Carbon-Enhanced Metal-Poor Stars in the Milky Way

Great Barriers II

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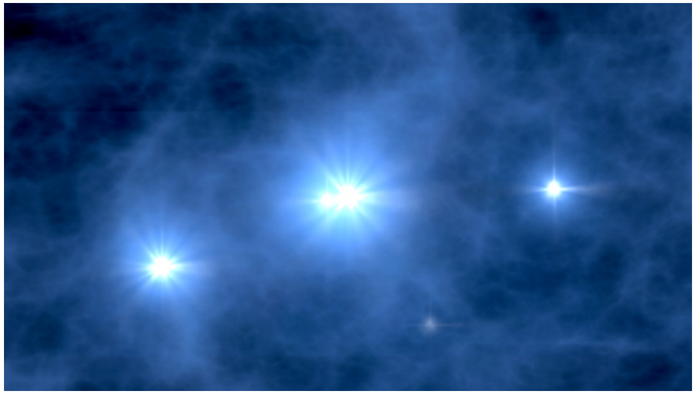
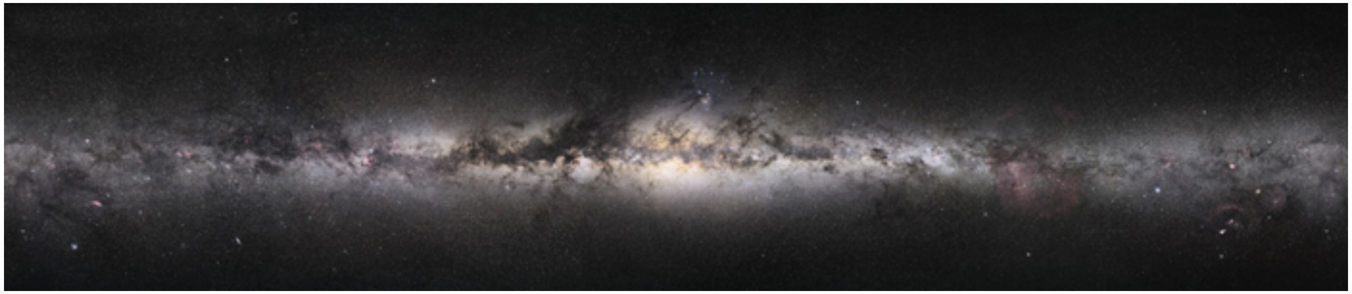
Why CEMP Stars?

- CEMP stars in the Milky Way are archaeological relics.
- Important touchstone → origin of the elements
- ***Stellar archaeology:*** **the chemical abundances of old stars in our Galaxy tell us about the very first stars in the Universe.**

To learn about the first stars, we only need to look in our own "backyard"!





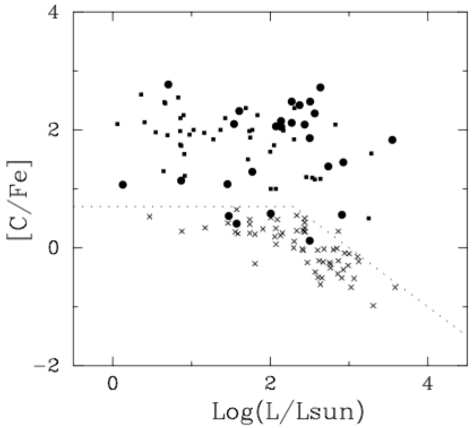
[Fe/H] = 0	solar	
[Fe/H] < -1	metal-poor	(MP)
[Fe/H] < -2	very metal-poor	(VMP)
[Fe/H] < -3	extremely metal-poor	(EMP)
[Fe/H] < -4	ultra metal-poor	(UMP)
[Fe/H] < -5	hyper metal-poor	(HMP)
[Fe/H] < -6	mega metal-poor	(MMP)

The Fossils: CEMP Stars

- CEMP: Carbon-Enhanced Metal-Poor
- Beers & Christlieb (2005): [Fe/H] < -1.0, [C/Fe] > +1.0

