Halo substructures traced by BHB and RR Lyrae in SDSS

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We present a sample of candidate Blue Horizontal Branch and RR Lyrae stars selected from the Sloan Digital Sky Survey (SDSS) DR-5 and SEGUE. On the basis of SDSS imaging and spectrophotometric data which allowed us to estimate atmospheric parameters (effective temperature, gravity, and metallicity), we analyse their distribution and look for substructures, possible fossil signatures of past merging events.

BACKGROUND:

In a CDM Universe, galaxies like the Milky Way grow by mergers of dwarf galaxies; this theory predicts the presence of substructures due to accretions experienced over their lifetime.

Recent observations have shown that considerable structure is still present in the halo of the Milky Way, indicating that such events have had role in its formation history (e.g. Ibata et al. 1994;Majewski et al 1996;Helmi et al. 1999;Ivezić et al. 2000). The Galactic halo may retain memory of its merging history in the form of fossil streams of stars which, although sometimes of very low spatial density, may be detectable as stellar groups with coherent kinematics and metallicities.

Studies of the kinematics of various stellar populations in the Galaxy have long been limited - especially in the inner halo - by the availability of large samples of stars with known distances, metallicity and kinematics.

The Sloan Digital Sky Survey (SDSS; York et al. 2000) with **SDSS-I** (8000 deg^2 of imaging data, position and multicolor photometry of ~100 million stars at $|b|>40°$) **& SEGUE** (+3500 deg^2 imaging data at lower Galactic latitudes and 250 000 medium resolution -R=2000- spectra) is a powerful tool to understand the properties of the Milky Way and uncover halo structures.

MOTIVATIONS & EXPECTATIONS:

In the outer regions of galactic halos debris from galaxy accretion can remain spatially or kinematically coherent many Gyr. This implies that such structures can be detected from low-dimensionality surveys, such as 2D spatial (using two sky coordinates), 3D (+distance) or 4D (+radial velocities) maps.

Many surveys (SDSS: Yanny et al. 2000, Newberg et al. 2007; the Spaghetti Project Survey: Morrison et al. 2000; the QUEST RR Lyrae Survey: Vivas et al. 2001; 2MASS: Rocha-Pinto et al. 2003) have discovered debris using this approach, which requires suitable tracers to probe the outer Galaxy. Typical tracers are giant stars, e.g. BHB, RR Lyrae.

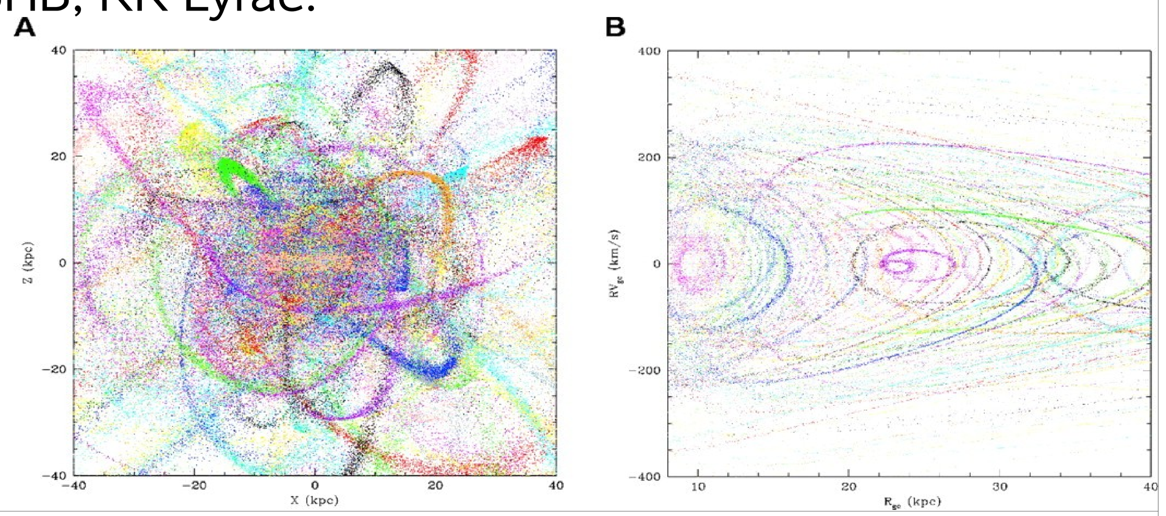


Fig. 1. CDM simulation of the Milky Way halo built up through accretion of 100 dwarf galaxies, with different merging events marked by different colors and shown (left and right) in two coordinate frames.
(Image courtesy of P. Harding).

