Bayesian distances and extinctions for giants observed by *Kepler* and APOGEE

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Jun 2015

Introduction

- Understand how the Galaxy was formed and evolved: precise stellar properties - distances, masses and ages;
- **Red giants**
  - Luminous stars: can be seen in all regions of the Galaxy;
  - Large range in mass, age, chemical composition and evolutionary stage.
- Several **surveys** are being carried out to better comprehend the structure and evolution of the Galaxy.

APOKASC

Apache Point Observatory Galactic Evolution Experiment

Spectroscopic data:

$T_{\rm eff}$, $\log g$, $[Fe/H]$, $[X/H]$

Kepler Asteroseismic Science Consortium

Asteroseismic data:.

ρ, M, R, $\log g$, evol. st.

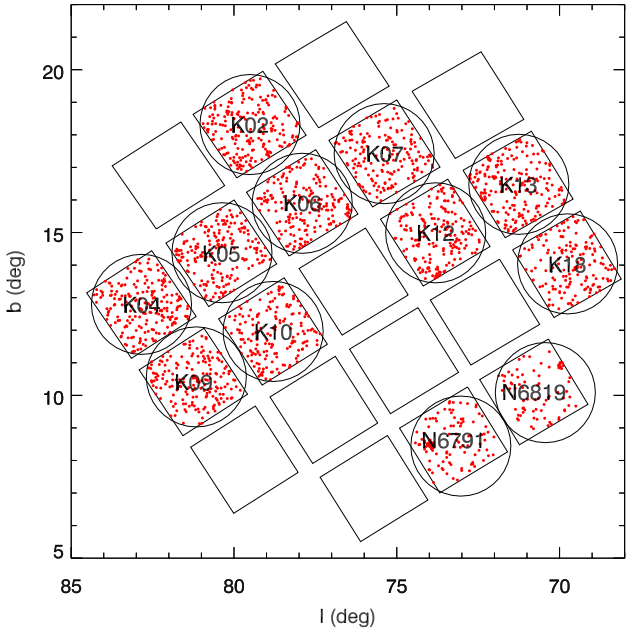


Figure: Position of APOKASC fields (circles) in Galactic coordinates relative to the *Kepler* field (squares).

~10,000 stars were already observed, out of 2,000 are part of the first APOKASC public release (Pinsonneault et al. 2014) with distance and extinctions published in Rodrigues et al. (2014).

Asteroseismology

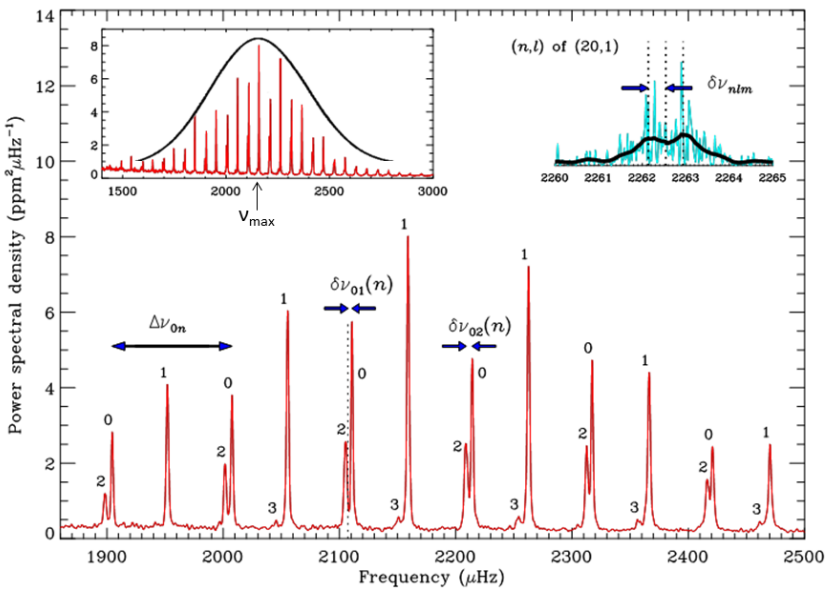
Oscillation spectrum $\rightarrow$ two asteroseismic global parameters:

1. **Large frequency separation** $\Delta\nu$: dominant frequency spacing in near regular pattern of high overtones,

$$\Delta\nu \propto \rho^{1/2} \propto M/R^3.$$

2. **Frequency of maximum power** $\nu_{\max}$ of the Gaussian-like modulation of the power spectrum,

$$\nu_{\max} \propto gT_{\text{eff}}^{-1/2} \propto M/R^2 T_{\text{eff}}^{-1/2}.$$



Asteroseismology

- Adopting homology relations from solar values:

$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2},$$

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}.$$

- With $T_{\rm eff}$ and $R \Rightarrow L = 4\pi R^2 T_{\rm eff}^4$;
- With L and $C_B \Rightarrow M_{\rm abs}$;
- With m and $M_{\rm abs} \Rightarrow (m - M_{\rm abs} - A_V) = 5\log(d/10{\rm pc})$.

