ABSTRACT

Maybe you thought carbon stars (with C/O>1) were all highly evolved, asymptotic giant branch (AGB) stars? Dwarf carbon (dC) stars are actually for more common than C giants and have accreted carbon-rich material from a former AGB companion, yielding a white dwarf (WD) and a dC that has gained both significant mass and angular momentum. Some dC systems have undergone a planetary nebula phase, and some may evolve to become the more famous CH, CEMP, or Ba giants. Most dCs seem to be from older, metal-poor kinematic populations where perhaps it is easier to achieve C-O. Given the well-known anticorrelation of age and activity, dCs would thus not be expected to show significant X-ray emission related to coronal activity. However, accretion spin-up might be expected to cause rejuvenated magnetic dynamos in these post-mass-transfer binary systems. We describe our Chandra pilot study of 6 dC stars selected from the SDSS for Hα emission and/or a hot WD companion, to test whether their X-ray emission strength and spectral properties are consistent with a rejuvenated dynamo. We detect all six, with log Lx from 28.5 to 29.7, and log L/L⊙ ~3, preliminary evidence that dCs can be active at a level consistent with stars that have short rotation periods of several days or less. Further, upcoming Chandra observations will help determine the amount of accreted mass and provide constraints for simulations.

Dwarf Carbon Stars? Innocent Bystanders

- The first proven dC (G77-61; Dahn+1977) was found by its.
- Many further dCs were recognized from their large proper motions (Green et al. 1991, Downes et al. 2004). In a handful of cases, the "smoking gun" of AGB mass transfer was revealed as a hot DA white dwarf companion (Heber et al. 1993, Liebert et al. 1994).
- dC stars are known to exist across a wide range of colors corresponding approximately from mid-M to late-F (Green 2013, 2019), suggesting that they are "innocent bystanders":  ANY star can be dumped on by a former C-AGB companion. This CMD from (Green+ 2019) shows colors corresponding approximately from mid-M to late-F (Heber et al. 1993, Liebert et al. 1994).
- Simulations of de Kool & Green (1995) predicted a bimodal orbital period distribution for dCs, centered on periods of a few years and a few decades.
- Several are now known with much shorter periods, such as J12501+5254 (Morgan+2017), with a 2.9d period and RV semi-amplitude k=99 km/s, shown below.

Dwarf Carbon Stars Indeed Live in Binaries

- A variety of non-AGB stars show enhanced carbon and/or s-process abundance that are similarly extrinsic, including some red giant stars. The CH, Ba and the carbon enhanced metal poor (CEMP-s) stars (Lucatello et al. 2005) are all consistent with 100% binary fraction with WD companions. These all likely evolved from dC stars, and have been studied much more often than dC stars only by virtue of their greater luminosity.
- All dC stars should thus be in binary systems. Are they?
  - The prototype dC, G77-61 is in a 245d binary orbit with an unseen companion (Dearborn+1986) and is extremely metal poor (Plez & Cohen 2005).
  - Whitehouse+2018 showed that 21 of 28 dC stars had variable radial velocities consistent with 100% binary fraction.
  - Roulston+2019 found a large binary fraction and some extreme DBαS by analyzing sparsely-sampled RVs for 241 dCs from SDSS-IV Time Domain Spectroscopic Survey (MacLeod+2017).
  - Simulations of de Kool & Green (1995) predicted a bimodal orbital period distribution for dCs, centered on periods of a few years and a few decades.

Smoking Guns

- About 1% of dC stars clearly show a composite spectrum, where a DA white dwarf spectrum is visible in the blue.
- They are either dA/dC examples at left were discovered among SDSS spectra by Green (2015).
- They bolster the argument that all dC stars are likely post-accretion dC binaries (Pietsch et al. 2012) which, when eclipsed (P=1.2d), reveals a dC star (bottom; Middle+2013)
- Hard X-rays from CSPNe could be due to accretion onto compact hot WD, or coronal emission from accretion spin-up of the dC (Spada+2010)