First application of a Kinetic Inductance Detector (KID) Camera to Pulsar Science in the Millimetre Regime

Pablo Torne[1,2,*], J. Macías-Perez[3], B. Ladjelate[1], A. Ritacco[1,4,5], M. Sánchez-Portal[1], S. Berta[6], G. Paubert[1], M. Calvo[7], G. Desvignes[8,9], R. Karuppusamy[9], S. Navarro[1], D. John[1], S. Sánchez[1], J. Peñalver[1], M. Kramer[9,10], and K. Schuster[1]

[1] Instituto de Radioastronomía Milimétrica (IRAM), Granada, Spain; [2] East Asian Observatory (EAO), Hawaii, USA; [3] Laboratoire de Physique Subatomique et de Cosmologie (LPSC), Grenoble, France; [4] Institut d'Astrophysique Spatiale (IAS), Orsay, France; [5] Laboratoire de Physique de l'École Normale Supérieure, Paris, France; [6] Institut de Radioastronomie Millimétrique (IRAM), Grenoble, France; [7] Institut Néel, Grenoble, France; [8] LESIA, Observatoire de Paris, France; [9] Max-Planck-Institut für Radioastronomie (MPIfR), Bonn, Germany; [10] Jodrell Bank Centre for Astrophysics, Manchester, UK

Abstract

The investigation of pulsars between millimetre and optical wavelengths is challenging due to the faintness of the pulsar signals and the relative low sensitivity of the available facilities compared to 100-m class telescopes operating in the centimetre band. The Kinetic Inductance Detector (KID) technology offers large instantaneous bandwidths and a high sensitivity that can help to substantially increase the ability of existing observatories at short wavelengths to detect pulsars and transient emission. This work presents the first successful application of KID technology to the study of pulsars in the millimetre band. We used the NIKA2 camera on the IRAM 30-m Telescope, and detected the emission from the radio magnetar XTE J1810-197 at the camera's two operating bands, 150 and 260 GHz (λ=2.0 and 1.15 mm). This is the first report of short millimetre emission from XTE J1810-197 after its reactivation in December 2018, and it is the first time that the source is detected at 260 GHz, which gives us new insights into the radio emission process of the star.

More info: "Detection of the magnetar XTE J1810–197 at 150 and 260 GHz with the NIKA2 Kinetic Inductance Detector Camera"
Torne et al. (2020), Astronomy & Astrophysics Letters (accepted) arXiv:2007.02702

* contact author: torne (at) iram.es

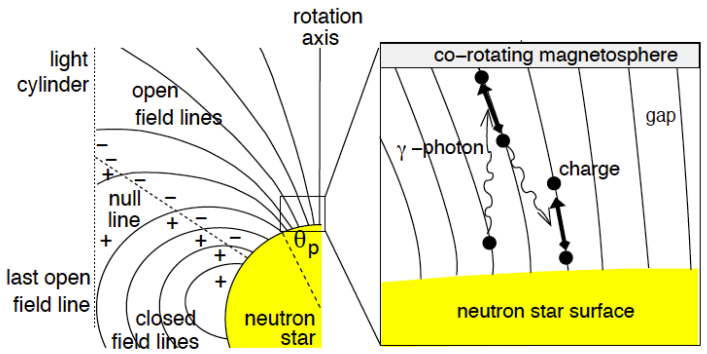
Context

Open question

1. The radio emission mechanism of pulsars is still a mystery
   - Emission is coherent, but not pure relativistic synchrotron
   - Unknown amplification process

?

see e.g., Melrose (2017)

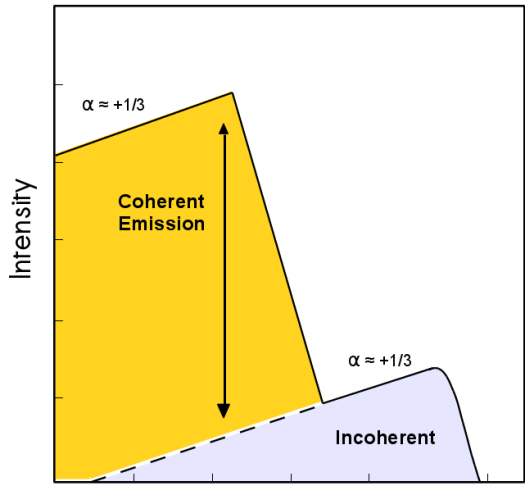


Credit: Lorimer & Kramer (2005)

Input from observations

2. Obtaining Spectral Energy Distributions (SED) and emission properties of pulsars enables tests and refinement of pulsar magnetospheric and emission models

Adapted from Michel (1982)



