BRITE and Chaotic Pulsation in Cepheids

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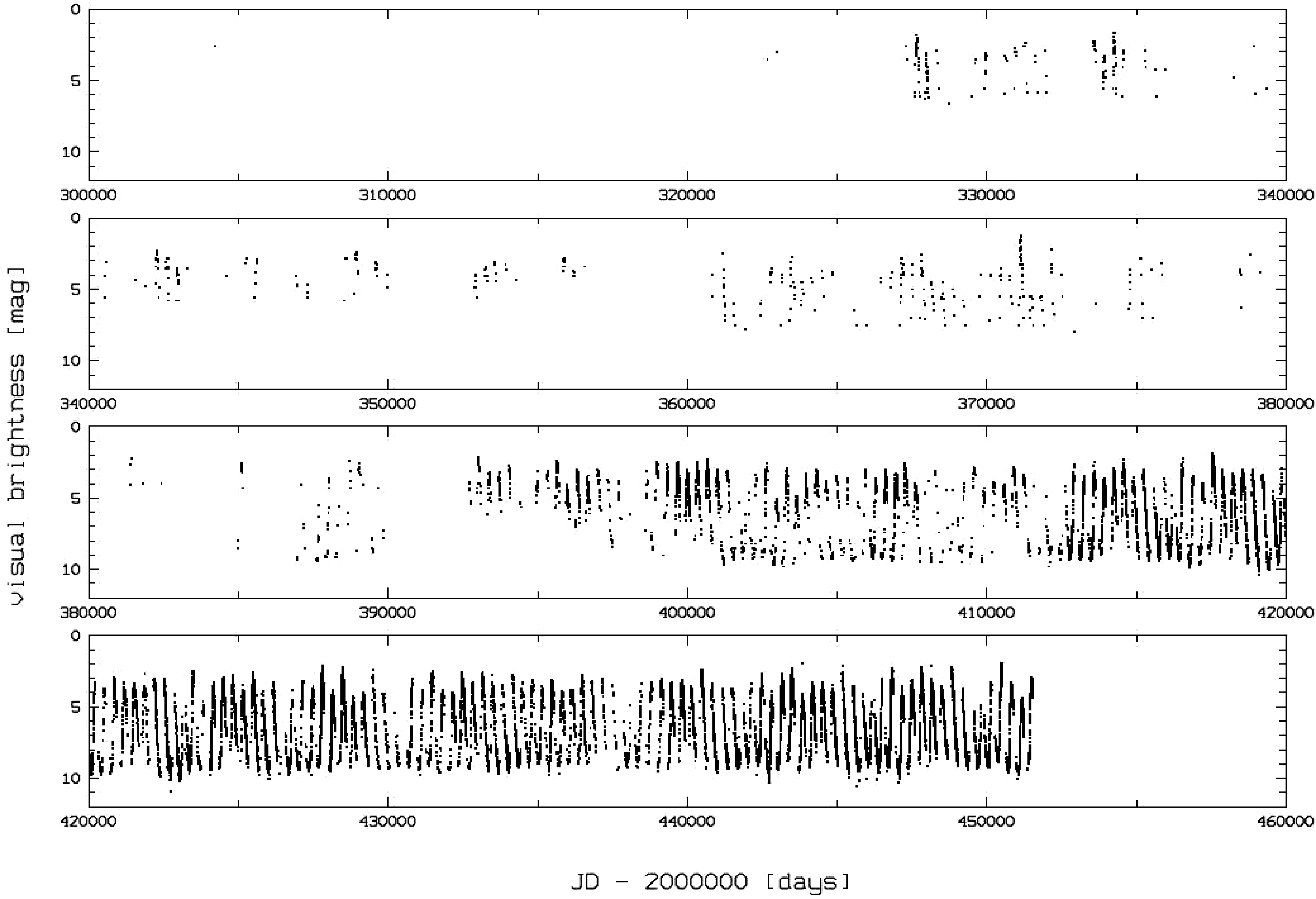
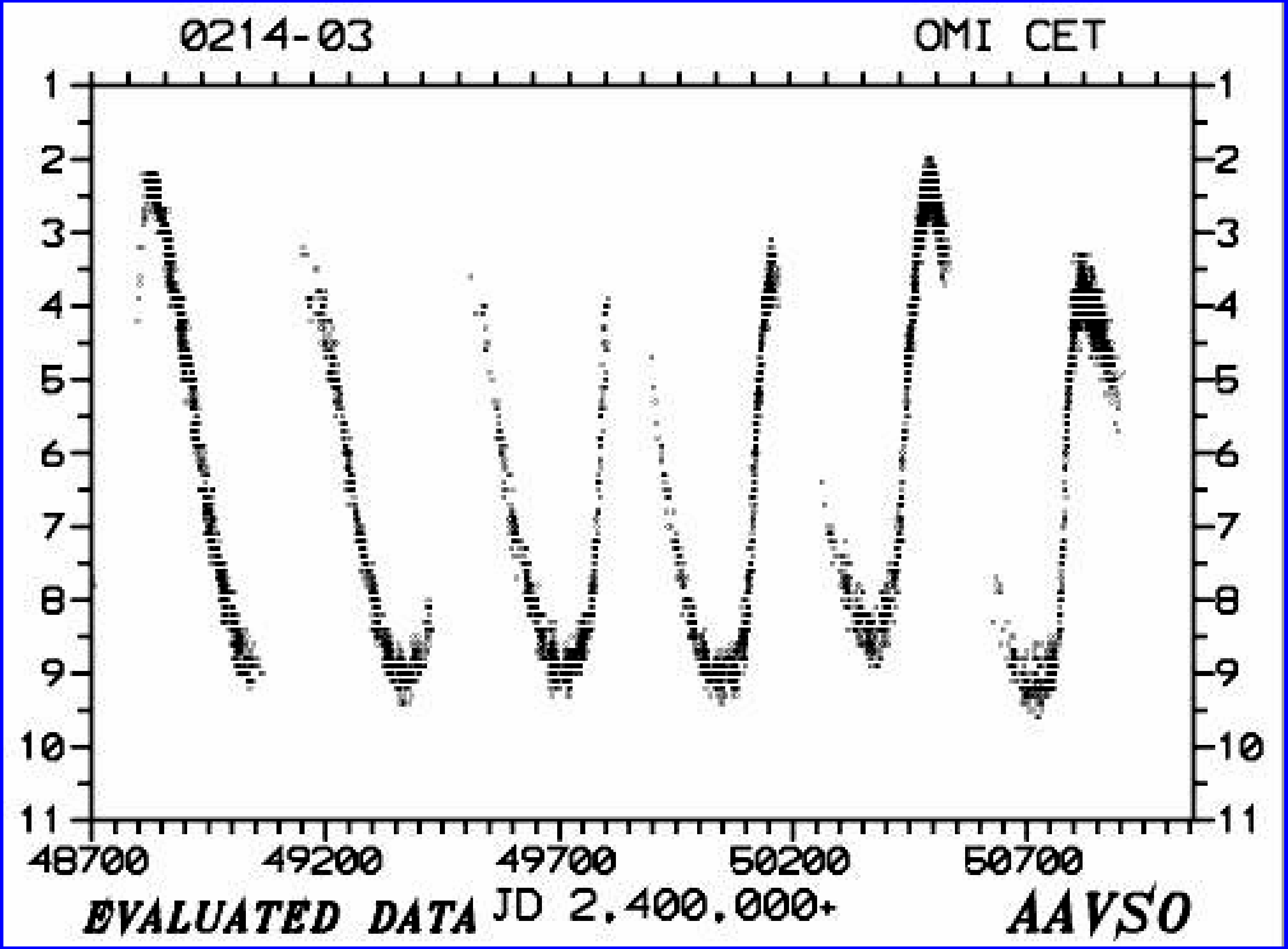
How can astrophysics be advanced through regular monitoring of bright pulsating variables?

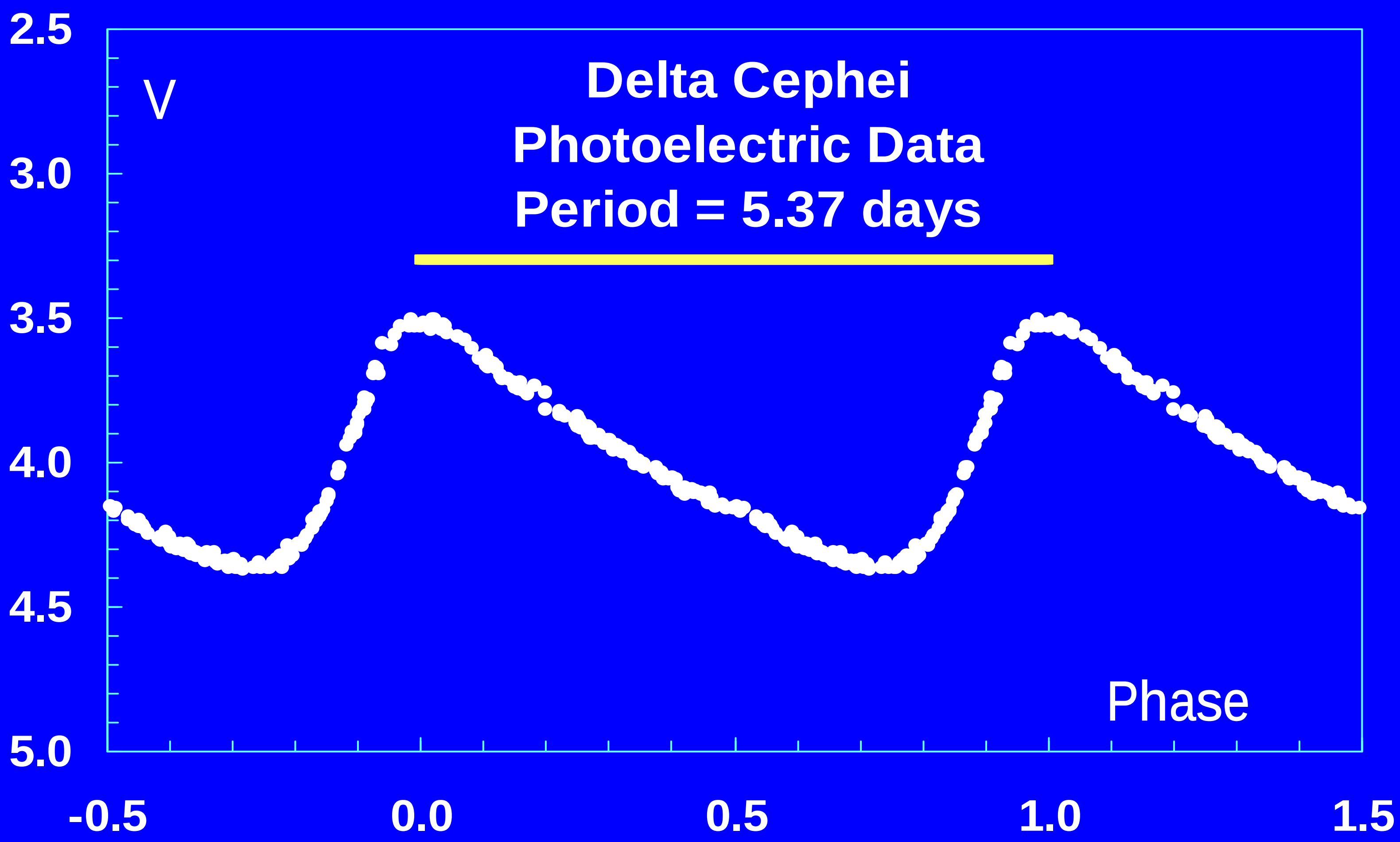
Answer: There are ~40 Cepheids plus many other pulsators (SRCs, Mira, δ Sct) visable without optical aid, and the nature of their pulsation is still not well understood, even after a century or more of study.



