Ageing Exoplanet host stars

Gyrochronology, Asteroseismology, and Exoplanets

Guy R. Davies

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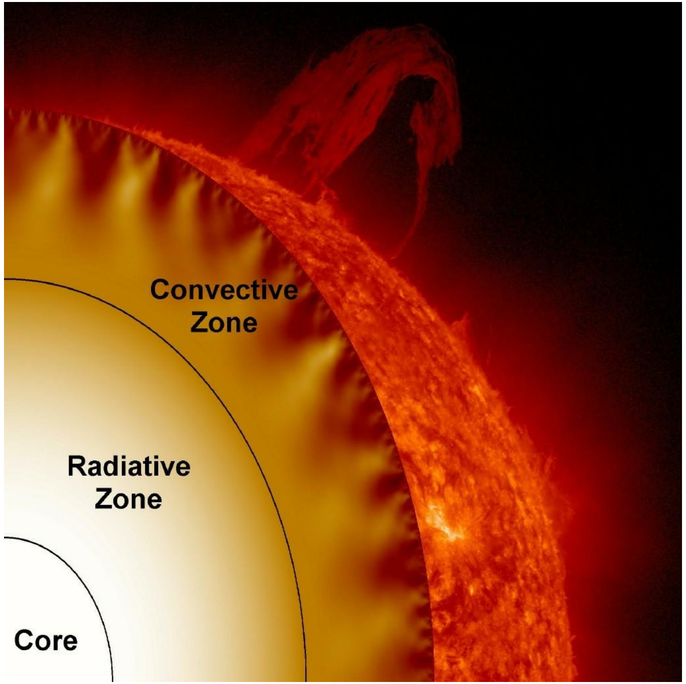
How do you "age" a star?



Astrophysics: The inner lives of red giants

Travis S. Metcalfe

Nature **471**, 580–581 (31 March 2011) | doi:10.1038/471580a

"Just as in Hollywood, the age of a star is not always obvious if you look only at the surface"

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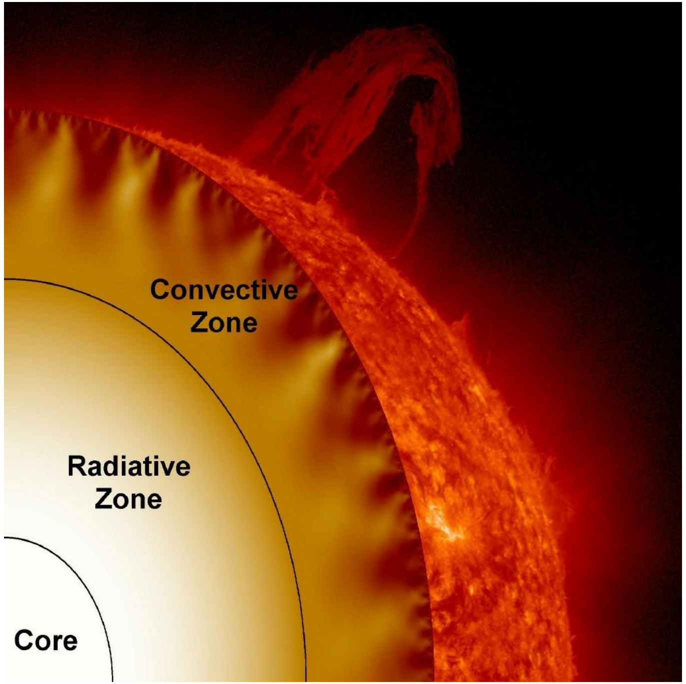
How do you “age” a *solar-like* star?



- **Li abundance at the surface.**
- **Rate of surface rotation.**
- **Levels of surface activity.**
- **Ratio of helium to hydrogen in the core.**

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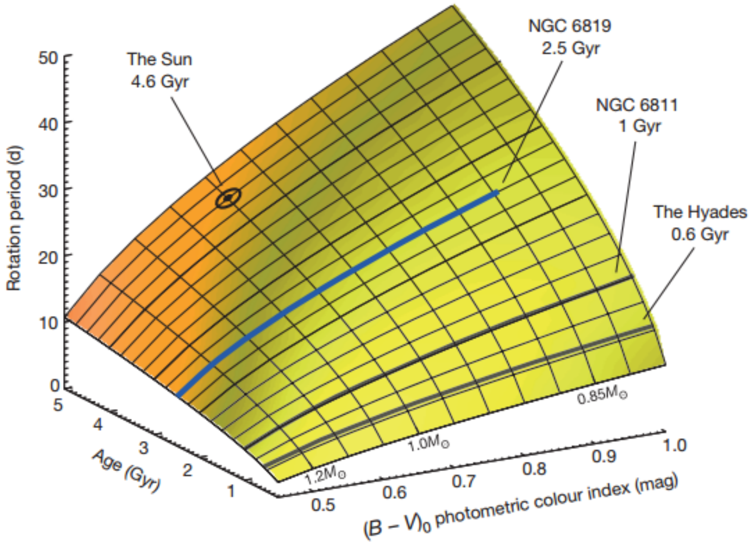
A spin-down clock for cool stars from observations of a 2.5-billion-year-old cluster

Søren Meibom[1], Sydney A. Barnes[2], Imants Platais[3], Ronald L. Gilliland[4], David W. Latham[1], Robert D. Mathieu[5]