WHAT WE DO - I
Atmospheric parameters

We derived models to estimate Teff, log g, [Fe/H] from the observed SDSS/SEGUE stellar spectra via non linear regression models trained on

- pre-classified observed data
- synthetic stellar spectra

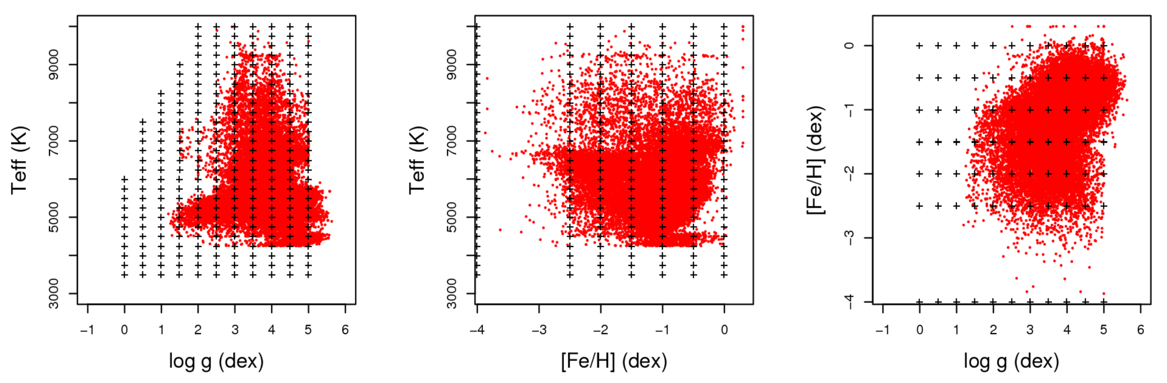


Fig. 2.The grid of stellar atmospheric parameters Teff, logg, and [Fe/H]. The synthetic parameters (plus symbols) are presented in comparison with previously estimated atmospheric parameters (dots) for 38 731 SDSS/SEGUE spectra.

with accuracies of 170/170 K in Teff, 0.36/0.45 dex in log g, 0.19/0.26 dex in [Fe/H] respectively (Re Fiorentin et al. 2007).

Here we apply them on a total of 258 347 stellar spectra: 194 172 spectra listed in SDSS-I & 89 600 spectra on the current SEGUE plates.
In addition, this sample has *ugriz* photometry and radial velocities.

WHAT WE DO - II
Candidate selection & distance estimate

We select from the spectro-photometric sample in **SDSS-I & SEGUE** (# 239 726, after multiple observations handled) a set made of

BHB (# 1692):

spectro-photometric (Sirko et al. 2004)
→ d=f(M_g=0.7)

RR Lyrae (# 1669):

photometric (Ivezić et al. 2005)
+ Teff in 6100-7400 K
+ log g in 3-4 dex
→ d=f(M_g=a[Fe/H]+b)

We derive their spatial distribution.

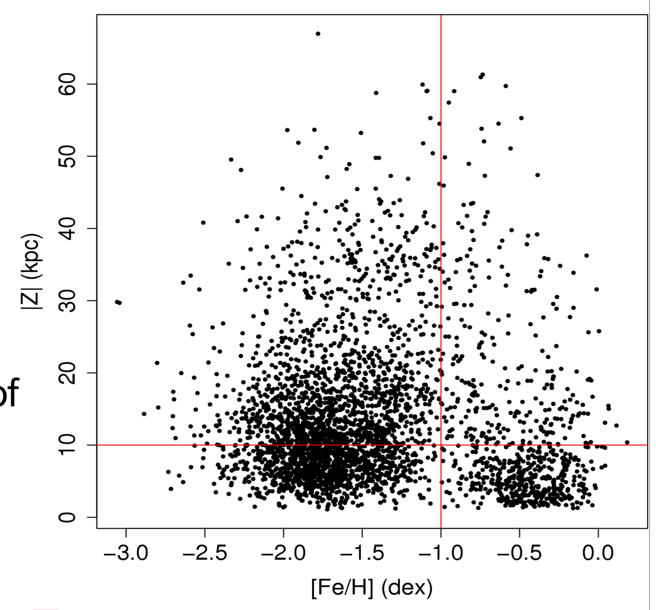


Fig. 3. Metallicity as a function of hight from the galactic plane of the 3361 stars selected as BHB or RR Lyrae.

