An Observational Study of Extremely Metal-Poor Stars

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INT workshop, Seattle

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Metal-Poor Stars $[\mathrm{Fe/H}] < -1$

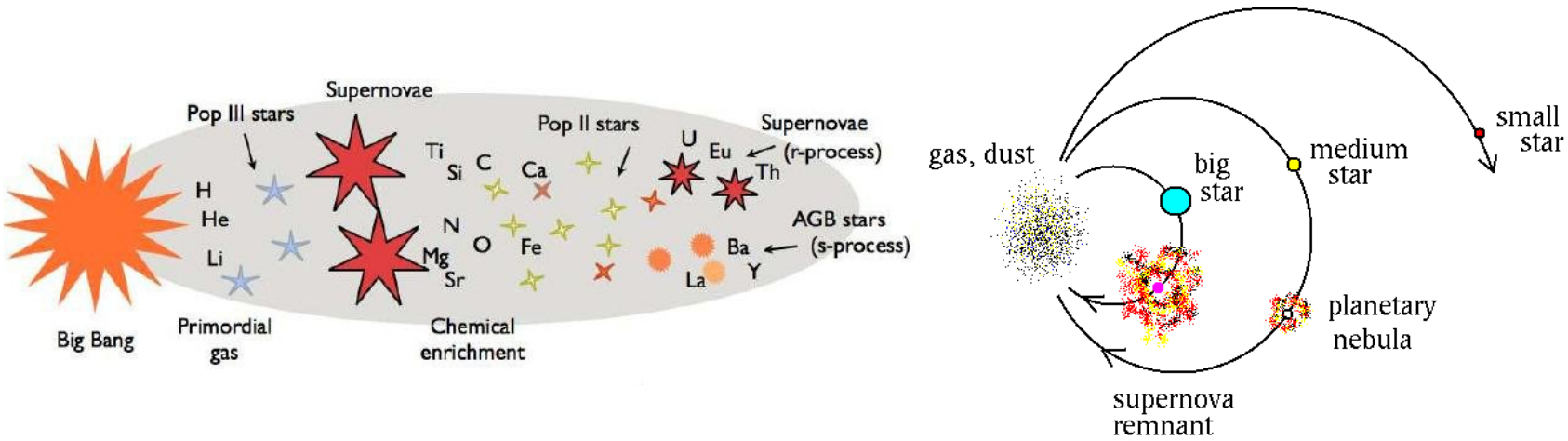

Figure from: Jacobsen & Frebel 2014

- Nature of sites for the first nucleosynthesis
- Initial mass function of the first stars

Carbon Enhanced Metal-Poor (CEMP) Stars

- ∼20% of metal-poor stars are carbon enhanced, $[\mathrm{C/Fe}] > 0.7$
- Number increases with decreasing metallicity
- Subclasses
  - CEMP-s enriched in slow neutron-capture elements, $[\mathrm{Ba/Fe}] \geq 1$
  - CEMP-r enriched in rapid neutron-capture elements, $[\mathrm{Eu/Fe}] \geq 1$
  - CEMP-rs enriched in both slow and rapid neutron-capture elements, $0.0 < [\mathrm{Ba/Eu}] < 0.5$
  - CEMP-no not enriched in neutron-capture elements, $[\mathrm{Ba/Fe}] < 0.0$

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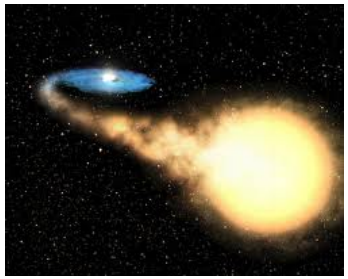
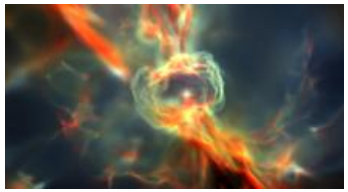
Carbon-Enhanced Stars, Formation Scenarios



- Mass transfer from a binary companion
  - Radial velocity



- First stars life and death
  - Abundances

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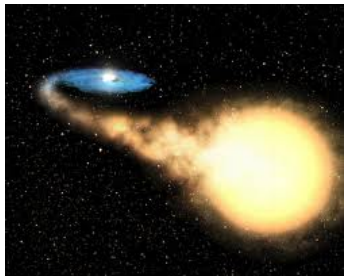

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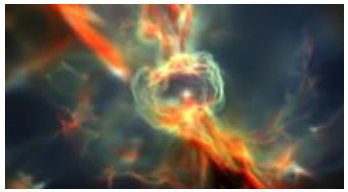

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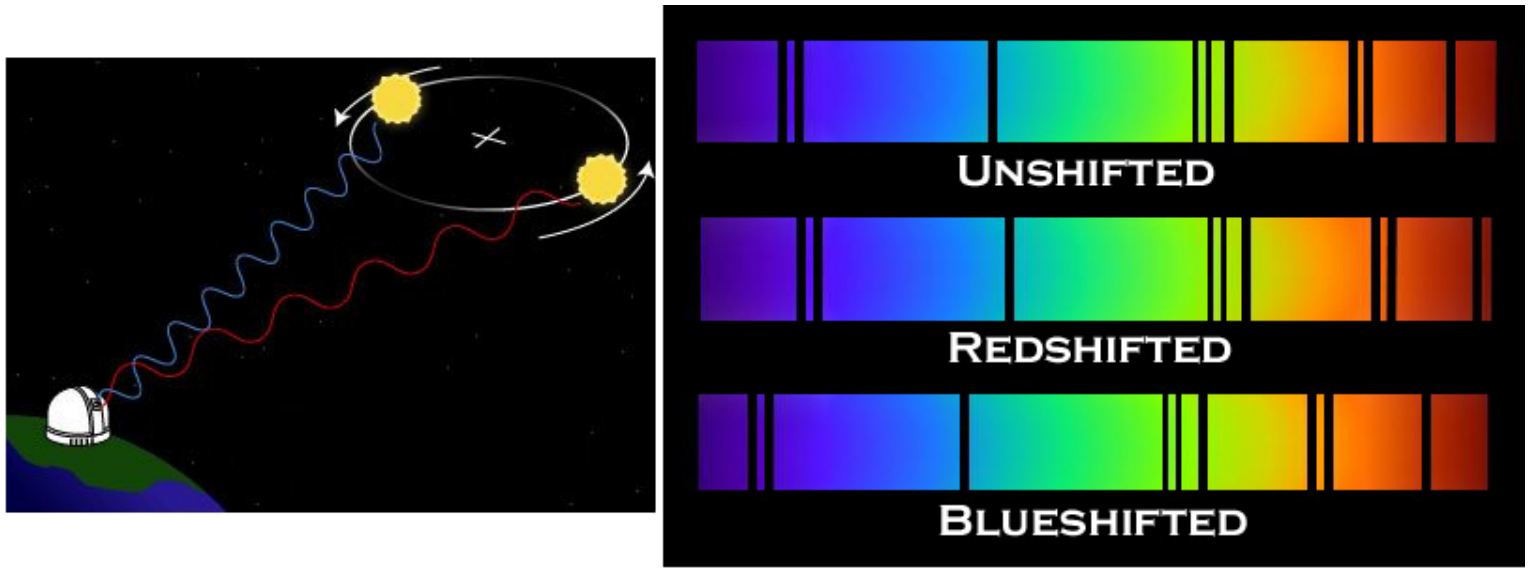
Mass Transfer form Binary Companion

