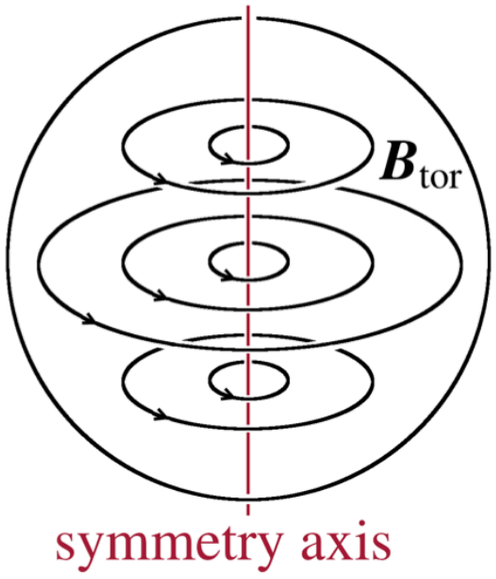
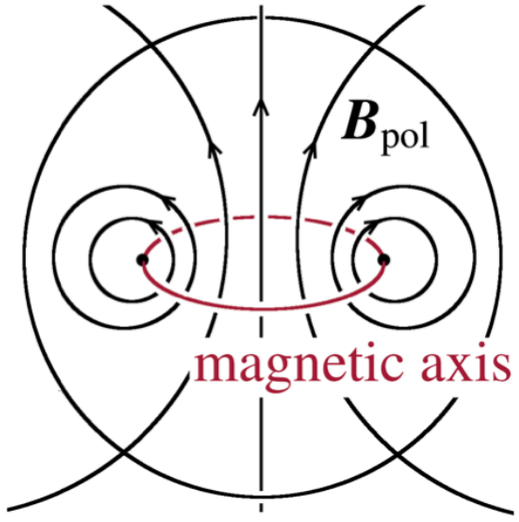
Pulse search in precessing magnetars

- L_X ~ 10^{33} - 10^{35} erg/s > $\dot{E}_{rot}$
- Long period & Fast decay
  P ~ 2 - 12s
- Strong B estimated by spin down
  B_{surf} ~ 10^{14} G - 10^{15} G
- 30+ detected

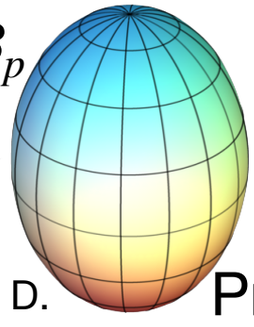




Marlene +2015

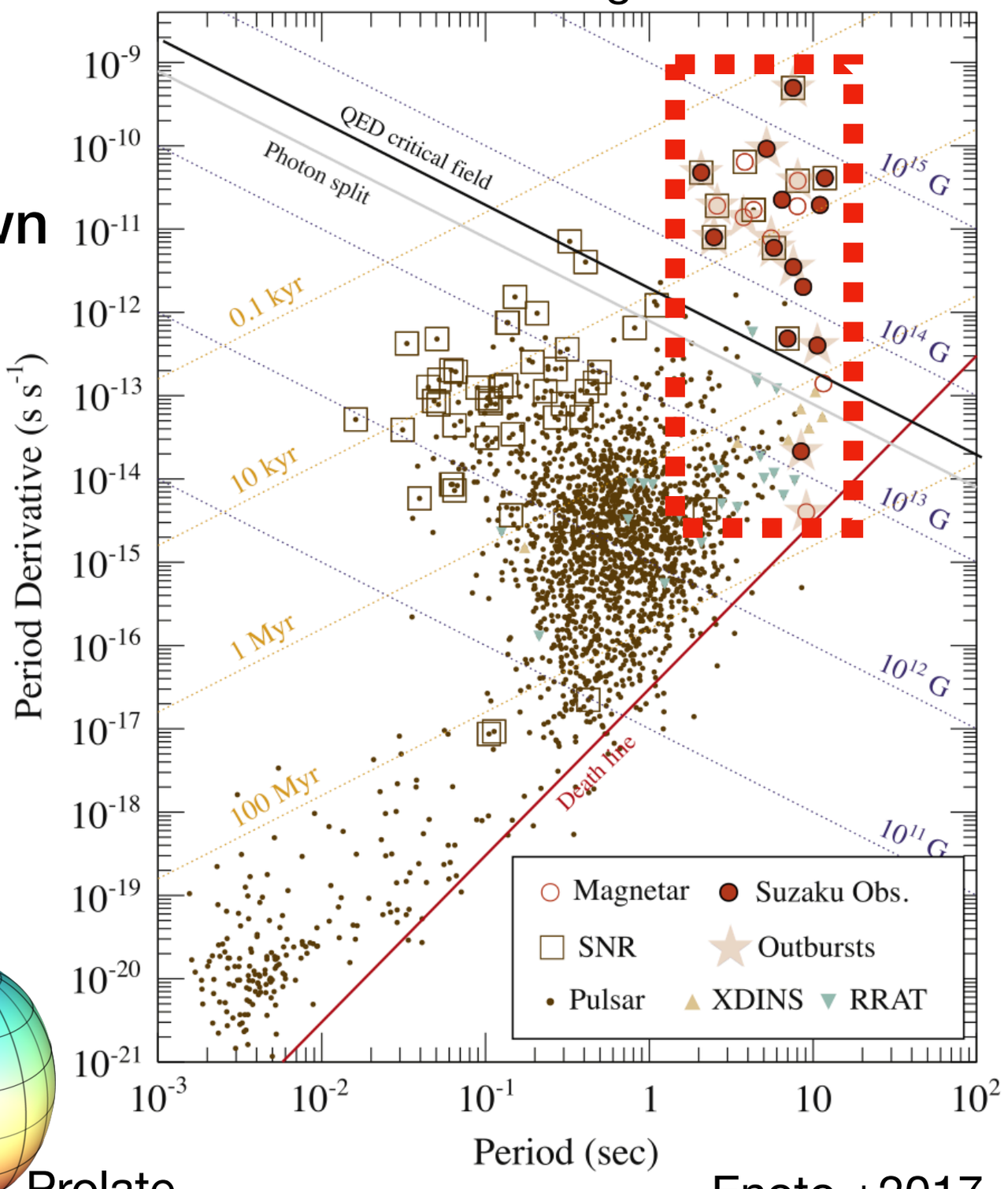
$$\frac{B_{toroidal}}{B_{poloidal}} \rightarrow P_\theta \text{ varies} \rightarrow$$

