Properties of the halo

Halo stars are predominantly very old, like the metal poor globular clusters

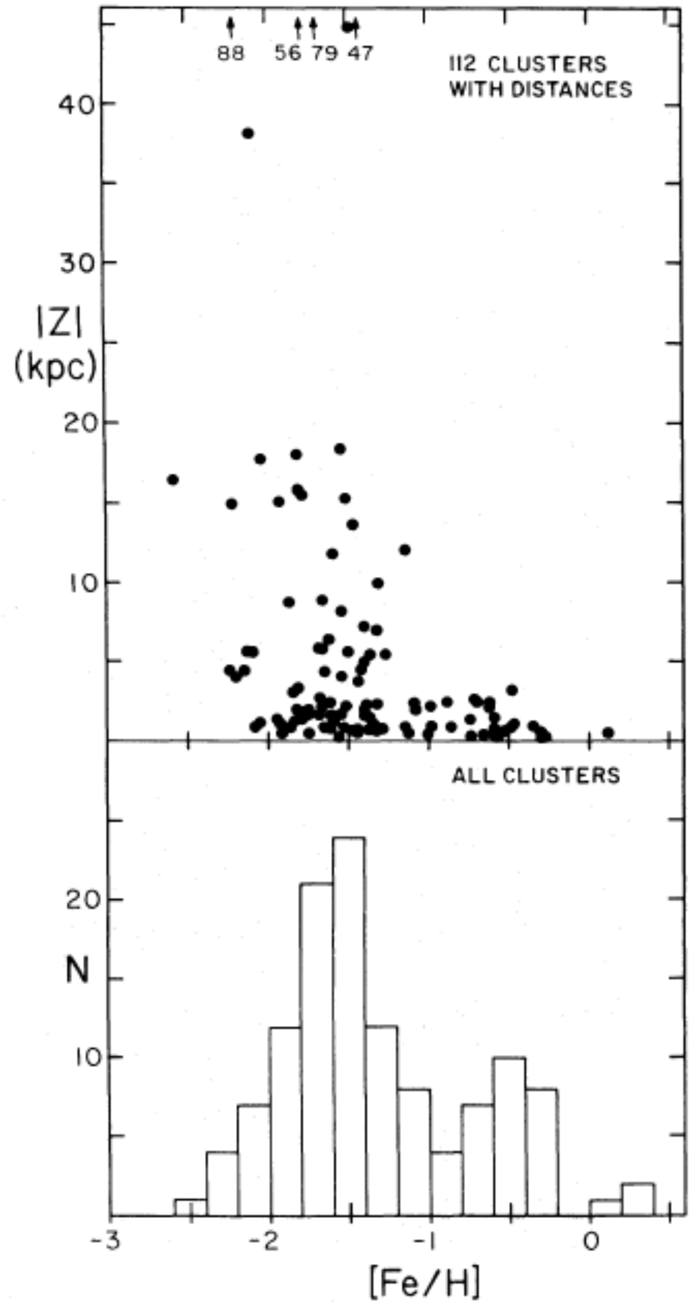
They are metal poor: almost all have $[Fe/H] < -1$

They have a very centrally concentrated density distribution: $\rho \propto r^{-3}$ or even steeper

All of these properties suggest that the stellar halo was part of the earliest stars to form in the Milky Way

Globular clusters

Zinn (1985) showed that most of the globular clusters in the MW belong to the halo, but some are more metal rich and belong to a (thick) disk subsystem



Halo clusters vs field stars

Stars in globular clusters only constitute about 1% of the halo field stars

Field stars in the halo hard to identify because halo stars are so rare: first done via proper motion surveys (why?)

