Relativistic modeling for soft X-ray pulses of magnetars

マグネター表面の定常放射モデル

Speaker：Chushu Qu (屈楚舒)

Collaborator ：Y. Suwa, T. Enoto

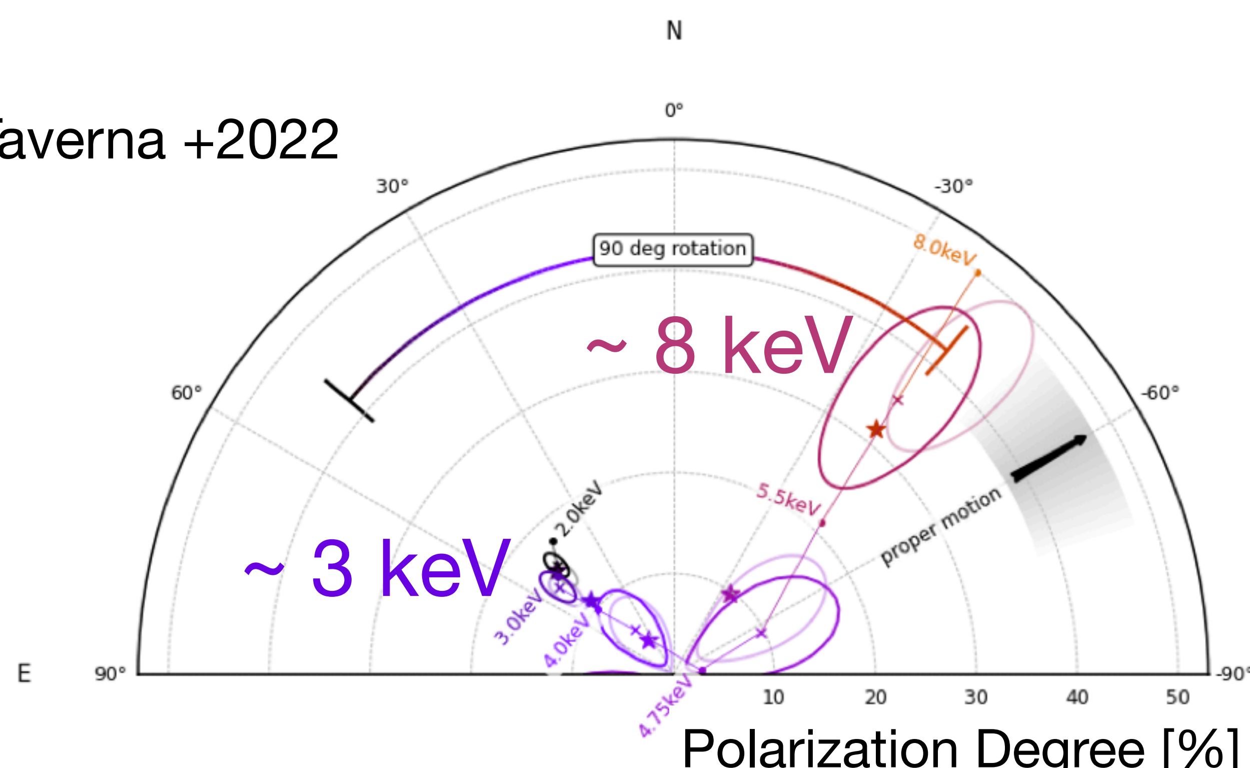
University of Tokyo (Komaba) D1

Magnetars (SGR/AXP)

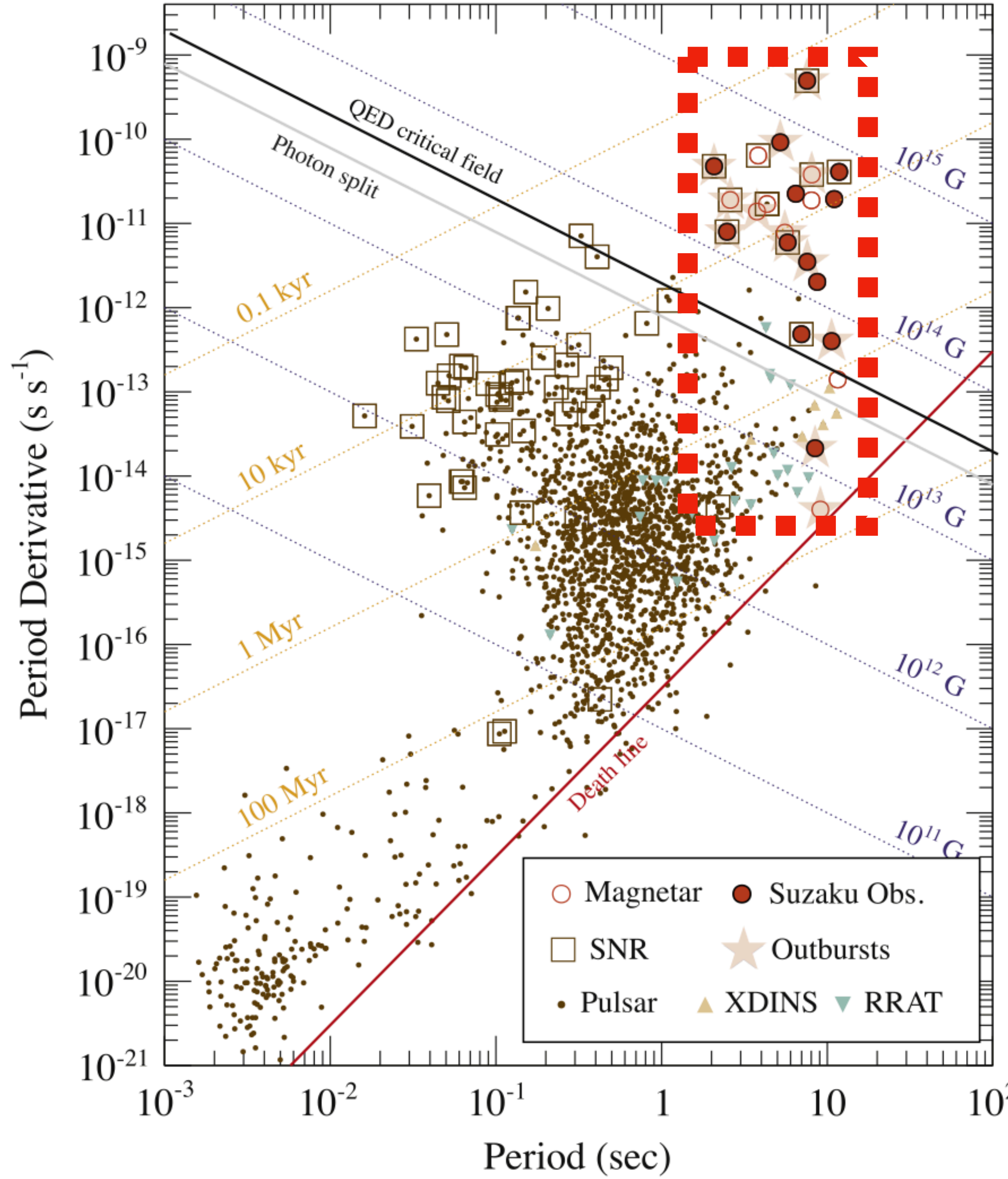
Soft Gamma-ray Repeater
Anomalous X-ray Pulsar

- L_X ~ 10^{33} - 10^{35} erg/s > $\dot{E}_{rot}$
- Long period & Fast decay
  P ~ 2 - 12s
  $\dot{P}$ ~ 10^{-13} - 10^{-10} s/s
- Strong magnetic field
  B_{surf} ~ 10^{14} G - 10^{15} G
- 30+ confirmed

Taverna +2022



P-$\dot{P}$ Diagram



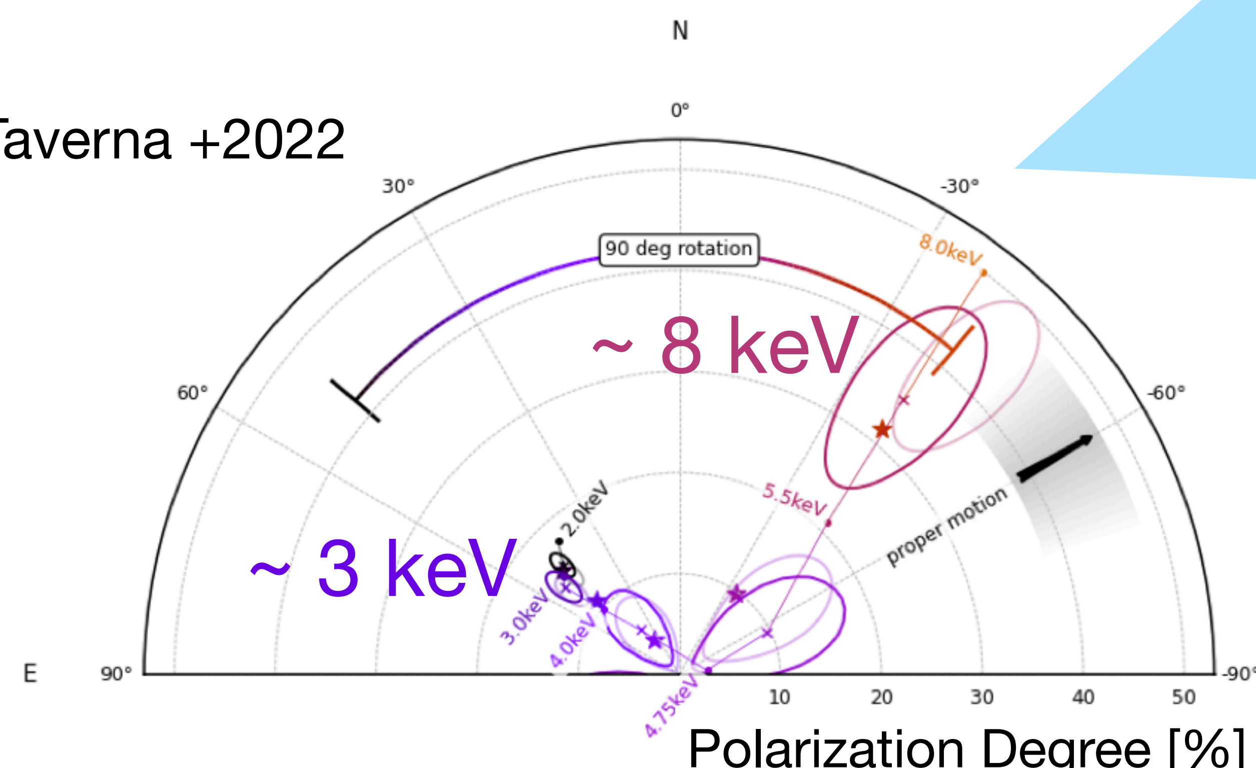
Enoto +2017

Magnetars (SGR/AXP)

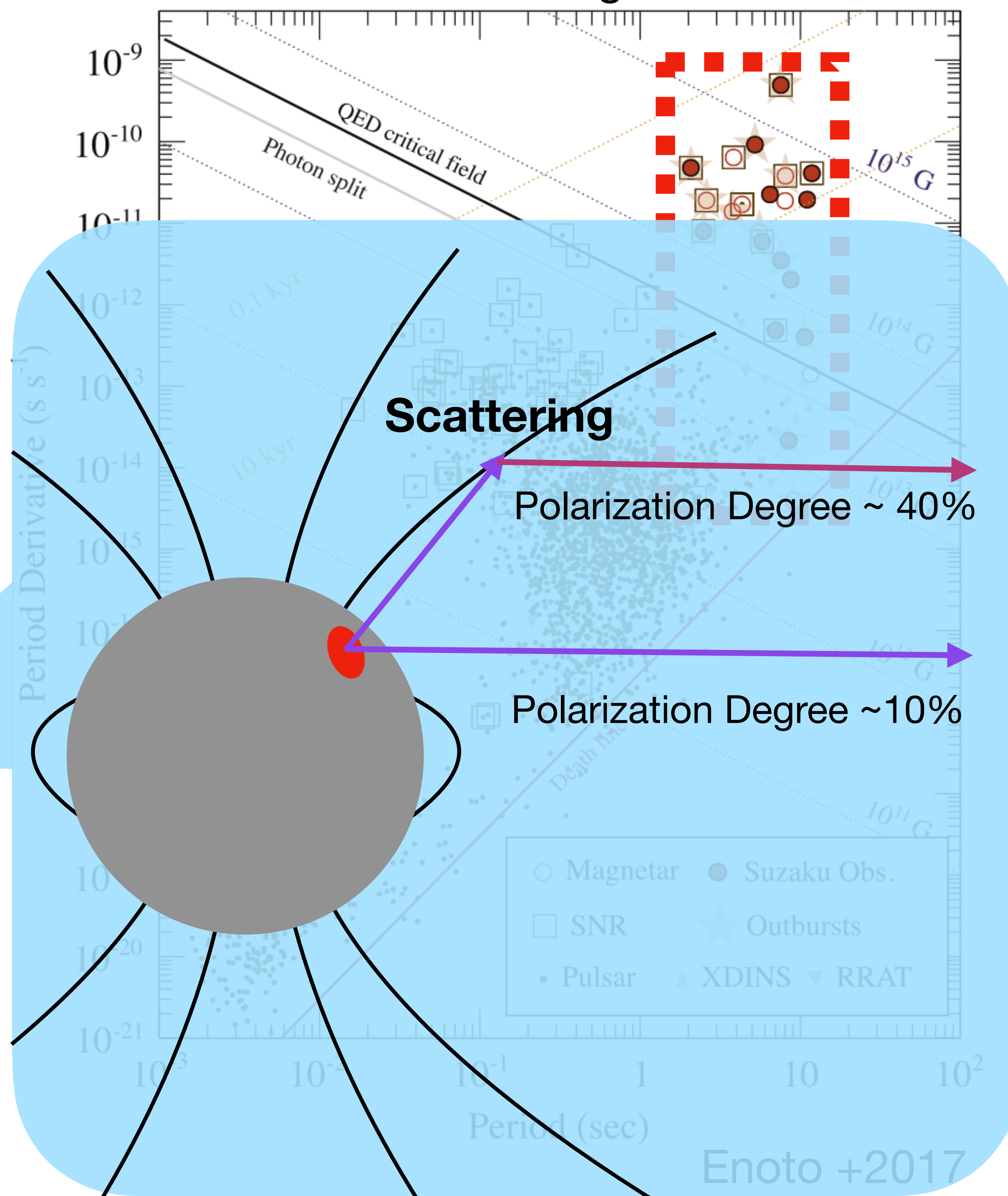
Soft Gamma-ray Repeater
Anomalous X-ray Pulsar

- L_X ~ 10^{33} - 10^{35} erg/s > $\dot{E}_{rot}$
- Long period & Fast decay
  P ~ 2 - 12s
  $\dot{P}$ ~ 10^{-13} - 10^{-10} s/s
- Strong magnetic field
  B_{surf} ~ 10^{14} G - 10^{15} G
- 30+ confirmed

Taverna +2022



P-$\dot{P}$ Diagram

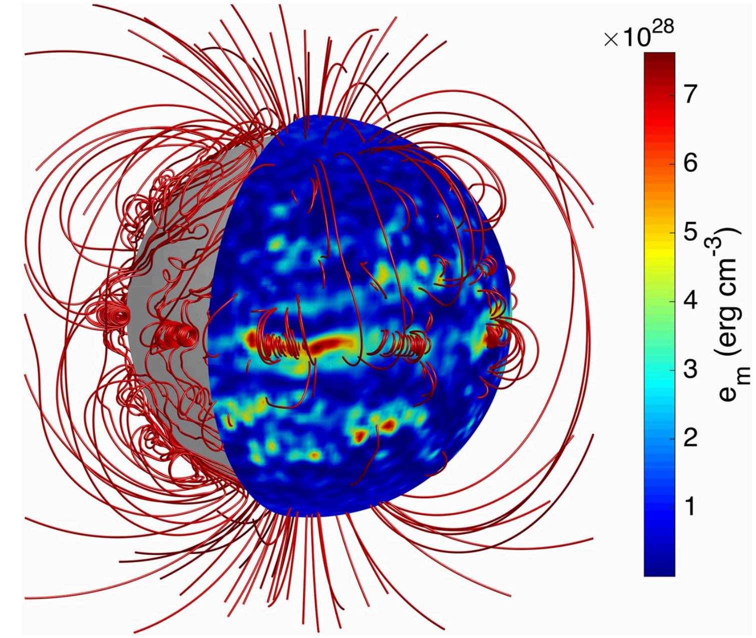


X-ray emission of Magnetar

Soft X-ray emission

↓

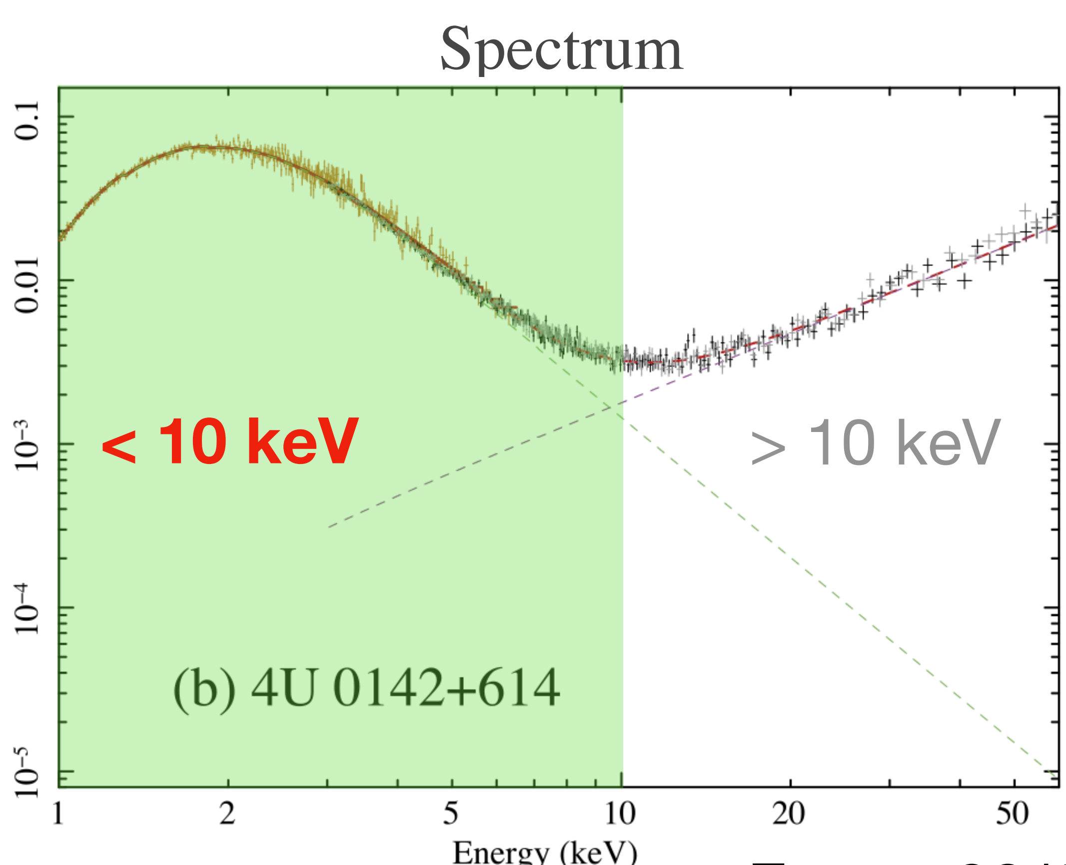
Hard X-ray emission



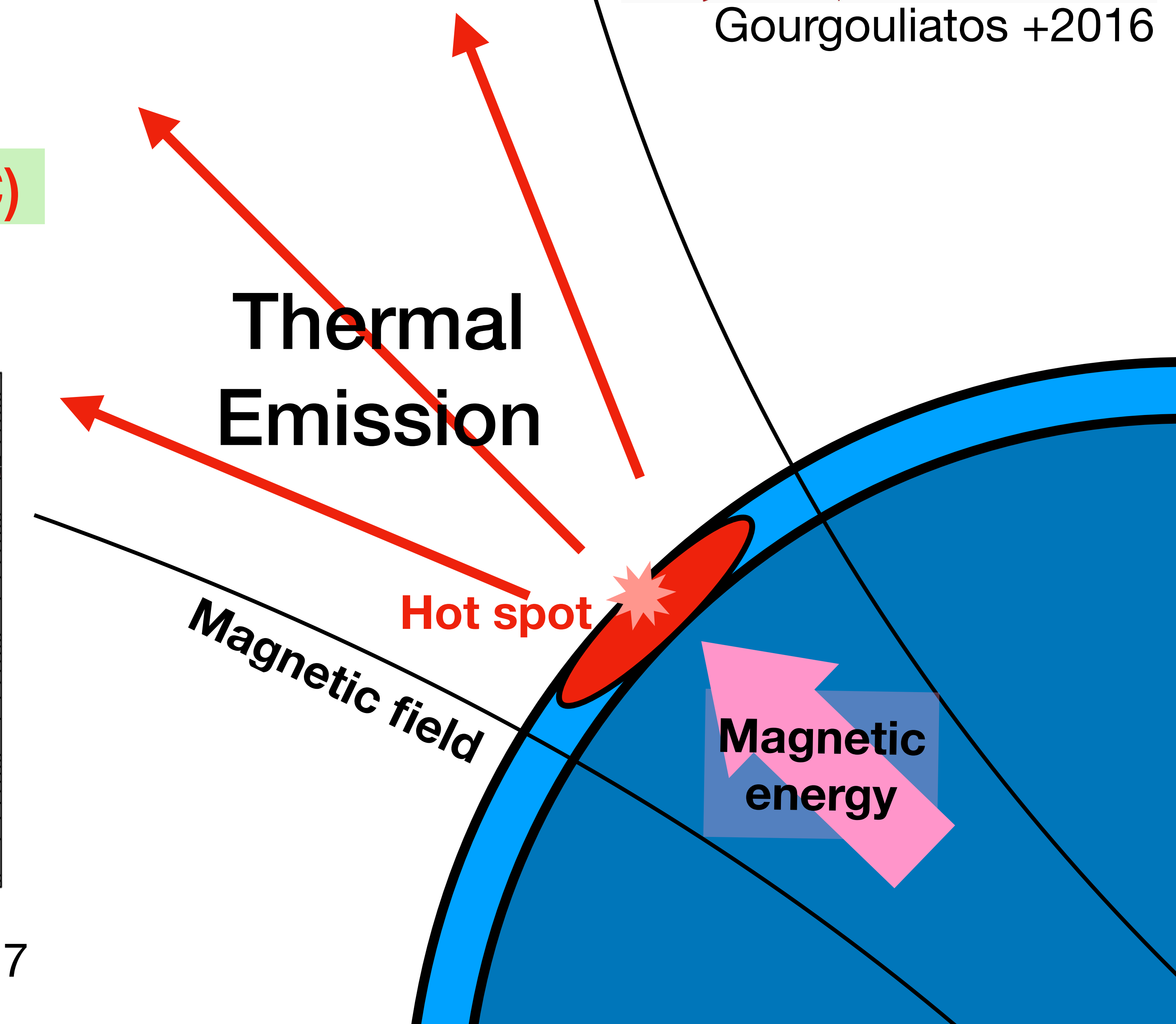
Gourgouliatos +2016

Soft X-ray Component (SXC)

from neutron star surface

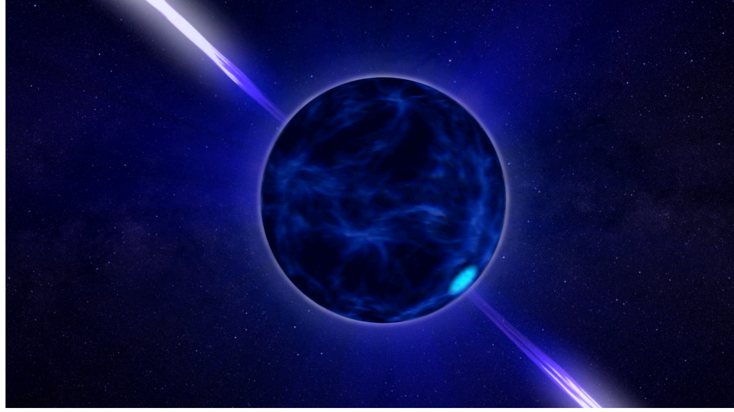


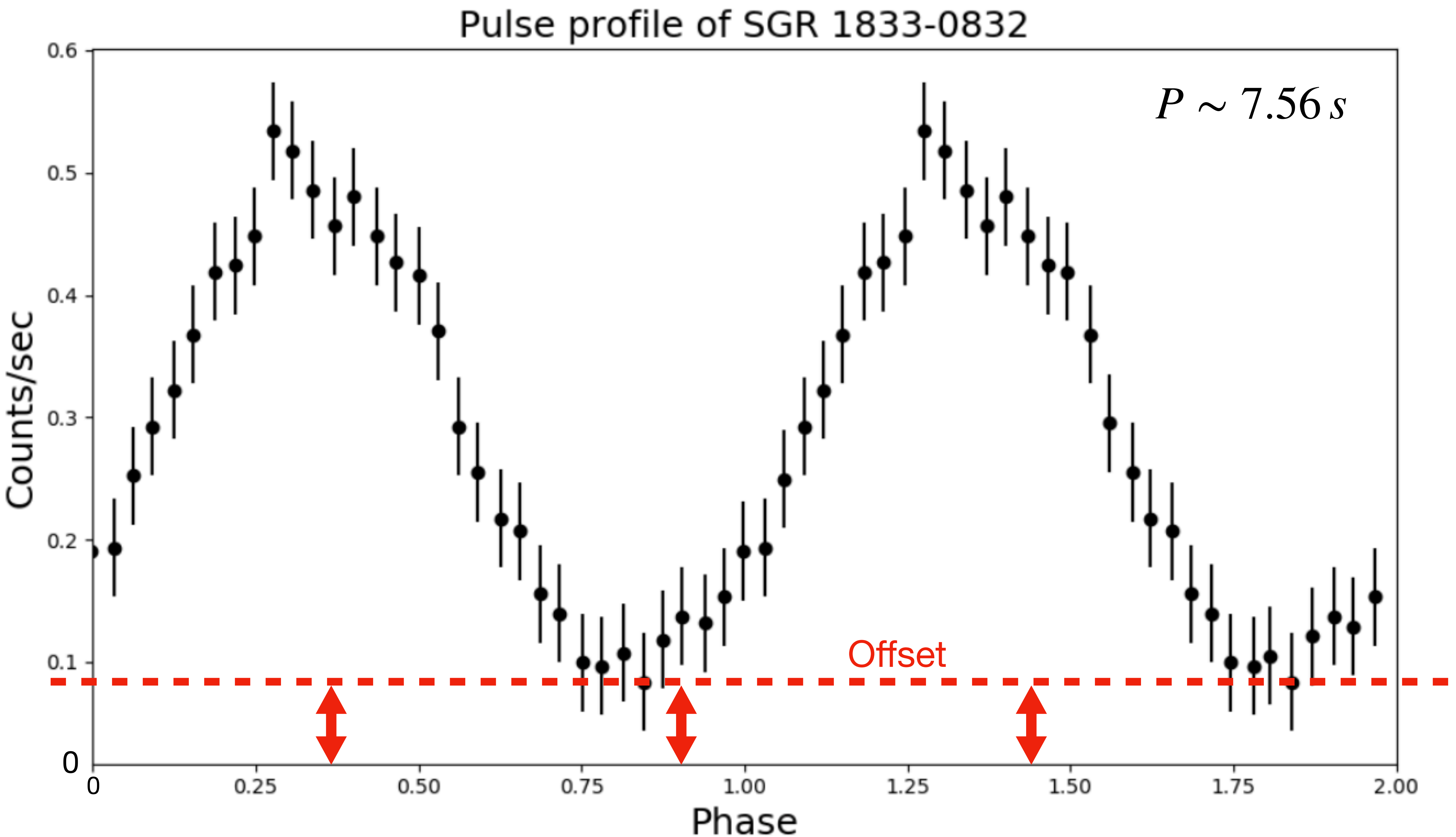
Enoto+2017



Pulse profile

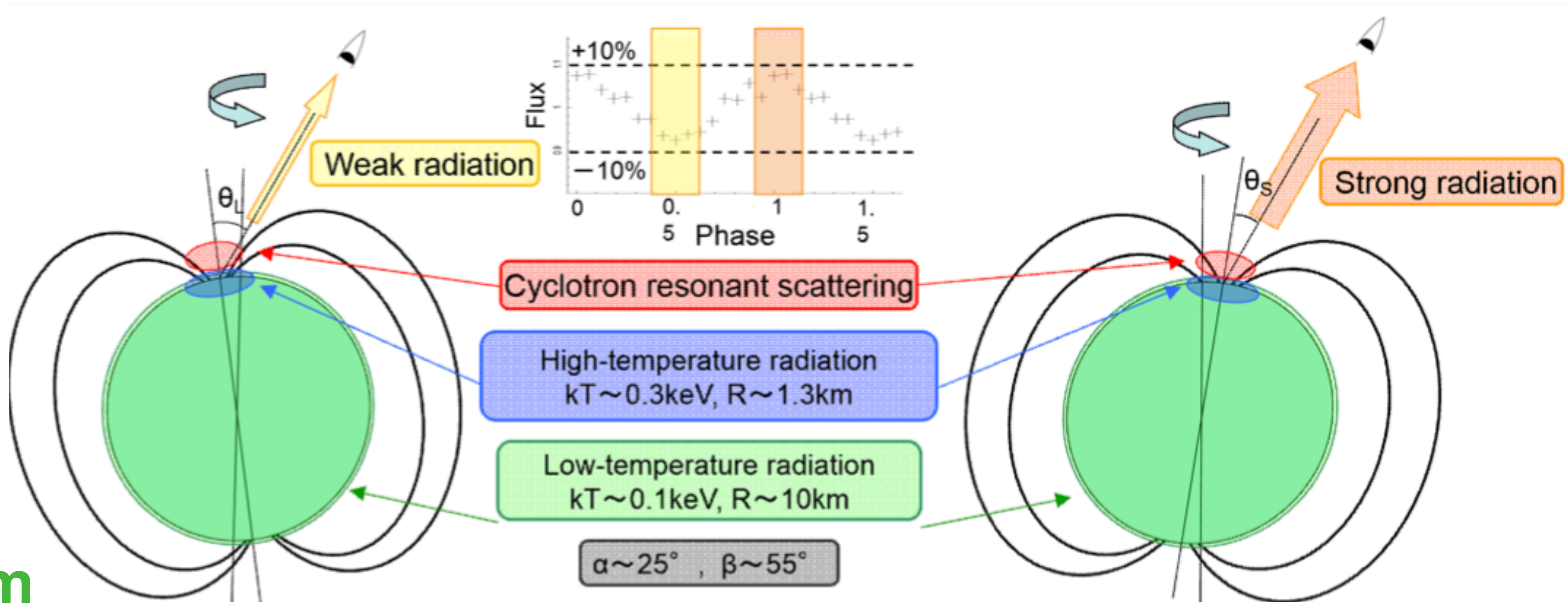
How to explain the offset?





Emission flux never reach 0 !