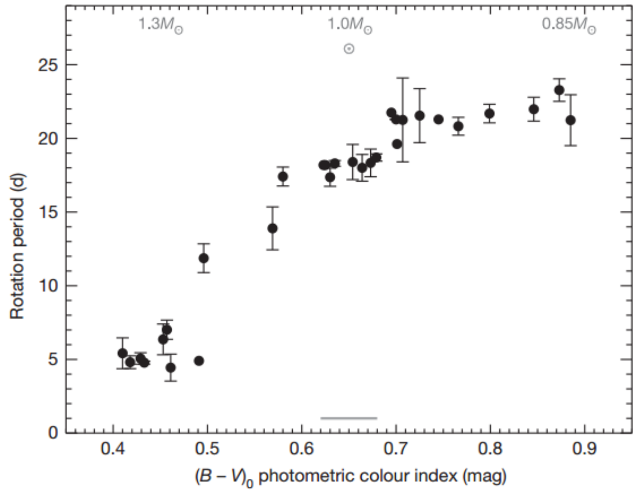


Figure 2 | The colour–period diagram for NGC 6819. The distribution of rotation periods as a function of de-reddened colour index $(B-V)_0$ for 30 cool photometric, proper-motion, and radial-velocity members of the 2.5 Gyr open star cluster NGC 6819. The measurements define a tight dependence of rotation period on colour (mass). The symbols and error bars respectively indicate the means and standard deviations of multiple measurements for the same star when available. The location of the Sun (4.56 Gyr) in the diagram is marked with a grey solar symbol. Stellar masses in solar units are given along the top horizontal axis at the corresponding colours. Solar-mass stars with $(B-V)_0$ between 0.62 and 0.68 mag (interval marked by grey line near the bottom horizontal axis) have a mean period of 18.2 d with a standard deviation of 0.4 d.

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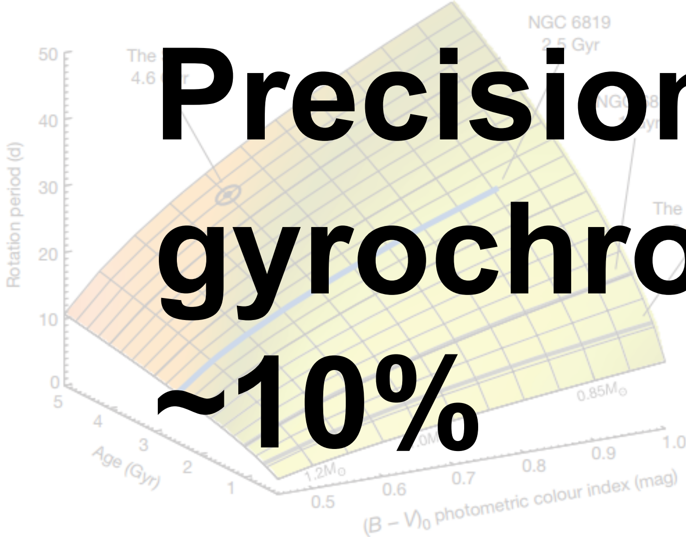
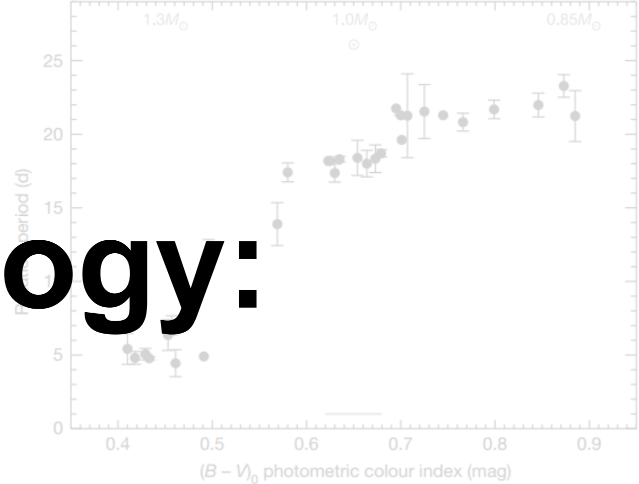


Precision of gyrochronology: ~10%



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Rotation and magnetism of *Kepler* pulsating solar-like stars

Towards asteroseismically calibrated age-rotation relations

R. A. García[1], T. Ceillier[1], D. Salabert[1], S. Mathur[2], J. L. van Saders[3], M. Pinsonneault[3], J. Ballot[4,5], P. G. Beck[1,6], S. Bloemen[7], T. L. Campante[8], G. R. Davies[1,8], J.-D. do Nascimento Jr.[9,10], S. Mathis[1], T. S. Metcalfe[2,11], M. B. Nielsen[12,13], J. C. Suárez[14], W. J. Chaplin[8] A. Jiménez[15,16], and C. Karoff[11]

