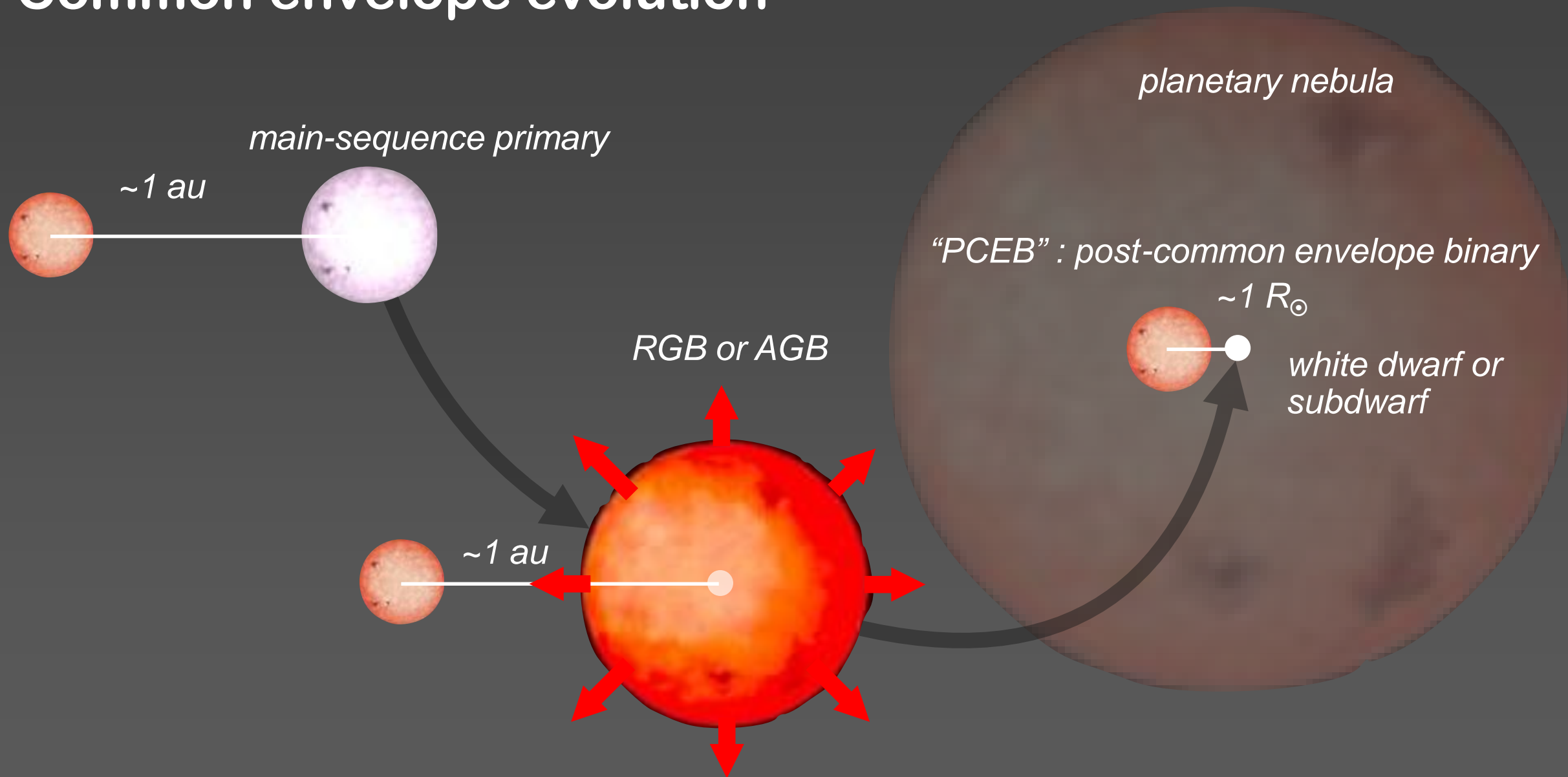


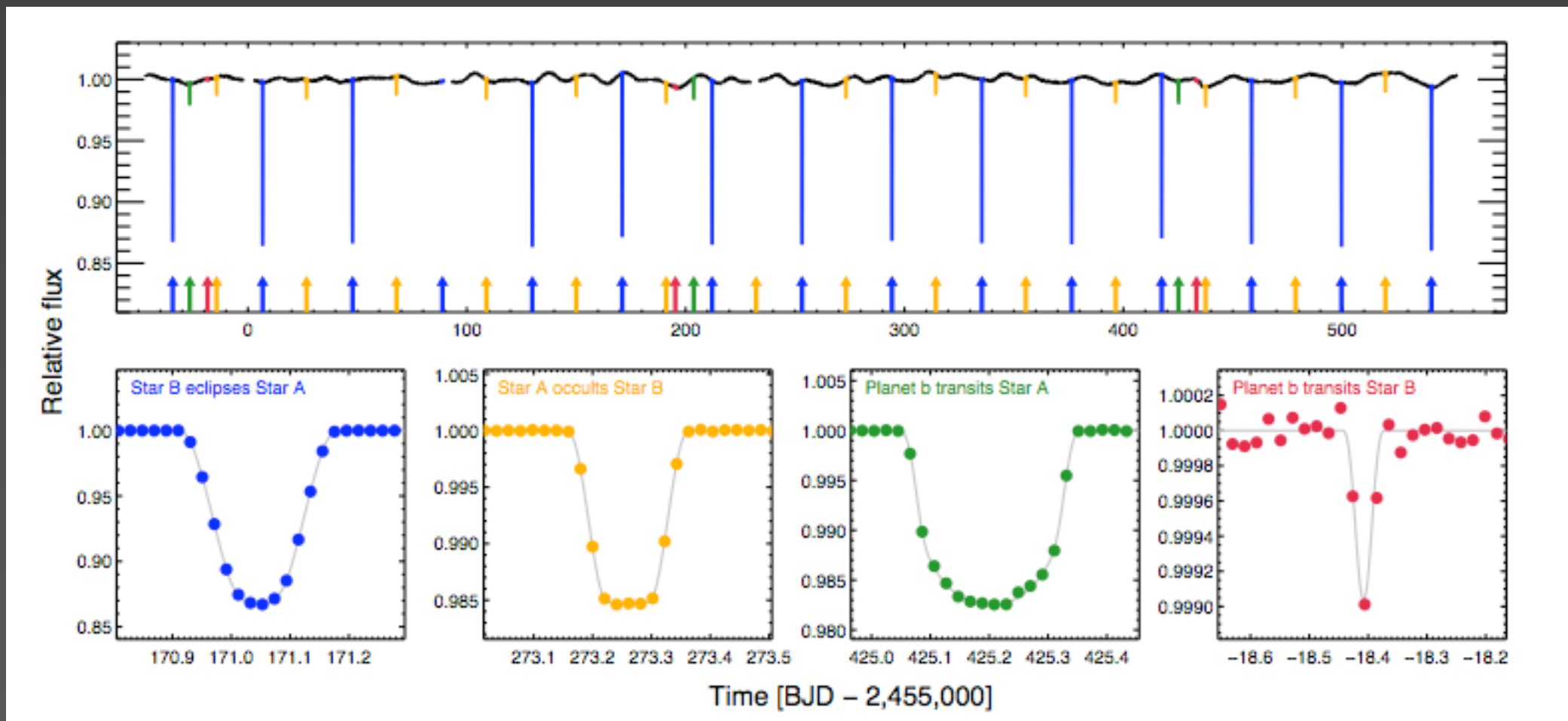
# Observations of circum- binary exoplanets beyond the Main Sequence: Eclipsing Post common envelope CBPs

Klaus Beuermann, Stefan Dreizler, Paul Breitenstein,  
Frederik Hessman, Tim-Oliver Husser, Erwin Schwab

