Carbon-Enhanced Metal-Poor Stars with SOAR

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Outline

BACKGROUND

- Types of CEMP Stars
- Carbon Production Mechanisms

SCIENCE WITH SOAR

- Oxygen Abundances: OSIRIS
- Survey to Identify New CEMP Stars: Goodman HTS

Carbon-Enhanced Metal-Poor (CEMP) Stars

- [Fe/H] < -1.0 and [C/Fe] > +1.0
- A significant fraction of metal-poor stars have been shown to have an enhancement of carbon
- This fraction appears to *increase with decreasing metallicity*

CEMP Fractions

[Fe/H] < -2.0 ---> 20%
[Fe/H] < -3.0 ---> 30%
[Fe/H] < -3.5 ---> 40%
[Fe/H] < -4.0 ---> 100%

(Lucatello et al. 2006; Christlieb et al. 2002; Frebel et al. 2005; Norris et al. 2007)

Different Types of CEMP Stars

(as defined in Beers & Christlieb 2005)

- **CEMP-s:** s-process element enhancement
  - **[Ba/Fe] > +1.0 and [Ba/Eu] > +0.5**
- **CEMP-r:** r-process element enhancement
  - [Eu/Fe] > +1.0
- **CEMP-r/s:** both s- and r-process enhancement
  - 0.0 < [Ba/Eu] < +0.5
- **CEMP-no:** no neutron-capture element enhancement
  - **[Ba/Fe] < 0.0**

CNO: The Elements of *Life!*

...But HOW and WHERE were they formed?

HOW? Reactions that form C, N, O are well-understood

Carbon ---> Triple-α

Nitrogen ---> CNO cycle

Oxygen ---> α-capture onto ^{12}C

WHERE? A more complicated question

Different types of CEMP stars (i.e. n-capture/no n-cature) =

Different astrophysical sites of carbon-production at early times!

CEMP-s: Most common type of CEMP star

1) Metal-poor AGB star (where s-process and carbon-production occurs) in a binary system

2) Mass-transfer from AGB star to lower-mass binary companion

3) Binary companion NOW observed as a CEMP-s star

WHERE? A more complicated question

CEMP-no: The second-most common CEMP star

Progenitor of these types is less well-understood

Massive, rapidly-rotating, mega metal-poor ([Fe/H] < -6.0) stars would be proficient producers of CNO with no n-capture-element production

(Meynet et al. 2006; Hirschi et al. 2006; Meynet et al. 2010)

Faint early supernovae undergoing extensive mixing and fallback → Heavy CNO production

Ito et al. 2009 (and references within)

Looking Back: *WAY Back*

Evidence of CEMP-no pattern in Damped Ly-α System

Mon. Not. R. Astron. Soc. **000**, 1–13 (2010) Printed 4 November 2010 (MN LATEX style file v2.2)

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

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Accepted . Received ; in original form

ABSTRACT

We present high resolution observations of an extremely metal-poor damped Lyα system, at $z_{\rm abs} = 2.3400972$ 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 ~ 20 greater than reported in any other damped Lyα system. In analogy to the carbon-enhanced metal-poor stars in the Galactic halo (with [C/Fe] $> +1.0$), this is the first reported case of a carbon-enhanced damped Lyα system. We determine an upper limit to the mass of ^{12}C, $M(^{12}{\rm C}) \leqslant 200\ M_{\odot}$, which depends on the unknown gas density n(H); if $n({\rm H}) > 1\,{\rm cm}^{-3}$ (which is quite likely for this DLA given its low velocity dispersion), then $M(^{12}{\rm C}) \leqslant 2\ M_{\odot}$, consistent with pollution by only a few prior supernovae. We speculate that DLAs such as the one reported here may represent the 'missing link' between the yields of Pop 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).

Key words: galaxies: abundances – galaxies: evolution – quasars: absorption lines – quasars: individual: J0035−0918 – stars: carbon – stars: Population III

Science with SOAR

In order to fully understand the origin of carbon-production, we need to determine elemental abundances for a large number of CEMP stars

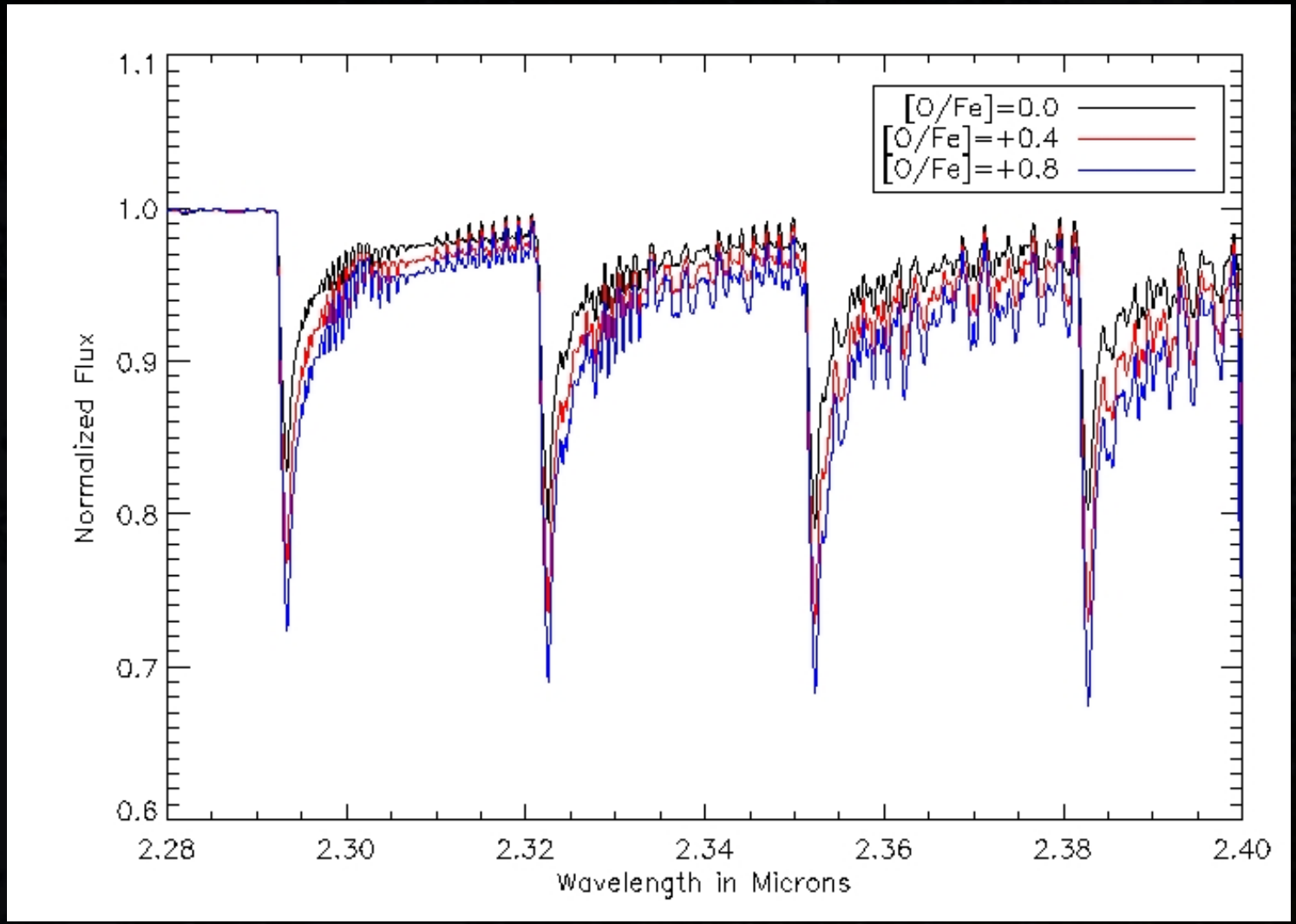
Enter SOAR!

