The Red Clump stars from LAMOST data: the outer disk of Milky Way

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Outline

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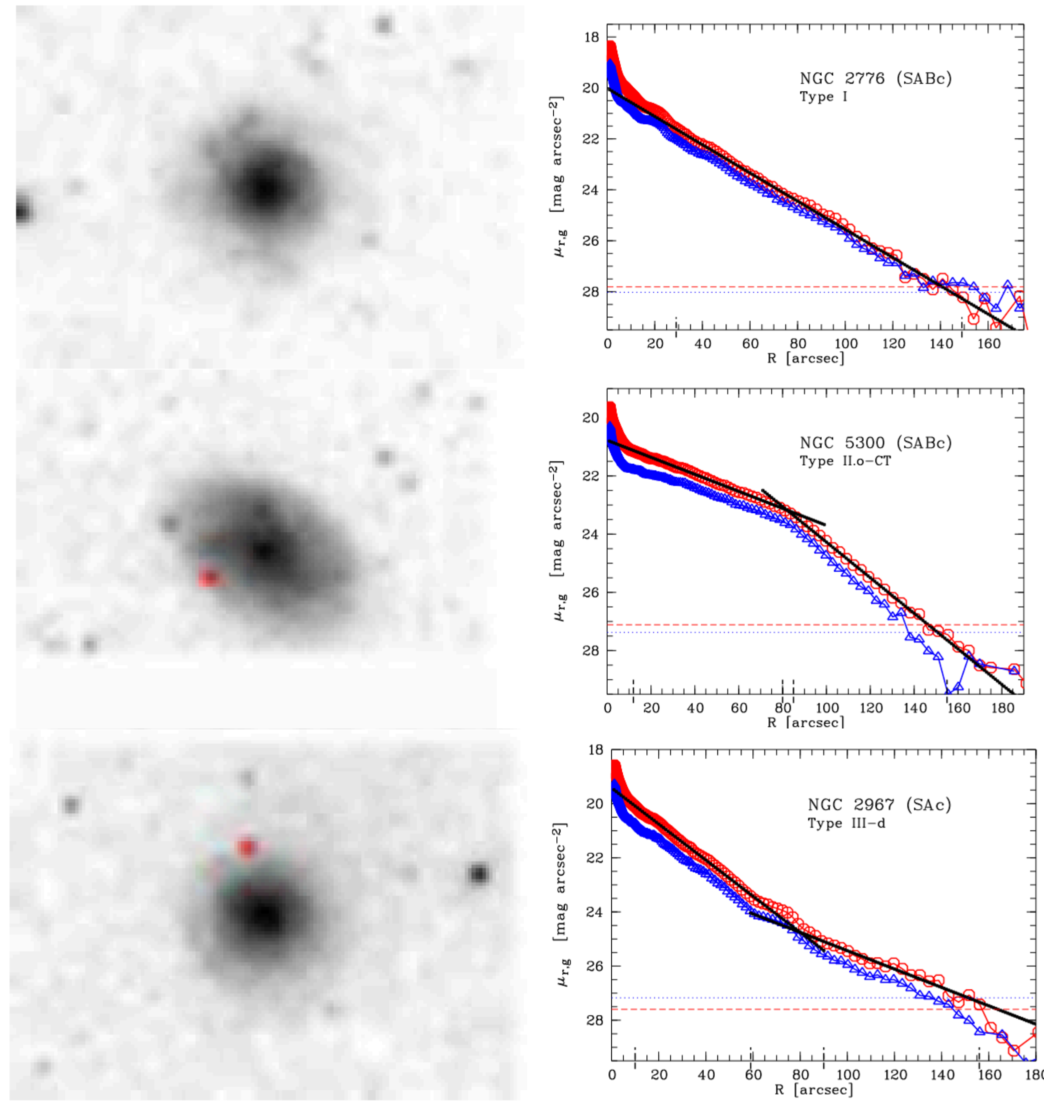
Motivation

In recent years, it is realized that the **secular evolution** may play very important role to radially reorganize the mass profile and the metallicity distribution in a galactic disk. Simulations show that the secular evolution of the discs can significantly alter the properties, from the age distribution to the stellar density profile, of the outer disc (Roskar et al. 2008; Debattista et al. 2006).

Pohlen & Trujillo (2006) found that the outer discs show three different types of profiles, exponential, down-bending, and up-bending. The mechanisms leading to these differences are not quite clear so far.



