The Chemical Abundance Distribution in NGC 6791: Calibration Cluster for APOGEE

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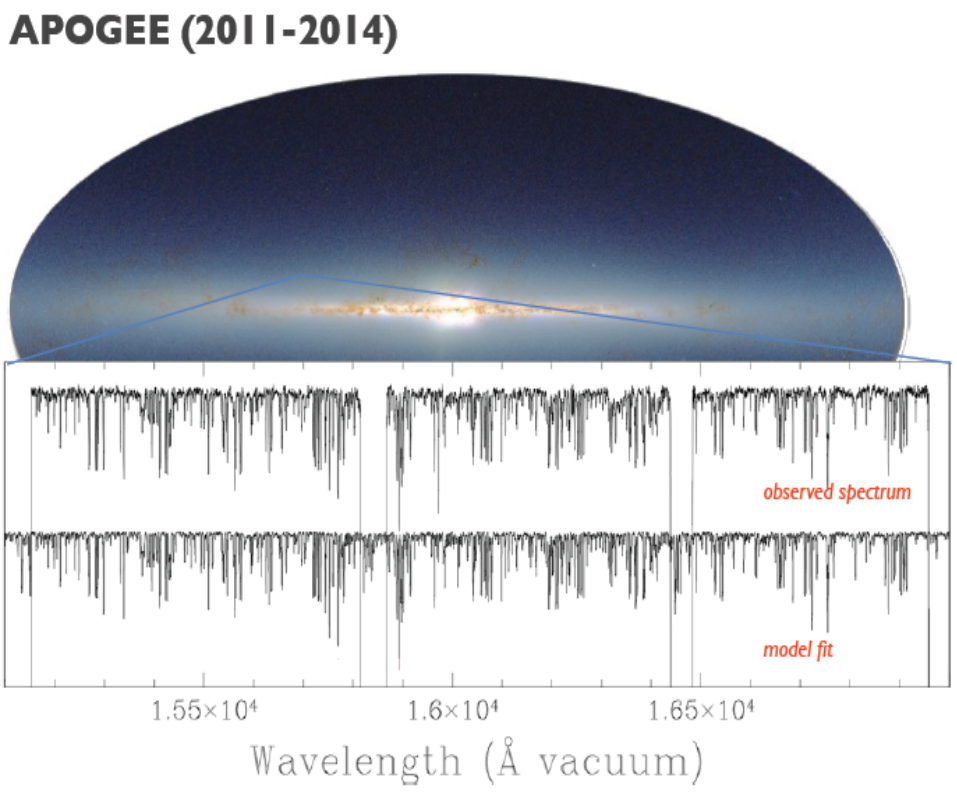
& the **APOGEE Team**

The open cluster NGC 6791 is among the oldest, most massive and metal-rich open clusters in the Galaxy. High-resolution *H*-band spectra from the Apache Point Observatory Galactic Evolution Experiment (APOGEE) of 11 red giants in NGC 6791 are analyzed for their chemical abundances of iron, oxygen, sodium, as well as 12 other elements. The abundances of all elements are found to be homogeneous (with abundance dispersions at the level of ~ 0.05 - 0.07 dex) in these cluster red giants, which span much of the red-giant branch (Teff ~ 3500K - 4600K), and include two red-clump giants. From the infrared spectra, this cluster is confirmed to be among the most metal-rich clusters in the Galaxy (<[Fe/H]> = 0.34 ± 0.06), and is found to have a roughly solar value of [O/Fe] and slightly enhanced [Na/Fe]. The previously reported double population of cluster members with different Na abundances is not found among the studied sample.