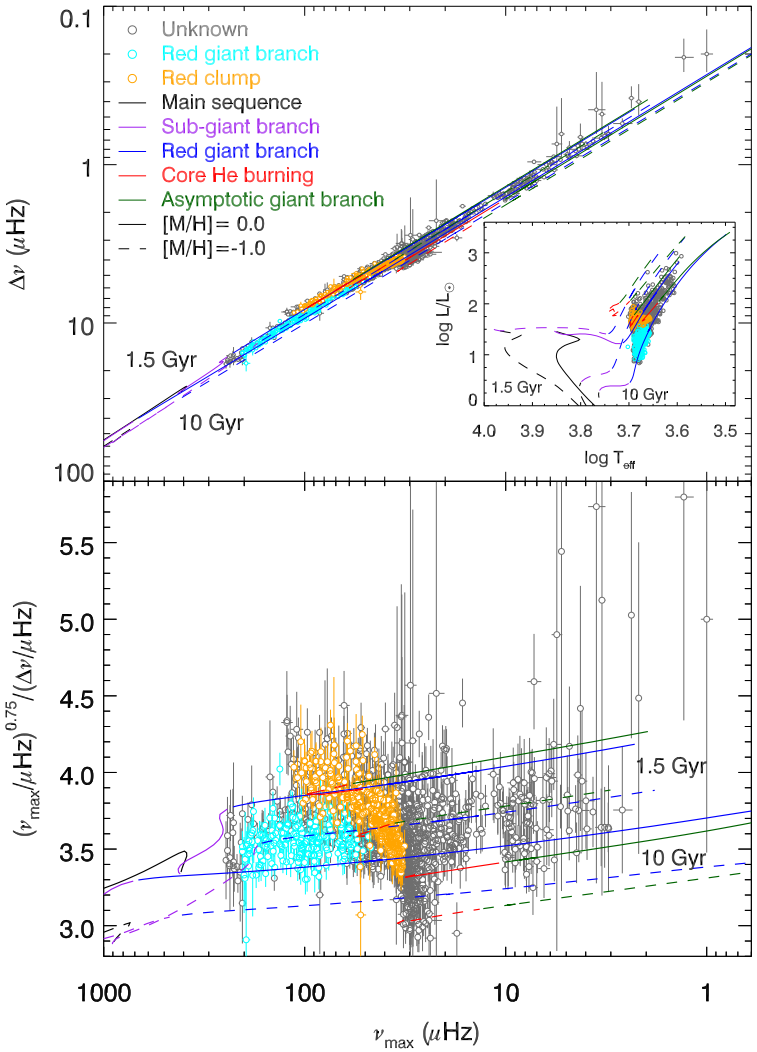
Bayesian Method

- PARAM code estimates stellar properties by comparing observational data with the values derived from stellar models – dataset of theoretical isochrones;
  - PARSEC v1.1 from the Padova-Trieste stellar evolution group (Bressan et al. 2012).

$$P(\mathcal{M},\ \mathcal{R},\ \log g,\ \tau,\ \rho,\ M_\lambda) \propto$$
$$p(\mathcal{M},\ \tau,\ [\mathrm{M/H}]) \times L([\mathrm{M/H}],\ T_{\mathrm{eff}},\ \Delta\nu,\ \nu_{\max})$$

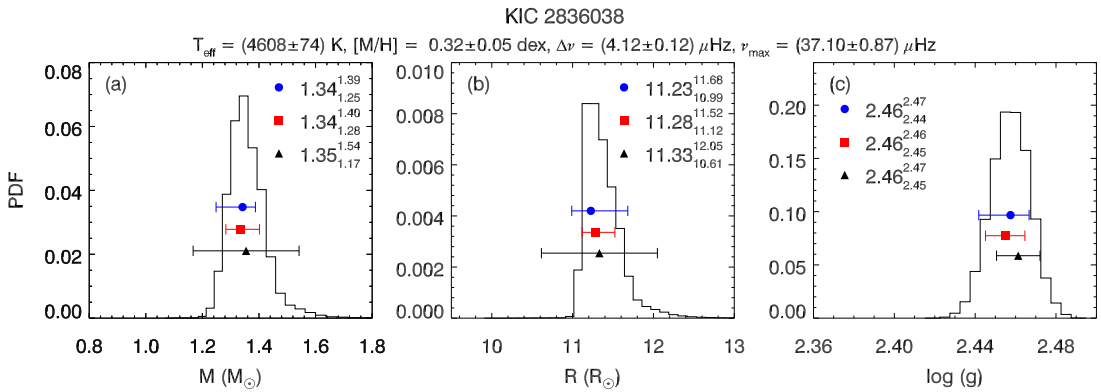
$$d = 10^{0.2\mu_0+1} = 10^{0.2(m_\lambda - M_\lambda - A_\lambda)+1}$$

