# Prospects for wide field multi-object spectroscopic instrumentation

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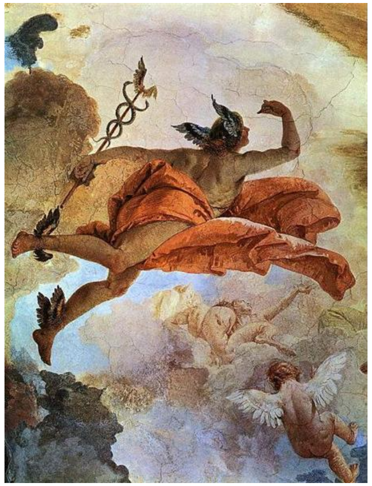
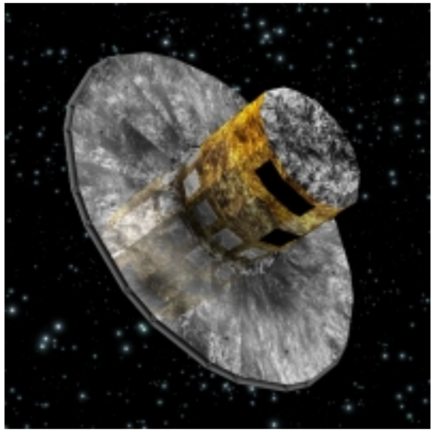




I will concentrate on *high resolution* multi-object survey spectroscopy
(detailed chemical abundances of large samples of stars)

## Science Drivers

- Galactic Archaeology
- Stellar physics
  Galactic bulge and disk
  Globular clusters
  Interstellar medium

  LMC
  Dwarf spheroidal galaxies

Close synergy with Gaia data

# Planned high resolution MOS survey instruments

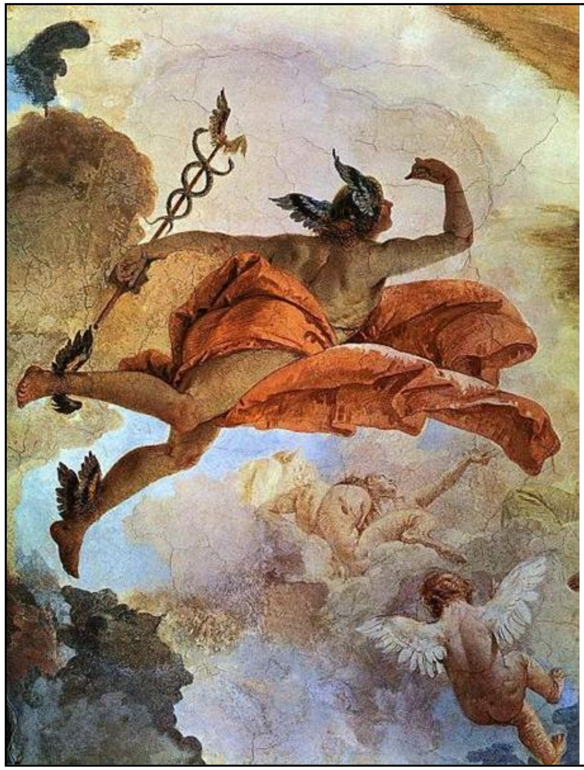
HERMES (AAT)

APOGEE (APO SDSS-III)

GYES (next talk)

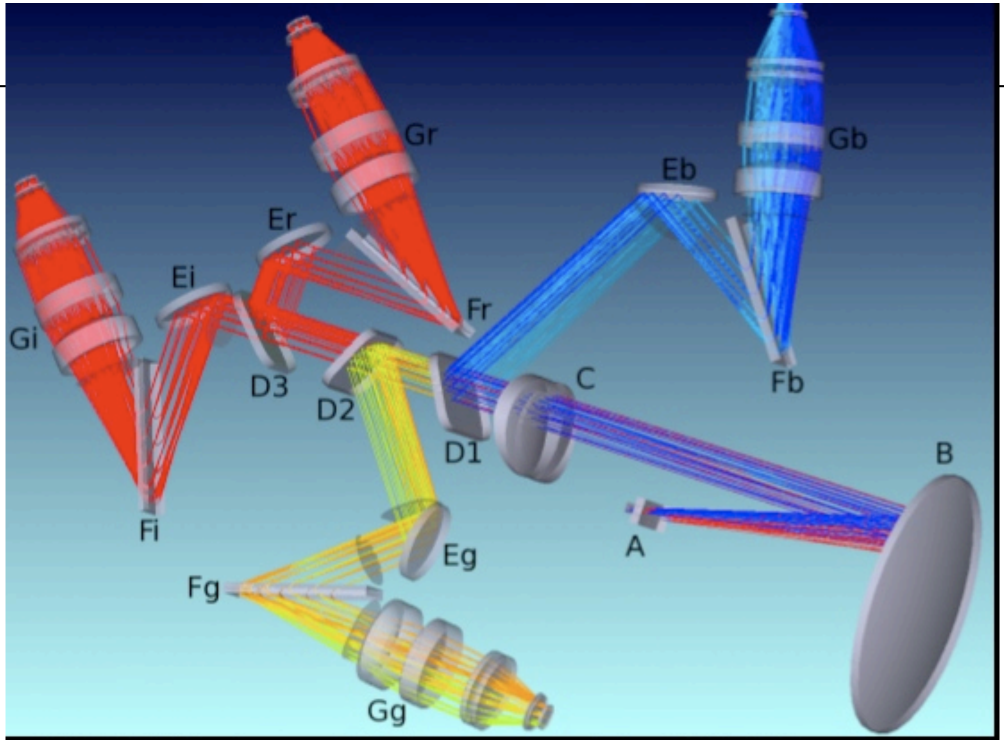
LAMOST (Xinglong)

