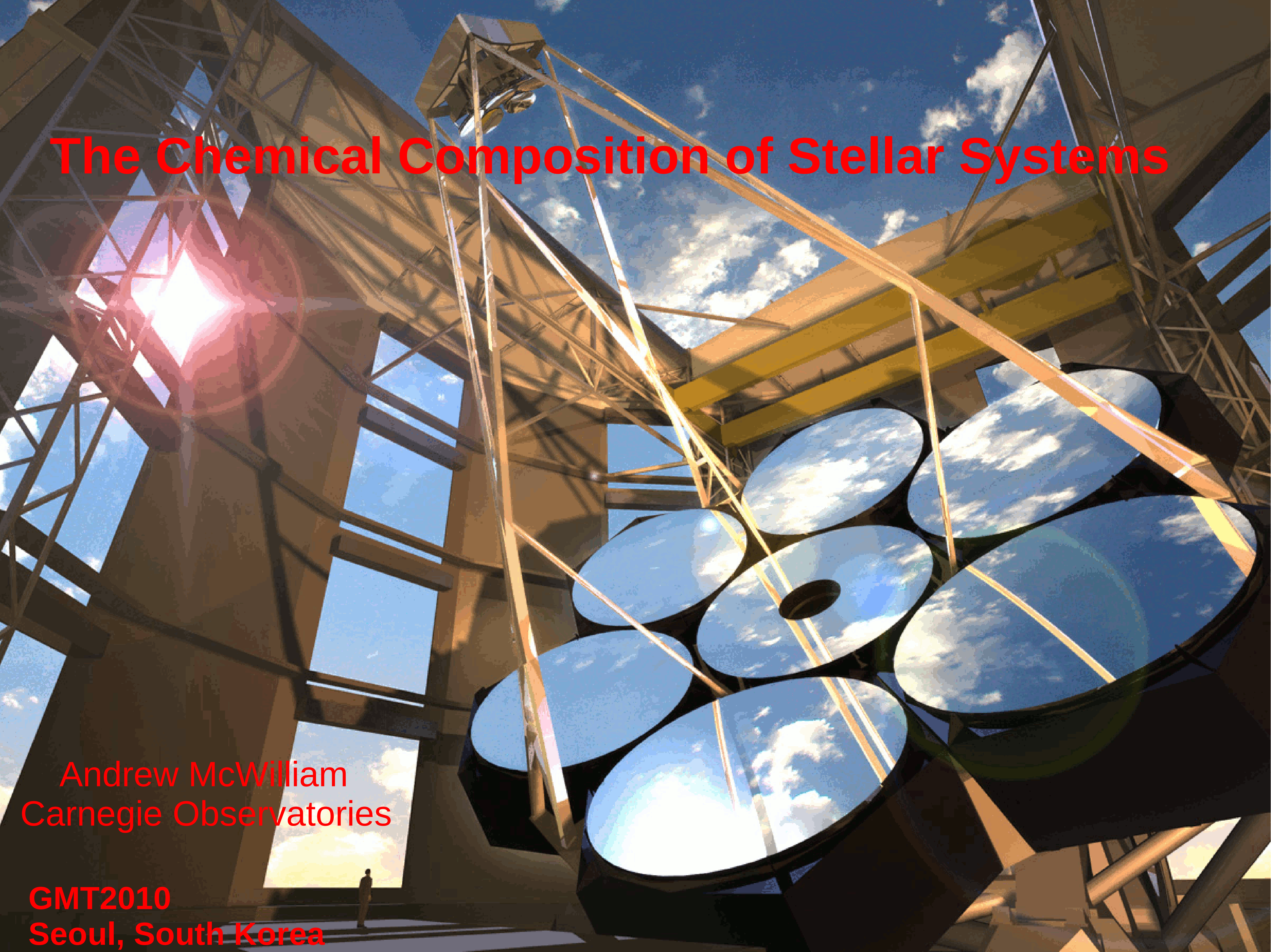

The Chemical Composition of Stellar Systems

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GMT2010
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My Science Goals

To understand nucleosynthesis and chemical evolution in stellar systems using the fossil record of star formation contained in the chemical composition.

I would like to know:

1. **The detailed element yields from stars**
2. **How chemical evolution occurs in different stellar systems**

(3. **How galaxies are assembled**)

4. The parameters of the first stars

Need to solve nucleosynthesis and chemical evolution simultaneously

Study composition/chemical evolution in all environments

⟶ all galaxy types, all sub-components

Diagnostic Element Ratios:

Various element ratios are useful chemical evolution probes, for SFR, IMF, formation timescale, inflow/outflow etc.

[α/Fe]	(O,Mg,Si, S, Ca, Ti)	SNII/SNIa ratio, t~1Gyr, SFR, SF bursts
[Mg/Ca], [O/C]		SNII masses/IMF
[O/Mg]		stellar winds
r-process	(Eu, Dy, Gd)	SNII?
Na, Al		SNII, z-dependent
Mn		SNIa, SNII, z-dependent
Cu		SNII progenitors, z-dependent
s-process	(Y,Sr,Ba,La,Nd)	low mass AGB stars (0.2 $\rightarrow$ 5 Gyr)
ls/hs	[Y/La]	AGB metallicity, inflow/outflow
[Rb/Zr]		intermediate mass AGB (50 $\rightarrow$ 200Myr)
[Fe/H]		MDF “yield”, inflows/outflows

Dependence of chemical composition on environment

(c.f. Tinsley 1979)

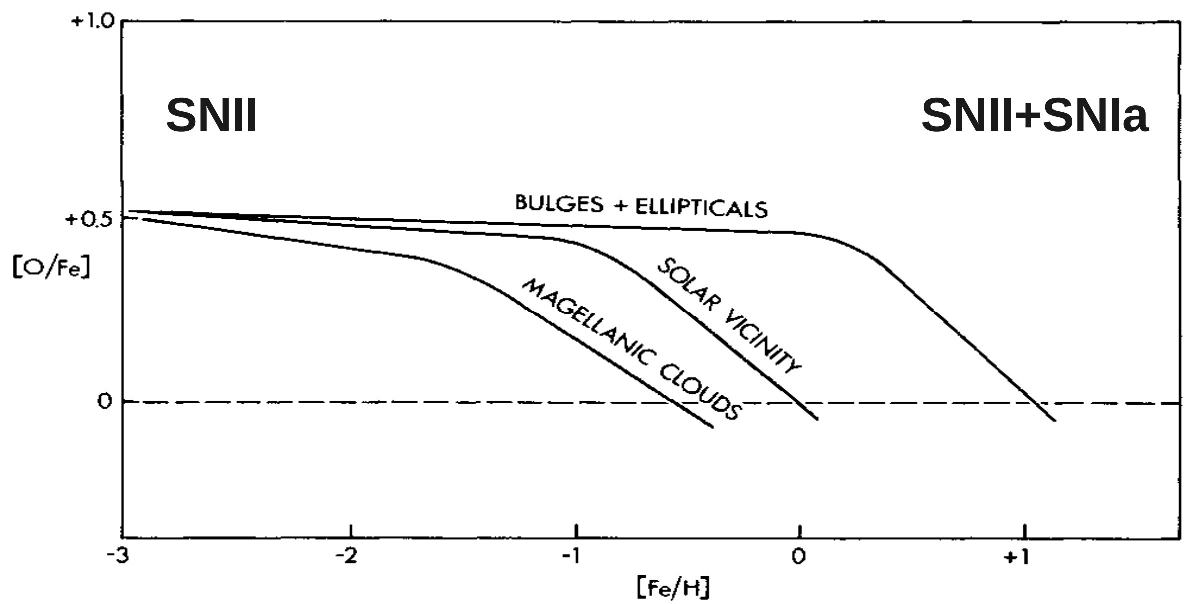


FIG. 4.—A sketch of the predicted [O/Fe] vs. [Fe/H] relations in different systems as a consequence of their different [Fe/H]-t relations.

