Old Metal-Poor Stars: Observations and Implications for Galactic Chemical Evolution

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Why the Fascination with Metal-Poor Stars ?

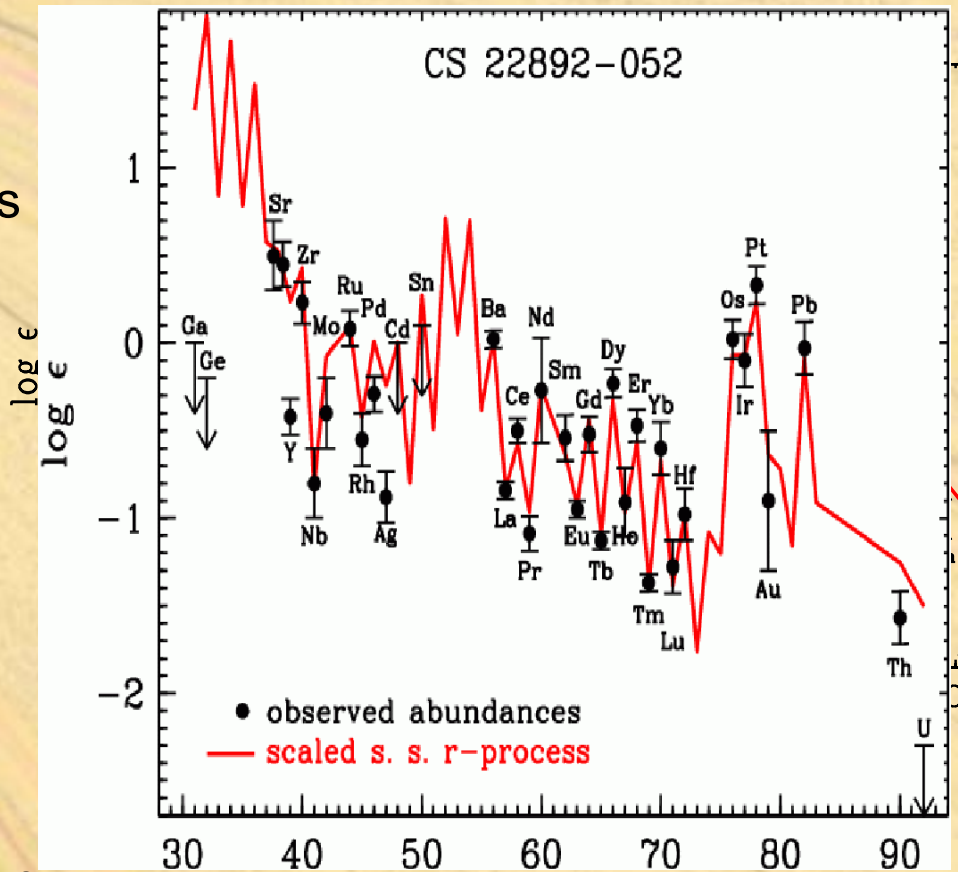
- Extremely metal-poor (MP) stars have recorded the heavy element abundances produced in the first generations of stars in the Universe
- The shape of the low-metallicity tail of the Metallicity Distribution Function will (eventually) show structure that reveals the characteristic abundances of major epochs of star formation in early Galaxy
- Identification of relatively rare objects amongst MP stars, e.g., r-process / s-process enhanced stars that can be studied at higher resolution to understand detailed predictions of nucleosynthesis models

The Importance of Neutron-Capture Enhanced Metal-Poor Stars

- Early generation (low metallicity) stars have recorded the direct astrophysical elemental patterns of, e.g., the s-process and the r-process
- Predictions and tests of nuclear physics (mass models, measurements of fundamental properties of nuclei, operation of n-capture processes) can be compared with observations of these rare stars that exhibit the variety of neutron-capture patterns produced in nature
- Determination of absolute frequency of various abundance patterns is required to construct astrophysically consistent models for formation of the elements
- Require large samples of, in particular, r-process-enhanced, metal-poor stars in order to place constraints on the nature of the r-process, its site(s), examination of possible variation in abundance patterns from star to star, and of course…
- Cosmo-chronometry (with Th and U)

The Importance of r-process Enhanced Metal-Poor Stars

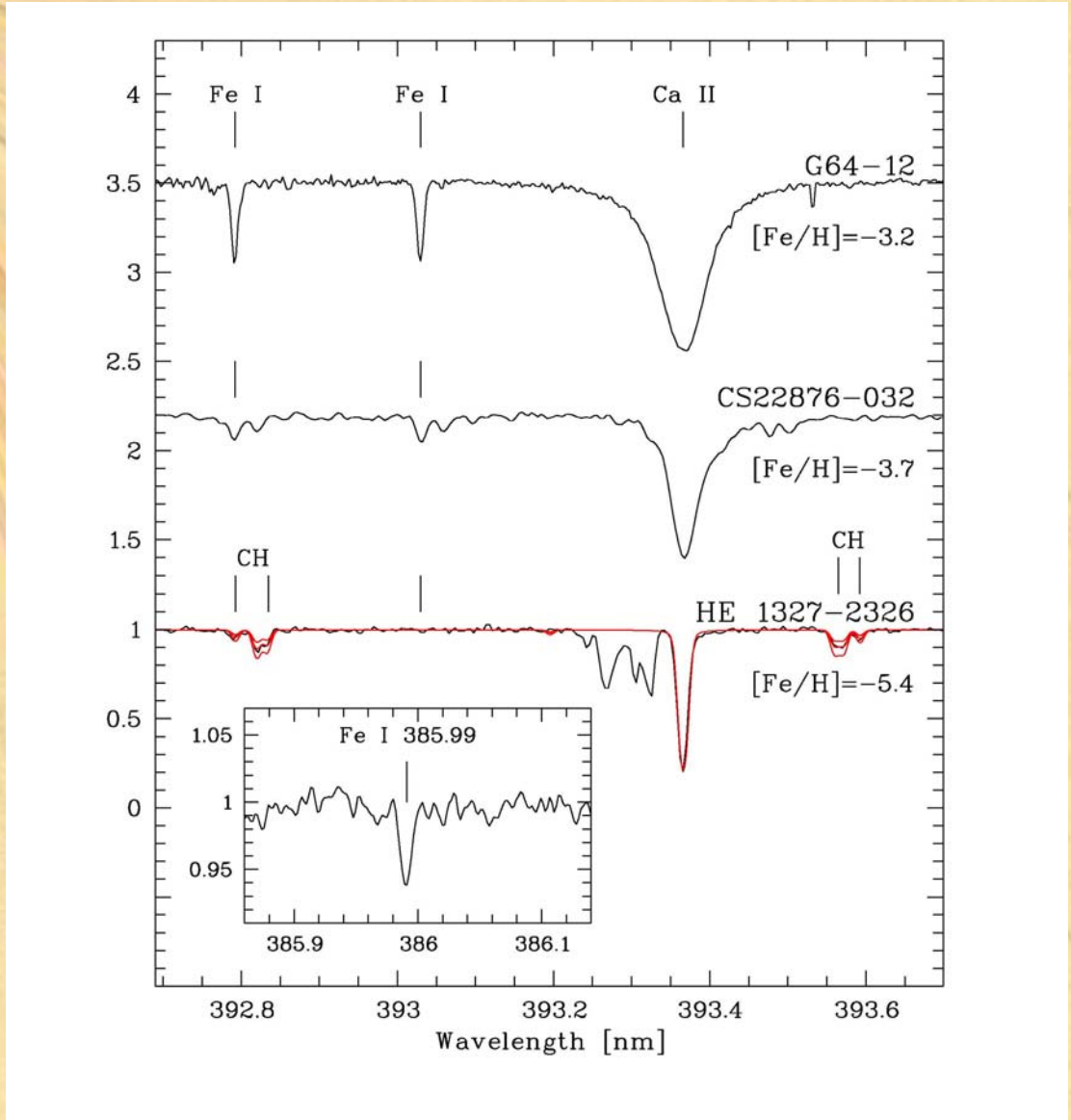
- CS 22892-052: [Fe/H] = –3.1;
  [r/Fe] = +1.7
- All r-I and r-II stars have patterns for 56 < Z < 76 that match the solar r-process component extremely well (Sneden et al. 2003)
- Most have measurable lines of Th, and other stable r-process elements, upon which cosmo-chronometric age limits can be placed
- Some have measurable lines of U, providing tighter constraints on age estimates



