Understanding the radio stars population with ASKAP

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Credit: CSIRO

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Stellar radio emission

Stars across all spectral types show radio emission due to a range of processes

Incoherent emission ($T_B < 10^{12}$ K)

- Gyrosynchotron emission
- Synchrotron emission

Coherent emission

- Plasma emission
- Electron cyclotron maser emission

References:

Dulk (1985), ARA&A, 23, 169

Bastian et al. (1990), ApJ 353, 265

Gudel (2002), ARA&A, 40, 217

Benz & Gudel (2010), ARA&A, 48, 241

Compared to other wavebands, a relatively small fraction of stars are detected in radio

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Composite: C. Carter / G. Hallinan (Caltech), P. Donn

Motivation for studying radio stars with ASKAP

1. Characterise the radio stars population – what fraction of stars emit radio?
2. Identify and study individual stars, and in particular rare systems
3. Understand the variability of radio stars in preparation for SKA surveys

Previous studies have mostly either been:

- Detailed studies of stars identified as interesting at other wavebands; *(e.g. Mutel & Lestrade (1985), Linsky et al. (1992), Trigilio et al. (2011), Villadsen & Hallinan (2019))*
- Large continuum surveys, in which it is hard to conclusively identify stars due to lack of other radio information

ASKAP allows us to conduct large unbiased surveys for radio stars.
In particular, with circular polarisation and variability information.

The Australian SKA Pathfinder (ASKAP)

- 36 x 12m dishes
- Frequency range = 700 – 1800 MHz
- Total collecting area = 4072 sq m
- Field of view = 30 sq deg
- Bandwidth = 300 MHz
- Maximum baseline = 6 km

- 9 survey science projects
- Full surveys started in 2023
- All data public once it has been scientifically validated
  See CASDA archive https://research.csiro.au/casda/

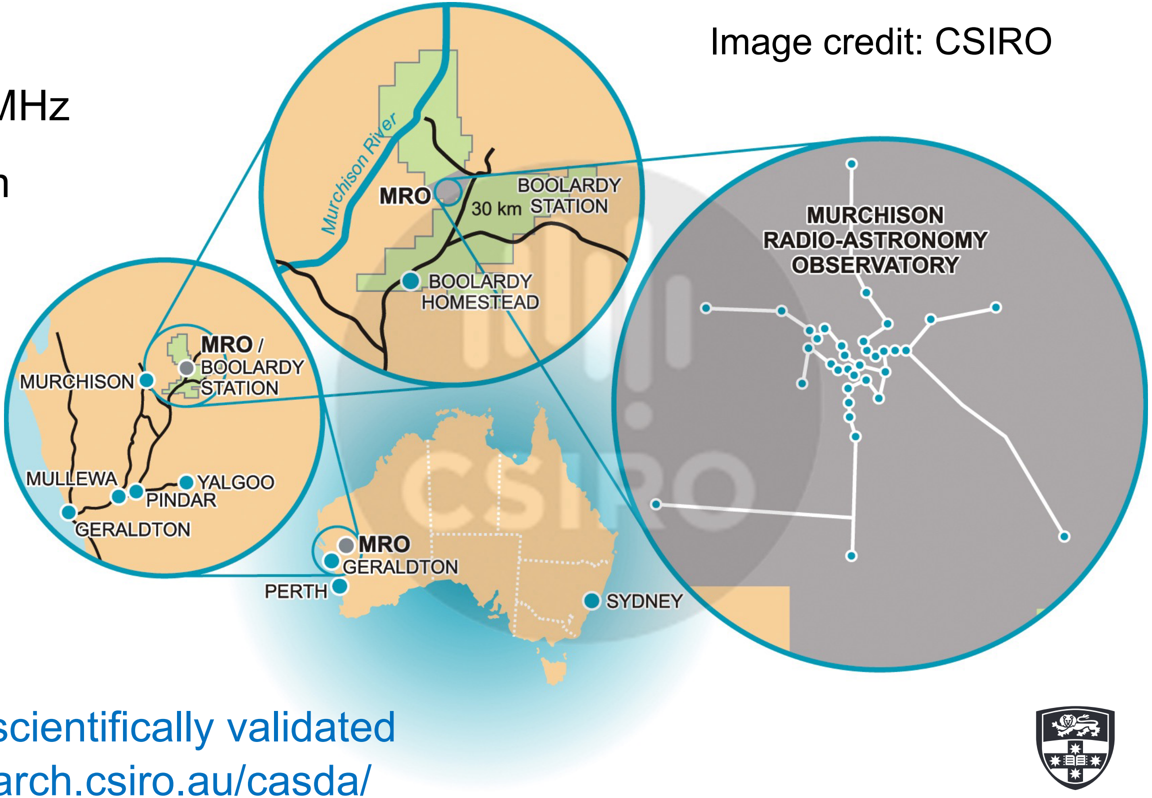

Image credit: CSIRO

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The Rapid ASKAP Continuum Survey