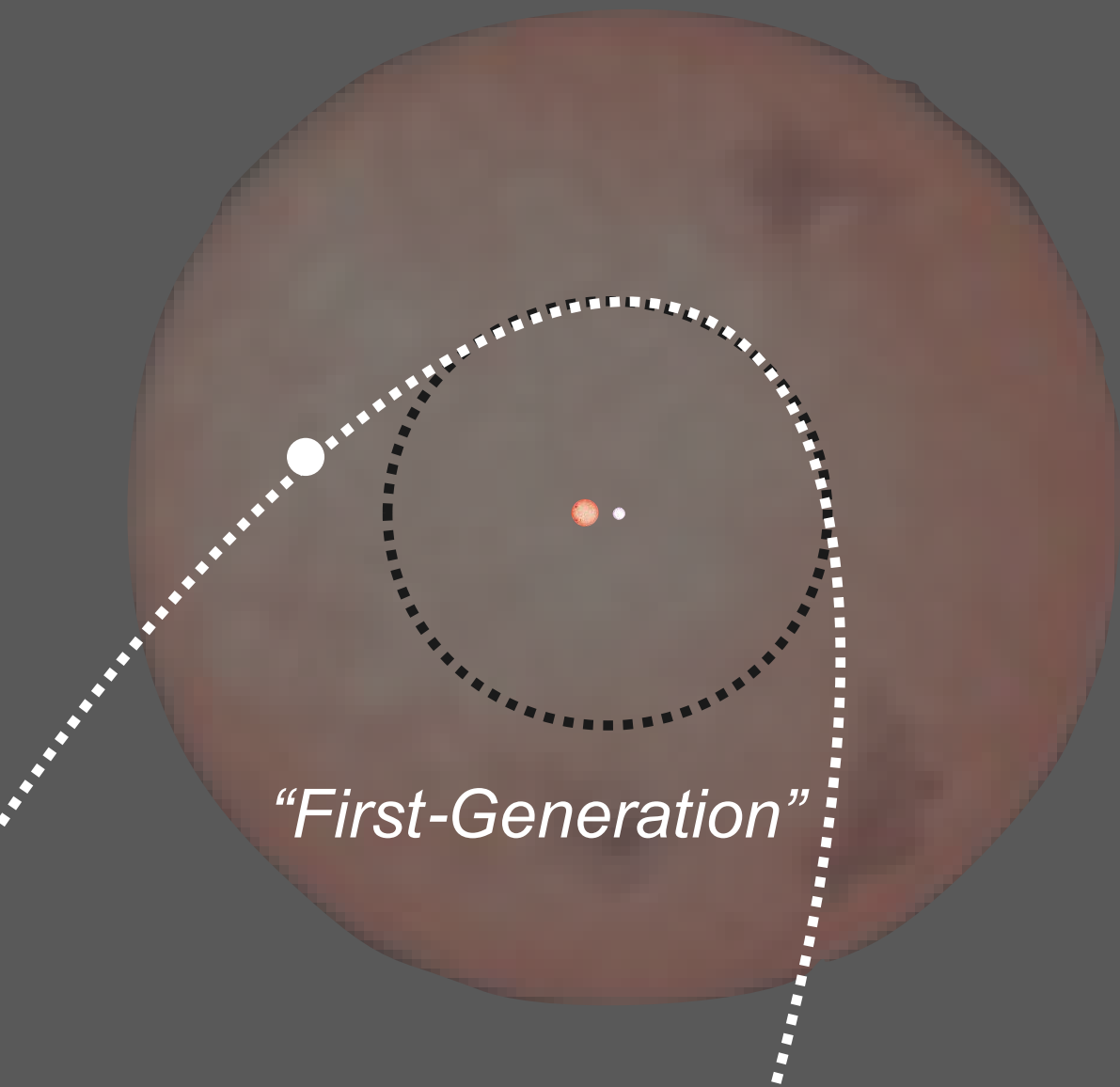
# Common envelope evolution



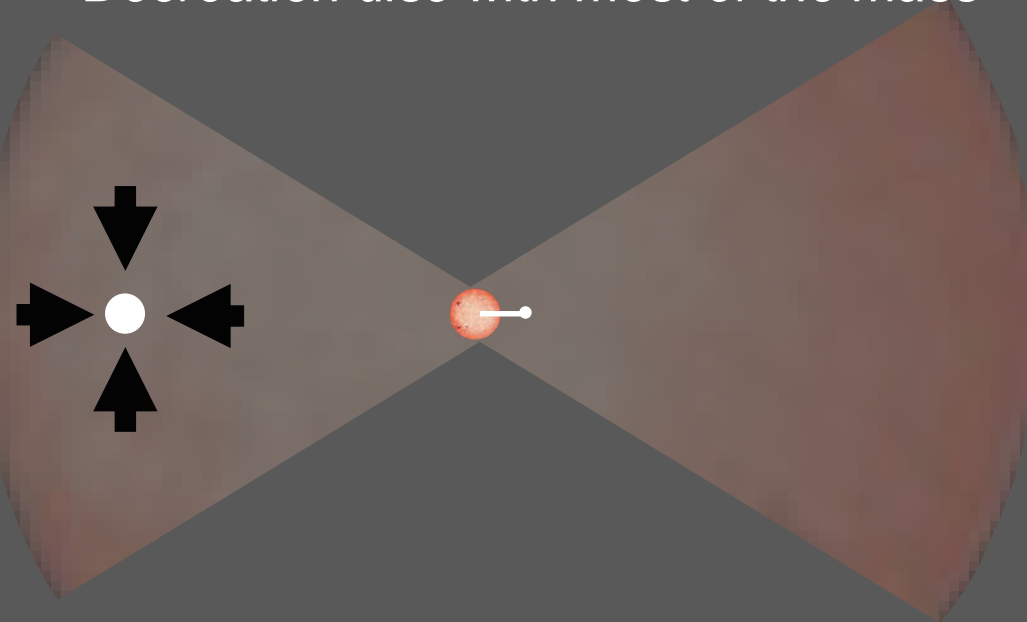
# Circum-binary planets on the MS: Kepler-16



