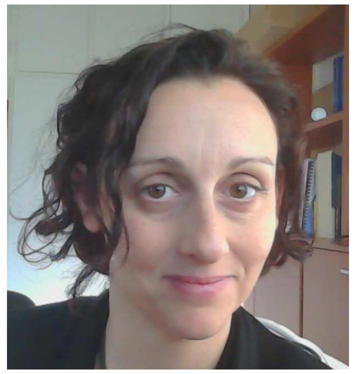


ocreevey@oca.eu

Seismic Inference of 58 Stars using full-length Kepler data sets

Orlagh Creevey, Travis Metcalfe, David Salabert, Mathias Schultheis, Rafael Garcia, Savita Mathur, Frédéric Thévenin

Observatoire de la Côte d'Azur, Nice, France; Space Science Institute, Boulder, CO, USA; CEA, Saclay, France

We present stellar properties of 58 stars from a seismic inference using full-length data sets from Kepler (mass, age, radius, distances). These stars comprise active stars, planet-hosts, solar-analogs, and binary systems. By employing the frequency separation ratios, we test the applicability of the Kjeldsen et al (2008) empirical surface correction. Ensemble analyses exhibit interesting trends, for example, with mixing-length parameter or effective temperature. We present ages of binary components and characterise some planetary systems.

1. Observations and Methods

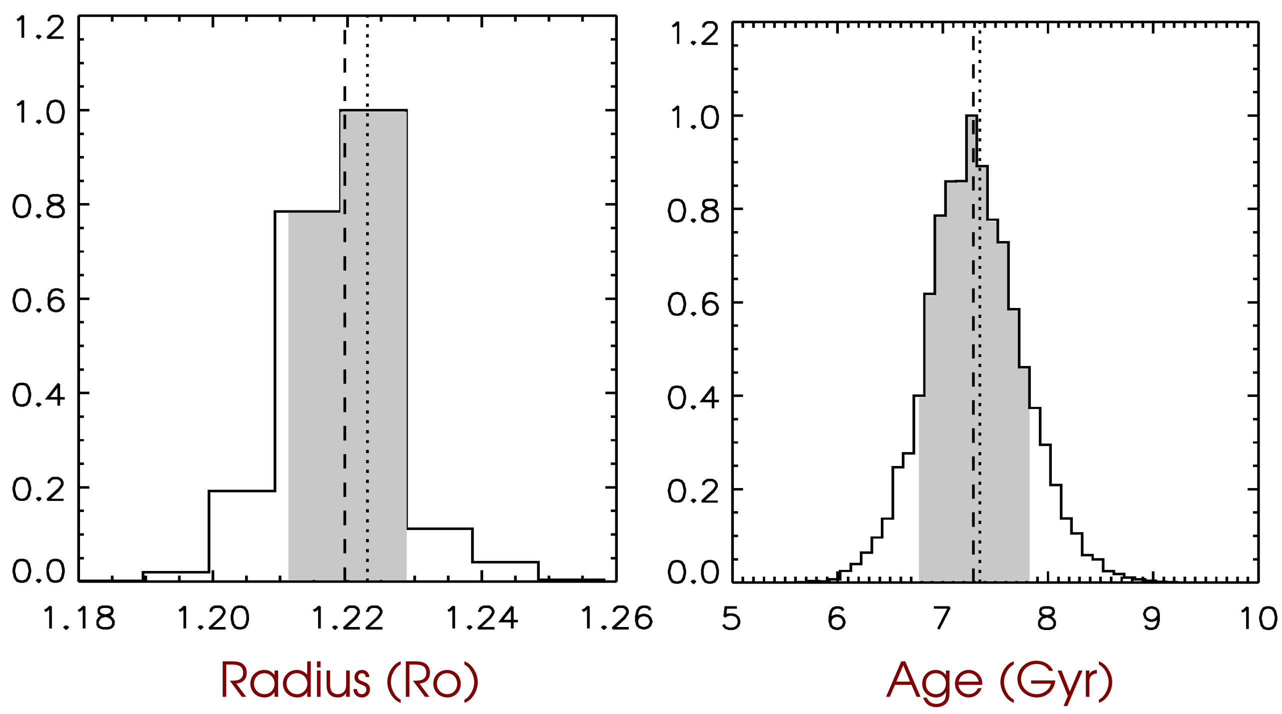


Fig 1: Probability density distributions of stellar radius and age for KIC12069424. Shaded area denotes 68% area, with median (dashed) and AMP best model (dotted).

