

# The Living with a Red Dwarf Program: Observing the Decline in dM Star FUV Emissions With Age

Scott G. Engle<sup>\*,†</sup>, Edward F. Guinan<sup>\*</sup> and Trisha Mizusawa<sup>\*</sup>

<sup>\*</sup>*Villanova University, Department of Astronomy & Astrophysics, 800 E. Lancaster Ave, Villanova, PA 19085, USA*

<sup>†</sup>*James Cook University, Centre for Astronomy, Townsville QLD 4811, Australia*

**Abstract.** Red Dwarf (dM) stars are overwhelmingly the most numerous stars in our Galaxy. These cool, faint and low mass stars make up  $> 80\%$  of all stars. Also dM stars have extremely long life times ( $> 50\text{--}100$  Gyr). Determining the number of red dwarfs with planets and assessing planetary habitability (a planet's potential to develop and sustain life) is critically important because such studies would indicate how common life is in the universe. Our program – “Living with a Red Dwarf” – addresses these questions by investigating the long-term nuclear evolution and the coronal and chromospheric properties of red dwarf stars with widely different ages ( $\sim 50$  Myr – 12 Gyr). One major focus of the program is to study the magnetic-dynamo generated coronal and chromospheric X-ray-FUV/UV emissions and flare properties of a sample of dM0–5 stars. Observations carried out by FUSE of a number of young to old dM stars provide important data for understanding transition region heating in these stars with deep convective zones as well as providing measures of FUV irradiances. Also studied are the effects of X-ray–FUV emissions on possible hosted planets and impacts of this radiation on their habitability. Using these data we are constructing irradiance tables (X–UV irradiances) that can be used to model the effects of XUV radiation on planetary atmospheres and possible life on planetary surfaces. The initial results of this program are discussed.

**Keywords:** stars: red dwarfs, dM stars, rotation, age; stars: individual (CD-64 1208, AU Mic, HIP 107345, HIP 31878, AD Leo, EV Lac, Proxima Cen, IL Aqr, SZ UMa); FUV; FUSE

## INTRODUCTION & BACKGROUND

The “Living with a Red Dwarf” program aims to understand the magnetic activity, dynamo structure and plasma physics (along with determining the X-ray–FUV–UV [XUV] spectral irradiances) of dM stars with widely different rotations, ages and correspondingly different levels of magnetic activity. For a more in-depth summary of the program and some preliminary results, see Guinan & Engle (2009). This program is an extension of the ongoing “Sun in Time” program which primarily targets main-sequence G-stars (Guinan et al. 2003). Another important aspect of the Living with a Red Dwarf program is the determination of rotation periods for dM stars of reliably known ages, in order to form a well-populated Age-Rotation relationship. This is done through available survey photometry (such as the invaluable All Sky Automated Survey – ASAS – Pojmanski (2001)) in addition to continued multi-band photometry we have carried out for the past  $\sim 5$  years. When accomplished, the rotation and age data can be combined with our XUV irradiances and emissions to delineate dM star magnetic evolution over time.

The FUSE spectral region contains important chromospheric and transition region diagnostic emission lines that can be used to characterize energy transfer and stellar

**TABLE 1.** dM Stars in the FUSE Archive

Star Name	FUSE Name	V-mag	Spec. Type	Age	Rotation
CD-64 1208	CD-64D1208	9.2	M0	0.010 ( $\beta$ Pic)	1.22
AU Mic	HD197481	8.61	M0Ve	0.010 ( $\beta$ Pic)	4.86
HIP 107345	HIP107345	11.72	M1	0.025 (Tuc-Hor)	4.5
HIP 31878	CD-61D1439	9.70	M1V	0.050 (AB Dor B4)	0.47
AD Leo	BD+20D2465	9.43	M4.5Ve	0.200 (Rotation)	2.23
EV Lac	BD+43D4035	10.09	dM4.5+dM4.5	0.300 (UMa Group)	4.38
Proxima Cen	GJ551	11.05	dM5e	$\sim 5.8 \pm 0.4$ ( $\alpha$ Cen System)	83.2
IL Aqr	GLIESE876	10.17	dM5	$\sim 6-8$ (Rotation)	116.46
SZ UMa	SZUMA	9.32	M1V	8–12 (Old Disk)	149.7