IMF

SFR

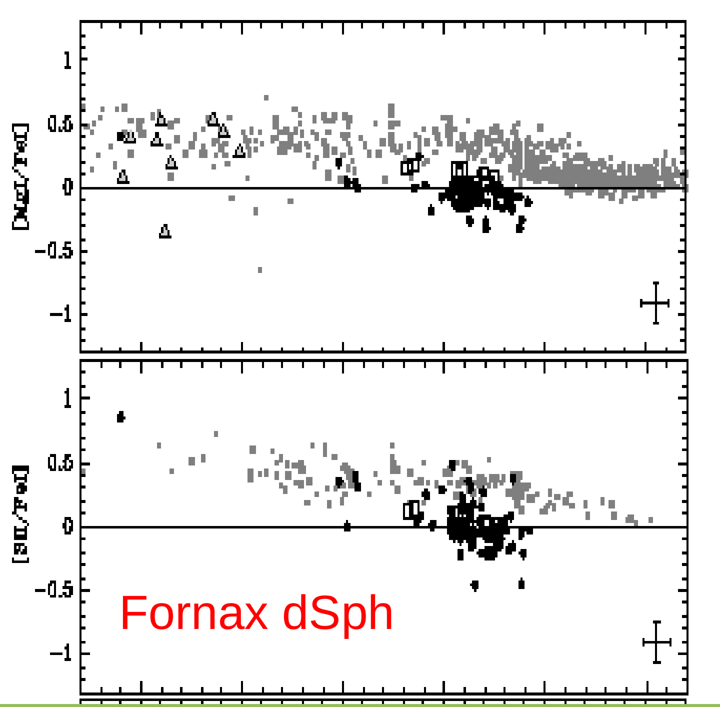
[O/Fe] dependence on SFR (Matteucci & Brocato 1990)

Expect [α/Fe] enhanced in bulge, low in dwarf galaxies.

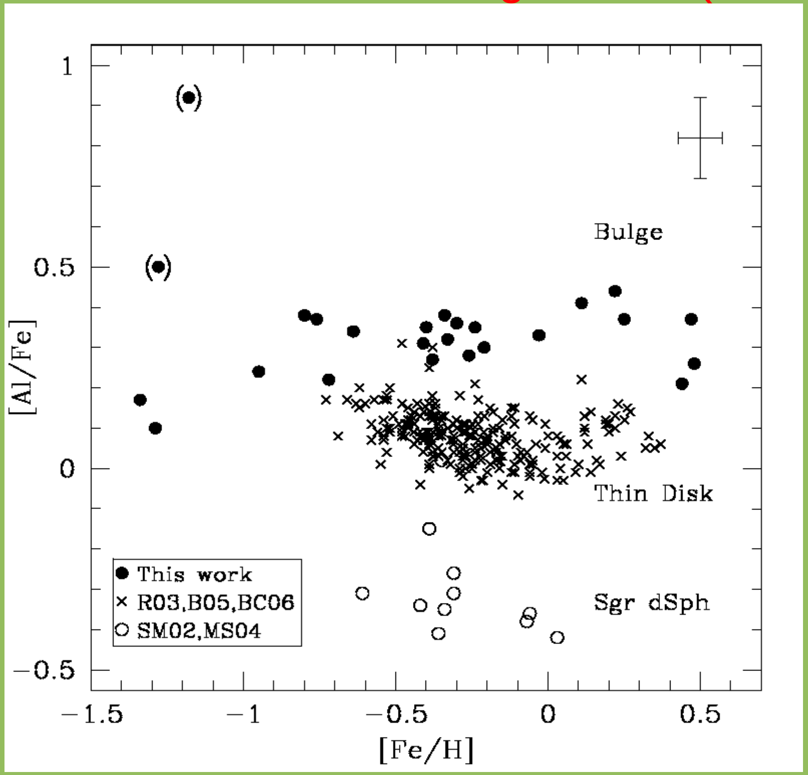
Element ratios should vary from galaxy to galaxy:

Letarte et al. (2010)

[alpha/Fe]

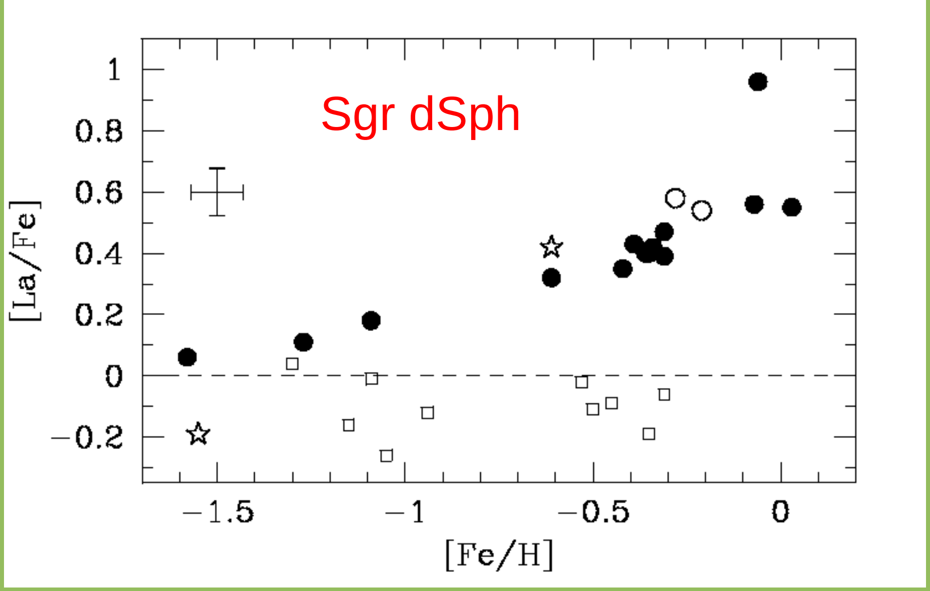


Fulbright et al. (2007)



