

# Polarised signatures from highly magnetised isolated neutron stars

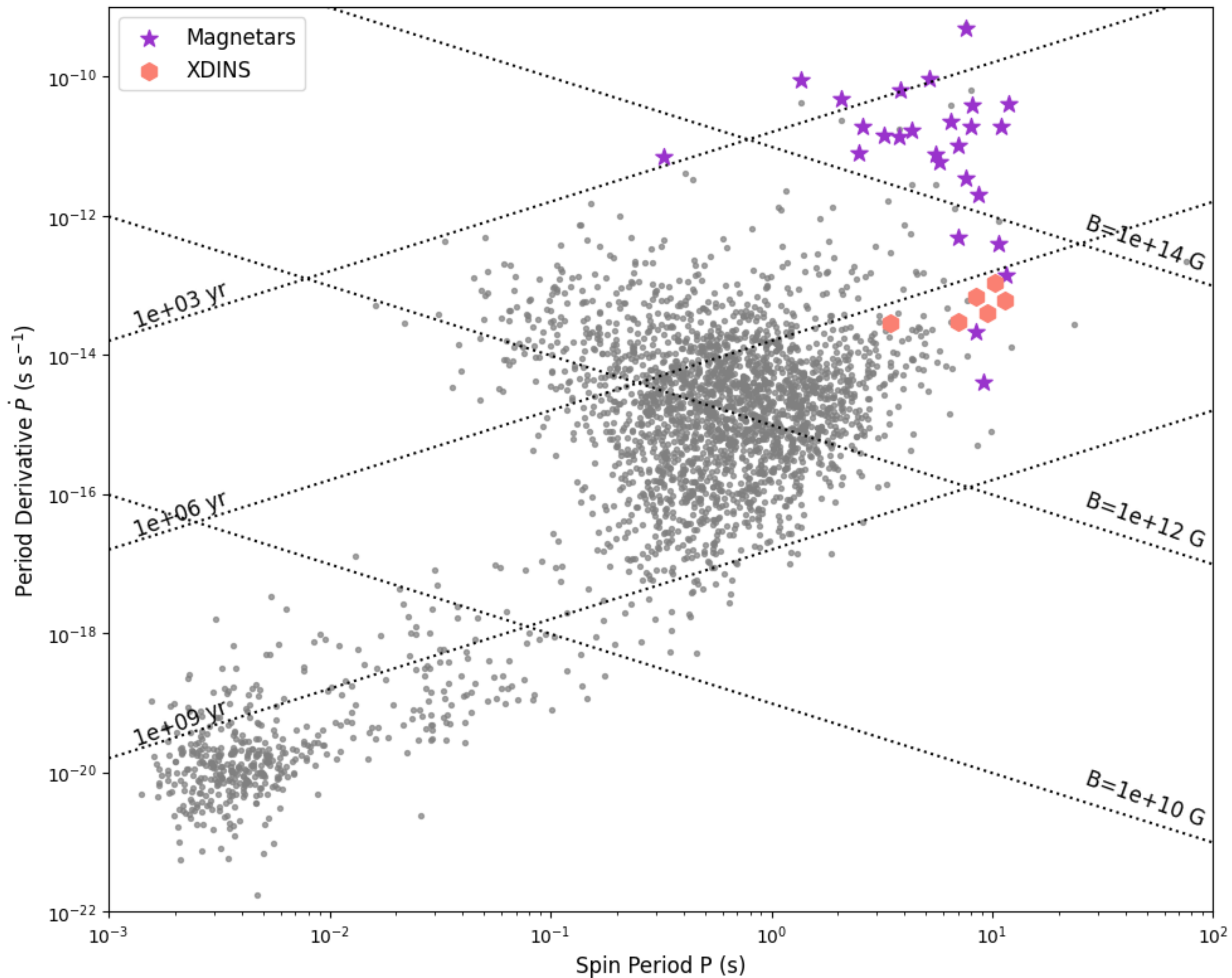
**Ruth Kelly**

MSSL, UCL  
University of Padova

NewAthena Rising: SWG4, ICE-CSIC Barcelona, Spain  
2nd - 5th June 2026

# Magnetars

- Highly magnetised
- Isolated
- Young



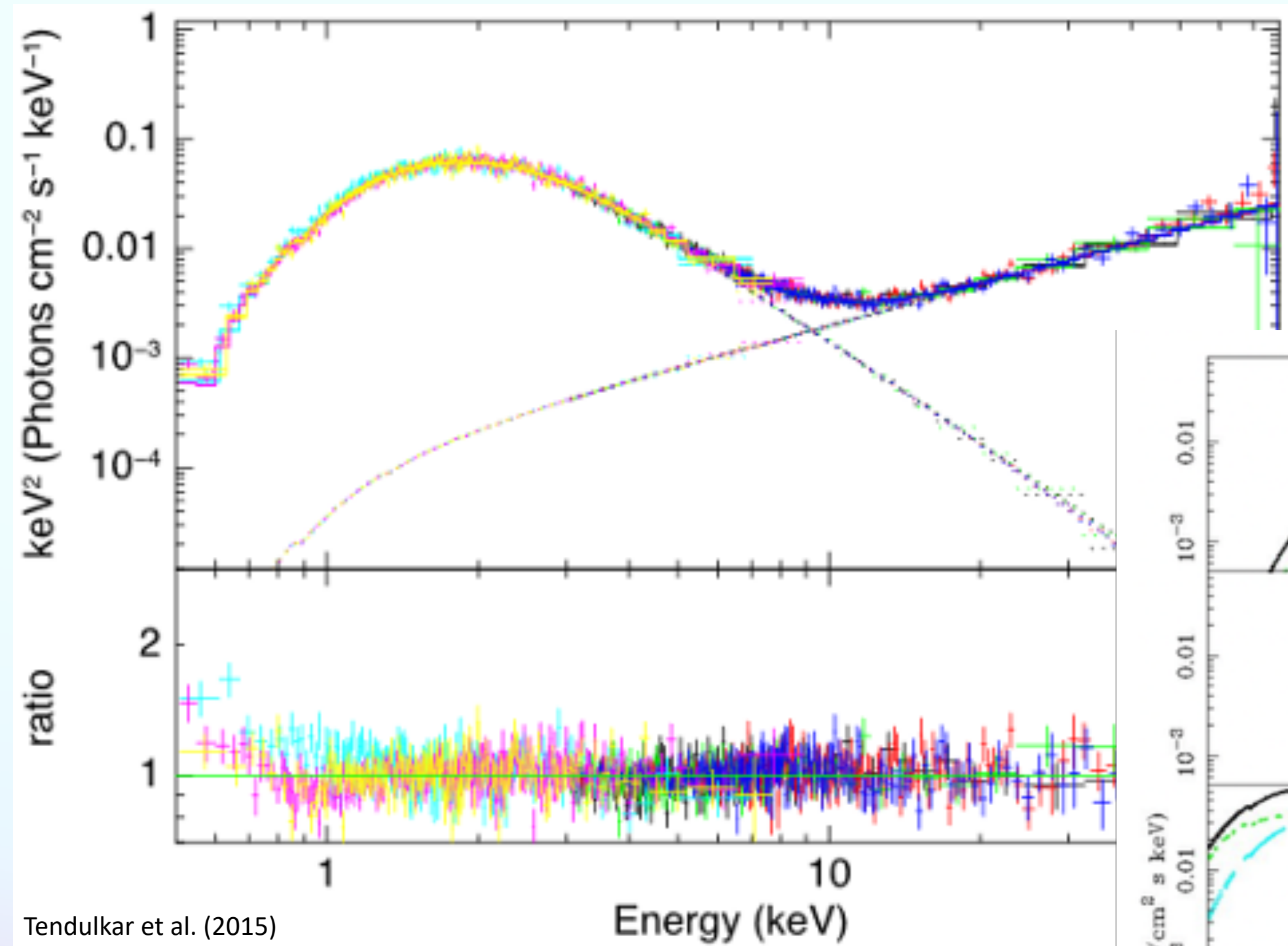
Magnetic field greater than  
the Quantum Critical Field