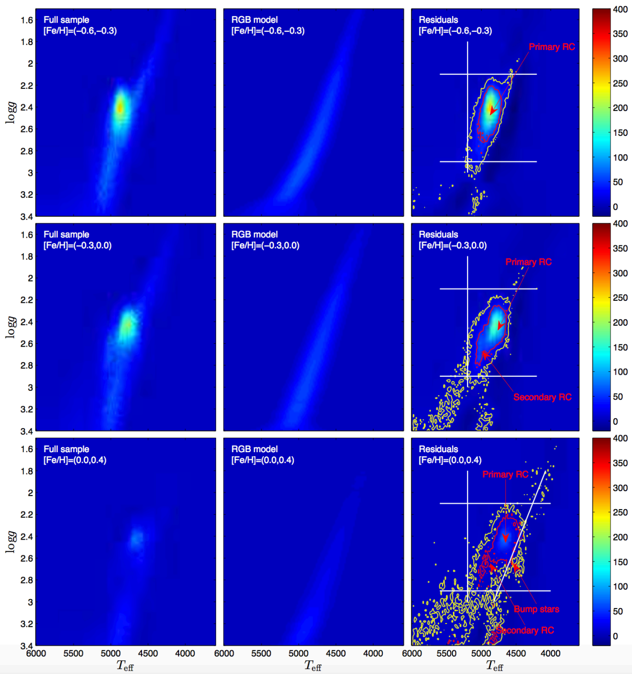
(Pohlen & Trujillo 2006)

Motivation

For the case of the Milky Way, since it allows for the observations of the individual stars, it takes a great advantage in the studies of the Galactic outer disc.

Lopez-Corredoira et al. (2002) showed that the Galactic outer disc is substantially flared and warped.
Moreover, a puzzling substructure, the Monoceros ring, in the Galactic anti-center direction has been unveiled by Newberg et al. (2002) from the star count of the turnoff stars. Momany et al. (2006) claimed that this is likely the effect of the warp and flare, while Ǵomez et al. (2016) showed that the interaction among the satellites, Galactic halo and the disc can also induce such kind of feature.
Furthermore, Xu et al. (2015) discovered that the star counts in the north and south of the Galactic mid-plane of the outer disc are not symmetric but display wave-like oscillations.
Recently, Liu et al. (2017) found that the disc has no truncation but exponentially expands to 19 kpc and then smoothly transition to the stellar halo.

The nature of the outer disc can be learnt not only from the spatial structures and stellar kinematics, but also from the features of **the stellar populations**. In general, the chemical abundances and the age can well characterize the stellar populations.



Red Giants:

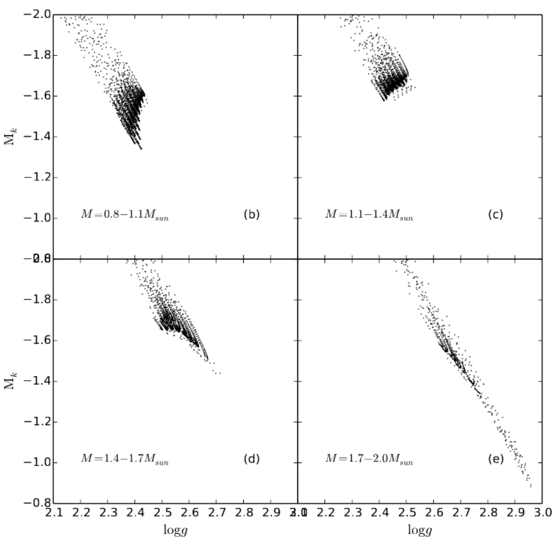
$$\log g \subset (0.9, 3.5)$$

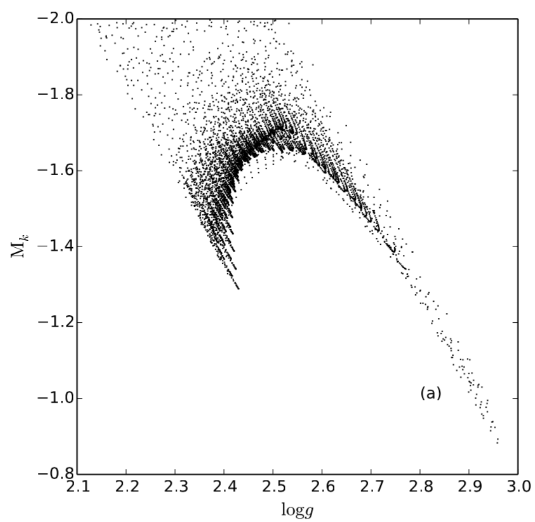
$$[\mathrm{Fe/H}] \subset (-0.6, 0.4)$$

$$T_{\rm eff} \subset (3600, 6000)$$

$$\mathrm{S/N} > 10$$

$$N_{\rm RGB}(T_{\rm eff}, \log g) = N(\log g) \times \exp\left[-\frac{(T_{\rm eff} - T(\log g))^2}{\sigma^2(\log g)}\right]$$