AMP (amp.phys.au.dk, Metcalfe, Creevey & Christensen-Dalsgaard, 2009) is a free software that uses an automatic approach (genetic algorithm) to model asteroseismic data. In Sept 2015 we included an option to model the frequency separation ratios exclusively (Fig3), and we updated the statistical analysis to derive reliable uncertainties that reflect a broad range of input stellar unknowns, such as initial helium abundance (Fig1). Applying the updated version to the Sun reveals a 1.00±0.03 Mo star at an age of 4.54±0.28 Gyr (using star-like errors and Teff and (M/H) only). A comparison with existing literature values of radii, luminosities and distances (Fig2) supports our properties.

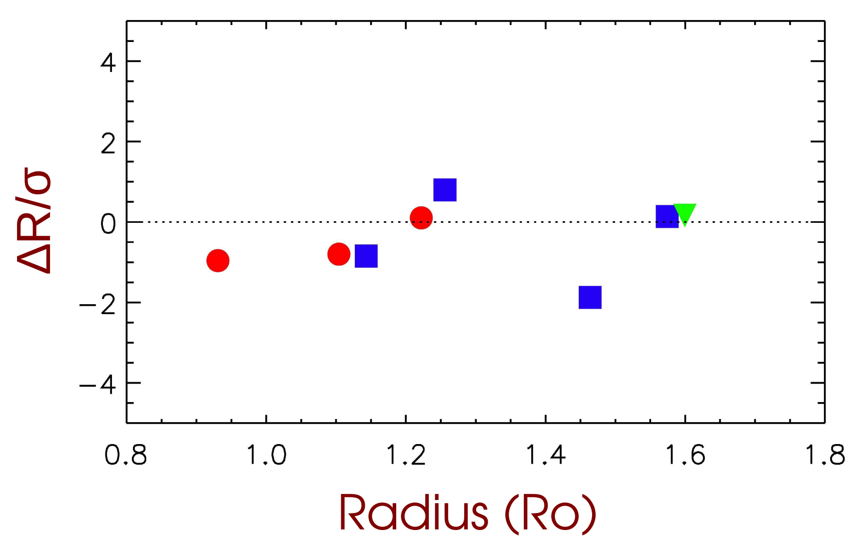
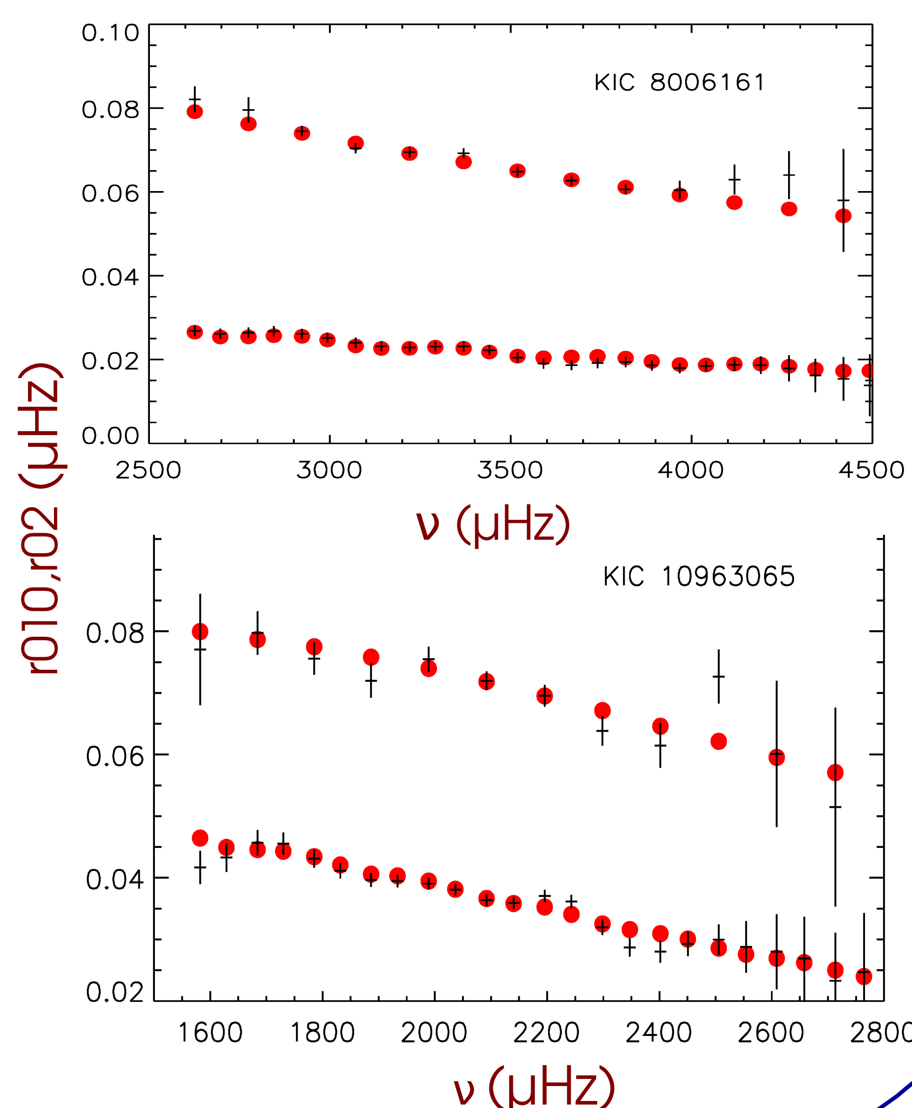


