Overview and Early Results

Mathias Schultheis
Observatoire de la Cote d'Azur

for the APOGEE Team

APOGEE at a Glance

- The Apache Point Observatory Galactic Evolution Experiment
- The 4th (and final) SDSS-III project (2011 – 2014)
- A high-resolution, high signal-to-noise spectroscopic survey
- Operates in the near-infrared (H band): 1.51-1.68 m
- Will target ~10^5 RGB stars sampling the bulge, disk, and halo
- Stellar parameters and abundances for ~15 elements

More numbers!

- Goal S/N = 100/pixel
- R ~ 22,500
- 300 fibers at a time, 3 deg^2 FOV
- RV precision: <0.1 - 0.5 km/s
- Abundance precision: <0.1 dex
- Chemical elements including Fe,C,N,O,other α, odd-Z, etc..

Top Level Science Requirements

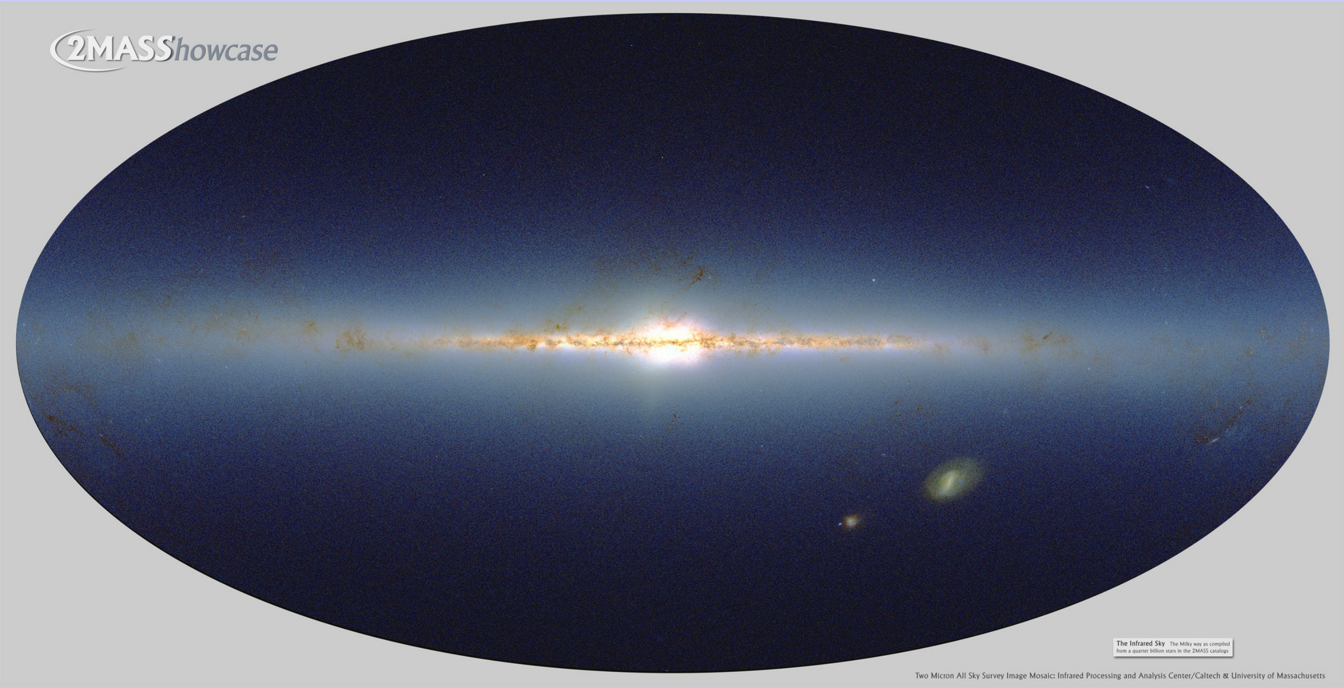
First large scale, systematic, uniform spectroscopic study of all major Galactic stellar populations to understand:

- chemical evolution at precision, multi-element level (including preferred, most common metals CNO) -- sensitivity to SFR, IMF
- tightly constrain GCE and dynamical models (bulge, disk, halo)
- access typically ignored, dust-obscured populations
- Galactic dynamics/substructure with very precise velocities
- order of magnitude leaps:
  ~2-3 orders larger sample than previous high *R* GCE surveys
  ~2 orders more high *S/N*, high *R* near-IR spectra ever taken

Broad Science Goals

- A *3-D chemical abundance distribution* (many elements), MDFs across Galactic disk, bar, bulge, halo.
- Probe *correlations between chemistry and kinematics*
- Constrain *SFH and IMF* of bulge/disk as function of radius, metallicity/age, chemical evolution of inner Galaxy.
- Detailed study of *Galactic bar and spiral arms* and their influence on abundances/kinematics of disk/bulge stars.
- Measure Galactic *rotation curve* (include spec. p., Gaia pm)
- Search for and probe chemistry/kinematics of (low-latitude) *halo substructure* (e.g., Monoceros Ring).
- Combine with existing/expected optical, NIR and MIR data and *map Galactic dust distribution* using spec. p's, constrain variations in extinction law
- Look for early generations of stars and/or their signatures in the chemistry of the *most metal-poor bulge stars*

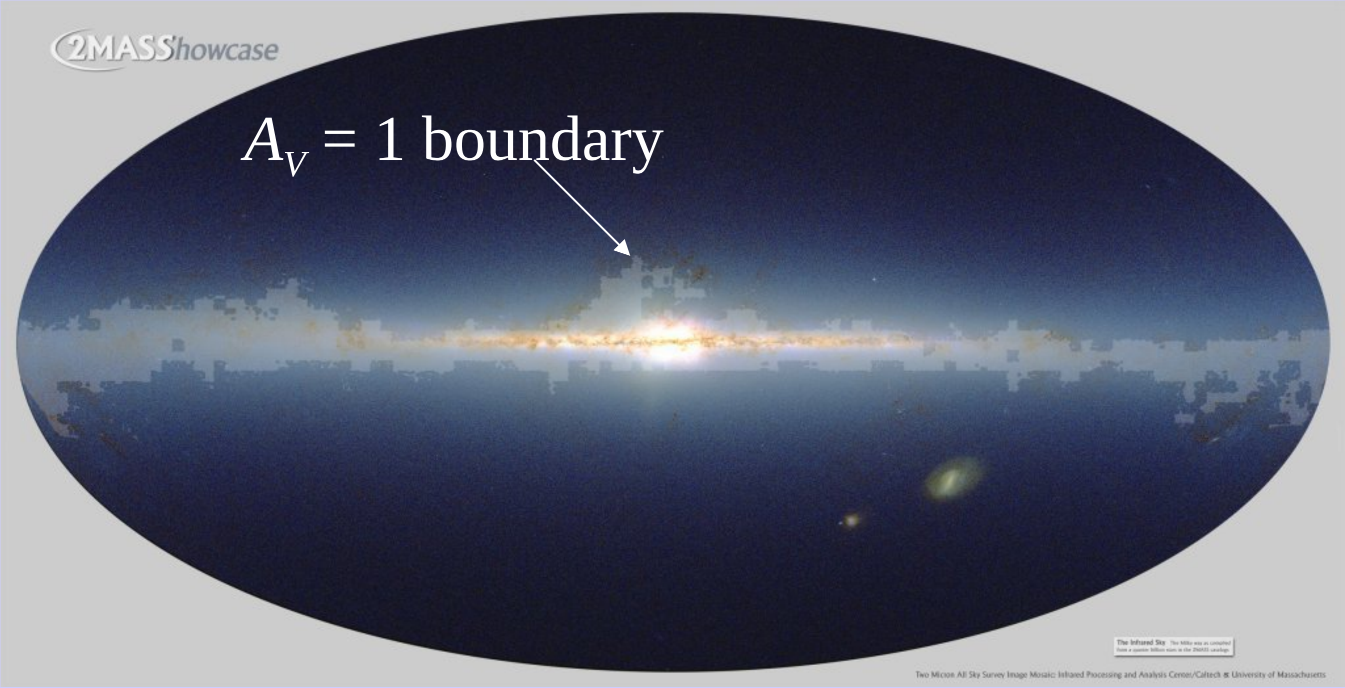
Advantages of a Hi-res H-band Survey



- **Red giants/red clump/AGB are bright in NIR.**
- **Complete point source sky catalogue to *H* < 14 available from 2MASS, augmented by GLIMPSE and UKIDSS where available.**

No need for new photometry!

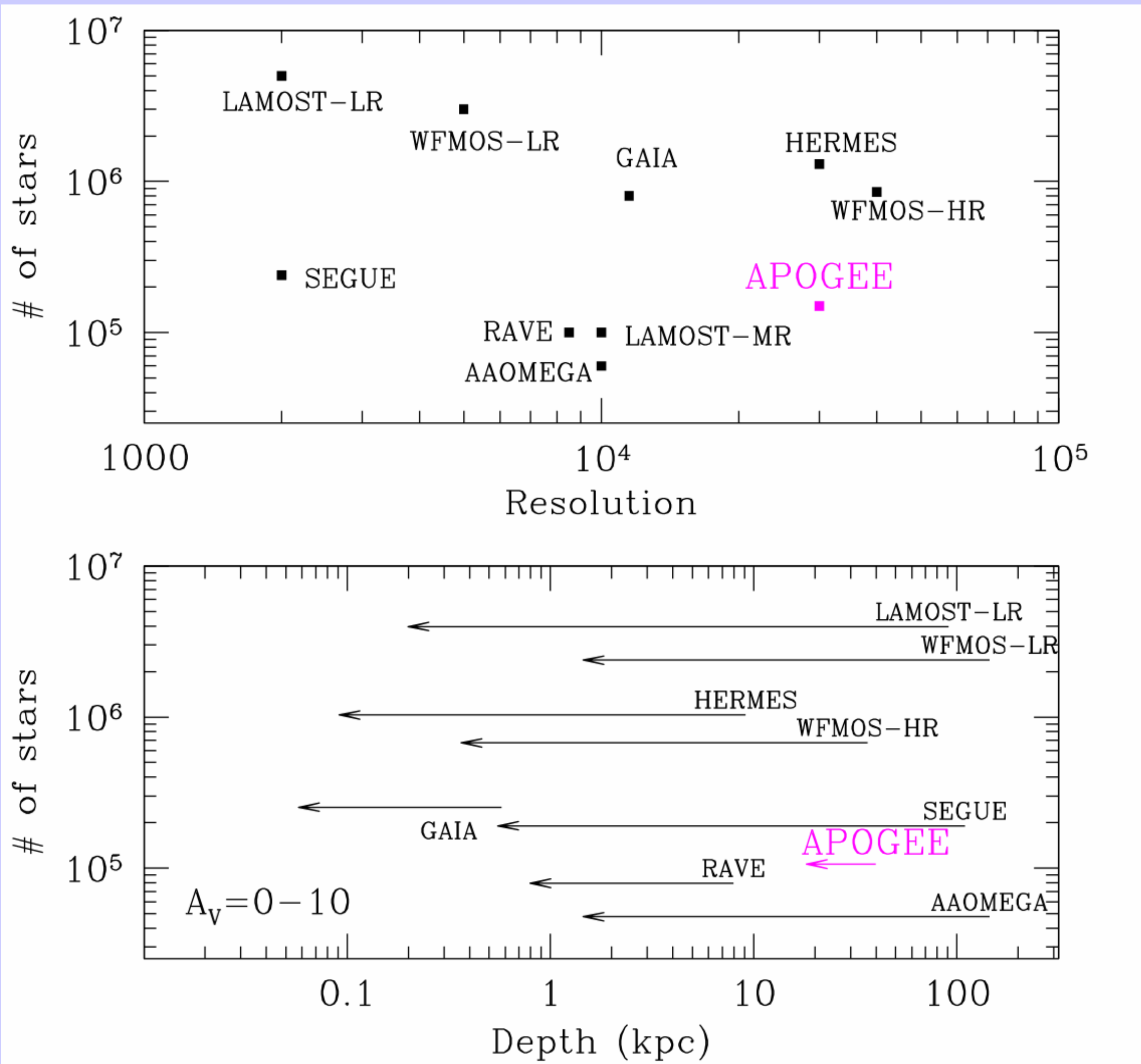
Advantages of a Hi-res H-band Survey



- A_H / A_V = 0.17
- Access to dust-obscured galaxy
- Precise velocities and abundances for giant stars across the Galactic plane, bar, bulge, halo => HOMOGENEITY
- Low atmospheric extinction makes bulge accessible from North
- Avoids thermal background problems of longer λ

APOGEE In Context

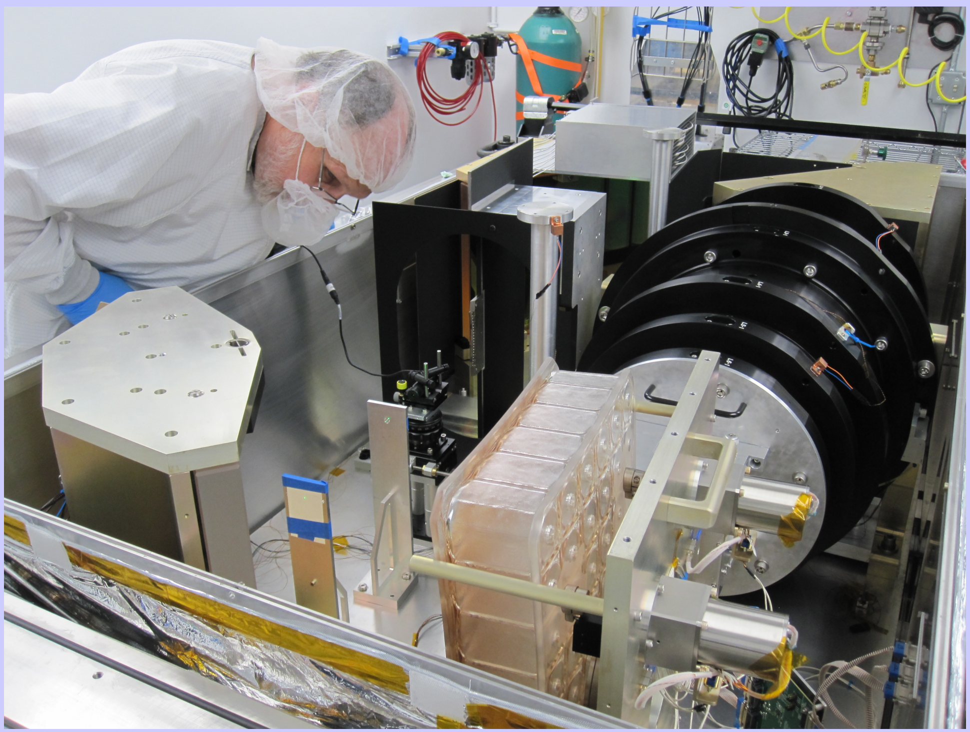
- Complements many recent and imminent surveys:

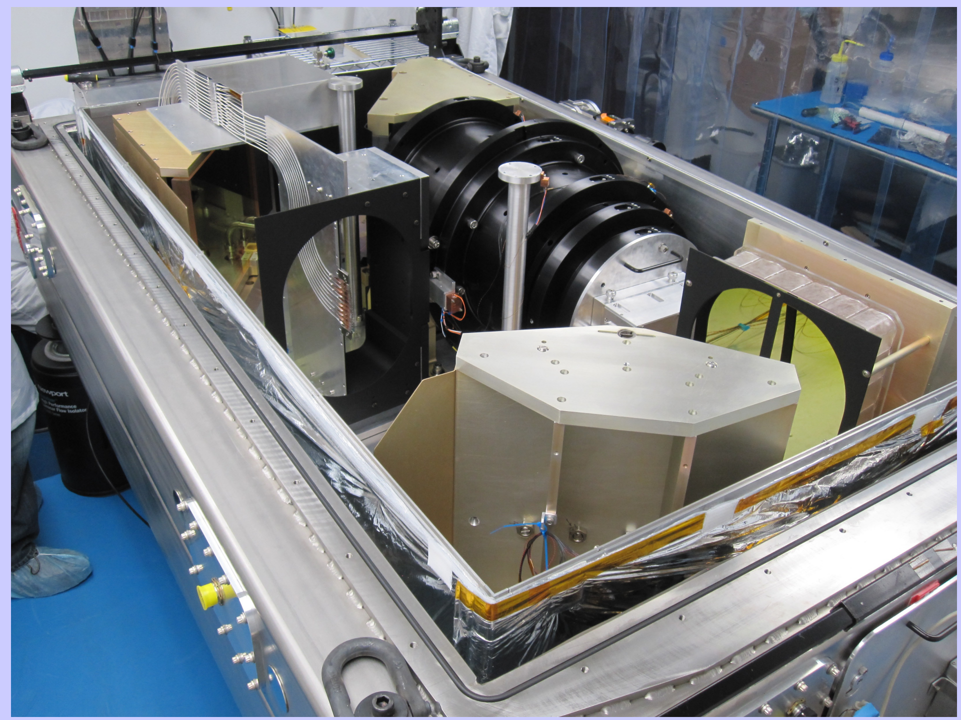


HERMES/GALAH

The APOGEE Instrument

- Built at the University of Virginia with private industry and other SDSS-III collaborators.
- The APOGEE instrument employs a number of novel technologies to achieve 300-fiber multiplexing / high resolution / infrared.





Photos by S.R. Majewski

September 2011:
APOGEE Begins Survey Operations

First APOGEE+Sloan 2.5-m observations of Galactic bulge, May 2011.
(in full moon, at >2 airmasses, and towards lights of El Paso).

