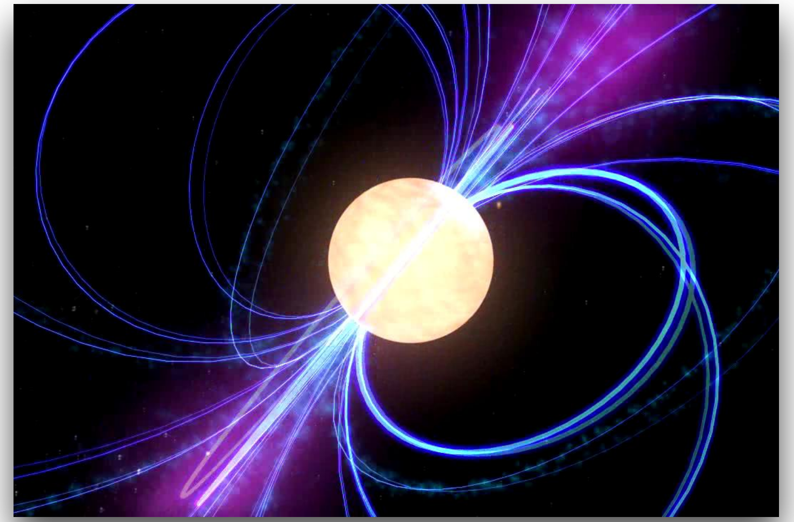
JCMT Users Meeting, ASIAA - Taipei (Taiwan), 6–8 November 2019

Observing pulsars at (sub)millimetre wavelengths



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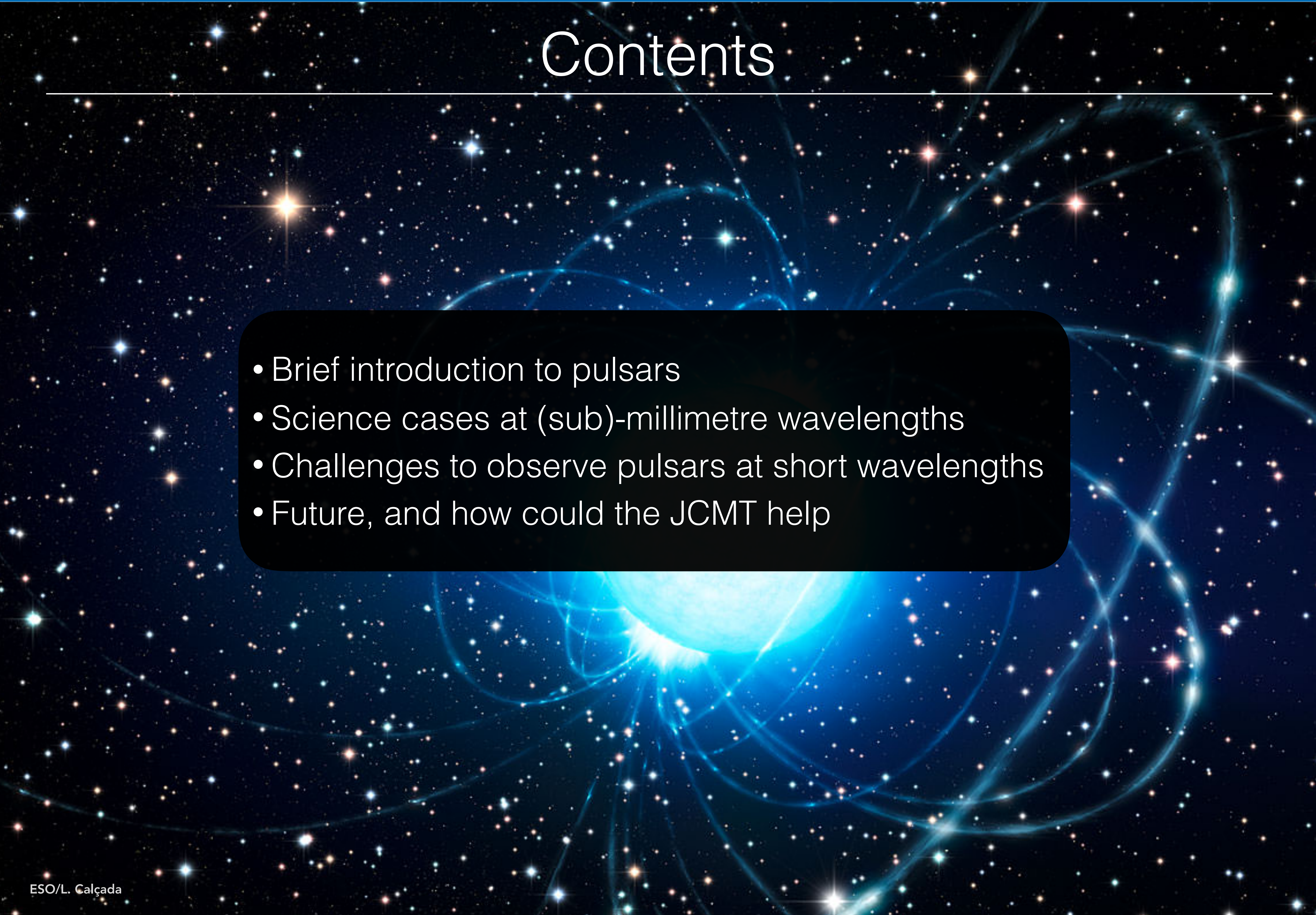
(Grenoble, France / Granada, Spain)

Contents

- Brief introduction to pulsars
- Science cases at (sub)-millimetre wavelengths
- Challenges to observe pulsars at short wavelengths
- Future, and how could the JCMT help



Pulsars

The Crab Nebula

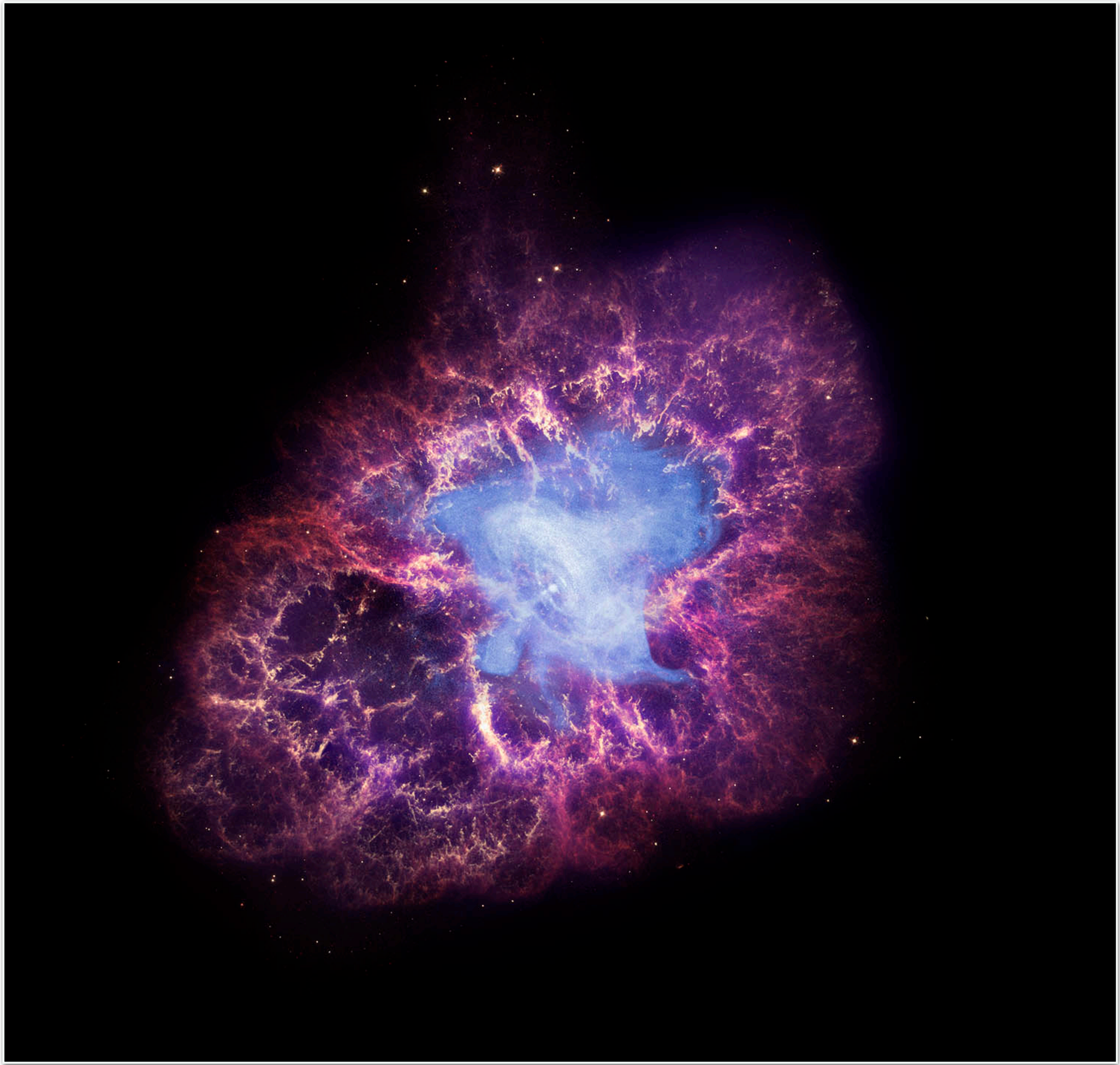


Image credit: X-ray: NASA/Chandra; Optical: Nasa/Hubble; Infrared: NASA/Spitzer.

