Globular cluster stars in the Galactic halo

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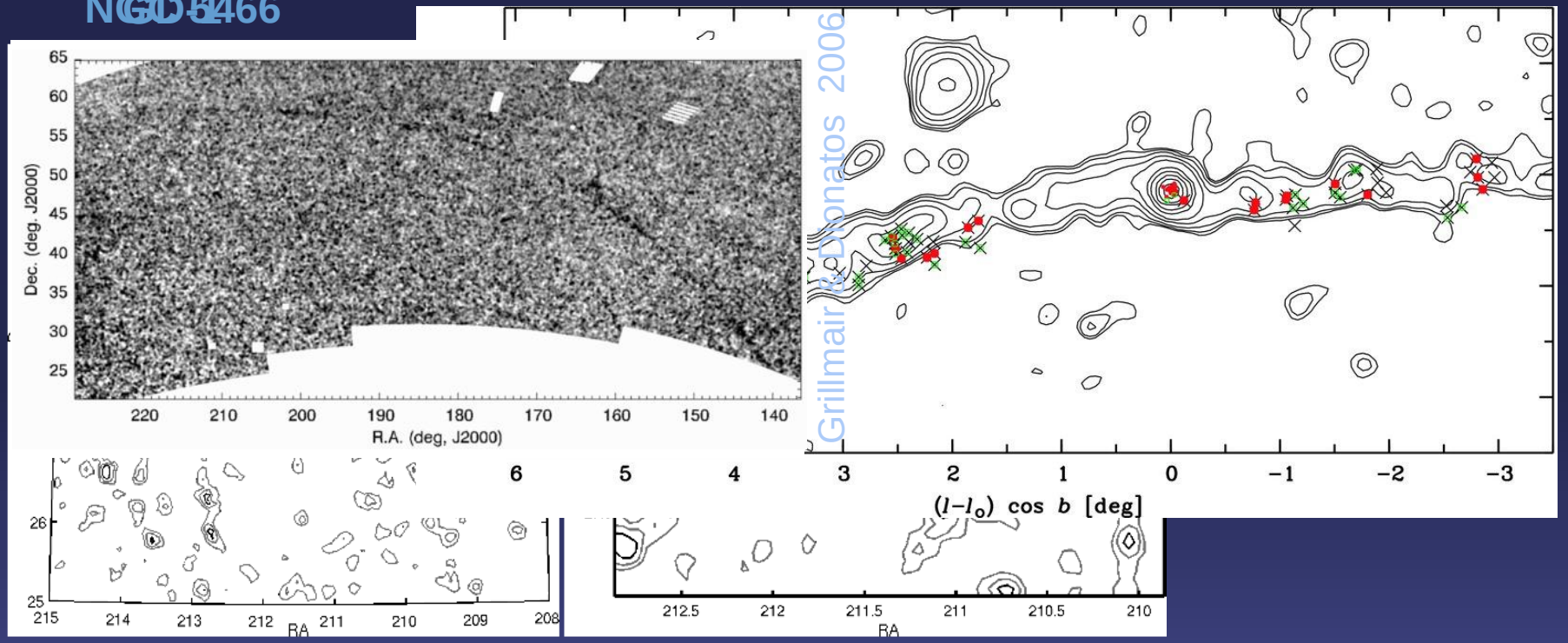
The starting point