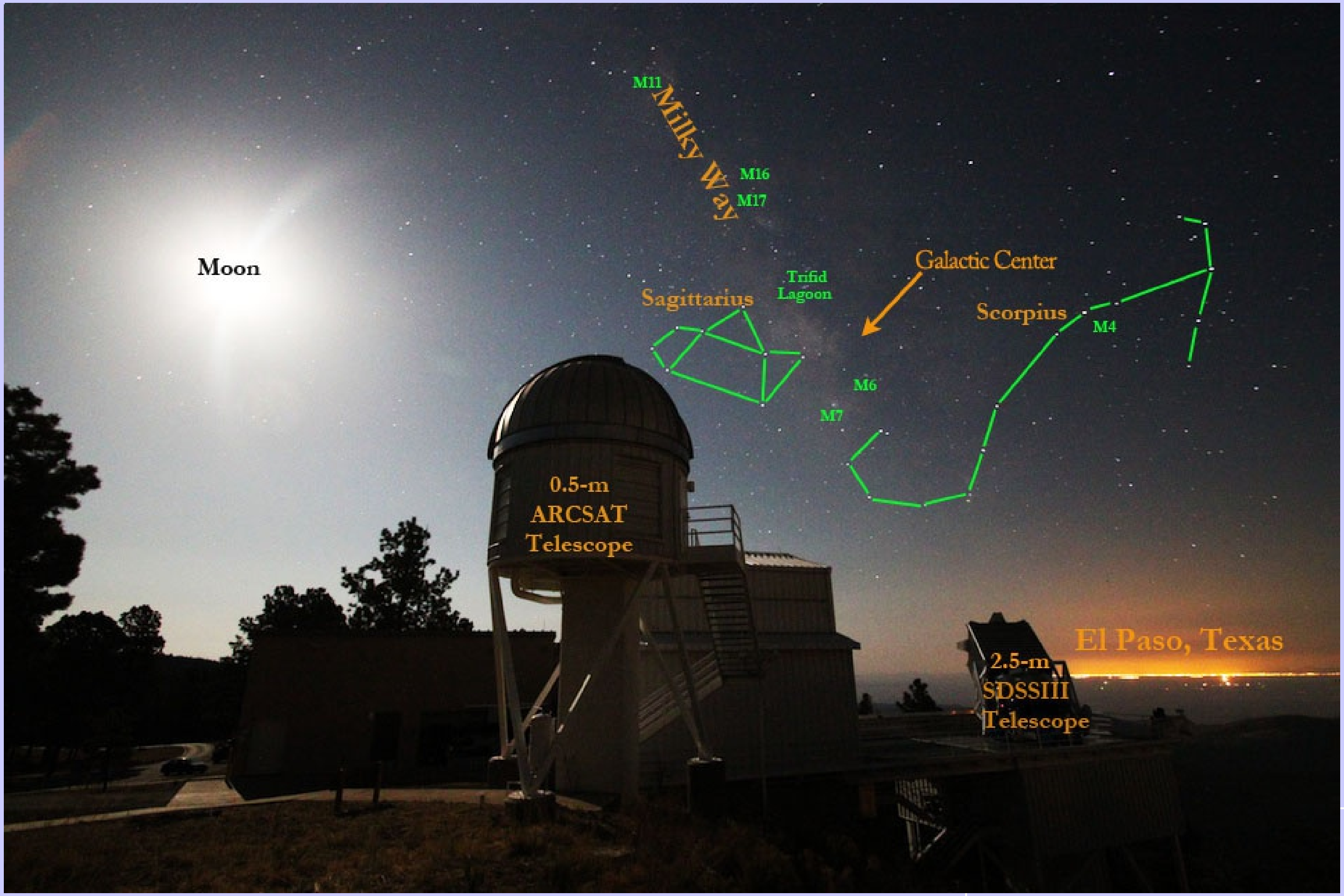


Photo by S.R. Majewski

Observations to Date

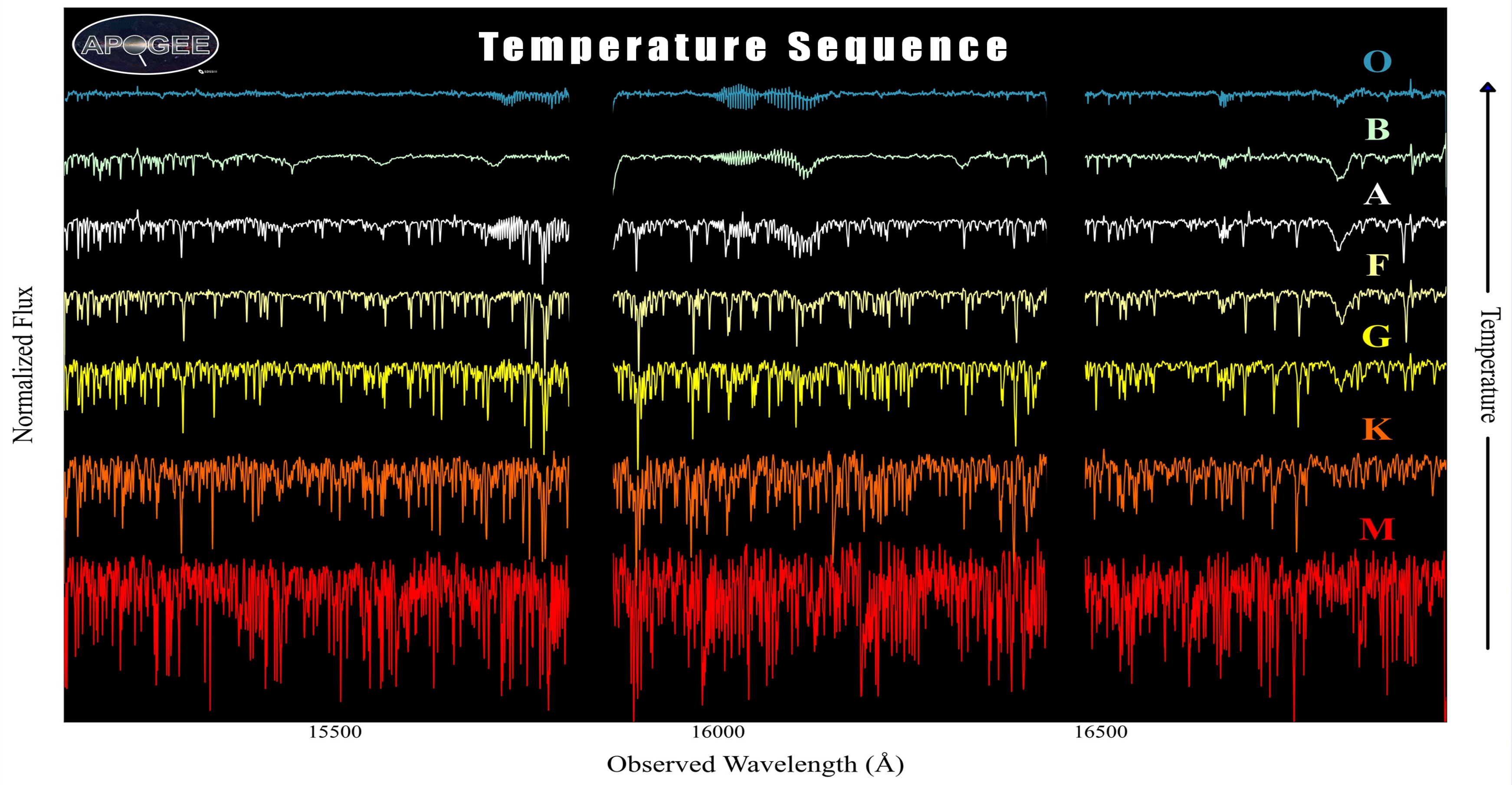
May-December "Science" Observations (~79 nights):

~262 "successful" visits (~1 hour each)

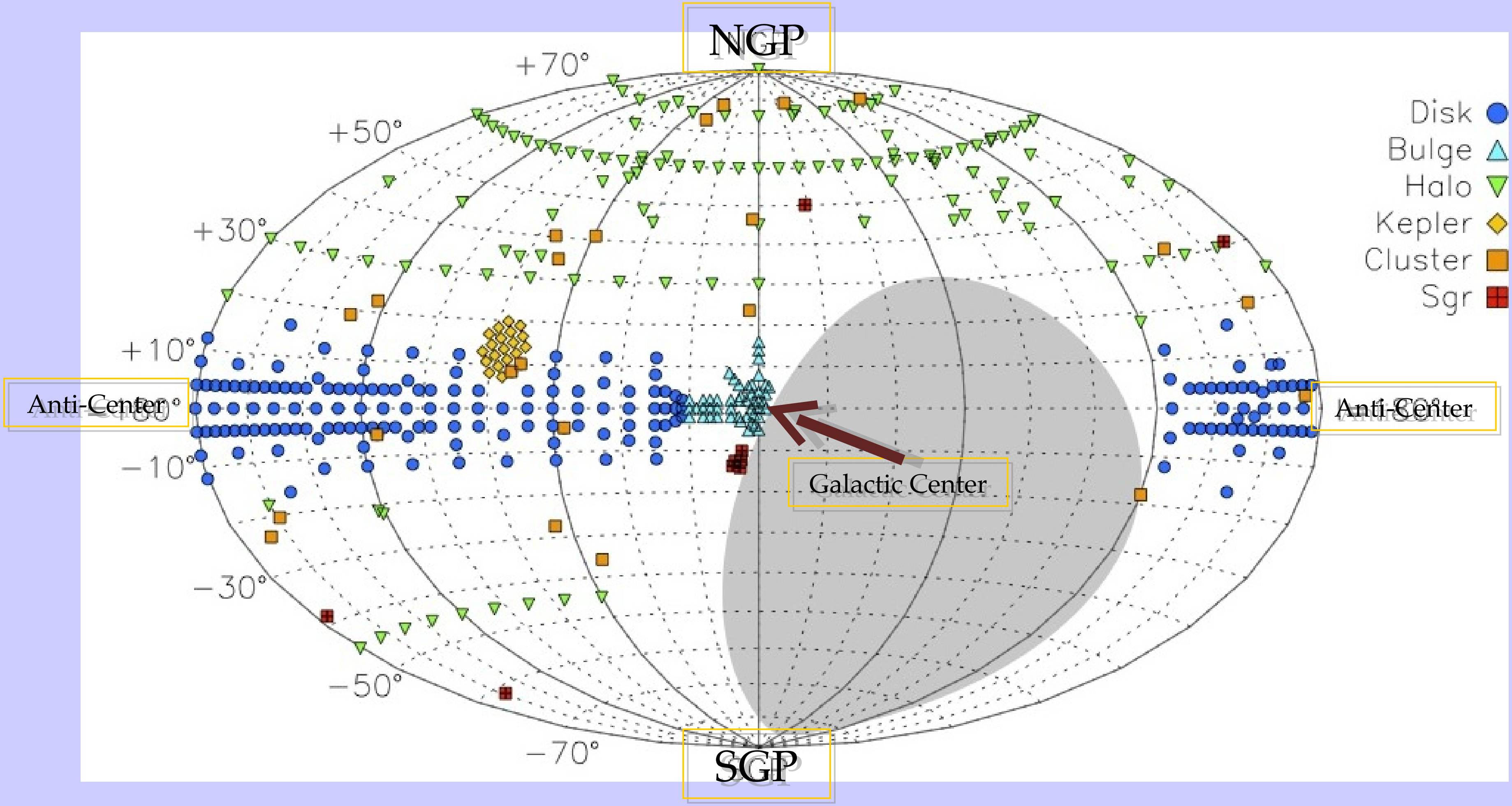
~140 separate plates

~104 unique f elds (24 one-visit bulge f elds "completed")

~55,000 science spectra (S/N > 60)



Sky coverage

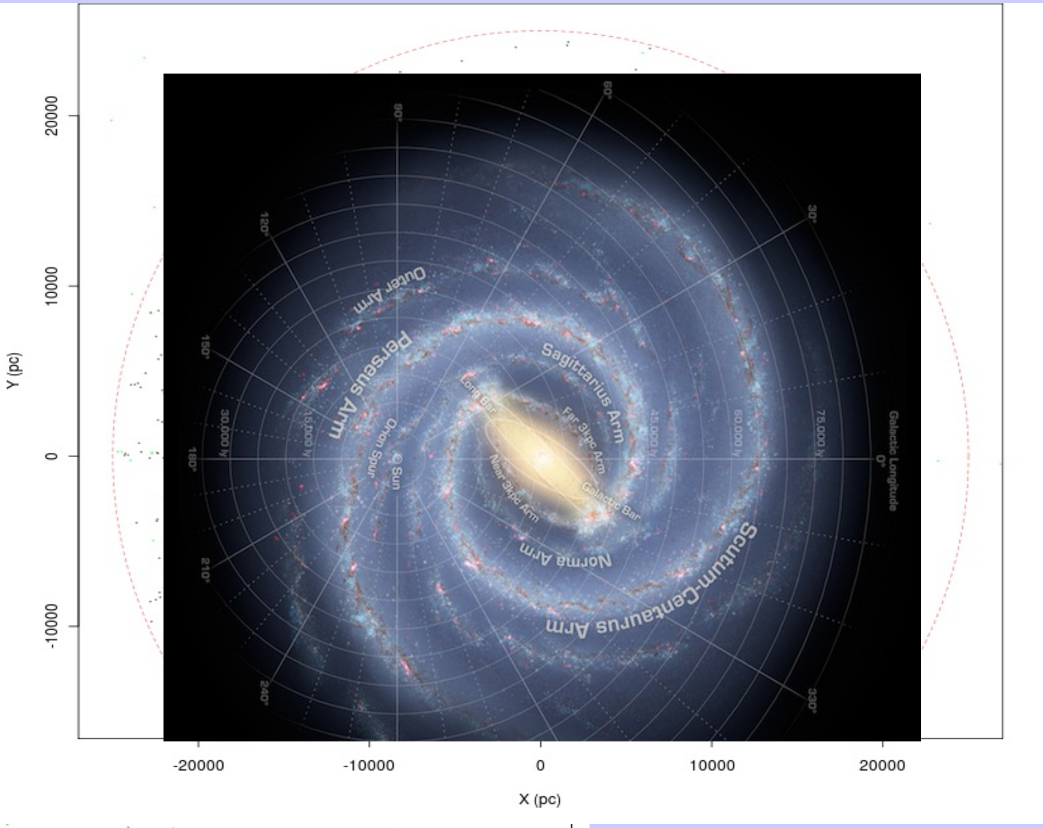


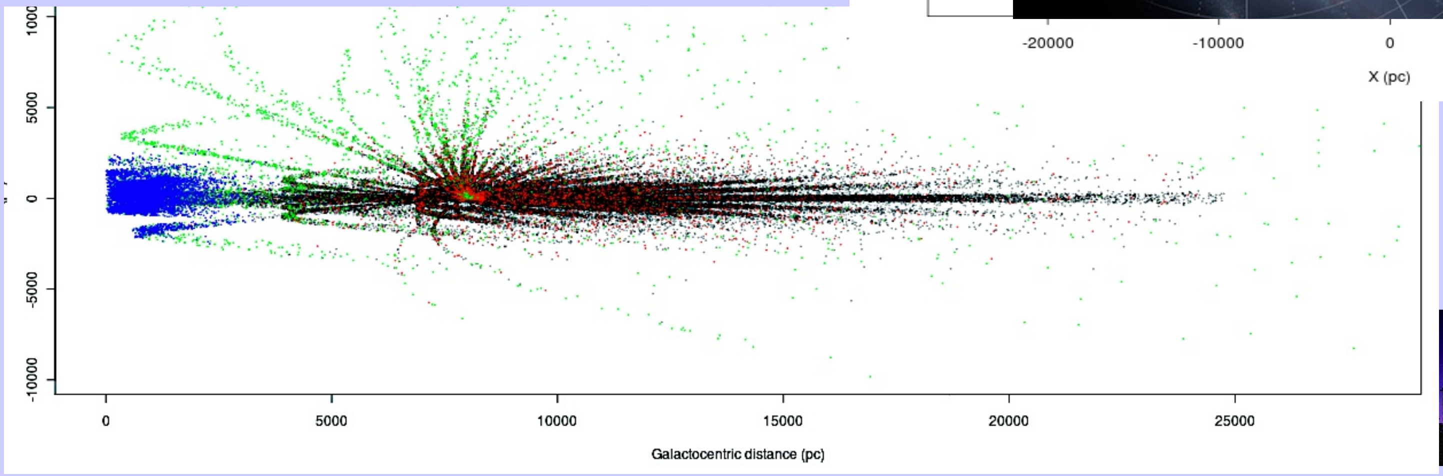
Anticipated Spatial Distribution

<u>For currently selected fields</u>

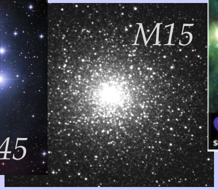
Bulge	*8000 stars*
Thin disk	*84100 stars*
Thick disk	*4300 stars*
Halo	*4500 stars*

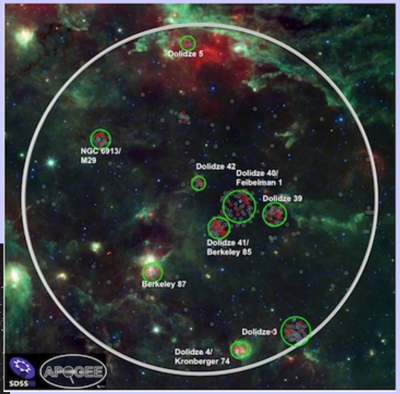
79% giants





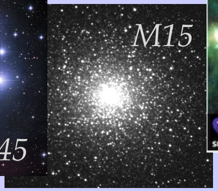
Additional Target Samples

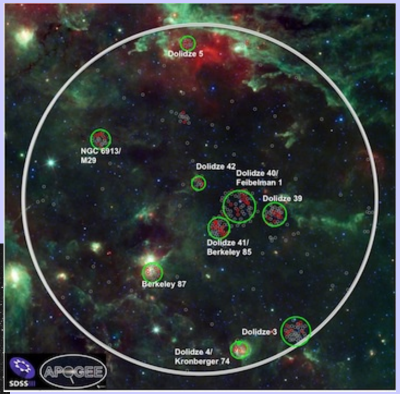




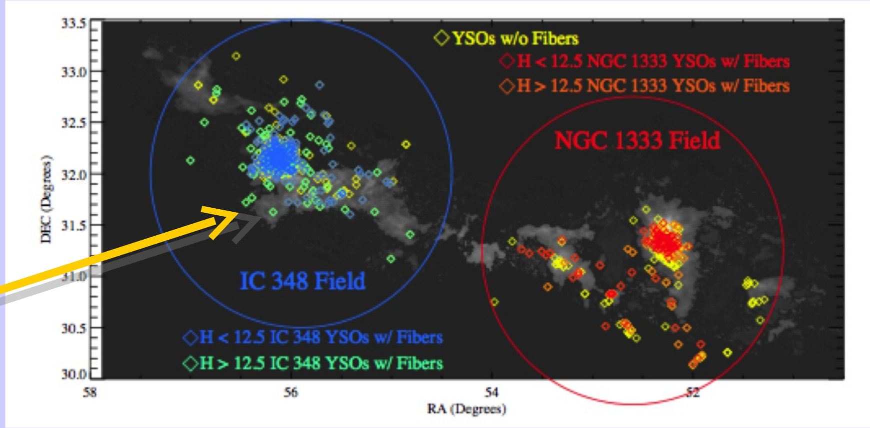
- Open and globular clusters
- Overlap with other surveys: BRAVA, SEGUE-II, *Kepler*, GAIA-ESO

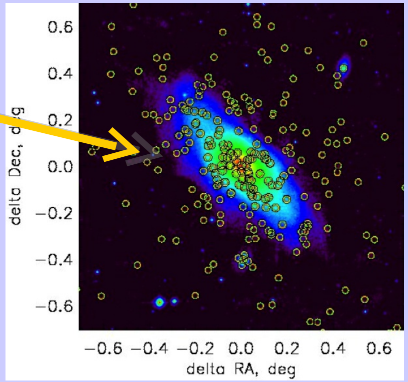
Additional Target Samples





- Open and globular clusters
- Overlap with other surveys: BRAVA, SEGUE-II, *Kepler*, GAIA-ESO
- 15 ancillary programs:
  - M dwarfs & companions
  - Eclipsing Binaries
  - Embedded YSOs
  - M31 Globular Clusters
  - B[e] (Emission Line) Stars
  - Massive MW Stars
  - And more!



