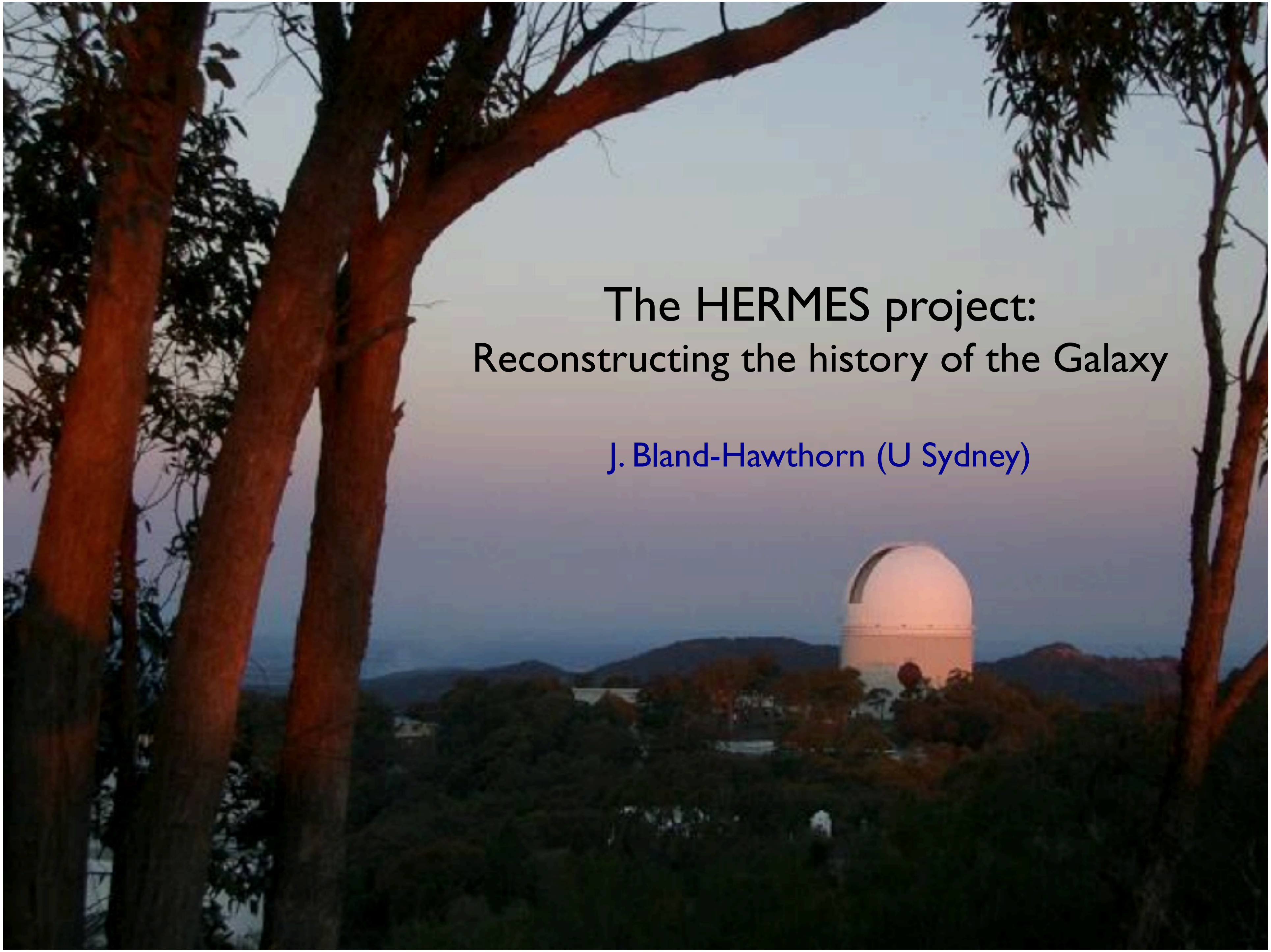


The HERMES project:
Reconstructing the history of the Galaxy

J. Bland-Hawthorn (U Sydney)

January 2013

Hilo 2013

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 (*bvri*) ~ 1000 Å

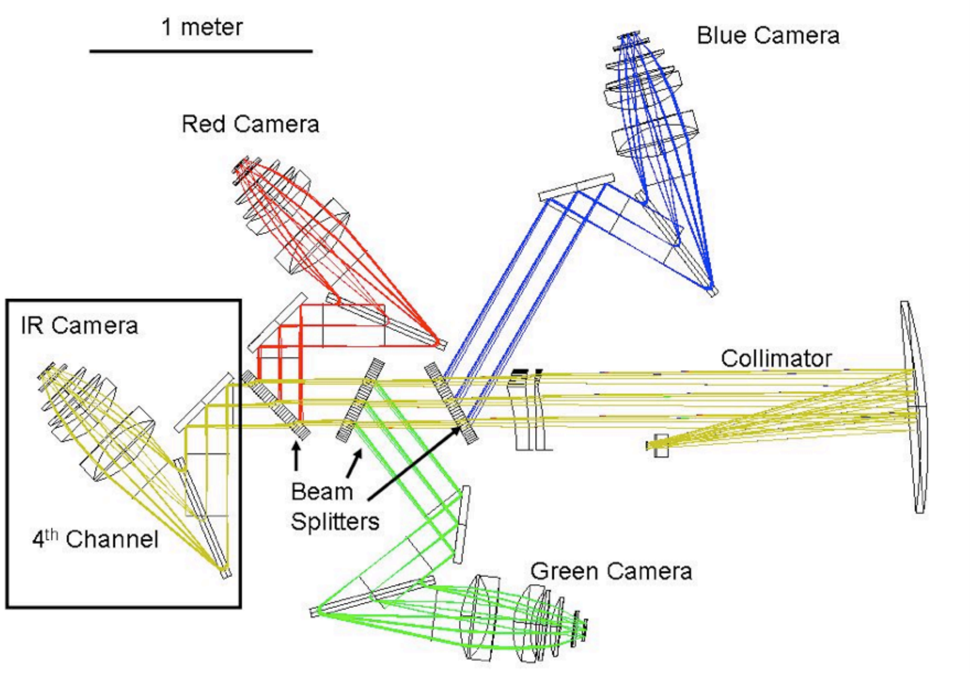
First light 2013B

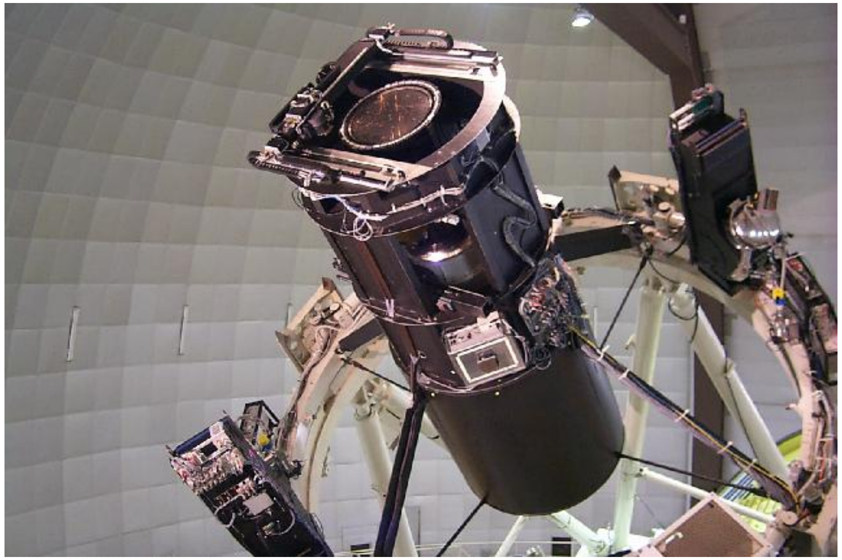
Team of about 40, mostly from Australian institutions

