10\%$ of WDs are in DWD systems in the separation range $\lesssim 4\,\mathrm{AU}$ within which the data are sensitive to binarity. The Galactic WD merger rate per WD is $\sim 1 \times 10^{-11}$ per year. Integrated over the Galaxy lifetime, this implies that 8.5-11% of all WDs ever formed have merged with another WD. If most DWD mergers end as more-massive WDs, then some $\sim 10\%$ of WDs are DWD-merger products, consistent with the observed fraction of WDs in the "high-mass bump" in the WD mass function, now seen with new clarity in Gaia DR2. The implied Galactic DWD merger rate is 4.5-7 times the Milky Way's specific SN Ia rate. If most SN Ia explosions come about from the mergers of some DWDs then $\sim 15\%$ of all WD mergers must lead to a SN Ia.

26. **Binarity of the local white dwarf population**

Silvia Toonen (University of Amsterdam)

Can we understand the multiplicity of the local WD sample from a theoretical point of view? Population synthesis methods are often applied to estimate stellar space densities and event rates, but how well are these estimates calibrated? This can be test by a comparison with the 20 pc sample of WDs. I will discuss the multiplicity of the sample, and our modeling of this population with a population synthesis approach. I will show that overall the space densities are well calibrated, except for resolved double white dwarfs. Furthermore, I will show that the low binary fraction of WD systems (25%) compared to Solar-type MS-MS binaries (50%) is consistent with theory, and is mainly caused by mergers in binary systems, and to a lesser degree by WDs hiding in the glare of their companion stars. Finally, I will show that theory predicts that 10-30% of all single WDs are formed through a a merger in a binary system. This affects the use of WDs as age estimators, and I will present our latest efforts in determining the size of the age offset.

27. **Evolution and surface abundances of Type Iax remnants**

Michael Zhang (Caltech), Jim Fuller (Caltech), Josiah Schwab (UCSC), Ryan Foley (UCSC)

Type Iax supernovae are a mysterious class of transients. Members of this class have similar spectra and light curve shape to the more common type Ia SNe, but with lower line velocities, fainter peak magnitudes, and much less uniformity between events. One potential explanation is that these explosions are deflagrations of carbon-oxygen white dwarfs which, unlike Type Ia SNe, never turn into detonations. If such is the case, the exploding white dwarf may survive. We simulate these carbon-oxygen white dwarfs with MESA from shortly after their explosion all the way down the white dwarf cooling track, taking into account diffusion and radiative levitation, to predict their evolution and surface abundances. Since the explosion process is poorly understood, we run simulations on a grid that accounts for different possible white dwarf masses and explosion energies. We find that radiative levitation is significant at temperatures above $T_{\rm eff} = 10^5\,$K, greatly increasing surface abundances of heavy elements. Iron is an especially common and enthusiastic levitator. As the white dwarf cools, levitation rapidly becomes less important. By $5 \times 10^4\,$K, gravitational settling dominates levitation for all white dwarfs we simulate. The timescale of the evolution depends most sensitively on the thickness of the high-entropy envelope created by the supernova, ranging from $\sim 10^4$ years for a 10% envelope fraction to $\sim 10^6$ years for a 90% envelope fraction. We use these simulation results to comment on potential runaway SN Iax progenitors such as LP 40-365, whose properties have recently been refined by Gaia DR2 data.

28. **Tidal disruption events of white dwarfs: a clue to search for intermediate mass black holes**

Ataru Tanikawa (University of Tokyo)

It is important to find intermediate mass black holes (IMBHs) by measuring black hole mass, since a few IMBHs have been observed so far. Tidal disruption events (TDEs) of white dwarfs (WDs) by IMBHs can be a clue to search for IMBHs. WD TDEs illuminate only IMBHs, since WDs are just swallowed by massive black holes. We have studied WD TDEs by numerical simulation, and have shown detonation emerges in the middle of WD TDEs, which is so-called "tidal detonation". The tidal detonation yields large amounts of radioactive nuclei, such as Nickel-56. WD TDEs will have radioactive luminosity powered by these nuclei, similarly to type Ia supernovae. We will present observational features of WD TDEs.

Atmospheric parameters of White Dwarfs: spectroscopy models, observations, and experimental astrophysics

29. **25 years of using the spectroscopic method: where do we stand?**

    Pierre Bergeron (Université de Montréal)

    The spectroscopic technique, which consists in fitting high signal-to-noise optical spectra with the predictions of state-of-the-art model atmospheres, has routinely been used for over 25 years to measure the atmospheric parameters of DA white dwarfs, and DB stars as well. I will review the technique, the progress we have made, and more importantly, I will attempt to assess its validity and also try to identify some of the current challenges in the physics of white dwarf atmospheres related to the use of the spectroscopic technique.

30. **The Wootton Center for Astrophysical Plasma Properties: At-Parameter Experimental Astrophysics**

    Don E. Winget (UT Austin), Michael H. Montgomery (UT Austin)

    The core principle of the Wootton Center for Astrophysical Plasma Properties (WCAPP) is to perform "at-parameter" experiments recreating the cosmic plasma conditions we find in stars and accretion disks. This extends the reach of astronomy from a purely observational to an experimental science. Our current experiments investigate weaknesses in stellar opacities, uncertainties in the line-broadening models for White Dwarfs, and the unknown physics of supermassive black hole accretion disks. This experimental suite will be extended to other astrophysical environments and problems. WCAPP will support five graduate students and three postdocs. Further WCAPP co-investigators include Roberto Mancini (University of Nevada Reno), Craig Wheeler (UT Austin), and Keith Hawkins (UT Austin). Each will work with a graduate student involved in the intersection of astronomy and experimental physics. We will discuss the impact of these new capabilities on astronomy as we transition into a new scientific era.

31. **Challenges and Progress Toward Modeling Carbon/Oxygen White Dwarf Spectra**

    Thomas Gomez (Sandia National Laboratories), T. Nagayama (Sandia National Laboratories), C. Fontes (Los Alamos National Laboratory), D. Kilcrease (Los Alamos National Laboratory), M. Montgomery (University of Texas), D. Winget (University of Texas)

    Some white dwarfs have atmospheres dominated by carbon and/or oxygen; these exotic stars are thought to be among the most massive white dwarfs (and are candidates for type Ia supernovae progenitors). The masses of these objects are usually determined by fitting model spectra to the measured spectra. White dwarf photospheres are so dense that the line broadening is dominated by electron and ion collisions; the line widths are sensitive to gravity/mass. Line broadening of multi-electron systems (such as carbon and oxygen) is complicated due to the interaction of more than two quantum particles. Current models of electron-collisional broadening for the simplest multi-electron systems (Li-like atoms) are highly uncertain; models underestimate the measured broadening by a factor of two. This means that modeling carbon and oxygen will be even more uncertain. We discuss the relevant physical effects and present progress toward modeling the broadening of 3-electron atoms. We discuss the impact this will have on line broadening of carbon and oxygen.

32. **Helium at white dwarf photosphere conditions: experimental line widths and shifts**

Marc Schaeuble (UT Austin, Sandia National Laboratories) T. Nagayama (Sandia National Laboratories) J. E. Bailey (Sandia National Laboratories) T. A. Gomez (Sandia National Laboratories) D. E. Winget (UT Austin) M. H. Montgomery (UT Austin)

We present preliminary experimental He line shift and width measurements at White Dwarf star photosphere conditions. These data were collected as part of the Z Astrophysical Plasma Properties collaboration on Sandia National Laboratories Z-machine, the largest pulsed x-ray source on earth. We show that our experimental He data are directly applicable to the solution of two major observational discrepancies that have plagued He WD mass-determination methods for years. The issue of the large spectroscopic log g increases observed for low-temperature helium WDs is examined using our experimental investigation of neutral broadening in He plasmas. Furthermore, difficulties in performing gravitational redshift measurements of these stellar objects is addressed with Stark shift measurements. Our preliminary data suggests that current theories cannot properly model either of these processes, which further highlights fundamental shortcomings in our understanding of helium atomic physics. An example of the latter application is the potential future use of these helium data to guide theoretical developments in continuum-lowering models for two-electron atoms.

33. **Improved, Tested and Applied: A New Generation of Cool White Dwarf Atmosphere Models**

Simon Blouin (Université de Montréal), Patrick Dufour (Université de Montréal), Nicole Allard (Institut d'Astrophysique de Paris), Piotr M. Kowalski (Forschungszentrum Jülich)

The photosphere of cool, helium-rich white dwarfs is notoriously tricky to model due to its fluid-like density. Using modern ab initio calculations, we have developed a new generation of atmosphere models that include an accurate description of the equation of state, chemical equilibrium and opacities under these high-density conditions. We show that our new models successfully fit objects that were poorly reproduced by previous models, notably those showing metal absorption lines. These new models are then used to shed new light on the evolution of cool white dwarfs based on a rigorous and homogeneous analysis.

