TRacing the Accretion History of the Milky Way Through ChemicAl Tagging

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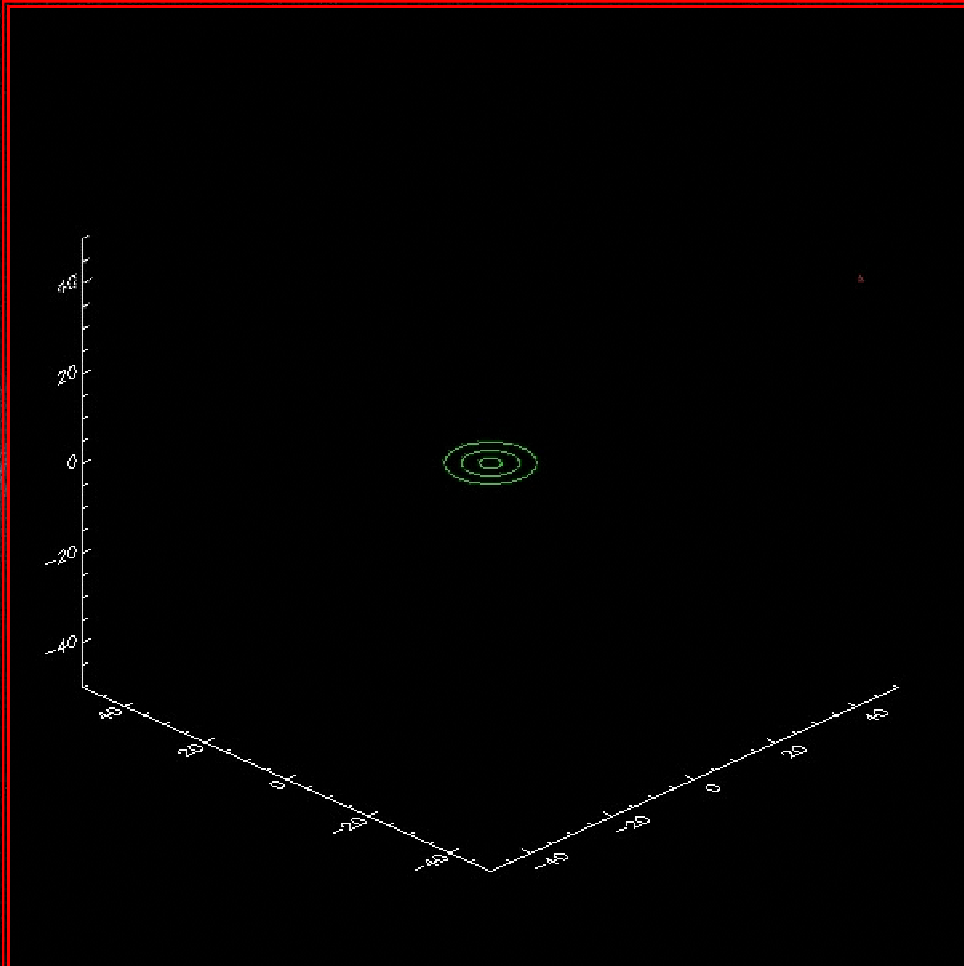
Australian Government Department of Industry