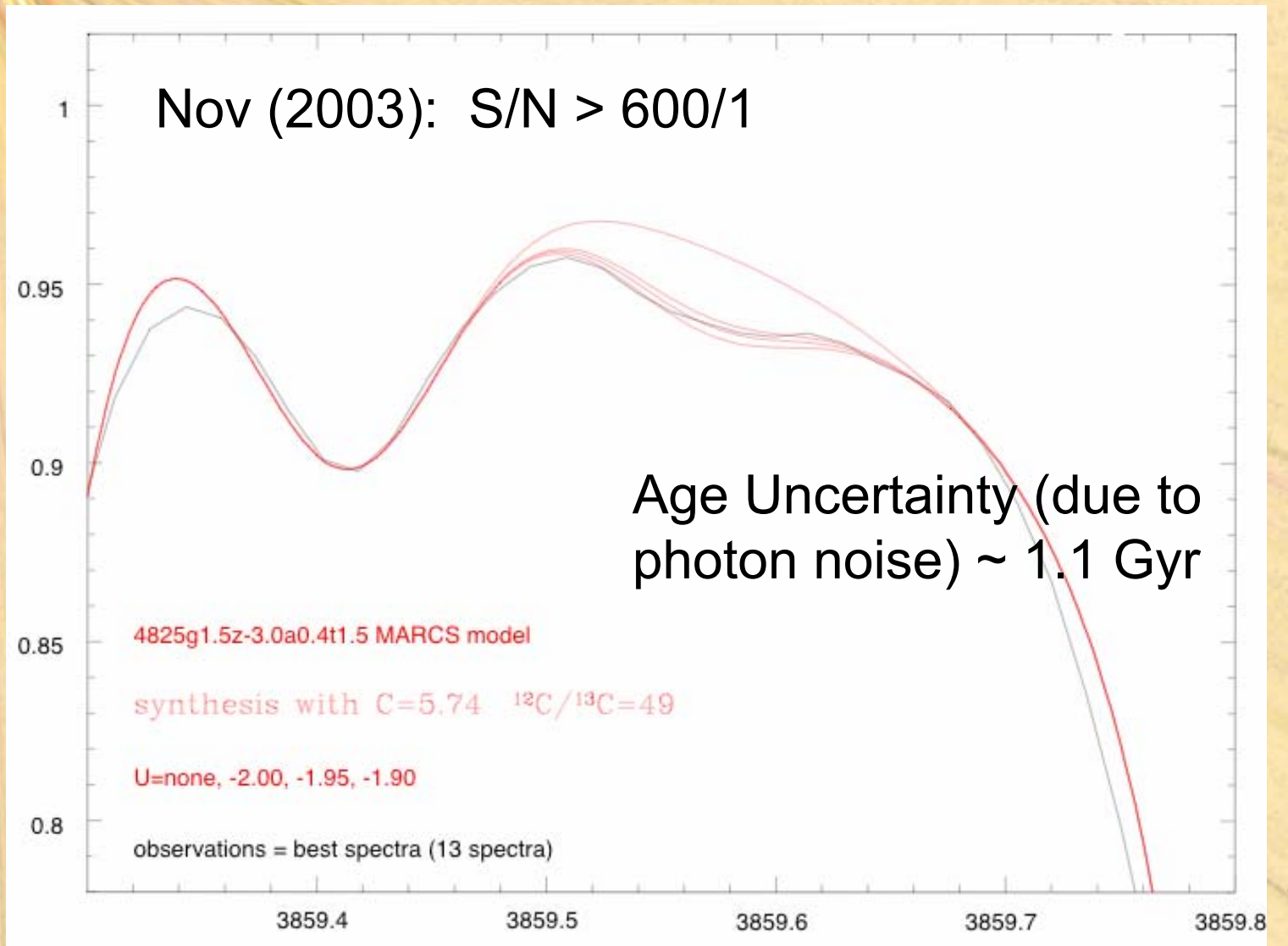
Examples of Recent Progress

- Discovery of Hyper Metal-Poor star HE 1317-2326
  - [Fe/H] = -5.6 (Frebel et al. 2005)
- New Measurements of U and Pb in CS 31082-001
  - (Cayrel et al. 2005)
- Hamburg/ESO R-Process-Enhanced Star Survey (HERES) observations of [Fe/H] < -2.0 giants
  - Barklem et al. (2005)
  - "Snapshot" spectroscopy (R ~ 20,000, S/N ~ 30/1) of ~ 400 VMP giants with VLT/UVES
  - Discovery of 8 new r-II stars ; 35 new r-I stars; numerous s-process-enhanced stars, numerous carbon-enhanced stars
  - Discovery of new "U Star": CS 29497-004 (Hill et al. 2005)

HE 1327-2326: The New Record Holder

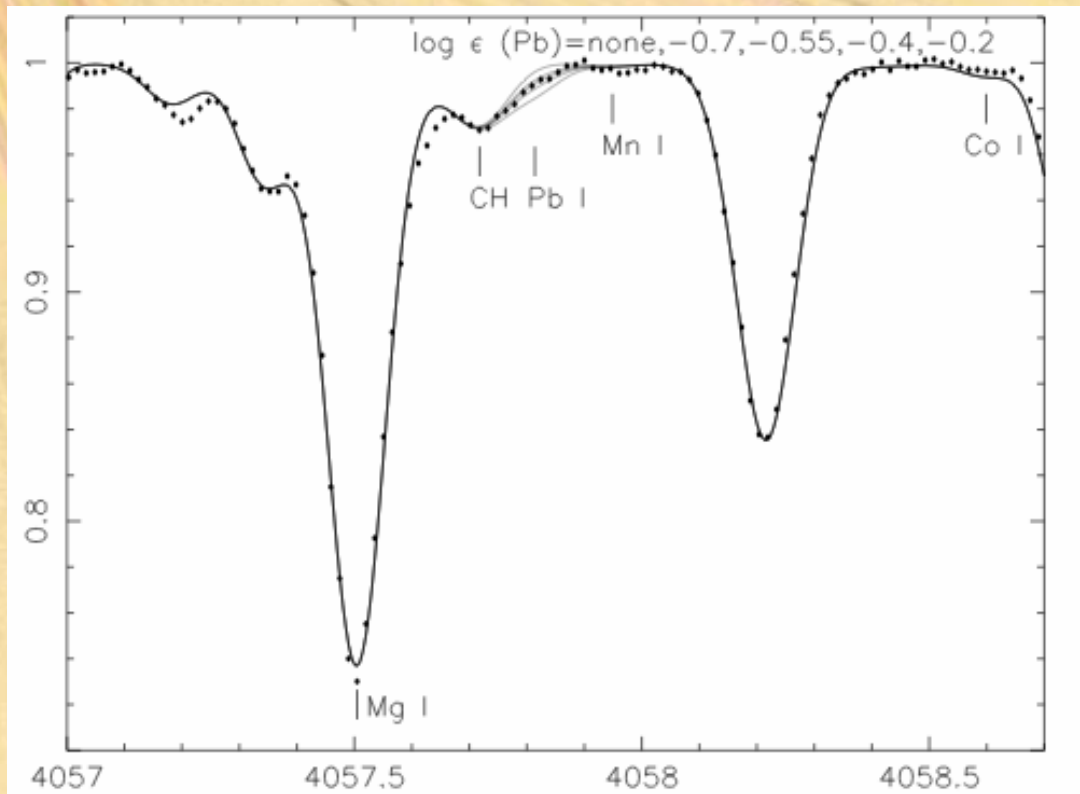


A New Measurement of the U line in CS 31082-001



CS 31082-001: So LITTLE Lead!

- 13 exposures of 90min each needed to obtain more than an upper limit for lead.
- Abundance (LTE) found : log(Pb/H) = -12.55 ±0.15 (or -0.55 ± 0.15 on the scale log(nH)=12).

