The Frequency of Low Metallicity Stars in the Galaxy and Present and Future Surveys

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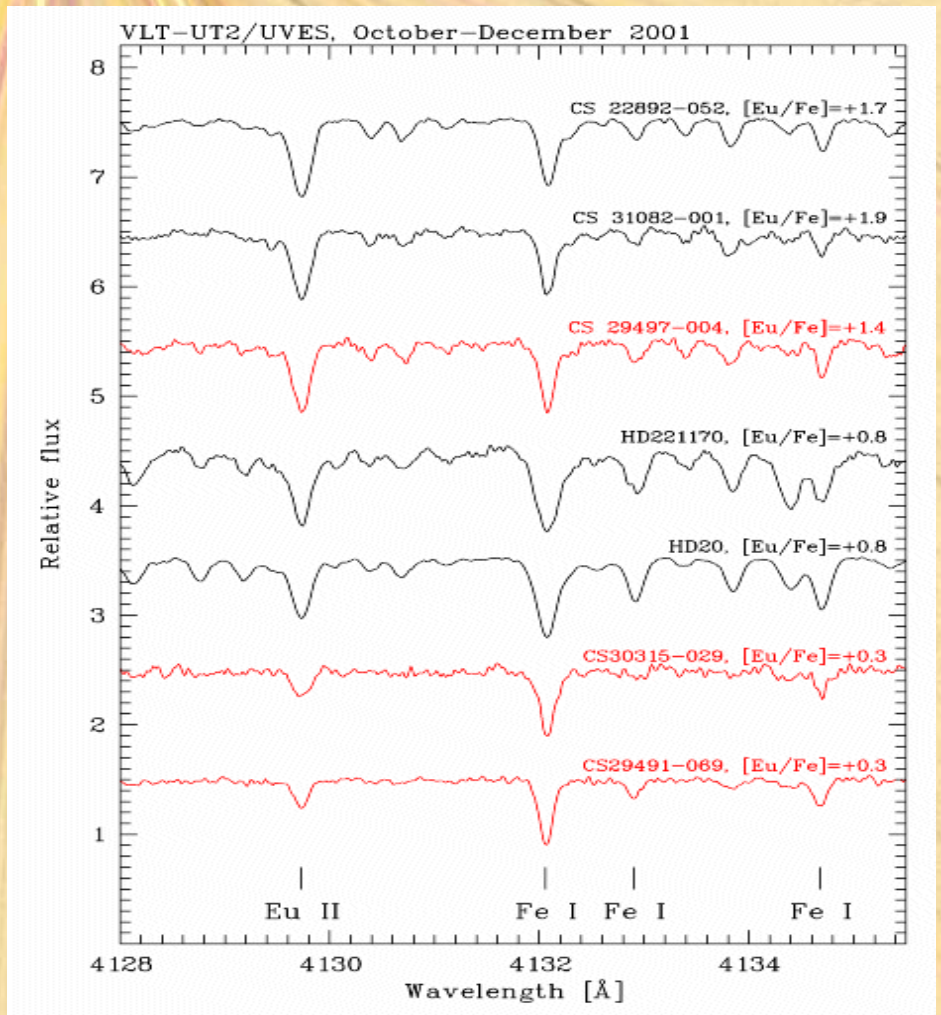
Examples of Recent Progress

- 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)

HERES Eu Survey Spectra and Results to Date

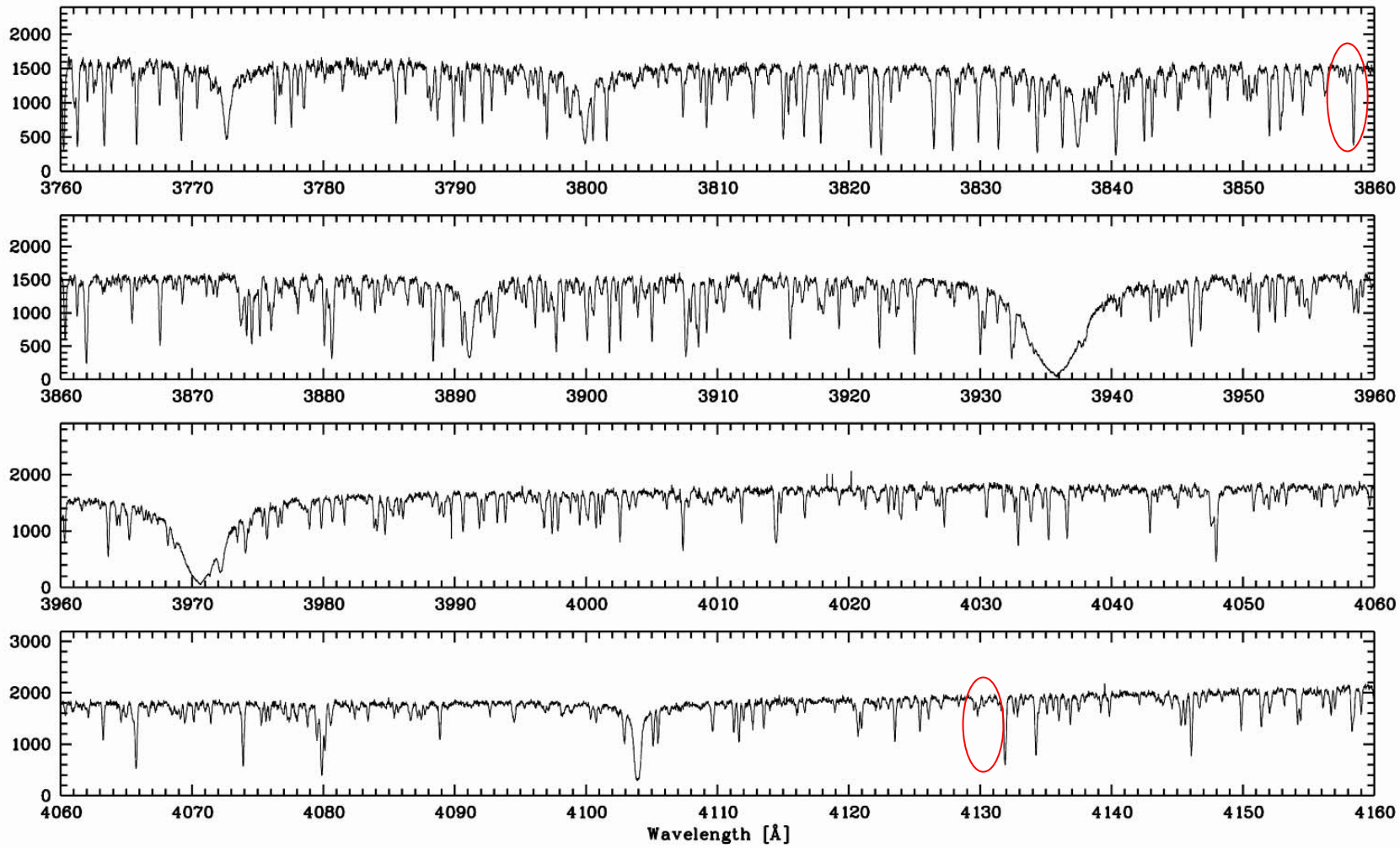


- HERES is based on “snapshot” high-resolution spectroscopy
- Neutron-capture-enhanced stars indicated by presence of Eu 4129
- 8 new r-II stars with [r/Fe] ≥ +1.0
- 35 new r-I stars with [r/Fe] > + 0.3