34. **First 3D simulations of white dwarfs with pure-helium atmospheres**

Elena Cukanovaite (University of Warwick) P.-E. Tremblay (University of Warwick) B. Freytag (Uppsala University) H.-G. Ludwig (Zentrum für Astronomie der Universität Heidelberg) P. Bergeron (Université de Montréal)

The numerous spectroscopic studies of white dwarfs have resulted in accurate determinations of the effective temperatures and surface gravities of these stellar remnants, which are important inputs for determining fundamental properties such as their mass distribution and cooling ages. However, these analyses require sophisticated and detailed atmospheric models and synthetic spectra. One major shortcoming of current 1D model atmospheres is the use of mixing length theory (MLT) to treat convective energy transport. MLT is an approximation that hinges on a free parameter called the mixing length which must be calibrated empirically. Although much effort has gone into precisely calibrating the mixing length, for DB white dwarfs it has proven to be a challenge. Fortunately, 3D atmospheric models do not have to be tuned in such a way. This has been clearly shown for DA white dwarfs where the so called high-log(g) problem, accepted to be the consequence of the mixing length approximation, was much better interpreted with the help of 3D models. In this talk, we present the first-ever 3D helium-atmosphere models in relation to both spectroscopic and asteroseismic analyses of DB white dwarfs.

35. **High-precision Atomic Physics Laboratories in Space: White Dwarfs and Subdwarfs**

Alexander Landstorfer (University of Tübingen), Thomas Rauch (University of Tübingen), Klaus Werner (University of Tübingen)

Stellar atmospheres are prime laboratories to determine atomic properties of highly ionized species. Reliable opacities are crucial ingredients for the calculation of stellar atmospheres of white dwarfs and subdwarfs. A detailed investigation on the precision of many iron-group oscillator strengths is still outstanding. To make progress, we used the Space Telescope Imaging Spectrograph to measure high-resolution spectra of three hot subdwarfs that exhibit extremely high iron-group abundances. The predicted relative strength of the identified lines are compared with the observations to judge the quality of Kurucz's line data and to determine correction factors for abundance determinations of the respective elements. We present preliminary results of this analysis.

36. **The Mystery of Missing Metals in DQ Stars**

Jay Farihi (University College London), P. Dufour (Université de Montréal), T. Wilson (University College London)

It is well established that at least 30% of DA and DB stars exhibit metal lines from external accretion, but there is a marked dearth of these signatures among the DQ stars. We have completed a high-resolution optical spectroscopic study of DQ stars and found only 2 of 23 stars exhibit the Ca II K line, meaning less than 10% of DQ stars share a heritage with DA and DB stars. Furthermore, the inferred mass of metals in these stars is tiny when compared to the masses of metals falling onto DA and DB stars. We will present a numerical assessment of these differences, which in turn constrain the nature and origin of the DQ stars. The observations are likely most consistent with a high-mass progenitor or merger origin.

37. **A further investigation of the DA and DB white dwarfs from the Sloan Digital Sky Survey**

Cynthia Genest-Beaulieu (Université de Montréal), Pierre Bergeron (Université de Montréal)

We present a detailed spectroscopic analysis of all the DA and DB white dwarfs identified spectroscopically in the SDSS, up to the 12th data release. We discuss in particular the photometric and spectroscopic temperatures scales, as well as the mass determinations inferred from spectroscopy and from trigonometric parallaxes measured by Gaia. We also discuss the spectroscopic evolution of DA and DB stars by combining the spectroscopic results of both subsamples.

38. **A photospheric survey of three hot, metal polluted white dwarf stars**

Simon P. Preval (University of Leicester), Martin A. Barstow (University of Leicester), Matthew Bainbridge (University of Leicester), Nicole Reindl (University of Leicester), Thomas Ayres (University of Colorado), Jay B. Holberg (University of Arizona), Sarah Casewell (University of Leicester), Matthew Burleigh (University of Leicester), Simon Joyce (University of Leicester)

Theoretical work concerning the unification of fundamental forces in our universe tout the possibility that fundamental constants may vary in the presence of strong gravitational fields. In the case of the fine structure constant, variation presents itself as minute variations in the centroid wavelength of an electronic transition, and is largest in the case of transitions in heavy, highly ionised ions. As part of a project to detect these variations, we obtained high resolution ($> 140,000$) UV spectra of three hot, metal polluted DA white dwarfs; WD0455-282, WD0621-376, and WD2211-495 using the Hubble Space Telescope. In this talk, we present our spectroscopic analyses of these objects, providing measurements of the atmospheric abundances, as well as the surface gravity ($\log g$) and the effective temperature ($T_{\rm eff}$). We also provide comparisons between spectroscopic measurements from these stars to those inferred from photometric measurements from Gaia.

39. **A Systematic, Spectroscopic Survey and Analysis of Southern DAVs**

Josh Fuchs (Texas Lutheran University), Bart Dunlap (University of North Carolina at Chapel Hill), Chris Clemens (University of North Carolina at Chapel Hill), J.J. Hermes (University of North Carolina at Chapel Hill), Erik Dennihy (University of North Carolina at Chapel Hill)

We have collected and analyzed spectra of over 160 DAVs using the SOAR Goodman Spectrograph. Because it employs a single instrument and data processing pipeline, this survey

provides the most systematically consistent set of atmospheric parameters ever collected. We quantify how ten choices in the standard data reduction and spectral fitting routines change results for $T_{\rm eff}$ and $\log g$, and suggest observing, data reduction, and analysis approaches to minimize these systematics. We will show how this uniform set of atmospheric parameters allows for the prediction and confirmation of new outbursting DAVs, the identification of potential double degenerate DAVs, and the relative ordering of DAV Teff.

Pulsating white dwarfs

40. **White dwarf evolutionary models for asteroseismology**

    Alejandra D. Romero (Universidade Federal do Rio Grande do Sul)

    I will present a new grid of white dwarf sequences resulting from full evolutionary computations. The stellar masses cover the intermediate and high mass range. Massive white dwarf sequences were computed using the MESA evolutionary code, covering a stellar mass range between 1.02 and 1.30 solar masses. In the intermediate mass regime, the sequences were computed using the LPCODE evolutionary code, with stellar masses between 0.51 and 0.7 solar masses. These sequences are employed in asteroseismological studies complemented with those presented in Romero et al. (2012, 2013).

41. **The impact of pre-white dwarf evolution on the pulsational properties and asteroseismological inferences of ZZ Ceti stars**

    Francisco De Gerónimo (FCAG-UNLP, IALP-CONICET), L. Althaus (FCAG-UNLP, IALP-CONICET), A. Córsico (FCAG-UNLP, IALP-CONICET), A. Romero (UFRGS), S.O. Kepler (UFRGS)

    ZZ Ceti stars are pulsating white dwarfs with a carbon-oxygen core build up during the core helium burning and thermally pulsing Asymptotic Giant Branch phases. Through the interpretation of their pulsation periods by means of asteroseismology, details about their origin and evolution can be inferred. The whole pulsation spectrum exhibited by ZZ Ceti stars strongly depends on the inner chemical structure. At present, there are several processes affecting the chemical profiles that are still not accurately determined. We present a study of the impact of the current uncertainties of the white dwarf formation and evolution on the expected pulsation properties and on the stellar parameters inferred from asteroseismological fits of ZZ Ceti stars. Our analysis is based on a set of carbon-oxygen core white dwarf models that are derived from full evolutionary computations from the ZAMS to the ZZ Ceti domain. We considered models in which we varied the number of thermal pulses, the amount of overshooting, and the carbon-alpha reaction rate within their uncertainties. We explore the impact of these major uncertainties in prior evolution on the chemical structure and expected pulsation spectrum. We find that these uncertainties yield significant changes in the g-mode pulsation periods being those found during the TP-AGB phase the most relevant for the pulsational properties and the asteroseismological derived stellar parameters of ZZ Ceti stars. We conclude that the uncertainties in the white dwarf progenitor evolution should be taken into account in detailed asteroseismological analyses of these pulsating stars.

42. **Evolution and asteroseismology of extremely low-mass white dwarfs**

    Leila M. Calcaferro (University of La Plata), Alejandro H. Córsico (University of La Plata) and Leandro G. Althaus (University of La Plata)

Many extremely low-mass (ELM) white-dwarf (WD) stars are currently being found in the field of the Milky way. They are probably produced by strong mass-loss episodes at the RGB phase of low-mass (LM) stars in binary systems before the He-flash onset. Some of them exhibit long-period g-mode pulsations and constitute a class of variable (ELMVs). The pulsational spectrum of these stars shifts as they evolve. We have explored the rate of period change studying its dependence with the mass and effective temperature for different evolutionary stages. We have also performed detailed asteroseismological fits to all known variable LMWDs, employing a set of fully evolutionary models that are representative of low-mass He-core WDs. Since there are strong uncertainties about the precise value of the thickness of the H envelope, and some asteroseismological solutions are not unique, we have expanded the space of parameters by incorporating the thickness of the H envelope, generating new evolutionary sequences. We have performed asteroseismological fits with this new set of sequences to search for a representative model. Here, we summarize our main findings and we also show our recent results.

43. **The evolutionary status and pulsations of the Blue Large-Amplitude Pulsators (BLAPs)**

Alejandro H. Córsico (UNLP, Argentina), Alejandra D. Romero (UFRGS, Brazil), Leandro G. Althaus (UNLP, Argentina), Ingrid Pelisoli (UFRGS, Brazil), S. O. Kepler (UFRGS, Brazil)

The Blue Large-Amplitude Pulsators (BLAPs) constitute a new class of pulsating stars. They are hot stars with effective temperatures of $\sim 30000\,\mathrm{K}$ and surface gravities of $\log g \sim 4.9$, that pulsate with periods in the range 20–40 min. Until now, their origin and evolutionary state, as well as the nature of their pulsations, have not been unveiled. In this presentation, we propose that: (i) BLAP stars are the hot, high-mass ($\sim 0.34\,\mathrm{M}_{\odot}$) counterpart of the already known pulsating pre-Extremely Low Mass (pre-ELMV) white dwarf stars, that are He-core low-mass stars resulting from interacting binary evolution, (ii) regarding their pulsations, the observed periods are consistent with highorder nonradial gmode pulsations or, in the case of the shortest periods, also by loworder radial modes, including the fundamental radial mode, and (iii) pulsation modes with periods compatible with those observed in BLAPs can be excited through the kappa mechanism associated to the Z-bump in the opacity.

