Multi-frequency Study On The Mode Switching Of PSR J0614+2229

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Outline

① Background
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1. Background

- ~60 mode changing pulsars (hereafter MCPs) has been reported in 100+ papers (total no. of pulsars 2700+), ~5 MCPs with phase offset;

![Phase stable](image1)

![Phase offset](image2)
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- PSR J0614+2229 is a special and young MCP (Ferguson & Boriakoff 1980) whose intensity and phase undergo changing quasi-periodically;

Ferguson & Boriakoff 1980

Rajwade et al. 2016
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- Seymour et al. (2014) reported that the phase of normal profile is more advanced than the burst state both at 0.3 GHz and 1.4 GHz in MJD 54898;
- Rajwade et al. (2016) noticed that the relationship between pulse phase and flux inverted at 0.8 GHz in MJD 56756 compared with 0.3/0.1 GHz.
2. Our work

- We processed the longest observation from Parkes’ historical data in 50cm, 20cm and 10cm bands, and collected the data in the literature.

| ID   | MJD          | Receiver | $\nu$  | $\Delta \nu$ | $\Delta \nu_{\text{ch}}$ | $T_{\text{sub}}$ | $N_{\text{sub}}$ | $N_{\text{bin}}$ |
|------|--------------|----------|--------|--------------|---------------------------|-------------------|------------------|-----------------|
| 2005a| 53658.80926  | 5010CM   | 686    | 256          | 0.125                     | 59.6209          | 51               | 1024            |
| 2005b| 53667.80810  | H-OH     | 1369   | 256          | 0.125                     | 59.9563          | 18               | 1024            |
| 2005c| 53658.80926  | 1050CM   | 3100   | 1024         | 1.0                       | 59.6209          | 51               | 1024            |
2. Our work

- Spectral difference between two modes.

| UT        | MJD       | Telescope | $\nu$ (MHz) | $I_T$ (mJy) | $I_A$ (mJy) | $I_R$ (mJy) | $I_A/I_R$  | Ref.  |
|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-----------|-------|
| 2005 Oct. 15 | 53658.80926 | Parkes   | 653         | 6.7(5)      | 7.0(4)      | 6.0(2)      | 1.2(1)  | 2005a |
| 2005 Oct. 24 | 53667.80810 | Parkes   | 1369        | 2.2(4)      | 2.6(1)      | 1.4(1)      | 1.9(1)  | 2005b |
| 2005 Oct. 15 | 53658.80926 | Parkes   | 3100        | 0.3(2)      | 0.40(5)     | 0.19(3)     | 2.1(4)  | 2005c |
| 2009 Mar. 3-8 | 54893-54898 | Arecibo  | 327         | –           | 0.28(3$^3$) | 0.57(7$^5$) | 0.49(7$^5$) | SLR14 |
| 2009 Mar. 2-8 | 54892-54898 | Arecibo  | 1400        | –           | 0.032(4$^3$) | 0.032(4$^3$) | 1.0(2$^1$) | SLR14 |
| 2014 Apr. 9  | 56756     | LOFAR    | 150         | 88(44)      | –           | –           | –       | RSL+16 |
| 2014 Apr. 9  | 56756     | Arecibo  | 327         | 13.8(8)     | 11.1(1)     | 13.1(3)     | 0.85(2) | RSL+16 |
| 2014 Apr. 9  | 56756     | Green Bank | 820        | 16.1(1.7)   | 18.7(1.9)   | 16.4(2)     | 1.14(12) | RSL+16 |
| 2016 Jan.   | 57391     | LOFAR    | 150         | 75(32)      | –           | –           | –       | GKK+17 |
| 2007-2016   | –         | Parkes   | 728         | 8.8(8)      | –           | –           | –       | JSK+18 |
| 2007-2016   | –         | Parkes   | 1382        | 3.3(2)      | –           | –           | –       | JSK+18 |
| 2007-2016   | –         | Parkes   | 3100        | 0.76(6)     | –           | –           | –       | JSK+18 |
2. Our work

- Spectral difference between two modes.
2. Our work

- Frequency dependence of phase offset and pulse width.

