THE FIRST STARS AND HEAVY METAL PRODUCTION

Ian U. Roederer, University of Michigan

Finding the UV-Visible Path Forward: A Community Workshop to Plan the Future
of UV/Visible Space Astrophysics
NASA GSFC, 25 June 2015

This talk summarizes two whitepapers submitted to the 2015 COPAG call for large astrophysics missions to be studied by NASA prior to the 2020 Decadal Survey:

"The First Stars and the First Metals"
(I.U. Roederer, A. Frebel, T.C. Beers)

"The Origin of Elements Heavier than Iron"
(I.U. Roederer, J.S. Sobeck, J.E. Lawler)

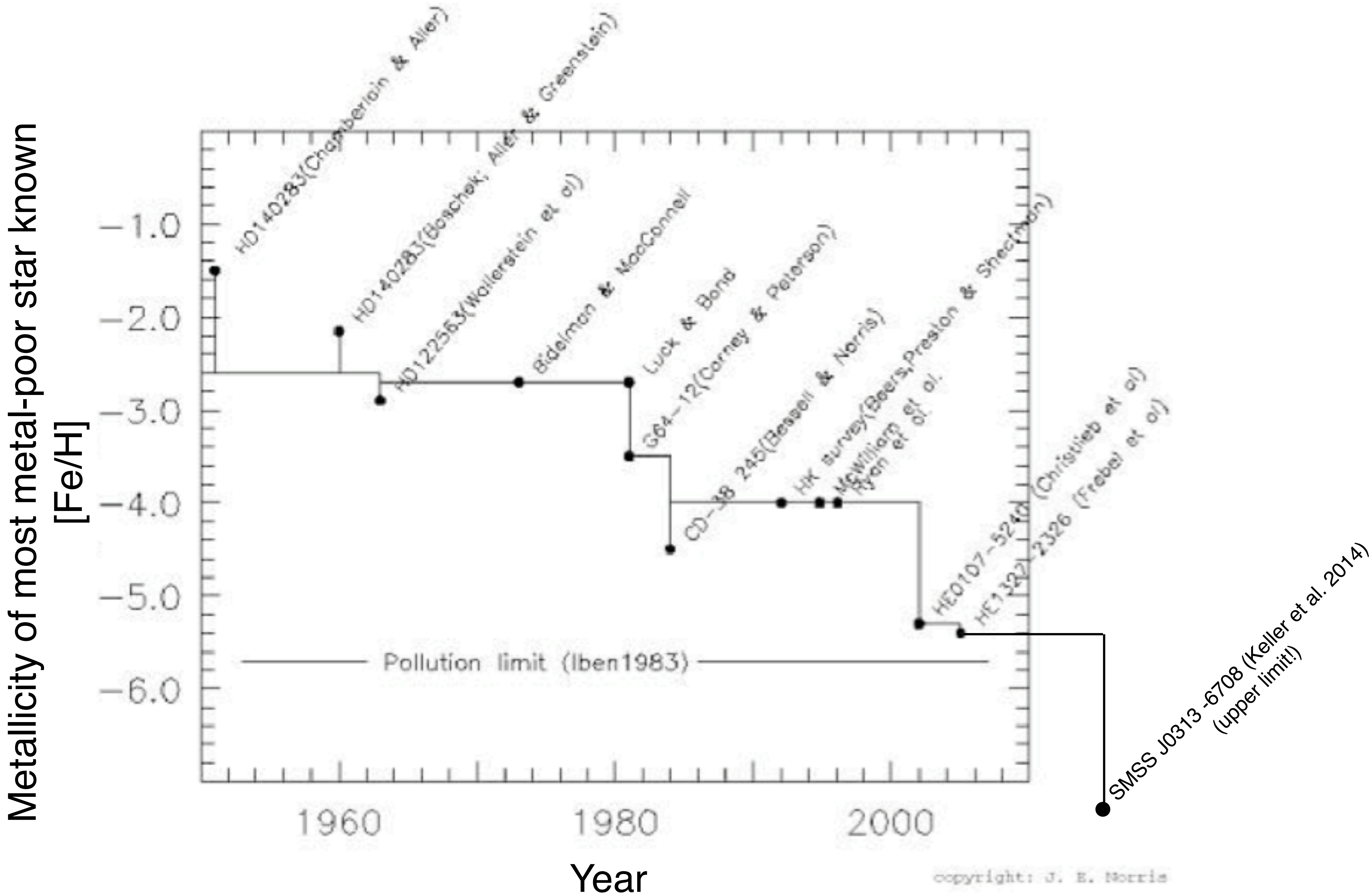
These whitepapers describe observations designed to address several Cosmic Origins science questions:

How did the first stars influence their environments?
How were the chemical elements dispersed through the CGM?
How did galaxies form and evolve?
How did baryons destined to form planets grow to heavy atoms?

