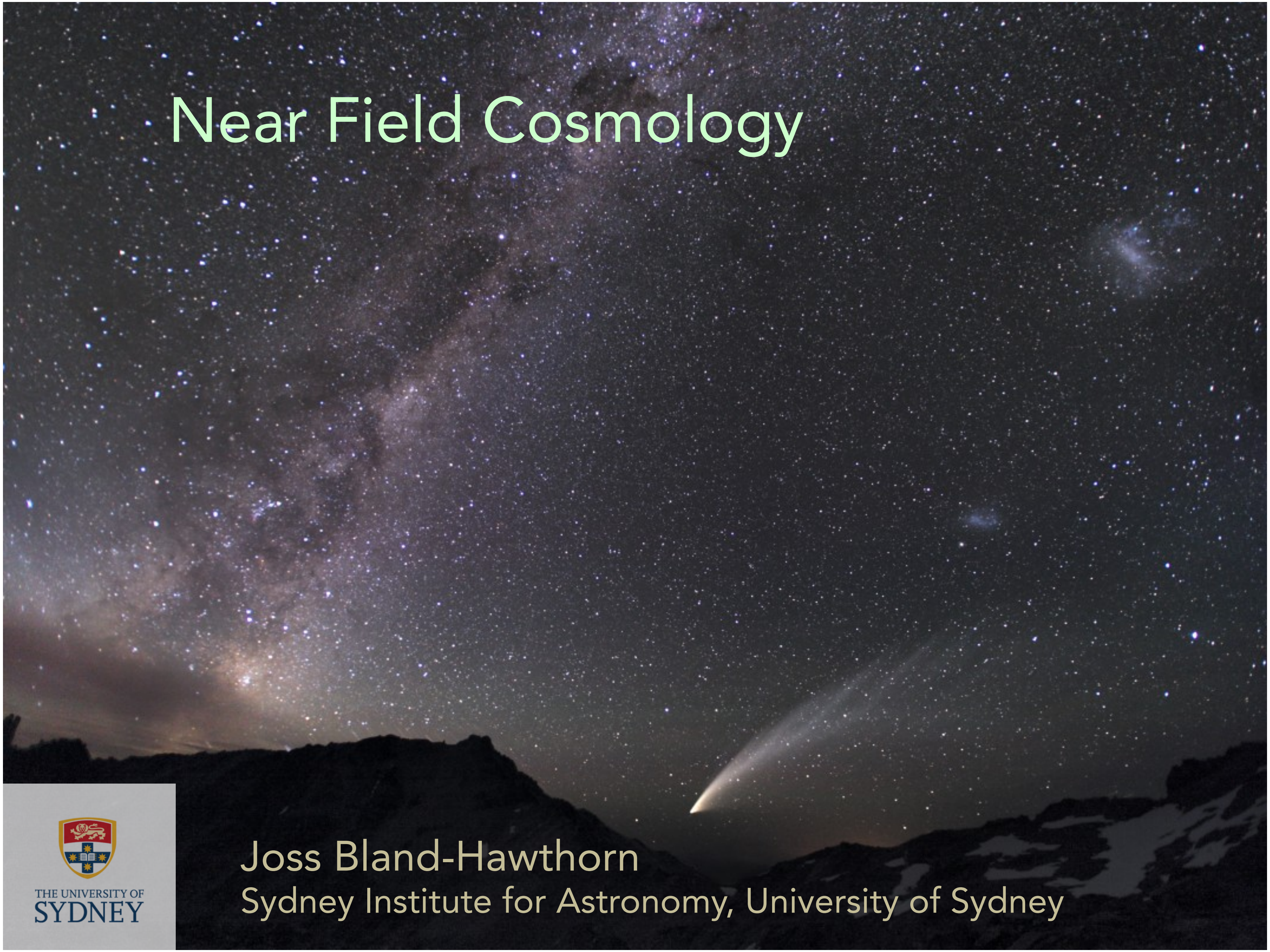
Near Field Cosmology



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THE UNIVERSITY OF SYDNEY

Near Field Cosmology:
The domain of resolved stellar populations

To understand the dominant physical processes in the early Universe ($z>1$) from the local stellar record

Most activity took place before $z\sim1$
but half of all stars are older than 8 Gyr

JBH & Freeman 2000; Freeman & JBH 2002; Bromm & Yoshida 2011; Frebel & Norris 2015

DIVERSITY OF ABUNDANCE PATTERNS OF LIGHT NEUTRON-CAPTURE ELEMENTS IN VERY-METAL-POOR STARS

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2017

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Study based on data collected with the Subaru Telescope, operated by the National Astronomical Observatory of Japan.
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ABSTRACT

We determine the abundances of neutron-capture elements from Sr to Eu for five very-metal-poor stars ($-3<$[Fe/H]<-2) in the Milky Way halo to reveal the origin of light neutron-capture elements. Previous spectroscopic studies have shown evidence of at least two components in the r-process; one referred to as the "main r-process" and the other as the "weak r-process," which is mainly responsible for producing heavy and light neutron-capture elements, respectively. Observational studies of metal-poor stars suggest that there is a universal pattern in the main r-process, similar to the abundance pattern of the r-process component of solar-system material. Still, it is uncertain whether the abundance pattern of the weak r-process shows universality or diversity, due to the sparseness of measured light neutron-capture elements. We have detected the key elements, Mo, Ru, and Pd, in five target stars to give an answer to this question. The abundance patterns of light neutron-capture elements from Sr to Pd suggest a diversity in the weak r-process. In particular, scatter in the abundance ratio between Ru and Pd is significant when the abundance patterns are normalized at Zr. Our results are compared with the elemental abundances predicted by nucleosynthesis models of supernovae with parameters such as electron fraction or proto-neutron-star mass, to investigate sources of such diversity in the abundance patterns of light neutron-capture elements. This paper presents that the variation in the abundances of observed stars can be explained with a small range of parameters, which can serve as constraints on future modeling of supernova models.

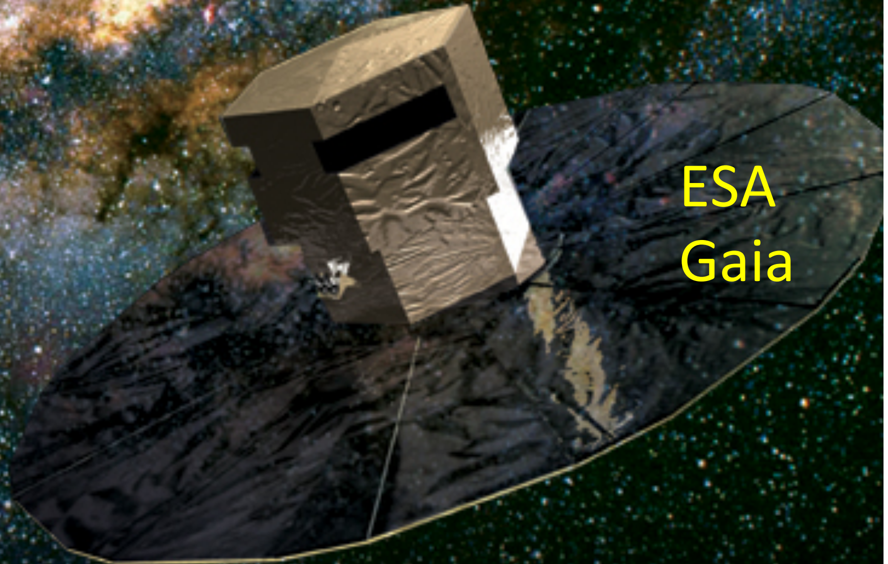
Subject headings: metal-poor stars: general — nuclear reactions, nucleosynthesis, abundances

GALAH Galactic Archaeology with HERMES

AAT spectrograph observes 30 elements for million stars

SIfA (and Australia) is a world leader in galactic archaeology.

Developments: Galaxia code unites data from GALAH, RAVE, Kepler and Gaia surveys. Syd and Radius codes measure seismic, stellar parameters from asteroseismic data. GALAH, K2 pipeline reduction code; photonic comb calibration, etc.



USyd team: Bedding, JBH, De Silva, Khanna, Kos, Lewis, Li, Murphy, Sharma, recent: Huber, Stello

Things *never* stand still…

Increasing computer power enables remarkable things…

We need to rethink instrument design from the standpoint of data analysis, e.g. Europe's Airbus.

Monte Carlo methods for Bayesian Data Analysis in Astronomy

2018

Sanjib Sharma[1]

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Xxxx. Xxx. Xxx. Xxx. YYYY. AA:1–48

This article's doi:
10.1146/((please add article doi))

Keywords

Methods: data analysis, numerical statistical

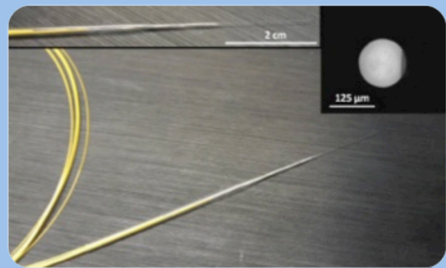
Abstract

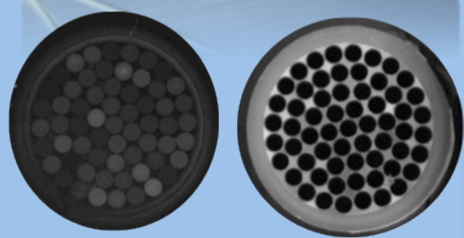
Monte Carlo based Bayesian data analysis has now become the method of choice for analyzing and interpreting data in almost all disciplines of science. In astronomy, over the last decade, we have also seen a steady increase in the number of papers that employ Monte Carlo based Bayesian analysis. New, efficient Monte Carlo based methods are continuously being developed and explored. In this review, we first explain the basics of Bayesian theory and discuss how to set up data analysis problems within this framework. Next, we provide an overview of various Monte Carlo based methods for performing Bayesian data analysis. Finally, we discuss advanced ideas that enable us to tackle complex problems and thus hold great promise for the future. We also distribute downloadable codes (`http://www.physics.usyd.edu.au/~sanjib/mcmc/`) that implement some of the algorithms and examples discussed here.

