The ATCA, from milliseconds t minutes

High time resolution and (future) pulsar capabilities

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With Shi Dai, Chris Phillips, Stefan Osłowski

2025-04-08

ATCA Science Day

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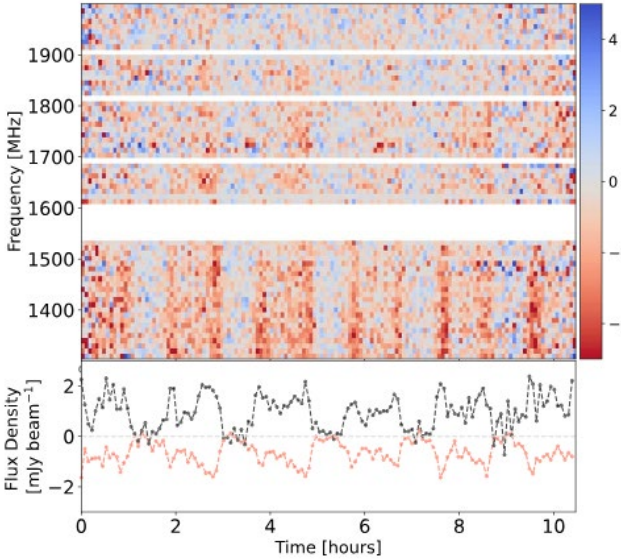
Australia's National Science Agency

The ATCA as a “fast” timescale monitoring facility

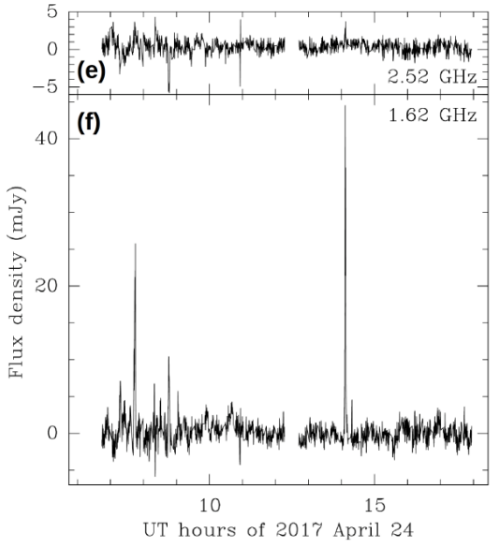
This talk will:

- Touch on CABB-era pulsar and short-timescale transient science
- Present science opportunities at millisecond-minute timescales
- And possible future capabilities that could be afforded by the BIGCAT system

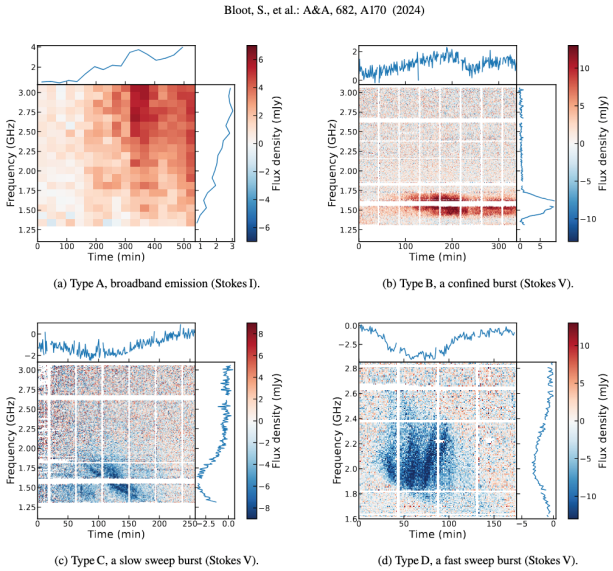
A sample of fast timescale bursts on active stars



Rose et al. 2023



Perez-Torres et al. 2021



Bloot et al. 2024
(see upcoming talk!