McWilliam & Smecker Hane (2005)

s-process

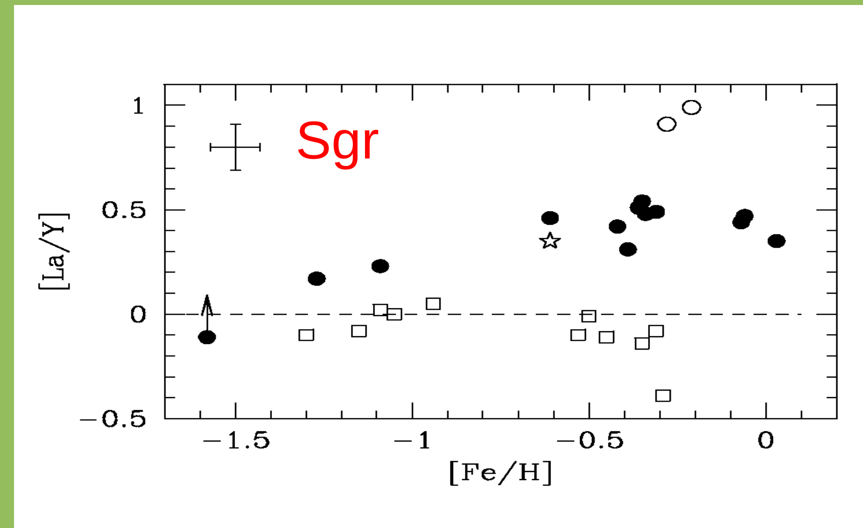


Aluminium

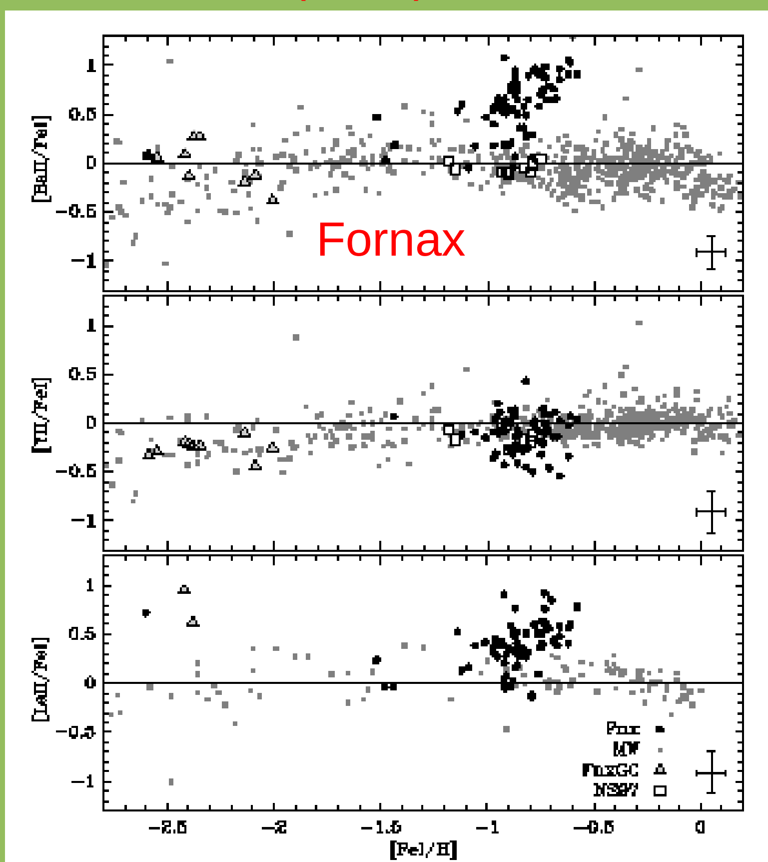
(~85% Fe is from SNIa in Sgr)

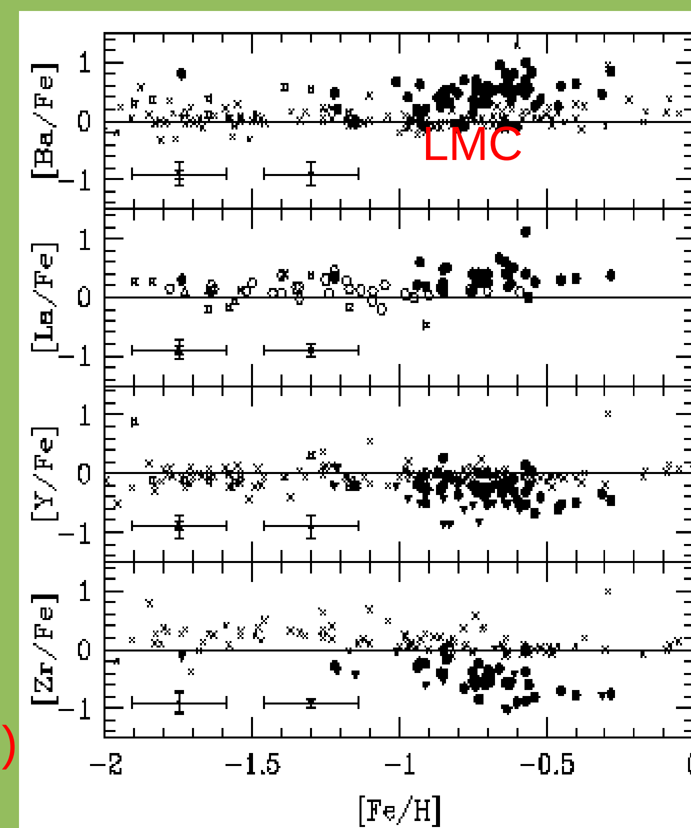
Unexpected: S-Process Enchancements in Dwarf Galaxies

McWilliam & Smecker Hane (2005)



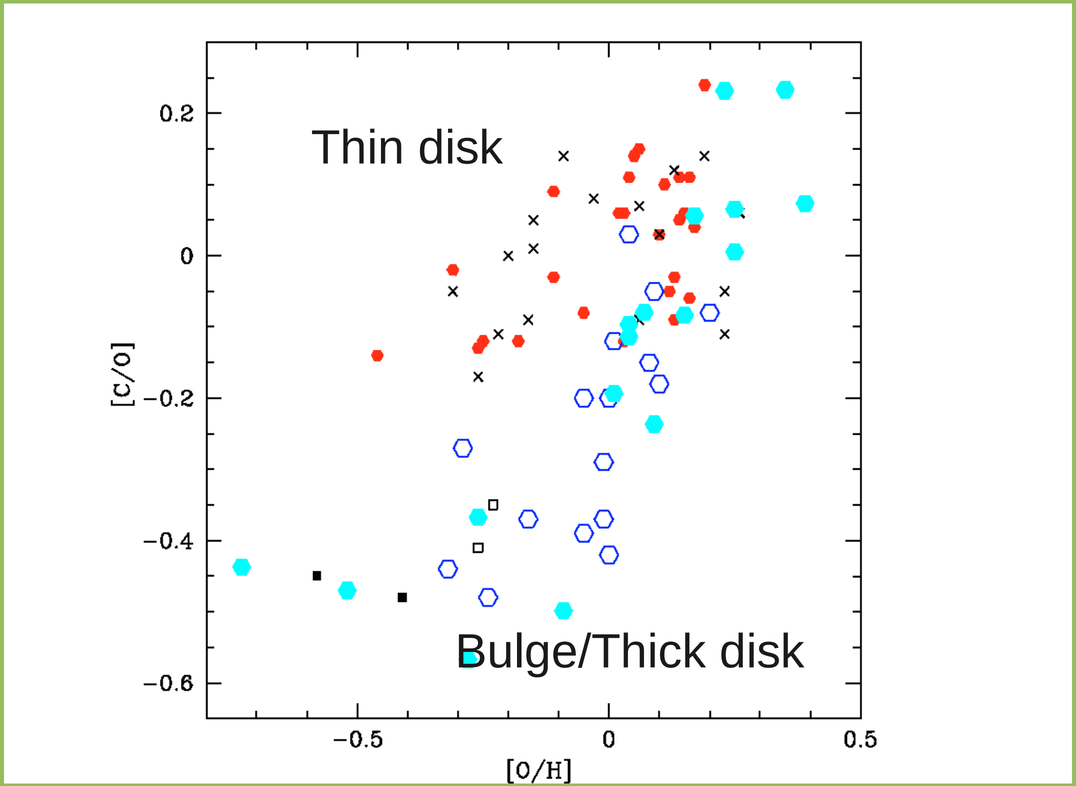
Letarte et al (2010)