Radial velocity shift



The Nordic Optical Telescope

Starting Assumptions

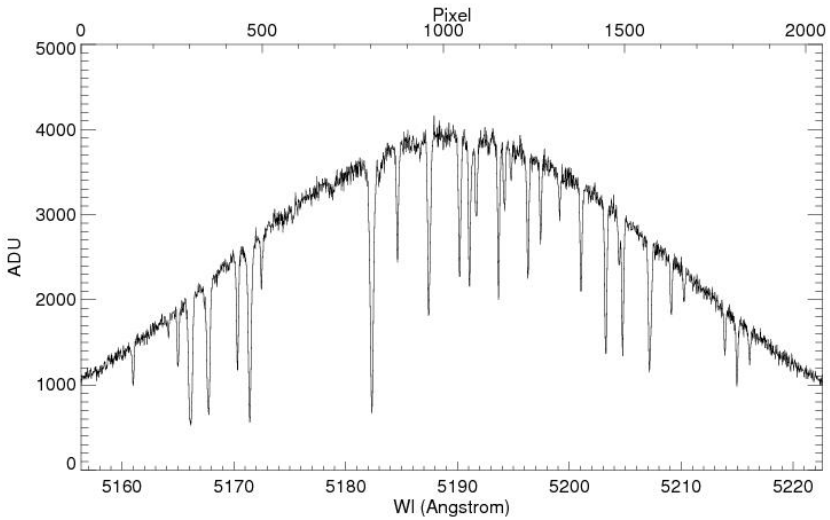
- 100% binary frequency (variable radial velocity)
- Long periods: 100 - 10,000 days
- Low velocity amplitudes: 1 - 5 kms^{-1}
- Low orbital eccentricities

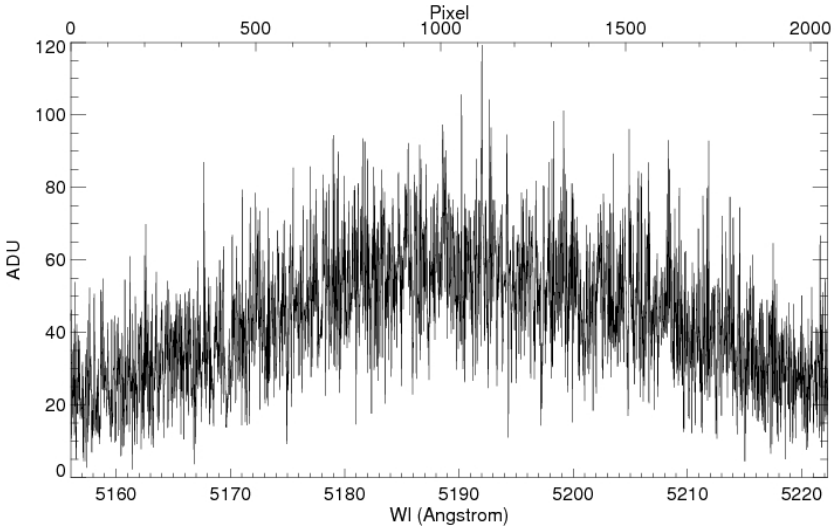
By analogy with the CH and BaII stars

Observations

- Sample size today: 45 stars
- Resolution $\sim$ 45,000
- Low signal to noise ratio $\sim$ 10 (only RVs)
- One or more observation/month, for 7 years so far
- $\sim$ 12 spectra/star

Good and bad spectrum

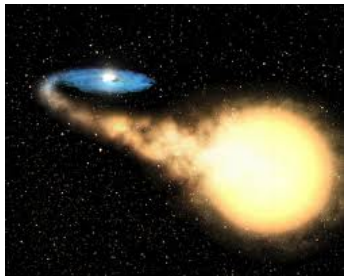




Data Analysis

- Cross Correlation with Template
  - Strongest, spectrum with max signal
  - Coadded, all spectra are shifted to common radial velocity and coadded
  - Delta, synthetic spectrum
- Difficulties
  - Low metallicity
  - Pecular abundances
  - Low signal to noise spectra
- Precision
  - Detect variations down to ~ 300m/s

Carbon-Enhanced Stars Formation Scenarios



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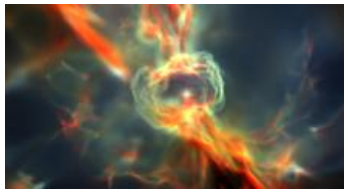