HERMES @ AAT (first light 2013B)

$15M investment up front: 400 fibres
over 2^{o} field, optical

New $15M 4-arm spectrograph,
R=28,000, ~250A bands in *bvri*





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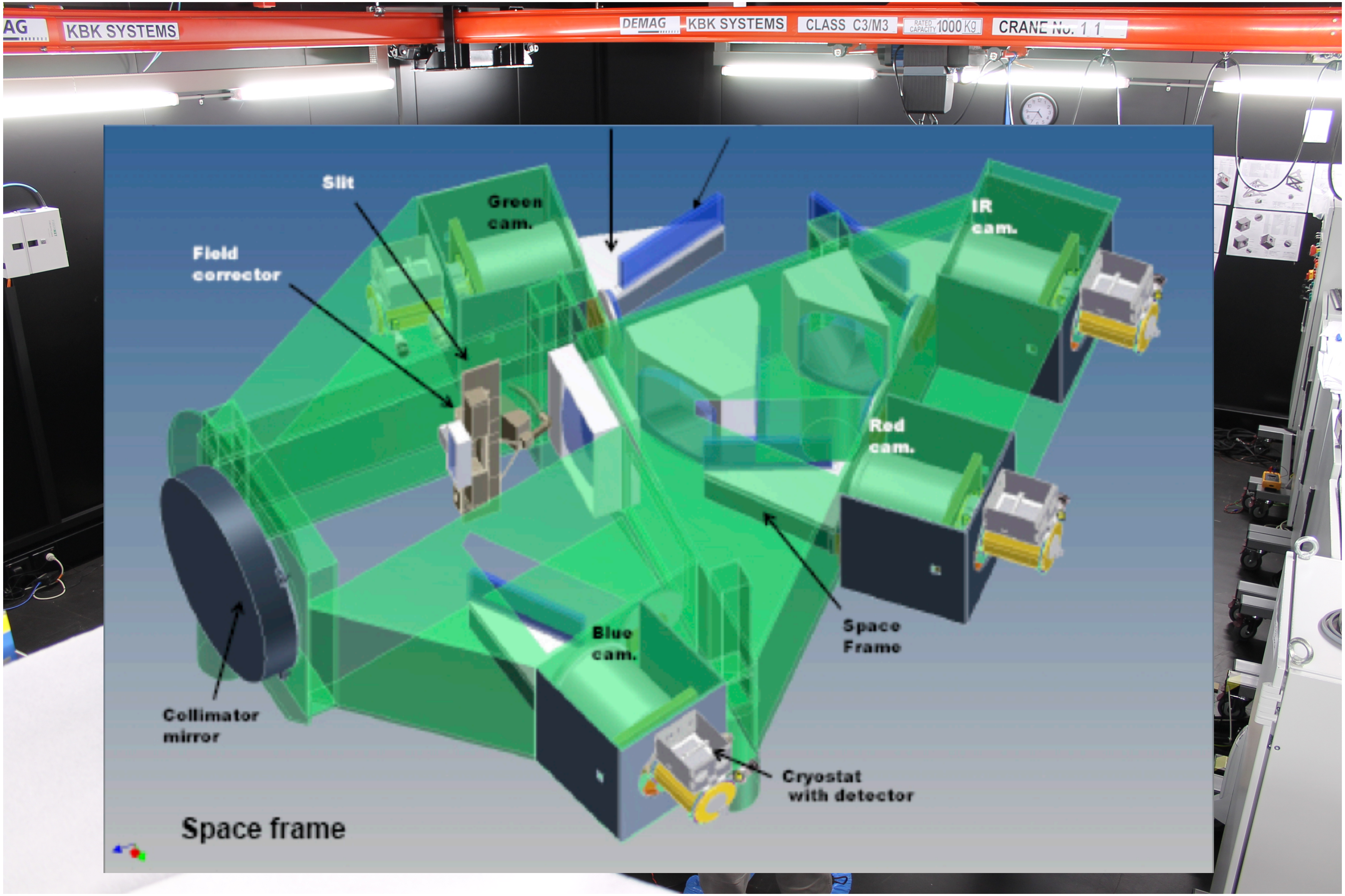
AG
KBK SYSTEMS
DEMAG
KBK SYSTEMS
CLASS C3/M3
RATED CAPACITY 1000 Kg
Slit
Green cam.
Field corrector
IR cam.
Red cam.
Space Frame
Blue cam.
Collimator mirror
Cryostat with detector
Space frame

A recent workshop to discuss HERMES science

Hilo 2013

GALAH Survey Team

Managing Members:

Ken Freeman (ANU) - Principal Investigator

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

Gayandhi De Silva (AAO) - HERMES Project Scientist

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Liz Wylie de Boer (ANU)

Stefan Keller (ANU)

Tomaz Zwitter (Uni. Ljubljana)

Dan Zucker (AAO)

Sarah Martell (AAO)

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Andrew Cole (Uni. Tas)

Peter Cottrell (Uni. Christchurch)

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Gary Da Costa (ANU)

Paul Dobbie (AAO)

Simon Ellis (Uni. Syd)

Chris Flynn (Uni. Syd)

Elaina Hyde (Macq)

Michael Ireland (AAO/Macq)

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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)

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Simon O'Toole (AAO)

Quentin Parker (AAO/Macq)

Sanjib Sharma (Uni. Syd)

Rob Sharp (ANU)

Jeffrey Simpson (Uni. Christchurch)

Chris Sneden (Uni. Texas)

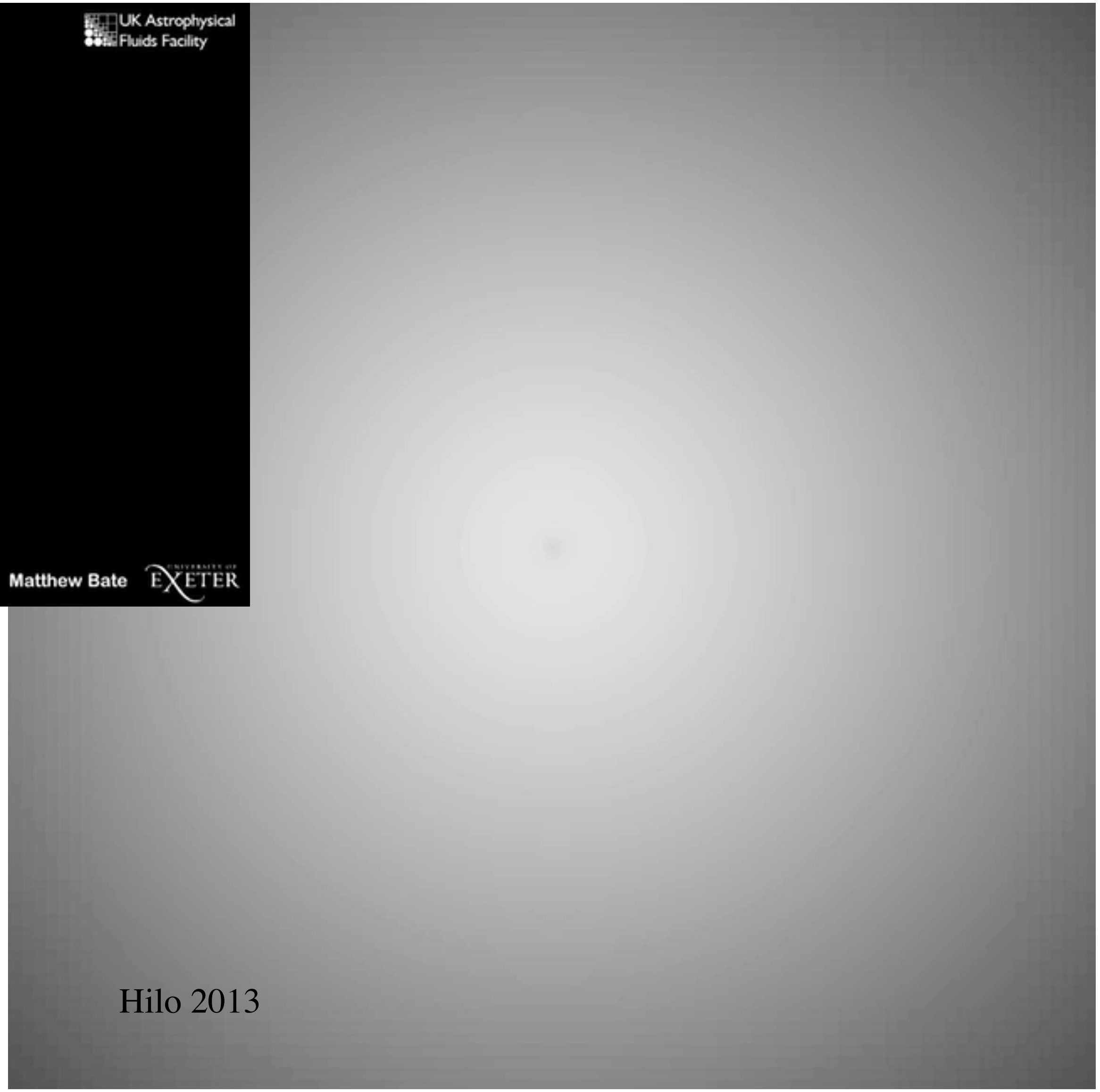
Chris Tinney (UNSW)