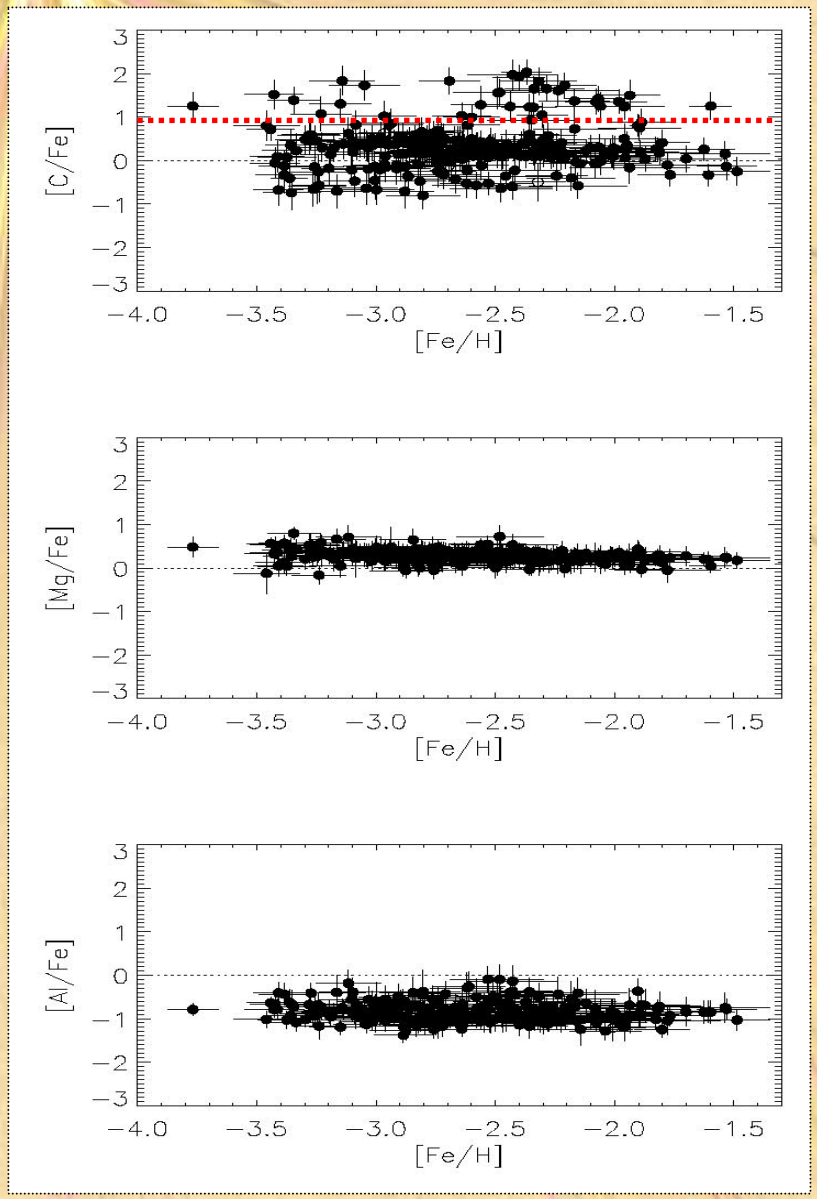
The apparent frequency of r-II stars is ~ 5 % of giants with [Fe/H] < -2.5

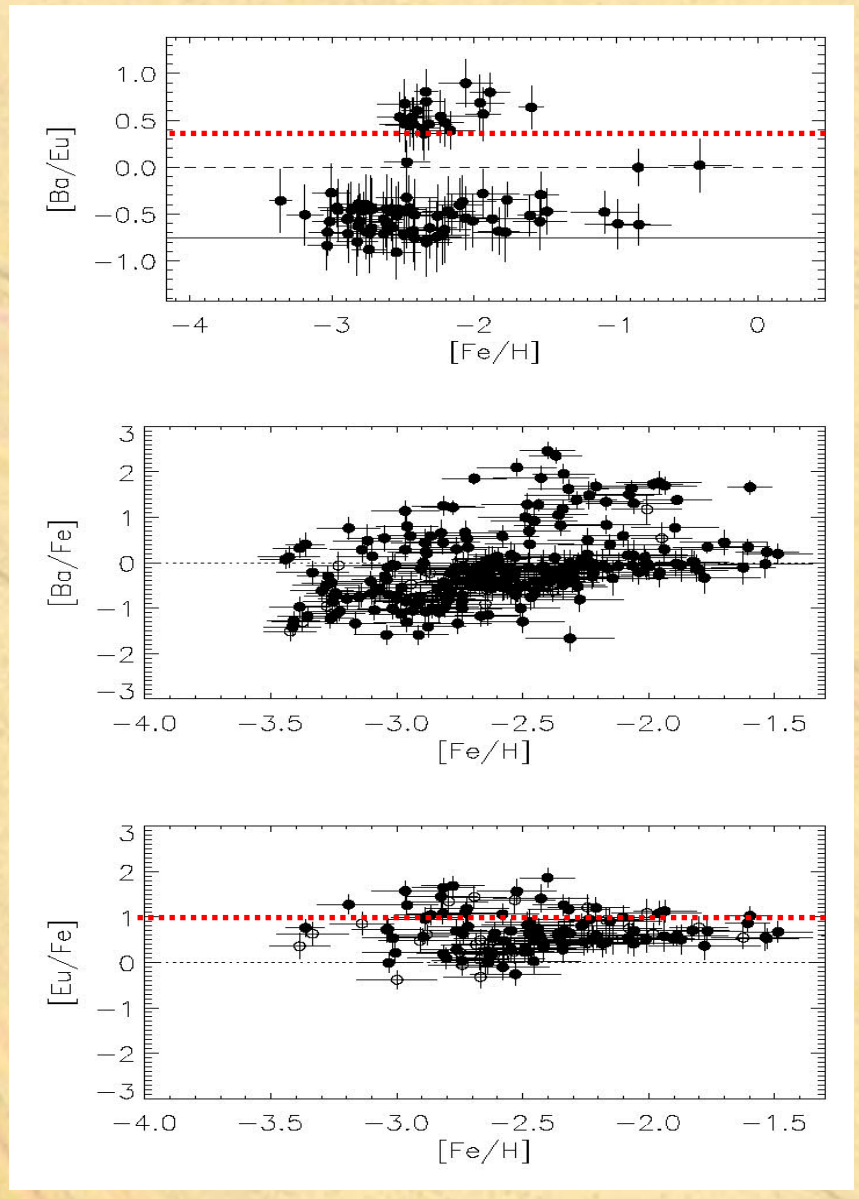
HERES Survey: Other Elements !

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



The Power Of Large N: 274 Stars from HERES





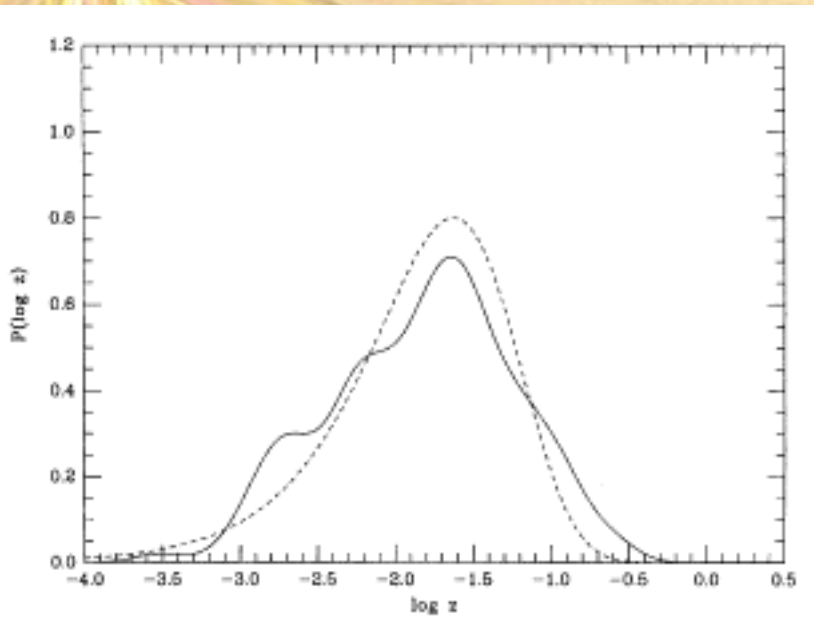
Historical Background

- The distribution of metallicities ([Fe/H]) in stars of the halo has been intensively studied for over 25 years
  - Especially since recognized that halo contains stars with [Fe/H] < -2.5 (lowest metallicity globular clusters)
  - Long limited by small number statistics, in particular for [Fe/H] < -2.0