Survey	Frequency (MHz)	Bandwidth (MHz)	Resolution (arcsec)	Sky Coverage (sq deg)	Sensitivity (mJy/beam)	Polarization
RACS*	887.5, 1367.5, 1655.5	288	15	36,656	~0.25	IQUV
SUMSS + MGPS-2	843	3	45	10,300	1.5	RC
NVSS	1346, 1435	42	45	33,800	0.45	IQU

New primary radio reference survey at ~1 GHz (-90° < δ < +49°)

- **RACS-low** (887.5 MHz, bw = 288 MHz): McConnell et al. (2020), PASA, 37, 48 (3 epochs)
- **RACS-mid** (1367.5 MHz, bw = 144 MHz): Duchesne et al. (2023), PASA, 40, 34
- **RACS-high** (1655.5 MHz, bw = 200 MHz): Duchesne et al. *in prep.*

All data is publicly available: https://research.csiro.au/racs/home/data-2/

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The ASKAP VAST survey

https://www.vast-survey.org

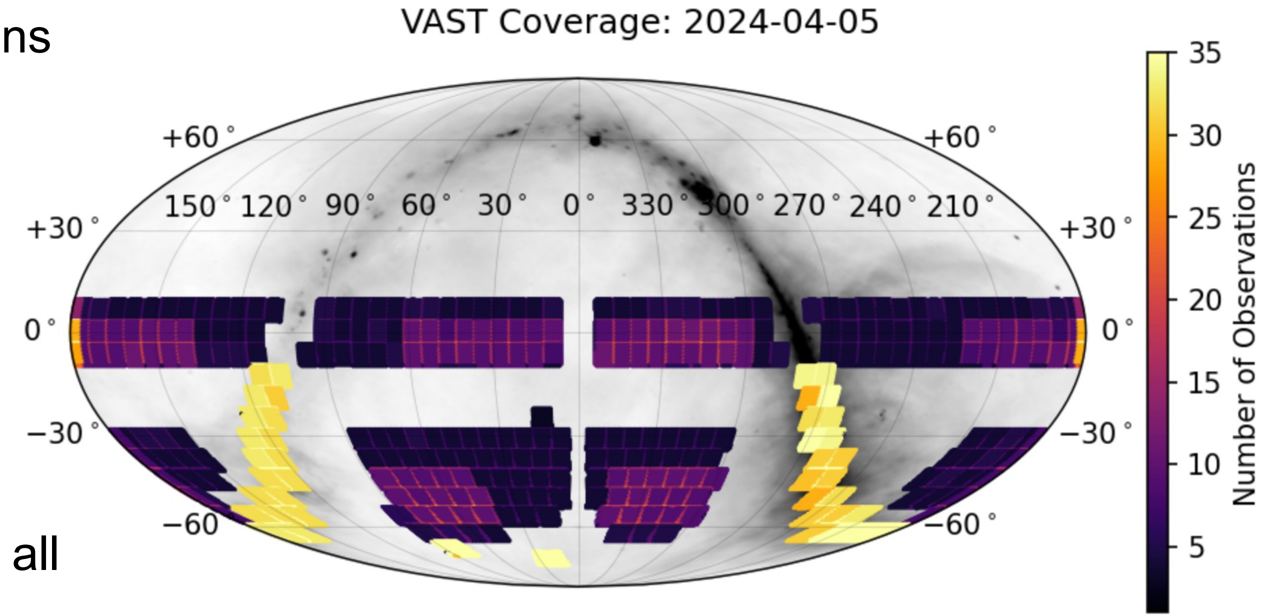
Integration time: 12 mins
250 μJy rms

Area: 14,000 sq deg
Time: 2,100 hours

Spanning ~4 years
Started: Q1 2023

Commensal access to all other ASKAP surveys

Extragalactic + Galactic Plane & MC



Low band: 888 MHz, Mid-band 1368 MHz

Murphy et al. (2013), PASA, 30, 6
Murphy et al. (2021), PASA, 38, 54

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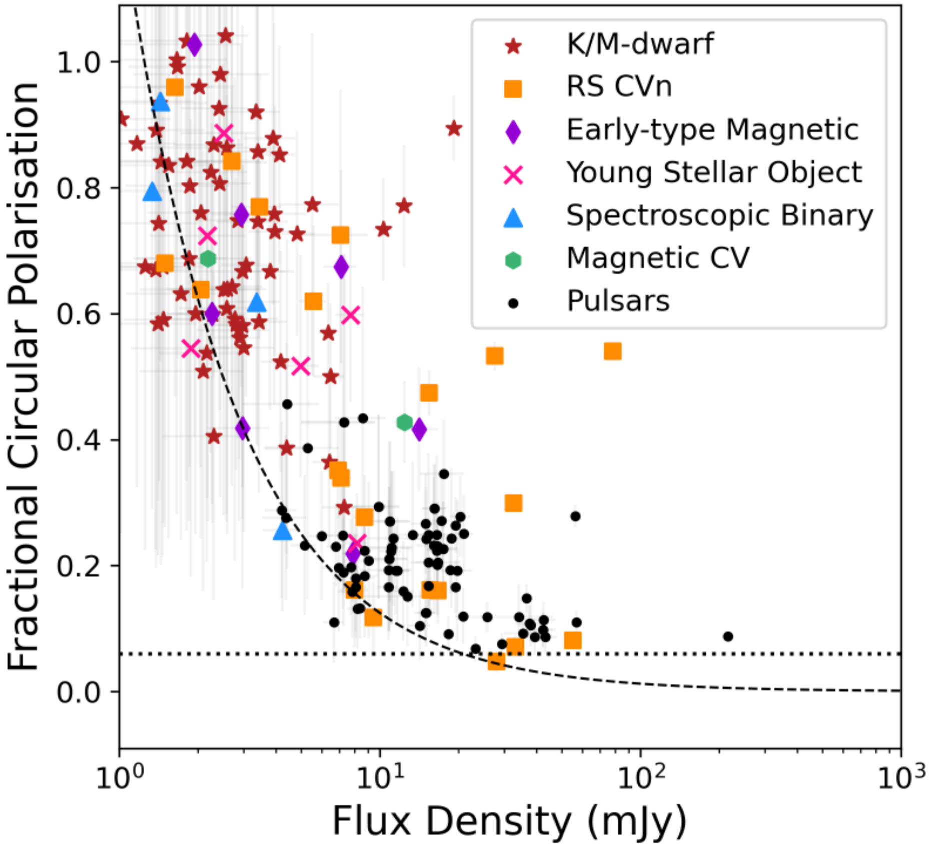
Searching for radio stars in circular polarisation

- Most sources in radio continuum images are AGN
- AGN circular polarisation fraction << 1%
- Only a few object classes have significant (>6%) circular polarisation (stars + pulsars)
- RACS-low → 33 radio stars
- VAST Pilot → 36 radio stars