The Apache Point Galactic Evolution Experiment

APOGEE: High-resolution infrared spectroscopic survey of the stellar populations of the Galaxy

- Chemical Abundance Survey of the Galaxy reaching regions with high extinction

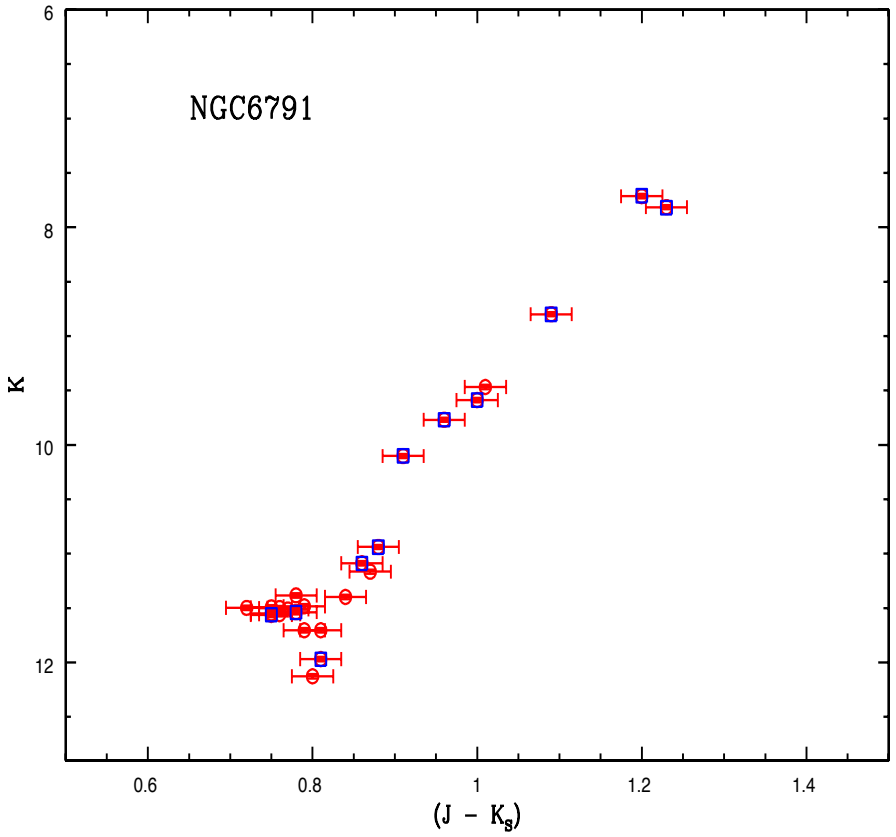


- One of Sloan-III experiments
- 300 fiber, R ~ 22,500, cryogenic spectrograph
- H-band: 1.51-1.68μ
- Typical S/N = 100 @ H=12.5 for 3-hr integration
- Bright time of Sloan telescope between 2011 – 2014
- Over 130,000 2MASS-selected giant stars probing all Galactic pops

NGC 6791 with APOGEE: A good place to start

- The abundance APOGEE pipeline ASPCAP needs to be verified and tested; this requires a manual and 'classical' abundance analysis of stars in calibration clusters.

- **NGC6791**: Calibration cluster at the very high-metallicity end
- Metal-rich and cool giants = hard— good test for ASPCAP + how much we can push the analysis
- Kepler cluster: Synergy with Kepler > More precise parameters for the stars
- Target stars: span the full RGB + 2 clump giants (over-plotted blue boxes on CMD diagram)
- This study of NGC6791 > First Chemical Abundance study with the full suite of elements probed in **APOGEE** data



NGC 6791: A Unique Open Cluster?

Where NGC 6791 resides today:
Roughly 1 kpc from the Galactic plane; above the plane unlike most open cluster population

- First in-depth study by Kinman (1965)
- Very Metal-rich ([Fe/H]~+0.4 dex)
  One of the most metal-rich clusters
- Old - ~8 Gyr and unusually massive (~5000 Msun)
- One of the oldest open clusters in the Galaxy;

Does not easily fit a general Galactic age–metallicity relation given its very old age and very high metallicity

- Both a red clump as well as an extended horizontal branch (Platais et al. 2011; Buzzoni et al. 2012).
- Highly Eccentric Orbit (e~0.6)
- Capture or migration from inner Galaxy?

  - Carraro et al. (2006) –R_{gc} ~ 6-20 kpc; Bedin et al. (2006)
  - Jilkova et al. (2012) > low probabiliy it migrated from the inner Galaxy

- Surviving nucleus of some larger system?
  A captured small galaxy??????