Takahashi +2014



Hot spot

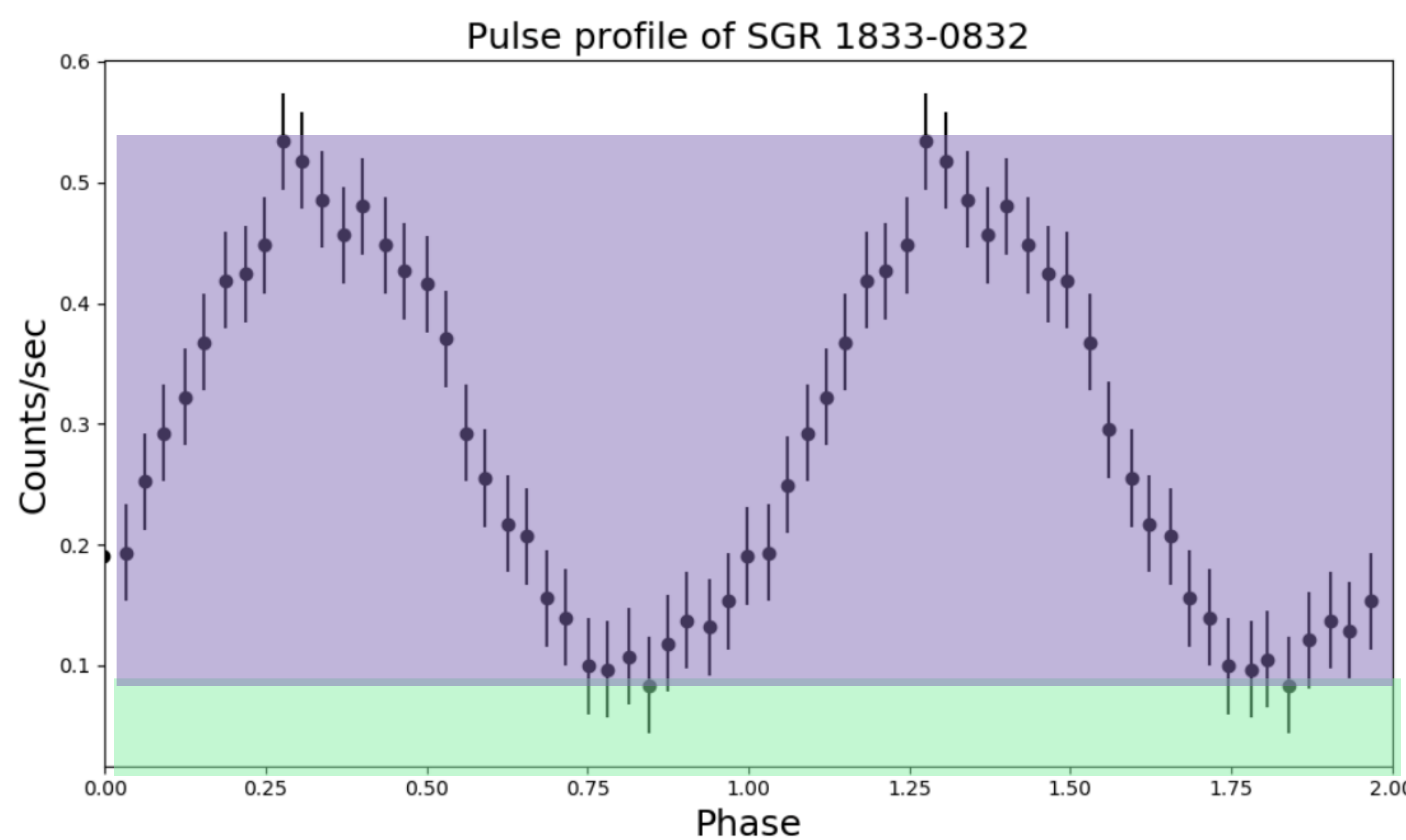
+

Emission from entire surface

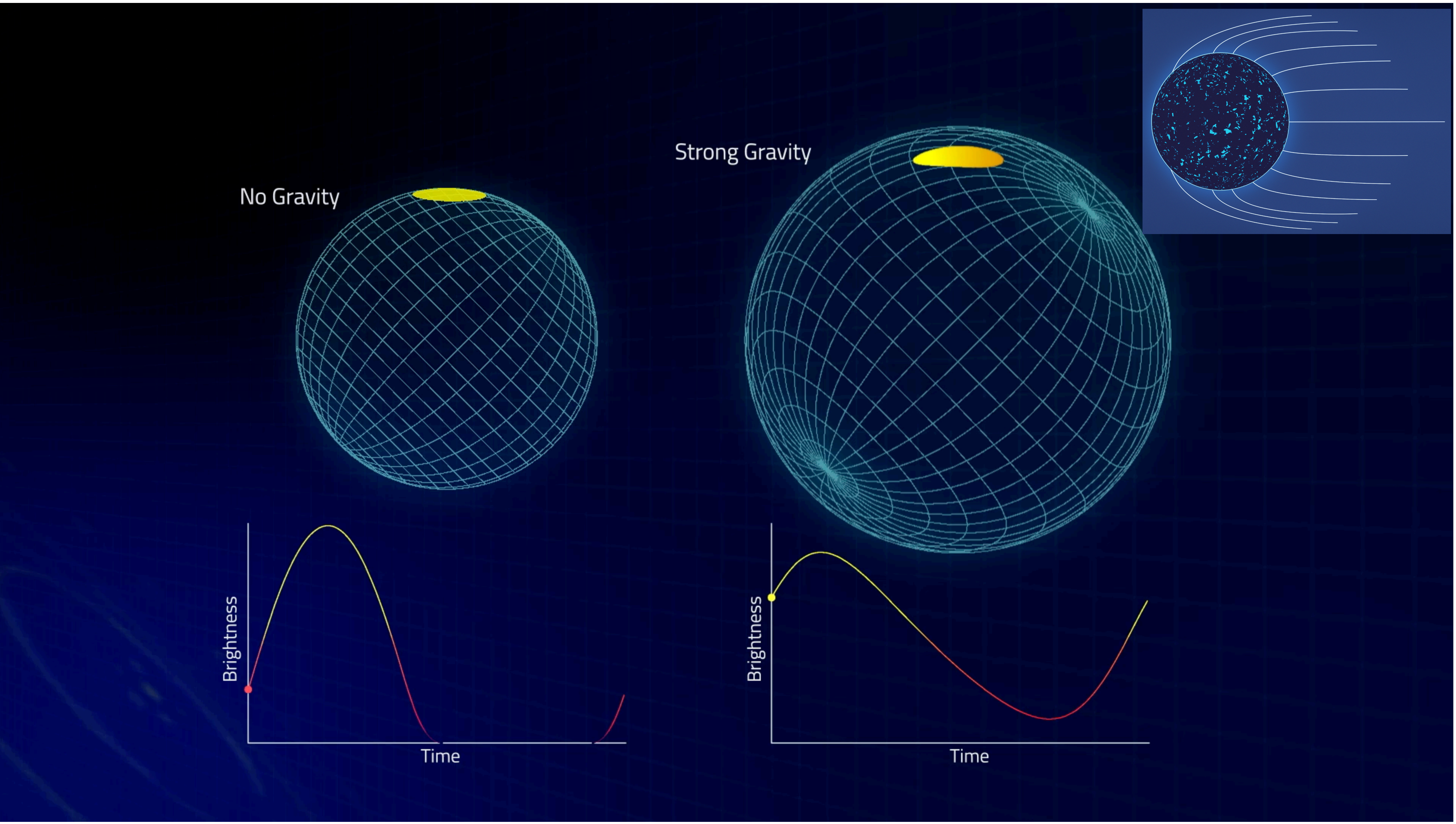
Modulation

+

Offset



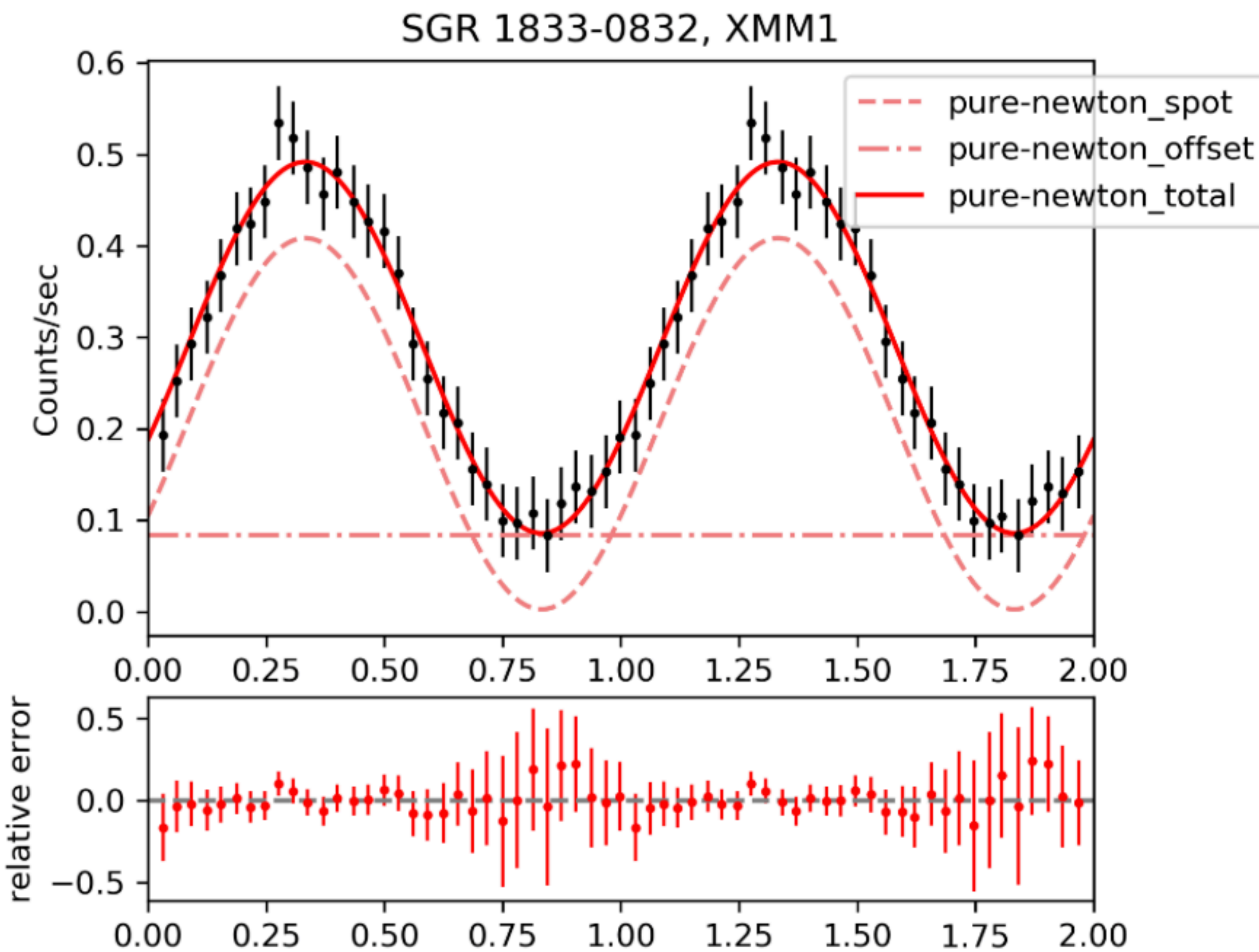
Offset could be explained by GR



Credits: NASA NICER Group

Pulse profile of SGR 1833-0832

Newtonian

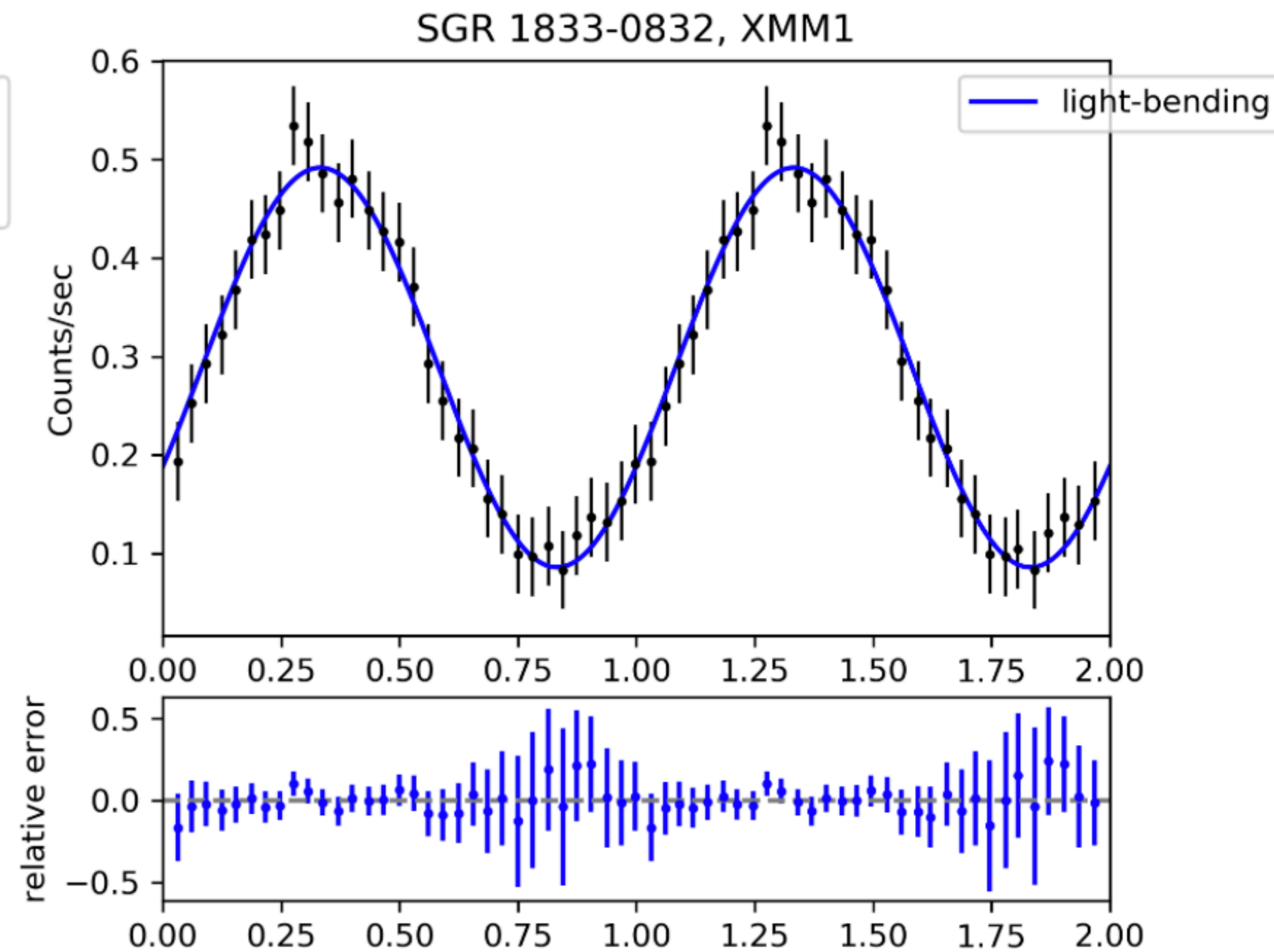


Hot spot

+

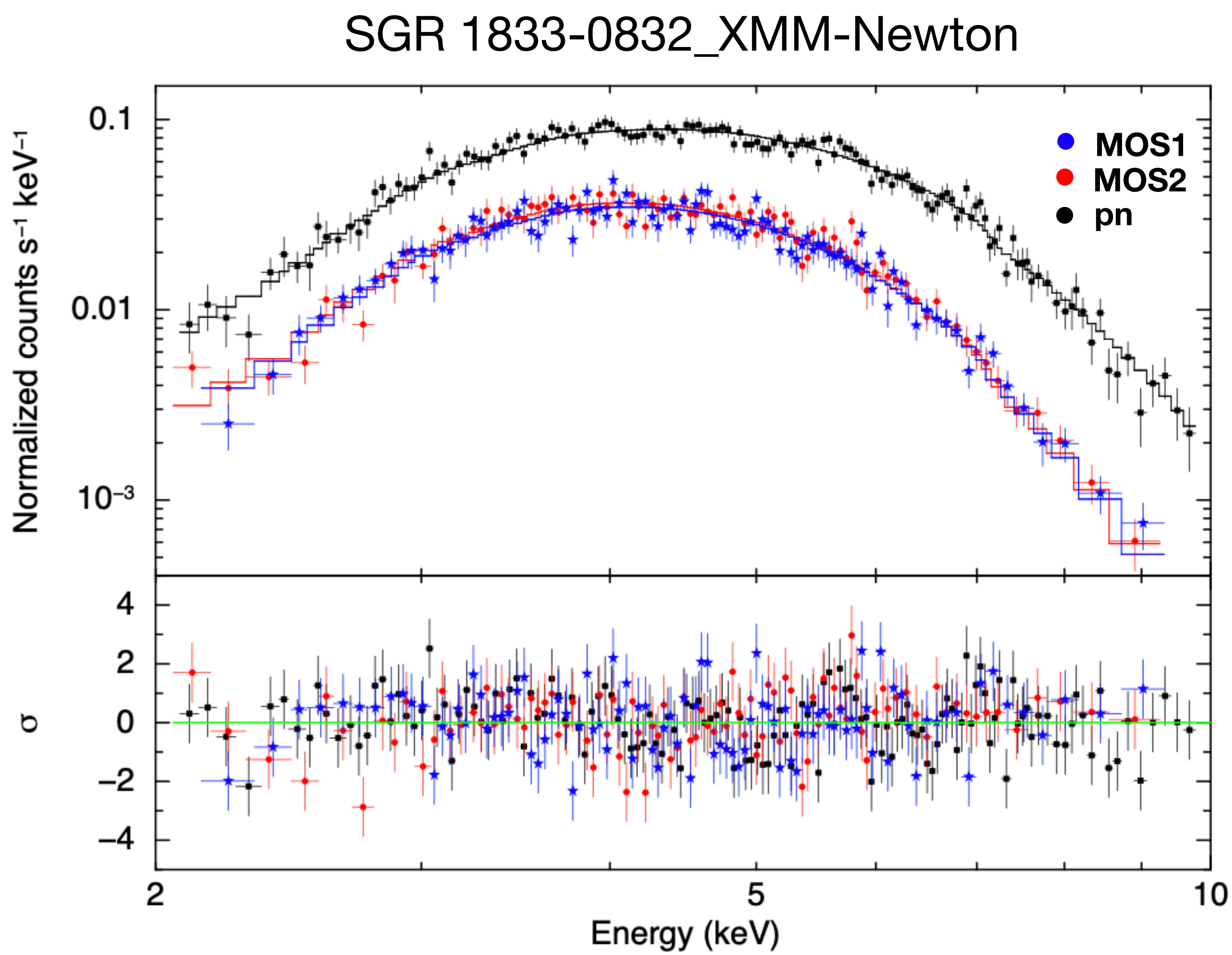
Emission from entire surface

Relativistic

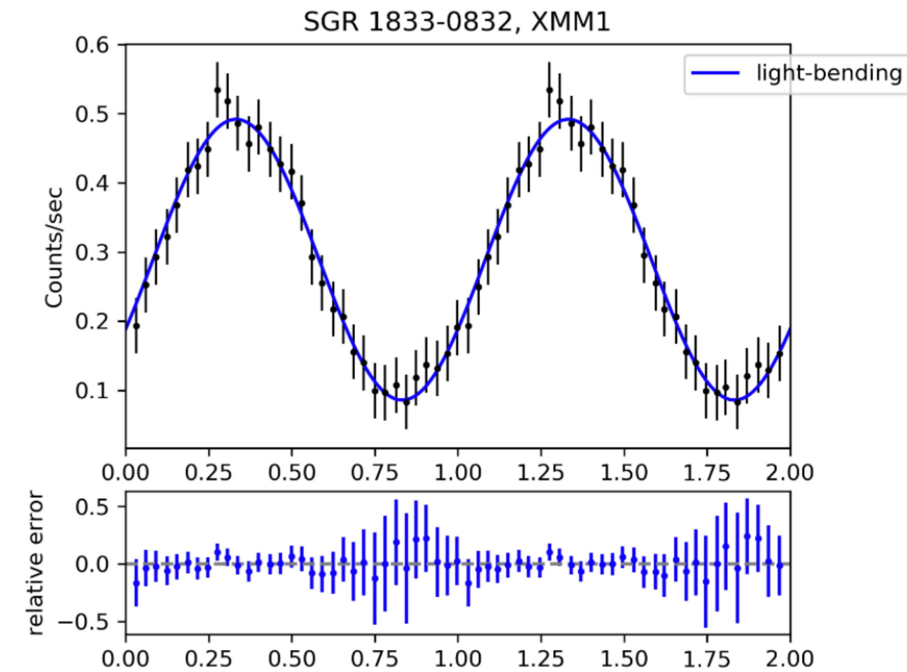


Hot spot

Spectrum of SGR 1833-0832



Single blackbody fits well



Relativistic

Hot spot only

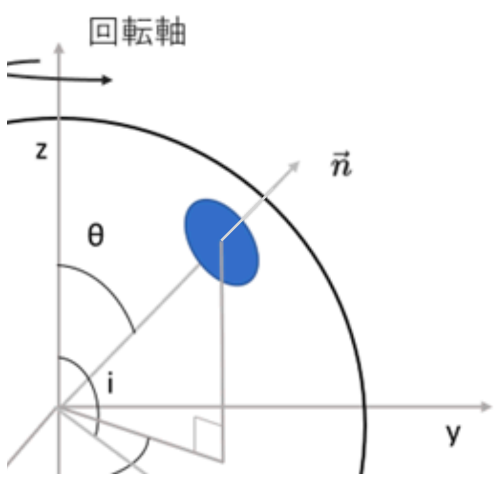
More natural

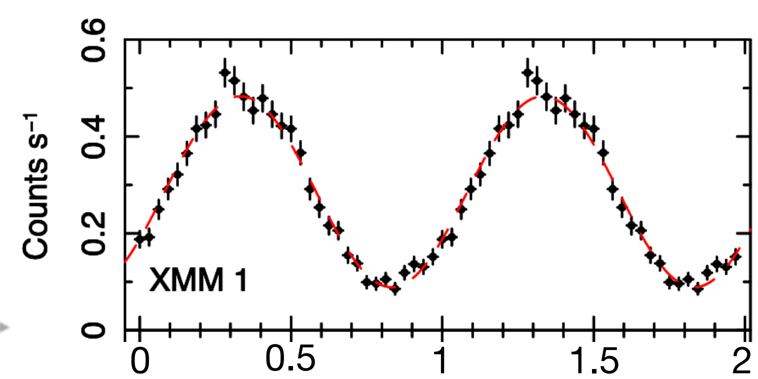
Esposito +2011

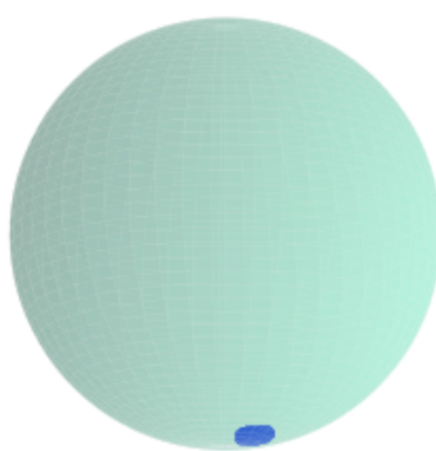
Radius comparison: timing & spectral

assuming a circular radiation area, $r_g = \frac{1}{3}$

Estimating the size of hotspots from pulse profile





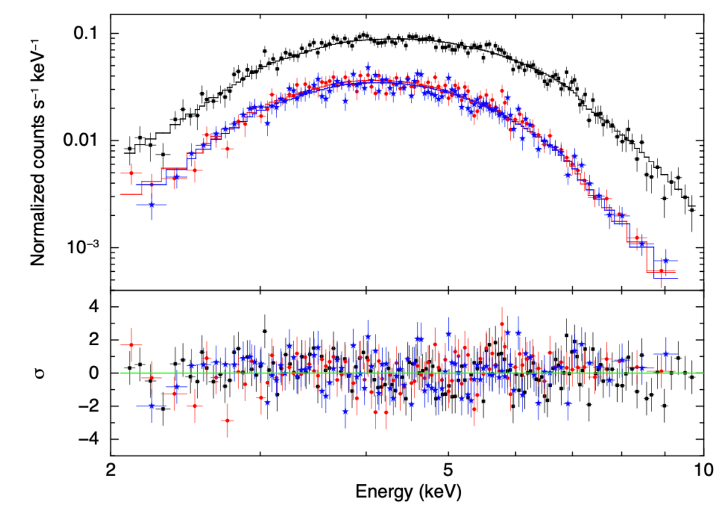


Radiation radius

Estimating the size of hotspots from spectrum

$$L = S\sigma T^4$$

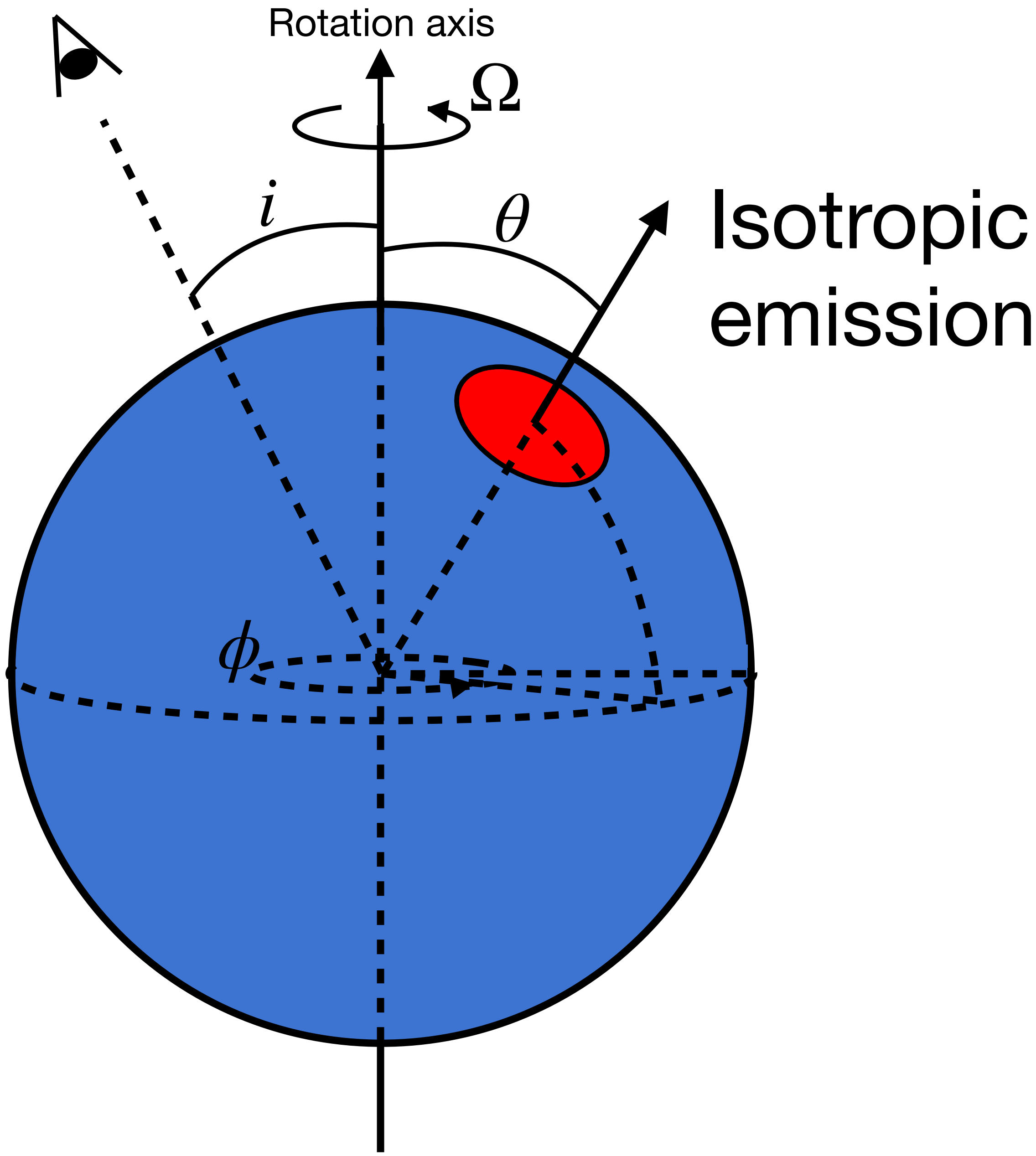
$$L_{obs} = \frac{S_{obs}}{4\pi D^2} L$$

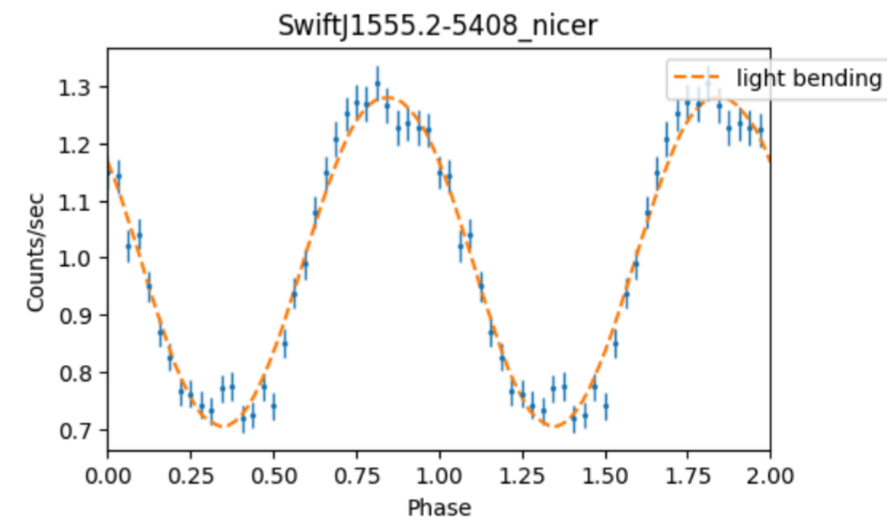


T: blackbody temperature
D: distance
S: emission area

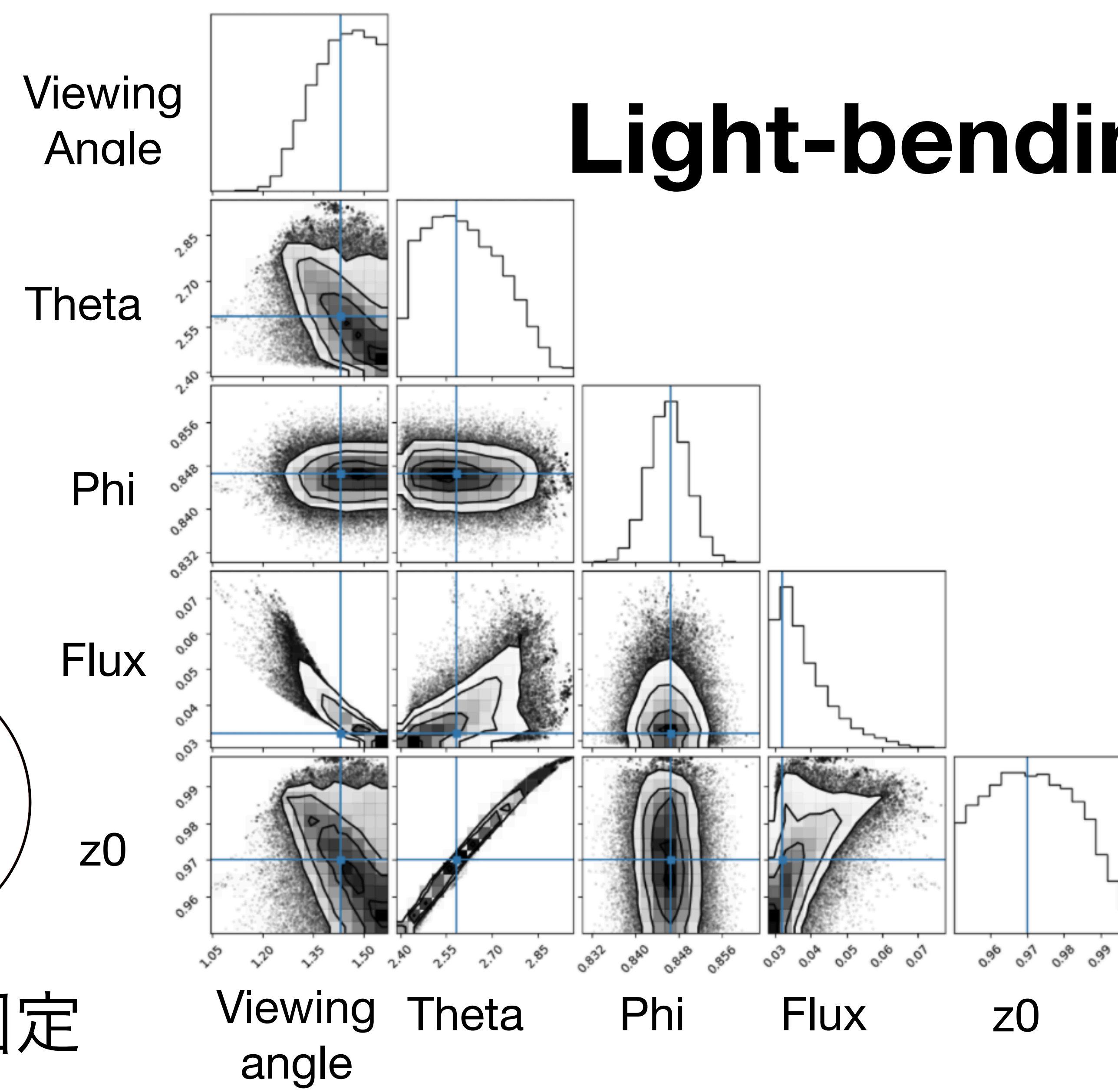
Time-averaged projection of the radiation radius

Parameter estimation





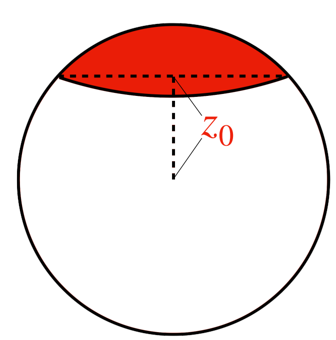
Light-bending



i: inclination (viewing angle)

θ: colatitude φ: longitude

z_0: size of hot spot

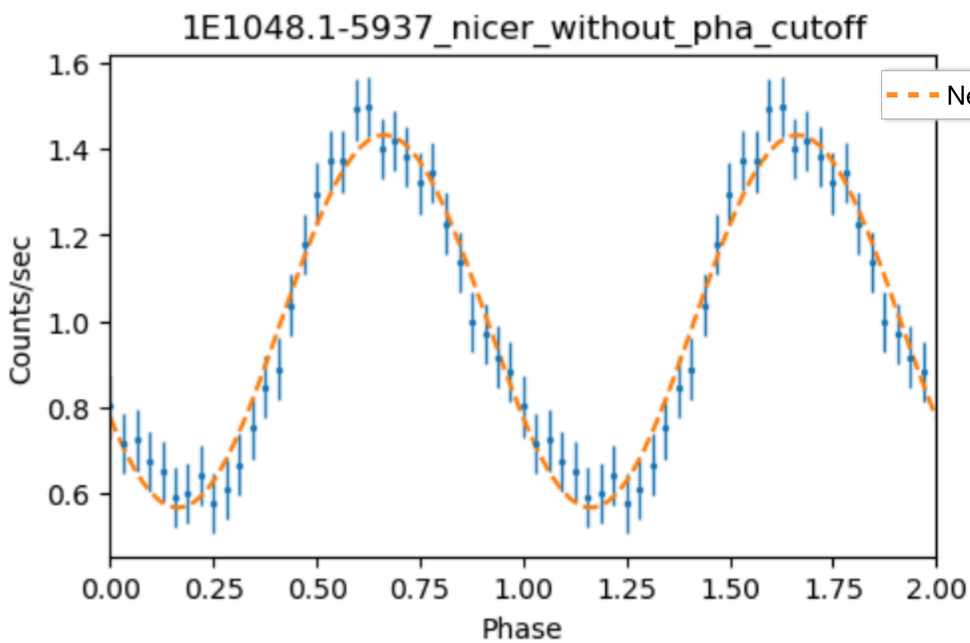


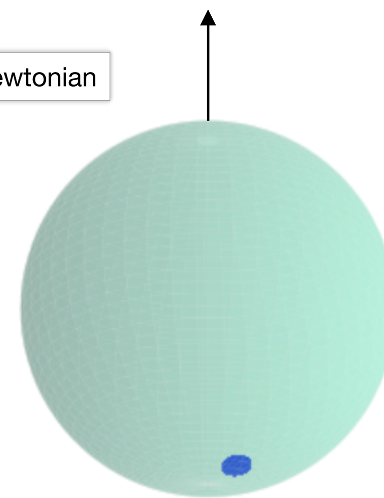
Normal prior $\{i, \theta, \varphi, m, z_0\}$ r_g固定

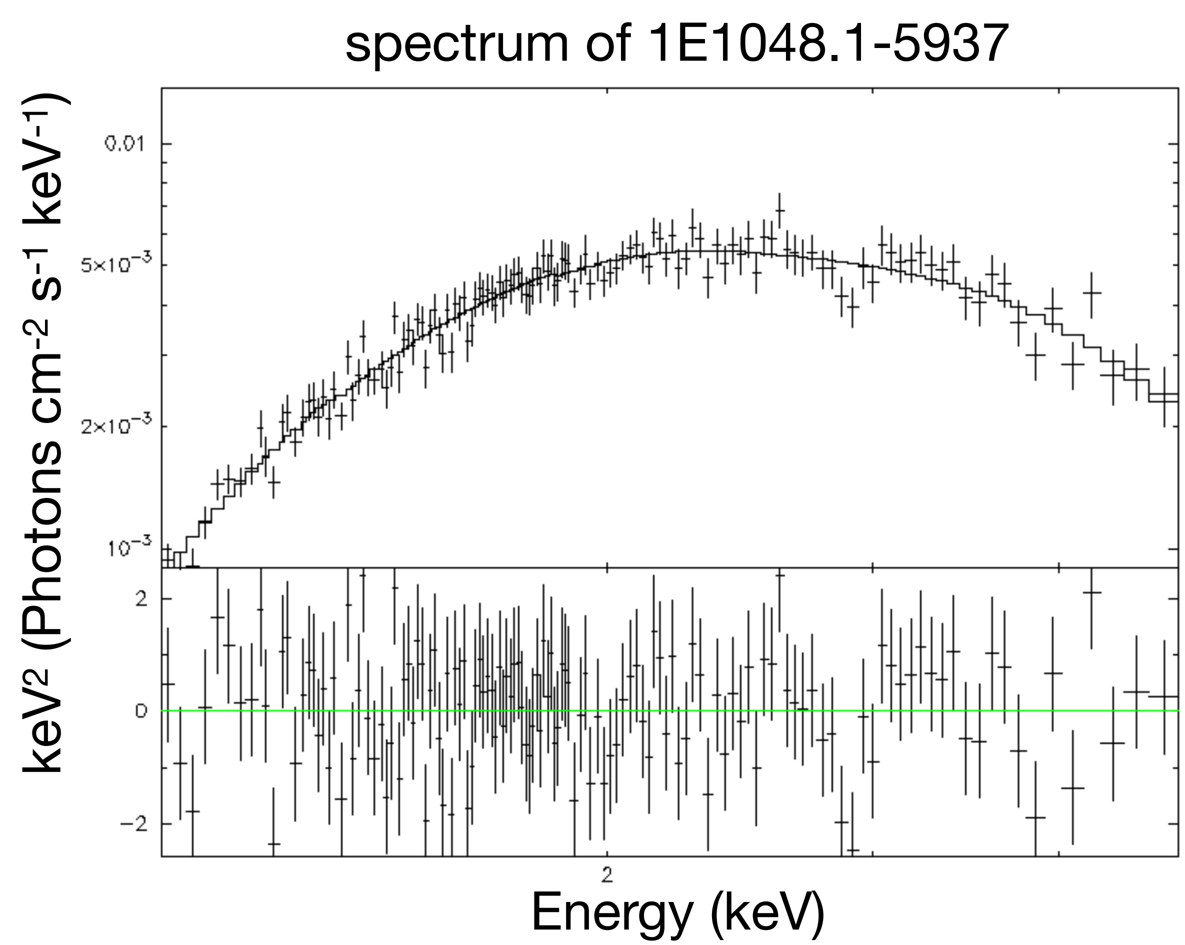
Hot spot size: 1E 1048.1–5937

Timing R

Spectral R







Timing: R_{max}=1.64 km Newtonian Spectral: $\langle R_{\perp} \rangle$ =3.10km

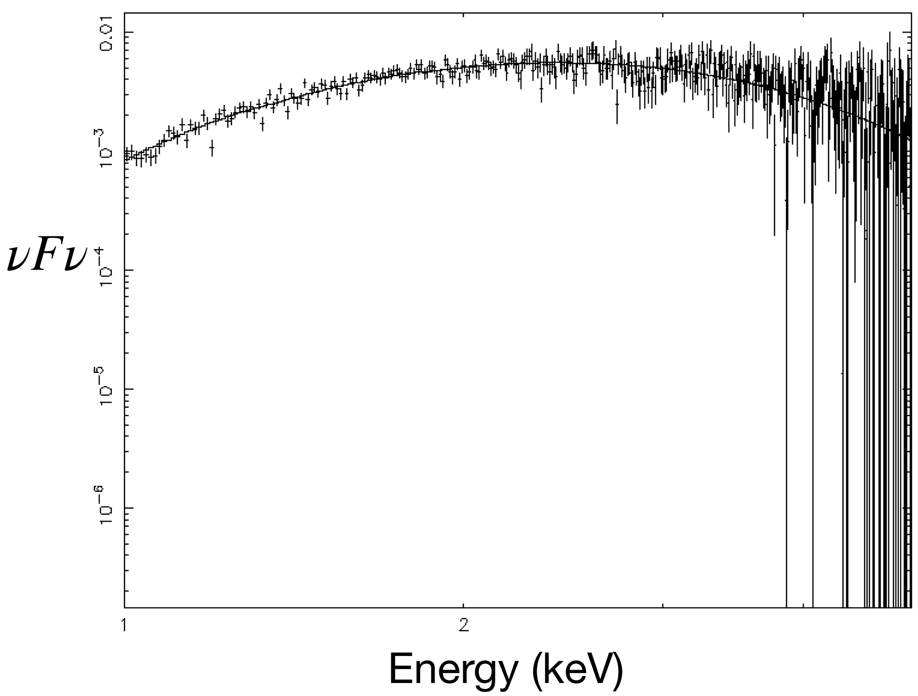
Timing: R_{max}=1.79 km Relativistic Spectral: $\langle R_{\perp} \rangle$ =1.69km

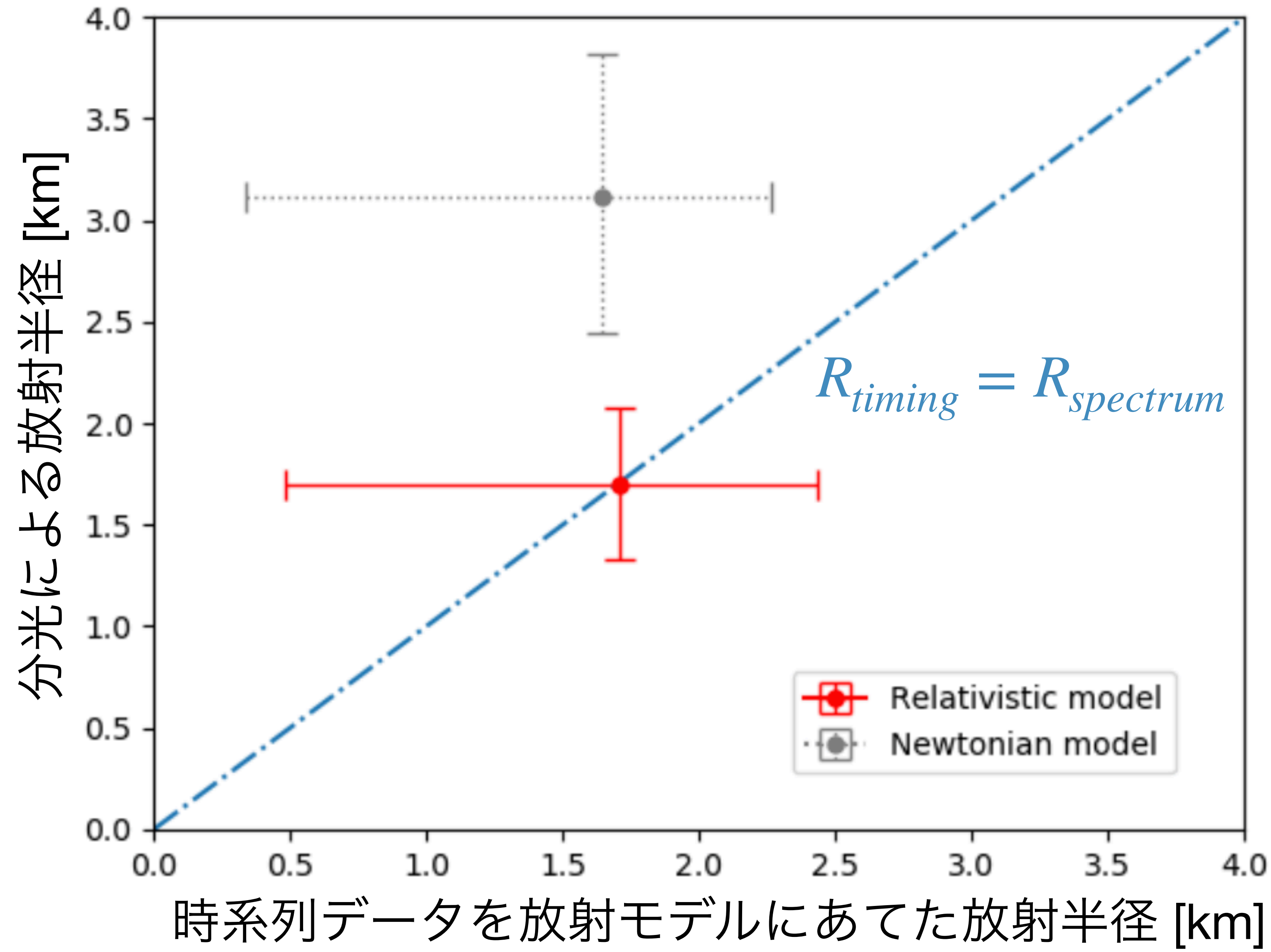
R = 12 km

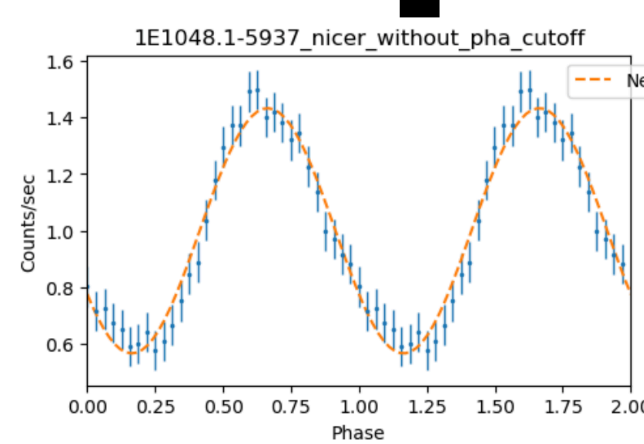
Distance = 9.0 (1.7) kpc

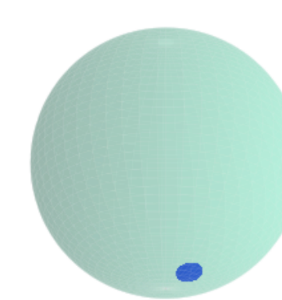
Martin +2006

もしこのような結果が出たら...





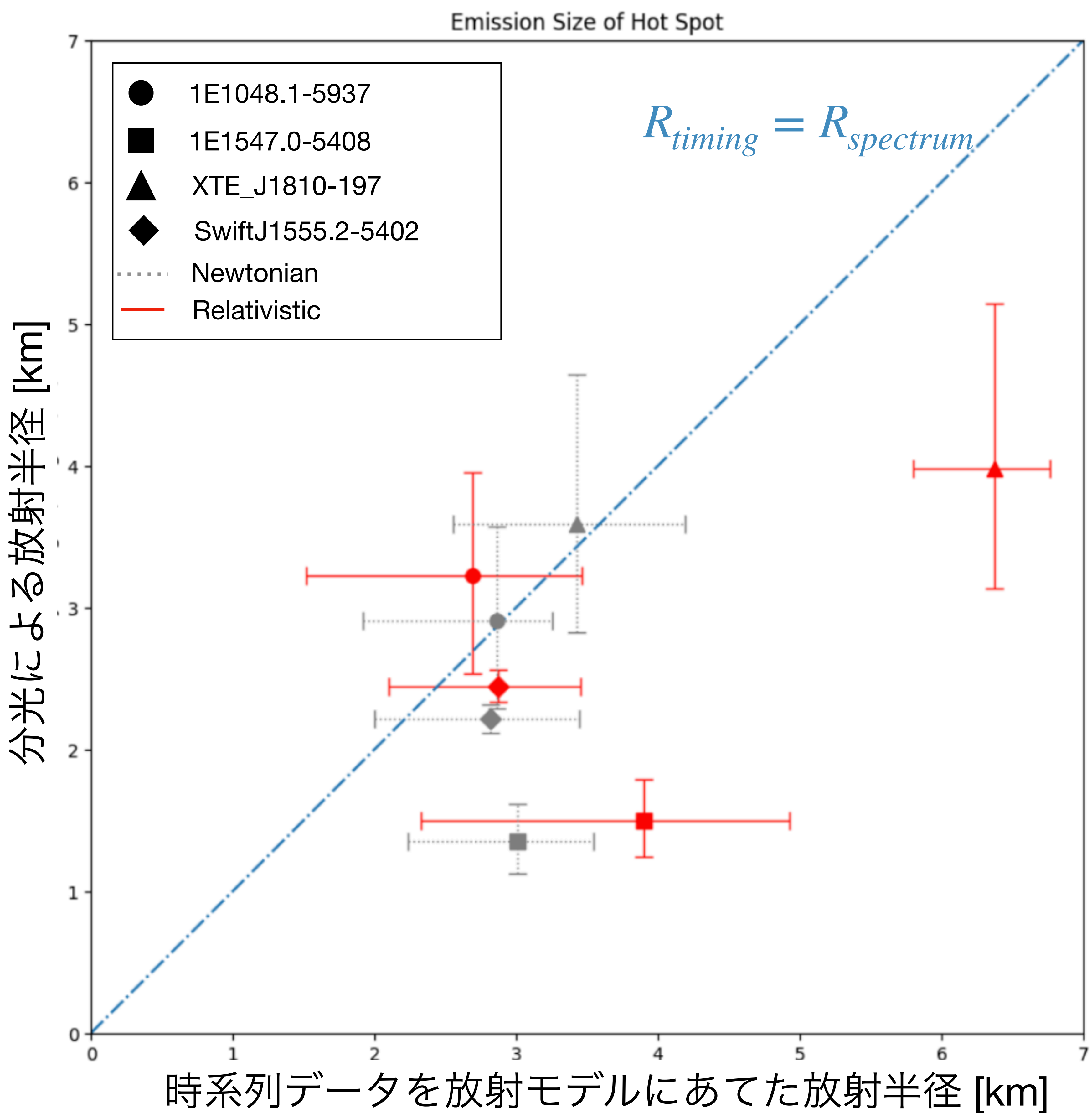




Compare the results

$R_{spectrum}$ **and** R_{timing}

Results with 1σ error



まとめ

Motivation

soft X-ray emissionはマグネターを理解する重要な切口

Method & Assumption

Soft X-ray の観測解析＋ホットスポットによるパルス波形の再現

放射領域は円状、放射はisotropic、全ての星に適用するGR効果は同じ

~1.4$M_\odot$ ~12 km

有限サイズ
一般相対論近似
} 時系列解析＋分光解析 (相対論修正)

Future work

放射領域の温度構造

放射領域の形状

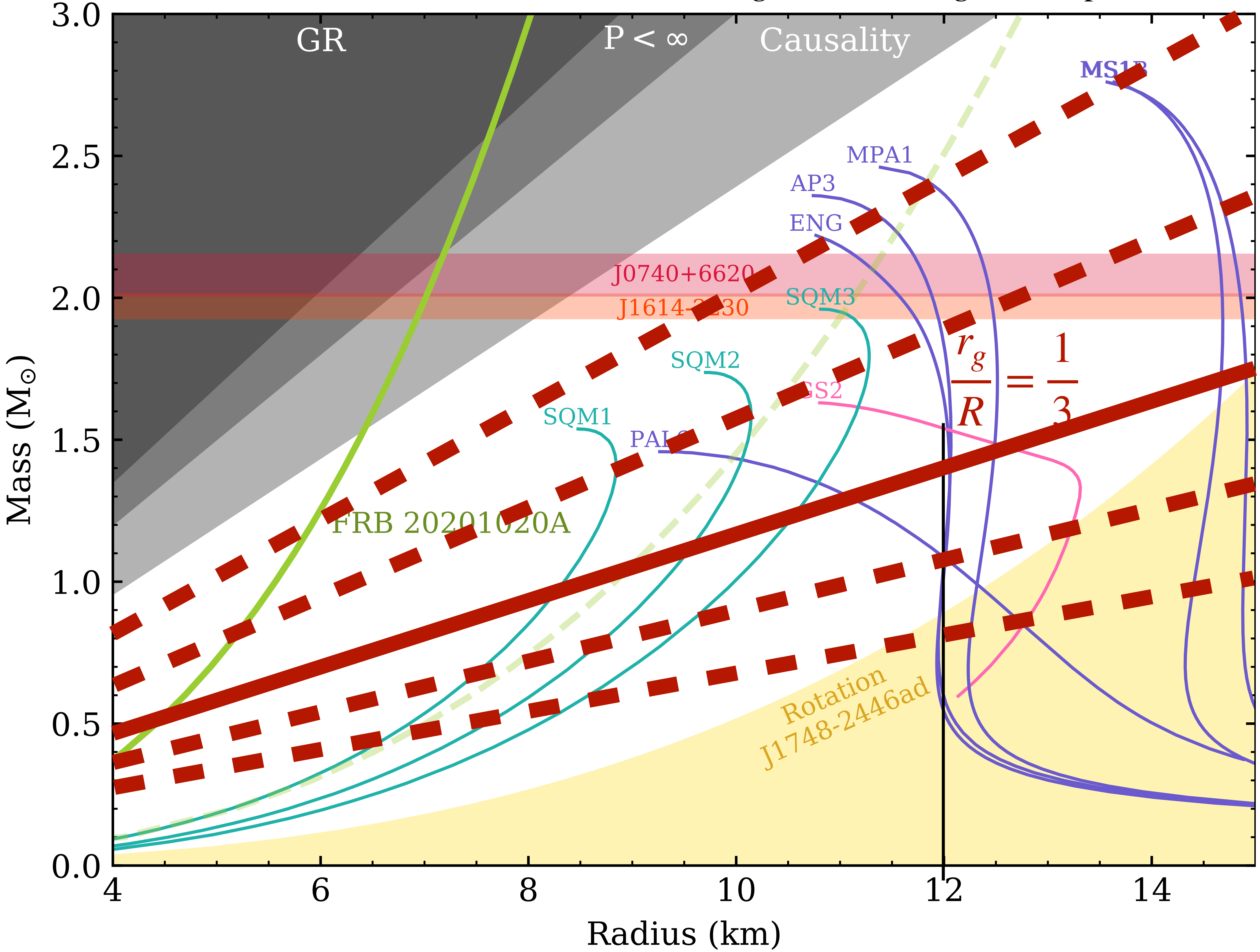
コンパクトネスをフリーパラメータにする

展望

$\{i, \theta, \varphi, m, z_0\}$　r_g固定

⬇

$\{i, \theta, \varphi, m, z_0, r_g\}$　$R_{timing} = R_{spectral}$



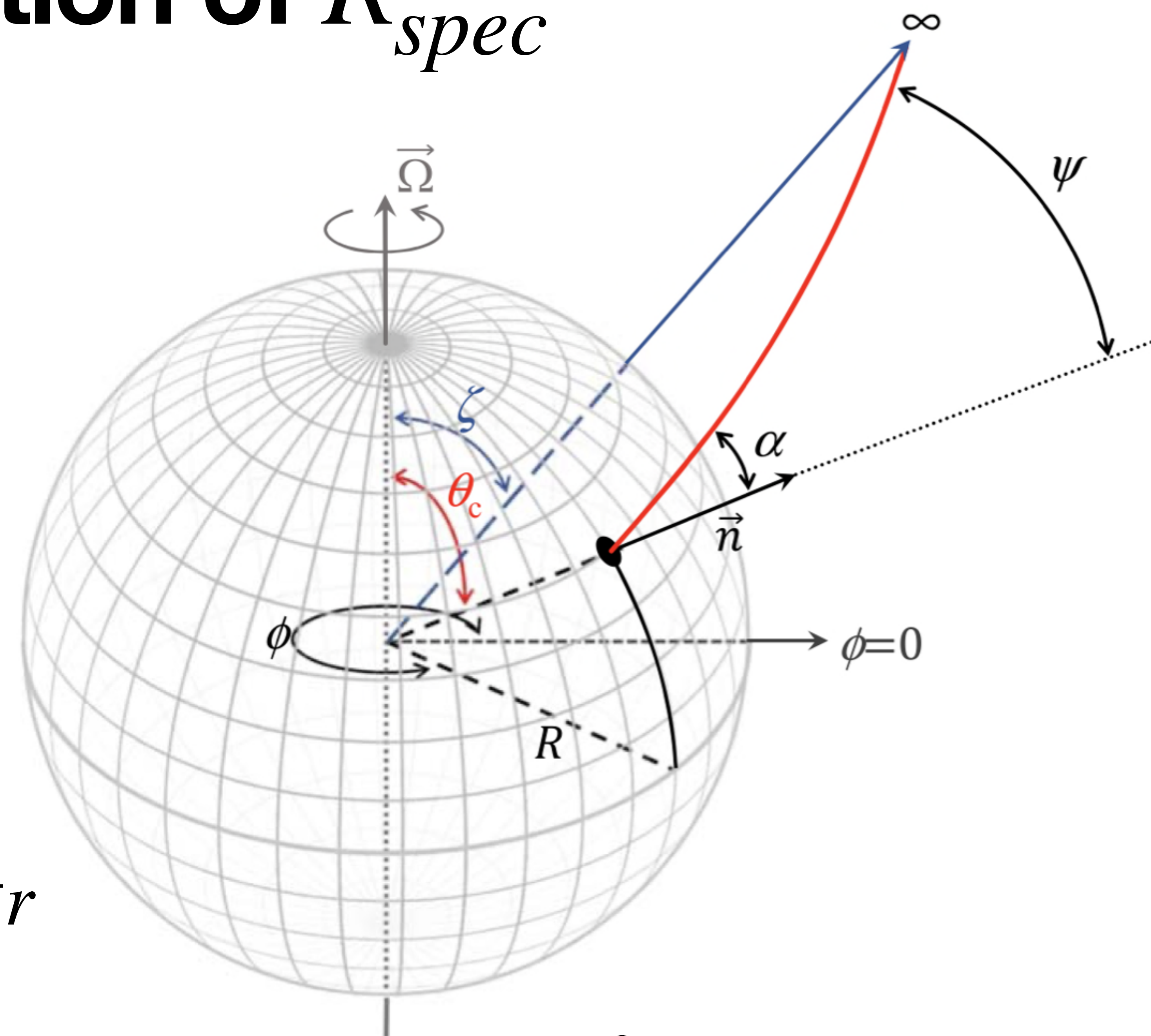
Relativistic correction of R_{spec}

Newtonian R_{spec}

Gravitational Redshift

Observed Flux

Relativistic R_{spec}



$$S \propto \frac{L}{T^4} \quad r_{corr} \sim (1 - r_g/R)^{3/4} r$$

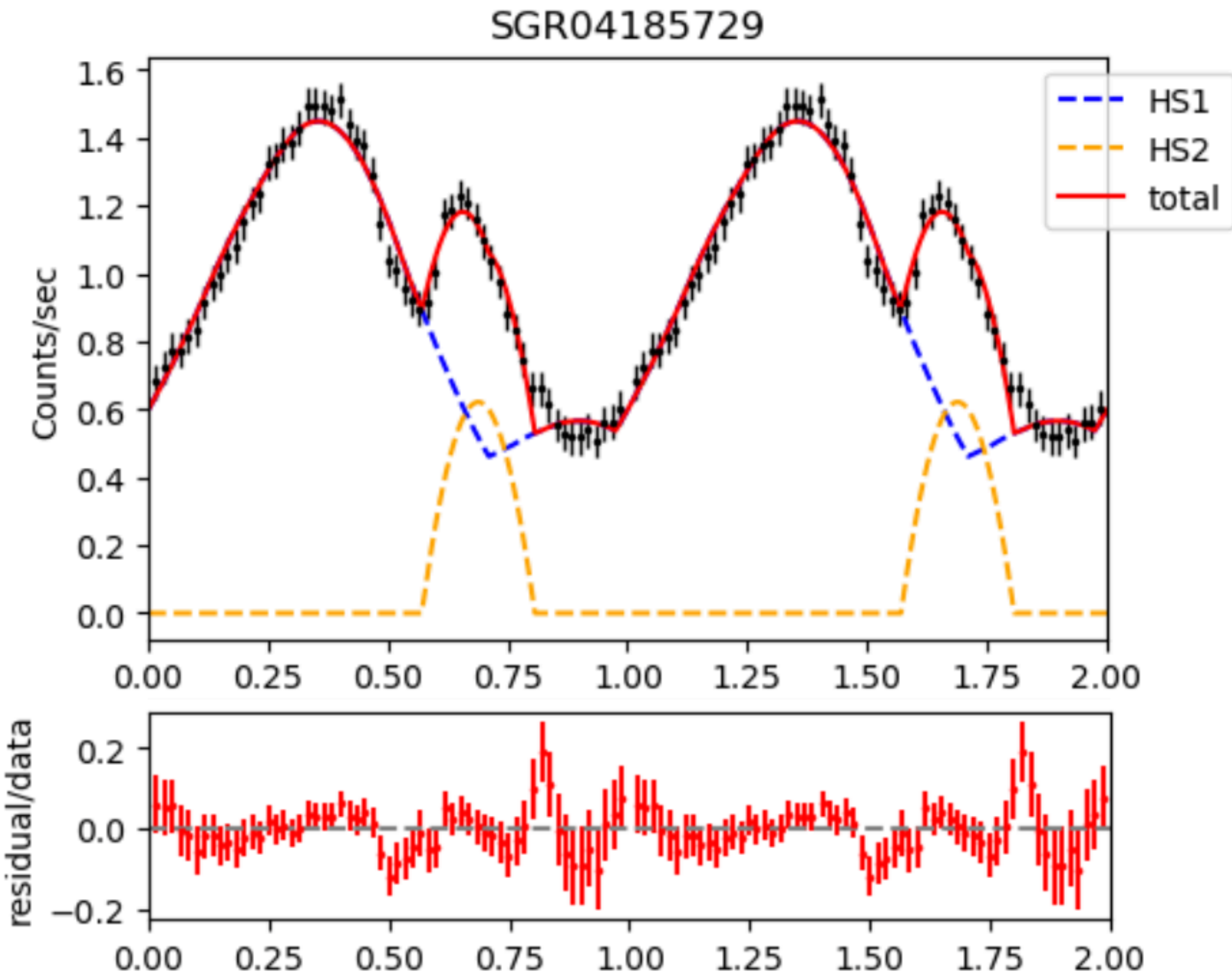
$$T \to E : E = \delta(1 - \frac{r_g}{R})^{1/2} E'$$

$$L : dF(E) = (1 - \frac{r_g}{R})^{1/2} \delta^3 I'(E', \alpha') \cos\alpha' \frac{d\cos\alpha}{d\cos\psi} \frac{dS'}{D^2}$$

