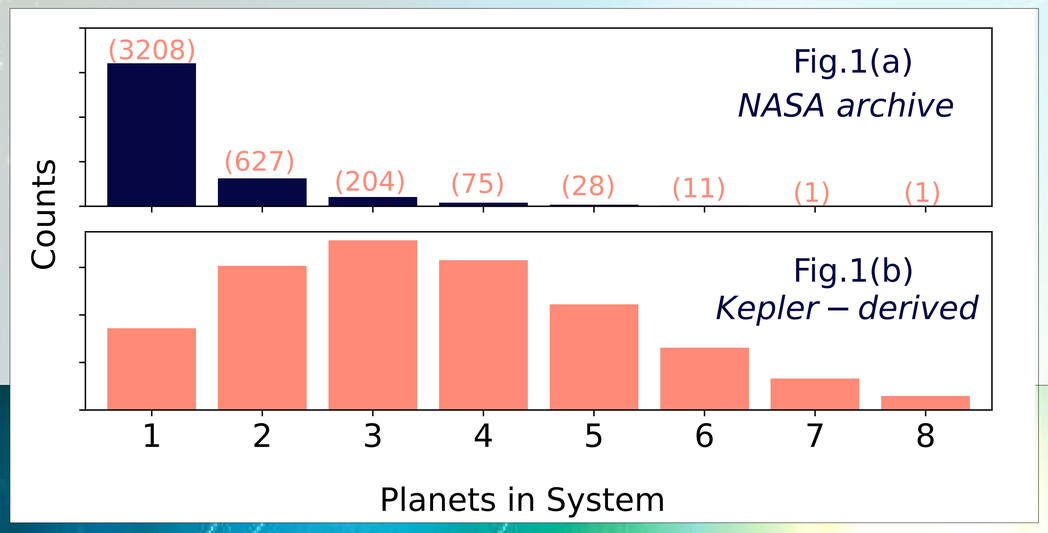
Three close-in planets with a long-period Saturn-mass companion: optimizing RV planet detections

Adam Stevenson[1], Carole Haswell[1], John Barnes[1], Jo Barstow[1], Matthew Standing[2]

[1] School of Physical Sciences, The Open University, UK; [2] ESA - European Space Astronomy Centre, Spain.

