Young \([\alpha/Fe]\)-enhanced stars discovered by CoRoT and APOGEE: What is their origin?

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Received March 25, 2015; accepted ...

ABSTRACT

We report the discovery of a group of apparently young CoRoT red-giant stars exhibiting enhanced \([\alpha/Fe]\) abundance ratios (as determined from APOGEE spectra) with respect to solar values. Their existence is not explained by standard chemical evolution models of the Milky Way, and shows that the chemical-enrichment history of the Galactic disc is more complex. We find similar stars in previously published samples for which isochrone-ages could be reliably obtained, although in smaller relative numbers. This might explain why these stars have not previously received attention. The young \([\alpha/Fe]\)-rich stars are much more numerous in the CoRoT-APOGEE (CoRoGEE) inner-field sample than in any other high-resolution sample available at present because only CoRoGEE can explore the inner-disc regions and provide ages for its field stars. The kinematic properties of the young \([\alpha/Fe]\)-rich stars are not clearly thick-disc like, despite their rather large distances from the Galactic mid-plane. Our tentative interpretation of these and previous intriguing observations in the Milky Way is that these stars were formed close to the end of the Galactic bar, near corotation – a region where gas can be kept inert for longer times than in other regions that are more frequently shocked by the passage of spiral arms. Moreover, this is where the mass return from older inner-disc stellar generations is expected to be highest (according to an inside-out disc-formation scenario), which additionally dilutes the in-situ gas. Other possibilities to explain these observations (e.g., a recent gas-accretion event) are also discussed.

Key words. Galaxy: abundances, disc, formation, stellar content – Stars: fundamental parameters – asteroseismology

1. Introduction

One of the pillars of Galactic Archaeology is the use of stellar \([\alpha/Fe]\) abundance ratios as an indirect age estimator: \([\alpha/Fe]\)-enhancement is an indication that a star has formed from gas enriched by core-collapse supernovae; longer-timescale polluters, such as supernovae of type Ia or asymptotic giant-branch stars, did not have sufficient time to enrich the interstellar medium (Pagel 2009; Matteucci 2001). High-resolution spectroscopy of the solar neighbourhood stars, for which Hipparcos parallaxes are available (e.g., Haywood et al. 2013), have indeed shown this paradigm to work well. One of the best examples is the very local (\(d < 25 \text{ pc}\)) volume-complete sample of solar-like stars by Fuhrmann (2011 and references therein), for which it was possible to obtain robust isochrone ages for a small number of subgiants, which confirmed that stars exhibiting \([\alpha/Fe]\)-enhancements were all older than \(\sim10 \text{ Gyr}\) and identified them as thick-disc stars. Fuhrmann’s data also show a clear chemical discontinuity in the \([\alpha/Fe]\) vs. [Fe/H] plane, which can be interpreted as the result of a star-formation gap between the thick and thin discs (Chiappini, Matteucci, & Gratton 1997; Fuhrmann 2011).

However, as we demonstrate in this Letter, \(\alpha\)-enhancement is no guarantee that a star is actually old. Only recently has it become possible to obtain more precise ages for field stars far beyond the solar circle, thanks to asteroseismology, with CoRoT (Baglin et al. 2006) and Kepler (Gilliland et al. 2010). Even more important, the CoRoT mission allows for age and distance determination of stars spanning a wide range of Galacticentric distances, as shown by Miglio et al. (2013a,b). The latter authors have shown that when asteroseismic scaling relations are combined with photometric information, mass and age can be obtained with a precision of about 10\% and 30\%, respectively, even for distant objects\(^1\). High-resolution spectroscopy of the seismic targets plays a key role, not only allowing for more precise ages and distances, but also providing full chemical and kinematical information.

We have initiated a collaboration between CoRoT and APOGEE (the Apache Point Observatory Galactic Evolution Experiment; Majewski et al., in prep.). APOGEE is a high-resolution (\(R \sim22,000\)) infrared survey (\(\lambda = 1.51 – 1.69 \mu\text{m}\)) and part of the Sloan Digital Sky Survey III (Eisenstein et al. 2011) SDSS-III), which uses the Sloan 2.5 m telescope (Gunn et al. 2006). Here, we analyse data from the SDSS-III Data Release 12 (DR12; Alam et al. 2015), which contains 690 red-giant stars.

