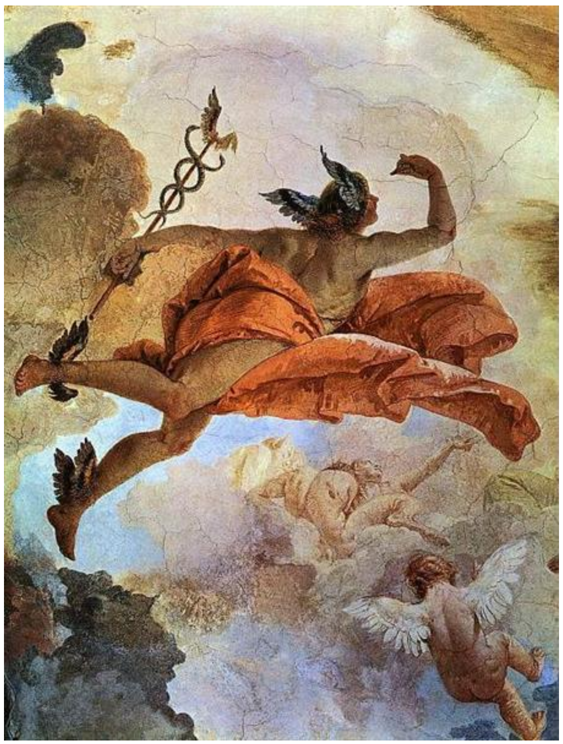
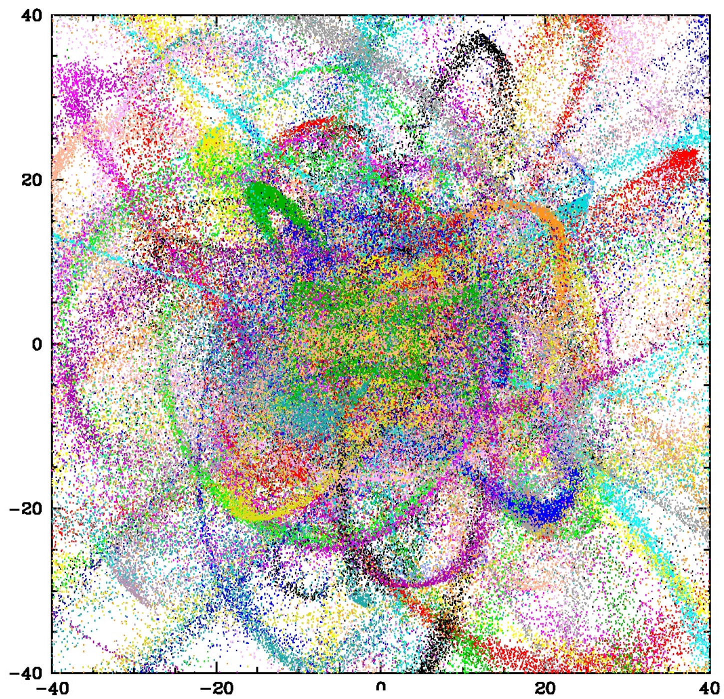
The HERMES project

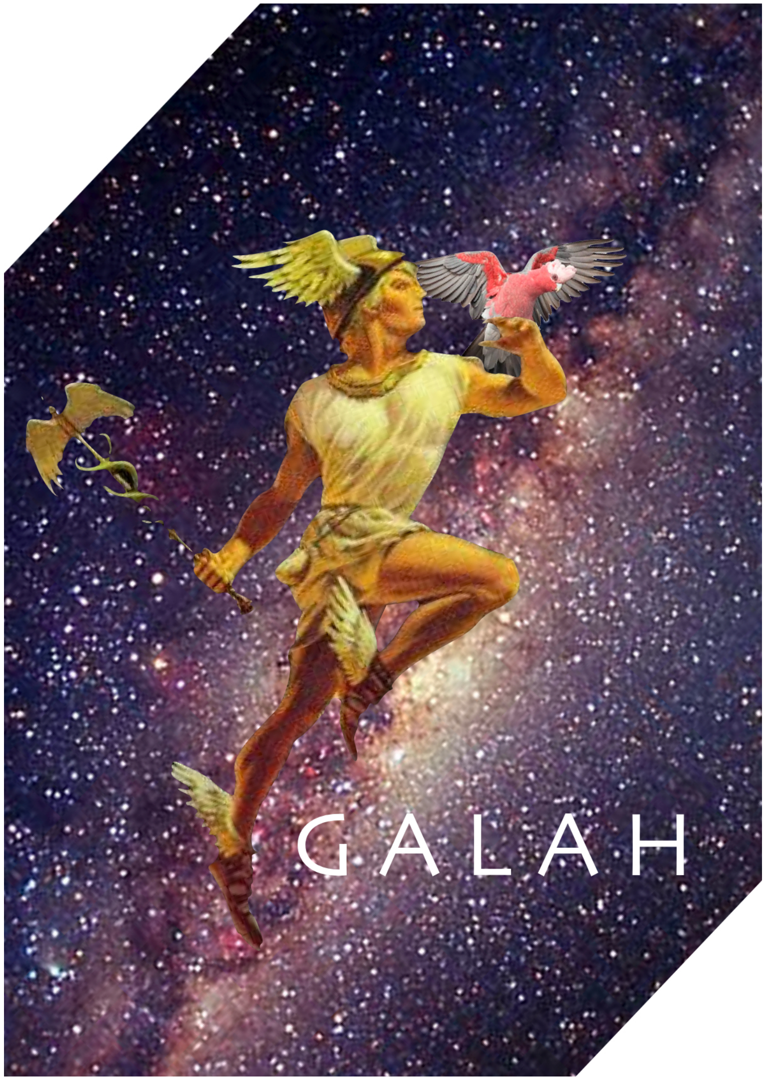
Reconstructing Galaxy Formation

Ken Freeman
RSAA, ANU



The metallicity distribution
in the Milky Way discs
Bologna
May 2012





HERMES is a new high-resolution fiber-fed multi-object spectrometer on the AAT

- spectral resolution 28,000 (also R = 45,000 mode)
- 400 fibres over π square degrees
- 4 bands (BGRI) ~ 1000 Å
- First light late 2012

Main driver: the GALAH survey (Galactic Archaeology with HERMES)

Team of about 40, mostly from Australian institutions

The goals of galactic archaeology

Aim to reconstruct the star-forming aggregates that built up the disk, bulge and halo of the Galaxy

Some of these dispersed aggregates (clusters, accreted galaxies) can be still recognised kinematically as stellar moving groups.

For others, the dynamical information was lost through disk heating and mixing processes, but they are still recognizable by their chemical signatures (chemical tagging).

A major goal is to identify
how important mergers and accretion events were
in building up the Galactic disk and the bulge.

CDM predicts a high level of merger activity which conflicts
with some observed properties of disk galaxies.

