

PROMPT:

An effective tool for studies of pulsating stars

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THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

Bart Dunlap, Chris Clemens

SKYNET Team: D. Reichart, A. LaCluyze, J. Haislip,
K. Ivarsen, M. Nysewander

Fortnightly Fluctuations in the O-C Diagram of CS 1246

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Goodman
Laboratory



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The Tools at UNC-Chapel Hill

SOAR Telescope



- 4.1-m aperture
- Cerro Pachon, Chile

PROMPT (part of SKYNET)



- array of 5 robotic telescopes
- 0.4-m apertures
- Cerro Tololo, Chile
- 100% automated

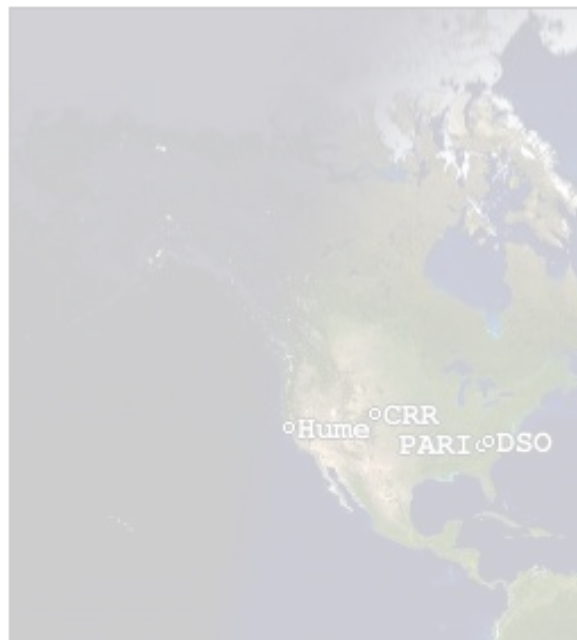
Skynet sunlight map



Copyright © Warner Bros. Pictures

	Sunrise (EST)	Sunset (EST)
Everest	7:53 PM	7:12 AM
CTIO	5:27 AM	6:27 PM
CRR	8:49 AM	7:41 PM
Hume	9:57 AM	8:53 PM
HampdenSydney	6:58 AM	5:58 PM
DSO	7:09 AM	6:11 PM
Morehead	2:59 AM	2:01 PM
Dolomiti	1:14 AM	11:48 AM
PARI	7:14 AM	6:18 PM
Yerkes	7:57 PM	6:43 AM

Skyenet sunlight map



SKYNET - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://skynet.unc.edu/index.php?selection=observations&newobs=new

Most Visited Getting Started Latest Headlines

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Welcome to
SKYNET

Home My Account Our Scopes Observation Manager Site Manager Error Log GRB Manager Account Manager

Log off
bbarlow
Feb 09 22:31:26 UTC
2455237.43850 JD

Tools and Info
[Skynet sunlight map](#)
[Nightly image count](#)
[Total image counts](#)
[Telescope activity plots](#)
[Observation planner](#)
[Skynet Live](#)
[Recent images](#)
[View idle times](#)
[CMG Weather](#)

New Observation
[Back]

Look up object coordinates by name:

Observation Name: RA: (HMS) : :

DEC: ° ' "

If interrupted...
Continue on same tele.

Priority: Max Airmass:

Group:

Don't start before (UTC):

Select filters:
☐ U ☐ gprime ☐ Blue
☐ B ☐ rprime ☐ Rc
☒ V ☐ iprime ☐ Ic
☐ R ☐ zprime ☐ Clear
☐ I ☐ Open ☐ Halpha
☐ Lum ☐ Red ☐ OIII
☐ uprime ☐ Green

Max Sun Elevation:



Terminators

Harvard	9:57 AM	8:53 PM
Sydney	6:58 AM	5:58 PM
	7:09 AM	6:11 PM
Morehead	2:59 AM	2:01 PM
Dolomiti	1:14 AM	11:48 AM
PARI	7:14 AM	6:18 PM
Yerkes	7:57 PM	6:43 AM

PROMPT as a Tool for Studying Pulsators

The PROMPT



Advantages

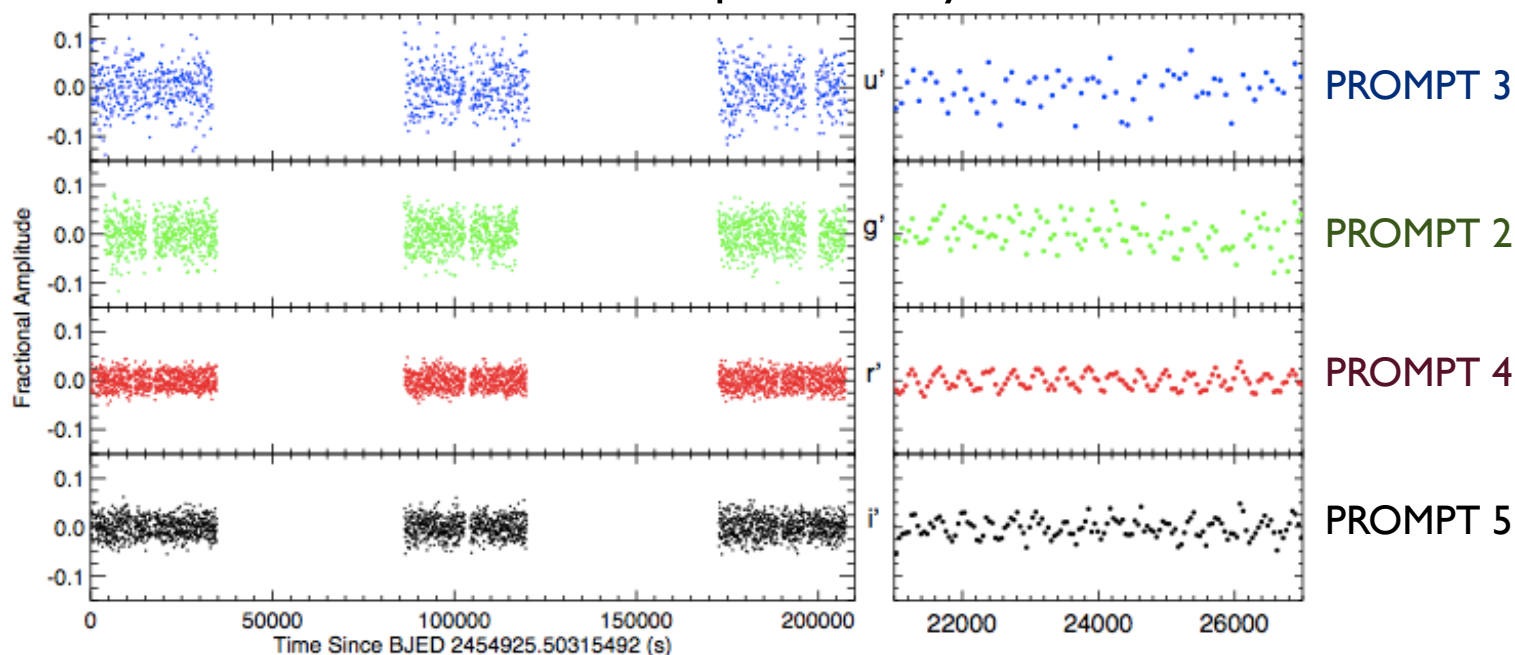
- great observing site
- 10' x 10' F.O.V.
- multi-color photometry easy
- lots of time available to us

Disadvantages

- small apertures

PROMPT as a Tool for Studying Pulsators

Simultaneous, multi-color photometry of CS 1246



Advantages

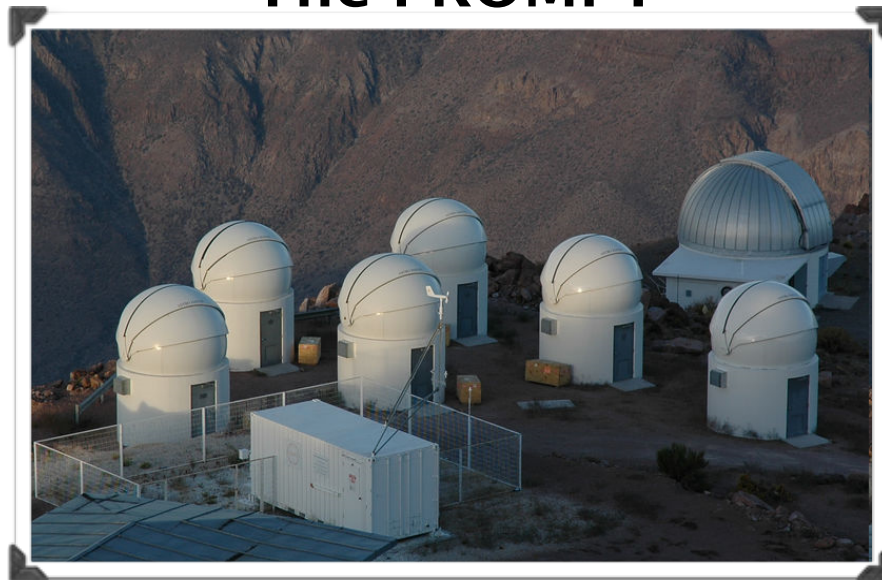
- great observing site
- 10' x 10' F.O.V.
- multi-color photometry easy
- lots of time available to us

Disadvantages

- small apertures

PROMPT as a Tool for Studying Pulsators

The PROMPT



Advantages

- great observing site
- 10' x 10' F.O.V.
- multi-color photometry easy
- lots of time available to us

