

JOINT X-RAY+RADIO POLARIZATION CHARACTERISTICS OF THE MAGNETAR 1E 1547.0-5408

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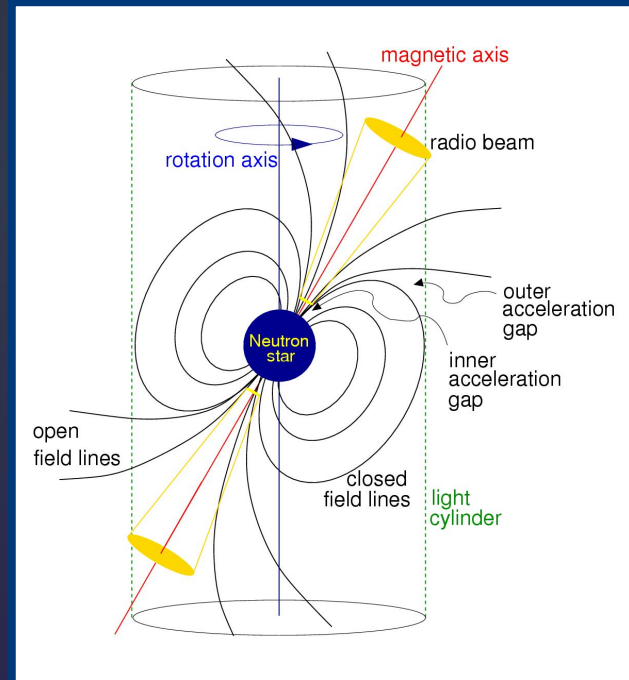
NEUTRON STARS – LABORATORIES FOR EXTREME PHYSICS

Compact objects formed from massive star

➤ ~ 3000 NS's discovered to date

Misaligned magnetic axis causes beamed EM radiation

Can be observed according to period P and period derivative $\dot{P}$



MAGNETARS – LABORATORIES FOR EXTREME PHYSICS

25 confirmed

- Discovery rate steady $\sim 1/\text{yr}$

Young: $\tau = 1\text{-}10$ kyr

- Some found within X-ray supernova

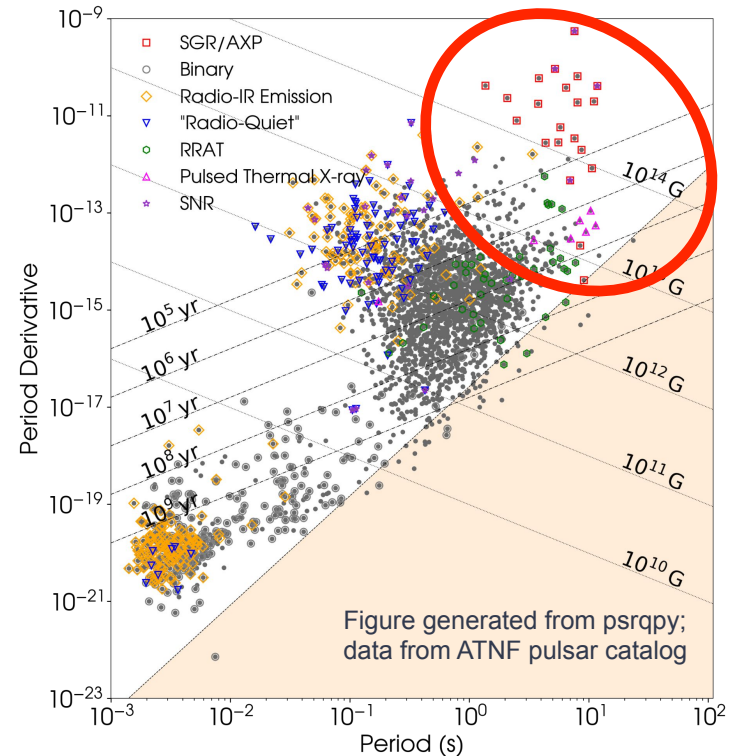
Strong X-ray emitters

- $L_x \sim 10^{33-36}$ ergs/cm²/s

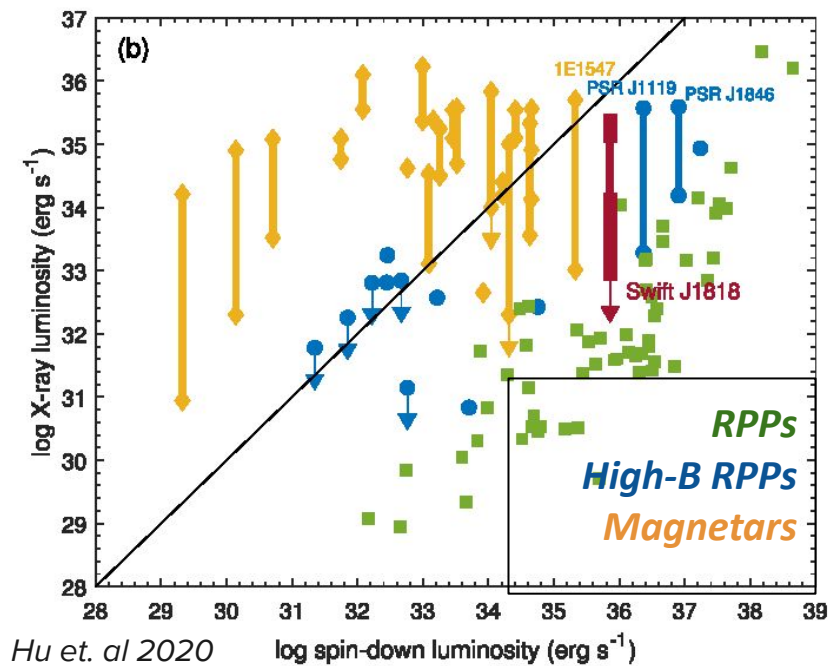
Ultra-strong magnetic fields

- Surface dipolar fields $\sim 10^{14}\text{-}10^{15}$ G

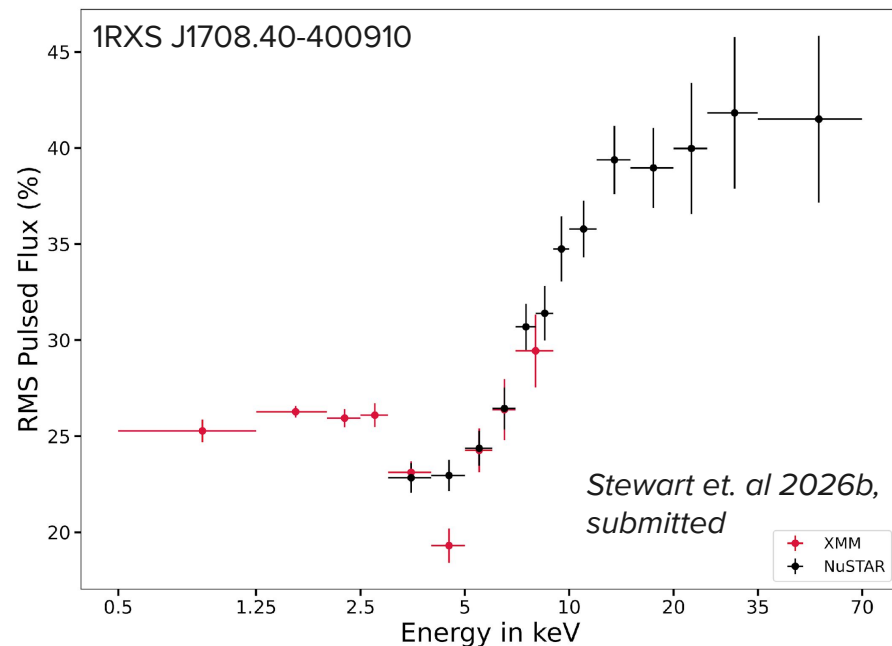
Variability over 10 decades in time- and energy-scales



X-RAY PERSISTENT EMISSIONS



*Rotational energy loss cannot power X-ray emission
Decay of super strong B-field is the alternative*



*Highly pulsed emission which can exhibit strong
energy-dependence*

X-RAY SPECTRAL CHARACTERISTICS

Thermal blackbody component from the surface of the star

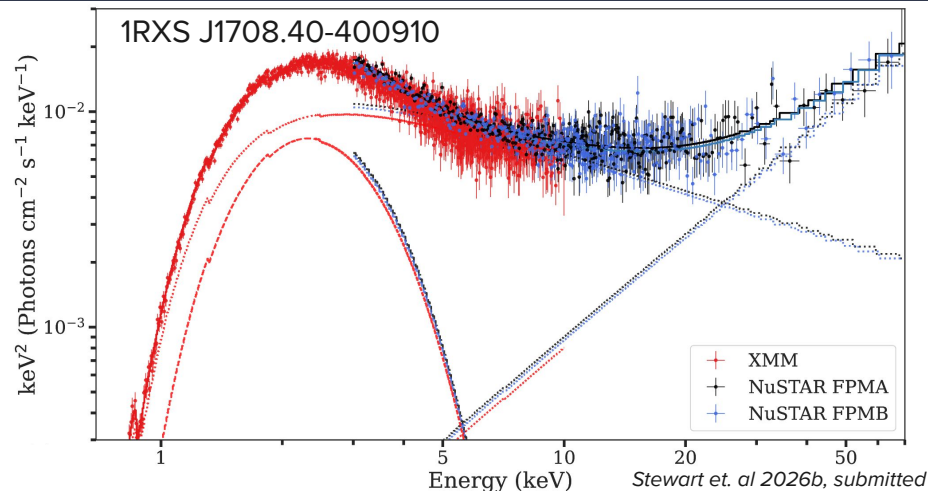
- ($kT \sim 0.3 - 0.7$ keV)
- Can reach ~ 1.0 keV in BB+BB

Soft power law dominates above 3-4 keV (phenomenologically fits the magnetosphere distortions)

- ($\Gamma \sim 2-4$)

Hard power law seen at higher energies (other nonthermal processes, RICS?)

