Discovery of a shock-compressed magnetic field in the north-western rim of the young SNR RX J1713.7-3946 with X-ray polarimetry

IXPE Imaging X-Ray Polarimetry Explorer

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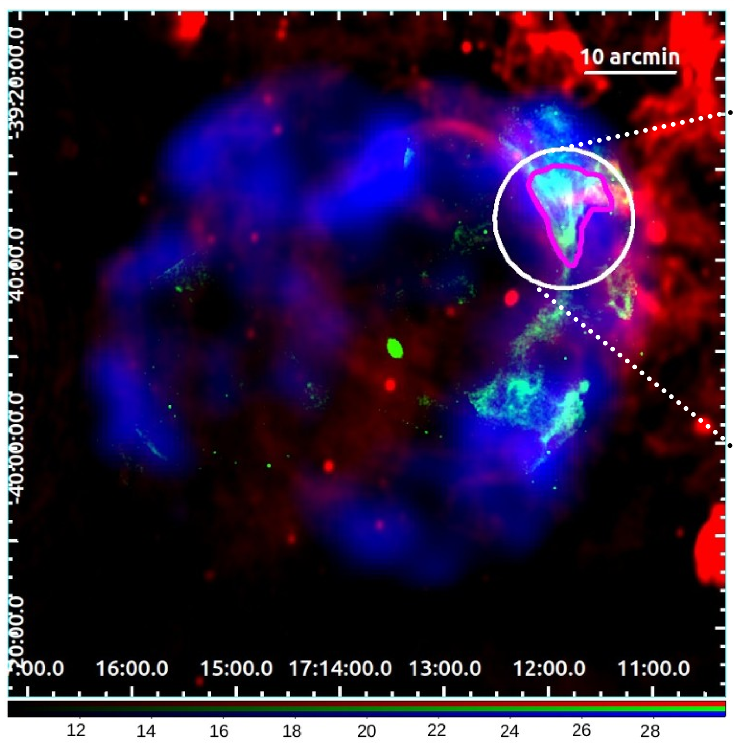
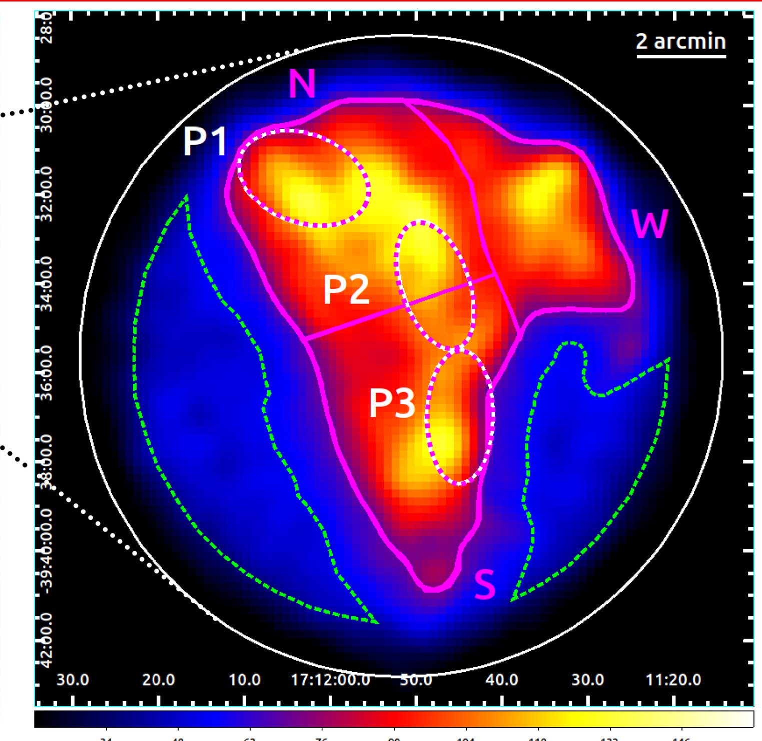
ABSTRACT