- Globular clusters dissolve

NGC 5466

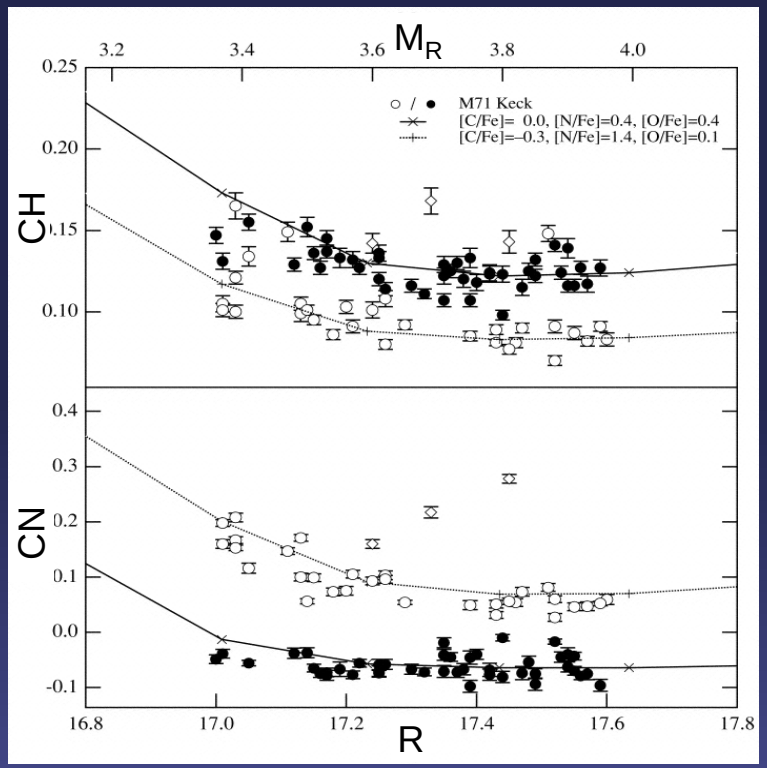


Grillmair & Dionatos 2006

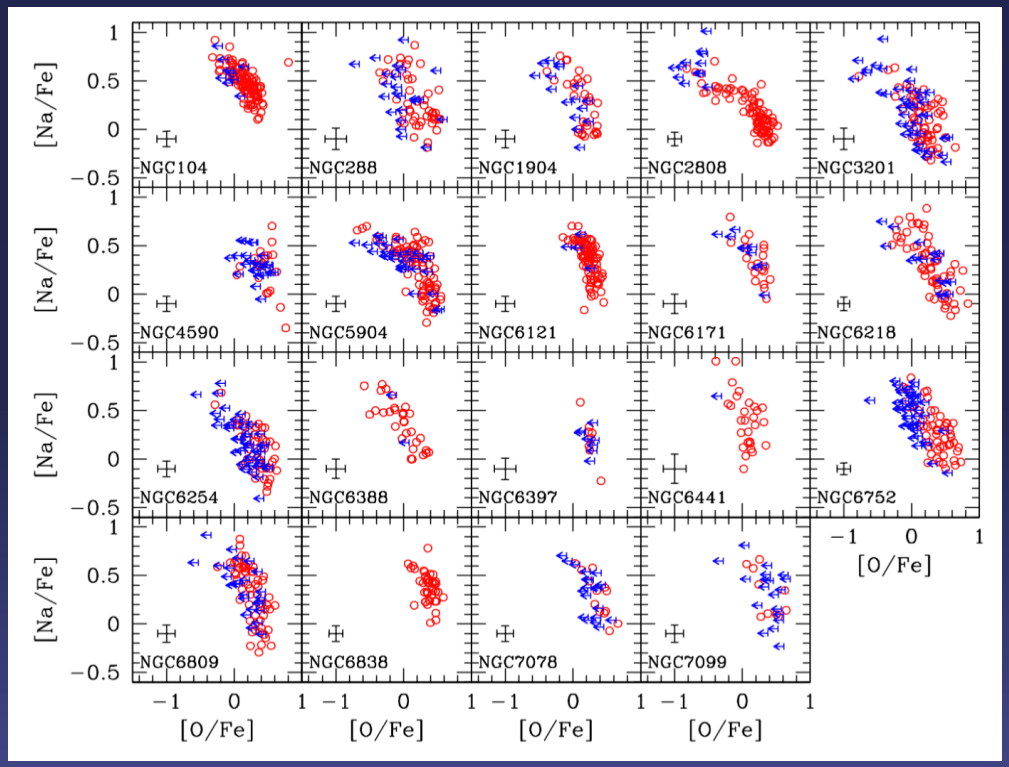
Odenkirchen et al. 2003

What's the signal?