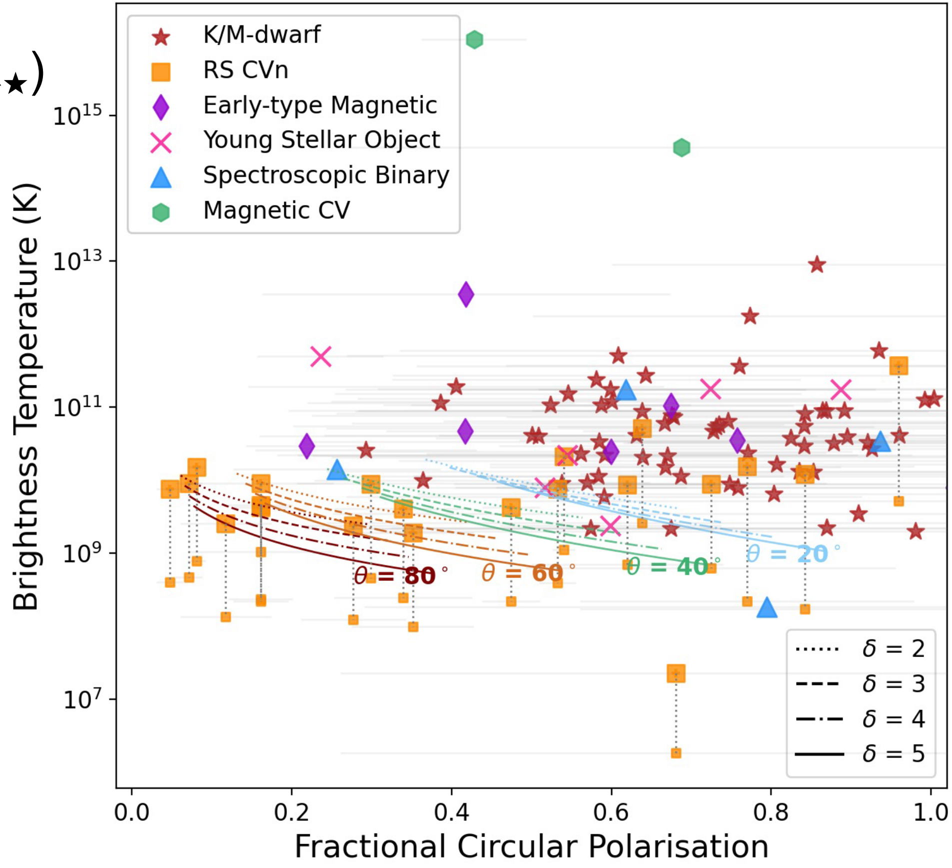


Pritchard et al. (2021), MNRAS, 502, 5438
Pritchard et al. (2024), MNRAS, 529, 1258

What mechanism drives circularly polarised emission?

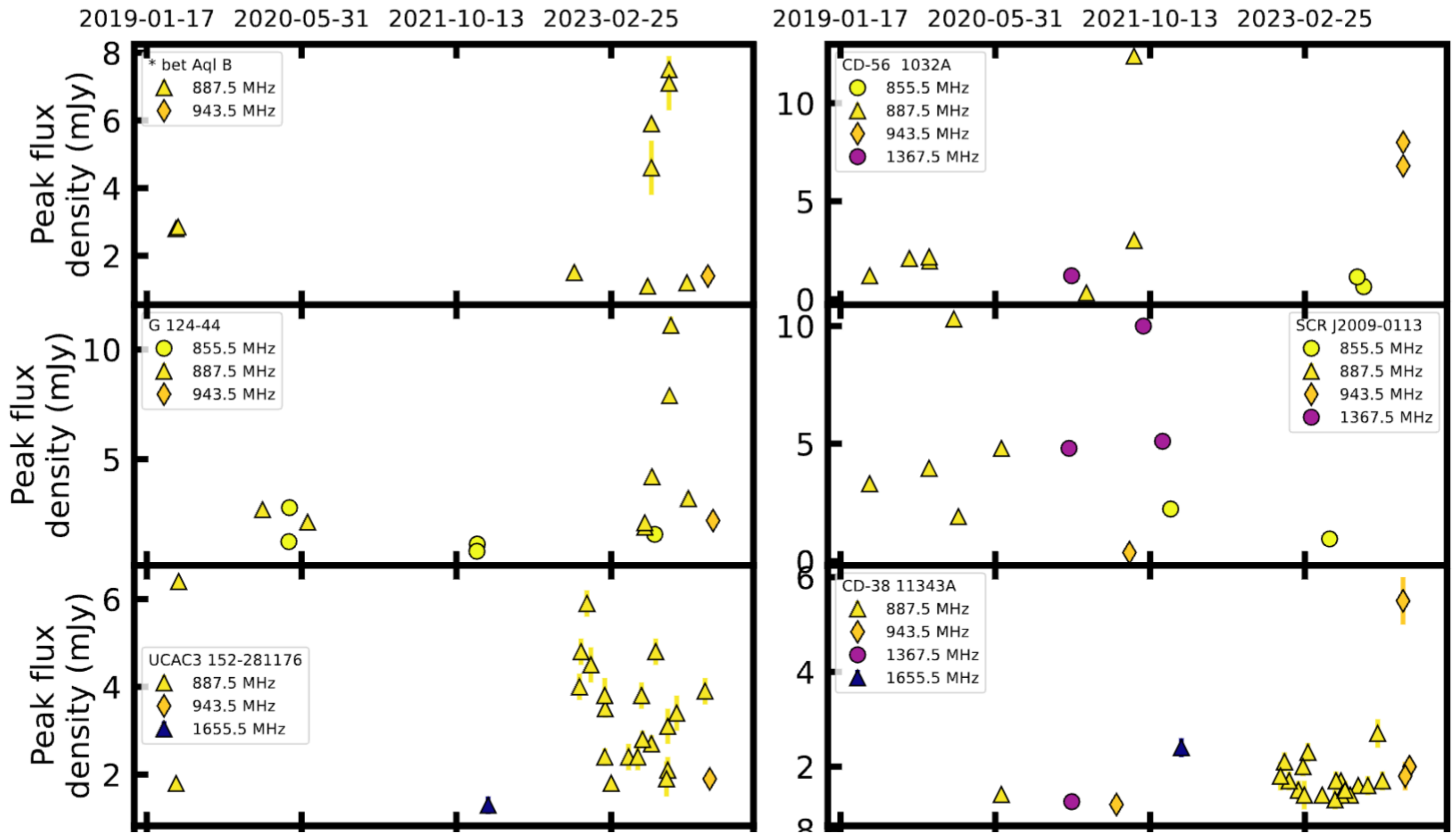
- Brightness temperature lower limits ($3R_\star$)
- Empirical models for optically thin gyrosynchrotron emission (Dulk 1985)

