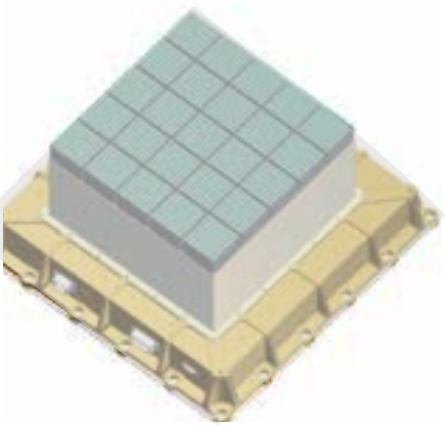
ICRC2021

Polarization measurements of the Crab Pulsar with POLAR

Hancheng Li
on behalf of POLAR collaboration



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CONTENT

1 Introduction of POLAR detector

◎ Construction

- 25 x 64 scintillator bar array
- MAPMT

◎ Capability

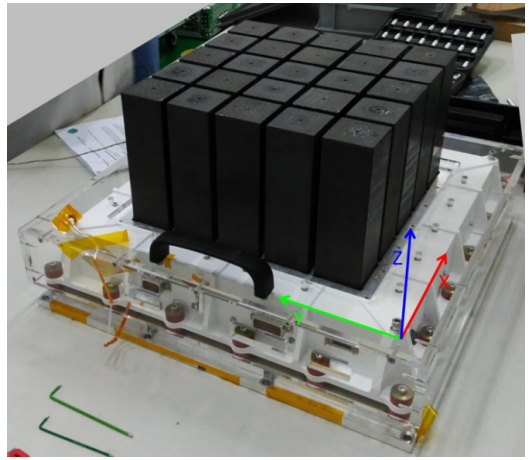
- Energy range: $15 - 500$ keV
- Eff. area: $\sim 400\ \mathrm{cm}^2$
- FoV: $\sim 2\pi\ \mathrm{sr}$

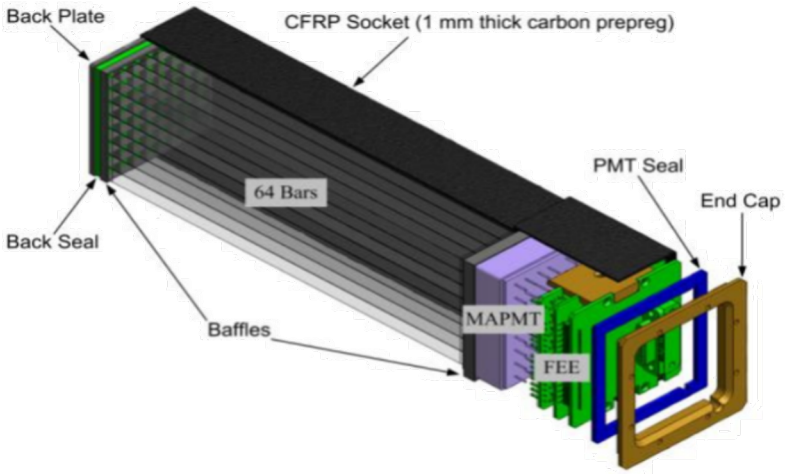
◎ Principle

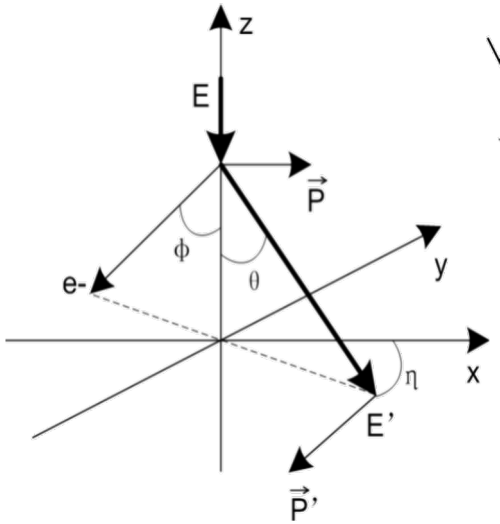
- Compton-scattering Klein-Nishina
- Modulation of azimuth angle
- Polarization reconstruction