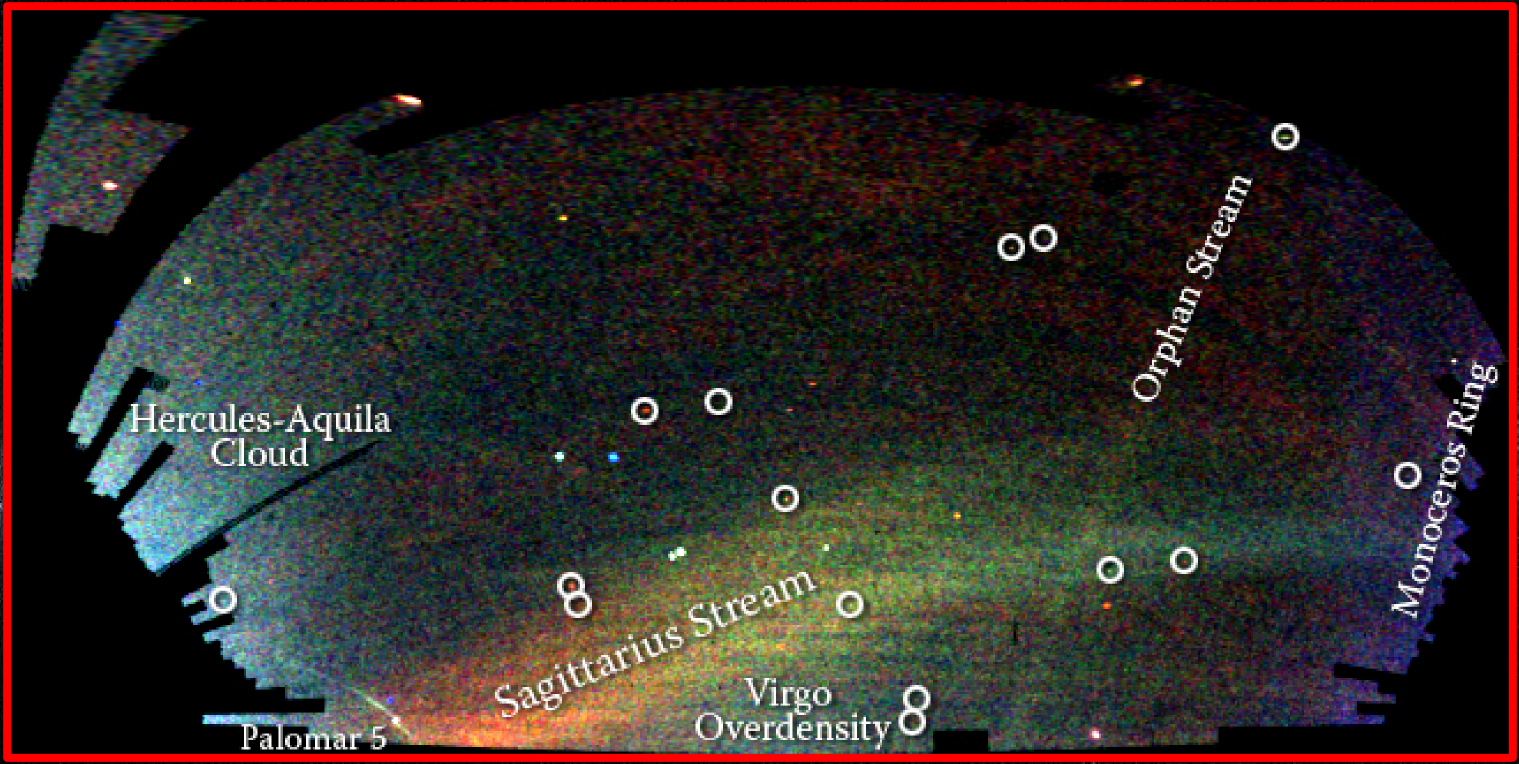
AAO

Accretion Happens



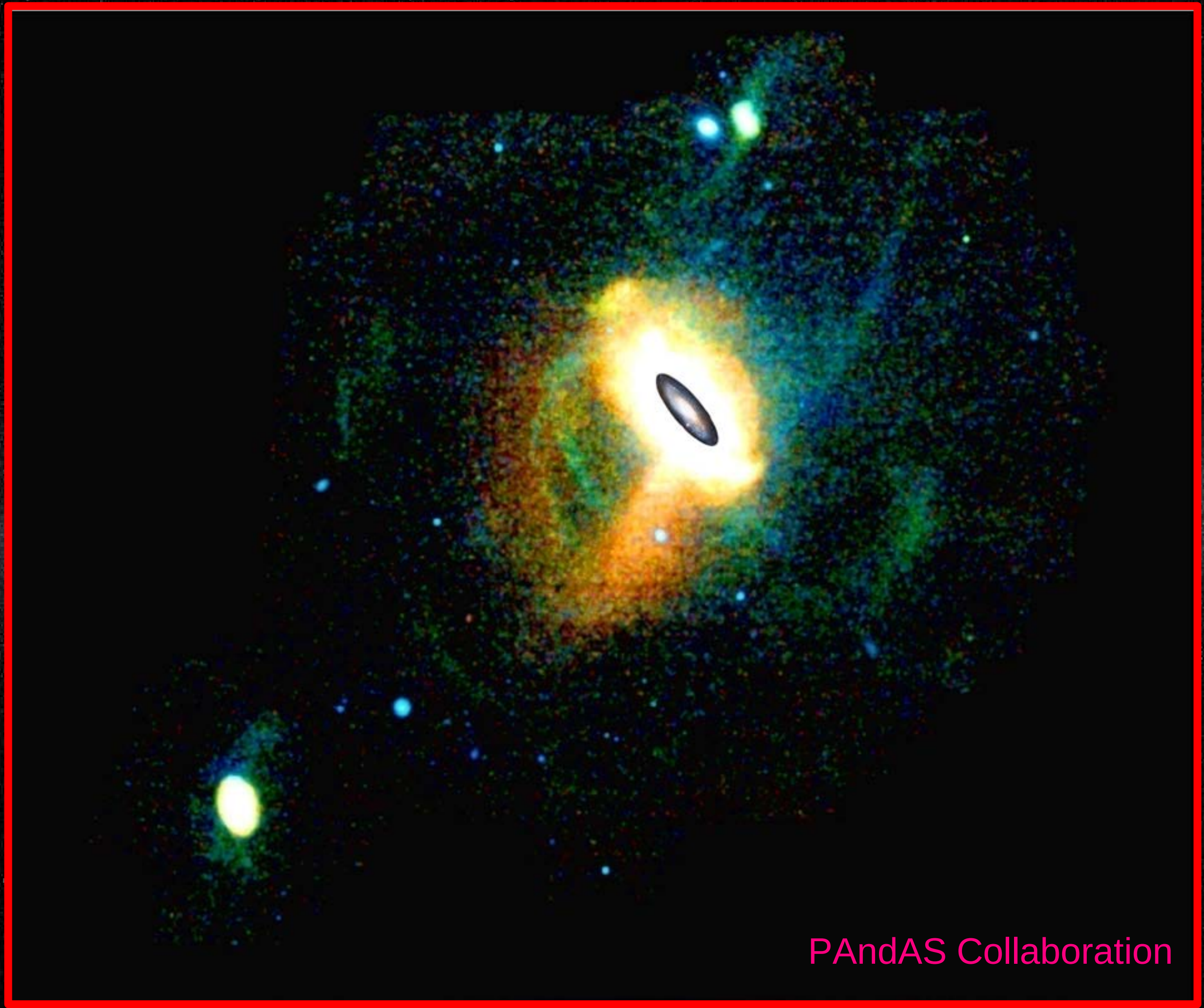
Johnston & Bullock

The Milky Way



Belokurov + SDSS

M31



Phased but Confused

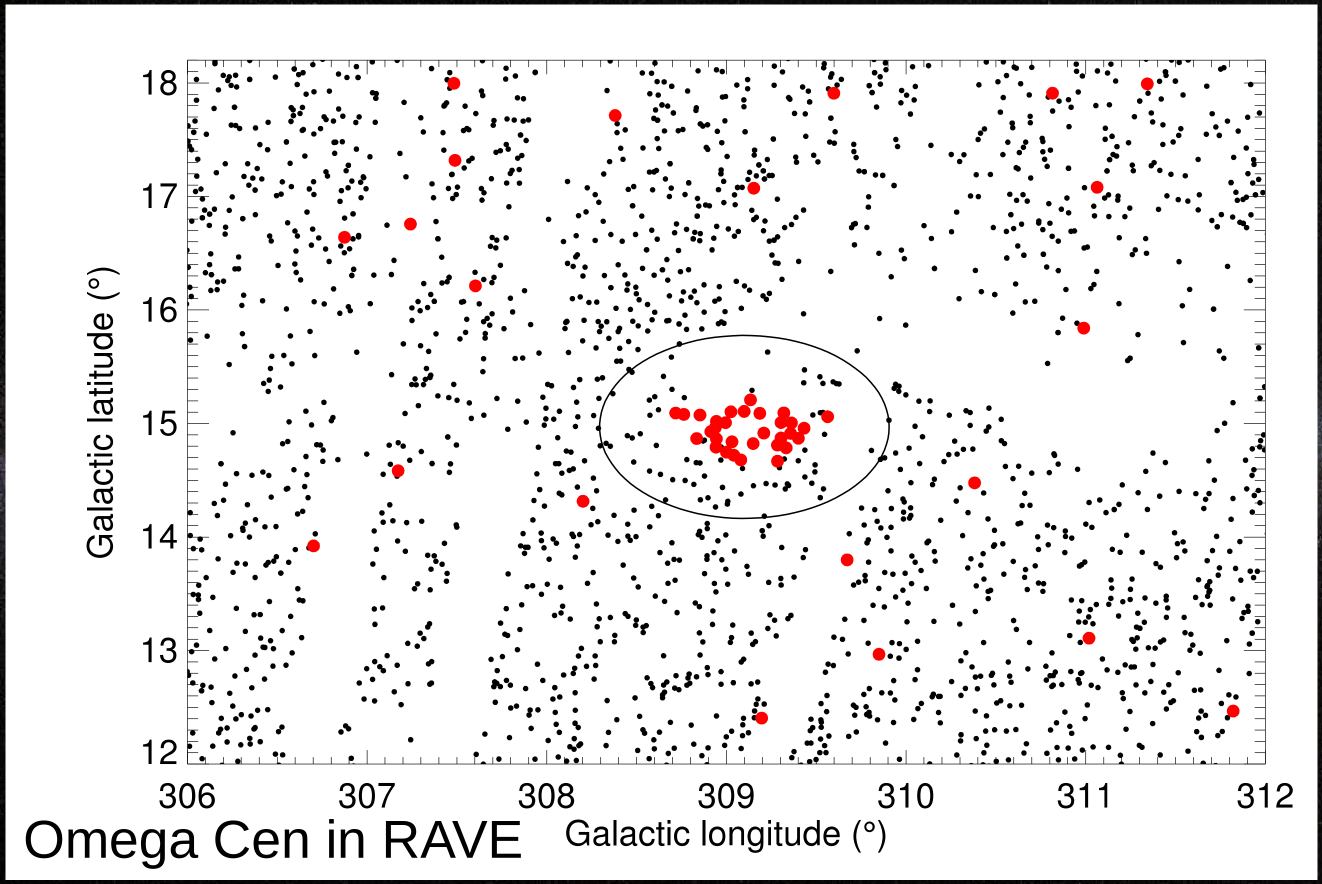
Accreting Material Gets… Accreted

- Stars from accreted dwarfs and globular clusters lose their *spatial* coherence over time through largely stochastic processes
- An accreted star's kinematics will change, but its chemical composition with remain essentially unchanged from birth to near death ➔ "stellar DNA"