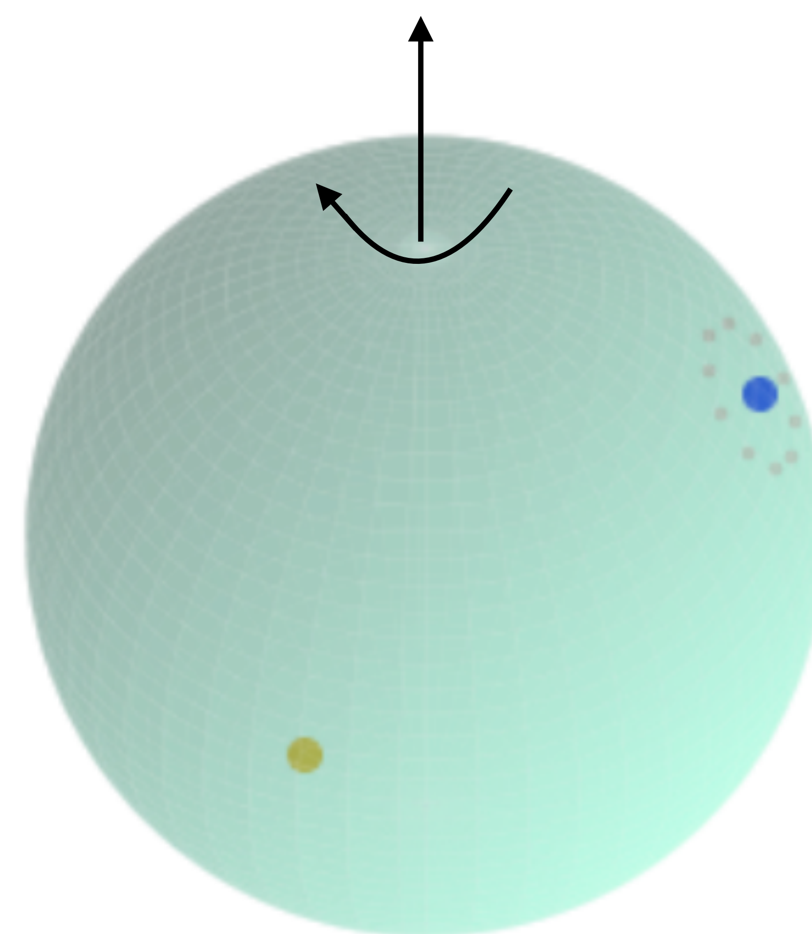
δ: Doppler factor

r_g: Schwarzschild radius

Multi-peak pulse profile

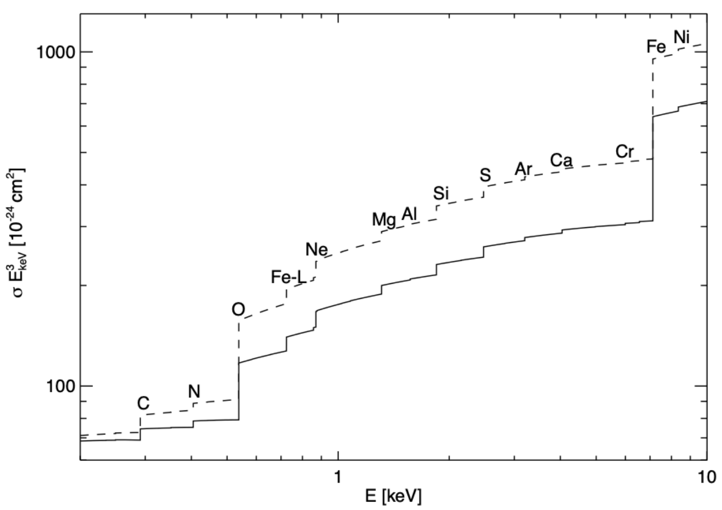


Best fit of relativistic model

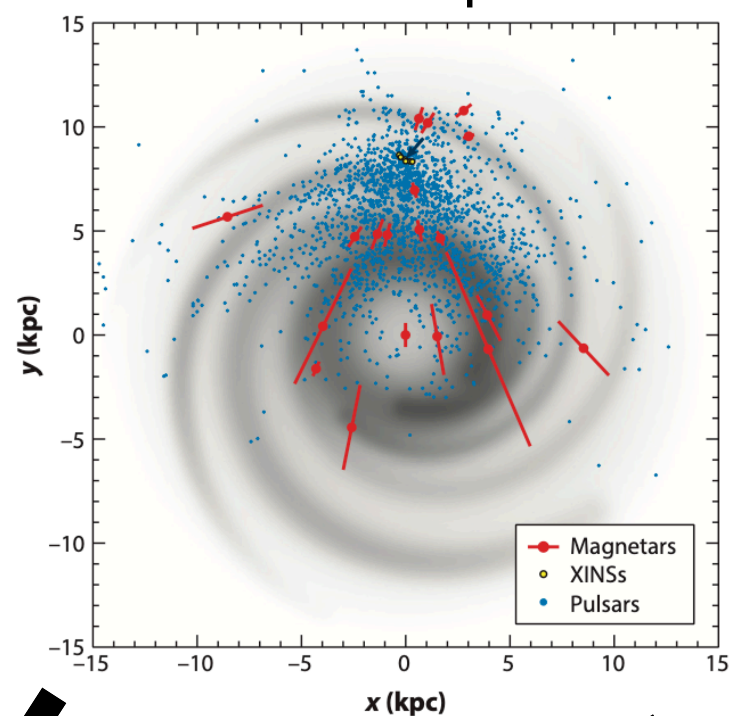


Distance of magnetars

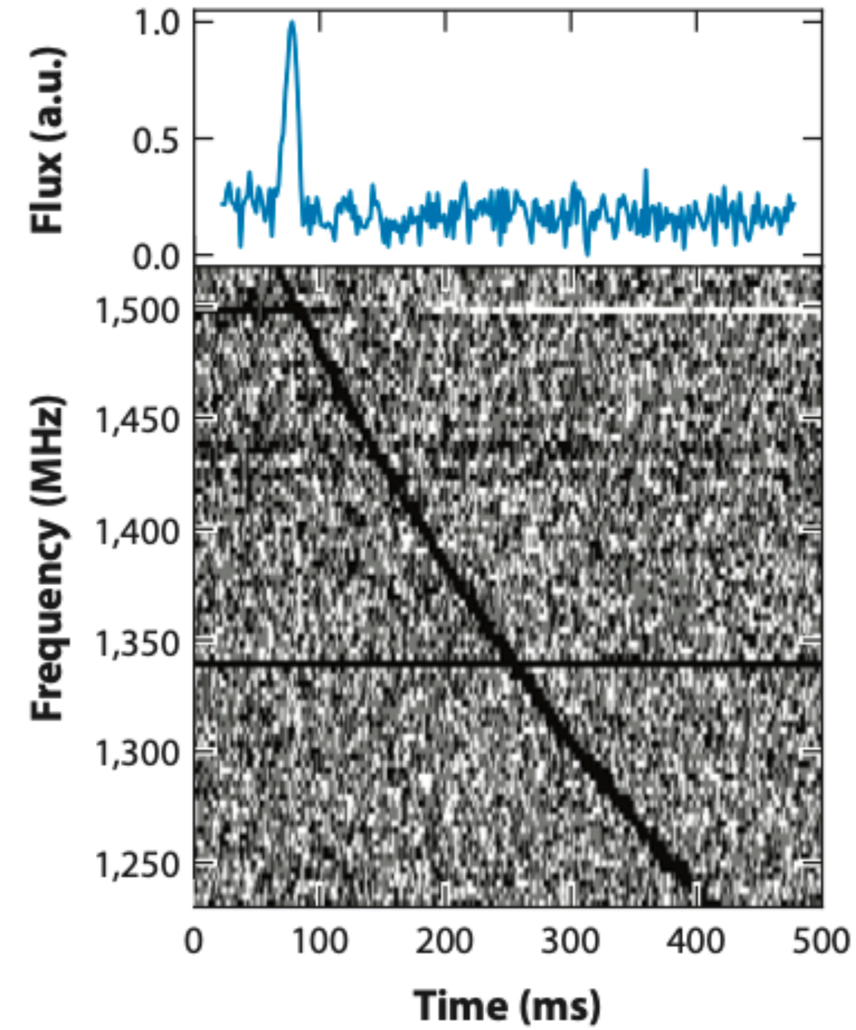
Wilms +2000



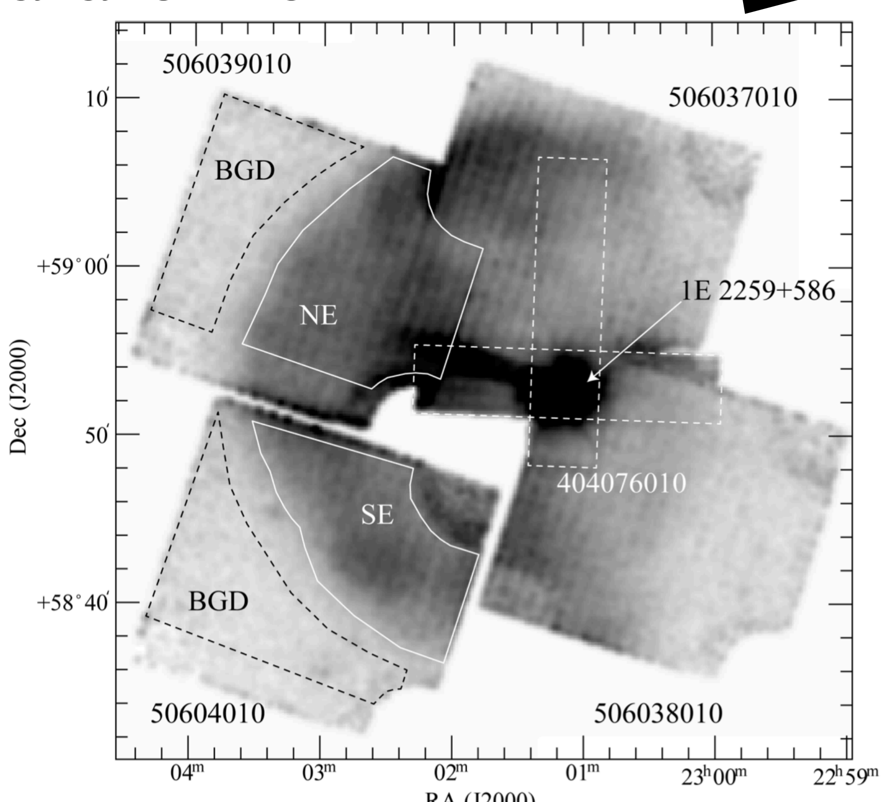
Kaspi +2017

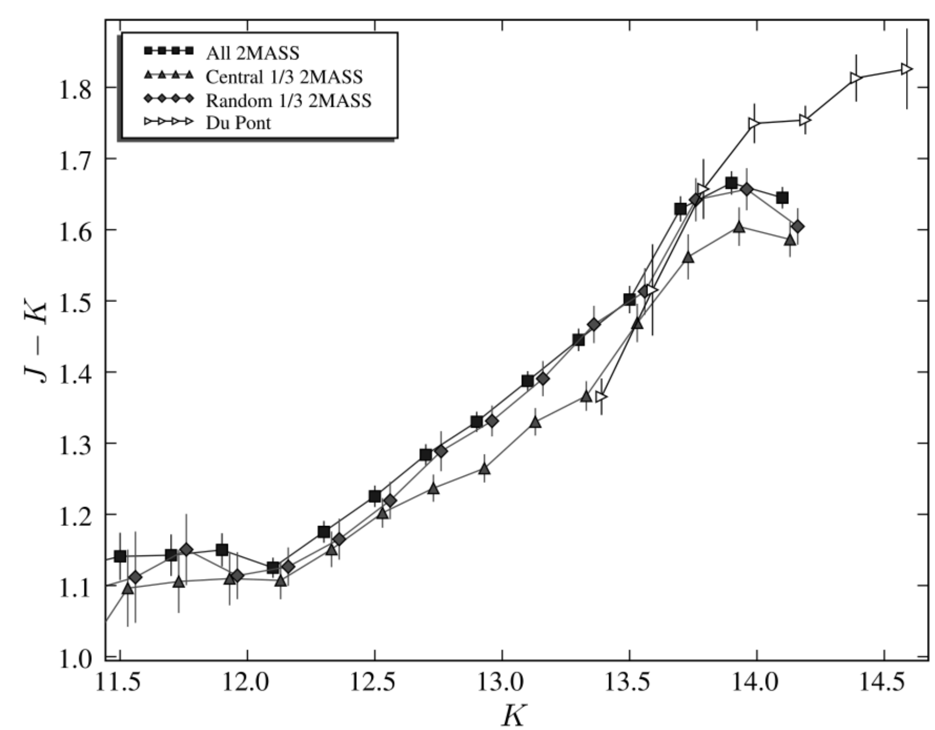


Cordes +2017



Nakano +2017



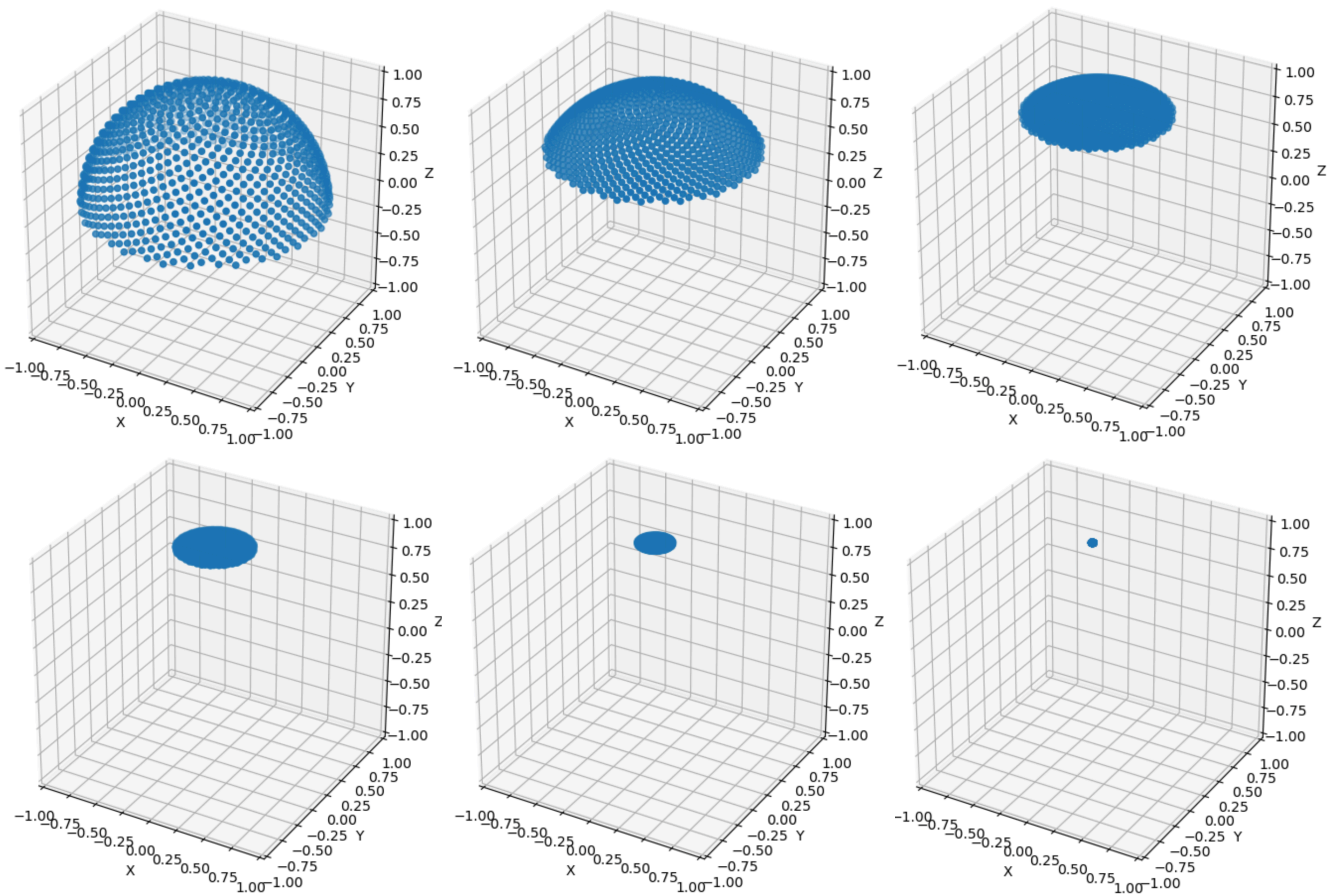


$$A_V = \frac{(J-K)_{\rm peak} - (J-K)_0}{0.164}$$

$$d = 10^{0.2(K - M_K - 0.112 A_V)} \times 10\ {\rm pc}$$

Durant +2006

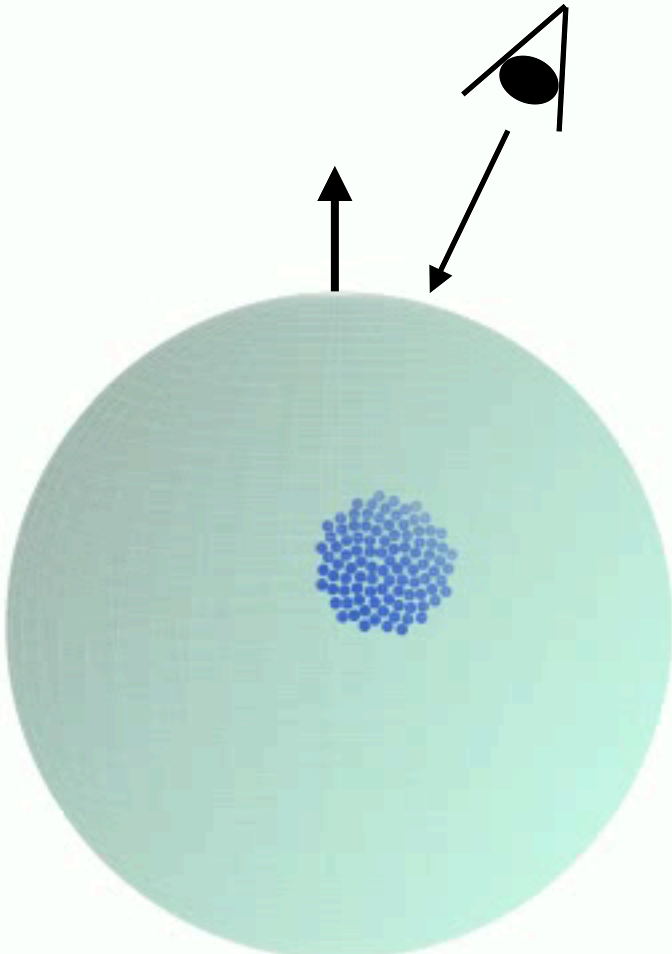
Estimate the size of hot spot



Arrange several point source spots to reproduce the size

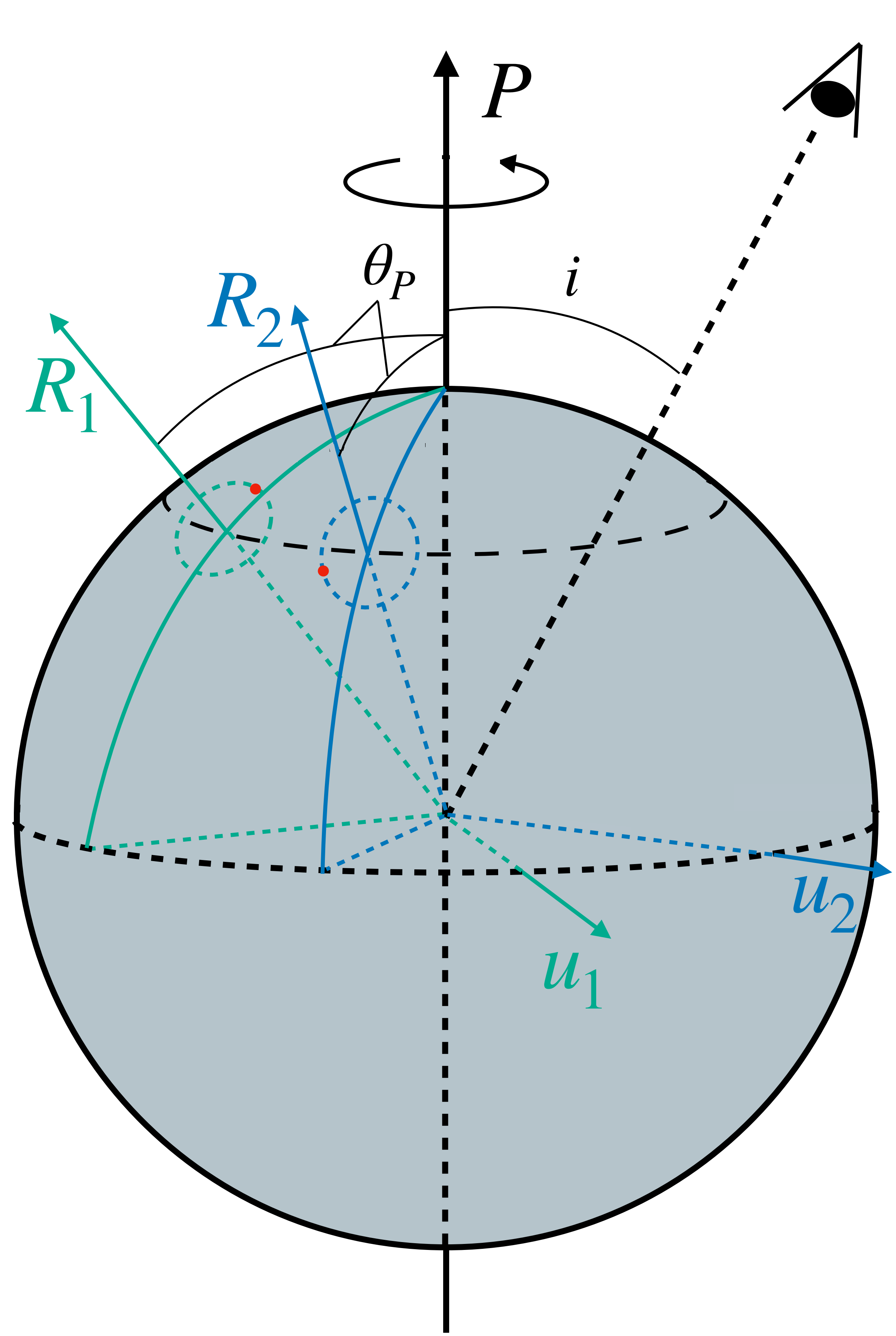
Circular hot spot

Uniform temperature



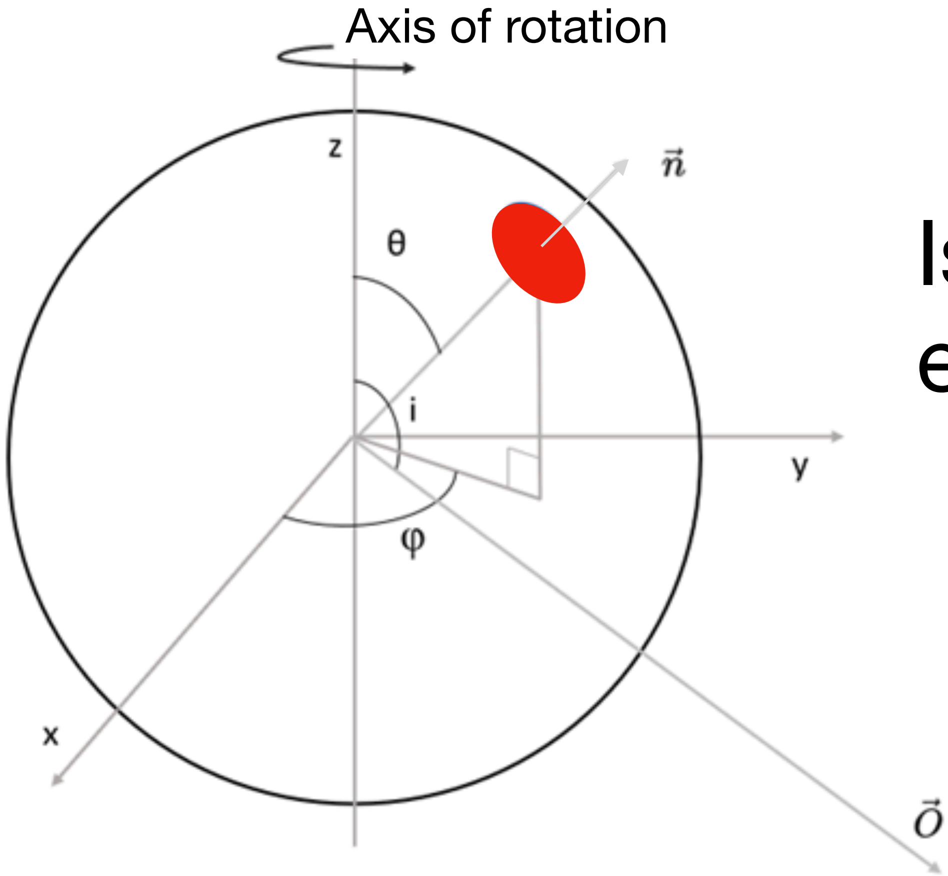
$$\omega_P = \frac{2\pi}{T_P} \qquad \vec{u} = \begin{pmatrix} -\cos(\omega_P t + \phi) \\ -\sin(\omega_P t + \phi) \\ 0 \end{pmatrix}$$

$$\overrightarrow{M_R} = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} \cos\theta_P + \begin{pmatrix} 0 & -u_z & u_y \\ u_z & 0 & -u_x \\ -u_y & u_x & 0 \end{pmatrix} \sin\theta_P + \begin{pmatrix} u_x^2 & u_x u_y & u_x u_z \\ u_y u_x & u_y^2 & u_y u_z \\ u_z u_x & u_z u_y & u_z^2 \end{pmatrix} (1 - \cos\theta_P)$$



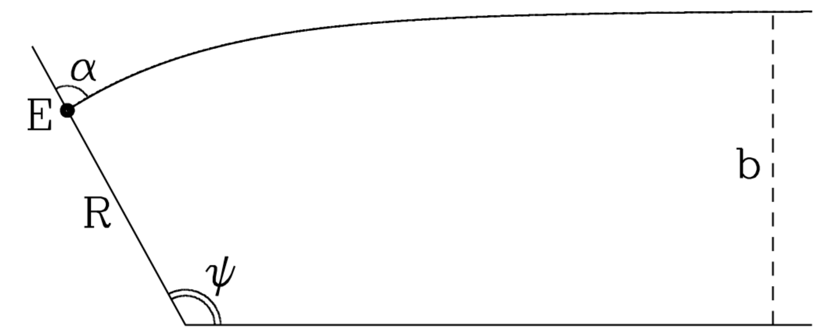
Hot spot emission - Flux

Compactness: $\frac{r_g}{R} = \frac{1}{3}$



Isotropic emission

Observer



Beloborodov 2002

$$1 - \cos\alpha = (1 - \cos\psi)(1 - \frac{r_g}{R})$$

$$x^k = (t, r, \theta, \psi)$$

$$u^k = \frac{dx^k}{d\lambda}$$

$$\psi = \int_R^\infty \frac{-u^\psi}{u^r} dr = \int_R^\infty \frac{dr}{r^2}[\frac{1}{b^2} - \frac{1}{r^2}(1 - \frac{r_g}{r})]^{-1/2}$$

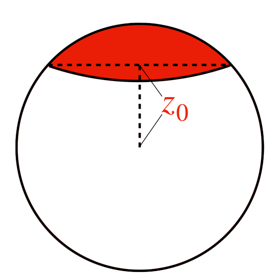
$$\sin\alpha = \frac{b}{R}\sqrt{1 - \frac{r_g}{R}}$$

$$dF = \frac{Ib}{R^2}|\frac{db}{d\cos\psi}|\frac{dS}{D^2} = (1 - \frac{r_g}{R})I_0(\alpha)\cos\alpha\frac{d\cos\alpha}{d\cos\psi}\frac{dS}{D^2}$$

i: inclination (viewing angle)

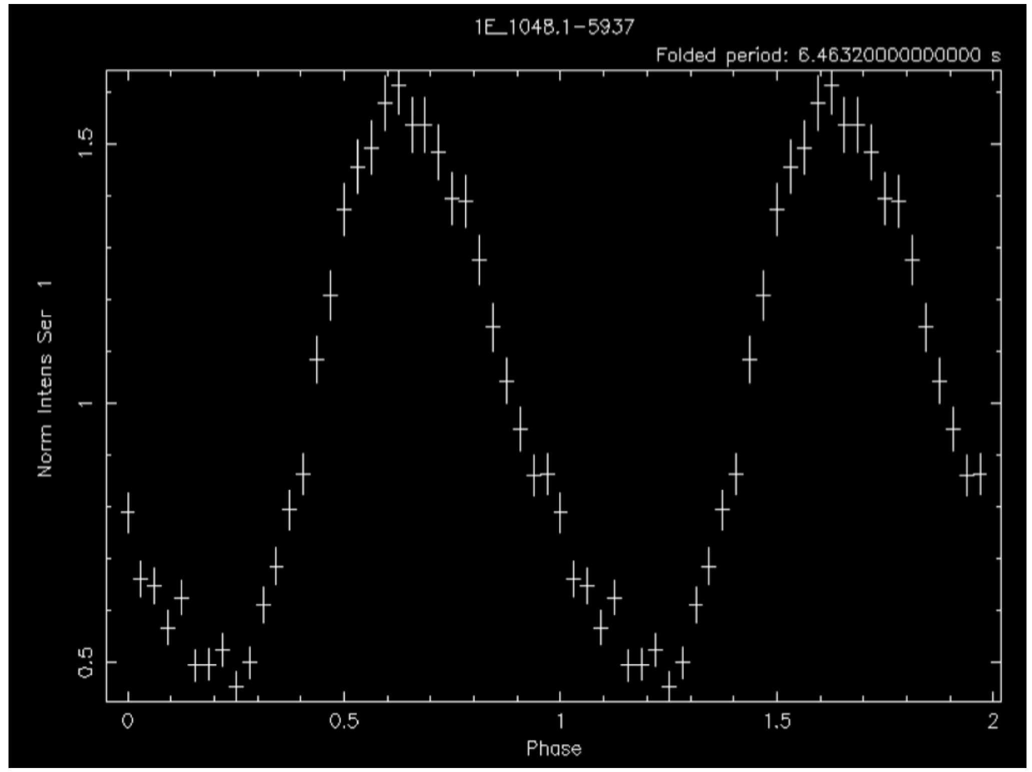
θ: colatitude φ: longitude

z_0: size of hot spot

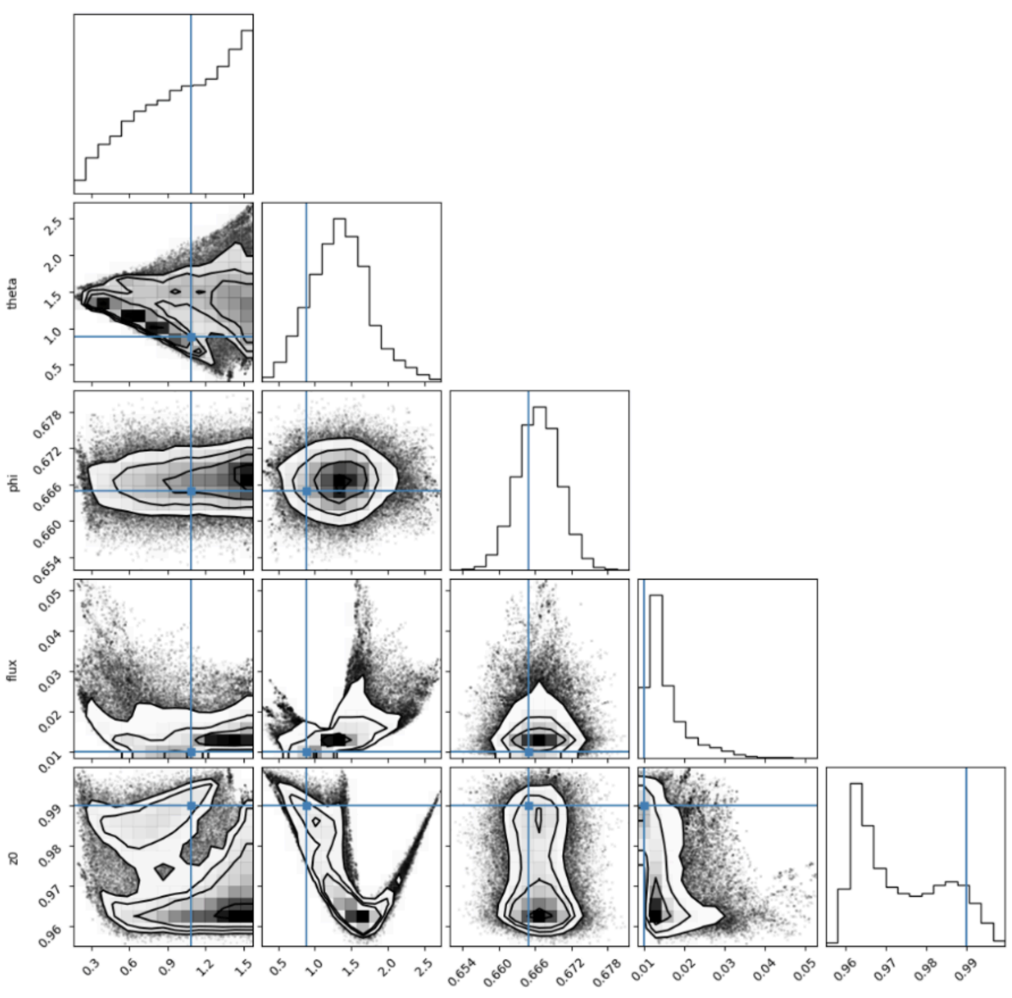


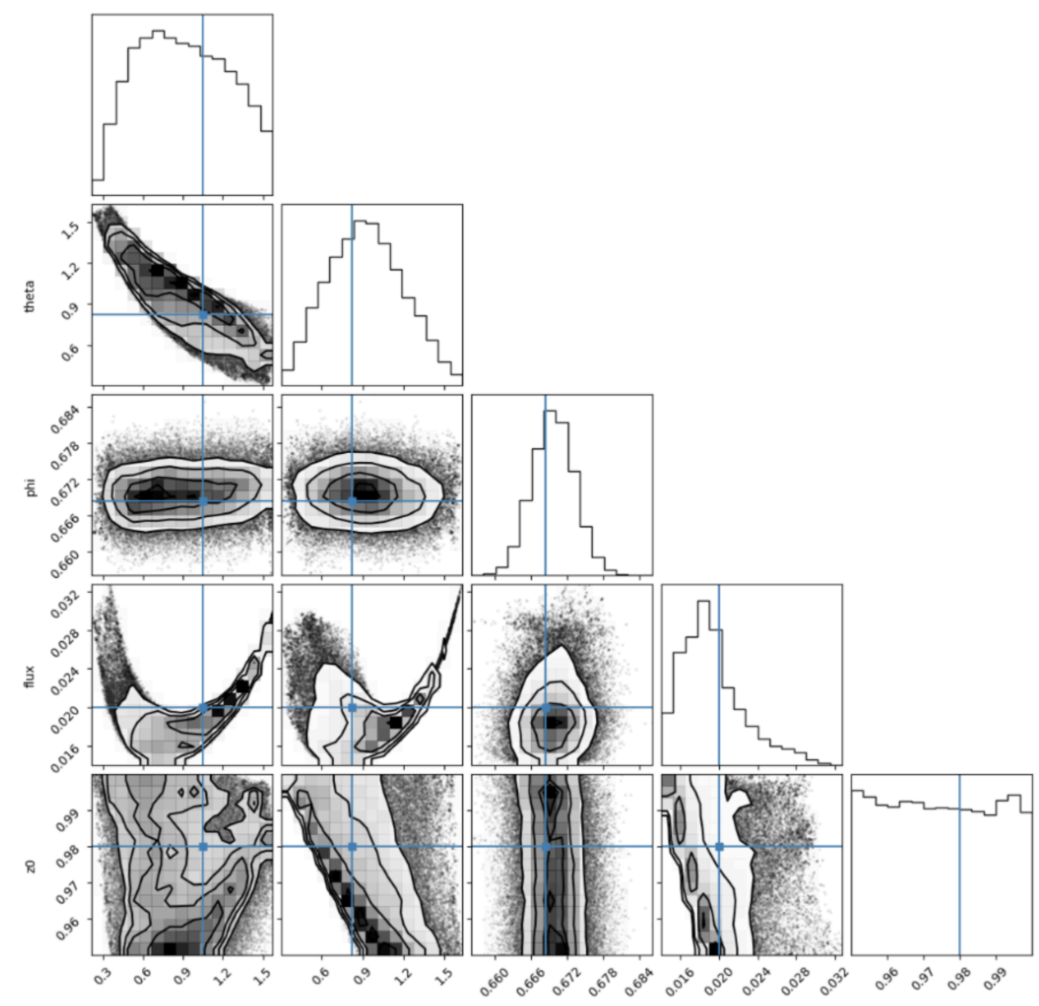
$$\mu(t) = \sin\theta\sin i\cos\Omega t + \cos\theta\cos i$$

$$F = \mu(i, \theta, \varphi)(1 - \frac{r_g}{R}) + \frac{r_g}{R}$$

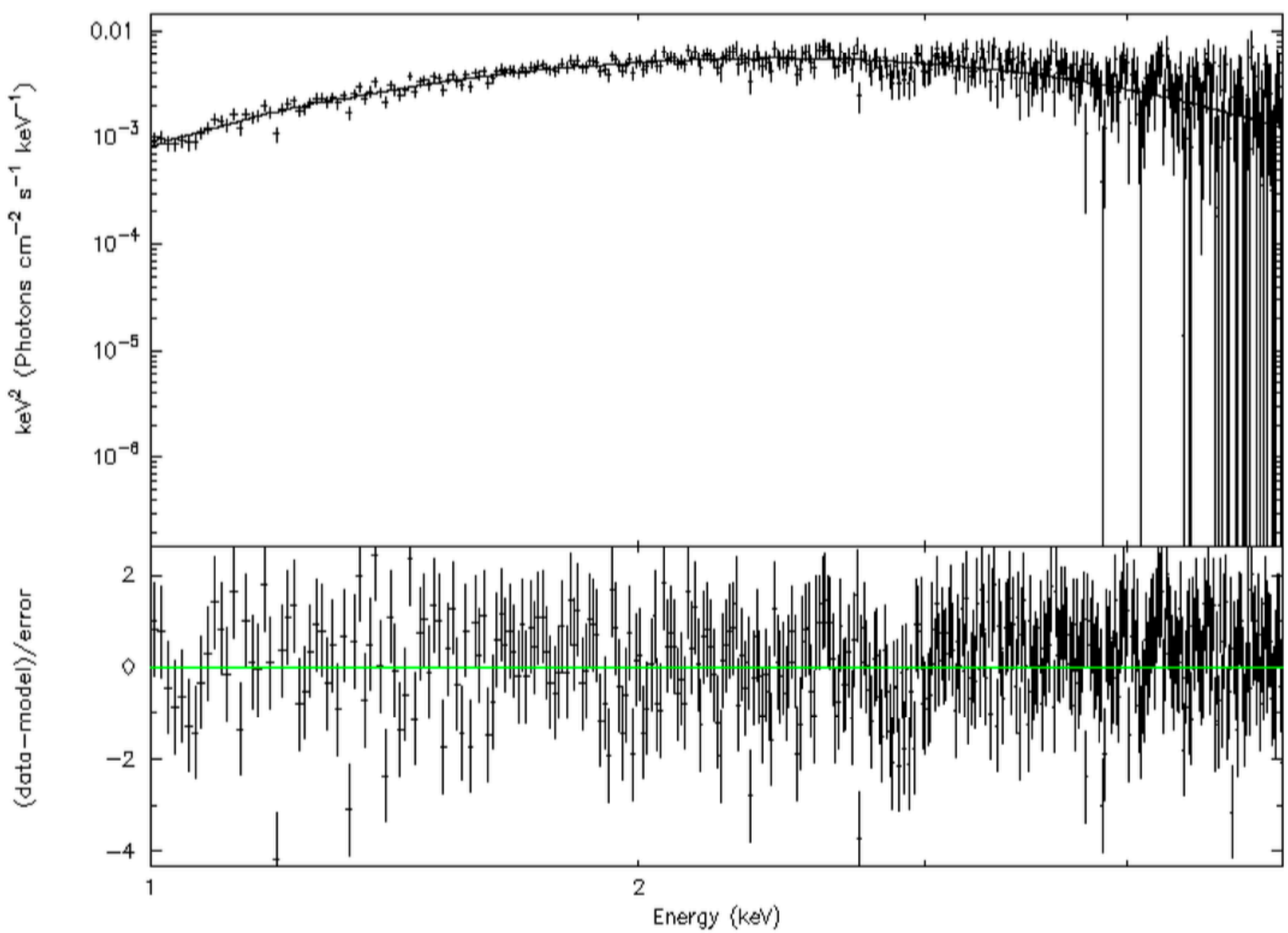


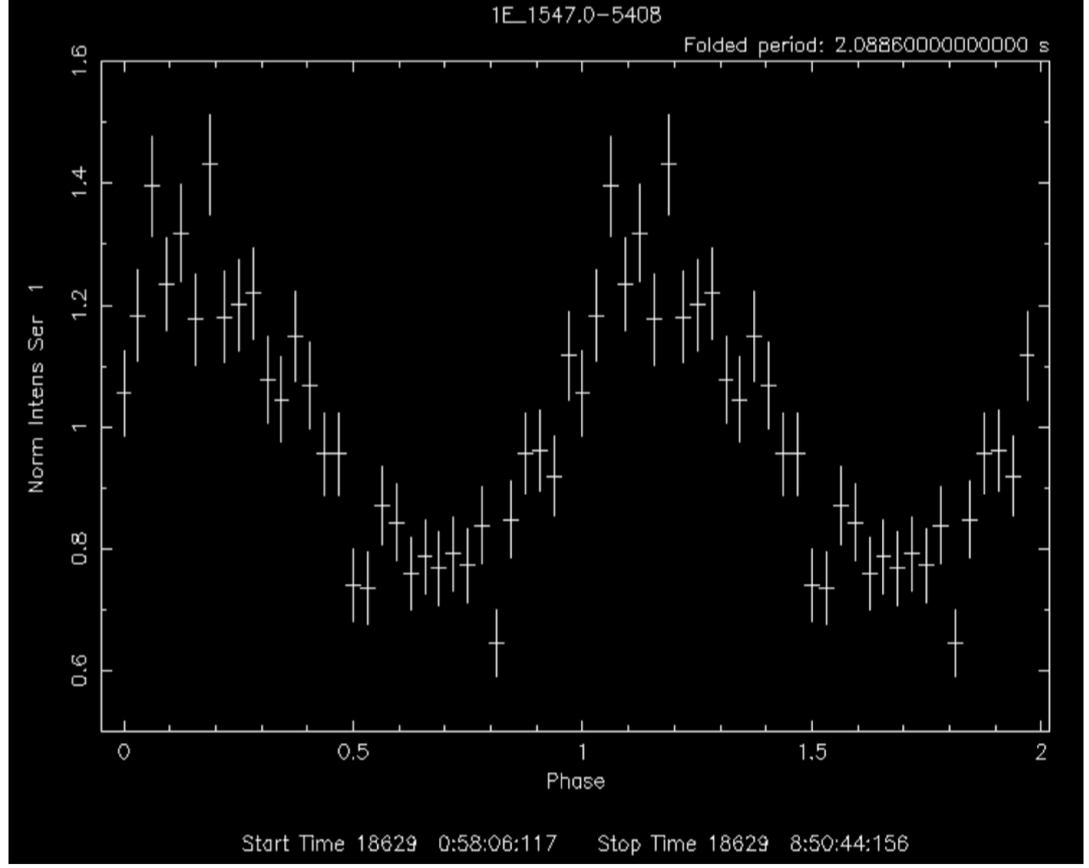
Model	i	θ	ϕ	m	z_0
Newtonian	$1.0811^{+0.3617}_{-0.4628}$	$1.3364^{+0.3745}_{-0.3977}$	$0.6666^{+0.0034}_{-0.0035}$	$0.0138^{+0.0062}_{-0.0025}$	$0.9711^{+0.0161}_{-0.0086}$
Relativistic	$0.8852^{+0.3973}_{-0.3479}$	$0.9190^{+0.2924}_{-0.2793}$	$0.6696^{+0.0035}_{-0.0035}$	$0.0188^{+0.0036}_{-0.0026}$	$0.9745^{+0.0175}_{-0.0170}$



