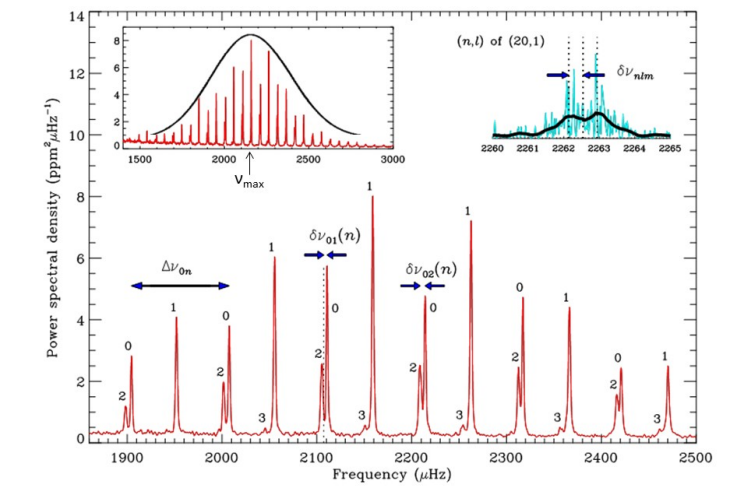
Galactic archaeology from large asteroseismic surveys

Léo Girardi – OAPD

(With input from a lot of people, esp. The PRIN INAF 2014 team)



The most basic stellar parameters asteroseismology can tell us:

- Adopting homology relations from solar values:

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

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

- 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 $M_{\rm abs} \Rightarrow (m - M_{\rm abs} - A_V) = 5\log(d/10{\rm pc})$. → distance

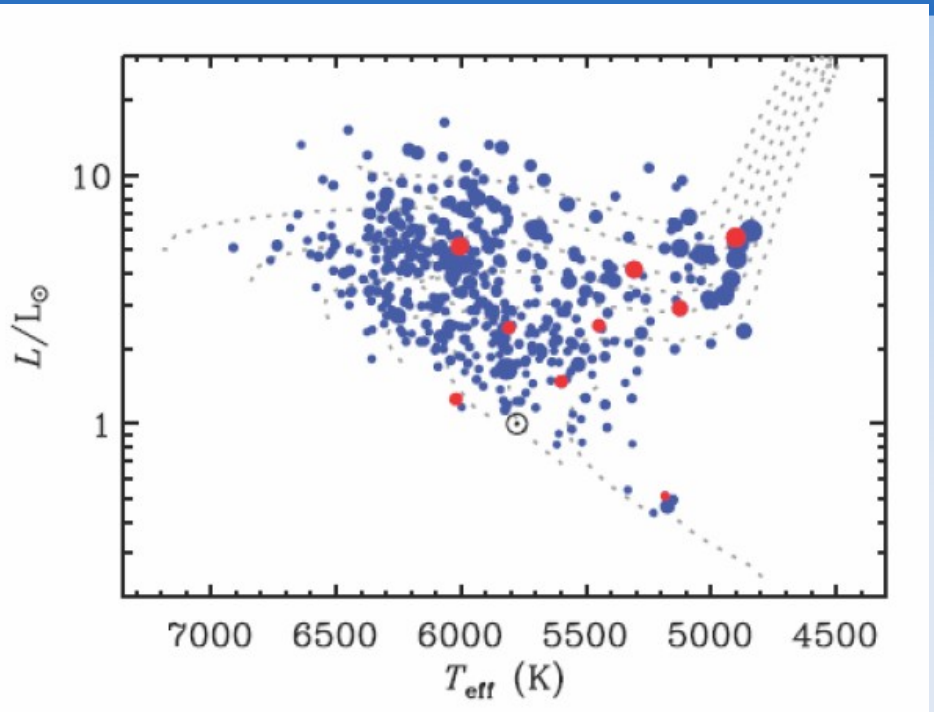
(Teff from spectroscopy)

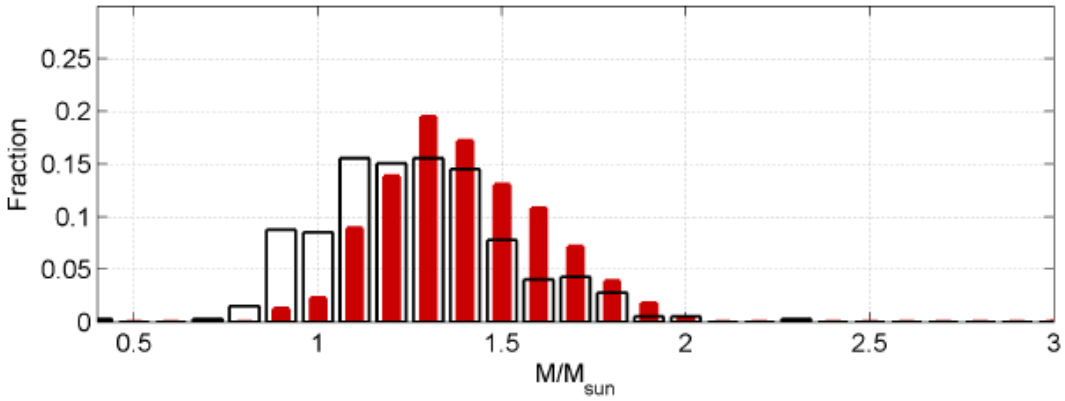
This for thousands of single stars at tens of kpc !

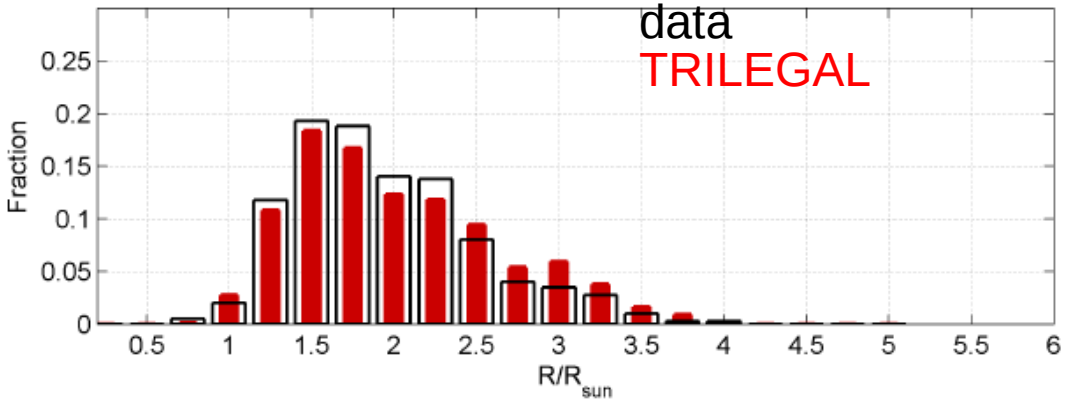
Ensemble asteroseismology X Galactic models