Fig2: Comparison of derived and existing literature radius estimates.

Fig3: Comparison of frequency models (red points) and data (crosses) for two stars.



2. Properties of Stars

A homogenous analysis was performed on the 58 stars (57 Kepler + Sun). Only the frequency ratios were analysed along with Teff and (M/H). A HR diagram shows the main properties of the sample (Fig4). The stars vary from 0.8 – 1.5 Mo with -0.9 <(Fe/H)< 0.3, and cover the main sequence and subgiant region only.

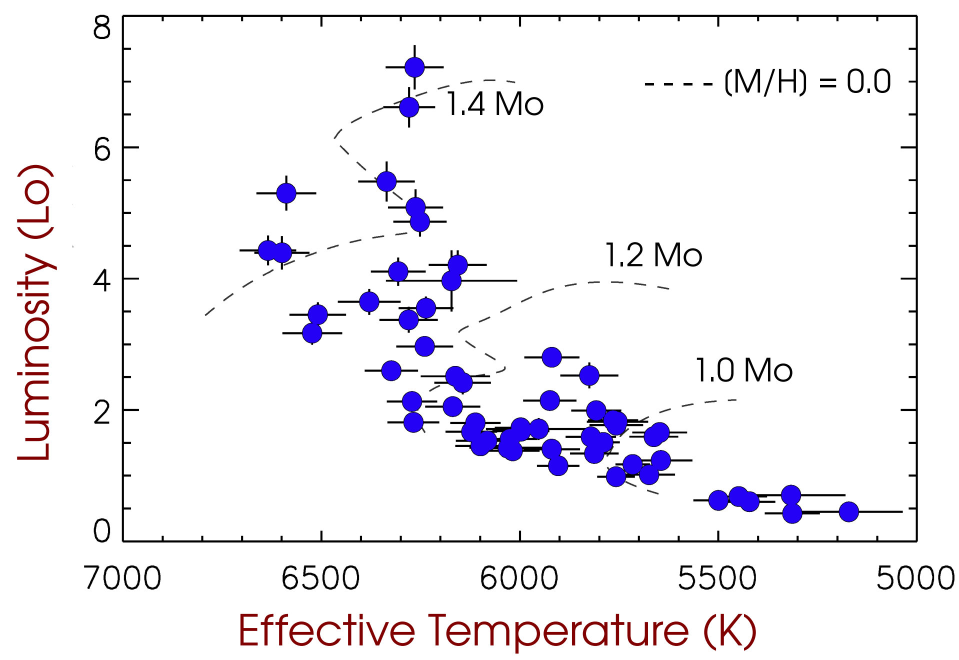
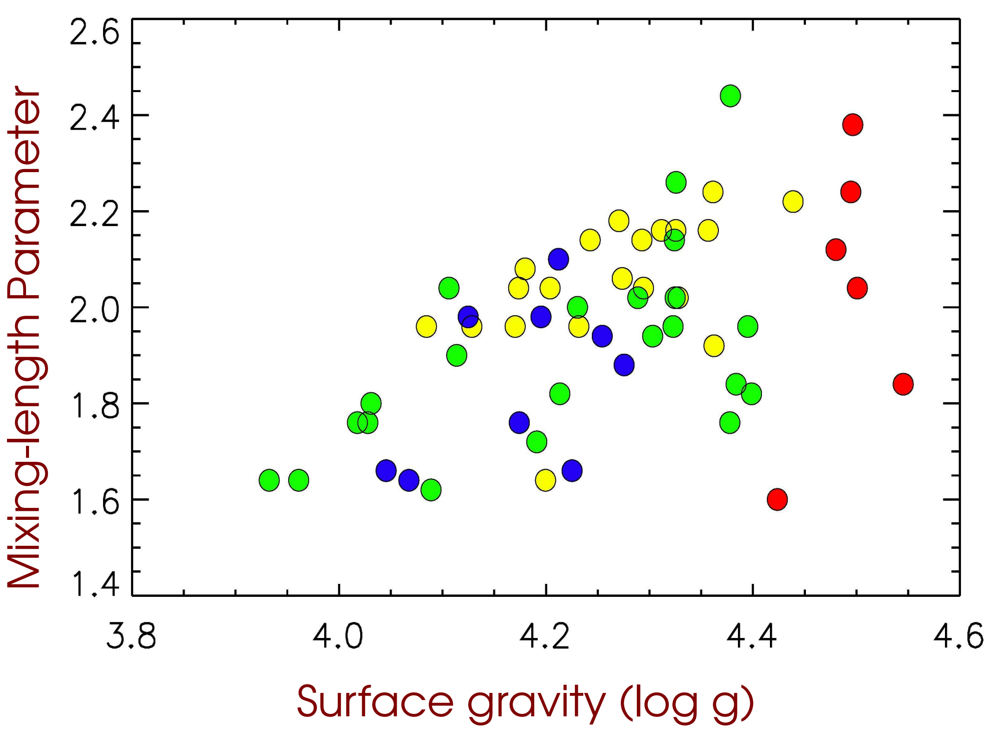


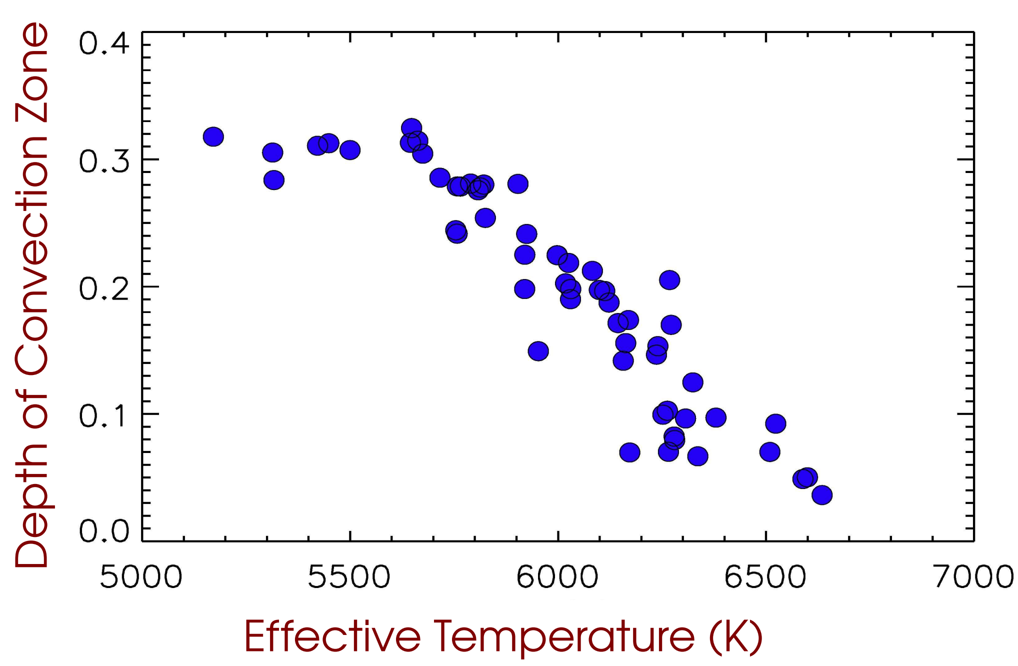
Fig4: HR diagram showing the properties of the sample



Using the ensemble of results we find trends among generally unconstrained parameters, such as mixing-length parameter, depth of the convection zone and spectroscopic parameters (Fig5ab).

