## **Pulsar Emission Mechanism**



## Michael Kramer

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# **A pulsed signal from space**





# **...and the emission is broadband**





with exceptions...

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#### **Flux density across frequencies**  $\overline{ }$  $\overline{\mathbf{B}}$ PO BOAT BILLION (MHz) *S* (mJy) *S* (mJy)



sumption that we can successfully correct for diffractive effects



 $\mathbf{G}$ epochs adjacent to our observing period, we take the value of  $\sim$ 

Fundamental Physics in Radio Astronomy Max-Planck-Institut für Radioastronomie to diffractive and refractive ISS, resulting in the intrinsic flux

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Fundamental Physics in Radio Astronomy Max-Planck-Institut für Radioastronomie to diffractive and refractive ISS, resulting in the intrinsic flux

# **Spectra: normal pulsars**



See Maron et al. (2000) – Spectral index mean -1.7 Spectral change at mm-wavelengths? (e.g. Kramer et al. 1997)



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# **Spectra: normal pulsars**



See Maron et al. (2000) - Spectral index mean -1.7 strongly suggesting again that the spectrum is changing, i.e., i.e., i.e., i.e.,  $\alpha$ 

Spectral change at mm-wavelengths? (e.g. Kramer et al. 1997) Ciral Change at min-wave. triggered the observations of  $B_3$  at  $87.55$  $t_{\text{ref}}$  of  $\alpha$  in some pulsars at  $\alpha$ millimeter (e.g. Kramler et al. W  $\frac{1}{2}$ 



Fundamental Physics in Radio Astronomy **Max-Planck-Institut für Radioastronomie**  $H = H \times H$  is a great help with the observations and  $\mathbf{F}$ 

stimulating discussions. We are grateful to the receiver

# **Spectra: millisecond pulsars**



Mostly simple power laws

Kramer et al. (1999)

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# **Nulling**

Single pulses of PSR 1133+16





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# **Nulling**

#### $\blacksquare$ Ses of PSR 1133+16  $\blacksquare$

80

80



6.1. Comparison with previous nulling studies

# **Average pulse shape is (usually) stable**





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# **Profile changes: moding**



A mode change in the radio emission from the pulsar PSR1822 — 09

D. Morris<sup>\*</sup>, D. A. Graham and N. Bartel Max-Planck-Institut für Radioastronomie, Aufdem Hügel 69, D-5300 Bonn 1, Federal Republic of Germany

Received 1980 October 6

<sup>1</sup> Introduction

Summary. A mode change has been detected in the 1720-MHz and 2650-MHz radiation from PSR  $1822 - 09$ . At low average intensities the first component of the main pulse abruptly drops to very small intensity. To within our measurement errors the interpulse remains unchanged. The evidence is consistent with a model in which the main pulse and interpulse originate at opposite magnetic poles.

This note is to report the detection of a mode change in the radio frequency radiation from



# **Profile changes: moding**

## See Backer (1970)

# (e)  $B1237+25$

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Fig. 1.2. Integrated pulse profiles for a sample of nine pulsars. With the

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#### **Multifrequency study of PSR 1822-09**

J.A. Gil<sup>1,2</sup>, A. Jessner<sup>1</sup>, J. Kijak<sup>1,2</sup>, M. Kramer<sup>1</sup>, V. Malofeev<sup>1,3</sup>, I. Malov<sup>3</sup>, J.H. Seiradakis<sup>1,4</sup>, W. Sieber<sup>5</sup> and R. Wielebinski<sup>1</sup>

- <sup>1</sup> Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
- <sup>2</sup> Astronomical Centre, Pedagogical University, Lubuska 2, 65-265 Zielona Góra, Poland
- <sup>3</sup> Radio Astronomy Department, P.N. Lebedev Physical Institute, Academy of Sciences, 117924, Moscow, Russia
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Received February 4, accepted August 6, 1993



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sight and the beam centre. 1981MNRAS.194P <sup>1</sup> Introduction

# **Profile changes: millisecond pulsars**



Fig. 1. Aramer et al. (1999) as seen as seen as seen of PSR Julie changes of PSR Julie 2014



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# **Profile changes: millisecond pulsars**

THE ASTROPHYSICAL JOURNAL LETTERS, 867:L2 (7pp), 2018 November 1 https://doi.org/10.3847/2041-8213/aae713 © 2018. The American Astronomical Society. All rights reserved.



Mode Changing and Giant Pulses in the Millisecond Pulsar PSR B1957+20

Nikhil Mahajan<sup>1</sup>  $\Phi$ , Marten H. van Kerkwijk<sup>1</sup>  $\Phi$ , Robert Main<sup>1,2,3</sup>  $\Phi$ , and Ue-Li Pen<sup>2,3,4,5</sup> <sup>1</sup> Department of Astronomy and Astrophysics, University of Toronto, 50 St. George Street, Toronto, ON M5S 3H4, Canada; mahajan@astro.utoronto.ca<br><sup>2</sup> Canadian Institute for Theoretical Astrophysics, University of Toronto, <sup>4</sup> Perimeter Institute for Theoretical Physics, 31 Caroline Street North, Waterloo, ON N2L 2Y5, Canada<sup>5</sup> Canadian Institute for Advanced Research, 180 Dundas Street West, Toronto, ON M5G 1Z8, Canada Received 2018 July 1; revised 2018 October 1; accepted 2018 October 8; published 2018 October 24





#### Profile changes: long-term changes varying with time. Any variability in the profile adversely affects d. Iuik-luiin c nificant change in the average pulse pulse profile of PSR  $\alpha$  $A \cap C$ published profiles of this pulsar. Table 1 includes a summary of available data, where the date and observing frequency are given

