Observing pulsars at (sub)millimetre wavelengths

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Introduction

Pulsars

The Crab Nebula

Pulsars

The Crab Nebula

X-ray: NASA/Chandra; Optical: Nasa/Hubble; Infrared: NASA/Spitzer.

Point-like masses with ultra-precise clocks attached
• Pulsars enable **high-precision astronomy in a wide variety of fields**, e.g.:

**Interstellar medium**
- J. Williamson

**Gravity tests**
- jb.man.ac.uk

**Gravitational Waves**
- D. Champion (MPIfR)

**Ultra-dense matter**
- ESO

**Binary evolution**
- NASA/CXC/M. Weiss

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JCMT Users Meeting, ASIAA - Taipei, 6–8 November 2019
1. Understand Radio Emission Mechanism

- Models make predictions that we can try to test with observations
- Emission processes can be frequency dependent
- Some effects may only be observable at very short wavelengths (< ~few mm)
  * (Sub)Millimetre regime is a very valuable input for models
  * VERY scarce data available (4 PSRs at 3mm and 2 mm and 2 PSRs at 1 mm)

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2. Pulsars in the Galactic Centre

- Galactic Centre contains very promising pulsar systems
  - Probe gravitational potential of the region
  - Star forming history
  - Measure Galactic Centre gas properties with precision
  - Pulsar – Supermassive Black Hole system

★ … and the strongest scattering in the Galaxy

\[ \tau_{\text{scattering}} \propto \nu^{-4} \]

see e.g., Lorimer & Kramer (2005)
2. Pulsars in the Galactic Centre

- **Pulsar – Supermassive Black Hole = Best Gravity / Black Hole laboratory in the Galaxy**
- A powerful **synergy** with the S-stars and the black hole shadow

K. Liu et al. (2012)

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**Stars**

Credit: BHC

**EHT shadow**

Credit: EHT Collaboration et al. (2019)

**Pulsars**

Credit: MPIfR/N. Wex

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see Psaltis, Wex & Kramer (2016)
Main challenge to study pulsars at short-\( \lambda \)

- Pulsars are generally **extremely faint** radio sources
- **Steep spectral sources** → even weaker at short wavelengths

Objectives at (sub)mm-\( \lambda \):

\[
\alpha < -1.2 \quad (70 \text{ pulsars})
\]

\[-0.5 < \alpha < +1.0 \quad (\text{Magnetars})\]

Steep spectrum *on average*

\[
S \propto \nu^\alpha
\]

\(<\alpha> = -1.8 \pm 0.2
\]

Maron et al. (2000)
Observing pulsars at (sub)mm- wavelengths

- To be able to detect the weak pulsations at short wavelengths we need sensitivity:
  - Good sites for low $T_{\text{sky}}$
  - Big collecting areas for high Gain
  - “Nice” receivers $\rightarrow$ Low $T_{\text{rec}}$, 'Gaussian' noise properties
  - Large bandwidths

Minimum detectable flux density at S/N level

$$S_{\text{min}} = \beta \frac{(S/N_{\text{min}}) T_{\text{sys}}}{G \sqrt{n_p t_{\text{obs}}} \Delta \nu}$$

- Good sites and state-of-the-art receivers
- Big collecting areas
- Long integration times
- Large instantaneous bandwidths
Focus on the Instantaneous Bandwidth

- Bolometer / Kinetic Inductance (KID) technology
- Large instantaneous bandwidths at (sub)mm- telescopes
- See e.g., SCUBA2 @ JCMT: Holland et al. (2013), NIKA2 @ IRAM 30-m: Adam et al. (2018)

\[ S_{\text{min}} = \beta \frac{(S/N_{\text{min}}) T_{\text{sys}}}{G \sqrt{n_p t_{\text{obs}}} \Delta \nu} \] [Jy]

Bolometers / KIDs up to 2-3x more sensitive than typical SiS Rx

but can they be used to observe pulsars?

https://www.eaobservatory.org/jcmt/instrumentation/
See also Holland et al. (2013)
First Pulsar Detection with KID camera

- Magnetar AXP1810–197 with NIKA2 @ IRAM 30-m, 1 hr observation on 23-March-2019
- Proof of concept, no major issues. Worked beautifully well!

Time series with 2 mm array
(1.3 mm not shown)

Sampling time ≈ 43.7 ms

Individual pulsations of the neutron star seen!

+ “well-behaved” noise

Torne et al. in prep

Future, and how could JCMT help

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JCMT Users Meeting, ASIAA - Taipei, 6–8 November 2019
JCMT well suited for [1 – 0.4] mm window

Future, and how could JCMT help

PSR J1745-2900
(2014 July 21-24th + Aug 24th)

Averaged Mean Flux Density (mJy)

Frequency (GHz)

PSR J1745-2900
(2015 March 4-9th)

Averaged Mean Flux Density (mJy)

Frequency (GHz)

Torne et al. (2015)

Torne et al. (2017)
JCMT well suited for [1 – 0.4] mm window

Future, and how could JCMT help

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Summary

(Sub)mm- observations cover a window of pulsar emission highly unexplored, enabling certain tests of emission models not possible only at cm-wavelengths.

At short millimetre wavelengths the scattering effect is negligible and may be the only way to observe pulsars very close to SMBH Sgr A*, enabling unique black hole physics and gravity tests.

Pulsars are generally weak and steep spectral sources, making their detection and study at short radio wavelengths very challenging.

The JCMT is one of the few instruments in the world with potential for those pulsar studies at (sub)mm- wavelengths, particularly in the window [1 – 0.4] mm.

Thank you!