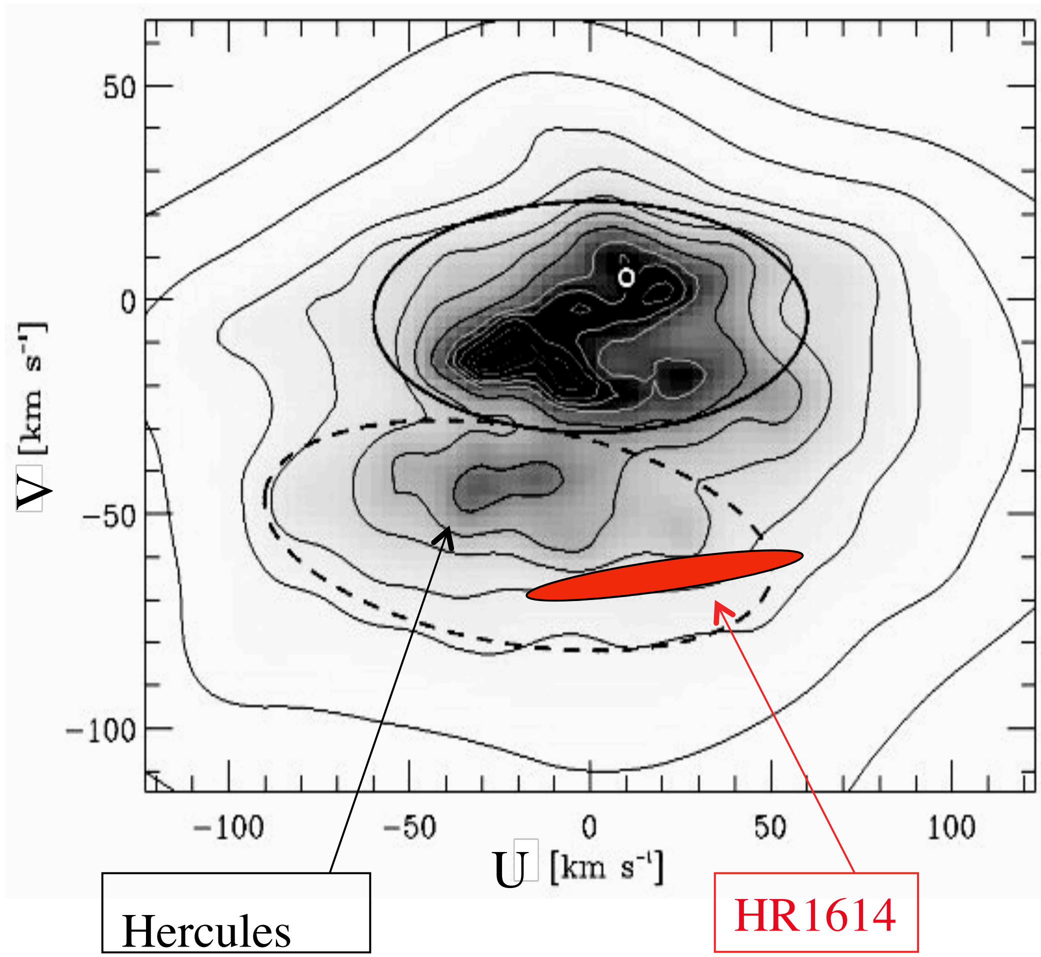
Try to find the debris of groups of stars, now dispersed,
that were associated at birth, either

- because they were born together in a single Galactic star-forming event, or
- because they came from a common accreted galaxy.

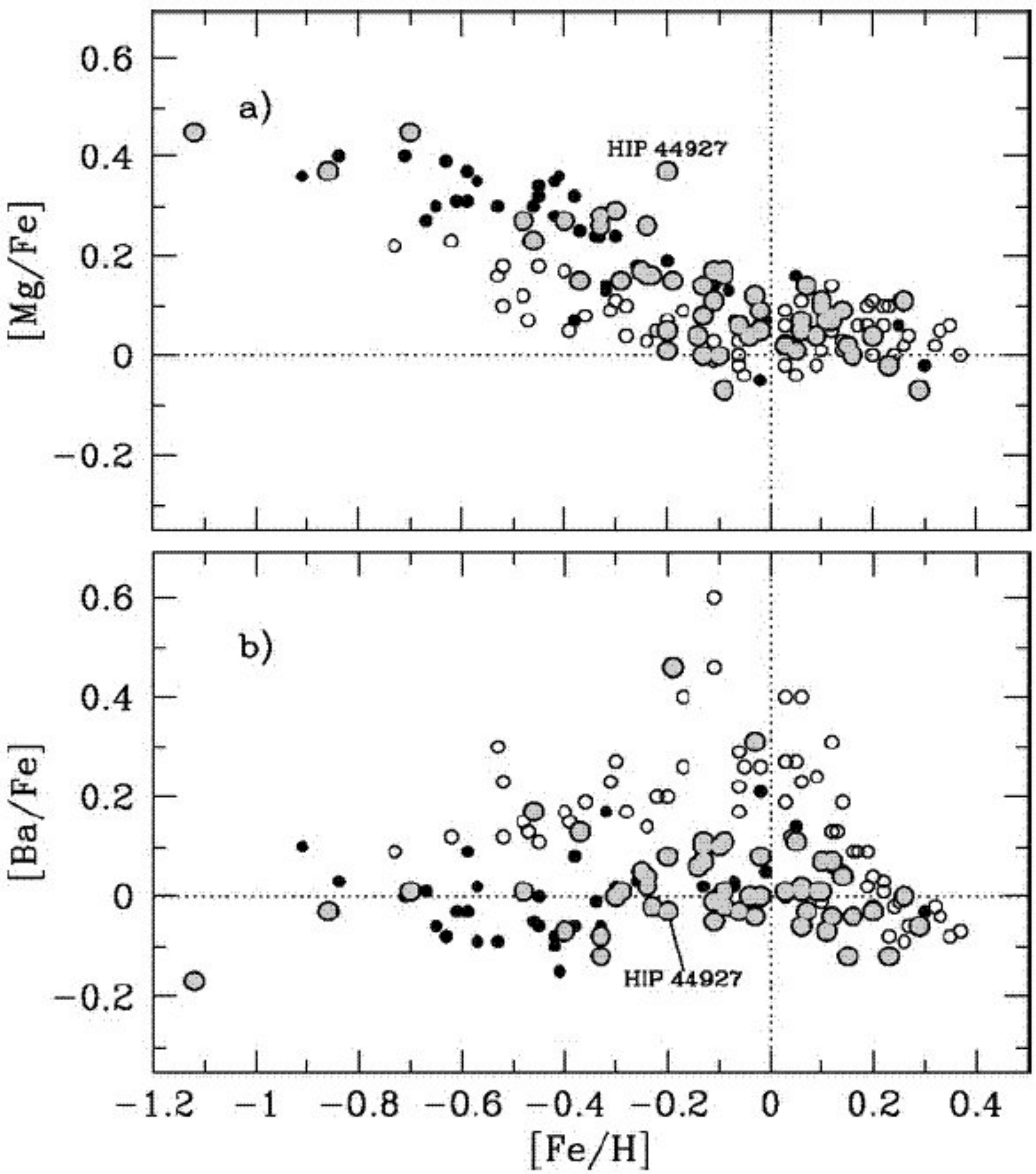
Galactic halo shows kinematical substructure - believed to be the remains of accreted objects that built up the halo

The galactic disk also shows kinematical substructure : usually called moving stellar groups. The stars of the moving groups are all around us

- Some are associated with dynamical resonances (bar) or spiral structure (eg Hercules moving group)
- Some are debris of star-forming aggregates in the disk (eg the HR1614 and Wolf 630 moving groups), partly dispersed into extended regions of the Galaxy
- Others may be debris of infalling objects, as seen in ΛCDM simulations (Arcturus group ?)