~300,000 RGB stars

~120,000 RC candidates

(Wan, Liu, Deng et al. 2015)

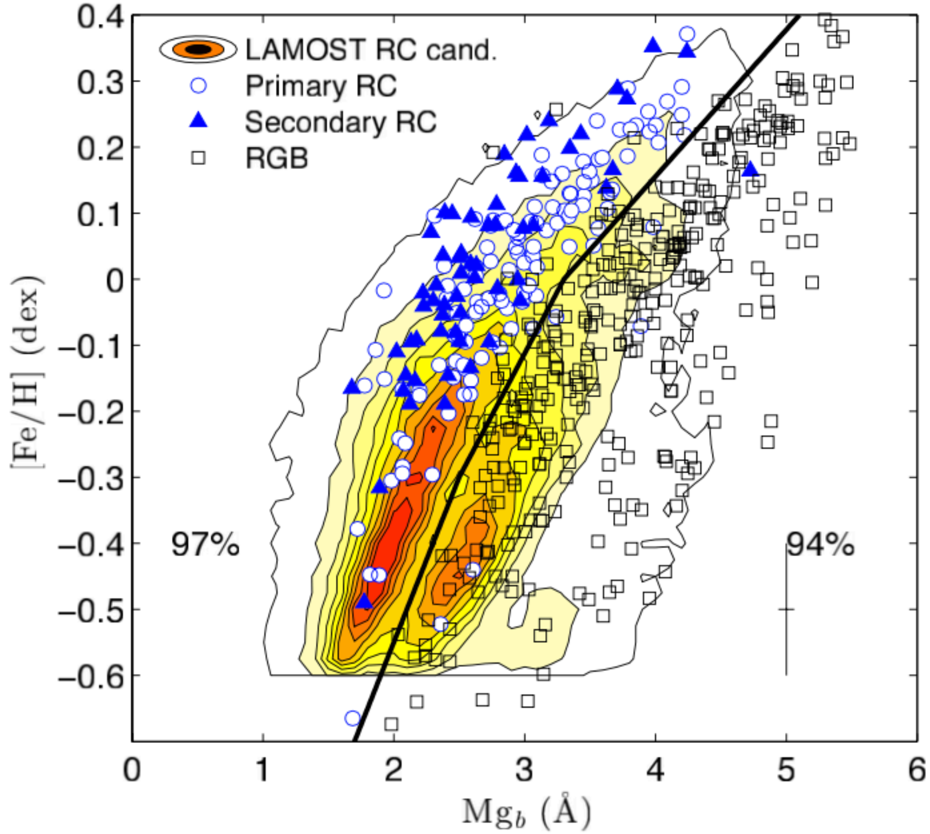


Figure 1. The distribution of the RC candidate stars from Wan et al. (2015) in the [Fe/H]-Mg$_b$ plane. The contours show the number density of the LAMOST RC candidates. The black rectangles, blue circles, and blue filled triangles are the RGB stars, the primary, and the secondary RC stars identified by Stello et al. (2013), respectively. The black solid line indicates the empirical separation between the RGB (below) and the RC (above) stars.

~120,000 RC candidates

~80,000 RC stars

(Tian, Liu, Wan et al. 2016)