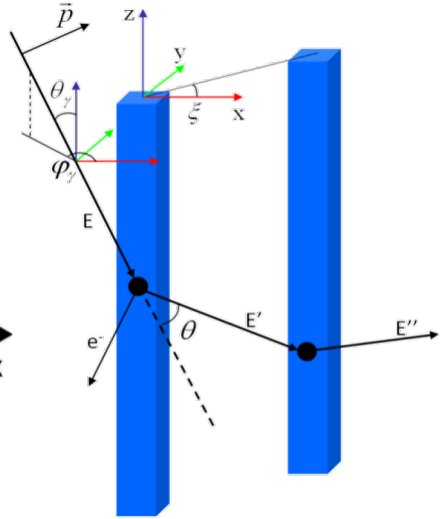
◎ Operation in orbit

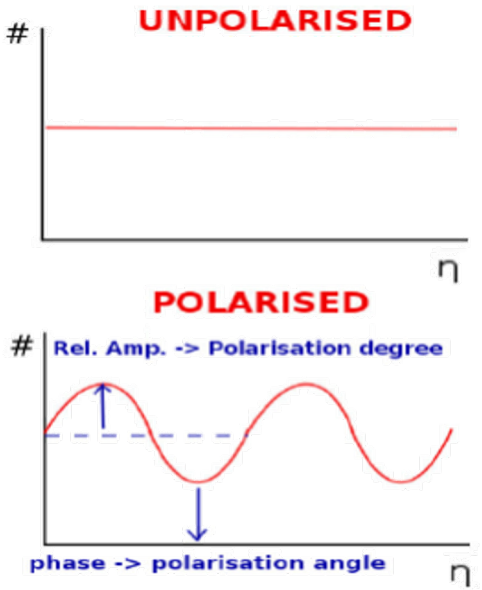
- Chinese Tiangong-2 space lab
- 2016.9.15 launch, 6 months data
- Scanning mode with wide FoV











$$\frac{d\sigma_C}{d\Omega} = \frac{r_e^2}{2}\,\varepsilon^2\left\{\varepsilon + \varepsilon^{-1} - \sin^2\theta + \sin^2\theta\cos\left[2\left(\eta + \frac{\pi}{2}\right)\right]\right\}$$

2 Pulsar search with POLAR data

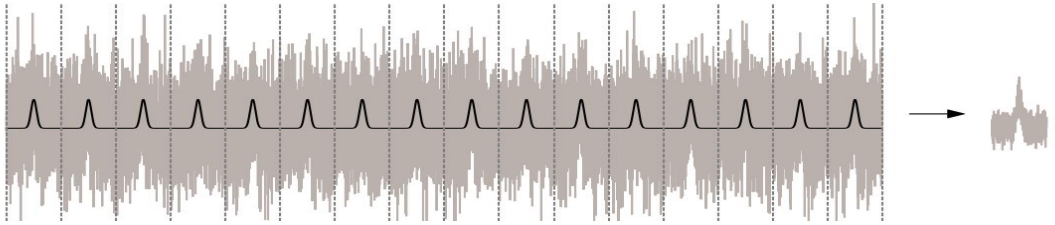
◎ Timing analysis

- Correction on time of arrival: SSB clock

$$T_{\mathrm{SSB}} = T_{\mathrm{obs}} + T_{\mathrm{clk}} + \Delta_R + \Delta_S + \Delta_E + \Delta_P + \Delta_B + \cdots,$$

- Periodic parameters and phase folding

$$\phi_i = f_0(t_i - t_0) + \frac{1}{2} f_1 (t_i - t_0)^2 + \frac{1}{6} f_2 (t_i - t_0)^3 + \frac{1}{24} f_3 (t_i - t_0)^4 + \cdots$$



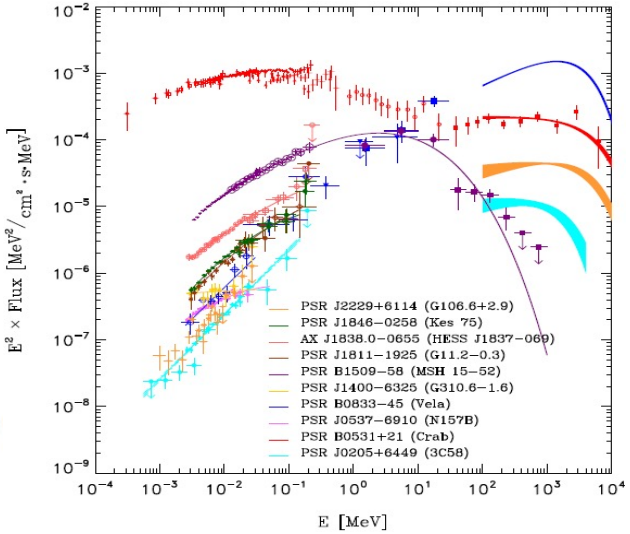


表 2.1 Crab 脉冲星和 B1509-58 的最佳自转参数

Parameters	Crab pulsar	B1509-58
t_0 (MJD)	57697.040344079745	55336.0
f_0 (Hz)	29.6484272934(4)	6.59709206418
f_1 (Hz s^{-1})	-3.689865(1)E-10	-6.6531338E-11
f_2 (Hz s^{-2})	1.16(1)E-20	1.8948E-21
f_3 (Hz s^{-3})	3.4(3)E-28	0.0

