

Bayesian mass and age estimates for transiting extrasolar planet host stars.

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Abstract

We describe a method to derive the probability distribution for the mass and age of a transiting extrasolar planet host star from its observed properties. We use this method to show that the gyrochronological ages of some transiting exoplanet host stars are significantly less than their isochronal ages.

The analysis of the light curve produced by a planetary transit yields an accurate estimate for the radius of the star relative to the semi-major axis of the planet's orbit, R_{\star}/a , provided that the eccentricity of the orbit is known. This estimate can be combined with Kepler's laws to estimate the density of the host star. The density of 213 planet host stars are shown versus their effective temperatures in Fig. 1. The mass and age of the star can be estimated by comparing these measurements together with other constraints such as $[\text{Fe}/\text{H}]$ and the star's luminosity, to stellar models. We have developed a Bayesian Markov Chain Monte Carlo method called **bagemass** to calculate the probability distribution for the mass and age of planet host stars given these observed constraints, i.e., their joint posterior probability distribution. The method is described fully in Maxted et al., A&A 575, 36, 2015. The method has been tested using precise mass and radius measurements for detached eclipsing binary stars and is found to be reliable for stars that do not rotate too rapidly.

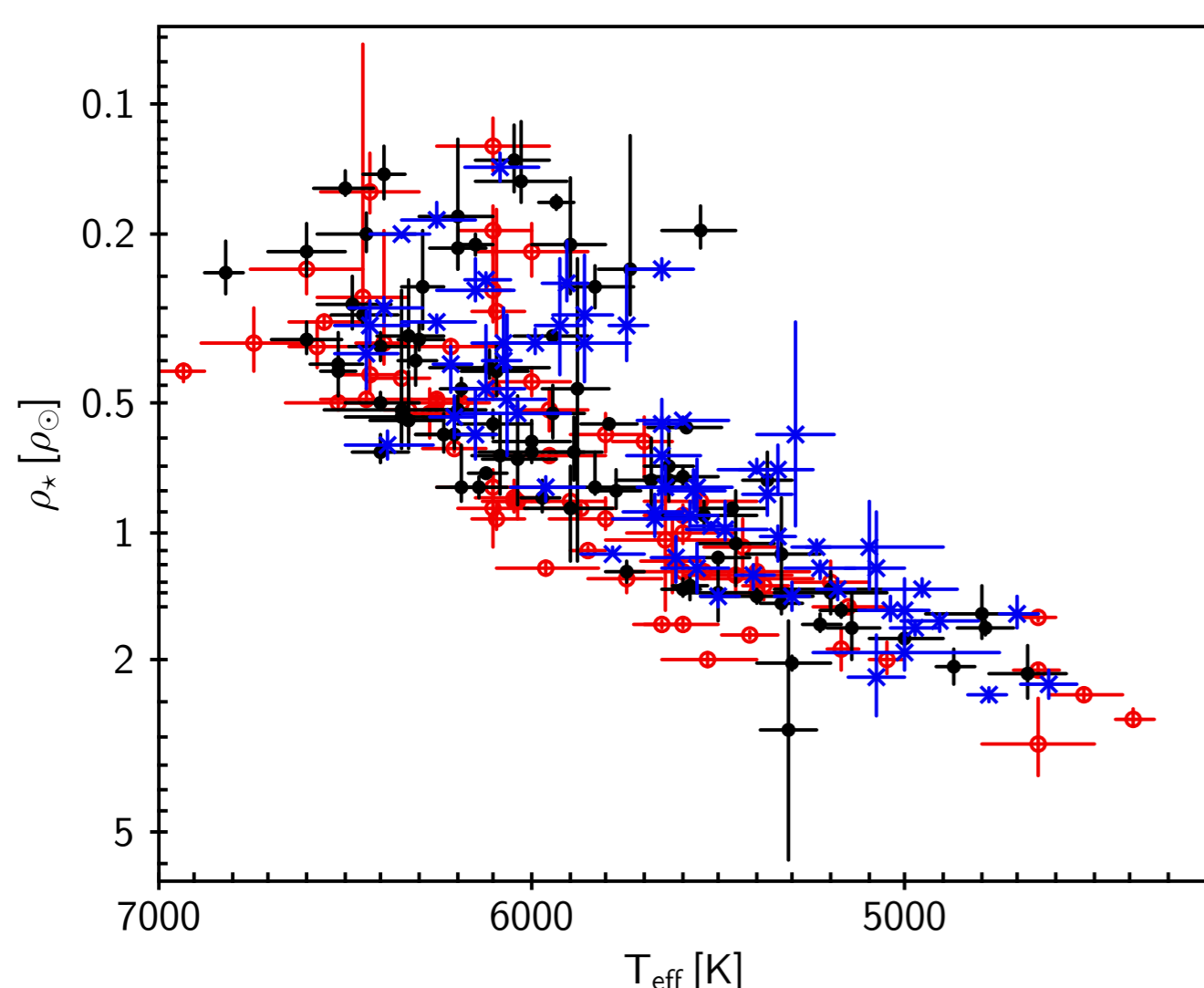


Figure 1. Mean stellar density versus effective temperature for transiting extrasolar planet host stars. Symbols/colours denote the following metallicity ranges: $[\text{Fe}/\text{H}]_s < 0.0$ – open circles/red; $0.0 \leq [\text{Fe}/\text{H}]_s \leq 0.15$ – dots/black; $[\text{Fe}/\text{H}]_s > 0.15$ – crosses/blue.