- Unique but universal GC abundance pattern
  - He N Na Al,Si
    C O,F Mg



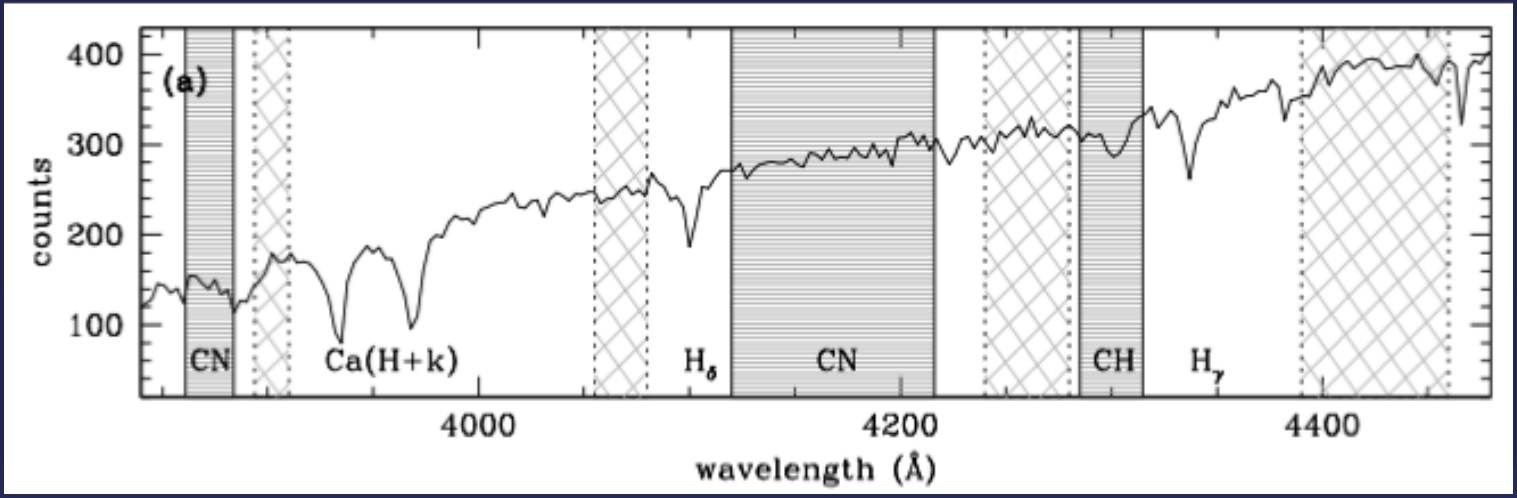
Briley & Cohen 2001



Carretta et al. 2009

The initial project

- Look for CN-strong field stars



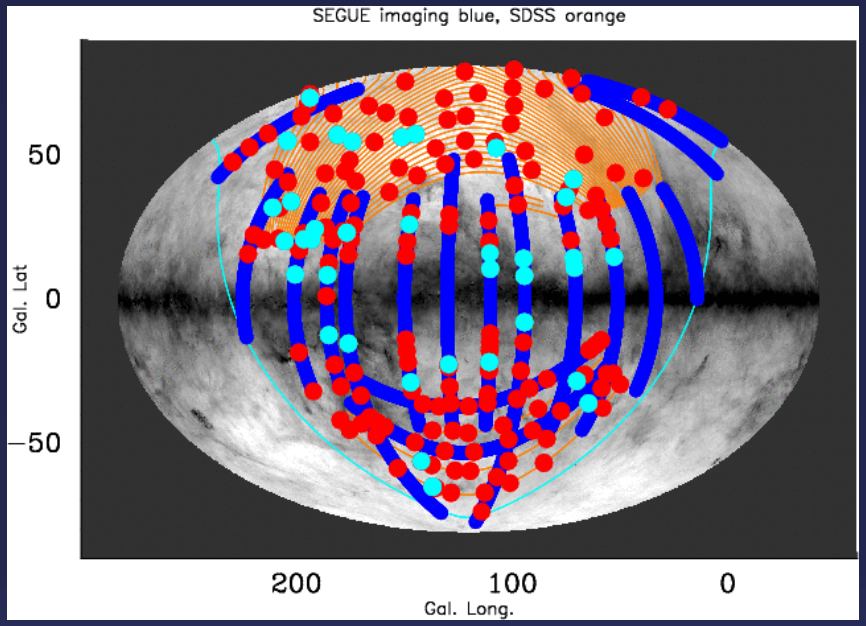
Lardo et al. 2012

Most likely to succeed?

