

# A circumbinary planet in 2M1938+4603


*Andrzej Baran  
Pedagogical University of Cracow*



Mind if  
I join?



# 2M1938+4603

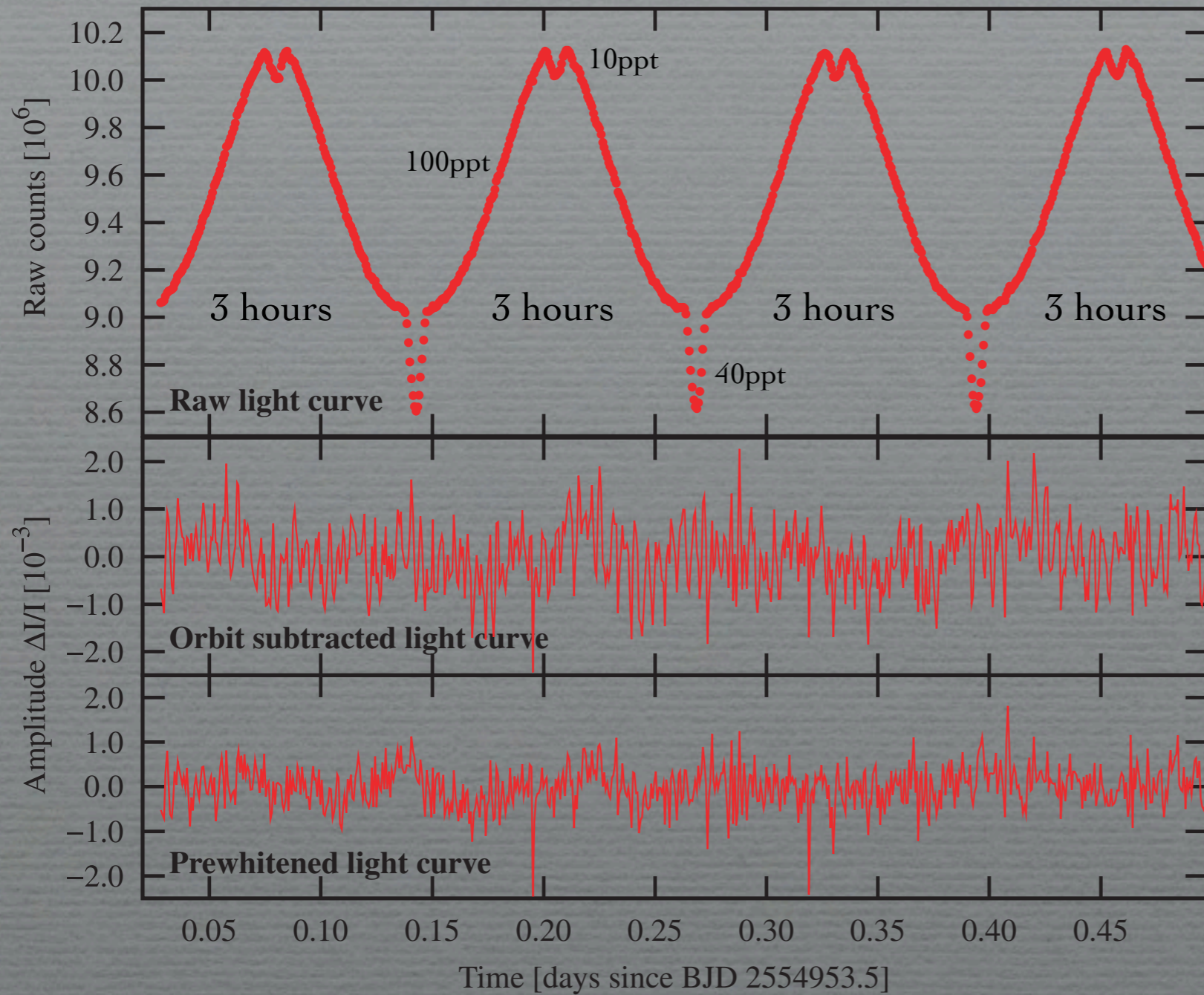


M dwarf  
 $T \approx 3500\text{K}$