Globular Clusters as Accreting Satellites

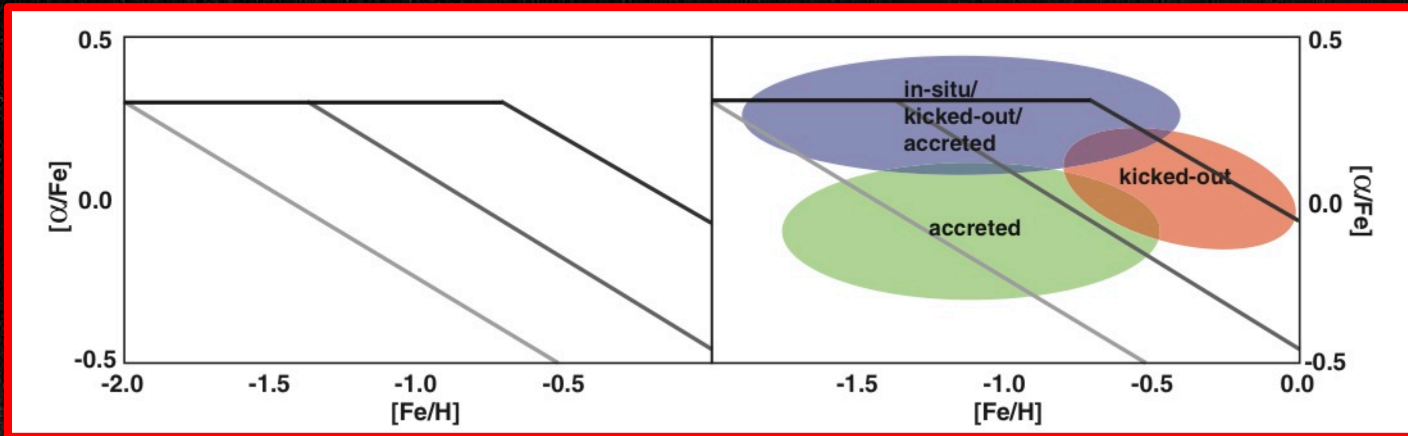
- Almost all globular clusters (GCs) exhibit characteristic abundance patterns – e.g., Na – O anticorrelations – for which the leading explanation is extended (or multiple generations of) star formation
- A number of GCs also show a significant range in [Fe/H] and / or distinct stellar populations → enrichment by SNe Ia, extended star formation histories →surviving cores / central star clusters of dwarf galaxies (à la M54)?
- At least two GCs with metallicity spreads also have extended diffuse stellar “halos” extending for hundreds of pc
- The fraction of MW halo stars originating in GCs has been estimated at between ~17% and ~50% (Martell+ 2010,2011; Caretta et al. 2010)

Globular Clusters as Accreting Satellites



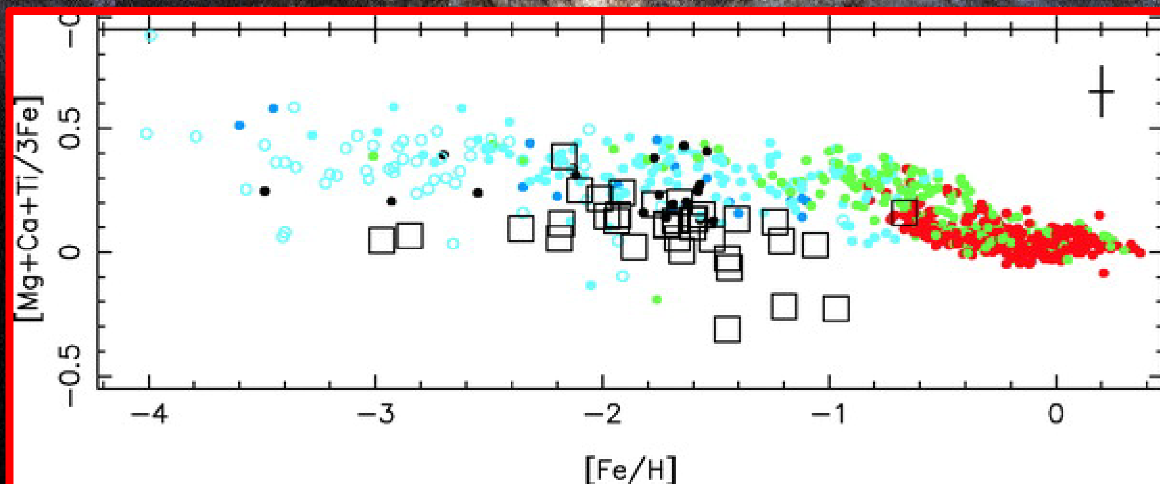
Anguiano+, MNRAS (submitted)

Abundance Characteristics of Accreted Stars: Dwarf Galaxies



Sheffield+ 2012

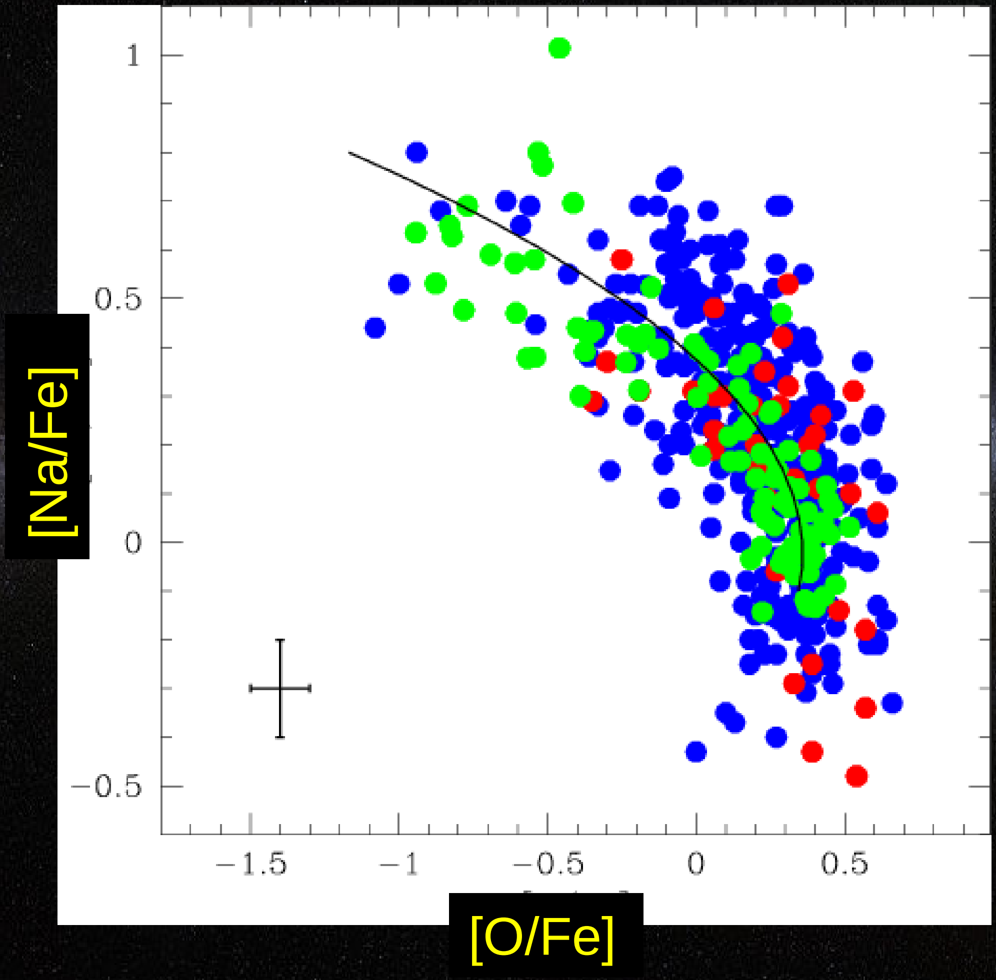
[α/Fe]



Venn+ 2004

[Fe/H]

