Ages, masses and radii of Pop I and II stars and planetary systems

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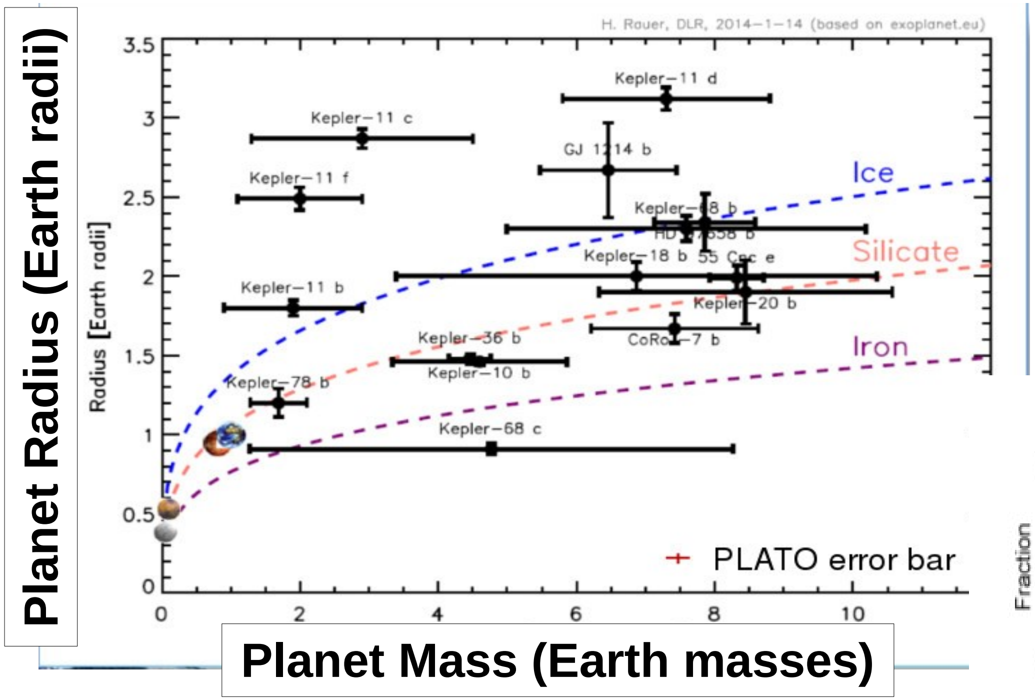
Outline

- Motivation & Stellar properties
- Seismic and Kepler recent results
- An old metal-poor Halo star: HD 140283
- A faint planetary-host: CoRoT-30
- Conclusions

Motivation

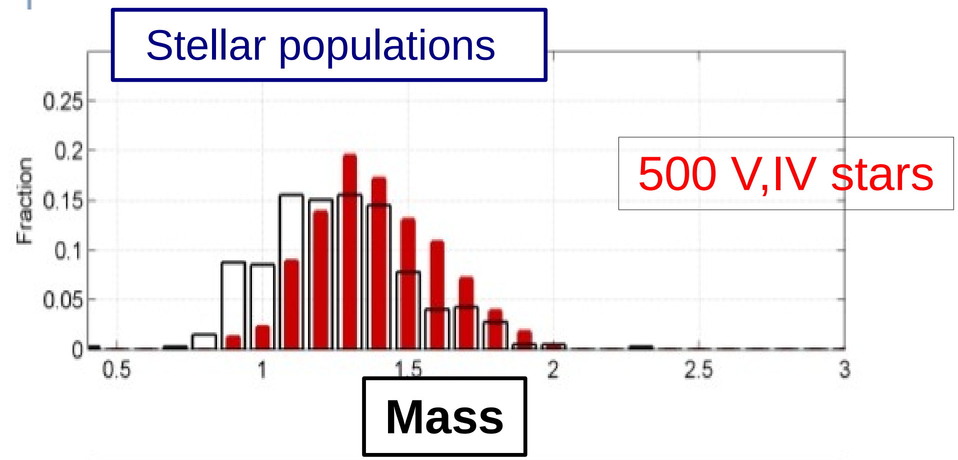
- Characterisation of objects
- Astrophysical processes evolve with time
- Planetary characterisation
- Transport processes in stars
- Chemical evolution of Galaxy

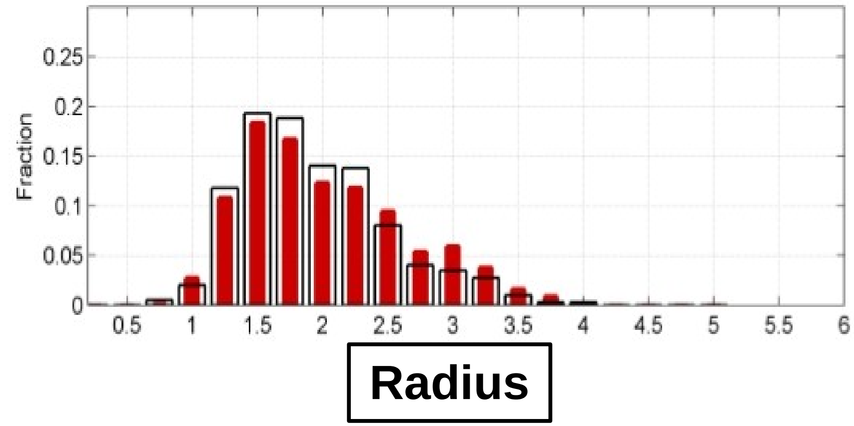
Motivation



Planet properties are known only to precision of host properties

Extracted from H. Rauer PLATO presentation





Chaplin et al.incl
Creevey (2011) Science

What are stellar properties and what do we observe?

Photometry
Reddening excess
Parallaxes
Spectroscopy
Visibilities
Frequencies
Light/RV curves

Distance
Interstellar extinction
Bolometric flux
Angular diameters
Teff/log g/[Fe/H]
Velocities
Mean density
Mass / Radius
Inclination

Radius R
Mass M
Age t
Luminosity L
Surface gravity g
Initial composition
Effective temperature
Atmospheric composition

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For faint single stars

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For bright single stars

What are stellar properties and what do we observe?

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Spectroscopy
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Bolometric flux
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Velocities
Mean density
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Inclination

Radius R
Mass M
Age t
Luminosity L
Surface gravity g
Initial composition
Effective temperature
Atmospheric composition

For detached binaries (resolved??)

Ages of single stars

- Model-independent methods
  - Sun: radioactive dating techniques of meteorites
  - Oldest stars: nucleocosmochronometry
  - Youngest stars: kinematics
  - All stars: empirical relations (rotation, activity, Li)
  - Upper limit: 13.7 Gyr
- Model-dependent
  - All stars: stellar evolution models

