Galactic Bulge Science

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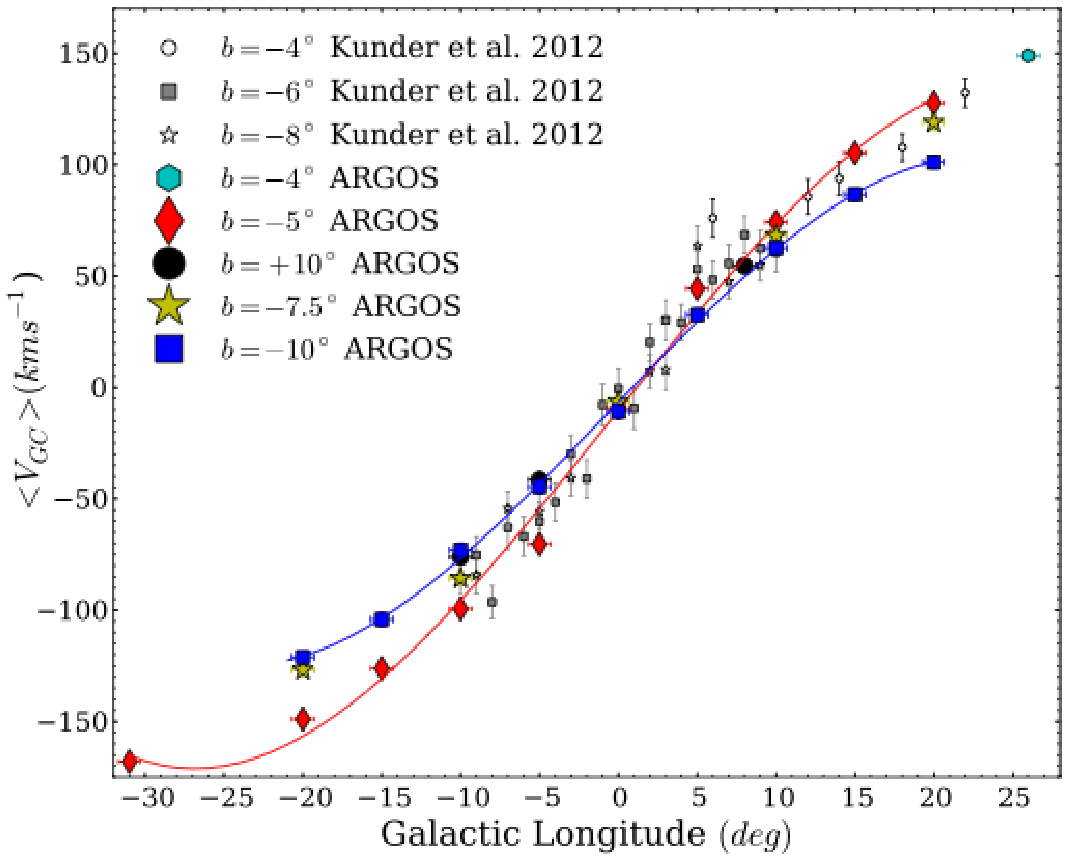
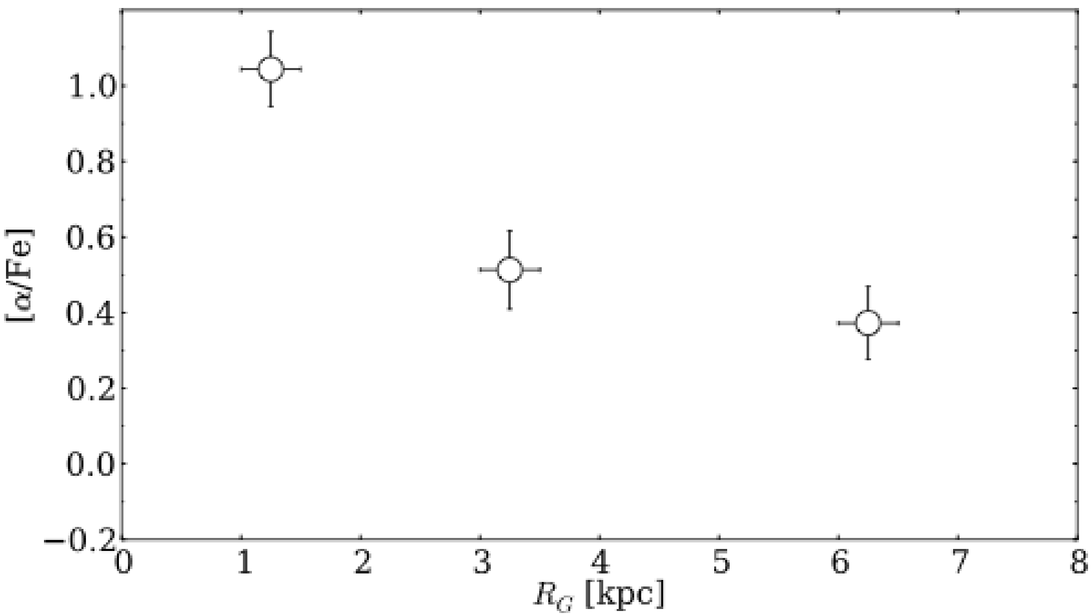
The Galactic bulge was long thought to be a merger product. We now know that boxy bulges like the bulge of the Milky Way are not primarily merger products : they come from bar forming and bar buckling instabilities of the disk itself (Athanassoula 2005, Ness et al 2012). The formation of the bulge is closely related to the inner disk.