Fred Watson (AAO)

David Yong (ANU)

Huge challenge – the sequence of events that yields stars over cosmic time

star-forming cloud ~500 $M_{\odot}$ (Bate)



Galactic disk (Agertz)

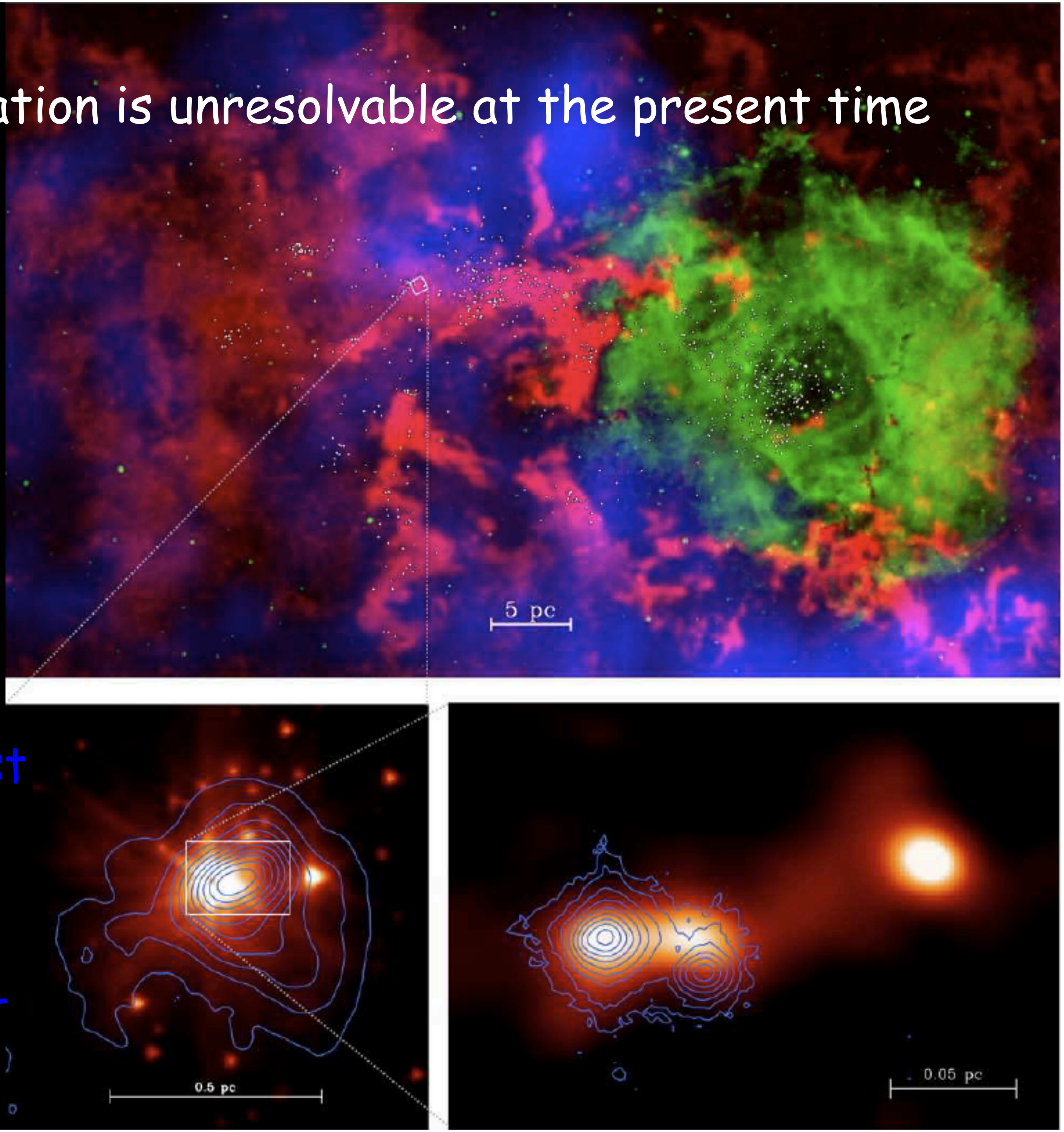
Cluster formation is unresolvable at the present time

