(Present and) Future Surveys for Metal-Poor Stars

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SDSS

Why the Fascination with Large Numbers of Metal-Poor 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 the early Galaxy

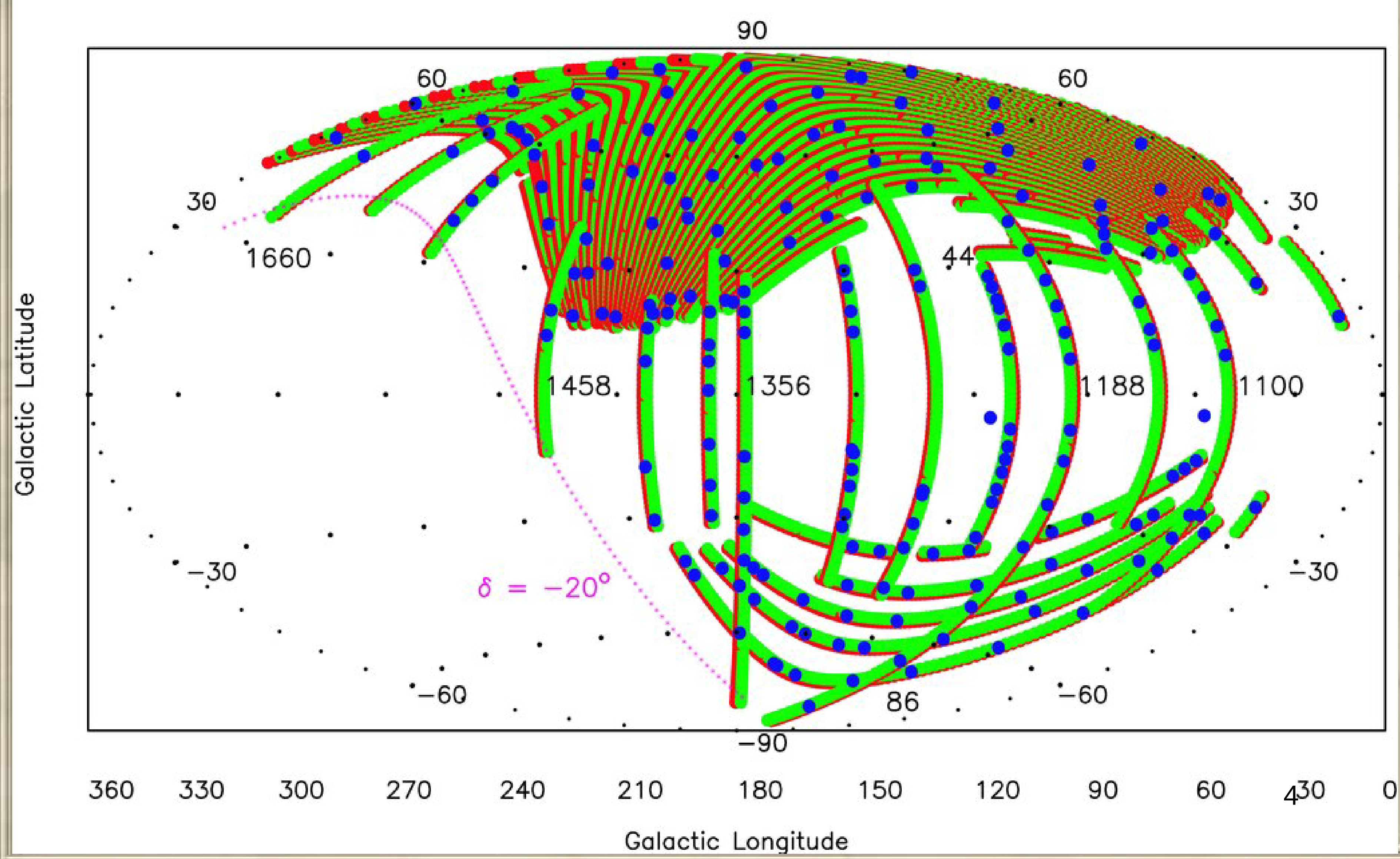
- **Changes** in the nature of the **MDF** as a function of distance may reveal the assembly history of the MW

- 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

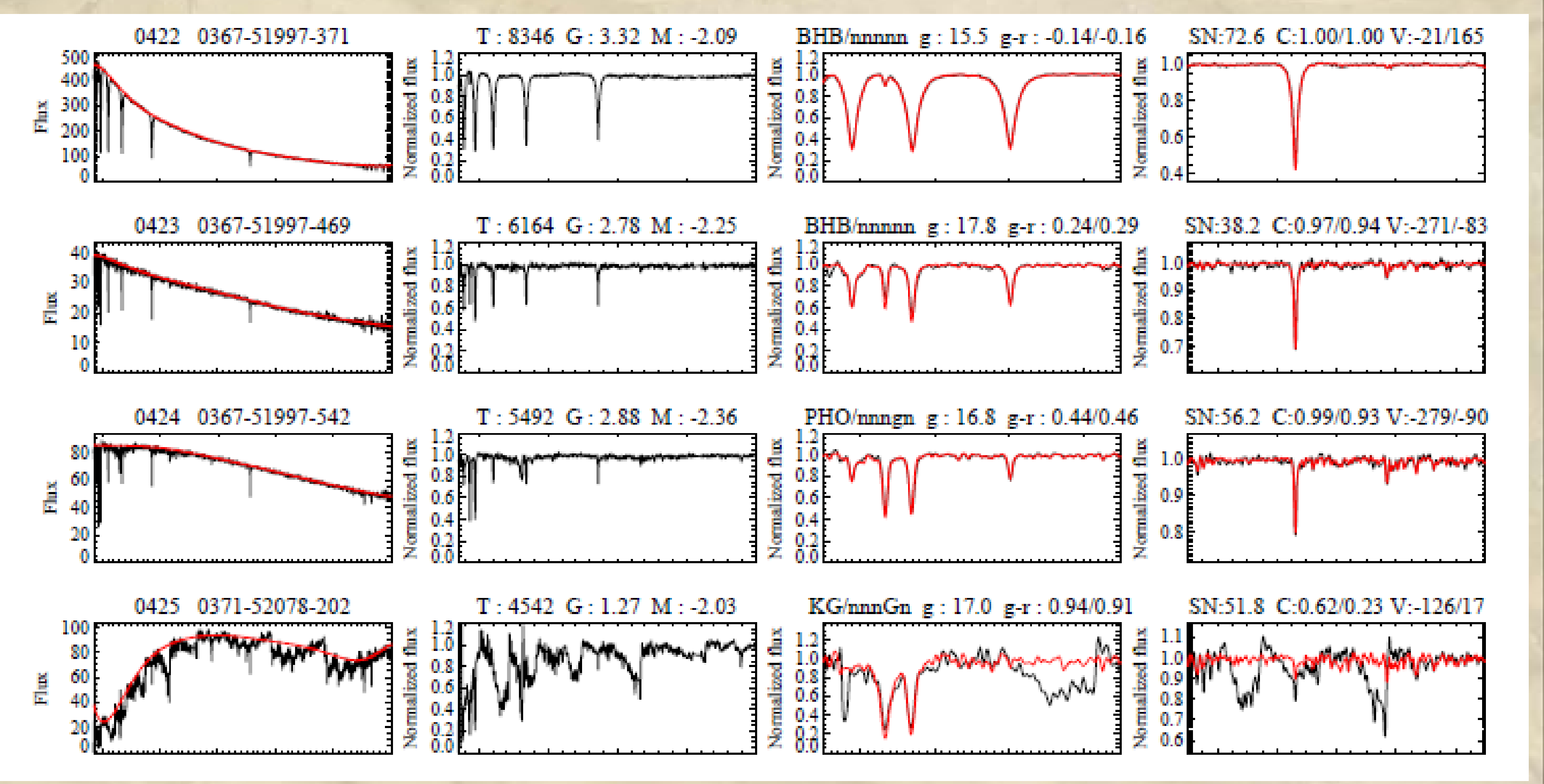
SDSS/SEGUE-1/SEGUE-2

- **SDSS --** obtained broad-band *ugriz* photometry for over 300,000,000 objects, many of them stars
- **SDSS --** also obtained medium-res (R ~ 2000) spectroscopy for some 100,000 stars (mostly WD, CV, BHB, FTO, G dwarfs, M dwarfs, and calibration stars)
- **SEGUE-1 --** targeted BHB, FTO, G dwarfs, MP stars, K giants (about 250,000)
- **SEGUE-2 --** had similar targets but, refined selection algorithm, push to include more outer-halo tracers (120,000)
- **In Total –** About 500,000 stellar spectra, roughly 400,000 of which have available atmospheric params (Teff, log g, [Fe/H]) from the SSPP (SEGUE Stellar Parameter Pipeline)

The SDSS/SEGUE Footprint (l, b)