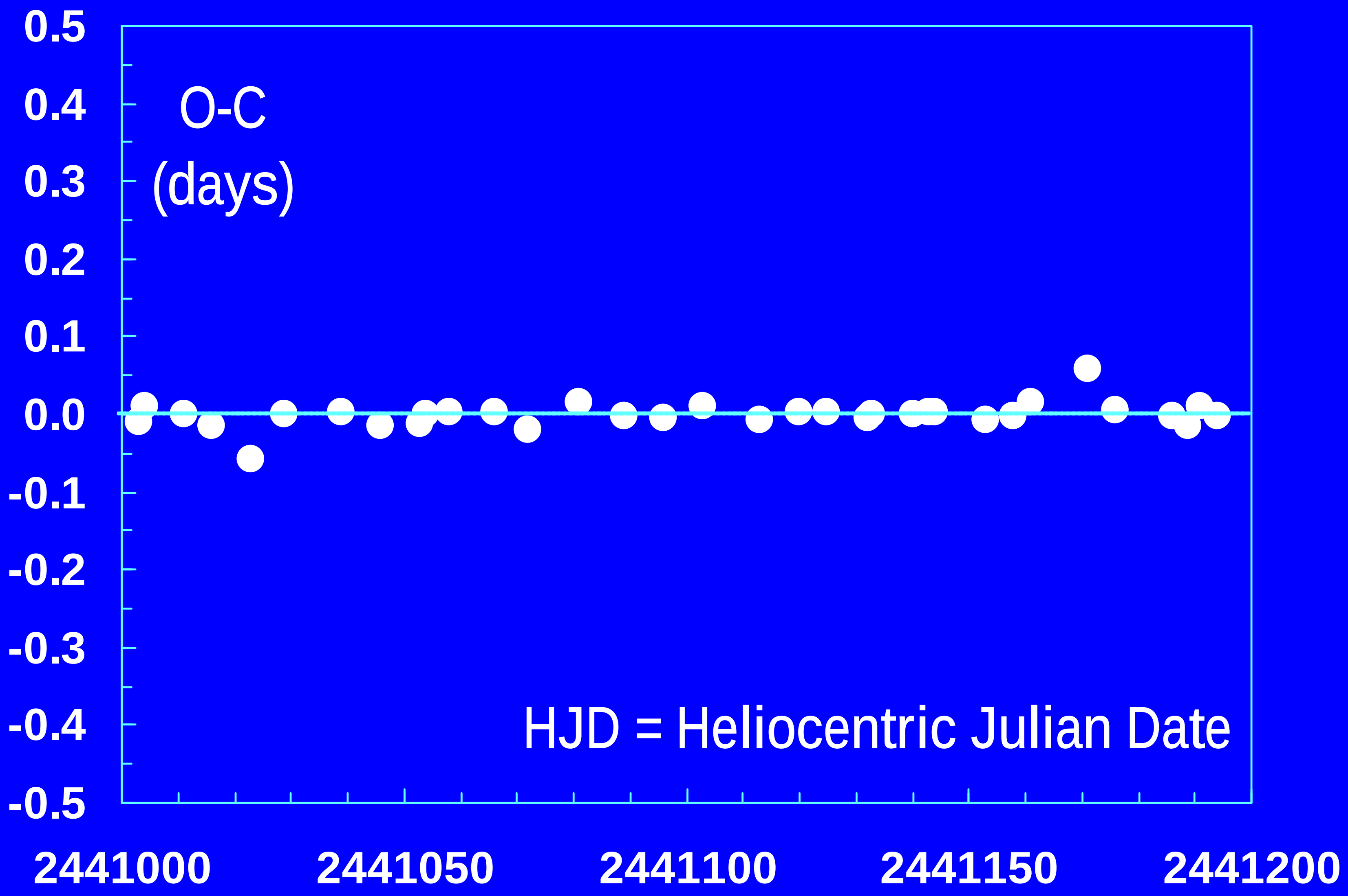
Regular pulsation in Mira (P = 332 days).



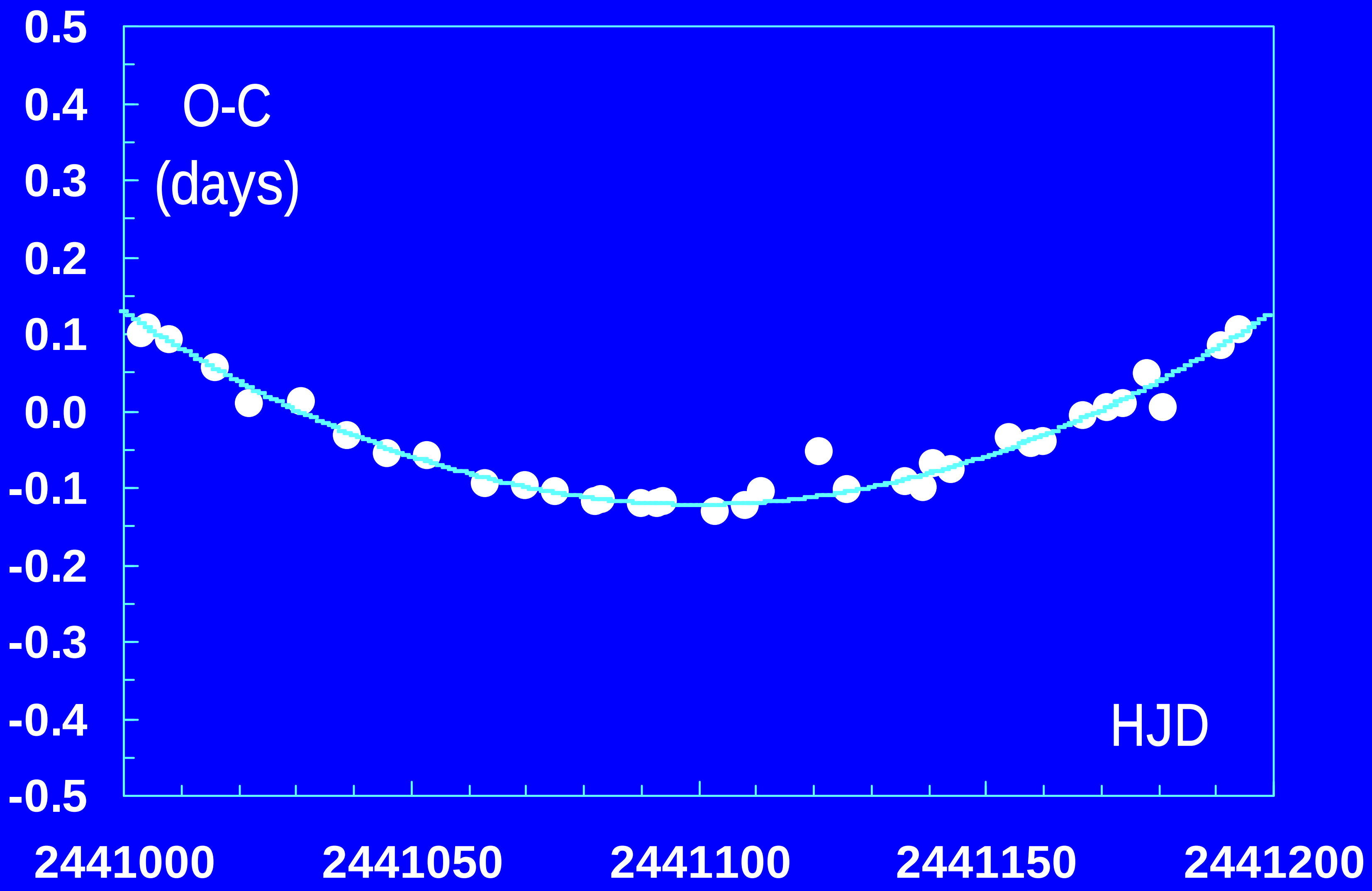
The amplitude varies, as well as the time of light maximum (less obvious).



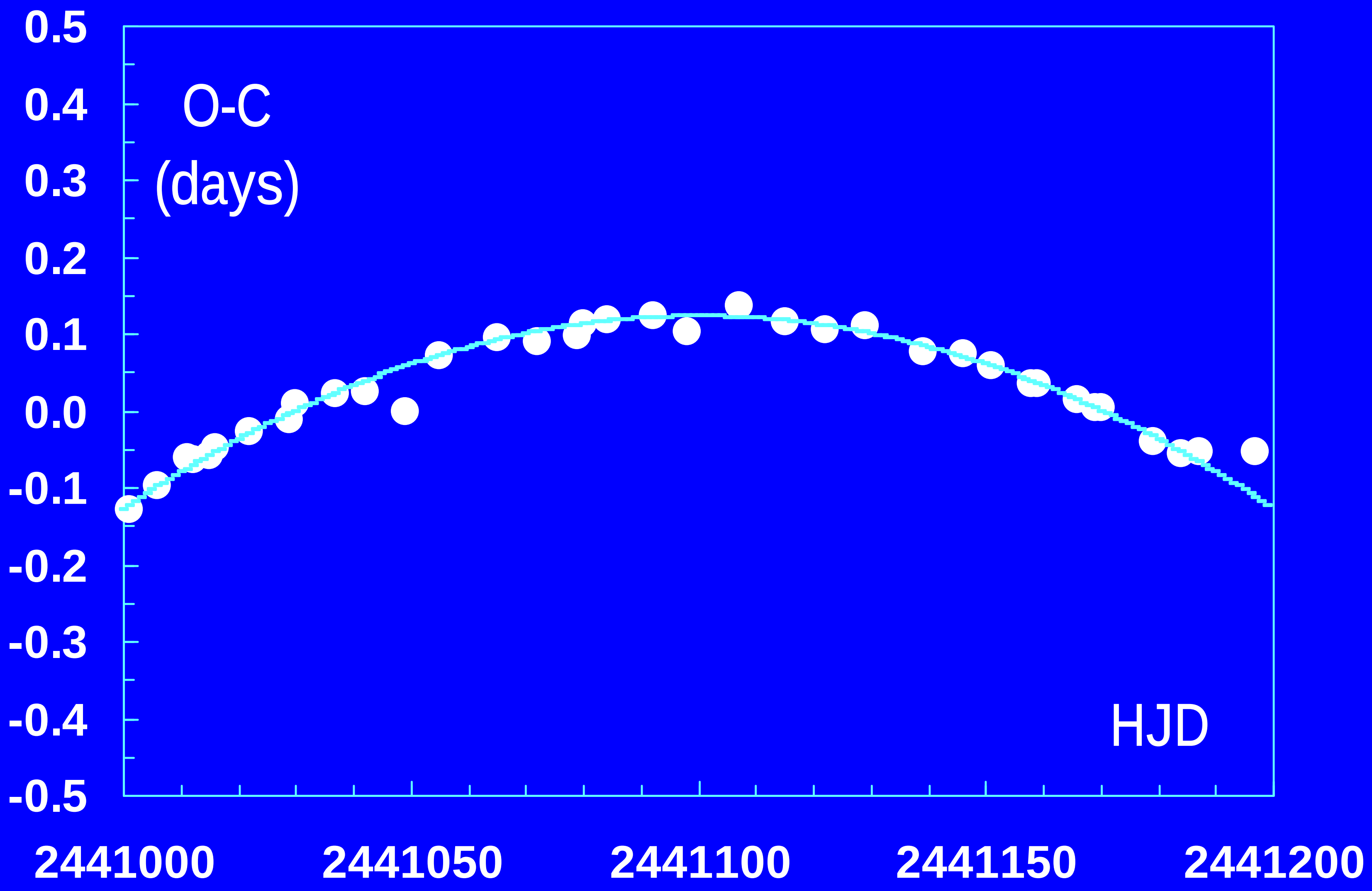
It is also true for Cepheids, but less obviously. Phased photoelectric observations of δ Cephei exhibit small scatter that may not be entirely from observational errors.



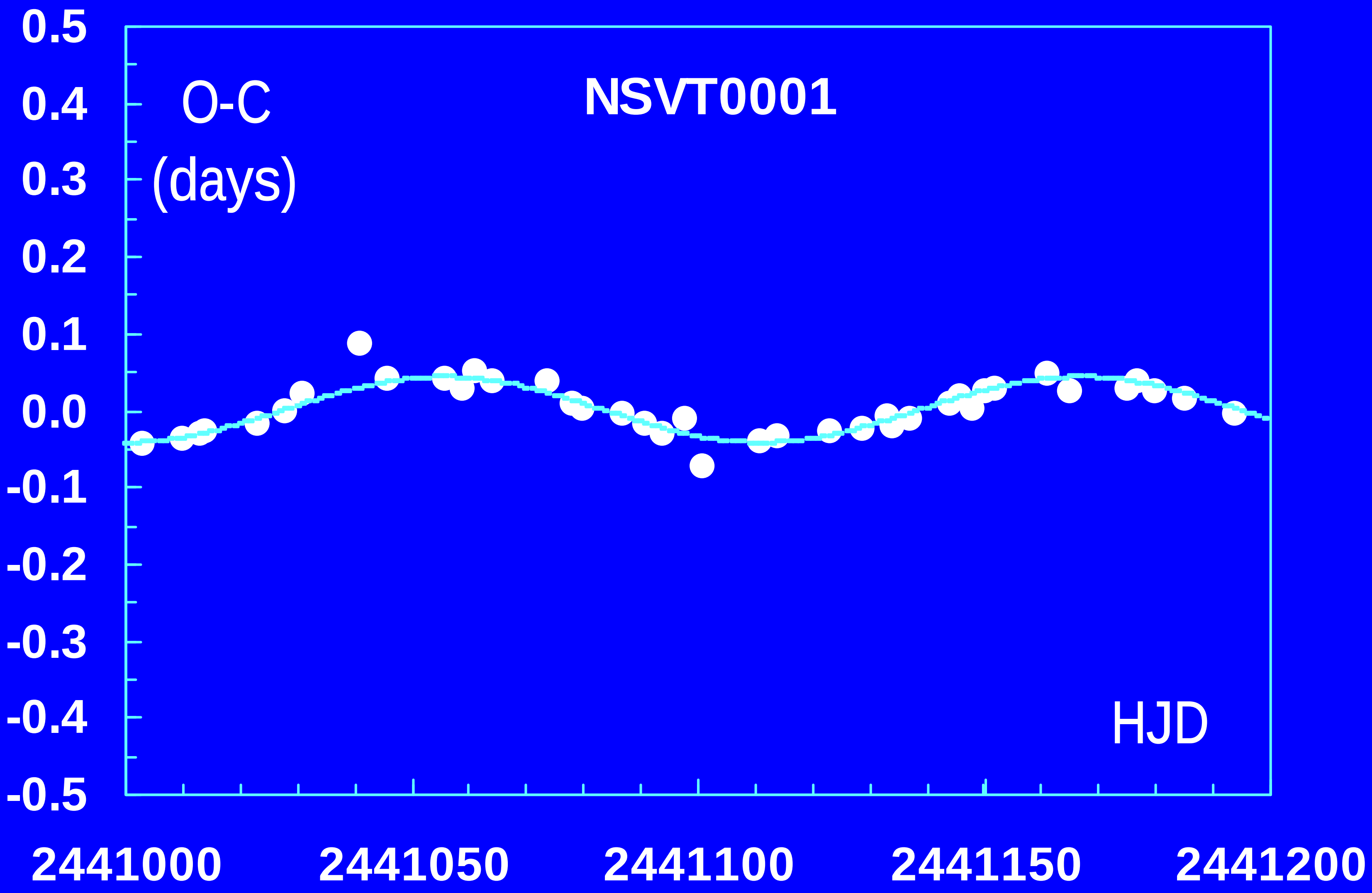
O–C diagrams: comparing Observed and Computed times for maximum, period constant.