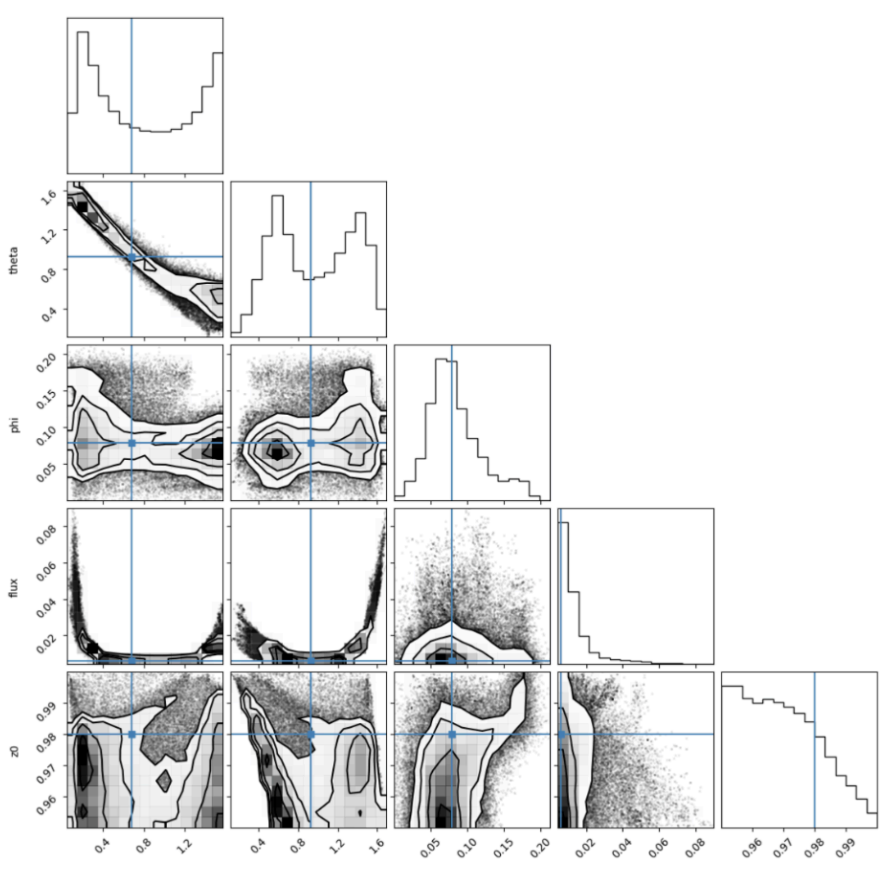


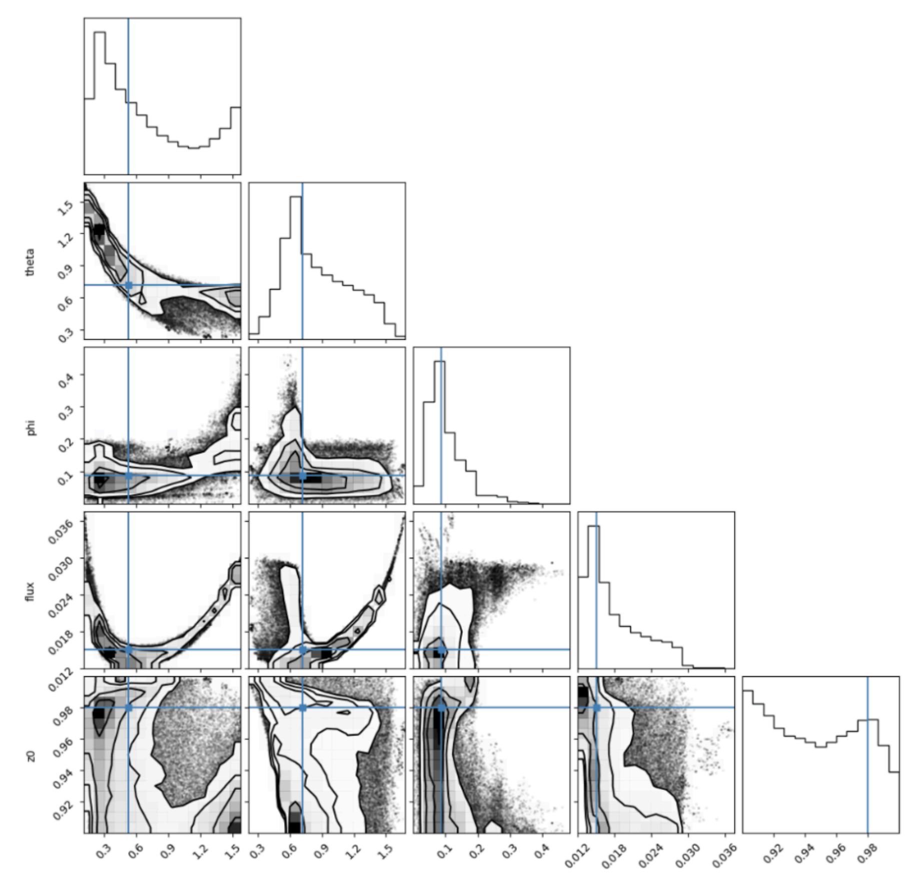
Component	Parameter	Unit	Value	
TBabs	nH	10^{22}	0.415224	+/- 2.54227E-02
bbodyrad	kT	keV	0.592422	+/- 7.76394E-03
bbodyrad	norm		10.4616	(-0.633666, 0.681573)



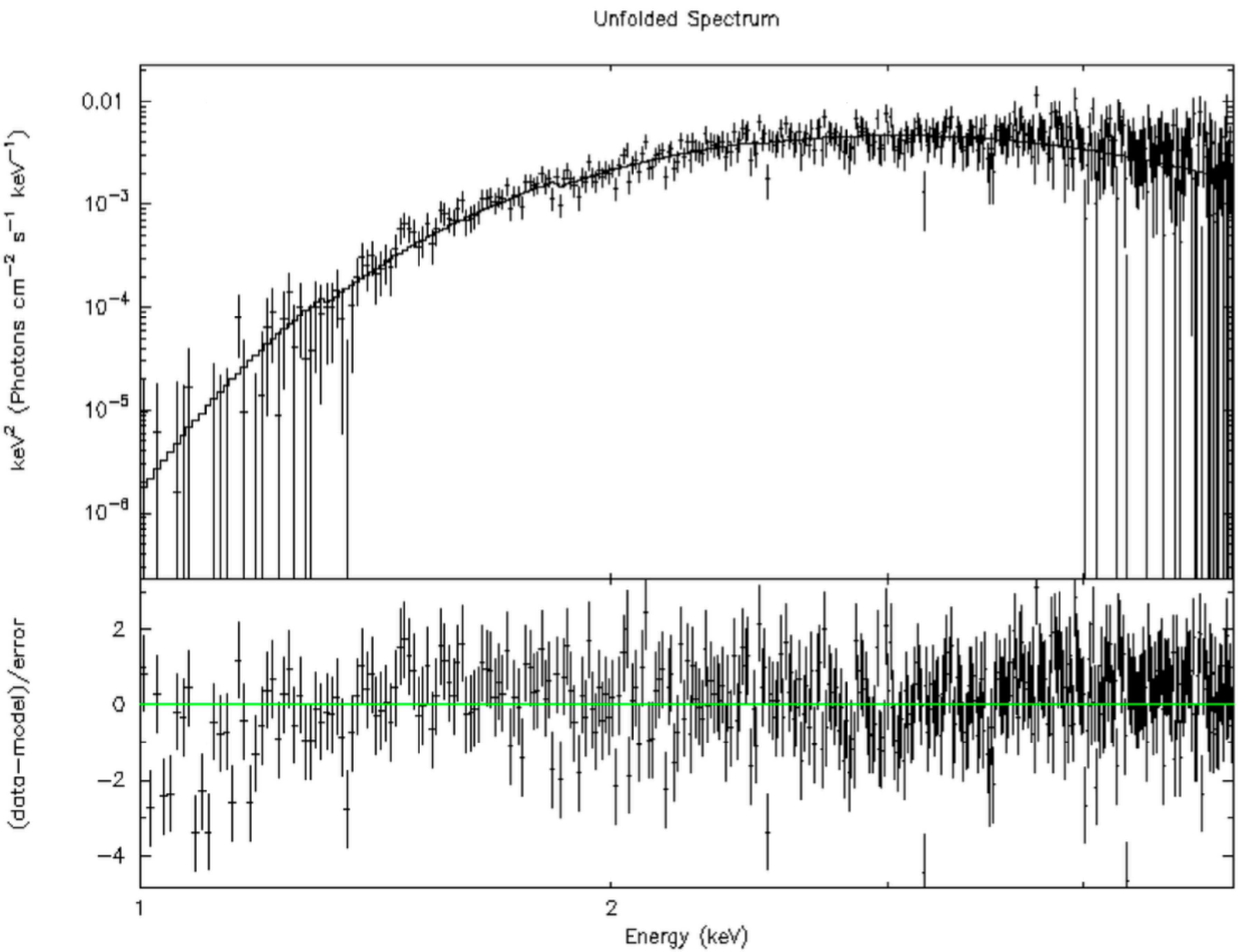


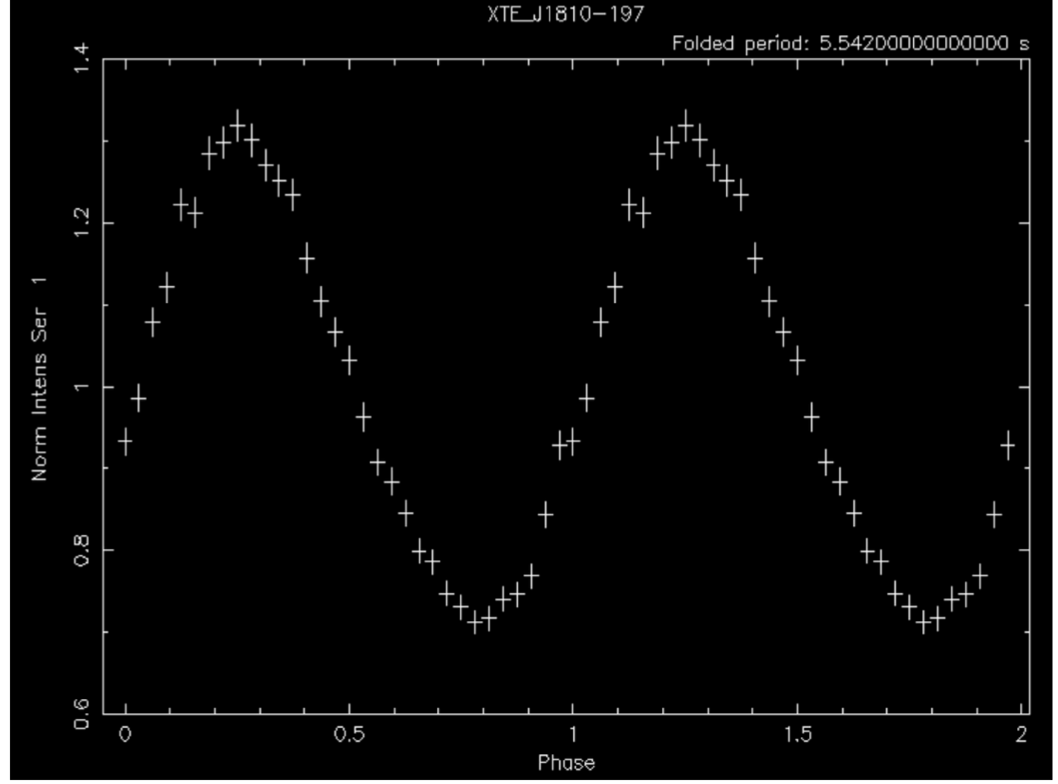
Model	i	θ	ϕ	flux	z_0
Newtonian	$0.6921^{+0.7283}_{-0.4703}$	$0.9610^{+0.4727}_{-0.4333}$	$0.0766^{+0.0413}_{-0.0257}$	$0.0099^{+0.0087}_{-0.0037}$	$0.9680^{+0.0145}_{-0.0127}$
Relativistic	$0.5422^{+0.7511}_{-0.2927}$	$0.7925^{+0.4367}_{-0.2305}$	$0.0856^{+0.0697}_{-0.0312}$	$0.0162^{+0.0072}_{-0.0025}$	$0.9458^{+0.0352}_{-0.0339}$



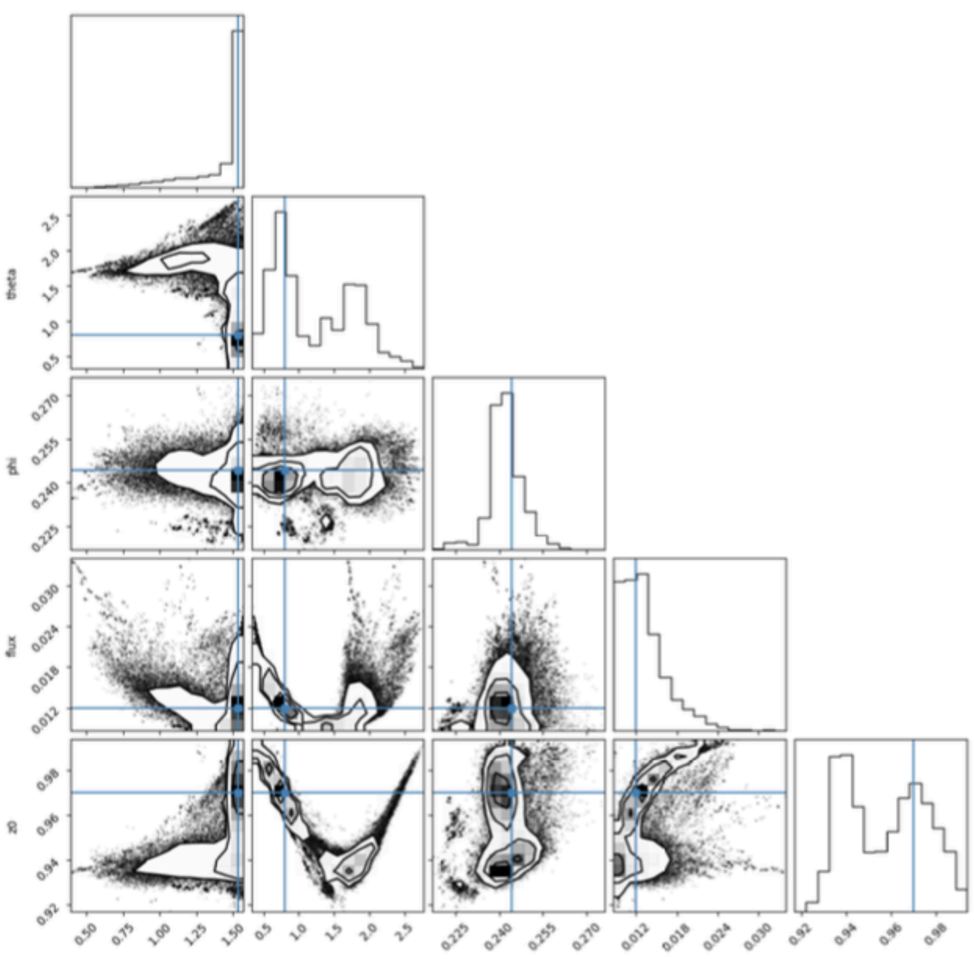


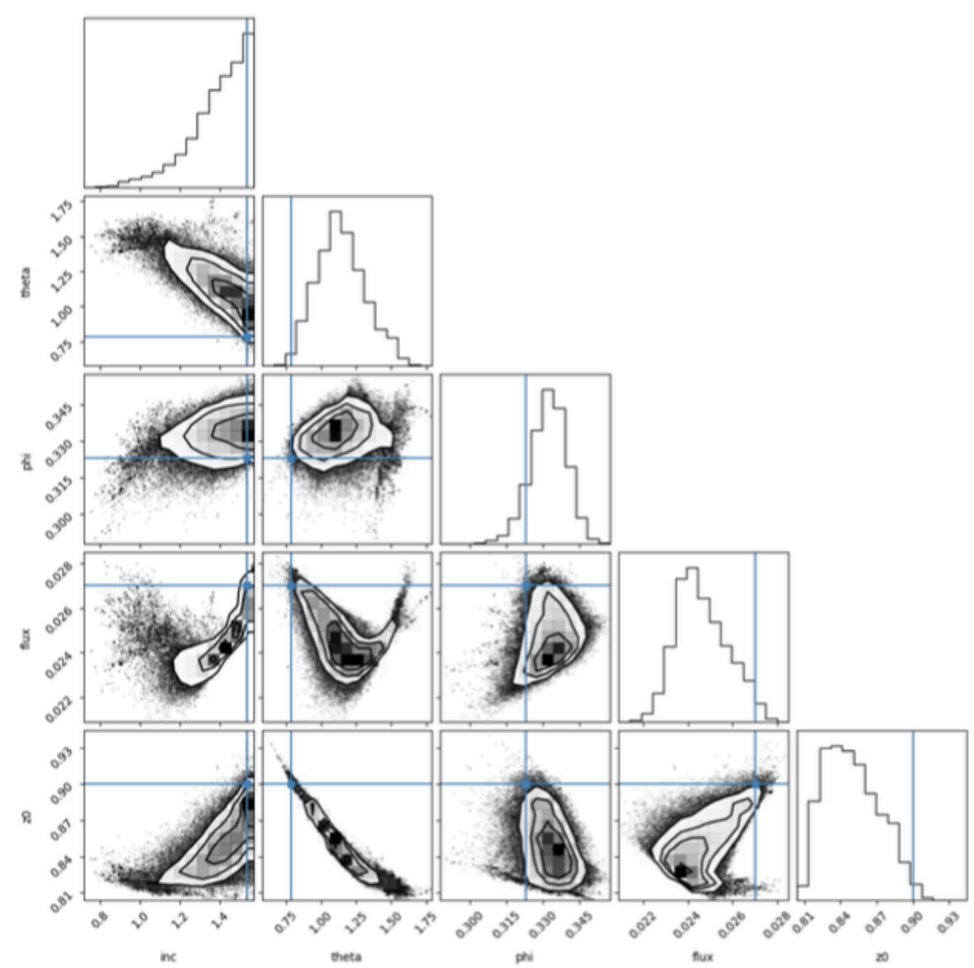
Component	Parameter	Unit	Value	
TBabs	nH	10^{22}	2.60107	+/- 0.117590
bbodyrad	kT	keV	0.652883	+/- 1.66112E-02
bbodyrad	norm		9.08002	(-1.16442, 1.35952)



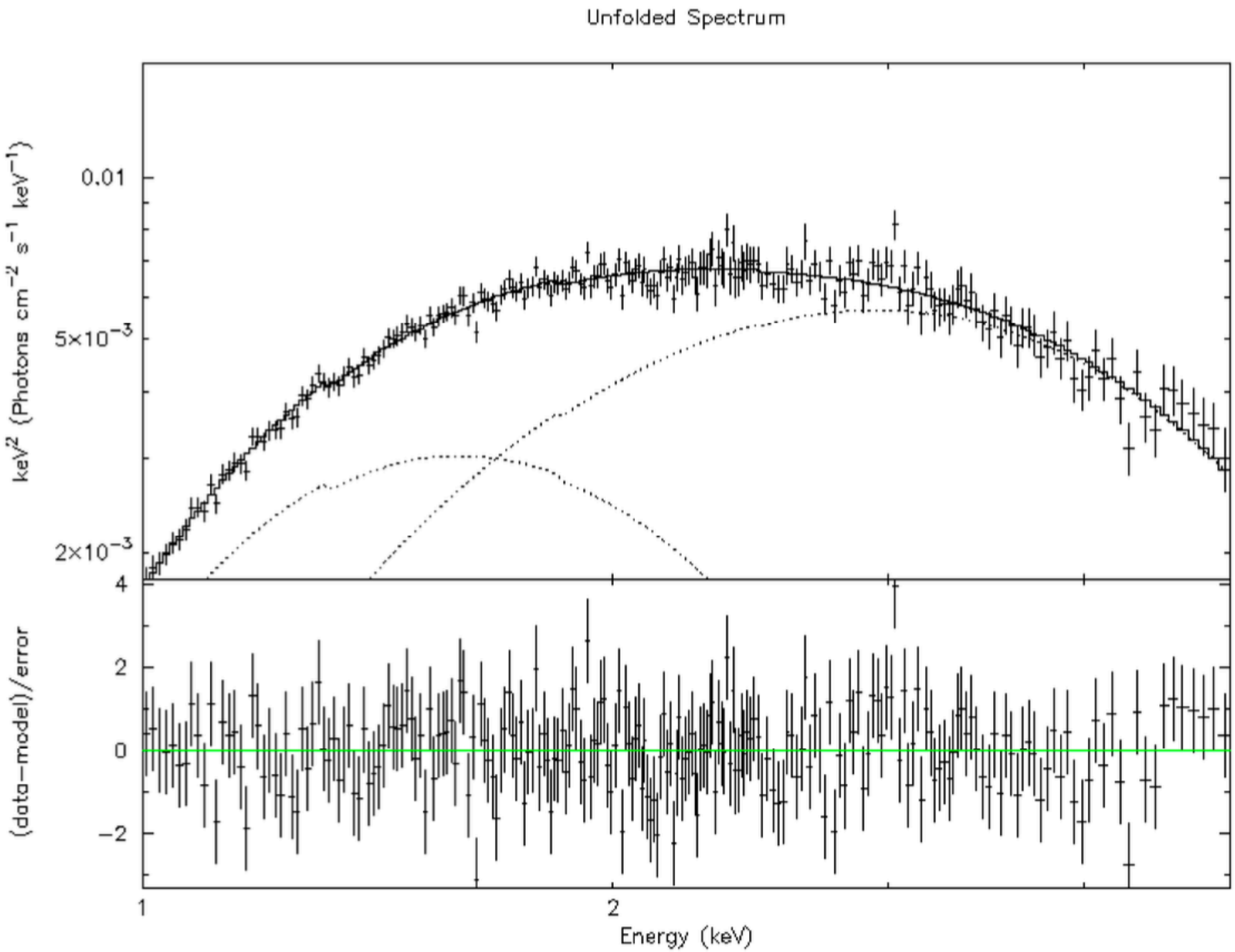


Model	i	θ	ϕ	flux	z_0
Newtonian	$1.5259^{+0.0352}_{-0.3109}$	$1.0009^{+0.8596}_{-0.3616}$	$0.2417^{+0.0058}_{-0.0038}$	$0.0125^{+0.0036}_{-0.0027}$	$0.9583^{+0.0188}_{-0.0212}$
Relativistic	$1.4191^{+0.1110}_{-0.1694}$	$1.1306^{+0.1858}_{-0.1637}$	$0.3324^{+0.0069}_{-0.0075}$	$0.0245^{+0.0014}_{-0.0009}$	$0.8474^{+0.0279}_{-0.0215}$



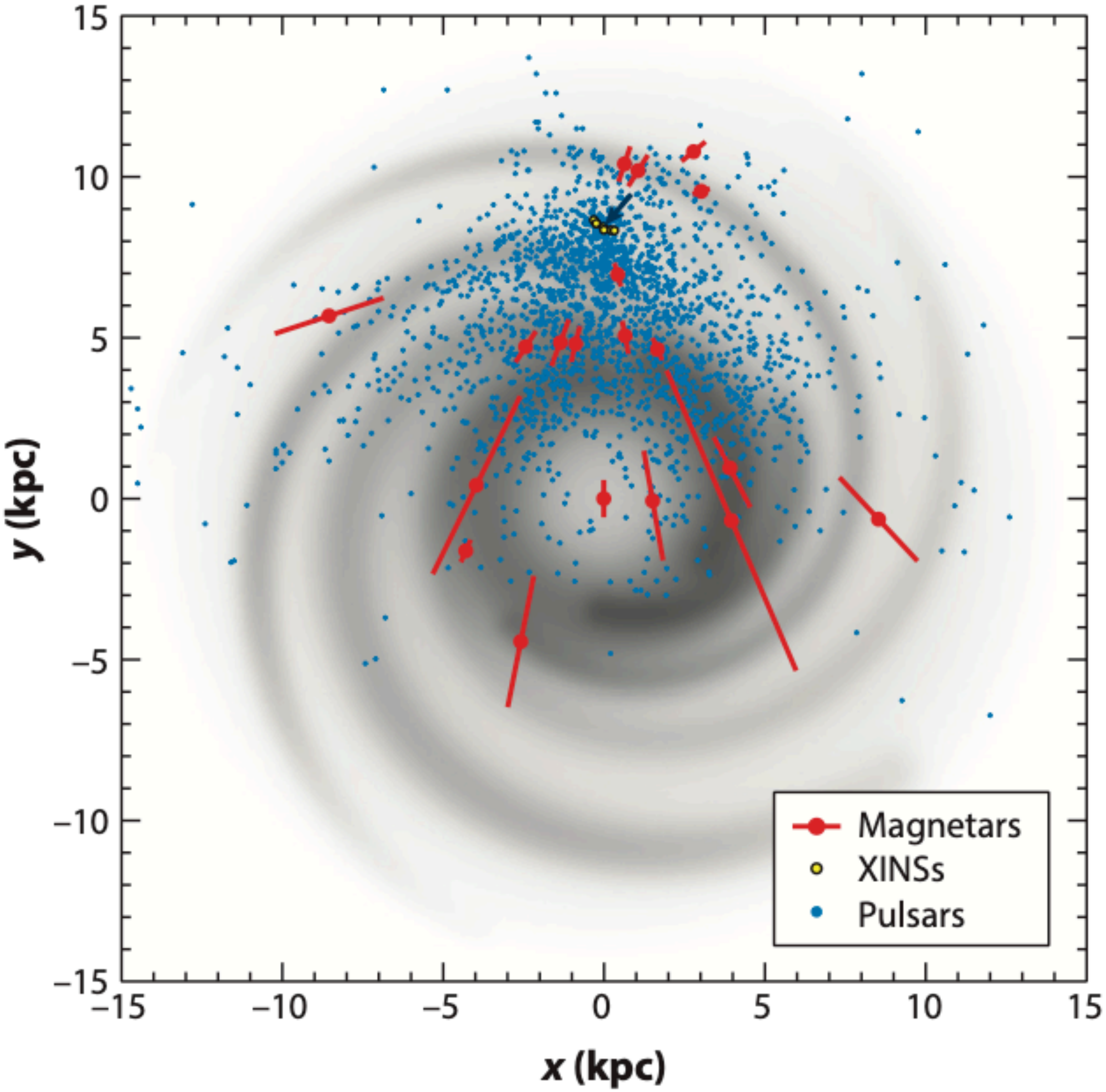


Component	Parameter	Unit	Value	
TBabs	nH	10^{22}	0.522468	+/- 3.67344E-02
bbodyrad	kT	keV	0.315604	+/- 1.57237E-02
bbodyrad	norm		9.34077	(-22.0933, 29.4895)
bbodyrad	kT	keV	0.707795	+/- 1.77547E-02
bbodyrad	norm		4.99888	(-0.722572, 0.73365)

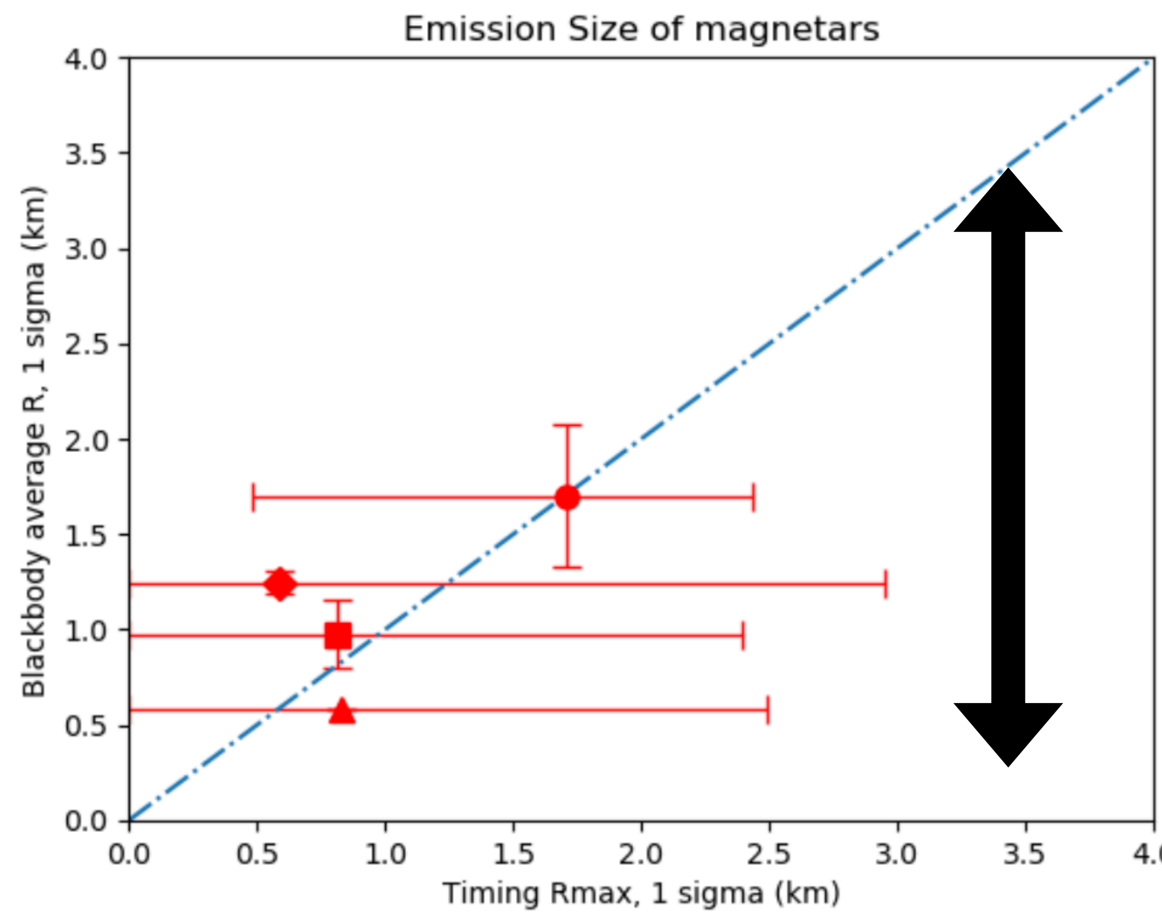


おまけ

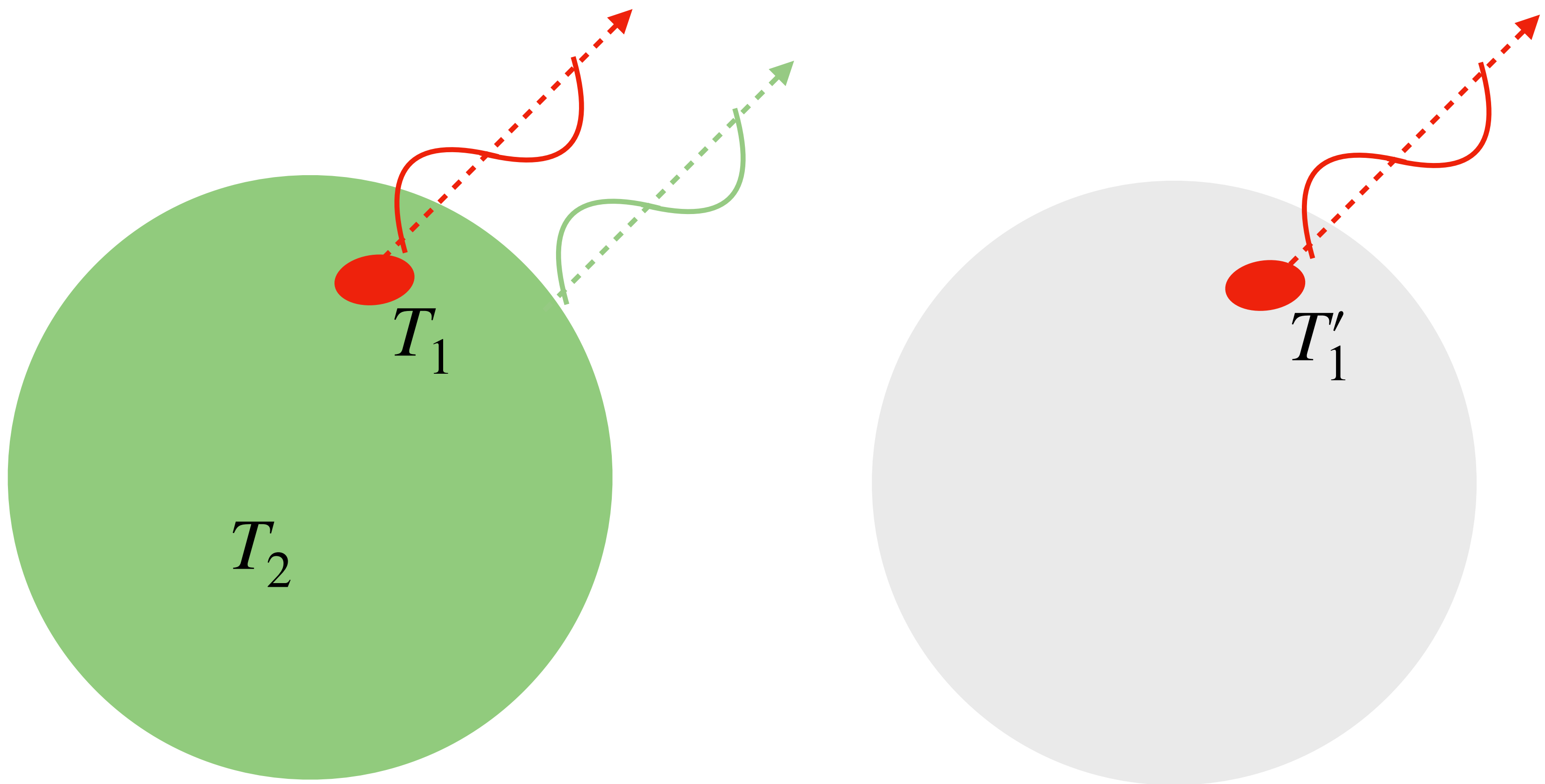
Kaspi +2017



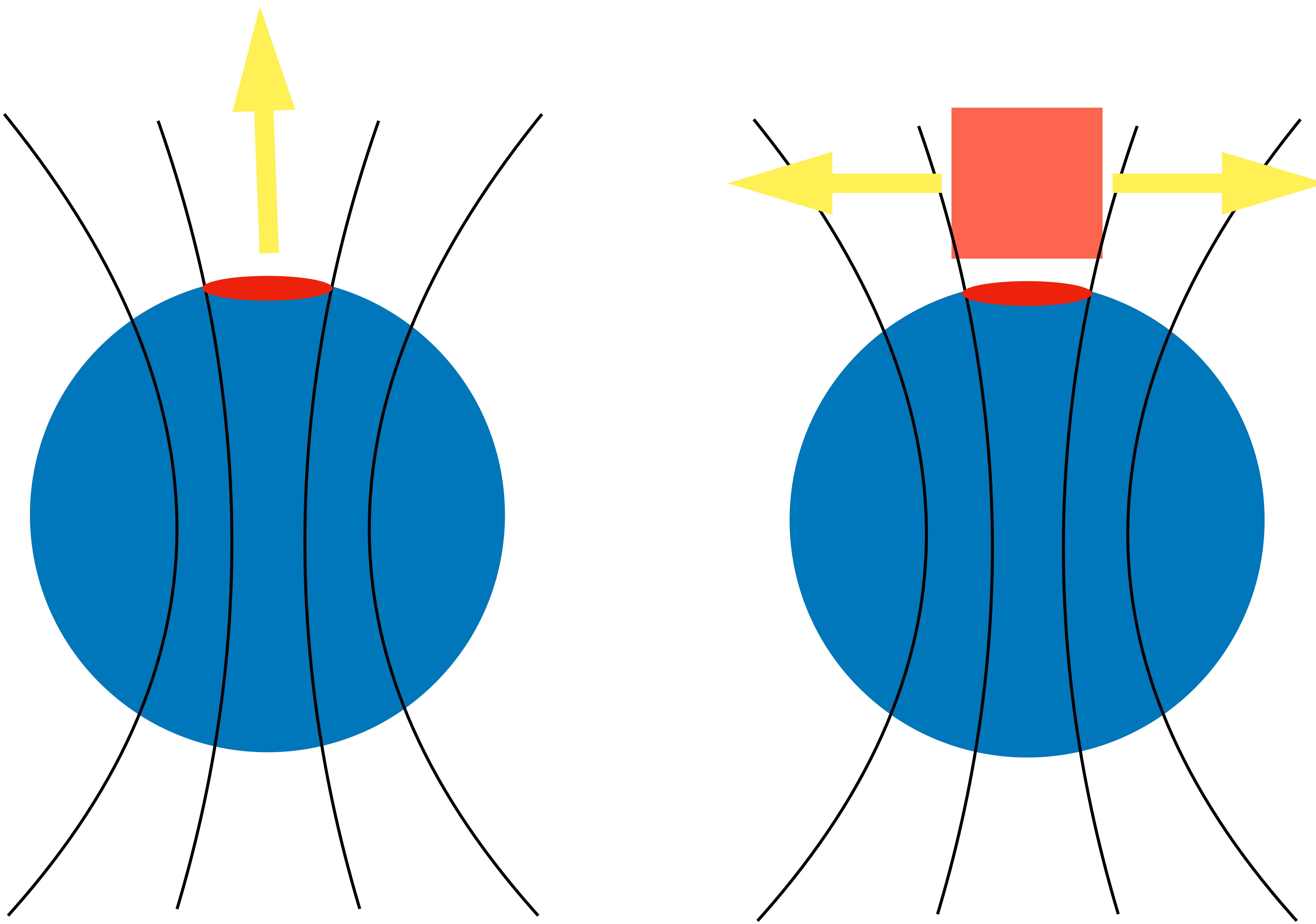
マグネターの距離によって



上下に移動する



T_1
T_2
T_1'



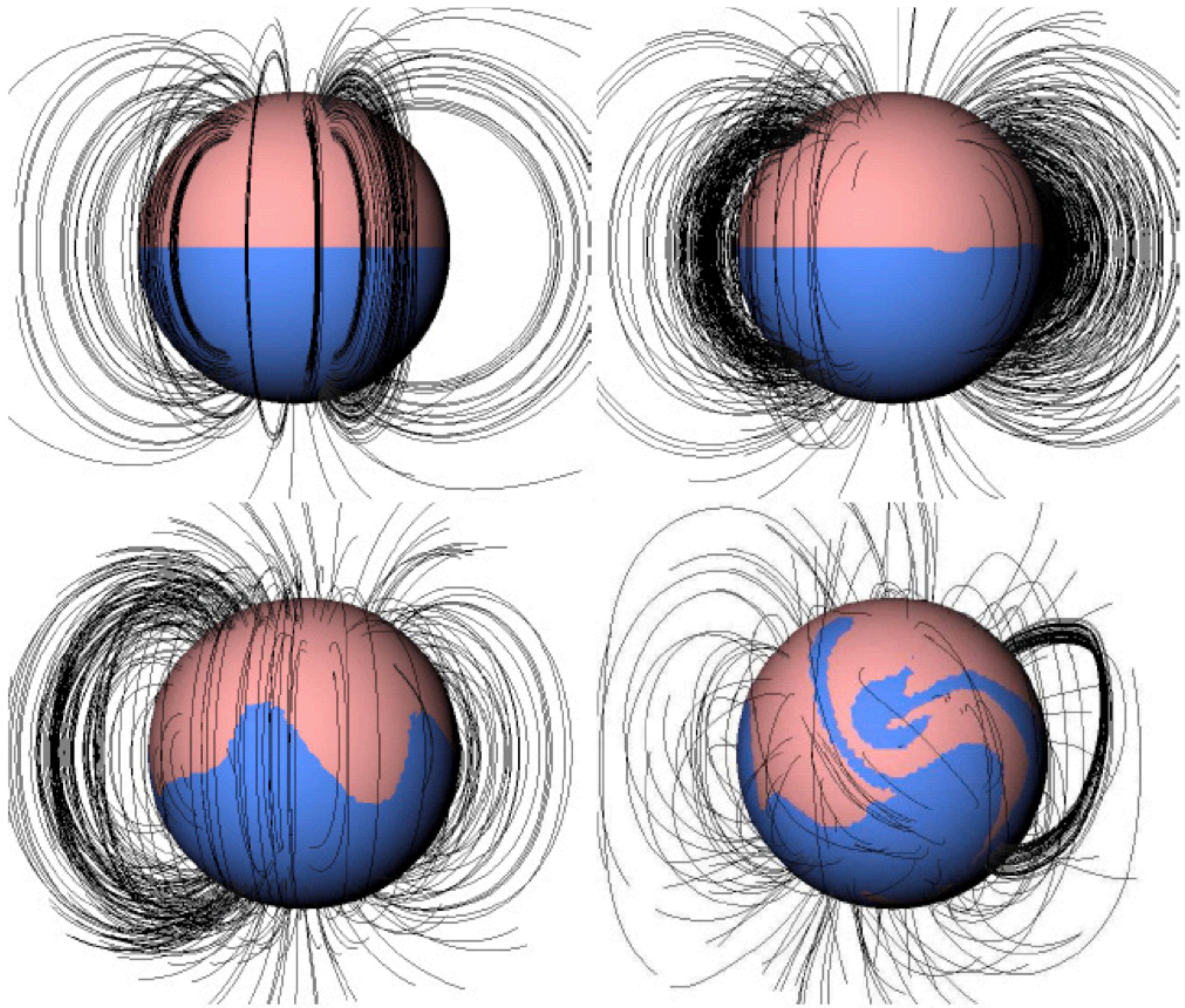
Assuming dipolar magnetic field:

$$\epsilon = \frac{2}{3}\frac{B^2R^6\omega^4}{c^3} = \frac{32\pi^4}{3}\frac{B^2R^6}{P^4c^3}$$

$$E_{rot} = \frac{1}{2}I\omega^2 = \frac{1}{2}I(\frac{2\pi}{P})^2 \quad \dot{E}_{rot} = \frac{dE_{rot}}{dt} = -4\pi^2 I\frac{\dot{P}}{P^3}$$

