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Can active late-type stars contribute to the Galactic lithium abundance?

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Abstract Lithium abundances in our Galaxy and especially ^{6}Li abundances provide important constraints on our understanding of Big Bang Nucleosynthesis (BBNS), stellar evolution and the creation of light elements by cosmic rays in the ISM. ^{6}Li has been detected in energetic solar events, one chromospherically active binary and several dwarf halo stars. Continuing our work on active late-type stars with high lithium abundances, we expand our study to consider if the flare origin of lithium created by spallation can contribute significantly to the Galactic abundance of lithium. We previously derived $\frac{^6\mathrm{Li}}{^7\mathrm{Li}} = 0.030 \pm 0.010$ for active K dwarf GJ 117 using VLT UVES observations. We find $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratios of 0.02 and 0.10 for two other stars in our sample, GJ 182 and EUVE J1145–55.3A, respectively. Considering that these later type, active stars have significant flare rates and stellar winds, we have estimated the contribution of these stars to the Galactic lithium abundance. Given that K and M stars comprise over 84% of our Galaxy and that many of these can have significant stellar winds, we conclude that spallation in stellar flares can contribute 1% and up to 5% of the Galactic lithium abundance.

Key words: stars: abundances — stars: activity — Galaxy: abundances

1 INTRODUCTION

Only four light isotopes, D, ^{3}He, ^{4}He and ^{7}Li, were produced in significant quantities in the standard Big Bang Nucleosynthesis (BBNS) models, and reconciling their abundances, especially for ^{7}Li, with many modern-day observations of stars and the interstellar medium (ISM) is fraught with difficulties (Fields et al. 1996). For example, ^{6}Li is only produced in very small quantities in the standard BBNS model, roughly $3 \times 10^{-14} - 6 \times 10^{-14}$ for ^{6}Li (Vangioni-Flam et al. 2000). This is far below the $\sim 1 \times 10^{-10}$ ^{6}Li Galactic estimate (Vangioni-Flam et al. 1999) and the observed ^{7}Li/H of $\sim 1.6 \times 10^{-10}$ (the so-called Spite plateau which is a direct function of O/Fe metallicity) is found to predominate among the metal-poor Pop II halo stars (Spite & Spite 1982; Fields & Olive 1999). Explaining ^{6}Li abundances identified for halo stars and in the ISM has been a challenge (e.g., Vangioni-Flam et al. 1999). The leading explanation for the creation of ^{6}Li is in Galactic Cosmic Ray Nucleosynthesis (GCRN) (Fields & Olive 1999; Vangioni-Flam et al. 2000). ^{6}Li is a fragile element and is consumed at stellar temperatures of $\sim 2 \times 10^6$ K with much of its destruction happening during the pre-main sequence phase. Thus, little ^{6}Li is expected as stars arrive on the zero-age main-sequence. However, this expectation is in contradiction to many observational results from the 1990s and 2000s. Earlier observational results first detected ^{6}Li on the halo dwarf HD 84937 (Smith et al. 1993). Follow-up studies have confirmed this detection and have also verified the presence of the isotope in BD+26° 3578 (Smith et al. 1998; Hobbs & Thorburn 1997). However, more recent results have noted significantly lower $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratios for HD 84937 (Lind et al. 2013) and BD+26° 3578 (García Pérez et al. 2009), and this has renewed interest in a possible plateau in the ^{6}Li abundance. Large Li abundances were also discovered in X-ray selected stars observed with *ROSAT* (Randich et al. 1997, 1998) and *Extreme Ultraviolet Explorer* (*EUVE*) (Mathioudakis et al. 1995). Additionally, an unexpected increase in ^{6}Li abundances has been observed during a long flare on a chromospherically active binary (Montes & Ramsey 1998), and in energetic solar flares (Murphy et al.

1990; Ramaty et al. 2000). These ^{6}Li detections have been attributed to spallation reactions.