Disadvantages

- small apertures

O-C Diagram Basics

- 'O-C' = 'observed - calculated'
- used to measure small differences in arrival times of photons
- same timing method used to find planets around pulsars

$$C = T_o + P_o E$$

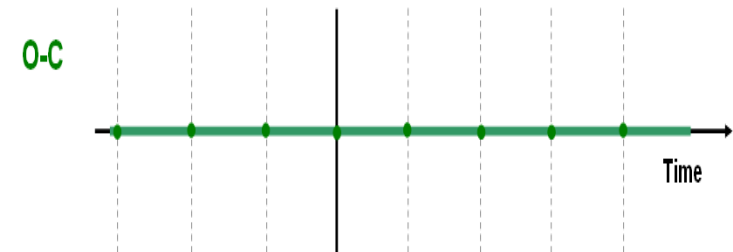
T_o - time at cycle $E=0$

P_o - period at T_o

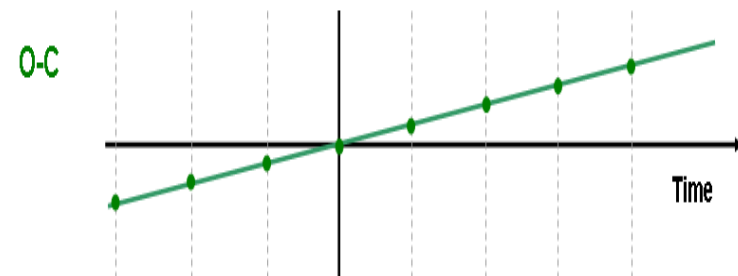
E - cycle #

○ taken from data

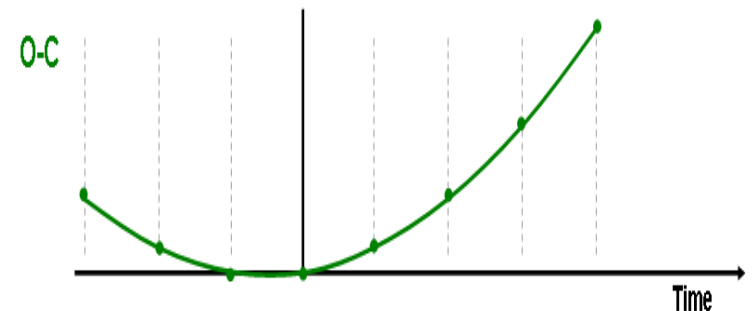
1. Period correct and constant



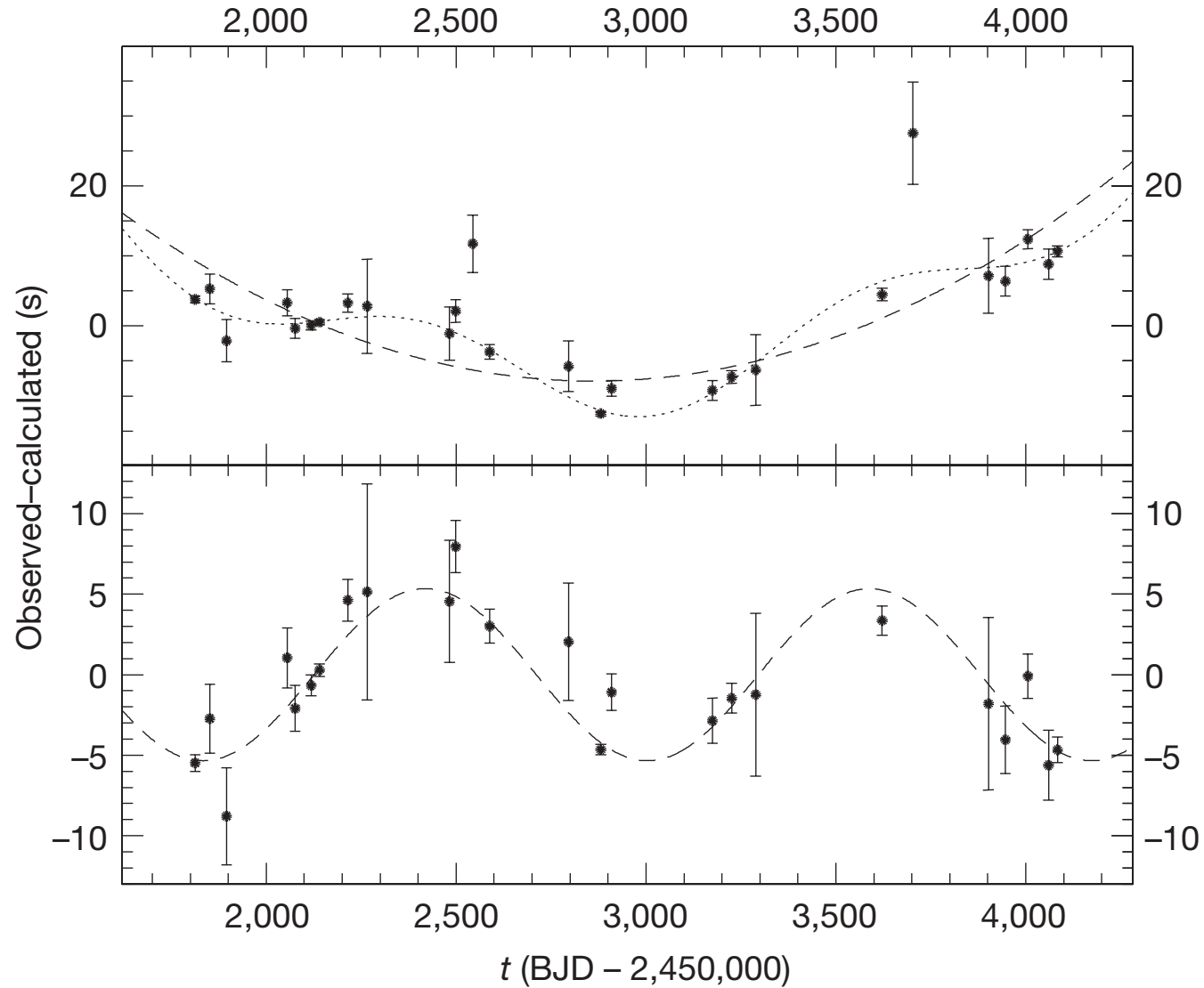
2. Period wrong but constant



3. Period increasing

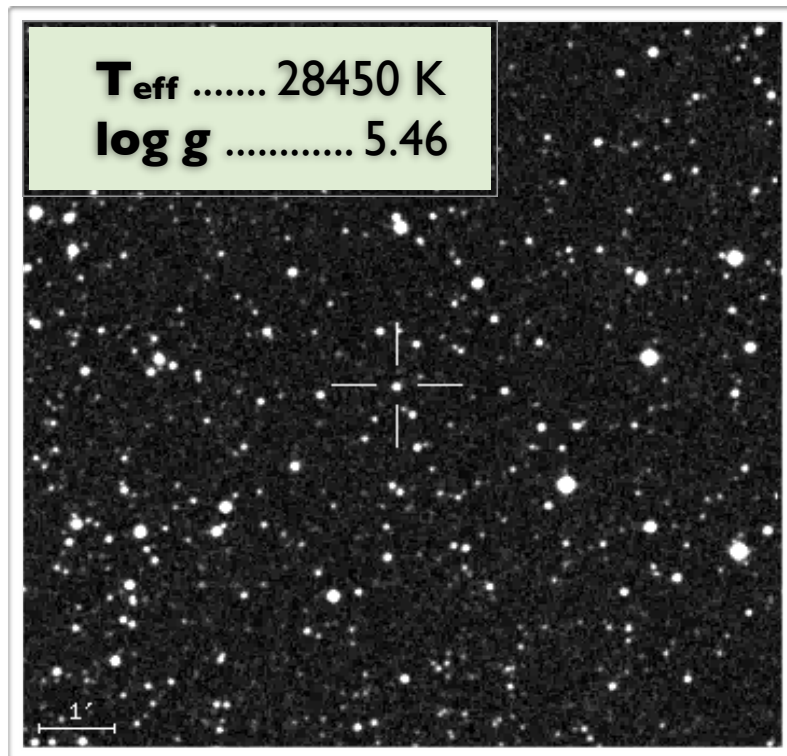


Example O-C Diagram: V391 Pegasi

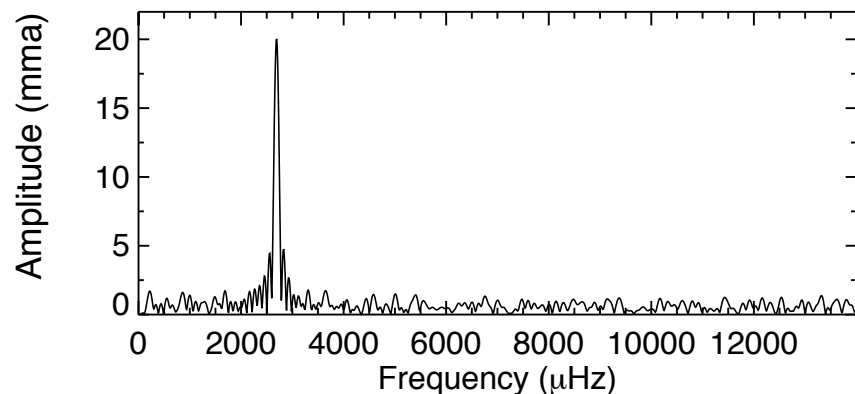
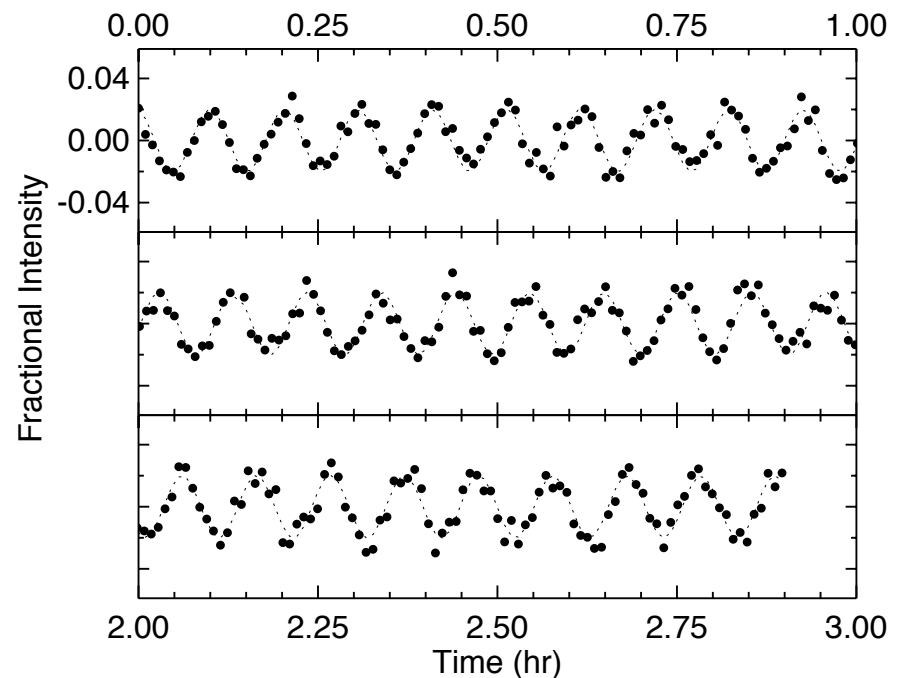