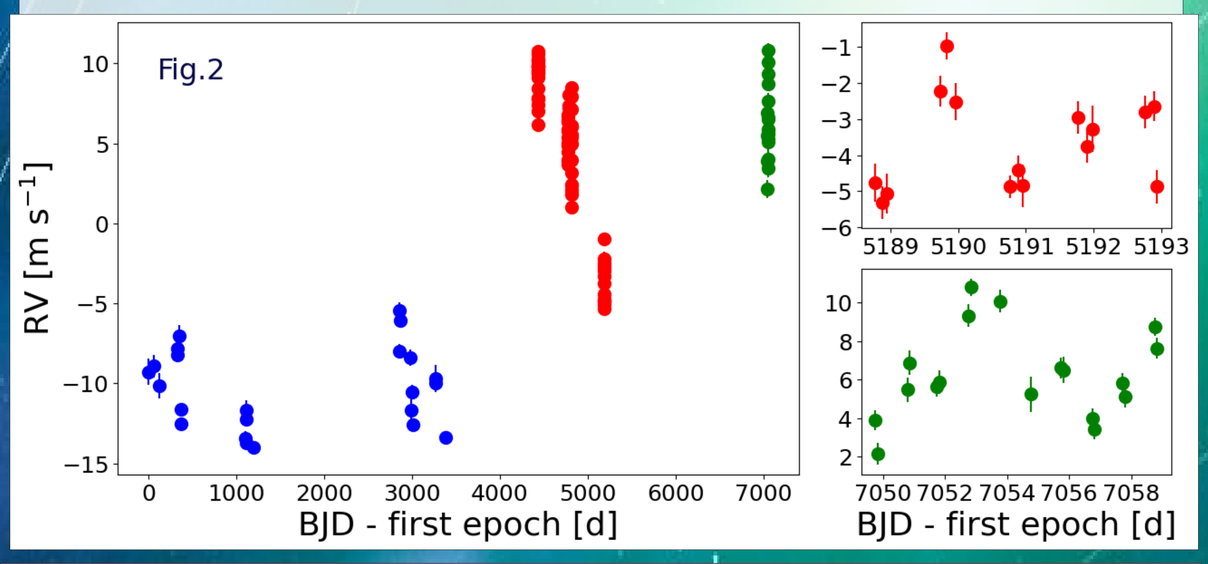
Multi-planet Systems

- Kepler found that **low-mass planets are very common** [e.g. *Mulders+2018*]
- Forward models generating underlying population from Kepler demographics **predict far more multiplanet systems** than we currently observe (Fig.1) [*NASA archive; He, Ford & Ragozzine 2019*]
- We have failed to find most of the planets orbiting bright nearby planet hosts
- Where are the missing planets?



Finding N_p

- Difficult to determine **how many planets** are causing RV modulation
- **Sampling**, **biases**, and semi-amplitudes close to instrumental **stability** make it hard to recover planets
- Instrumental **offsets** introduce another nuisance parameter – e.g. HARPS fibre upgrade, covid warm-up (colours in Fig.2)