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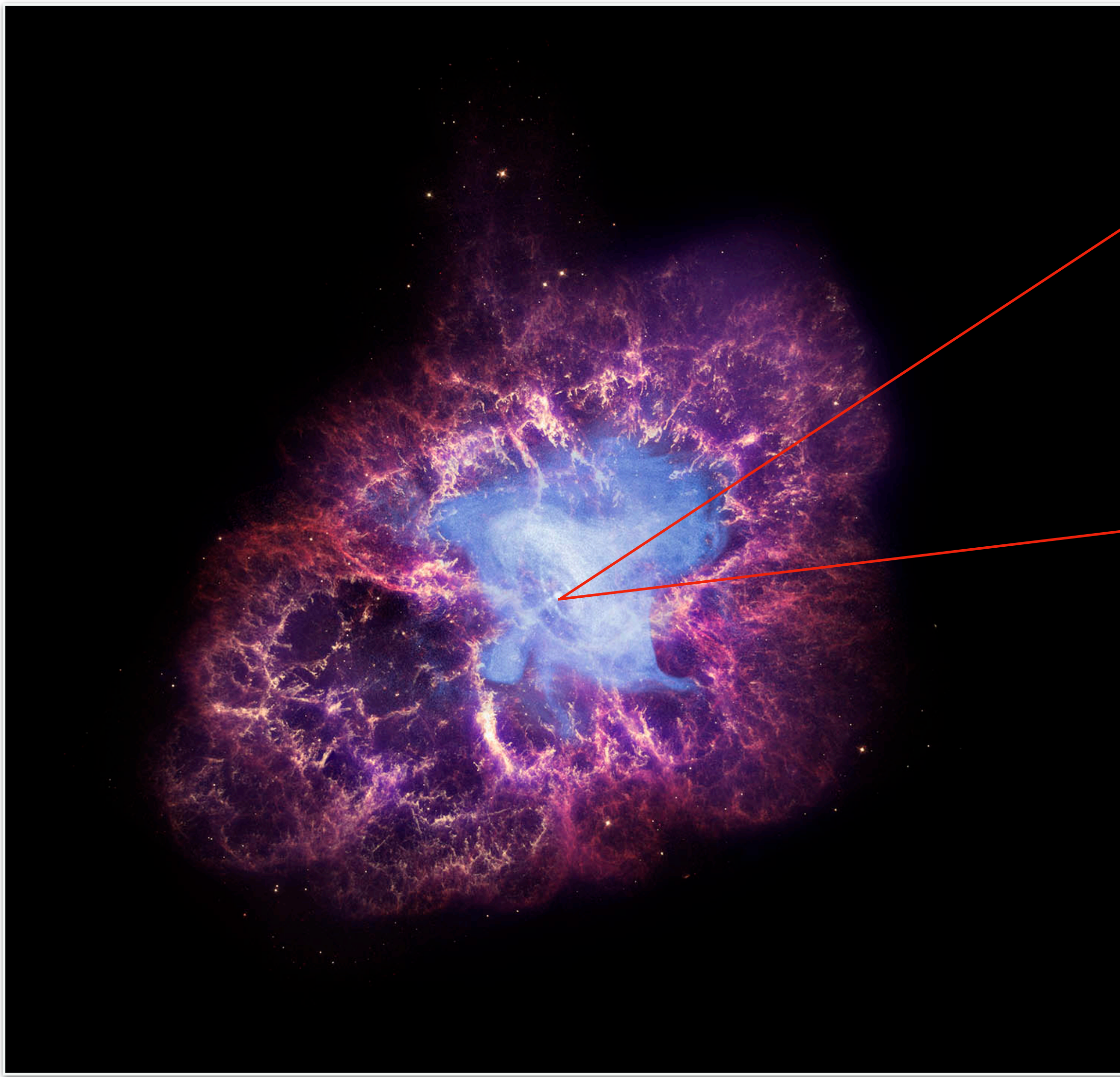

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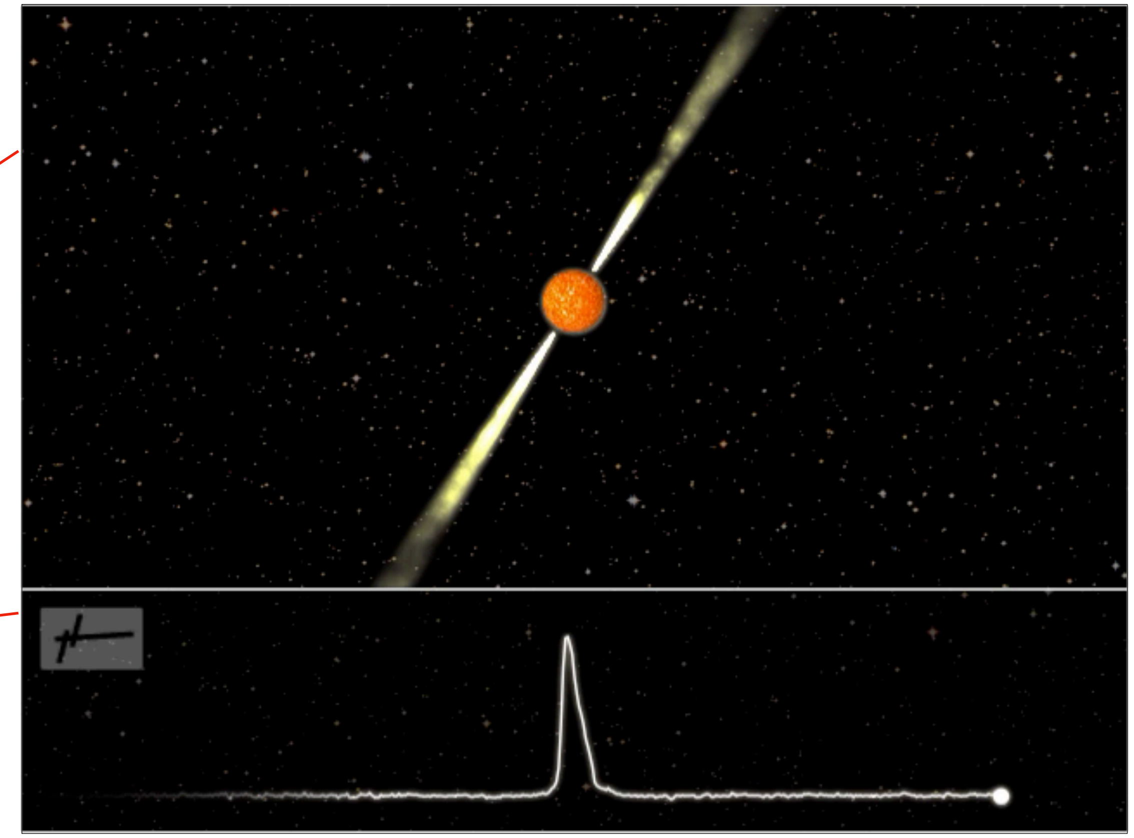
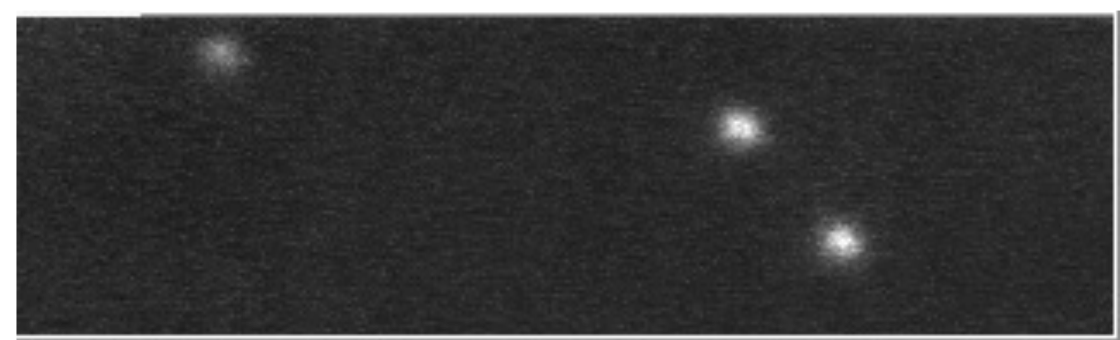
J. van Leeuwen