Kepler data: first ~500 stars

Chaplin et al. 2011



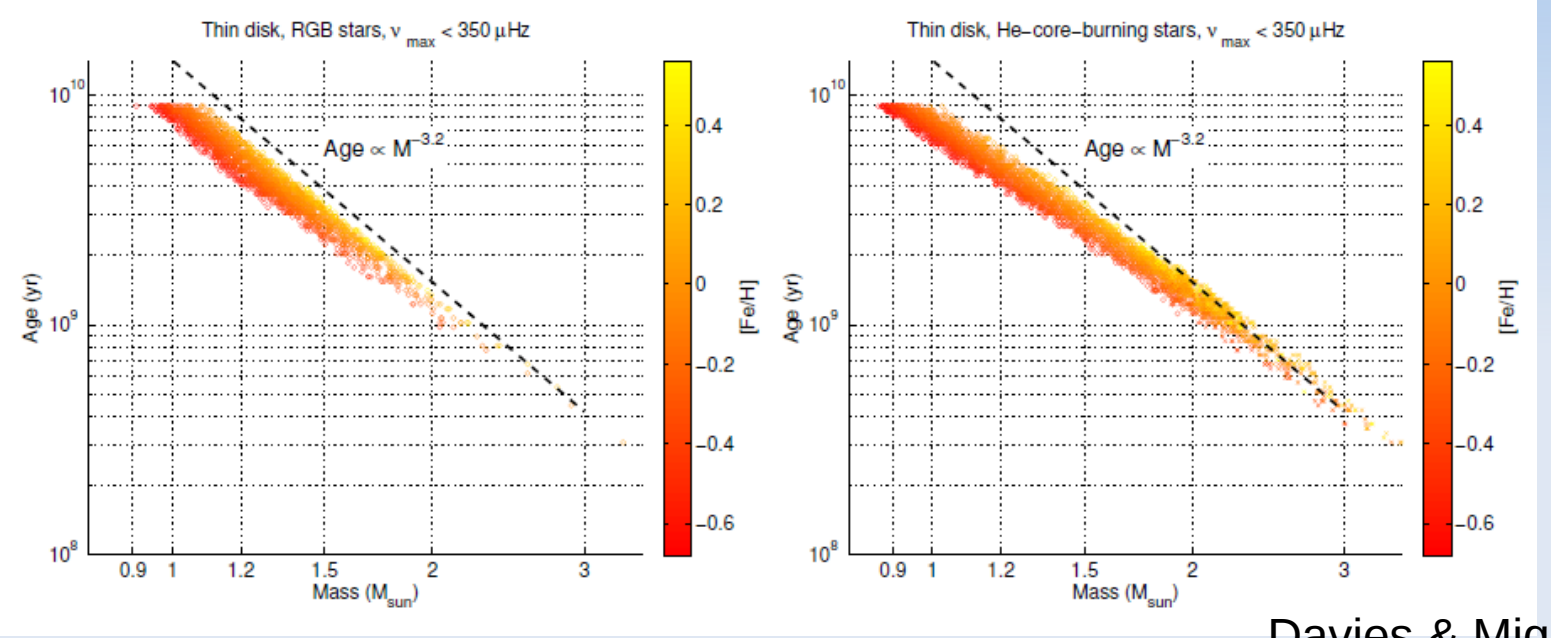




Discrepancy in mass distribution
– Bad modeling of Kepler detection bias?
– Failure of TRILEGAL Milky Way model?

But who cares about stellar masses?

- For giants, mass gives a **direct measure of** (main sequence) **age**

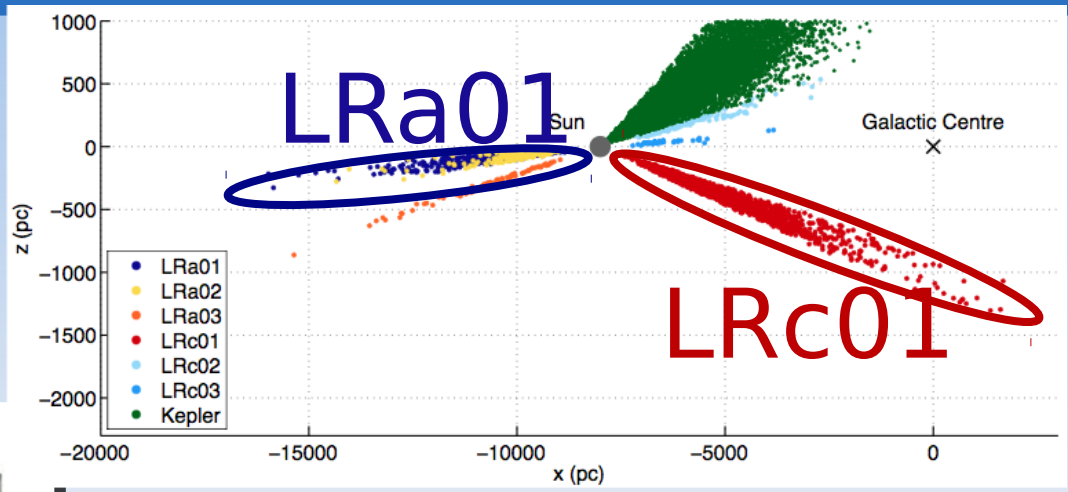


Davies & Miglio 2016

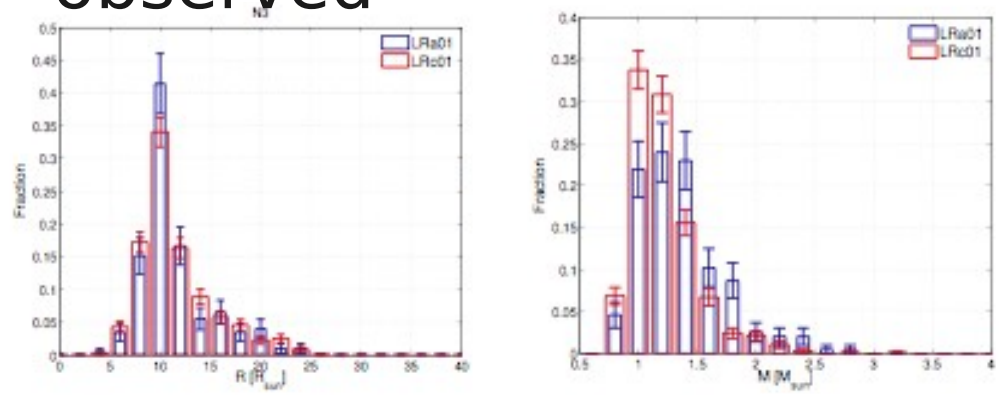
- Even for the noisiest Kepler/CoRoT targets, present age errors <30%, **much smaller than any other method** applied to single stars
- Complications (being solved): %-level deviations from scaling relations, mass loss
- Competing method, *isochone fitting with Gaia parallaxes*, will actually be *calibrated* with asteroseismic samples!

