The Nature of the Galactic Halo(s) as Revealed by SDSS/SEGUE

INAF

MICHIGAN STATE UNIVERSITY

Timothy C. Beers
Department of Physics & Astronomy
Michigan State University
& JINA: Joint Institute for Nuclear Astrophysics

SDSS

Direct Collaborators

- Daniela Carollo (INAF, Italy /JINA)
- Young Sun Lee (MSU / JINA)
- Sivarani Thirupathi (MSU / JINA)
- Brian Marsteller (MSU / JINA)
- John Norris (ANU / SEGUE)
- Masashi Chiba (Tohuku University, Japan)
- Carlos Allende Prieto (Univ. of Texas)
- Constance Rockosi (UCSC)
- Brian Yanny (FNAL)
- Heidi Newberg (RPI)
- Jeffrey Munn (USNO)

Why the Fascination with Large Numbers of MP Stars ?

- Extremely MP stars have recorded the heavy element abundances produced in the first generations of stars
- The shape of the low-metallicity tail of the Metallicity Distribution Function (MDF) will (eventually) show structure that reveals the characteristic abundances of major epochs of star formation in early Galaxy
- Change in the nature of the MDF as a function of distance may reveal the assembly history of the MW
- Determination of the frequency of various elemental abundance signatures, e.g., enhancement of [C/Fe], [alpha/Fe], etc.
- Identification of relatively rare objects amongst MP stars, e.g., r-process / s-process enhanced stars

Previous Efforts to Find Metal-Poor Stars in the Galaxy

- Concentrated on
  - High proper-motion stars (e.g., Carney et al., Ryan & Norris)
  - In-situ prism surveys (e.g., HK survey, HES)
- In total, such surveys have identified
  - ~ several thousand stars with [Fe/H] < -2.0
  - ~ several hundred stars with [Fe/H] < -3.0
- Inspired numerous several large-scale high-resolution spectroscopic follow-up efforts
  - Cayrel et al. (2004) "First Stars" (VLT/UVES) (~100 stars)
  - Christlieb et al. (2004) "HERES Survey" (VLT/UVES) (~350 stars)
  - Cohen et al (2002) "0Z Survey" (Keck/HIRES) (~100 stars)
  - Aoki et al. (in prog) "UMP Star Survey" (Subaru/VLT) (~ 50 stars)

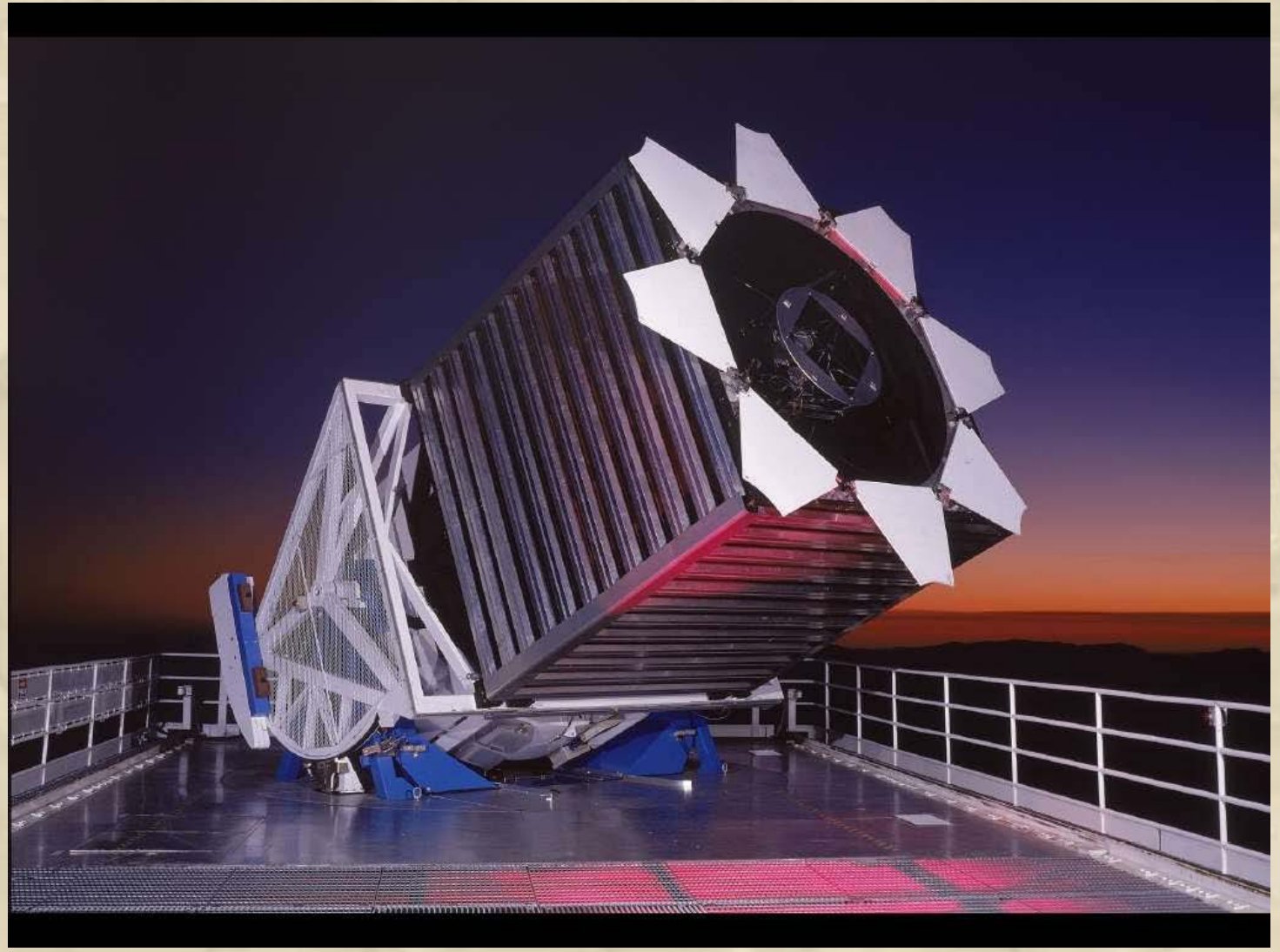
New Efforts for Finding Very Metal-Poor Stars

- Stellar observations at medium-resolution have been obtained during the course of the Sloan Digital Sky Survey (SDSS)
  - Calibration of spectrophotometry / telluric bands
  - Directed studies (e.g., BHB stars, C-rich stars)
  - “Failed QSO” targets
- New stellar observations being obtained during the course of SDSS extension program SEGUE

SEGUE: The Sloan Extension for Galactic Understanding and Exploration

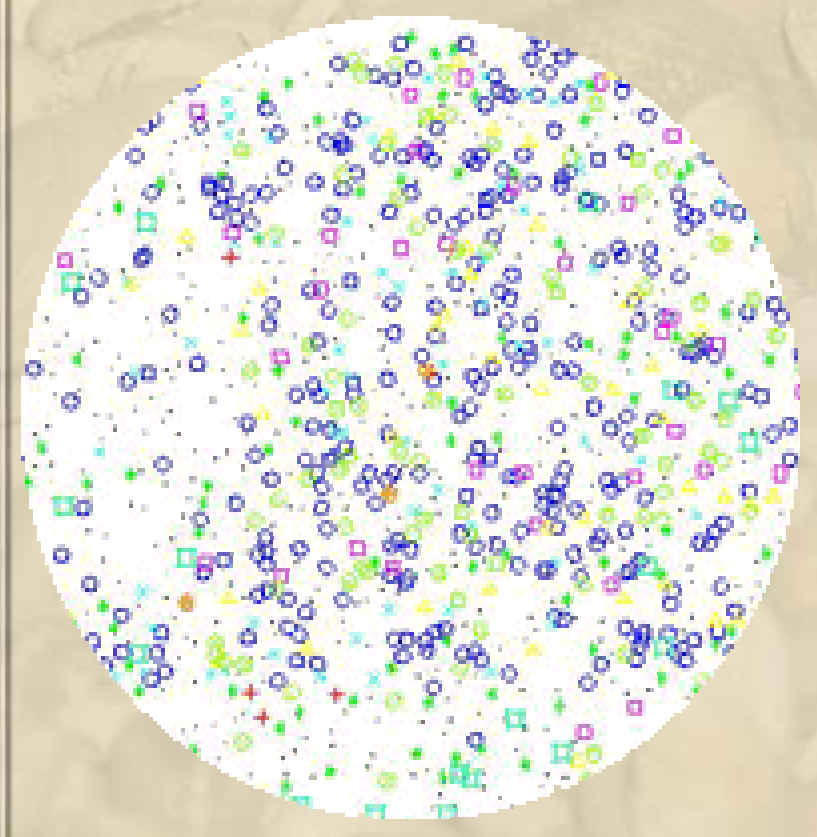
- Use existing SDSS hardware and software to obtain:
  - 3500 square degrees of additional *ugriz* imaging at lower Galactic latitudes
    - Stripes chosen to complement existing areal coverage; includes several vertical stripes through Galactic plane
- Medium-resolution spectroscopy of 250,000 "optimally 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