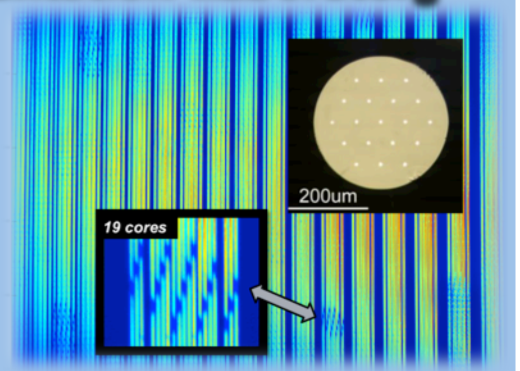
SAIL Sydney Astrophotonic Instrumentation Laboratory

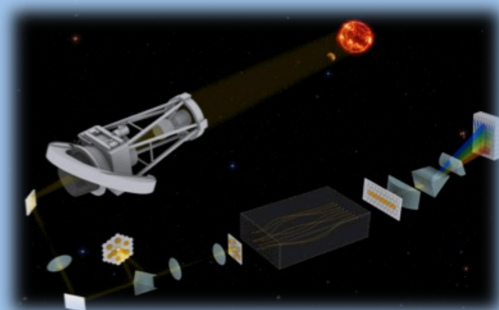
SAIL is the University of Sydney Astrophotonic Instrumentation Laboratory - a world leader in astronomical photonic instrumentation

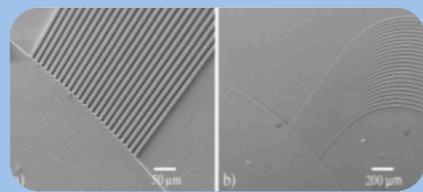
Research into Astrophotonics is the use of photonic techniques and devices to manipulate our collection and processing of light for the purpose of improving our ability to probe and hence understand the universe. It has many applications and new technologies are constantly being developed.











astrophotonics

USyd Team: Betters, Bland-Hawthorn, Bryant, Cvetojevic, Leon-Saval, Lindley, Min, Neo, Norris, O'Byrne, Richards, Robertson, Tango, Tuthill .....

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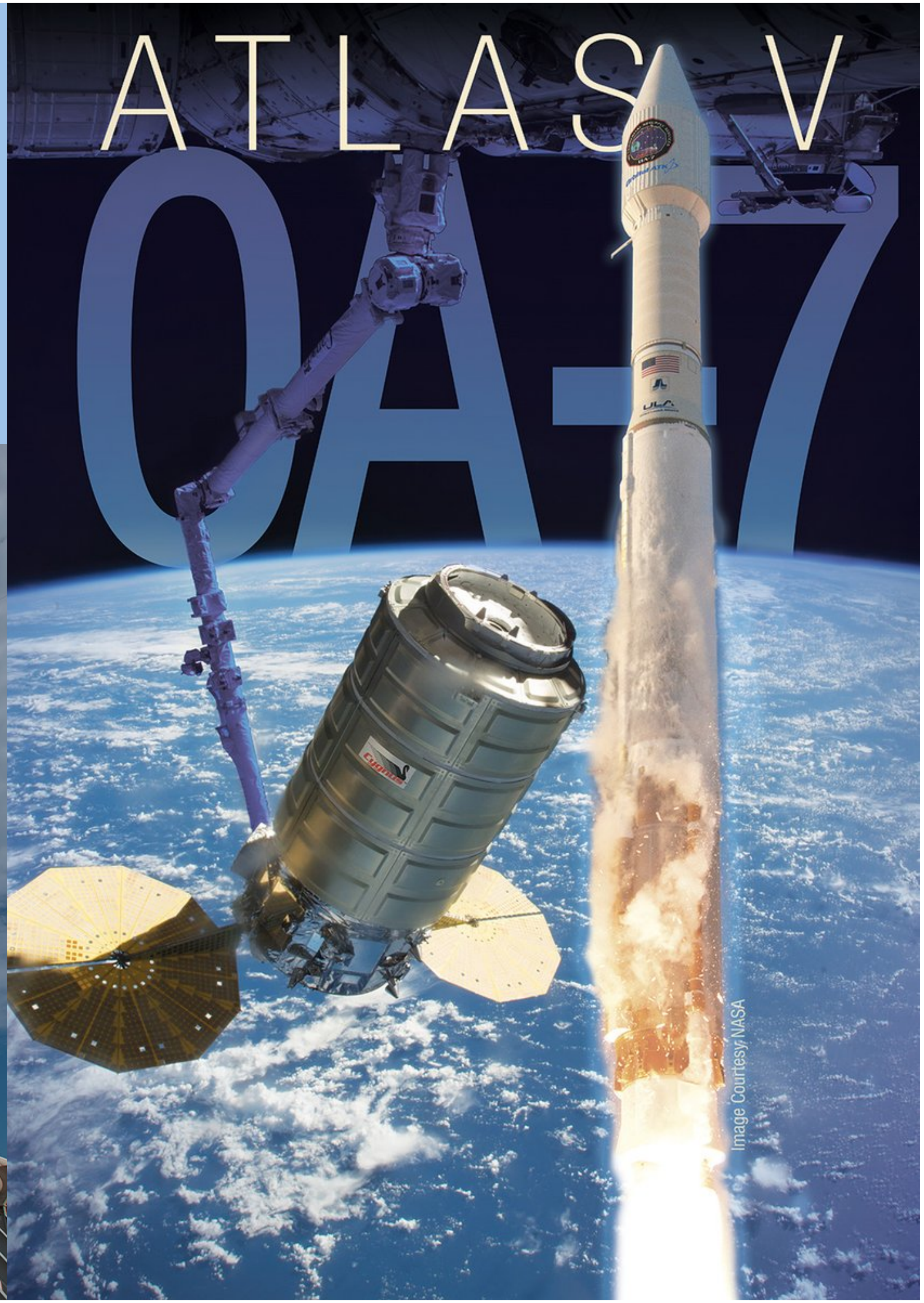
QB50 waiting for launch to
the Space Station… any day now:

28 Mar



Mapping the aberrations of a wide-field spectrograph using a photonic comb

Joss Bland-Hawthorn,[1,2,3*] Janez Kos,[3] Christopher H. Betters,[1,2,3] Gayandhi De Silva,[3,4] John O'Byrne,[2,3] Rob Patterson,[5] Sergio G. Leon-Saval[1,2,3]