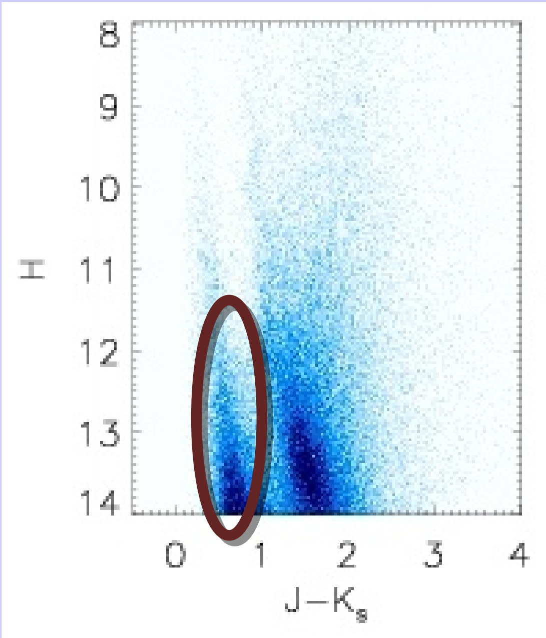


Target sample

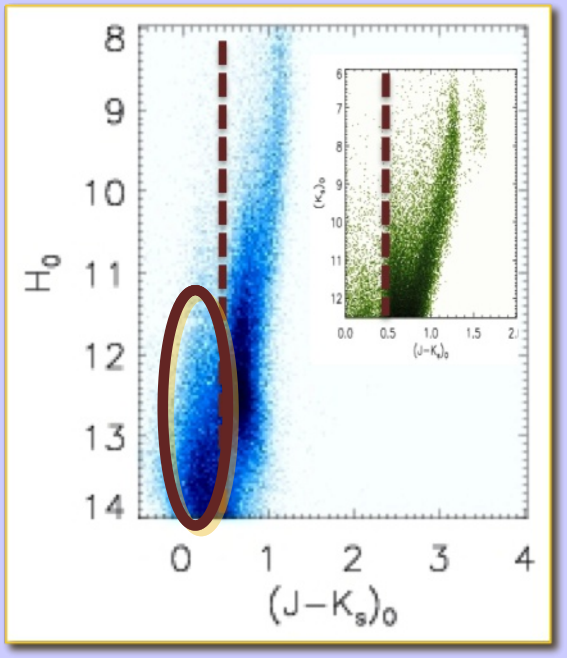
Goal: 10^5 red giant stars (red clump + 1st ascent RGB)

- Wide, minimally-biased range of age and [Fe/H]
- Selection criteria limited to a dereddened color limit!

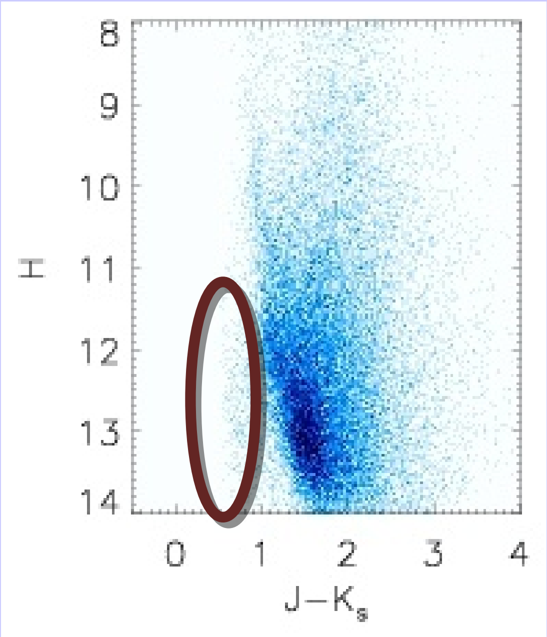
Uncorrected 2MASS, (*l*,*b*) = (60,0)



After RJCE reddening correction



After “giant star” color cut



Majewski, Zasowski & Nidever (2011)

TRILEGAL model; Girardi et al. (2005)

Stellar Abundances Pipeline

<u>**Basic reduction pipeline**</u>

Producing 1-D,   -calibrated spectra & RVs in near real time.

Some details (super-persistence, airglow) not implemented.

Instrument stability, standard s/w yields   (RV)s <~100 m/s.

<u>**APOGEE Stellar Parameters & Chemical Abundances Pipeline**</u>

7 parameter f ts (T_{eff}, log g,   [Fe/H], [C/Fe], [N/Fe], [/Fe])

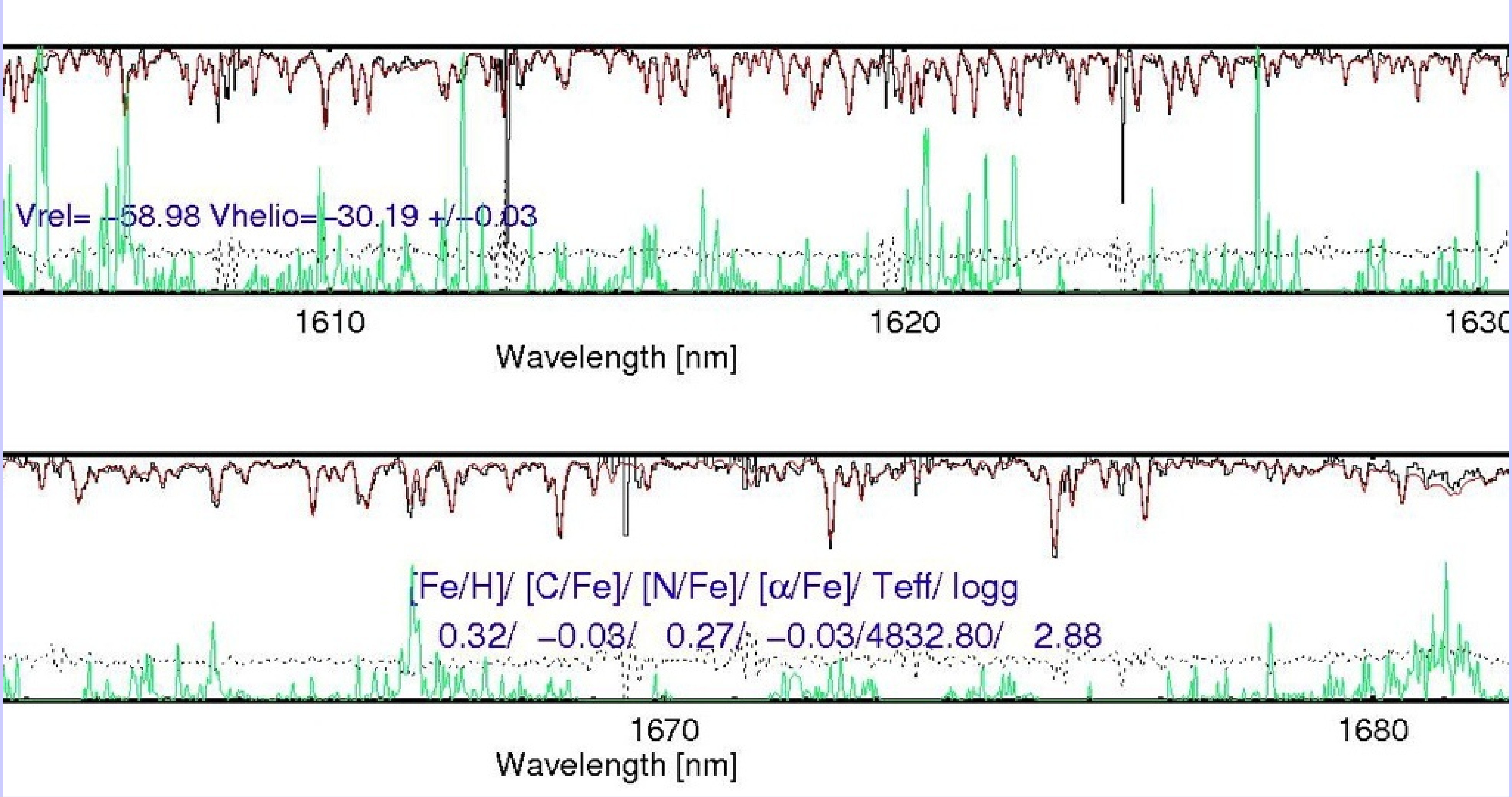
working for 3600 < T_{eff} < 4900 K (970,200 synthetic spectra).

[Fe/H], [C/Fe] mostly reliable; working on some systematics in T_{eff}, log g, [N/Fe], [/Fe], but good internal accuracy.

4750 < T_{eff} < 6500 K atmospheres grid f nished.

Useful tests against Kepler seismology (~2,800 stars so far).

Stellar Abundances Pipeline



Abundances & Stellar Parameters

- 1.5 million elemental abundances to 0.1 dex internal accuracy: unprecedented, very challenging, must be done automatically… uncharted territory!

- ASPCAP: χ^2 optimization against synthetic spectral libraries.

1. Fundamental parameters (e.g., T_{eff}, log g, [Fe/H], C/Fe, N/Fe, O/Fe, ...) using full APOGEE spectral window (1.51-1.69 μm).

2. Derivation of other elemental abundances (Na, Mg, Al, Si, S, K, Ca, Ti, V, Mn, Co, Ni) from narrow, optimal windows for each element.

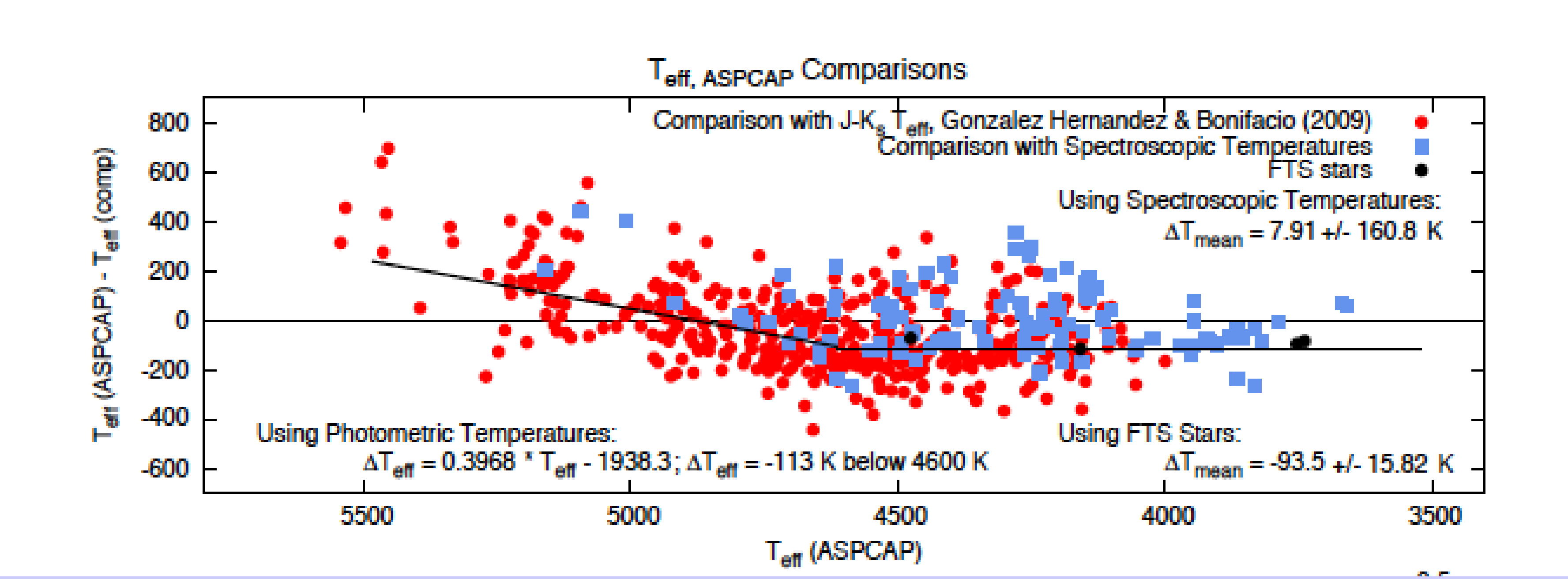
A minute/star/processor (4.4 days on 16 processors for 100,000 stars)

Calibration of stellar Parameters

Calibration stars using standard stars, open clusters, globular stars and Kepler observations

Tcorr = Teff(ASPCAP) – 0.3968*Teff(ASPCAP) + 1983.3   4600 < Teff < 5500

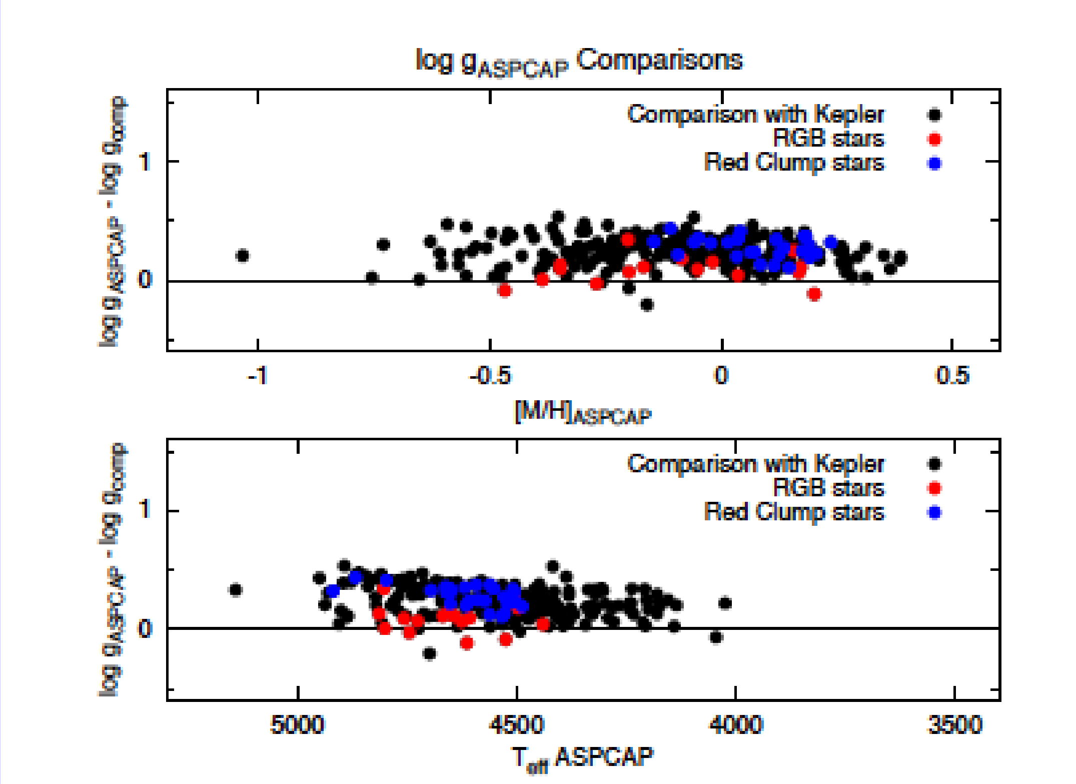
Tcorr = Teff(ASPCAP) + 113.3   3500 < Teff < 4600



Mészaros et al. (2013)

Calibration of stellar Parameters

Gravities

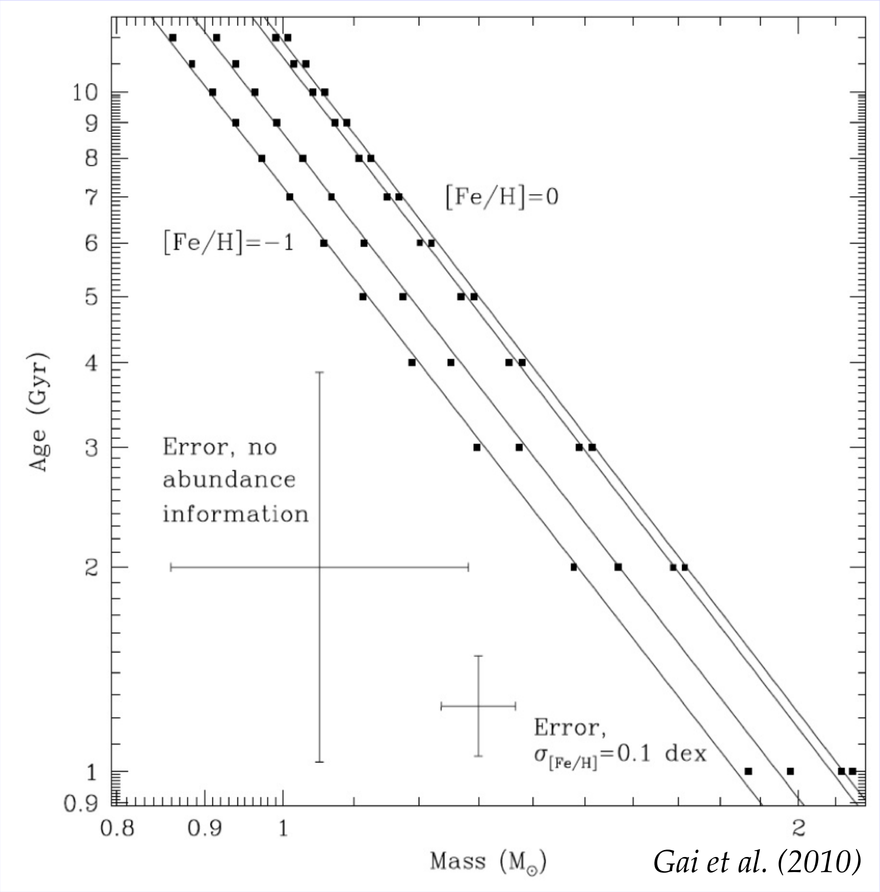


Mészaros et al. (2013)