Cambridge University

Point-like masses with ultra-precise clocks attached

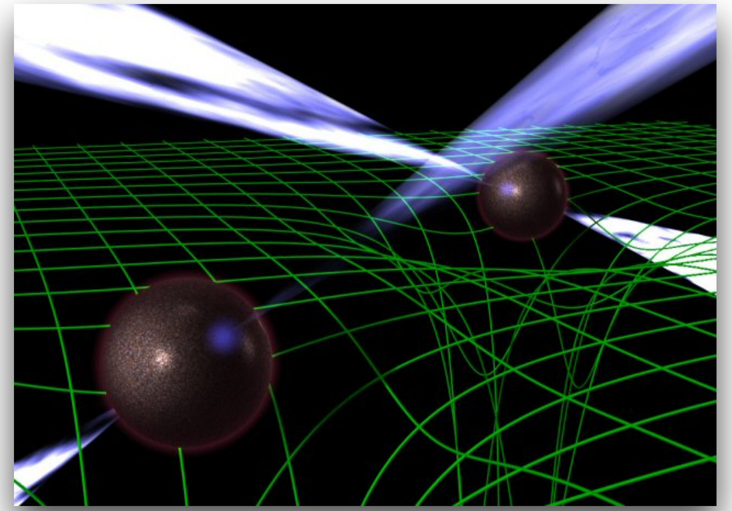
Pulsar Science

- Pulsars enable **high-precision astronomy in a wide variety of fields**, e.g.:

Interstellar medium

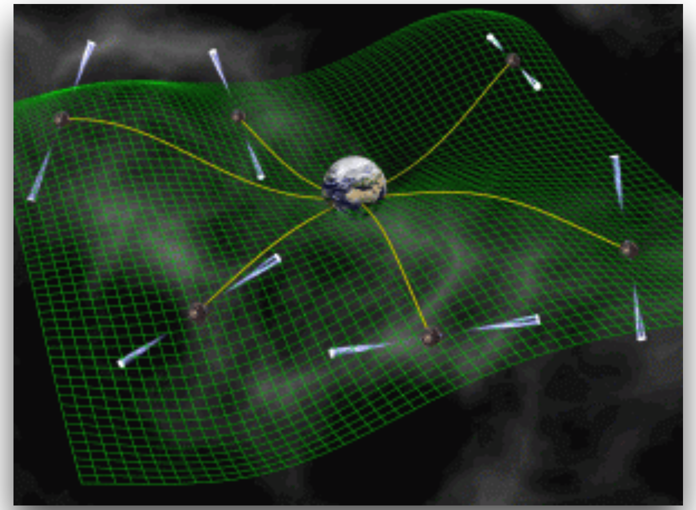
J. Williamson

Gravity tests



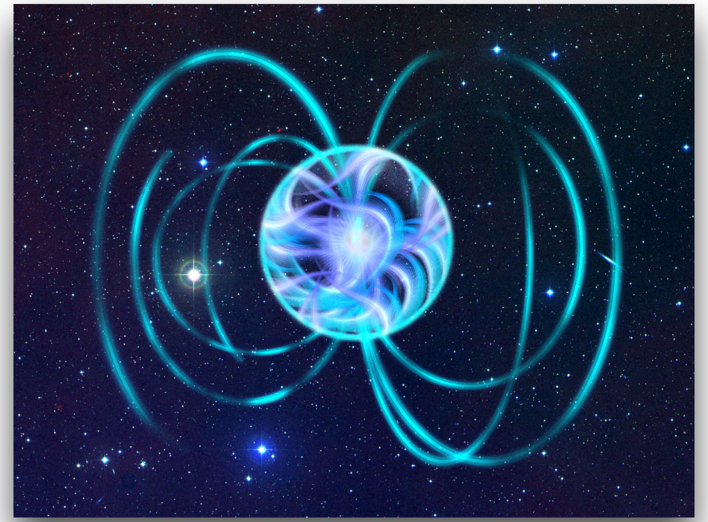
jb.man.ac.uk

Gravitational Waves



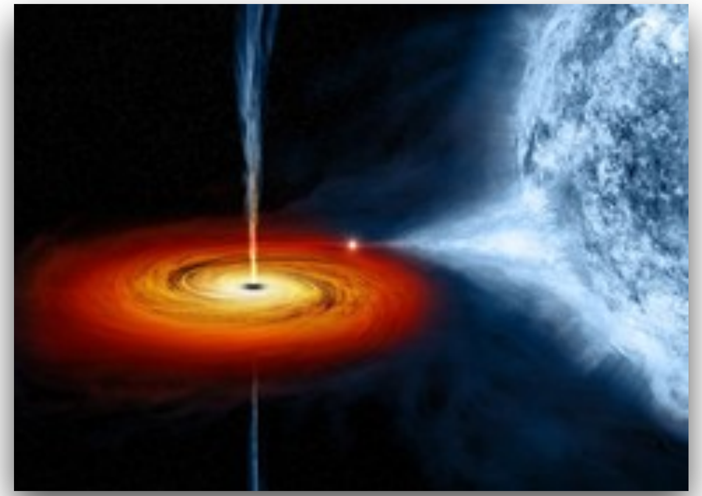
D. Champion (MPIfR)

Ultra-dense matter



ESO

Binary evolution



NASA/CXC/M. Weiss

1. Understand Radio Emission Mechanism

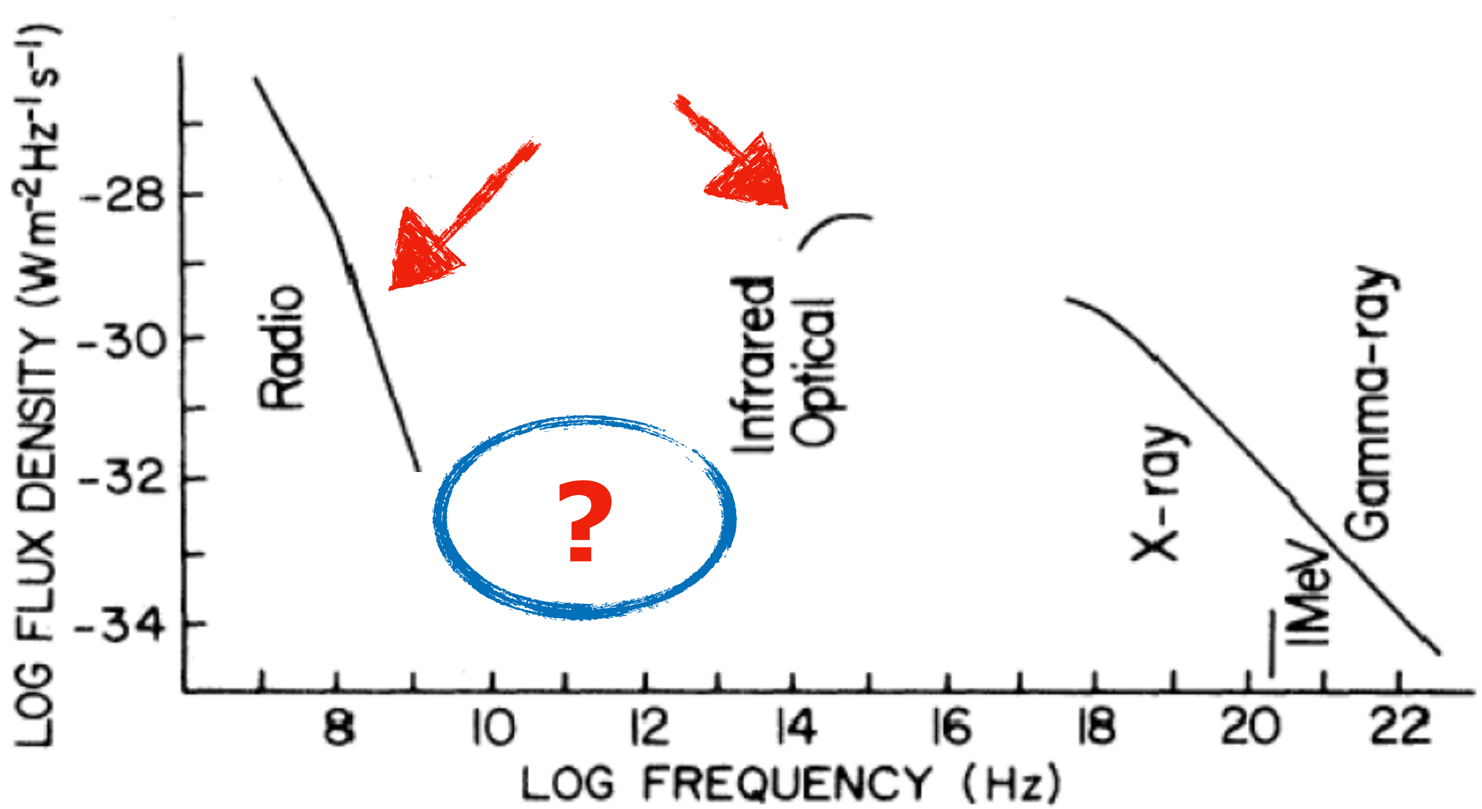
- Models make predictions that we can try to test with observations
- Emission processes can be frequency dependent
- **Some effects may only be observable at very short wavelengths (< ~few mm)**

⋆ **(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)

[Morris et al. (1997), Camilo et al. (2007), Torne et al. (2015, 2016, 2017, in prep.), K. Liu et al., accepted]

Spectrum of Crab Pulsar



Adapted from Smith (1977)