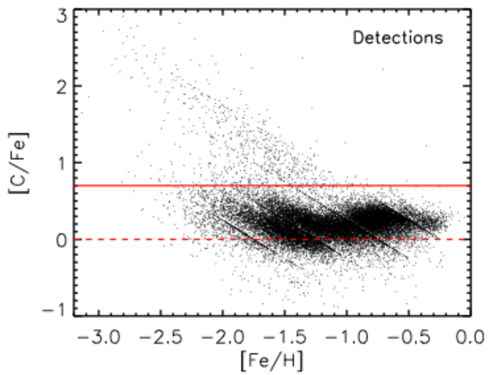
Neutron-capture-rich stars	
r-I	$0.3 \leq$ [Eu/Fe] $\leq +1.0$ and [Ba/Eu] < 0
r-II	[Eu/Fe] $> +1.0$ and [Ba/Eu] < 0
s	[Ba/Fe] $> +1.0$ and [Ba/Eu] $> +0.5$
r/s	$0.0 <$ [Ba/Eu] $< +0.5$
Carbon-enhanced metal-poor stars	
CEMP	[C/Fe] $> +1.0$
CEMP-r	[C/Fe] $> +1.0$ and [Eu/Fe] $> +1.0$
CEMP-s	[C/Fe] $> +1.0$, [Ba/Fe] $> +1.0$, and [Ba/Eu] $> +0.5$
CEMP-r/s	[C/Fe] $> +1.0$ and $0.0 <$ [Ba/Eu] $< +0.5$
CEMP-no	[C/Fe] $> +1.0$ and [Ba/Fe] < 0