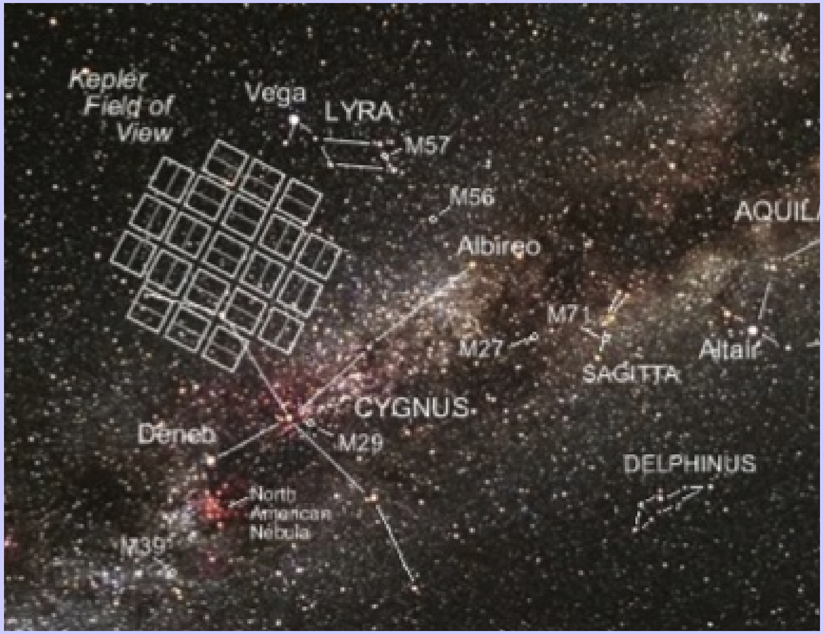
SCIENCE

APOGEE-Kepler Asteroseismology and Chemical Abundances Collaboration (AKACAC)

Combination of APOGEE and Kepler data will provide a sample of several thousand *field stars with both age and detailed chemical composition information*

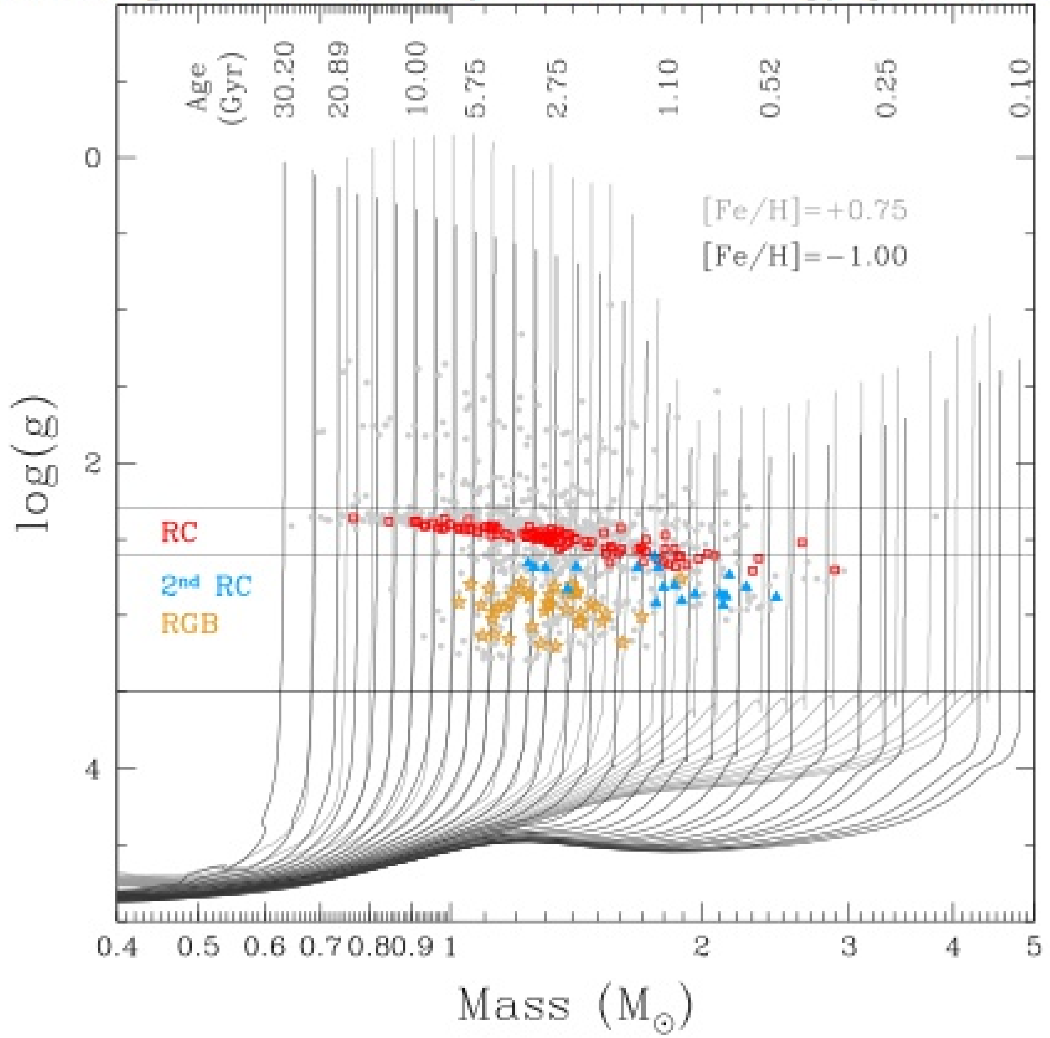


Gai et al. (2010)



Early Science Highlights

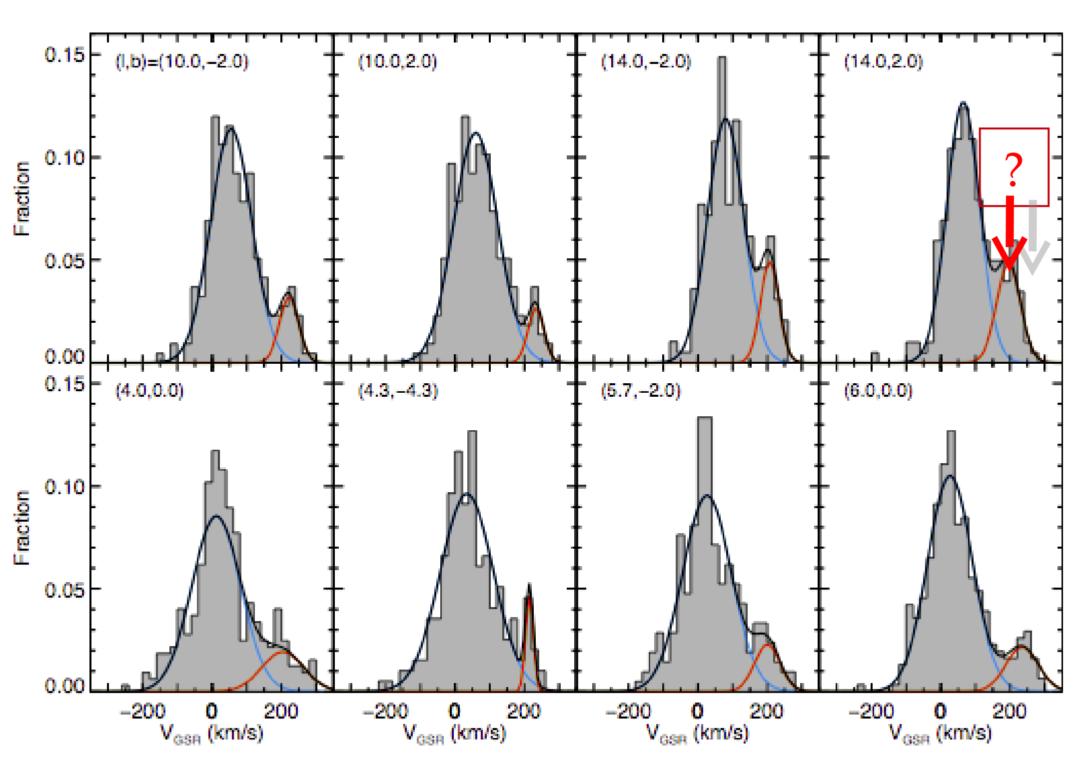
- Stellar ages from the APOKASC *(Epstein/Pinnsoneault et al.)*
  - To date, ~2800 Kepler stars (mostly asteroseismology giants) observed by APOGEE.

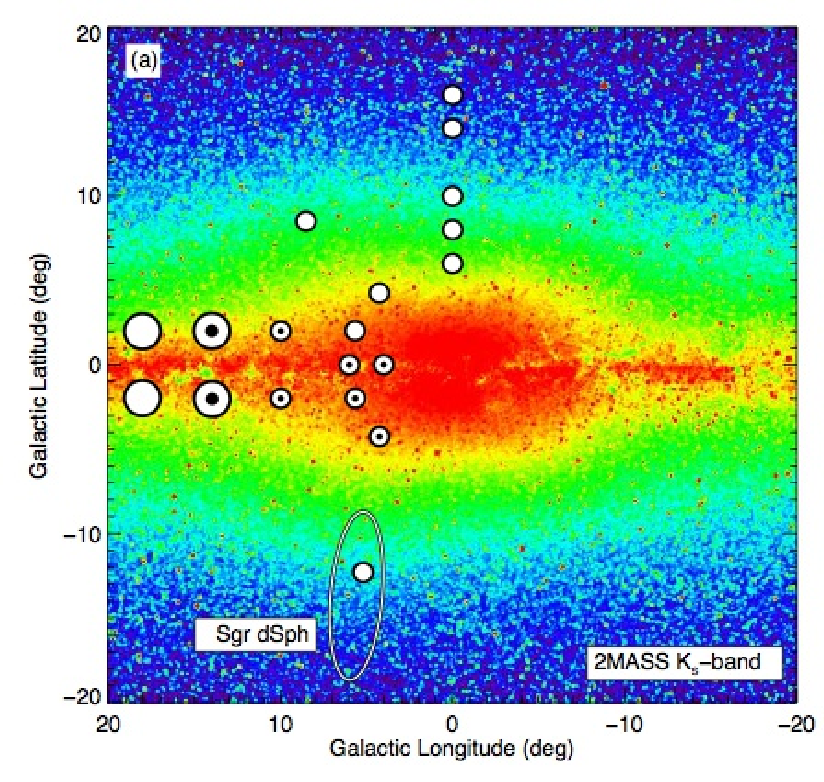


Early Science Highlights

- *Detection of high velocity stars in Galactic bulge/bar*

(Nidever/Zasowski et al. 2012)

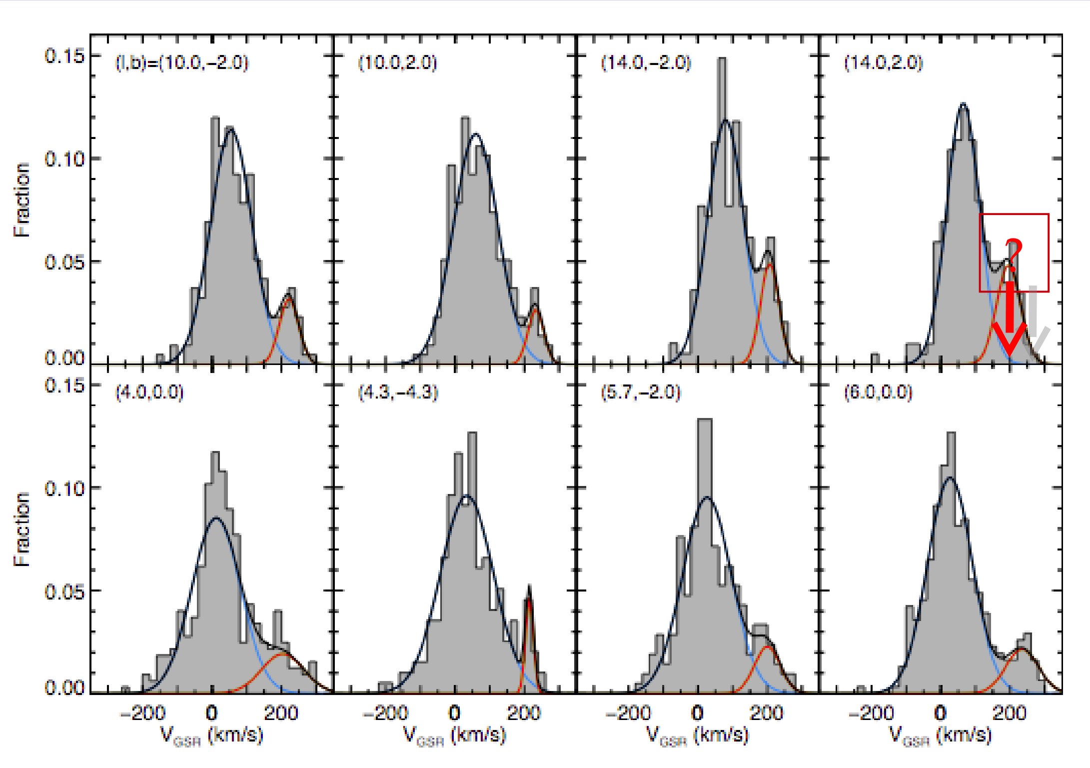




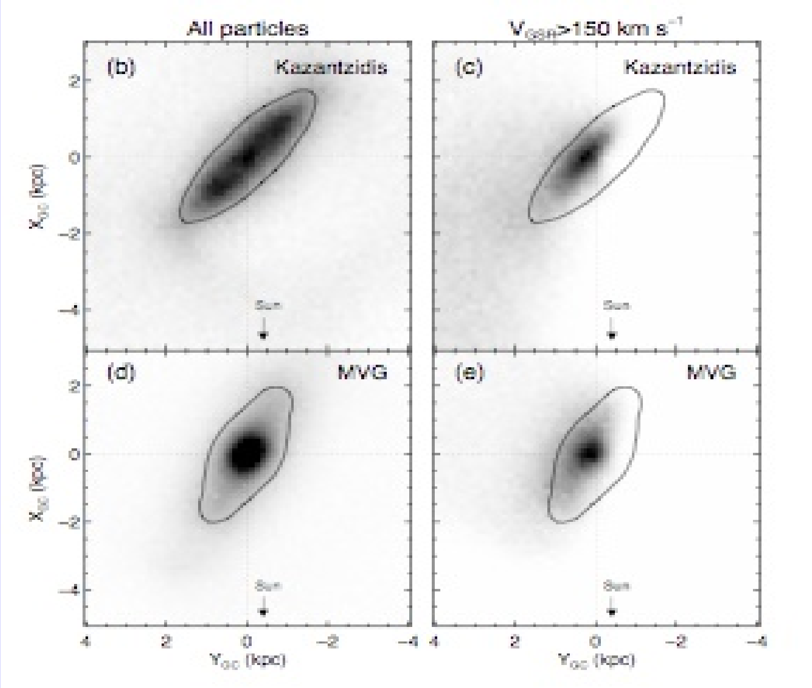
Early Science Highlights

- ***Detection of high velocity stars in Galactic bulge/bar***

(Nidever/Zasowski et al. 2012)



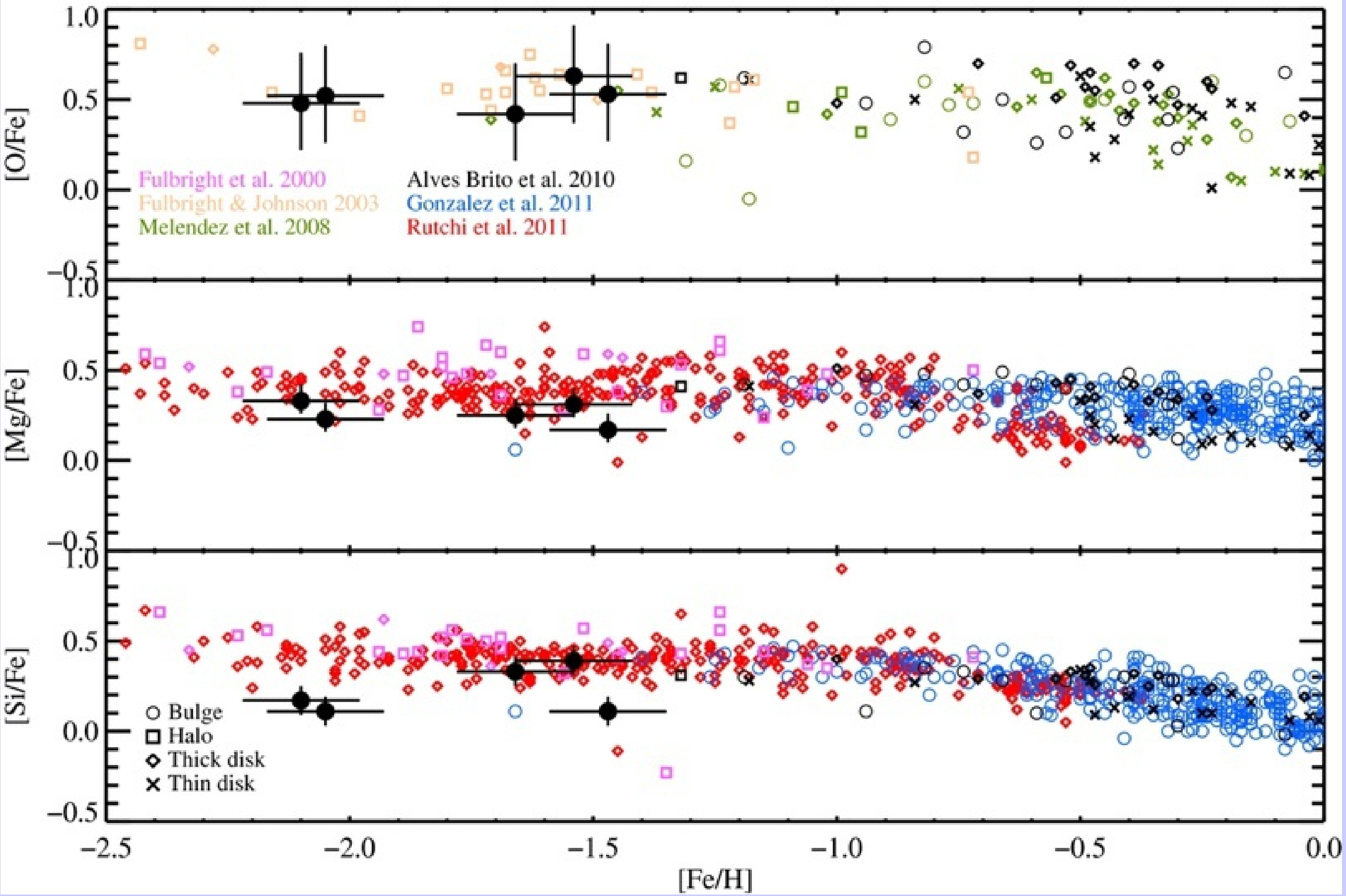
Seem to be a family of stars on leading edge of bar.