$B_t > B_p$



Sam D. Prolate

P-$\dot{P}$ Diagram



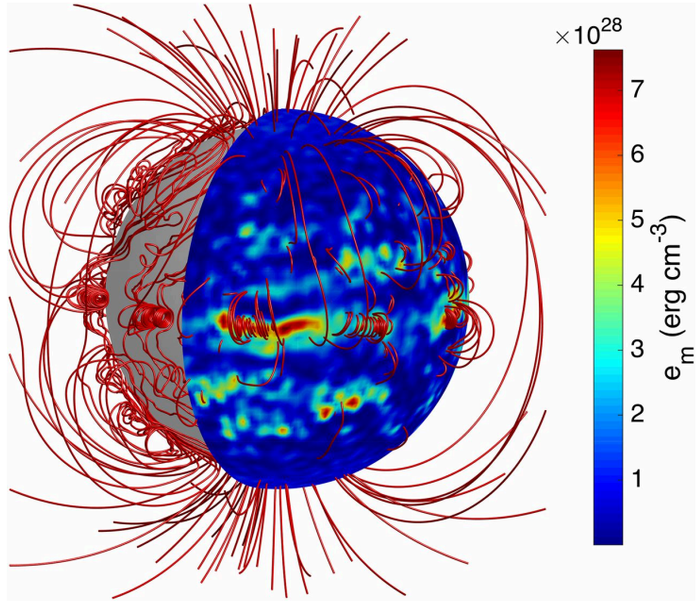
Enoto +2017

X-ray emission of Magnetar

Distribution of hotspot

⬇

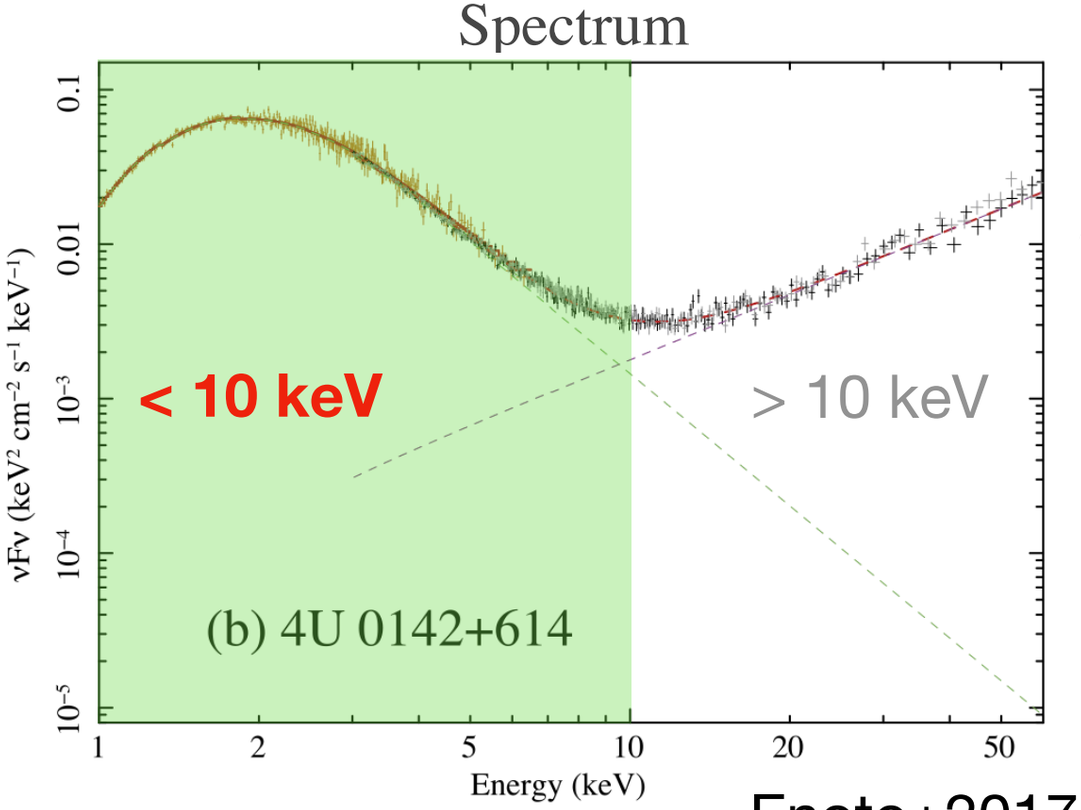
Distribution of magnetic field



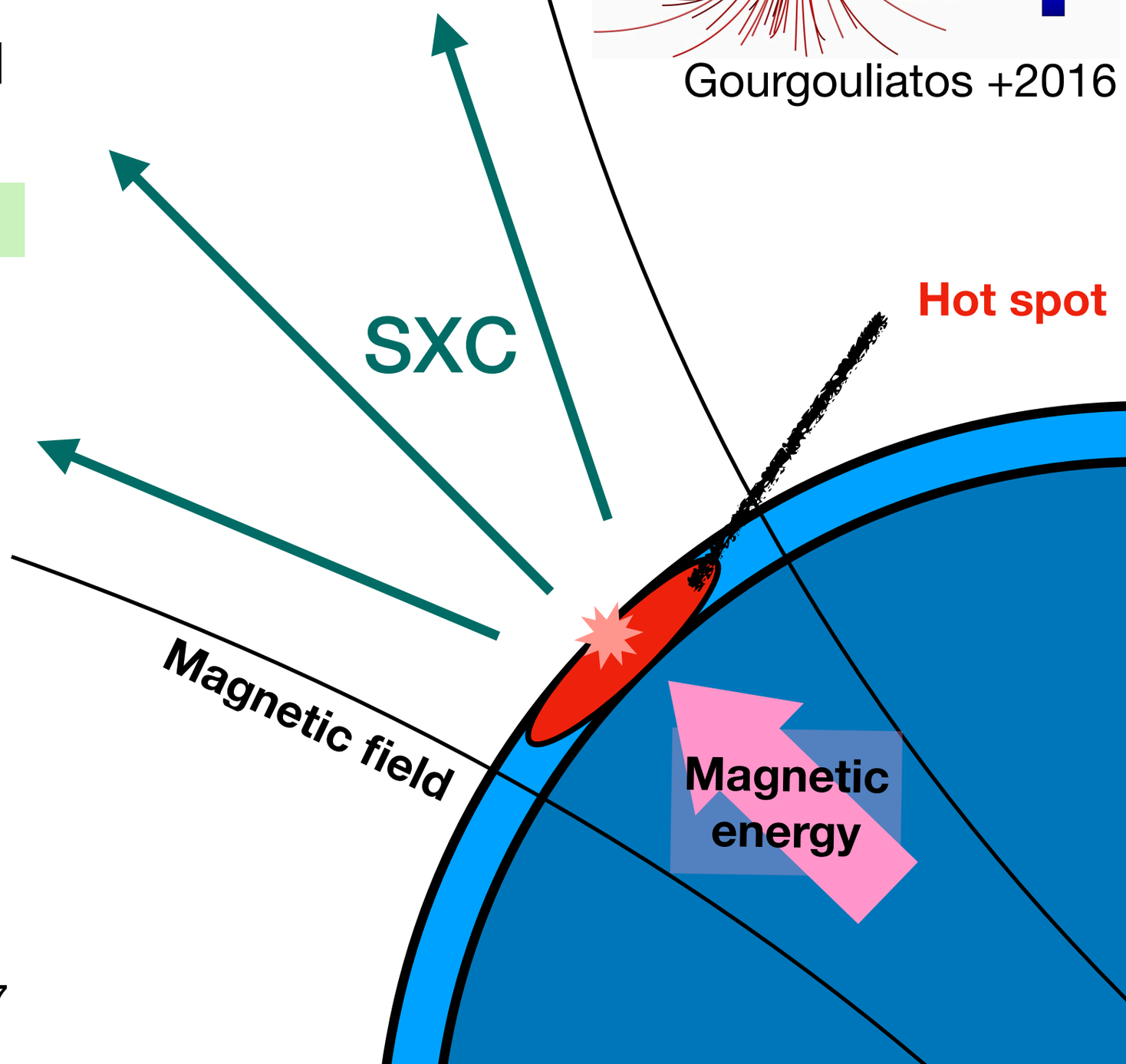
Gourgouliatos +2016

Soft X-ray Component (SXC)