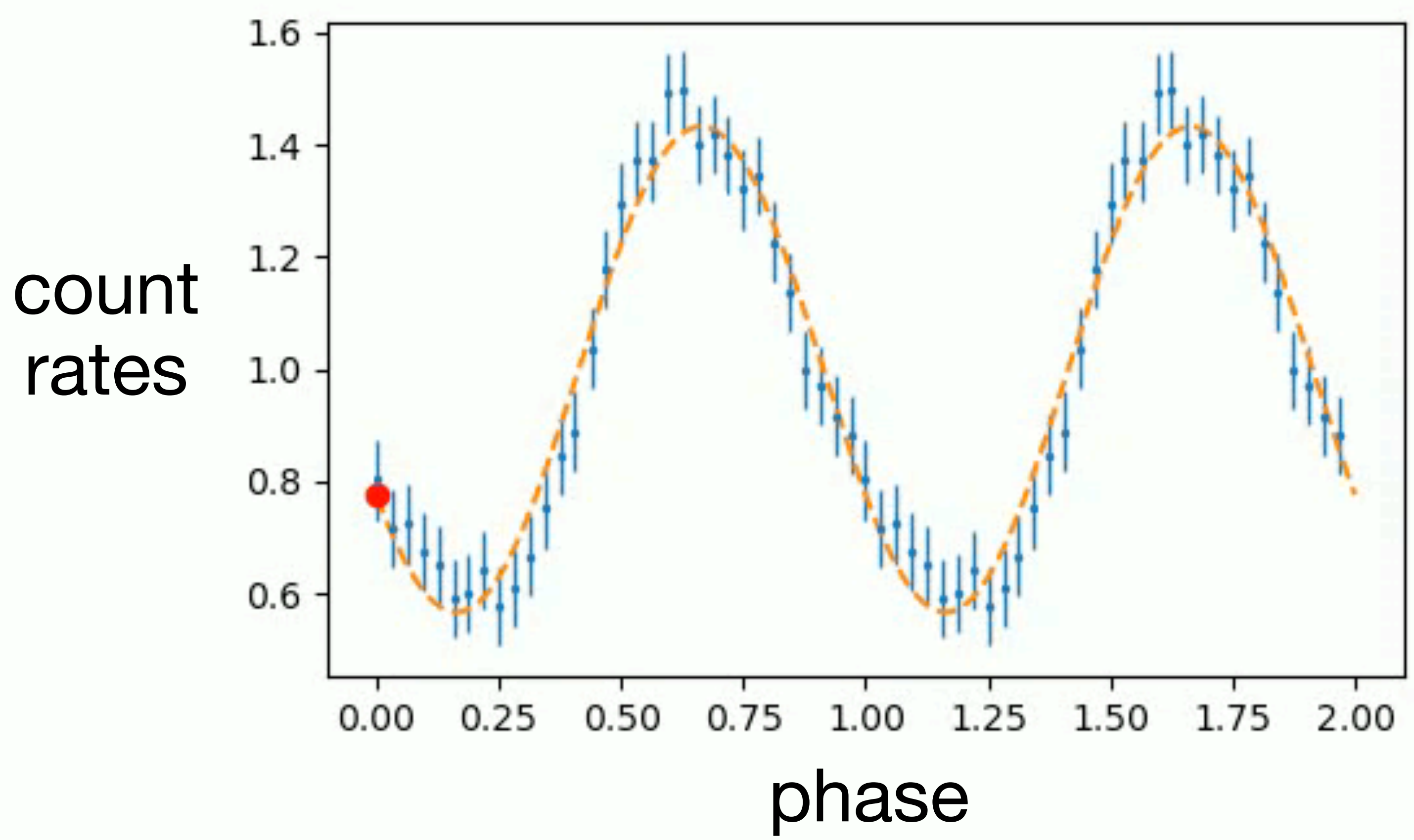
$$\epsilon = \dot{E}_{rot} \rightarrow B_{surf} \propto \sqrt{P\dot{P}}$$

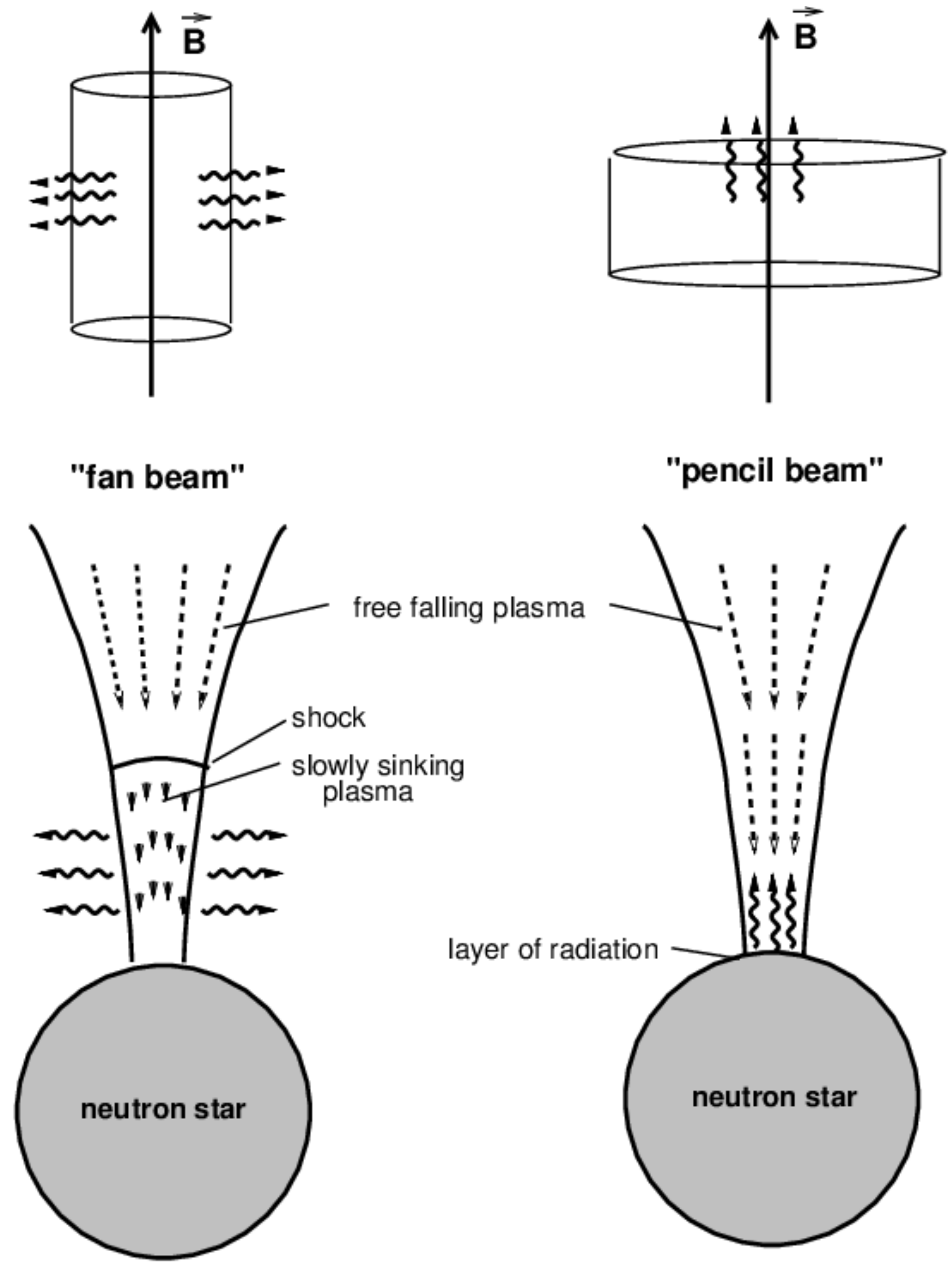
Evolution of the magnetic field in magnetars
Numerical MHD
Braithwaite & Spruit 2006



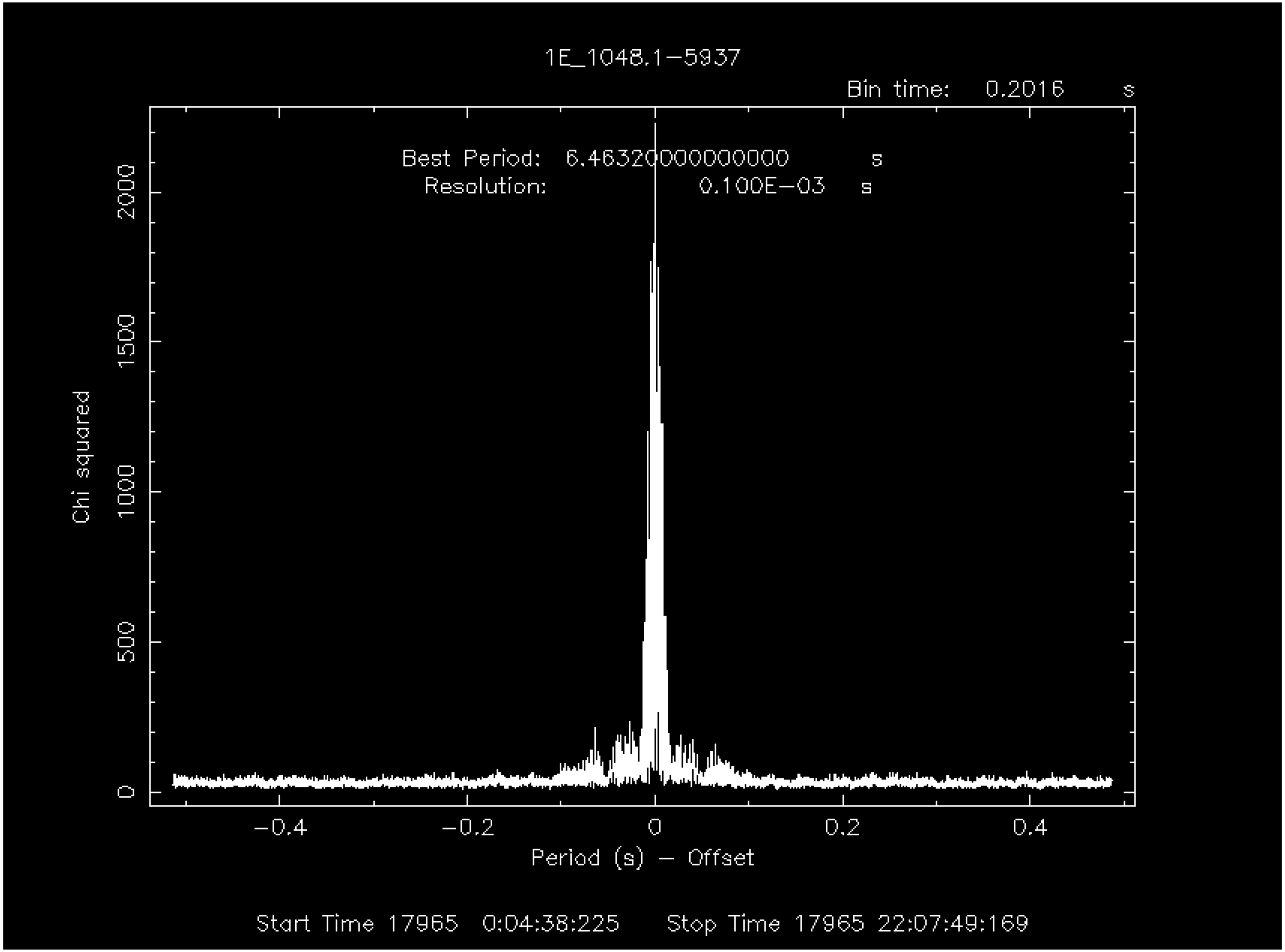
観測方向: 赤道に近い

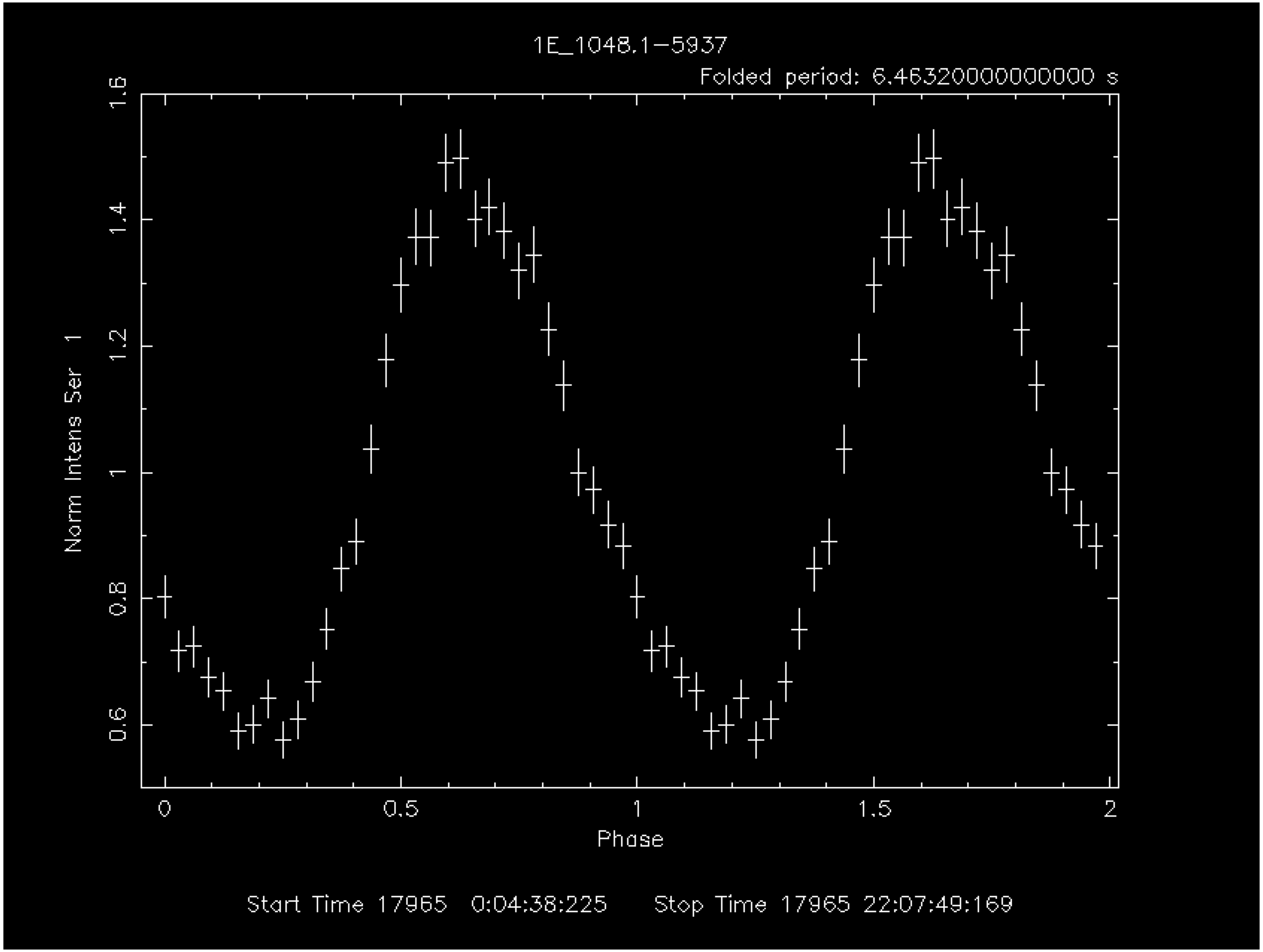
左回り回転

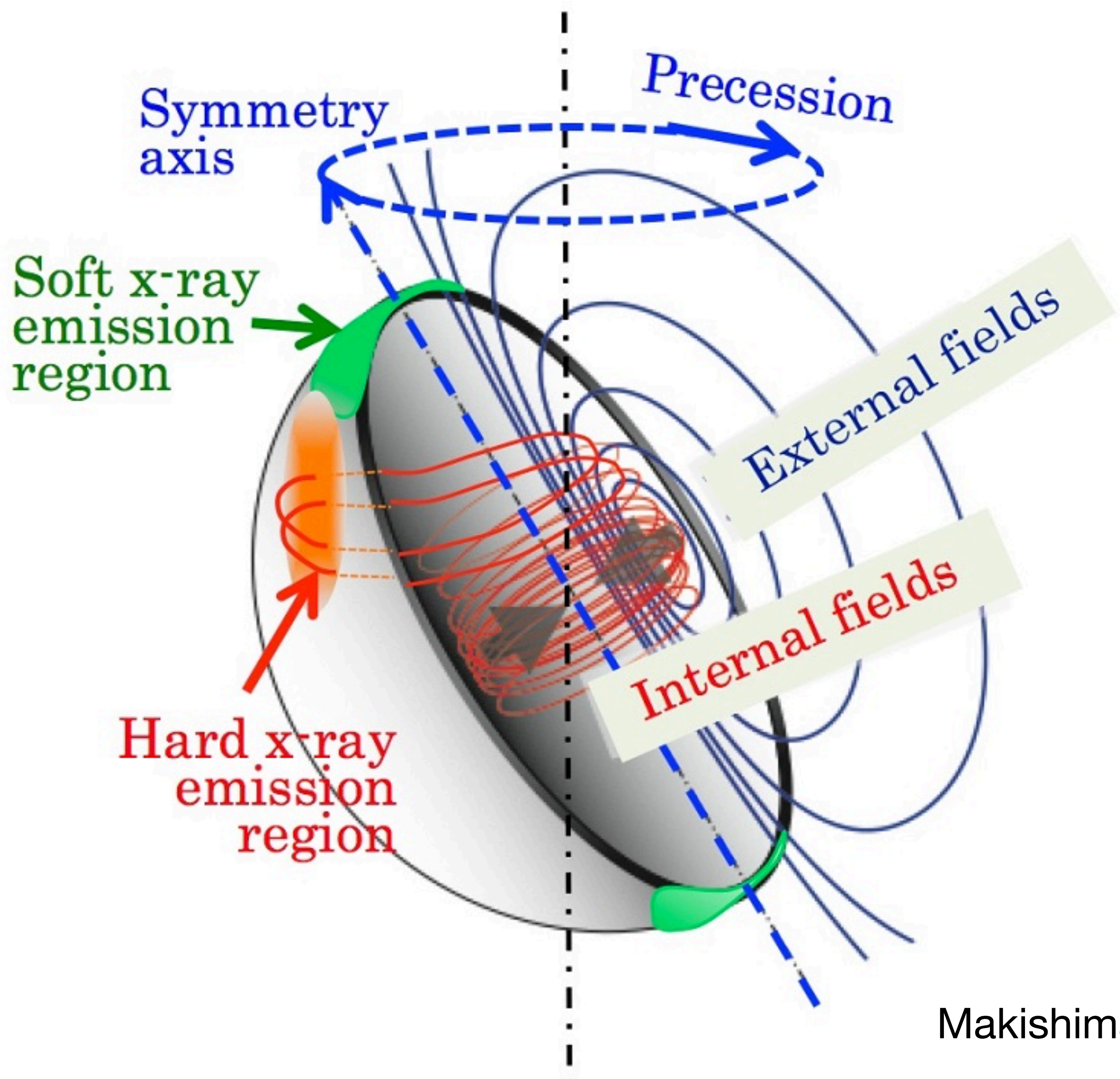




G. Schonherr+ 2007

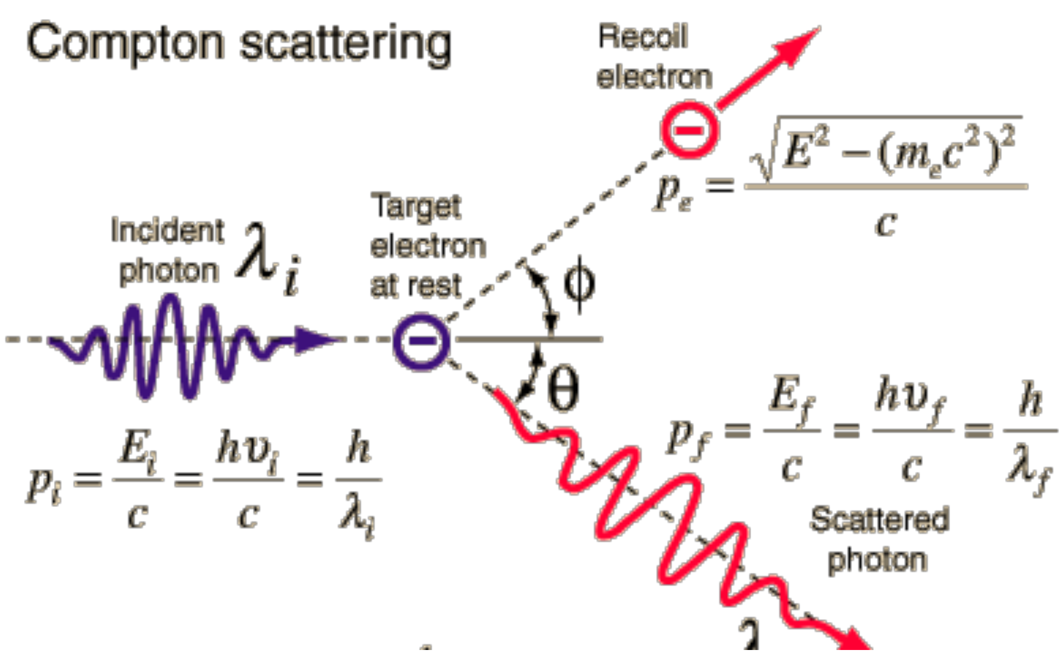

1E_1048.1-5937
Bin time: 0.2016 s
Best Period: 6.46320000000000 s
Resolution: 0.100E-03 s
Chi squared
0
500
1000
1500
2000
−0.4
−0.2
0
0.2
0.4
Period (s) − Offset
Start Time 17965 0:04:38:225 Stop Time 17965 22:07:49:169


1E_1048.1-5937
Folded period: 6.46320000000000 s
Norm Intens Ser 1
1.6
1.4
1.2
1
0.8
0.6
0
0.5
1
1.5
2
Phase
Start Time 17965 0:04:38:225 Stop Time 17965 22:07:49:169

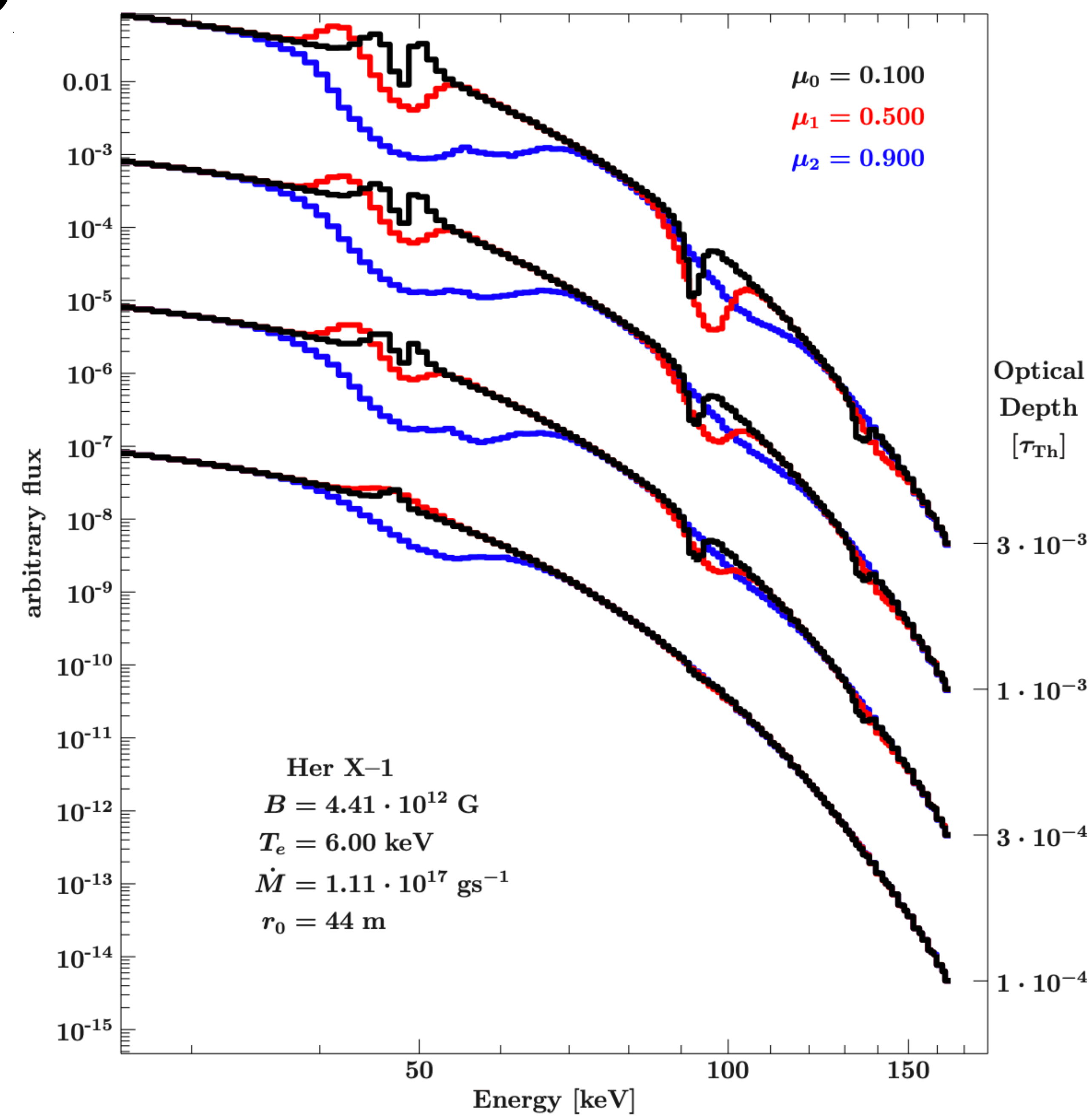


Makishima +2014

ard X-ray Component (HXC)



Source: hyperphysics.phy-astr.gsu.edu



ℏω ~ m_e c^2

ω: ローレンツ運動の頻率

Distance of magnetars

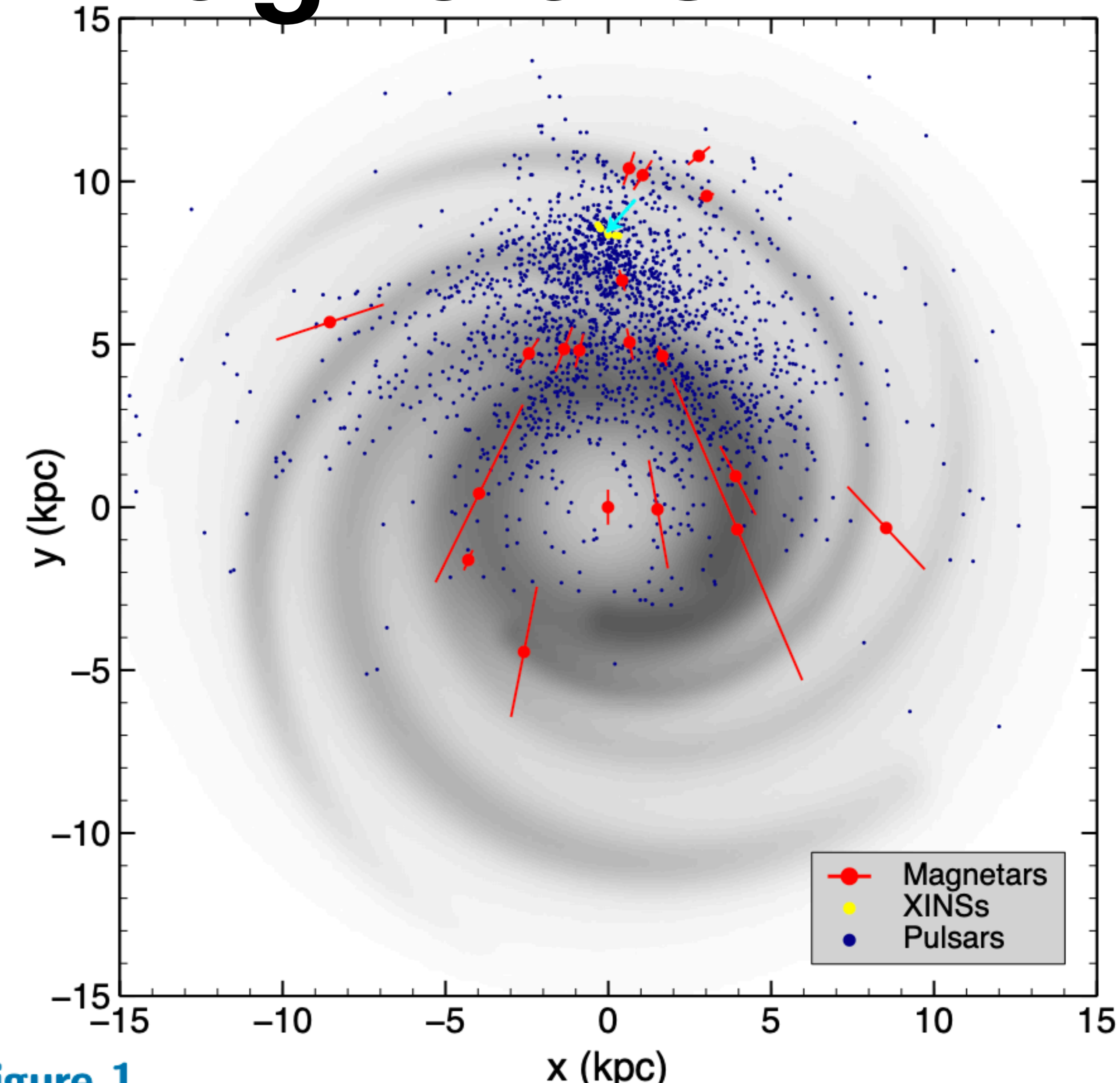
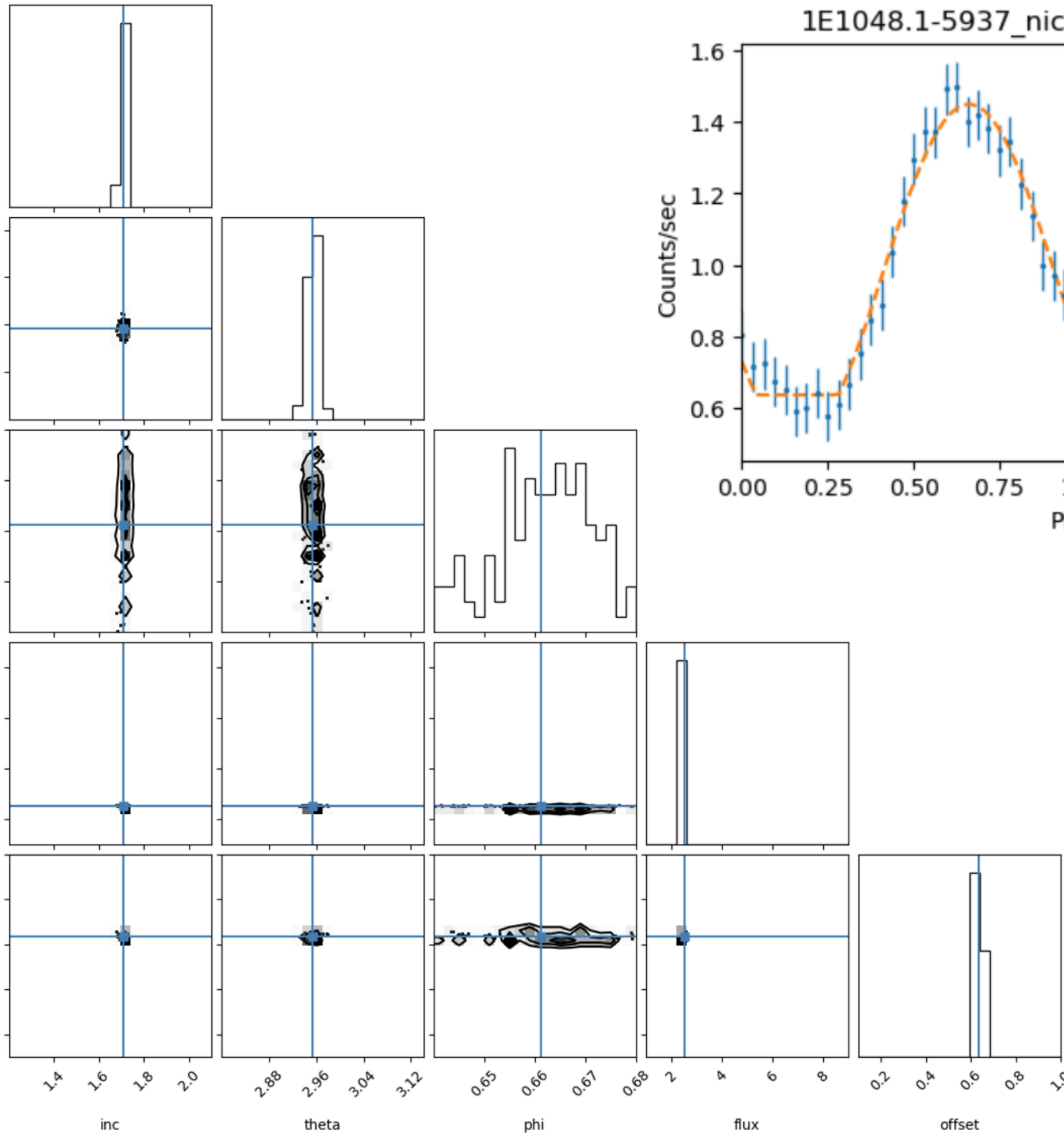
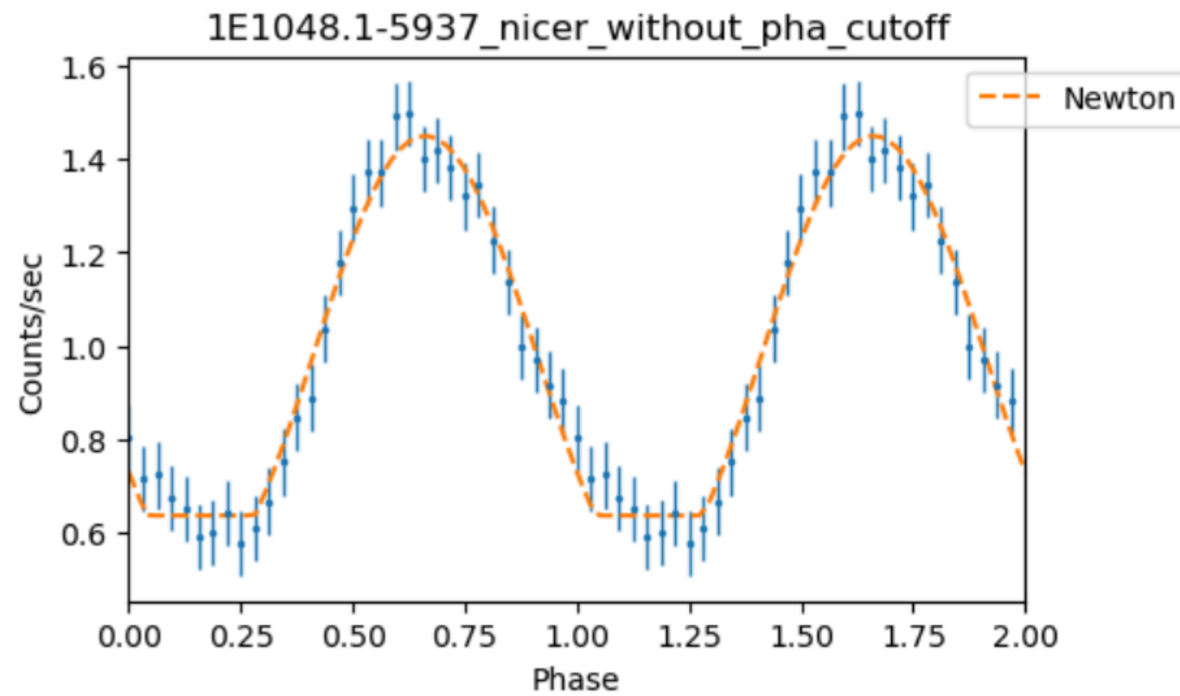


Figure 1

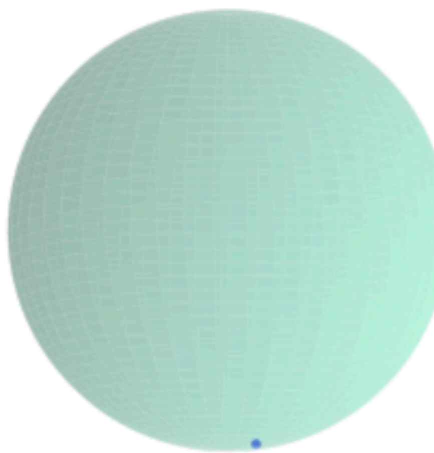
Kaspi+ 2017

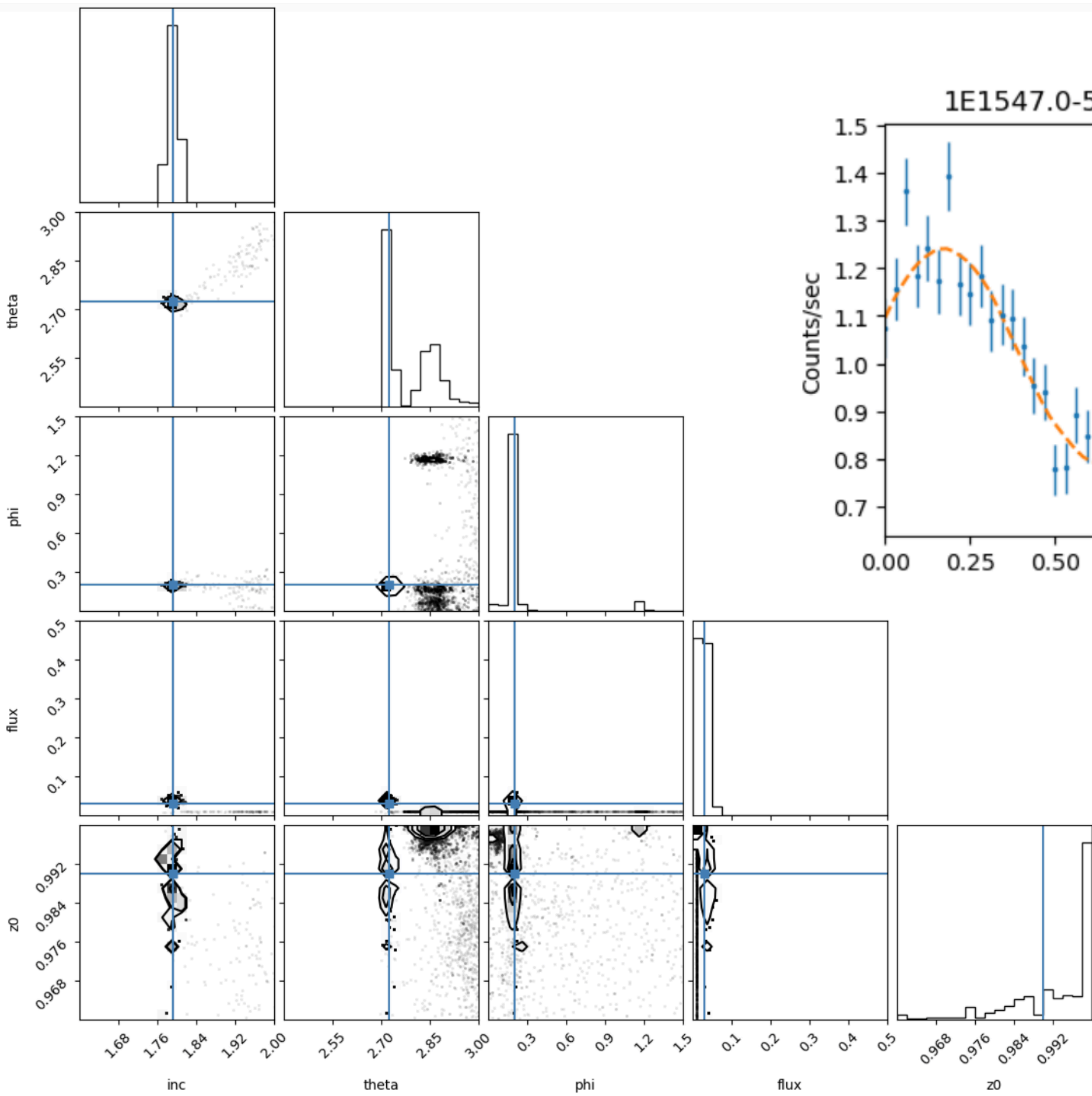


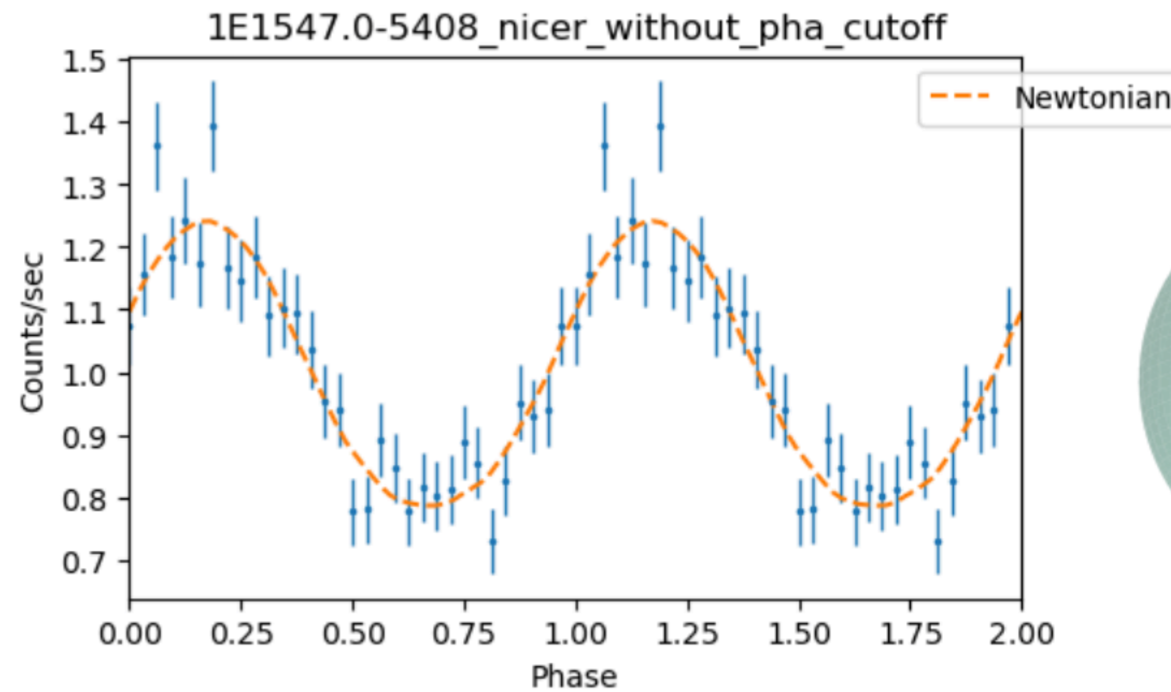
theta
phi
flux
offset
inc
theta
phi
flux
offset