To test the theory of the formation of boxy bulges, we need chemical and kinematical observations of large samples of stars throughout the bulge and inner disk. High resolution observations are needed in order to measure a range of elements produced by nuclear processes that have distinct timescales and locations (SNII, SNIa, AGB stars), in order to understand the star formation history and chemical evolution that occurred before and during the formation of the bulge.

The data available already from medium resolution surveys show that the boxy bulge has the characteristic cylindrical rotation pattern predicted by the disk instability picture (e.g. Howard et al 2009, Ness et al 2012). It has so far been difficult to determine whether there is also a minor merger-generated classical bulge component. This is important, because it would affect our understanding of the early evolution of the inner Galaxy. Stellar kinematics cannot answer this question because a small classical bulge is rapidly spun up by the torque of the bar/bulge, and its kinematics become indistinguishable from those of the main bar/bulge itself (Saha et al 2012). Again, we depend on detailed chemical studies of many elements in many stars to identify the presence of a separate classical bulge component.

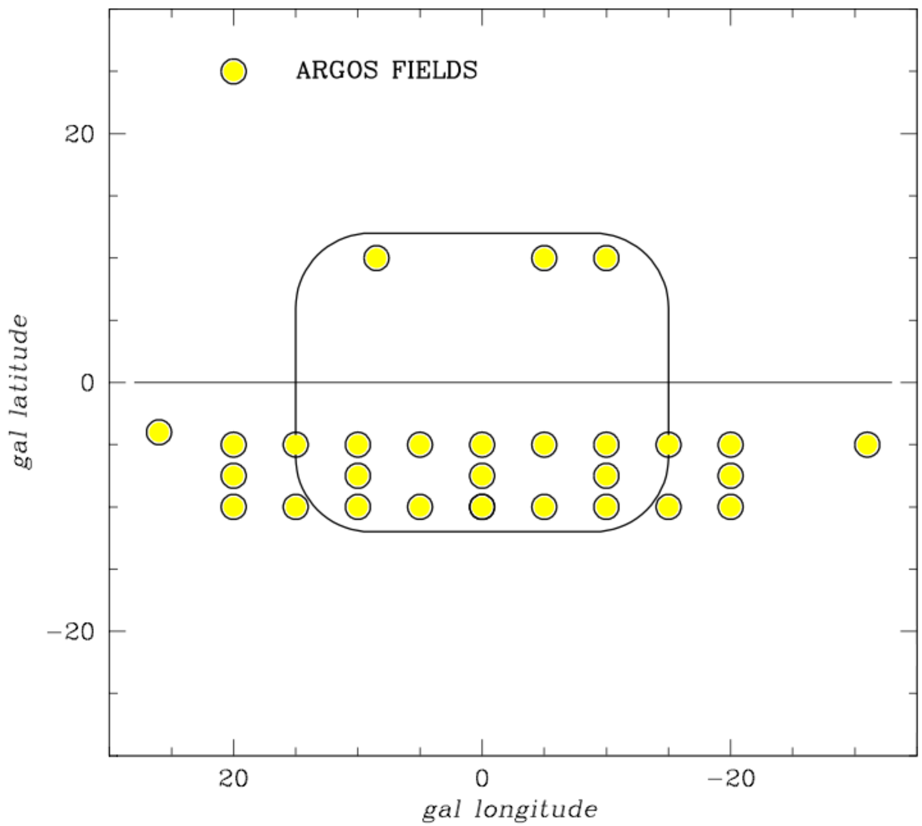


Simulations show that the first stars to form in our Galaxy are likely to be concentrated to the bulge region (e.g. Tumlinson 2010). They are "in the bulge but are not of the bulge". They formed in small overdensities in the early universe at z > 10, before the Galaxy itself had formed, and were subsequently accreted by the Galaxy. Recent medium resolution surveys of the bulge, like the ARGOS/AAT survey (Freeman et al 2012), have identified a population of metal poor stars in the bulge region with metallicities as low as [Fe/H] = −3. These are candidates for the first stars. Detailed high resolution studies of these stars will show whether they are chemically different from the stars of the inner halo which are also expected to be found in this region.



α-enhancement of the 27 most metal-poor ARGOS stars : all have [Fe/H] < -2.0. The innermost stars are the most α-enhanced. Stars that formed at z = 10 are likely to be highly α-enhanced.

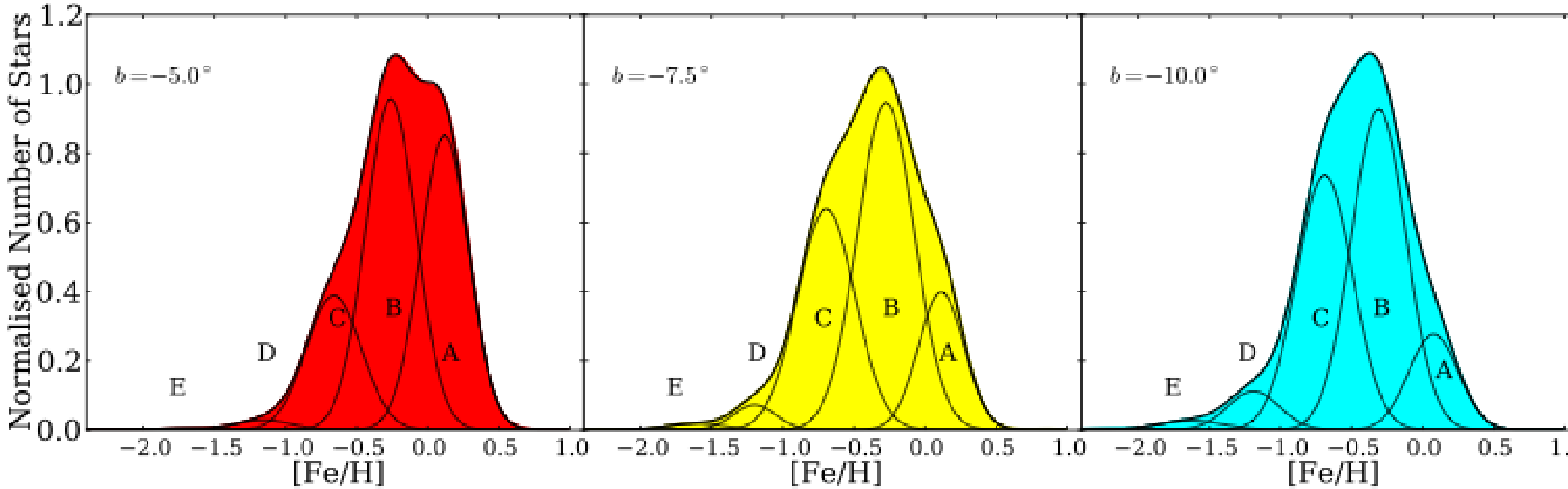
Current state of chemical studies of the Galactic bulge



