Red Giant Seismology

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STELLAR ASTROPHYSICS CENTRE

Content of the talk

- The role of Red Giants in Astrophysics
  - Age of stars
  - Sensitive to stellar physics
- Red Giants in detached Eclipsing Binary systems
  - Accurate stellar parameters
- Stellar clusters with Red Giants
  - Same age and metallicity for all stars
- Nearby Red Giants with measured radii
  - Extra constraints on radius and luminosity
- Future directions

- Goal: Improve determination of stellar masses to an accuracy of a few percent and correspondingly stellar ages from the present 30% to perhaps 10% accuracy.

How to obtain accurate stellar parameters: Mass *M* and radius *R*

The most accurate results come from studies of detached binary systems. Recent results (Brogaard et al. 2018) for three detached eclipsing binary systems with a Red Giant component observed by *Kepler* give the following values:

Object	Mass M	Radius R
KIC 7037405	1.170(20)	14.000(93)
KIC 9540226	1.378(38)	13.06(16)
KIC 9970396	1.178((15)	8.035(74)

which corresponds to mass uncertainties of 1.7%, 2.8% and 1.3% and radius uncertainties of 0.7%, 1.2% and 0.9%. Gaulme et al. 2017 reaches 3-4% uncertainties.

Angular radii from interferometry could lead to as good a precision, but the parallax or limb darkening is often the dominating source of uncertainty. For bright stars (<5.7) GAIA is not likely to help.

Problems with mass and age determination

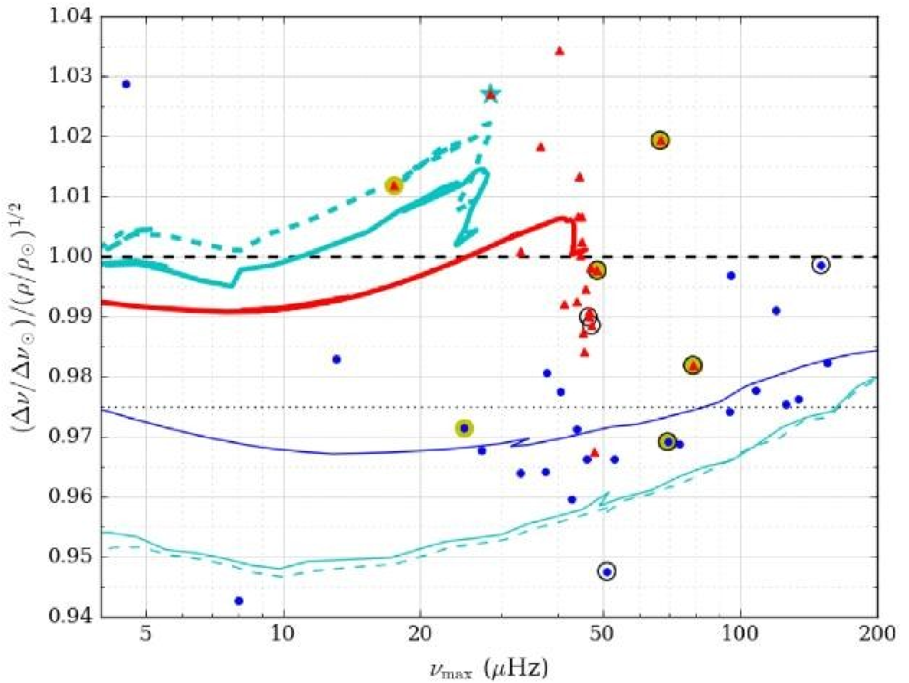
- Corrections needed to scaling relations (mass, radius)
- Problems with the effective temperature scale T_{eff}
- Binary stars (rebirth of mergers)
- Rotation on Main Sequence (mixing and increase of age, changes early evolution)
- Core mixing (increases age)
- Stellar modeling differences (data, physics)

