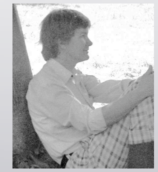
C+N+O in NGC 6752 & NGC 1851

David Yong (ANU)
Frank Grundahl (Aarhus)
John Norris (ANU)
+ two cameos



Centro de Novas Oportunidades
CNO
Instituto de Educação e Formação do Sorraia

Outline

- **Introduction**
- N measurements
- C+N+O in NGC 6752 and NGC 1851
- The NGC 1851 merger hypothesis
- High precision differential [X/Fe] in NGC 6752

Why do we care about globular clusters?

- They are the **oldest Galactic objects** for which reliable ages can be obtained and are (arguably) the first bound systems to have formed in the protogalactic era

- Chemical abundances offer insight into (a) their **formation and evolution** as well as (b) the physical processes occurring during the earliest phases of Galaxy formation

Simple stellar populations?

- Globular clusters are the **best example of a simple stellar population**, i.e., a single (a) age, (b) helium abundance, (c) metallicity, and (d) initial mass function (Renzini & Buzzoni 1986)

However ...

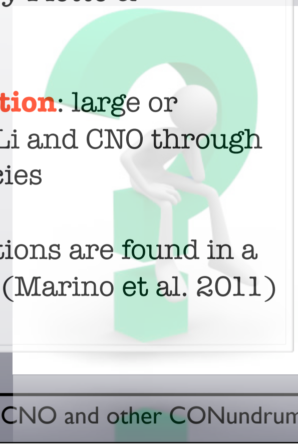
- **CNO variations** were known from 1970's onwards (Norris, Smith etc)
- **Na variations** were discovered in the late 1970s' onwards (Cohen, Da Costa, Peterson etc)
- **O, Na, Mg, Al variations and correlations** (Kraft, Sneden, Carretta, Gratton etc 1990's onwards)

Multiple stellar populations!

- **Enormous complexity in colour magnitude diagrams**: multiple main sequences, subgiant branches, giant branches, horizontal branches (e.g., extensive work by Piotto & collaborators)

- **Enormous diversity in chemical composition**: large or bimodal distributions in all elements from Li and CNO through to alpha, Fe-peak and neutron-capture species

- **Not just omega Centauri!** Multiple populations are found in a growing number of clusters including M22 (Marino et al. 2011) and LMC clusters (Milone et al. 2009)



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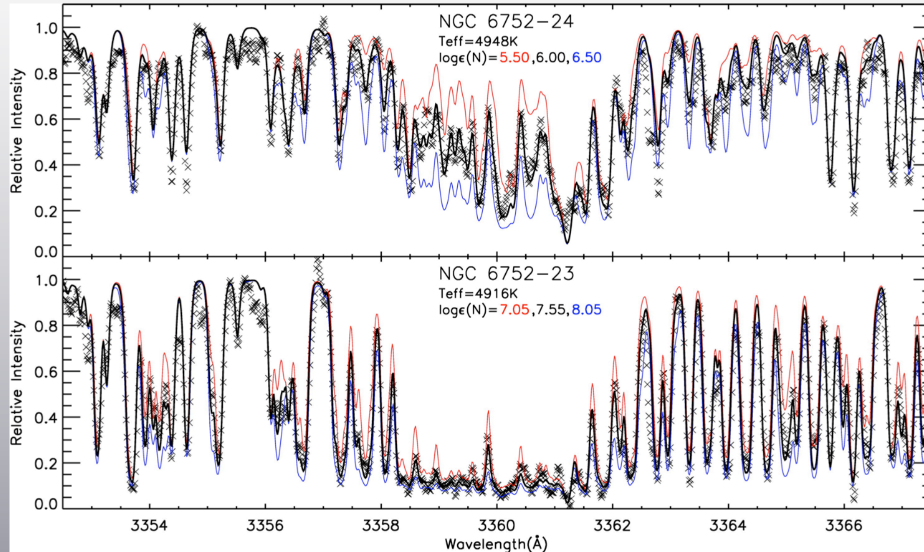
N measurements