From hot NS surface

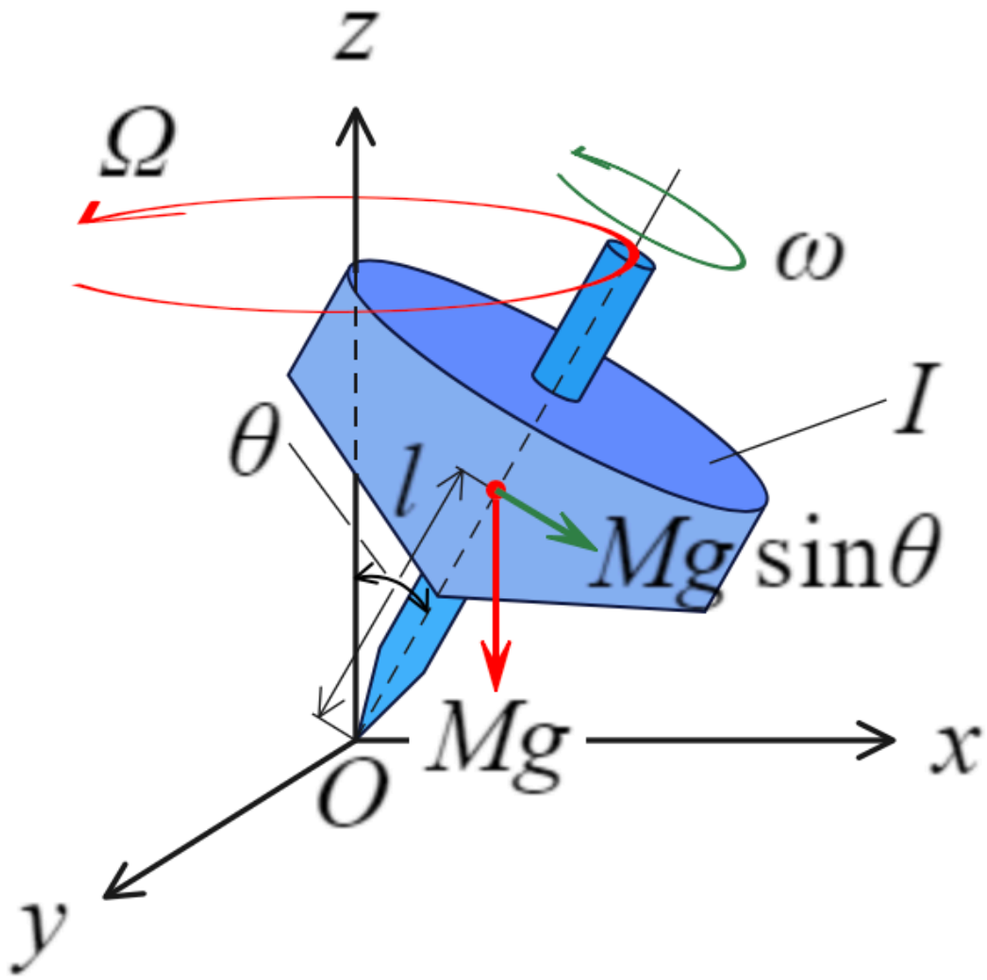


Enoto+2017



Precession

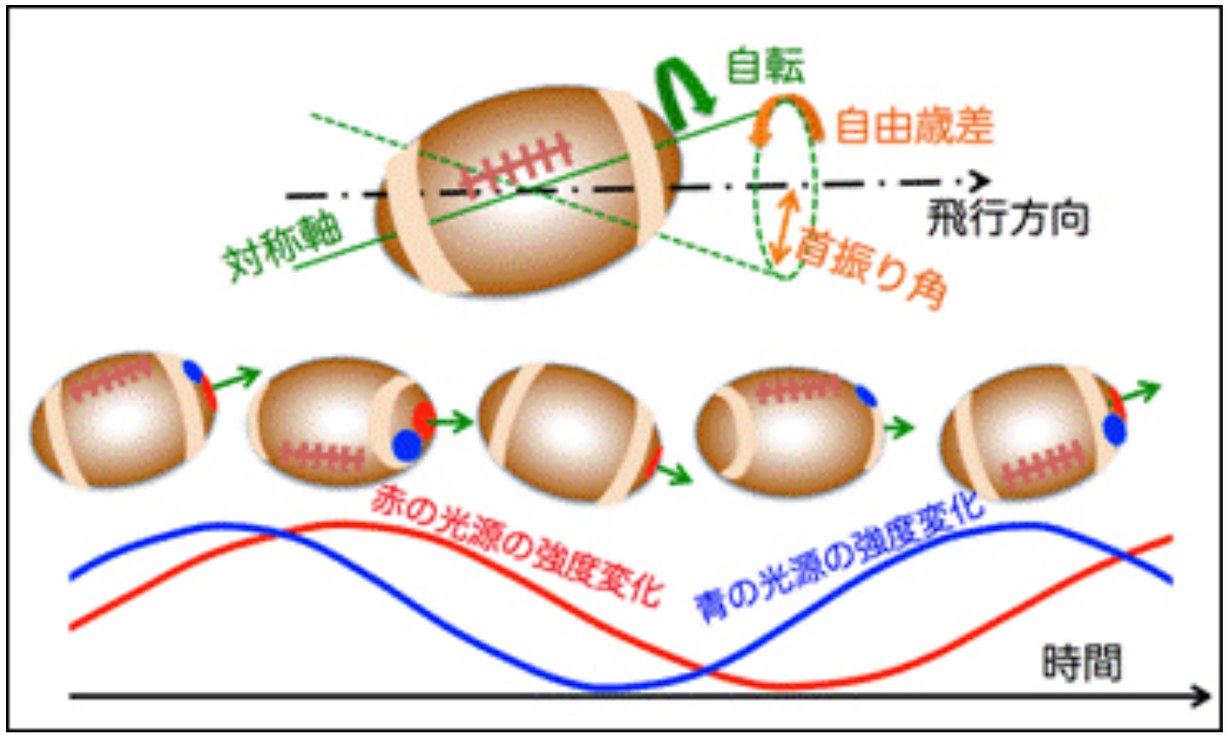
- （Forced） precession



The angular momentum changes due to the torque of an external force

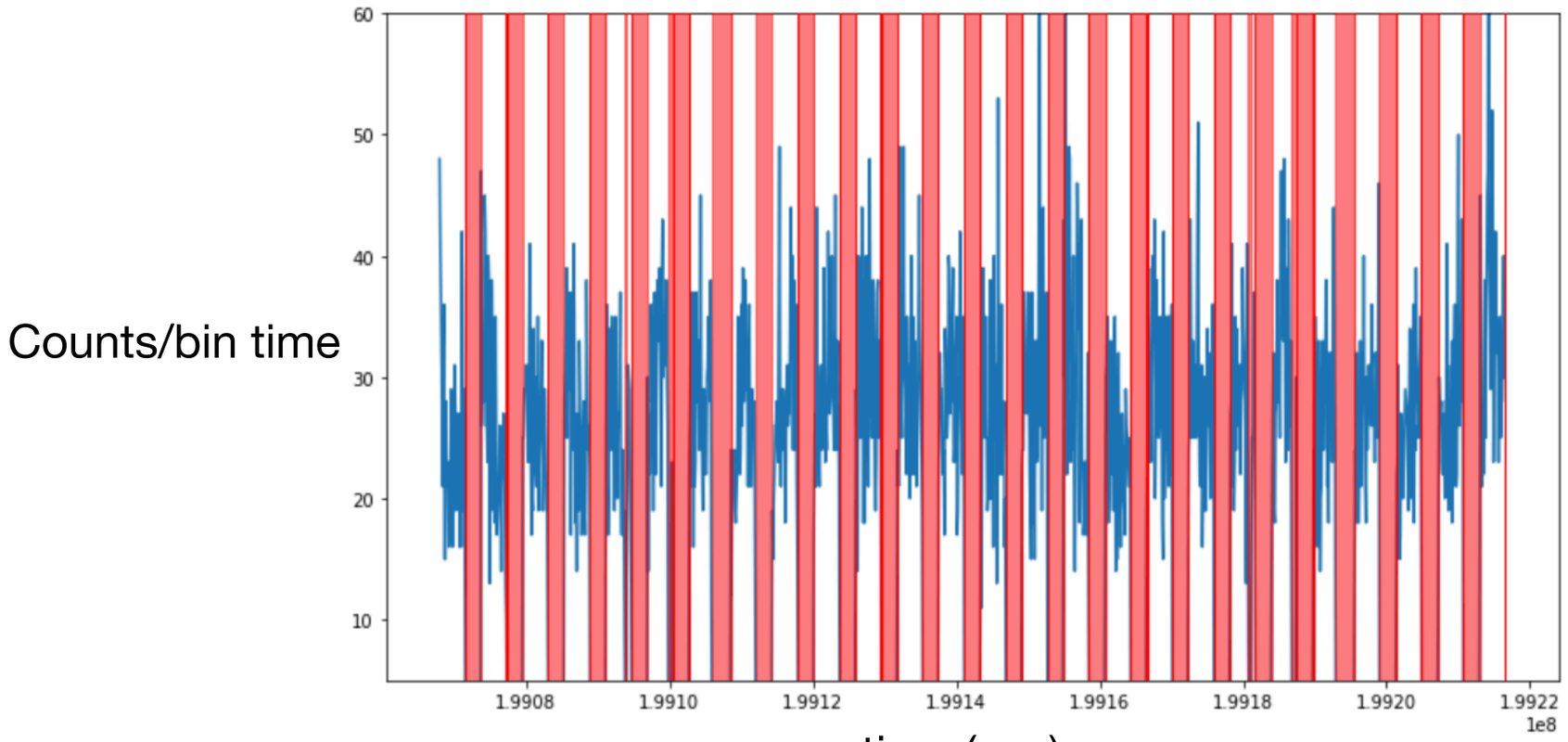
https://yomoriki.com/mechanics/9413/

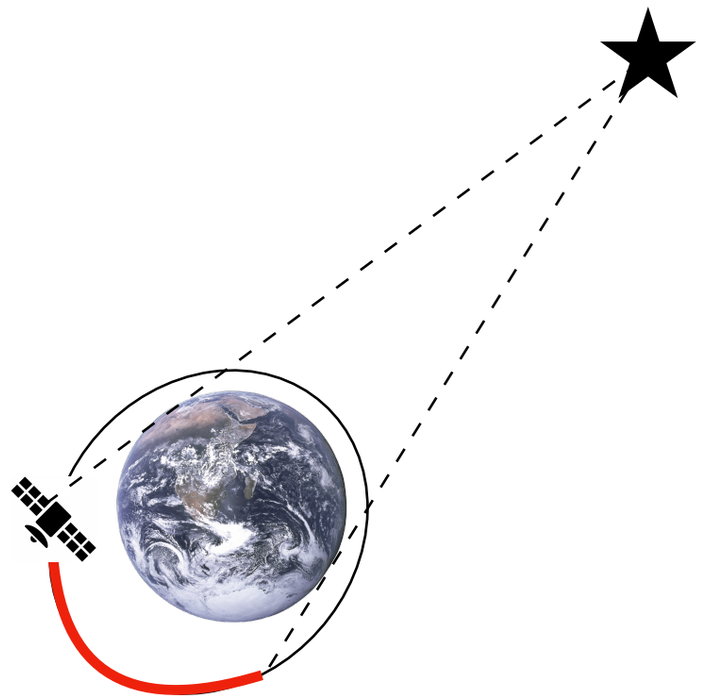
- Free precession（rare）



Caused by the misalignment between the angular momentum direction and the inertia axis