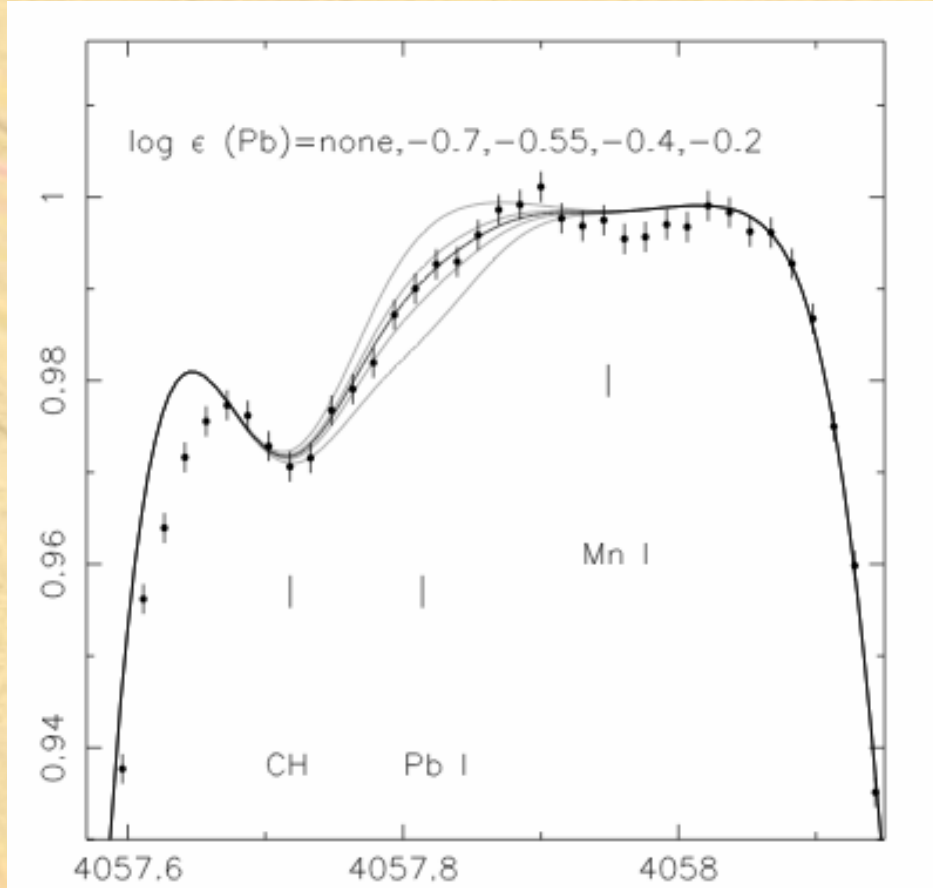


Contrary to Expectation…

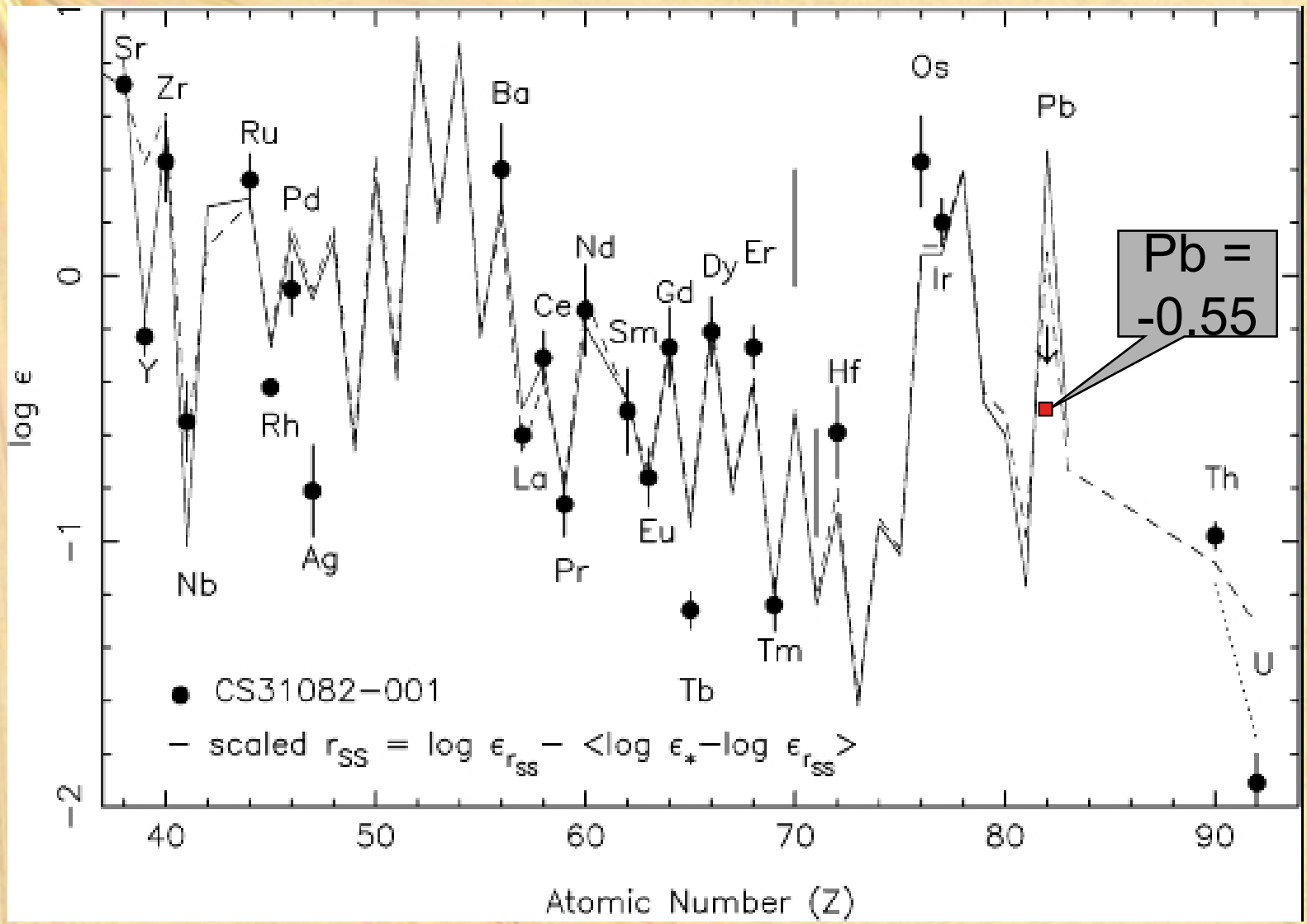
• This is what is expected ONLY from the decay of the three actinides ^{238}U, ^{235}U and ^{232}Th, without other contribution!

• Current attempts to reproduce the neutron capture elements in the solar system produce much more lead by direct channels

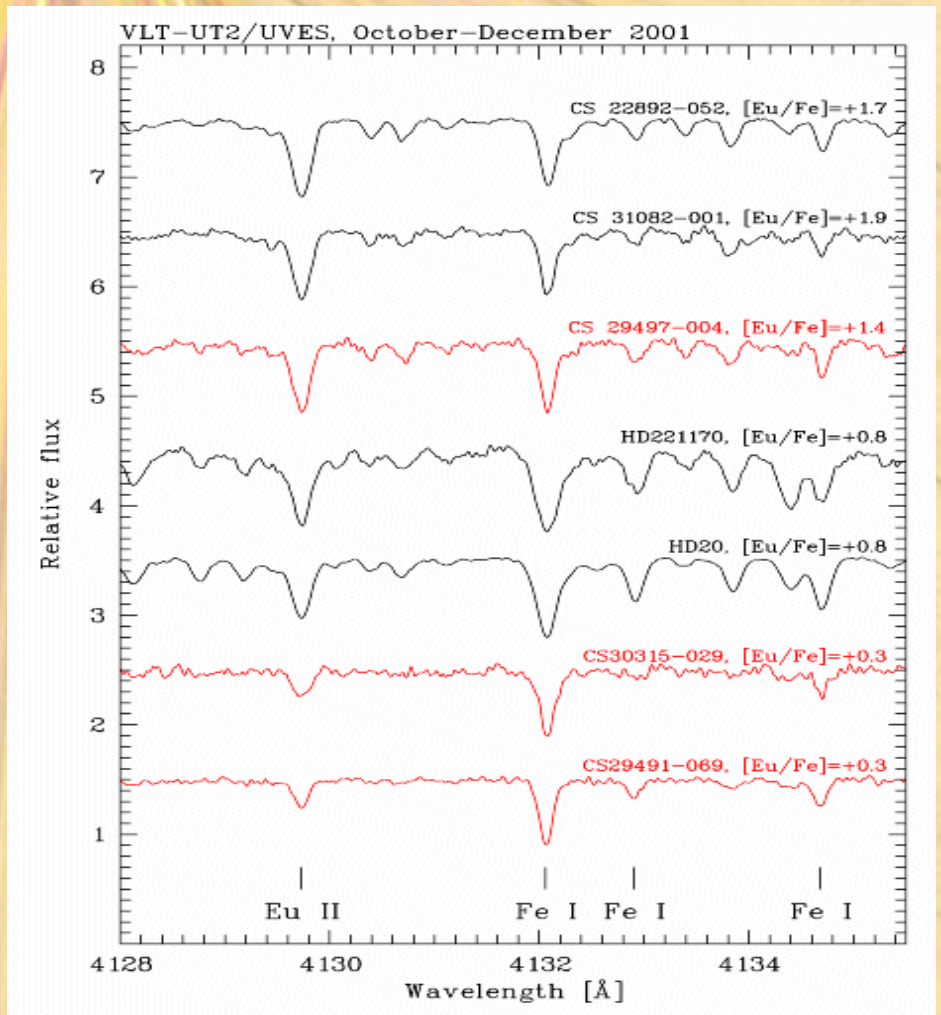
• But.....NLTE , and *r*-element estimates in solar-system may also present problems