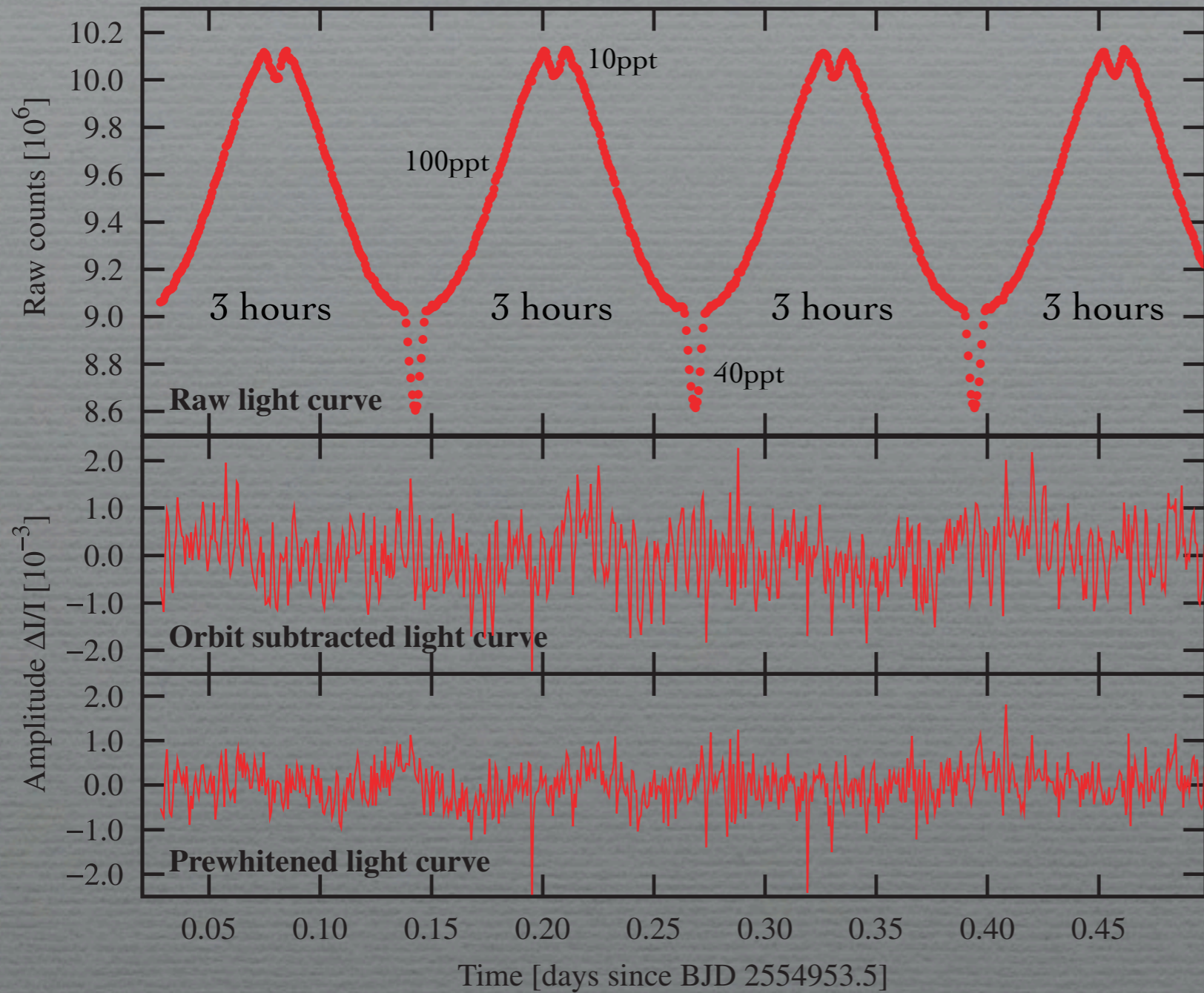


sdB  
 $T \approx 30000\text{K}$

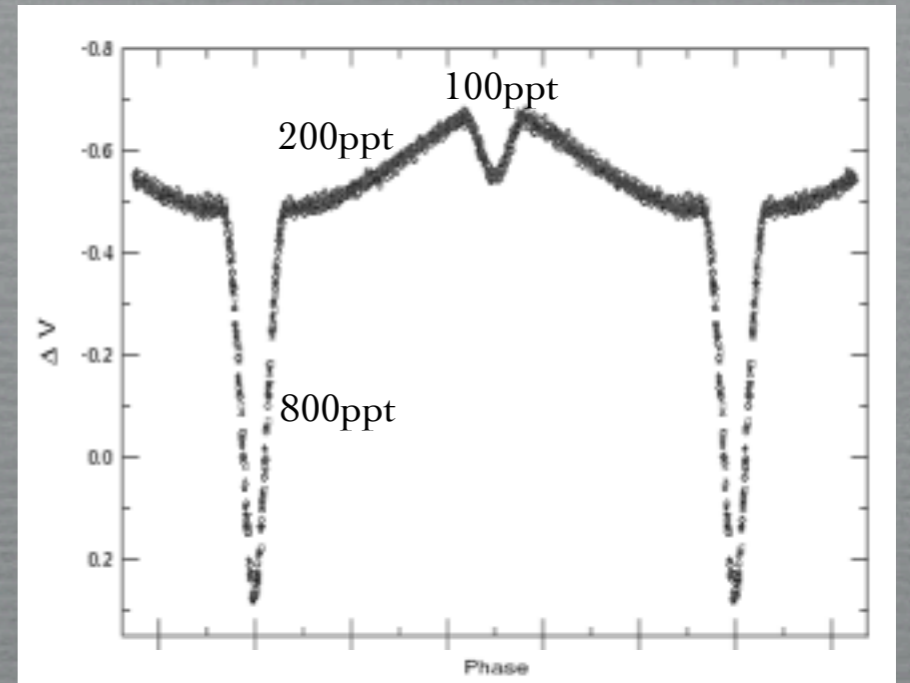
# Q0 light curve



# Q0 light curve

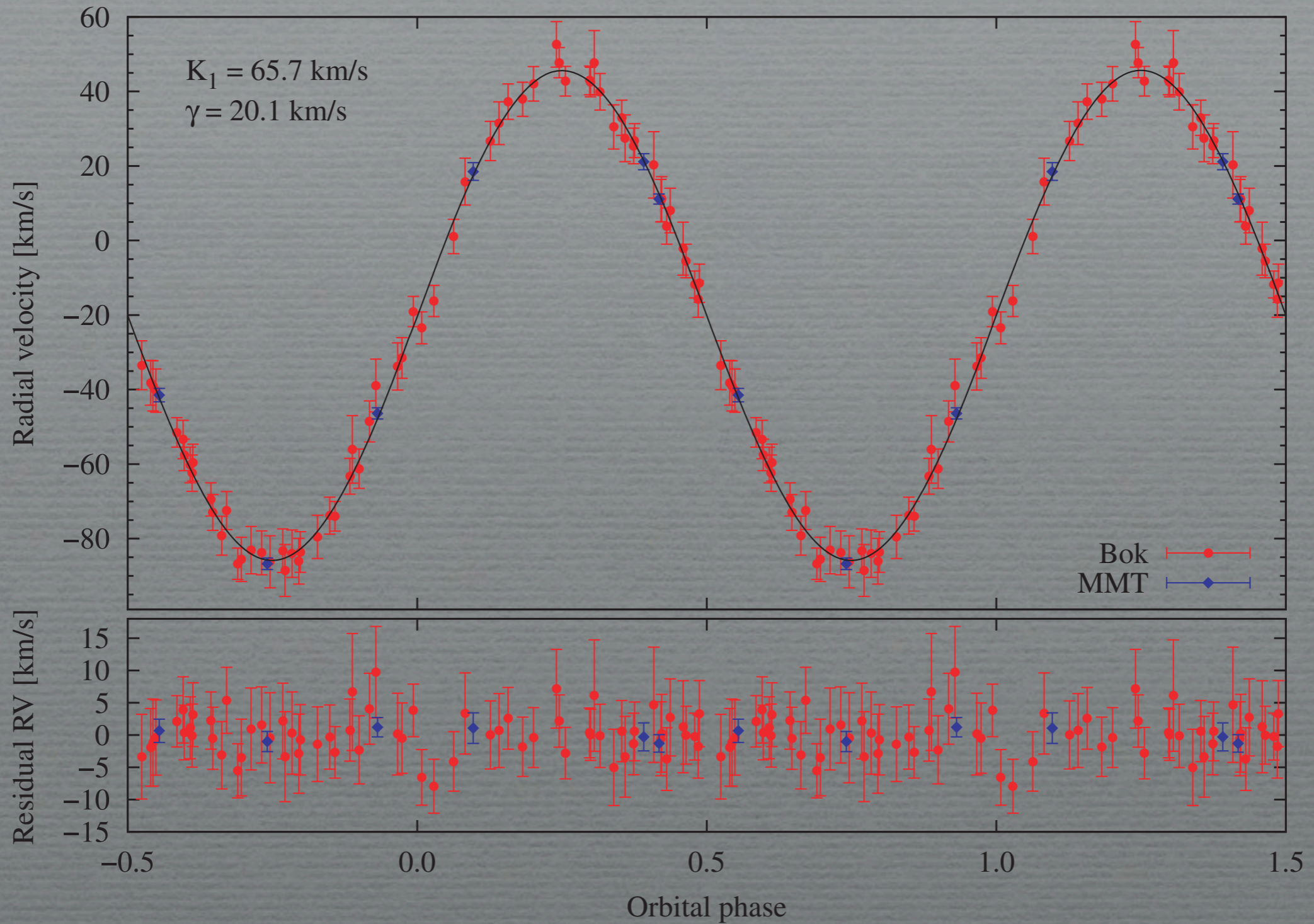