SDSS -- The Telescope and Data

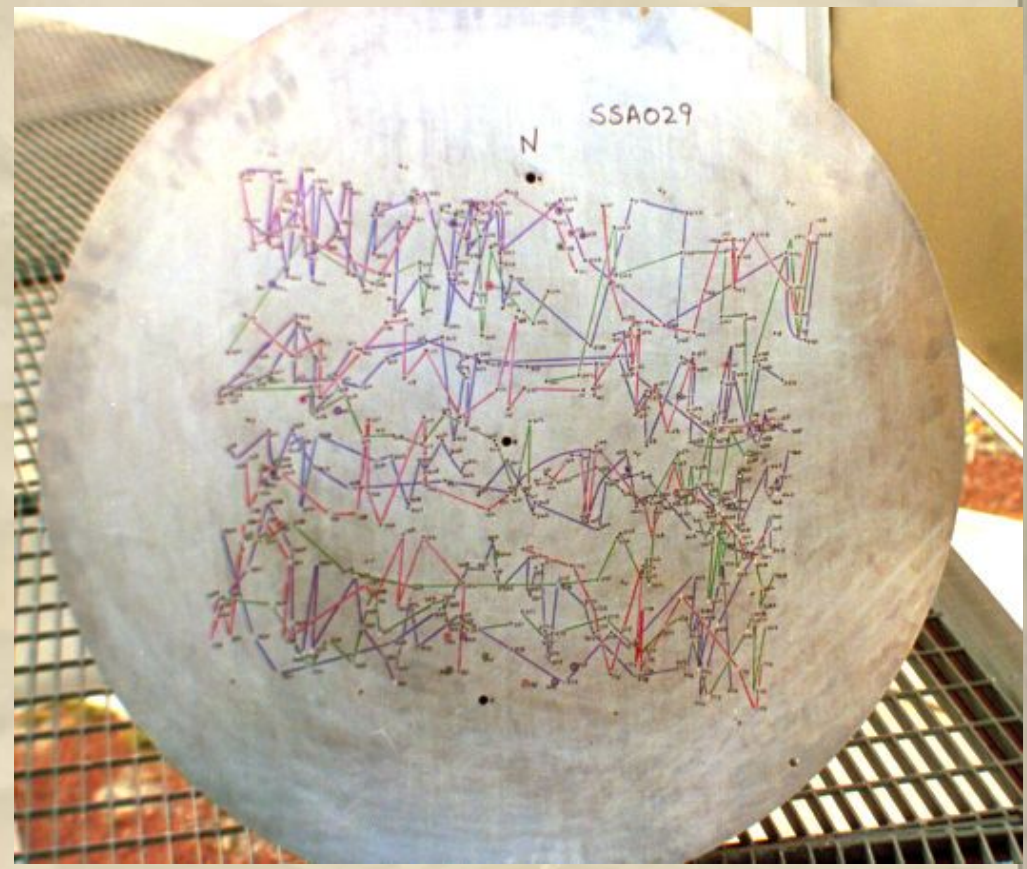


ARC 2.5m SDSS Telescope (3 deg FOV)

The SDSS Spectrograph Plug Plate

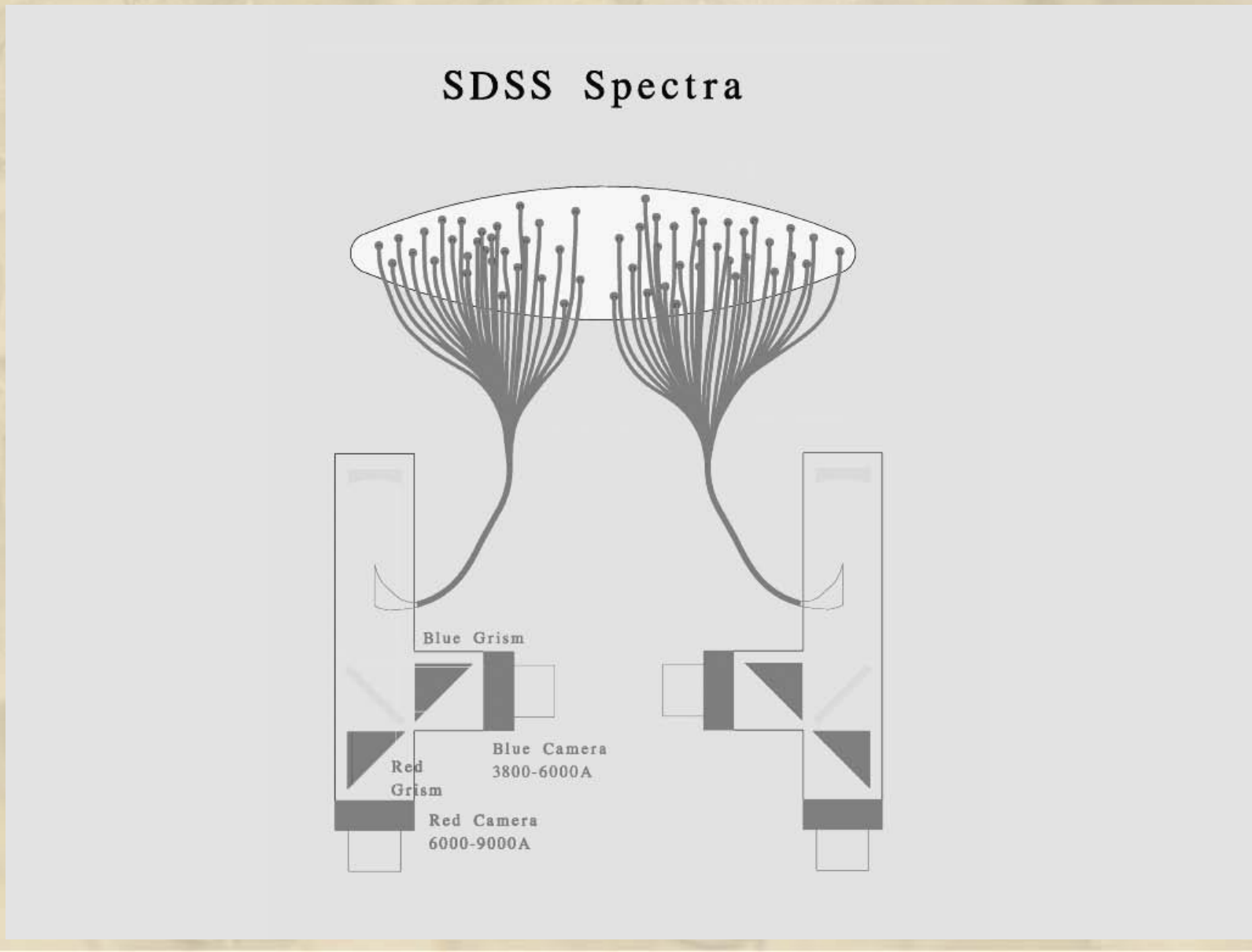


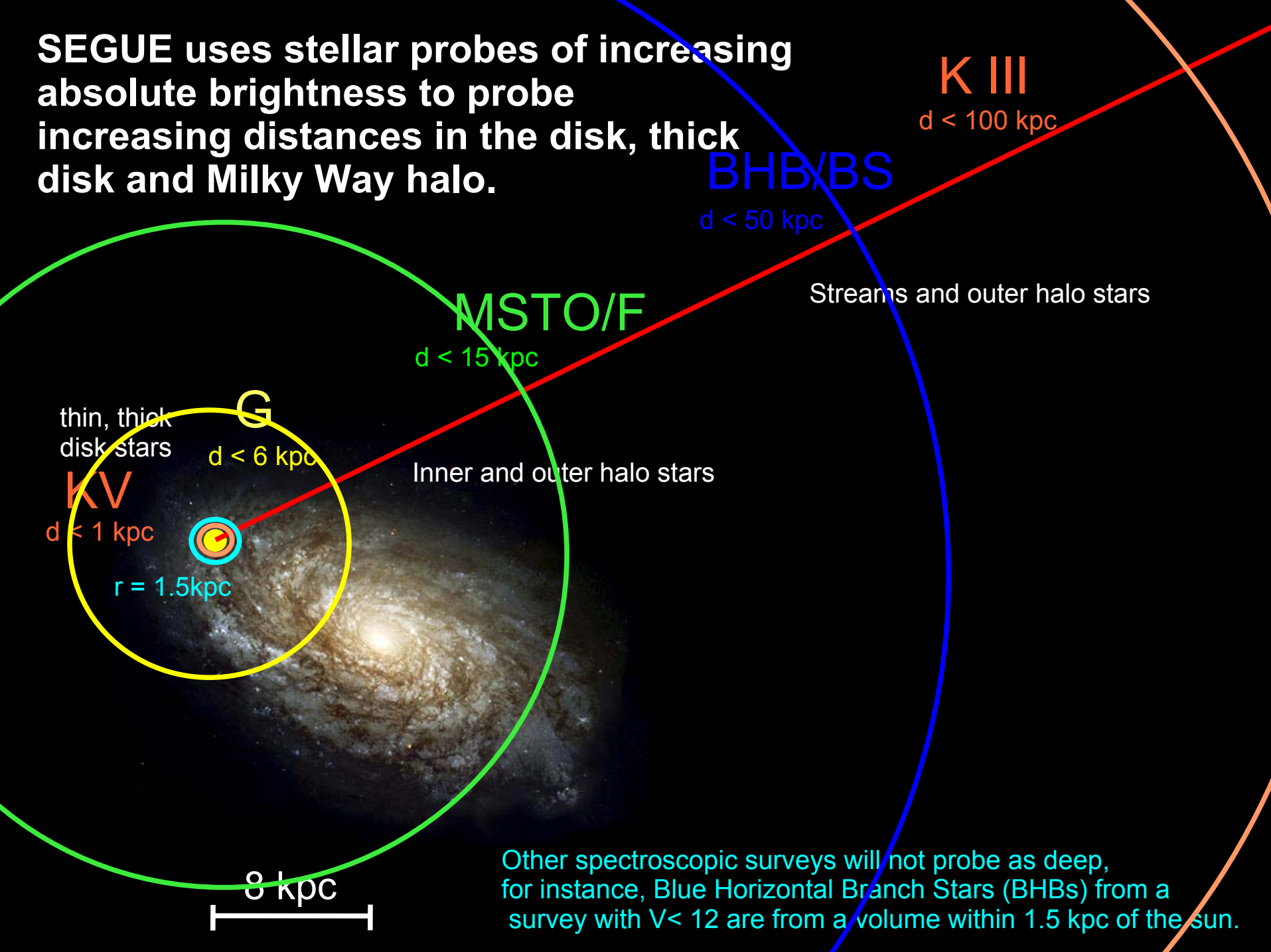
Identification of targets on the sky



A prepped and drilled plate

A Cartoon Version




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.