44. **Limits on Mode Coherence Due To a Non-static Convection Zone**

Mike Montgomery (UT-Austin), Don Winget (UT-Austin), JJ Hermes (UNC)

A handful of DAVs have modes that are observed to exhibit extreme stability over time scales of decades. Other DAVs, and indeed other modes in these same “stable” stars, show both amplitude and phase changes, sometimes on time scales as short as a few days or a week. More recently, K2 observations have shown a correlation between the width of peaks in the FTs of long-period ($> 800\,\mathrm{s}$) modes versus those of short-period ($< 800\,\mathrm{s}$) modes. We show how this can be explained in terms of modes whose region of propagation brings them in contact with the base of the surface convection zone, and we hypothesize that its changing depth (induced by the pulsations) results in the lack of coherence of these modes. This may also have relevance for the red edge of the instability strip and for the amplitude limits of these modes.

45. **Toward a systematic cartography of the chemical stratification inside white dwarfs from deep asteroseismic probing of ZZ Ceti stars**

Stephane Charpinet (Univeristé de Toulouse), N. Giammichele (Université de Toulouse), P. Brassard (Université de Montréal), G. Fontaine (Université de Montréal)

DA-type white dwarfs account for 80% of all white dwarfs and represent, for most of them, the ultimate outcome of the typical evolution of low-to-intermediate mass stars. Their internal chemical stratification is strongly marked by passed, often uncertain, stellar evolution processes that occurred during the helium (core and shell) burning phases, i.e., from the horizontal branch through AGB and post-AGB stages. Pulsating white dwarfs, in particular the "cool" DA-type ZZ Ceti variables, offer an outstanding opportunity to dig into these stars by fully exploiting their asteroseismic potential. We have shown that with our most recent tools dedicated to that purpose, a complete cartography of the stratification of the main constituants of a white dwarf can be obtained, leading in particular to strong constraints on the C/O core structure produced by the processes mentionned above. This opens up the way toward a systematic exploration of white-dwarf internal properties. In this contribution, we discuss the prospects of doing so, notably in the context of K2 and TESS space missions, and we show our most recent results obtained from the analysis of ZZ Ceti pulsators.

46. **Asteroseismic cartography of hydrogen-deficient white dwarfs: evidence of a new evolutionary channel**

Noemi Giammichele (Université de Toulouse, Centre National de la Recherche Scientifique, Centre National dtudes Spatiales), S. Charpinet (Université de Toulouse, Centre National de la Recherche Scientifique, UPS, Centre National dtudes Spatiales), A. S. Baran (Missouri State University; Suhora Observatory and Krakow Pedagogical University), G. Fontaine (Université de Montréal), P. Brassard (Université de Montréal)

White dwarf stars can be seen as stellar fossiles that keep buried in their interior many features from their past evolution. By studying their internal chemical composition, we have access to a wealth of information regarding key processes in stellar physics. We contrast the seismic results obtained for two pulsating hydrogen-deficient white dwarfs from the Kepler and Kepler 2 missions and discuss the possible events that can lead to distinct internal chemical signatures.

47. **Rolling in their Graves: White Dwarf Rotation as a Function of Mass**

JJ Hermes (UNC Chapel Hill), et al.

We have more than tripled the number of rotation rates measured for isolated pulsating white dwarfs thanks to extensive space-based photometry from Kepler and K2. Using follow-up optical spectroscopy to measure overall masses, we have put the first constraints on white dwarf rotation as a function of mass, constraining the endpoints of angular momentum evolution in isolated stars. We find that 0.51-to-0.73-solar-mass white dwarfs, which evolved from 0.9-to-3.0-solar-mass ZAMS progenitors, have a mean rotation period of 35 hr with a standard deviation of 28 hr, with notable exceptions for higher-mass white dwarfs. Our raw and reduced data, still growing with every K2 Campaign, are available for the community to (re-)analyze at `http://www.k2wd.org.`

48. **Confirmation of rotational inferences in pulsating white dwarfs**

Steven D. Kawaler (Iowa State University), Agnes Kim (Penn State Scranton), JJ Hermes (University of North Carolina)

As the endpoints of evolution for stars like our Sun, white dwarfs provide critical tests of our understanding of a variety of processes that govern stellar evolution. With the advent of long high-duty cycle time series photometry from space, we have begun to explore, in detail, the rotation of white dwarfs. Other studies of rotation in red giants and main sequence stars can link to the white dwarfs to provide tight constraints on angular momentum transport models. For white dwarfs, though, confirmation of the asteroseismic inference of rotation through independent observations has been lacking. Here, we report on the K2 target PG 0112+104, and show that the rotation rate measured via asteroseismology is confirmed through direct photometric detection of the surface rotation period. We can also constrain the internal rotation rate with depth. Other targets of K2 may also provide confirmation, or, even better, challenge the simple picture.

49. **Massive pulsating WD stars**

Barbara Castanheira (Baylor University/UT Austin) et al.

Massive pulsating white dwarf stars are extremely rare, because they are the final product of intermediate-mass stars, which are less common than low-mass stars. In addition, their intrinsic small size makes them fainter than the normal-mass white dwarf stars ($\sim 0.6\,M_{\odot}$). Our motivation to look for this type of variable is to be able to study in detail their internal structure and therefore derive generic properties for the outcome of the evolution of intermediate mass stars, below $10\,\mathrm{M}_{\odot}$. Using the 2.1 m Otto Struve Telescope at McDonald Observatory, we discovered nearly a dozen of massive pulsating white dwarfs. These stars might be massive enough that their cores have a significant crystallized portion, up to about 50%. In this talk, I will present an asteroseismic study of these stars individually, and as a class. Our results will provide important constrains on intermediate-mass stellar evolution, as well as the opportunity to study solid state physics at extreme conditions.

50. **A Natural Classification Scheme for hot ZZ Ceti Stars**

J. Christopher Clemens (UNC-Chapel Hill), Bart Dunlap (UNC-Chapel Hill), Charlie Mace (UNC-Chapel Hill), Dan Hirst (UNC Chapel Hill), J.J. Hermes (UNC Chapel Hill)

The Kepler and K2 missions have revealed a wealth of new mode period and rotational splitting measurements for the hot, stably-pulsating ZZ Ceti stars. Combining these new measurements with all prior data reveals a richly patterned set of modes and leads us to develop a natural classification scheme. We will show how the classification of stars by subtype in this scheme both reflects structural similarities, and reveals at least two distinct underlying populations of stars. Using published models and model grids, we will show that these populations require two different strategies to model, and likely correlate with different evolutionary histories. We will describe how our new scheme can be employed to classify new Gaia ZZ Cetis efficiently using very short time series photometric observations.

51. **Ensemble properties of pulsational outbursts from cool ZZ Cetis observed by Kepler/K2**

Keaton J. Bell (Max Planck Institute for Solar System Research), J. J. Hermes (UNC), M. H. Montgomery (UT-Austin), D. E. Winget (UT-Austin)

Extensive Kepler observations of ZZ Ceti (hydrogen-atmosphere pulsating white dwarf) variables in the original and K2 mission fields have revealed a new outburst-like transient phenomenon that is common near the cool edge of the instability strip. We provide an updated census of this new variable subclass, which currently consists of at least 13 known members. The sample is now large enough to study the relationships between various outburst properties, and we present here the first ensemble analysis of pulsational outbursts from ZZ Cetis.

52. **Application of screened Coulomb potential in fitting DBV star PG 0112+104**

Yanhui H. Chen (Chuxiong Normal University)

With 78.7 d of observations for PG 0112+104, a pulsating DB star, from Campaign 8 of Kepler 2 mission, Hermes et al. made a detailed mode identification. A reliable mode identification, with 5 $\ell = 1$ modes, 3 $\ell = 2$ modes, and 3 $\ell = 1$ or 2 modes, was identified. Grids of DBV star models are evolved by WDEC with element diffusion effect of pure Coulomb potential and screened Coulomb potential. Fitting the identified modes of PG 0112+104 by the calculated ones, we studied the difference of element diffusion effect between adopting pure Coulomb potential and screened Coulomb potential. Our aim is to reduce the fitting error by studying new input physics. The starting models including their chemical composition profile are from white dwarf models evolved by MESA. They were calculated following the stellar evolution from the main sequence to the start of the white dwarf cooling sequences. The optimal parameters are basically consistent with that of previous spectroscopic and asteroseismological studies. The pure and screened Coulomb potential lead to different composition profiles of the C/O-He interface area. High k modes are very sensitive to the area. However, most of the

observed modes for PG 0112+104 are low k modes. The σ RMS taking the screened Coulomb potential is reduced by 4 per cent compared with taking the pure Coulomb potential when fitting the identified low k modes of PG 0112+104. Fitting the Kepler 2 data with our models improved the σRMS of the fit by 27percent.