Another Look at Pb in CS 31082-001



HERES Eu Survey Spectra and Results to Date

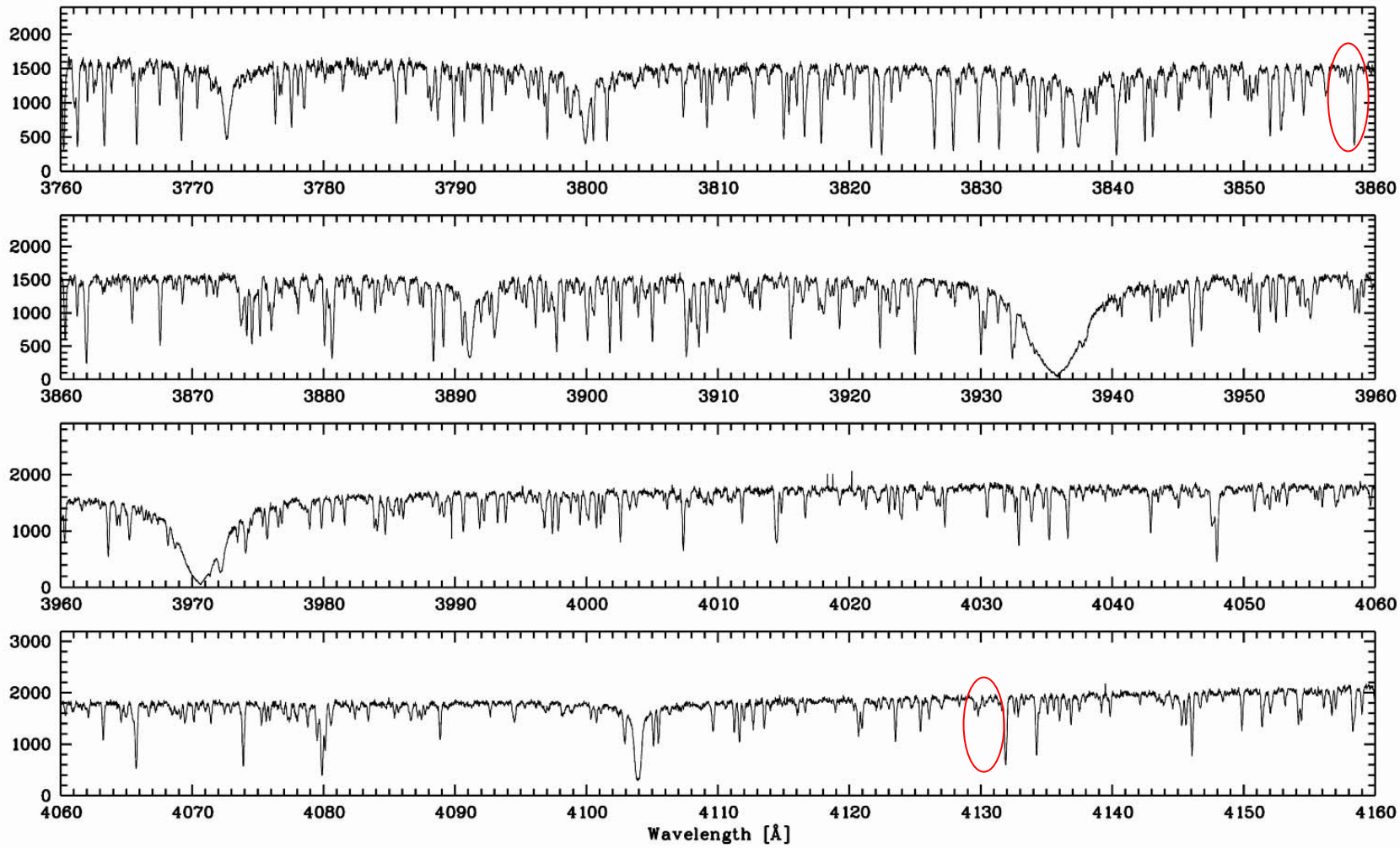


- HERES is based on “snapshot” high-resolution spectroscopy
- Neutron-capture-enhanced stars indicated by presence of Eu 4129
- 8 new r-II stars with [r/Fe] ≥ +1.0
- 35 new r-I stars with [r/Fe] ~ + 0.3

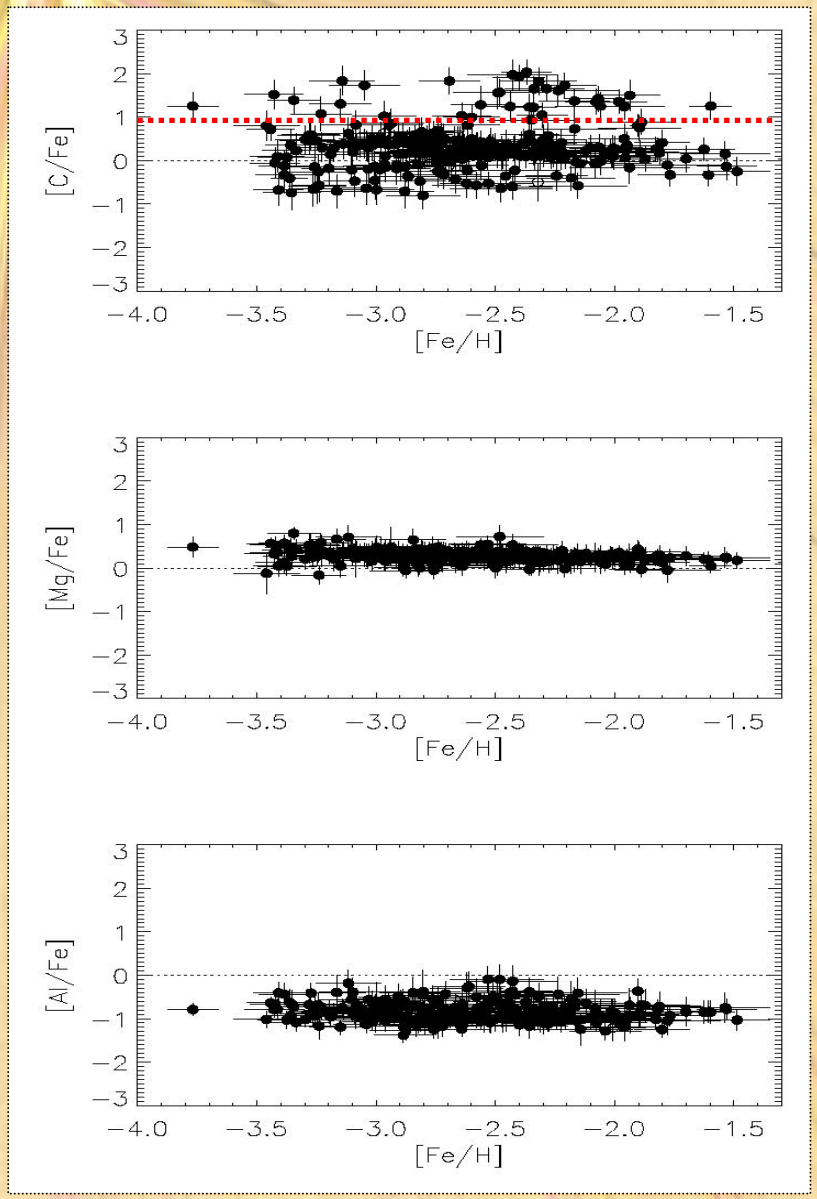
The apparent frequency of r-II stars is ~ 5 % of giants with [Fe/H] < -2.5

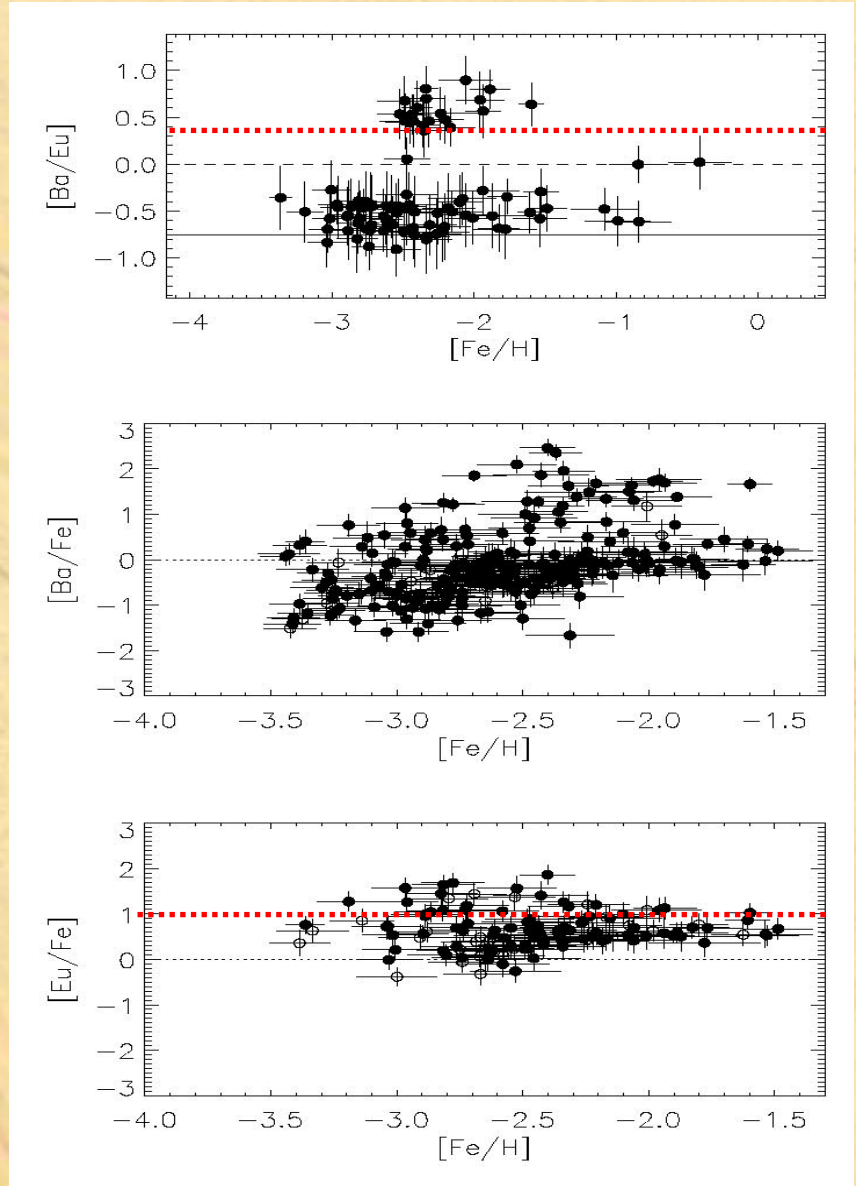
HERES Survey: Other Elements !

