Mem. S.A.It. Suppl. Vol. 22, 92

Memorie della
Supplementi

The discovery of 14 lithium-rich red giants in Milky Way dwarf satellite galaxies

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Abstract. Lithium is efficiently destroyed via the ^{7}Li(p, α)^{4}He reaction when the temperature reaches $T > 2.5 \times 10^6$ K . The standard model of stellar evolution predicts that with convective envelopes reach such high temperatures, the evolved red giants more luminous than the luminosity bump function should have the lithium abundance below $A(Li) = 1.5$. Nonetheless, Li-rich red giants do exist. We present 15 Li-rich red giants—14 of which are new discoveries—in Milky Way dwarf satellite galaxies, including the most-metal poor, Li-enhanced star known to date([Fe/H] $= -2.82$, $A(\mathrm{Li})_{\mathrm{LTE}} = 3.64$). Because nine of the stars have Lithium abundance larger than the universe's primordial value, the lithium must be created in the stars themselves rather than save from the destruction. The high li abundances show no clear correlation with the metallicity, surface gravity, effective temperature, evolutionary stage, or any other measurable parameters.

Key words. stars: abundances — galaxies: dwarf — Local Group

1. Introduction

Lithium, in the form of ^{7}Li, was the third most abundant element in the universe. This fragile element is destroyed efficiently when the temperature reaches 2.5×10^6 K . So lithium is an important probe to understand the stellar structure and the physical mechanism inside the star. Because the destruction rates exceeded creation rates as the star evolving, today Li is among the least abundant of the elements lighter than Zn.

The large samples of metal-poor stars in the Milky Way halo (Spite & Spite 1982; Gratton et al. 2000) and metal-poor globular cluster (Lind et al. 2009b; Mucciarelli et al. 2011) show that there is a "Spite Plateau" exist: the Li abundance remain at the value A(Li)=2.3[1] until the first dredge-up on the subgiant brunch. Then the Li abundance decreases as the surface temperature falls down. For the red giants more luminous than the luminosity bump function, the convective envelops are

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[1] $A(\mathrm{Li}) = 12 + \log[n(\mathrm{Li})/n(\mathrm{H})]$ where n is the number density of atoms.

deep enough to bring the materials from the deeper, hotter layers to the stellar surface, causing the overall Li depletion. The Li abundance in this phase should be below $A(Li) = 1.5$, any giants with the abundance lager than it are considered as "Li-rich". The researches on the Milky Way field stars show that this phenomenon seems to happen about 1% of the metal-poor giants (Ruchti et al. 2011; Brown et al. 1989; Monaco et al. 2011).

With the high space density for multi-object spectrographs observation and the member stars' uniform distance which eases the determination of evolutionary state and Li abundance, dwarf spheroidal galaxies (dSphs) are excellent places to search for Li-rich giants. We present here the discovery of 14 Li-rich red giants in five dSph galaxies. Before our work, only three Li-rich giants are known in the Local Group dSphs (Domínguez et al. 2004; Monaco & Bonifacio 2008) (we confirm the D461 in Draco in our samples).

2. Lithium measurement

Kirby et al. (2010) obtained spectra of 2961 red giants in eight dSphs with the DEIMOS medium-resolution, multi-object spectrograph (Faber et al. 2003) on the Keck II telescope (R=6500). The distance of the samples are from 85 ∽ 220 kpc. The sample is random because the stars were not chosen for any property that could predict Li enhancement. Of these data 2054 spectra cover the Li I resonance line region at 6708 Å with signal-to-noise ratios SNR > 10 pixel^{-1}. The SNR here is quantified in the vicinity of the Li line by computing the inverse standard deviation of continuum-normalized pixels in 6703.9Å--6705.9Å and 6709.9Å-6711.9ÅẆe found 15 spectra with strong Li resonance lines, one of the star, D461 in the Draco dSph, is a already and the first known Li-rich giant in MW dwarf galaxies discovered in 2004 (Domínguez et al. 2004). The other 14 stars belong to five dwarf galaxies: Sculptor, Fornax, Leo I, Leo II, and Canes Venatici I. We use Na doublet around 8190 Å to confirm again that these stars are not the dwarfs nearby but the dSphs members.

