# GECAM
# 脉冲星监测与研究

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袁建平、仝号、闫林丽等

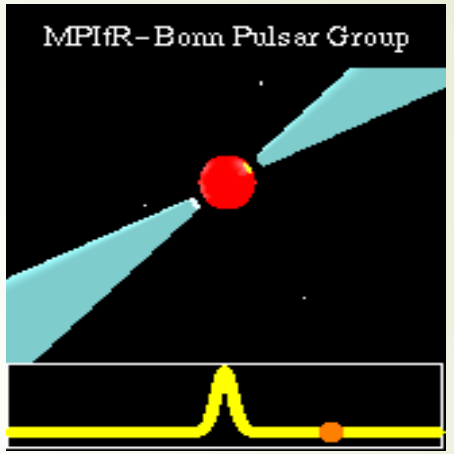
2020-10-31

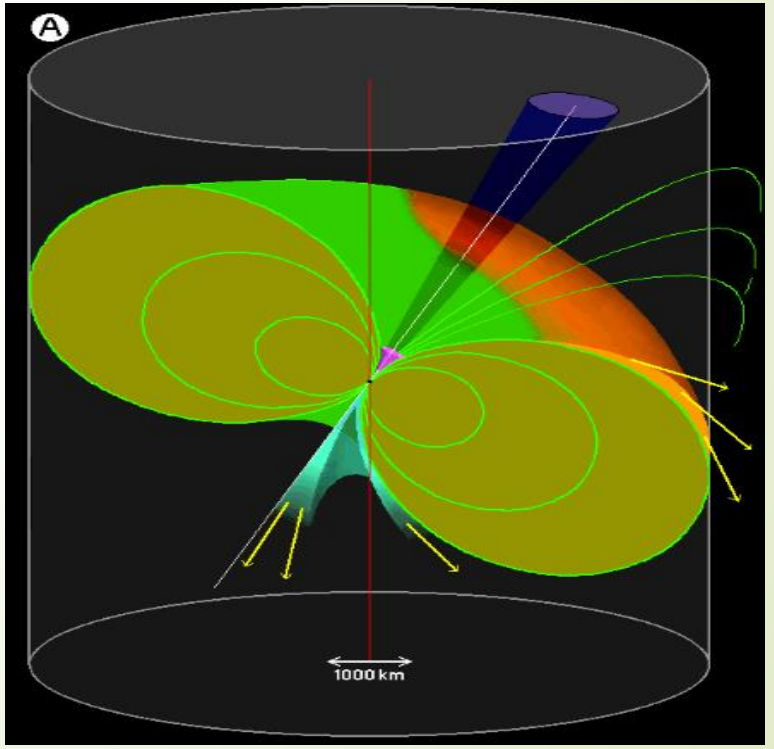
# 内容

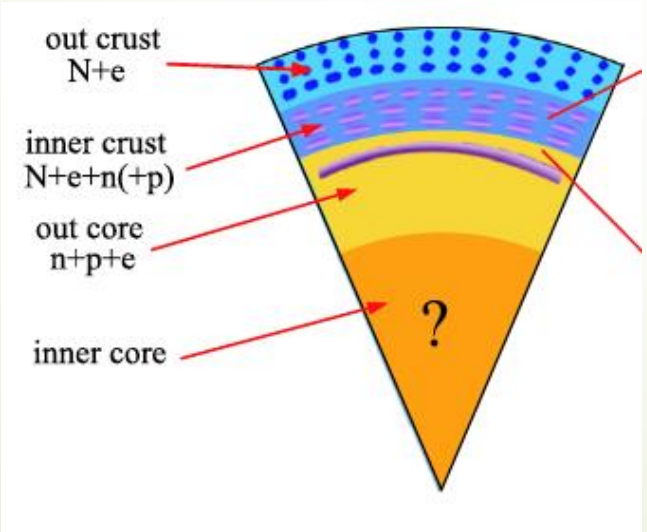
- 脉冲星
- 自转演化、周期跃变、状态改变
- MeV脉冲星搜索
- 数据处理流程
- 总结

# 脉冲星

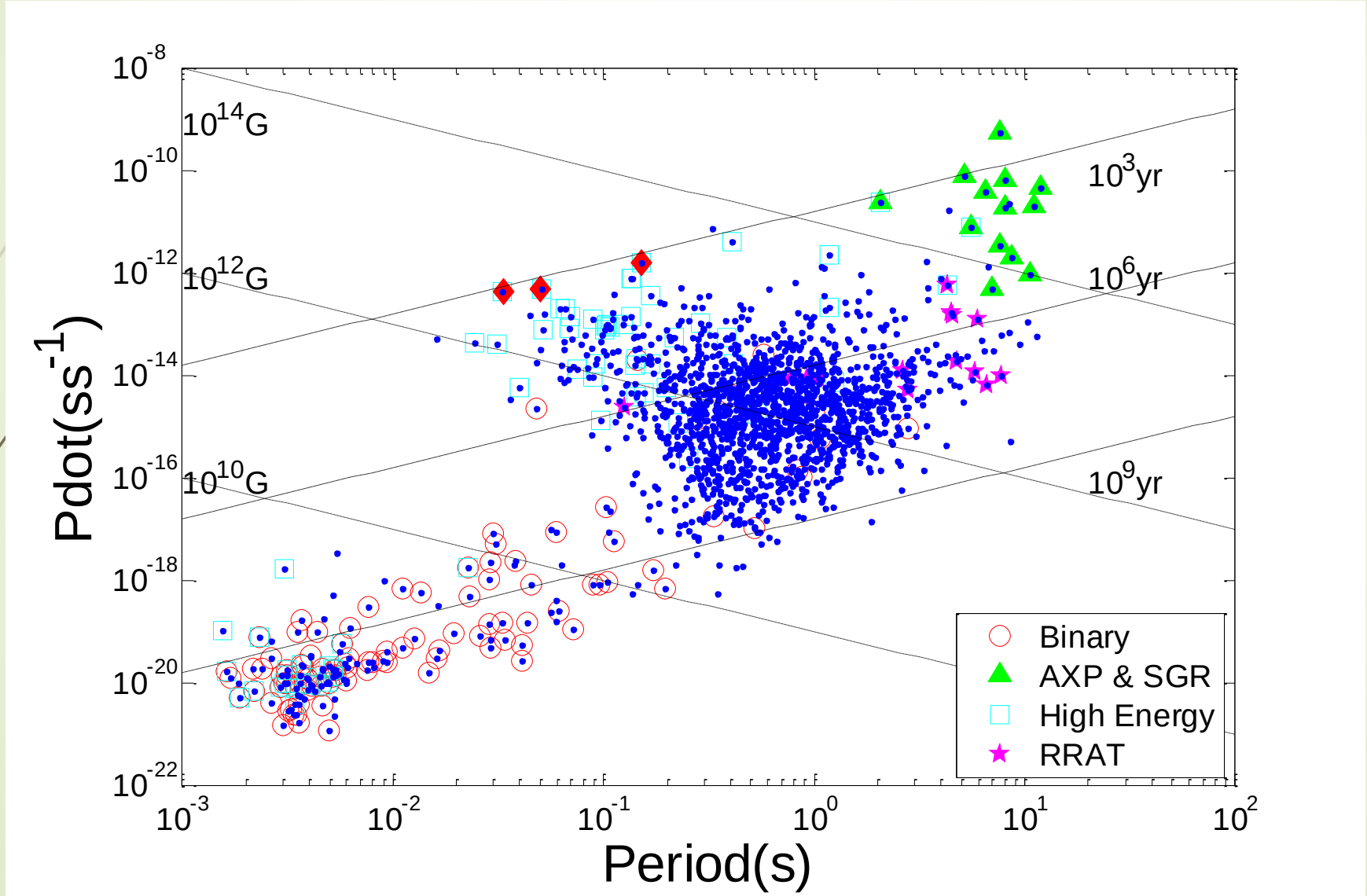
- 旋转的磁化中子星
- 辐射模型
  - Outer gap
  - Slot gap
  - Annular gap
  - …
- 中子星EOS



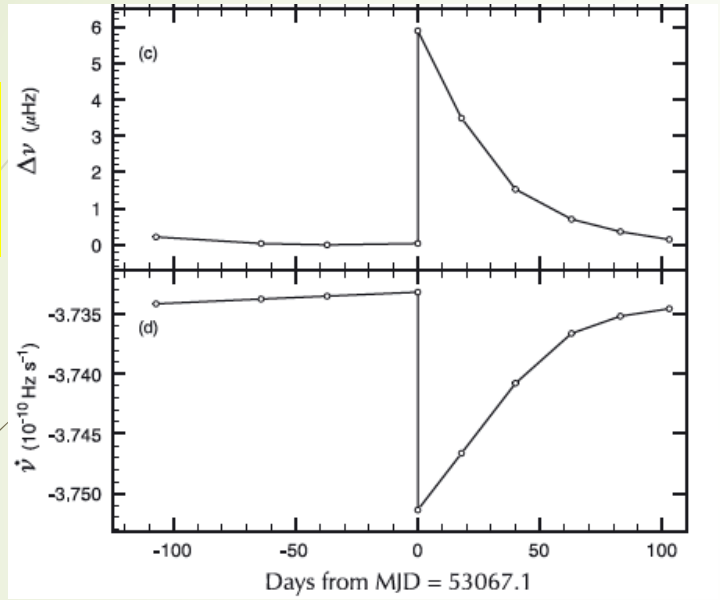



# 脉冲星


$10^{-8}$
$10^{-10}$
$10^{-12}$
$10^{-14}$
$10^{-16}$
$10^{-18}$
$10^{-20}$
$10^{-22}$
Pdot($ss^{-1}$)
$10^{14}$G
$10^{12}$G
$10^{10}$G
$10^{3}$yr
$10^{6}$yr
$10^{9}$yr
Binary
AXP & SGR
High Energy
RRAT
$10^{-3}$
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
$10^{2}$
Period(s)

# 周期跃变

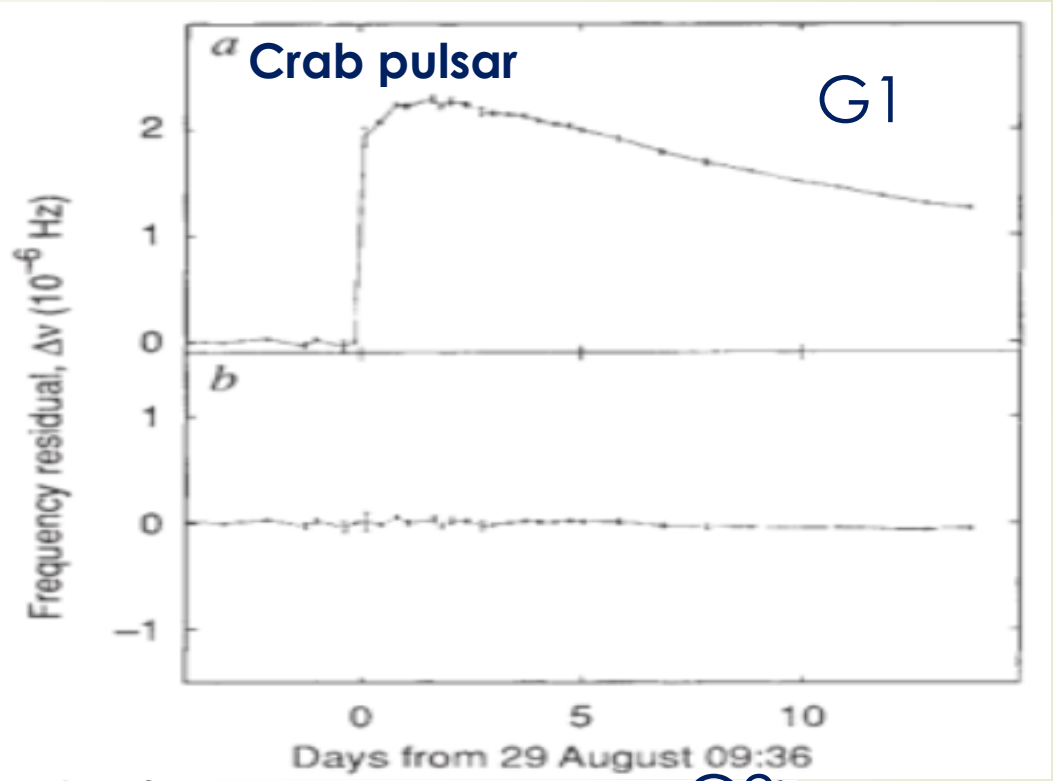
Typical glitches

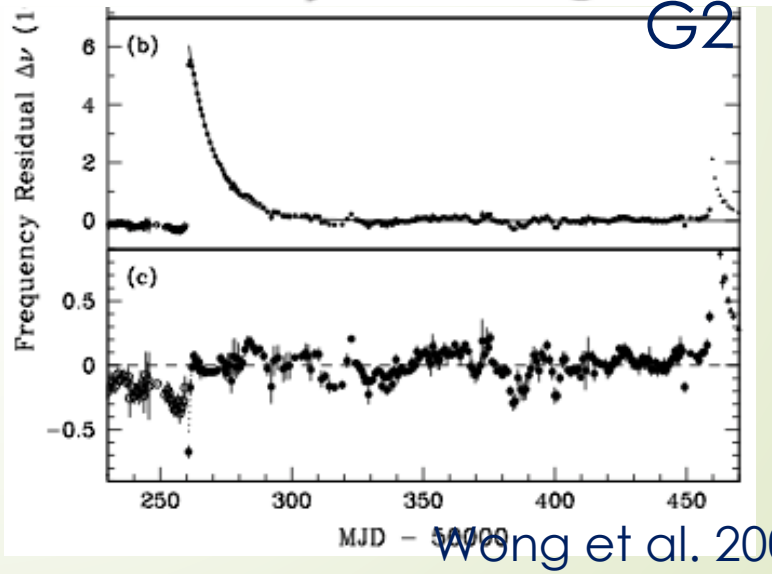



$$\Delta\nu = \Delta\nu_p + \Delta\dot{\nu}_p t + \frac{1}{2}\Delta\ddot{\nu}_p t^2 + \sum_n \Delta\nu_n e^{-t/\tau_n}$$