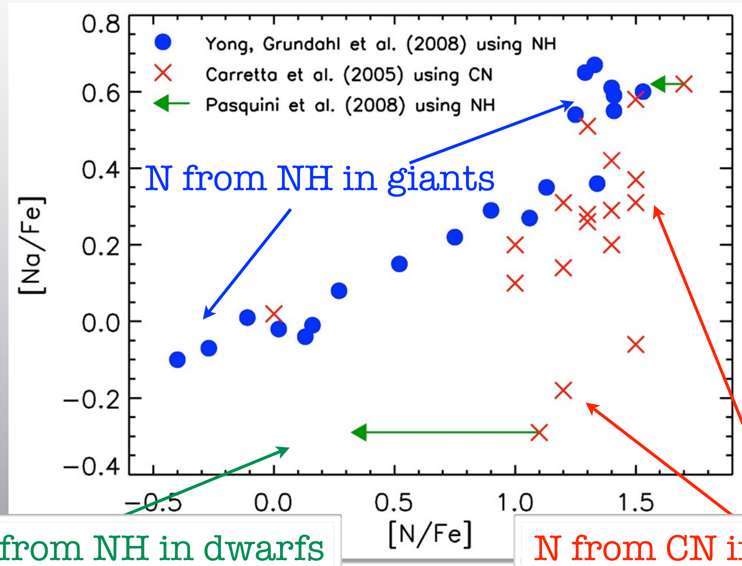
- **Many/most measurements of N come from the CN molecular lines (3883Å, 4216Å, 8005Å)**
- The first problem is that the C abundances are required
- The second problem is that the O abundances are also required (due to the CO molecule and molecular equilibrium)

- **The better(?) way to measure N is from NH (3360Å)**
- Requires no knowledge of C or O abundances
- But this is a crowded region with low flux
- With some help from some friends (Grundahl, Johnson, Asplund) + 27 hours of UVES spectra, let's take a look at 21 stars in NGC 6752 ...