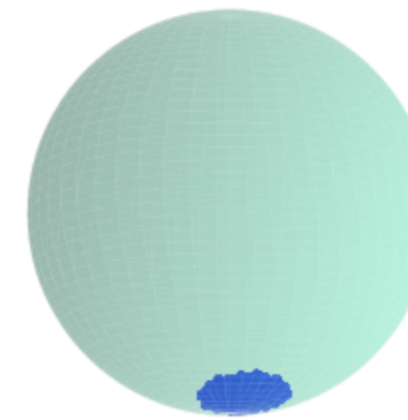


1E1048.1-5937_nicer_without_pha_cutoff
Newton
Counts/sec
Phase

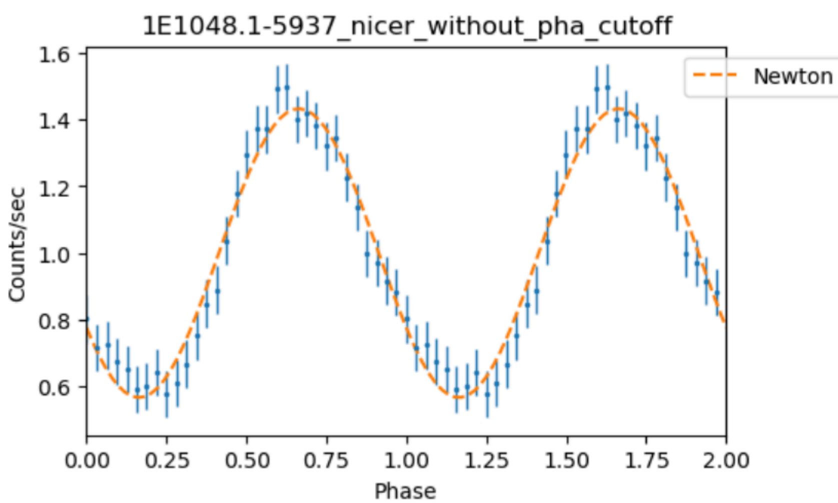


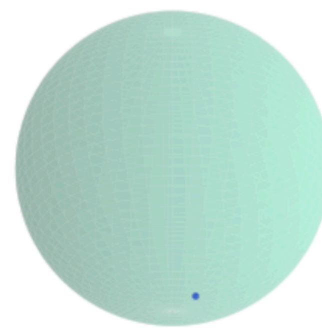

theta
phi
flux
z0
inc
theta
phi
flux
z0

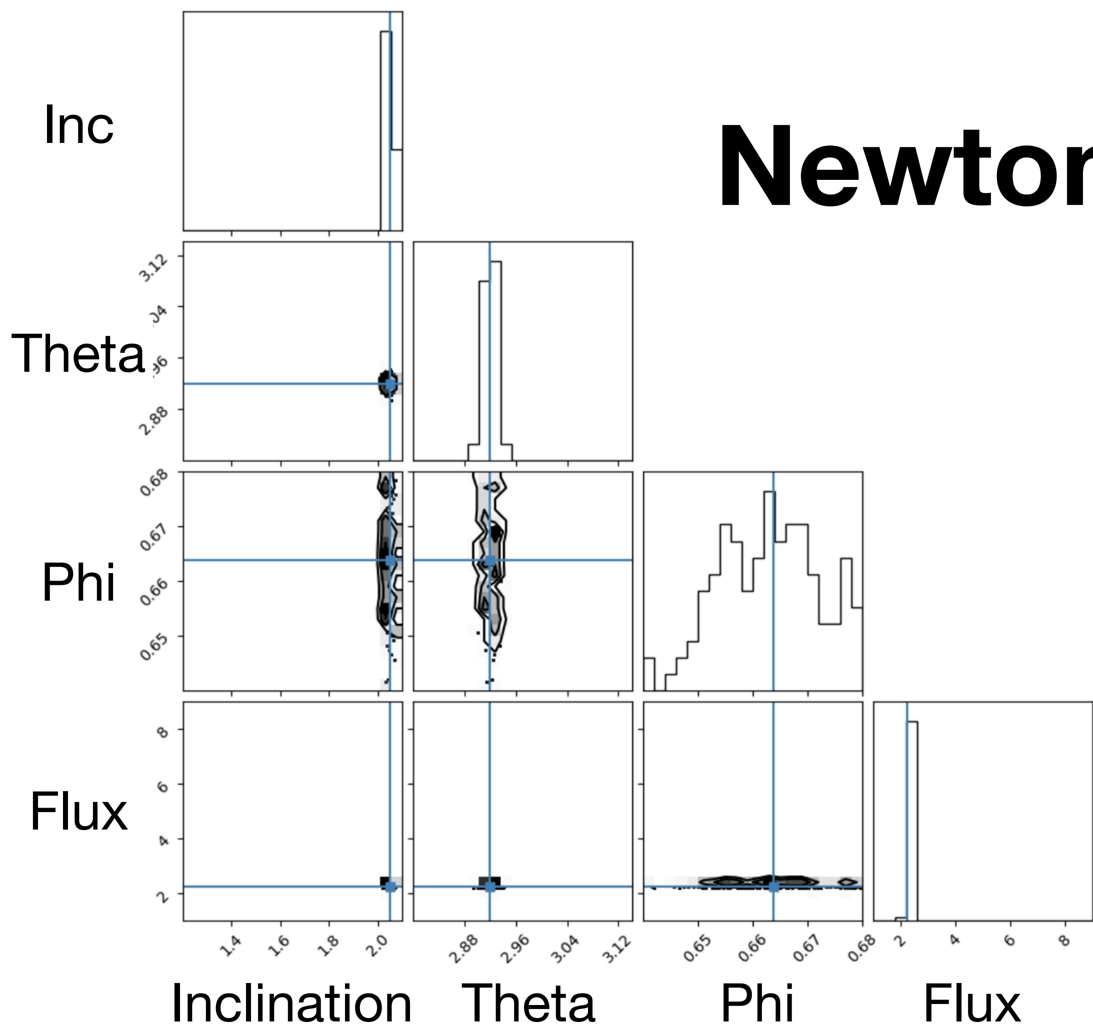

1E1547.0-5408_nicer_without_pha_cutoff
Newtonian
Counts/sec
Phase



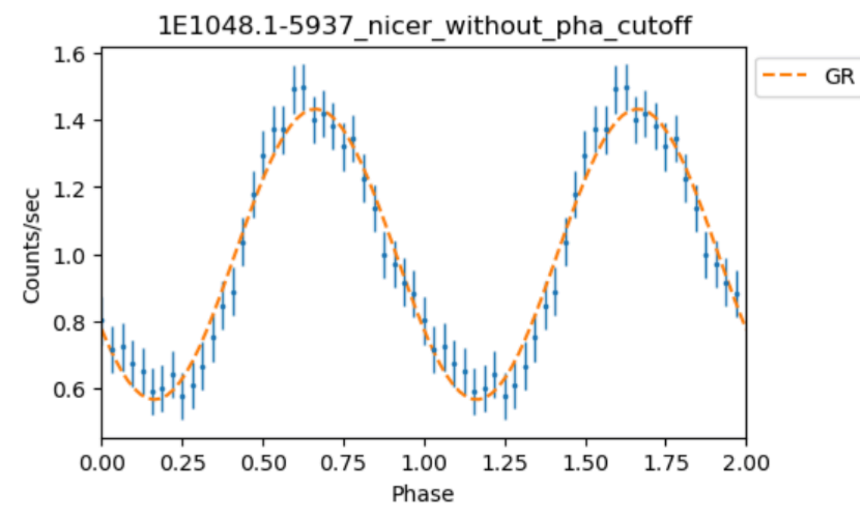
Newtonian

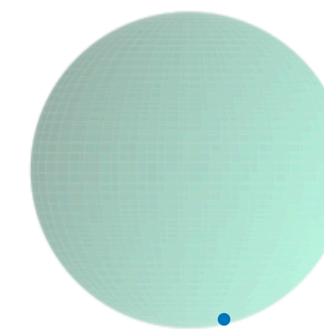


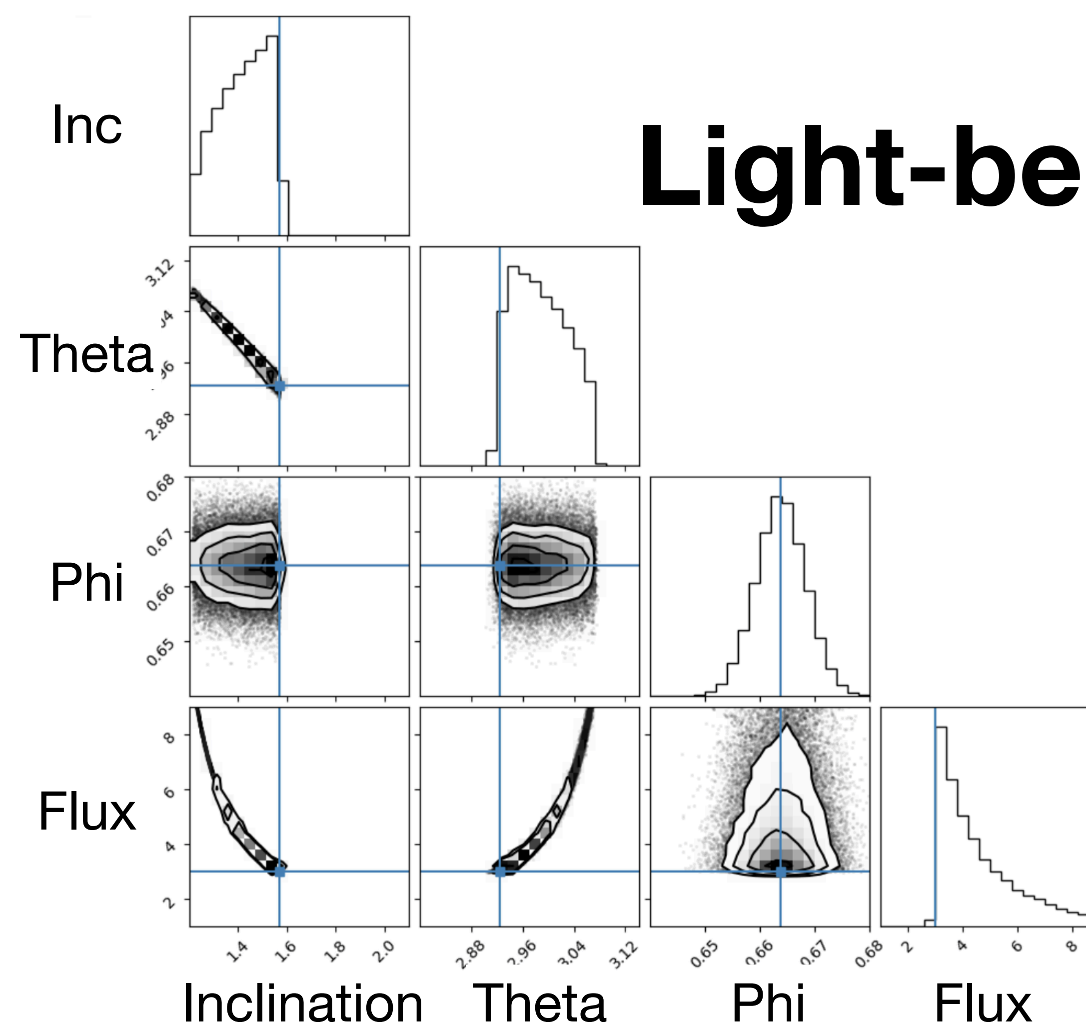




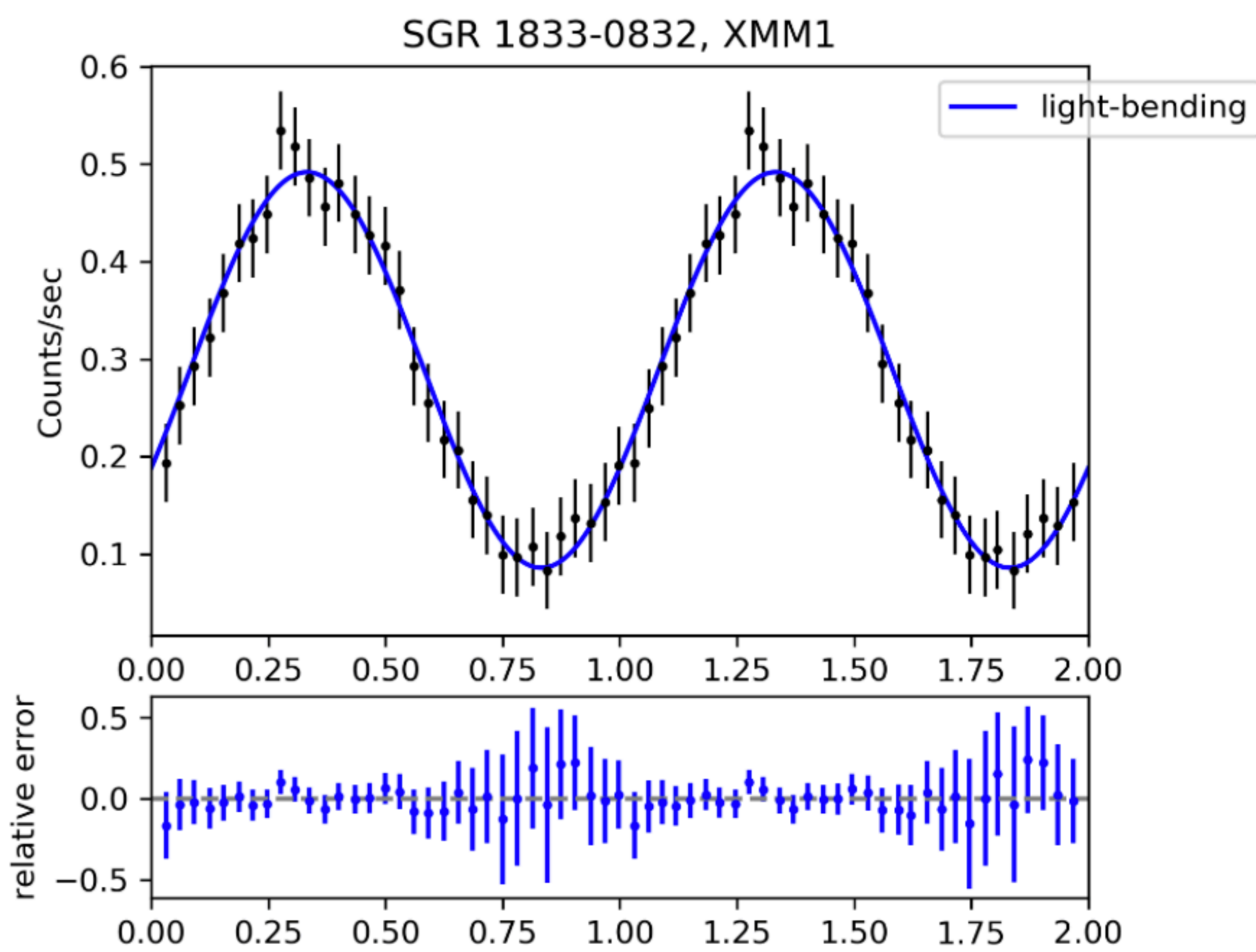
Light-bending





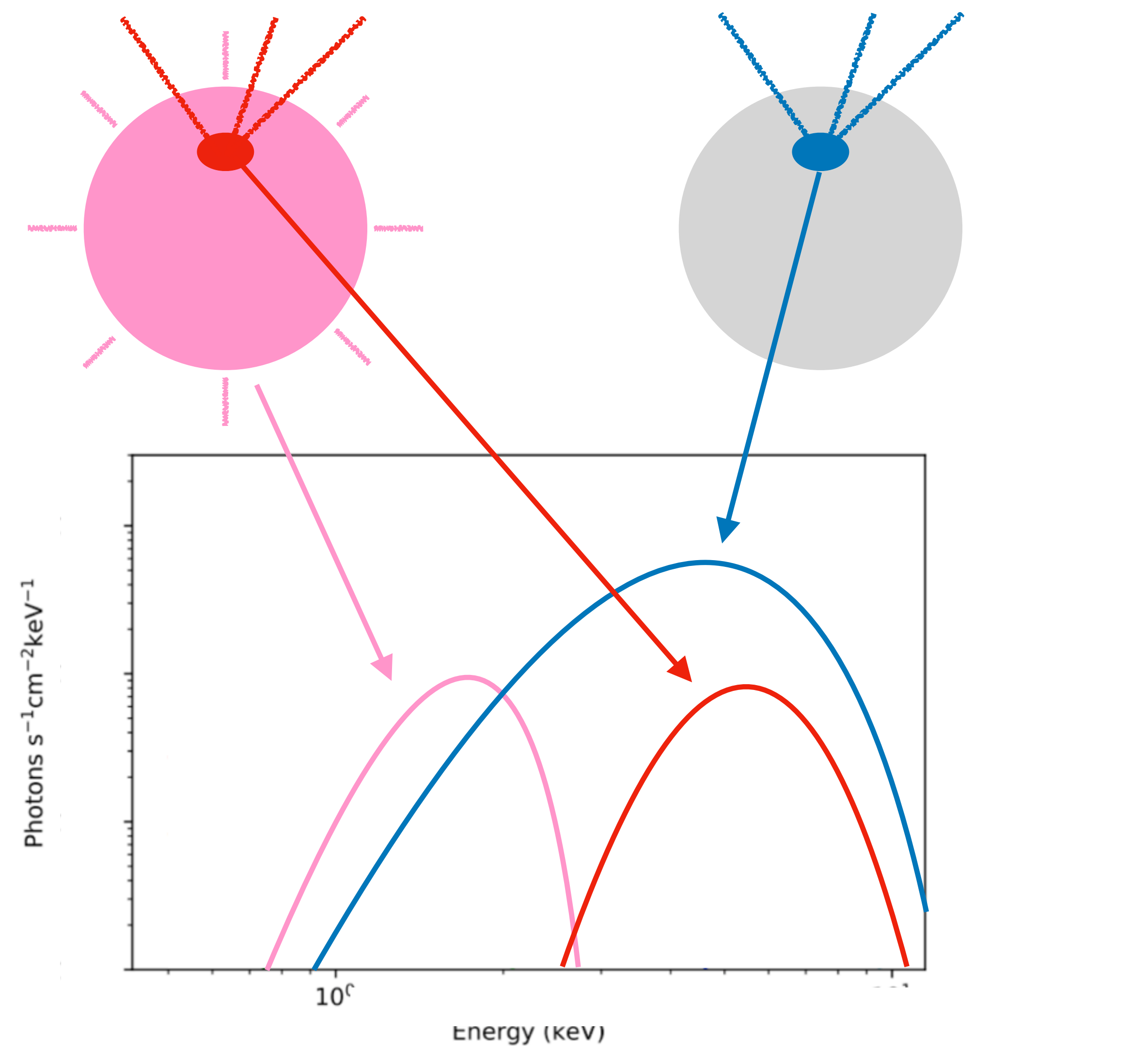


gradient descent fitting



$$relative\,error = \frac{Obs \pm \Delta - Exp}{Obs}$$

Newtonian **Light-bending**

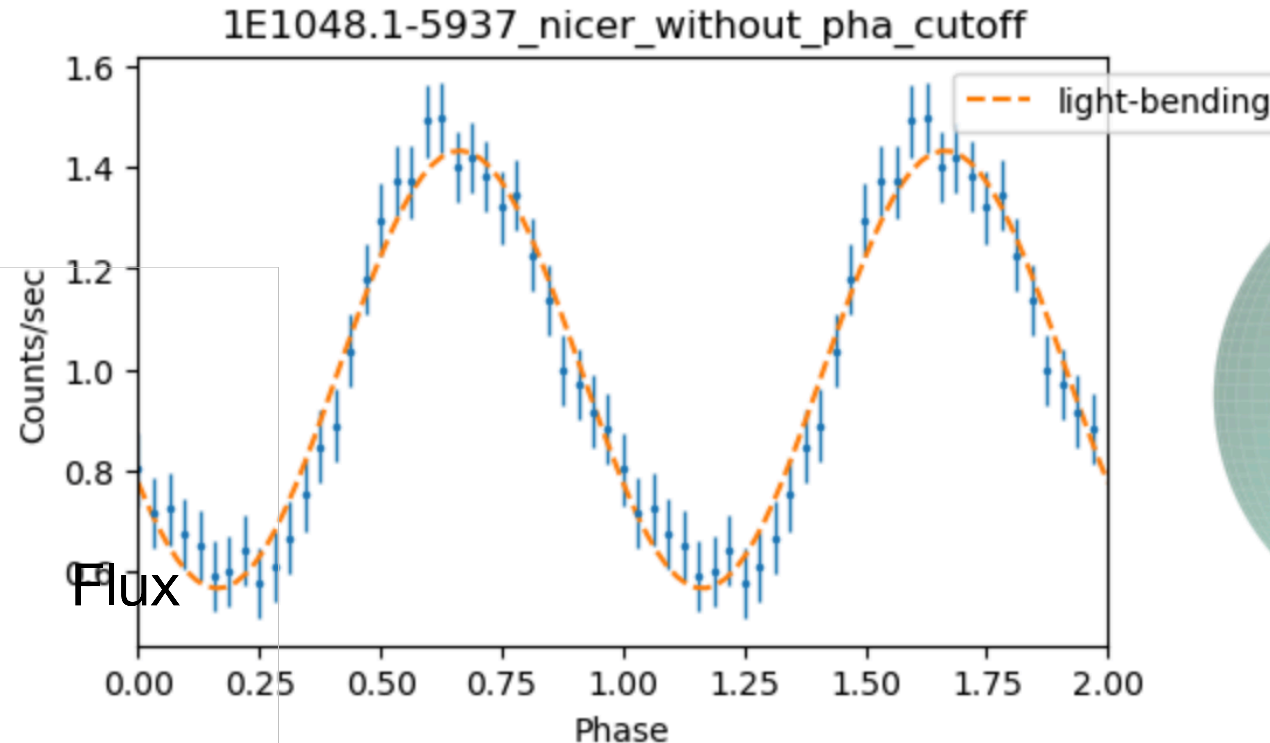


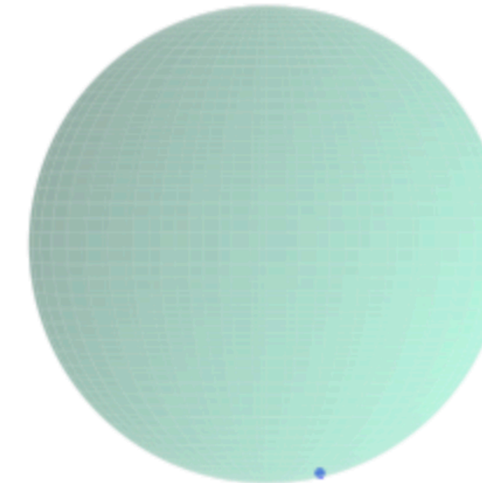
$$E_{rot} = \frac{1}{2}I\omega^2 = \frac{1}{2}I(\frac{2\pi}{P})^2$$

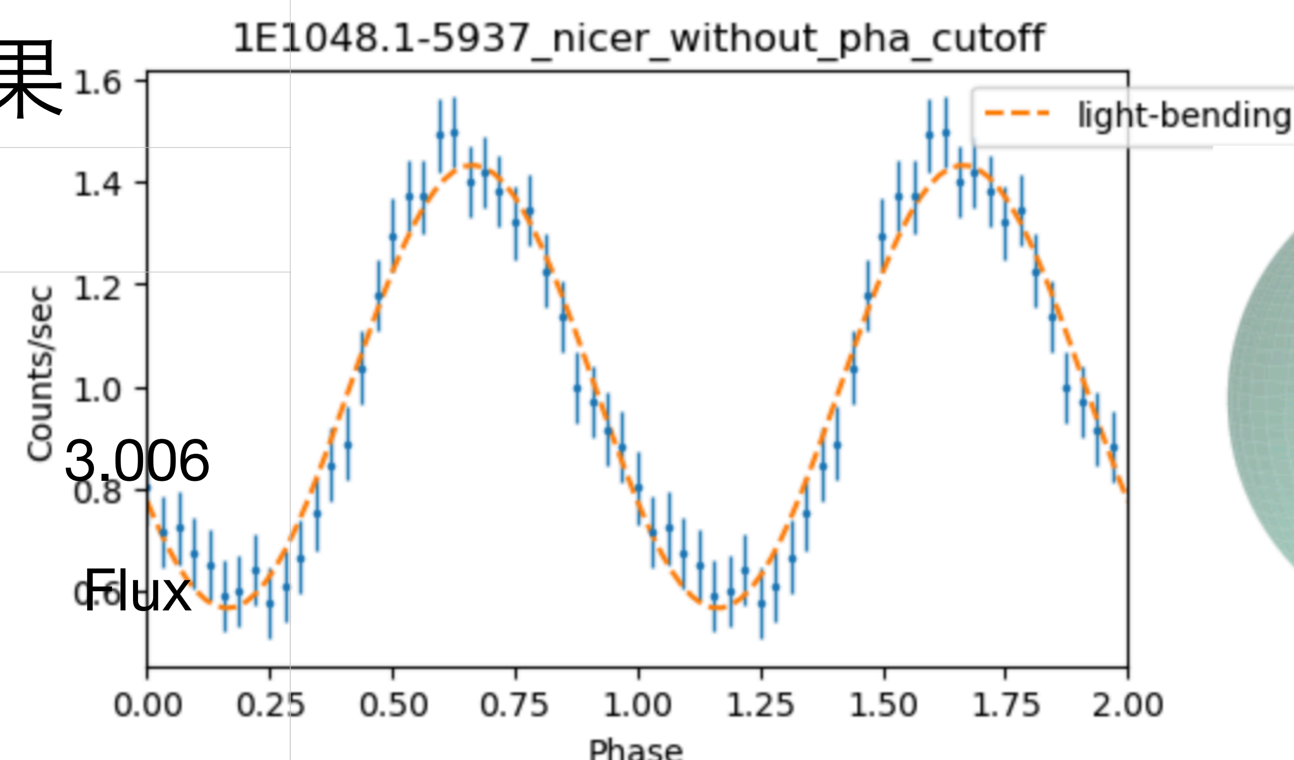
$$\dot{E}_{rot} = \frac{dE_{rot}}{dt} = -4\pi^2 I \frac{\dot{P}}{P^3}$$

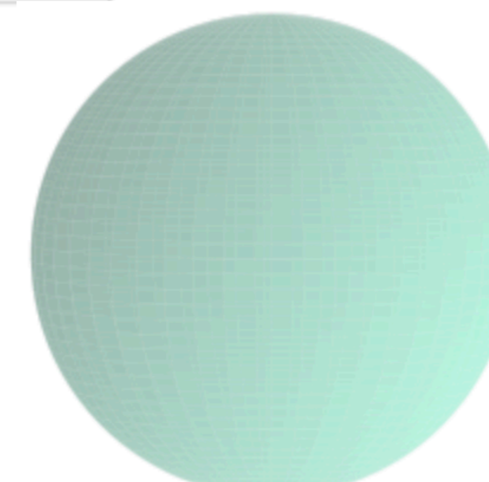
Initial guessによっての異なるフィッティング結果

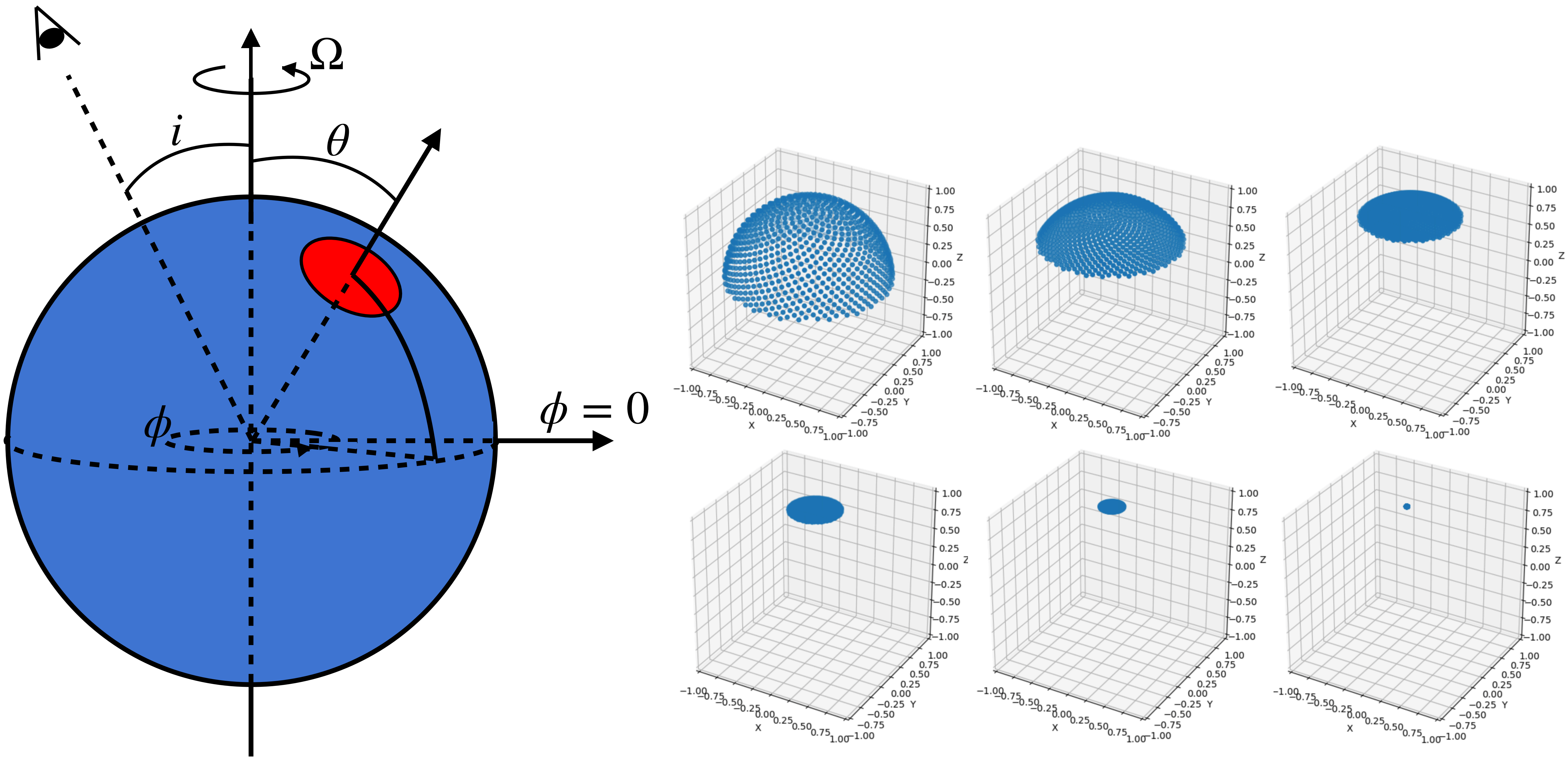
Viewing Angle	Theta	Phi	Flux
89.93	167.53	38.03	3.006
Viewing Angle	Theta	Phi	Flux





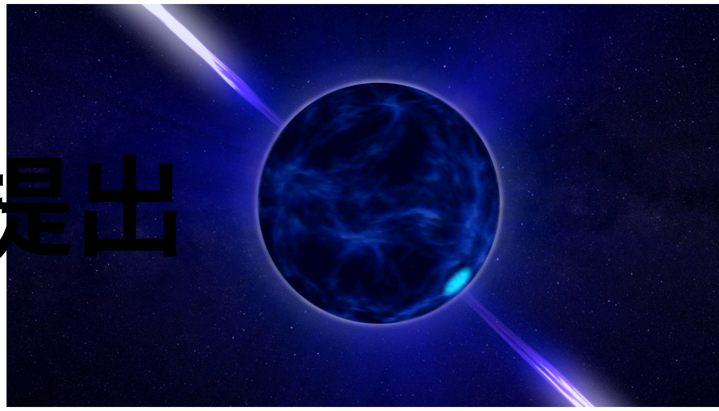


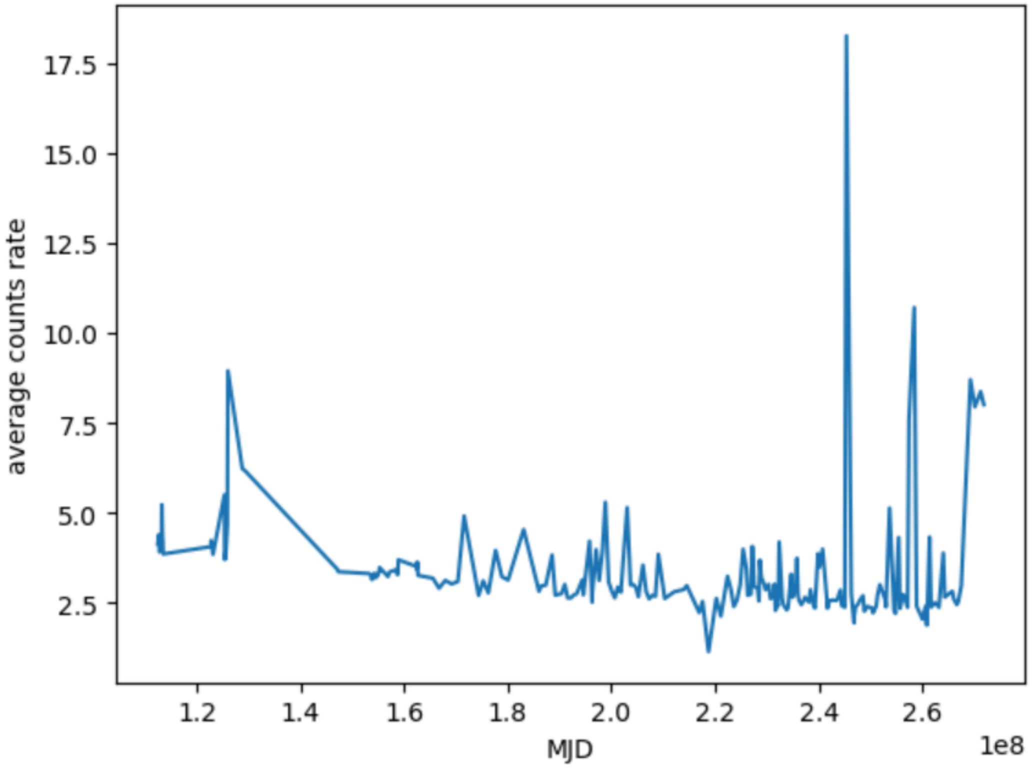




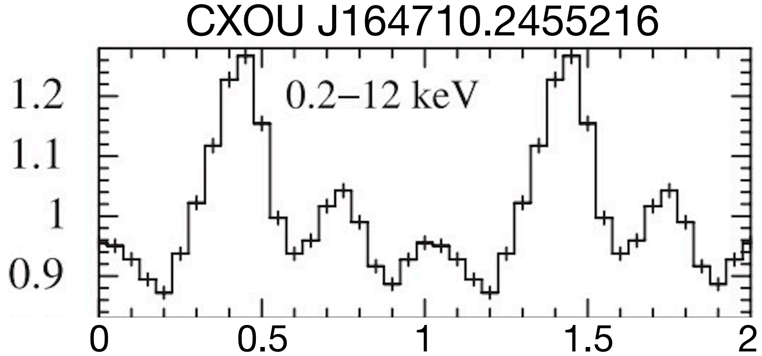
Ω
i
θ
ϕ
ϕ = 0
X
Y
Z

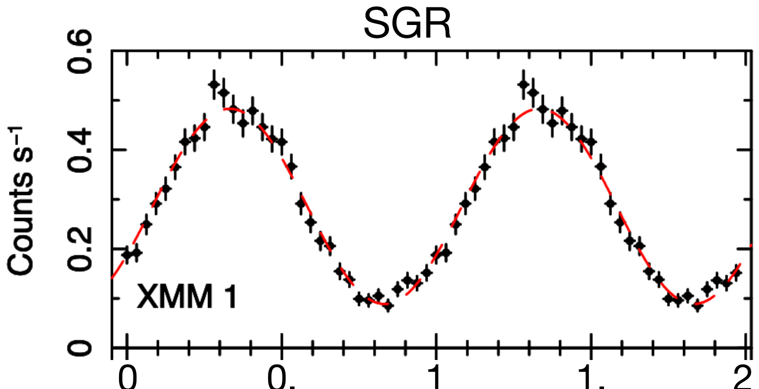
Quiescent emission
長期的なlight curve → パルス波形の提出

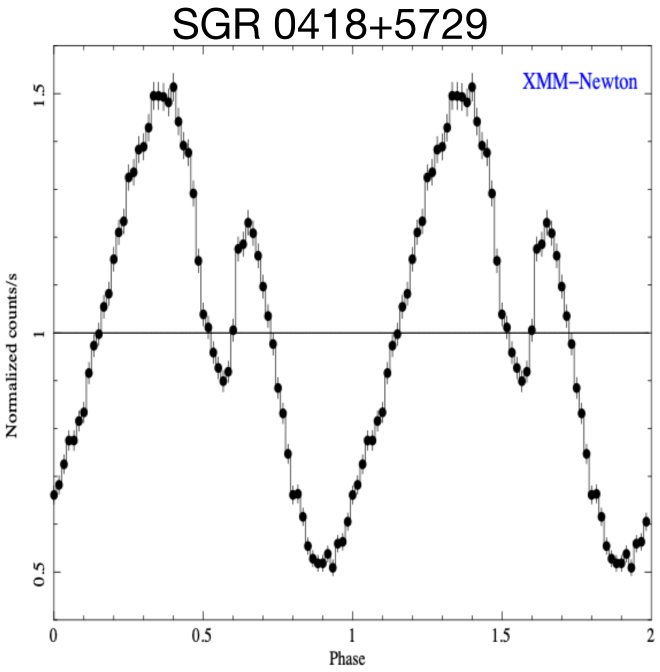


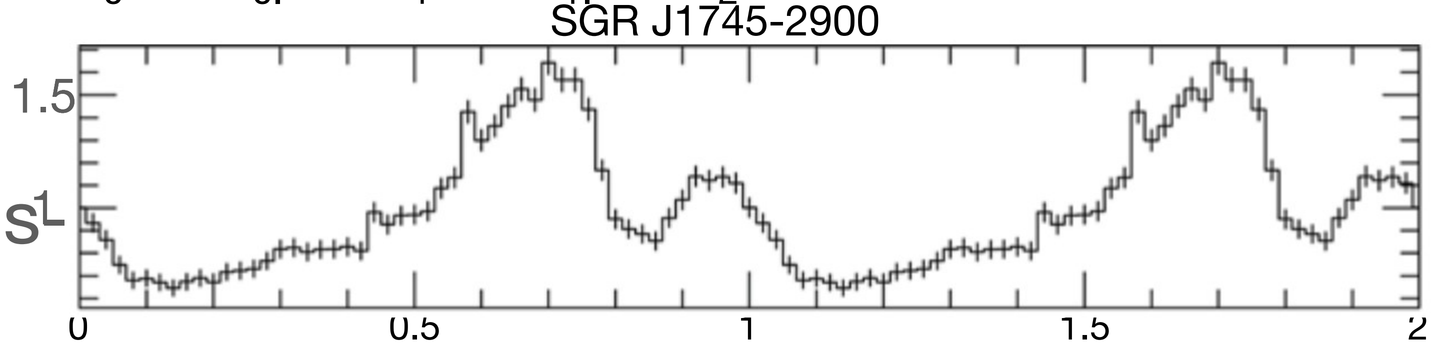


~ 10^35 erg s-1 >> L_{SD} ~ 10^33 erg s-1

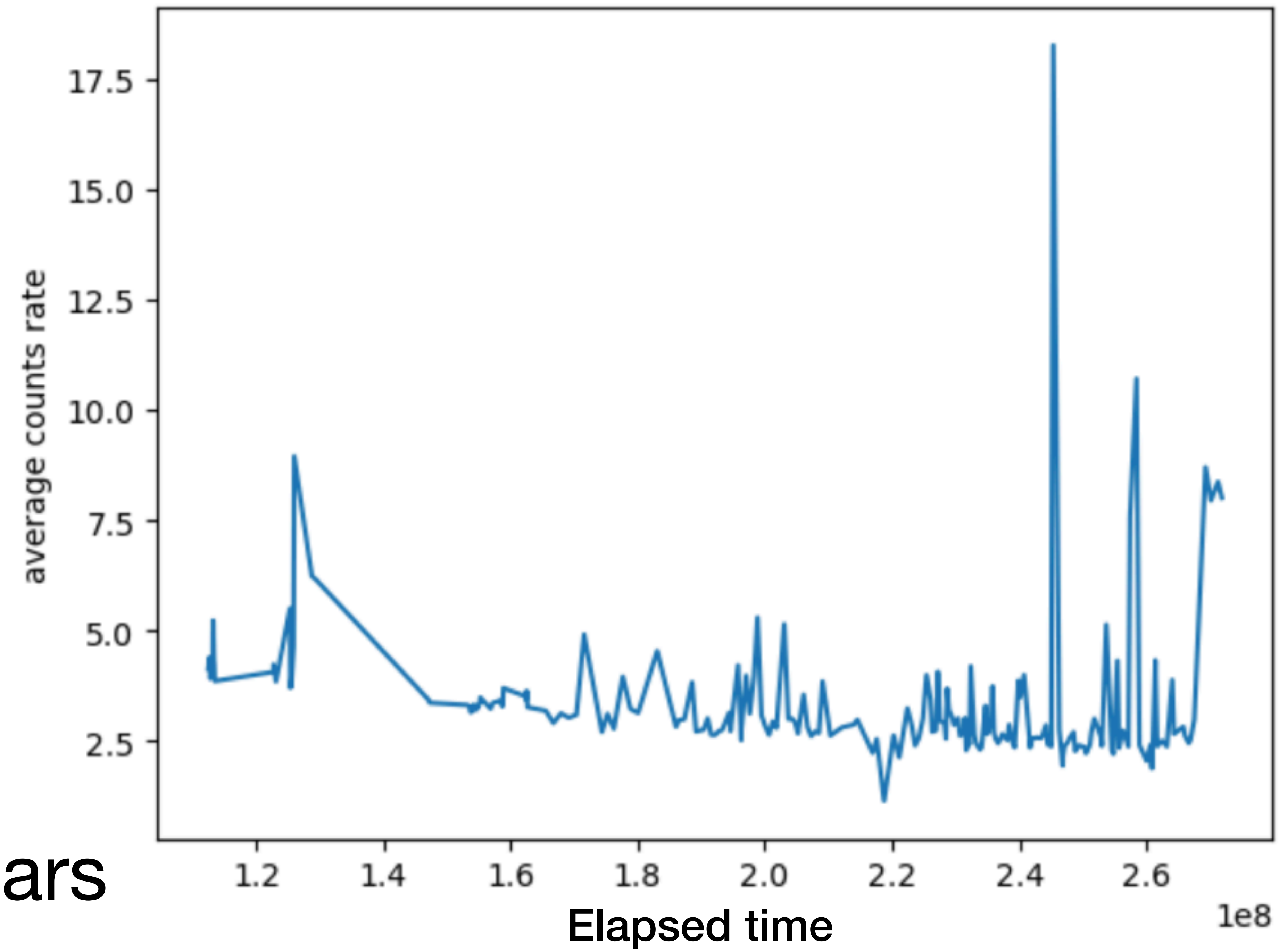








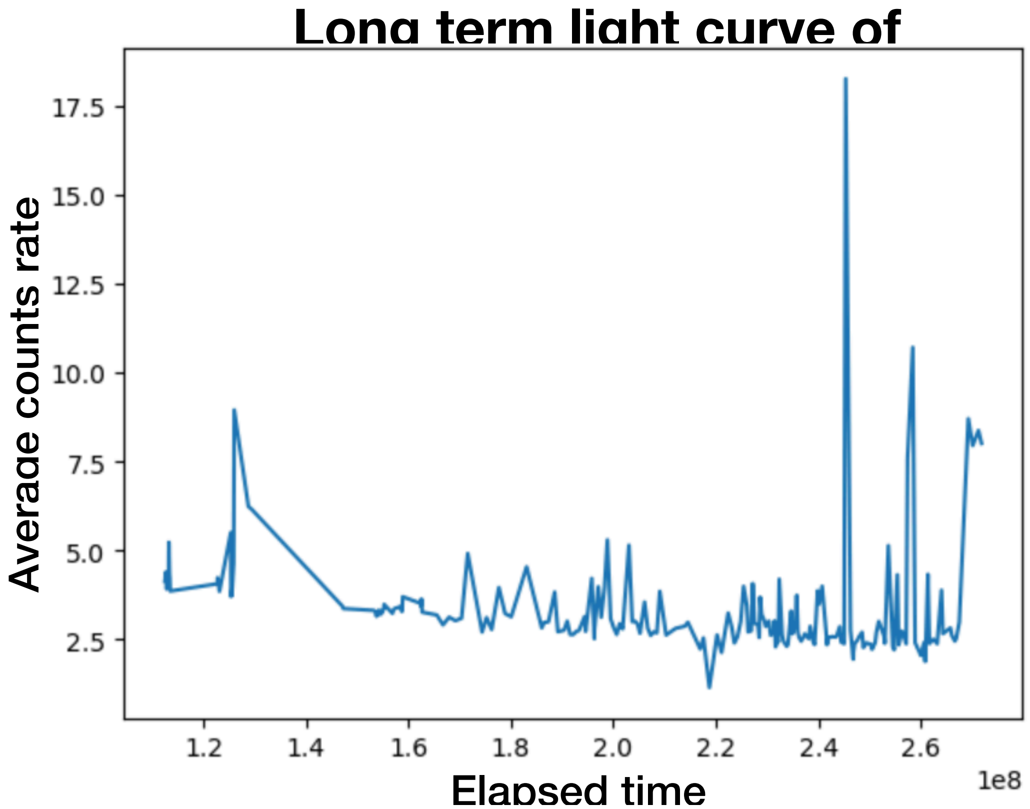
Naik et al. 2008 Esposito et al. 2018 Camero et al. 2014 Kaspi et al. 2008