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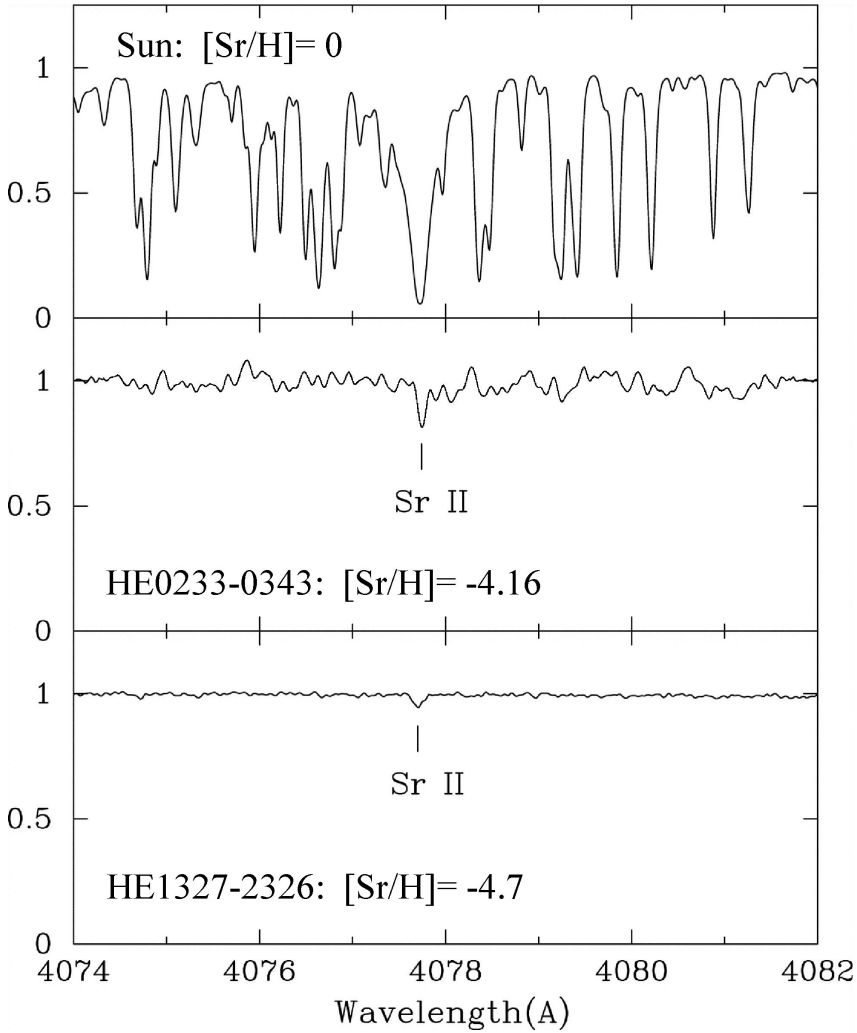
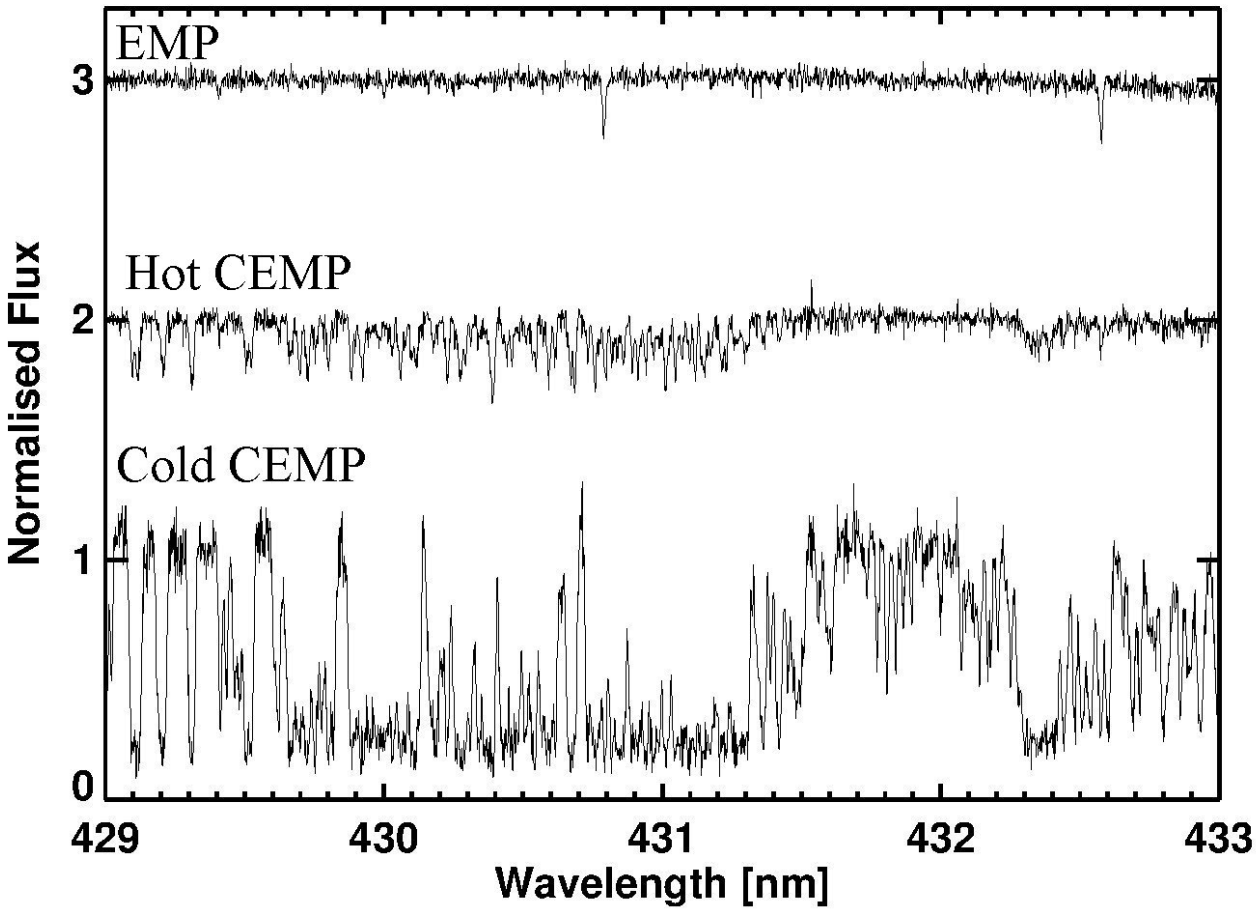
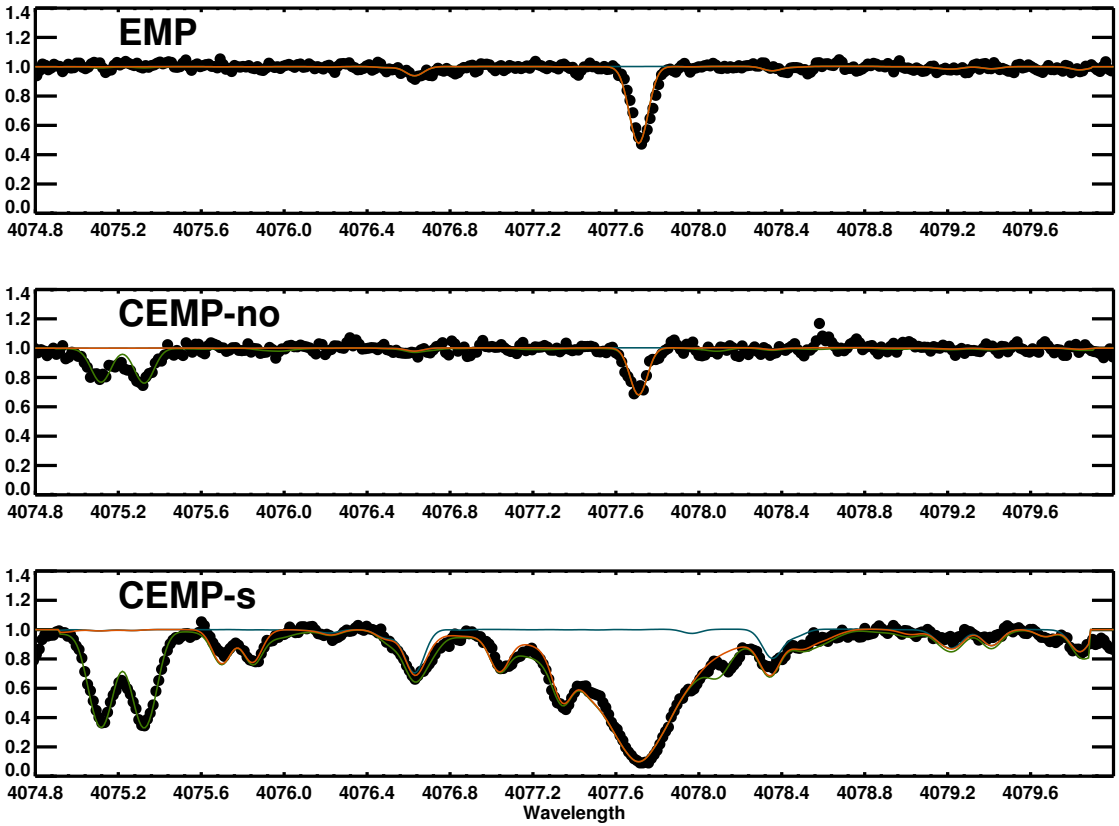
Metal-poor