  - Carraro et al. (2006)

A really unique open cluster?

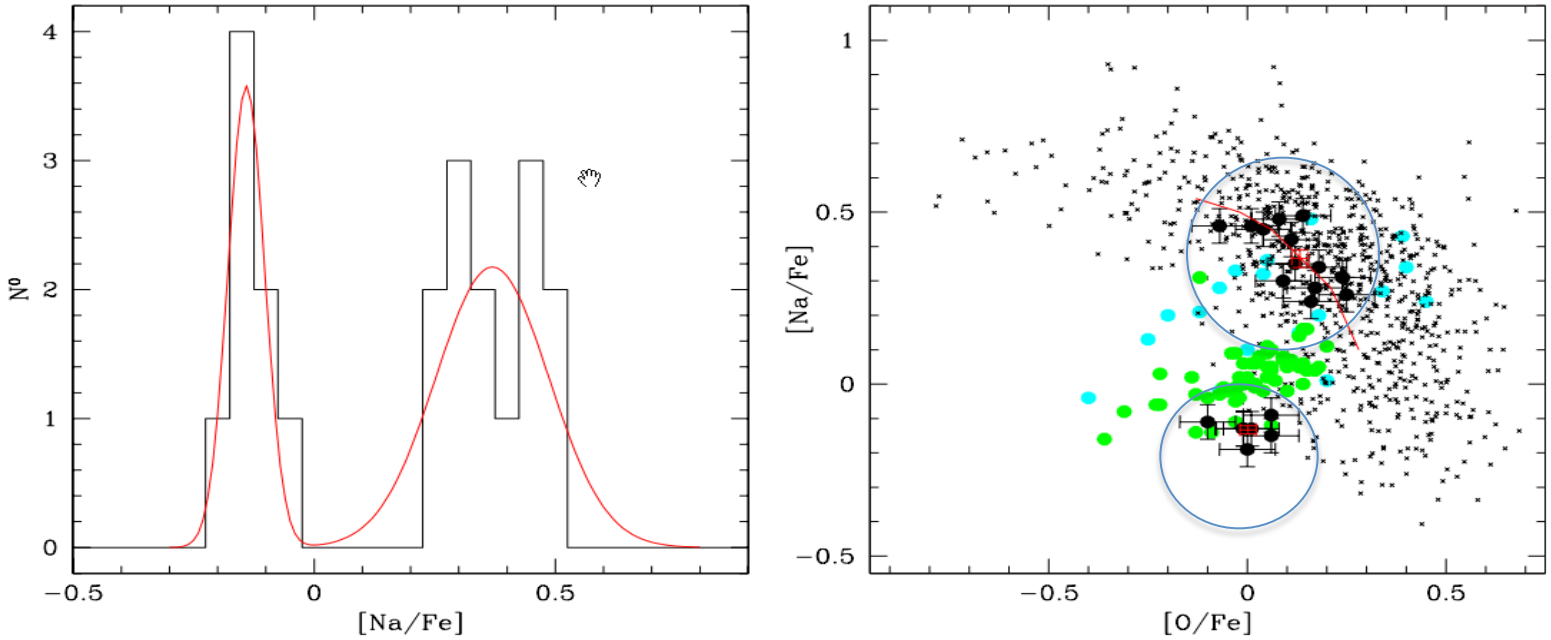
Recent Exciting Results (Geisler et al. 2012):

Two populations in Sodium (@-0.2 and +0.4 dex in Na/Fe)

Completely Unprecedented! for open clusters !

Challenges the hypothesis of OC having single population

(??similarly to multiple populations in globular clusters)???



ure 4. Left: histogram of the [Na/Fe] abundance ratio distribution (lines) with a two-Gaussian fit (curves). Right: [Na/Fe] vs. [O/Fe] for stars in NGC 67
les with error bars), GC stars (crosses), metal-rich ([Fe/H] > −0.2) field stars (green filled circles), and the means for OCs from De Silva et al. (2009) (b
les). The mean GC anticorrelation is shown by the red curve.

color version of this figure is available in the online journal.)