- Requires intensive effort to find **small planets in multiple systems**



The Past

- Traditionally, RV planet searches **recursively** compute periodograms, subtracting off Keplerian signals and iterating
- This can find the **wrong signals** in the case of complex multiplanet systems, and sub-optimal sampling [*Barnes+2023*]
- **False-alarm levels** to define significance are **not consistent**, and requires assumption that noise is uncorrelated
- **Aliasing** can seriously confuse the ability to manually select periodicities, impacting subsequent signals drastically (Fig.3)

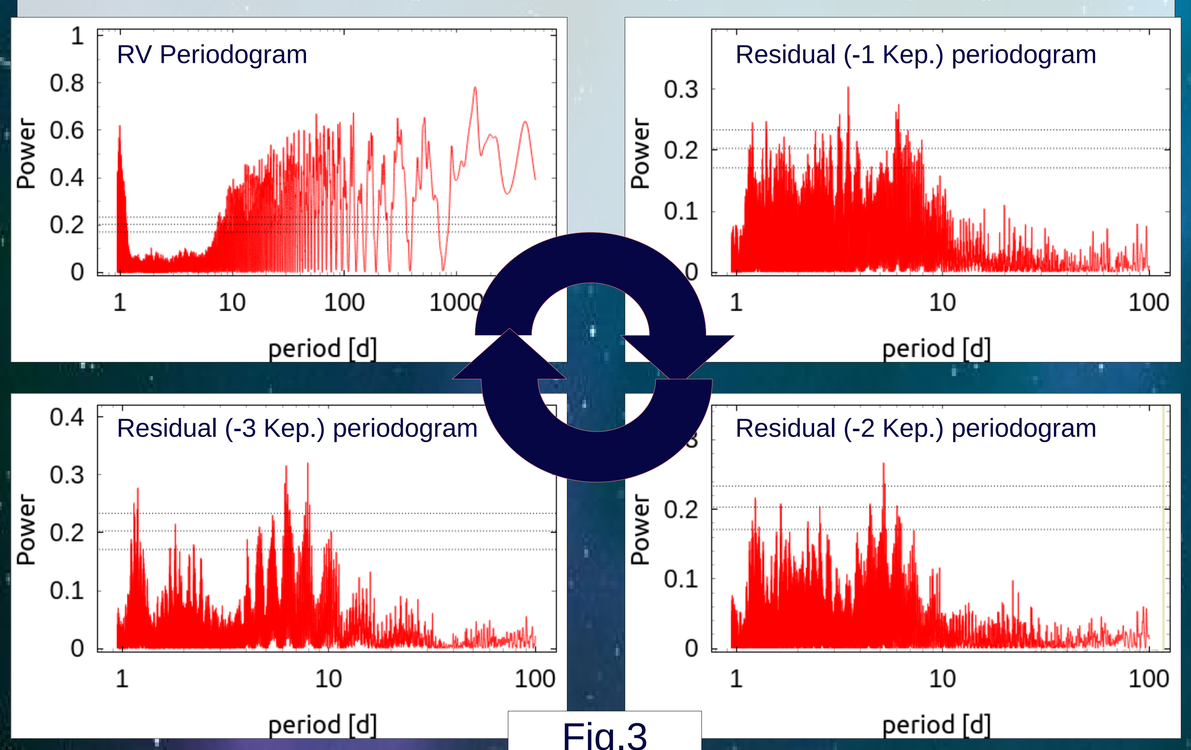
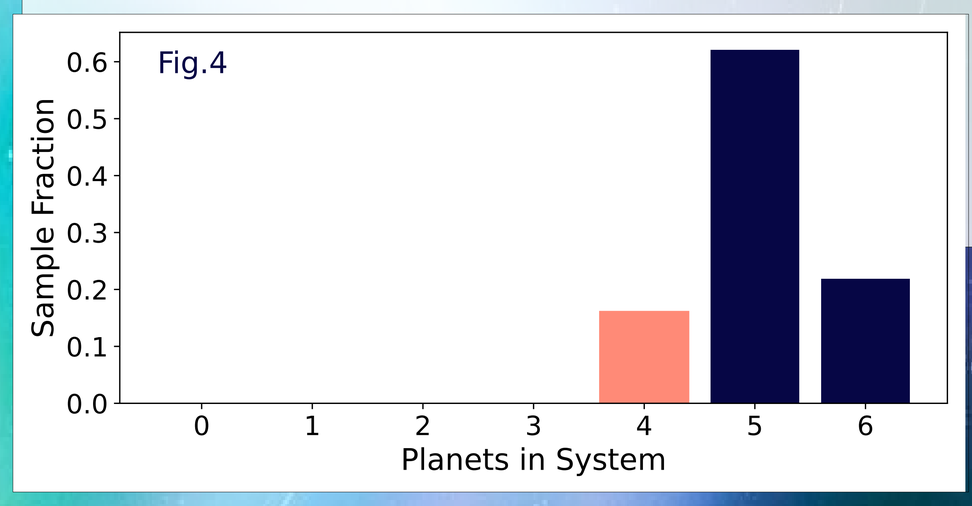