Hectochelle (MMT)
M2FS (Magellan)
FLAMES/GIRAFFE (VLT)



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

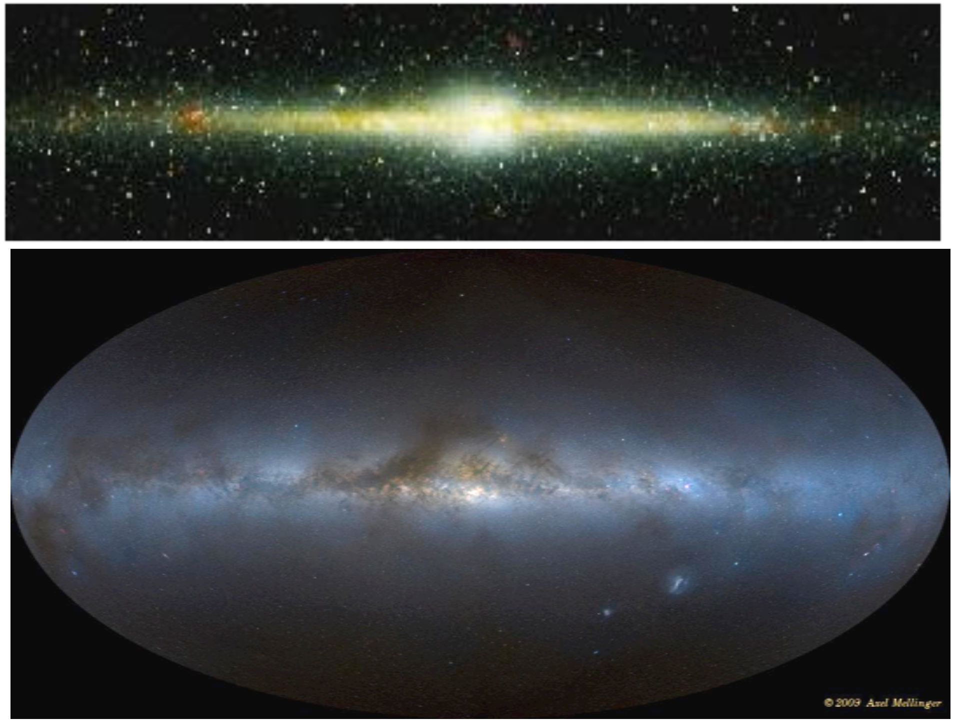
spectral resolution 28,000
(high resolution option 50,000)
400 fibres over π square degrees
4 VPH gratings ~ 1000 Å
First light ~2012 on AAT



The four wavelength bands are chosen to detect lines of elements needed for *chemical tagging*

# APOGEE

SDSS-III, H-band
($A_H / A_V = 0.16$)
300 fibers, 7 $\deg^2$
R ~ 20,000
2011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SN ~ 100 spectra of about 100,000 giants with $H < 13$