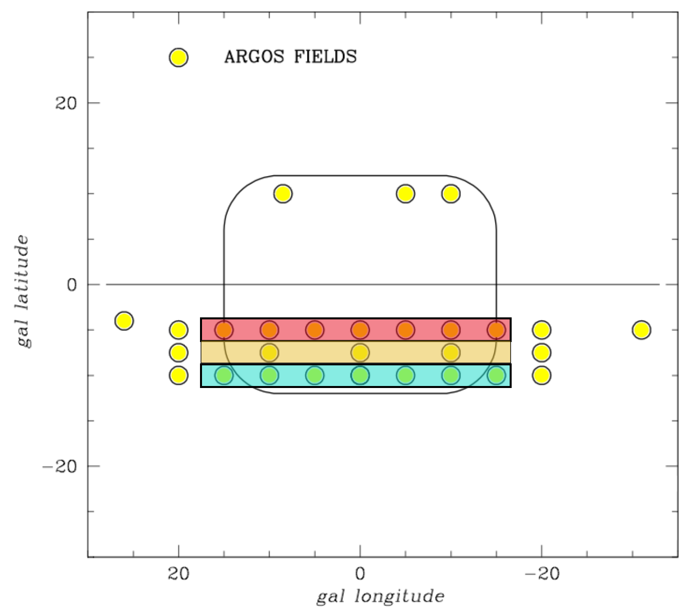
ARGOS (R = 11,000) measured [Fe/H] and [α/Fe] for 28,000 stars in the bulge and adjacent disk. In every field, the MDF shows 3 main components plus two metal-poor components. The fractions change with galactic latitude.

The MDF generalised histograms show 5 components for $R_G < 3.5$ kpc

4200 2000 4000



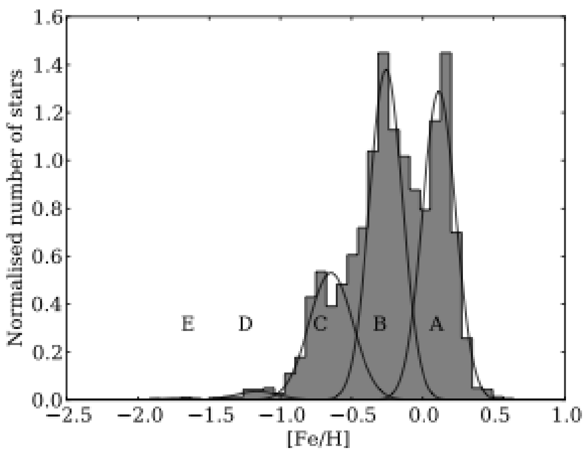
	[Fe/H]
A	0.12 ± 0.02
B	-0.27 ± 0.02
C	-0.70 ± 0.01
D	-1.18 ± 0.01
E	-1.68 ± 0.05



