THE UNIVERSITY OF IOWA

A Search for Exoplanets orbiting Post-Common-Envelope Binaries using Eclipse Timing Variations

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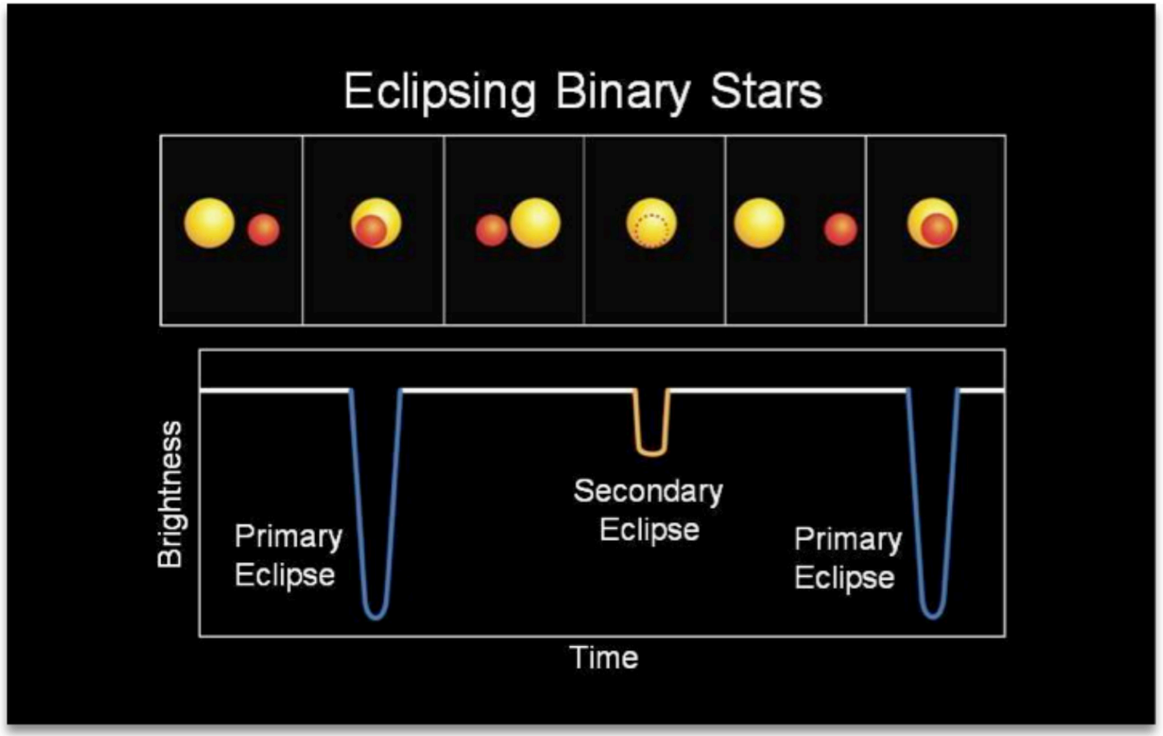