Empirical test of scaling relations in NGC 6819

Handberg et al. 2016

RGB stars, 1.6Msun track

RC stars, 1.6Msun track



From: NGC 6819: testing the asteroseismic mass scale, mass loss and evidence for products of non-standard evolution

Mon Not R Astron Soc. 2017;472(1):979-997. doi:10.1093/mnras/stx1929

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Stellar Clusters with Red Giants with seismic measurements

Instrument	Cluster	Age	Metallicity
Kepler	NGC 6791	8 Gy	[Fe/H] = 0.30
Kepler, Handberg et al. 2016	NGC 6819	2.5 Gy	[Fe/H] = 0.02
Kepler, Sandquist et al. 2016	NGC 6811	1.05 Gy	[Fe/H] = -0.09
CoRoT	NGC 6633	500 My	[Fe/H] = -0.09
K2, Stello et al. 2016	M 67	4 Gy	[Fe/H] = 0.01
K2, Miglio et al. 2016	M 4	13 Gy	[Fe/H] = -1.1
K2, SONG Arentoft et al. 2018	Hyades	600-800 My	[Fe/H] = 0.15

Colour-Magnitude Diagram for NGC 6811

Sandquist et al. 2016

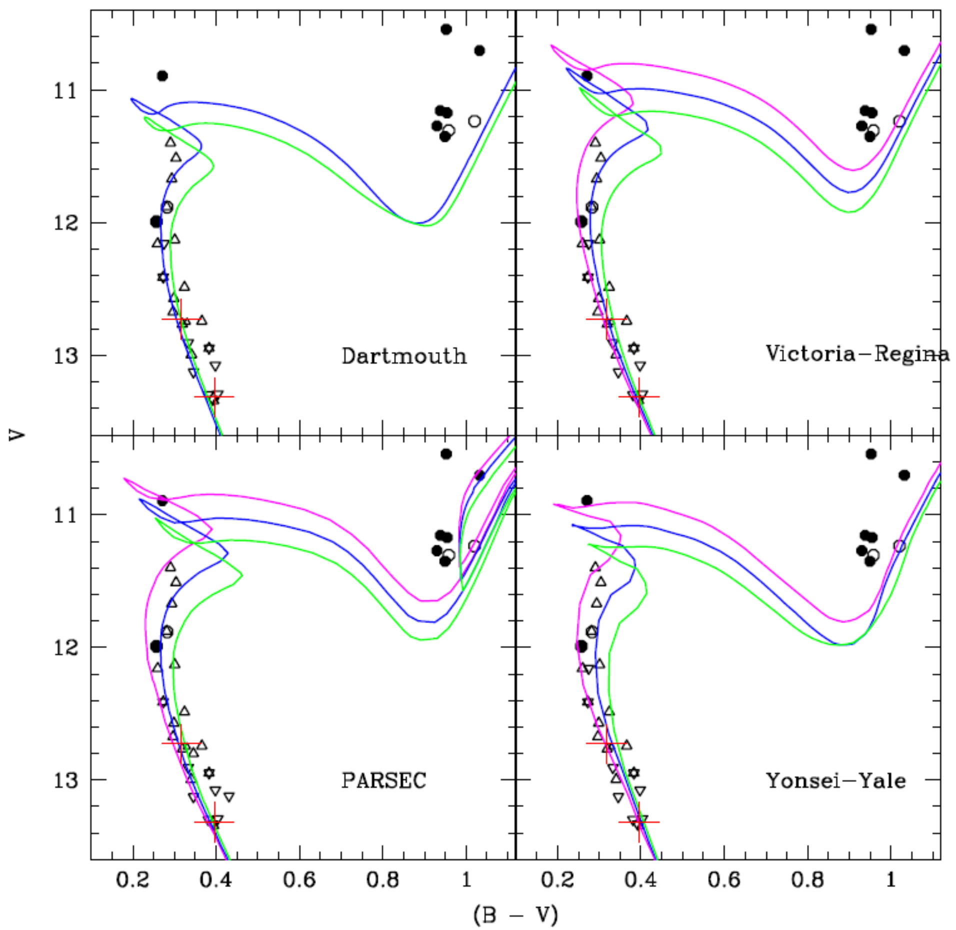

Figure 11. CMD comparison for fixed reddening [$E(B-V) = 0.07$], distance modulus [$(m-M)_V = 10.47$], and metallicity. Model isochrones have ages of 0.9 Gyr (magenta), 1.0 Gyr (blue), and 1.1 Gyr (green) for Dartmouth ($Z = 0.0147$), Victoria-Regina ($Z = 0.0150$), PARSEC ($Z = 0.0147$), and Yonsei-Yale ($Z = 0.0147$) isochrones. Points have the same meaning as in Figure 8.

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M-R diagram for NGC 6811

Sandquist et al. 2016

The Astrophysical Journal, 831:11 (36pp), 2016 November 1 Sandquist et al.