$5 \times 10^5\ M_o$

2.6 mm CO
21 cm HI
DSS optical

Left:
850 µm cold dust
3.6 µm cluster

Right:
1.2 mm cold dust
4.9 µm cluster

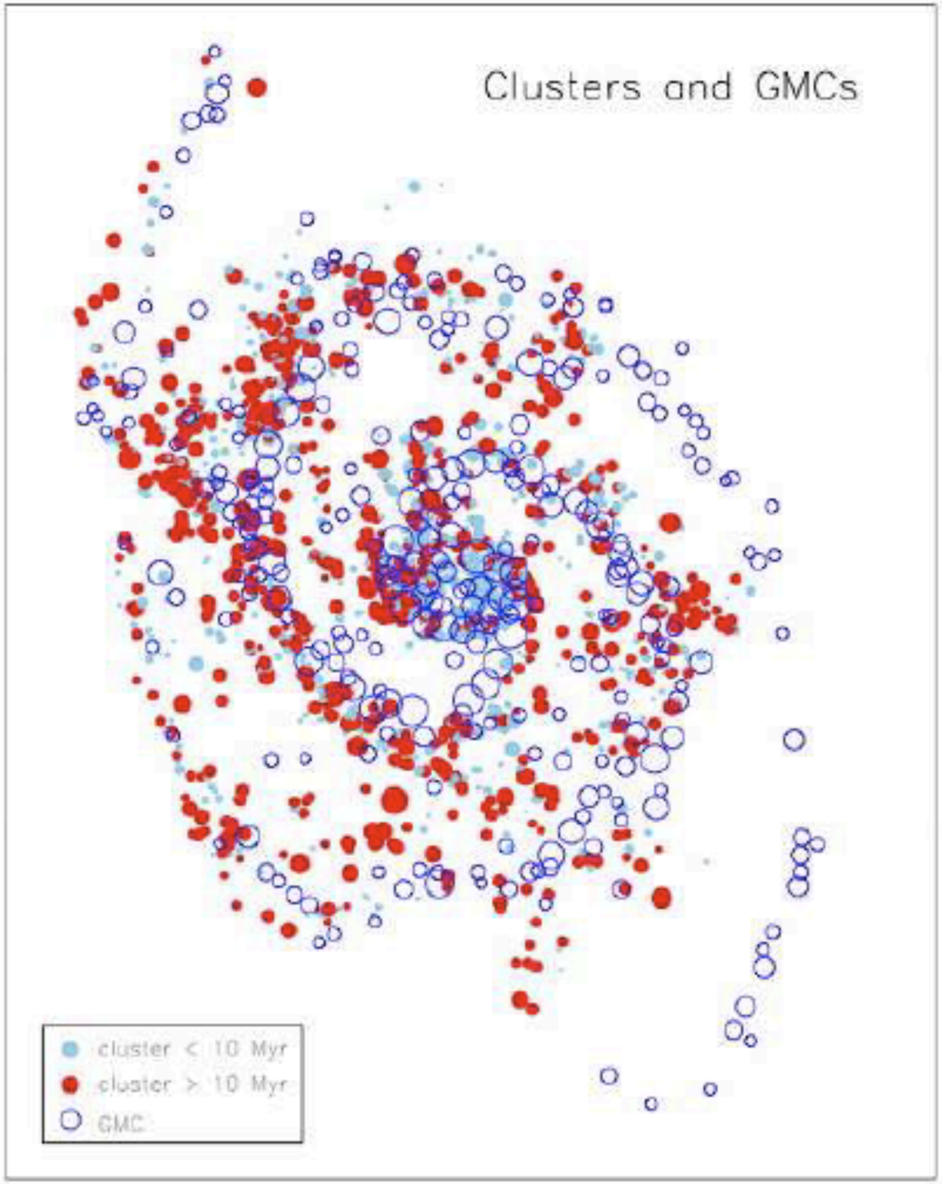


Slide caption

Figure 1. The scales of star formation. The upper panel shows a composite view of the Rosette nebula and accompanying cloud. The nebula, shown in green from a Digitized Sky Survey image, is powered by a collection of massive stars at the centre of a large cluster. The red image is 2.6 mm emission from the CO molecule and indicates the presence of a Giant Molecular Cloud, about 50 pc in diameter and mass $2 \times 10^5\,M_\odot$ [9]. The blue image shows the intensity of the neutral hydrogen 21 cm line, and reveals an atomic envelope around the cloud [10], either the remnants of the diffuse gas from which the molecular cloud formed or photodissociated gas due to the surrounding ultraviolet radiation field. The lower panels zoom in on the star formation process. The left panel shows contours of 850 μm emission from a cold dusty envelope around a deeply embedded cluster, imaged at 3.6 μm. The right panel shows 4.9 μm contours from embedded protostars on a 1.2 mm interferometric image of 3 dusty cores lying in a filament at the centre of the clump [11]. The scale bars decrease by an order of magnitude in each panel demonstrating the enormous change in scale from cloud to clump to core.

Formation & destruction have a coupled environmental dependence.
We see strong dependences **within** and **between** galaxies.

M51: Scheepmaker+09



Formation & destruction

We observe a ***cluster mass function*** that arises from a complex coupling between these two processes.

Formation requires dense gas, high pressures & accretion flows.

Destruction is caused by 2-body relaxation (minor) and tidal shocks (major), i.e. rapidly changing tidal field, interaction with GMCs. Both mechanisms wipe out the low mass clusters first.

So destruction is most efficient in regions of high star formation, i.e. ***infant mortality*** must be very high.

Note: we are assuming fixed **cluster formation efficiency**; if this is very low, clusters can disperse rapidly because the hot young stars blow the gas away.

More massive clusters have been observed in mergers/starbursts

incl. formation of globular clusters

Key parameters are:

CMF slope, γ
CMF age distribution
maximum mass, M_{MAX}

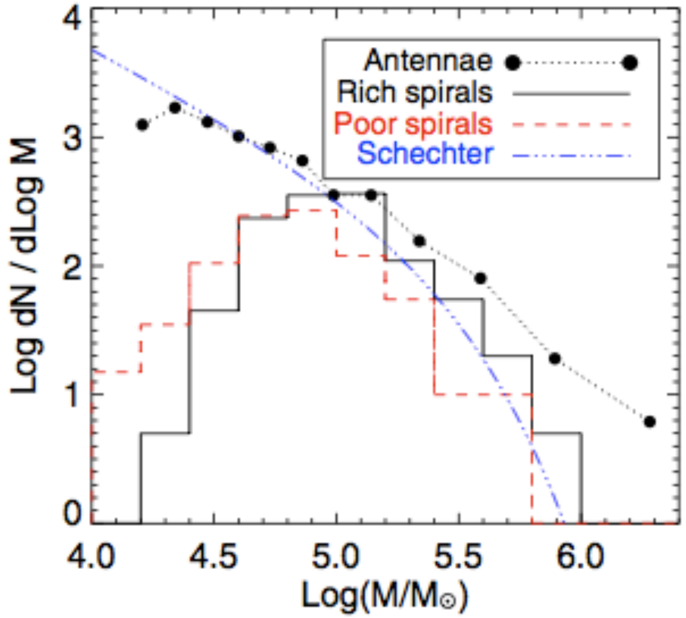


Fig. 6. Combined cluster mass functions for the two galaxies with more than 100 clusters each (NGC 5236, NGC 6946) and those with less than 40 clusters each. Clusters with ages $<2 \times 10^8$ years are included. Also shown is the mass function for young clusters in the Antennae (Zhang & Fall 1999) and a Schechter function with $M_c = 2.1 \times 10^5 M_\odot$ and $\alpha = -2$.

This is also what we observe at $z > 1$

Turbulent star forming disks, supermassive star clusters ~ $10^{6\text{-}8}\ M_{\odot}$

These ancient star clusters have now dissolved into the Galaxy.


All open clusters to date are found to be chemically uniform in all elements
JBH, Krumholz & Freeman 2010:
manifesto for chemical tagging

GOAL: To measure the strength of migration with cosmic time

The Astrophysical Journal, 713:166–179, 2010 April 10 doi:10.1088/0004-637X/713/1/166