Best Available "Complete" MDFs

- The difficulty of isolating a "fair" sample of halo stars based on in-situ surveys has left astronomers with little choice but to isolate likely halo stars based on their motions
- The primary "kinematic studies" which reach to interesting low [Fe/H], based on a proper-motion selection
  - Carney et al. (1994)
  - Norris & Ryan (1991)

The Complete MDF's

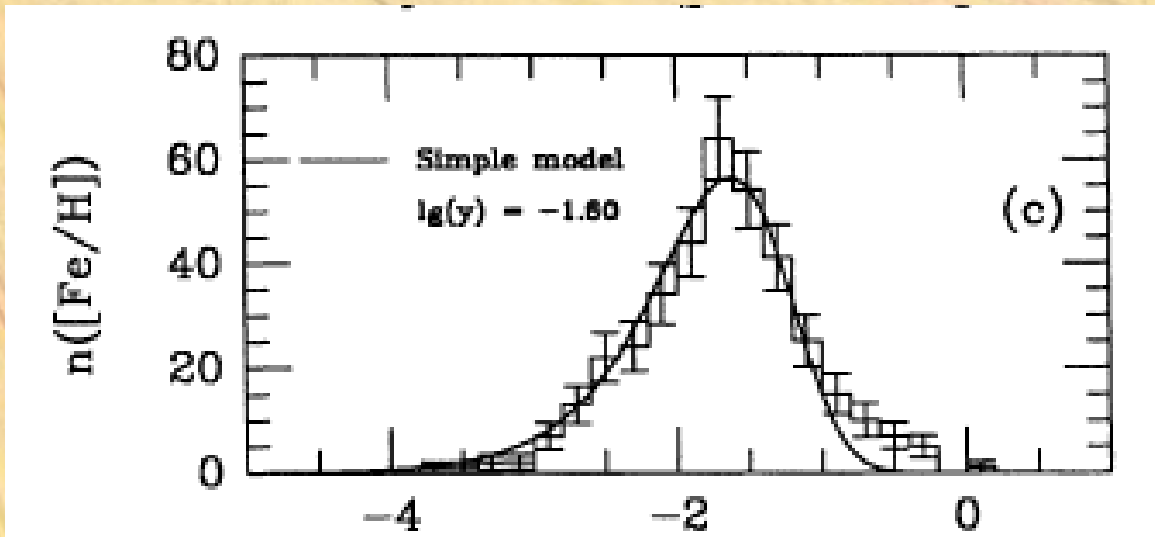


Carney et al. (1996)

Note use of "generalized histogram" rather than counts

Ryan and Norris (1991)

Note use of counts



Remaining Questions Concerning the halo MDF

- What is the shape of the low-metallicity “tail” of the halo MDF ? Is it continuous ?
- What is the low-metallicity cutoff of the tail of the halo MDF ?
- Is the halo MDF constant throughout the halo, e.g., with distance ?
- Can the details of the halo MDF be accounted for by contemporary galaxy assembly models ?

Answers to the Above Require…

- Substantially larger samples of low metallicity stars, ideally chosen without kinematic bias, especially with [Fe/H] < -2.0
- Measurements of distances, radial velocities, and where possible, proper motions, for these same samples

Summary of Present Progress

- HK Survey (formerly known as Preston-Shectman survey)
  - Stars selected visually from objective-prism plates
  - Follow-up UBV photometry and 1-2 A spectroscopy
- Hamburg/ESO Survey (HES)
  - Stars automatically selected from objective-prism plates
  - Follow-up BVRI photometry and 1-2 A spectroscopy
- Stellar Component of Sloan Digital Sky Survey
  - Public data (through DR3) includes some 70,000 stars with available ugriz photometry and 2.5 A resolution spectroscopy over 3800-9000 A
  - Many stars included for use in calibration of reddening and spectrophotometry of the SDSS main survey, which samples the low-metallicity turnoff of the halo

Observational Follow-Up
HK, HES, DR3

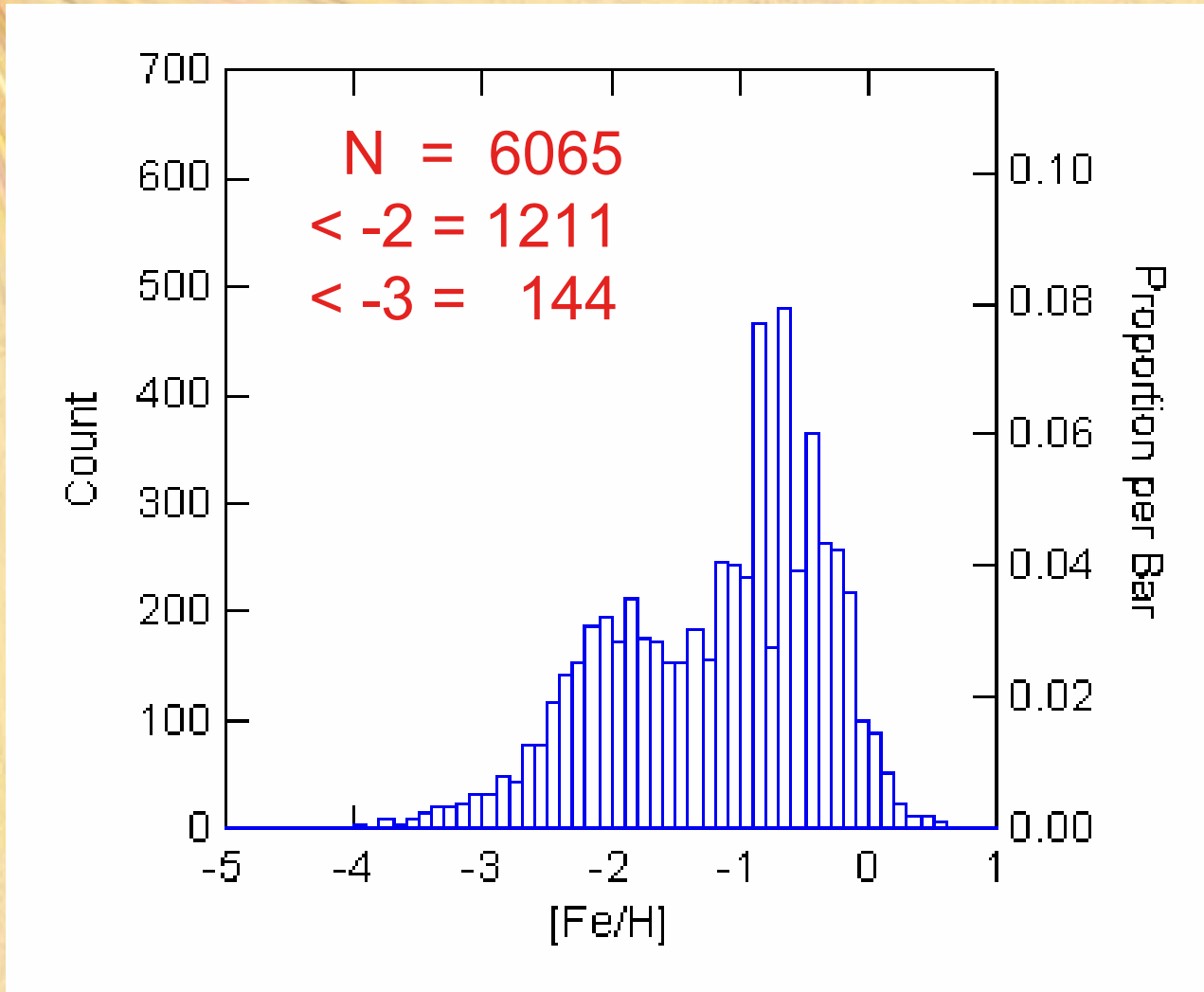
Survey	Spectra	Unique	UBV	J-K
HK	14488	11212	4944	10438
HES	7465	6212	812	5078
DR3	71396	~70000	…	…

Note: Roughly 40% of HK + HES spectra obtained in past three years with UK Schmidt + 6dF