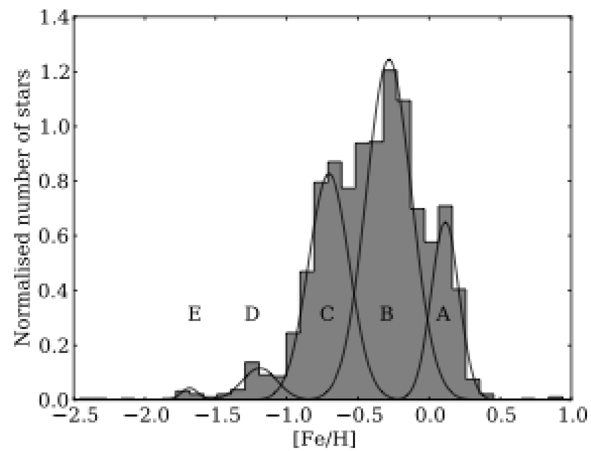
A is strong, C is weak at b = -5°

A is weak, C is strong at b = -10°

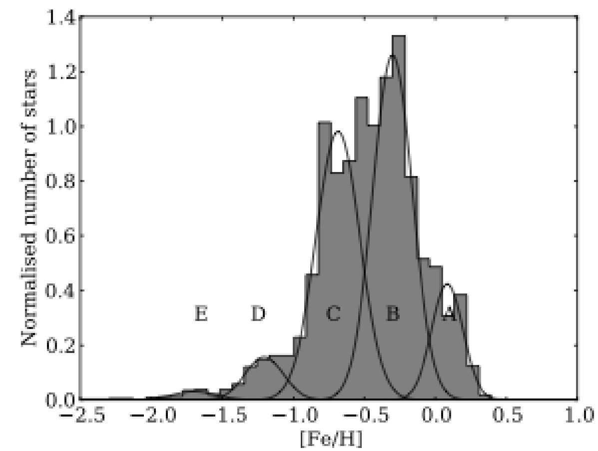
The boxy/peanut structure is defined by A and B only



(a) $l \pm 15°, b = -5°$



(b) $l \pm 15°, b = -7.5°$



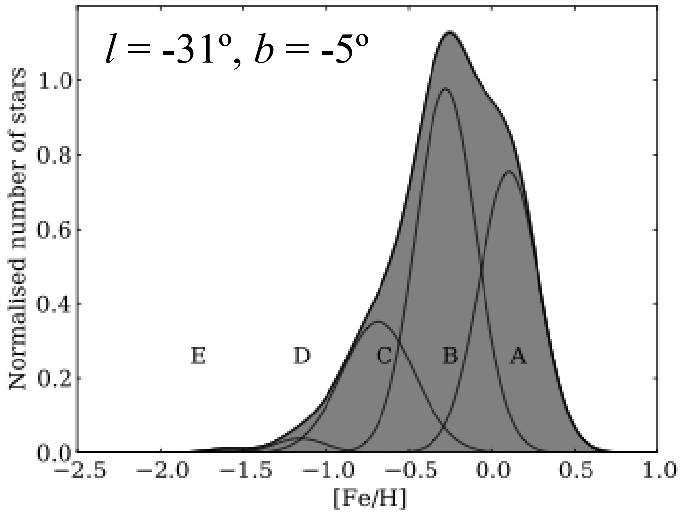
(c) $l \pm 15°, b = -10°$

Same MDFs as conventional histograms with same gaussian components.
$R_G < 3.5$ kpc. See change of relative weights with latitude

Bayesian Information Criterion gives optimal number of components between 4 and 5