Galactic bulge and disk are primary science drivers

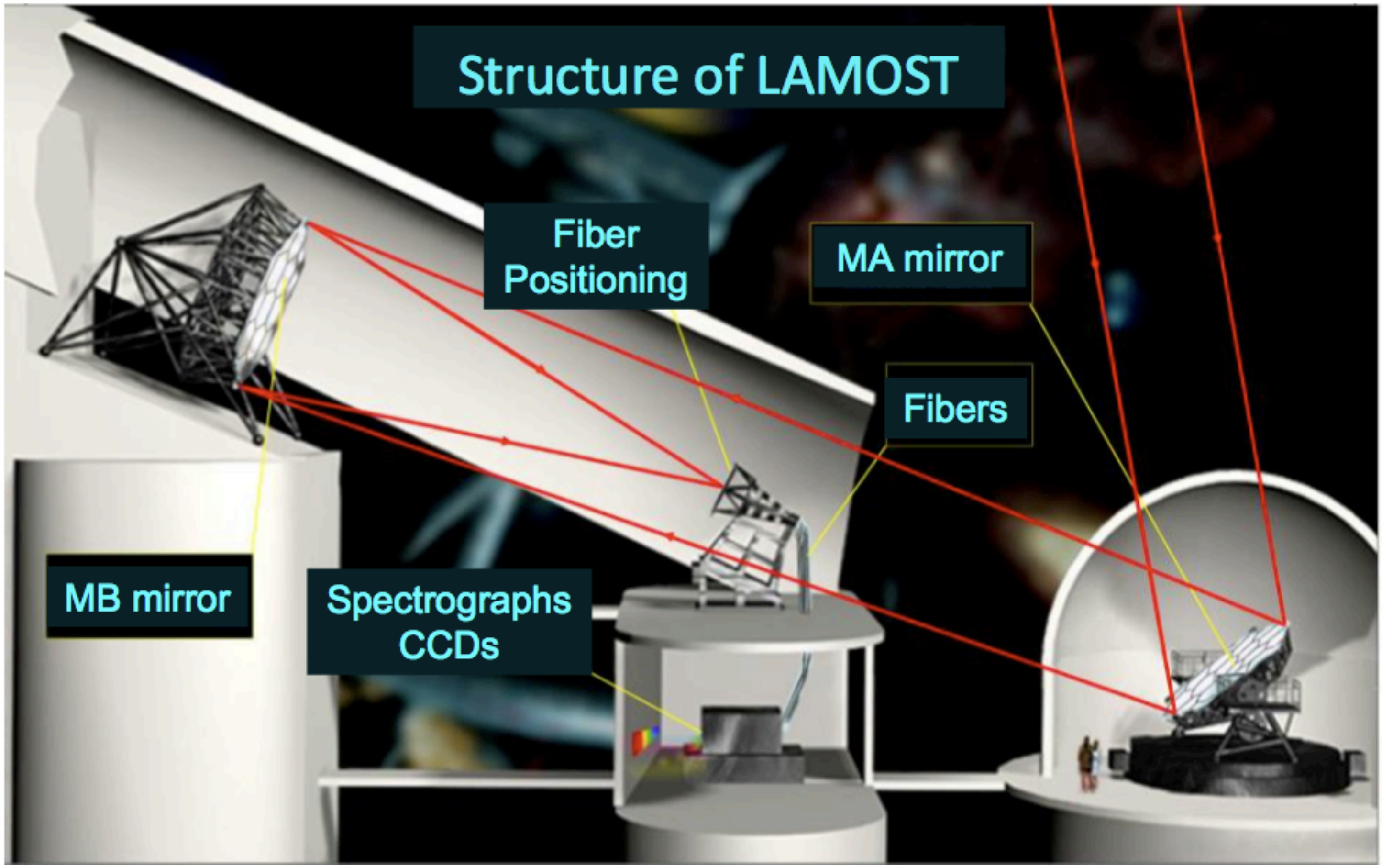
Precision velocities and abundances of CNO, Na, Al, α- and Fe-peak elements for chemodynamics

Synergy with the JASMINE NIR astrometry projects

# LAMOST

4-m Schmidt

Multi-object spectroscopy with 4000 fibers, 20 $deg^2$. Currently commissioning low resolution spectroscopy: high resolution spectroscopy is goal for future



The rest of this talk is mainly about
the scientific motivation
for HERMES and the HERMES survey,
to illustrate the prospects for
multi-object high resolution spectroscopy
in the Gaia era

# The goals of galactic archaeology

We seek signatures or fossils from the epoch of Galaxy formation, to give us insight about the processes that took place as the Galaxy formed.

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

Some of these dispersed aggregates can be still recognised kinematically as stellar moving groups.

For others, the dynamical information was lost through disk heating 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 many observed properties of disk galaxies.

Try to find 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.