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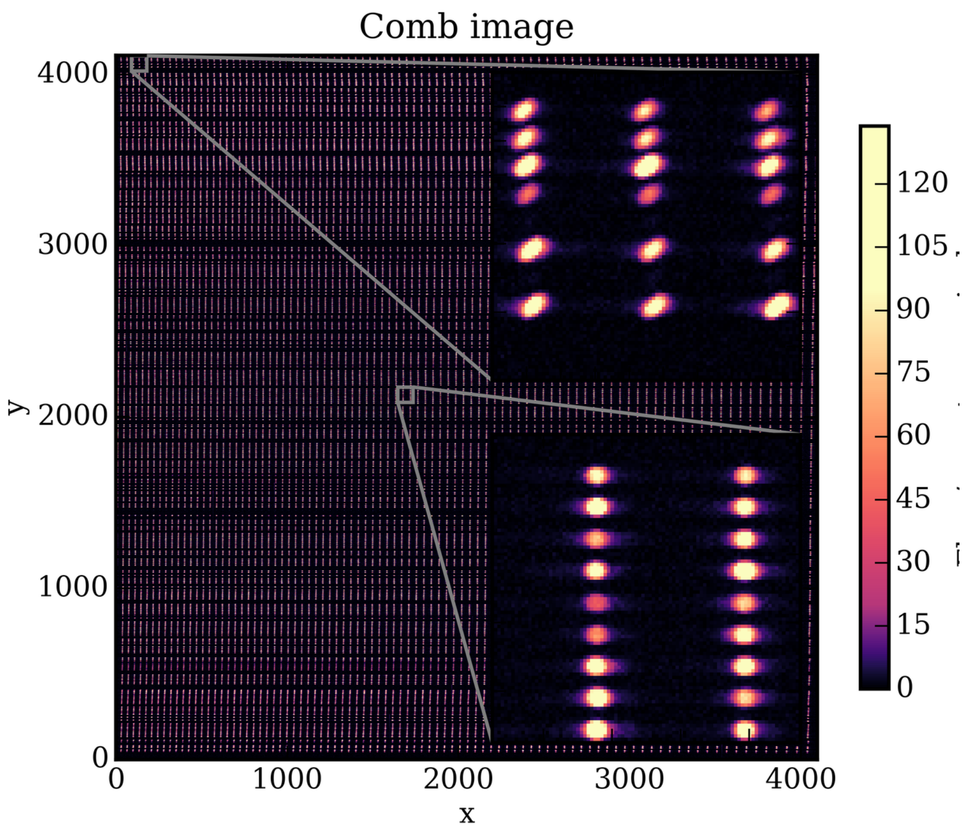
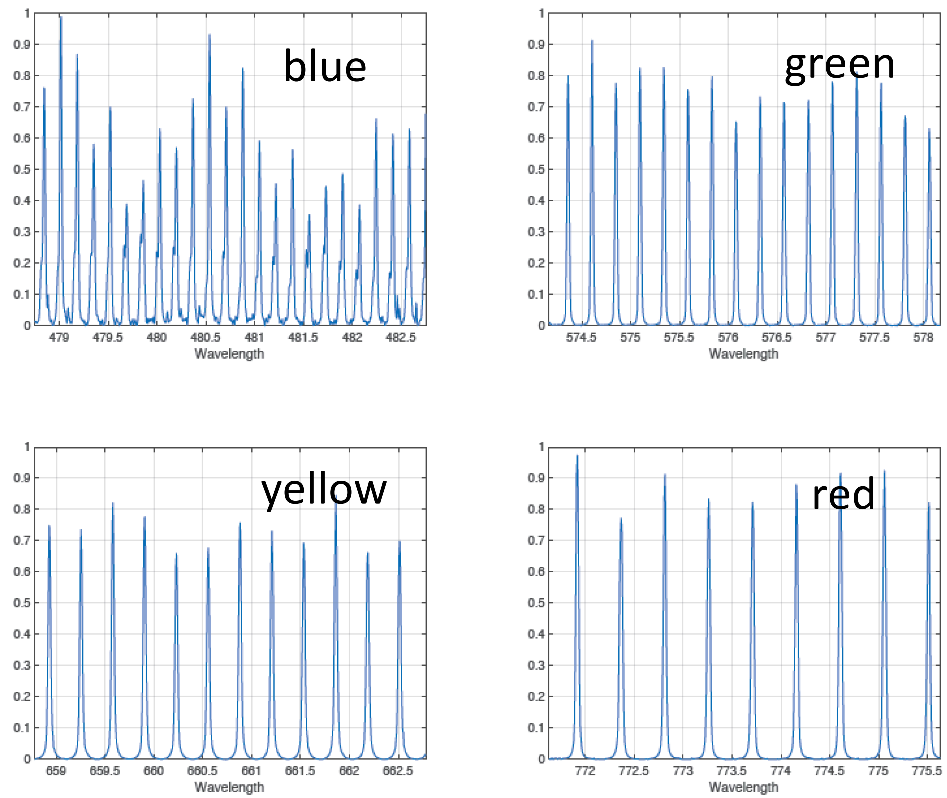
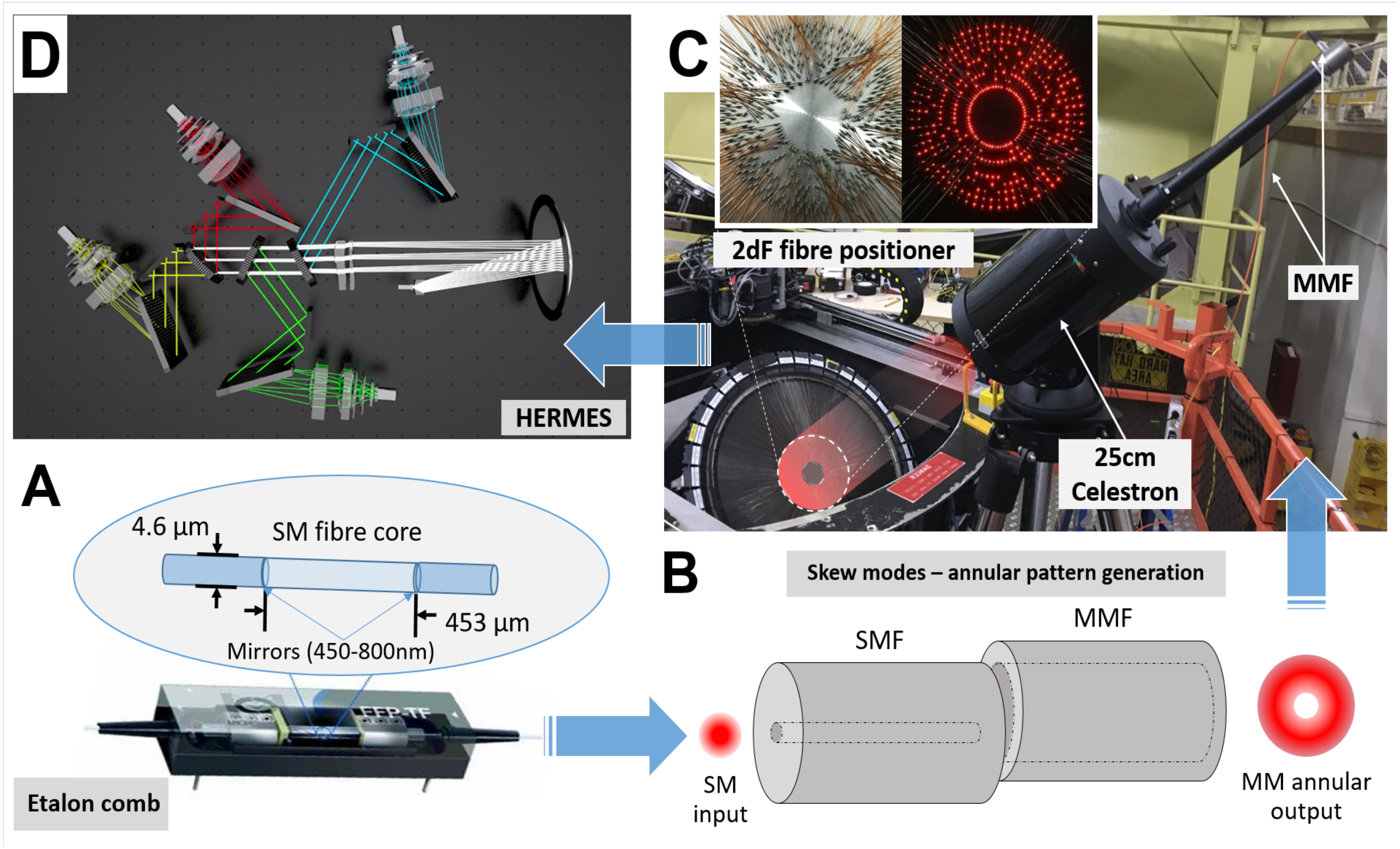
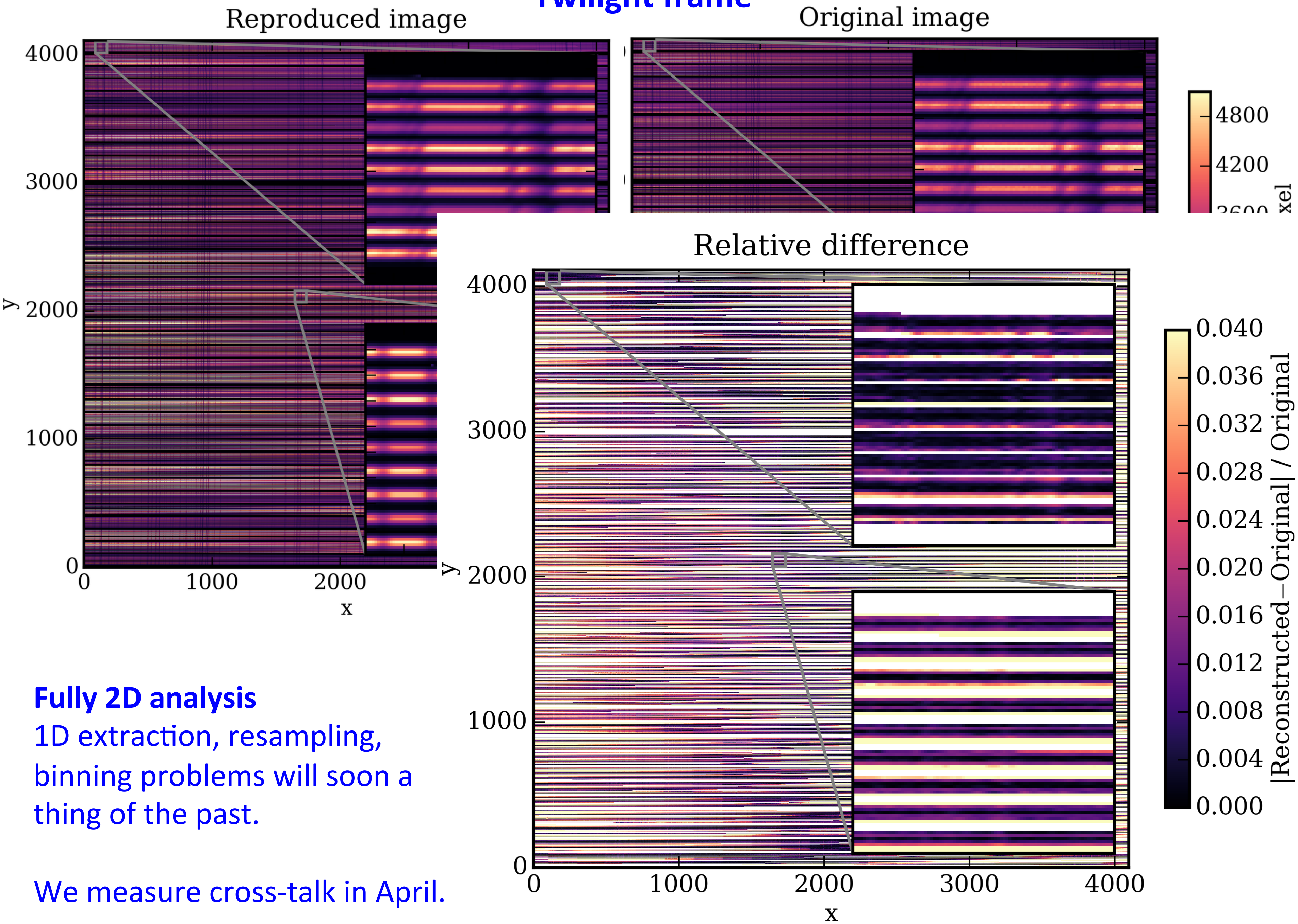




Photonic comb injection into HERMES multi-object spectrograph



Twilight frame



Fully 2D analysis

1D extraction, resampling, binning problems will soon a thing of the past.