Silvotti et al. (2007)

CS 1246 – a rapidly-pulsating sdB (sdBV_r) star

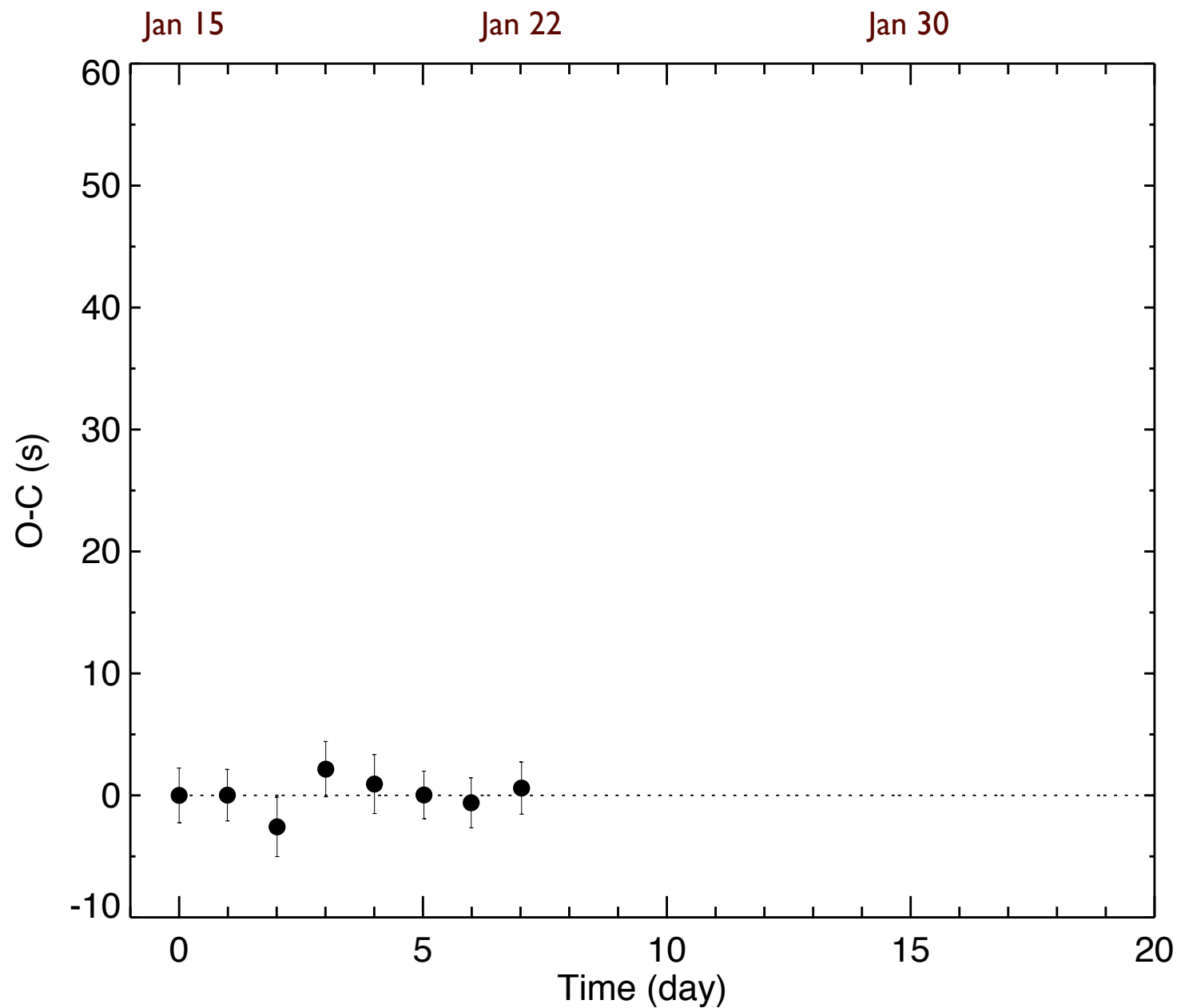


Period 371 seconds
Frequency 2690 μHz
Amplitude 2%
Spherical degree $l=0$?

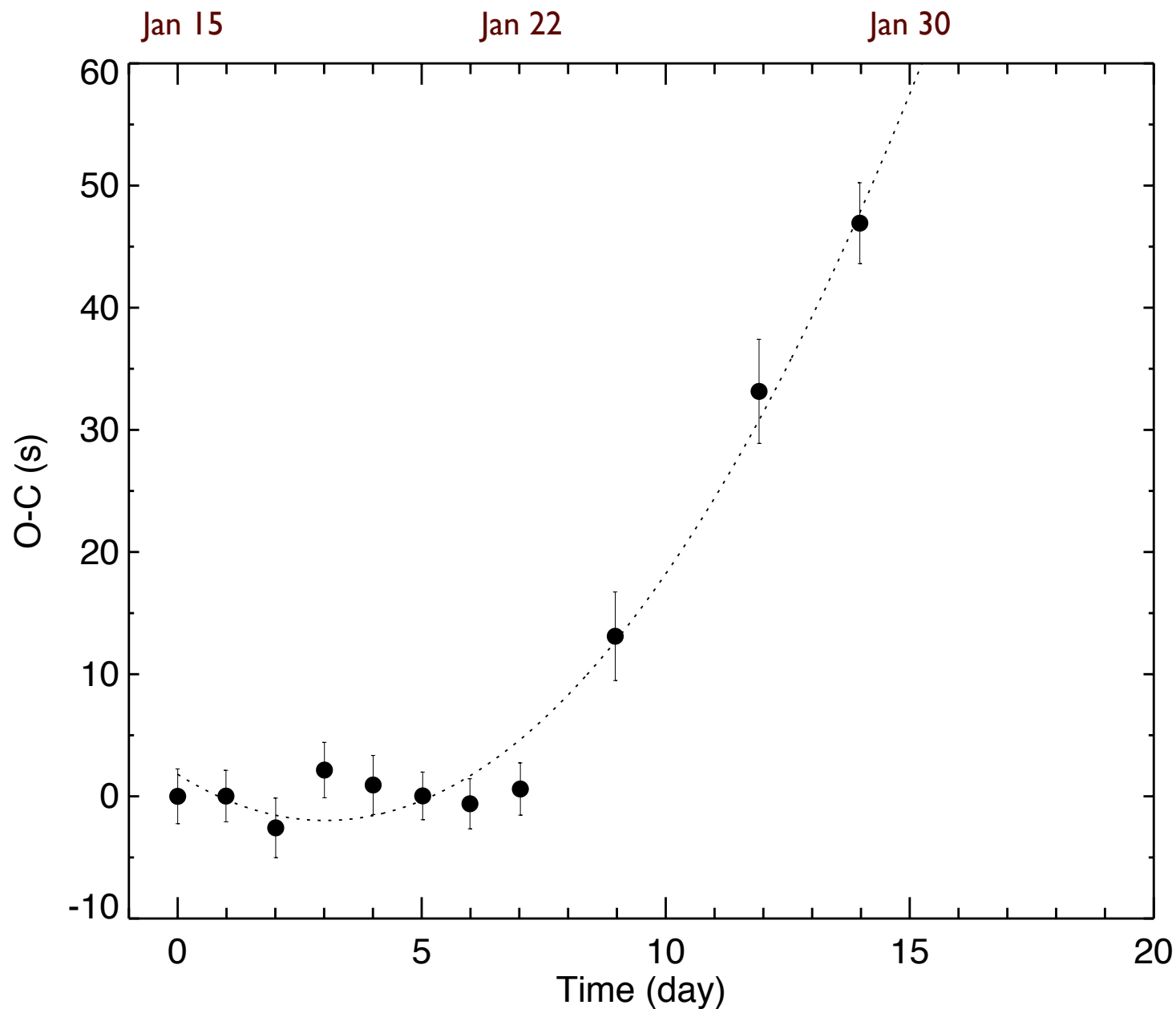


Barlow et al. (2010)