New Definition for CEMP Stars



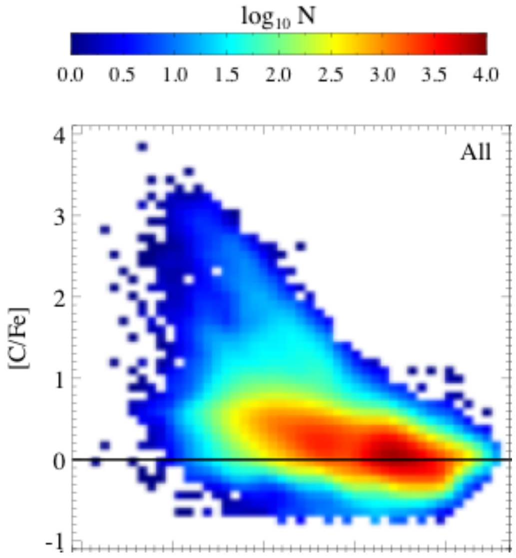
Aoki et al. 2007

26 CEMP stars



Carollo et al. 2012

SEGUE



Lee et al. 2013

SEGUE

[C/Fe] ≥ + 0.7

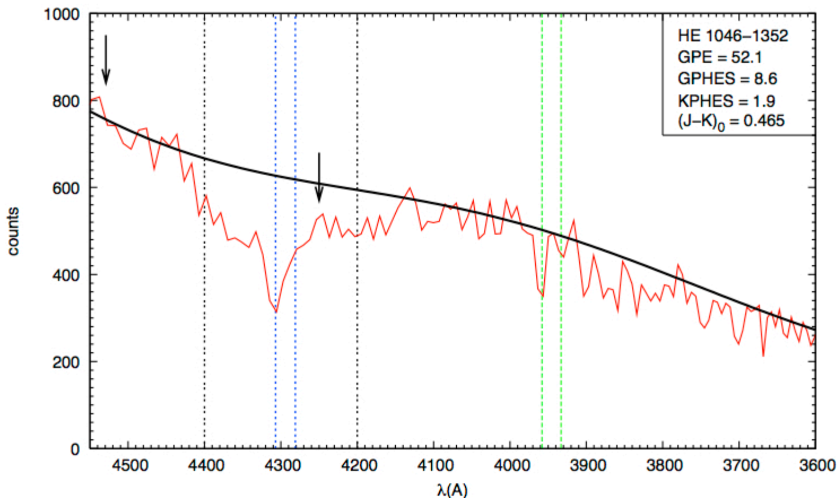
CEMP Fractions

- The fraction of CEMP stars increases with decreasing metallicity
  - [Fe/H] < -2.5 → 20% CEMP
  - [Fe/H] < -3.0 → 30% CEMP
  - [Fe/H] < -3.5 → 40% CEMP
  - **[Fe/H] < -4.0 → 80% CEMP**
  - **[Fe/H] < -5.0 → 100% CEMP**

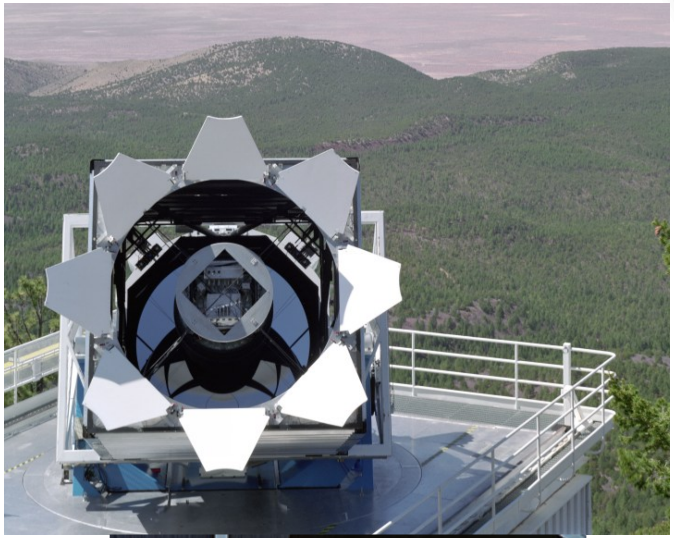
CEMP stars are not all the same! There are several different classes of CEMP stars with distinct chemical signatures.

How do we find CEMP stars? **Placco et al. 2010,2011**

1. Large-scale surveys → discovery of MP stars.
2. We know that a large fraction of these are CEMP stars.
3. So, we look for the "defining characteristic" of carbon enhancement in the low-resolution spectra MP stars.

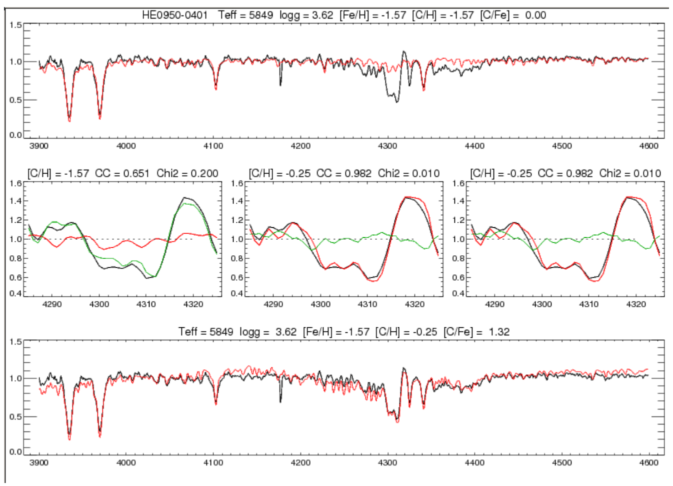


CH molecular absorption in CEMP stars is usually evident even at low spectral resolution!