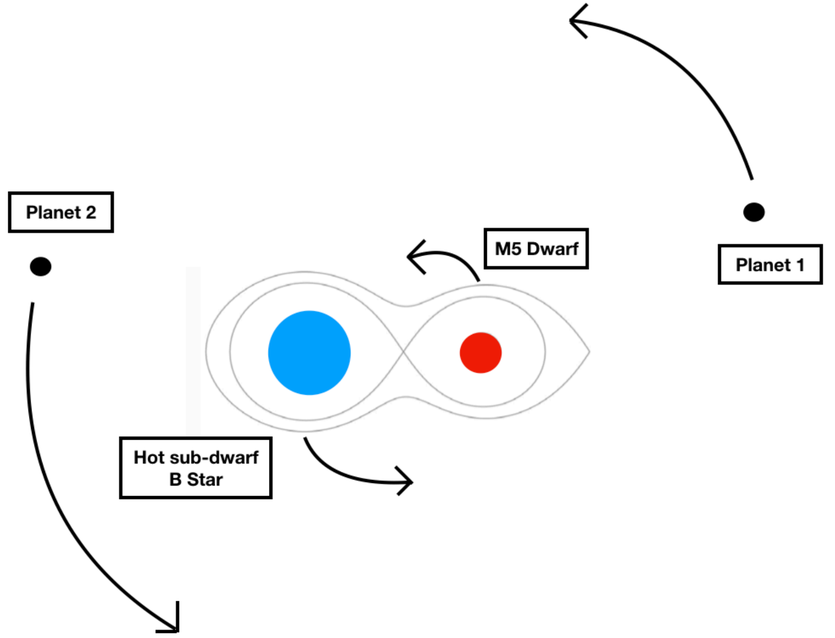
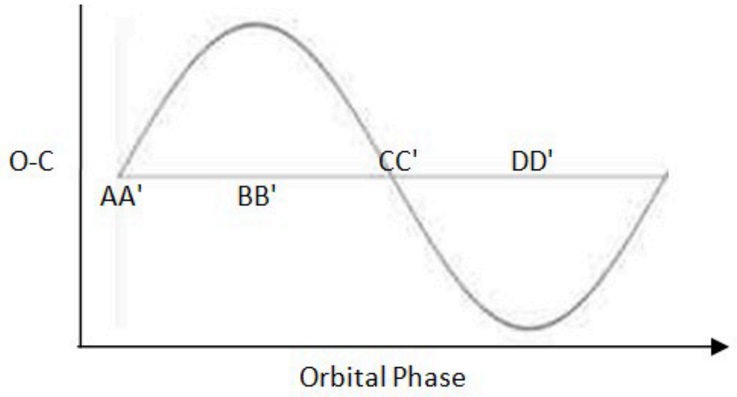
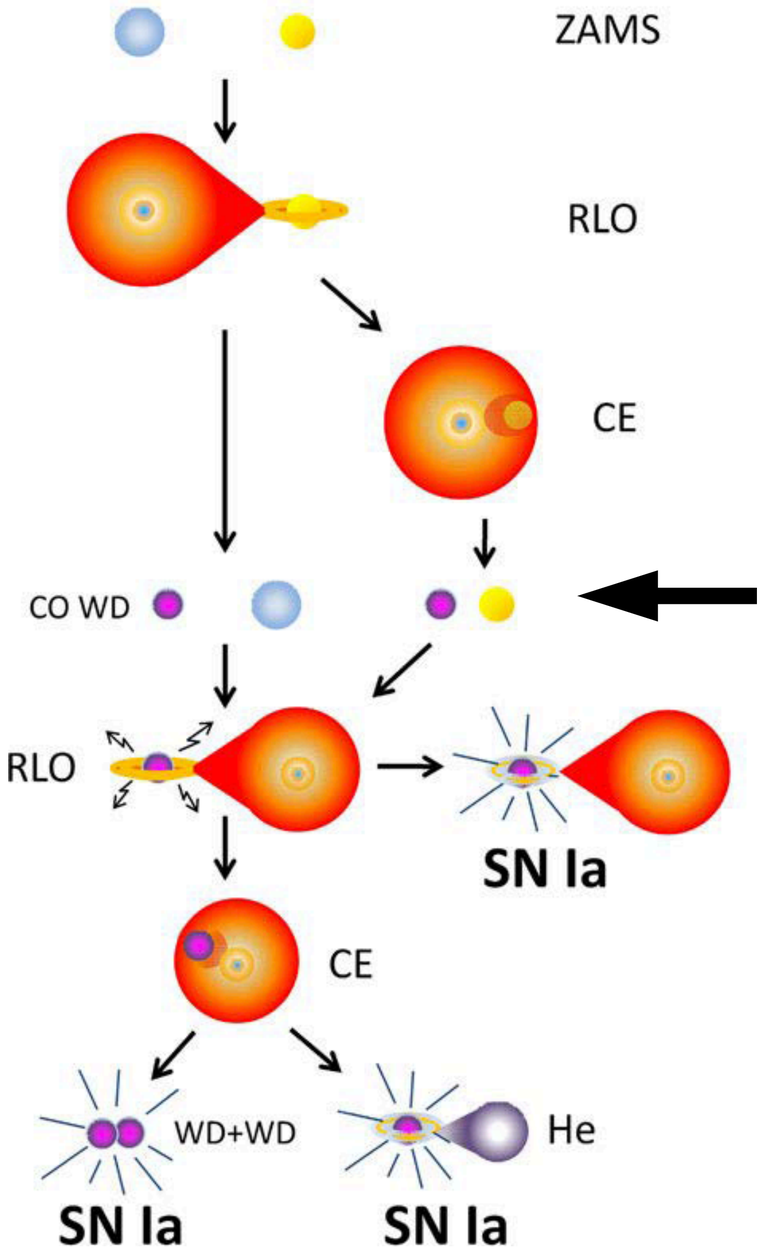
Is this period variation an evidence of exoplanet?







