University of
St Andrews

PUSHING THROUGH THE SUB M/S RV REGIME

USING TWEAKS(KIMA+SCALPELS)

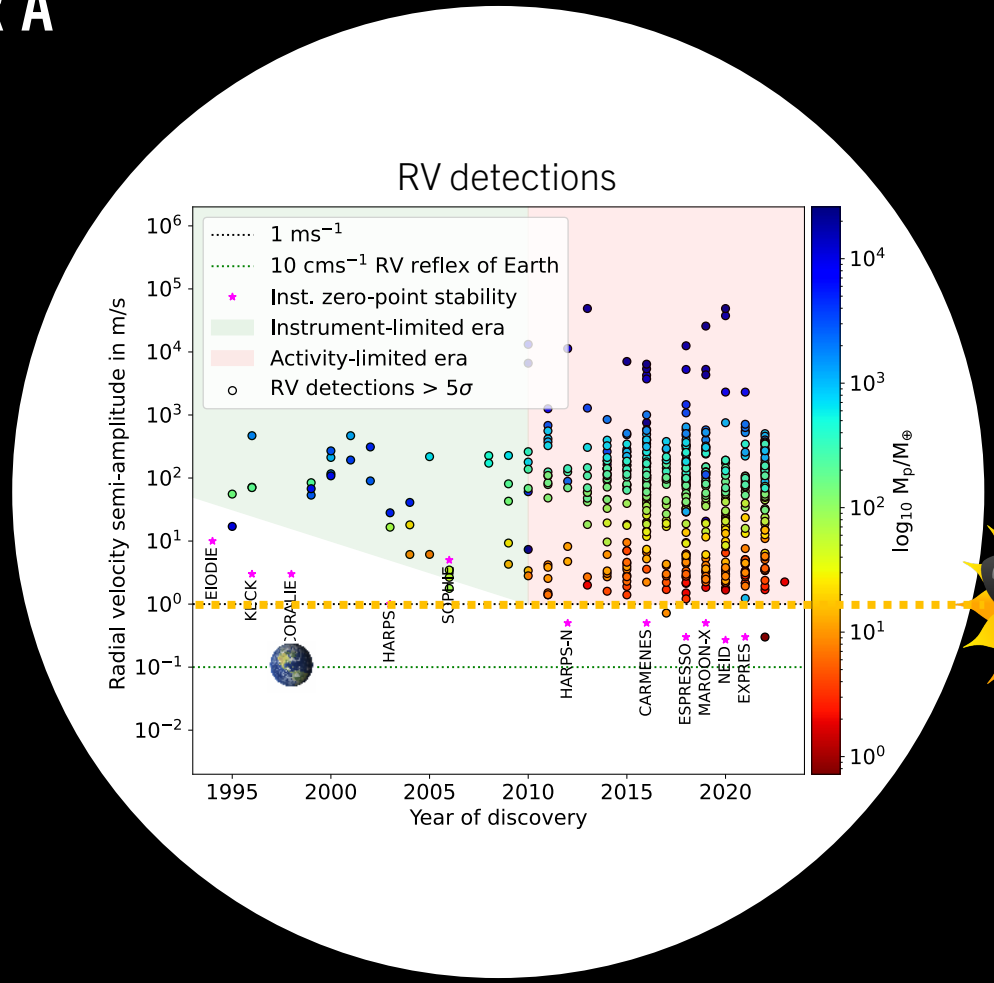
ANCY ANNA JOHN

PROF. ANDREW COLLIER CAMERON

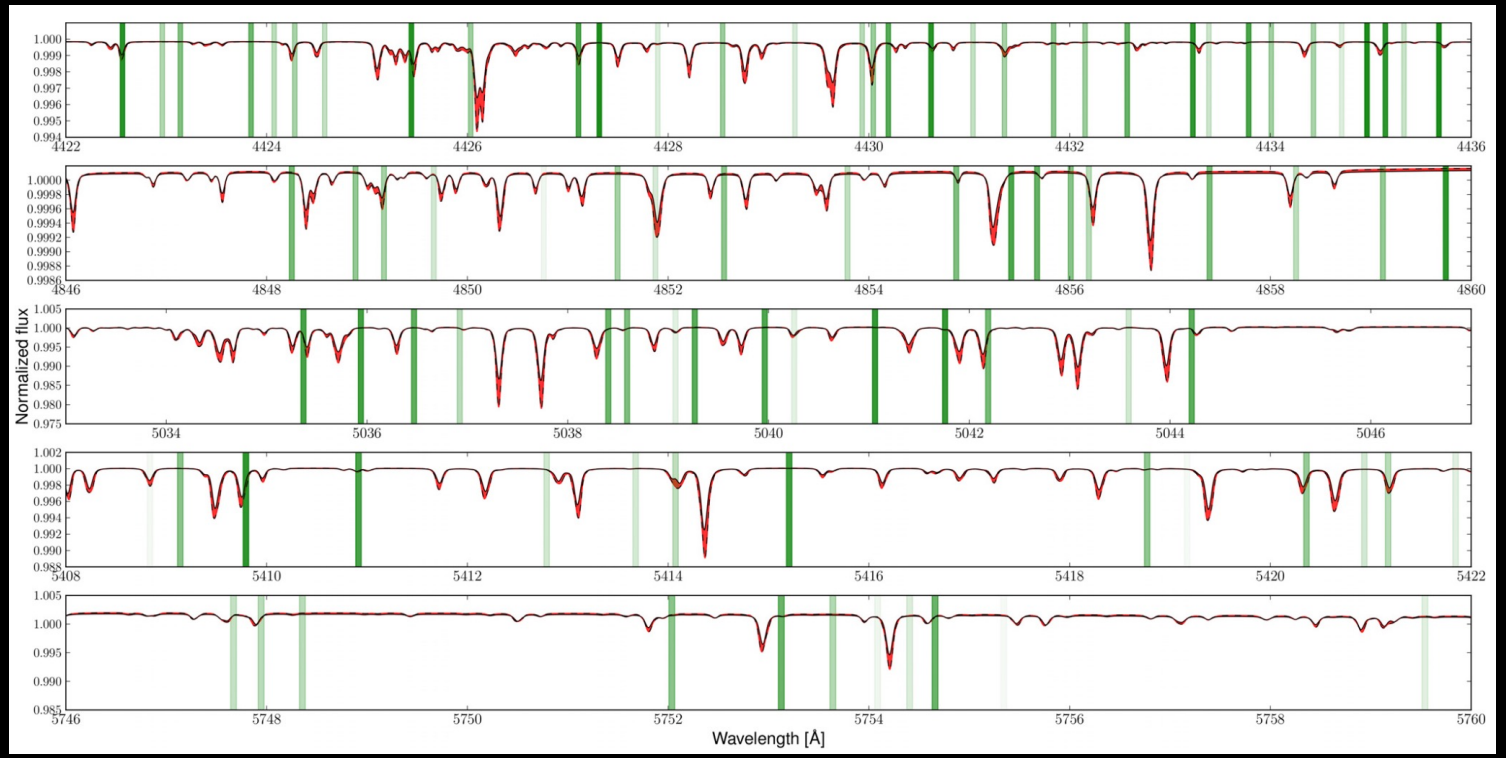
HARPS-N TEAM

STELLAR ACTIVITY LIMITED ERA

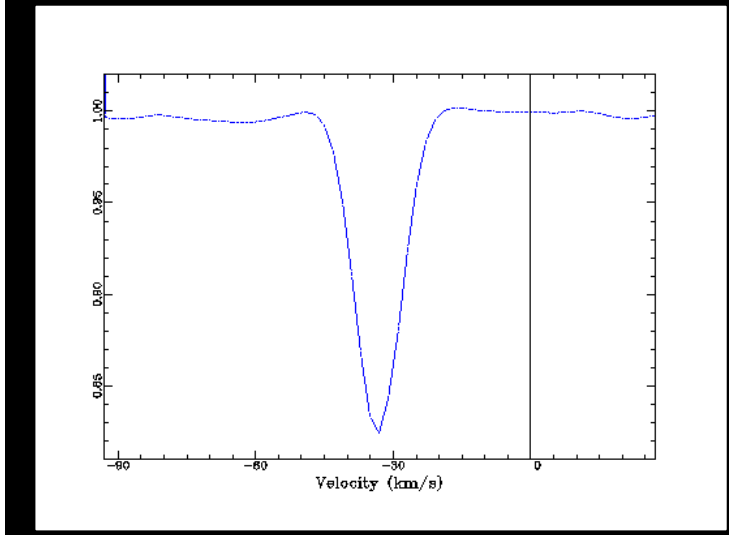
- RV precision of 0.1 m/s is required for the detection of Earth twins.
- Improvement (decline) in detection threshold is no more proportional to the instrumental precision.
- Stellar variability saturation limit at ~ 1m/s !
  - Granulation / Super granulation
  - Spots
  - Faculae / Plages
  - P-mode oscillations
  - Convective blue shift



MEASURING RV BY CROSS-CORRELATION



Digital line mask



