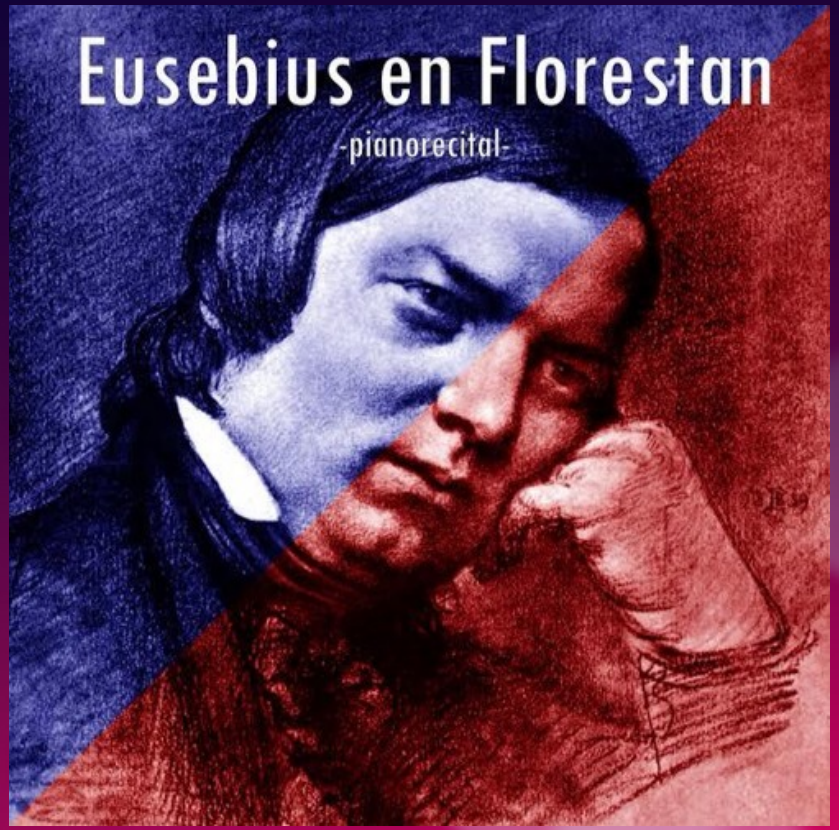
Primordial *r*-process dispersions in M15 and M92

Evan N. Kirby (University of Notre Dame)

Mikhail Kovalev (Max Planck Institute for Astronomy)
Alexander Ji (University of Chicago)

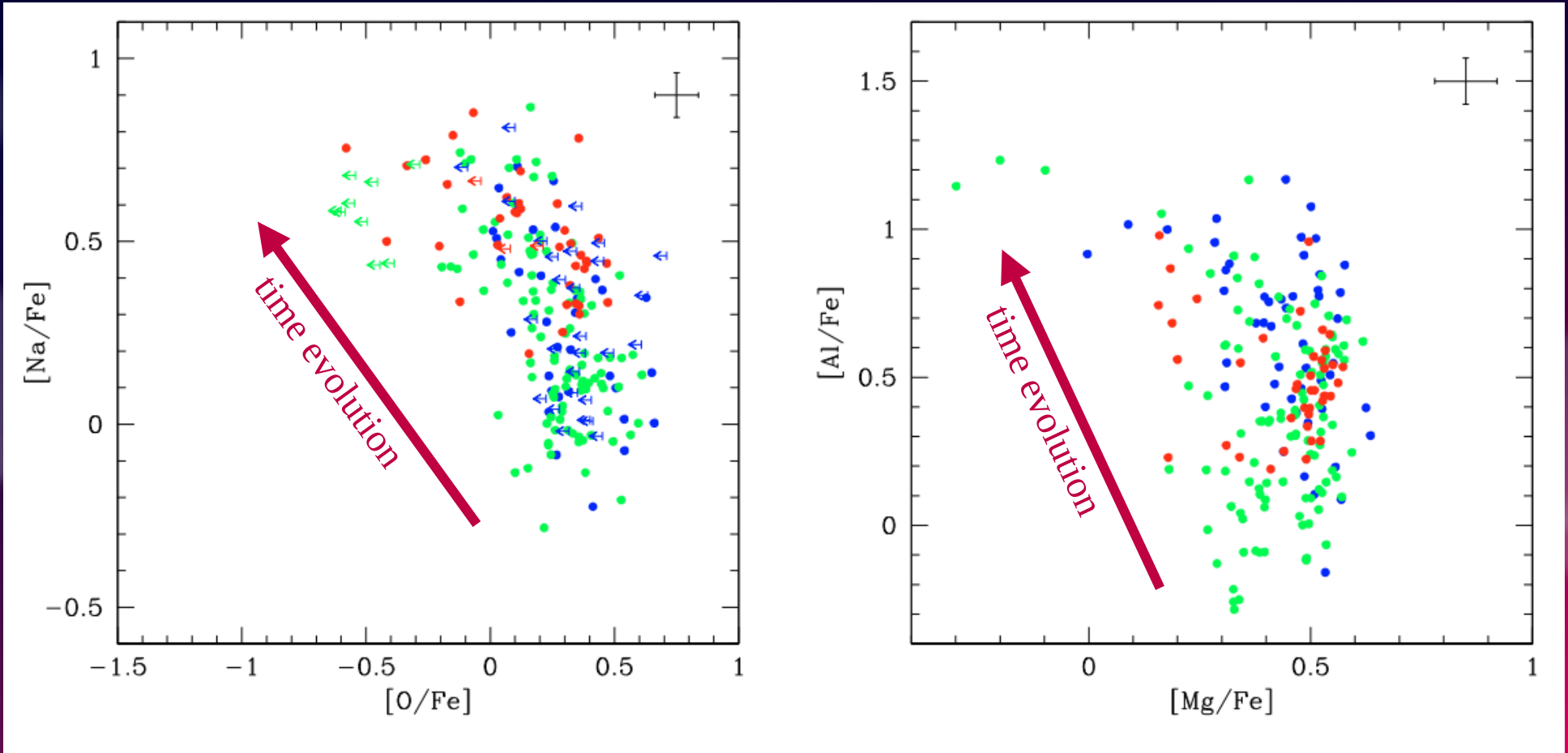
M15

M92



Robert Schumann

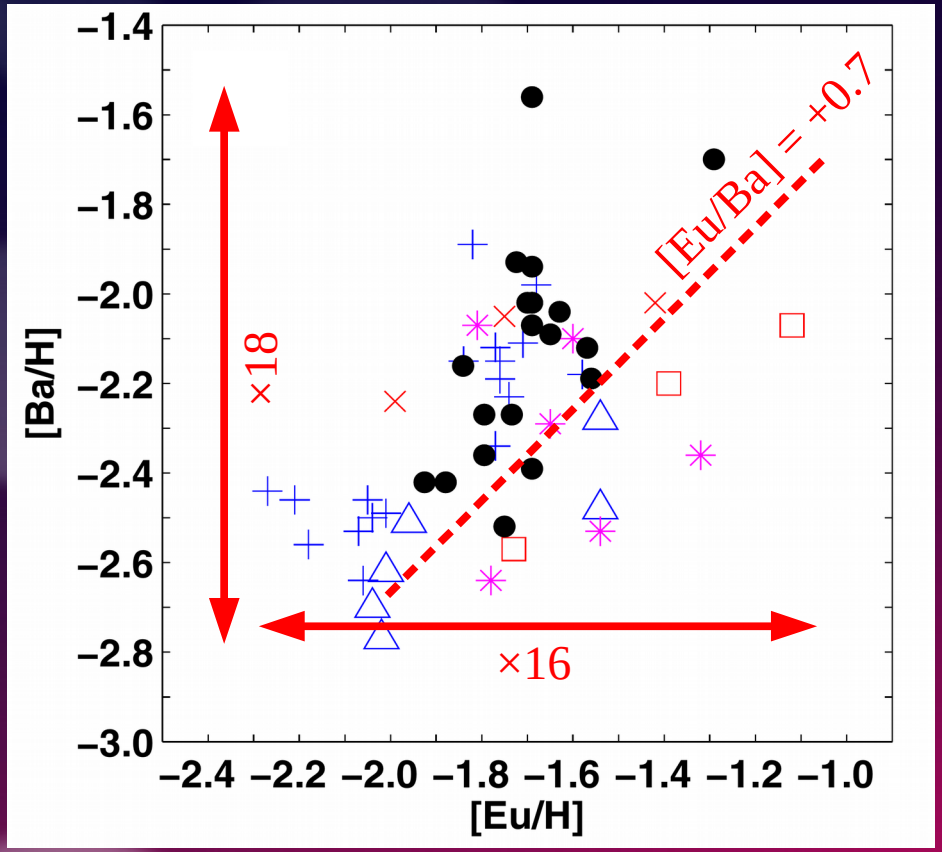
Globular clusters have complex stellar populations.



Carretta et al. 2009, A&A, 505, 139

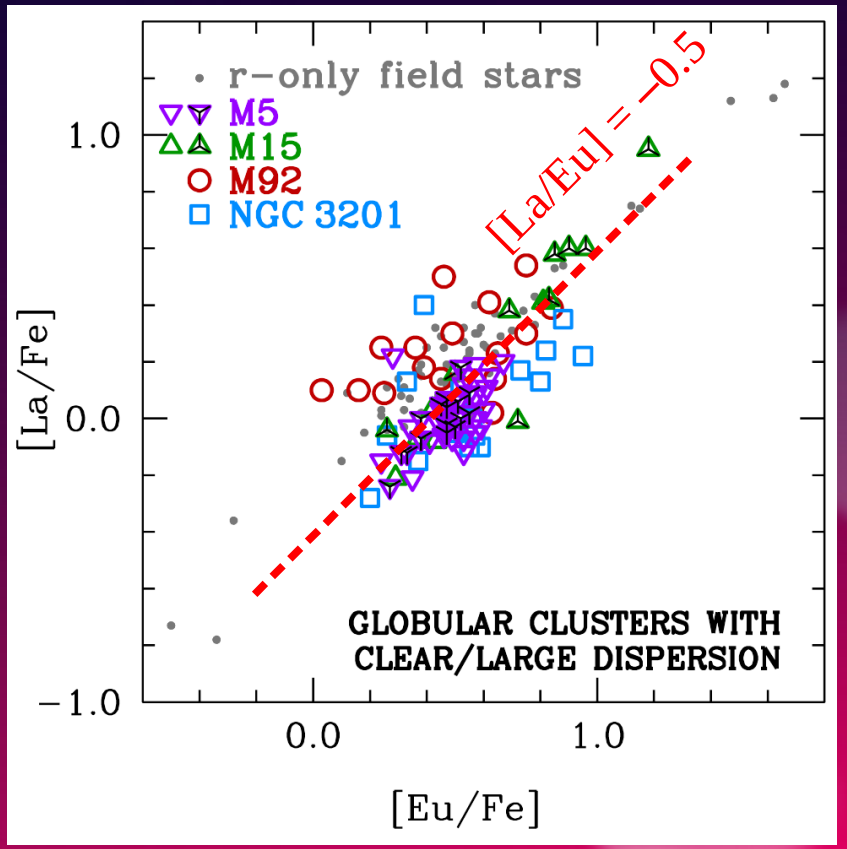
Neutron-capture dispersion in globular clusters is rare.