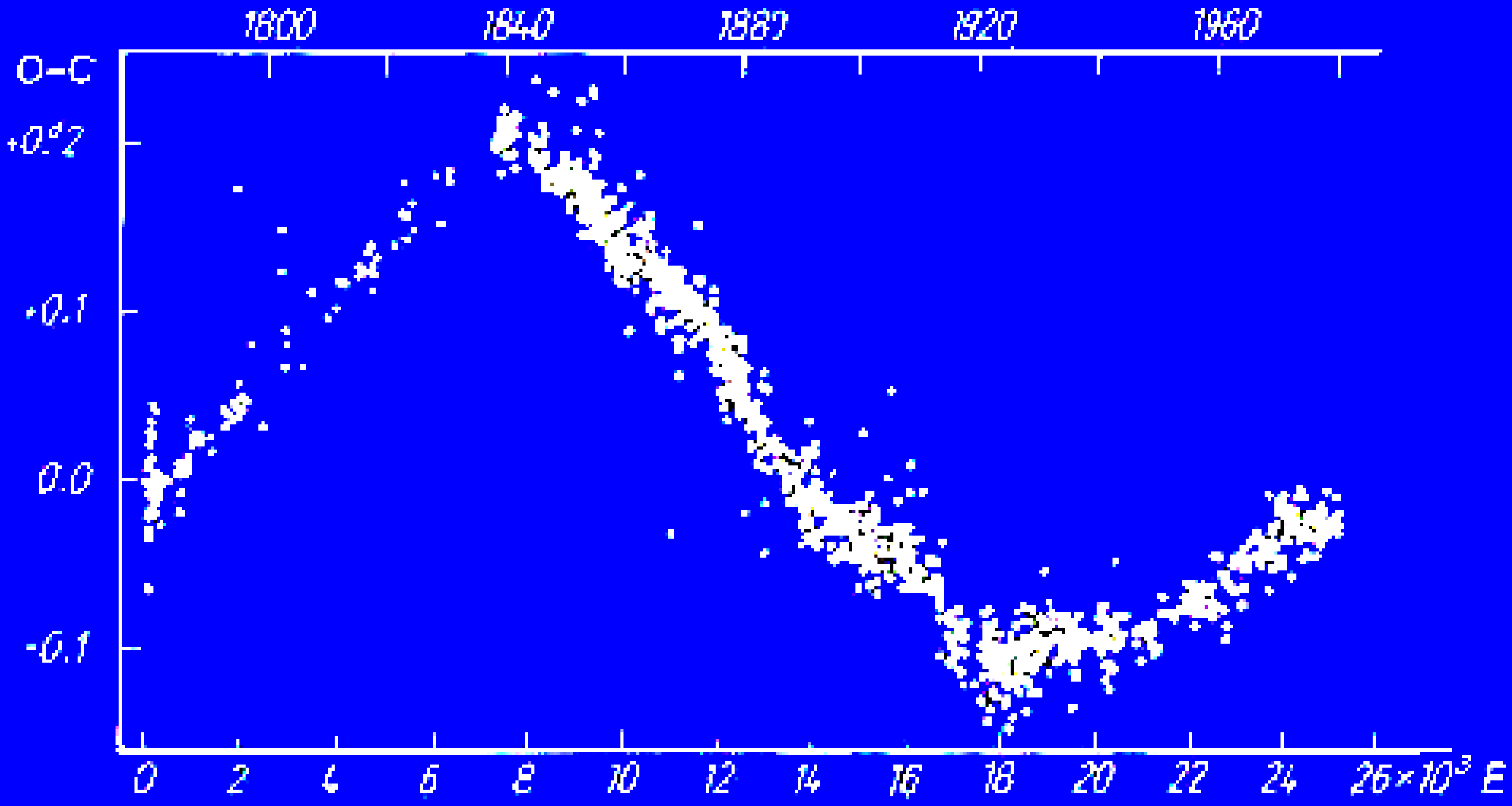
O–C diagram when the period increases at a constant rate.



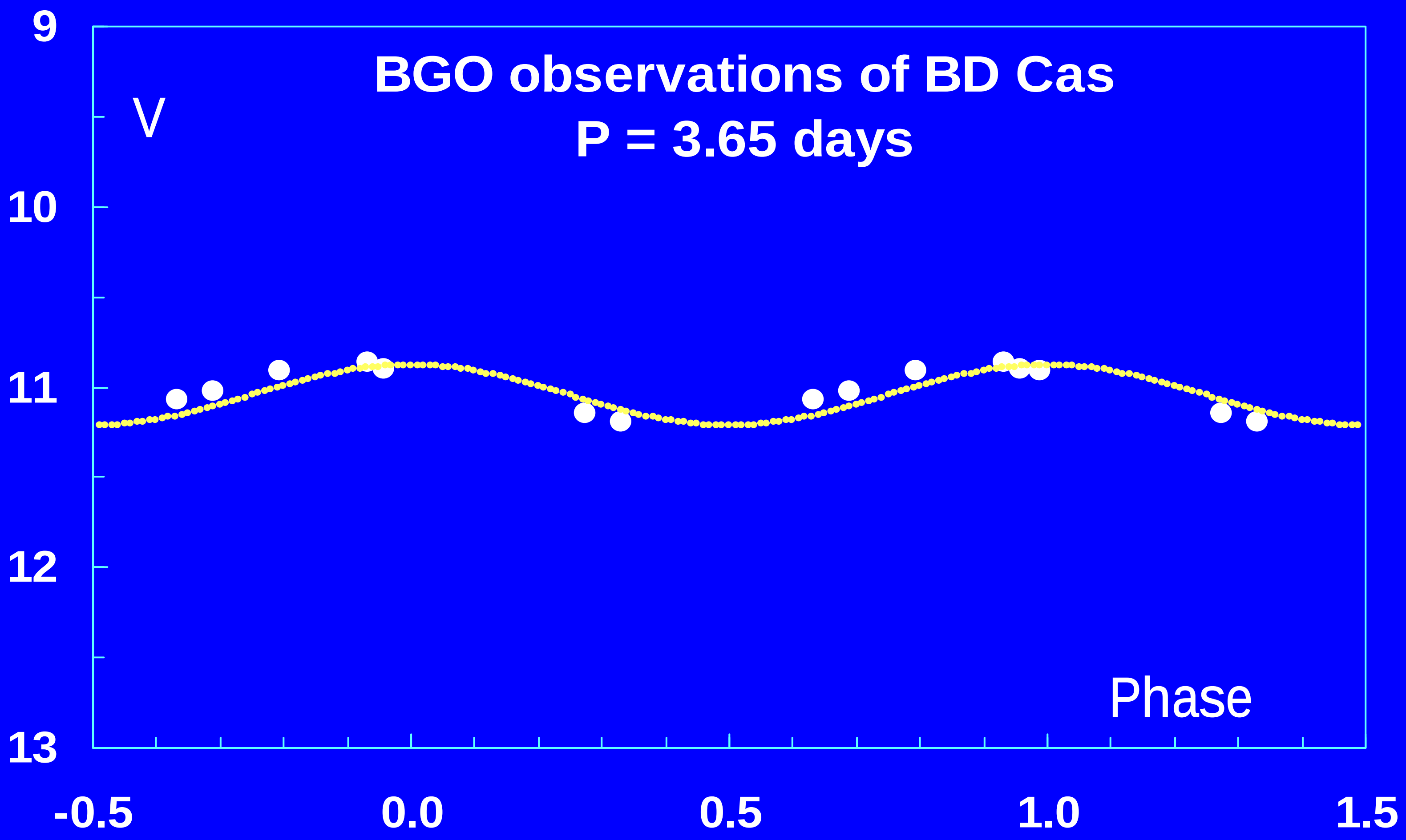
O–C diagram when the period decreases at a constant rate.



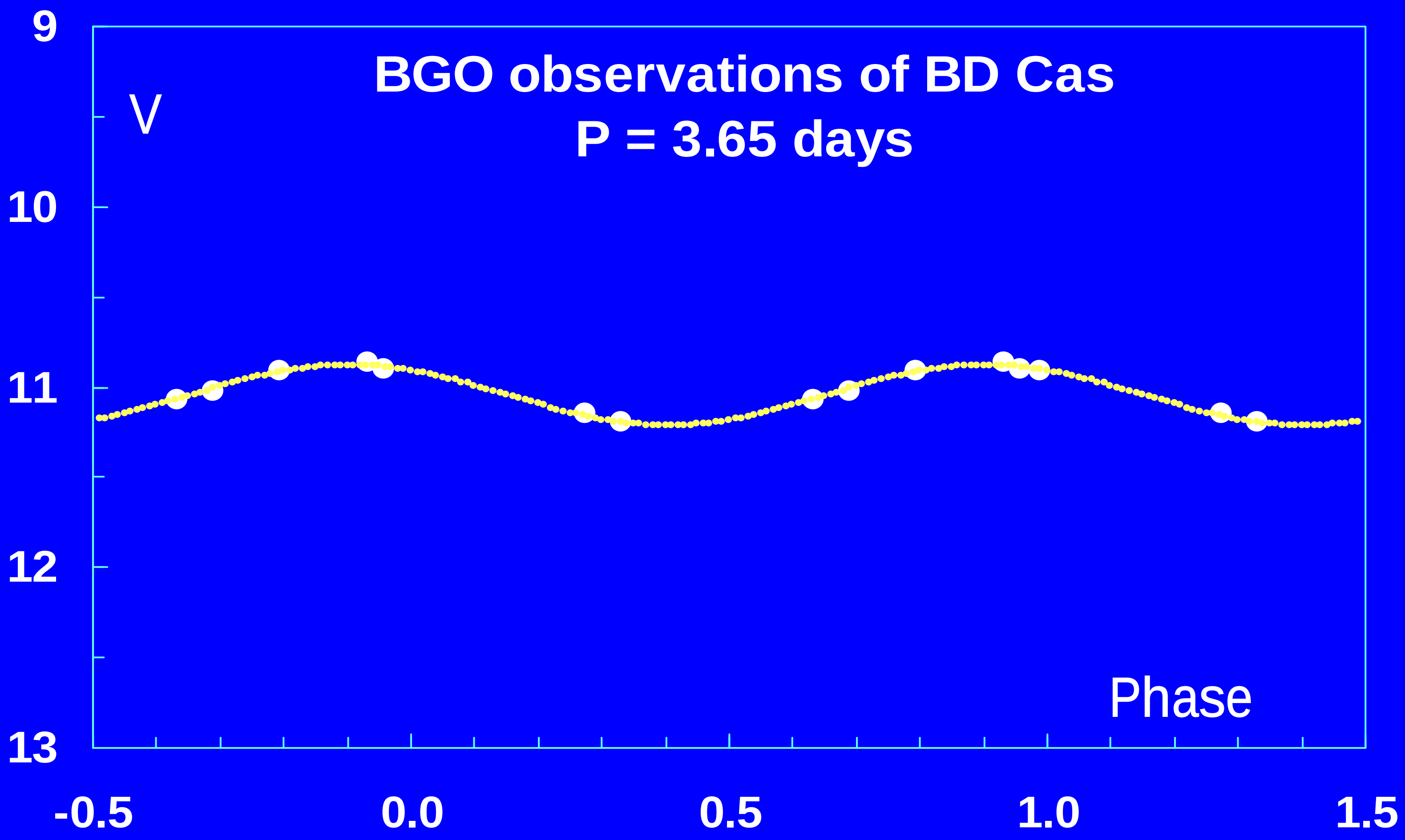
O–C diagram reflecting orbital motion about a companion.