Ages of single stars

- Model-independent methods
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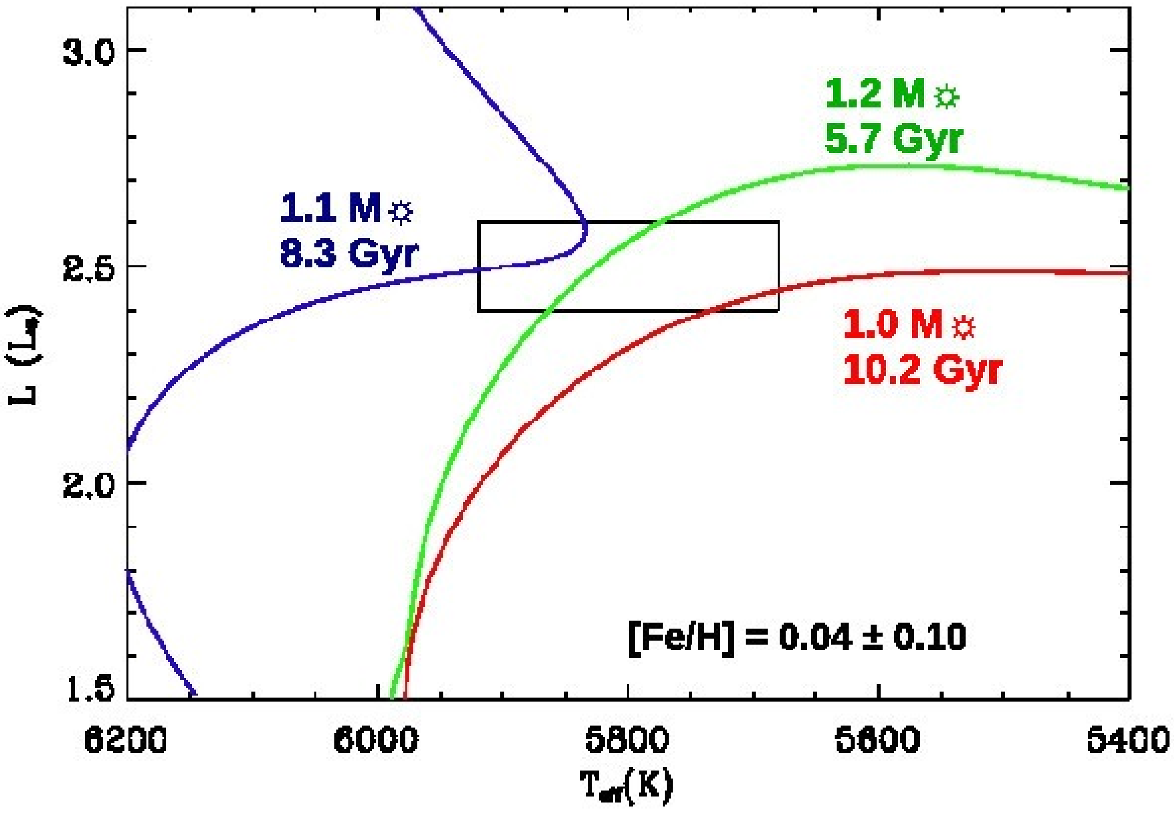
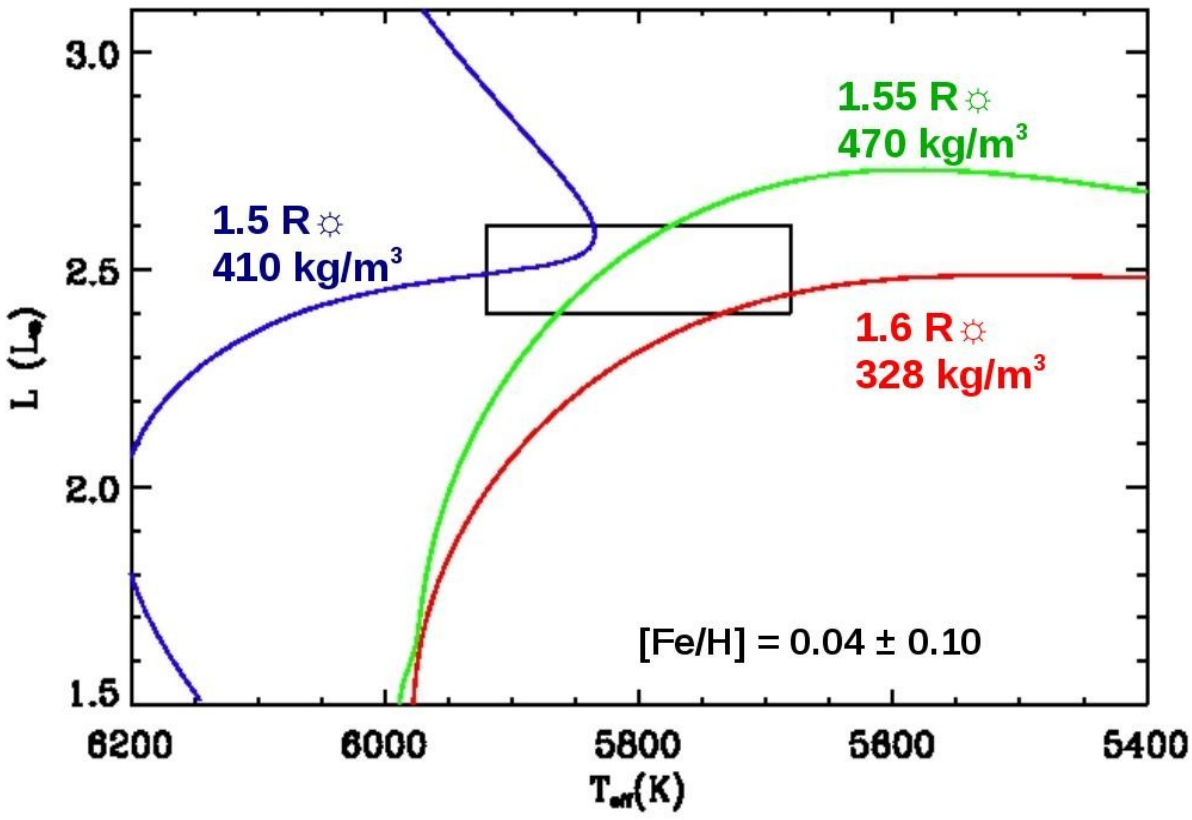
- **Model-dependent**
  - **All stars: stellar evolution models**

