Asteroseismic measurement of the inclination angle: characterizing exoplanetary systems

Charlotte Gehan

Collaborators: B. Mosser, E. Michel, M. S. Cunha

PLATO 2021 Conference

October 12, 2021

Stellar inclinations: characterization of exoplanetary systems

- Inclinations i → **required to constrain the obliquity** ψ of the planetary system (Winn & Fabrycky 2009, Chaplin+ 2013, Huber+ 2013, Winn & Fabrycky 2015, Campante+ 2016):

$$\cos\psi = \sin i \, \sin i_{\rm p} \, \cos\lambda + \cos i \, \cos i_{\rm p}$$

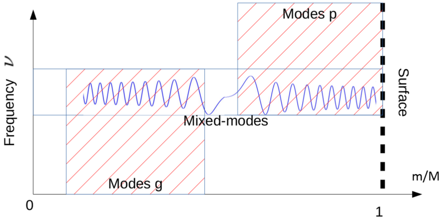
  - $i_{\rm p}$ → inclination of the planetary orbit; constrained from the transit lightcurve,
  - λ → projected spin-orbit angle; constrained through high-resolution spectroscopy (Rossiter-McLaughlin effect).

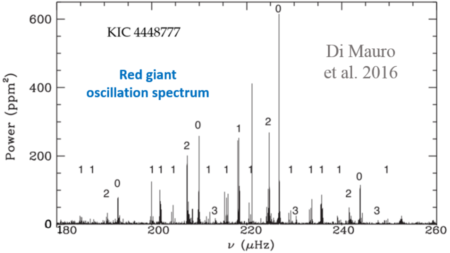
→ **Inclination measurements are important to understand the formation and dynamics of transiting exoplanetary systems**.

- Although the majority of **exoplanets** are detected around main-sequence stars, **a few hundreds are known to orbit evolved stars** → crucial to constrain:
- theoretical models of planet engulfment by the expanding host star;
- the stellar evolution effect on the orbital and physical properties of planetary systems.

Stellar inclinations: the case of red giants exhibiting mixed modes

- **Red giants** → **mixed-modes**, i.e. coupling between pressure waves in the convective envelope and gravity waves in the radiative interior.
- Gravity-dominated (g-m) mixed-modes → **probe the red giant core**.
- G-m mixed-modes split by rotation are well separated inside oscillation spectra → **accurate measurements of *i* easier to obtain compared to main-sequence stars** (Kamiaka+ 2018).





Credits: C. Pinçon

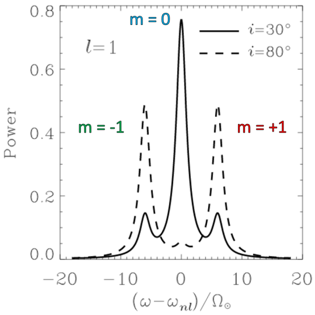
Stellar inclination measurements: where are we standing

- Kamiaka+ (2018) → systematic check of the accuracy of the seismic measurement of i **only on the main-sequence**.
- Corsaro+ (2017), Mosser+ (2018) & Kuszlewicz+ (2019) → seismic measurement of i for a **limited number of red giants** (few dozen).
- ∼ **1100 *Kepler* red giant branch stars** studied by Gehan+ (2018) → g-m mixed-modes and rotational splittings are disentangled, **measurement of i possible**.

→ **Large-scale study of i for evolved stars: unprecedented, major stepping stone in the understanding of planetary formation, evolution and death**.

Stellar inclinations: principle of the seismic measurement

- Inclination $\rightarrow$ impacts the **visibility of dipole mixed-modes split by rotation**:
  - Low inclination $\rightarrow$ only $m = 0$ modes visible.
  - High inclination $\rightarrow$ only $m = \pm 1$ modes visible.
  - Intermediate inclination $\rightarrow$ $m = \{-1, 0, +1\}$ modes visible.

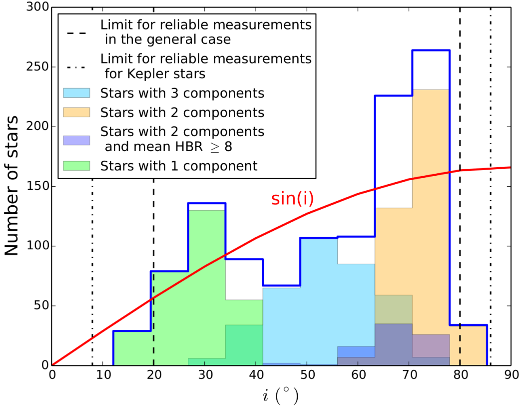


Gizon & Solanki (2003)

$$\tan(i) = \sqrt{\frac{P_1 + P_{-1}}{P_0}}$$

P_{m} $\rightarrow$ mean height-to-background ratio for all modes with azimuthal order m

- **Automated analysis of 1139 *Kepler* stars** on the red giant branch for which the azimuthal order of mixed modes was identified by Gehan+ (2018).



Gehan et al. (2021)

– **Rotation axes** expected to be **randomly oriented** → inclinations are expected to follow a **distribution in sin (i)**, i.e. an 'isotropic' distribution.

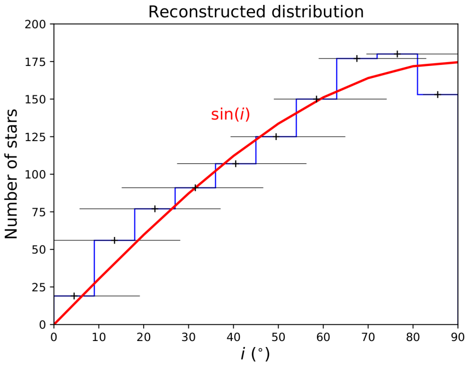
– Stars with $m = \{-1, 0, +1\}$ modes visible → **measurement** of i.