- ($\Gamma \sim 0.5-1.5$)

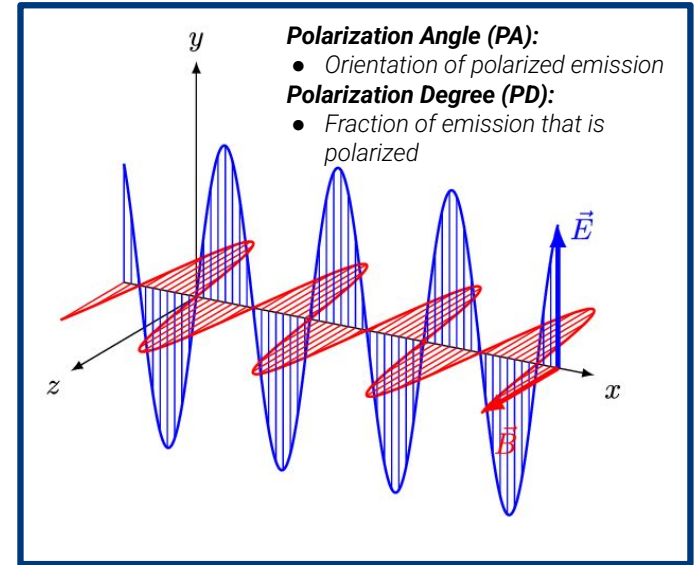


X-RAY POLARIZATION OFFERS NEW DIMENSION

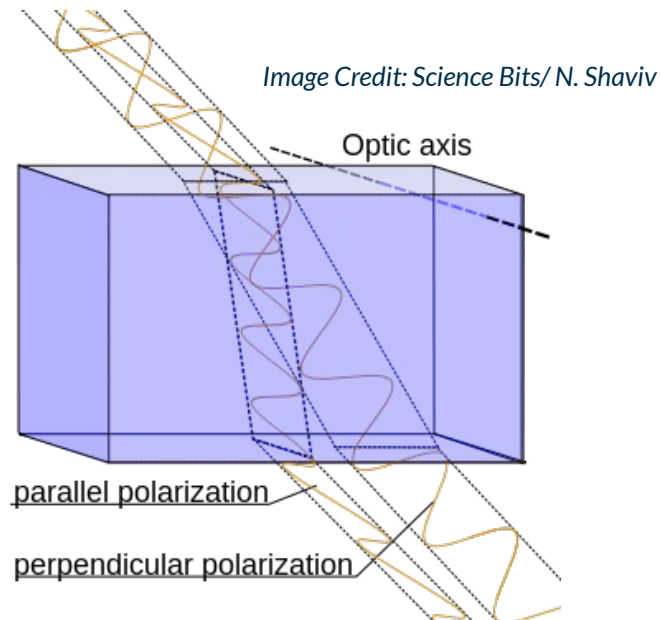
Magnetars are highly polarized due to their strong magnetic fields

X-ray polarization directly probes:

- High-B radiative processes
- QED effects (e.g. mode conversion, vacuum birefringence, see Taverna et al. 2024)

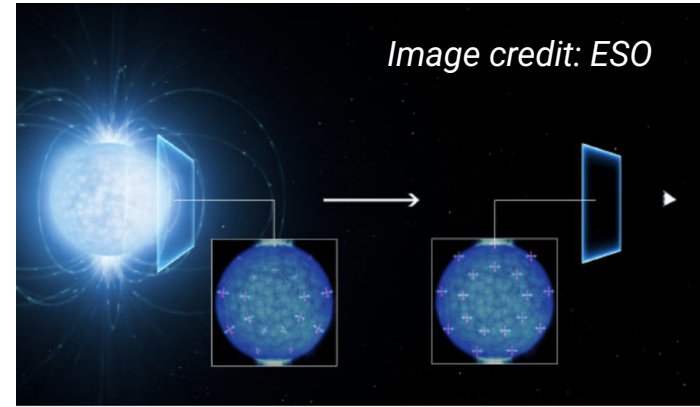
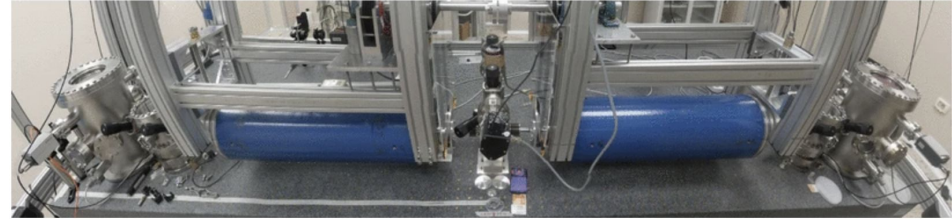


SCIENTIFIC MOTIVATION FOR OBSERVATION WITH IXPE



- Could lead to clues about **vacuum birefringence**, a QED effect not yet directly detected in labs or astrophysical settings...

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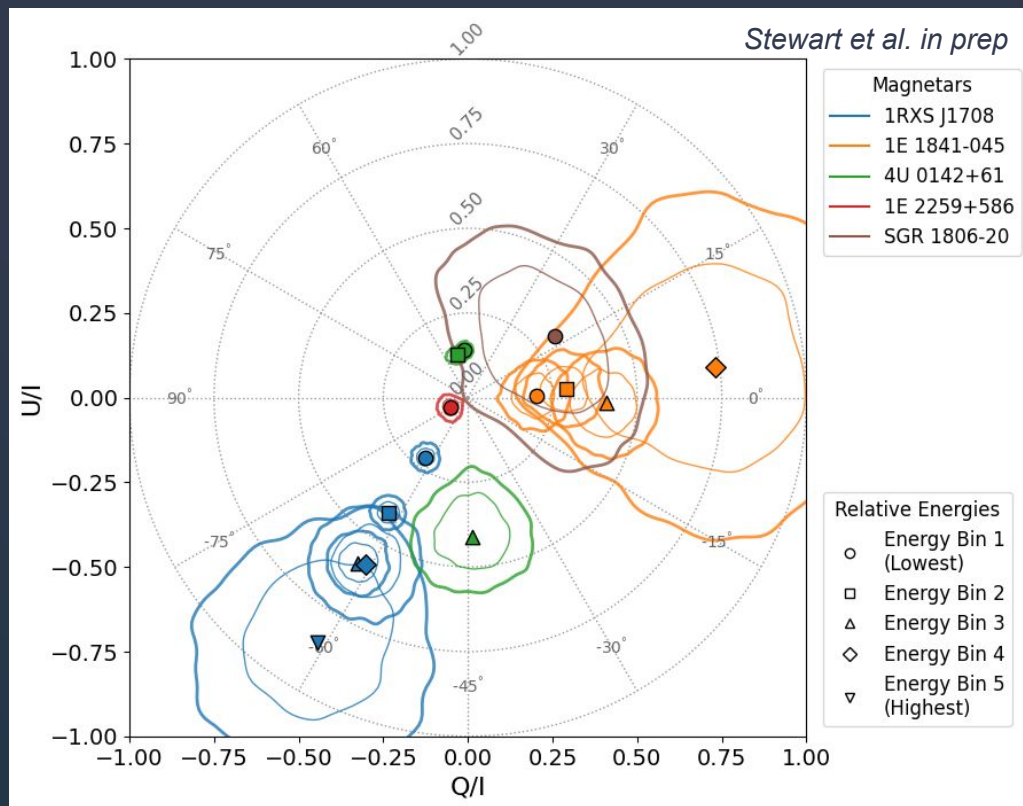