Model dependent ages

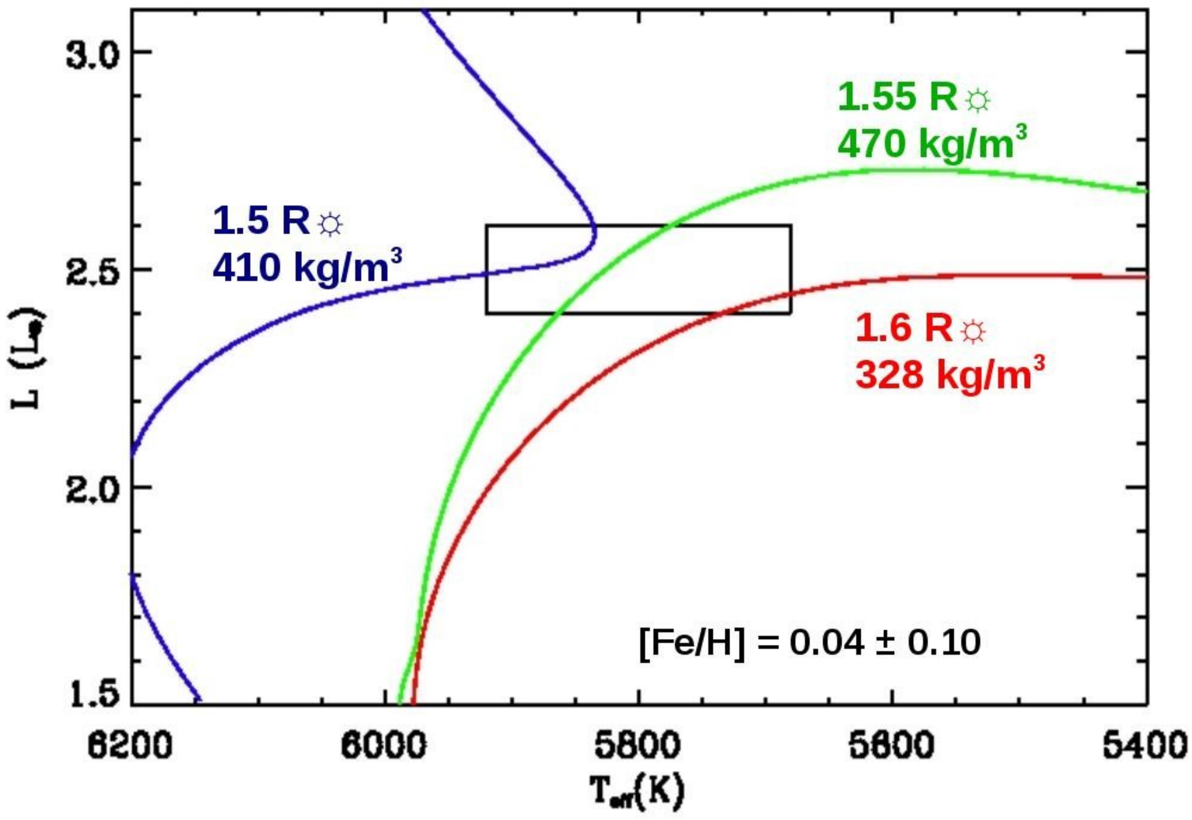


Assuming Teff and L are accurate

Model dependent ages



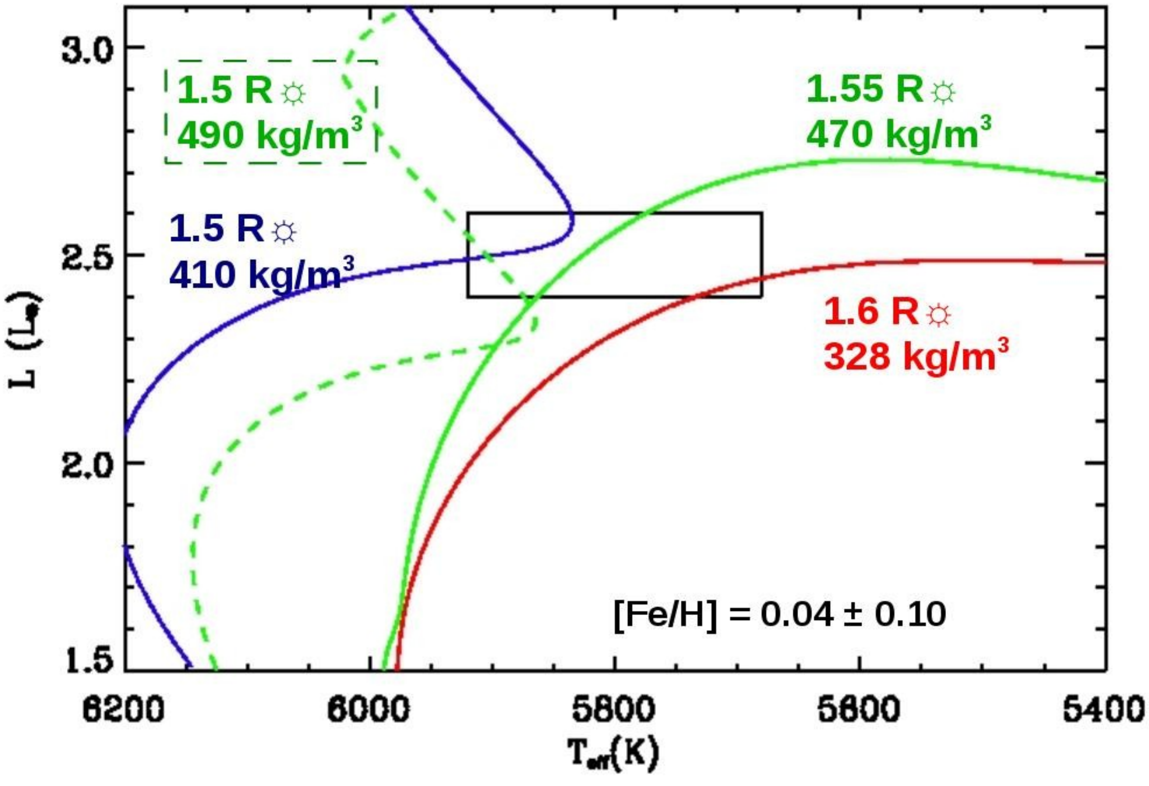
Model dependent ages



$$\langle \Delta\nu_{n\ell} \rangle \simeq \sqrt{\frac{M}{R^3}} \langle \Delta\nu_{n\ell} \rangle_\odot$$

Mean density -> asteroseismology / planetary transits
Radius -> distance + interferometry / surface brightness relations
OR asteroseismology

Model dependent ages



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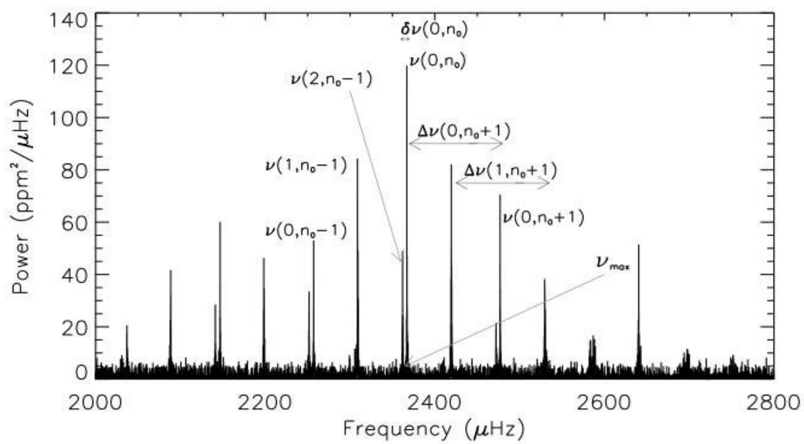
Asteroseismic benchmarks

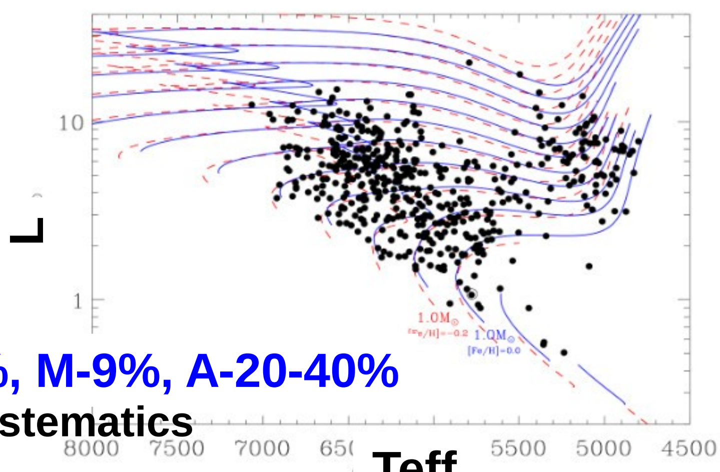
Typical power spectrum of sun-like oscillations



$$\Delta\nu_0 = \left(2\int_0^R \frac{dr}{c}\right)^{-1} \qquad c_s^2 = \frac{\gamma P}{\rho}$$

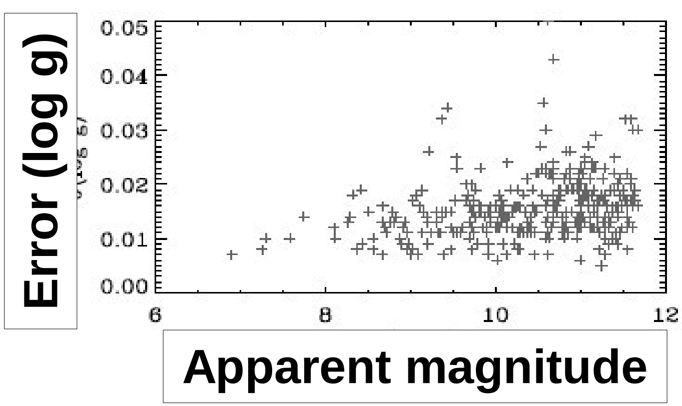
	HD49933[(1)]	Sun[(2)]
Mass (M☼)	1.12 ± 0.03	1.010 ± 0.008
Age (Gyr)	2.9 ± 0.4	4.65 ± 0.17