CS 31082-001: [Fe/H] = -2.9 HERES Blue Spectrum

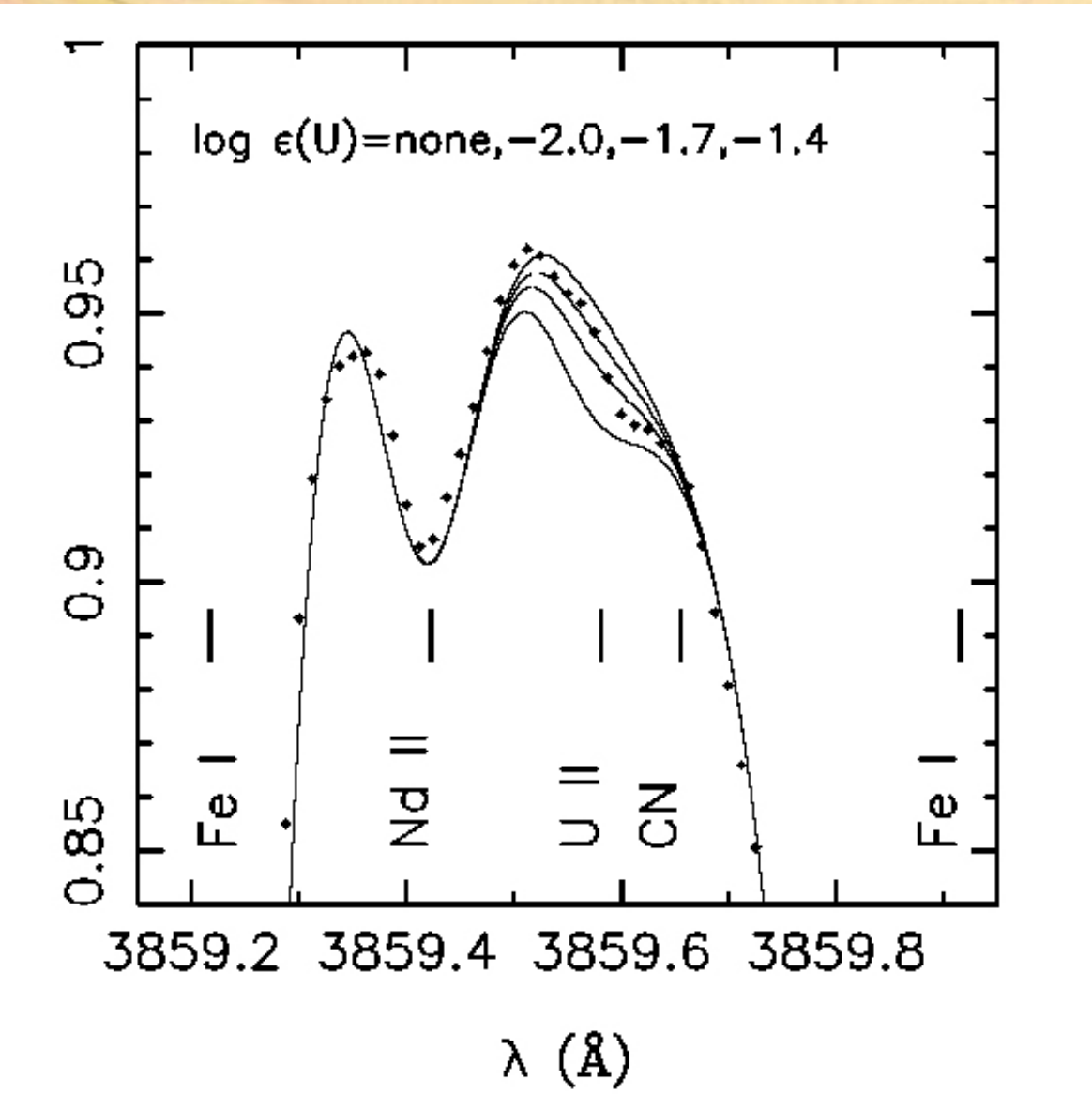


The Power Of Large N: 274 Stars from HERES

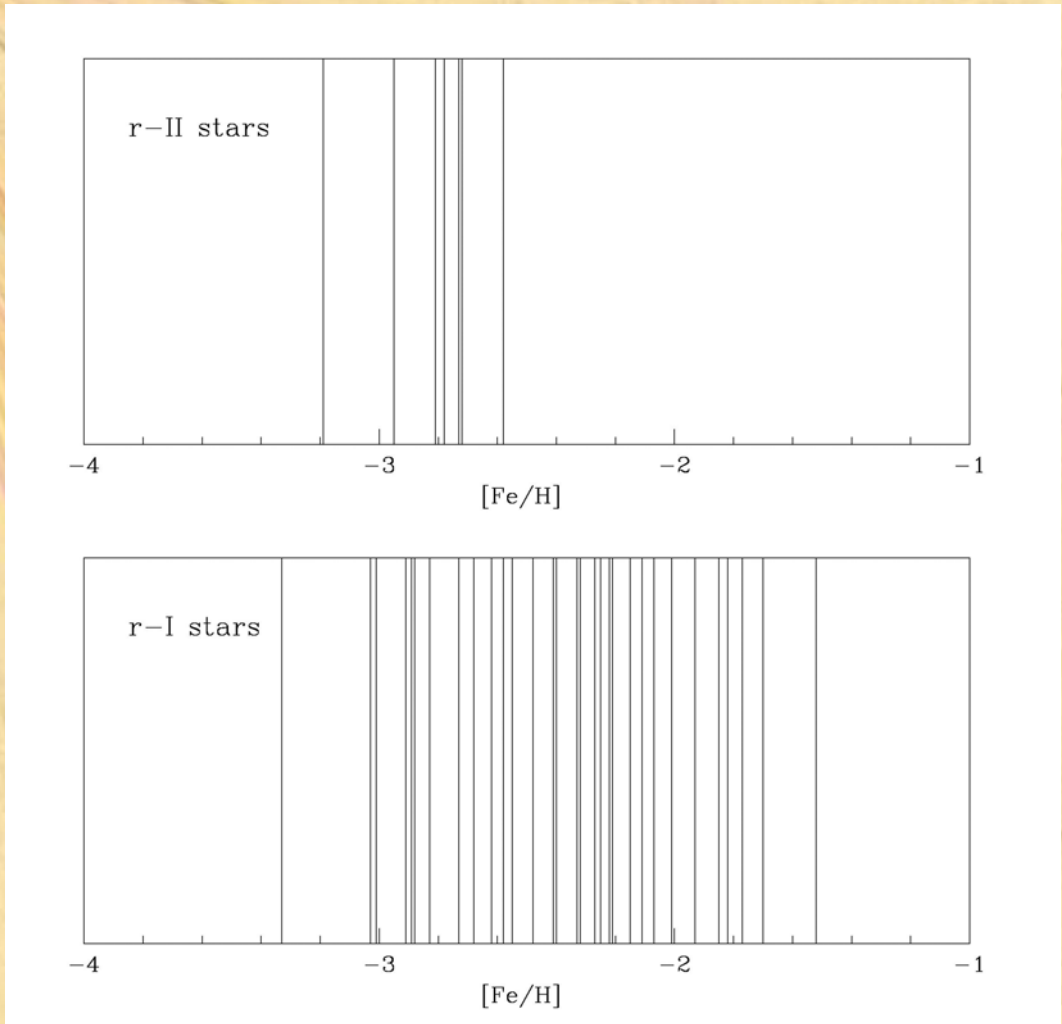




A New R-Process Enhanced Star with Uranium Detected: CS 29497-004 !