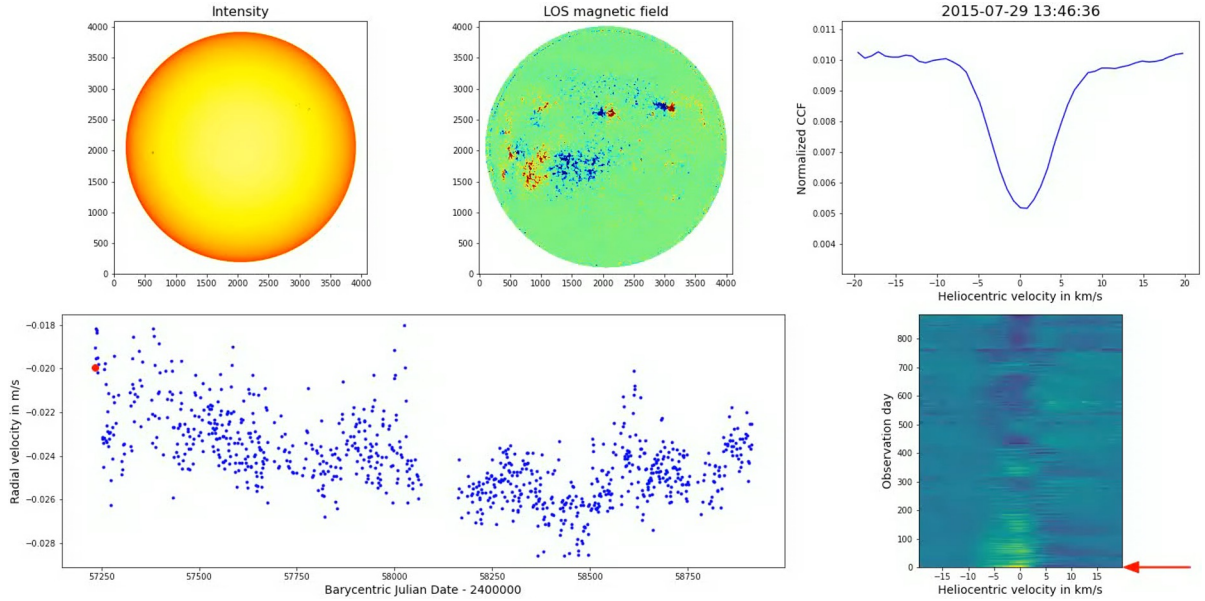
CCF

then, fitting a gaussian to the CCF

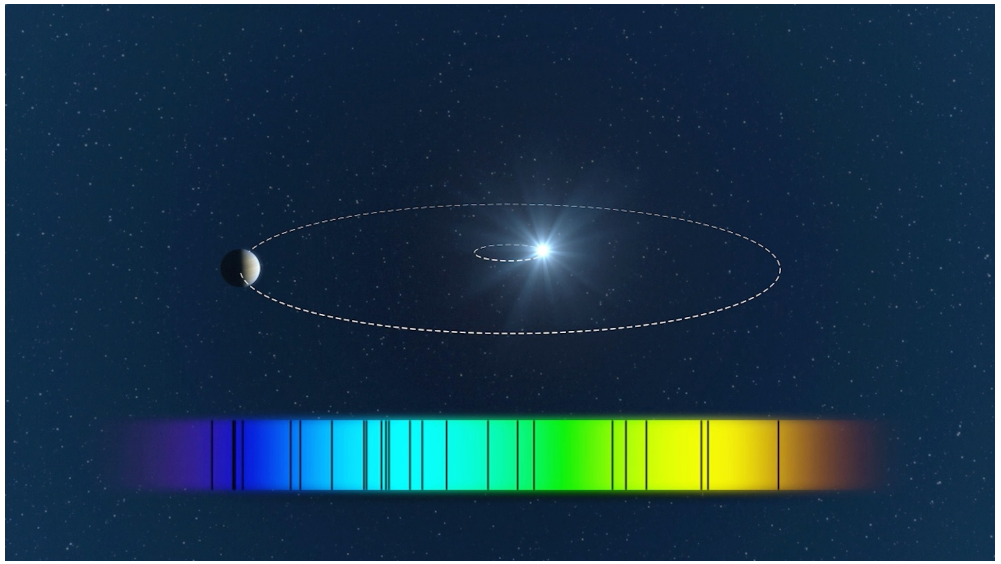
UNDERSTANDING THE PROBLEM

Line **Shape** changes

Shift to the spectrum



Credits: Marylyn Rosenquist



Credits: ESO

MODELLING STELLAR ACTIVITY IN LITERATURE

Time domain

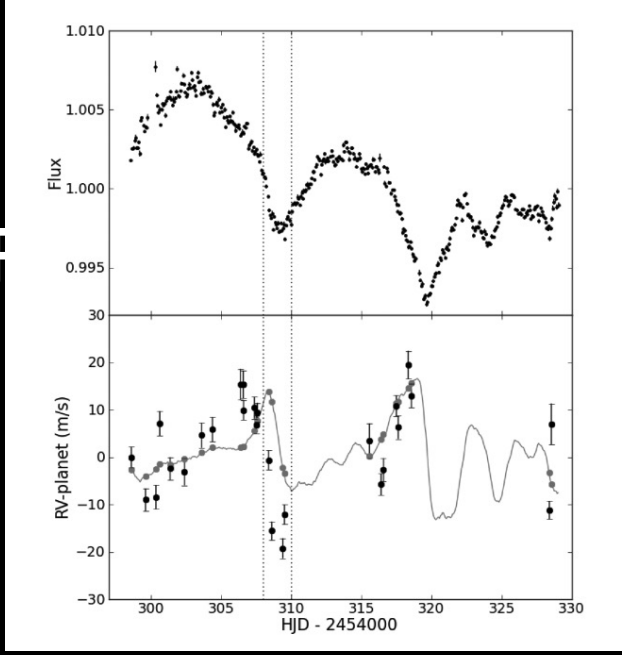
- Photometry to predict stellar activity impact on RVs - Aigrain et.al 2012
- GP to model correlated noise induced by stellar activity - Haywood et.al 2014
- Modelling RV timeseries with a planet component and stellar activity component using kima - Faria et.al 2018
- Multivariate GP modelling of RV and activity indicator time-series - Rajpaul et.al 2015, Barragan et.al 2021