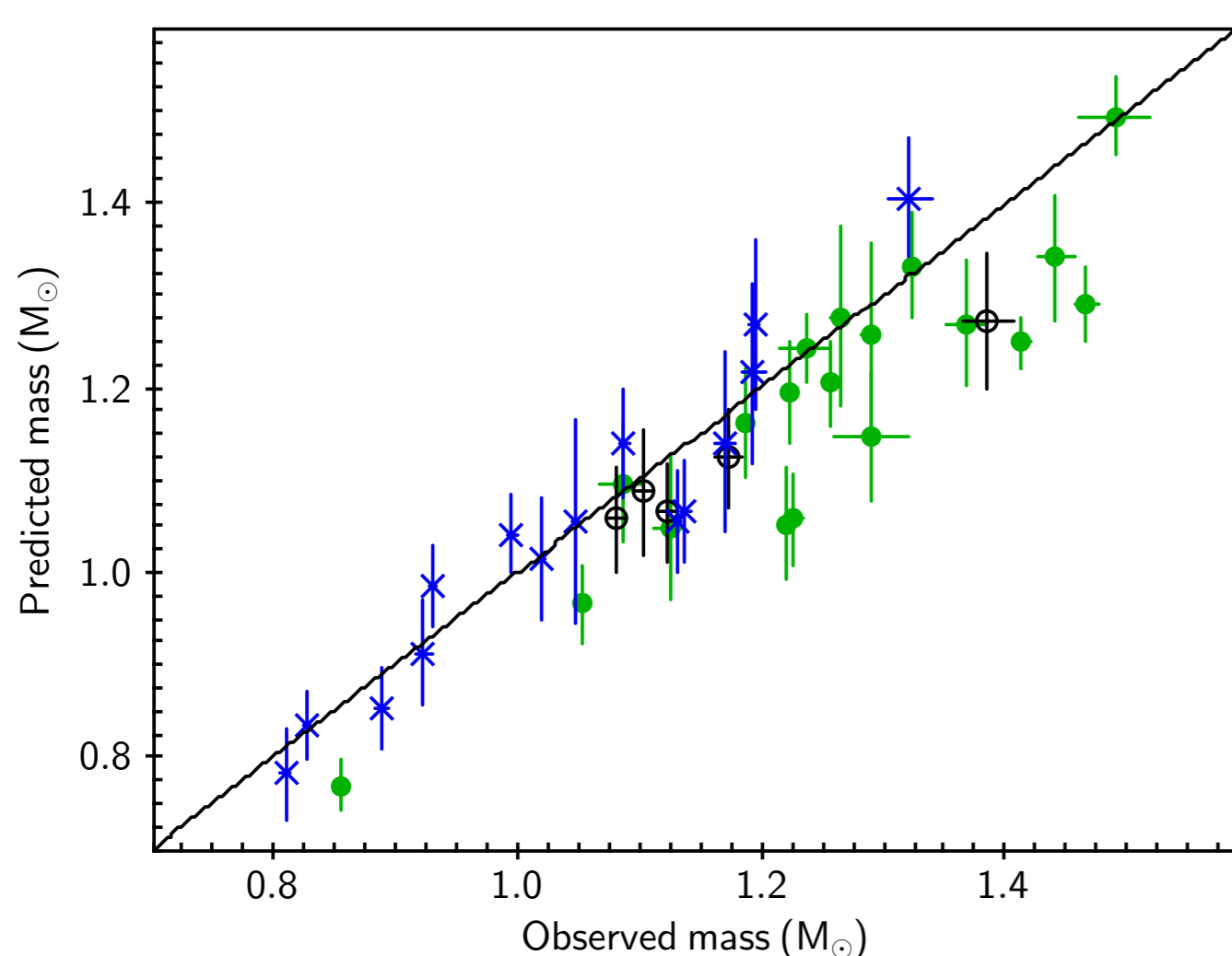


Figure 2. Mass estimates for stars in detached eclipsing binary star systems calculated using **bagemass**. Symbols/colours denote the following orbital period ranges: $P_{\text{orb}} < 6$ d – filled circles/green; $6 < P < 12$ d – open circles/black; $P > 12$ d – crosses/blue.

