

# Enabling Galactic Archaeology: the spectroscopy needed by large asteroseismic surveys

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- "*Galactic archaeologists sift through stellar fossil records to uncover the history of our nearby universe*" (Roskar & Debattista)

where the *stellar record* is essentially given by spectroscopy+astrometry:

1. Surface abundances of several metals
2. Radial velocities
3. Distances, proper motions, etc.

# Enabling Galactic Archaeology: the spectroscopy needed by large asteroseismic surveys

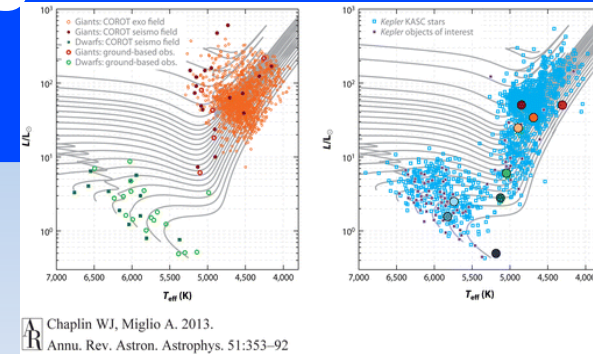
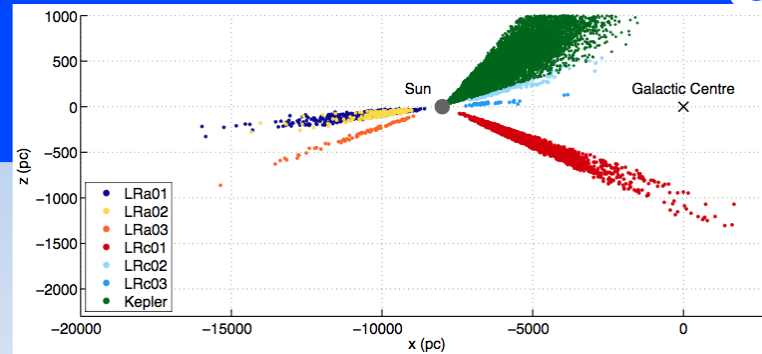
Until recently, spectroscopy+astrometry was also providing the proxies for stellar ages, e.g. alpha-enhancement and/or kinematics to distinguish young/old thin/thick disk

but what about:

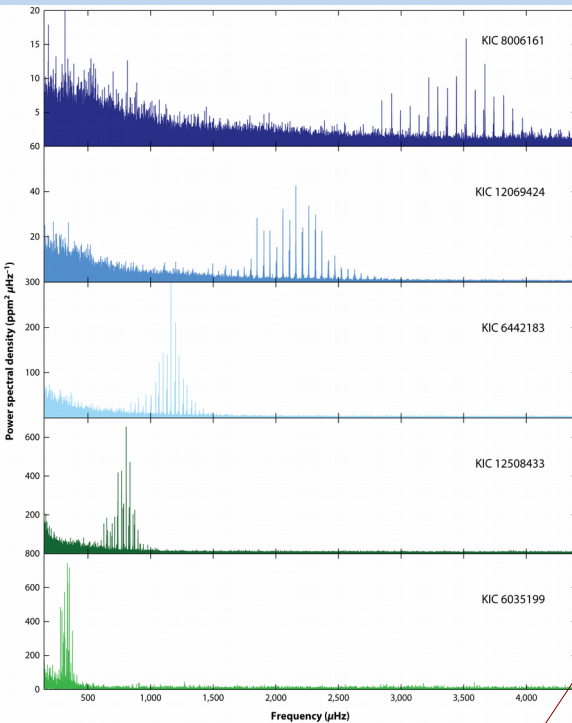
- Alpha-enhanced young (massive) stars (Martig+17) ?
- Impostors from inner/outer disk (radial migration; Roskar+11)

Direct ages are needed – or at least a sample of reliable primary age calibrators.