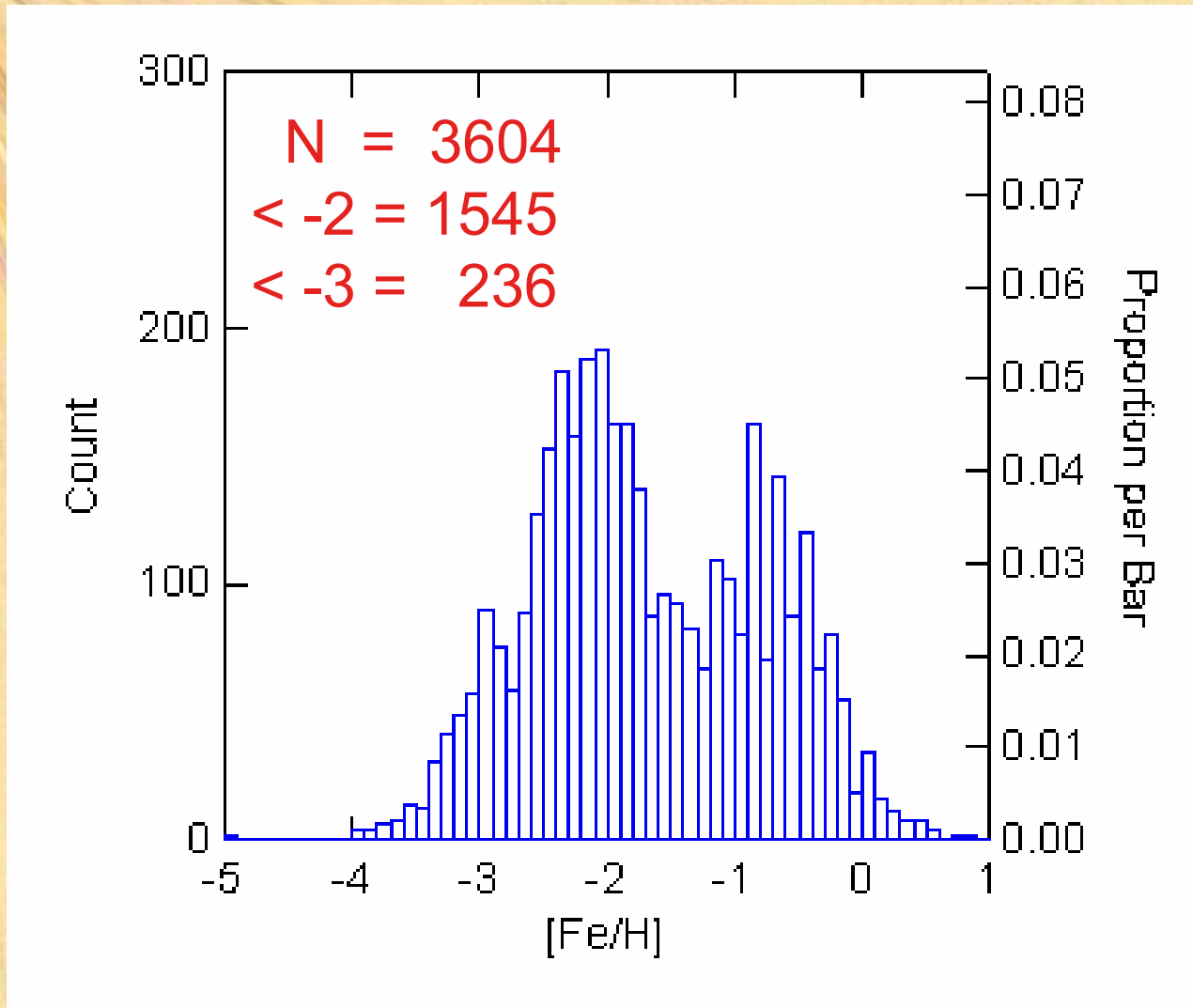
Determination of Metallicities for HK and HES Targets

- Application of the Beers et al. (1999) calibration of KP vs. (B-V)o – where available, or based on estimated (B-V)o from HP2 (Balmer line index), for warmer stars
- Application of newly developed Artificial Neural Network calibration of KP vs. (J-K)o, for cooler stars
- For clearly carbon-enhanced stars, application of Rossi et al. (2005) calibration based on KP vs. (J-K)o for stars with measured [Fe/H] and [C/Fe]

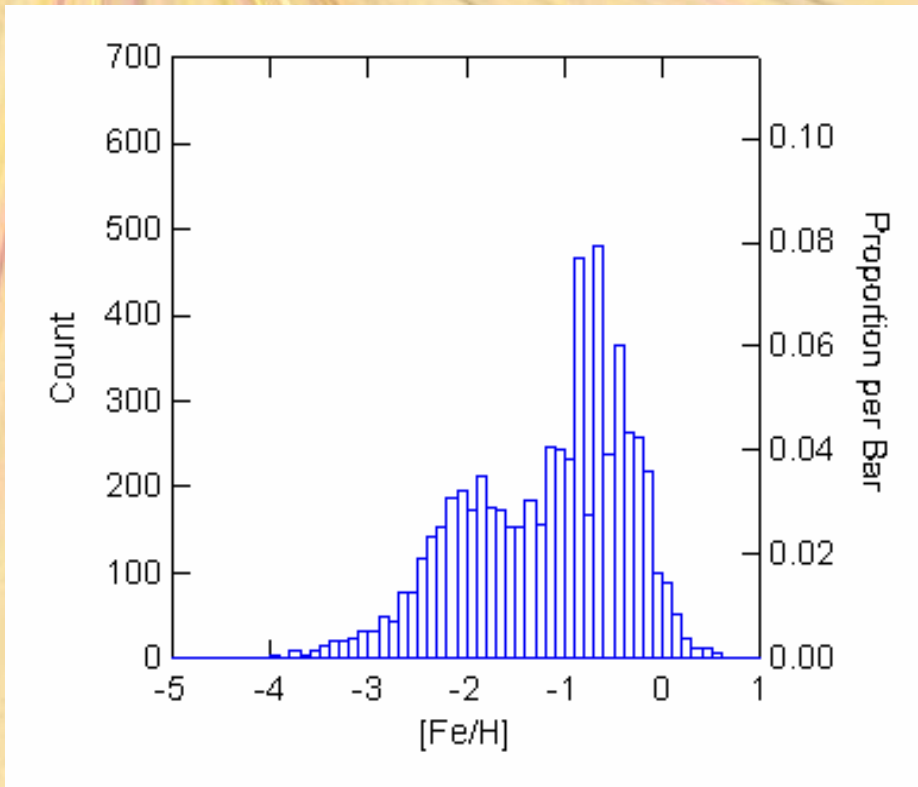
Preliminary "As Observed" MDF: HK Survey

