X-ray Emission and Mass Transfer: the *Dwarf* Carbon Stars

Paul Green*(SAO), Rodolfo Montez (SAO), Fernando Mazzoni (U.Mass, Lowell), Joseph Filipazzo (STScI), Scott F. Anderson(UWa), Orsola De Marco(Macquarie U.), Jeremy Drake (SAO), Jay Farihi(UCL) , Adam Frank(U.Roch), Joel H. Kastner (RIT), Brent Miszalski (SAAO) and Ben Roulston (BU)

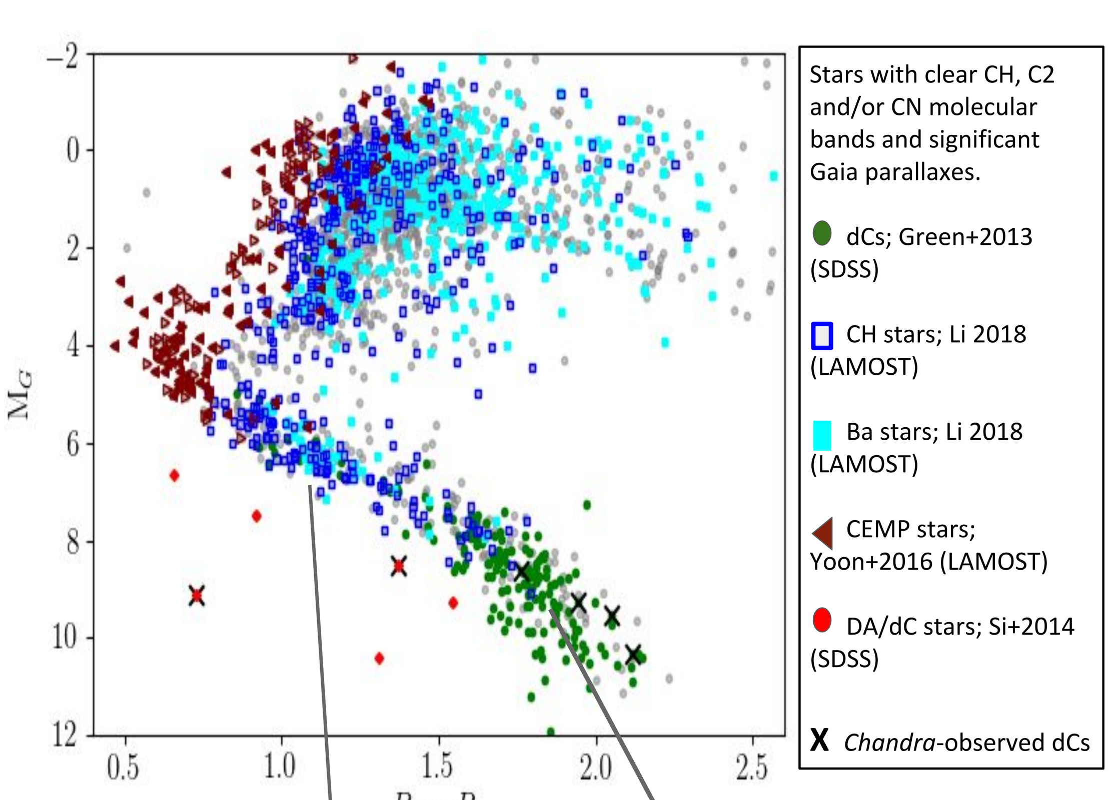
*pgreen@cfa.harvard.edu

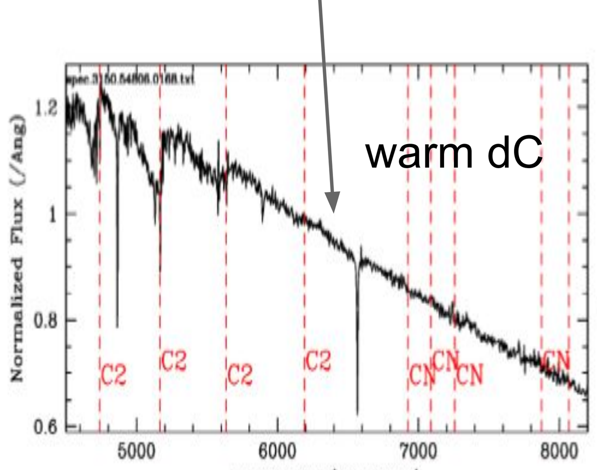
ABSTRACT

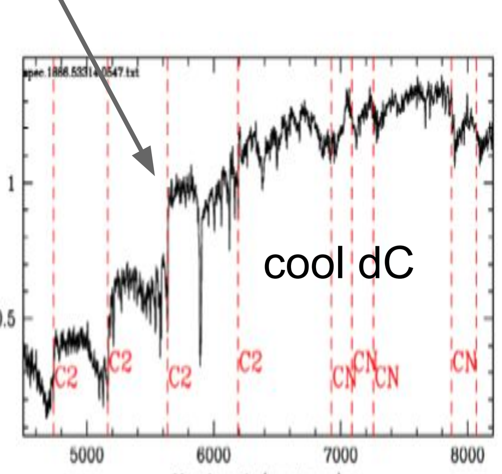
Maybe you thought carbon stars (with C/O>1) were all highly evolved, asymptotic giant branch (AGB) stars? **Dwarf carbon (dC) stars are actually *far more common* than C giants** and have accreted carbon-rich material from a former AGB companion, yielding a white dwarf (WD) and a dC star that has gained 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 dCs selected from the SDSS for Halpha 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_X/L_{Bol} ~ -3, preliminary evidence that dCs may 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

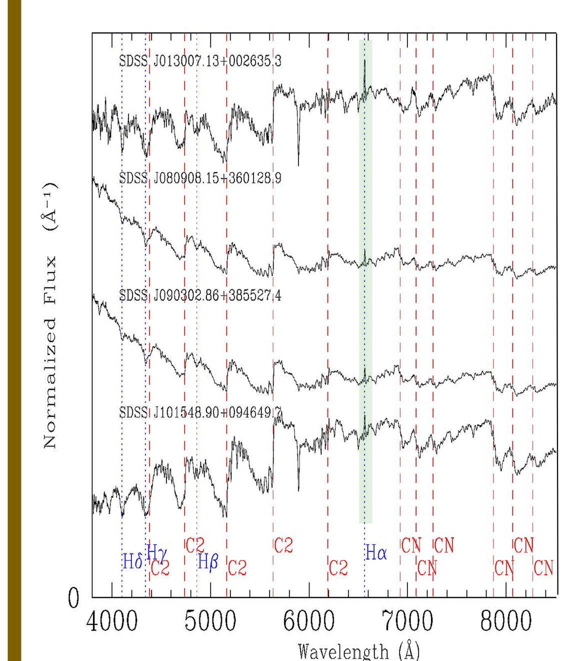
- The first proven dC (G77-61; Dahn+1977) was found by its high proper motion.
- Many further dCs were recognized from their large proper motions (Green et al. 1991, Downes et al. 2004). In a handful of cases, the "smoking gun" of AGB binary mass transfer was revealed as a hot DA white dwarf companion (Heber et al. 1993, Liebert et al. 1994).
- dC stars are now 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 *only* stars with C>O.