Likely Numbers of Detected MP Stars from SEGUE

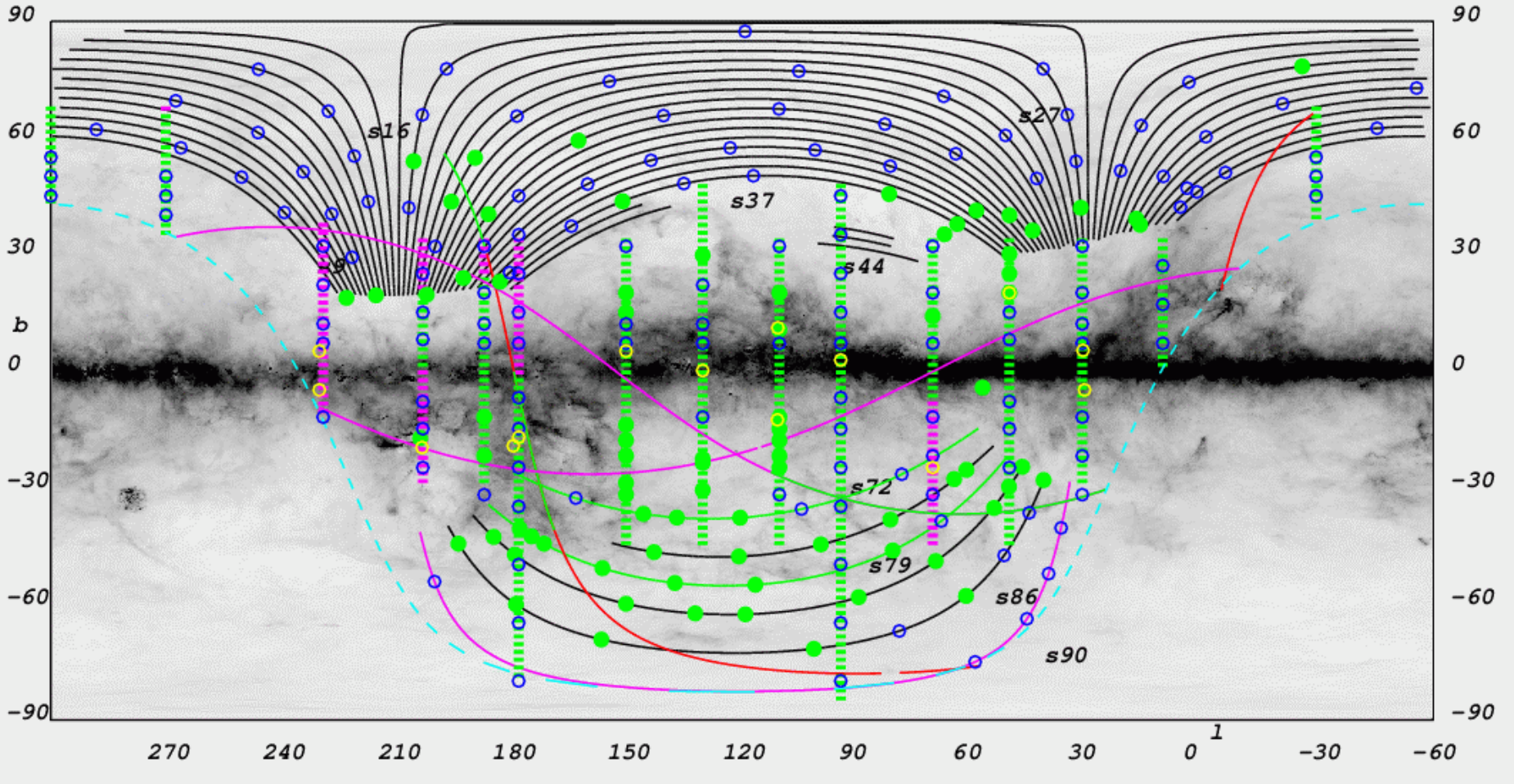
- Actual numbers will depend on the shape of the halo Metallicity Distribution Function

–	[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)

Present Status of SEGUE

- SEGUE
  - Tests of target selection algorithms carried out fall 2004 and spring 2005
  - Began taking “real” data in July 2005
  - To date, approximately 3/4 of imaging (3000 square degrees) and over 1/2 of spectroscopy (125,000 stars) observed
    - First public release of SEGUE data (year 1 = DR-6) in June 2007, to include parameters for stars in DR-5 as well.
  - Essentially final version of SEGUE Spectroscopic Parameter Pipeline completed / revisit for DR-7
  - High-resolution follow-up of SEGUE stars for validation and refinement of spectroscopic pipeline underway (HET / Subaru / Keck)

SEGUE observing plan and status as of May 2007



SDSS Imaging scan

Planned SEGUE scan (3500 sq deg)

Sgr stream planned scan

Completed SEGUE imaging

Declination = -20 degrees

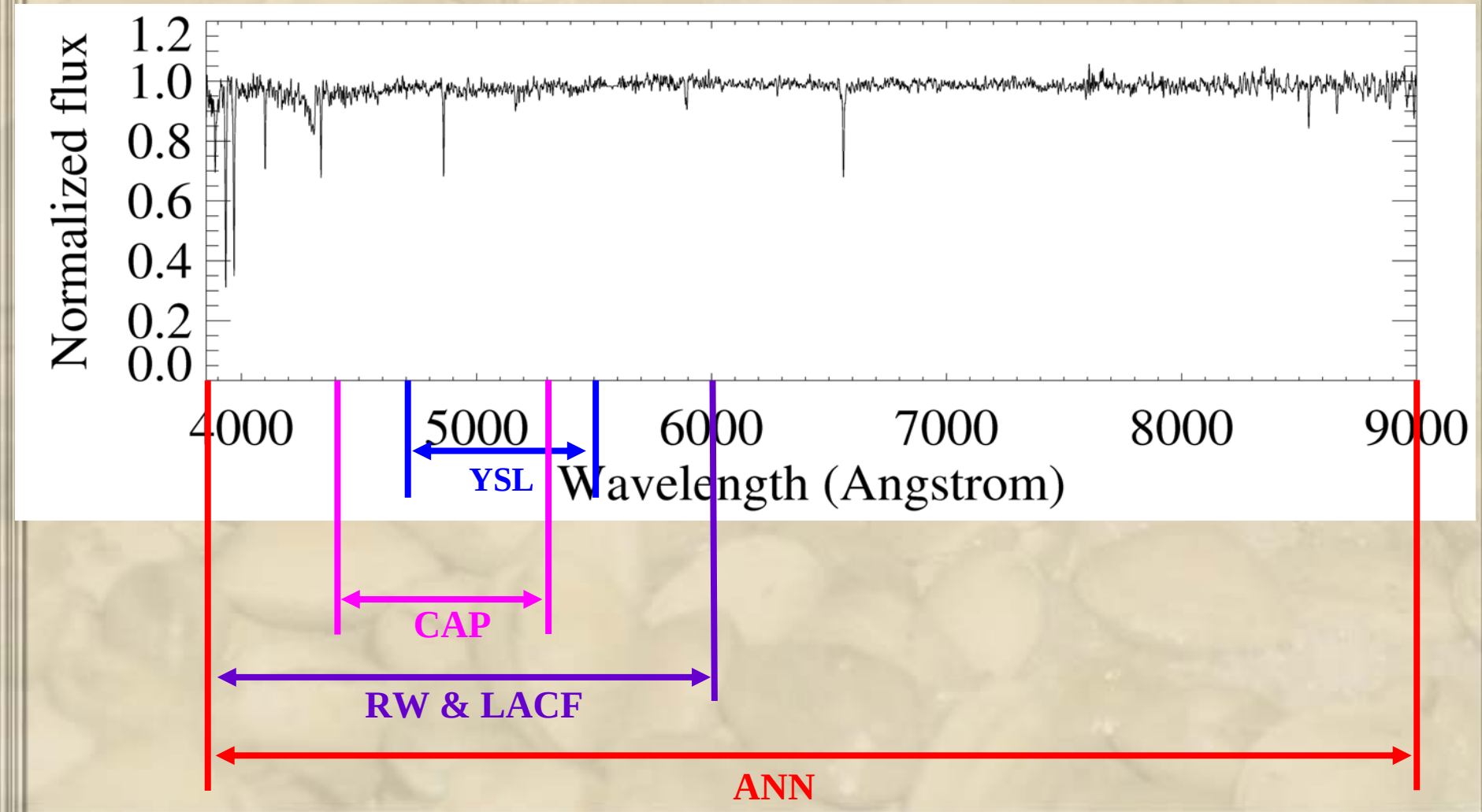
Planned SEGUE grid pointings (200)

Planned targeted SEGUE pointings(60)

Completed SEGUE plate pointing

SSPP - Methodology I

There are 9 methods for determining [Fe/H], 7 for log g, and 5 for T_{eff}. Each approach makes use of different wavelength coverage or line bands for estimating parameters.



