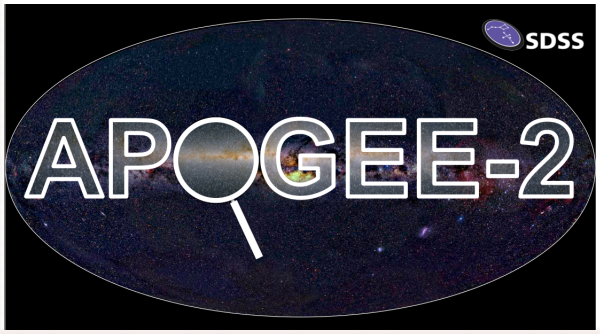
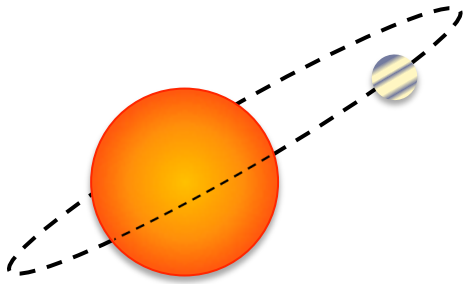
Getting to Know the Substellar Hosts in the APOGEE-2 Survey

Joleen Carlberg

Oct.12, 2017





Outline

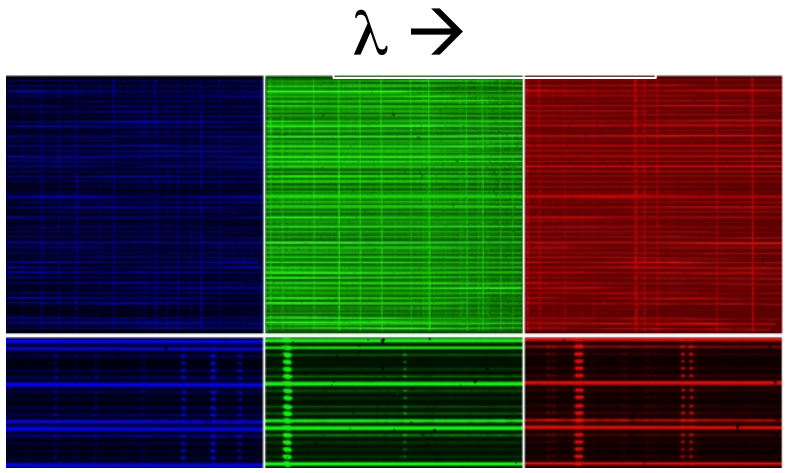
- APOGEE 1 and 2: Galactic surveys moonlighting as RV surveys
- Why APOGEE and why red giants?
- Know thy jitter, find thy planets

Getting to know APOGEE

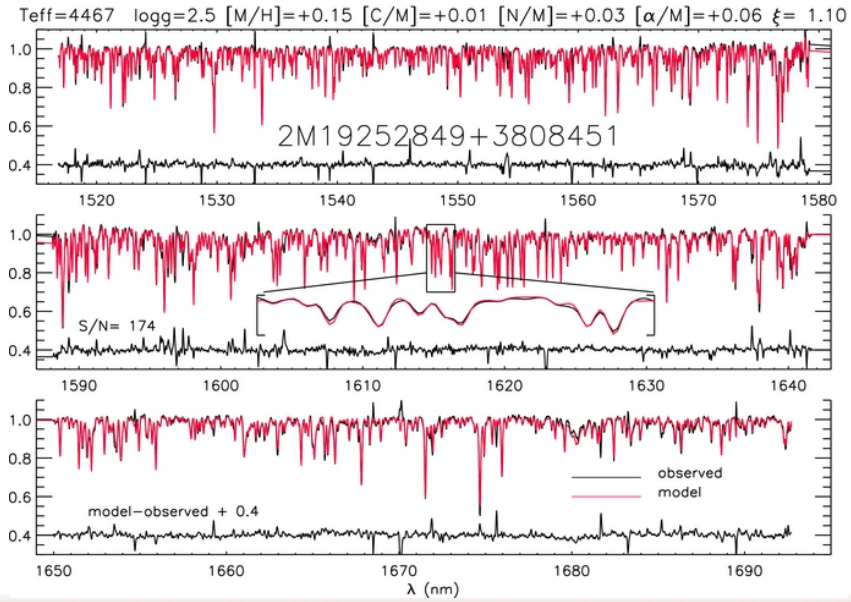
APOGEE = Apache Point Observatory Galactic Evolution Experiment

Key points:

1. Multi-object IR spectrograph (H band)
2. velocity precision: ~100 m/s
3. 3+ epochs, 100,000's red giants
4. APOGEE-1: ended in 2014
5. APOGEE-2: on-going