THE LONG-TERM EVOLUTION OF THE GALACTIC DISK TRACED BY DISSOLVING STAR CLUSTERS

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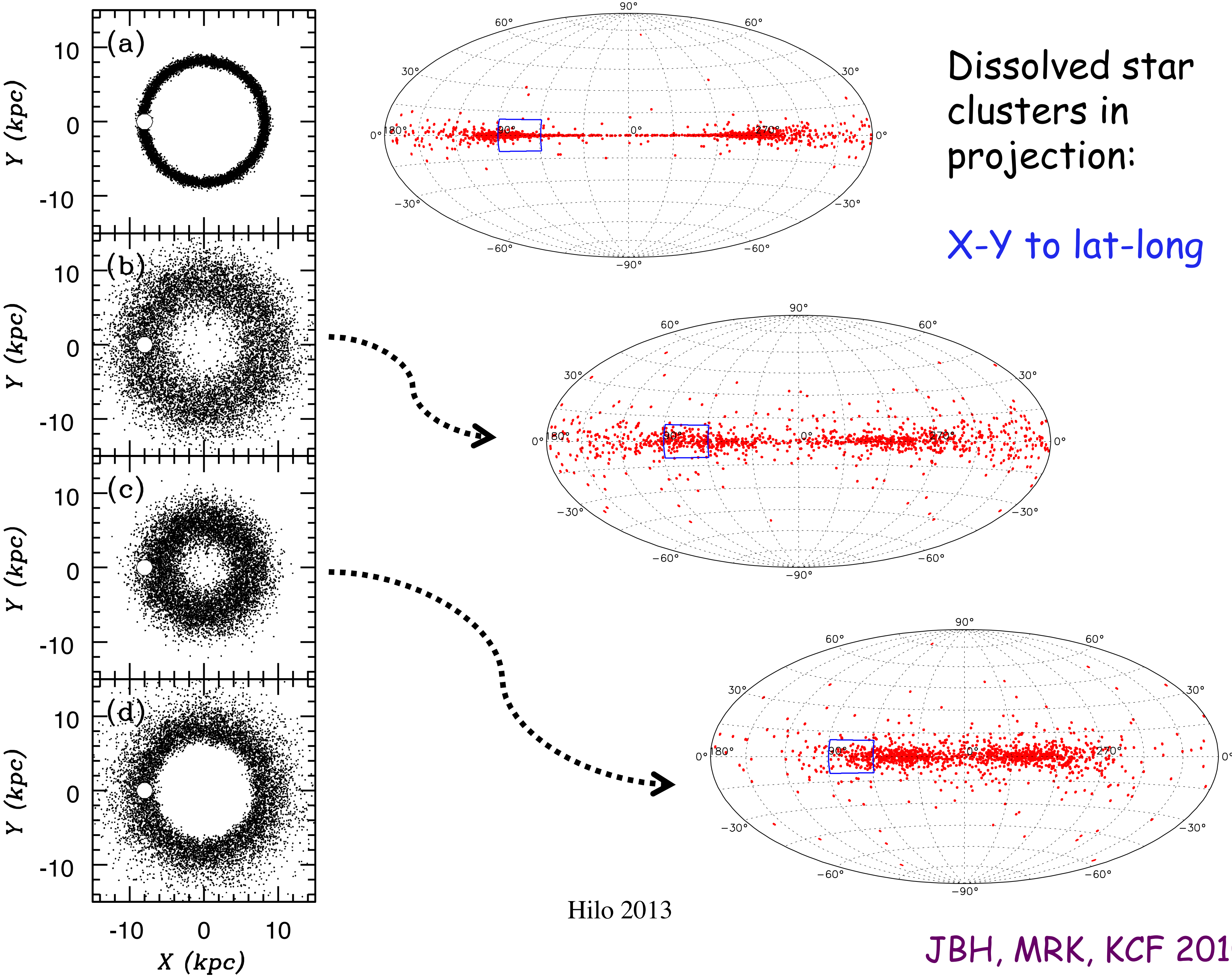
ABSTRACT

The Galactic disk retains vast amount of information about how it came to be and how it evolved over cosmic time. However, we know very little about the secular processes associated with disk evolution. One major uncertainty is the extent to which stars migrate radially through the disk, thereby washing out signatures of their past (e.g., birth sites). Recent theoretical work finds that such "blurring" of the disk can be important if spiral arms are transient phenomena. Here we describe an experiment to determine the importance of diffusion from the Solar circle with cosmic time. Consider a star cluster that has been placed into a differentially rotating, stellar fluid. We show that all clusters up to $\sim 10^4\ M_\odot$ in mass, and a significant fraction of those up to $\sim 10^5\ M_\odot$, are expected to be chemically homogeneous, and that clusters of this size can be assigned a unique "chemical tag" by measuring the abundances of $\lesssim 10$ independent element groups, with better age and orbit determinations allowing fewer abundance measurements. The star cluster therefore acts like a "tracer dye," and the present-day distribution of its stars provides a strong constraint on the rate of radial diffusion or migration in the Galactic disk. A star cluster of particular interest for this application is the "Solar family"—the stars that were born with the Sun. If we were able to identify a significant fraction of these, we could determine whether the Sun was born at its present radius or much further in. We show all-sky projections for the Solar family under different dynamical scenarios and identify the most advantageous fields on the sky for the experiment. Sellwood & Binney have argued for strong radial transport driven by transient spiral perturbations: in principle, we could measure the strength of this migration directly. In searching for the Solar family, we would also identify many thousands of other chemically homogeneous groups, providing a wealth of additional information. We discuss this prospect in the context of the upcoming HERMES high-resolution million-star survey.

Key words: Galaxy: disk – Galaxy: evolution – Galaxy: kinematics and dynamics – open clusters and associations: general – stars: abundances – stars: solar-type

Online-only material: color figures



Dissolved star clusters in projection:

X-Y to lat-long

Hilo 2013

JBH, MRK, KCF 2010

How massive a uniform star cluster?

Cloud dynamical time (Tan+ 06)

$$t_{\rm cr} = \frac{0.95}{\sqrt{\alpha_{\rm vir} G}} \left(\frac{M}{\Sigma^3}\right)^{1/4}$$

M = cloud gas mass ~ 10^6 M_o
Σ = cloud col. density ~ 0.3 g cm^{-2}

The cloud's virial ratio $\alpha_{\rm vir} \approx 1-2$ is the ratio of kinetic to gravitational energy. So if $t_{\rm form}$ = 4 $t_{\rm cr}$ then

$$t_{\rm form} \approx 3.0 \left(\frac{\epsilon}{0.2}\right)^{-1/4} \left(\frac{M_*}{10^4\, M_\odot}\right)^{1/4} \ {\rm Myr}$$

$$\epsilon = M_*/M = 0.2$$

i.e. fraction of cloud ➔ stars

We conclude that star clusters up to 10^4 M_o are **chemically uniform** (80% up to 10^5 M_o) since t_{SN} > 3 Myr for most SNe in these clusters.

JBH, Krumholz & Freeman 2010

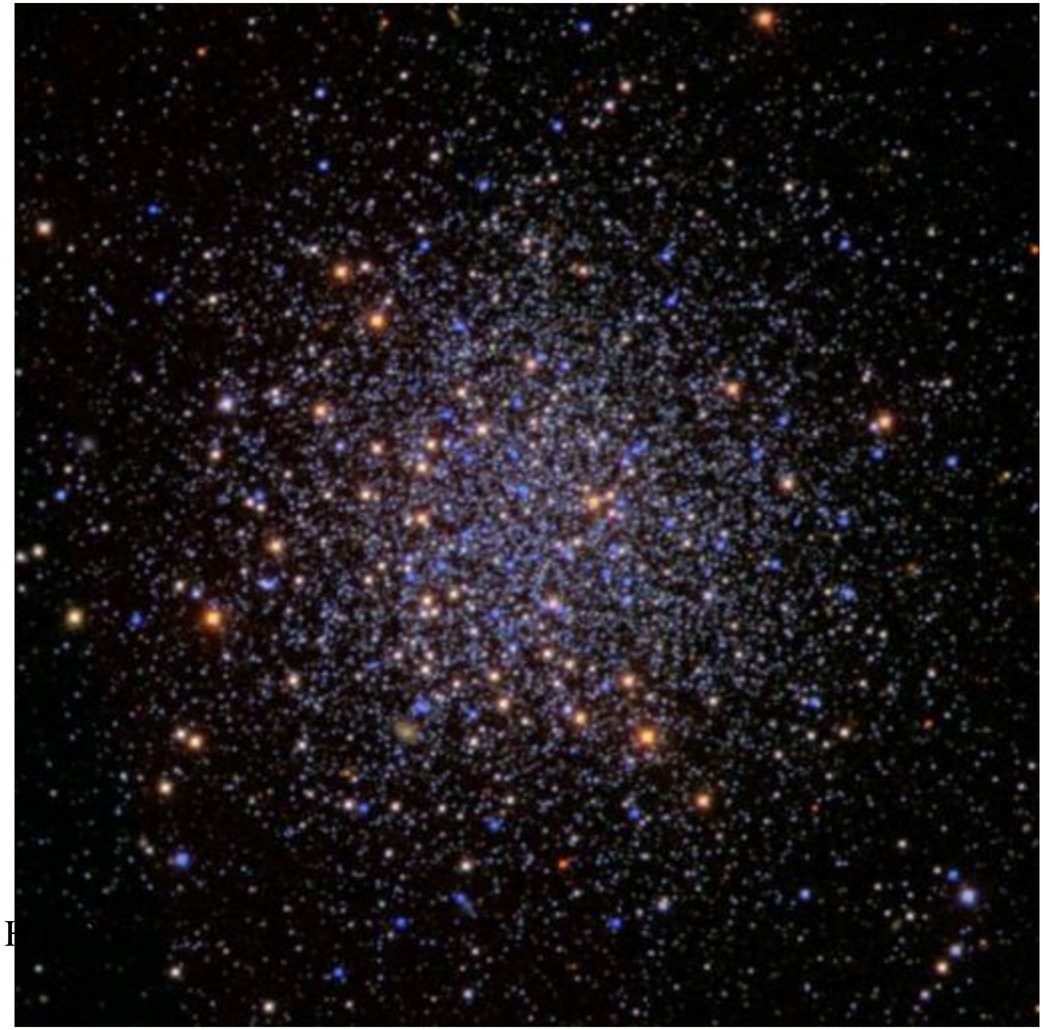
What about uniformity in globular clusters?