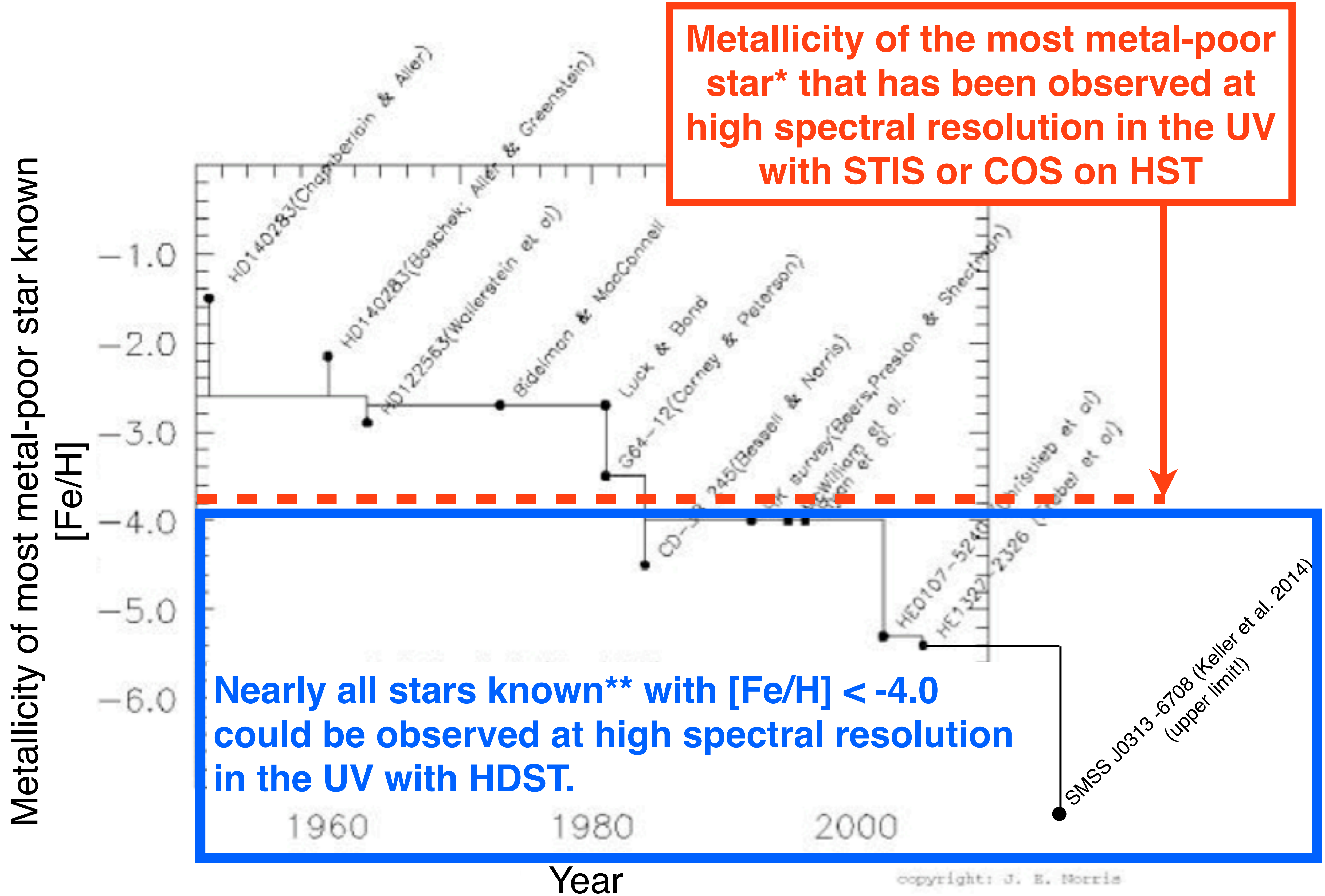
Reminder:

We don't (usually) observe metals in the star that produced them.

High-quality UV spectra collected with HST demonstrate the potential to use the metal abundance patterns in late-type stars to study stellar physics and metal recycling across a Hubble time.