# Twisted magnetosphere

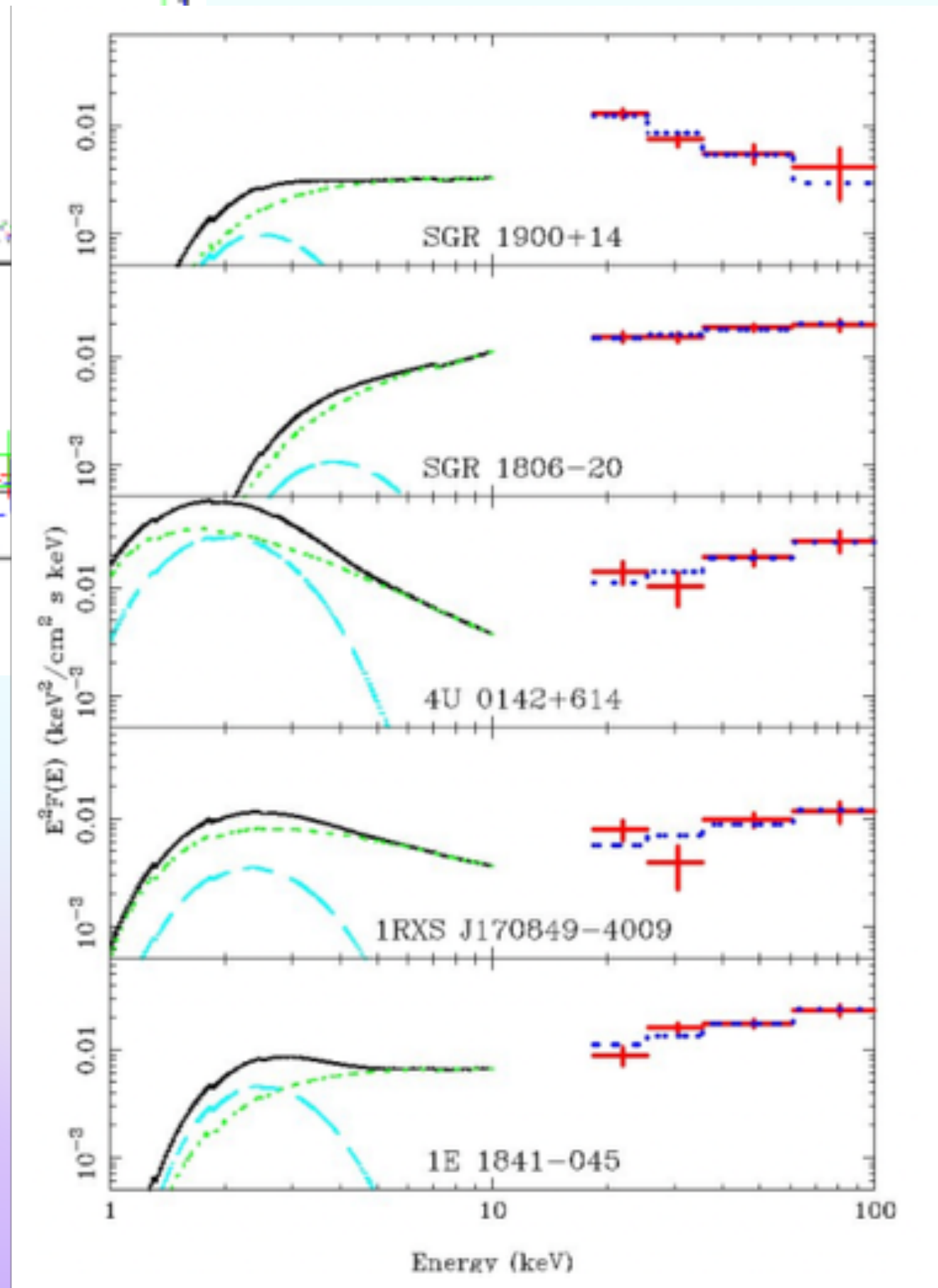
- Strong internal field  $\sim 10^{16}$  G
  - Toroidal component  $\gtrsim$  poloidal
- Toroidal field cause crust to **yield**
  - Transfer helicity to external field
- Twists are **non-potential**
  - Sustained by charged particles



# Emission - magnetar



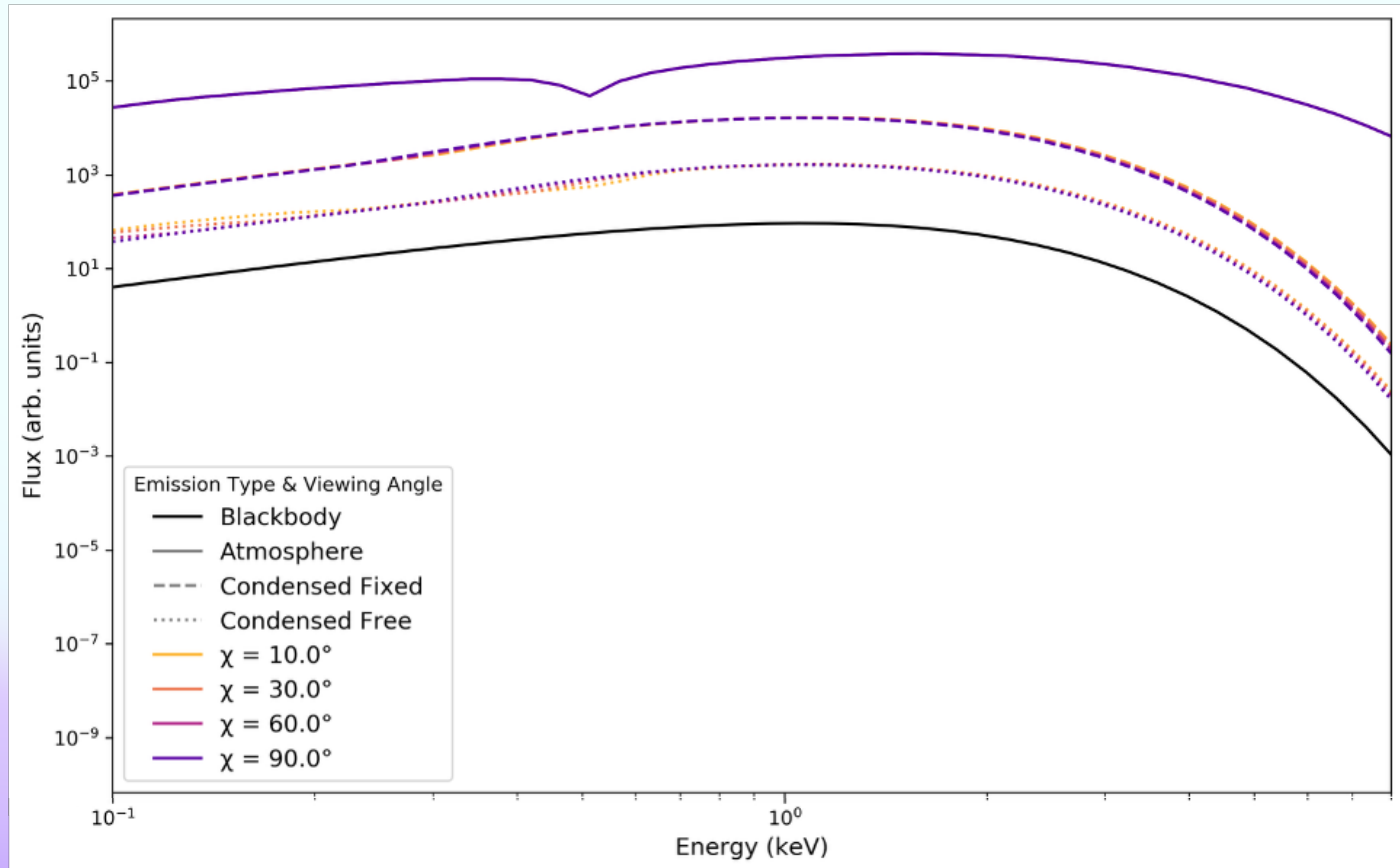
Tendulkar et al. (2015)



- X-ray detected in hard and soft
- Multi-component
  - Thermal and non-thermal
- Above 10 keV - Powerlaw
- Below 10keV:
  - Blackbody + Blackbody
  - Blackbody + Power-law