# HW Vir

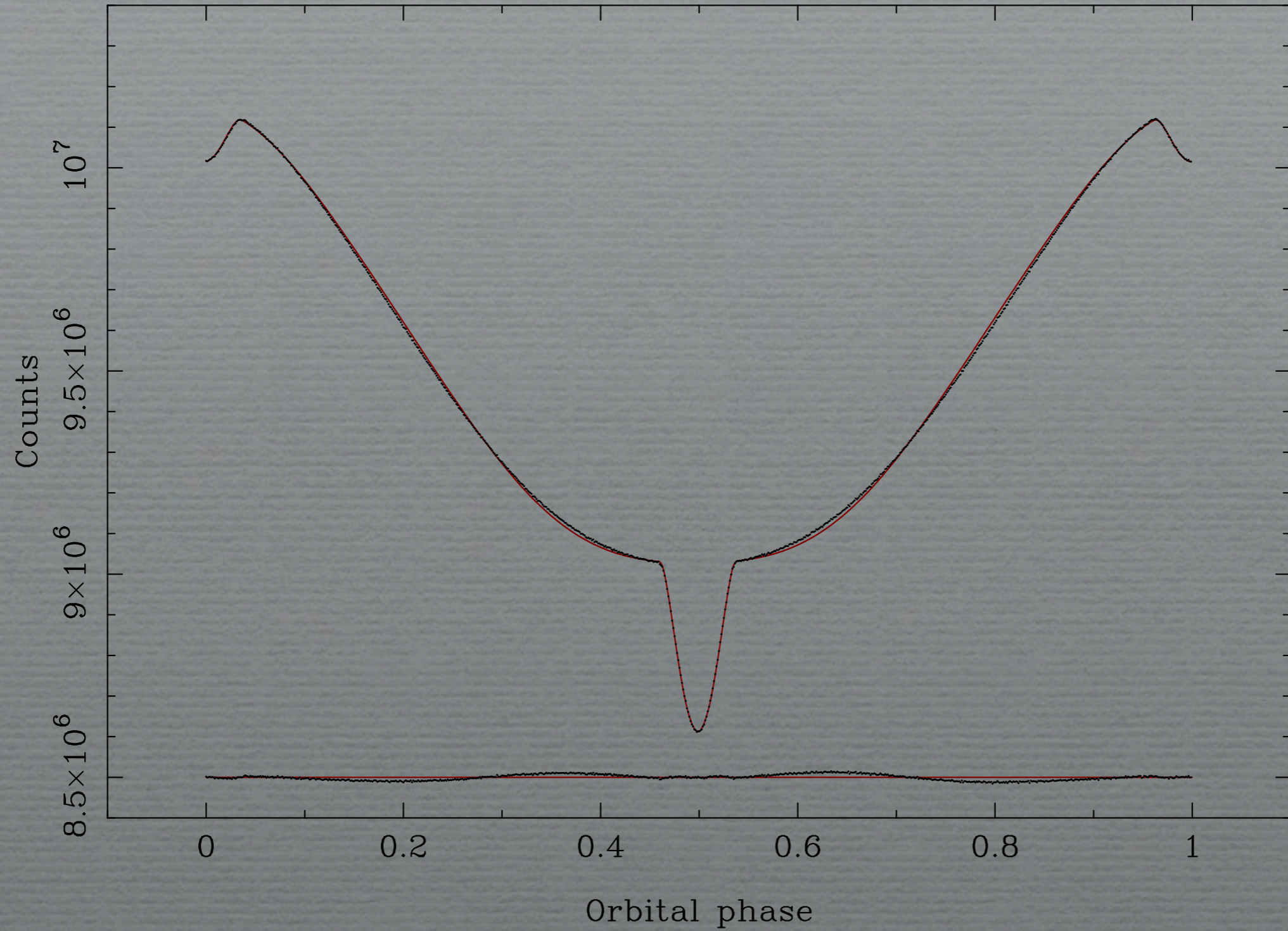


Lee et al., 2009, AJ, 137, 3181

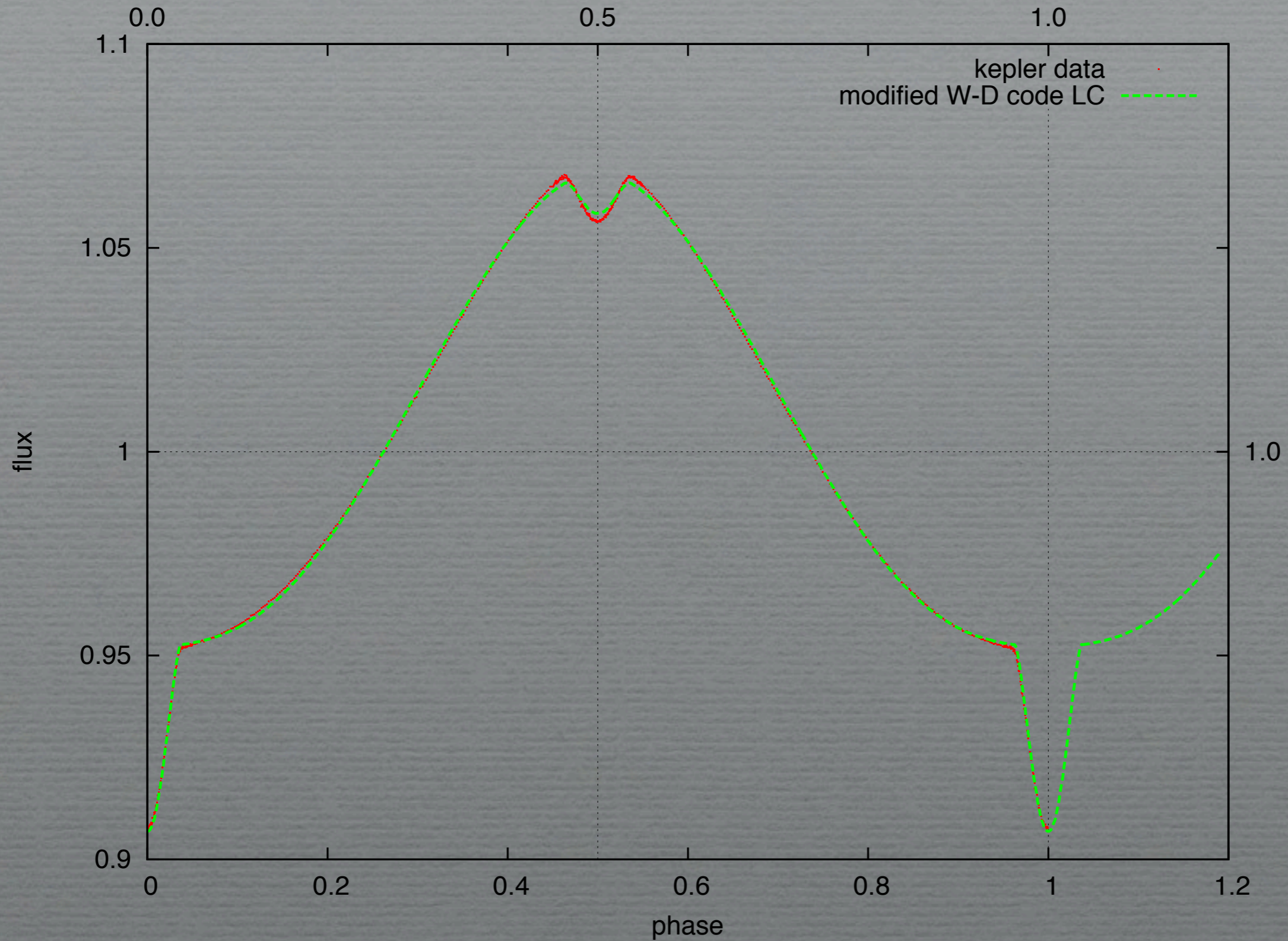
# Radial velocity curve



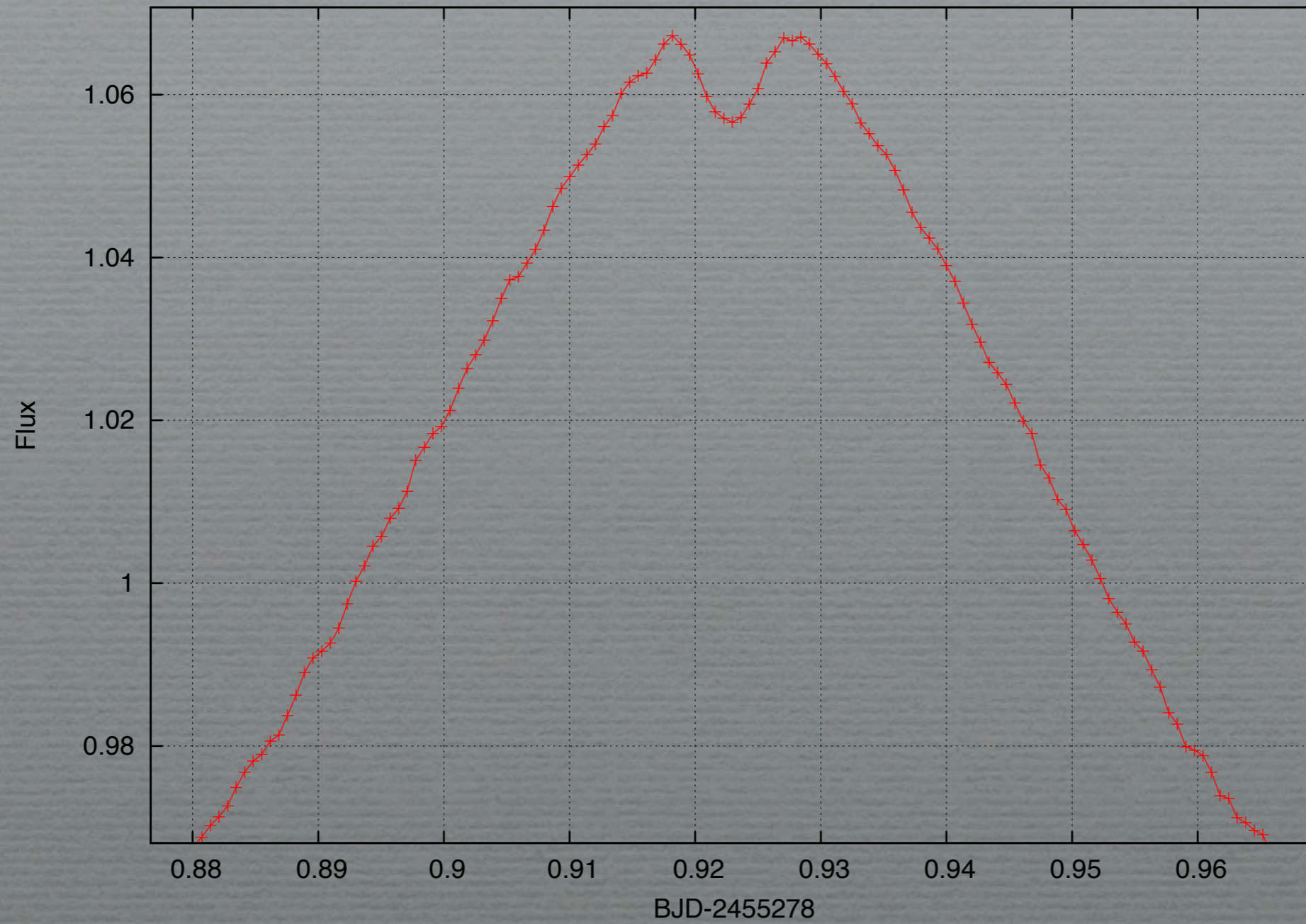
# Modeling the binary trend (Q0 data)