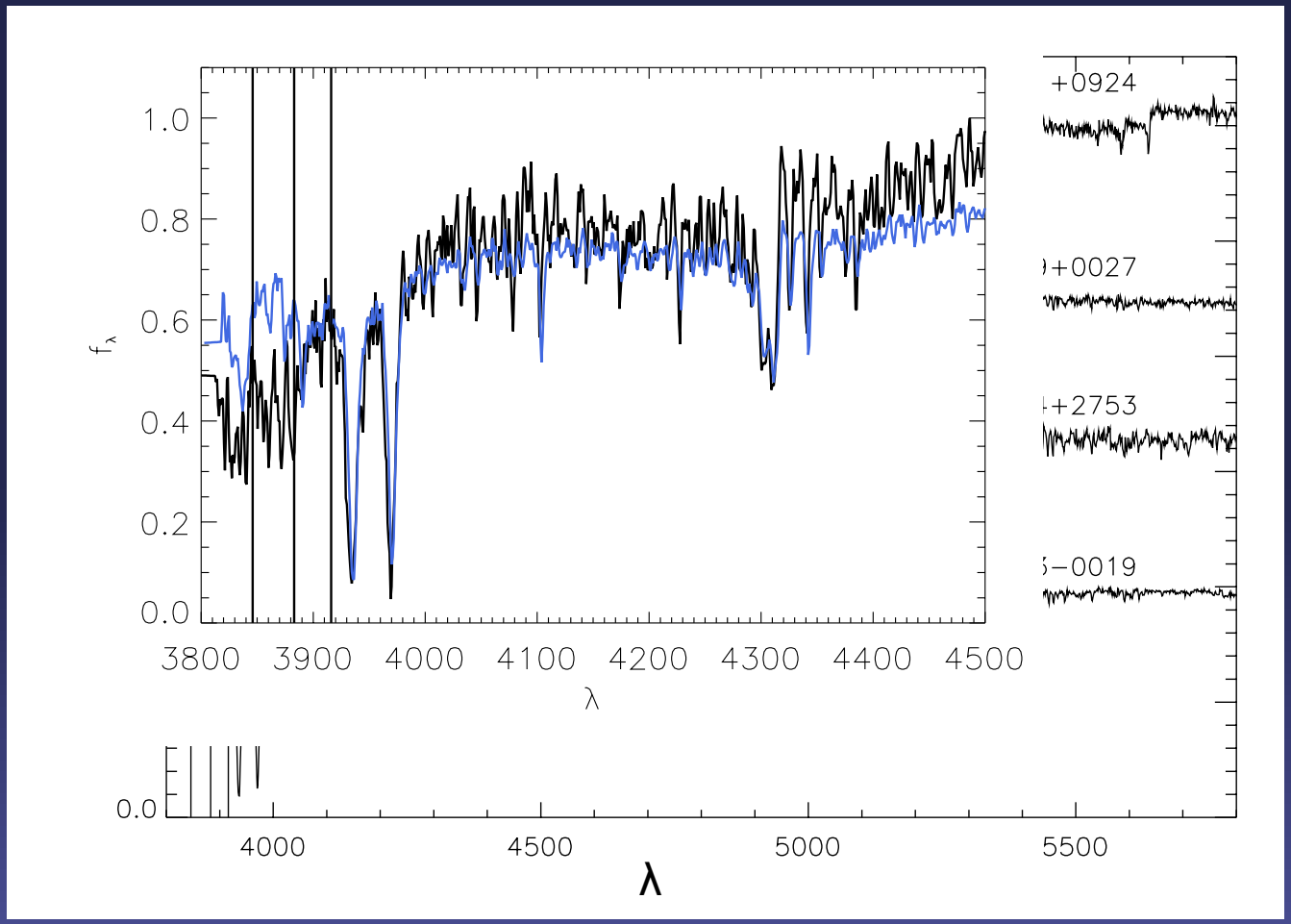
- Not really, at the start
  - Previous searches had not found any cluster-like stars in the field
    - Pilachowski et al. 1996, Gratton et al. 2000
  - Method was hopelessly inefficient
    - Side project during thesis observing

SDSS changes everything

- SEGUE: Spectroscopic extension of the SDSS, targeted at specific stellar populations
  - Low-metallicity stars
  - BHB stars
  - G, K dwarfs
  - K giants
- 640-fiber spectrograph, 7 deg^2 field of view, R~2000, broad wavelength coverage
  - 360,000 stars