Sun: [Sr/H]= 0
Sr II
HE0233-0343: [Sr/H]= -4.16
Sr II
HE1327-2326: [Sr/H]= -4.7
1
0.5
0
4074
4076
4078
4080
4082
Wavelength(A)

Carbon rich


EMP
Hot CEMP
Cold CEMP
Normalised Flux
0
1
2
3
429
430
431
432
433
Wavelength [nm]

CEMPs



only Fe, no C+N, all

Sample and Method

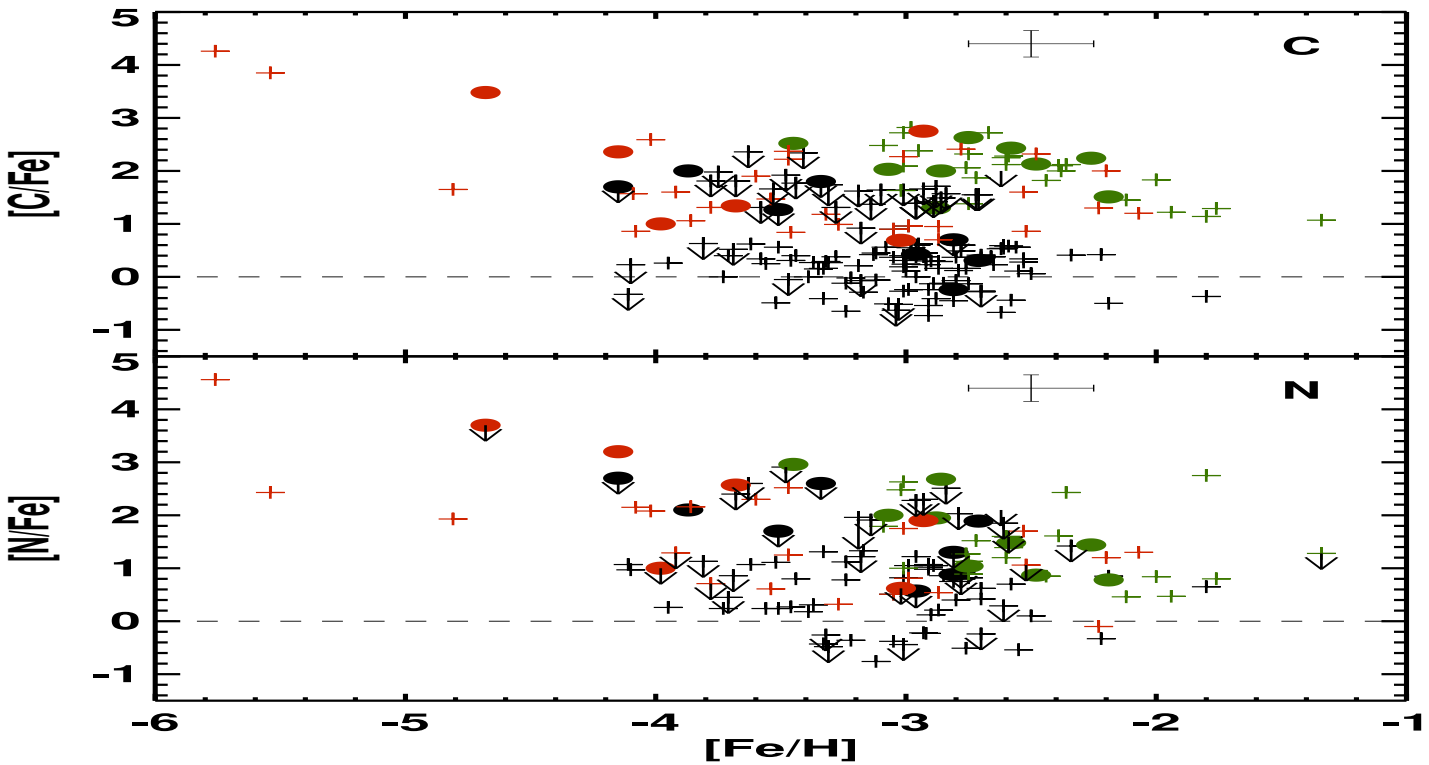
- ∼25 stars observed with VLT/UVES
- 1D LTE MOOG analysis
- Kurucz model atmospheres with $[\alpha/\mathrm{Fe}]$=+0.4
- T_{eff} from infrared flux method, Logg from Y^2 isochrones assuming age=10Gyr and $[\alpha/\mathrm{Fe}]$=+0.3
- Same method as The Most Metal Poor Stars project. (Yong et al 2013)
- Over 200 homogeneously analysed stars.

Stars in the Sample

Number	$[Fe/H] < -4$	$[Fe/H] < -3$	$[Fe/H] < -2$	$[Fe/H] < -1$
Total	12	102	208	213
C-enhanced	8	25	55	59