# Binary fit - another try (Q5-17 data)

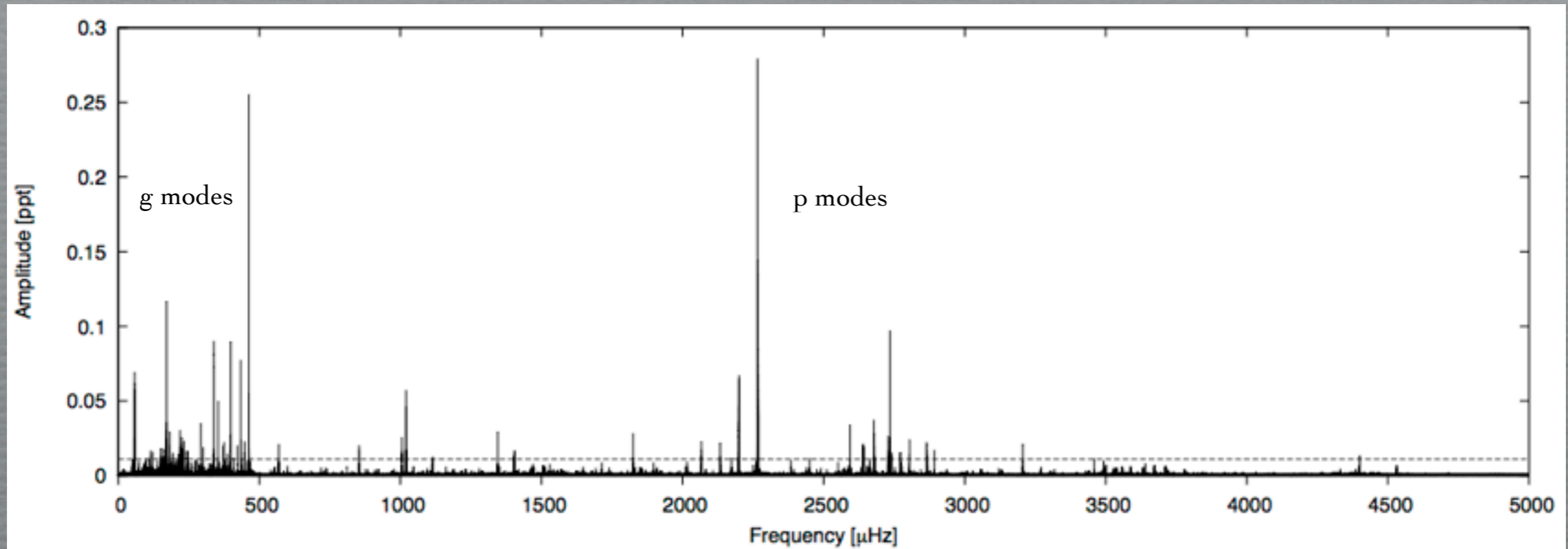


# Stellar pulsations





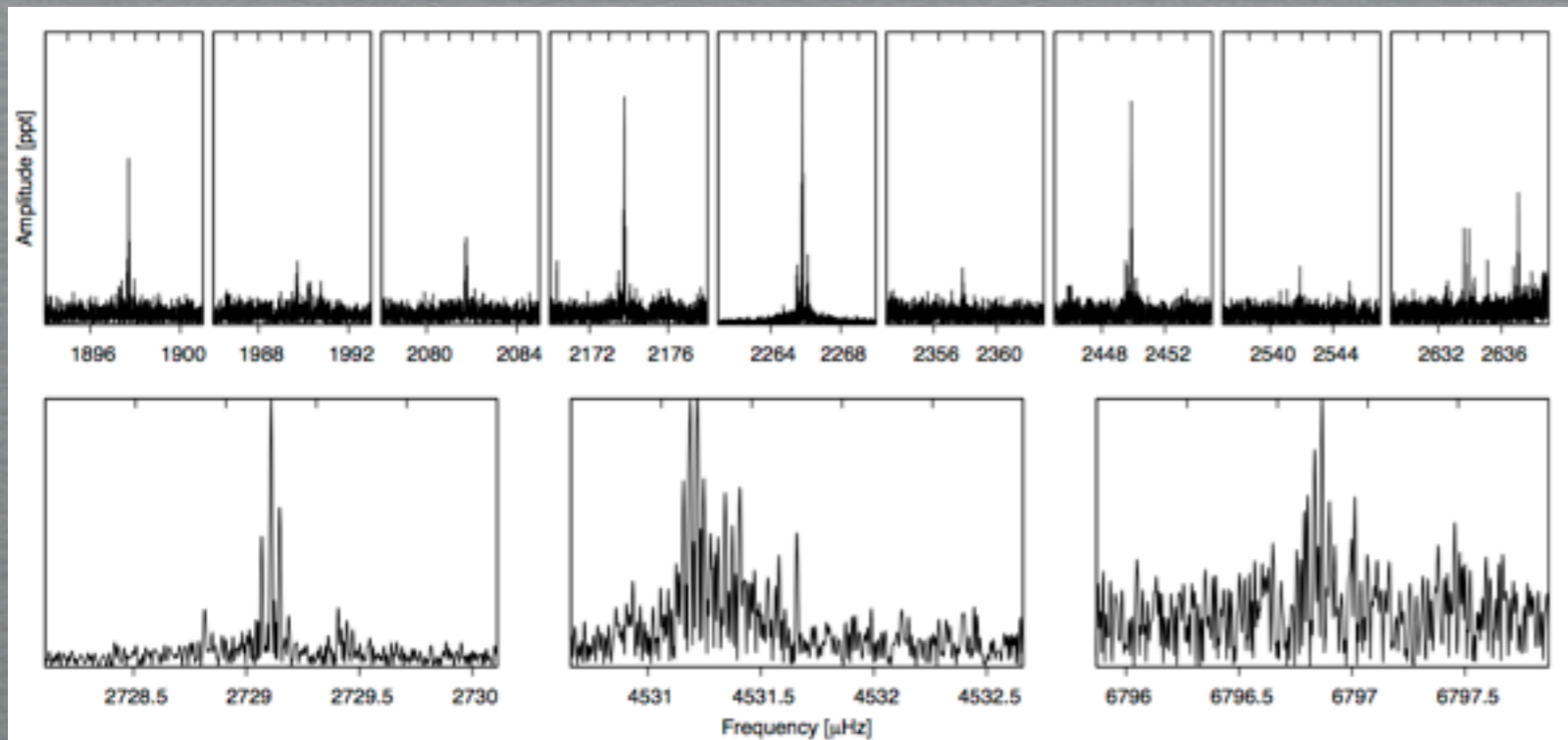
# Amplitude spectrum (Q5-17 data)