https://www.japan-acad.go.jp/japanese/news/2015/031201.html



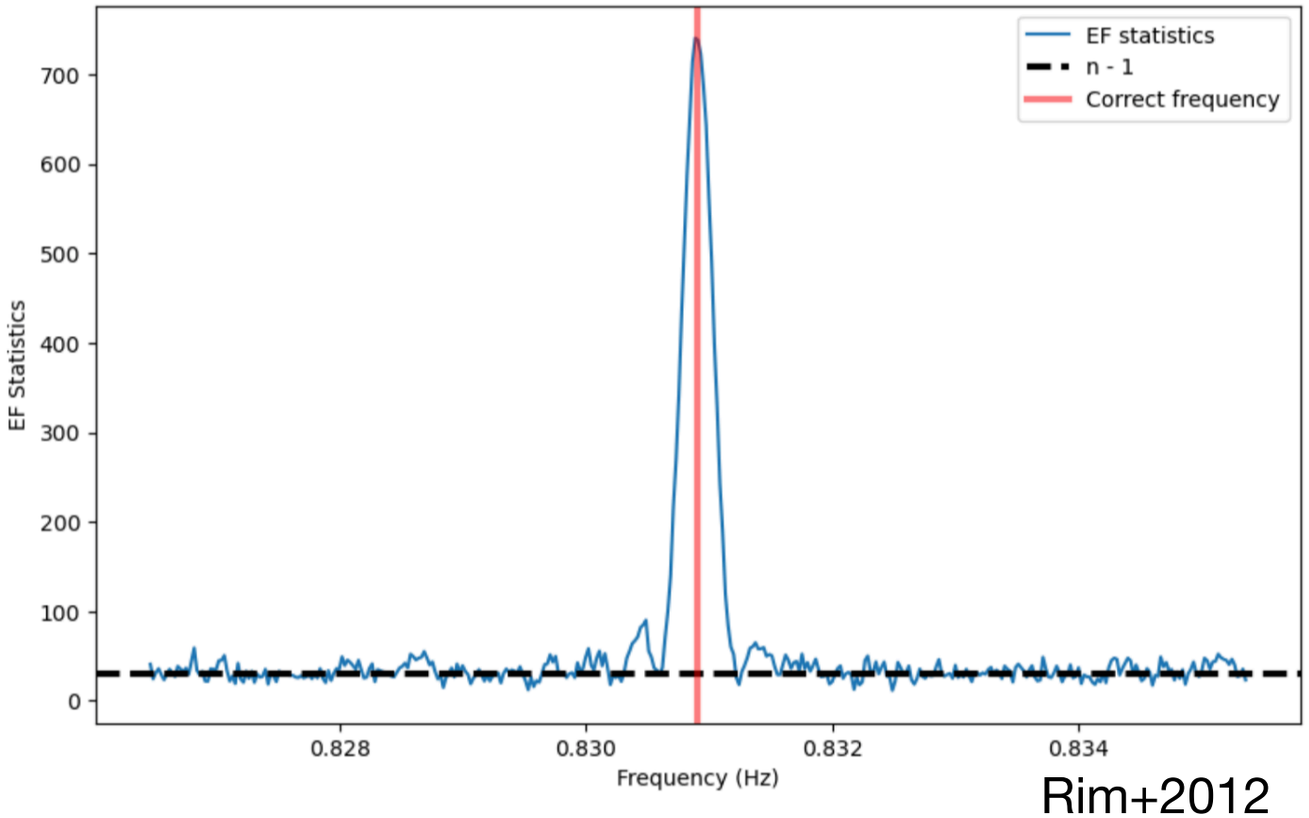


Epoch folding

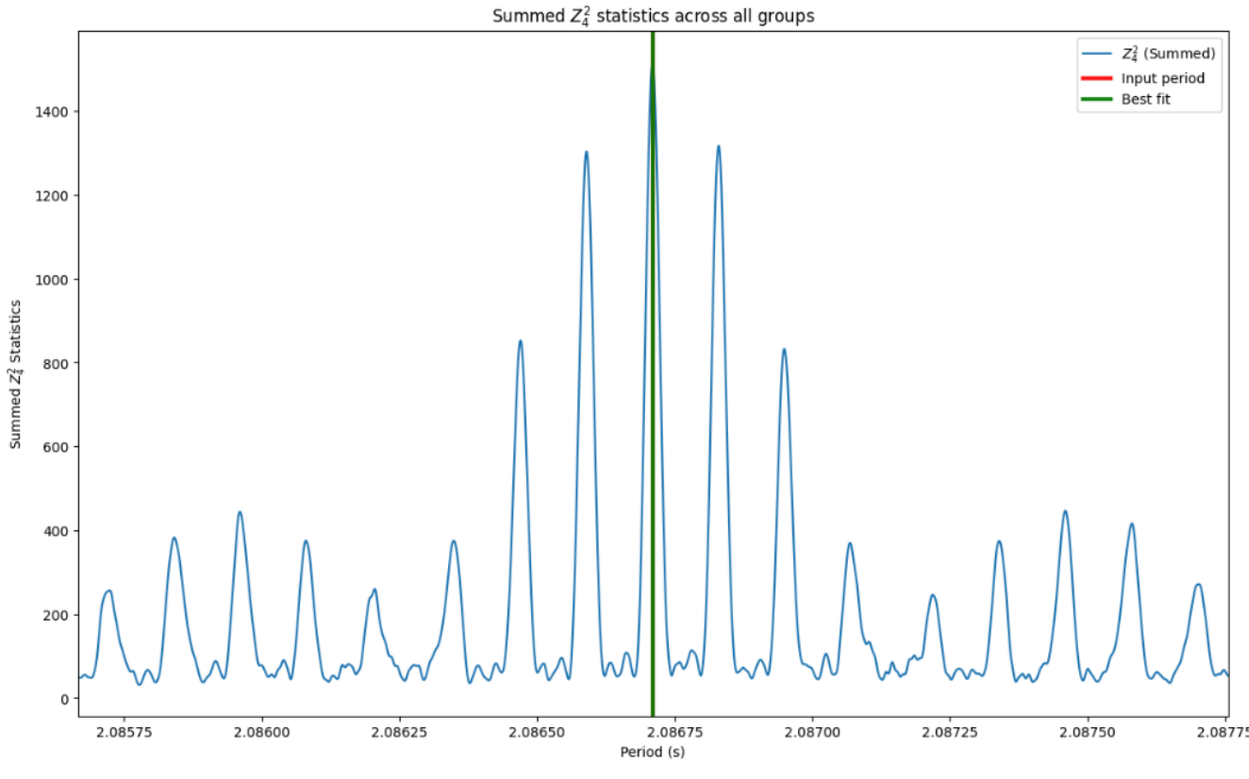
$$S = \sum_i \frac{(P_i - \overline{P})^2}{\sigma^2}$$

$$Z_n^2 = \frac{2}{N} \sum_{k=1}^{n} \left[\left(\sum_{j=1}^{N} \cos k\phi_j \right)^2 + \left(\sum_{j=1}^{N} \sin k\phi_j \right)^2 \right]$$

Z^2 search

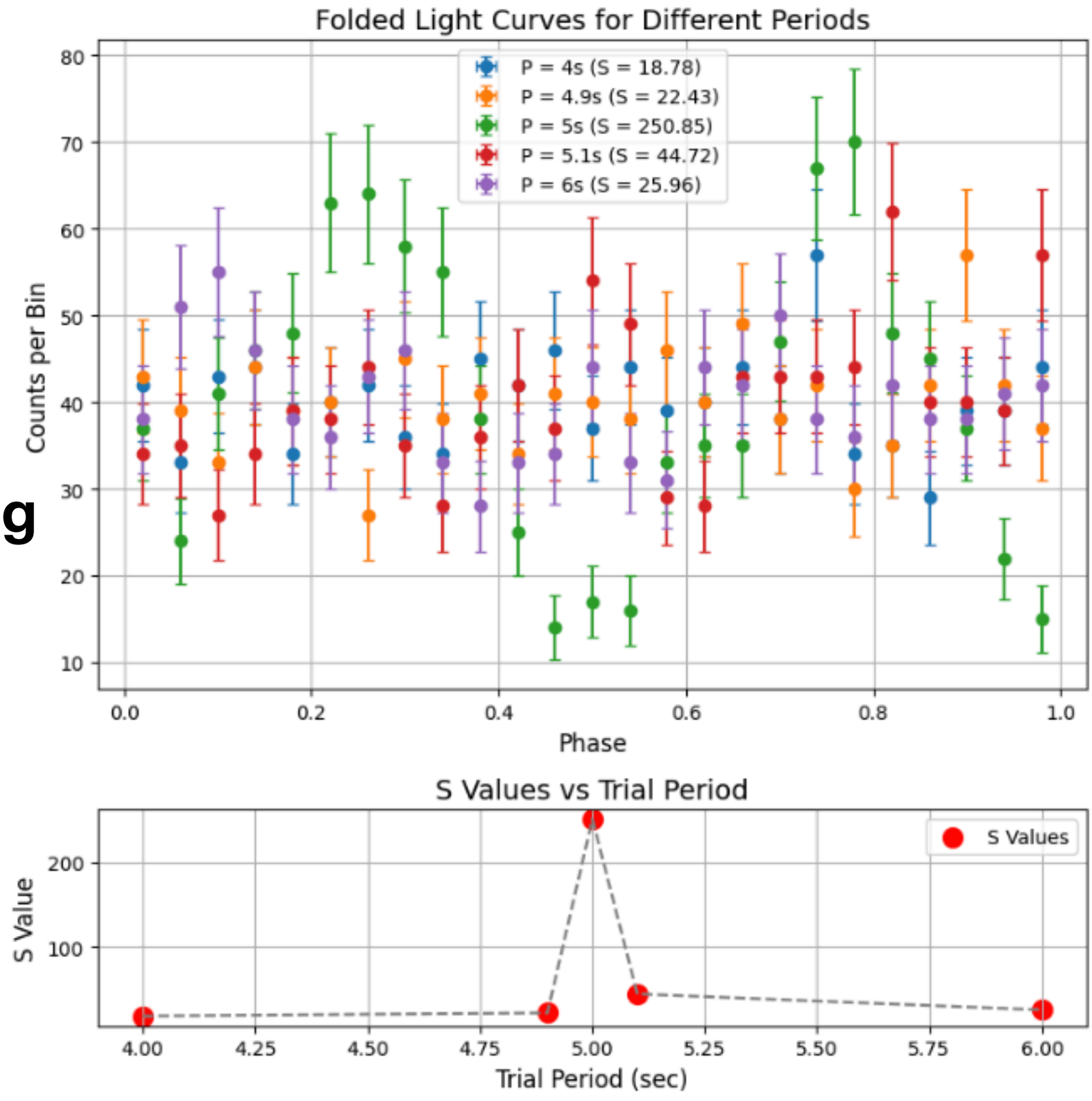


Rim+2012



Epoch folding

$$S = \sum_i \frac{(P_i - \overline{P})^2}{\sigma^2}$$



Z^2 search

$\phi = t \times \frac{1}{P}$, t is photon arrive time, P is period we search

$$Z_n^2 = \frac{2}{N} \sum_{k=1}^{n} [(\sum_{j=1}^{N} \cos k\phi_j)^2 + (\sum_{j=1}^{N} \sin k\phi_j)^2]$$

If distribution of ϕ are flat, then $k(\phi_l - \phi_m)$ will be random value among $(0, 2k\pi)$

$$\sum_{l=1}^{N} \sum_{m=1, m\neq l}^{N} (\cos k\phi_l \cos k\phi_m + \sin k\phi_l \sin k\phi_m) + \sum_{j=1}^{N} (\cos^2 k\phi_j + \sin^2 k\phi_j)]$$