Ensemble asteroseismology of giants = Galactic Archaeology

Miglio et al. 2013

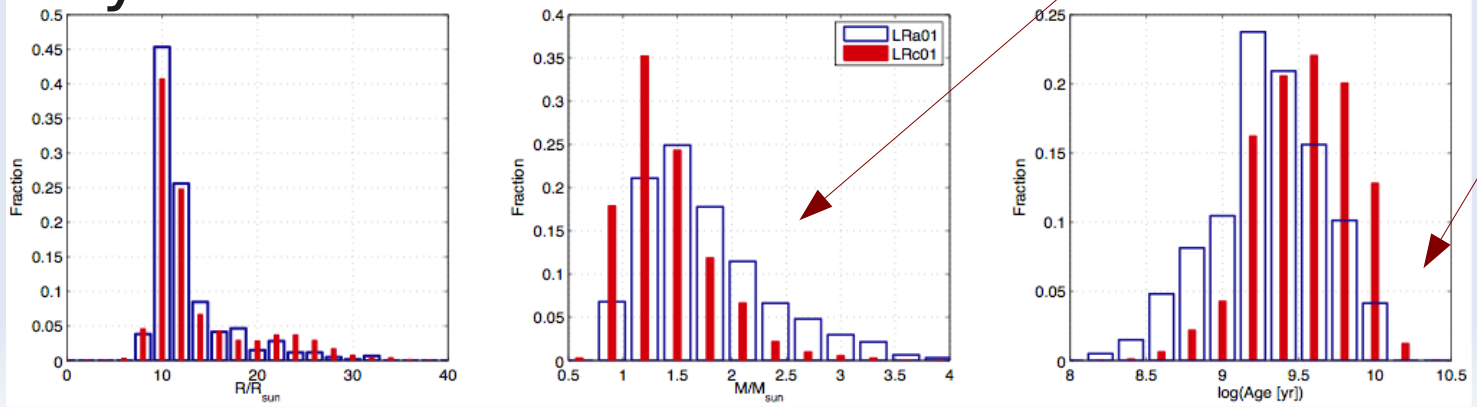


observed



TRILEGAL

synthetic



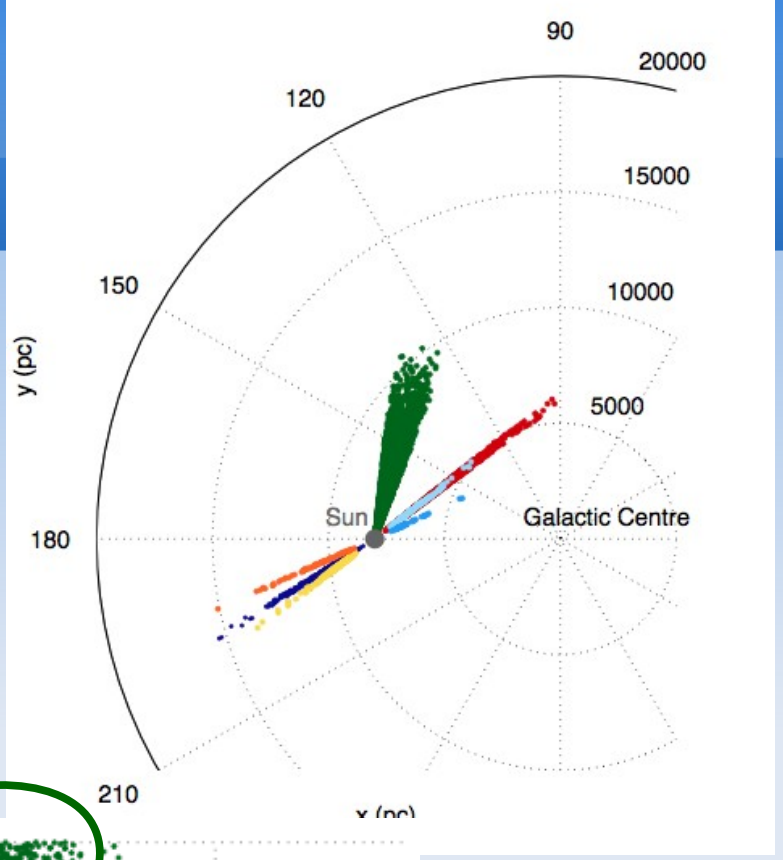
Mean mass is smaller in LRc01

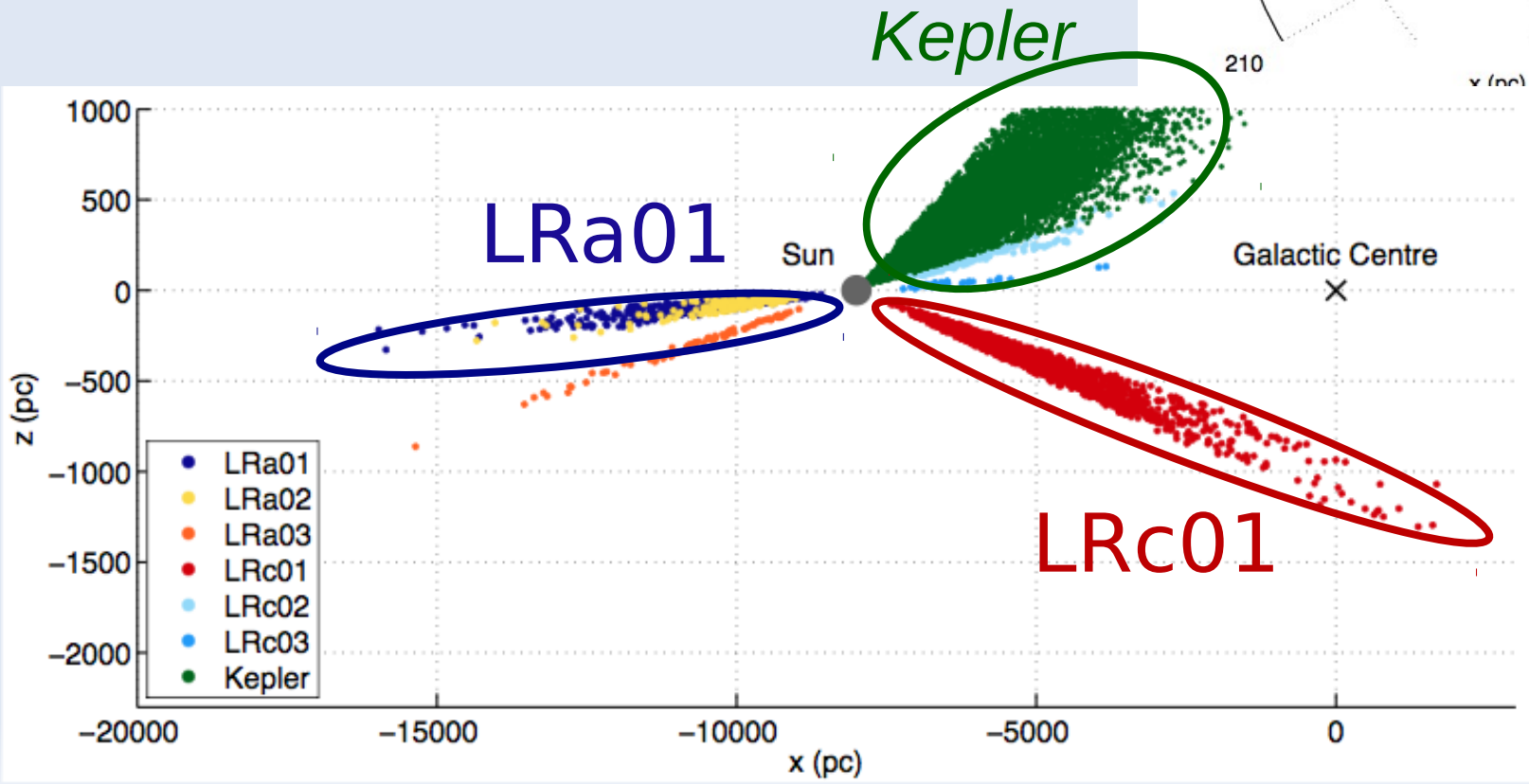
Interpretation: mostly due to larger heights of LRc01 implying larger ages