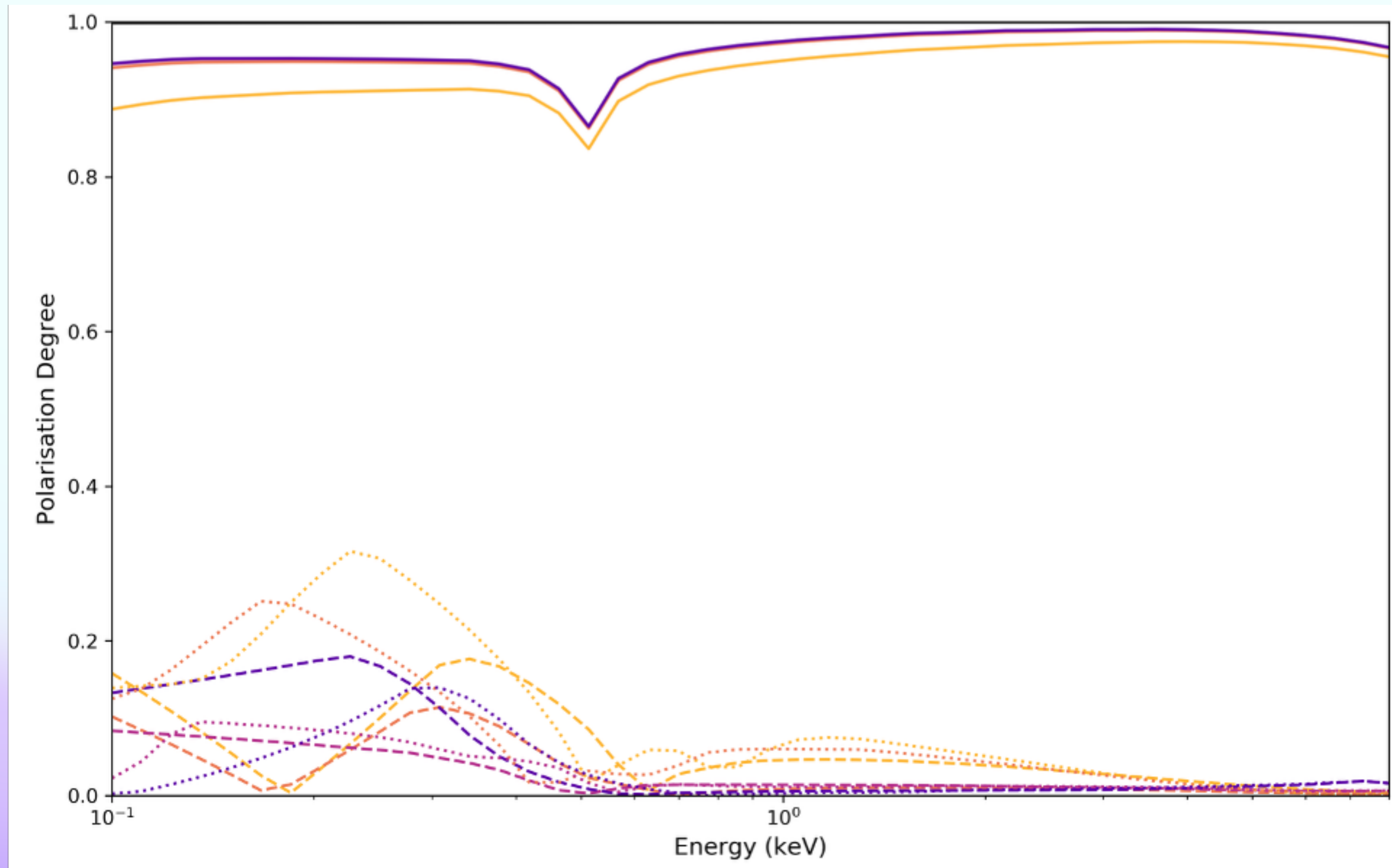
# Thermal Emission

- Atmosphere
- Condensed surface



# Thermal Emission

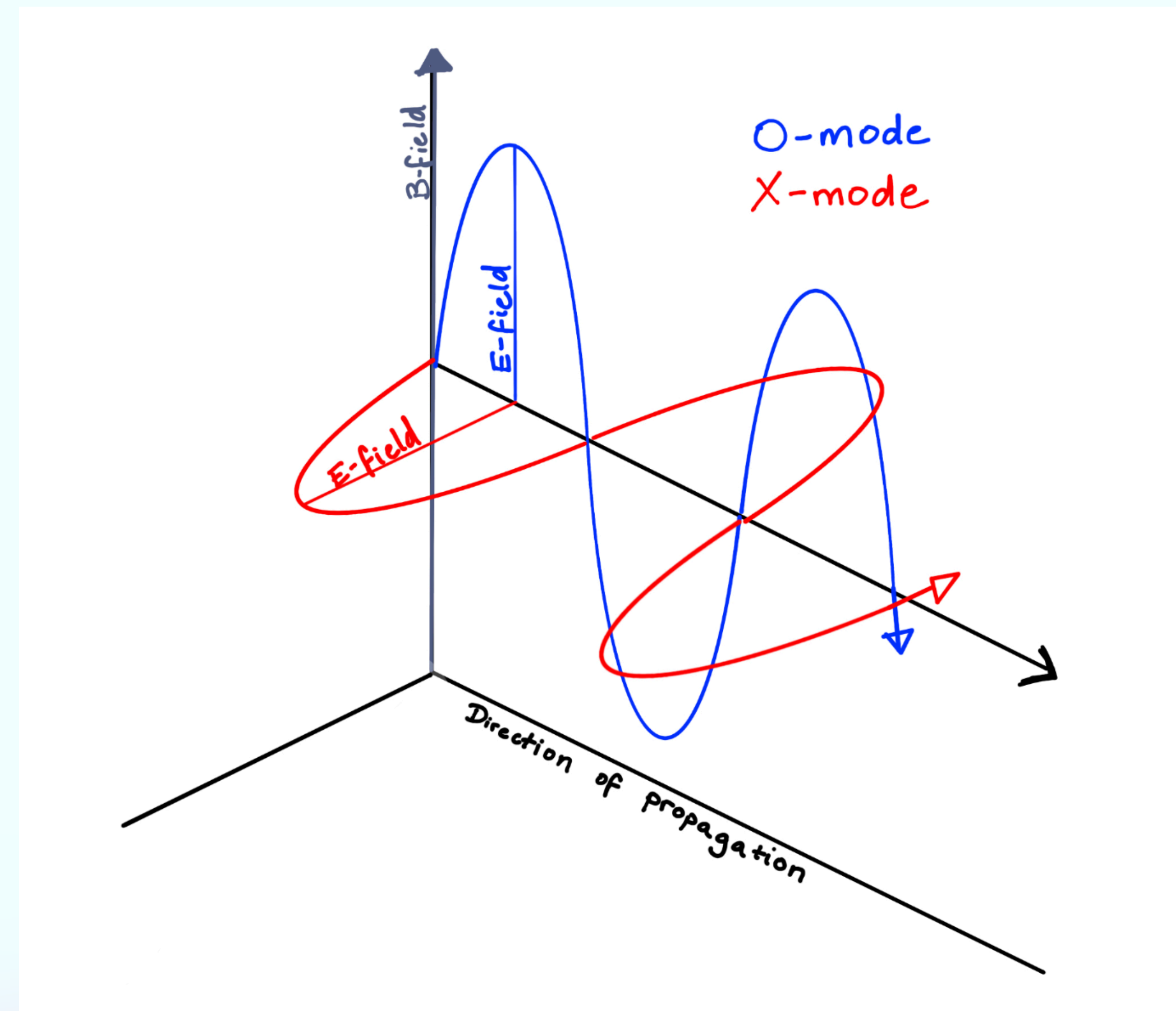
- Atmosphere
- Condensed surface



# Polarisation

(In a magnetised atmosphere)

- Strong B-field
- Motion of charged particles free only along field lines - quantised perpendicular
- Photons polarised in two possible states
- Two “normal” modes
  - Ordinary “O-mode”
  - Extraordinary “X-mode”



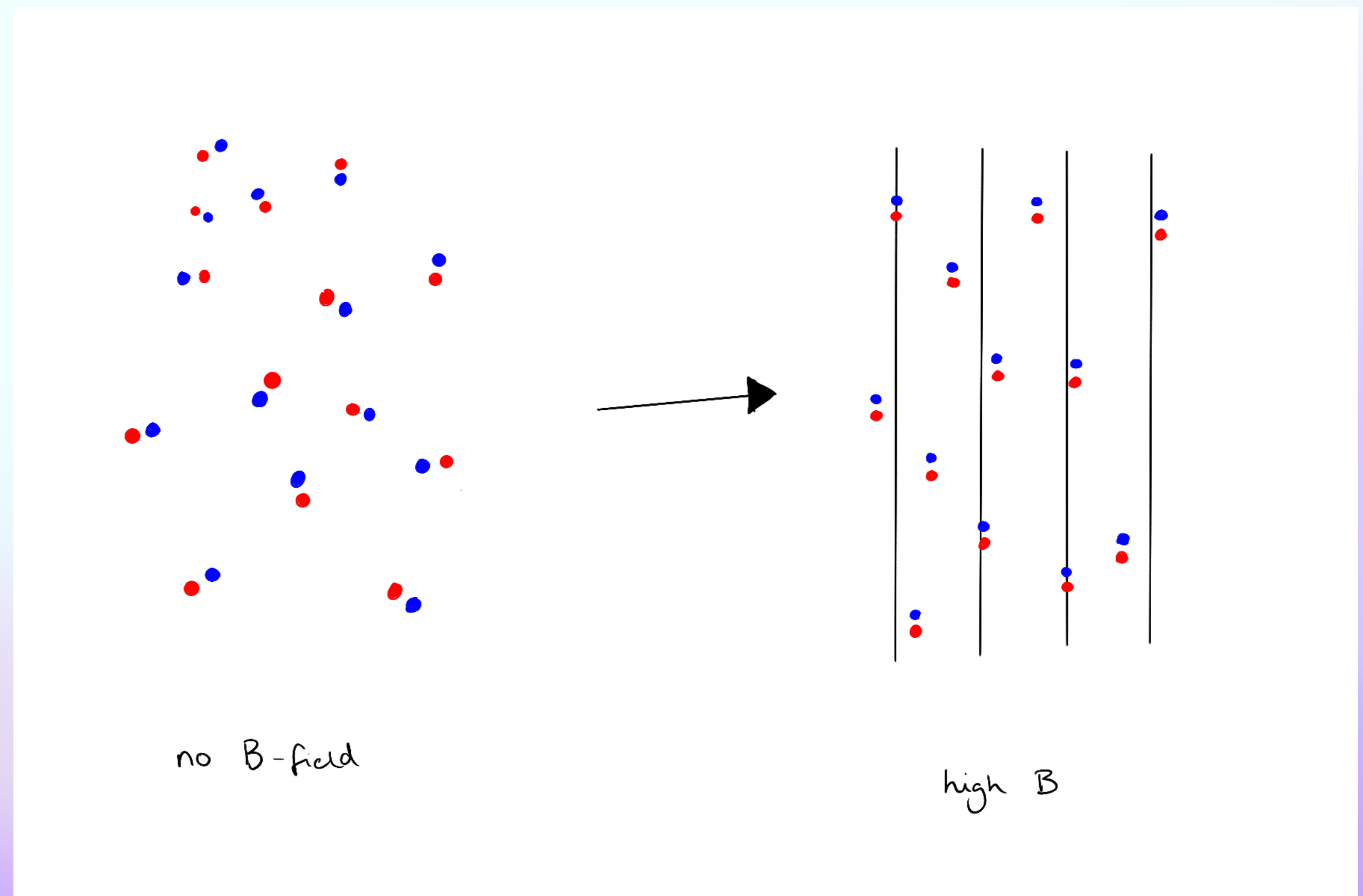
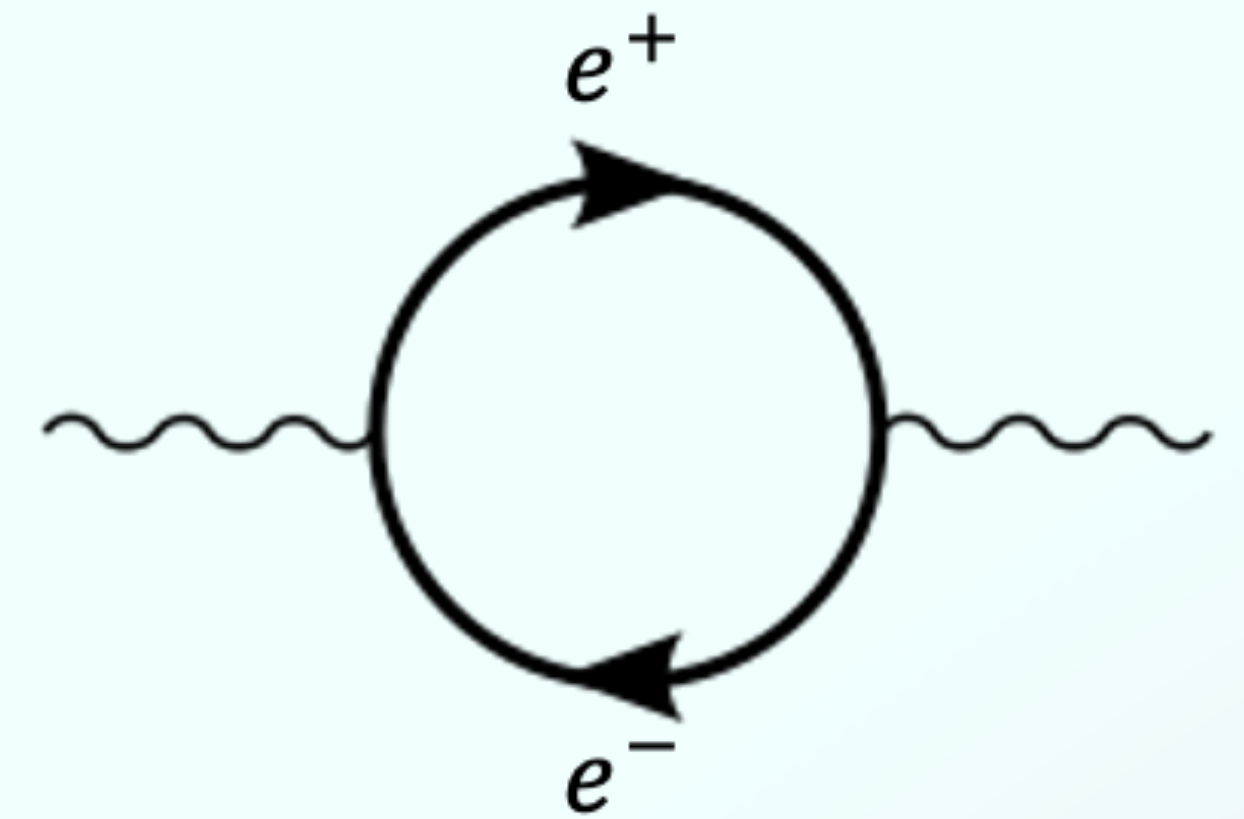
Opacities are very different