Metallicity of most metal-poor star known [Fe/H]
Year
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
1960
1980
2000
HD140283(Chamberlain & Aller)
HD140283(Baschek; Aller & Greenstein)
HD122563(Wallerstein et al)
Bidelman & MacConnell
Luck & Bond
G64-12(Carney & Peterson)
CD-38 245(Bessell & Norris)
HK survey(Beers,Preston & Shectman)
McWilliam et al.
Ryan et al.
HE0107-5240 (Christlieb et al)
HE1327-2326 (Frebel et al)
Pollution limit (Iben1983)
SMSS J0313 -6708 (Keller et al. 2014)
(upper limit!)
copyright: J. E. Norris



* BD+44 493 (V = 9.1) —— Placco, Beers, Roederer, et al. (2014, ApJ, 790, 34)

** Currently about 20 such stars are known, and more are expected to be found in future surveys.

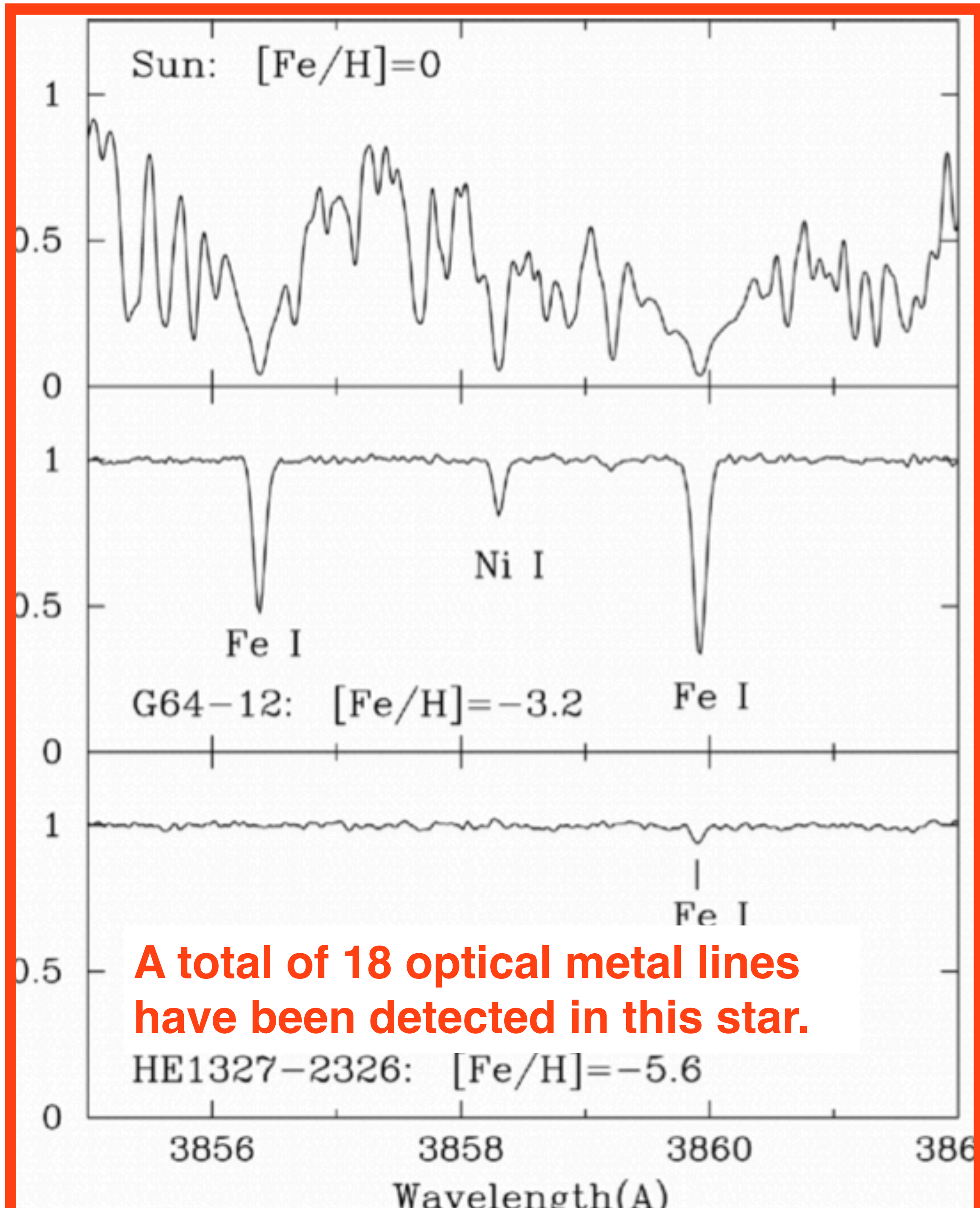
Why observe low-metallicity stars in the UV with HDST?

Most of the metal absorption lines are found only in the UV.