We measure cross-talk in April.

Topics in Near Field Cosmology

Dark matter
Geometry, structure, origin of warps, accretion planes
Substructure, testing of CDM cosmologies
Dark matter/baryon connection, concentration

Black hole
Black hole – bulge – halo connection
Cusp removal, bulge formation

Chemistry
BBNS, new particles
First stars: signatures of first black holes
Formation sites: first elements, nuclides, r, s
Early evolution of metals, age-metallicity relations

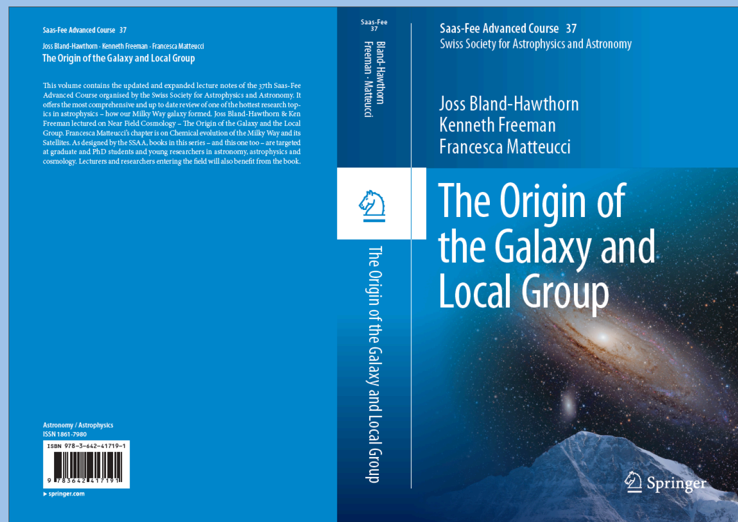
Dwarf galaxies
Local reionization, structural properties
First galaxies, second generation stars

Galactic archaeology
Chemtag reconstruction of least massive systems
Assembly history (SFH) of major components, G dwarf

Galaxy/M31 comparison
Differential history, total baryon inventory

Problems
Stellar ages, stellar models
Migration, blurring
Model complexity, interpretation
Matching simulations to Local Group
Shot noise statistics

Important
Galaxy framework (e.g. Galaxia)
Local framework (e.g. CLUES)
Cosmological framework (e.g. EAGLE)



Saas Fee 2014 book freely available on my homepage under Downloads.

Can we detect specific signatures of the first stellar generations today?

Beers & Christleib 2005, ARAA
Aoki et al 2009, 2013, 2017
Bromm & Yoshida 2011, ARAA
Karlsson, Bromm & JBH 2013, RMP
Frebel & Norris 2015, ARAA

The lowest mass galaxies have very few star forming events and are the most affected by **reionization**. They may preserve the clearest signal of what happened in the early universe.

Can we detect specific signatures of the first stellar generations today?

We don't know yet since our "**first star" models** produce chemical signatures that we can't easily relate to the most metal poor stars (in our Galaxy) or to the most metal poor clouds at the highest redshifts.

Are we looking in the wrong place?

Metal poor star, [Fe/H] < -5

Faint dwarf

Globular cluster:

These are a puzzle. [Fe/H] = -1.5 but many are >12 Gyr old!

Are we seeing the signature of reionization in ultrafaint dwarfs?

Brown+ 2014
Weisz+ 2014a,b
Frebel, Simon & Kirby 2014
Webster+ 2014, 2015a,b
JBH, Sutherland & Webster 2015
Ritter+ 2015
Sluder+ 2015
Simon+ 2015
Ji, Frebel & Bromm 2015
Webster, Frebel & JBH 2016

The lowest mass galaxies have very few star forming events and are the most affected by **reionization**. They may preserve the clearest signal of what happened in the early universe.

THE ASTROPHYSICAL JOURNAL

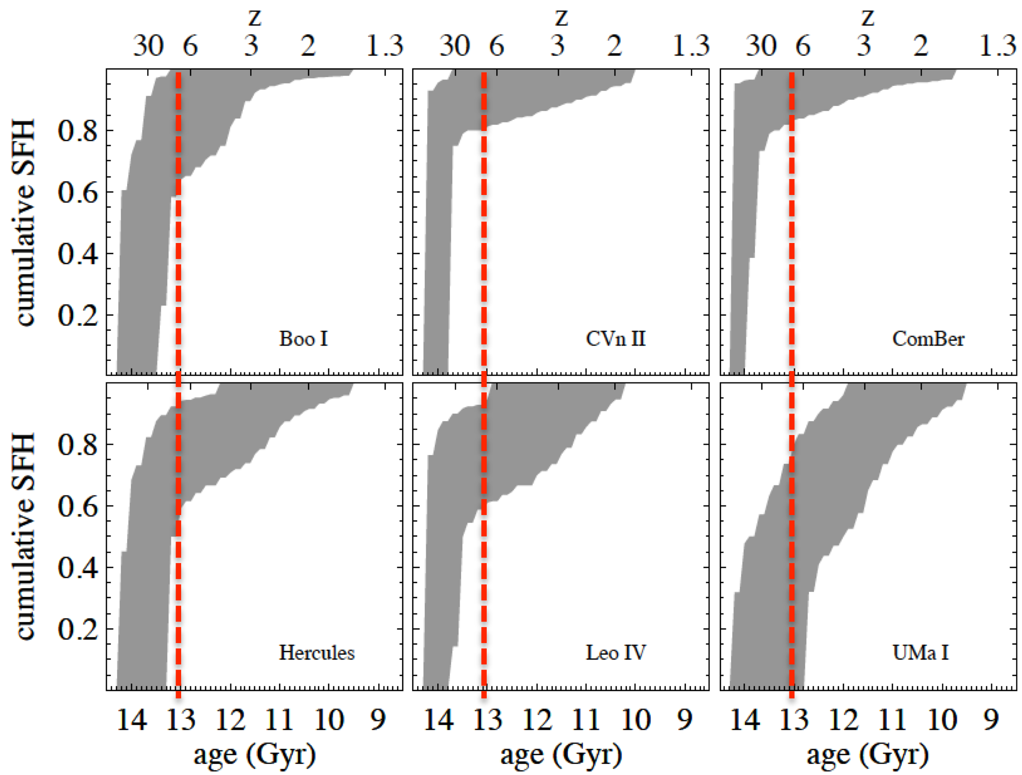
The Astrophysical Journal > Volume 796 > Number 2

Thomas M. Brown *et al.* 2014 *ApJ* **796** 91 doi:10.1088/0004-637X/796/2/91

THE QUENCHING OF THE ULTRA-FAINT DWARF GALAXIES IN THE REIONIZATION ERA*

Thomas M. Brown[1], Jason Tumlinson[1], Marla Geha[2], Joshua D. Simon[3], Luis C. Vargas[2], Don A. VandenBerg[4], Evan N. Kirby[5], Jason S. Kalirai[1,6], Roberto J. Avila[1], Mario Gennaro[1], Henry C. Ferguson[1], Ricardo R. Muñoz[7], Puragra Guhathakurta[8], and Alvio Renzini[9]

75% of stars formed by z ~ 10



ACS/HST, DEIMOS/Keck
Victoria-Regina isochrones

New method:

identify ancient star clusters in UFDs
through chemical tagging

JBH+ 2010a,b
Karlsson+ 2012
Karlsson, Bromm & JBH 2013
Webster, Frebel & JBH 2015

Chemical tagging in the lowest mass dwarf galaxies will allow us to associate stars that were born together.

The Astrophysical Journal, 721:582–596, 2010 September 20 doi:10.1088/0004-637X/721/1/582

THE CHEMICAL SIGNATURES OF THE FIRST STAR CLUSTERS IN THE UNIVERSE

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ABSTRACT

The chemical abundance patterns of the oldest stars in the Galaxy are expected to contain residual signatures of the first stars in the early universe. Numerous studies attempt to explain the intrinsic abundance scatter observed in some metal-poor populations in terms of chemical inhomogeneities dispersed throughout the early Galactic medium due to discrete enrichment events. Just how the complex data and models are to be interpreted with respect to "progenitor yields" remains an open question. Here we show that stochastic chemical evolution models to date have overlooked a crucial fact. Essentially, all stars today are born in highly homogeneous star clusters and it is likely that this was also true at early times. When this ingredient is included, the overall scatter in the abundance plane [Fe/H] versus [X/Fe] ($\mathcal{C}$-space), where X is a nucleosynthetic element, can be much less than derived from earlier models. Moreover, for moderately flat cluster mass functions ($\gamma \lesssim 2$), and/or for mass functions with a high mass cutoff ($M_{max} \gtrsim 10^5\ M_\odot$), stars exhibit a high degree of clumping in $\mathcal{C}$-space that can be identified even in relatively small data samples. Since stellar abundances can be modified by mass transfer in close binaries, clustered signatures are essential for deriving the yields of the first supernovae. We present a statistical test to determine whether a given set of observations exhibit such behavior. Our initial work focuses on two dimensions in $\mathcal{C}$-space, but we show that the clustering signal can be greatly enhanced by additional abundance axes. The proposed experiment will be challenging on existing 8–10 m telescopes, but relatively straightforward for a multi-object echelle spectrograph mounted on a 25–40 m telescope.