Looking at the data



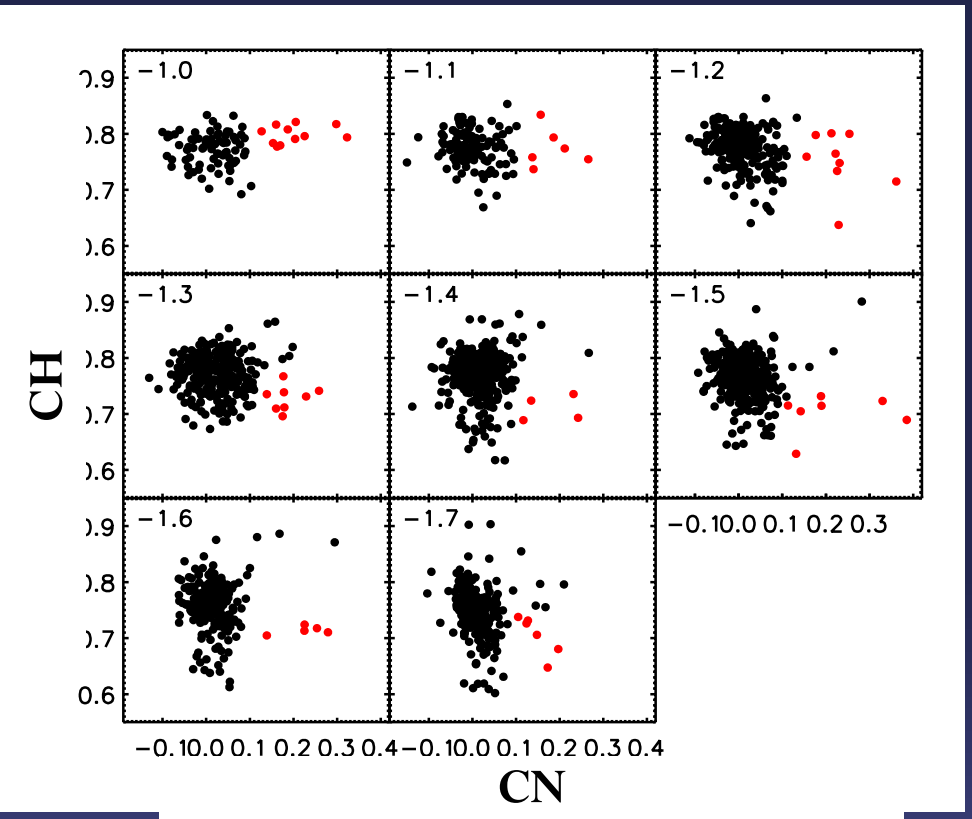
Carbon star

CEMP star

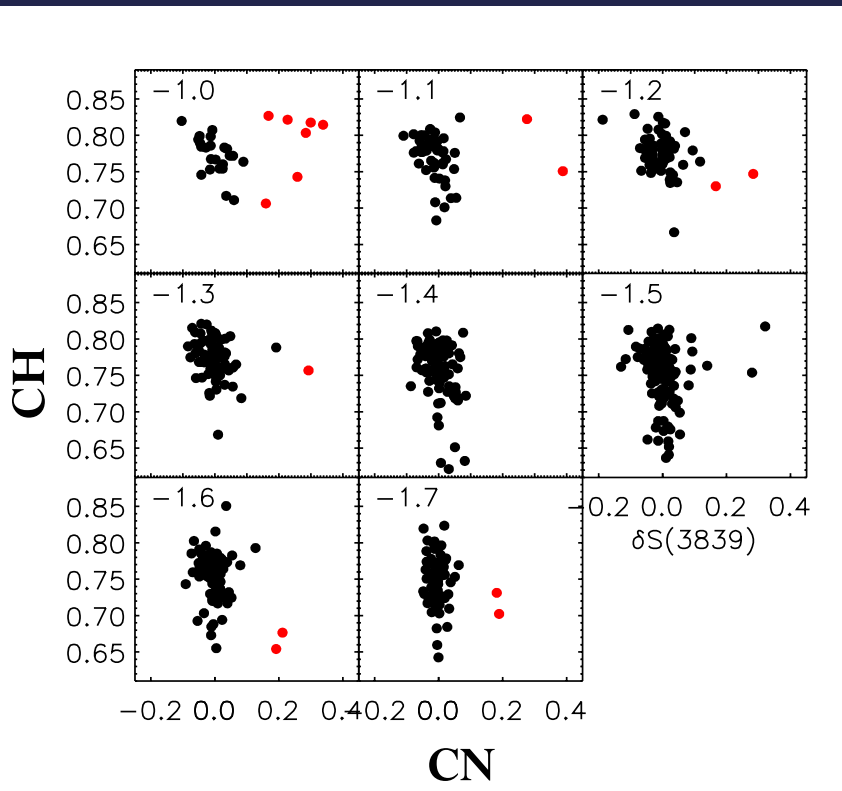
CN-strong star

Typical halo star

“Chemical tag” of GC formation



Martell & Grebel 2010



Martell et al. 2011

“Chemical tag” of GC formation

- Carretta et al. 2010
  - Collected literature data for halo+thick disk+bulge stars, found six with high [Na/Fe]
- Ramirez et al. 2012
  - Collected spectra for low-α dwarfs from Nissen & Schuster halo sample, found 2/67 with low [O/Fe] and high [Na/Fe]