(1) Creevey & Bazot, 2011
(2) Metcalfe, Creevey & Christensen-Dalsgaard, 2009



R-3%, M-9%, A-20-40%
+ Systematics

Chaplin et al. Incl. Creevey 2013



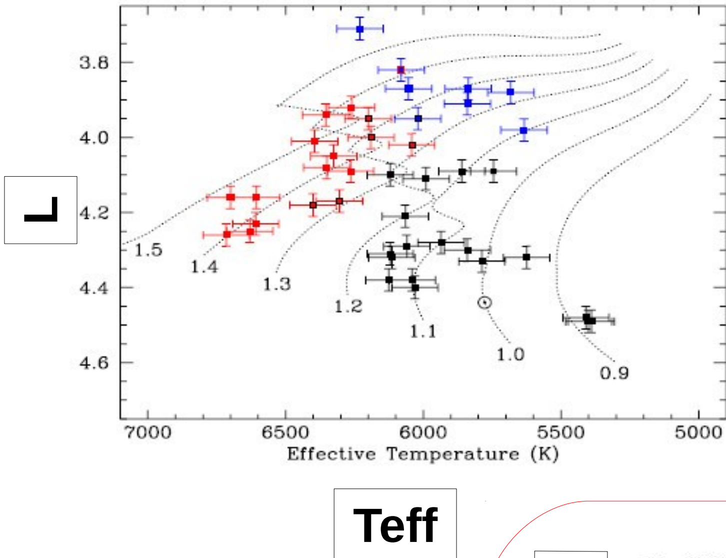
Logg < 0.02 dex

Creevey, Thevenin et al. 2013

42 Kepler benchmark stars

Kepler

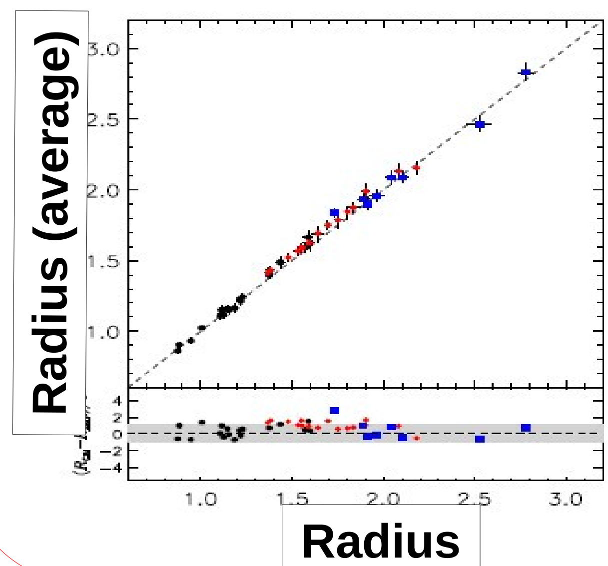
Homogenous sample of 42 stars

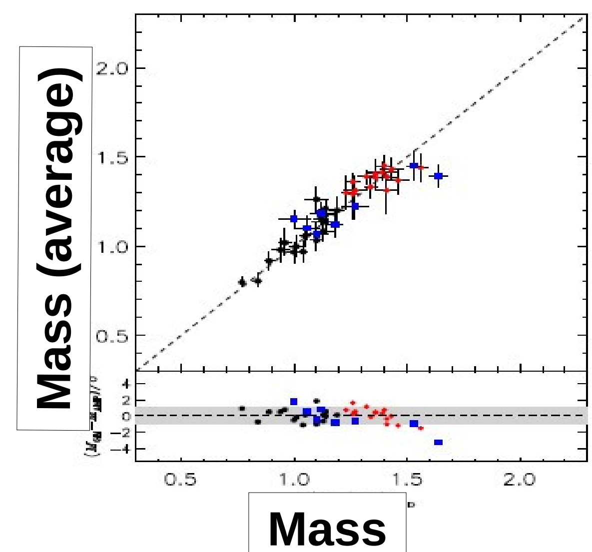


- -- March-December 2010
- -- Frequencies from Appourchaux et al. 2012
- -- Teff, [Fe/H] from Bruntt et al. 2012
- -- Modelling with AMP