- Emission is highly polarised in the X-mode

# Vacuum Birefringence

The “holy grail” of X-ray Polarimetry

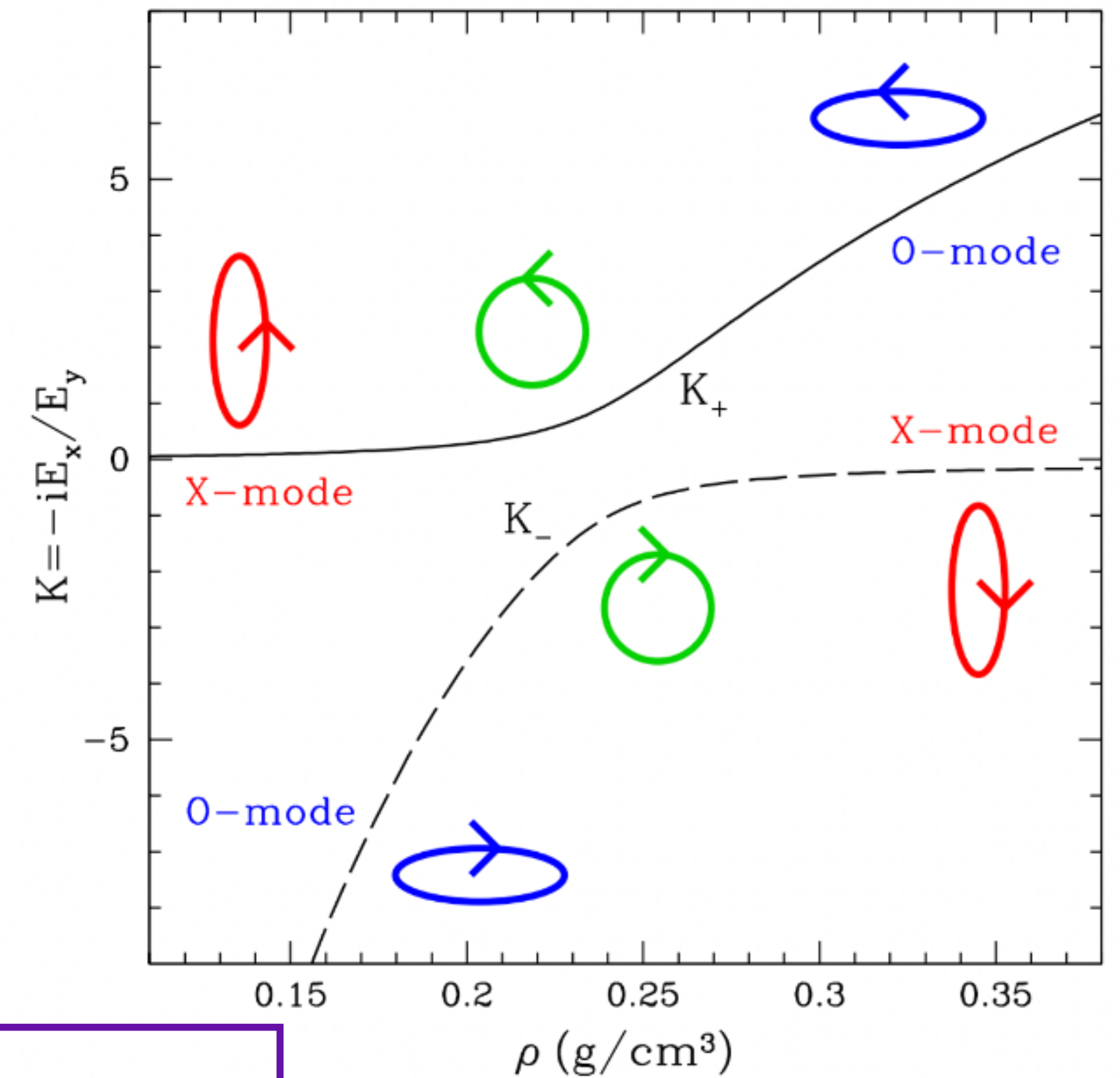
- Strong magnetic field
- Virtual pairs
- Vacuum becomes polarised
- Two normal modes propagate



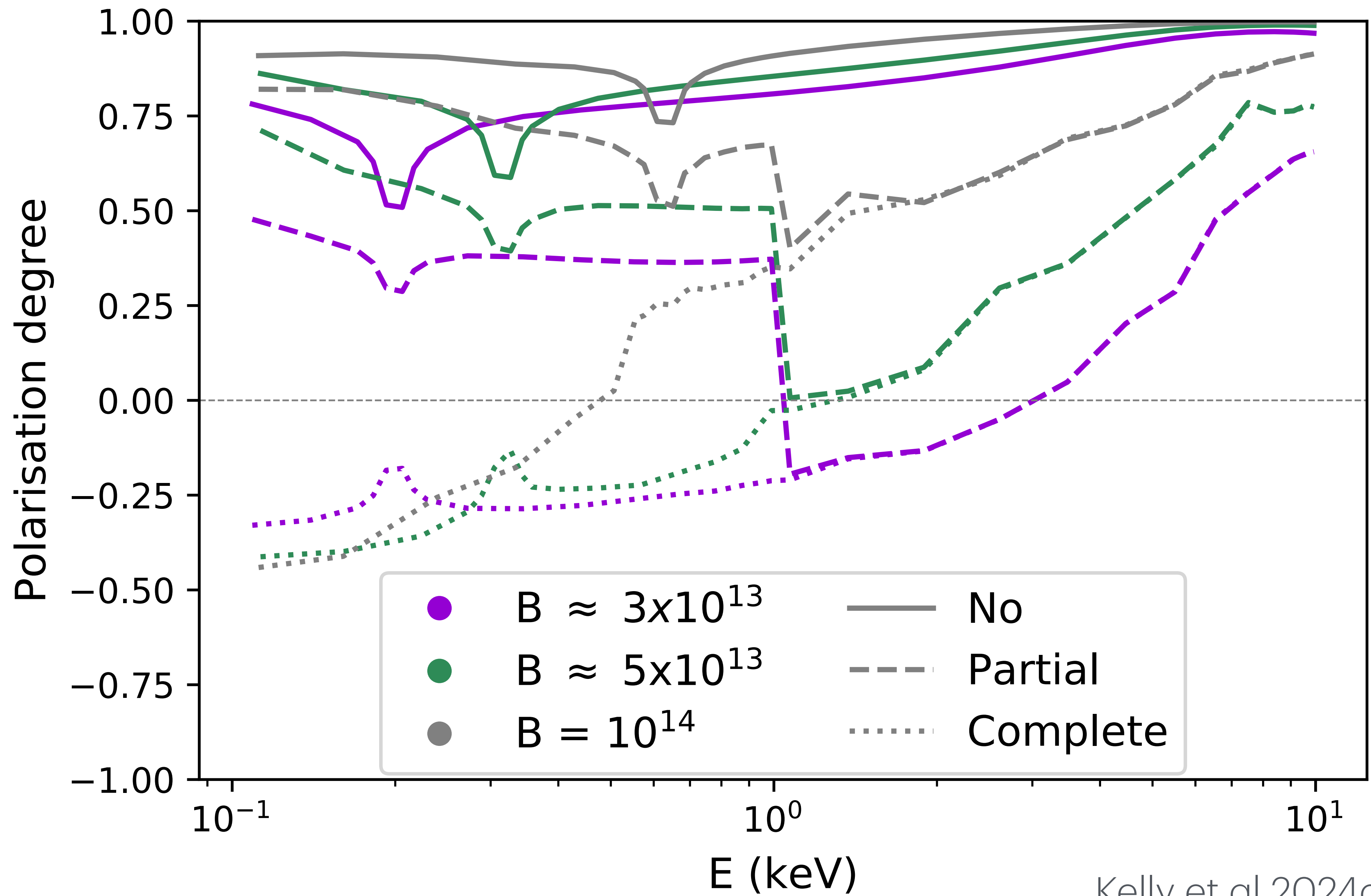
# Mode conversion

## Vacuum Resonance

- Both plasma and vacuum are birefringent - contribute to dielectric tensor of atmosphere
- Balance -> vacuum resonance
  - Modal description ???