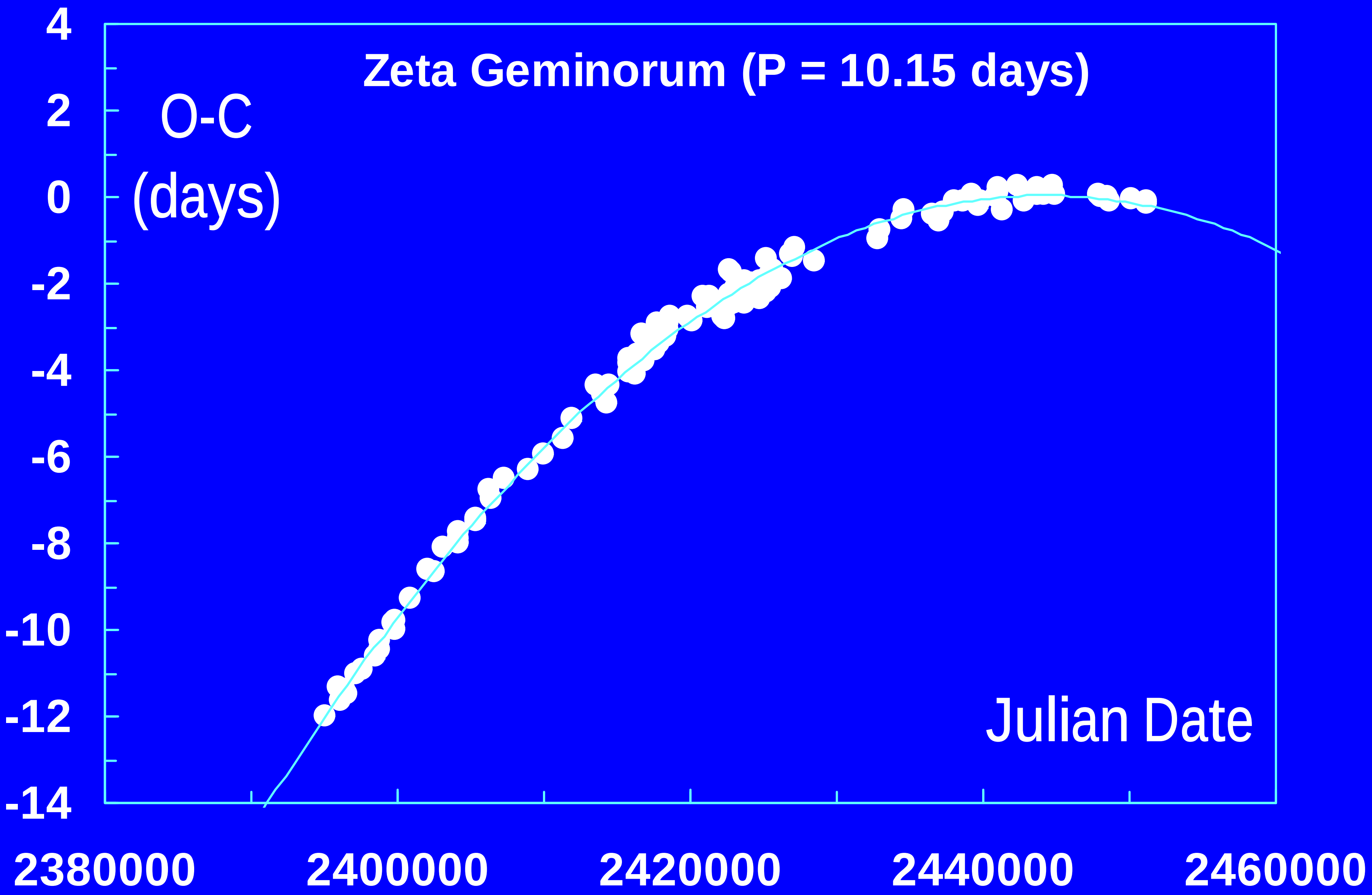
e.g., O–C data for the $2^d.867$ eclipsing binary Algol reveal the existence of a third star.



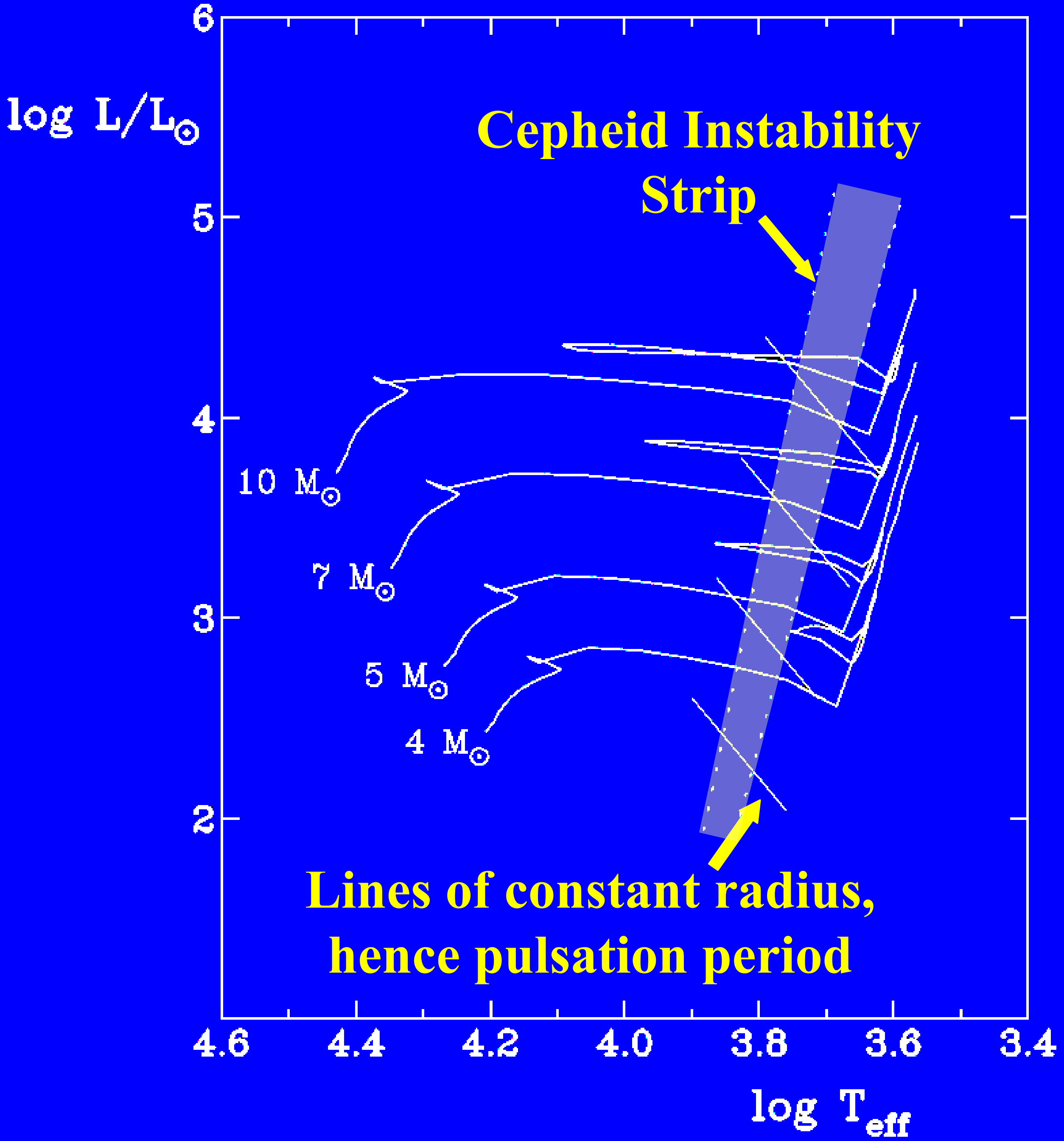
One need not actually observe light maximum to determine when it occurs: CCD observations of BD Cas relative to a reference sine wave.



The entire light curve is matched to a reference standard (here a sine wave) to establish the phase offset of light maximum ($\Delta V = \pm 0^m.01$).



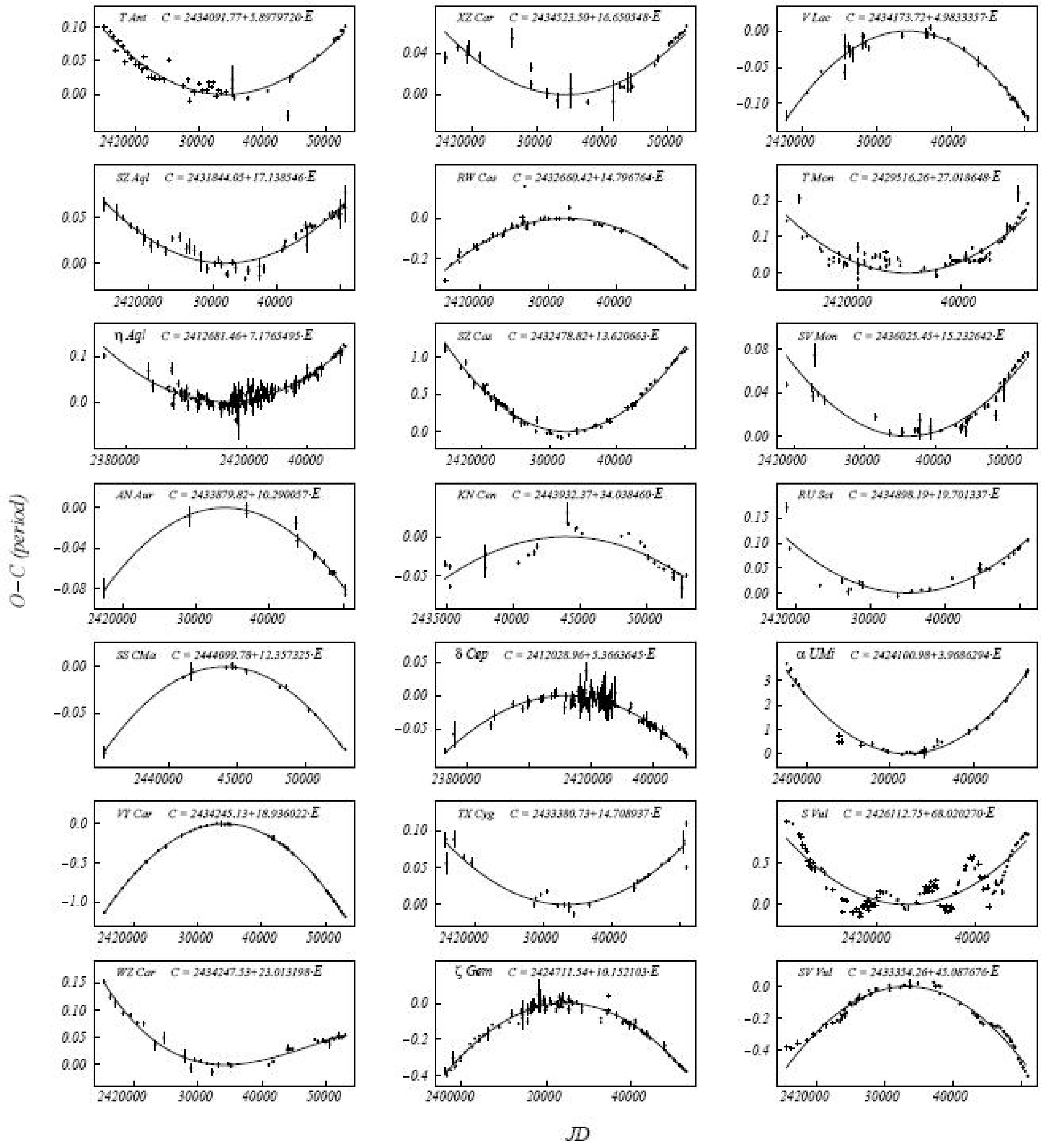
O–C diagram for ζ Gem illustrating its regular period decrease of –3.167 ±0.040 s/yr.



