Stellar Oscillations and Exo-planets

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"Asteroseismology is very important for transiting exo-planet surveys."

Pieter Degroote, KU Leuven

ESO/L. Calçada
Exo-planet transit surveys

- Observe a part of the sky \textit{continuously} for a "long" time (2y for our system)
- Analyse the light curves; exclude false positives (eclipsing binaries,...)
- Determine the orbital period of planet around star
- Determine relative \textbf{Mass} and \textbf{Radius} of the \textbf{Star} and \textbf{Planet}.

\begin{itemize}
  \item The transit technique gives access to the \textit{ratio} of planet to star radii, so that the \textit{planet sizes} cannot be determined if the star radii are not perfectly known.
\end{itemize}

\textbf{Transit light curves based on Spitzer.}
**Asteroseismology**

= study of **pulsating stars** = study of **stellar oscillations**

- Observe a pulsating star **continuously** for a "long" time; record light curve
- Perform a **Fourier transform** of the light curve
- Determine the **pulsation frequencies**
- Match these **observations** with **models**

⇒ This reveals the internal structure of the star.
Why combine Asteroseismology with Transits?

⇒ With Asteroseismology the Mass and Radius of the star can be determined.

⇒ Together with transit information, the Mass and Radius of the planet can be determined.

Transit observations alone only lead to relative radii.

⇒ Additionally, the Age of the star and consequently the age of planet can be determined.

This works well for solar-like stars or stars with pronounced outer convection layers (SPBs, b Ceph,..*).

* Note that these are probably too short lived to form planets.
Combining Transits AND Asteroseismology

- One data set
- Remove the signal of the transiting planet
- Apply Fourier Transform on the remaining Light Curve
- Perform the frequency analysis
- Constrain Mass and Radius of the star/planet SIMULTANEOUSLY with high precision.
The solar example - Helioseismology

- The Sun exhibits 5-min oscillations with a relatively simple signal – "solar-like oscillations".
- Apply asteroseismological techniques:
Solar like oscillations - Helioseismology

- Large separation: $\Delta \nu$
- Small separation: $\delta \nu$

"Separation" between pulsation frequencies; $n$: order $l$: degree

![Graph showing amplitude vs. frequency with identified peaks and labels for $\Delta \nu$, $\delta \nu$, $\Delta \nu_0$, $\delta \nu_1$, and $\delta \nu_0$ with spectral lines for $(n, l)$ values such as $(19,1)$, $(19,2)$, $(19,3)$, $(20,0)$, $(20,1)$, $(20,2)$, $(20,3)$, $(21,0)$, $(21,1)$, $(21,2)$, and $(22,0)$.]
Solar like oscillations - Helioseismology

- **Large separation** – mean density:
  \[ \Delta \nu \approx (2 \int_0^R \frac{dr}{c})^{-1} \propto \sqrt{\rho} \quad \Rightarrow \quad \Delta \nu \propto \sqrt{M/R^3} \]

- **Small separation** – core (e.g. age):
  \[ \delta \nu \approx \Delta \nu \int_0^R \frac{dc}{dr} \frac{dr}{r} \]

- **Uncertainty in Radius** ≤ 2%
- **Uncertainty in Mass** ~10%
- **Uncertainty in Age** ~10%
Solar like oscillations - Helioseismology

From Brown et al. or Kjeldsen & Bedding: seismic scaling relation:

\[ \nu_{\text{max}} \propto g \sqrt{T_{\text{eff}}} \propto \frac{M}{R^2 \sqrt{T_{\text{eff}}}} \]

\[ \Delta \nu \propto \sqrt{\rho} \propto \sqrt{\frac{M}{R^3}} \]

\[ \nu_{\text{max}}, \Delta \nu, (T_{\text{eff}}) \Rightarrow R, M, L \]
Summary

**Transit alone**

→ relative radii and masses of the star and planet

**Combined with Asteroseismology**

→ interior structure of parent star
→ density of the star
→ absolute stellar mass and radius → absolute planetary radius and mass
→ accurate age of the planetary system
Questions

Why do we need to find even more exo-planets (>1000)?
• Answer to "how typical is our Solar System?"
• Study the full range of planet masses, down to Earth sized and smaller.
• Need to include intermediate and large orbital distances.

But this has already been done with CoRot!!
• CoRot had two "Eyes", one for transit detection, one for asteroseismology.

But this has already been done with Kepler!!
• The Kepler targets are rather faint and simultaneous asteroseismology can best be done on brighter targets.