# Asteroseismology



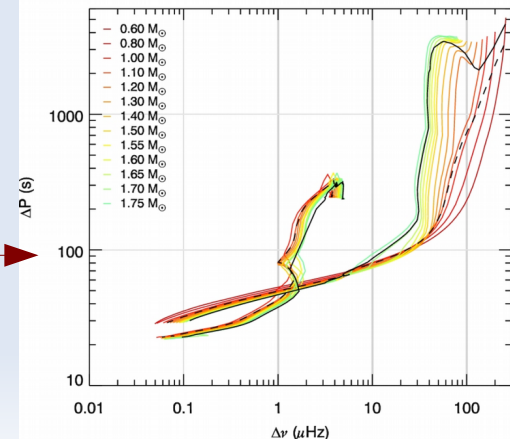
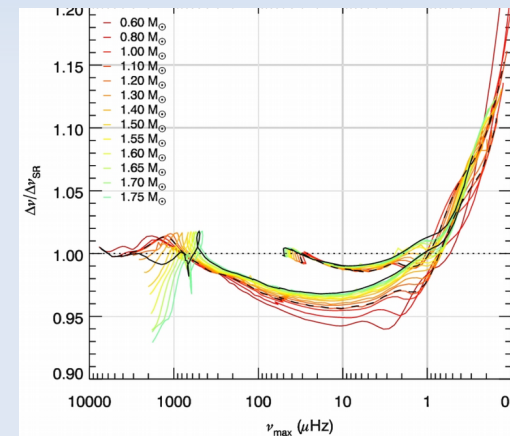
Chaplin WJ, Miglio A. 2013. Annu. Rev. Astron. Astrophys. 51:353-92



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The **asteroseismic revolution** started with CoRoT+ Kepler + homogeneous spectroscopic parameters:

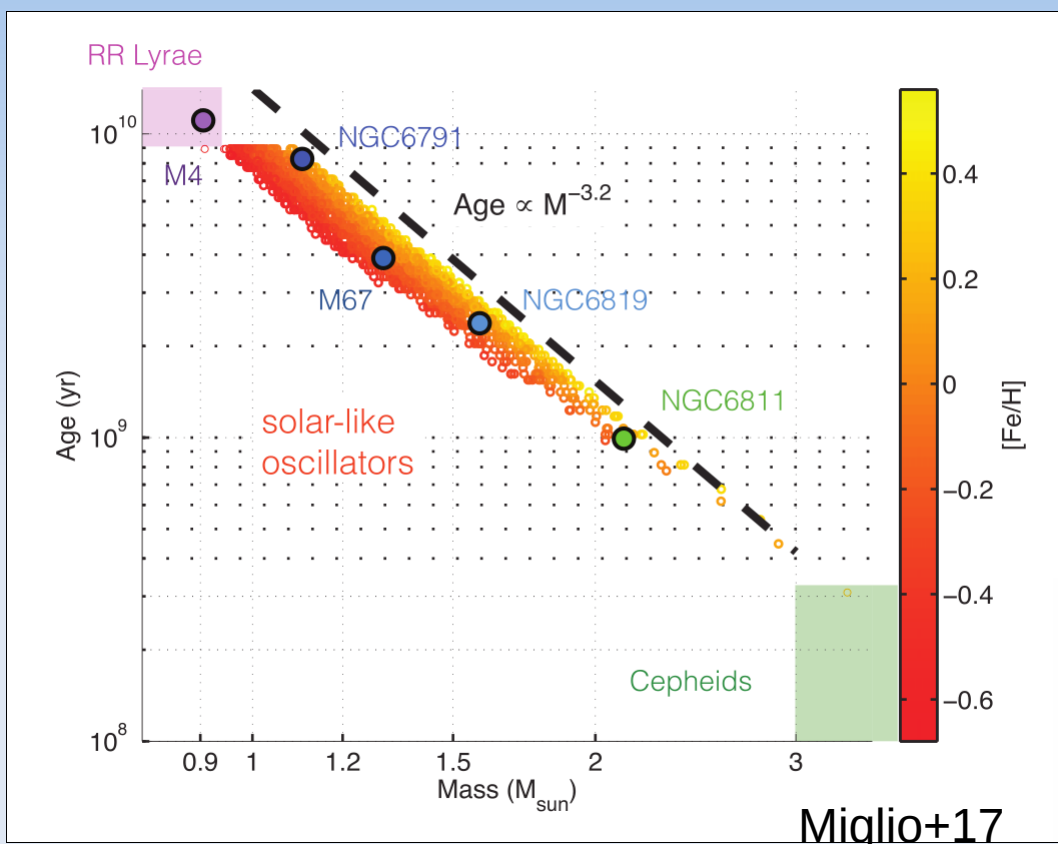
- ~20 000 dwarfs+giants, including 3 well-observed clusters, with reliable masses (hence ages for giants), radii (hence distances) from scaling relations. *Errors of few % even for stars several kpc away.*
- Direct estimate of integrated mass loss on RGB (Miglio+12), direct mass for Globular cluster stars (Miglio+17),
- Accurate ages* expected as we better constrain overshooting,  $Y(Z)$ , mixing-length (Prada Moroni+16), and as we go beyond the use of scaling relations (Rodrigues+17). *Stellar models required.*