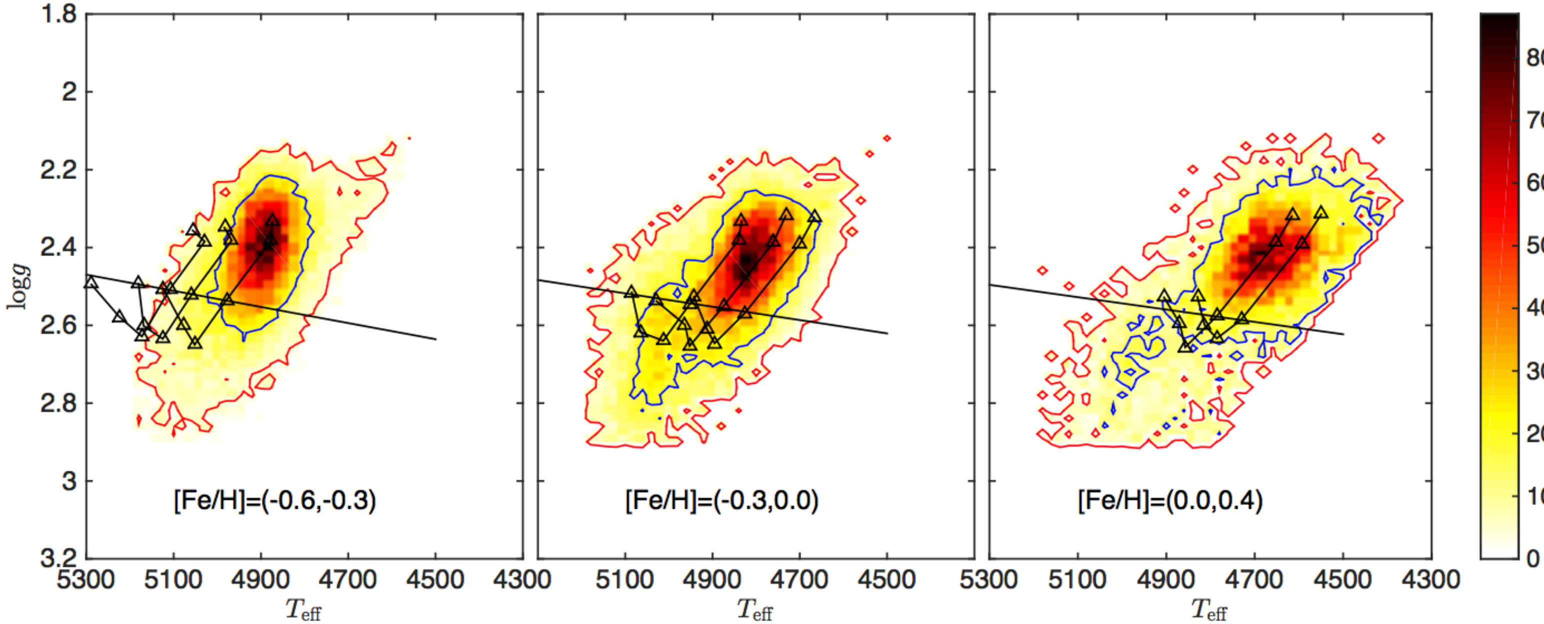


Figure 2. The separation of the young and old RC stars in three [Fe/H] bins, -0.6<[Fe/H]<-0.3 (left panel), -0.3<[Fe/H]<0 (middle panel), and 0<[Fe/H]<0.4 (right panel). The black triangles are the isochrones for the helium core burning stars from Bressan et al. (2012). From the left to the right in the left panel, the isochrones are at [Fe/H]=-0.6, -0.5, and -0.4. For each isochrone, the triangles present for 0.2, 0.5, 1.0, 2.0, 3.0, and 5.0 Gyr from left to top-right. In the middle panel, the isochrone tracks are at [Fe/H]=-0.3, -0.2, and -0.1 from left to right, respectively. In the right panels, the isochrones are at [Fe/H]=0.1 and 0.3 from left to right, respectively. The straight lines are the best fit separation lines at 2 Gyr in different ranges of [Fe/H]. Below the lines are the isochrone-based young population with age< 2 Gyr and above are the old population with age> 2 Gyr.

(Tian, Liu, Wan et al. 2016)

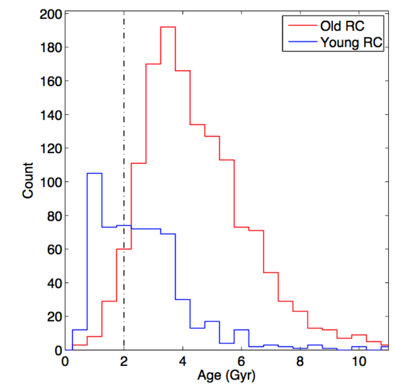


Figure 3. The distribution of the age for the isochrone-separated young (blue line) and old (red line) RC stars. The age is derived from Martig et al. (2016). The vertical black dot-dashed line indicates the position of 2 Gyr.