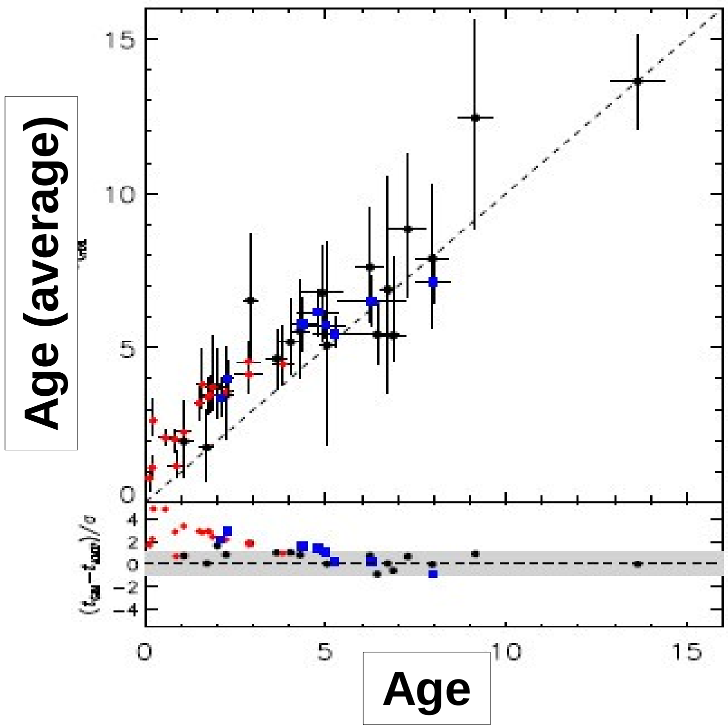
Metcalfe, Creevey et al. submitted

σ(R) ~ 1.2%
σ(M) ~ 2.8%



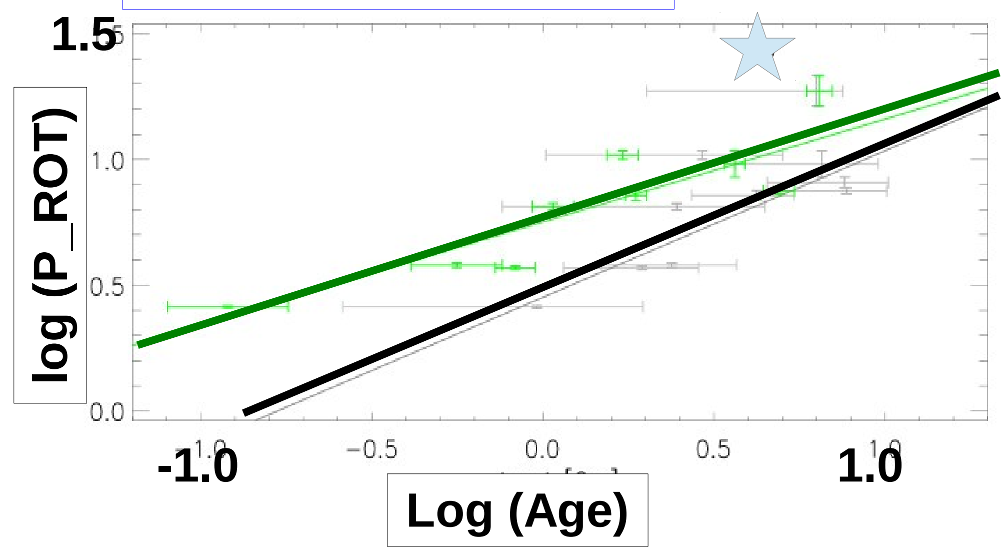


42 Kepler benchmark stars



Median precision in age ~ 7.9%

Age-Rotation relations



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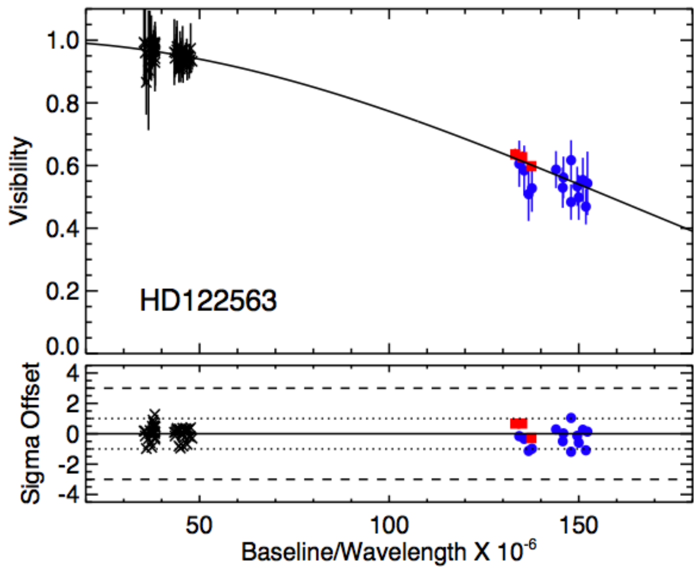
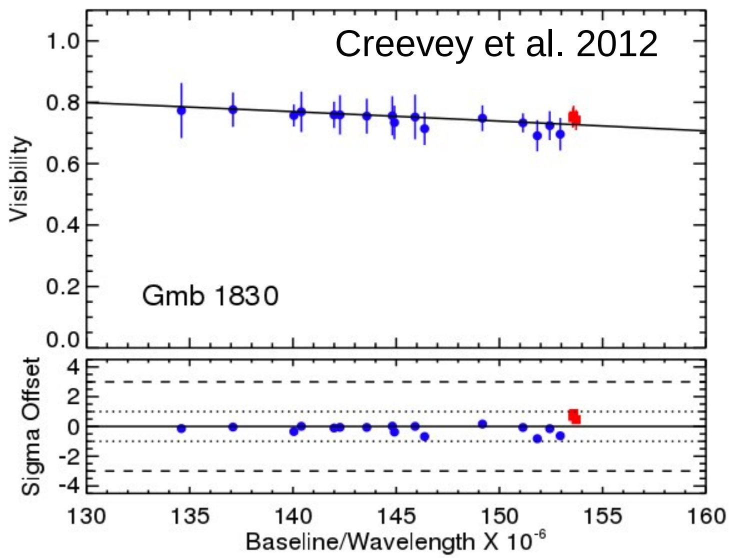
Interferometric observables



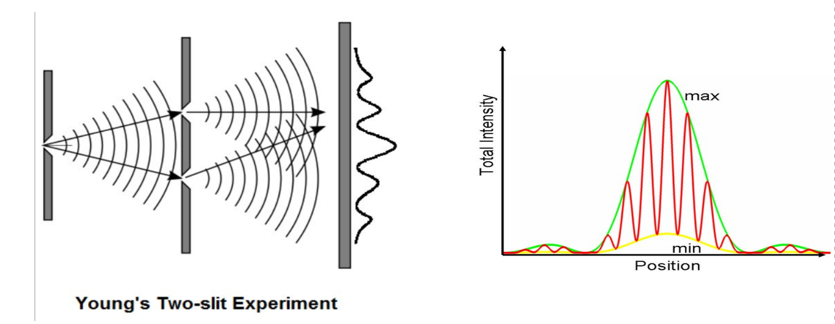


$$V = \text{Visibility} = \frac{(I_{max} - I_{min})}{(I_{max} + I_{min})}$$

$$V = \frac{2J_1(x)}{x}$$

$$x = \pi B \theta \lambda^{-1}$$

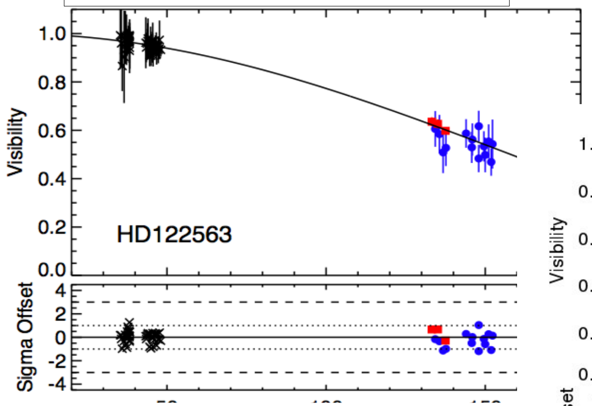
Angular diameter



Credits: Stigmatella aurantiaca and wikipedia

Angular diameters of Pop II stars

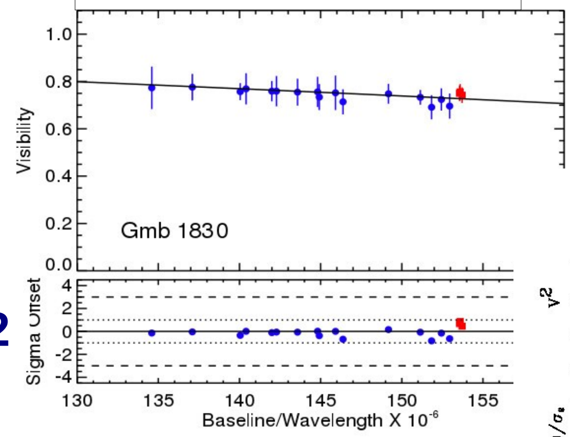
HD 122563 b=+65



Creevey, Thevenin et al. 2012

θ= 0.948±0.012 mas

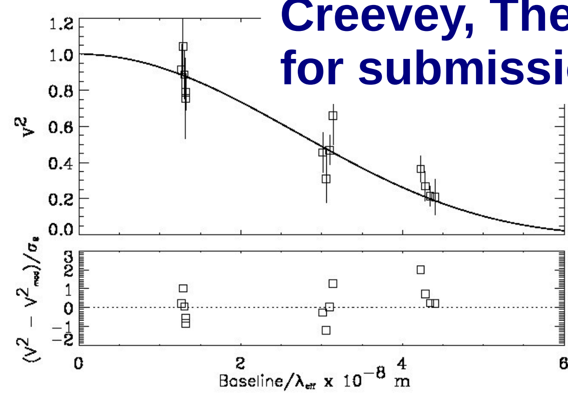
HD 103095 b=+73



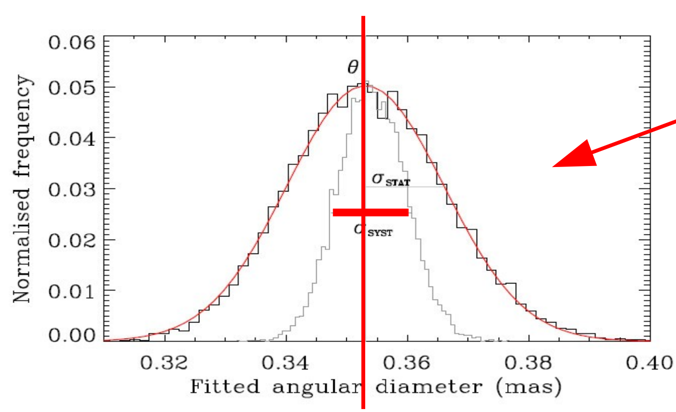
θ = 0.679±0.015

HD 140283 b=+33

Creevey, Thevenin et al. for submission 2014



θ = **0.353**±0.012stat



Assymetric systematic error

Angular diameters

$$R = \frac{\theta}{\pi}$$

$$T_{\rm eff} = \left(\frac{4}{\sigma_{\rm SB}} \frac{F_{\rm bol}}{\theta^2} \right)^{0.25}$$