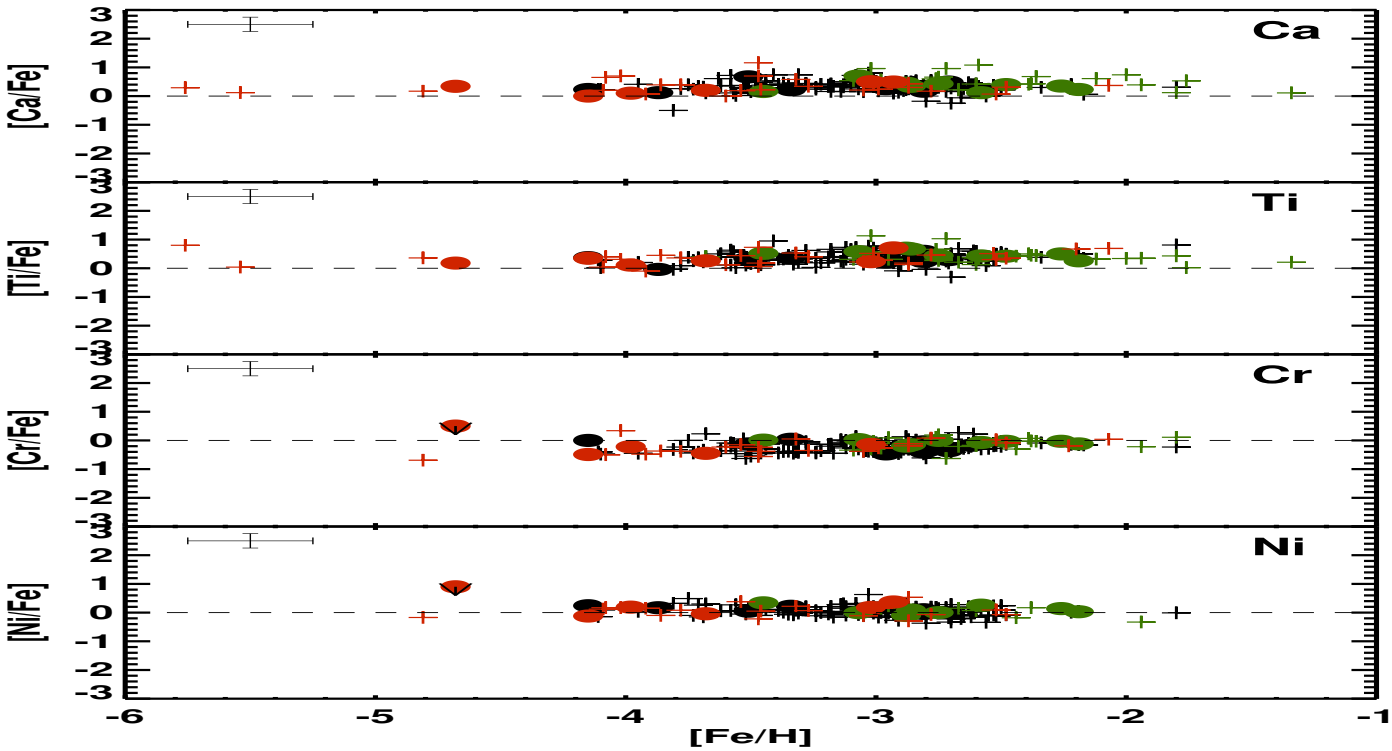
Normal: 155	CEMPno: 24	CEMPs: 29	CEMPrs: 5
$[Fe/H] < -1$	$[Fe/H] < -1$ $[C/Fe] > 0.7$ $[Ba/Fe] < 0.0$	$[Fe/H] < -1$ $[C/Fe] > 0.7$ $[Ba/Fe] > 0.0$ $[Ba/Eu] > 0.5$	$[Fe/H] < -1$ $[C/Fe] > 0.7$ $[Ba/Fe] > 0.0$ $0.0 < [Ba/Eu] < 0.5$

Carbon and nitrogen



- Hansen et al 2014 and in prep, + Yong et al. 2013, EMP, CEMPs and CEMPno

Alpha and iron



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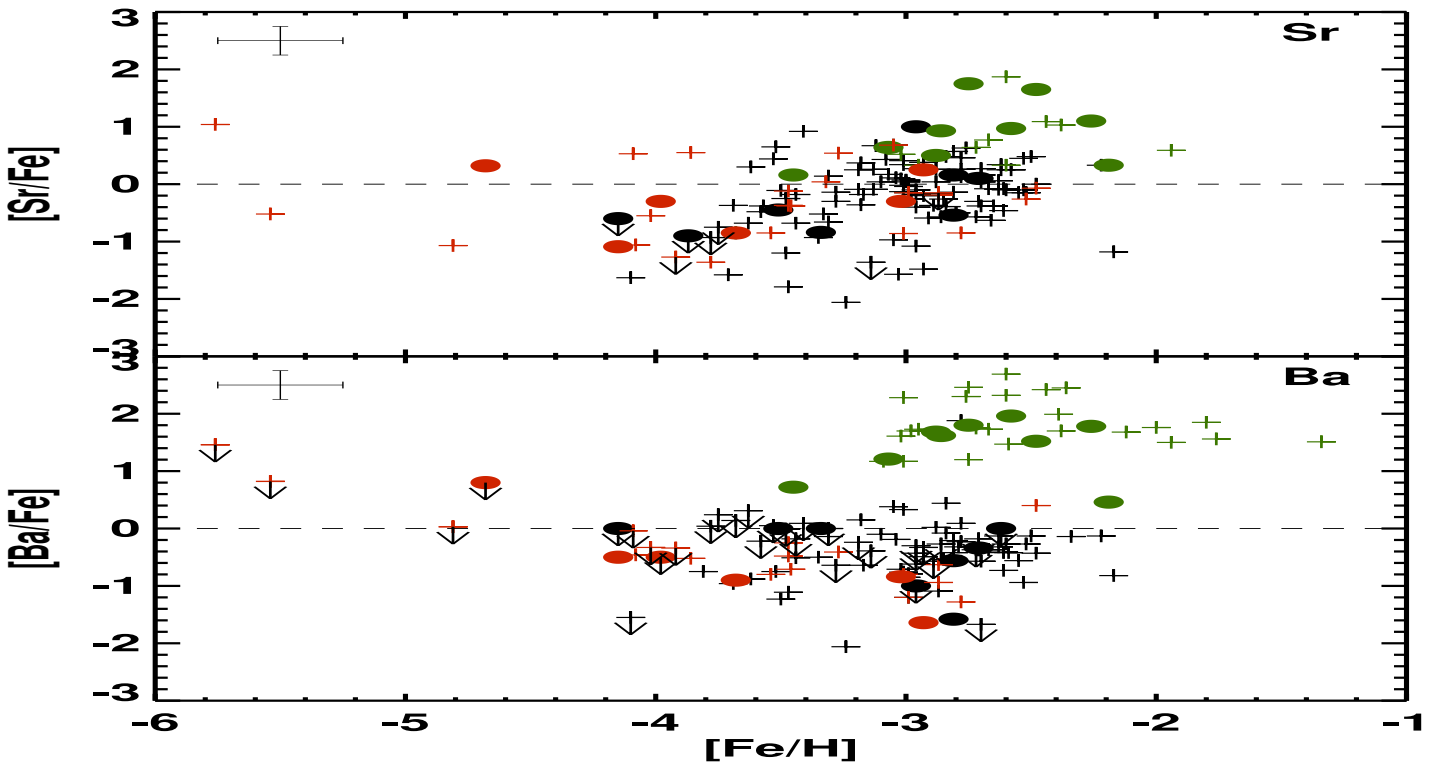
Neutron capture