Mignani et al 2016

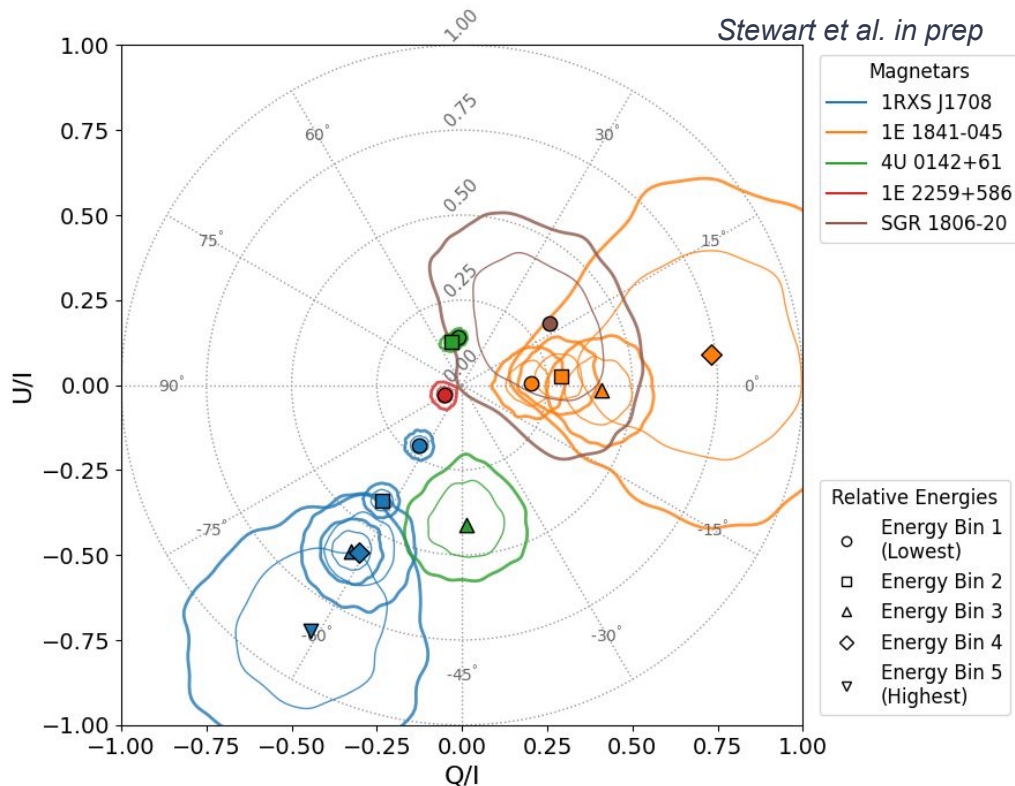
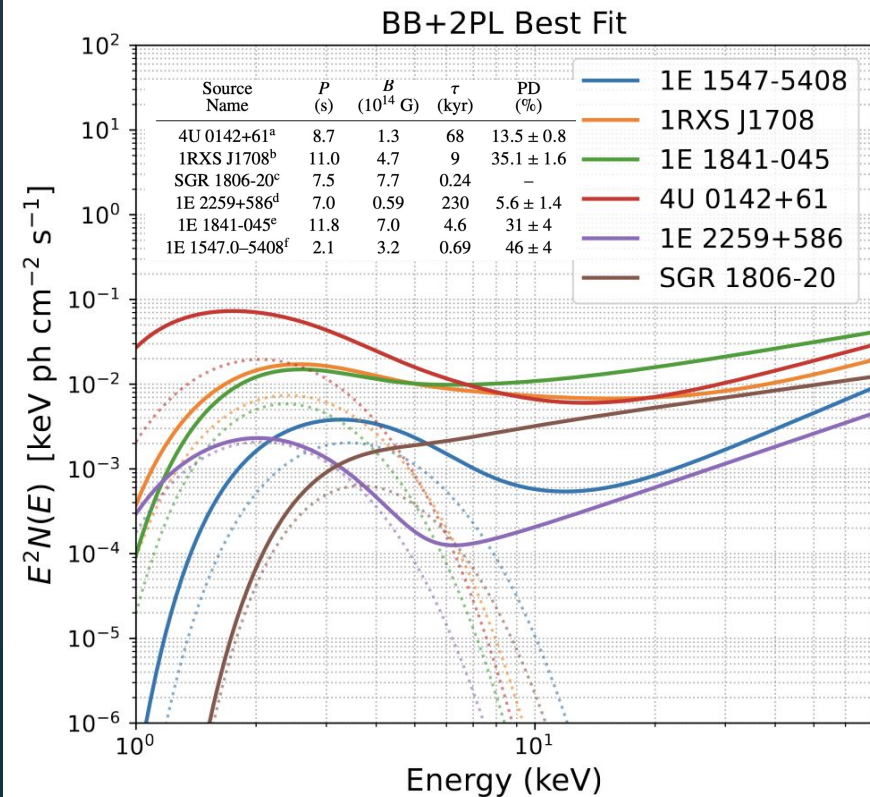
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IXPE REVEALS NEW INSIGHTS INTO MAGNETAR EMISSION

- ★ 4U 0142+61 (Taverna et al. 2022)
 - NICER, NuSTAR, IXPE
- ★ 1RXS J1708-4009 (Zane et al. 2023)
 - NuSTAR, NICER, XMM, IXPE
- ★ SGR 1806-20 (Taverna et al. 2024)
 - NICER, NuSTAR, IXPE
- ★ 1E 2259+586 (Heyl et al. 2024)
 - NuSTAR, NICER, XMM, IXPE
- ★ 1E 1841-045 (Rigoselli et al. 2024, Stewart et al. 2024)
 - NICER, NuSTAR, IXPE
- ★ 1E 1547-5408
 - NICER, Parkes-Murriyang, IXPE



IXPE REVEALS NEW INSIGHTS INTO MAGNETAR EMISSION

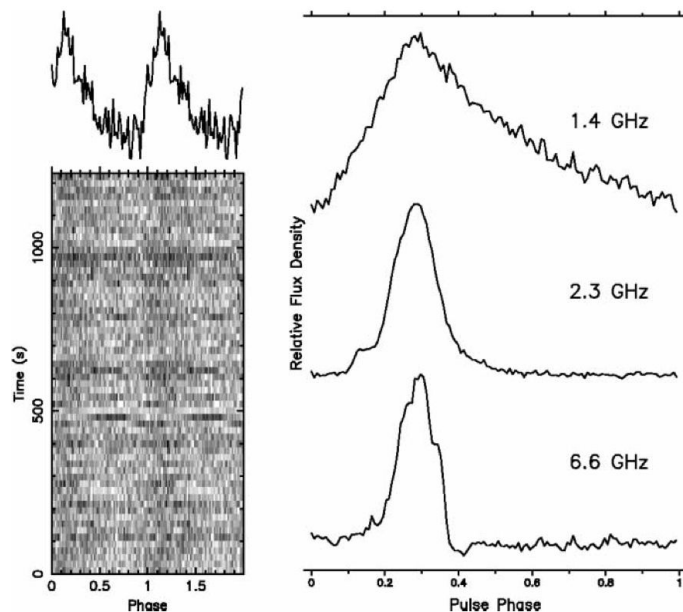


MAGNETAR 1E 1547.0-5408 & THE 2025 JOINT OBSERVATION



DISCOVERY

- Discovered in X-rays by *Einstein Observatory*
(Lamb et al. 1981)
- 2nd radio loud magnetar identified
(Camilo et al. 2007)
 - Period ≈ 2.1 s,
 - $\dot{P} \approx 2.318 \times 10^{-11} \text{ s s}^{-1}$,
 - $B \approx 2.2 \times 10^{14} \text{ G}$



(Camilo et al. 2007)

PERSISTENT CHARACTERISTICS

- Spectral behavior generally well described by either a 2BB+PL model or a BB+2PL model
(Coti Zelati et al. 2020, see also Lower et al. 2023)