Abundance Characteristics of Accreted Stars: Globular Clusters

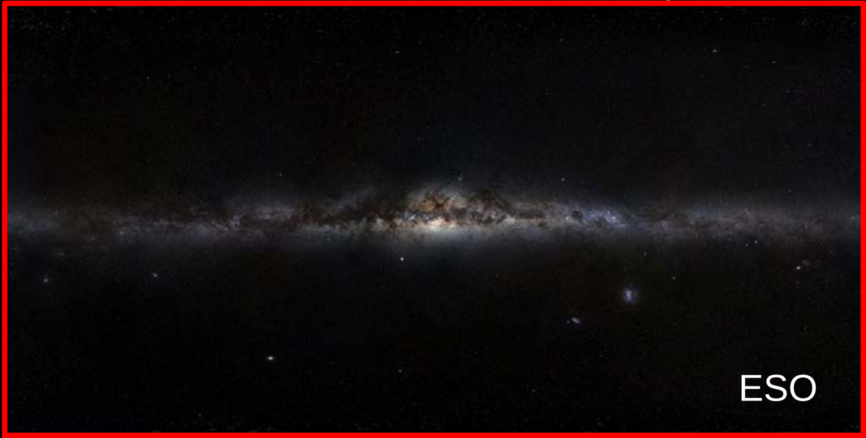


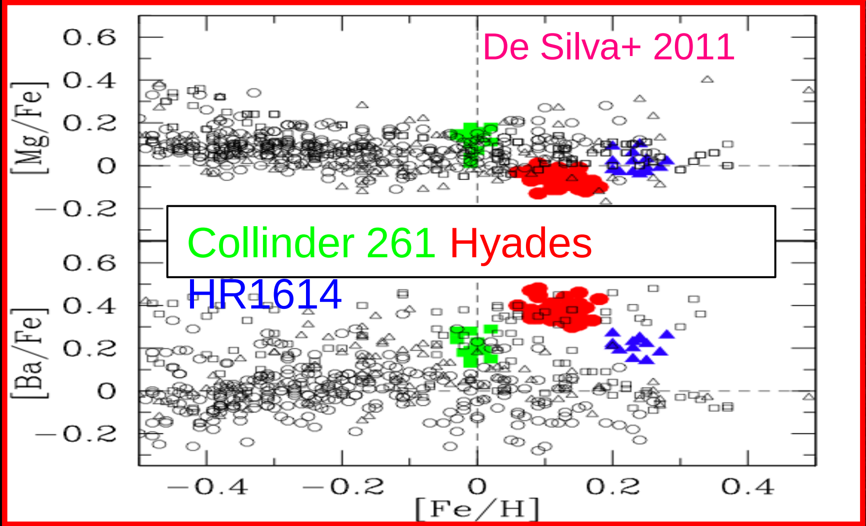
Carretta et al. 2006

Chemical Tagging

Family Reunions through Chemical Tagging?

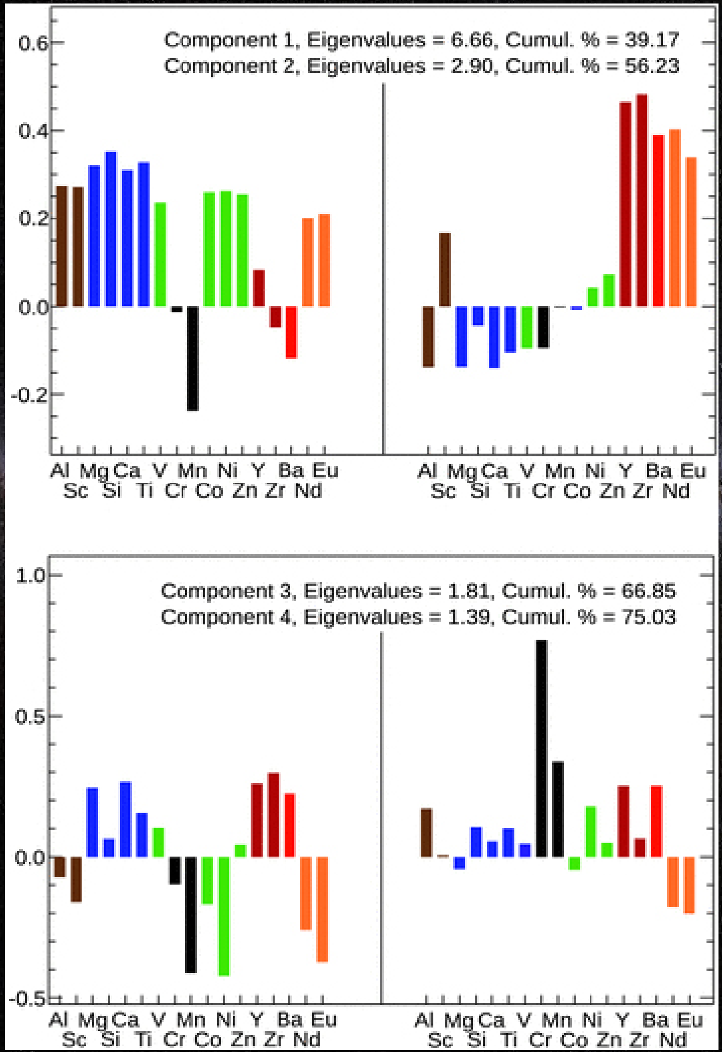
- Traces of the Milky Way's building blocks (remnants of star formation and accretion events) survive in distinct stellar abundance patterns and can be revealed by chemical tagging (e.g., Freeman & Bland-Hawthorn 2002; Mitschang+ 2013)
- Beyond simply identifying likely accreted stars by their gross abundance patterns, we can use tagging to group stars which formed together by their detailed elemental abundances