Present asteroseismic samples

CoRoT LRs: ~3000 stars
Mosser et al. 2010

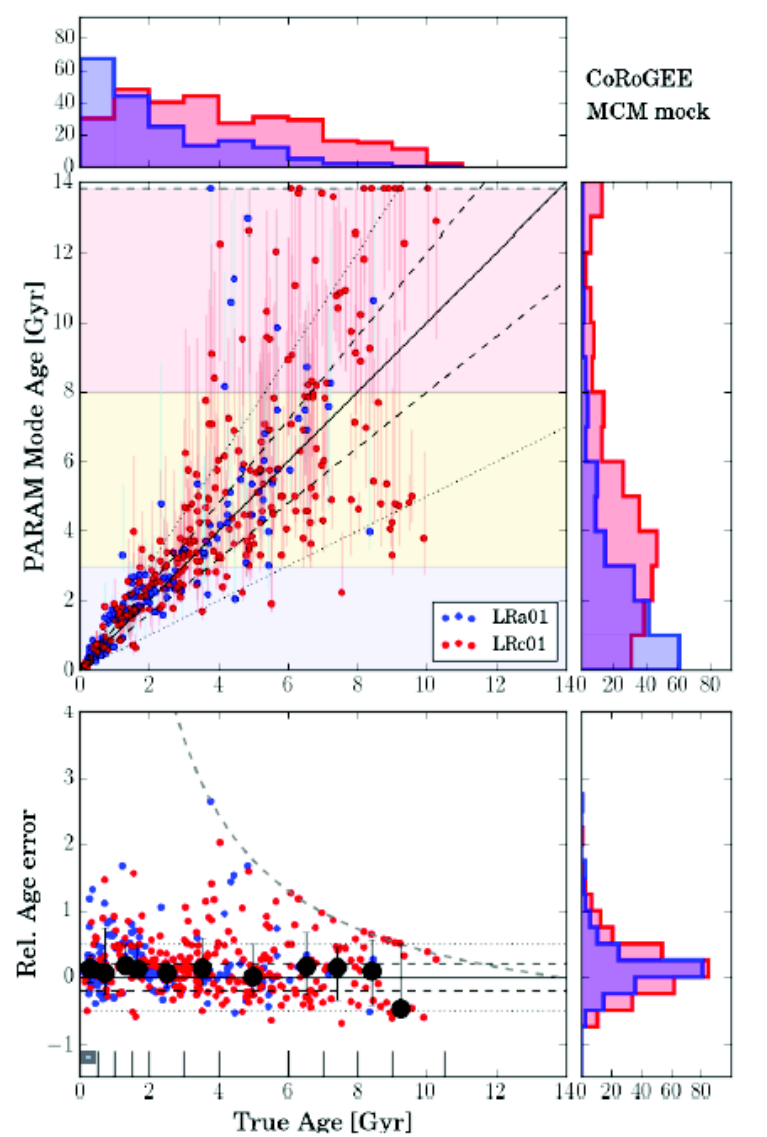
Kepler data: ~15000 stars
Hekker, Stello, Mosser et al., 2011-2015



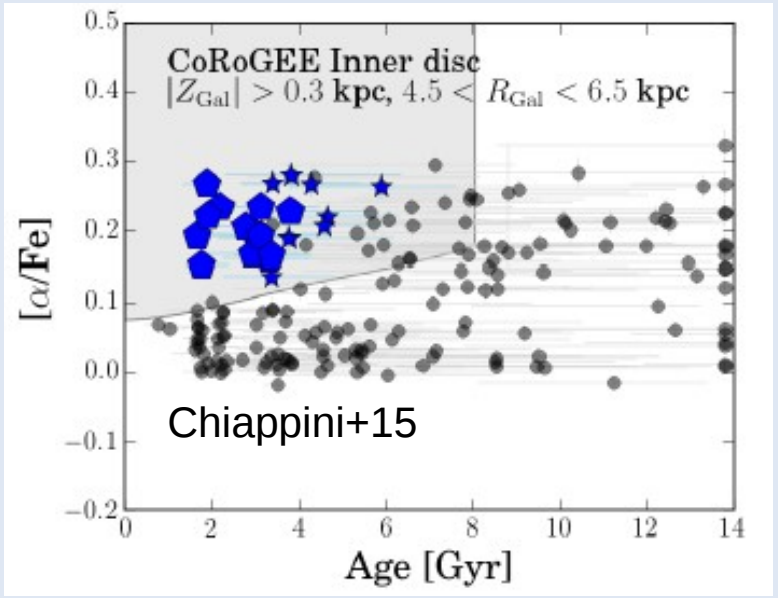


CoRoT results

- Two fields have a simple selection function
- Easily simulated from chemo-dynamical models (Anders+16)

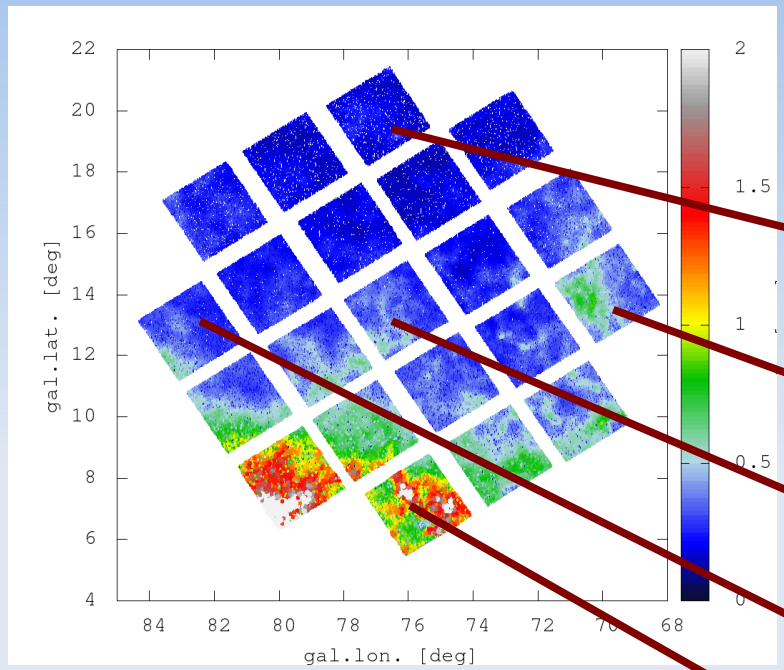


Evidence that inner disk stars migrated to Solar Neighborhood (Anders+15)