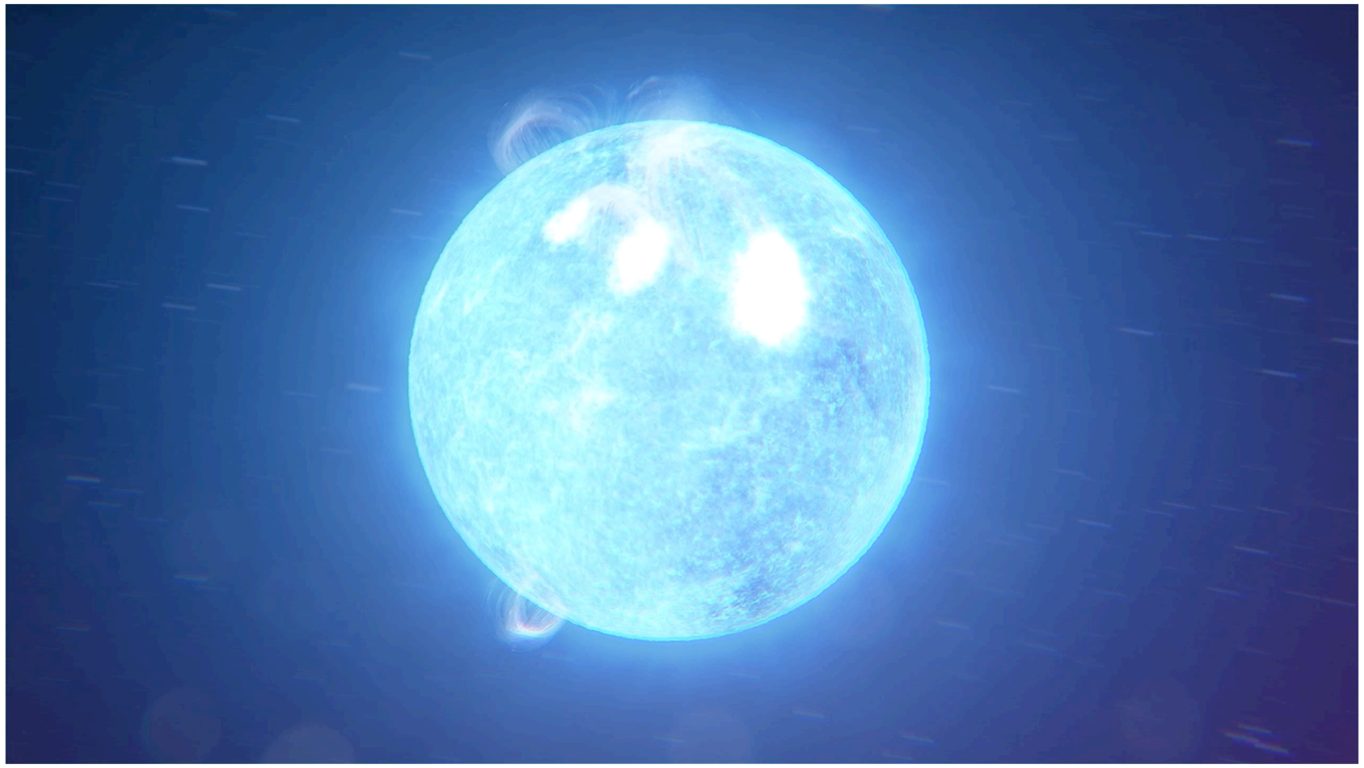


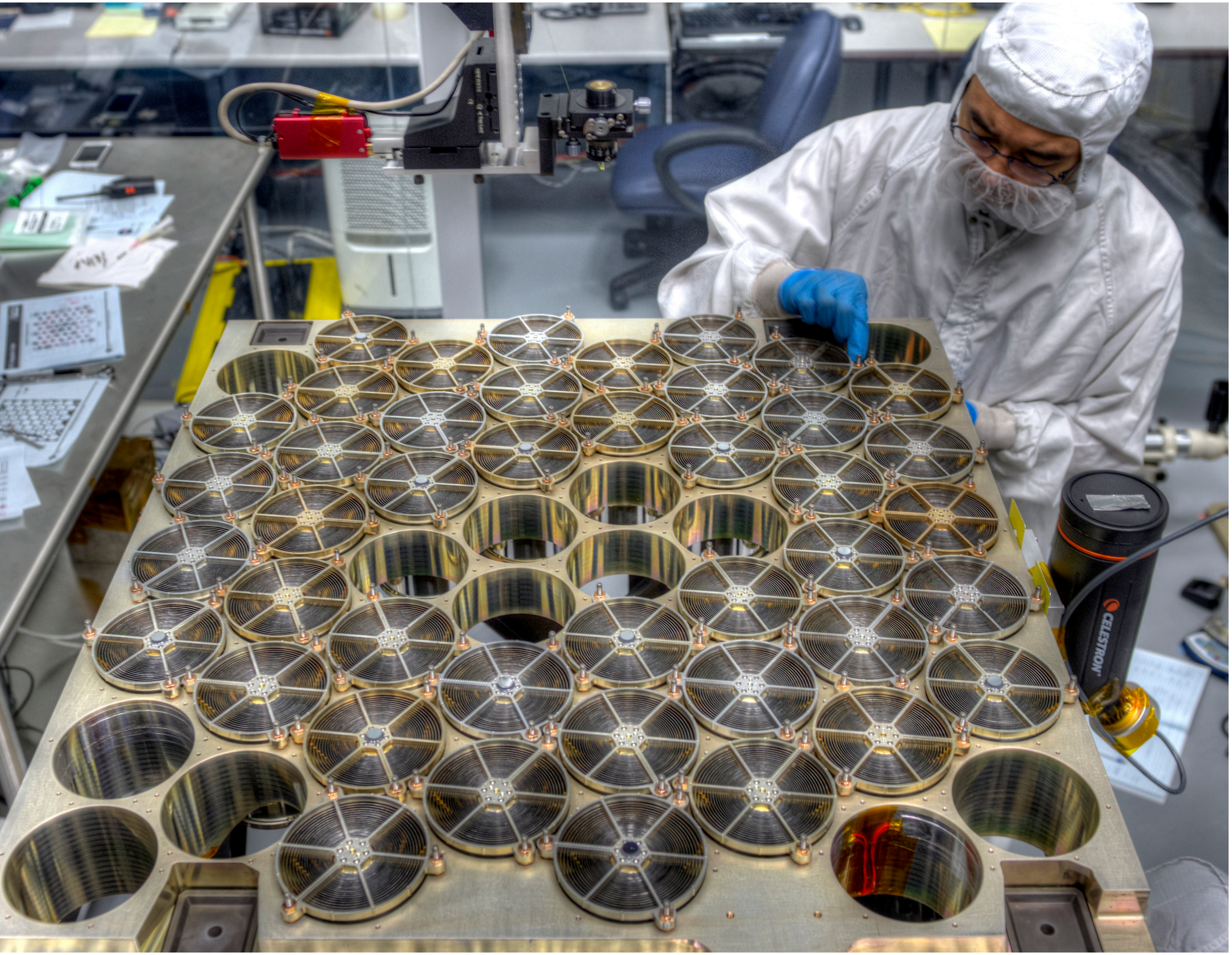
~ 4 years

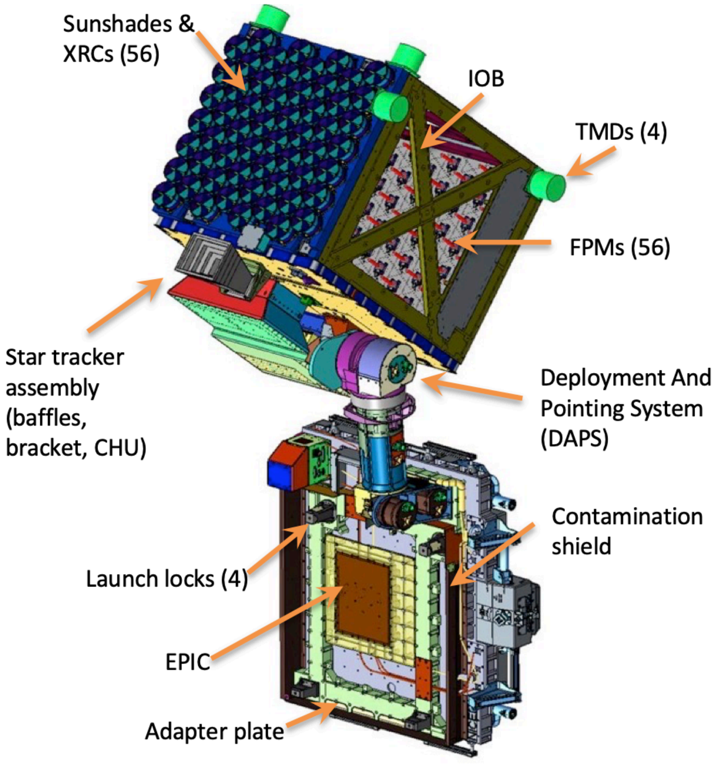
2014-01-01T00:00:00 UTC = 2014-01-01 00:01:07.184 TT

Folded light curve of quiescent emission

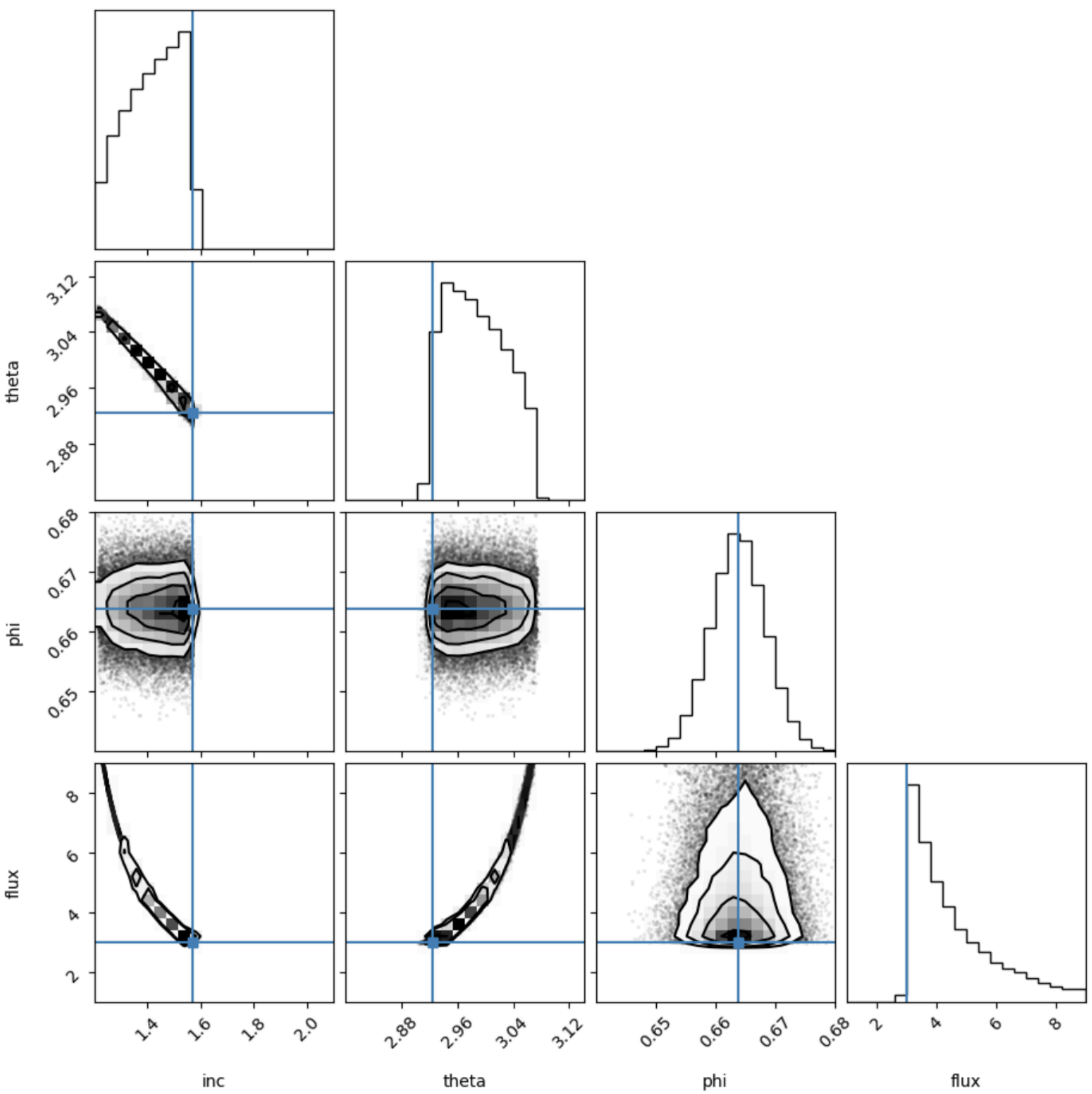


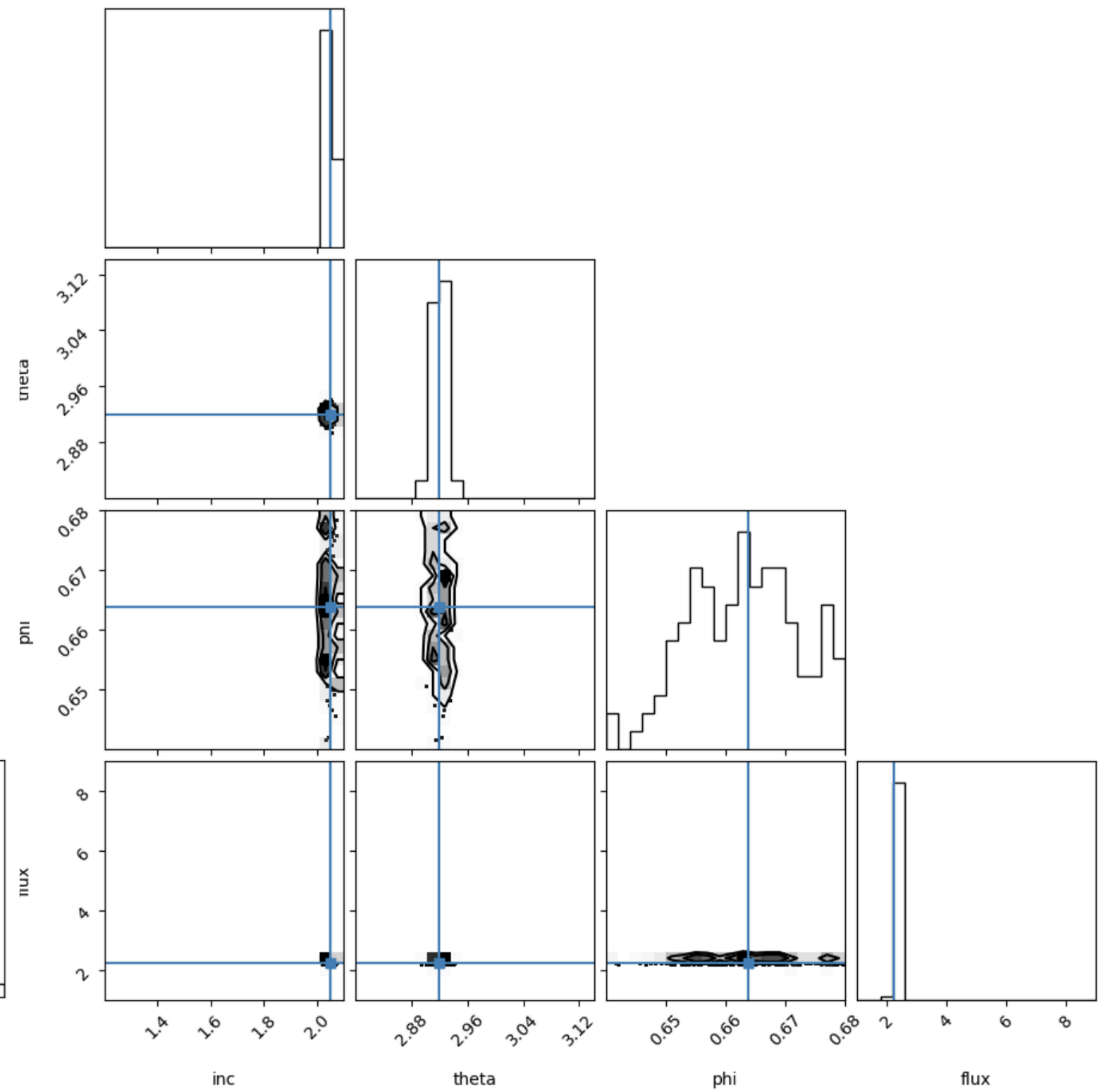




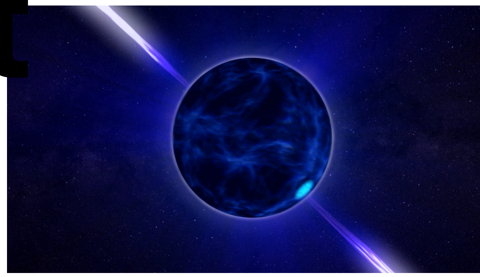


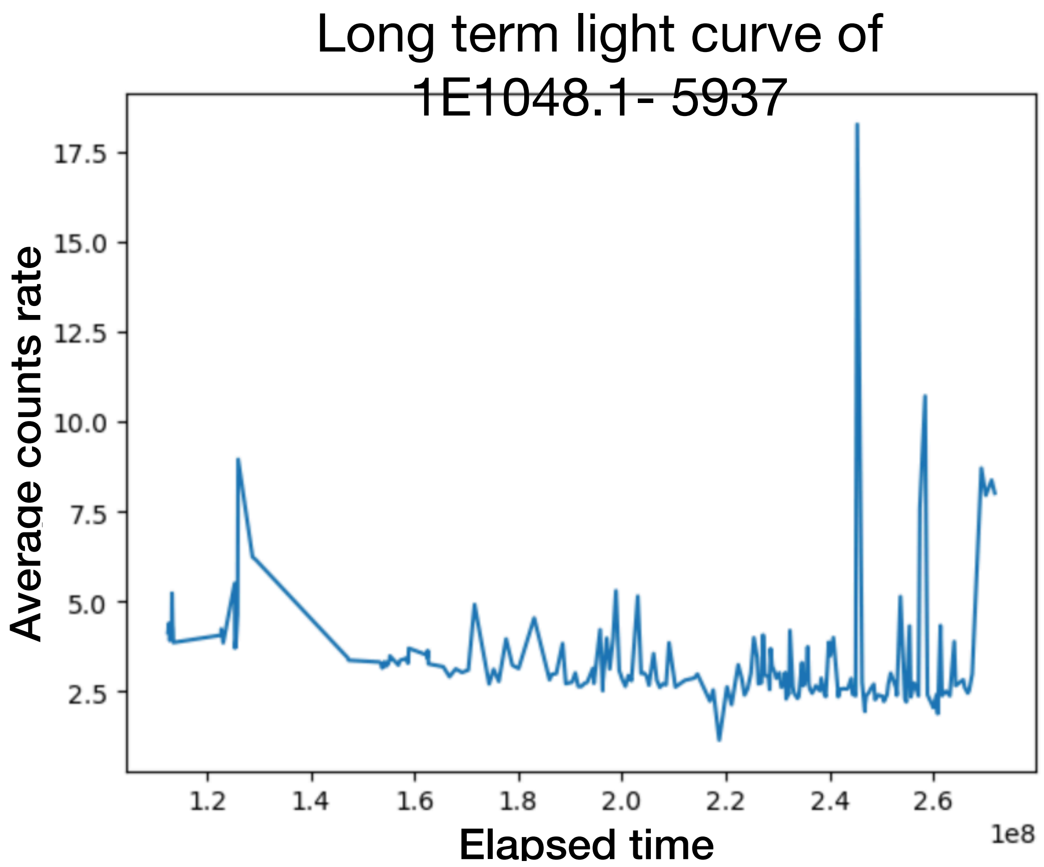
Sunshades & XRCs (56)
IOB
TMDs (4)
FPMs (56)
Star tracker assembly (baffles, bracket, CHU)
Deployment And Pointing System (DAPS)
Contamination shield
Launch locks (4)
EPIC
Adapter plate

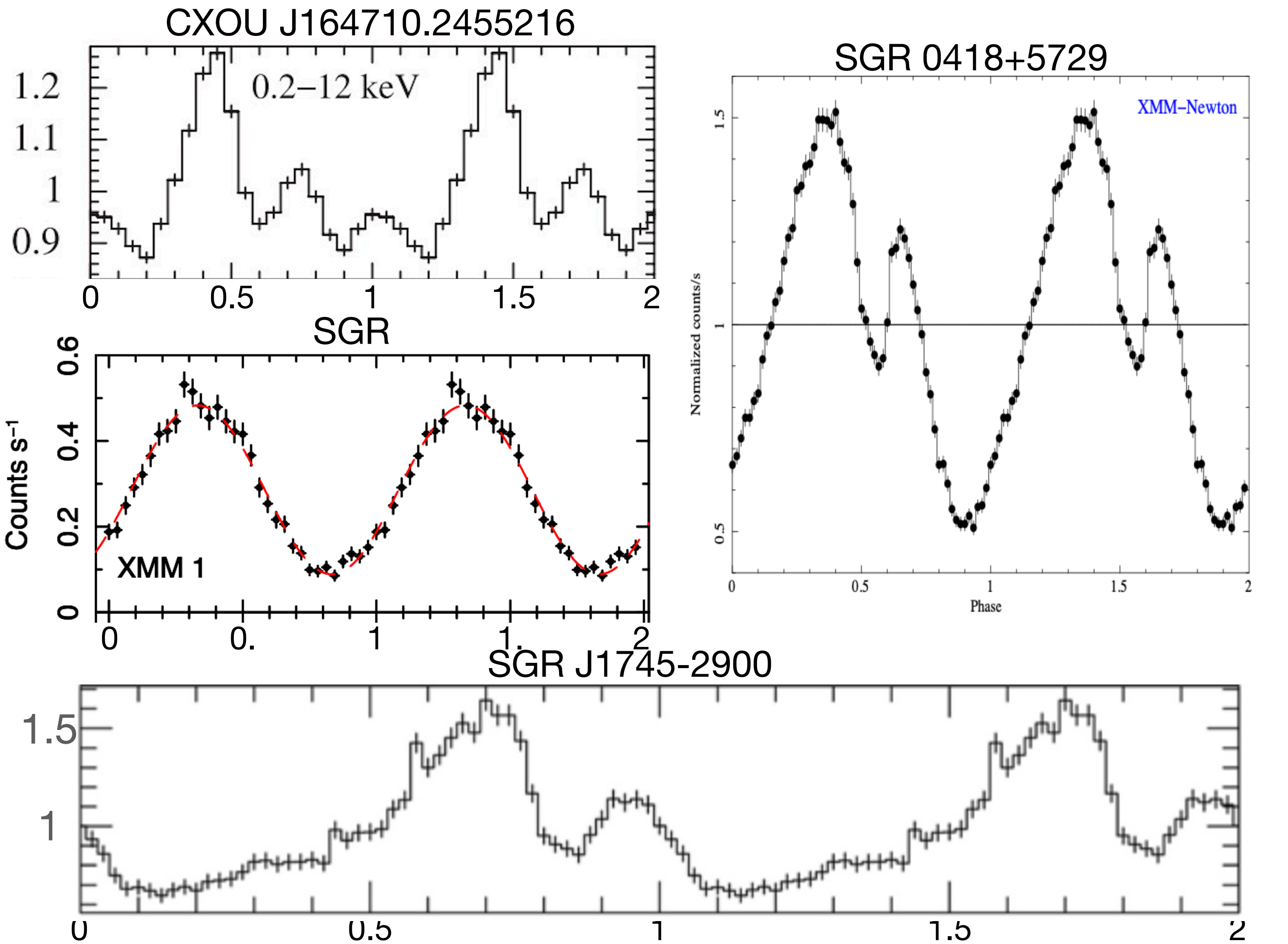

theta
phi
flux
inc
theta
phi
flux


inc
theta
phi
flux

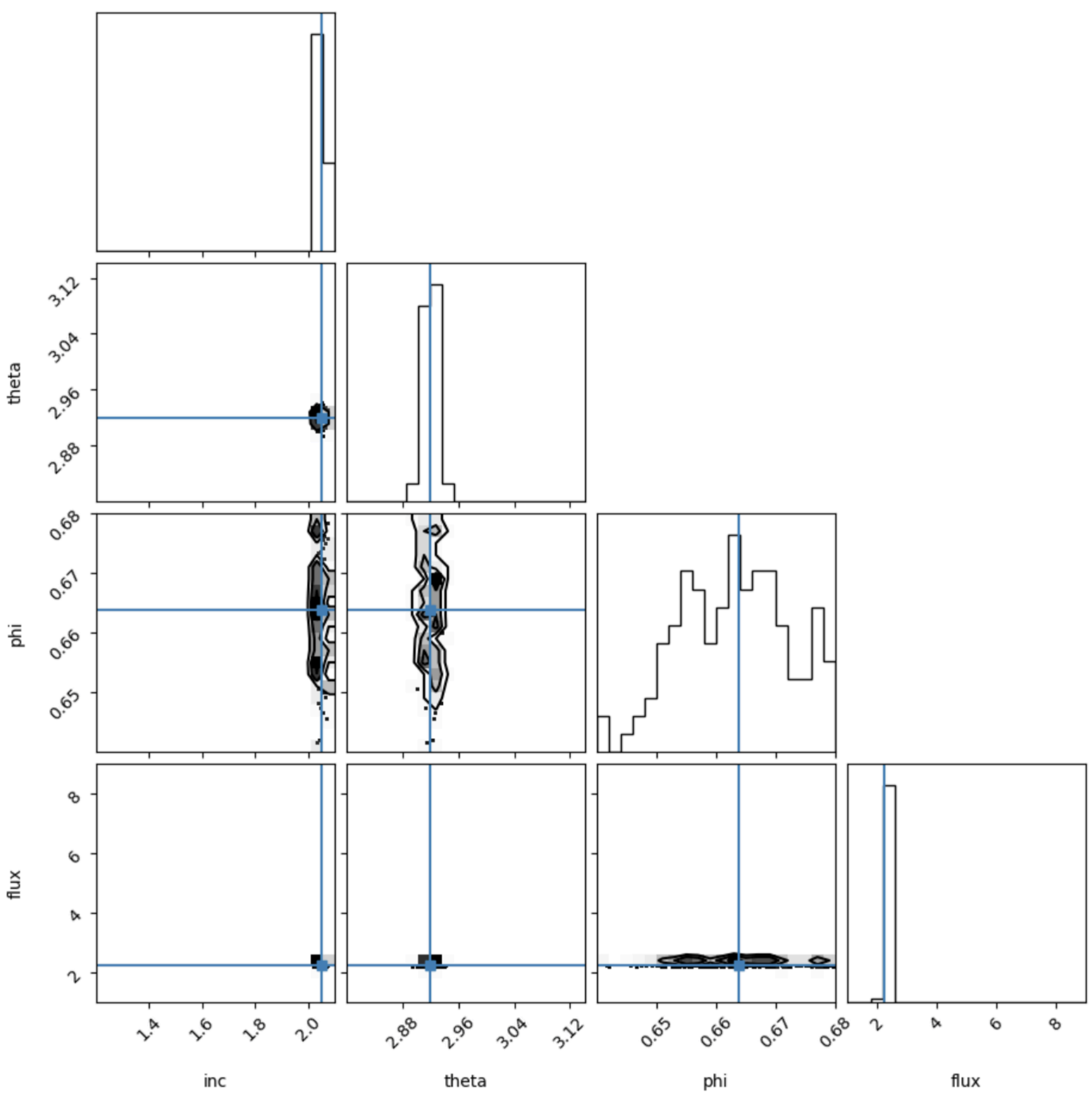
Folded light curve of quiescent emission



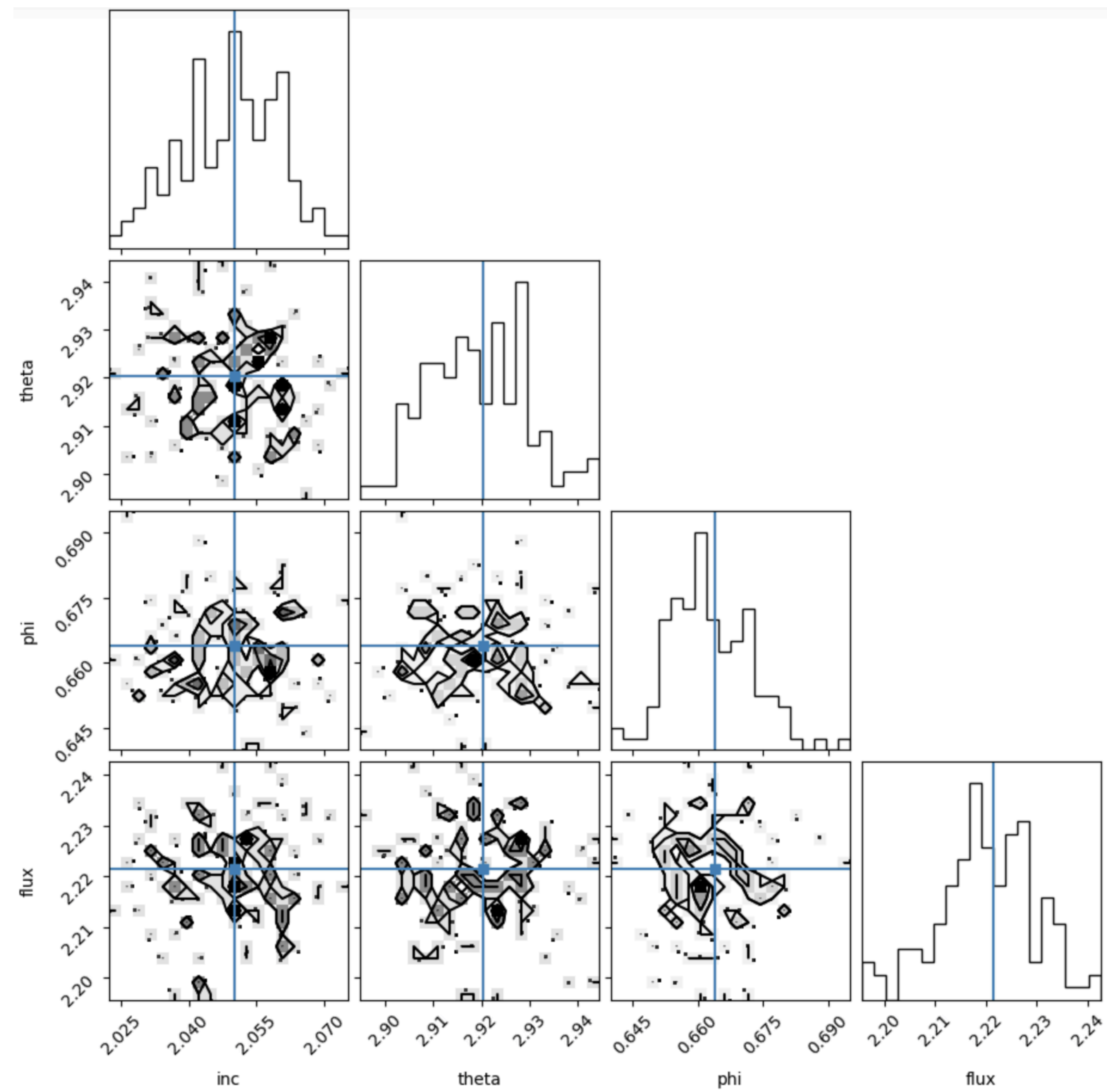




Naik et al. 2008 Esposito et al. 2018 Camero et al. 2014 Kaspi et al. 2008



theta
phi
flux
3.12
3.04
2.96
2.88
0.68
0.67
0.66
0.65
8
6
4
2
1.4
1.6
1.8
2.0
2.88
2.96
3.04
3.12
0.65
0.66
0.67
0.68
2
4
6
8
inc
theta
phi
flux



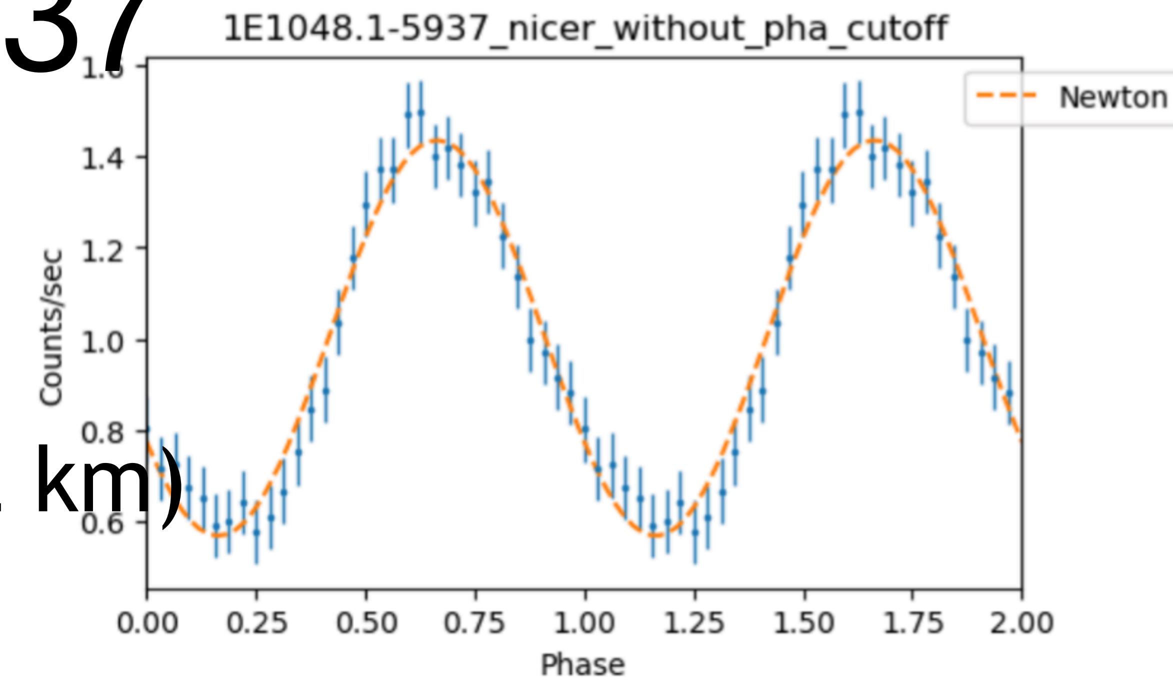
theta
phi
flux
2.94
2.93
2.92
2.91
2.90
0.690
0.675
0.660
0.645
2.24
2.23
2.22
2.21
2.20
2.025
2.040
2.055
2.070
2.90
2.91
2.92
2.93
2.94
0.645
0.660
0.675
0.690
2.20
2.21
2.22
2.23
2.24
inc
theta
phi
flux

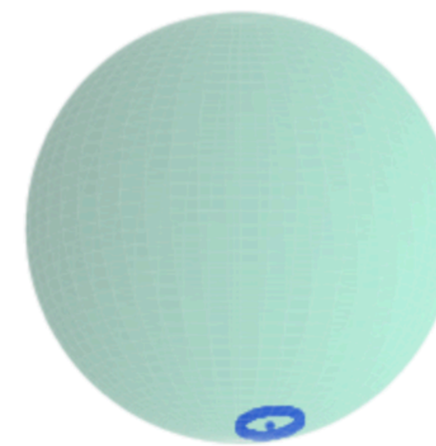
1E 1048.1–5937

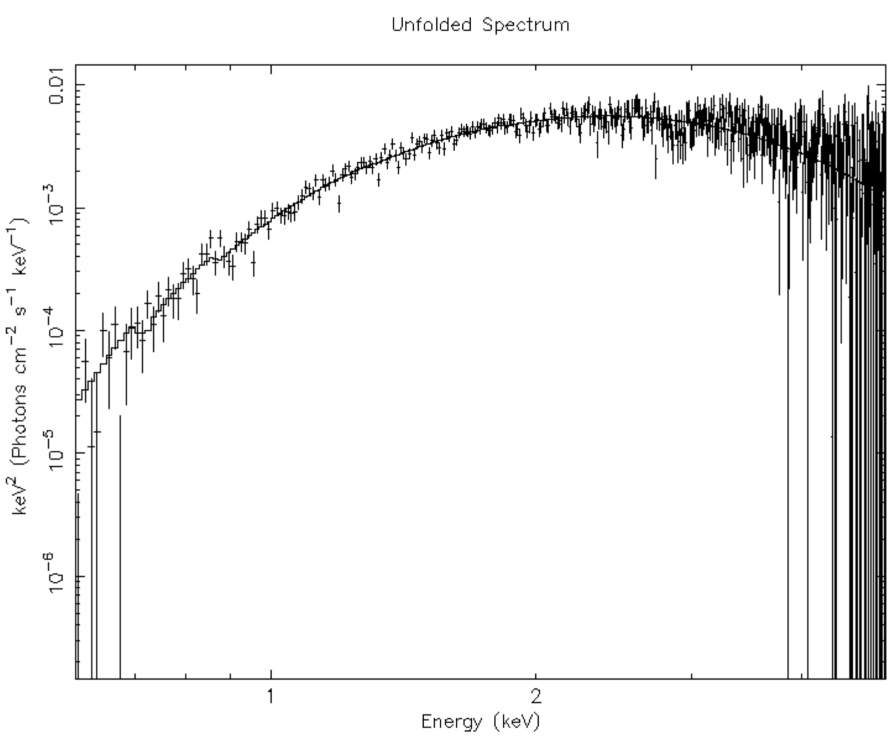
distance:9.0(1.7) kpc

Timing: <1.68 km
(assuming R_mag = 12 km)

Spectral: 3.1 km





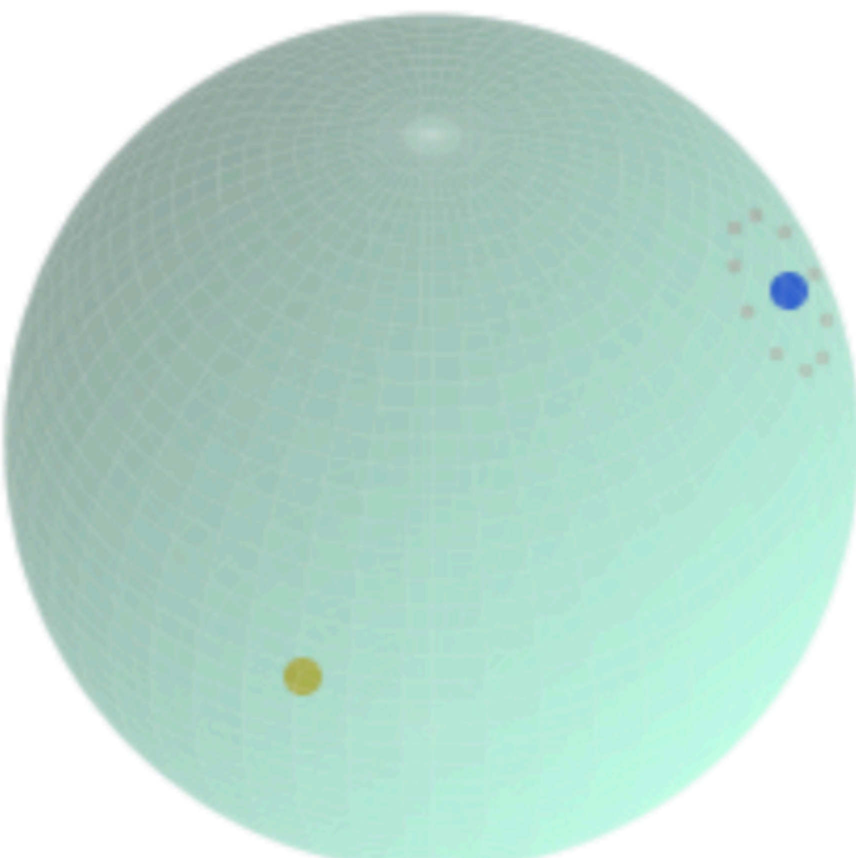



```
========================================================================
Model TBabs<1>*bbodyrad<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   TBabs      nH         10^22    0.481820     +/-  1.55807E-02
   2    2   bbodyrad   kT         keV      0.566435     +/-  6.07963E-03
   3    2   bbodyrad   norm                12.6060      +/-  0.614127
________________________________________________________________________


Fit statistic  : Chi-Squared                 483.80     using 439 bins.

Test statistic : Chi-Squared                 483.80     using 439 bins.
 Null hypothesis probability of 5.64e-02 with 436 degrees of freedom
XSPEC12>plot
XSPEC12>plot eeuf
```

波形解析



スペクトル解析

$$A(E) = \frac{K \times 1.0344 \times 10^{-3} E^2 dE}{\exp(E/kT) - 1}$$

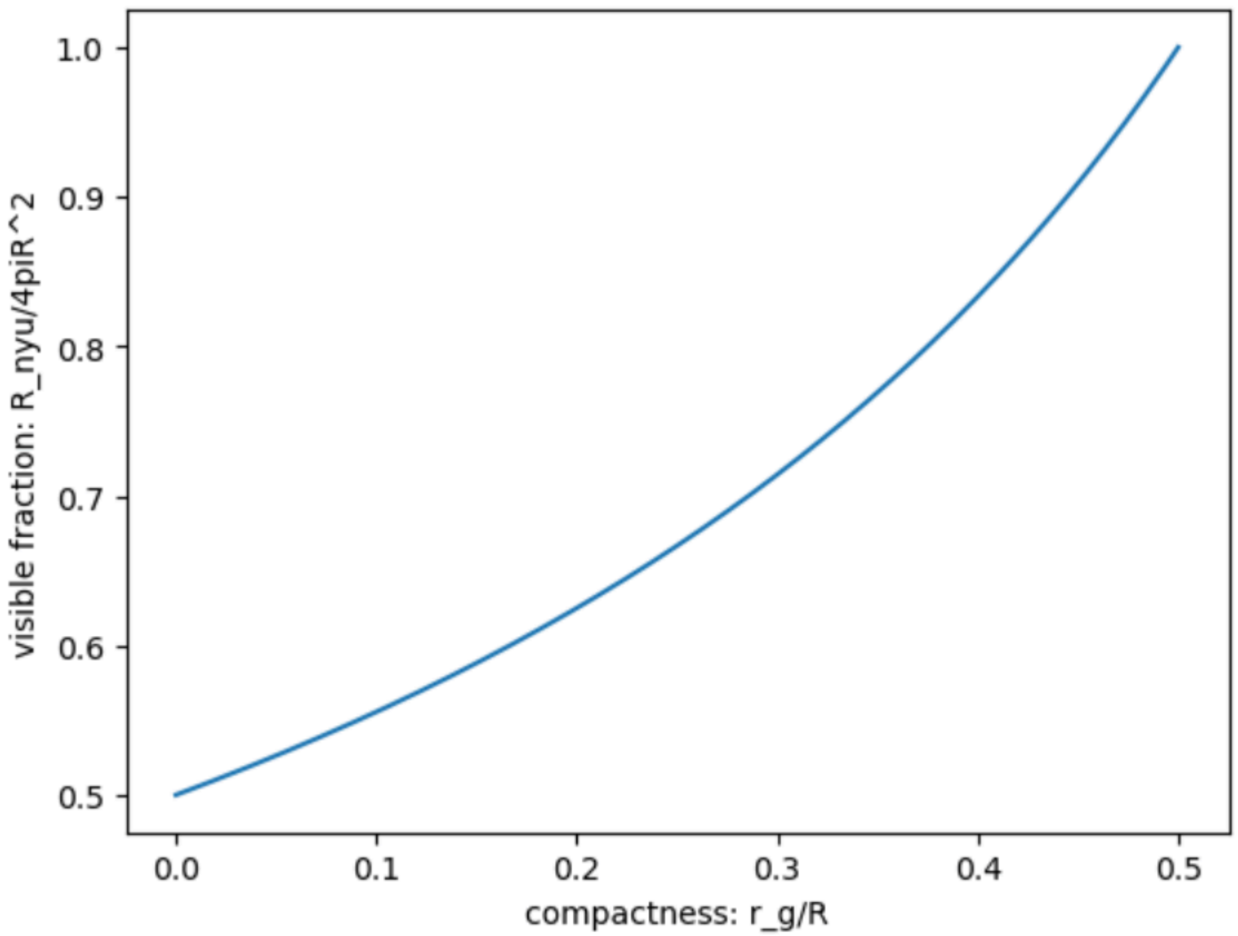
par1= kT	temperature keV
norm= K	R_{km}^2/D_{10}^2 , where R_{km} is the source radius in km and D_{10} is the distance to the source in units of 10 kpc.