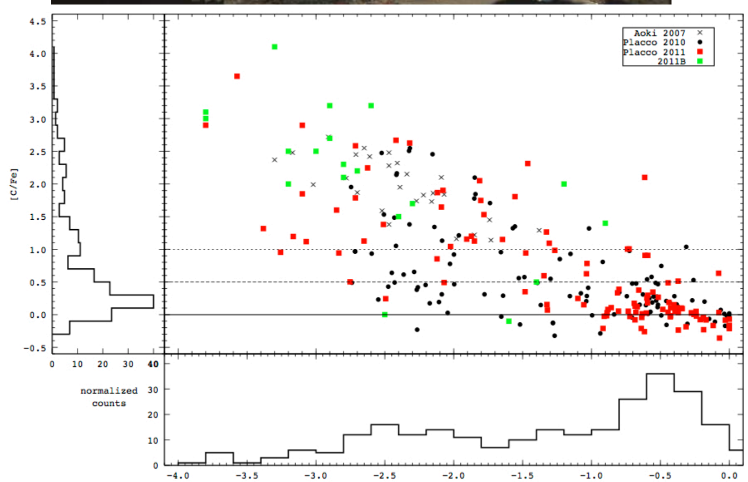


How do we find CEMP stars? **Placco et al. 2010,2011**

Moderate-resolution follow-up spectra allow us to confirm CEMP stars.



This survey technique has so far led to the discovery of hundreds of new CEMP stars. (Observations of about 1000 CEMP candidates.)

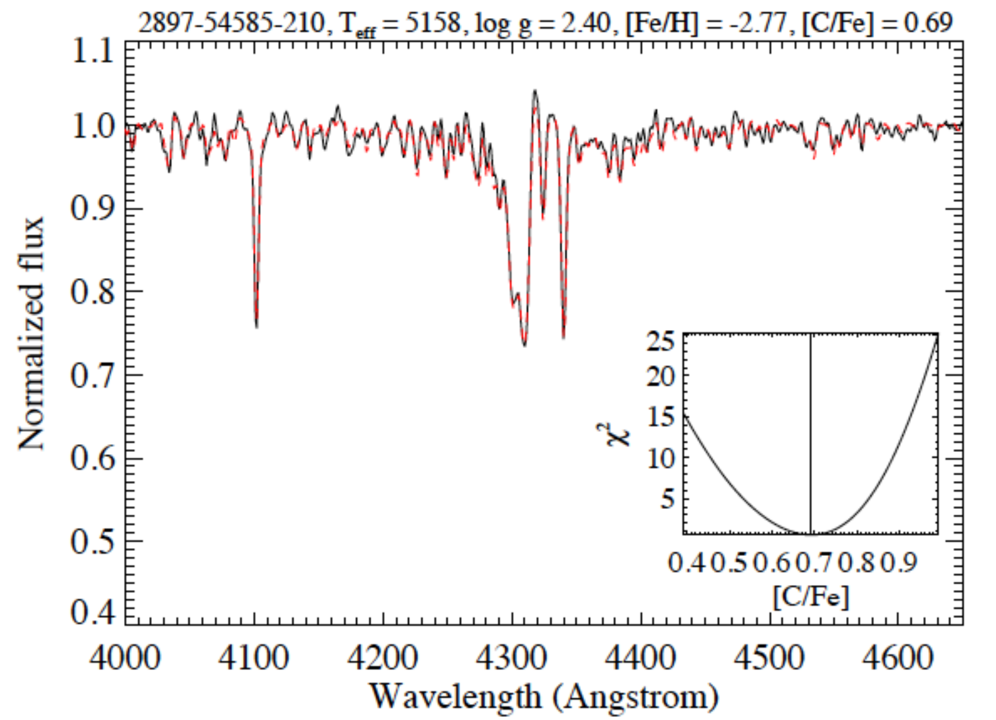


How do we find CEMP stars?

- Bigger surveys!