A Close Up Look at the SSPP Results

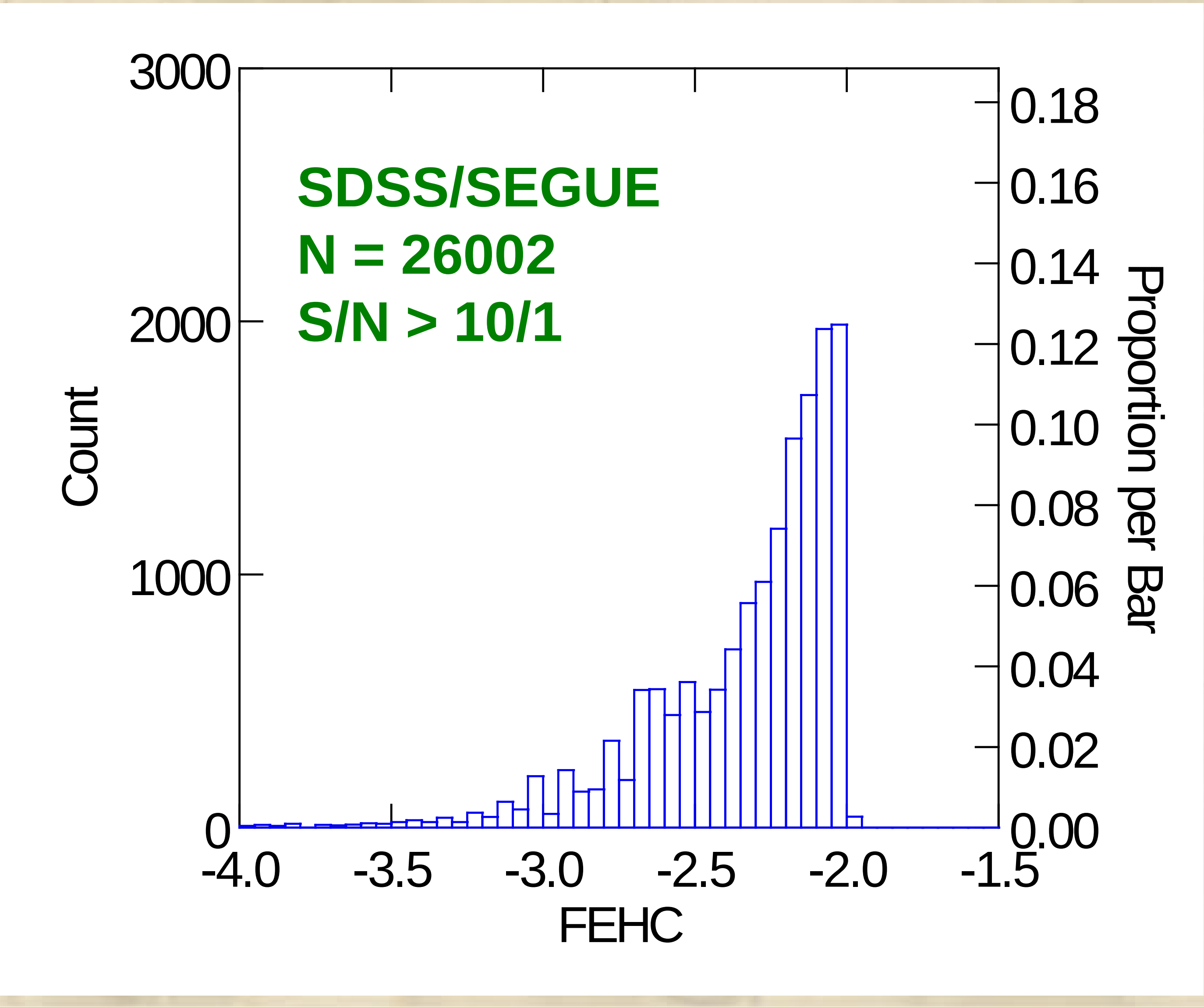


Known MP Stars – Pre and Post SDSS/SEGUE-1/SEGUE-2

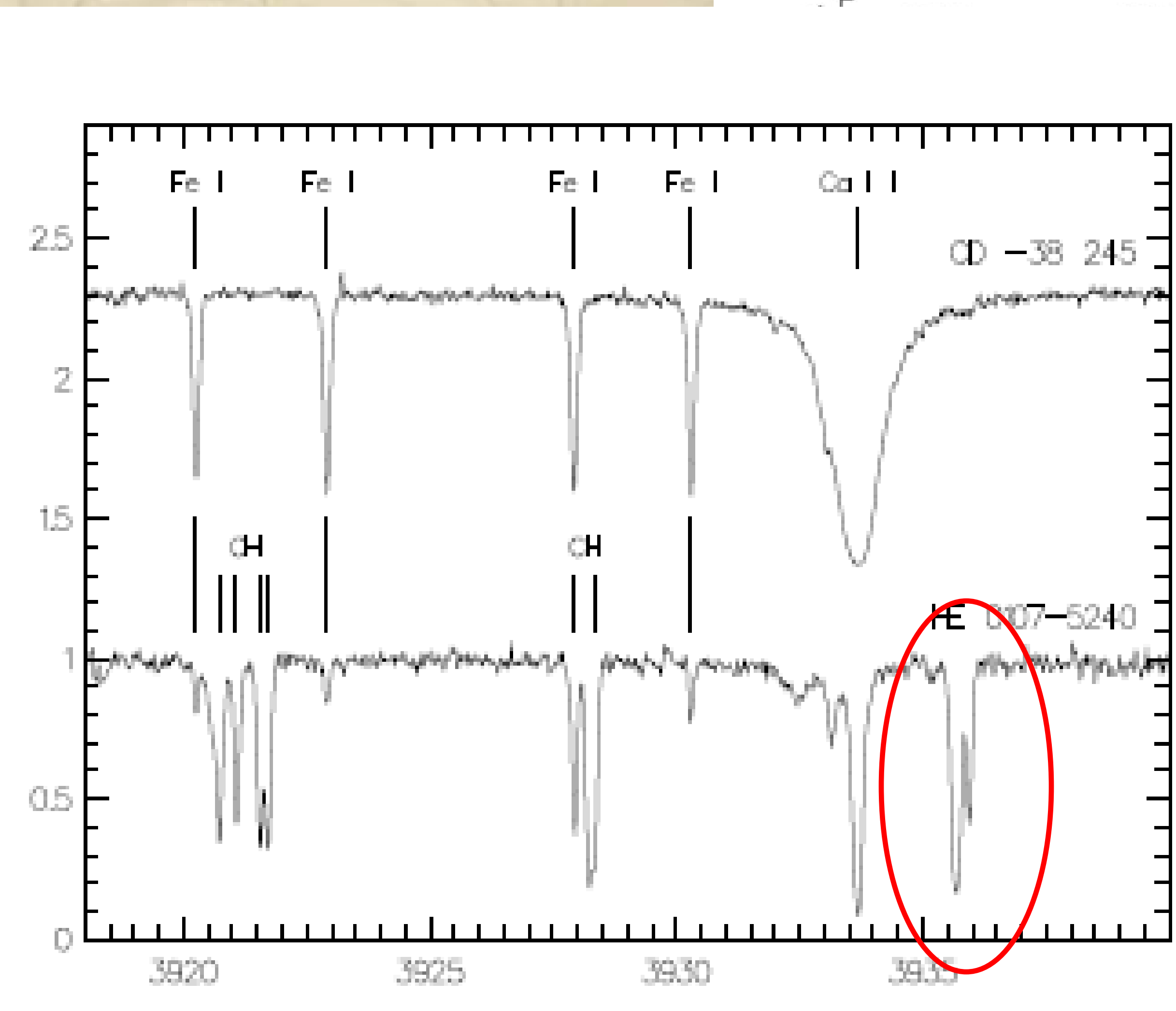
Name	Metallicity	Pre	Post
Metal-Poor	[Fe/H] < -1.0	15,000	150,000+
Very Metal-Poor	[Fe/H] < -2.0	3,000	30,000+
Extremely Metal-Poor	[Fe/H] < -3.0	400	1000+
Ultra Metal-Poor	[Fe/H] < -4.0	5	5
Hyper Metal-Poor	[Fe/H] < -5.0	2	2
Mega Metal-Poor	[Fe/H] < -6.0	0	0

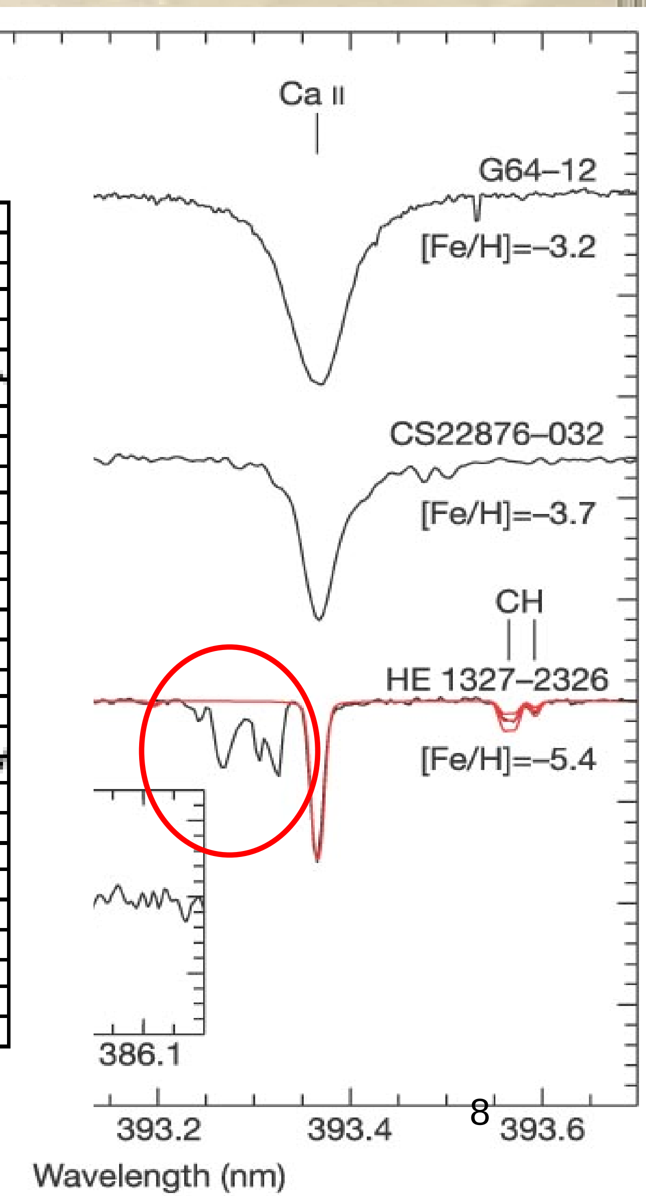
Only includes stars with S/N > 10/1, 4500 < Teff < 7000

Latest and Greatest from SDSS/SEGUE



Limitations from Contamination by Interstellar CaII

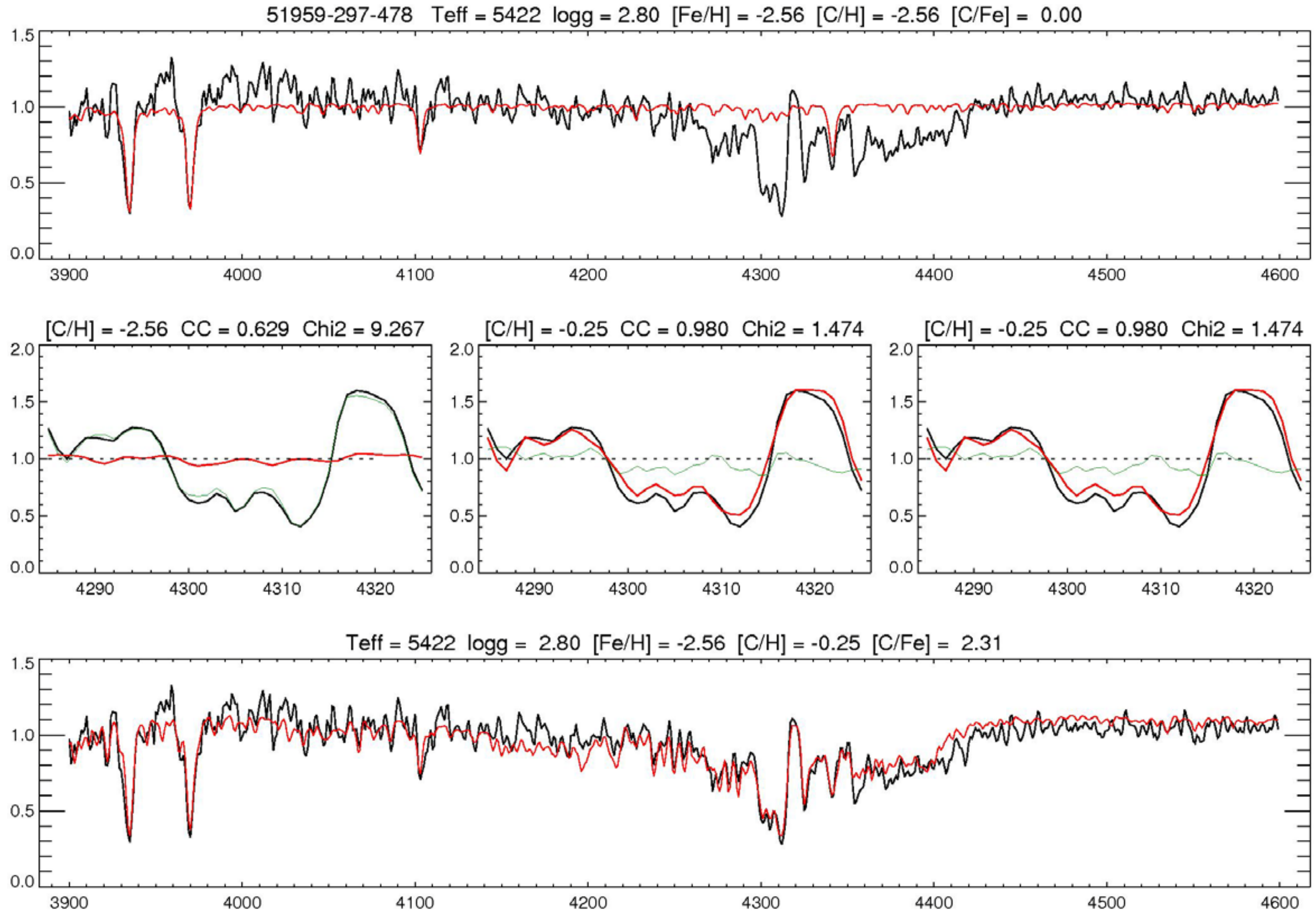




[C/Fe] For SDSS/SEGUE Stars

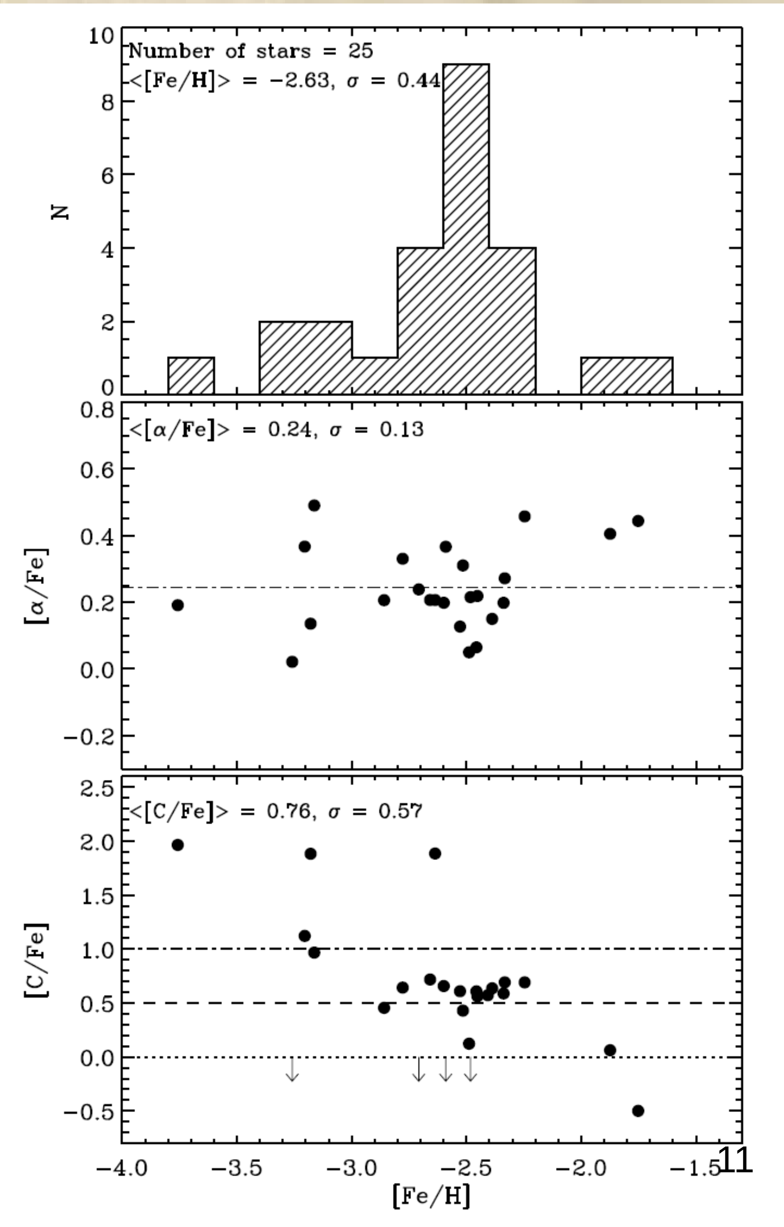
- [C/Fe] can probe the IMF / binarity fraction of progenitors of Milky Way components – distribution and frequency may vary between, e.g., inner/outer halo, TD and MWTD
- Global frequency as a f([Fe/H]) provides constraints on AGB models and non-AGB sources of carbon
- C-rich stars may include additional EMP/UMP/HMP stars
- Now have detections for > 200,000 SDSS/SEGUE stars, limits for many more