Common Envelope Evolution



(Zero Age Main Sequence)

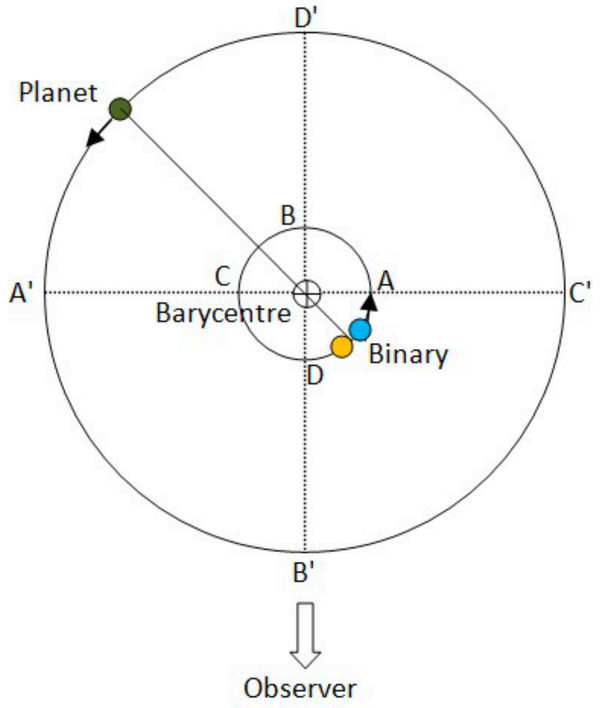
(Roche Lobe Overflow)

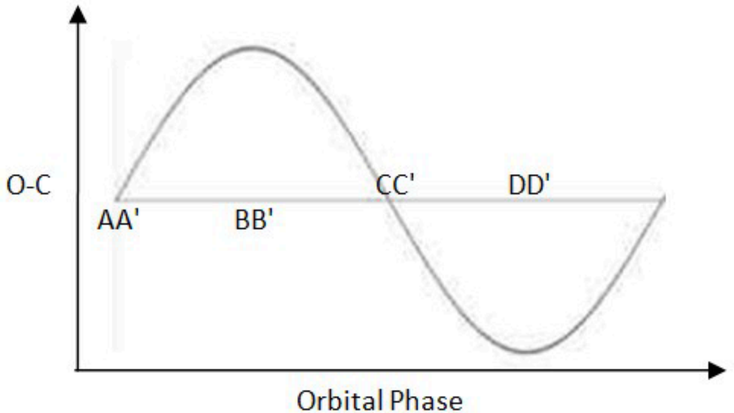
(Common Envelope)

PCEB (Post-Common Envelope Binary)

Timing Variation Mechanism

- **Other possible Causes of Period Variation:**
  - Mass transfer
  - Applegate's Mechanism?
  - apsidal motion?
  - Light travel time effect?





A Model for Timing Variations

$$T(E) = T_0 + P_0 E + \frac{1}{2}\frac{dP}{dt} P_0 E^2 + \sum \tau_i$$

Linear Ephemeris

Quadratic Ephemeris (Apsidal Motion?)

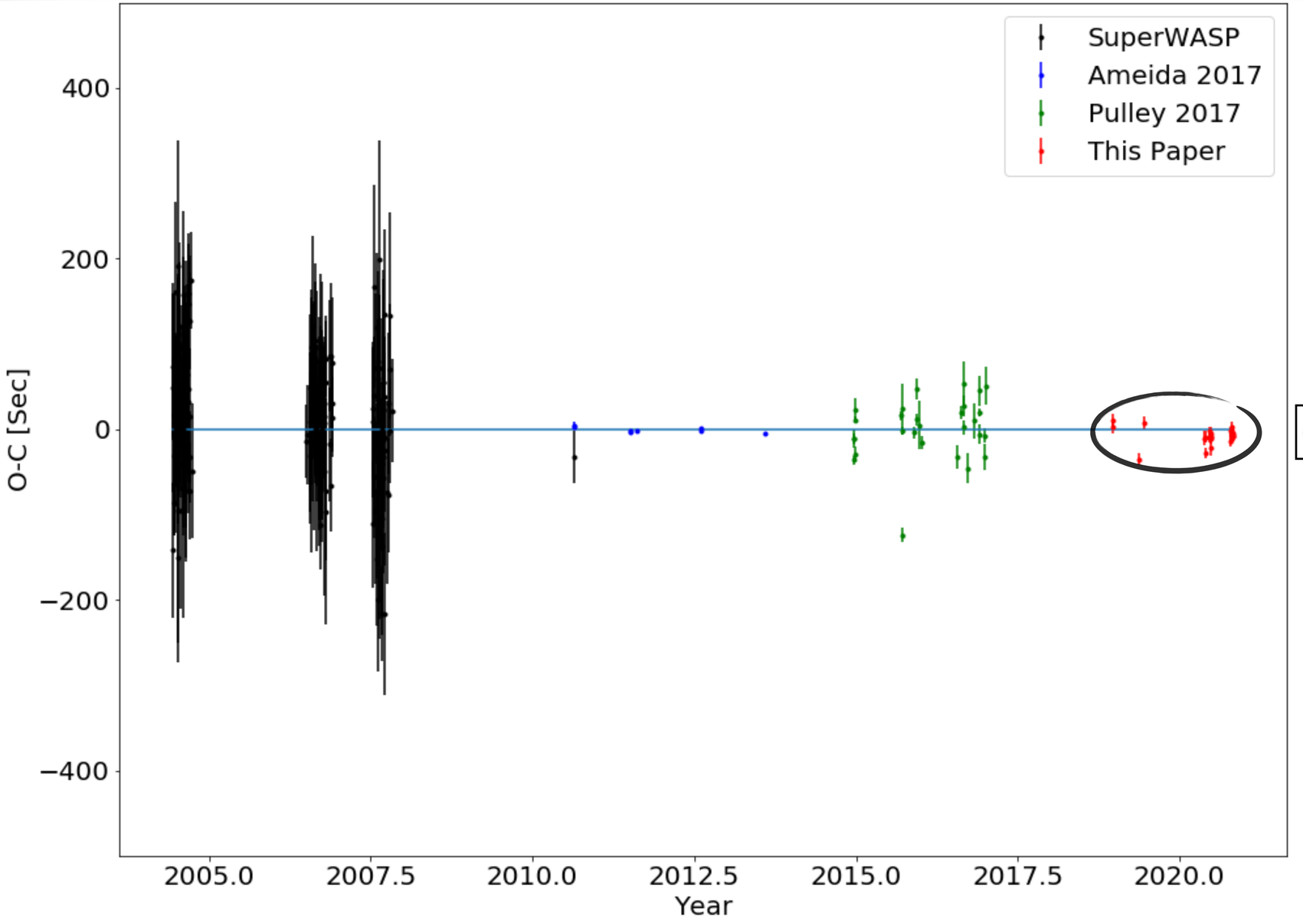
Light Travel Time(LTT) (Planets)

