Current performance of seismic diagnostics and stellar parameter determination

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Fundamental properties of stars
(from asteroseismology)

- Mass, Radius, Age (mean density, surface gravity)

  => planet properties and age of exoplanetary system

- Stellar inclination

  => Stellar obliquity

- Internal physics and dynamics of stars
  (e.g., depth of convective envelopes, presence/extent of convective cores, stellar rotation, etc)

  => Improve stellar models

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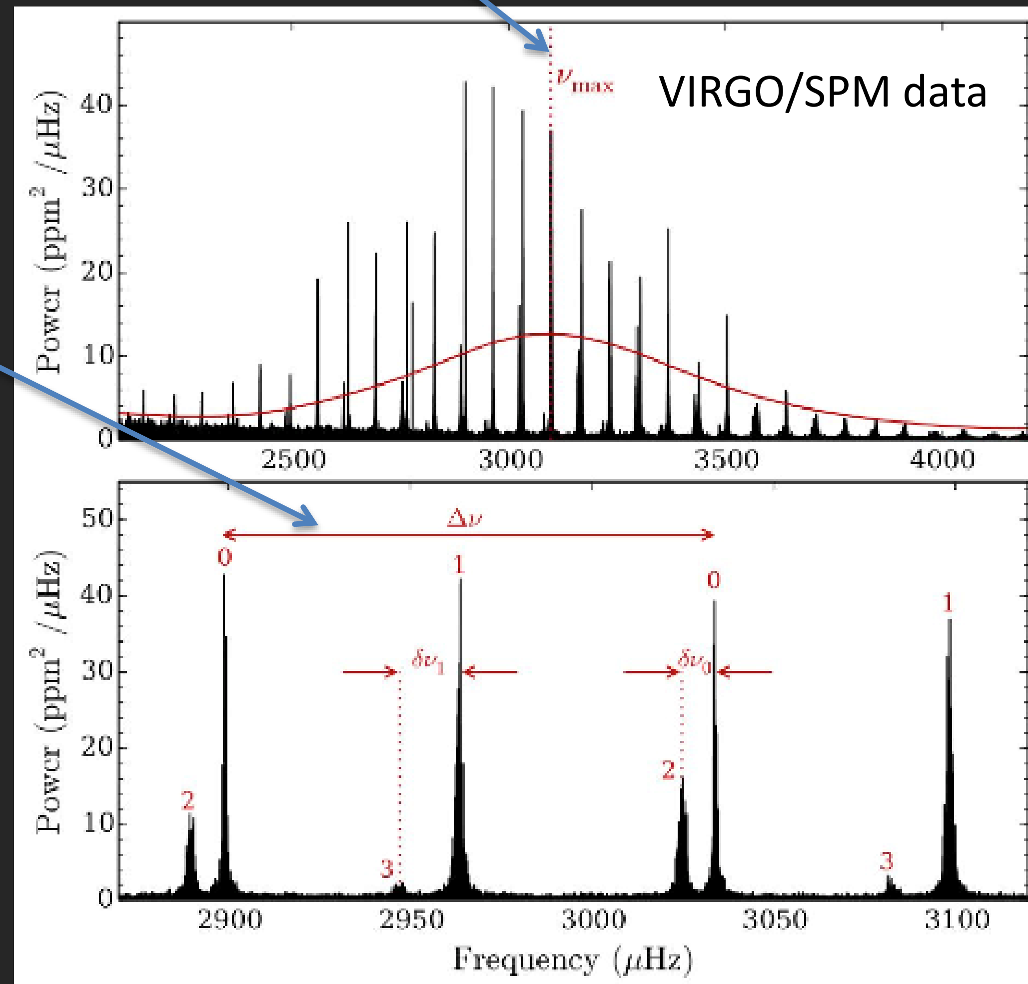
Seismic Observables

- Frequency of maximum power: ν_{max}

- Large separation: $\Delta\nu$



Seismic Observables

- Frequency of maximum power: ν_{max}

$$\nu_{\mathrm{max}} \propto g T_{\mathrm{eff}}^{-1/2}$$

- Large separation: $\Delta\nu$

$$\langle \Delta \nu_{nl} \rangle \propto \langle \rho \rangle^{1/2}$$

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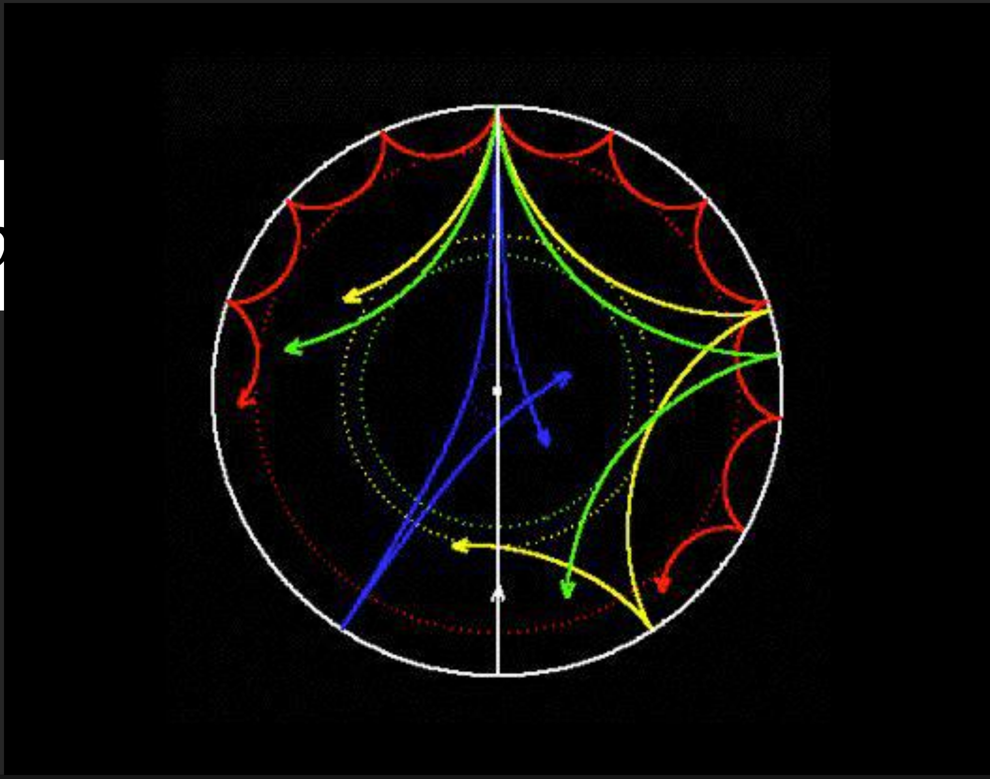

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- Individual frequencies

- Frequency ratios / separations ; phases

Non-seismic Observables

- + T_{eff}
  For precise radius and surface gravity determination

- + Metallicity
  To better constrain stellar masses and ages

- Luminosity, interferometric radius, etc (when available)

Procedures for inference of stellar properties

- Scaling relations
- Forward Modelling
- Signatures of rapid structural variations
- Seismic Inversions

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Procedures for parameter inference

- Direct use of scaling relations

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$$\nu_{\max} \propto g T_{\text{eff}}^{-1/2}$$

$$\langle \Delta \nu_{nl} \rangle \propto \langle \rho \rangle^{1/2}$$

$$\frac{R}{R_\odot} \approx \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\overline{\Delta\nu}}{\overline{\Delta\nu_\odot}}\right)^{-2}\left(\frac{T_{\text{eff}}}{T_{\text{eff},\odot}}\right)^{1/2},$$

$$\frac{M}{M_\odot} \approx \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3}\left(\frac{\overline{\Delta\nu}}{\overline{\Delta\nu_\odot}}\right)^{-4}\left(\frac{T_{\text{eff}}}{T_{\text{eff},\odot}}\right)^{3/2}$$

- Provide R and M only
- Uncertainties are larger than the requirements for PLATO (~5% in radius and ~10% in mass for dwarfs)

Procedures for parameter inference

- Forward Modelling

Procedures for parameter inference

- Forward Modelling

  - Fit a set of observables:

$$\{y_i\} = \{T_{\text{eff}}, [\text{Fe/H}], (L), seismic\}$$

with uncertainties σ_i

  - With theoretical observables produced from models with parameters

$$\{a_j\} = \{M, Y_0, (Z_0), (\alpha_{\text{MLT}}), (\text{ov}),\ \text{age},\ \text{etc}\}$$

Procedures for parameter inference

- Different approaches to forward modelling

- ≠ physics
  (evolutionary codes ; micro/macrophysics)

- ≠ combinations of observables
  (individual frequencies; ratios; phases; global seismic)

- ≠ model parameter space and ways to explore it
  (grid / models on demand)

- ≠ methods to find best model (optimisation)