Quantitative Chemical Tagging

Principal Componen t Analysis

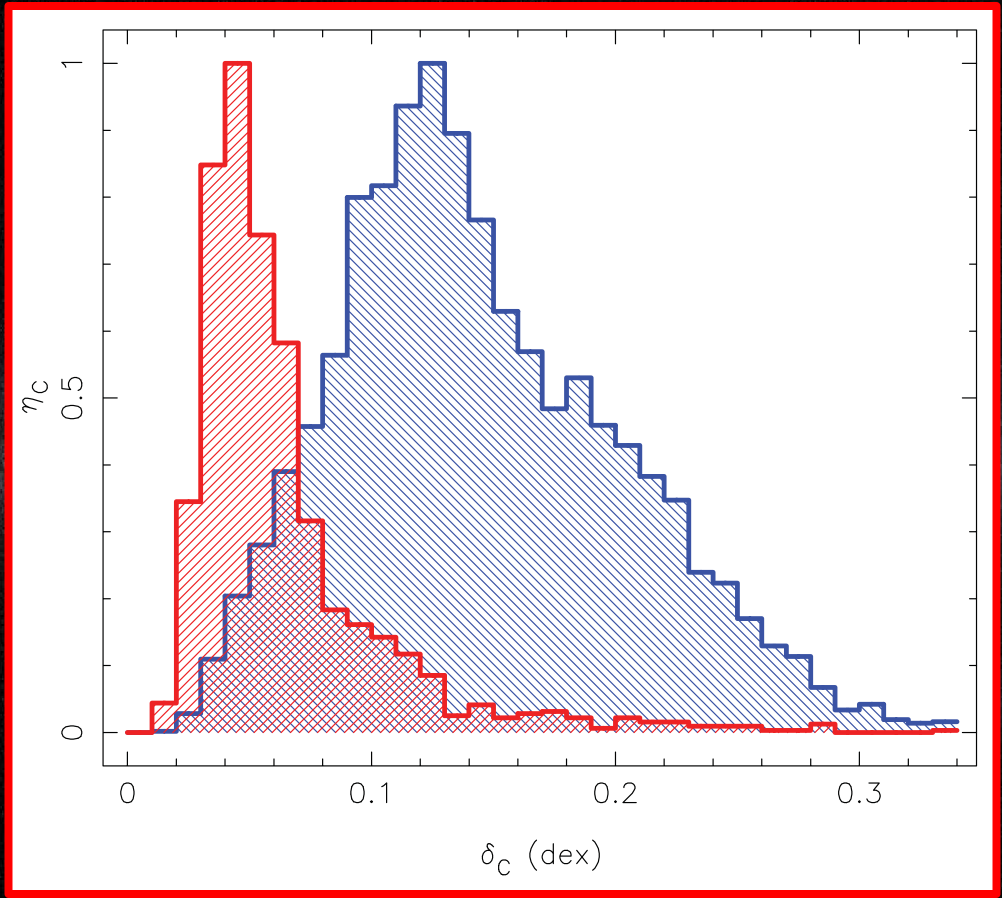


Ting+ 2012

Quantitative Chemical Tagging

Manhattan Distance Metric

$$\delta_C = \sum_{C=1}^{N_C} \omega_C \frac{|[C/Fe]^i - [C/Fe]^j|}{N_C}$$



*Calibration based on OC literature data (heterogeneous)

Mitschang+ 2013, 2014

Quantitative Chemical Tagging

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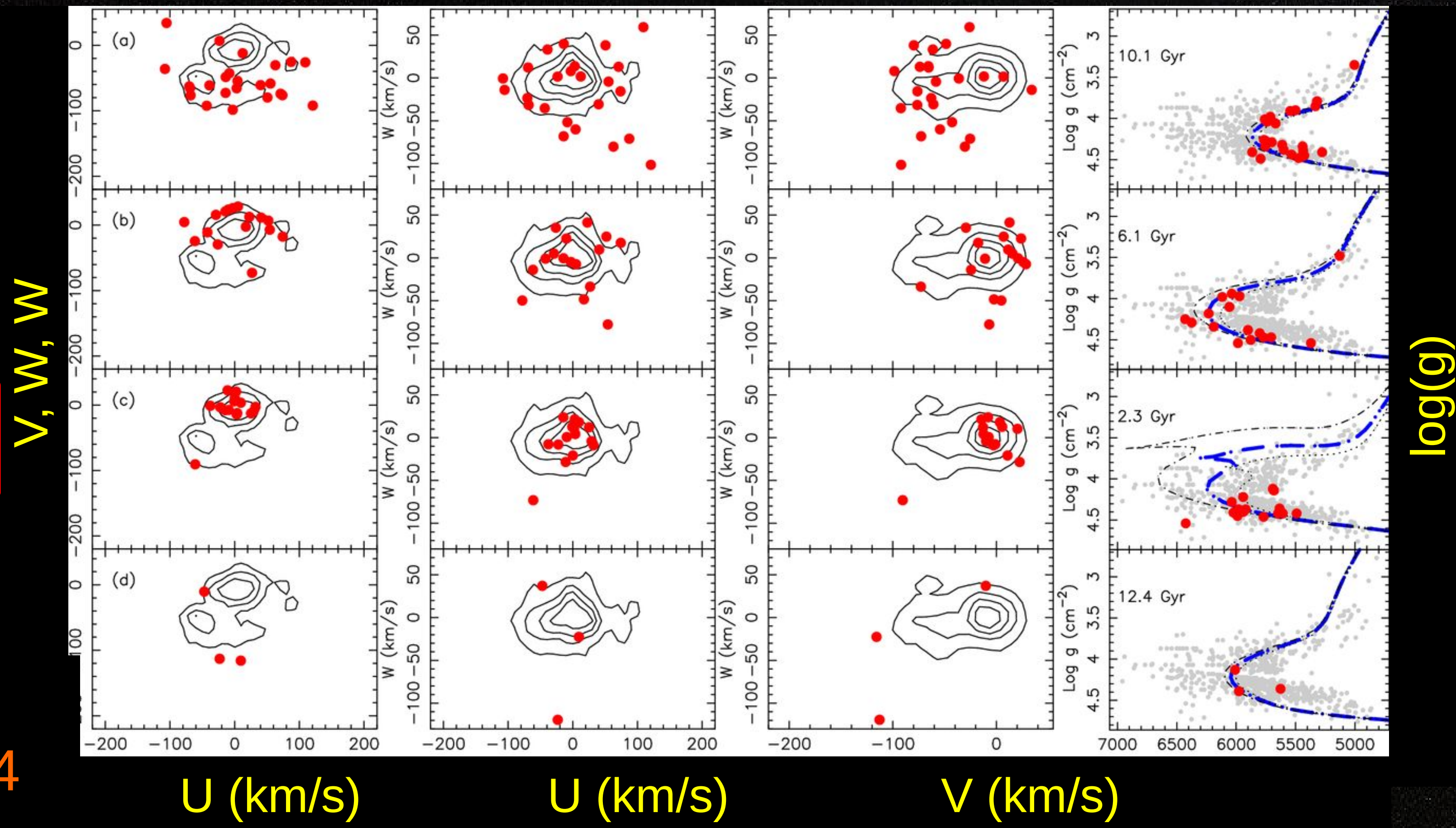
Application to Bensby+ 2014 sample



Mitschang+ 2013, 2014

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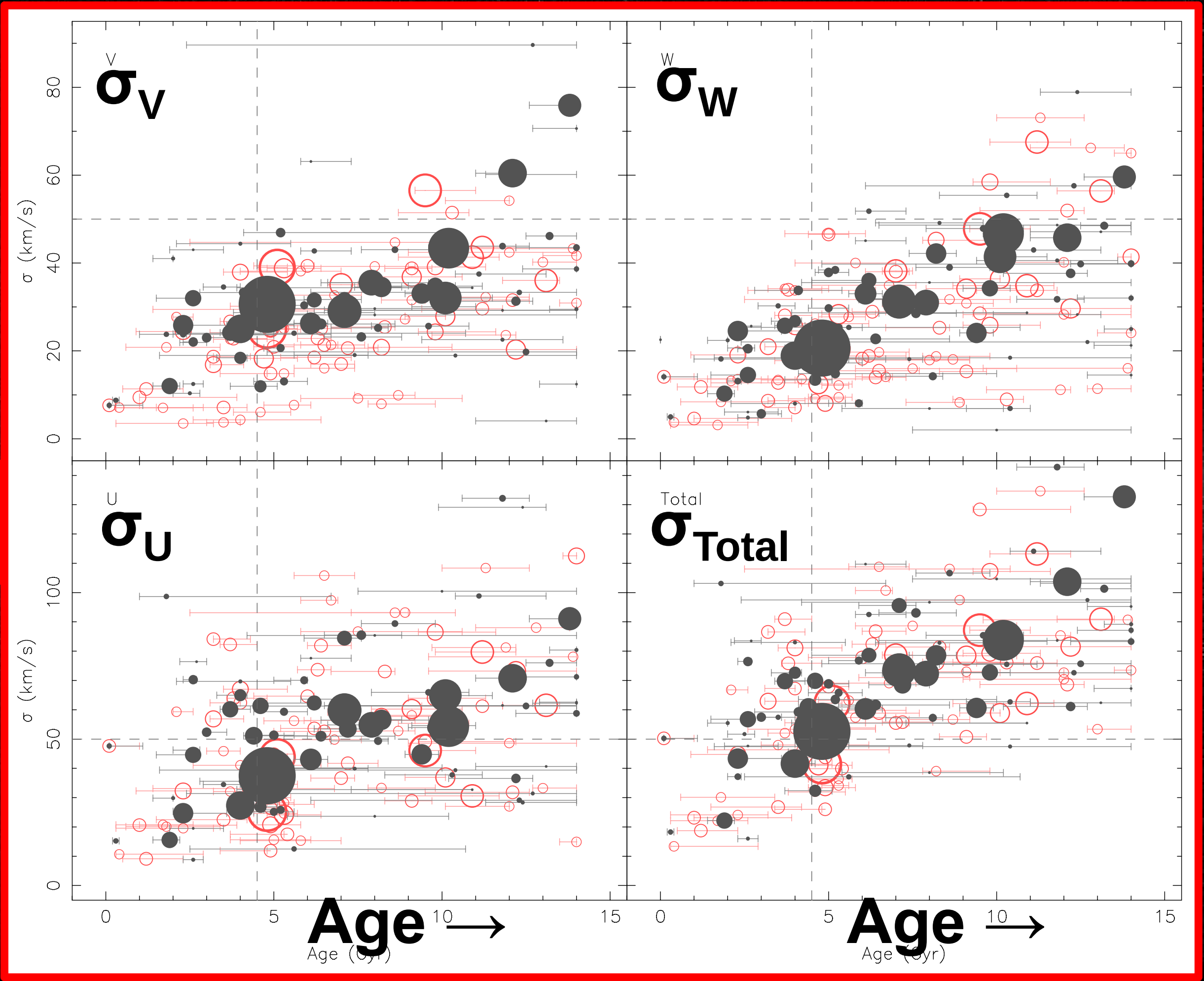