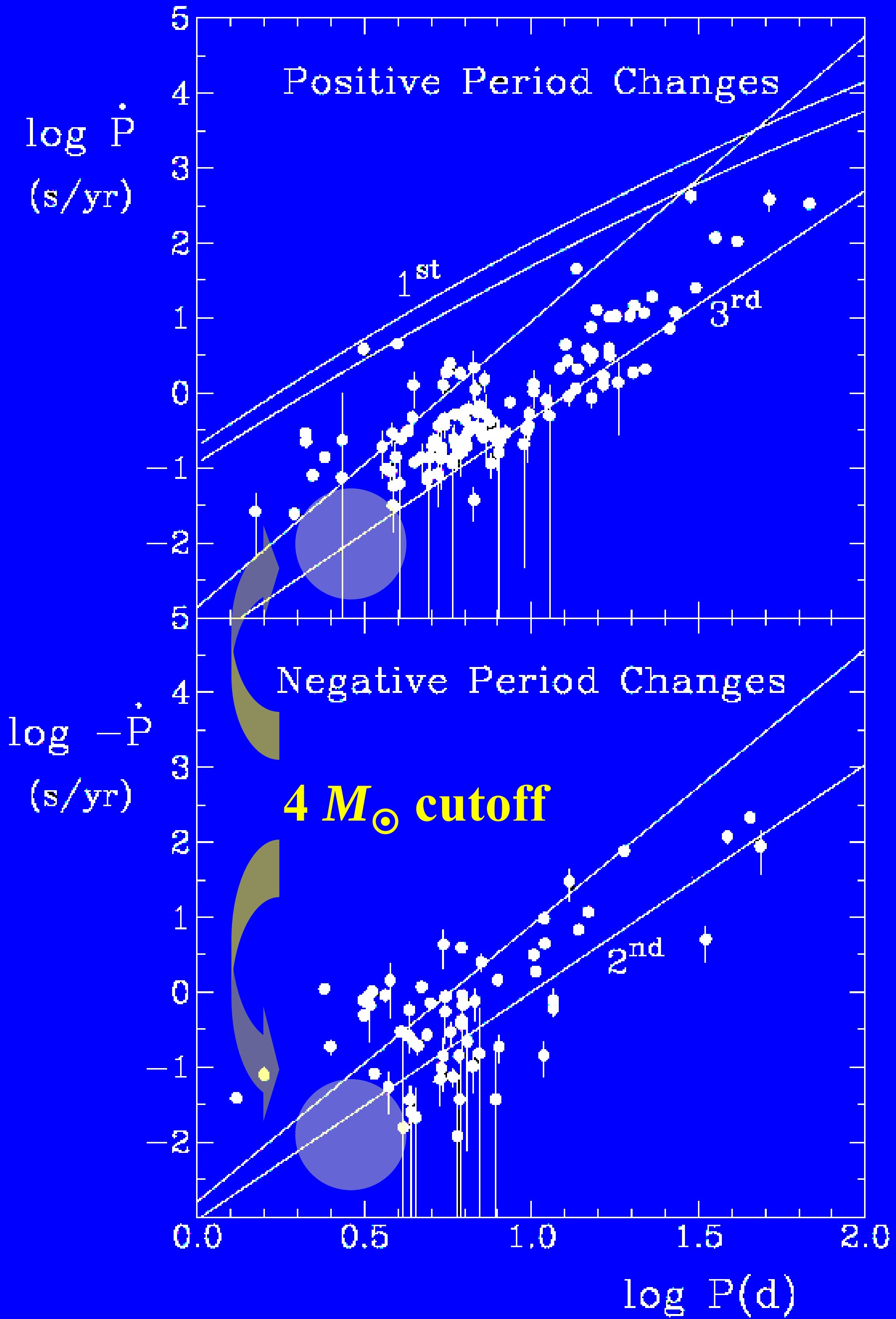
Cepheid Instability Strip

Lines of constant radius, hence pulsation period

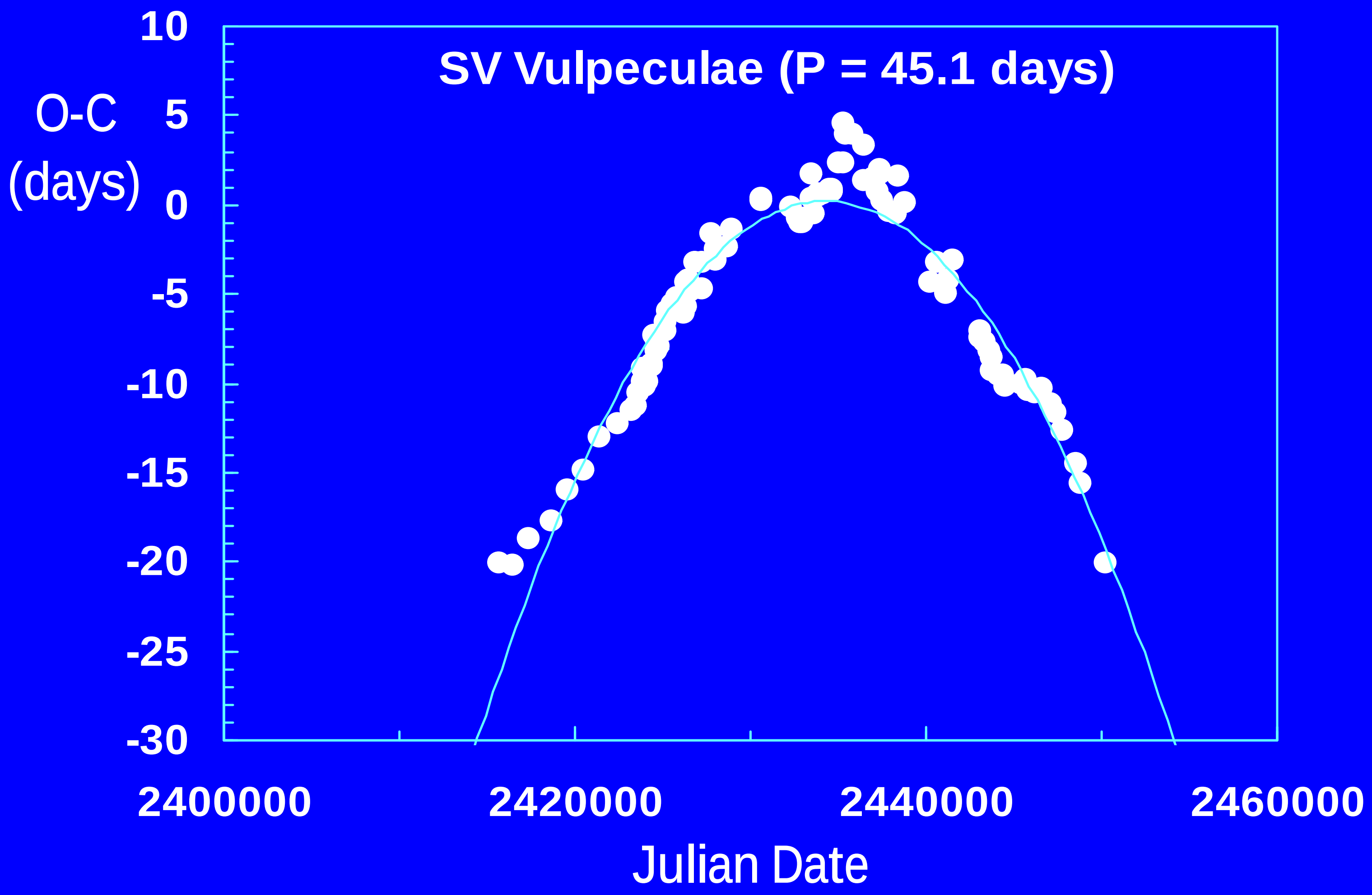
Differences in rate of period change at specific pulsation periods relate to position within the instability strip and crossing mode.



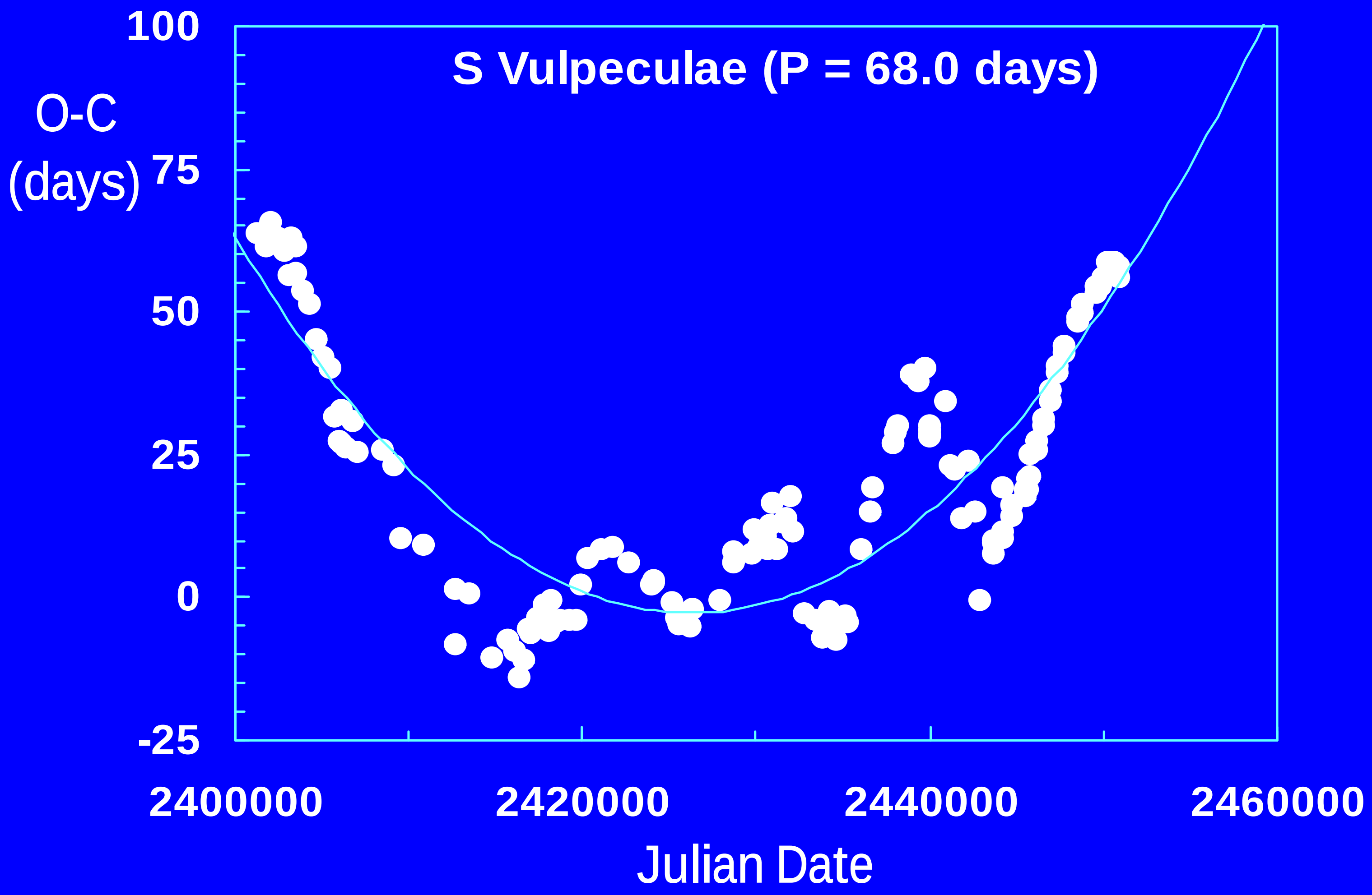
O–C diagrams for a selection of Cepheids exhibiting regular period changes.



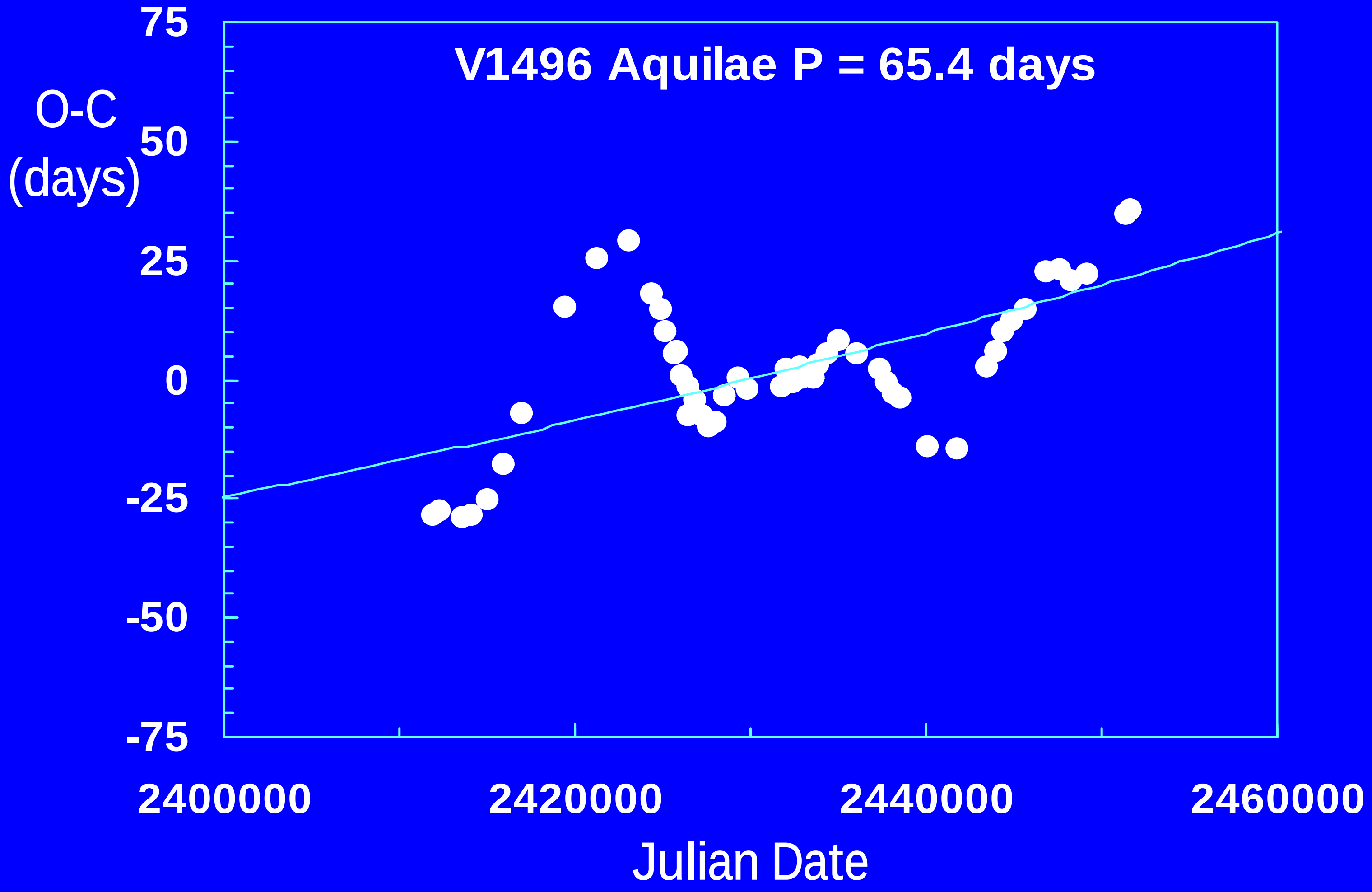
Observed rates of period change in Cepheids generally agree with predictions from stellar evolutionary models, but some differences are apparent. Note that specific crossing modes can be identified by direction and rate of period change.