If this interpretation is correct, a negative RV counterpart should be found in the IV quadrant

Early Science Highlights

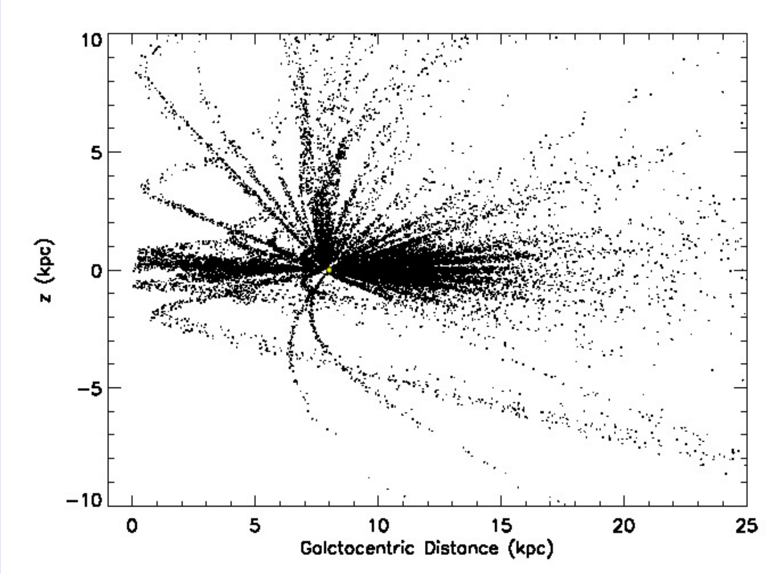
- ***Metal poor tail of the Galactic bulge***

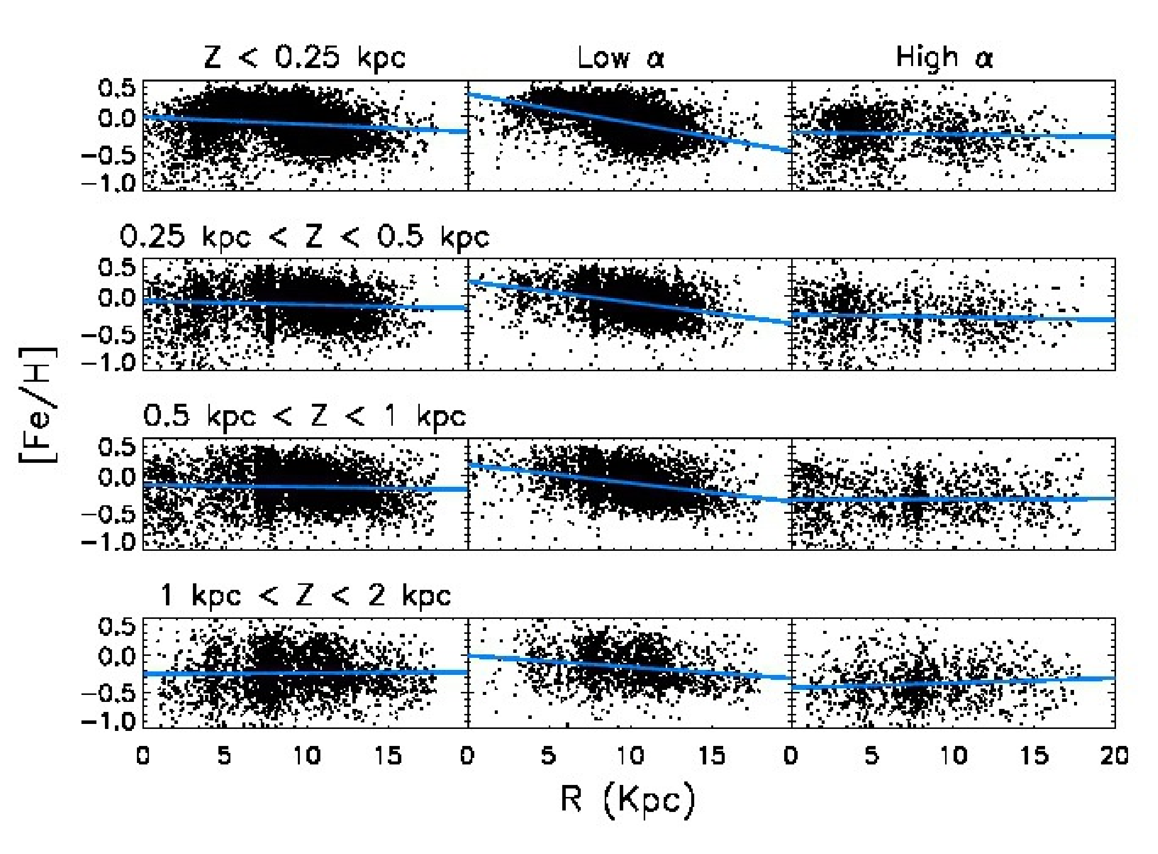


García Pérez et al. (2013)

Early Science Highlights

- *Metallicity gradients in the disk (Holtzman/Hayden et al.)*
- ***Distances from ASPCAP + RJCE dereddenings.***

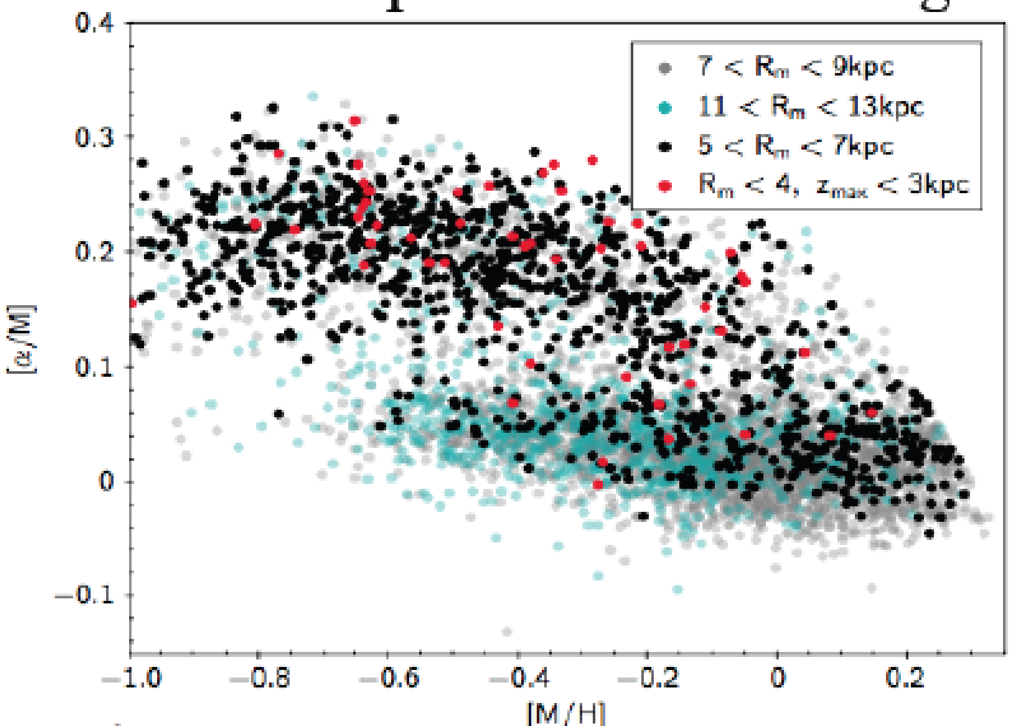


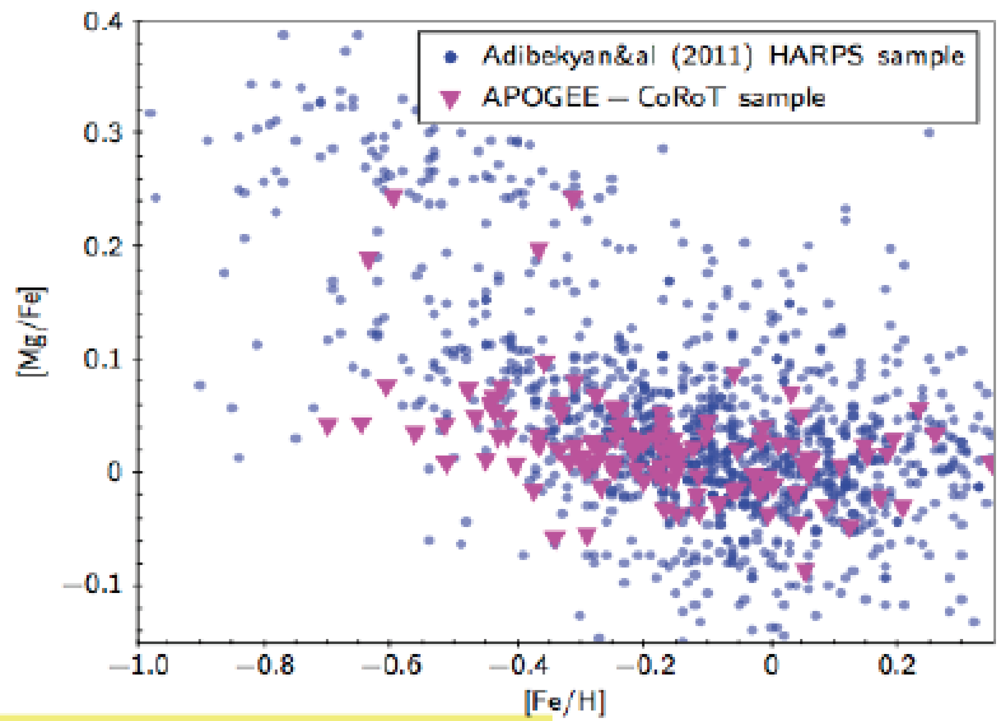


Chemodynamical models

Preliminary results (Chiappini, Anders, Santiago, Girardi et al. = BPG):

- APOGEE data show a clear gap in [α/Fe], as seen in other high res samples.
- CoRoT Ira01 field: as expected, mostly thin disk and just few percent thick disk.
- [α/Fe] > 0.1 stars seen in all mean radius bins (even outer disk).
- Local sample (7 < Rm < 9 kpc) extends to low metallicity.
- Outer sample contributes to extend low metallicity end of thin disk (as shown by Haywood), but other mean radius bins contribute as well.
- Favorable comparison to HARPS high res, high S/N sample.

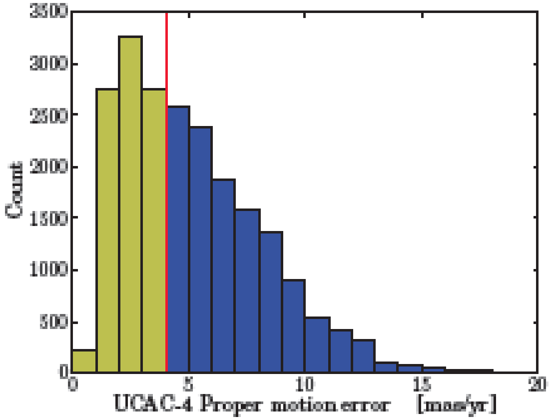


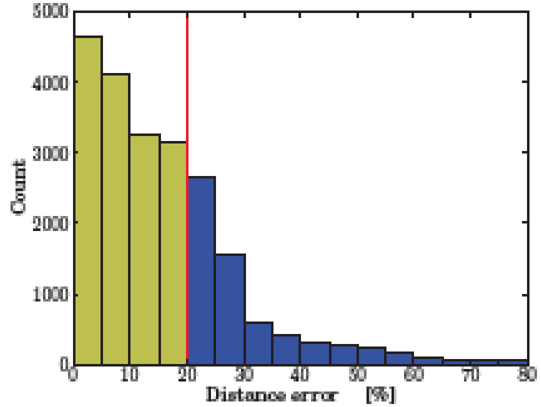


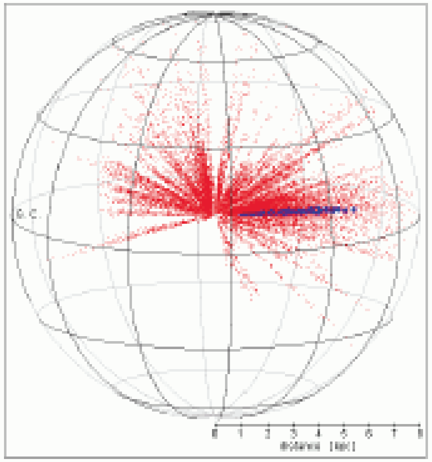
Chemodynamical models

Preliminary results (Chiappini, Anders, Santiago, Girardi et al. = BPG):
- ASPCAP + RVs + UCAC4 proper motion data to calculate orbital information.

Pruning to best proper motions and distance estimates.



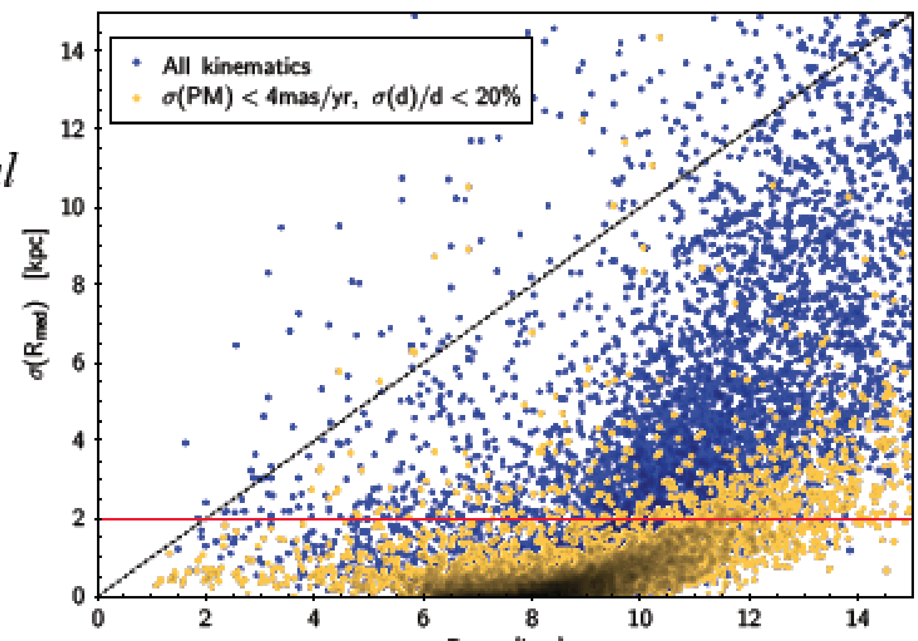


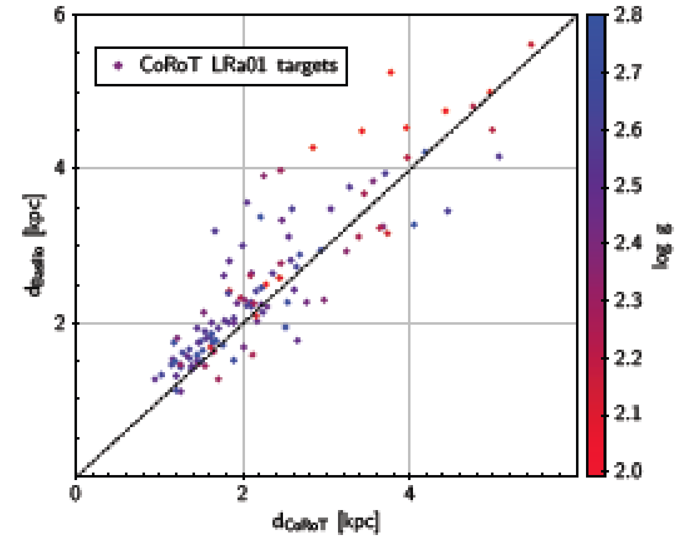


3D spatial distribution.

Blue is CoRoT Ira01 field stars with ASPCAP data.

Errors in one of the derived orbital parameters: mean radial distance, Rm.