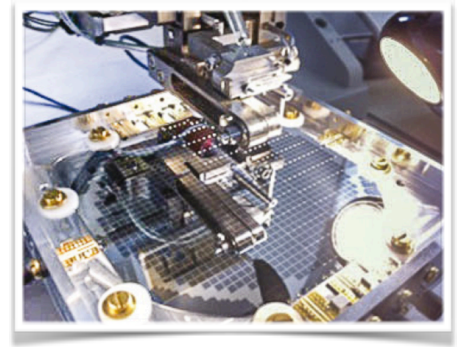
Challenge & Solution

3. Pulsars are extremely weak in radio and steep spectral sources → so becomes even weaker as wavelength decreases

We need sensitive instrumentation, specially for small telescopes (D≲70m)

↓

Kinetic Inductance Detectors (KIDs)
= large arrays, large bandwidth, low noise



NIKA2 KID array; Credit: Institut Neel

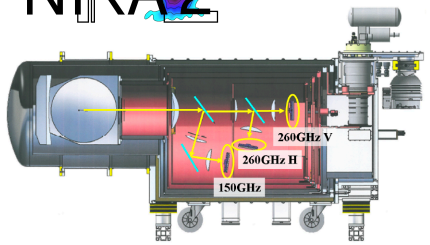
+details: Torne et al. (2020), A&A Letters arXiv:2007.02702

Description of the work

New KID camera at the IRAM 30m Telescope

- 2896 KIDs, FoV ~ 6.5 arcmin
- 150 and 260 GHz simultaneously (λ=2.0 and 1.15 mm)
- 45-GHz bandwidth per frequency band
- $NEFD_{150}$ = 9 mJy $s^{1/2}$; $NEFD_{260}$ = 30 mJy $s^{1/2}$
- Linear polarisation at 260 GHz
- High time sampling capabilities

NIKA2



+

NIKA2: Adam et al. (2018), Perotto et al (2020)

+

Reactivation of radio magnetar XTE J1810—197

- Rare, transient pulsar
- No radio emission for 10 years, suddenly re-starts in Nov-Dec. 2018 (ATel #12284, Levin et al. 2019)
- Flat spectral index in radio band (rare property of magnetars)
- Followed up with other receiver (EMIR@IRAM30m) confirms it was bright at millimetre wavelengths

=

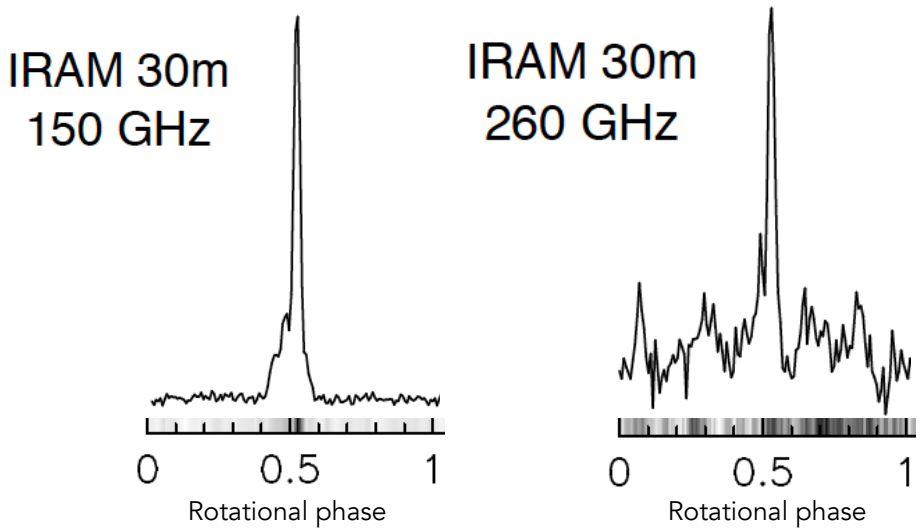
Opportunity to test NIKA2 (KIDs) for pulsar observations !