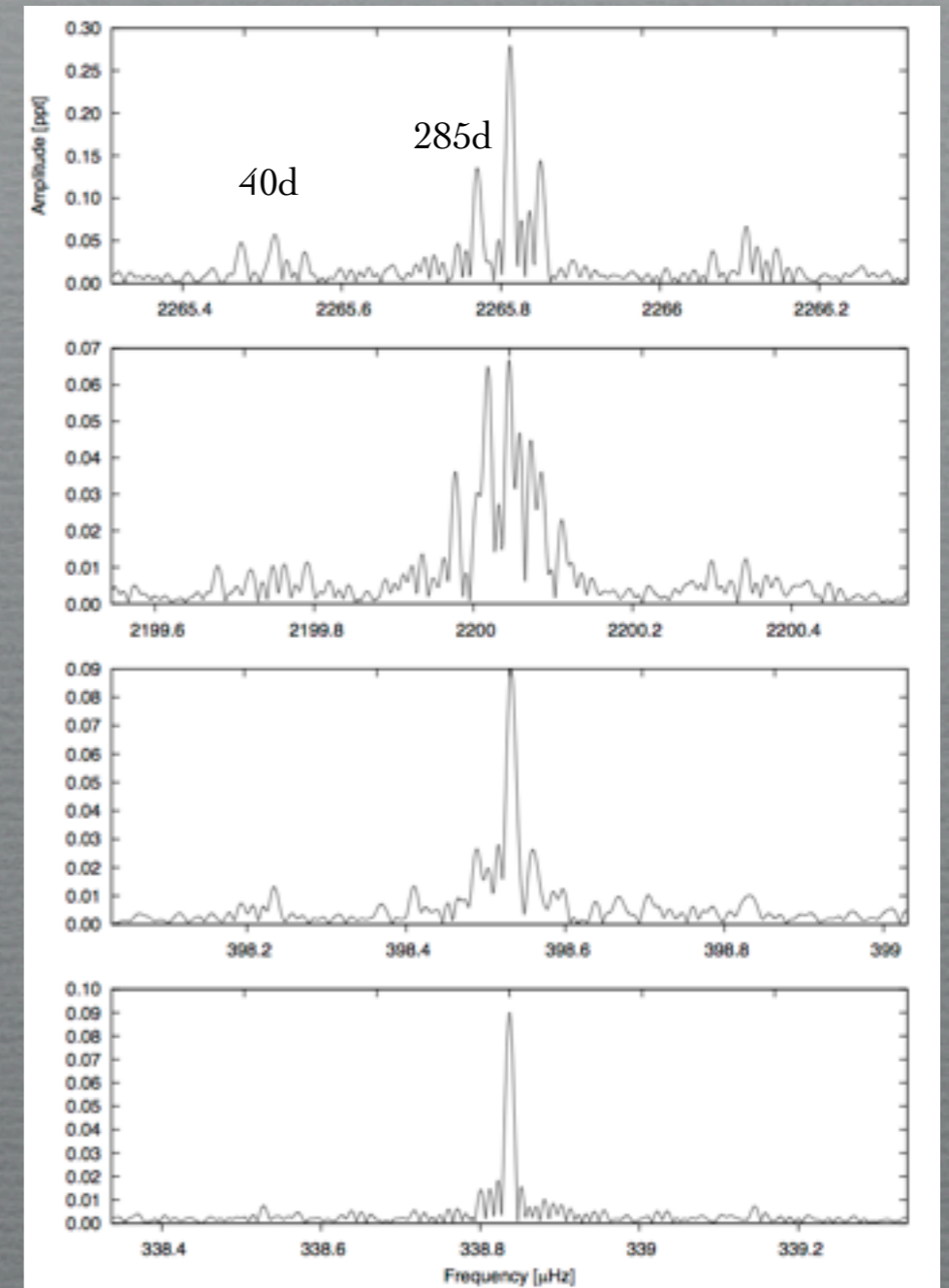
the binary trend removed with splines

# No multiplets found

orbital aliases

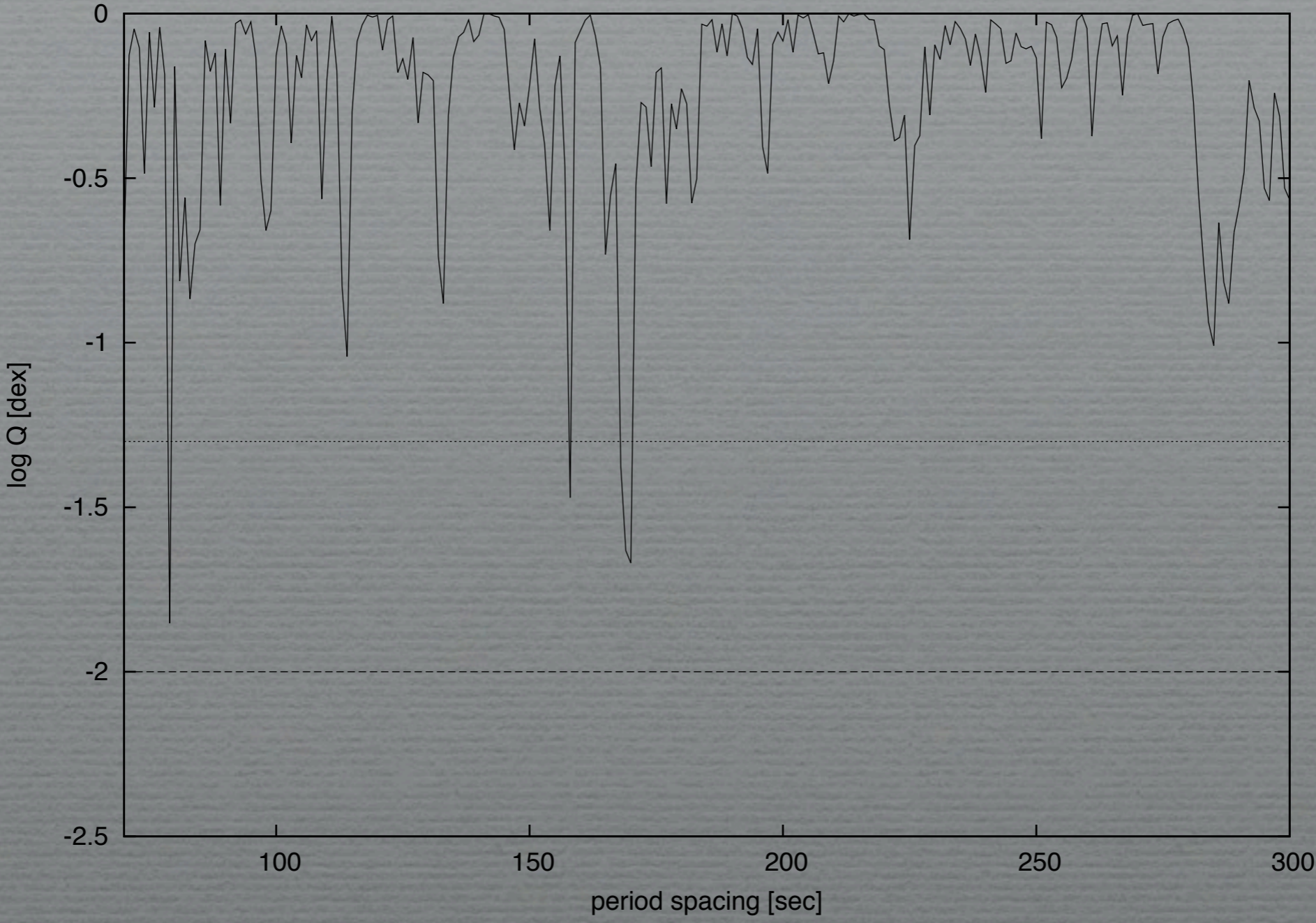


combination frequencies

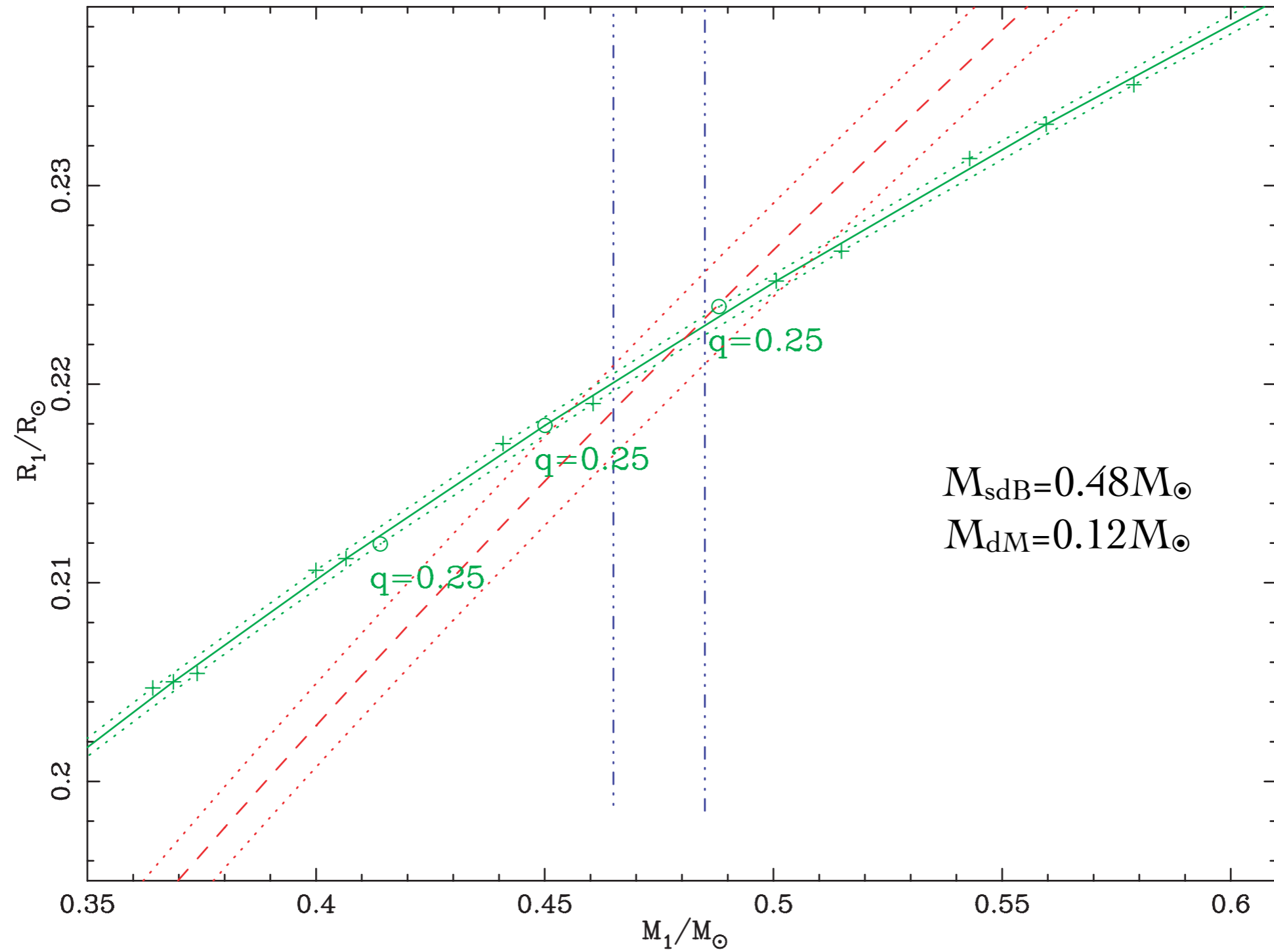


around peaks

# Kolmogorov-Smirnov test



# Mass estimation



Rømer delay  $\Rightarrow$  the offset of the secondary eclipse