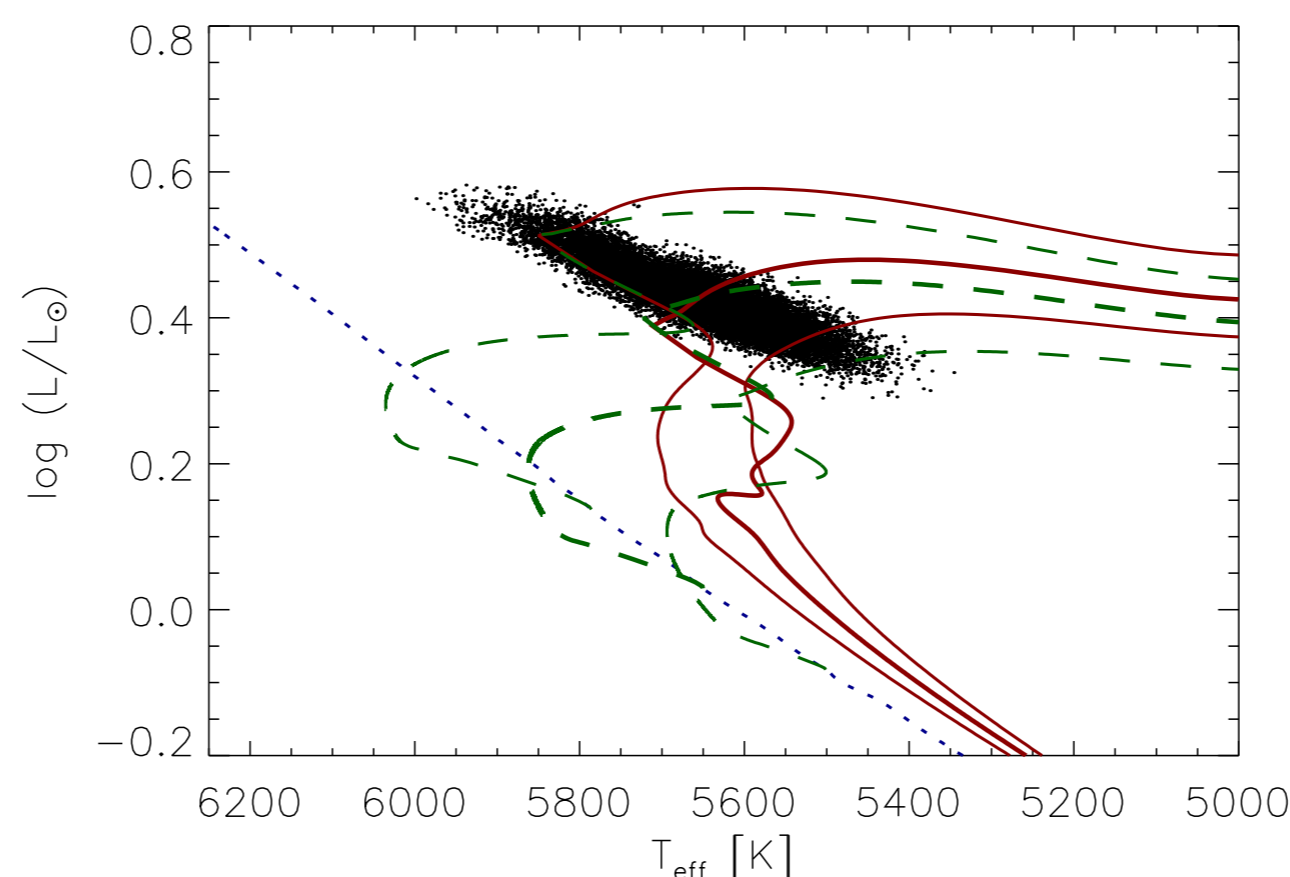


Figure 3. Left panel: Results of our MCMC analysis for HAT-P-13 in the Hertzsprung-Russell diagram. Black dots are individual steps in the Markov chain. The dotted line (blue) is the ZAMS. Solid lines (red) are isochrones for ages 6.6 ± 1.2 Gyr. Dashed lines (green) are evolutionary tracks for masses $1.21 \pm 0.06 M_{\odot}$. All isochrones and tracks are for $[\text{Fe}/\text{H}] = 0.47$. Right panel: Joint posterior distribution for the mass and age and HAT-P-13 from our MCMC analysis.

Stars are born rotating rapidly and can then lose angular momentum if they have a magnetised stellar wind. This observation leads to methods to estimate the age of single late-type stars from their rotation period, a technique known as gyrochronology. We have compiled a sample of 28 transiting exoplanet host stars with measured rotation periods, including two stars (HAT-P-21 and WASP-5) for which we use data from the WASP project to make the first-reported measurements of the rotation period based on the light curve modulation in these stars.

The gyrochronological age depends on the assumed stellar mass, and the isochronal age is also correlated with mass (Fig. 3), so it is not straightforward to compare these two age estimates. We used equation (32) from Barnes (2010, ApJ, 722, 222) to calculate the gyrochronological age of the star in our sample for every mass value in the Markov chain. Fig. 5 shows the joint probability distribution for the isochronal and gyrochronological ages of CoRoT-13 estimated in this way. Note that the two age estimates are strongly correlated and have non-Gaussian distributions.

The results of applying this method to our sample of 28 stars is shown in Fig. 6. It is clear that the gyrochronological age is significantly less than the isochronal age for about half of the stars in this sample. This can be taken as evidence for tidal spin-up of the planet host star in some cases, but not all. This point and the details of our method are discussed fully in a forthcoming paper in A&A.