SDSS/SEGUE: Lee et al. 2013

[Fe/H] < -1.0	4827
[Fe/H] < -1.5	3880
[Fe/H] < -2.0	1995
[Fe/H] < -2.5	515
[Fe/H] < -3.0	55
[Fe/H] < -3.5	2

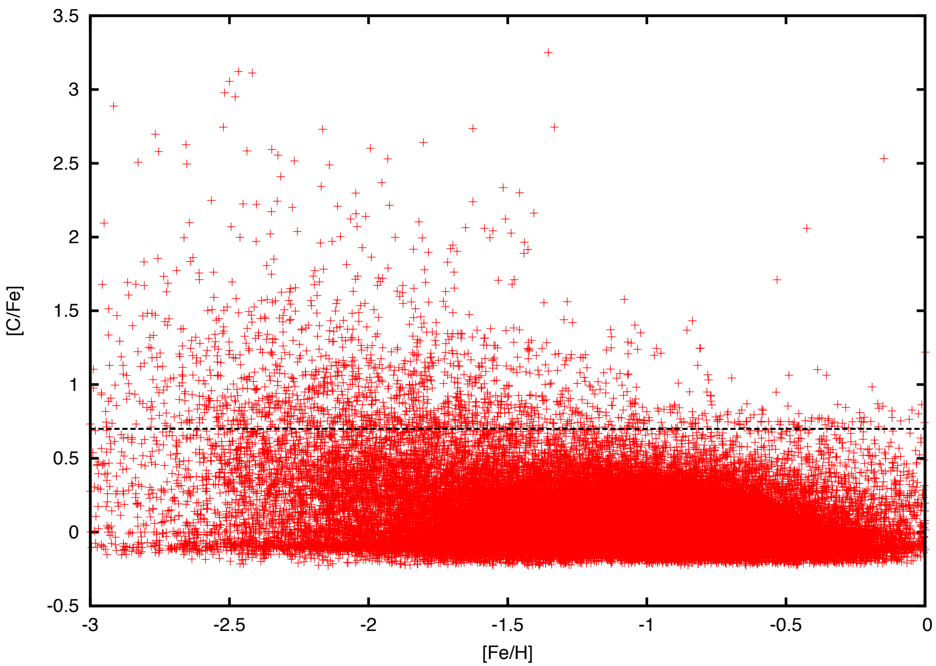


How do we find CEMP stars?

- Bigger surveys!

AEGIS: Keller et al.

[Fe/H] < -1.0	1523
[Fe/H] < -1.5	1279
[Fe/H] < -2.0	765
[Fe/H] < -2.5	271
[Fe/H] < -3.0	71
[Fe/H] < -3.5	26



CEMP-*s* Stars

- 80% of all CEMP stars observed are CEMP-*s*.
- [Fe/H] < -1.0, [C/Fe] > +0.7, [Ba/Fe] > +1.0
- Enhancement of carbon and *s*-process
- Typical metallicities -3.0 < [Fe/H] < -1.0

For details on s-process in AGB stars,

Shingles and Karakas presentations.

CEMP-*s* Stars

1. Star is in a binary system with an intermediate-mass star
2. Intermediate-mass AGB stage → C and *s*-process.
3. Transfer of mass from primary to secondary.
4. Secondary star is now enhanced in carbon and *s*-process material.
5. **We observe the secondary as a CEMP-*s* star**

We compare our CEMP-s abundances to theoretical predictions. ***Stancliffe et al. 2013***

CEMP RR Lyrae Stars

Prior to this year, only two CEMP RR Lyrae stars:

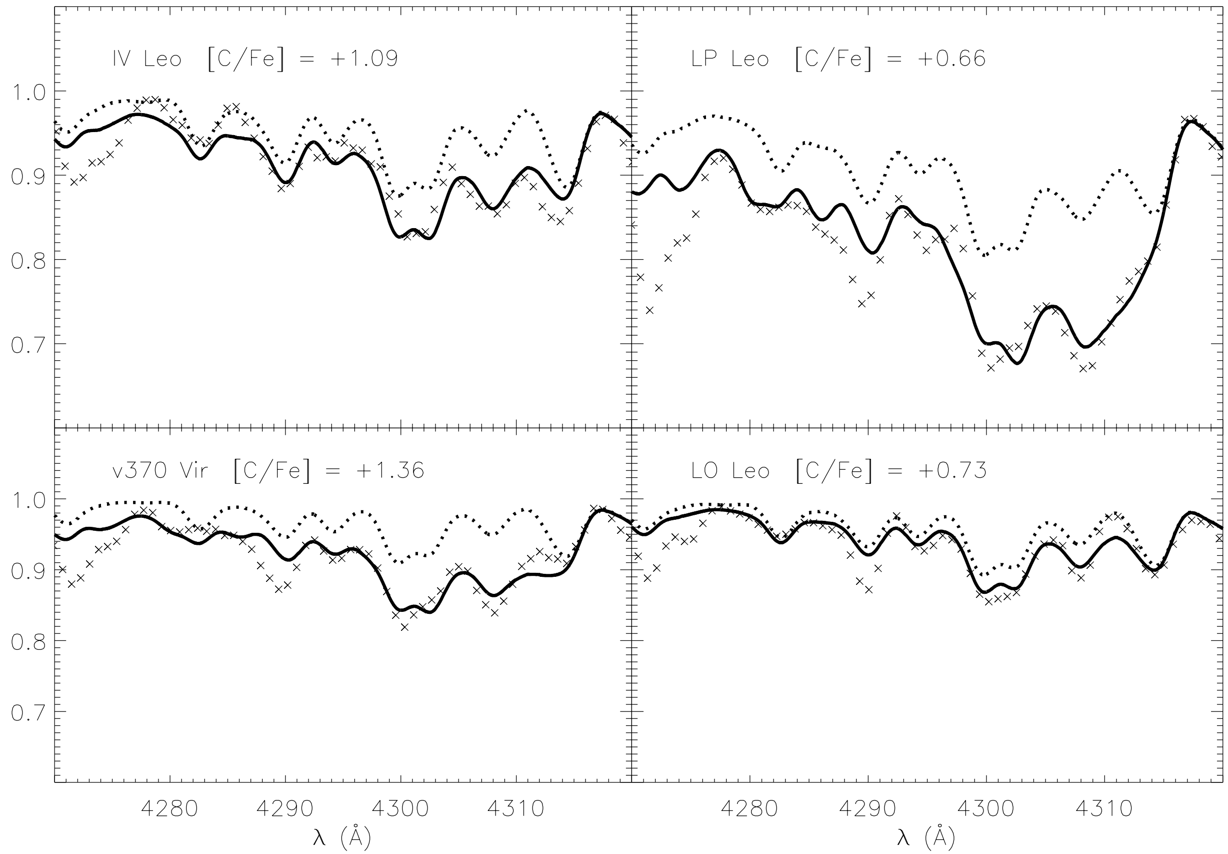
TY Gru (Preston et al. 2006)
SDSS J1707+58 (Kinman et al. 2012)

Pilot study with WiFeS/ANU2.3m to confirm new CEMP RR Lyr.

8 stars observed, 7 with [Fe/H] < -1.0 & [C/Fe] > +0.7

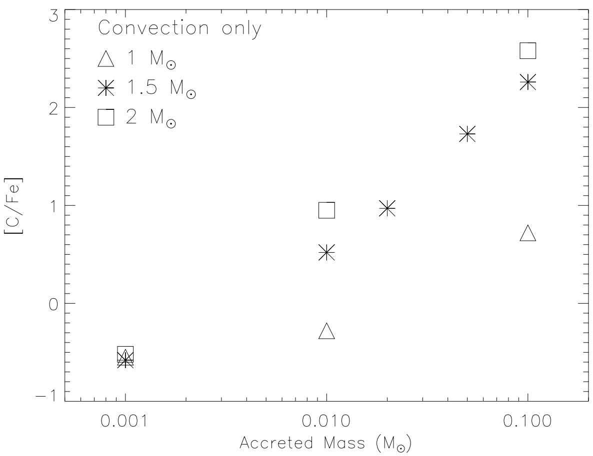
Increase in sample size by ~4x!