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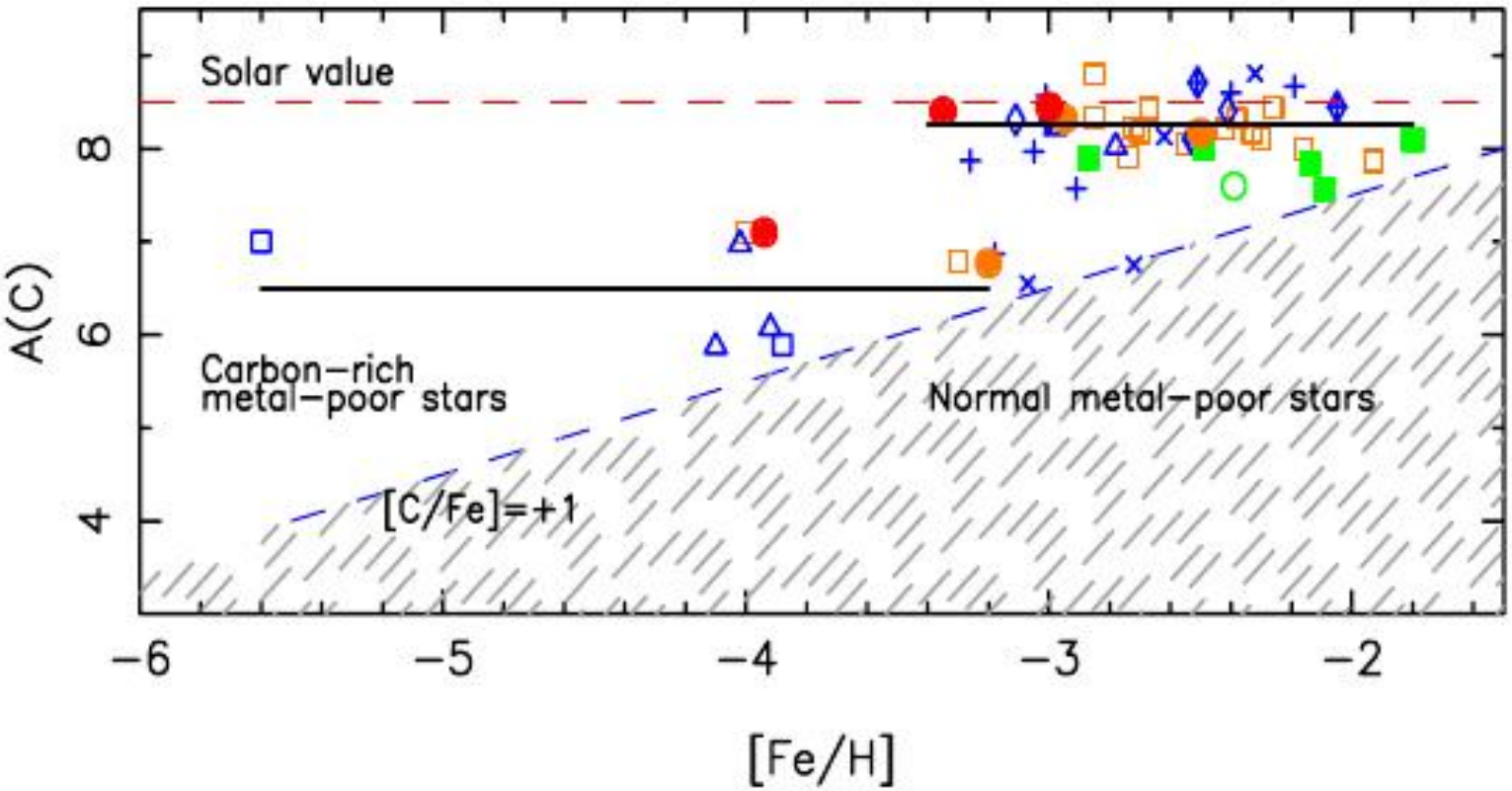
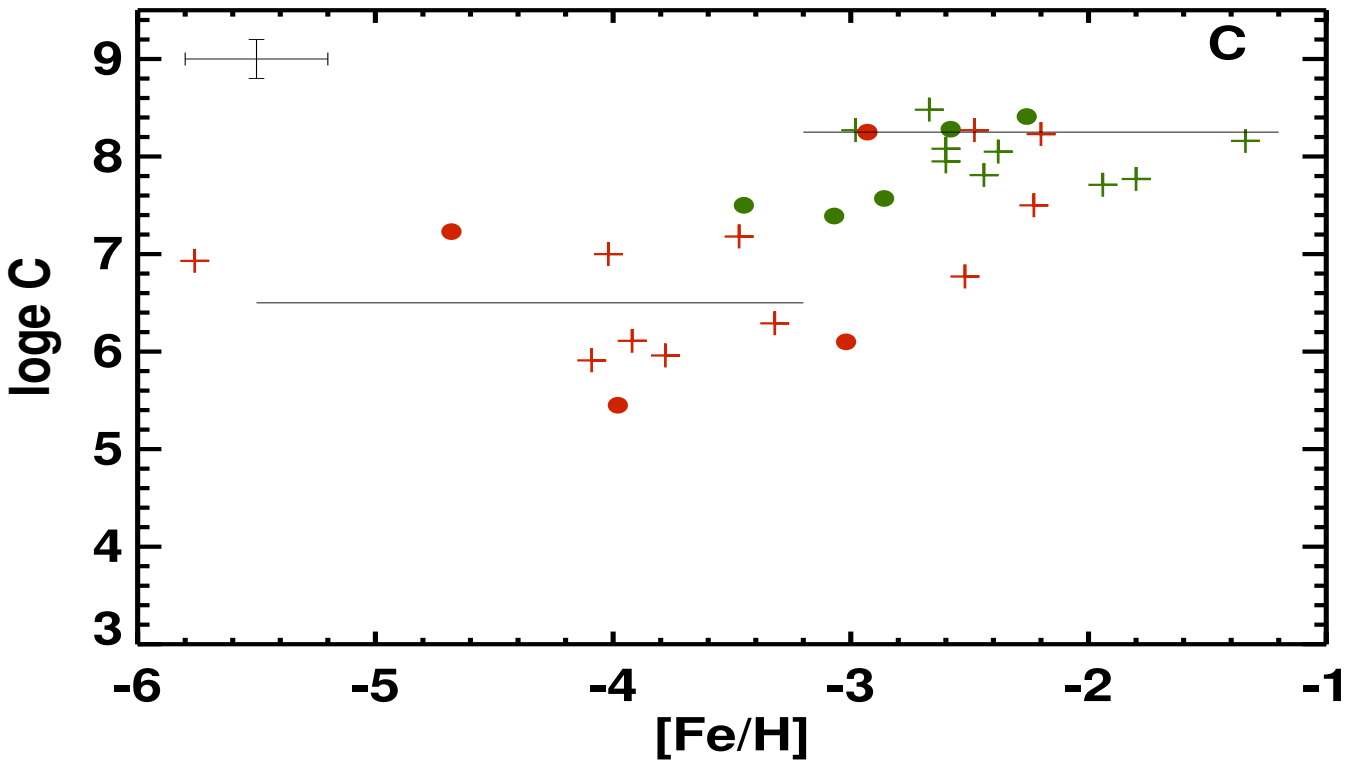
Carbon