The ATCA's role in following up variable/unusual pulsar candidates

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **528,** 5730–5741 (2024) https://doi.org/10.1093/mnras/stae033
Advance Access publication 2024 January 8

Discovery of radio eclipses from 4FGL J1646.5−4406: a new candidate redback pulsar binary

Andrew Zic,[1★] Ziteng Wang,[2,3★] Emil Lenc,[1] David L. Kaplan,[4] Tara Murphy,[2,5] A. Ridolfi,[6,7] Rahul Sengar,[4] Natasha Hurley-Walker,[3] Dougal Dobie,[5,8] James K. Leung,[1,2,5] Joshua Pritchard[1,2,5] and Yuanming Wang[5,8]

The Astrophysical Journal, 930:38 (13pp), 2022 May 1 https://doi.org/10.3847/1538-4357/ac61dc

Discovery of PSR J0523-7125 as a Circularly Polarized Variable Radio Source in the Large Magellanic Cloud

Yuanming Wang[1,2,3], Tara Murphy[1,3], David L. Kaplan[4], Teresa Klinner-Teo[1], Alessandro Ridolfi[5,6], Matthew Bailes[3,7], Fronefield Crawford[8], Shi Dai[9], Dougal Dobie[3,7], B. M. Gaensler[10,11], Vanessa Graber[12], Ian Heywood[13,14,15], Emil Lenc[2], Duncan R. Lorimer[16,17], Maura A. McLaughlin[16,17], Andrew O'Brien[4], Sergio Pintaldi[18], Joshua Pritchard[1,2,3], Nanda Rea[12,19], Joshua P. Ridley[20], Michele Ronchi[12], Ryan M. Shannon[3,7], Gregory R. Sivakoff[21], Adam Stewart[1], Ziteng Wang[1,2,3], and Andrew Zic[2,22]

The Astrophysical Journal, 884:96 (6pp), 2019 October 10 https://doi.org/10.3847/1538-4357/ab397f

Serendipitous Discovery of PSR J1431-6328 as a Highly Polarized Point Source with the Australian SKA Pathfinder

David L. Kaplan[1], Shi Dai[2], Emil Lenc[2], Andrew Zic[2,3], Joseph K. Swiggum[1], Tara Murphy[3], Craig S. Anderson[4], Andrew D. Cameron[2], Dougal Dobie[2,3], George Hobbs[2], Jane F. Kaczmarek[2,5], Christene Lynch[6,7], and Lawrence Toomey[2]
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[3] Sydney Institute for Astronomy, School of Physics, University of Sydney, Sydney, New South Wales 2006, Australia
[4] CSIRO Astronomy & Space Science, 26 Dick Perry Avenue, Kensington, WA 6151, Australia
[5] CSIRO Astronomy and Space Science, Parkes Observatory, P.O. Box 276, Parkes NSW 2870, Australia
[6] International Centre for Radio Astronomy Research—Curtin University, 1 Turner Avenue, Bentley, WA 6102, Australia
[7] ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D)
Received 2019 June 20; revised 2019 August 5; accepted 2019 August 6; published 2019 October 14

The Astrophysical Journal, 961:175 (11pp), 2024 February 1 https://doi.org/10.3847/1538-4357/ad0fe8

Discovery of a Young, Highly Scattered Pulsar PSR J1032-5804 with the Australian Square Kilometre Array Pathfinder

Ziteng Wang[1], David L. Kaplan[2], Rahul Sengar[2], Emil Lenc[3], Andrew Zic[3], Akash Anumarlapudi[2], B. M. Gaensler[4,5,6], Natasha Hurley-Walker[1], Tara Murphy[7,8], and Yuanming Wang[8,9]

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **507,** 3888–3898 (2021) https://doi.org/10.1093/mnras/stab1979
Advance Access publication 2021 July 13

