K2-3: a system of small-size and low-mass planets orbiting a nearby M dwarf

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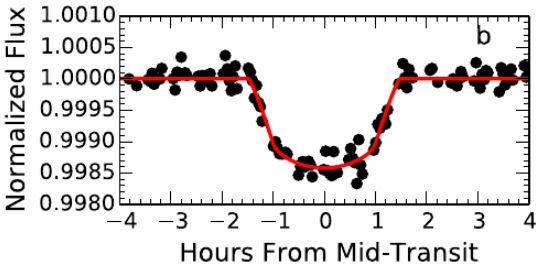
Proposal title

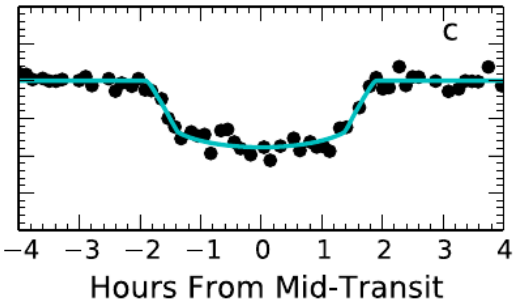
Precise planetary mass determination in radial velocity data collected with the HARPS and HARPS-N spectrographs: facing the challenges posed by the time sampling and the presence of stellar noise

SCIENCE

K2-3
M0V,
$M=0.6M_{sun}$

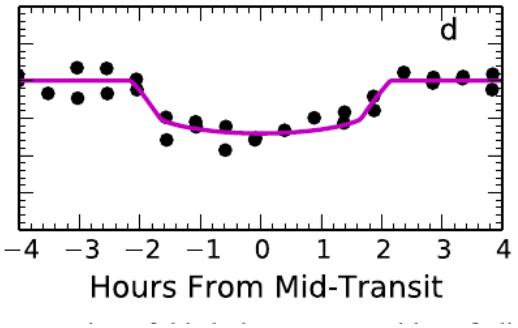


P=10 days
R= 2.47±0.40Re



P=24.6 days
R=1.69±0.21 Re

Transits discovered by K2



Potentially habitable

P=44.6 days
R=1.61±0.20 Re

We have radii...we want the planet masses!

More than 300 RVs collected over 2.5 years by two different teams and with two different high-res/high stability spectrographs

Lot of investment in observing time due to peculiarity of this system

Several challenges to face!

Mitigating stellar activity and let the planets pop up in the RVs

- MCMC framework
- Using **Gaussian process (GP) regression** to model the stellar signal in the RVs jointly with three planetary orbital equations

$$\ln p(\{y_n\} \mid \{t_n\}, \{\sigma_n^2\}, \theta) = -\frac{1}{2}\boldsymbol{r}^{\mathrm{T}} K^{-1}\boldsymbol{r} - \frac{1}{2}\ln\det K - \frac{N}{2}\ln 2\pi$$

Is the likelihood function to be evaluated

where $r = \begin{pmatrix} y_1 - f_\theta(t_1) \\ y_2 - f_\theta(t_2) \\ \vdots \\ y_N - f_\theta(t_N) \end{pmatrix}$

and **K** is a NxN covariance matrix with elements defined by a **quasi-periodic** kernel

- The computing time to evaluate the likelihood goes as $O(N^3)$
- For K2-3 the number of free parameters is 19

Results on real data

* Stellar activity is well modelled

* Planet K2-3 b is precisely retrieved

* Planet K2-3 c is less precisely retrieved, but it’s there

* Planet K2-3 d is undetected: can we guess *why*?

We used simulations to investigate the effects of data sampling, activity noise and RV internal errors in preventing the detection of K2-3d in our dataset.

We also used simulations to propose a way for better constraining K2-3d mass

We injected a signal with K=1 m/s and ephemeris of K2-3d, and used
1) real epochs;
2) dense sampling for season 2017 (a dream for a planet hunter!)
and **run hundreds of GP analysis in total**

This is where CHIPP comes on the stage!

TECHNICALITIES

How CHIPP helped me

- All the software is written in Python
- The MCMC and GP modules are coded by D. Foreman-Mackey (emcee and George packages) and freely available
- There’s some degree of parallelization
- I used Trieste and Catania computing resources since 2016 to carry out similar analysis
- In the framework of CHIPP only some fine tuning was necessary (thanks, Fabio!)
- One simulation typically ran for 6-8 hours. Not particularly faster than on my laptop, but **hundreds of simulations have run!**

A typical script

```
#!/bin/bash
## Name of the job
#PBS -N simulazioni_for_paper
#PBS -q medium
#PBS -l select=1:ncpus=24:mem=64gb
#PBS -l place=scatter:excl
##PBS -l walltime=96:00:00
#PBS -l walltime=24:00:00
#PBS -o logs/
#PBS -e logs/
#PBS -A chipp_k23


qsub /home/mdamasso/sub_new_normal
```

Conclusions

- I got 100,000 CPU hrs for my proposal
- The paper is submitted: CHIPP simulations provided relevant results (and CHIPP is duly acknowledged!)
- The study involved a large collaboration, but I could not find computing resources elsewhere
- I have reached the expected goal in terms of number of simulations and computing hours allocated
- Future studies like that about K2-3 system will be frequent and with few technical changes (improved parallelization foreseen). CHIPP resources will be very important for me especially in terms of computing time to perform ‘K2-3 like’ analysis
- Should I mention a weak point: decrease the queue time when all/many projects are running (if this makes sense...)