2-D Spectrogram (Ahn+ 2014)

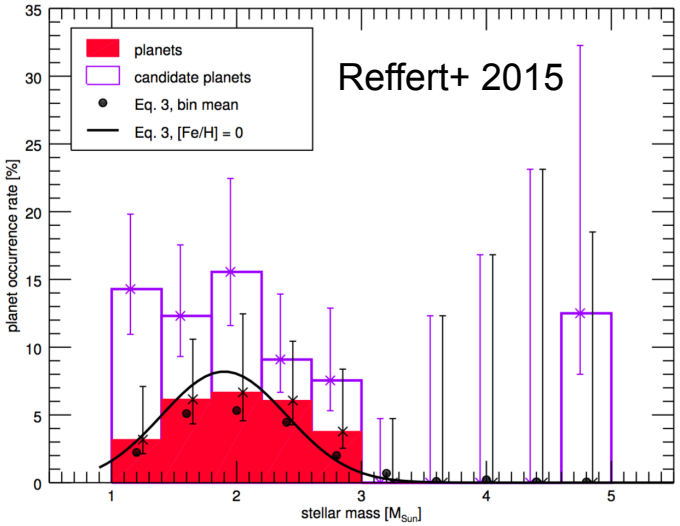


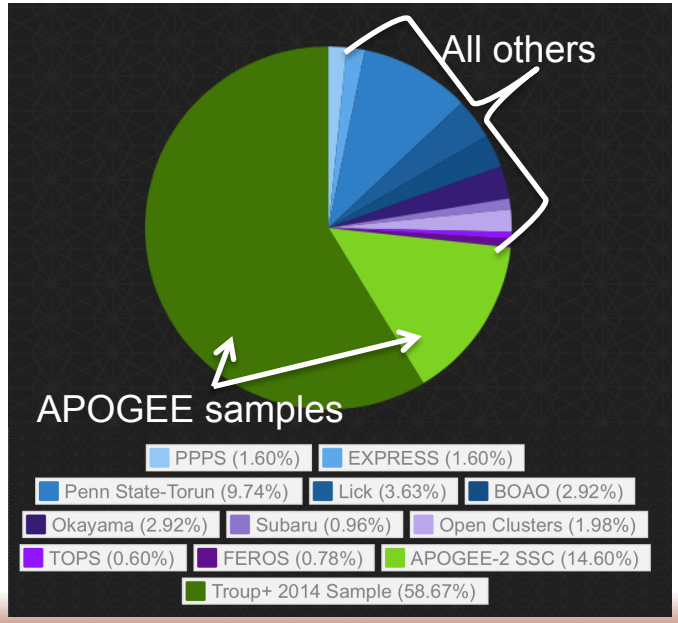
Extracted 1-D Spectrum (Ahn+ 2014)

More details available at sdss.org

Why APOGEE and why RGs?

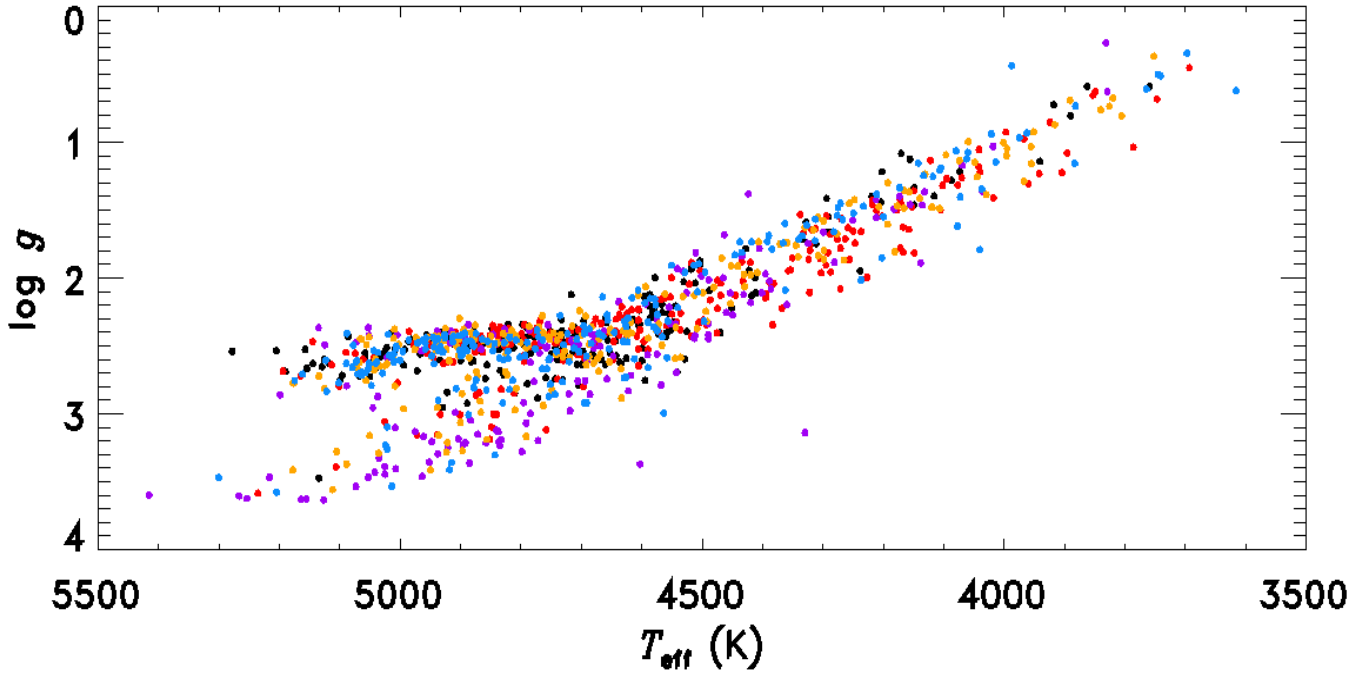
- Red giants often neglected, but:
  - even high mass RGs are slow rotators
  - can explore system evolution
- APOGEE
  - Sample sizes outstrips other red giant companion surveys
  - Control sample (stars with no companions) is simultaneously observed
  - $T_{\rm eff}$, log g, [Fe/H], A(X), homogenously derived and calibrated to clusters, asteroseismic targets