[C/Fe] for SDSS/SEGUE Stars

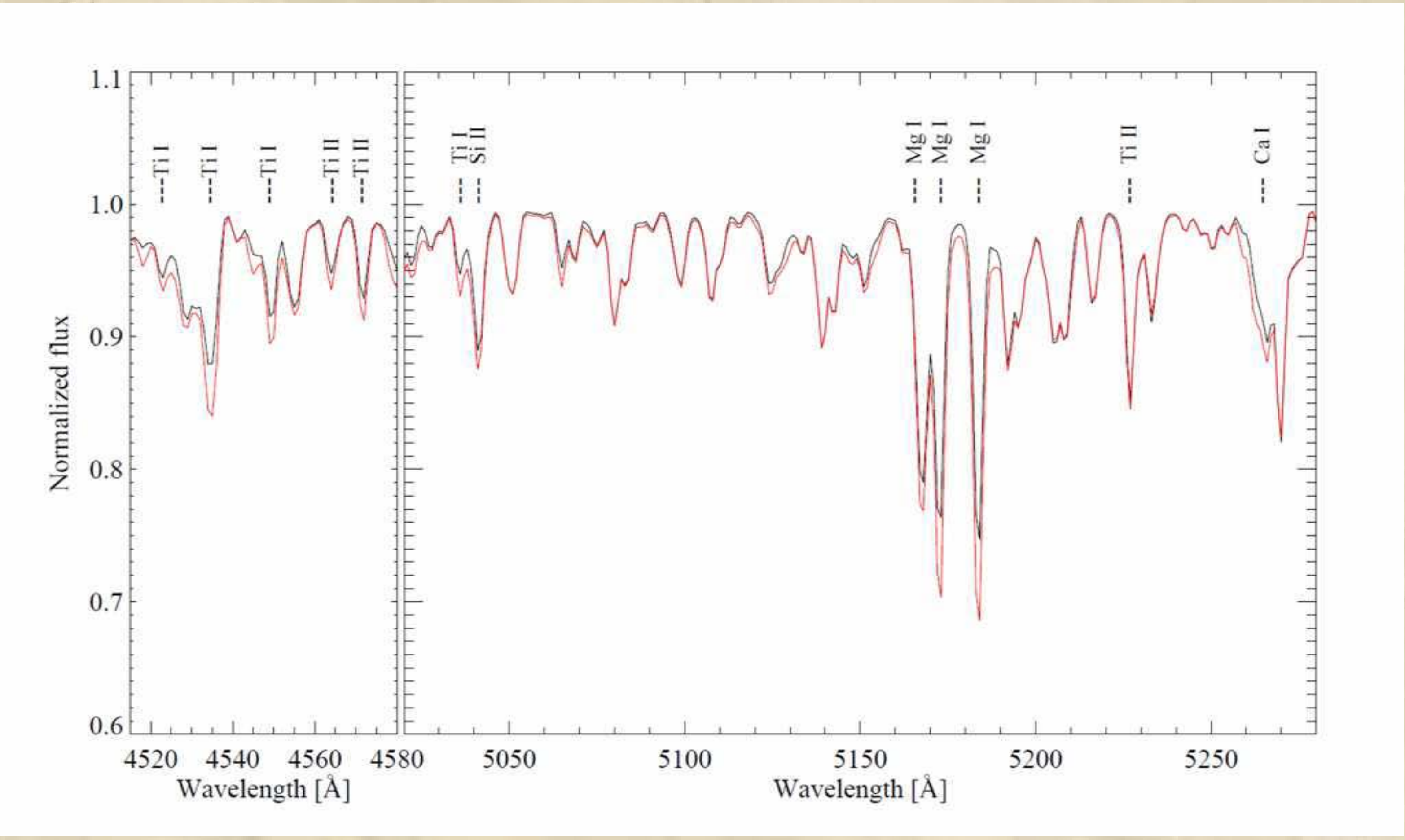


The MW Outer-Halo and the SDSS Ultra-Faint dSphs

- Bootes I observed with LRIS on Keck (Lai et al. in preparation)
- R = 2000, analyzed with the n-SSPP
- [C/Fe] also estimated
- LOADED with CEMP stars **– 70% have [C/Fe] > 0.50**



[α/Fe] for SDSS/SEGUE Stars



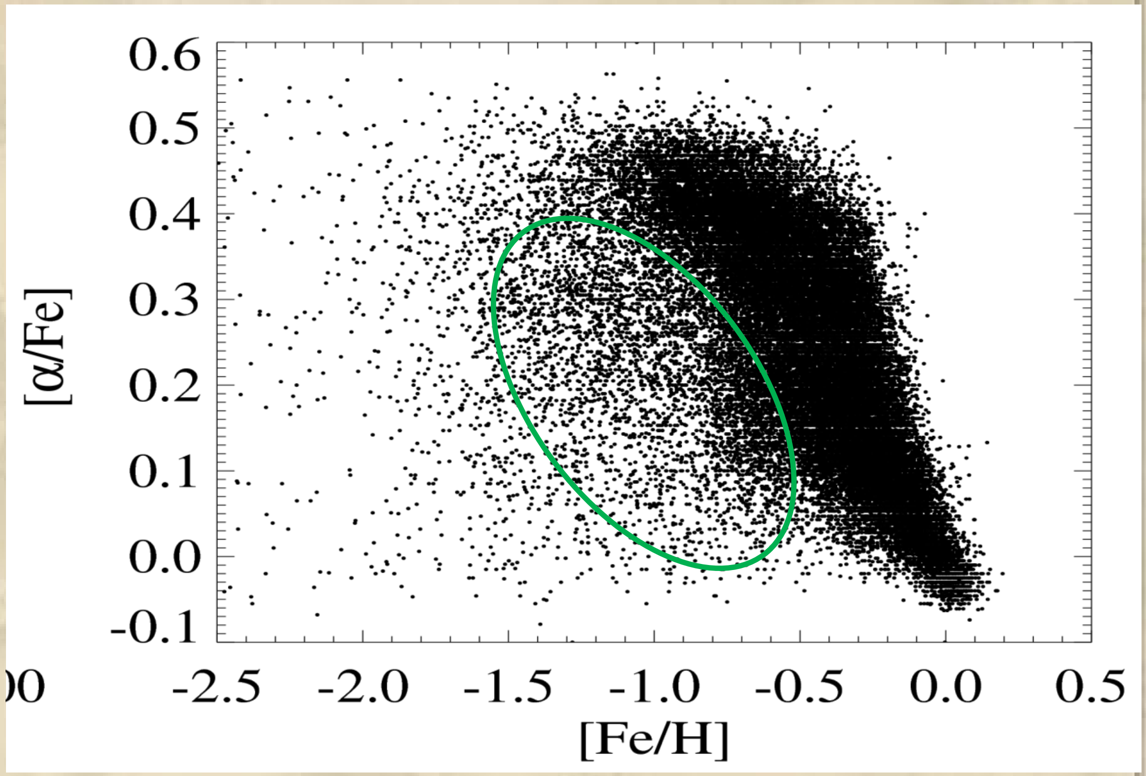
- **Primarily a measure of Ti and Mg**

[α/Fe] for SDSS/SEGUE Stars

- [α/Fe] ratios are critical probes of the **environment** in which metal-poor stars were born (masses of parent sub-halos)

- [α/Fe] ratios are critical probes of the **accretion history** of the Galaxy (Johnston et al. 2008)

- Can estimate **to < 0.1 dex** for stars in SDSS/SEGUE with S/N > 20/1 (Lee et al. 2010, in prep)



Roughly 45,000 F/G dwarfs, S/N > 20/1

ARTICLES

Carollo et al. 2007 Nature 450, 1020-1025

Two stellar components in the halo of the Milky Way

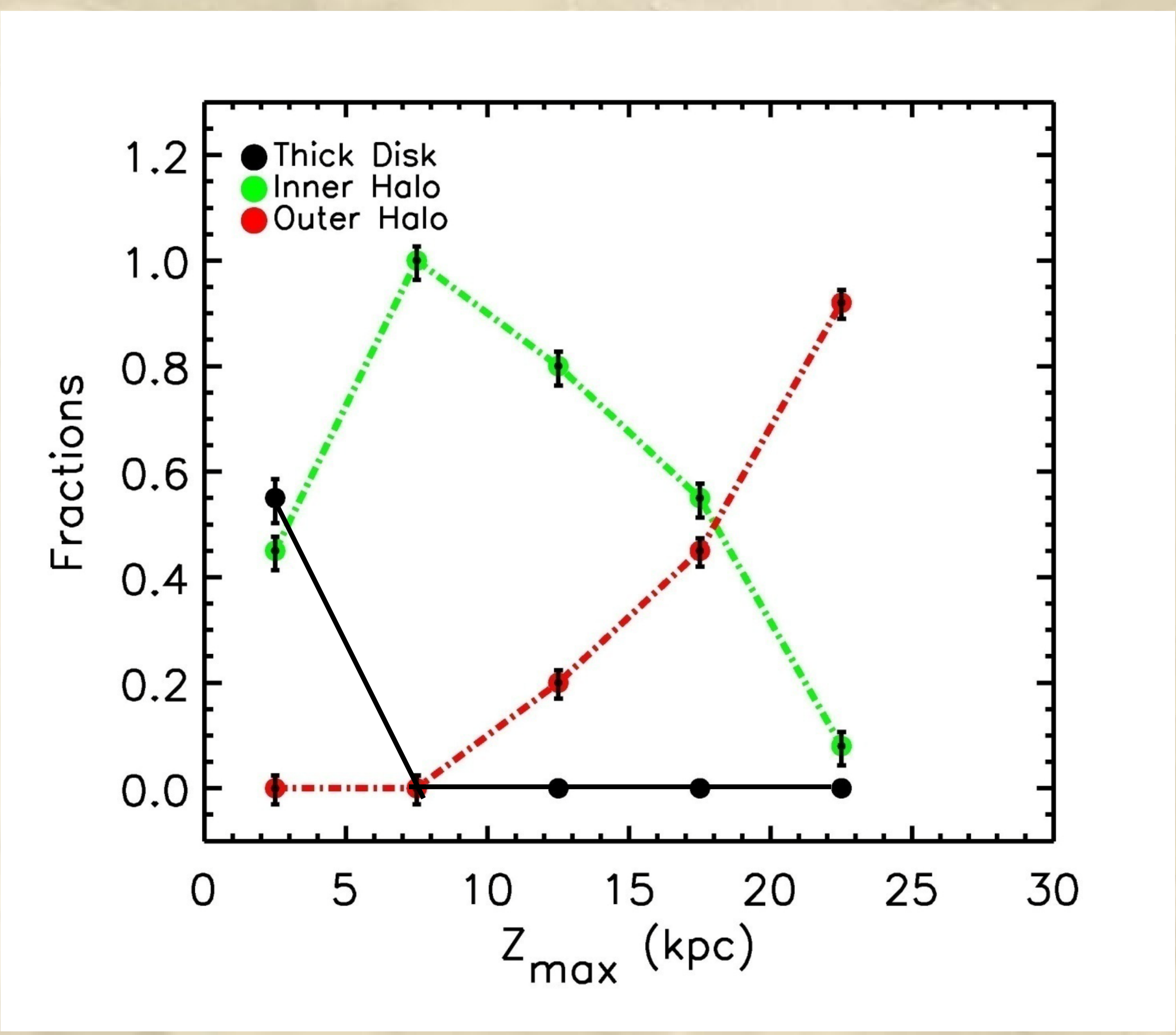
Daniela Carollo[1,2,3,5], Timothy C. Beers[2,3], Young Sun Lee[2,3], Masashi Chiba[4], John E. Norris[5], Ronald Wilhelm[6], Thirupathi Sivarani[2,3], Brian Marsteller[2,3], Jeffrey A. Munn[7], Coryn A. L. Bailer-Jones[8], Paola Re Fiorentin[8,9] & Donald G. York[10,11]

The halo of the Milky Way provides unique elemental abundance and kinematic information on the first objects to form in the Universe, and this information can be used to tightly constrain models of galaxy formation and evolution. Although the halo was once considered a single component, evidence for its dichotomy has slowly emerged in recent years from inspection of small samples of halo objects. Here we show that the halo is indeed clearly divisible into two broadly overlapping structural components—an inner and an outer halo—that exhibit different spatial density profiles, stellar orbits and stellar metallicities (abundances of elements heavier than helium). The inner halo has a modest net prograde rotation, whereas the outer halo exhibits a net retrograde rotation and a peak metallicity one-third that of the inner halo. These properties indicate that the individual halo components probably formed in fundamentally different ways, through successive dissipational (inner) and dissipationless (outer) mergers and tidal disruption of proto-Galactic clumps.