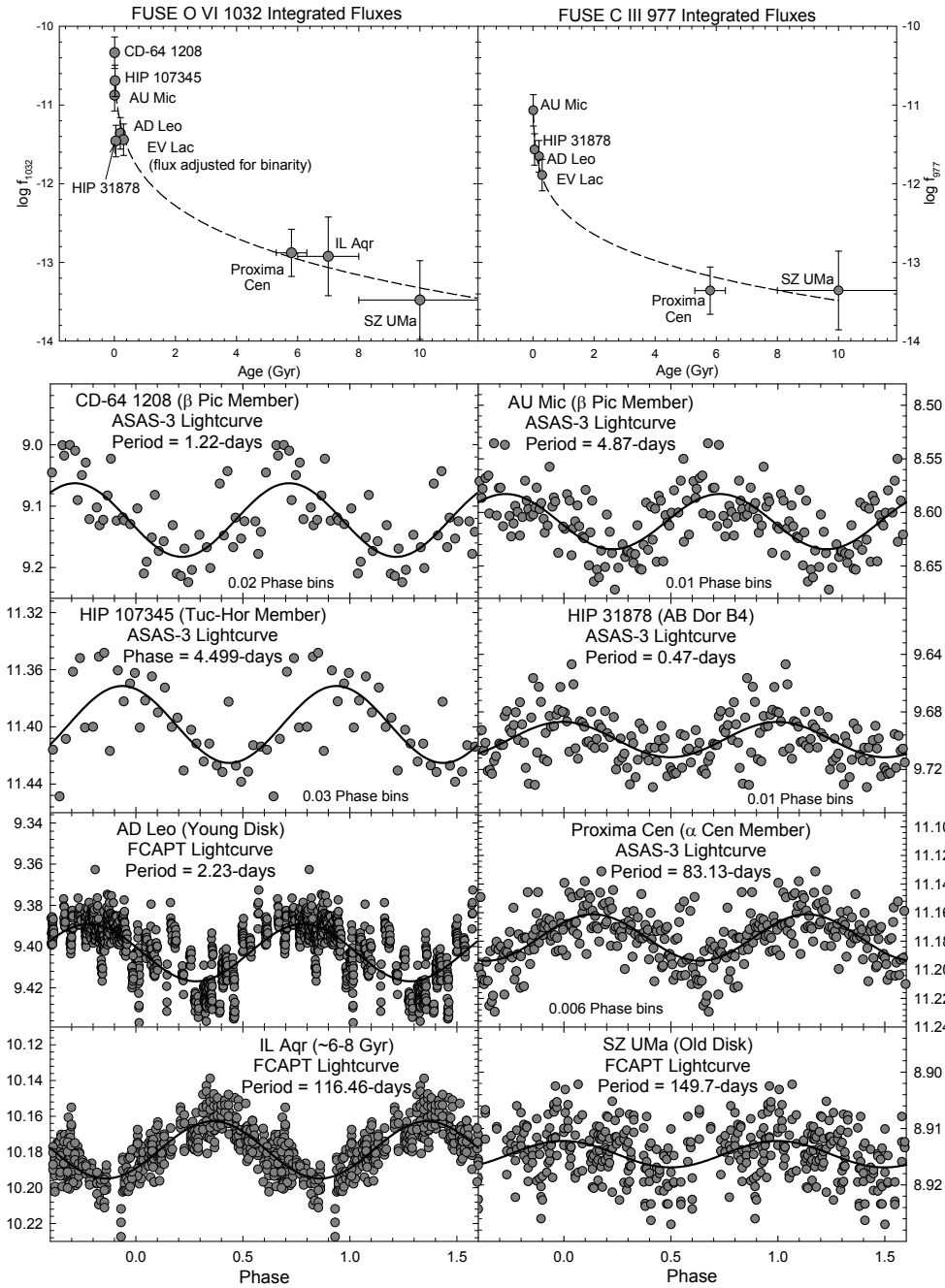
atmospheric structure while the ratio of C III 1176/977 fluxes contains valuable information about the electron pressure. This spectral region is also important for gauging the FUV emissions of dM stars (mostly contributed by the H I Lyman series, C III and O VI emissions). This is critical to assess the photochemical and photoionization evolution of planetary atmospheres and ionospheres and the possible development of life on extrasolar planets (Kasting 1997; Guinan & Ribas 2002; Kasting & Catling 2003; Guinan et al. 2003; Ribas et al. 2005). Table 1 lists the dM stars observed by FUSE and some of their physical properties most relevant to the program. Stellar ages have been assigned as follows: CD-64 1208 –  $\beta$  Pic Association member; AU Mic –  $\beta$  Pic Association; HIP 107345 – Tucana-Horologium Association; HIP 31878 – AB Dor Moving Group, Subgroup B4; AD Leo – Rotation-Age Relation; EV Lac – UMa Group; Proxima Cen –  $\alpha$  Cen System isochronal fits; IL Aqr – Rotation-Age; SZ UMa – Old Disk Space Motions (memberships from López-Santiago et al. (2006) & Montes et al. (2001)). Our program had an approved proposal for FUSE observations to begin filling in the large age gap for dM stars of  $\sim 1-6$  Gyr but, unfortunately, the FUSE satellite suffered its fatal malfunction before the observations could be carried out.