# Formation of circum-binary objects



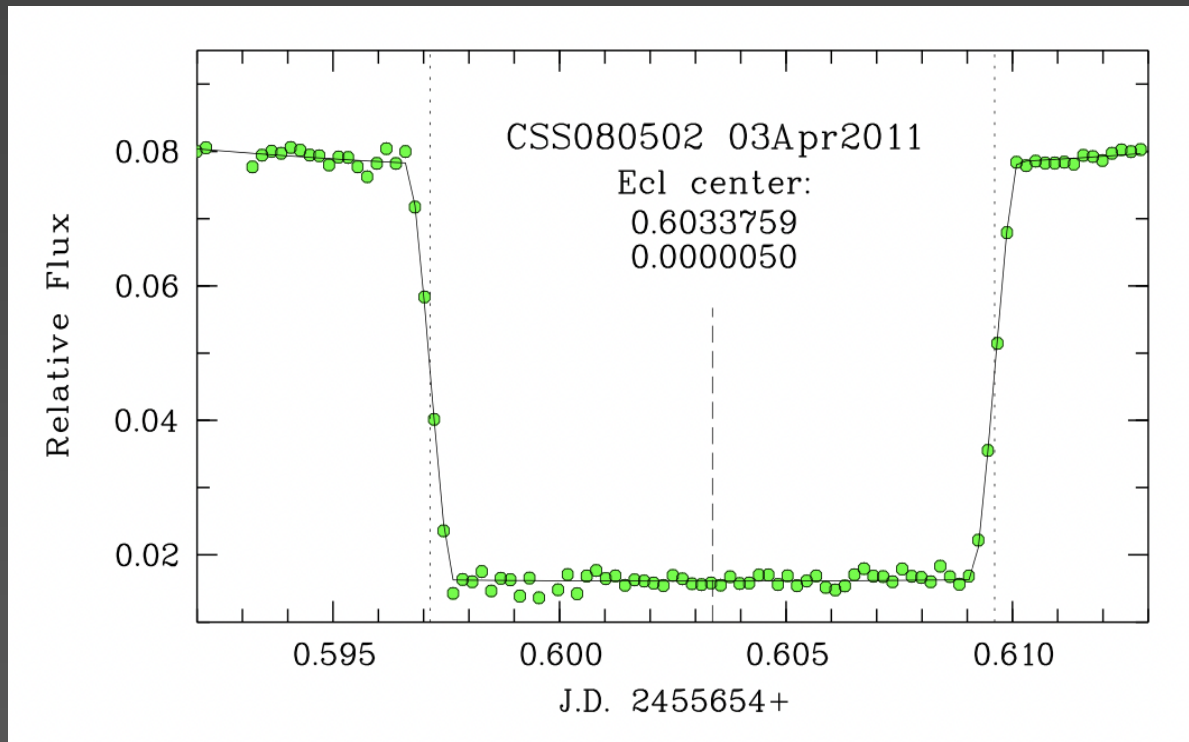
*Decretion disc with most of the mass*



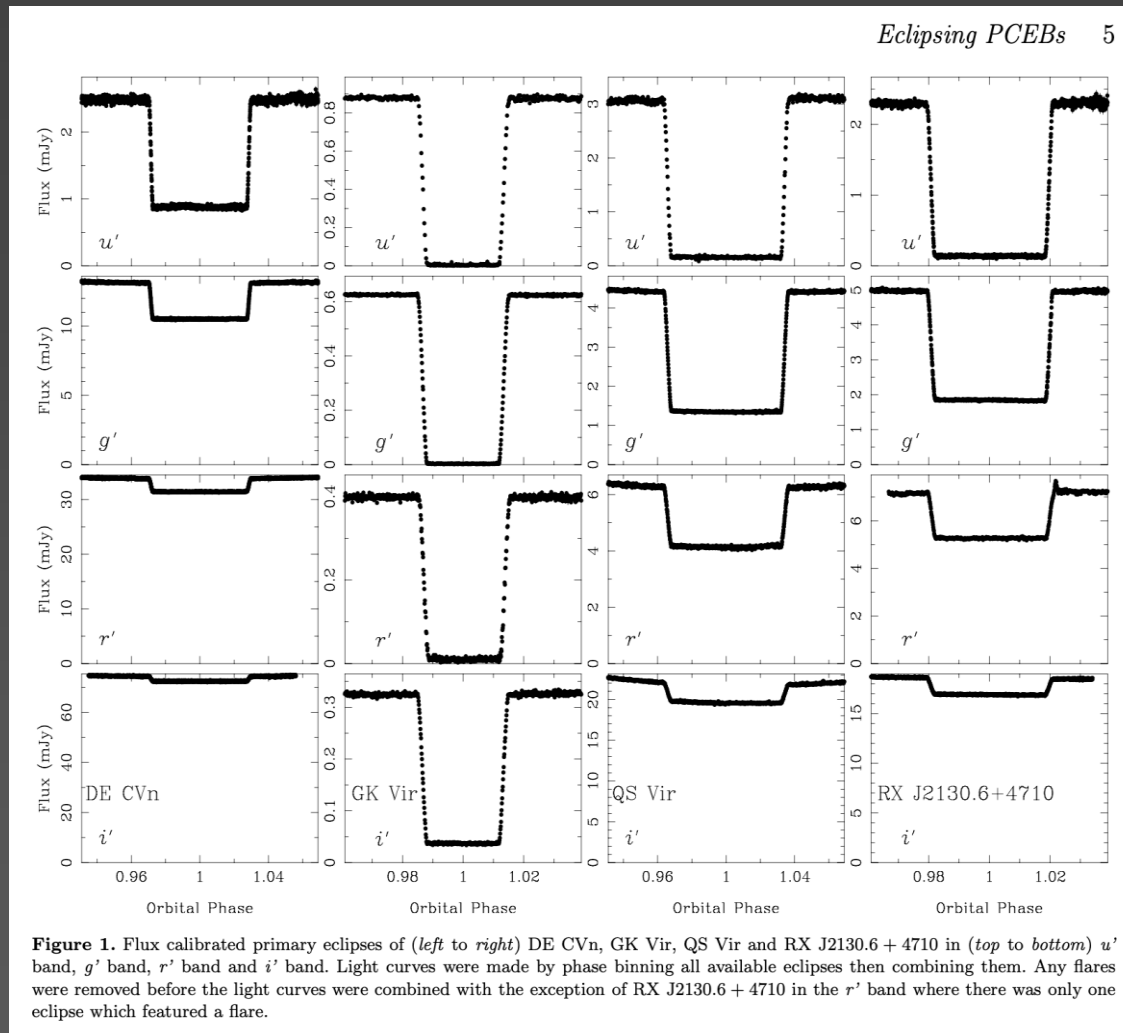
*“Second-Generation”*

*Schleicher et al. 2015*

# WD eclipse photometry

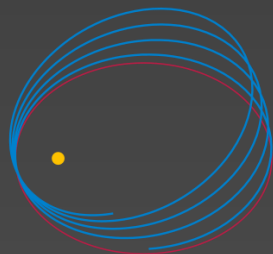


MONET 1.2m

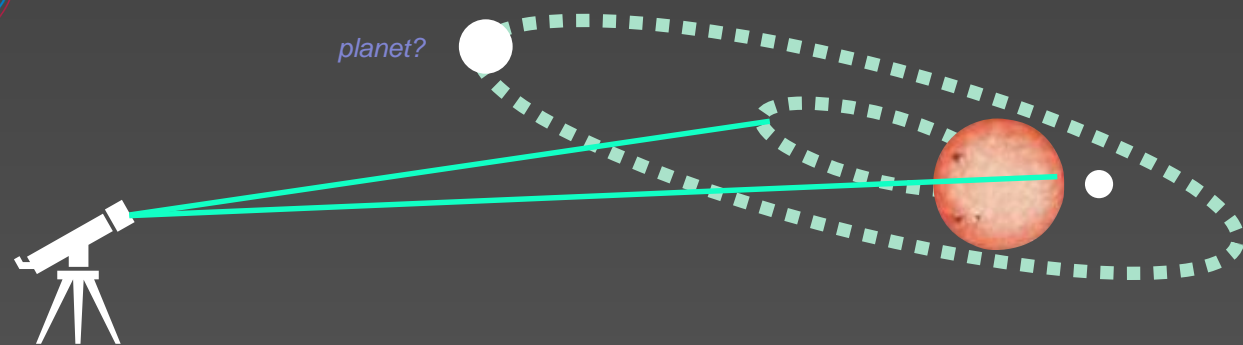


# Sources of orbital period variations

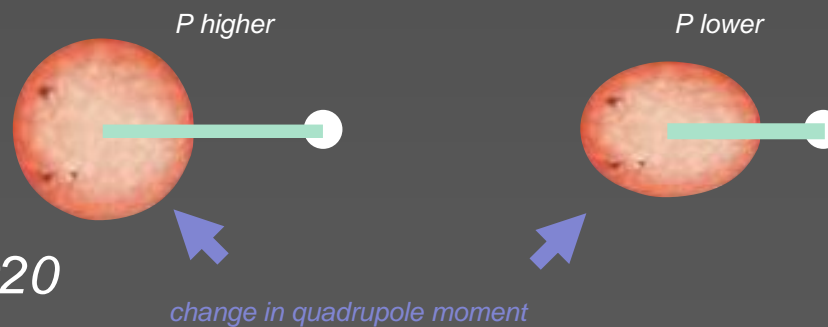
Apsidal precession?



Circumbinary companion(s)?

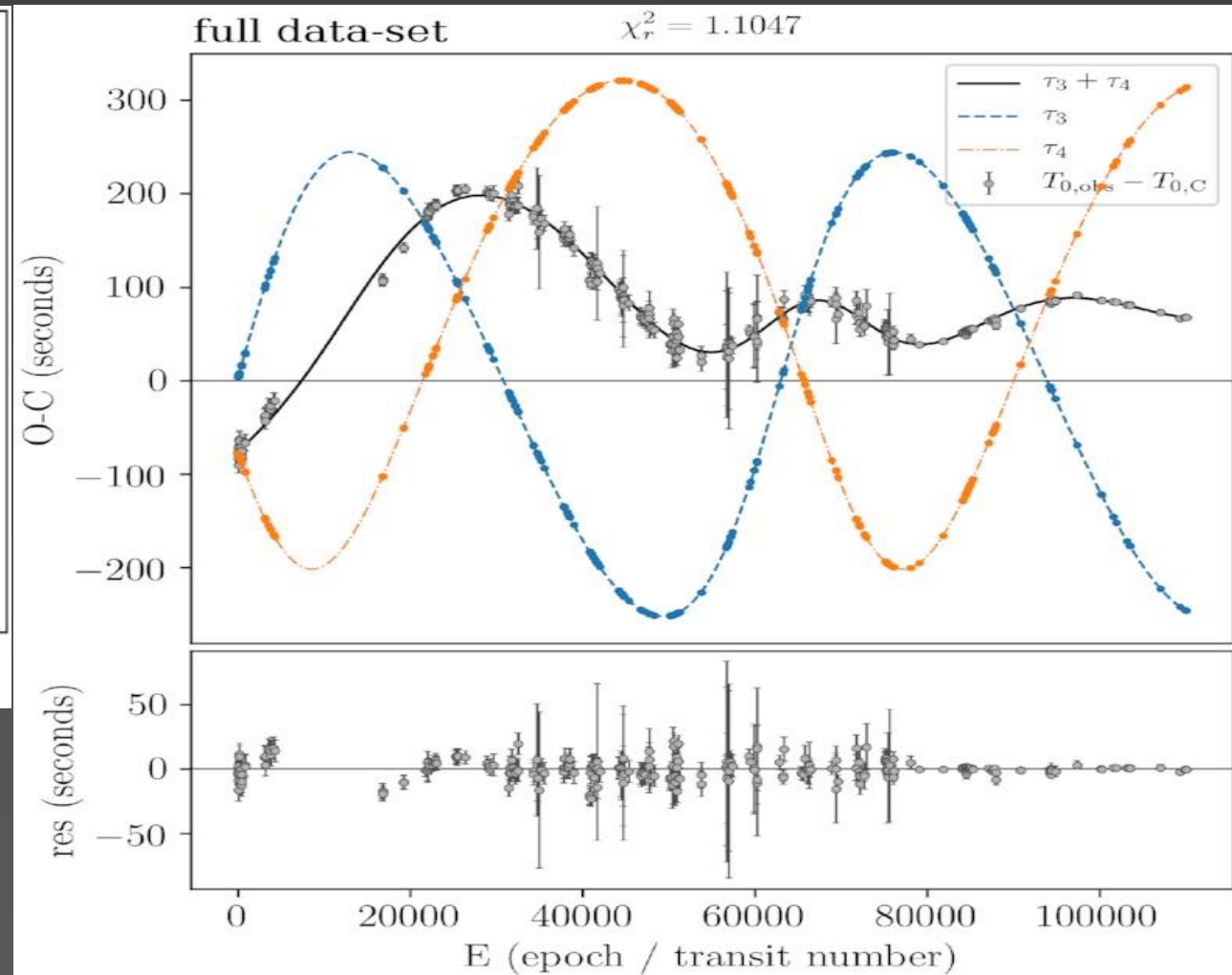
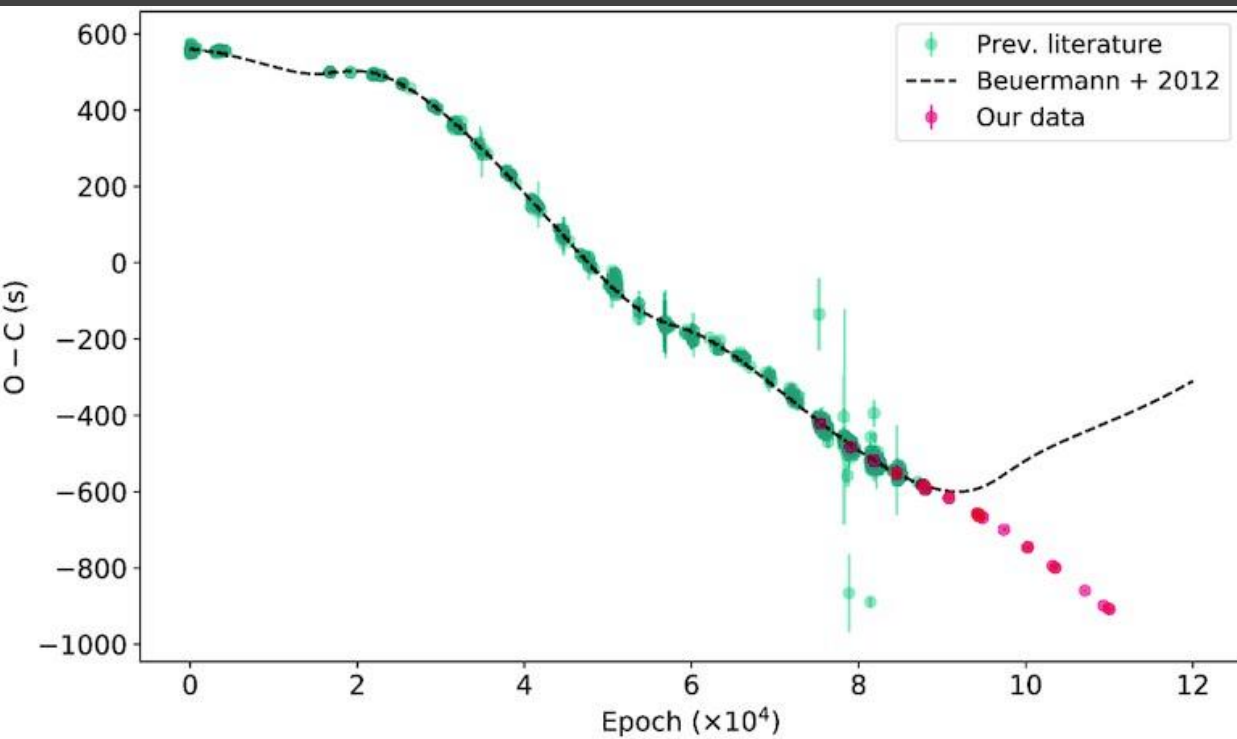


Spin-orbit coupling?