SSPP - Methodology II

YSL (Lee et al. 2007, submitted)

- uses χ^2 minimization with synthetic templates over the wavelength range of T_{eff} (4700-5500Å), log g(5150-5220 Å), [Fe/H] (5220-5500 Å, 3900-4000 Å)
- grid of synthetic spectra :
  T_{eff} = 3500~10000 K(Δ 250 K), log g =0.0 ~ 5.0(Δ 0.5), [Fe/H]=-4.0 ~ +0.5(Δ 0.5)

ANN (Re Fiorentin et al. 2007, A&A in press)

- trains network on SEGUE spectra with previously estimated parameters and estimates T_{eff}, log g, and [Fe/H]

RW (Wilhelm et al. 1999)

- fits Balmer lines with Voigt or Gaussian profiles for T_{eff}, the G-band for log g, and the Ca II K line and other metallic indices for [Fe/H]
- grid of synthetic spectra :
  T_{eff} = 3500~9750 K(Δ 250 K), log g =1.0 ~ 4.5(Δ 0.5), [Fe/H]=-3.0 ~ +0.0(Δ 0.5)

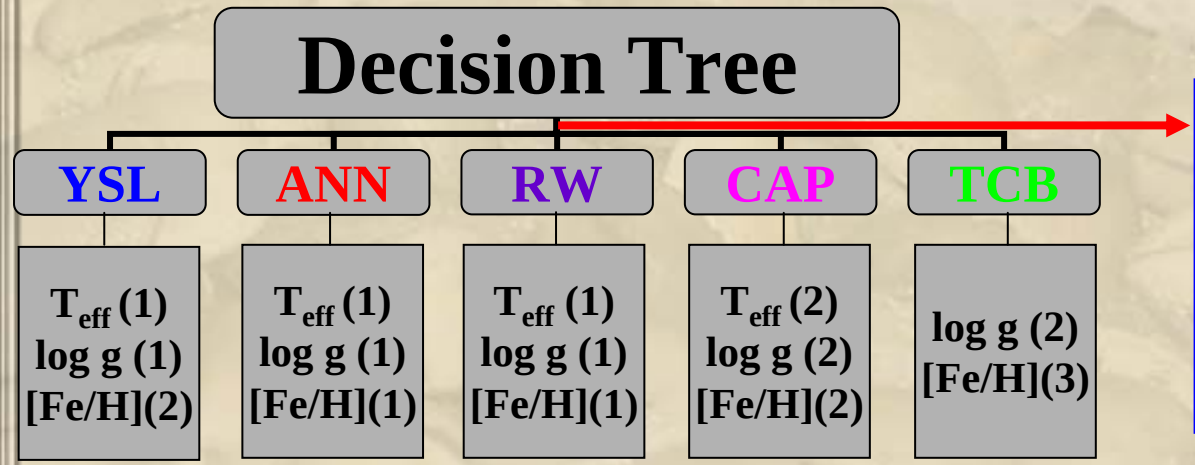
CAP (Allende Prieto et al. 2006)

- uses χ^2 minimization with different synthetic spectral templates (k24 and ki13) over (4400 – 5300 Å) for T_{eff}, log g, and [Fe/H]
- grid of synthetic spectra (k24) :
  T_{eff} = 4500~9250 K(Δ 500 K), log g =1.5 ~ 5.0(Δ 0.5), [Fe/H]=-4.83 ~ +0.63(Δ 0.5)
- grid of synthetic spectra (k24) :
  T_{eff} = 4500~7750 K(Δ 500 K), log g =1.0 ~ 5.0(Δ 0.5), [Fe/H]=-3.83 ~ +0.63(Δ 0.5)

TCB (Beers et al. 1999)

- uses (*B*-*V*)/Ca II K (3933 Å), Ca II Triplet (around 8550 Å) line index, and LACF for [Fe/H] and Ca I (4227 Å) and MgH (around 5170 Å) line index for log g.

SSPP - Methodology III

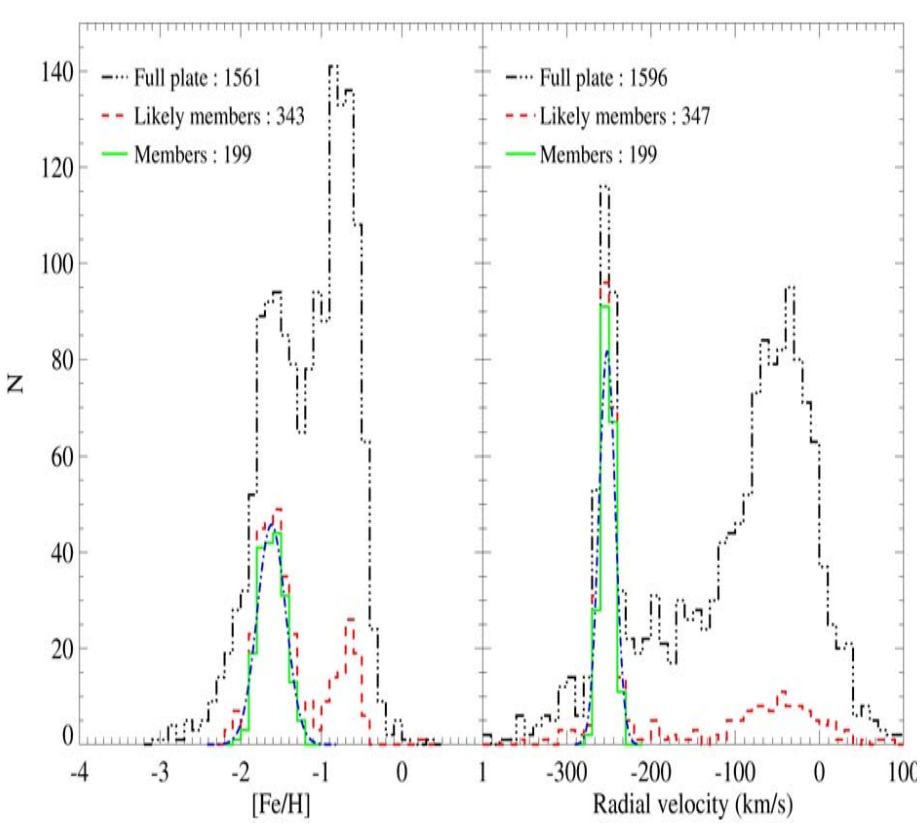


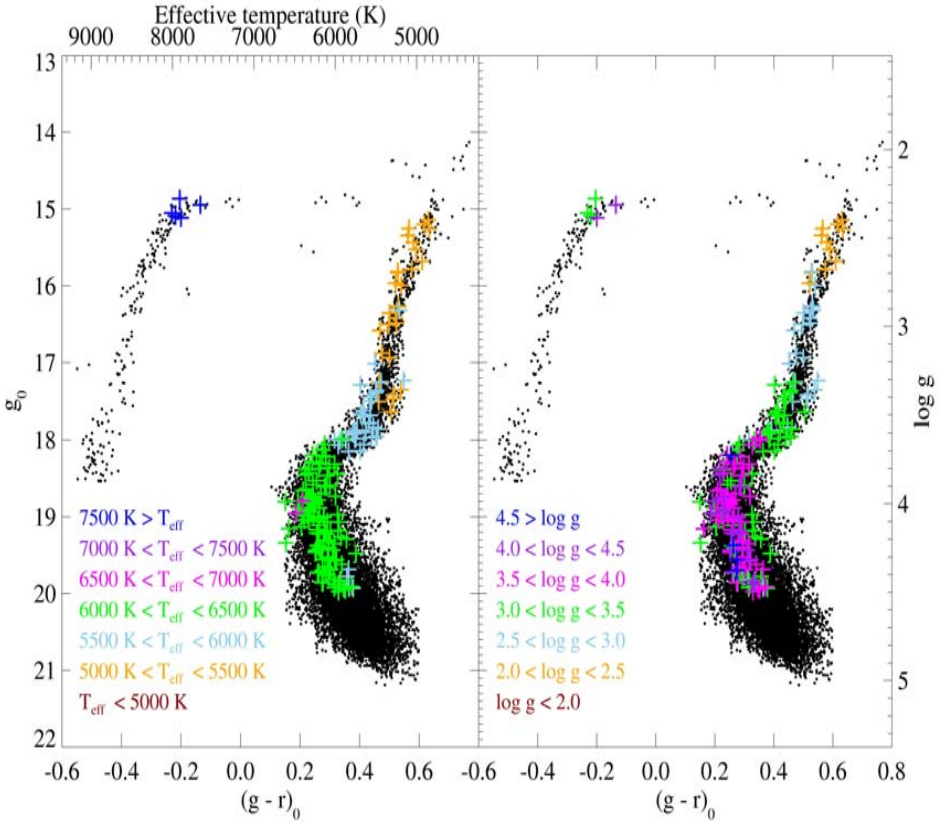
Determine which method is available, mostly depending on T_{eff}, and calculate robust mean from available parameters.

(The number in parenthesis is the number of estimates.)

Validation with Globular Clusters

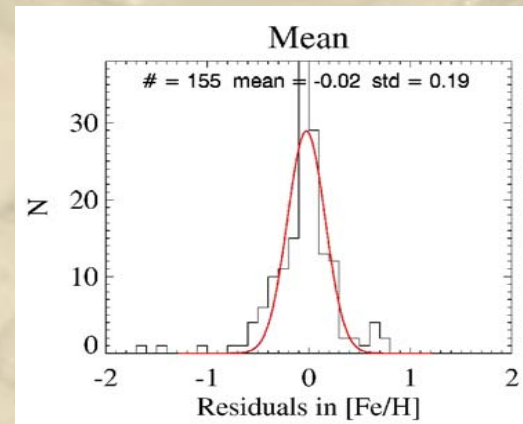
After selecting member stars of M 13, the cluster metallicity is calculated by fitting a Gaussian (left panel). We obtained [Fe/H] = -1.62 (-1.63, Kraft & Ivans 2003) with σ=0.18. We also examined T_{eff} and log g distribution of the members on CMD (right panels). Note how well the temperature and gravity are estimated along the CMD (see Lee et al. 2007 for more clusters and details).