**Vela pulsar**: 4 components
None of them are spin-up processes
Dodson et al. 2002,564,85

Slow glitch/Anti-glitch



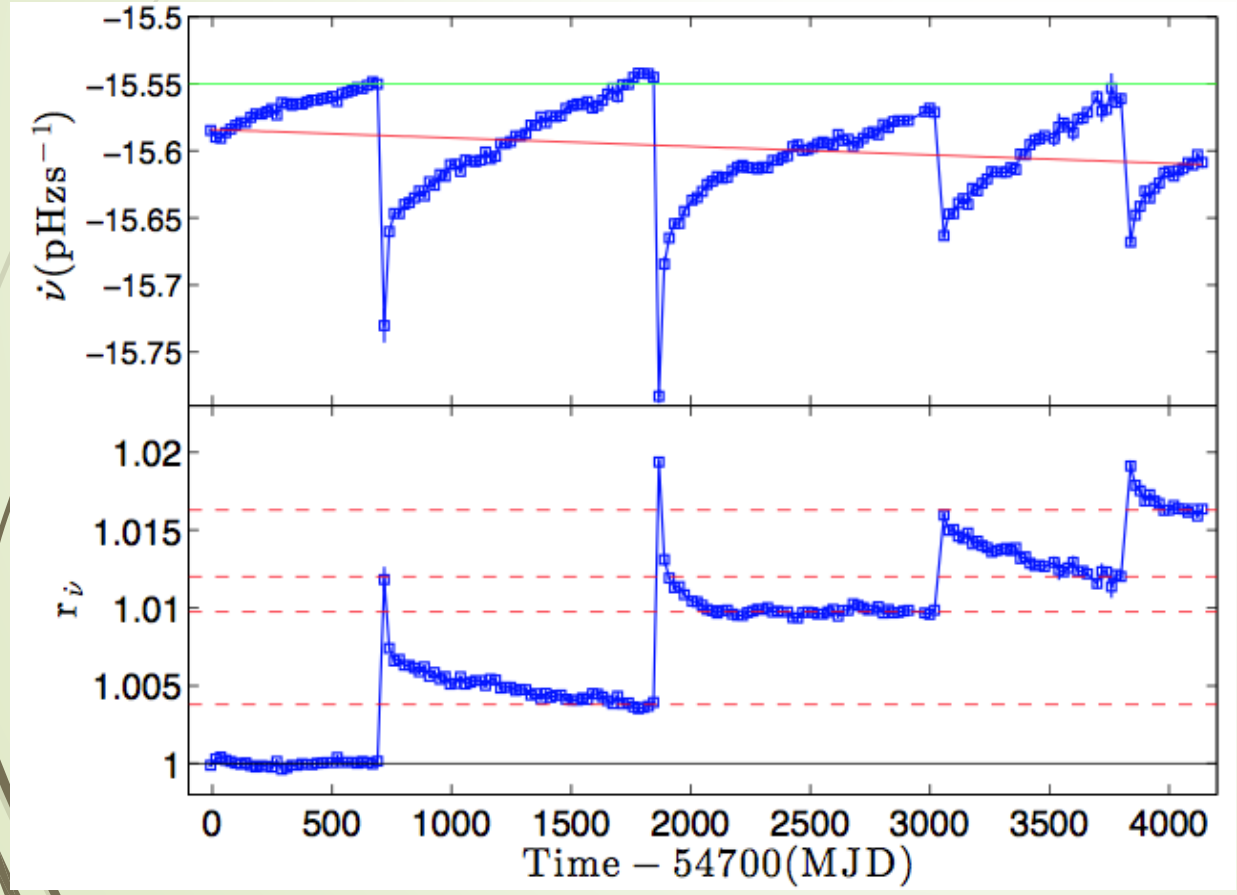



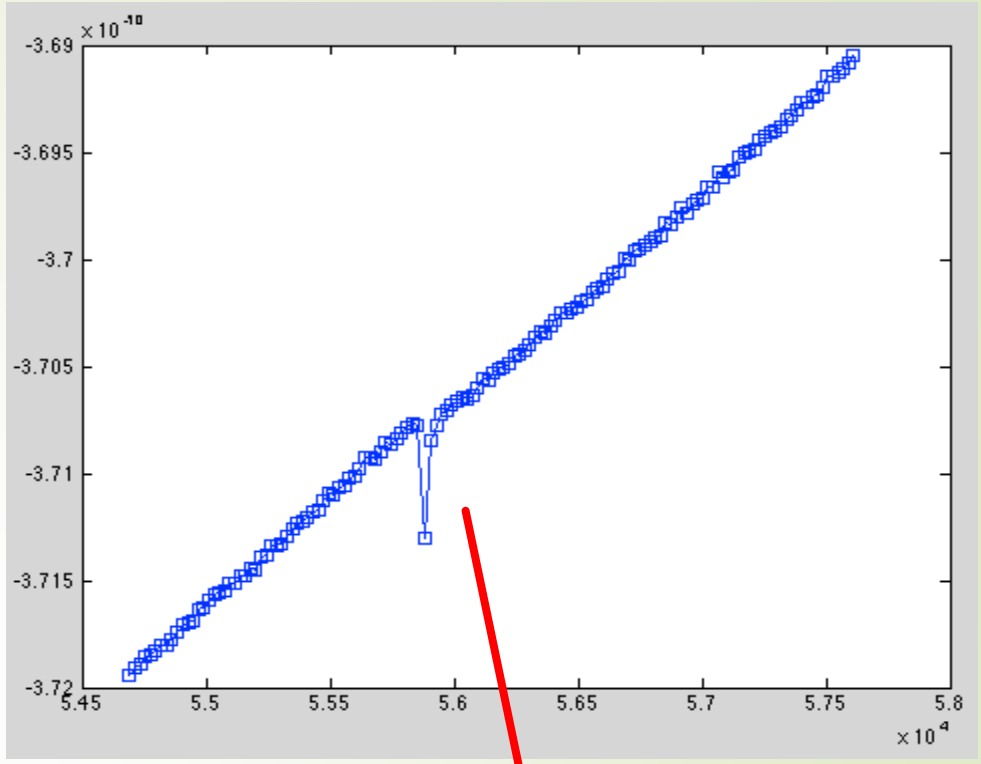

Lyne et al. 1992

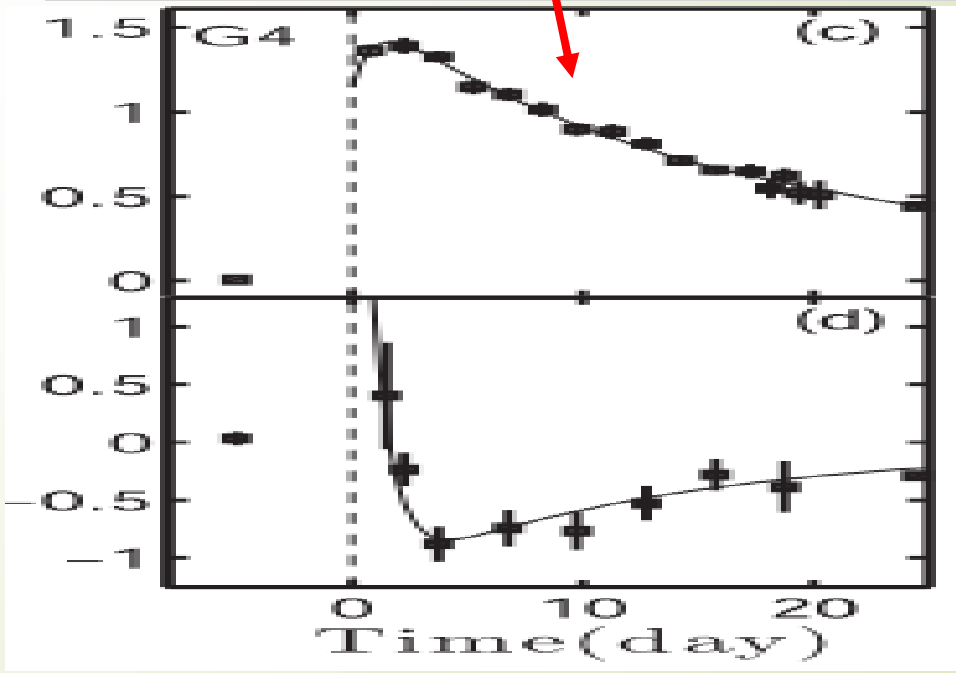
Wong et al. 2003

# 自转演化

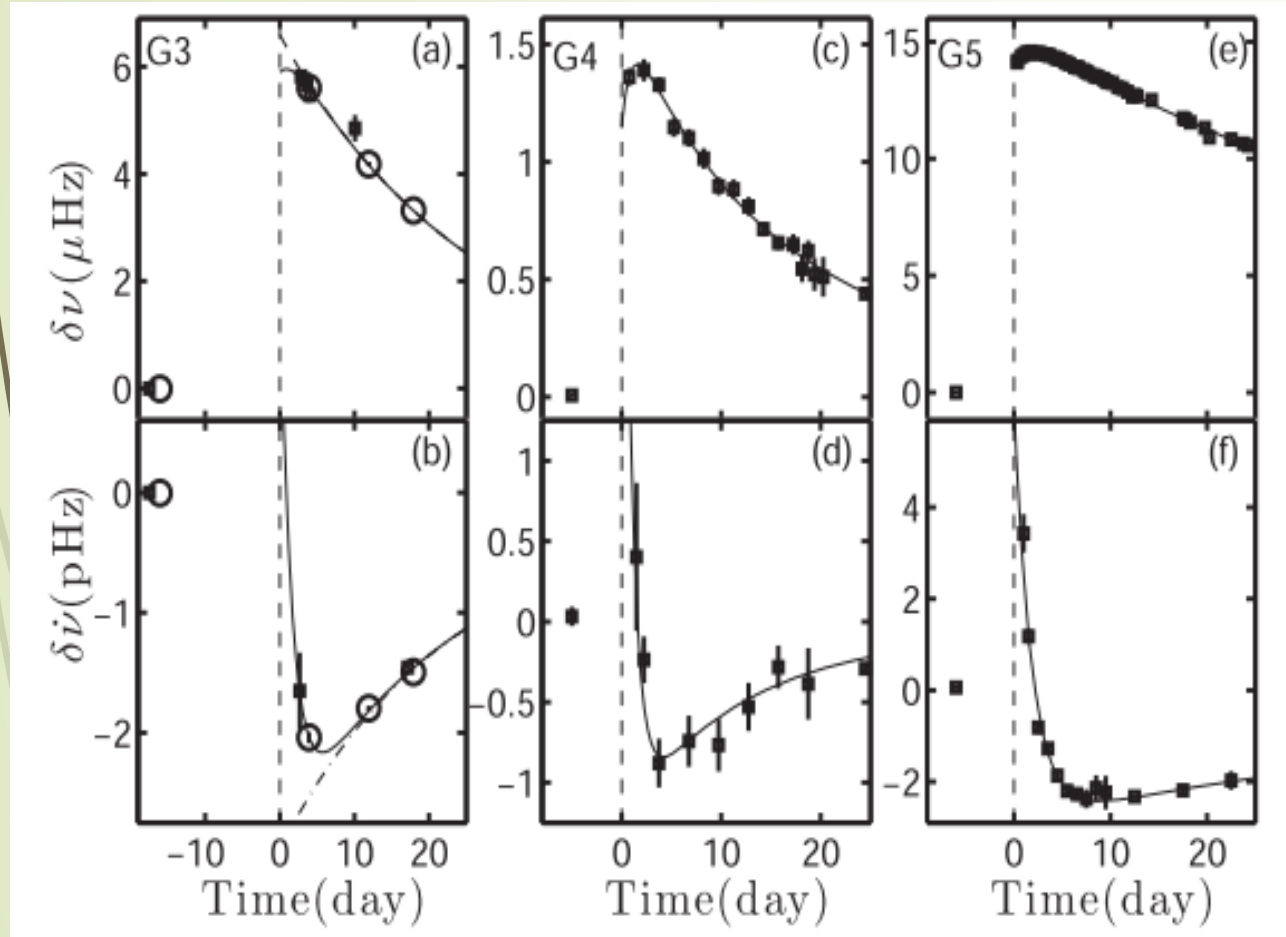
- 蟹状星云脉冲星

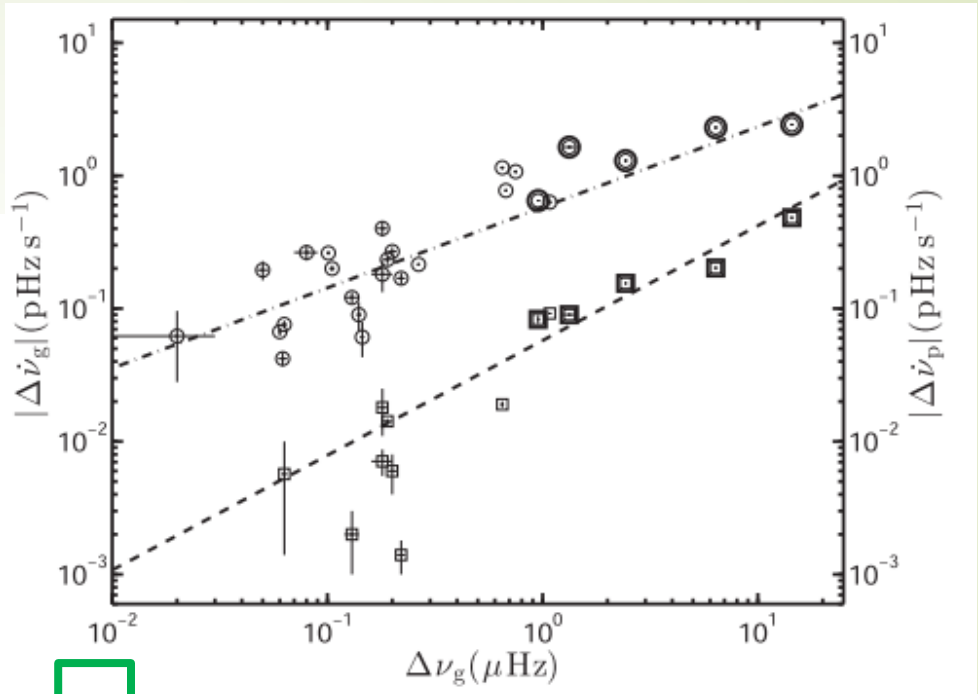


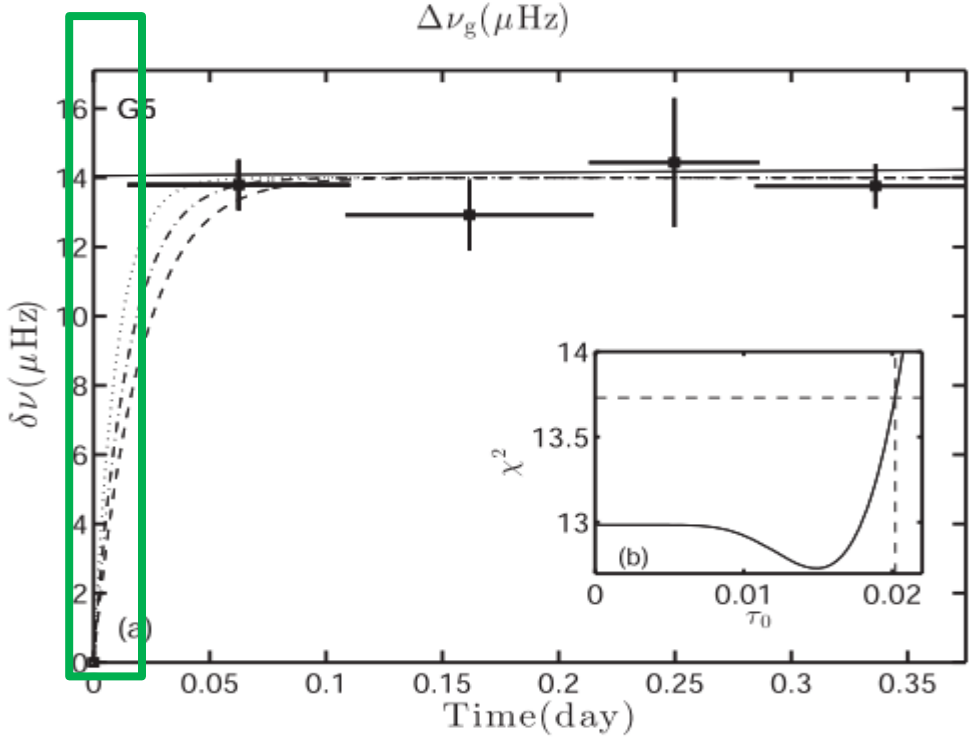



# 自转演化



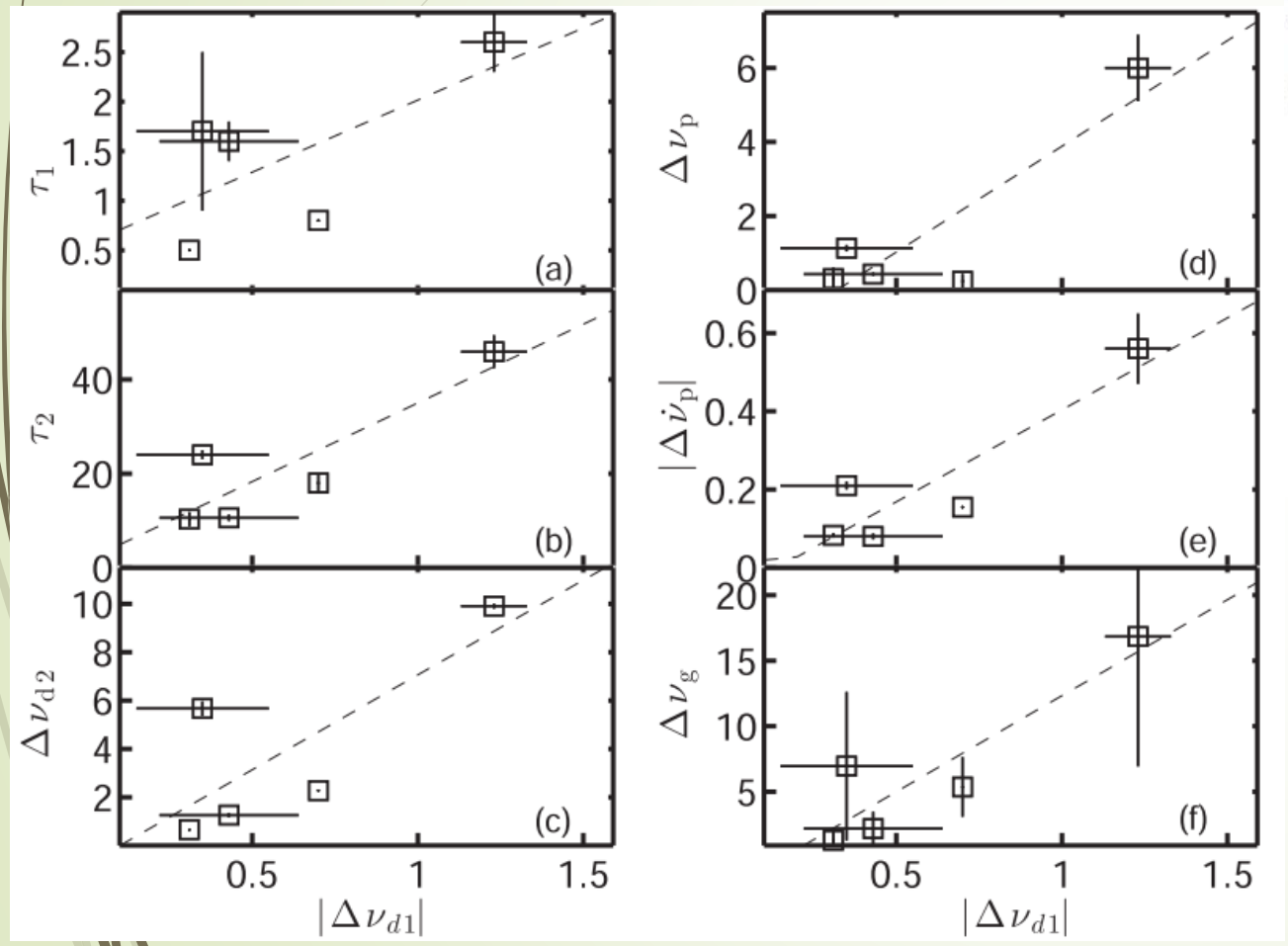



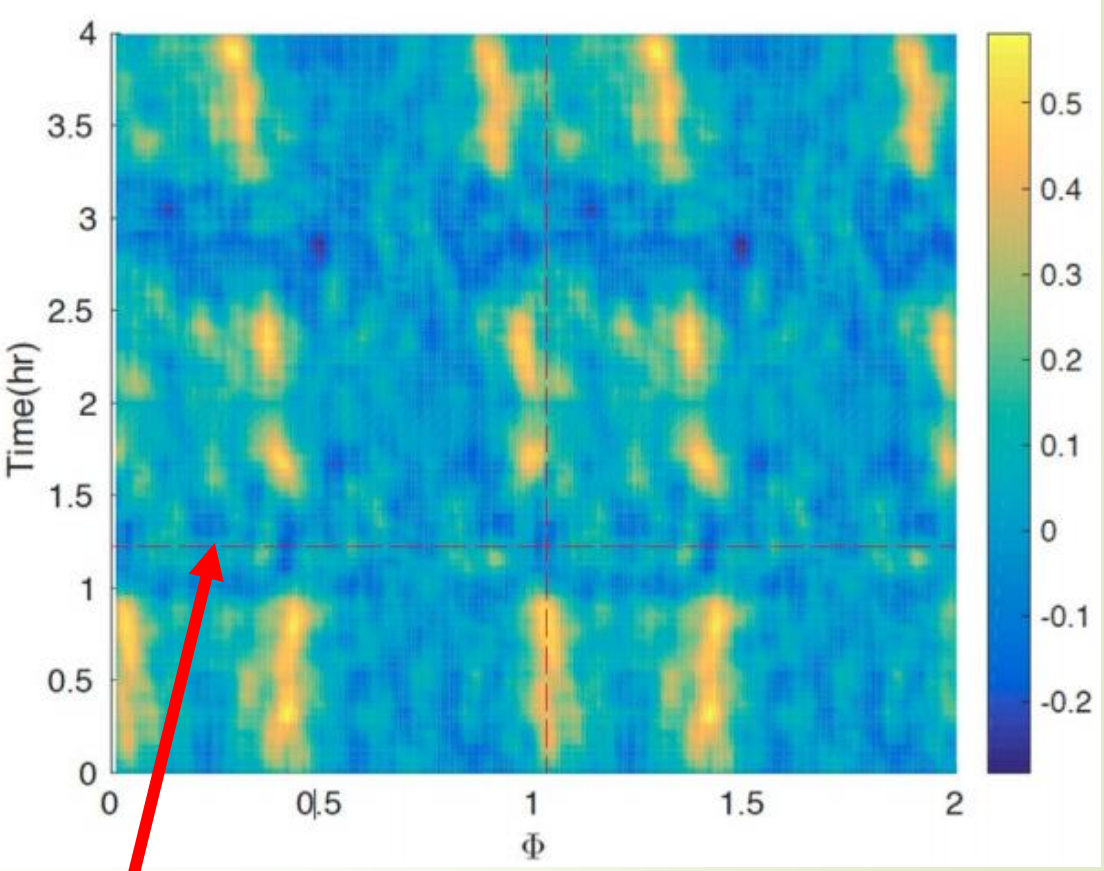

GBM

**Crab pulsar**
**Delayed spin-up process**

Lyne et al. 1992
Wong et al. 2001
Ge et al. 2020

# 自转演化



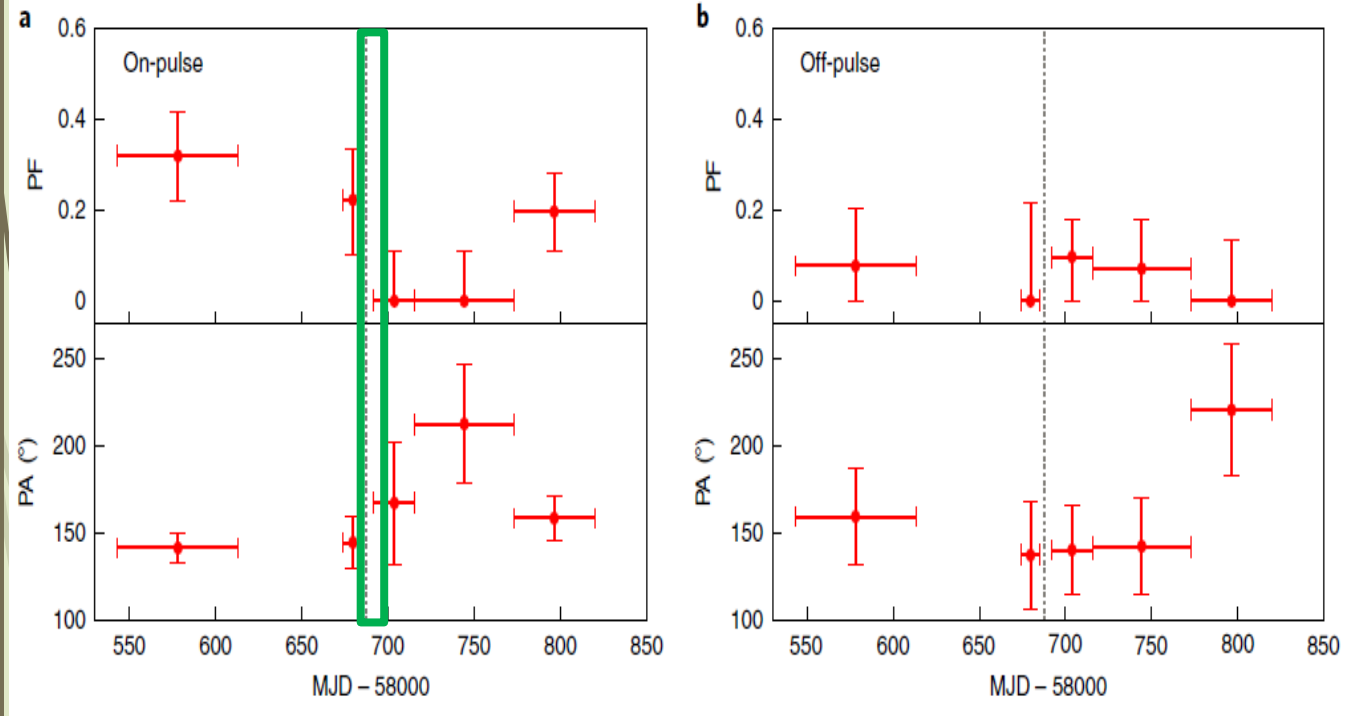



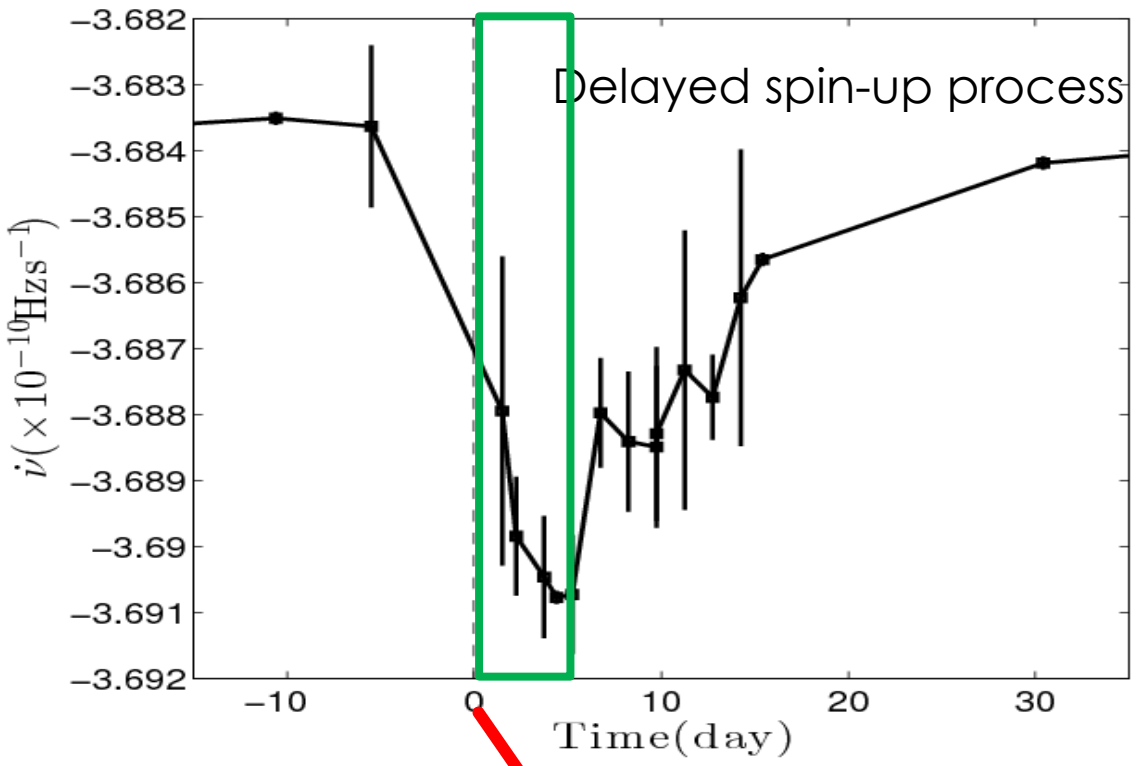

时标短

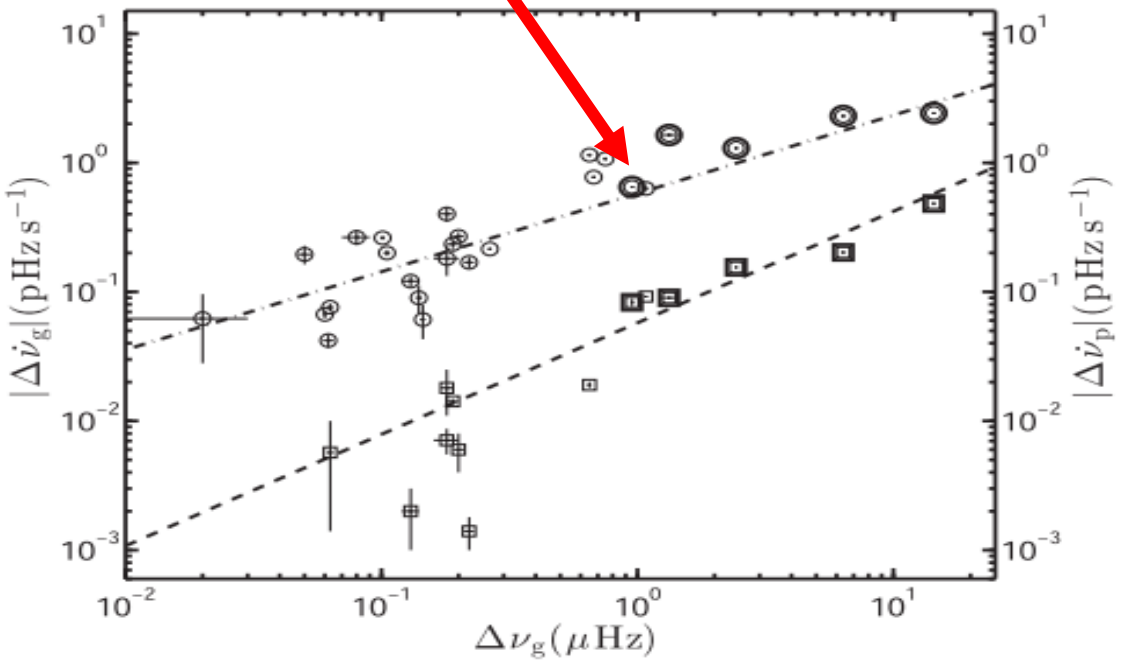
观测覆盖时间少

之前的Crab周期跃变时刻几乎处在GAP中

