EXTINCT STARS AND EVISCERATED PLANETS: USING OBSERVATIONS OF WHITE DWARF POLLUTION TO UNDERSTAND THE FORMATION, COMPOSITION AND EVOLUTION OF PLANETARY SYSTEMS.

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Introduction: Our Sun is a middle-aged, main-sequence star that will eventually evolve into a bloated red giant before finally shrinking and ending its life as a compact, dense white dwarf. During this evolution, the swollen Sun will engulf Mercury, Venus and perhaps the Earth, pulverize many asteroids and comets, and leave rocky and icy debris strewn throughout the Solar System. The outer planets and Kuiper belt will survive, but in an altered state, orbiting the cold, dead Solar white dwarf. The vast majority of stars will, like the Sun, end their lives as white dwarfs, and we know of over 1000 confirmed planets orbiting stars that will become White Dwarfs.

What happens to these planetary systems? What can we learn from these ancient white dwarf planetary systems about the formation, composition and evolution of all planetary systems?

Observational evidence for the survival of planetary systems into the white dwarf phase comes from the presence of elements heavier than helium detected in the atmospheres of white dwarfs [1,2,3,4]. There is now unambiguous evidence that this material is from planetary bodies that survived the star's evolution, and which were accreted onto the atmosphere of the white dwarf [5,6,7,8]. This accreted material is hence referred to as white dwarf "pollution". Observations of disintegrating planets/asteroids (e.g. in the WD 1145+017 system, [9]) as well as the detection of gas and dust discs around white dwarfs, combine to inform us how the polluting planetary material arrived in the atmosphere of the white dwarfs. Not only do such observations tell us that white dwarf planetary systems are as common as around main sequence stars, but they also provide unique insights that are difficult to deduce observationally on the main sequence.

It is currently impossible to observationally determine the bulk chemical composition of an exo-planet residing hundreds of light years away. We might infer a planet's composition from studies of its atmosphere or bulk density, but observations of polluting planetary material in the atmospheres of white dwarfs provide a (so far) unique way to investigate the bulk composition of exo-planetary material. In fact, we know the composition of some planetary bodies swallowed by white dwarfs better than we know the composition of minor planets in our own Solar System. Spectra yield ratios of key species, such as Mg/Si and C/O, which tell us about the physical properties, and potentially the geology, of any planets that may have formed out of this material. For the foreseeable future, the only way to determine the composition of exo-planets and exo-asteroids will be through spectroscopic observations of their eviscerated remains in white dwarf atmospheres.

Current and upcoming space missions and ground-based facilities are poised to transform our understanding of white dwarf planetary systems. By 2020, the combined efforts of the Gaia, Euclid, K2 and TESS missions will have increased the number of known white dwarf discs and minor planets by orders of magnitude and likely lead to the discovery of the first giant planets around white dwarfs, while JWST will transform our ability to identify specific minerals in the debris orbiting white dwarfs.

I will discuss the crucial interdisciplinary work that will required for the white-dwarf community to be able to capitalize on the extant knowledge of meteoriticists, cosmochemists, and astronomers and work in concert to plan the investigations required to truly understand white dwarf systems. Doing so will allow the community to extract the unique data that only white dwarf systems can supply on the fundamental processes governing the formation and evolution of planetary systems.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Zuckerman et al. 2003, ApJ, 596, 477. [2] Zuckerman et al. 2010, ApJ, 722, 725. [3] Barstow et al. 2014, MNRAS, 440, 1607. [4] Koester et al. 2014, A&A, 566, A34. [5] Graham et al. 1990, ApJ, 357, 216. [6] Jura 2003, ApJL, 584, L91. [7] Debes et al. 2012, ApJ, 747, 148. [8] Bear & Soker 2013, New Astronomy, 19, 56.[9] Vanderberg A. et al., 2015, Nature, 526, 546