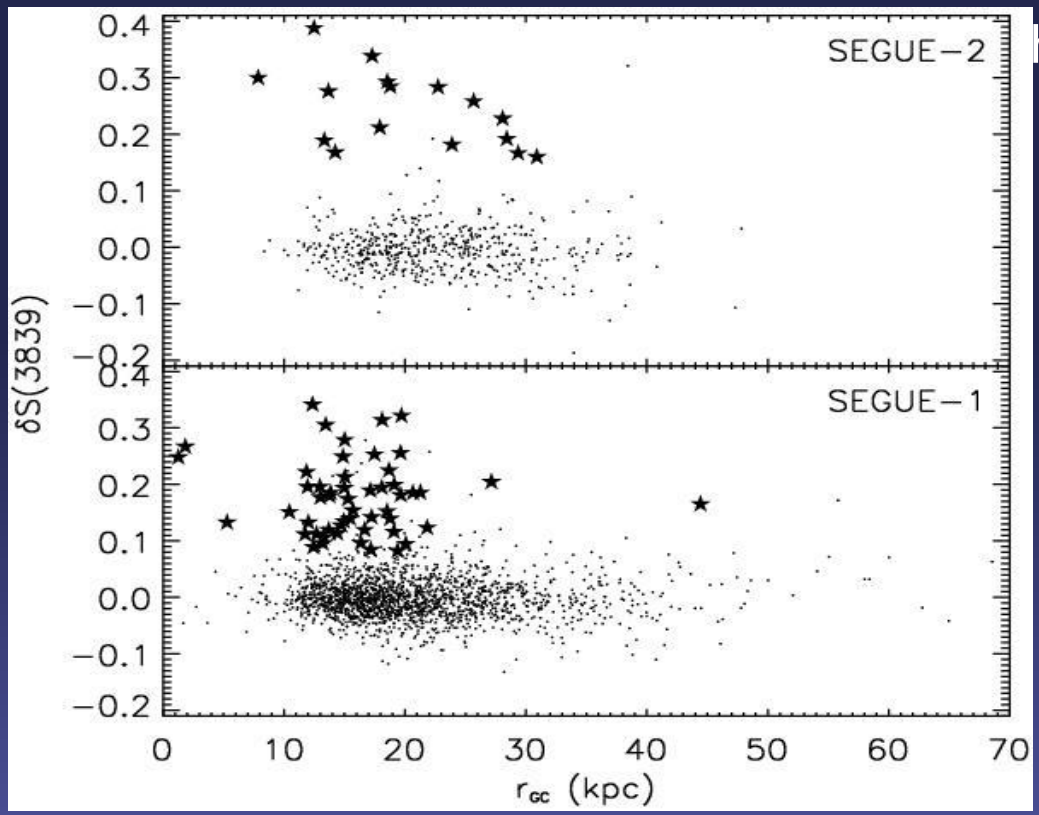
First interesting thing

- What fraction of halo stars formed in globular clusters?
  - Cluster formation process
  - How stars were transferred from clusters to the field
  - If CN-strong stars in the field are from completely dissolved clusters and the initial/final mass ratio is 10:
    - At least 17% of halo stars formed in globular clusters
    - That's a minimum: we can't observe stars from clusters that didn't self-enrich

Recent interesting thing

- Look at the orbits
  - We noticed that the CN-strong stars had a smaller typical distance from the Galactic center

halo population (cf. Carollo



Martell et al. 2011

Terminology!

- “Inner/outer halo population” versus “inner/outer halo region”
- Definitions based on orbits/based on present positions, with significant overlap