Two extreme steep-spectrum, polarized radio sources towards the Galactic bulge

S. D. Hyman,[1★] D. A. Frail,[2★] J. S. Deneva,[3] N. E. Kassim,[4★] S. Giacintucci,[4] J. E. Kooi,[4] T. J. W. Lazio,[5] I. Joyner,[1] W. M. Peters,[4] V. Gajjar[6] and A. P. V. Siemion[7]
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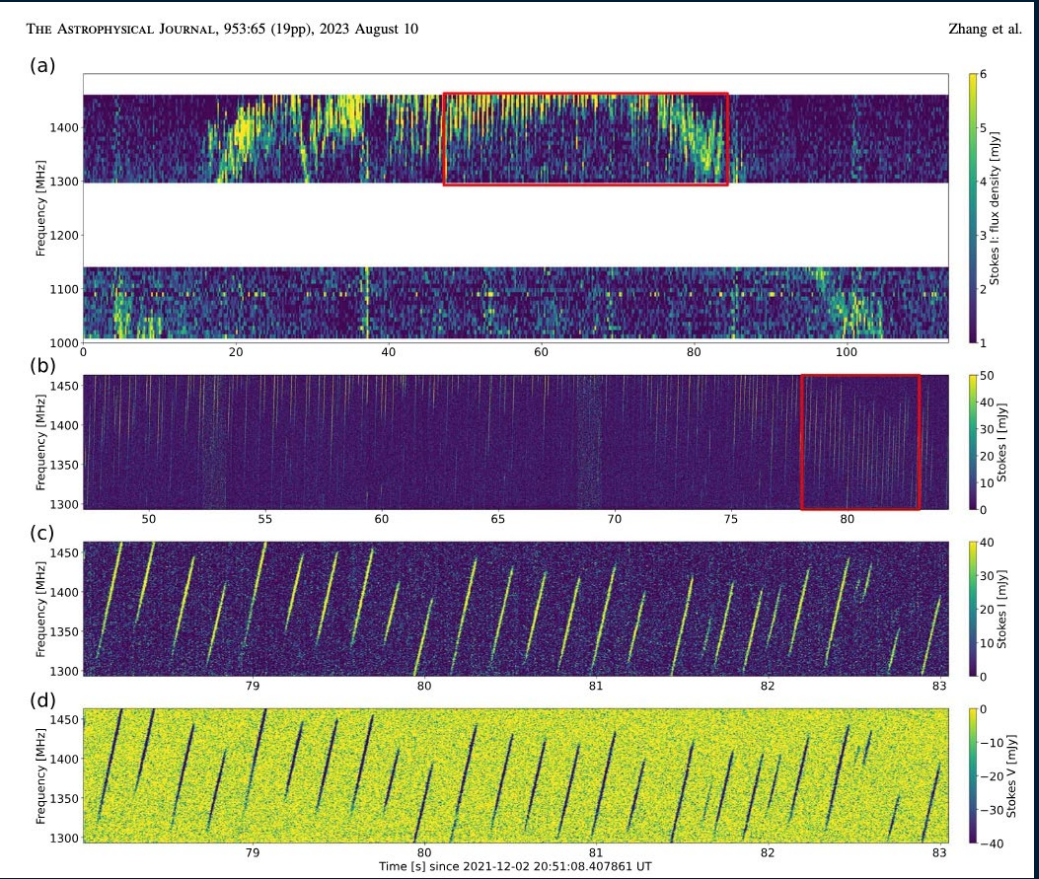
Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **475,** 942–954 (2018) doi:10.1093/mnras/stx3281
Advance Access publication 2017 December 21

An image-based search for pulsars among *Fermi* unassociated LAT sources

D. A. Frail,[1★] P. S. Ray,[2] K. P. Mooley,[3†] P. Hancock,[4,5] T. H. Burnett,[6] P. Jagannathan,[1,7] E. C. Ferrara,[8] H. T. Intema,[9] F. de Gasperin,[9] P. B. Demorest,[1] K. Stovall[1] and M. M. McKinnon[1]