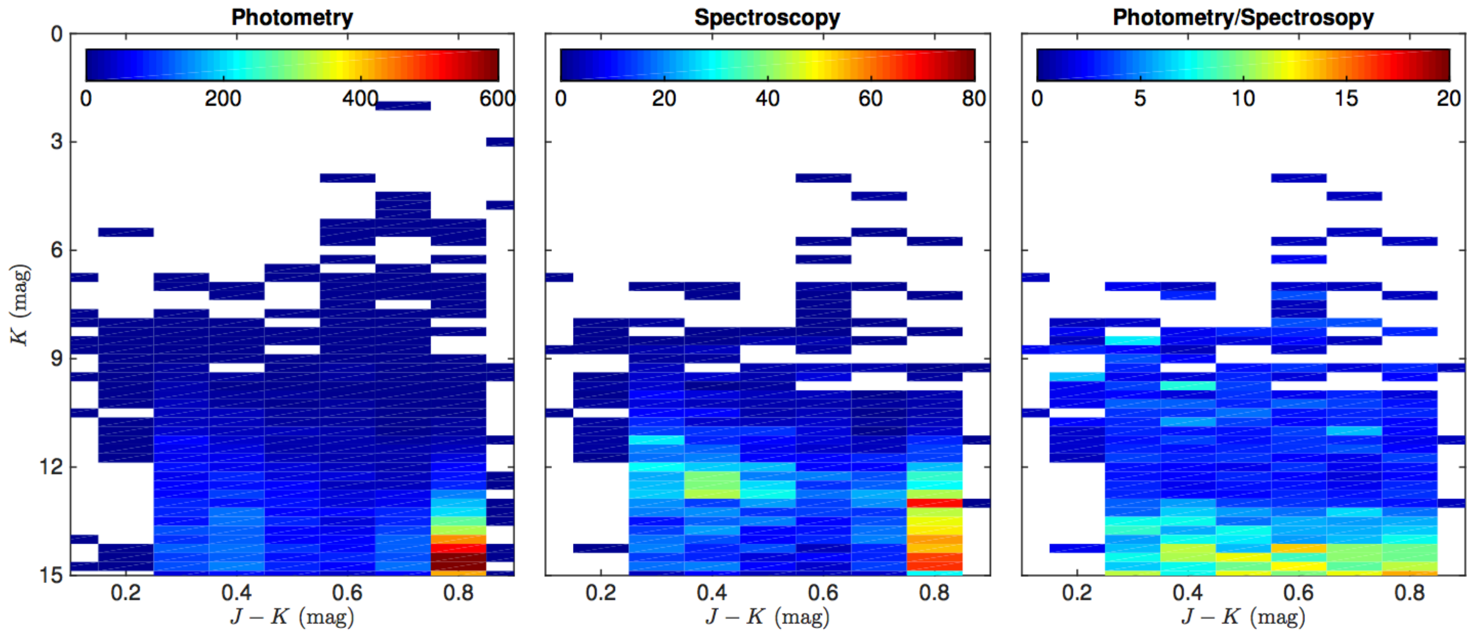


Fig. 2 The left panel shows the number density of stars in $J-K$ vs. K diagram for the complete mock stars. The color codes the stellar count within each small $J-K$–K bin. The colorbar indicates the scale of the number density. The middle panel shows the similar number density map in the $J-K$ vs. K plane for the selected spectroscopic stars based on the selection function **T1**. The right panel displays the map of $S^{-1}(J-K, K)$ for **T1**. The color scales are indicated in the colorbar located above the panel.

$$\nu_{ph}(D|c,m,l,b) = \nu_{sp}(D|c,m,l,b)S^{-1}(c,m,l,b),$$

$$S(c,m,l,b) = \frac{\int_0^\infty \nu_{sp}(D|c,m,l,b)dD}{\int_0^\infty \nu_{ph}(D|c,m,l,b)dD}$$

$$\begin{aligned} Pr([D, D+\Delta D]|c,m,l,b) &= \int_D^{D+\Delta D} p_{ph}(D|c,m,l,b)dD \\ &\doteq p_{ph}(D|c,m,l,b)\Delta D. \end{aligned}$$

$$Pr([D, D+\Delta D]|c,m,l,b) = \frac{\nu_{ph}(D|c,m,l,b)}{\int_0^\infty \nu_{ph}(D|c,m,l,b)dD}\Omega D^2\Delta D.$$

$$p_{ph}(D|c,m,l,b)\Delta D = \frac{\nu_{ph}(D|c,m,l,b)}{\int_0^\infty \nu_{sp}(D|c,m,l,b)dD}\Omega D^2\Delta D.$$

$$p_{sp}(D|c,m,l,b)\Delta D = \frac{\nu_{sp}(D|c,m,l,b)}{\int_0^\infty \nu_{sp}(D|c,m,l,b)dD}D^2\Delta D.$$

(Liu, Xu, Wan et al. 2017)