The Substellar Companion Hosts

- APOGEE-2 Substellar Companion (SSC) fields
  - 5 APOGEE-1 fields; 24+ visits by end of APOGEE-2
  - ~1300 red giants



The Substellar Companion Hosts

- APOGEE 1 & 2: stars with ≥8 visits (~6,000 RGs)
  - Define: Σ_{RV} = stddev((**RV**-median(RV))/$\sigma_{\mathbf{RV}}$)

RVs for individual visits

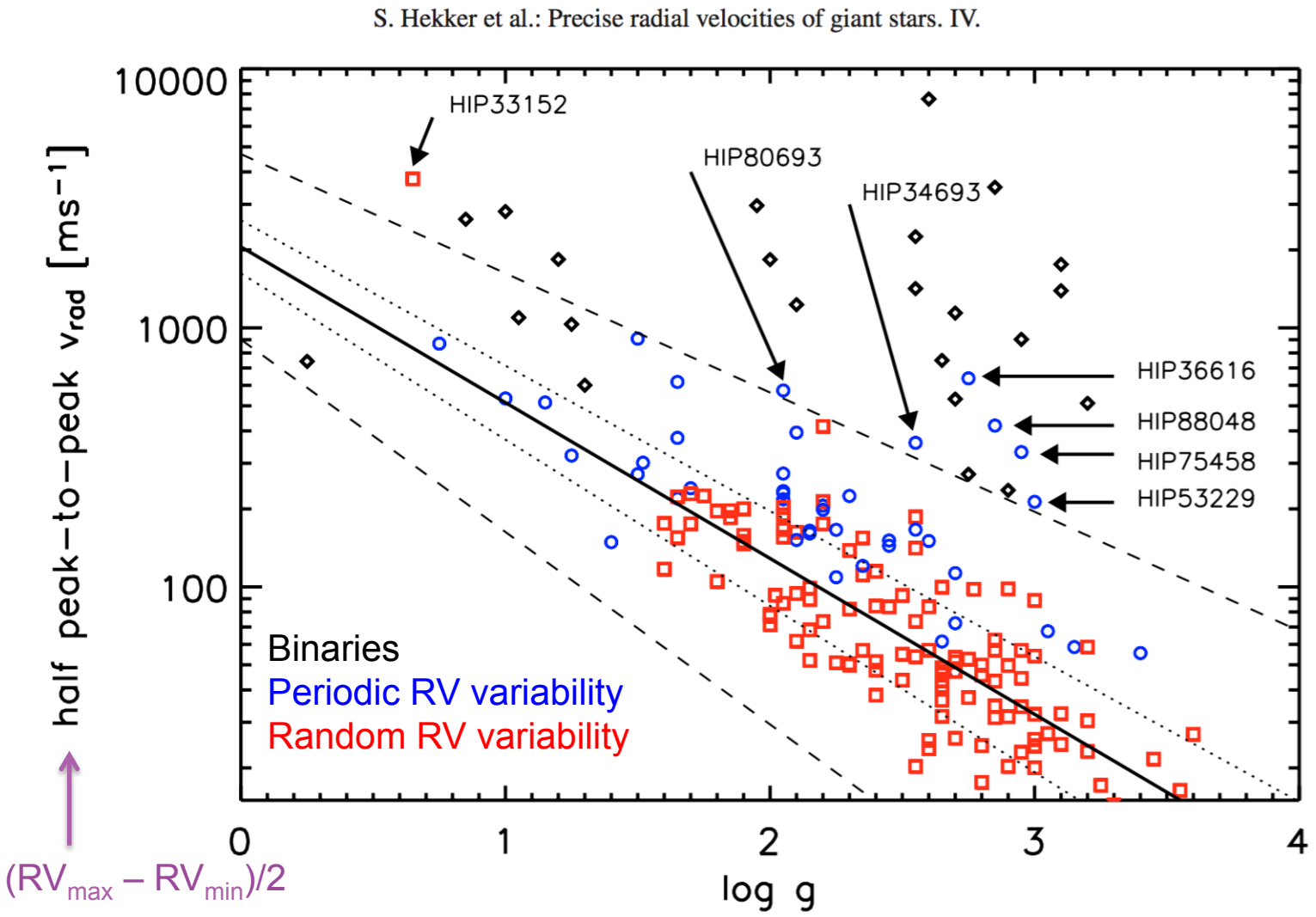
RV uncertainties