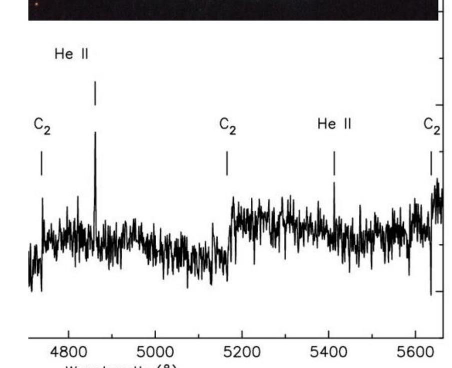




Smoking Guns



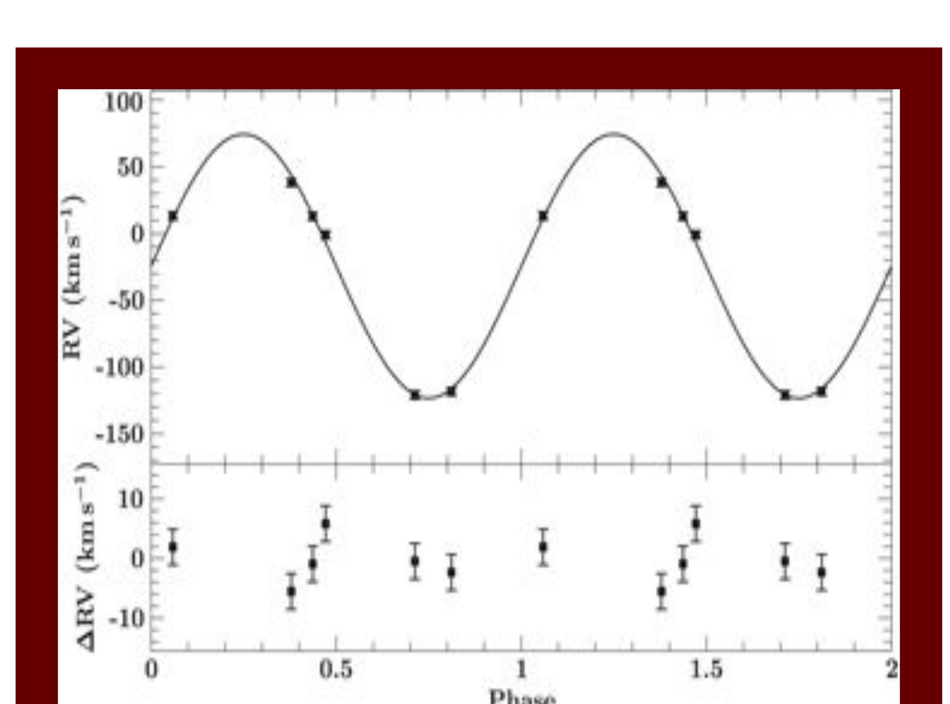
- About 1% of dC stars clearly show a composite spectrum, where a DA white dwarf spectrum is visible in the blue.
- The DA/dC examples at left were discovered among SDSS spectra by Green (2013).
- They bolster the argument that all dC stars are likely post mass-transfer binaries (PMTBs).
- For the vast majority, only the dC star spectrum is visible, while presumably the white dwarf has cooled beyond detectability.
- Uniquely, dCs can be instantly identified in intermediate resolution spectra as PMTBs.



- Spectacular morphologies of Planetary Nebulae are probably due to binary companions.
- 'The Necklace' PN (*top*) has a hard spectrum, X-ray-luminous central star, common among such objects (Kastner +2012) which, when eclipsed (P=1.2d), reveals a dC star (*bottom*; Miszalski+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 (ala Montez+2010)

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 ΔRVs 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.
  - Several are now known with much shorter periods, such as **J12501+2524** (Margon+2017), with a 2.9d period and RV semi-amplitude *K*=99 km/s, shown below.