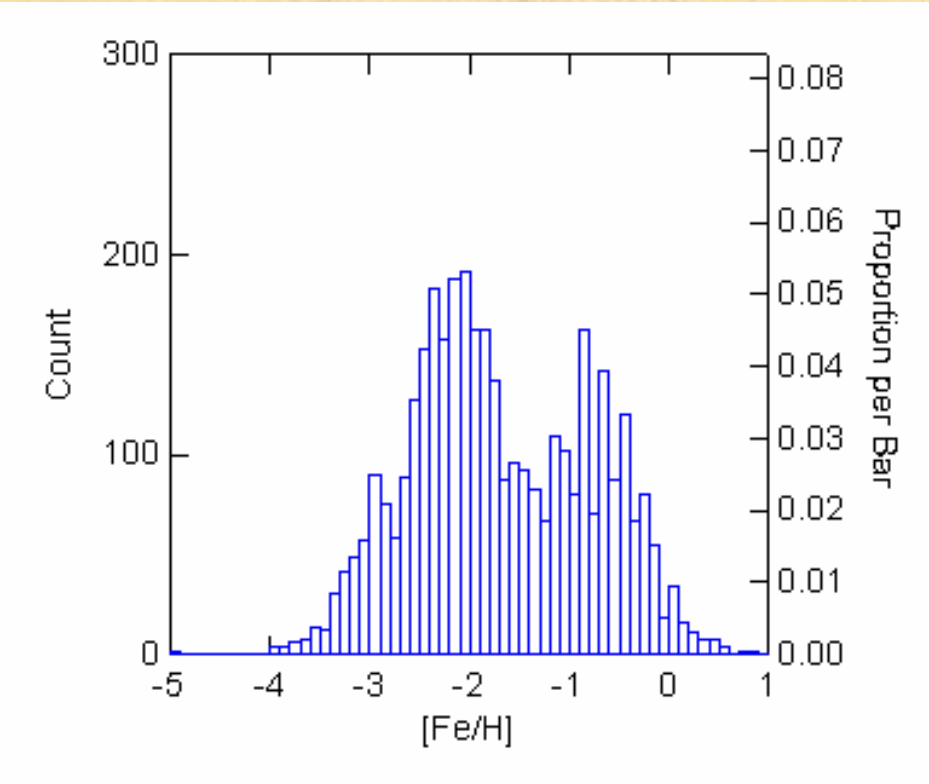


Preliminary "As Observed" MDF: Hamburg/ESO Survey



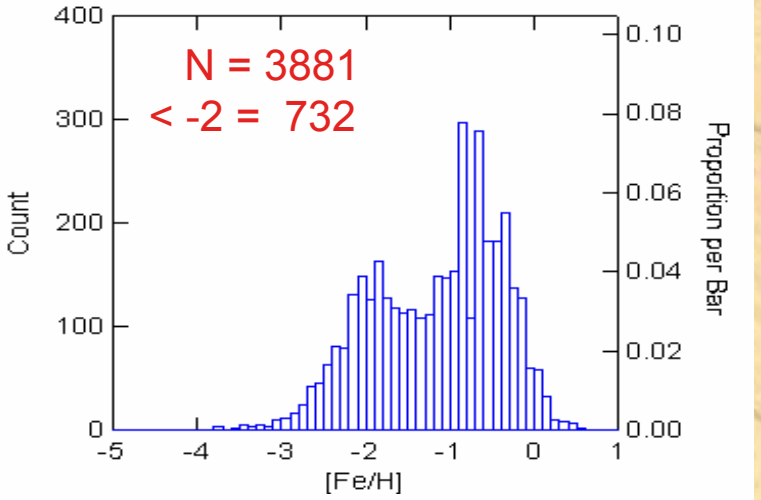
Comparison of MDFs for HK Survey and HES



