The power of circular polarization to reveal missing populations of pulsars

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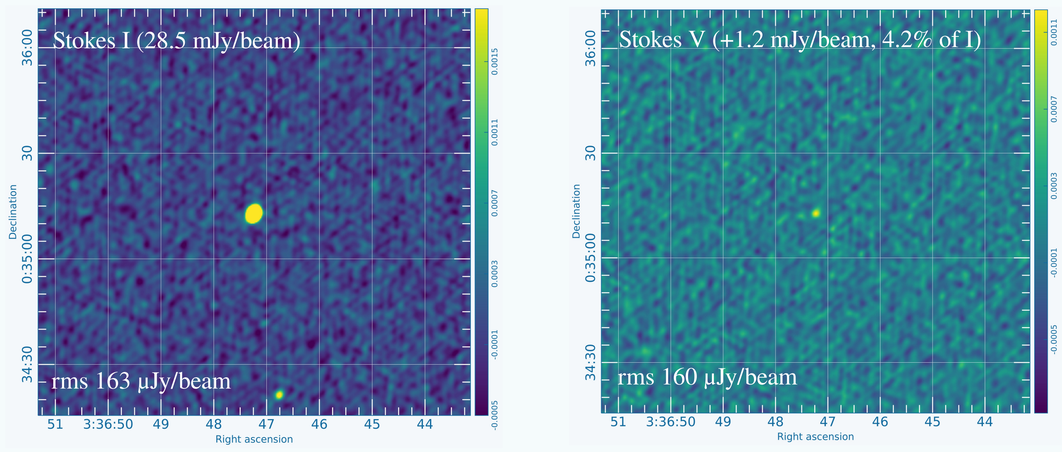
Circular Polarization Observations using the VLA Sky Survey

The VLA Sky Survey is a shallow (70-120 µJy/beam) all-sky survey covering the Nothern hemisphere sky >40º declination at 2-4 GHz with 2.5 arcsecond resolution using the Karl G. Jansky Very Large Array (https://science.nrao.edu/vlass/).

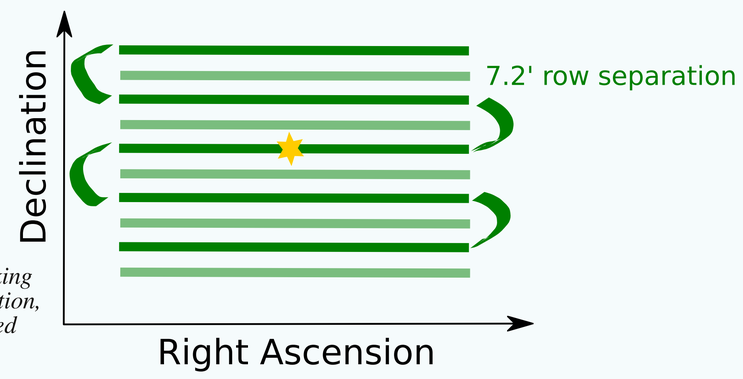
Standard Products are: Continuum images, spectral cubes, and potentially full polarization cubes

Circular polarization is not a standard product generated by the survey team.

Variable Star HR 1099 in VLASS

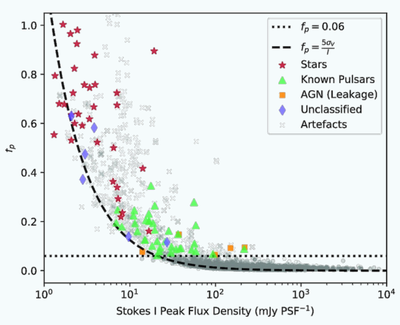


Stokes V leakage for VLASS OTF scans

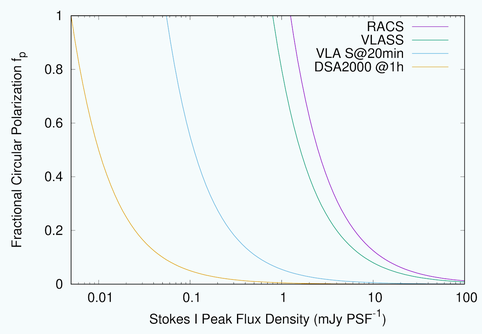


VLASS on-the-fly sky mosaicking strategy, with 7.2' row separation, 1.5' per integration (scan speed ~20º/hour).