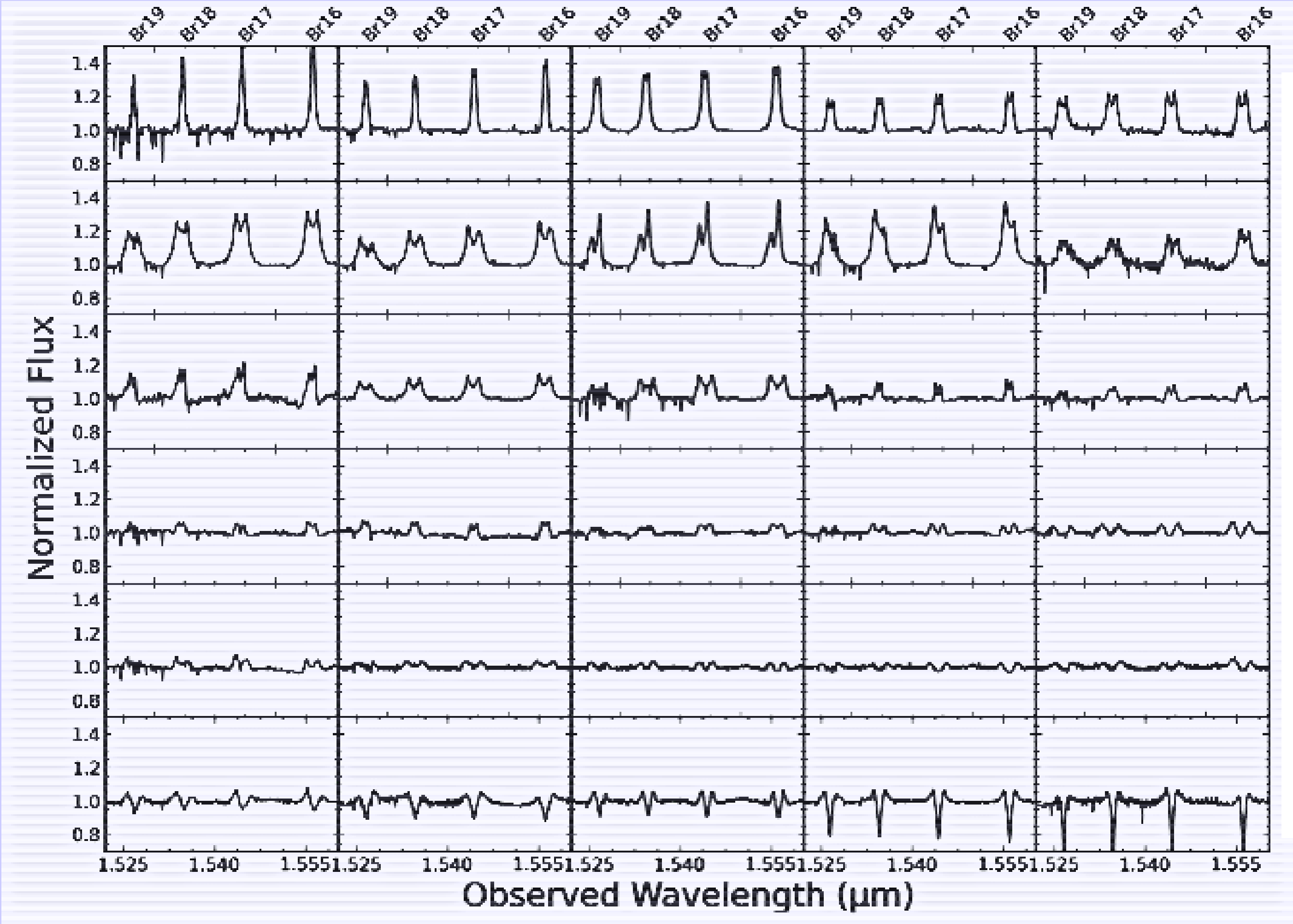


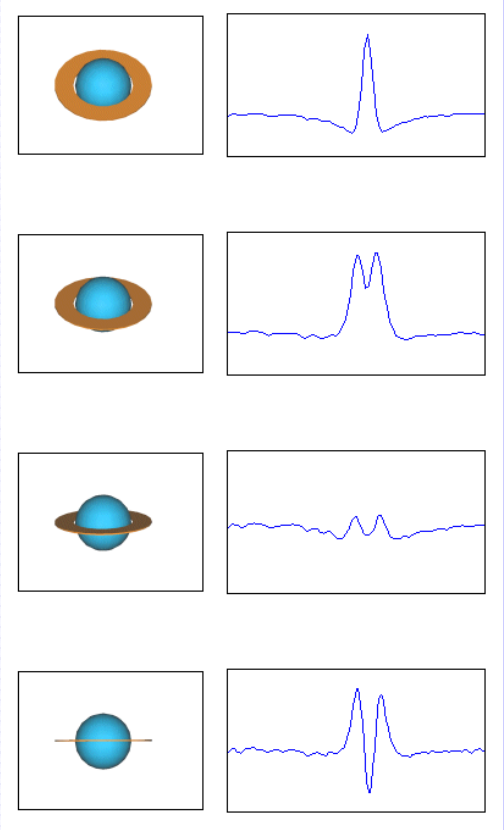


Comparison of CoRoT distances to ASPCAP data + asteroseismic log g.

Early Science Highlights

- ***Be stars found among telluric standards (Chojnowski et al.)***

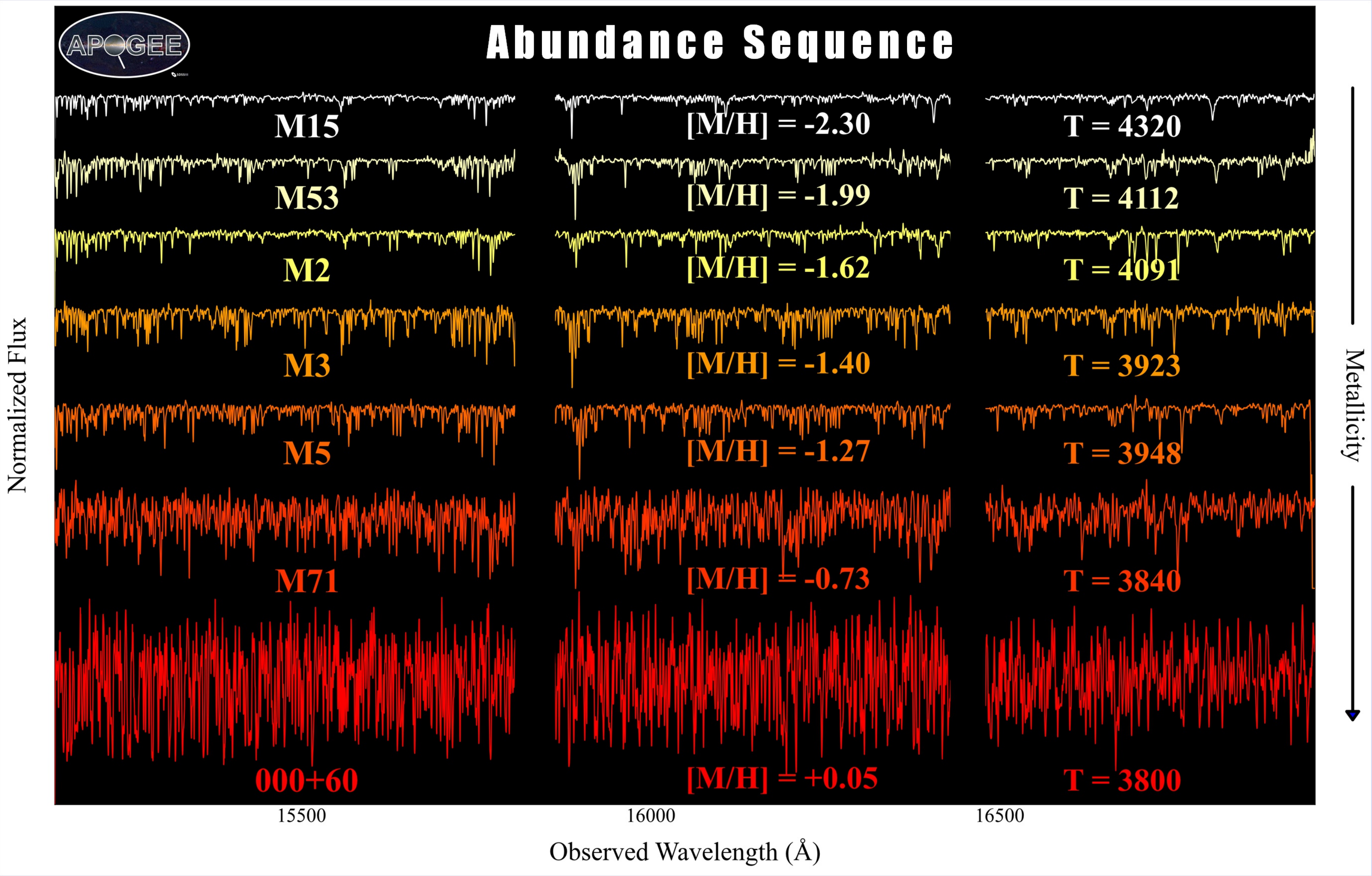




Brackett Line Emission

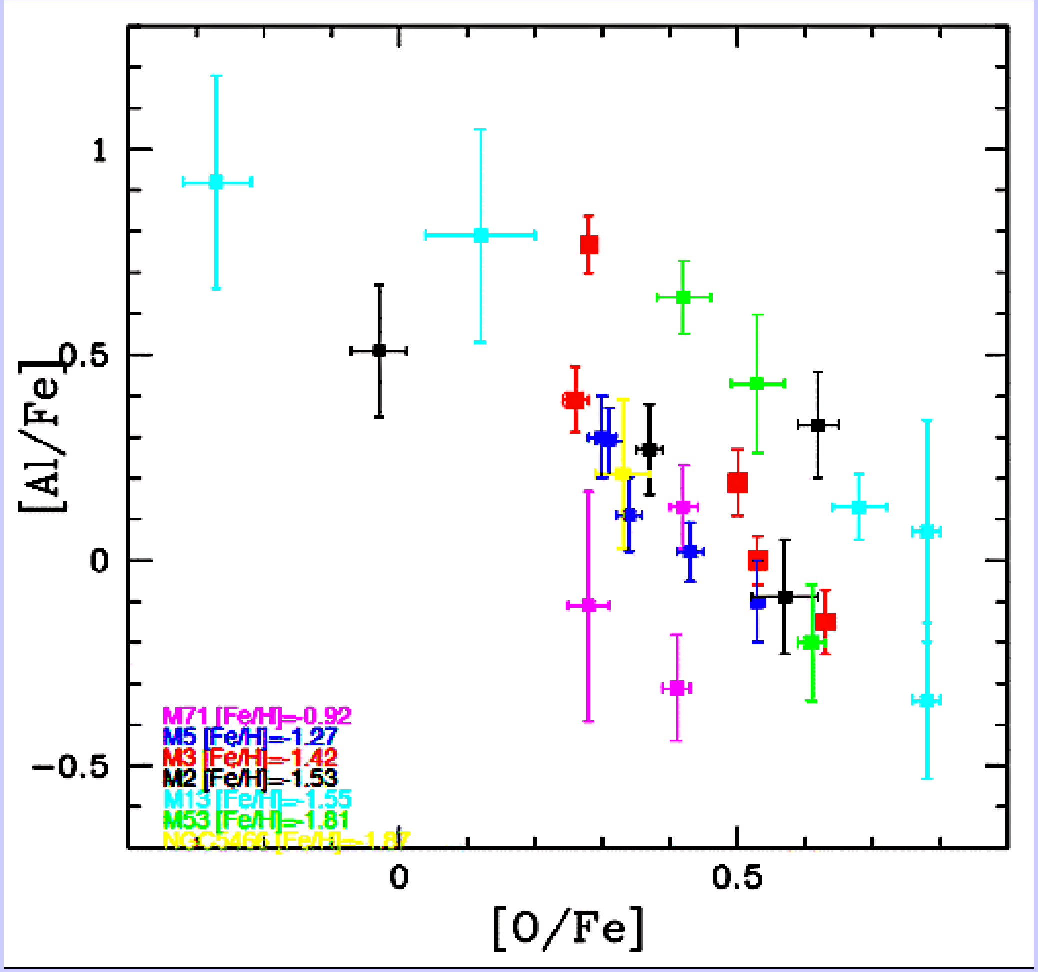
Early Science Highlights

- *Globular cluster stars are both science and calibration targets.*

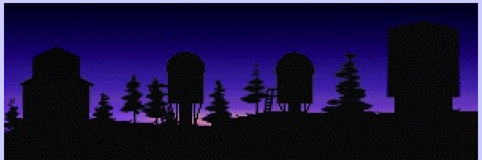


Early Science Highlights

- *Globular cluster chemistry (Shetrone, Smith et al.)*

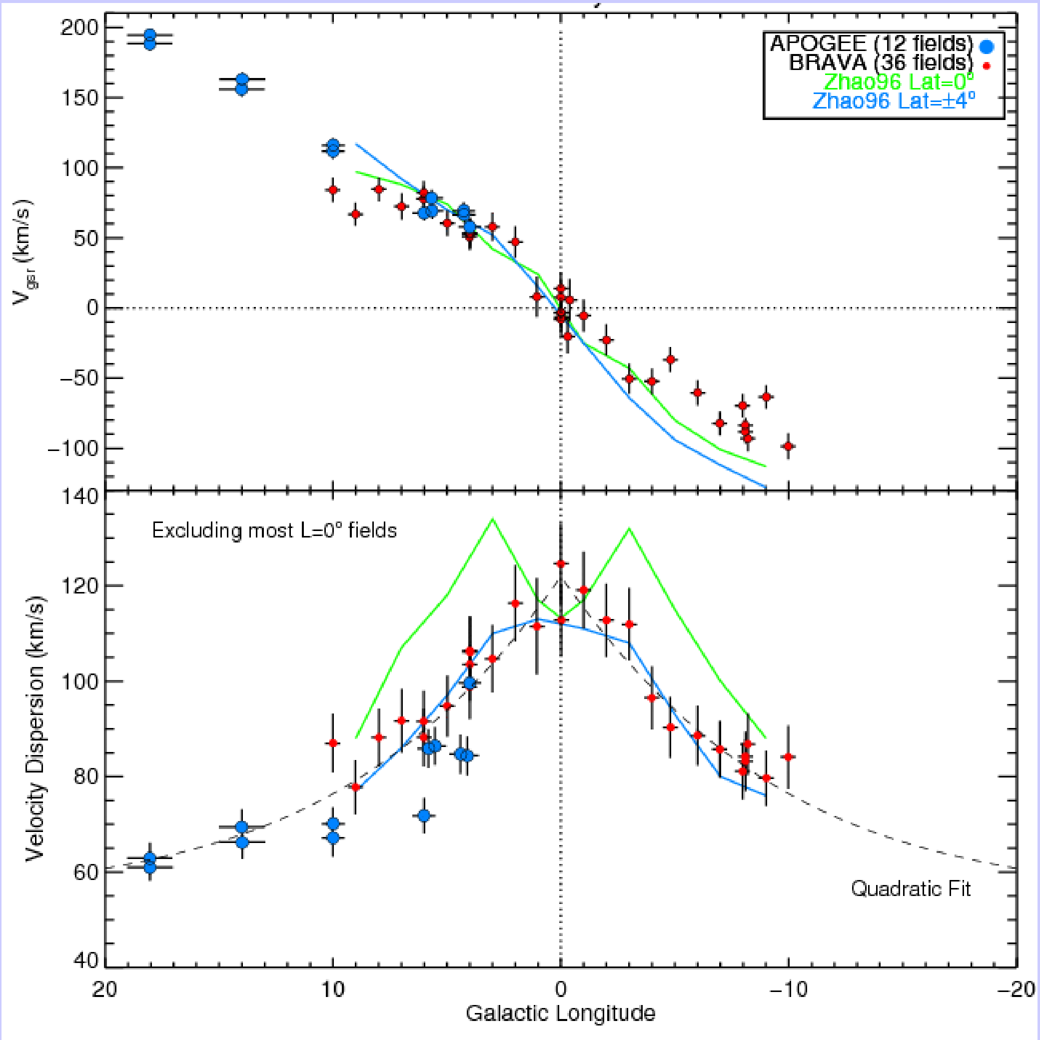


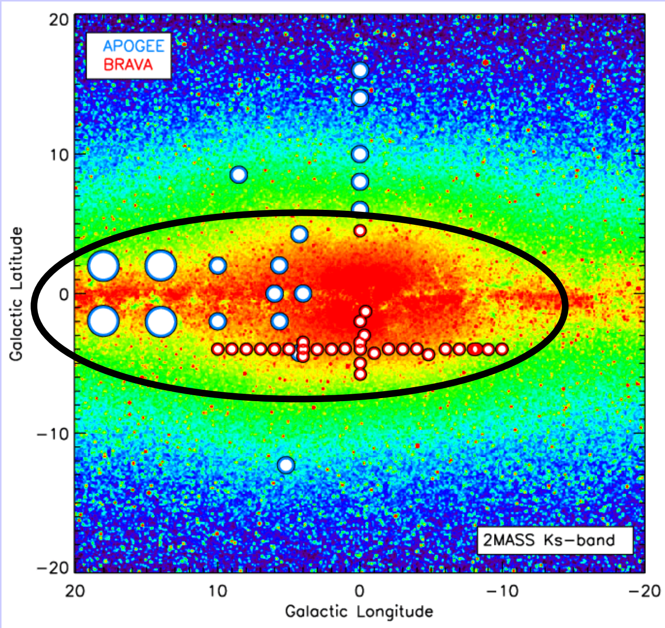
- Al-O anticorrelation (from manual reduction of selected stars).
- Many more globular/open clusters and stars/cluster available.