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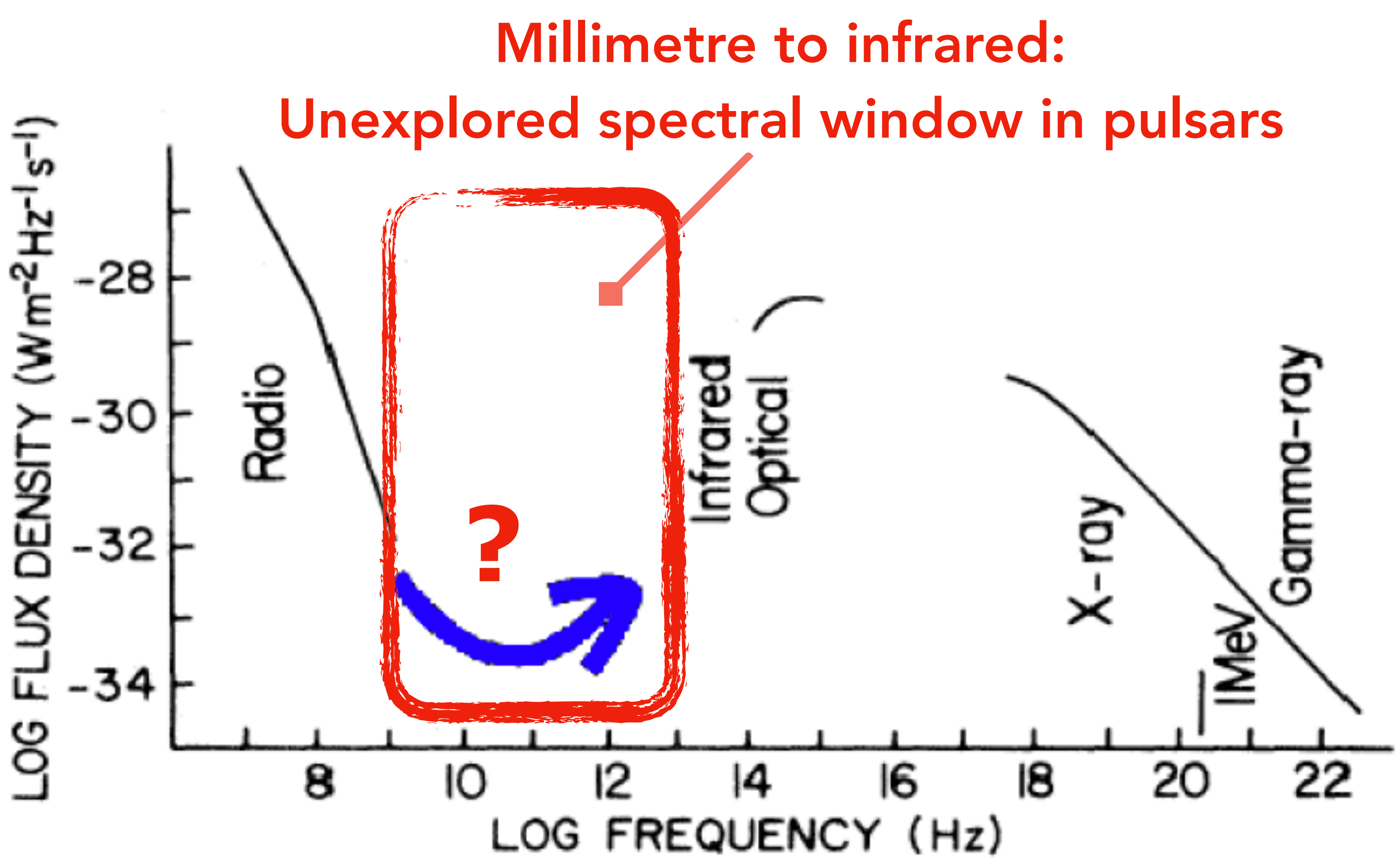
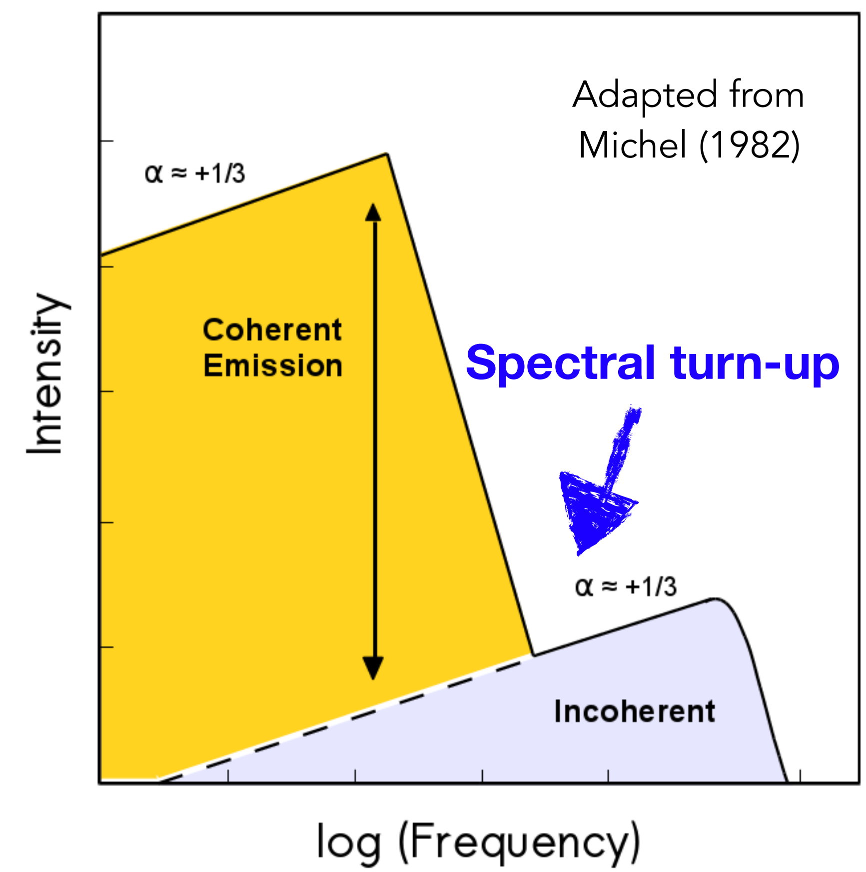
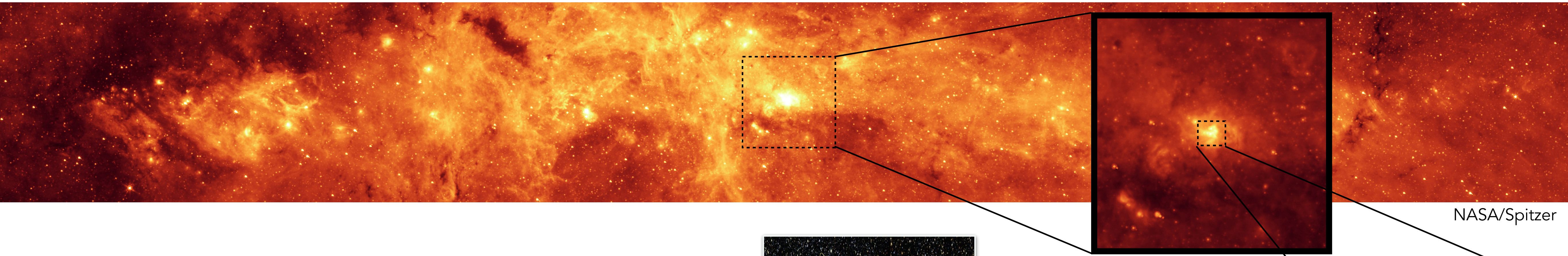


Adapted from Smith (1977)

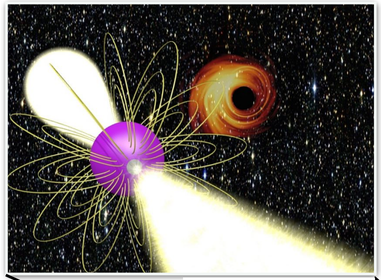
Model: Coherence breakdown



2. Pulsars in the Galactic Centre

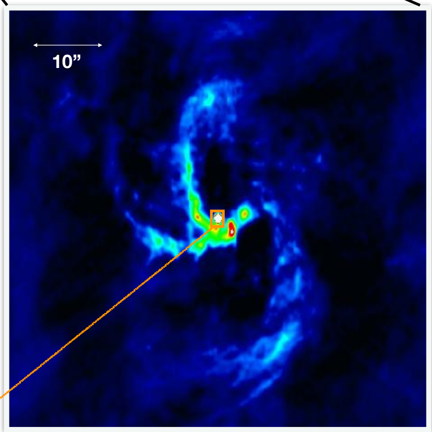


NASA/Spitzer

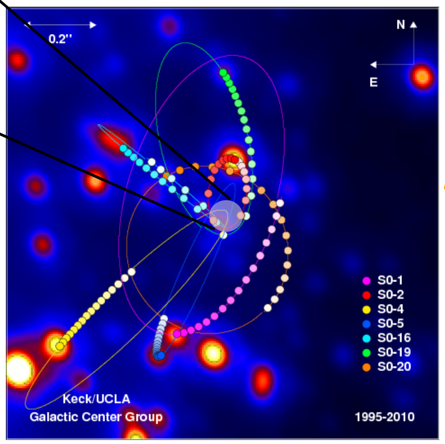


BlackHoleCam

Zoom into the Galaxy Centre

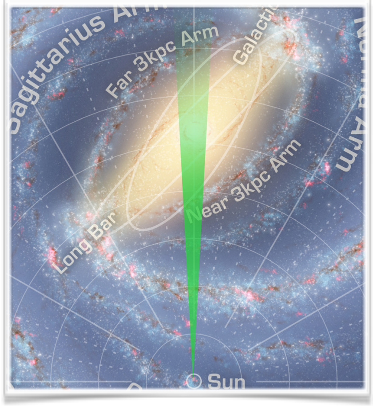


K.Y. Lo / VLA



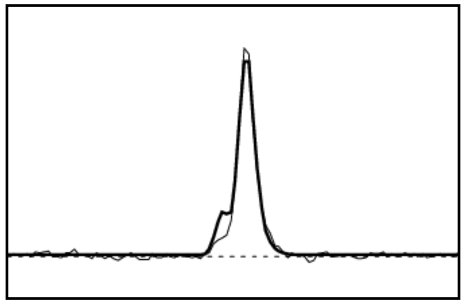
- **Galactic Centre contains very promising pulsar systems**
  - Probe gravitational potential of the region
  - Star forming history
  - Measure Galactic Centre gas properties with precision
  - **Pulsar – Supermassive Black Hole system**