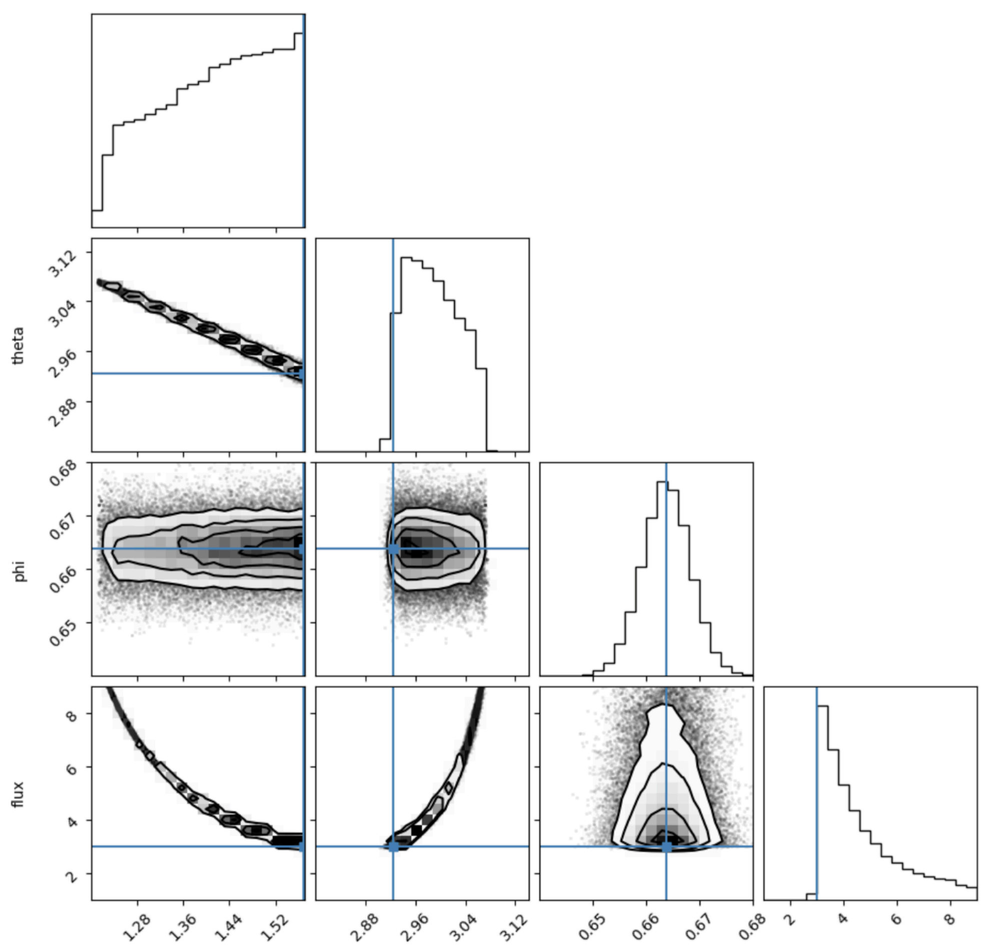
Name	P	dP/dt	B_{surf}	dE/dt	Tau_c	N_H	PL Index	BB Temp	Unabs F_x{a}	Distance	L_x{b}	Assoc?	Opt/IR?	Bands? {c}	Activity?	RA, Dec
	(s)	(10^{-11} s/s)	(10^{14} G)	(10^{33} erg/s)	(kyr)	(10^{22} cm^{-2})		(keV)	(10^{-12} erg/s/cm^2)	(kpc)	(10^{33} erg/s)					(J2000)
CXOU J010043.1−721134	8.020392(9) [mgr+05]	1.88(8) [mgr+05]	3.9	1.4	6.8	0.063$^{+0.020}_{-0.016}$* [tem08]	…	0.30(2) + 0.68$^{+0.09}_{-0.07}$* [tem08]	0.14* [tem08]	62.4(1.6) [hgd12b]	65	SMC [lfmp02]	maybe	X O?	…	01^{h}00^{m}43.14^s, −72°11′33.8″ [lfmp02]
4U 0142+61	8.68869249(5) [dk14]	0.2022(4) [dk14]	1.3	0.12	68	1.00(1)* [rni+07]	3.88(1)* [rni+07]	0.410$^{+0.004}_{-0.002}$* [rni+07]	67.9* [rni+07]	3.6(4)* [dv06b]	105	…	yes	H X O I	bursts, glitches	01^{h}46^{m}22.407^s, +61°45′03.19″ [hvk04]
SGR 0418+5729	9.07838822(5) [rip+13]	0.0004(1) [rip+13]	0.061	0.00021	36000	0.115(6) [rip+13]	…	0.32(5) [rip+13]	0.0020$^{+0.0014}_{-0.0010}$ [0.012(1) (0.5–10 keV)] [rip+13]	~2 [vck+10]	0.00096	…	no	X	bursts, transient magnetar	04^{h}18^{m}33.867^s, +57°32′22.91″ [vck+10]
SGR 0501+4516	5.7620695(1) [cpr+14]	0.594(2) [cpr+14]	1.9	1.2	15	0.88(1)* [cpr+14]	3.84(6)* [cpr+14]	0.50(2)* [cpr+14]	1.7 [19(1) (0.5–10 keV)]* [cpr+14]	~2 [lkb+11]	0.81	SNR HB 9? [GCN8149]	yes	H X O	bursts	05^{h}01^{m}06.76^s, +45°16′33.92″ [gwk+10]
SGR 0526−66	8.0544(2)* [tem+09]	3.8(1)* [tem+09]	5.6	2.9	3.4	0.604$^{+0.058}_{-0.059}$* [phs+12]	2.50$^{+0.11}_{-0.12}$* [phs+12]	0.44(2)* [phs+12]	0.55 [1.58$^{+0.13}_{-0.20}$ (0.5–10 keV)]* [phs+12]	53.6(1.2) [hgd12a]	189	LMC, SNR N49?, SL 463 (young star cluster) [khg+04]	no	X	bursts, giant flare	05^{h}26^{m}00.89^s, −66°04′36.3″ [kkm+03]
1E 1048.1−5937	6.457875(3) [dkg09]	2.25* [dkg09]	3.9	3.3	4.5	0.97(1)* [tgd+08]	3.14(11)* [tgd+08]	0.56(1)* [tgd+08]	5.1(1)* [tgd+08]	9.0(1.7)* [dv06b]	49	GSH 288.3−0.5−28? (stellar wind bubble) [gmo+05]	yes	H X O	bursts, glitches	10^{h}50^{m}07.14^s, −59°53′21.4″ [wc02]
1E 1547.0−5408	2.0721255(1)* [dksg12]	4.77* [dksg12]	3.2	210	0.69	3.2(2)* [bis+11]	4.0(2)* [bis+11]	0.43(3)* [bis+11]	0.54 [0.37$^{+0.01}_{-0.03}$ (0.5–10 keV)]* [bis+11]	4.5(5)* [tve+10]	1.3	SNR G327.24−0.13 [gg07]	maybe	H X O? R	bursts, transient magnetar	15^{h}50^{m}54.124^s, −54°18′24.11″ [dcrh12]
PSR J1622−4950	4.3261(1) [lbb+10]	1.7(1)* [lbb+10]	2.7	8.3	4.0	5.4$^{+1.6}_{-1.4}$ [ags+12]	…	0.5(1) [ags+12]	0.045$^{+0.063}_{-0.028}$ [0.11$^{+0.09}_{-0.04}$ (0.3–10 keV)] [ags+12]	~9 [lbb+10]	0.44	SNR G333.9+0.0 [ags+12]	no	X R	…	16^{h}22^{m}44.89^s, −49°50′52.7″ [ags+12]
SGR 1627−41	2.594578(6) [etm+09]	1.9(4) [ebp+09]	2.2	43	2.2	10(2)* [eiz+08]	2.9(8)* [akt+12]	…	0.25$^{+0.17}_{-0.10}$* [akt+12]	11.0(3)* [ccdd99]	3.6	CTB 33 (radio complex), MC −71, SNR G337.0−0.1 [ccdd99]	no	X	bursts, transient magnetar	16^{h}35^{m}51.844^s, −47°35′23.31″ [wpk+04]
CXOU J164710.2−455216	10.610644(17)* [akac13]	<0.04* [akac13]	<0.66	<0.013	>420	2.39(5) [akac13]	3.86(22) [akac13]	0.59(6) [akac13]	0.25(4) [akac13]	3.9(7)* [kd07]	0.45	Westerlund 1 (massive star cluster) [mcc+06]	no	X	bursts, transient magnetar	16^{h}47^{m}10.20^s, −45°52′16.90″ [mcc+06]

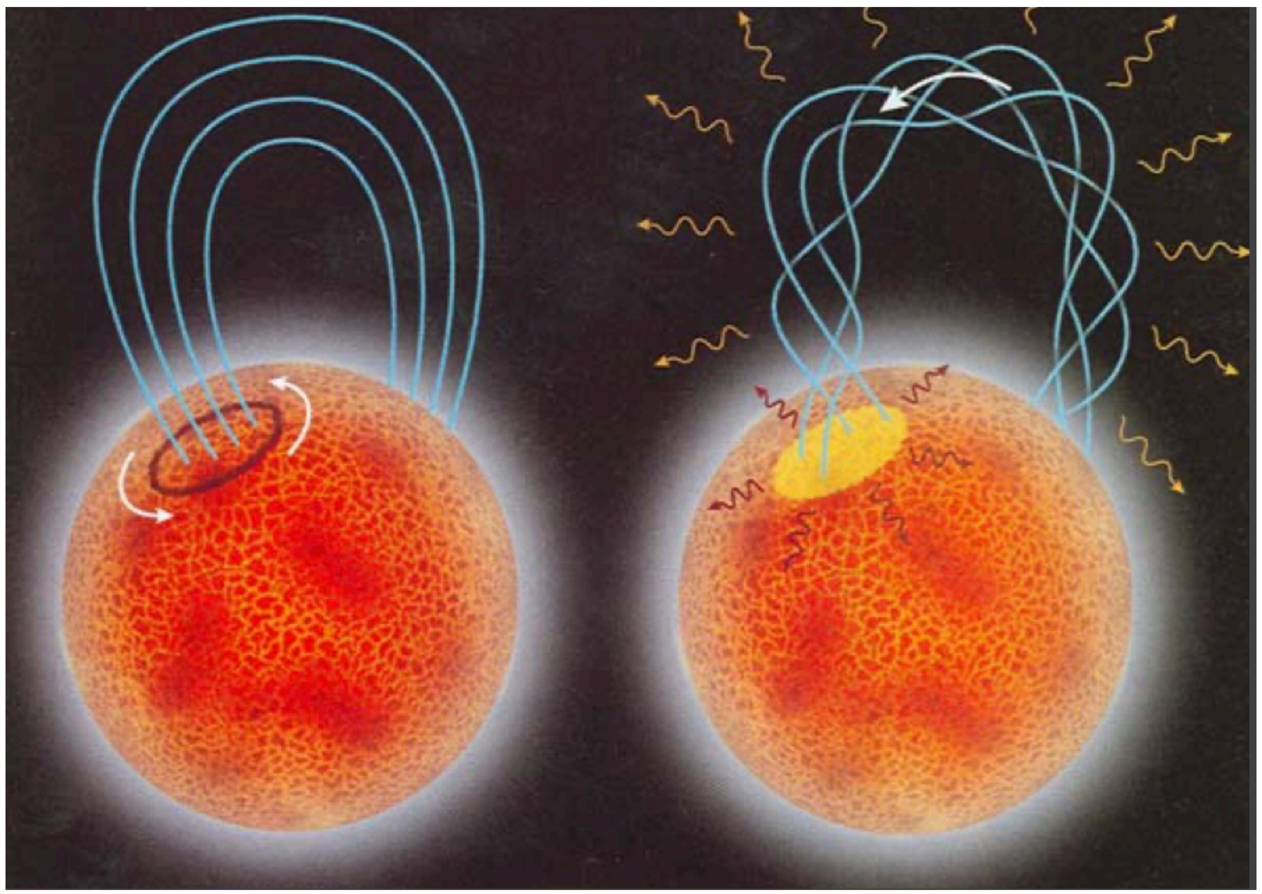
How GR effect works on pulse profile

$R : magnetar\ radius \qquad r_g : Schwarzschild\ radius$

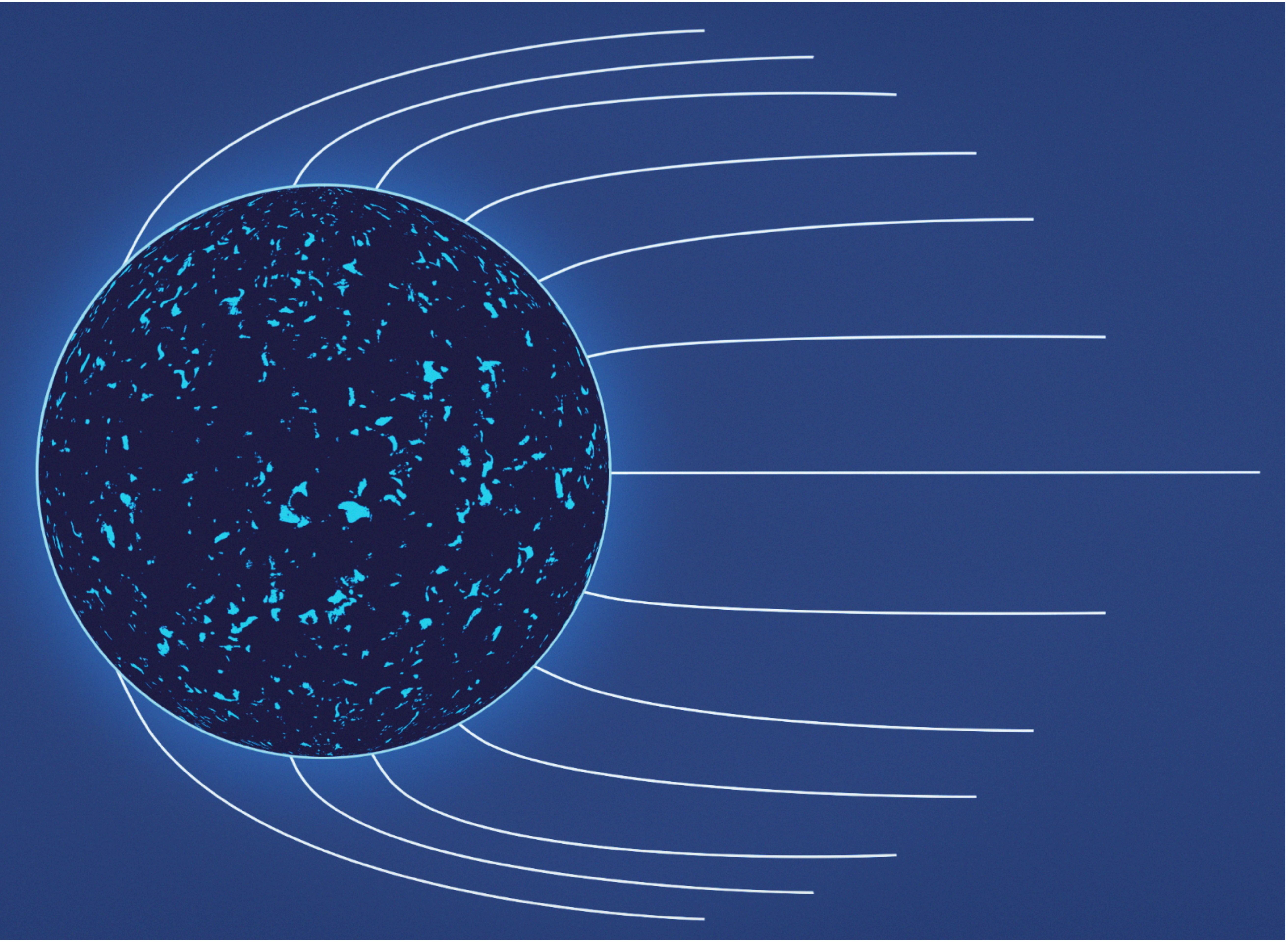
$$\frac{r_g}{R} = \frac{1}{3} \qquad F = \mu(i, \theta, \phi)(1 - \frac{r_g}{R}) + \frac{r_g}{R}$$



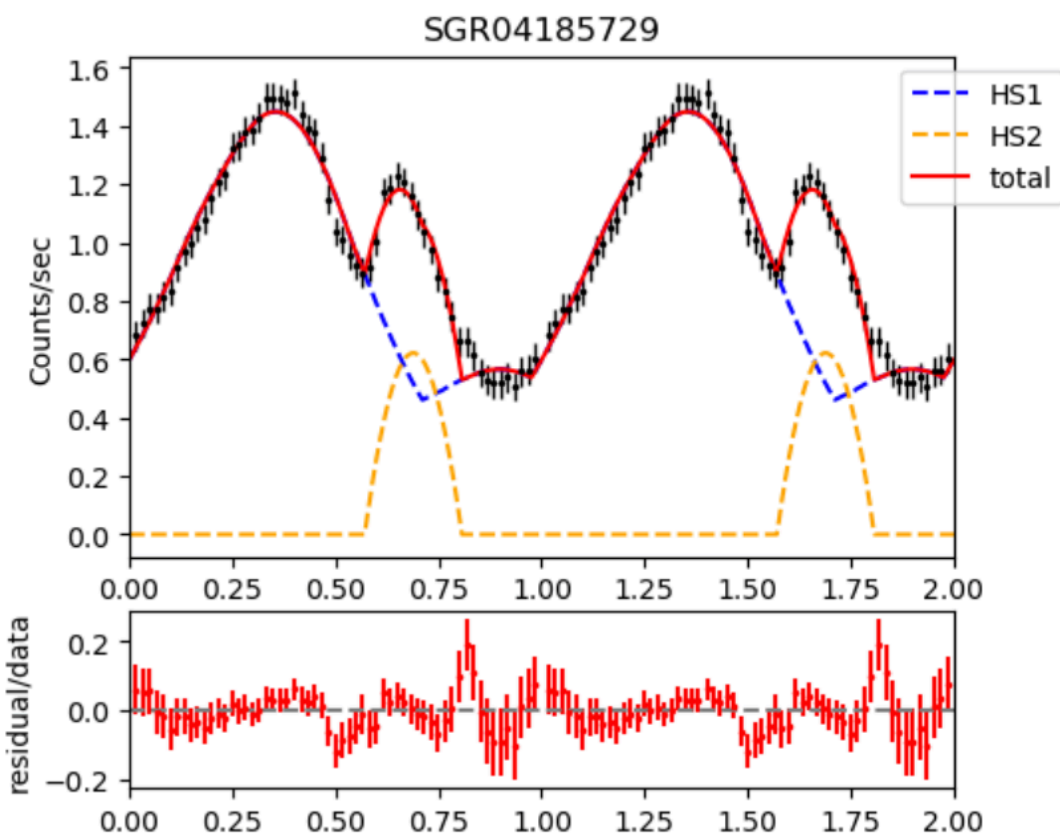


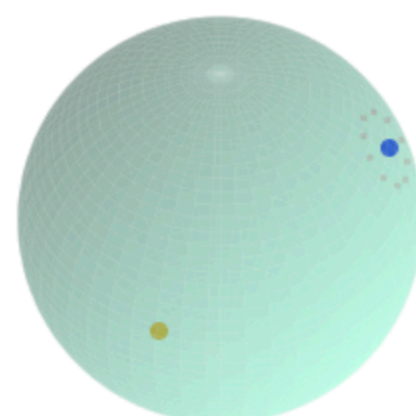


1833−08	904006010	$3.8^{+0.1}_{-0.1}$	17.6(4.5)	$7.9^{+0.3}_{-0.2}$	$35.6^{+9.3}_{-8.8}$	9.6(5)	1.08(4)	0.7	···	−0.38(40)	1.37 (167)



しかし…



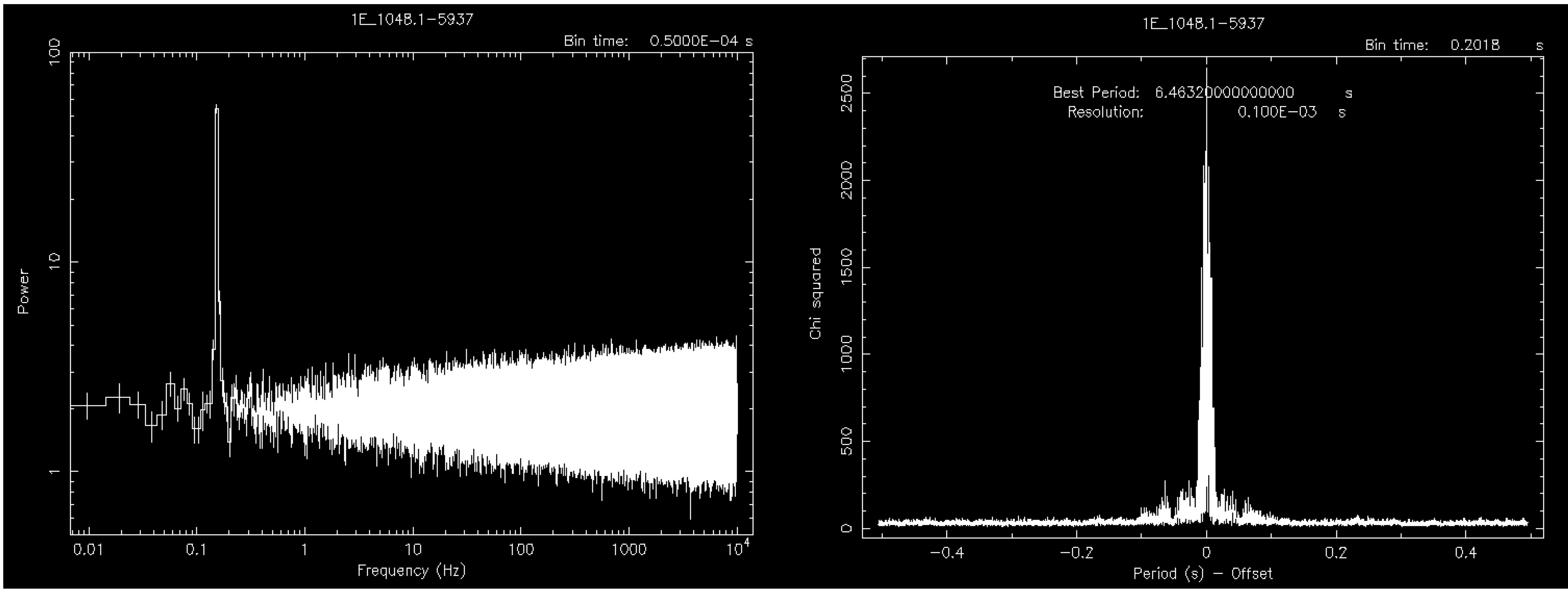


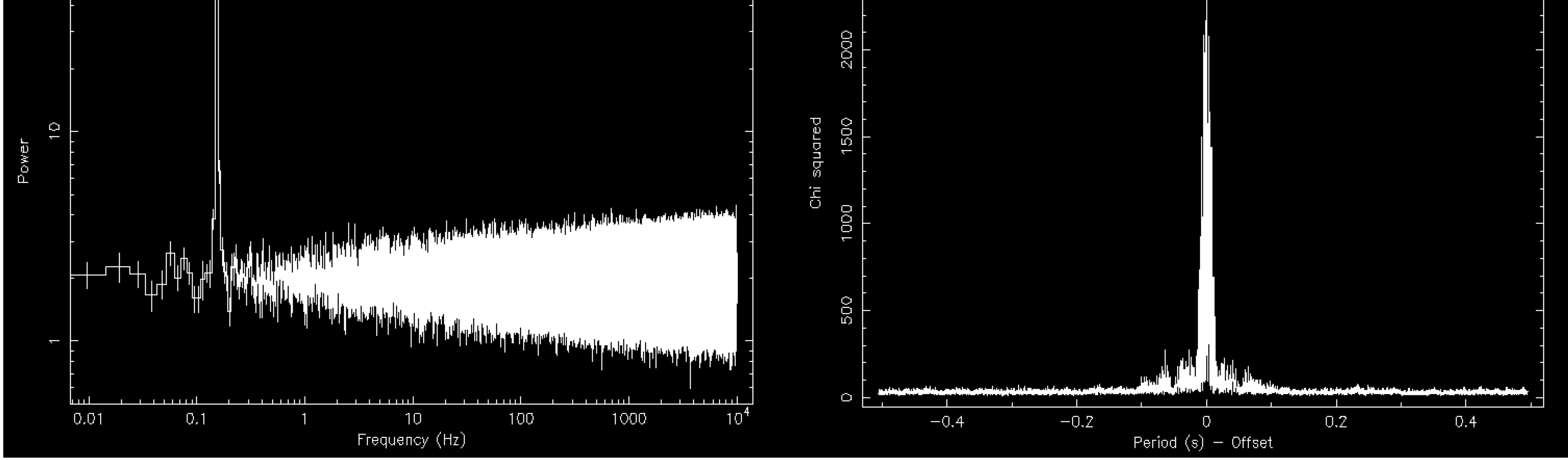
Local minimumとの

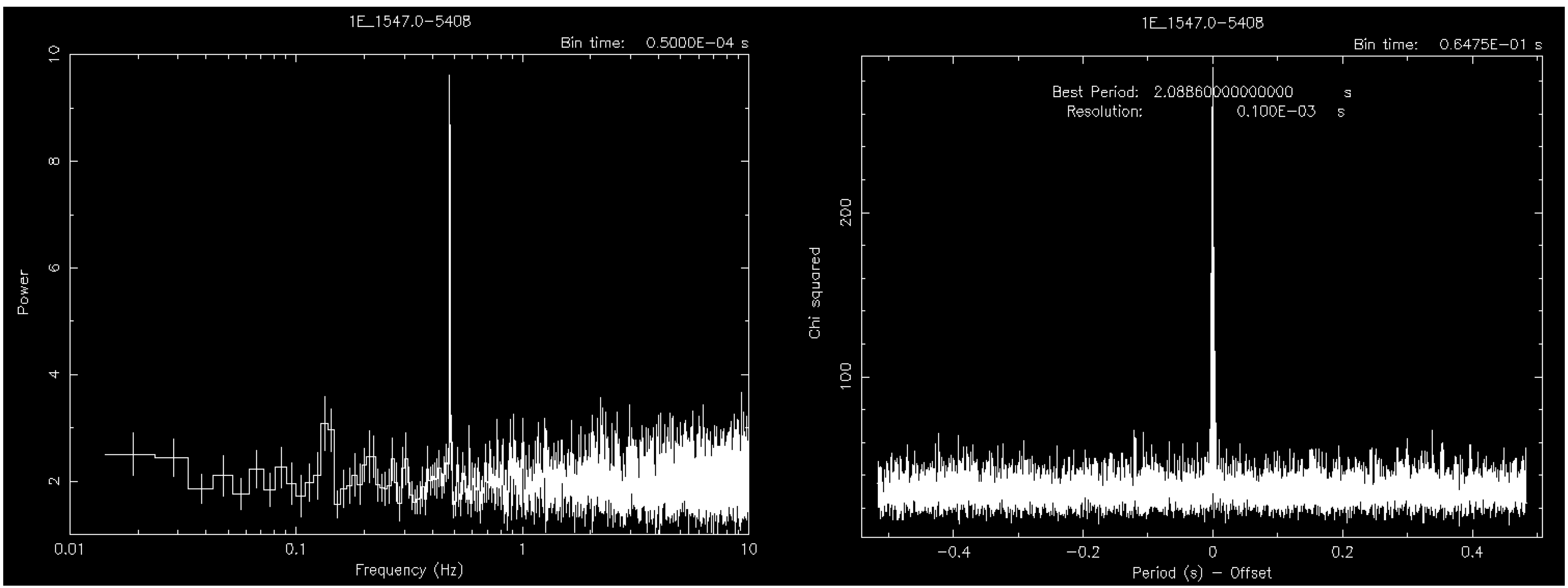
モデル関数の精

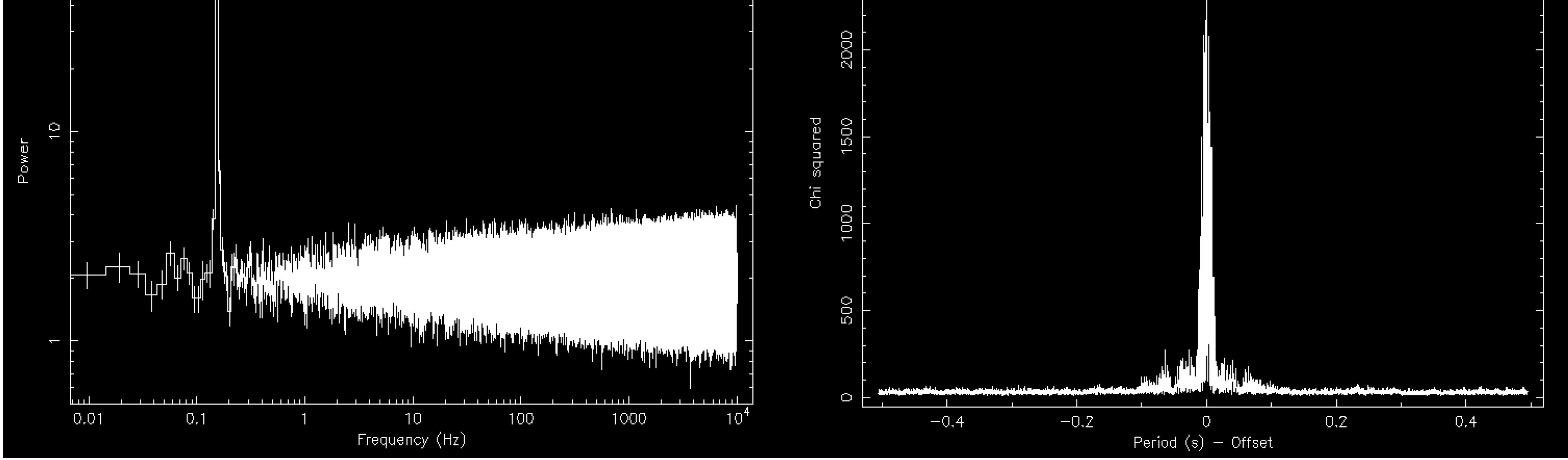
パラメータ縮

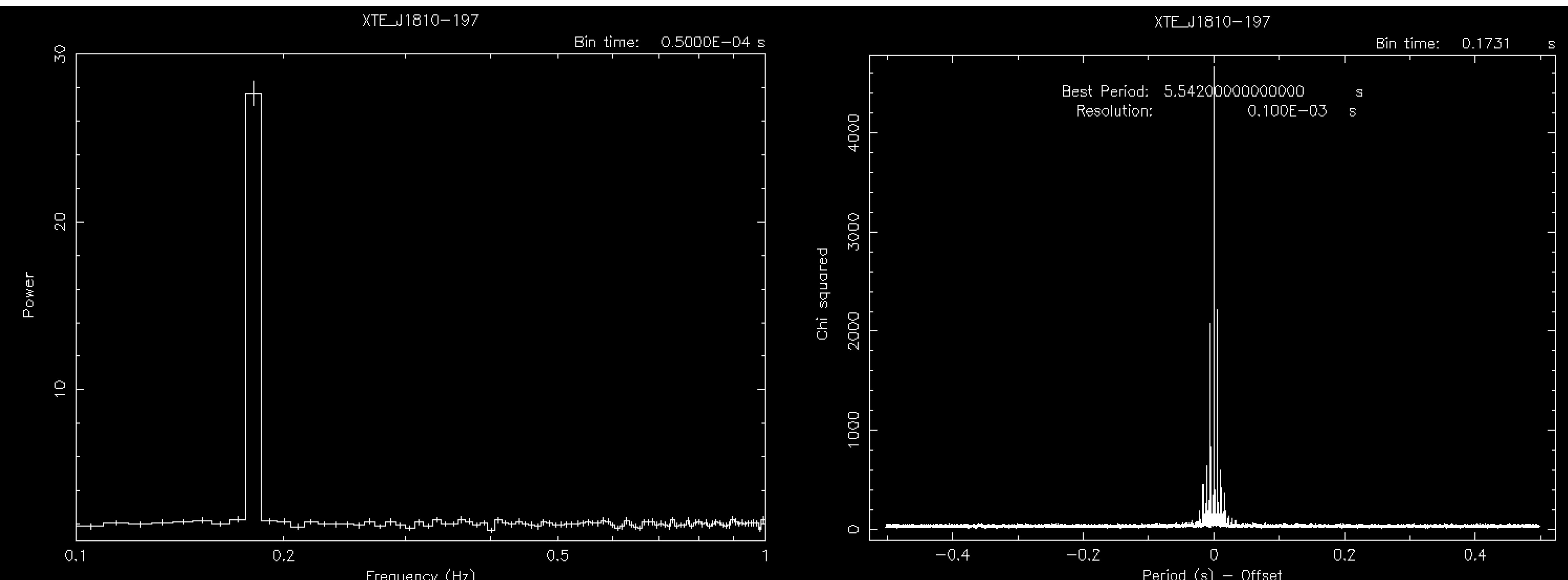
そもそもフィッティングは reliable なのか？

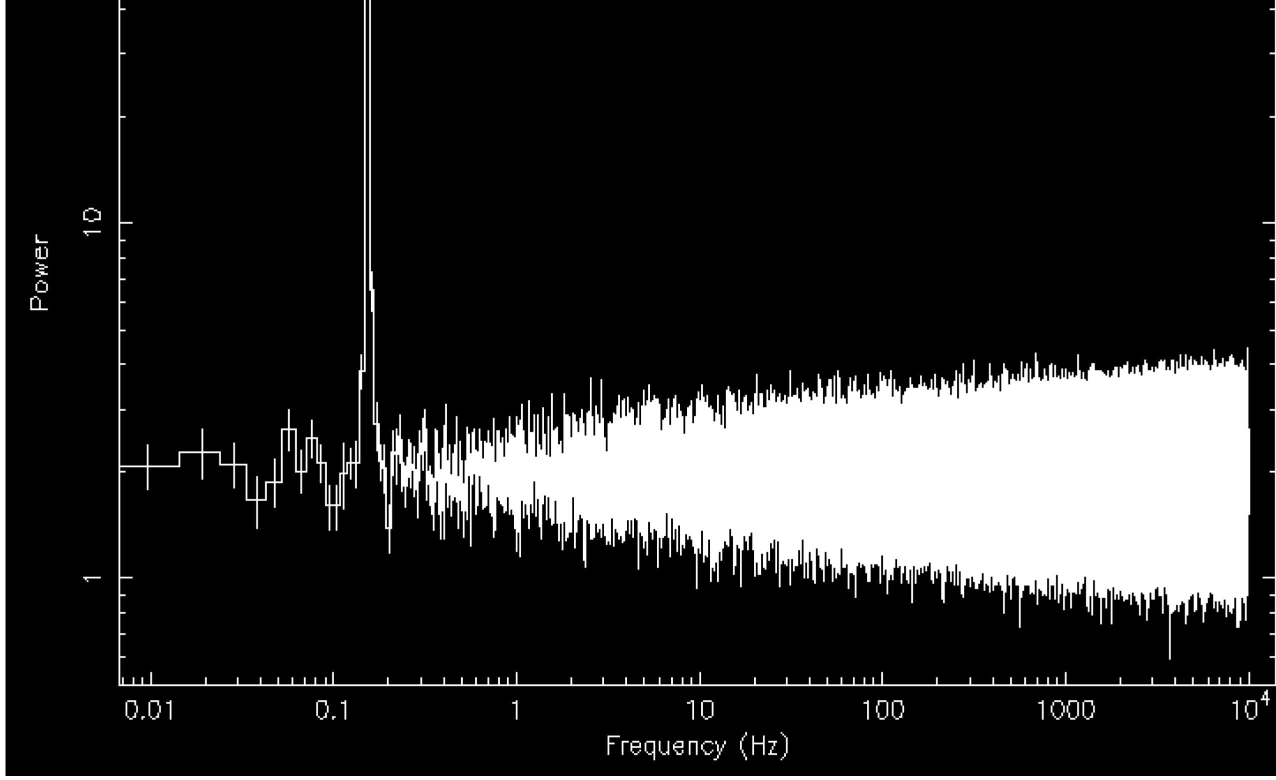

1E_1048.1-5937
Bin time: 0.5000E-04 s
Power
Frequency (Hz)
1E_1048.1-5937
Bin time: 0.2018 s
Best Period: 6.46320000000000 s
Resolution: 0.100E-03 s
Chi squared
Period (s) − Offset

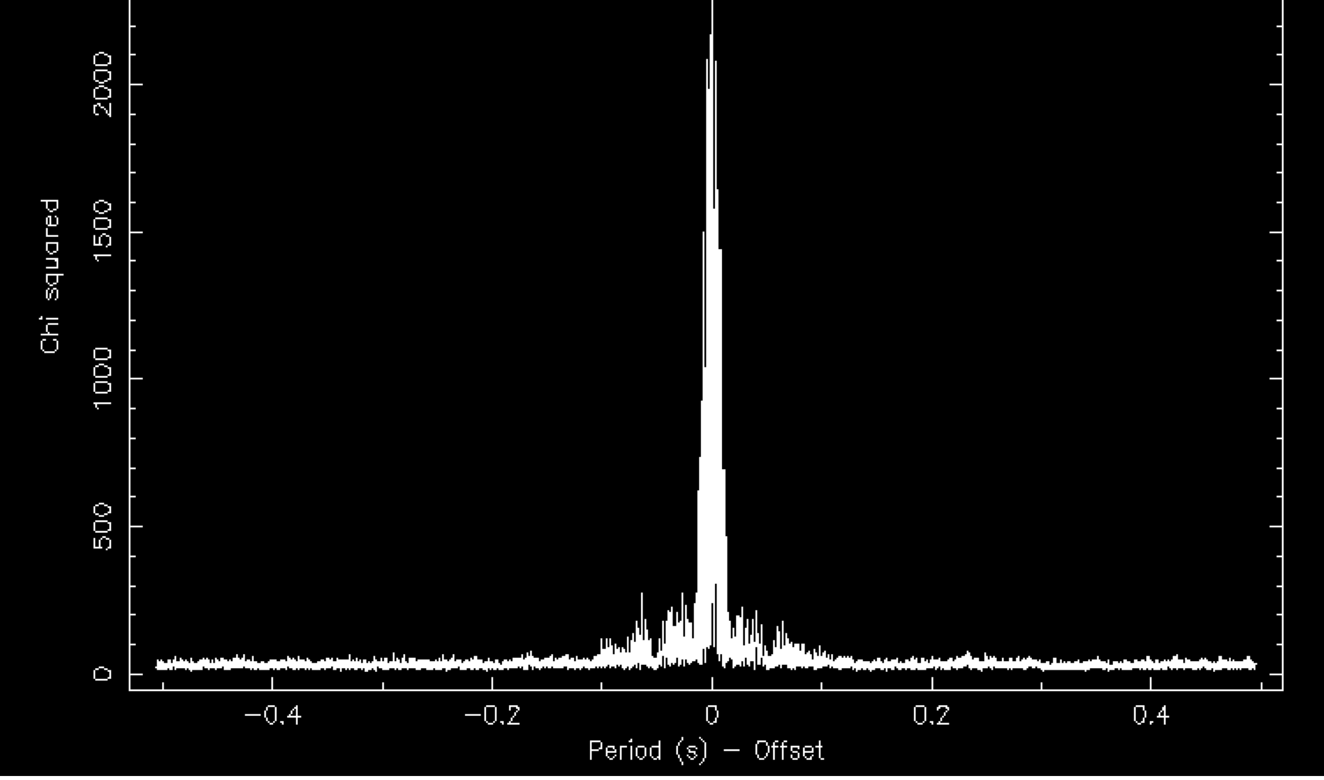

Power
Frequency (Hz)
0.01
0.1
1
10
100
1000
10^4
Chi squared
Period (s) − Offset
0
500
1000
1500
2000
−0.4
−0.2
0.2
0.4

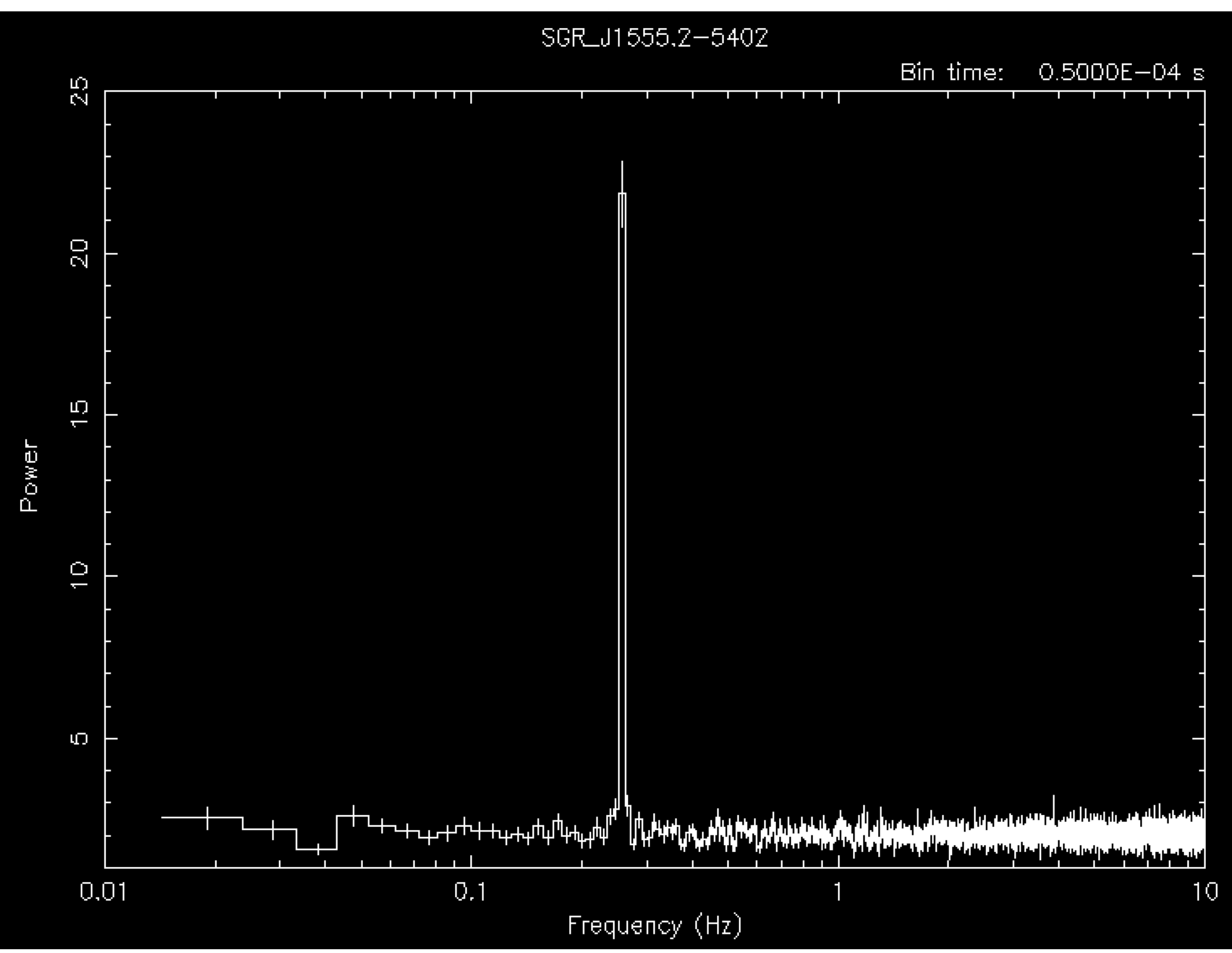

1E_1547.0-5408
Bin time: 0.5000E−04 s
Power
Frequency (Hz)
2
4
6
8
10
0.01
0.1
1
1E_1547.0-5408
Bin time: 0.6475E−01 s
Best Period: 2.08860000000000 s
Resolution: 0.100E−03 s
Chi squared
100
200
Period (s) − Offset
−0.4
−0.2
0
0.2
0.4

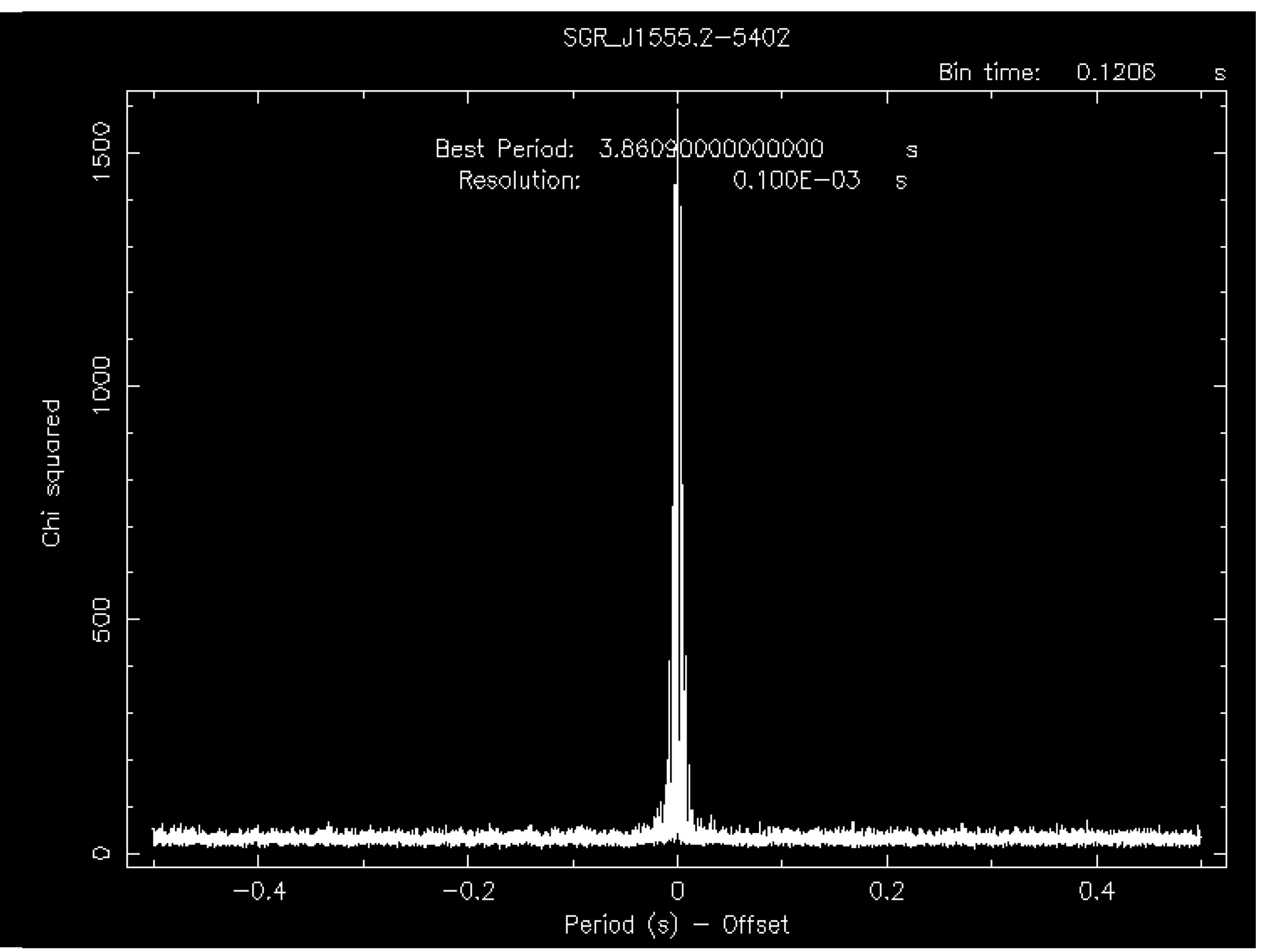

Power
Frequency (Hz)
Chi squared
Period (s) − Offset


XTE_J1810−197
Bin time: 0.5000E−04 s
Power
Frequency (Hz)
XTE_J1810−197
Bin time: 0.1731 s
Best Period: 5.54200000000000 s
Resolution: 0.100E−03 s
Chi squared
Period (s) − Offset


Power
10
1
0.01
0.1
1
10
100
1000
10^4
Frequency (Hz)


Chi squared
2000
1500
1000
500
0
−0.4
−0.2
0
0.2
0.4
Period (s) − Offset


SGR_J1555.2-5402
Bin time: 0.5000E−04 s
Power
25
20
15
10
5
0.01
0.1
1
10
Frequency (Hz)


SGR_J1555.2-5402
Bin time: 0.1206 s
Best Period: 3.86090000000000 s
Resolution: 0.100E−03 s
Chi squared
1500
1000
500
0
−0.4
−0.2
0
0.2
0.4
Period (s) − Offset