  - Low Σ_{RV} (< 2.5): No significant RV variability (4750 RGs)
  - High Σ_{RV} (≥ 2.5): Significant variability (1280 RGs)
    - 270 – no periodicity
    - 340 – periodicity, reliable Keplerian orbits → "Gold Sample" (see Troup+ 2016) → Companion hosts
    - 670 – other periodic variables

Stellar jitter + unidentified companions

(see Troup+ 2016 for analysis on DR12 results)

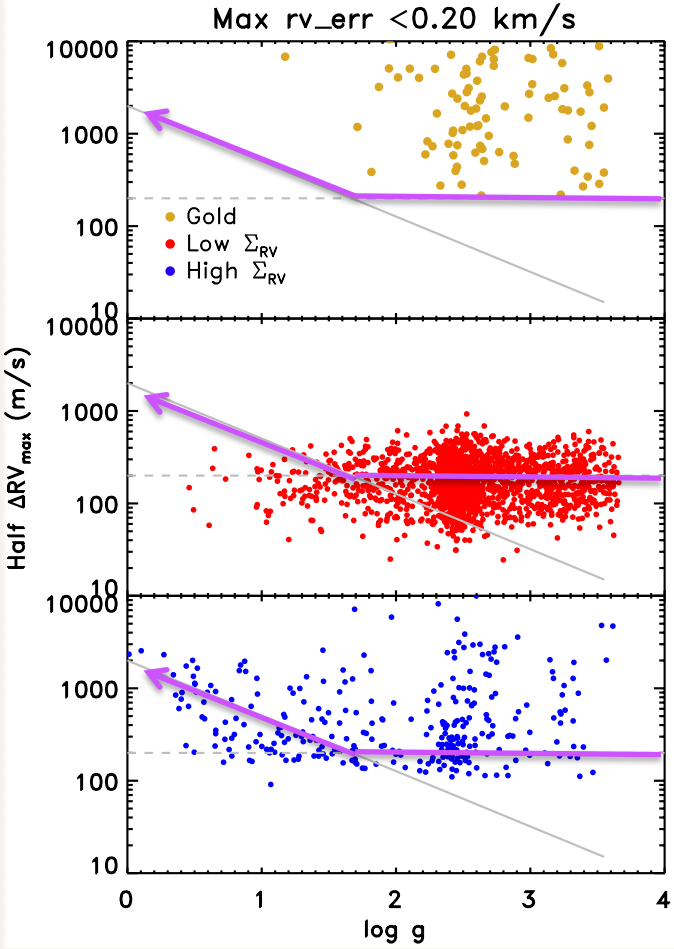
Stellar Jitter (optical, RGs)