M15 is the most convincing example of this phenomenon …



Worley et al. 2013, A&A, 553, 47

… but there were hints that M15 is not alone.



Roederer 2011, ApJL, 732, L17

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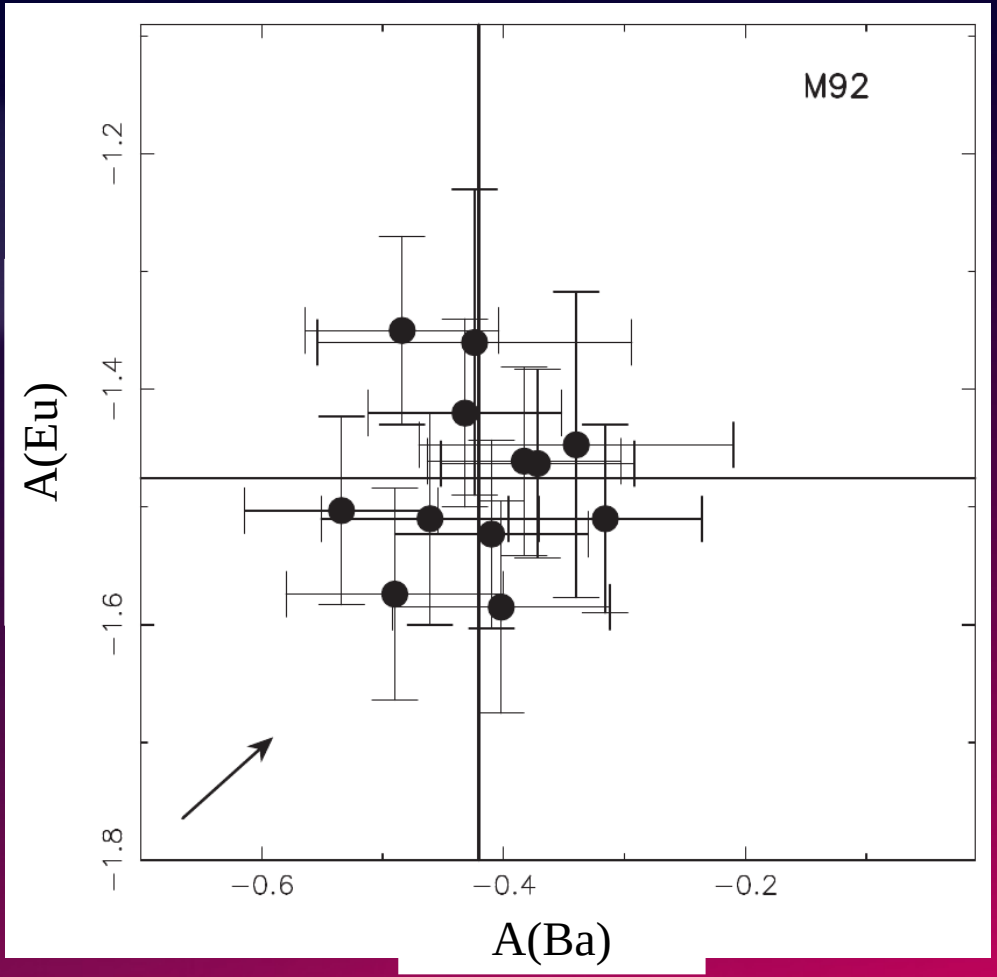
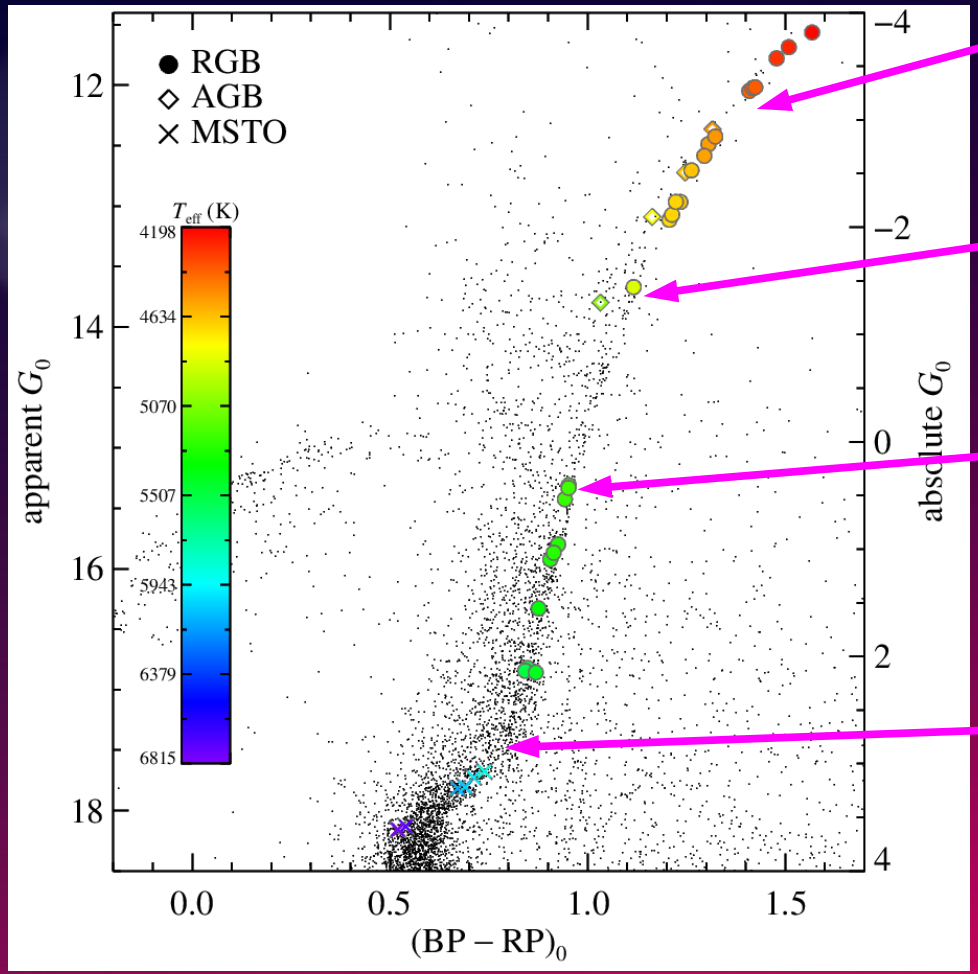


Cohen 2011, ApJL, 740, L38

I dug into the Keck Observatory Archive to find high-quality HIRES spectra of stars in M92.



S/N = 138

S/N = 89

S/N = 72

S/N = 50

Spectra observed by
- J. Cohen
- F. Chaffee
- M. Bolte

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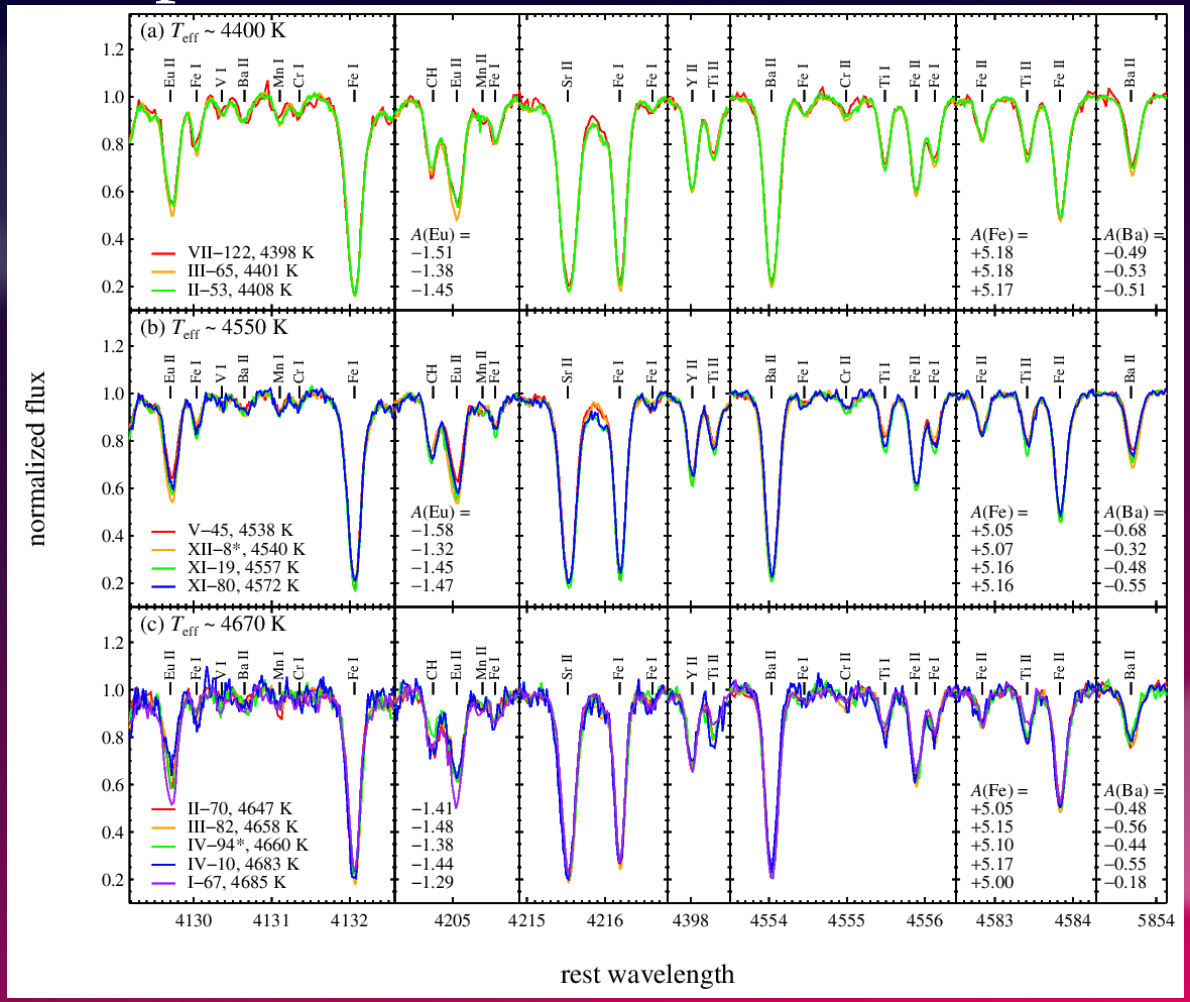