Validation observations on 3C 286 in two separate on-the-fly mosaicks, crossing the calibrator either at the center of a row or in-between rows. In both cases observed Stokes V leakages were at the level of ~0.6% of Stokes I peak intensity. Concluding that beam leakages are mostly averaged out by this observing strategy.



Circular polarization survey for radio stars from the Rapid ASKAP Continuum Survey (RACS) detected radio emission coincident with 33 known stars, 37 known pulsars, and 6 detections of unknown origin. The above figure shows classification of visually inspected candidates. The dashed line indicates a $5\sigma_V$ detection threshold, where σ_V = 0.25 mJy PSF^{-1} (Pritchard et al. 2021).

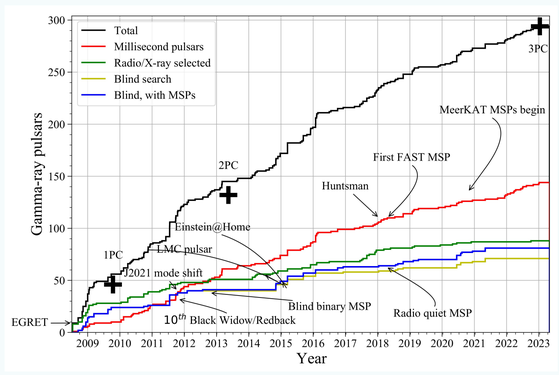


Comparison of expected sensitivity to circularly polarized emission between RACS, VLASS, pointed VLA observations (20 min at S-band or 40 min at L-band), and one hour using DSA2000. DSA2000 will provide two orders of magnitudes deeper coverage as compared to RACS and VLASS.

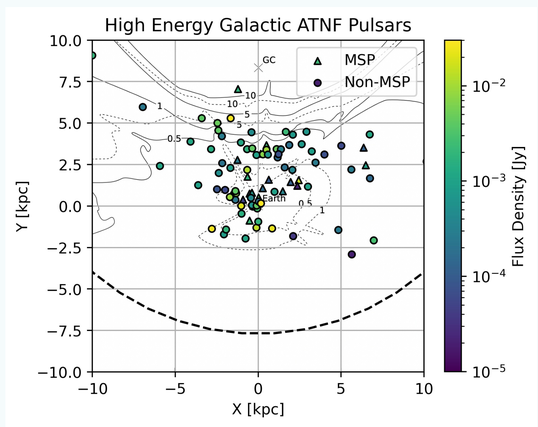
Missing Young Gamma-ray Pulsars

With more than 300 γ-ray pulsars detected by Fermi and an unabated pace of pulsar discoveries, it has long been assumed that there are few new radio-loud pulsars to be found in the Galactic plane (GP). The 4FGL-DR3 catalog (Abdollahi et al. 2022) presents a doubling in the number of pulsar-like unassociated γ-ray sources (UAS) to about one quarter of all detected GP sources. It is our hypothesis that the growing population of UAS in the GP are in fact the missing radio-loud young, energetic pulsars that are hidden from standard pulse searches by interstellar scattering.

We are observing with the VLA a sample of steep-spectrum radio sources found in UAS to detect circular polarization.



Cumulative number of known γ-ray pulsars, beginning with the launch of Fermi. The crosses show the numbers included in the first (1PC), second (2PC), and third (3PC) catalogs of Fermi pulsars and their publication dates (Fermi/LAT collaboration).