★… and the **strongest scattering in the Galaxy**

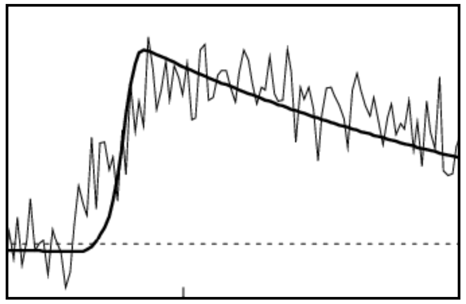


NASA/JPL

610 MHz



243 MHz



$$\tau_{scattering} \propto \nu^{-4}$$

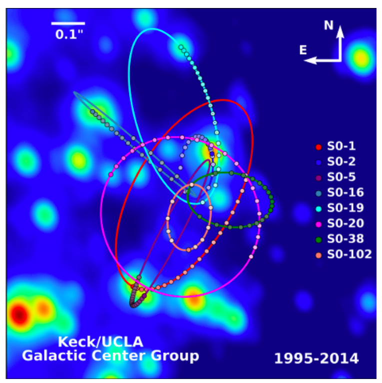
see e.g., Lorimer & Kramer (2005)

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

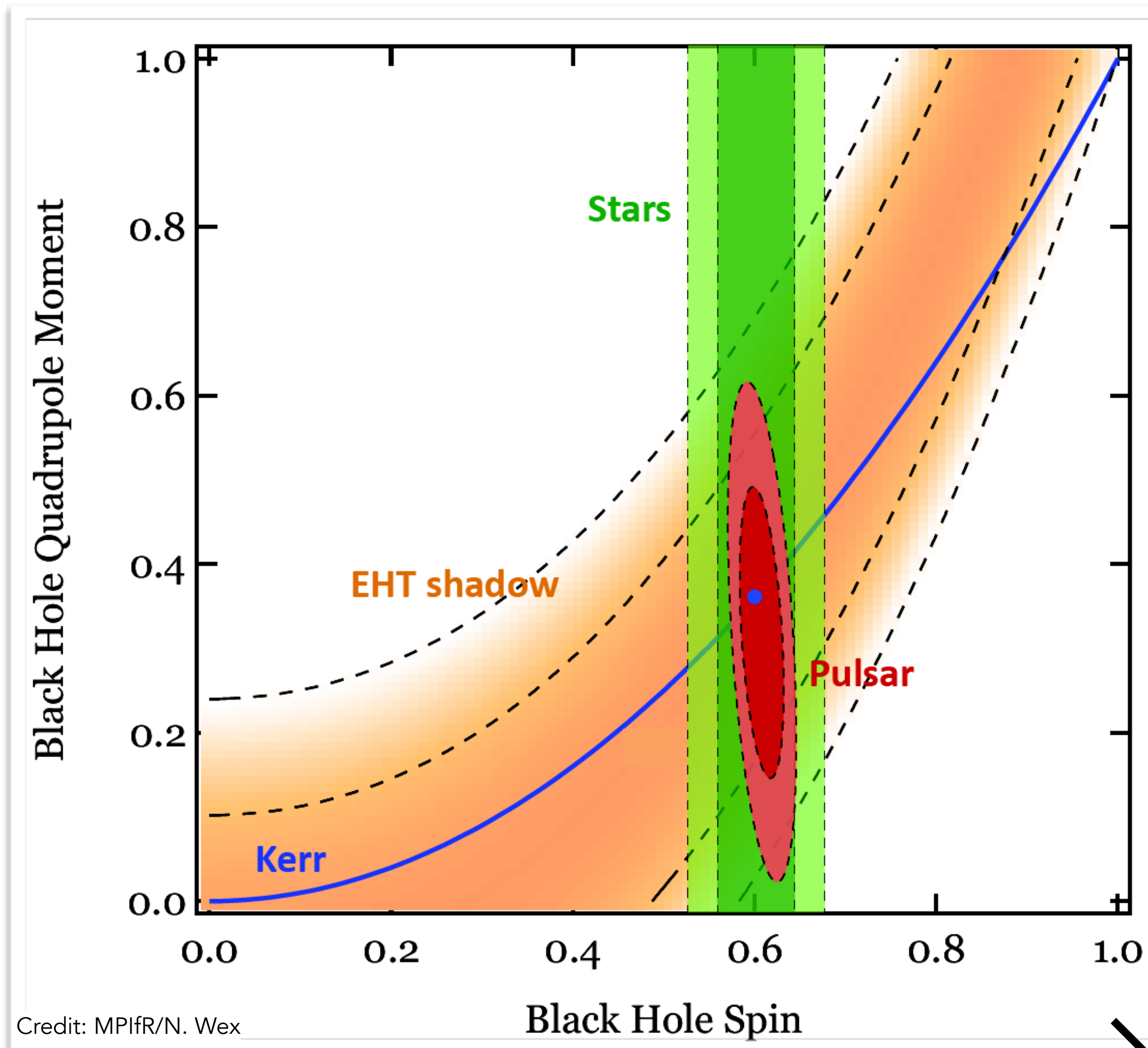
K. Liu et al. (2012)

Stars

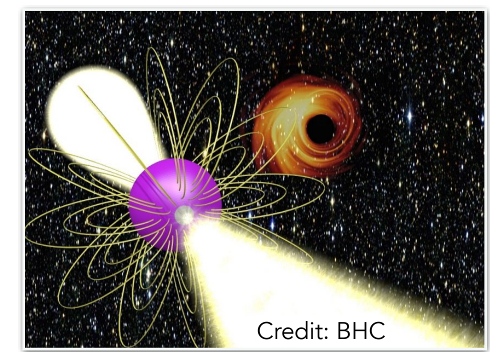


EHT shadow

EHT Collaboration et al. (2019)



Pulsars



see Psaltis, Wex & Kramer (2016)

Event Horizon Telescope

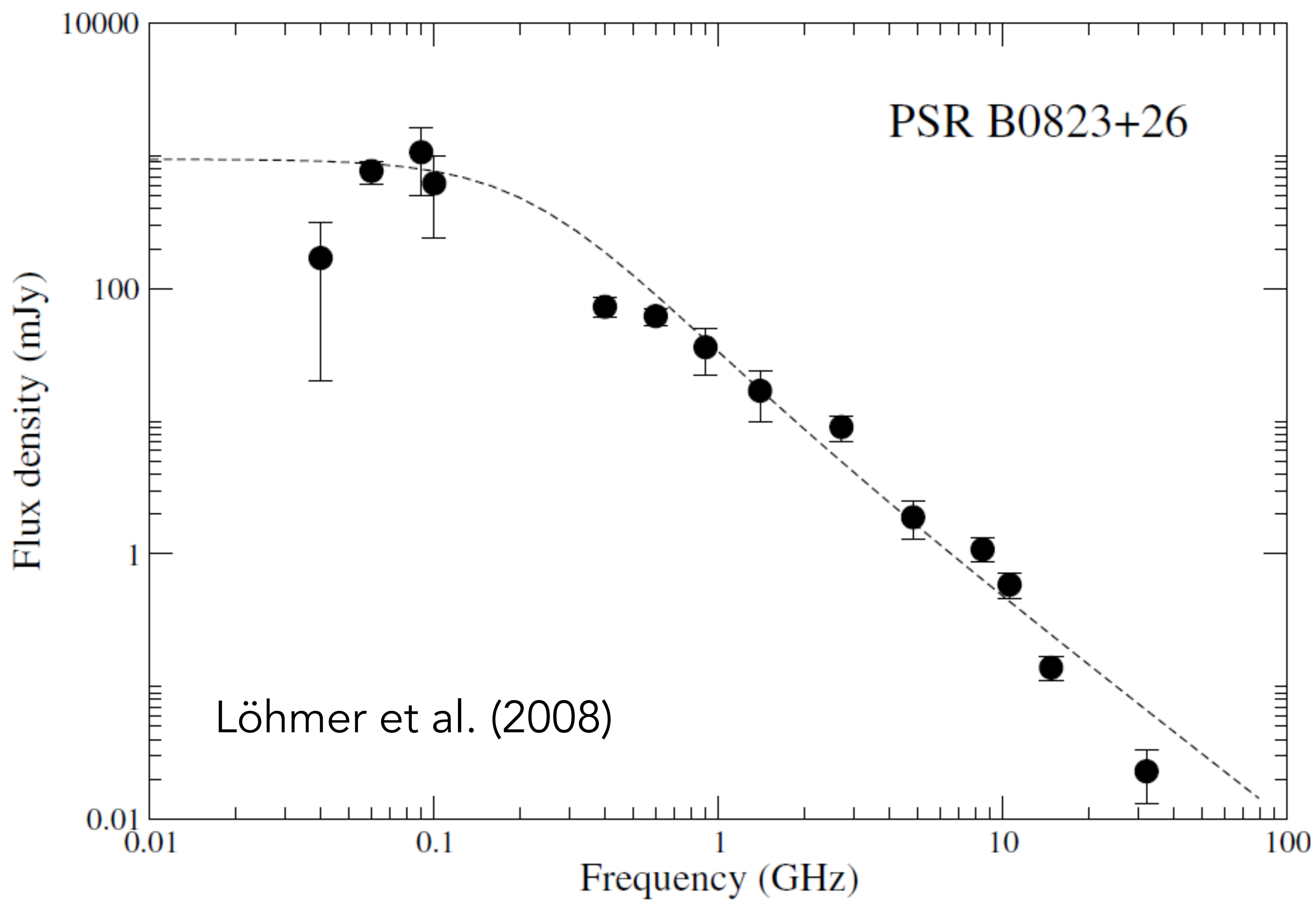
Main challenge to study pulsars at short-λ