More detailed chemical inventory → more details about the first stars (NEAR-FIELD COSMOLOGY)

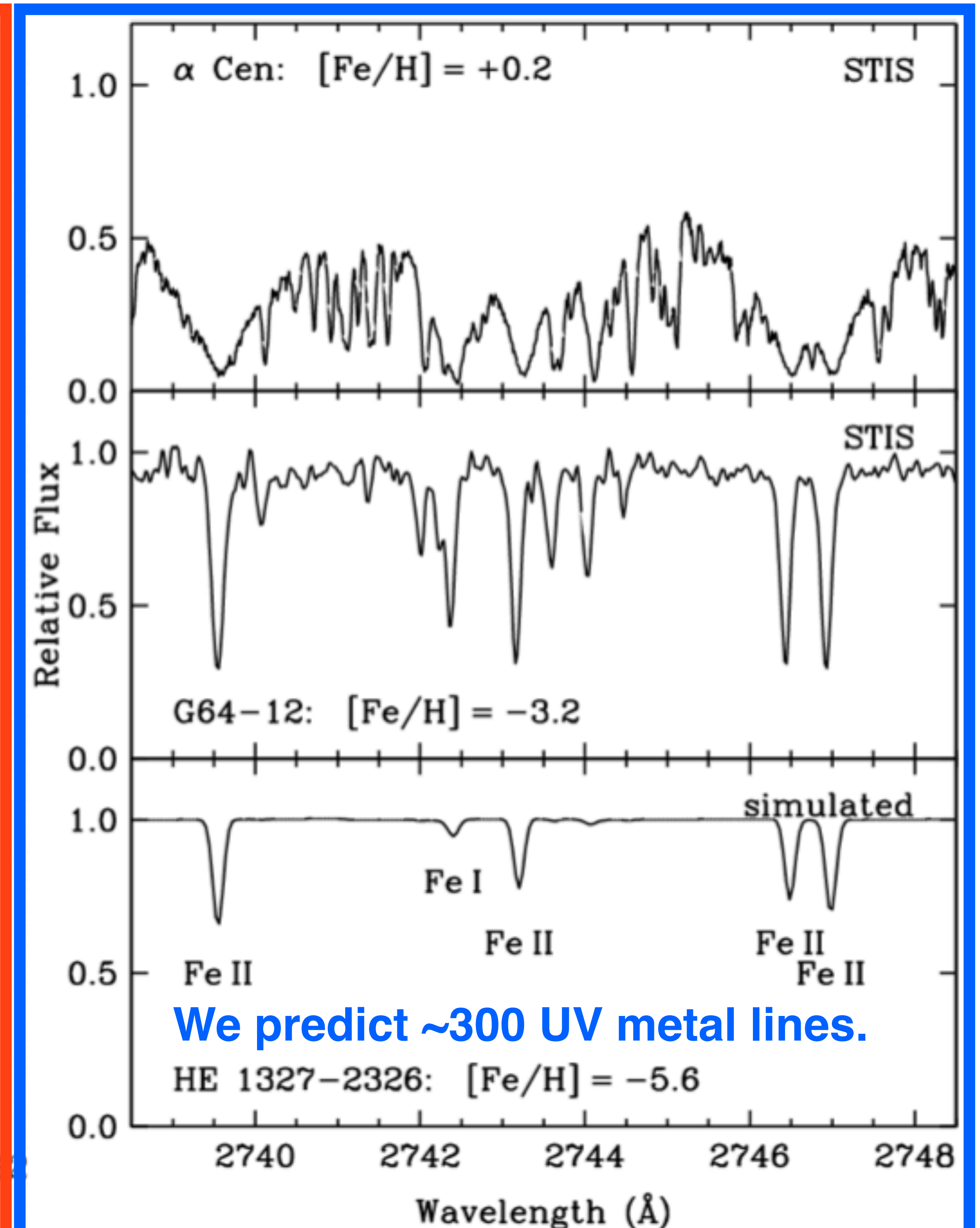
Metal lines in the optical nearly disappear at the lowest metallicities. In the UV, there are expected to be hundreds of metal lines. HDST could obtain high-quality spectra like these for nearly all of the lowest-metal-poor stars known (and those found in the future).

OPTICAL



Aoki et al. (2006, ApJ, 639, 897)

UV



G dwarf at solar metallicity

G subgiant at low metallicity

G subgiant at *ridiculously-* low metallicity

What are the origins of the elements heavier than iron?

Broadly speaking, these elements are formed by rapid neutron-capture reactions (the r-process) or slow neutron-capture reactions (the s-process).