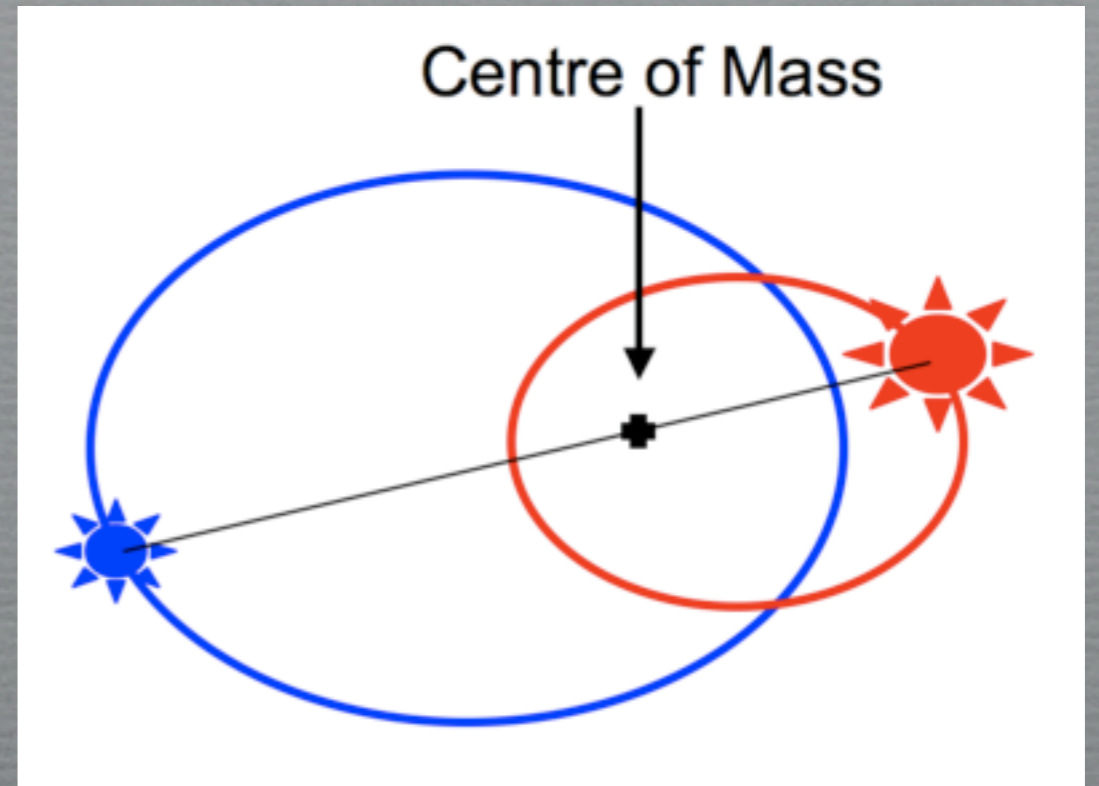
$$\Delta t_{\text{LT}} = \frac{PK_2}{\pi c} (1 - q)$$

$$M_1 = \frac{K_2}{2\pi GP} (2PK_2 - \Delta t_{\text{LT}}\pi c)^2,$$

$$M_2 = (2PK_2 - \Delta t_{\text{LT}}\pi c)^2 \left( \frac{K_2}{2\pi GP} - \frac{\Delta t_{\text{LT}}c}{2GP^2} \right)$$