- RSCVns and Algols consistent with gyrosynchrotron
- → coherent mechanisms for other types (in particular K/M-dwarfs)



Pritchard et al. (2021), MNRAS, 502, 5438

Multi-epoch sampling of radio stars



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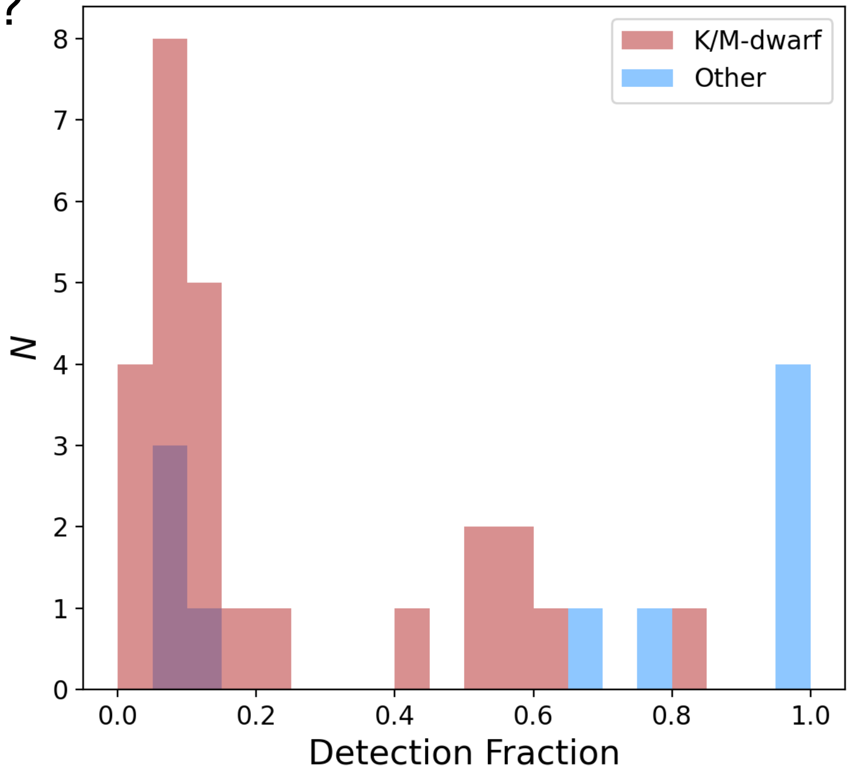
Driessen et al., arXiv 2404074180

Multi-epoch samples puts constraints on burst rate

- How large is the detectable population?
- Consider 25 pc volume
- Detection fraction = N_d / N_o
- Median detection fraction <10%
  → >50 radio loud K/M-dwarfs
- ~500 optical/IR K/M-dwarfs in survey volume within 25pc
- → >10% of K/M-dwarfs produce luminous radio bursts