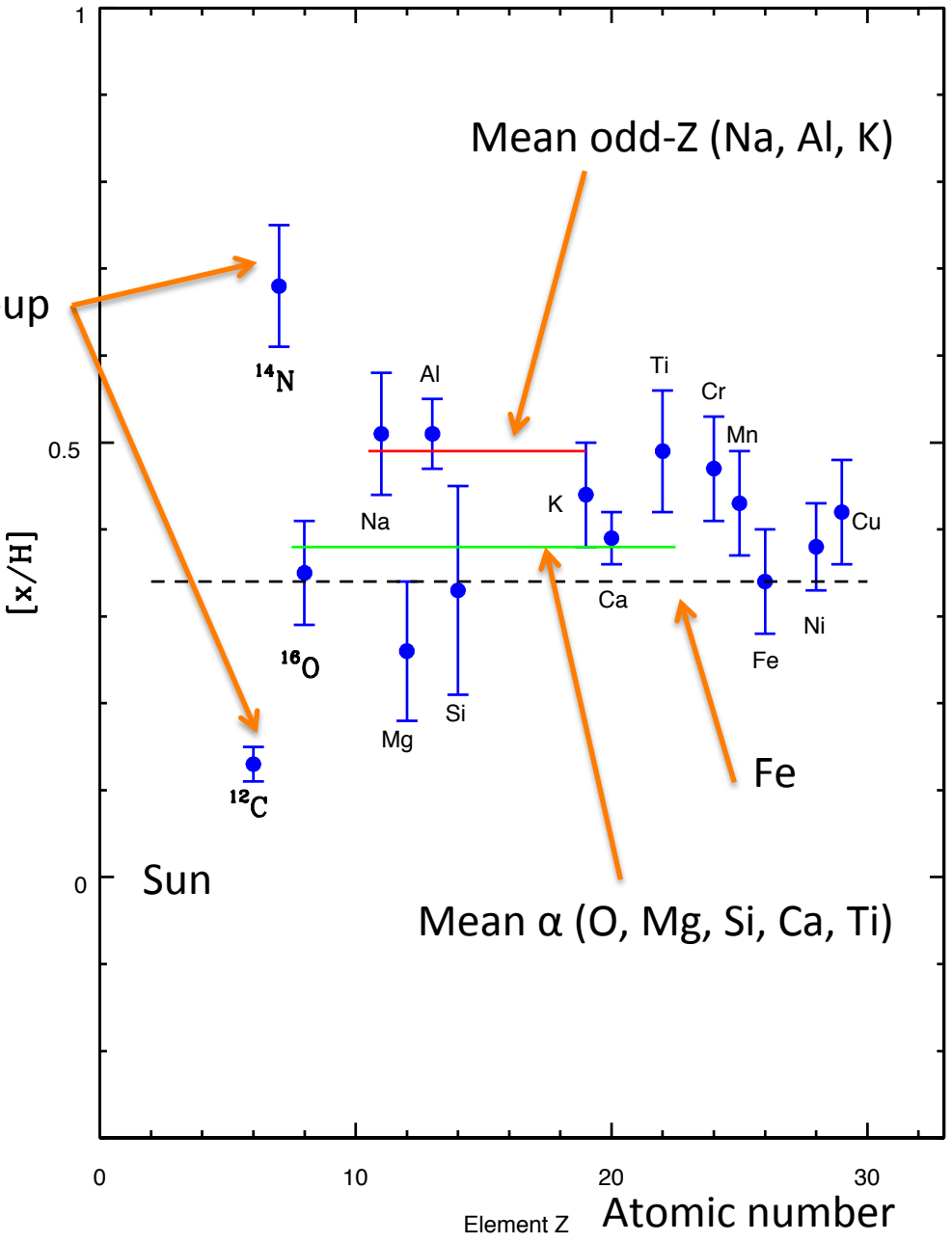
NGC6791 with APOGEE

- Sample: 11 cluster members targeted by APOGEE (Frinchaboy et al. 2013, Zasowski et al. 2013, Johnson et al.)
- APOGEE spectra: Pipeline reduced DR10 (Nidever, Holtzman et al.)
- Spectroscopic Analysis: Standard in 1-D LTE
- Spectrum Synthesis of 14 elements covered in the APOGEE spectral range: C, N, O, Al, Mg, Si, K, Ca, Ti, Cr, Mn, Na, Ni and Cu
- Synthesis code: MOOG + Kurucz Models for solar scaled metallicities (Meszaros, Allende Prietro et al. 2012)
- Line list: ASPCAP line list (Shetrone, Bizyaev et al. in preparation)
- Teff : Used an average of 2 calibrations: Bessell et al. (1998); Garcia Hernandez & Bonifacio (2009)
- Log g: Used the distances from the astereoseismology study by Basu et al. (2011) and the bolometric corrections from Bessel et al. (1998) and used the RGM mass from Basu et al. (2011) M=1.2 Msun

Results:

Takeaway Chemistry

- Cluster is chemically **homogenous** to the level ~0.06 dex (star-to-star scatter)
- Very metal-rich [Fe/H]=+0.34 +/- 0.06 (black dashed line)
- Clear signature of 1st dredge-up (^{12}C & ^{14}N - CN cycling)
- [α/H] not enhanced relative to [Fe/H]; Solar scaled [α /Fe] (O, Mg, Si, Ca, Ti —green line)
- Slight enhancement of odd-Z light elements (Na, Al, K) relative to Fe —metallicity dependent yields from SN II
- Fe- Peak elements not clear that it is different from Fe at this point;



Using 28 APOGEE Open Clusters to Map Gradients

NGC 6791

- Average gradient:
  -0.09 +-0.03 dex/kpc
- Perhaps not inconsistent with a change of slope at