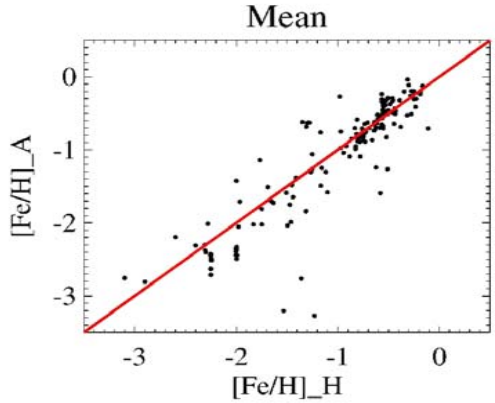


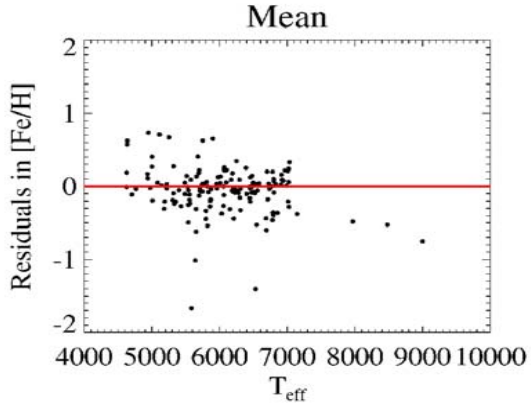


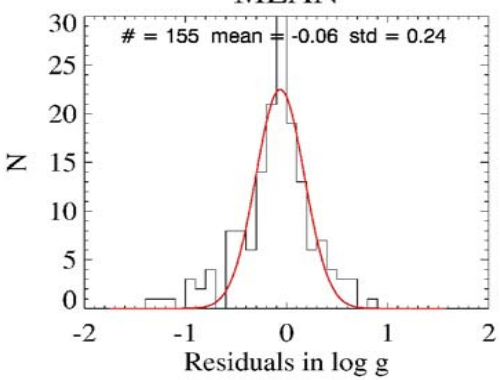
High-Res Observations To Date

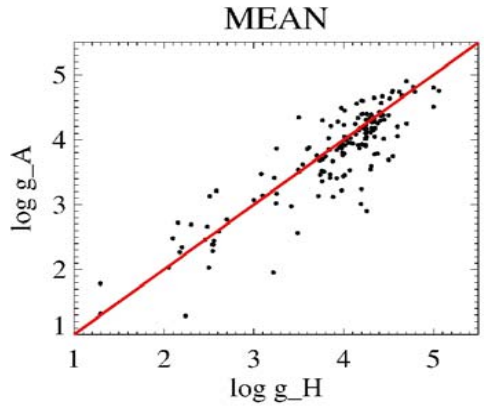
Telescope	Instrument	Resolution $R=\lambda/\Delta\lambda$	Wavelength Coverage Å	No. stars
HET	HRS	15000	4500 - 7000	112
Keck	HIRES	45000	3000-10000	24
Keck	ESI	6000	3000-10000	27
Subaru	HDS	45000	3000-5800	11

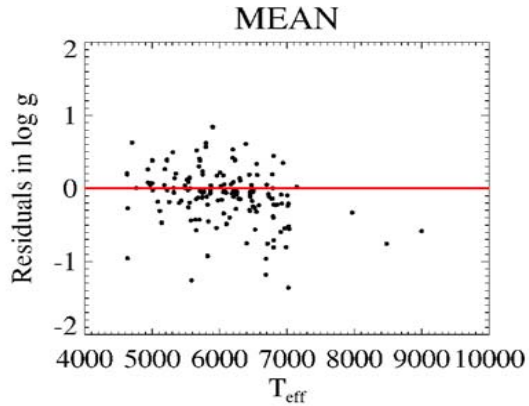

Mean
= 155 mean = -0.02 std = 0.19
N
Residuals in [Fe/H]