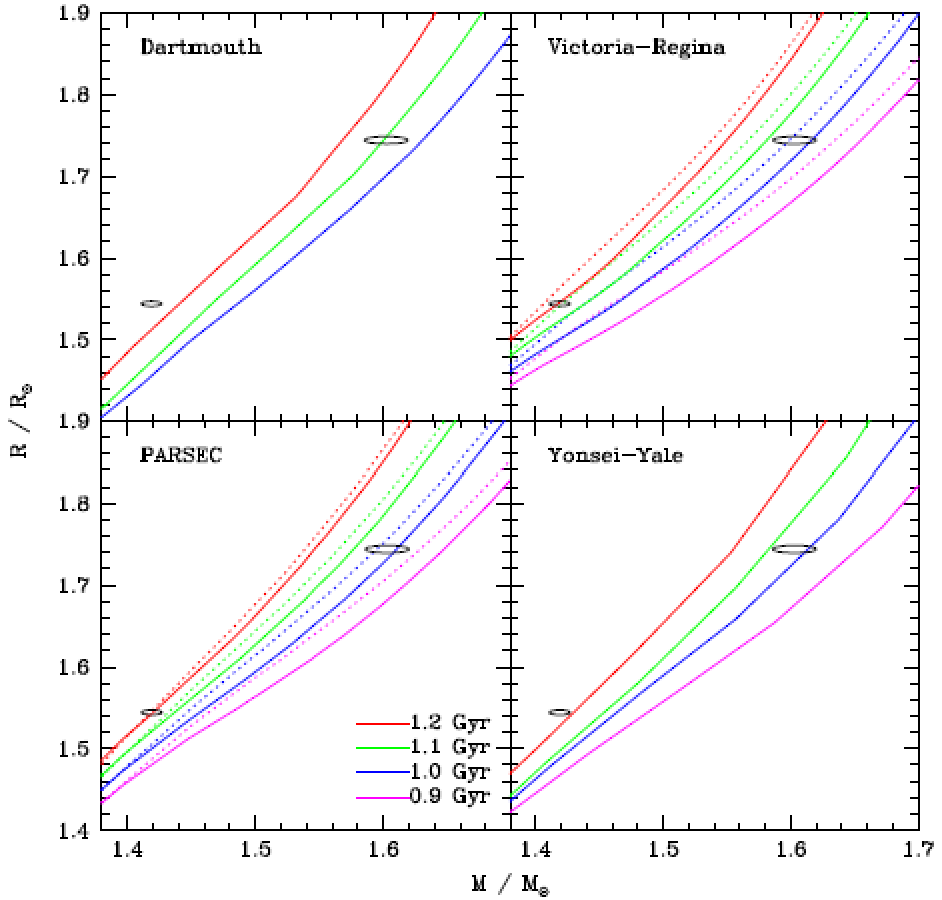

Figure 10. Mass–radius plot for the members of KIC 9777062 with 1σ uncertainty ellipses. Models have ages of 0.9, 1.0, 1.1, and 1.2 Gyr (from bottom to top) for Victoria-Regina (VandenBerg et al. 2006), PARSEC (Bressan et al. 2012), and Yonsei-Yale (Demarque et al. 2004) models, while the Dartmouth (Dotter et al. 2008) models have ages of 1.0, 1.1, and 1.2 Gyr. Solid line isochrones use $Z \approx 0.0137$ in all panels but Victoria-Regina. In the PARSEC panel, the dotted lines show $Z = 0.0167$. In the Victoria-Regina panel, our preferred Z is midway between the solid and dashed lines ($Z = 0.0125$ and 0.015, respectively).

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Colour-Magnitude Diagram for NGC 6819

Handberg et al. 2018

Peakbagging NGC 6819 987