No globular clusters with [Fe/H] less than ~-2.5, while most metal poor known field star has [Fe/H]<-7.0

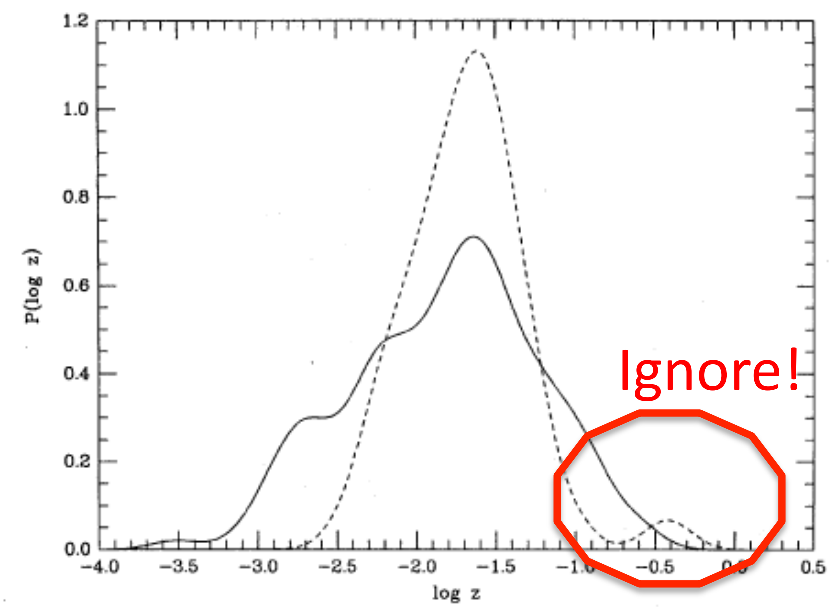


FIG. 16. The generalized metallicity histogram for the globular cluster (dashed line) and field (solid line) samples. The metal-rich bump in the cluster distribution is Terzan 7.

Carney et al 1996, using large proper motion survey for halo stars

Proper motion star samples

Q: Why are proper motion samples particularly well suited to study of the halo metallicity distribution? What are they much less well suited for?

Q: Why do you think I told you to ignore the metal rich end of the metallicity distributions in the Carney et al Figure?

Smooth vs accreted halo

Early views of the halo (informed by small samples with strong selection biases) assumed that it was a smooth population

But ideas from hierarchial galaxy formation theory in the 70s and 80s -- that large objects formed by accretion of smaller ones – gave the expectation that our halo might at least partially be formed by accretion of smaller galaxies

Q: why was this not also an expectation for the thin disk?

The Sagittarius dwarf galaxy

While studying stellar velocities in a bulge/halo transition region, Ibata et al discovered the Sgr dwarf galaxy

It was behind the bulge at the edge of the disk, and tidally distorted!