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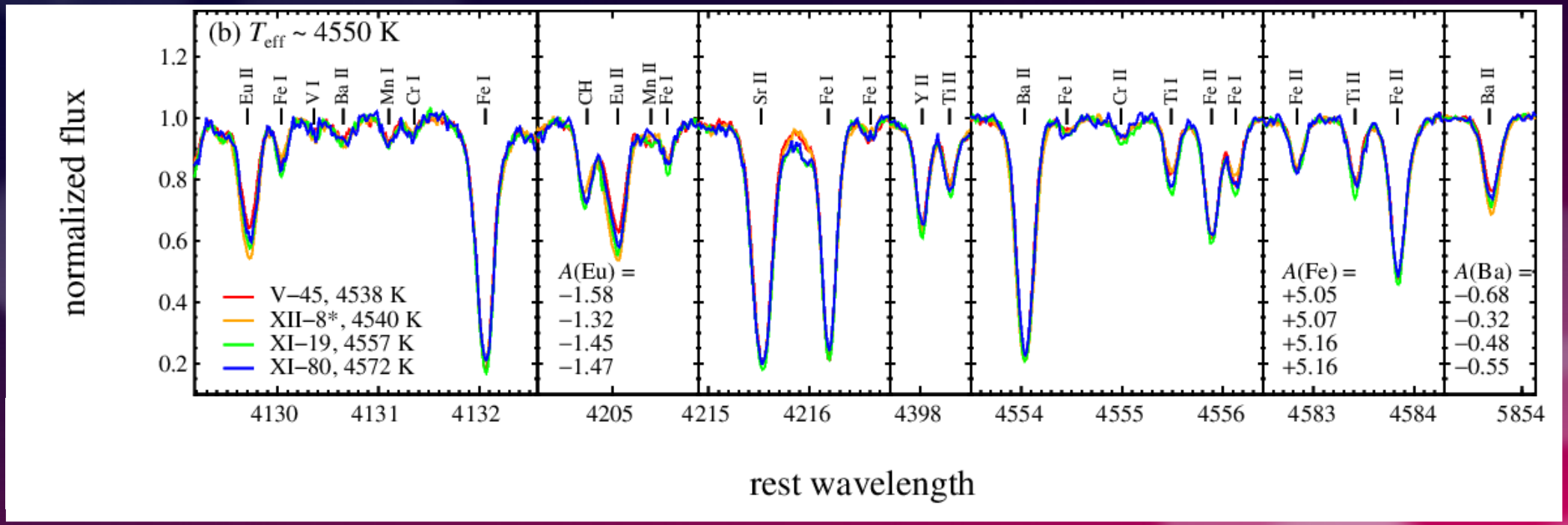
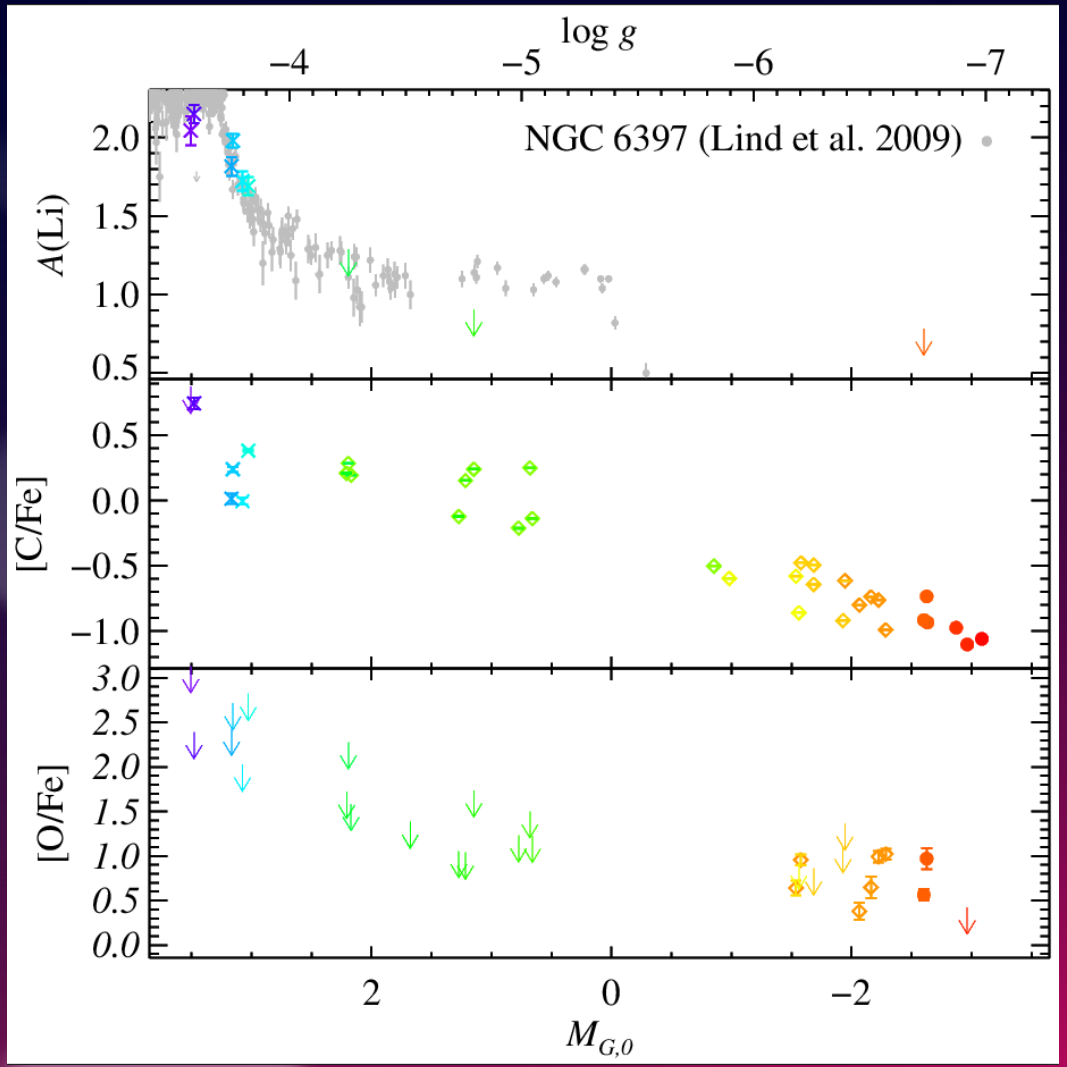
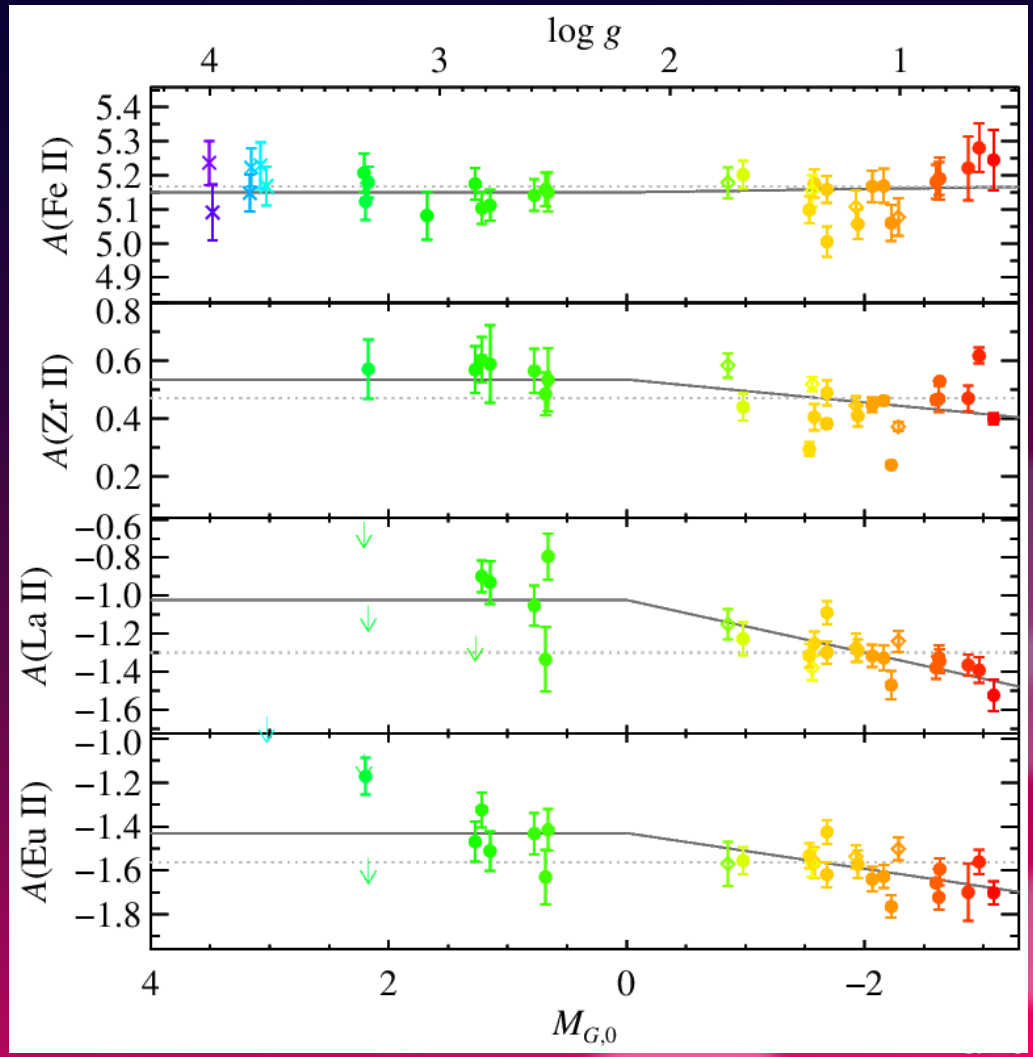
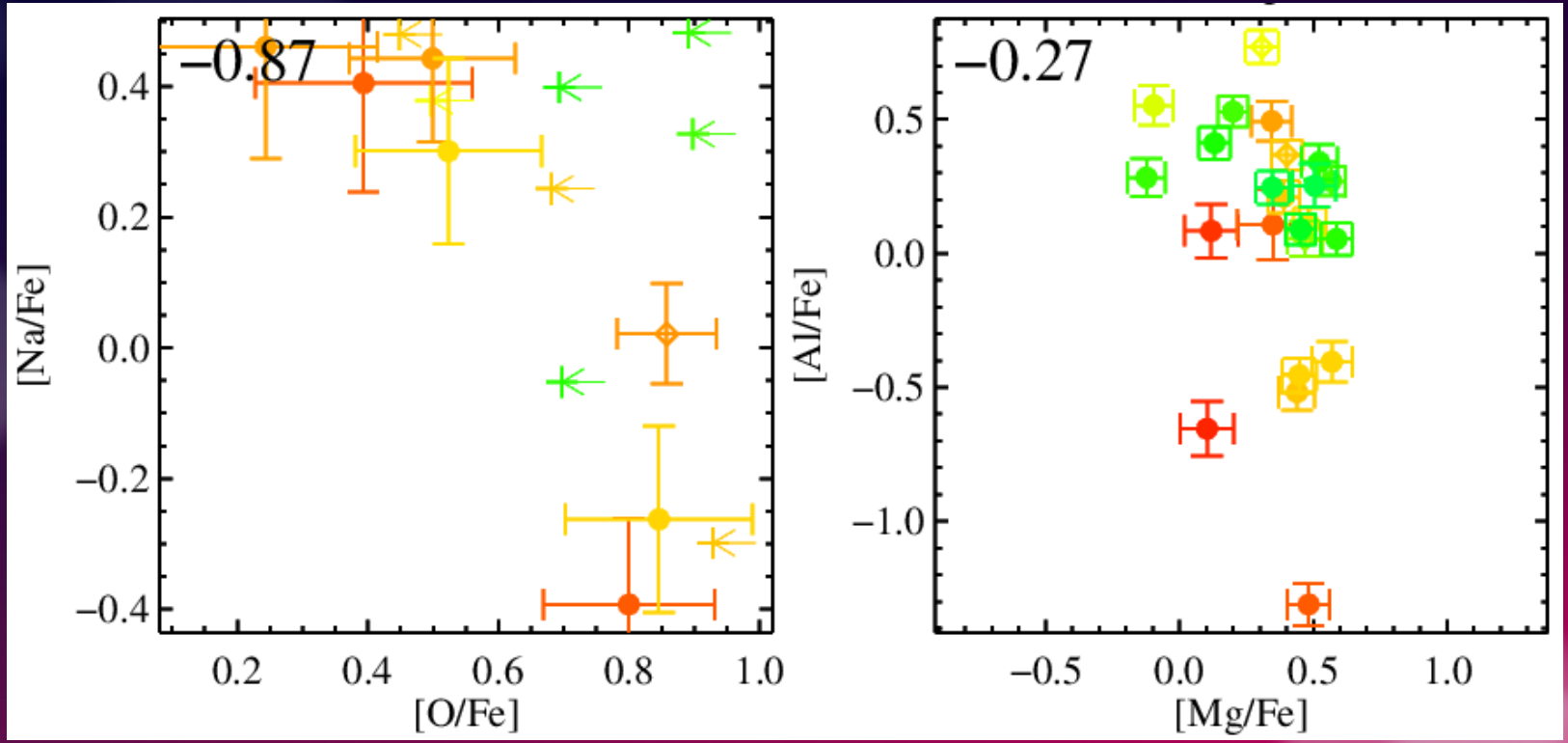