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

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

# Ages for Galactic Archaeology



Ages come from mass-age relation of giants – limited theoretical uncertainty

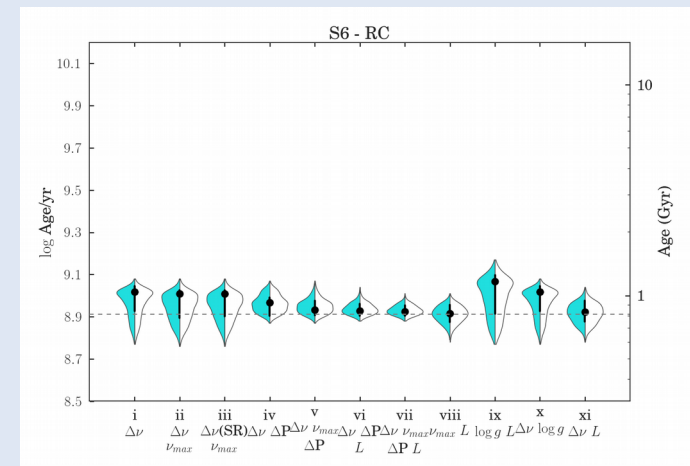
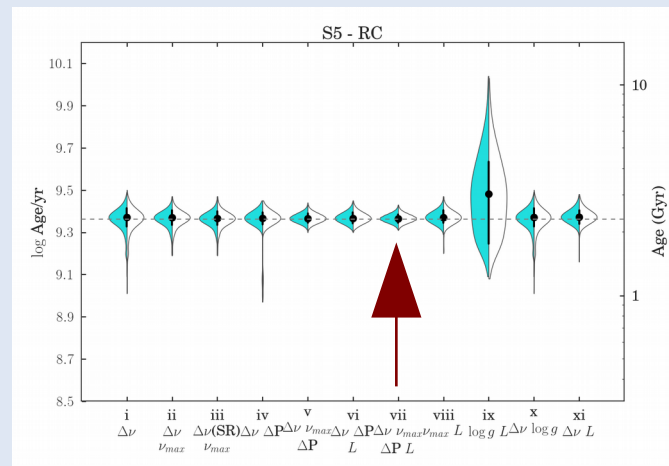
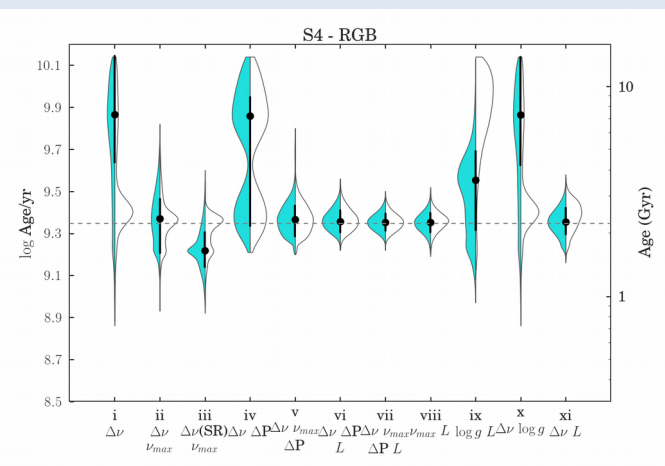
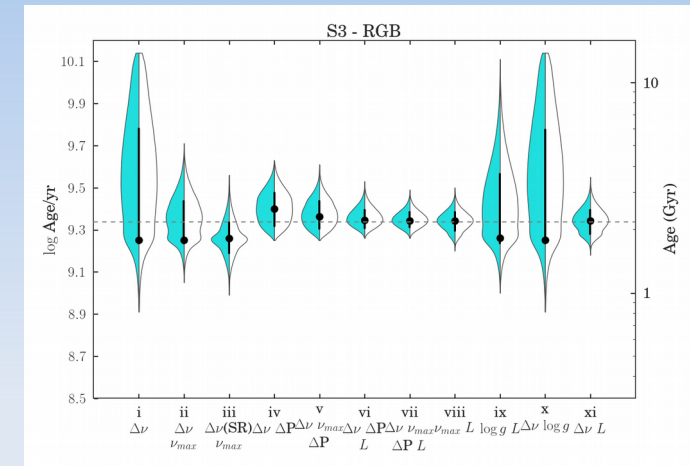
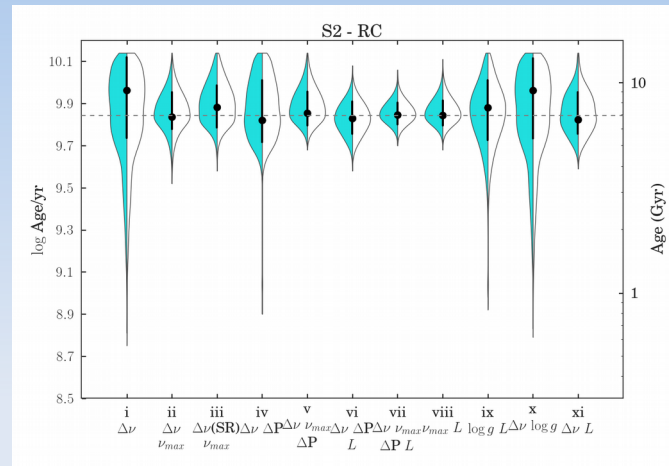
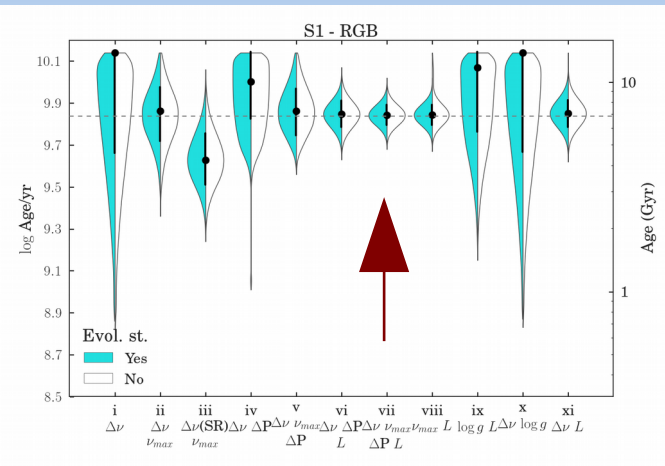
Red giants have the right ages for archaeology ( $10^8$  to  $10^{10}$  yr), large range of distances (up to  $\sim 15$  kpc in CoRoT+Kepler), and easier spectroscopic analysis

*For these stars, gyrochronology, chromospheric, or Li-depletion boundary methods do not work.*

These are the ages being used to calibrate other age indicators – e.g. The Cannon and C/N methods (Ness & Martig + APOGEE papers).