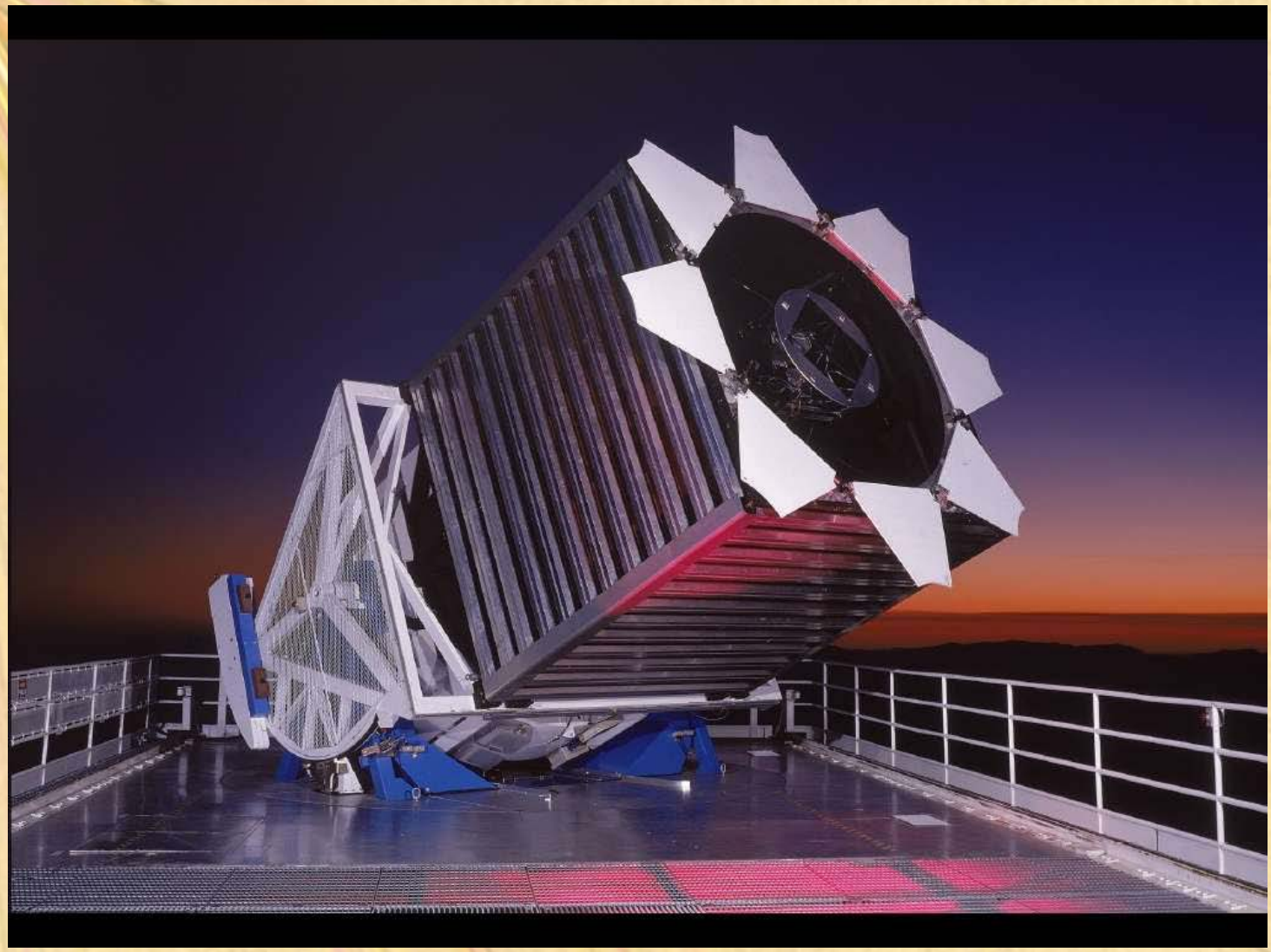
Distribution of [Fe/H] for r-process Enhanced Stars from HERES



The Sloan Digital Sky Survey

- The most ambitious astronomy project ever undertaken
  - Obtain accurately calibrated imaging of 10,000 square degrees of (northern) sky, in five filters (*ugriz*)
  - Obtain medium-resolution spectroscopy for
    - 1,000,000 galaxies
    - 100,000 quasars
- Has been fully operational since ~ Jan 1999
- Completed its primary imaging mission in July 2005

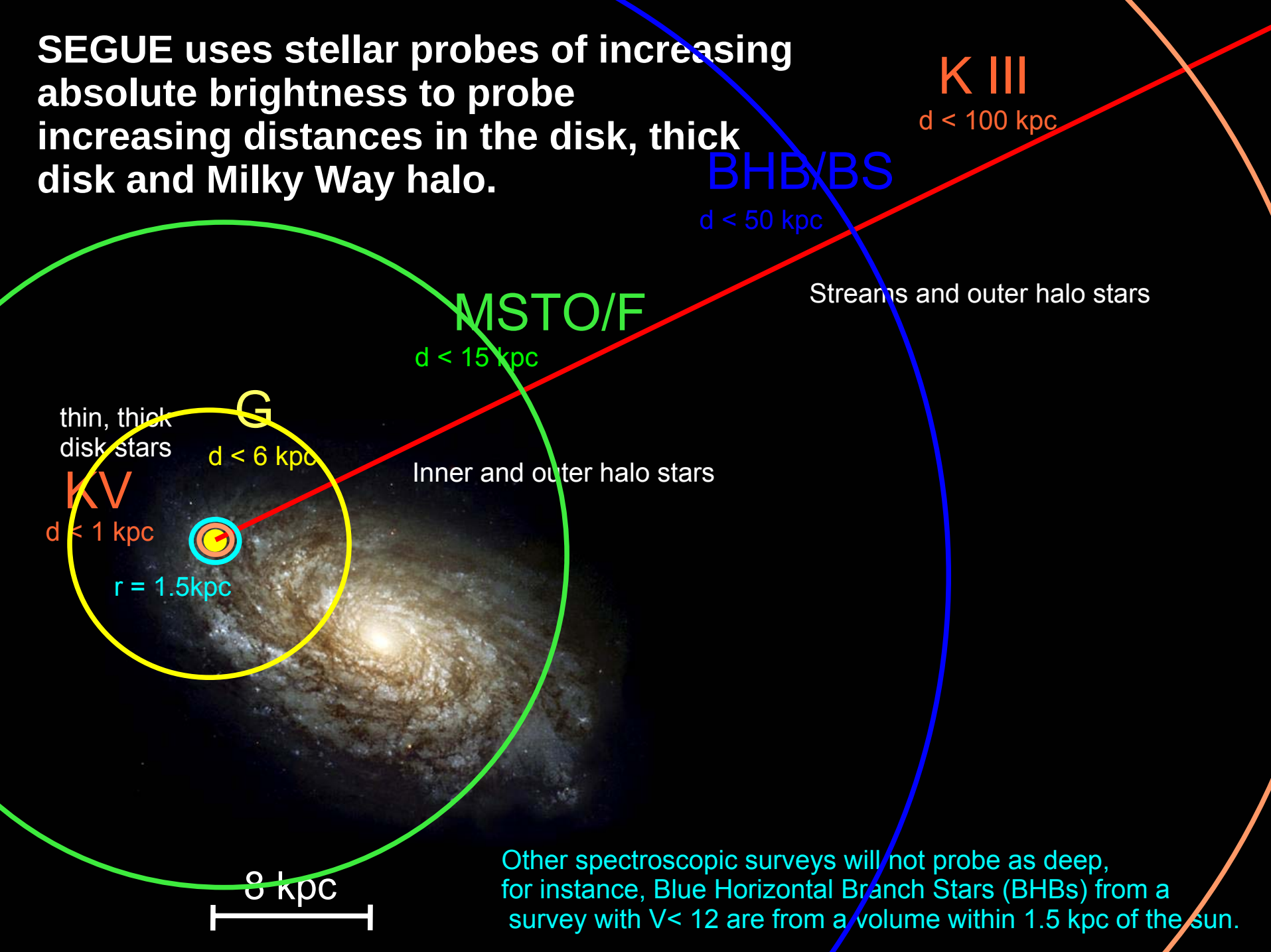
SDSS -- The Telescope and Data



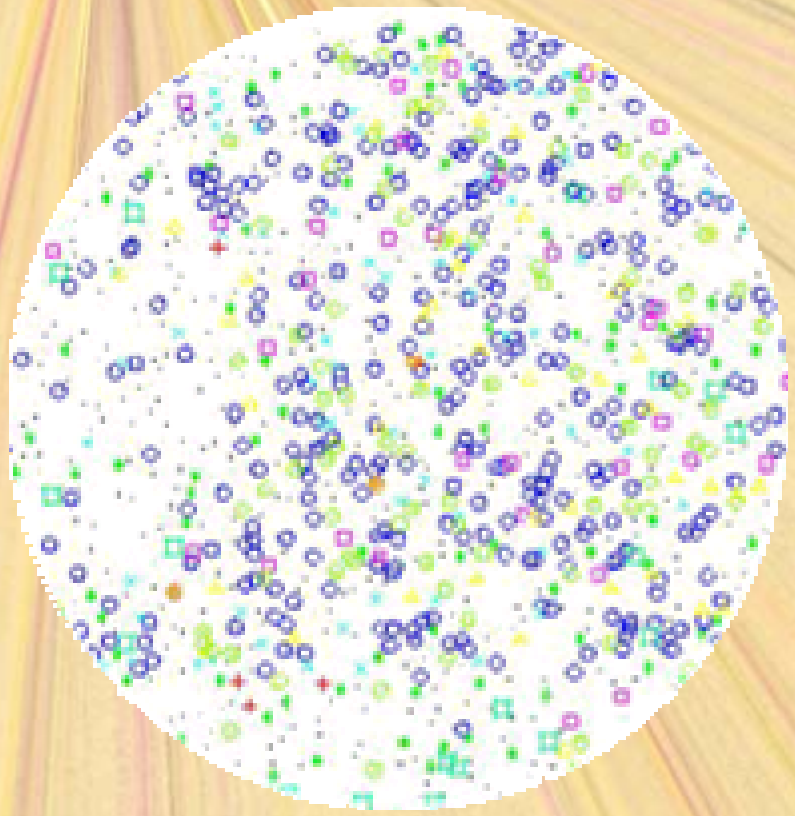
ARC 2.5m SDSS Telescope (3 deg FOV)