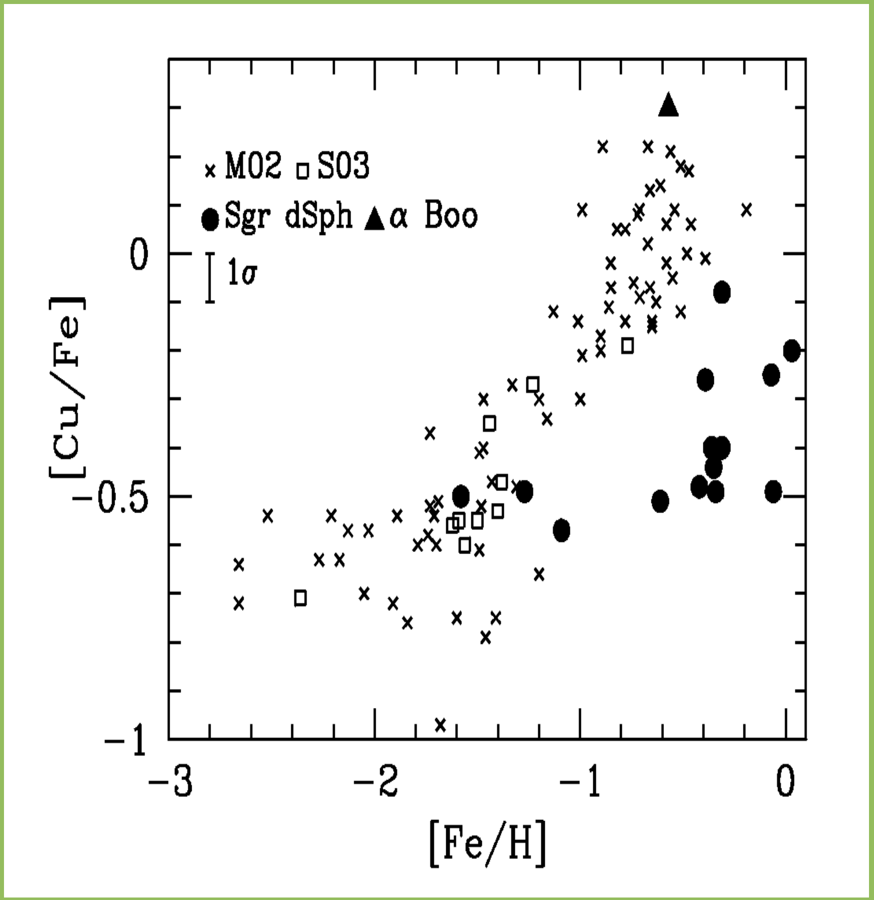




Pompeia et al. (2008)

More examples:





[Cu/Fe] in Sgr dSph

(Also seen in LMC, Omega Cen)

Blue points: bulge/thick disk
Red/black points: thin disk

Much composition variation are seen, but nearly all were not predicted!

Dwarf galaxies shows severe leaky-box chemical evolution, strongly affected by outflows (anti G-dwarf problem) and low SFR, with abundances characteristic of low metallicity, low mass AGB stars. This is a general mode of evolution for low mass galaxies.

We expect that the more massive dwarf galaxies lose a smaller fraction of mass, and as a result show smaller amplitude abundance effects.

Beyond the Local Group: sampling all galaxy types

Problem:
GMT echelle abundances for single RGB stars within Local Group only.

But, the Local Group does not contain all galaxy types, and we need composition for many giant galaxies (Es and Spirals).

Solution:
Globular Cluster Integrated-Light High-Resolution Abundances

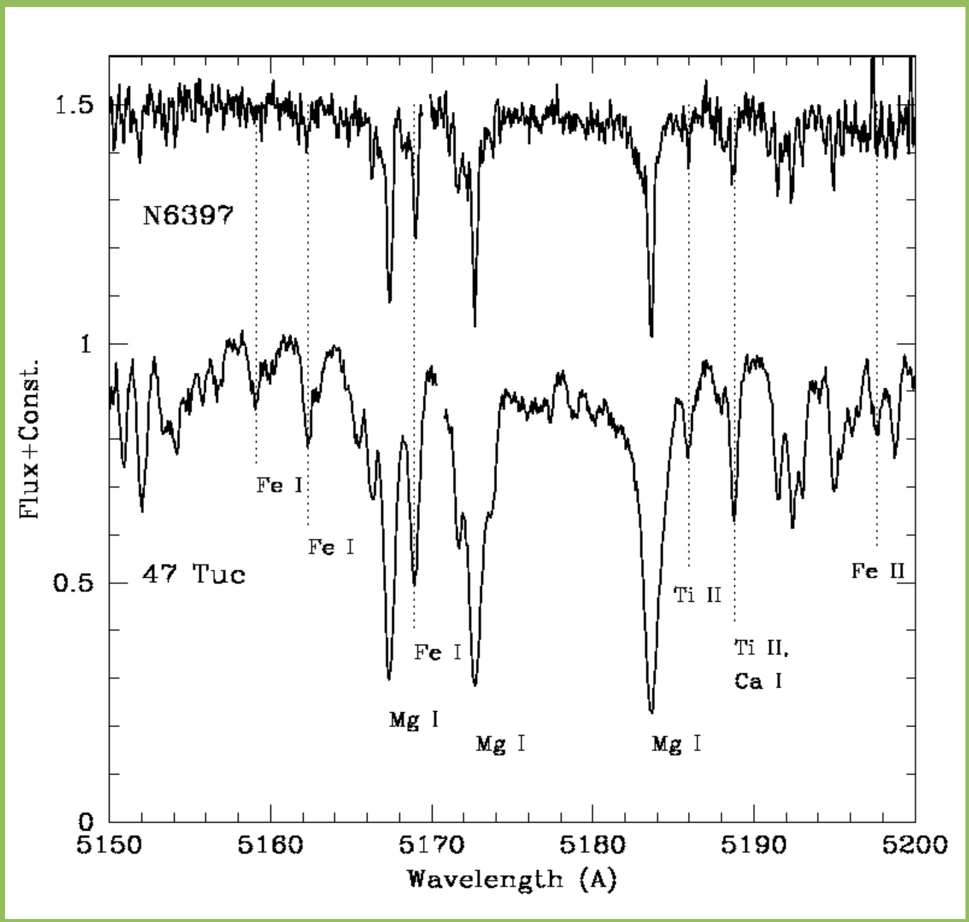
Luminous Mv~ -10
Low velocity dispersion → narrow lines
Many lines from many elements
Ages from 0 to 13 Gyr