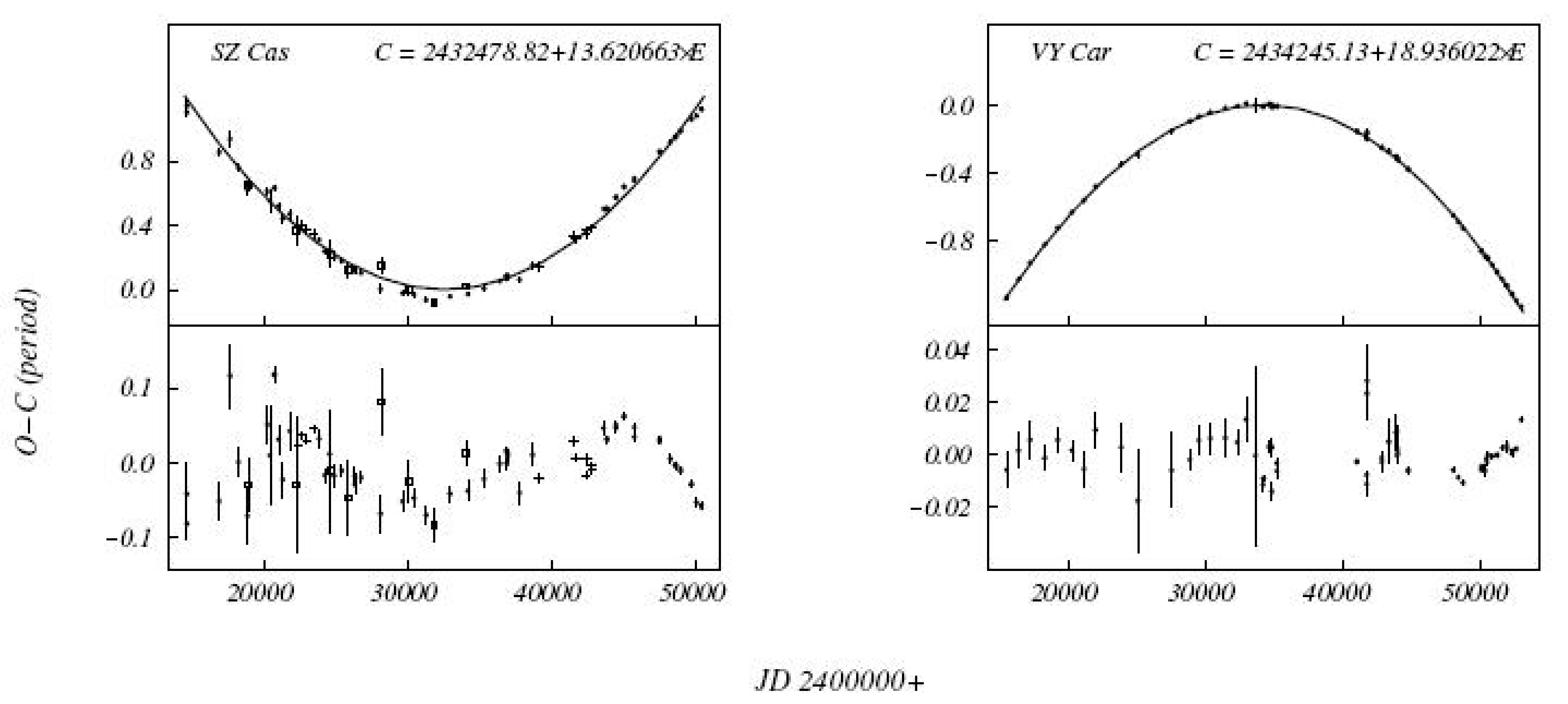
Non-evolutionary effects: random period changes in the long period Cepheid SV Vul are superposed upon evolutionary trends.



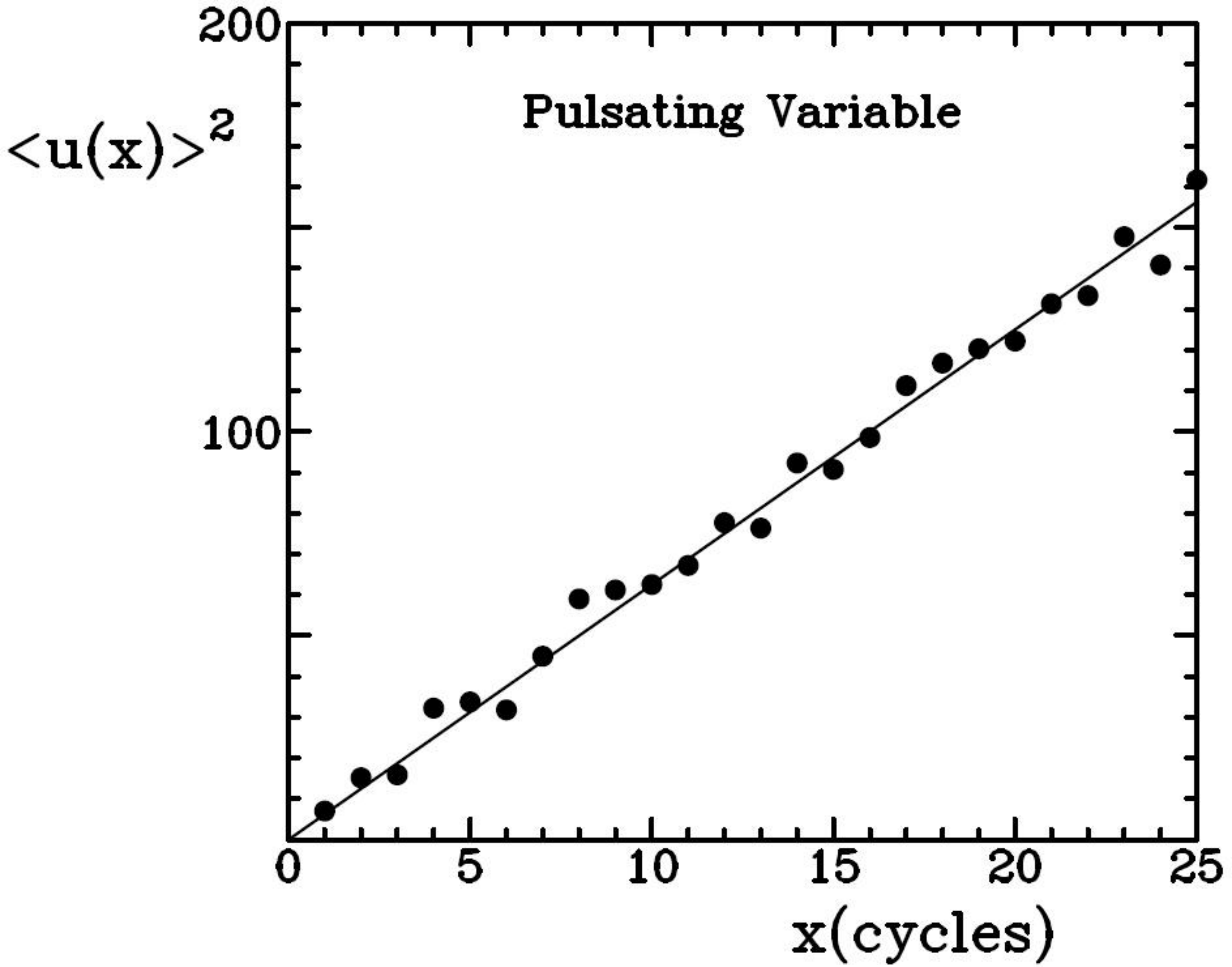
Random period changes are more dominant in the long period Cepheid S Vul.



Random period changes dominate evolutionary effects in the long period Cepheid V1496.

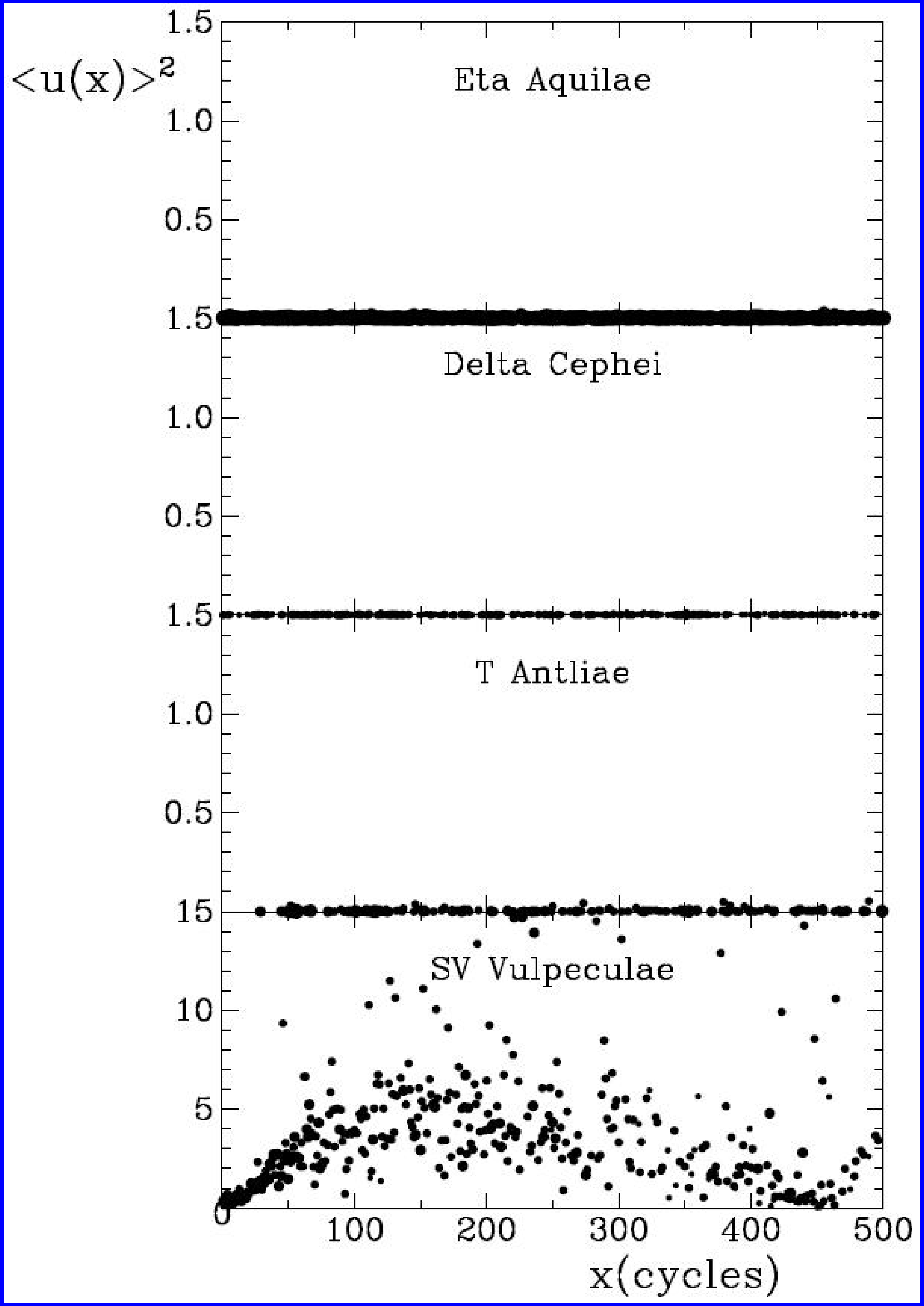


Random changes in period are detected from the O–C residuals and their temporal variations.