De Silva et al 2007

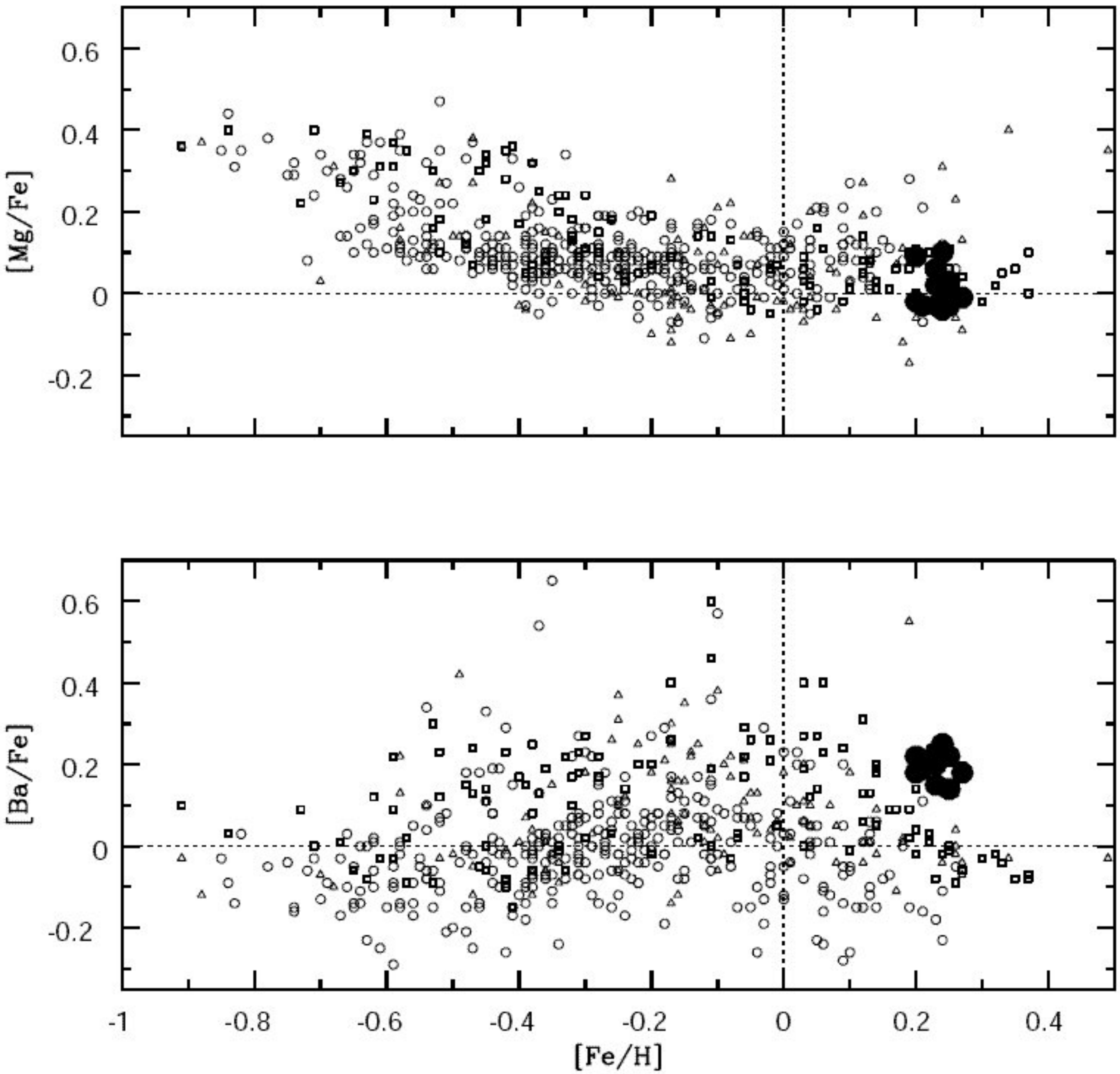


○ Hercules group

• o Field stars

The chemical abundances of Hercules Group stars cannot be distinguished from the field stars. This is a *dynamical* group, not the relic of a star forming event.

Bensby et al 2007



- HR 1614
- o field stars

The HR 1614 stars (age 2 Gyr) are chemically homogeneous. They are probably the dispersed relic of an old star forming event.

De Silva et al 2007

Although the disk does show some surviving <u>kinematic</u>
substructure in the form of moving stellar groups,
a lot of dynamical information was lost
in the the subsequent heating and radial mixing
by spiral arms and
giant molecular clouds.

Most dispersed aggregates would not now be recognizable dynamically

However ... we are not restricted to dynamical techniques.
Much fossil information is locked up in the
detailed distribution of chemical elements
in stars.

Chemical Tagging

Use the detailed chemical abundances of stars to tag or associate them to common ancient star-forming aggregates with similar abundance patterns (eg Freeman & Bland-Hawthorn ARAA 2002)

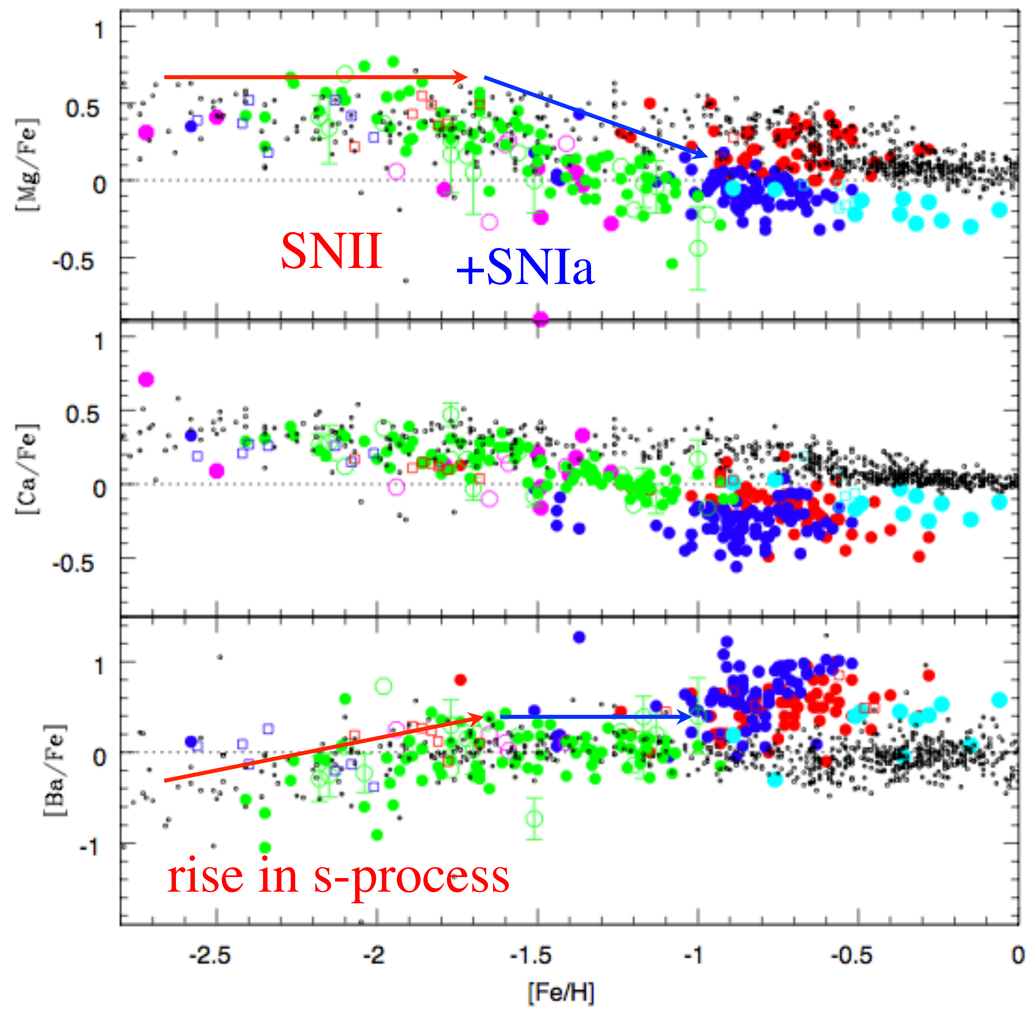
The detailed abundance pattern reflects the chemical evolution of the gas from which the aggregate formed.