$$\tau_i = \frac{K_i}{\sqrt{1 - [e_i cos(\omega_i)]^2}} \cdot \left[\frac{1 - e_i^2}{1 + e_i cos(\nu_i)} sin(\nu_i + \omega_i) + e_i sin(\omega_i) \right]$$

Number of Planets: $i = 1,2,3...$

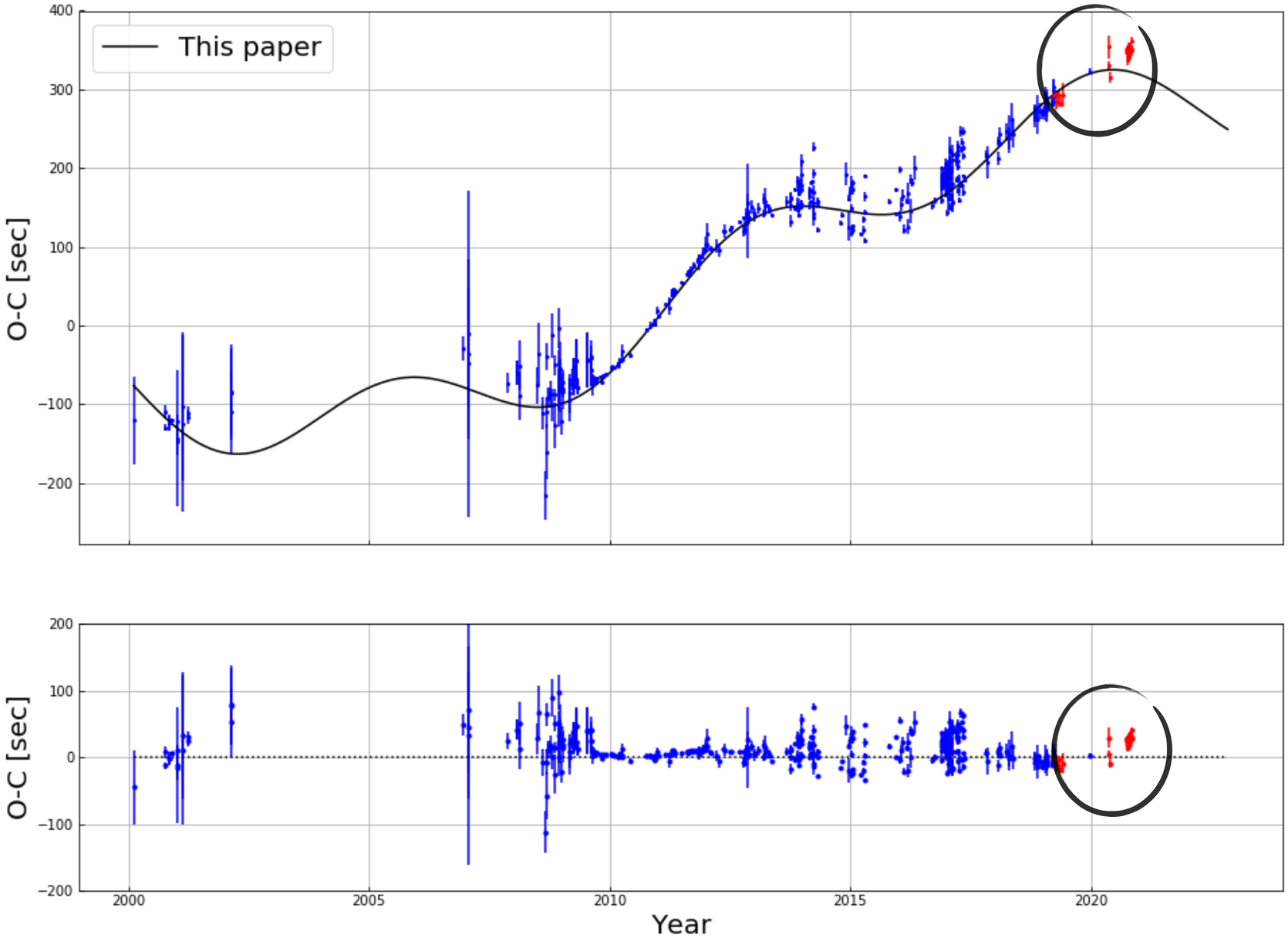
(Irwin 1959)