Other trends with luminosity are expected.

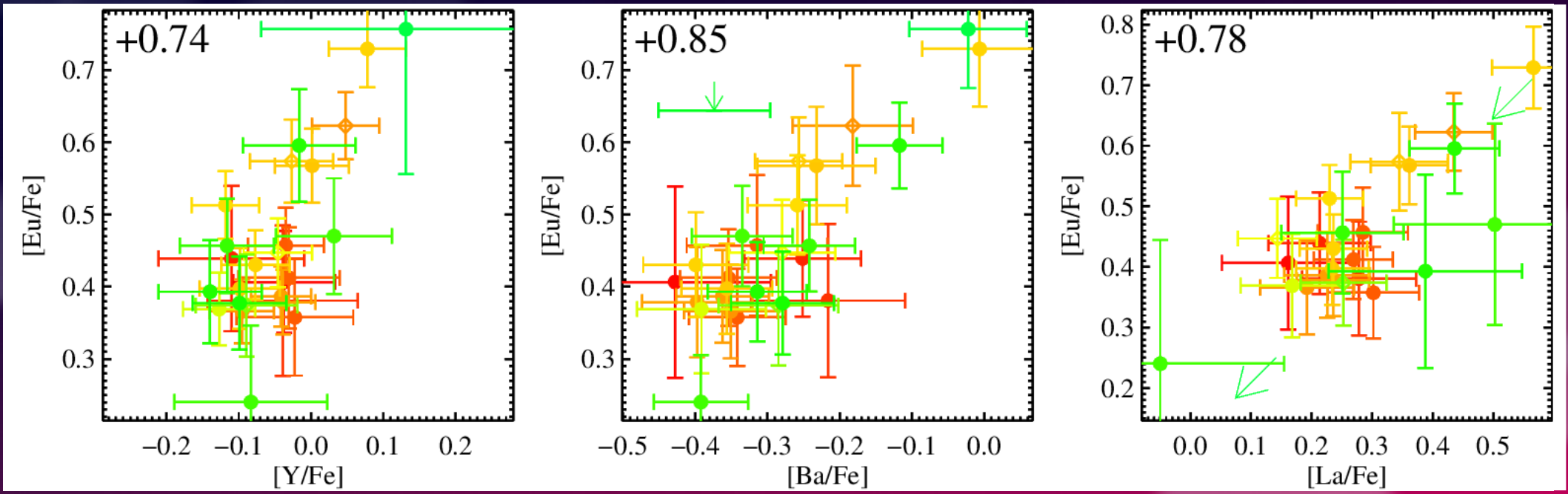




M92 exhibits typical light element abundance anti-correlations.



M92 has a 0.5 dex (×3) dispersion in neutron-capture elements.



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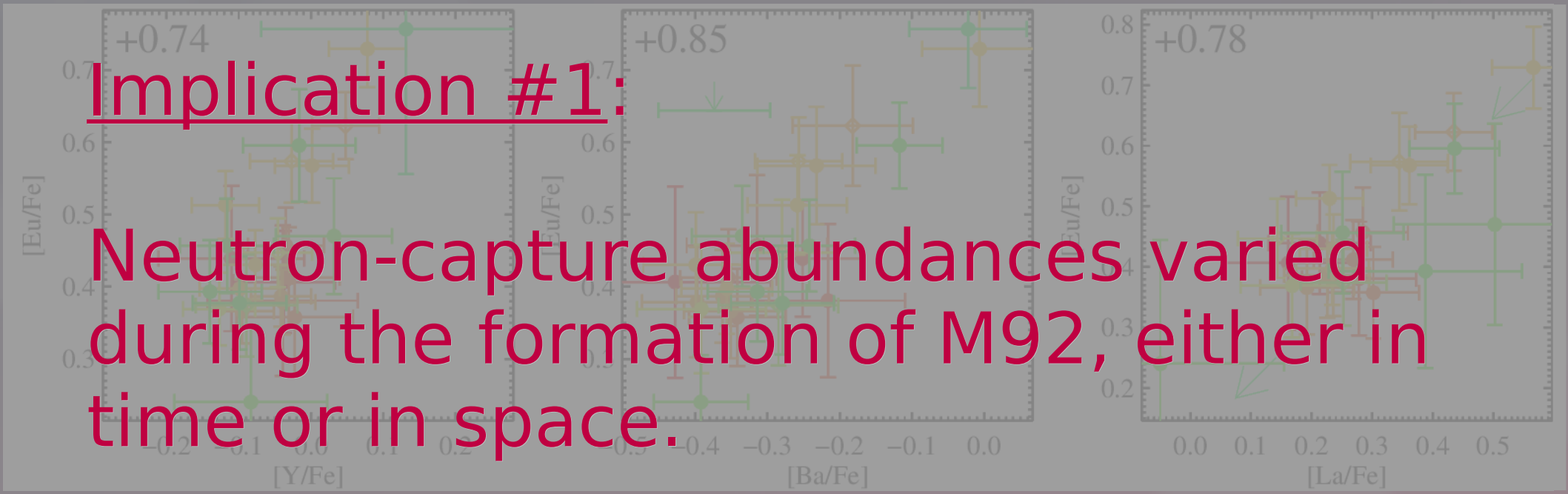
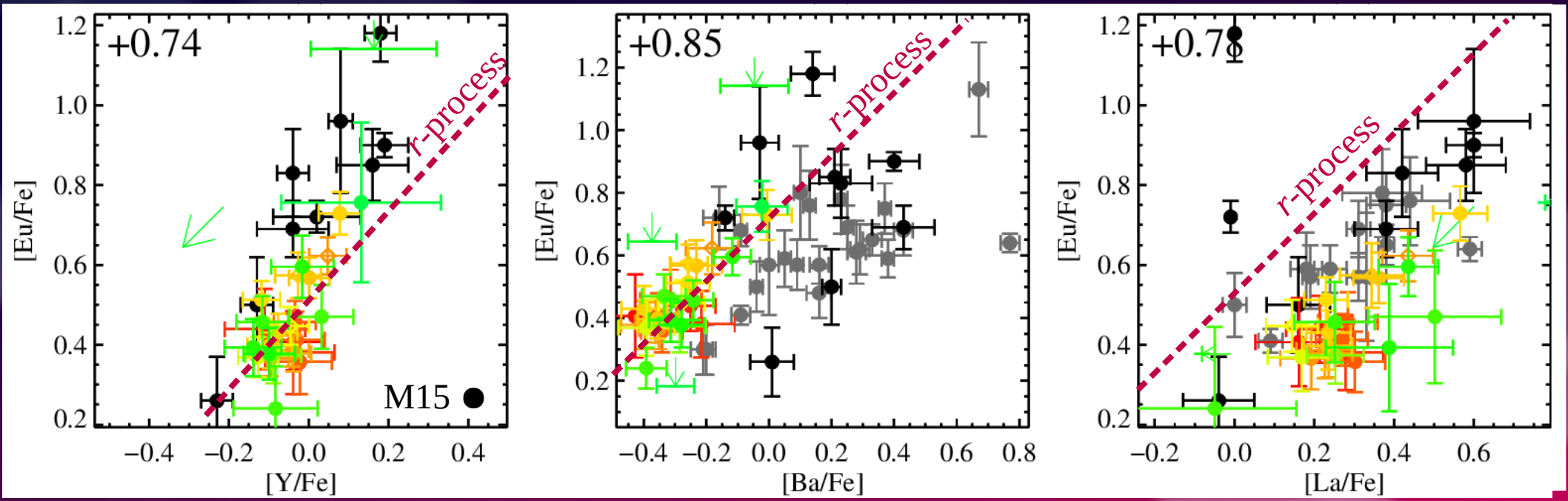


Implication #1:

Neutron-capture abundances varied during the formation of M92, either in time or in space.