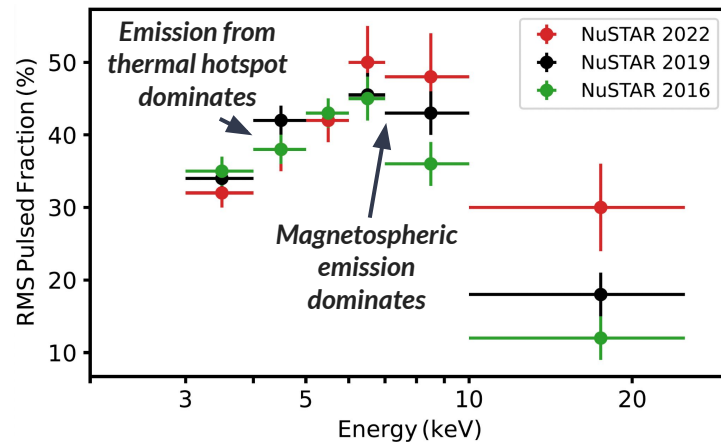
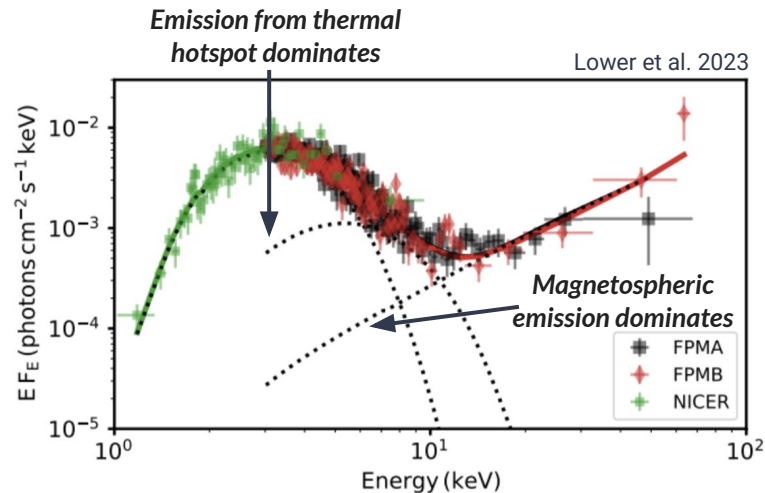
- For 2BB+PL case:

- BB1 $kT = 0.65$ keV
- BB2 $kT = 1.2$ keV

- For BB+2PL case:

- BB $kT = 0.65$ keV
- PL $\Gamma = 3.8$

- RMS pulsed-fraction $\sim 33\%$ at 2 keV, increasing to $\sim 45\%$ at 6 keV



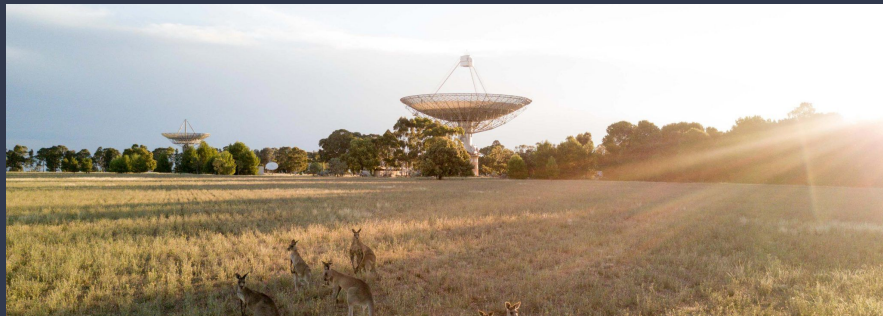
SCIENTIFIC MOTIVATION FOR OBSERVATION WITH IXPE

- Possesses bright persistent flux and large pulsed fraction
 - Allows for detailed energy-resolved, phase-resolved, and spectro-polarimetric analysis
- Radio observations could provide unique constraints on geometry
- Search for evidence of exotic quantum electrodynamic (QED) effects

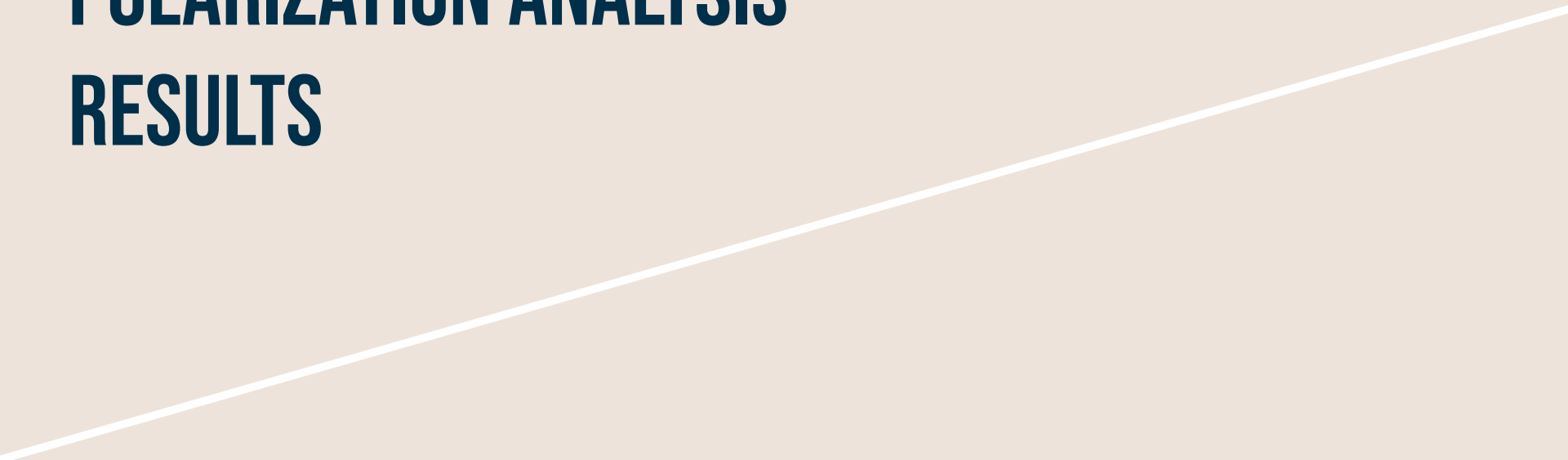
OBSERVATIONAL CAMPAIGN

Images: NASA, CSIRO

- Observed with *IXPE*, *Murriyang/Parkes*, and *NICER* between March 26 and April 13, 2025
 - Coordinated coverage to overlap with *IXPE* as much as possible
- *IXPE* total livetime ~ 500 ks
- ***First joint radio + X-ray polarization measurement of a magnetar***

