(the importance of) Deriving (atmospheric) stellar parameters

Nuno C. Santos
Centro de Astrofísica, Universidade do Porto
Instituto de Astrofísica e Ciências do Espaço
Why stellar parameters are important in exoplanets

- Stellar properties may influence our ability to detect/validate/characterize planets, completeness (e.g. spectral type, activity, ...)

Thursday, December 4, 2014
Why stellar parameters are important in exoplanets

- Stellar properties may influence our ability to detect/validate/characterize planets, completeness (e.g. spectral type, activity, ...).

- Observed correlations between planet and stellar properties are observed (clues to formation/evolution):
  - Stellar properties: abundances, luminosity, mass, irradiation, activity, ...
  - Planet properties: internal structure (metallicity), radius, orbital parameters...
Why stellar parameters are important in exoplanets

- Stellar properties may influence our ability to detect/validate/characterize planets, completeness (e.g. spectral type, activity, ...)

- Observed correlations between planet and stellar properties are observed (clues to formation/evolution):
  - Stellar properties: abundances, luminosity, mass, irradiation, activity, ...
  - Planet properties: internal structure (metallicity), radius, orbital parameters...

- Stellar parameters are crucial for the determination of planet properties
  - Planet mass, radius, density, composition => stellar mass, radius, [M/H]
  - System’s age => stellar age
  - Atmospheres and habitability => stellar irradiation (temperature, luminosity, activity...)

Thursday, December 4, 2014
What do we get from asteroseismology?
What do we get from asteroseismology?

Scaling relations:

\[
\frac{\Delta \nu}{\Delta \nu_\odot} \sim \sqrt\frac{M/M_\odot}{(R/R_\odot)^3}
\]

\[
\frac{\nu_{\text{max}}}{\nu_{\text{max, } \odot}} \sim \frac{M/M_\odot}{(R/R_\odot)^2 \sqrt{(T_{\text{eff}}/T_{\text{eff, } \odot})}}
\]

Derive M, R, assuming you know Teff
What do we get from asteroseismology?

Models
(M, X, Y, $\alpha_{ML}$, age, overshooting, ...)

Observables

Observations
(Teff, [M/H], L, R, $\delta\nu$, $\Delta\nu$, $v_{\text{max}}$)

Final parameters
(M, R, age...)

Grid approach
(forward modeling)
What do we get from asteroseismology?

**Models**
(M, X, Y, $\alpha_{ML}$, age, overshooting, ...)

**Observables**
(Teff, $[M/H]$, L, R, $\delta \nu$, $\Delta \nu$, $v_{\text{max}}$)

**Final parameters**
(M, R, age...)

**Grid approach**
(forward modeling)

Derive M, R, and age, assuming we know seismic parameters BUT also (at least) the Teff and $[M/H]$ (see Chaplin+ 2014 for discussion on impact)
Two messages

- FG stars: we need Teff and [M/H] to derive stellar parameters for asteroseismology analysis
  - With what precision can we get these parameters?

- However, for K and M dwarfs asteroseismology likely not to the rescue
  - Rely entirely on derivation of atmospheric parameters
Temperatures: what precision?
Effective temperatures: precision for FGK stars

Temperatures from iron ionization and excitation equilibrium

\[ <T_{\text{eff\_diff}} > \approx 30 \text{ K} \]
A word of caution

- Different groups can obtain different $T_{\text{eff}}$ values for same stars (e.g. Smiljanic et al. 2014)
A word of caution

Different groups can obtain different $T_{\text{eff}}$ values for same stars (e.g. Smiljanic et al. 2014)
Effective temperatures: M-dwarfs, higher spread

GI 876
M2V - M4V
d = 4.69 pc
L = 0.0122 L\(_{\odot}\)
4 planets

Interferometry
\(T_{\text{eff}} = 3129\text{K}\)
\(R = 0.3761\ R_{\odot}\)

NIR
\(T_{\text{eff}} = 3473\text{K}\)
\(R = 0.3053\ R_{\odot}\)

Optical-LowRes
\(T_{\text{eff}} = 3297\text{K}\)
\(R = 0.3388\ R_{\odot}\)

Optical-HighRes
\(T_{\text{eff}} = 2954\text{K}\)
\(R = 0.4220\ R_{\odot}\)

(Von Braun+ 2011, 2014)
(Rojas-Ayala+2012)
(Mann+ 2013)
(Neves+ 2013)

GI 581
M2V - M3V
d = 6.21 pc
L = 0.01205 L\(_{\odot}\)
4 planets

\(T_{\text{eff}} = 3498\text{K}\)
\(R = 0.2990\ R_{\odot}\)

\(T_{\text{eff}} = 3534\text{K}\)
\(R = 0.2930\ R_{\odot}\)

\(T_{\text{eff}} = 3294\text{K}\)
\(R = 0.3373\ R_{\odot}\)

\(T_{\text{eff}} = 3248\text{K}\)
\(R = 0.3469\ R_{\odot}\)

Rem: similar issues for [Fe/H]