# 自转演化

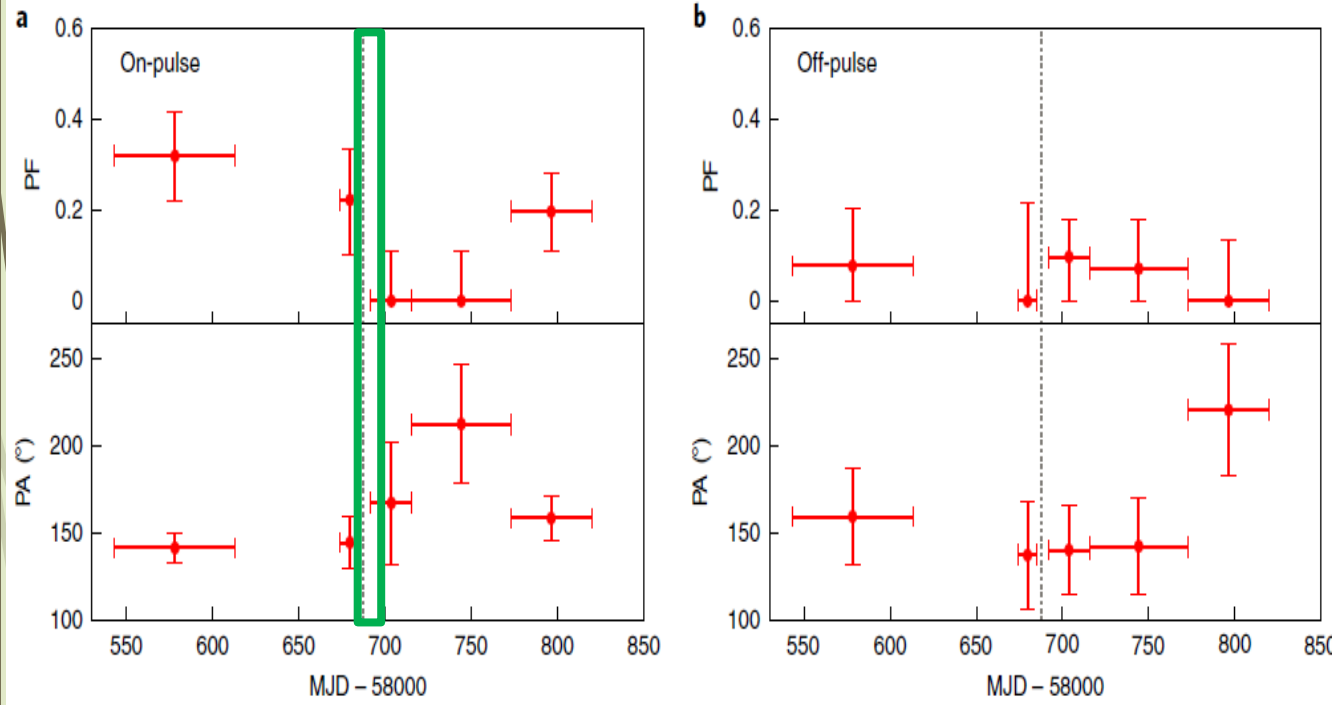


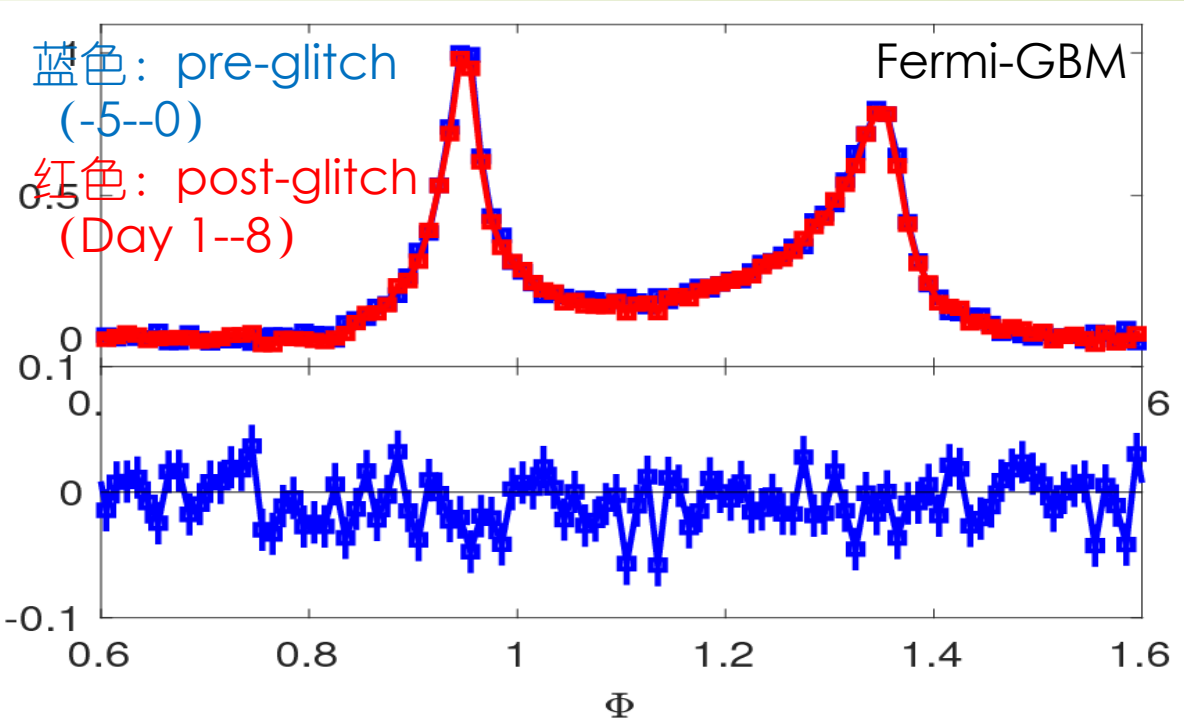



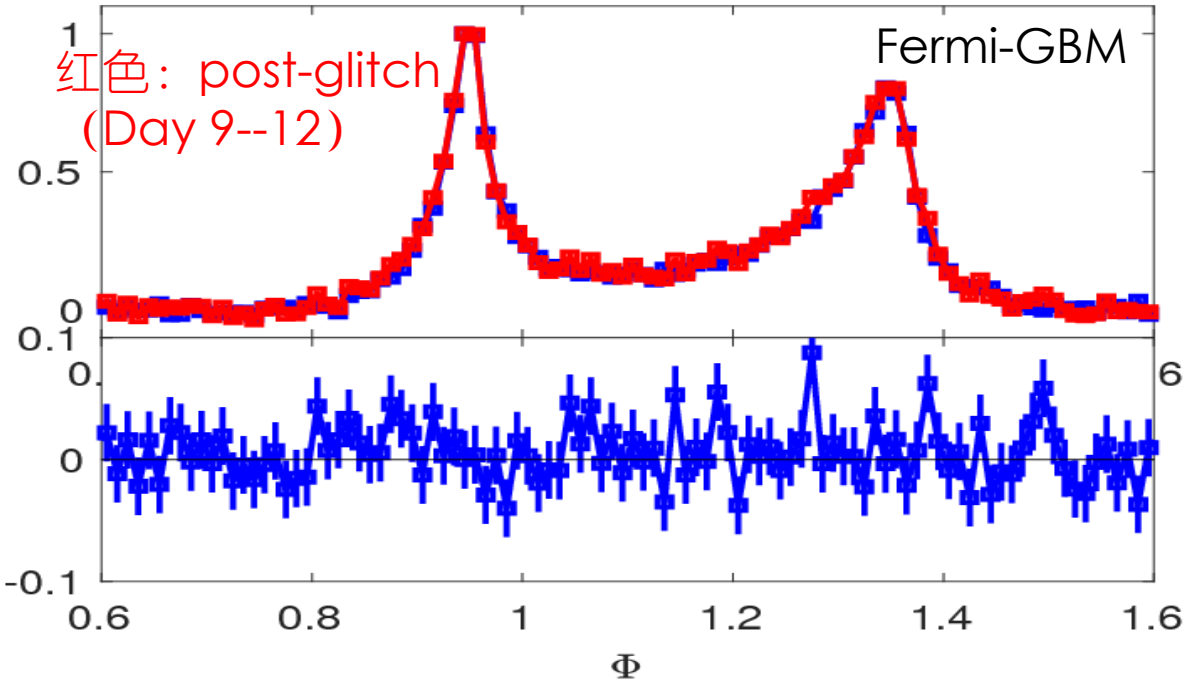




Glitch 2019 （58687.59），偏振演化
Feng et al. 2020

# 自转演化

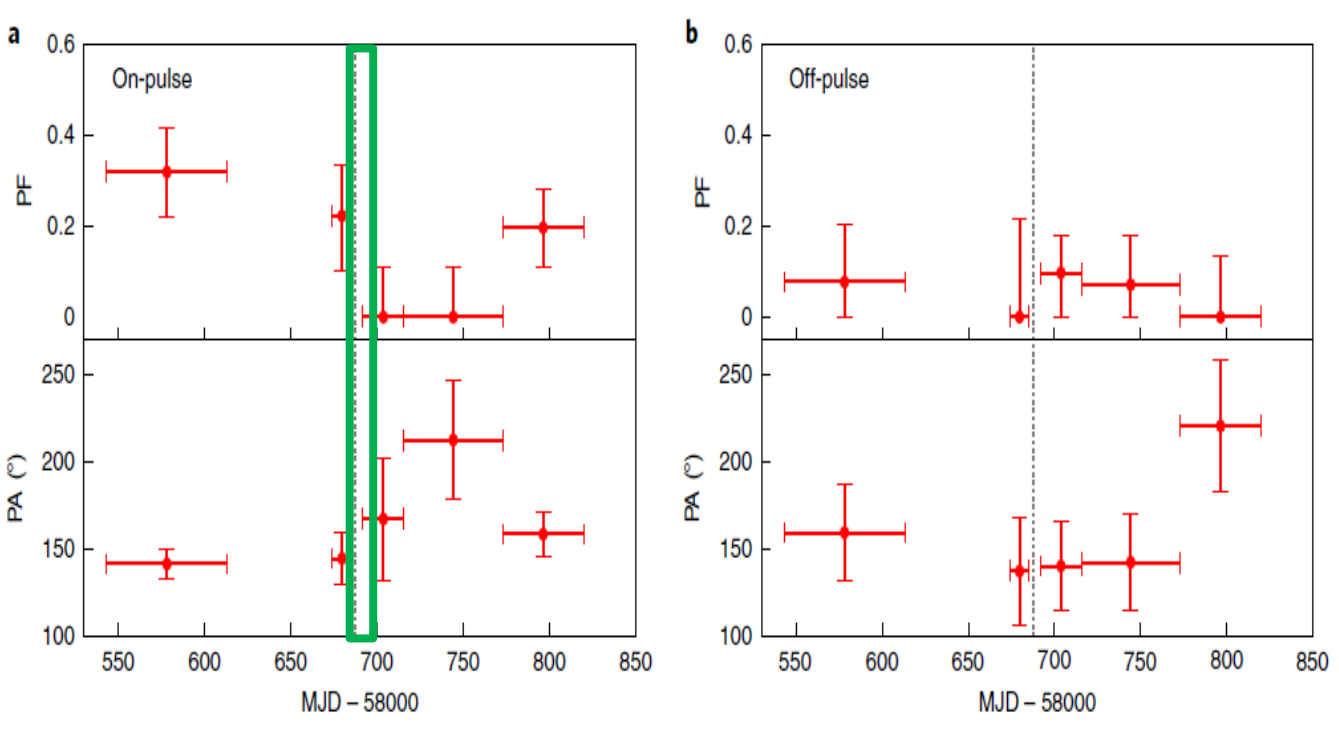


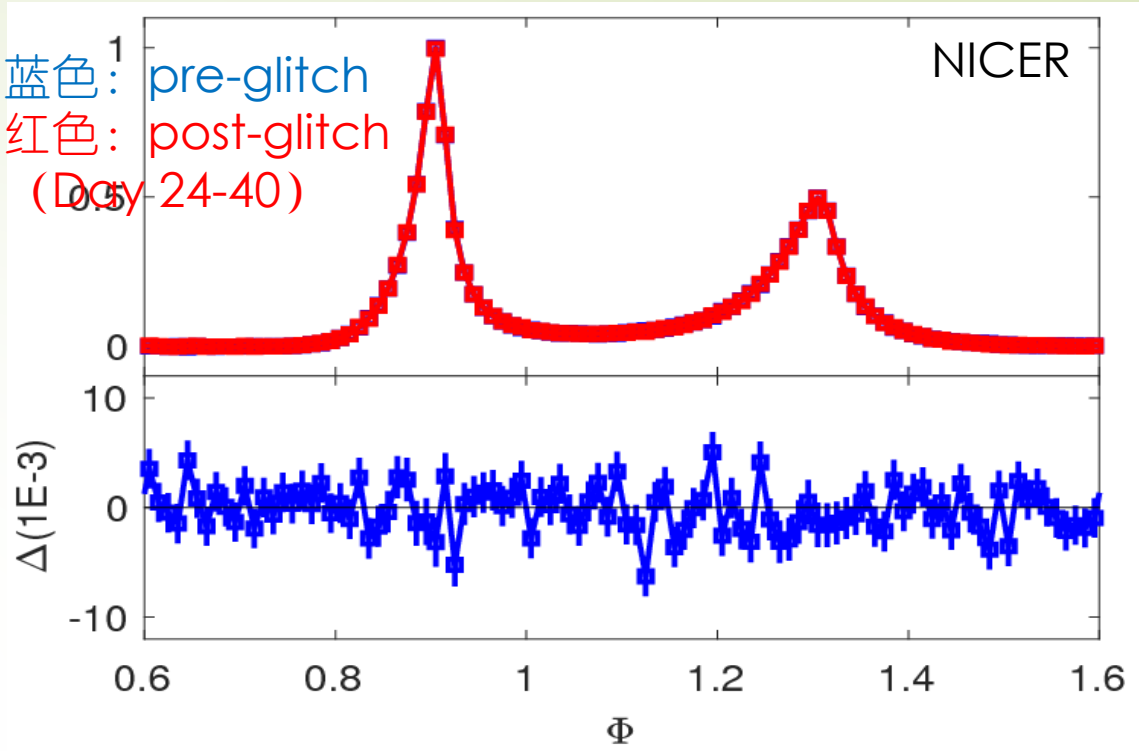



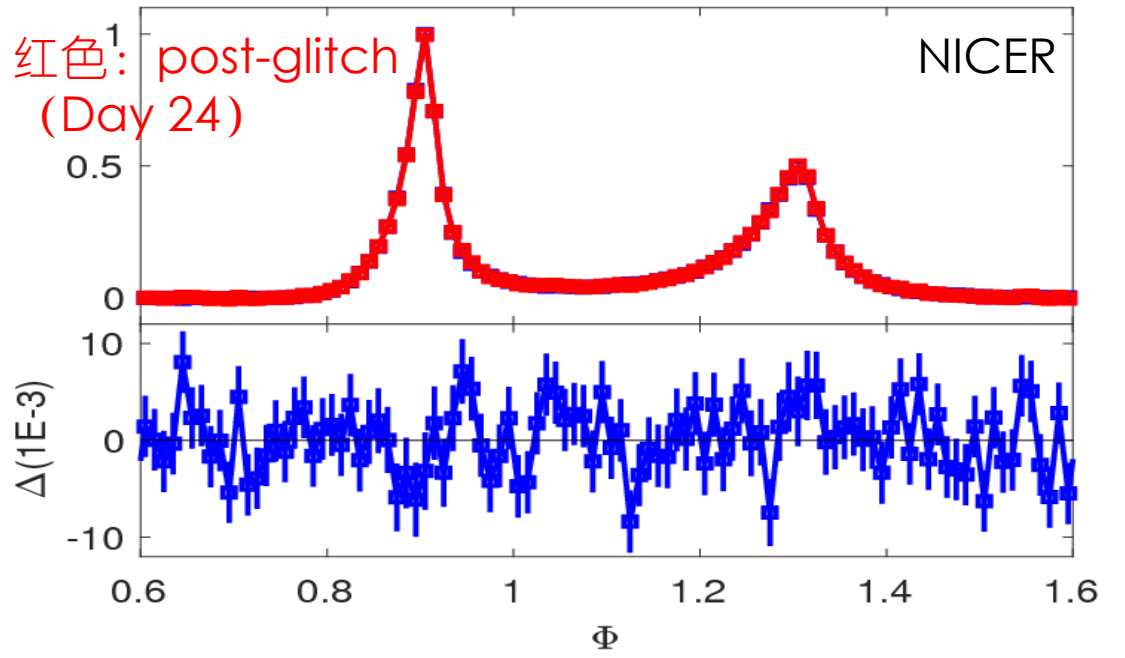




Glitch 2019 （58687.59），偏振测量
Feng et al. 2020
GBM脉冲轮廓：**无显著变化**

# 自转演化




Glitch 2019 （58687.59），偏振测量
Feng et al. 2020
NICER脉冲轮廓（1-6keV）：无显著变化

# Crab 巨脉冲 - 光学脉冲增亮

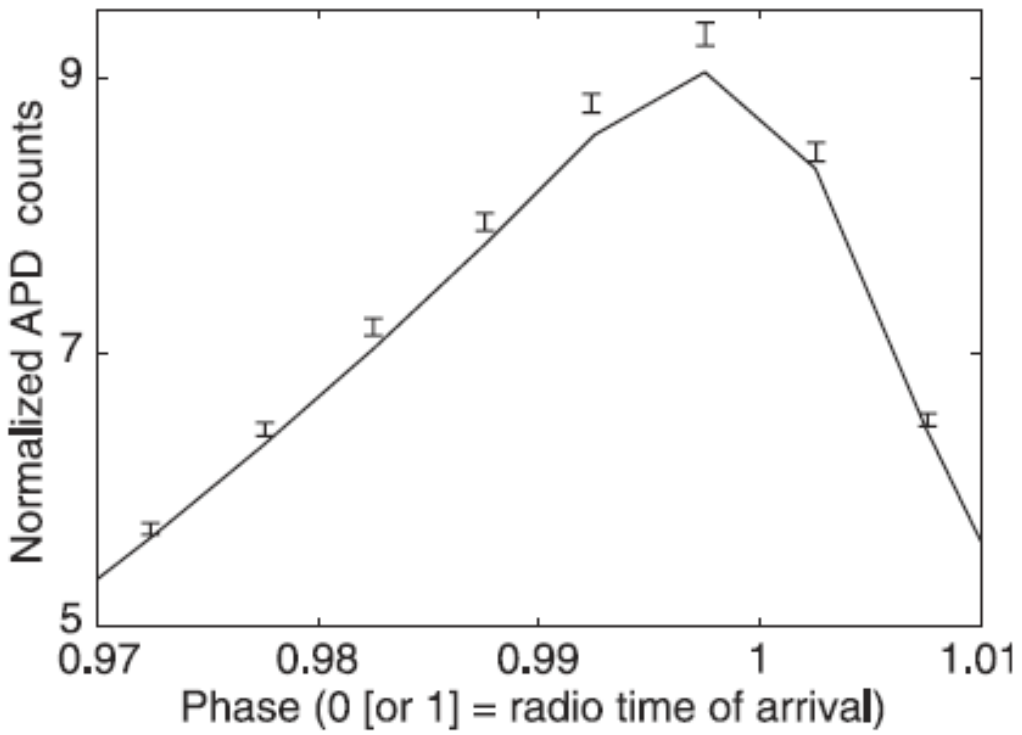
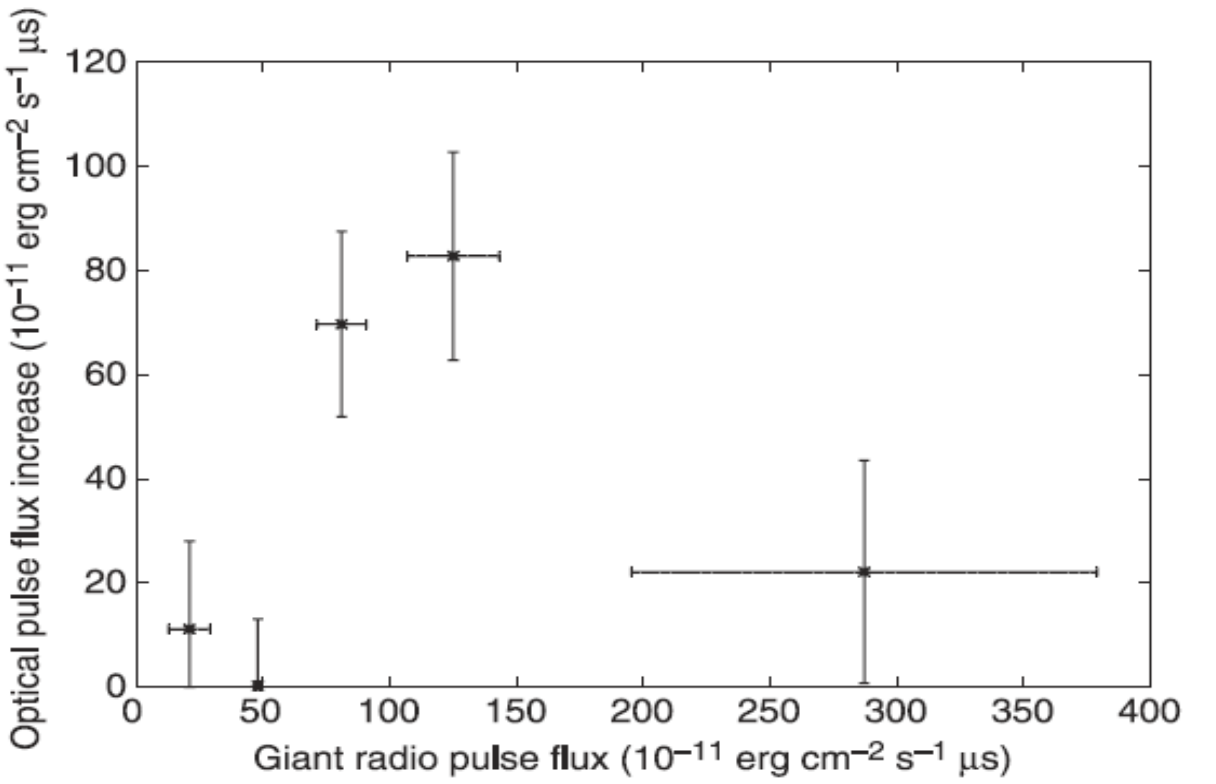



**Fig. 2.** The mean optical "giant" pulse superimposed (with its error bars) on the average optical pulse. The average pulse is determined from the 40 pulsar periods centered on the GRP, but not including it, from both nights of observation.