CEMP RR Lyrae Stars

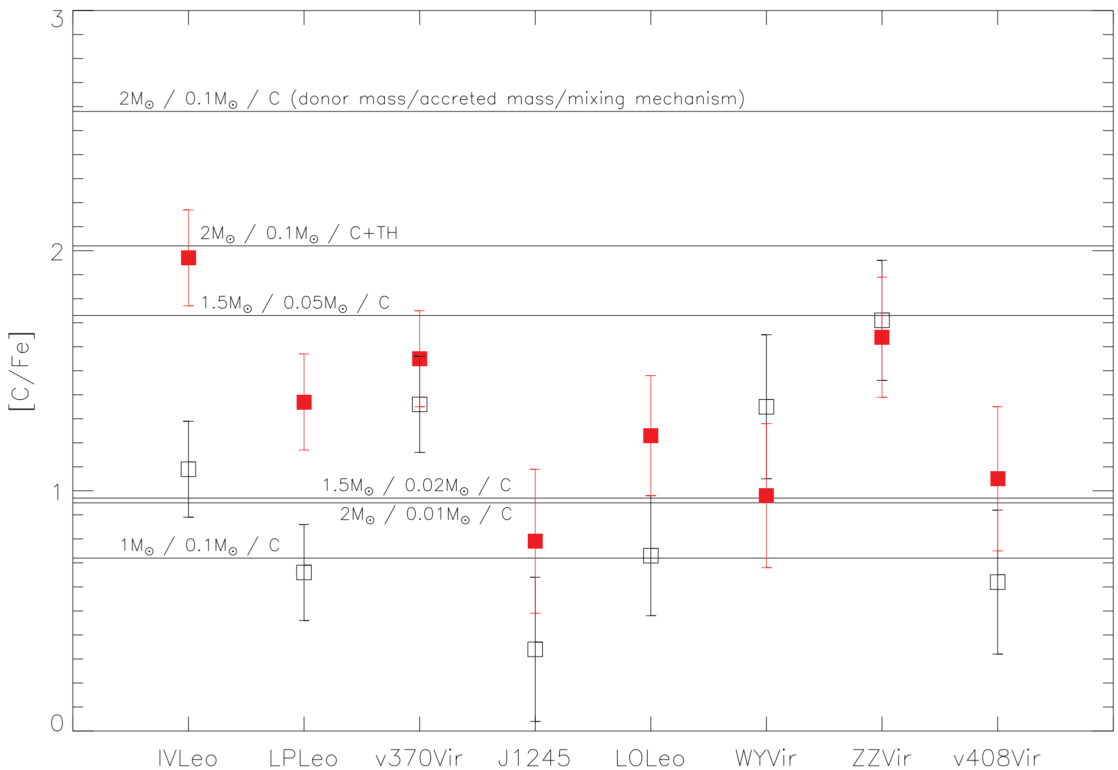


Kennedy et al. 2014

Comparison to Stancliffe et al. predictions



Theoretical abundances of CEMP-*s* stars.



Comparison of observed C abundances with various model scenarios.

Conclusion: *The AGB donors of these stars were likely around 1.5 to 2 solar masses. These stars accreted a few hundredths of a solar mass of C- and s-process-enhanced material.*

Kennedy et al. 2014

CEMP-no Stars

- 20% of all CEMP stars
- [C/Fe] > +0.7, [Ba/Fe] < 0.0
- Dominate the CEMP stars at [Fe/H] < -3.