Most of the Galactic lithium produced in the stellar flares of these stars comes by spallation of p, α and $\alpha - \alpha$ particles into CNONe atoms (Canal 1974; Canal et al. 1975; Livshits 1997). With the majority of stars in the Milky Way being of K or M spectral types, we consider if this can also contribute to the Galactic abundance of lithium and especially ^{6}Li. Evoli et al. (2008) argue a mechanism in addition to cosmic ray spallation in Galactic star formation is needed to explain current ^{6}Li abundances. Tatischeff & Thibaud (2007) contend that spallation reactions of ^{3}He in stellar flares can contribute to the production of ^{6}Li in metal-poor halo stars, and in Tatischeff & Thibaud (2008), these authors argue for lithium production in flare stars to explain abundances observed in open clusters. Alternately, Prantzos (2012) purport that the uncertainties in lithium production from stellar sources is too large to get a meaningful answer, but more recently, Prantzos et al. (2017) conclude the stellar production rate is unknown at present. However, we assert these studies do not include the possible contribution from active flare stars and recent studies better quantifying the frequency (Hilton 2011) and energetics (Pye et al. 2015) of the Galactic population of flare stars. We claim spallation may explain the lithium abundances in several active stars (Christian et al. 2005), and this lithium must populate the ISM to influence the Galactic abundance. Stellar winds may expel lithium to the local stellar environment from active late-type K and M stars. Recent results have revealed a stellar mass loss for K and M stars from $10^{-14}\,M_\odot\,\mathrm{yr}^{-1}$ to $\geq 10^{-10}\,M_\odot\,\mathrm{yr}^{-1}$ (Airapetian et al. 2010).

The main goals of this study are to investigate if the creation of ^{6}Li and ^{7}Li in stellar flares can contribute significantly to the abundance of lithium in our Galaxy. In Section 2 we will review the number of lithium atoms that can be produced in stellar flares by spallation. In Section 3 we present our previous work on searching for ^{6}Li in several active K and M stars. In Section 4 we estimate the number of K and M stars using the initial mass function (IMF) and estimates from the literature. In Section 5 we will review the stellar mass-loss process in K and M stars. Section 6 showcases our derived abundances of ^{7}Li/H and ^{6}Li/H by utilizing the results of lithium creation and the expected mass losses found, and utilizes newer estimates for the frequency and energetics of flare stars in our Galaxy. We also compare our findings to previous works. Finally, in Section 7 we summarize our results and discuss future work.

2 EXPECTED LITHIUM PRODUCED BY SPALLATION

We revisited previous work on the estimates of the number of lithium atoms produced during stellar flares (Canal 1974; Canal et al. 1975, 1980; Livshits 1997). These researchers calculated the amount of mean energy lost ($\eta_{\rm Li}$) during spallation which inversely translates into the amount of energy needed to create one lithium atom

$$\eta_{\rm Li} = \int_E^\infty \varepsilon(E)\Phi(E)dE/F_{\rm Li}\,, \quad \text{(energy needed for one lithium atom)} \tag{1}$$

where $\varepsilon(E)$ is the stopping power found by $\varepsilon(E) = A/E$, in which $A = 2Z^2 \times 10^{-21}\,\mathrm{MeV^2\,atom^{-1}\,cm^2}$ and $E = 1\,\mathrm{MeV\,nucleon^{-1}}$, the cutoff energy implemented for this analysis (Canal et al. 1975, 1980), and Z is the atomic number of the incoming particles ($Z = 1$ for protons and $Z = 2$ for helium). $\Phi(E)$ is the spectrum of kinetic energy per nucleon ($\approx E^{-\gamma}$) for $\gamma = 2$, 3, 3.4, 4.8 and 6. $F_{\rm Li}$ is the formation probability of generating one lithium atom.

We apply these estimates for lithium creation, and the fact that flares on late-type dwarfs are $10^4 - 10^5$ times more energetic than their solar counterparts.