53. **The empirical limits of the DB instability strip**

Zachary P. Vanderbosch (University of Texas at Austin) J.J. Hermes (University of North Carolina at Chapel Hill) Agnès Bischoff-Kim (Penn State Worthington Scranton) Michael H. Montgomery (University of Texas at Austin) Don E. Winget (University of Texas at Austin)

With recent discoveries from McDonald Observatory and K2, we now observe pulsations in 39 helium atmosphere white dwarfs (DBs; DBVs for pulsators) with spectroscopic effective temperatures between roughly 21,000 – 31,000 K, a range 3,000 K wider than what current theory predicts for the DB instability strip (22,000 – 29,000 K). This discrepancy is likely caused by two main factors: (1) undetected trace hydrogen in low-S/N spectra which may cause systematic overestimates of temperatures up to 3000 K, and (2) an incomplete understanding of the physics and efficiency of convection in DBVs. To better define the empirical extent of the DB instability strip, we present here our current efforts to increase the sample size of known DBVs using both McDonald Observatory and the Kepler spacecraft. 12 new DBVs have been discovered from McDonald and 4 from K2. Our McDonald sample also includes 23 objects observed not to vary (NOV) above 5ppt which place additional constraints on the extent and purity of the DB instability strip. The long-baseline and relatively uninterrupted K2 data provides a unique opportunity to perform detailed asteroseismic analyses of DBVs. One K2 object in our sample exhibits clear rotational splittings allowing for a measurement of the rotation period of the white dwarf as well as identification of the eigenmodes. Lastly, we report on the development of a spectroscopic program to put better constraints on the [H/He] abundances for these objects and limit the systematic errors associated with undetected H.

54. **An Update on Pulsations in Accreting White Dwarfs**

Paula Szkody (University of Washington), Anjum Mukadam (University of Washington)

Since the last WD Workshop, there is continuing evidence that long (hrs to days) periodicities are being found in white dwarfs that are undergoing accretion in close binary systems. Pulsation modes remain a possible explanation but proof remains elusive. We will compare the known properties of accreting pulsating white dwarfs with those in ZZ Ceti stars. While sky surveys continue to proliferate, the discovery of accreting pulsators is not rising proportionally. Reasons for this discrepancy as well as future needs will be discussed.

55. **GW Lib: the ultimate observing campaign**

Boris Gaensicke (University of Warwick), Odette Toloza (University of Warwick), JJ Hermes (UNC), Elme Breedt (University of Cambridge), Danny Steeghs (University of Warwick), *Koji Mukai (GFSC), Paula Szkody (University of Washington), Dean Townsley (University of Alabama)*

A small number of white dwarfs in cataclysmic variables exhibit non-radial pulsations. As the envelope of these white dwarfs is continuously enriched with helium accreted from the companion star, they are not confined to the canonical DAV and DBV instability strips, and the characteristics of their pulsations remain poorly explored. We present the results of a co-ordinated 88-day campaign on GW Lib, the prototype of this class of pulsators, using K2, HST and Swift. The short-cadence K2 data shows a persistent modulation at $\sim 20\,\mathrm{min}$, plus two harmonics, super-imposed by periods lasting two to ten days during which a larger-amplitude variability with a period of $\sim 4\,\mathrm{h}$ is present. The simultaneous HST observations confirm that both types of variability are related to temperature variations of the white dwarf. We will discuss the results of this campaign in the context of the current theories of non-radial pulsations in mixed H/He envelopes.

56. **On epsilon-driven pulsations in VV 47**

Paulina Sowicka (Nicolaus Copernicus Astronomical Center), Gerald Handler (Nicolaus Copernicus Astronomical Center), and David Jones (Instituto de Astrofísica de Canarias, Universidad de La Laguna)

Almost 100 years ago Sir Arthur Eddington described a mechanism dependent on nuclear energy generation rate capable of maintaining stellar pulsations, but even today, convincing evidence for it operating in any kind of pulsating star is missing. This nowadays called epsilon mechanism has been proposed to operate in many different types of pulsating stars, most notably in pulsating pre-white dwarfs. If pulsating CSPN of the GW Vir type still had hydrogen-burning shells, in addition to pulsations driven by the classical kappa mechanism, they should also show oscillations driven by the epsilon mechanism (Kawaler 1988). Gonzalez Perez et al. (2006) observed the central star of planetary nebula VV 47 and described its power spectrum as extremely complicated and highly variable, finding peaks in a broad range of frequencies. The shortest period modes they discussed could be explained by the so far elusive epsilon mechanism but were somewhat below the detection limit. We report results of new observations of VV 47 carried out to verify these assertions, as well as re-analysed the data set in which oscillations were claimed. In this talk, I am going to compare these results, and discuss the case for the presence of epsilon-driven pulsations in VV 47.

57. **Nonradial Pulsations in Post-outburst Novae**

William M. Wolf (Arizona State University), Richard H. D. Townsend (University of Wisconsin-Madison), Lars Bildsten (Kavli Institute for Theoretical Physics, University of California)

After an optical peak, a classical or recurrent nova settles into a brief (days to years) period of quasi-stable thermonuclear burning in a compact configuration nearly at the white dwarf (WD) radius. During this time, the underlying WD becomes visible as a strong emitter of supersoft X-rays. Observations during this phase have revealed oscillations in the X-ray emission with periods on the order of tens of seconds. A proposed explanation for the source of these oscillations is internal gravity waves excited by nuclear reactions at the base of the hydrogen-burning layer. In this talk, we present the first models exhibiting unstable surface g-modes with periods similar to oscillation periods found in galactic novae. However, when comparing mode periods of our models to the observed oscillations of several novae, we find that the modes that are excited have periods shorter than that observed. We conclude by proposing and exploring a new source for these oscillations under current investigation.

Structure and Evolution of White Dwarfs

58. **Examining Gravitational Dependence of the Fine Structure Constant using Hot White Dwarf Stars**

Matthew B. Bainbridge (University of Leicester), Martin A. Barstow (University of Leicester), Nicole Reindl (University of Leicester), Simon P. Preval (University of Leicester), Thomas R. Ayres (University of Colorado), John K. Webb (University of New South Wales), John D. Barrow (University of Cambridge), Jay B. Holberg (University of Arizona)

Probing the variation of fundamental constants of nature (like the fine structure constant, alpha) tests the deepest depths of our current knowledge of the universe, helping to informing the next frontier in physics. Hot white dwarf stars, with strong gravitational fields and typically containing numerous absorption lines, provide a unique means to directly probe a potential relationship between gravity and alpha. By observing small shifts in the wavelength of the absorption lines of heavy metals (such as Fe and Ni), when compared to laboratory spectra, we can constrain a possible variation in alpha. We have previously demonstrated our approach and the potential of such an analysis using high-resolution HST/STIS spectra towards a sample of 9 hot white dwarf and sub-dwarf stars. However, there are many challenges and potential systematic effects involved in the measurement of these minute wavelength shifts. We present our latest work to address these challenges including: a) the application of a unique "Artificially Intelligent" algorithm, b) the use of a low-gravity sub-dwarf as a reference for the wavelength shifts, and c) the results of applying our methodology to three new high signal-to-noise, high resolution white dwarf spectra spanning a range of gravitational potentials.

59. **Mass-loss on the road: from post-AGB to white dwarf**

Jiri Krticka (Masaryk University), Jiri Kubat (Astronomical Institute), Iva Krtickova (Masaryk University)

We study mass-loss of white dwarf progenitors along their evolution from post-AGB stage. We use our global (unified) wind models with comoving-frame radiative transport and NLTE atomic level populations to predict the structure of radiatively driven winds. Line-driven winds are triggered in a very early stage of post-AGB evolution and fade away at the white dwarf cooling track. We predict the mass-loss rates and terminal velocities as a function of stellar parameters. Winds significantly influence the ionizing radiation especially during the formation of a planetary nebula. We discuss the implications of our results for the evolution of the stellar remnant, for its properties, and for the structure of the planetary nebula.

60. **Heavy-Metal Skull - Spectral Analysis of the Exciting Star of the Skull Nebula**

Lisa Löbling (University of Tuebingen; European Southern Observatory)

In the intershell region of asymptotic giant branch (AGB) stars, slow neutron-capture nucleosynthesis produces heavy elements beyond iron. Post-AGB stars that experienced a final-

flash event and became hydrogen-deficient therein exhibit their intershell material at the surface. The brightest (V = 11.78 mag) of these, WD 0044-121, is the PG 1159-type central star of the Skull Nebula (NGC 246). We present a spectral analysis of this extremely hot (about 150 000 K) and massive (0.8 solar masses) star by means of state-of-the-art non-LTE model atmospheres based on ultraviolet spectra obtained with FUSE, HST/STIS, and UVES. We compare its evolutionary status with other hydrogen-deficient post-AGB stars.

61. **The hot white dwarf in the peculiar binary nucleus of the planetary nebula EGB6**

Klaus Werner (University of Tuebingen), T. Rauch, (University of Tuebingen), J.W. Kruk (NASA GSFC)

EGB6 is an extended, faint old planetary nebula with an enigmatic nucleus. The central star is a hot DAOZ type WD. An unresolved, compact emission knot was discovered to be located 0.166 arcsec away from the WD and it was shown to be centered around a dust-enshrouded low-luminosity star. It was argued that the dust disk and evaporated gas (photoionized by the hot WD) around the companion are remnants of a disk formed by wind material captured from the WD progenitor when it was an AGB star. We analyzed the hot WD to determine its atmospheric and stellar parameters. In addition, we examined the UV spectrum of the hot nucleus of a similar object with a compact emission region, Tol 26.