Wavelength domain

- Doppler imaging to model stellar activity & planet induced variation in spectral line profiles - Klein et.al 2022
- Neural networks to separate activity signals from COM RV shifts - de Beurs et.al 2021
- De-trending the RVs for line shape variations using the SCALPELS basis vectors - Collier Cameron et.al 2021

and many more…

MODELLING STELLAR ACTIVITY IN LITER



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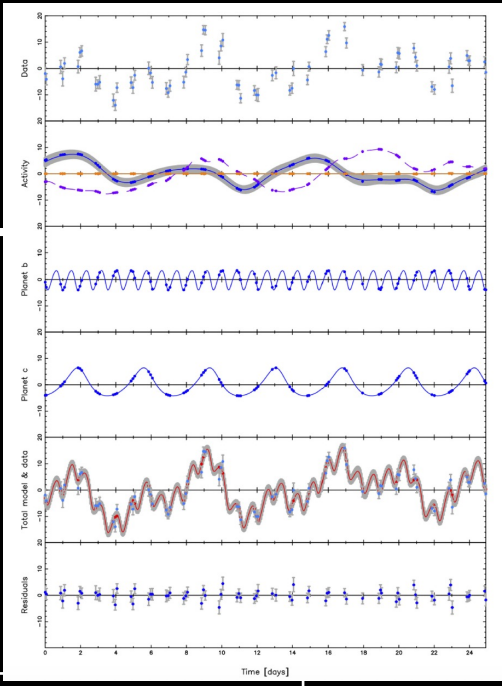

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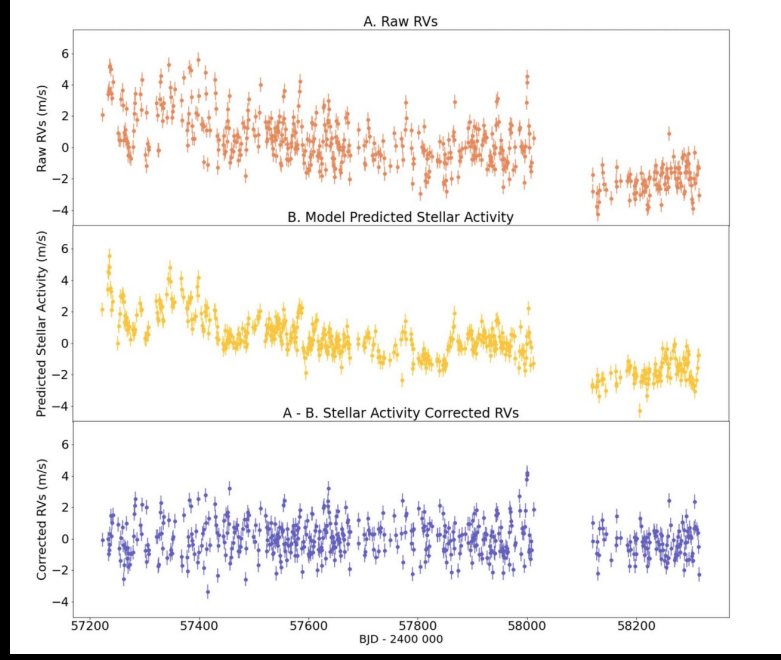

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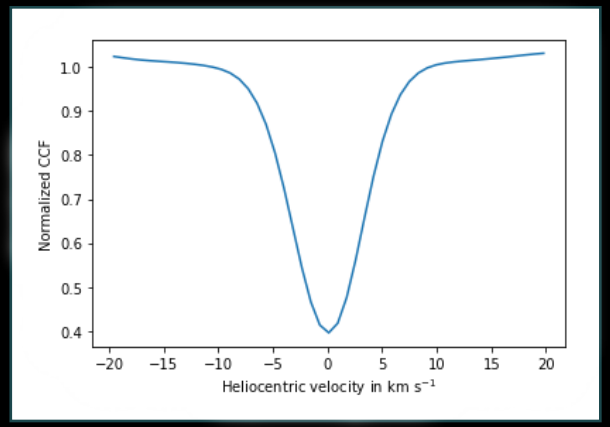
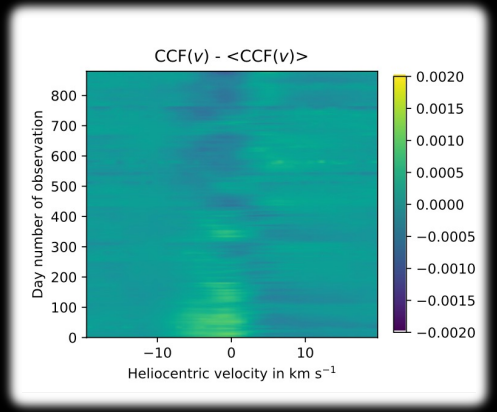
WHAT DOES SCALPELS DO?

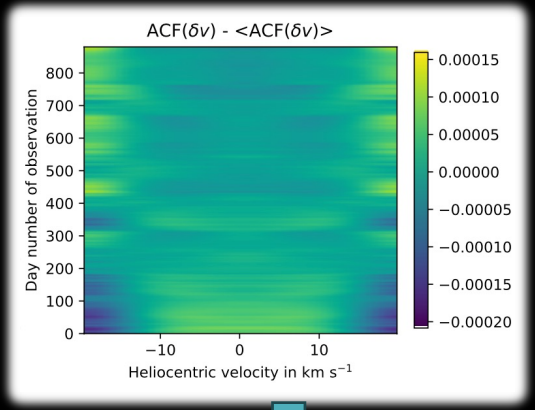
Individual CCF



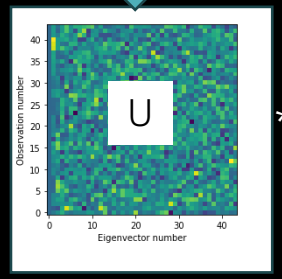
Residual CCF timeseries



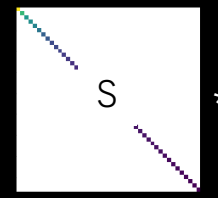
Residual ACF timeseries



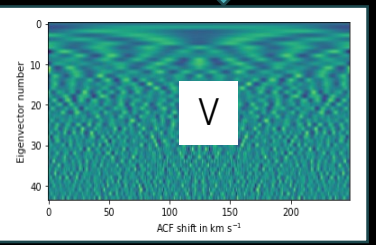
Singular Value Decomposition



Basis vectors



Eigen values



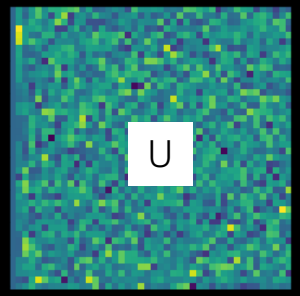
Eigen vectors
(shape-change modes)