## Rømer delay vs eccentricity

$$\Delta t_e \simeq \frac{2Pe}{\pi} \cos \omega$$



$e$  changes linearly with the secondary offset

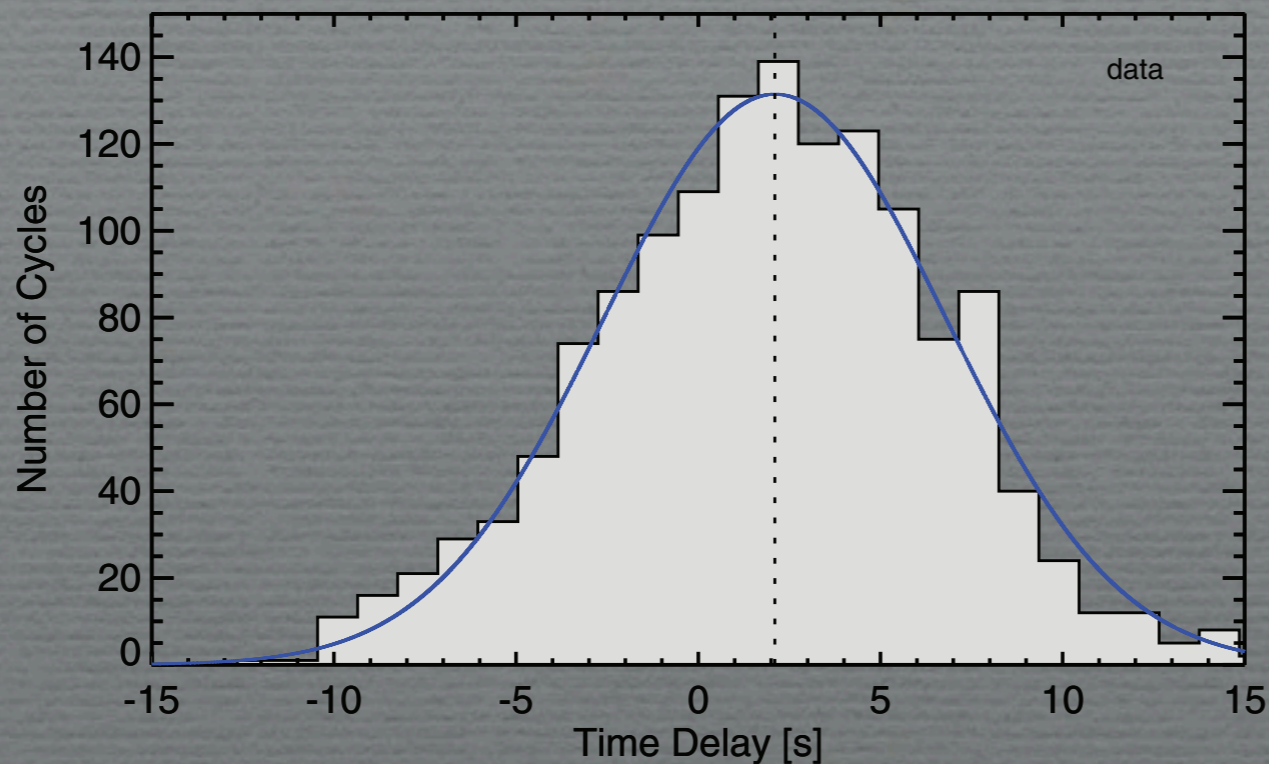
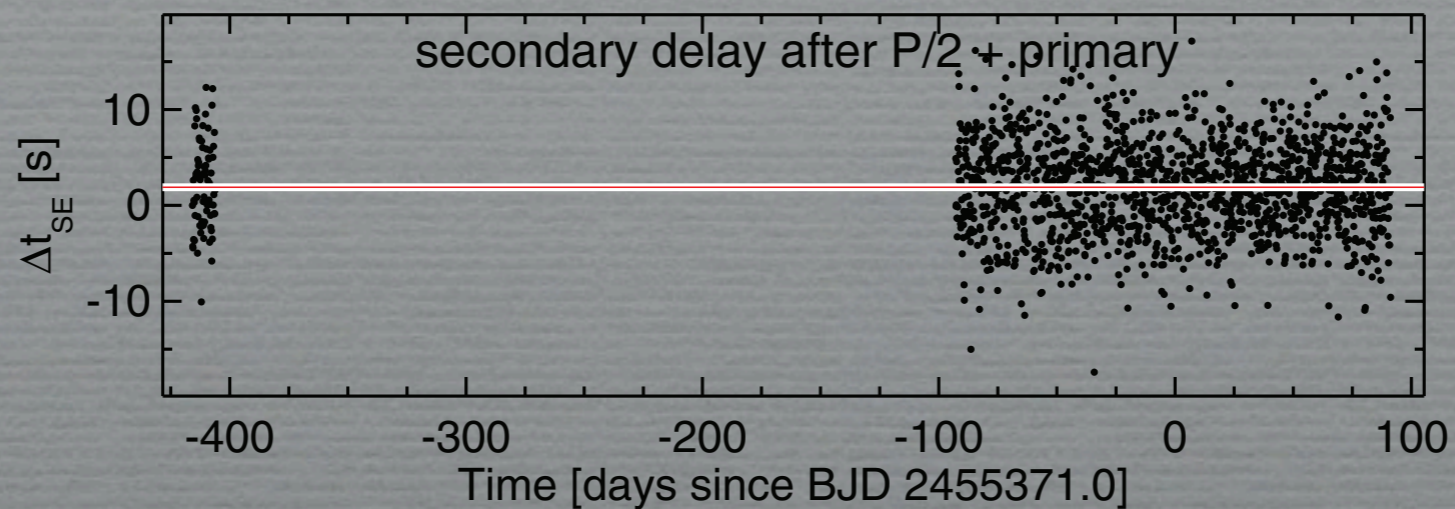
$$\Delta t_e = 1-10 \text{ sec}$$



$$e = 0.00015 - 0.0015$$

# Mass estimation - another try

Q5-6 data



$$\Delta t_{SE} = 2 \text{ sec}$$



$$M_{sdB} = 0.37 M_{\odot}$$

$$M_{dM} = 0.10 M_{\odot}$$

OR



$$e = 0.0003$$

# Mass estimation - our try

Q5-17 data

$$\Delta t_{SE} = 1.76 \text{ sec}$$

↓

$$M_{sdB} = 0.26 M_{\odot}$$

$$M_{dM} = 0.08 M_{\odot}$$

OR

↓

$$e = 0.0003$$

$$M_{sdB} = 0.48 M_{\odot}$$

↓

$$\Delta t_{LT} = 2.27 \text{ sec}$$

and

$$e = 0.00008$$

$$\Rightarrow \Delta t_{SE} = 1.76 \text{ sec}$$



What's wrong with this star?