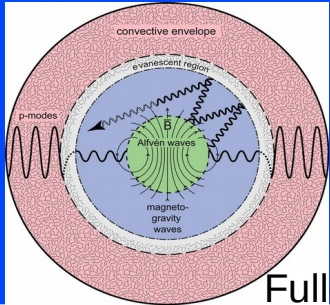
(related distances are also documenting offsets in Gaia DR2 parallaxes – e.g. Davies+18, Stassun+18, Khan+19 – hence improving isochrone ages for Gaia)

# Accuracies depends on asteroseismic parameters available:



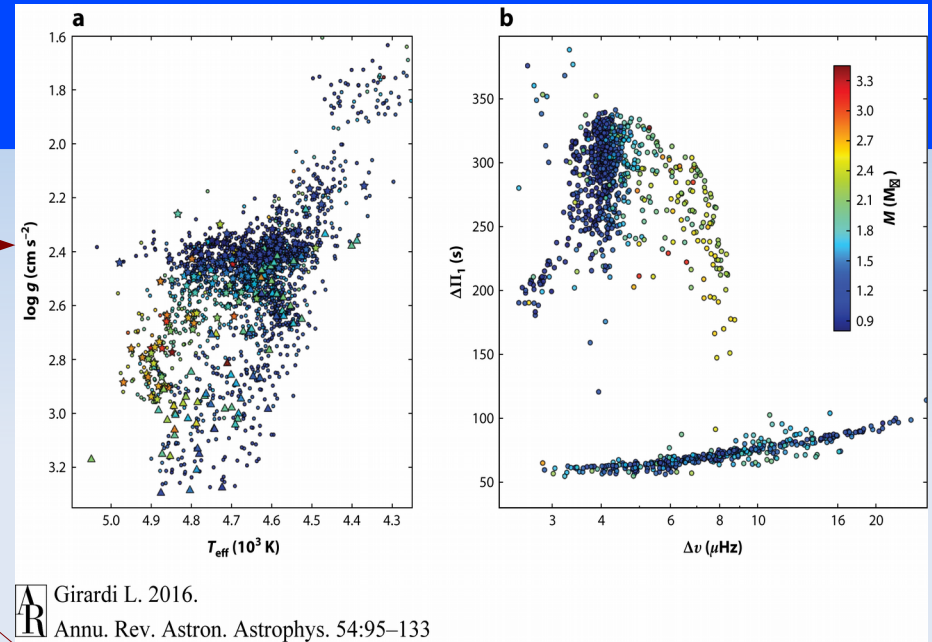
Rodrigues+17 – tests with several combinations of asteroseismic parameters – ages <10% are possible, especially with Kepler-quality data + Gaia/LSST parallaxes