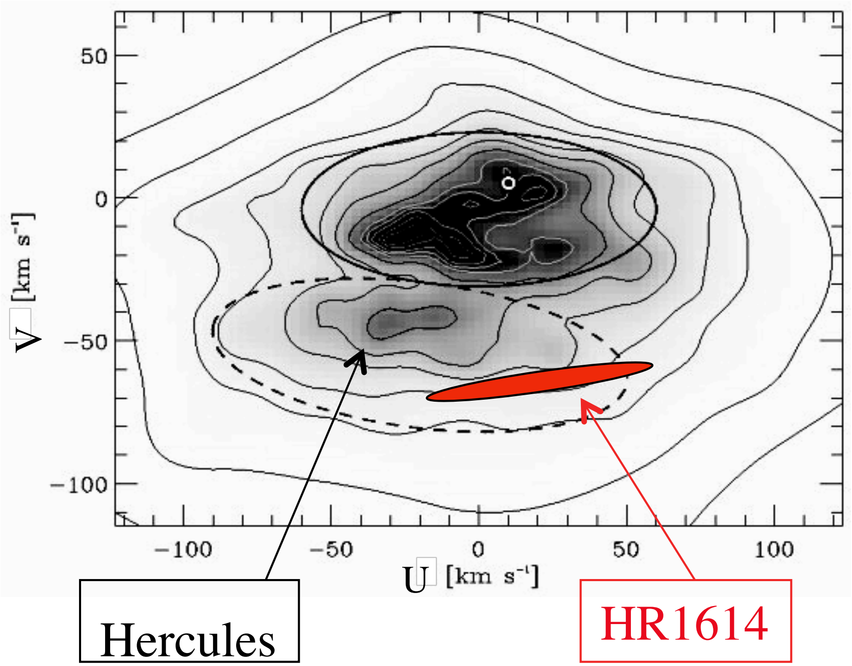
# Stellar Moving Groups in the Disk

The galactic disk shows kinematical substructure in the solar neighborhood: groups of stars moving together, usually called moving stellar groups (Eggen)

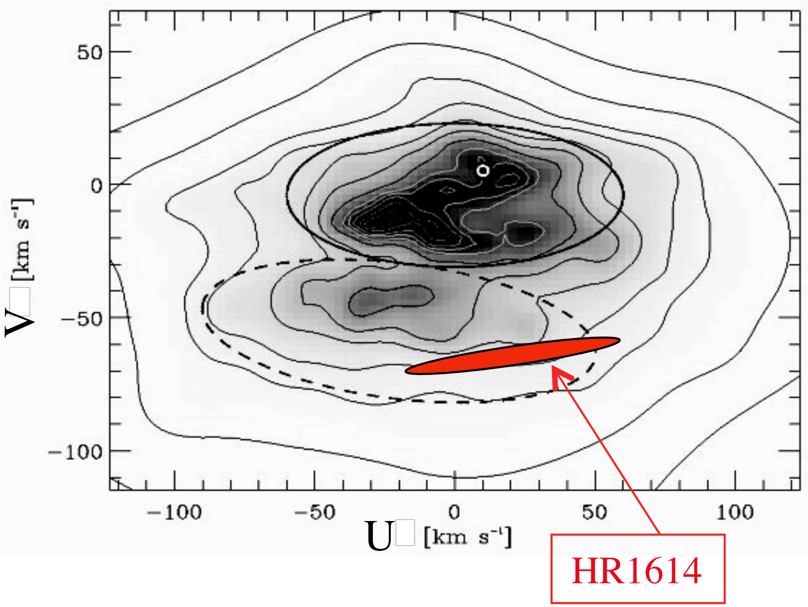
- Some are associated with dynamical resonances (eg bar - Hercules group): don't expect chemical homogeneity or age homogeneity (eg Famaey et al 2008)

- Some are debris of star-forming aggregates in the disk (eg the chemically homogeneous HR1614 group). these could be useful for reconstructing the history of the galactic disk.

- Others may be debris of infalling objects, as seen in ΛCDM simulations: eg Abadi et al 2003 (simulations), Wylie de Boer et al 2010 (debris of ω Cen galaxy)



Old (2 Gyr) moving groups like HR1614 which have retained memory of their motions are rare.



Most groups of stars that formed together have dispersed, and the effects of galactic heating and radial mixing have erased memory of their common motion.

How do we identify the debris of these groups ?

# Chemical Tagging

Use the detailed chemical abundance patterns of individual stars (e.g. thick disk stars) to associate them with common ancient star-forming aggregates with similar abundance patterns (eg Freeman & Bland-Hawthorn 2002)