N measurements



N measurements

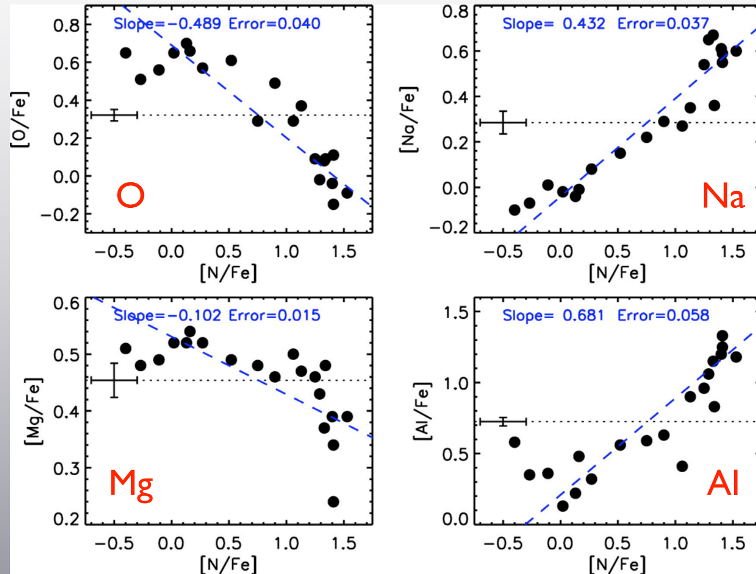


N from NH in dwarfs

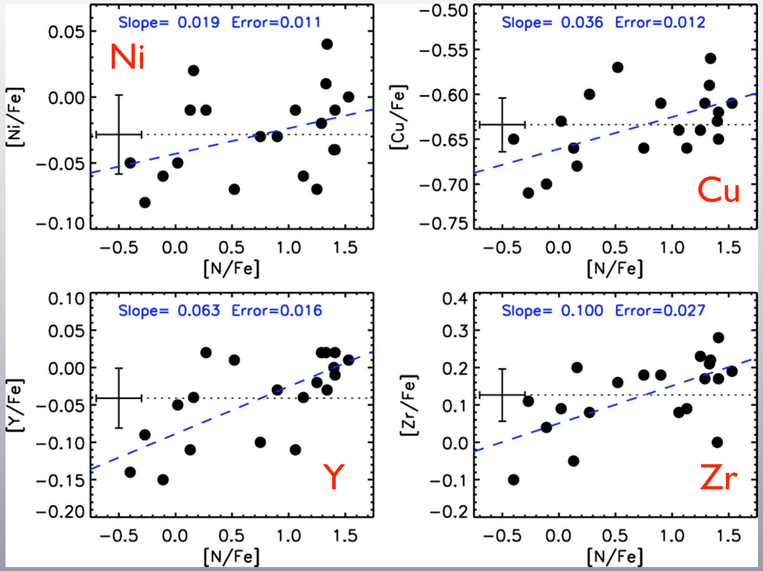
N from CN in dwarfs

Large systematic differences

Usual correlations



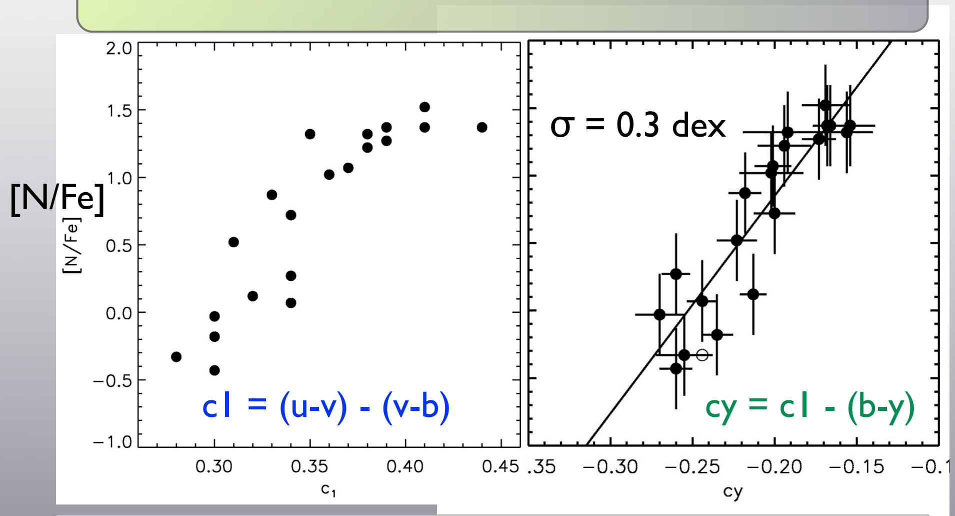
Unexpected correlations



Testing analysis/models

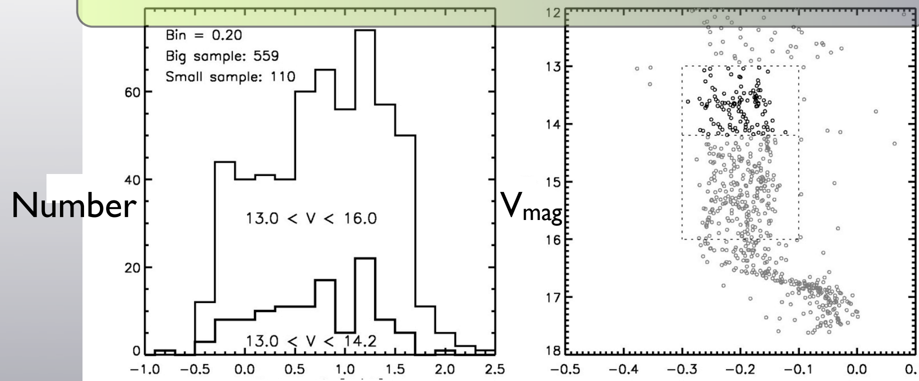
- Would the abundances change if we used model atmospheres with appropriate N, O, Na, Mg and Al abundances?
- **Yes!**
- But the change would be very small ~0.02 dex
- And these correlations between N and heavier elements would in fact become **STRONGER!**

Strömgren photometry and N



Strömgren "u" filter includes the 3360Å NH molecular lines

Photometric N distributions



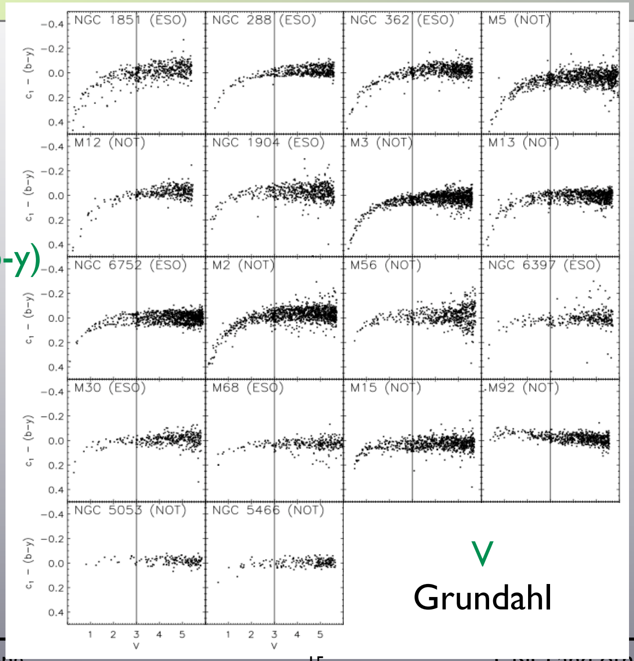
Photometric [N/Fe]

cy = c1 - (b-y)

Distribution increases with increasing N (cf CN behaviour)