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

$\alpha \subset$ [-3.5 — +1]

Some (a few) are ~flat!

Typical pulsar spectrum:



Steep spectrum *on average*

$$S \propto \nu^{\alpha}$$

$\langle\alpha\rangle$ = -1.8 ± 0.2

Maron et al. (2000)

Objectives at (sub)mm-λ:

$\alpha > -1.2$ (70 pulsars)

$-0.5 < \alpha < +1.0$ (Magnetars)

Observing pulsars at (sub)mm- wavelengths

- To be able to detect the weak pulsations at short wavelengths **we need sensitivity:**
  - Good sites for low Tsky
  - Big collecting areas for high Gain
  - "Nice" receivers → Low Trec, 'Gaussian' noise properties
  - Large bandwidths

Minimum detectable flux density at S/N level

Good sites and state-of-the-art receivers

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

Big collecting areas

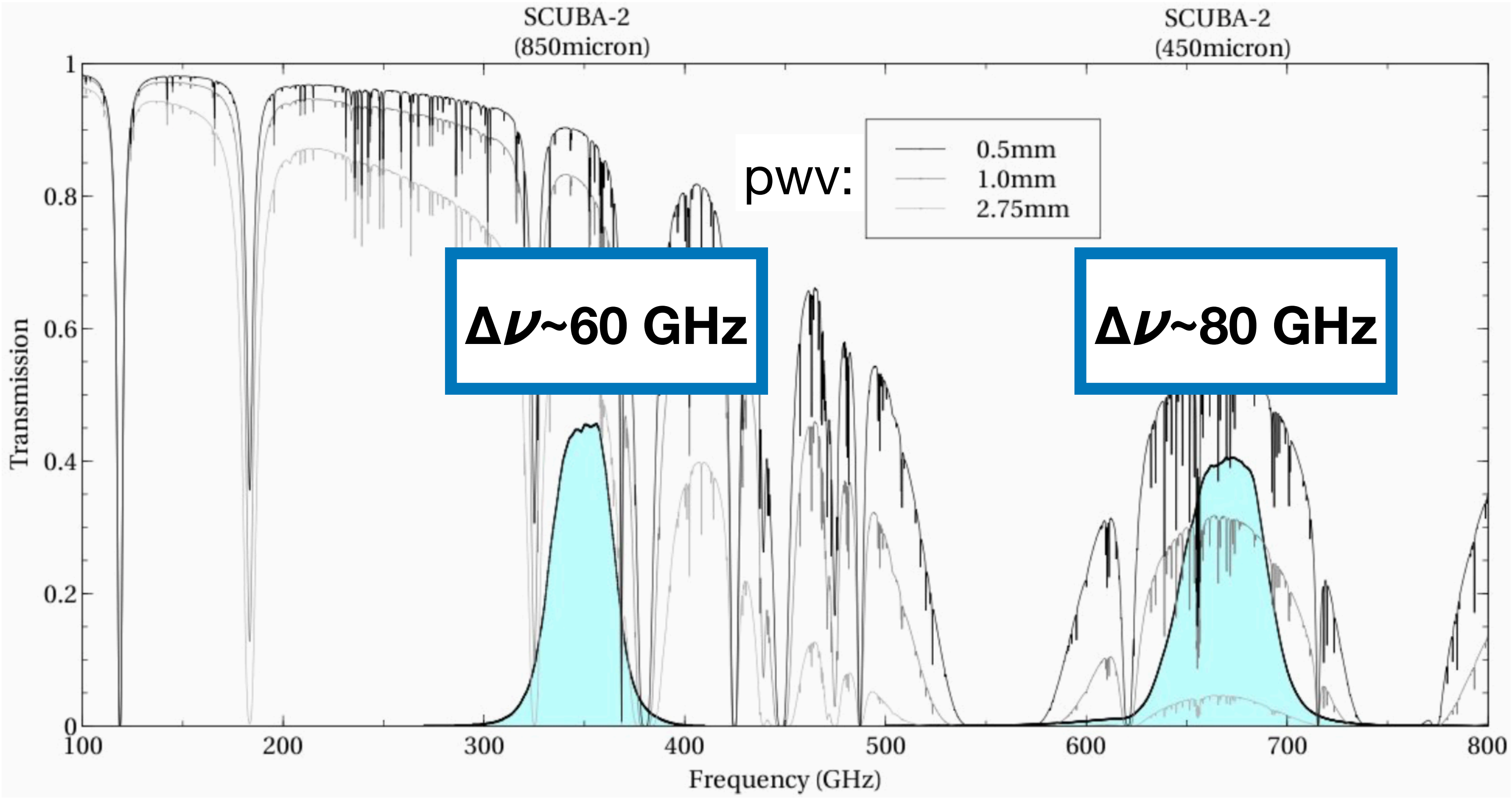
Long integration times

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)

SCUBA2 @ JCMT frequency coverage:



https://www.eaobservatory.org/jcmt/instrumentation/
See also Holland et al. (2013)

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

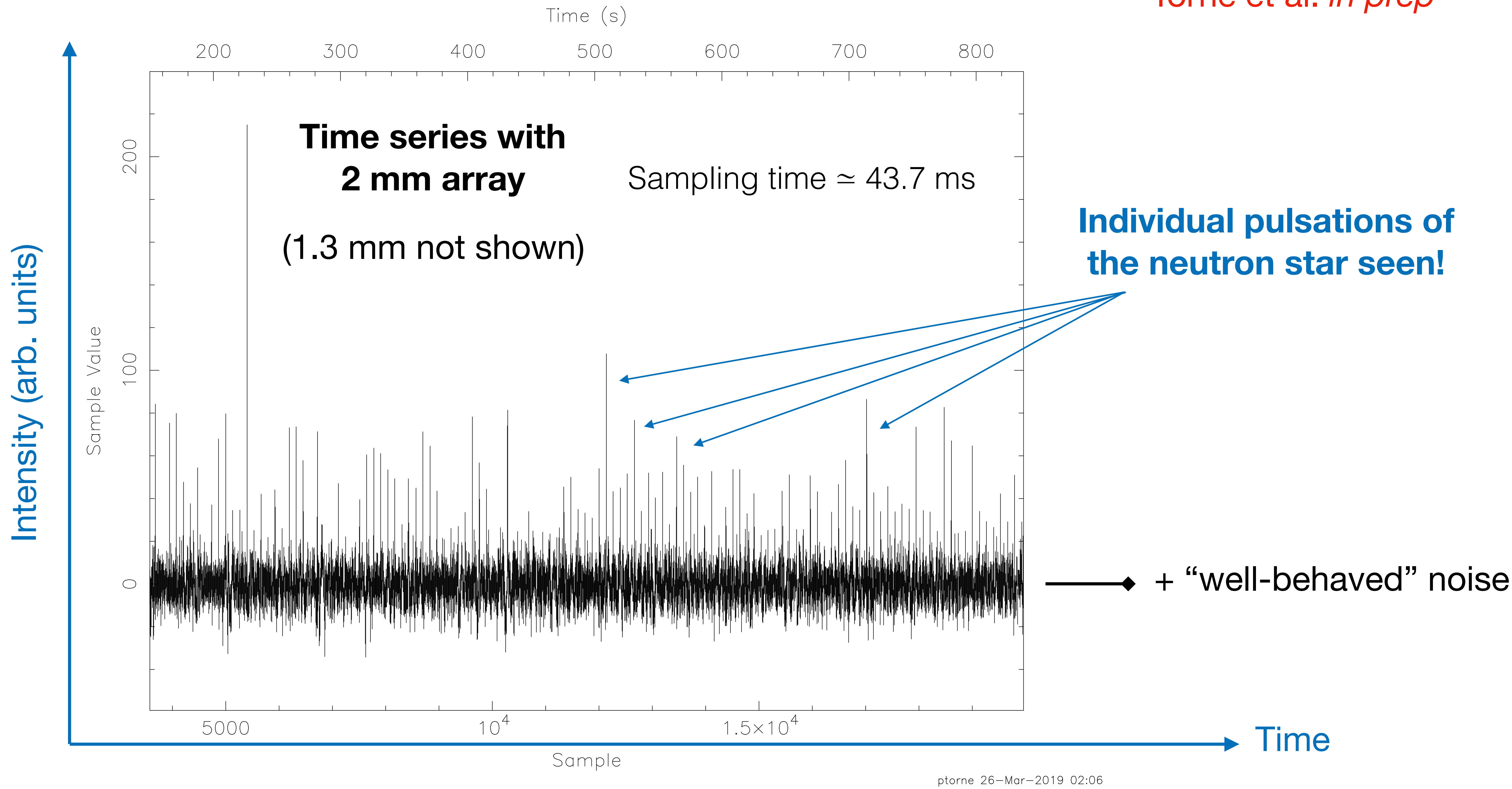
Bolometers / KIDs up to 2-3x more sensitive than typical SiS Rx

but can they be used to observe pulsars?