D. Carollo et al. (2010) Kinematic Analysis of DR-7 "Calibration Stars"

- Follow-on of work from D. Carollo et al. (2007), demonstrating existence of **inner/outer halo populations**, based on 32,360 unique calibration stars
- Determination of velocity ellipsoids for thick disk, MWTD, inner, outer halos
- Modeling of fractions of various components in local sample (d < 4 kpc)

Fractions of Components



Implications

- **One can now** target **outer-halo** stars in order to elucidate their chemical histories **([α/Fe], [C/Fe]),** and possibly their accretion histories

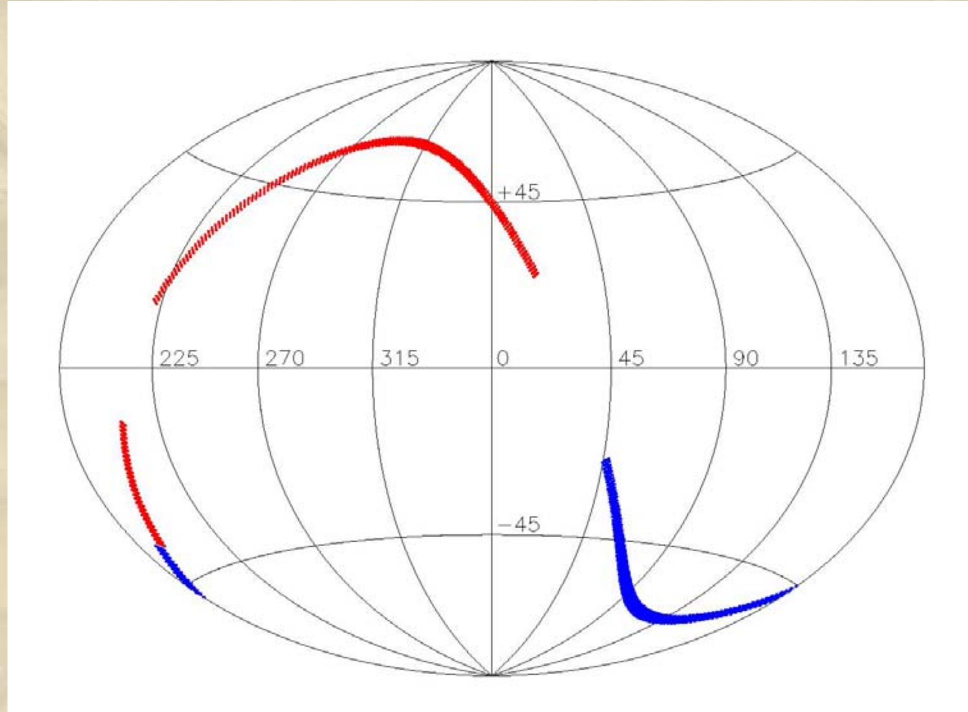
- **One can now** preferentially **SELECT outer-halo** stars based on proper motion cuts in the local volume

- **One can now** take advantage of the lower [Fe/H], in general, of outer-halo stars to find the most metal-poor stars **(all three stars with [Fe/H] < -4.5 have properties consistent with outer-halo membership)**

- **One can soon** constrain models for formation / evolution of the Galaxy that take **all of the chemical and kinematic information** into account (e.g., Tumlinson 2006)

SDSS Stripe 82

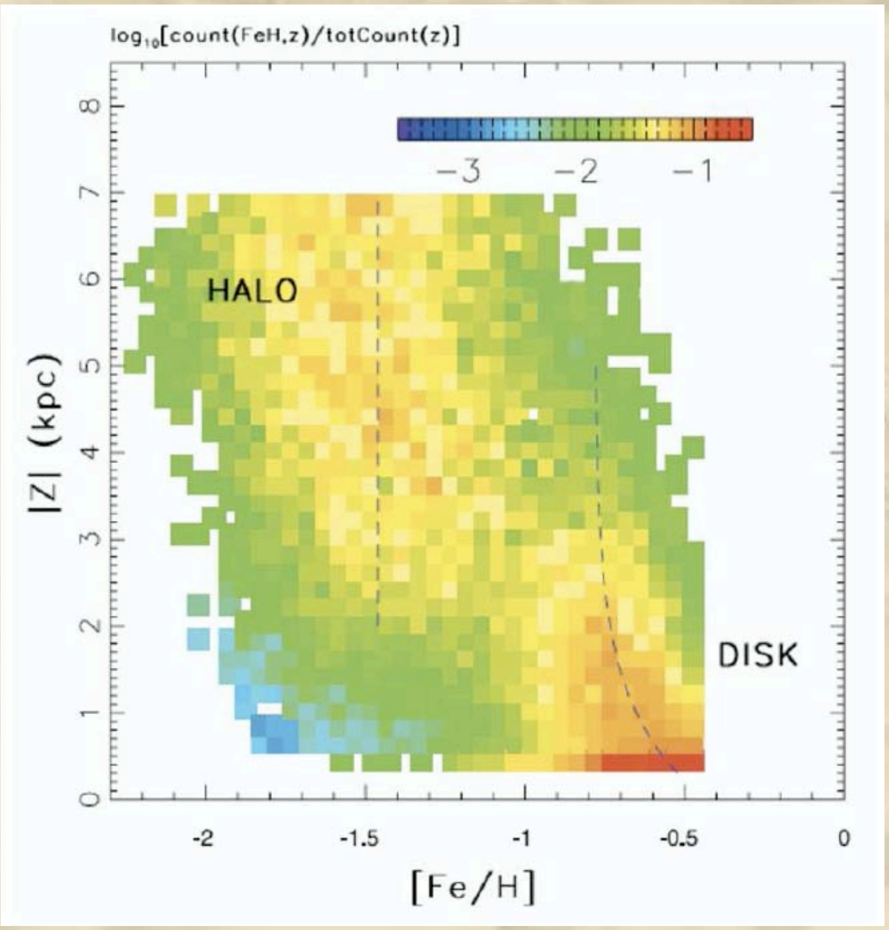
- Multiply imaged during SDSS-II for the Supernova Survey
- Best (yet) ground-based ugriz photometry available
- Errors in all bands
  < 0.01 mags



Stripe 82 in BLUE

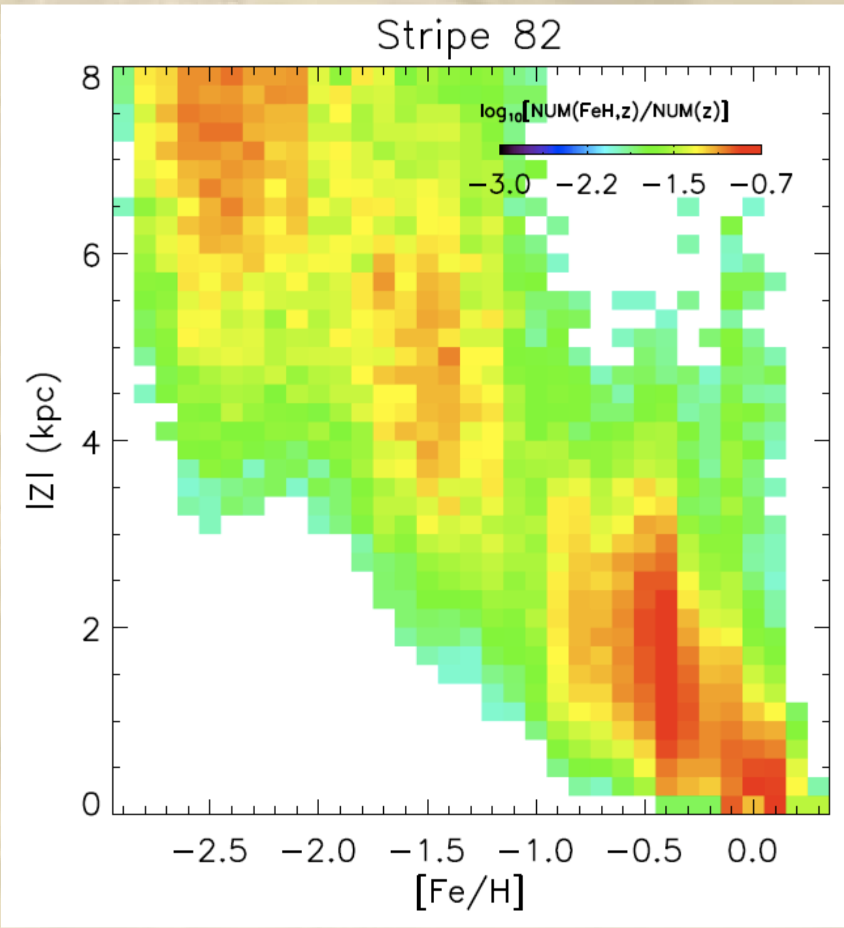
Metallicity Distribution

An et al. 2010 (Preliminary)



Ivezic et al. (2008)

