Bayesian model comparison as a tool to determine the number of planets in multi-body systems

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

Nicolas Unger, Damien Ségransan

nicolas.unger@unige.ch

INTRODUCTION

- **Goal:** Determine the number of planets in a system.
- We don't want to claim false positives or miss planets that are present in the data.
- Quick metrics like the false alarm probability (FAP) or the Bayesian Information Criterion (BIC) can help but are not robust enough.

METHOD

For each target we first do a quick analysis with the DACE platform. We look for the most significant periodic signals in the radial velocity timeseries and for possible long/short term trends in activity indicators. We find the best fit for the Keplerians and terms for drift/detrending until no more significant signals appear in the periodogram.

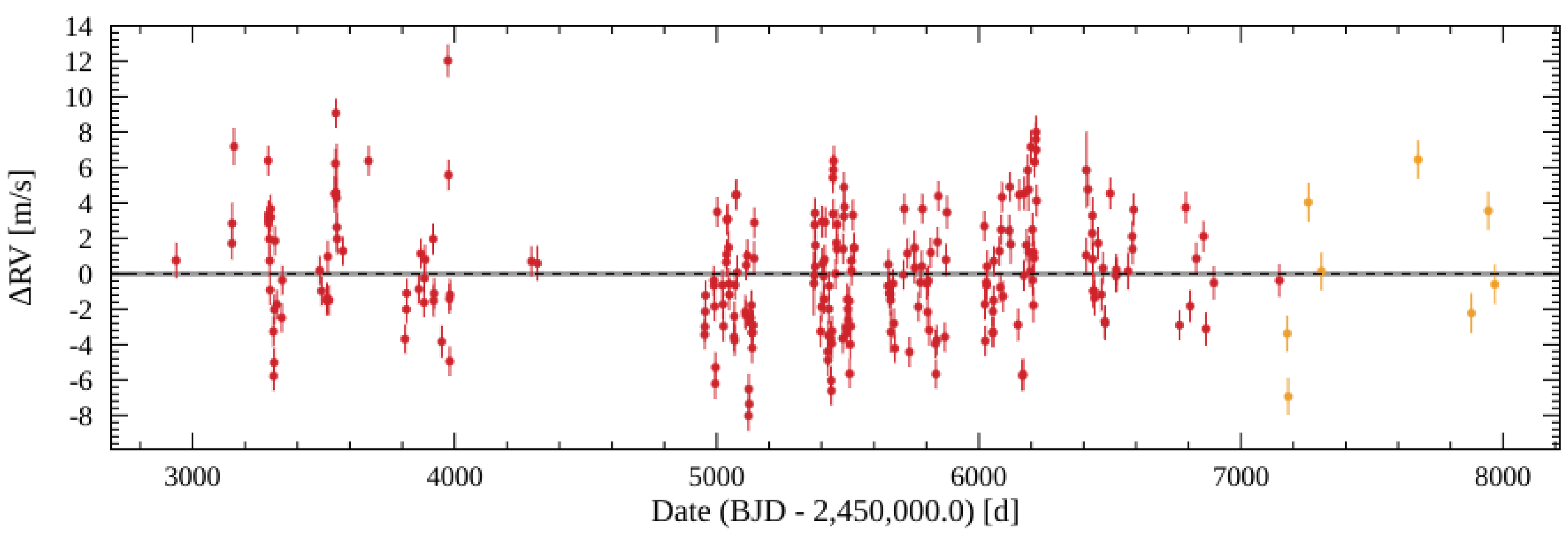


Figure 1: Example Radial Velocity timeseries taken with HARPS

The model consists of:

- n-Keplerian curves to model the planetary signals.
- Polynomial drift to fit long-term activity cycles.
- Additional white noise term (jitter) for each instrument.