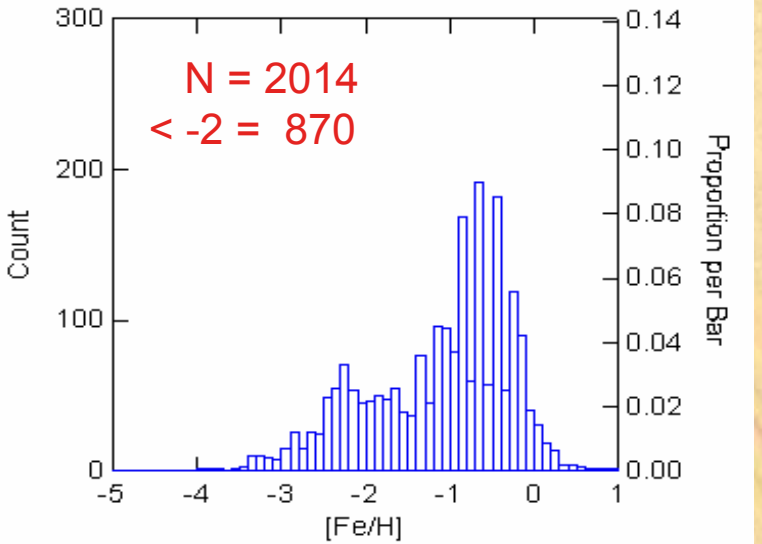


Comparison of MDFs for HK Survey and HES – Dwarfs and Giants

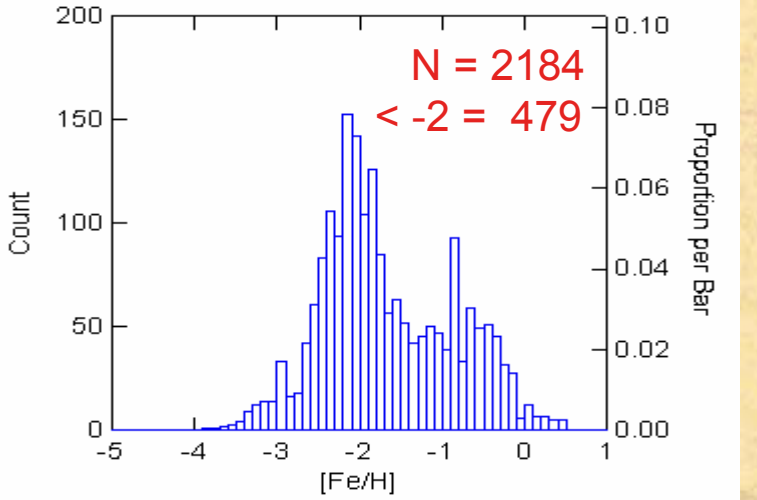
HK Dwarfs



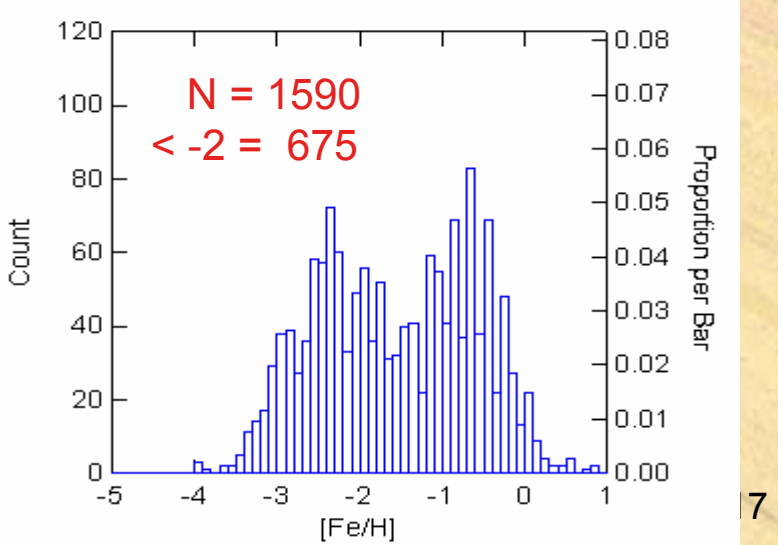
HK Giants



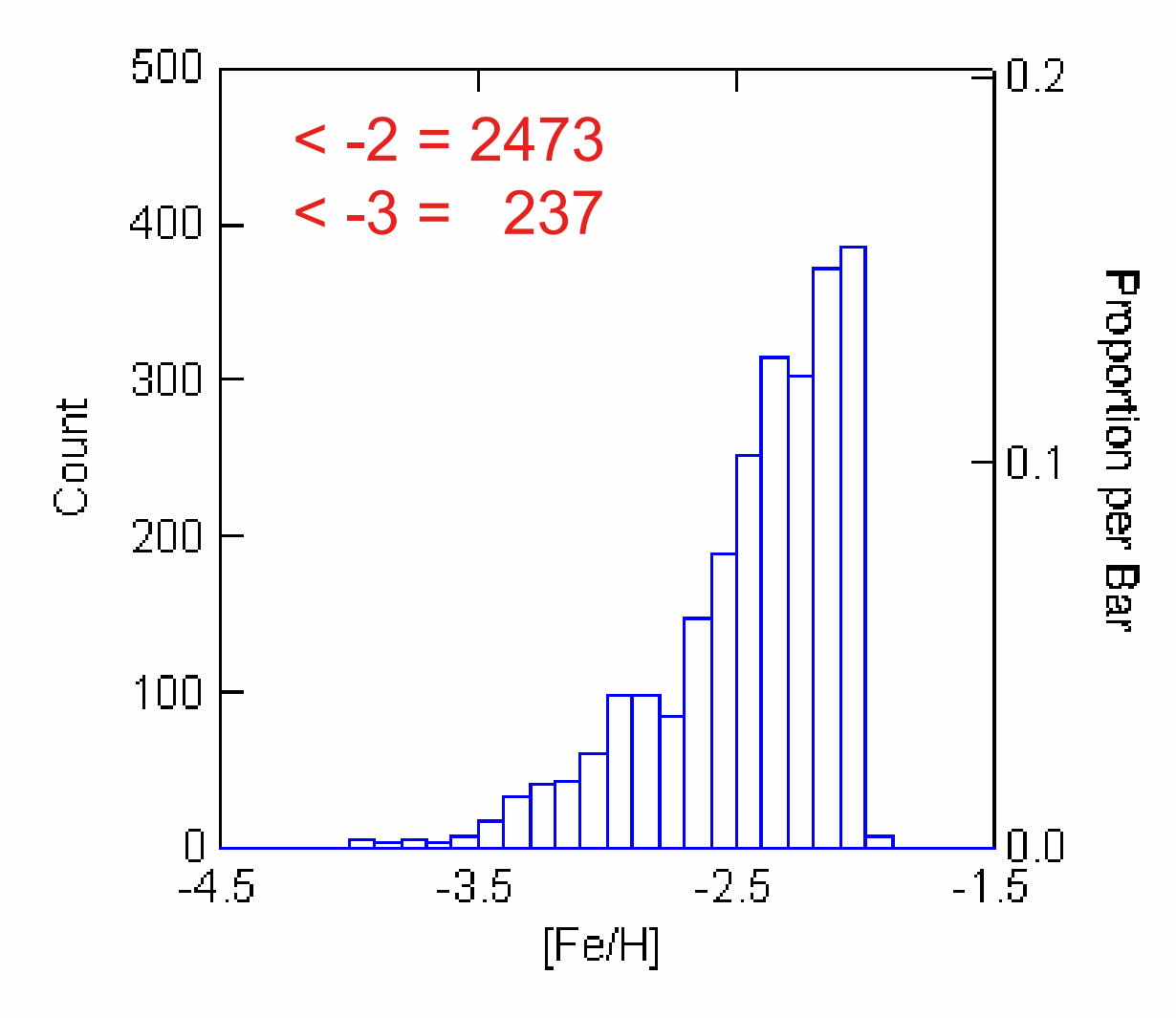
HES Dwarfs



HES Giants

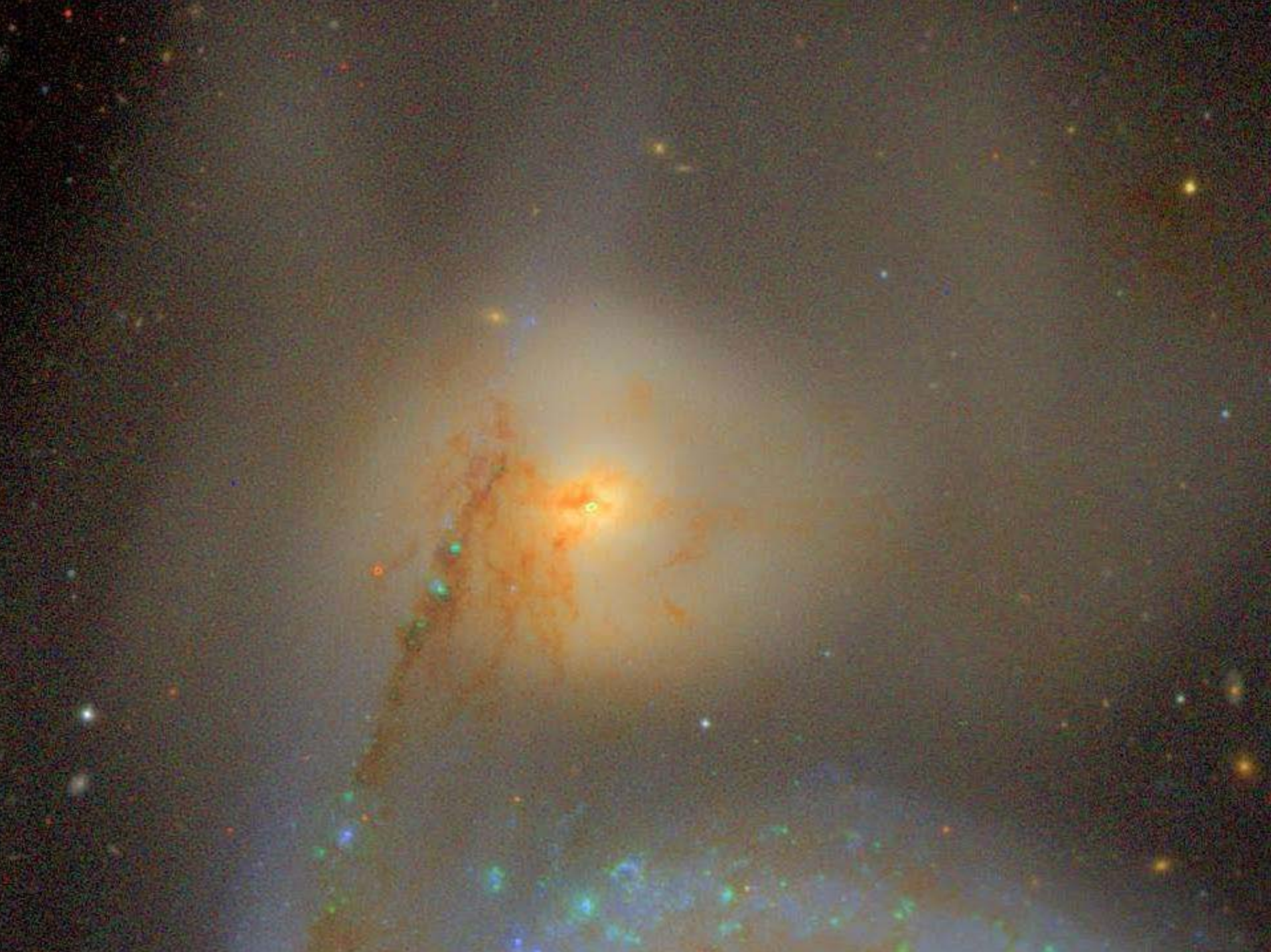


Preliminary "As Observed" MDF: HK + HES Surveys (Close Up)



What Remains to be Accomplished ?