A menagerie of multimescale transients



Zhang et al. 2023

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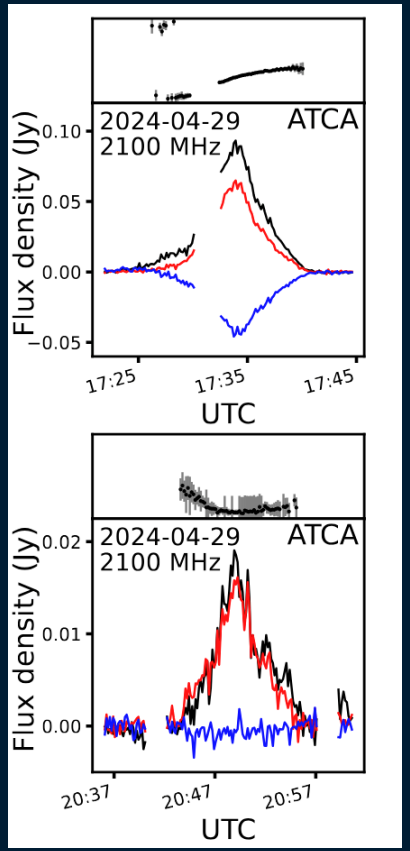
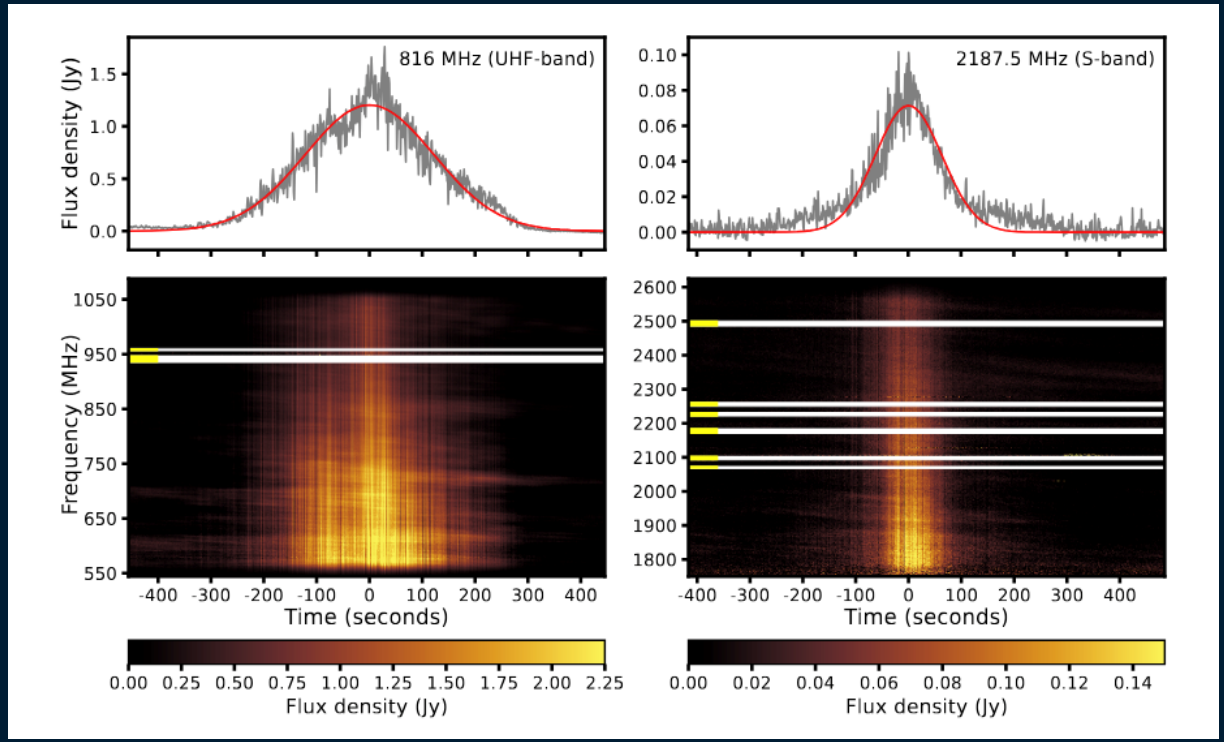