Spite et al 2013

Carbon



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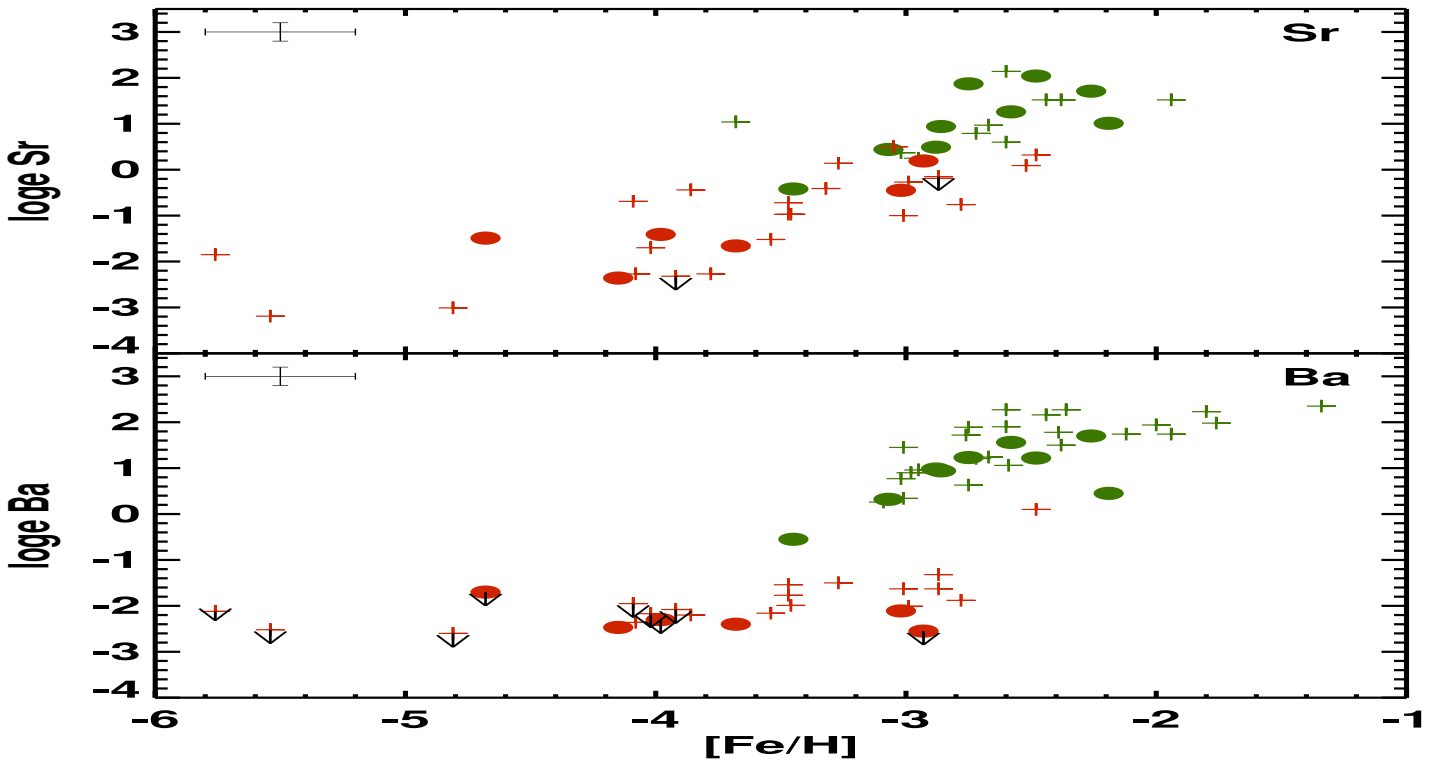

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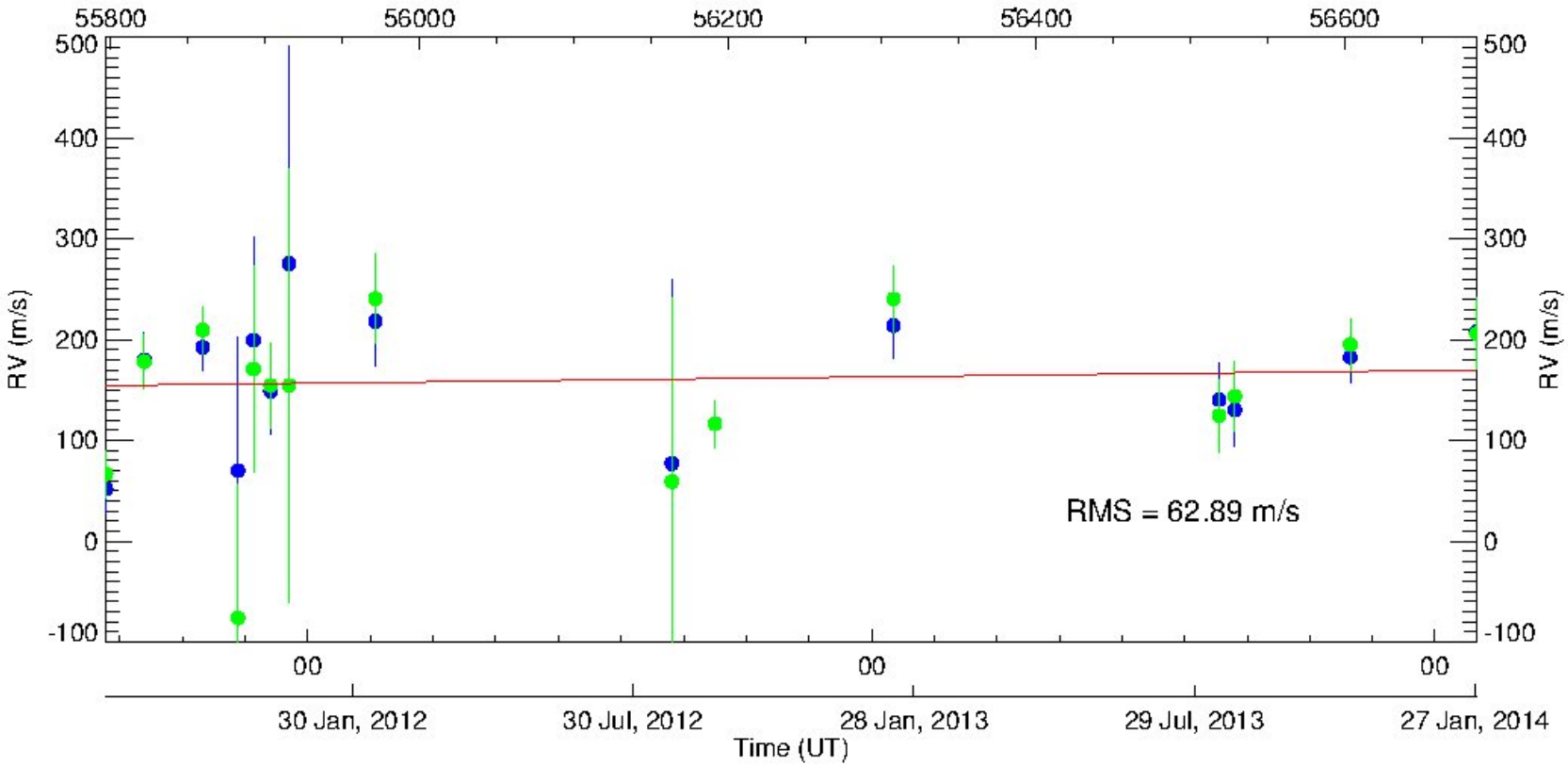
CEMPno