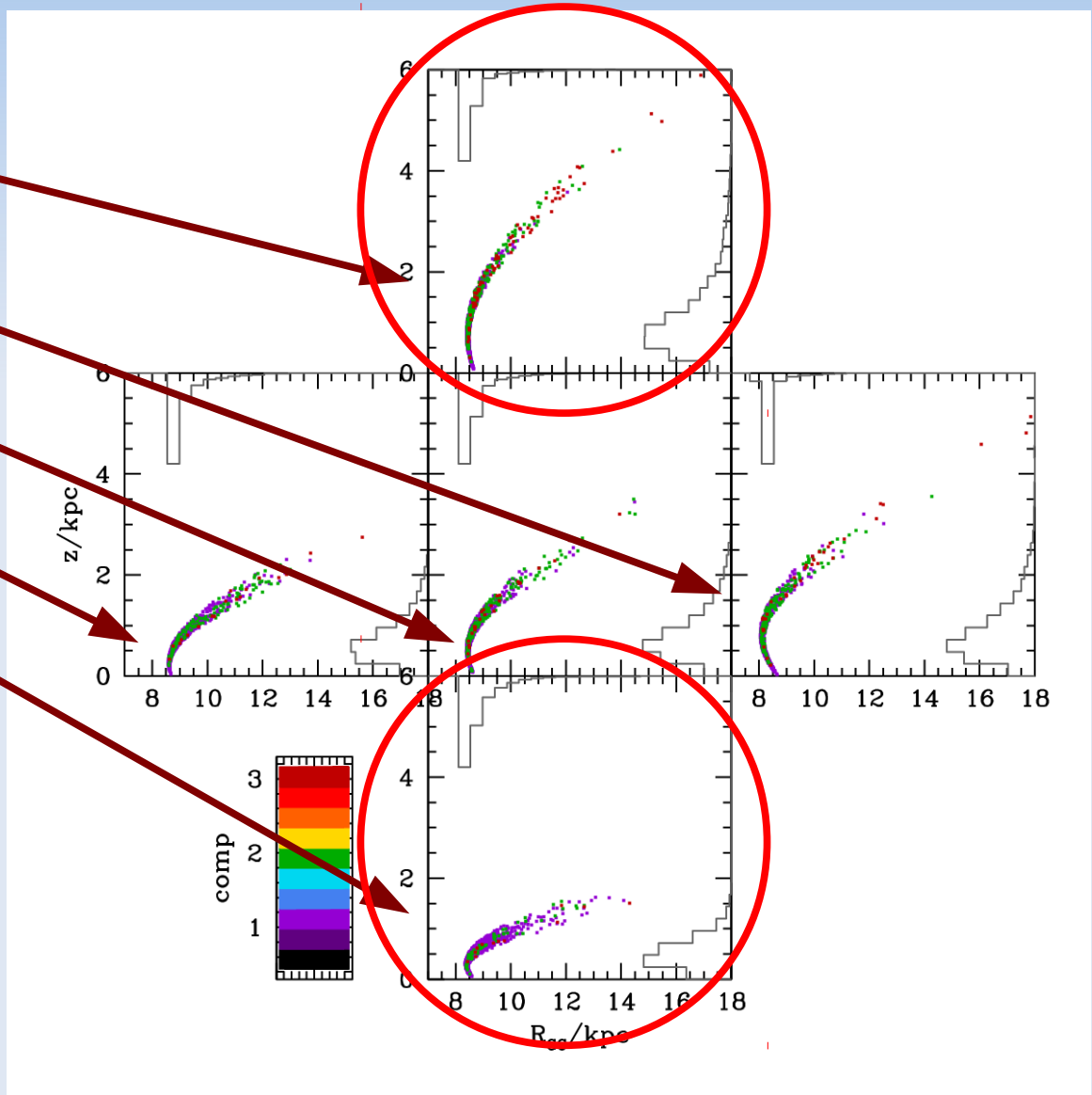
Alpha-enhanced **young** stars

Kepler field: ideal for z-structure



Taking 1000 giants/field
Kepler<16 mag

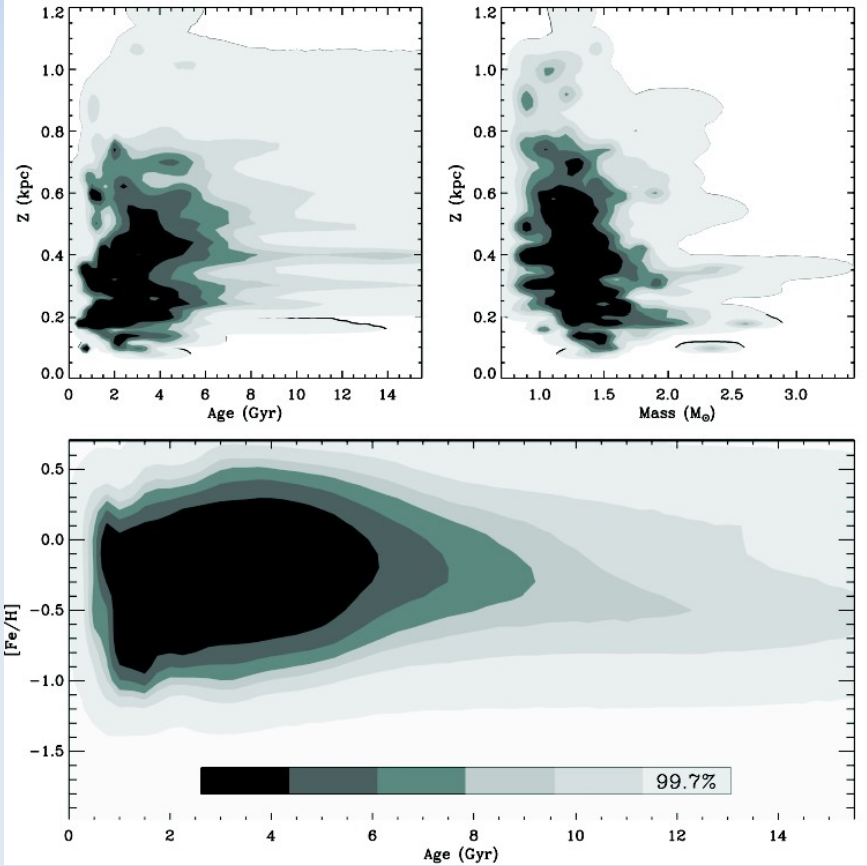
Sampling thin+thick disks at the Solar Circle,
+ a bit of halo within 15 kpc