SEGUE: The Sloan Extension for Galactic Understanding and Exploration

- Fully funded ($15 Million: Sloan Foundation / NSF / Partners (JINA) for operation through July 2008
- Use existing SDSS hardware and software to obtain:
  - 3500 square degrees of additional *ugriz* imaging at lower latitudes
  - Medium-resolution spectroscopy of 250,000 "optimally selected" stars in the thick disk and halo of the Galaxy
    - 200 "spectroscopic plate" pairs of 45 / 135 min exposures
    - Objects selected to populate distances from 1 to 100 kpc


SEGUE uses stellar probes of increasing absolute brightness to probe increasing distances in the disk, thick disk and Milky Way halo.
K III
d < 100 kpc
BHB/BS
d < 50 kpc
Streams and outer halo stars
MSTO/F
d < 15 kpc
Inner and outer halo stars
thin, thick disk stars
G
d < 6 kpc
KV
d < 1 kpc
r = 1.5kpc
8 kpc
Other spectroscopic surveys will not probe as deep, for instance, Blue Horizontal Branch Stars (BHBs) from a survey with V< 12 are from a volume within 1.5 kpc of the sun.

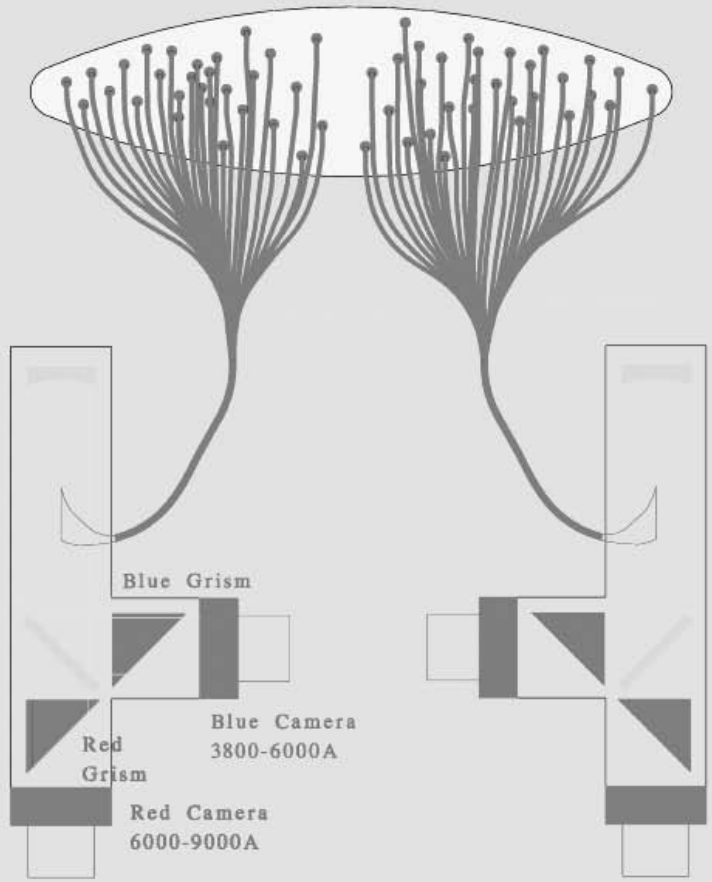
The SDSS Spectrograph Plug Plate



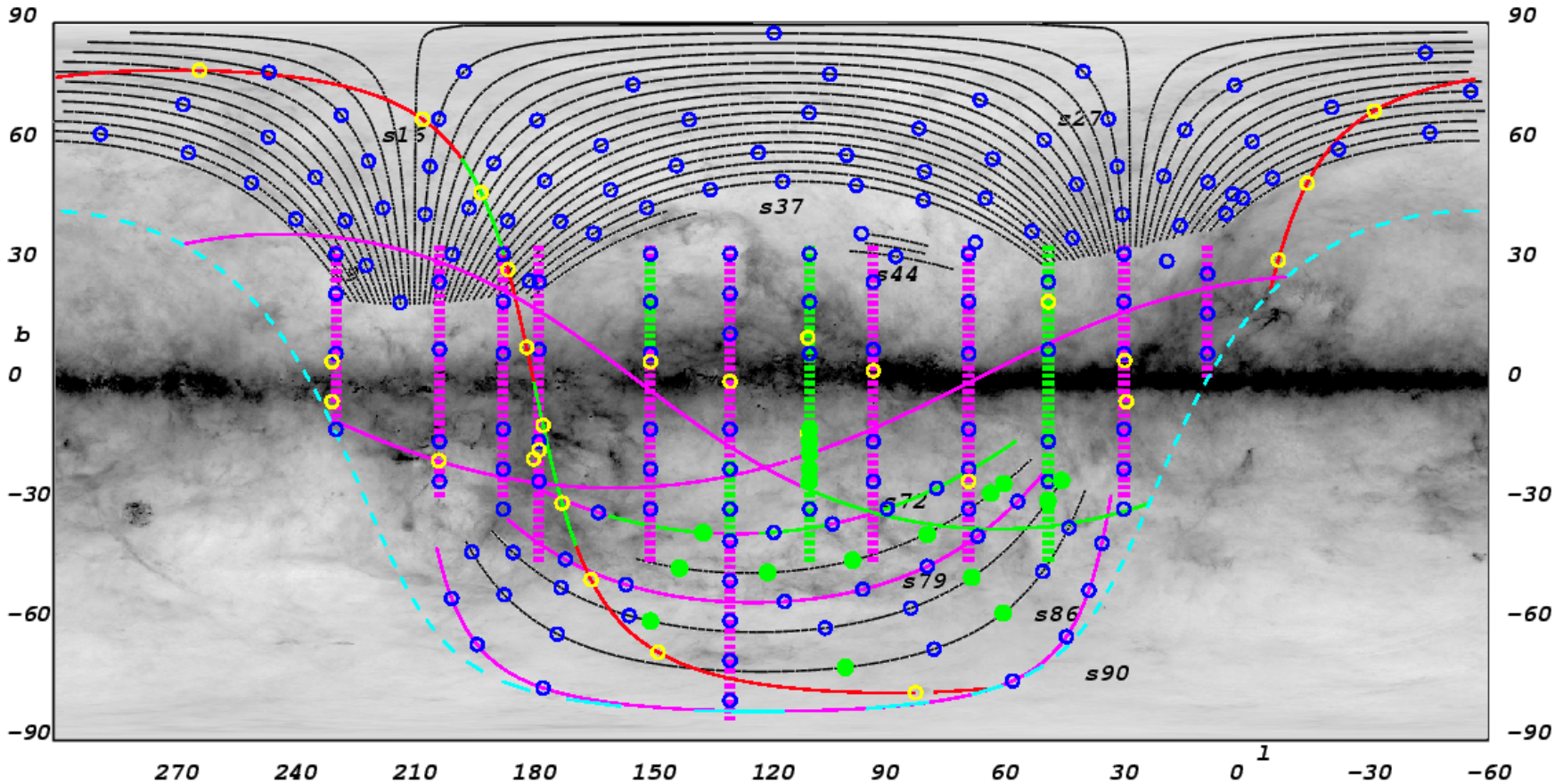
Identification of targets on the sky

A prepped and drilled plate

A Cartoon Version



SEGUE observing plan and status as of July 2005



SDSS Imaging scan

Planned SEGUE scan (3500 sq deg)