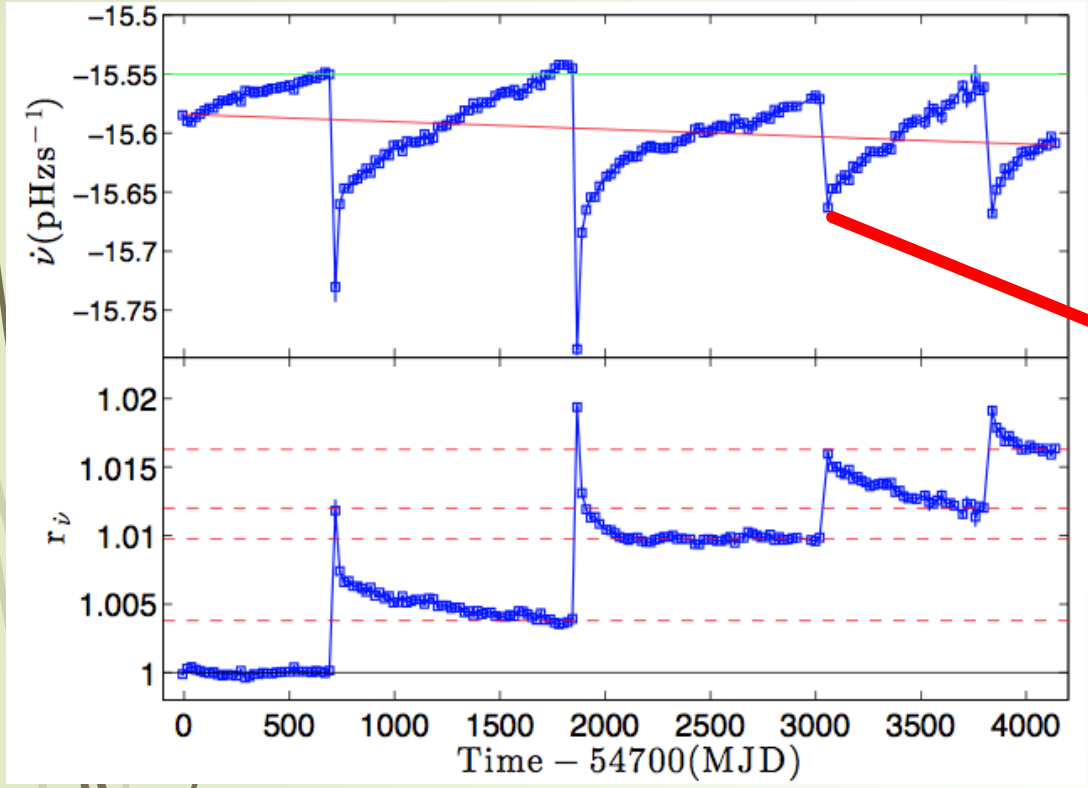
Shearer et al.2003

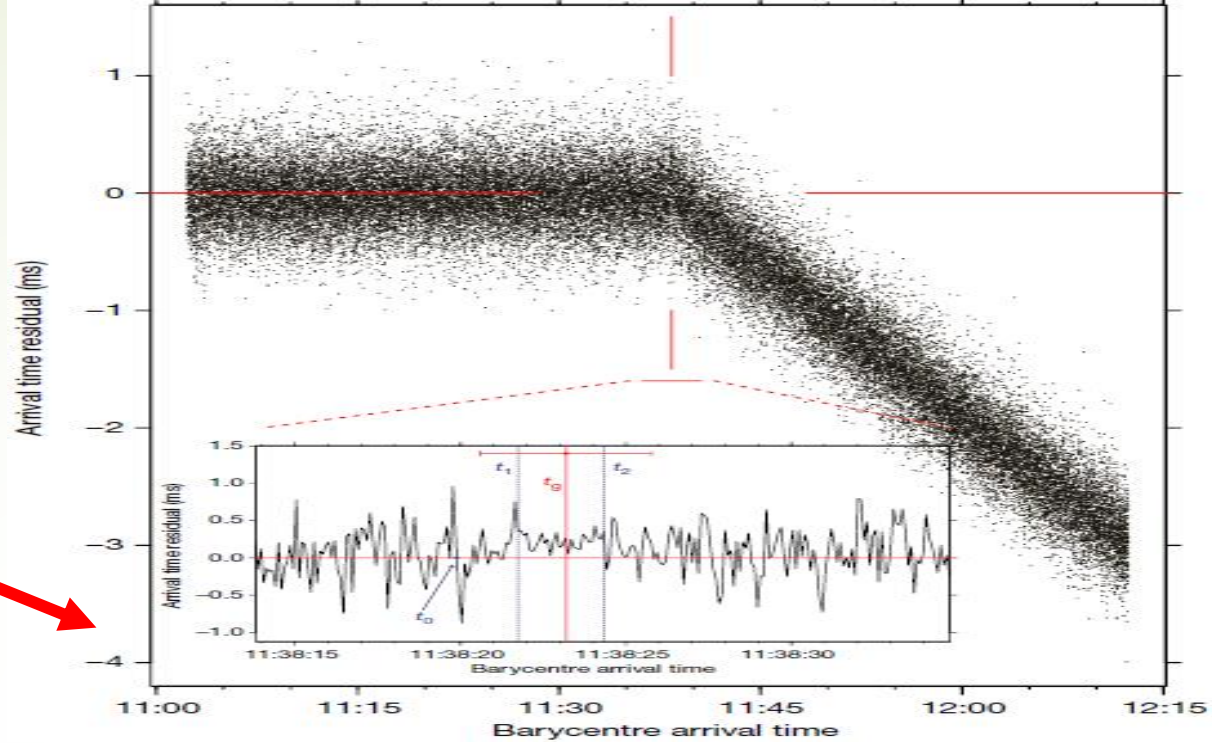


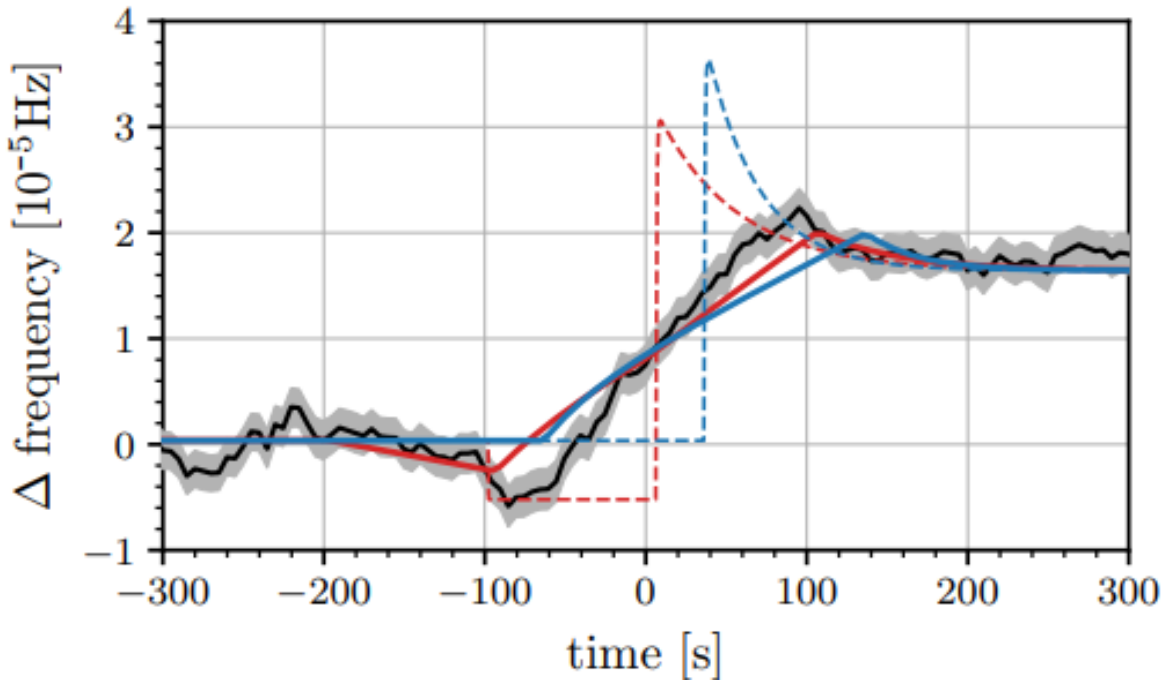

Crab pulsar :
Giant radio pulse (GRP)
Optical enhancement

**X-ray enhancement ?**

# Vela



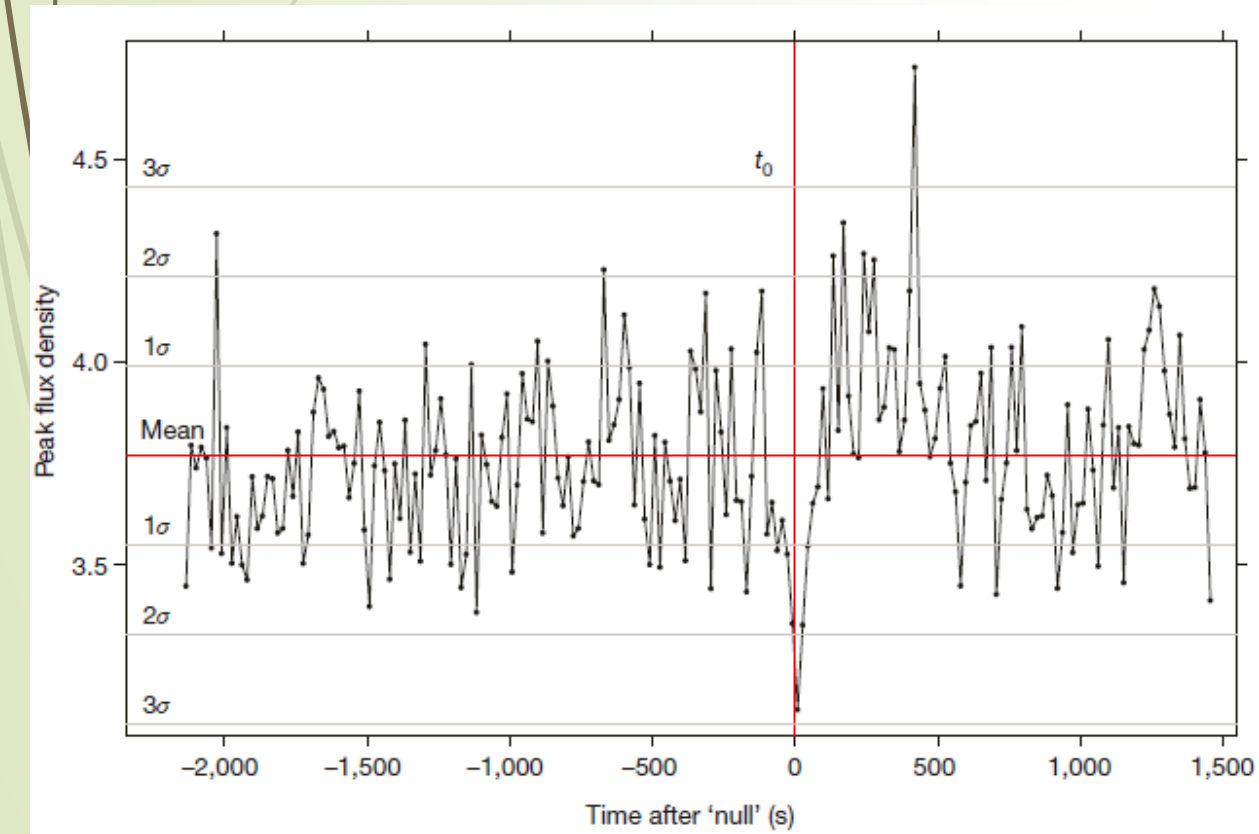



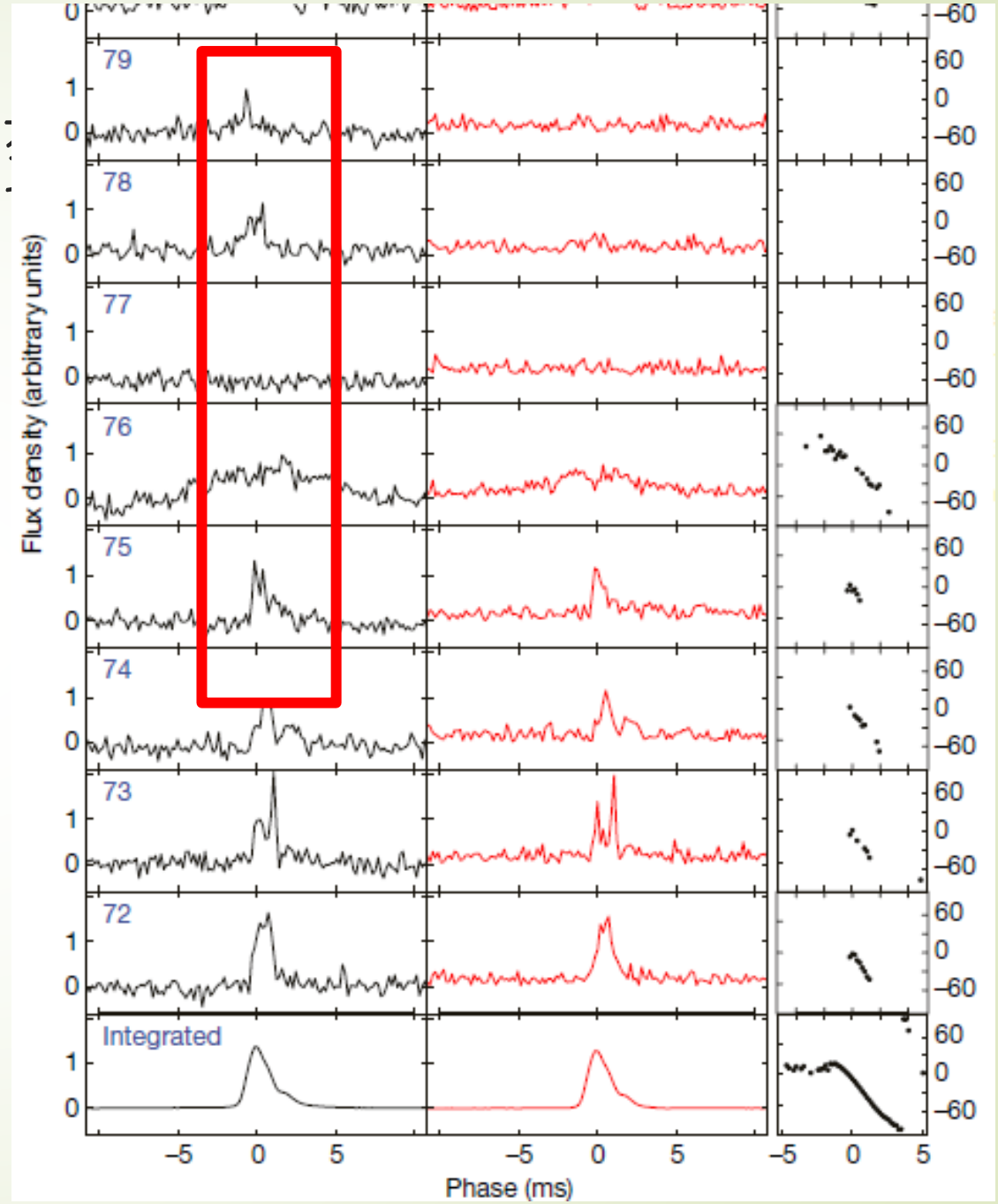

周期跃变上升时标 < 12.4秒

Ashton et al. 2019

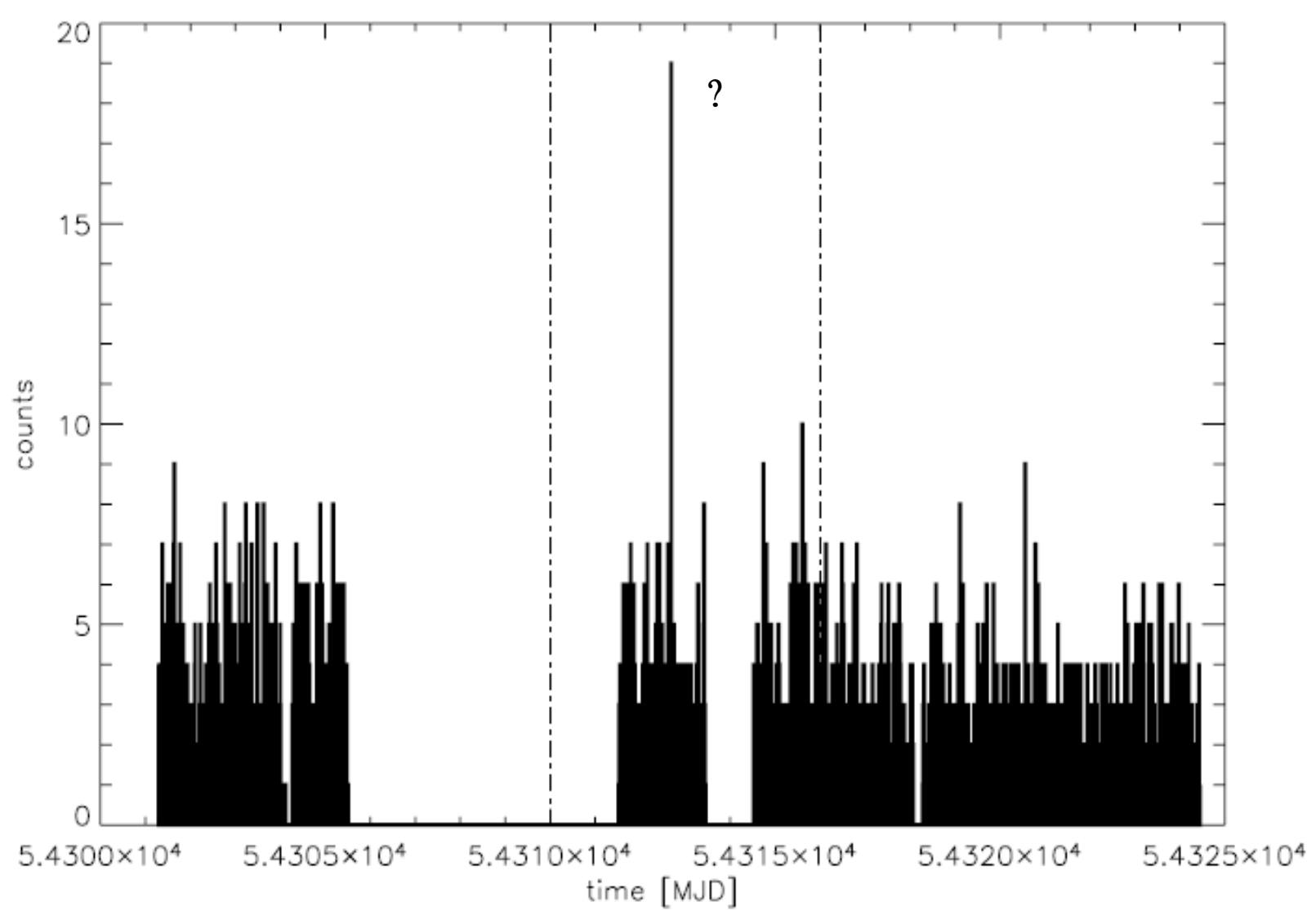
# Vela -2016周期跃

- 射电波段
- 周期跃变是否引发X-rayflare？限制？
- GBM 处于地球遮挡，HXMT处于SAA



# Vela pulsar




Vela glitch MJD: 54313

**Possible flare**

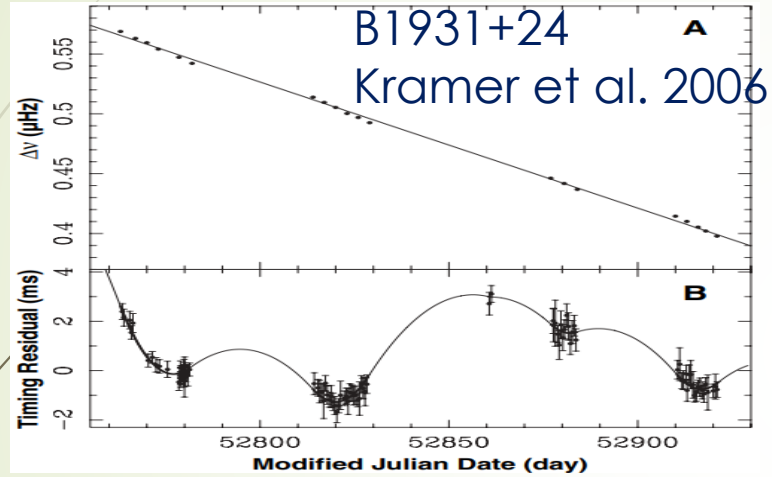
联合:
**GECAM: 时间覆盖率高**
**Insight-HXMT**
**Fermi-GBM/LAT**
AGILE ?

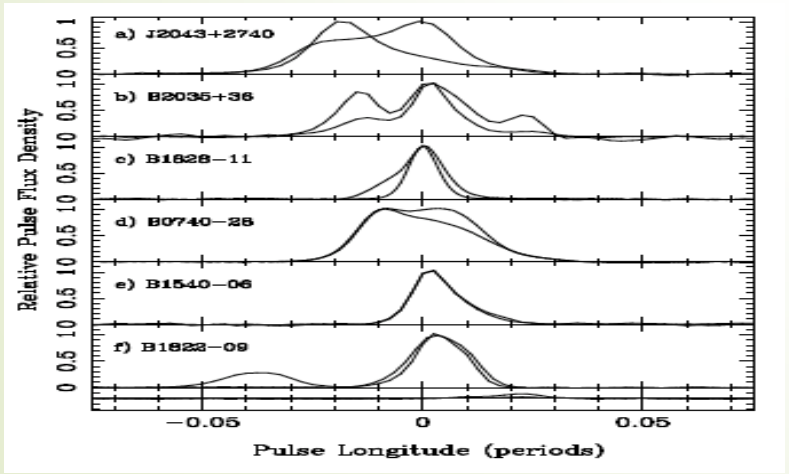
搜索周期跃变时是否存在flare:
Glitch时刻
位置

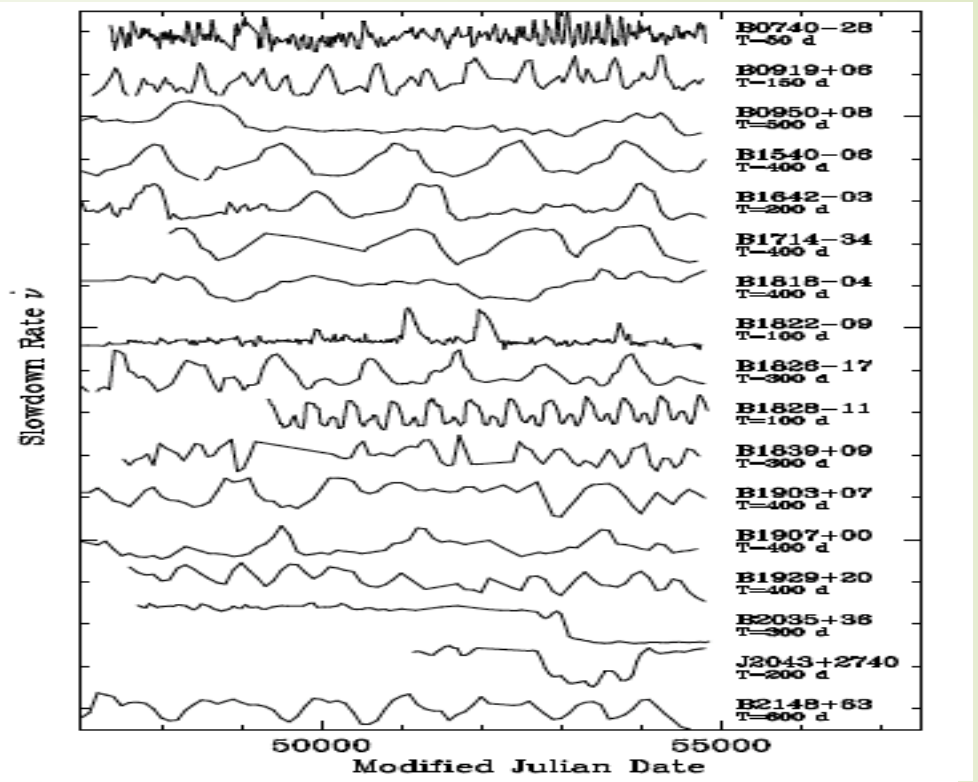
上限 ?