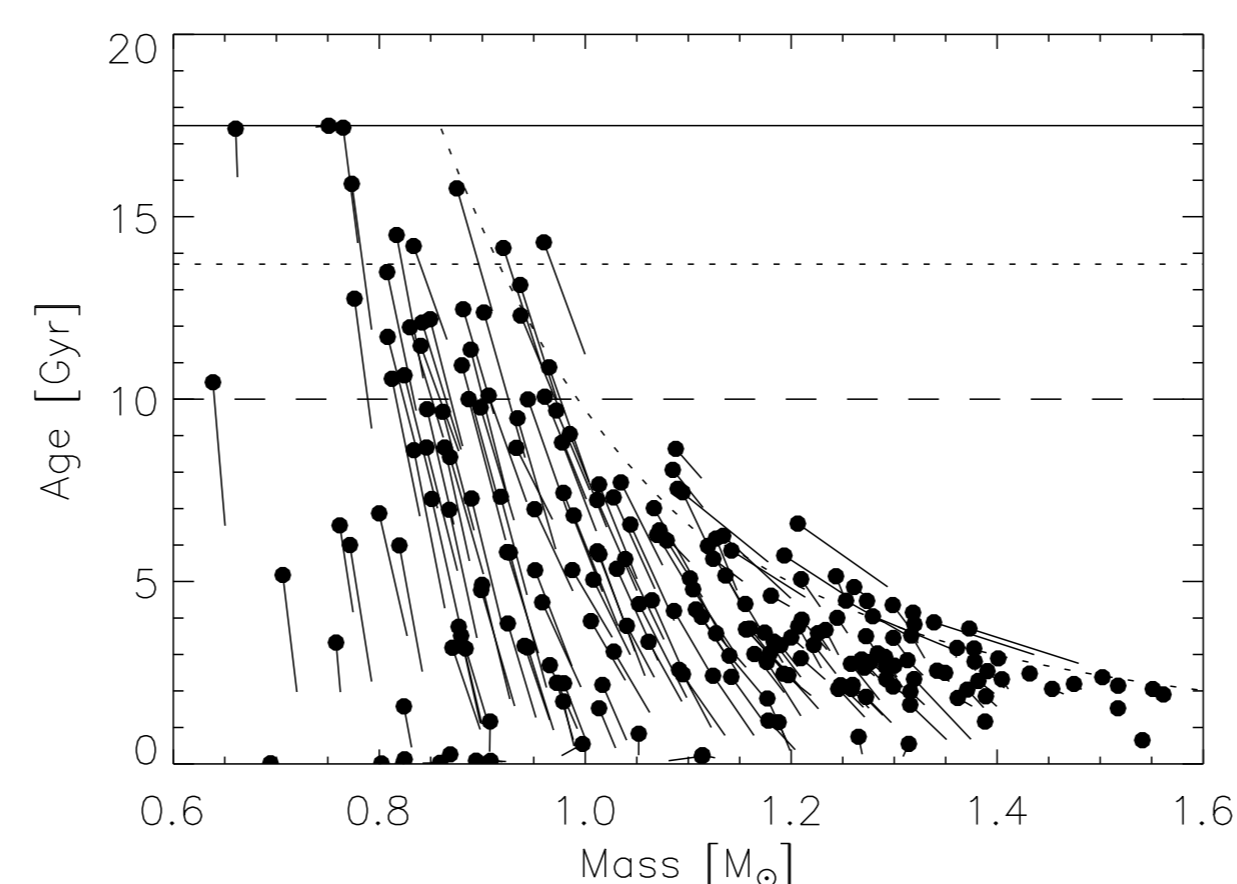


Figure 4. Masses and ages that give the best fits to the observed properties of the planet host stars shown in Fig. 1. Horizontal lines indicate the age of the Galactic disc (dashed), the age of the Universe (dotted) and the largest age in our grid of stellar models (solid). The curved dotted line shows the terminal age main sequence (TAMS) for stars with solar composition. Lines show the effect of changing the mixing-length parameter in the model from $\alpha_{\text{MLT}}=1.78$ (solar value) to $\alpha_{\text{MLT}}=1.58$ to simulate the supposed reduction in convective efficiency in magnetically active stars.