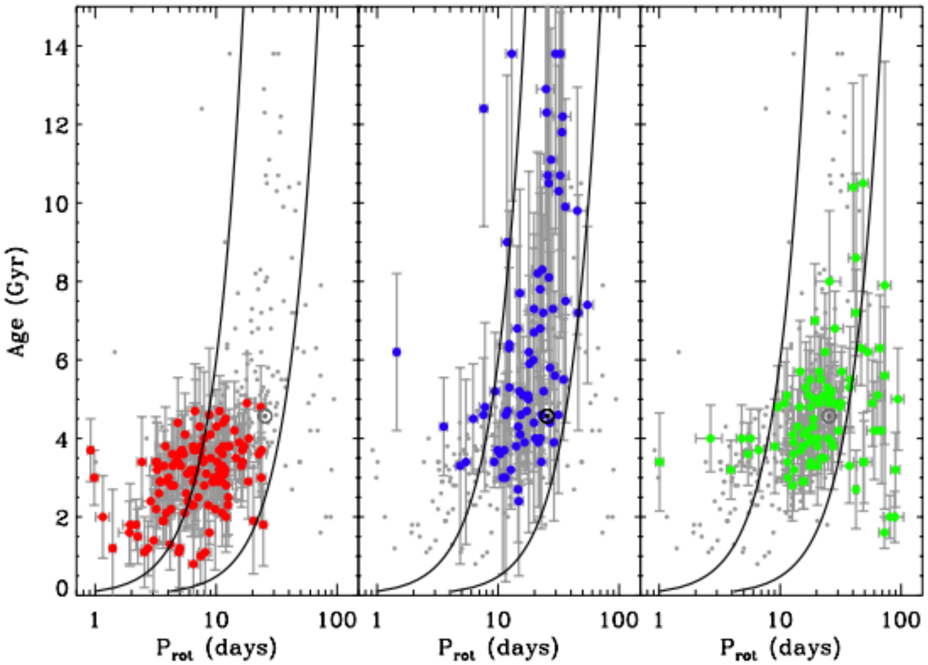

Fig. 8. Rotation periods measured in the this work as a function of grid-modelling asteroseismic ages taken from Chaplin et al. (2014). Stars have been divided into hot (red), dwarfs (blue) and subgiants (green) as defined in Fig. 3. The solid black curves represent the period-age relationships from Mamajek & Hillenbrand (2008), plotted for B-V =0.5 and B-V = 0.9, corresponding to late-F to early-K spectral types. The position of the Sun in the diagram is indicated by the ⊙ symbol and colour-coded as in Fig. 4.

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Calibrating Gyrochronology using Kepler Asteroseismic targets

Ruth Angus,[1⋆] Suzanne Aigrain,[1] Daniel Foreman-Mackey,[2] and Amy McQuillan[3]

[1] *Department of Physics, University of Oxford, UK*

[2] *Centre for Cosmology and Particle Physics, New York University, New York, NY, USA*

[3] *School of Physics and Astronomy, Raymond and Beverly Sackler, Faculty of Exact Sciences, Tel Aviv University, 69978, Tel Aviv, Israel*

Markov Chain Monte Carlo methods were used to explore the posterior probability distribution functions of the gyrochronology parameters and we carefully checked the effects of leaving out parts of our sample, leading us to find that no single relation beween rotation period, colour and age can adequately describe all the subsets of our data. The *Kepler* asteroseismic stars, cluster stars and local field stars cannot all be described by the same gyrochronology relation. The *Kepler* asteroseismic stars may be subject to observational biases, however the clusters show unexpected deviations from the predicted behaviour, providing concerns for the overall reliability of gyrochronology as a dating method.

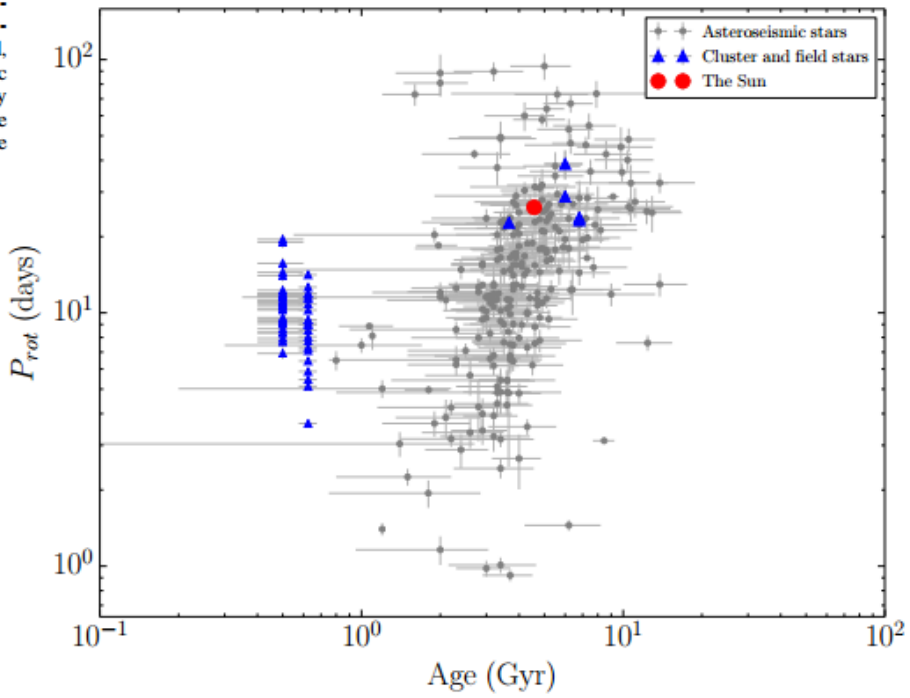

Figure 1. Photometric rotation period vs age for 310 *Kepler* targets (grey circles) plus cluster and field stars (blue triangles). The Sun is shown as a red circle.

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[1] Department of Physics, University of Oxford, UK
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Precision of gyrochronology: ?