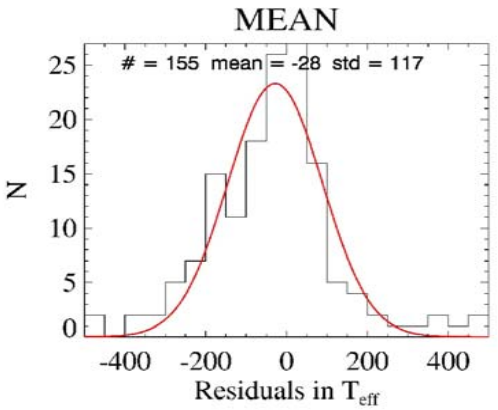

Mean
[Fe/H]_A
[Fe/H]_H

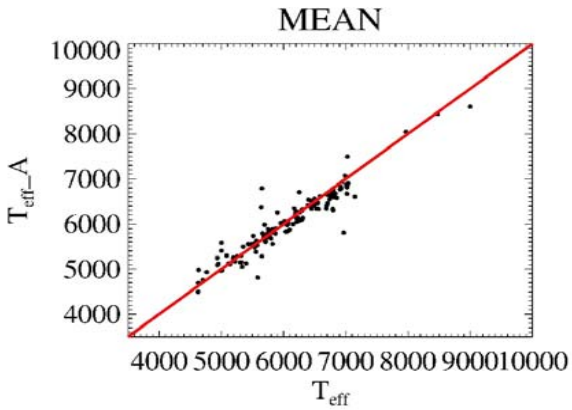

Mean
Residuals in [Fe/H]
T_eff

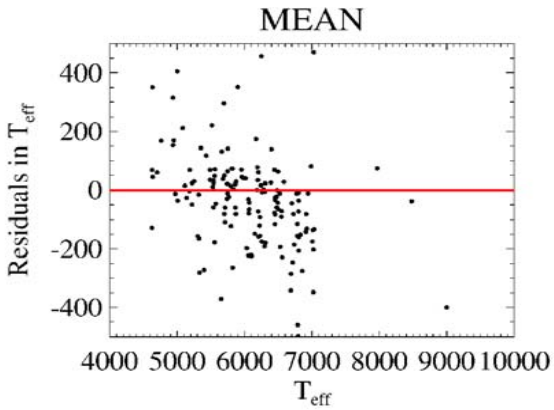

MEAN
= 155 mean = -0.06 std = 0.24
N
Residuals in log g


MEAN
log g_A
log g_H

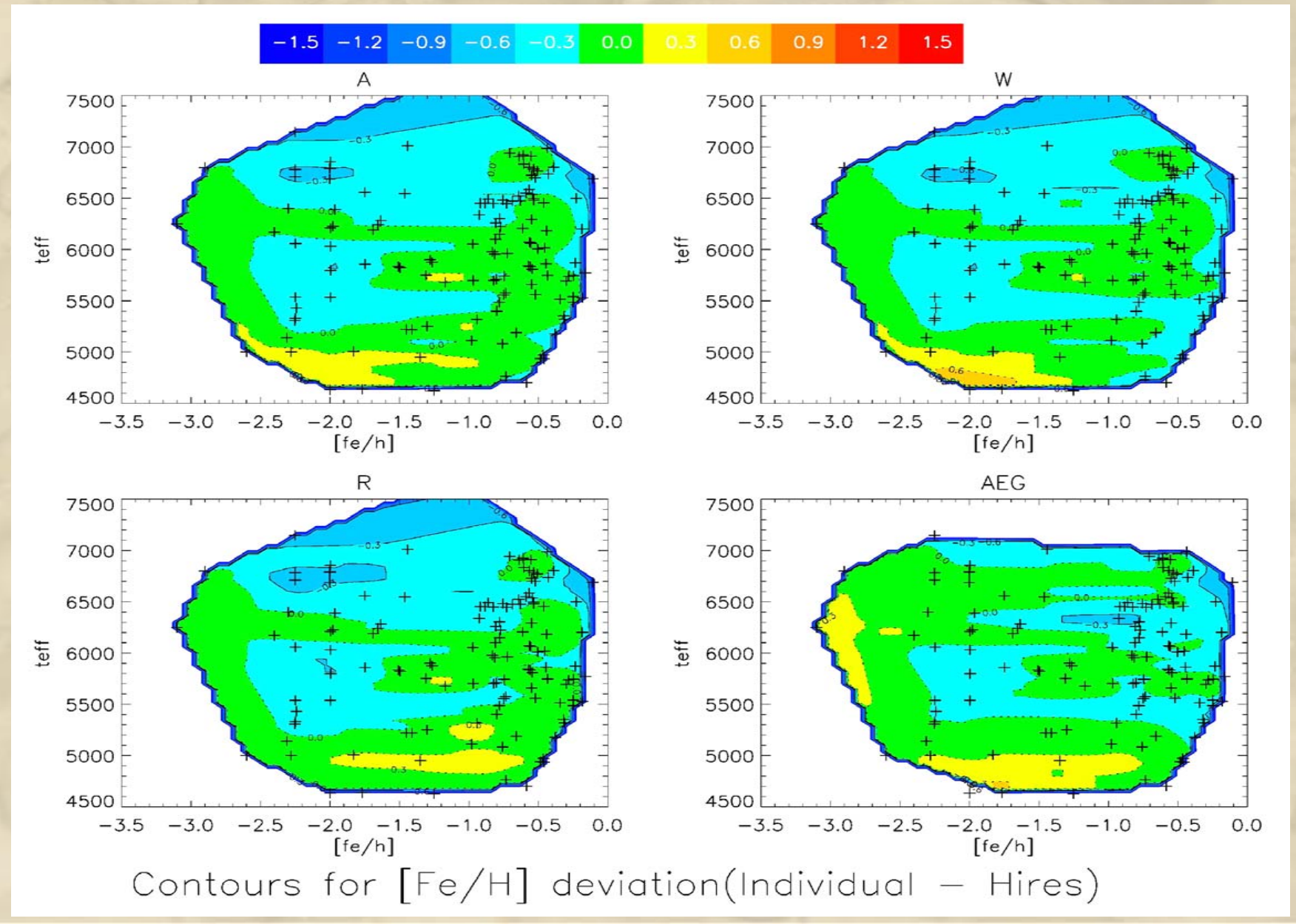

MEAN
Residuals in log g
T_eff

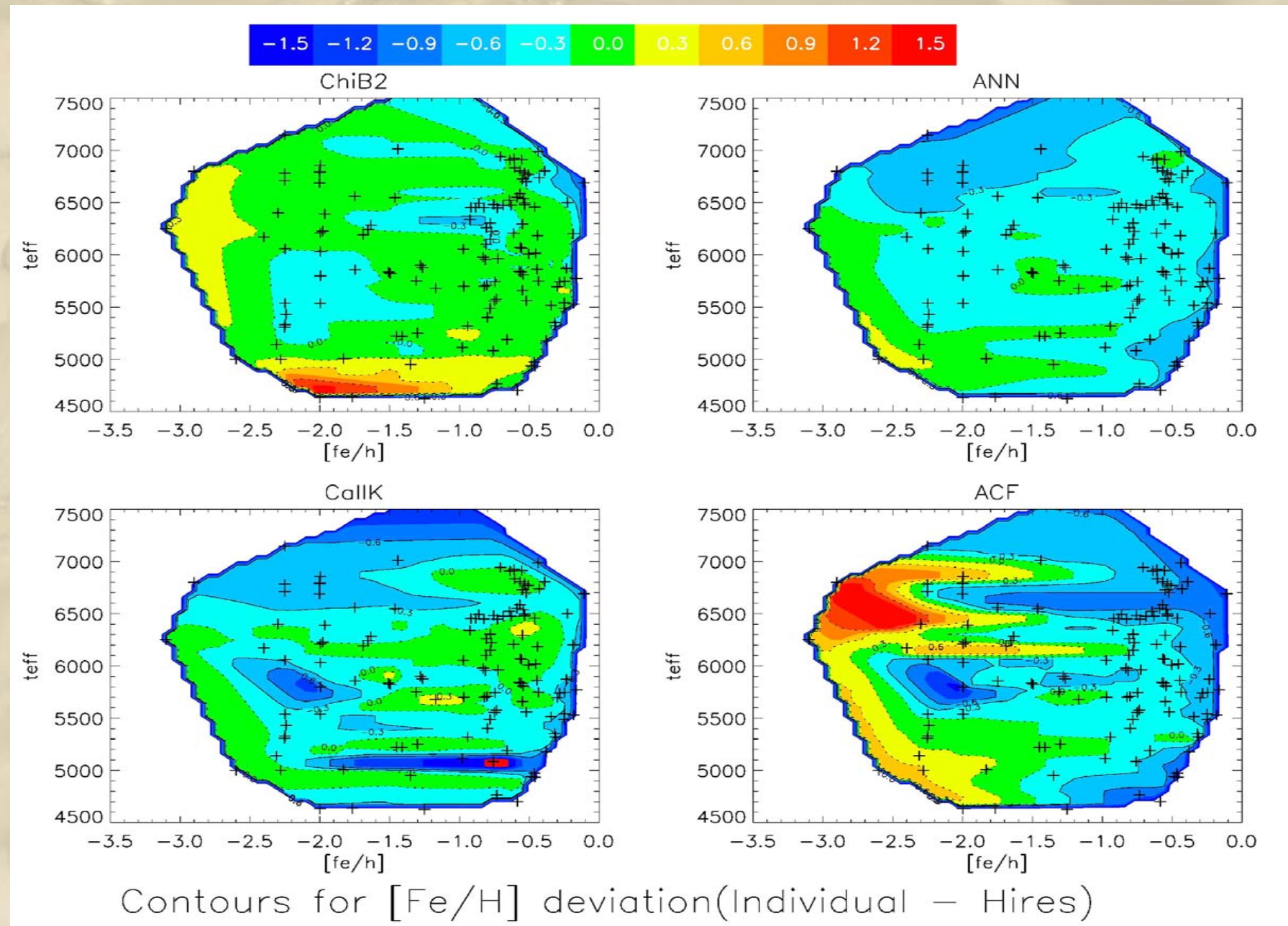

MEAN
= 155 mean = -28 std = 117
N