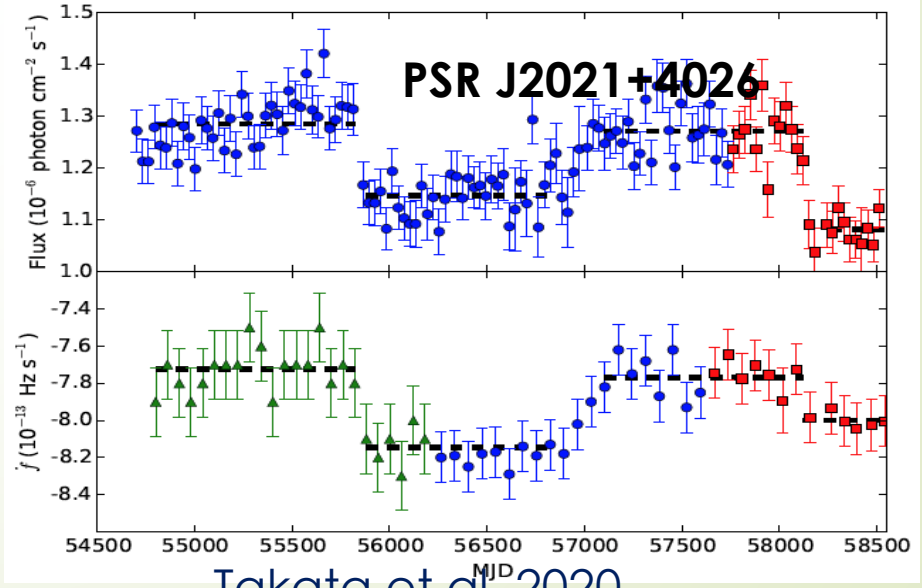
# 状态转换

- 磁层变化



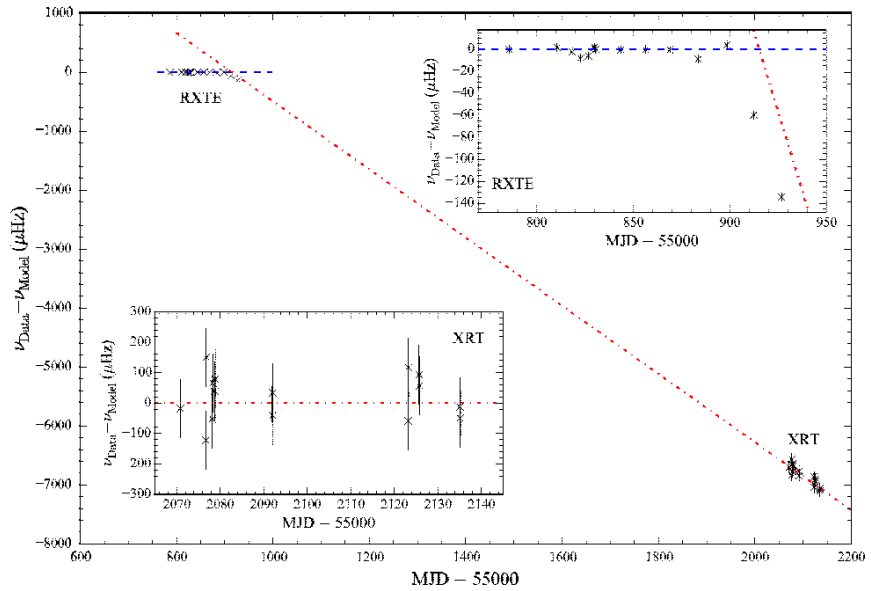




Lyne et al. 2010. 特征年龄~百万年

Takata et al. 2020

# B0540-69

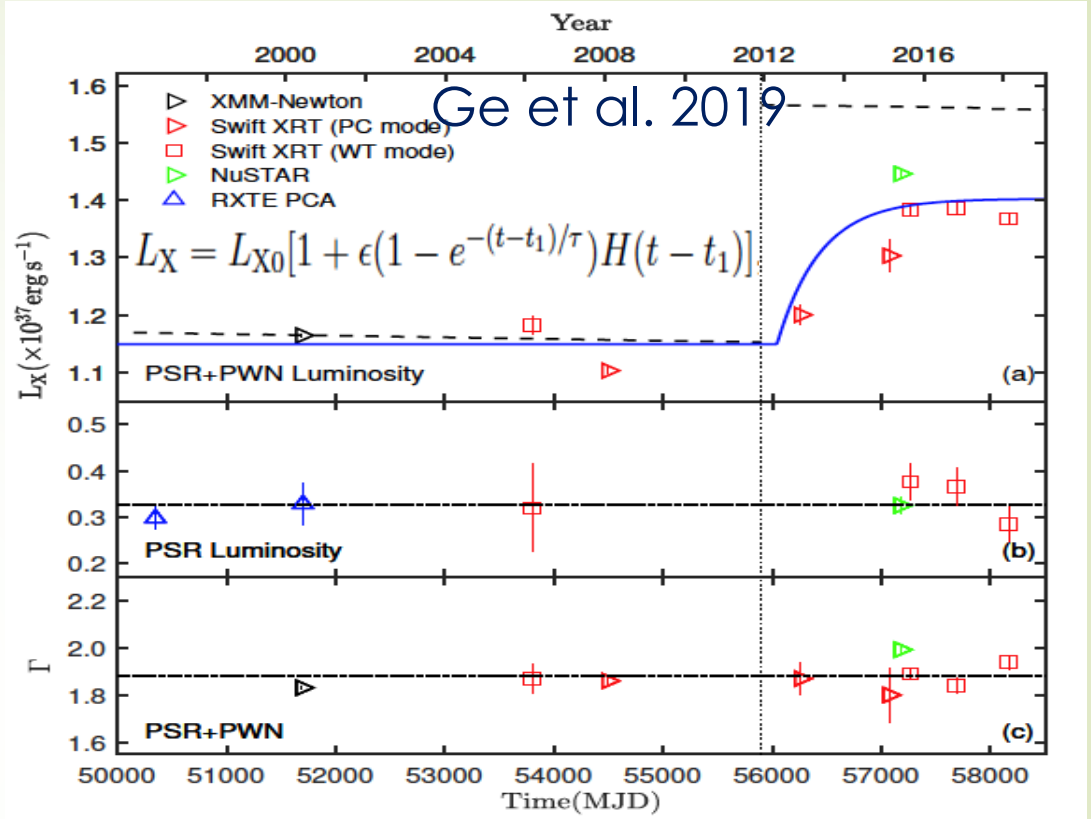



Marshall et al. 2015

| Parameter | Pre-transition 2011 | 2015 |
|---|---|---|
| Epoch (Modified Julian Date) | 55892.352587464 | 57077.537772223 |
| Phase | 0.000 (15) | 0.000 (23) |
| $\nu$ (Hz) | 19.72655182 (1) | 19.70077383 (4) |
| $\dot{\nu}$ ($10^{-10}$ s$^{-2}$) | −1.86322 (2) | −2.52871 (8) |
| $\ddot{\nu}$ ($10^{-21}$ s$^{-3}$) | 3.249 (fixed) | 3.249 (fixed) |

**Note.** The numbers in parentheses are the 90% confidence errors quoted in the last digit.

Spin-down rate transition（SRT）~36%




Ge et al. 2019

**n = 2.5** $n$ is $0.031 \pm 0.013$ (90% confidence)

- 脉冲星脉冲轮廓/光度不变
- 脉冲星风云增加32(8)%

**上升时标400 day**

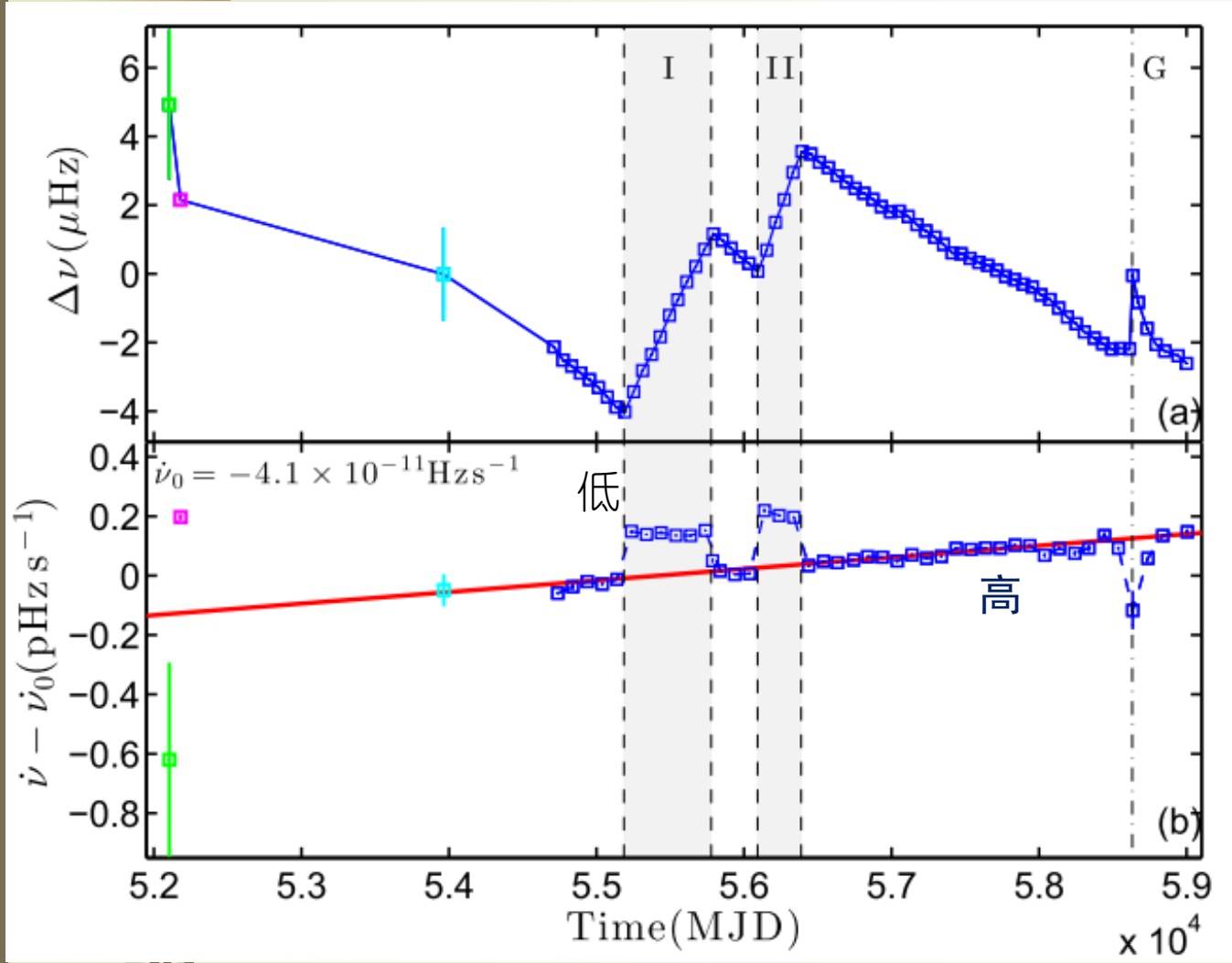
**脉冲星风云处磁场** $0.78^{+4.50}_{-0.28}$ mG

制动指数在快速恢复中
Wang et al. 2020

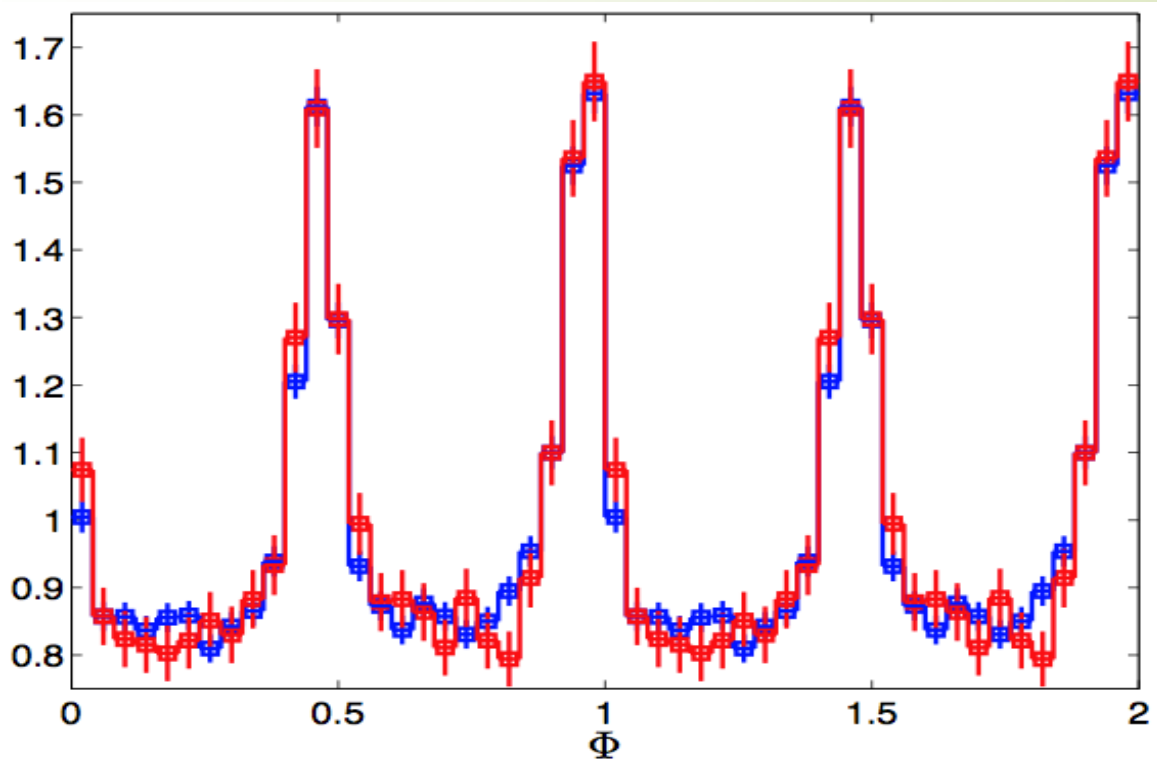
# PSR J1124-5916

第二颗年轻脉冲星存在状态改变
状态改变：0.4%
制动指数：~ 1.98

与B0540-69类似




Ge et al. 2020




伽玛射线脉冲轮廓没有变化

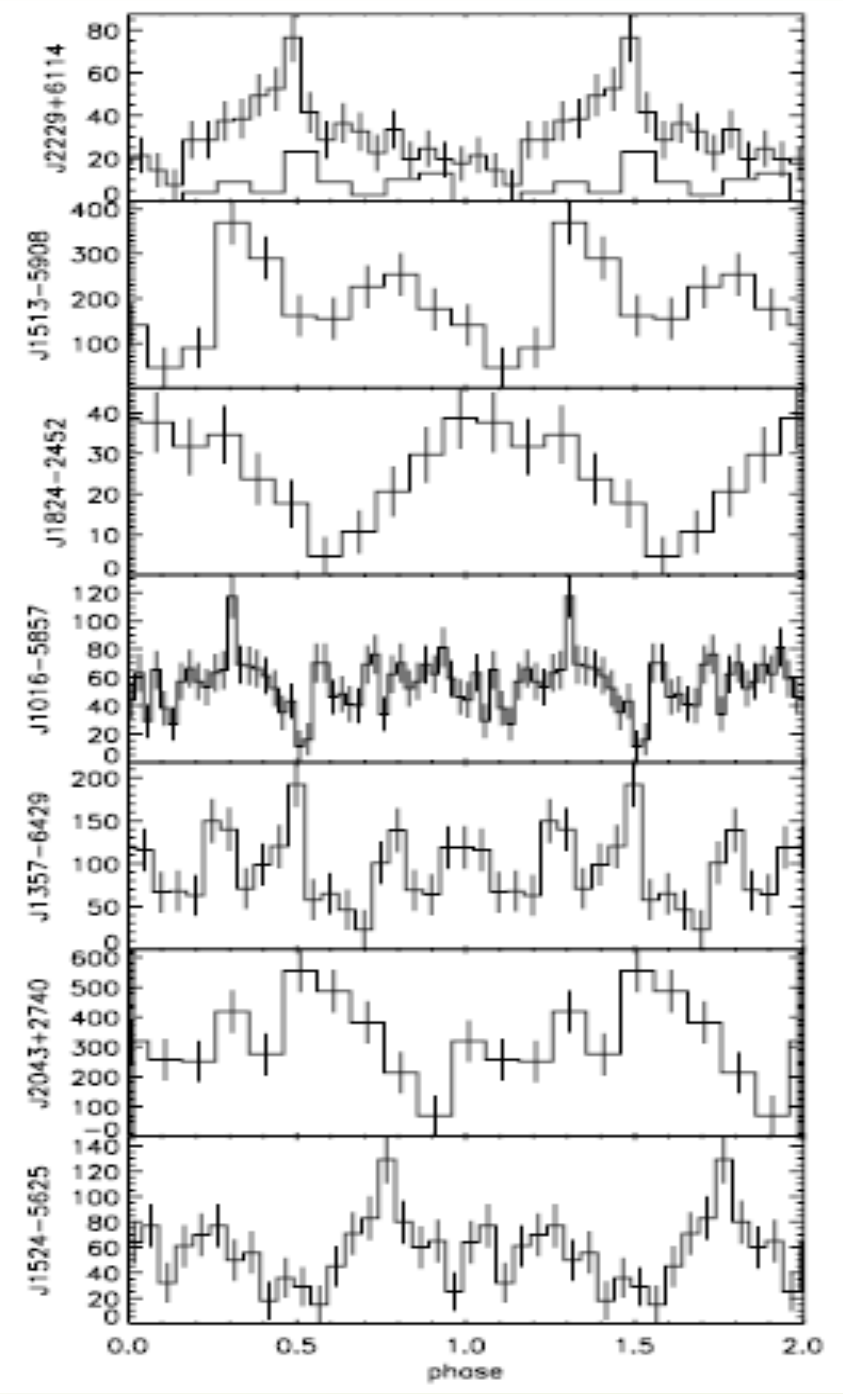
# 软伽玛射线脉冲搜索

- GBM：
- AGILE：
- 软伽玛脉冲星 (Kuiper et al. 2015): **18**
- 慧眼结果： Crab、B1509-58、 Vela

**Table 1**

Emission Parameters of the Seven Pulsars Discussed in the Text (Firmly Detected Gamma-Ray Pulsars are Reported in the Upper Part of the Table)

| PSR Name | G.Lon. (deg) | G.Lat. (deg) | $P$ (ms) | $\tau^{a}$ (yr) | $D^{a}$ (kpc) | $\log \dot{E}$ (erg $s^{-1}$) | $\chi^2_{red}(N_{st})^{b}$ | $\sigma_{time}{}^{c}$ | $\sigma_{space}{}^{d}$ | $F_\gamma{}^{d}$ | $\log L_\gamma{}^{e}$ (erg $s^{-1}$) | $L_\gamma/\dot{E}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J2229+6114 | 106.65 | 2.95 | 51.6 | $1.0 \times 10^4$ | 12.0 | 37.35 | 6.0(36) | 5.0 | 7.5 | $26 \pm 4$ | 35.36 | 0.01 |
| J1513−5908 | 320.32 | −1.16 | 150.7 | $1.6 \times 10^3$ | 5.8 | 37.25 | 4.2(3) | 4.0 | 6.4 | $34 \pm 6^{f}$ | 35.04 | 0.006 |
| J1824−2452 | 7.80 | −5.58 | 3.0 | $3.0 \times 10^7$ | 4.9 | 36.35 | 4.2(1) | 4.2 | 3.6 | $18 \pm 5$ | 34.62 | 0.02 |
| J1016−5857 | 284.08 | −1.88 | 107.4 | $2.1 \times 10^4$ | 9.3 | 36.41 | 6.0(69) | 4.8 | 12.3 | $62 \pm 6^{f}$ | 35.71 | 0.2 |
| J1357−6429 | 309.92 | −2.51 | 166.1 | $7.3 \times 10^3$ | 4.1 | 36.49 | 5.2(7) | 4.7 | 1.8 | <14 | < 34.35 | < 0.007 |
| J2043+2740 | 70.61 | −9.15 | 96.1 | $1.2 \times 10^6$ | 1.1 | 34.75 | 4.1(1) | 4.2 | 0.6 | <6 | < 32.84 | < 0.01 |
| J1524−5625 | 323.00 | 0.35 | 78.2 | $3.2 \times 10^4$ | 3.8 | 36.51 | 4.6(4) | 4.3 | 1.0 | <16 | < 34.34 | < 0.007 |

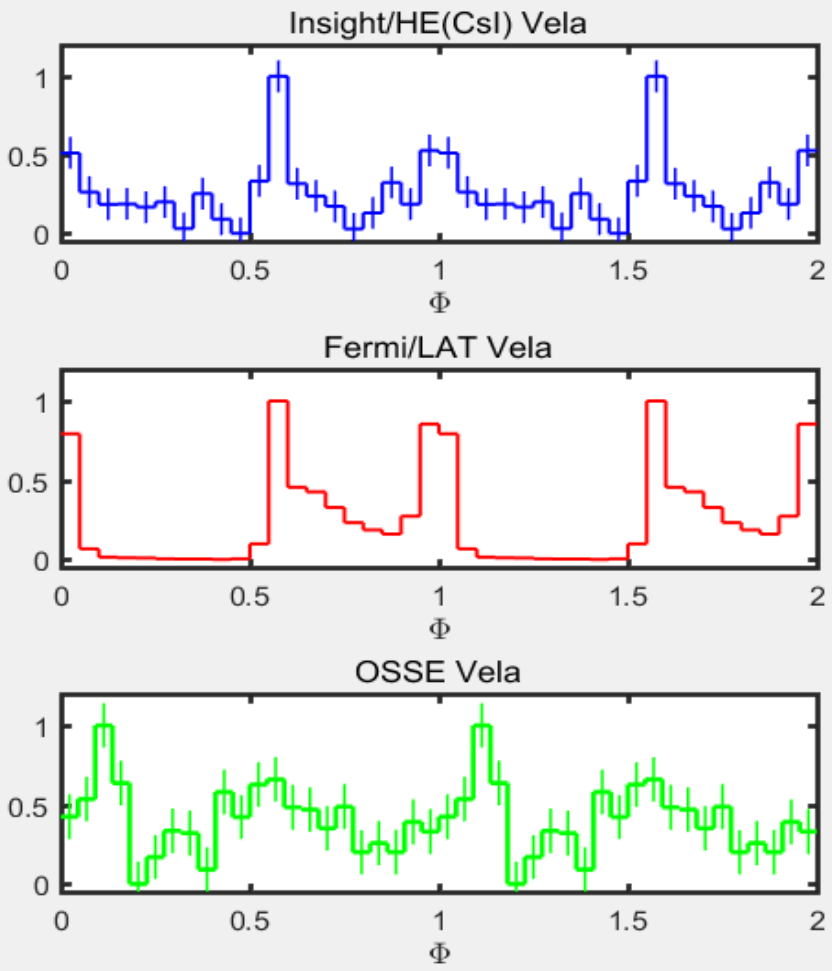


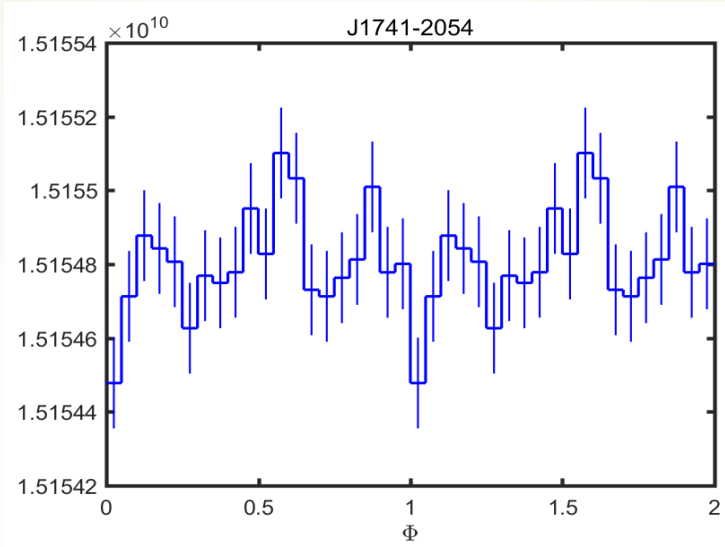
# 软伽玛射线脉冲搜索

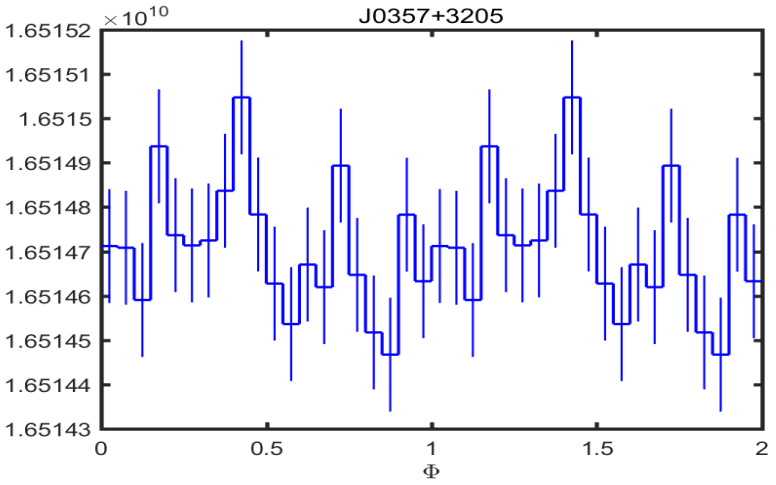
| PSR Name | RA | Dec |
|---|---|---|
| J0357+3205 | 59.468641 | 32.090186 |
| J0633+0632 | 98.43423294 | 6.543040311 |
| J1048-5832 | 162.0508333 | -58.53494444 |
| J1057-5226 | 164.4951667 | -52.44897222 |
| J1732-3131 | 263.1397396 | -31.5229928 |
| J1809-2332 | 272.4596207 | -23.55960258 |
| J1836+5925 | 279.0570337 | 59.424989 |
| J0007+7303 | 1.7565 | 73.05230556 |
| J1028-5819 | 157.1164958 | -58.31811806 |
| J1418-6058 | 214.6779604 | -60.963525 |
| J1709-4429 | 257.4280333 | -44.48562222 |
| J1826-1256 | 276.5351709 | -12.94271483 |
| J1907+0602 | 286.9780992 | 6.03803425 |
| J2021+3651 | 305.27275 | 36.85133333 |
| J2229+6114 | 337.272 | 61.23591667 |
| J0835.3-4510 | 128.83585 | -45.17 |
| J1952+3252 | 298.242525 | 32.8779191 |