Fig.3

The Future

- Using **kima**: fits Keplerians **simultaneously**, sampling from posterior distributions with **nested sampling** (NS) [*Faria+2016*]
- NS allows computation of marginalised likelihood (**evidence**). Ratio of evidences, 'Bayes Factor' (BF) used to compare models varying N_p
- **AMD stability** can be checked for posterior sample acceptance --> can use less restrictive eccentricity priors [*Faria+2023*]
- Optimal **number of planets (BF>150)** recovered [*Trotta 2008*]



HD 28471

- Fig.4 shows BF>150 for **4 planets**
- Long period Saturn-mass planet (~1470 d), with 3 inner planets with ***P* = 2.9, 6.2, 8.9 d** (*m*sin*(i)* all below 5 $M_\oplus$)
- Weak evidence (BF~4) for 5th planet on 1.6d orbit --> need additional data
- **Kima** allows us to get a much clearer picture of system
- Planets close to 1:2:3 resonance --> require precise periods to confirm

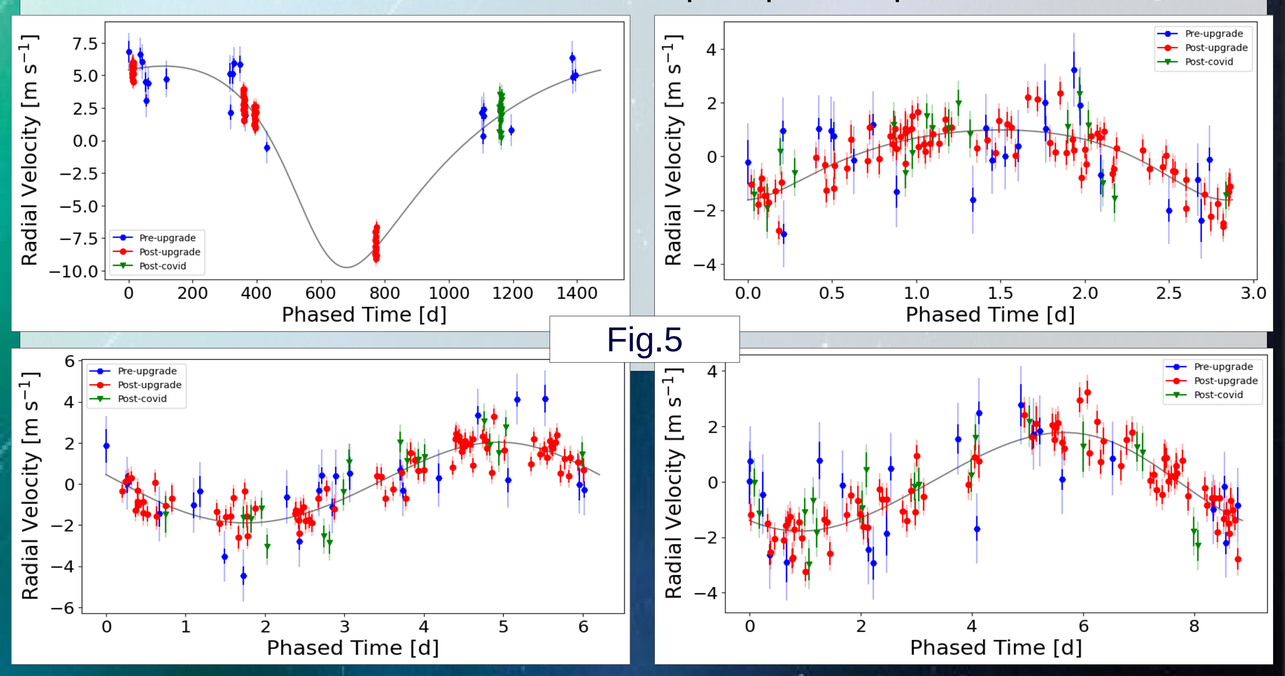
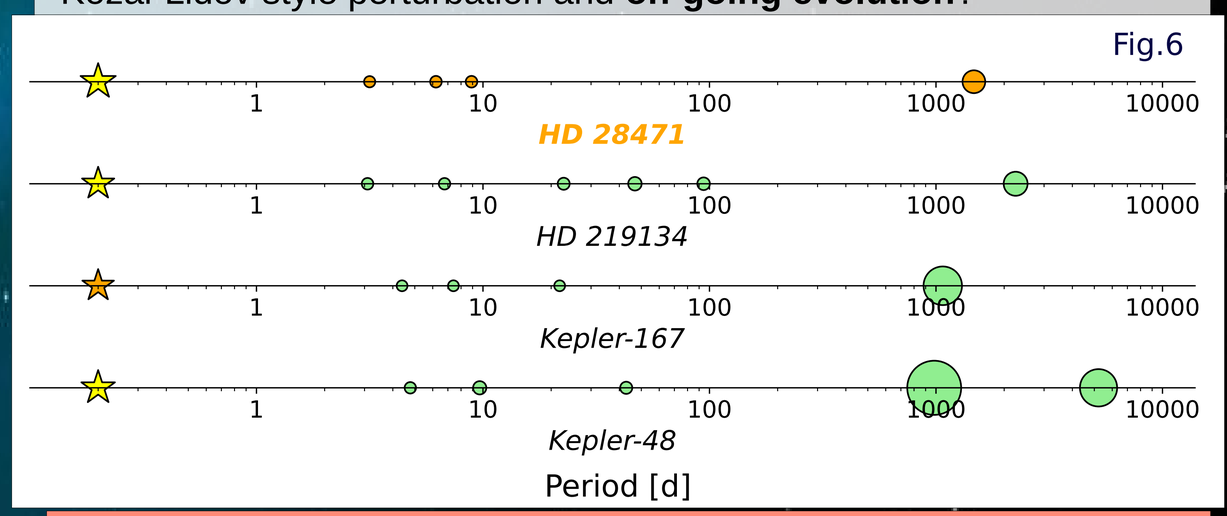


Fig.5

So what?

- Systems with multiple (>3) close-in **super-Earths and an outer giant are rare** - some examples below (Fig.6) [*NASA archive*]
- Outer planet may be required to perturb small planets inwards
- Many compact multiplanet systems may be **missing a companion** – efficient RV analysis needed where transits less frequent/likely
- Outer planet in **HD 28417** more eccentric than others – evidence of Kozai-Lidov style perturbation and **on-going evolution**?



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