Key words: galaxies: dwarf – Galaxy: abundances – Galaxy: evolution – Galaxy: formation – galaxies: star clusters: general

Online-only material: color figures

GMT + Manifest + G-Clef was the motivation for this paper. We really need this to feed ~10 fibres over the full 20' field.

How massive a uniform star cluster?

JBH et al (2010)

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_{form} = 4 t_{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 <u>all</u> open clusters up to 10^5 M_o are uniform since t_{SN} > 3 Myr for most SNe in these clusters. For globular densities, the upper mass limit is 10^7 M_o !!

2D abundance space

Simulated galaxy on 8m (top) and on GMT (bottom):

N ~ 1×10^6 stars

M ~ 3×10^5 M_o

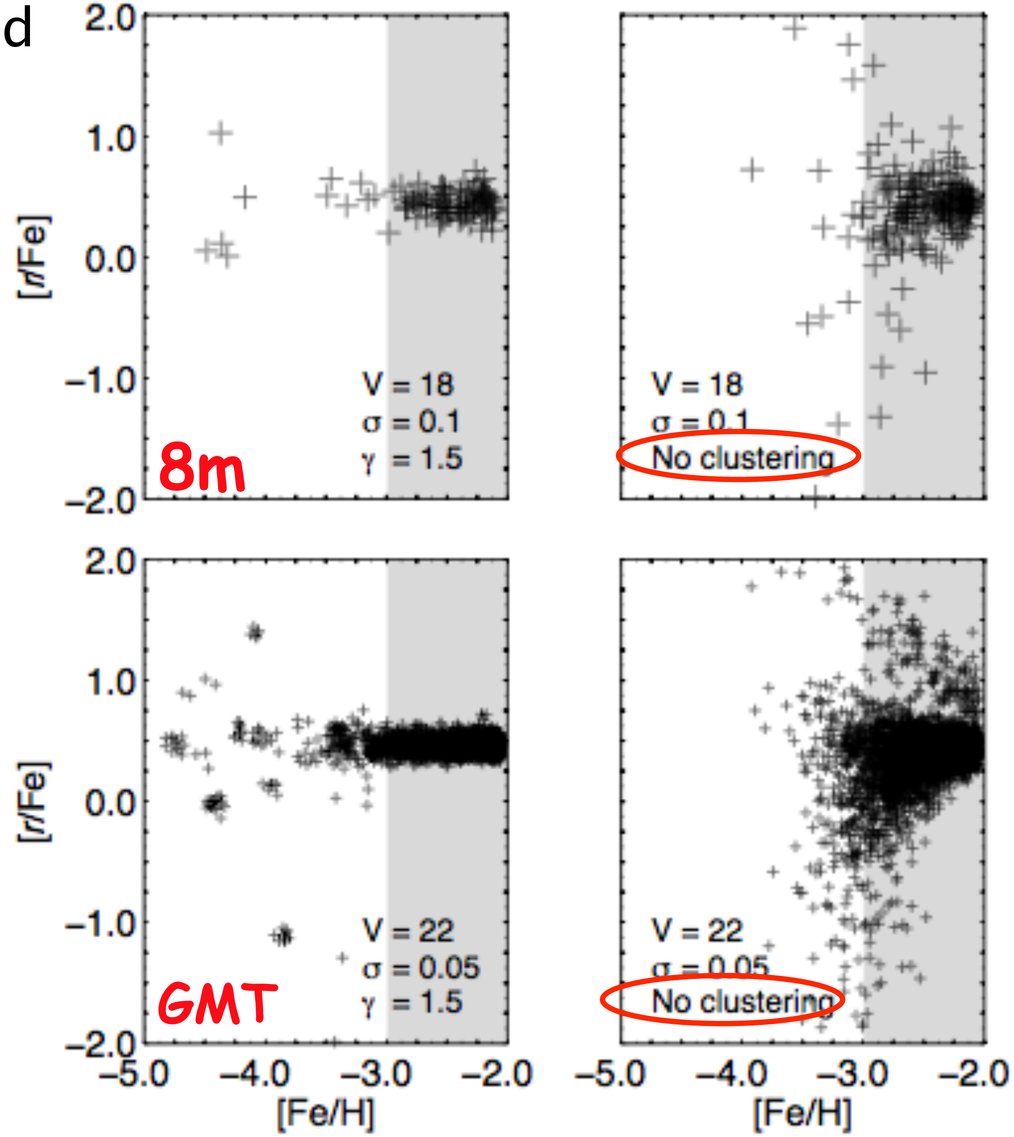
L ~ 1×10^5 L_o

D ~ 30 kpc

i.e. 10 stars with [Fe/H] < −3

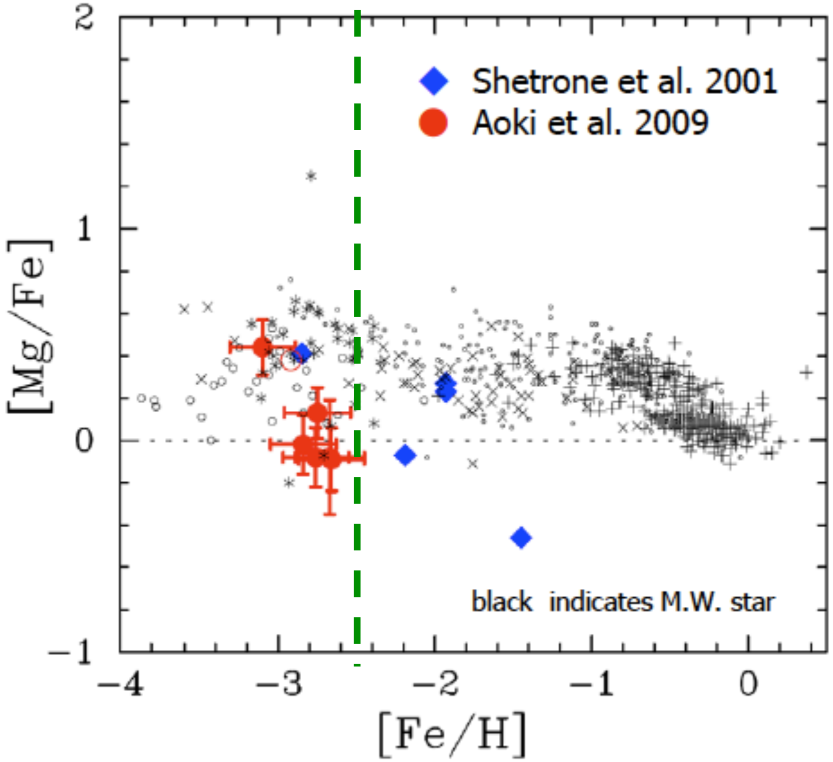
2D clustering seen by 8m

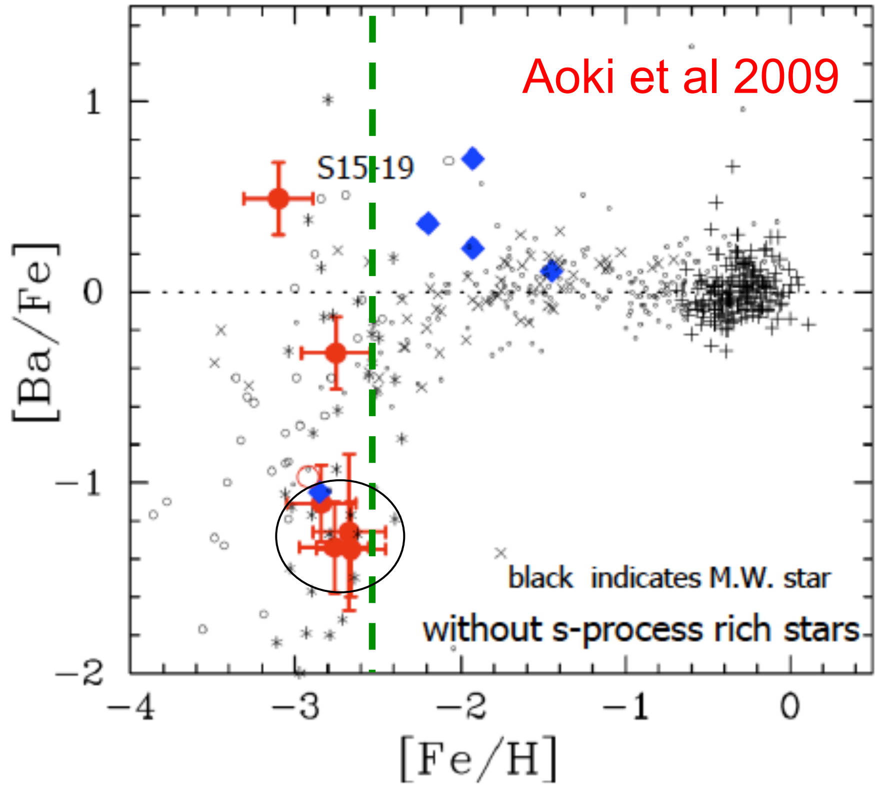
➔ stronger signal in 3D

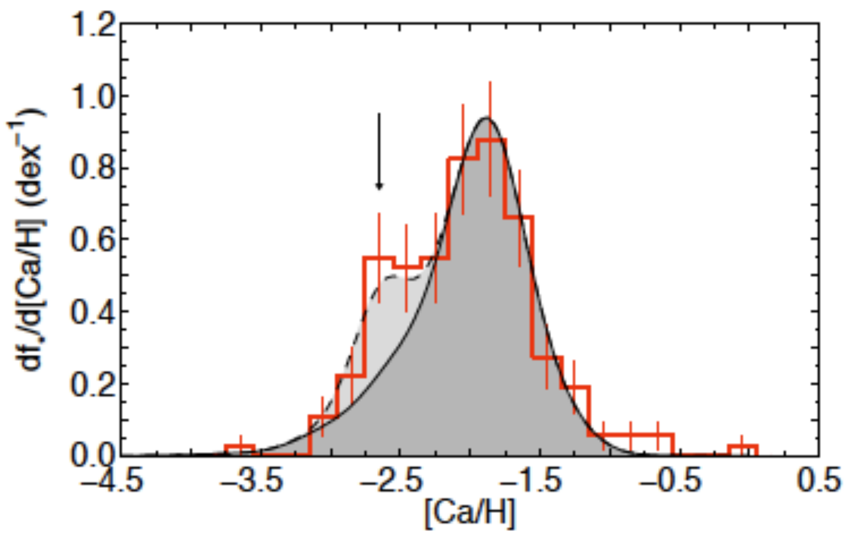


Sextans: relic star cluster?