M92 has a 0.5 dex (×3) dispersion in neutron-capture elements.



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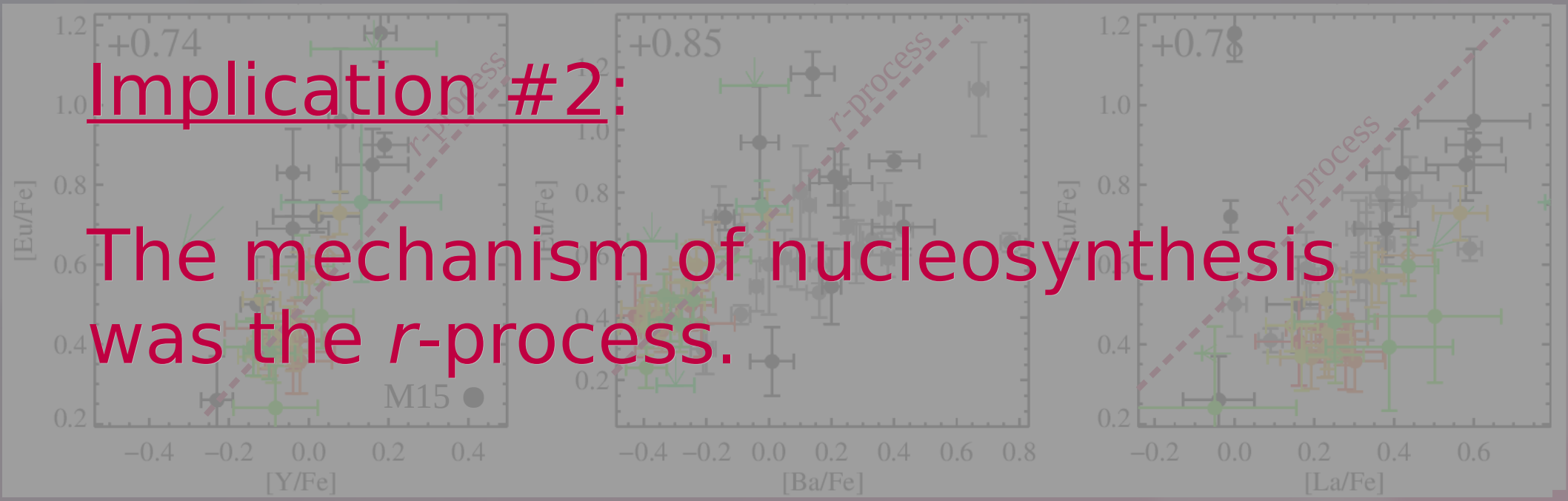
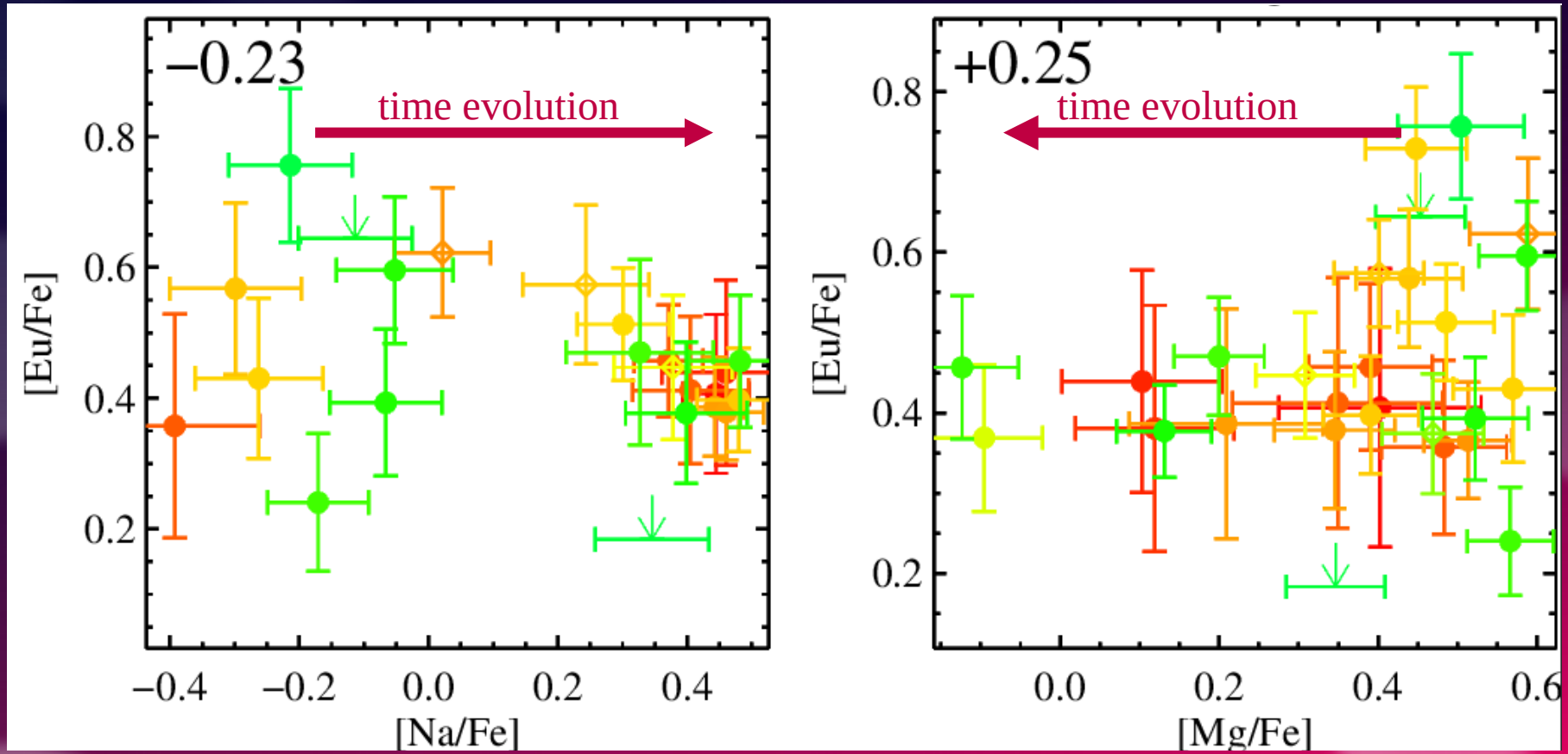


Implication #2:

The mechanism of nucleosynthesis was the *r*-process.

There might be a reduction in *r*-process dispersion over time.



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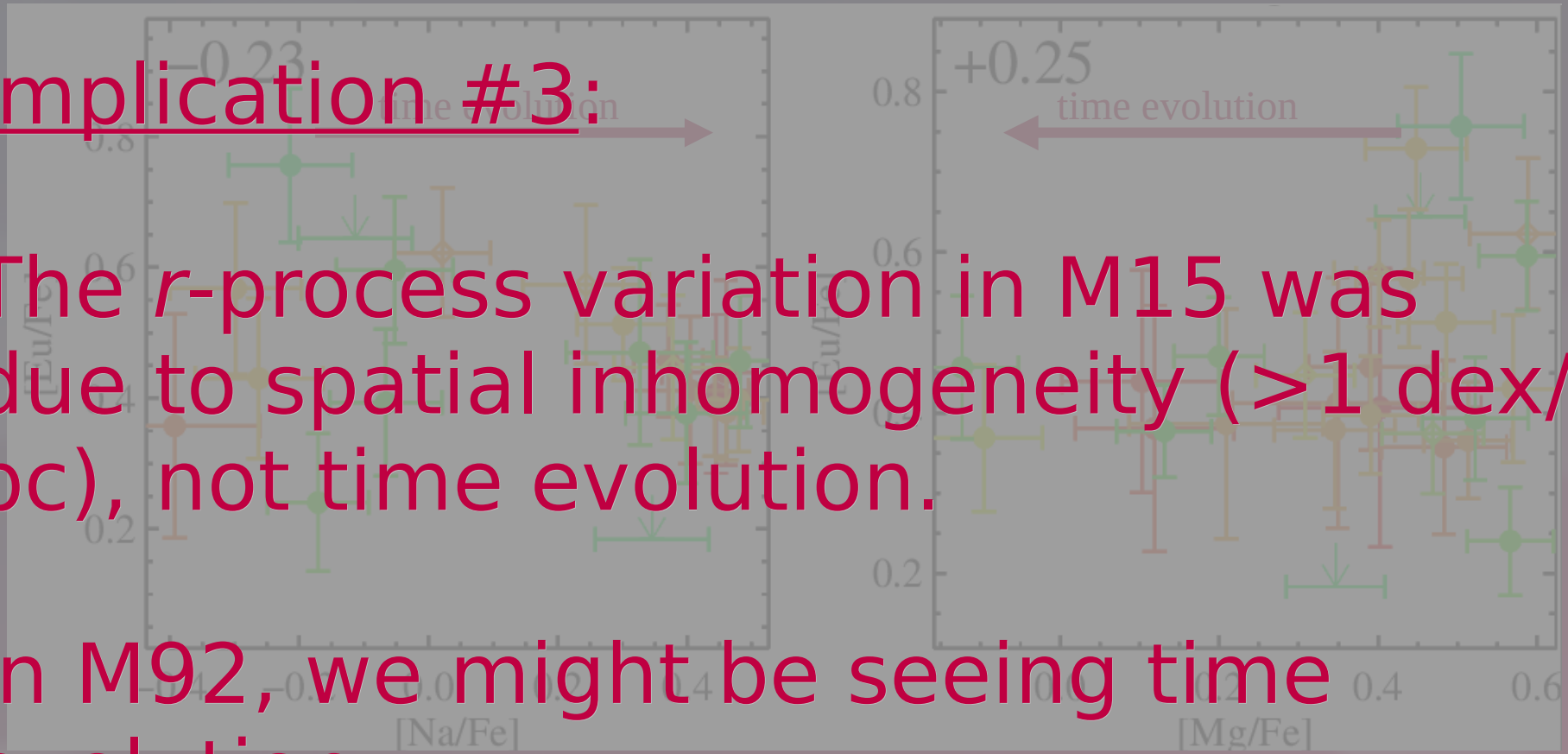
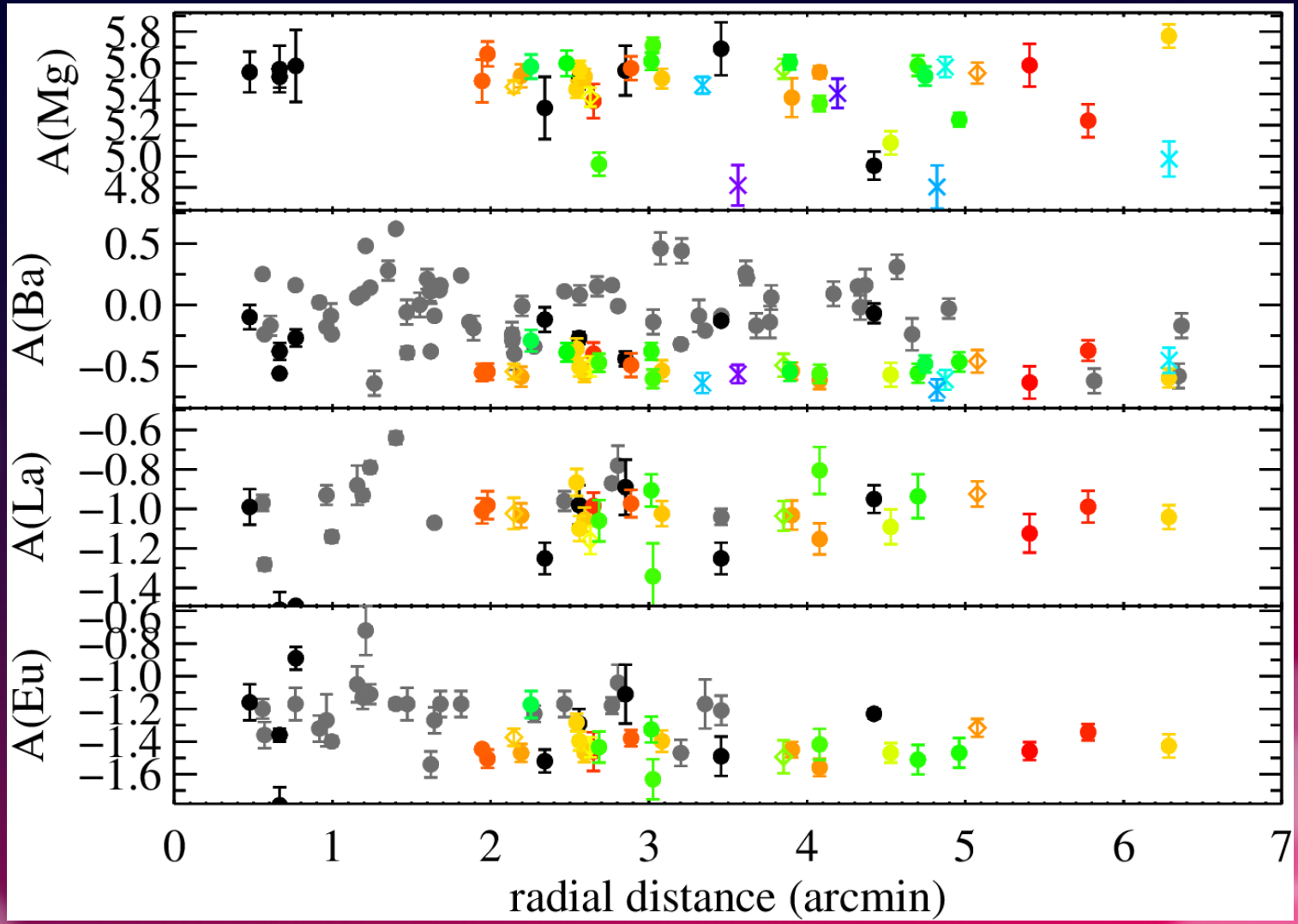