Stellar Jitter in APOGEE RG's

Hekker+ 2008 "half peak-to-peak vs log g" stellar jitter relationship

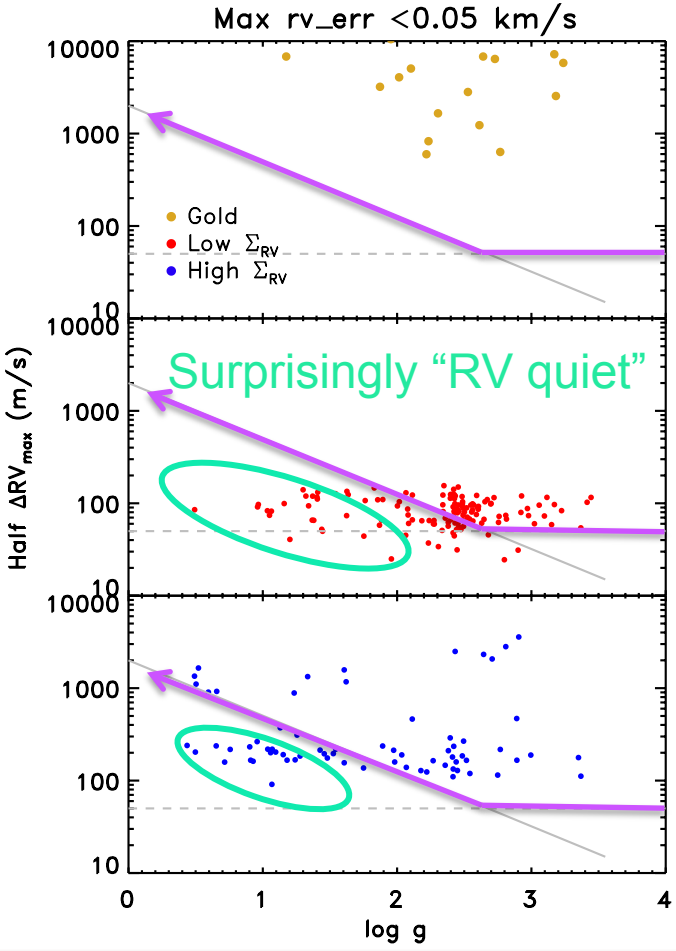
Expected lower bound RV variability



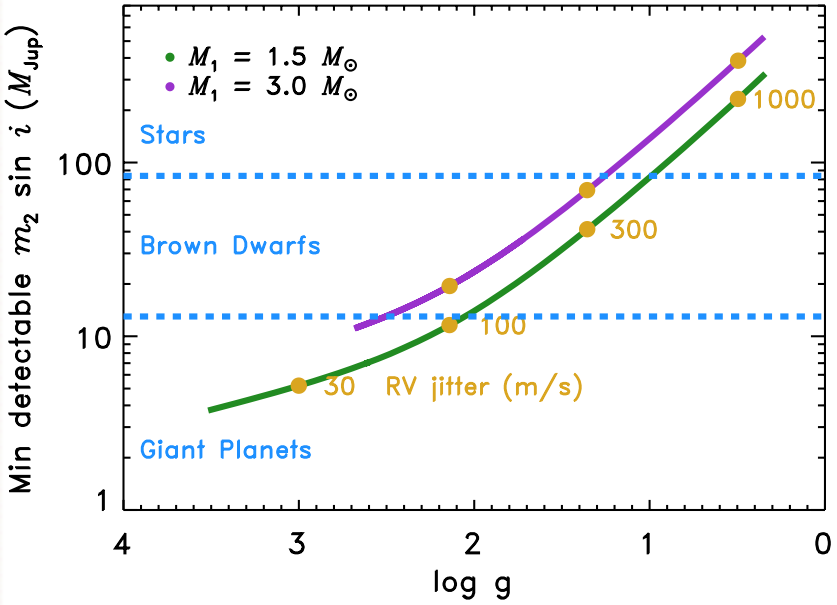
"Gold sample" (Troup+ 2016): likely has companions

Low Σ_{RV}: variability may largely be instrumental

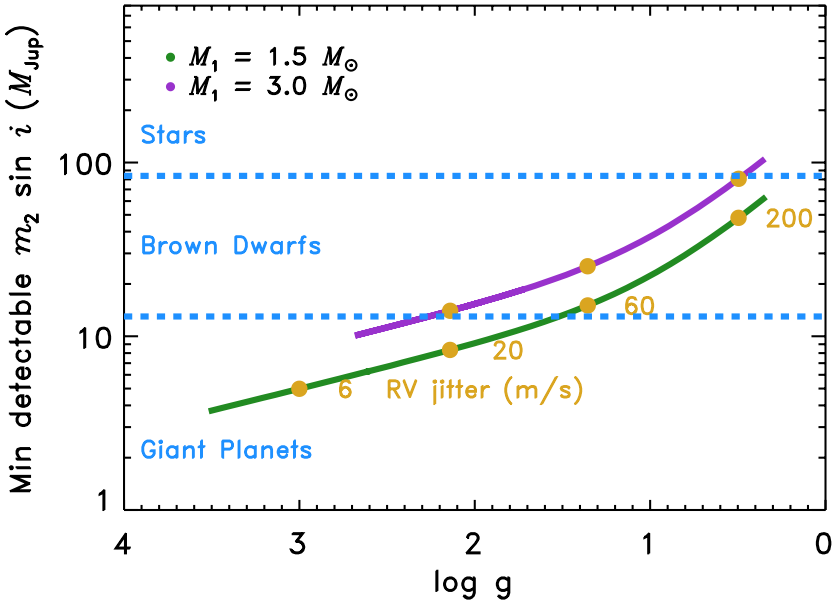
High Σ_{RV}: variability above instrumental



How does this affect detectability?