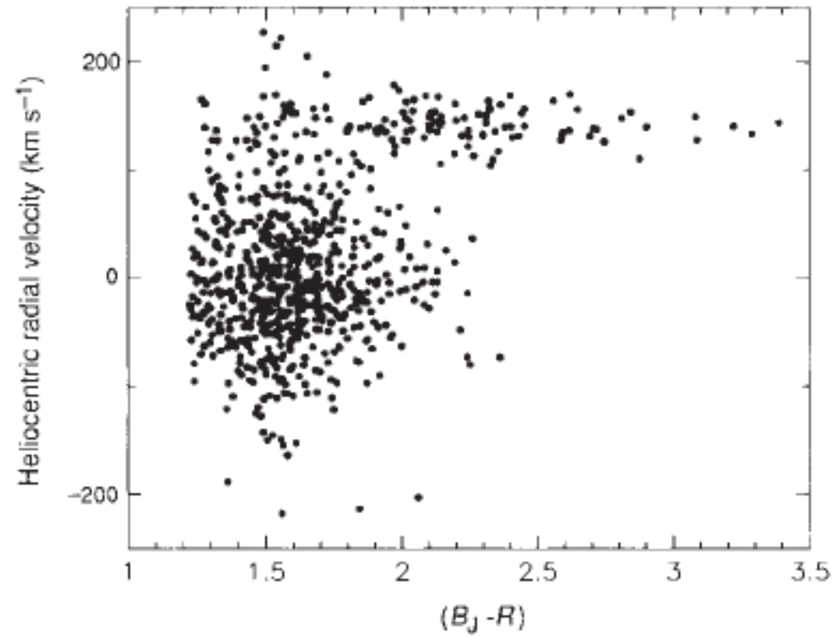
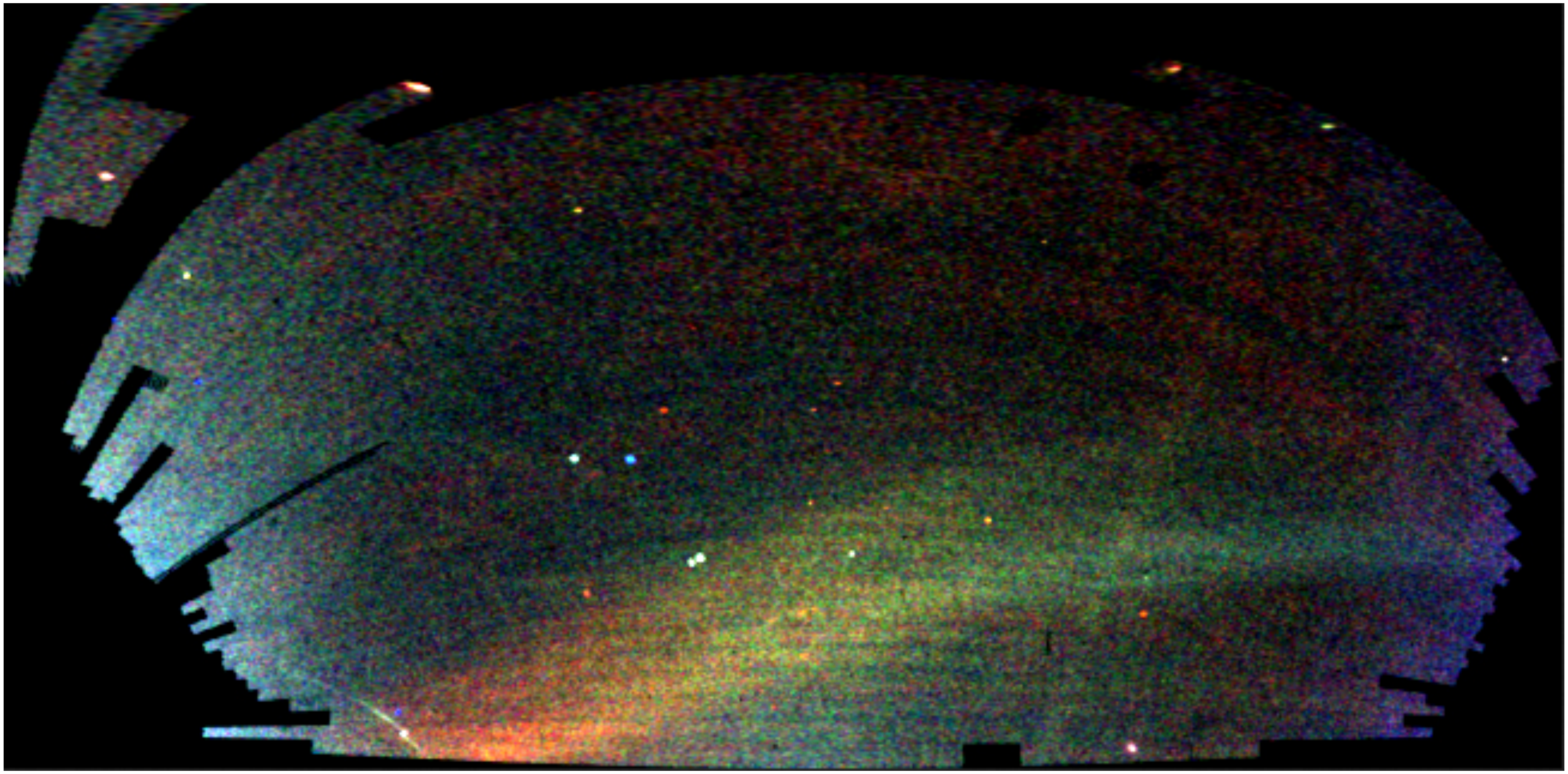


FIG. 1 The heliocentric radial velocity–colour distribution for three selected regions at Galactic coordinates $l=5°$, $b=-12°$, $-15°$ and $-20°$. The population with mean velocity of 0 km s^{-1} and dispersion 70 km s^{-1} is the expected Galactic bulge. There is a clear excess of stars at a common velocity of ~140 km s^{-1} extending to (B_J-R) colours >3. This feature does not appear in any of the other regions for which spectroscopy has been obtained. The excess of stars is most prominent at $l=5°$, $b=-15°$ but is also unambiguously present in the other two regions.