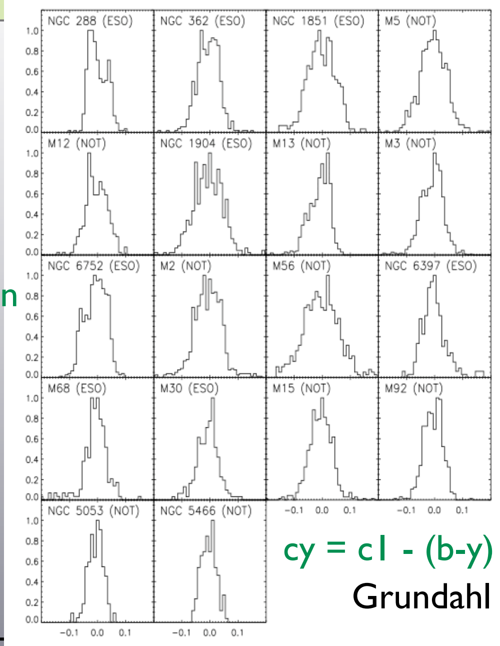
All clusters+luminosities

cy = c1 - (b-y)



cy or [N/Fe] distribution

Relative fraction



cy = c1 - (b-y)

Grundahl

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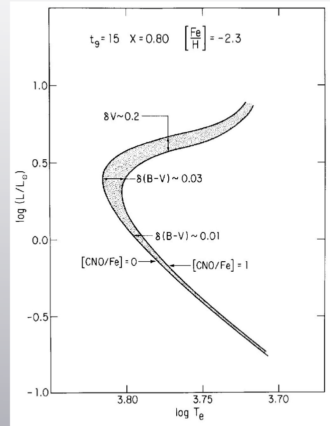
C+N+O

The C+N+O abundance sum has important implications for

- Age determinations for subgiant branch stars ==> interpretation of multiple subgiant populations

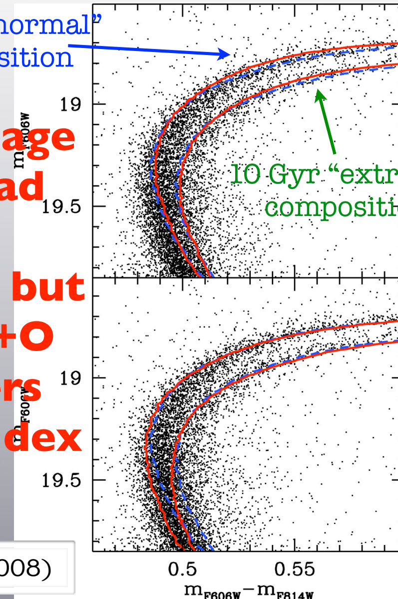
- Abundance variations in globular clusters (observations(?) = constant; models predict ≠ constant)

CNO: Subgiant branch



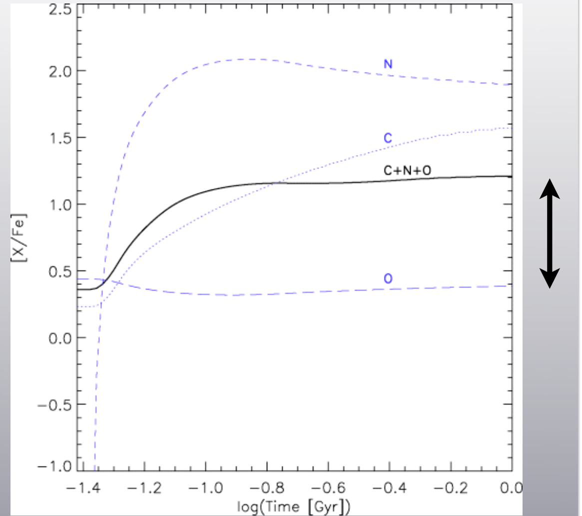
Rood & Crocker (1997)

1 Gyr age spread or coeval but C+N+O differs by 0.3 dex



NGC 1851 (Cassisi et al. 2008)

CNO: Abundance variations



Fenner et al. (2004)

variation expected in the C+N+O abundance sum when producing ONaMgAl variations

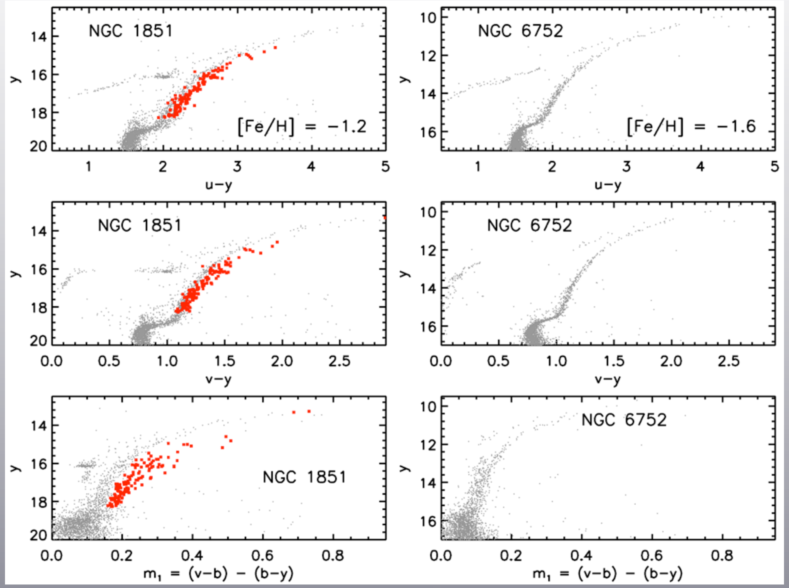
Previous C+N+O measurements?