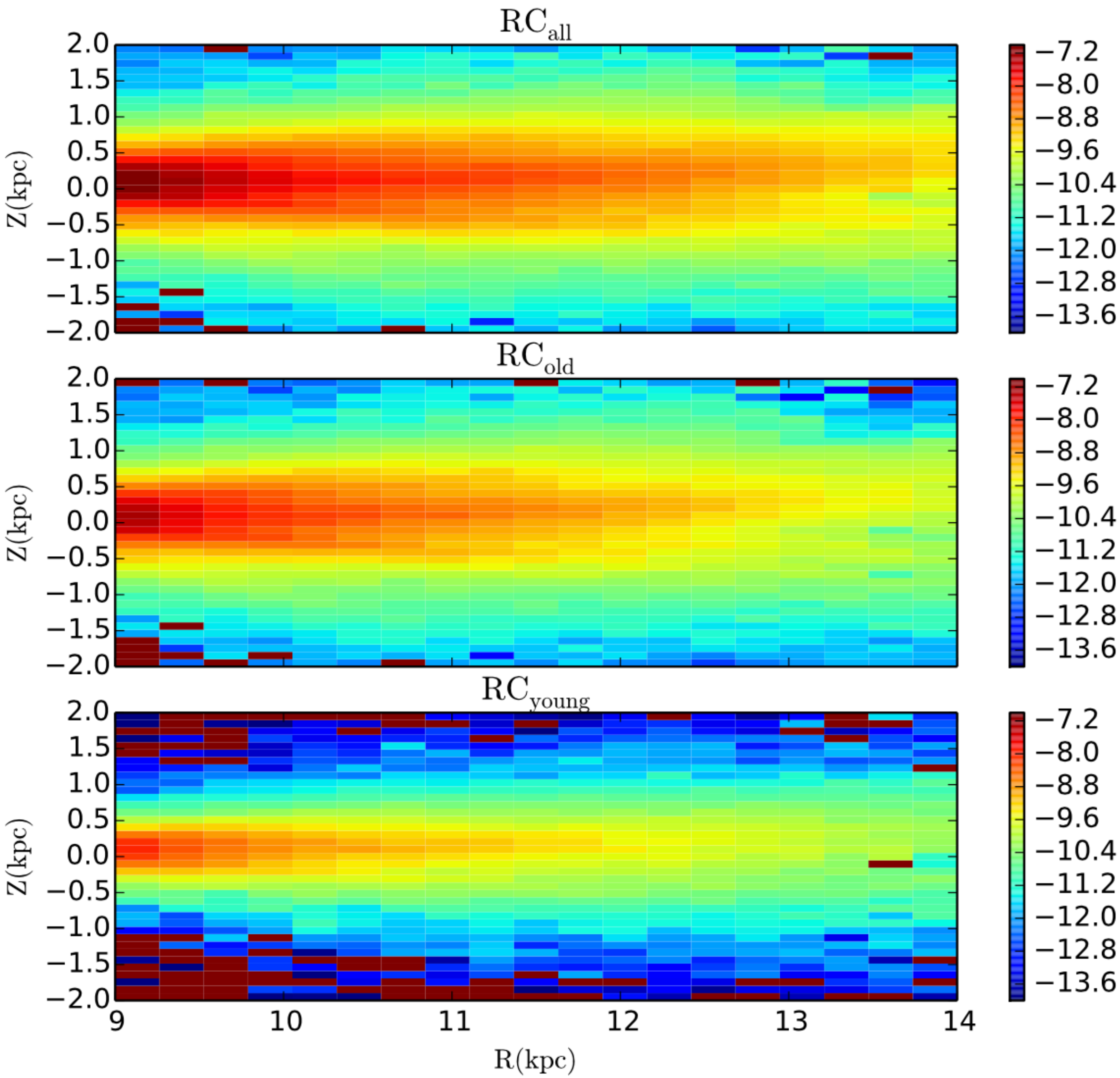
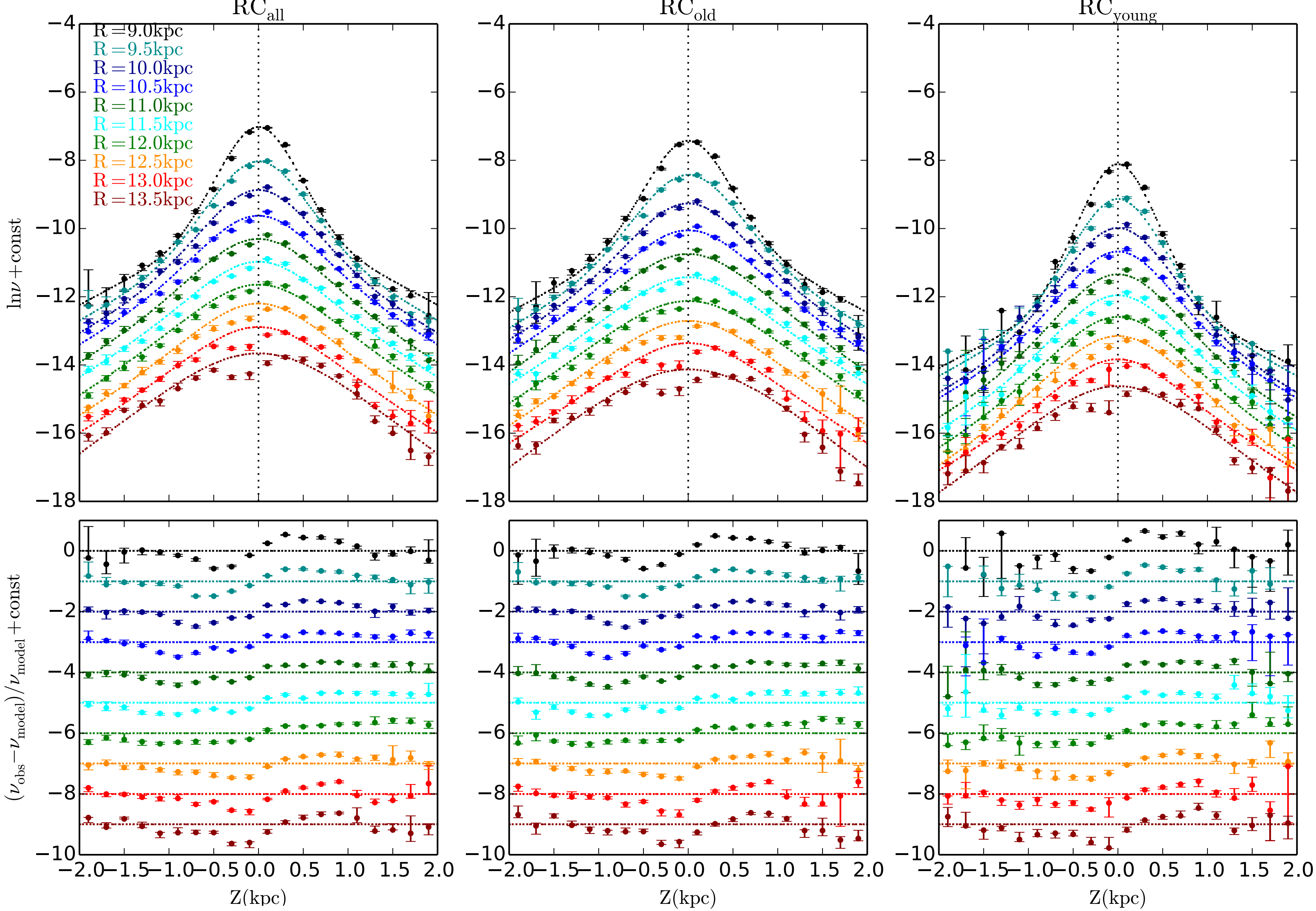