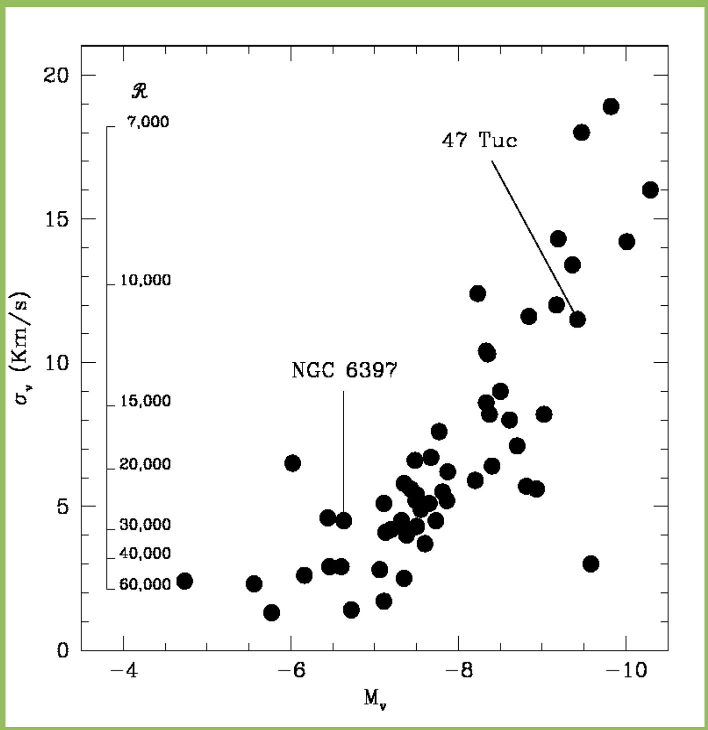
Challenges: HB morphology, self enrichment

47 Tuc: same results as RGB stars (McWilliam & Bernstein 2008)
M31 (Colucci et al. 2010), M33, M31,LMC,SMC,NGC 205 in progress

GC Integrated-Light Abundances

Line widths

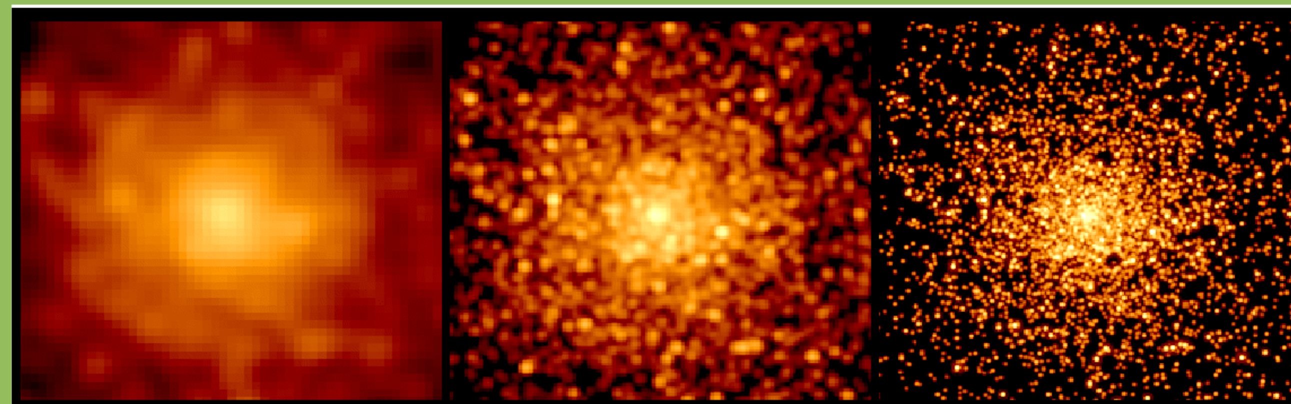




Narrow GC lines in integrated-light

Globular Clusters in Cen A (3.9 Mpc) with GMT

HST Gemini GMT

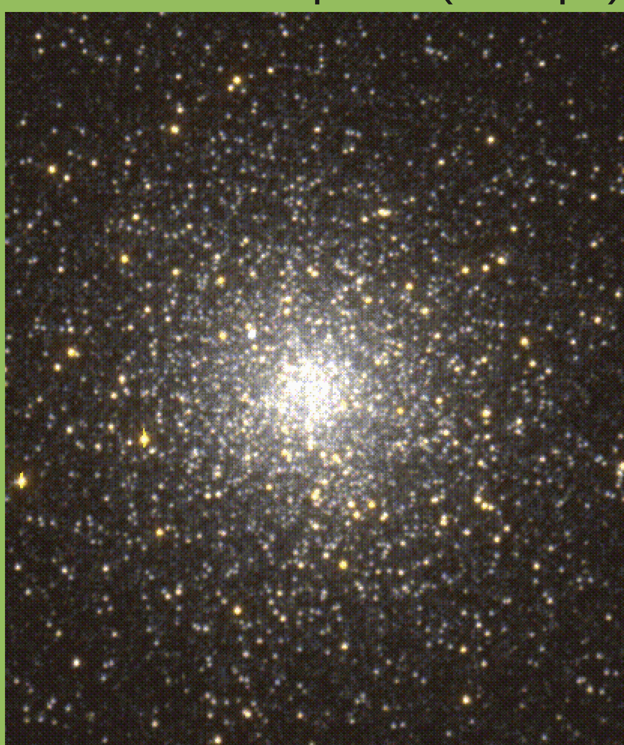


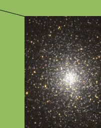
2 arc sec

H Band Image

CMD photometry

47 Tuc Optical (4.4 kpc)





0.45 arc sec

6.6 x 8.0 arc min (r_h=2.8 arc min)

Cen A (DM~28.0 = 3.9 Mpc)

