EXPECTATIONS FOR THE CONFIRMATION OF PROXIMA C FROM A LONG-TERM RADIAL VELOCITY FOLLOW-UP

Fabio Del Sordo (1), **Mario Damasso** (2)
(1) Institute of Astrophysics, FORTH, Heraklion, Greece
fabiods@ia.forth.gr, skype: fabiodelsordo

(2) INAF OATo, Italy - mario.damasso@inaf.it

for details see
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.Introduction.

Context. Proxima c, a candidate exoplanet orbiting Proxima Centauri, was detected with the radial velocity method [1]. Its long orbital period (~5.2 years), and the small semi-amplitude of the induced Doppler signal (~1.2 m/s), make this detection challenging and the target worthy of a follow-up in the next years. Proxima c is particularly interesting also because it may be observable also with direct imaging [2,3] and via astrometry [1,4,5,6].

Aims. We intend to evaluate the impact of future data on the statistical significance of the detection through realistic simulated radial velocities to be added to the published dataset, spanning up to one orbital period of Proxima,c in the time range 2019-2023.

Problem I:

Question: If Proxima c exists, and hence has an imprint on the radial velocities, which observational effort is needed to confirm it in the next 5 years?

Strategy: We analyze six possible scenarios, as described in the following table. Here, for each scenario we indicate the number of simulated RVs, the total number of RVs in each dataset, the time-span and an estimate of the relative observational effort in hours. In each case, the simulated data contain an injected signal consistent with the orbit of Proxima c calculated in [1].

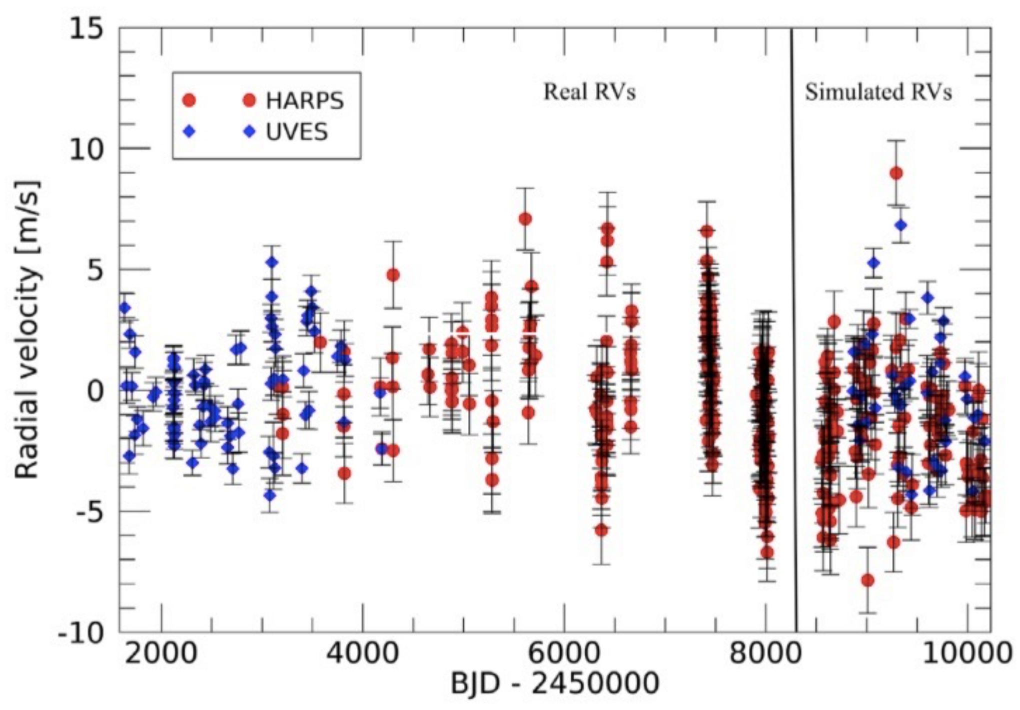
Scenario	Description	$N_{RV,sim}$	$N_{RV,tot}$	Time-span (yr)	T_{obs} (h)
H19	Includes real epochs of observations of Proxima carried out with HARPS [program 102.C-0339(A)] from 2019 March 7 through 2019 September 2 , for a total of 57 spectra spanning 39 nights. We considered $N = 39$ epochs to simulate nightly binned RVs. Since this is a set of epochs corresponding to observations actually performed, it is included in all the following data sets.	39	318	19.5	14.3
H19–23	HARPS simulated data for epochs during 2020–2023. For each of the four years and for every simulated RV data set, first we randomly selected one epoch per week satisfying our assumed observational constraints. Then, we randomly selected 80 epochs out of the $32*4 = 128$ total sample. An average number of 20 RVs yr^{-1} can be considered as a conservative estimate for a real follow-up campaign with HARPS focused on Proxima c.	119	398	23.5	14.3+40
H19+U20–23	Simulated UVES measurements during 2020–2023. For each of the four years and for every simulated RV data set, first we randomly selected one epoch per week among those satisfying our assumed observational constraints. Then, we randomly selected 40 epochs out of the $32*4 = 128$ total sample. An average number of 10 RVs yr^{-1} can be considered as a conservative estimate for a real follow-up campaign with UVES focused on Proxima c.	79	358	23.5	14.3+26.7
H19+All 20–23	A combination of data sets H19–23 and H19+U20–23.	159	438	23.5	14.3+66.7
H19–23 RV+	Same as H19–23, but, instead of having 20 RVs yr^{-1} on average, here, we increase the average number to 40 RVs yr^{-1}. This sample is randomly selected within the total of good epochs per year according to the observational constraints. The total of 160 simulated RVs in the 4-yr time-span is less conservative than the previous scenario, none the less still realistic.	199	478	23.5	14.3+80
H19–21	HARPS simulated data. 60 randomly selected epochs, both in 2020 and 2021, among those satisfying our assumed observational constraints.	159	438	21.5	14.3+60