Lee et al. 2024



Lee et al. 2024

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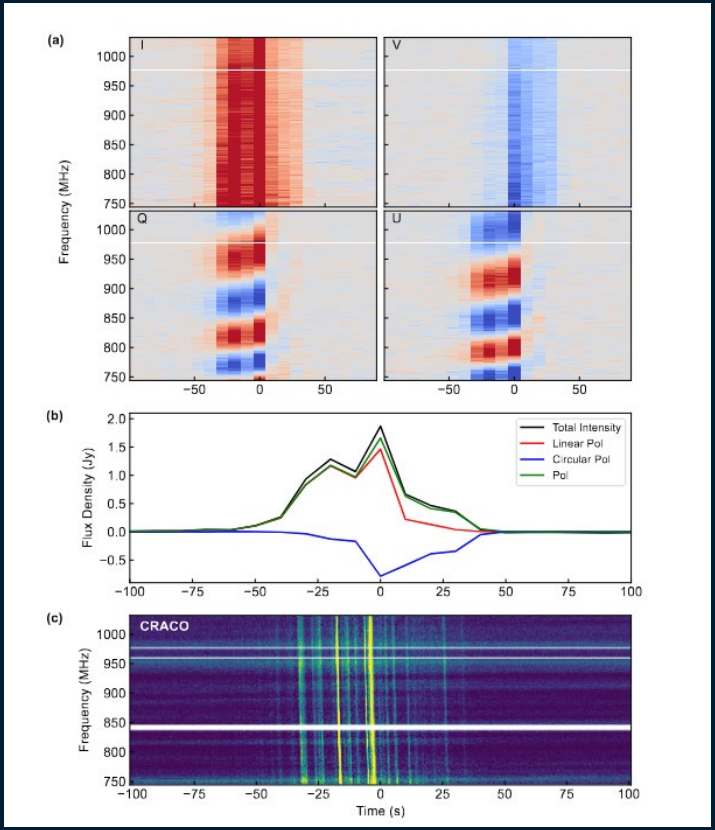
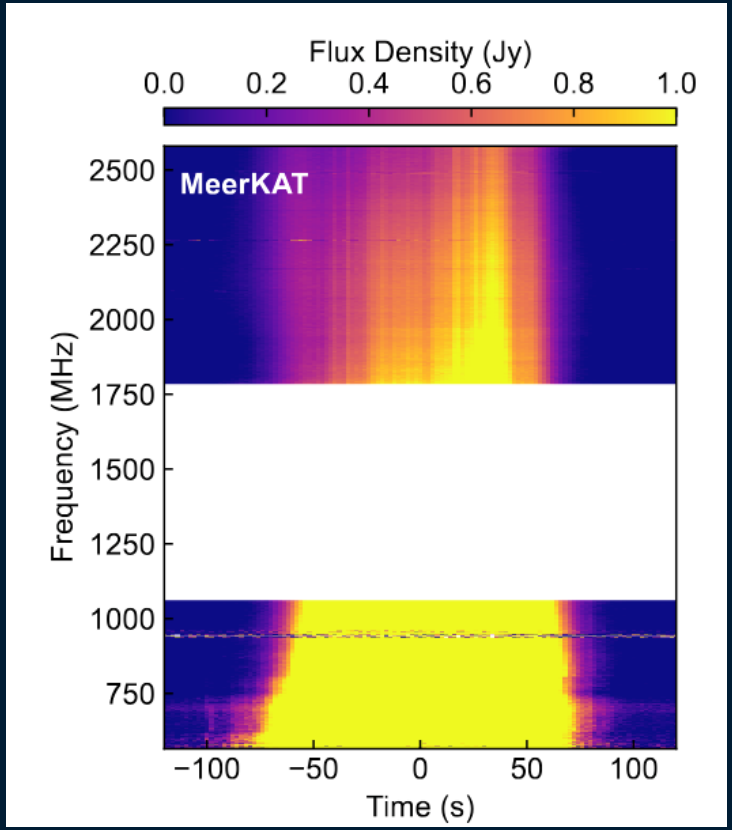


Wang et al. 2024



Wang et al. 2024

The (potential of) high time resolution capability on ATCA

We have seen examples of science outcomes with existent ATCA capability

Many of the science outcomes would have been enhanced by high-time resolution ATCA capability