+details: Torne et al. (2020), A&A Letters arXiv:2007.02702

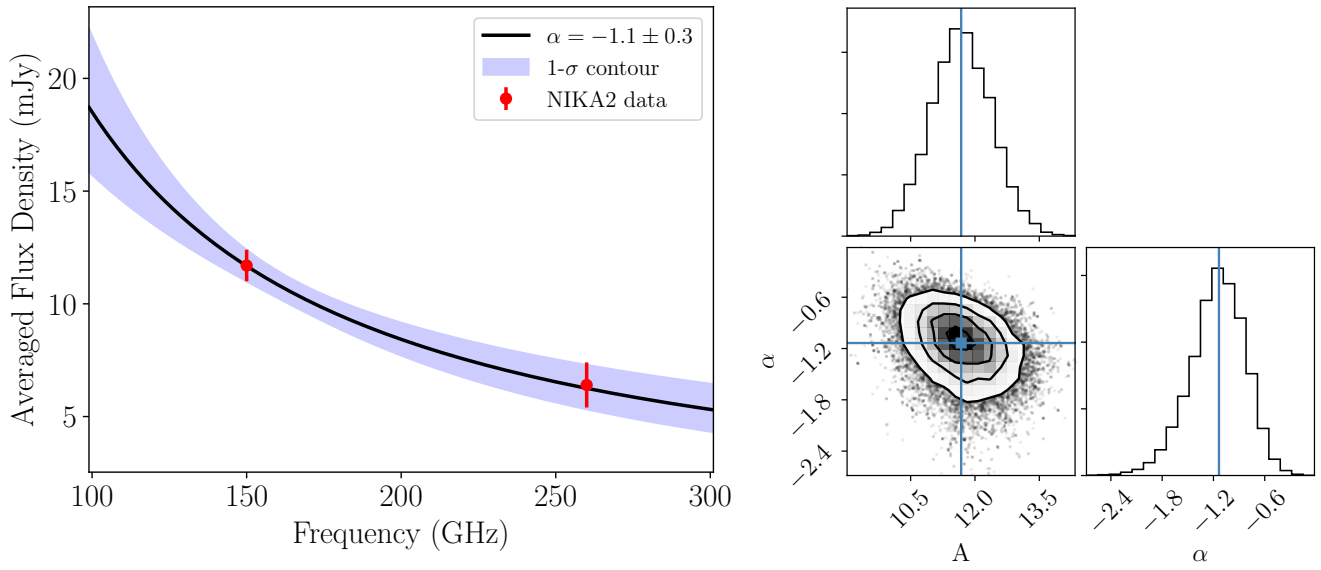
Results (I)

- Detected the pulsar clearly in the two frequency bands 150 and 260 GHz. First-ever detection of the source at 260 GHz
- Strong, short-term variability of flux density detected (≈50% in tens of minutes)
- Spectral index different to what is measured at cm-wavelengths: variability, scintillation, or complex spectral shape?
- Shorter-wavelength observations encouraged! (sub-millimetre, infrared, UV) → contact us if collaboration desired

Average pulse profiles of XTE J1810—197



Spectral index fit

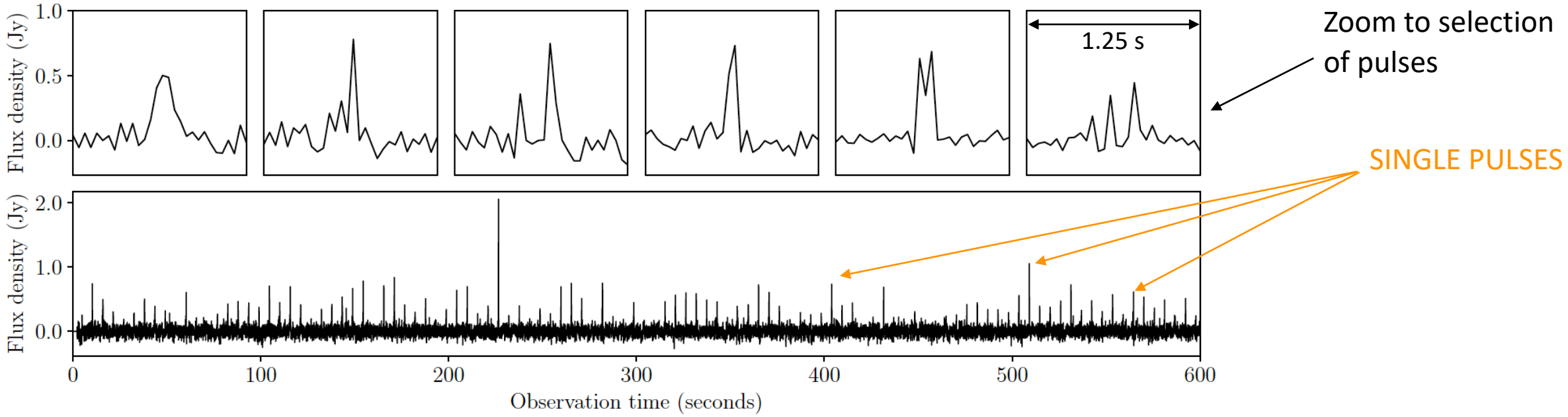


+details: Torne et al. (2020), A&A Letters arXiv:2007.02702

Results (II)

- 150-GHz emission so intense, and NIKA2 so sensitive, that we see *individual pulsations* with every rotation of the star
- We can use the so-called “single pulses” to estimate the brightness temperature of the emission region
- $T_B >> 10^{17}$ K → rule out incoherent mechanisms, need coherent process to reach such high values
- To find a coherence breakdown, need to go to even higher frequencies (submm — infrared — optical)