$$t_{\mathrm{cr}} = \frac{0.95}{\sqrt{\alpha_{\mathrm{vir}} G}} \left(\frac{M}{\Sigma^3} \right)^{1/4}$$

$\Sigma \sim 3$ g cm^{-2}

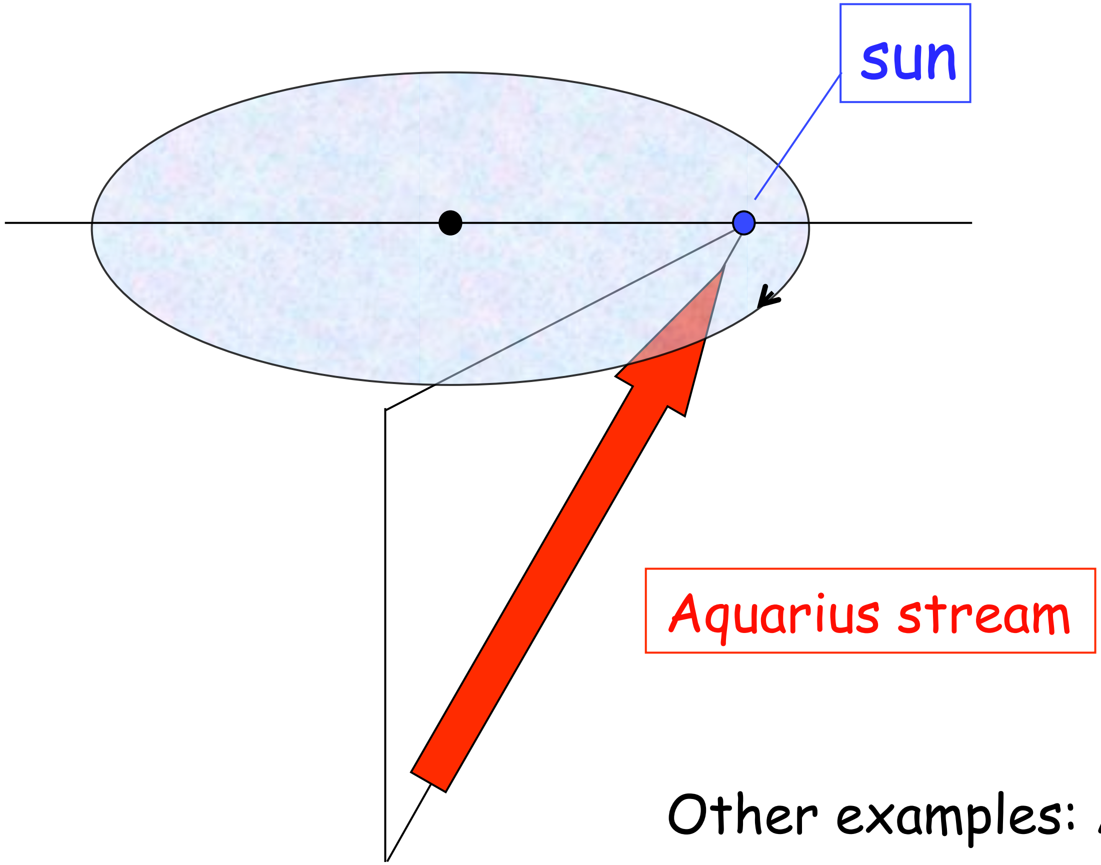
Dynamical time 6x shorter

Dense star clusters can be chemically uniform even with masses $\geq 10^7$ M_o !!



A recent example of chemical tagging in Galactic archaeology:

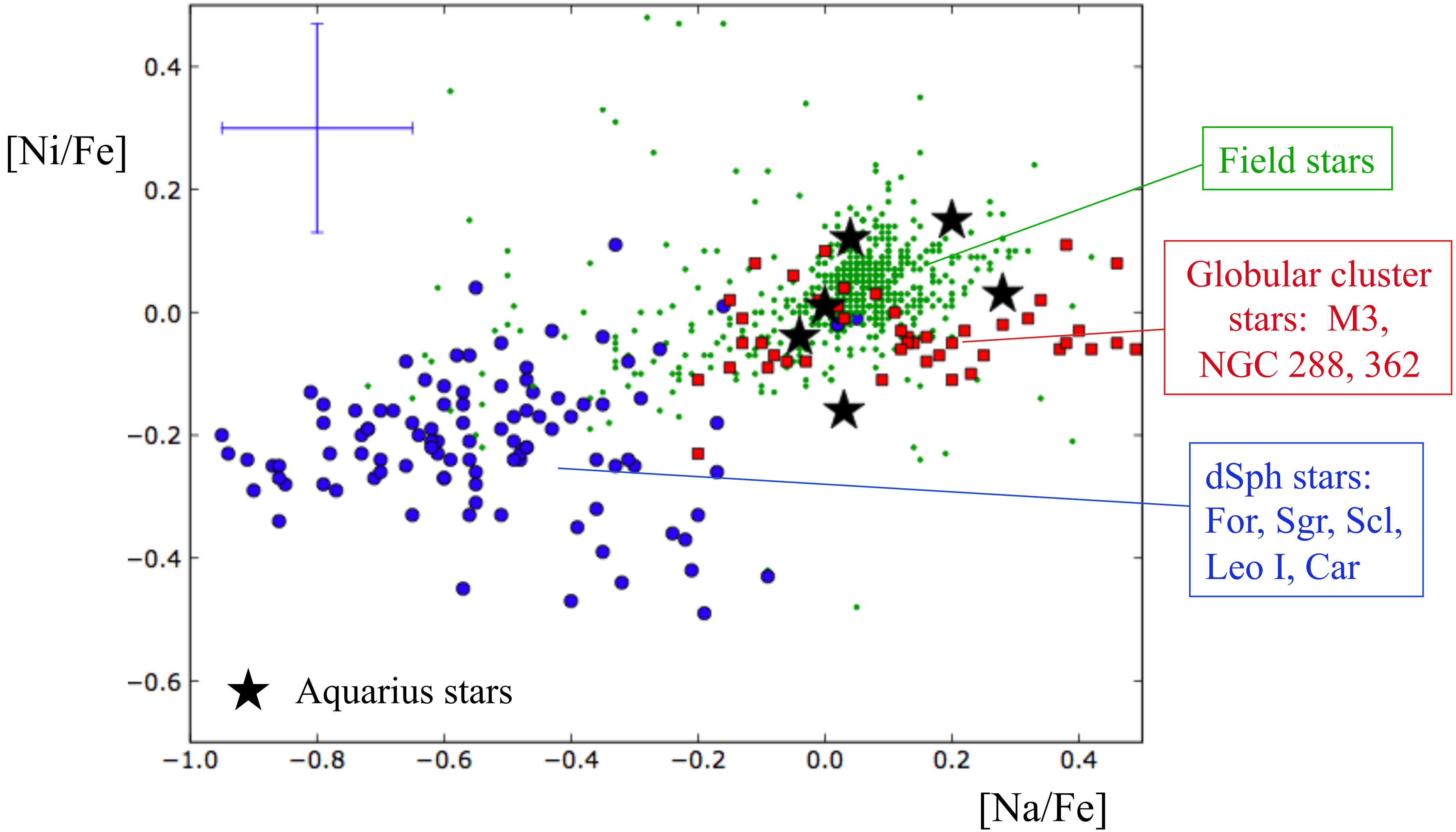
Wylie de Boer et al (2012) used the chemical tagging techniques to identify the nature of the Aquarius stream (Williams et al 2011).
This is a stream of halo stars identified from the RAVE survey.
It is coming directly towards the sun from near $l = 50^o$, $b = -60^o$, and its stars extend along the line of sight from 200 pc to 10 kpc.