~10 kpc

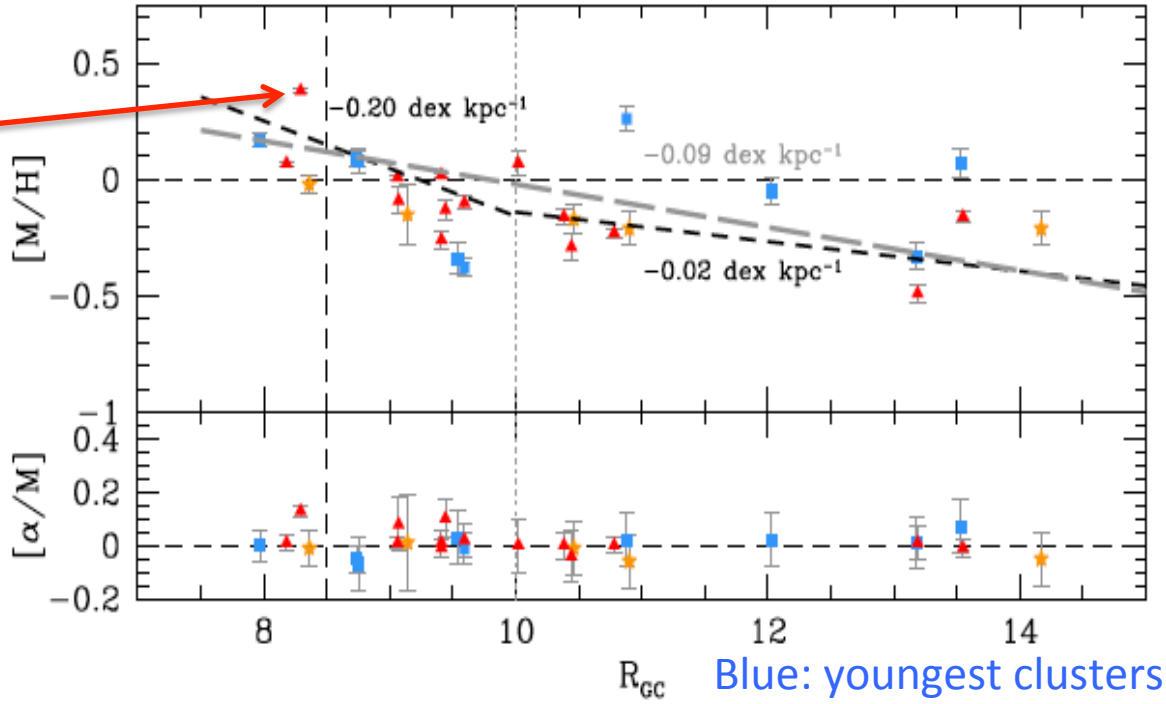
- Decreasing metallicity to

~ 10 Kpc + Plateau [Fe/H] ~ -0.4

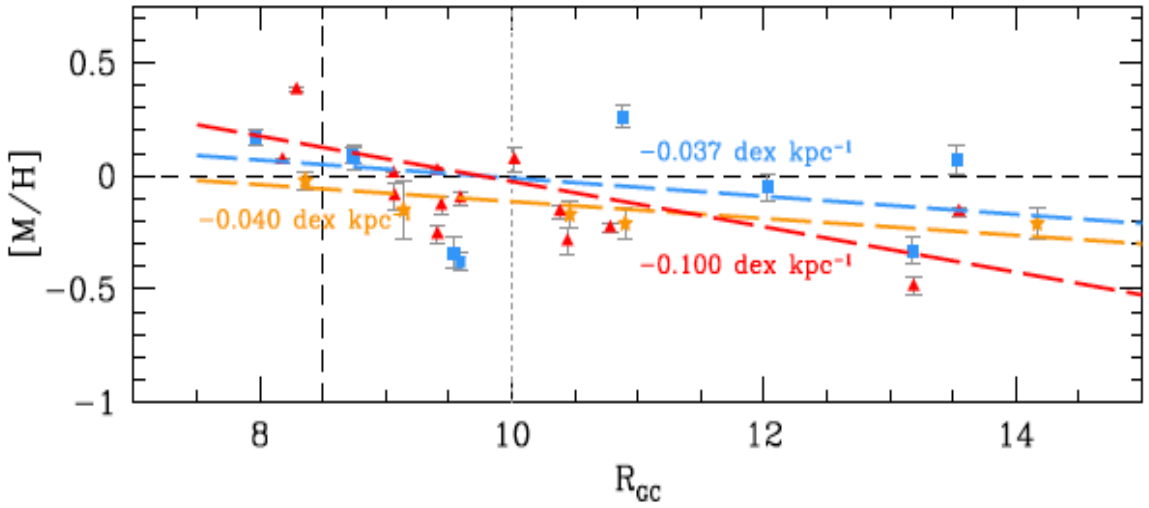
Gradients as a function of age

- Flattening with time? Looks like it…possibly but need more data (coming…)
- Oldest pops: -0.1 dex/kpc
- Youngest pops: ~ -0.04 dex/kpc

ASPCAP RESULTS
Frinchaboy et al. (2013)