Results on simulated data

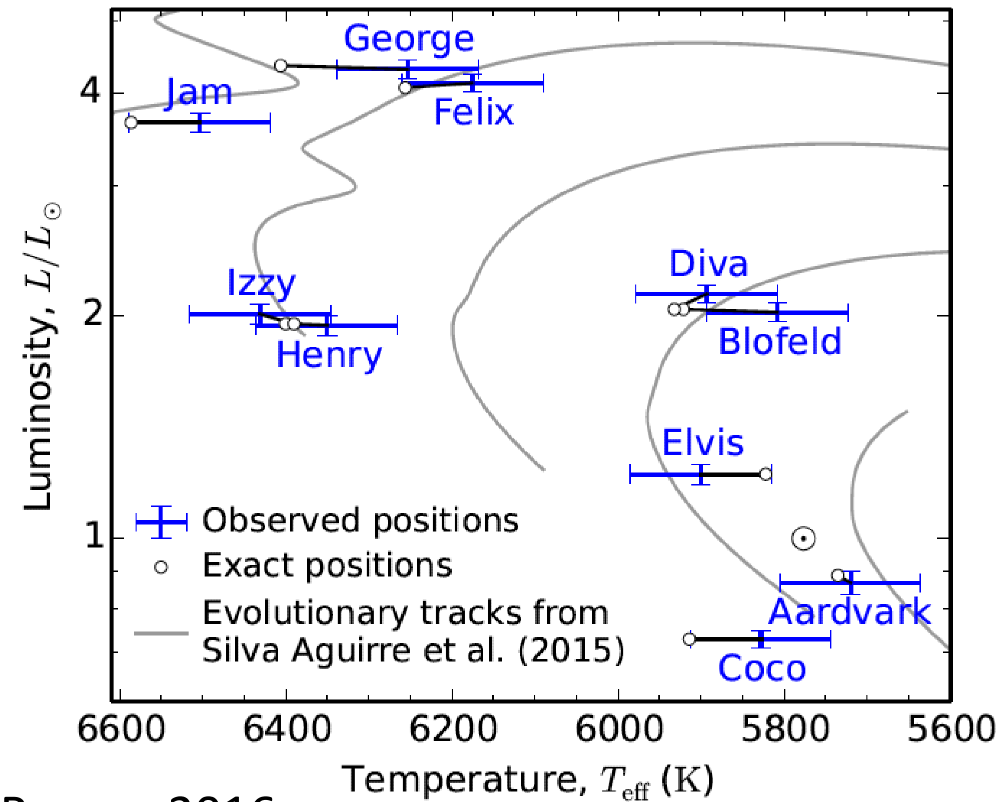
✧ Exercise 1: From Reese et al. 2016

- $\{y_i\}=\{T_{eff},[Fe/H],(L/L_\odot),seismic\}$
- 1 yr obs per star
- 8 different pipelines

$5735\ K < T_{eff} < 6586\ K$

$0.73 < L/L_\odot < 4.36$

$0.78 < M/M_\odot < 1.33$



Reese+ 2016

Results on simulated data

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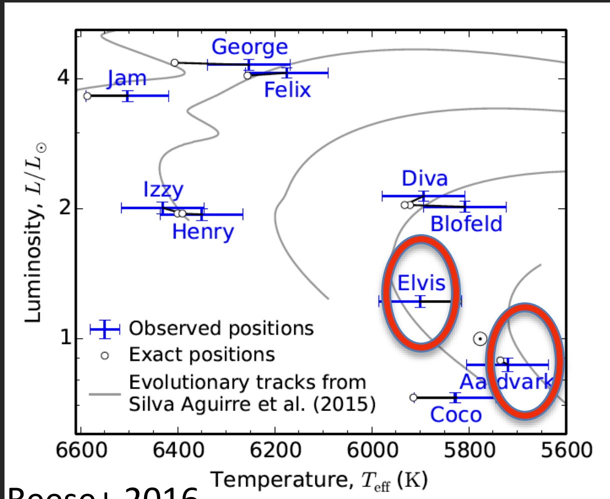

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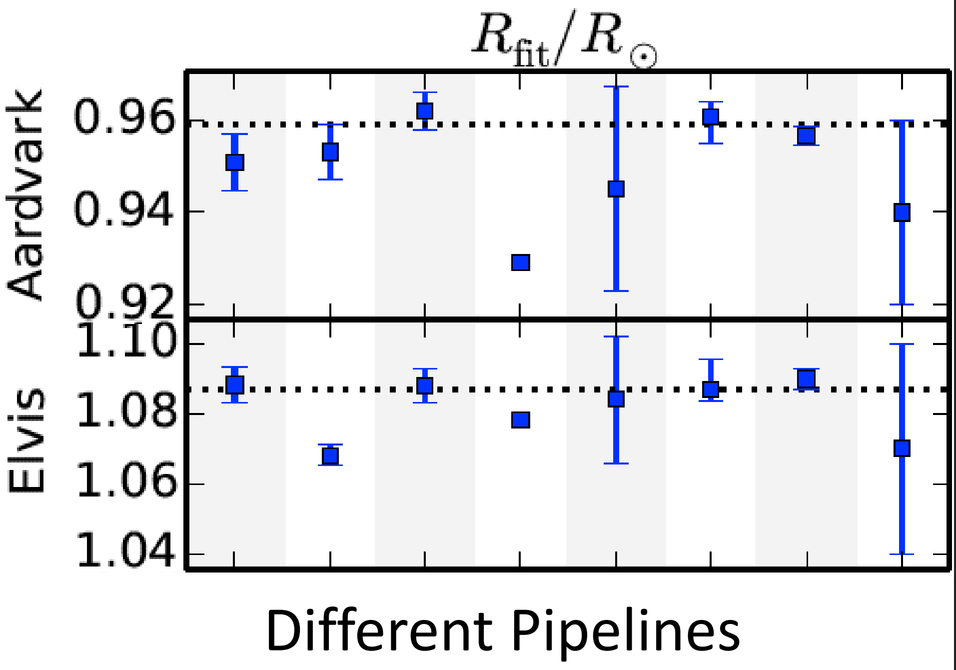

Adapted from Reese+ 2016

➢ Average error and biases

Aardvark	Elvis
ε_{rel} = 1.47 %	ε_{rel} = 0.88 %
b_{rel} = -0.99 %	b_{rel} = -0.49 %

$$\varepsilon_{\rm rel.} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_i^{\rm fit}-p^{\rm exact}}{p^{\rm exact}}\right)^2}$$

$$b_{\rm rel.} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_i^{\rm fit}-p^{\rm exact}}{p^{\rm exact}}\right)$$

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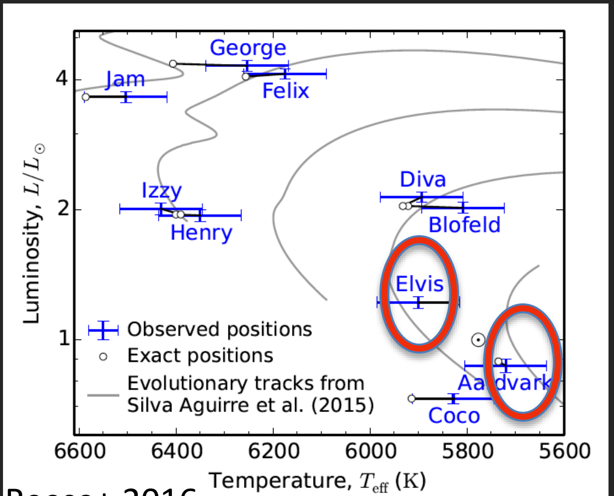

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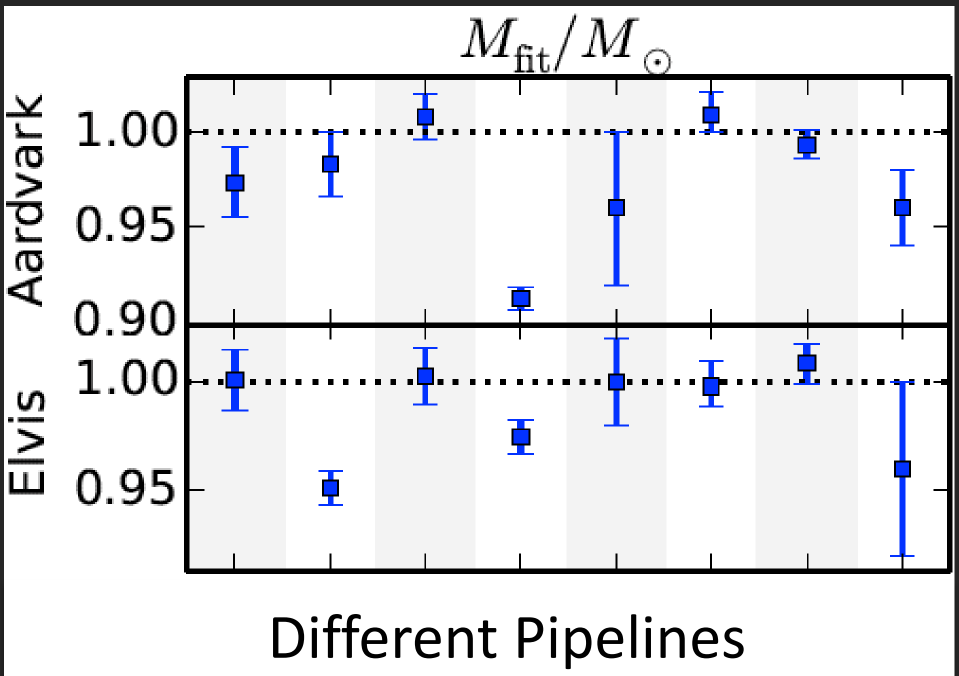