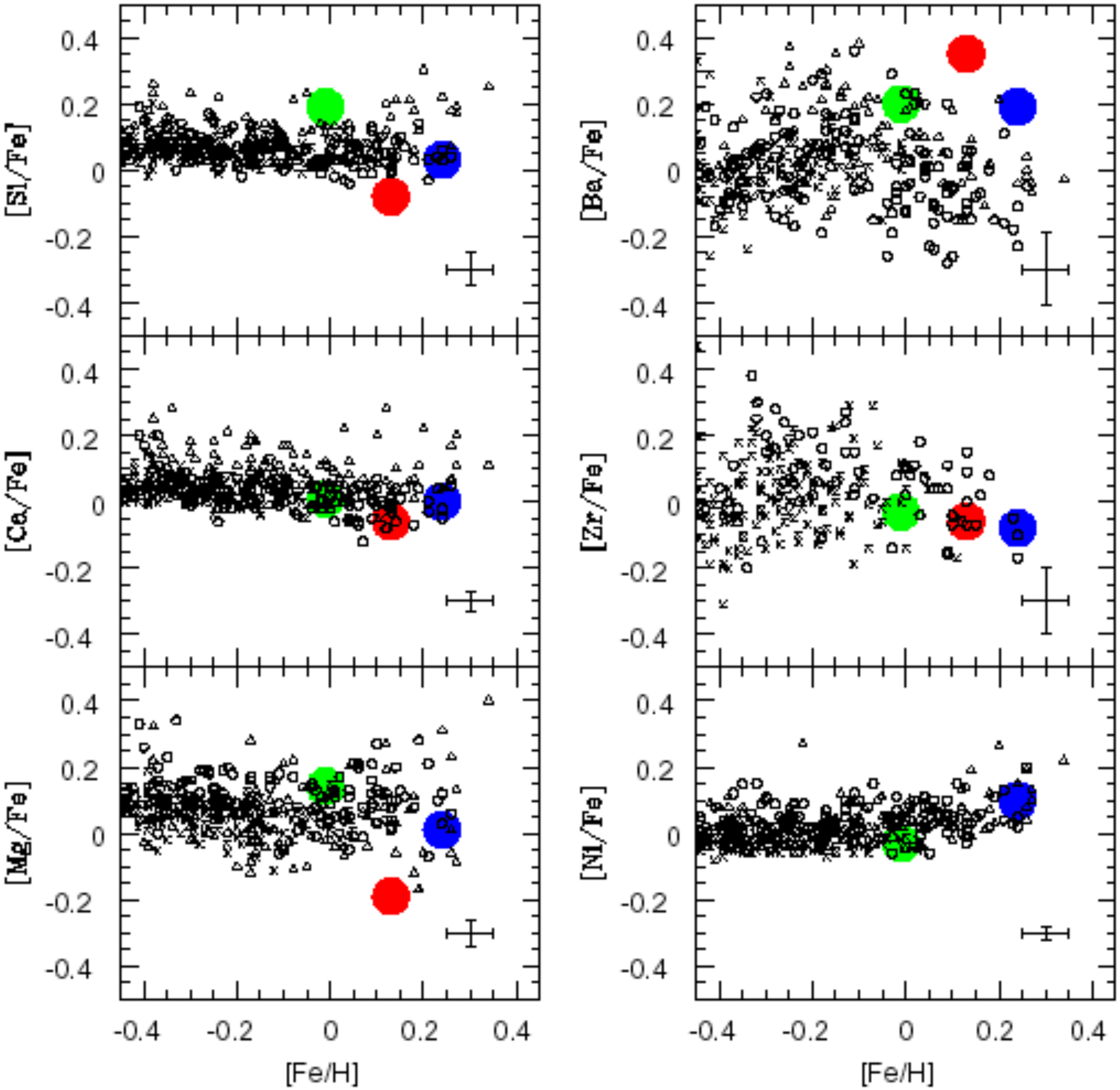
The detailed abundance pattern reflects the chemical evolution of the gas from which the aggregate formed.

Different supernovae provide different yields (depending on mass, metallicity, detonation details, ejected mass ...)
leading to scatter in detailed abundances,
especially at lower metallicities (enrichment by only a few SN)

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. Chemical tagging will work well if

- 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)

Testing the last two conditions were the goals of Gayandhi de Silva's work on open clusters: they appear to be true.
See G. de Silva et al (2008) for more on chemical tagging