These same components are seen all over the bulge and surrounding disk

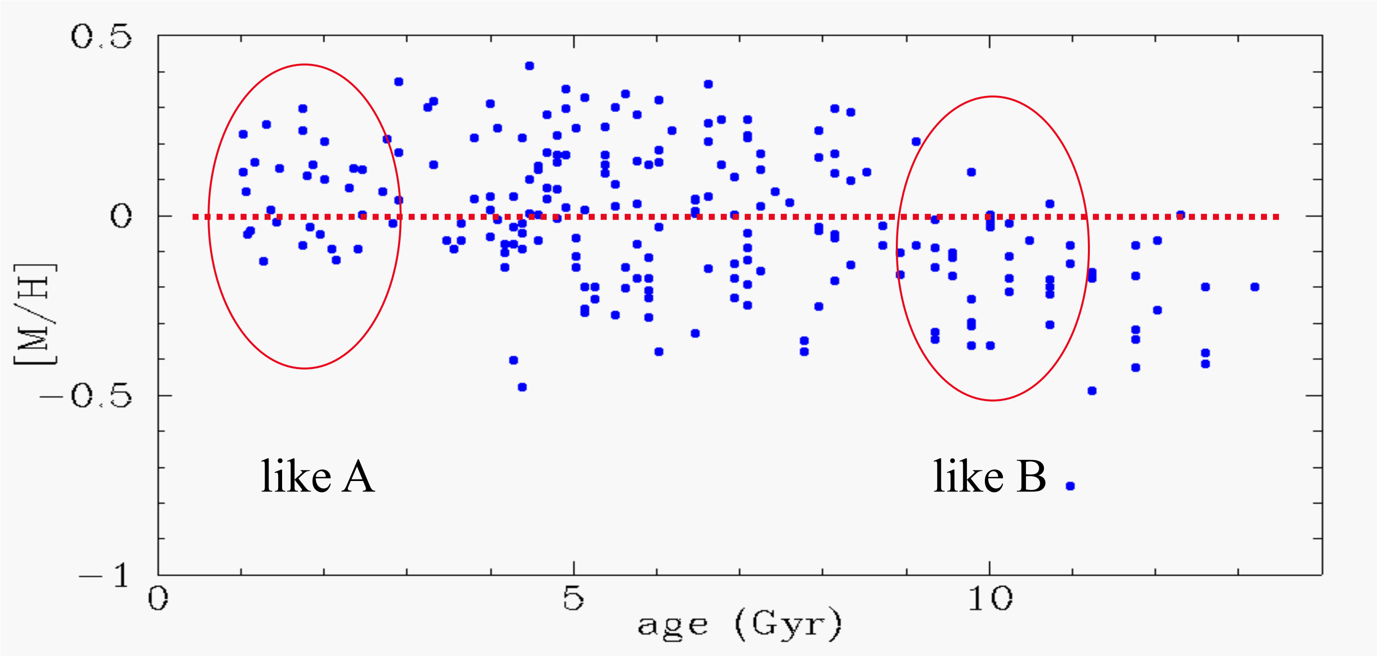
Interpretation of components



The disk took ~ 2 Gyr to evolve chemically and dynamically before going bar-unstable and buckling into the peanut structure, so the components A-C are trapped relics of the Galactic disk from ~ 8 Gyr ago.

The instability process generated a mapping of the stars of the early disk into the boxy/peanut structure. In this way, the bulge preserves a dynamical imprint of the chemical distribution of the disk at the time that the buckling occurred. The bulge is a chemical snapshot of the MDF of the early disk captured in the bar.

The mapping of disk into bulge depends on the location and motions of the stars at the time of the instability. Kinematically colder stars can suffer strong radial and vertical migration, and can therefore be strongly involved in the peanut structure (components A and B).



The age-metallicity relation near the sun

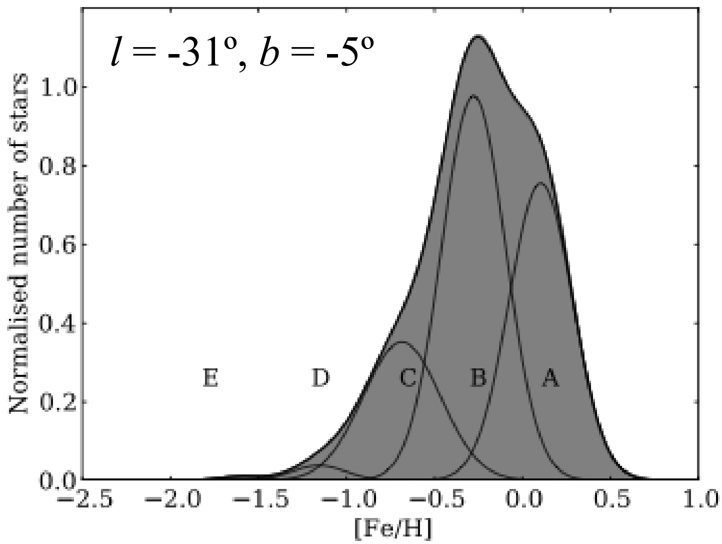
10 Gyr ago, the stars of the disk already had a spread in [Fe/H] from about 0 to -0.5, like component B. The younger disk stars have [Fe/H] values from about +0.4 to -0.1, like component A.