Autocorrelation Function is invariant to shifts

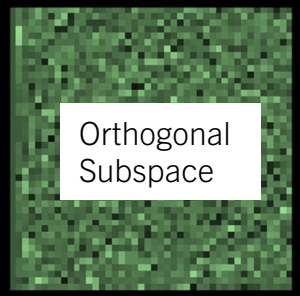
Collier Cameron et al 2021

SIGNAL SEPARATION

Radial Velocity



RV component induced by line **shape** changes



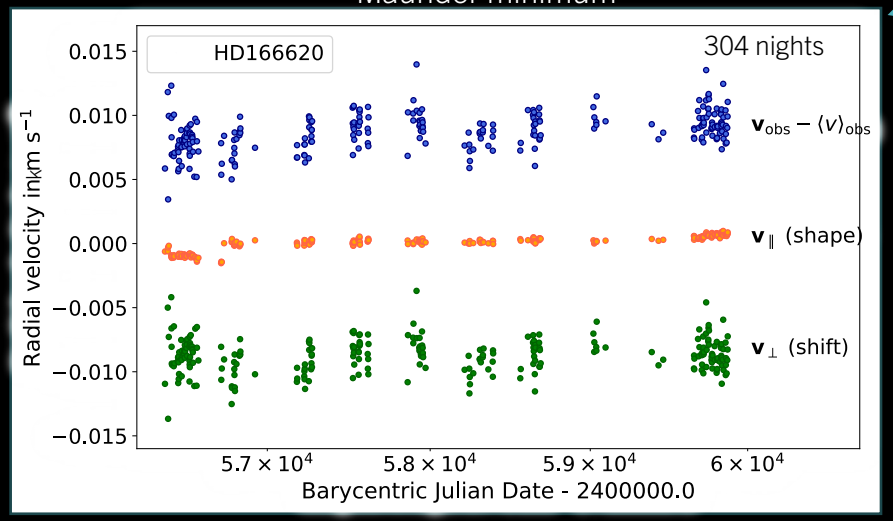
RV component induced by **shifts**

Collier Cameron et al 2021

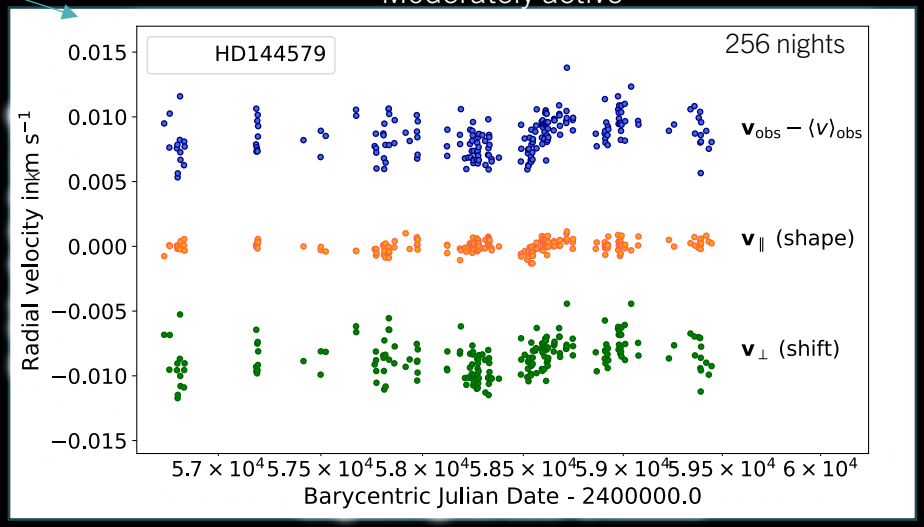
HARPS & HARPS-N TARGETS

(Rocky Planet Search targets)