# Clusters vs nearby field stars

Hyades
Coll 261
HR1614

De Silva 2007

## Chemical studies can also help to identify disk stars which came in from outside in disrupting satellites

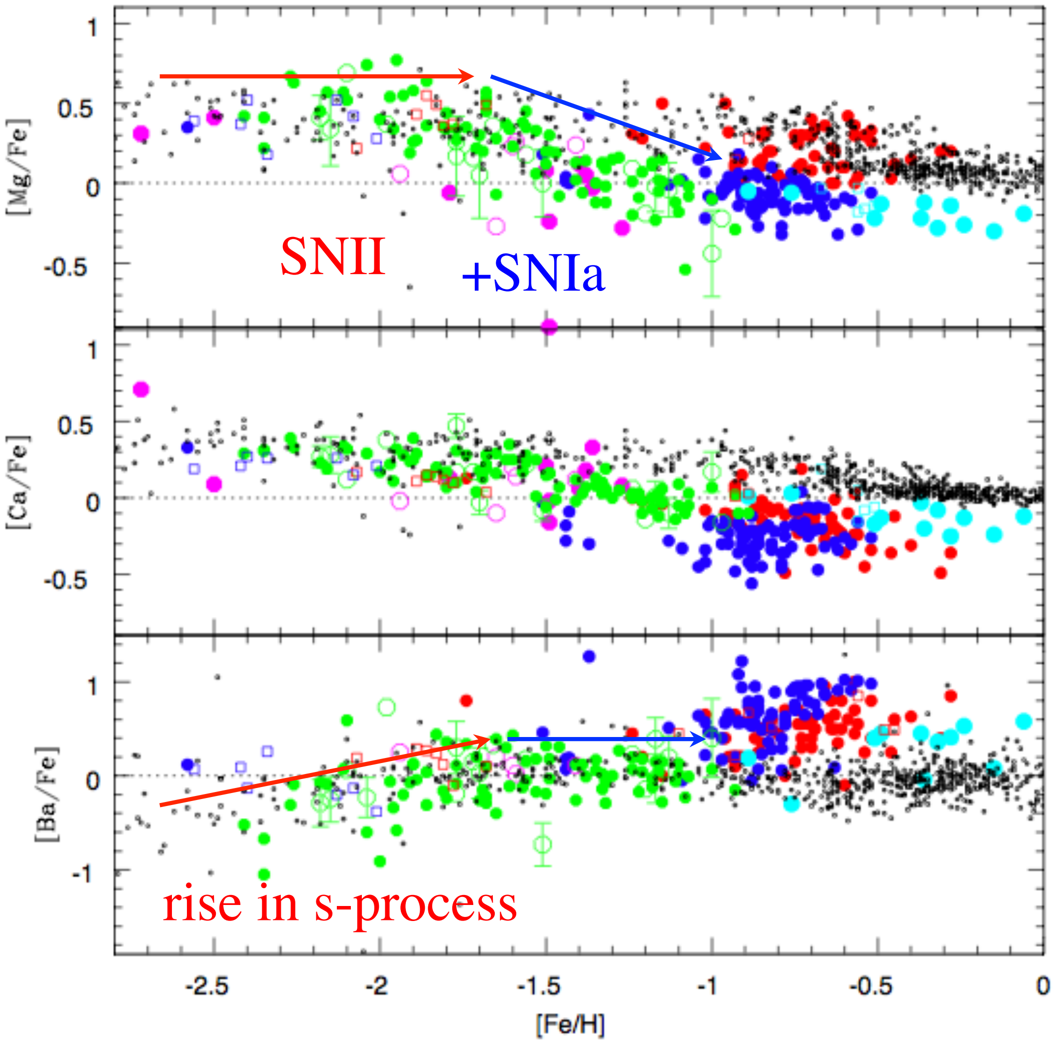
The detailed chemical properties of surviving satellites (the dwarf spheroidal galaxies) vary from satellite to satellite, and are different from the more homogeneous overall properties of the disk stars. ⊙

We can think of a chemical space of abundances of elements O, Na, Mg, Al, Ca, Mn, Fe, Cu, Sr, Ba, Eu for example (~35 measurable elements). The dimensionality of this space is probably between about 7 and 9. Most disk stars inhabit a sub-region of this 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

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

# Abundance ratios reflect different star formation histories



- Each galaxy has had a different evolutionary track
- The position of the **knee** forms a sequence following SFH-timescales (and somewhat the galaxy total luminosity)
- s- process (*AGB product*) very efficient in galaxies with strong SFR at younger ages (<5Gyrs): Fnx > LMC > Sgr > Scl
- r/s-process elements can be used as another clock (*or even 2 clocks: r/s transition knee, and start of rise in s* )
- AGB lifetimes + s-process yields are metallicity-dependent (*seeds*)

- Abundance pattern in the metal-poor stars everywhere undistinguishable ? Seems to be the case for stars in the exended low-metallicity populations.

Venn 2008

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 the prime science driver for HERMES

# Galactic Archaeology with HERMES

400 fibers in $\pi$ deg$^2$ matches the stellar density at $V \sim 14$ at intermediate Galactic latitudes

4-m telescope, resolution 28,000, expect SNR = 100 per resolution element at $V = 14$ in 60 minutes

Imagine a large survey reaching to $V = 14$

Old disk dwarfs are seen out to distances of about 1 kpc
Disk giants ........................................ 6
Halo giants ........................................ 15

Fractional contribution from galactic components

| | Dwarfs | Giants |
|---|---|---|
| Thin disk | 0.58 | 0.20 |
| Thick disk | 0.10 | 0.07 |
| Halo | 0.02 | 0.03 |