Credit: B. Rojas-Ayala

Thursday, December 4, 2014
Effective temperatures: M-dwarfs, higher spread

GI 876
M2V - M4V
D = 4.69 pc
L = 0.0122 L\textsubscript{Sun}
4 planets

*Interferometry*
- $T\text{eff} = 3129$K
- $R = 0.3761 R\text{Sun}$

*Near-Infrared (NIR)*
- $T\text{eff} = 3473$K
- $R = 0.3053 R\text{Sun}$

*Optical-LowRes*
- $T\text{eff} = 3297$K
- $R = 0.3388 R\text{Sun}$

*Optical-HighRes*
- $T\text{eff} = 2954$K
- $R = 0.4220 R\text{Sun}$

GI 581
M2V - M3V
D = 6.21 pc
L = 0.01205 L\textsubscript{Sun}
4 planets

- $T\text{eff} = 3498$K
- $R = 0.2990 R\text{Sun}$

- $T\text{eff} = 3534$K
- $R = 0.2930 R\text{Sun}$

- $T\text{eff} = 3294$K
- $R = 0.3373 R\text{Sun}$

- $T\text{eff} = 3248$K
- $R = 0.3469 R\text{Sun}$


Credit: B. Rojas-Ayala

Rem: similar issues for [Fe/H]
The issue with surface gravity: influence of $T_{\text{eff}}$ and [Fe/H]
Surface Gravities (log g): effect on Teff and [Fe/H]

![Graph showing the relationship between surface gravities and temperature effectiveness and metallicity.](image)

For all three methods, we find that the goodness of fit (as constrained minus unconstrained) increases as a function of the change in log g. This is left free.

Differences between the results with unconstrained surface gravities (log g) vs. log g, for each of the three methods. The panels show the differences in the surface gravities (log g) and the metallicity ([Fe/H]) for the three methods: SPC, SME, and MOOG.

- **SPC**
  - ΔT_{eff} (K) vs. Δ log g (cgs)
  - Δ[Fe/H] (dex) vs. Δ log g (cgs)
- **SME**
  - ΔT_{eff} (K) vs. Δ log g (cgs)
  - Δ[Fe/H] (dex) vs. Δ log g (cgs)
- **MOOG**
  - ΔT_{eff} (K) vs. Δ log g (cgs)
  - Δ[Fe/H] (dex) vs. Δ log g (cgs)

Torres et al. (2012)
Surface Gravities (log g): comp. with “transit” values

90 transit hosts analysed

\[ \rho_* + k^3 \rho_p = \frac{3\pi}{GP^2} \left( \frac{a}{R_*} \right)^3 \]

Spectroscopic surface gravity not well constrained.
Transit light curve surface gravity more precise and accurate

Mortier et al. (2014)
But: “transit” log g values may also be inaccurate!

Huber et al. (2013)
But: “transit” log g values may also be inaccurate!

See also Kipping (2014)

Huber et al. (2013)
Surface Gravities (log g): comp. with asteroseismology

86 FGK stars analysed

Use large separation $\Delta \nu$, maximum frequency $\nu_{\text{max}}$, effective temperature $T_{\text{eff}}$, metallicity [Fe/H], and PARSEC isochrones.

Asteroseismic surface gravity more precise and accurate

Mortier et al. (2014)
Surface Gravities (log g): effect on Teff and [Fe/H]

- Errors in logg: no strong influence for derived Teff and Fe/H!

Mean differences
68 K and 0.04 dex
Mean absolute deviation
28.5 K and 0.02 dex

Same systematic, but small trends as with the transit sample

Mortier et al. (2014) - see also Torres et al. (2012)
The good news:

- The effect on planet R_pl and M_pl is really small

Using the Torres et al. (2010) calibration to derive stellar Mass/Radius we derive uncertainties of the order of <2% in Mass and <1.5% in Radius for the planets.
The good news:

- The effect on planet $R_{pl}$ and $M_{pl}$ is really small
- A correction can be applied (comparing log $g$ from spectroscopy and asteroseismology)

Using the Torres et al. (2010) calibration to derive stellar Mass/Radius we derive uncertainties of the order of $<2\%$ in Mass and $<1.5\%$ in Radius for the planets

\[ y = (-3.89 \pm 0.23) \cdot 10^{-4} \cdot x + (2.10 \pm 0.14) \]

Mortier et al. (2014)
Abundances of different elements
Abundances of other elements

- Different stars present different abundance ratios

![Graph showing abundance ratios of thick and thin disk stars]

Abundance ratios vary factor of ~2!

Adibekyan+ (2012)
Abundances of other elements

- Different stars present different abundance ratios
- How can these alter the formation/composition of the planets?

Thick disk

Abundance ratios vary factor of ~2!

Thin disk

Adibekyan+ (2012)
Different disk abundances => different planets

- Simulated planets considering different C/O ratios (using abundances in the Sun and HD4203 as reference)
- Influence of abundances of C, O, Mg, and Si

Carter-Bond et al. (2013)
Abundances of other elements: accuracy problem?

Elemental abundances derived by different teams (blind test - Hinkel et al., in prep.)
Stellar parameters (Teff, [M/H]) fundamental to derive R, M, age, ...
- Fine for FGK dwarfs, but care is needed (e.g. logg problem)
- More difficult for M’s... (work ongoing)
- We will rely (“entirely”) on Teff and abundances for K and M dwarfs (no asteroseismology)

Precise abundances of different elements needed
- Relevant for planet modeling
- For study of star-planet connection
- For stellar modeling?

Follow-up strategy needed to well characterize the stars
Thank you!

Questions?
Questions for discussion

- How much are seismic-derived parameters model dependent (systematics between models, etc)?
- How sensitive is seismology to:
  - Errors in Teff, [Fe/H], abundance radius (alphas), overshooting?
- What can be the role of seismology follow-up (Doppler)? K-dwarfs?
- How precise can we have parameters for M-dwarfs and earlier type stars?
- Stellar activity: how much can it alter the derivation of stellar and planetary properties? (and how can we get rid it?)
- What is the real gain of using GAIA data?