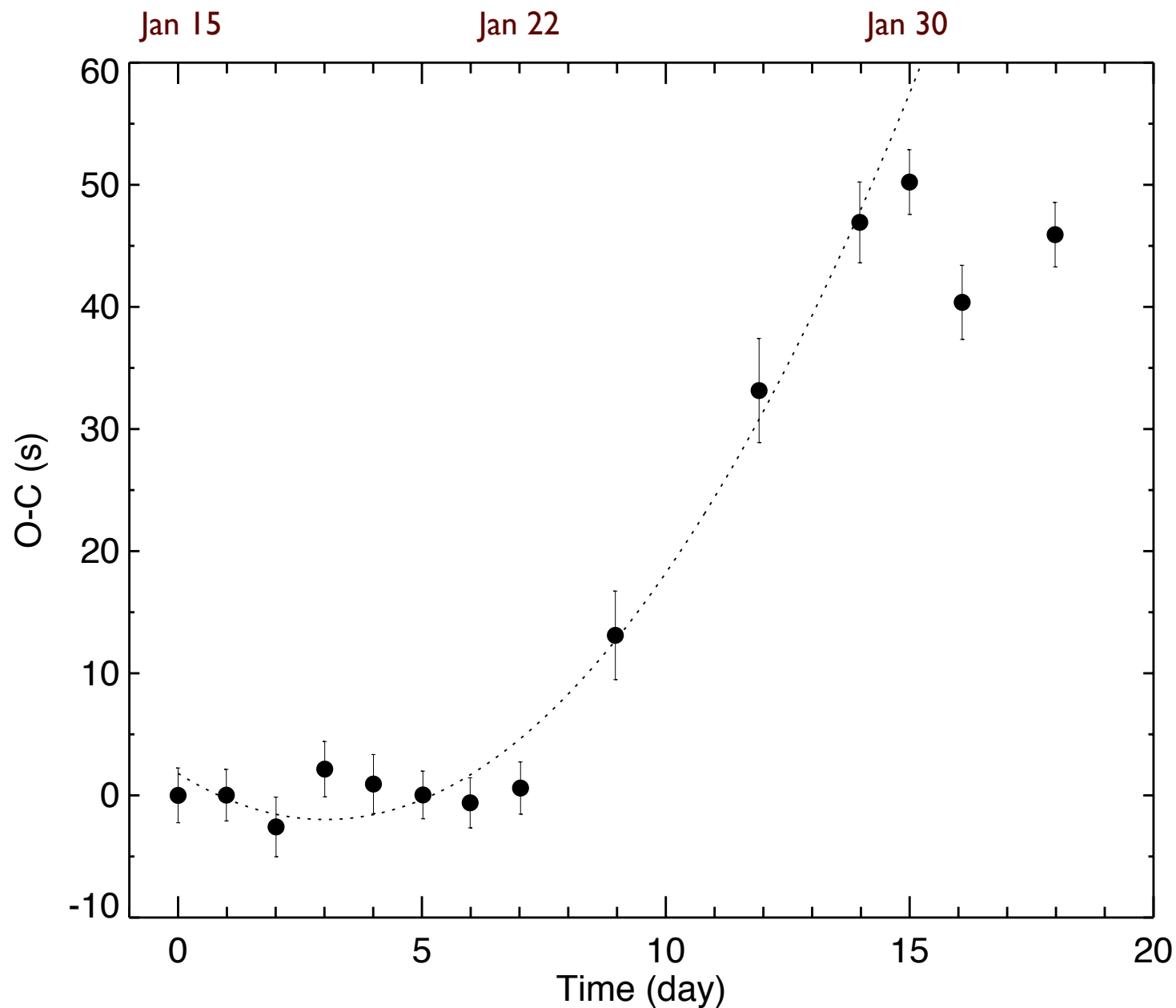
The O-C Diagram of CS 1246: Week 1



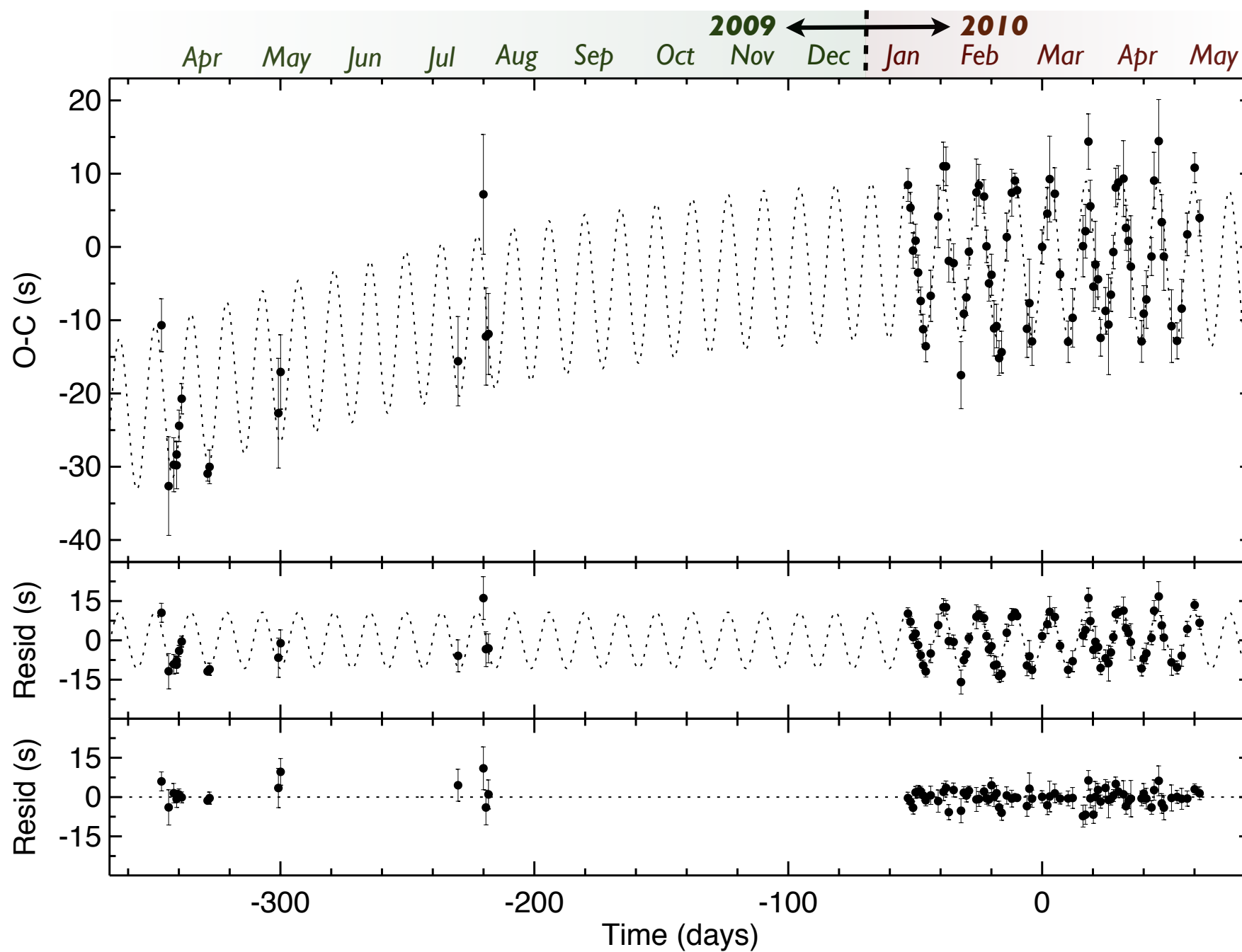
The O-C Diagram of CS 1246: Week 2



The O-C Diagram of CS 1246: Week 2+

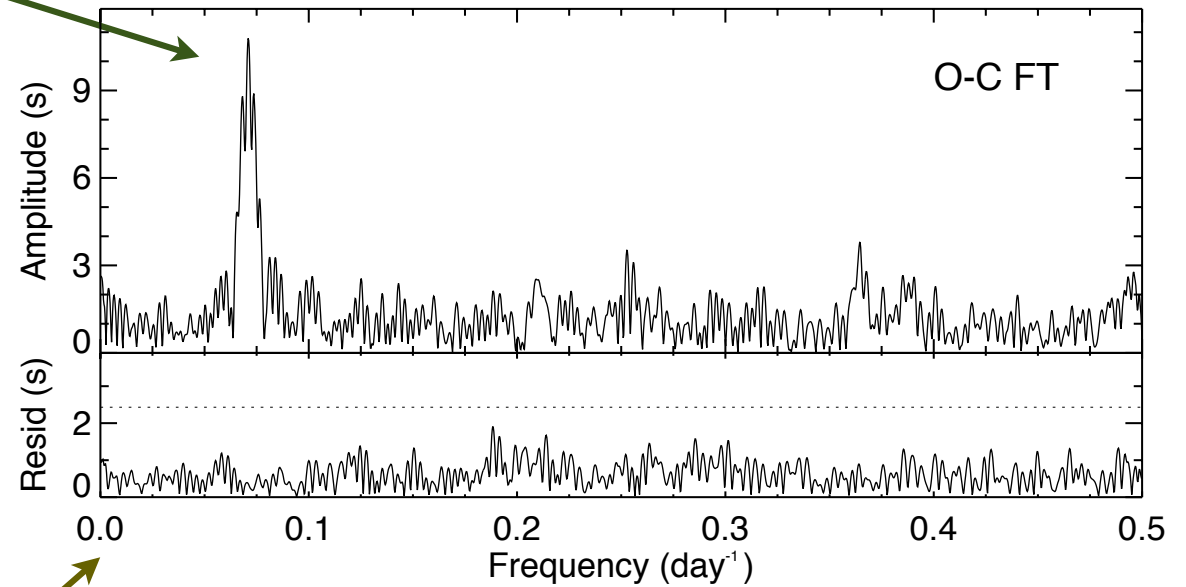


The O-C Diagram of CS 1246



Fourier Transform of the O-C Diagram

Period 14.1 days
Amplitude 10.7 s

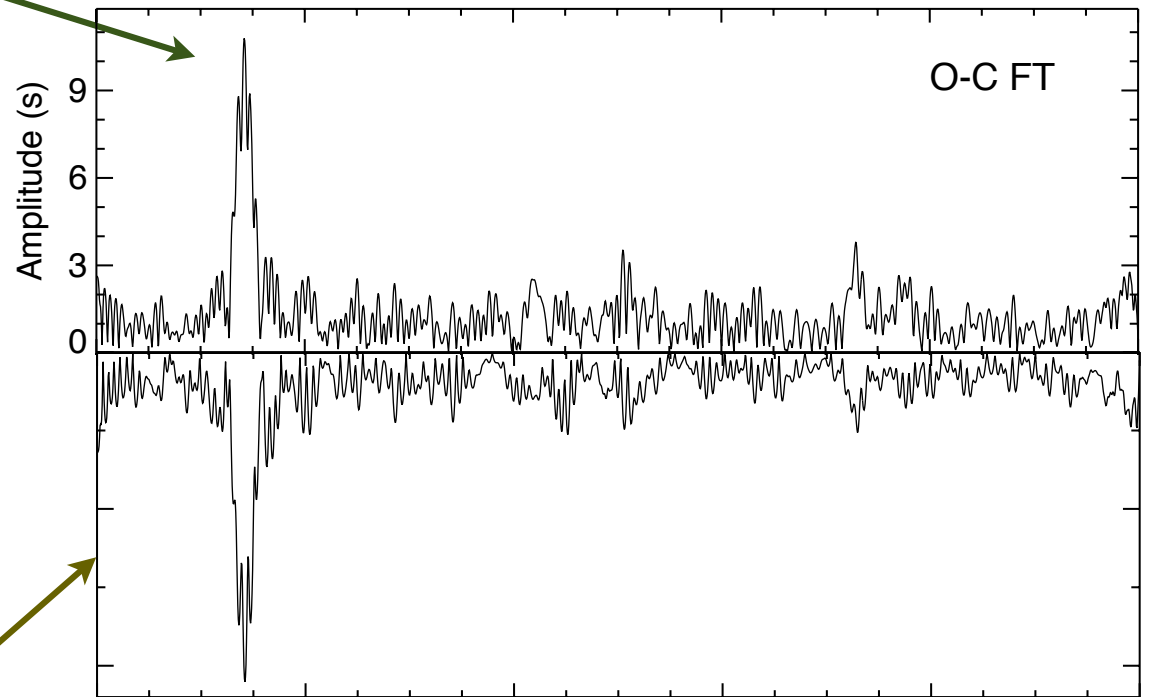


Mean Noise Level:
0.75 s

Fourier Transform of the O-C Diagram

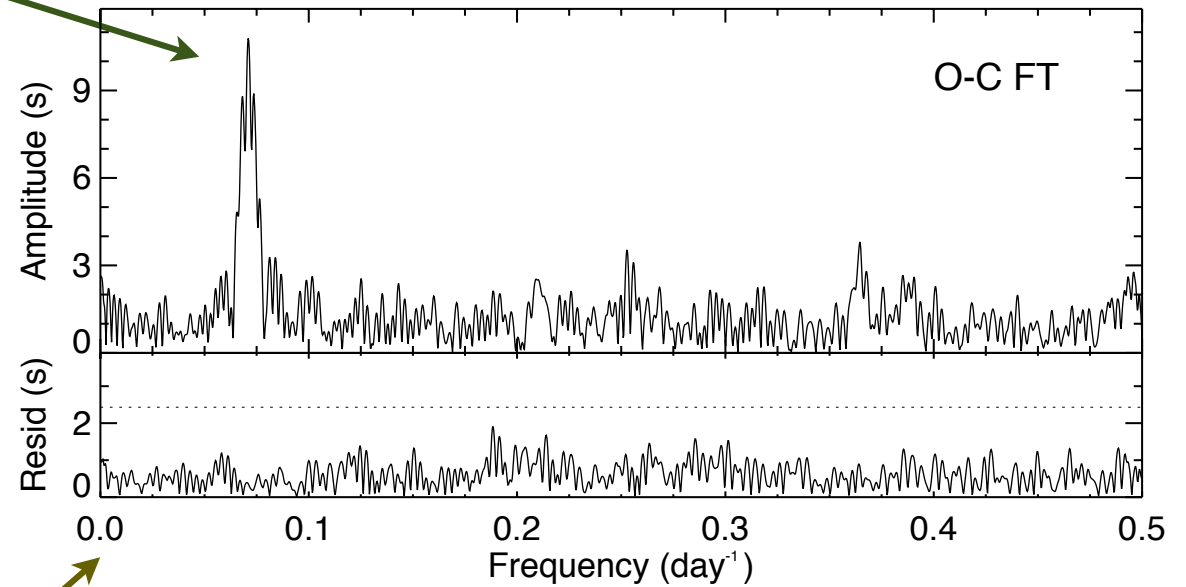
Period 14.1 days
Amplitude 10.7 s

Mean Noise Level:
0.75 s



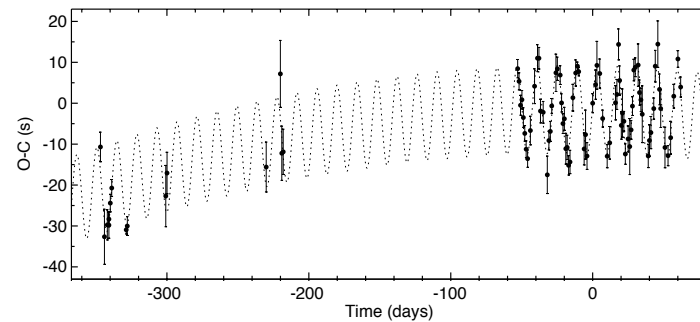
Fourier Transform of the O-C Diagram

Period 14.1 days
Amplitude 10.7 s

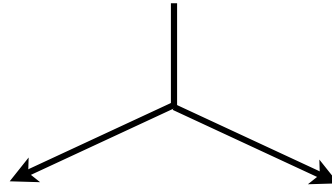


Mean Noise Level:
0.75 s