– Stars with **only** $m = \pm 1$ or **only** $m = 0$ modes visible → only an **estimate** of i.

Stellar inclinations: recovering an unbiased distribution

- **Overcoming this observational bias** $\rightarrow$ **taking into account uncertainties** on the measured and estimated i values using probability density functions.
- **Isotropic distribution** $\rightarrow$ **recovered**.

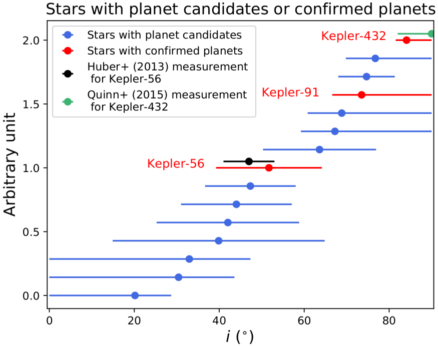
$\rightarrow$ **We characterize the biases affecting stellar inclination measurements**.

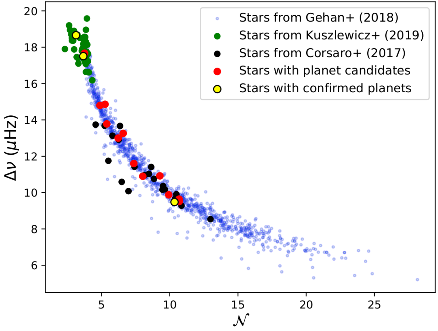


Gehan et al. (2021)

Stellar inclinations: possible and confirmed planet host red giants

- **12 RGB stars with planet candidate(s) → high potential obliquities for 7 stars**.
- **3 RGB stars with confirmed planet(s) →** inclination measurements compatible with those available from other studies; high obliquity confirmed for the multiplanetary system Kepler 56 (Huber+ 2013).
- **One evolved red giant with a confirmed planet → Kepler 91!**

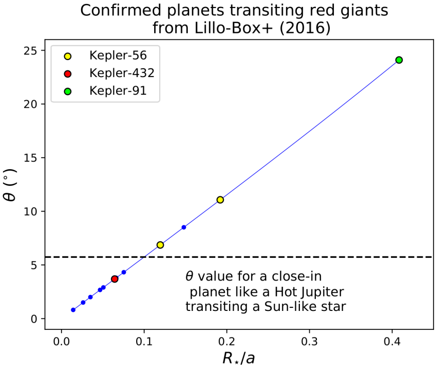




Gehan et al. (2021)

Stellar inclinations: red giants with confirmed planet(s)

- Obliquity: $\cos\psi = \sin i \sin i_\mathrm{p} \cos\lambda + \cos i \cos i_\mathrm{p}$; **transiting planets** $\rightarrow \boldsymbol{i_\mathrm{p} \simeq 90^\circ}$.
- However, a transit can still occur if $(90^\circ - \theta) \leq i_\mathrm{p} \leq (90^\circ + \theta)$ with $\theta = \arcsin(R_\star/a)$ (Betty & Seager 2010).
- **Approximation** $i_\mathrm{p} \simeq 90^\circ \rightarrow$ **OK for planets transiting Sun-like stars, but not anymore for planets transiting evolved stars** with larger radii.



Gehan et al. (2021)

Wrap-up

- ~ 1100 *Kepler* red giant branch stars analysed to derive seismic measurements of the inclination angle $\rightarrow$ observational limitation, $i \lesssim 10^\circ$ and $i \gtrsim 85^\circ$ inaccessible to measurements.

- Underlying statistical distribution of inclinations $\rightarrow$ recovered when taking into account individual uncertainties on the inclination measurement.

- Analysis of 12 RGB stars with planet candidate(s) $\rightarrow$ 7 systems should present large obliquities should a transiting planet(s) be confirmed.

- Analysis of 3 RGB stars with confirmed planet(s) $\rightarrow$ inclination in agreement with previous measurements; 1 evolved RGB host star!

- Determination of the obliquity $\rightarrow$ careful in approximating $i_{\rm p} \simeq 90^\circ$ for evolved stars!

- **General and automated approach $\rightarrow$ can be applied to PLATO solar-type pulsators on the main-sequence** for which oscillation modes are identified.


thank you
gracias
danke
merci
obrigado
謝謝
ngiyabonga
teşekkür ederim
спасибо
Баярлалаа
рахмат
dank je
tapadh leat
mochchakkeram
go raibh maith agat
dziękuje
bedankt
sukriya
kop khun krap
terima kasih
grazie
arigatô
dakujem
мерси
takk
taiku
sagolun
hvala
mauruuru
감사합니다
ευχαριστώ
ありがとう
tack
welalin
barka
mersi
spas
kia ora
vinaka
blagodaram
misaotra
matondo
paldies
grazzi
mahalo
хвала
asante
manana
obrigada
murakoze
tenki
chokrane
mamnun
дякую
djiere dieuf
tau
chnorakaloutioun
gratias ago
gracies
sulpay
trugarez
shukriya
merce
dhanyavadagalu
diolch
tanemirt
rahmet
xiexie
najis tuke
kam sah hamnida
rahmat
didi madloba
mèsi
dekuji
sobodi
enkosi
bayarlalaa
gracie
nanni
nandri
dhanyavad
kiitos
dankie
faafetai lava
köszönöm
dankon
akun
spasibi