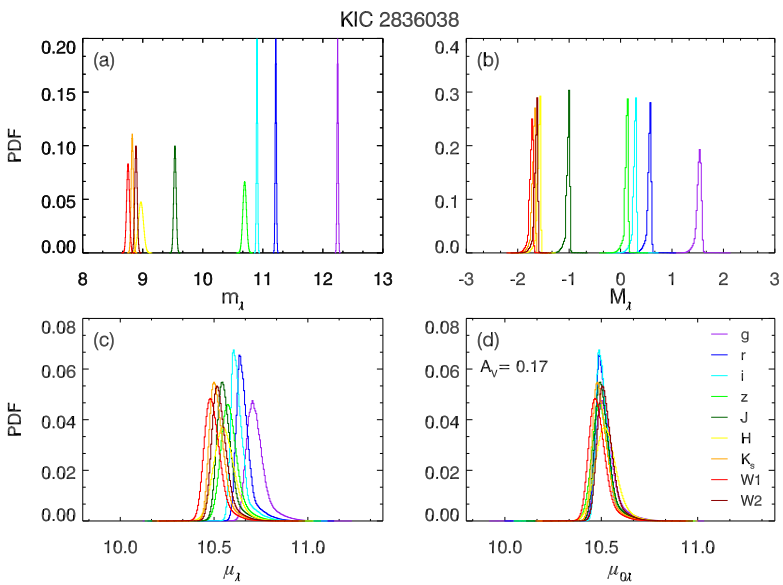
$$A_\lambda(A_V)$$

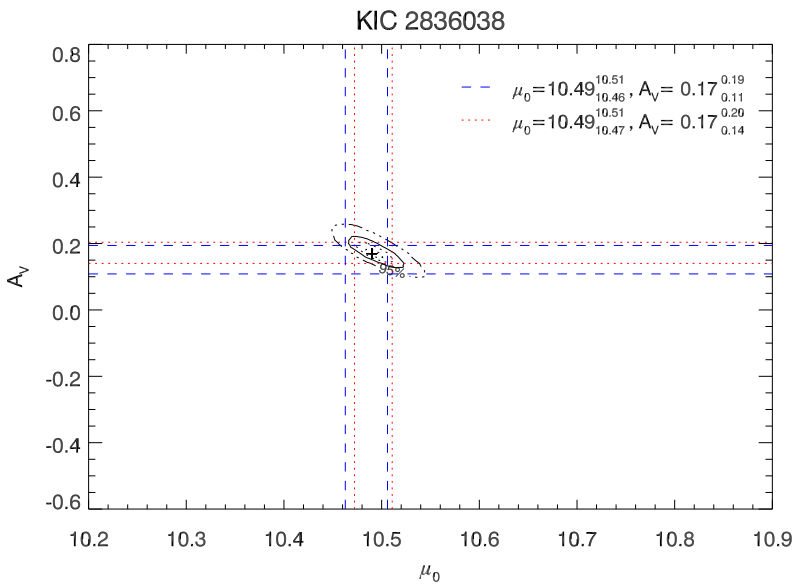


Stellar Properties PDFs

Well-behaved, single-peaked PDFs:

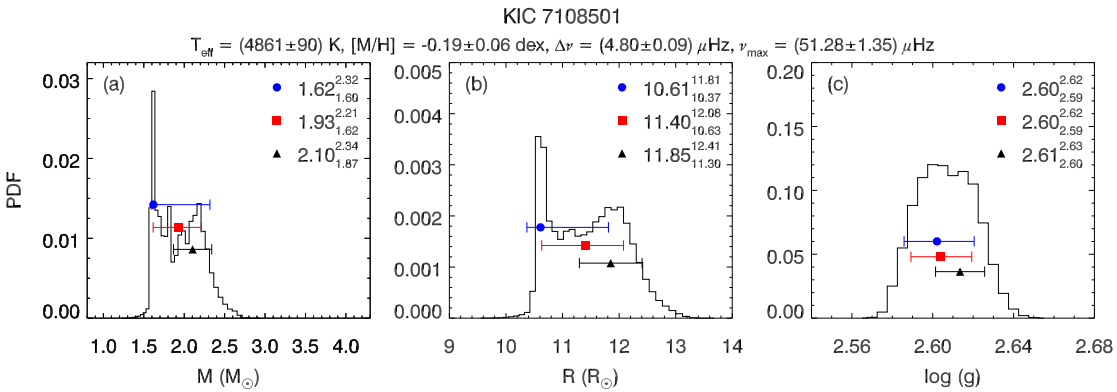


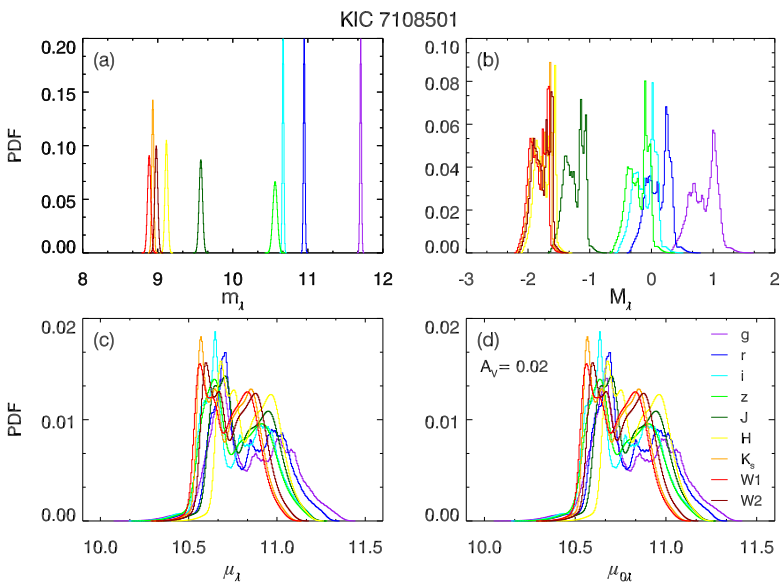


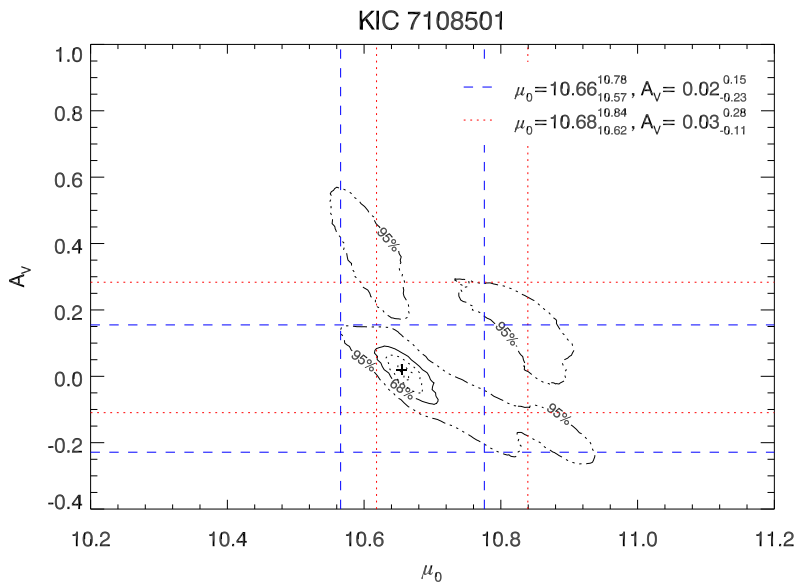


Stellar Properties PDFs

Broad, multiple-peaked PDFs:

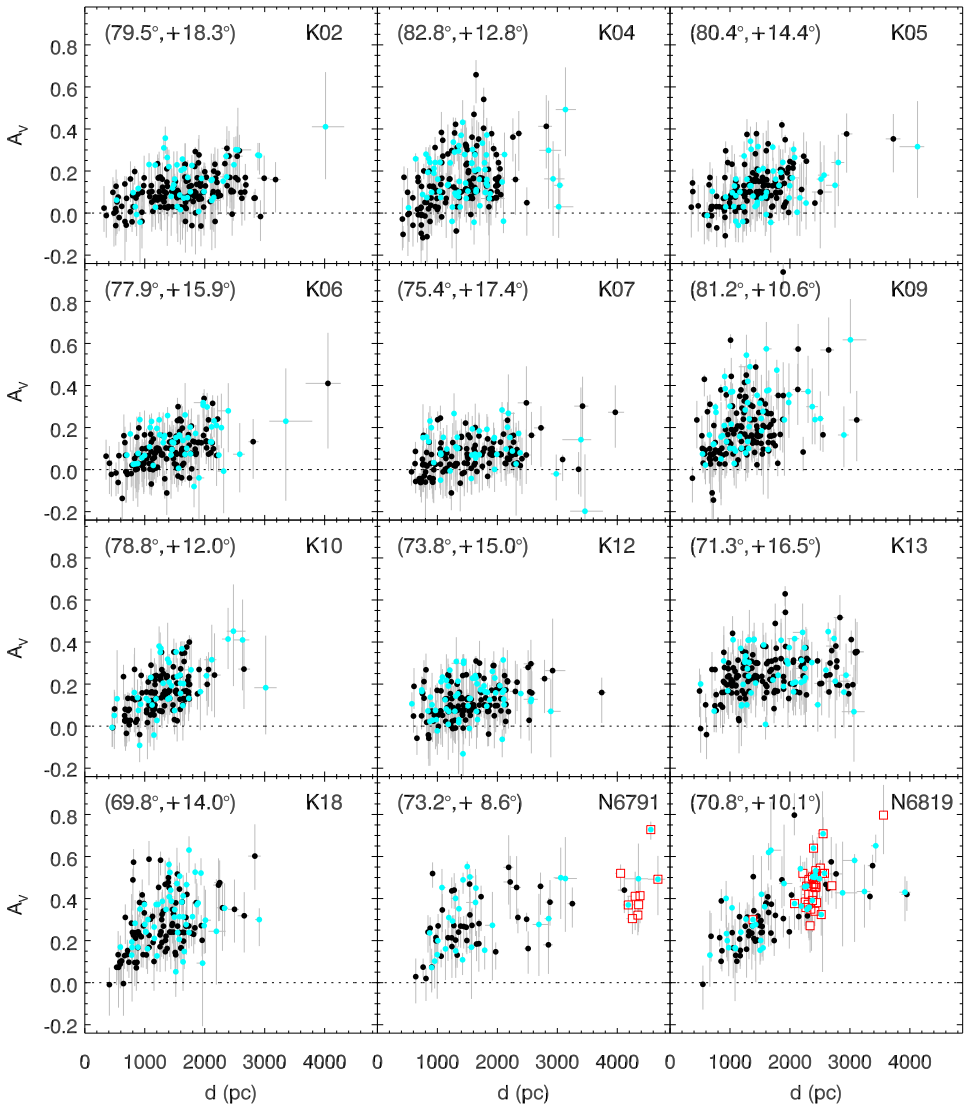






Distances and extinctions

- Most of the observed stars are located within 2 kpc, whereas almost all stars are within 4 kpc;
- Typical median uncertainties are $\sigma(d)/d = 0.018$ and $\sigma(A_V) = 0.077$ mag.



Extinction maps

- SFD: some evident similarities in the position of the highly extincted regions.

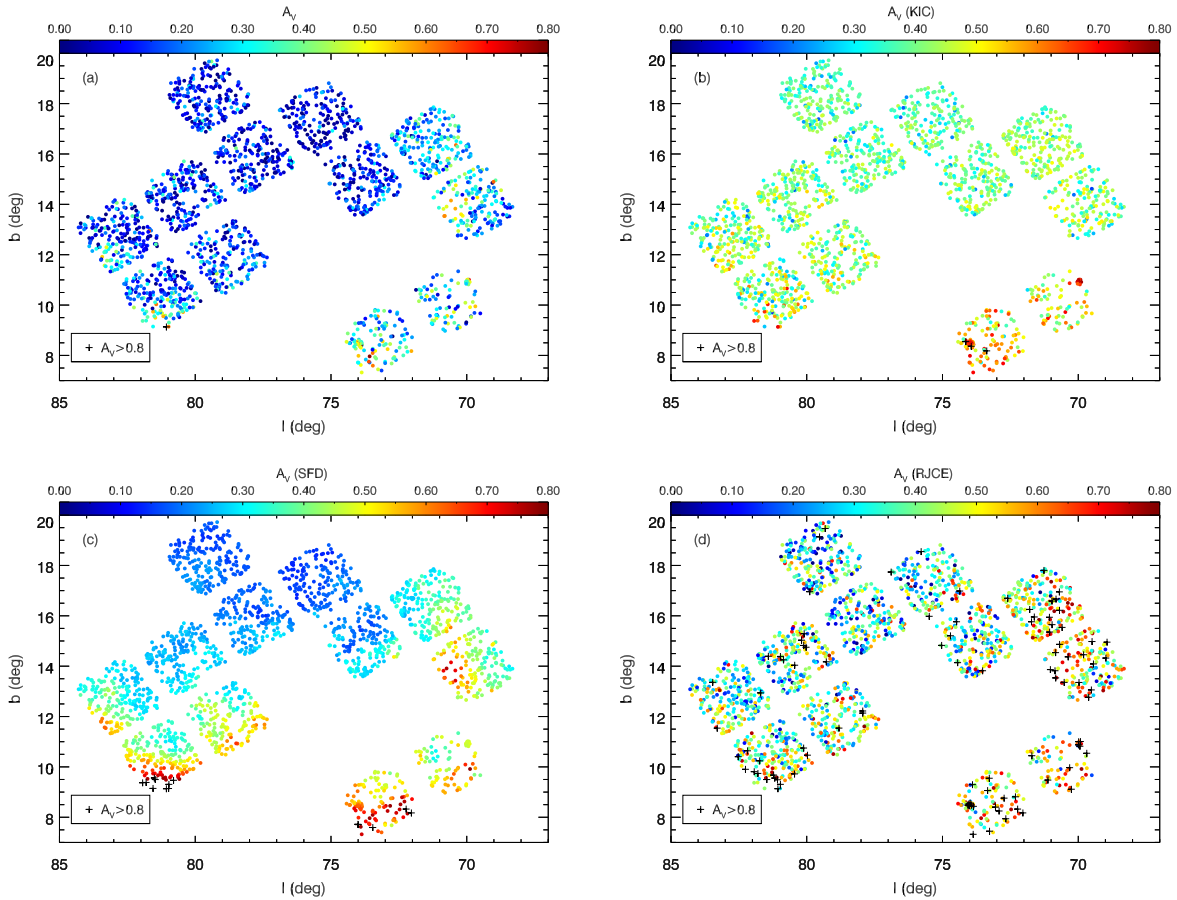
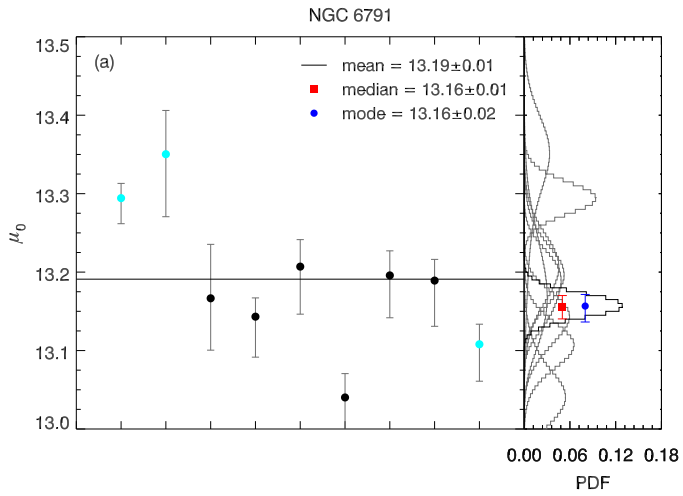