*Applegate 1992; Völschow et al. 2018; Lanza 2020*

# HW Vir: The best fit is not necessarily a good fit



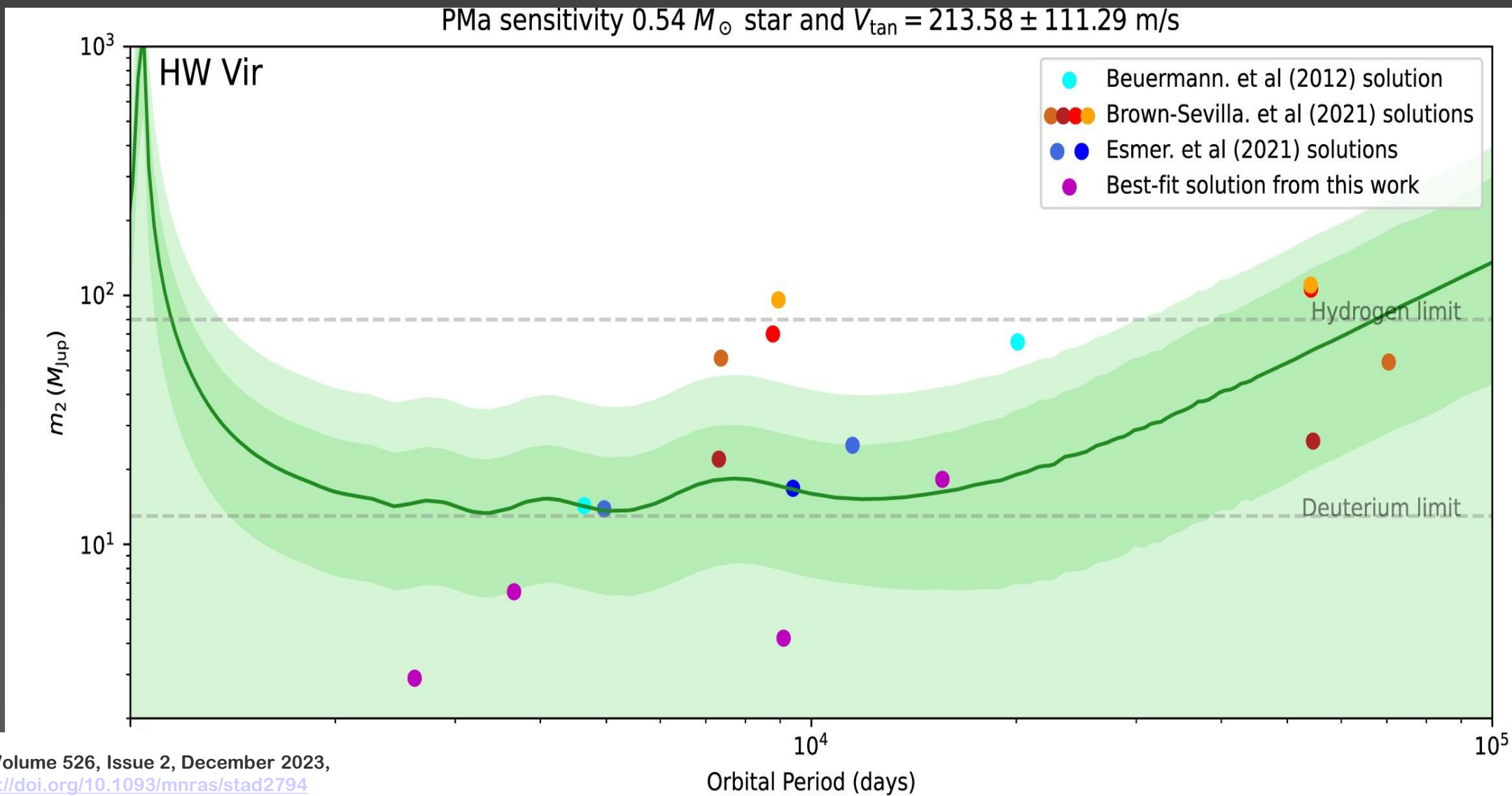
*Brown-Sevilla et al, Mon Not R Astron Soc, Volume 506, Issue 2, September 2021, Pages 2122–2135, <https://doi.org/10.1093/mnras/stab1843>*