BAYESIAN MODEL COMPARISON

We make use of Bayes Formula to compare the probabilities of different models:

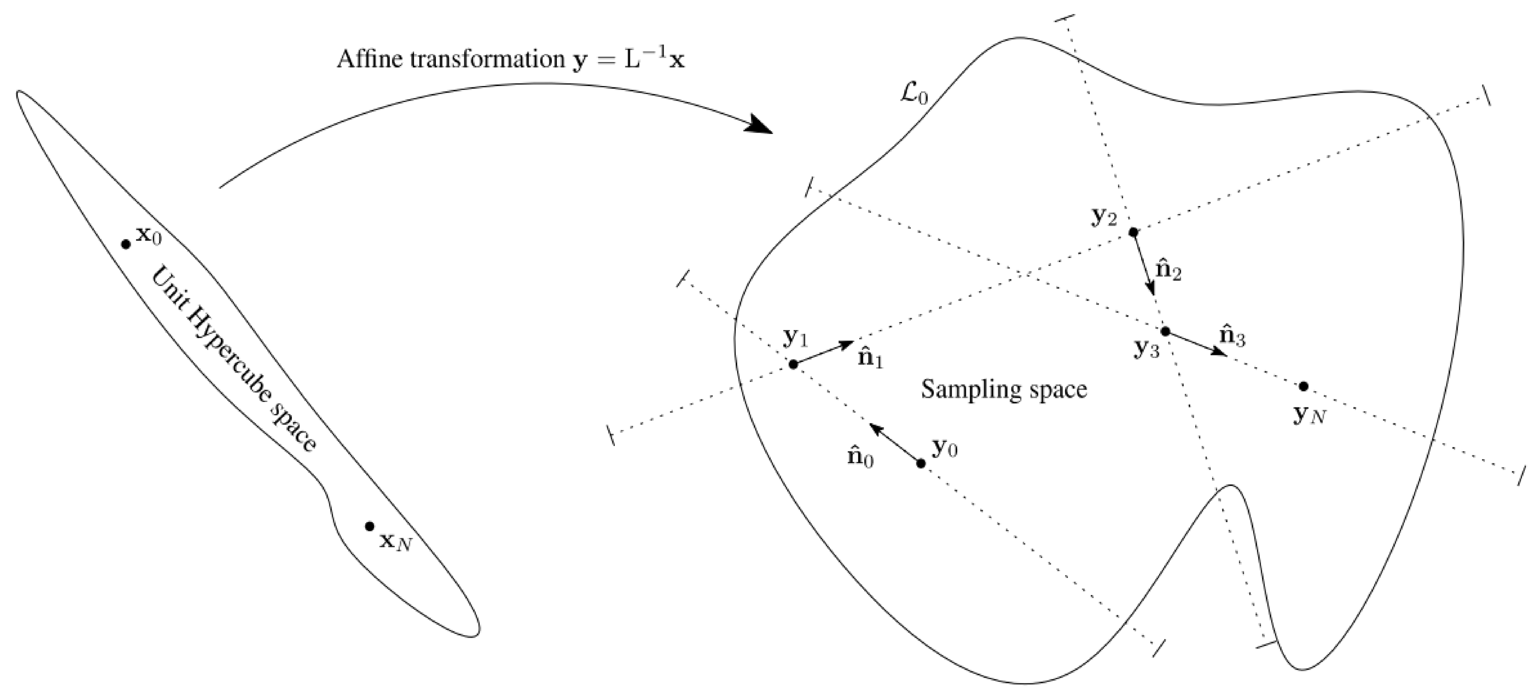
$$p(\mathcal{M}_i|D) = \frac{p(D|\mathcal{M}_i)p(\mathcal{M}_i)}{p(D)} \qquad O_{12} = \frac{p(\mathcal{M}_1|D)}{p(\mathcal{M}_2|D)}$$

$$\mathcal{Z} = p(D|\mathcal{M}_i) = \int \mathcal{L}(\theta)\pi(\theta)d\theta$$

Z is also called the Bayesian evidence. This is a tricky calculation because it involves solving a high dimensional integral. The integral has as many dimensions as free parameters in the model, which can be >30 for models with more than 4-5 planets.