► Gradient of [Fe/H] wrt Z.
► Two distinct populations, disk & halo appear!

WHAT WE DO - III
Halo tracers selection

We identify a set of stars in the outer halo defined as those having:

[Fe/H] < -1.0 dex (low metallicity)
|Z| > 10 kpc (outside plane&inner halo zone)

The "clean" halo sample contains 1533 stars.

Their distribution, though partly inhomogeneous due to observational constrains, looks like...

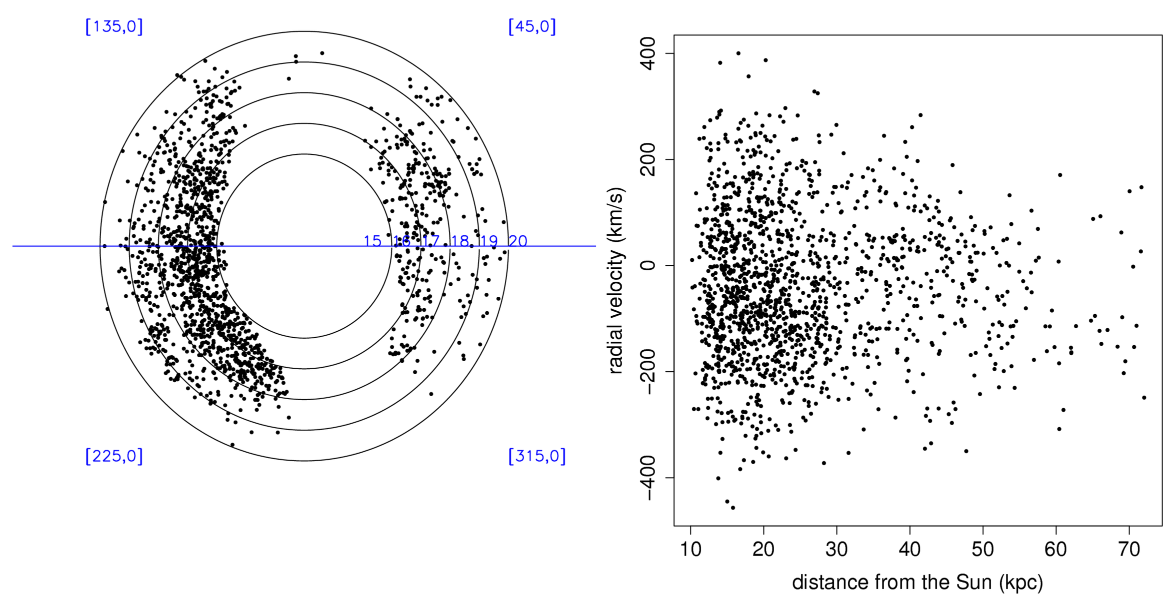
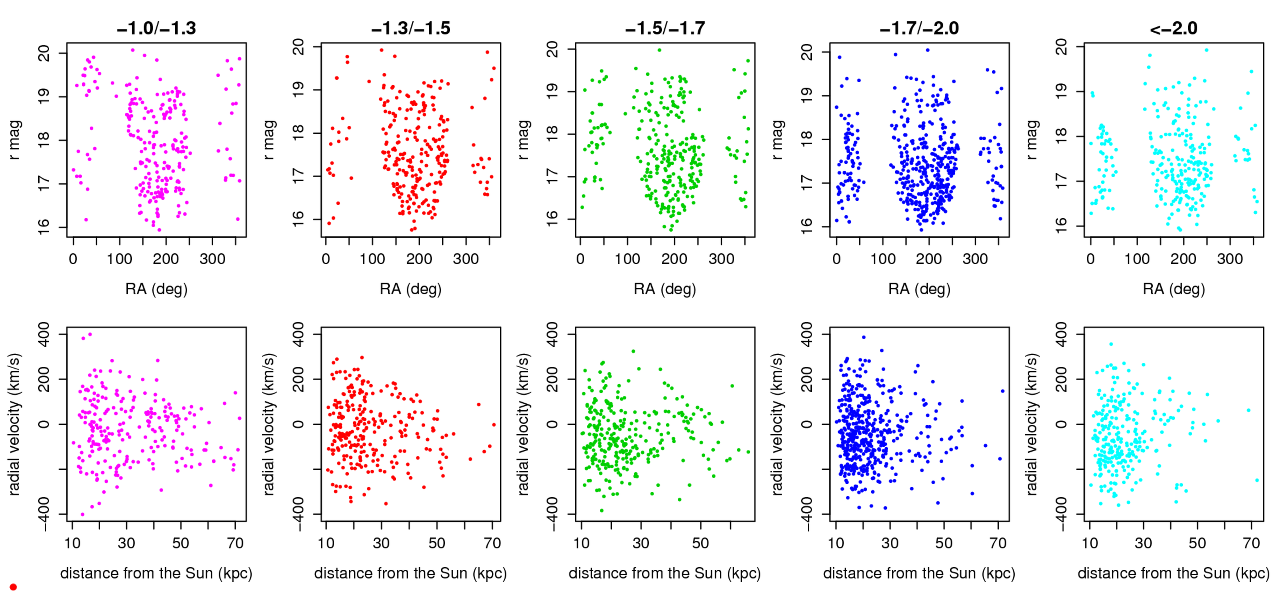