Residuals in T_eff


MEAN
T_eff_A
T_eff

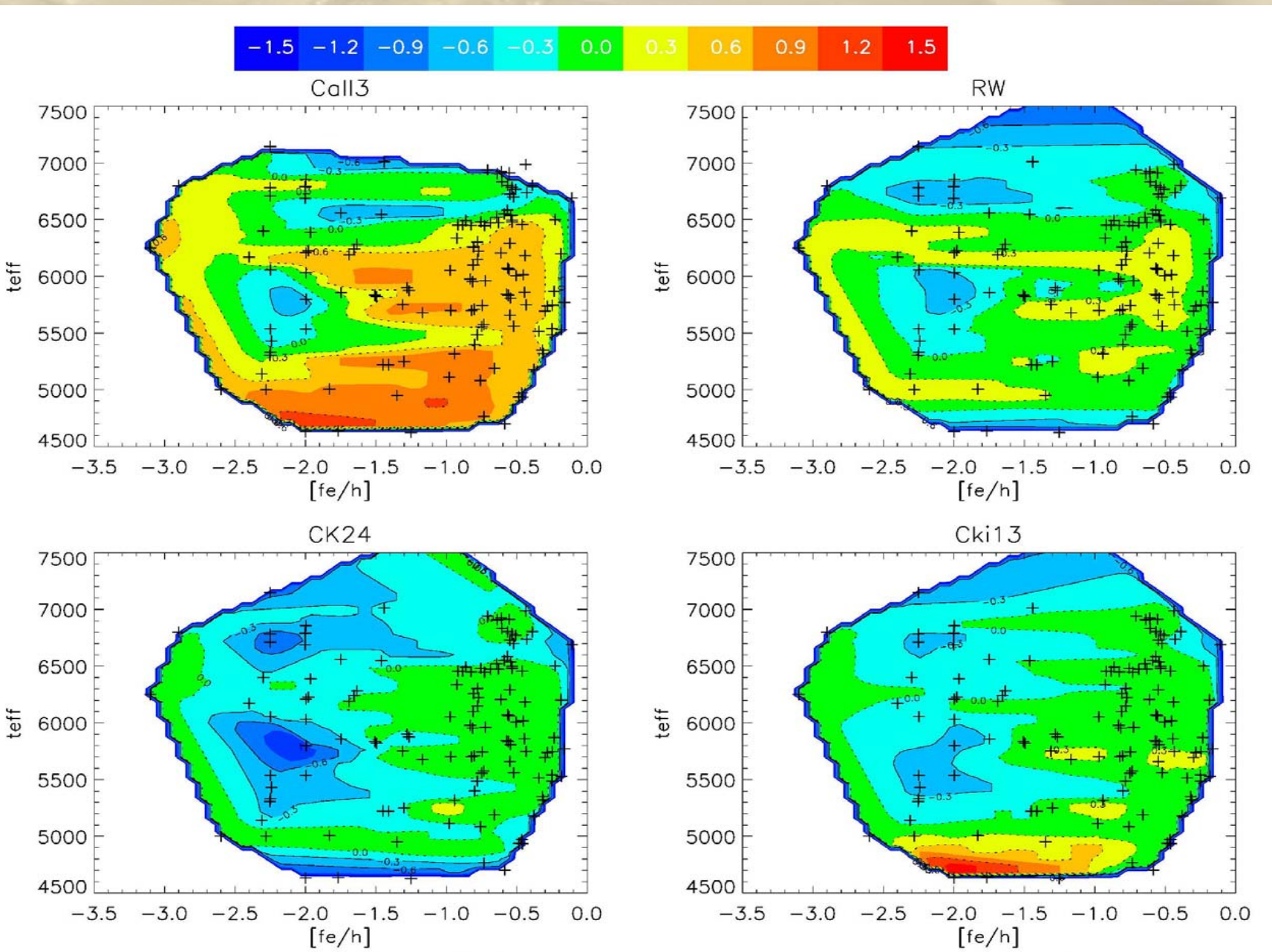

MEAN
Residuals in T_eff
T_eff

Recalibration of Individual Techniques



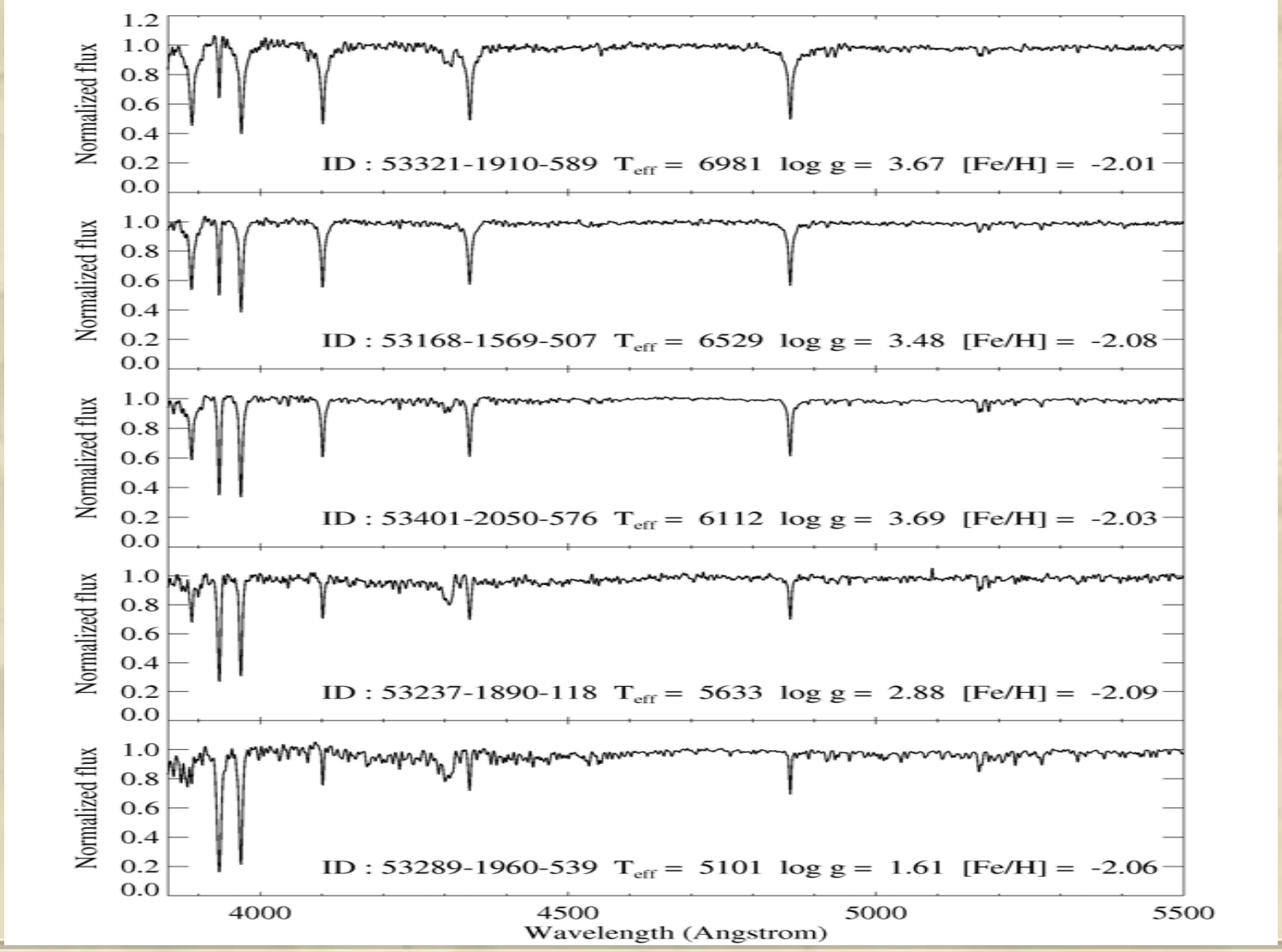


Contours for [Fe/H] deviation(Individual − Hires)

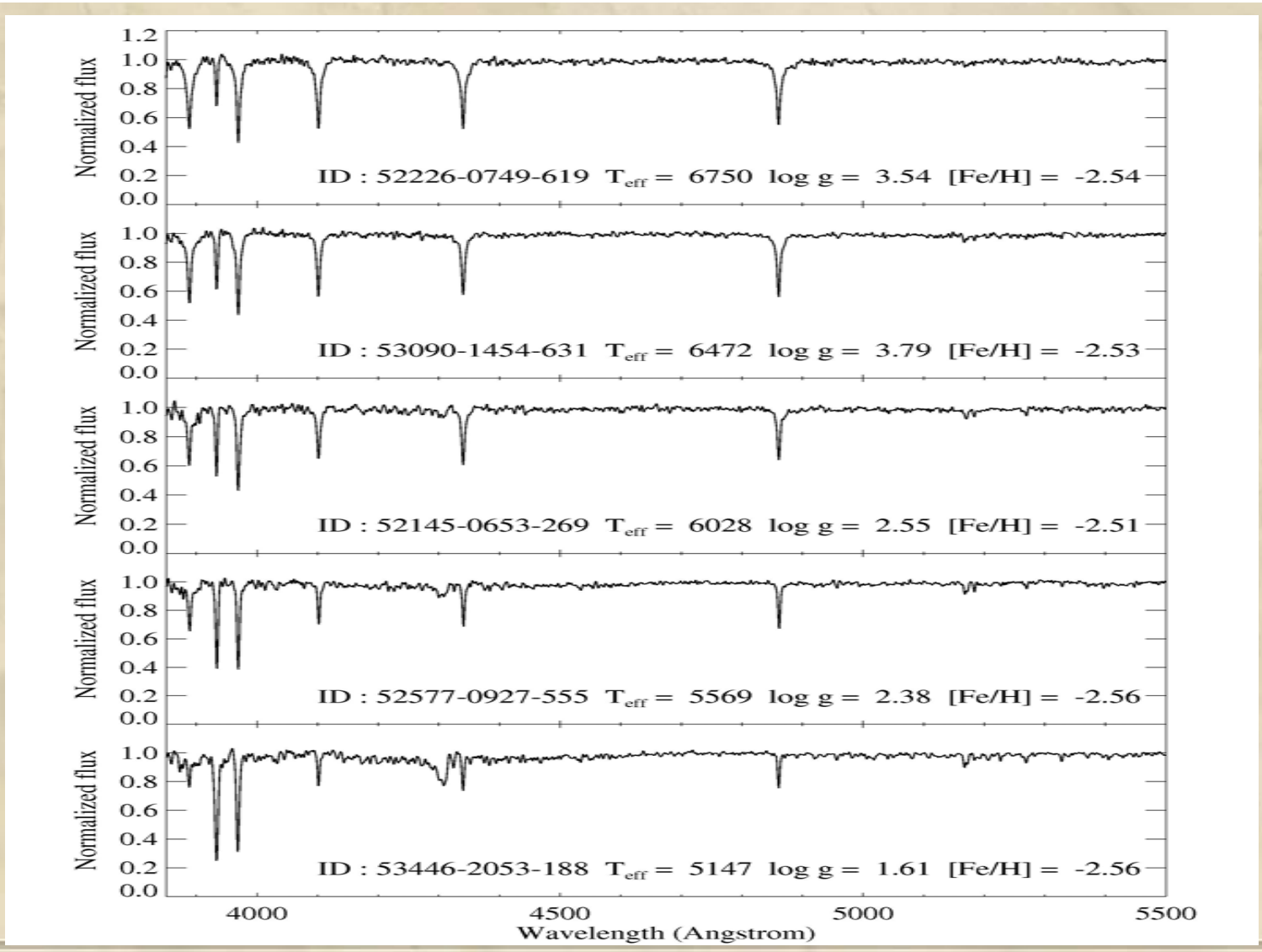


Contours for [Fe/H] deviation(Individual − Hires)

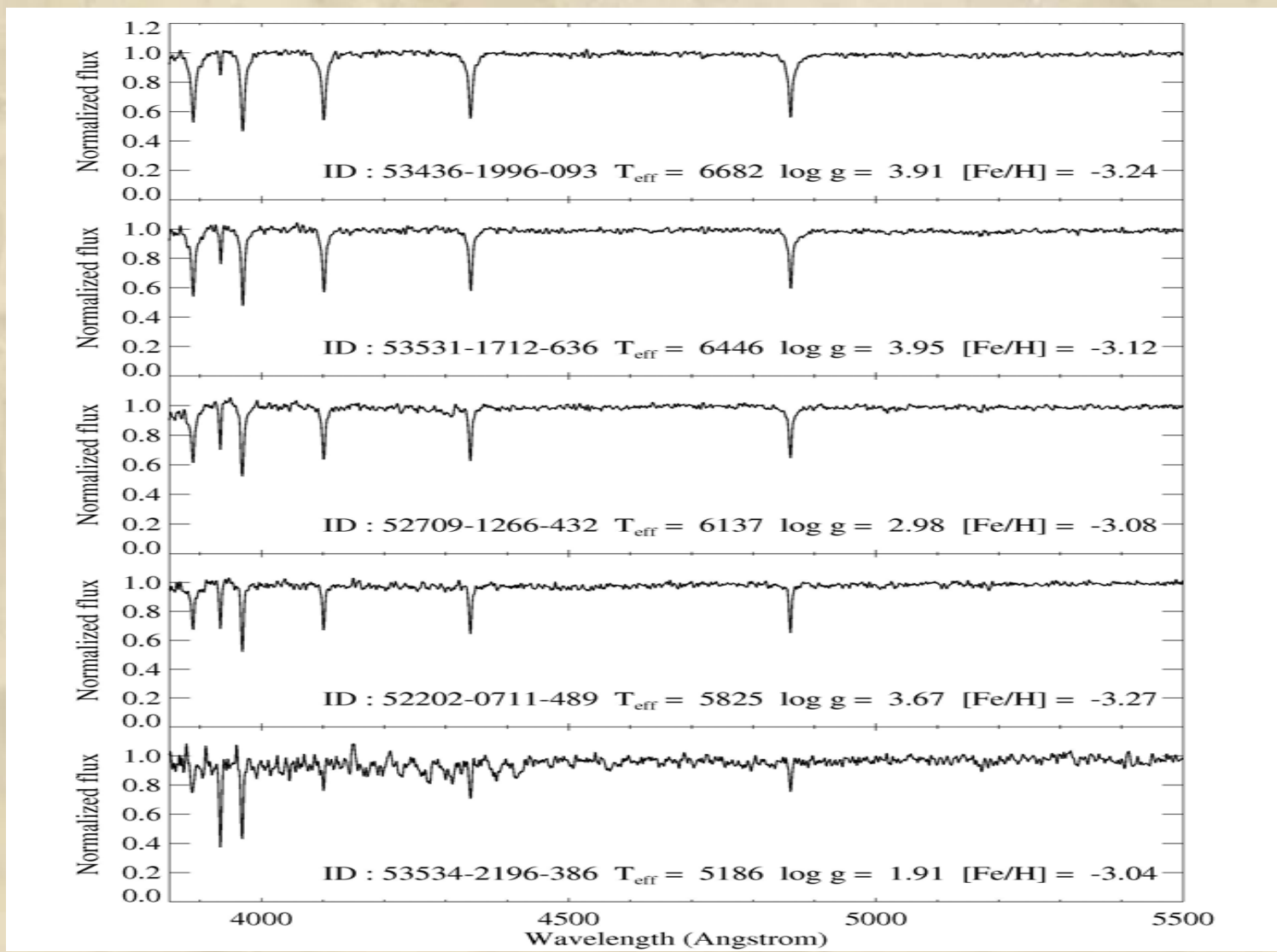
Sample SDSS-I Spectra with [Fe/H] ~ −2.0