3 LITHIUM IN K STAR GJ 117, M STAR GJ 182 AND K STAR EUVE J1145–55.3A

Measurements of ^{6}Li in stellar spectra are very difficult and rely on modeling of the increased width and red asymmetry of the 6707.8 Å doublet. Measuring ^{6}Li becomes particularly difficult in active late-type stars where large rotational velocities will smear the line profiles. The problem is further complicated by the occurrence of blends from Ti I and CN bands (e.g., Reddy et al. 2002). These problems aside, we were able to select a sample of active stars with rotational velocities less than $\sim$6 km s^{-1}. The observations occurred in December 2002 with the Very Large Telescope (VLT) Kueyen Telescope and UV-Visual Echelle Spectrograph (UVES). The observational set-up and analysis of these spectra with the PHOENIX models have been reviewed in Christian et al. (2005, 2008). Briefly, we calculated theoretical spectra employing the general stellar atmosphere code PHOENIX (Hauschildt et al. 1995; Allard & Hauschildt 1995) and utilizing the local thermodynamic equilibrium (LTE) atmosphere models from the NextGen series of Hauschildt et al. (1999) with the effective temperature and gravity for each star in our sample. The ^{6}Li resonance doublet was included in PHOENIX by adding the wavelengths and gf values from Smith et al. (1993) into the master line list (Kurucz

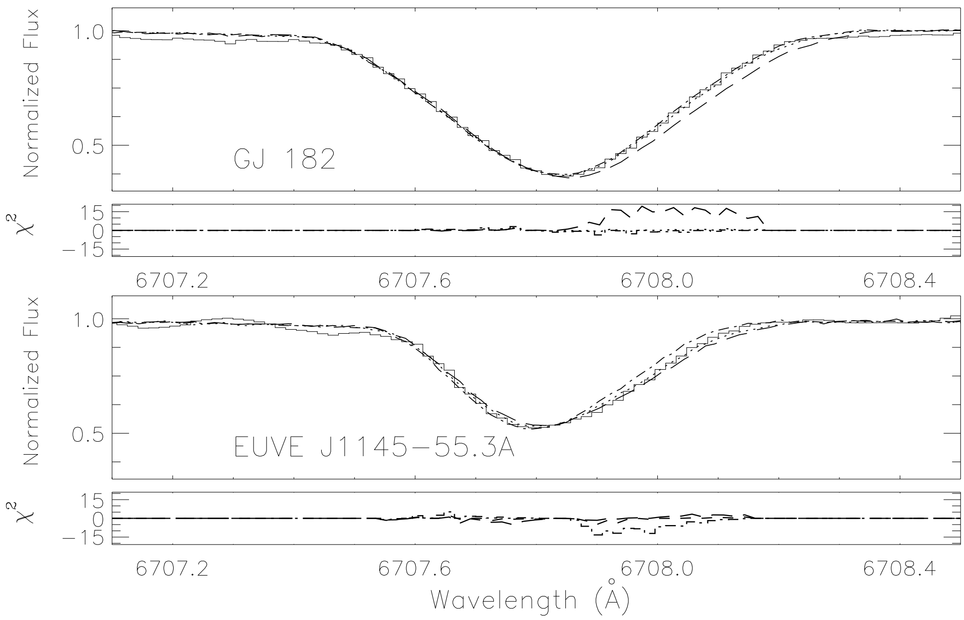

Fig. 1 VLT UVES spectra of GJ 182 and EUVE J1145–55.3A for the Li I 6707.8 region plotted as *solid histograms*. For each panel, overplotted are the PHOENIX models for different values of $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratios. For GJ 182 (*upper panel*), the $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratios featured are 0.0 (*dash-dotted line*), 0.02 (*dotted line*) and 0.10 (*long-dashed line*). For EUVE J1145–55.3A (*lower panel*), the $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratios displayed are 0.0 (*dash-dotted line*), 0.10 (*dotted line*) and 0.15 (*long-dashed line*). The narrow panel below each spectrum depicts the residuals from the difference of the data minus the models.

1995) and models were created for the fraction of $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ranging from 0.0 to 0.2 in increments of 0.01. We plot sample VLT spectra fitted with PHOENIX models for GJ 182 and EUVE J1145–55.3A in Figure 1, with different values of $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ isotope ratio. We then compared the observed VLT spectra and PHOENIX model profiles using χ^2 statistics with a grid of models in steps of $\frac{^6\mathrm{Li}}{^7\mathrm{Li}} = 0.01$. From this comparison, the most probable model with $\chi^2 \sim 1$ was determined. Figure 2 displays the $\Delta\chi^2$ computed for the model grid and plotted with the sign preserved. Our VLT study found ^{6}Li was in the range of 2 to 10% for our sample of *EUVE*-selected active stars.