- Recent X-ray polarimetric measurements by the **Imaging X-ray Polarimetry Explorer (IXPE)** have **revealed radial magnetic fields** near particle acceleration sites in young SNRs, including **Cassiopeia A**, **Tycho**, and **SN 1006** (***Vink et al. 2022, Ferrazzoli et al. 2023, Zhou et al. 2023***).
- We present the spatially-resolved IXPE X-ray polarimetric observation of the northwestern rim of **SNR RX J1713.7-3946.**
- **For the first time, our analysis shows that the magnetic field in particle acceleration sites of this SNR is oriented tangentially with respect to the shock front.**
- Because of the lack of precise Faraday-rotation measurements in the radio band, this was not possible before.
- The average measured **polarization degree (PD)** of the synchrotron emission is 12.5 ± 3.3%, lower than the one measured by IXPE in SN 1006, comparable to the Tycho one, but notably higher than the one in Cas A.
- On sub-parsec scales, localized patches within RX J1713.7-3946 display PD up to 41.5 ± 9.5%.
- The **polarization angle (PA)** is compatible with a shock-compressed magnetic field
- either a radial net magnetic field upstream of the shock, or partial reisotropization of the turbulence downstream by radial magneto-hydrodynamical instabilities, could explain the observed PD.
- From comparison of PD and magnetic field distribution with **γ-rays** and ^{12}**CO** data, new inputs in favor of a **leptonic origin of the γ-ray emission**.



RGB image:
- Radio: 20 cm ATCA,
- X-rays: 0.5 – 7 keV Chandra,
- γ-rays:>2 TeV HESS



IXPE 2 – 5 keV image
- Magenta: IXPE regions of interest
- **White:** IXPE f.o.v.
- **Green:** background regions

RESULTS

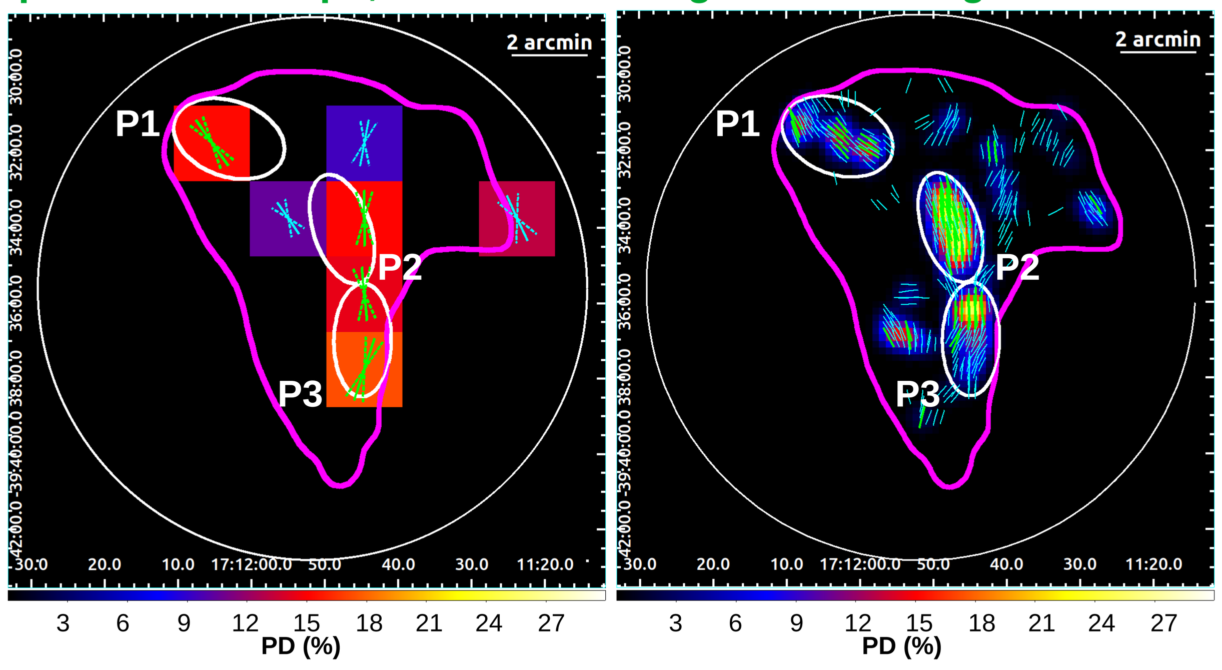
From polarization maps, evidence of magnetic field aligned with the shock.