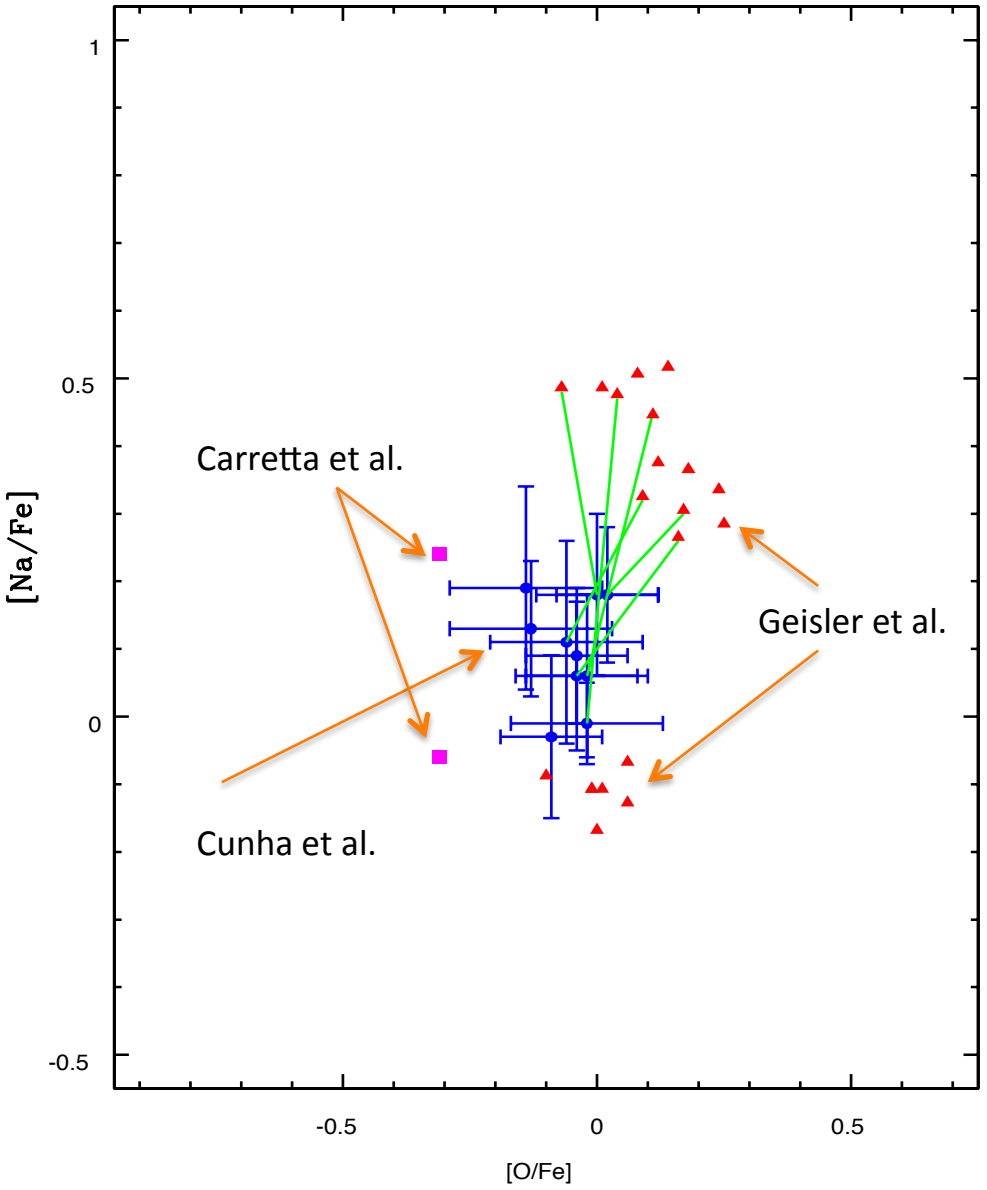


Blue: youngest clusters
Red: oldest clusters



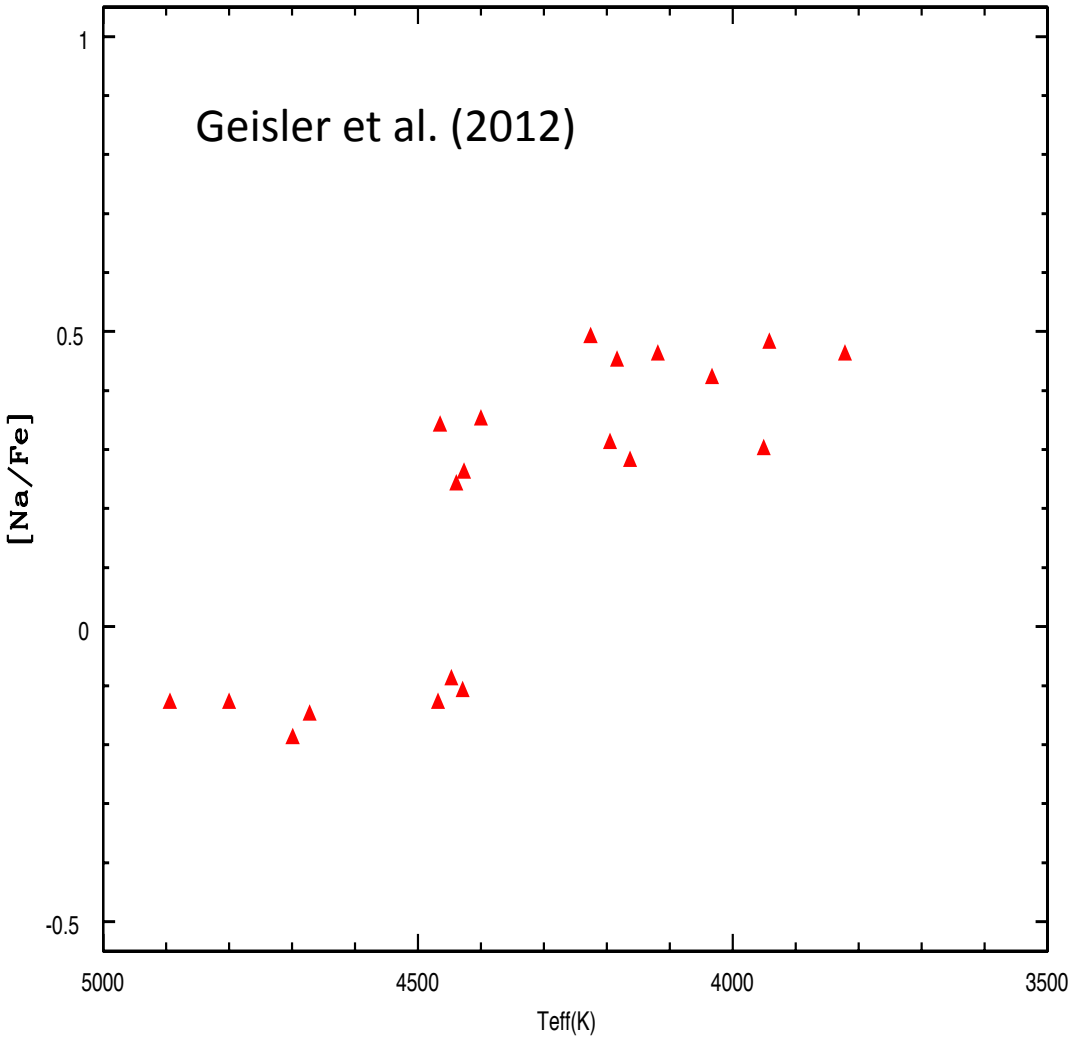
Focus on Sodium and Oxygen in NGC 6791

- Comparison of [Na/Fe] and [O/Fe]
- We find a single Na population consistent within our uncertainties
- Our Na abundance results fall ~ in the middle of Geisler et al.'s two populations
- Green lines connect stars in common in the two studies
- Very few studies have both Na & O…
- Caretta et al. (2007) study has only 2 stars… fall roughly within our Na abundance distribution …



Strong T_{eff} Dependence: not expected

- Take away point may be that at [Fe/H] ~+0.4 Na in the optical is difficult
- They use: Na I lines 6154A and 6160A > affected by CN. Could be the problem?
- Although blending in the H-band is an issue, seems to be even worse in the optical (?)
- APOGEE well positioned to tackle the metal-rich populations of the inner Galaxy/bulge/center



Conclusions & the Future

- We have presented chemical abundances for a sample of stars in the unique cluster NGC6791
  Caution: results are for a 1-D LTE analysis; no discussion on the uncertainties

- These are the first measurements of the abundances of 15 chemical elements from APOGEE observations

- We find NGC 6791 to have [Fe/H]= +0.34 +/- 0.06 confirming that it is very metal rich with small scatter

- We do not confirm the two Na populations found in Geisler et al. (2012)

- The trends of the abundances with metallicities generally stay closer to solar for most elements with the largest offsets (~0.1 dex) for Na, Al and K.

- But these are preliminary results; stay tuned…. LOTS OF WORK TO DO!

- APOGEE well positioned to tackle the metal-rich populations of the inner Galaxy/ bulge/center + APOGEE2