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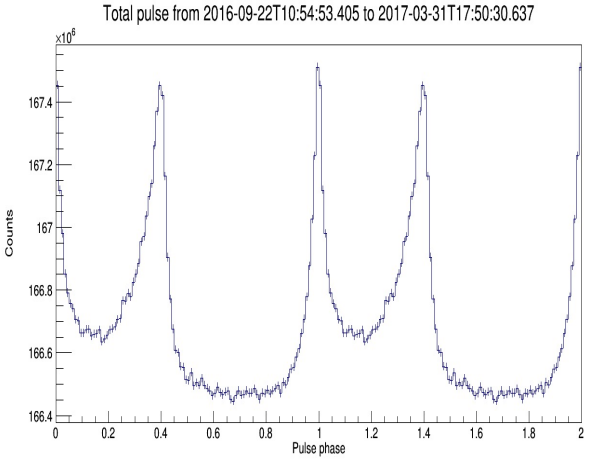
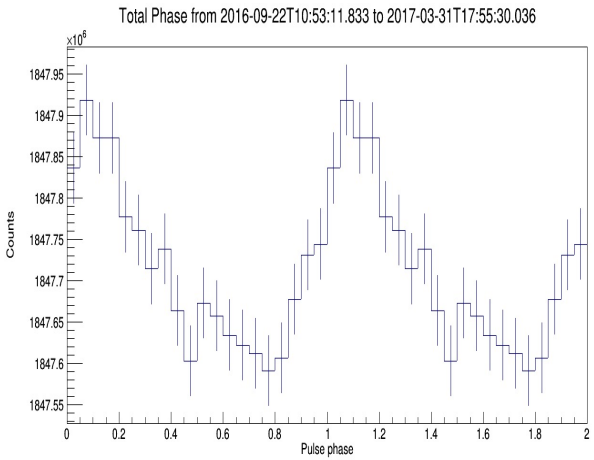




◎ Confirmed Pulsars: to be continued

- Crab Pulsar (bottom left)
- PSR B1509-58 (bottom right)

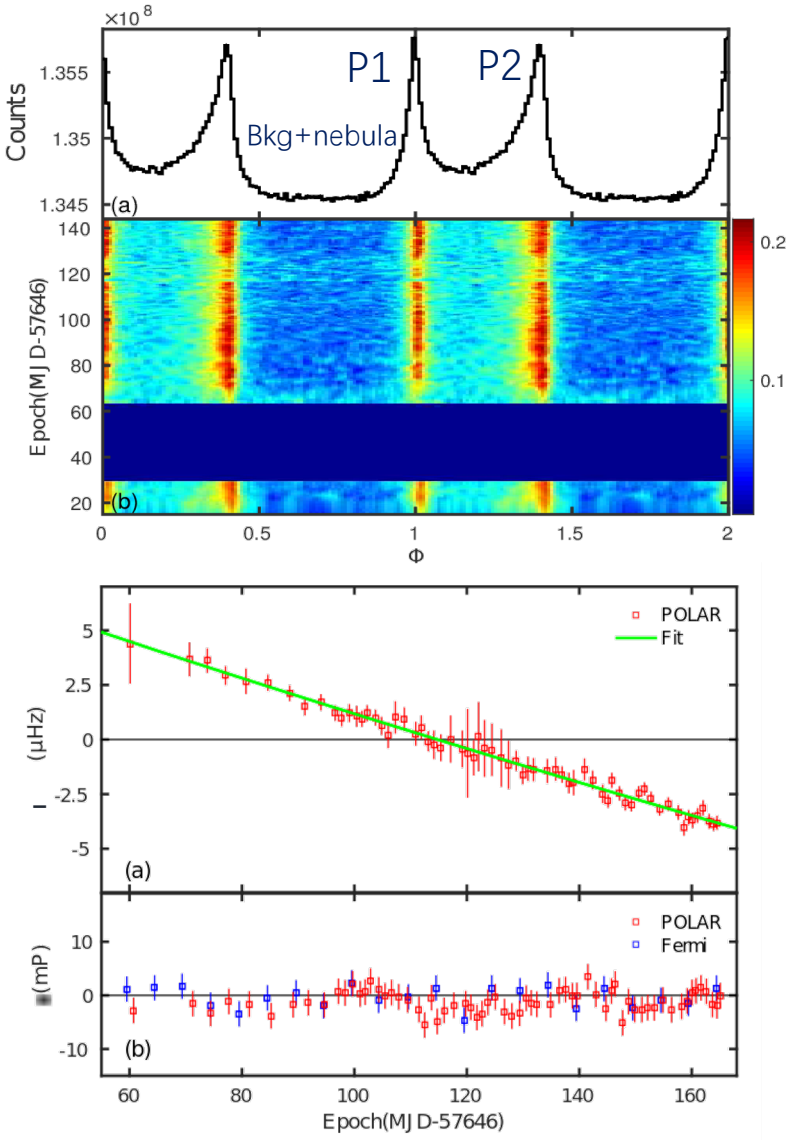
3 Spectroscopy of the Crab pulsar

◎ Pulsation v.s. time
- X-ray phase zero as ref.
- Peak aligned perfectly
- Gap->shutdown