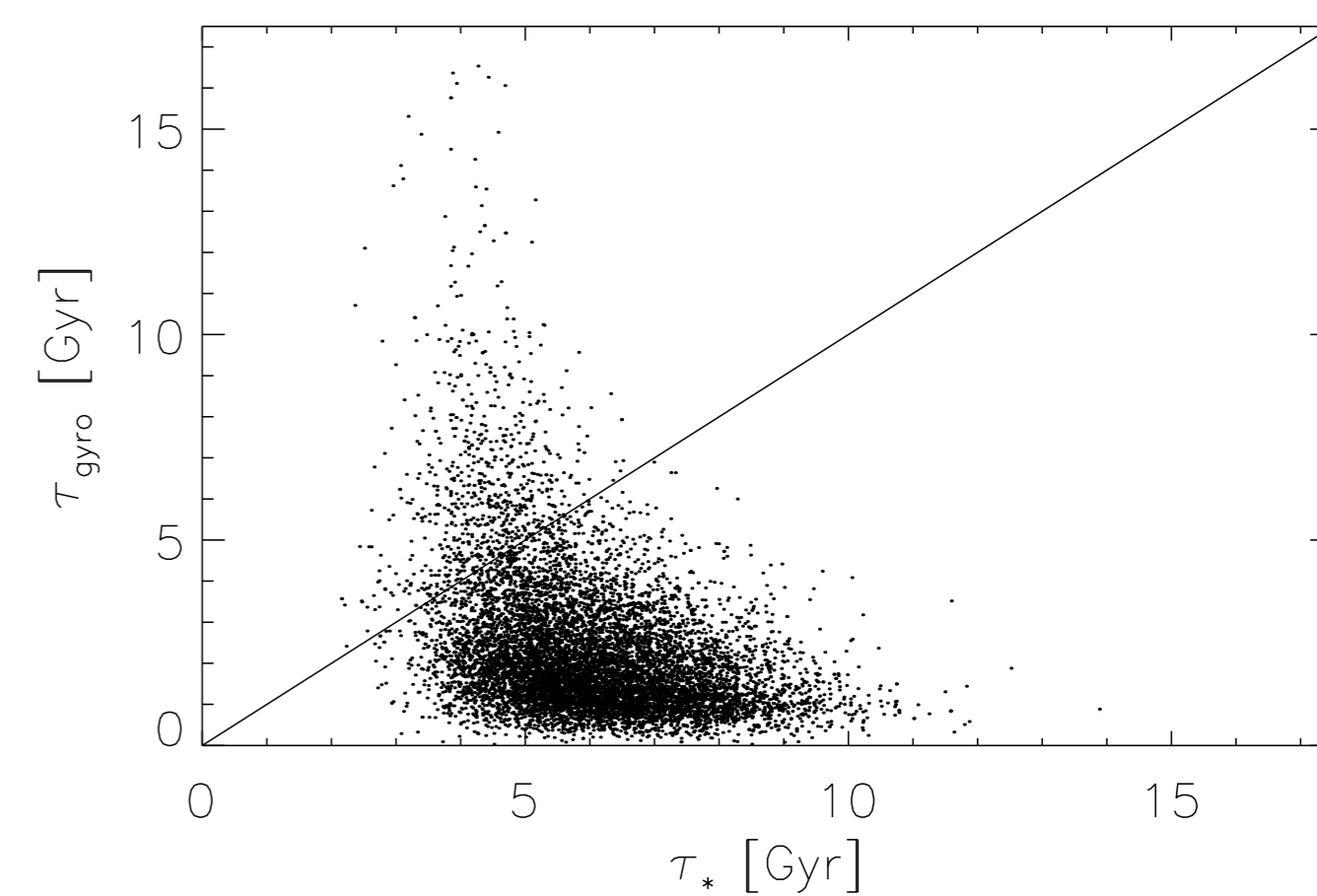