Adapted from Reese+ 2016

➢ Average error and biases

Aardvark	Elvis
ε_{rel} = 3.88 %	ε_{rel} = 2.43 %
b_{rel} = -2.51 %	b_{rel} = -1.32 %

$$\varepsilon_{\rm rel.} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_i^{\rm fit}-p^{\rm exact}}{p^{\rm exact}}\right)^2}$$

$$b_{\rm rel.} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_i^{\rm fit}-p^{\rm exact}}{p^{\rm exact}}\right)$$

Results on simulated data

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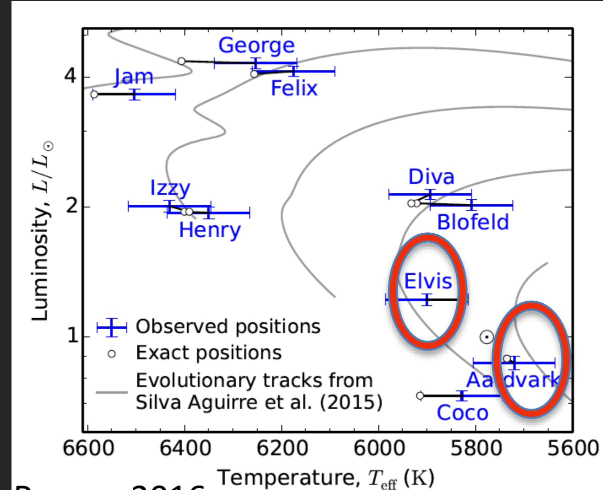

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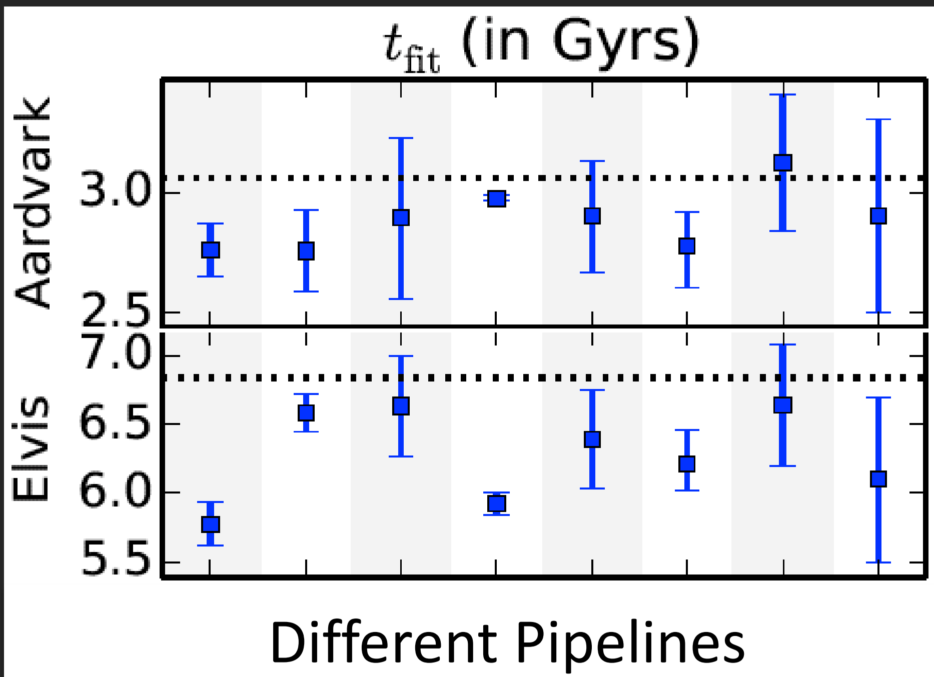


Adapted from Reese+ 2016

➢ Average error and biases

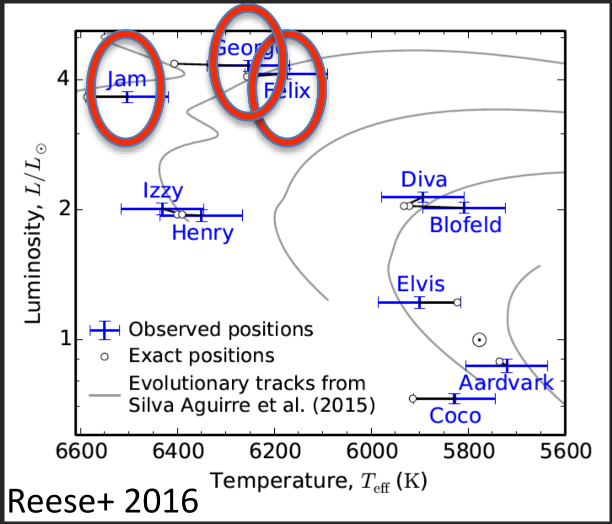
Aardvark	Elvis
ε_{rel} = 6.81 %	ε_{rel} = 9.35 %
b_{rel} = -5.66 %	b_{rel} = -8.16 %

$$\varepsilon_{\rm rel.} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_i^{\rm fit} - p^{\rm exact}}{p^{\rm exact}}\right)^2}$$

$$b_{\rm rel.} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_i^{\rm fit} - p^{\rm exact}}{p^{\rm exact}}\right)$$

Results on simulated data

- Exercise 1: From Reese et al. 2016
  - Average error and biases



		Felix	George	Jam
R	ε_{rel}	2.93 %	1.23 %	1.63 %
	b_{rel}	-1.08 %	0.87 %	1.00 %
M	ε_{rel}	6.16 %	3.74 %	4.71 %
	b_{rel}	-3.27 %	2.08 %	3.37 %
Age	ε_{rel}	40.18 %	33.93 %	33.32 %
	b_{rel}	20.18 %	-6.72 %	-23.15 %

Results on simulated data

✧ Exercise 2: From W120 (PLATO-LESLIA-PSPM-TS-01)

PLATO "reference" star:

$M=1.12\ M_{\odot}$

$R=1.20\ R_{\odot}$

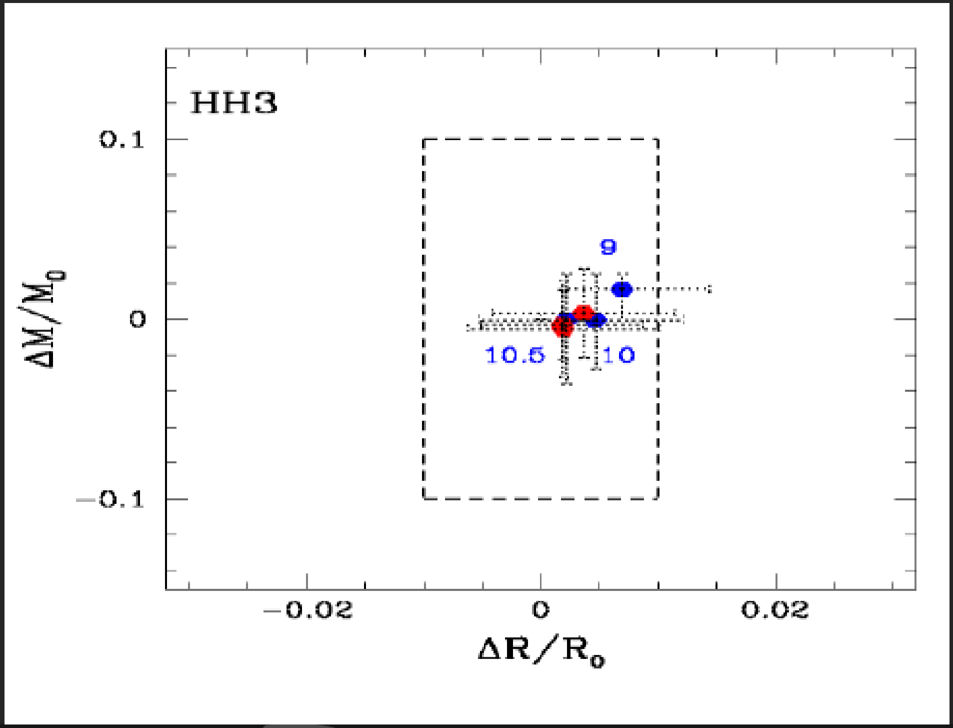
Age=3.44 Gyr

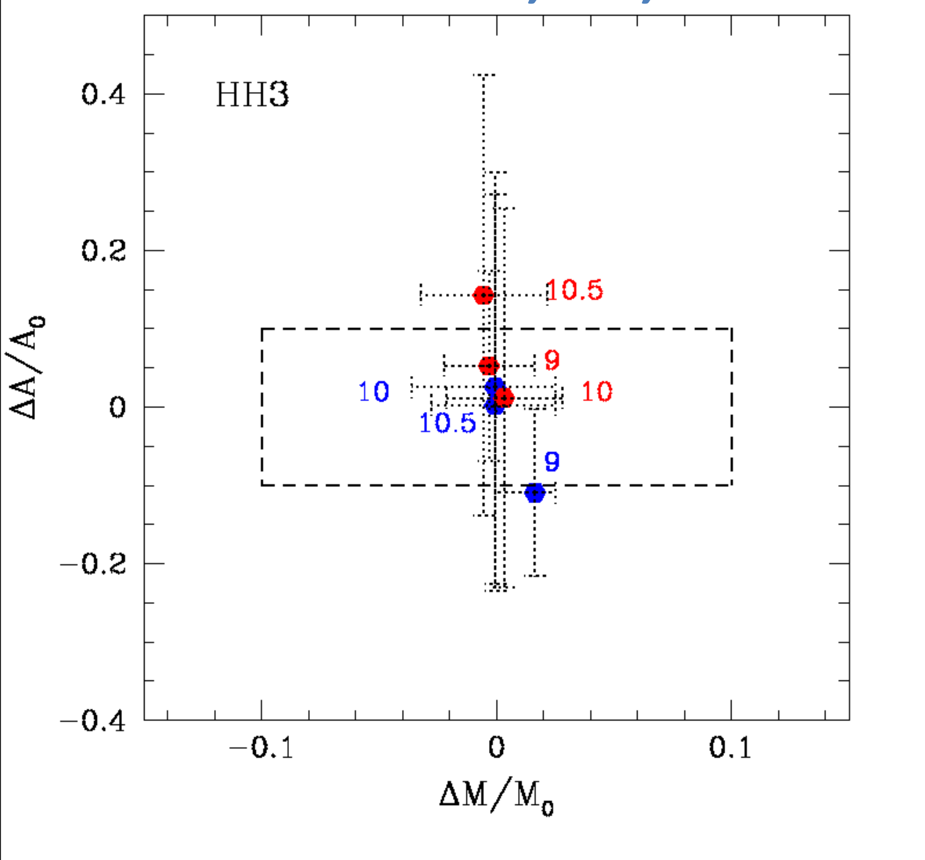
➤ Simulations were performed for V=9, V=10, and V=10.5, 2 yr observations, accounting for the PLATO Noise levels.

Results on simulated data

- Exercise 2: From W120 (PLATO-LESLIA-PSPM-TS-01)
  - $\{y_i\}=\{T_{eff},[Fe/H],(L/L_\odot),\text{seismic}\}$
  - 2 different pipelines

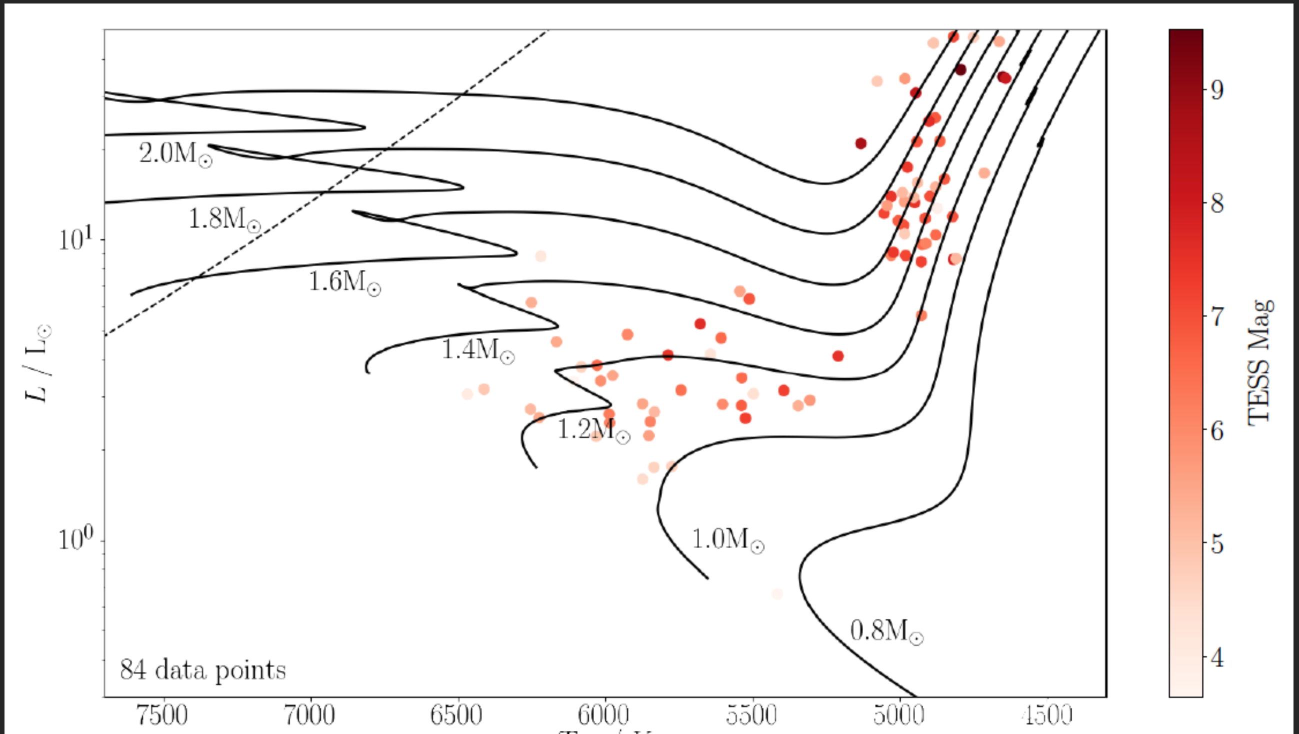
For V= 9; 10; 10.5





Results on simulated data

- Exercise 2: Campante et al.



Campante+ (priv com.)

Sample: 100 planet-host stars ; ~50% are evolved stars

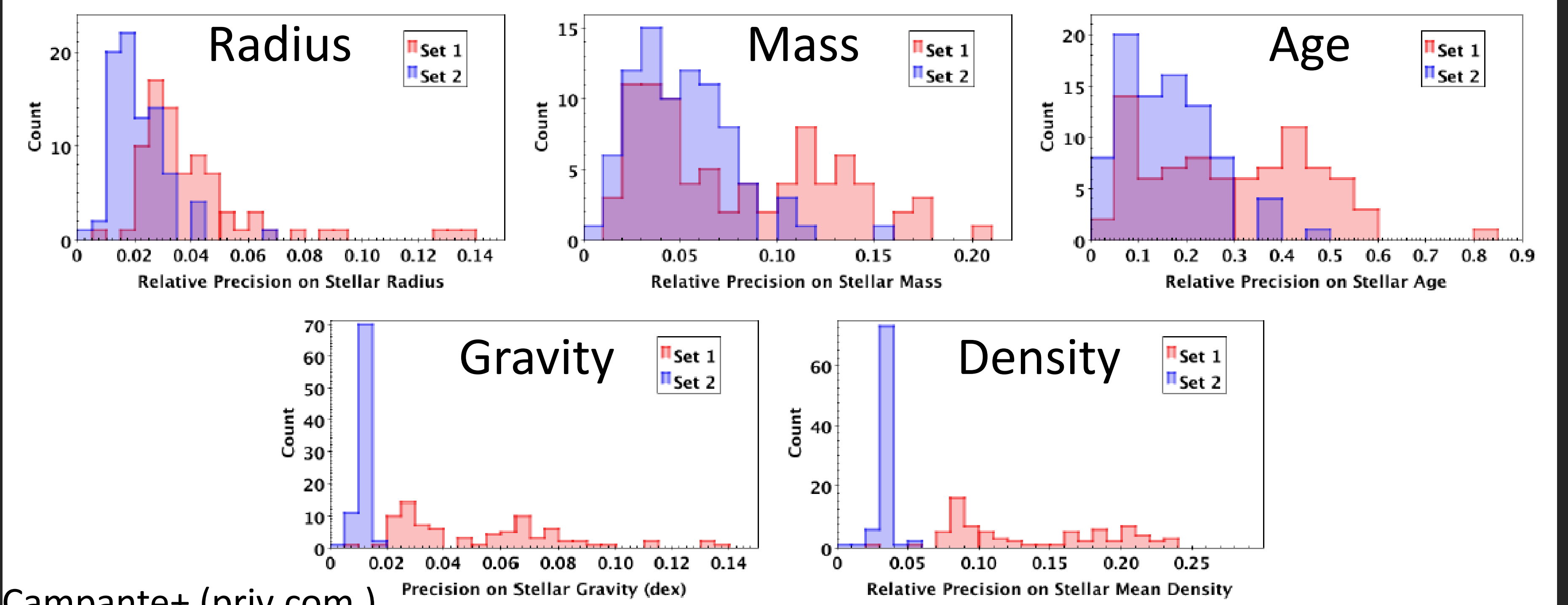
Expected Δν and ν_{max} from TESS mission

Results on simulated data

✧ Exercise 2: Campante et al.