Rotation Curve and Velocity Dispersion

Major Axis





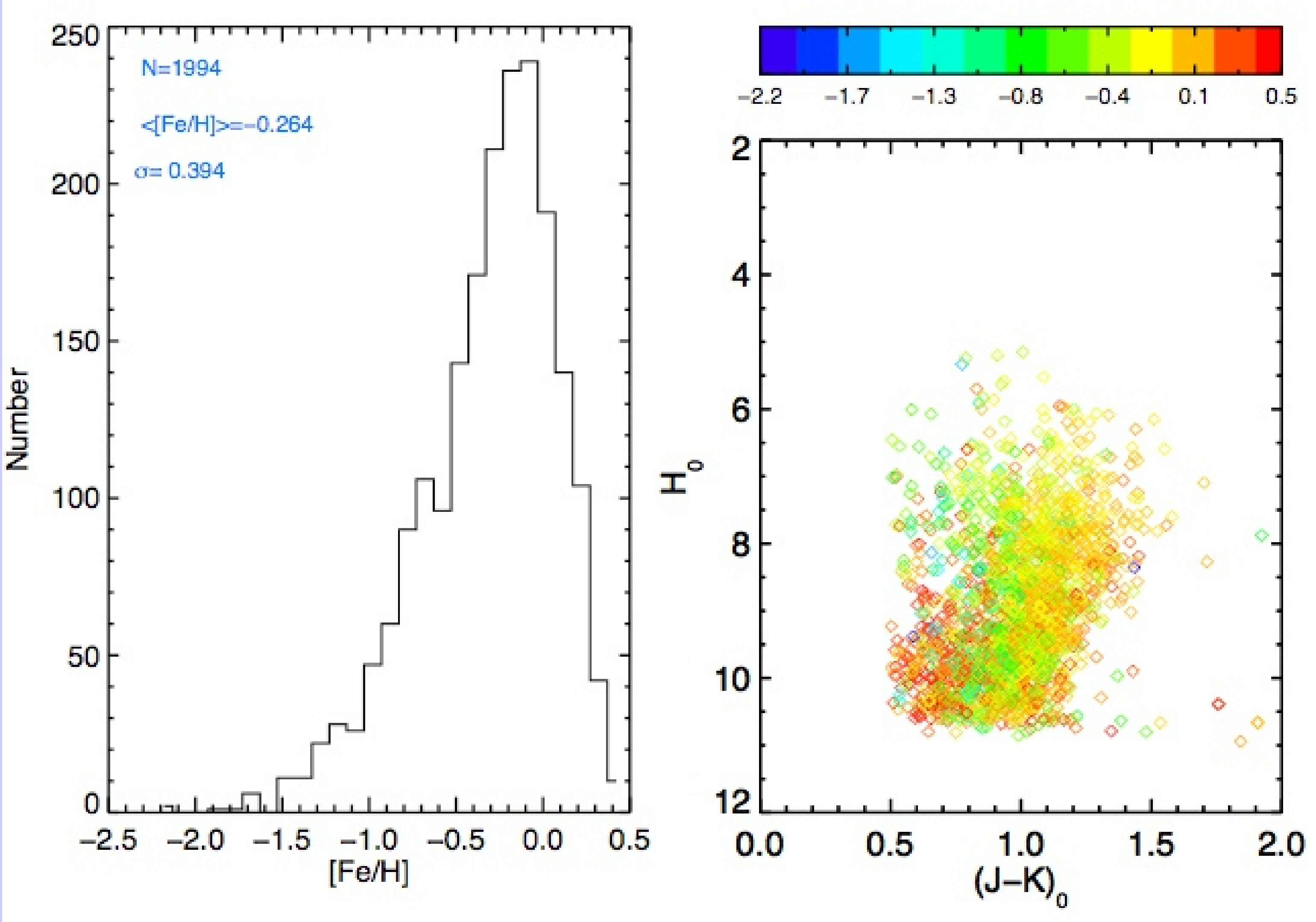
- Rotation curve and dispersion prof le *mostly* consistent with BRAVA data and Zhao model.
- Some possible disk contamination in the midplane.

Bulge Metallicity Distribution

Global metallicity distribution and CMD of the bulge from APOGEE data.

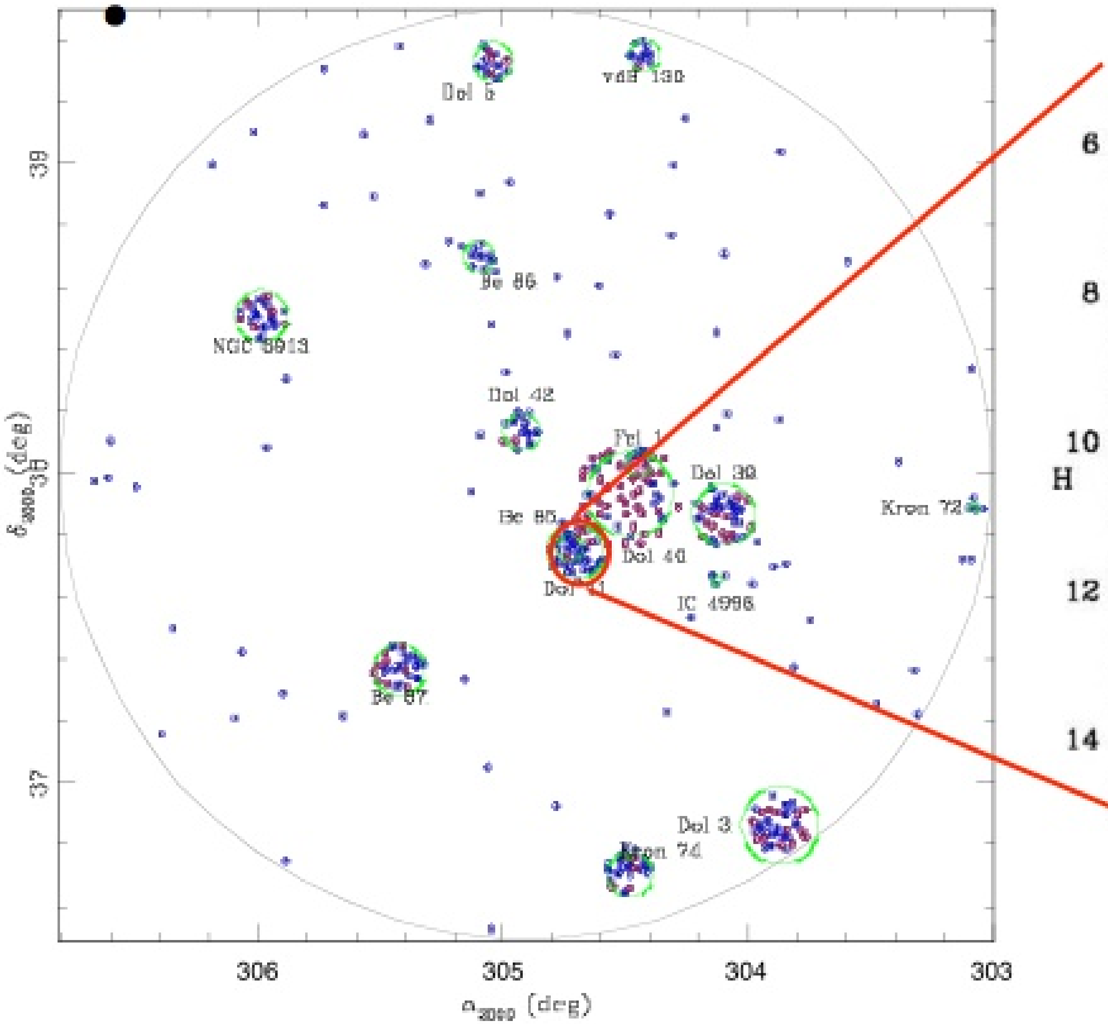
(Ana Garcia-Perez et al.)

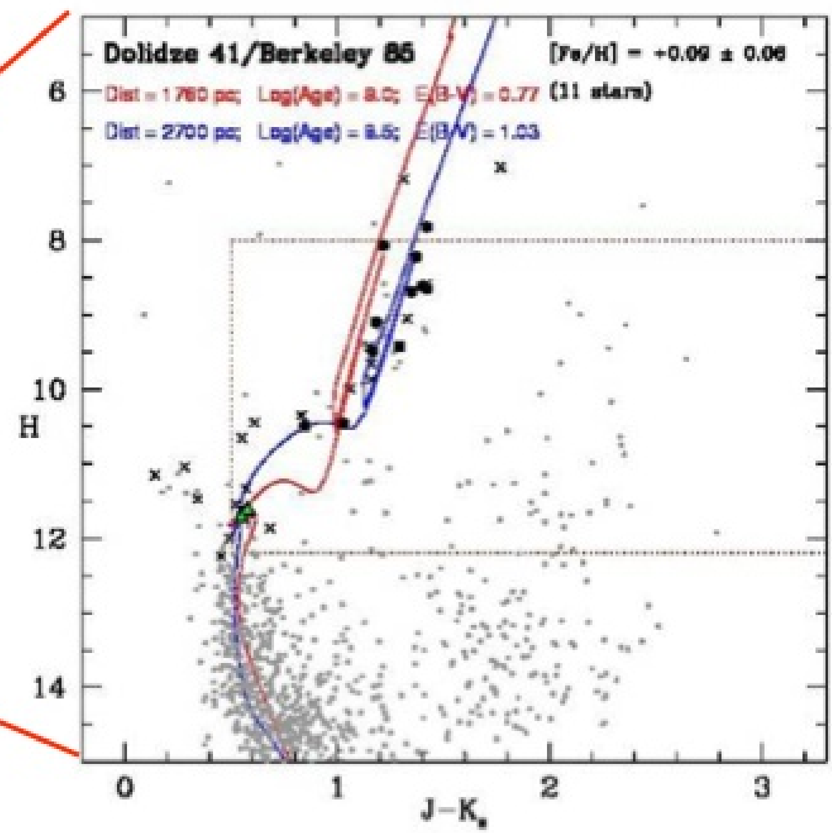
[Fe/H] color coded

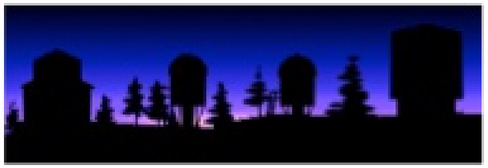


Early Science Highlights

- Improving knowledge about open clusters (*Frinchaboy et al.*)

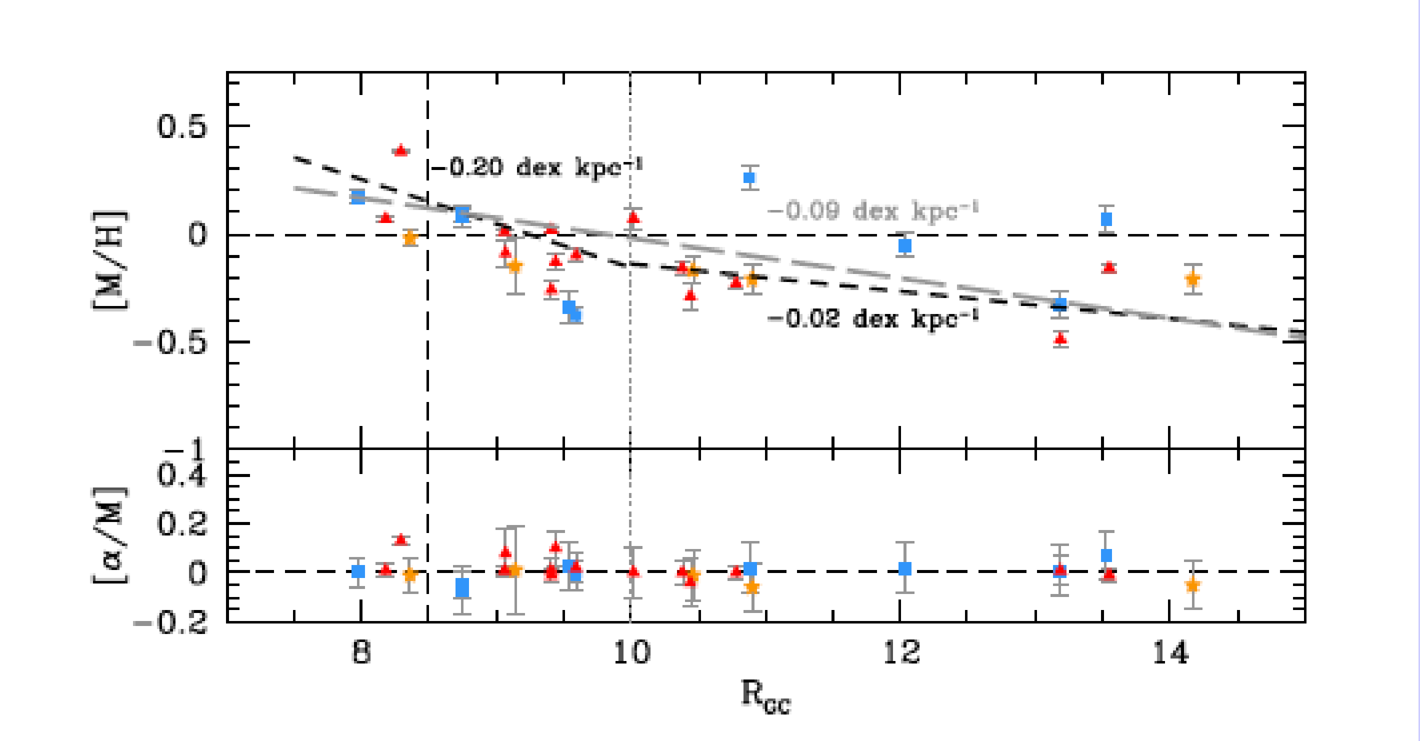






Open Clusters

No gradient in alpha
Metallicity gradient for R < 10 kpc, flat for R > 10 kpc



Frinchaboy et al. (2013)

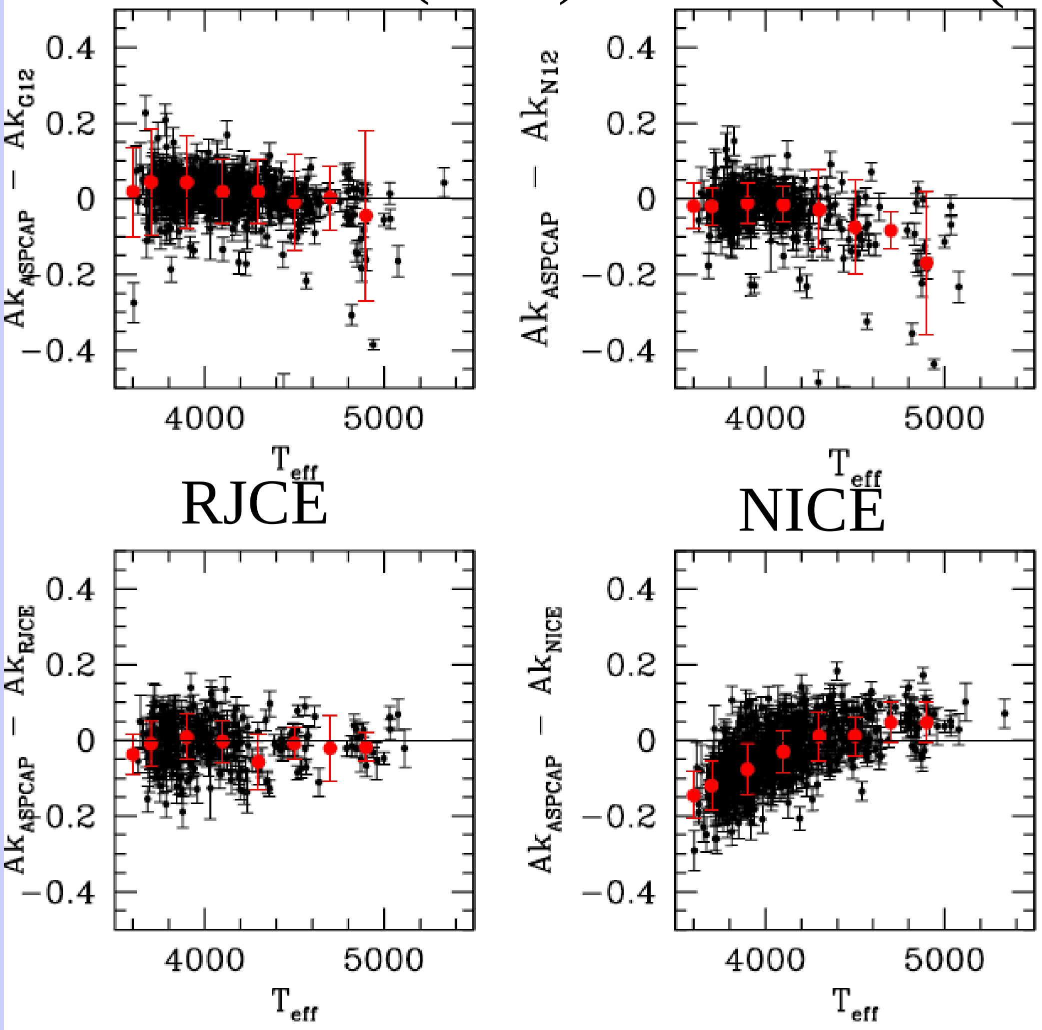
2D-extinction

APOGEE can test 2D extinction models

(Schultheis et al.)

Gonzalez et al. (2012) Nidever et al. (2012)

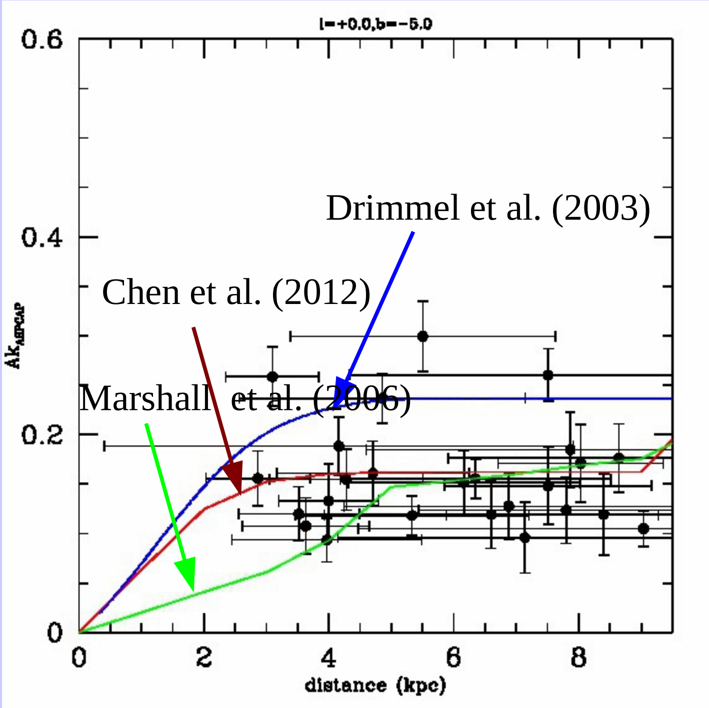
RJCE NICE

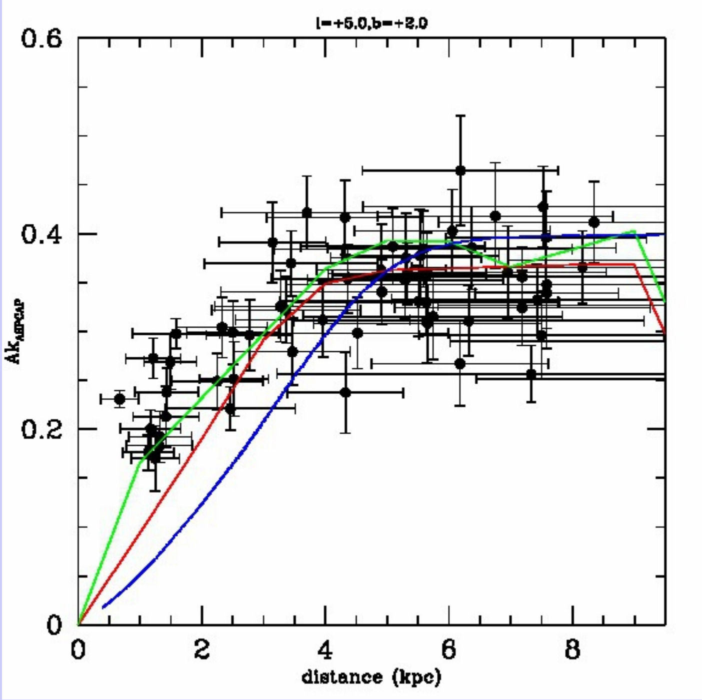


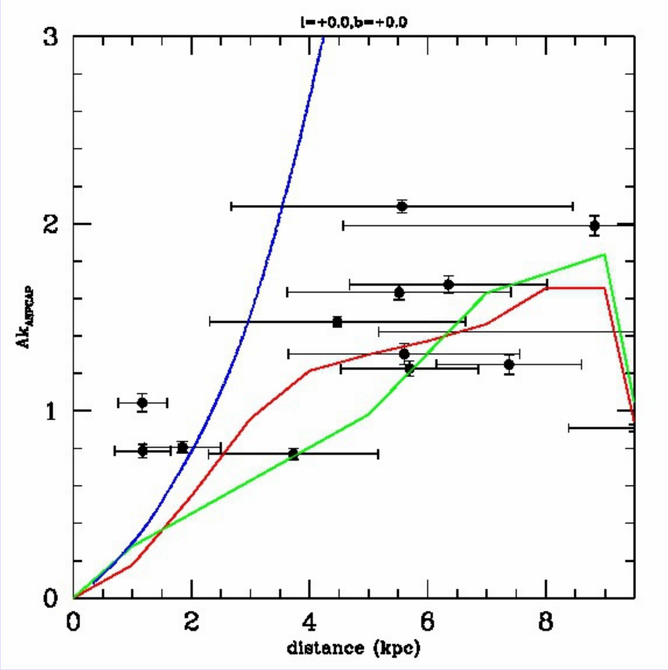
3D-extinction

APOGEE can test 3D extinction models

(Schultheis et al.)