62. **Spectral analysis of the binary nucleus of the planetary nebula Hen 2-428**

Nicolle L. Finch (University of Leicester), N. Reindl (University of Leicester), M. A. Barstow (University of Leicester), S. L. Casewell (University of Leicester), S. Geier (Universitat Potsdam), V. Schaffenroth (Universitat Potsdam), M. M. Miller Bertolami (Instituto de Astrofisica de La Plata), S. Taubenberger (Max Planck Institut fur Astrophysik, Garching)

Hen 2-428 is a binary system surrounded by a planetary nebula with an orbital period of 4.2 hr and is a potential supernova type Ia progenitor. Santander-Garcia et al. (2015) concluded from their photometry and radial velocity analysis that the double-degenerate core had a combined mass which significantly exceeds the Chandrasekhar limit. Garcia-Berro et al. (2016) explored alternative scenarios to explain the observational evidence, as the high mass conclusion is highly unlikely within predictions from stellar evolution theory. They constrain lower masses from the light-curves, and conclude that the supernova Ia progenitor status is prematurely given. We present results from the first quantitative non-LTE spectral analysis of Hen 2-428, which allows us to derive the effective temperatures, surface gravities and helium abundance of the two central stars. Based on these results, as well as improved dynamical masses, we discuss the implications of the supernova Ia progenitor status of Hen 2-428.

63. **Approaching a better understanding of the mysterious hot wind white dwarfs**

Nicole Reindl (University of Leicester)

The so-called hot wind white dwarfs represent probably the least understood group of white dwarfs. The optical spectra of these stars show ultra-high excitation absorption lines (e.g. OVIII), which is something that has never been observed in any other astrophysical object. The occurrence of these obscure features requires a dense environment with temperatures in the order of 10^6 K, far exceeding the stellar effective temperature. This phenomenon has never been observed in any other astrophysical object and badly awaits an explanation since more than twenty years. Here, we report on recent investigations and discoveries about these mysterious objects.

64. **An Exploration of Spotted White Dwarfs from K2**

Joshua Reding (University of North Carolina at Chapel Hill), et al.

The Kepler K2 mission has discovered a significant population of white dwarf stars which exhibit photometric variability due to surface inhomogeneities likely related to magnetism. These "spotted" white dwarfs span not only temperature regimes where we expect convection to dominate white dwarf photospheres, but also where radiation should dominate. We present an exploration of spotted white dwarfs as a function of various physical characteristics, including temperature, magnetic field strength, and rotational period, in order to better understand the origins of these photometric variations.

65. **The origin of magnetic fields in white dwarfs**

Lilia Ferrario (The Australian National University)

The origin of magnetic field in stars, from pre-main sequence to the compact star stage, is still one of the main unanswered questions in astrophysics. It is very curious that there is not a single magnetic white dwarf paired with a non-degenerate companion star in a non-interacting binary. In order to explain this peculiar finding, we cannot employ a process that impedes the formation of a strong magnetic field in a proto-white dwarf when it has a companion, because such a process would prevent the formation of magnetic cataclysmic variables (MCVs) consisting of a magnetic white dwarf accreting mass from a red dwarf companion. This is the reason why we have proposed that fields in certain classes of magnetic stars are generated through a dynamo mechanism during common envelope evolution. The closer the cores of the two stars are drawn before the envelope is ejected, the stronger the final field of the star emerging from common envelope will be. The strongest fields occur when the two stars merge and form an isolated magnetic white dwarf. If the two stars do not merge but come out of common envelope just before mass transfer starts, they become the progenitors of the MCVs. In this talk I will present very recent results on the generation and distribution of fields in isolated magnetic white dwarfs showing that stellar merging can indeed explain the strong fields observed in these objects.

66. **Luminosity and cooling evolution of highly magnetized white dwarfs**

Mukul Bhattacharya (University of Texas at Austin), Banibrata Mukhopadhyay (Indian Institute of Science), Subroto Mukerjee (Indian Institute of Science)

White dwarfs have an isothermal electron-degenerate core and non-degenerate surface layers where cooling occurs primarily by the diffusion of photons. Recently, it has been shown that the mass of white dwarfs with high magnetic fields can be significantly larger than the Chandrasekhar mass-limit. These super-Chandrasekhar white dwarfs can also be used to explain over-luminous type Ia supernovae, anomalous X-ray pulsars and soft gamma-ray repeaters. In addition to the mass, large magnetic fields can also affect the thermal properties of the white dwarfs such as conduction, cooling, luminosity, etc. We investigate the luminosity and cooling of highly magnetized white dwarfs by evaluating the temperature and density profiles in the surface layers. The magnetostatic equilibrium and photon diffusion equations are solved in a Newtonian framework to obtain the properties of white dwarfs at the core-envelope interface. With the increase in field strength, the interface temperature increases whereas the interface radius decreases. For a given white dwarf age and fixed interface radius or temperature, we show that the luminosity decreases significantly (up to $\sim 10^{6} - 10^{-9}$ solar luminosity) as the magnetic field strength increases ($\sim 10^{9} - 10^{12}$ G) at the interface. This is remarkable as it argues for magnetized white dwarfs to be dimmer and be practically hidden in the H-R diagram. We also show that the cooling rates corresponding to these luminosities is not appreciable, especially for the strong fields under consideration.

67. **Searching for and modelling the weakest white dwarf magnetic fields**

John D. Landstreet (University of Western Ontario and Armagh Observatory), Stefano Bagnulo (Armagh Observatory)

We have been searching for magnetic fields in white dwarfs (MWDs) down to the $< Bz >\sim 1-2$ kG level, using ISIS (WHT), FORS. (ESO VLT) and ESPaDOnS (CFHT). This project is intended to characterise the frequency and distribution of field strengths at the low magnetic field limit of detection, and to use these data to help to understand how a field evolves as a MWD ages. We are also obtaining series of observations of weak-field white dwarfs for the purpose of modelling the surface field geometry. This project has already led to the discovery of kG-level magnetic fields in two white dwarfs, and obtained time series for modelling of three stars. Magnetic variations have been discovered in two MWDs, and successfully modelled.

68. **High-Accuracy Predictions for Magnetic White Dwarf Spectra with Heavy Elements beyond the Paschen-Back Regime**

Stella Stopkowicz (University of Mainz), Florian Hampe (University of Mainz)

Magnetic fields alter the evolution of electronic states. For weak to moderate magnetic field strengths, this evolution may be accounted for by the Zeeman- or Paschen-Back effect. In this way, Dufour et al. (2015) and Hardy et al. (2016) were able to assign spectra containing C, Na, Mg, and Ca in white dwarfs with magnetic fields of about 4-20 MG using a model atmosphere code. For even stronger fields, Coulomb- and Lorentz forces become competitive

and a non-perturbative treatment of the magnetic field is required. For example, through sophisticated full-configuration interaction (FCI) calculations (Jordan et al. (1998), Becken et al. (1999)), the spectrum of GD 229 was shown to stem from a Helium atmosphere at 300-700 MG. Unfortunately, FCI computations are too expensive to be used for elements with more than 3-4 electrons in strong magnetic fields. In quantum chemistry, the golden standard for high-accuracy calculations is coupled-cluster (CC) theory which yields results often in comparable quality to FCI though with much higher computational efficiency. We have therefore developed a CC and equation-of-motion CC code (Stopkowicz et al. (2015) and Hampe et al. (2017)) for the treatment of atoms and molecules in strong magnetic fields. In this contribution, we present first results for carbon in strong magnetic fields discussing the evolution of states as well as transition moments (oscillator strengths) as a function of the magnetic field, aiming for predictions for white-dwarf spectra with strong magnetic fields.

69. **The Initial-Final Mass Relation for Stars from 0.85 to 8 Msun**

Jeffrey D. Cummings (Johns Hopkins University), Jason Kalirai (Space Telescope Science Institute), Pier-Emmanuel Tremblay (University of Warwick)

The spectroscopic study of white dwarfs provides both their mass, cooling age, and intrinsic photometric properties. For white dwarfs in the field of well-studied star clusters, this intrinsic photometry can be used to test cluster membership. Comparison of a member white dwarf's cooling age to its total cluster's age gives the evolutionary timescale of its progenitor star, and hence the initial mass. This initial-final mass relation (IFMR) gives critical information on how a progenitor star evolves and loses mass throughout its lifetime, and how this changes with progenitor mass. Our work presents a uniform analysis of 81 white dwarfs spanning from progenitor masses of 0.85 to 8 Msun. Comparisons of our work to theoretical IFMRs show consistency in their shapes, but the semi-empirical IFMR is systematically ~ 0.1 Msun more massive than theory predicts and a moderate dispersion remains that cannot be explained by errors. I will discuss possible explanations for these differences, including the important effects of rotation on stellar evolution and what challenges remain.

70. **The Initial Final Mass Relation From 1 to 7 Solar Masses: A Monte Carlo Approach with the Addition of the new M67 White Dwarf sample**

Paul Canton (University of Oklahoma), Kurtis Williams (Texas A&M Commerce), Alex Gianninas (University of Oklahoma), Mukremin Kilic (University of Oklahoma)

The initial-final mass relation (IFMR) maps a star's initial, or ZAMS mass, to its final mass as a white dwarf (WD). With a recent analysis of the aged solar-metallicity open star cluster M67 we revisit the IFMR with new constraints in the initial-final mass parameter space. We reanalyze data from a total of five open clusters for internal consistency. We show, with a Monte Carlo simulation, that the historically illustrated perpendicular error bars along the initial and final mass axes fail to illustrate the complicated correlation between the initial and final mass from using the standard procedure for deriving initial masses for WDs in open clusters. We include objects from elsewhere in the literature which have been analyzed in

a consistent manner to our reanalyzed sample, and apply the results of our Monte Carlo simulation for 64 objects to rederive the IFMR. Our relation derives from unprecedented internal consistency, spanning a range from 1 to 7 solar masses in ZAMS mass and 0.50 to 1.18 solar masses in WD mass.