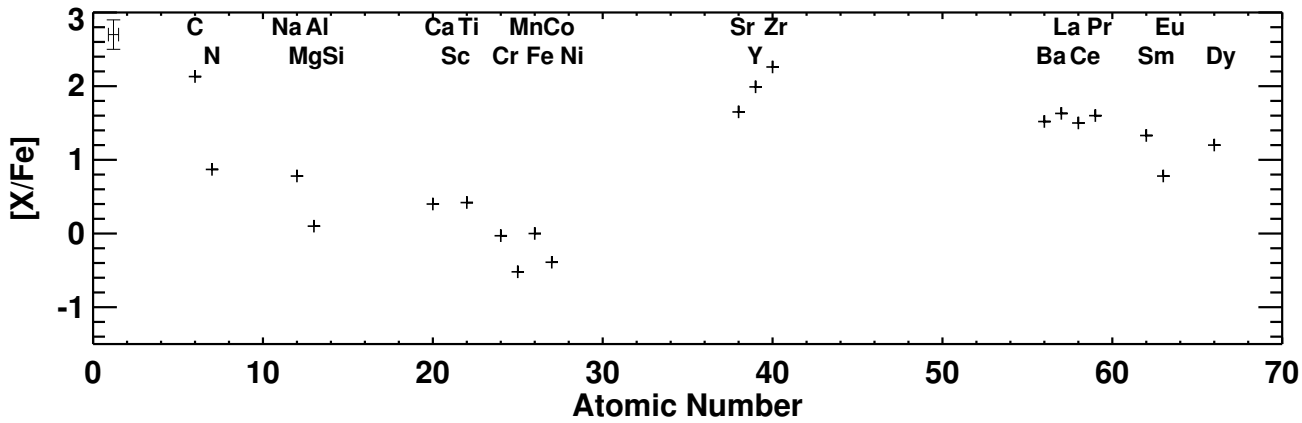
- The most metal poor stars known are CEMPno stars
- Alpha and iron group elements behave like normal EMP stars
- See neutron capture elements, Sr and Ba
- Carbon and Ba abundance plateau at $\log \epsilon(C) \sim 6.5$ and $\log \epsilon(Ba) \sim -2$
- 21 CEMPno stars monitored, 5 binaries (Hansen et al. in prep)

CEMPno radial velocity



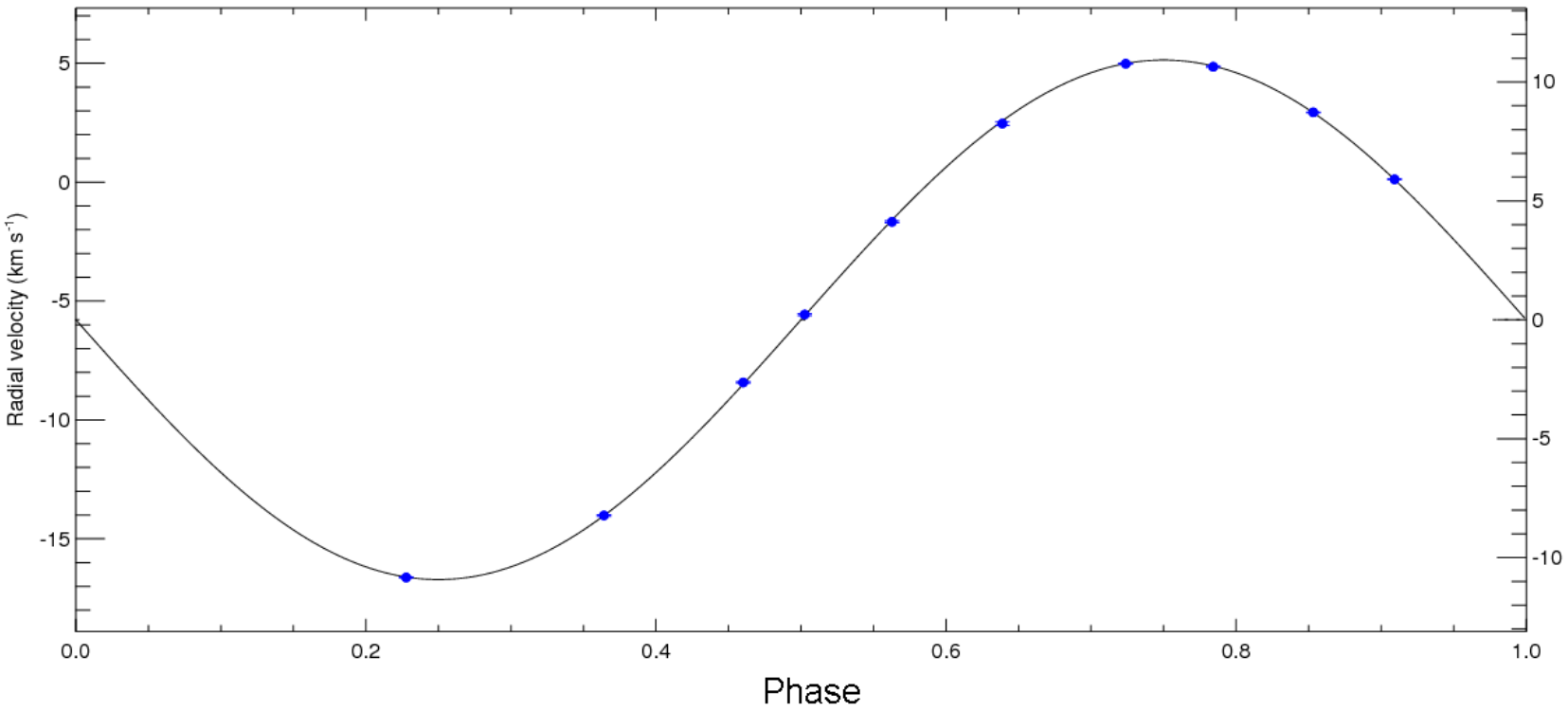
Hansen et al. in prep.

CEMPs



- Large carbon over abundances
- Alpha and iron group elements behave like normal EMP stars
- Strongly enhanced in s-process elements, Ba, La, Ce.....
- Large fraction of CEMP stars are CEMPs
- 12 CEMPs stars monitored, 10 binaries (Hansen et al. in prep)

CEMPs Binary



Period: 447 days, Semi-amplitude: 10.9km/s, Hansen et al. in prep.

Summary

CEMPs

- Binary
- Abundances pattern signature of metal-poor AGB stars.

CEMPno

- Not binary
- Abundance pattern signature of first stars.

Thank You.

Collaborators: Camilla J. Hansen, Norbert Christlieb, Tim Beers, David Yong, Mike Bessel, Johannes Andersen, Birgitta Nordstrom.