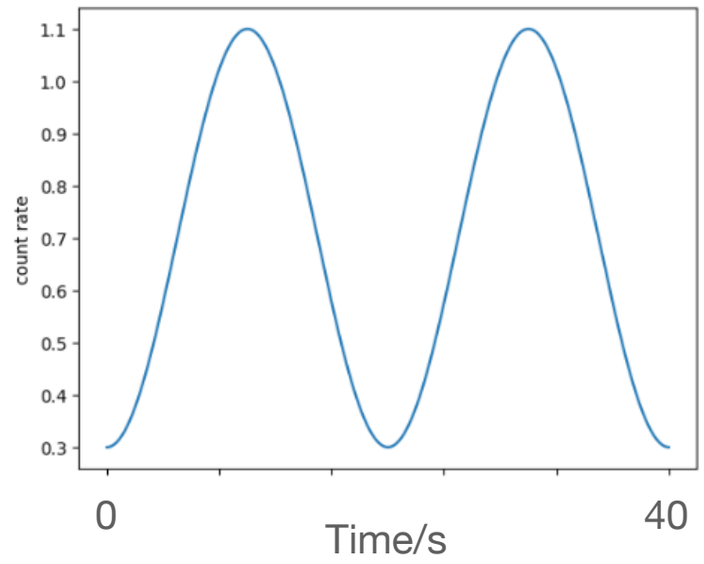
$$Z^2 \to \frac{2}{N} \sum_{k=1}^{n} N$$

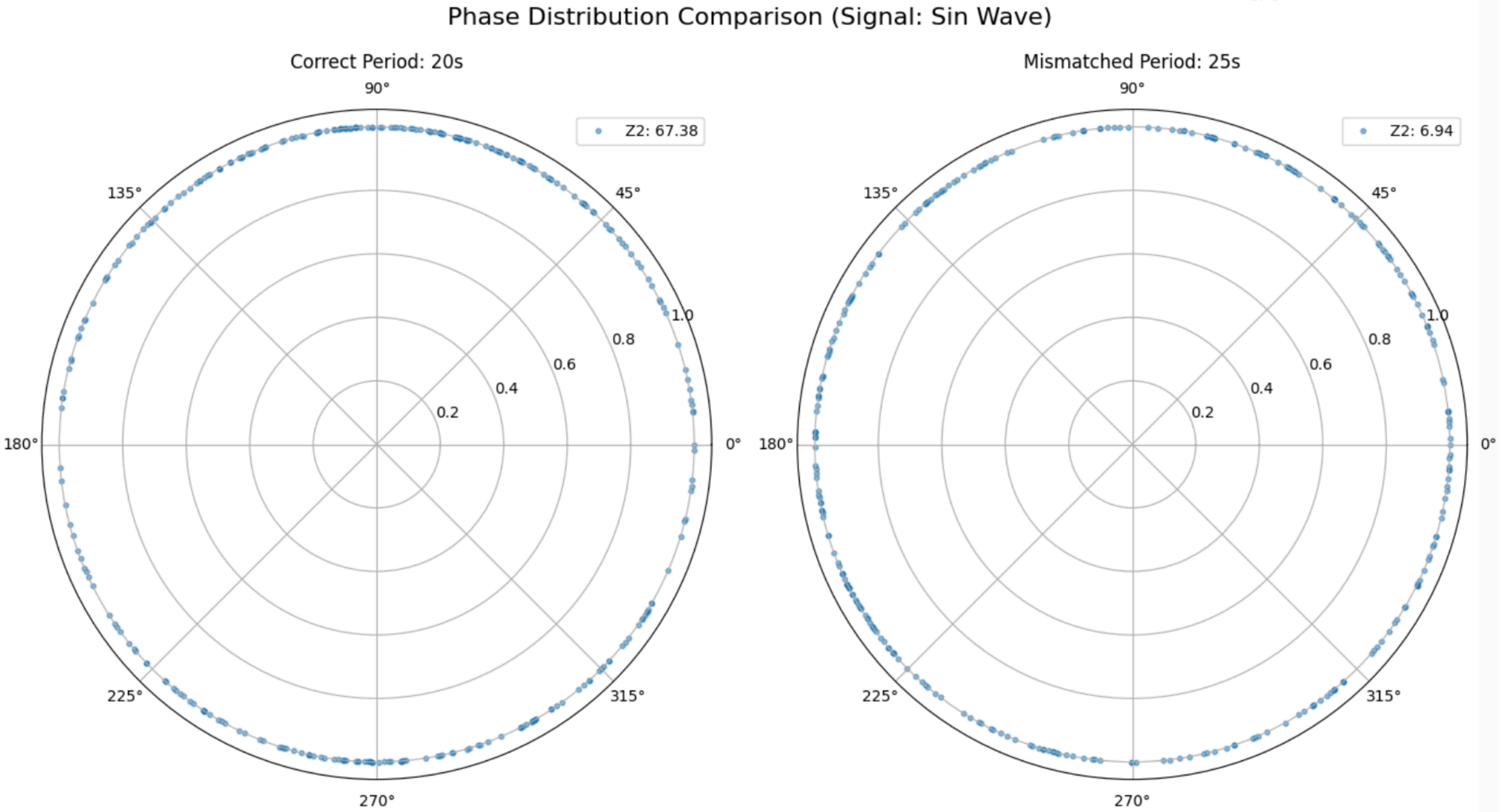
But if ϕ has some bias in distribution, then $k(\phi_l - \phi_m)$ will also have its bias

$$Z_n^2 = \frac{2}{N} \sum_{k=1}^{n} [N + \sum_{l=1}^{N} \sum_{m=1, m\neq l}^{N} \cos(k\phi_l - k\phi_m)]$$

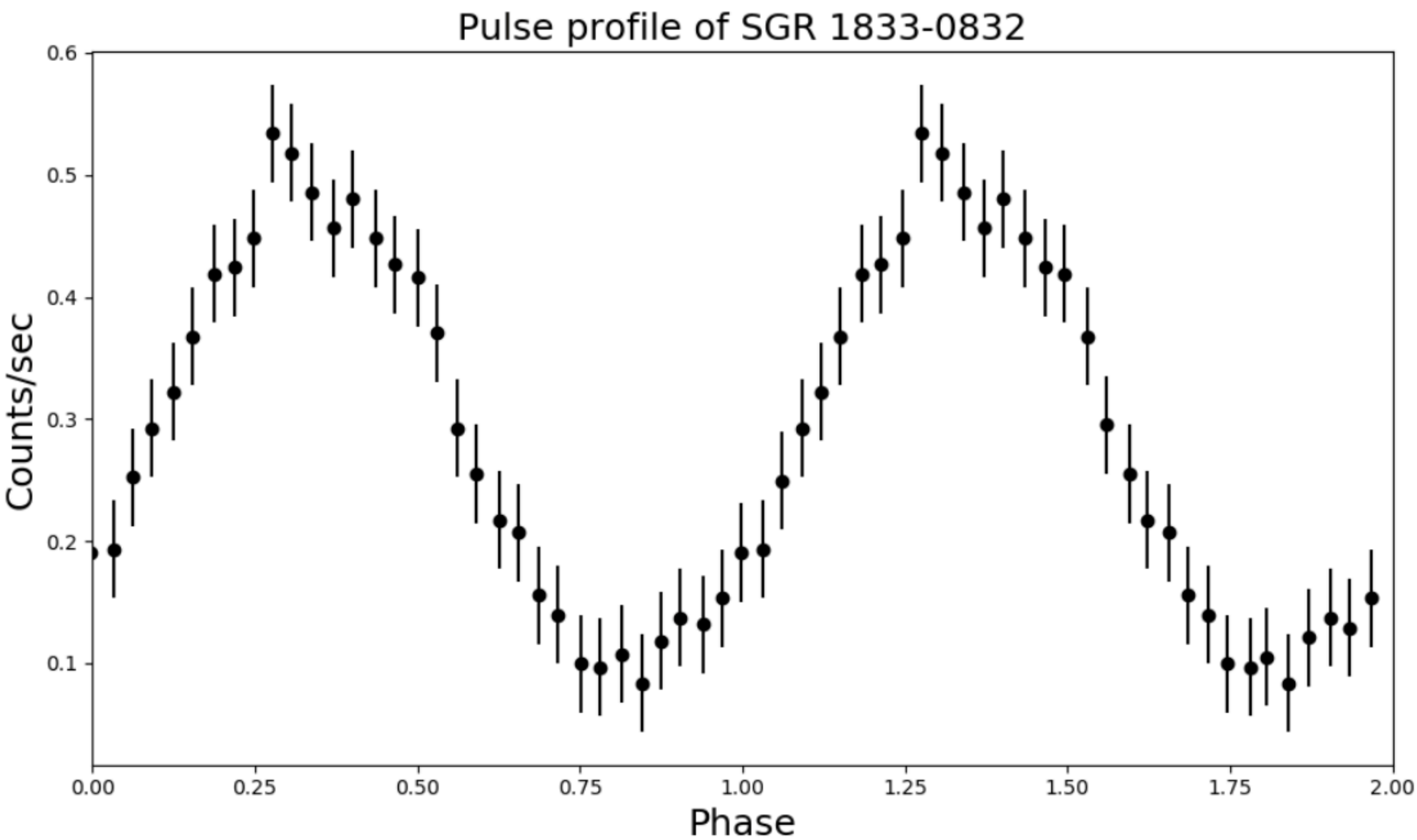
$$Z^2 \gg \frac{2}{N} \sum_{k=1}^{n} N$$