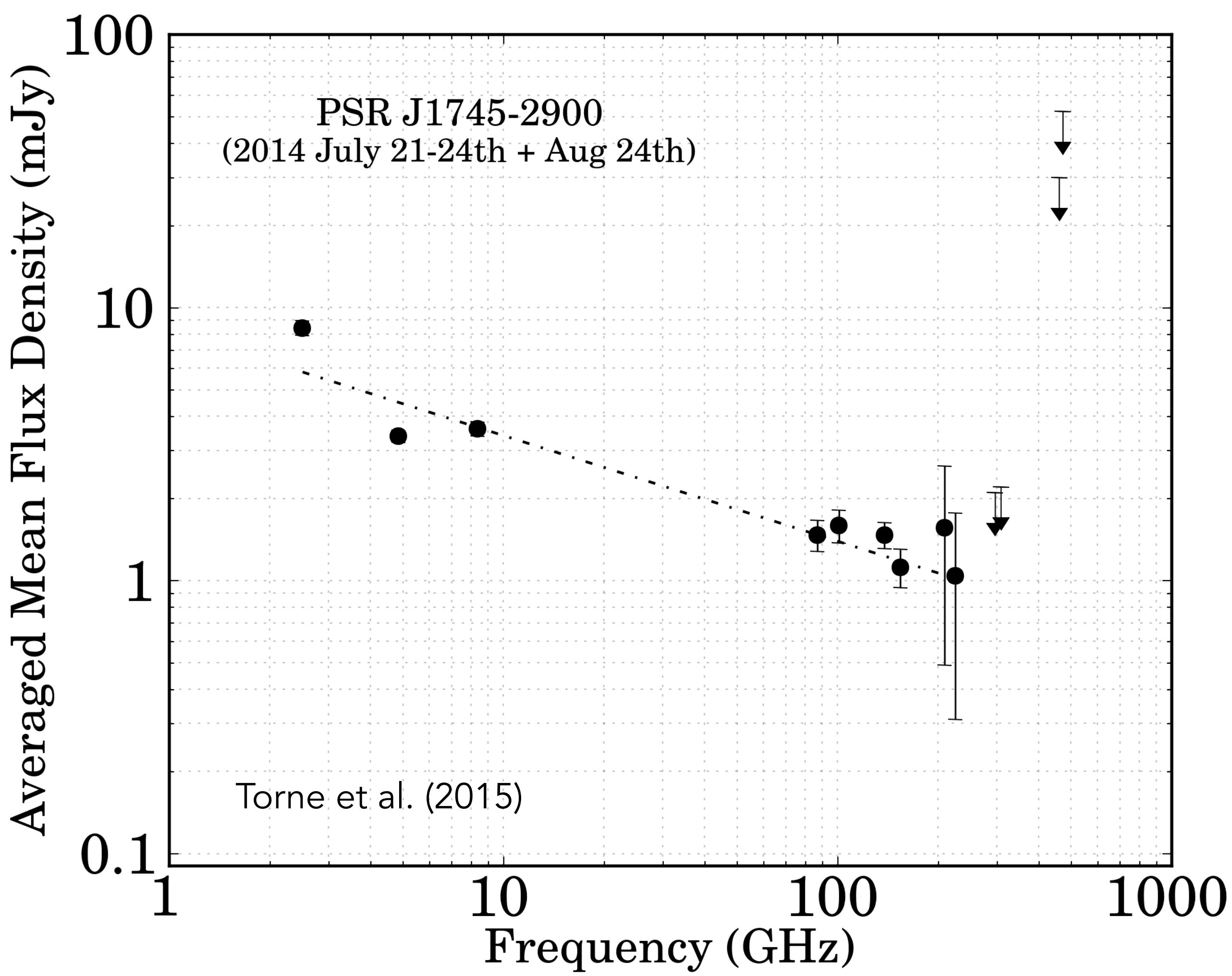
YES → First Pulsar Detection with KID camera

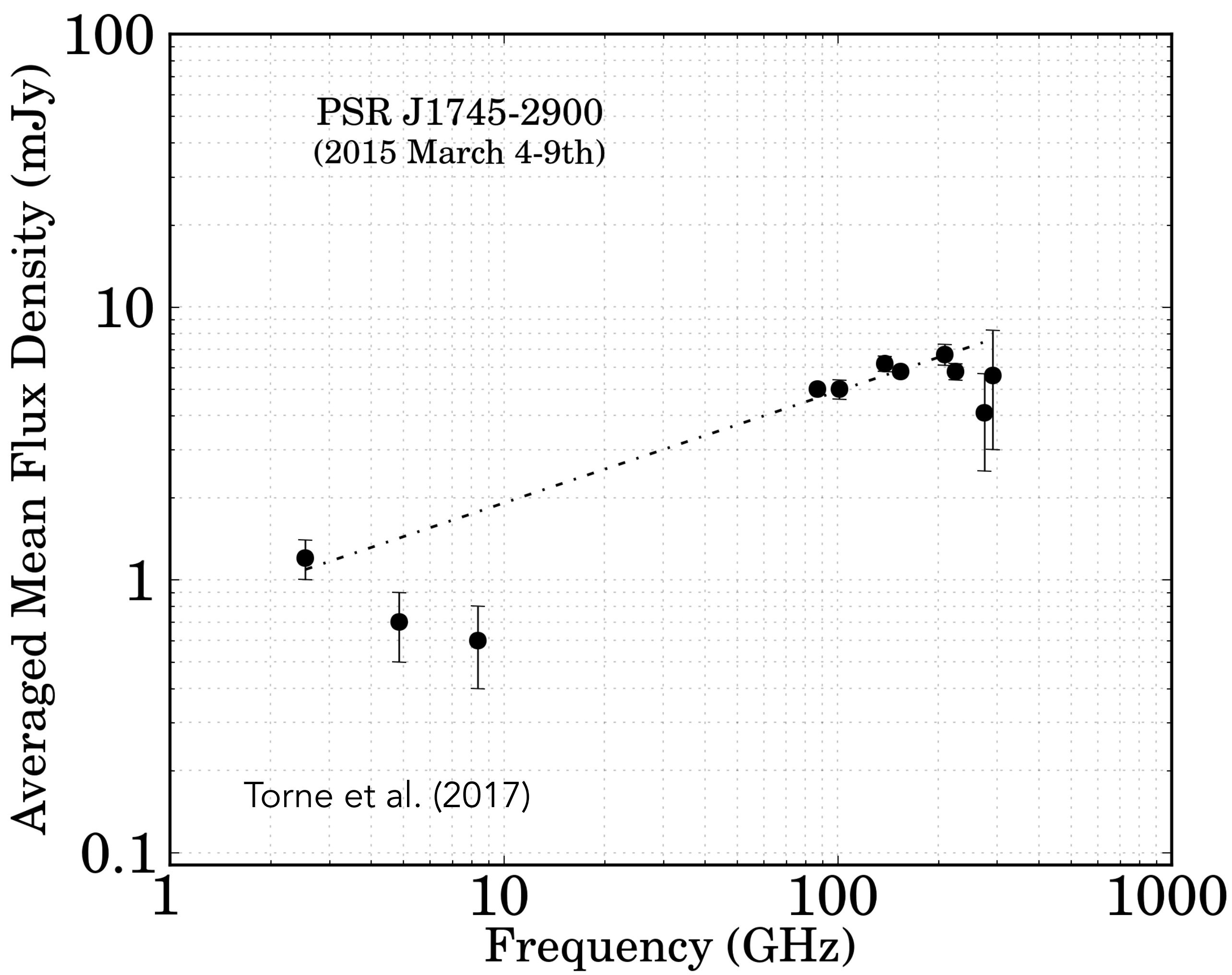
- Magnetar AXP1810–197 with NIKA2 @ IRAM 30-m, 1 hr observation on 23-March-2019
- Proof of concept, no major issues. Worked beautifully well!