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# HIPARCOS+GAIA constraints

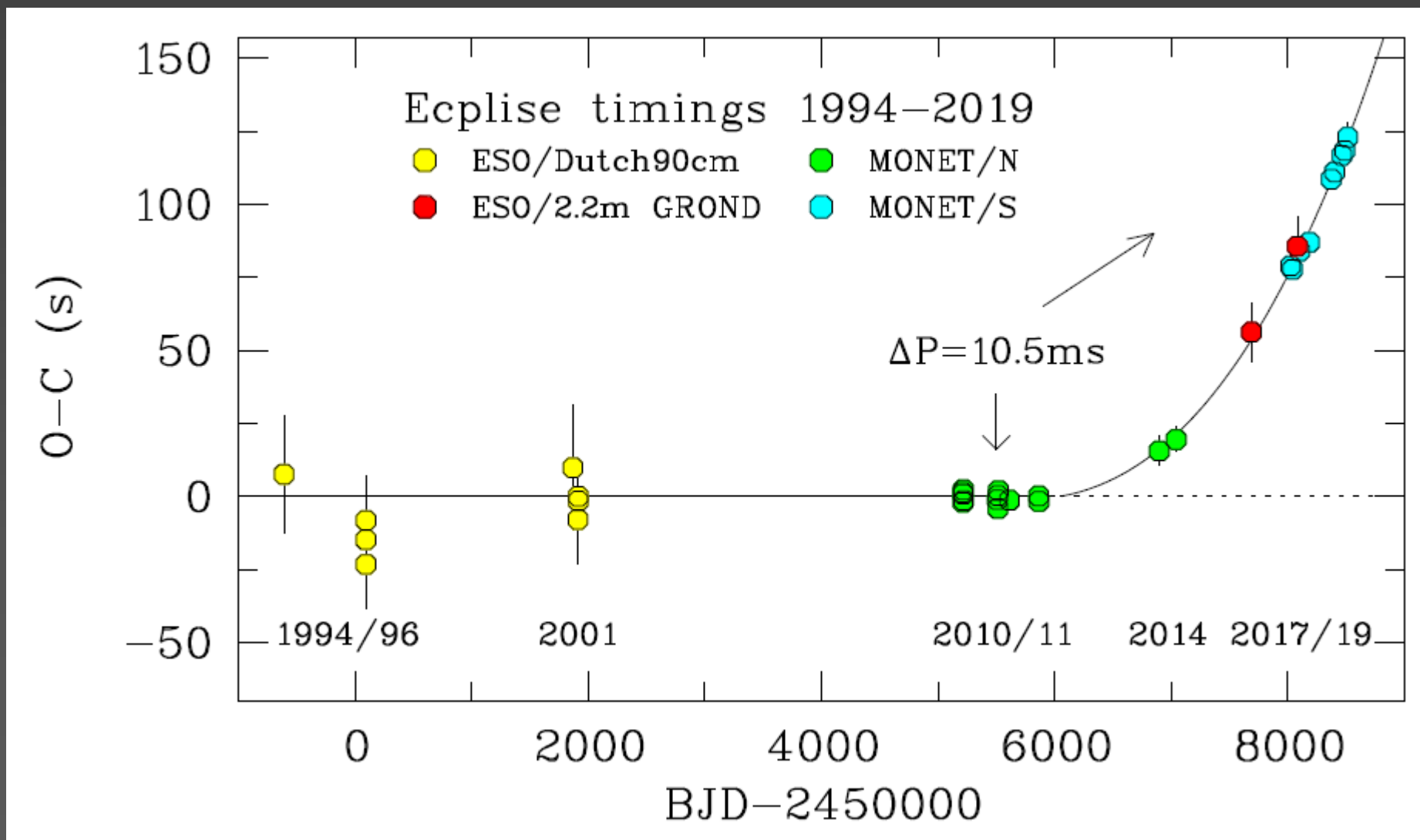
*Baycroft et al. 2023*





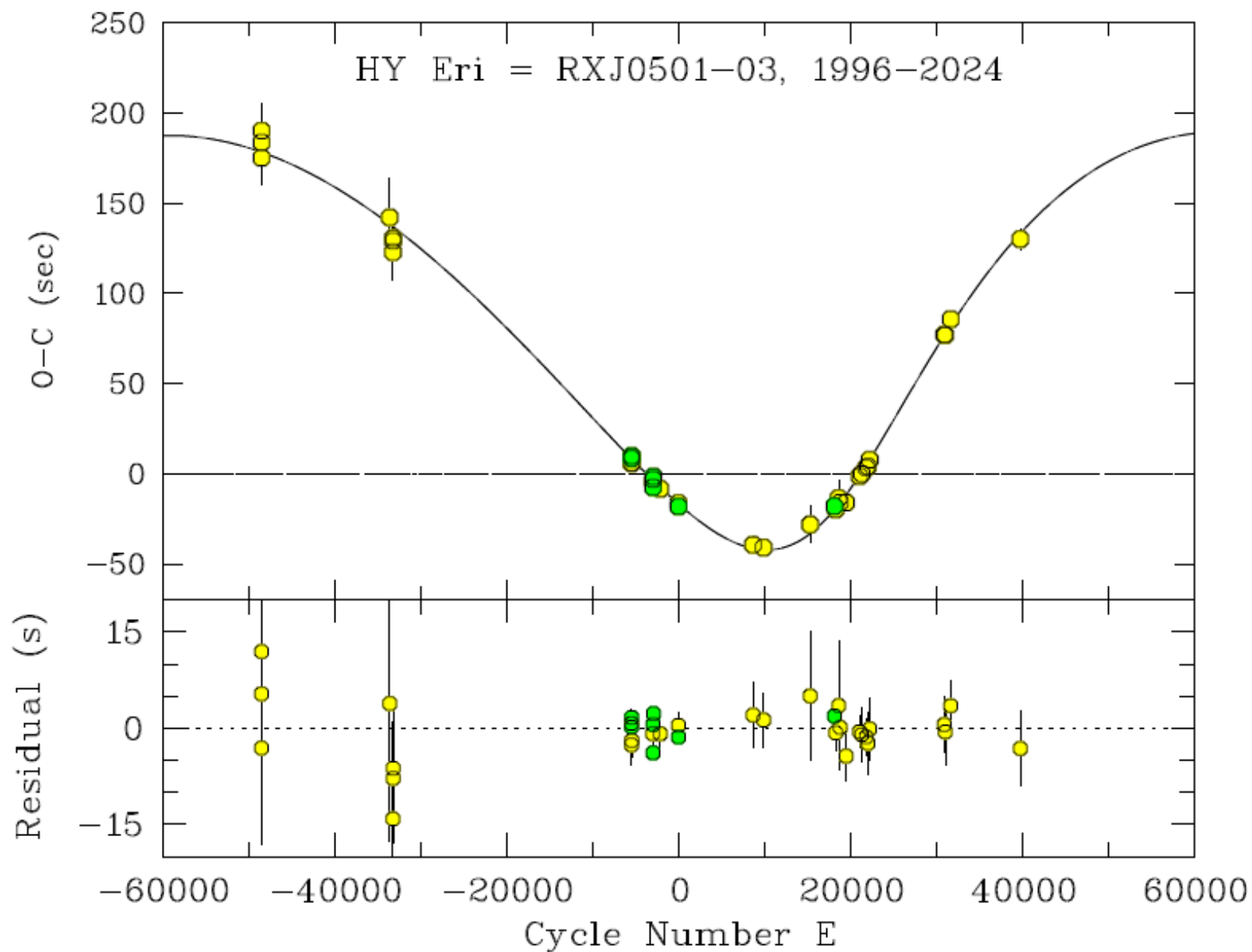
# HY Eri: Things can change

Beuermann et al. 2020

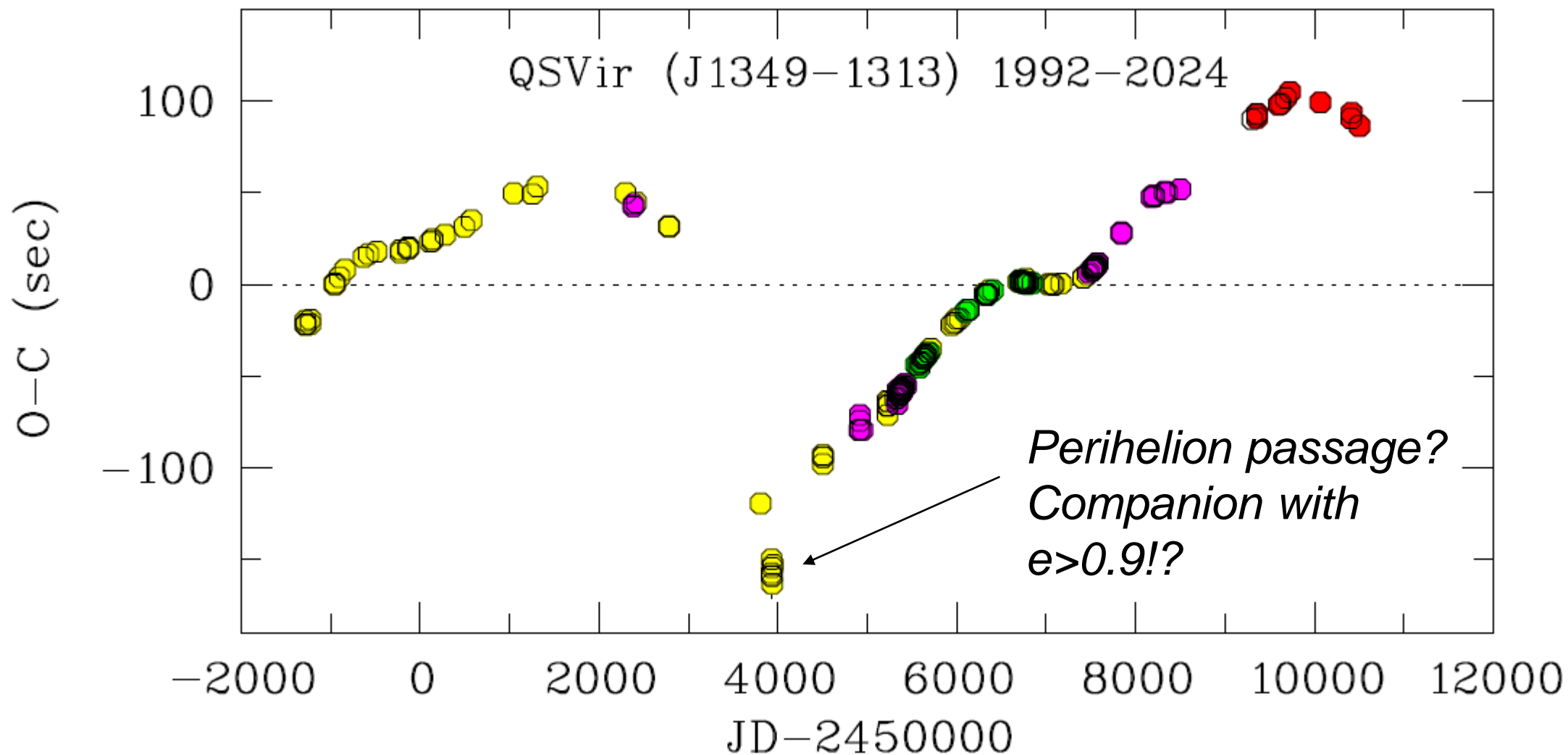


# EY Eri: Things can change

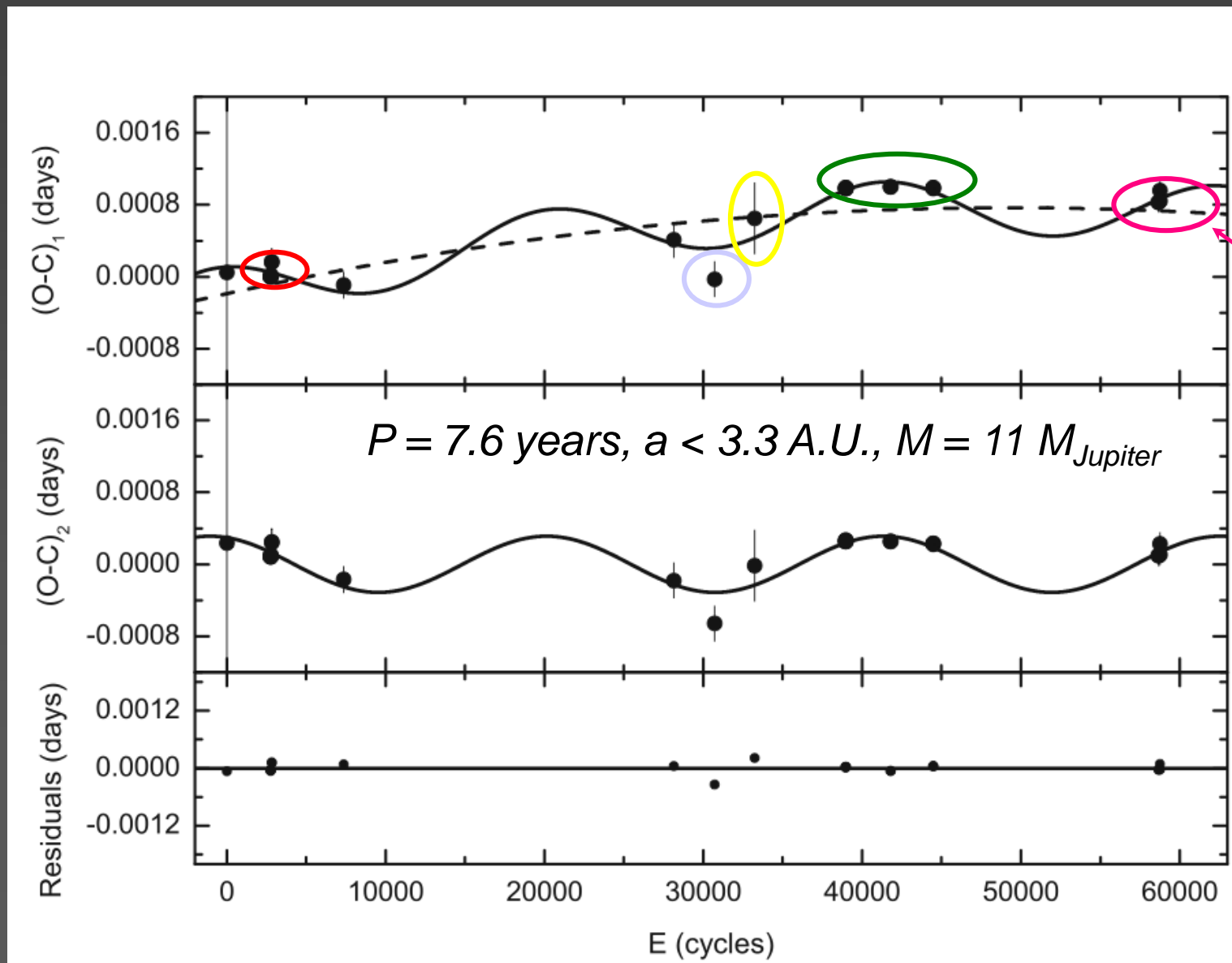
*1 planet fit  
(preliminary)*



# QS Vir: What is going on here?



# NN Ser: A former good candidate for CPBs

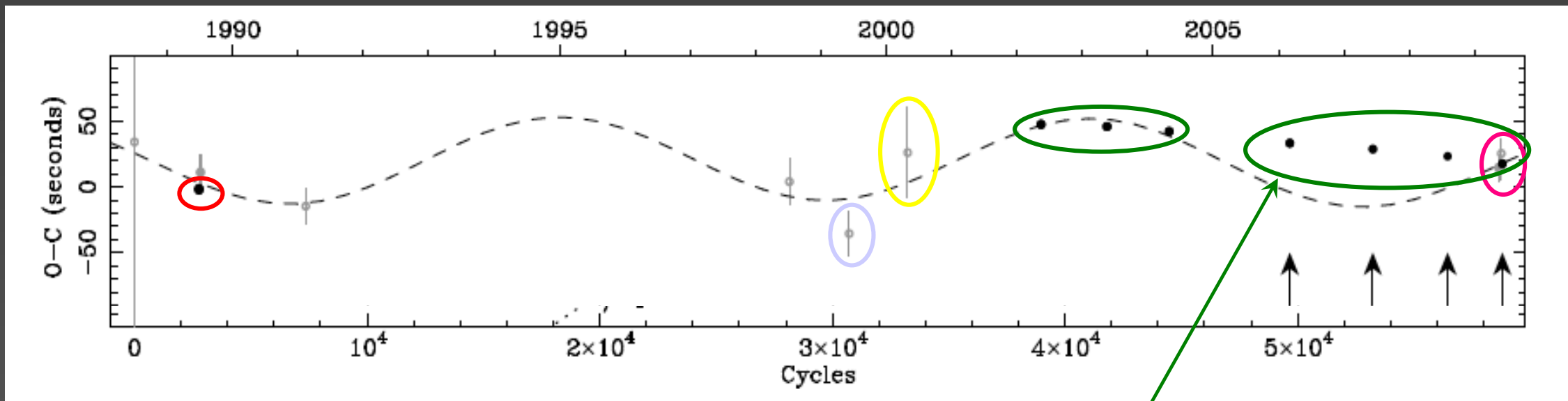


- MCCP
- VLT
- Bialkow