Implication #3:

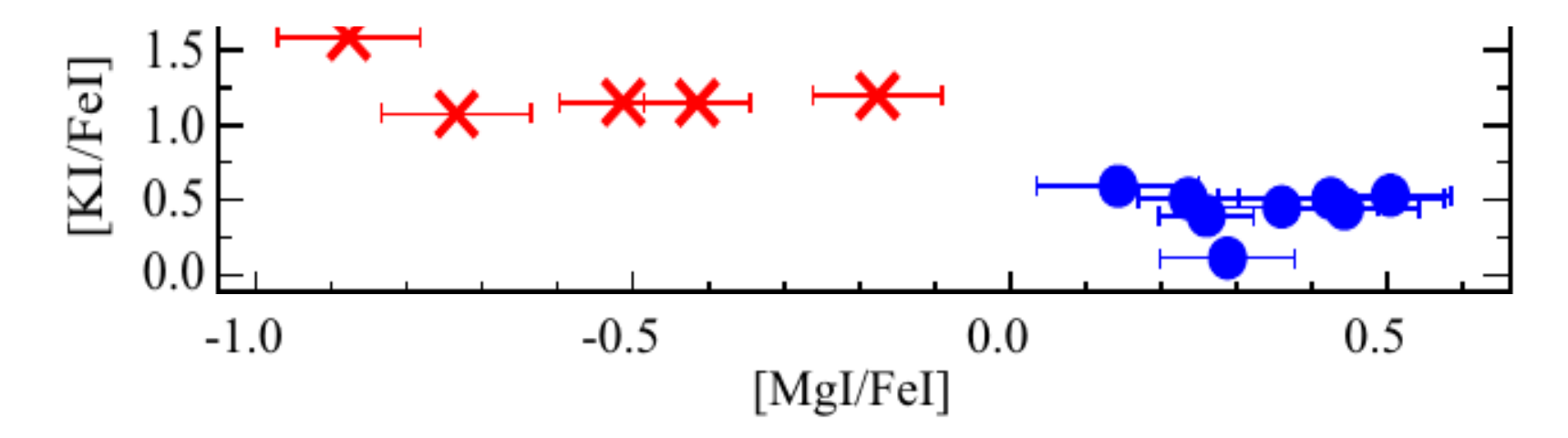
The *r*-process variation in M15 was due to spatial inhomogeneity (>1 dex/pc), not time evolution.

In M92, we might be seeing time evolution.

Abundances do not depend on location in the cluster.

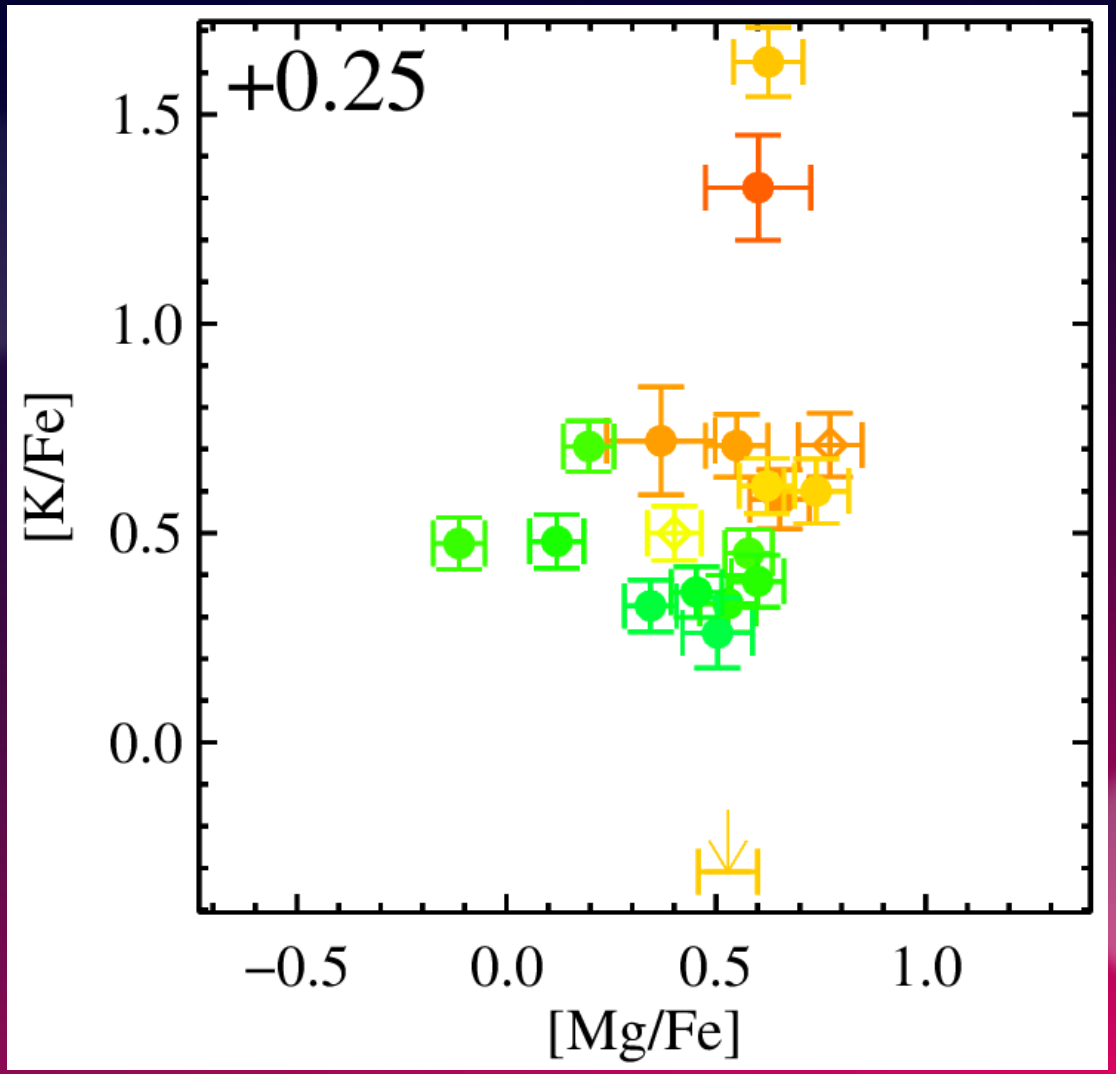


NGC 2419 has a unique potassium signature.