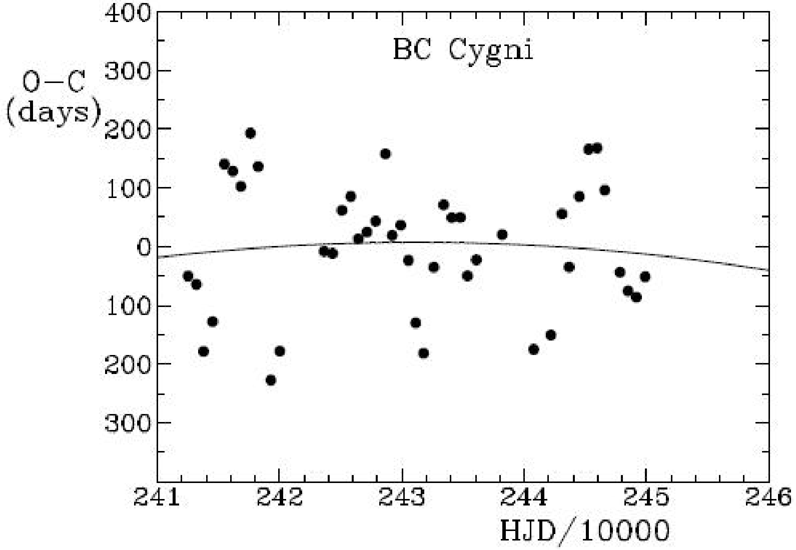


$$\langle u(x) \rangle^2 = 2a^2 + xe^2$$

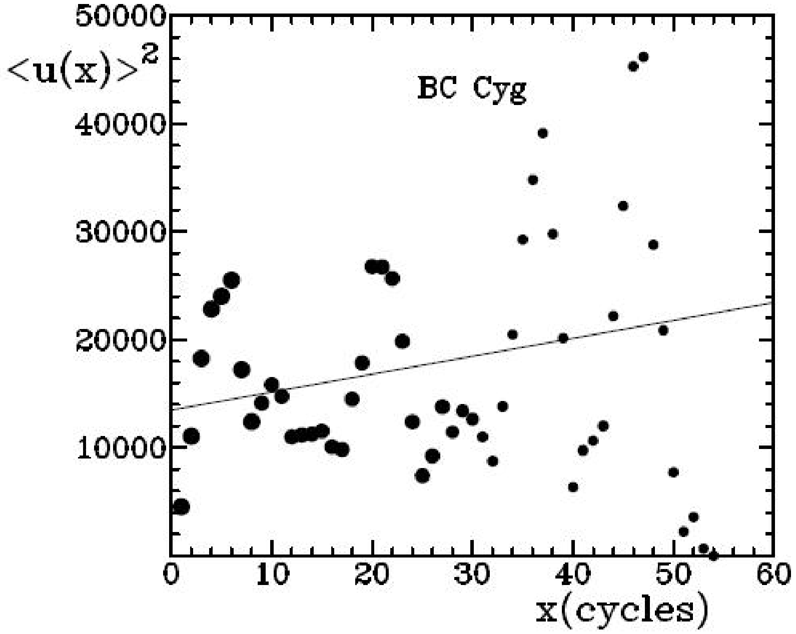
Average O–C differences <*u(x)*> correlate with random period changes *e* and measuring uncertainties *a* (Eddington and Plakidis 1929).



Eddington tests on many Cepheids fail to detect random period changes because light curves are often constructed from averages over many cycles.

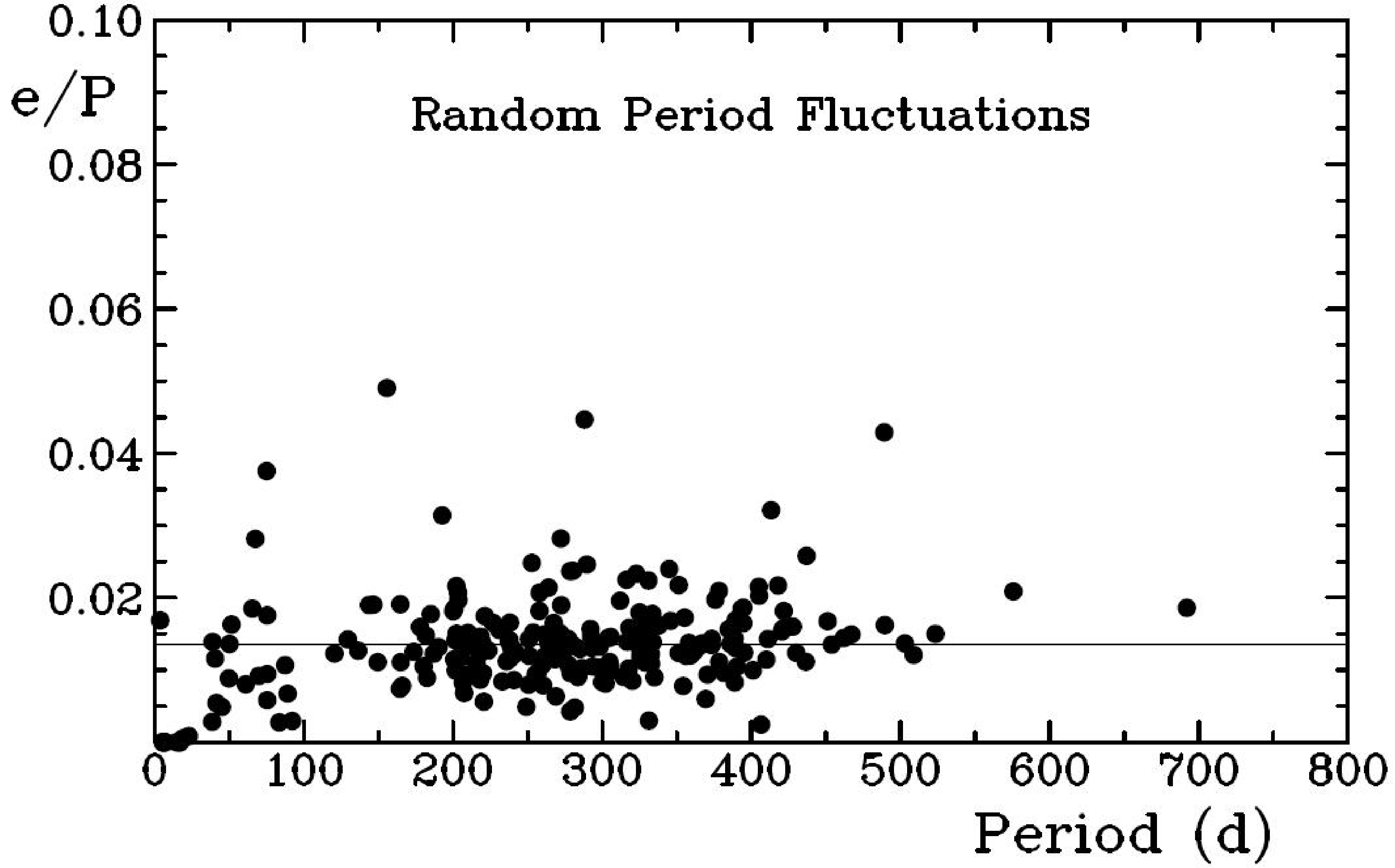


O–C trends for the M supergiant BC Cyg.

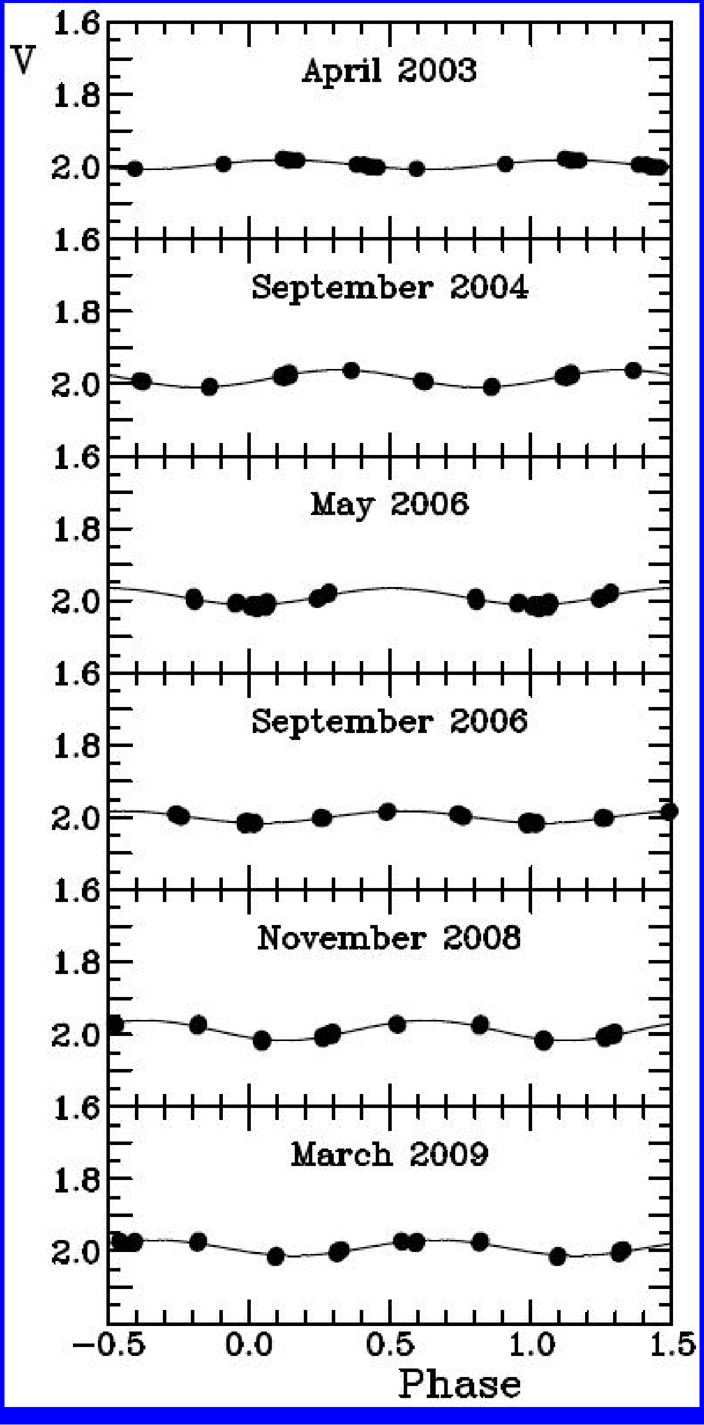


An Eddington-Plakidis test for BC Cyg.

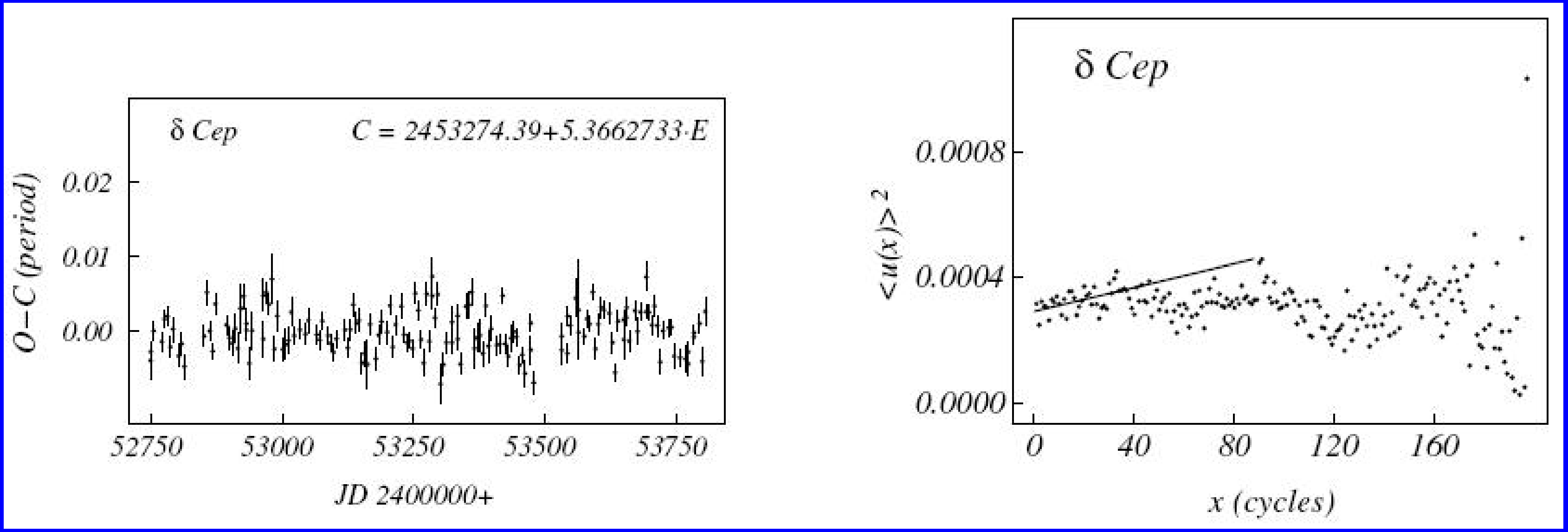
Random period changes are relatively easy to detect in long period pulsators, such as BC Cyg (M3 Ia, P = 700^d).



