C+N+O in NGC 6752 & NGC 1851

David Yong (ANU)
Frank Grundahl (Aarhus)
John Norris (ANU)

+ two cameos

Centro de Novas Oportunidades
Instituto de Educação e Formação do Sorraia
- **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)
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
- **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 ...
KraftFest: Yong

CNO and other CONundrums

N measurements

- Yong, Grundahl et al. (2008) using NH
- Corretto et al. (2005) using CN
- Pasquini et al. (2008) using NH

N from NH in giants

N from NH in dwarfs

N from CN in dwarfs

Large systematic differences
Usual correlations

- **O**
  - Slope: 0.489
  - Error: 0.040

- **Na**
  - Slope: 0.432
  - Error: 0.037

- **Mg**
  - Slope: -0.102
  - Error: 0.015

- **Al**
  - Slope: 0.681
  - Error: 0.058
Unexpected correlations

- Ni
- Cu
- Y
- Zr
- 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

- $c_1 = (u-v) - (v-b)$
- $cy = c_1 - (b-y)$
- $\sigma = 0.3$ dex

\[
[N/Fe] = c_1 - (b-y)
\]
Photometric N distributions

Photometric [N/Fe]

Distribution increases with increasing N (cf CN behaviour)

c_y = c_1 - (b-y)
All clusters+luminosities

cy = c1 - (b-y)

Grundahl
cy or \([N/Fe]\) distribution

\[ cy = c1 - (b-y) \]

Grundahl

Relative fraction
- 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
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

10 Gyr “normal” composition

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

10 Gyr “extreme” composition

Rood & Crocker (1997)

NGC 1851 (Cassisi et al. 2008)

KraftFest: Yong

CNO and other CONundrums
CNO: Abundance variations

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

Fenner et al. (2004)
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
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.
IT IS NOT REASONABLE TO ALWAYS EXPECT TO OBSERVE 3360Å NH, SO WHAT DO WE GET FROM 8000Å CN?
KraFtFest: Yong

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)
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

Mean σ

ENORMOUS SPREAD IN C+N+O!

Four stars from Yong+ (2009) re-analysed

10 new stars

KraftFest: Yong
NGC 1851 vs. 6752: C+N+O

CLEAR DIFFERENCES IN CNO CONTENT
NGC 1851 vs 6752: CMDs

CMD DIFFERENCES DUE TO C+N+O?
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

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
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!
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**

Jorge Meléndez (Univ. Sao Paulo)
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?
- 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**
$\Delta[\text{Fe/H}]$ vs. Teff

$\mu$ (50,100,150,200,all) = 0.003, 0.001, 0.005, 0.004, -0.003
$\sigma$ (50,100,150,200,all) = 0.003, 0.003, 0.010, 0.014, 0.016
$\Delta [\text{Fe/H}]$ vs. $\Delta [\text{Al/Fe}]$
$\Delta[Ni/Fe]$ vs. $Teff$
$\Delta[\text{Ni/Fe}]$ vs. $\Delta[\text{Al/Fe}]$
### 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