- E.g. MeerKAT often used for follow-up of relatively bright sources primarily because of its dual imaging + beamforming ability
- In other cases, simultaneous Murriyang + ATCA observations needed to be arranged – difficult to schedule

Ultra-high time resolution & high-precision pulsar “fold-mode” not historically in ATCA’s wheel-house

- Murriyang will continue to provide the highest-sensitivity pulsar observations below ~5 GHz among ATNF fleet

The (potential of) high time resolution capability on ATCA

Proposal: use [spare] BIGCAT GPU capacity to form pulsar data products (search and fold) using tied array beams

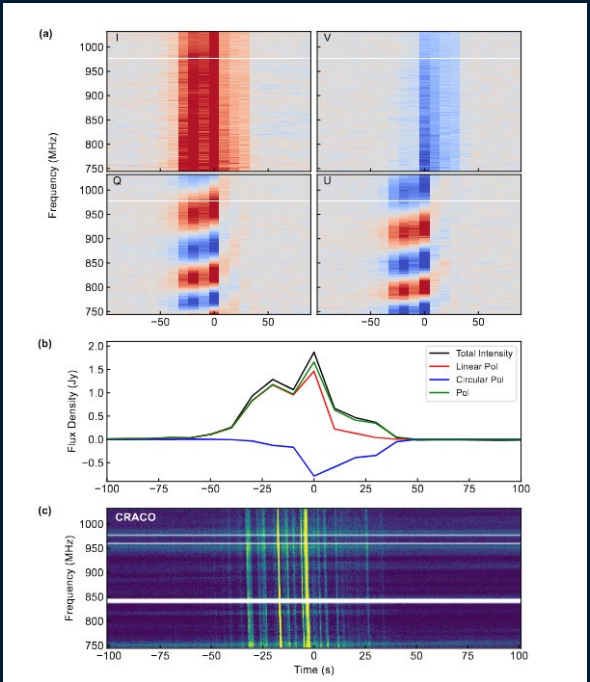
Options:

- Commensal imaging + beamformed pulsar products – similar to e.g. PTUSE on MeerKAT:
  would depend on having < 8GHz continuum bandwidth (e.g. 16cm receiver will only use 2 GHz bandwidth)
- Pulsar data products on their own, e.g. multiple tied array beams

Science Cases

1. Flexible timescale follow-up of Galactic variables and transients
2. Sensitive, multi-timescale monitoring (e.g., active stars, interplanetary scintillation, repeating FRBs)
3. An ATCA tied-beam pulsar survey at ~6 GHz?

Science case #1/#2: Transient/pulsar follow-up and monitoring



Wang et al. 2024

Many transients exhibit variability across multiple timescales

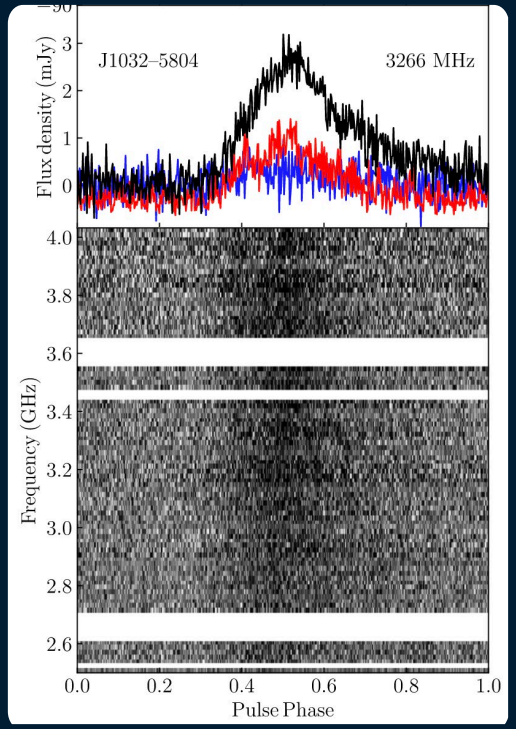
ATCA does not currently provide high time-resolution capability; searching for ”long-duration” (> 10s duration) transients is difficult with Murriyang (single-dish gain variations)