# Asteroseismology

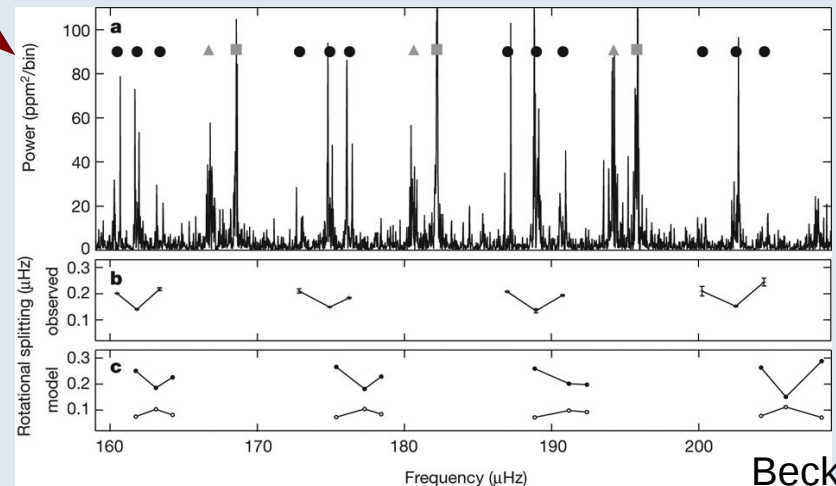
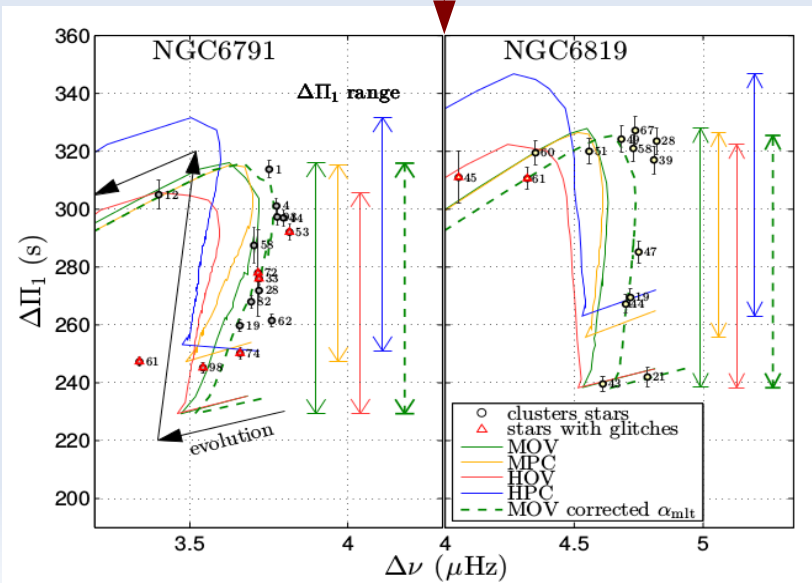


Fuller+15

- Evolutionary stage from period spacing of g modes (Bedding+11, Vrad+16)
- Constraints on rotational evolution: fast core rotation in giants (Beck+12), suggestion of strong core magnetic fields (Fuller+15), alignment of spin axis in clusters (Corsaro+17)
- Period spacing distribution of red clump stars → direct constraining core overshooting and near-core T gradient (Bossini+16+17:  $\sim 0.5 H_p$  with adiabatic gradient) – hence more robust ages!