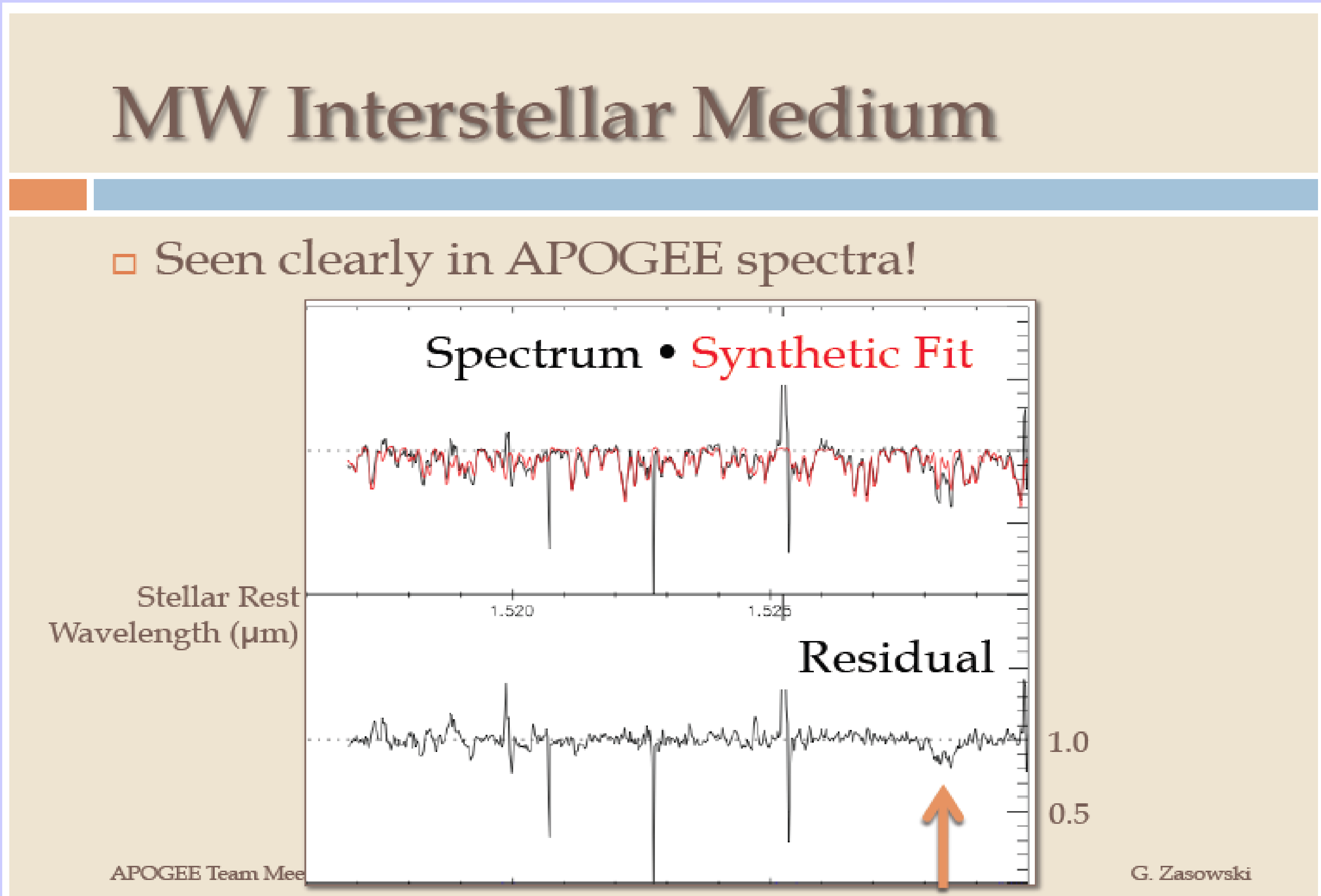






DIBs in APOGEE

Zasowski et al.



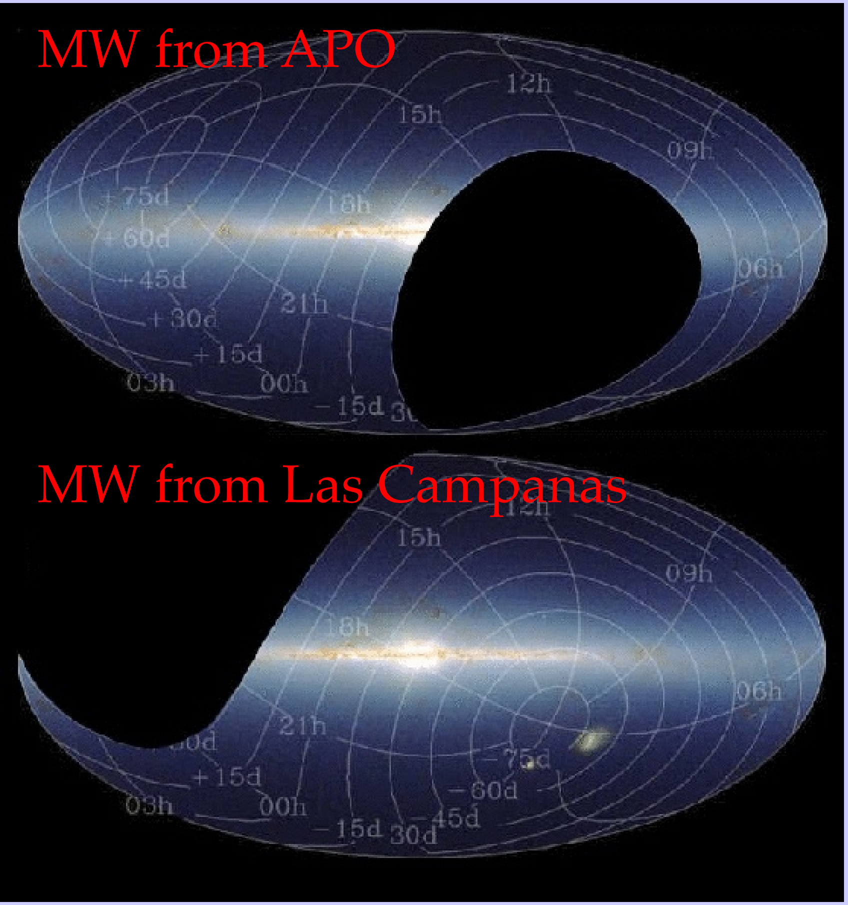
Data Products

- APOGEE data releases will include:
  - Target selection information
    - Sufficient to reconstruct sampling functions
  - Spectra across full APOGEE spectral window (1.51-1.69 μm)
    - Reduced, calibrated 1-D spectra with error, pixel flag
    - *S/N* > 100 per pixel (Nyquist limit)
  - Velocity data (< 150 m/s precision)
    - Radial velocities, *v* sin*i,* variability information (multiple epochs), errors
  - Stellar atmospheric parameters from matches to synthetic libraries
    - Via simultaneous 7-D optimization of T_{eff}, log *g*, [Fe/H], [α/Fe]
    - Uncertainties, covariances
  - Chemical abundances (≤ 0.1 dex internal accuracy)
    - Na, Mg, Al, Si, S, K, Ca, Ti, V, Mn, Co, Ni

- **First public releases in SDSS3's DR10 (July 2013)**

Looking Ahead....

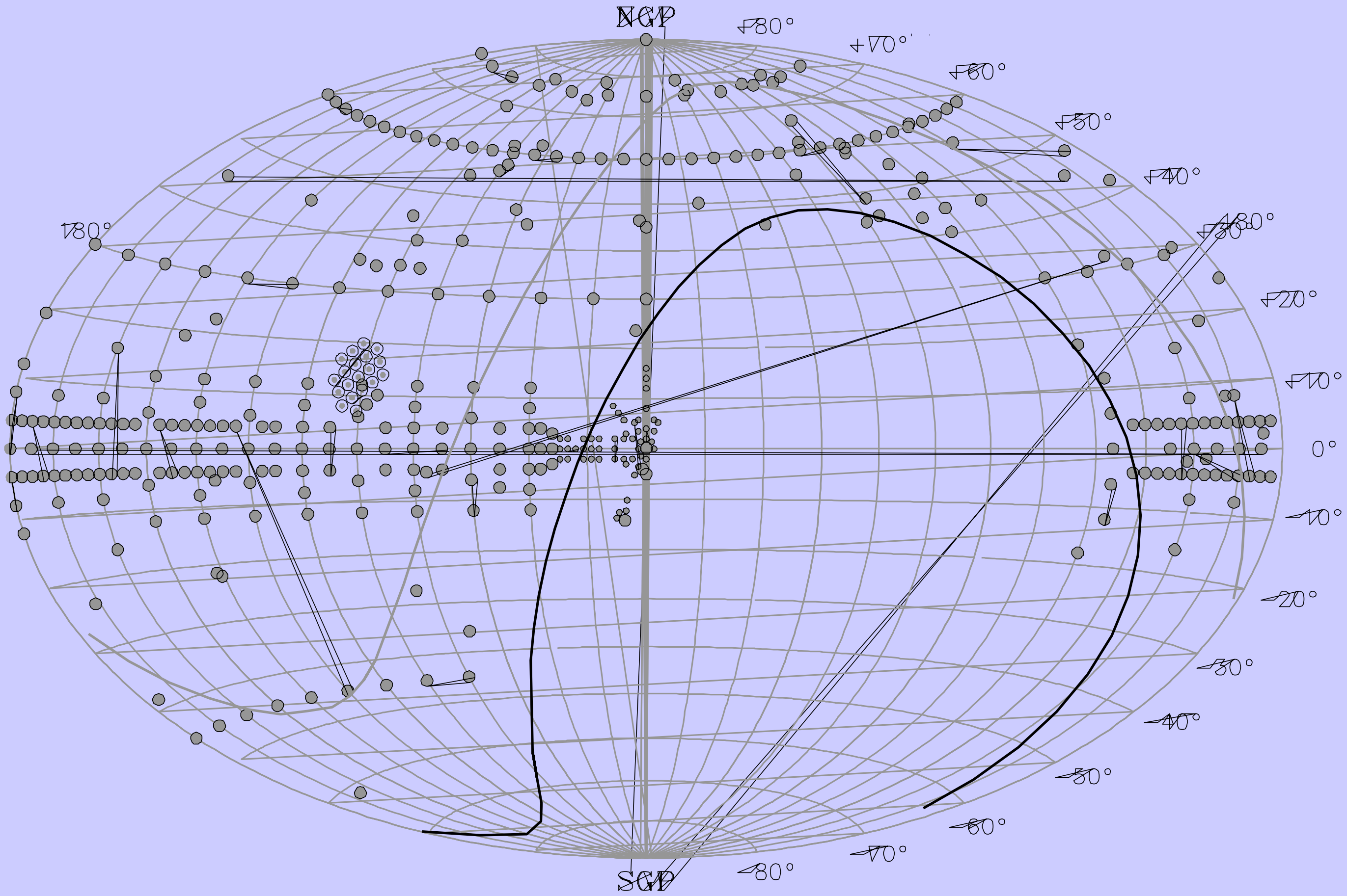
- After Sloan 3 (AS3): APOGEE-II, **APOGEE-II South?**



- Clone spectrograph, use LCO's 2.5-m du Pont telescope
- Sample of 100,000+ bulge/bar stars with 15 RVs and 15 element abundances
- Explore Local Group members: Sgr, Magellanic Clouds, ω Cen
- Clusters with $\delta < 0°$
- Test disk/bulge/bar symmetry
- Overlap with $>10^4$ Small-JASMINE proper motions in bulge, plus other bulge surveys

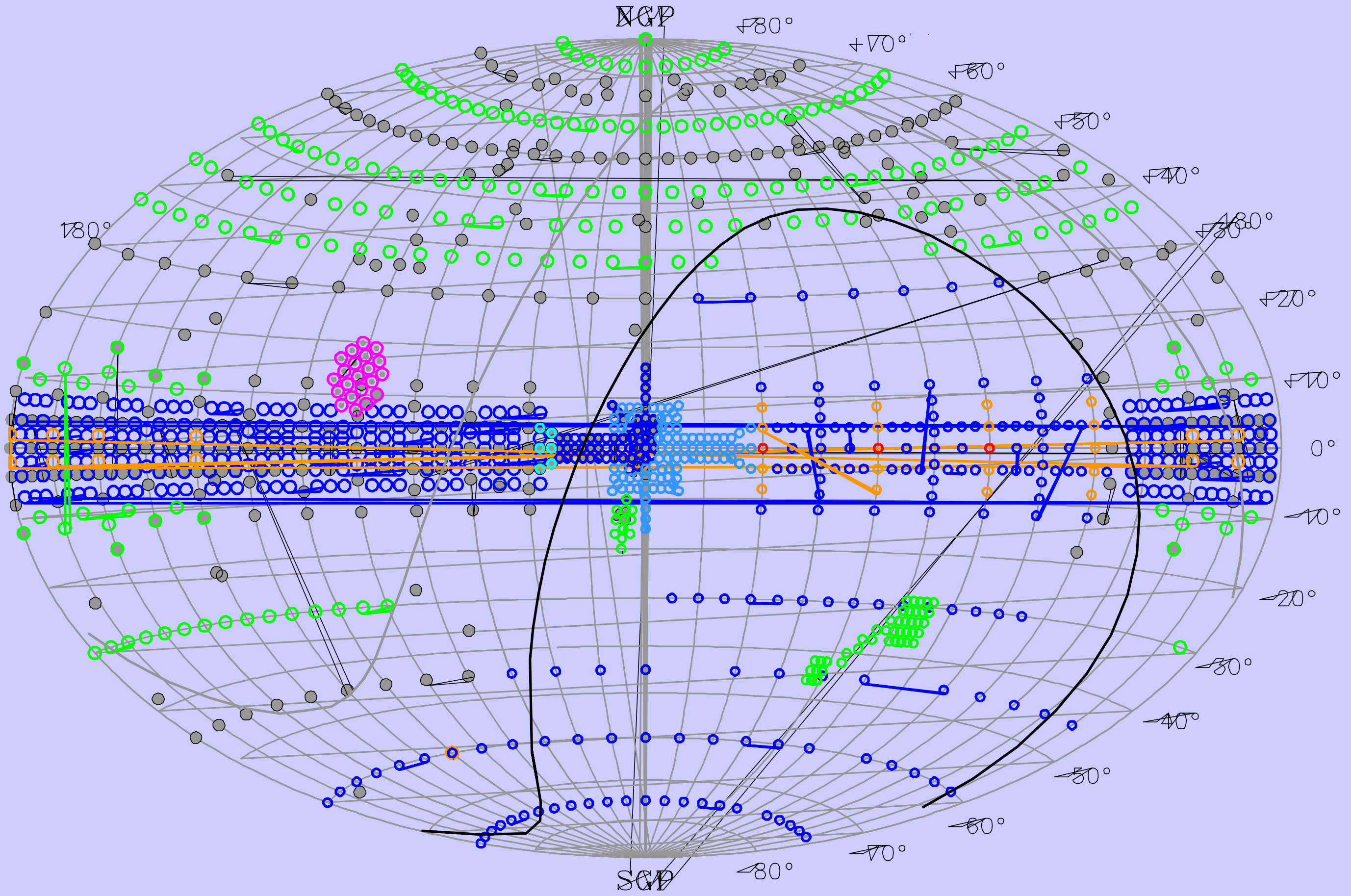
Looking Ahead....

- 100,000 stars in APOGEE by 2014



Looking Ahead....

- Potentially nearing 500,000 stars in APOGEE-II N & S!



THANK YOU

Ongoing Effort

- ***Some half dozen technical papers in progress.***
- ***Several science papers in progress, some published***
- ***DR10: First APOGEE data release (summer 2013).***
- ***All "Year 1" (May 2011-July 2012) data***
- ***Targeting & suppl. data (e.g., photometry, proper motions, cat. source)***
- ***Extracted, calibrated 1-D spectra***
- ***RVs, RV variability, v sin i***
- ***T_{eff}, log g, , [Fe/H], [/Fe], C, N***