Radius : direct constraint for mass, age, and logg
: direct comparison with seismic R

Teff : direct determination only mildly dependent on models (flux)

Teff & logg : abundance analyses

Teff & R : mixing-length parameter

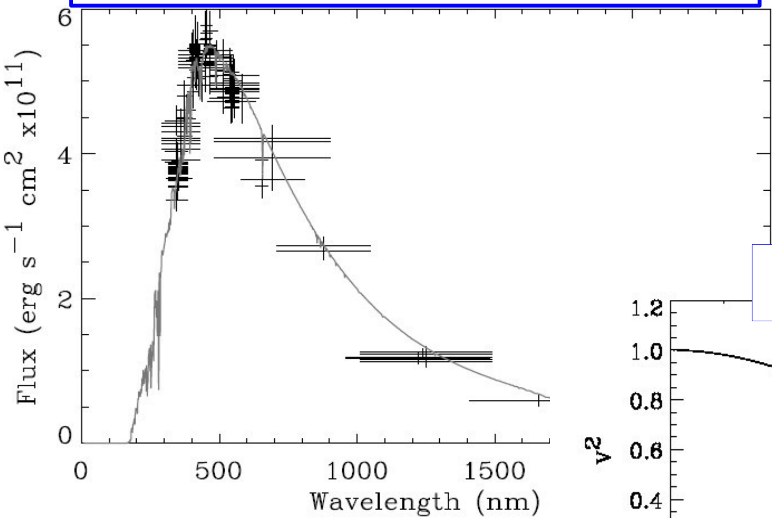
Metal-poor stars:

Oldest stars in Galaxy: - ages and initial composition for formation scenarios
- chemical evolution

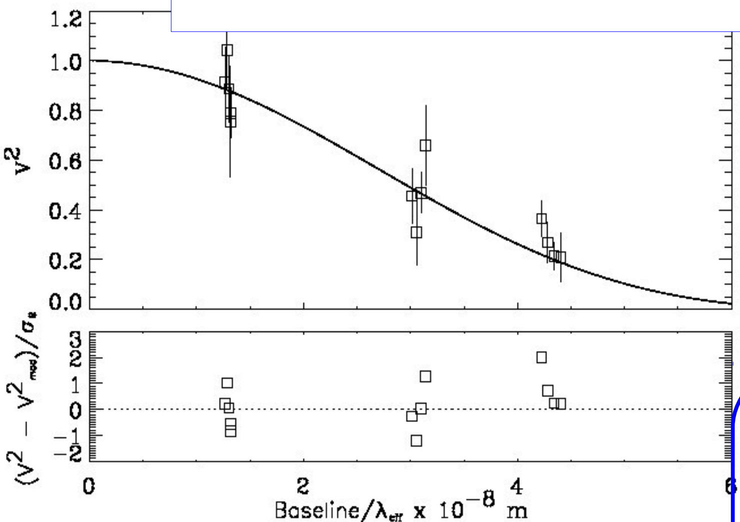
Poorest in metals: - Teff scale poorly calibrated
- model atmospheres need complex treatment
- Treatmentof physics in models

HD 140283

Fbol = 4.274 ± 0.027 e8erg/s/cm^2



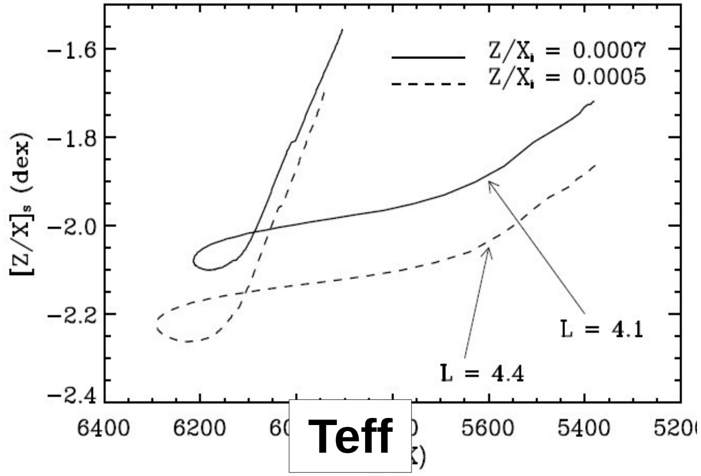
Θ = 0.353±0.012 mas



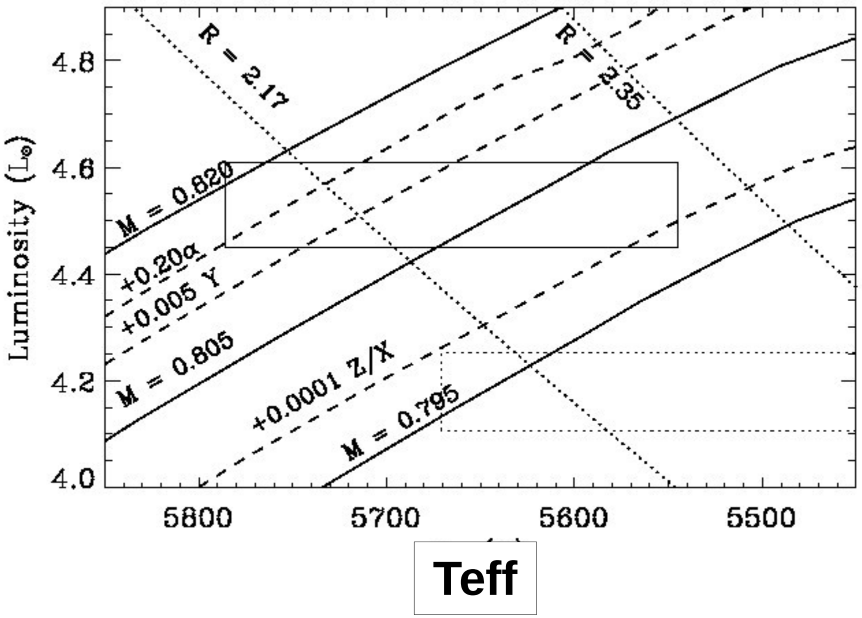
Av = 0.111 mag

Teff = 5565 ± 120 K
R = 2.21 ± 0.10 R$_\odot$
L = 4.53 ± 0.08 L$_\odot$
[M/H] = -2.1 ± 0.2
[Fe/H] = -2.6 ± 0.1

HD 140283



Calibrated extra-mixing with NGC6397 using CESAM2K



M = 0.805 ± 0.015 Mo
Age = 12.1 ± 0.9 Gyr
Logg= 3.65 ± 0.05
α = 1.0 (α_sol = 2.0)