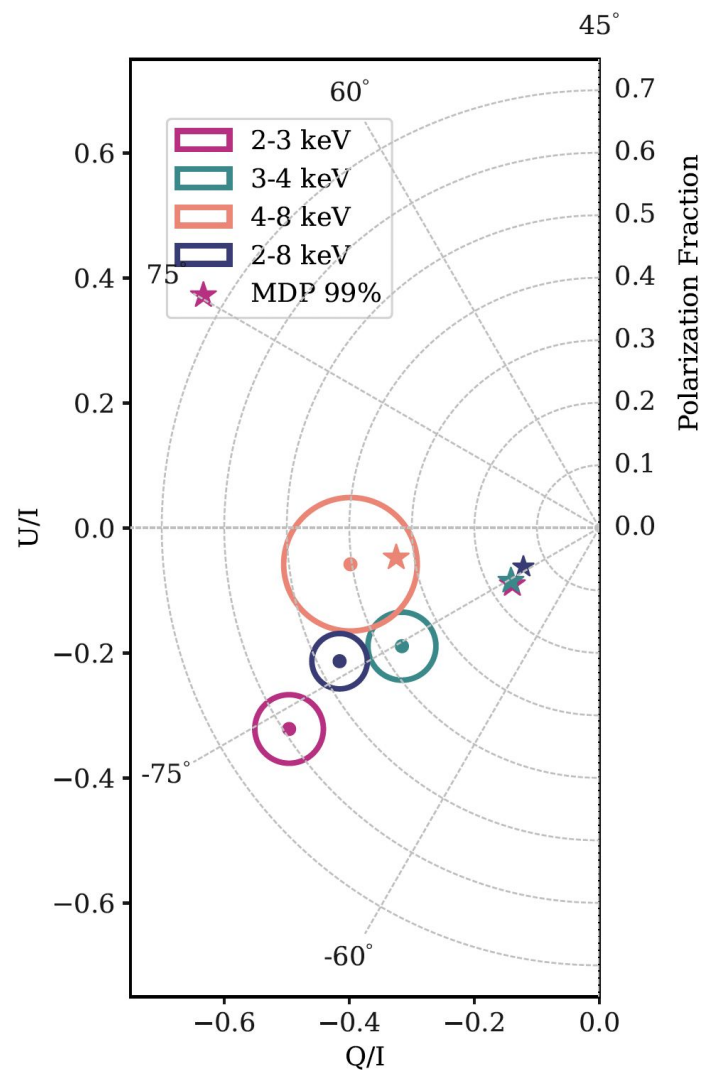


JOINT X-RAY+RADIO POLARIZATION ANALYSIS RESULTS



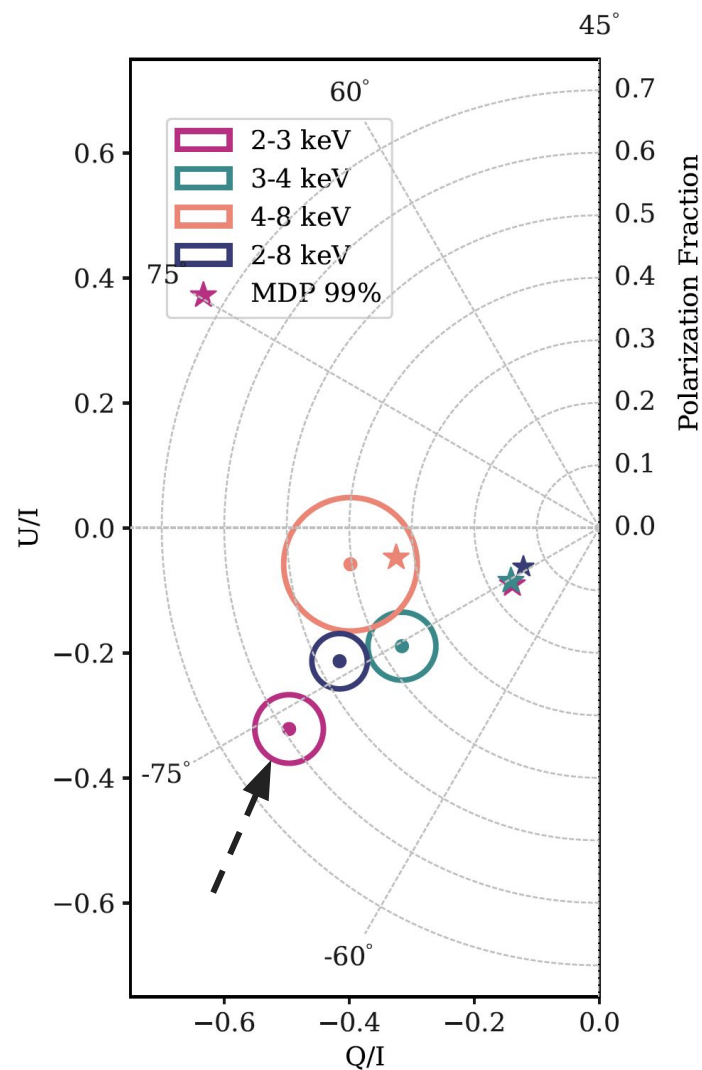
IXPE POLARIZATION CHARACTERISTICS

- Polarization Degree:
 - 2-8 keV PD: $46 \pm 4 \%$
 - 2-3 keV PD: $58 \pm 5\%$
 - 3-4 keV: $37 \pm 5\%$
 - 4-8 keV PD: $40 \pm 11\%$
- Polarization Angle :
 - 2-8 keV: $-76^\circ \pm 3^\circ$



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NICER+IXPE

SPECTRO-POLARIMETRY

Model:

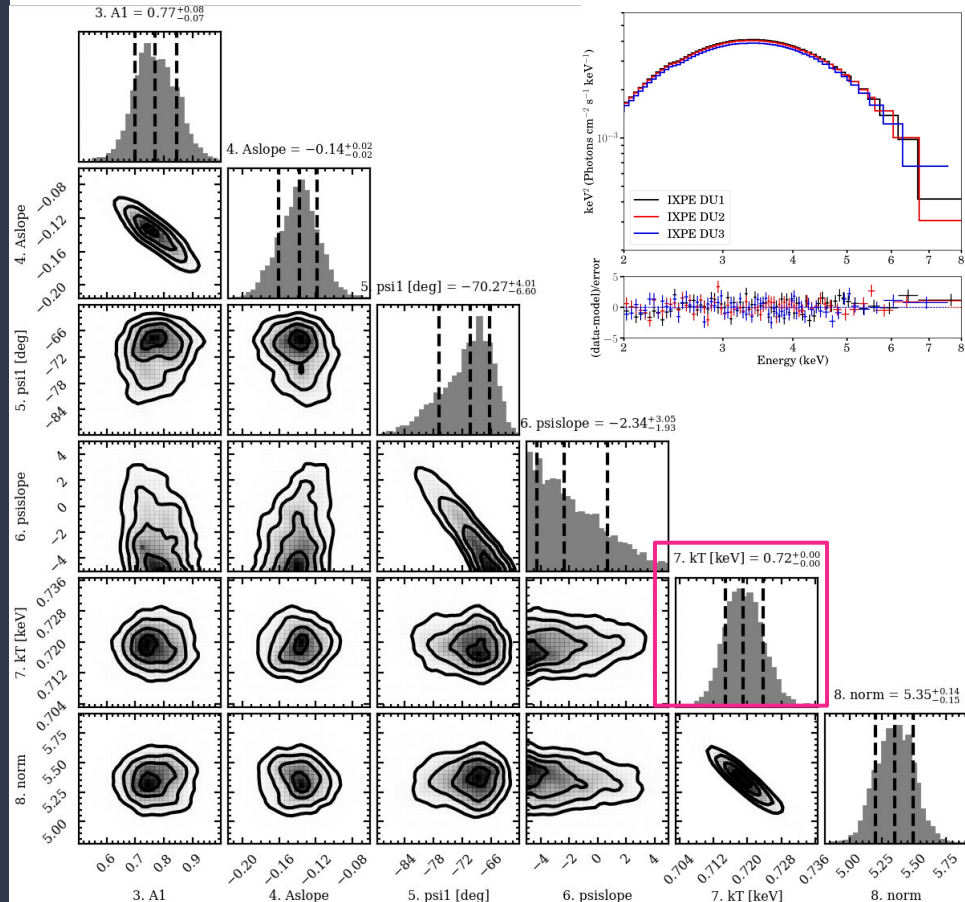
Absorbed Blackbody with Linear Polarization Component

PD @ 1 keV	0.80 +/- 7E-02
PD slope	-0.15 +/- 2E-02
PA @ 1 keV	-67 +/- 7
PA slope	-4 +/- 3
BB kT (keV)	0.72 +/- 0.01
BB norm	5.3 +/- 0.2

$$R^2 \rightarrow 1.07 \text{ km}^2$$

$$L_x \rightarrow 3.7\text{e}34 \text{ erg/s}$$

$$\text{Flux BB} \rightarrow 1.49 \text{ +/- } 0.009 \text{ e-11 ergs/cm}^2\text{/s}$$



- Hot BB temps and B-field make condensed surface scenario unlikely for this source (Medin & Lai 2007)

NICER+IXPE

SPECTRO-POLARIMETRY

Model:

Absorbed Blackbody with Linear Polarization Component

PD @ 1 keV **0.80 +/- 7E-02**

PD slope -0.15 +/- 2E-02

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PA slope -4 +/- 3

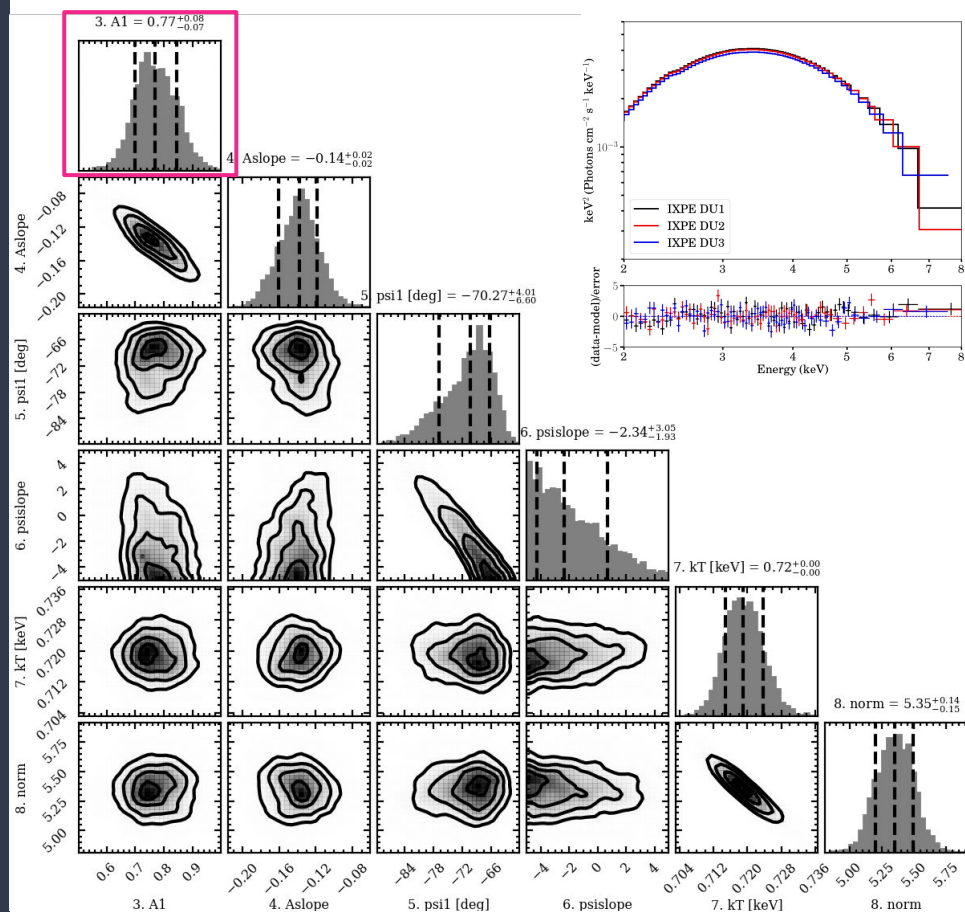
BB kT (keV) 0.720 +/- 5E-03

BB norm 5.3 +/- 0.2

$R^2 \rightarrow 1.07 \text{ km}^2$

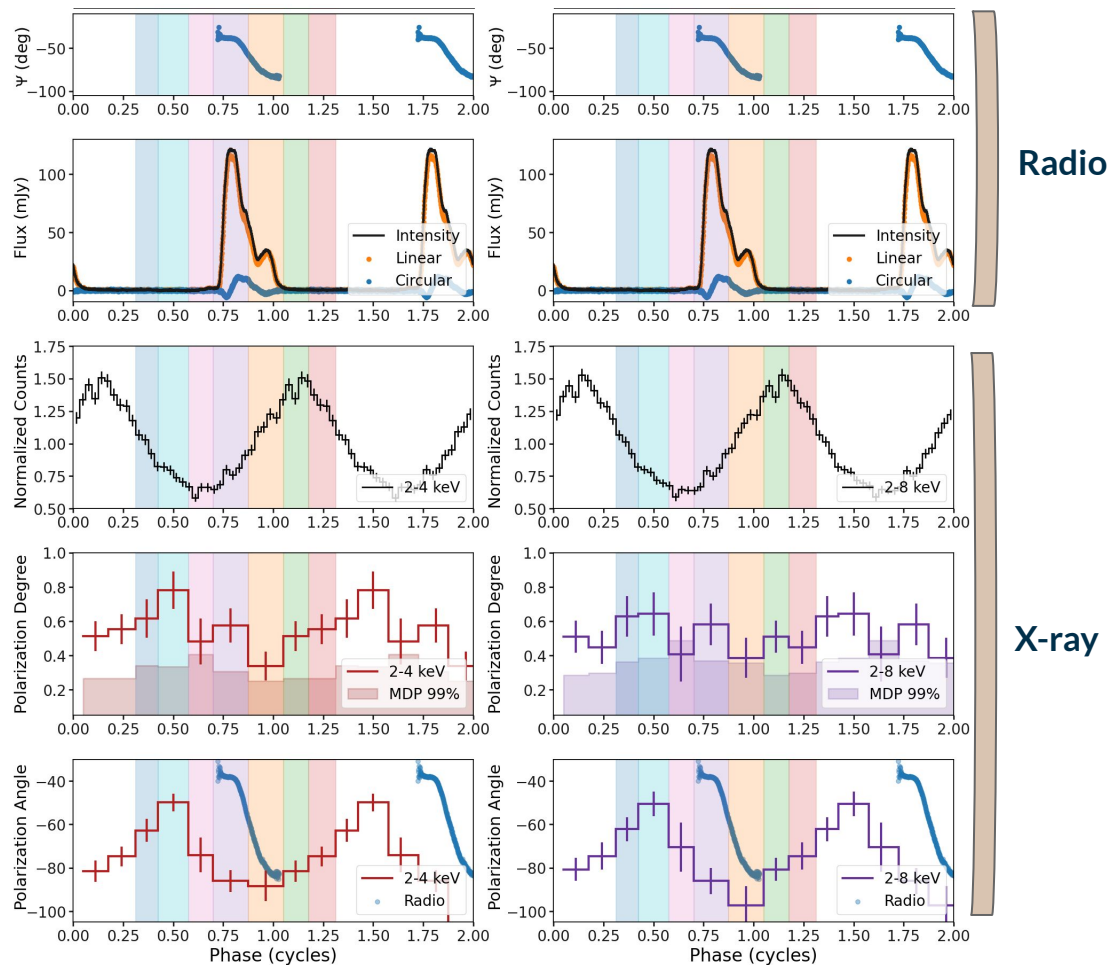
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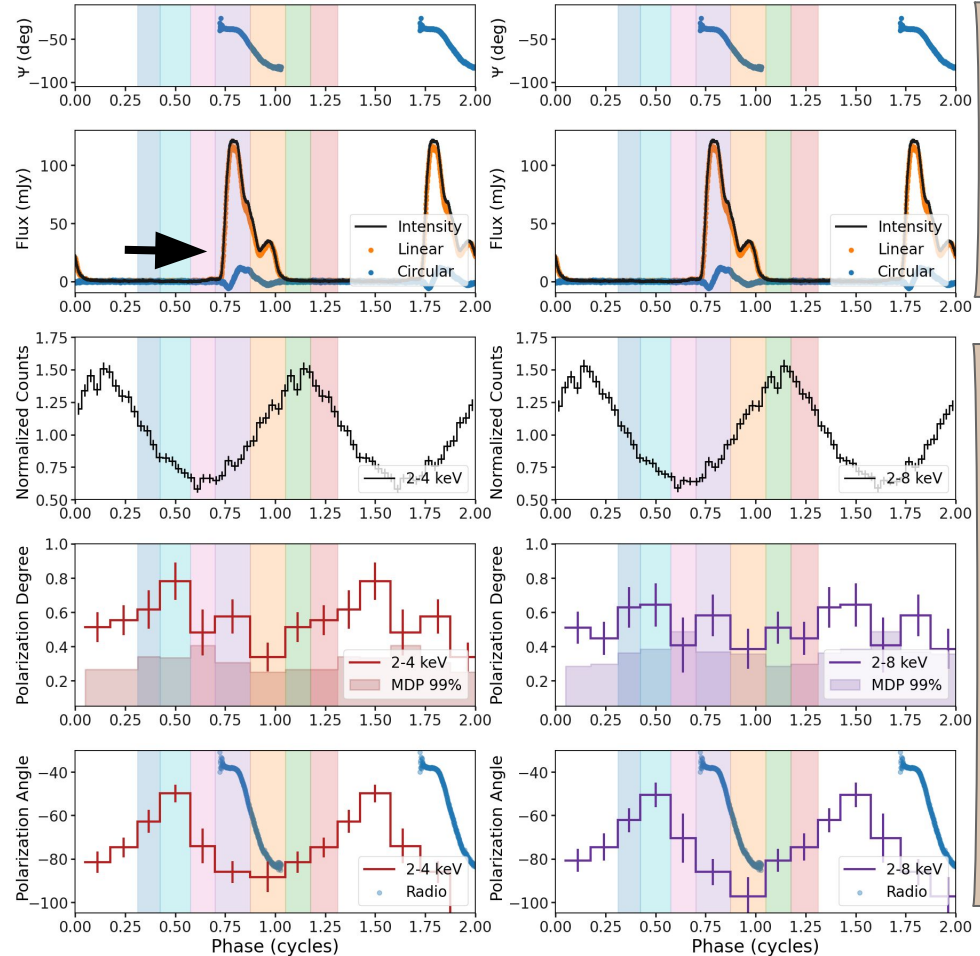
- Magnetized atmosphere could possibly achieve large PDs at certain geometries (Taverna et al. 2026, Taverna et al. 2024, Hu et al. 2022)

PHASE-RESOLVED RADIO + X-RAY CHARACTERISTICS



PHASE-RESOLVED RADIO + X-RAY CHARACTERISTICS

- Radio intensity duty cycle
~25% - unique characteristic
of the source
 - Typical pulse-width for
pulsars & magnetars is
few percent
(e.g. Jankowski 2019)
- Implies nearly-aligned
rotator (i.e. line-of-sight
crosses open magnetic field
lines at radio pole)