Chemical studies of the old disk stars in the Galaxy can help to identify disk stars that are the debris of common dispersed star-forming aggregates and also those which came in from outside in disrupting satellites

The detailed chemical properties of surviving satellites (the dwarf spheroidal galaxies) vary from satellite to satellite, and are different from the overall properties of the disk stars.

Evolution of abundance ratios reflects different star formation histories

Venn (2008)



LMC Pompeia, Hill et al. 2008
Sgr Sbordone et al. 2007
Fornax Letarte PhD 2007
Sculptor Hill et al. 2008 + Geisler et al. 2005
Carina Koch et al. 2008 + Shetrone et al. 2003
Milky-Way Venn et al. 2004

We can think of a chemical space of abundances of elements Na, Mg, Al, Ca, Mn, Fe, Cu, Zr, Ba, Eu … for example (25 measurable elements with HERMES). The dimensionality of this space is 8 to 9.
Most disk stars inhabit a sub-region of this space.

Stars from chemically homogeneous aggregates will lie in tight clumps In C-space.

Stars which came in from satellites may be different enough to stand out from the rest of the disk stars in chemical space.

With this chemical tagging approach, we may be able to detect or put observational limits on the satellite accretion history of the galactic disk

Wylie de Boer et al (2010) have already used the chemical peculiarities of ω Centauri to identify field stars that were probably stripped from it or its parent dwarf galaxy when it was accreted by the Milky Way.

For chemical tagging to work in reconstructing the star formation history of the disk ….

- stars form in large aggregates - believed to be true
- aggregates are chemically homogenous
- aggregates have unique chemical signatures defined by several elements which do not vary in lockstep from one aggregate to another. Need sufficient spread in abundances from aggregate to aggregate so that chemical signatures can be distinguished with accuracy achievable (~ 0.05 dex differentially)

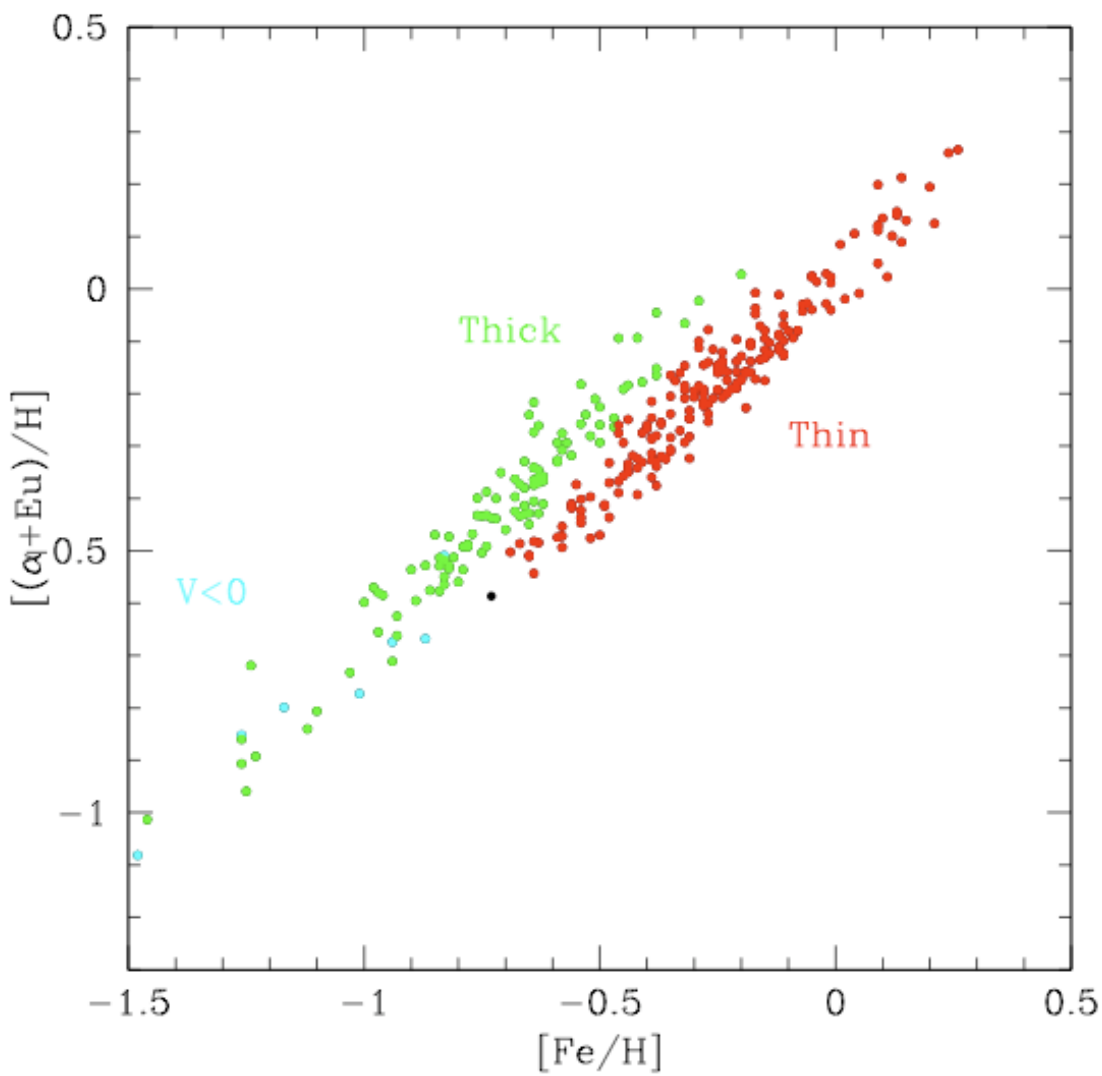
The last two conditions appear to be true:
see e.g. G. de Silva et al (2009), Pancino et al (2009)
Internal metallicity distributions have measured dispersions
$\sigma \sim 0.02$ to 0.07

Chemical tagging is not just assigning stars chemically to a particular population (thin disk, thick disk, halo)

Chemical tagging is intended to assign stars chemically to a common origin in substructure which is no longer detectable kinematically.

Chemical tagging needs a high resolution spectroscopic survey of about 10^6 stars, homogeneously observed and analysed….. this is a prime science driver for HERMES

The Galactic thick disk could be particularly interesting ...