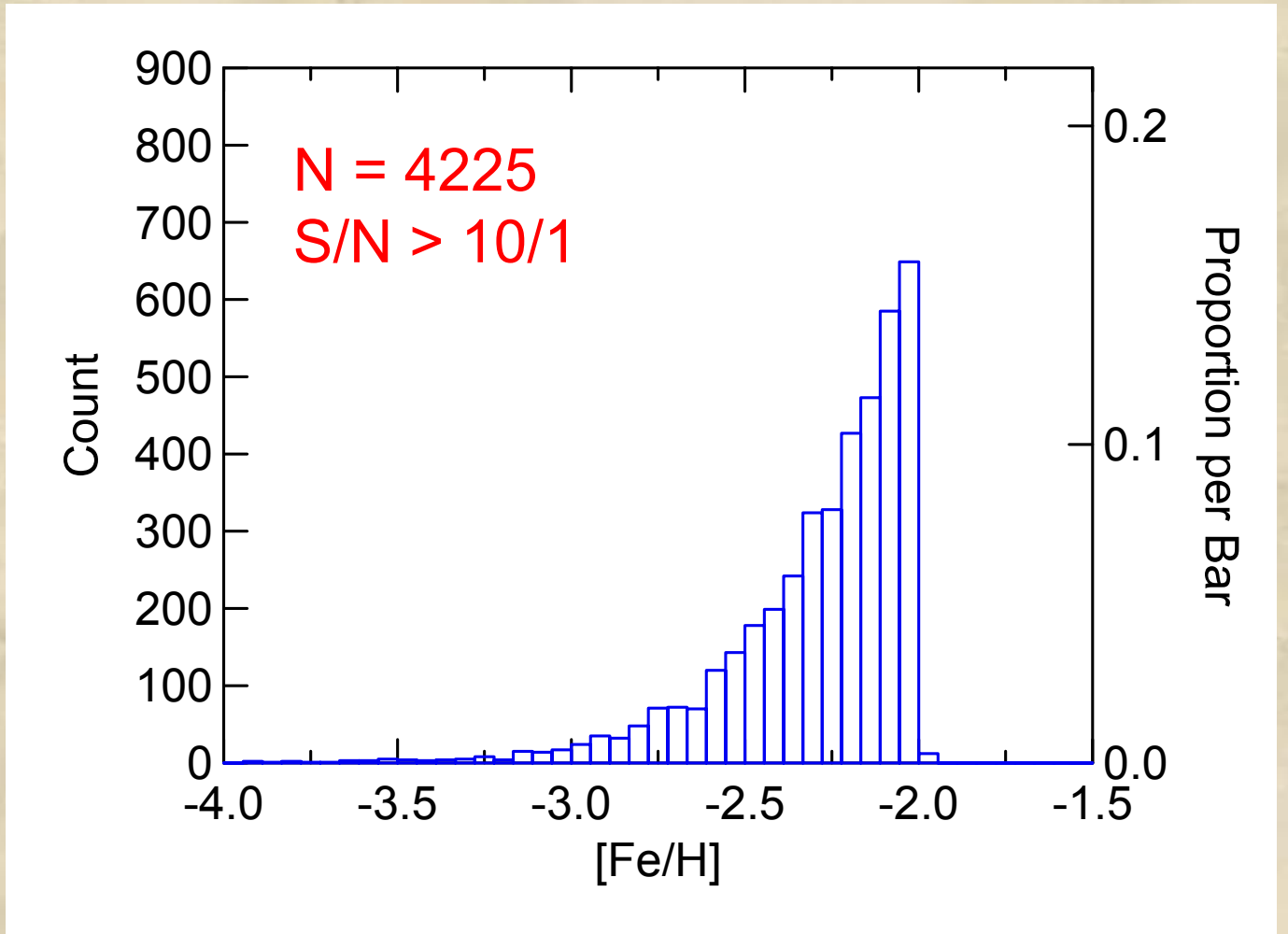
Sample SDSS-I Spectra with [Fe/H] ~ −2.5



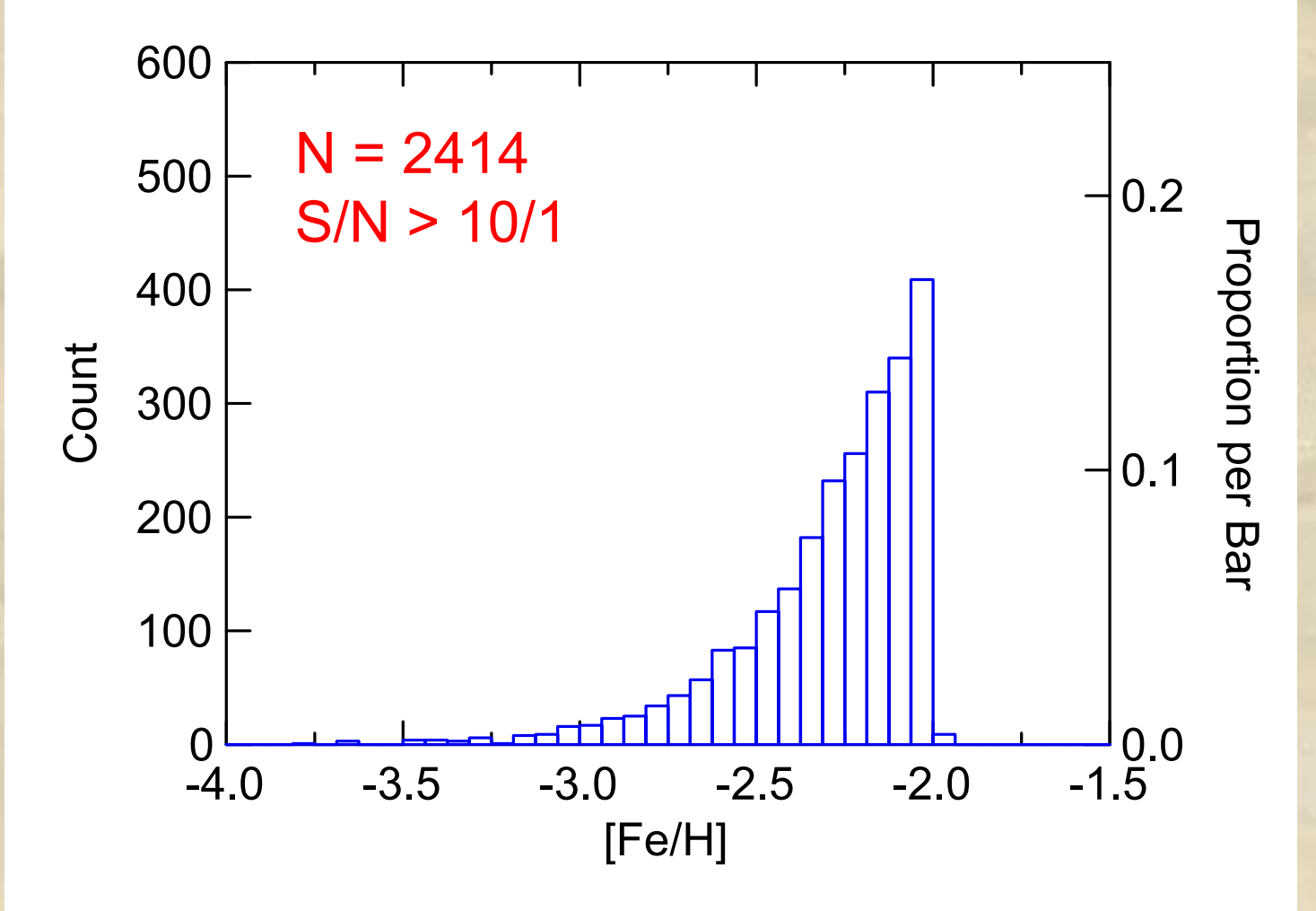
Sample SDSS-I Spectra with [Fe/H] < −3.0



The Low-Metallicity Tail of the Metallicity Distribution Function of SDSS-I Stars



The Low-Metallicity Tail of the Metallicity Distribution Function of SEGUE Stars



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