Set 1: $\{y_i\}=\{T_{eff}, [m/H], L\}$

Set 2: $\{y_i\}=\{T_{eff}, [m/H], L, \Delta\nu, \nu_{max}\}$

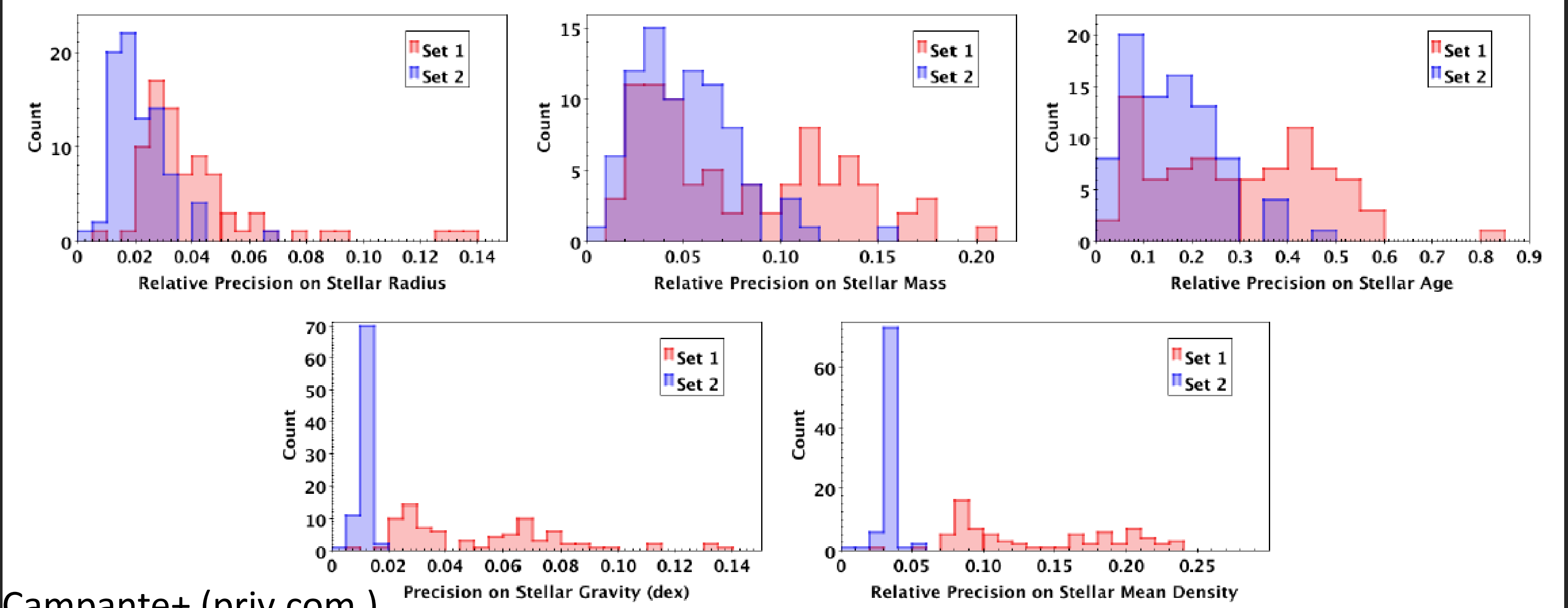


Campante+ (priv com.)

Results on simulated data

✧ Exercise 2: Campante et al.

Statistic	R	M	Age	$\log g$ (dex)	$\bar{\rho}$
Median	1.9 % (3.4 %)	4.6 % (6.7 %)	15 % (30 %)	0.012 (0.052)	3.4 % (15 %)



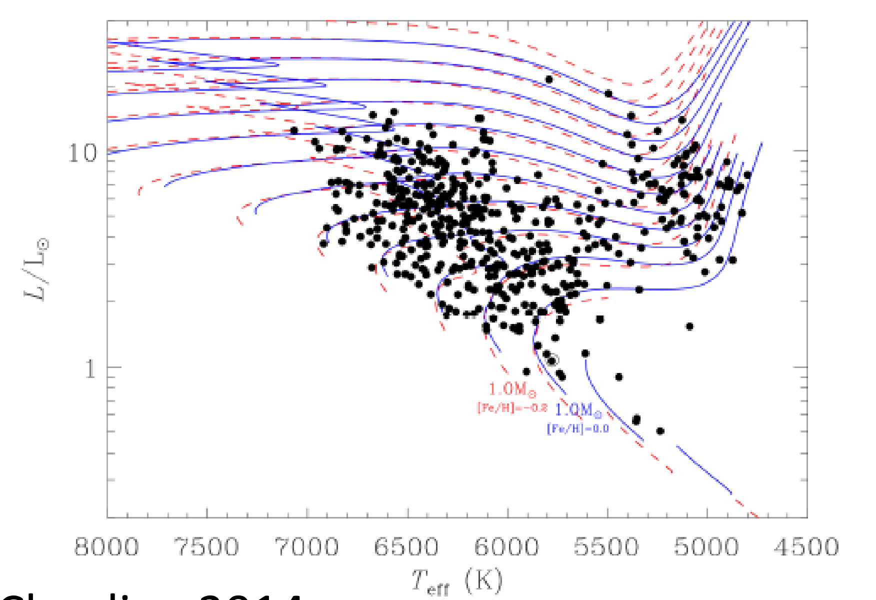
Campante+ (priv com.)

Results from real data

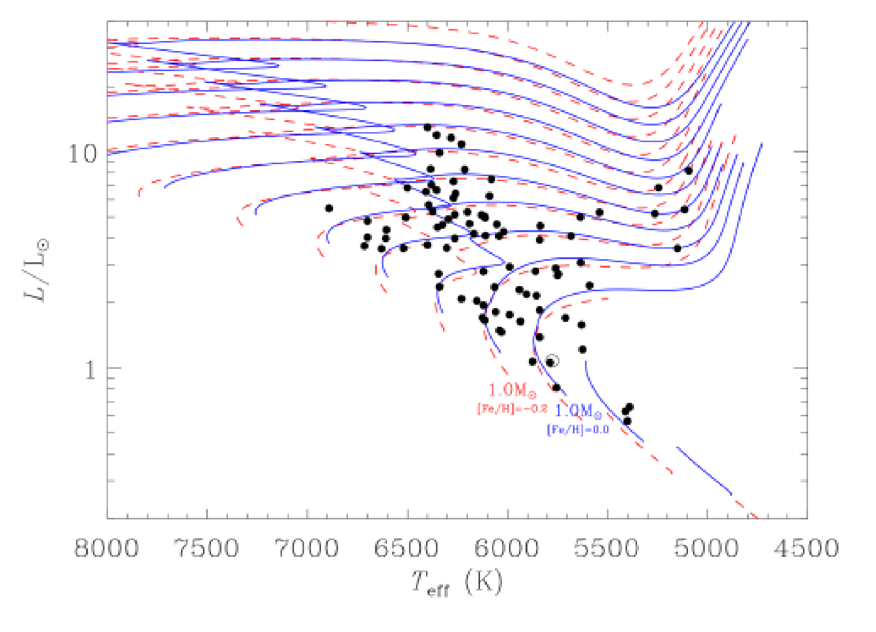
- Study 1: Chaplin et al. 2014
  - $\{y_i\}=\{T_{eff}, [Fe/H], \Delta\nu, (\nu_{max})\}$
  - 1 month obs per star
  - 6 different pipelines

Set 1: ~500 stars
T_{eff} from photometry
[Fe/H]=-0.2±0.3 dex

Set 2: 87 stars
T_{eff} and [Fe/H] from spect.