Periodic emission from a T8 dwarf

See posters by Kovi Rose & Robert Kavanagh

WISE J062309.94–045624.6

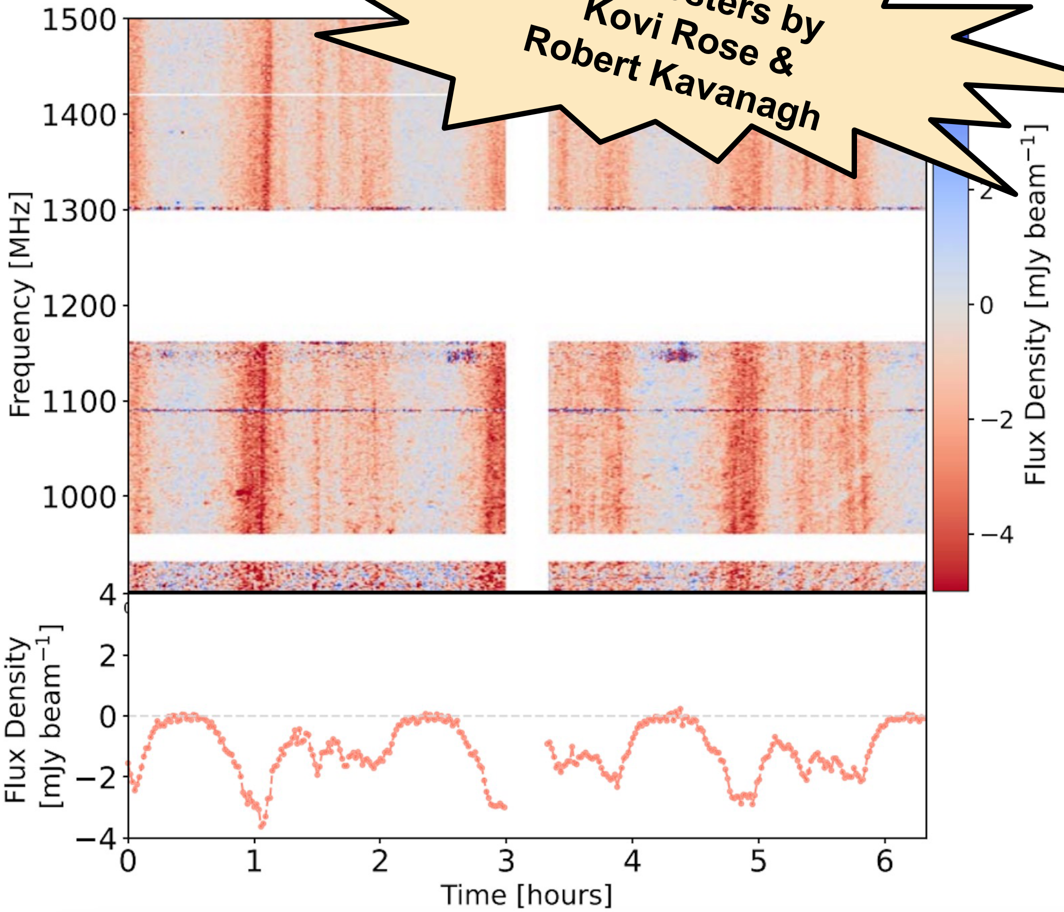
Sub-dwarf (<0.075 M_solar)
Teff = 699 K
Distance = 11.44pc

Detected in RACS (66% Stokes V)