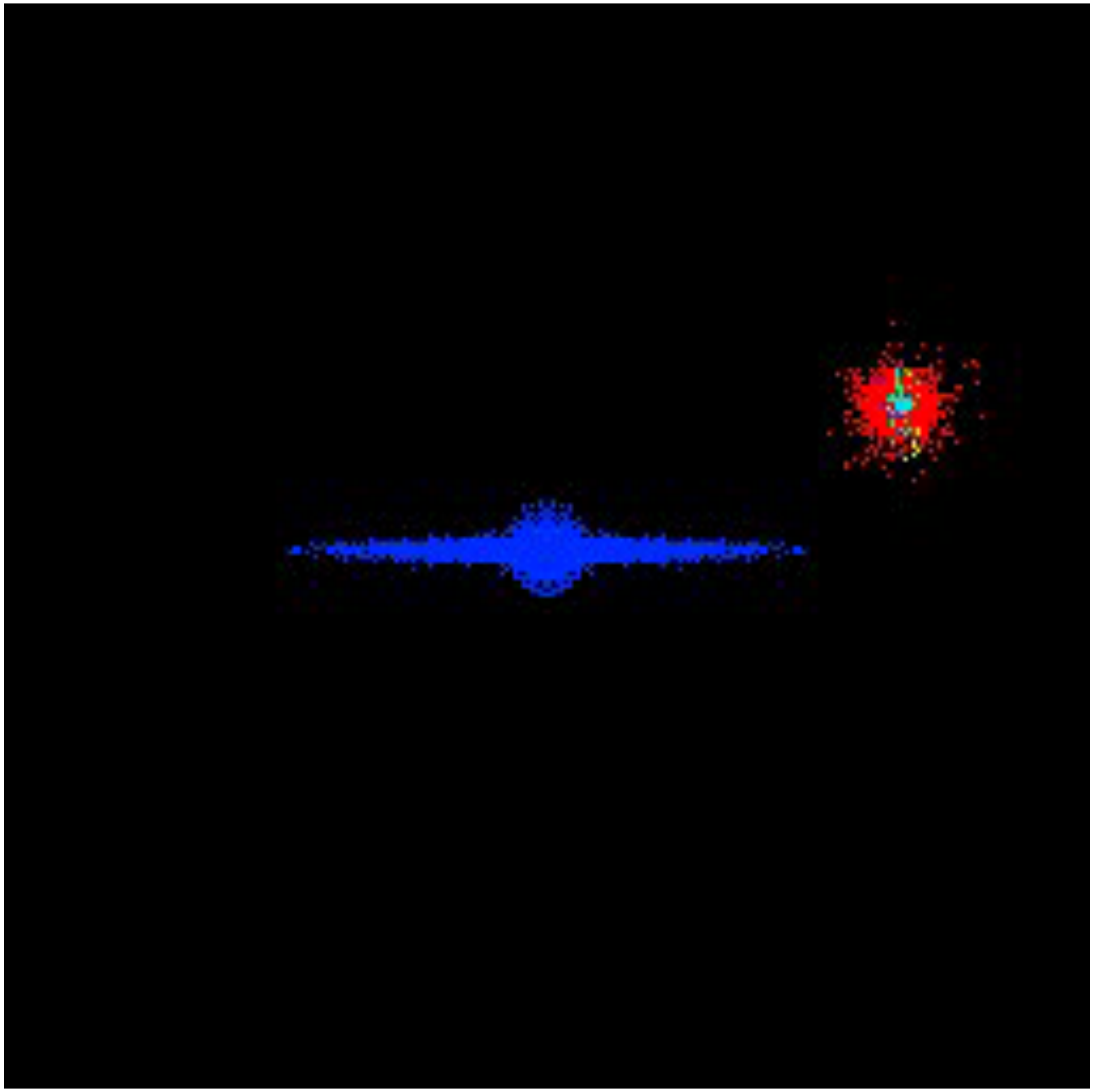
Ibata et al 1994

Sgr is disrupting



Belokurov et al (2006) looked at stars with halo turnoff colors in SDSS data. Major feature is Sgr stream but we also see Monoceros (blue) and Orphan stream and a globular cluster stream at bottom left