[(α + Eu)/H] vs [Fe/H] for thin and thick disk stars near the sun

The thick disk is chemically distinct

Navarro et al (2010), Furhmann (2008), Bensby (2004)

Thick disks are very common in other galaxies: they provide about 10% of the disk mass in large spirals, and are old (> 8 Gyr) and moderately metal-poor. Their formation is not yet understood. Some possible formation routes:

- heating of the early stellar disk by accretion events or minor mergers
- stellar debris of ancient merger events
- star formation associated with early large gaseous accretion events
- radial migration of kinematically hot stars from inner Galaxy
- dissolution of giant clumps in high-z galaxies

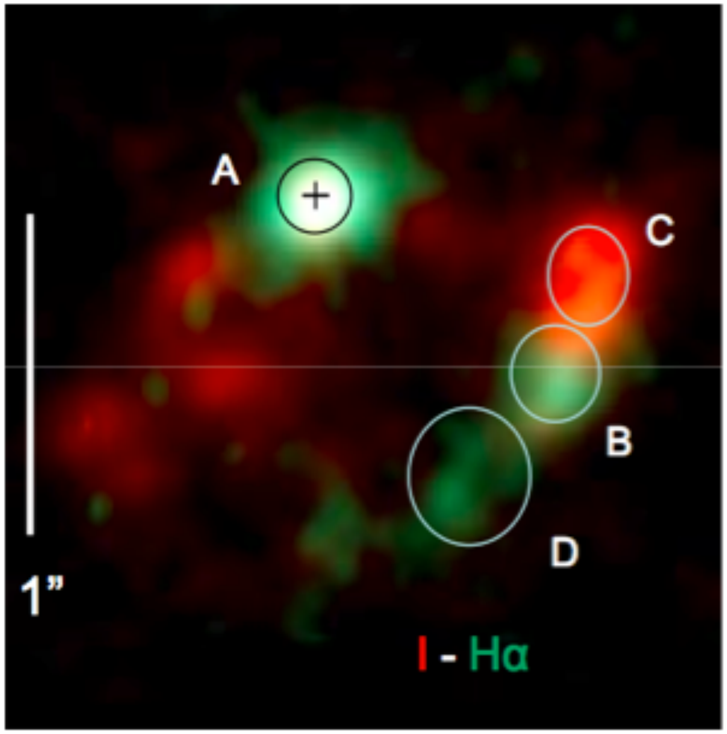
The clump cluster galaxies

Many high-z galaxies show massive starbursting clumps: masses up to 10^9 $M_\odot$ and star formation rates of ~ 20 $M_\odot$ yr^{-1}.

These clumps are short-lived (< 10^8 yr) and may disperse to form the thick disk (Bournaud et al 2009). If this is correct, the thick disk would have formed from a relatively small number of clumps.

If these massive clumps were chemically homogenous (e.g. Bland-Hawthorn et al 2010), then it will be fairly easy to identify the debris of a small number of clumps from their distribution in chemical C-space.

ZC406690 z=2.19



Genzel et al 2010

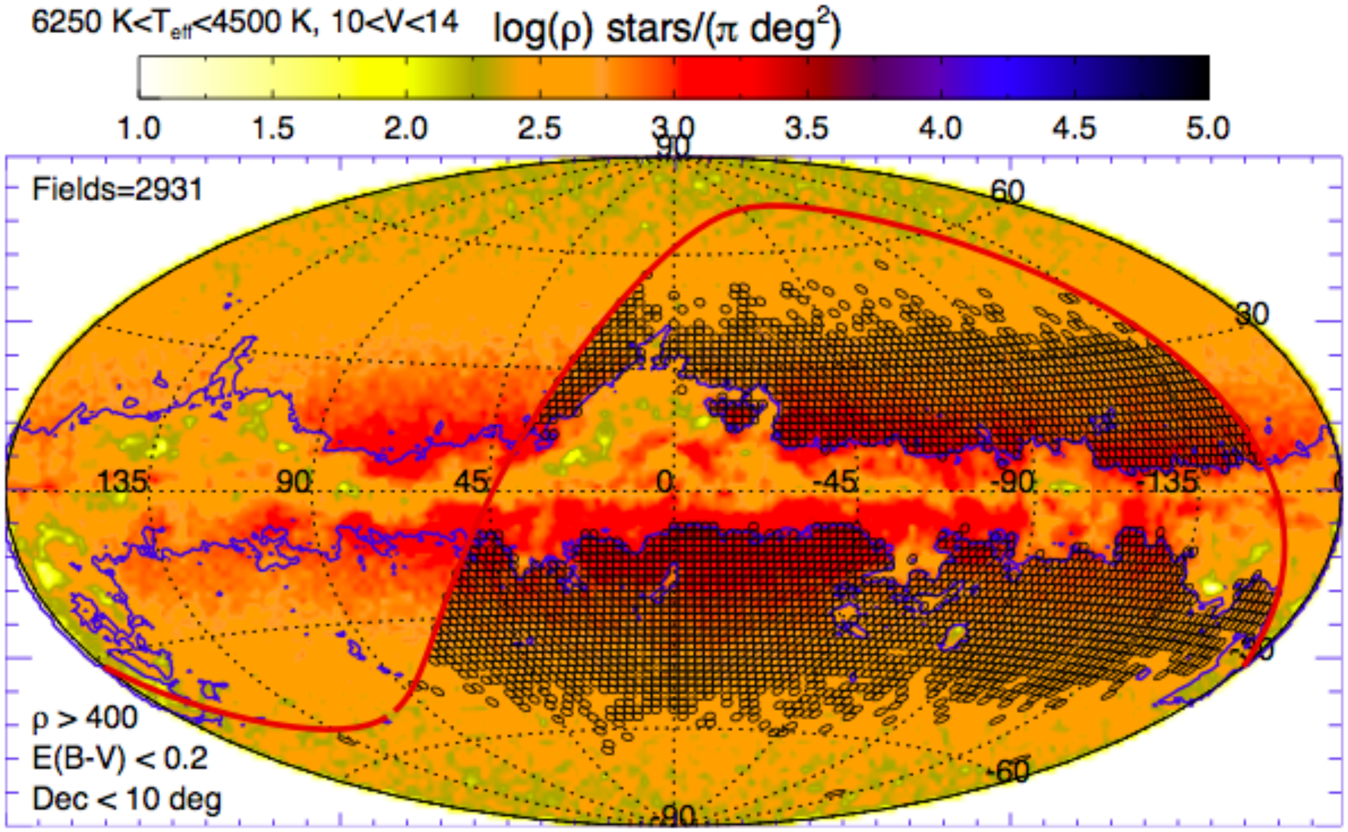
Galactic Archaeology with HERMES

We are planning a large stellar survey down to V = 14
(matches the fiber density)

Cover about half the southern sky (|b| > 25) :
10,000 square degrees = 3000 pointings
gives 1.2 x 10^6 stars