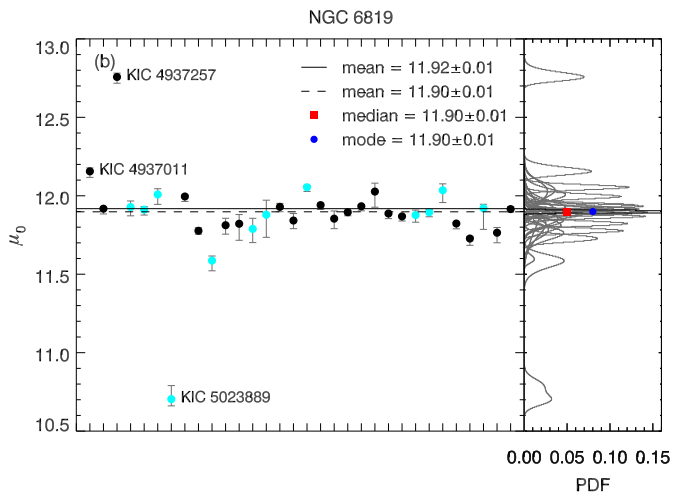
Figure: Maps derived from the KIC (Brown et al. 2011), from Schlegel, Finkbeiner & Davis (1998, SFD), and with the Rayleigh-Jeans Colour Excess (RJCE, Majewski et al. 2011) method.

Clusters

- **NGC 6791:** 9 stars in APOKASC are classified as seismic members by Stello et al. (2011).
  $\Rightarrow \mu_0 = 13.16 \pm 0.02$ mag.
- **NGC 6819:** 32 stars selected by the same authors are in the APOKASC sample, out of 29 were classified as seismic members.
  $\Rightarrow \mu_0 = 11.90 \pm 0.01$ mag.

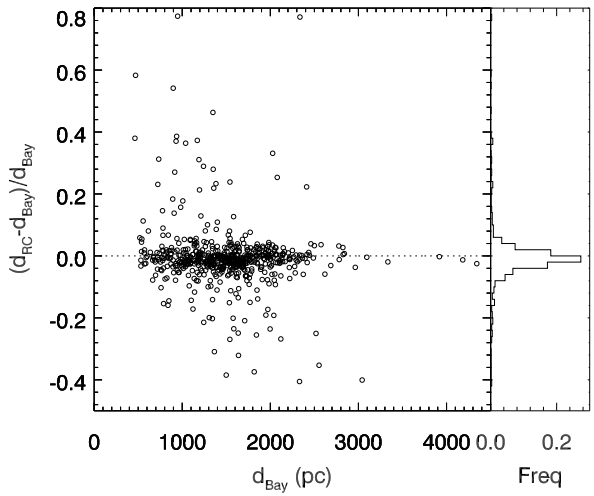
- The modes in the μ_0 PDFs compare well with Basu et al. (2011):
  NGC 6791: $\mu_0 = 13.11 \pm 0.06$ mag,
  NGC 6819: $\mu_0 = 11.85 \pm 0.05$ mag.