- UltraCam
- Lijiang

Quian et al. 2009

1 planet

# NN Ser: A former good candidate for CPBs

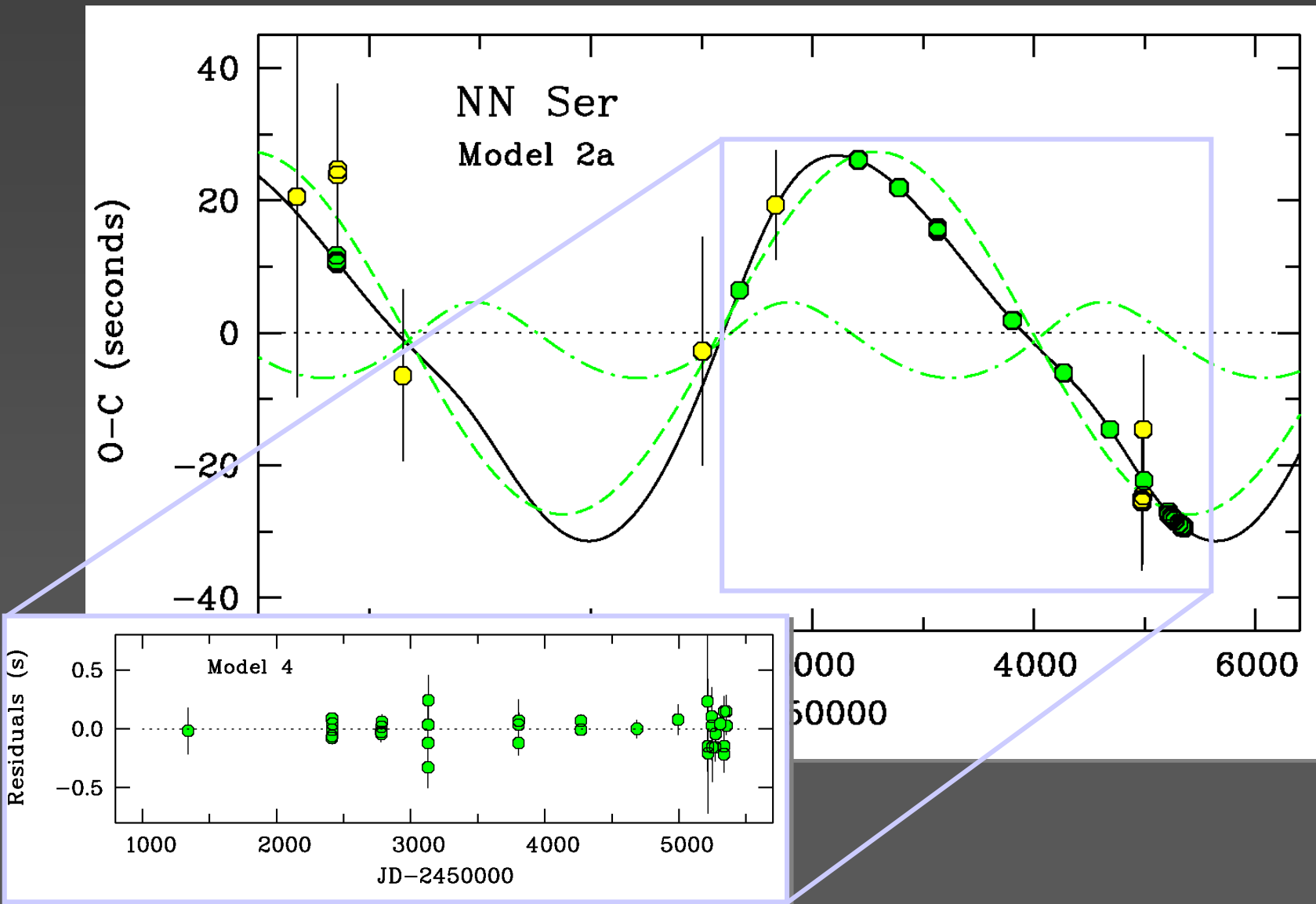


*Parsons et al. 2010*

*Very bad fit: No planet*

- MCCP
- VLT
- Bialkow
- UltraCam
- Lijiang

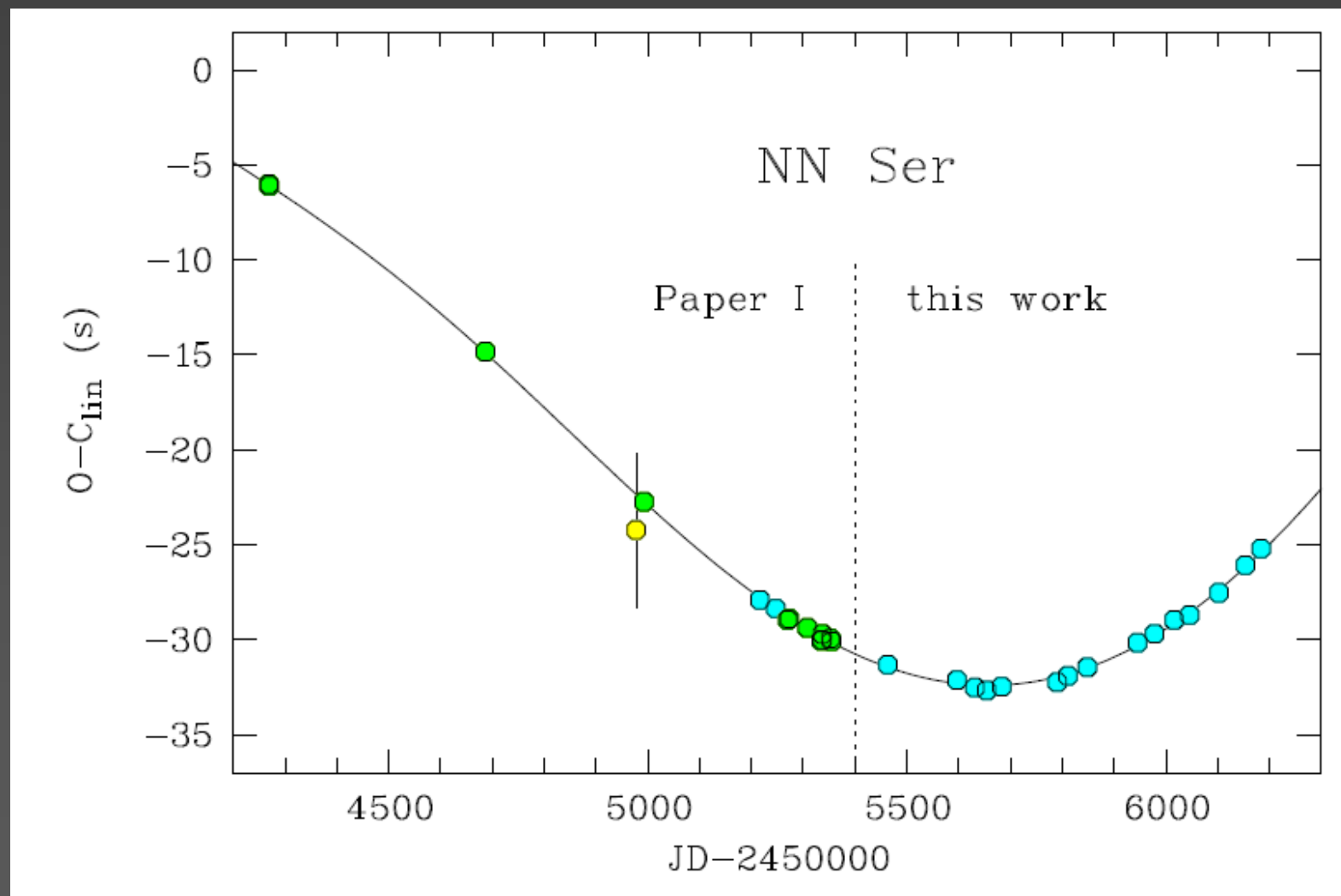
# NN Ser: A former good candidate for CPBs



*Beuermann et al.  
2010*

*2 planets in 2:1  
resonance*

# NN Ser: A former good candidate for CPBs



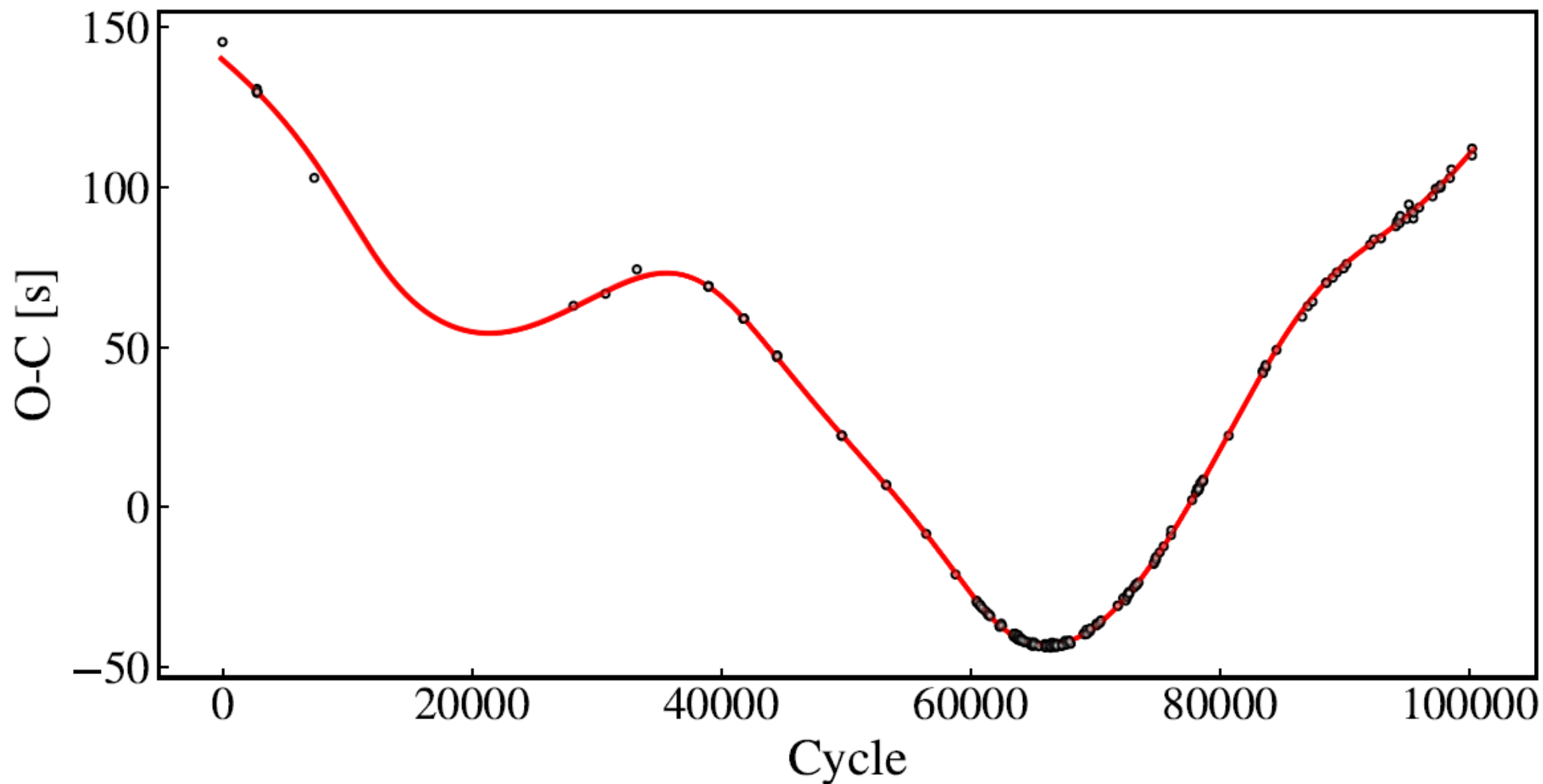
*Still a good fit,  
dynamical stable  
configurations possible*