ATCA dual imaging + beamformed mode would provide a solution

Science use-cases:

- Follow-up of variable pulsar candidates – e.g. eclipsing “spider” systems, other exotic systems
- Measure pulse microstructure and interstellar dispersion from “long period transients”
- Resolving fundamental emission components from active stars
- High-frequency followup of repeating FRBs and possible corresponding persistent radio sources

Science case #3: pulsar searches and surveys



Wang et al. 2023

- **The challenge**:
  Pulsars with high dispersion measures are difficult to detect due to scattering/pulse smearing, especially at low frequencies – many have been missed in previous search efforts (e.g. Lower et al. 2024, Wang et al. 2023)

- **The significance**:
  High DM pulsars, particularly those in the Galactic Center and Bulge, scientifically important for studying phenomena like the GC Fermi excess and testing relativity.

- **A high-frequency survey may yield low-hanging fruit**:
  A major pulsar survey of the Galactic Bulge at high frequencies using multiple tied-array beams could be enabled by GPUs (however, total capacity may be limited)

Conclusions and the future

ATCA has played an important role in following up and monitoring a wide range of Galactic variables and pulsars

High time resolution capability afforded by BIGCAT GPUs will broaden the scienctific excellence possible with the ATCA

Have a science case? Contact us.

Why notMurriyang or MeerKAT?

- ATCA primary beam is ~11 arcmin at 5 GHz; Parkes PB is ~4 arcmin
  - ~8x FoV of Parkes
- Similar SEFD to Parkes at 8 GHz: ~48 Jy (vs. 43 Jy for Parkes): ATCA survey speed > Parkes survey speed
- Parkes cannot make high-angular resolution maps
- MeerKAT cannot observe above 3.5 GHz; ATCA's sweet spot is 5-9 GHz
- Ability of ATCA to rapidly follow up sources of interest is a strength

Pulsar binning mode: unveiling relativistic winds, bubbles, and mor

The Astrophysical Journal Letters, 959:L2 (7pp), 2023 December 10 https://doi.org/10.3847/2041-8213/ad0bfc

A Spatially Resolved X-Ray Polarization Map of the Vela Pulsar Wind Nebula

Kuan Liu[1], Fei Xie[1,2], Yi-han Liu[3,4], Chi-Yung Ng[3], Niccolò Bucciantini[5,6,7], Roger W. Romani[8], Martin C. Weisskopf[9], Enrico Costa[2], Alessandro Di Marco[2], Fabio La Monaca[2], Fabio Muleri[2], Paolo Soffitta[2], Wei Deng[1], Yu Meng[1], and En-wei Liang[1]
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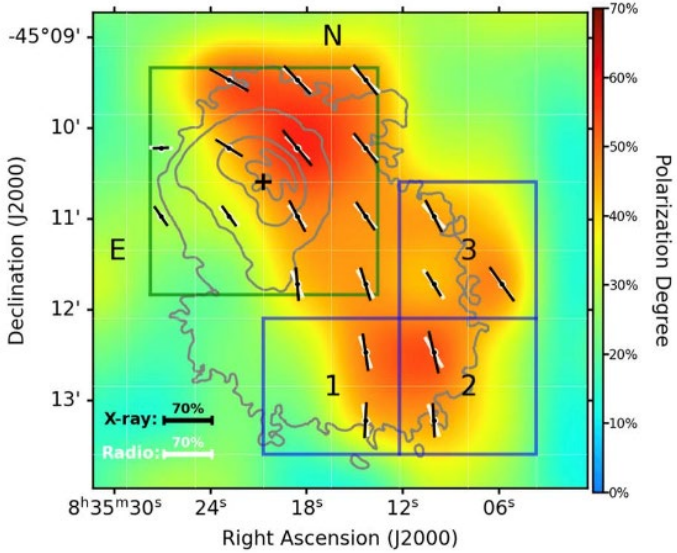