Highlights from this meeting:

Chiaki's talk:

CEMP-no DLA

A carbon-enhanced metal-poor damped Lyα system: probing gas from Population III nucleosynthesis?*

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ABSTRACT
We present high-resolution observations of an extremely metal-poor damped Lyα system (DLA), at $z_{abs} = 2.340\,0972$ in the spectrum of the QSO J0035−0918, exhibiting an abundance pattern consistent with model predictions for the supernova yields of Population III stars. Specifically, this DLA has [Fe/H] $\simeq -3$, shows a clear 'odd–even' effect, and is C-rich with [C/Fe] $= +1.53$, a factor of $\sim$20 greater than reported in any other DLA. In analogy to the carbon-enhanced metal-poor stars in the Galactic halo (with [C/Fe] $> +1.0$), this is the first known case of a carbon-enhanced DLA. We determine an upper limit to the mass of ^{12}C, $M(^{12}\mathrm{C}) \leq 200\,\mathrm{M}_{\odot}$, which depends on the unknown gas density n(H); if $n(\mathrm{H}) > 1\,\mathrm{cm}^{-3}$ (which is quite likely for this DLA given its low velocity dispersion), then $M(^{12}\mathrm{C}) \leq 2\,\mathrm{M}_{\odot}$, consistent with pollution by only a few prior supernovae. We speculate that DLAs such as the one discovered here may represent the 'missing link' between the yields of Population III stars and their later incorporation in the class of carbon-enhanced metal-poor stars which show no enhancement of neutron-capture elements (CEMP-no stars).

CEMP-no stars are formed directly from the material made in the first stars!

CEMP-no Stars

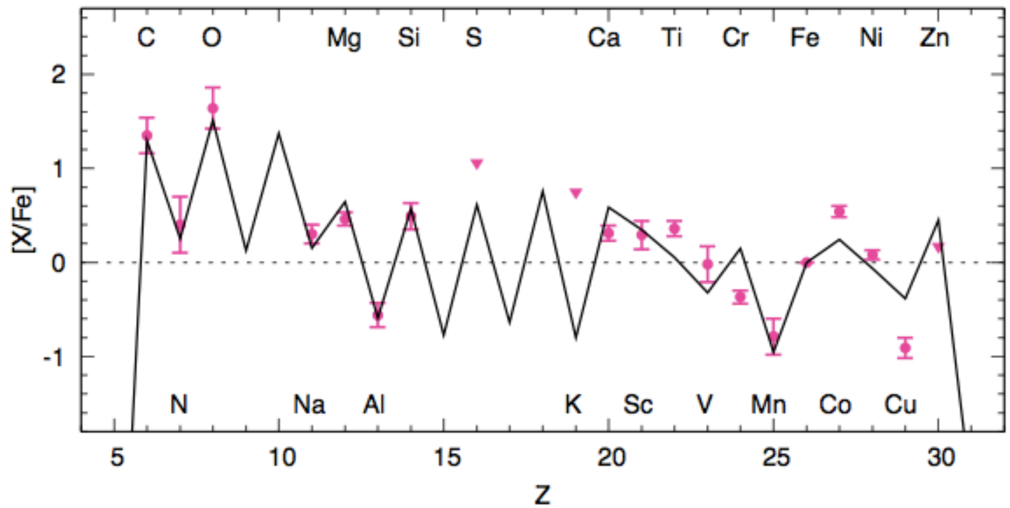
- 20% of all CEMP stars
- [C/Fe] > +0.7, [Ba/Fe] < 0.0
- Dominate the CEMP stars at [Fe/H] < -3.

Highlights from this meeting:

BD+44:493: Ito et al. 2013

Chiaki's talk:

Mixing/fallback SNe



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Highlights from this meeting:

Stefan's talk:

Home » News & events » ANU astronomers discover oldest star

ANU astronomers discover oldest star

MONDAY 10 FEBRUARY 2014

A team led by astronomers at The Australian National University has discovered the oldest known star in the Universe, which formed shortly after the Big Bang 13.7 billion years ago.

The discovery has allowed astronomers for the first time to study the chemistry of the first stars, giving scientists a clearer idea of what the Universe was like in its infancy.

"This is the first time that we've been able to unambiguously say that we've found the chemical fingerprint of a first star," said lead researcher, Dr Stefan Keller of the ANU Research School of Astronomy and Astrophysics.

"This is one of the first steps in understanding what those first stars were like. What this star has enabled us to do is record the fingerprint of those first stars."

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