\(^1\) The quoted uncertainties in Miglio et al. (2013a) were computed assuming global seismic parameter uncertainties from Mosser et al. (2010). Similar age uncertainties are found here, despite using spectroscopic information – as we have now adopted not only individual uncertainties but also a more conservative uncertainty estimate for the seismic parameters (details can be found in Anders et al. 2015, in prep.).
stars in the CoRoT fields LRa01 and LRc01 from an ancillary APOGEE campaign.

The CoRoT-APOGEE sample (CoRoGEE) studied here is briefly described in Sect. 2 while a more detailed description can be found in Anders et al. (2015, in prep.; hereafter A15). The latter paper describes the analysis performed to extract the main stellar properties for this sample, such as masses, radii, ages, distances, extinctions, and kinematic parameters. The authors also present some immediate results that can be obtained with the CoRoGEE sample, such as the variation of the disc metallicity gradient with time or age-chemistry relations outside the solar vicinity. In the present Letter, we focus on a group of stars which, despite being enhanced in \([\alpha/Fe]\), appear to be relatively young. Because these stars, at first sight, challenge the currently accepted paradigm, we carry out several tests to consolidate our assigned ages and abundances in our companion paper. In Sect. 3 we identify the young high-\([\alpha/Fe]\) stars and describe their main properties, and in Sect. 4 we discuss possible interpretations for their origin. Our main conclusions are summarised in Sect. 5.

2. Observations

The CoRoT data we employed are a subset of the larger sample analysed by Miglio et al. (2013). Red-giant oscillation spectra have been analysed as in Mosser et al. (2010). The global seismic parameters \(\Delta v\) and \(v_{\text{max}}\) were measured following the method described in Mosser & Appourchaux (2009). When possible, a more precise determination of the large spacing was derived from the correlation of the power spectrum with the universal red-giant oscillation pattern (Mosser et al. 2011). Outliers to the \(\Delta v\)-\(v_{\text{max}}\) relation, which would correspond to unrealistic stellar masses, were excluded.

These targets were observed by APOGEE, and the high-resolution infrared spectra were analysed with the APOGEE Stellar Parameter and Chemical Abundances Pipeline (ASPCap; Mészáros et al. 2013, García Pérez, al., in prep.). Here, we adopted internally calibrated DR12 abundances (Holtzman et al. 2013) see more details in A15).

We used the Bayesian code PARAM (da Silva et al. 2006) to estimate stellar parameters. Masses, ages, distances, and extinctions were obtained with an updated version of the code (Rodrigues et al. 2014), which uses the combined photometric, seismic, and spectroscopic information to compute the probability density functions of these stellar properties. The final sample adopted here contains 622 red giant stars from the CoRoT LRa01 \(((t, b) = (212, -2))\) and LRc01 \(((t, b) = (37, -7))\) fields, for which a high-quality spectroscopic criteria are fulfilled (APOGEE spectra with SNR \(> 90\), 4000 K \(< T_{\text{eff}} < 5300\) K, \(1 < \log g < 3.5\)), b) the PARAM code converged, and c) the seismic and calibrated spectroscopic \(\log g\) are consistent within 0.5 dex. For this sample, statistical uncertainties of about 0.02 dex in \(\log g\), 3% in radius, 8% in mass, 25% in age, and 2.5% in distance were obtained (more details can be found in A15.). As a caveat, stellar ages might still be affected by systematic uncertainties related to different stellar models and helium content, among other sources of errors (Lebreton et al. 2014, Lebreton & Goupil 2014, Martig et al. 2015, Miglio et al., in prep.).

Our dataset is complemented with similar information coming from two other high-resolution samples for which isochrone ages were available, the F & G solar-vicinity stars of Bensby, Feltzing, & Oey (2014), and the Gaia-ESO first internal data release of UVES spectra analysed in Bergemann et al. (2014). The total number of stars in each sample is reported in Table 1.

3. Discovery of young \([\alpha/Fe]\)-rich stars in the Galactic disc

Figure 1 presents the age-\([\alpha/Fe]\) abundance relation for two local high-resolution spectroscopy samples: GES-UVES (Bergemann et al. 2014) and Bensby, Feltzing, & Oey (2014). The lower row shows the same relation for our CoRoGEE sample split into 1) outer-field (LRa01) stars, 2) inner-field (LRc01) stars with \(Z_{\text{Gal}} < 0.3\) kpc, and 3) inner-field stars with \(Z_{\text{Gal}} > 0.3\) kpc. The latter is necessary because for the inner field, stars of different heights below the mid-plane span different Galacticentric distance ranges. This behaviour is a consequence of the way the LRc01 CoRoT field was positioned (see Fig. 2, for more information on the population content of the LRc01 and LRa01 fields, see Miglio et al. 2013a).