Our range is consistent with the estimates of Ramaty et al. (2000) for energetic solar flares. Employing convective zone masses from Pinsonneault et al. (2001), we can estimate the number of hydrogen atoms and subsequently the number of ^{6}Li and ^{7}Li atoms for each star. The derived ^{6}Li for each star uses the stars' lithium abundance A(Li) and our measured $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratio. These results indicate a range of 10^{45} to 10^{46} ^{7}Li atoms in each star and $\approx 2 \times 10^{43}$ to 5×10^{44} ^{6}Li atoms. These numbers are presented in Table 1. The last column of Table 1 (Col. (7)) lists the number of ^{6}Li and ^{7}Li atoms produced from the spallation reactions reviewed in Section 2. The exact numbers are not critical but indicate that spallation in stellar flares can produce a significant amount of ^{7}Li and ^{6}Li in active stars and with these lower mass stars as the dominant population in the Galaxy, it is worth investigating if these can contribute to the Galactic lithium abundance and its effect on our understanding of the present-day lithium abundances. In the next section, we calculate the number of these low mass stars in the Galaxy and the strength of their stellar winds that may contribute to the lithium abundance in our Galaxy.

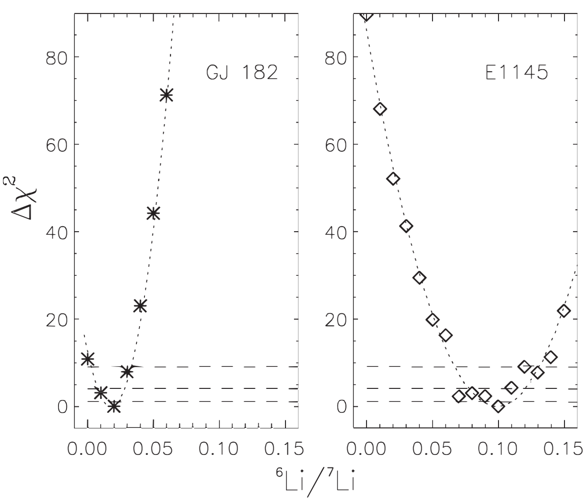

Fig. 2 $\Delta\chi^2$ as a function of the $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratio for Li I model line profiles for GJ 182 (*left panel*) and EUVE J1145–55.3A (*right panel*).

Table 1 Observed and Estimated Lithium Atoms for our Sample Stars

Object Name (1)	A(Li)⋆ (2)	$\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ (3)	CVZ H Atoms (derived) (4)	CVZ ^{7}Li atoms (derived) (5)	CVZ ^{6}Li atoms (derived) (6)	Calculated ^{6}Li Calculated ^{7}Li (7)
GJ 117	2.45	0.03	5.75×10^{55}	1.6×10^{46} Gyr^{-1} 5.0×10^{29} s^{-1}	4.9×10^{44} Gyr^{-1} 1.56×10^{28} s^{-1}	3.27×10^{44} Gyr^{-1} 1.1×10^{46} Gyr^{-1} γ=3–3.4
GJ 182	1.30	0.02	5.98×10^{55}	1.19×10^{45} Gyr^{-1} 3.78×10^{28} s^{-1}	2.38×10^{43} Gyr^{-1} 7.6×10^{26} s^{-1}	4.72×10^{43} Gyr^{-1} 2.4×10^{45} Gyr^{-1} γ=4
EUVE J1145–55.3A	1.60	0.10	5.09×10^{55}	2.02×10^{45} Gyr^{-1} 6.41×10^{28} s^{-1}	1.02×10^{44} Gyr^{-1} 6.41×10^{27} s^{-1}	2.35×10^{44} Gyr^{-1} 2.35×10^{45} Gyr^{-1} γ=3.4

Column (1): Star name; Col.(2): A(Li), measured lithium abundance (Christian & Mathioudakis 2002; Christian et al. 2005);
Col.(3): $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratio from this work; Col.(4): Number of H atoms in the convective zone derived from spectral type (Pinsonneault et al. 2001);
Col.(5): Number of ^{7}Li atoms in the convective zone derived from the observed lithium abundance for each star, A(Li);
Col.(6): Number of ^{6}Li atoms in the convective zone derived from the observed lithium abundance for each star, A(Li) and the $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratio;
Col.(7): Estimate of the number of lithium atoms produced by spallation (Canal 1974; Canal et al. 1975, 1980). ⋆: A(Li)= log(n[Li]) + 12.