Wylie de Boer & Freeman 2013

A has an MDF like the younger stars of the thin disk near the sun. It is strongly involved in the peanut structure (like B) but is more concentrated to the Galactic plane. Its strong response to the peanut structure could be because it was a bit colder than B (also younger and more metal-rich)

B is the backbone of the peanut structure, with similar fractions at $b = -5^o$ and -10^o. In the instability scenario, it would represent the bulk of the early disk at the time of the bar-forming instability when most of the disk had abundances between about 0 and -0.5

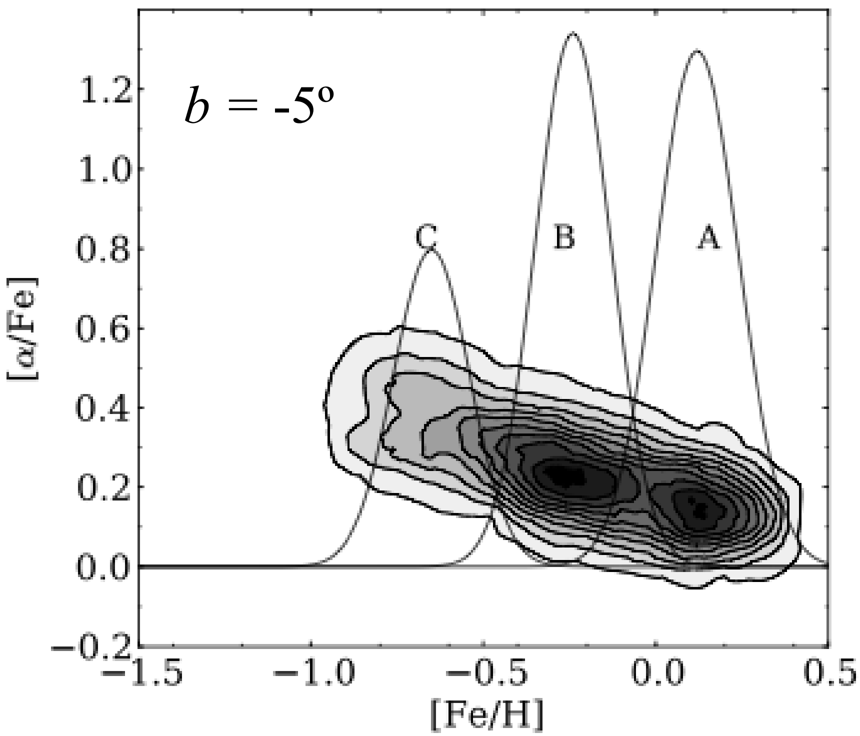
C has an MDF like the thick disk near the sun and we identify it with the early inner thick disk. It was probably present in the inner Galaxy before the instability. It is not involved in the peanut structure because the thick disk is hotter and less responsive.



D and E are likely to be stars of the inner halo

The next step is to make a large high resolution survey of bulge stars. High resolution spectroscopy of bulge giants gives abundances of elements from a wide range of element groups (light elements, alpha elements, Fe-peak and n-capture elements). This will provide more insight into the formation and chemical evolution of the bulge than is available from the limited current data for large medium-resolution surveys which give only [Fe/H] and [α/Fe].