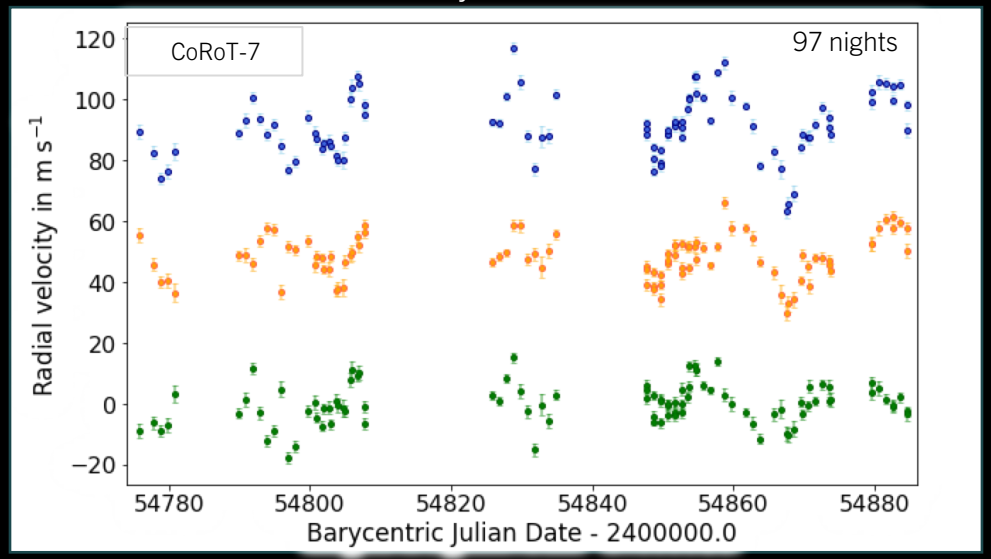
Maunder minimum



Moderately active

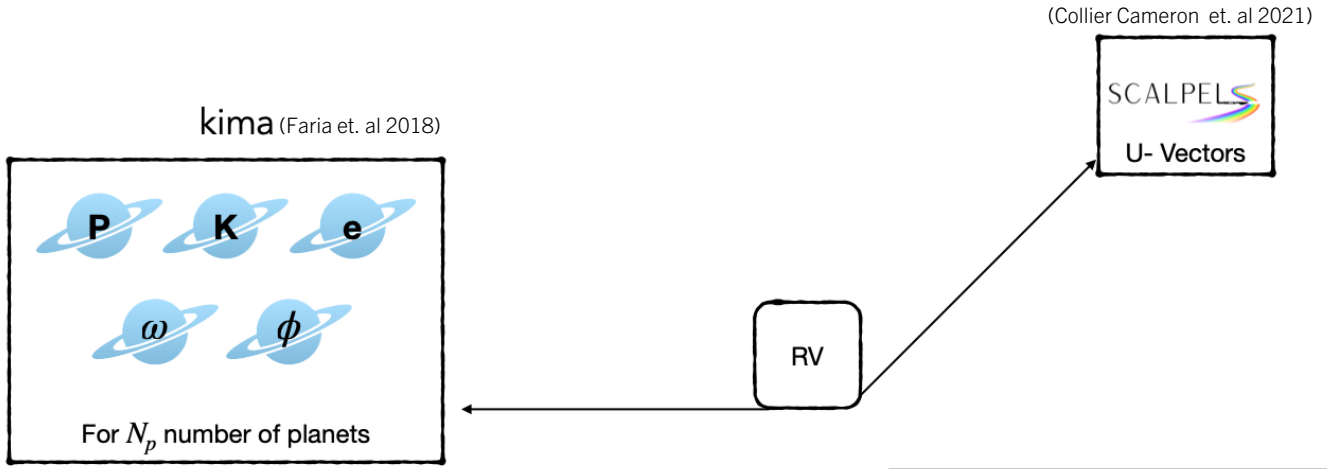


Very active

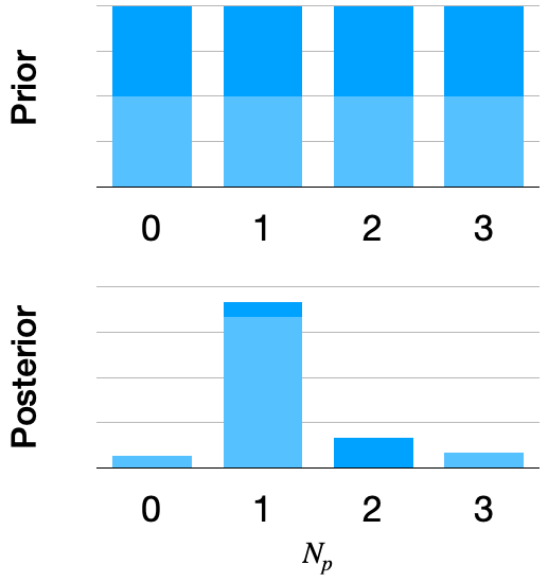


TWEAKS Anna John et al 2022, 2023 (under review)

(Time and Wavelength domain stEllar Activity mitigation using Kima and SCALPELS)



- Models N_p keplerians based on suitable priors
- Decorrelation with GP and/or SCALPELS activity proxies
- Posteriors for orbital and activity decorrelation parameters
- Bayesian evidence for model comparison
- Uses Diffusive Nested Sampling (Brewer et al 2009)

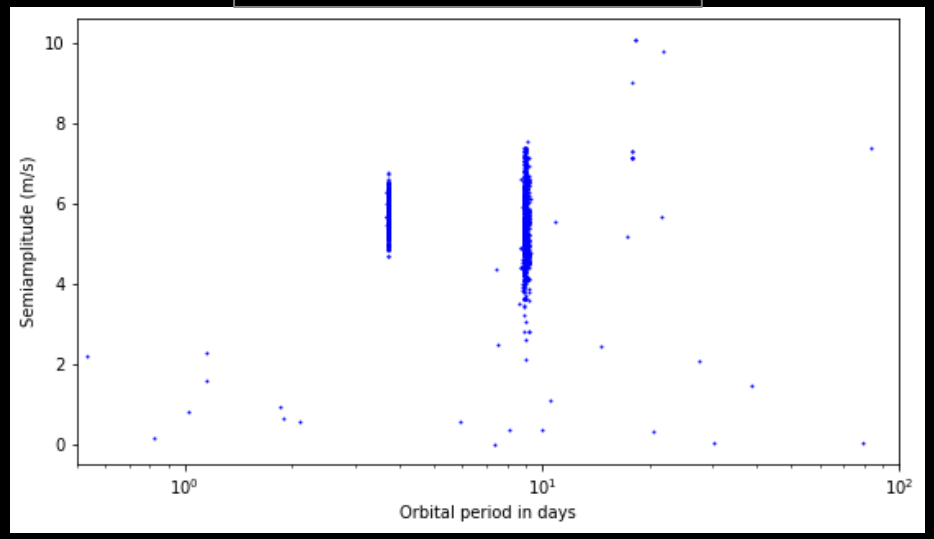


COROT-7

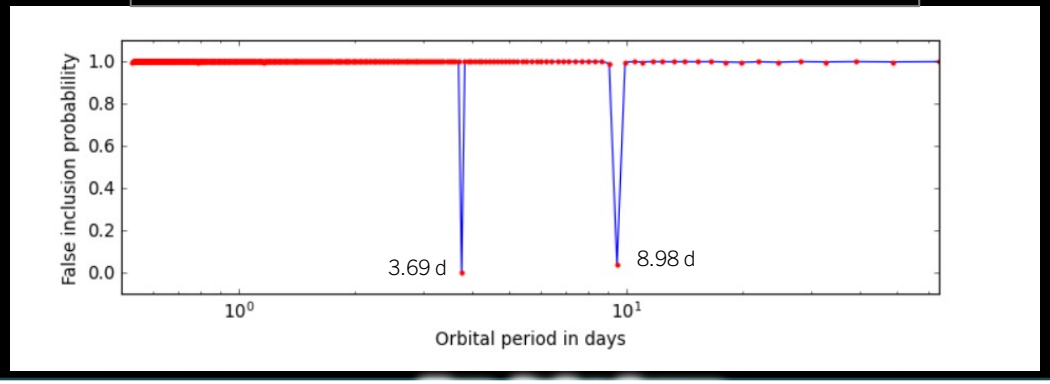
Background

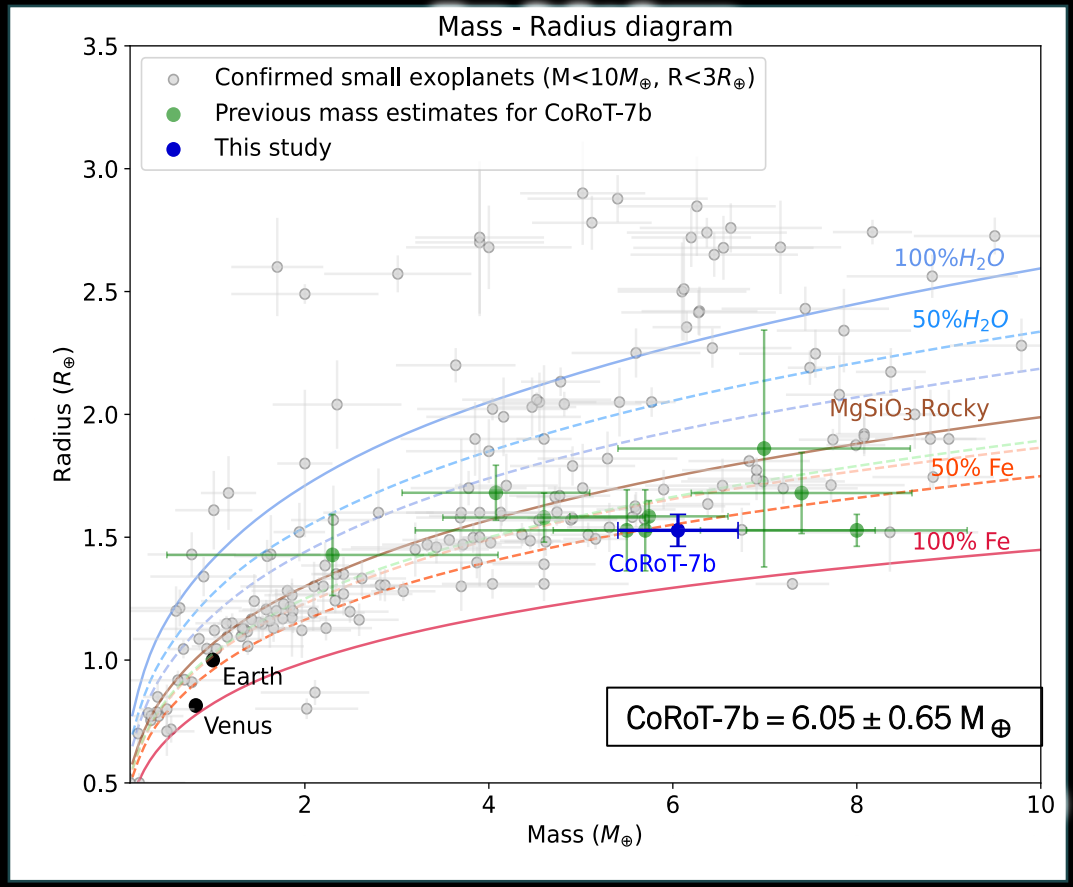
- 2 known planets
  - 0.85 d (transiting), 3.69 d (Queloz et al 2009)
- 3rd candidate signal at 8.98 d (Hatzes et al 2010)
  - later deemed as an activity signal (Haywood et al 2014, Faria et.al 2018)
- Mass of transiting planet poorly constrained (2-8 $M_\oplus$).