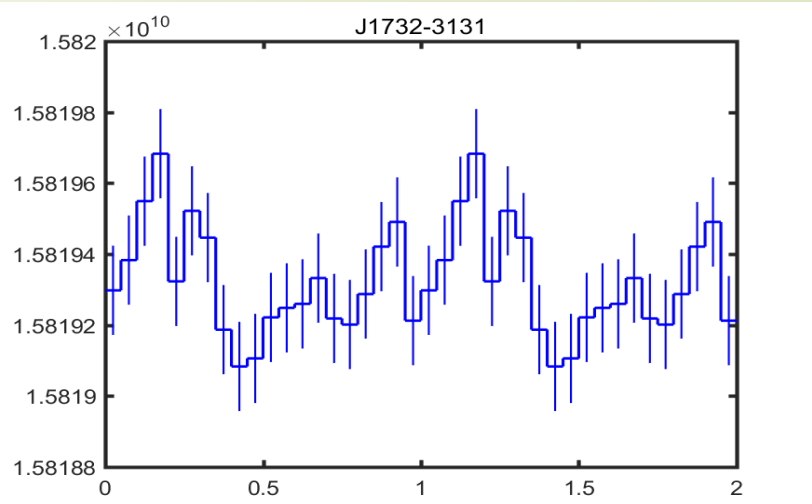
| | | |
|---|---|---|
| J1413-6205 | 213.374703 | -62.09398737 |
| J1429-5911 | 217.4942905 | -59.19349982 |
| J1459-6053 | 224.8749513 | -60.88908324 |
| J1718-3825 | 259.5565208 | -38.42168333 |
| J1741-2054 | 265.4908333 | -20.90333333 |
| J1954+2836 | 298.5797938 | 28.60166424 |
| J1958+2846 | 299.666957 | 28.76496081 |
| J0659+1414 | 104.9507056 | 14.23916713 |
| J1044-5737 | 161.1366557 | -57.6220268 |
| J1509-5850 | 227.3630417 | -58.84891667 |
| J1620-4927 | 245.173 | -49.46030556 |
| J1746-3239 | 266.7289458 | -32.6655 |
| J1846+0919 | 281.6081746 | 9.329524714 |
| J1957+5033 | 299.4122549 | 50.55511881 |
| J2028+3332 | 307.08275 | 33.53454444 |
| J2030+3641 | 307.5010867 | 36.6908753 |
| J2030+4415 | 307.7139583 | 44.26058333 |
| J2055+2539 | 313.9539867 | 25.66689863 |
| J2139+4716 | 324.983125 | 47.27027778 |
| J0633+1746 | 98.47620417 | 17.77066111 |
| J1813-1246 | 273.3490486 | -12.76633743 |
| J1833-1034 | 278.389875 | -10.56875 |
| J1803-2149 | 270.7901333 | -21.82027778 |
| J1124-5916 | 171.1629167 | -59.27222222 |
| J2111+4606 | 317.8505417 | 46.10869444 |
| J2238+5903 | 339.6177816 | 59.06133751 |
| J0106+4855 | 16.60441667 | 48.93105556 |

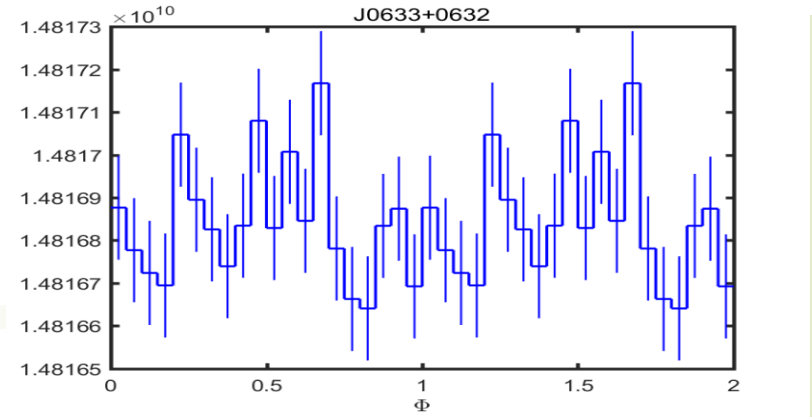
# 软伽玛射线脉冲搜索

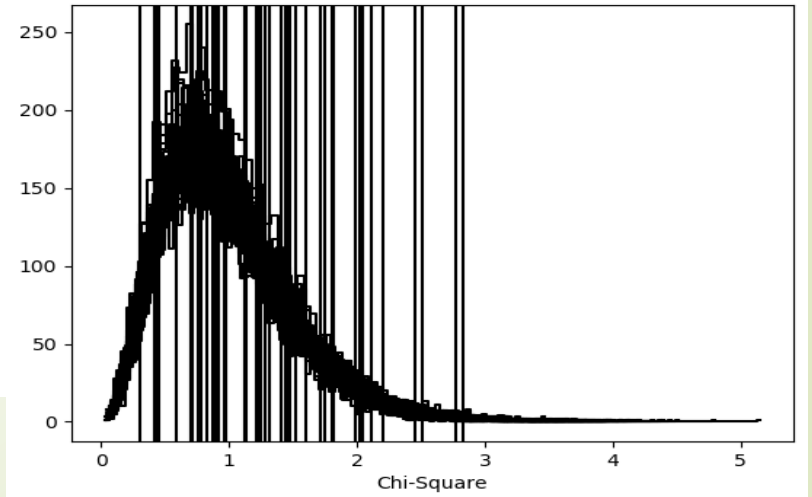


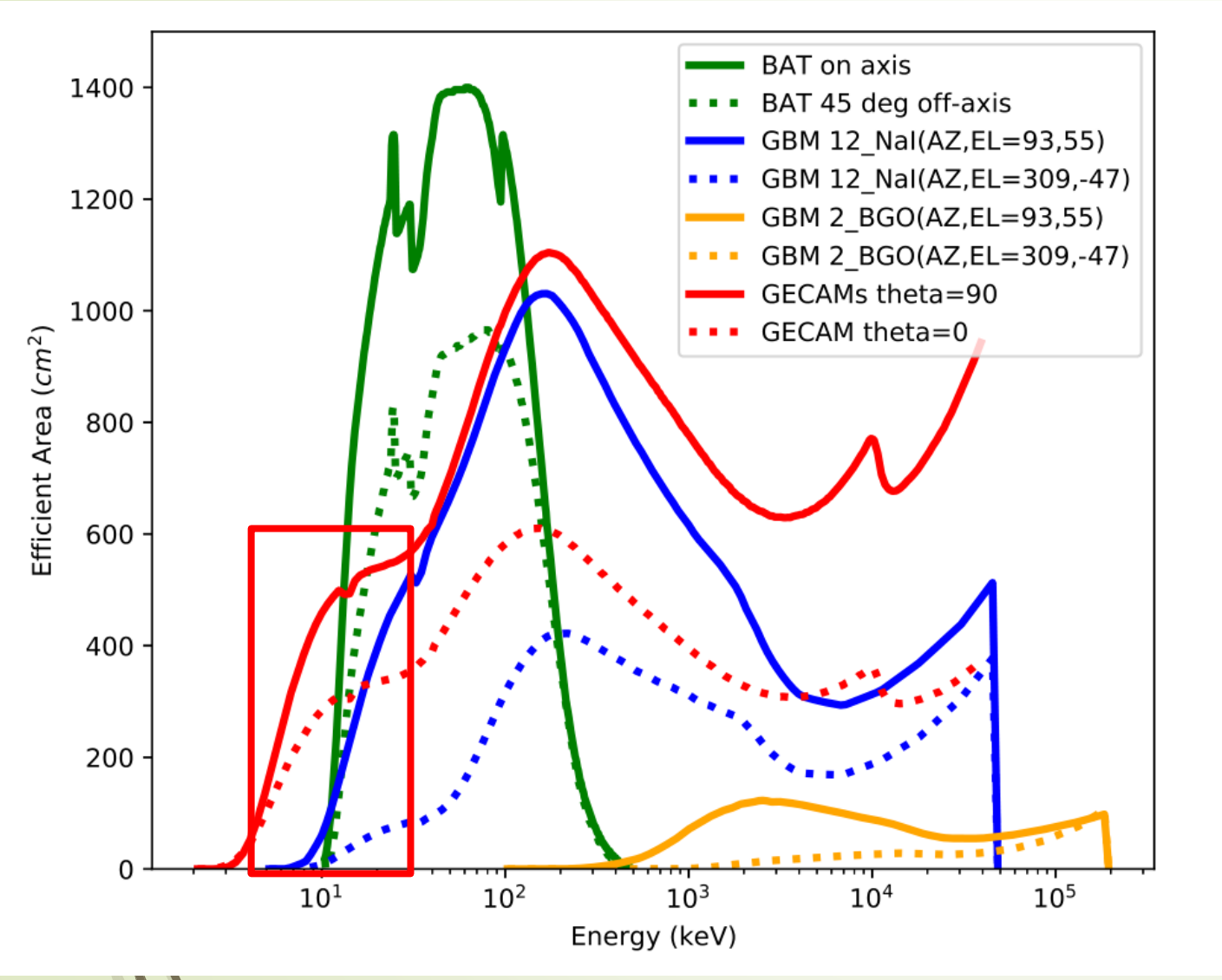




慧眼HXMT结果

# GECAM




**GECAM**:

宽能段

大视场

连续覆盖（>90%）

低能段优势

**脉冲星的连续监测**

**长时间累计脉冲**

**部分脉冲星的连续计时（独立？）**

数据需求：

事例数据、轨道文件、姿态

数据处理流程 （类似慧眼HXMT/HE-CsI）

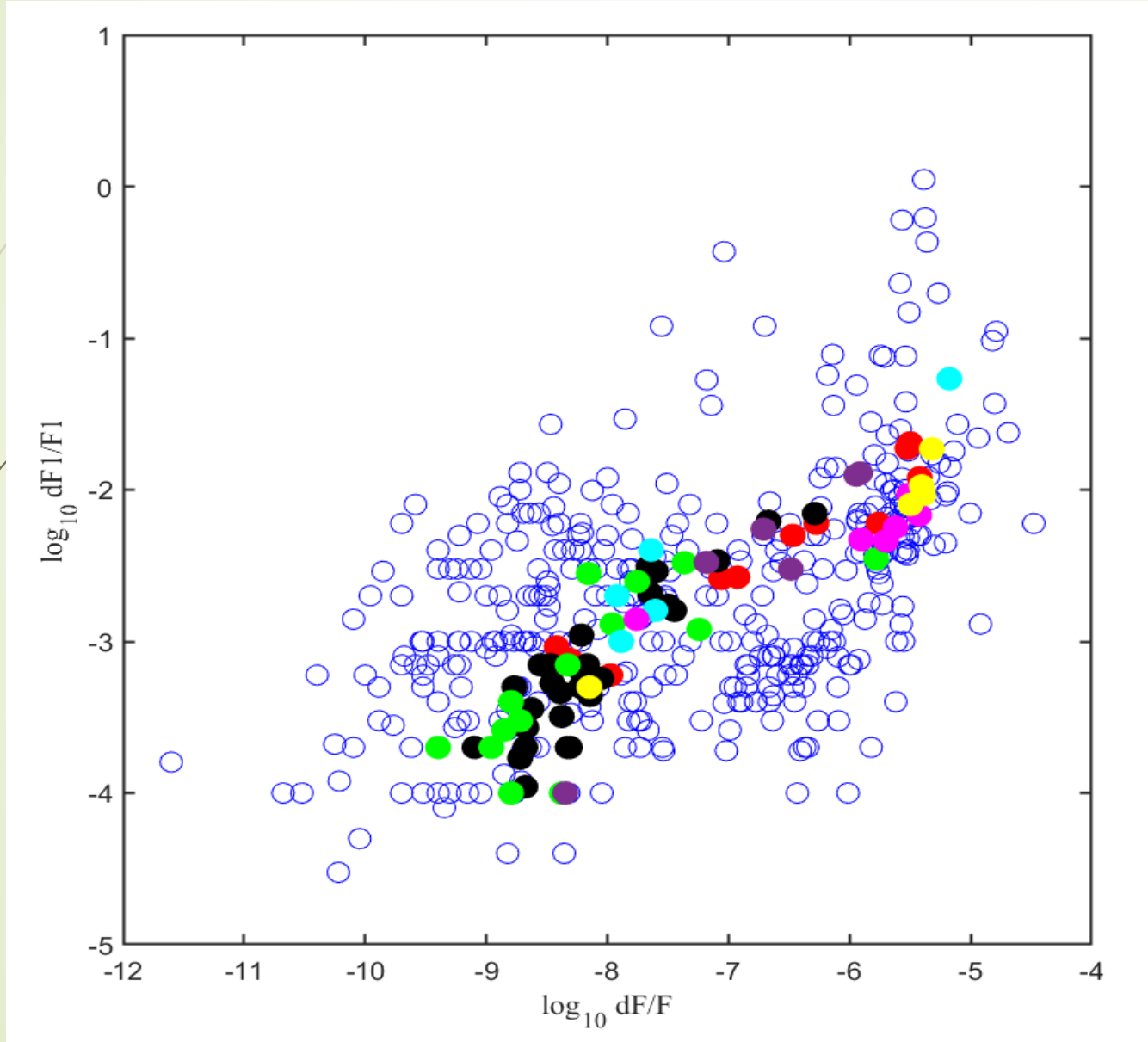
产生伪事例数据、SSB修正、ELV计算、周期搜索/星历折叠、计时分析

# 总结

- 脉冲星自转演化：监测部分源，周期跃变触发后续观测
- 脉冲星周期跃变/状态改变行为：是否出现新的成分，周期跃变时标限制，是否有对应的flare等
- 寻找和证认潜在软伽玛射线脉冲辐射的脉冲星

- 联合处理：
  - **GECAM**、Insight-HXMT-HE/CsI，Fermi-GBM/LAT等

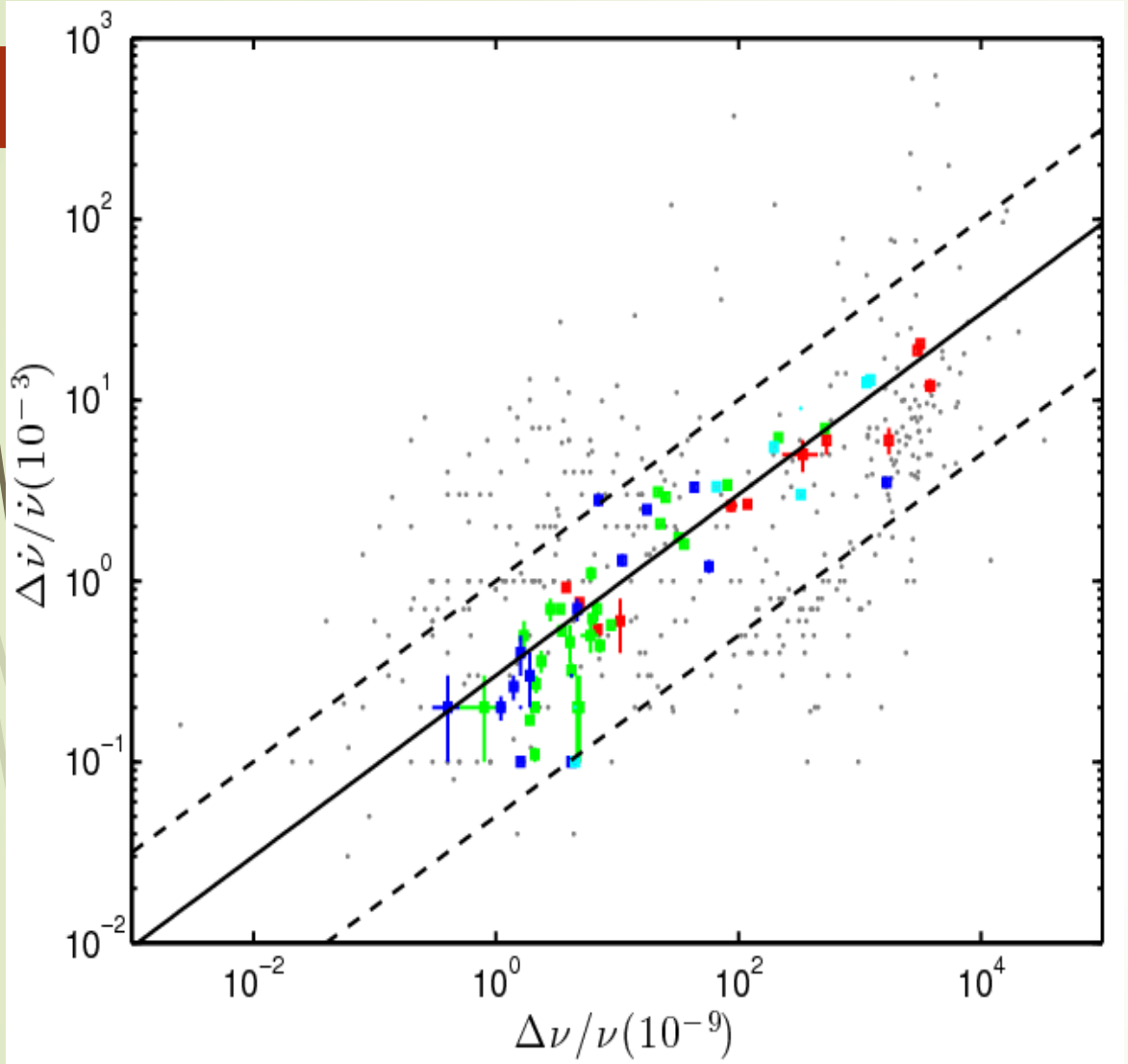
蓝色空心数据点是Jodrell Bank提供的所有周期跃变的参数，彩色实心点是选定的几颗脉冲星的参数。

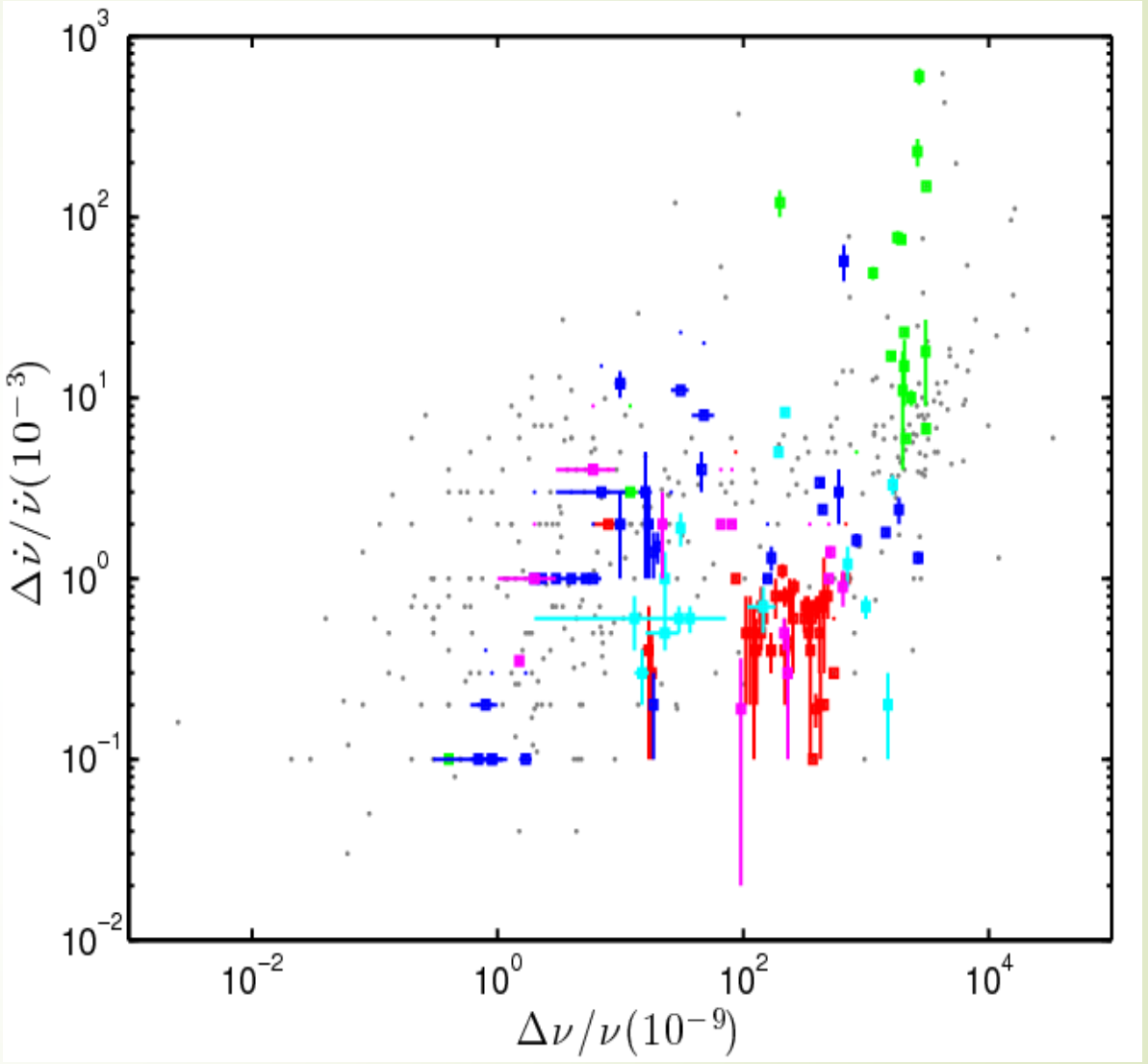



这几颗脉冲星的周期跃变自转频率和自转频率变化幅度之间似乎具有相关性

这个相关性是这几颗脉冲星独有的，有的脉冲星发生的周期跃变次数也多，但是不具有相关性

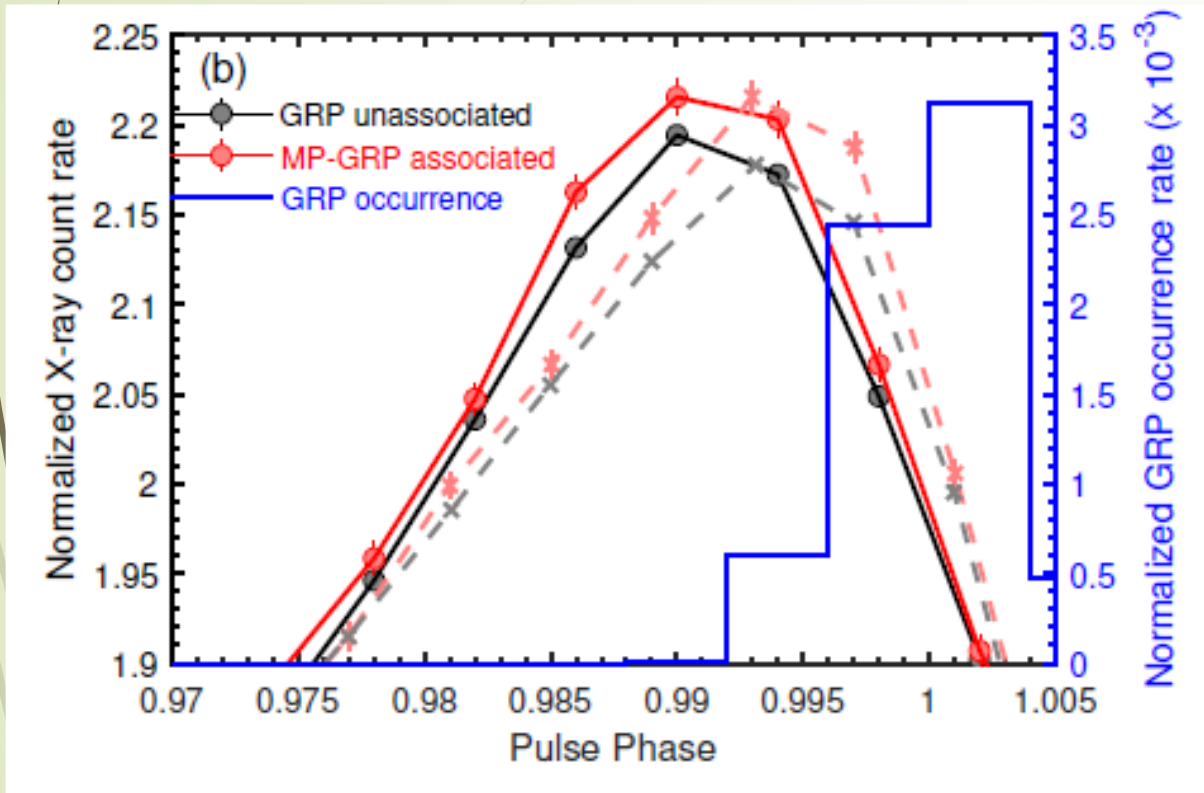
相关性是因为数据点少，还是因为选择效应？我个人认为这些相关性对应着某些物理限制，目前还没有找到这几颗源的显著共同点