The stream appears to be the debris of a disrupted GC rather than a dwarf galaxy. Its stars

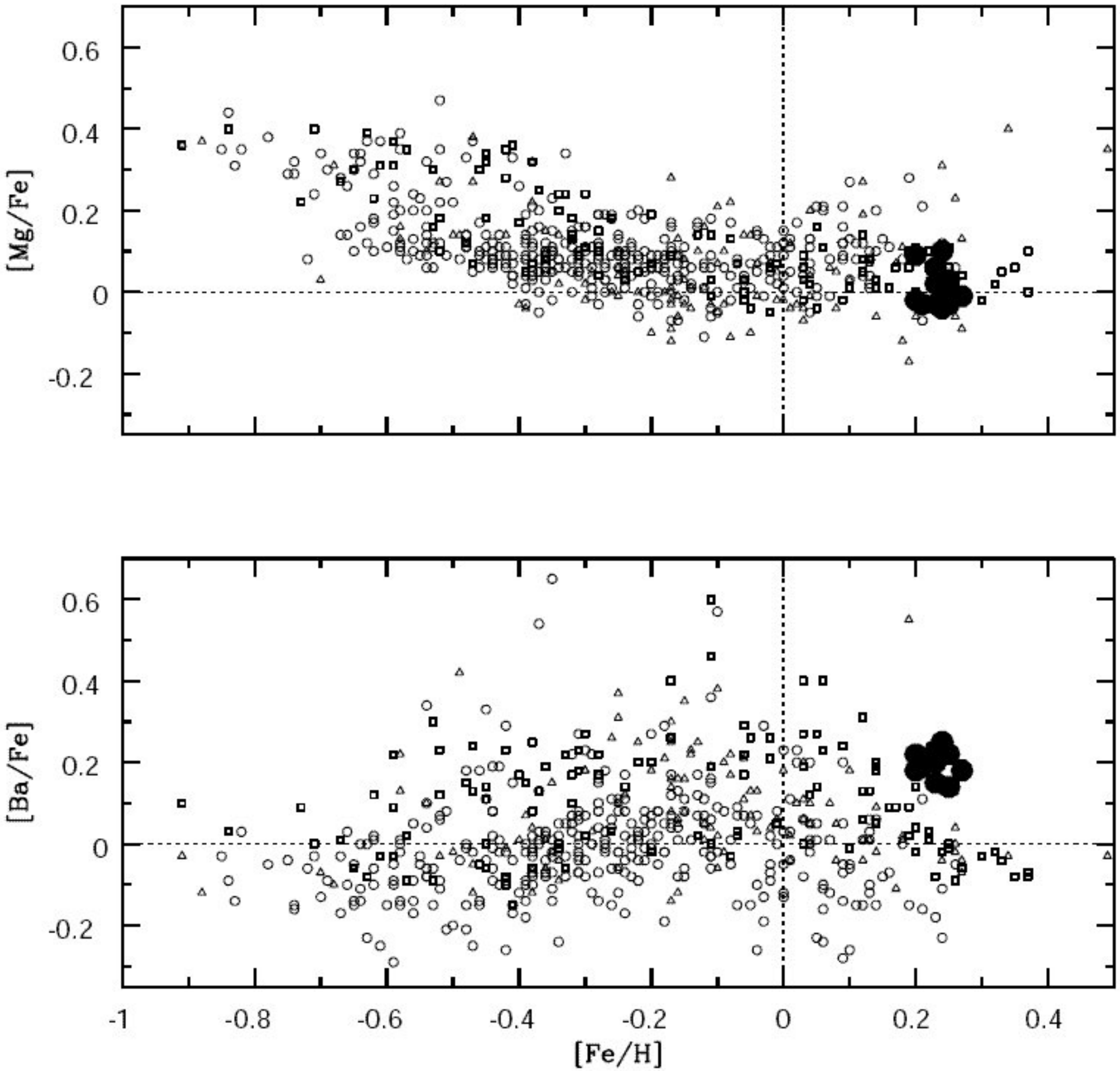
- are homogeneous in heavy elements (σ[Fe/H] = 0.09 dex),
- show the Na-O anticorrelation like GCs and
- lie with GC stars in the Ni-Na plane

Other examples: Argus, Wolf 630, HR 1614, ...



Ni-Na relation for globular cluster stars and dwarf spheroidal galaxy stars.
(Comes from slower star formation rate in dSph galaxies than globular clusters.)
Aquarius stars are more consistent with globular cluster debris.

Wylie de Boer et al (2012)



- • 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

The GALAH experiment

A major goal of Galactic archaeology is to identify observationally how important mergers and accretion events were in building up the Galactic thick disk, thin disk and bulge.

So how many unique element signatures will we need?