To our knowledge (?) ... no one has measured the abundance sum C+N+O using

(a) the **best indicators** for each element (CH, NH, [OI])
(b) using **high-resolution** spectra (R > 30K) &
(c) for a **large sample** of stars (N > 10)

NGC 6752 is bright
NGC 1851 is a peculiar cluster with a double subgiant branch, double red giant branch, bimodal horizontal branch, and spread in s-process element abundances

NGC 1851 vs 6752: CMDs



NGC 6752: C+N+O

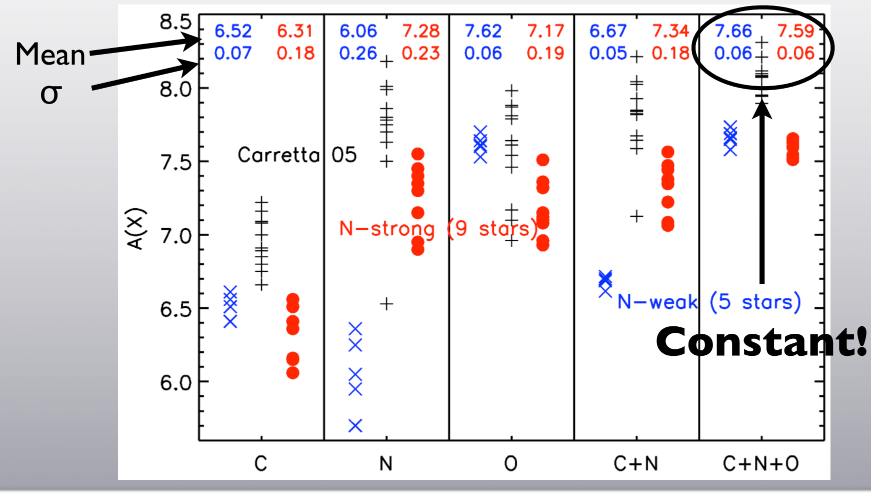
Spectra from UVES & FLAMES+GIRAFFE+IFU

For this project, we only have ~20 NH measurements, so we decided that
(a) N=15 objects at R ≈ 35K is more valuable than
(b) N=100 objects at R ≈ 20K,
i.e., ***maybe spectral resolution matters***

We have spectra of

(a) 3360Å NH to obtain N (UVES)
(b) 4300Å CH to measure C (IFU)
(c) 6300Å [OI] to measure O (UVES)

NGC 6752: C+N+O



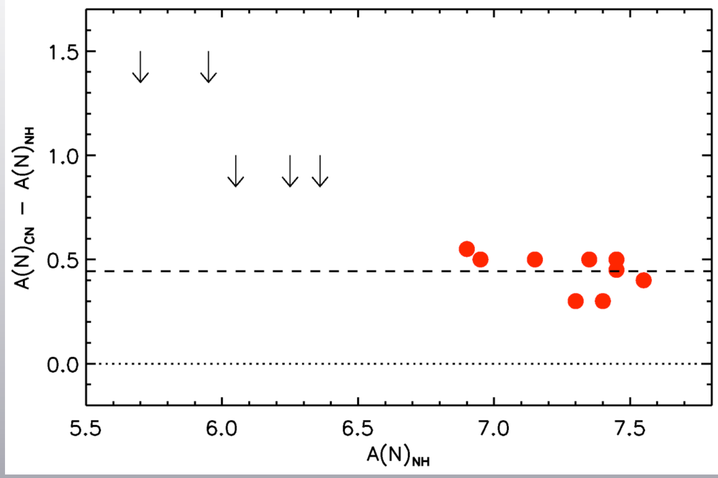
C+N+O SEEMS CONSTANT AT THE 0.06 DEX LEVEL

NGC 6752: C+N+O

... BUT

IT IS NOT REASONABLE TO ALWAYS EXPECT TO OBSERVE 3360Å NH,
SO WHAT DO WE GET FROM 8000Å CN?

3360Å NH vs. 8000Å CN



A (CONSTANT?) 0.44 DEX OFFSET!

N(3360NH) vs. N(8000CN)

HOW DID THIS HAPPEN?
WHICH VALUE DO YOU BELIEVE?