If confirmed, this would be the most metal poor star cluster to date (Karlsson+ 2012)







The stellar “cluster” seems to clump in other abundances

Aoki et al 2009

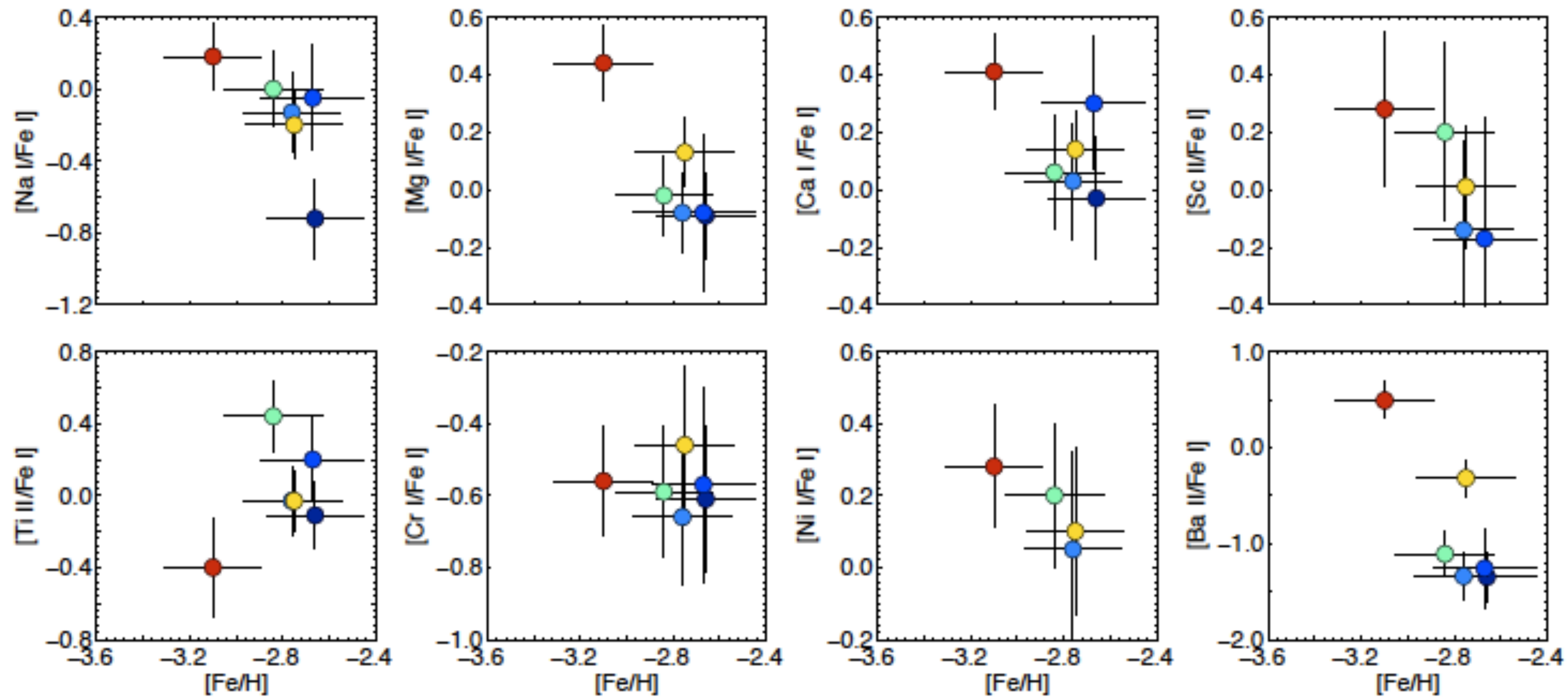
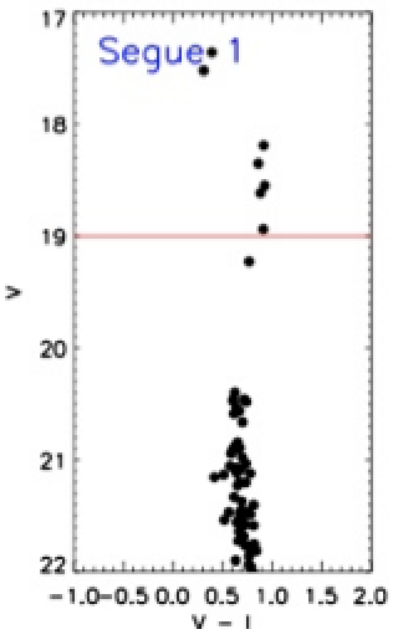


FIG. 1.— Chemical abundance ratios of six very metal-poor stars in the Sextans dSph. Abundance data are taken from Aoki et al. (2009). Stars are color coded according to their [Mg/Fe] ratio. The three stars with nearly identical [Mg/Fe] (colored in blue) also have very similar [Fe/H]. These stars all clump together in Ti, Cr, and Ba, as well. One of the “blue” stars, S 10 − 14, is substantially deficient in Na. The scandium abundance could not be measured in S 10 − 14, while Nickel could not be measured in S 10 − 14 and S 14 − 98.

If confirmed, this would be the most metal poor star cluster to date (Karlsson+ 2012)

SEGUE 1: AN UNEVOLVED FOSSIL GALAXY FROM THE EARLY UNIVERSE*

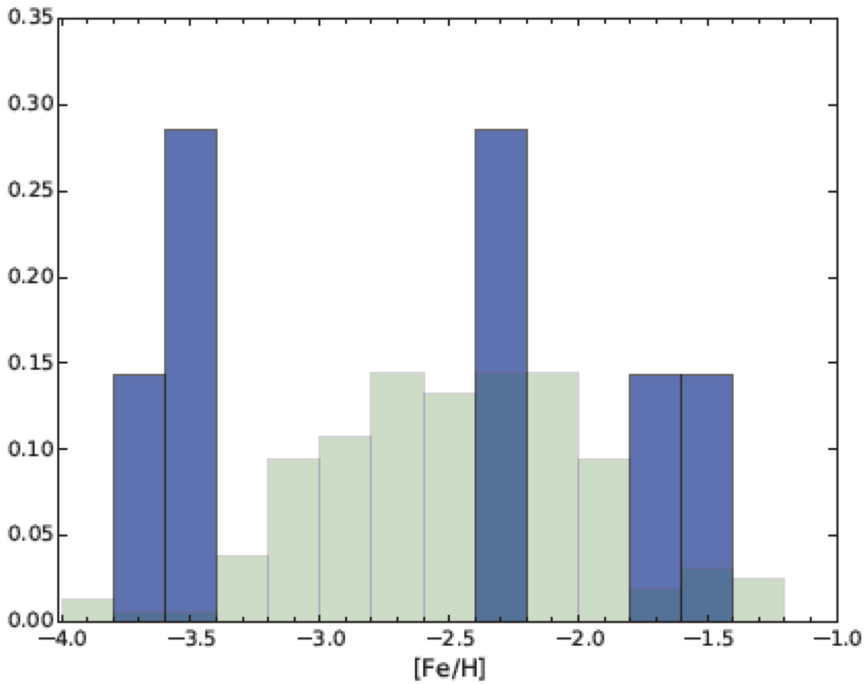
Anna Frebel[1], Joshua D. Simon[2], and Evan N. Kirby[3,4]
[1] Kavli Institute for Astrophysics and Space Research and Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[2] Observatories of the Carnegie Institution of Washington, Pasadena, CA 91101, USA
[3] Center for Galaxy Evolution, Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA
Received 2013 December 14; accepted 2014 March 13; published 2014 April 16



[a/Fe] = 0.5

[Sr/H], [Ba/H] suppressed

T_{SF} < 30-50 Myr



The clumping is statistically significant (Webster, Frebel & JBH 2015)

What is the statistical significance of "clustering" in abundance space?

What can we learn?

Method: 1. build models of UFD formation and evolution; 2. insert cluster formation; 3. test for clustering signatures; 4. attempt to unravel the sequence of events.