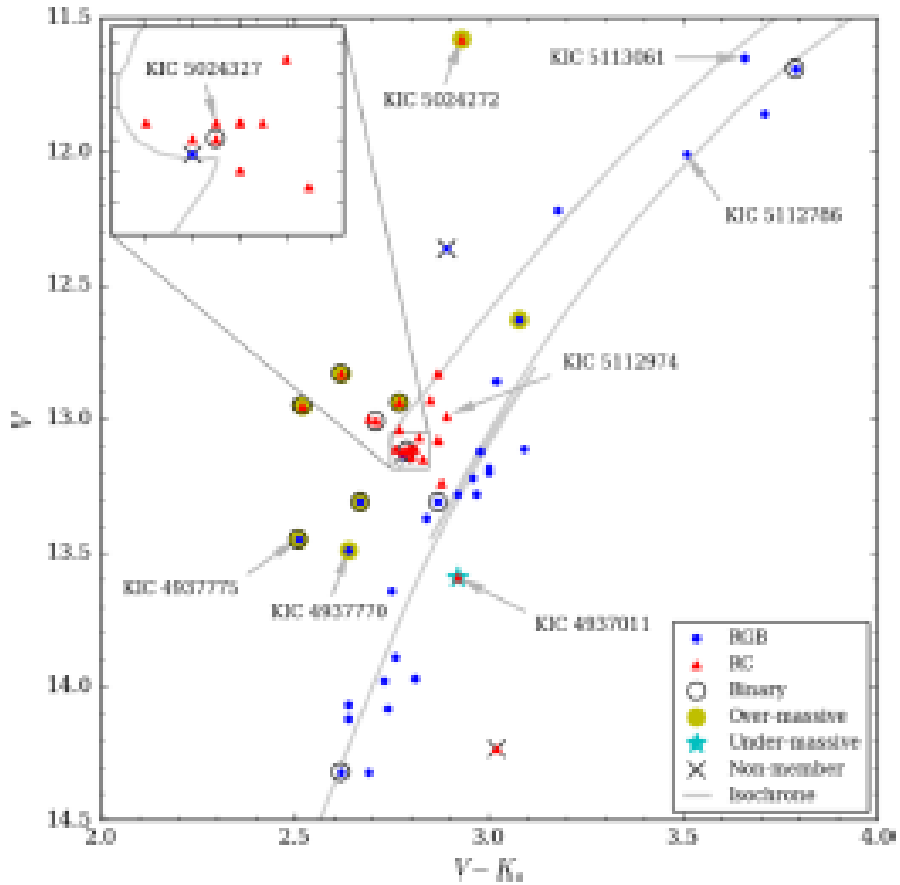

Figure 3. Colour–magnitude diagram of the observed giants in NGC 6819. The isochrone is from PARSEC (Bressan et al. 2012).

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Nearby Red Giants with seismic parameters

With the SONG network (even a single site) we now have a ground based observing facility, where results comparable to what one can get from space can be obtained.

The luminosity fluctuations obtained from space have a much better duty cycle and multiplex possibilities (many stars simultaneously), but groundbased velocity observations have a better S/N and go to lower frequencies.

Stellar Observations Network Group

The SONG dome and container at Izana, Tenerife, in operation since spring 2014. China and Australia in preparation!!