Examples of work done to study these elements in the UV with HST:

"HST Observations of Neutron-Capture Elements in Very Metal-Poor Stars"
Sneden et al. (1998, ApJ, 496, 235)

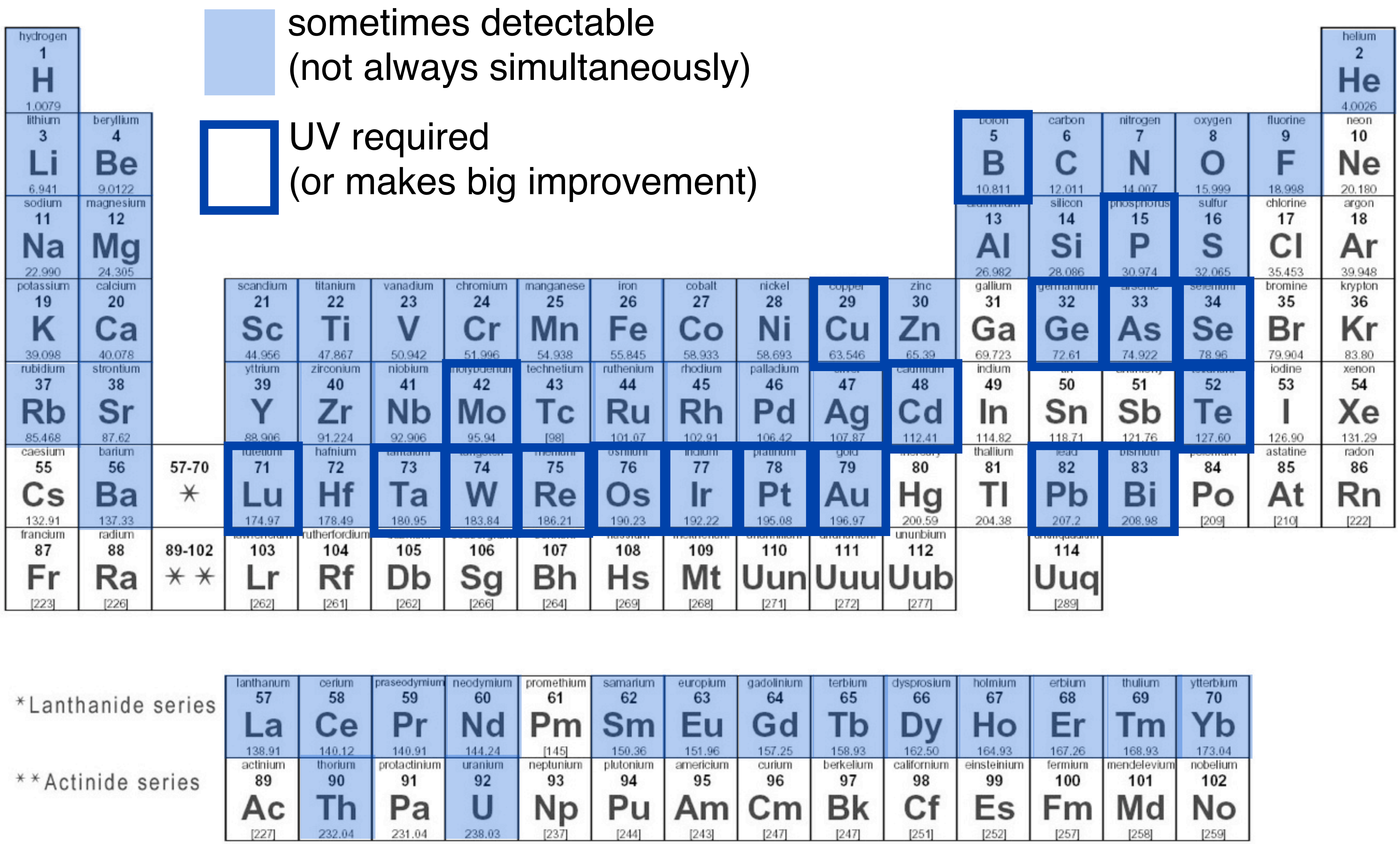
"HST Observations of Heavy Elements in Metal-Poor Galactic Halo Stars"
Cowan et al. (2005, ApJ, 627, 238)

"New HST Observations of Heavy Elements in Four Metal-Poor Stars"
Roederer et al. (2012, ApJS, 203, 27)