HS2231+2441



Our Observations

HS0705+6700: quadratic + 3 planets model

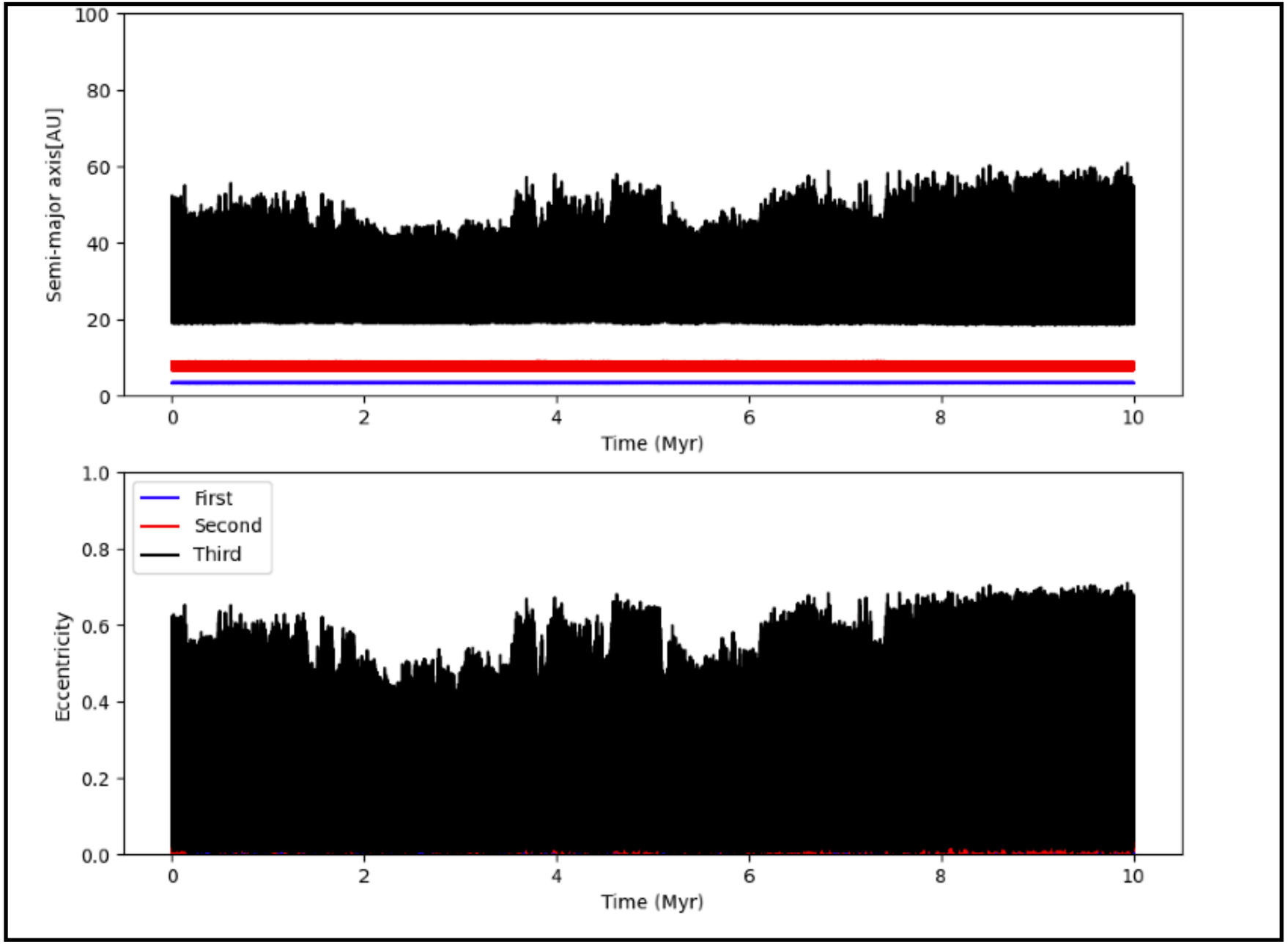


Our Observations

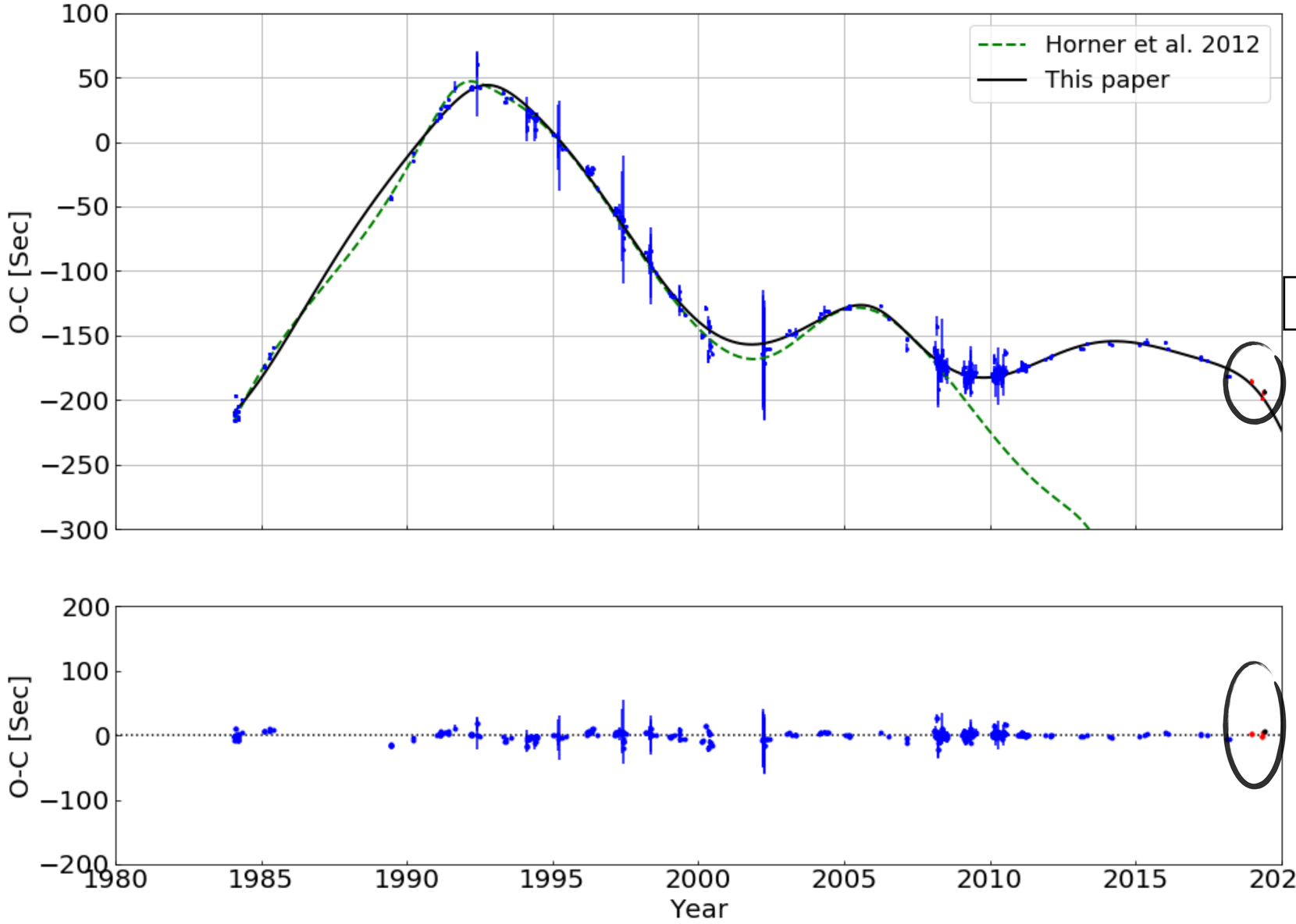
Best-fit parameters for the quadratic plus three planet model

Parameter	Fitted Values		Unit	
	Inner Binary			
T_0	2451822.762013		BJD	
P_0	0.095646609		day	
$\frac{dP}{dt}$	$4.97(12) \cdot 10^{-12}$		s/s	
	Substellar component parameters			
	LTT 1	LTT 2	LLT3	units
e	$0.0^{+0.03}_{-0.0}$	$0.01^{+0.02}_{-0.01}$	$0.05^{+0.03}_{-0.03}$	
asin(i)	$3.26^{+0.02}_{-0.26}$	$8.36^{+0.44}_{-0.15}$	$20.27^{+1.13}_{-0.74}$	AU
ω	$3.69^{+3.37}_{-0.1}$	$3.86^{+0.23}_{-0.08}$	$6.22^{+0.47}_{-0.47}$	rad
Min. Mass	$20.27^{+0.18}_{-0.19}$	$21.30^{+0.73}_{-0.71}$	$2.44^{+0.59}_{-0.70}$	M_J

Lifetime of PCEBs
~ 100 million years!