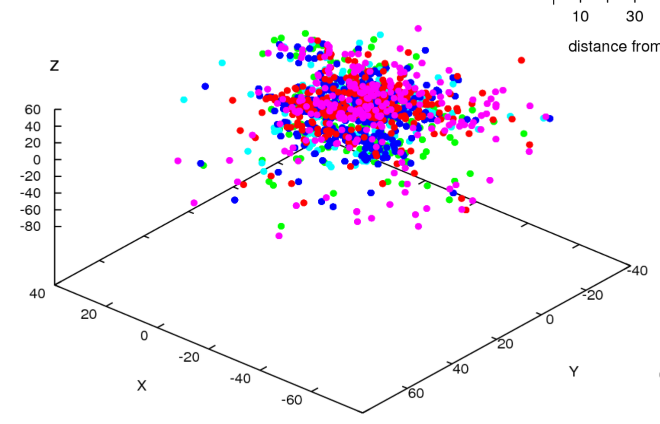
Fig. 4. Polar wedge plot of right ascension vs. r magnitude (left) and distance vs. radial velocity (right) for the 1533 selected tracers.

► not smooth, but clumpy...

WHAT WE FIND: Hints of substructures in the outer halo

Fig. 5. The right ascension vs. r magnitude (upper) and distance vs. radial velocity (lower) distribution for the 1533 selected tracers divided in bins of decreasing metallicities (from left to right).





...and the observed overdensities present coherent metallicities!

Fig. 6. Galactic distribution for the same sample. Different colors highlight stars in the metallicity ranges as in Fig. 5.

Cluster search strategy

1. analysis of RV and [Fe/H] distribution among clumps in position space.

2. quantifying, in comparison to different representative random samples, deviations from a smooth distribution due to substructures by

Two-Point Correlation function:
$\xi = \langle DD \rangle / \langle RR \rangle - 1$
$\langle DD \rangle$:number of pairs of particles in our data with separation less than a given value;
$\langle RR \rangle$: number of pairs of random particles with separation less than *that* given value.

in a 4/5 dimensional space, separation defined by a metric:
M=funct(l,b; d; RV/[Fe/H])

ξ would measure the excess of pairs of stars -likely streams member from a common progenitor- which can spread spatially but have a tight relation between position and velocity at a given location within a given separation, above that expected from a random sample.

CONCLUSIONS

► Based on stellar atmospheric parameters which we have estimated from SDSS spectra we can better select objects for tracing Galactic substructure than by using photometry alone.

► Among this sample of BHB and RR Lyrae stars we found hints of substructures in the outer halo via clumping in spatial, metallicity and RV spaces. Such clumps could indicate stars with a common origin. To confirm and extend this we are developing techniques for quantifying the significance of such overdensities via comparison with models.

► Space astrometric missions, such as Gaia, will collect samples of millions of stars with very accurate positions and kinematics which will dramatically improve the reliability of such conclusions.

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