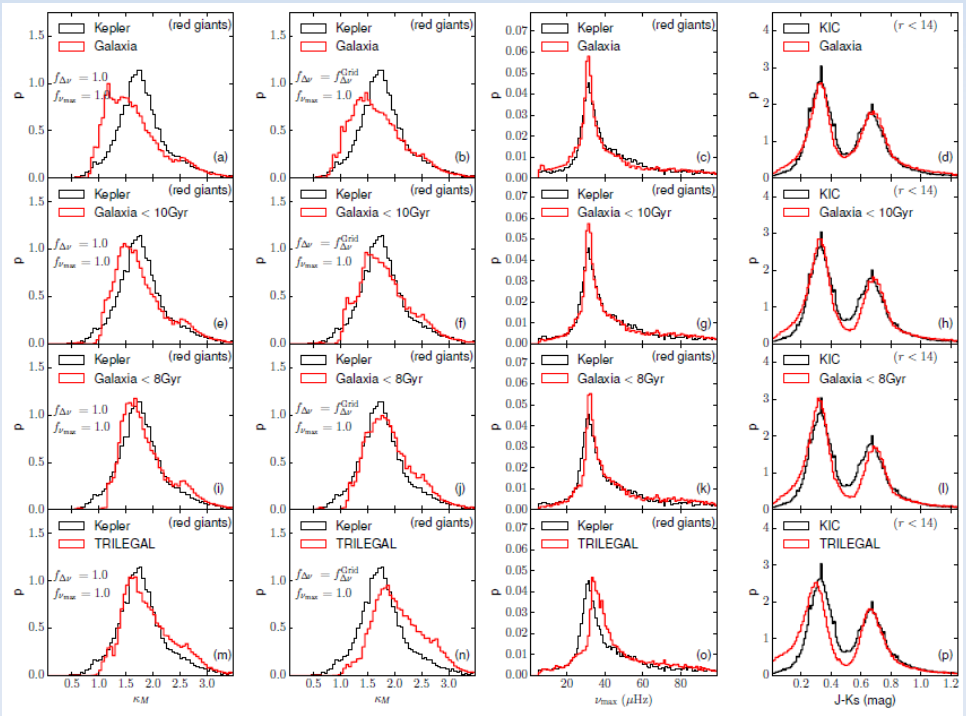
Kepler results

- Results depend on simulating a very complicated selection function
- Attempts to *measure* it (Hekker+13) impeded by Kepler's failure

Nonetheless:



First attempt to derive the age x scale height relation from SAGA (Casagrande+16)

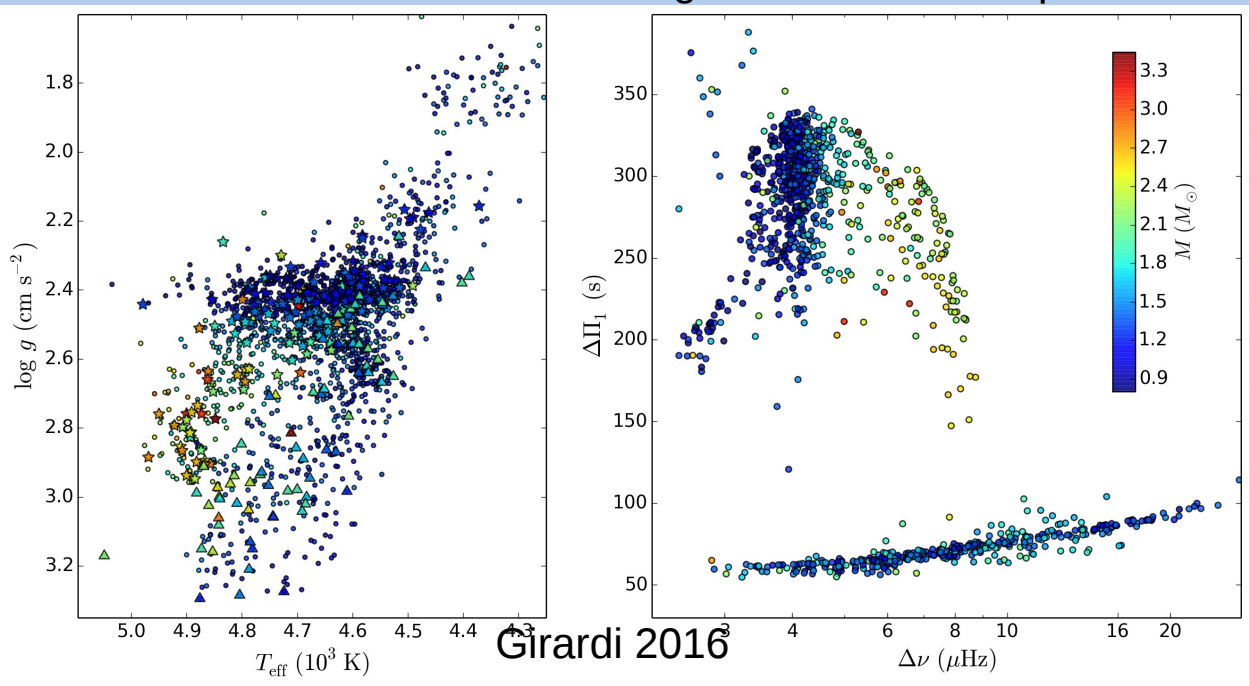


First quantitative tests on Milky Way star count models, now using age contraints (Sharma+16)

Kepler results

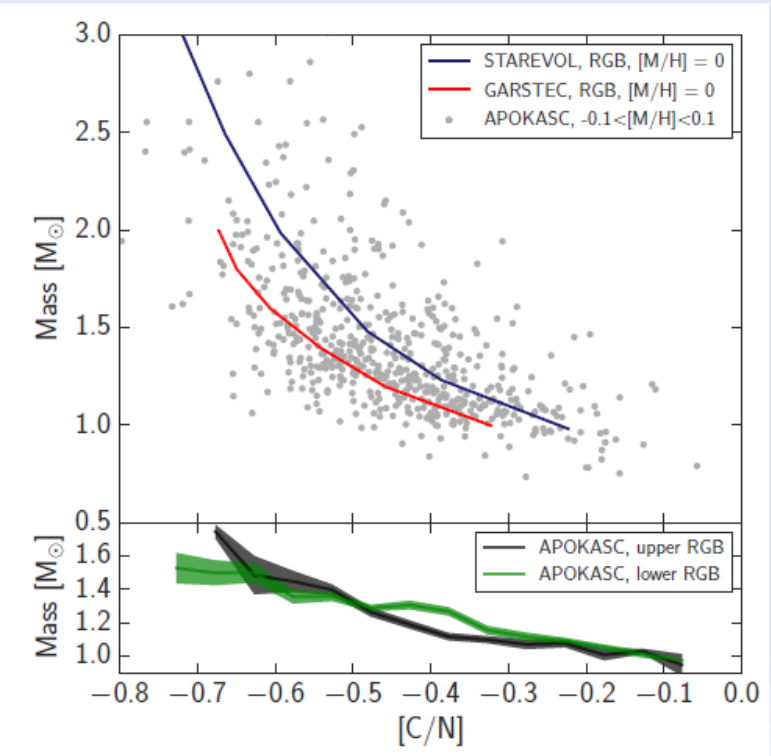
And many other exciting results:

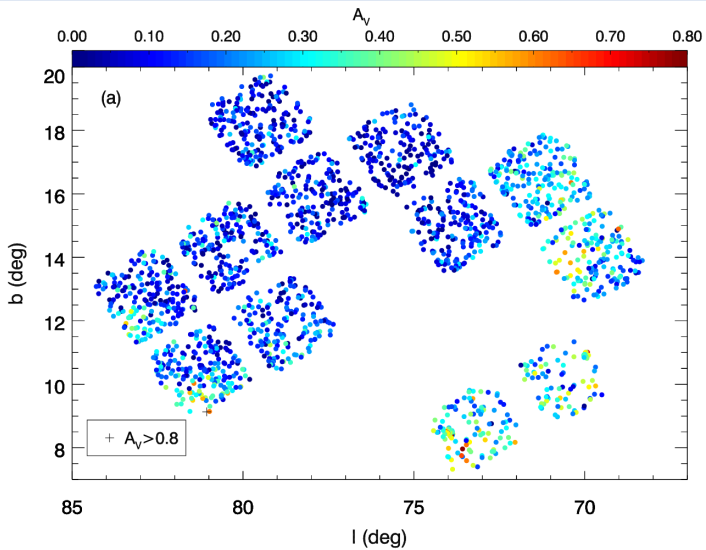
APOKASC stunning views of red clump+SRC:



Girardi 2016

Empirical [C/N] X age relation (Martig+16)



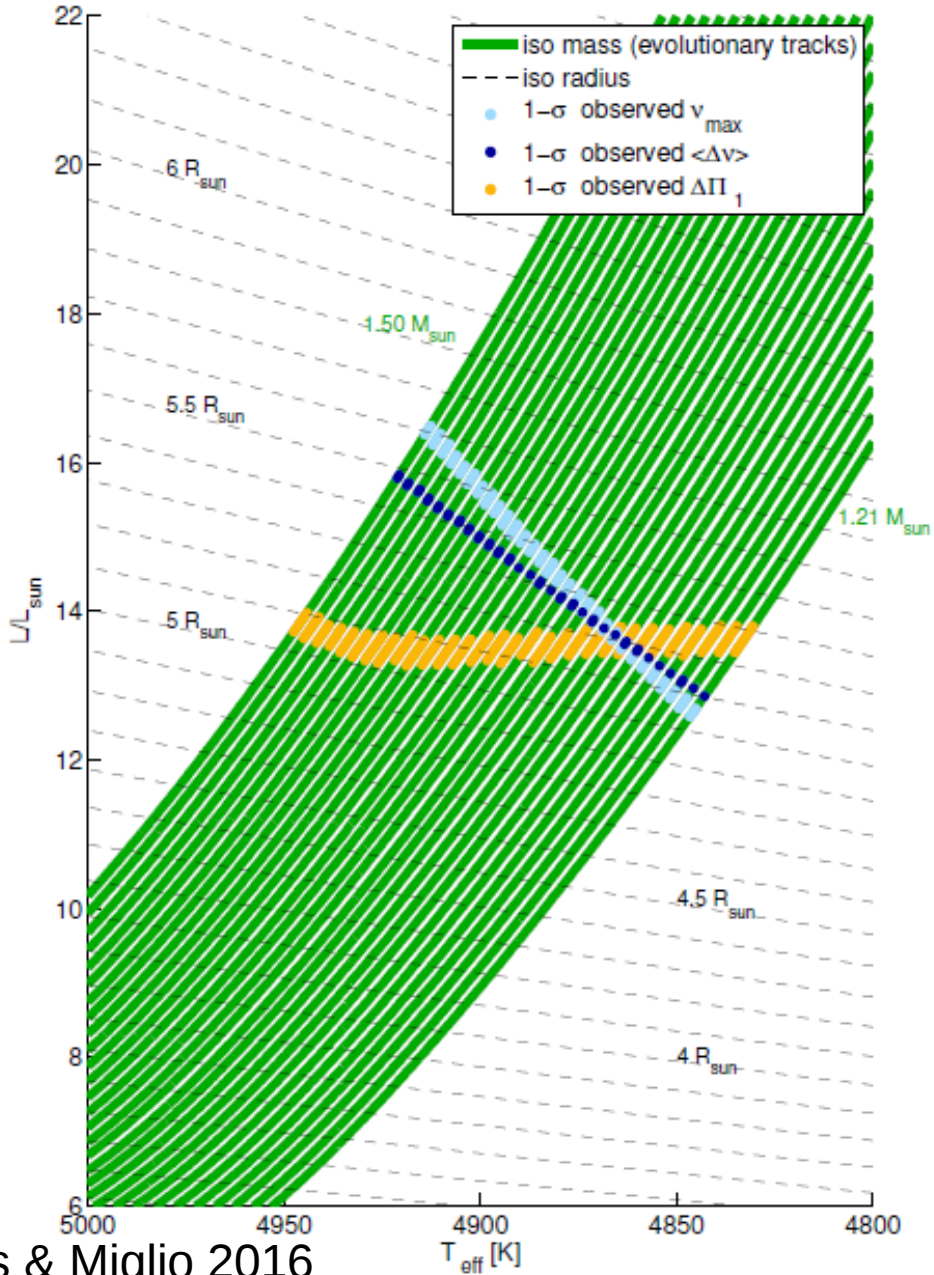


3D reddening maps (Rodrigues+14)

Kepler results

This is only the beginning:

- Homogeneous HR spectroscopy included ~20% of *Kepler* sample (it will be ~70% in next APOKASC catalog)
- Additional asteroseismic parameters will further decrease mass errors