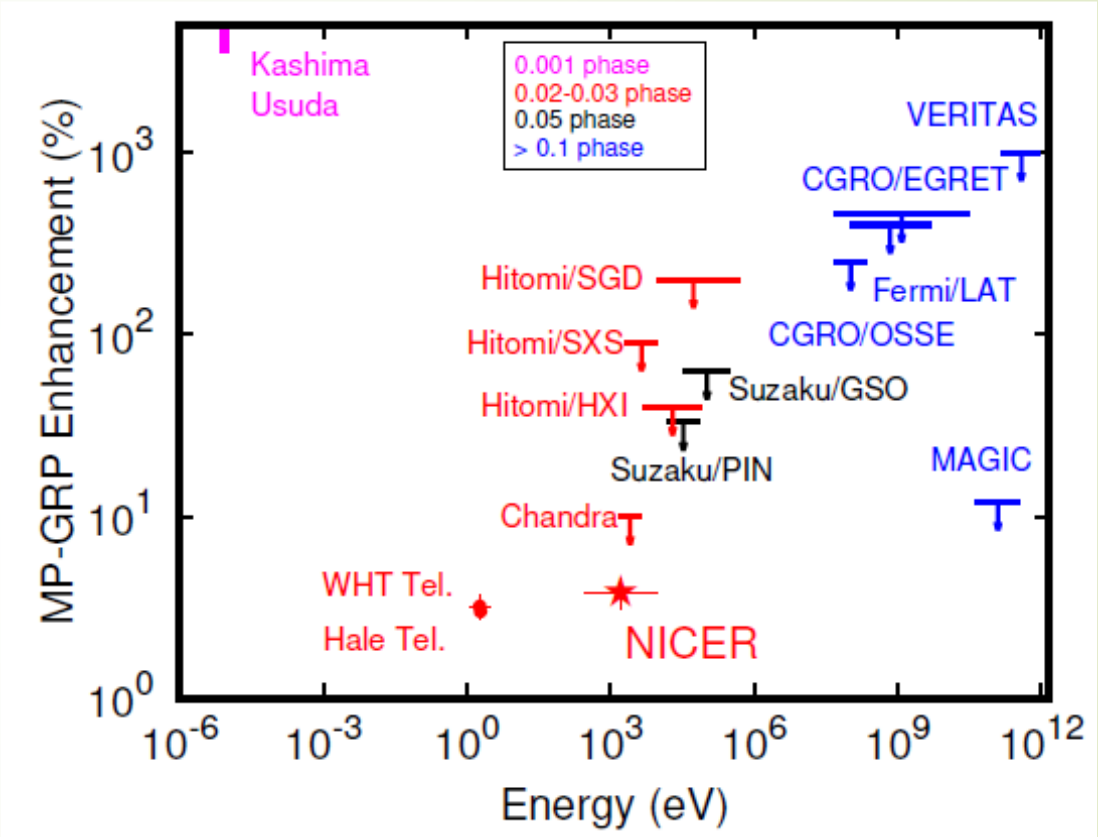

$10^3$
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$\Delta\dot{\nu}/\dot{\nu}(10^{-3})$
$10^{-2}$
$10^0$
$10^2$
$10^4$
$\Delta\nu/\nu(10^{-9})$


$10^3$
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$\Delta\dot{\nu}/\dot{\nu}(10^{-3})$
$10^{-2}$
$10^0$
$10^2$
$10^4$
$\Delta\nu/\nu(10^{-9})$

积累样本

# Crab pulsar

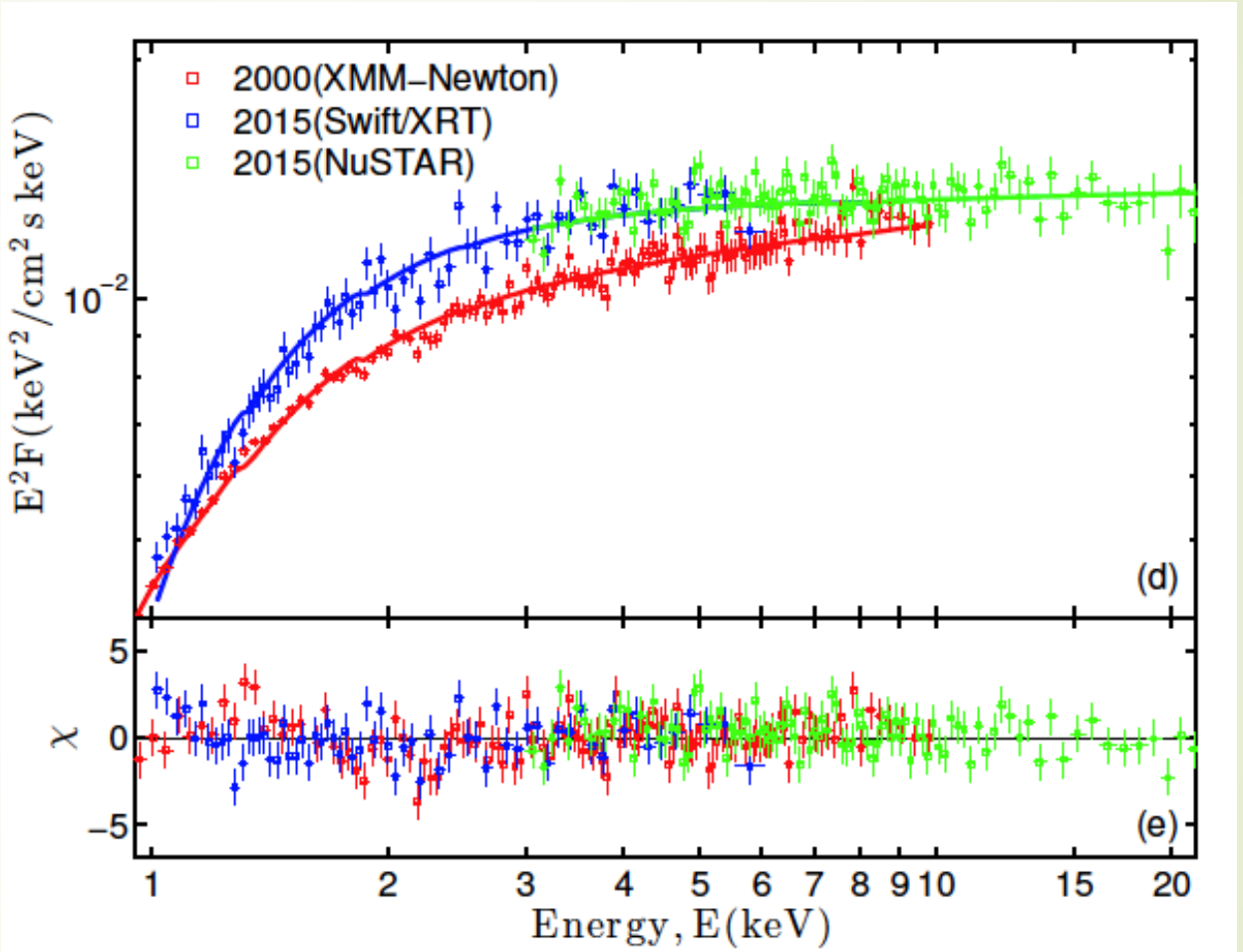


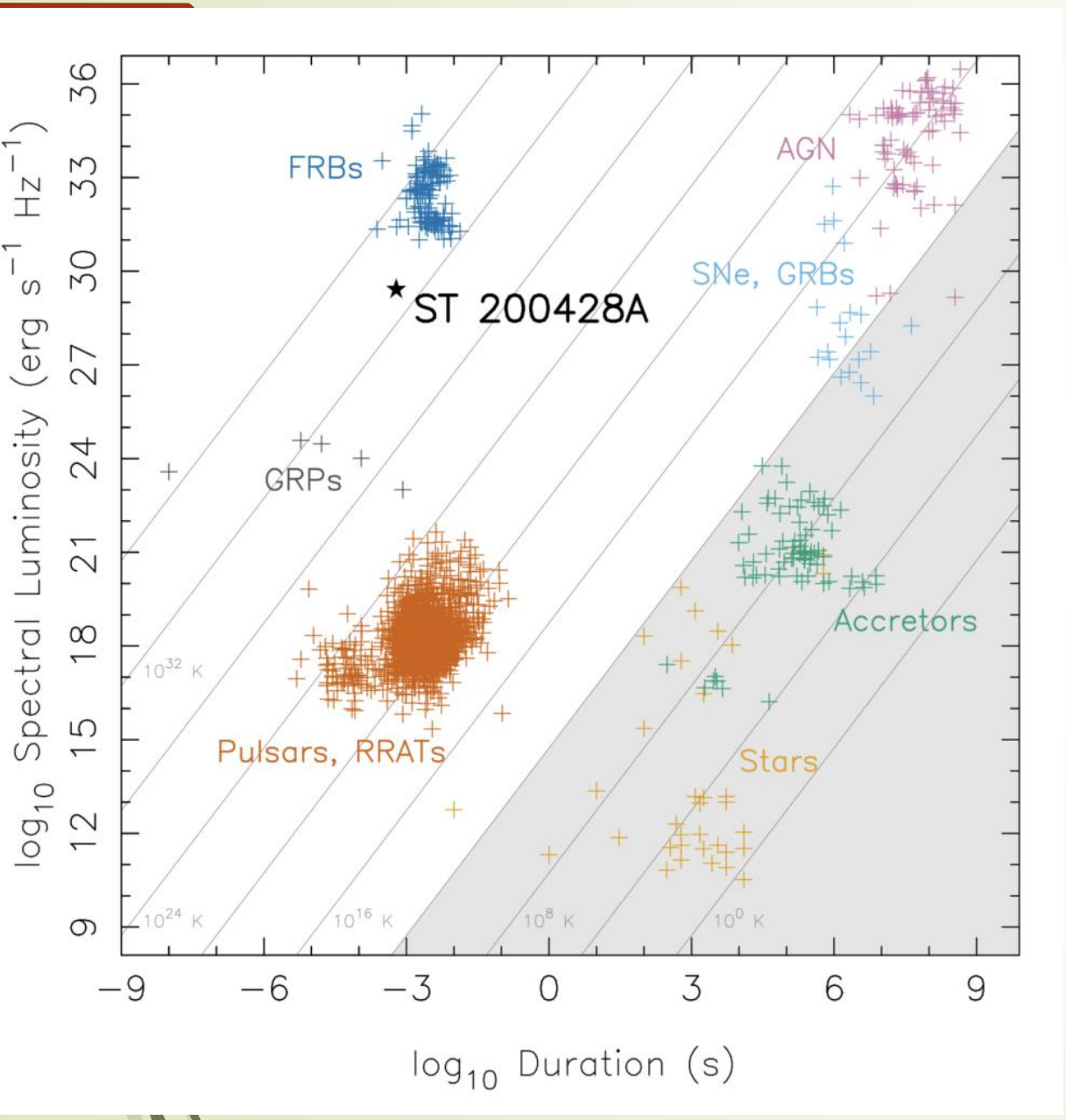

Enoto et al. 2020

# B0540-69

- Observations from XMM－Newton、Swift／XRT、NuSTAR
- The luminosity of PSR+PWN enhances by 22%

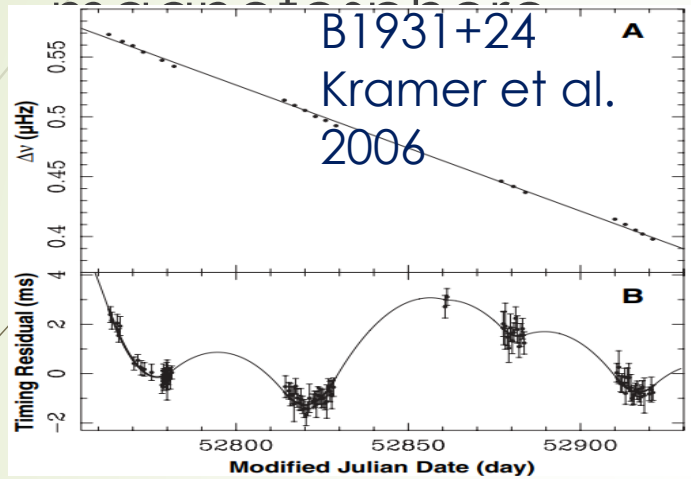


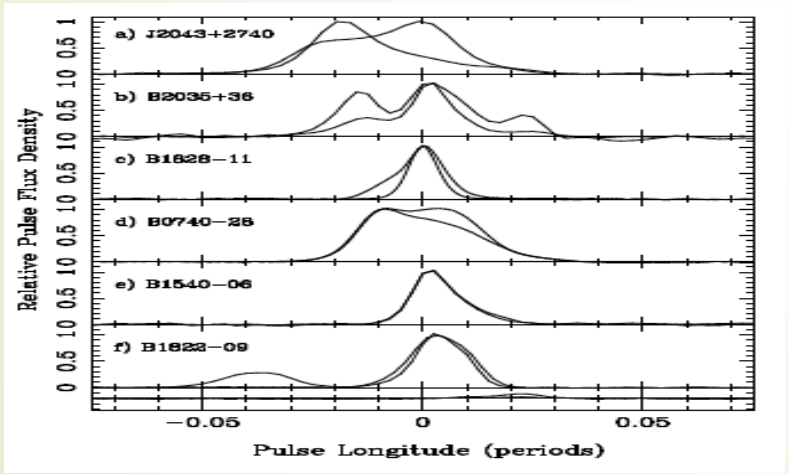

Ge et al. 2020


FRBs
ST 200428A
GRPs
Pulsars, RRATs
AGN
SNe, GRBs
Accretors
Stars
$10^{32}$ K
$10^{24}$ K
$10^{16}$ K
$10^{8}$ K
$10^{0}$ K
$\log_{10}$ Spectral Luminosity (erg $s^{-1}$ $Hz^{-1}$)
$\log_{10}$ Duration (s)
9
12
15
18
21
24
27
30
33
36
−9
−6
−3
0
3
6
9