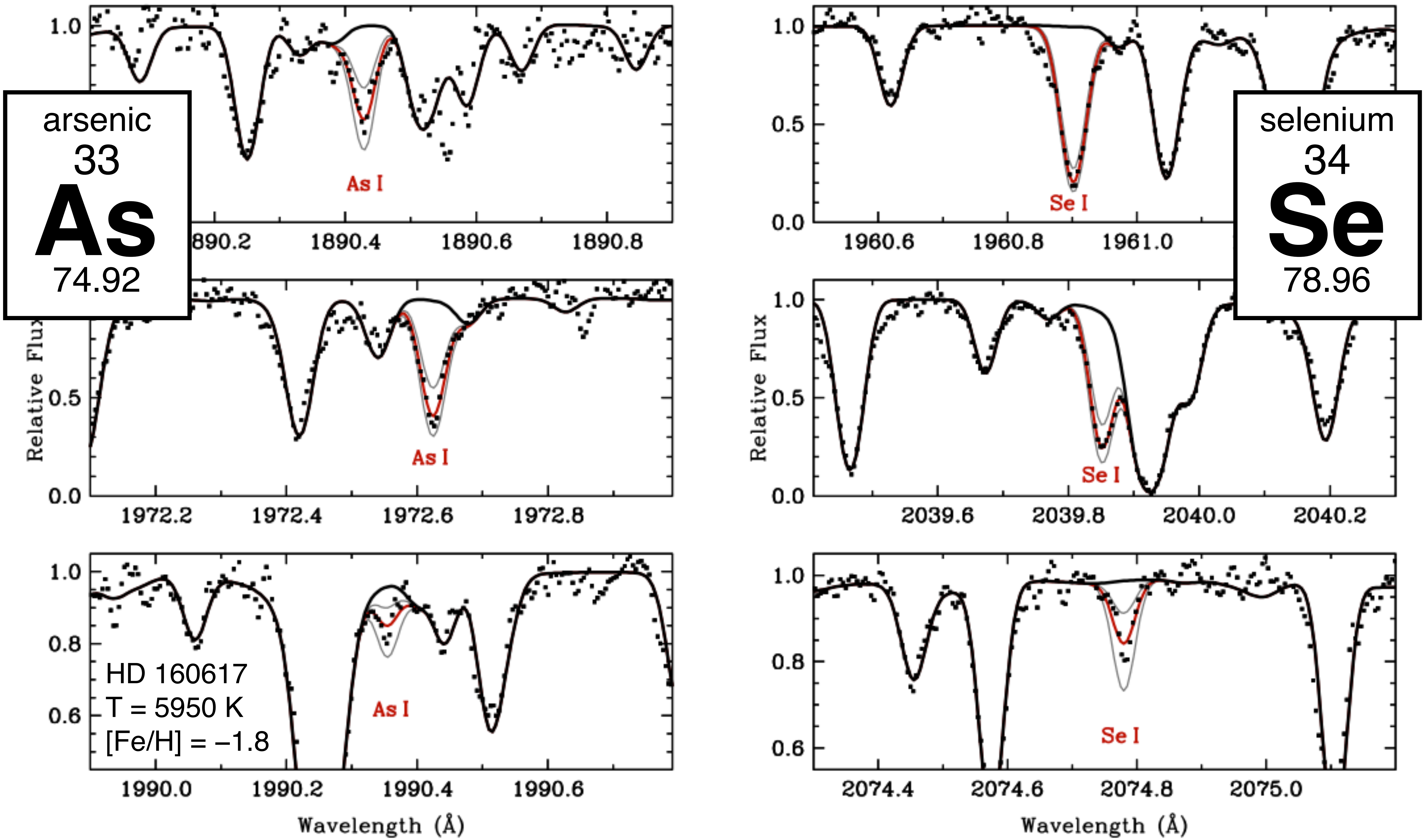
"Detection of Elements at All Three r-process Peaks in the Metal-Poor Star HD 160617"
Roederer & Lawler (2012, ApJ, 750, 76)

"First Stars XVI. HST/STIS abundances of heavy elements in the uranium-rich metal-poor star CS 31082-001"
Siqueira-Mello et al. (2014, A&A, 550, A122)

UV spectroscopy enables a 40% increase in the number of heavy elements that can be detected in late-type stars.