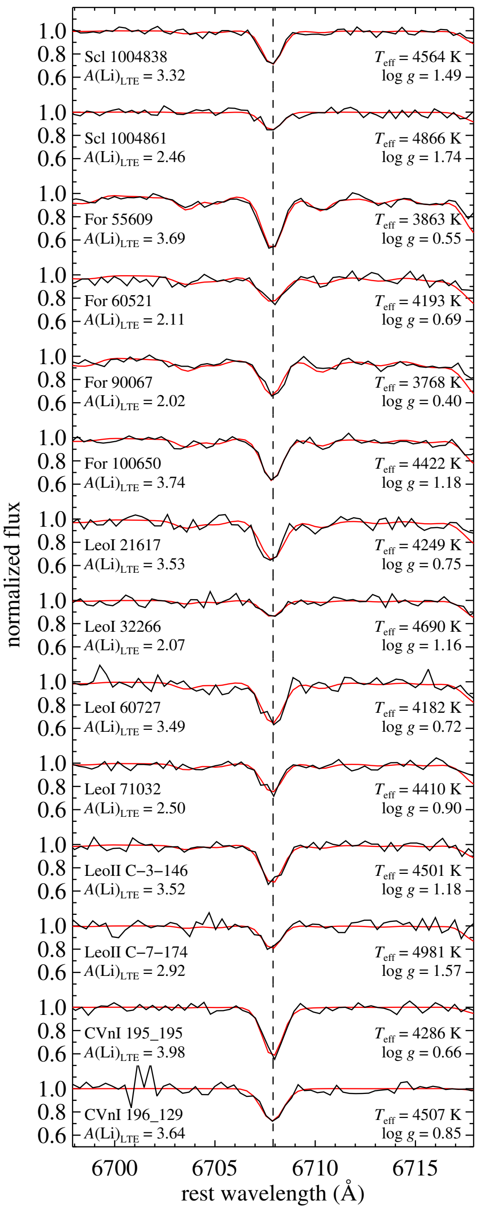

Fig. 1. A small region of DEIMOS spectra centered on the Li I 6708 multiplet (dashed vertical line) for each of the 14 dSph giants with detectable Li. The observed spectra (black) have been normalized to have unit continuum, which is shown as the dotted line. The red curves show the best-fitting synthetic spectra.

Table 1. Stellar Parameter and Lithium Abundances

Star Name	$T_{\rm eff}$ (K)	log g (cm s^{-2})	[Fe/H]	EW(Li I λ6708)	$A(Li)$	$\sigma_{\rm noise}$
Scl 1004838	4564	1.49	-1.59 ± 0.11	363 ± 19	3.32	0.12
Scl 1004861	4866	1.74	-1.70 ± 0.12	193 ± 28	2.46	0.15
For 55609	3863	0.55	-0.73 ± 0.11	694 ± 24	3.69	0.10
For 60521	4193	0.69	-0.86 ± 0.11	382 ± 34	2.11	0.13
For 90067	3768	0.40	-0.68 ± 0.11	503 ± 23	2.02	0.30
For 100650	4422	1.18	-0.95 ± 0.11	492 ± 27	3.74	0.14
LeoI 21617	4249	0.75	-1.10 ± 0.11	546 ± 52	3.53	0.37
LeoI 32266	4690	1.16	-1.35 ± 0.12	175 ± 31	2.07	0.13
LeoI 60727	4182	0.72	-1.42 ± 0.12	514 ± 49	3.49	0.39
LeoI 71032	4410	0.90	-1.29 ± 0.11	322 ± 28	2.50	0.15
LeoII C-3-146	4501	1.18	-1.40 ± 0.11	449 ± 31	3.52	0.16
LeoII C-7-174	4981	1.57	-1.24 ± 0.12	225 ± 42	2.92	0.15
CVnI 195_195	4286	0.66	-2.61 ± 0.12	527 ± 18	3.98	0.20
CVnI 196_129	4507	0.85	-2.82 ± 0.13	380 ± 35	3.64	0.23

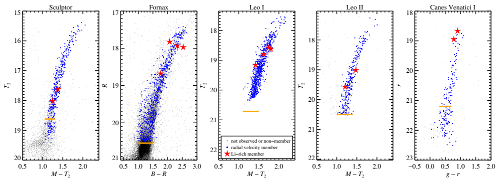

Fig. 2. Color-magnitude diagrams for the dwarf galaxies in which Li-rich giants were detected. Blue points indicate radial velocity members. Red, five-pointed stars indicate the Li-rich stars, which are also radial velocity members. The orange horizontal lines indicate the approximate position of the RGB bump. This magnitude was calculated with Ferraro et al.'s (1999) formula assuming the average age (Orban et al. 2008) and metallicity (Kirby et al. 2011) of the galaxy. The colors and magnitudes of the Li-rich stars indicate that they are low-mass giants more luminous than the RGB bump.

Figure 1 shows the Li-rich stars' spectra around the Li line, and Table 1 gives the previously measured (Kirby et al. 2010) temperatures, surface gravities, and metallicities for these stars. In order to illustrate the Li resonance lines are strong and easily detected, we measured the equivalent widths (EWs) by fitting Gaussians. The EWs of the detected Li lines range from 175 to 694 mÅ. Table 1 gives the EWs. The color-magnitude diagrams are shown in Figure 2, the Li-rich stars are marked with red, five-pointed stars.

We used spectral synthesis to quantify the Li abundances with MOOG code and ATLAS9 model atmospheres (Kurucz 1993; Kirby 2011) in local thermodynamic equilibrium (LTE). The Li abundances are listed in Table 1, ranging from 2.02 to 3.98. One of them, 196_129 in CVnI, is the most-metal poor Li-rich giant known to date. Table 1 also reports the random error $\sigma_{\rm noise}$ on A(Li) from spectral noise.