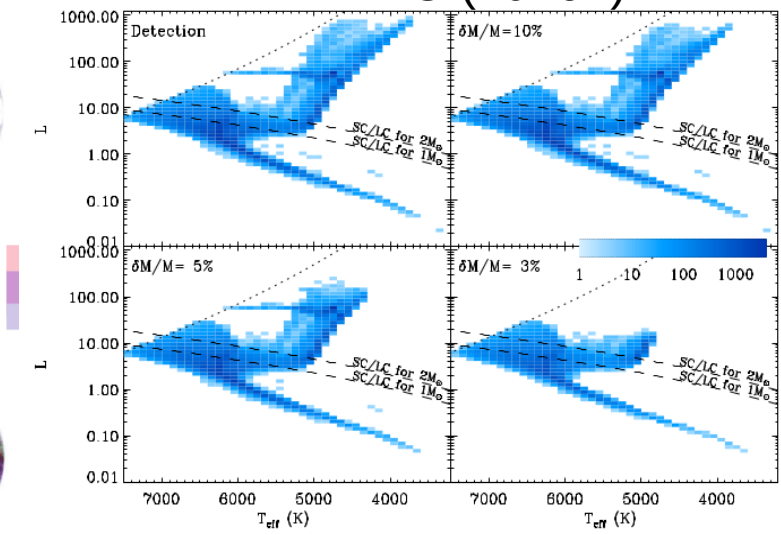
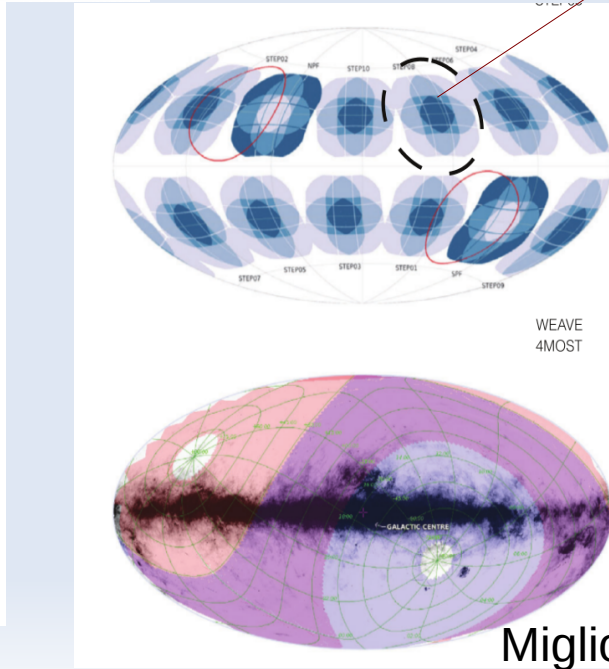
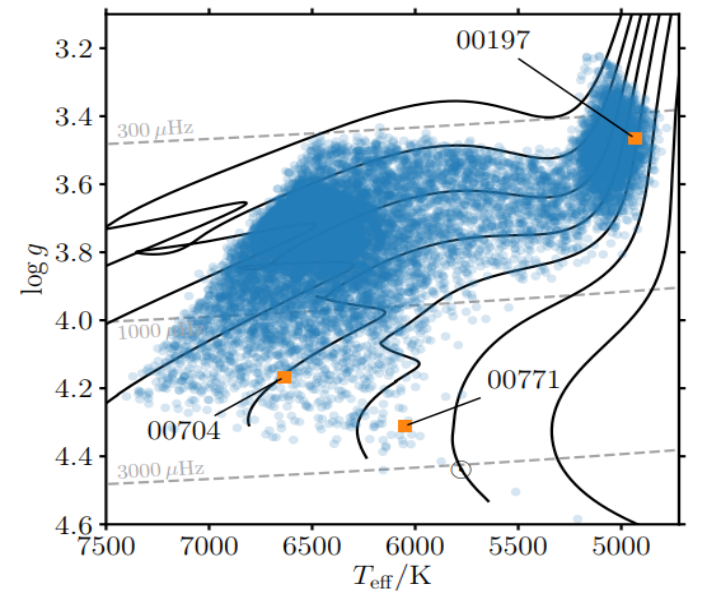