| $\nu$ (MHz) | $\Delta \Phi$ (deg.) | $\Delta \mu$ (deg.) | $W_{50, A}$ (deg.) | $W_{50, B}$ (deg.) | Ref. |
|------------|----------------------|---------------------|-------------------|-------------------|------|
| 686        | 2.81(16)             | 1.44(14)            | 9.46(15)          | 6.24(15)          | 2005a|
| 1369       | –                    | 1.94(13)            | 7.34(12)          | 6.24(13)          | 2005b|
| 3100       | –                    | 1.86(17)            | 7.12(14)          | 6.06(15)          | 2005c|
| 430        | 2.15(16)             | –                   | 5.15(16)          | 4.73(16)          | FB80 |
| 327        | 1.59(54)             | –                   | 6.23(54)          | 7.26(54)          | SLR14|
| 1400       | 2.27(54)             | –                   | 7.66(54)          | 6.33(54)          | SLR14|
| 327        | 1.52(32)             | –                   | 5.80(32)          | 6.84(32)          | RSL+16|
| 820        | 1.63(16)             | –                   | 6.98(16)          | 6.30(16)          | RSL+16|
2. Our work

- Frequency dependence of phase offset and pulse width.
2. Our work

- Correlation between the peak amplitude and phase for mode B.
2. Our work

- 脉冲辐射的偏振位置角 (PPA) 可以由 RVM 模型描述：
  
  经典 RVM 模型和 SGP 点；

  \[
  \tan (\psi - \psi_0) = \frac{\sin \alpha \sin (\phi - \phi_0)}{\sin \zeta \cos \alpha - \cos \zeta \sin \alpha \cos (\phi - \phi_0)}
  \]

  \[
  \left( \frac{d\psi}{d\phi} \right)_{\max} = \left( \frac{d\psi}{d\phi} \right)_{\phi_0} = \frac{\sin \alpha}{\sin \beta}
  \]

- 相对论性 RVM 模型；

  \[
  \tan (\psi_r - \psi_s + \Delta \psi_1) \approx \frac{\sin \alpha \sin (\phi_{obs} - \phi_f + \Delta \phi_r)}{\sin \zeta \cos \alpha - \cos \zeta \sin \alpha \cos (\phi_{obs} - \phi_f + \Delta \phi_r)}
  \]

- 辐射高度。

  \[
  \Delta \phi_r \approx - \frac{2r}{R_{ic}}
  \]
2. Our work

- 偏振

![Graphs showing PPA (deg) and Flux Density (mV) at 686 MHz, 1369 MHz, and 3100 MHz.](image-url)
2. Our work

- 辐射区域
- 辐射区高度变化：$-70 \pm 40 \text{ km, } -110 \pm 70 \text{ km, } -270 \pm 150 \text{ km}$

| Freq/MHz | Mode | $L_{10}/^\circ$ | $R_{10}/^\circ$ | $\phi_{\text{prof}}/^\circ$ | $\phi_0/^\circ$ | $\psi_0/^\circ$ | $r_{\text{BCW}}/ \text{ km}$ |
|----------|------|----------------|----------------|-----------------|----------------|---------------|------------------|
| 686      | A    | 76.0(6)        | 90.5(1.1)      | 83.3(6)         | 90.7(2)        | 39.3(9)       | 520(40)         |
| 686      | B    | 77.6(5)        | 90.2(5)        | 83.9(4)         | 91.2(2)        | 41.7(9)       | 510(30)         |
| 1369     | A    | 269.8(7)       | 283.8(5)       | 276.8(4)        | 284.1(2)       | -30.8(9)      | 510(30)         |
| 1369     | B    | 271(2)         | 284(1)         | 278(1)          | 284.9(5)       | -28(2)        | 480(80)         |
| 3100     | A    | 287(1)         | 300.5(8)       | 293.8(7)        | 299.1(5)       | 57(2)         | 370(60)         |
| 3100     | B    | 289(2)         | 300.3(9)       | 294.6(9)        | 301(1)         | 64(6)         | 450(90)         |

注：括号中为参数末位的误差值。
2. Our work

- 辐射区域
- 辐射区高度变化: \(-70 \pm 40 \text{ km}, -110 \pm 70 \text{ km}, -270 \pm 150 \text{ km}\)
- 辐射区经度变化:
2. Our work

- Implication to spectral properties of the emission beams.
3. Summary

- Mode dependent spectra
- Mode dependent Thorsett relationships
- Frequency independent phase offset
- Mode dependent phase-flux correlations
- 磁场位形在模式变换时基本不变
- SGP点偏移方向和辐射窗口中心偏移方向相同

- 辐射区高度: A < B
- 辐射区经度: A < B
- Different spectral distributions

- Phase-resolved spectra
4. References

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Thanks for Your Attention!