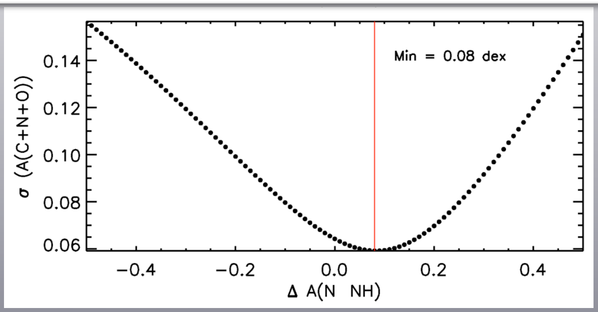
Audience vote?

(a) NH: C+N_NH+O = 7.62 (sigma=0.06)

(b) CN: C+N_CN+O = 7.87 (sigma = 0.11)

Optimal N abundances

If we demand that C+N+O=constant, then what is the optimal "shift" for N that produces the smallest dispersion?



NGC 1851: C+N+O

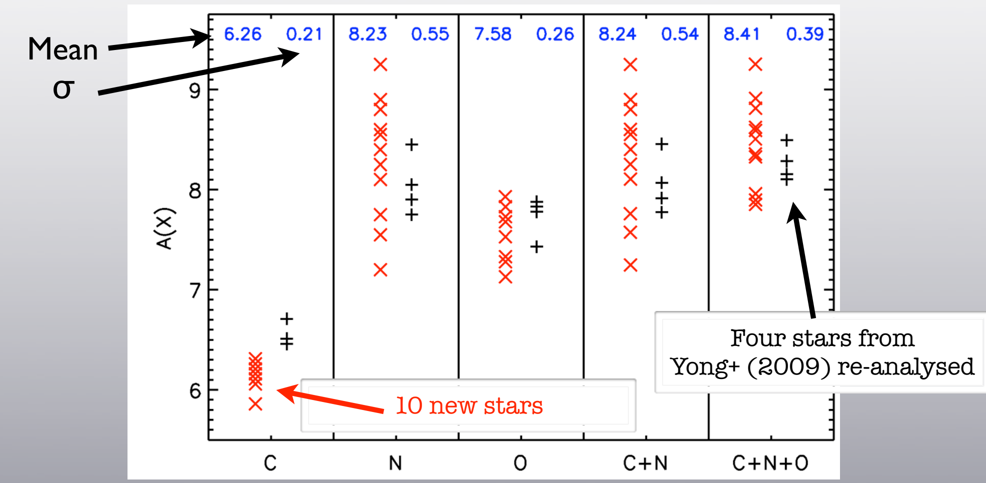
Conflicting results in the literature

A large spread (Yong, Grundahl + 2009) vs.
No spread (Villanova+ 2009)

Spectra from FLAMES+GIRAFFE+IFU

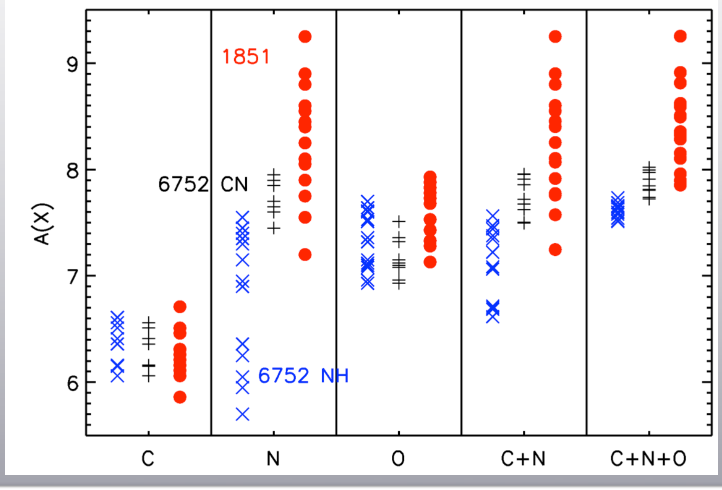
(a) 4300Å CH to measure C (IFU)
(b) 8005Å CN to measure N (IFU)
(c) 6300Å [OI] to measure O (IFU)

NGC 1851: C+N+O



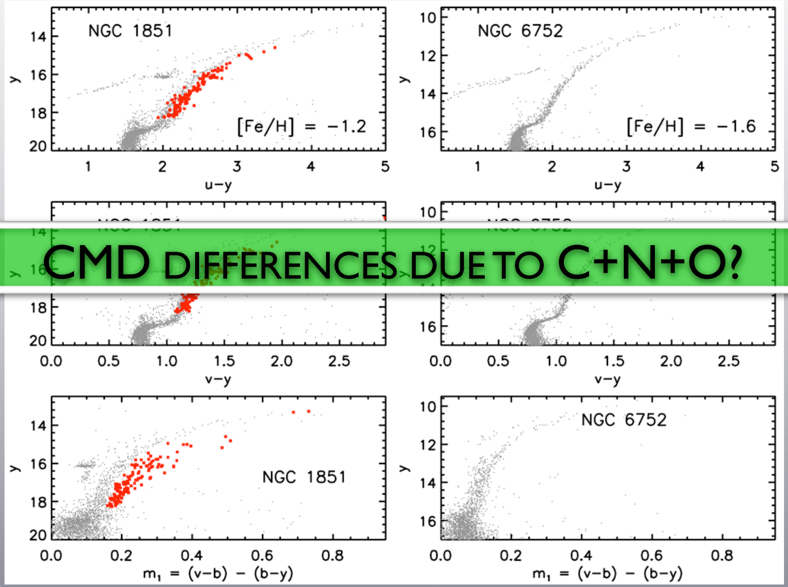
ENORMOUS SPREAD IN C+N+O!