Torne et al. *in prep*



JCMT well suited for [1 – 0.4] mm window





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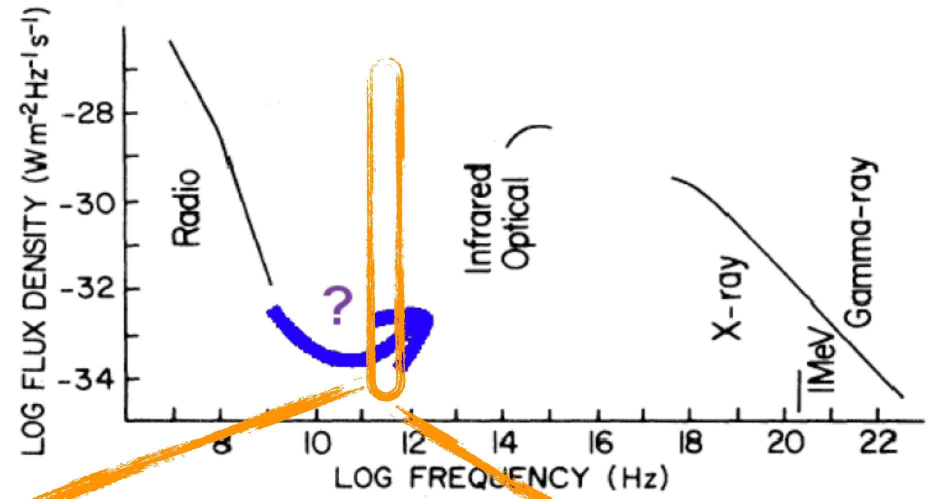

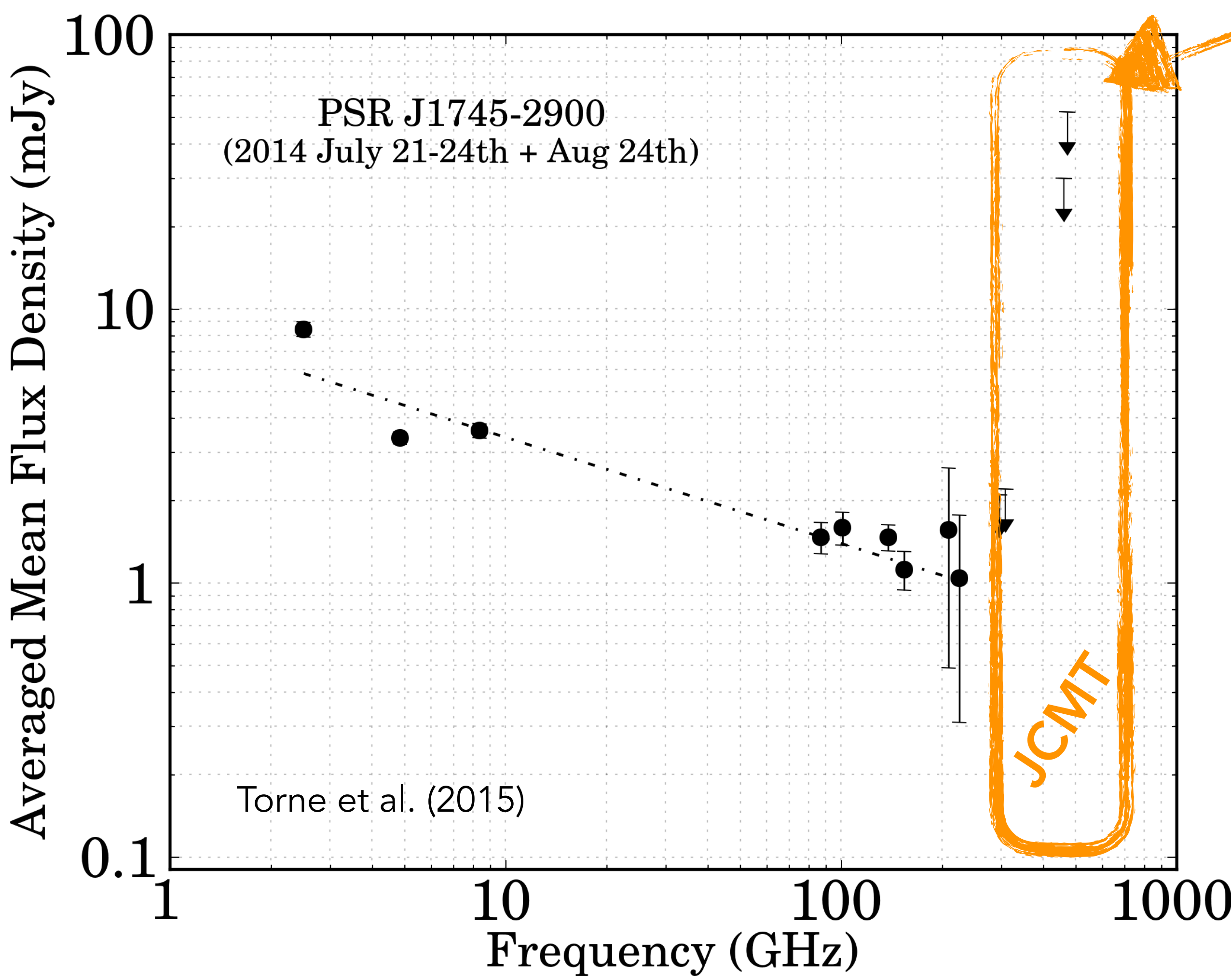

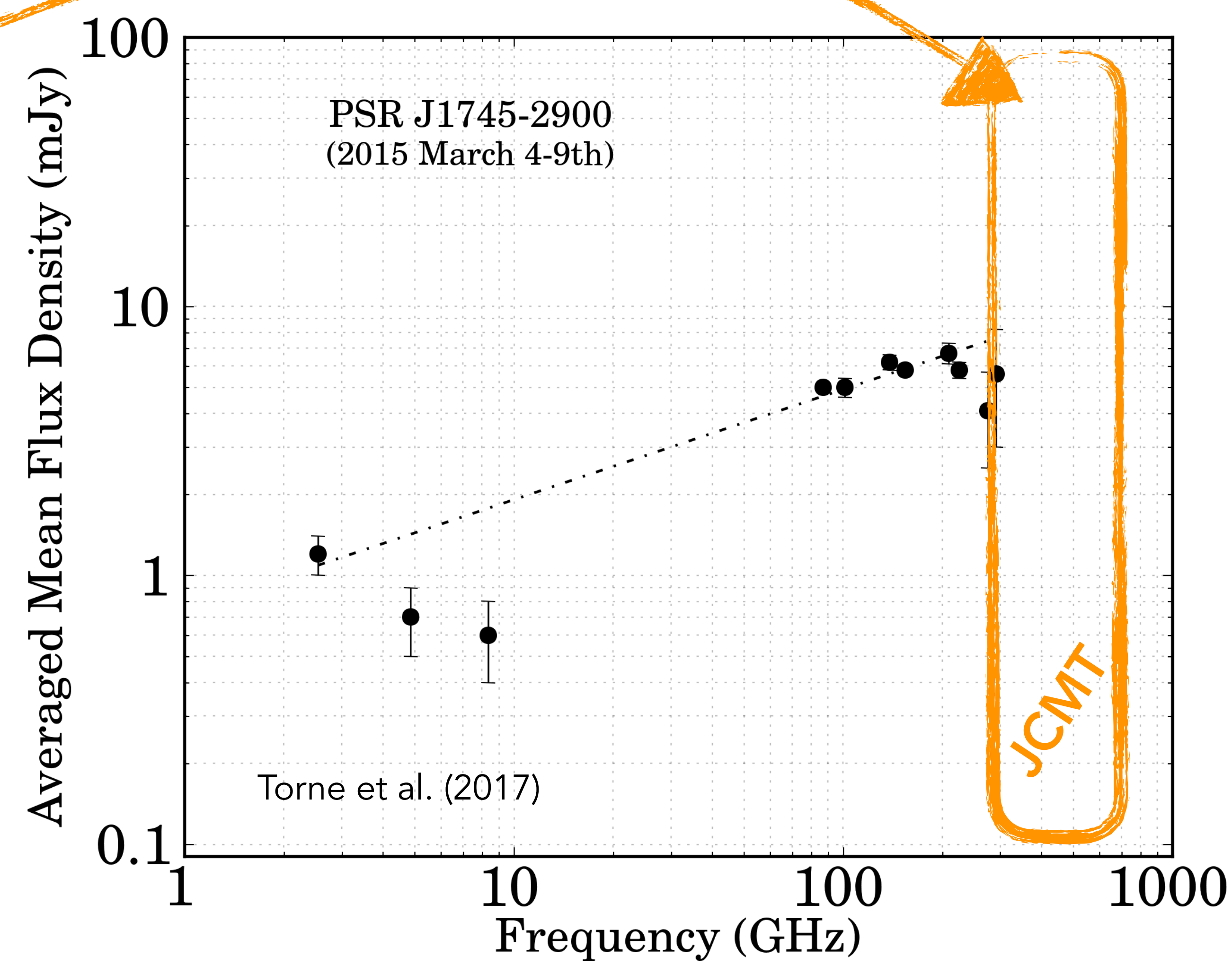

Summary

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

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 !