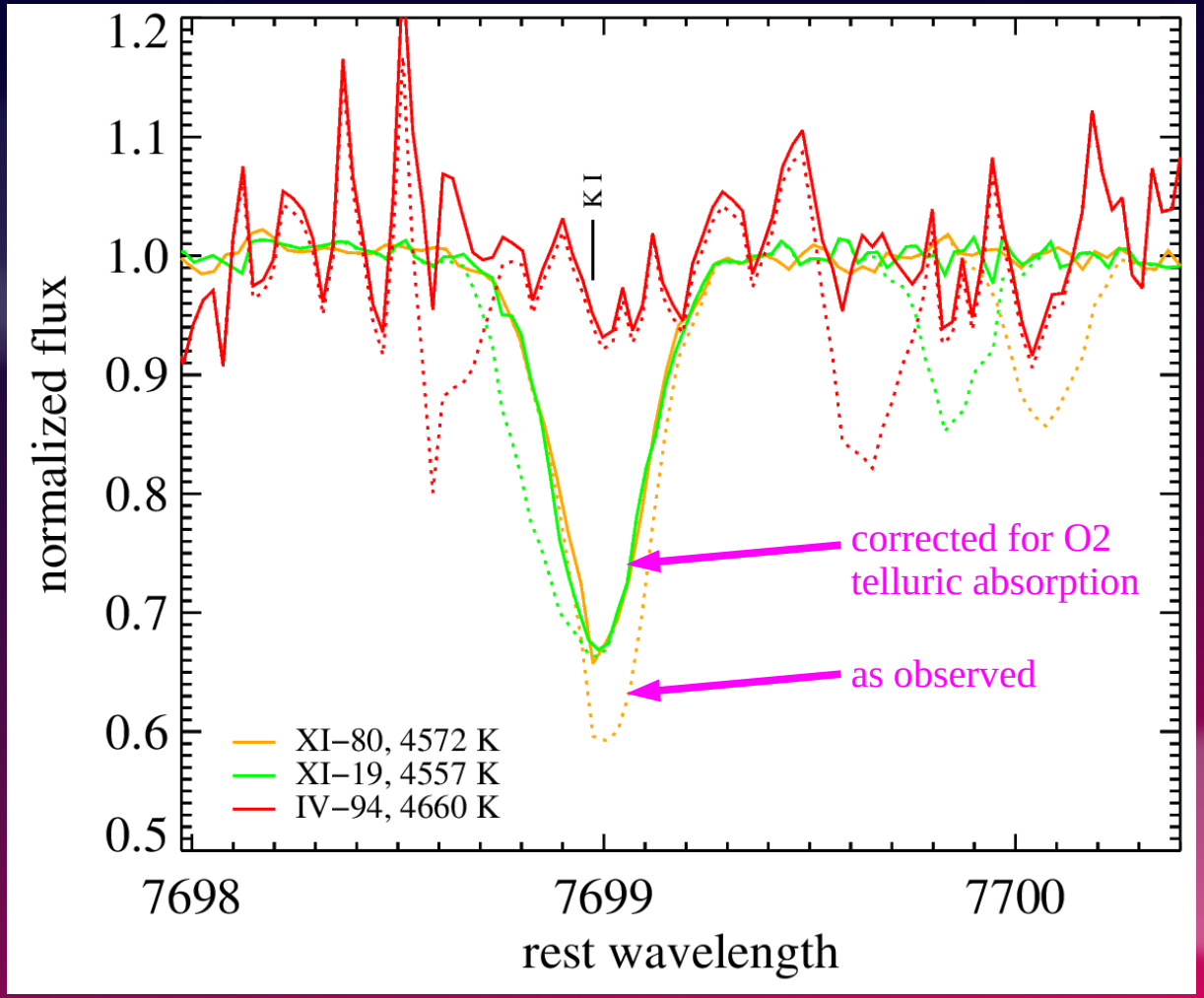


Cohen & Kirby 2012, ApJ, 760, 86

M92 has its own potassium weirdness.



One star is completely devoid of potassium!

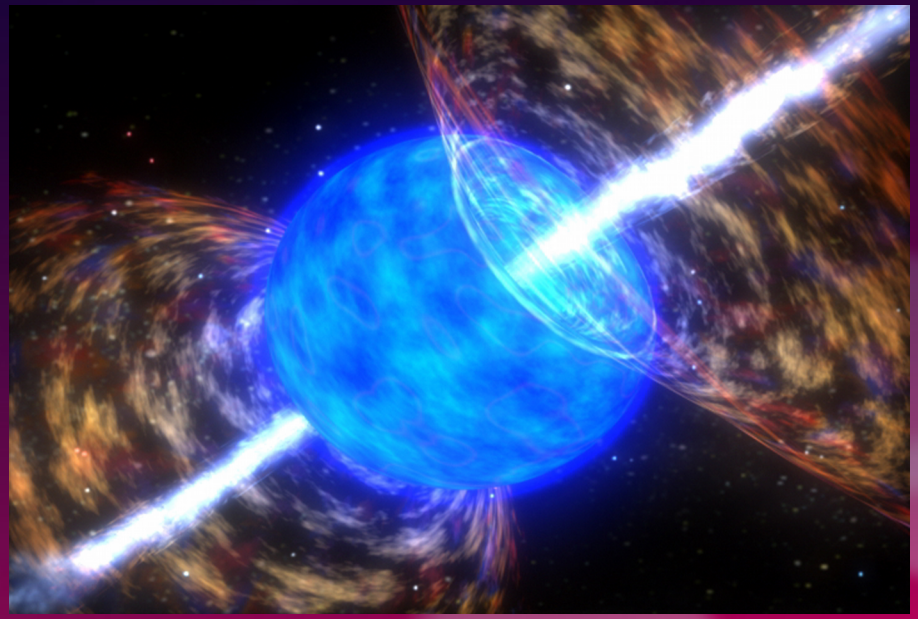


Where does the *r*-process come from?

Neutron star mergers

Sonoma State/NSF/LIGO/Simmonet, ESO/Calcada/Kornmesser
Lattimer & Schramm 1974, 192, 145
Kasen et al. 2017, Nature, 551, 80
+many others

Death of massive stars?

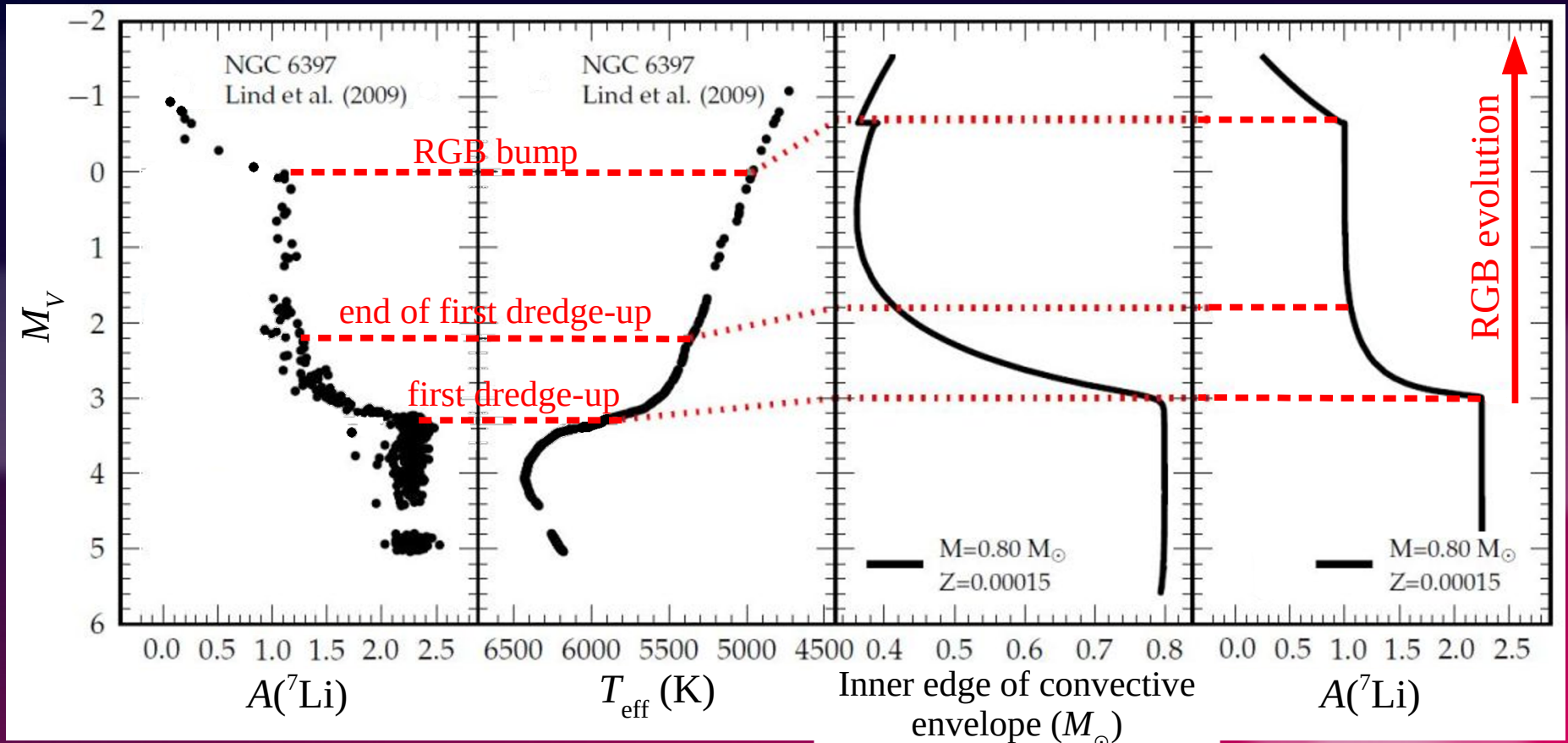


NASA/SkyWorks Digital
Qian & Woosley 1996, ApJ, 471, 331
Siegel, Barnes & Metzger 2019, Nature, 569, 241
+many others

Is the *r*-process in M15 from external pollution?