100 m/s instrumental precision + Hekker+ 2008 stellar jitter



100 m/s instrumental precision + reduced stellar jitter (factor of 5)

Summary

- APOGEE-2 has 5 dedicated fields to search for SSCs
- Additional “many epoch” targets in APOGEE 1 & 2 afford opportunity to
  - study the intrinsic infrared RV variability of red giants
  - discover and characterize more companions
- Leveraging the full weight of the APOGEE survey (huge numbers of well-characterized red giants) provides robust measurements of $T_{\rm eff}$, log g, evolutionary stage, mass, [Fe/H], etc.

The SSC team

Nathan De Lee
Northern Kentucky Univ.

Steve Majewski
University of Virginia

Nick Troup
Salisbury University

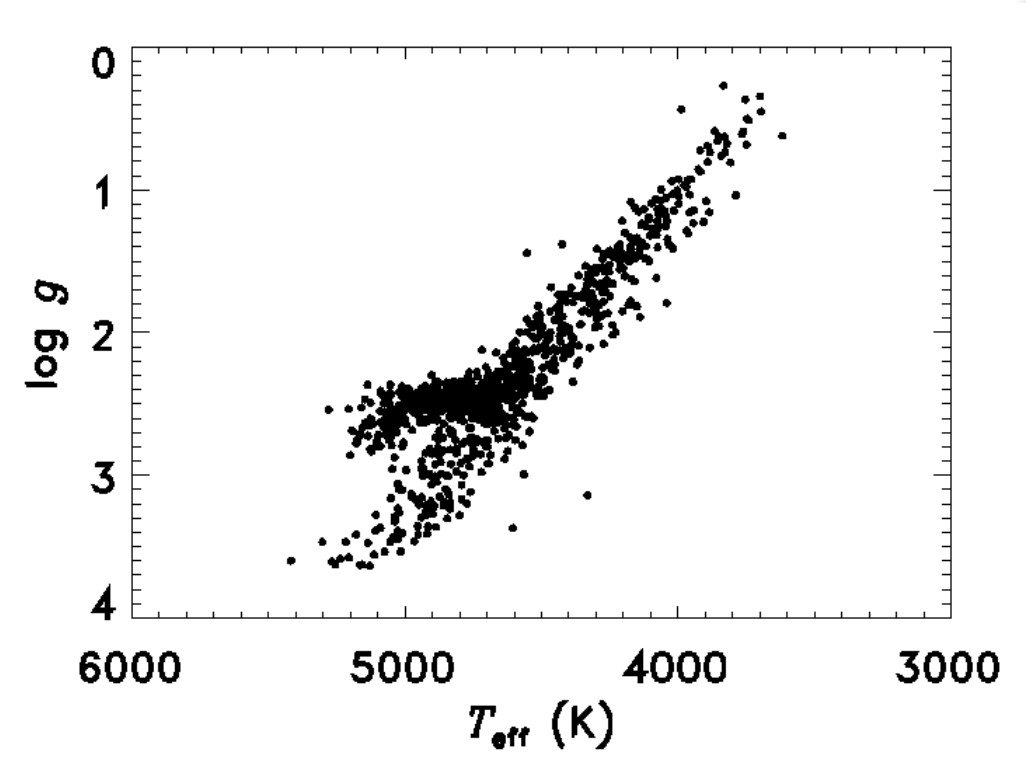
David Nidever
Montana State University

Joleen Carlberg
STScI

+ many, many more on the APOGEE 1 & 2 teams…

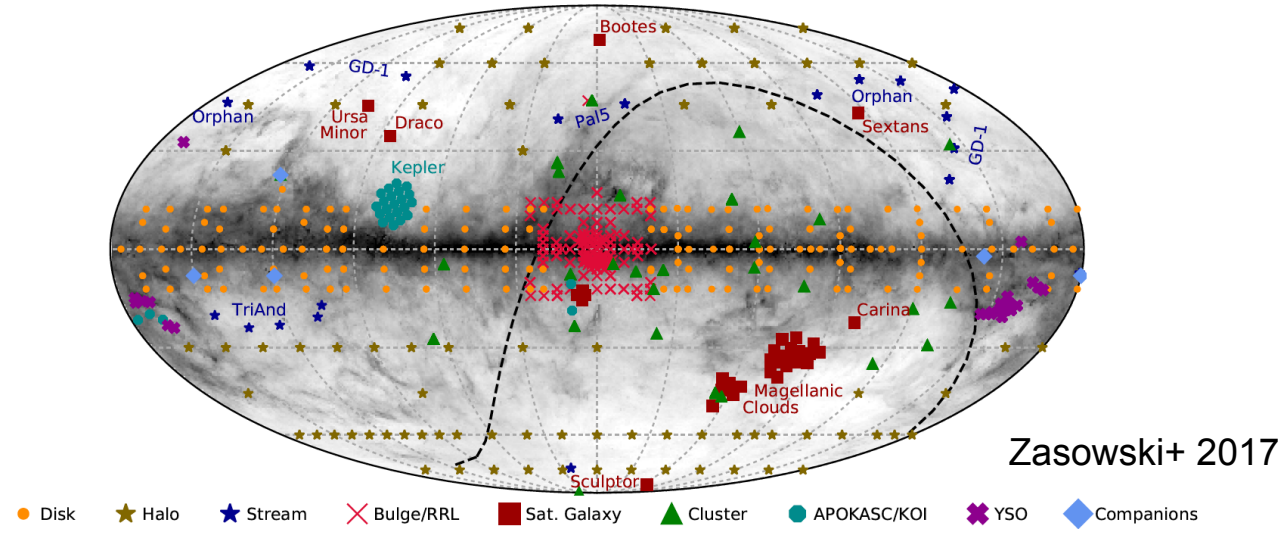
SSC Field Progress

- Field: #new / # requested
  - COROTA2-RV: 14/24
  - N188-RV: 7/11 (+ 5)
  - 120-08-RV: 5/22
  - 150-08-RV: 8/22
  - 180-08-RV: 7/21