IXPE polarization map binned with 2' pixels.

The vectors represents the PD and magnetic field direction with their uncertainties.

Green > 3 σ detection

Cyan > 2 σ detection



IXPE polarization map smoothed with a 1' Gaussian Kernel.

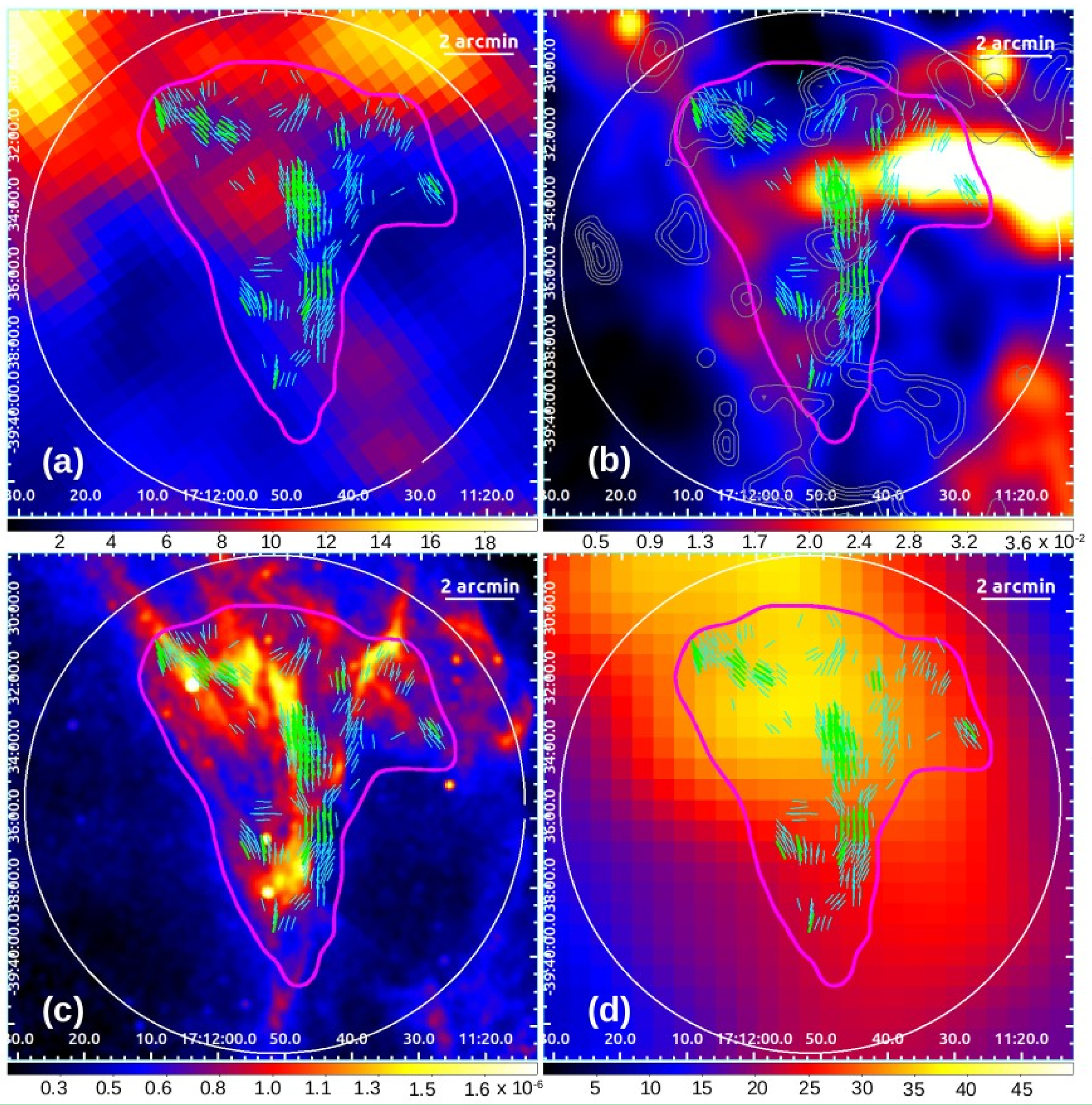
The vectors represents the PD and magnetic field direction.