NESTED SAMPLING

We implemented the Nested Sampling algorithm PolyChord (Handley et al. 2016) to estimate the Bayesian evidence. This algorithm uses the Slice Sampling technique to find new live points.

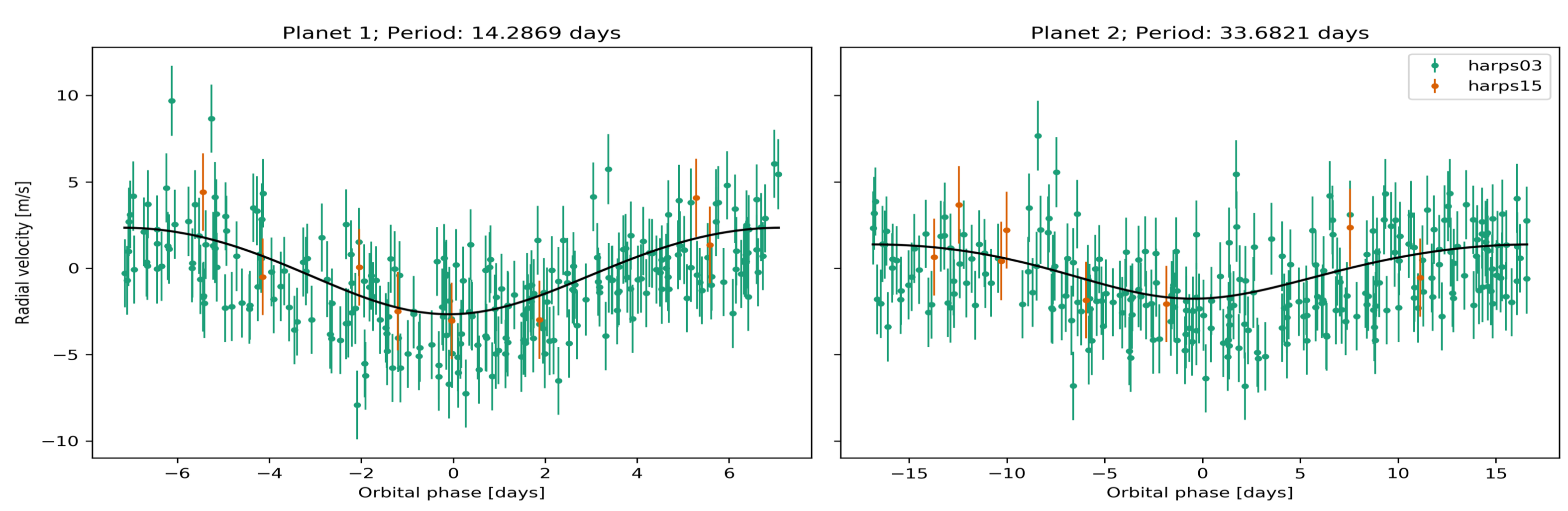


DATA ANALYSIS

We use PolyChord to compute the Bayesian evidence for models with different number of planets. We usually want a difference in log(Z) greater than 5 to validate a model. Example results:

Model	Log(Z)	$\log(Z_n/Z_{n-1})$
0 planets	-673.3±0.3	-
1 planet	-625.9±1.2	47.5±1.2
2 planets	-605.3±1.5	20.6±1.9
3 planets	-603.5±2.3	1.8±2.9

This system has two very clear periodic signals at 14 and 33 days and a third one a bit less significant at 18 days. This last signal is not supported by the data as shown by Bayesian model comparison.



Having a robust answer on the number of planets in a system will help us understand better the dynamics of a particular system but it also gives us better information about the population of multi-planet systems.

I'm happy to answer any questions. Just email me or write me a message in Slack.