$300\ M_\odot < M_\star < 3000\ M_\odot$ 10^5/Gyr

$3000\ M_\odot < M_\star < 30{,}000\ M_\odot$ 10^4/Gyr

Without good ages, we need ~ 10^6 signatures to reach low $M_\star$

<u>This is very challenging</u>

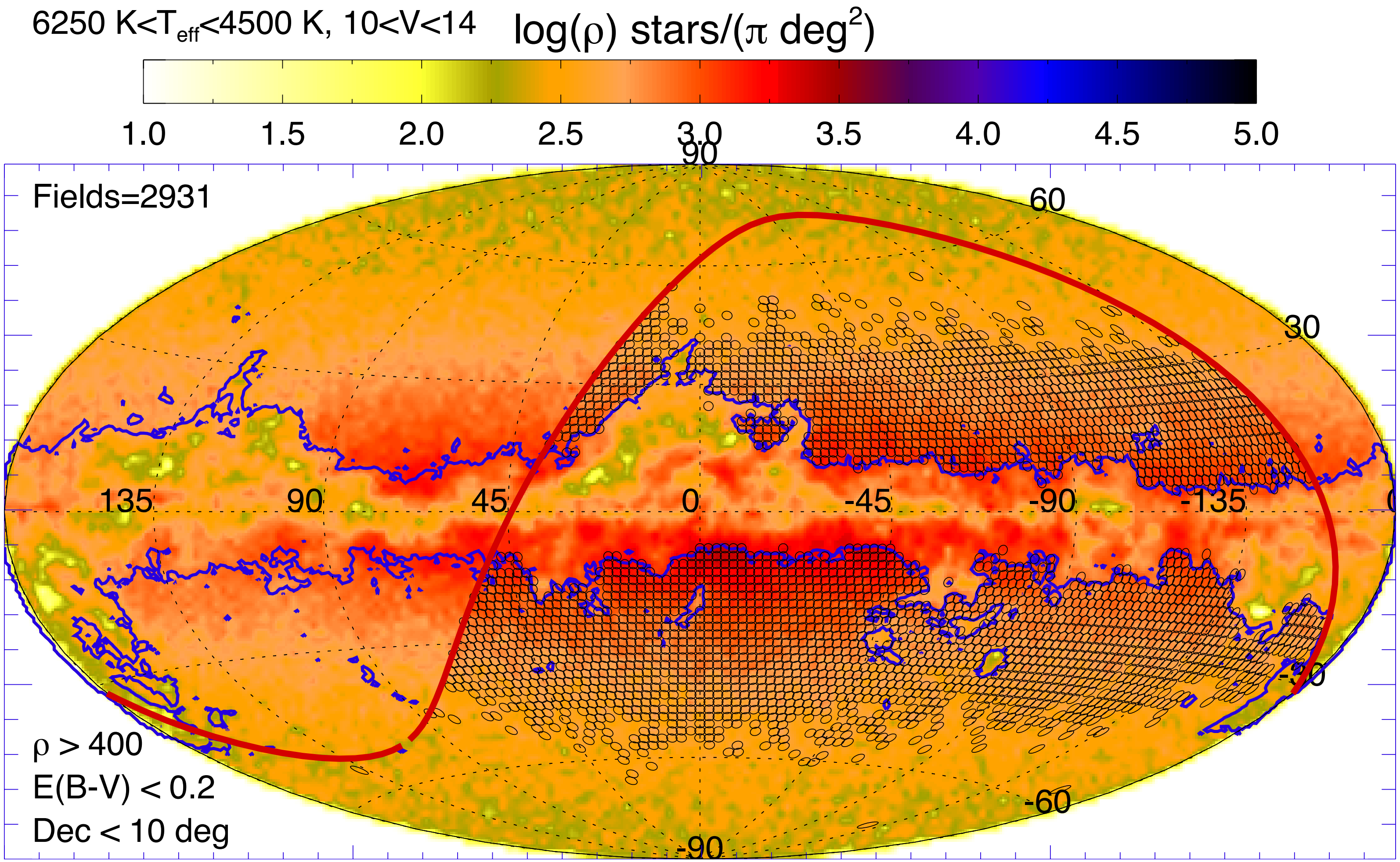
Say we measure 8 independent element groups with 5 unique abundance levels, this gives us 5^8 ~ 400,000 signatures.

Chemical pipeline by Wylie de Boer, Sneden & d' Orazi gives spectroscopic stellar parameters and abundances for 25 elements, 8-9 chemical classes

The search for progenitor formation sites

APASS, 2MASS input catalogue

Goal: million star survey to V = 14 @ R=28,000
SNR ~ 100 per res. in 1 hr, 3000 pointings, 400 clear nights

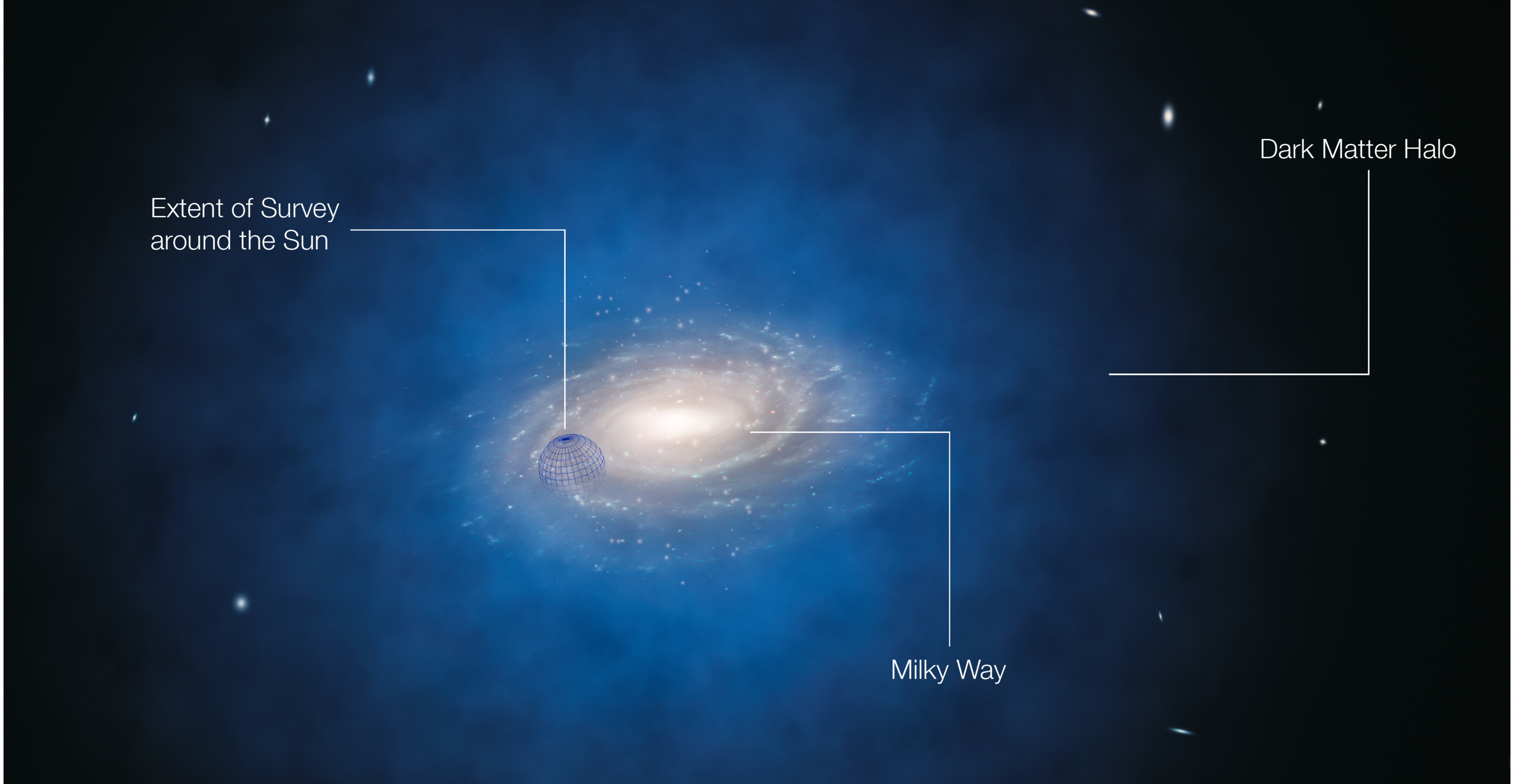


Galaxia code

Fractional contribution from Galactic components

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

Most of the GALAH stars are local dwarfs...



ngCFHT: one idea is to push deeper and reach the bulge

Summary

- Cluster formation is lies beyond our observational horizon.
- Reconstructing star clusters is necessary to relate cluster age distributions to **cluster formation history**.
- Reconstructed CMFs and alpha/Fe distributions will tell us about **major vs. minor mergers** with cosmic time.
- Cluster reconstruction will tell us a great deal about **major vs. gradual migration events** in the past (JBH+ 2010).
- If strong migration is real, *in situ* information is scrambled, thus detailed chemistry via HERMES is essential to progress.

Chemical tagging:

"connecting stars to their birth sites through their lifelong tags"

- Freeman & JBH (2002)
- JBH & Freeman (2004)
- De Silva+ (2006, 2007ab, 2009, 2011)
- JBH+ (2010ab)
- Ting+ (2012)
- Mitschang+ (2013)