Figure 1. The stellar density maps for the RCall (top panel), RCold (middle panel), and RCyoung (bottom panel) in the R–Z plane. The colors indicate values of the $\ln \nu$.

DR3: ~100,000 RC stars

150<l<200 & |Z|<2 kpc:
~70,000 RC stars

(Wan, Liu, Deng et al. 2017)



$$\nu_{thin}(Z|R) = (1 - f_t(R))\,\mathrm{sech}^2\left(\frac{Z}{2h_{z,thin}(R)}\right)$$

and

$$\nu_{thick}(Z|R) = f_t(R)\mathrm{sech}^2\left(\frac{Z}{2h_{z,thick}(R)}\right),$$

(Wan, Liu, Deng et al. 2017)

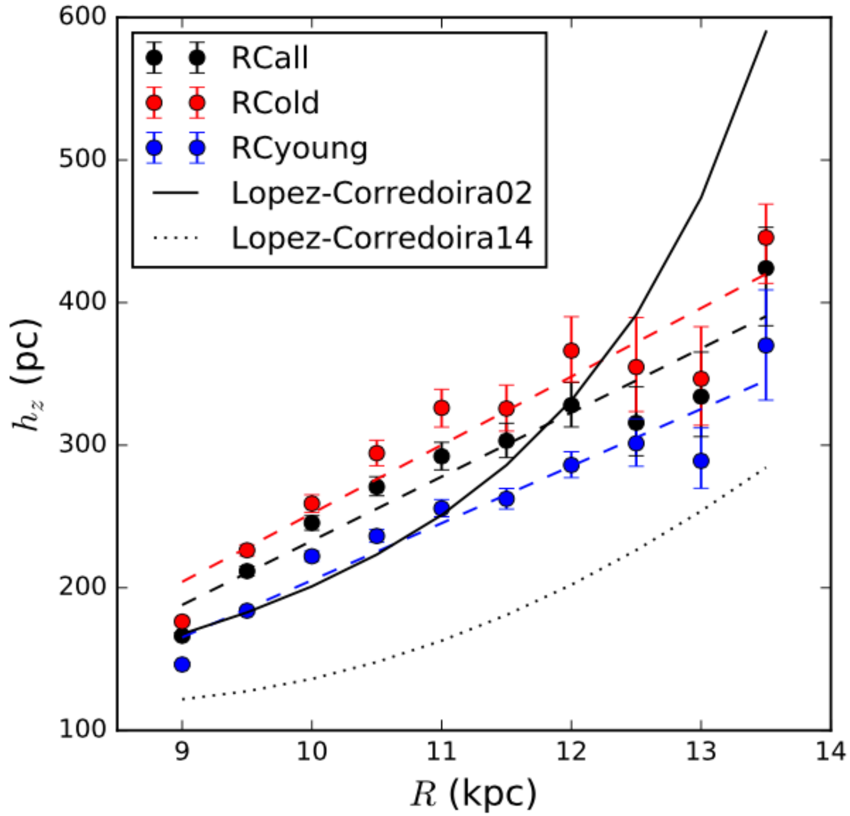


Figure 2. The derived scale heights as functions of $\boldsymbol{R}$ for the RCall (black dots), RCold (red dots), and RCyoung (blue dots) populations, respectively. The dashed lines represent for the best linear fits about the scale heights for the corresponding populations with same colors. The black solid line is the scale height from LC02 divided by 2. The black dotted line indicates the scale height from López-Corredoira & Molgó (2014) divided by 2 as well.