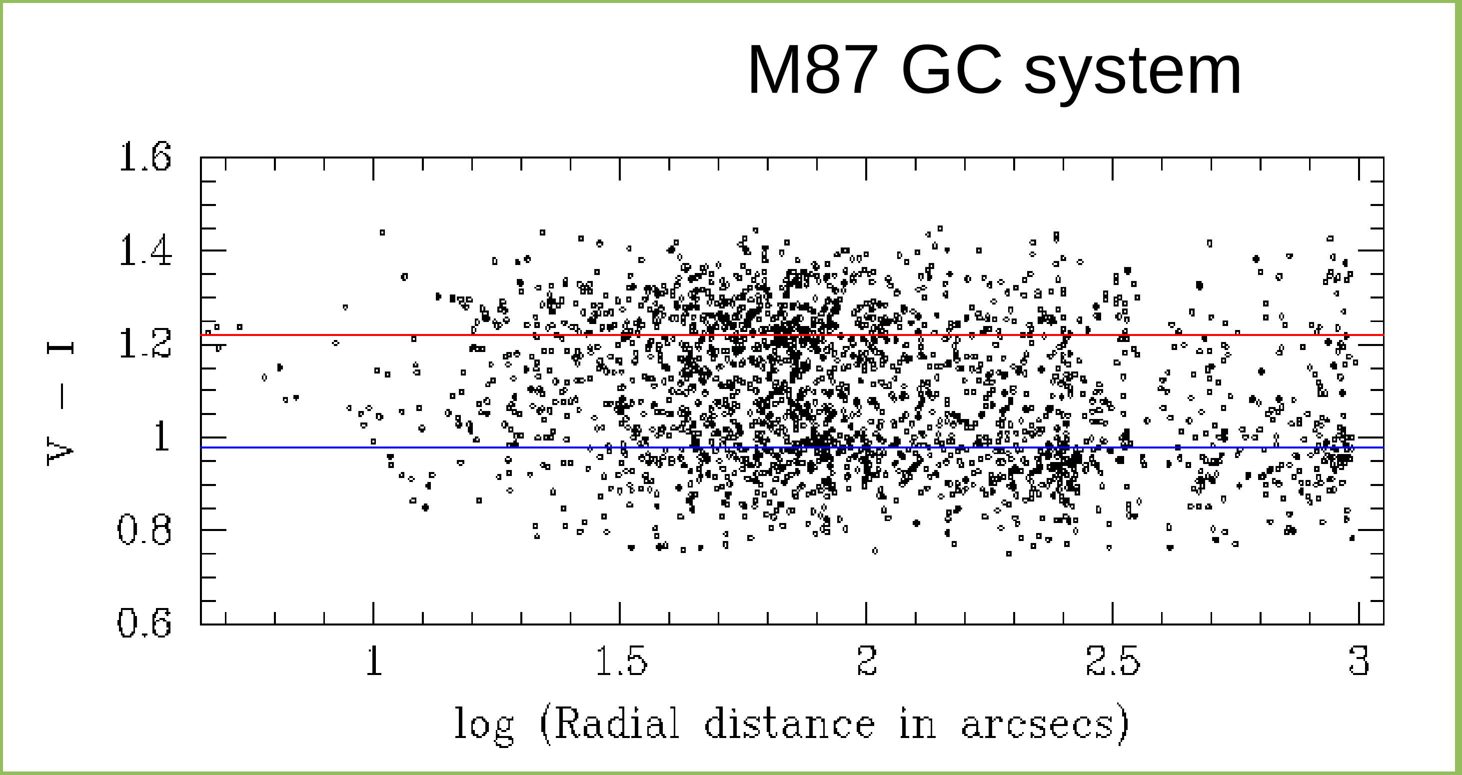
~2000 GCs in Cen A

Q.What was the mass-assembly history of Cen A?
How much of it formed, and when?

Use diagnostic abundance ratios to understand IMF, SFR, SF bursts, inflows, outflows and formation time for Cen A.

Attempts to use Lick indices to measure [Mg/Fe] (e.g. Woodley et al 2010) result in scatter diagrams.

The Holy Grail... GCs in Virgo
⟶ sample all galaxy types



16.8 Mpc (m-M)~31

For Mv=-10 GCs V~21, S/N=50 in 17hrs
(@R=40,000)

Merging Galaxies to ~100 Mpc

Merging galaxies produce young, massive, GCs that are bright enough to be seen to ~100Mpc.

Spikes/ enhancements in [α/Fe] ratios expected (r-process, Rb?)

The Antennae galaxies 22 Mpc

Extreme Metal-Poor Stars , Population III, & Low-Luminosity Dwarf Galaxies

EMP stars can tell us about:

- characteristics of the first stars (population III)
- the astrophysical site of the r-process and light n-capture elements
- element yields from individual supernova events

Stars in Low-luminosity dwarf galaxies can inform on:

- stochastic chemical evolution, & yields from individual SNe
- IMF at low metallicity, and population III
- related to the building blocks of large galaxies
- the effect on dark matter on Chemical Evolution

EMP stars are long lived relics from the earliest phase of star formation. Their composition contains a fossil record of the massive stars of this epoch.

Predicted Population III Nucleosynthesis Yields:

- McKee & Tan (2008) → pop III.1 stars mean mass ~140, range 60-320 Msun

- Heger & Woosley (2002) performed nucleosynthesis calculations for 140<M<260 Msun zero metallicity SNe → pair instability supernovae (PISN).

→ Large odd-even effect, e.g. Δ [Mn/Fe] $\geq$ 1 dex.

→ **These ratios are NOT SEEN in EMP stars**

Where are they?

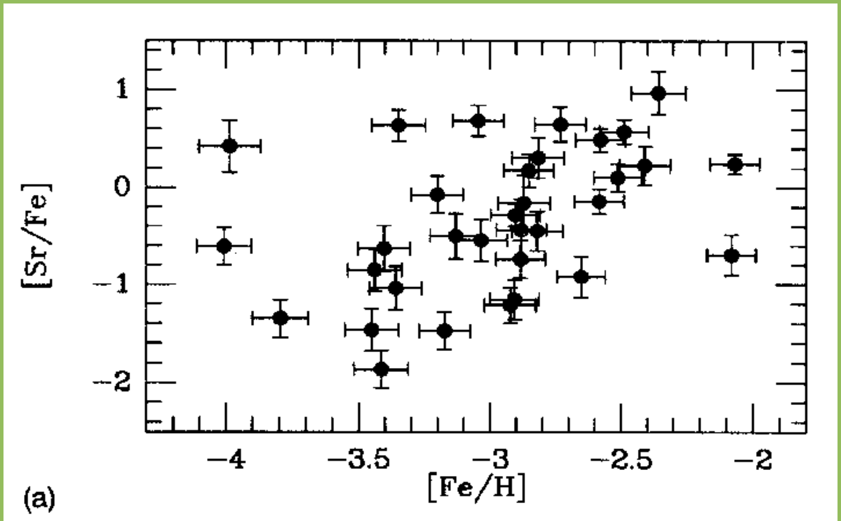
- Central regions of massive galaxies (e.g., Brook et al. 2007)

- But some EMP stars found in dwarf galaxies.
  Expect the ultra-low luminosity galaxies to contain most EMP stars

Some things learned from the chemical composition of EMP stars:

300-fold range in [Sr/Fe] indicates inhomogeneous chemical evolution.