Chaplin+ 2014



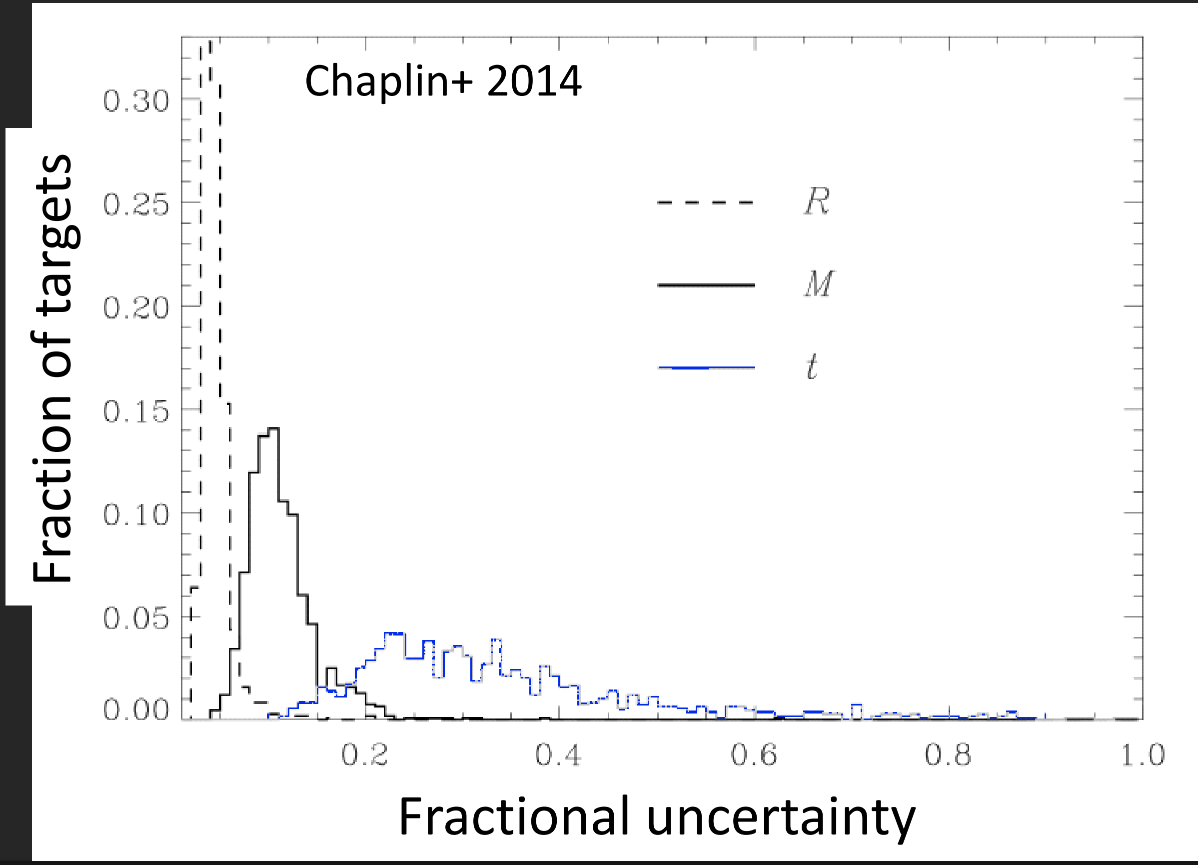
Results from real data

✧ Study 1: Chaplin et al. 2014

Set 1 : The worst case scenario

Median uncertainties
(formal plus grid scatter)

Radius: 4.4%
Mass: 10.8%
Age: 34%



Results from real data

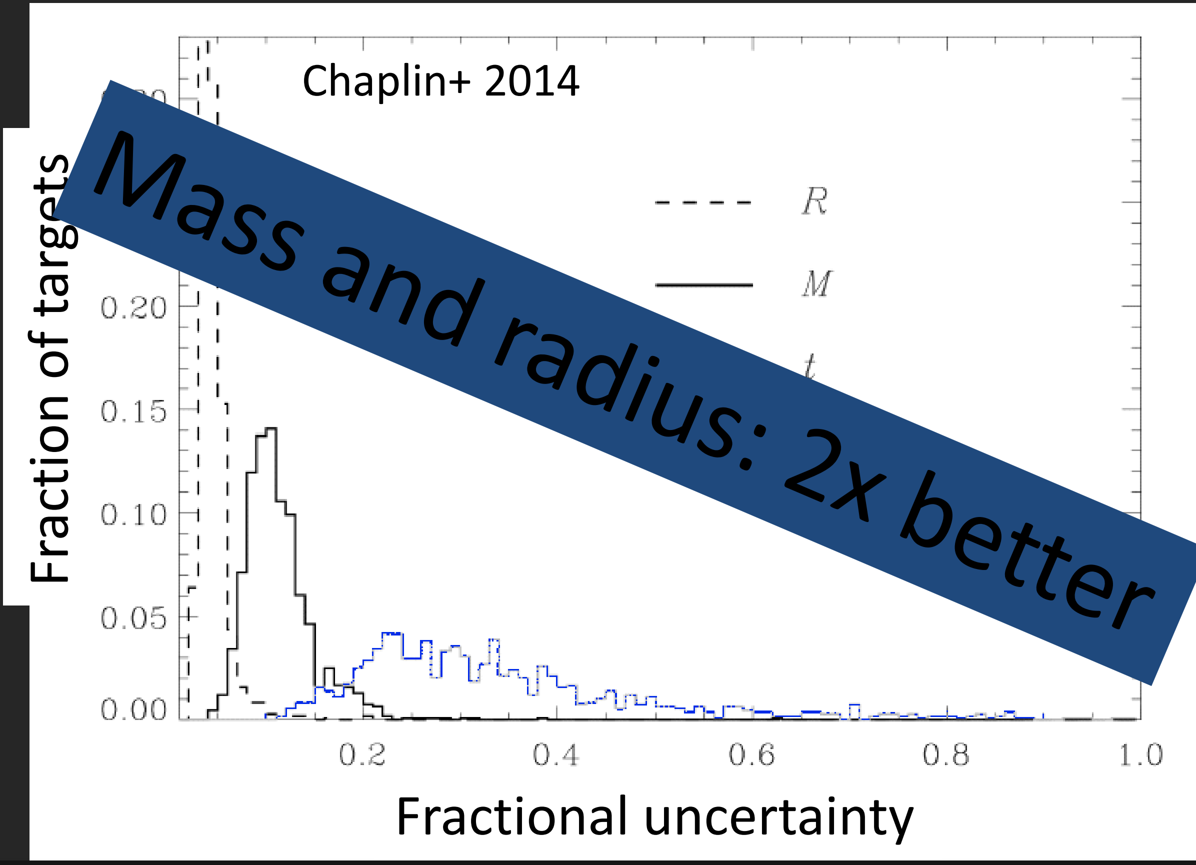
✧ Study 1: Chaplin et al. 2014

Set 2: The impact of spectroscopy

Median uncertainties
(formal plus grid scatter)

Radius: 2.2%
Mass: 5.4%
Age: 25%

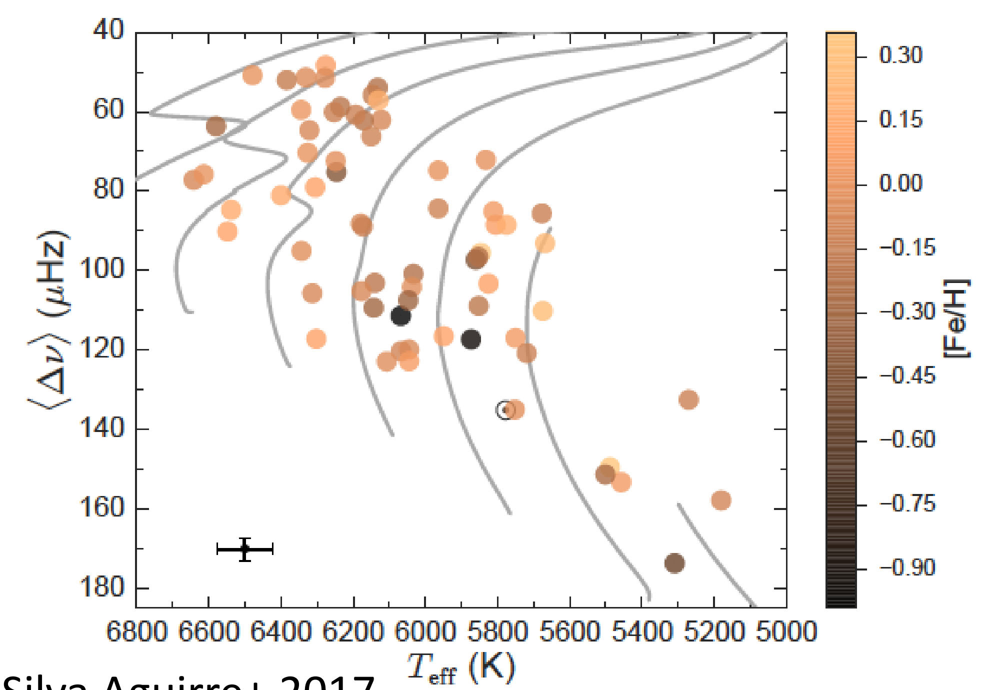
(σ < 30% for 80% stars !)