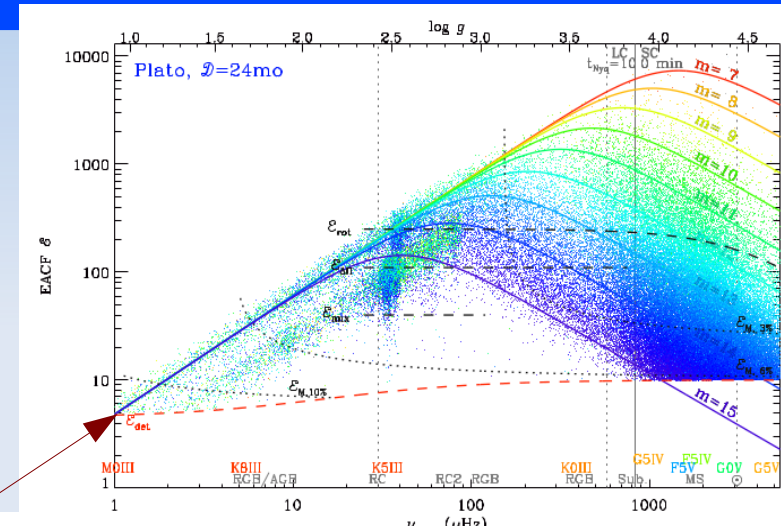
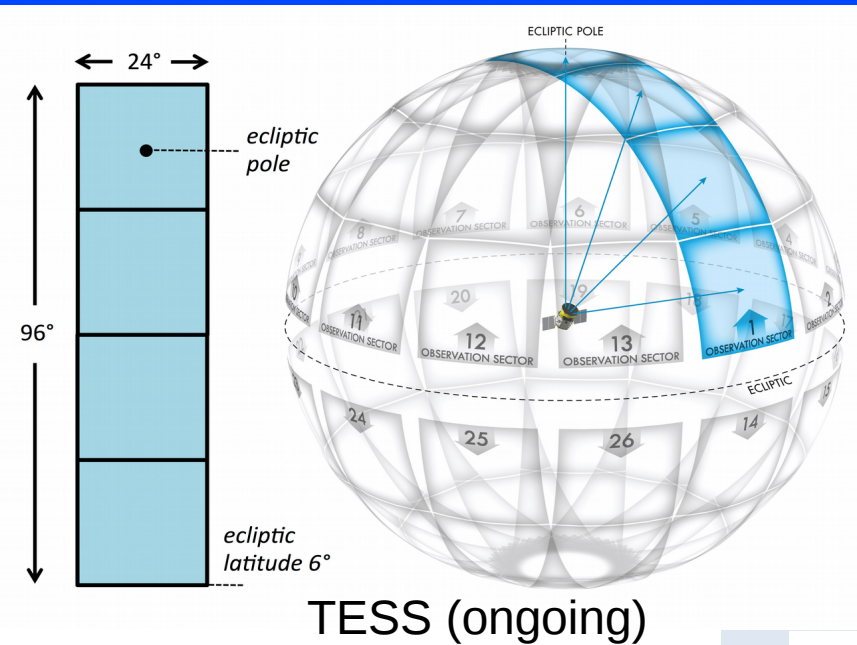
Girardi L. 2016. Annu. Rev. Astron. Astrophys. 54:95–133