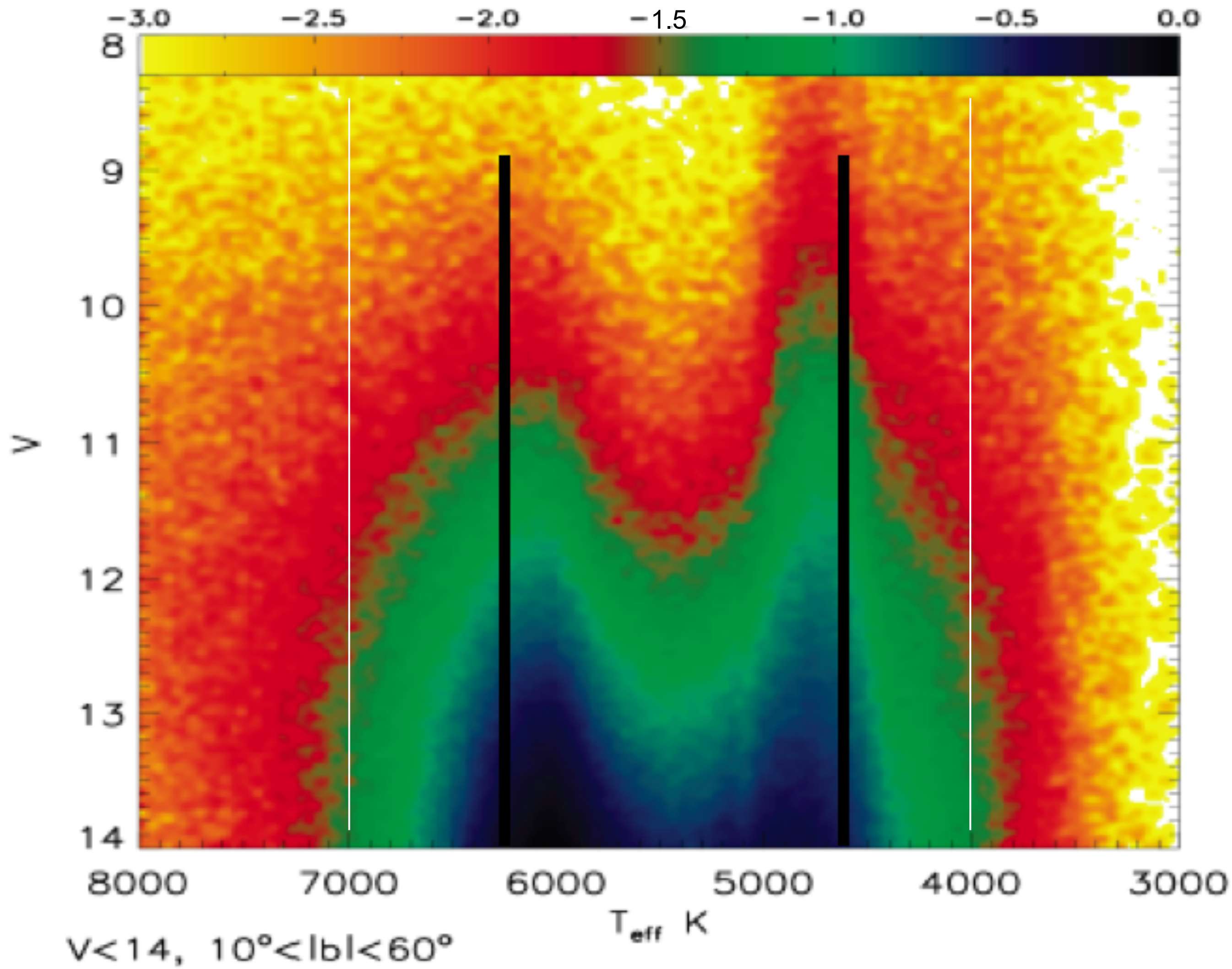
At V = 14, R = 28,000, expect SNR = 100
per resolution element in 60 minutes

Do ~ 8 fields per night for ~ 400 clear nights
(bright time program)



Galaxia survey tool (Sharma & Bland-Hawthorn) : choose fields with low reddening and high enough stellar density to fill the fibers.

Chemical pipeline by Wylie de Boer, Sneden & d'Orazi gives spectroscopic stellar parameters and abundances for 25 elements



Relative densities of stars with V < 14, 10 < |*b*| < 60

Fractional contribution from Galactic components

	Dwarf	Giant
Thin disk	0.58	0.20
Thick disk	0.10	0.07
Halo	0.02	0.03

Old disk dwarfs are seen out to distances of about 1 kpc
Disk clump giants 5
Halo giants 15

About 9% of the thick disk stars and about
14% of the thin disk stars
pass through our 1 kpc dwarf horizon

Assume that all of their formation aggregates are now
azimuthally mixed
right around the Galaxy, so all of their formation sites are
represented within our horizon

Simulations (JBH & KCF 2004, JBH et al 2010) show that a random sample of 1.2 x 10^6 stars with V < 14 would allow detection of about

- 20 thick disk dwarfs from each of about 4,500 star formation sites

- 10 thin disk dwarfs from each of about 35,000 star formation sites

** A smaller survey means less stars from a similar number of sites*

- Can we detect ~ 35,000 different disk sites using chemical tagging techniques ?

Yes: we would need ~ 7 independent chemical element groups, each with 5 measurable abundance levels to get enough independent cells (5^7) in chemical space.
(4^8 is also OK)

- Are there 7 independent elements or element groups ?

Yes: we can estimate the dimensionality of chemical space …

The dimensionality of the HERMES chemical space

The 25 HERMES elements: Li C O Na Al K
Mg Si Ca Ti
Sc V Cr Mn Fe Co N Cu Zn
Y Zr Ba La Nd Eu

Ting, KCF et al (2011) made principal component analysis (PCA) of element abundances [X/Fe] from several catalogs: metal-poor stars, metal-rich stars, open clusters, Fornax dwarf spheroidal galaxy.

PCA includes detailed simulation of effects of observational errors on the apparent dimensionality of the C-space, element by element.

Outcome: the HERMES C-space has dimensionality = 8 to 9 for all of these samples:

- metal-poor stars (Barklem, Cayrel: 281 stars: [Fe/H] < -2)
- metal-rich stars (Reddy: 357 stars: [Fe/H] > -1)
- open clusters (Carrera & Pancino: 78 clusters)
- Fornax dwarf galaxy (Letarte et al: 80 stars)

The open clusters, which cover R_G = 6 to 20 kpc, have about one more dimension than the metal-rich solar neighborhood stars.

The principal components are vectors in C-space of element abundances [X/Fe]: identifiable with nucleosynthetic processes e.g. light and heavy s-process elements

HERMES and GAIA

GAIA is a major element of a HERMES survey

GAIA (~ 2015) will provide precision astrometry for about 10^9 stars

For V = 14, $\sigma_\pi = 10$ μas, $\sigma_\mu = 10$ μas yr^{-1} : this is GAIA at its best

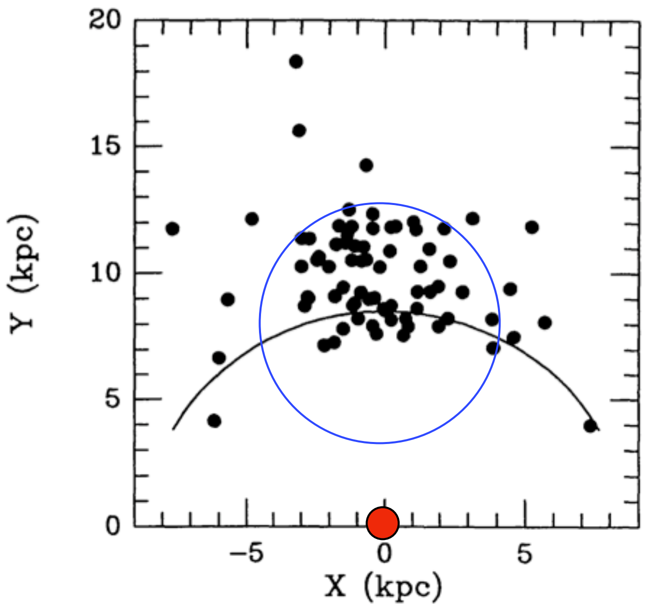
(1% distance errors at 1 kpc, 0.7 km s^{-1} velocity errors at 15 kpc)

⇒ accurate transverse velocities for all stars in the HERMES sample, and

⇒ accurate distances for all of the survey stars

⇒ therefore accurate color-(absolute magnitude) diagram for all of the survey stars: independent check that chemically tagged groups have common age.