NGC 1851 vs. 6752: C+N+O



CLEAR DIFFERENCES IN CNO CONTENT

NGC 1851 vs 6752: CMDs



CMD DIFFERENCES DUE TO C+N+O?

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Kenji Bekki (Univ. Western Australia)

NGC 1851: the merger of two clusters?

NGC 1851 is a peculiar cluster with a double subgiant branch, double red giant branch, bimodal horizontal branch, and spread in s-process element abundances

Carretta, Gratton, Lucatello et al. (2010) first suggested that NGC 1851 might be the product of the merger of two clusters

(a) a metallicity dispersion

(b) differences in the radial profiles of the “metal-poor” and “metal-rich” populations

NGC 1851: the merger of two clusters?

Bekki has performed numerical simulations that show the merger scenario is plausible

- two clusters can merge (due to the low stellar velocity dispersion of the host) and form the nuclear star cluster of a dwarf galaxy
- the dark matter halo and stellar envelope of the dwarf galaxy can be stripped by the Galactic tidal field leaving behind the nucleus (i.e., NGC 1851) and a diffuse stellar halo (as observed by Olszewski et al. 2010)
- **expect 3 populations**, GC1, GC2 & field stars from the nuclear region of the dwarf

Contact Kenji Bekki for more details!

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- **High precision differential [X/Fe] in NGC 6752**

Jorge Meléndez (Univ. Sao Paulo)

Unprecedented precision

Jorge Meléndez, and collaborators, have pioneered analysis techniques that have led to the unprecedented precision level of 2% (0.01 dex), a ~five-fold improvement

- how chemically homogeneous are globular clusters?

- with increased precision, can we detect/confirm unexpected correlations and possibly identify indirect He differences?

Method

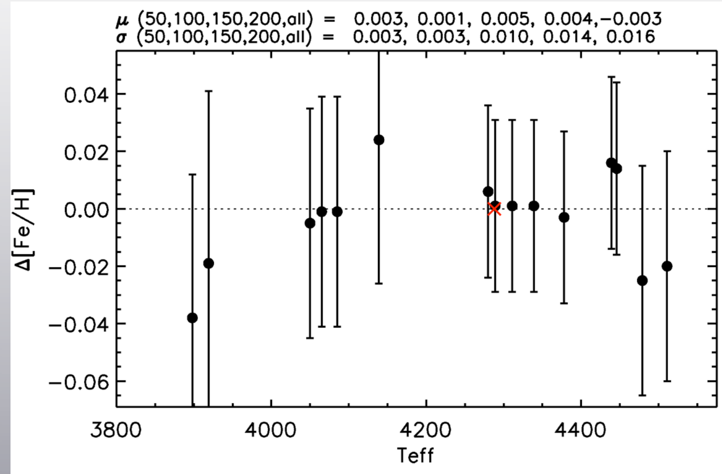
- measure thousands of EWs using Stetson's DAOSPEC, compare these measurements to our "hand" measures and **only use lines with <100mÅ measured in all stars**

- choose a **reference** star (median Teff and median O-Na-Mg-Al)

- vary Teff/logg/micro/[Fe/H] until the ***line-by-line Fe abundance differences*** show (i) zero slope vs. L.E.P, (ii) zero slope vs. reduced EW, (iii) zero difference between FeI and FeII and (iv) [Fe/H] derived matches model [Fe/H]

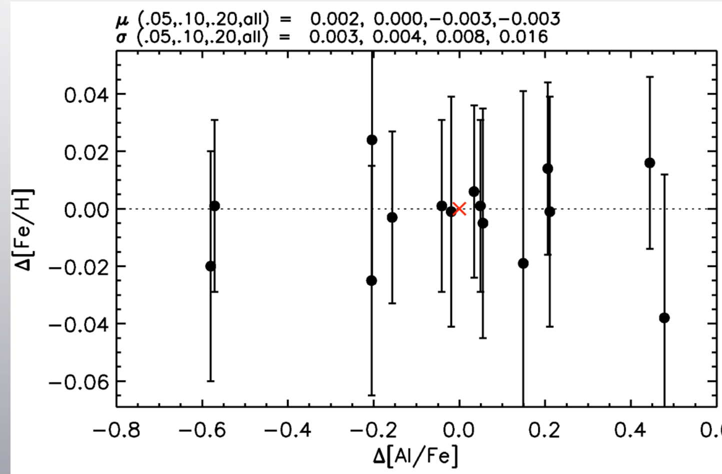
- armed with the **best differential model parameters, compute A(X) for all species**