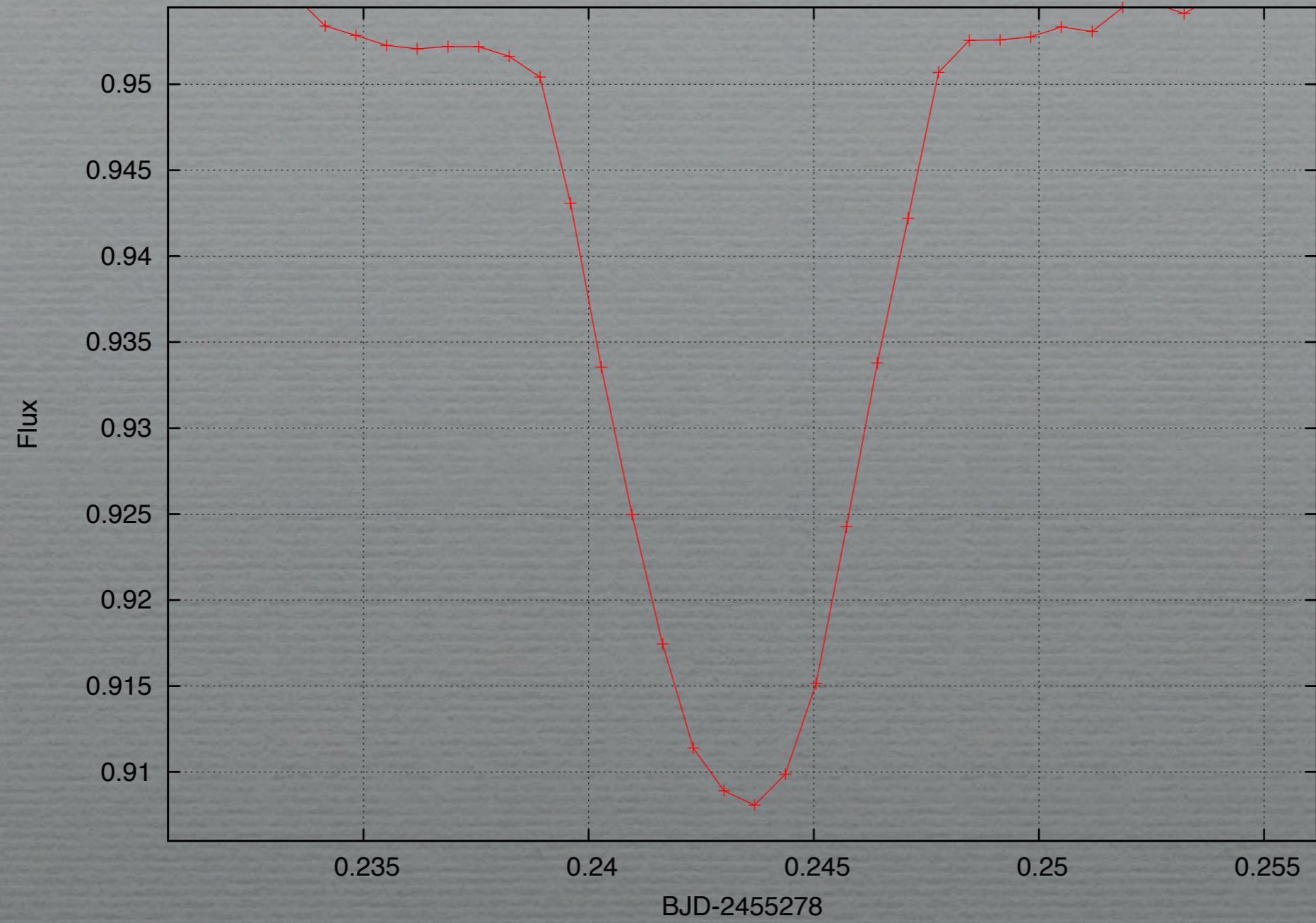
either

**this star sucks**

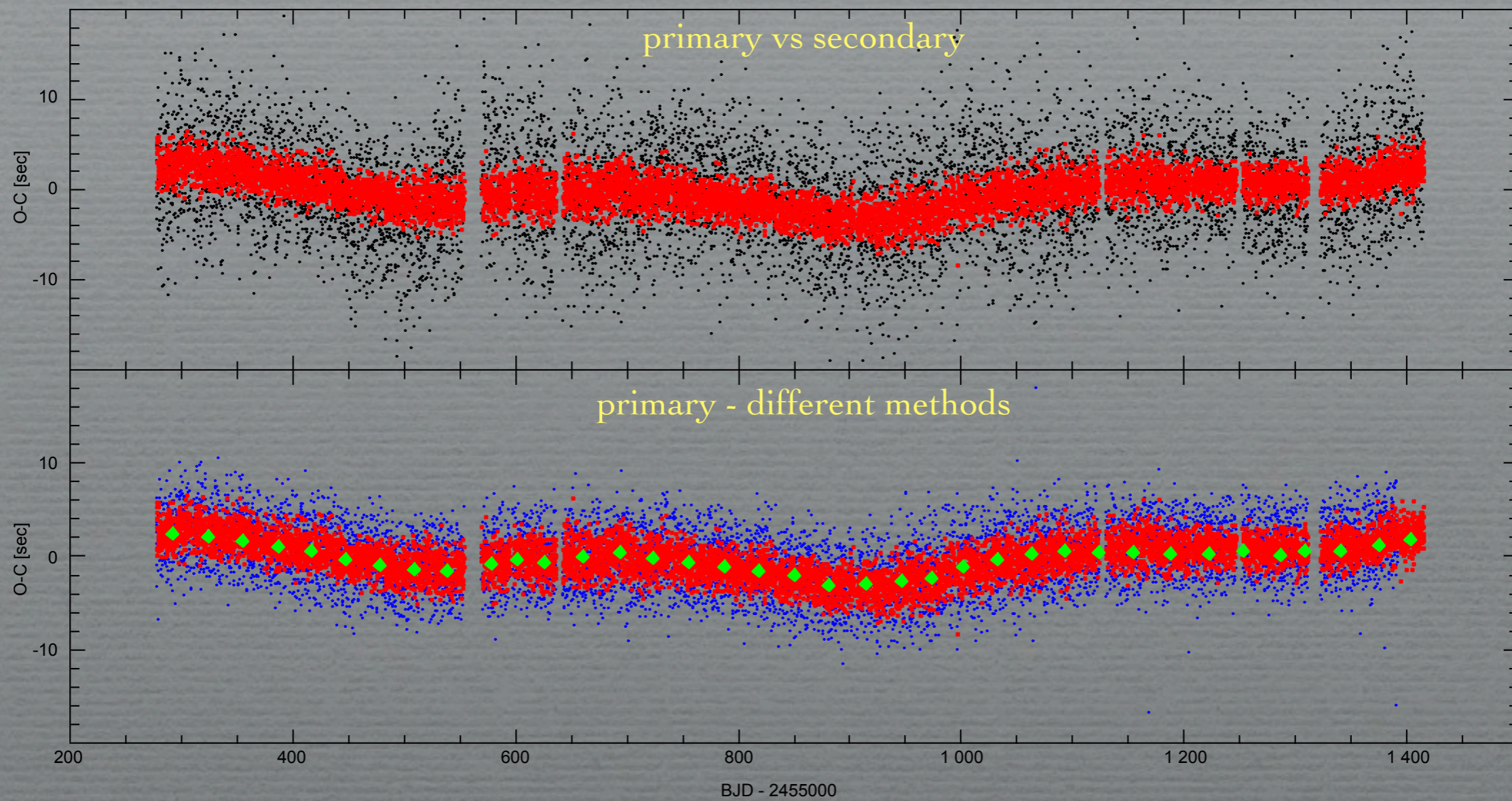
or

**we suck**

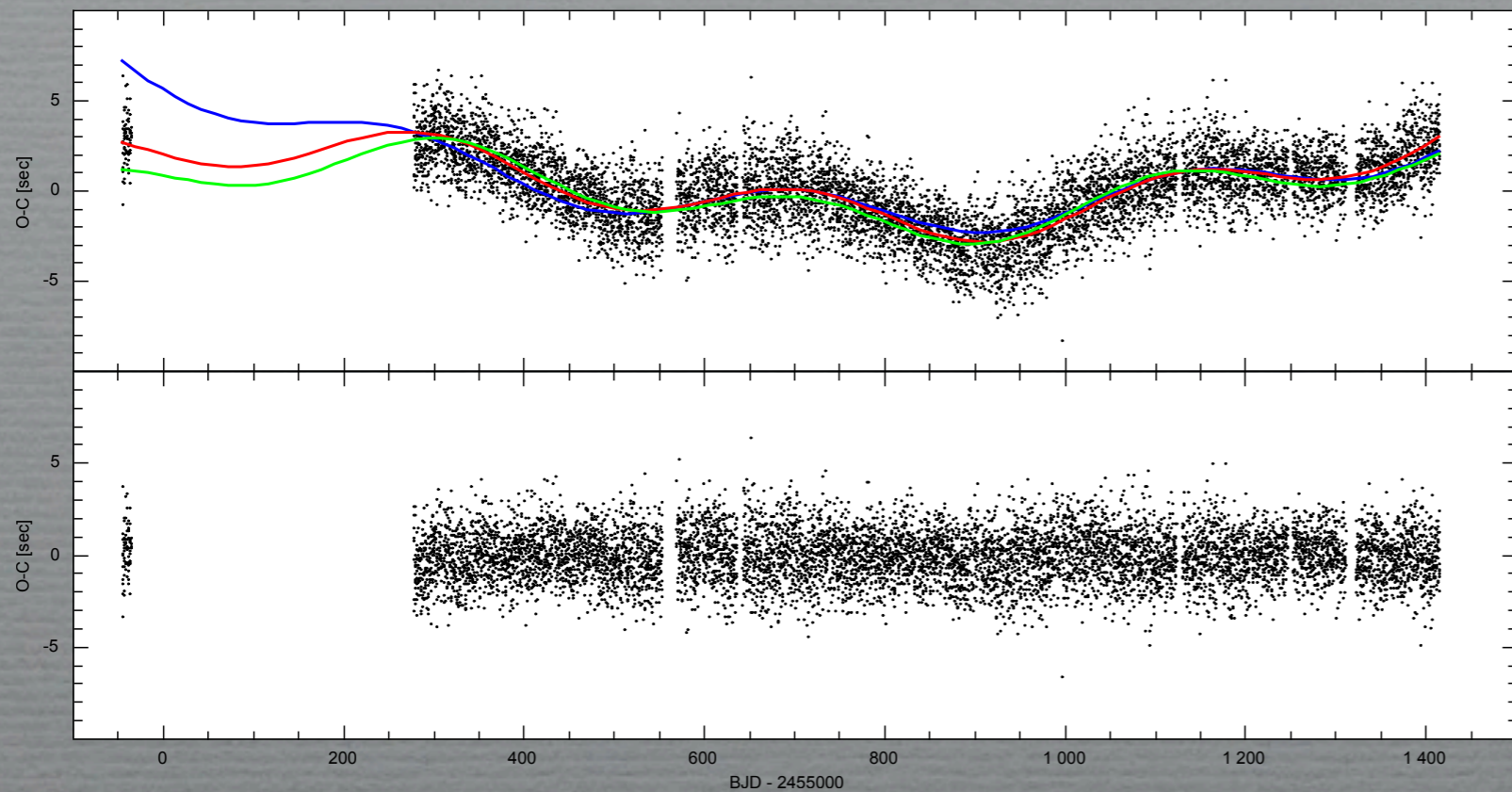
# How about the mid-times of eclipses?



# O-C diagram calculated from Q5-17



# O-C diagram - model fit



---

---

Binary system	
reference epoch	2455276.60843(3) BJD
orbital period	0.125765282(5) days
period change rate	$4.13(2) \cdot 10^{-11}$ s/s
inclination	69.45(20) deg
$M_1$	0.48(3) $M_{\odot}$
$M_2$	0.12(1) $M_{\odot}$
$K_1$	65.7(6) km/s

---

---

Third body	
orbital period	416(2) days
orbital radius	0.92(2) AU
$M_3$	1.9(1) $M_{Jupiter}$

---

---

## Planets harbored by sdB stars

object	# of planets	tool used
V391 Peg	1	pulsations
HW Vir	2	eclipse mid-times
NY Vir	1+1?	eclipse mid-times
NSVS14256825	2	eclipse mid-times
HS0705+6700	brown dwarf	eclipse mid-times
2M1938+4603	1+1?	eclipse mid-times
KIC5807616	2	reflection effect
KIC10001893	3	reflection effect