1) Unprecedented numbers of [O/Fe] estimates with OSIRIS
2) New Survey to identify CEMP stars with Goodman

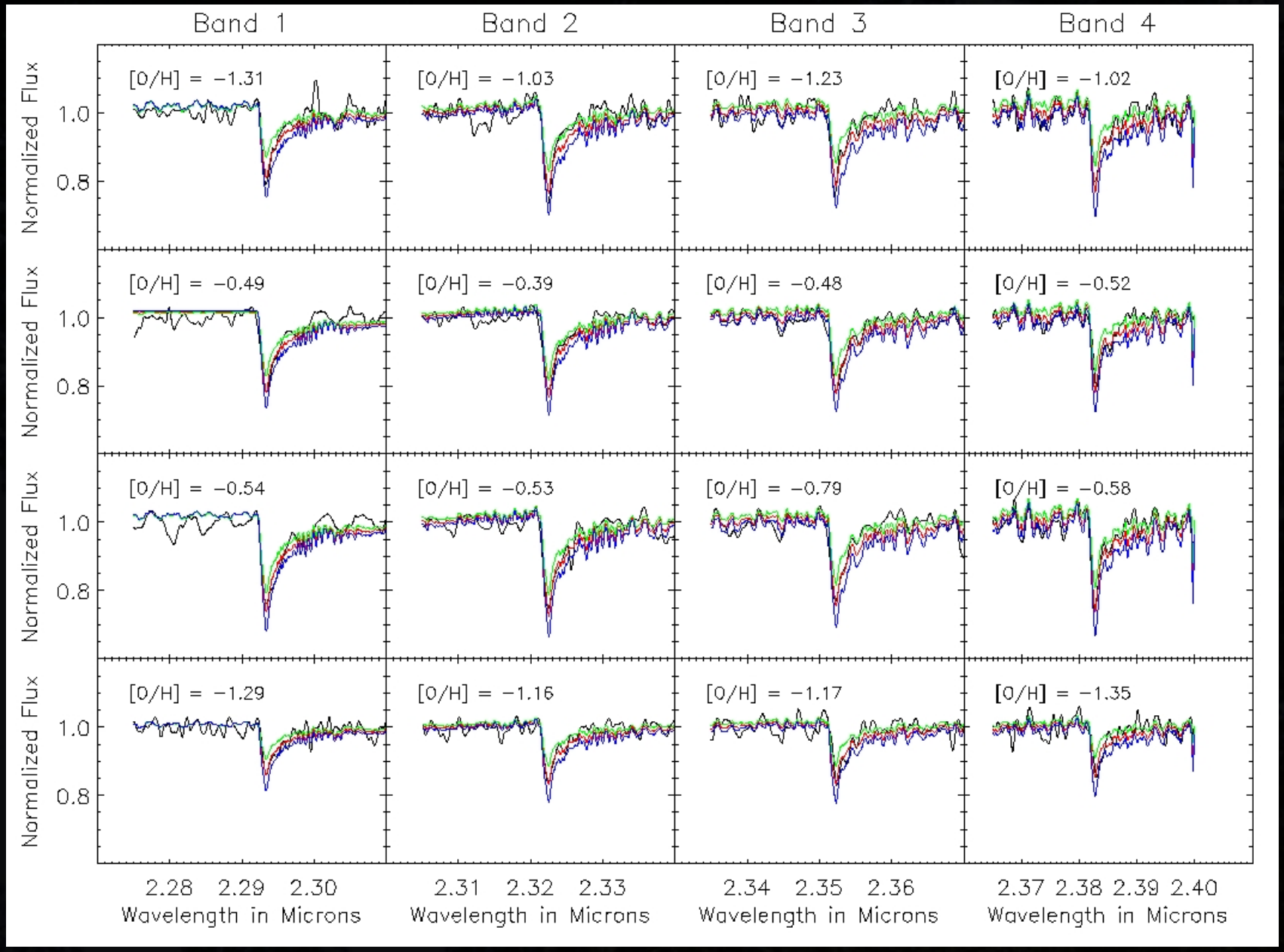
Oxygen Abundances: OSIRIS on SOAR

- Near-IR region of spectrum ideal for [O/Fe]
- Large CO rovibrational features around 2.3μm
- [O I] 6300 Å line weak in metal-poor stars
- Difficult to get [O/Fe] in optical spectra unless high-resolution data is available
- With OSIRIS on SOAR, we now have *new [O/Fe] estimates for 57 CEMP stars!*