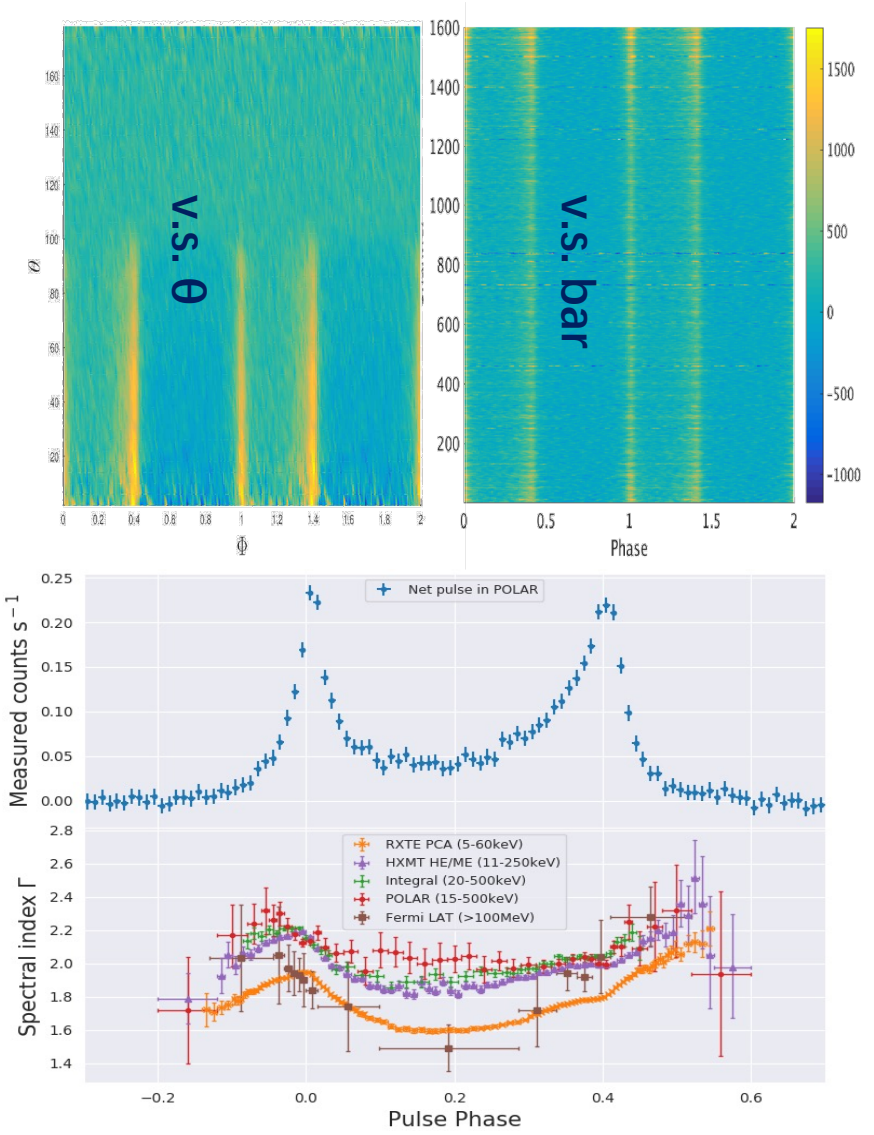
◎ Periodical para fitting
- Agree with Fermi data
- RMS ~85μs

◎ Pulsation v.s. θ & bar:
- Visibility up to 102°
- Every bar has a good detection
  > extract modulation curves

◎ Phase-resolved spectroscopy
- Comparable with other results
- Calibrated responses of POLAR



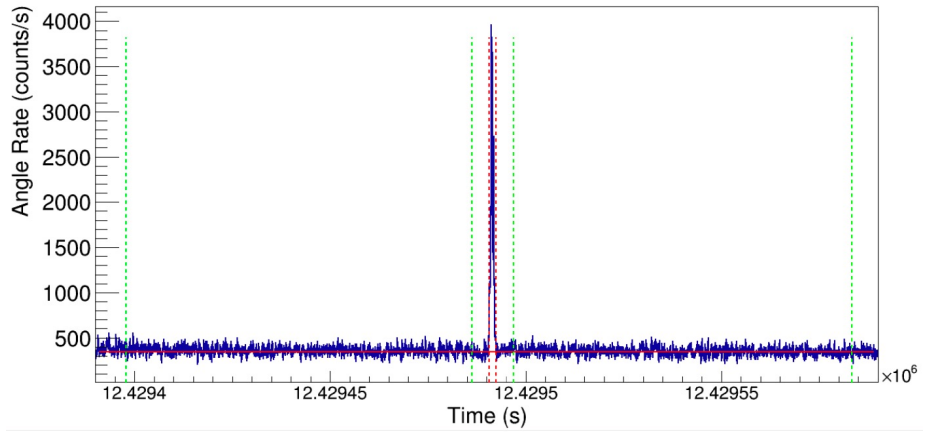
Li H.C. et al (2017)