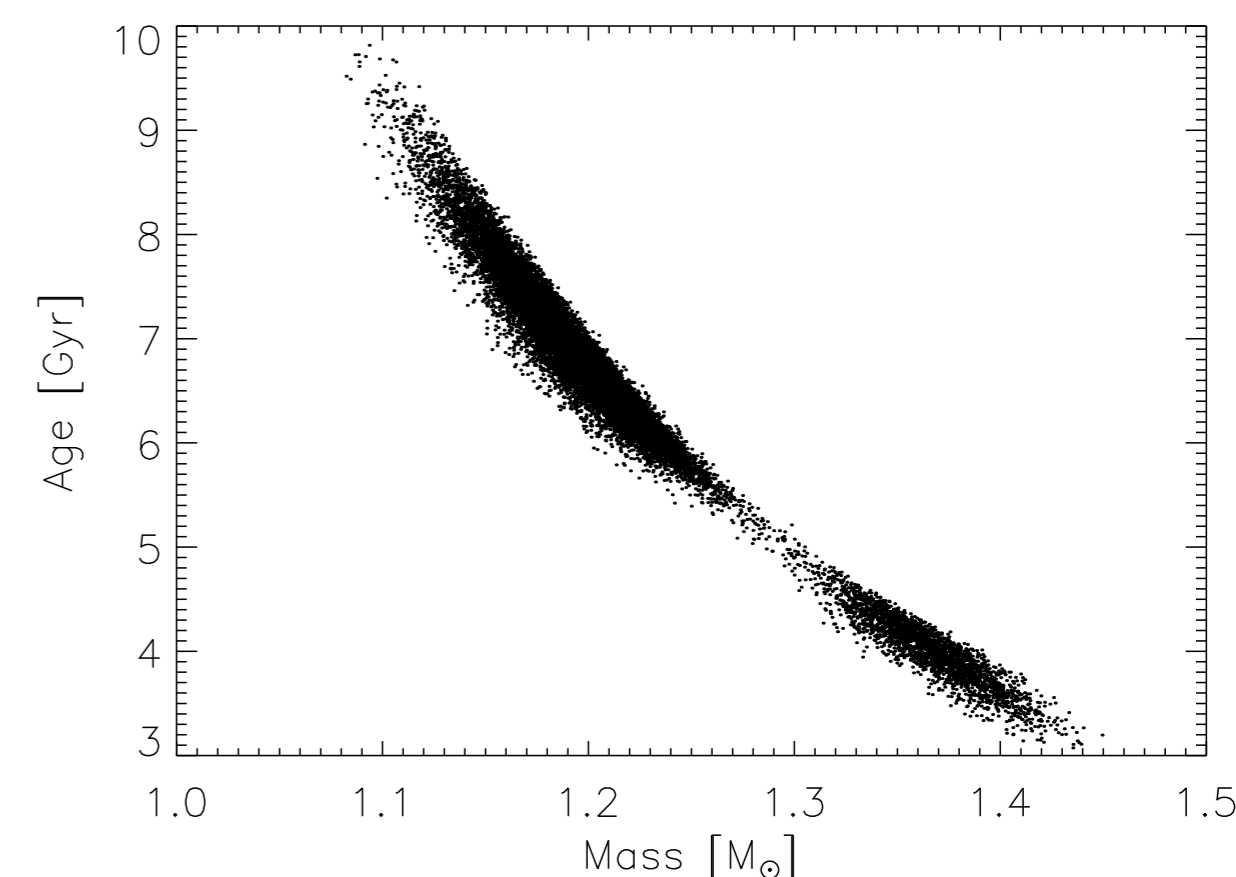