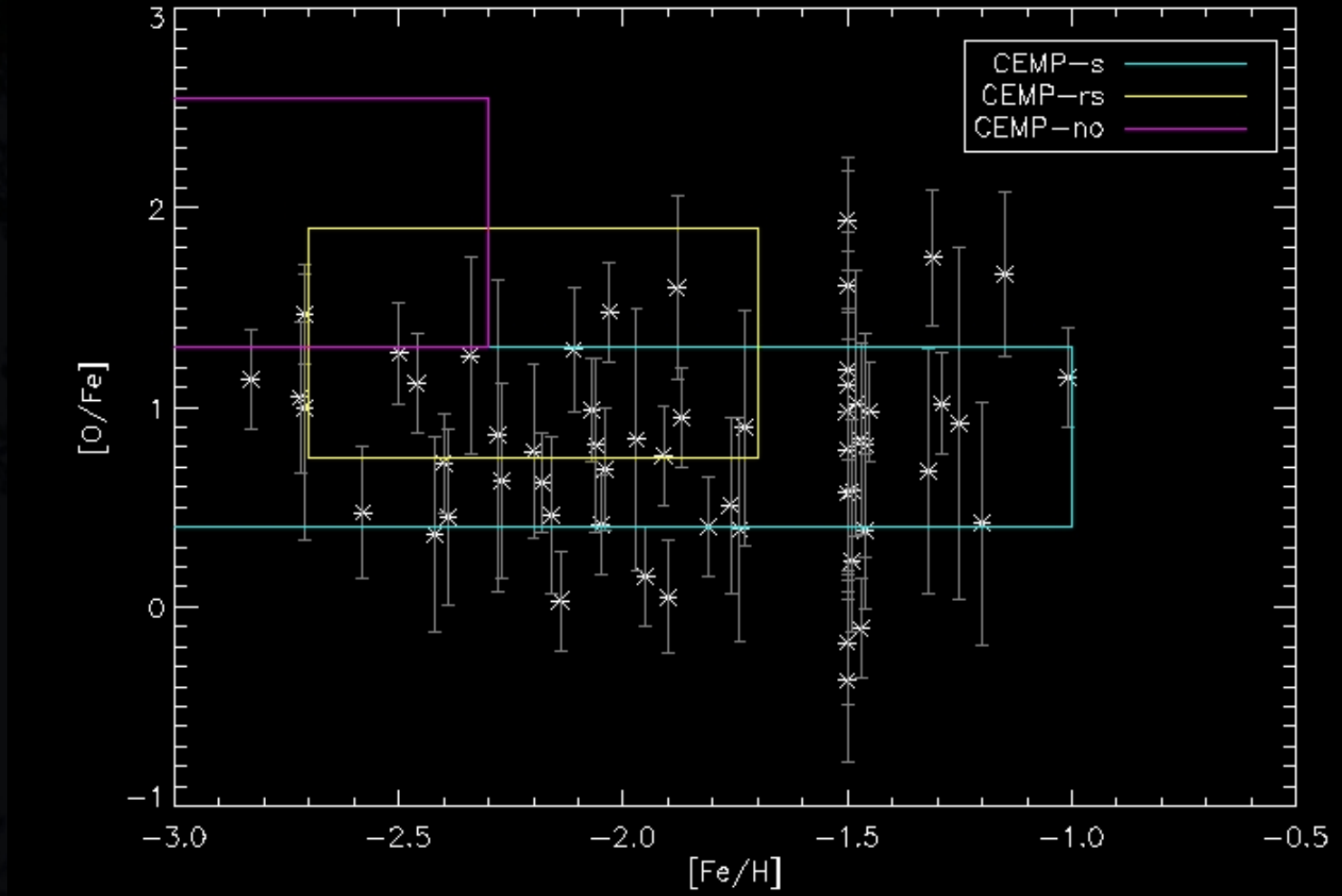
CO Features with Changing O abundance



OSIRIS Data


Band 1
Band 2
Band 3
Band 4
[O/H] = −1.31
[O/H] = −1.03
[O/H] = −1.23
[O/H] = −1.02
[O/H] = −0.49
[O/H] = −0.39
[O/H] = −0.48
[O/H] = −0.52
[O/H] = −0.54
[O/H] = −0.53
[O/H] = −0.79
[O/H] = −0.58
[O/H] = −1.29
[O/H] = −1.16
[O/H] = −1.17
[O/H] = −1.35
Normalized Flux
1.0
0.8
2.28 2.29 2.30
2.31 2.32 2.33
2.34 2.35 2.36
2.37 2.38 2.39 2.40
Wavelength in Microns

CEMP Stars with Neutron-Capture-Element Enhancement



A New CEMP Survey with SOAR

The Astronomical Journal, 139:1051–1065, 2010 March doi:10.1088/0004-6256/139/3/1051

A SEARCH FOR UNRECOGNIZED CARBON-ENHANCED METAL-POOR STARS IN THE GALAXY

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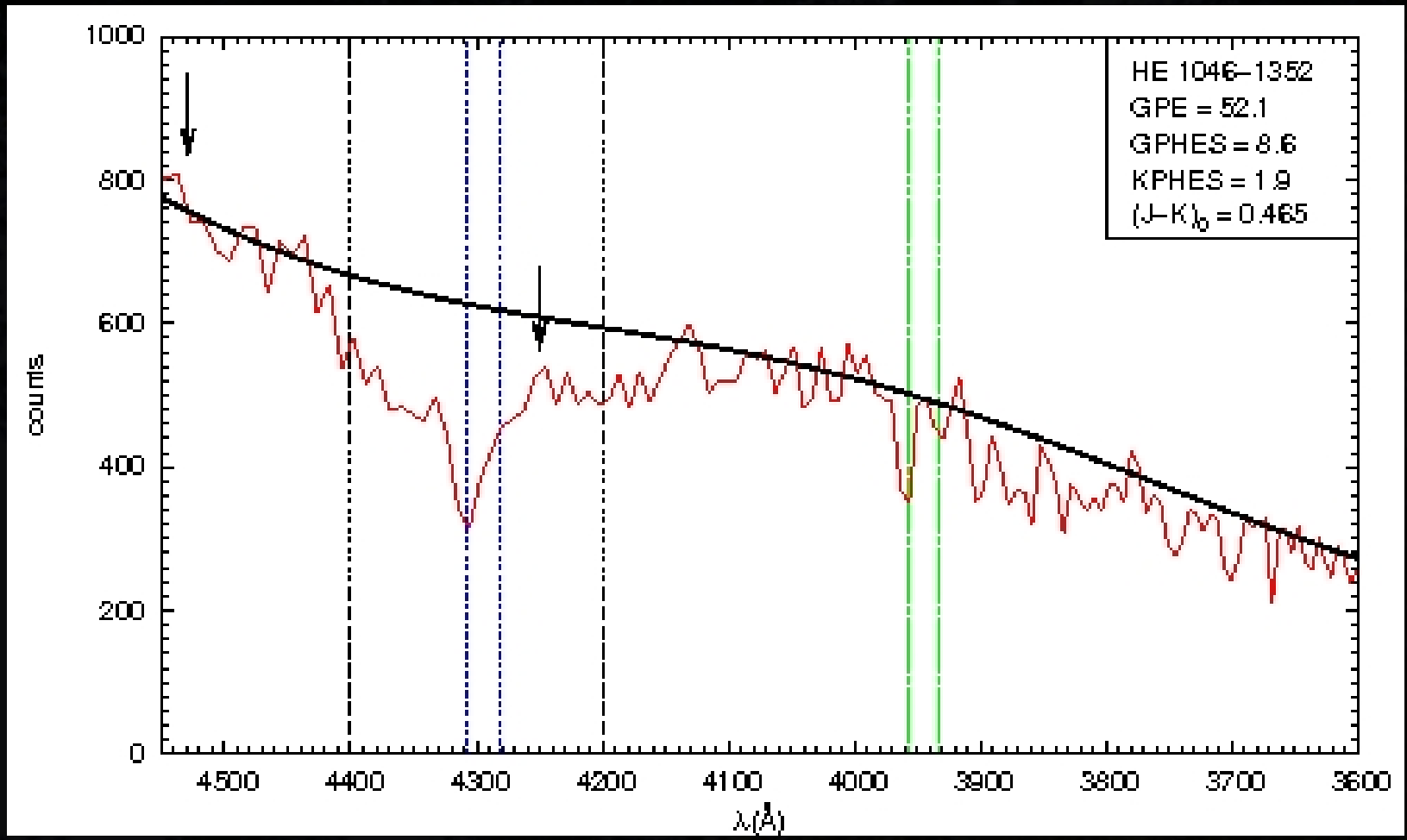
ABSTRACT