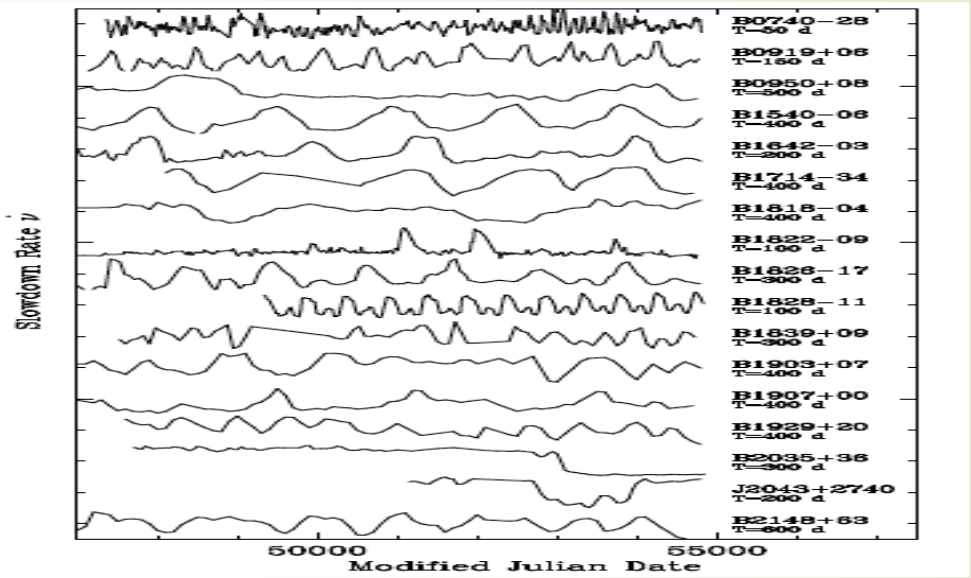
# State transition

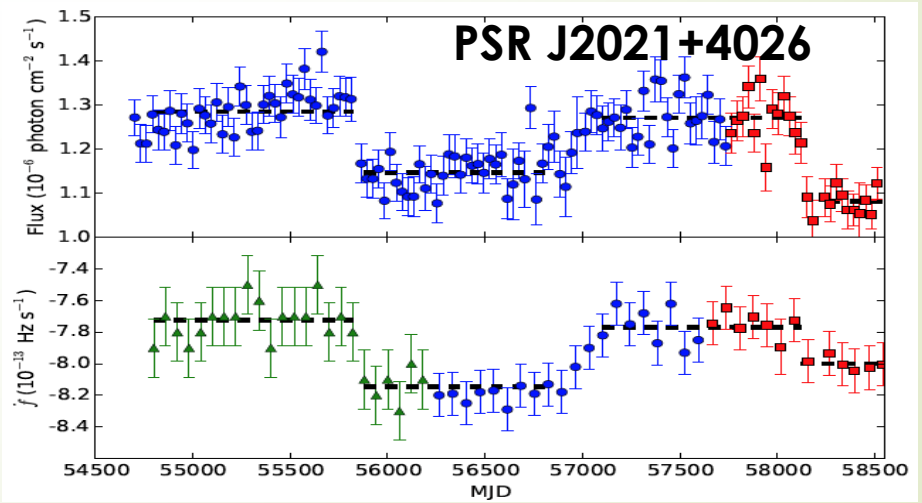
- Change of magnetosphere



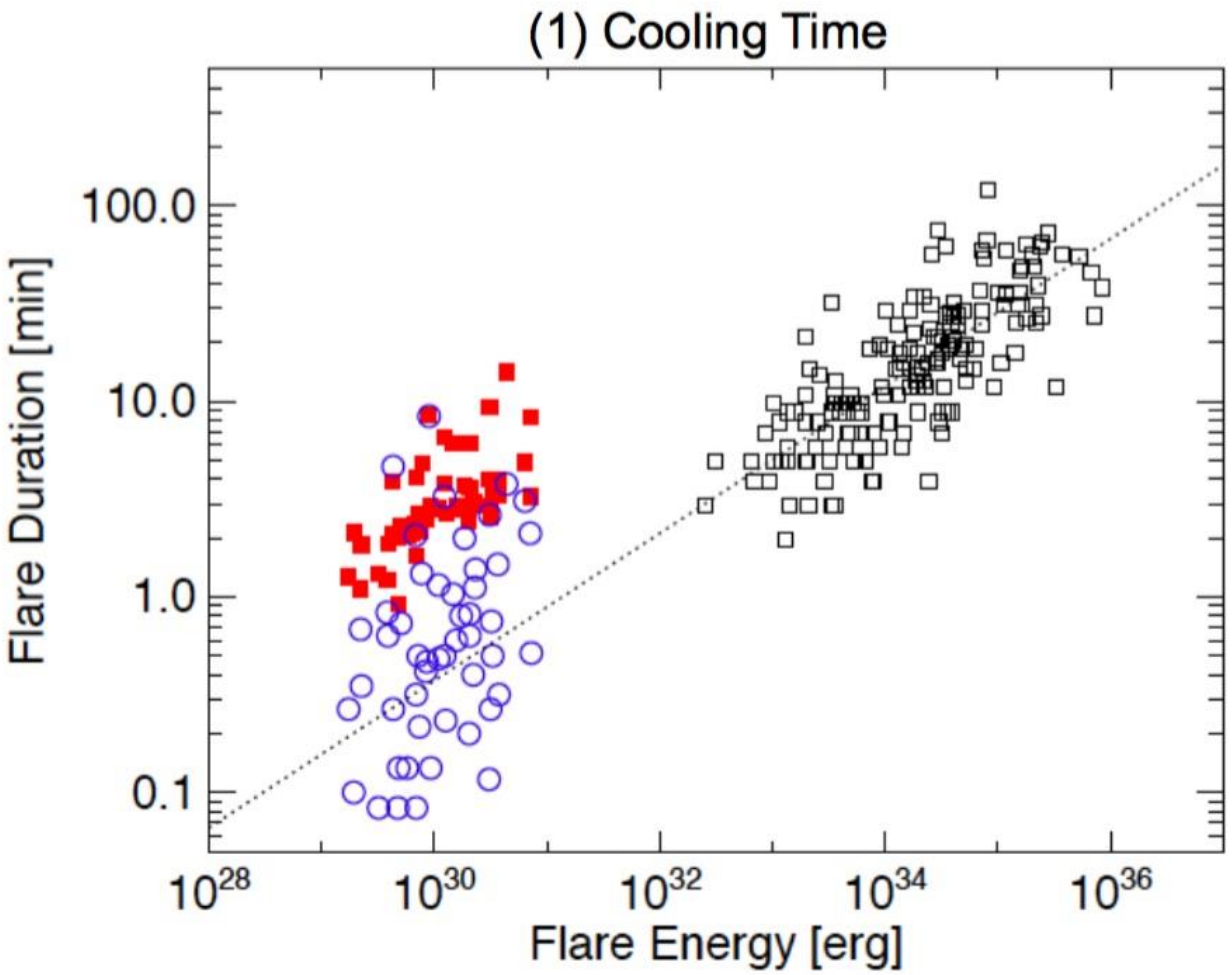



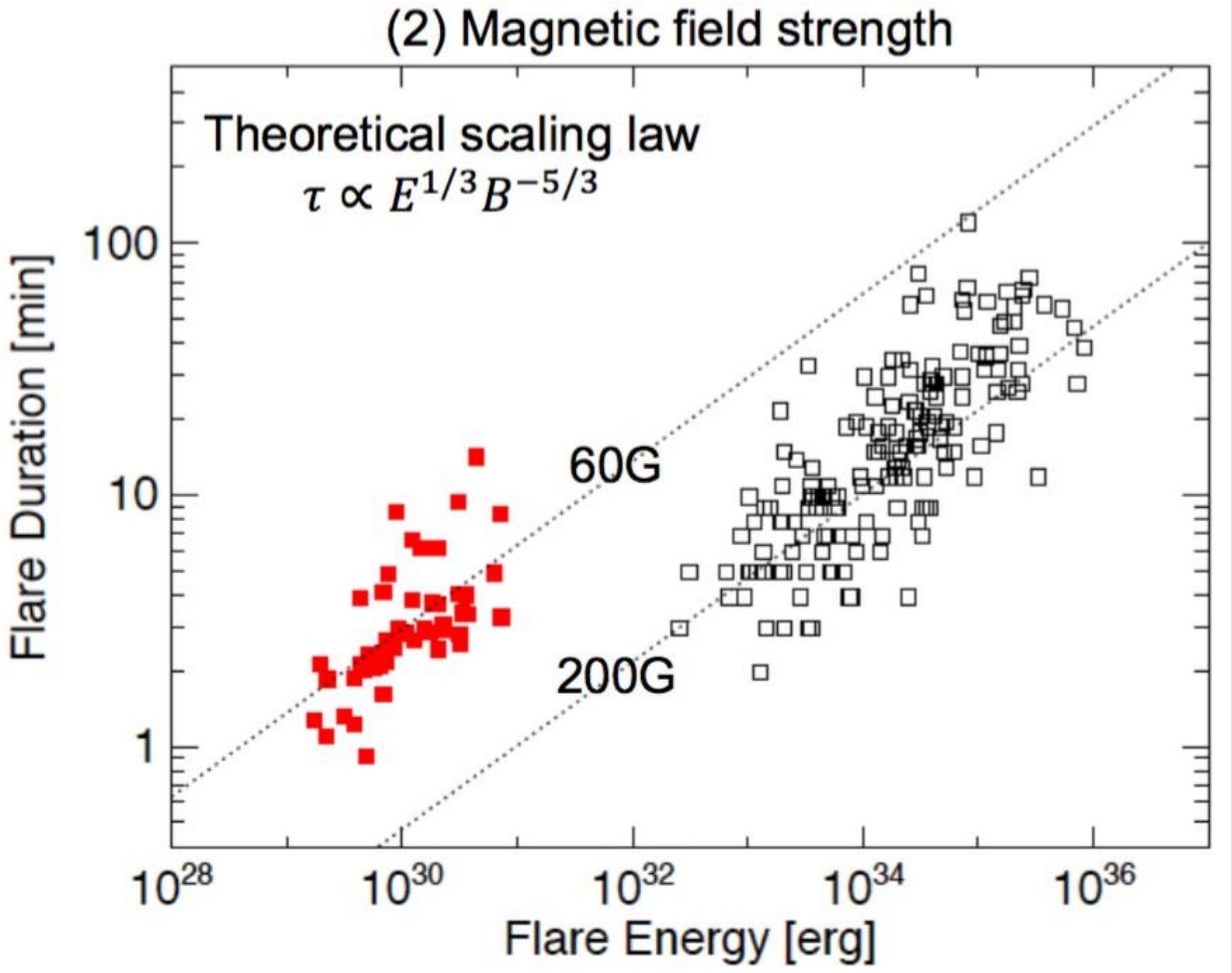

Lyne et al. 2010. tau_c~10^5-10^6 yrs



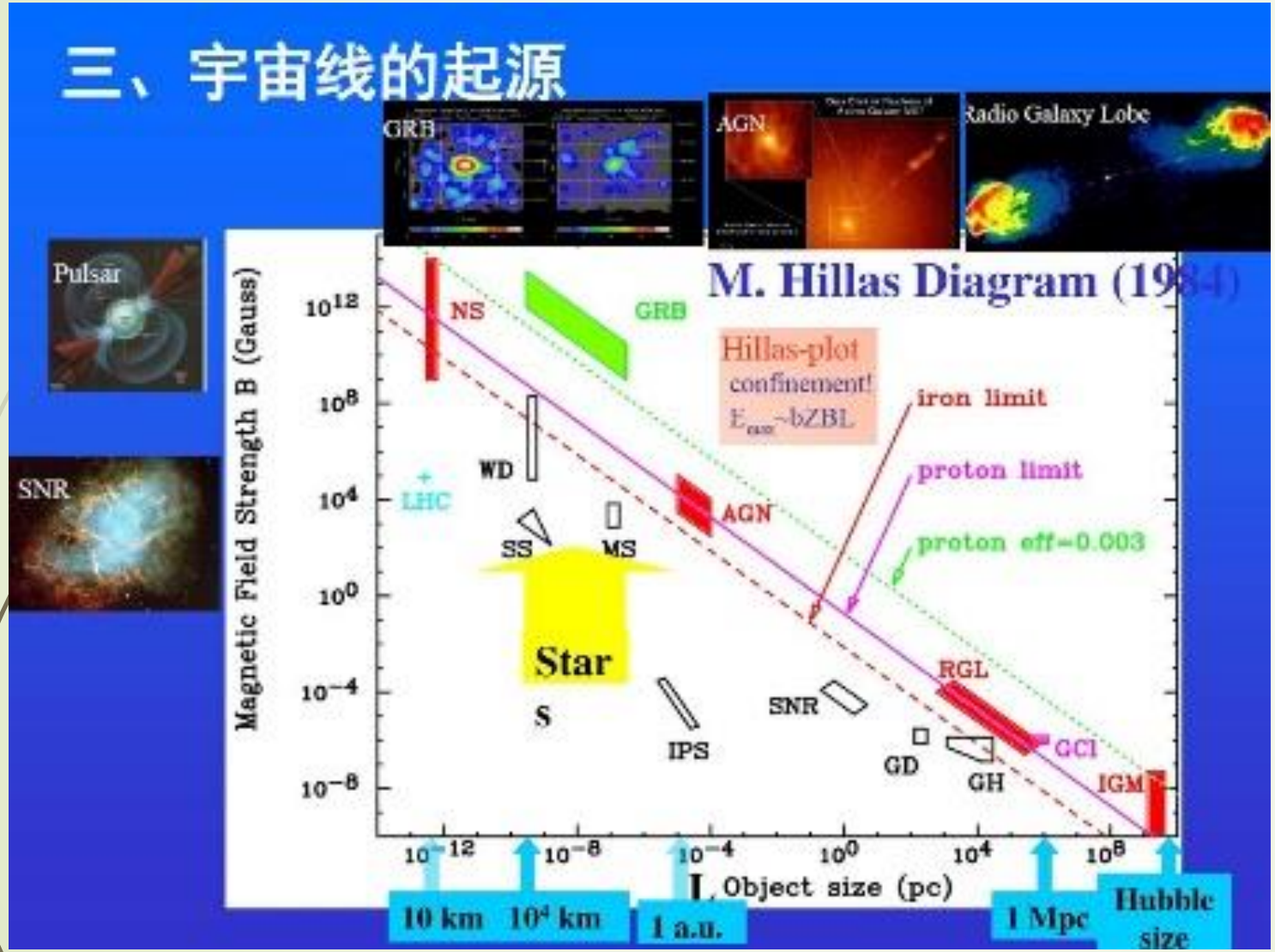




Takata et al. 2020

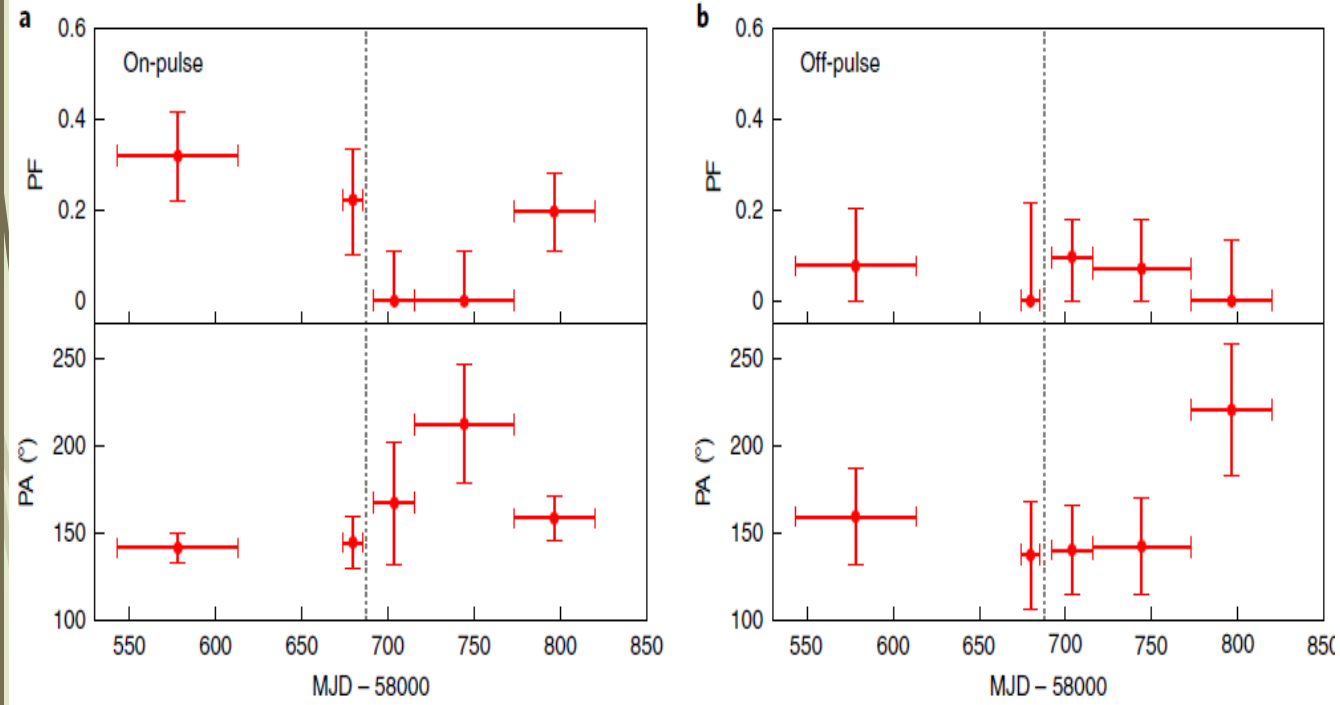

(1) Cooling Time
Flare Duration [min]
100.0
10.0
1.0
0.1
$10^{28}$
$10^{30}$
$10^{32}$
$10^{34}$
$10^{36}$
Flare Energy [erg]

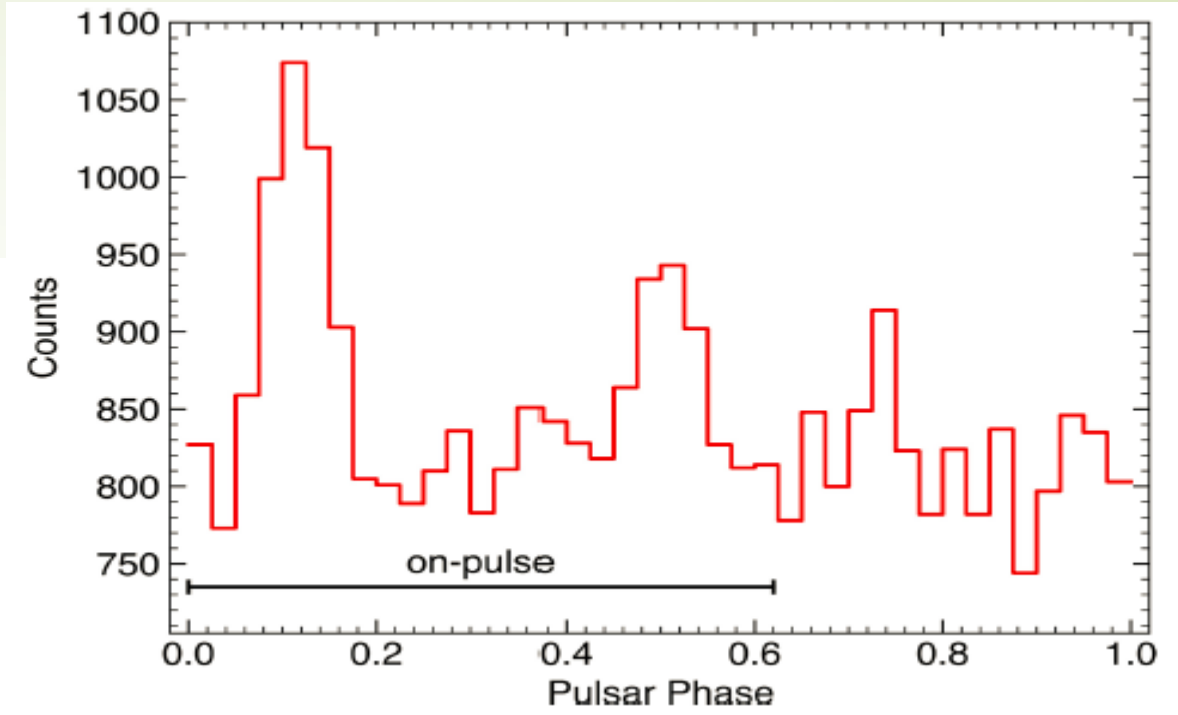

(2) Magnetic field strength
Theoretical scaling law
$\tau \propto E^{1/3}B^{-5/3}$
Flare Duration [min]
100
10
1
60G
200G
$10^{28}$
$10^{30}$
$10^{32}$
$10^{34}$
$10^{36}$
Flare Energy [erg]

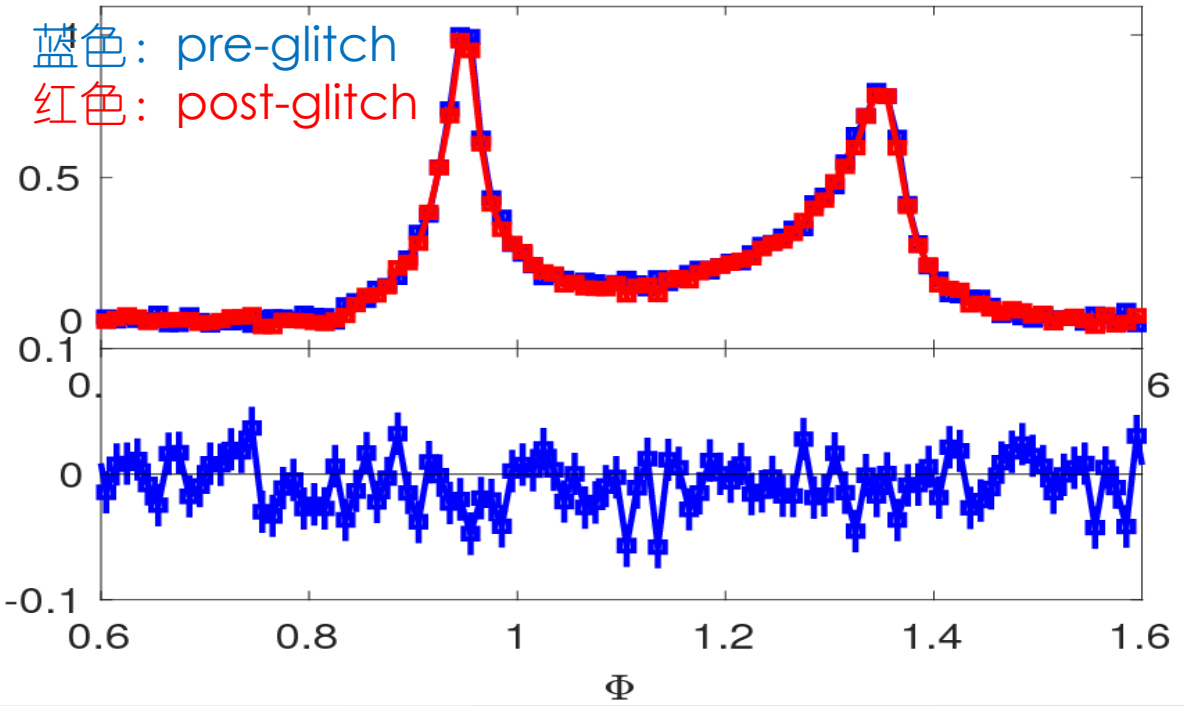
# 三、宇宙线的起源


GRB
AGN
Radio Galaxy Lobe
Pulsar
SNR
M. Hillas Diagram (1984)
Magnetic Field Strength B (Gauss)
$10^{12}$
$10^{8}$
$10^{4}$
$10^{0}$
$10^{-4}$
$10^{-8}$
NS
GRB
Hillas-plot
confinement!
$E_{max}$~bZBL
iron limit
proton limit
proton eff=0.003
WD
LHC
AGN
SS
MS
Star
S
IPS
SNR
RGL
GCI
GD
GH
IGM
$10^{-12}$
$10^{-8}$
$10^{-4}$
$10^{0}$
$10^{4}$
$10^{8}$
Object size (pc)
10 km
$10^4$ km
1 a.u.
1 Mpc
Hubble size

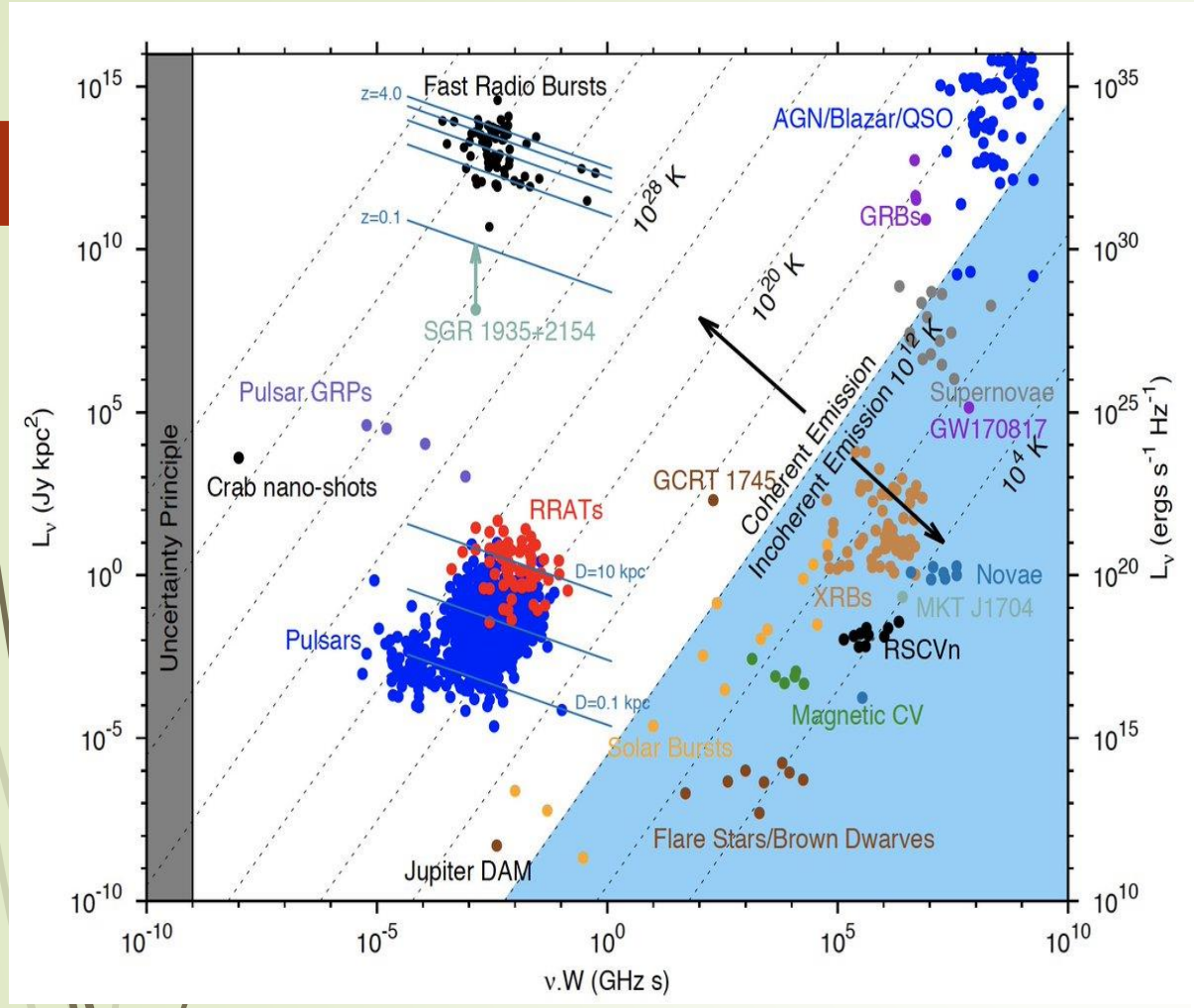
# 自转演化

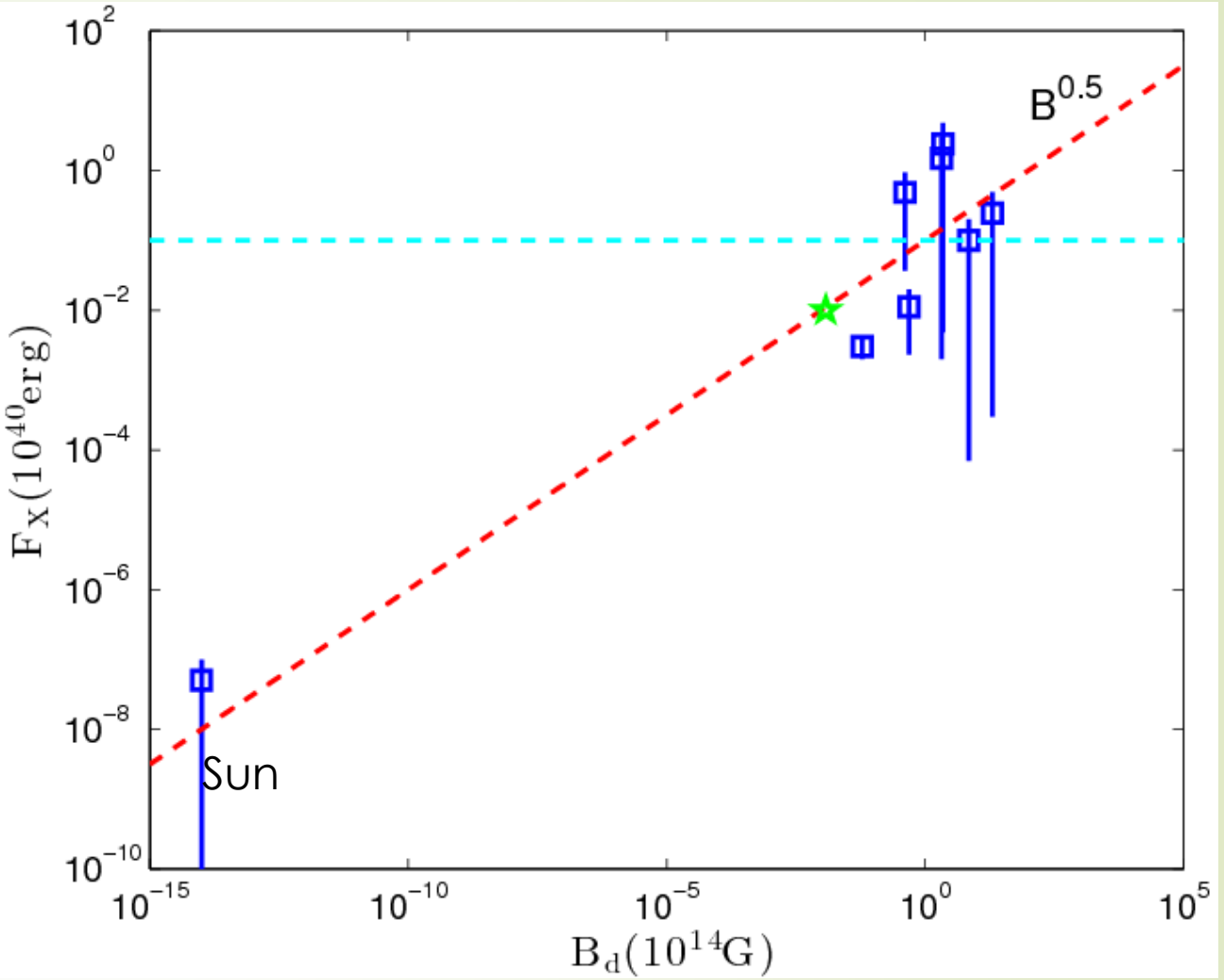



Glitch 2019 （58687.59），偏振演化
Feng et al. 2020
GBM脉冲轮廓：无显著变化




Crab pulsar glitch ?
Bs – 1e12 G ~ 1E38? (Surface)
Blc – 1e6-1e8 G ~1E34 - 1E36?