*A transient component in PSR J0738*−*4042* 253

phenomenon; there are no contradictory observations at a particular frequency. This is clearly seen in the representative,  $\ell$ noise ratio (S/N) profiles in Fig. 1, all showing additional leading





#### **The Finest Measurement Ever Made?**

HERE'S AN ASTRONOMY TRIVIA QUESTION: What is the smallest individual thing that has been observed at the largest distance? Three radio astronomers at Iodrell Bank in England can lay good claim to having the answer. The item in question is only 0.1 millimeter tall, yet the astronomers measured it from about

12,000 light-years away - a size-to-distance ratio of  $10^{-24}$ 

This observation, as many readers will guess, involves a pulsar, an ultradense neutron star some 20 kilometers wide spinning roughly once a second. Pulsars would provide many entries in any Guinness Book of Physics Records. Using the



# **Profile changes: periodicities**

### PSR B1828-11



January 2001 | Sky & Telescope

Stairs et al. (2000)

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## **Intermittent pulsars**

- Distinct phases of radio silence, up to two years!
- First, B1931+24, week/month timescale
- Spin-down changes with changing plasma
- Unique insight into magnetosphere
- Several more now known
- Difficult to find (and confirm)
- Significant fraction of population?





## **Timing noise, mode changing, nulling & intermittency**

Lyne et al. (2010)



## **Magnetars: almost all radio quiet**

- Some magnetars visible as transient radio sources
- Radio triggered by outburst?
- Emission properties with similarities to pulsars but also different
- Complementary information to high energies
- First discovery of magnetar in radio blind search (Levin et al. 2010)
- Four radio-loud magnetars known, one in Galactic Centre (Eatough et al. 2013, Torne et al. 2015, 2016)
- Timing very noisy related to profile changes?



 $\ldots$   $\ldots$   $\ldots$   $\ldots$   $\ldots$ Levin et al. (2019)



Pulse Phase (msec)





- Elliptically polarised
- Up to 100%
- Often S-like PA swing
- Degree of polarisation lower at high freq.



## **Orthogonal modes**







#### **Orthogonal modes** 1<br>|
| removal of baselines, the data were corrected for cross-talk  $\blacksquare$  modac power.





## **Orthogonal modes – not always broadband**



# **Profile properties**







# **Profile properties**







#### **Profile properties - MSP**  $d_{\alpha}$  is not considered as  $f(x)$ re properties - i highly polarized depolarize rapidly, while the weakly polobserved for MSPs.



 $2.7$  and 4.9 GHz, the observed changes are fairly small, the observed changes are fairly small, the observed changes are fairly small, the contract of the c

 $5000$  internal with reference to the peaks of the peaks of the peaks of the outer-



# **Profile properties – A comparison**





# **Profile determined by line-of-sight**





# **Profile determined by line-of-sight**





# **Patchy vs cone**





## **In reality**

Desvignes et al. (2019)





#### **(Spherical) Geometry** In the simple picture, plasma flows from the surface along the open



$$
\sin^2\left(\frac{W}{4}\right) = \frac{\sin^2(\rho/2) - \sin^2(\beta/2)}{\sin\alpha \cdot \sin(\alpha + \beta)}
$$

and angular radius of the emission cone, ρ.

angle of the cone

$$
\cos \rho = \cos \alpha \cos(\alpha + \beta) + \sin \alpha \sin(\alpha + \beta) \cos\left(\frac{W}{2}\right)
$$

$$
(4 f) \sin \alpha \cdot \sin(\alpha + \beta)
$$
  
(Gil *et al.* 1984). Sometimes, the equivalent form 
$$
\tan \theta = -\frac{3}{2 \tan \rho} \pm \sqrt{2 + \left(\frac{3}{2 \tan \rho}\right)^2}
$$

 $20$  and  $20$  and  $20$   $\pm$  30°, this relationship simplifies to  $\pm$  20°  $\pm$ 

Equation (3.23) is valid for the last open dipolar field lines, the opening



#### **Rotating Vector Model** ponents both follow points both follow products for the scaling values for the scaling values for the scaling factor, kinner  $\mathbf{S}$  and  $\mathbf{S}$  and  $\mathbf{S}$  and  $\mathbf{S}$  and  $\mathbf{S}$  and  $\mathbf{S}$ (1993). However, the interpretation of the interpretation of the data remains controversial remains controversial remains controversial remains controversial remains controversial remains controversial remains controversi



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## **Best evidence for RVM interpretation**

New results on relativisitic binary (Desvignes, et al. 2019)

- Our line-of-sight has crossed the pole of interpulse!

-





#### **Emission heights: geometrical** and is shown in Figure 3.4. For regions close to the magnetic axis (i.e. θ <sup>&</sup>lt;<sup>∼</sup> heights: geometrica ical



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**Emission height...?** and provincial simplifies to experimental simplifies to experime and is shown in Figure 3.4. For regions constanting  $\frac{1}{2}$ 



## **Aberration effects: PA vs Profile shifts**



## **Aberration effects: PA vs Profile shifts**







## **Aberration effects: PA vs Profile shifts**



## **Emission heights as function of distance to pole**









## **Emission heights as function of distance to pole**



gives a large beaming fraction of 0.52 but with

Distance from magnetic axis (deg)

axis for the pulsars in our sample. The green shaded area indicate





## **Emission heights as function of frequency**









## **Acceleration gaps**







## **Acceleration gaps**





## **On the emission mechanism**

- Radio is only tiny fraction of energetics
- It has to be coherent
- Properties are determined by coherent mechanism
- It may (must) break down at a certain frequency
- It cannot be synchrotron emission
- There is always curvature radiation, but not sufficient
- Plasma radiation process, e.g. free electron maser?
- Current flow is understood
- New computations are promising
- Questions remain:

beam structure, nulling/moding/drifting, emission height