We have developed a new procedure to search for carbon-enhanced metal-poor (CEMP) stars from the Hamburg/ESO (HES) prism-survey plates. This method employs an extended line index for the CH *G* band, which we demonstrate to have superior performance when compared to the narrower *G*-band index formerly employed to estimate *G*-band strengths for these spectra. Although CEMP stars have been found previously among candidate metal-poor stars selected from the HES, the selection on metallicity undersamples the population of intermediate-metallicity CEMP stars ($-2.5 \leqslant$ [Fe/H] $\leqslant -1.0$); such stars are of importance for constraining the onset of the s-process in metal-deficient asymptotic giant branch stars (thought to be associated with the origin of carbon for roughly 80% of CEMP stars). The new candidates also include substantial numbers of warmer carbon-enhanced stars, which were missed in previous HES searches for carbon stars due to selection criteria that emphasized cooler stars. A first subsample, biased toward brighter stars ($B < 15.5$), has been extracted from the scanned HES plates. After visual inspection (to eliminate spectra compromised by plate defects, overlapping spectra, etc., and to carry out rough spectral classifications), a list of 669 previously unidentified candidate CEMP stars was compiled. Follow-up spectroscopy for a pilot sample of 132 candidates was obtained with the Goodman spectrograph on the SOAR 4.1 m telescope. Our results show that most of the observed stars lie in the targeted metallicity range, and possess prominent carbon absorption features at 4300 Å. The success rate for the identification of new CEMP stars is 43% (13 out of 30) for [Fe/H] < -2.0. For stars with [Fe/H] < -2.5, the ratio increases to 80% (four out of five objects), including one star with [Fe/H] < -3.0.

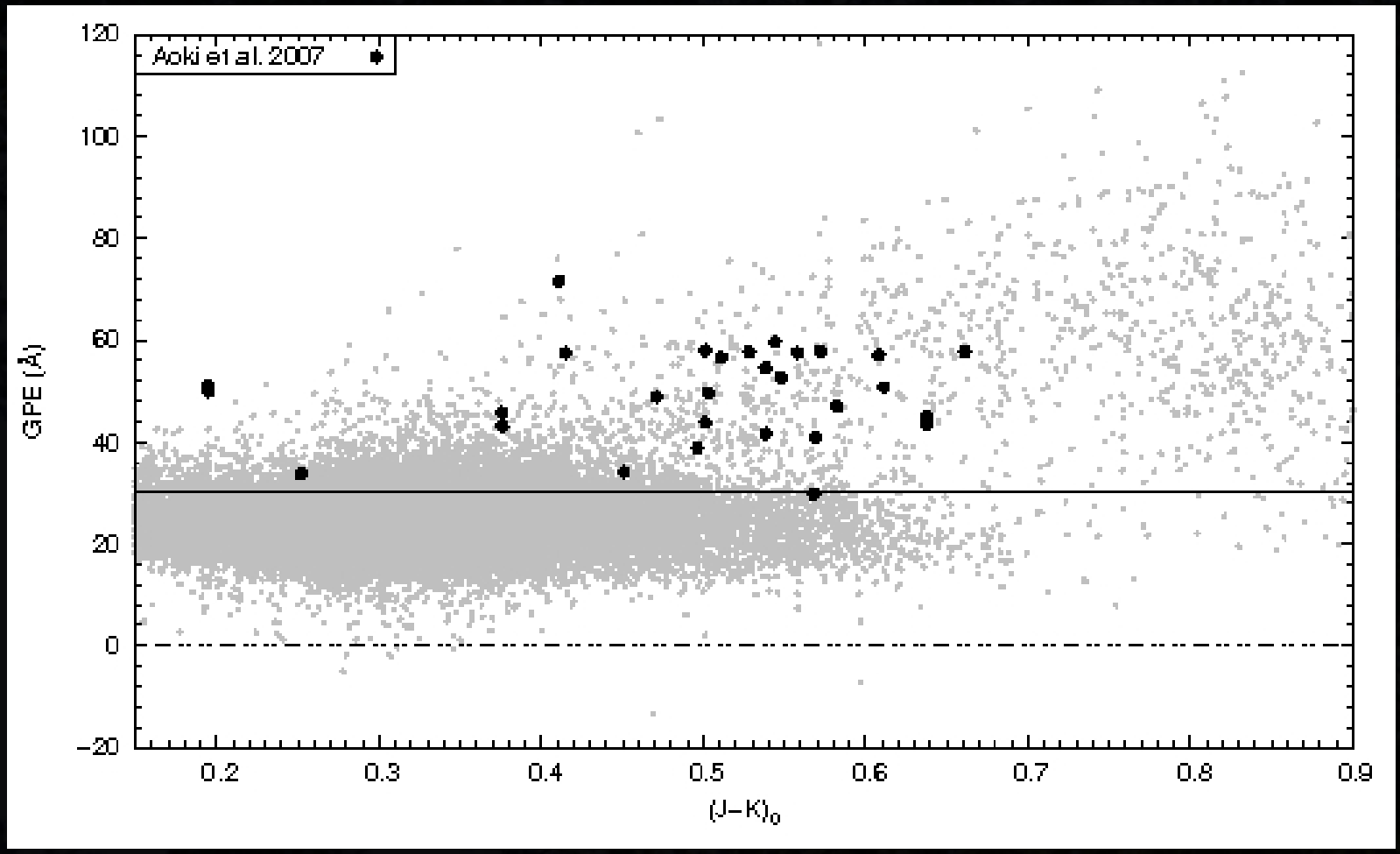
Key words: Galaxy: halo – stars: abundances – stars: carbon – stars: Population II – surveys – techniques: spectroscopic