Fitting the O-C Values



$$O - C = \Delta T + \Delta PE + \frac{1}{2} P \dot{P} E^2 + A \sin \left(\frac{2\pi E}{\Pi} + \phi \right)$$



Pulsation

Period (P)..... 371.691692 s
P-dot (\dot{P})..... 1.8×10^{-11}

Phase Oscillation

Period (Π)..... 14.105 days
Amplitude (A)..... 10.7 s

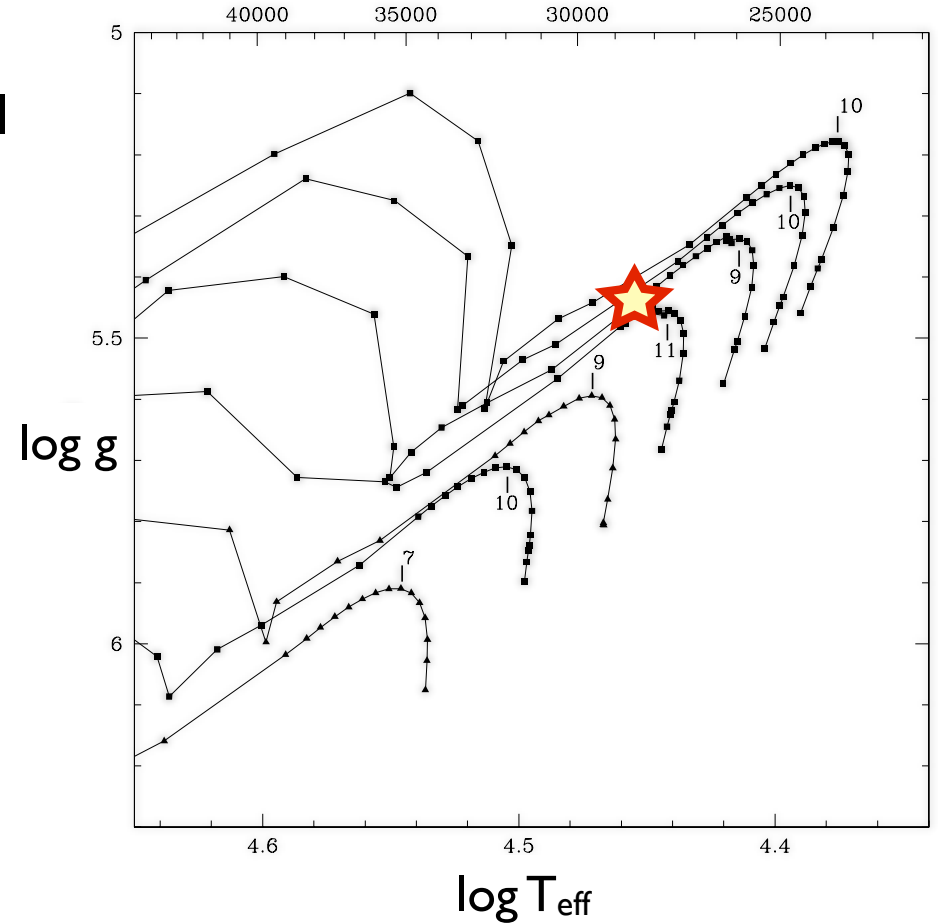
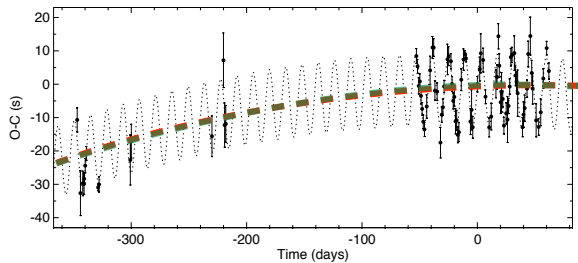
(Upper) Limit on P-dot

$$\dot{P} = -(1.8 \pm 0.3) \times 10^{-11}$$

(1 second in 1768 years)



CS 1246 is contracting
Helium in core almost depleted



Charpinet et al. (2002)

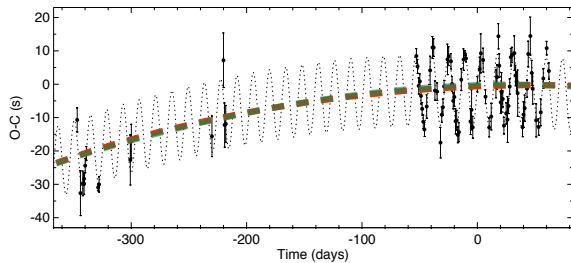
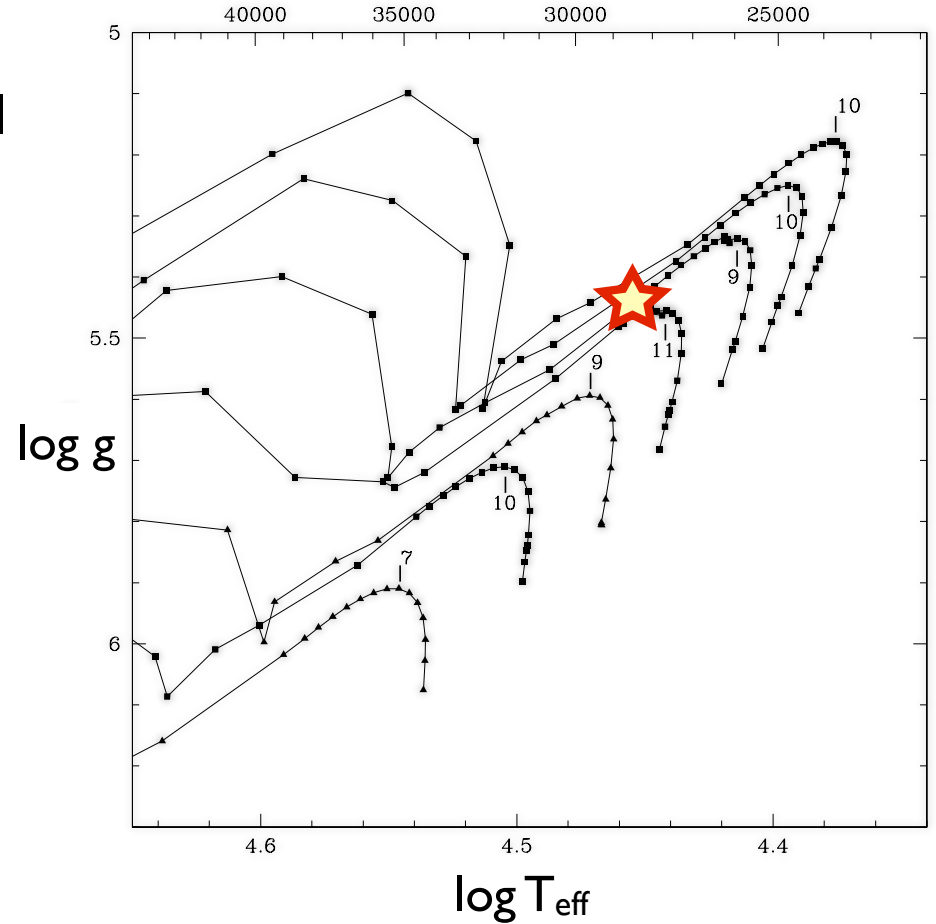
(Upper) Limit on P-dot

$$\dot{P} = -(1.8 \pm 0.3) \times 10^{-11}$$

(1 second in 1768 years)