- No mode conversion
- Complete mode conversion
- Partial mode conversion
  - Adiabatic mode conversion

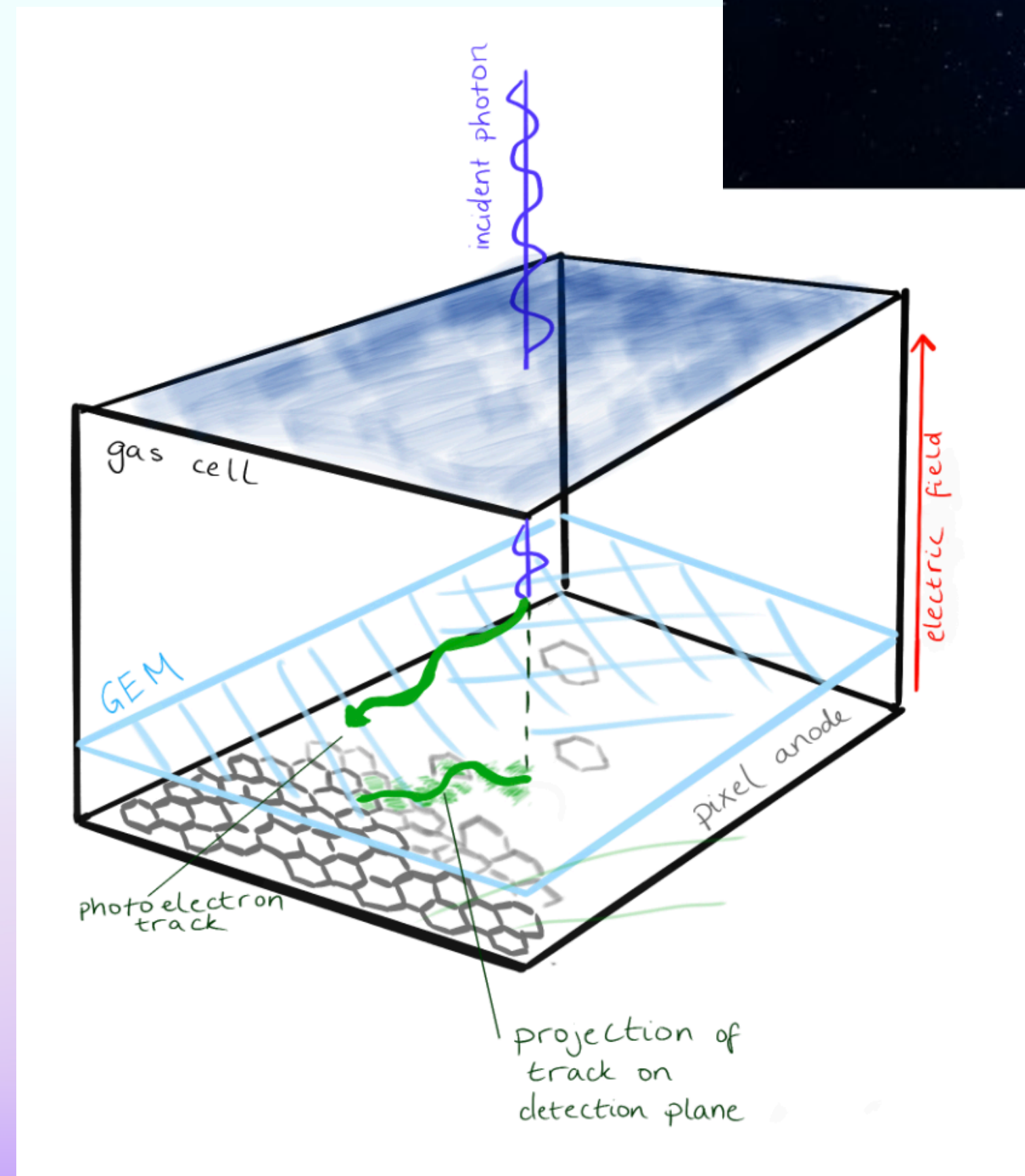


Kelly et al 2024a

# IXPE

## NASA-ASI mission

- Launched December 2021
- 2-8 keV
- 6 magnetars
  - 4U 0142+61
  - 1RXS J1708
  - SGR 1806-20
  - 1E 2259+586
  - 1E 1841-045
  - 1E 1547.0-5408



# IXPE

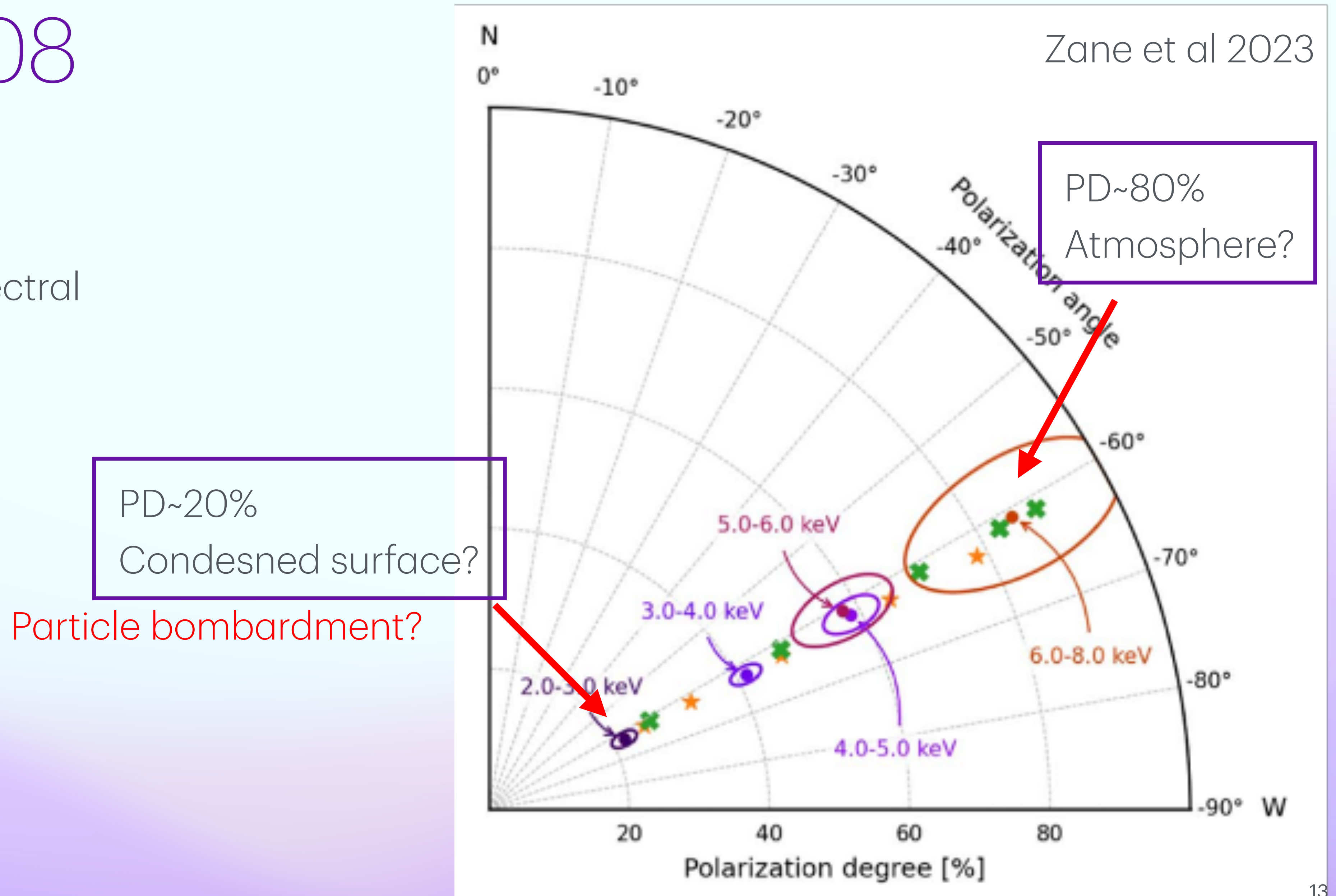
- 6 magnetars
  - 4U 0142+61
  - 1RXS J1708 - quasi-simultaneous Swift + NICER
  - SGR 1806-20 - XMM-Newton
  - 1E 2259+586 - XMM-Newton + NICER
  - 1E 1841-045 - NuSTAR
  - 1E 1547.0-5408 - NICER + Parkes radio telescope