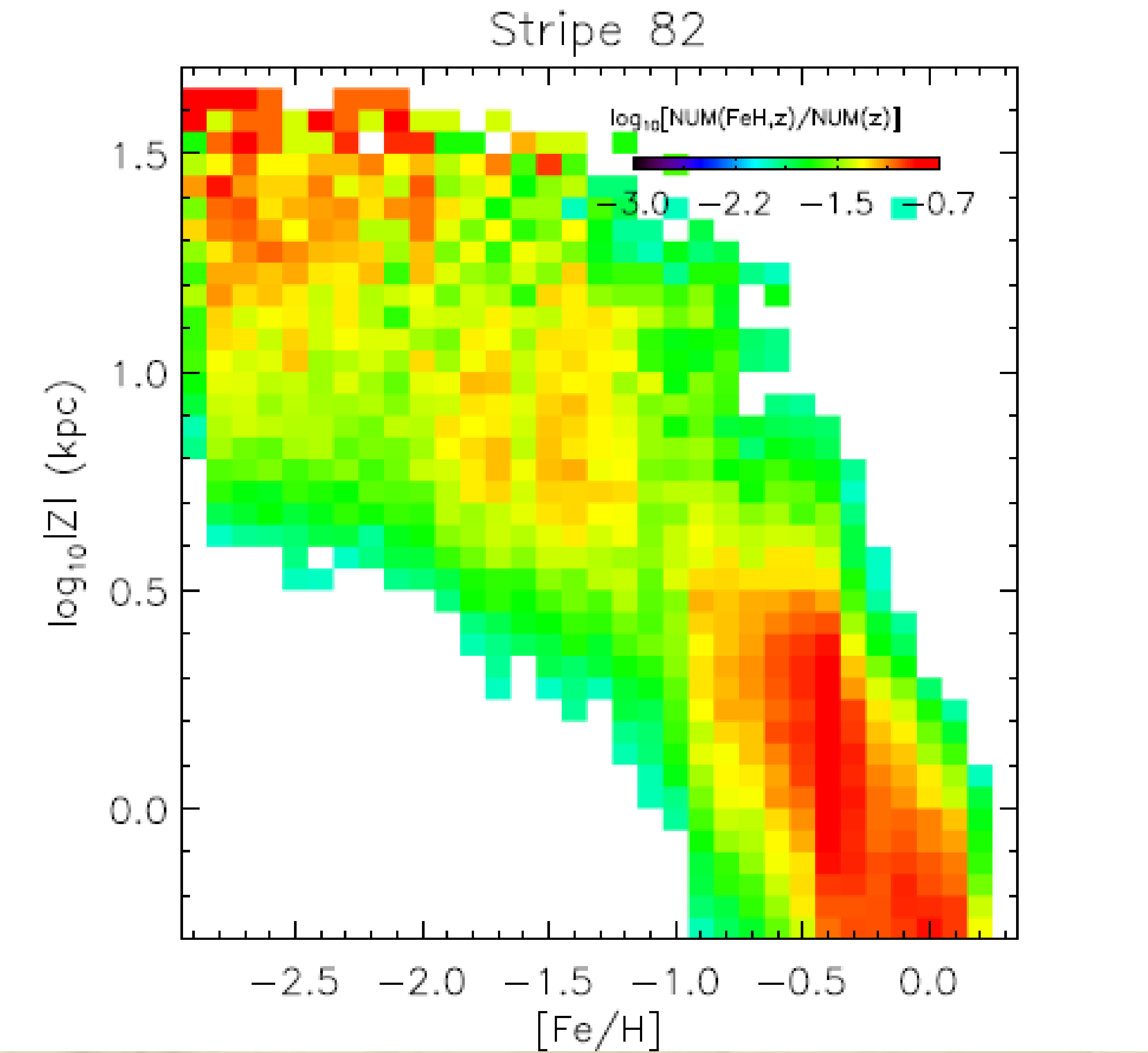
u g r i z



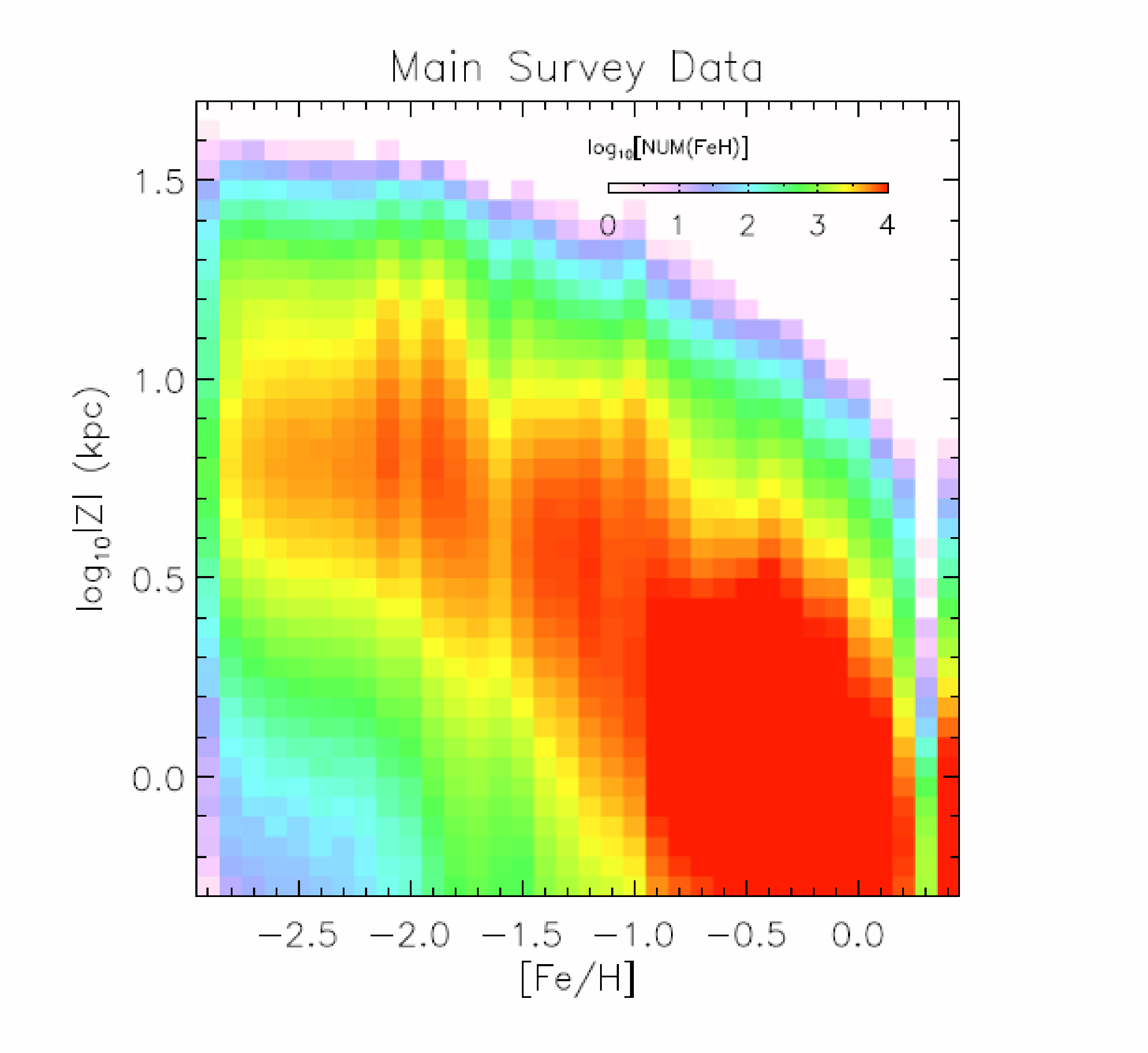
***Recalibrated* isochrones**

u g r i z

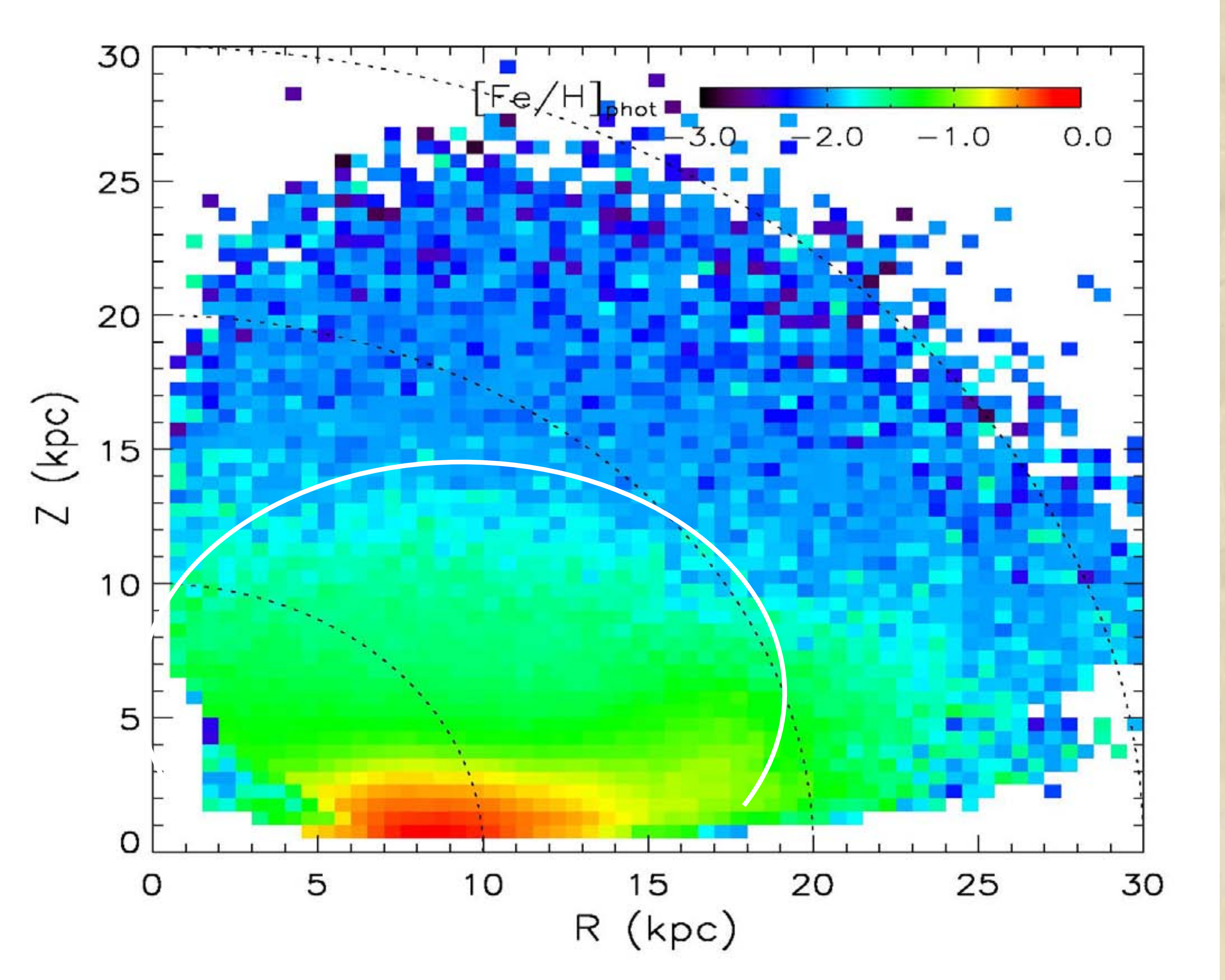
Reaching to 30 kpc in Stripe 82



Full Survey Data



Currently Best Metallicity Map



The Evolving Astronomer

- An observational astronomer **used** to mean someone who is active in **collecting** data
- This paradigm has now shifted, and will continue to shift further in the future
- As observational astronomer is rapidly coming to mean someone who is active in **understanding** and **interpreting** data collected by someone else

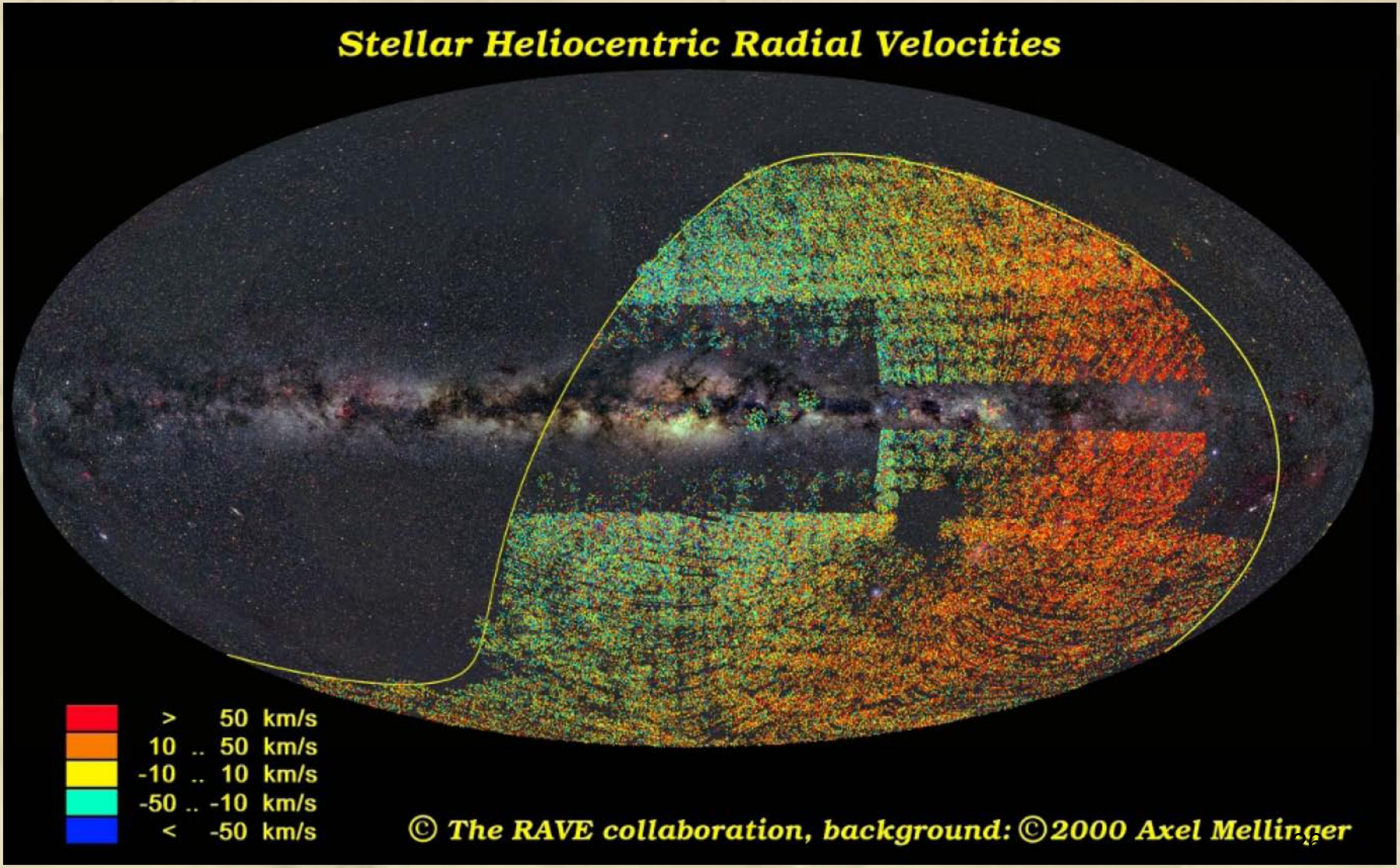
Examples

• SDSS-I, II, and III	1999-2014
• RAVE	2003-2012
• LAMOST	2010-2015
• SkyMapper	2010-2015
• HERMES	2013-2017
• Gaia	2013-2018
• LSST	2014-2024

RAVE

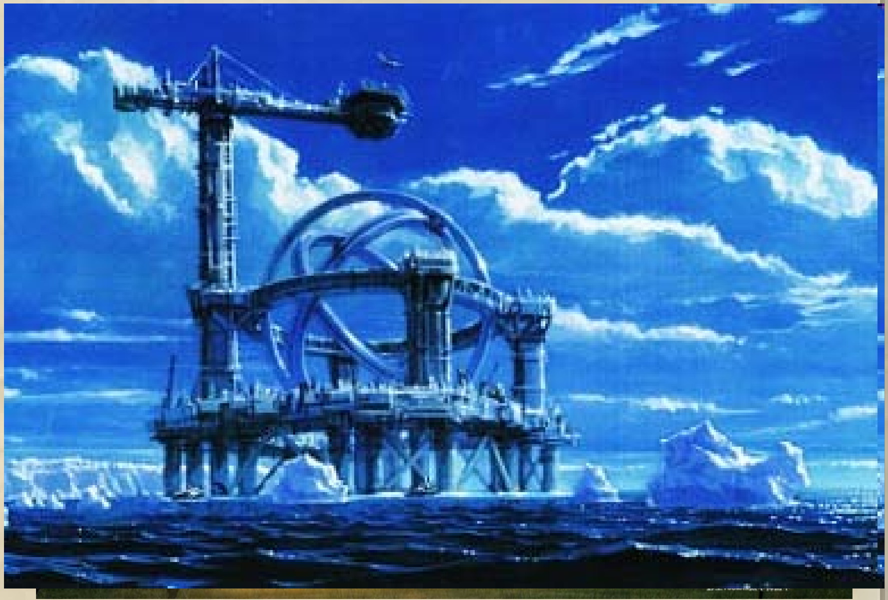
- Now conducting a survey to measure the radial velocities, metallicities and abundance ratios for up to a million stars using the 1.2-m UK Schmidt Telescope of the, over the period 2003 - 2010.
- The survey represents a giant leap forward in our understanding of our own Milky Way galaxy, providing a vast stellar kinematic database.
- The main data product will be a southern hemisphere survey of about a million stars. This survey would comprise 0.7 million thin disk main sequence stars, 250,000 thick disk stars, 100,000 bulge and halo stars, and a further 50,000 giant stars including some out to 10 kpc from the Sun.