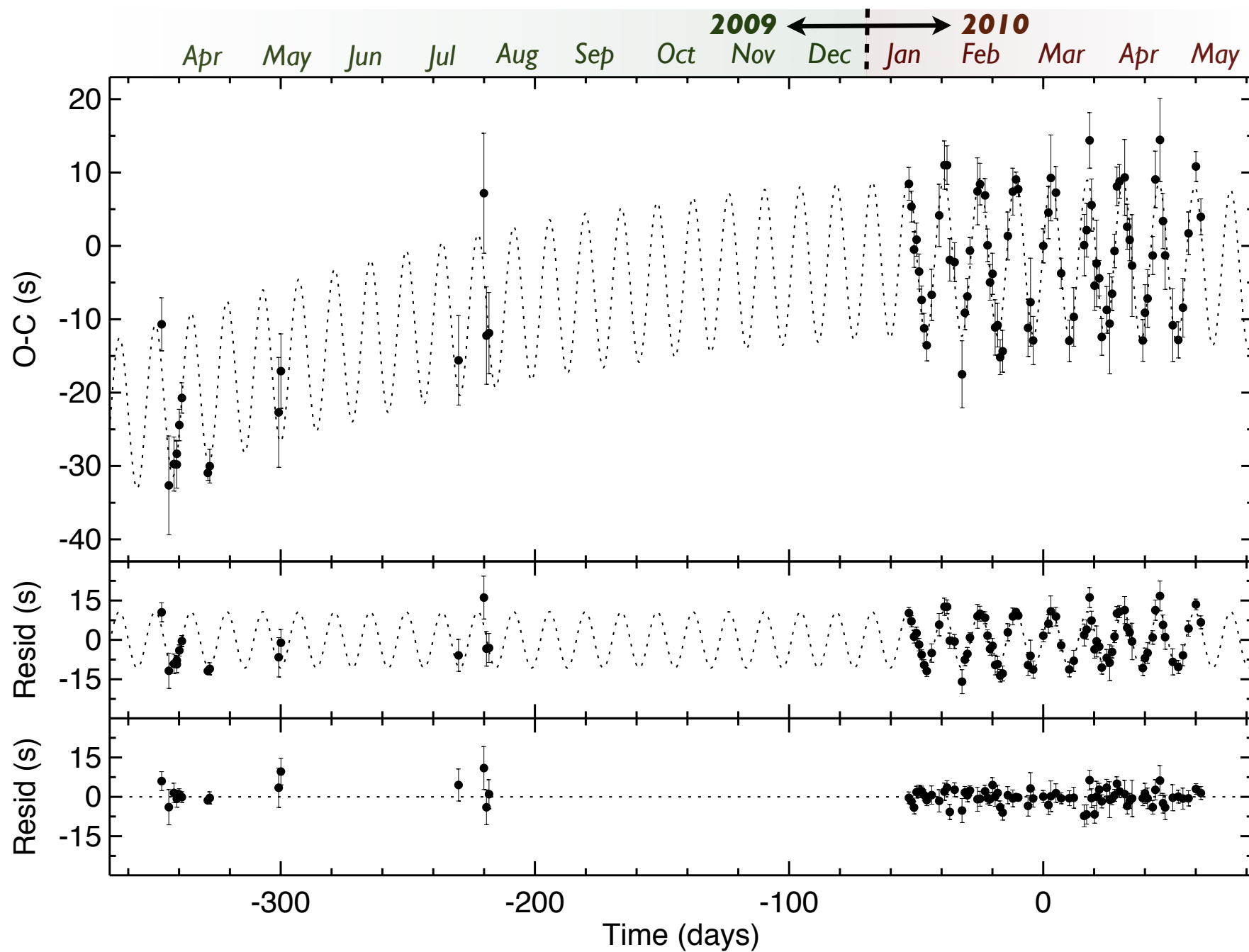


CS 1246 is contracting
Helium in core almost depleted



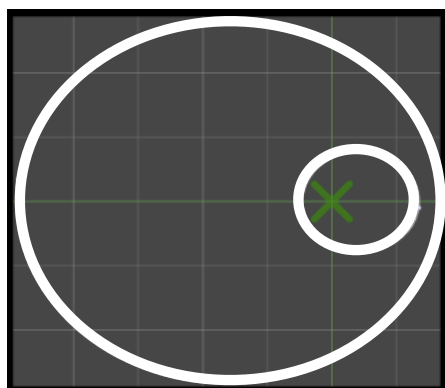
Charpinet et al. (2002)

The O-C Diagram of CS 1246

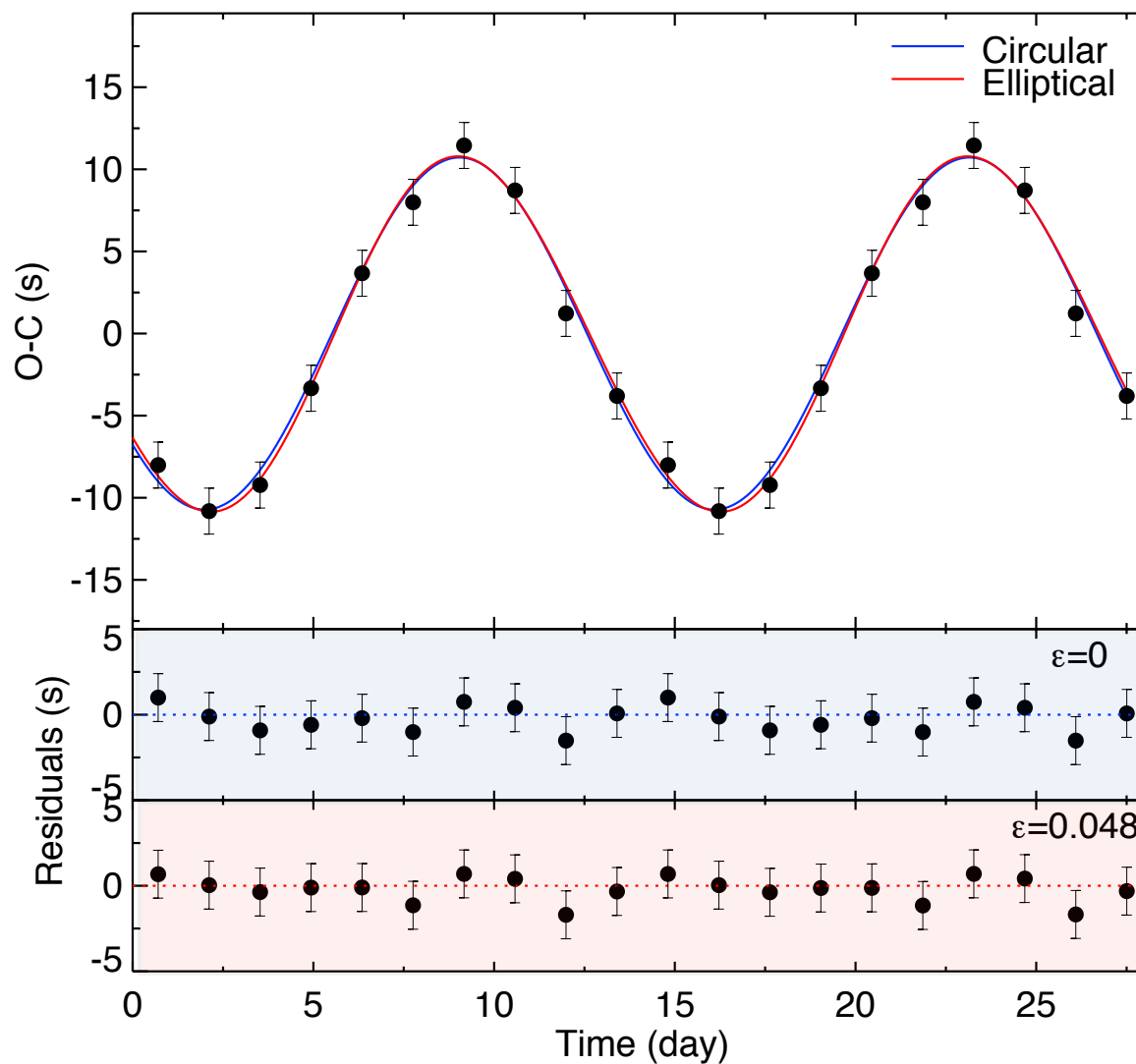
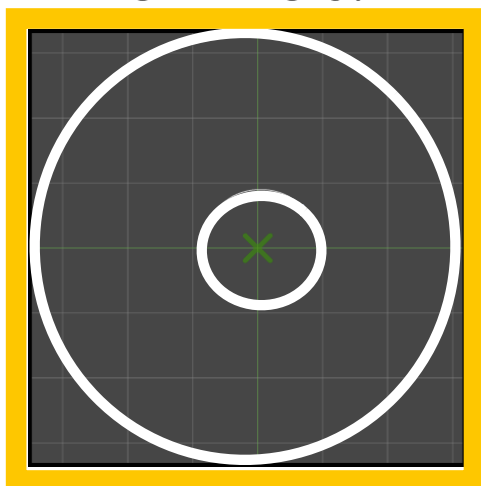


The phase-folded O-C diagram

highly-elliptical?



or not?