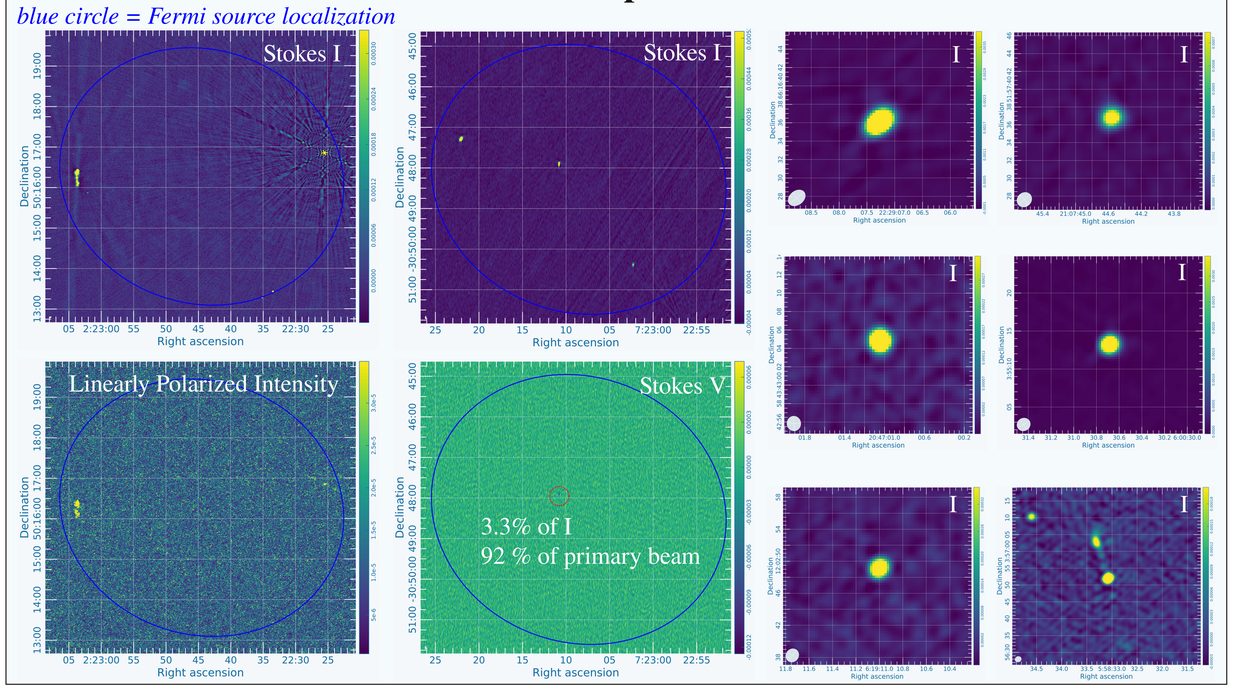
Contours of interstellar scattering for two radio surveys (dashed=PMPS, solid=HTRU) for lines of sight at b = 0 at 1.3 GHz adopted from Fig. 1 of Keith et al. (2010) with the distribution of all high energy pulsars with known distances and with Galactic latitudes of b < |10º| listed by the ATNF pulsar catalog (Manchester et al. 2005). We note how the distribution of Fermi pulsars is closely clustered around the Sun and appears to trace contours that indicate constant pulse broadening timescales (shown at 0.5, 1, 5, and 10 ms).

- Target selection from Multi-survey Catalog (Bruzewski et al. 2023):
  - Galactic latitude |b|<10˚
  - Galactic longitude 80˚<|l|<280˚
  - Declination >-35˚
  - Spectral index -3 < α < -1.5
  - Peak intensity >1 mJy/beam (at either L or S-bands)

- Observations at L and S-band in 2023; Already observed 48 targets in B configuration
- Preliminary results: ***No convincing detection of circular polarization so far***
  39 extended sources, 8 point sources (3 linearly polarized), 1 non-detection
- Stokes V wide-field imaging in CASA requires a-projection correction (currently buggy in tclean task)

Examples

blue circle = Fermi source localization



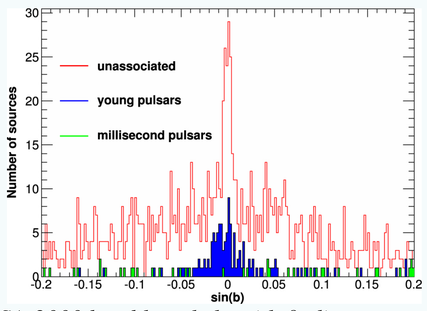
Circular Polarization Observations with DSA-2000

Circular Polarization is a key and somestimes unique probe for magnetic fields with a variety of applications, e.g. through detection of Zeeman splitting, to study stars, or find new exotic pulsar systems that have resisted traditional search methods.

What will DSA-2000 bring:

- A two orders of magnitude increase (or better) in sensitivity for continuum all-sky surveys and variability monitoring at cm-wavelengths.

- The ability to detect circularly polarized radio emission from stars and pulsars at unprecedented rates.



Will DSA-2000 be able to help with finding more young γ-ray pulsars? Above Fig. 18 from Abdollahi S. et al. 2022.