Table 1

Results: In the best case scenario (H19-23 RV+) Proxima c becomes significant at 4 σ. We still see that the Bayesian evidence mildly depends on the priors chosen to carry on the analysis. We notice that spreading observations in five years (H19–23) is a better strategy than concentrating many observations in three years (H19–21, 159 additional data points). This points out that **following one entire orbit of Proxima c brings more information** on its orbital parameters with respect to a dense monitoring limited in time.

.Methodology.

Figure 1



1) We simulate RV data sets of Proxima obtained with HARPS and UVES, which are the instruments used to detect Proxima b and c, conceiving different scenarios. For each of them we simulate 20 data sets (see Table 1).

The proposed scenarios are arbitrary, but they are based on past observational campaigns and on what we deem an affordable observing strategy to in-depth probe this exoplanetary system. In Figure 1 we see an example of the analyzed datasets.

2) We analyze the mock datasets with Gaussian process regression in a Bayesian framework, jointly modelling the planetary signals and the correlated term due to the stellar activity (see [1,8]): the correlated noise is fitted with a quasi-periodic function described by the covariance matrix k(t,t').

$$k(t,t') = h^2 \exp\left[-\frac{(t-t')^2}{2\lambda^2} - \frac{\sin^2\left(\dfrac{\pi(t-t')}{\theta}\right)}{2w^2}\right] + \left(\sigma^2_{\mathrm{instr,\,RV}}(t) + \sigma^2_{\mathrm{inst,\,jit}}\right)\delta_{t,t'}$$

We then build some figures of merit to assess the expectations for each scenario (see Table 4 of [7] for details).

Problem II:

Question: If Proxima c does not exist, is it possible to disprove its existence in the next five years only with RVs?

Strategy: We analyze the scenarios H19-23, H19+U20-23, H19+All20-23 in table 1, and esclude the cases which do not cover 5 years or have a very high cadence. In each of this scenario we **do not inject** the signal of Proxima c: the simulated data therefore contain only the signal of Proxima b and the stellar activity as calculated in the best-fitting solution for the corresponding one-planet model in [1].

Results: In the three analyzed scenarios, a signal with a period of ~1900 days still appears, but its significance substantially lowers on average (1.9 σ in the lowest case). The Bayesian evidences for the one-planet and two-planet models become equivalent. In other words, a signal compatible with Proxima c would still persist in the data, but its statistical evidence would not be enough to claim we are seeing an exoplanet.

.Conclusions.

Five years of observations, approximately equivalent to one orbit of Proxima c, **should not bring the detection above a 4-σ significance**, nor will strongly improve the Bayesian evidence of the two-planet model with respect to the one-planet model. Meanwhile, a confirmation, or disproval, can arrive from astrometry with the *Gaia* satellite. At the same time, in the hypothesis that only Proxima b exists, we show that a signal, with about the predicted orbital period of Proxima c still shows up, but its average statistical significance decreases substantially. **We then forecast that it will also be challenging to completely disprove the existence of Proxima c with only five more years of RVs.** These results may be useful also for planning observations for detecting exoplanets in the poorly populated area of the parameter space where long orbital periods coexist with small induced radial velocities.

.References.

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