Note: data plotted twice for visualization purposes

System Parameters

Param	Value	Error	Units	Comment
Π	14.105	± 0.011	days	orbital period
K	16.6	± 0.6	km s^{-1}	RV semi-amplitude ^a
f	0.0066	± 0.0007	M_{\odot}	mass function
ϵ	0.045	± 0.019		orbital eccentricity
ϕ	185	± 20	degrees	orbital periastron angle
a	0.0910	± 0.0003	AU	separation distance ^b
	0.0963	± 0.0003	AU	separation distance ^c
$m \sin i$	0.115	± 0.005	M_{\odot}	minimum companion mass ^{bd}
	0.129	± 0.005	M_{\odot}	minimum companion mass ^{cd}

^a circular orbit approximation

^b assuming an sdB mass of $0.39 M_{\odot}$

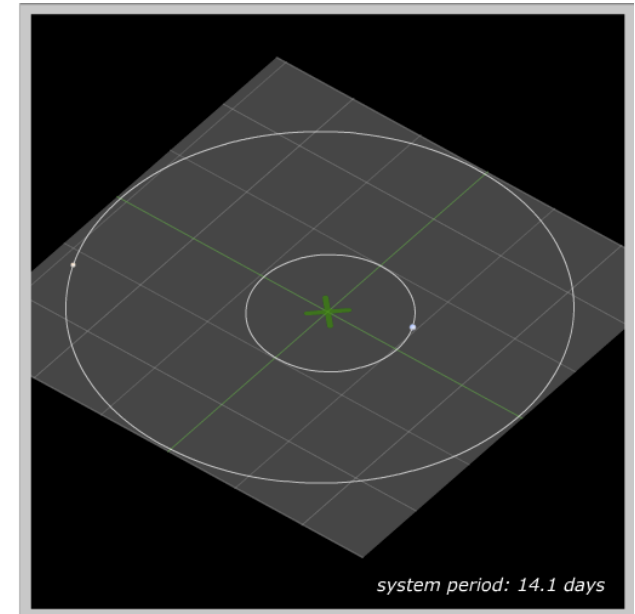
^c assuming the canonical sdB mass of $0.47 M_{\odot}$

^d assumes no error bar on the sdB mass

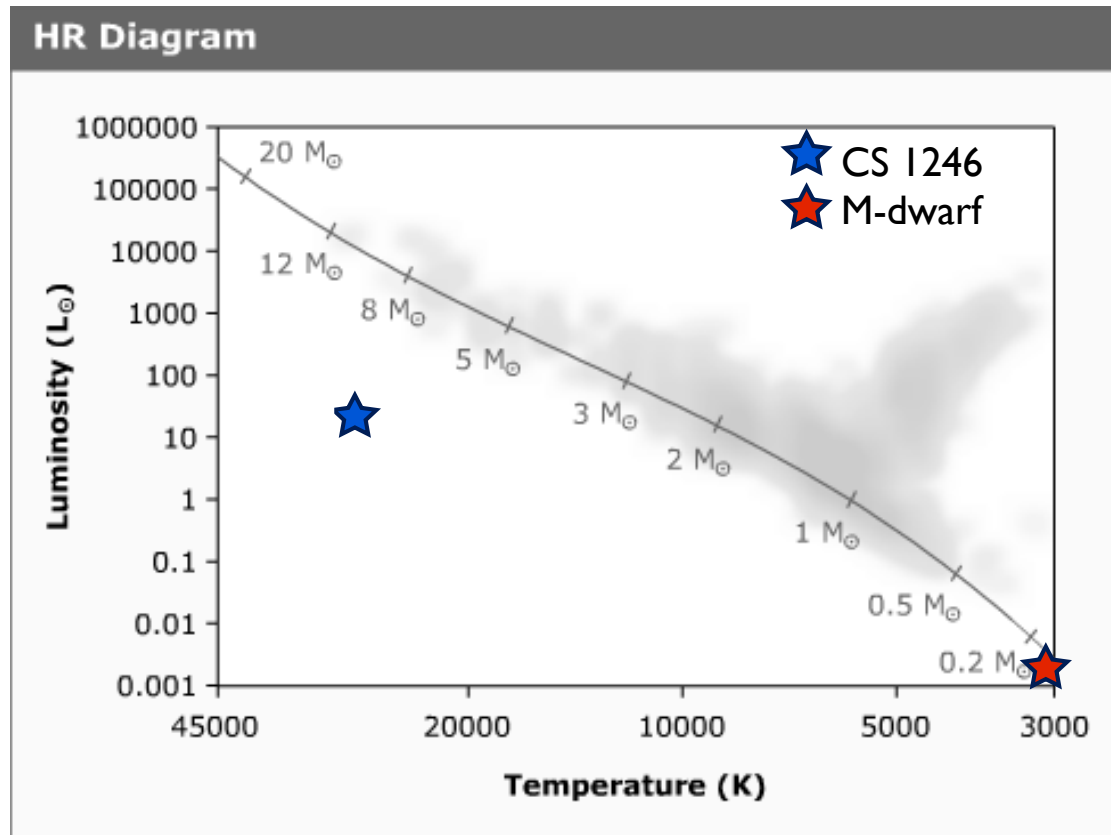
What is the companion?

- $m \sin i = 0.12 M_{\text{sun}}$
- 95% probability $m < 0.45 M_{\text{sun}}$
- no optical signature of companion