The New *G*-band Index: *GPE*

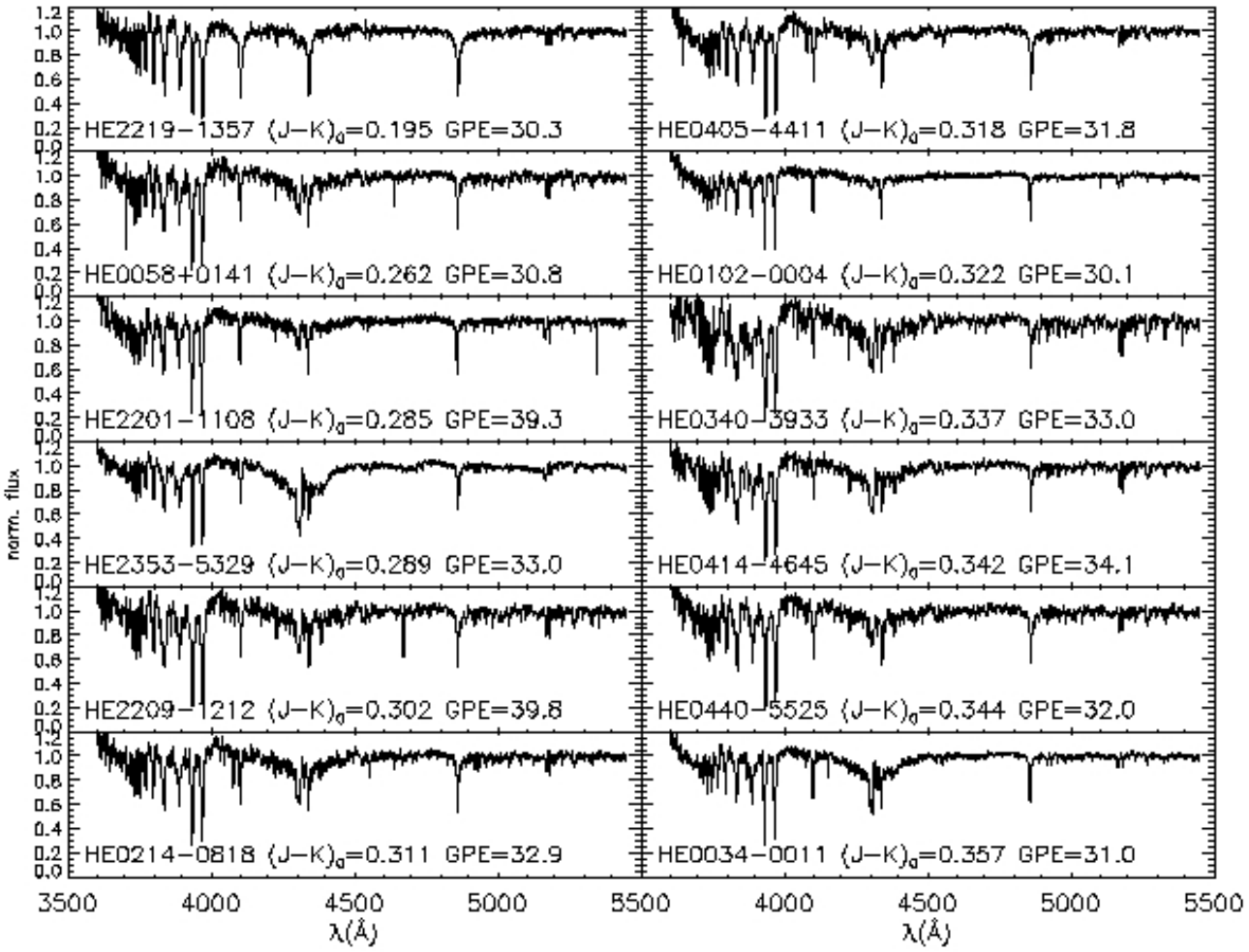


See Vinicius Placco's poster for the most recent selection techniques

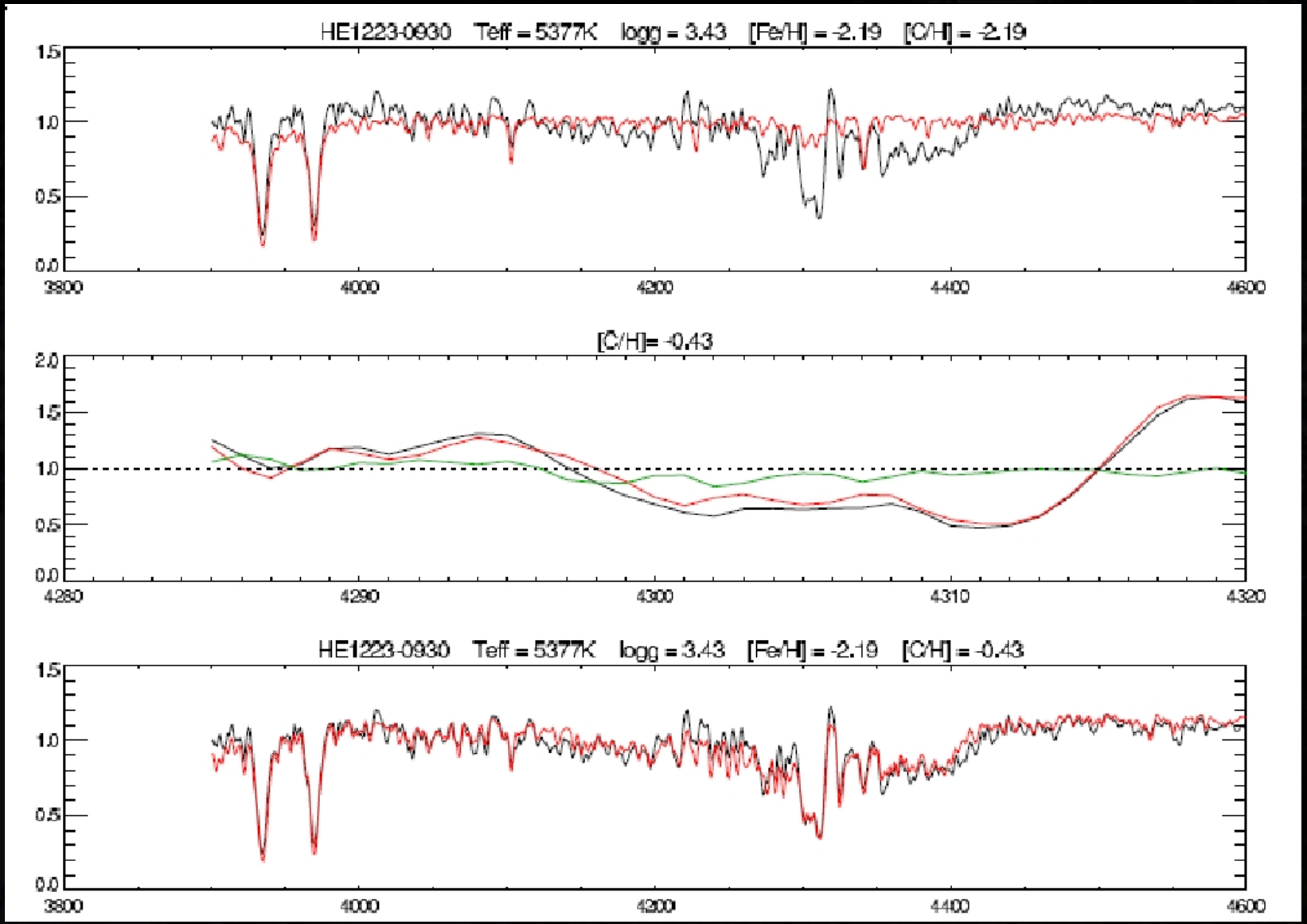
The GPE Cutoff Value



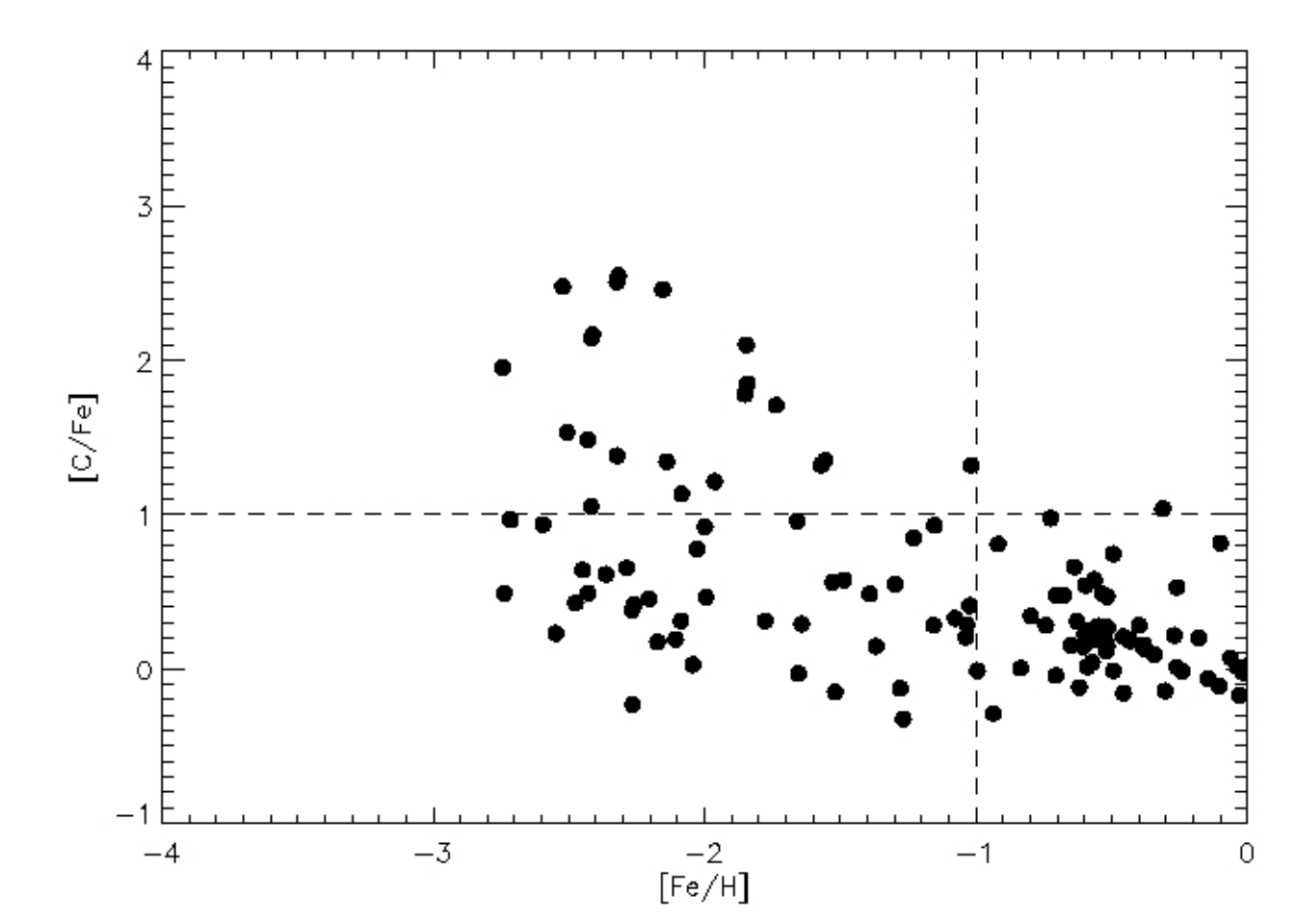
Goodman HTS Spectra



Estimating Carbon Abundances