The radio to GeV picture of PSR B1259-63 during the 2021 periastron passage

M. Chernyakova[1,2★], D. Malyshev,[3] B. van Soelen[4], S. Mc Keague,[1] S. P. O'Sullivan[5] and D. Buckley[4,6,7]
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Radio Study of the Pulsar Wind Nebula Powered by PSR B1706-44

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Received 2022 May 12; revised 2022 December 15; accepted 2023 January 9; published 2023 March 8

Radio properties of the magnetar near Sagittarius A* from observations with the Australia Telescope Compact Array

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CSIRO Astronomy and Space Science, Australia Telescope National Facility, PO Box 76, Epping, NSW 1710, Australia

Accepted 2013 June 28. Received 2013 June 17; in original form 2013 May 14

The Astrophysical Journal, 842:100 (14pp), 2017 June 20 https://doi.org/10.3847/1538-4357/aa762e

Discovery of a Synchrotron Bubble Associated with PSR J1015–5719

C.-Y. Ng[1], R. Bandiera[2], R. W. Hunstead[3], and S. Johnston[4]
[1] Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong; ncy@bohr.physics.hku.hk
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[3] Sydney Institute for Astronomy (SIfA), School of Physics, The University of Sydney, NSW 2006, Australia
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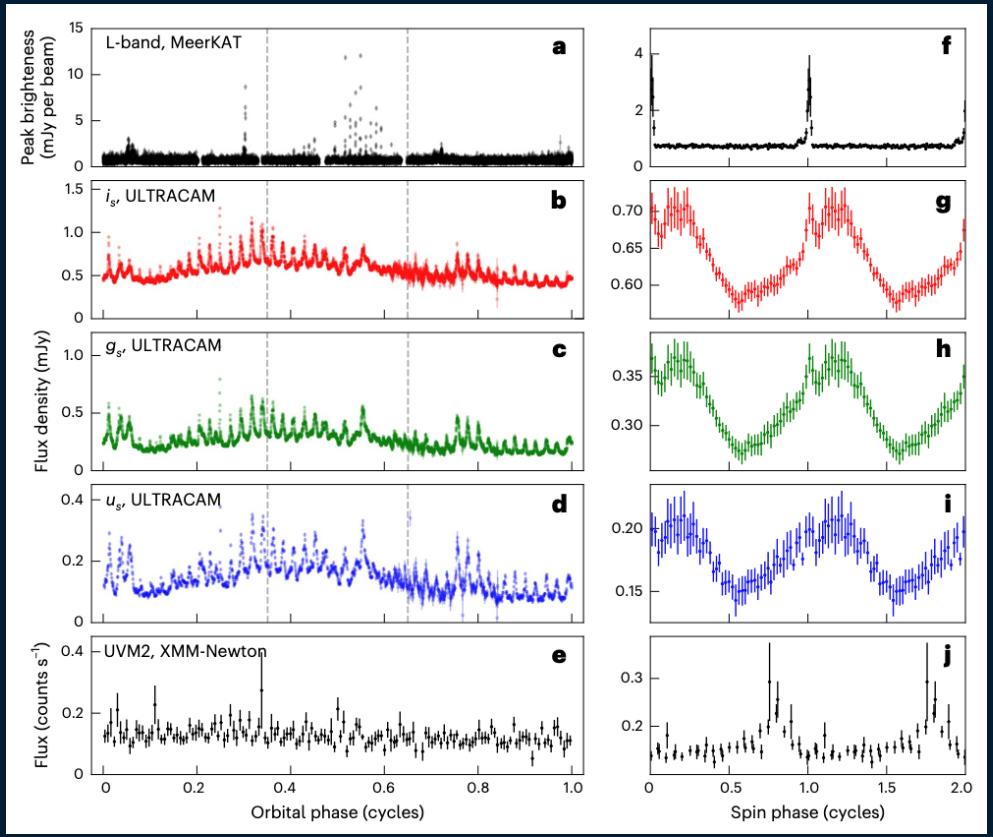
Received 2016 November 6; revised 2017 May 11; accepted 2017 May 29; published 2017 June 20

A menagerie of multimescale transients



Pelisoli et al. 2022