71. **Outliers in globular clusters: the case of 47 Tucanae**

Fabiola Campos (University of Texas at Austin), I. Pelisoli (Universidade Federal do Rio Grande do Sul), S. Kamann (Georg-August-University; Liverpool John Moores University), T.-O. Husser (Georg-August-University), S. Dreizler (Georg-August-University), A. Bellini (Space Telescope Science Institute), E. L. Robinson (University of Texas at Austin), D. E. Winget (University of Texas at Austin), S. O. Kepler (Universidade Federal do Rio Grande do Sul), M. H. Montgomery (University of Texas at Austin), Alina G. Istrate (University of Wisconsin-Milwaukee), A. Dotter (Harvard-Smithsonian Center for Astrophysics)

We used HST multicolor photometric data of the globular cluster 47 Tucanae to find 39 outliers from the single-star model tracks in the color-magnitude diagram. All these objects are likely members of 47 Tucanae. By comparing those sources with evolutionary models, we were able to show that the majority of those sources are likely binary systems. We have also compared with X-ray source catalogues and found no nearby sources. We concluded that these outliers are most likely formed by a white dwarf and a main-sequence star and a small number of possible double-degenerate systems.

72. **Diffusion and Other Mixing for Pollution Inferences in White Dwarfs**

Evan Bauer (University of California, Santa Barbara), Lars Bildsten (Kavli Institute for Theoretical Physics)

Polluted white dwarfs (WDs) require detailed modeling of surface mixing to understand accretion rates and compositions of parent bodies that supply polluting material. Much modeling of the pollution process relies on assuming an equilibrium between diffusive sedimentation and metal accretion supplied to the WDs surface convective envelope. However, recent work is calling attention to the importance of additional mixing processes such as convective overshoot and the thermohaline instability. We present results from a large grid of MESA models indicating that this additional mixing can lead to inferred accretion rates that are several orders of magnitude higher than previous estimates. WDs with hydrogen atmospheres at effective temperatures above 10,000 K require rates as large as 10^{13} g/s to explain observed Calcium abundances. Mixing other than diffusion may also inhibit chemical separation between metals, resulting in systematic effects on inferences of compositions for the rocky bodies that are the ultimate source of polluting metals.

73. **High resolution simulations of DA white dwarf surface convection**

Florian Zaussinger (BTU Cottbus-Senftenberg), Friedrich Kupka, Mike Montgomery (UT Austin), Christoph Egbers

The outermost shell of many white dwarfs contains a convective layer. Even if the latter is very thin ($< 10\,\mathrm{km}$), it is important for mixing processes of accreted material, observed radiation, and possibly also the pulsational stability of the whole object. During a long and thus easily observable phase white dwarfs have effective temperatures T_{eff} of about 10000 K – 14000 K, since the time scale to reach such temperatures by cooling is already 1 Gy and the evolution through this temperature range is of similar extent. Here, we focus on DA (hydrogen-rich) white dwarfs with values of T_{eff} around 12000 K. For typical surface gravities ($\log g = 8$) this is at the transition from shallow to deep convection zones. Due to very high gravitational acceleration the material is overturned about five times per second over the distance of a few kilometers. Three-dimensional radiation hydrodynamical simulations of such objects have been calculated by us assuming a fully compressible flow and realistic microphysics. Compared to previous work our simulations feature a much larger extent of the simulation domain at similar or higher resolution. Highly turbulent granules at the surface are found, among others, which are qualitatively comparable to the convection cells observed at the surface of the Sun. Selected simulations are performed with spatial resolutions down to 5 m. A statistical analysis of the convective processes as function of T_{eff} reveals structural differences between the convection zones found for each given T_{eff}.

74. **Investigating Convective Overshoot in White Dwarfs**

Tim Cunningham (University of Warwick), Pier-Emmanuel Tremblay (University of Warwick)

Observational studies of metal polluted white dwarfs is the only way to precisely characterise the composition of rocky exoplanetary material. White dwarfs develop convection zones in their pure H or He envelopes as they cool, mixing the accreted metals before they leave the observable layers by microscopic diffusion. This increases their settling timescale compared to a star with a non-convective atmosphere and constraining this timescale is crucial for models of evolved exoplanetary systems. Using the CO5BOLD 3D radiation-hydrodynamics code, we are modelling H-dominated white dwarf atmospheres in the temperature range 11,000-18,000 K where convection is existent, yet confined to a region small enough to allow modelling of the full vertical extent of the convective and overshoot regions. We will present the first 3D simulations of degenerate stars with tracer particles that directly measure the macroscopic diffusion of metals in the overshoot layers below the convective zone. Our results suggest that the inclusion of macroscopic overshoot diffusion leads to an increase in mixed mass compared to 1D models of 1-3 orders of magnitude. We will discuss some of the implications on our understanding of accretion, diffusion and composition of exoplanetary material.

75. **The sdA puzzle: solved?**

Ingrid Pelisoli (UFRGS), S. O. Kepler (UFRGS), D. Koester (University of Kiel), B. G. Castanheira (Baylor University, UT Austin), A. D. Romero (UFRGS), L. Fraga (LNA)

The Universe is not old enough for white dwarfs with mass lower than 0.3 solar masses to have formed through single evolution. For this reason, most white dwarf catalogues excluded objects with $\log g < 6.5$. However, over 50% of stars above one solar mass are in binaries, 25% out of which are predicted to interact, leading to the formation of exotic objects including the so-called extremely-low mass white dwarfs (ELMs) with $M < 0.3\,\mathrm{M}_\odot$. Our understanding of these multiple evolutionary paths is still fragmentary, making observational input of utmost importance. We extended the white dwarf search in the Sloan Digital Sky Survey (SDSS) to lower $\log g$, to find cool and low-mass ELMs missed by biased criteria of previous searches. This lead to the discovery of thousands of objects with hydrogen-dominated spectra and physical properties in the ELM range, which have been called subdwarf A stars (sdAs). Multiple evolutionary paths have been suggested for the sdAs. On one hand, time-resolved spectroscopy revealed many are not in close binaries, as expected for the (pre-)ELMs. Yet their apparent magnitude implies distances of over 8 kpc when a main sequence radius is assumed, while observed proper motions suggest d < 2 kpc. These discrepancies made their nature an open question to be answered by the Gaia parallax, which allows to constrain their radii, and hence their luminosity class. We will discuss the nature of these stars and implications to our theories of stellar evolution and Galaxy formation in light of Gaia data.

76. **The origin of single low-mass white dwarfs**

Monica Zorotovic (Universidad de Valparaiso), M. R. Schreiber (Universidad de Valparaiso), J. Vos (Universidad de Valparaiso), M. Vukovic (Universidad de Valparaiso), R. Ostensen (Missouri State University)

Low-mass helium-core white dwarfs (WDs) with masses below 0.5 Msun are known to be formed in binary star systems. Unexpectedly, a significant fraction of them seems to be single. On the other hand, in cataclysmic variables (CVs), a large number of low-mass WD primary stars is predicted but not observed. Here I present an empirical model for CV evolution recently developed, that could explain both, the high average WD masses in CVs and the fraction of low-mass WDs observed among single WDs, as well as several other disagreements between theory and observation of CVs. In this new model, consequential angular momentum loss causes especially CVs with low-mass WDs to merge and form single stars. Our simulations show that merging CVs might be the dominant channel leading to the formation of low-mass single WDs. I will also discuss the evolution of the long period binary HE 0430-2457, which contains the first extremely low-mass pre-WD without a close companion known so far. We recently suggested that this pre-WD is probably the result of the merger of the inner binary in a hierarchical triple system.

77. **Formation and evolution of hybrid He-CO white dwarfs and their properties**

Yossef Zenati (Israel Institute of Technology), Silvia Toonen (University of Amsterdam), Hagai B. Perets (Israel Institute of Technology)

White dwarfs (WDs) are the stellar core remnants of low mass (8 $\mathrm{M}_\odot$) stars. They are typically divided into three main composition groups: Oxygen-Neon (ONe), Carbon-Oxygen (CO) and

Helium (He) WDs. The evolution of binary systems can significantly change the evolution of the binary stellar components. In particular, striping the envelope of an evolved star can give rise to a core remnant, which can later evolve into a WD with significantly different composition. Here we focus on the formation and evolution of hybrid HeCO WDs. We follow the formation and stellar evolution of such WDs for a range of initial conditions and provide their detailed structure, mass-radius relation and luminousity-temperature evolution. We find that both low-mass WDs ($< 0.45\,\mathrm{M}_{\odot}$, typically thought to be He-WDs) and intermediate-mass WDs($0.45 < M_{WD} \leq 0.7$, typically thought to be CO-WDs) could in fact be hybrid HeCOWDs, with 5–25 (75–95)% of their mass in He (CO). We use population synthesis calculations to infer the birth rate and properties of such WDs. We find that hybrid HeCO-WD comprise the majority of young ($< 2\,\mathrm{Gyr}$) WDs in binaries, but are more rare among older WDs in binaries. The high frequency and large He content of such WDs could have an important role in WD-WD mergers, and may give rise to sub-Chandrasekhar thermonuclear supernova explosions.