Whose light curve is sinusoidal



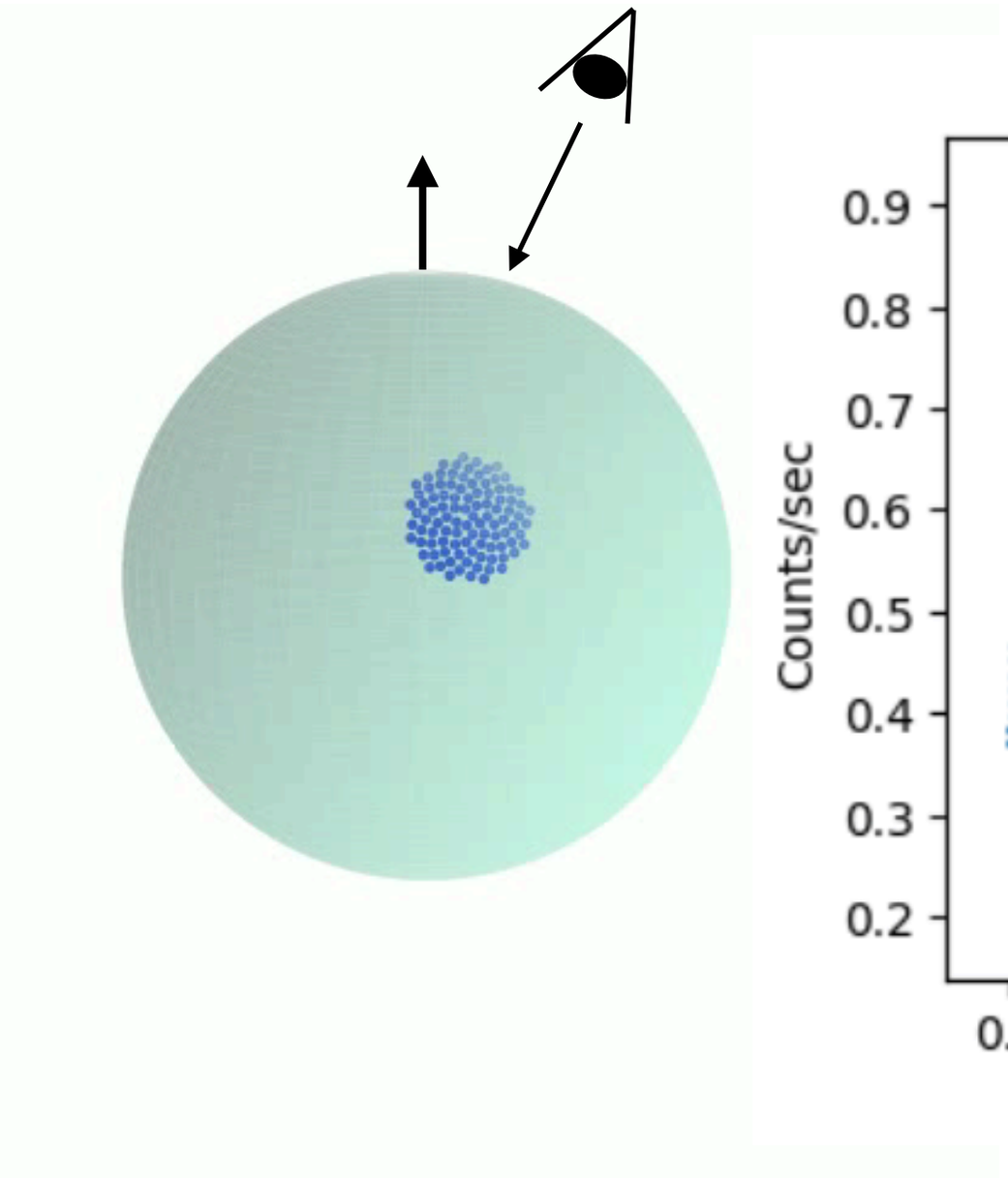


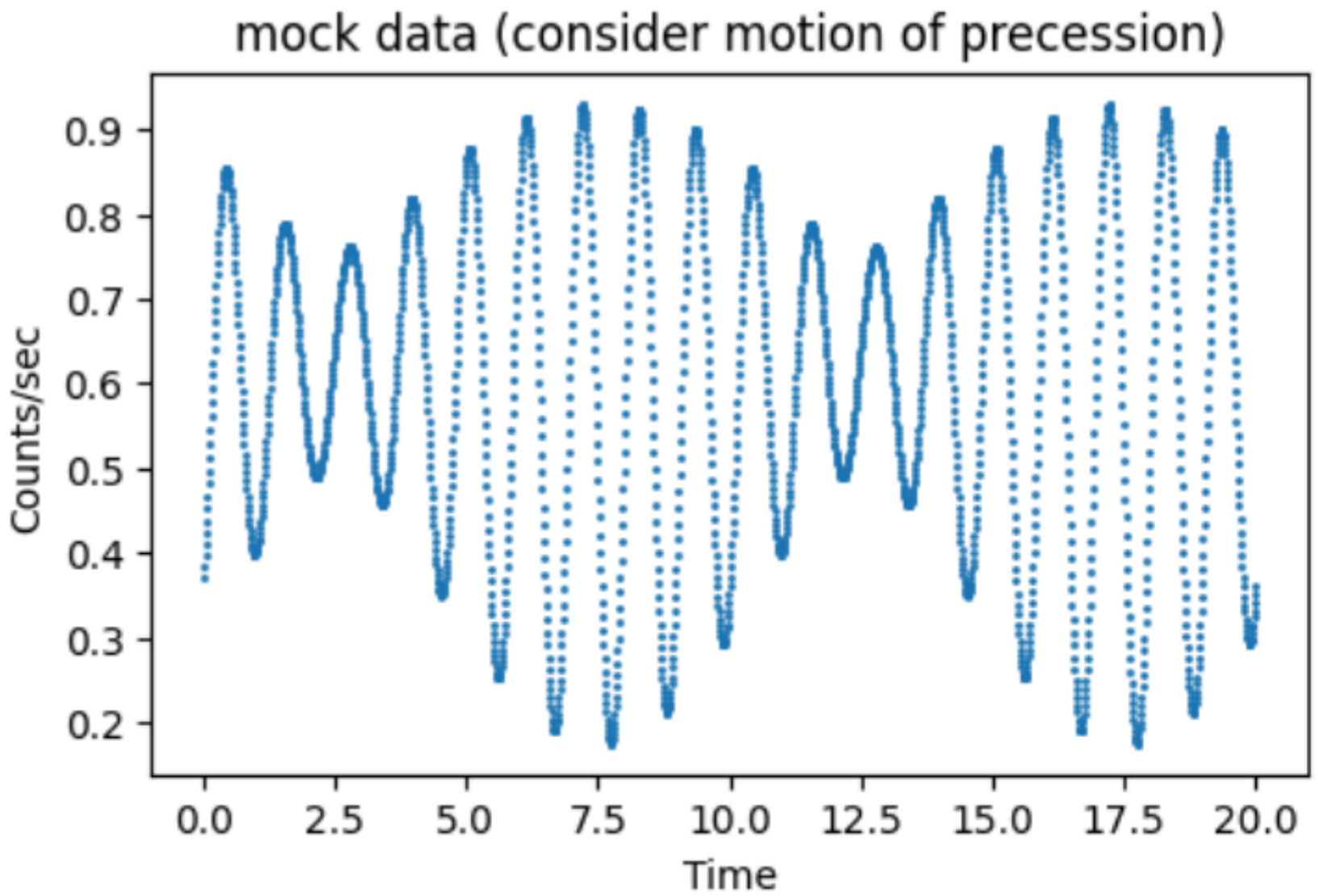
Normal pulse profile of a magnetar



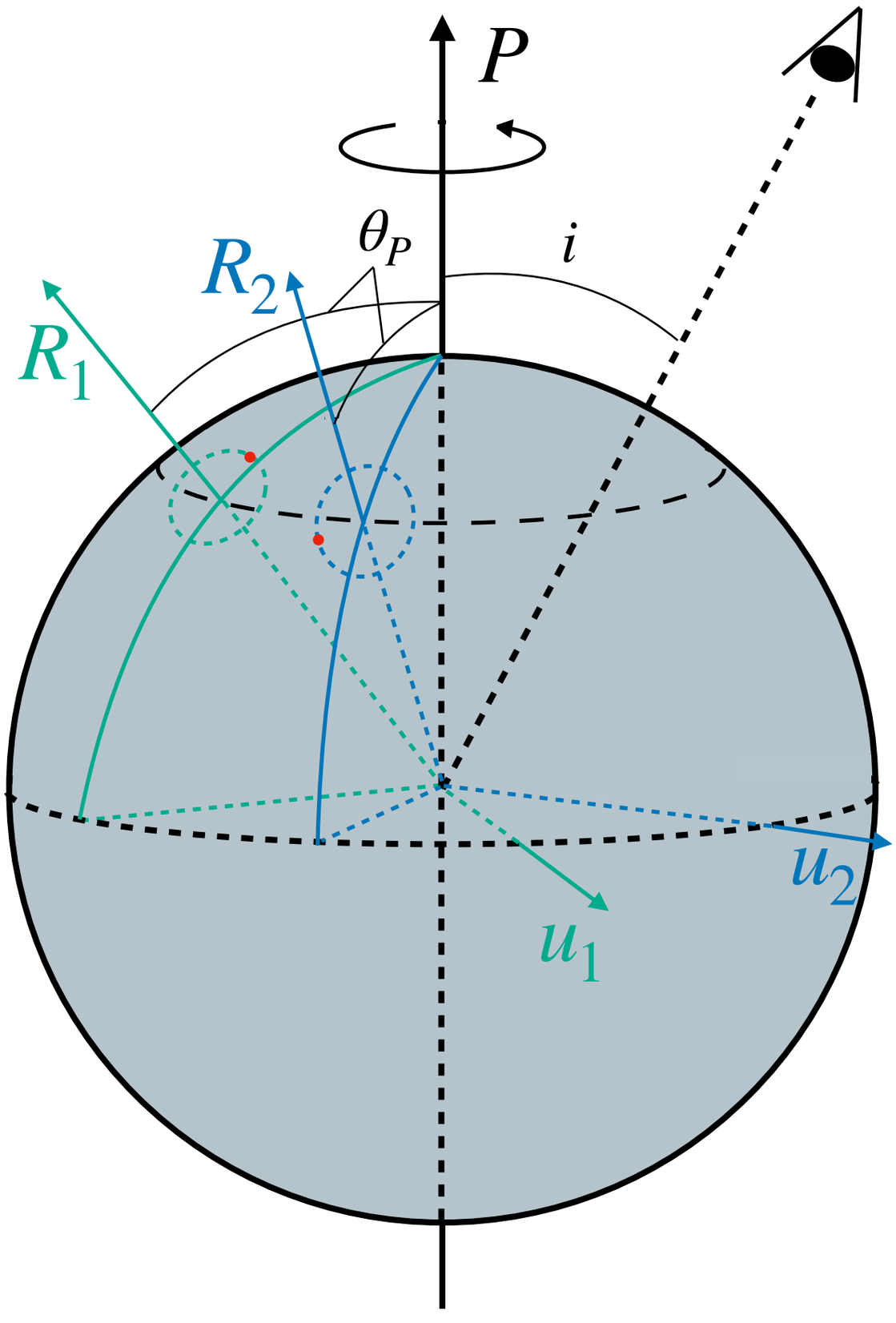
If direction of angular momentum is not parallel to major axis