# 1RXS J1708

$$B \sim 5 \times 10^{14} \text{ G}$$

- BB+PL or BB+BB spectral decomposition

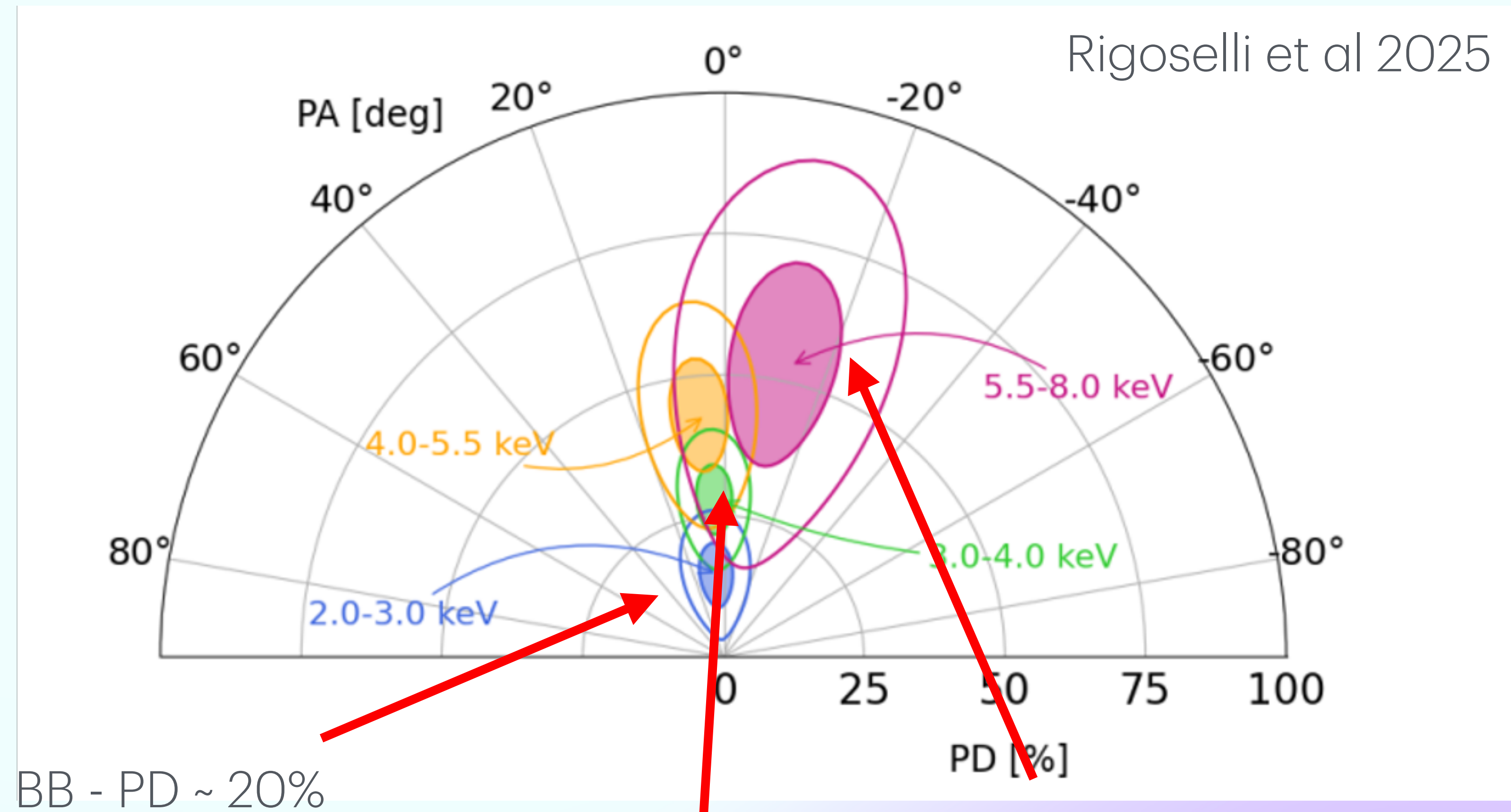
Zane et al 2023



# 1E 1841-045

$$B \sim 7 \times 10^{14} \text{ G}$$

- Three component spectrum:
  - BB+BB+PL
  - BB+PL+PL



BB - PD ~ 20%

Condensed surface

Particle bombardment

PL - PD > 65%

Synchrotron radiation

RICS

PL - PD ~ 33%

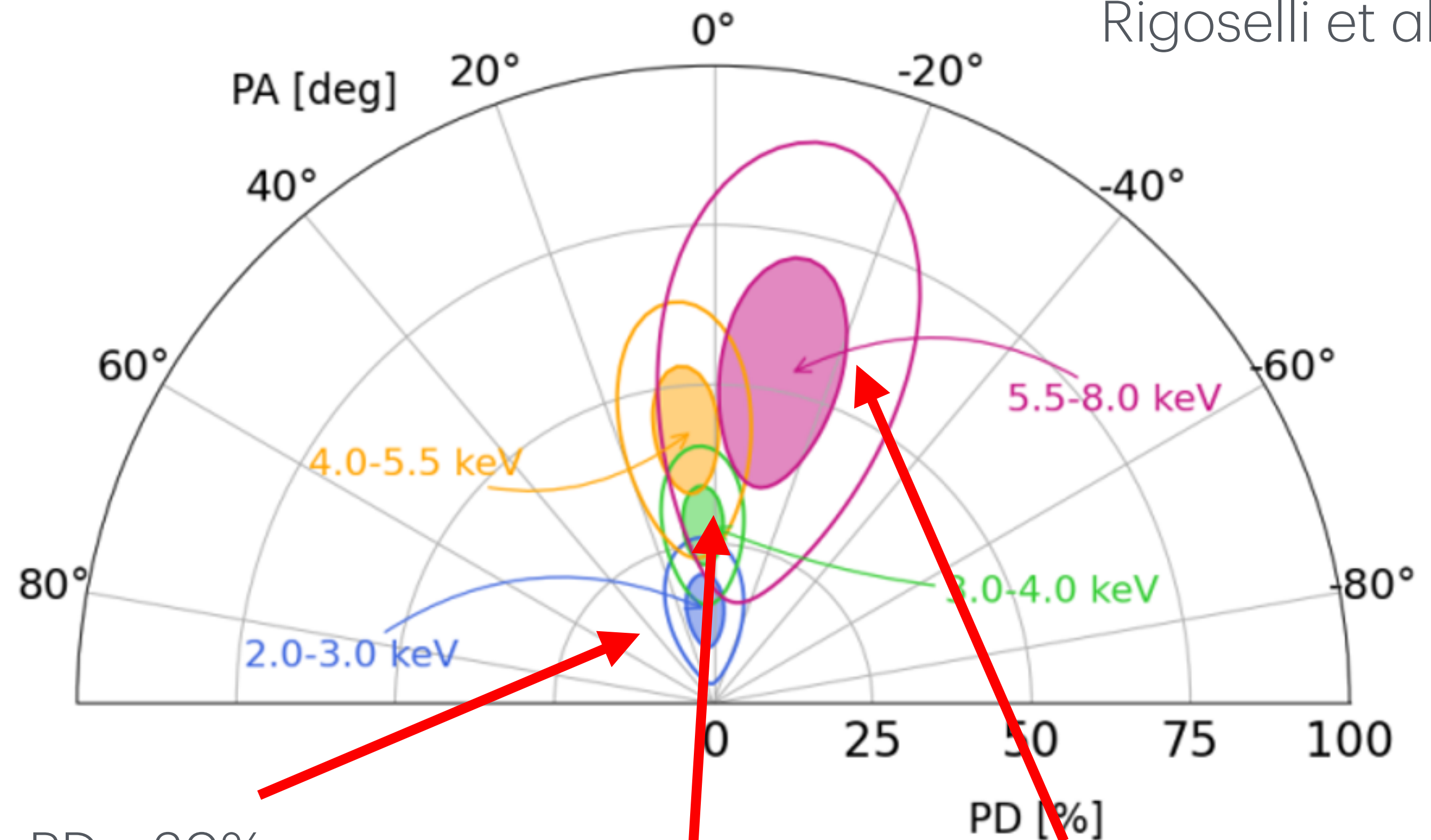
RCS

# 1E 1841-045

$$B \sim 7 \times 10^{14} \text{ G}$$

- Three component spectrum:
  - BB+BB+PL