Green > 3 σ detection

Cyan > 2 σ detection

The IXPE results in a multifrequency context

In all panels, we show the IXPE field of view as a white circle and the IXPE 2−5 keV contours in magenta.
In cyan and green we show the magnetic field lines, obtained through Gaussian smoothing of the IXPE data with > 2σ and > 3σ, respectively.



Molecular environment:

Mopra ^{12}CO image of the NW of RX J1713 integrated in the -6 to -16 km^{-1} velocity range.

Radio band:

ATCA 20cm image of the NW region of RX J1713: the grey contours are the radio polarization levels, each level corresponding to a 2% PD increase

High-resolution X-rays:

Chandra exposure-corrected mosaic of 0.5−7 keV images of the NW of RX J1713.

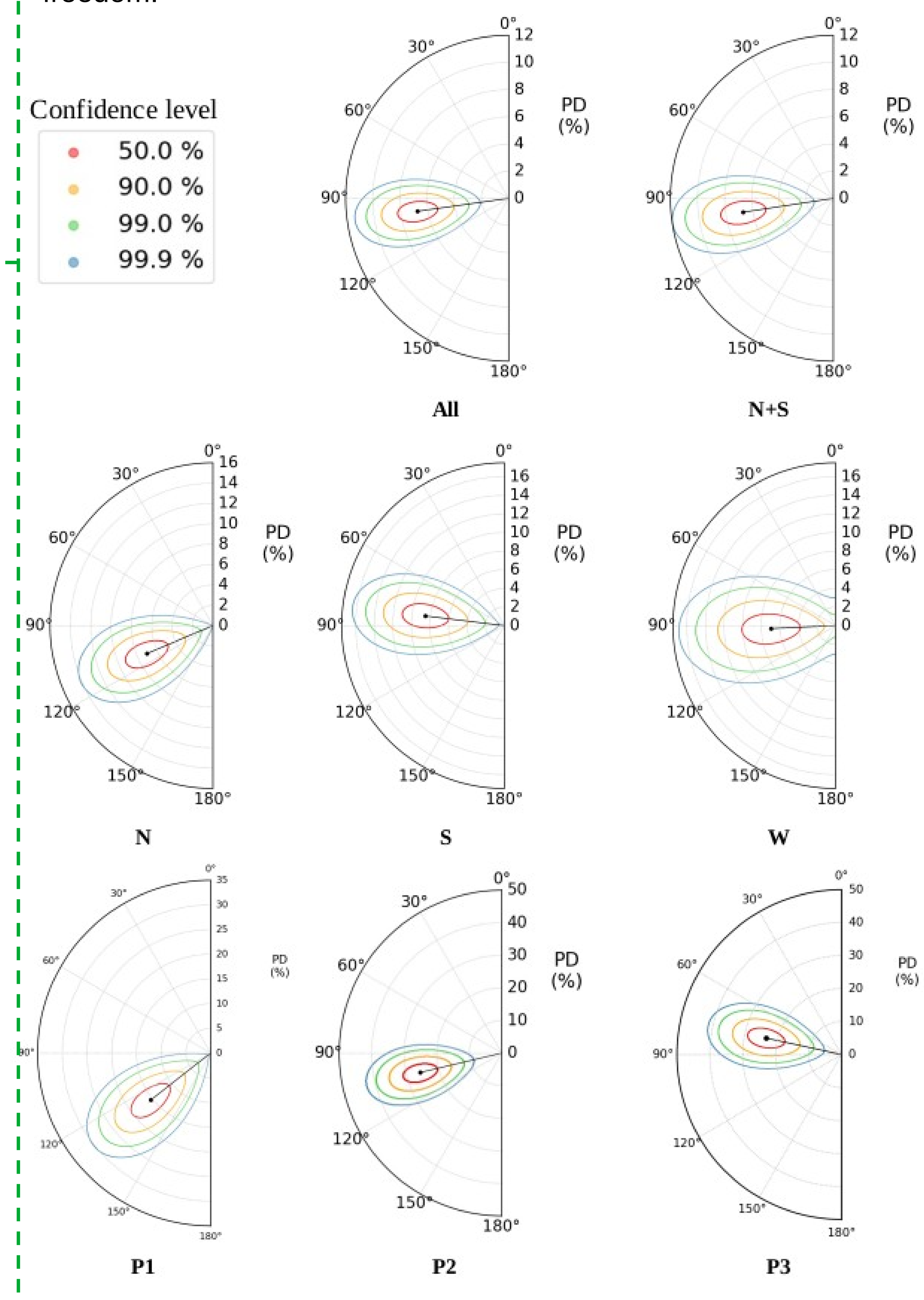
Gamma rays:

HESS >2 TeV excess count map of the NW of RX J1713

Region-by-region results

Polarization plots by region of interest in the 2−5 keV energy band: in each polar plot, we show the **observed** PD and PA in the radial and position angle coordinates, respectively. The black dots mark the measured PD and PA values.

The confidence levels are based upon χ2 with two degrees of freedom.



CONCLUSIONS

1) Behavior of the magnetic field

Main finding: differently from Cas A, Tycho, and SN 1006, that in the X-rays exhibit a radial magnetic field, here we found a magnetic field that follows the shock, i.e. "tangential".

Interpretation: compression of an upstream isotropic turbulence (*Bykov et al. 2020*).

Implications: the distinctly different magnetic field geometry inferred for RX J1713 suggests fundamental differences in the development of the ordered field component among different SNRs.

2) Magnetic field turbulence

We can place constraints on the relative magnitudes of the ordered and turbulent components of the magnetic field through the observed PD.

We use the *Bandiera & Petruk 2016* model to describe the connection between observed PD, photon spectral index Γ, and turbulence level of then magnetic field $\delta B/B_0$.

We propose two scenarios to explain the observed PD:
- **Assume that in the upstream there is a net radial magnetic field.**
- **Assume that the turbulence has partially reisotropized downstream** (maybe due to other instabilities acting to stretch the radial component)

3) Bohm factor and age

- We discuss two scenarios that this SNR allows us to test:
  I. **the closer the Bohm factor to unity is, the lower the PD would be: even with a Bohm factor close to unity, RX J1713 can achieve the observed PD if the magnetic field if the magnetic field is perpendicular to the shock normal.**
  II. **younger SNRs have lower PD** (shocks are faster and magnetic fields are more turbulent), whereas older remnants tend to have higher PD: **plausible given that this SNR is older than the other reported.**

4) Comparison with other wavelengths

- **Radio band: first time we map the magnetic field of this source**, as radio polarization measurements were affected by large Faraday rotation; discuss possible similarities with other co-age SNRs mapped by Meerkat
- **γ band:** evidence in **favor of the leptonic model**.

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Check our paper: ***Ferrazzoli et al. 2024***, accepted for publication in **ApJL**, and references therein