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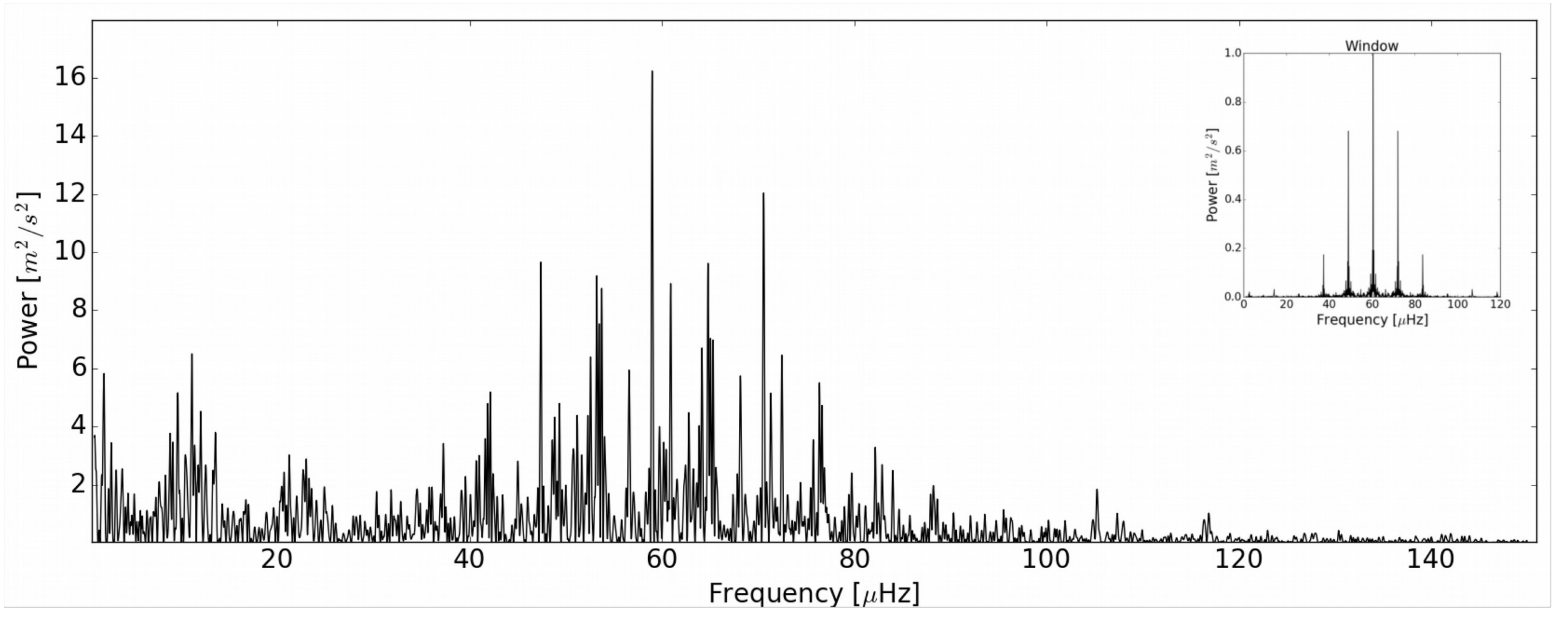
Power spectrum of 46 LMi



Frandsen et al. 2018

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The Red Giant 46 LMi

For this nearby star we have an angular diameter and a parallax:

Angular diameter 2.54 +- 0.03 mas (Nordgreen et al. 1999)
Parallax 34.38 +- 0.21 mas (van Leuwen 2007)

leading to a radius *R* = 7.95 +- 0.11 Rsun.

With SONG observations, over a time period of 55 days with some gaps, using the interferometric radius as a constraint we find a mass for the star of *M* = 1.09 +- 0.04.