Beck+12

Constraints to overshooting + angular momentum = even more robust ages

TESS and PLATO will expand present seismic databases by factors of >50, nearly all-sky.



# What is needed

## To enable Galactic Archaeology:

- The minimum: Teff homogeneous measurements, to  $\ll 100$  K, for  $\sim 100\,000$  asteroseismic targets, all-sky, to get masses from the "corrected scaling relations" ( $< 5\%$  accuracies in mass,  $10\%$  in age)
- The advisable: + homogeneous abundances for several elements + radial velocities of APOGEE/GES quality ( $R \gg 10000$  + wide window)
- The top: + time series RV to detect binarity and rotational modulation
- Given the premises, these things *will happen*. The only question is **who will take active part in the future consortia between spectroscopic (SDSS-V, 4MOST, WEAVE) and asteroseismic (KASC, TASC, PLATO) teams.**

## To catch the train:

- Invest in asteroseisology. Who invested to exploit CoRoT + Kepler seismic data (e.g. Sydney, Hawaii, Birmingham, Leuven, Aarhus), do not regret
  - Won at least 6 ERC grants!
  - Lead CoRoT+KASC agreements with all major spectroscopic surveys (SDSS/APOGEE, GALAH, GES)
- Situation in Italy:
  - Despite efforts by some individuals and small groups (Brera, Catania, Padova, Pisa, Roma), no positions in asteroseismology for  $> 12$  years