Fig5a: Mixing-length parameter, as a function of logg and Teff (<5600 K, 5600 K < 6000 K, 6000 K < 6300 K, > 6300 K)

Fig5b: Depth of convection zone as a function of Teff



3. Surface Correction

Using 1D structure models leads to a systematic offset between the observed and model frequencies (Fig6), the so-called *surface term*, which arises from the inability to correctly model the super-adiabatic outer layers of the star. Kjeldsen et al. (2008) propose an empirical surface correction to directly model the seismic frequencies (Fig7). As the seismic frequency ratios used here are insensitive to the surface term, we can then test the validity of the proposed empirical correction (Fig8).

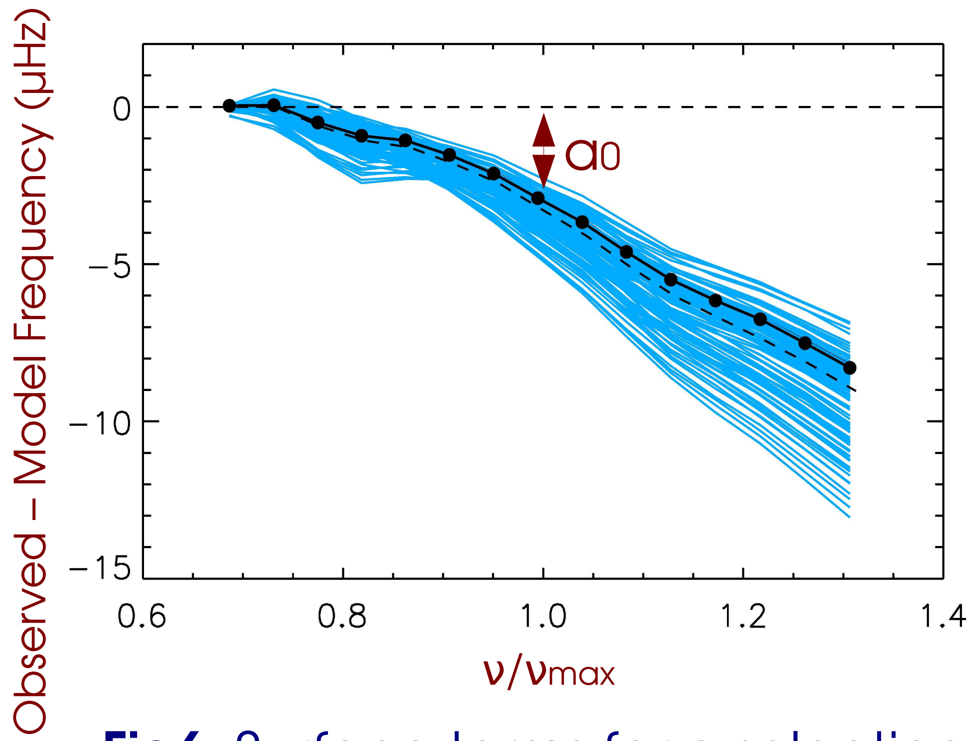


Fig6: Surface terms for a selection of 100 of 'good' solar models.