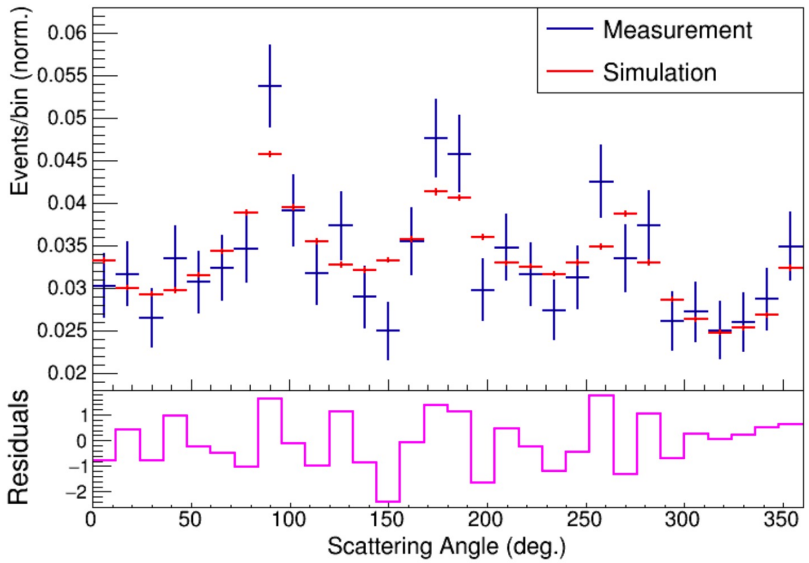


Li H.C. et al (2019)

4 Polarimetry of the Crab pulsar

GRB: use time interval to subtract BKG

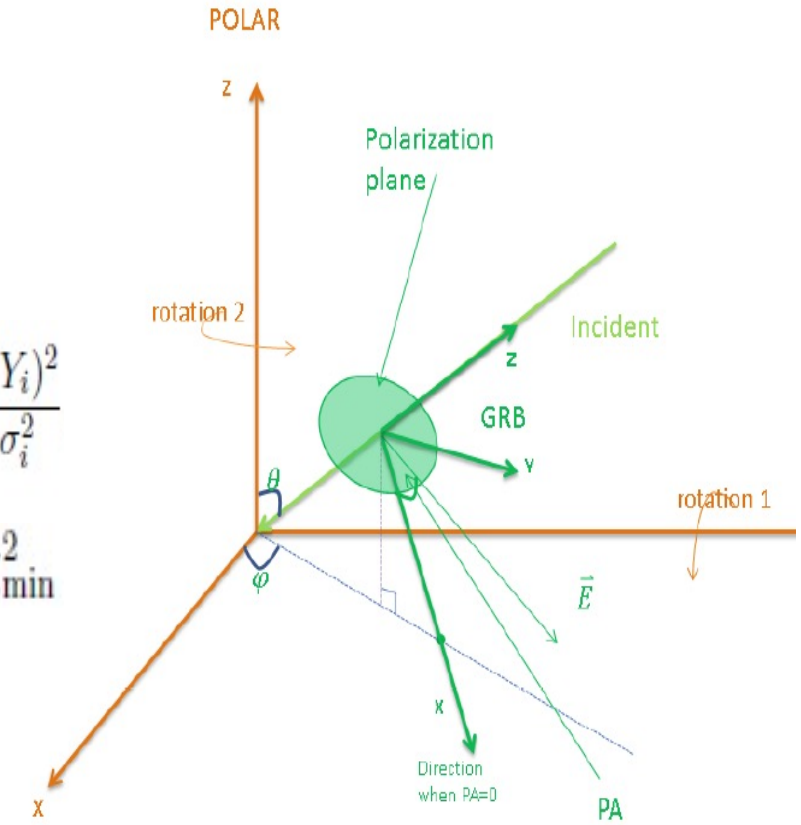


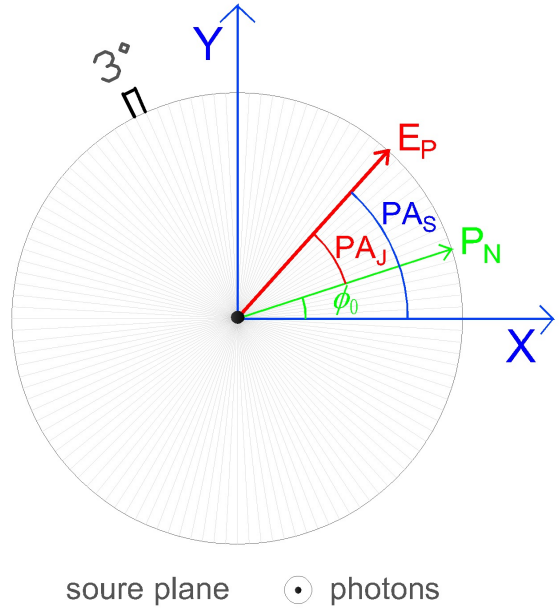


$$\chi^2 = \sum_{i=1}^{n} \frac{(X_i - Y_i)^2}{\varepsilon_i^2 + \sigma_i^2}$$

$$\Delta\chi^2 = \chi^2 - \chi^2_{\min}$$

Crab pulsar: use phase interval (0.6-0.8 bkg+nebula)
Additional para 1: incident direction
Additional para 1: rotation of the source