Δ[Fe/H] vs. Teff

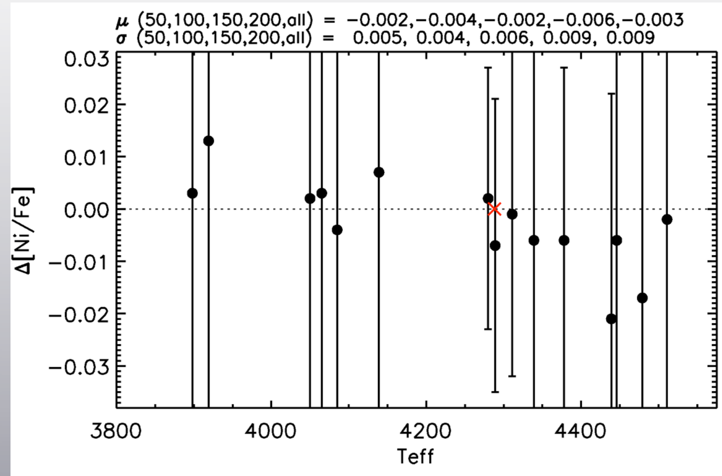


μ (50,100,150,200,all) = 0.003, 0.001, 0.005, 0.004, −0.003
σ (50,100,150,200,all) = 0.003, 0.003, 0.010, 0.014, 0.016
0.04
0.02
0.00
−0.02
−0.04
−0.06
Δ[Fe/H]
3800
4000
4200
4400
Teff

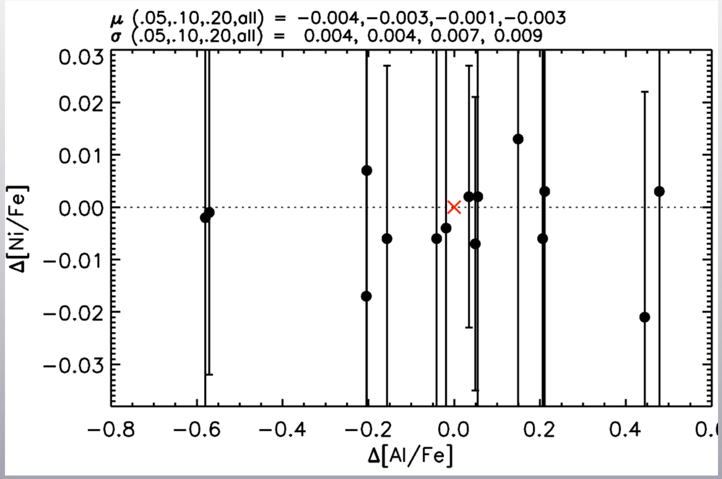
Δ[Fe/H] vs. Δ[Al/Fe]



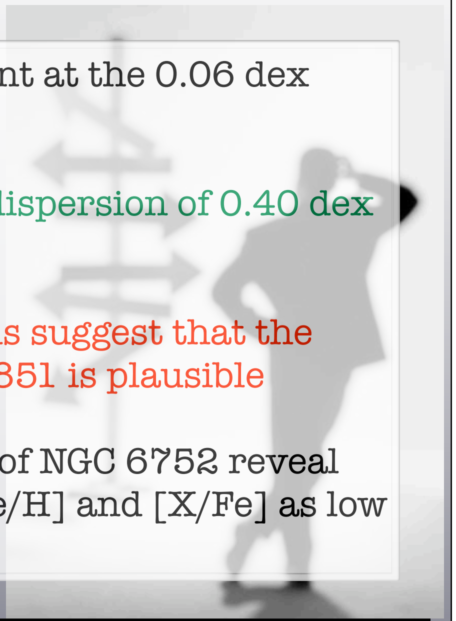
Δ[Ni/Fe] vs. Teff



Δ[Ni/Fe] vs. Δ[Al/Fe]



Summary



- C+N+O in NGC 6752 is constant at the 0.06 dex level

- C+N+O in NGC 1851 shows a dispersion of 0.40 dex (an amplitude of 1.40 dex)

- Bekki's numerical simulations suggest that the merger hypothesis for NGC 1851 is plausible

- Strictly differential analyses of NGC 6752 reveal chemical homogeneity for [Fe/H] and [X/Fe] as low as 0.01 dex