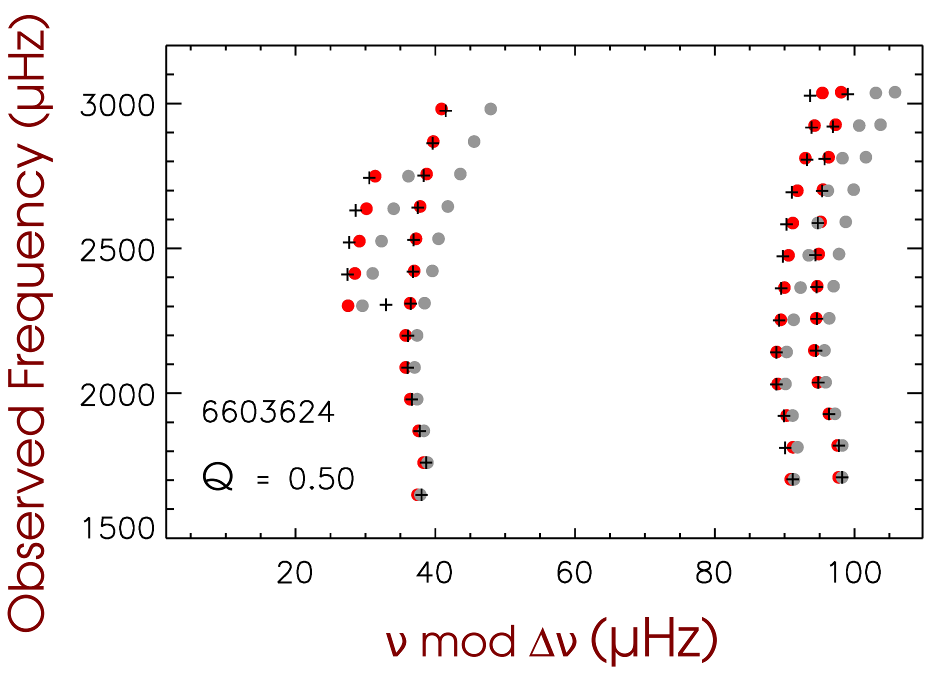
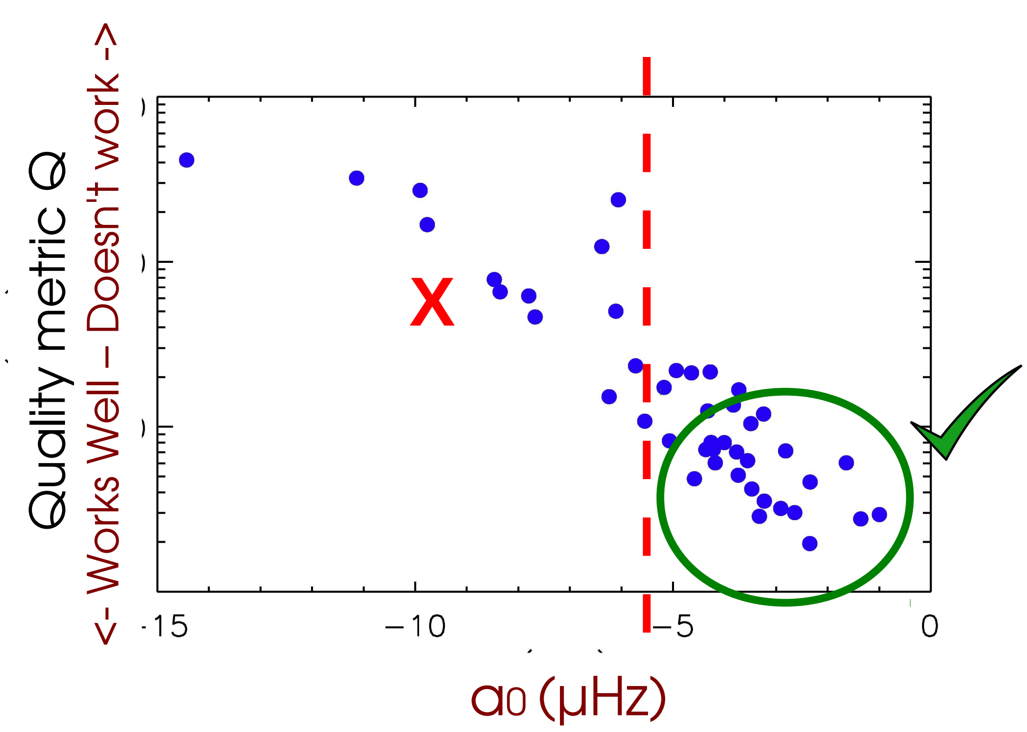


Fig7: Echelle diagram for KIC 6603624, showing data (+) and model (grey) and corrected (red) frequencies. The correction is calculated directly from the comparison of models using the formula

$$\delta\nu = a_0 \left(\frac{\nu_{i,\mathrm{obs}}}{\nu_{\mathrm{max}}}\right)^b$$

Fig8: We define a quality metric Q based on the match between the corrected model and data. Here we show how Q varies with a_0. The figure indicates that the empirical surface correction works well when a_0 is small. Based on this criteria we define a range of parameters where the correction is applicable... watch for Creevey et al.