78. **Sirius B and the gravitational redshift**

Simon Joyce (University of Leicester), Martin Barstow (University of Leicester), Jay Holberg (University of Arizona), Howard Bond (Pennsylvania State University), Sarah Casewell (University of Leicester), Matt Burleigh (University of Leicester)

The 3rd of the original three tests of general relativity proposed by Einstein was a measurement of the gravitational redshift effect, which predicts that light escaping from a massive body will be shifted to longer wavelengths. A measurement of the gravitational redshift of Sirius B was first attempted in 1925 and was considered a resounding success. It later became apparent that both the predicted and measured values had been severely underestimated. Since that time, more accurate redshift measurements have found a smaller but still significant over-estimate of the mass of the white dwarf when compared to the the dynamical and spectroscopic methods. We present new measurements of Sirius B using HST which have resolved this discrepancy and provide a valuable test of the high mass end of the mass-radius relationship for white dwarfs.

White dwarfs in binaries: with stellar and substellar companions, double degenerates, CVs, etc.

79. **Accreting White Dwarfs in Close Binaries: Surface Temperatures and Abundances**

Edward M. Sion (Villanova University), Patrick Godon (Villanova University)

We present new results on surface temperatures, and chemical abundances of accreting white dwarfs in cataclysmic and symbiotic binaries. The presence of accreted heavy elements in their WD atmospheres suggests either dredgeup of metals in the white dwarf from the effects of ongoing dwarf nova episodes or contamination of the Roche lobe-filling donors by repeated past nova explosions. We present new confirmatory evidence that one such accreting white dwarf is in a triple system, consisting of a cataclysmic variable orbiting a red giant. (This research is supported by NASA ADP Grant NNX17AF36G to Villanova University.)

80. **Constraining the Milky Way potential by combining gravitational wave and electromagnetic observations of double white dwarf binaries**

Valeriya Korol (Leiden Observatory), Elena Maria Rossi (Leiden Observatory), Enrico Barausse (IAP)

The upcoming LISA mission is the only experiment that offers the opportunity to study the Milky Way through gravitational wave radiation, exploiting the signal from Galactic double white dwarf (DWD) binaries. In the coming years, a large number of DWDs can be simultaneously detected in both electromagnetic (e.g. with Gaia and LSST) and gravitational wave radiation. This will provide a unique opportunity to perform a multi-messenger tomography of the Galaxy. In this talk, I will show that LISA will detect DWDs far and wide, mapping also the opposite side of the Galaxy and that this will allow: (1) to provide strong and unique constraints on the scale length parameters of the Milky Way stellar components using LISA data alone, and (2) to compute the rotation curve and derive competitive estimates for the disc and the bulge masses using LISA plus optical counterparts.

81. **High precision studies of white dwarfs in eclipsing binaries**

Steven Parsons (University of Sheffield)

I will present high precision ($< 2\%$), model independent, mass and radius measurements for 26 white dwarfs in detached eclipsing binaries and use these to test the theoretical white dwarf mass-radius relationship. In particular, these measurements probe the crossover range between carbon-oxygen and helium core white dwarfs. I'll also show how these precise measurements can be used to constrain the mass of the surface hydrogen layer and test the accuracy of white dwarf spectroscopic fits.

82. **White dwarf collisions and the meteoritic Ne-E anomaly**

Jordi Isern (ICE,CSIC/IEEC), Eduardo Bravo (UPC)

The analysis of noble gases in primitive meteorites has shown the existence of anomalous isotopic abundances when compared with the Solar values. In particular it has been found that some graphite grains contain a unexpected high abundance of neon-22. This excess of neon-22 is usually attributed to the radioactive decay of sodium-22 produced in the O/Ne burning layer of a core collapse supernova. In this talk we speculate about a different origin, the disruption of a white dwarf by a compact object (white dwarf, neutron star or black hole).

83. **A pulsation ephemeris for AR Sco**

Tom Marsh (University of Warwick), Vik Dhillon (University of Sheffield), Stuart Littlefair (University of Sheffield), Tariq Shahbaz (Instituto de Astrofisica)

AR Sco is a white dwarf close binary which uniquely shows pulses on the white dwarf's spin period from X-ray to radio wavelengths. In the 2016 discovery paper, a measurement of the spin-down rate of the white dwarf was made which suggested that the white dwarf was losing rotational energy sufficiently rapidly to power the flux seen from the system in excess of the photospheric flux of its component stars; the spin-down luminosity was found to exceed the electromagnetic luminosity excess by more than an order of magnitude. However, the ephemeris that led to this measurement, which was based upon sparse survey data, has recently been ruled out by Potter and Buckley with the help of intensive high-speed photometry. This leaves AR Sco's spin derivative as yet undetected, and whether the system is powered by the white dwarf's spin-down luminosity, an open question. In this talk, an analysis of three years of pulsation data will be presented to examine the feasibility of establishing a pulsar-like pulsation ephemeris for AR Sco. Simultaneous data in five bands from a new camera HiPERCAM on the 10.6 m GTC will also be presented to examine the extent of wavelength-dependence in AR Sco's pulse times, and thus its potential as a timing reference source.

84. **Accretion Flows and Boundary Layers in Nonmagnetic Cataclysmic Variables Using X-ray Observations**

Solen Balman (Middle East Technical University)

I will review X-ray emission from nonmagnetic CVs mainly dwarf novae and nova-likes at low and high states compare with theoretical expectations, and concentrate on specific examples. X-rays provide valuable diagnostics for disk structure and accretion flow in the inner regions of the accretion disk of CVs. I will discuss the nature of the plasma and its ionization structure in the X-ray emitting region in the light of high and low resolution spectroscopy. The X-ray data indicates existence of accretion flows that are non-ionization equilibrium plasma as hot flows (ADAF-like flows) merged with the referred boundary layers. These boundary layers are found to stay mostly optically thin in high and low states of nonmagnetic CVs. There is enough evidence in the other wavelengths to support this. I will elaborate on the inner disk structure. CVs constitute laboratories to study accretion flows, gas dynamics, outflows and transient outbursts under a variety of astrophysical plasma conditions in relation with XRBs and AGNs.

85. **Dynamical Masses of White Dwarfs in Nearby Visual Binaries**

Howard E. Bond (Penn State University)

I will discuss astrophysical results based on dynamical masses measured using the Hubble Space Telescope and ground-based telescopes for three visual binaries in which one component is a white dwarf. I will also present an HST measurement of the mass of the nearby white dwarf Stein 2051B, obtained from its relativistic deflection of the image of a background star. For all of these WDs, theoretical mass-radius relations agree extremely well with the measurements. In the case of the DA star 40 Eridani B, the theoretical relations clearly predict that it has a thin outer hydrogen layer.

86. **Gaia14aae: An Eclipsing AM CVn that challenges formation models**

Matthew Green (University of Warwick), Tom Marsh (University of Warwick), Danny Steeghs (University of Warwick), Thomas Kupfer (CalTech), ElmB́reedt (Cambridge), Vik Dhillon (Sheffield, IAC)

AM CVn-type binaries are ultracompact binaries with periods of 5-65 minutes, where each binary consists of a white dwarf accreting material from a degenerate or semi-degenerate companion. They are strong foreground sources of gravitational waves in the LISA frequency range, and are evolutionarily linked to double white dwarf binaries and cataclysmic variables. I will give a brief overview of the subject, including recently discovered systems and results from Gaia, before focusing on the question of how these binaries form. I will present data on the first known fully-eclipsing AM CVn, Gaia14aae. Stellar parameters measured from eclipse photometry of the system can provide strong constraints on the system's prior evolution. I will show that these properties do not agree fully with predictions based on any of the proposed formation channel, and are strongly inconsistent with a double-white dwarf progenitor system. The most likely progenitor seems to be either a binary consisting of a white dwarf + helium-burning star or an evolved cataclysmic variable, but both models require additional processes and/or fine-tuning to fit the data.

87. **Post common envelope binaries as tracers of M dwarf stellar winds**

David Wilson (UT Austin, Warwick), Boris Gaensicke (Warwick), Jeremy Drake (Smithsonian Astrophysical Observatory), Odette Toloza (Warwick)

We present Hubble Space Telescope ultraviolet spectroscopy of a sample of Post Common Envelope Binaries (PCEBs), which consist of a white dwarf with an M dwarf companion in a close but detached orbit. M dwarfs have emerged as prime targets in the search for potentially habitable planets beyond the Solar system, but the increased stellar activity that such planets will undergo, relative to Solar system planets, may have detrimental effects on their evolution and habitability. In particular, little is known about the effects of stellar winds due to the difficulty of stellar wind rate measurements. Our ultraviolet spectroscopy of PCEBs provides a pathway to measure the stellar winds of M dwarfs. The material from the M dwarf wind accretes onto the white dwarf, resulting in the contamination of the pure hydrogen photosphere of the white dwarf with traces of C, O, Si and other metals. Modelling the photospheric abundances allows us to measure the accretion rate onto the white dwarf and the composition of the M dwarf wind. From these measurements, we derive the stellar wind rate as a function of M dwarf type and spin period, and discuss the potential implications for planetary systems.