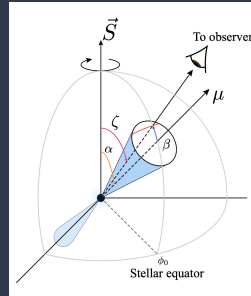


Radio

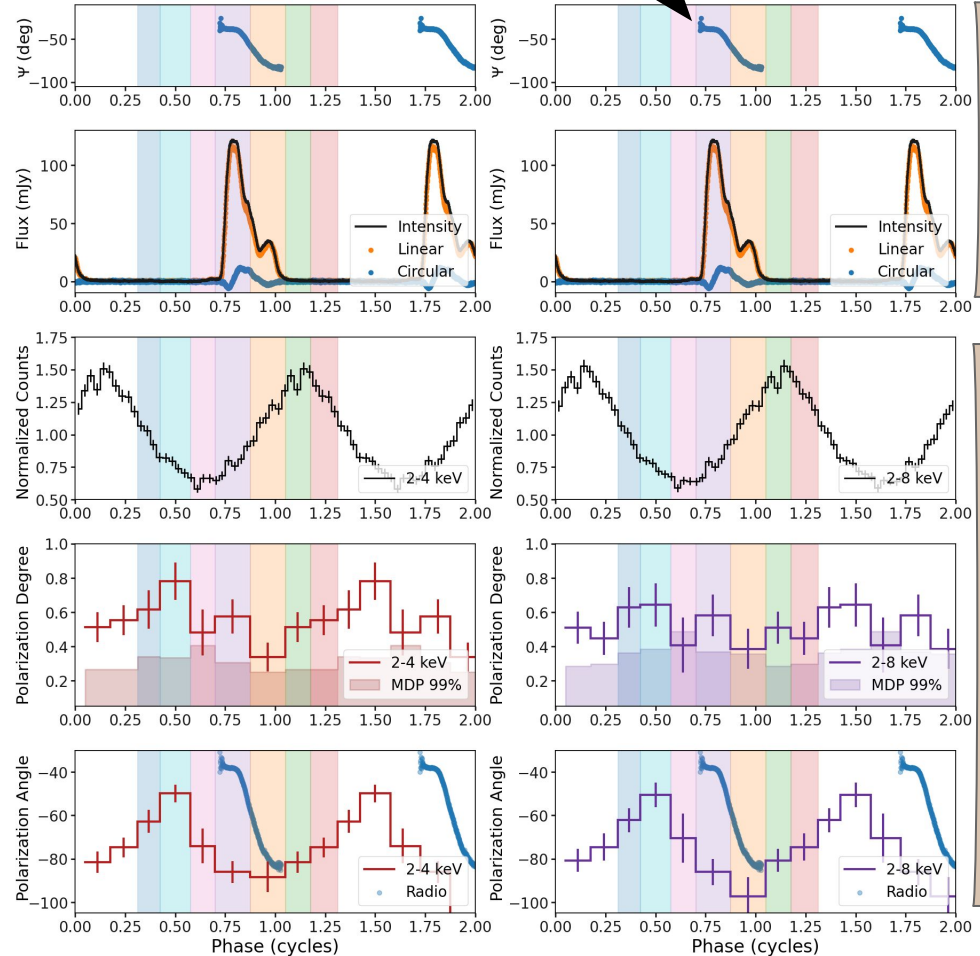
X-ray

PHASE-RESOLVED RADIO + X-RAY CHARACTERISTICS

- Radio exhibits characteristic S-curve in linear PA
- Implies nearly-aligned rotator (i.e. line-of-sight crosses open magnetic field lines at radio pole)
- RVM fit parameters:
 $\alpha = 2.4^\circ$ and $\beta = 2.9^\circ$
 $\rightarrow (\zeta = \alpha + \beta = 5.2^\circ)$



$$\alpha = 2.4 \text{ deg} \ \& \ \beta = 2.9 \text{ deg} \ \rightarrow (\zeta = \alpha + \beta = 5.2 \text{ deg})$$

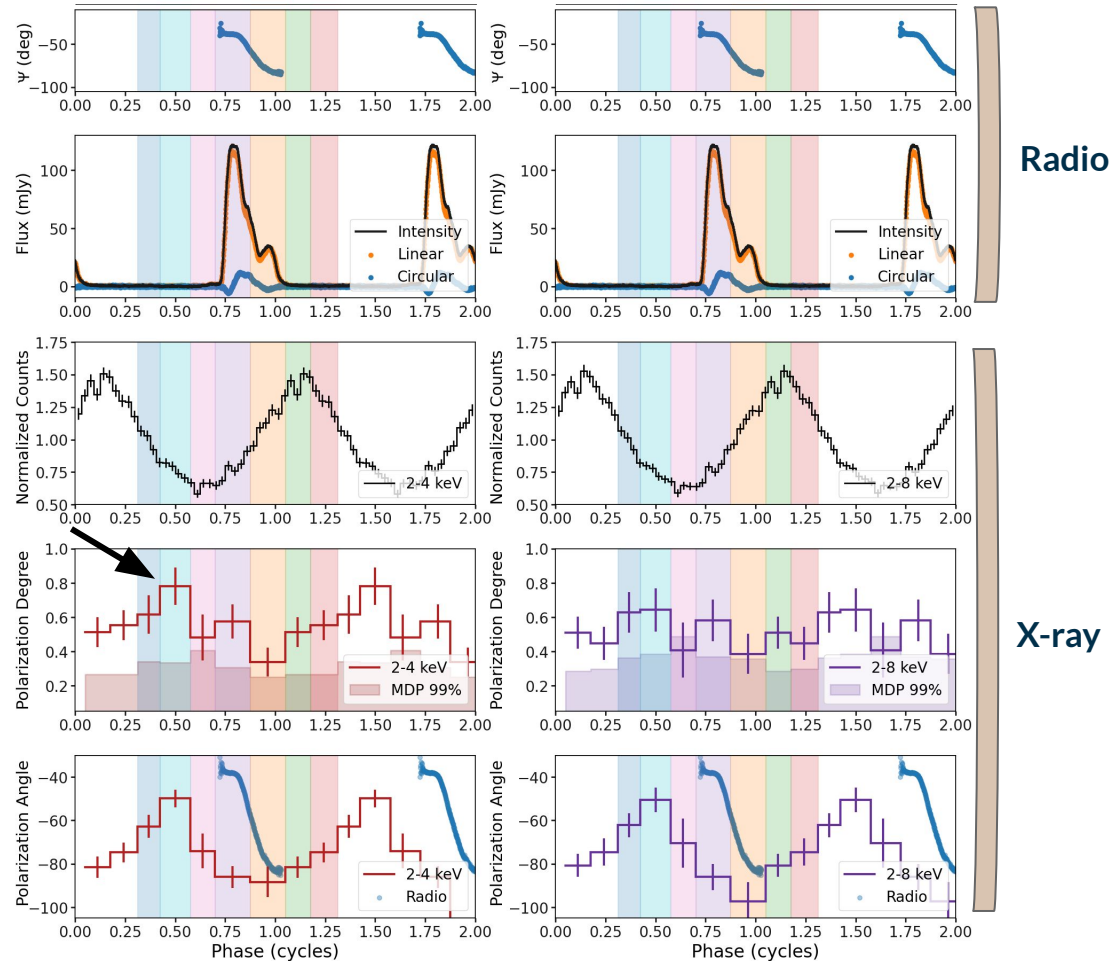


Radio

X-ray

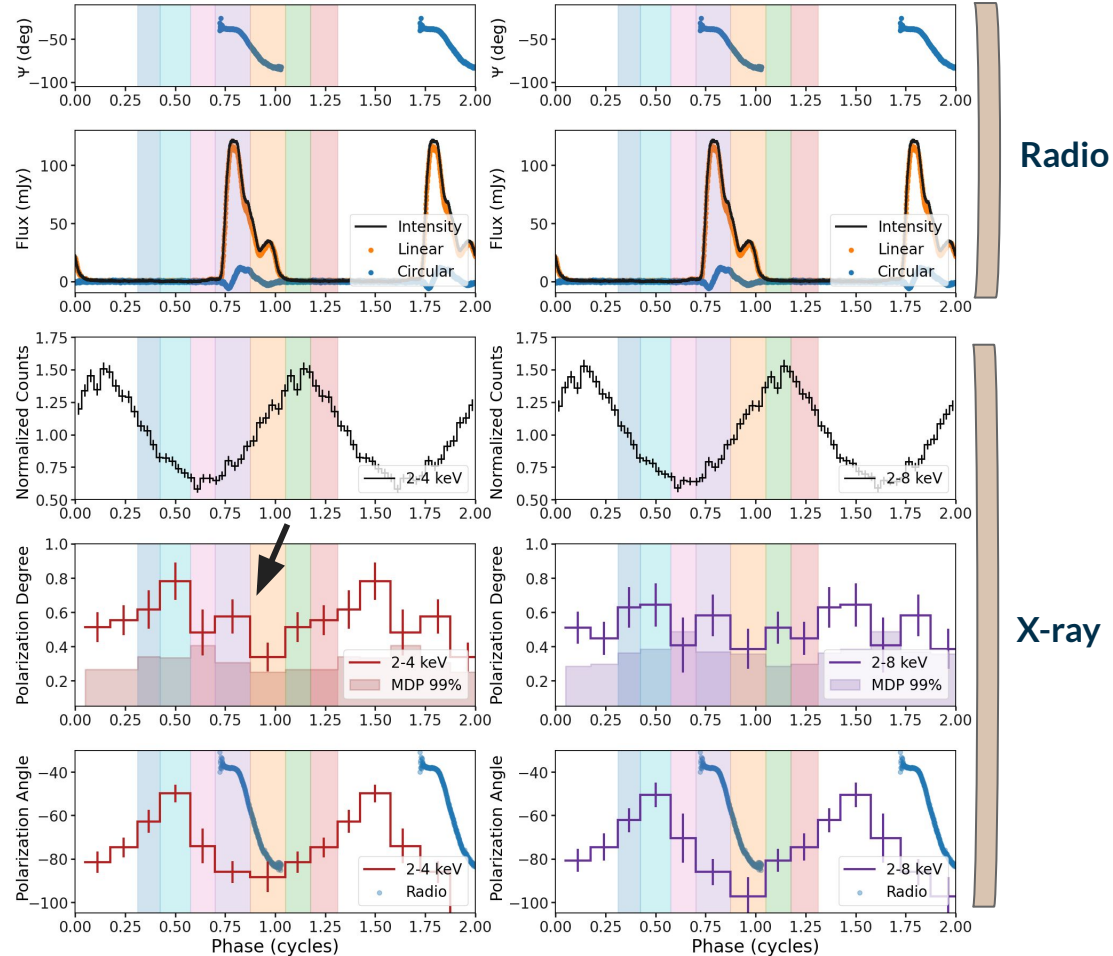
PHASE-RESOLVED RADIO + X-RAY CHARACTERISTICS