Bright metal-poor stars as benchmarks

- Casagrande et al. IRFM agrees -> Teff for all stars with IR photometry
- Calibration of Gaia: benchmark stars for model atmospheres and stellar properties
- Models with diffusion and a: globular clusters
- Chemical compositions and ages well-determined for sample of old stars: Y, DZ/DY, age
- FRIENDS: higher precision + more access
- Gaia: distances better precision

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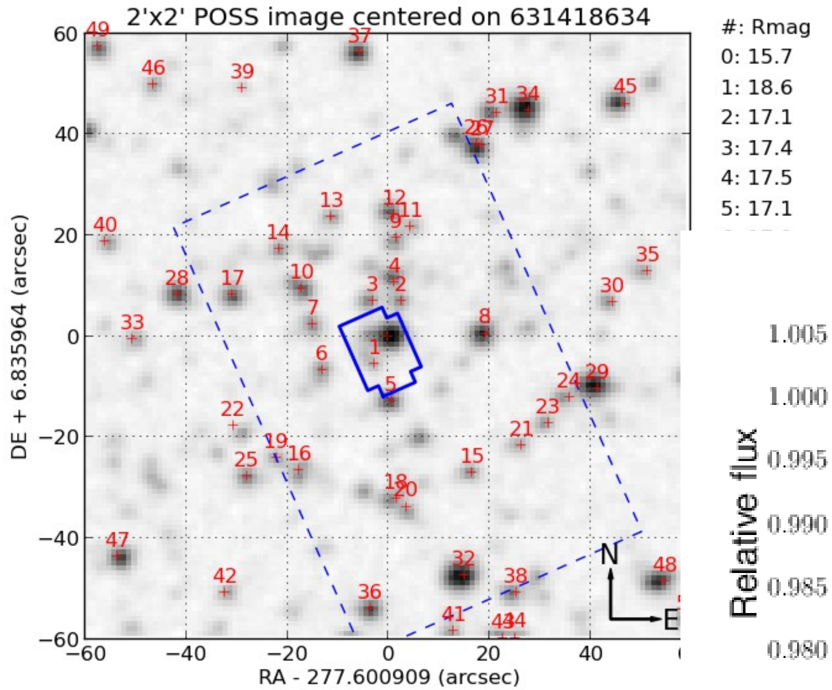
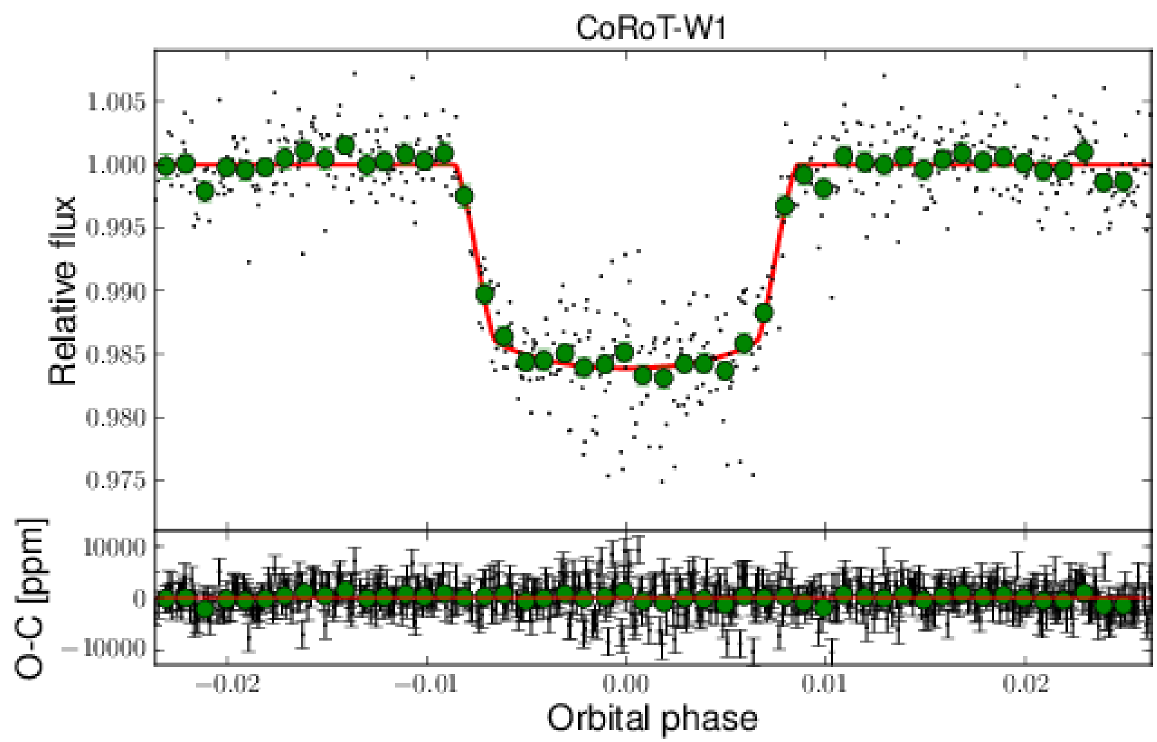
CoRoT-30 Observations



5 April 2011 to 30 June 2011
RA: -277 Dec: +6

Bordé et al. in prep.



CoRoT-30

Light curve and RV derived parameters

Period (d)	9.06004
Eccentricity	< 0.24
Inclination (deg)	>88
R_p/R_star	0.119
Stellar density (solar)	1.06
K_B (cm/s^2)	260

Planet

Mass

Radius

Age

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+

Stellar observed parameter

[M/H]	-0.05
log g	4.4
Teff (K)	5700
V (mag)	15.62
K (mag)	13.56
E(B-V)	0.20

Planet
Mass
Radius
Age

Stellar
Mass
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Luminosity
Distance

CoRoT-30

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Evolution + Atmosphere Models

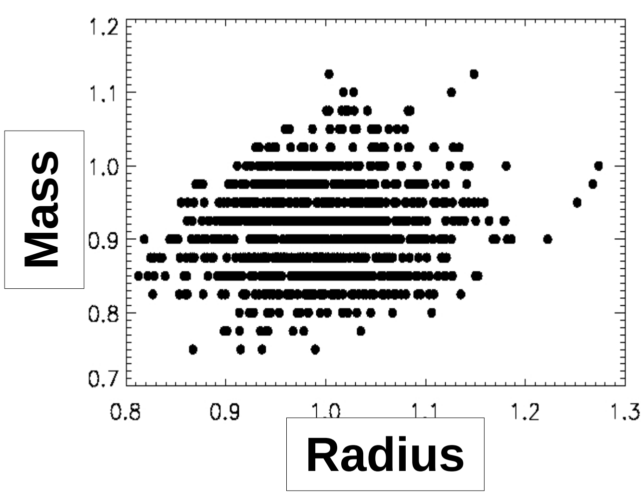
Stellar
Mass
Radius
Age
Luminosity
Distance

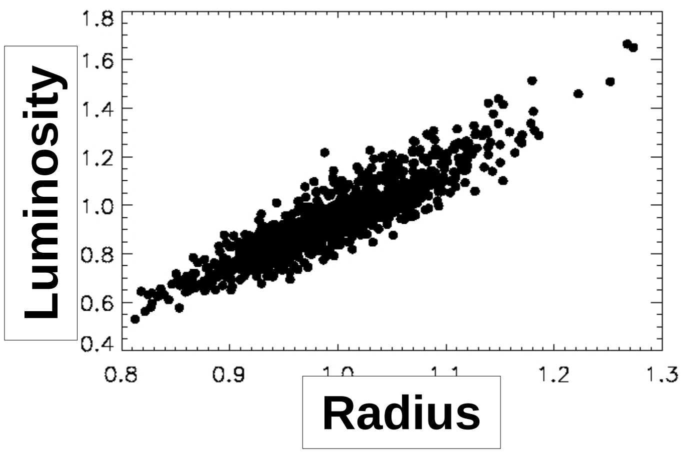
Planet
Mass
Radius
Age

Stellar parameters of CoRoT-30

Photometry -> Fit model atmospheres to determine angular diameter
Spectroscopy + angular diameter -> MC match to evolution models