## PRELIMINARY RESULTS OF THE PROGRAM

The top two plots of Fig. 1 illustrate the declining transition region (O VI 1032Å) and chromospheric (C III 977Å) emissions of dM stars with age, as observed by the FUSE satellite. Plotted are the integrated fluxes of the respective emission lines, all adjusted to the distance of Proxima Cen. Stars with no C III emissions plotted did not have sufficient night-time data to permit a measurement of the line. Note how the strongest emissions are from the three Pre-Main Sequence (PMS) stars – CD-64 1208, AU Mic & HIP 107345. This is most likely *not* an indicator of absolute emission strength, but a result of the increased surface area of the PMS stars, which have not yet fully contracted on to the Main Sequence. The two plots are set to the same scales, so one can easily see the nearly identical behaviors of the chromosphere & transition region.

The lower plots of Fig. 1 show the light curves for 8 of the FUSE targets (EV Lac has not yet been observed by us and is too far north for ASAS-3 photometry, but has a previously determined photometric rotation period of 4.376-days – Contadakis (1995)). The three “slow rotators” in the FUSE database are of particular interest.

**Proxima Cen** is a member of the  $\alpha$  Cen system. The rather accurate age of the



**FIGURE 1. Top** – The FUV (O VI [left] and C III) [right] integrated emission line fluxes from FUSE observations are plotted, indicative of transition region and chromospheric activity, respectively. One can easily see the diminishing emissions of these two atmospheric layers as the stars age. **Bottom** – The rotation V-band light curves for 8 of the FUSE observed dM stars are shown, making use of either ASAS-3 survey photometry, or FCAPT pointed photometry that we continue to carry out. Photometrically determined rotation periods can be much more accurate than spectroscopically determined ones, especially for longer rotation periods. Pertinent information for the target star and lightcurve are given in each plot.

star ( $\sim 5.8$  Gyr) comes from extensive isochronal studies of its companion star,  $\alpha$  Cen A. Such an accurate and “old” age for a dM star is singular to Proxima Cen and, accordingly, it has always been a star of great importance in our studies of the relationship between rotation, activity and age.

**IL Aqr** is presently known to host three planets, two of which are “Super Earths.” We have observed IL Aqr with the Four College Automatic Photoelectric Telescope (FCAPT), at Fairborn Observatory, since 2004. Until recently, our best fitting rotation period was in close agreement with that of Rivera et al. (2005). This past year, however, a better-covered minimum was observed and our best fitting period was lengthened to its current value of  $\sim 116.46$ -days. This indicates an age even older than that of Proxima Cen for a star with three currently known planets, and is rather exciting.

We successfully proposed for a FUSE observation of **SZ UMa** because its *UVW* space motions (133, -8, 0 – Delfosse et al. 1998) imply Old Disk–Halo membership and an age of  $\sim 8$ –12 Gyr. Its rotation period of  $\sim 149.7$ -days (determined from FCAPT photometry) is one of the longest we have found to date for a dM star.

## DISCUSSION

The photometrically determined rotation periods of all 9 dM stars in the FUSE database have been presented. Eight of these rotation periods have been determined by us from recently obtained survey (ASAS-3) or pointed (FCAPT) photometry. The ages of the dM stars have also been given along with their integrated C III 977Å and O VI 1032Å emission line fluxes, as observed by the FUSE satellite. This has permitted a study of the decline in dM star chromospheric and transition region emissions as they age. The data will be of use in understanding the FUV environments of dM stars, their magnetic activity over time, and also the possible habitability of planets hosted by them.

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