4 THE INITIAL MASS FUNCTION AND NUMBER OF LATE-TYPE STARS

The IMF is a functional relationship of the star formation rate to its mass (Salpeter 1955). Observational evidence indicates that more low-mass stars form in interstellar cloud fragments than high-mass stars. We can estimate the number of K and M stars in the Milky Way using the IMF function. We employ the newer IMF from the work of Kroupa (Kroupa et al. 1993; Kroupa 2001; Kroupa & Jerabkova 2019). Here the IMF power law, $\xi(m) \approx m^{-\alpha}$ has a break with $\alpha = 1.3$ for masses below $0.5\,M_\odot$ and $\alpha = 2.3$ for $0.5\,M_\odot < m < m_{\max}$. We use this number of K and M stars to determine the total amount of Galactic lithium. The FGKM stars are active because of their mid-level rotation rates, medium age and hospitable temperatures. We focus on the K and M stars because they are more active, have higher flaring rates and tend to exhibit more stellar mass loss than the F/G stars. The IMF demonstrates that there are fewer F/G stars in the Milky Way ISM. We estimate the fraction of K and M stars by integrating the IMF power law over the lower and upper mass ranges and normalizing this to the entire mass range. The IMF for the K stars is

$$\frac{\int_{0.5}^{0.79} m^{-2.3}dm}{\int_{0.08}^{0.5} m^{-1.3}dm + \int_{0.5}^{120} m^{-2.3}dm} \tag{2}$$

with all numbers representing the same parameters as aforementioned. The solution indicates that 17% of the approximately 400 billion stars are K stars and the IMF for the M stars yields

$$\frac{\int_{0.08}^{0.5} m^{-1.3}dm}{\int_{0.08}^{0.5} m^{-1.3}dm + \int_{0.5}^{120} m^{-2.3}dm}. \tag{3}$$

Equation (3) finds that about 61% of Milky Way stars are M stars. Taking all the results together for the active late-type K and M stars results in 78% (0.78) of 400 billion equals roughly 3.1×10^{11} K and M stars in the Milky Way. Other estimates conclude that about 12% of stars in the solar neighborhood are K stars, and over 80% are M stars (Ledrew 2001; Heller & Pudritz 2016). Thus, we have a range for the fraction of K and M stars from 0.78 to 0.90. We adopt an average value of 0.84 to estimate the amount of lithium in the Galaxy. In the next section, we will estimate the stellar mass loss for the K and M stars that can contribute to Galactic abundances, and subsequently estimate the total Galactic ^{6}Li and ^{7}Li.

5 STELLAR MASS LOSS

As K and M dwarfs spin down from the main-sequence before entering the red-giant phase, a significant amount of angular momentum and stellar mass-loss results and ranges from about $10^{-15}\,M_\odot$ yr^{-1} – $10^{-10}\,M_\odot$ yr^{-1} (Vidotto et al. 2011, 2014). Work done by Airapetian et al. (2010) on K and M giants points to stellar winds as large as $10^{-11}\,M_\odot$ yr^{-1}. Earlier observational studies found mass loss rates as large as a few times $10^{-10}\,M_\odot$ yr^{-1} (Mullan et al. 1992). More recent theoretical studies center on magnetohydrodynamic (MHD) winds as sources of mass loss with CNONe and H injection to the local stellar environment (Airapetian et al. 2010), even though the exact mechanism remains elusive (Vidotto et al. 2014; Airapetian et al.