Mitschang+ 2013, 2014

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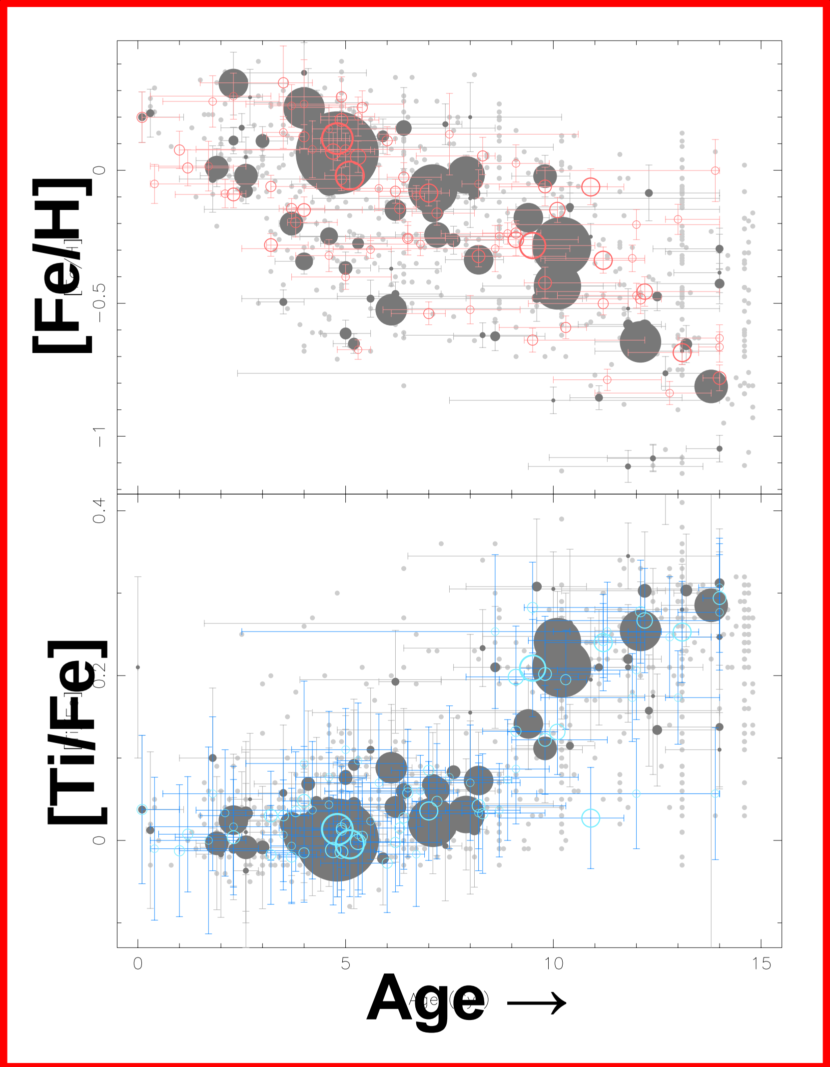
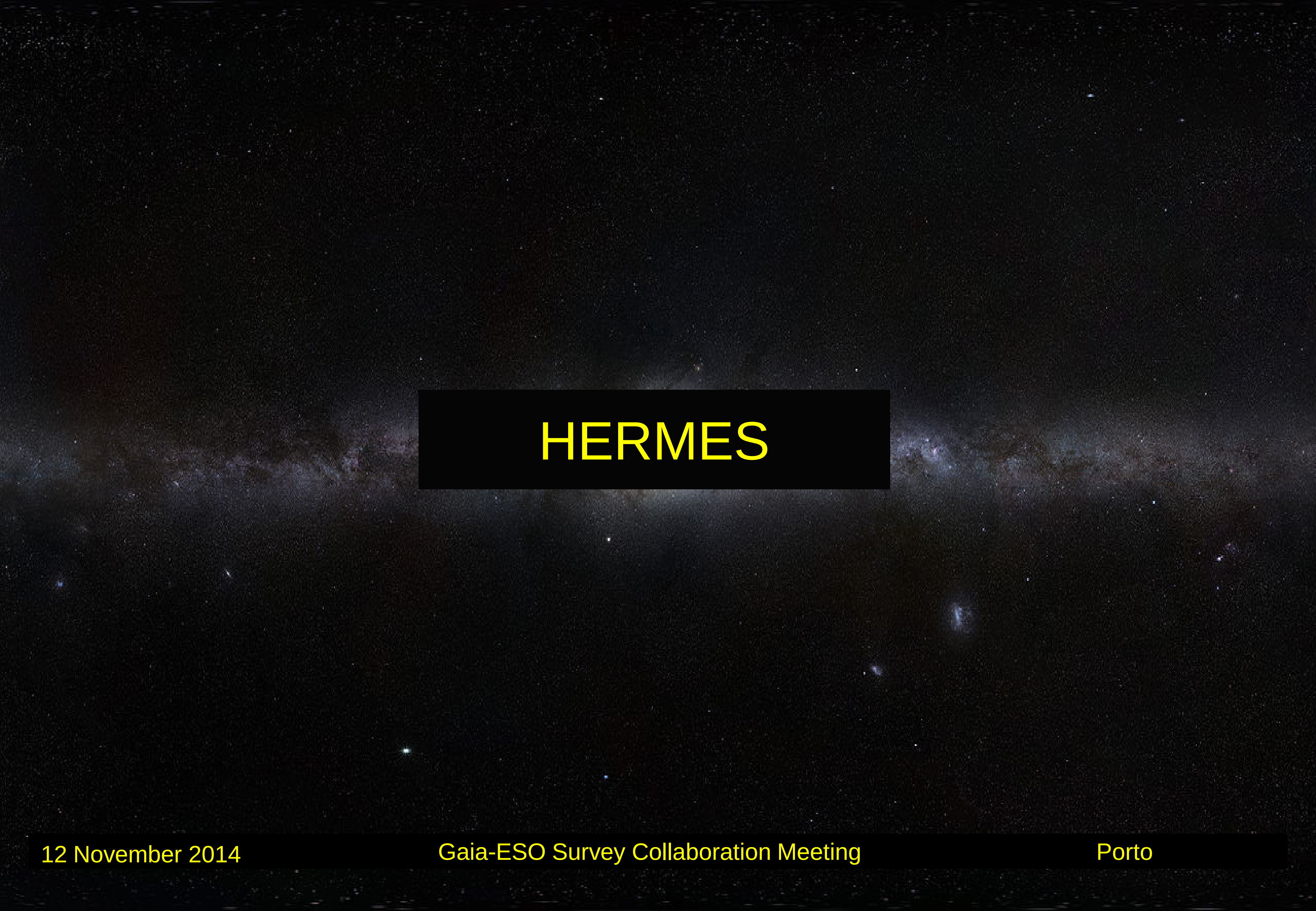