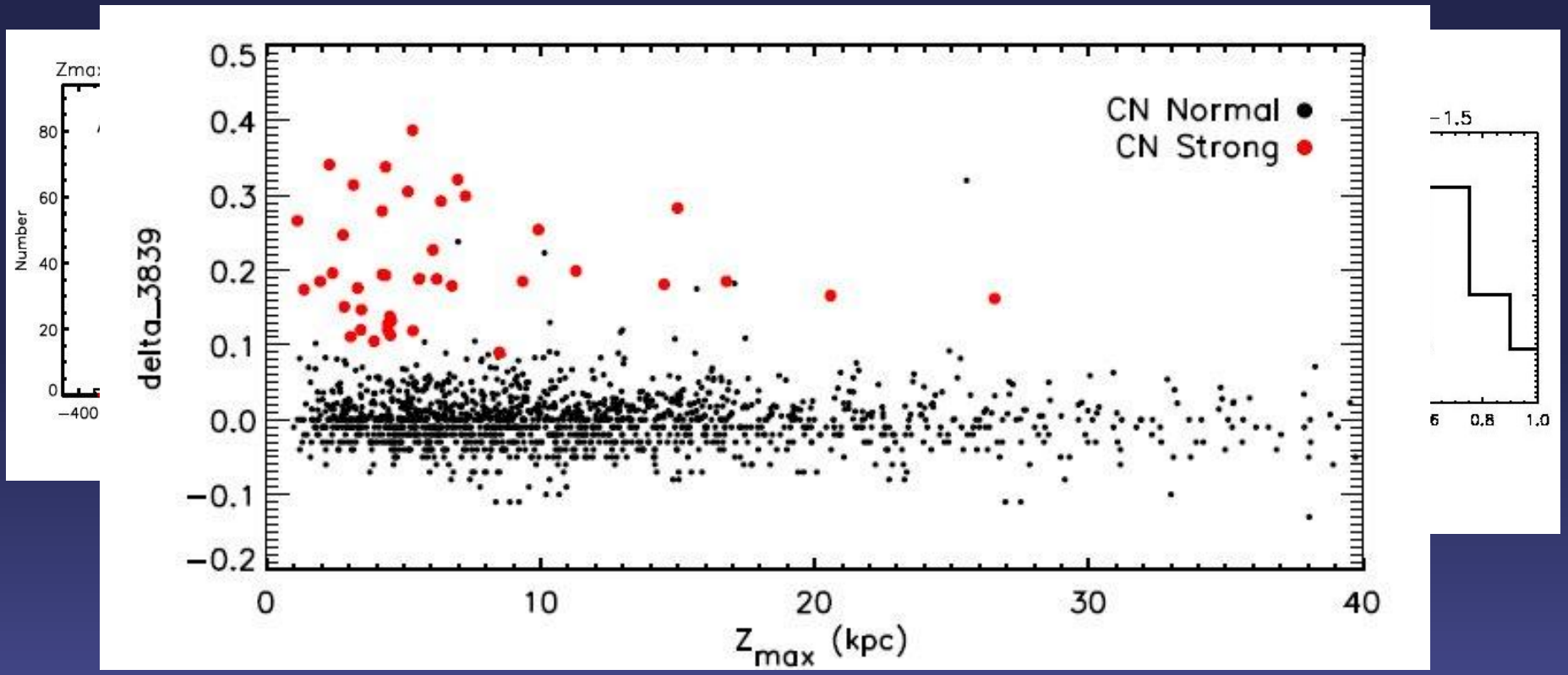
IHP: MDF peaked at [Fe/H] ~ -1.6, mainly located within ~20 kpc
IHR: located between 5 and 15-20 kpc, where the IHP dominates at -2< [Fe/H] < -1

OHP: MDF peaked at [Fe/H] ~ -2.2, mainly located beyond ~20 kpc
OHR: located beyond 20 kpc, where OHP dominates at [Fe/H] < -2.0

- This is useful when thinking about halo assembly
  - Indicates separate formation processes – cosmological origin
  - Numerical work by Tissera et al. 2013, Font et al. 2011

Look at the orbits

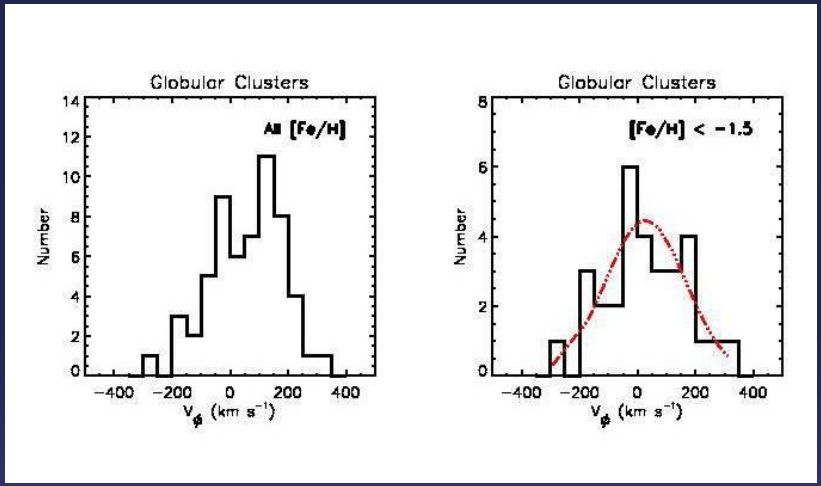
- Z_{max}, rotational velocity, eccentricity match well to inner halo