Tidal disruption of the Sgr dwarf



Movie from Kathryn Johnston, Columbia

Phase mixing

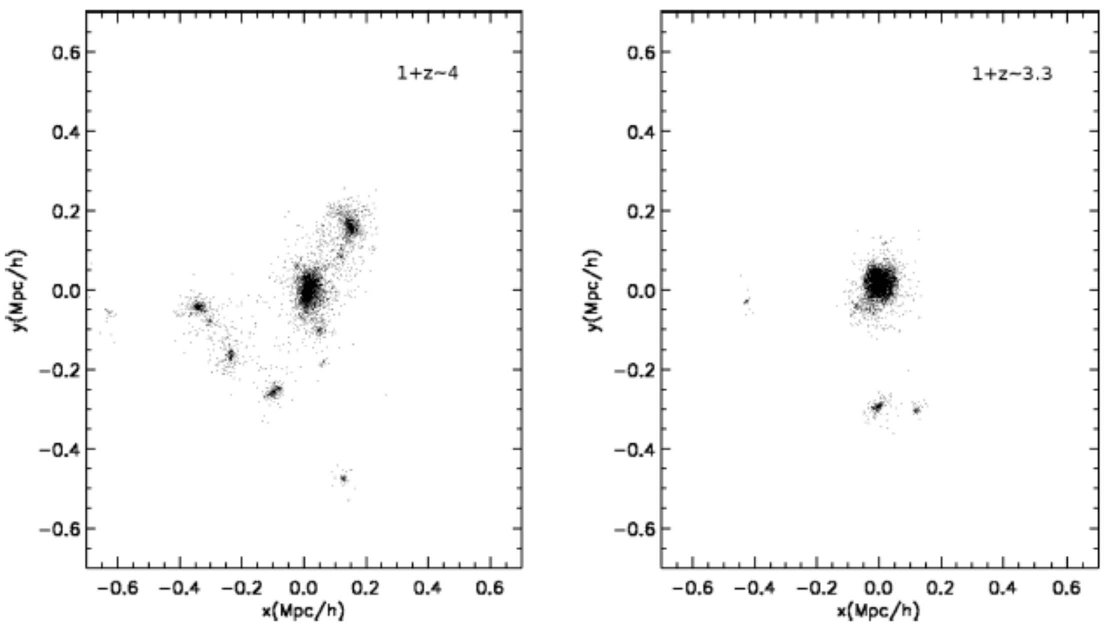
As the Sgr dwarf disrupts in the potential of the Galaxy, orbital energy and angular momentum are conserved, but the stars spread out spatially

Analogy: in a marathon, at the beginning all the runners are in the same place but their velocities vary a lot. After hours, the runners spread out spatially but, at any given position, velocities of runners are similar

Contrast: violent relaxation

If the gravitational potential in which the stars orbit is changing rapidly and strongly, quantities like orbital energy and angular momentum are NOT conserved

We saw this in the Zavala et al simulations of the formation of galaxies: early stages of inner halo formation