Mitschang+ 2013, 2014

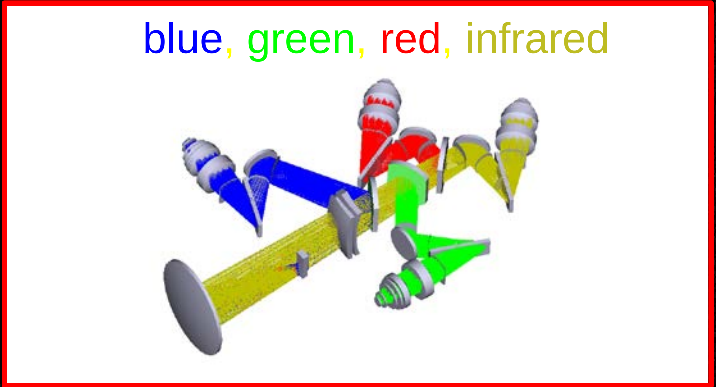


HERMES

HERMES

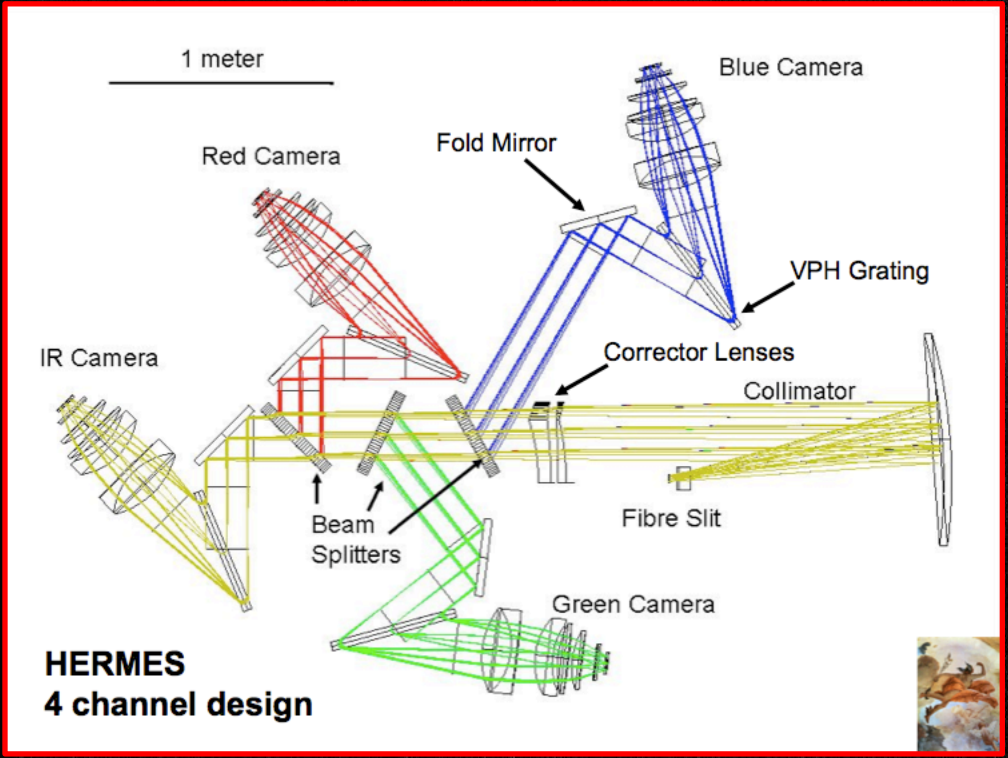
HERMES: The High Efficiency and Resolution Multi-Element Spectrograph

- Instrument built for the 3.9m Anglo-Australian Telescope (AAT)
- Primary science driver: chemical tagging / Galactic archaeology
- Commissioning: October – December 2013
- Pilot Survey: November 2013 – January 2014



HERMES Details

- 4 channels with VPH gratings and 4k^2 CCDs
- R~28,000, 200-300 Å/per channel (~1000Å total); higher resolution with a slitmask (R~50,000)
- For V~14, S/N ~ 100 in 1 hour, ~10% efficiency
- Works with 2dF top end: prime focus robotic positioner, 392 data fibres, 2^o field of view



HERMES and the AAT

- HERMES is now a facility instrument on the AAT, located at Siding Spring Observatory
- Most (but not all!) HERMES time has recently been allocated to the GALAH survey

GALAH

Galah Collaboration

A Variety of Horizontal Branch Morphologies

The GALAH Survey

Galactic Archaeology with HERMES Survey: designed to reconstruct the lost stellar substructures of the proto-Galaxy, and obtain a detailed physical picture of the formation and evolution of the Galaxy

Large Observing program

- ~10^6 stars, complete down to V~14
- ~3000 plate configurations (~400 stars per field) ➔~ 400 nights of bright time ➔~ 5yr survey duration
- Australian-led project, with international collaborators

Chemical Tagging

- Up to **29** elemental abundances per star, from 7 independent element groups
- Spectral synthesis via automated abundance pipeline
- Relative accuracy 0.05 – 0.1 dex
- First survey of its kind (and scope)

GALAH Stellar Parameters and Abundances from Spectra

- Parameters: T_{eff}, log(g), [Fe/H], ξ
- Properties: v_{rad}, v_{rot}, binarity, chromospheric activity, …
- To maximise chemical "resolution", select four wavelength regions to allow abundance measurements from a range of independent element groups:

- Light elements (Li, C, O, Na, Mg, Al)
- Other alpha-elements (Ca, Si, Ti)
- Fe and Fe-peak elements
- Light s-process elements (Sr, Zr)
- Heavy s-process elements (Ba)
- r-process (Eu)

Channel	Wavelengths
Blue	4708 – 4893Å
Green	5649 – 5873Å
Red	6481 – 6739Å
IR	7590 – 7890Å

GALAH Science

GALAH seeks to address basic questions about the formation and evolution of the Milky Way, including:

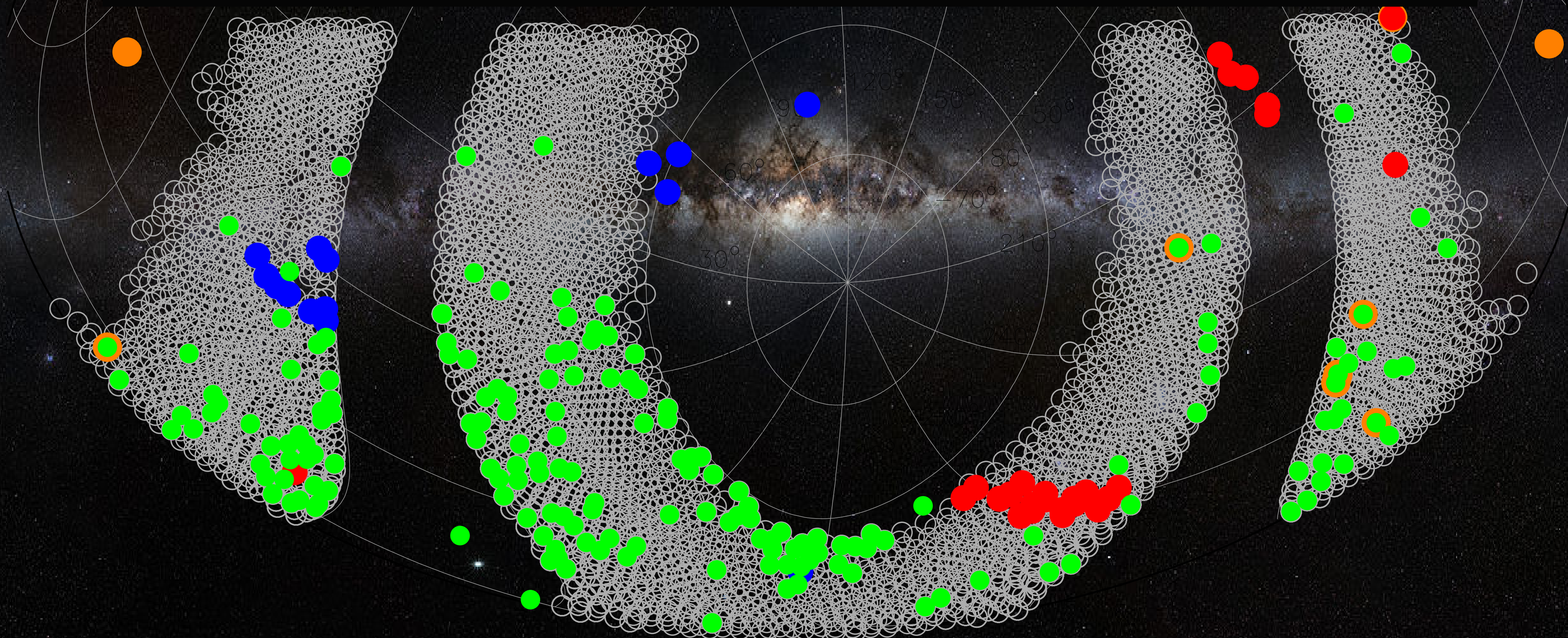
- What were the conditions of star formation during Galaxy assembly?
- When and where were the major episodes of star formation in the disk and what drove them?
- To what extent are the Galactic thin and thick disks composed of stars from merger events?
- In what conditions and types of systems did accreted stars form?
- How have the stars that formed *in situ* in the disk evolved dynamically?

Observability of and Expected Fractional Contribution from Galactic Components in GALAH

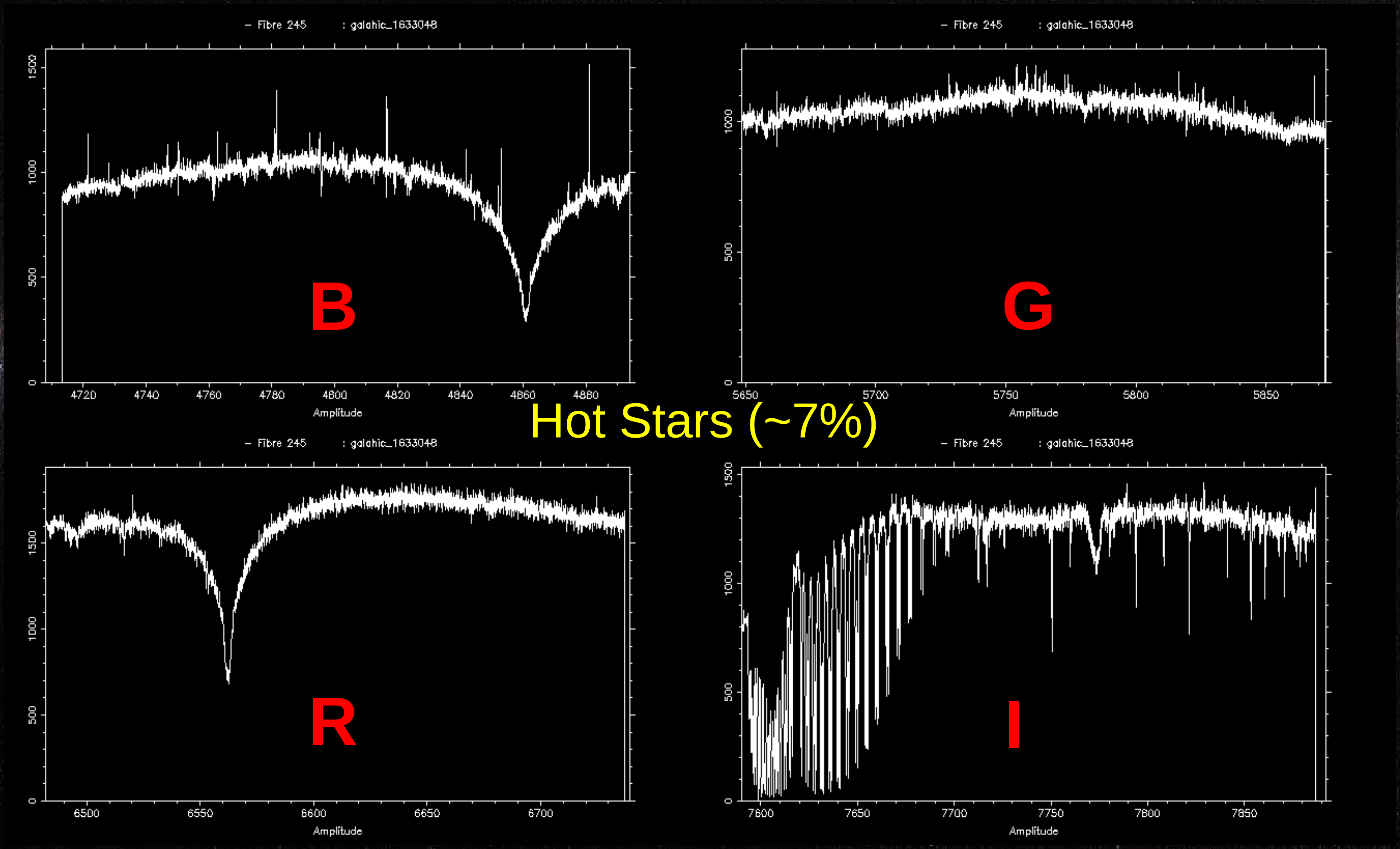
Thin Disk	1 kpc (~75%)
Thick Disk	6 kpc (~24%)
Halo giants	15 kpc (~1%)

GALAH Survey Progress

- Main survey, Feb 2014 – ??
- Latest tally: 77,668 survey stars and 5992 Kepler-2 stars



GALAH Sample Spectra



GALAH Synergies / Opportunities

GALAH has powerful synergies with GES and Gaia:

- GES: cross-calibration of abundances, parameters, RVs; GALAH will observe brighter stars, GES fainter stars ➔ probing different disk / halo samples (see talk by S. Martell)
- Gaia: proper motions, radial velocities and parallaxes for ~1 billion stars, + GALAH ➔ 6-D phase space info with detailed abundances for 0.1% of the Gaia sample (and Gaia will have 6-D data for *all* of the GALAH sample)

Summary

- Kinematics of accreted stars may change, but their abundances remain (mostly) the same
- Globular clusters are accreted, too – and some may be remnants / relics of dwarf galaxies
- Stars from dwarfs and globulars have characteristic abundance patterns
- Chemical tagging can potentially identify accreted stars (as well as *in situ* stars) with common origins
- The new HERMES spectrograph on the AAT is ideally suited for searching for chemical tagging
- GALAH, a 10^6 star spectroscopic survey now underway, will allow us to probe the accretion history of the disk and inner halo