4. Ages of planet-hosts and binaries

Our 58 stars comprise planet-hosts, active stars, binary systems, solar-analogs and old (popII) stars.

We determine their ages to ~10% precision. The accuracy can be tested by studying the results for the Sun: we retrieve a 4.54 Gyr old Sun (Fig9). Binary systems are modelled independently and consistent ages are derived (Fig10). We also characterise planets (Fig11).

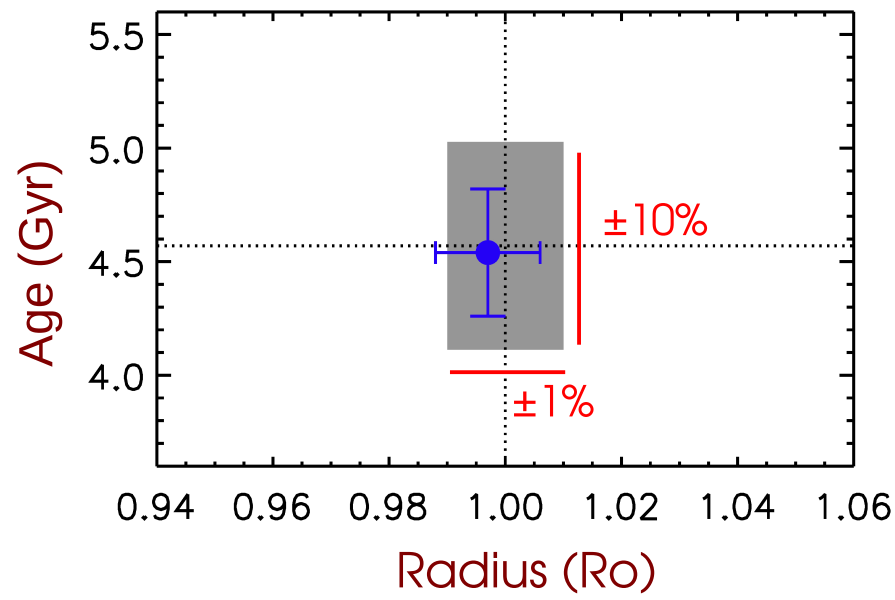


Fig9: Solar age and radius. We indicate in red the PLATO constraints on precision of a solar-type star