2010). Chromospheric shock modeling from photospheric sound wave activity (Airapetian et al. 2010) and other wind acceleration models attempt to solve this problem and arrive at a more accurate mass loss rate for K and M dwarfs (Wang & Sheeley 1990; Arge & Pizzo 2000; Cohen et al. 2007; Evans et al. 2012). From the above mass loss rate, we adopt $10^{-11}\,M_\odot\,\mathrm{yr}^{-1}$ for a typical K or M star. Utilizing this, we see that the amount of K and M stellar mass ejects $\approx 10^{-11}\,M_\odot\,\mathrm{yr}^{-1}$ or $2\times10^{22}\,\mathrm{g\,yr}^{-1}$. The next section will calculate the amount of ^{7}Li/H and ^{6}Li/H possibly ejected into the ISM.

6 TOTAL GALACTIC LITHIUM AND ^{7}LI AND ^{6}LI ABUNDANCES

We now estimate the amount of lithium contributed to the Milky Way by K and M stars through spallation. First we will estimate the number of active flare-stars with energetic enough flares to create lithium. We start with the number of stars in the Milky Way, reduced by the fraction of K and M stars, the amount of lithium these stars produce by spallation and the fraction they contribute via stellar winds. We have used the average of 84% K and M stars based on our estimate of the fraction of K and M stars from the IMF in Section 4 and estimates in the literature. We also include the fraction of time our late-type stars are flaring with flare energies greater than $10^{30}\,\mathrm{erg\,s^{-1}}$ ($\mathrm{f_{flare}}$), which we take from the work of Hilton (2011) for M stars, and conservatively use 30%. We are also encouraged that active K and M stars have high enough flare energies to produce lithium via spallation and Davenport (2016) ascertained an average flare energy of 10^{35} erg for a large sample of flare stars observed with *Kepler*, and Pye et al. (2015) derived an average flare luminosity of $\approx 5\times10^{29}\,\mathrm{erg\,s^{-1}}$ and energy outputs of 10^{32} to 10^{35} erg from an X-ray sample within 1 kpc of the Sun. We also further decrease our lithium estimate and require protons with kinetic energies above 10 MeV. Thus, we apply the ratio of the power contained in accelerated protons of kinetic energy above 10 MeV to the flare X-ray luminosity of ≈ 0.09 derived for the solar cycle (Lee et al. 1998). Thus, for the first part of the calculation, we find (using the higher estimate of 400 billion stars in the Milky Way), the number of active (lithium producing) K and M stars is

$$\begin{aligned} N[\text{flare stars}] &= \text{Number MW}_{\text{stars}} * \text{fraction KM}_{\text{stars}} * f_{\text{flare}} * f_{\text{proton}(>10\text{MeV})} \\ &= 400\times10^9\text{MW}_{\text{stars}} * 0.84\,\text{KM}_{\text{stars}} * 0.3 * 0.09 \\ &= 9.1\times10^9\text{stars}\,. \end{aligned} \tag{4}$$

Considering this stellar population, we now reduce the number of lithium atoms contributed to the ISM using an average mass loss rate from stellar winds and the lithium abundance determined in Section 3, and we estimate the contribution of K and M stars to the Galactic lithium abundance.

$$\begin{aligned} \text{Number[Li]} &= n[\text{Li}] * \text{Stellar\_Wind\_Loss} * N[\text{flare stars}] \\ &= 2.1\times10^{-10} * 4.0\times10^{38}H\,\mathrm{s}^{-1} * N[\text{flare stars}] \\ &\approx 8.4\times10^{28}\text{Li}\,\mathrm{s}^{-1} * 9.1\times10^9\text{stars} \\ &\approx 7.6\times10^{38}\text{Li}\,\mathrm{s}^{-1}\,, \end{aligned} \tag{5}$$

where we have converted the stellar mass loss rate of $10^{-11}\,M_\odot\,\mathrm{yr}^{-1}$ to $4.0\times10^{38}\,\mathrm{H\,s^{-1}}$, and we used an average lithium abundance (n[Li] $= 2.1\times10^{-10}$; A(Li) ≈2.3) from the original sample of extreme ultraviolet-selected active stars (Christian & Mathioudakis 2002) for those stars with measured lithium abundances. This A(Li) value is similar to, but slightly lower than, that measured for an active late-type star (A(Li) $= 2.5$; Mathioudakis et al. 1995) and similar to the average value of A(Li) ≈2 in Honda et al. (2015) for stars with superflares; two of this sample had A(Li) over 3.