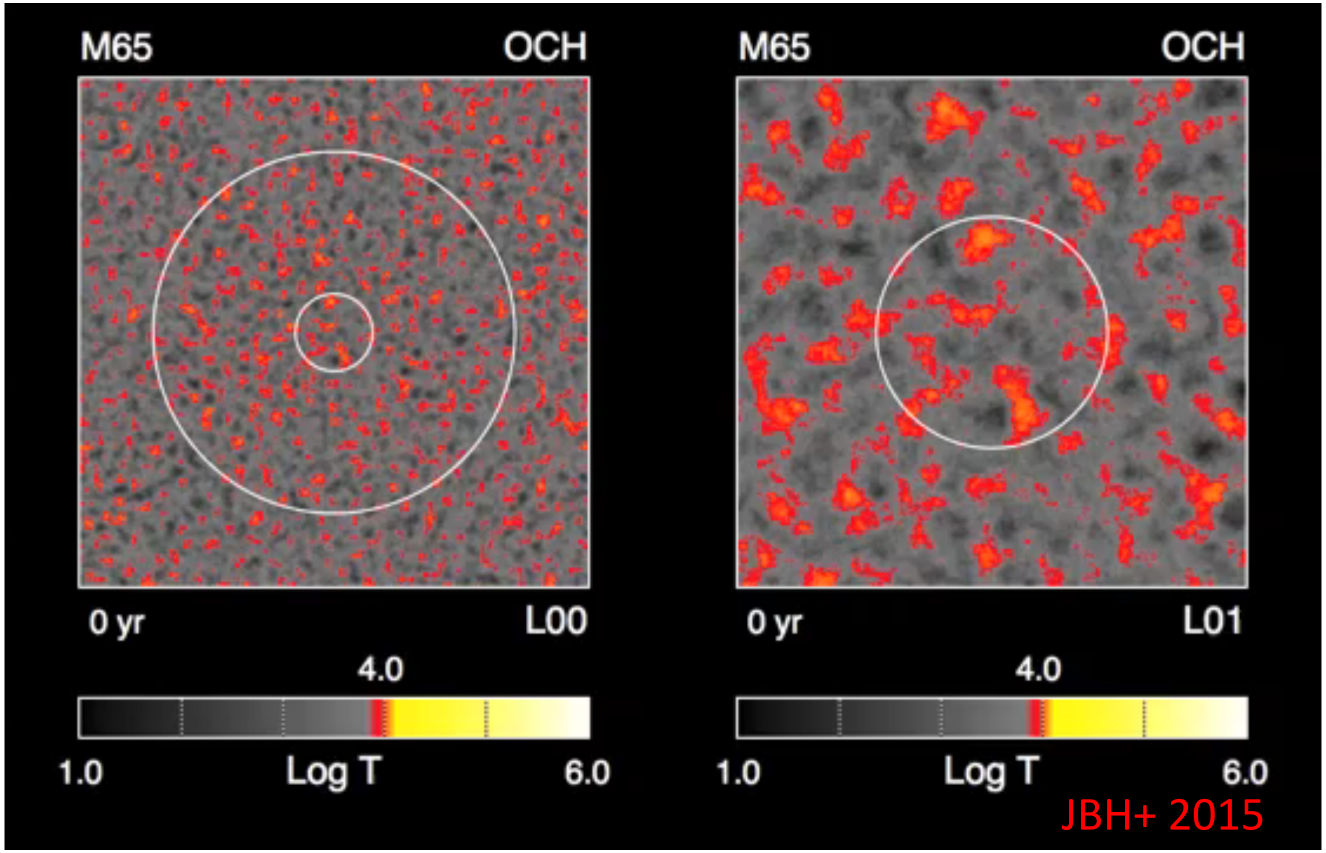
THE ASTROPHYSICAL JOURNAL

ULTRAFAINT DWARF GALAXIES—THE LOWEST-MASS RELICS FROM BEFORE REIONIZATION

Joss Bland-Hawthorn[1], Ralph Sutherland[2], and David Webster[3]

Published 2015 July 9 • • The Astrophysical Journal, Volume 807, Number 2

Gas in halos $M_{vir} \sim 10^7 M_\odot$ can survive pre-ionization & SN explosion of 25 $M_\odot$ star

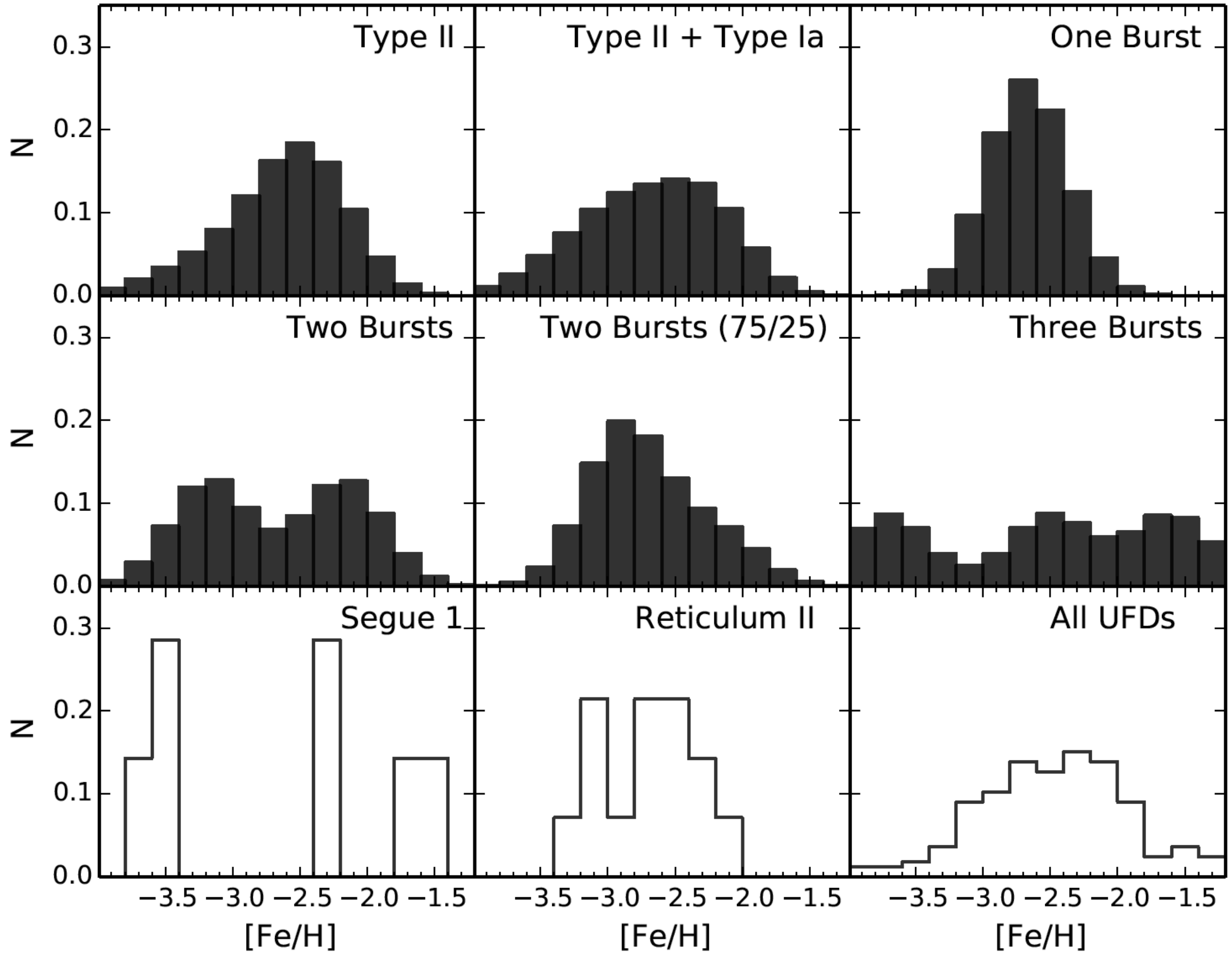


How:
1. off-centred star
2. fractal medium
3. resolved SN shock front
4. time dep. ionization
5. clustered SF through the **initial cluster mass function**

Results used in Webster+ 2014, 2015a,b,c

What do these [Fe/H] distributions look like ?

Only one dimension is shown below, but chemical tagging plays out in a multi-dimensional space.



T_{SF} < 50 Myr

STATISTICS OF CLUSTERED OVER RANDOM EVENTS

Webster, Frebel & JBH (2015)

Beale pseudo F-statistic (1969)

$$F^* = \frac{J_1^2 - J_2^2}{J_2^2} \frac{(N - c_2)c_2^{-2/p}}{(N-1) - (N - c_2)c_2^{-2/p}}$$

- N: number of abundance data points
- p: number of abundance dimensions
- c_2: number of clusters