Davies & Miglio 2016

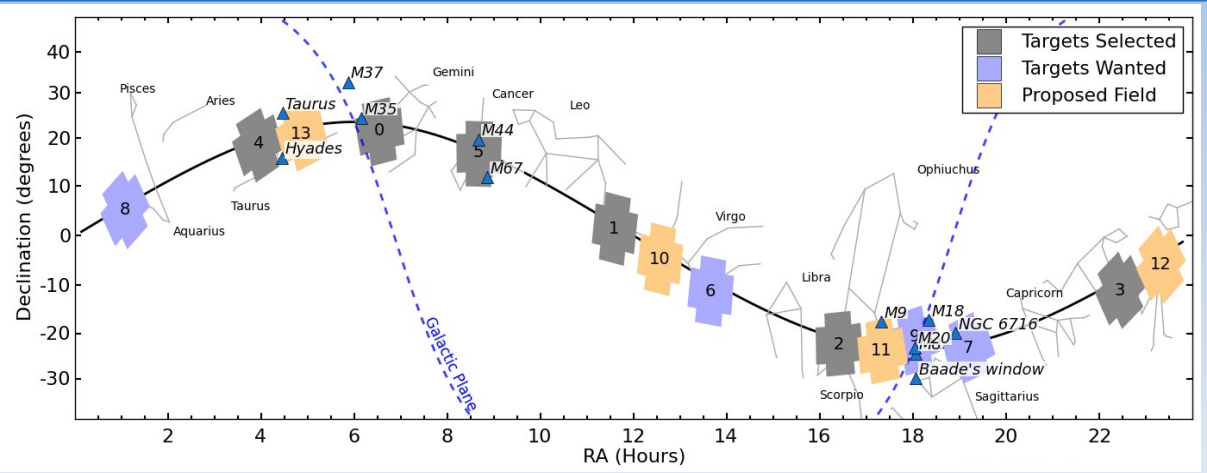
Main international consortia

- CoRoT – with Poretti, Montalban, ...
- KASC – open group since ~2014, many Italians involved
- AsteroSTEP – a ”calibration effort for Galactic Archaeology”, PI Andrea Miglio (includes Padova, Pisa, Roma, Bologna, Brera, Trieste people)

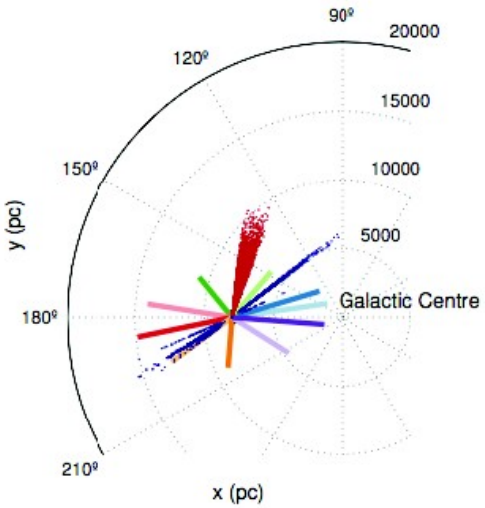
The asteroseismology + spectroscopy connection:

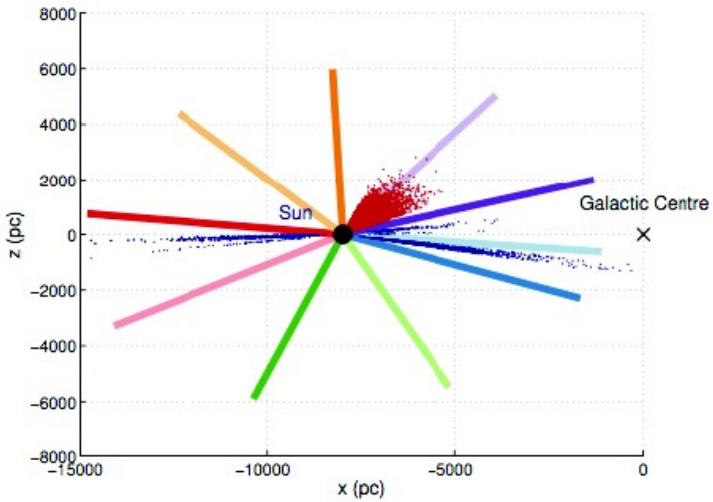
- SDSS/APOGEE + KASC (Kepler+K2) agreement → APOKASC, APOKASC-2, Padova (Girardi, Rodrigues, Moltalban) involved
- SDSS/APOGEE + COROT agreement → COROGEE (Montalban on Board)
- Gaia-ESO survey + COROT agreement (Montalban on Board + Zaggia, Momany)
- SAGA – based on Stroemgren photometry, Teramo (Cassisi, Pietrinferni) involved

The nearby future: K2



Ongoing and working fine for asteroseismology (Stello et al., Miglio et al. 2016)





CoRoT fields *Kepler* field

K2 Fields:

- F0 Near Galactic Anti-center M35, NGC2304
- F1 North Galactic Cap
- F2 Near Galactic Center M4, M80, M19, Upr Sco, rhoOph
- F3 South Galactic Cap
- F4 M45 (Pleiades), NGC1647, Hyades Taurus
- F5 M44 (Beehive), M67
- F6 North Galactic Cap
- F7 Near Galactic Center, NGC6717
- F8 South Galactic Cap, Uranus
- F9 Galactic Center, Baade's Window

Fig. 1.

Location in the Galaxy of stars with seismic constrcints observed by CoRoT, Kepler and in the fields monitored by K2 (taken from Miglio et al. 2015)

The future

TESS:

- NASA mission, INAF does not count

PLATO:

- INAF strongly involved (see tomorrow's talk)
- Asteroseismology is recognized as the basis for planetary systems characterization. Should include evolved stars since 1- they also contain planets, 2- strong contraints on MS evolution
- But number of giant targets still not written on paper! (hard to keep the interest of stellar people in this way)

Sinergies

- Gaia (next talk)
  - new parallaxes will reduce errors in asteroseismic R and hence in ages by <50%,
  - proper motions will add new interesting correlations
  - more importantly: asteroseismic samples will provide <u>the most robust calibrators</u> for Gaia-derived ages!
- LSST, Euclid, WFIRST: precise photometry and astrometry at faint limits, with indirect inference of ages, metallicities and distances – *relations calibrated with asteroseismic samples will then be applied overall across the Galaxy*

Survey	Area (deg^2)	Depth (5-sigma, AB)	
UKIDSS-LAS	4000	Ks=20.3	
VISTA-VHS	20,000	H=20.6	now
VISTA-VIKING	1500	H=21.5	
VISTA-VIDEO	12	H=24.0	
Euclid, wide (5 yr.)	15,000	H=24.0	2020-2024
WFIRST, deep (1 yr.)	2700	F3=25.9	2024
WFIRST, wide (1 yr.)	(4730)	F3 = 25.3-25.5	
LSST-deep-wide-fast (10yr)	18000	r~27.5	2022-2032

A future in INAF?

- Ensemble asteroseismology is ground-breaking science – unknown and unforeseen 10 years ago, when the goal was just to find planets
- Many foreign institutes/observatories reacted quickly, hiring and starting follow-up surveys. Got at least two ERC grants.

  And INAF? This is ***NOT*** the kind of thing that appears among ”INAF Big Projects”
- Main actors in this field have PhDs between 2000 and 2010, including some Italians abroad (Miglio, Casagrande). Was Italy any attractive to them? Will we also miss the next generation?
- Fertile ground for development in present stellar evolution groups, *if funded*. Any hope?