4 Polarimetry of the Crab pulsar

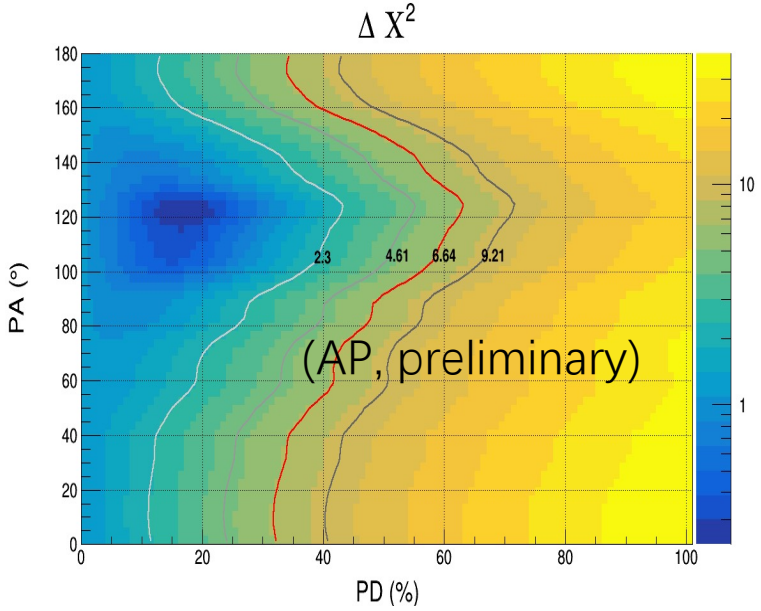
◎ Phase range:

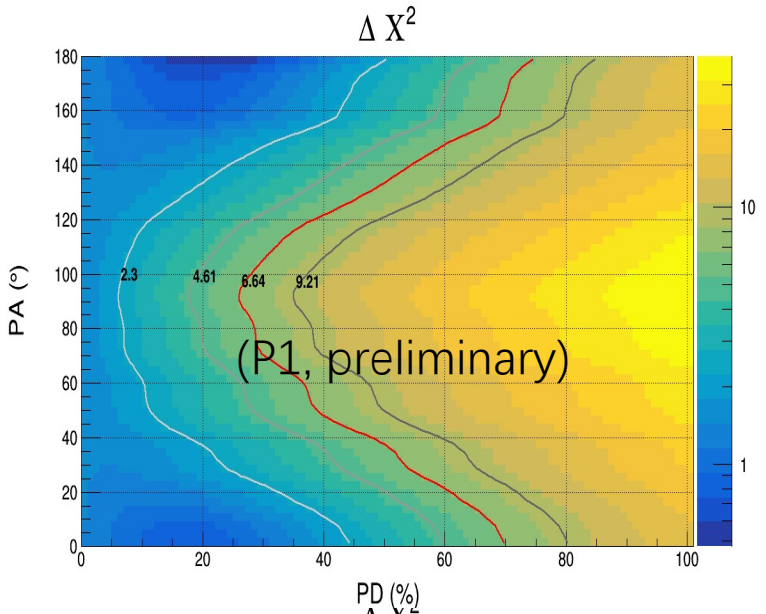
- Averaged-Phase (AP) : 0.0-1.0 ;
- P2 : 0.2-0.6 ;
- P1 : 0.8-1.2 ;

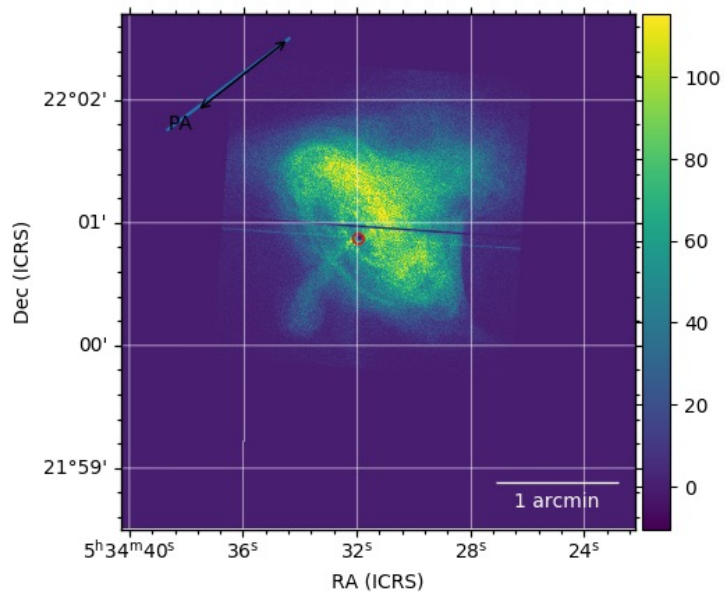
Phase range	PA(°)	PD(%)
AP (-Nebula)	120	17
P1	174	19
P2	81	23