We also show in Fig. 1 (upper-left panel) the predictions for the \([\text{Mg}/\text{Fe}]\) vs. age chemical evolution of Chiappini (2009) for different Galacticentric annuli of the thick and thin discs. These models assume that the thick disc was formed on much shorter timescales and with a higher star formation efficiency than the thin disc. The shaded area corresponds to a parameter space not covered by a standard chemical evolution model of the thick and thin discs. Figure 1 demonstrates that while most of the data can be explained by standard chemical evolution models plus observational uncertainties (most probably accompanied by significant radial mixing, as discussed in Chiappini 2009 and Minchev, Chiappini, & Martig 2013, 2014), several stars are found to possess rather high \([\alpha/Fe]\) ratios, despite their young ages, and hence cannot be accounted for by the models. These stars are depicted as stars (1\sigma-outliers) and pentagons (2\sigma-outliers) in all figures. The young \([\alpha/Fe]\)-rich stars are more numerous in the inner field (see Fig. 2 and Table 1).

Table 1 shows the occurrence rates of young \([\alpha/Fe]\)-rich stars in the different analysed samples. Interestingly, there is a sudden rise in the fraction of young \([\alpha/Fe]\)-rich stars when smaller Galacticentric distances are sampled (which is the case of the CoRoT LRc01 field for \(Z_{\text{Gal}} > 0.3\) kpc), and the absence of these stars in the Fuhrmann (2011) sample, as well as other less volumed-confined samples such as Ramírez et al. (2007) – which might be due to a statistical effect.

The young \([\alpha/Fe]\)-rich stars cover a wide range of stellar parameters (4200 K \(< T_{\text{eff}} < 5100\) K, \(1.7 < \log g < 2.7\); see also Fig. 10 of Martig et al. 2013). The abundance pattern of these stars compared to the entire CoRoGEE sample is displayed in Fig. 5. These stars are compatible with being formed from a gas that has not been processed by many stellar generations, as indicated by the systematically lower abundance of iron-peak ele-
Fig. 1. Age-[α/Fe] relation in different regions of the Galactic disc. Upper left panel: The grey curves indicate the predictions of the multi-zone Galactic chemical-evolution model of [Chiappini et al. (2009)] for the thin and thick discs, where different tracks were calculated for different Galactocentric annuli situated between 2 and 18 kpc from the Galactic Centre. The solar position is indicated in the diagram for the 6 kpc curve, the distance of the most probable birth position of the Sun ([Minchev, Chiappini, & Martig 2013]). Within these models, it is not possible to explain stars that fall into the grey-shaded region of the diagram: young, [α/Fe]-enhanced stars. The grey shadings provide a heuristic estimate of the typical 1σ uncertainties in [Mg/Fe] and age. Upper middle and right panels: The solar cylinder data from [Bensby et al. (2014), middle panel,] and the Gaia-ESO survey ([Bergemann et al. 2014, right panel]) show a clear correlation between isochrone-derived age estimates and relative [α/Fe] abundances. Stars whose age and abundance estimates are 1σ-incompatible with any of the chemical evolution curves are represented by stars; 2σ-outliers are represented by pentagons. Lower panels: The same diagram for the CoRoT-APOGEE sample. Left: the LRa01 outer-disc field. Middle: the LRc01 inner-disc field, close to the Galactic plane ([Chiappini et al. 2009]). Right: the LRc01 field, below the Galactic plane ([Zgal] < -0.3 kpc, [Rgal] < 6.5 kpc). In this region, the fraction of young α-enhanced stars is much larger than in all other regions. Considering normal stars alone, the age-[α/Fe] relation is much flatter than locally because the CoRoT stars span a wide range in Galactocentric distances.

Table 1. Abundance of young α-enhanced stars (yr) in recent high-resolution spectroscopic surveys.

