Fitting Multi-Planet Transit Models to CoRoT Time-Data Series by Evolutionary Algorithms

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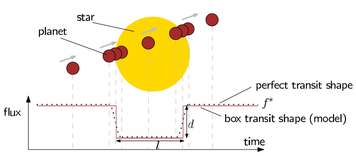
1 Introduction

Light curves of transiting planets can be approximated by rectangular signals of given period, the transit-length and depth, a time offset, and average out-of-transit stellar flux.



Fitting-Parameters (for each planet)

p orbital period
d transit depth
l transit length
τ time offset

Goal of Transit Detection Algorithms:
find optimal fit of parameterized model to observation data ⇒ parameter optimization problem

Fitting multi-planet models: computationally challenging task

2 Data/Objective

Data:
observation times $\vec{t}$
photon fluxes $\vec{f}$

Objective:
Let M be the number of planets, $\vec{x}$ the vector of all model parameters and f^* the out-of-transit stellar flux. The overall quality of a fit is then given by

$$f(\vec{x}, f^*, \vec{t}, \vec{f}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\phi(t_i) - f_i)^2},$$

where

$$\phi(t) = f^* - \sum_{j=1}^{M}\delta_j(t),$$

with

$$\delta_j(t) = \begin{cases} d_j & \text{if } \tau_j < t \bmod p_j \leq \tau_j + l_j \\ 0 & \text{otherwise.} \end{cases}$$

3 Basic considerations

- High number of optimization parameters ⇒ exhaustive search of discretized parameter space very time-consuming
- The frequently used Box-Least-Square algorithm is not directly applicable to multi-planet systems, as phase-folded signals w.r.t. the period of one planet are likely blurred by signals of the remaining planets
- Thus we approach the problem by heuristic techniques, i.e. a $(\mu, \lambda)-$Evolution Strategy, a self-adaptive population-based evolutionary algorithm

4 Algorithm

Properties:
- stochastic
- population-based
- evolutionary

$(\mu + \lambda)$-Evolution Strategy

P ← initialize population
evaluate(P)
while ¬ *termination-criterion* **do**
  $P' \leftarrow$ recombination(P)
  $P'' \leftarrow$ mutation(P')
  evaluation(P'')
  $P \leftarrow$ selection($P'' \cup P$)
end

Candidate Solution:
vector of parameters $\vec{x}$
e.g. $\vec{x} = (p_1, l_1, \tau_1, p_2, l_2, \tau_2)$

Recombination:
extended intermediate recombination, mainly for strategy parameters

Mutation:
primary operator; performed by adding a Gaussian variable

$$x'_i = x_i + \mathcal{N}_i(0, \sigma_i)$$

Strategy parameters σ_i
undergo itself process of modification ⇒ self-adaptation

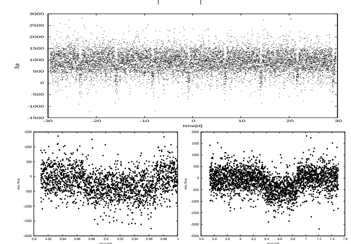
$$\sigma'_i = \sigma_i \cdot \exp(\mathcal{N}_i(0, const))$$

Transit-depths:
exact calculation for each candidate solution, based on $\vec{x}$

5 Results

Artificial data
Experiments are based on artificially created test-instances with different S/N ratios. Results are based on 100 runs with runtime limited to one hour.

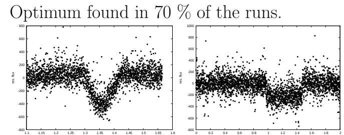
type	S/N	# opt. found
single planet	5	100 %
	3	99 %
two planets	5	80 %
	3	70 %



Example: 1) Raw data, 2,3) Phase-folded data of planets

Artificial systems in real CoRoT data
Artificial signals (S/N ≈ 2) have been added to CoRoT data. Near optimal solutions could be obtained in roughly 10% of the runs for 10 randomly selected photometric time-series (LRa01). Possibly due to misleading "red noise" these instances are hard to solve.

Example: IRa01 E2-3819
transit candidate with $p = 1.56$ d
additional artificial planet ($p = 5$ d, $l = 0.5$ d)
Optimum found in 70 % of the runs.



6 Conclusions & Future Work

- High detection efficiency and reliability for artificial test data
- Our experiments indicate that our method is very promising for finding multi-planet transit candidates in CoRoT data
- So far no transit-candidates found (maybe due to limited amount of computation time)
- Application of our algorithm to CoRoT data is ongoing

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