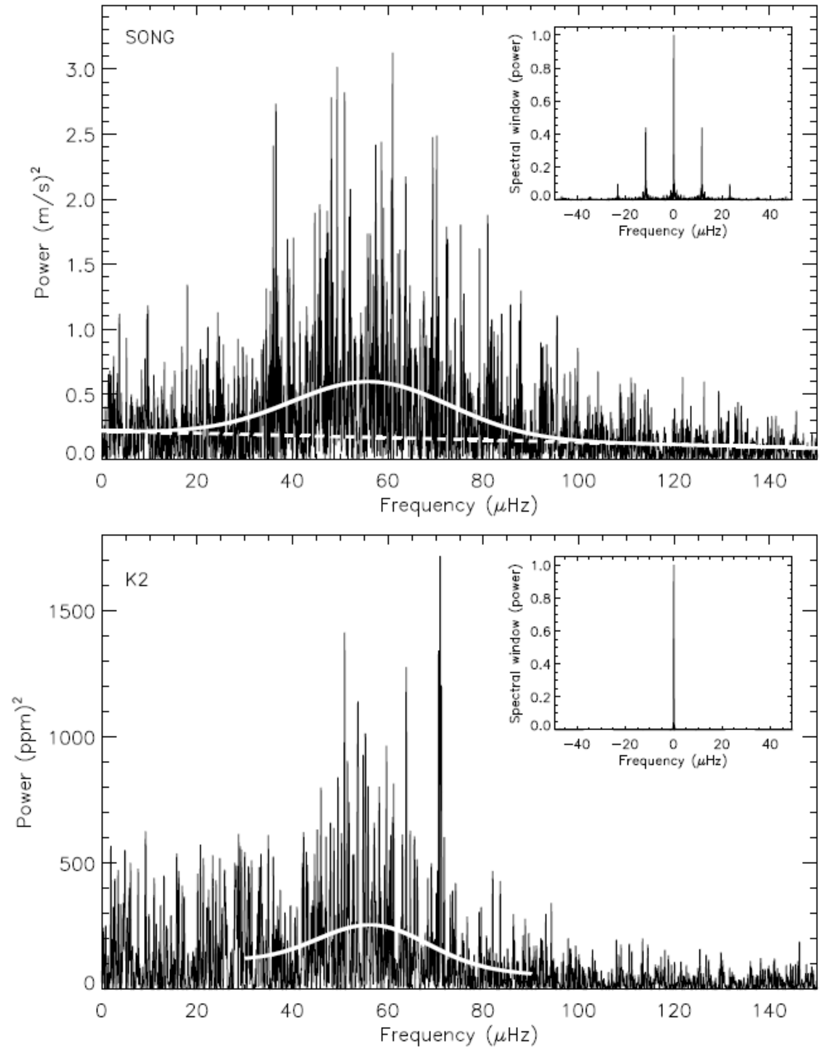
The analysis of the power spectrum of 46 LMi is done using *Kepler* stars as reference targets stretching the frequency of the power spectrum with a scale factor *s,* until maximum correlation is found. This *s* factor is then applied to the large separation of the reference star found in the APOKASC catalog.

The Hyades Cluster Red Giant eps Tau

SONG

K2

Arentoft et al. 2018



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The Red Giant eps Tau

This giant is of particular interest since it is a member of the Hyades cluster. In addition both groundbased (SONG) and space (K2) observations have been obtained.The SONG data alone suffers from a bad window function, but the K2 data enables a solution of the alias problem.