<table>
<thead>
<tr>
<th>Sample</th>
<th>[Rgal] [kpc]</th>
<th>N°</th>
<th>1-σ / 2-σ yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuhrmann et al. ([Bensby et al. (2014)]</td>
<td>8</td>
<td>424</td>
<td>0 / 0</td>
</tr>
<tr>
<td>Bensby et al. ([Bensby et al. (2014)]</td>
<td>8</td>
<td>714</td>
<td>8 (1.1%) / 1 (0.1%)</td>
</tr>
<tr>
<td>GES', [Zgal] &lt; 0.3 kpc</td>
<td>6 – 9</td>
<td>55</td>
<td>0 / 0</td>
</tr>
<tr>
<td>GES', [Zgal] &gt; 0.3 kpc</td>
<td>6 – 9</td>
<td>91</td>
<td>3 (3.3%) / 1 (1.1%)</td>
</tr>
<tr>
<td>LRc01'</td>
<td>9 – 14</td>
<td>288</td>
<td>3 (1.0%) / 2 (0.7%)</td>
</tr>
<tr>
<td>LRc01', [Zgal] &lt; 0.3 kpc</td>
<td>6 – 7.5</td>
<td>151</td>
<td>4 (2.6%) / 2 (1.3%)</td>
</tr>
<tr>
<td>LRc01', [Zgal] &gt; 0.3 kpc</td>
<td>4 – 6.5</td>
<td>183</td>
<td>21 (11.5%) / 13 (7.1%)</td>
</tr>
<tr>
<td>APOKASC'</td>
<td>7 – 8</td>
<td>1639</td>
<td>14 (0.8%)</td>
</tr>
</tbody>
</table>

Notes. (a) Galactocentric range covered by different samples (b) N° total number of stars in the sample, (c) The volume-complete sample of Fuhrmann ([Bensby et al. (2014)]), (d) Hipparcos volume ([Bensby et al. (2014)]), (e) DR1 ([Bergemann et al. (2014)]), (f) CoRoGEE, this work – see Appendix for detailed information on each star, (g) Martig et al. ([Bensby et al. (2014)]). Outliers were defined in a different manner than in the present work.

Fig. 3. Chemical-abundance patterns relative to oxygen for the CoRoT-APOGEE stars marked as chemically peculiar in Fig. 1 (blue hexagons, 2σ-outliers in the age-[α/Fe] diagram). The chemical abundance pattern of the rest of the CoRoT-APOGEE sample is presented in grey for comparison.
regions that are more often shocked by the passage of the spiral. In this region, gas can be kept inert for longer times than in other regions. 

Another interpretation is to assume that the region near the bar corotation is the site for the formation of the young \( \alpha \)]-rich stars. Processes responsible for creating these stars have been continuously working during the Milky Way evolution. A more plausible interpretation is to assume that the region near the bar corotation is the site for the formation of the young \( \alpha \)]-rich stars. In this region, gas can be kept inert for longer times than in other regions that are more often shocked by the passage of the spiral arms (Bissantz et al. 2003, Combes 2014). Additional dilution is expected from gas restored from the death of old low-mass stars in this inner disc region (Minchev, Chiappini, & Martig 2013).

If this interpretation holds and the process is still taking place in a region near the end of the Galactic bar, we also expect to find young metal-poor, \( \alpha \)]-enhanced stars in that same region of the Galactic plane. Interestingly, there are some intriguing young objects in the MW that might be related to the same phenomenon: a) the puzzling low-metallicity supergiant located near the end of the Galactic bar (Davies et al. 2009b), see discussion in Genovali et al. (2014) and Origlia et al. (2013), b) the young \( \alpha \)]-enhanced stars reported by Cunha et al. (2007) near the Galactic Centre, and, c) the unusual Cepheid BC Aql which, despite being young (Whitelock, priv. comm.) and located at \( R_{\text{Gal}} \sim 5 \) kpc, is also \( \alpha \)]-enhanced and metal-poor (Luck & Lambert 2011). Other Cepheids, recently discovered far from the Galactic plane on the opposite side of the Galaxy (Feast et al. 2014), also appear to be young (i.e., their period-age relations are compatible with ages \( \lesssim 130 \) Myr).