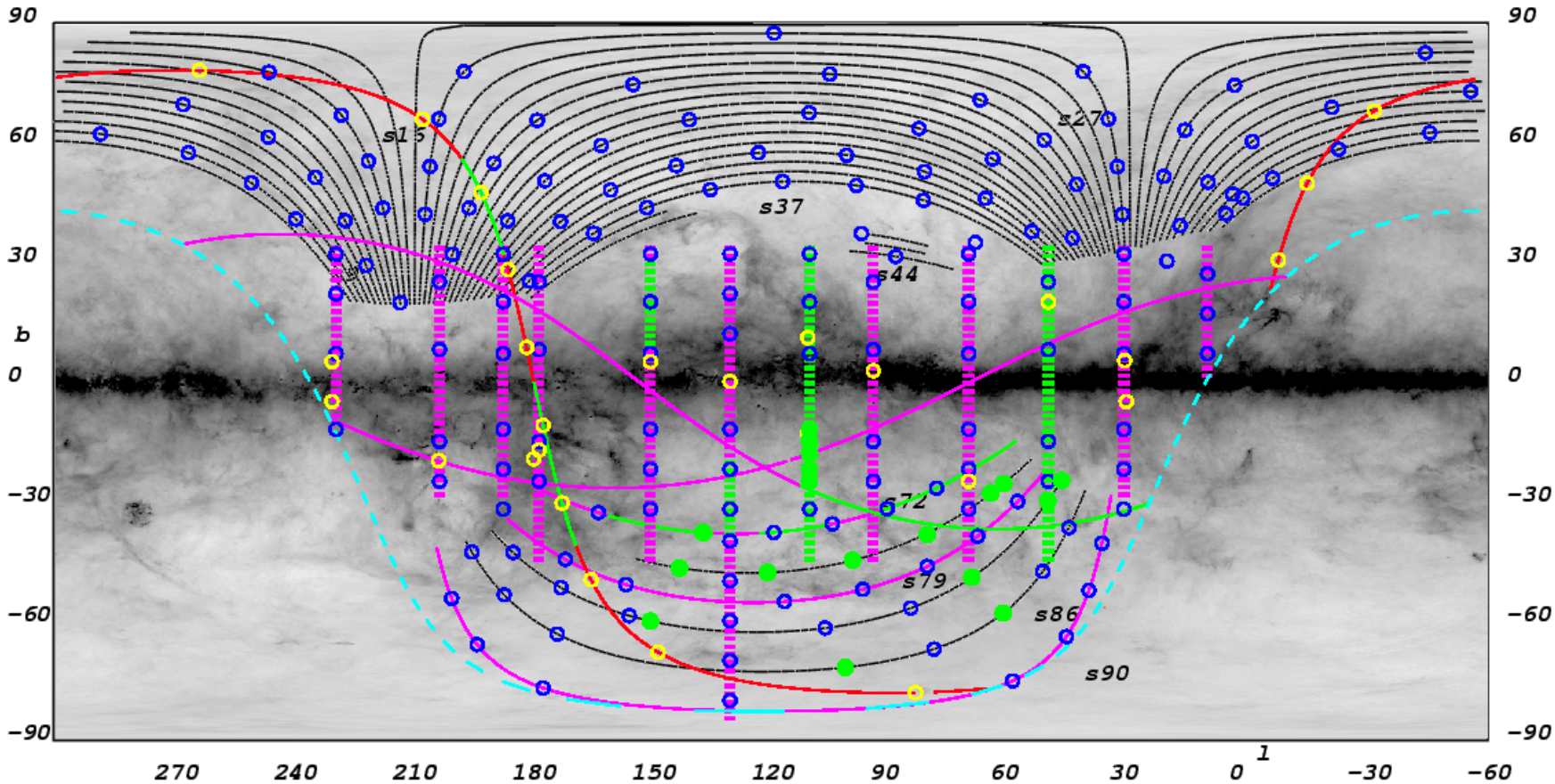
- Detailed checking of individual stars
- Additional UBV and/or BVRI photometry
- Searches for available proper motions
- Checking/averaging of radial velocities
- Validation of [Fe/H] < -3.0 spectra with improved S/N observations



SEGUE: The Sloan Extension for Galactic Understanding and Exploration

- Use existing SDSS hardware and software to obtain:
  - 3500 square degrees of additional *ugriz* imaging at lower latitudes
    - Stripes chosen to complement existing areal coverage; includes several vertical stripes through Galactic plane
  - 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 along each line of site
    - Proper motions available (from SDSS) for stars within ~ 5 kpc

SEGUE observing plan and status as of Oct 2005



SDSS Imaging scan

Planned SEGUE scan (3500 sq deg)

Sgr stream planned scan

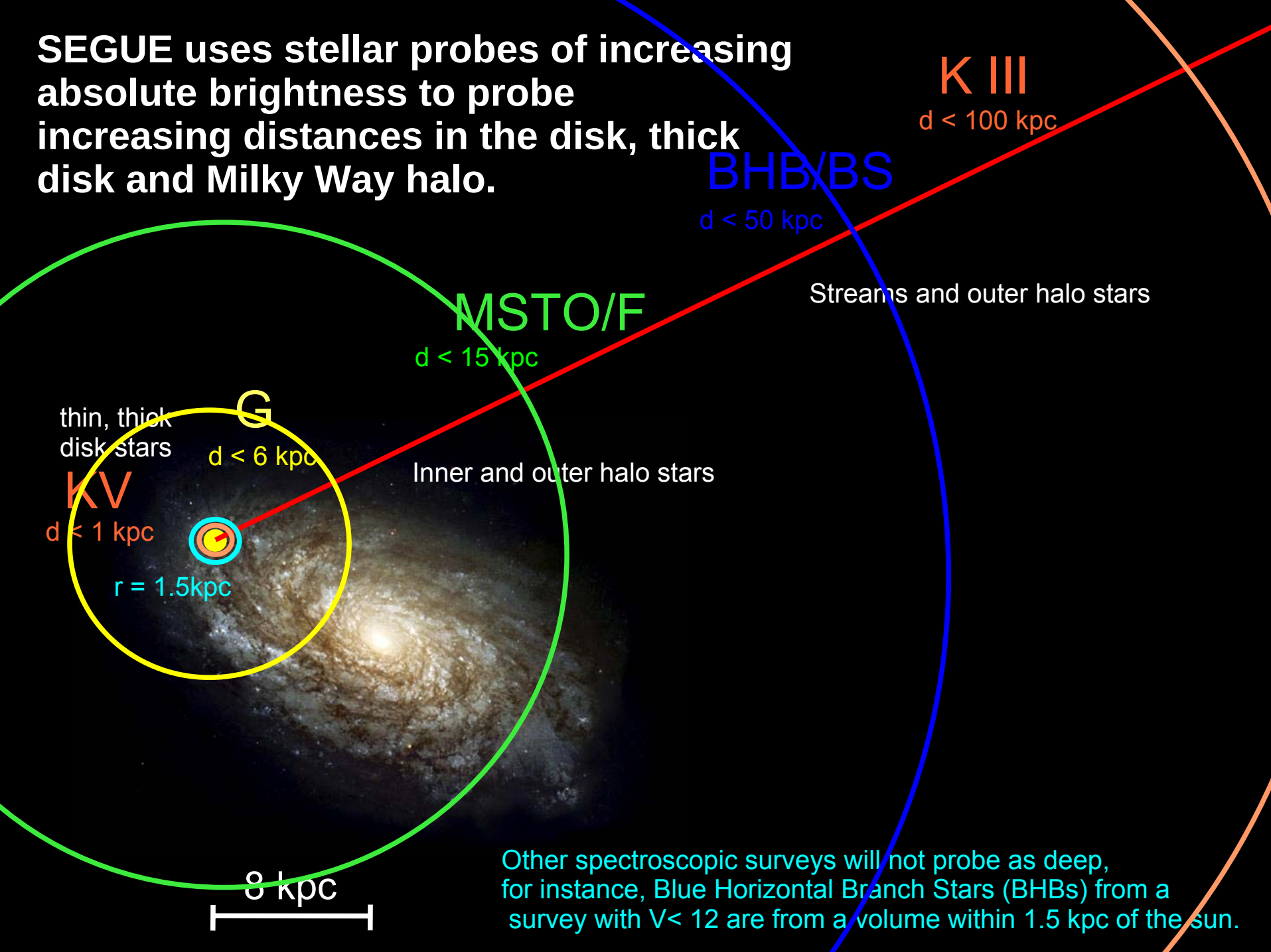
Completed SEGUE imaging

Declination = -20 degrees

Planned SEGUE grid pointings (140)

Planned targeted SEGUE pointings(60)