*Beuermann et al. 2013  
Bours et al. 2016*

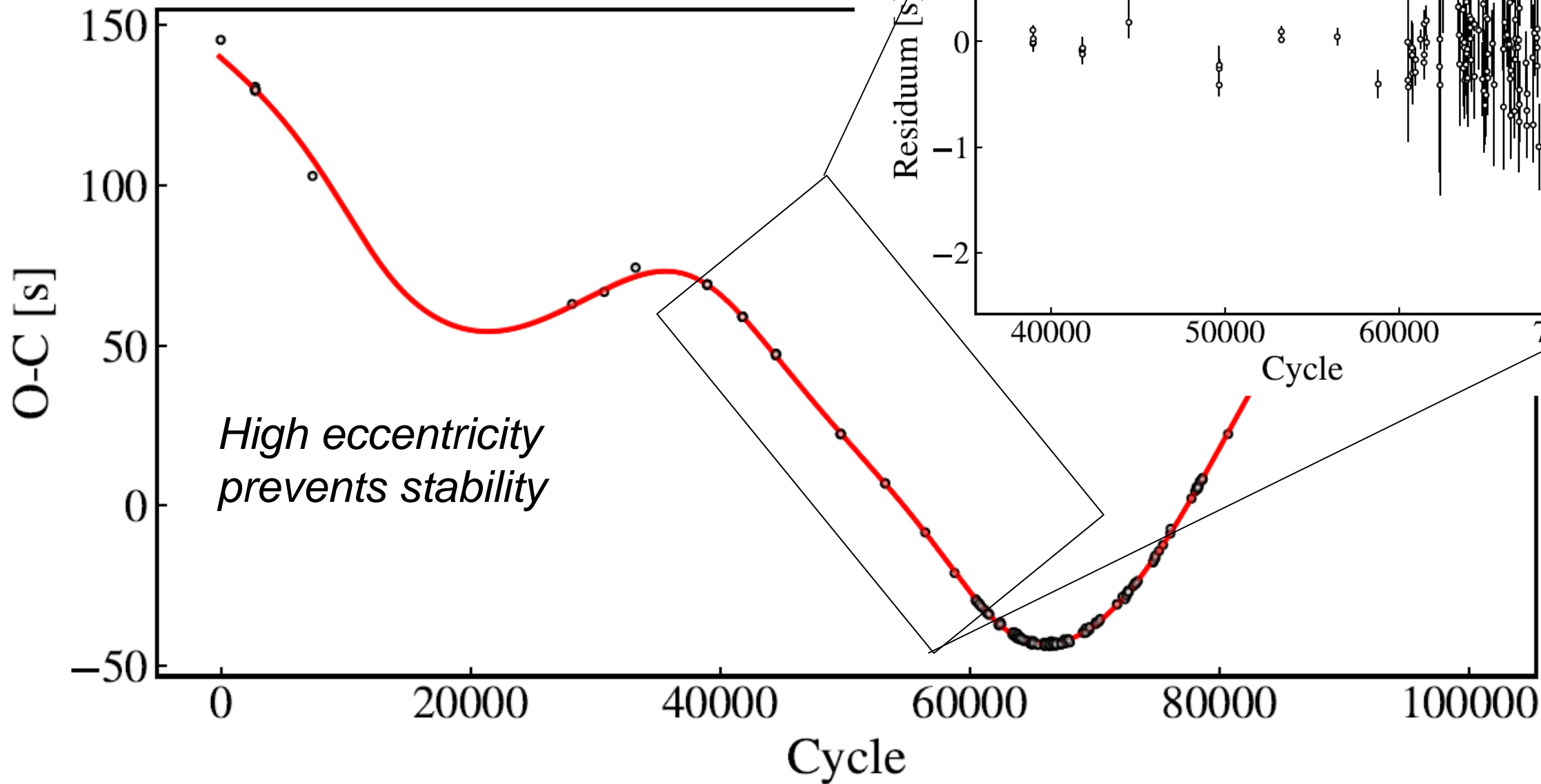


# NN Ser: A former good candidate for CPBs

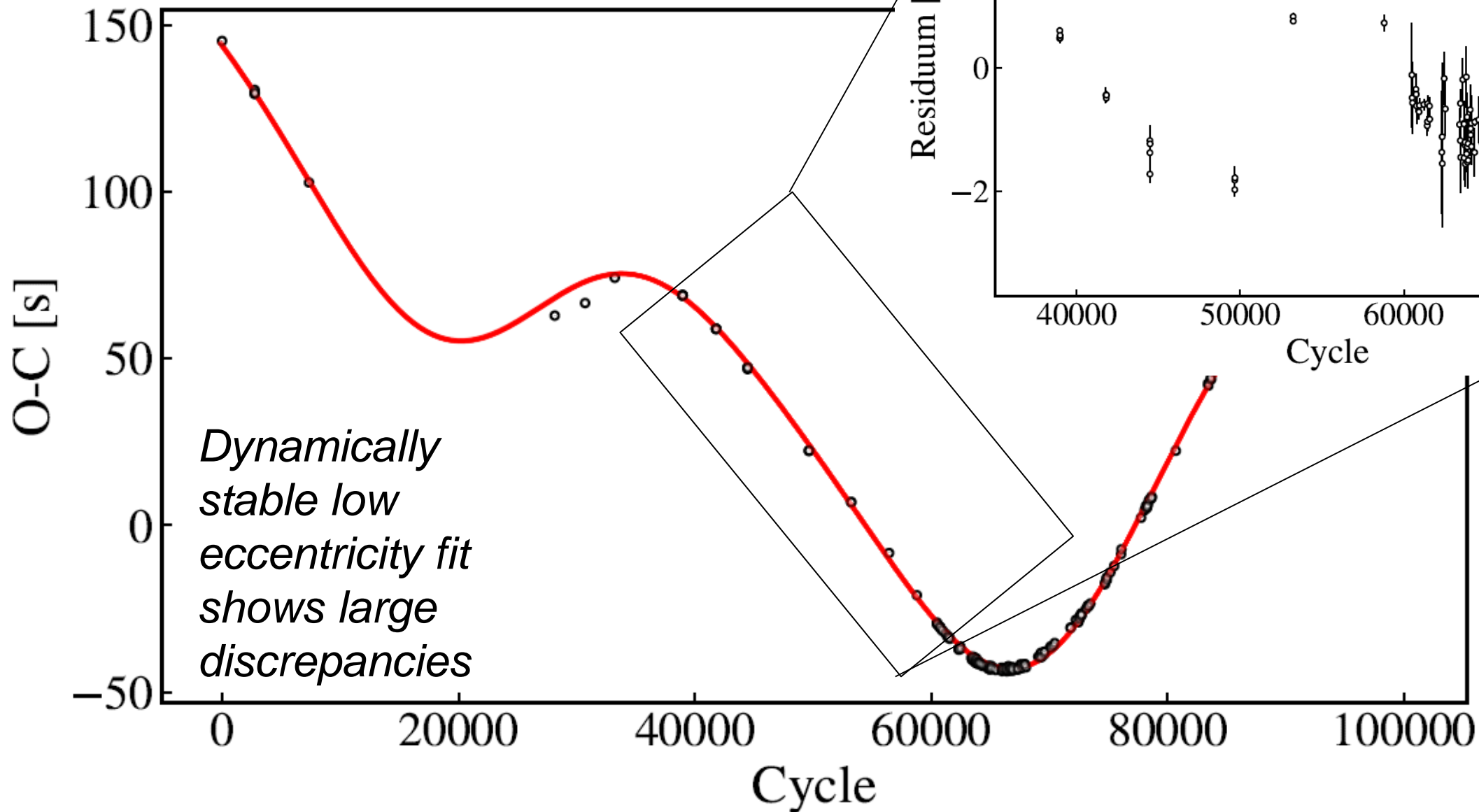
*Fit requires 3 companions*



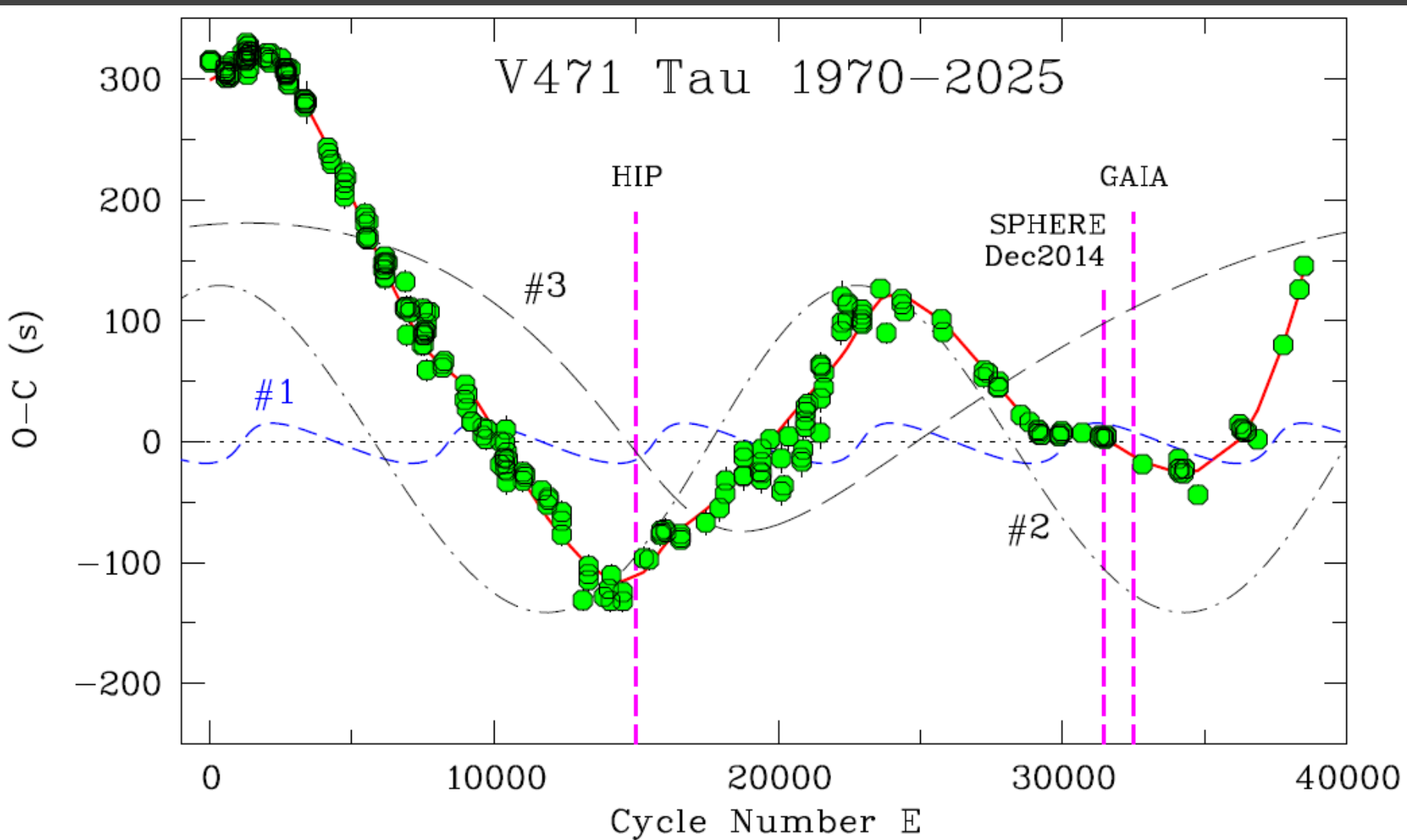
# NN Ser: A former good candi



# NN Ser: A former good candida



# V471 Tau: Impact of stellar activity



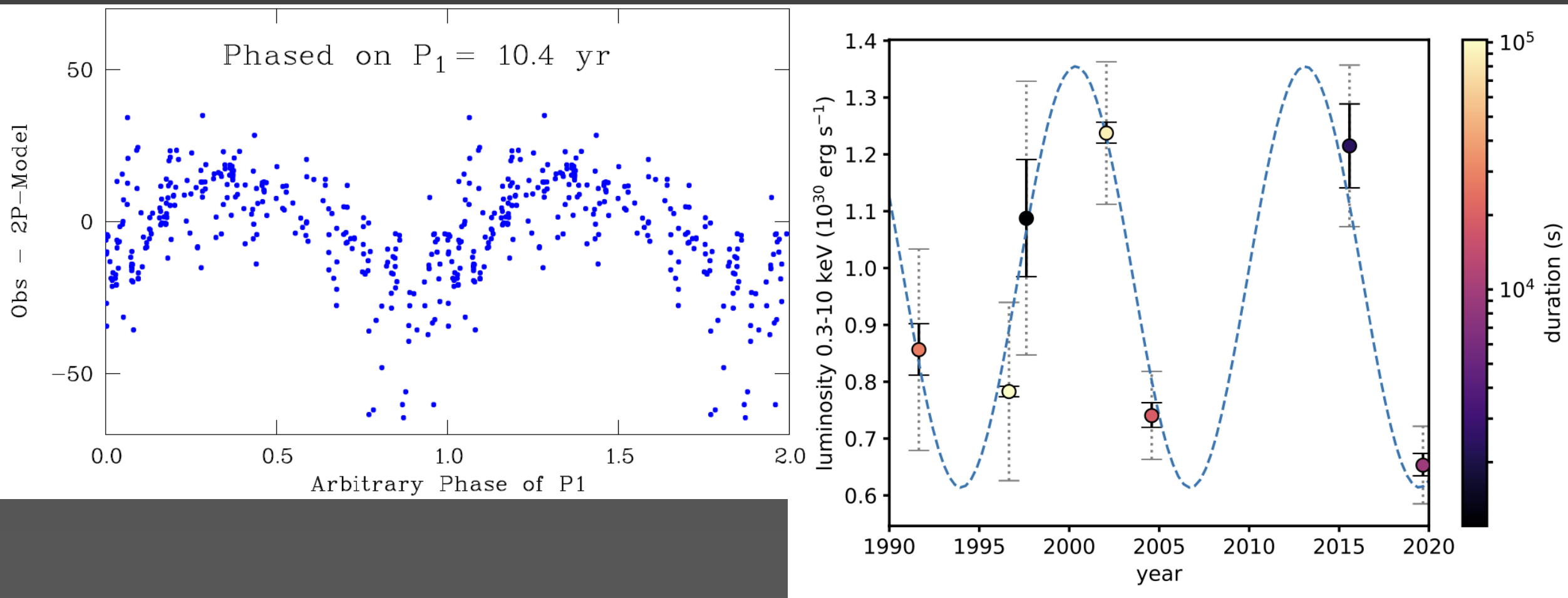
*Fit requires 3 companions:*

*Orbital stability?*

*SPHERE constraint?  
Hardy et al. (2015)*

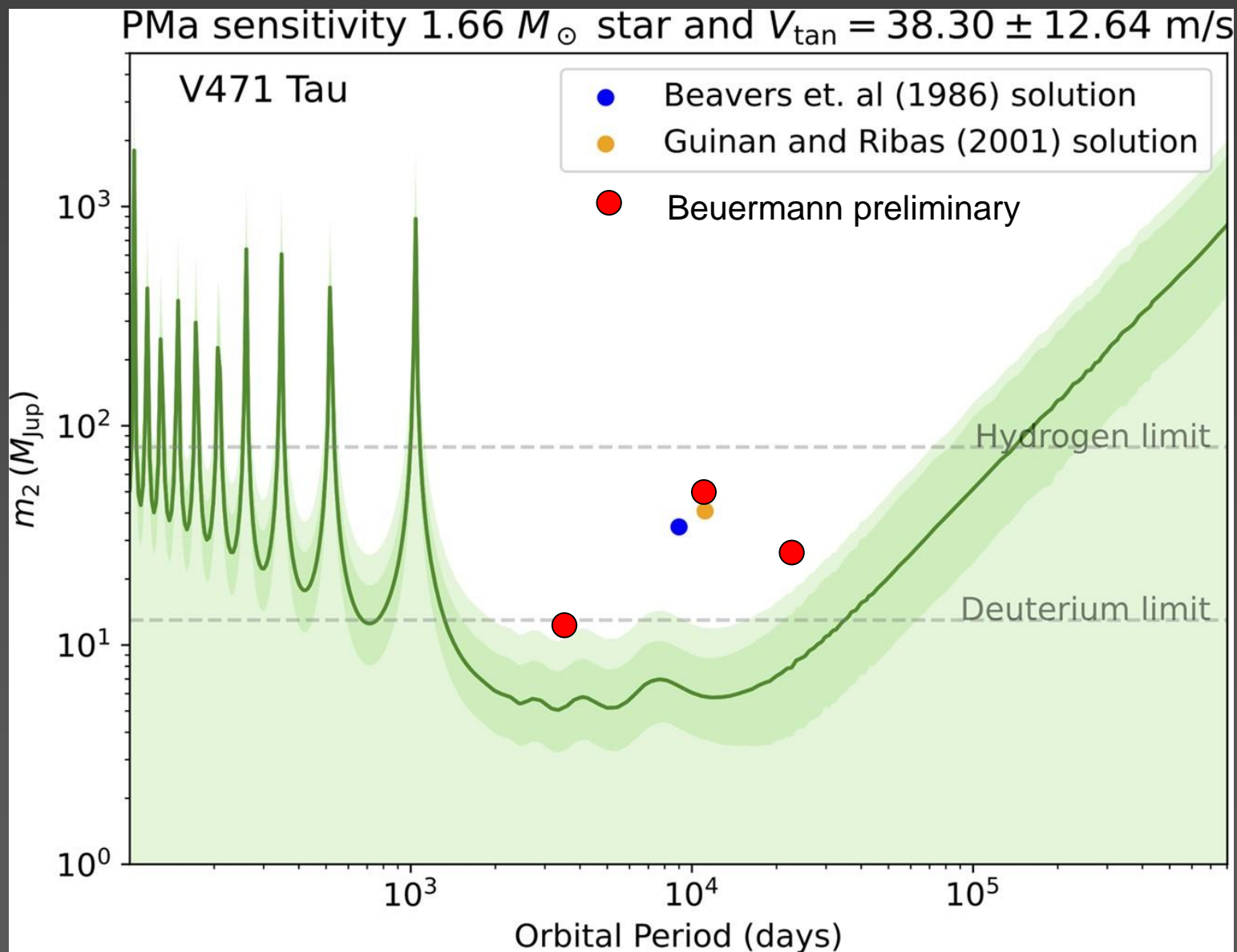
*GAIA+HIPARCOS  
constraints? Baycroft  
et al. (2023)*

# V471 Tau: Impact of stellar activity



# HIPARCOS+GAIA constraints

*Baycroft et al. 2023*



# Conclusion

- No consistent model available
- The very long periods in combination with the comparatively short observations and unknown binary period prevent finding unique solutions
- Orbital stability is in conflict with statistically good fits
  - No convincing multi-planet models for NN Ser, HW Vir, QS Vir, ...
- Stellar activity probably has an impact through the Applegate/Lanza mechanism
  - V471 Tau might be an example
- *GAIA* astrometry helps and will help to exclude long period ( $\sim > 30$ yr) companions and might confirm candidates