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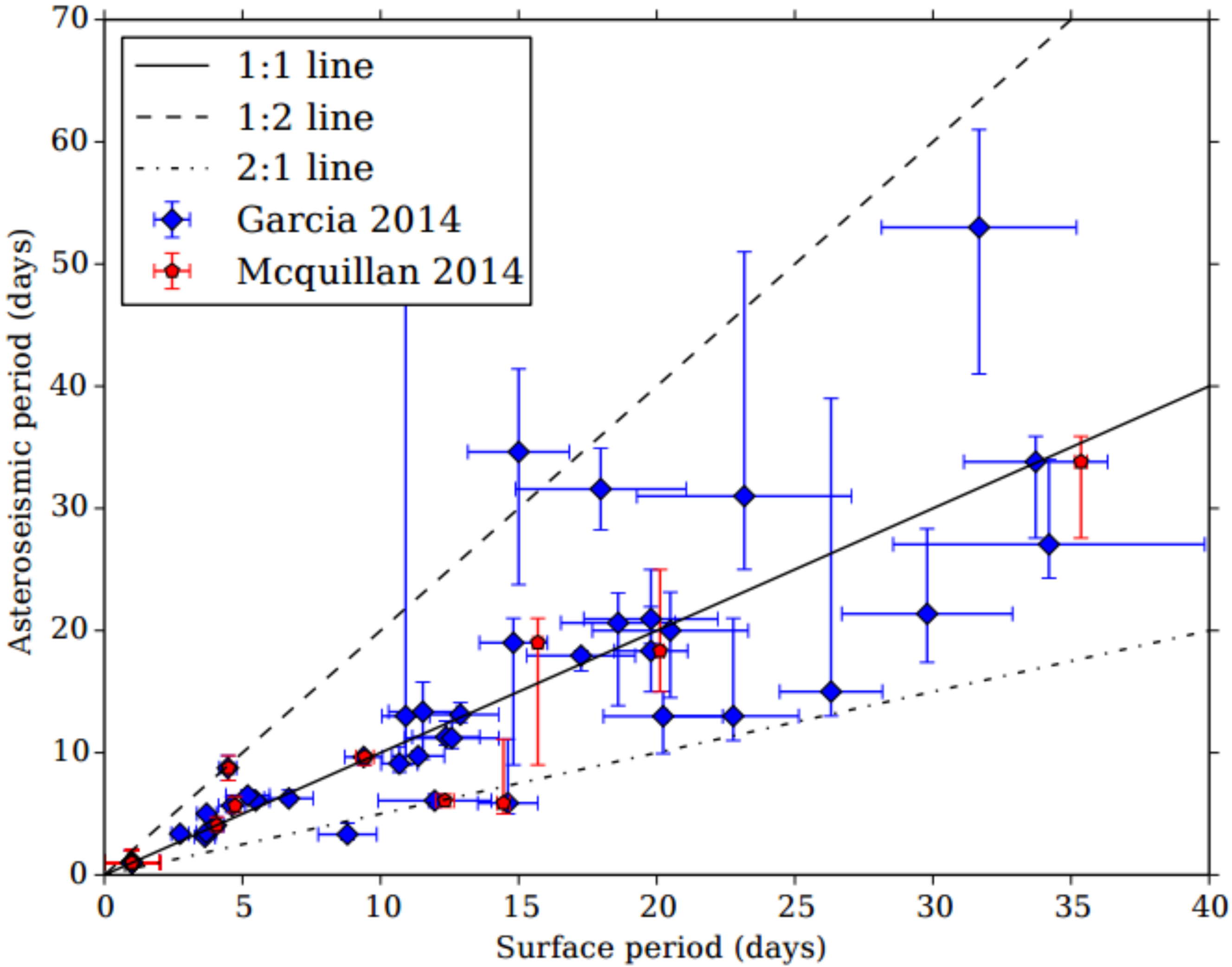
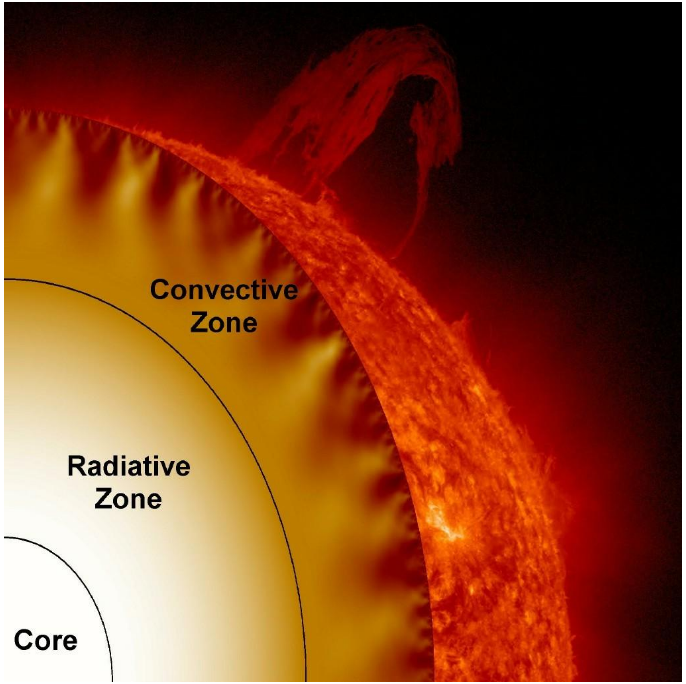
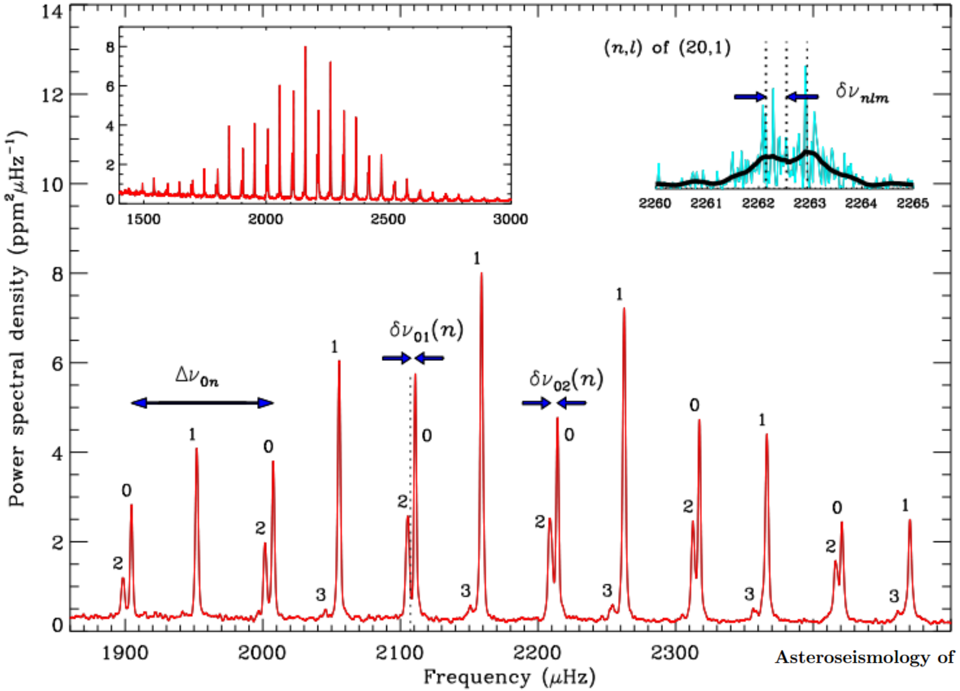