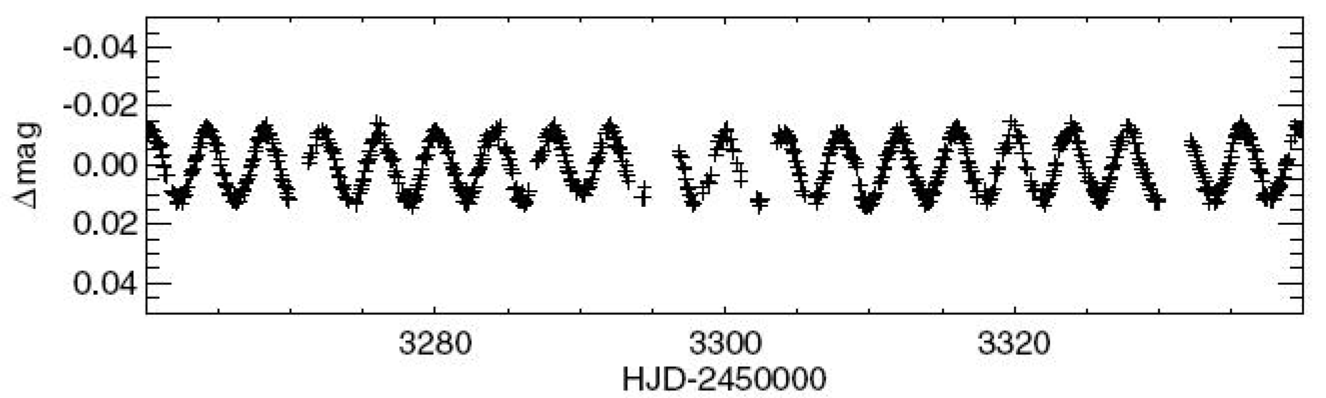
The ratio of randomness factor *e* to pulsation period *P* is ~constant for all pulsating stars: *e/P* = 1.36% ±0.05%.

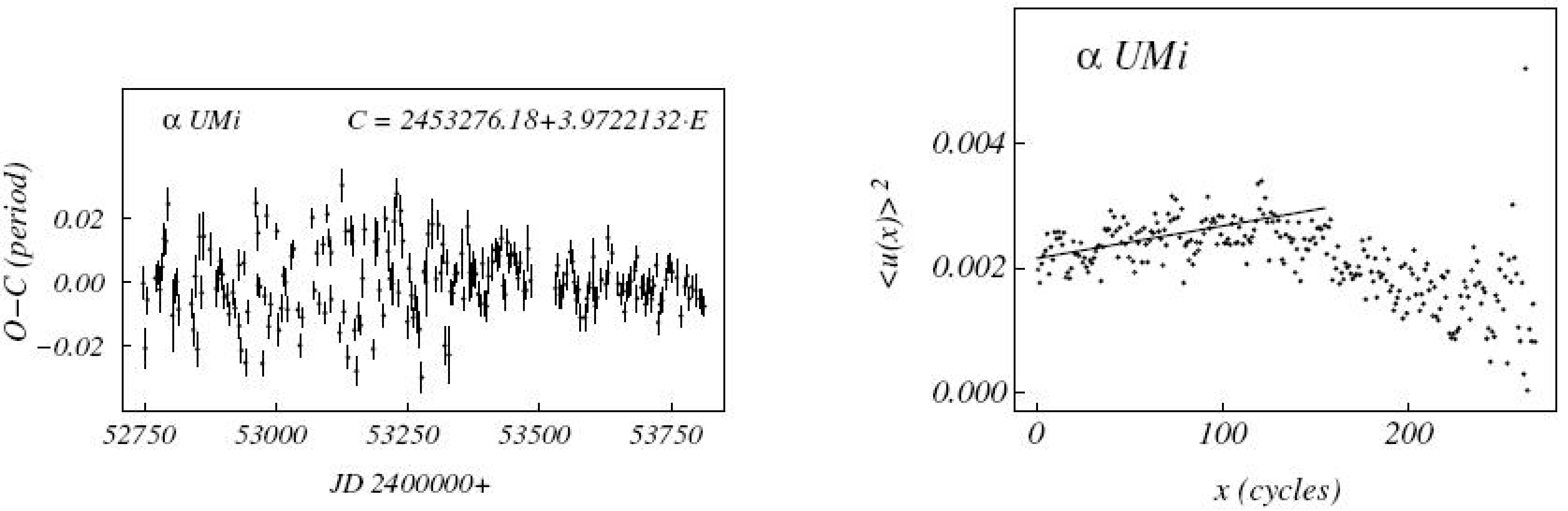


Detecting random changes in period for short period pulsators from ground-based observations is hampered by the lack of continuous monitoring: light curves for Polaris displayed here exhibit scatter larger than that expected from the photometric precision of the observations, ±$0^m.005$.

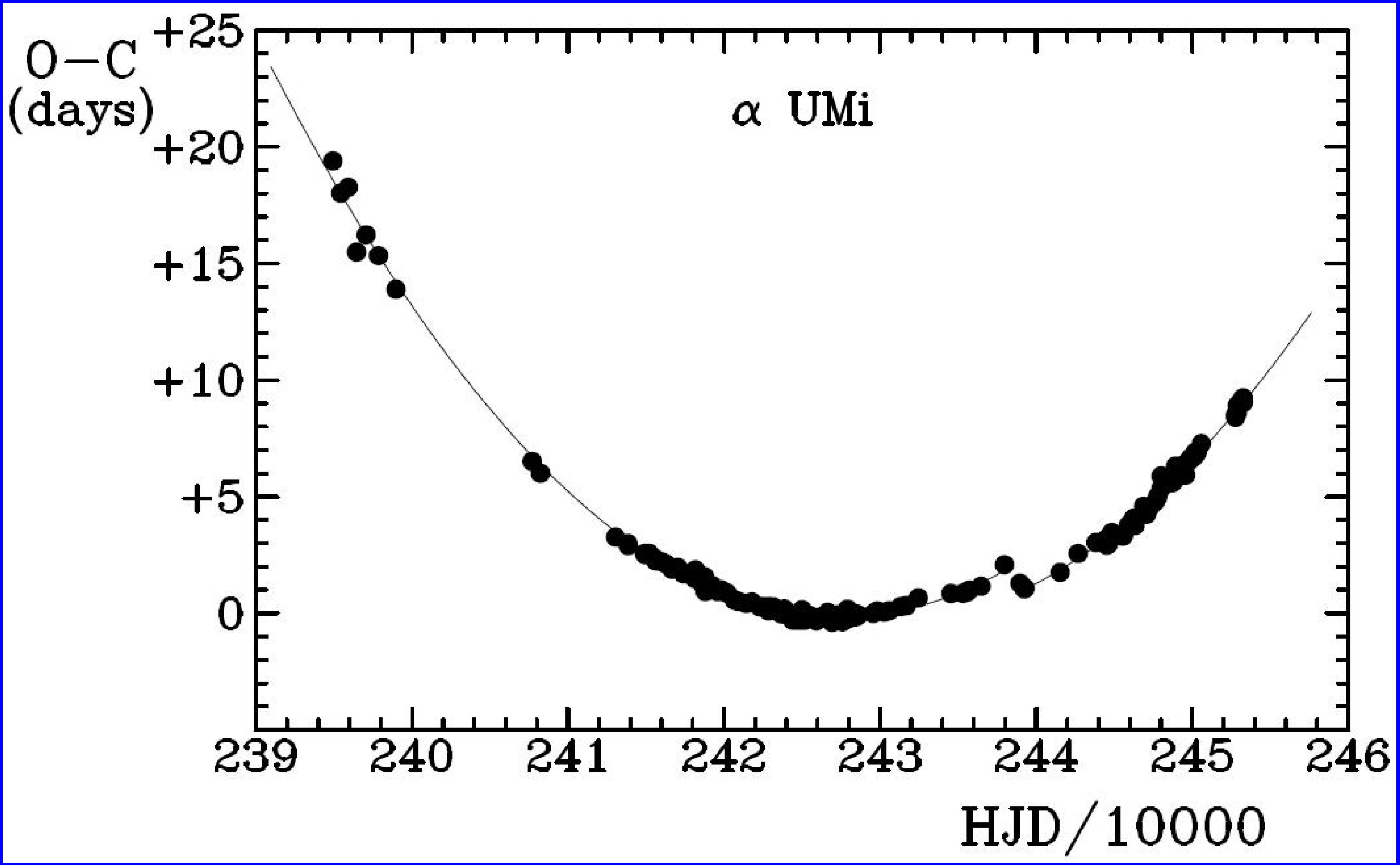


Continuous monitoring is needed to test for chaos in short period pulsators. Tests by Berdnikov & Stevens (2010) using SMIE observations of δ Cep from the Coriolis satellite (*e/P* = 0.03%).

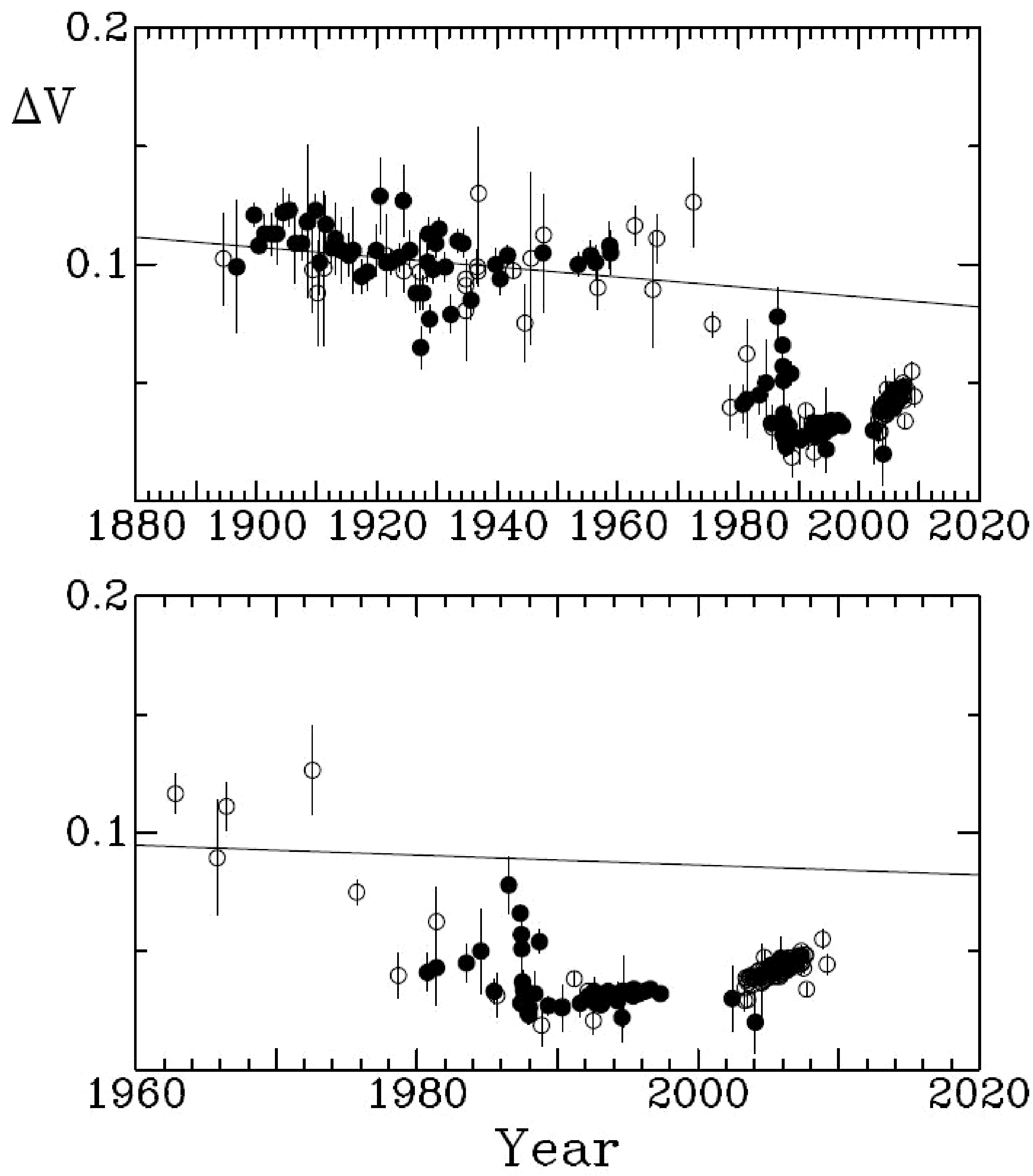




Similar tests by Berdnikov & Stevens (2010) on Polaris using SMIE observations from the Coriolis satellite (*e/P* = 0.06%). Note that *e/P* is smaller for these stars than for other pulsators.



Polaris (<V> = 1.99) is important to understand because it is the closest and most exotic Cepheid — note the glitch in its O–C data circa 1965.



The declining light amplitude of Polaris also underwent a precipitous drop following the glitch in 1965, although it has been slowly recovering over the past 20 years.

So: $M/M_\odot \sim P^{\frac{1}{2}}$ from cluster Cepheids

$\langle R\rangle/R_\odot \sim P^{\frac{3}{4}}$ from Baade-Wesselink analyses

Thus: $\langle g\rangle \sim M/\langle R\rangle^2 \sim P^{-1}$ for mean surface gravity

And: $P\rho^{\frac{1}{2}} = Q \sim PM^{\frac{1}{2}}/\langle R\rangle^{3/2}$

or $Q \sim P^{1/8}$ for the pulsation constant

So, for $L \sim \langle R\rangle^2\, T^4$

We have:

$$\frac{\dot{P}}{P} = \frac{6}{7}\frac{\dot{L}}{L} - \frac{24}{7}\frac{\dot{T}}{T}$$

for rate of period change