MeerKAT L-band dynamic spectrum
Period = 1.9 hr

EMCI aligned with stellar rotational period

Rose et al. (2023), ApJL, 951, L43



More interesting stellar systems on the way…

Found in Stokes V search

- 14% circular poln
- 68% linear poln
- Flux density = 23 mJy/bm

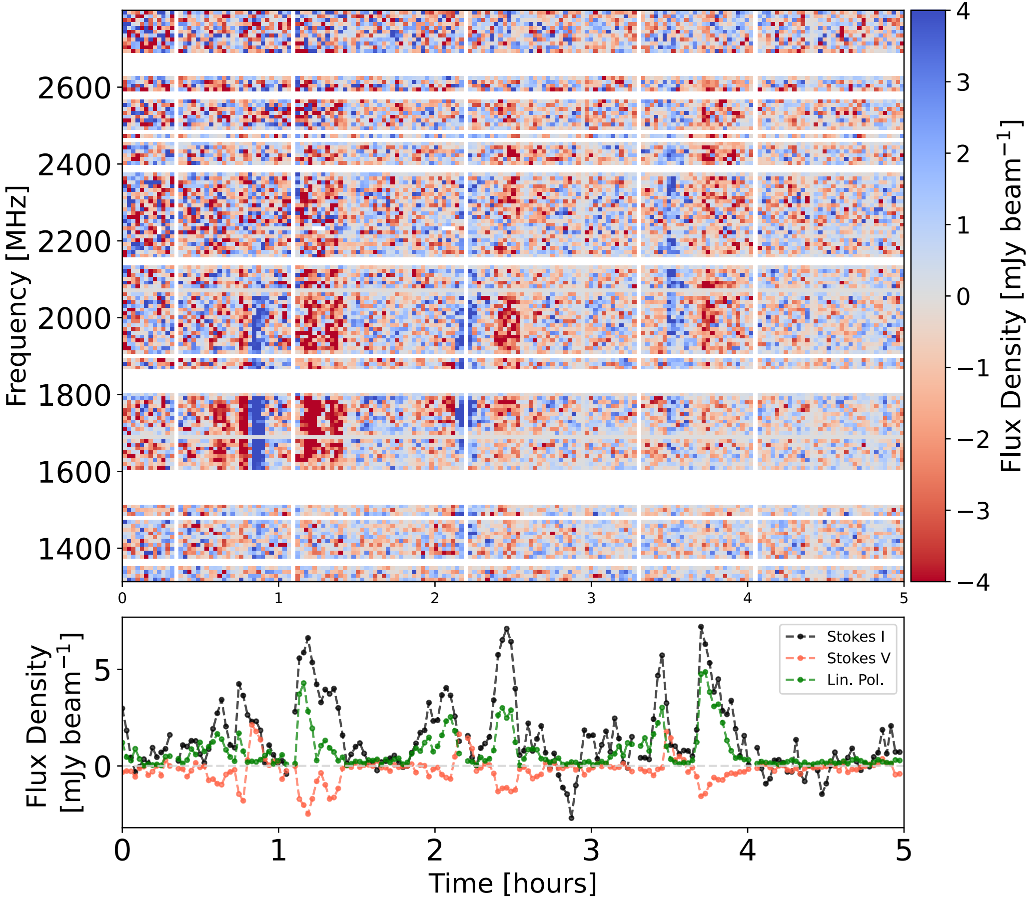
Clear periodic bursts

But also >20 hours with no bursts

Not detected in Parkes obs

Possible WD binary or other exotic binary system

Follow-up underway



Rose et al., in prep

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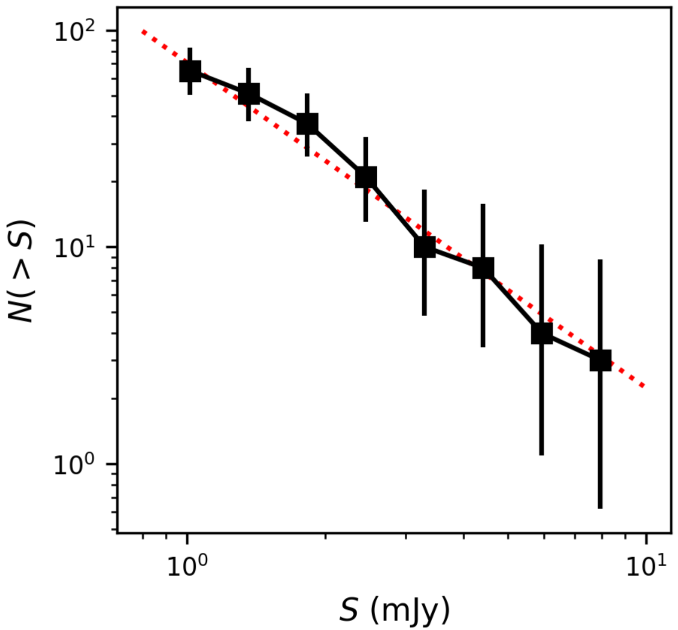
Summary and future plans



ASKAP and other pathfinders are transforming our capacity to understand the radio stars population

In RACS-low / VAST Pilot-low:

- 107 radio star detections
  - 7.9×10^{-4} deg^{-2}
- 67 of these are coherent K/M-dwarf radio bursts
  - 4.9×10^{-4} deg^{-2}

Full VAST survey (*underway!*) will detect ~300 radio stars per year

A 1-hour all-sky survey with SKA-mid should detect ~58,000 radio stars

If you're interested in joining VAST, email me (tara.murphy@sydney.edu.au)

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