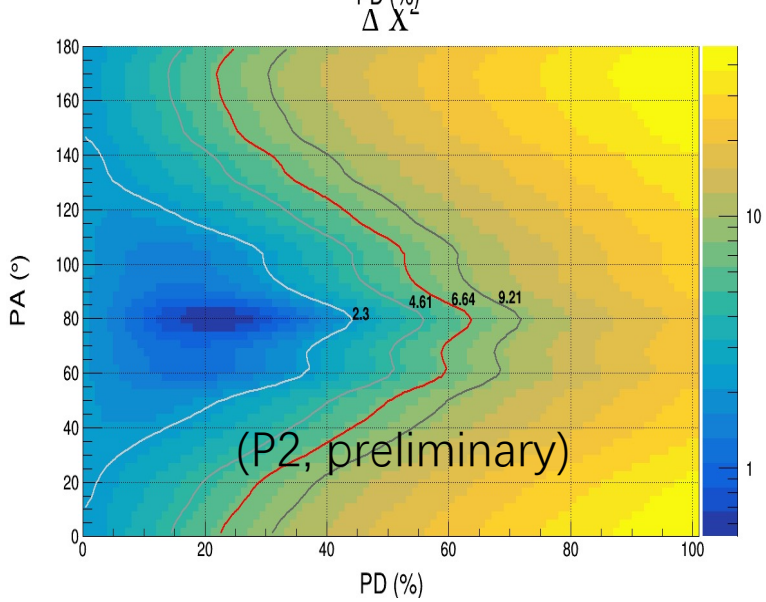
◎ Discussion

- On-going: Bayesian approach
- To be submitted soon
- Consistent with results of POGO+, etc









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Phase range	PA(°)	PD(%)
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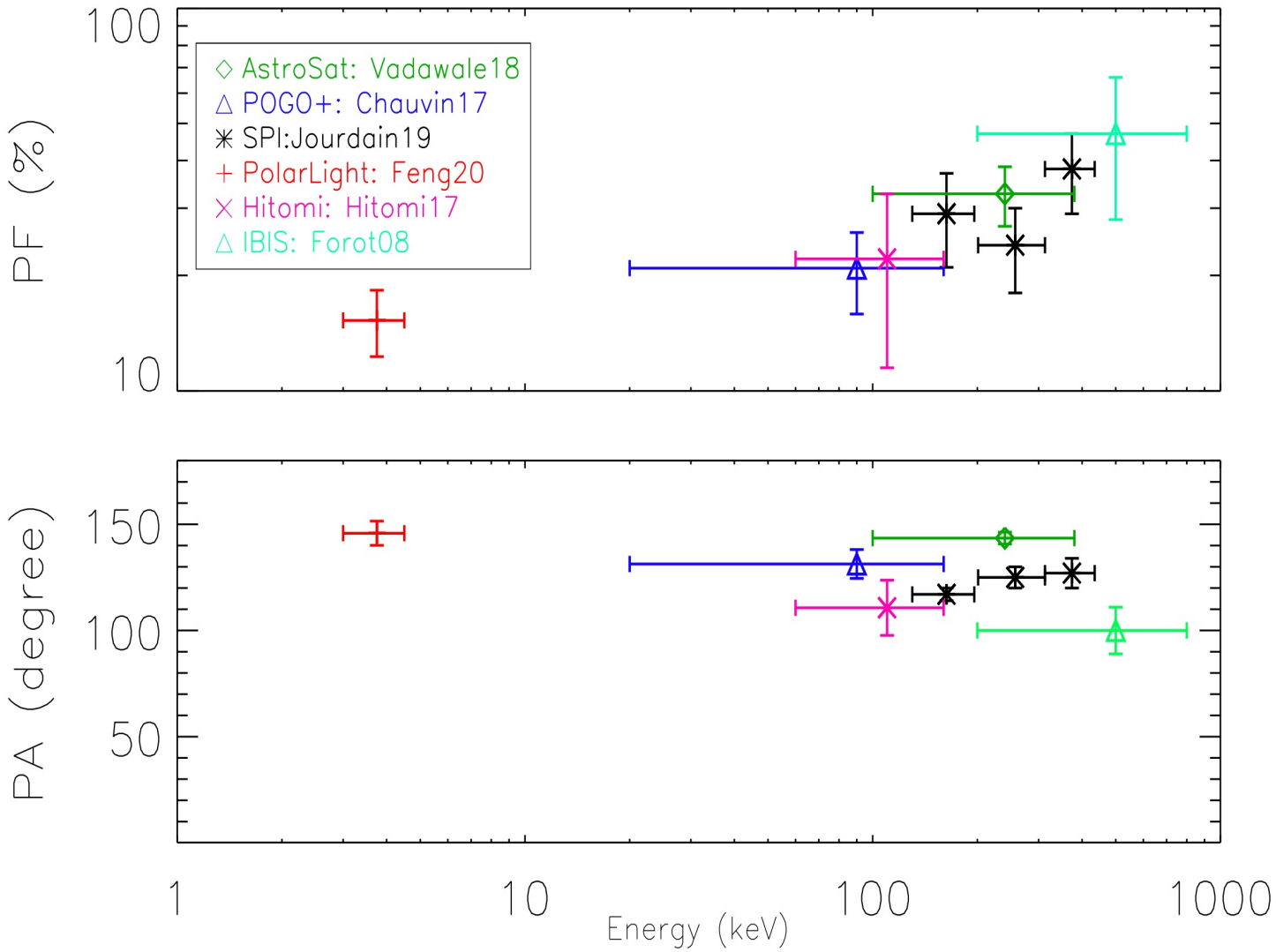
◎ Discussion