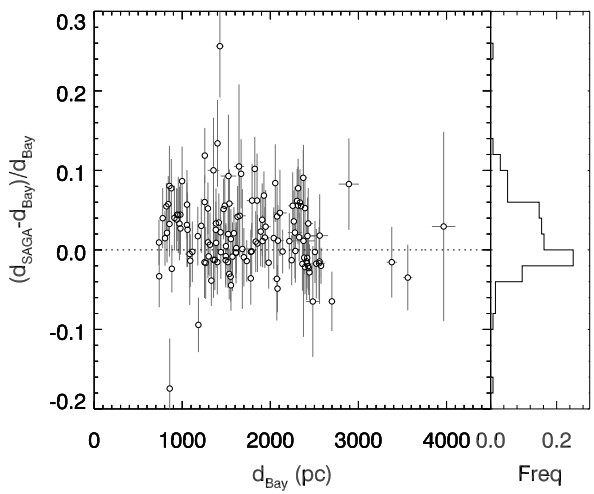




Distance catalogs

- **APOGEE red clump catalogue:** stars which, due to their values of $T_{\rm eff}$, $\log g$, $[\mathrm{M/H}]$, and 2MASS $(J-K_{\rm s})_0$, are very likely red clump stars with a well-defined absolute magnitude (Bovy et al., 2014).
- **SAGA catalogue:** stellar parameters are estimated by a combination of Strömgren photometry, the infrared-flux method, and several extinction estimates (Casagrande et al., 2014).
- The mean relative difference in distances is only $\sim 1\%$.





Ongoing Work

We are estimating stellar properties, distances and extinctions to all stars in the APOGEE survey without seismic information available: $T_{\rm eff}$, $[{\rm Fe/H}]$, $\log g$.

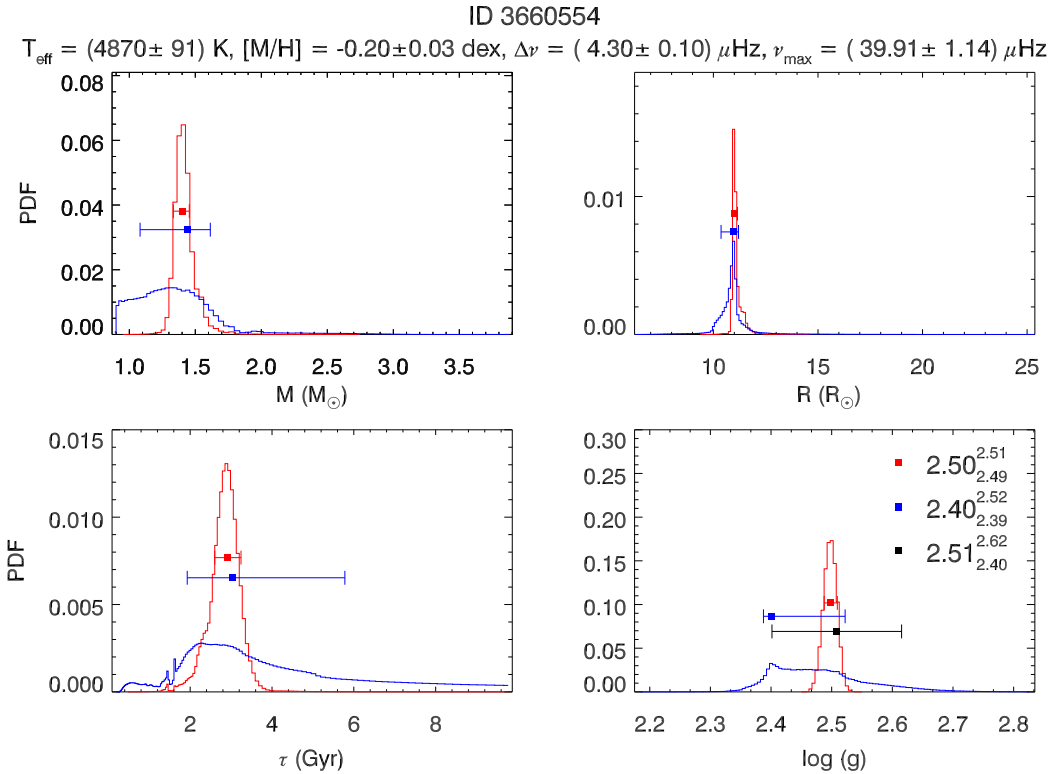


Figure: Red: $T_{\rm eff}$, $[{\rm M/H}]$, Δ_{nu}, $\nu_{\rm max}$; Blue: $T_{\rm eff}$, $[{\rm M/H}]$, $\log g$.