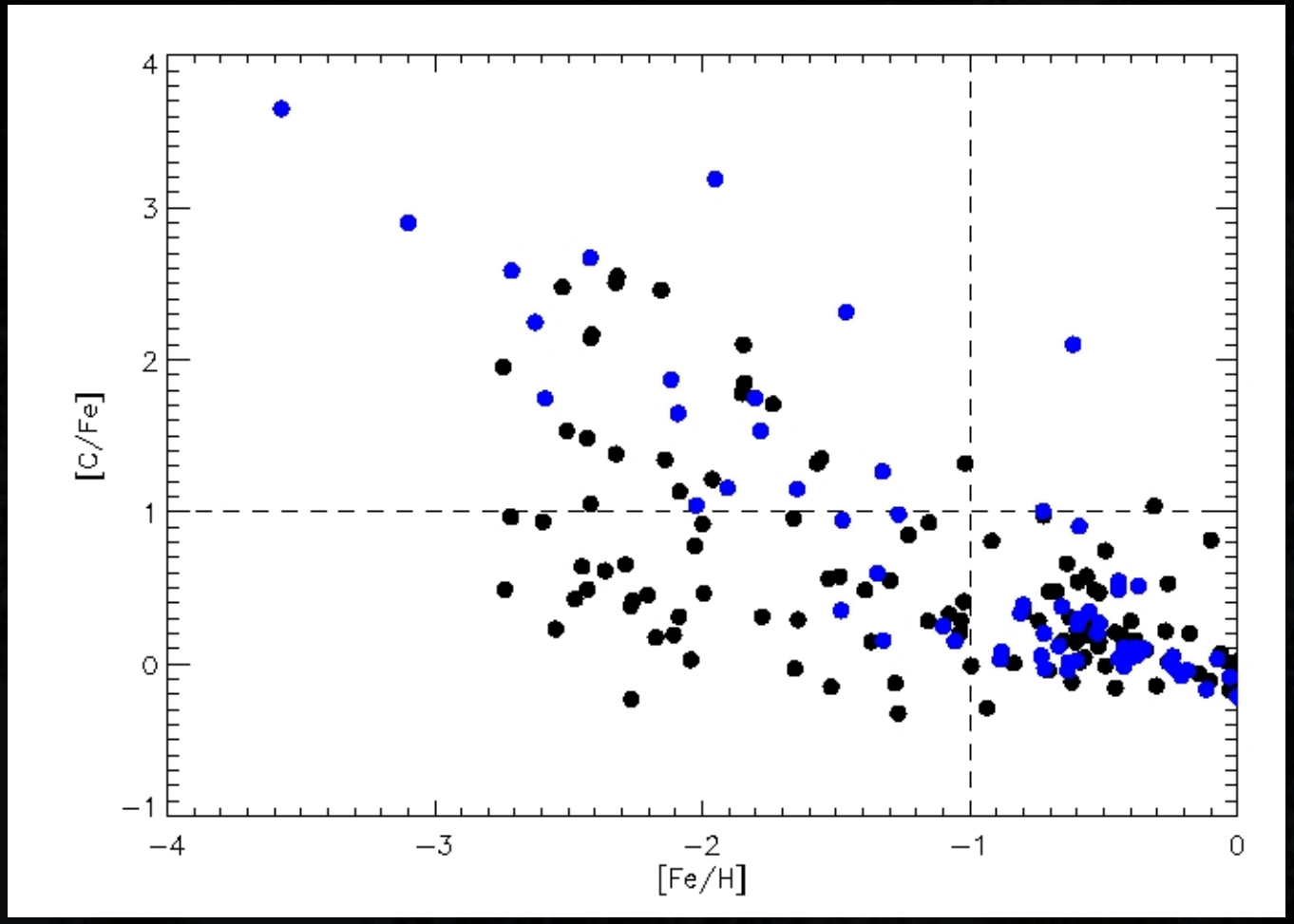
The Pilot Sample: Goodman on SOAR



[Fe/H] < -1.0: 36% CEMP

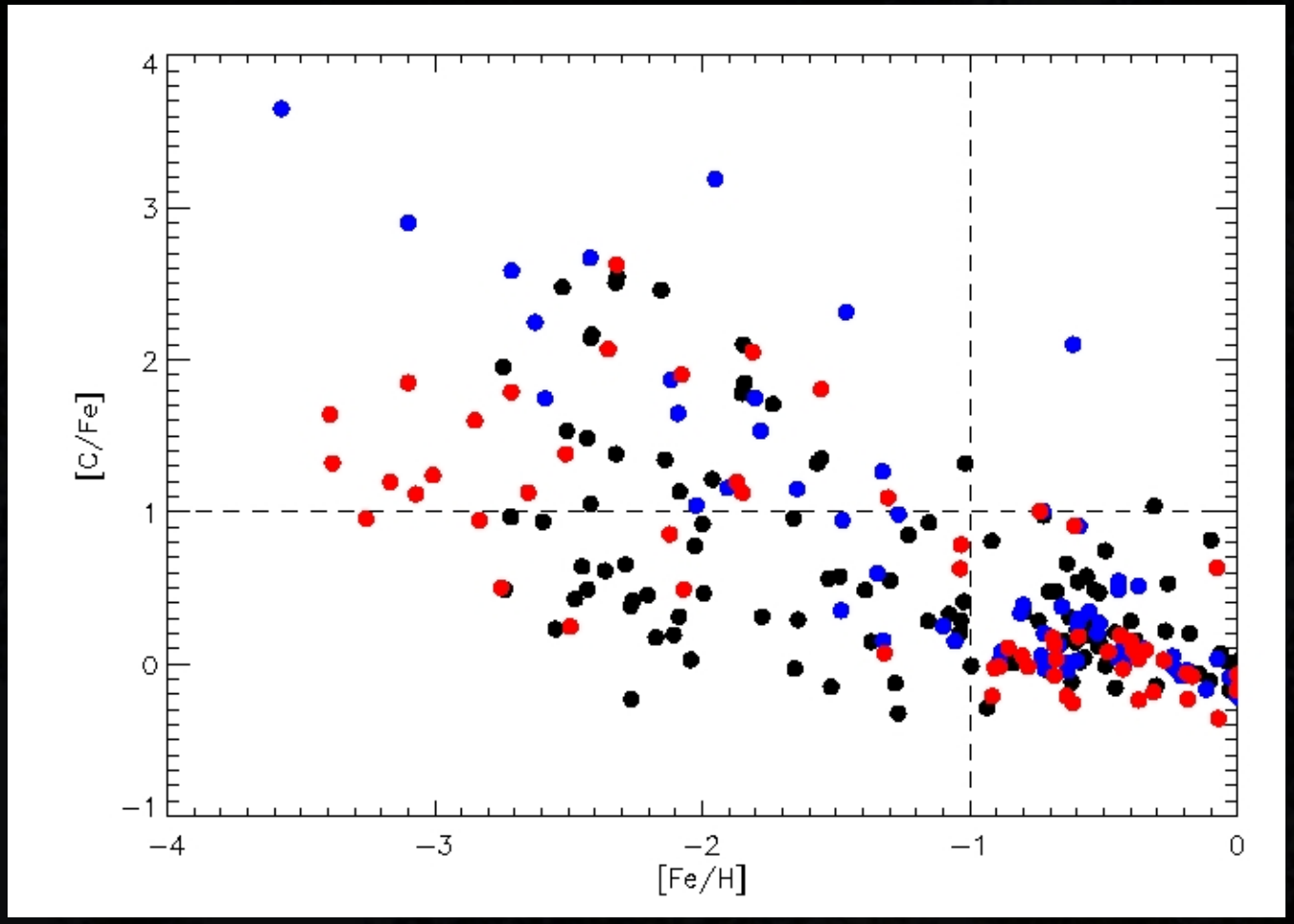
[Fe/H] < -2.0: 42% CEMP

Pilot Sample + GMOS on Gemini



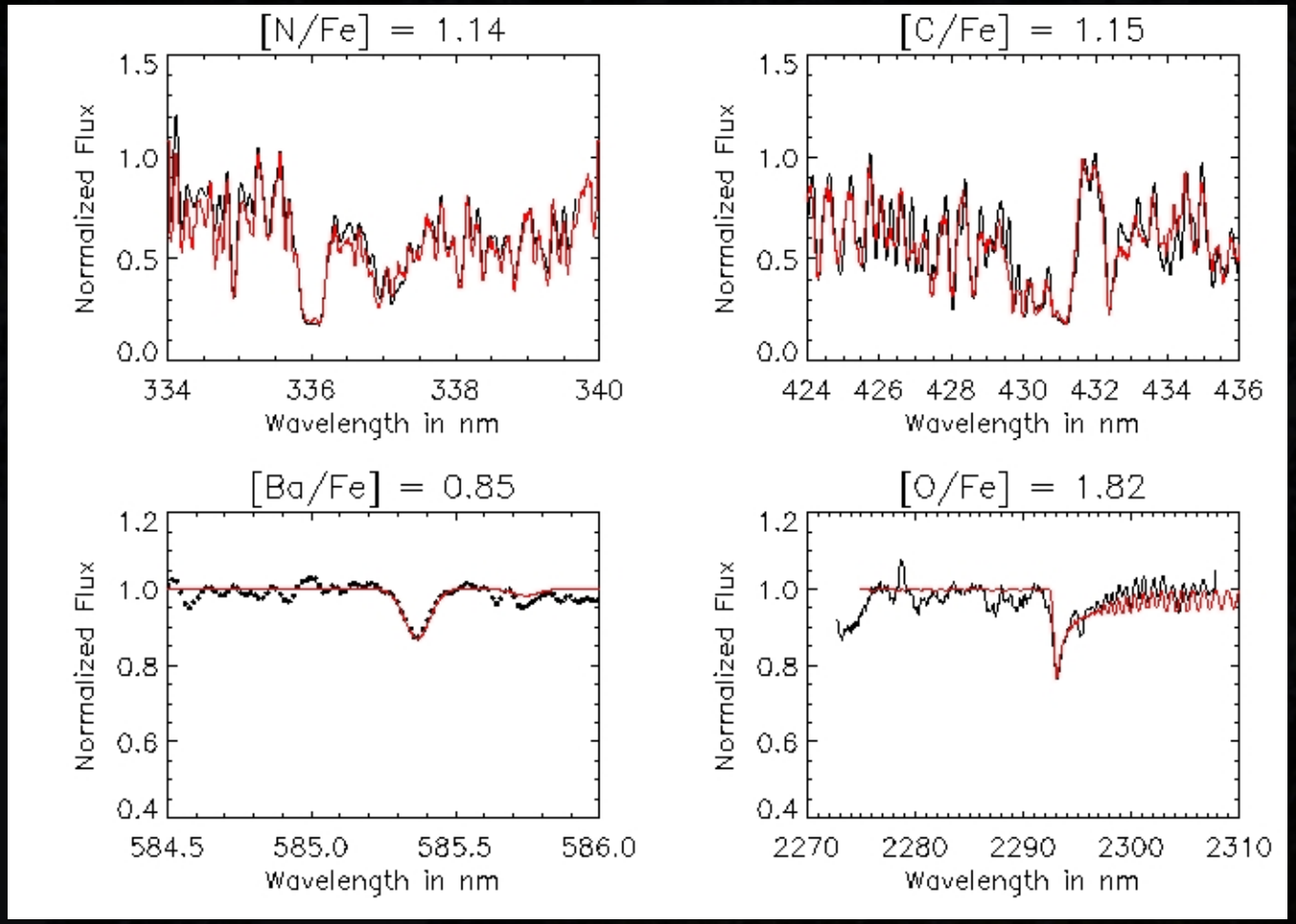
[Fe/H] < -1.0: 45% CEMP
[Fe/H] < -2.0: 55% CEMP
[Fe/H] < -3.0: 100% CEMP

Pilot + Gemini + New Goodman (2010,2011)



[Fe/H] < -1.0: 50% CEMP
[Fe/H] < -2.0: 59% CEMP
[Fe/H] < -3.0: 100% CEMP

Future Follow-up of Survey CEMP Stars using XSHOOTER



Conclusions

- Elusive oxygen abundances for CEMP stars easily and efficiently determined using OSIRIS on SOAR
- New CEMP survey effort began with the Goodman Spectrograph on SOAR
- Survey is currently being continued on SOAR and Gemini telescopes: ~250 stars observed so far
- ~60 new CEMP stars discovered! XSHOOTER and/or high-res follow-up in the near future


Thank you, SOAR!