The Substellar Companion Hosts

- APOGEE-2 Substellar Companion (SSC) fields
  - 5 APOGEE-1 fields; attain 24 visits by the end of APOGEE-2



Zasowski+ 2017

- APOGEE 8+ visits targets & the “Gold Sample” (Troup+ 2016)

Getting to know APOGEE

APOGEE = Apache Point Observatory Galactic Evolution Experiment

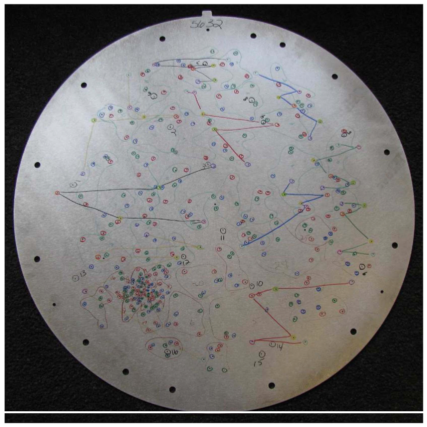
APOGEE-1 at a Glance:

- ☆ Bright time observations
- ☆ Spring 2011 – Spring 2014
- ☆ 150,000 giant and dwarf stars in the Galactic bulge, disk, and halo
- ☆ Resolution R~22,500, typical S/N > 100
- ☆ Wavelengths 1.51-1.70 μm
- ☆ Stellar parameters including log(g), T_{eff}, [Fe/H], [α/Fe]
- ☆ Abundance of 15 chemical species to 0.1 dex precision
- ☆ Velocity uncertainties < 100 m/s

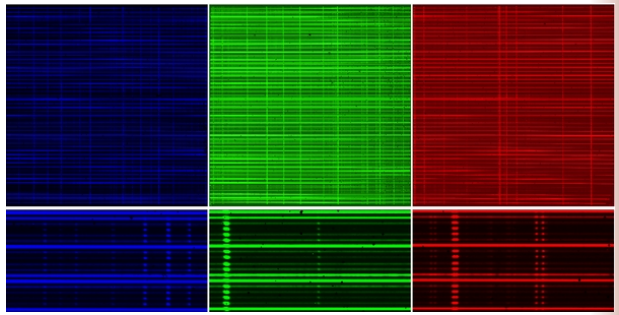
APOGEE-2 Technical Details

- ☆ Bright-time observations at APO and LCO
- ☆ Duration: Fall 2014 – Fall 2020
- ☆ Fiber Complement: 300 fibers per 7 deg^2 plate (APO) or 3.5 deg^2 plate (LCO)

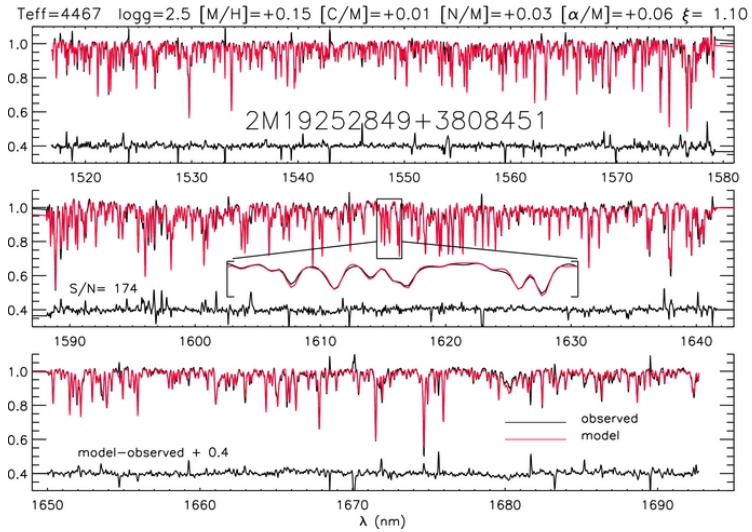
www.sdss.org



APOGEE plug plate (Majewski+ 2017)