	Mass	Radius	Age	Distance
Sun	1.00 (9)	1.00 (6)	6.2 (4.0)	
aCenA	1.10 (8)	1.22 (8)	6.7 (2.2)	
aCenB	0.95 (8)	0.87 (3)	7.1 (4.5)	
CoRoT-7	0.90 (7)	0.85 (3)	9.9 (4.1)	162 (12)





R = 1.00 (6)
M = 0.90 (9)
A = 7.9 (3.2)

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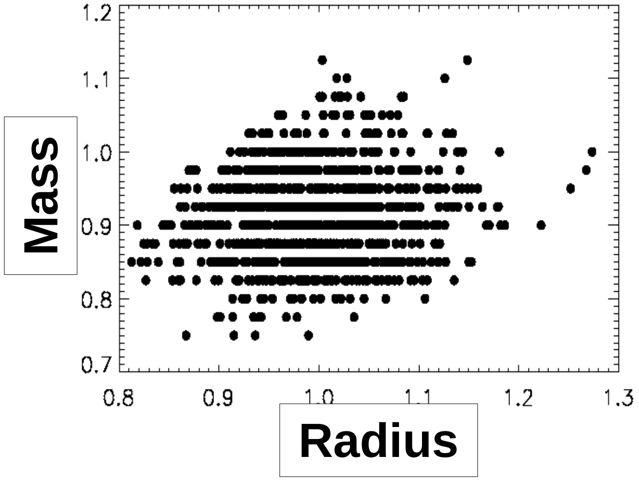
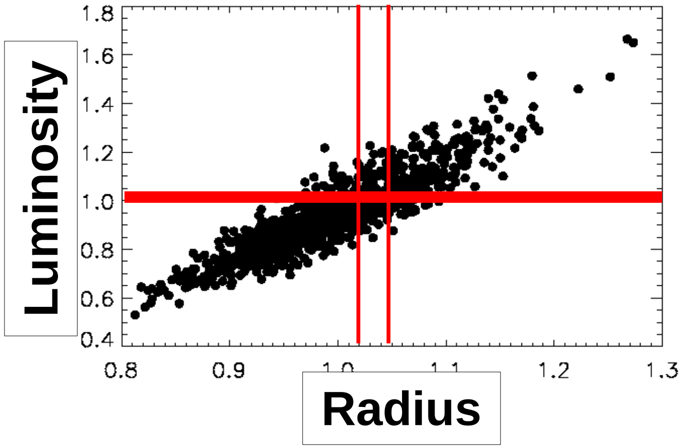


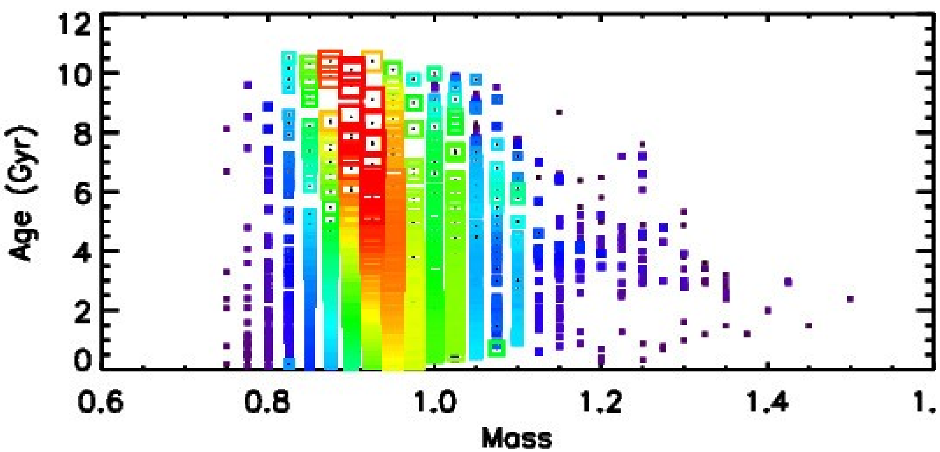


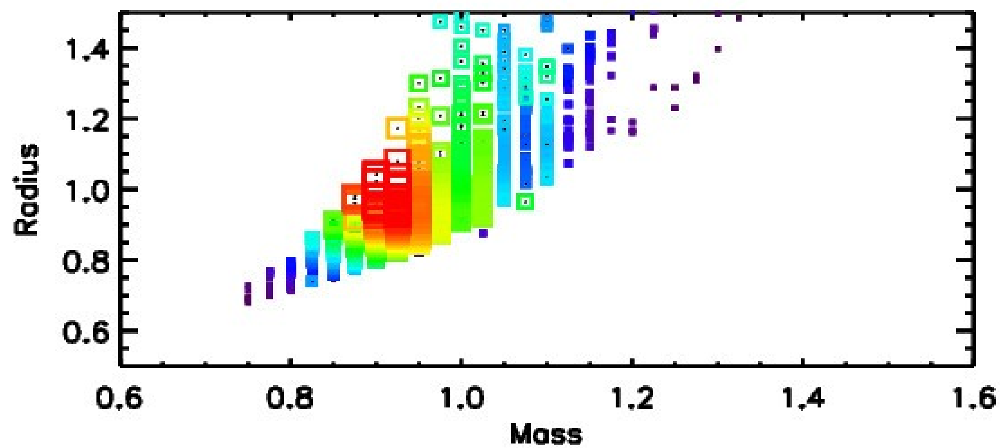
R = 1.00 (6)
M = 0.90 (9)
A = 7.9 (3.2)
(0.7)

Gaia distance!!!

Stellar parameters of CoRoT-30

MCMC in development: better determination of uncertainties and use of information





<u>Star</u>

Radius = 0.96 $R_{\odot}$
Mass = 0.90 $M_{\odot}$
Density = 1.10 $r_{\odot}$

→

<u>Planet</u>

Radius = 1.14 R_J

Mass = 2.85 M_J

Density = 2.6 g/cm^3

Age: main sequence ~ Sun

Conclusions

- Radius, mass, age are fundamental properties of interest to all aspects of astrophysics but are not usually observable.
- Sun is our most reliable calibrator. We need several such calibrators ([Fe/H], age, mass)
- Bright stars: precise properties allow us to test models, serve as bmarks
  - Seismic stars from Kepler: calibrate relations, such as age-rotation and scaling
  - HD140283: Metal-poor star: T, g, R, M, age,
- Fainter stars: use of improved models in efficient way
  - Planet CoRoT-30b: Combining observations + efficient algorithms
- Future: **Gaia**: distance + reddening -> luminosity constraint + Ages FLAME
  - **FRIENDS**: fainter stars and better precision/accuracy
  - **PLATO**: bright + seismology for planetary systems

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- Bright stars: precise properties allow us to test models, serve as bmarks
  - * Seismic stars from Kepler: calibrate relations, such as age-rotation and scaling independent radius, distance, Av
  - * HD140283: Metal-poor star: T, g, R, M, age, Av, Teff, L
- Fainter stars: use of improved models in efficient way
  - Av, R, L, M, A
  - * Planet CoRoT-30b: Combining observations + efficient algorithms
- Future: **Gaia**: distance + reddening -> luminosity constraint + Ages FLAME
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Thank you