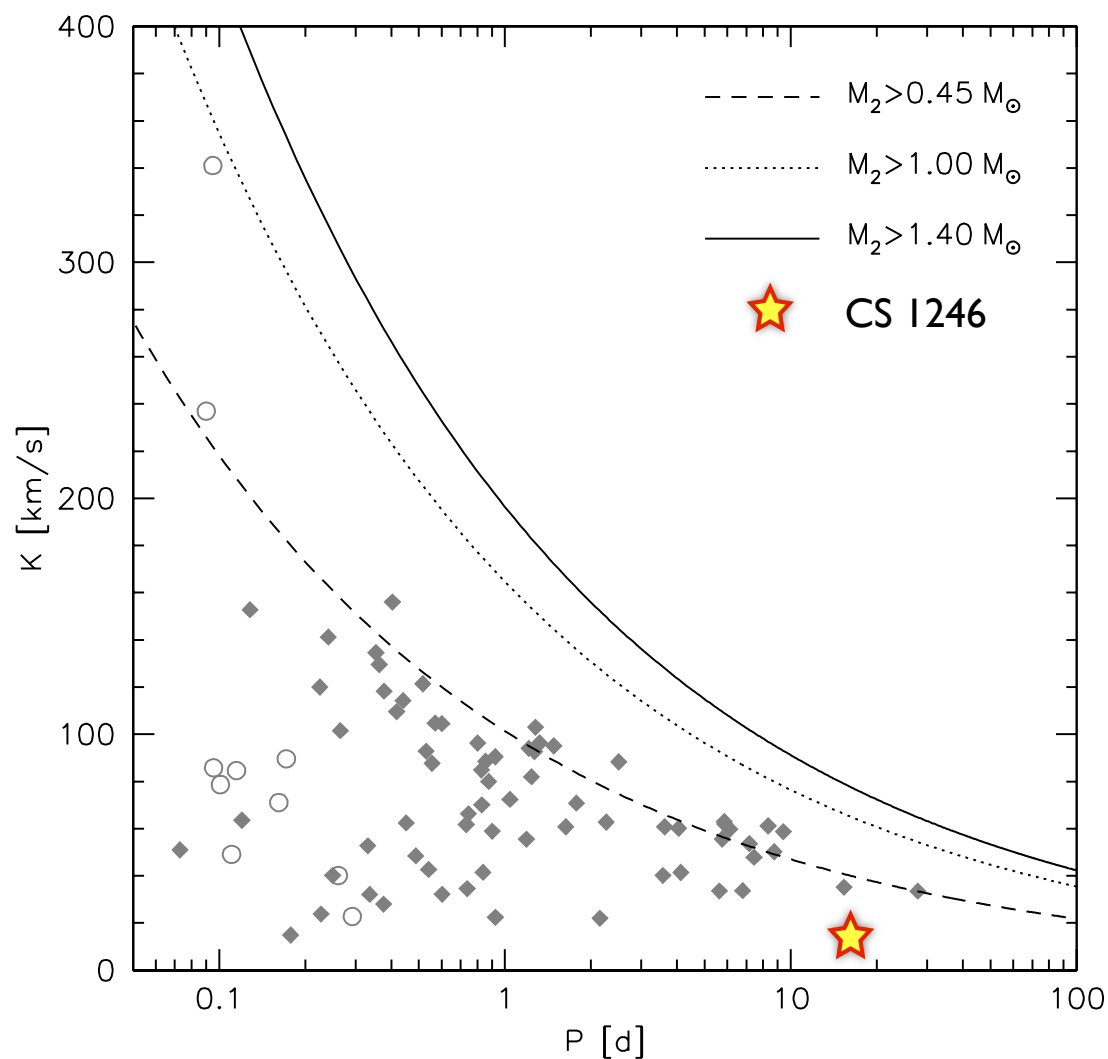
Scale System Model



**M-dwarf
or
white dwarf?**

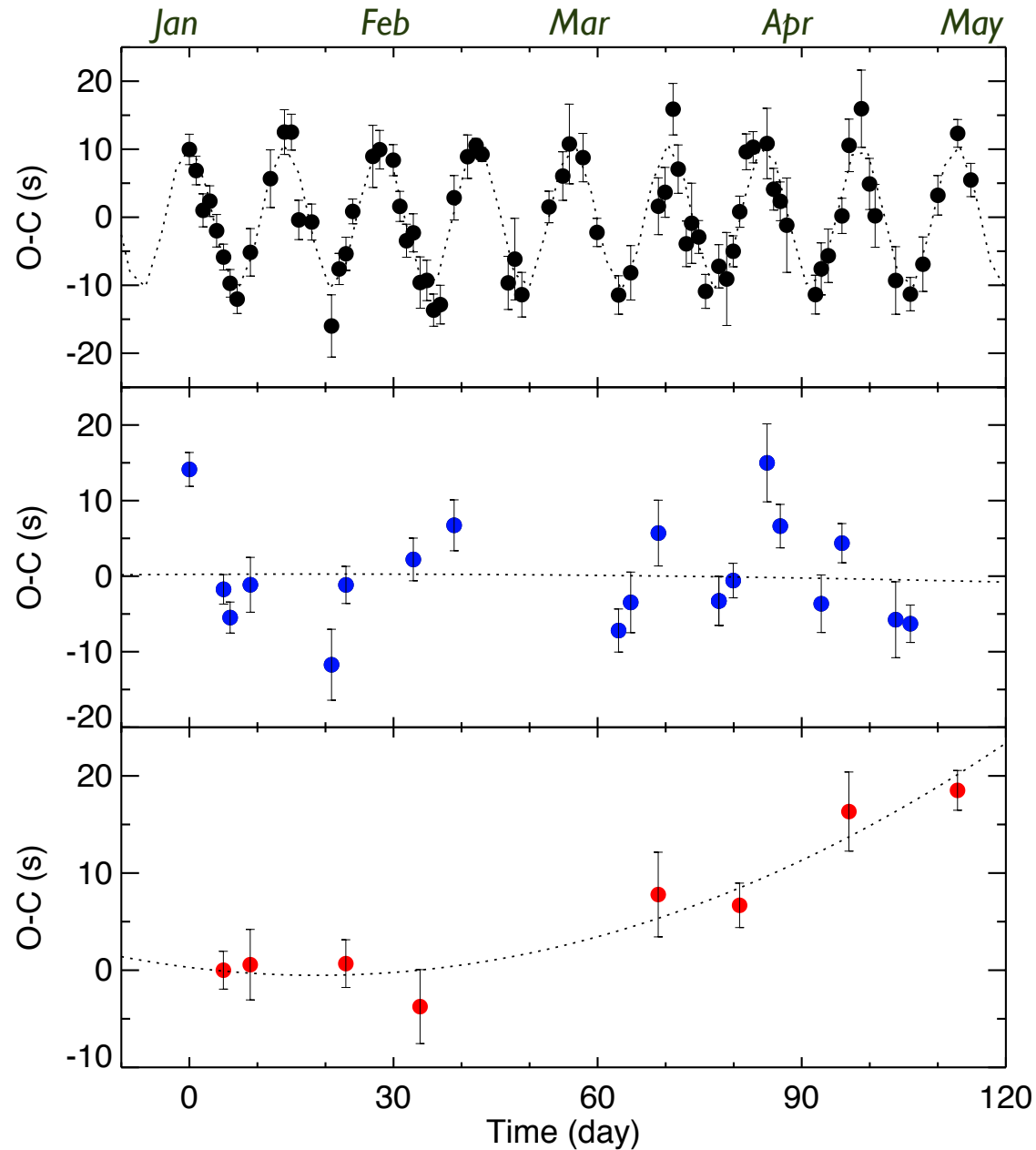


Known RV semi-amplitudes of sdB binary systems



Geier et al. (submitted)

Potential Sampling Effects



All light curves
from 2010

19 randomly-selected
light curves

8 light curves,
chosen specifically to
mimic P-dot

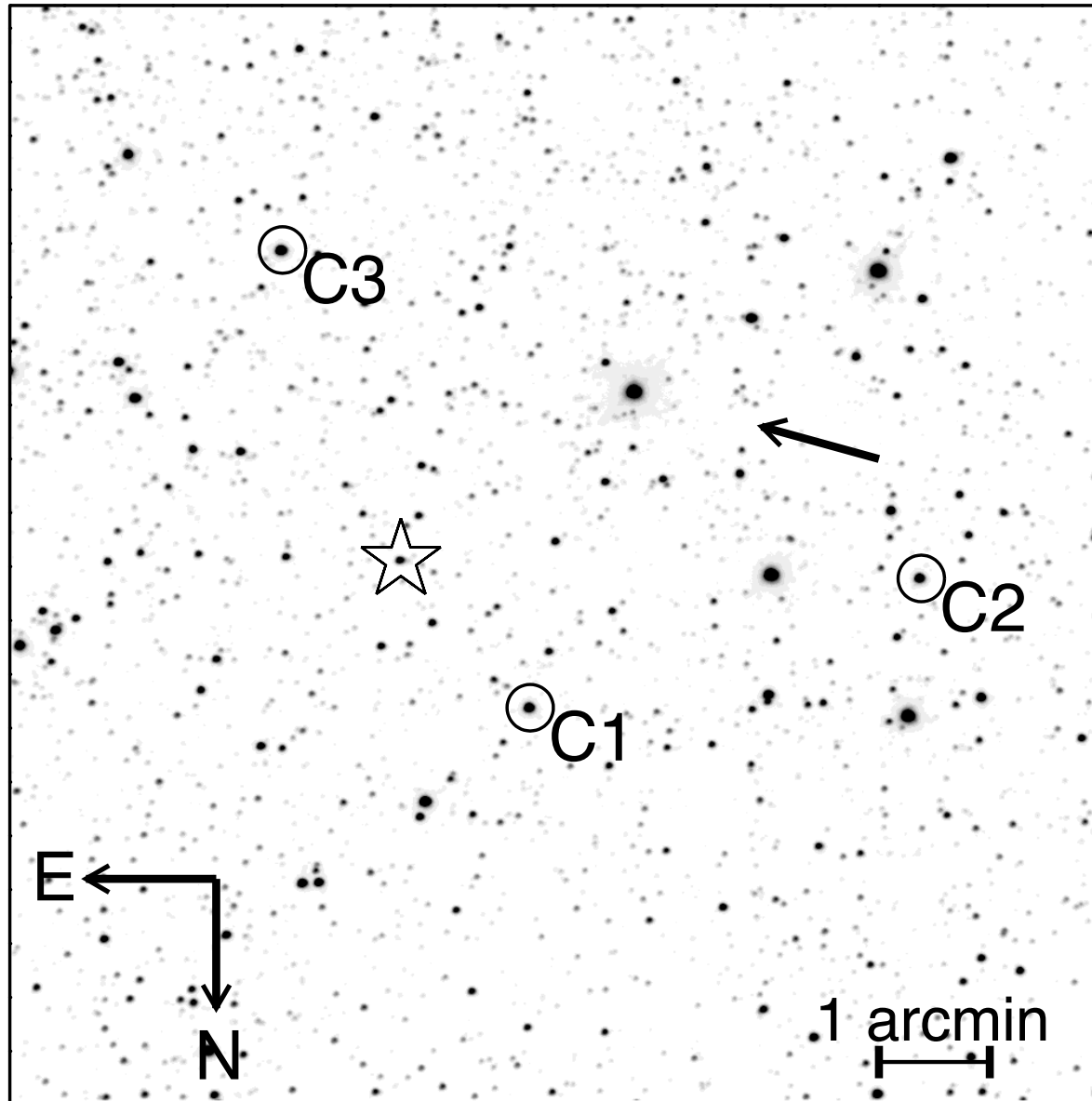
Summary & Future Work

- used O-C diagram to measure:
 - orbital reflex motion
 - P-dot
 - P-dot implies CS 1246 near core He-exhaustion
 - phase oscillation implies unseen companion
 - M-dwarf or white dwarf
-
- continue collecting O-C data
 - obtain RV measurements, compare to O-C results

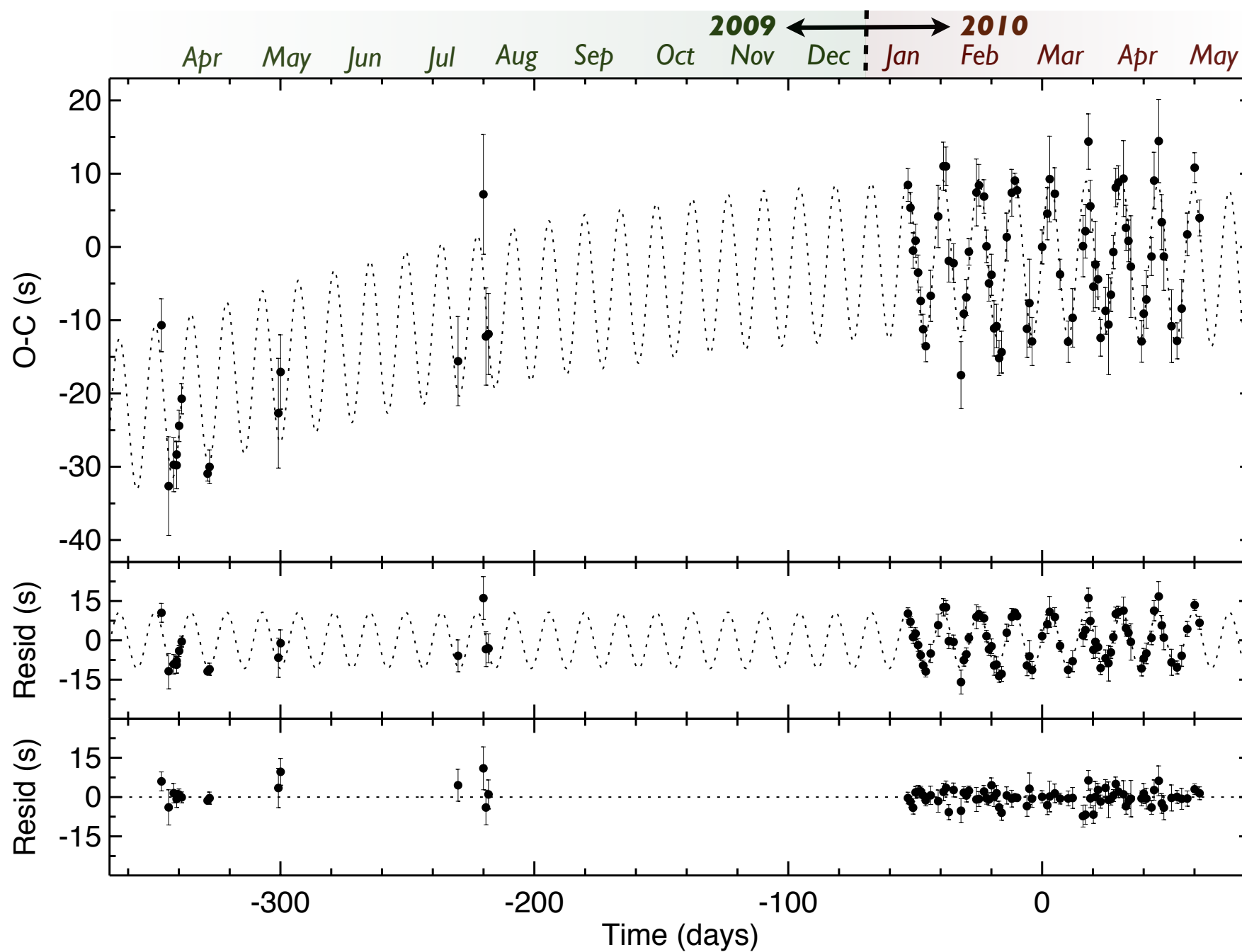
Expansion of SKYNET



CS 1246 Field



The O-C Diagram of CS 1246



Fortnightly Fluctuations in the O-C Diagram of CS 1246

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