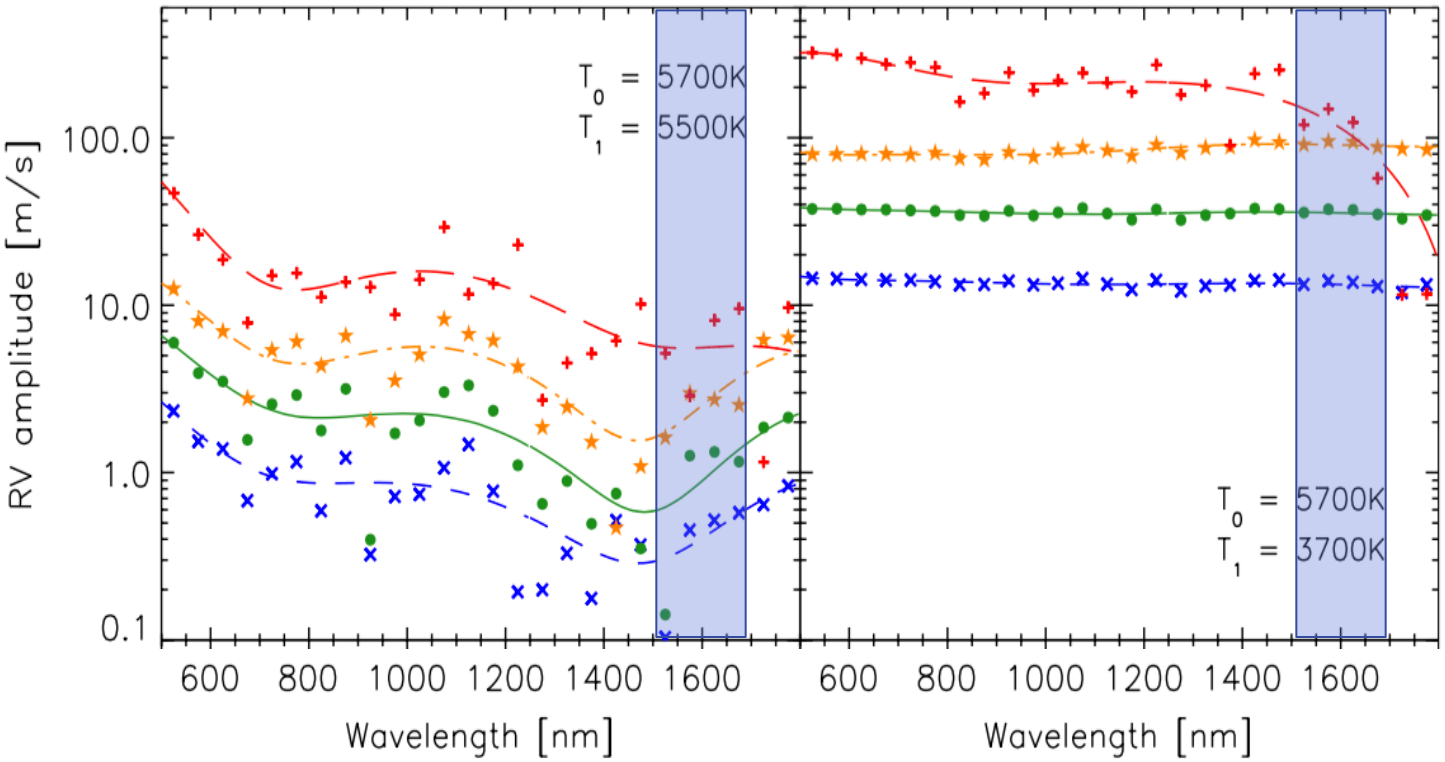


2-D Spectrogram (Ahn+ 2014)



Extracted 1-D Spectrum (Ahn+ 2014)

Stellar Jitter: Optical → IR



λ dependence of RV jitter in spot model is stronger for lower temperature contrasts (Reiners+ 2010)

The Substellar Companion Hosts

- APOGEE 8+ visit targets (~6,000 stars)
  - the Troup+ 2016 “Gold Sample”: show clear periodic RV variability, good Keplerian orbit solutions
  - ~800 stars, own which 340 are red giants