Posterior distribution



False Inclusion Probability (FIP) (Hara et al 2021)





Anna John et. al 2022

HARPS-N RPS TARGETS (2012-PRESENT)

False Inclusion Probabilities (FIP) (Hara et al 2021)

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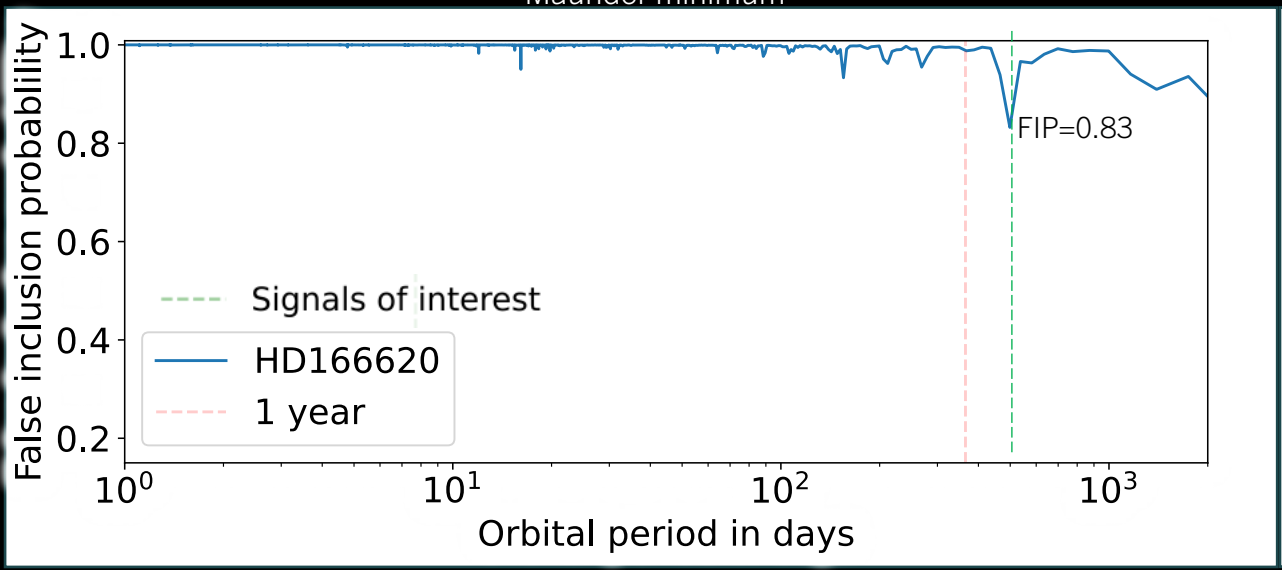
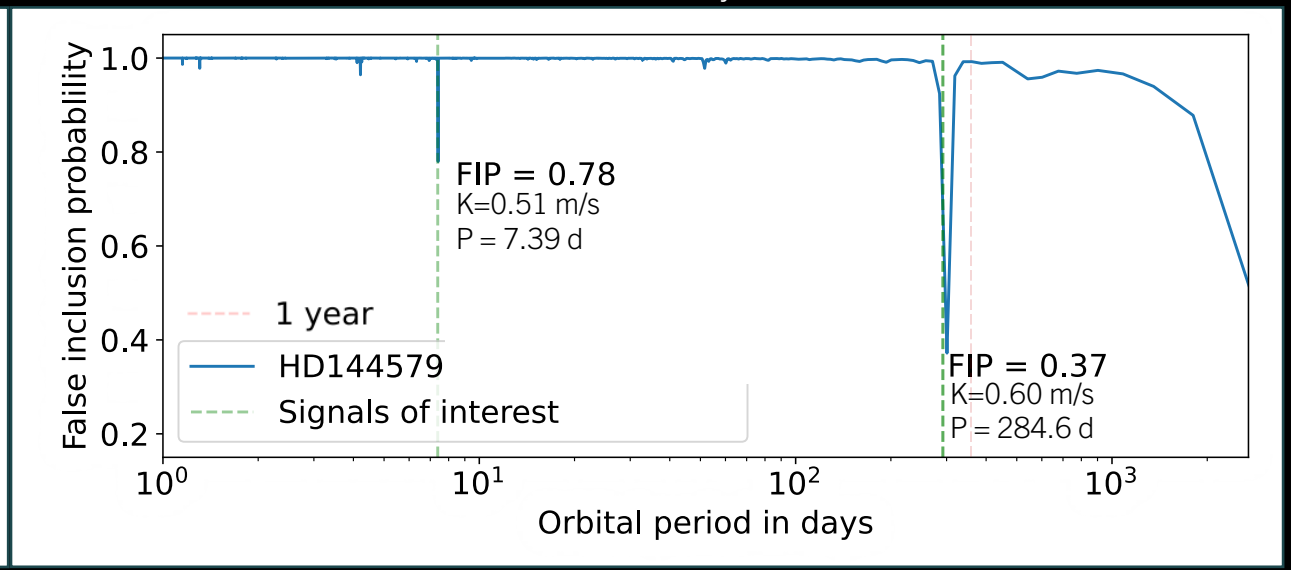
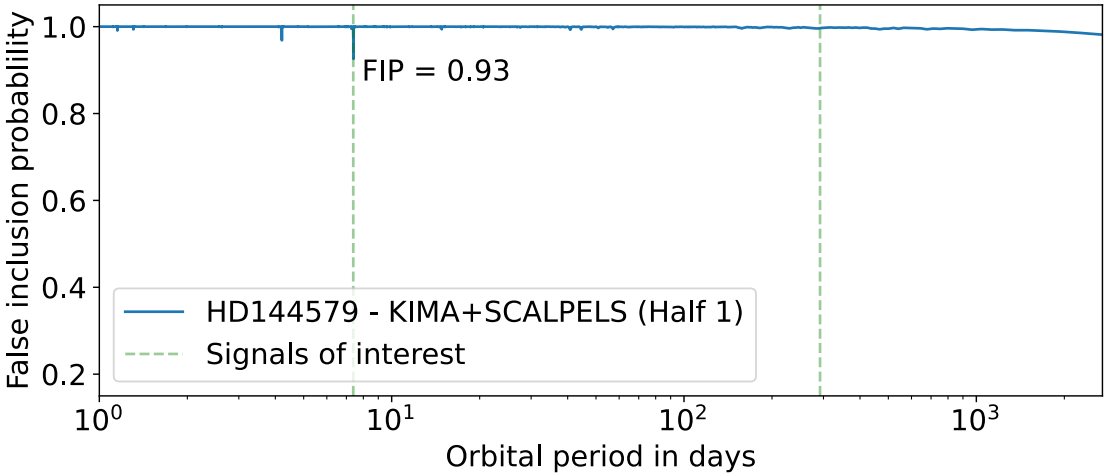