Zavala et al 08

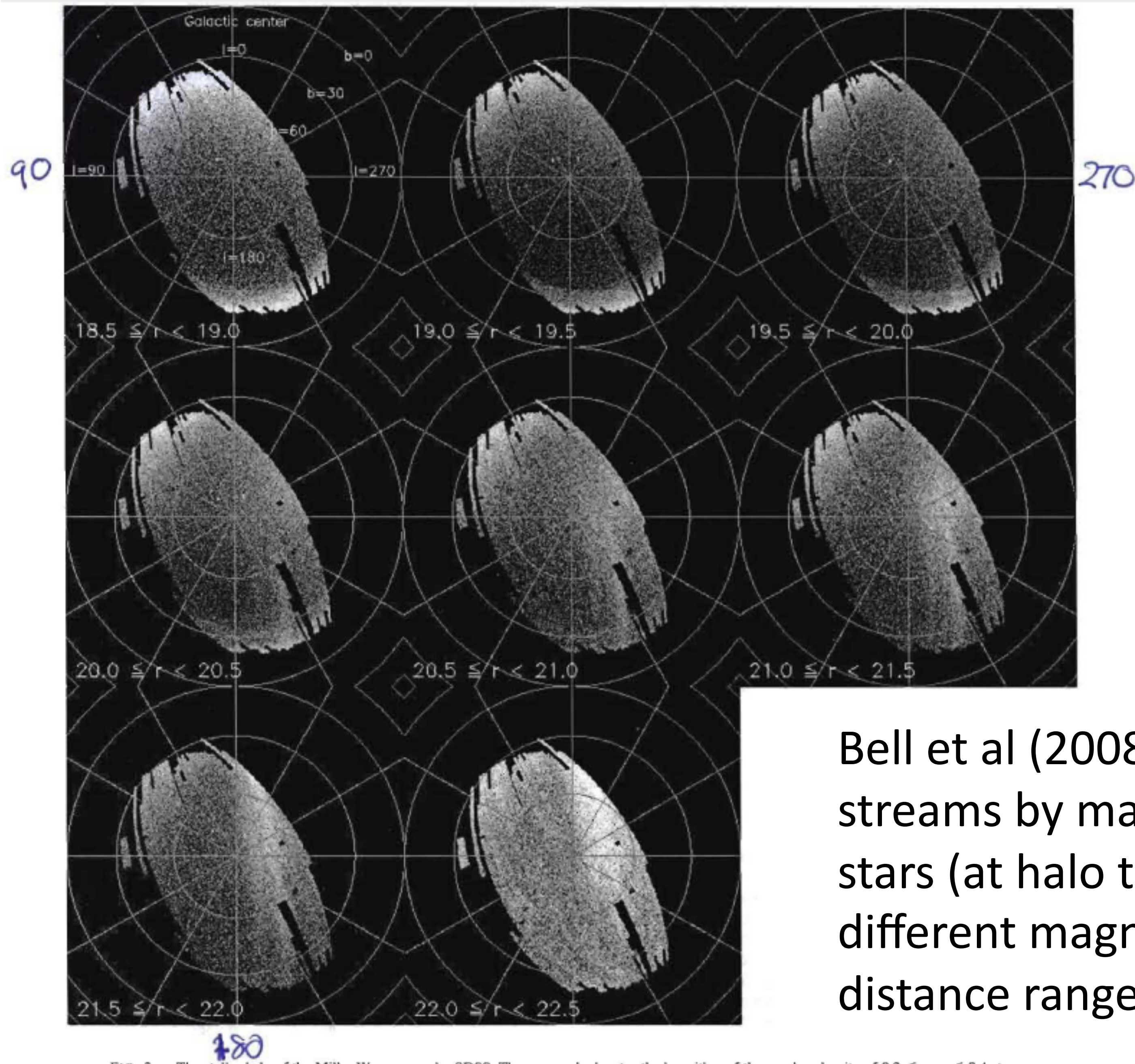


FIG. 3.— The stellar halo of the Milky Way as seen by SDSS. The grey scale denotes the logarithm of the number density of $0.2 \leq g-r \leq 0.4$ stars per square degree in eight different magnitude (therefore mean distance) slices; a Lambert azimuthal equal-area polar projection is used. The black areas are not covered by the SDSS DR5, and reflect the great circle scanning adopted by the SDSS when collecting its imaging data. Apparent 'hot pixels' are stellar overdensities from globular clusters and dwarf galaxies.

Bell et al (2008) show star streams by mapping blue stars (at halo turnoff) for different magnitudes (ie distance ranges)

Halo star kinematics

Kinematics : stellar orbits show a large range in both energy and angular momentum

→ many are quite elliptical

→ roughly as many on prograde and retrograde orbits

→ there is substructure both in their spatial distribution and in the distribution of energy and angular momentum