Figure 5. Joint posterior distribution for the age of CoRoT-13 estimated by our isochrone fitting technique and using gyrochronology.

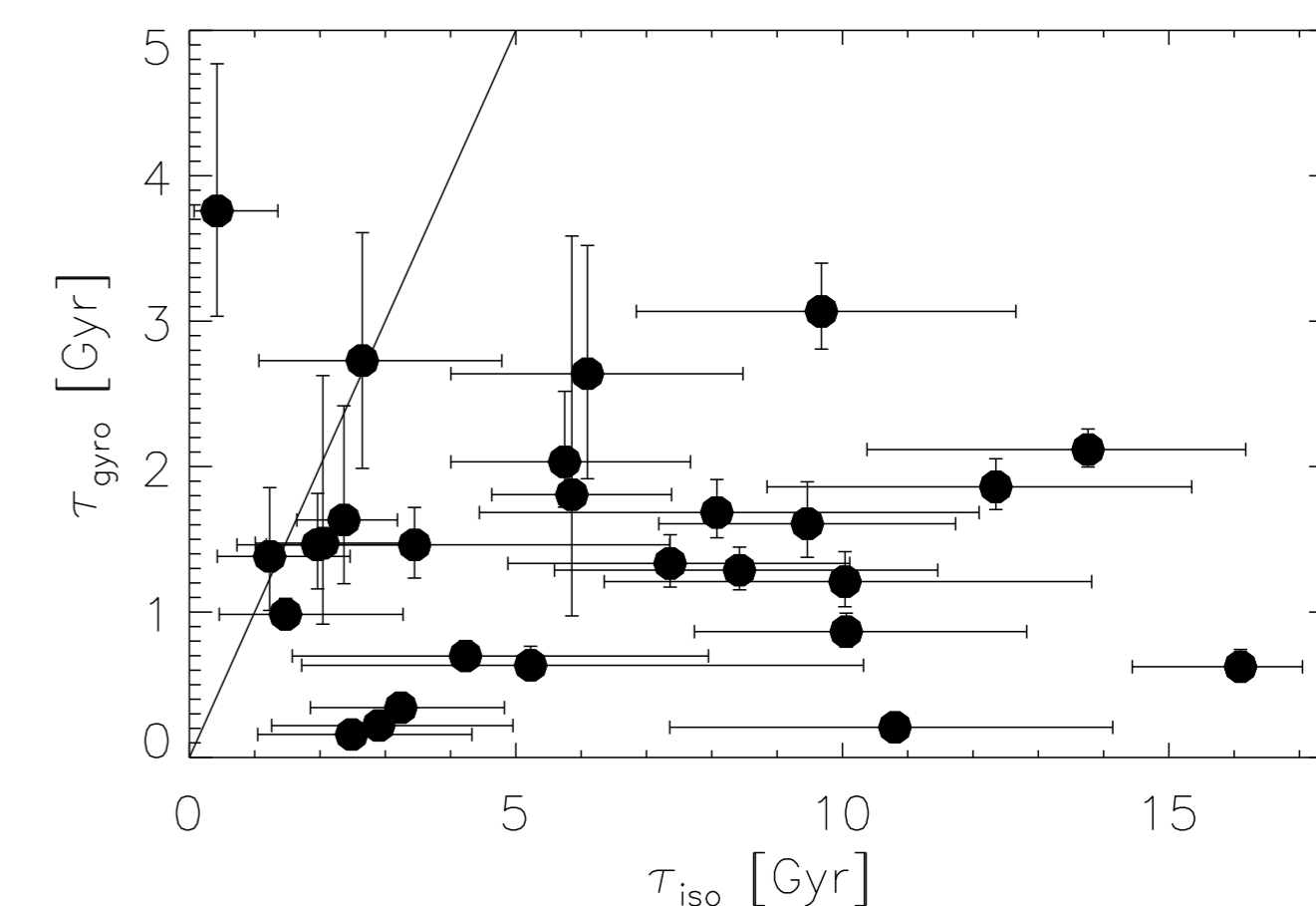


Figure 6. Gyrochronological versus isochronal ages for 28 transiting extrasolar planet host stars with rotation periods measured from star-spot modulation of their light curves.



The software to calculate Bayesian mass and age estimates for transiting planet host stars is called **bagemass** is available as an open-source software project at sourceforge.net/projects/bagemass/. Please contact Pierre Maxted if you would like a demonstration.