FRIEL



Chemical tagging in the inner Galactic disk

(expect ~ 200,000 survey giants in inner region of Galaxy)

The old (> 1 Gyr) surviving open clusters are all in the outer Galaxy, beyond a radius of 8 kpc.

Expect many broken open and globular clusters in the inner disk : good for chemical tagging recovery using giants, and good for testing radial mixing theory. The Na/O anticorrelation is unique to globular clusters, and will help to identify the debris of disrupted globular clusters.

GALAH Survey Team

Managing Members:

Ken Freeman (ANU) - Principal Investigator

Joss Bland-Hawthorn (Uni. Syd) - Principal Investigator

Gayandhi De Silva (AAO) - HERMES Project Scientist

Working Group Convenors:

Martin Asplund (ANU)

Liz Wylie de Boer (ANU)

Stefan Keller (ANU)

Tomaz Zwitter (Uni. Ljubljana)

Dan Zucker (AAO)

Sarah Martell (AAO)

Team members:

Maria Bergemann (MPA)

Mike Bessell (ANU)

Simon Campbell (Monash)

Russell Cannon (AAO)

Daniela Carollo (Macq)

Luca Casagrande (ANU)

Andrew Cole (Uni. Tas)

Peter Cottrell (Uni. Christchurch)

Valentina D'Orazi (Macq)

Gary Da Costa (ANU)

Paul Dobbie (AAO)

Simon Ellis (Uni. Syd)

Chris Flynn (Uni. Syd)

Elaina Hyde (Macq)

Michael Ireland (AAO/Macq)

Amanda Karakas (ANU)

Torgny Karlsson (Uni. Syd)

Chiaki Kobayashi (ANU)

John Lattanzio (Monash)

Geraint Lewis (Uni. Syd)

Karin Lind (MPA)

Maria Lugaro (Monash)

Arik Mitschang (Macq)

Ullise Munari (Asiago)

Simon Murphy (ANU)

John Norris (ANU)

Simon O'Toole (AAO)

Quentin Parker (AAO/Macq)

Sanjib Sharma (Uni. Syd)

Rob Sharp (ANU)

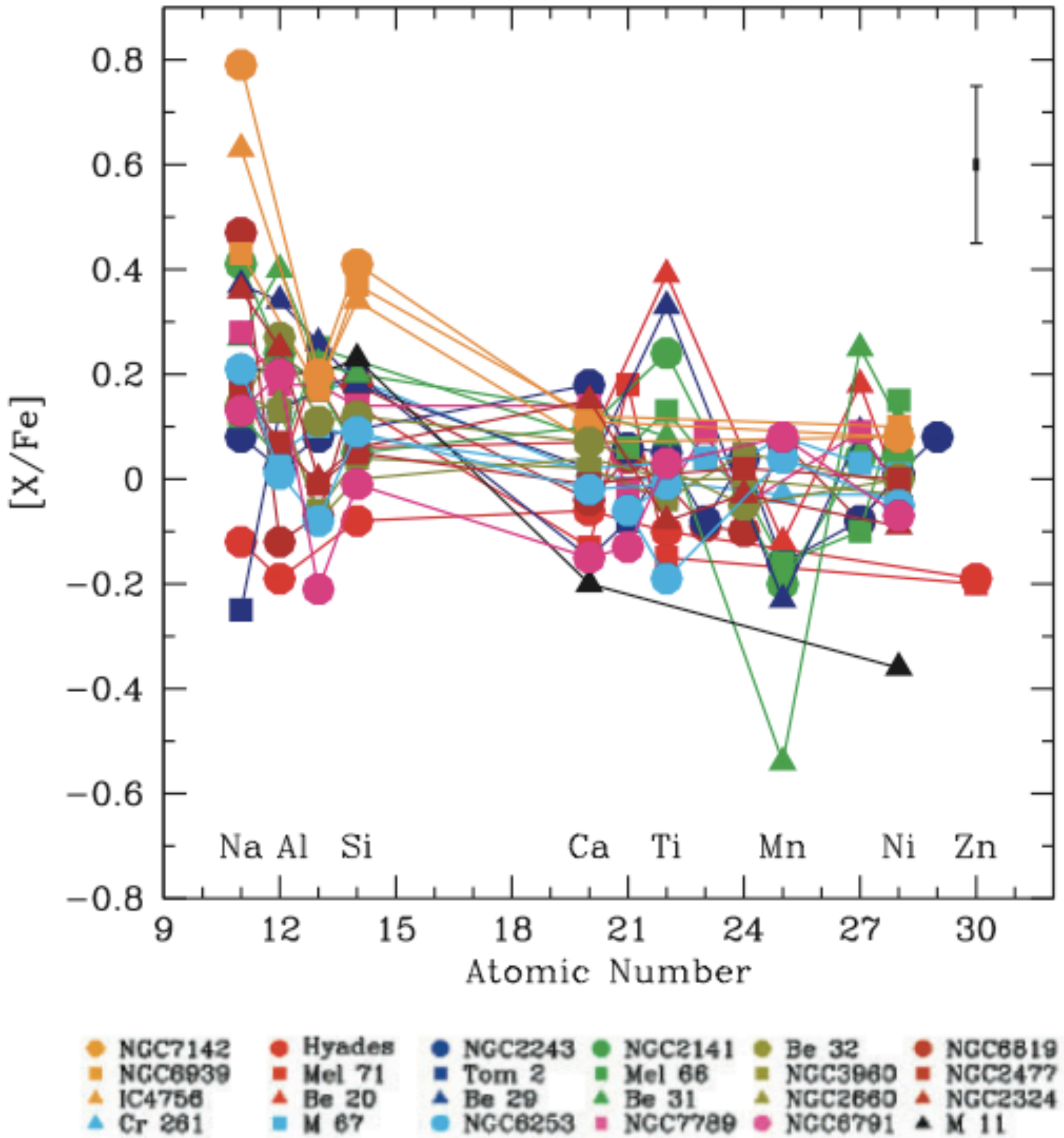
Jeffrey Simpson (Uni. Christchurch)

Chris Sneden (Uni. Texas)

Chris Tinney (UNSW)

Fred Watson (AAO)

David Yong (ANU)