Free precession





How to detect precession?



Pulse detection will be bothered by precession

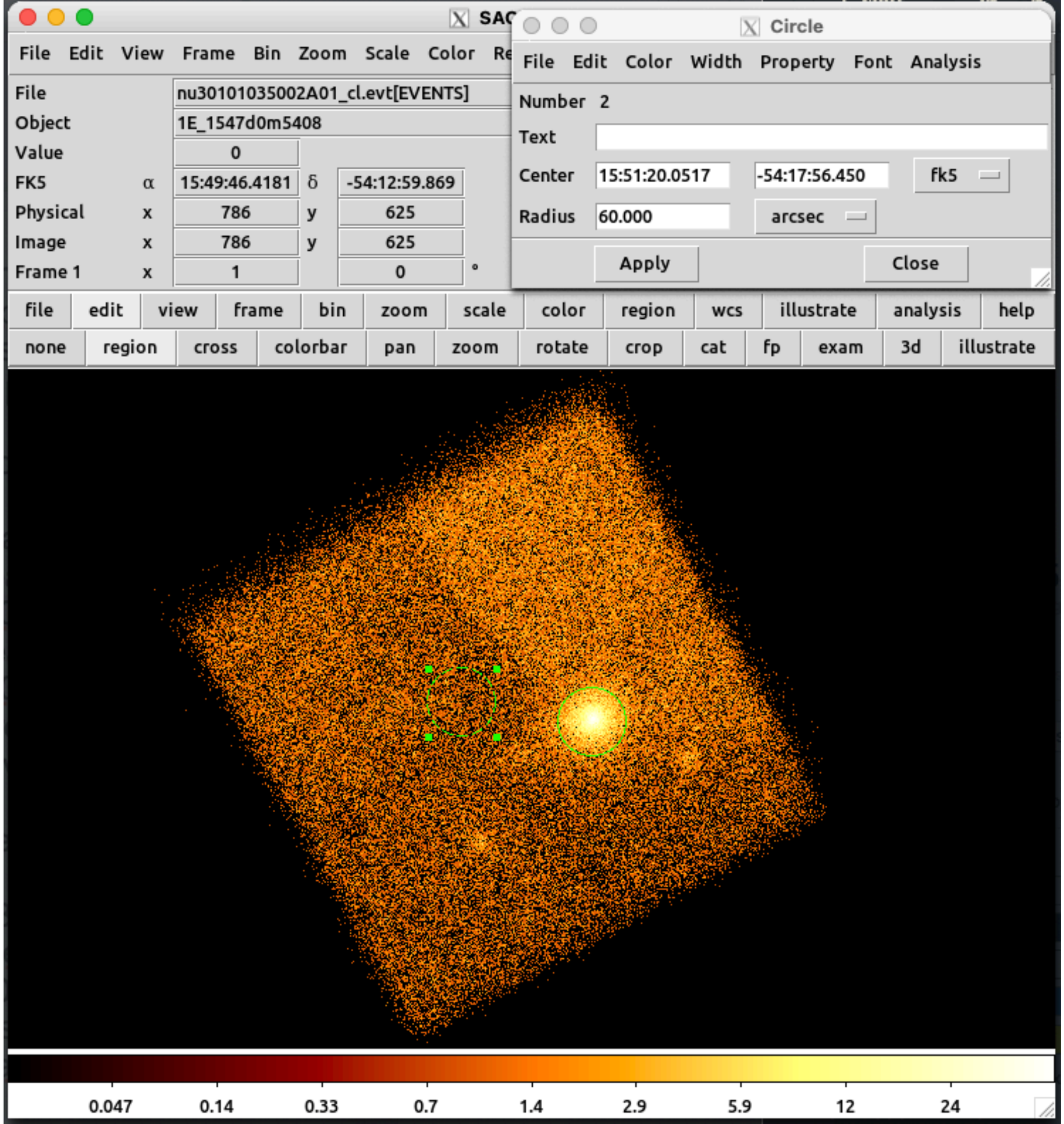
If we account this effect and give correction of precession to data, the Z^2 value of pulse search will be better