- Result of POLAR agree with others'
- Need high-precision measurement
- Need energy-resolved measurement
- Lack of measurement at ~10 keV



Arxiv: 2104.05244

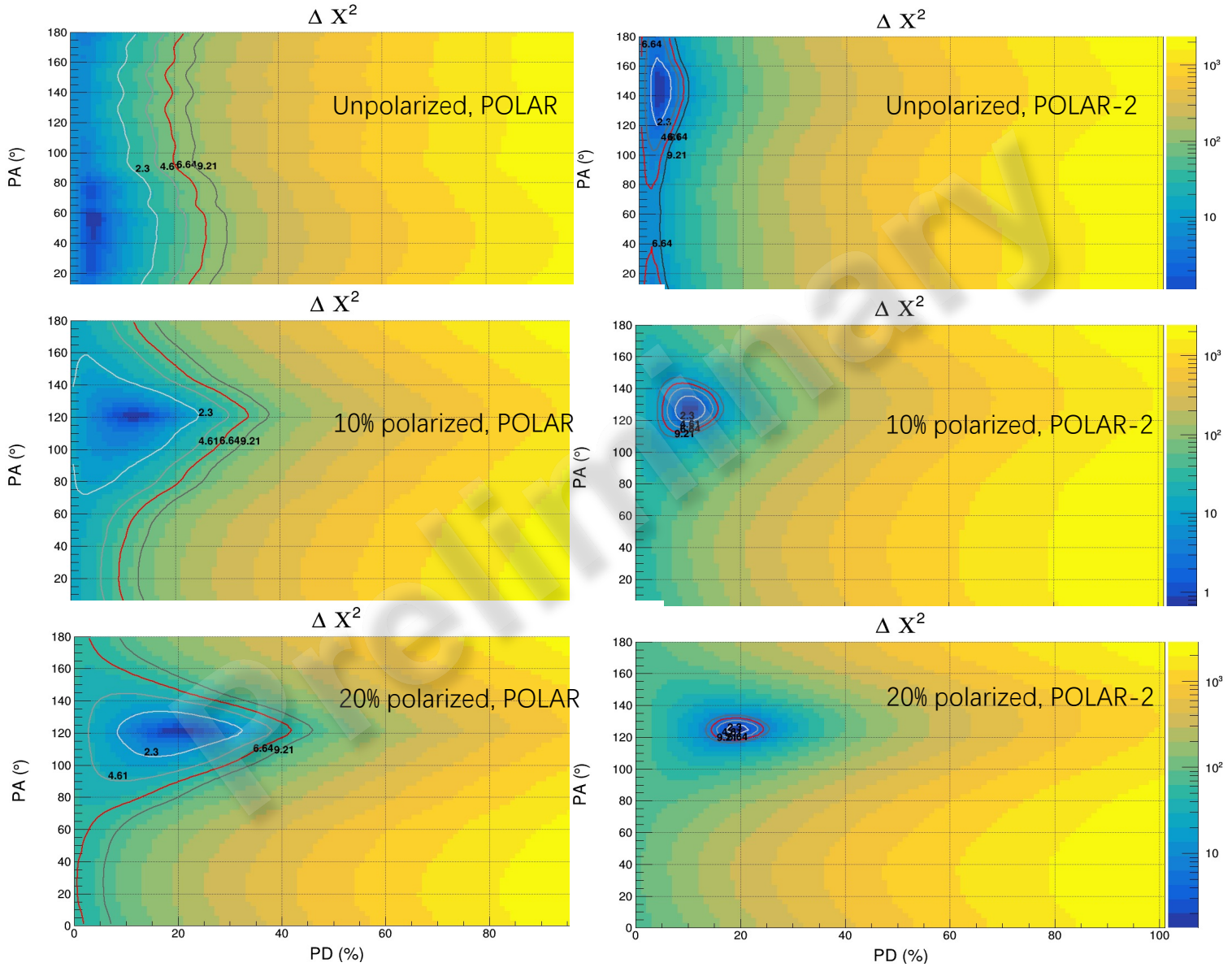
4 Polarimetry of the Crab pulsar

◎POLAR-2’ s advantages

- 4 times larger ARF
- Optimized bar length (less BKG)
- SiPM: lower energy threshold
- Longer exposure time->Higher SNR

◎ Prediction for 2 years obs.

- For a non-polarized input, it has more stringent upper-limit
- For a modest input, it could give ~5 sigma detection
- Finer Phase-resolved polarimetry
- Energy-resolved polarimetry
- Could hopefully do few more pulsars and some Solar flares…



5 Summary and outlook

- Pulsar search with POLAR data:

  A wide FoV Compton polarimeter could join in Pulsars studies

- Spectroscopy of the Crab pulsar:

  Spectral indices agree with other instruments

  Calibrated responses of POLAR from every incident direction

- Polarimetry of the Crab pulsar:

  Obtained results that are consistent with others

  Established methodology could be applied to any wide FoV polarimeter

  Could be also adapted for analysis of Long GRB/ Solar Flare

- Outlook: POLAR-2 will do these work much better than POLAR

Merci!
THANKS!
谢谢!
ありがとう!

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