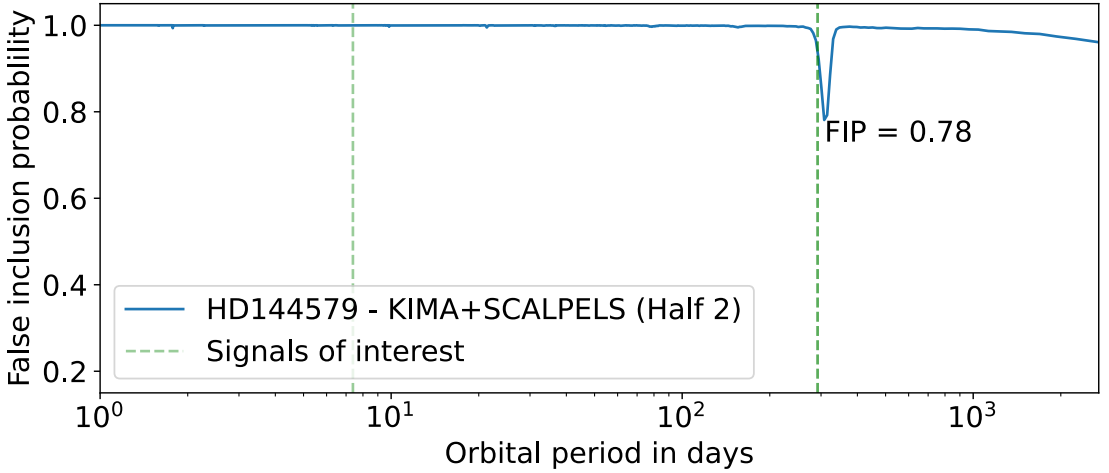
Moderately active



Anna John et. al 2023 (under review)

DATA SPLITTING TESTS

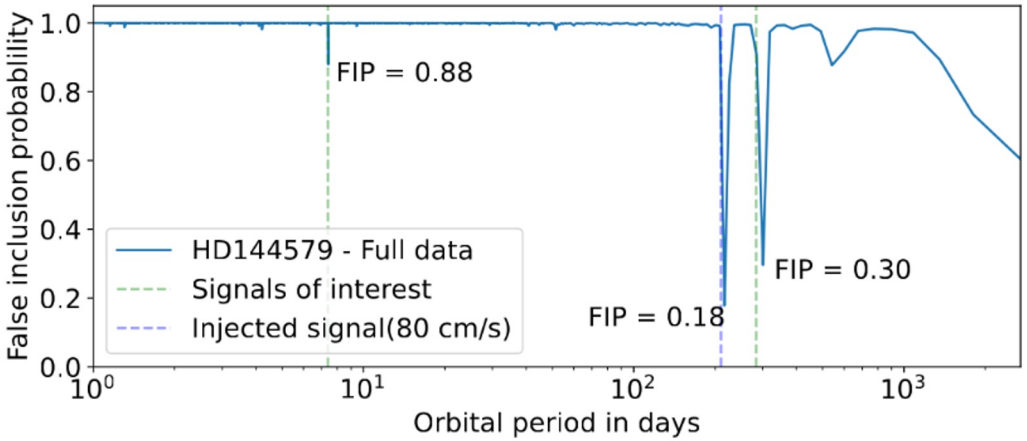


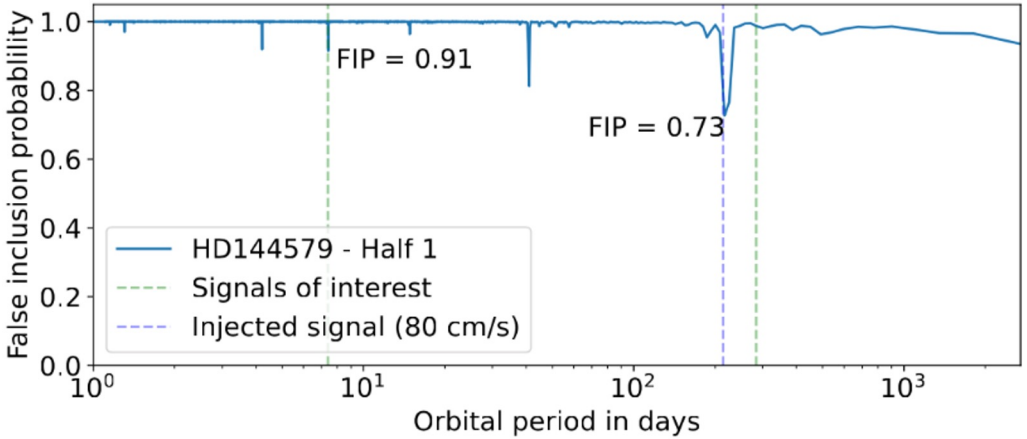


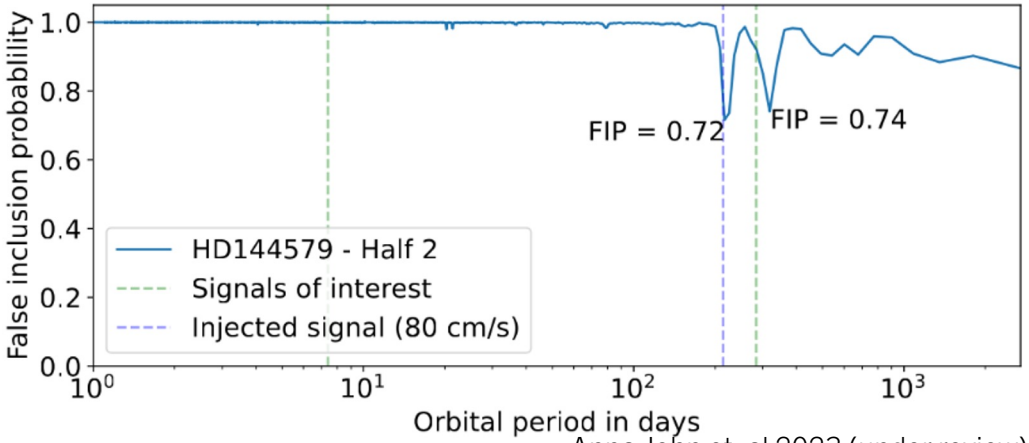
Sampling patterns can generate spurious signals in the posteriors, watch out!