$$t'_n = t_n - A \sin \frac{2\pi t_n}{T} - \psi$$

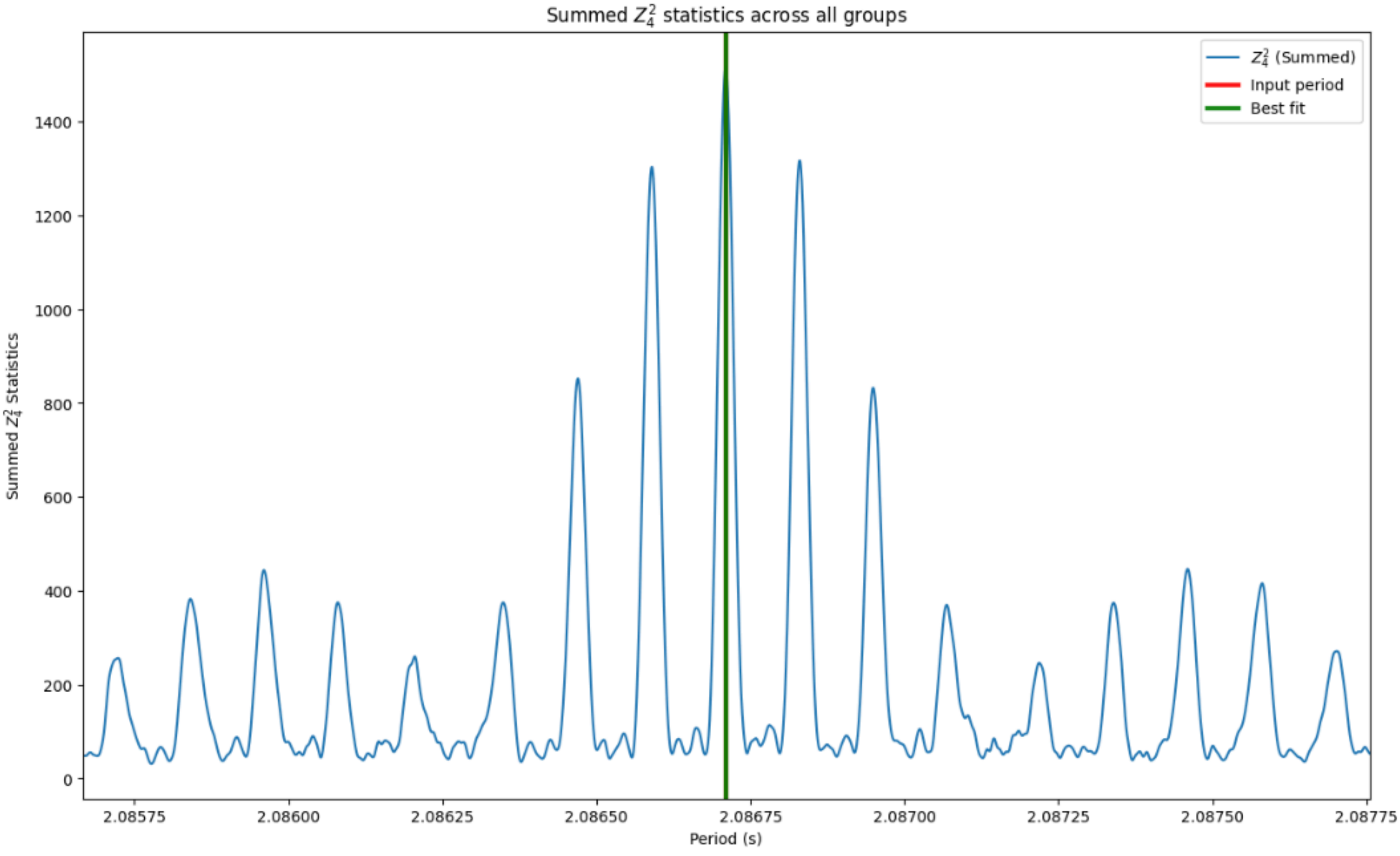
A: amplitude caused by precession

T: modulation period ψ: phase

1E1547.0-5408



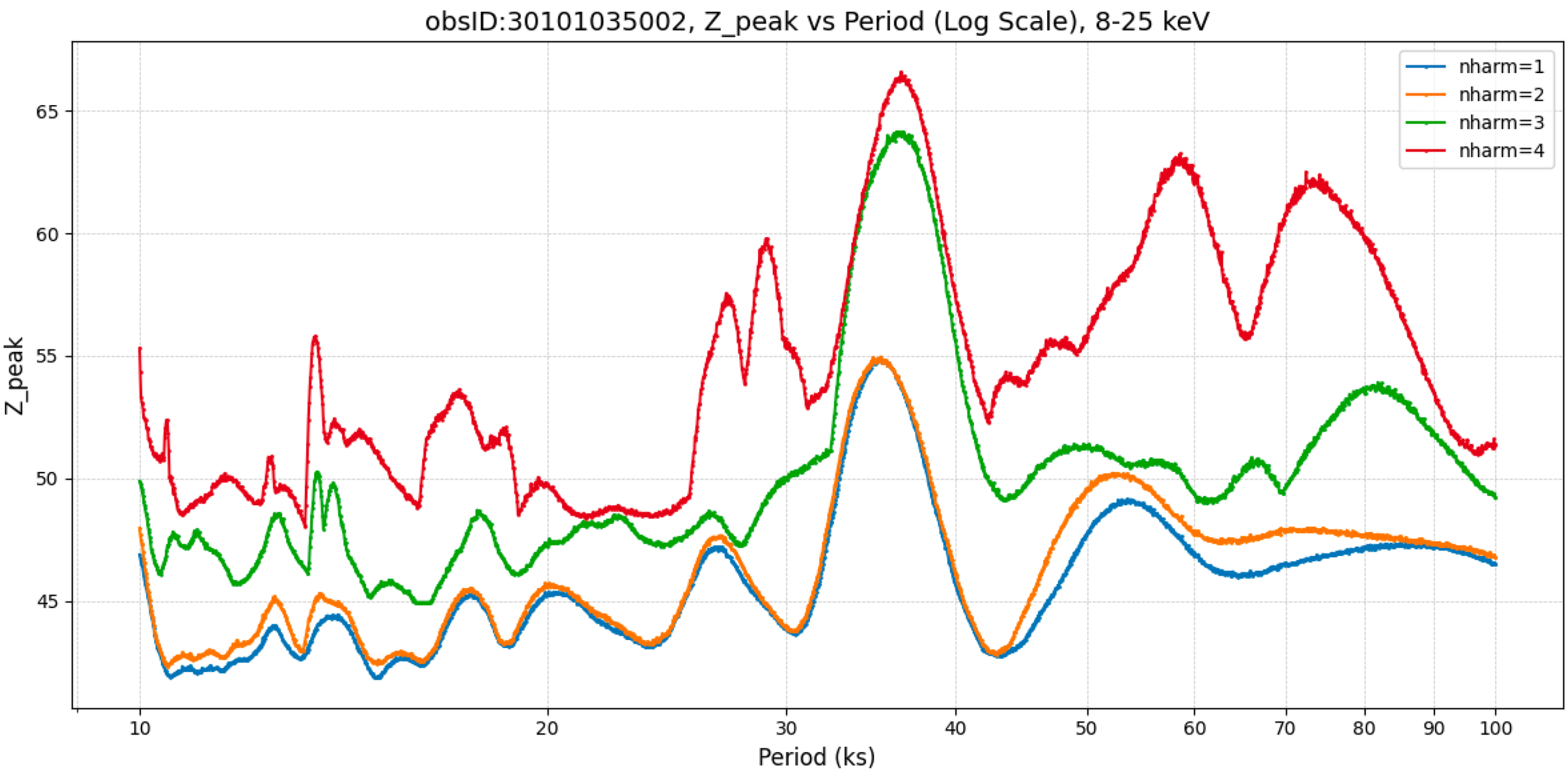
3-8keV pulse search



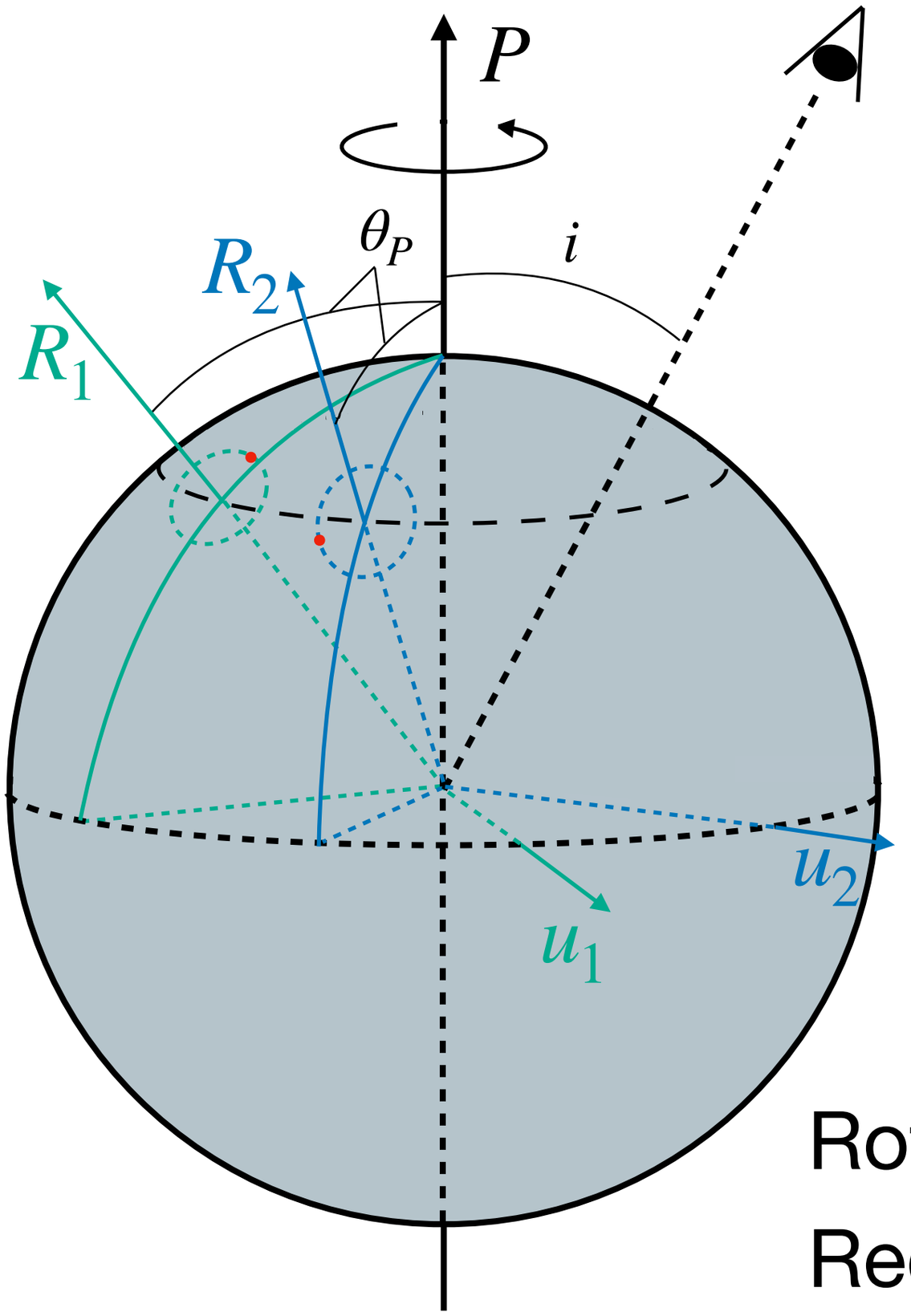
We couldn’t find pulse directly from 8-25 keV…

But if we consider precession correction

30101035002, 2016/4, 8-25 keV exposure= 83381 s



Precession model



$$\omega_P = \frac{2\pi}{T_P}$$

$$\vec{u} = \begin{pmatrix} -\cos(\omega_P t + \phi) \\ -\sin(\omega_P t + \phi) \\ 0 \end{pmatrix}$$

$$\overrightarrow{M_R} = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} \cos\theta_P +$$

$$\begin{pmatrix} 0 & -u_z & u_y \\ u_z & 0 & -u_x \\ -u_y & u_x & 0 \end{pmatrix} \sin\theta_P +$$

$$\begin{pmatrix} u_x^2 & u_x u_y & u_x u_z \\ u_y u_x & u_y^2 & u_y u_z \\ u_z u_x & u_z u_y & u_z^2 \end{pmatrix} (1 - \cos\theta_P)$$

Rotation axis R spin around P

Red point → center of hot spot

Summary

- Develop a pulse search analysis which consider precession
- Found possible precession period around 36 ks in 1E1547.0-5408
- Precession model which could generate the mock data

Future work

- Searching for more precession evidence of magnetars
- Apply precession model to give a better correction of precession
- Constrain $\frac{B_{toroidal}}{B_{poloidal}}$ of magnetars by observation