HW Vir: 4 planets model + quadratic term



Our Observations

Summary

- **HS2231+2441** No significant period variation
- **HS0705+6700** Stable three Planets Solution!
- **HW Vir** Excellent fit but unstable solution

Key questions:

- How well determined are the fitted parameters with degeneracy
- Other plausible hypothesis: Lanza-Applegate Mechanism?

Thank you!

Algorithm to Find Parameters of Chi Square Minima

1 Planet Solution:

- Grid Search + Downhill simplex

2 & 3 Planet Solutions:

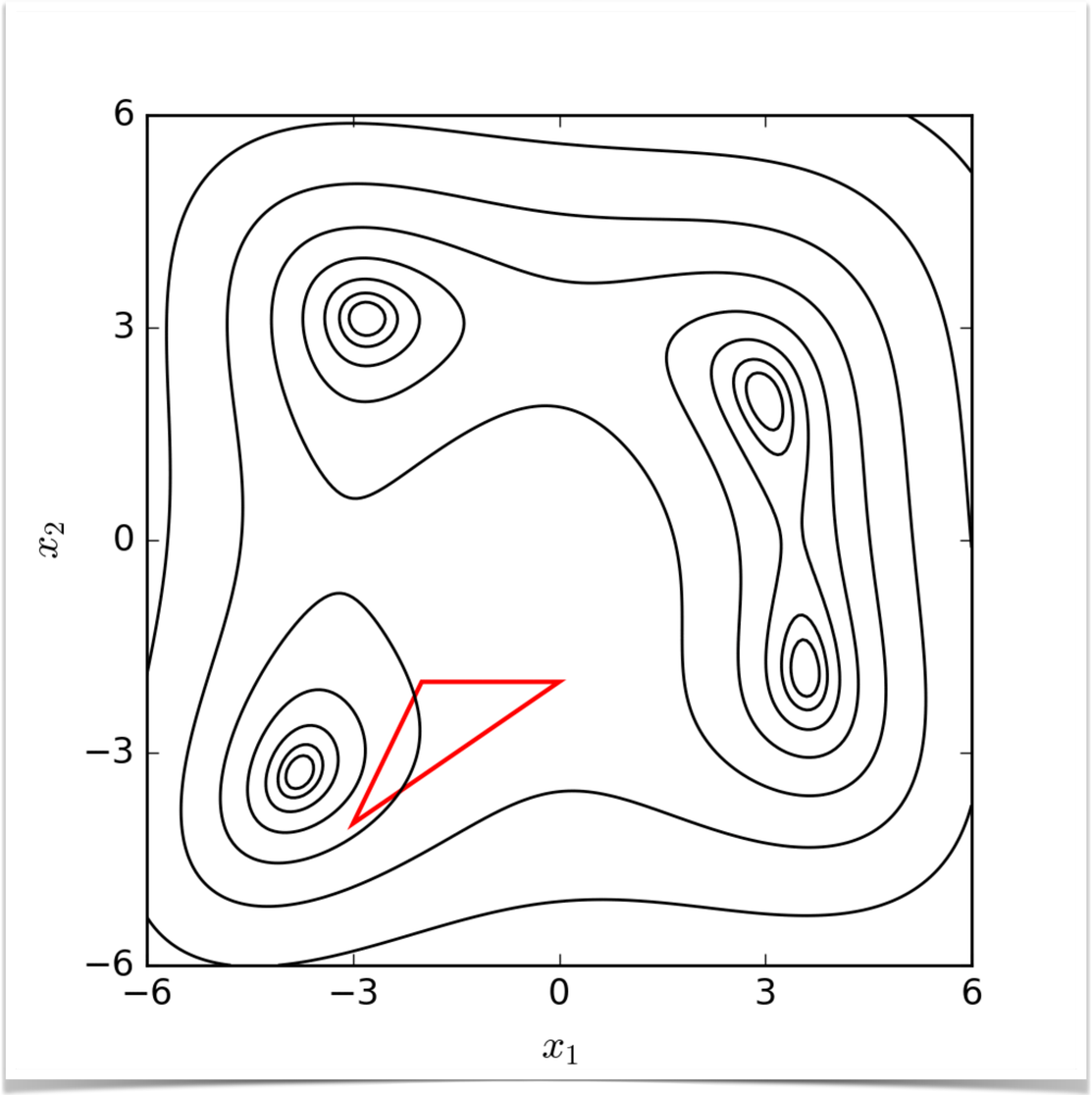
- Downhill simplex

Key Breakthrough:

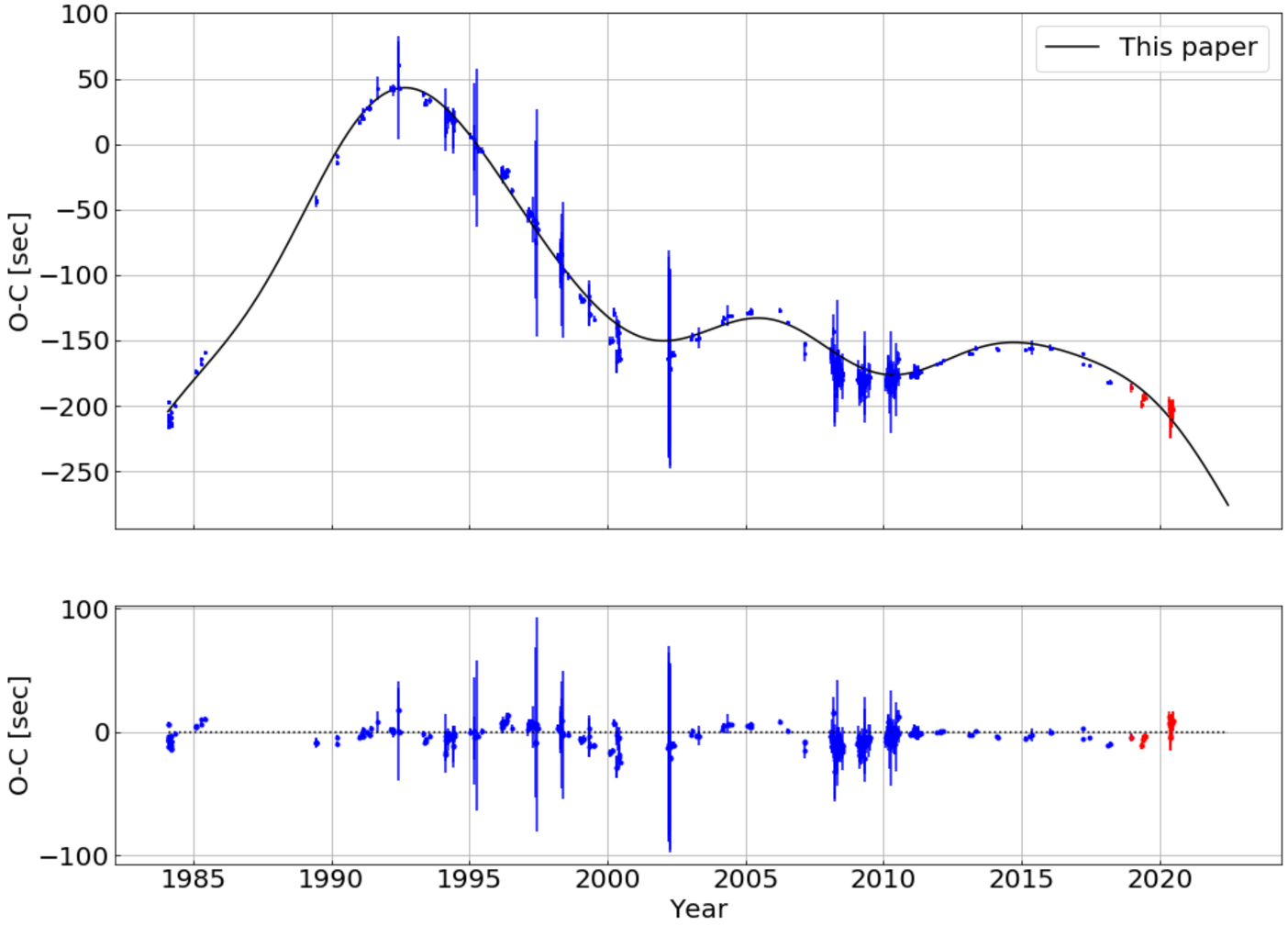
- Implement Levenberg–Marquardt nonlinear least-squares algorithm (LMFIT) with Hill criterion

- Use emcee minimizer to determine posterior distribution of the fitted parameters, characterize the uncertainties

Chi square surface



Best 4 planets fit
Unstable right away




```
1     1.88 Mjup      2.75 AU       0.00    343 deg
2     4.01 Mjup      3.88 AU       0.00    205 deg
3    12.28 Mjup      7.31 AU       0.21    167 deg
4     6.11 Mjup     24.66 AU       0.00    345 deg


Hill parameters
1-2 = 0.80
1-3 = 1.25
2-3 = 0.81
1-4 = 3.39
2-4 = 2.85
3-4 = 1.38
```

```
BJD0_0 = 2450280.28596 * day
P_binary_0 = 0.116719519 * day
Pdot_0 =  -1.39e-11
```