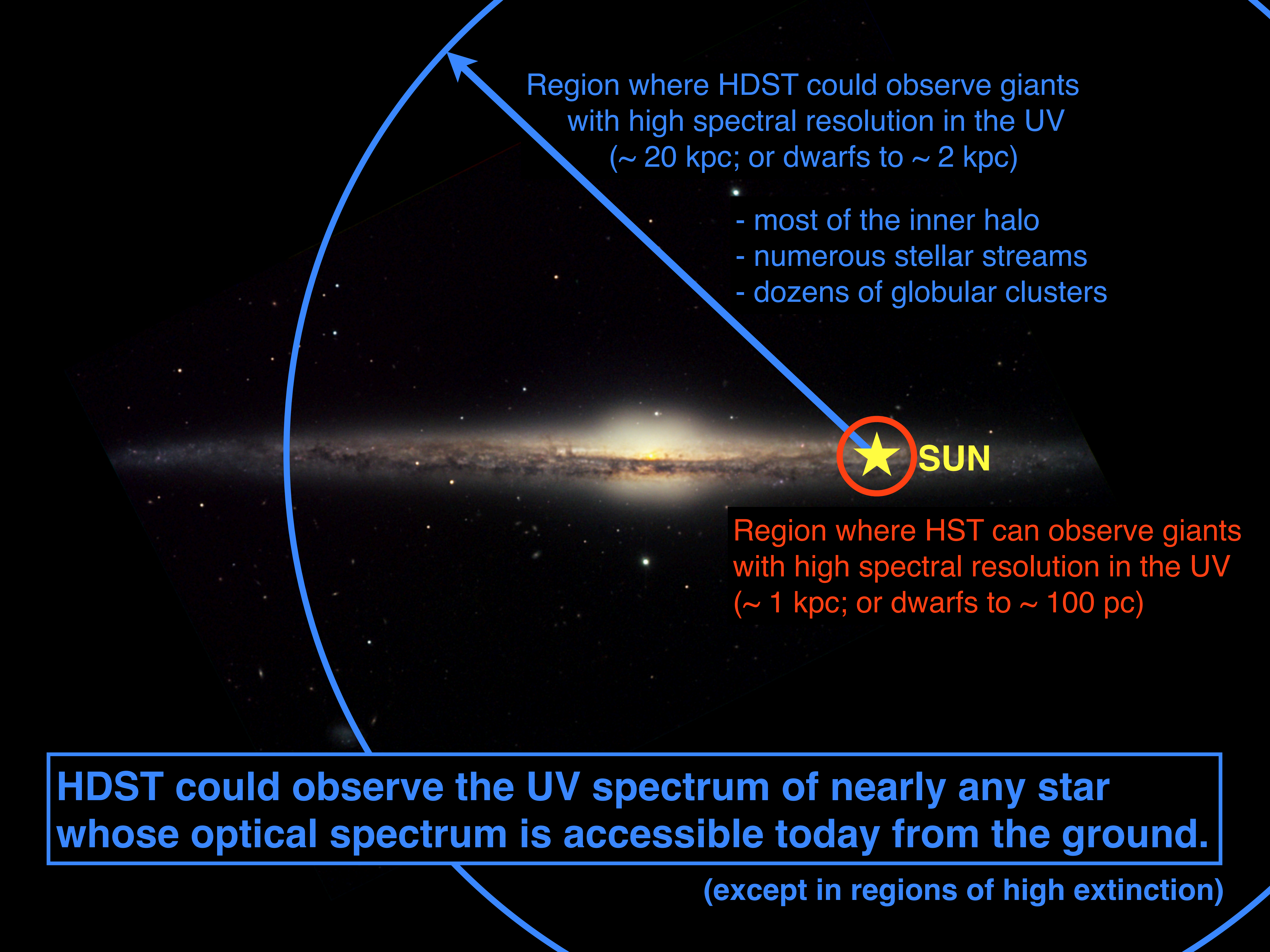


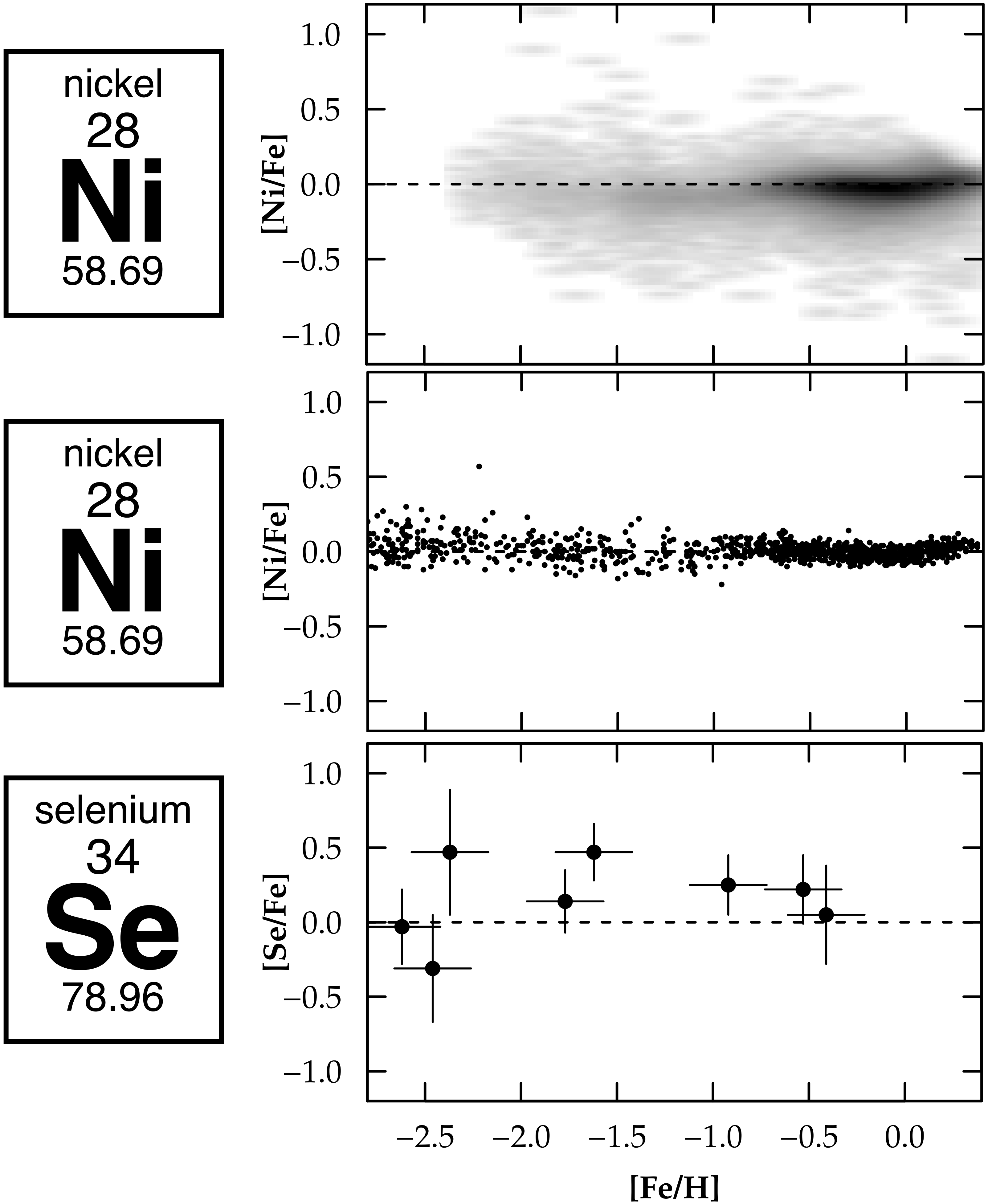
This is an example of the STIS high-resolution spectra that have been analyzed at present. HST has observed ~5-10 stars with similar data quality. HDST could observe ~10^2–10^3 stars.



Roederer & Lawler (2012, ApJ, 750, 76)


SUN
Region where HST can observe giants with high spectral resolution in the UV (~ 1 kpc; or dwarfs to ~ 100 pc)


Region where HDST could observe giants
with high spectral resolution in the UV
(~ 20 kpc; or dwarfs to ~ 2 kpc)
- most of the inner halo
- numerous stellar streams
- dozens of globular clusters
SUN
Region where HST can observe giants
with high spectral resolution in the UV
(~ 1 kpc; or dwarfs to ~ 100 pc)
HDST could observe the UV spectrum of nearly any star whose optical spectrum is accessible today from the ground.
(except in regions of high extinction)



~101,000 stars
observed with APOGEE

state of the art for dedicated ground-based multi-fiber abundance surveys

~1,500 stars
observed by individuals

state of the art for ground-based single-star high-resolution abundance surveys

does a good job of characterizing the basic features found in the APOGEE dataset that is ~two orders of magnitude larger

~10 stars
observed by STIS

state of the art for UV high-resolution abundance "surveys"

HDST could transform this into hundreds of stars, comparable to our best ground-based single-star efforts at the present time

SUMMARY

The UV is a critical spectral domain for studies of stellar abundances because some key metal absorption lines are found only in the UV.

HDST would enable us to obtain high-S/N and high spectral resolution in the UV for nearly all of the lowest-metallicity stars known.

HDST would enable us to target the "gold standard" stars for understanding the physics of the r-process and s-process, rather than observing only the brightest targets that may or may not be helpful.

TECHNICAL REQUIREMENTS

High spectral resolution: R~60,000 optimal
(R ~ 100,000 ideal; R ~ 30,000 minimum acceptable)

High signal-to-noise: S/N ~ 100 after co-adding exposures

Broad wavelength coverage (1700 to 3100 Å) in a single exposure
(or covered in no more than two exposures)

Multi-object capability would be nice, but it is not strictly required for the science cases presented here.