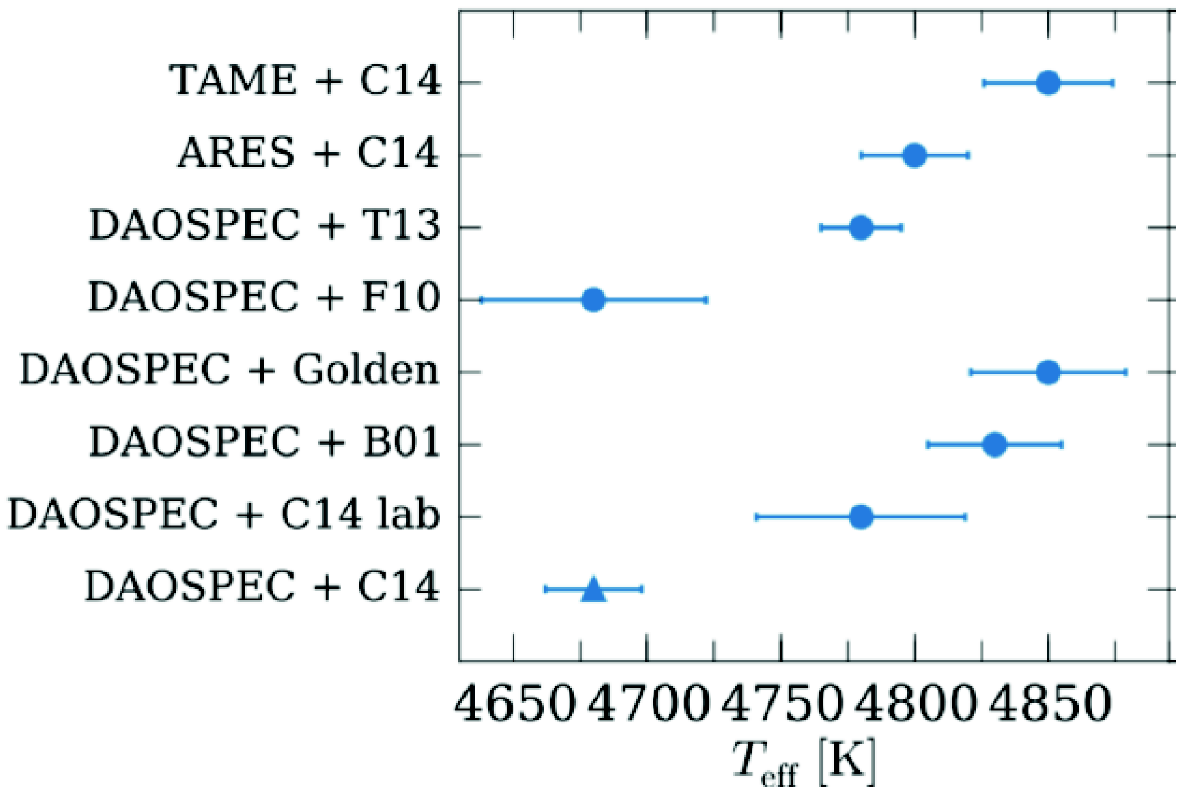
Analysing the SONG data the maximum frequency delta nu and the large separation numax can be determined and, using corrections to scaling relations (Rodrigues et al. 2017), a mass M = 2.458+-0.073 is found, slightly lower than previous determinations.

The result indicate that *eps Tau is in the RGB phase*, which is in contrast to the conclusion from the CM diagram, which indicates that *the four bright RGs in the Hyades are all Red Clump stars*. Further observations and analysis are required to solve the conflict.

The delta P can not be found, and other discriminators between the RGB and RC status do not lead to answers either.

Temperature from spectroscopy of a Red Giant

D. Slumstrup 2018



Spectroscopic temperatures are inaccurate!

Some conclusions about SONGs role in stellar physics

- Due to its flexible scheduling SONG is the perfect instrument for measuring accurate parameters *R* and *M* in binary systems including a RG with magnitudes down to V=9 mag. That will cover most systems detected by K2 or TESS

- On bright RGs SONG can produce radial velocity power spectra with a S/N comparable to the S/N in *Kepler and TESS* intensity power spectra.

- SONG can contribute to the determination of corrections to the asymptotic relations and/or the temperature scale.

- With parallaxes from GAIA (DR2?) and angular diameters from interferometry we can determine the stellar parameters (except metallicity!!) without spectroscopy.

References

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