De Silva et al 2009

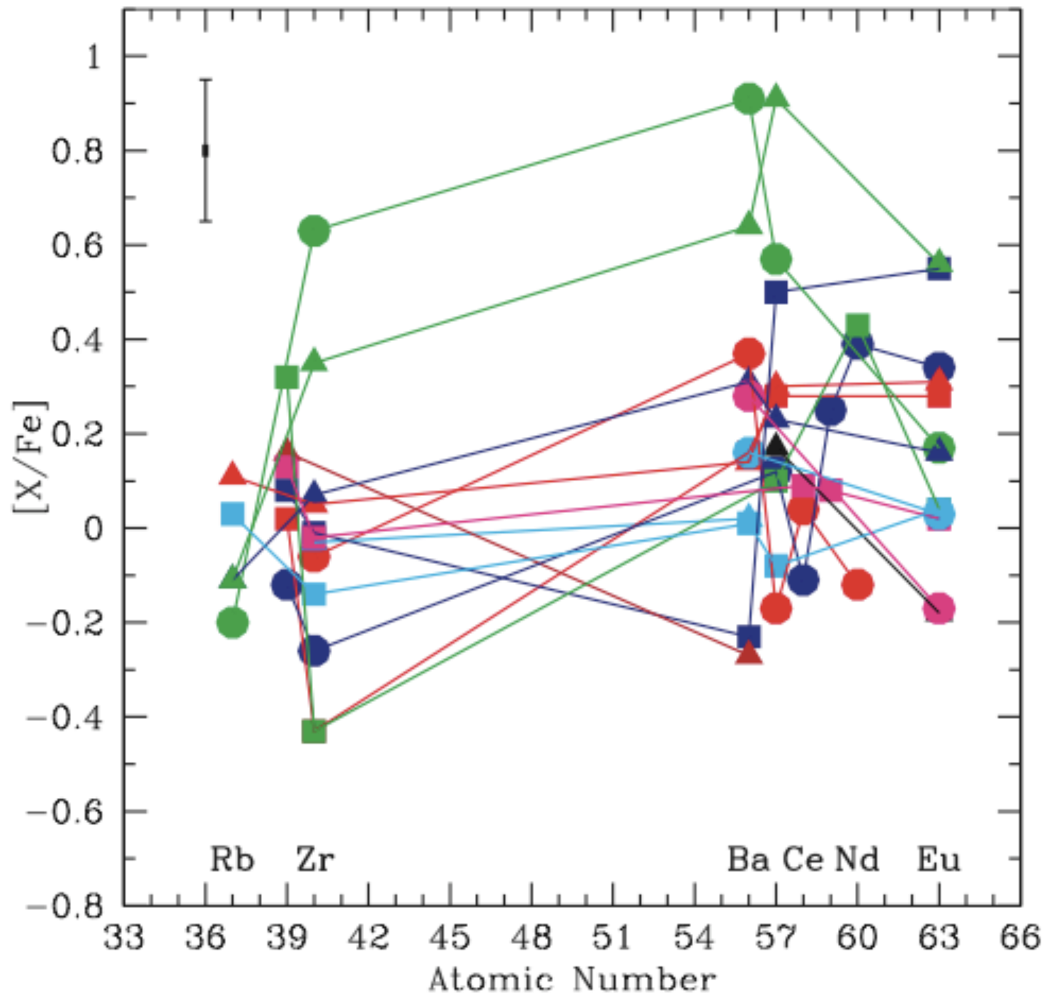
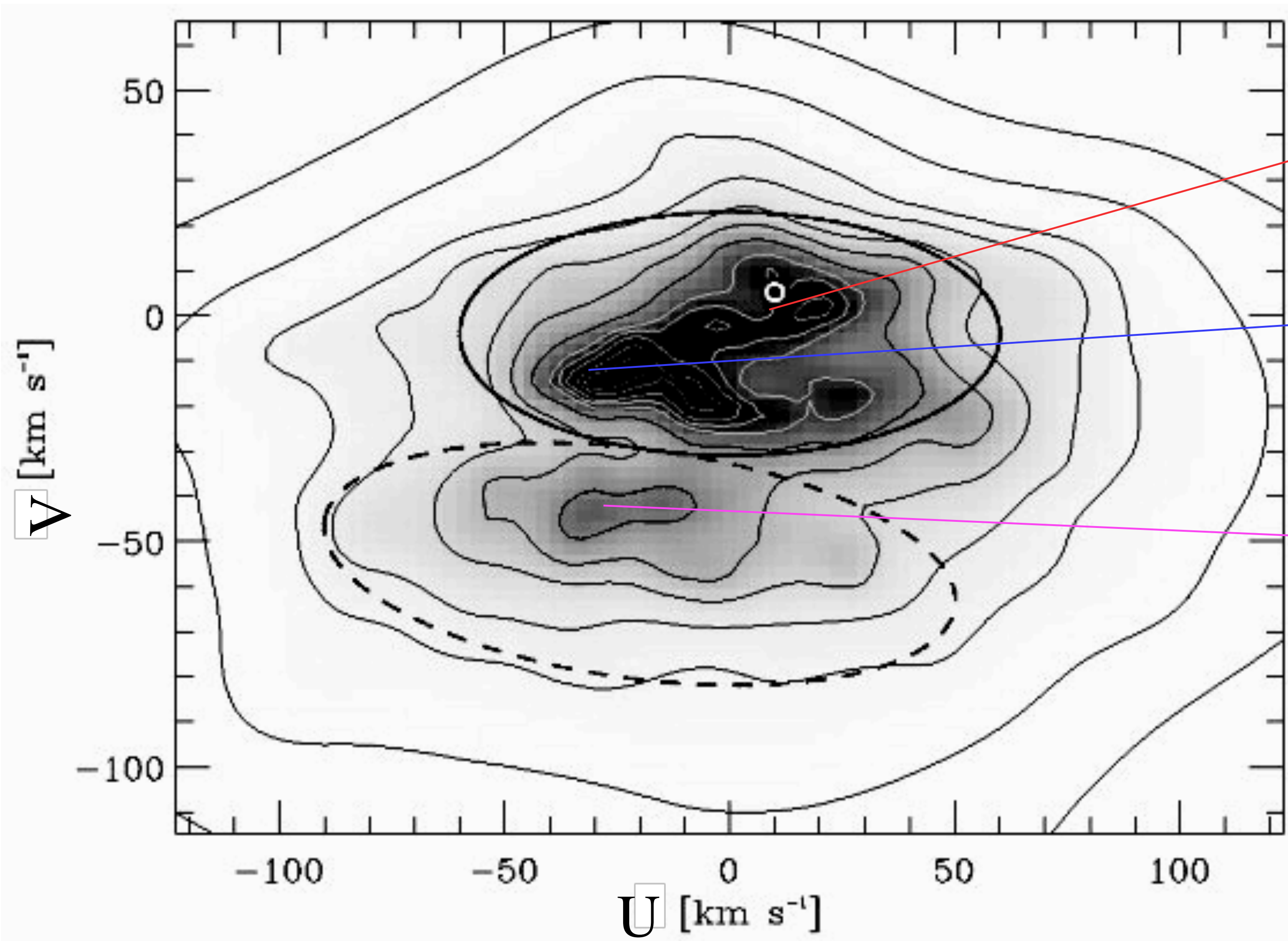


Figure 2 Abundances of old open clusters relative to Fe for elements from Rb to Eu. The symbols are the same as in Figure 1.

De Silva et al 2009

The Hercules group is associated with local resonant kinematic disturbances by the inner bar : OLR is near solar radius (Hipparcos data) : Dehnen (1999)



Sirius and Hyades streams - mainly younger metal-rich stars

Hercules disturbance from OLR -mainly later-type stars

(U,V are relative to the LSR)

Dehnen 1999