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

For the halo, the HERMES halo giants are visible out to 15 kpc, so we sample a large fraction of the galactic halo

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

- 20 *thick disk* dwarfs from each of ~ 4,500 star formation sites
- 10 *thin disk* dwarfs from each of ~ 35,000 star formation sites

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

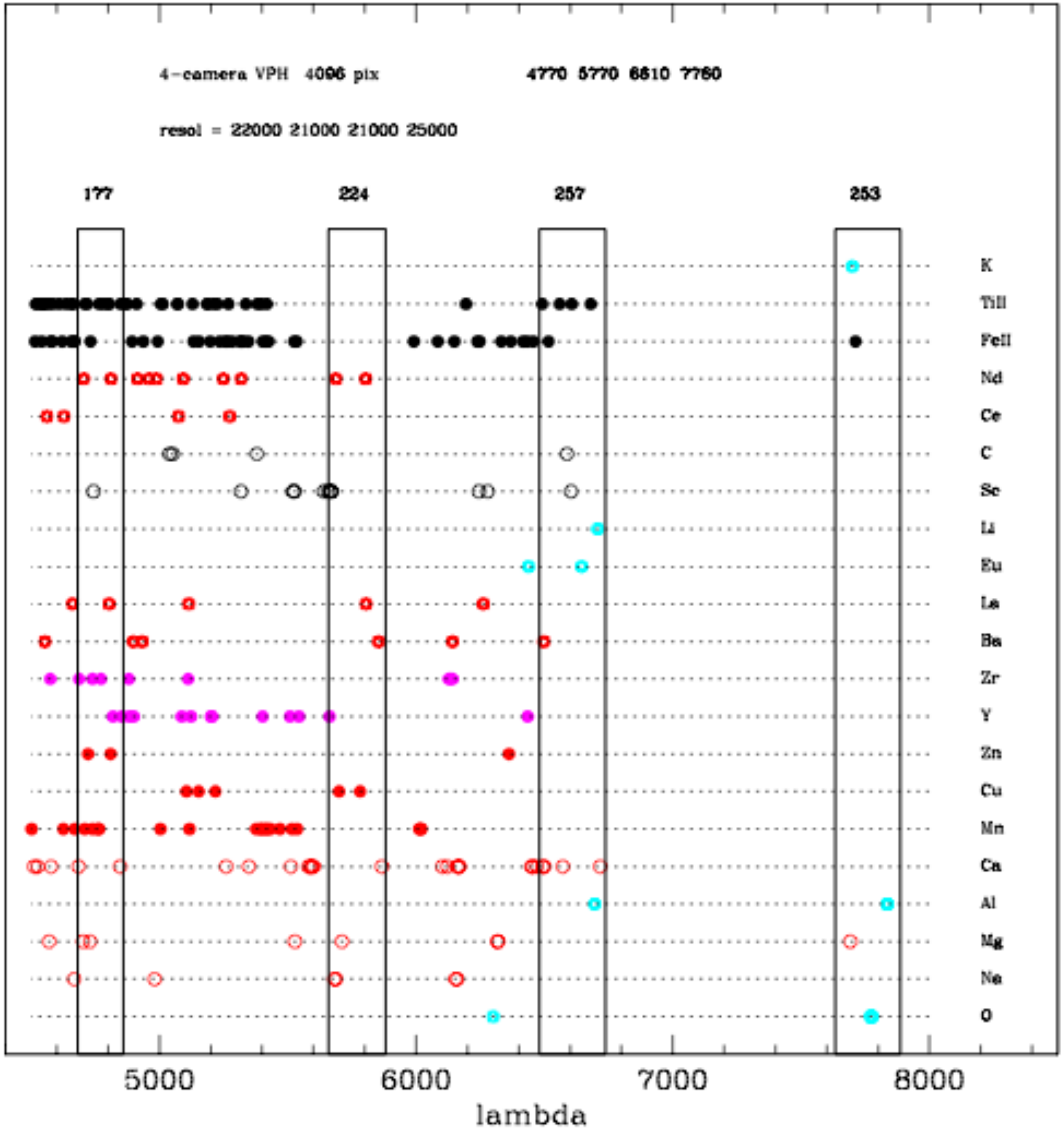
- Can we detect ~ 35,000 different disk sites using chemical tagging techniques ?

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

- Are there 7 independent elements or element groups ?

Yes: light elements (Na, Al)
Mg
other alpha-elements (O, Si, Ca, Ti)
Fe and Fe-peak elements
light s-process elements (Y, Zr)
heavy s-process elements (Ba, La)
r-process (Eu)

# HERMES wavelength bands



Data reduction and analysis:

AAO provides basic reduction: extraction, wavelength calibration, scattered light removal, sky subtraction

Science team provides abundance analysis pipeline, based on MOOG (C. Sneden),

A survey of $1.2 \times 10^6$ stars to $V = 14$
with HERMES would take 3000 pointings

Bright time program

~ 9 fields per night for ~ 330 clear nights:
5 year program.