Dust, disks, and planetary systems around white dwarfs

88. **G29-38: testing the homogeneity of the metal distribution**

Odette Toloza (University of Warwick), Boris Gansicke (University of Warwick), Detlev Koester (University of Kiel)

G29-38 has infrared excess due to the dusty debris disc and therefore the presence of metals observed in white dwarf atmosphere is explained by accretion from the debris. The accretion process is poorly understood, and it is not clear if the metal distribution across the white dwarf is homogeneously distributed. G29-38 presents non-radial pulsations which offer a unique opportunity to study the distribution of the metal abundances across the white dwarf surface, using the pulsations as a spotlight: As a consequence of the pulsations, localised areas on the white dwarf surface are heated by a few thousands of degrees, outshining the flux emitted from the unheated regions. Therefore, the ultraviolet spectroscopy is largely dominated by the flux from these heated regions. I have been analysing fast high-resolution ultraviolet spectroscopy obtained with the Cosmic Origins spectrograph (COS) mounted on the Hubble Space Telescope (HST), extracting the spectra from individual pulses. Modelling the spectral absorption features of silicon and carbon in these spectra using a state-of-the art atmosphere code, I find that the distribution of metals across the white dwarf surface does not show large variations, arguing against an accretion geometry limited to an equatorial belt.

89. **Convection Affects Magnetic Turbulence in White Dwarf Accretion Disks**

Matthew S. B. Coleman (IAS)

I examine the accretion disks which power outbursts in two types of white dwarf binary systems: dwarf novae (DNe) and AM CVns. Accretion disks in these systems are thermally unstable, causing some of the observed variations. The source of "normal outbursts" in these systems ultimately originates from ionization transitions (H for DNe and He for AM CVns). These ionization transitions cause significant temperature dependence in opacities and equation of states, culminating in the occurrence of convection within these accretion disks. Local stratified shearing-box simulations were used to show that this convection has a significant impact on the turbulence and dynamos generated by the magnetorotational instability (MRI). Most notably, convection enhances the stress to pressure ratio, often denoted by alpha. These results were then incorporated into the disk instability model to generate the first theoretical lightcurves for dwarf novae outbursts which incorporate MRI physics.

90. **Non-stellar Companions to White Dwarfs from Photometric Surveys**

Claudia Belardi (University of Leicester), Ian Braker (University of Leicester), Matt Burleigh (University of Leicester), Martin Barstow (University of Leicester), Sarah Casewell (University of Leicester), Liam Raynard (University of Leicester), Steven Parsons (University of Sheffield)

The discovery of the disrupting planetesimals orbiting WD1145+017 (a metal-polluted white dwarf with a known circumstellar debris disc) has provided us with important evidence that white dwarfs may be the hosts of planetary systems. Detecting a planet around such objects could significantly help us in understanding how systems like our own evolve after the Main Sequence stage. In addition, white dwarfs are known to have extended and long-lived habitable zones, due to their small sizes and their long cooling times. As a result, planets around them could be potential hosts for life. In this talk, I will present results from ground-based and space-based observations aimed at discovering similar systems to the one mentioned above.

91. **Dusty Exoplanetary Debris Disks in the Single-Temperature Blackbody Plane**

Erik Dennihy (UNC-Chapel Hill; Gemini Observatory), Chris Clemens (UNC-Chapel Hill), Bart Dunlap (UNC-Chapel Hill)

Dusty Exoplanetary Debris Disks in the Single-Temperature Blackbody Plane We present a bulk sample analysis of the metal polluted white dwarfs which also host infrared bright dusty debris disks, known to be direct signatures of an active exoplanetary accretion source. We explore the position of the dusty debris disk hosting white dwarfs in a "single-temperature blackbody plane", defined as the temperature and radius of a single-temperature blackbody as fitted to the infrared excess. We find that the handful of dust systems which also host gaseous debris in emission aggregate along the high temperature boundary of the dust disk region in the single-temperature blackbody plane. We discuss interpretations of this boundary in the context of why some dust disk systems host gaseous debris in emission while others do not, and how the single-temperature blackbody plane can be used for targeted searches of gaseous emission in the future.

92. **Infrared Variability of Two Dusty White Dwarfs**

Siyi Xu (Gemini Observatory), Kate Su (University of Arizona), Laura Rogers (University of Cambridge), Amy Bonsor (University of Cambridge), Dimitri Veras (University of Warwick)

About 4% of all white dwarfs show excess infrared radiation from a circumstellar dust disk. These disks are remnants of extrasolar minor planets that were tidally disrupted. Previously, we have reported one system WD J0959-0200, whose infrared luminosities dropped by $\sim 30\%$ within one year. We postulated that it could be caused by a new tidal disruption event or instability triggered by gas and dust. Here, we report two additional objects, whose infrared fluxes change on the timescale of a few years. We discuss different mechanisms that could contribute to the rapid changes of infrared luminosities of dusty white dwarfs.

93. **A Search for Habitable Planets Around White Dwarfs**

Kyra Dame (University of Oklahoma) Claudia Belardi (University of Leicester) Mukremin Kilic (University of Oklahoma) Armin Rest (Johns Hopkins University) A. Gianninas (Uni-

versity of Oklahoma) Sara Barber (House Committee on Science, Space, and Technology) Warren R. Brown (Smithsonian Astrophysical Observatory)

We present minute cadence photometry of 31732 point sources observed in a DECam pointing over eight consecutive half-nights. We use these data to search for eclipse-like events and other sources of variability. We identify 49 variables, including 40 new systems. These include 24 detached or contact stellar binaries, 1 eclipsing white dwarf + M dwarf binary, 15 Delta Scuti, three RR Lyrae, two ZZ Ceti, and one subdwarf A or low-mass white dwarf pulsator candidates. We do not find any significant evidence for minute-long transits around our targets, hence we rule out planetary transits around $\sim$ 370 white dwarfs that should be present in this field. We will also present updates from the remaining two fields in our survey.

94. **Accretion of a wet planetesimal by a warm DAB**

Matthew J. Hoskin (University of Warwick), B.T. Gaensicke (University of Warwick), O. Toloza (University of Warwick), R. Raddi (University of Warwick, Friedrich-Alexander Universitat), D. Koester (University of Kiel)

We report the identification of strong photospheric metal contamination of a warm (18,500K) DAB white dwarf. The photosphere, $\sim 5\%$ hydrogen by mass, shows absorption features from the common rock-forming metals of both core and crust material (Mg, Ca, Fe, Ni), along with a significant oxygen excess, suggesting that this star has accreted water-rich rocky material. We also confidently identify volatile elements (C, S, P). From the inferred hydrogen mass, assuming a fully mixed convection zone, we derive an upper limit of $\sim 10^{25}$ g of water that this star might have accreted throughout its history. Based on the detected oxygen excess we will impose further restrictions on the recent accretion of water by this star. Identifying the parent body composition will determine the likely origin of the body, and perhaps any evolution it has undergone since its formation. Aside from providing insight into the chemistry of planetary bodies, this star offers further evidence that the accretion of water is linked to the atmospheric evolution of helium dominated white dwarfs, as found by recent statistical analysis (Gentille-Fusillo+, 2017). The measured hydrogen abundance is such that the star cannot have evolved continuously with a helium dominated atmosphere (Rolland+, 2018), as the hydrogen radiative zone would not yet be convectively diluted, while mixing between helium and hydrogen convection zones does not occur until $\sim 10,000\,$K. This star is among the most hydrogen-rich of the few known DAB stars.

95. **A Planetesimal on a two hour period around a white dwarf**

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Up to half of all white dwarfs host remnants of planetary systems, inferred from the detection of photospheric metal pollution and circumstellar discs arising from the tidal disruption of

planetesimals. However, transits from a fragmenting planetesimal have only been detected in one system. I will report on the identification of a stable, two hour period in the strength and shape of the emission profiles originating from the gaseous debris disc around a metal polluted white dwarf. This is the first spectroscopic detection of a short period ($\sim$ hours) signal at a white dwarf hosting a debris disc. I argue that this signal is the orbital period of a solid body with significant internal strength orbiting within the debris disc. I also suggest that the gaseous disc in the system is generated by this body, either from sublimation or by interactions with the dust, and speculate that all observable gaseous debris discs host a closely orbiting planetesimal. I will finally discuss the possible links with other debris disc systems, which may also host planetesimals in close orbit.

96. **Mergers, Metals, and Massive White Dwarfs**

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Knowledge of planetary remnants around white dwarf stars can be combined with an initial-final mass relation to learn about the frequency and composition of planetary systems on the main sequence. In this context, massive white dwarfs are particularly valuable since they allow us to make inferences about planets on the upper main sequence where radial-velocity variations and transits are relatively difficult to detect. However, such inferences to the main sequence are valid only if the white dwarf evolved to its current state from a single star. For massive white dwarfs, this is not certain because some formed from mergers. We will show how removing a population of kinematically identified white dwarf merger remnants can clean the sample, enabling us to probe planetary properties on the main sequence with more confidence. In particular, we show that the population of massive hydrogen-atmosphere white dwarf stars in the ultraviolet spectroscopic sample of Koester et al. (2014) likely descended from massive single stars. The observed purity of their atmospheres, therefore, is evidence that their progenitors are bereft of planets.

97. **Polluted white dwarfs: new results from the VLT and the outlook in the Gaia era**

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We present a new analysis of nine southern white dwarfs with atmospheric pollution consistent with accretion from exoplanetary material. Deep observations with the VLT reveal abundances for multiple elements, allowing the nature of the material to be probed. A variety of compositions are seen, apparently united by the common theme of disrupted differentiated bodies but with a surprisingly wide range of sodium abundances. Compositions can only be reliably inferred if accretion is ongoing, which complicates the analysis unless the time since the last accretion event is known; we make an effort to estimate this. Looking ahead, we

discuss the prospects for this field in the light of the second data release from Gaia, which has multiplied the list of potential targets, helped to measure their masses and for the first time allowed them to be linked to their main-sequence neighbours.