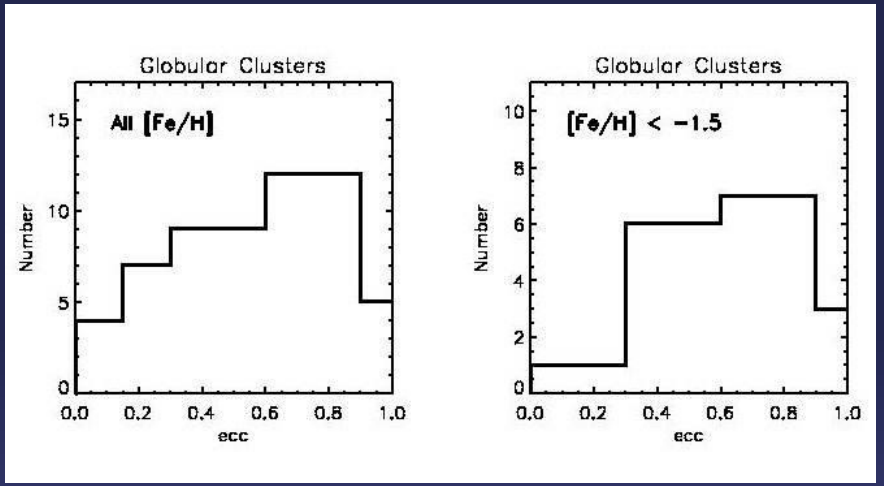


Carollo, SLM et al. 2013

Look at the orbits of GCs

- Clusters with proper motions from Cassetti-Dinescu, [Fe/H]<-1.5 (to match the field stars)





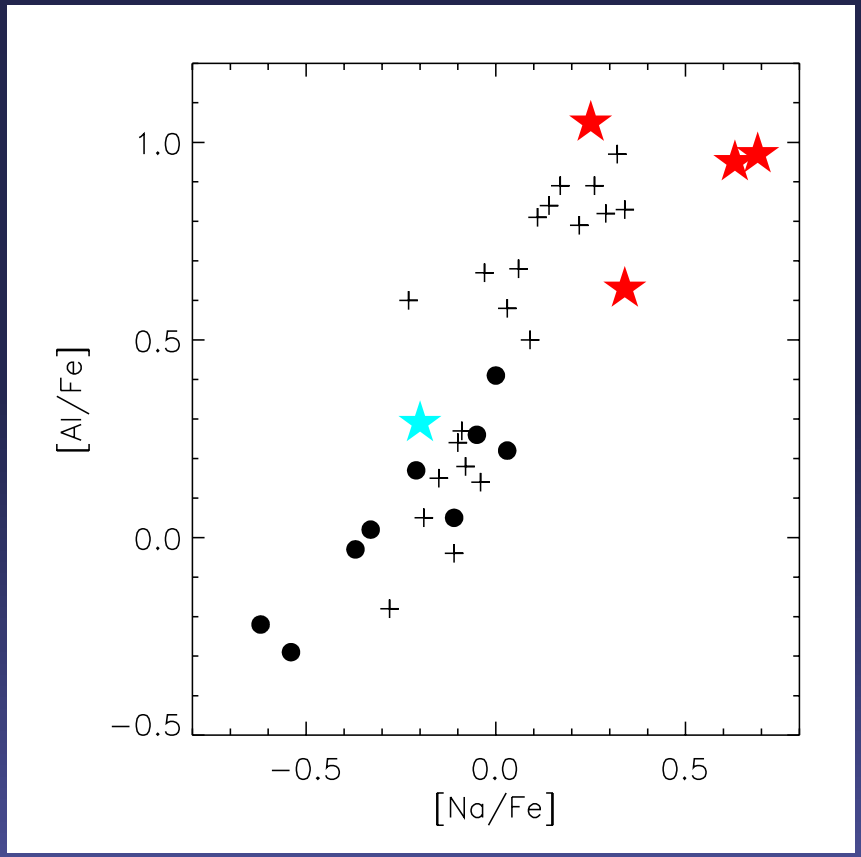
- Also consistent with inner halo population

Next interesting thing

- Double-check the chemistry
  - We assume that the O-Na pattern follows the C-N pattern, but typically can't check
    - Different reactions: CNO (>20 MK), NeNa (>35 MK), MgAl (>50 MK) cycles
    - Mg-Al doesn't always follow (Bastian et al. 2013)

Chemistry check

- High-resolution followup on CN-strong field stars (with M. Shetrone, D. Lai)
  - 24 CN-strong stars plus 16 CN-normal "control" stars observed at HET, plus 5 at Keck
  - Preliminary analysis: as expected
  - Full abundance analysis nearly complete



Chemistry check

- Working in the other direction (with S. Campbell, J. Simpson)
  - Low-resolution spe
    [N/Fe] for stars with
  - Ongoing: no conclu
  - I would guess that