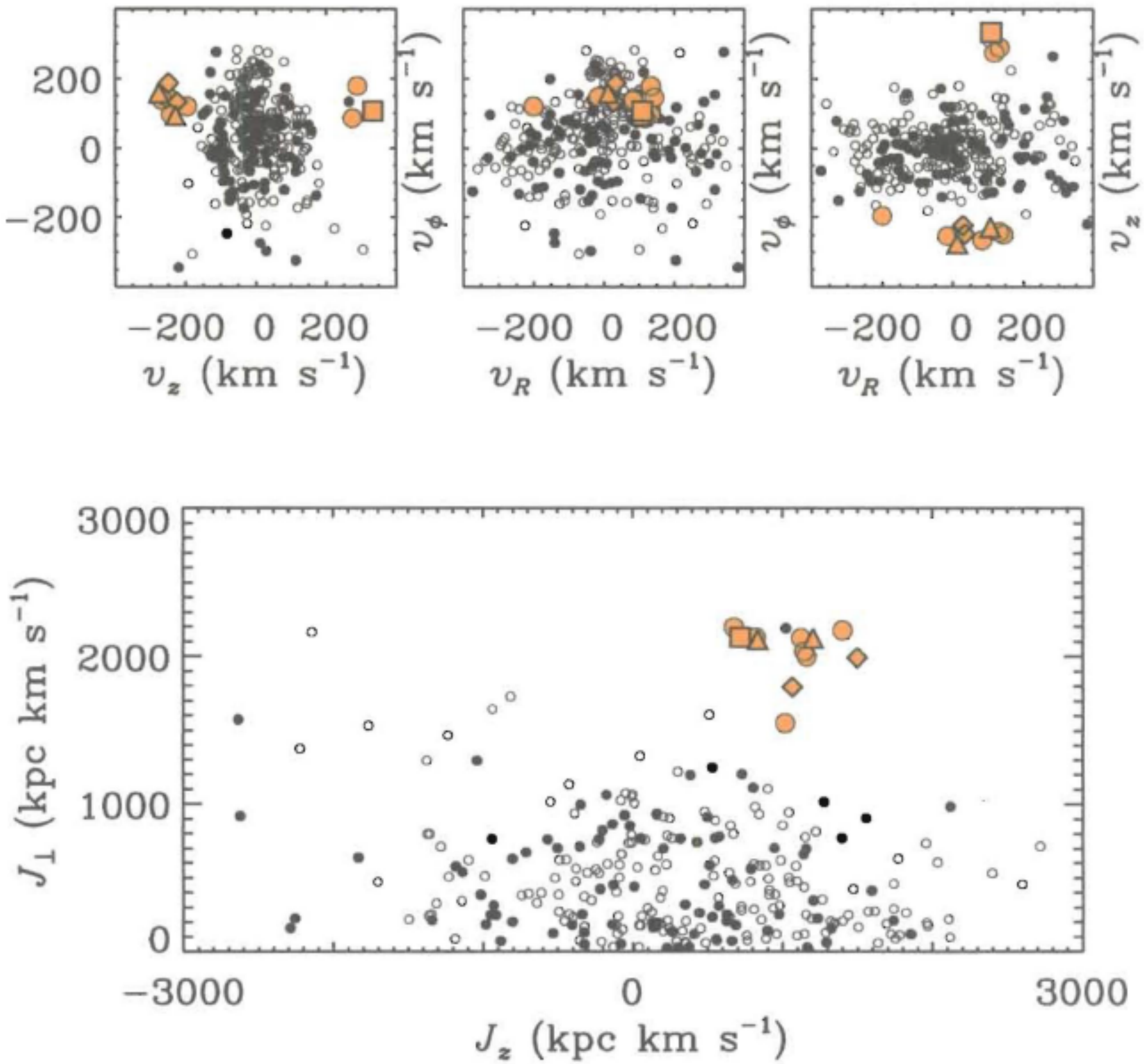
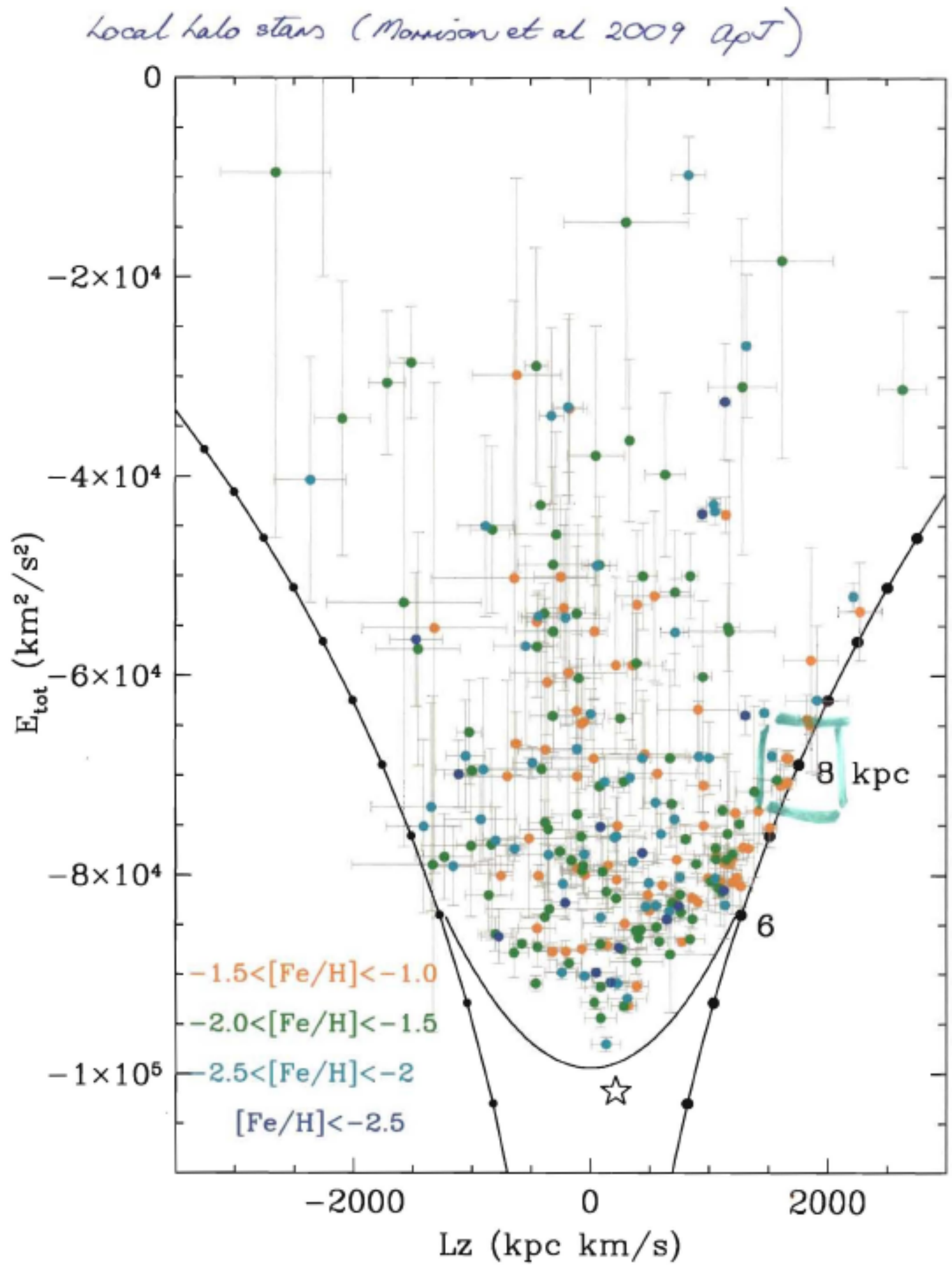


Figure 2: *from Helmi et al 1999*

Energy and angular momentum plot

- For a relatively low mass progenitor, dynamical friction will not apply (why?) so E and L are roughly conserved as stars are accreted into the halo
- E, L distribution is not smooth



Q: is this a situation where violent relaxation played a strong part?

The first star formation in the Milky Way would occur close to its center because the density is highest there.
So part of the inner halo should be formed in this way — in the early, chaotic conditions when stars first formed

Simulations differ a great deal about how far out into the halo the effects of violent relaxation should reach
Our local sample is NOT smooth in E, L and so suggests that it is only inside the Sun's radius that we might see this effect

BUT our dark halo continues to grow ..... new small objects are continually becoming bound to our halo.

These objects disrupt due to tidal effects, leaving star streams throughout the halo.

So the halo is likely to contain some stars formed 'in situ' really early, & others that formed in small satellites elsewhere and were accreted more recently.

Summary

Stars in the halo are rare (~1000:1 disk:halo near the Sun), metal weak and concentrated toward the galactic center

We now know that the debris from the disruption of the Sgr dwarf dominates the outer halo

There are many other streams too

It seems likely that much of the halo was made via accretion from small satellites which then tidally disrupted