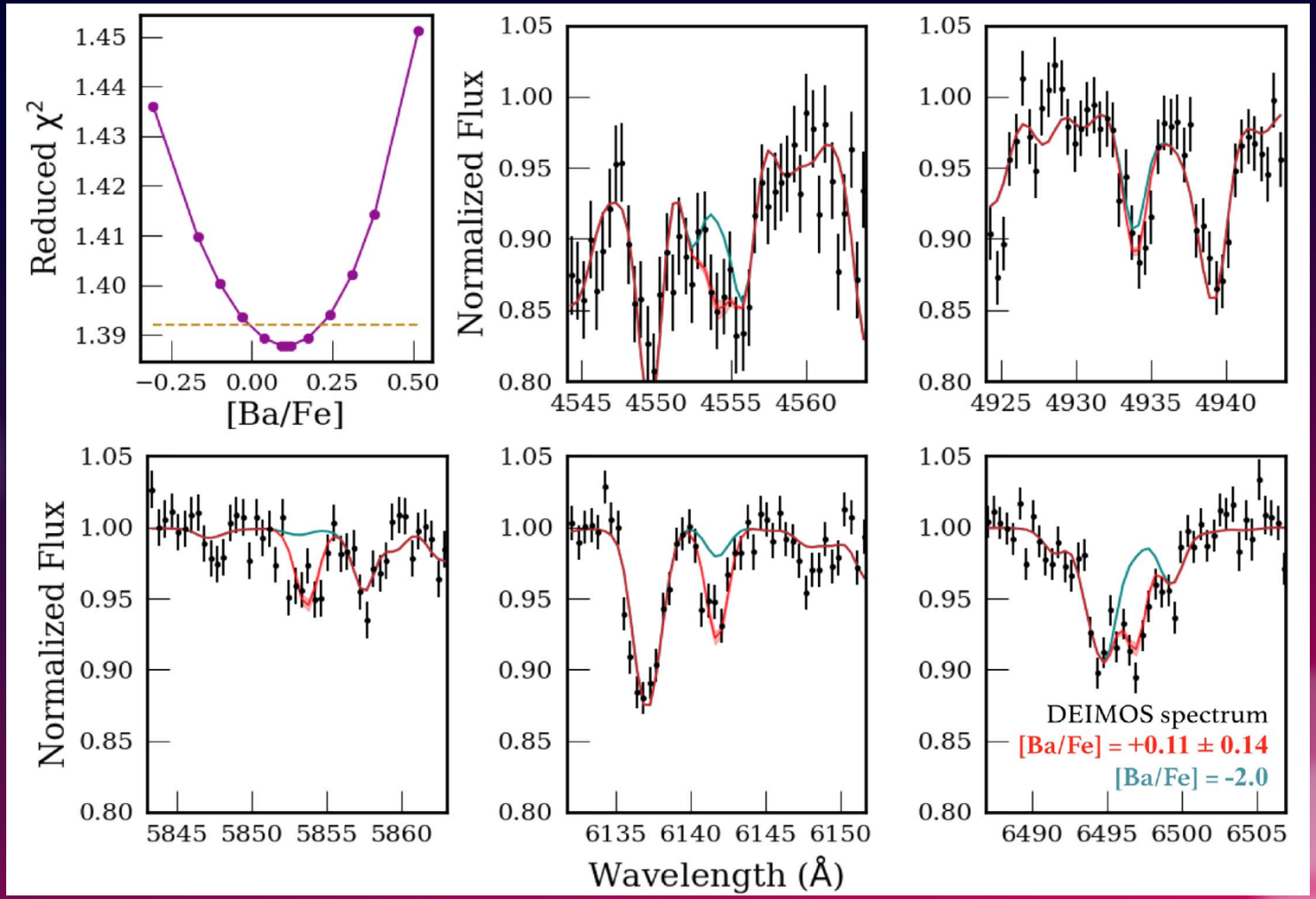
see Tsujimoto & Shigeyama 2014, ApJL, 795, L18

Lithium shows dilution on the RGB.



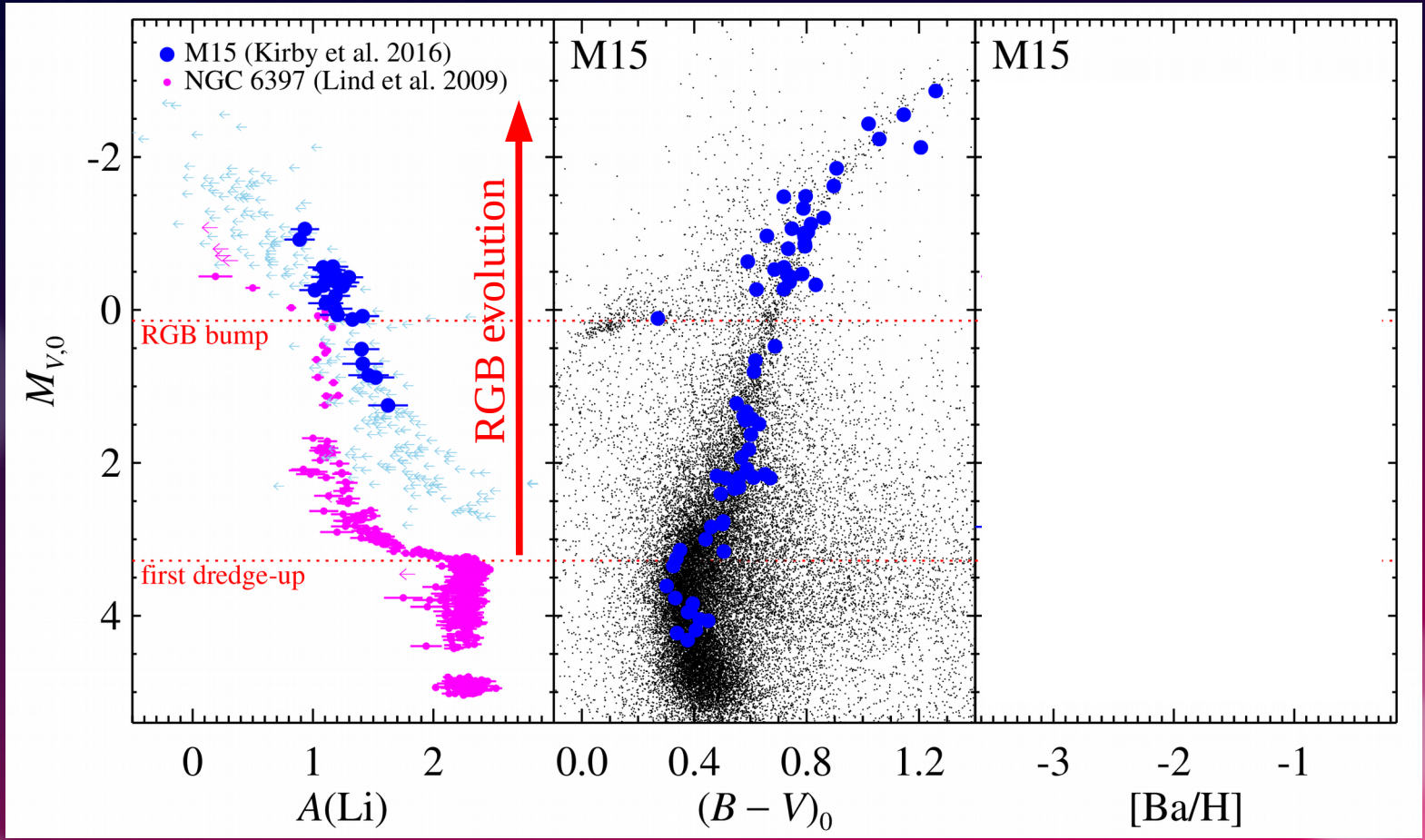
Lind et al. 2009, A&A, 503, 545

We measured Ba in M15 stars down to the main sequence.



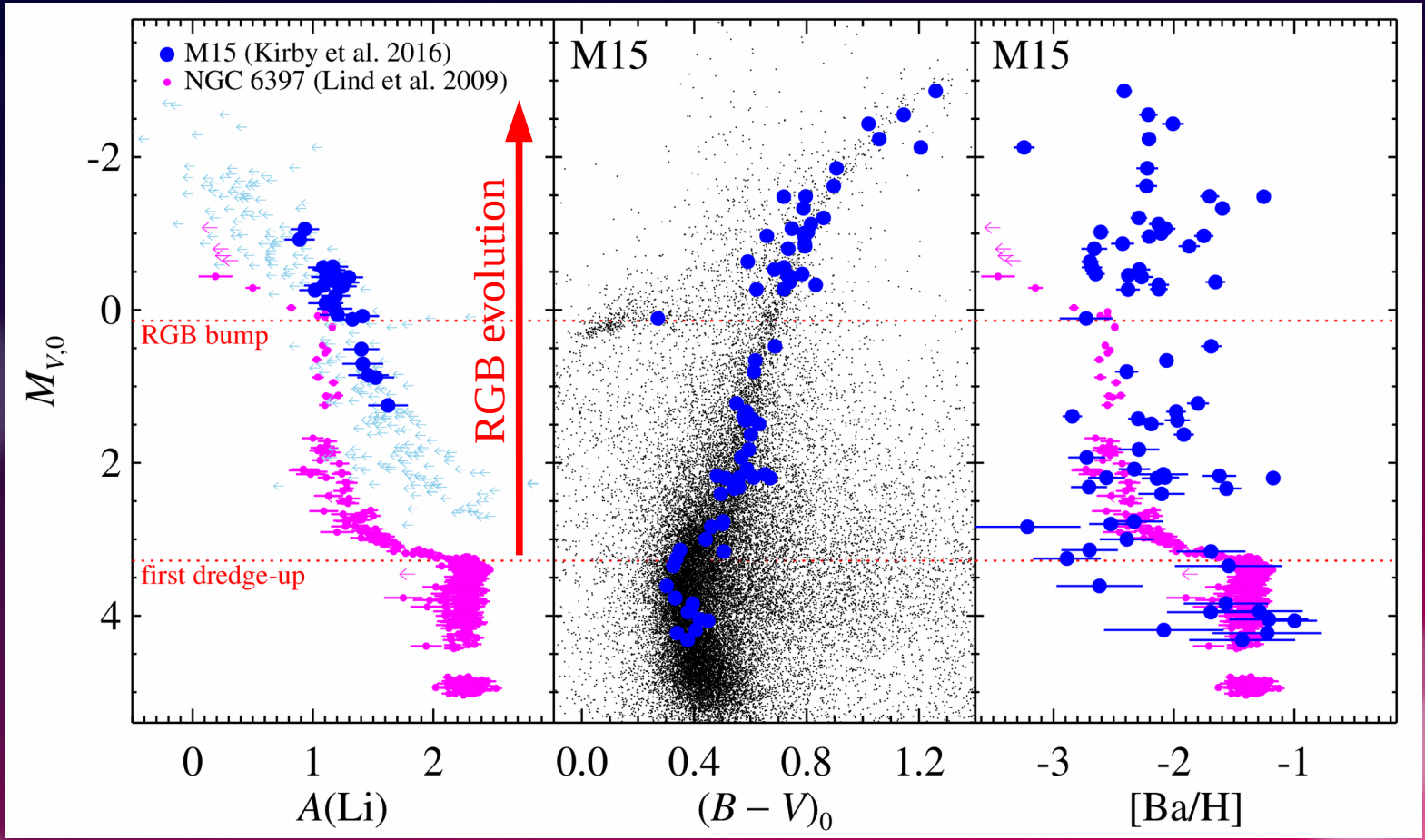
Duggan, Kirby, et al. 2018, ApJ, 869, 50

If Ba was externally polluted, then it should be diluted on the RGB.



Kirby et al. 2020, ApJL, 891, L13

The stars in M15 were born with the *r*-process.



Kirby et al. 2020, ApJL, 891, L13

Conclusions

- M92 (probably?) has a dispersion in *r*-process abundances, but it is less than in M15.
- The stars in M15 were born with their present *r*-process abundances.
- There is some evidence that M92 became well-mixed in the *r*-process late in its formation.
- I do not know anything about globular clusters.