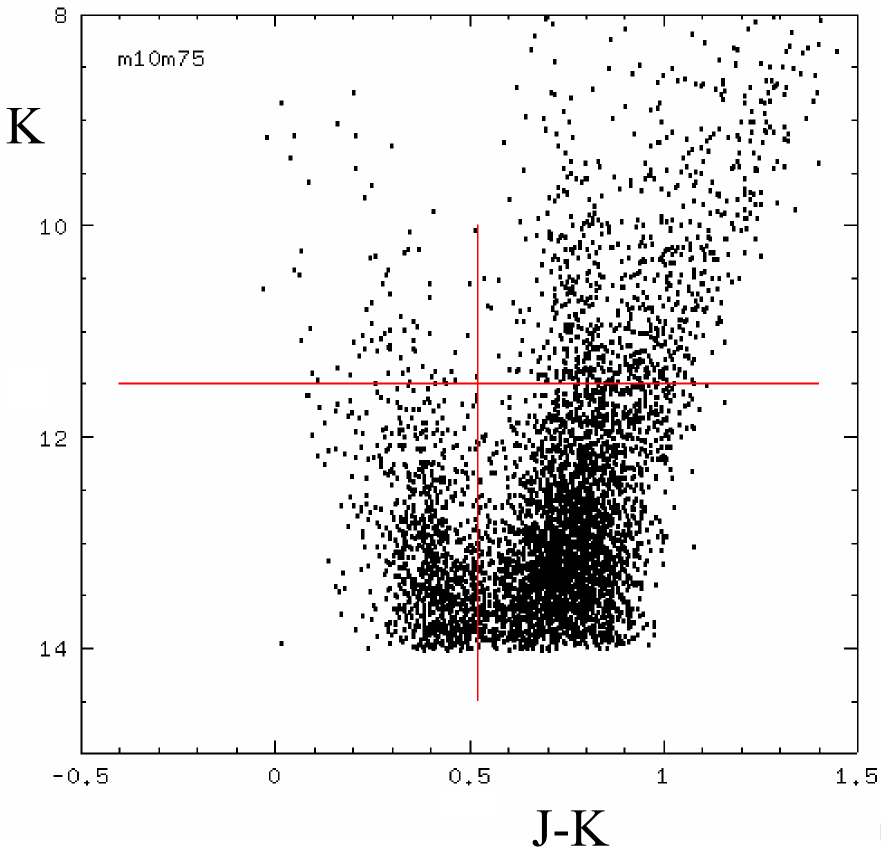
At the distance of the bulge, medium to high resolution spectroscopy of large samples of bulge stars is possible only for stars on the giant branch (except for the relatively rare bulge dwarfs that are being microlensed at any time). The primary targets for largescale high resolution spectroscopy of bulge stars are therefore likely to be the very abundant clump giants.



Essential to estimate distances to reduce contamination of bulge sample by foreground and background stars. Clump giants are ideal - accurate high resolution stellar parameters are needed to identify them. Distance errors of 0.7 kpc can be achieved. From the ARGOS survey, 28,000 stars was insufficient to map the [Fe/H] and [α/Fe] distribution: about 200,000 stars are needed.

Selection criteria should not exclude metal-poor giants.

A large high resolution survey of bulge giants is out of reach for existing telescopes. It needs a 10-m widefield dedicated facility



Bulge science with the ngCFHT

A high resolution survey of about 200,000 bulge giants

Assume 1-degree field, 800 high resolution fibers, 3600 sec gives SN = 120 at g = 18, R = 20,000

Will argue in next talk that there are real gains in having higher resolution: R ~ 45,000 - limiting magnitude need be only 0.5 mag fainter, so 3600 sec would give SN = 95 at g = 18, R = 45,000

Several MOS systems will soon be capable of R = 20,000 spectroscopy. ngCFHT will be largest telescope. g ~ 18 is out of reach for the 4-m telescopes. The ngCFHT niche is a large high resolution survey of the bulge accessible from Mauna Kea (the $l > 0$ part). Density of stars is high : plenty of stars within 1° field to fill 800 fibers.

Observational goal is to measure abundances of wide range of elements for stars in bulge and surrounding disk. The scientific goal is to understand the chemical evolution of the inner Galaxy in the context of the bulge formation event and its subsequent evolution.

From the medium-resolution ARGOS survey, it was clear that 28,000 stars is not enough to properly characterize the metallicity distribution function (MDF) variations over the bulge. To adequately investigate the detailed complexities of the MDF in the inner Galaxy, a sample of about 200, 000 stars is needed, covering the accessible regions of the bulge and inner disk. The relatively large field of the ngCFHT and the large number of fibers make it possible to consider a survey on this scale. It would be a great step forward in assessing the chemical state of the inner Galaxy.

The high resolution spectra would allow measurement of accurate radial velocities which could be useful for detecting very cold kinematic substructures in the inner galaxies if such substructures are present. They would be likely relics of gas infall and star formation in the inner Galaxy, or debris of small dense galaxies accreted by the Milky Way. A high resolution survey on this scale may also allow the chemical tagging of dispersed substructures which are no longer visible kinematically.