  - BB+PL+PL

Rigoselli et al 2025



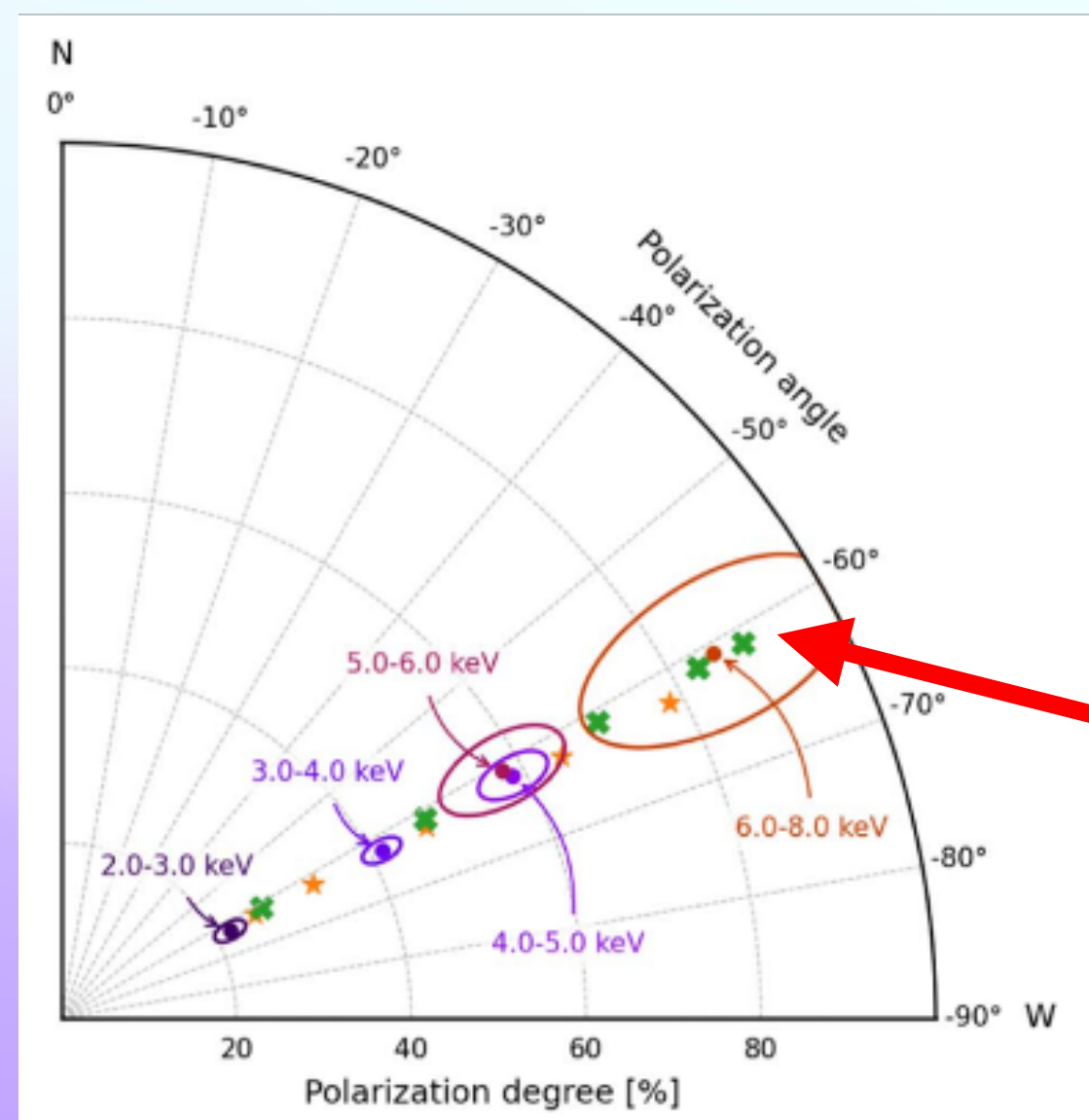
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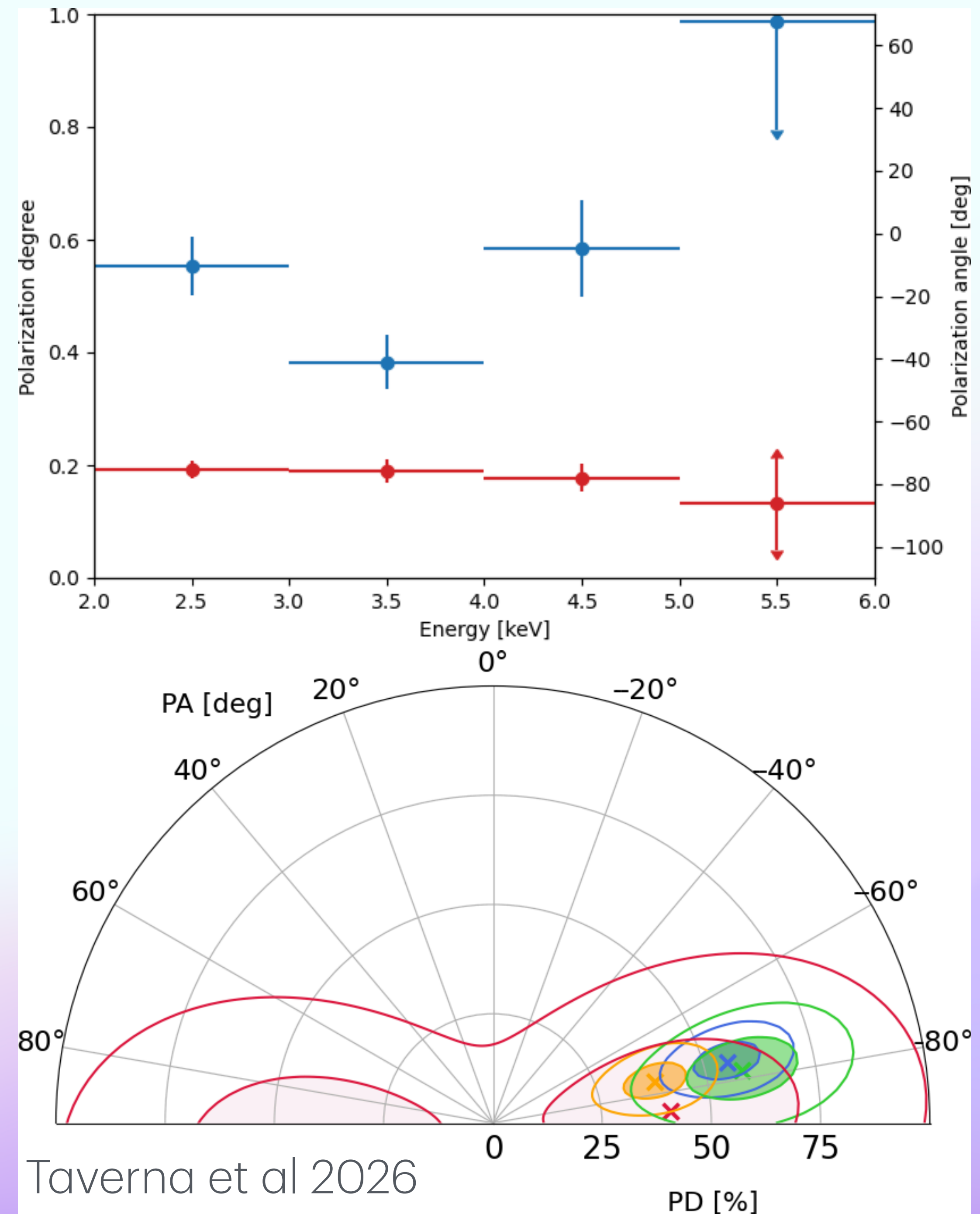
PL - PD ~ 33%  
RCS



# 1E 1547

$$B \sim 4 \times 10^{14} \text{ G}$$

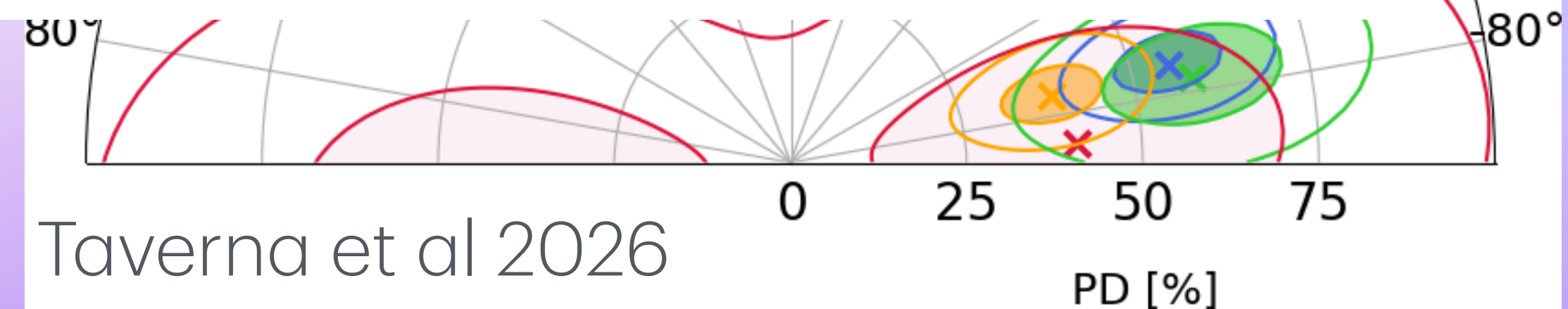
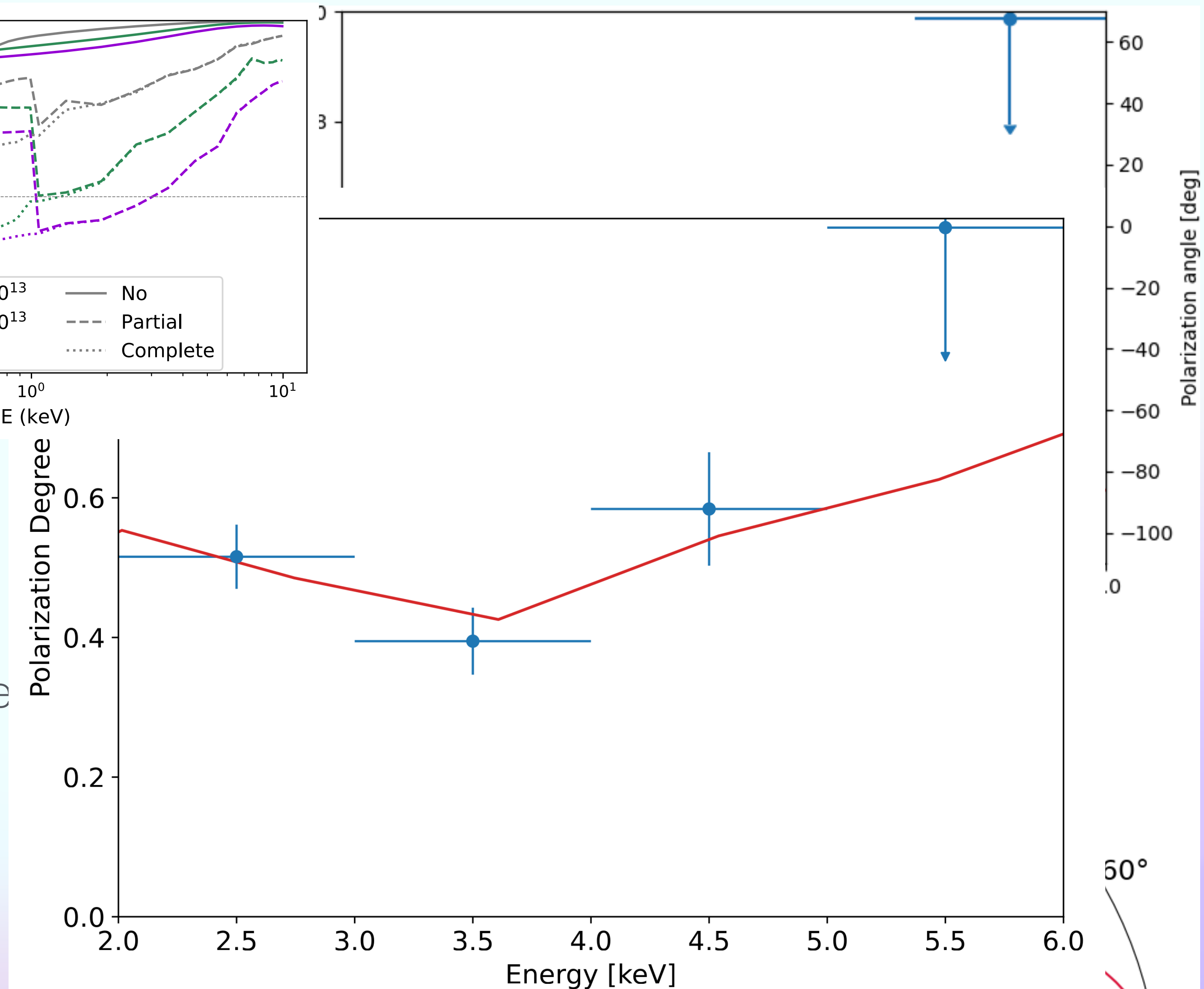
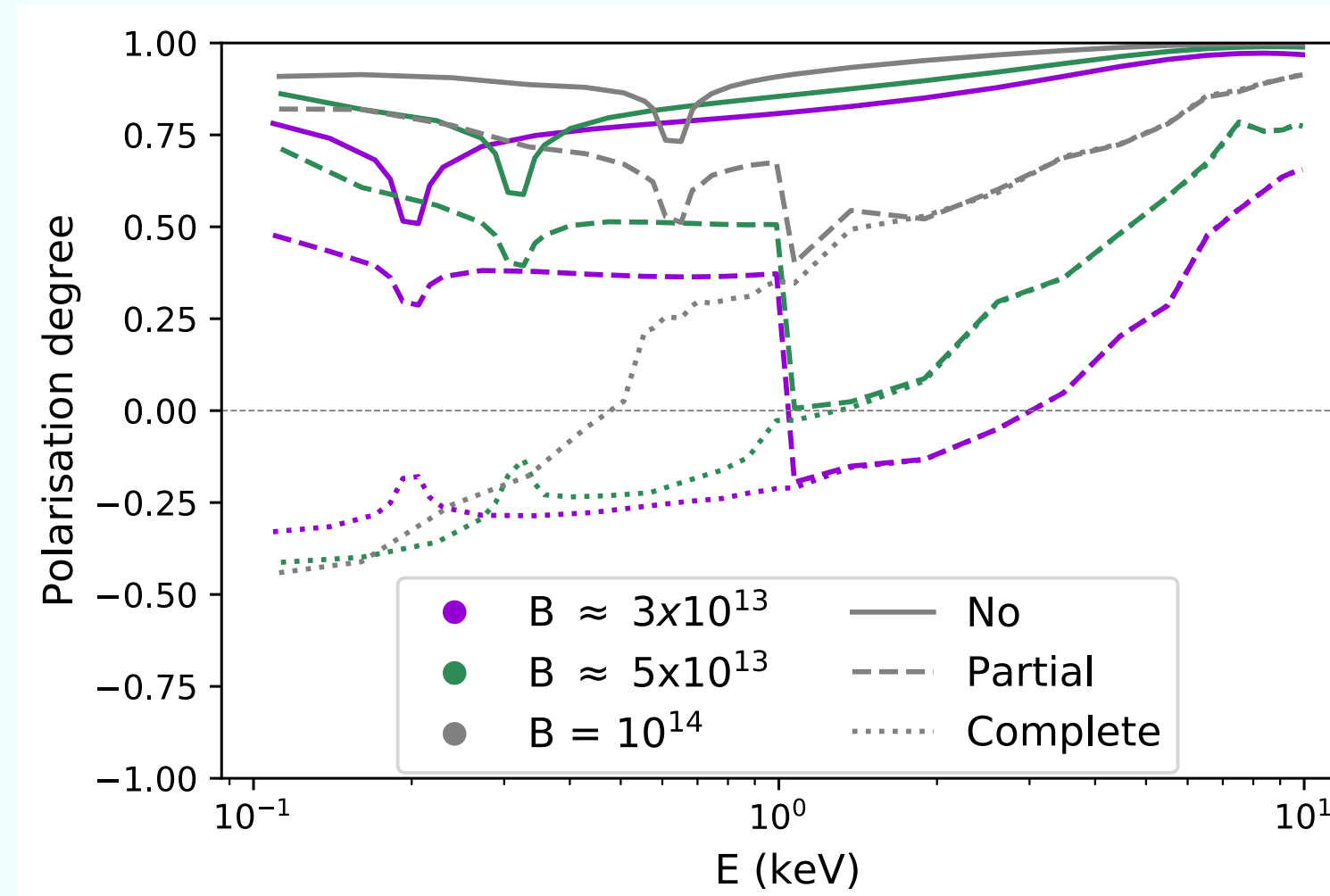
- Single component BB
- Emission likely from a single small hot spot
- No evidence of local minimum / feature in continuum - only hint in polarisation