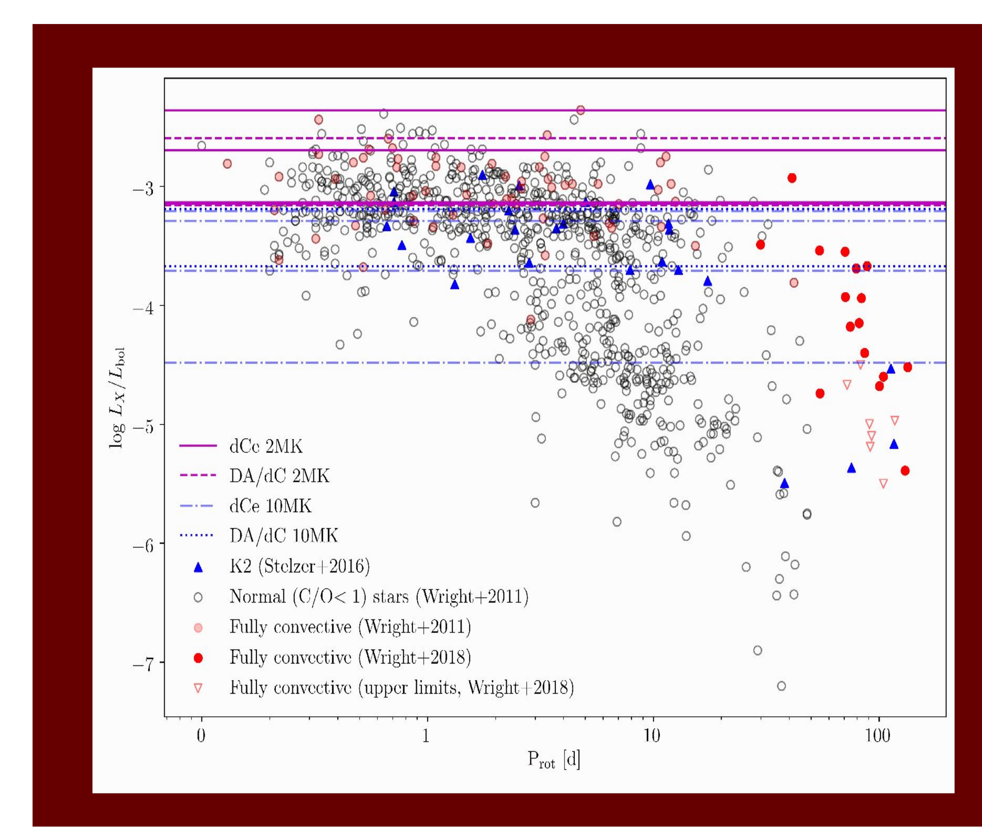


Chandra Observations & Analysis

- Our Chandra observations *all* resulted in (weak) detections of dC stars
- We assume 2MK and 10MK X-ray spectral models using CIAO `srcflux`
- Gaia DR2 provides reliable parallax distances for our sample
- We use SEDkit (Filippazzo+2015) to determine L_{Bol} from published optical-to-mid-IR photometry, using the Bayestar17 3D dust map for extinctions (Green+2018)

SDSSJ	Type	Chandra	Cts	Fx(2M)	Dist	L_{Bol}	M_i	logLx	logLx/L_{Bol}	
		ksec	*net*	*10^{-15}cgs*	*pc*	*$L_\odot$*	*SDSS*	*2MK*	*2MK*	*10MK*
0901+3238	dCe	18.32	2.9	2.8	585	-1.29	7.76	28.86	-3.42	-3.88
1015+0946	DA/dC	15.92	5.0	4.2	475	-1.37	8.06	28.95	-3.25	-3.64
1250+2524	dCe	24.64	15.5	10.5	282	-1.55	8.55	29.12	-2.91	-3.32
1519+5007	DA/dC	27.59	14.9	10.7	443	-1.55	8.83	29.32	-2.70	-3.18
1548+3418	DA/dC	16.02	3.9	3.6	231	-1.90	9.64	28.57	-3.11	-3.52
1637+2740	dCe	17.23	8.9	7.0	405	-1.62	8.93	29.10	-2.85	-3.25

Rotation Period vs. X-ray Luminosity Ratio



Stellar activity, parameterized by log L_X/L_{Bol} `saturates' below rotation periods P~3d. M/K dwarfs (C<O main-sequence stars) with known periods are plotted as symbols. We don't yet have periods for our Chandra dC sample, so we plot them as magenta (blue) lines. assuming a plasma temperature of TX=2 MK (TX=10 MK). Dashed (dotted) lines represent 2 DA/dC systems. Solid (dotted–dashed) lines are for the other dC systems.

Summary, Caveats and Future Work

- We used *Chandra* to observe the dCs most likely to yield a detection: nearby, showing Halpha emission lines, or a still-hot white dwarf companion.
- Based on L_X and L_X/L_{Bol}, dC stars are consistent with accretion-induced dynamo rejuvenation (AIDR).
- Our upcoming *Chandra* Cycle 21 time for a sample of 6 distance-selected dCs offers with Lx and Tx measurements for an unbiased sample.

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