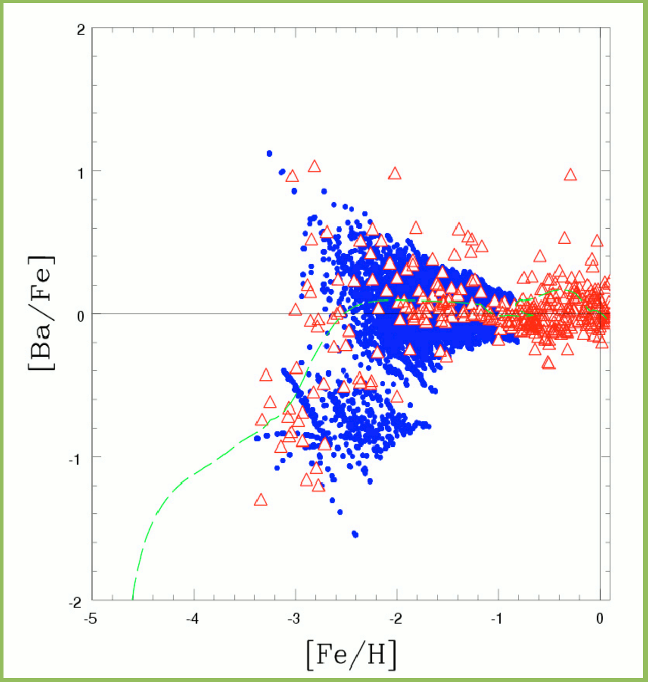
Observed [n-capture/Fe] range
→ minimum yield range



r-process rich SNe at most ~1/20 all SNe

r-process rich stars from individual SNe !

Funnel effect from averaging of element yields.

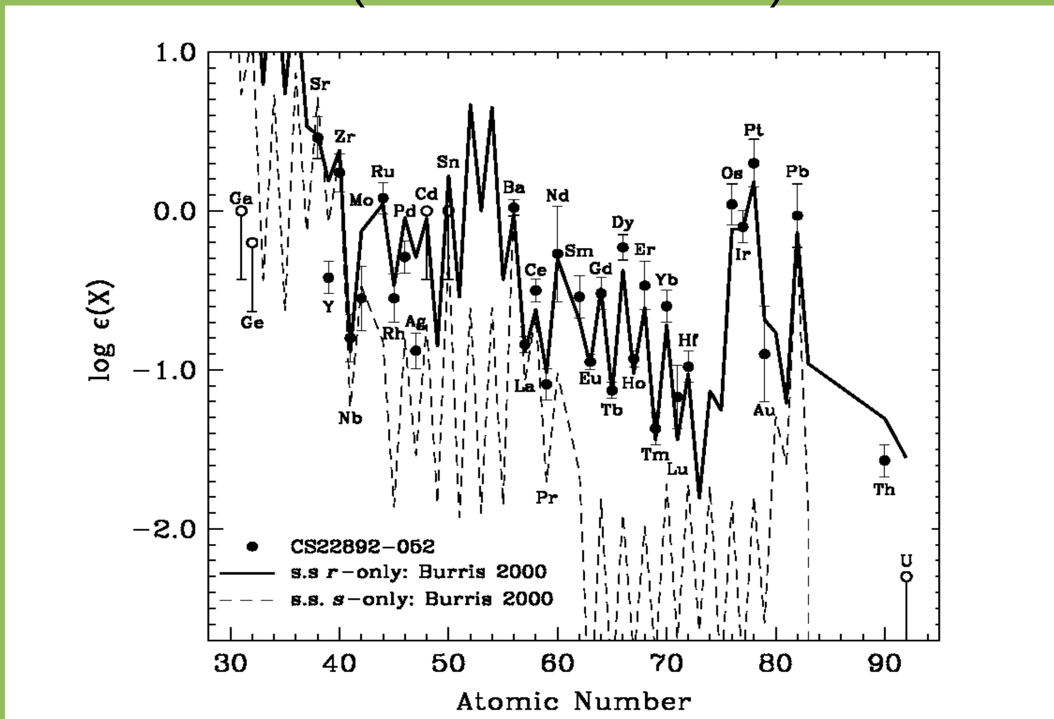


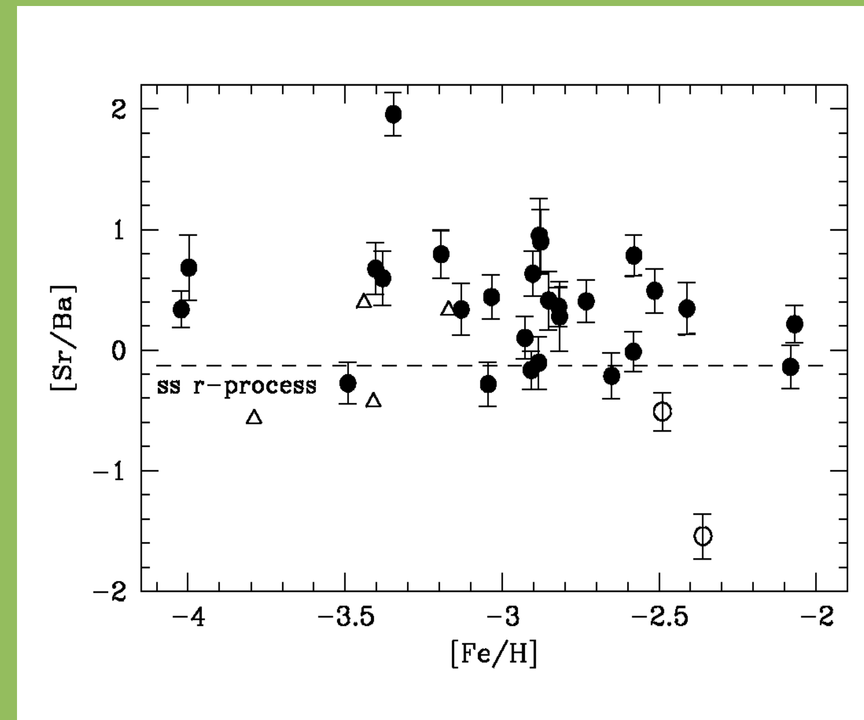
Stochastic Chemical Evolution (Cescutti et al. 2009)

A universal r-process ?