Davies et al. in prep

How do you “age” a solar-like star?





Asteroseismology of Solar-Type and Red-Giant Stars

William J. Chaplin, Andrea Miglio

School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

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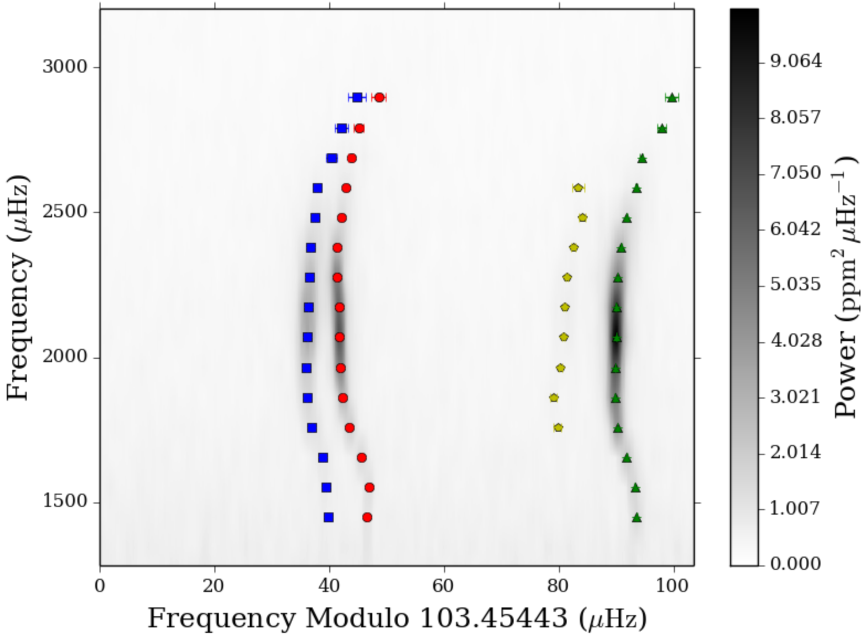
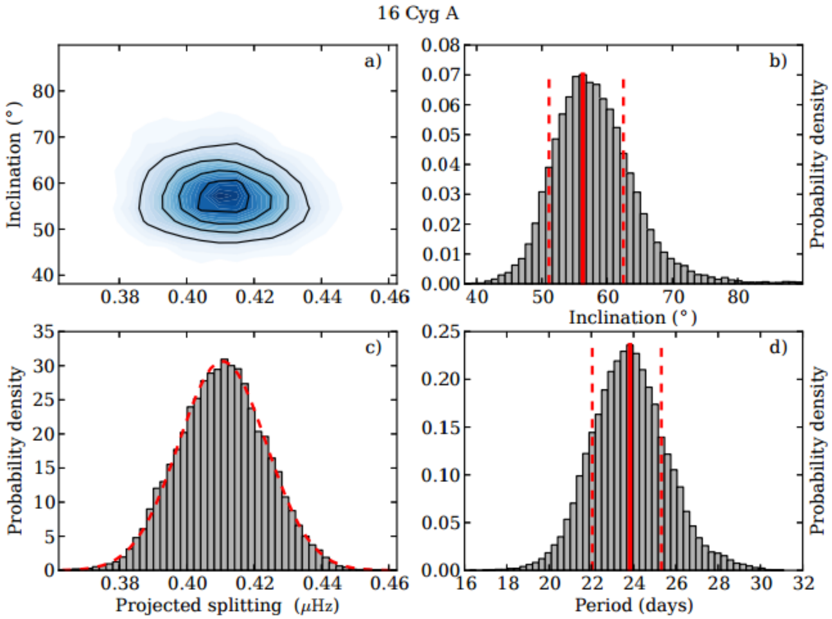
16 Cyg: Wide orbit and asteroseismic binary



	16 Cyg A	16 Cyg B	16 Cyg Bb
Age (Gyr)	6.8 ± 0.4^{a}	6.8 ± 0.4^{a}	6.8 ± 0.4
Mass	1.11 ± 0.02^{a} $M_{\odot}$	1.07 ± 0.02^{a} $M_{\odot}$	2.38 ± 0.04^{c} M_{Jup}
Radius	1.243 ± 0.008^{a} $R_{\odot}$	1.127 ± 0.007^{a} $R_{\odot}$	-
$B - V$	$0.64^{b} \pm 0.01$	$0.66^{b} \pm 0.01$	n/a
Orbital Period	$> 13000^{c}$ yr	$> 13000^{c}$ yr	798.5 ± 1.0^{c} days
Eccentricity	0.54 to 1^{d}	0.54 to 1^{d}	0.689 ± 0.011^{c}
Orbital Inclination (°)	100 to 160^{d}	100 to 160^{d}	$45/135^{c}$