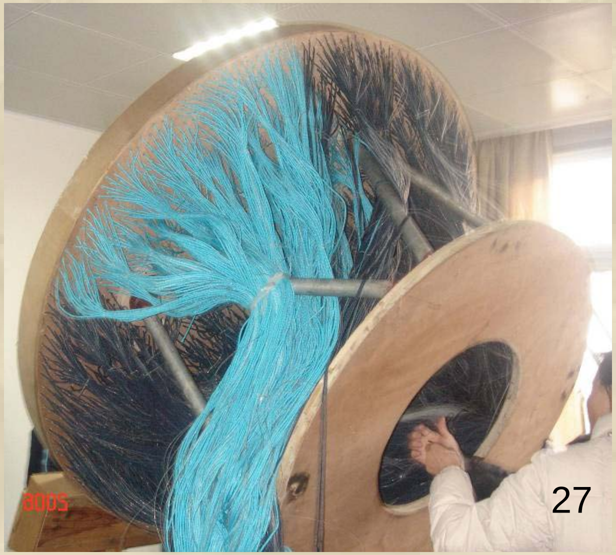
RAVE (as of 2010)



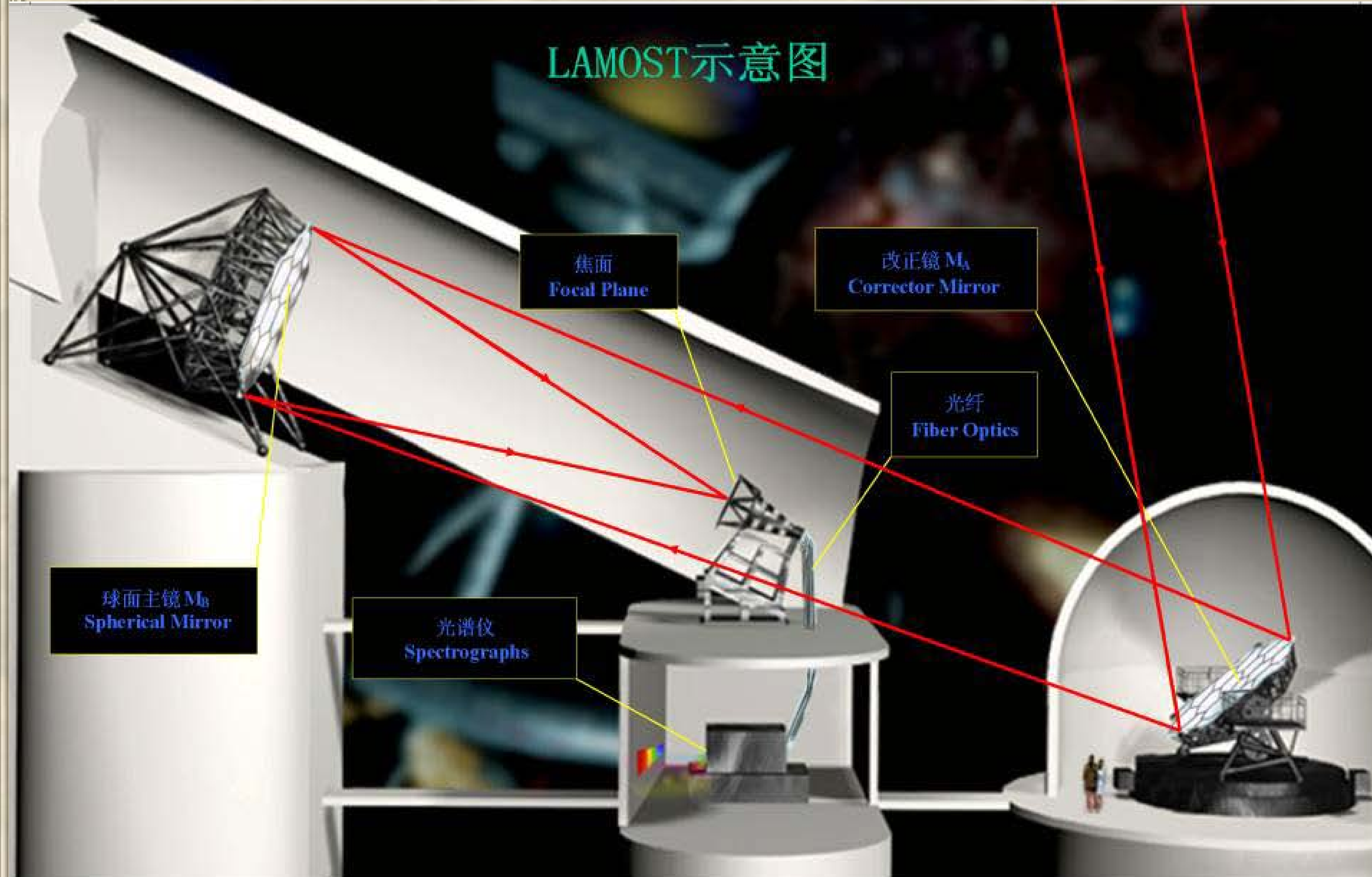
LAMOST

- Large Sky Area Multi-Object Fibre Spectroscopic Telescope
- A meridian reflecting Schmidt telescope
- Large aperture (4 meter) with a wide field of view (5 degrees)
- Located at Xinglong Observing Station in northern China (2 hours from Beijing)
- Up to 4000 fibers for spectroscopy
- Low to medium resolution spectroscopic survey
- First light Fall 2008
- Can obtain medium-res data for ~5 million stars over a 2-3 year period



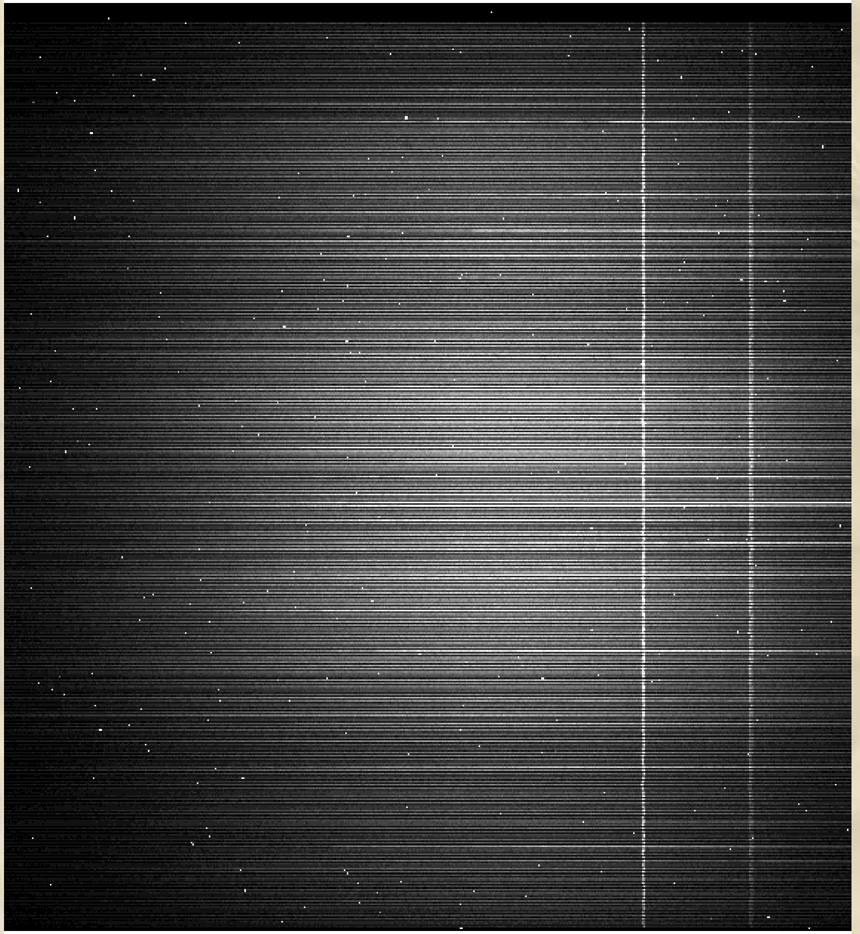


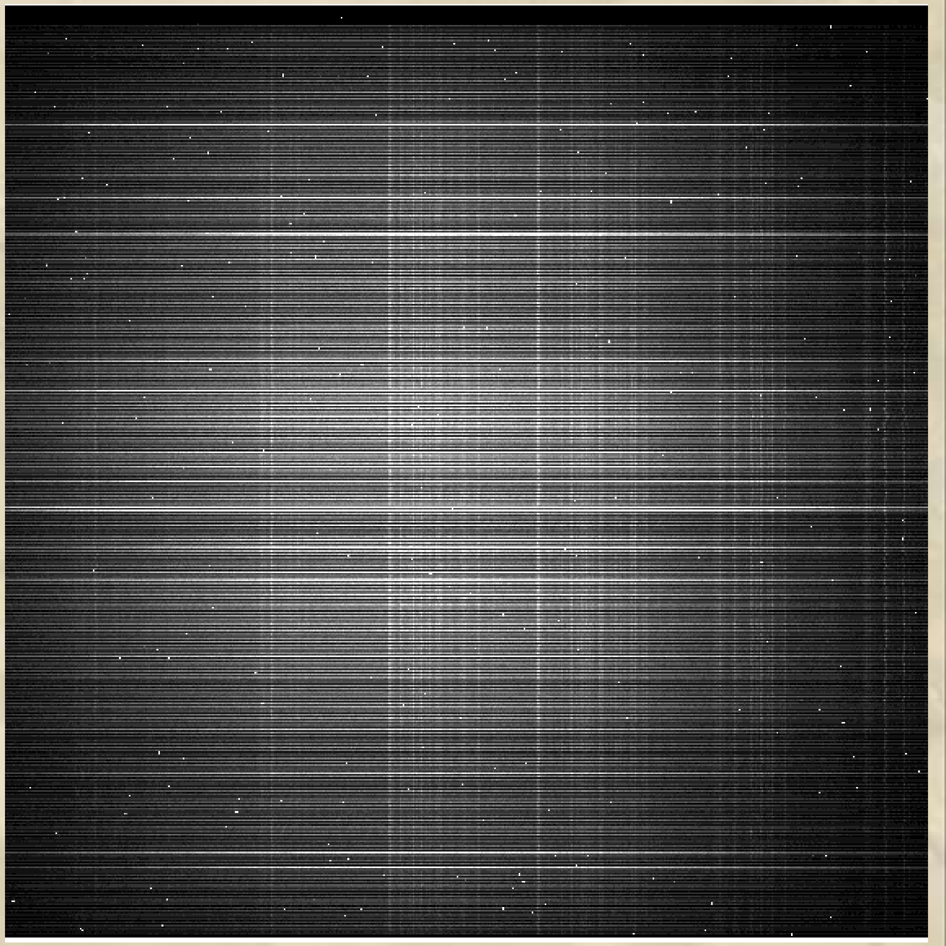
The Machine!