McWilliam (1998)

CS22892-052 (Sneden et al. 2003)





n-capture identical* to solar system r-process
(* except radioactives; Th, U cosmochronometers)

light/heavy dispersion

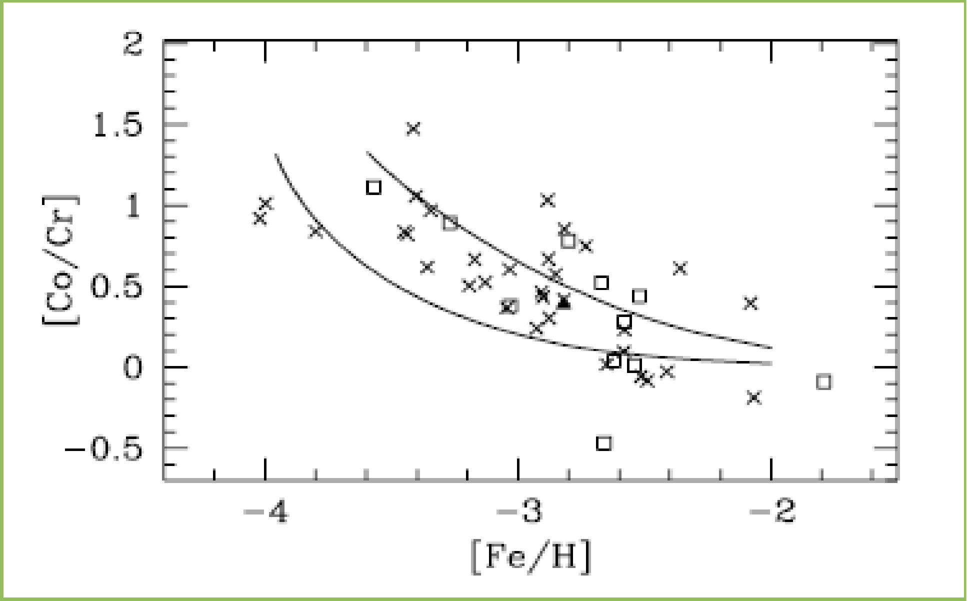
Two of the most pressing questions in nuclear astrophysics:

What is the astrophysical site and neutron source for the r-process?

What is the source and what nuclear processes lead to the dispersion of the light/heavy neutron-capture elements?

Towards the Primordial Composition

1. The [Co/Cr], and [Co/Fe] ratios in EMP stars



- Tight [Co/Cr] trend, declining from ~+1 near [Fe/H]=-4.
- Non-LTE does not explain high Co (Bergmann 2010)
- Dilution of pop III composition by pop II SN?
- Nomoto et al. (2005): high energy SNII (hypernovae) produce enhanced [Co/Cr]?

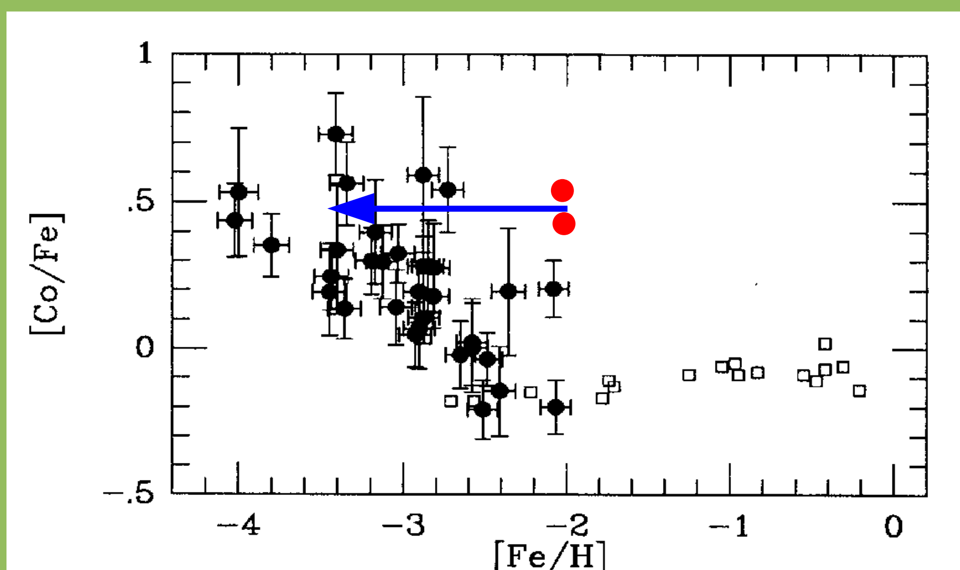
What masses and UV fluxes of the SNe progenitors produce the observed [Co/Cr] ratios?

Towards the Primordial Composition

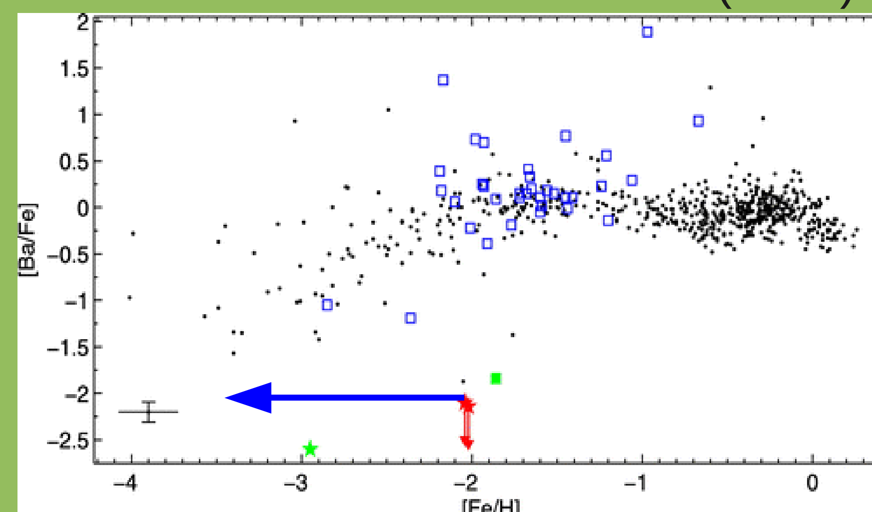
2. Her dwarf galaxy composition

- Two stars in the Her low luminosity dwarf galaxy show enhanced [Co/Fe] and [Ba/Fe] and [Sr/Fe] deficient by >2 dex, but [Fe/H]=-2.

- But this composition is typical of stars near [Fe/H]~-3.5



Koch et al. (2008)



- **Looks like primordial composition but at relatively high [Fe/H]**

Towards the Primordial Composition

2. Her dwarf galaxy composition (cont.)

- Her stars are enhanced in [Mg/Ca] ⟶ SNII mass ~35 Msun (cf WW95)
- Is this due to random sampling of IMF? ⟶ Suggests < 11 Type II SNe !
- But, zero metallicity stars born in ionized halo: M~40Msun, pop III.2, (Yoshida et al. 2007). No PISN signature.

Is this what the Her abundances are telling us?

Need to study detailed composition of many more stars in low luminosity dwarf galaxies.

LSST, DES, PANSTARRS should provide a list of hundreds of these dwarfs within reach of GMT optical echelle.

Conclusions:

1. The detailed chemical composition of stars and GCs using GMT echelle will probe the evolution of galaxies in unprecedented detail, out to the Virgo Cluster.

2. This will allow for a deeper understanding of nucleosynthesis yields, chemical evolution, and galaxy formation.

3. The study of EMP stars can provide measured nucleosynthesis yield ratios from individual SNe, to confront theoretical SN yields, and the origin of the r-process.

4. Chemical abundances of EMP stars and stars in low luminosity dwarf galaxies offer tantalizing clues to the characteristics of the **first stars**.

5. A GMT echelle spectrograph can make a significant impact on early galaxy evolution and the first stars, by studying the composition of low-luminosity dwarf galaxies from DES and LSST surveys.

The absence of a first light echelle on TMT means that the GMT project will be able to dominate these important areas.