For comparison, the Spite plateau for higher temperature stars than our sample has A(Li) ≈2.2 (Spite & Spite 1982), and models for the Galaxy's thin disk with A(Li) $\gtrapprox$ 2.5 (Prantzos et al. 2017). Thus, we find $\sim 7.6\times10^{38}$ lithium atoms per second are created (Eq. (5)), and this will contribute $\approx 2.4\times10^{56}$ lithium atoms in 10 Gyr. If we conservatively estimate the mass in the ISM in the Milky Way as $10^{10}\,M_\odot$, or $\approx\ 10^{67}$ H atoms, this results in a lithium abundance of 2.4×10^{-11} for the flare production in 10 Gyr. Kroupa et al. (1993) report an average ^{7}Li/H abundance in the local ISM of $\sim 2\times10^{-9}$ (Knauth et al. 2003; see their table 11). Our estimate for the lithium abundance (Li/H $\sim 2.4\times10^{-11}$ is 1.2% of this value. Alternately, if we consider active K and M stars contribute up to ≈10^{46} ^{7}Li Gyr^{-1} (from the average predicted lithium for spallation reactions expressed in the last column in Table 1) to their star, then this gives a fraction of ^{7}Li atoms of $\approx 10^{-10}$ for a typical stellar wind of $\approx 10^{56}$ H atoms Gyr^{-1}. This value is 5% of the measured ^{7}Li/H local ISM abundance and is within a factor of two of our above calculation, including the true activity levels of K and M stars.

Additionally, Ramaty et al. (2000) state that cosmic rays produce a maximum lithium abundance of 1.8×10^{-10} and our value from Equation (5) is similar to this value. This supports that flare stars can contribute to the overall lithium abundance in the Galaxy. The current paper builds on previous studies of lithium creation in stellar flares (e.g., Tatischeff & Thibaud 2008) and benefits from newer studies that provide better estimates for the number of flare stars in the Galaxy (Hilton 2011) and the distribution of flare energies (Davenport 2016) and luminosities (Pye et al. 2015). We also require flares with particle kinetic energies over 10 MeV and attempt to include a reasonable estimate for lithium expelled into the ISM in stellar winds. We admit that summing the lithium production of our sample of active stars over 10 Gyr does not take into account any age related effects. However by decreasing our sample by the fraction found for very active stars (i.e., Hilton 2011), we expect this will account for the older, less active stars. Although there are several assumptions in our estimate and it ignores the previously mentioned age-related effects, and there are uncertainties in the Li production rate in stellar flares (possibly from steeper power-laws in the kinetic energy of the input spectrum, making Li production much less efficient), we find that creation of lithium via spallation in active K and M stars with moderate stellar winds can contribute ≈1% to 5% of the lithium abundance observed in the ISM.

7 CONCLUSIONS

Based on our previous studies of active K and M stars with significant lithium abundances, we determined a $\frac{^6\mathrm{Li}}{^7\mathrm{Li}}$ ratio of 2 to 10% for stars in our sample. We interpreted this excess lithium, and especially the ^{6}Li, as being created by spallation during stellar flares. Based on these numbers, we have conservatively estimated 1% and up to 5% of the lithium in the ISM could be contributed by flare activity in K and M stars, and our values are similar to the lithium created by cosmic rays. This follows from K and M stars comprising over 84% of the Galaxy's stellar population and typical stellar mass loss rates of $10^{-11}\ M_\odot$ yr^{-1}. With the advent of larger telescopes and higher precision optical spectroscopy, additional fainter stars can be observed to search for enhanced lithium abundances, especially the detection of ^{6}Li in moderately active late-type stars. Such studies will further constrain our ^{6}Li/H and ^{7}Li/H estimates and provide important constraints on our understanding of light element abundances in the Galaxy and BBNS.

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