LAMOST示意图
焦面
Focal Plane
改正镜 M_A
Corrector Mirror
光纤
Fiber Optics
球面主镜 M_B
Spherical Mirror
光谱仪
Spectrographs


2006 12 28

Spectroscopic Data on CCDs





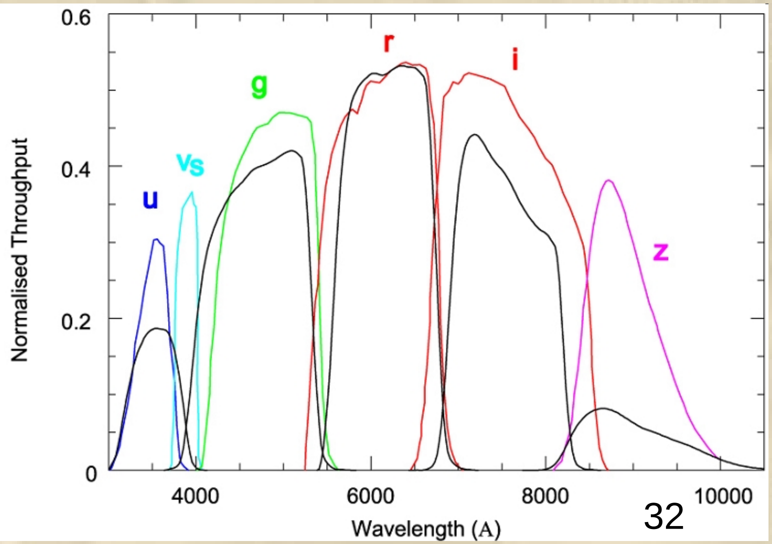
SkyMapper

- The SkyMapper Telescope is a 1.3m telescope with an 8-sq degree field of view
- Has an integrated16kx16k CCD mosaic with 0.5" pixels covering 5.7 square degrees
- Located at Siding Spring Observatory
- Fully automated
- Will conduct a multi-color, multi-epoch survey of the southern hemisphere known as the Southern Sky Survey.
- First Light 2009 / Now in commissioning

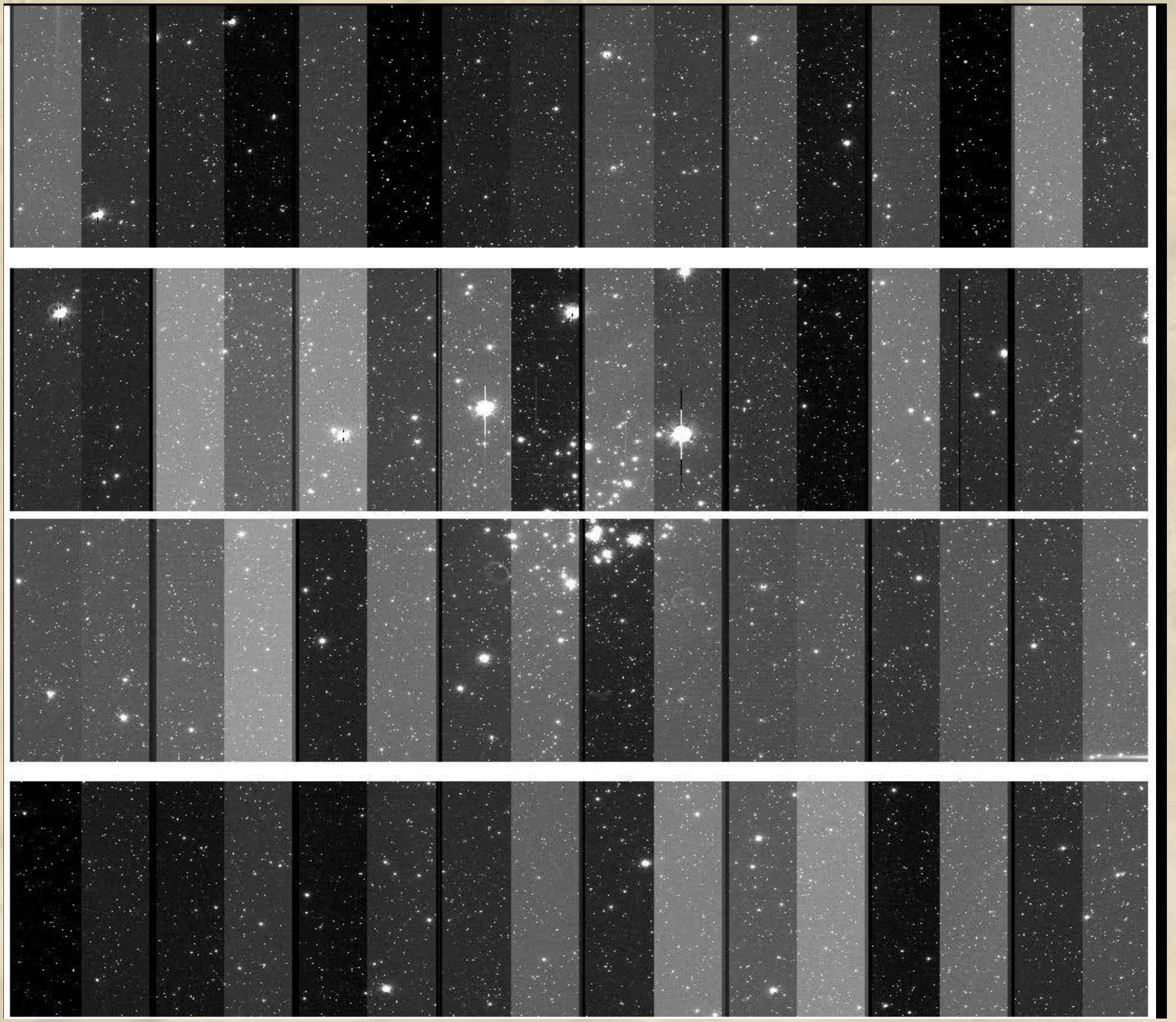
By choosing filter that optimize the data return for stellar astrophysics, SkyMapper will be able to **measure surface gravities and metallicities for 100,000,000 stars**

Identification of **100,000** stars with [Fe/H] < -2.0, **10,000** < -3.0, **hundreds of stars** < -4, **tens of stars** < -5.0

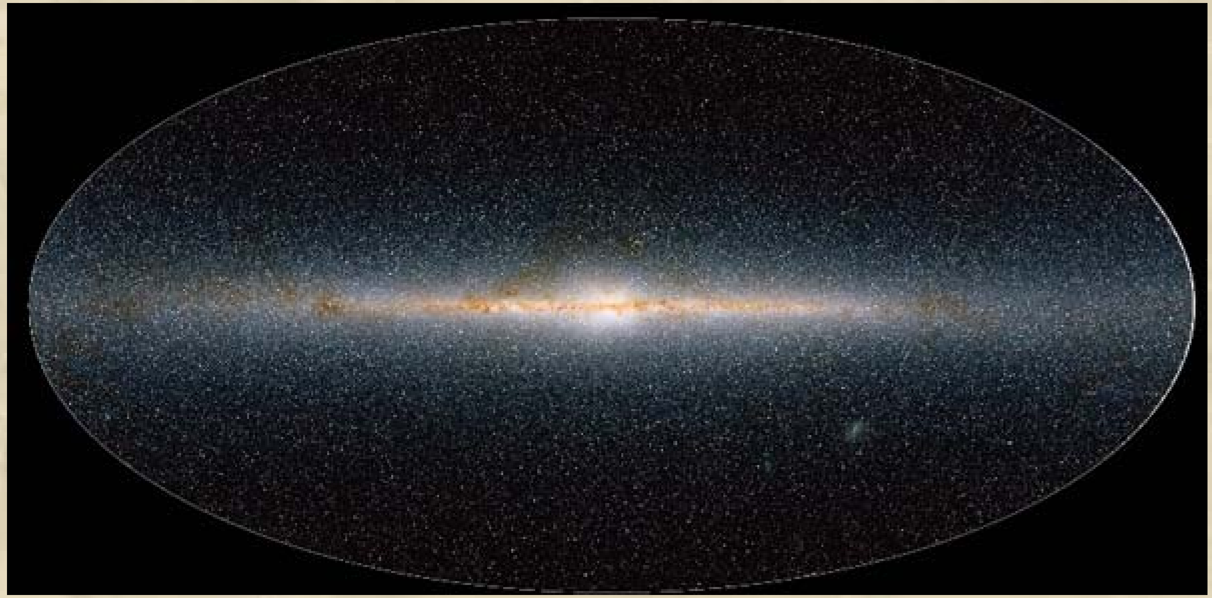
JINA-supported personnel have developed techniques that will be implemented by SkyMapper



First Data from SkyMapper

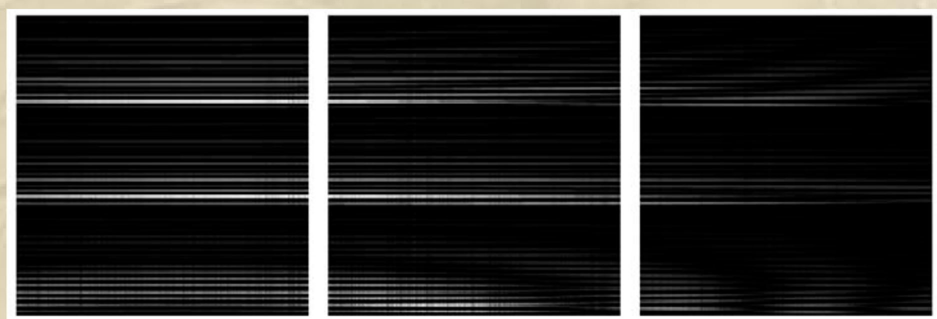


SDSS – APOGEE



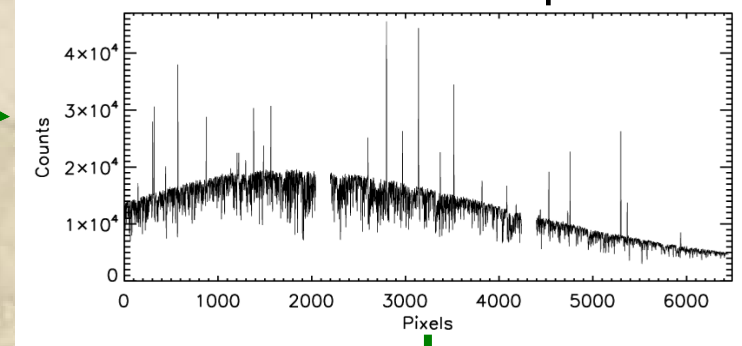
- Apache Point Observatory Galactic Evolution Experiment
- Bright time observations on ARC 2.5m telescope, beginning fall 2011
- APOGEE will produce the first systematic survey of the 3-D distribution functions of the abundances of 15 chemical elements that are key for the understanding of the star formation and chemical evolution of the Galaxy.
- This will be achieved by use of a new 300-fiber cryogenic high-resolution near-IR spectrograph that will provide access to regions of high extinction in the Galactic inner disk and bulge.

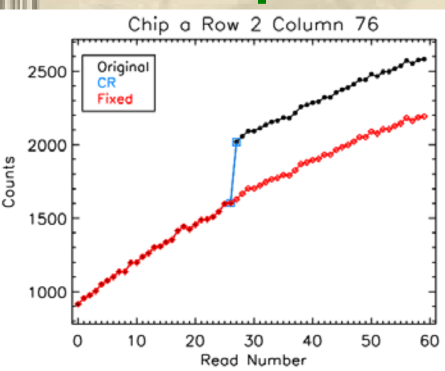
Data Processing



raw 2D exposure frame
(12M pixels)