3. Discussion

The universe's primordial value of Li is A(Li) = 2.72 (Coc et al. 2012). Nine of the stars in our sample have larger Li abundances. Therefor the Li in these stars must have been created since the Big Bang.

Hot bottom burning (HBB) is effective at producing ^{7}Li in asymptotic giant branch (AGB) stars with masses of about 4–7 $M_\odot$ (Iben 1975; Sackmann & Boothroyd 1992). The convective envelopes of these stars reach layers where ^{7}Be is created by the reaction ^{3}He$(\alpha,\gamma)^7$Be, then by Cameron-Fowler (1971) mechanism, Be was brought to the stellar surface and captured an electron via ^{7}Be$(e^-,\nu)^7$Li to produce Li. The colors and magnitudes of

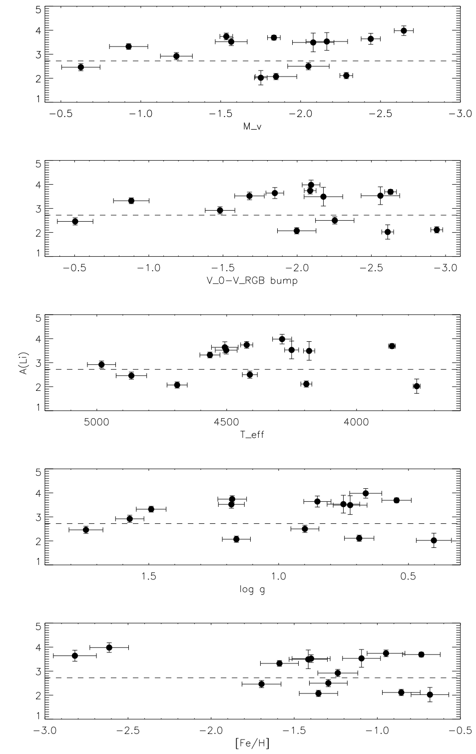

Fig. 3. The correlation between Li abundances A(Li) and absolute V magnitude, $V_0 V_{RGB\ bump}$, effective temperature, surface gravity and metallicity.

the RGB and AGB branches are hardly different for the old populations typical of dSphs, but our samples belong to the dwarf galaxies that are too old to host the 4–7 $M_\odot$ AGB stars. Therefor, HBB doesn't work for them.

These low-mass giants do not have the convective envelops deep enough to reach layers with ^{7}Be. If the Cameron-Fowler mechanism is operating in these stars, it requires "extra mixing" or "cool bottom processing (CBP)" (Boothroyd et al. 1995; Sackmann & Boothroyd 1999) to connect the base of the convective envelope to deeper regions of the star that contain Be. The CBP predicts that the giants at the RGB bump will be more Li-rich than the TIP-RGB stars, but our samples show no clear correlations between Li abundance and evolutionary state (see Figure 3, V_0- $- V_{RGB\ bump}$ represents the evolutionary state of the star). Ruchti et al. (2011) made the same conclusion for the Milky Way field stars. Figure 3 also shows the correlations between Li abundance and other stellar parameters: M_v, $T_{\rm eff}$, *log g* and [Fe/H]. The existence of Li-rich red giants and their abundances do not correlate with any measurable parameter. In addition to positions in the CMD, our stars' temperatures, surface gravities, iron abundances, and [α/Fe] abundance ratios are not unusual in any regard with respect to Li-normal stars in the same dwarf galaxies.

The typicality of metal-poor, Li-rich stars in all regards except Li abundance suggests that these stars haven't engulfed a planet or brown dwarf. They are unlikely to have an AGB companion to get the lithium via mass transfer neither, because the 4–7 $M_\odot$ AGB stars that can produce Li via HBB are not longer exist in the old dSphs. In fact, we could find no model in the literature that adequately explains the available observations for Li-rich, low-mass, metal-poor giants (Li enhancements as high as $A(\text{Li}) = 3.9$ even near the tip of the RGB, no concentration in the CMD, weak correlation with rotation).

Like other metal-poor, Li-rich giants (Ruchti et al. 2011), all of the strong Li detection stars in our sample are more luminous than the RGB bump (see Figure 2). Of the stars we searched, 1764 out of 2054 (86%) are above the RGB bump. The fraction of li-rich stars is 15 of 1764 (0.85%), which is consistent with previous works in the Milky Way (Ruchti et al. 2011; Brown et al. 1989; Monaco et al. 2011). However, the detectability of Li depends on the stellar temperature and Li abundance. Our spectra with lower SNRs could possibly harbor anomalously large Li lines, but we would possibly miss them in our visual search. Future work (X. Fu et al., in preparation) will make a more quantitative determination of the Li-rich fraction of red giants in our sample.

Acknowledgements. Support for this work was provided by NASA through Hubble Fellowship grant 51256.01 awarded to E.N.K. by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., for NASA, under contract NAS 5-26555. X.T.F. and P.G. acknowledge support by

NSF grant AST 09-37525. X.T.F. and L.D. thank NSFC for support by grants Nos. 10973015 and 11061120454. PG acknowledges NSF grant AST-1010039. The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.

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