Ongoing Work

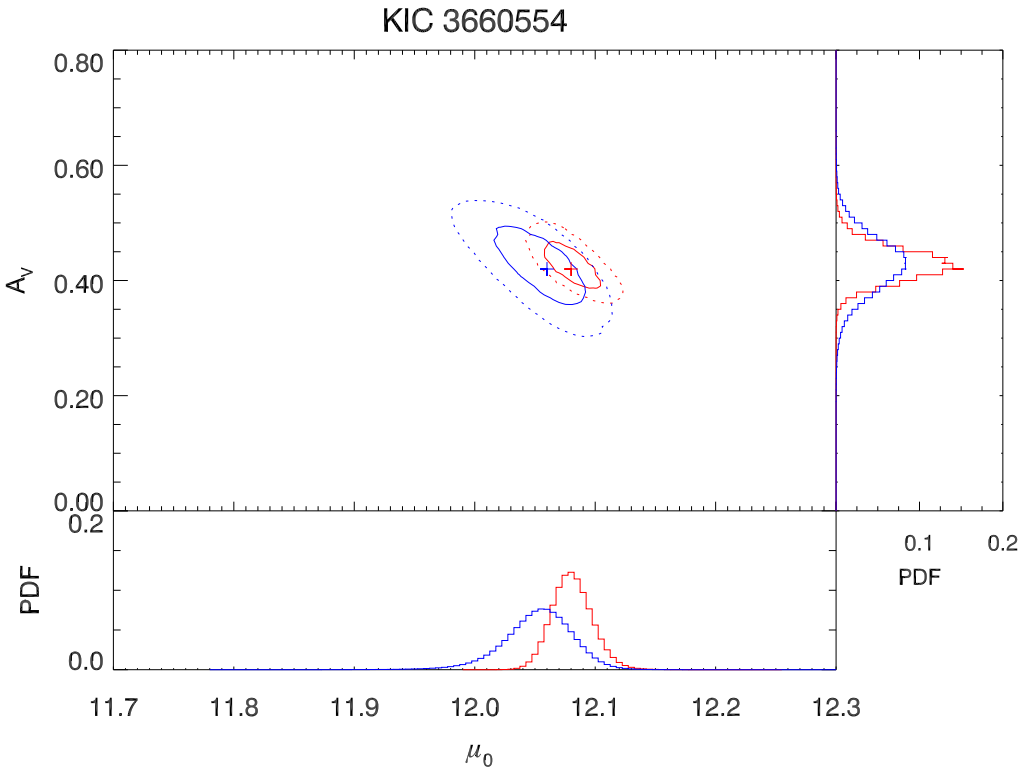


Figure: Red: $T_{\rm eff}$, [M/H], Δ_{nu}, $\nu_{\rm max}$; Blue: $T_{\rm eff}$, [M/H], $\log g$.

Ongoing Work

We are including detailed models of the seismic parameters $(\Delta\nu, \Delta\Pi)$ – Diego Bossini, Andrea Miglio, Josefina Montalban.

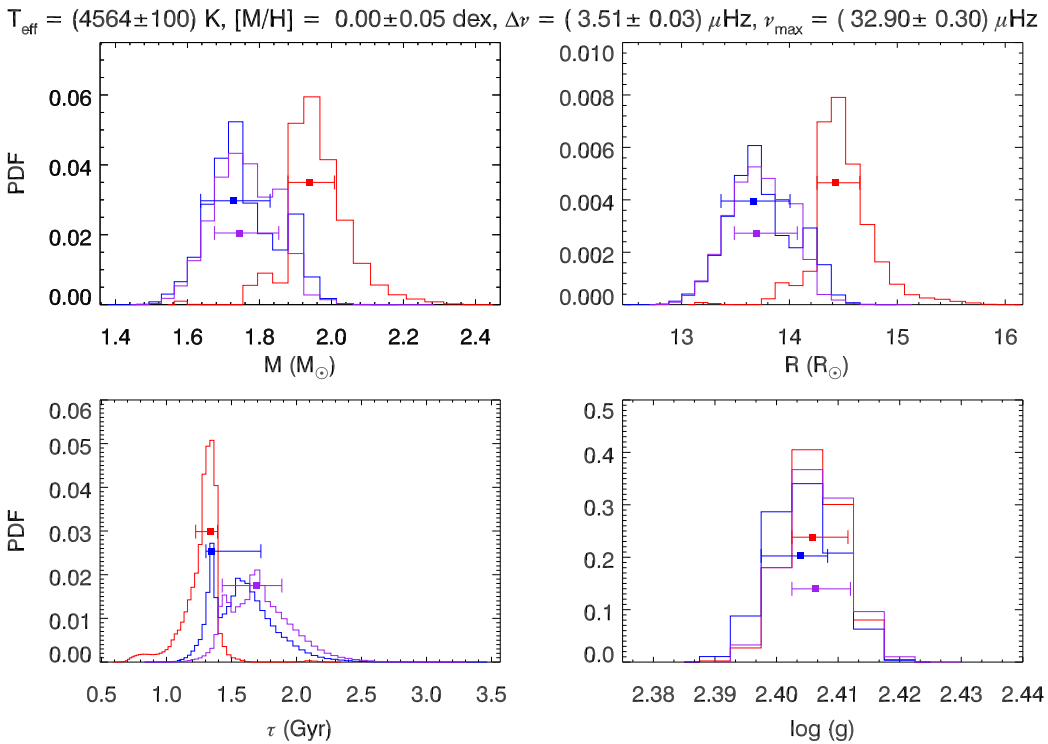


Figure: Red: $\nu_{\max}, \Delta\nu$; Blue: $\nu_{\max}, \Delta\nu(SR)$.

Thank you!