models with more parameters are penalized

$$J_1^2 = \Sigma_i (x_i - \mu)^2$$ unclustered simulation

$$J_2^2 = \Sigma_k \Sigma_{k_i} (x_{k_i} - \mu_k)^2$$ clustered simulation

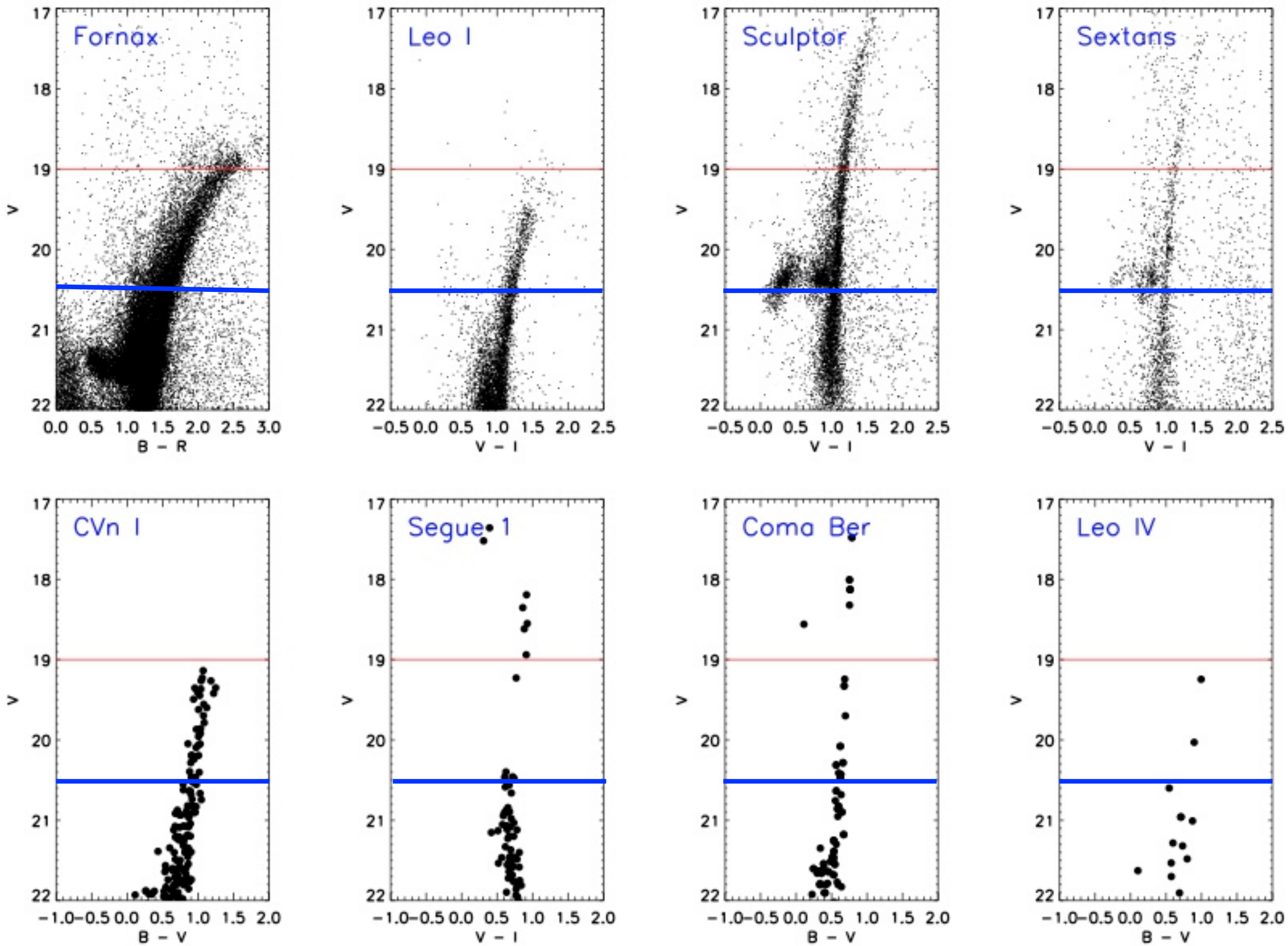
compare RMS differences between models (*k* peaks)

TABLE 1

PROBABILITY OF SEVEN STARS FORMING THREE OR MORE DISTINCT (SEPARATED BY 0.3 OR 0.55 DEX IN [FE/H]) GROUPS OF STARS.

Model	0.3 dex Unclustered	0.3 dex Clustered	0.55 dex Unclustered	0.55 dex Clustered
Gaussian	0.6%	3.7%	<0.01%	0.1%
Type II & Ia	5.1%	8.7%	0.2%	2.0%
Type II	3.4%	7.0%	0.1%	1.4%
Two bursts	6.7%	9.7%	0.3%	2.5%
Two bursts 75/25	3.2%	6.1%	0.1%	0.9%
Three bursts	5.6%	14.7%	2.7%	7.6%

A pressing need for UFDs to go deeper to get many more stars…



8m limit @ R=20K, V ~ 19, SNR ~ 30, 15 hours, **OPTICAL** (Frebel):
observe C, Na, Mg, Al, Si, Ca, Sc, Ti, Cr, Mn, Co, Ni, Zn, Ba, Sr

GMT/G-Clef (~10 objects in 20' field) limit @ R=20K should get us to V ~ 20.5

The importance of ancient star clusters

- The **cluster mass function** is a direct probe of the formation process (reionization, pressure, etc.)
- They can be **age-dated** more accurately than individual stars
- The summed stellar signature is the most reliable gauge of the **progenitor cloud** (indep. of binarity, mass transfer, mixing)
- These **building blocks** allow us to reconstruct the SFH more accurately
- We predict that a **reconstructed star cluster** will provide the first definitive statement on first star signatures

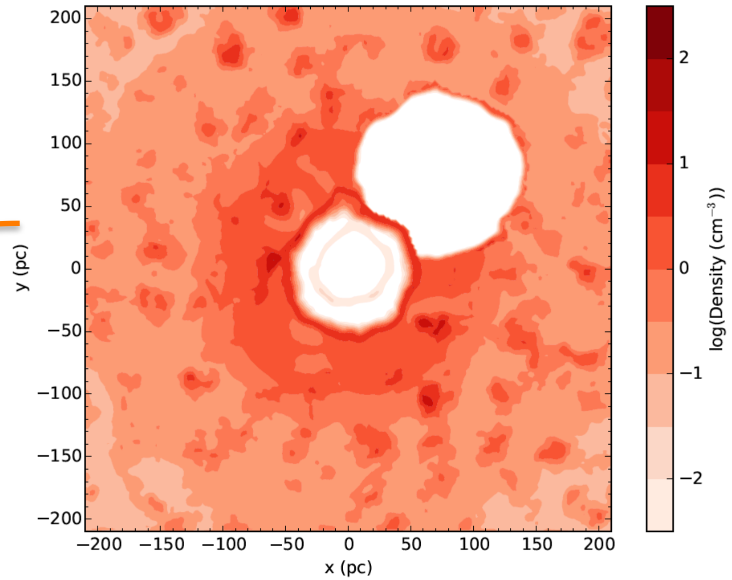
The Future:

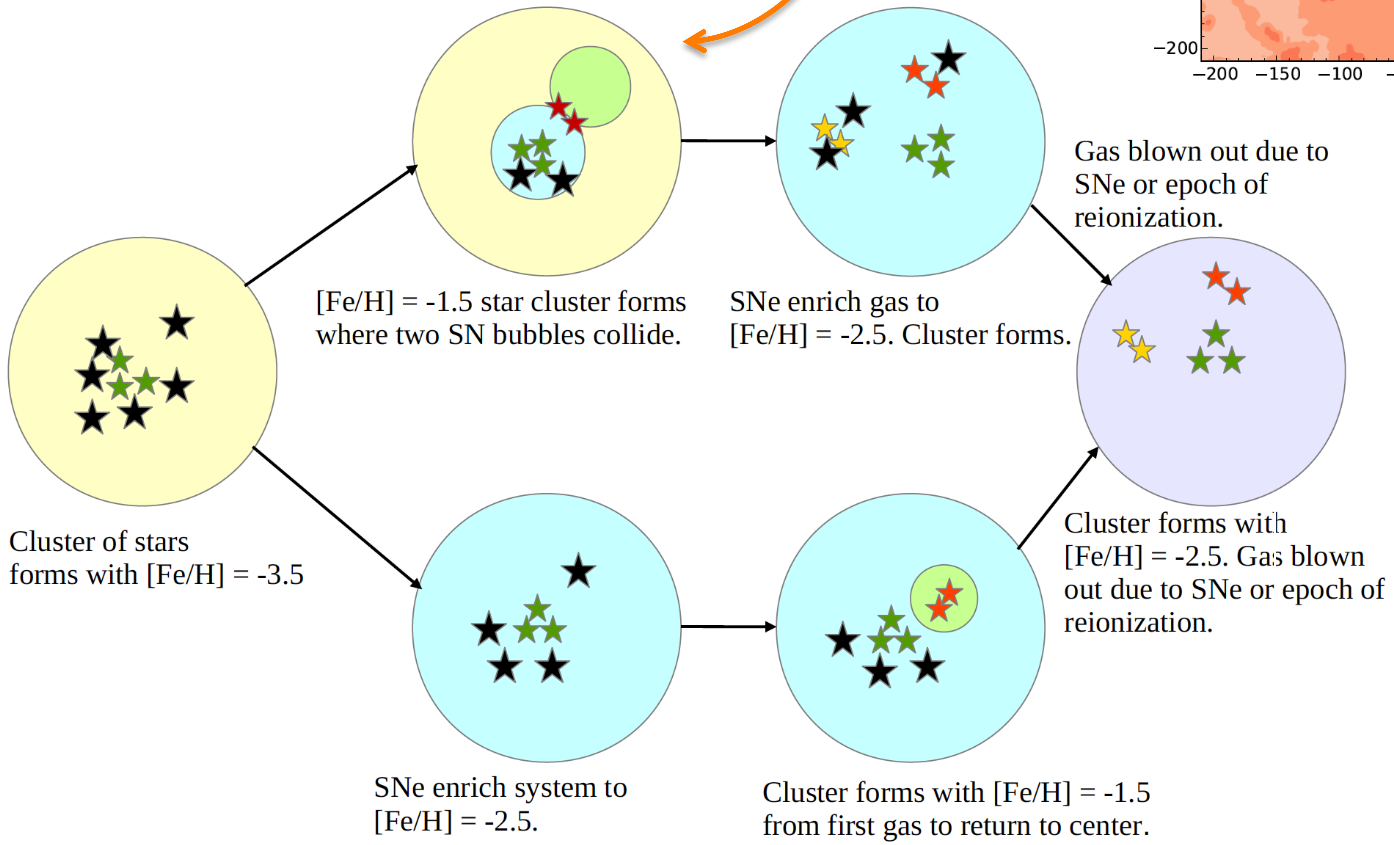
- We need a MOS HIRES instrument on any ELT **in optical**
- We need to resolve star clusters in numerical simulations

Can we unravel a SF event sequence?

Not with the limited abundance space [Fe/H], [a/Fe], [C/Fe] presently available.

But we can limit the options.





[Fe/H]=-1.5 is really difficult.

Lower path requires inhomogeneity.

Upper path requires v. special conditions.

Webster, Frebel & JBH (2015)

Where next with GMT ?

GALAH windows good if only have ~1 order

Single dot can represent multiple lines