Technical Challenges:

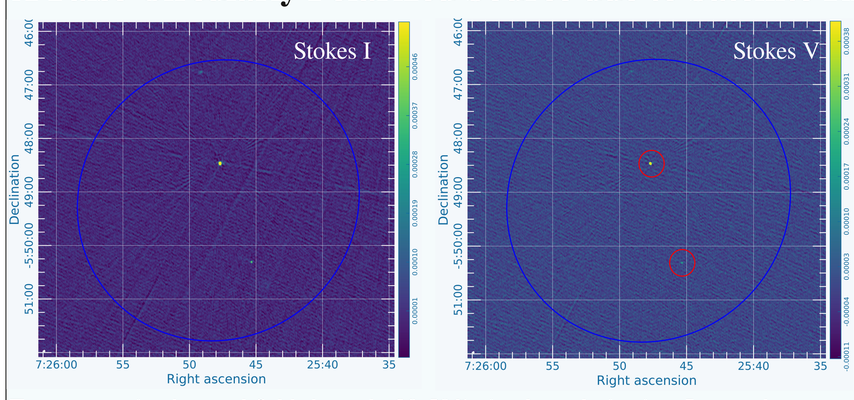
- Calibration can be a key challenge, depending on which feed design and signal processing path is chosen. While a linearly polarized feed simplifies circular polarization detection, it adds complication to obtain proper calibration of linear polarization. Vice versa, a circularly polarized feed creates challenges for calibrating circular polarization.

- High dynamic range in the analog and especially digital system is needed (e.g. high bitrate digitizers). As shown in the example of the VLA with 8 bit digitzers, the presence of bright interfering sources introduce artifical circular polarization due to uneven gain compression. Satellite interference, especially in cellphone bands, will be an issue!

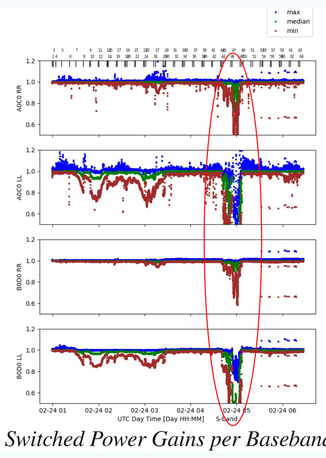
- Feed alignment is important to minimize polarized beam effects (e.g. squint) to simplify characterization for wide-field imaging, especially for shorter snapshot observations where averaging effects are less strong.

- Imaging algorithms for full Stokes widefield imaging need become more efficient to fully take advantage of DSA-2000 capabilities.

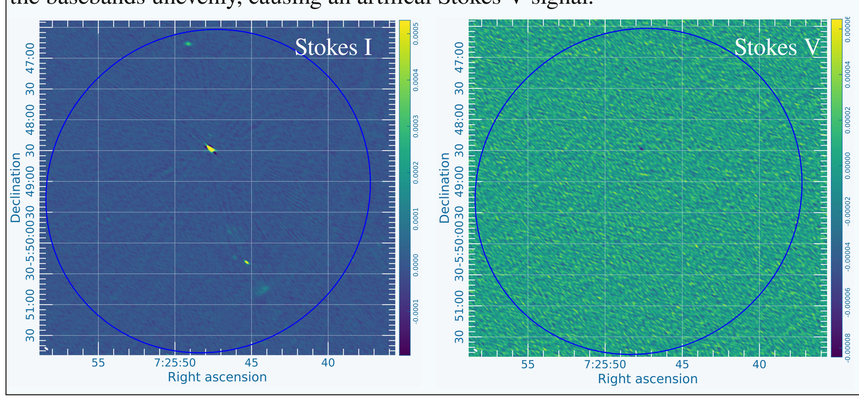
A False Circularly Polarized Source due to Satellite RFI



Two sources in observed field showed ~30-50% circular polarization. It turned out that we were observing in the geostationary satellite belt and RFI compressed the basebands unevenly, causing an artifical Stokes V signal.



Switched Power Gains per Baseband



Reobservation at hour angles looking West (toward the Pacific) avoided satellite interference. The Stokes V signals disappeared (leaving only a residual beam leakage of ~1%).

Better sensitivity revealed a lower surface brightness structure.

References

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Acknowledgments

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