Anna John et. al 2023 (under review)

INJECTION RECOVERY TESTS



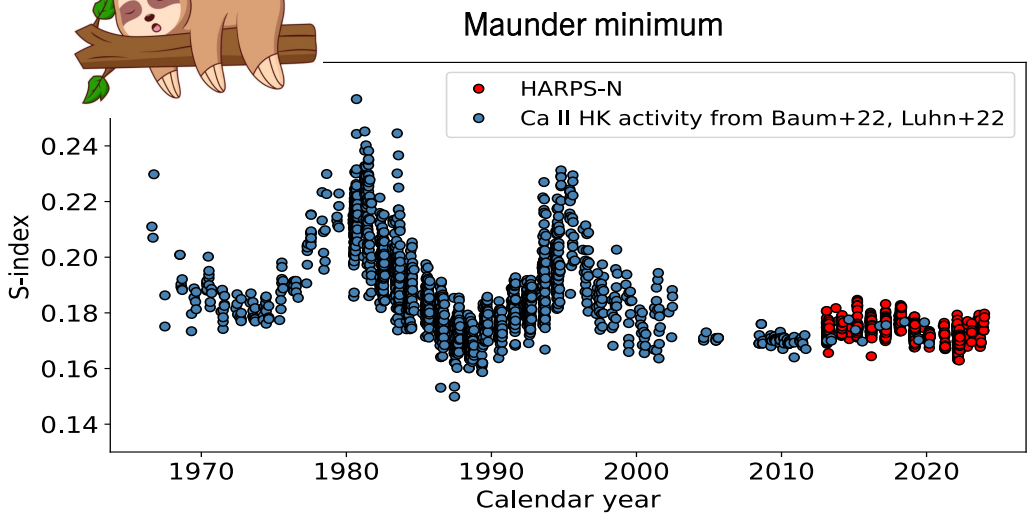


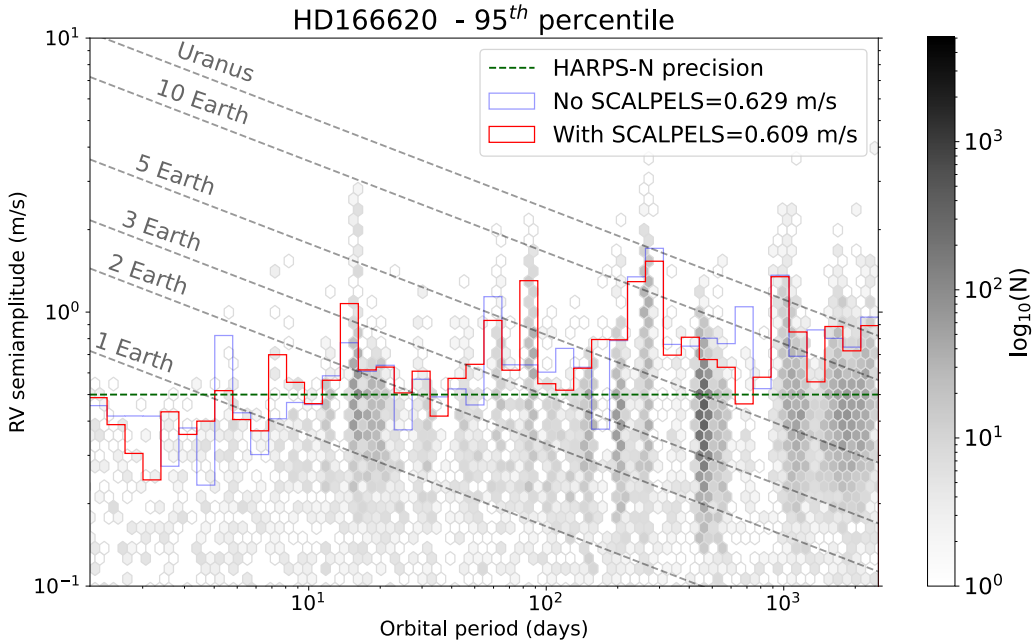


Anna John et. al 2023 (under review)

DETECTION LIMITS

inspired from Standing et. al 2022





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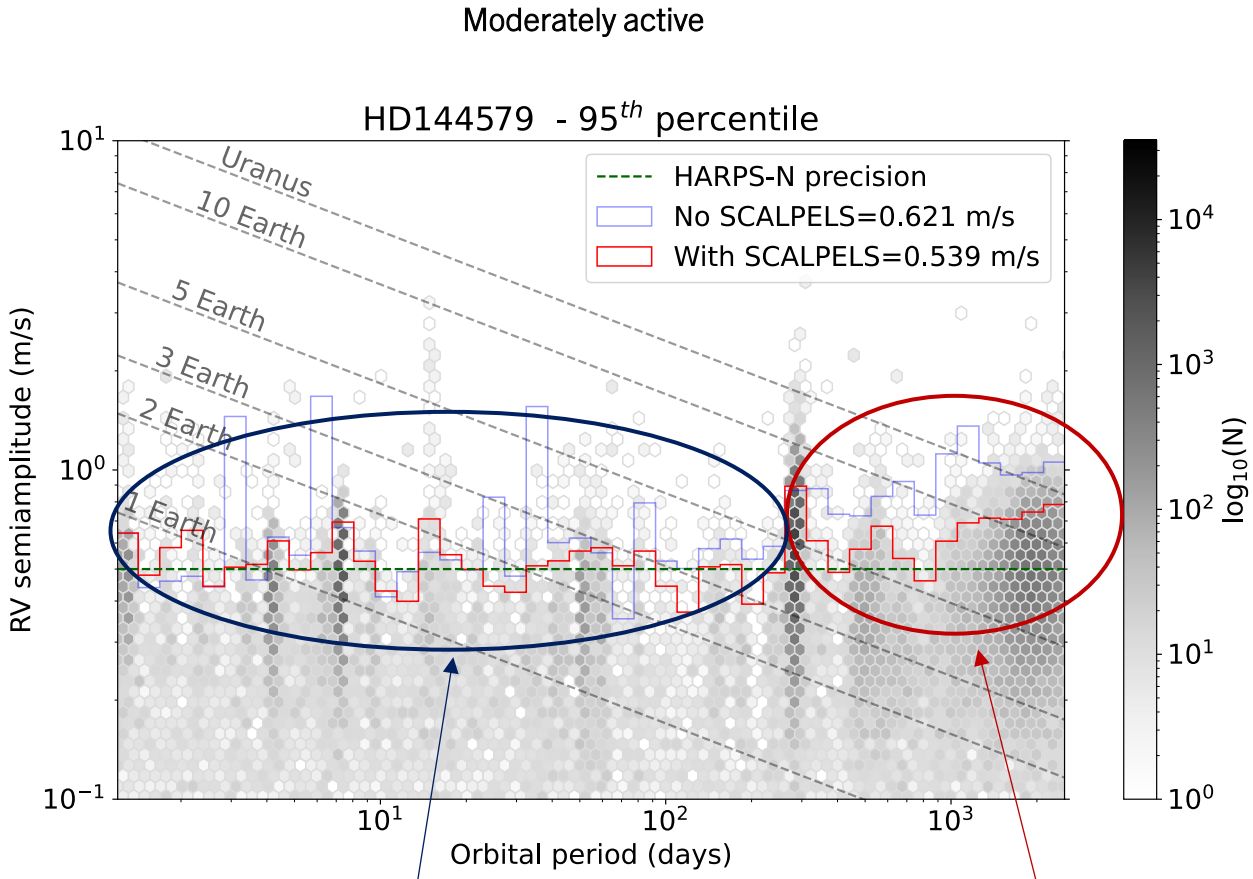

Anna John et. al 2023 (under review)

TAKE HOME

- Stellar activity mitigation using TWEAKS (SCALPELS+kima) offers RV detections in sub-m/s regime in HARPS-N data
- SCALPELS makes a significant improvement if even a small amount of stellar activity is present.
- CoRoT-7 is better modelled as a 3-planet system
- We are able to detect RV signals down to 54 cm/s, (calibration precision of HARPS-N = 50 cm/s)