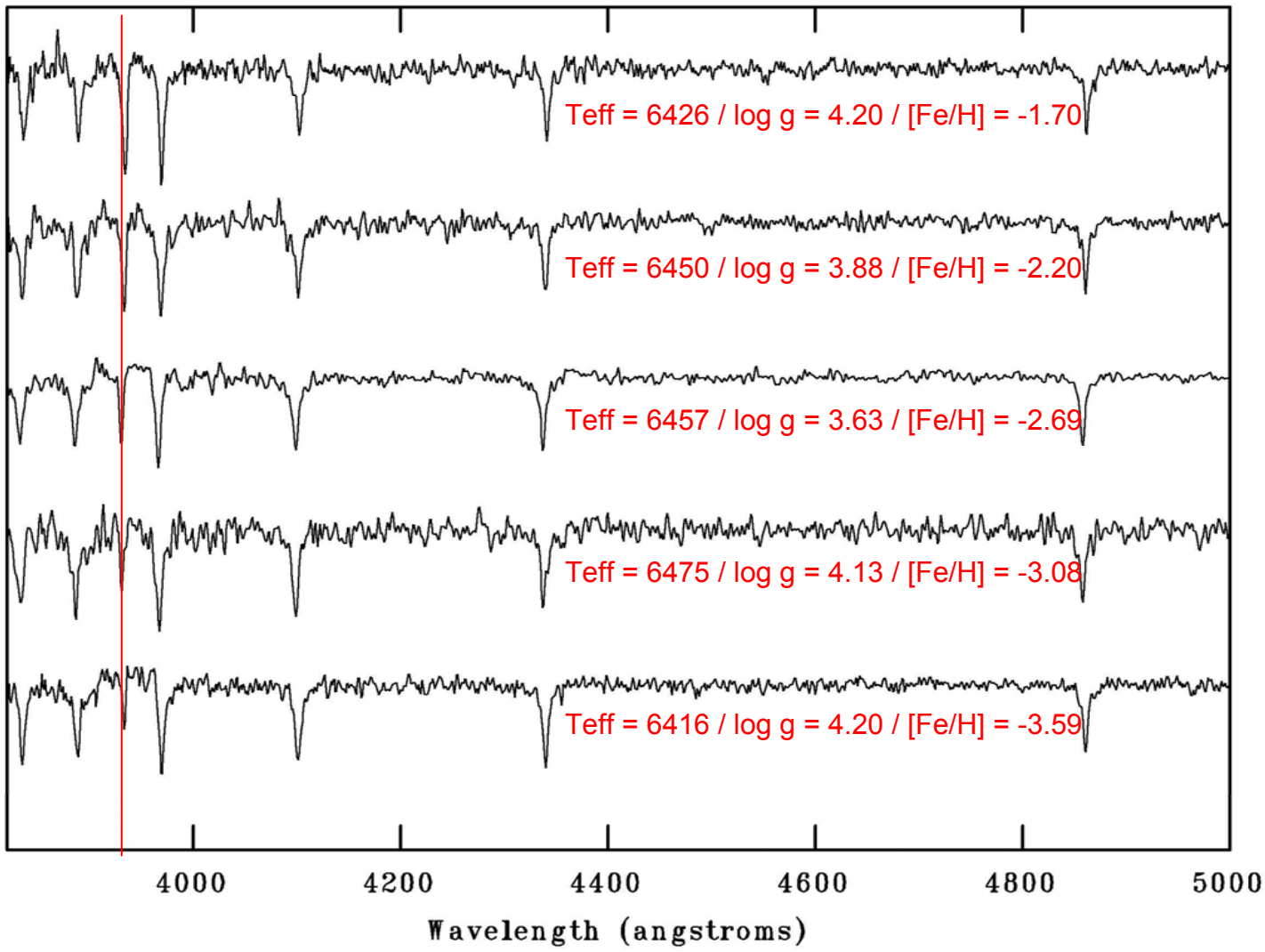
Completed SEGUE plate pointing


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
G
d < 6 kpc
thin, thick disk stars
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.

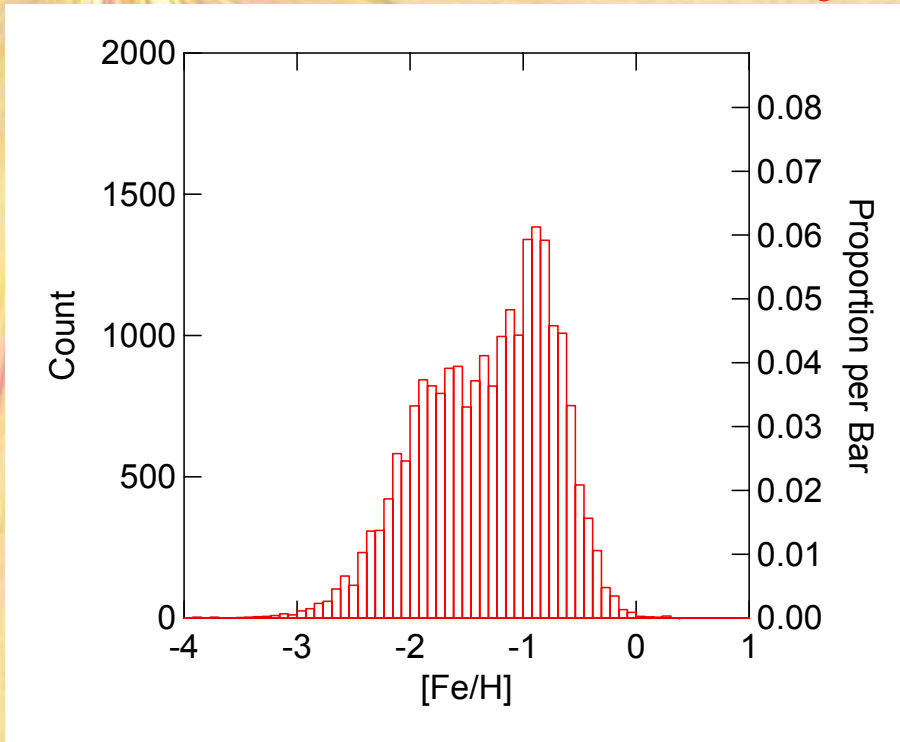
Determination of Metallicities and Atmospheric Parameters for SDSS Stars

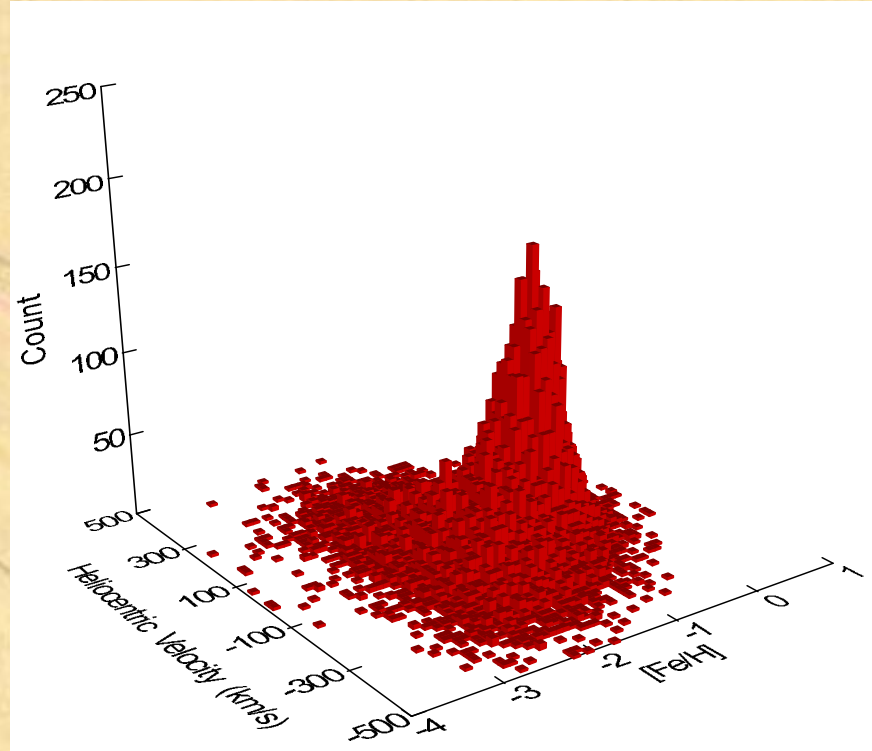
- 5 methods for abundance determination
  - KP vs. predicted (B-V)o
  - Autocorrelation Function vs. predicted (B-V)o
  - Ca Triplet vs. predicted (B-V)o
  - Ca K + metallic line regions + ugriz
  - Spectral/Photometric matching (ugriz)
- 4 methods for logg determination
  - CaI 4227 vs. predicted (B-V)o
  - MgH vs. predicted (B-V)o
  - MgH (and other gravity sensity features) vs. ugriz
  - Spectral/Photometric matching
- 2 methods for Teff determination
  - Balmer lines + ugriz
  - Spectra/Photometric Matching

Example Main-Sequence Turnoff Stars of Low Metallicity



SDSS DR3 -- Distribution of [Fe/H] and Velocity vs. [Fe/H]





- Even though SDSS does not specifically target the most metal-poor stars, it finds plenty of them !
- There are N ~ 3000 stars with [Fe/H] < -2.0 (with well-measured parameters) and cooler than the halo main-sequence turnoff included in DR-3, and N ~ 100 such stars with [Fe/H] < -3.0
- This is more than the SUM OF ALL PREVIOUS [Fe/H] < -2.0 stars found over the past half-century by other survey efforts

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