Asteroseismic inference on rotation, gyrochronology and planetary system dynamics of 16 Cygni

G.R. Davies[1,2,3], W.J. Chaplin[2,3], W.M. Farr[2], R.A. García[1], M.N. Lund[3], S. Mathis[1], T.S. Metcalfe[4,3], T. Appourchaux[5], S. Basu[6], O. Benomar[7], T.L. Campante[2], T. Ceillier[1], Y. Elsworth[2], R. Handberg[2,3], D. Salabert[1], D. Stello[8,3]



16 Cyg: Gyrochronology calibrator

Asteroseismic inference on rotation, gyrochronology and planetary system dynamics of 16 Cygni

G.R. Davies[1,2,3], W.J. Chaplin[2,3], W.M. Farr[2], R.A. García[1], M.N. Lund[3],
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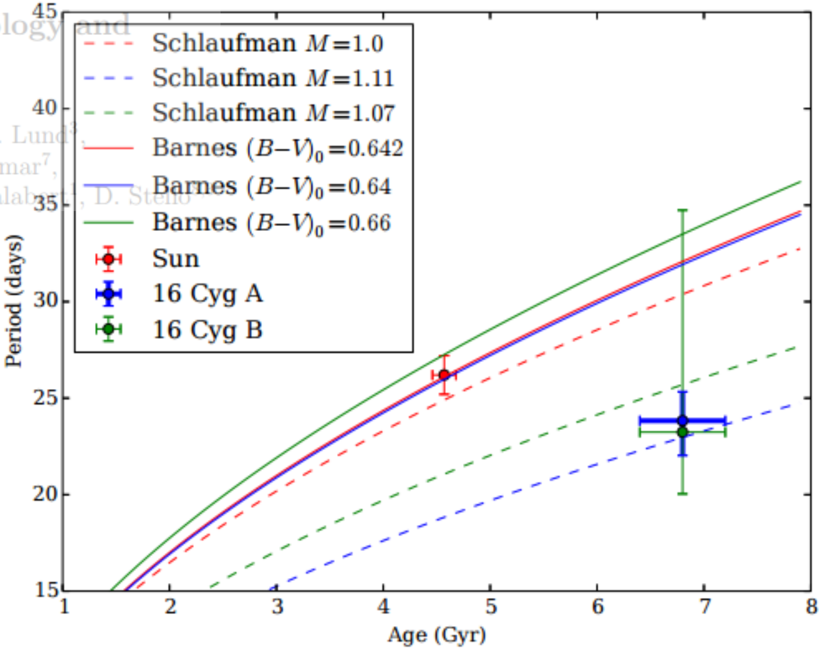

Figure 9. Asteroseismic rotation data points for 16 Cyg and the Sun on a period vs. age plot. Predictions using two common mass-age-period relations (Barnes 2007; Schlaufman 2010) are displayed.

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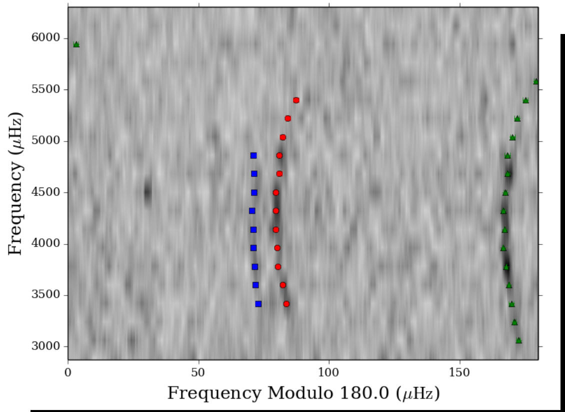
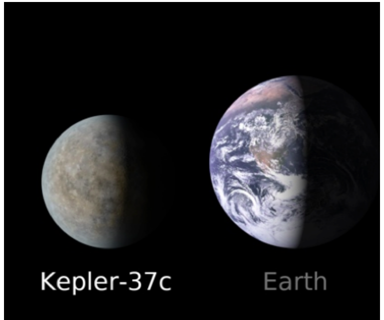
Old Exoplanets - Kepler 444





AN ANCIENT EXTRASOLAR SYSTEM WITH FIVE SUB-EARTH-SIZE PLANETS

T. L. Campante[1,2], T. Barclay[3,4], J. J. Swift[5], D. Huber[3,6,7], V. Zh. Adibekyan[8,9], W. Cochran[10], C. J. Burke[3,6], H. Isaacson[11], E. V. Quintana[3,6], G. R. Davies[1,2], V. Silva Aguirre[2], D. Ragozzine[12], R. Riddle[13], C. Baranec[14], S. Basu[15], W. J. Chaplin[1,2], J. Christensen-Dalsgaard[2], T. S. Metcalfe[2,16], T. R. Bedding[2,7], R. Handberg[1,2], D. Stello[2,7], J. M. Brewer[17], S. Hekker[2,18], C. Karoff[2,19], R. Kolbl[11], N. M. Law[20], M. Lundkvist[2], A. Miglio[1,2], J. F. Rowe[3,6], N. C. Santos[8,9,21], C. Van Laerhoven[22], T. Arentoft[2], Y. P. Elsworth[1,2], D. A. Fischer[17], S. D. Kawaler[23], H. Kjeldsen[2], M. N. Lund[2], G. W. Marcy[11], S. G. Sousa[8,9,21], A. Sozzetti[24], and T. R. White[25]

Table 2. Fundamental stellar properties.