Within our framework, we expect similar stars to have been forming in that same region (i.e., near the bar corotation) for the past 4-5 Gyr. As extensively discussed by Minchev, Chiappini, & Martig (2013, 2014), stars born at the corotation radius have a high probability of being expelled to an outer region via radial migration. This result suggests that the mechanism proposed here could have a strong effect on the thin disc by contaminating the entire disc with this metal-poor and \( \alpha \)]-rich population and that it might be related to the observed \( \text{Fe/H} \sim -0.7 \) floor in the abundance gradients. One possible observable signature of this process might be the intermediate-age \( \alpha \)-enhanced open clusters found by Yong, Carney, & Friel (2012) and references therein.

### 4. What is their origin?

One possible interpretation is that the young \( \alpha \)]-rich stars might be evolved blue stragglers, that is, binary mergers. These have a higher mass and thus look like a young population. However, these stars should be present in all directions, at all metallicities, but in smaller numbers (see discussion in Martig et al. 2015).

The young \( \alpha \)-rich stars appear to have been born from a relatively pristine gas, with metallicities above \( \text{Fe/H} \sim -0.7 \) (see Fig. 4 and Table A1). One possibility is that these are objects formed from a recent gas accretion event. One caveat here is that outliers are also present in older age bins, suggesting that the processes responsible for creating these stars have been continuously working during the Milky Way evolution. A more plausible interpretation is to assume that the region near the bar corotation is the site for the formation of the young \( \alpha \)]-rich stars. In this region, gas can be kept inert for longer times than in other regions that are more often shocked by the passage of the spiral.

![Fig. 4](image-url) 

**Fig. 4.** Radial [Fe/H] distribution (left: as a function of Galactocentric distance \( R_{\text{Gal}} \), right: w.r.t. the guiding radius \( R_g \)) over the extent of the Galactic disc (4-14 kpc range). As in Fig. 2 the CoRoGEE sample is shown in blue, the Bergemann et al. (2014) stars in red, and the (Bensby et al. 2014) sample in orange. Again, hexagons and stars represent the young \( \alpha \)]-enhanced stars defined in Fig. 1. The locations of Galactic cephids (black; data from Genovali et al. 2014) are also indicated.

### 5. Conclusions

In this Letter we reported the discovery of young \( \alpha \)]-enhanced stars in a sample of CoRoT stars observed by APOGEE (CoRoGEE). These stars have a lower iron-poor element content than the rest of the CoRoGEE sample and are more abundant towards the inner Galactic disc regions. Almost all of the young \( \alpha \)]-rich stars we discovered have guiding radii \( R_g \lesssim 6 \) kpc. Therefore, we tentatively suggest that the origin of these stars is related to the complex chemical evolution that takes place near the corotation region of the Galactic bar.

Unfortunately, some ambiguity remains because the inner Galactic regions accessible to CoRoT are above \( |Z_{\text{Gal}}| = 0.3 \) kpc. This situation is expected to improve by combining future APOGEE-2 data with Kepler seismology from the K2 Campaign (Howell et al. 2014), a goal for SDSS-IV. Further into the future, more information will be obtained from Gaia and the PLATO-2 mission (Rauer et al. 2014), both complemented by spectroscopy for example with the 4MOST facility (de Jong et al. 2014).

In a companion paper (Martig et al. 2015), we report the discovery of young-\( \alpha \)]-Fe]-rich stars in the Kepler field (although in smaller numbers). Finally, in an ongoing Gaia-ESO follow-up of the CoRoT inner-field stars, more of these stars are found (Valentini et al., in prep.), providing better statistics and complementing the results shown in this Letter.

**Acknowledgements.** The CoRoT space mission, launched on December 27 2006, was developed and operated by CNES, with the contribution of Austria, Belgium, Brazil, ESA (RSSD and Science Program), Germany and Spain. CC thanks A. Baglan, L. Storm and G. Cesati for helpful discussions. T.S.R. acknowledges support from CNPq-Brazil. LG acknowledges financial support from PRIN INAF 2014. TM thanks financial support from Belspo for contract PRODEX.
References


Pagel, B. E. J. 2009, Nucleosynthesis and Chemical Evolution of Galaxies


Yong, D., Carney, B. W., & Friell, E. D. 2012, AJ, 144, 95

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Appendix A: Best-candidate young α-enhanced stars

Table A.1 summarises our measured quantities for the best-candidate young α-enhanced stars (17 2σ-outliers; large pentagons in Fig. 1 and 11 1σ-outliers; stars in Fig. 1). We first report our input values: the adopted seismic parameters Δν and νmax (as computed by automatic as well as supervised analyses of the CoRoT light curves), ASPCAP spectroscopic parameters Teff, [Fe/H], [α/Fe], and the number of APOGEE observations, NAPD. We note that all stars in question have been observed at very high signal-to-noise ratios (S/N > 140 per resolution element). The radial-velocity scatter between subsequent observations is always smaller than 0.6 km/s; meaning that their values are consistent with all stars being single stars or widely separated binaries.