Sample of individual pulsations from XTE J1810—197 at 150 GHz



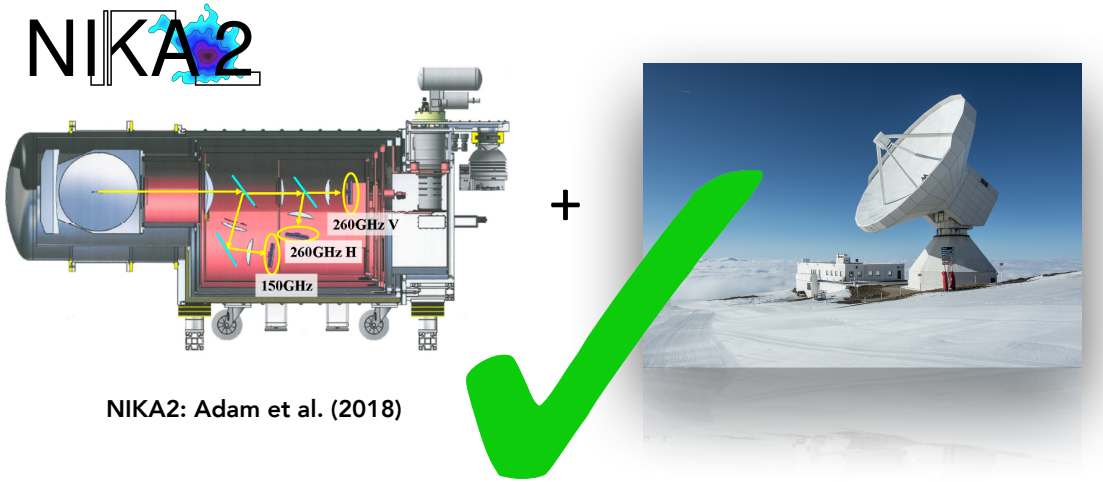
(Sampling time ≈ 43 ms)

+details: Torne et al. (2020), A&A Letters arXiv:2007.02702

Impact and Future

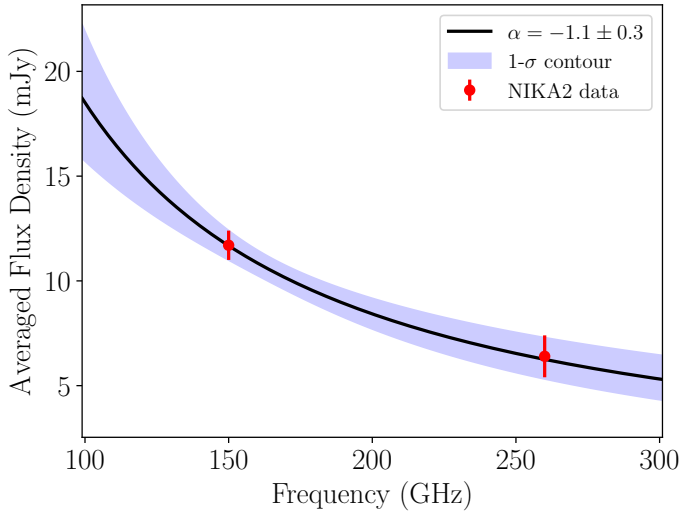
- KID technology can detect broadband pulsations in the millimetre band
- Similarly, KIDs (or alike technology) may be applied to pulsar observations at other (ideally shorter) wavelengths
- Sampling frequency is key, we need enough data points across each rotation of a pulsar to resolve the pulses
- Given the pulsar population, Fs = 100—500 Hz is desired. Lower sampling frequencies can work for slow pulsars
- Radio magnetar XTE J1810—197 is currently a great source for testing this type of observations at other telescopes
- XTE J1810—197 not observed between sub-millimetre — optical after its outburst in Dec. 2018 → opportunity!

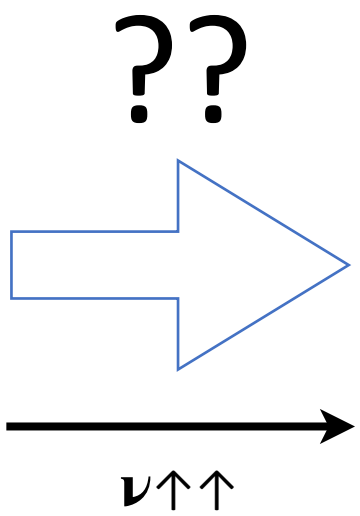
TECHNIQUE WORKS



NIKA2: Adam et al. (2018)

APPLY AT OTHER TELESCOPES?





+details: Torne et al. (2020), A&A Letters arXiv:2007.02702