Results from real data

- Study 2: Silva Aguirre et al. 2017
  - $\{y_i\}=\{T_{eff}$, [Fe/H], seismic$\}$
  - At least 1 yr obs per star
  - 7 different pipelines

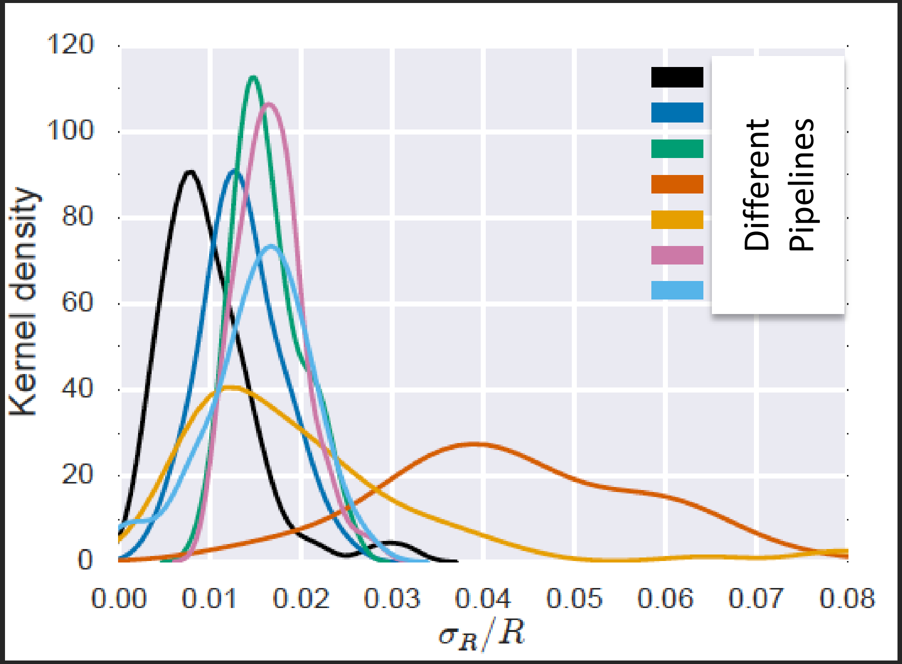
Kepler Legacy Sample

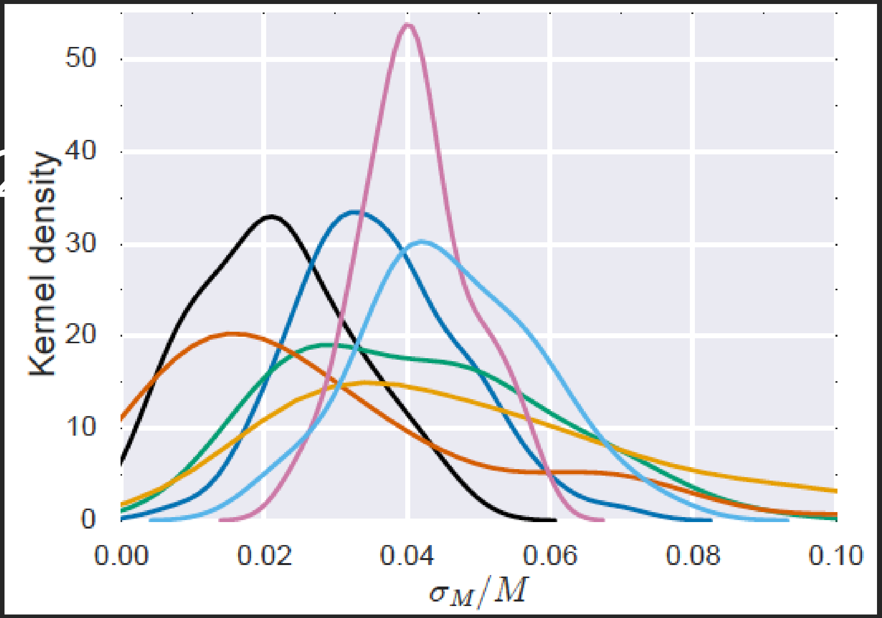


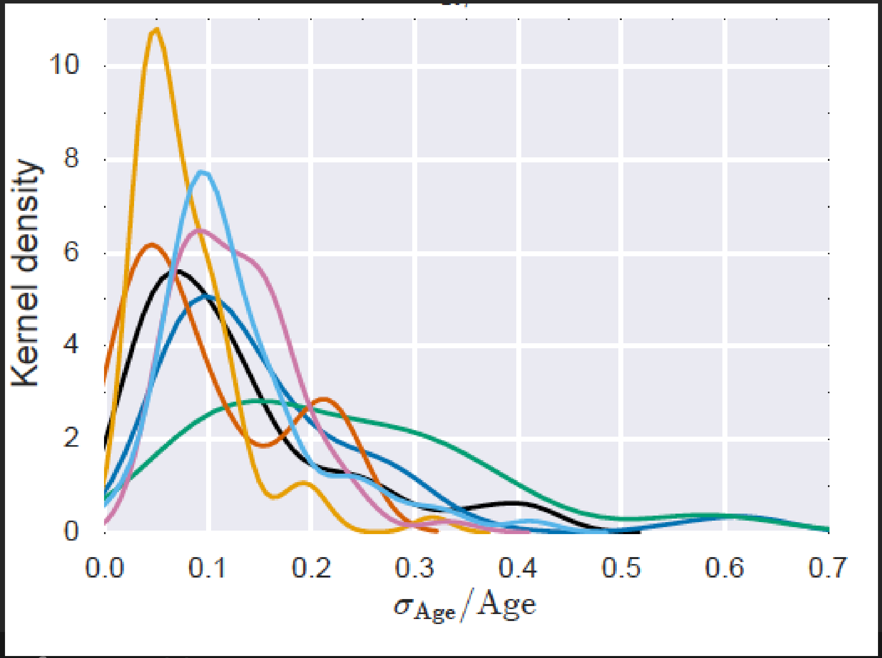
Silva Aguirre+ 2017

Results from real data

✧ Study 2: Silva Aguirre et al. 2







Range of median uncertainties

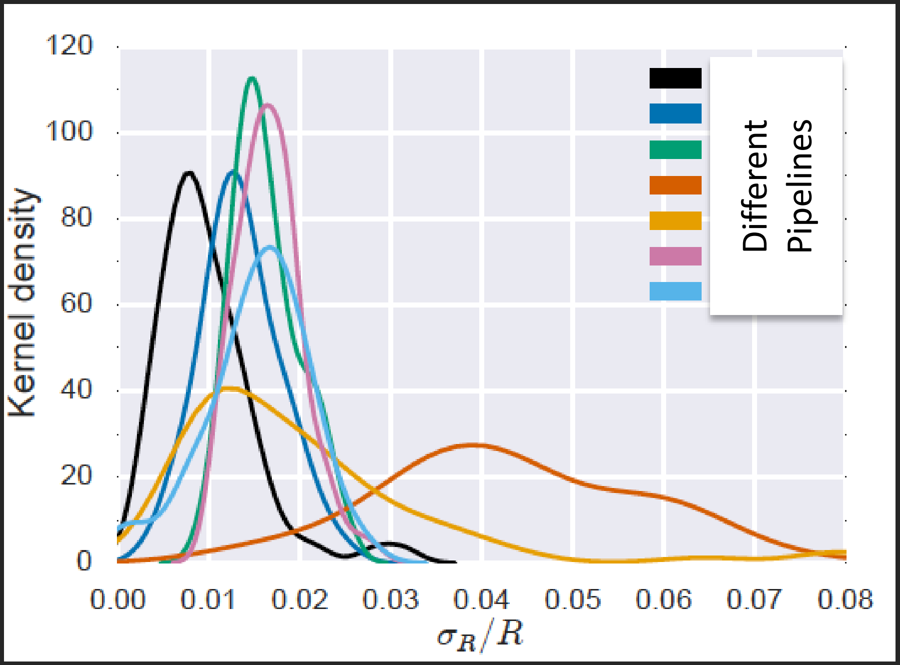
Radius: 1.3%-4.2%

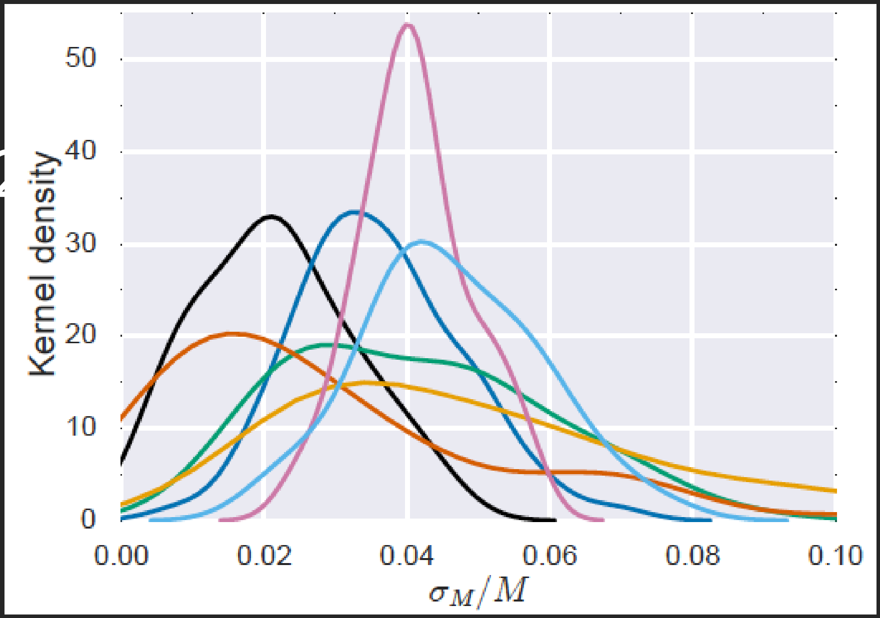
Mass: 2.3%-4.5%

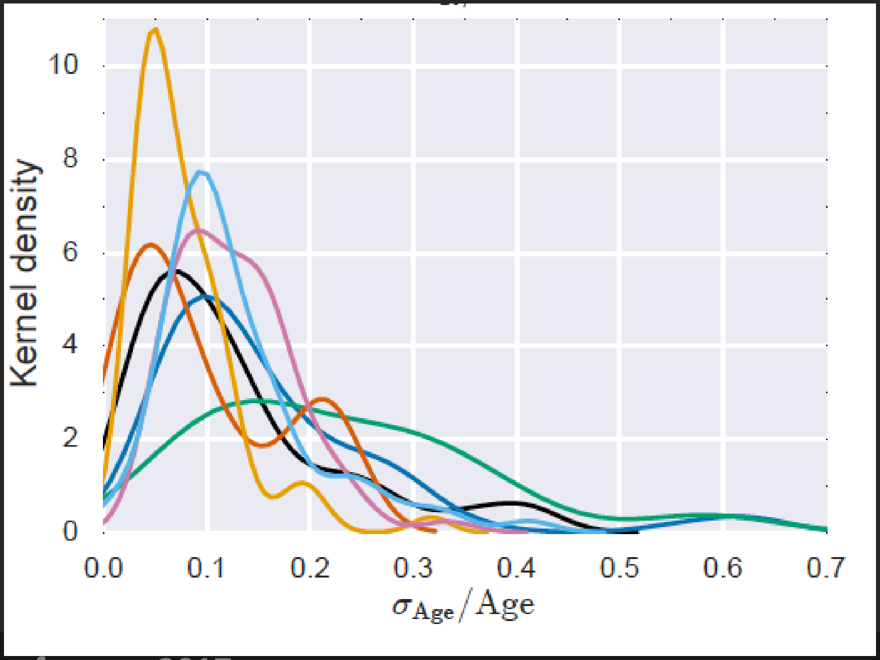
Age: 6.7%-20%

Results from real data

✧ Study 2: Silva Aguirre et al. 2







Average uncertainties

Radius: ~ 2%

Mass: ~ 4%

Age: ~ 10%

Benchmark stars

✧ Parameters from forward modelling are **model-dependent**

✧ Independent accurate determinations of the stellar parameters enables us to **identify biases**

Possible Benchmark stars