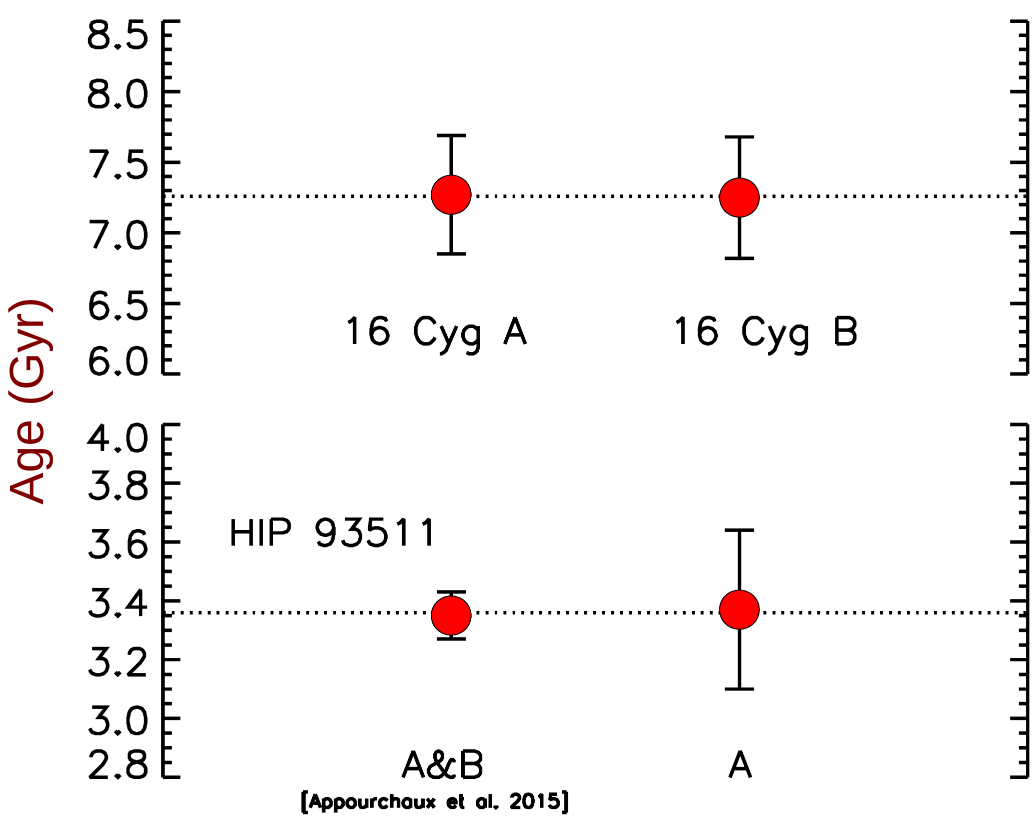


Fig10: Ages of the individual components of (top) 16 CygA & B, and (lower) component A of KIC 7510397 (Krazy) compared to an independent estimate of the age of the system (A&B).

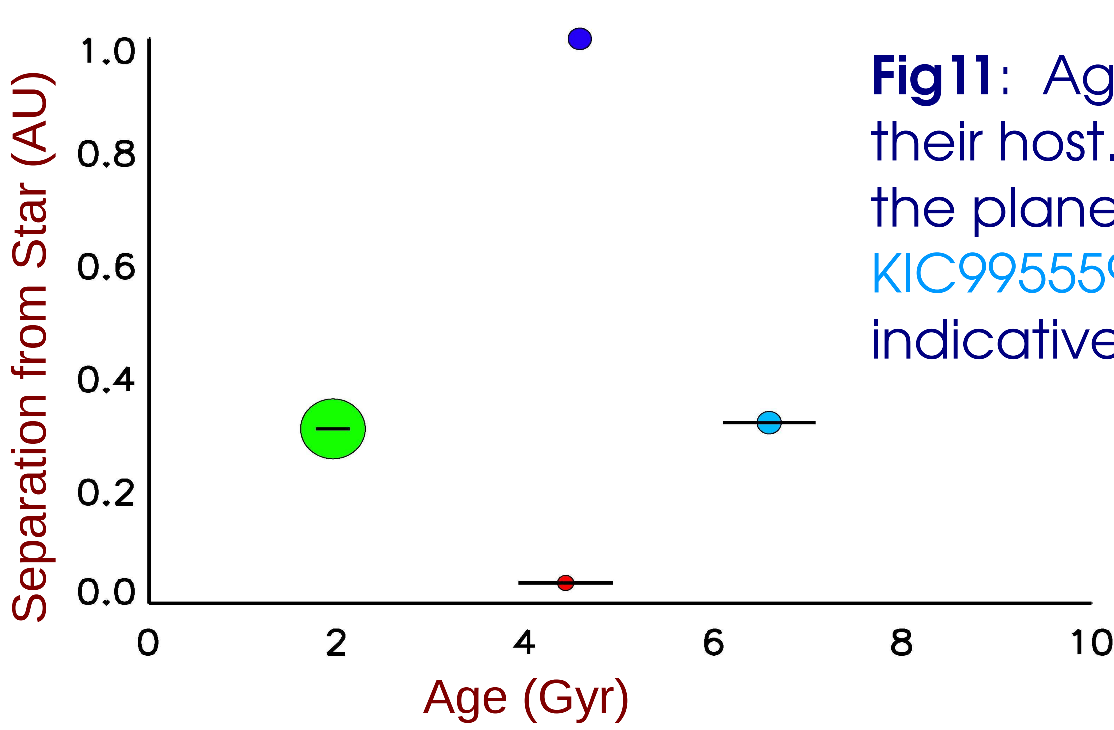


Fig11: Ages of planets and distances to their host. Symbol size is proportional to the planet radius. Earth, KIC9414417b, KIC9955598b, KIC10963065b (colour indicative of Teq).