### The age of galactic halo

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### 1, Galactic halo

- The Milky Way is surrounded by a stellar halo, whose origin is still not very clear.
  Eggen et al. (1962): rapid collapse.
  Searle & Zinn (1978): accretion of nearby satellite galaxies over several Gyrs.
- Recently, Carollo et al. (2007) argued that the halo is composed by the inner and the outer halo.
- However, Schonrich et al. (2011,2014) suggest that it is not true due to systematic bias in distance estimation.

This debate makes it very important that other parameters, e.g. age, may play a critical role to constrain the structure and origin of the stellar halo.



# 2, Methods to study the age of the stellar halo

- Globular clusters (Searle & Zinn 1978; Chaboyer et al. 1996; Sarajedini 1997).
- Age can be determined using the difference in the color between the main sequence turn-off and the base of the red giant branch (Sarajedini & Demarque 1990; Vandenberg et al. 1990).
- Abundances of radioactive species. e.g. thorium and uranium (Frebel et al.2007).
- Kalirai (2012) estimated age as  $11.4\pm0.7$  Gyr.
- Jofre & Weiss (2011) determined the age as 10-12 Gyr.

### 3, DATA Selection

Sample selected from SIMBAD database. (Guo jincheng, Liu Chao & Liu jifeng, RAA , 2016)

1, Stars within 1kpc.

2, With radial velocity, proper motion, metallicity, apparent magnitude B and V.

3, With parallax and errors of parallax are less than 100%.

36 219 stars are left in the end.

### 4, Kinematic Identification of the halo stars

First calculate the 3-D heliocentric velocities for these stars from their positions, parallaxes, proper motions, and radial velocities.

Move them to the frame with respect to the local standard of rest (LSR, remove effect of solar motion).

Calculate the probability of belonging to the halo, thick disk or thin disk

$$Prob = c \cdot exp(-\frac{U_{\text{LSR}}^2}{2\sigma_U^2} - \frac{(V_{\text{LSR}} - V_{asym})^2}{2\sigma_V^2} - \frac{W_{\text{LSR}}^2}{2\sigma_W^2}).$$

Define the probability ratio of belonging to the halo as:

$$f_{halo} = \frac{Prob_{halo}}{Prob_{halo} + Prob_{thin} + Prob_{thick}}.$$

Good candidate halo star >80%; possible halo star > 60%



# 5, The halo turn-off stars selected from HR diagram



### 6, Extinction correction and Sample contamination



- We constructed a 3-D extinction map based on Bailer-Jones (2011)
- According to Xin et al. (2007), the contamination of blue straggler stars in the main sequence turn-off is about 10%.
- We conducted a Monte Carlo simulation in order to determine the age of the halo.

# 7, The age of the halo as determined from halo field stars

Define B-V distance as the distance between a turn-off star and an isochrone with the same metallicity.

Assuming the error of B-V follows a Gaussian distribution with B-V median error of 0.02 mag as the standard deviation.

For each isochrone, we randomly add errors to the 63 turnoff stars. Then use a Gauss-Hermite function below to fit the distribution of B-V distance.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \left[ 1 + \frac{h_3}{\sqrt{3}} (2x^3 - 3x) + \frac{h_4}{2\sqrt{6}} (4x^4 - 12x^2 + 3) \right],$$

For one simulation, we derive the minimum of the B-V distance from the maximum peak of the derivative of the best fit.



## 7, The age of the halo as determined from halo field stars



Distribution of the boundary of B-V distance to the isochrone for 10.5 Gyr after 100 simulations.

After repeat a hundred runs of the simulation for each isochrone, the age is determined as 10.5 Gyr. The standard deviation (0.023 mag) of the normal fit is adopted as the error of the age.

Therefore, the age of the halo is constrained to be  $10.5 \pm 1.5$  Gyr. This result is in agreement with previous work.

GAIA mission:

Launched on Dec 2013, aims to construct the largest and most precise 3D space catalog.

~1 billion stars (1% of the Milky Way population), all stars brighter than magnitude 20.

For nearest stars, the accuracy of distance is expected to be 0.001%. For stars brighter than 15, GAIA will measure their positions to an accuracy of 24 microarcsecs.



Part1:

TGAS(Tycho-Gaia Astrometric Solution): ~2 million stars with Gmag<12 mag, parallax PM

Part2: Gaia data ~1 billion with position and G mag

Part3: RR Lyrae: 599 Cephied: 2595





0.0

0.5

1.0

B-V (mag)

1.5

**BS** contamination

Check in Toomre diagram







After 100 simulations--->11Gyr



Sigma=0.0504--->3.3 Gyr

 $11.0 \pm 3.3 \ Gyr$  (average B-V error = 0.066)

 $10.5 \pm 1.5$  Gyr (average B-V error = 0.02)

#### Next step:

- Determine ages of all halo stars
- Combine orbital information,
- Get rid of thick disk
- separate inner halo, outer halo.

#### **Only LAMOST?**

-5<[Fe/H]<-1.0, Teff<8000, |vr|<500, SNR\_B>15---->116820

 $200 \le \operatorname{sqrt}((v+220)^2+u^2+w^2) \le 500$ ----> 49412 left