# HERMES and GAIA

GAIA is a major element of a HERMES survey

GAIA will provide precision astrometry for HERMES sample

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

(1% distance errors for dwarfs at 1 kpc, 5 km s$^{-1}$ transverse velocity errors for giants at 6 kpc)

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

⇒ accurate distances for most of the survey stars

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

GAIA will detect many phase space substructures.

With high resolution MOS systems like HERMES, we will be able to determine *via element abundance signatures* which phase-space substructures are debris of star-forming events or accreted small galaxies, and which are dynamical artifacts (resonances).

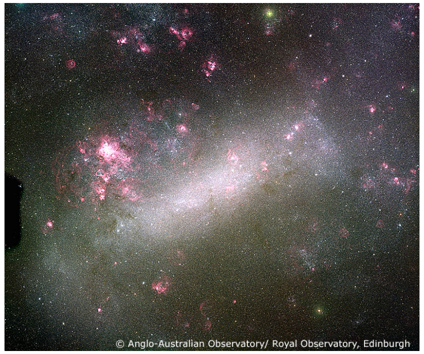
……………………………

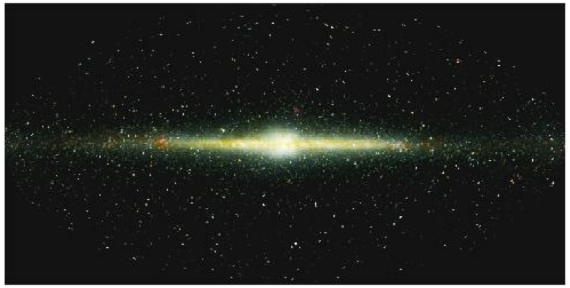
The main goal of the survey is unravelling the star formation history of the thin and thick disk and halo via chemical tagging.

The data products include:

- [Fe/H], [$\alpha$/Fe] and [X/Fe] for vast samples of stars from each Galactic component:
  thin and thick disks from $R_g = 2$ to 15 kpc
  halo out to $R_g = 20$ kpc

- HERMES + Gaia data will give the distribution of stars in [position, velocity, chemical] space for a million stars, and isochrone ages for about 200,000 stars



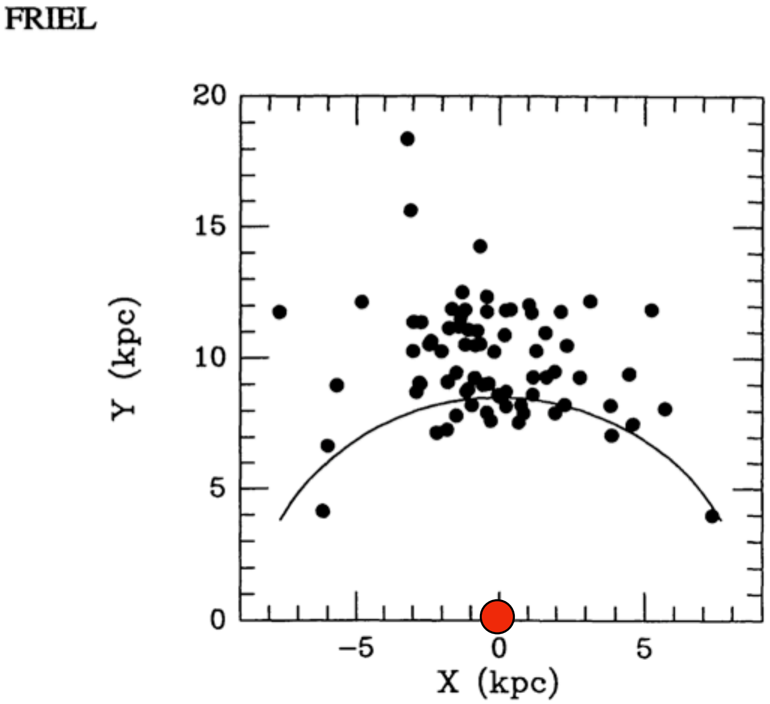


# HERMES: other (PI) science

Some needs longer exposures, down to V ~ 15 and fainter.

Some needs the high resolution option (R ~ 50,000)

Much of this science involves GAIA data also



# 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.

Young clusters are seen in the inner Galaxy but do not survive the tidal field and the GMCs.

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 anomaly is unique to globular clusters, and may help to identify the debris of disrupted globular clusters.