Sgr stream planned scan

Completed SEGUE imaging

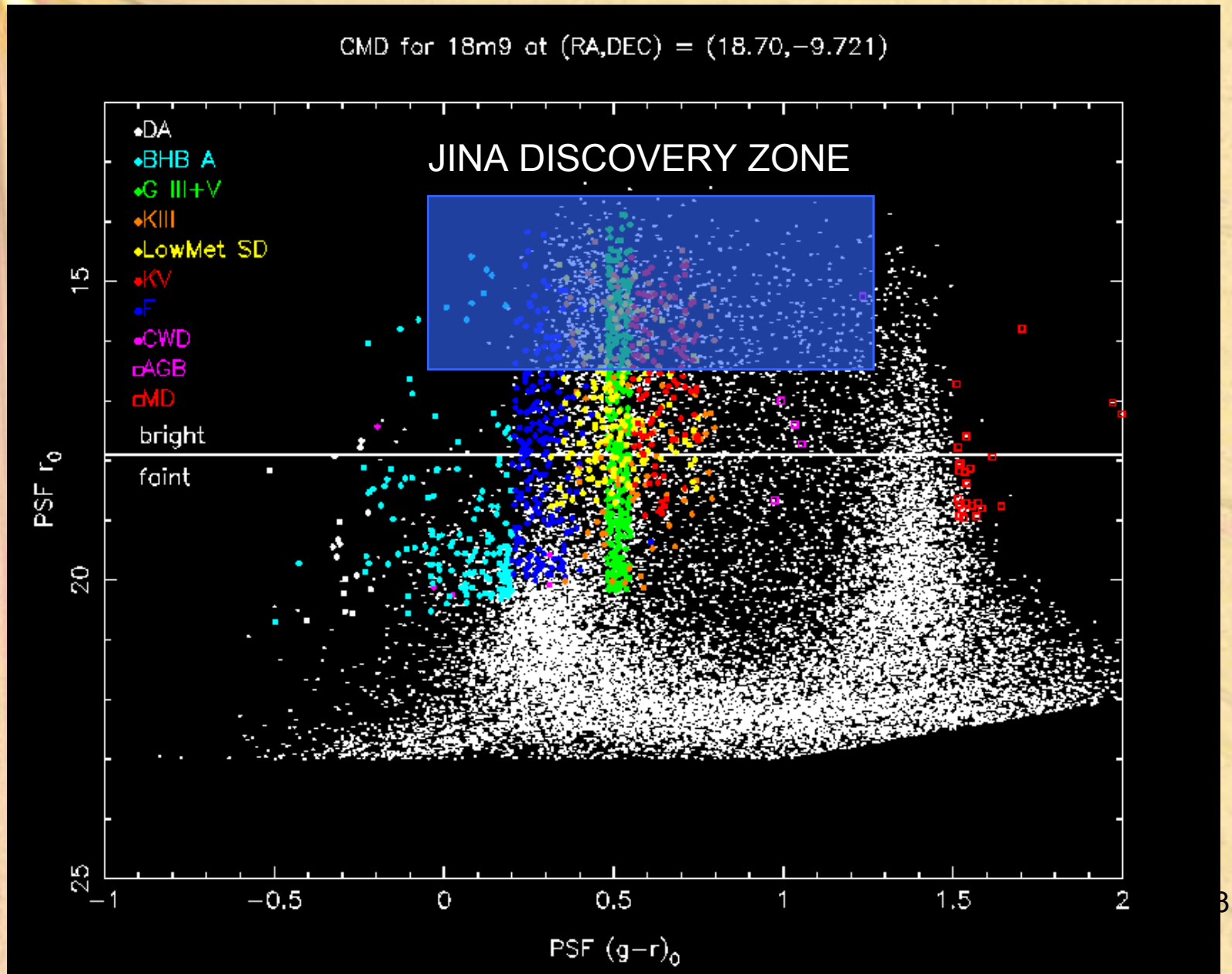
Declination = -20 degrees

Planned SEGUE grid pointings (200)

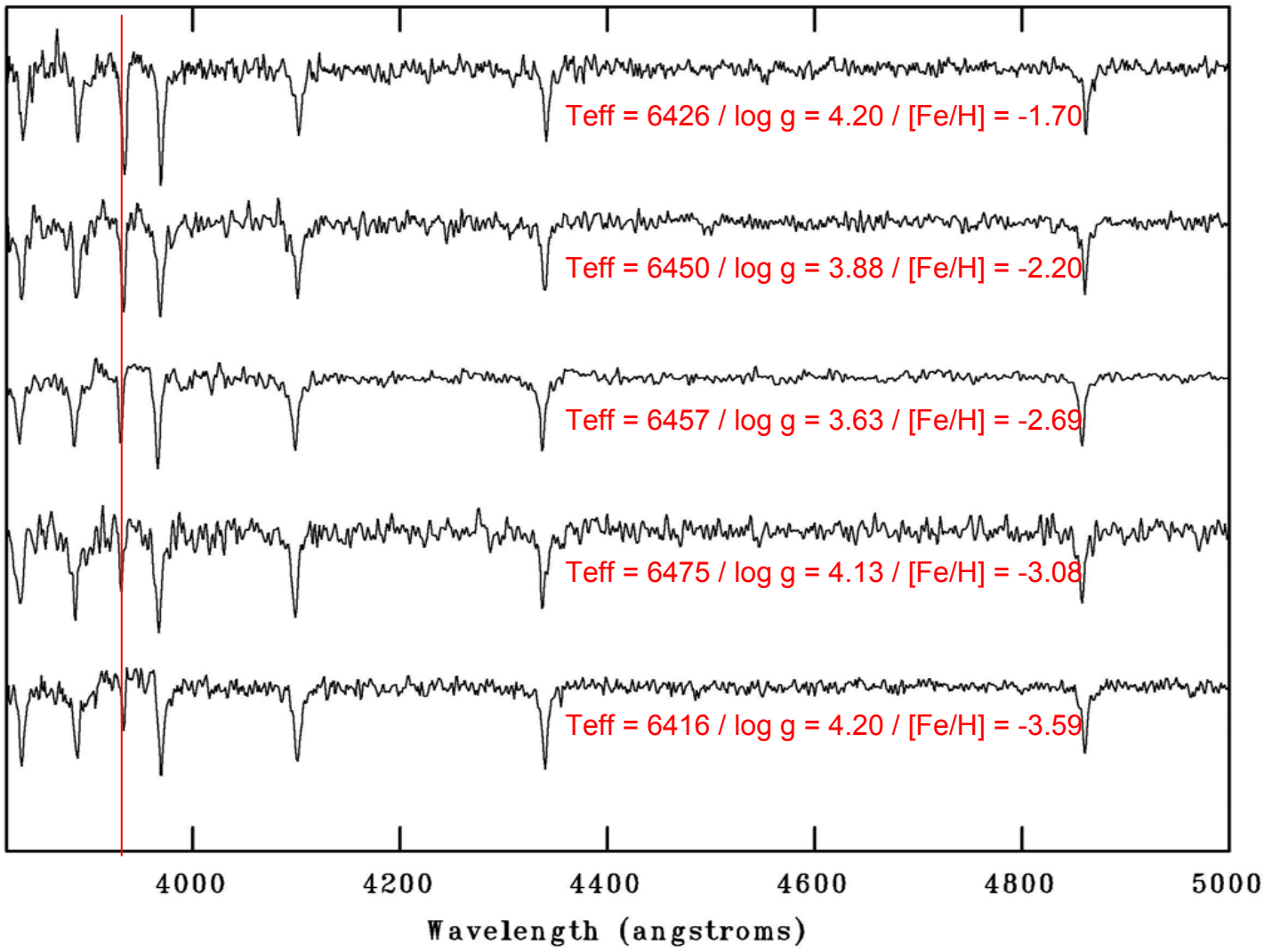
Planned targeted SEGUE pointings(60)

Completed SEGUE plate pointing

SEGUE Target Selection– “JINA-fied”



Example Main-Sequence Turnoff Stars of Low Metallicity



Likely Numbers of Detected MP Stars from SEGUE

- Actual numbers will depend on the shape of the halo Metallicity Distribution Function

–	[Fe/H] < -2.0	~ 20,000 (VMP)
–	[Fe/H] < -3.0	~ 2,000 (EMP)
–	[Fe/H] < -4.0	~ 200 ? (UMP)
–	[Fe/H] < -5.0	~ 20 ? (HMP)
–	[Fe/H] < -6.0	~ 2 ? (MMP)

The Plan of Attack

- SEGUE identification of bright MP giants with [Fe/H] < -2.0
- Brightest 2000-3000 taken to HET, etc., for “snapshot” high-resolution spectroscopy
- Most interesting (e.g., r-process / s-process-enhanced) stars thus identified taken to, e.g., Subaru/Keck/LBT, etc. for higher S/N determinations of elemental abundance patterns
- Construction of astrophysically-consistent scenarios to account for patterns and frequency of n-capture (and other) abundance patterns
- Note: Within 5-7 years, expect to be able to accomplish high-resolution surveys directly, targeting millions of individual stars

Suggested Questions…

- "I hear you have some cool SDSS imaging you would like to share – can I see some of that ?"
- "Tell me more about the million-star samples, in particular:
  - LAMOST (China)
  - Keck-ET (SDSS)
  - WFMOS (Gemini/Subaru)"

The SDSS Scrolling Sky

http://skyserver.sdss.org/dr1/en/tools/scroll/