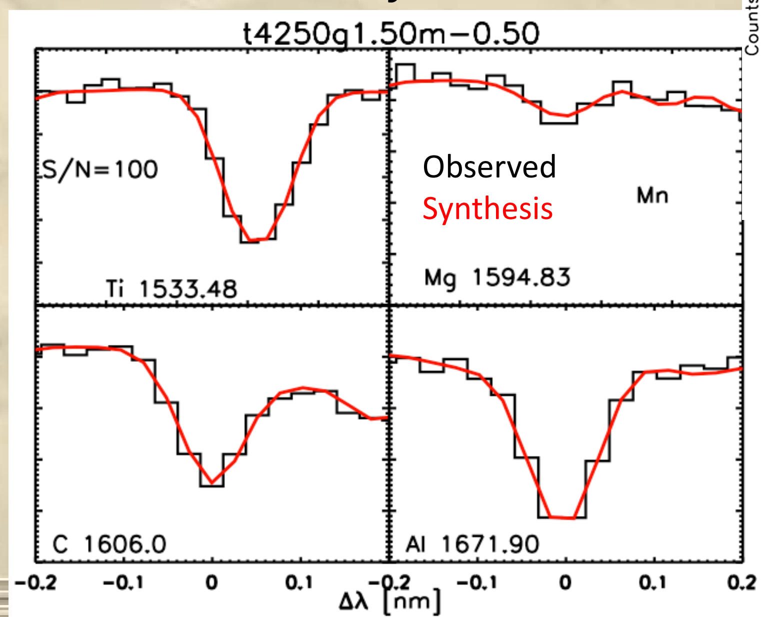
raw 1D extracted spectrum

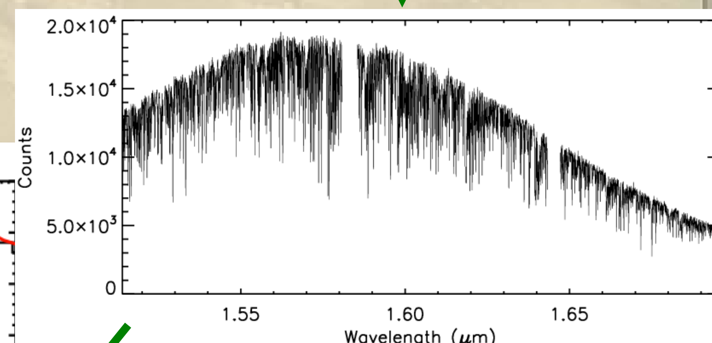




raw up-the-ramp calculation
(one pixel
from data cube)

stellar synthesis





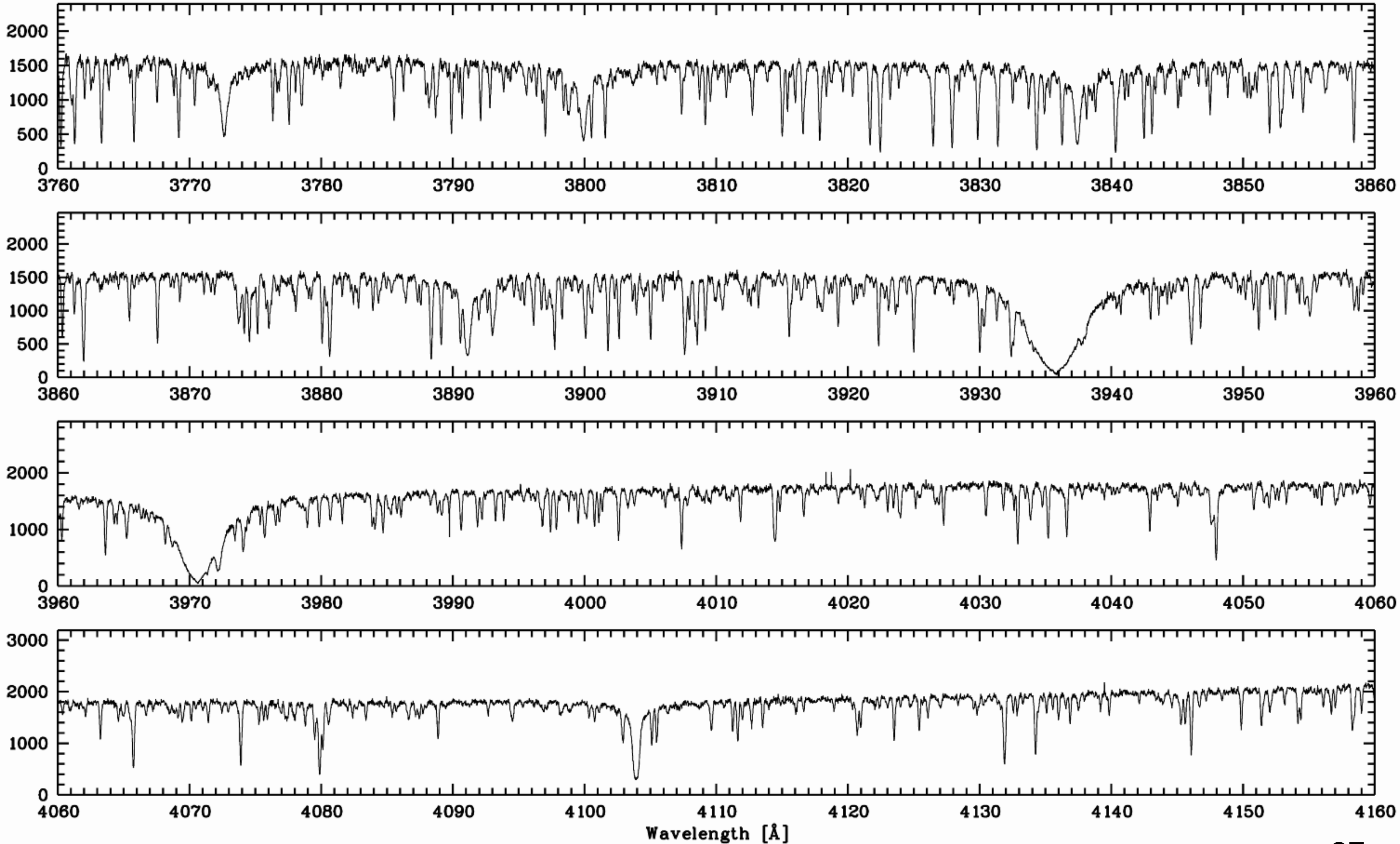
final 1D spectrum

HERMES

- **H**igh **R**esolution **M**ulti-object **E**chelle **S**pectrograph
- Will obtain high-resolution (R = 30,000) spectra using a 400 fibre instrument on the Anglo-Australian Telescope, beginning in 2012
- Primary mission will be Galactic Archeology for **several million stars**, but other targets possible as well
- Combining the abundance signatures and phase space locations for millions of stars will provide an **extraordinarily detailed insight** into the formation and structure of the Milky Way

Example High-Resolution Spectrum

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



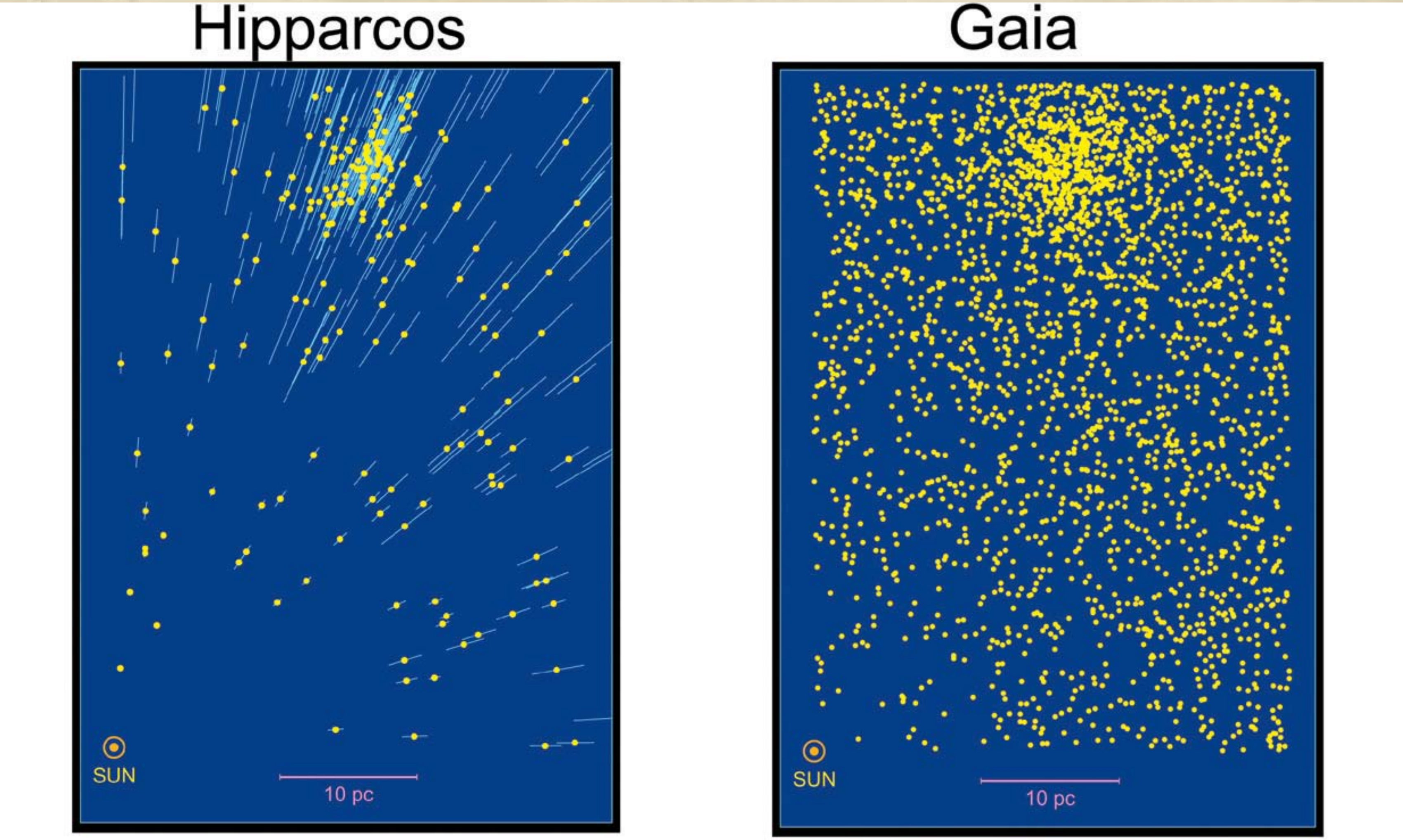
Gaia

- Gaia is a global space astrometry mission. Its goal is to make the largest, most precise **three-dimensional map** of our Galaxy by surveying an unprecedented number of stars - more than **a billion**

- It will monitor each of its target stars about 70 times over a five-year period, beginning in 2013, precisely charting their **positions, distances, movements, and changes in brightness**

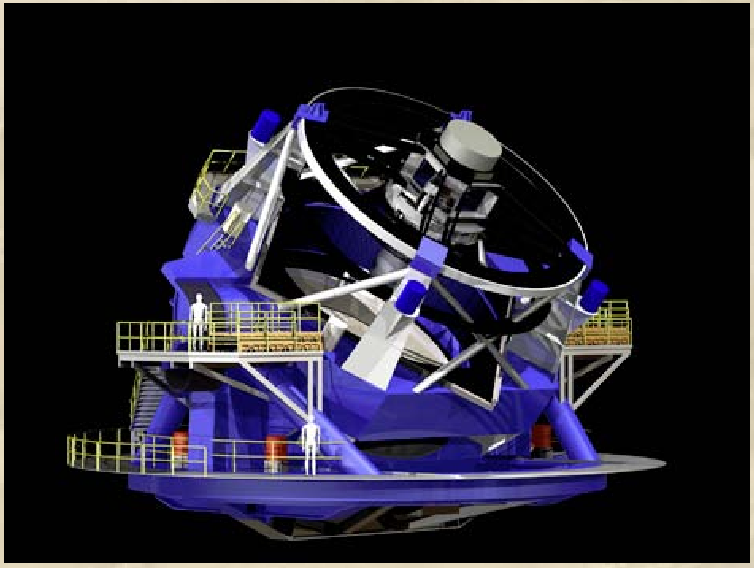
- Plans to obtain radial velocities and abundance information for an essentially **complete sample** of stars down to 15-16th magnitude
- Astrometric information for much fainter samples

Parallax Distances to Hyades Cluster

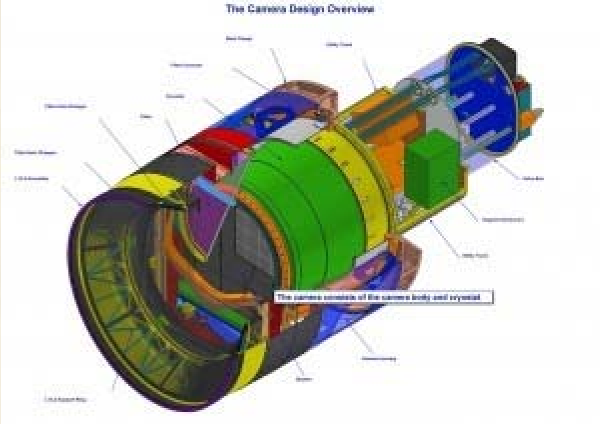


LSST

- Currently, the best large-area faint optical survey is SDSS: a digital color map of the sky r~ 22.5, 1-2 visits, 300 million objects
- **LSST = d(SDSS)/dt**: an 8.4m telescope to r~24.5 over a 9.6 deg^2 FOV over the entire southern hemisphere
- Images sky in two bands every three nights, **1000 visits over 10 years,** beginning in 2015
- LSST = Super-SDSS: an optical/near-IR survey of the observable sky in multiple bands (ugrizy) to r > 27.5 (co-added), producing a catalog of **10 billion stars and 10 billion galaxies**
- LSST: **a digital color movie of the sky**



Large Synoptic Survey Telescope



Take Away Points

- The new massive data sets arriving over the course of the next decade will require **changes in the way we explore** astronomical data, ask questions of the data sets, and test proposed models
- This will require **new skill sets**, some quite different than needed for exploring much smaller, highly selected data
- Complete, or nearly so, samples will enable calculation of **frequencies of observed phenomena**, tightly constraining proposed models which need to account for many presently **unknown quantities** (e.g., IMFs, binary fractions, modes of mass transfer, mixing, galaxy evolution, etc)