(Wan, Liu, Deng et al. 2017)

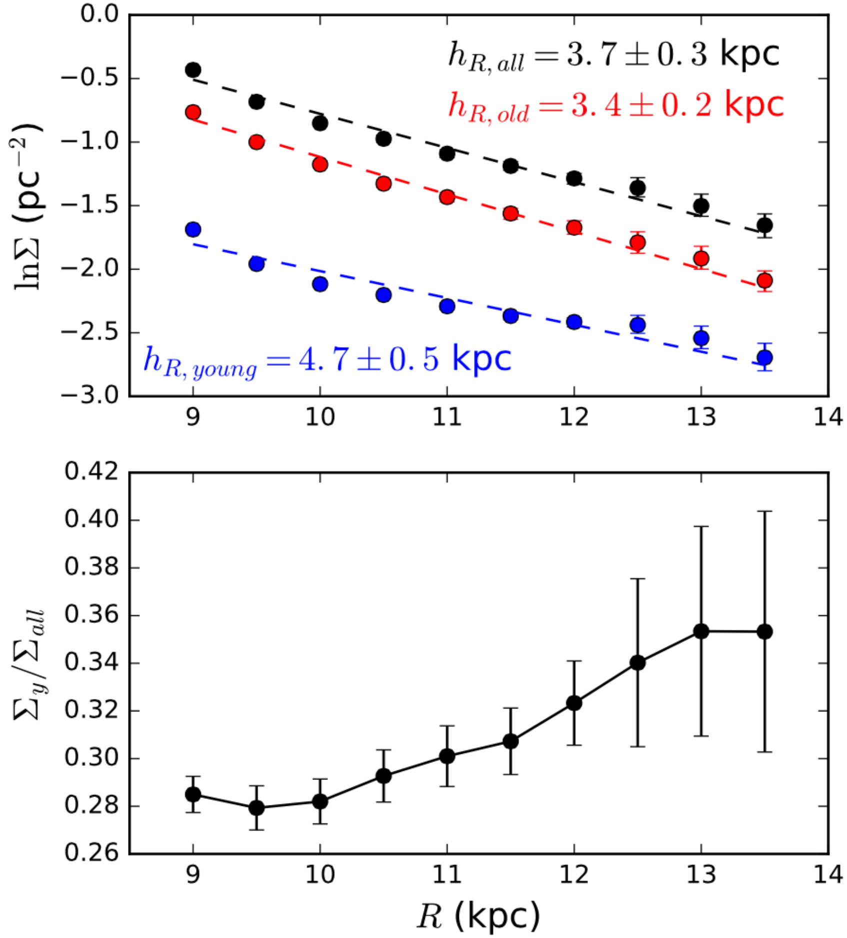


Figure 3. The top panel displays the surface stellar densities, in logarithmic form, as functions of R for the RCall (black dots), RCold (red dots), and RCyoung (blue dots) populations, respectively. The dashed lines represent for the best fit exponential profiles for the corresponding populations with the same colors. The bottom panel displays the ratio of the surface density for the RCyoung to RCall population.

(Wan, Liu, Deng et al. 2017)

Dis&Con

1.Interstellar extinction

Although the interstellar extinction may affect the stellar density measurements in some regions of the *R*–*Z* plane, it does not play an important role in the overall shape of the vertical density profiles.

2. Flare
From the stellar density profiles, we find that the younger and older RC populations in the outer disc are significantly flared. The flaring disc traced by both the populations show increasing scale heights with the Galactocentric radius of *R*. The intensity of the flaring seems not substantially correlated with the age of the thin disc populations.

3. The scale length of the surface density for the RCyoung population is 4.7 ± 0.5 kpc, which is significantly larger than the scale length of 3.4 ± 0.2 kpc for the RCold population. However, the scale heights for the RCyoung population are systematically smaller than those for the RCold population. Moreover, the fraction of the younger population is determined from the surface stellar density of the younger and older populations. It shows that the fraction of the RCyoung population moderately but consistently increases from 28% at $R = 9$ kpc to 35% at $R \sim 13$ kpc.