- Total X-ray polarization is high in both full IXPE band (2-8 keV) and the soft X-ray band (2-4 keV) in each phase bin
- 2-8 keV PD between ~40-60%
- 2-4 keV PD peaks at $\sim 74 \pm 11\%$ in cyan phase bin



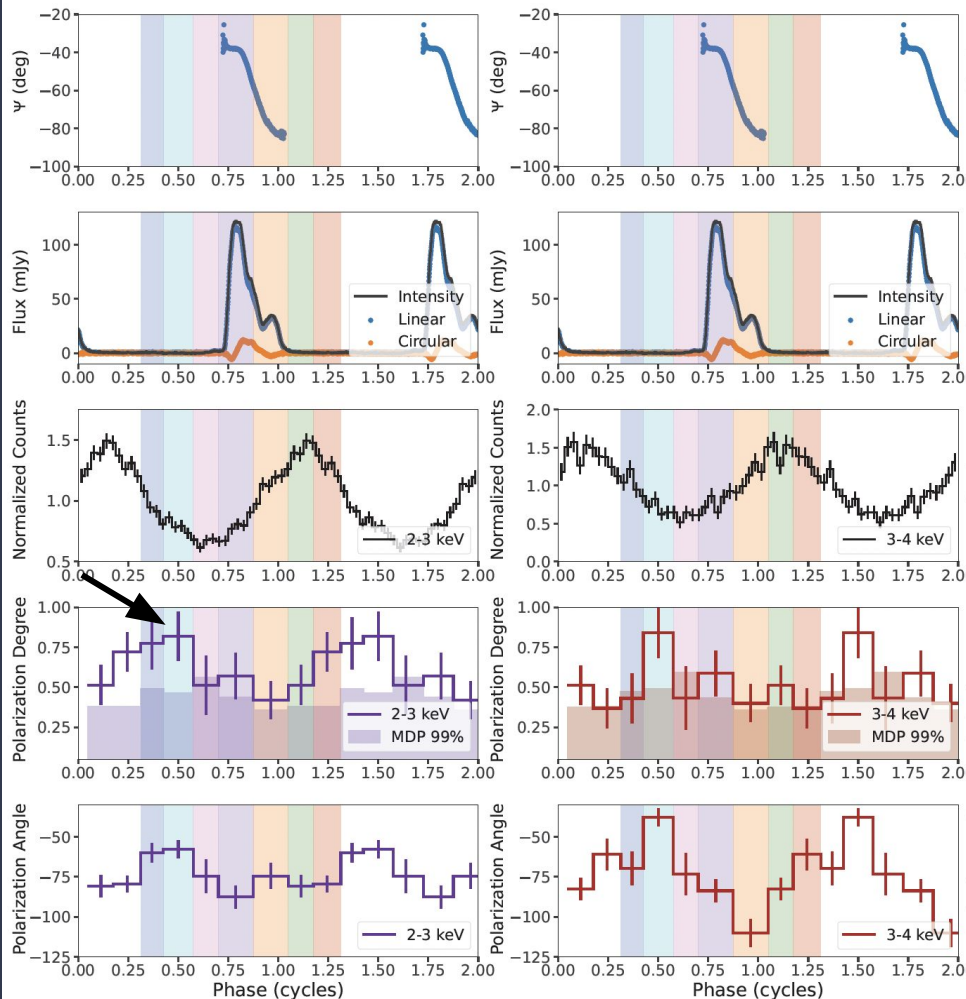
PHASE-RESOLVED RADIO + X-RAY CHARACTERISTICS

- Expect large net X-ray depolarization when crossing the pole
- 2-4 keV PD maximum at minimum achieves $34 \pm 8\%$



PHASE-RESOLVED RADIO + X-RAY CHARACTERISTICS

- 2-3 keV PD peaks at $82 \pm 15\%$ in cyan phase bin and minimizes at $42 \pm 12\%$
- Some effect must be suppressing mode-mixing and enhancing PD
 - Consistent with potential action of VB (see e.g. Taverna et al. 2020)



Radio

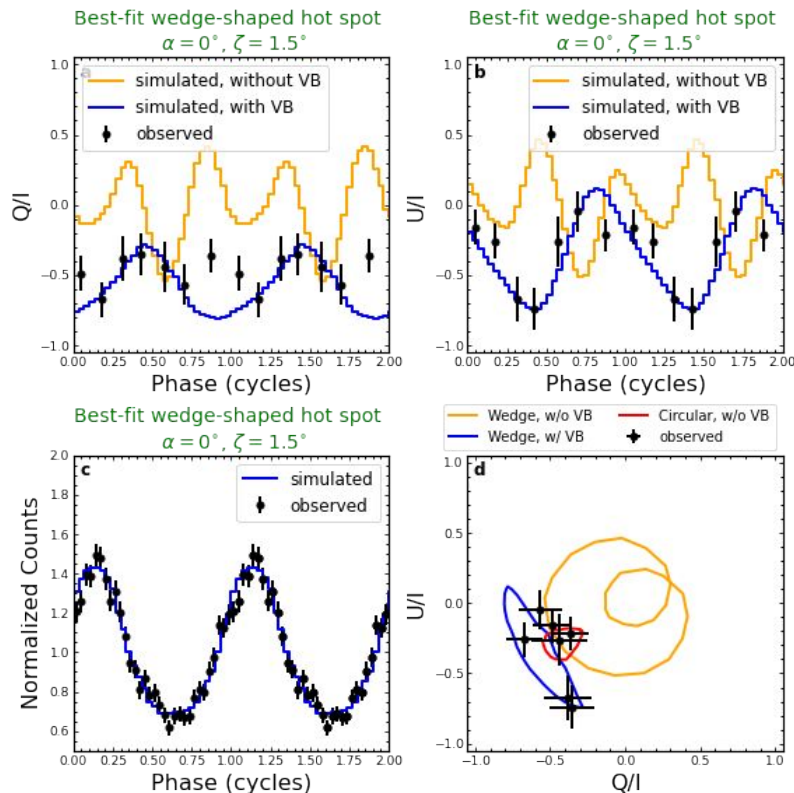
X-ray

PHYSICAL INTERPRETATIONS & NEXT STEPS

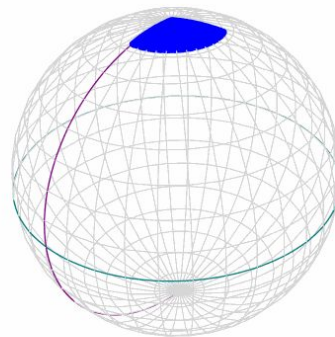


MODELING X-RAY INTENSITY AND POLARIZATION SIGNALS

CASE WITH VB OUTPERFORMS CASES WITHOUT VB



See also Dinh Thi et al 2026,
submitted





Read more in *Vacuum birefringence and the polarized X-ray emission of a radio-loud magnetar* by Stewart et al. 2026

NEXT STEPS



- Perform deep 1.5 Ms IXPE observation of 1E 1547.0-5408
 - Investigate potential mode conversion action
- Advance MAGTHOMSCATT models to include effects from vacuum resonance
- Utilize future soft X-ray polarimetry telescopes to probe <1 keV for confirmation of 80% PD at 1 keV

Thank you!