- Stars in reach of interferometry (for radii)
- Stars in particular binary systems

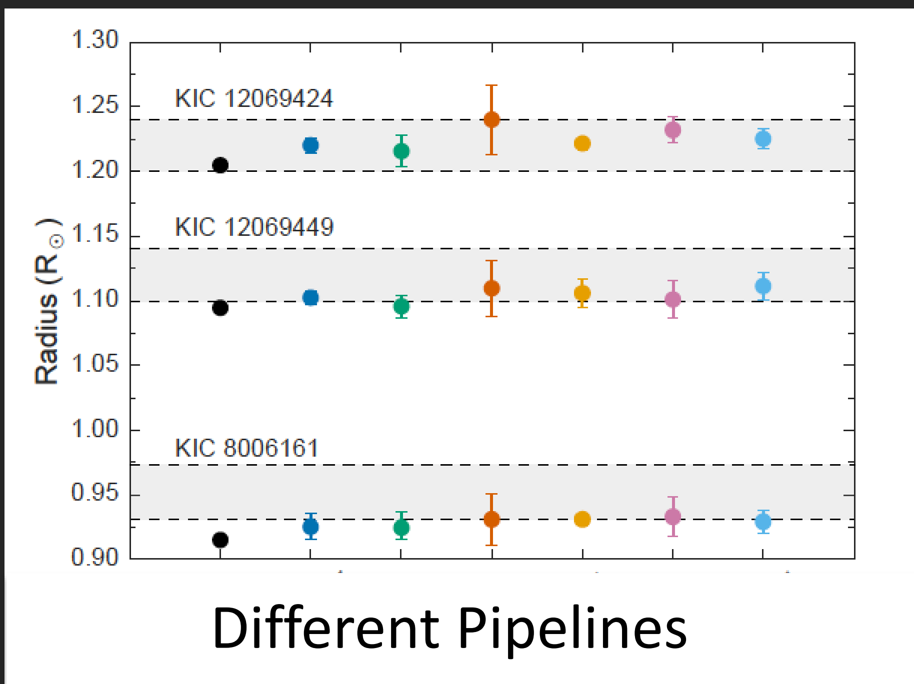
  Eclipsing +SB2 binaries (for radii and masses)

  SB2 + Astrometric or visual/interferometric (for masses)

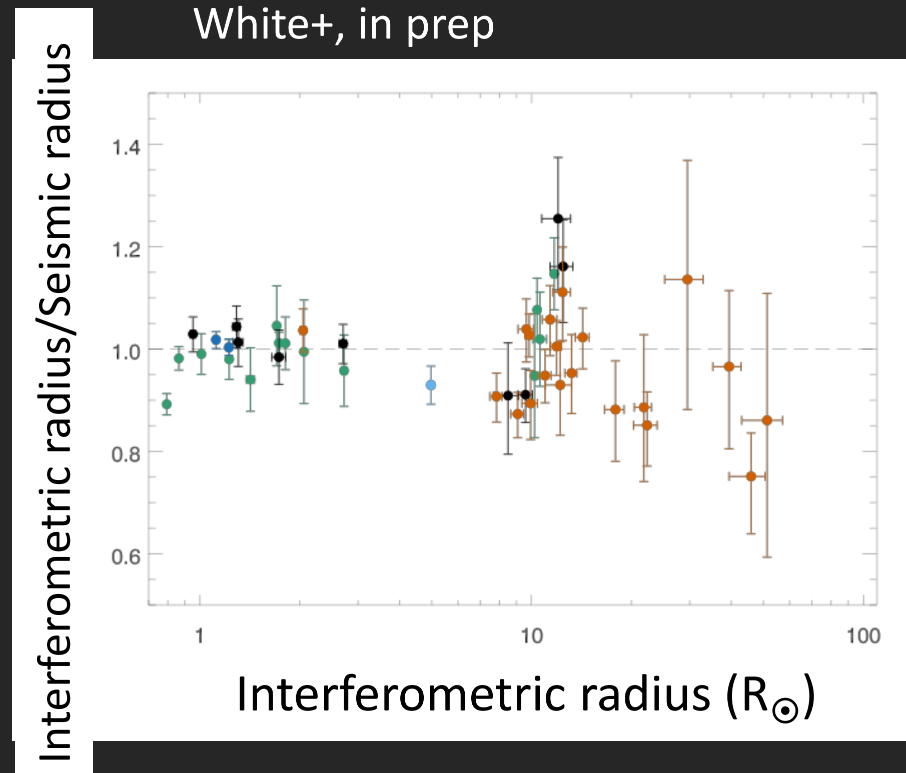
Benchmark stars

- Comparison with interferometric radius

Adapted from Silva Aguirre+ (2017)



White+, in prep



Conclusions

✧ Asteroseismic data, in particular oscillation frequencies **=>** M, R, and Age determined with higher precision.

✧ Precise Mass and Age determinations require knowledge of stellar metallicity.

✧ For a star not too different from the sun, and magnitude V≈8-10, Radius, Mass, and Age can be determined to precision better than ≈ 2%, 5%, and 10%, respectively.

✧ Forward modelling of large samples of Kepler targets provides average uncertainties of similar magnitude when individual frequencies are available.

Thank you for your attention

Obrigada!