Parameter	Value
$M/\mathrm{M}_\odot$	0.758 ± 0.043
$R/\mathrm{R}_\odot$	0.752 ± 0.014
$\log g_{\rm seis}$ (dex)	4.5625 ± 0.0095
$\langle\rho\rangle$ (g cm^{-3})	2.493 ± 0.028
t (Gyr)	$11.23^{+0.91}_{-0.99}$

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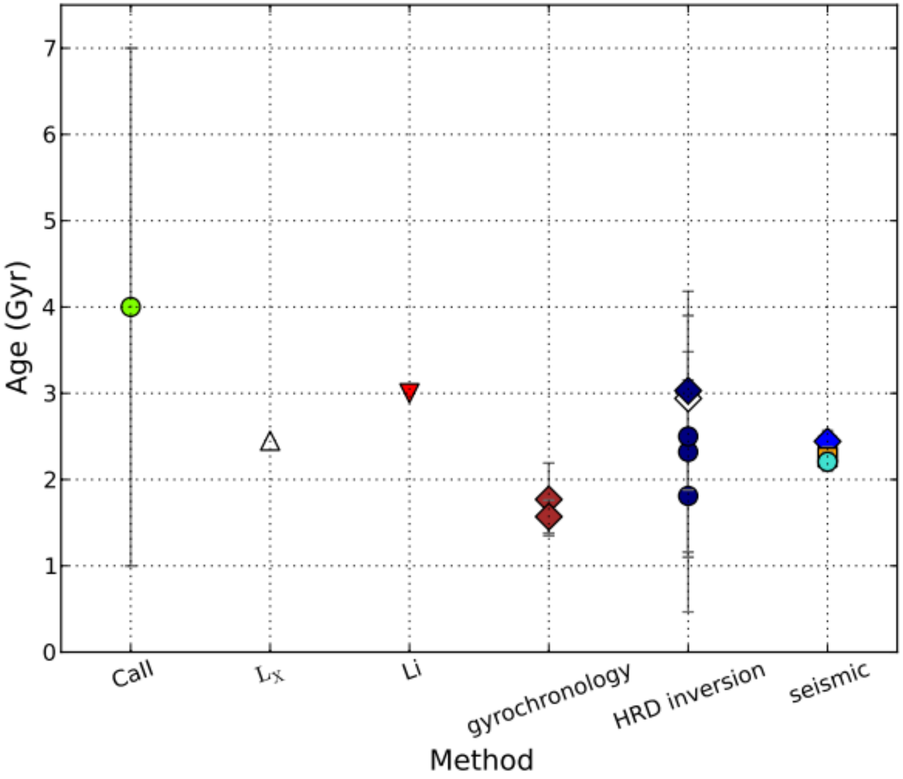
How does asteroseismology shape up?

Asteroseismology for "à la carte" stellar age-dating and weighing★,★★

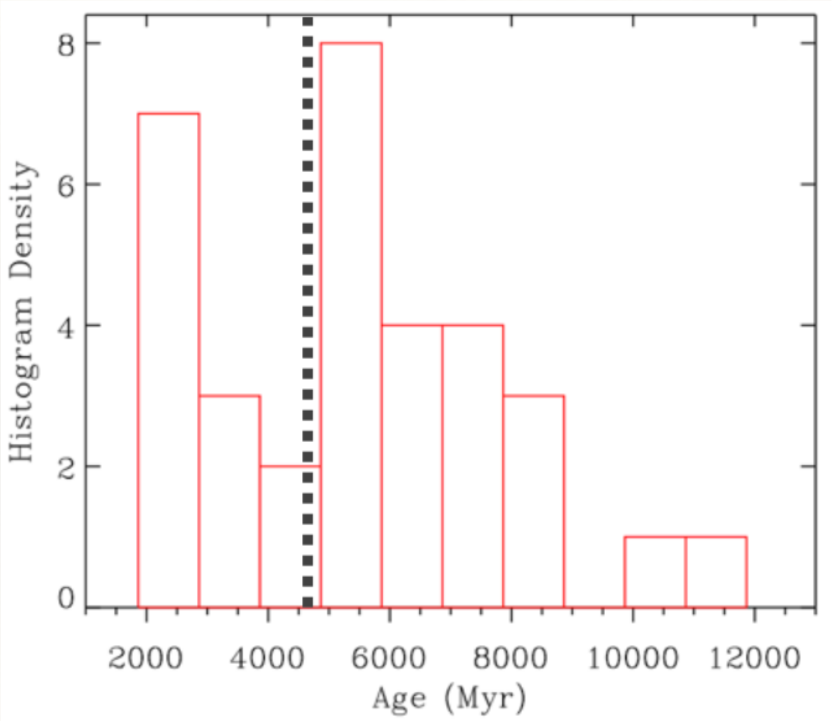
Age and mass of the CoRoT exoplanet host HD 52265

Y. Lebreton[1,2] and M. J. Goupil[3]



Empirical relations
vs
Model-dependent
results

Exoplanet host star ensemble



The Kages Project

- **35 host stars**
- **Precision in radii ~ 3%**
- **Precision in mass ~ 8%**
- **Precision in age ~ 15%**
- **Distances spanning 100 - 500 pc**

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Davies et al. in prep
Silva Aguirre et al. Submitted

Removing some of the model dependency ...