We also present the estimated stellar masses Mscale, as determined from seismic scaling relations and the 1σ upper-limits for the ages (as determined by PARAM). A comparison of the masses estimated by PARAM and those inferred directly from the scaling relations is reported in A15 for the full CoRoGEE sample. Also listed are the current Galactocentric positions RGal and ZGal and the guiding radius Rg of each star.

We also show a note on the quality of the light curves (Q) and a flag based on the supervised analysis. Because the automated and supervised analyses sometimes yield different results, we recomputed masses and ages using the individually obtained Δν and νmax values and updated uncertainties where necessary. As expected, the numbers of the young α-enhanced stars are slightly different. In Table A.1 we only report the robust 2σ- and 1σ–outliers.

However, these uncertainties have a small impact on our main result, as after the individual analysis, still 17 stars out of 20 seem to be younger than 4 Gyr. Individual supervised analysis shows that:

1. One star (CoRoT 101071033) had to be excluded from the parent sample due to the very poor quality of its light curve;
2. Four stars that seemed to be 2σ–outliers were shifted to older ages: CoRoT 101093867, 101071033, 102645343, and 10264381. Similarly, seven candidate 1σ–outliers fall out of the sample: CoRoT 101057962, 101041814, 102626343, 100886873, 101208801, 101212022, and 101227666.
3. CoRoT 101093867 is a complex case, where both Δν values appear as possible solutions; for six other stars, another solution is possible, because the lightcurve SNR is not high enough to undoubtedly resolve the radial/dipole mode possible mismatch (such cases cannot be seen in the general blind automated analysis);
4. For CoRoT 100958571, the solution obtained through supervised fitting, close to the one found by the automated pipeline, should be preferred. Also, for most of the remaining stars, slight improvements in the determination of the seismic parameters are possible.
Table A.1: Best-candidate young $\alpha$-enhanced stars: seismic and spectroscopic adopted parameters and uncertainties, stellar masses and ages, current Galactocentric positions $R_{\text{Gal}}$ and $Z_{\text{Gal}}$, and guiding-centre radii $R_{\text{g}}$.

<table>
<thead>
<tr>
<th>CoRoT ID</th>
<th>APOGEE ID</th>
<th>$\Delta v$</th>
<th>$\nu_{\text{max}}$</th>
<th>$Q^*$</th>
<th>$\Delta v^\beta$</th>
<th>$\nu_{\text{max}}^\beta$</th>
<th>Flag</th>
<th>N$_{\text{APO}}$</th>
<th>$T_{\text{eff}}$</th>
<th>[Fe/H]</th>
<th>$\sigma$/[Fe]</th>
<th>$M_{\text{APO}}$</th>
<th>$\tau_{600}^{\mu}$</th>
<th>$\tau_{1500}^{\mu}$</th>
<th>$R_{\text{Gal}}$</th>
<th>$Z_{\text{Gal}}$</th>
<th>$R_{\text{g}}$</th>
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Notes.  
* Quality of CoRoT lightcurve and the automated global fits; $^\beta$ Results of individual supervised fit to the lightcurves; $^c$ Flag on supervised fits (0 = automated and supervised fit are consistent within 1σ, 1 = there are two possible solutions for $\Delta v$ or $\nu_{\text{max}}$, due to the ambiguity of radial and dipole oscillation modes, 2 = supervised fit yields improved results); $^d$ Overall uncertainties: $\sigma_{\text{gal}} = 91$ K [Holtzman et al. 2015]; $^e$ 1σ age upper limit, using the seismic results from the automatic pipeline; $^f$ 1σ age upper limit, using the seismic results from the supervised seismic analysis; $^g$ Typical uncertainties: ~ 0.1 kpc, for the most distant stars in LRc01 ~ 0.5 kpc; $^h$ Typical uncertainties: < 0.1 kpc, for the most distant stars in LRc01 ~ 0.4 kpc;