Stellar acoustic radii, mean densities, and ages from seismic inversion techniques★

G. Buldgen[1], D. R. Reese[2], M. A. Dupret[1], and R. Samadi[3]

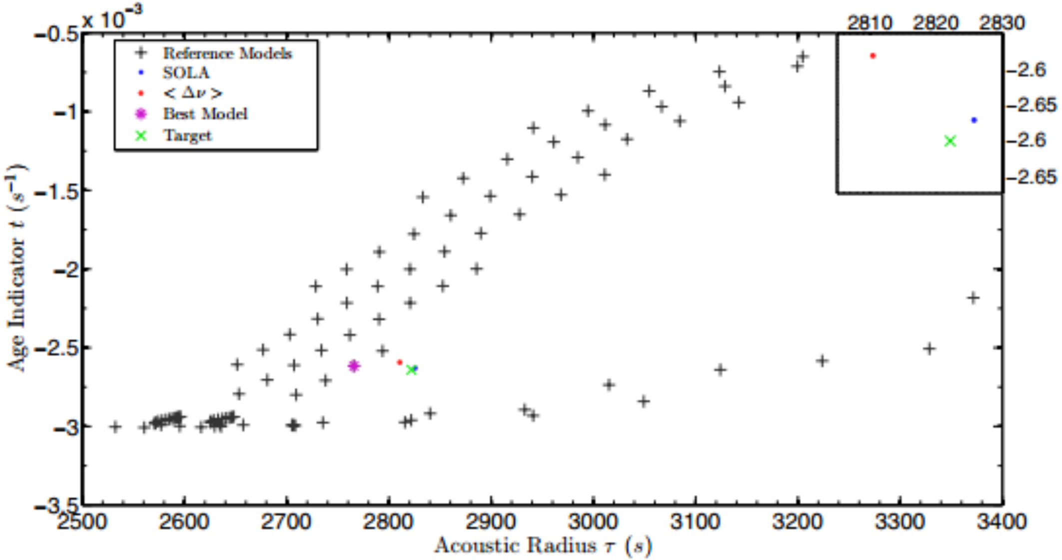

Fig. 5. Inversion results for the model with the best small frequency separation. In the main part of the figure, the grid models are represented by the black +, the best model is the purple ∗, model A' the green X, the SOLA result is in blue, and the large frequency separation result in red. The inset shows an enlarged view of the region around model A'.

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THE MASS-DEPENDENCE OF ANGULAR MOMENTUM EVOLUTION IN SUN-LIKE STARS

Sean P. Matt[1], A. Sacha Brun[2], Isabelle Baraffe[1,3], Jérôme Bouvier[4,5], and Gilles Chabrier[3,1]
[1]University of Exeter, Department of Physics & Astronomy, Physics Bldg., Stocker Road, Exeter, EX4 4QL, UK; s.matt@exeter.ac.uk
[2]Laboratoire AIM Paris-Saclay, CEA/Irfu Université Paris-Diderot CNRS/INSU, 91191 Gif-sur-Yvette, France
[3]École Normale Supérieure de Lyon, CRAL, 69364 Lyon Cedex 07, France
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[5]CNRS, IPAG, F-38000 Grenoble, France
Accepted by ApJ Letters

ABSTRACT

To better understand the observed distributions of rotation rate and magnetic activity of sun-like and low-mass stars, we derive a physically motivated scaling for the dependence of the stellar-wind torque on Rossby number. The torque also contains an empirically-derived scaling with stellar mass (and radius), which provides new insight into the mass-dependence of stellar magnetic and wind properties. We demonstrate that this new formulation explains why the lowest mass stars are

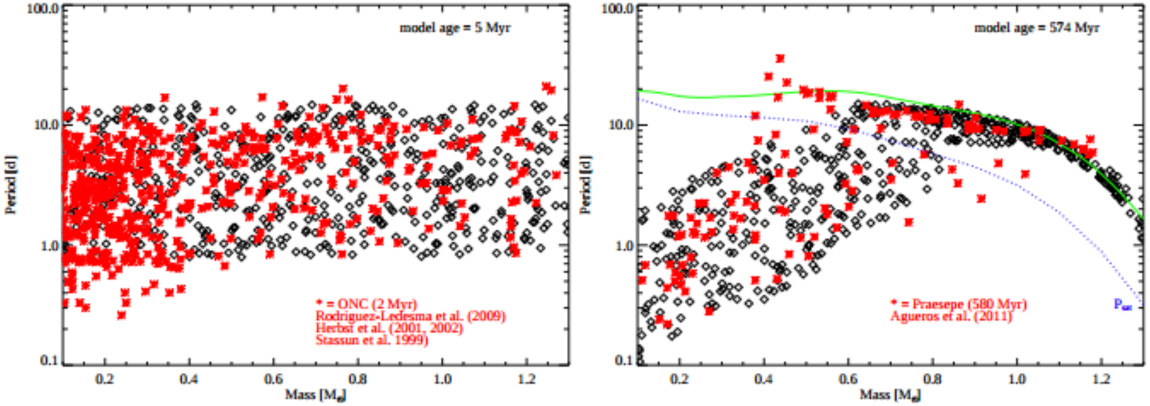

Figure 2. Observed rotation periods (red stars) from the ONC (left panel) and Praesepe (right panel), compared to our synthetic cluster stars (black diamonds). The left panel shows the synthetic initial conditions, chosen to approximate the observed range, but not the detailed distribution. The right panel shows the synthetic cluster, evolved to a similar age as Praesepe (as indicated). For reference, the green solid line shows the theoretical asymptotic spin rate of equation (11), and the blue dotted line delimits magnetically saturated and unsaturated stars. The model explains both the existence of rapidly rotating, low-mass stars, as well as the general mass-dependence of the slow-rotator sequence.

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