# 1E 1547

$B \sim 4 \times 10^{14}$  G

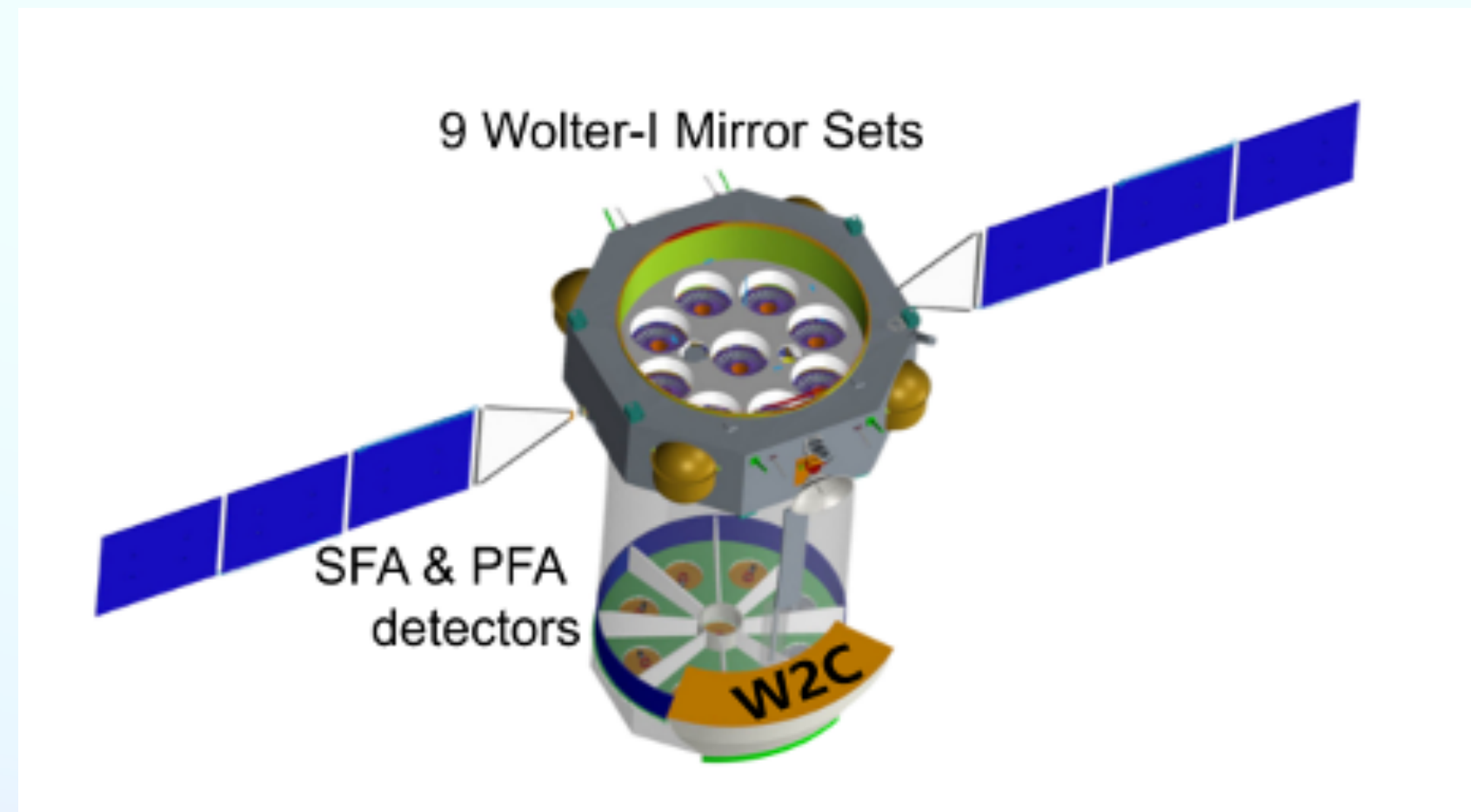
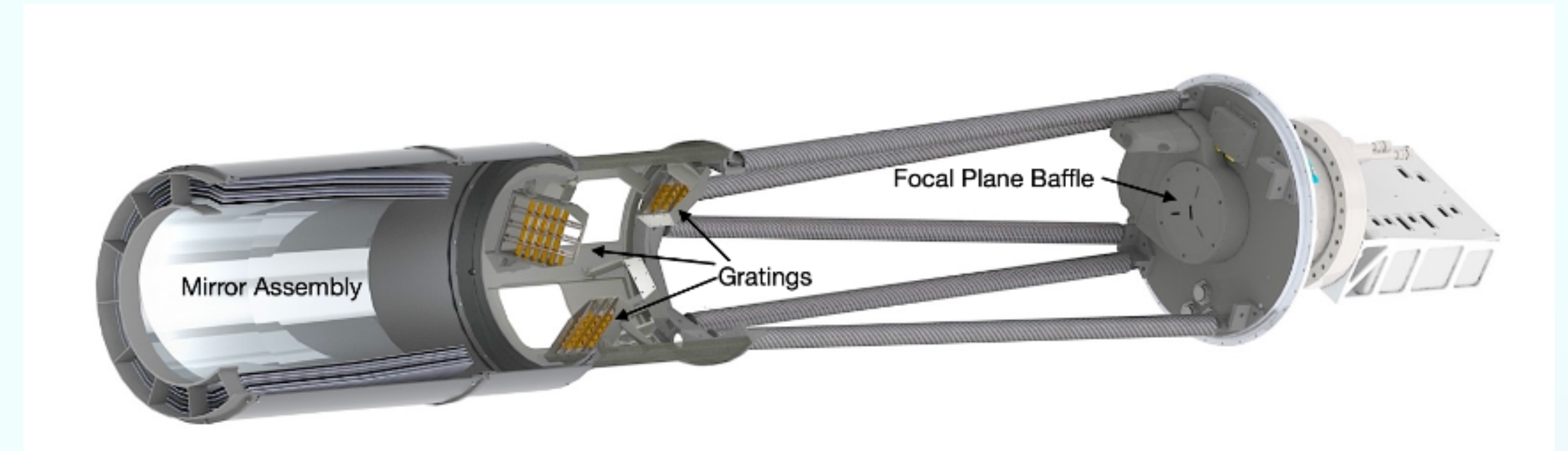
- Single component BB
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Taverna et al 2026

# Looking to the future

## eXTP and GOSoX



### GOSoX

- 2030
- 0.2-0.4 keV

### eXTP

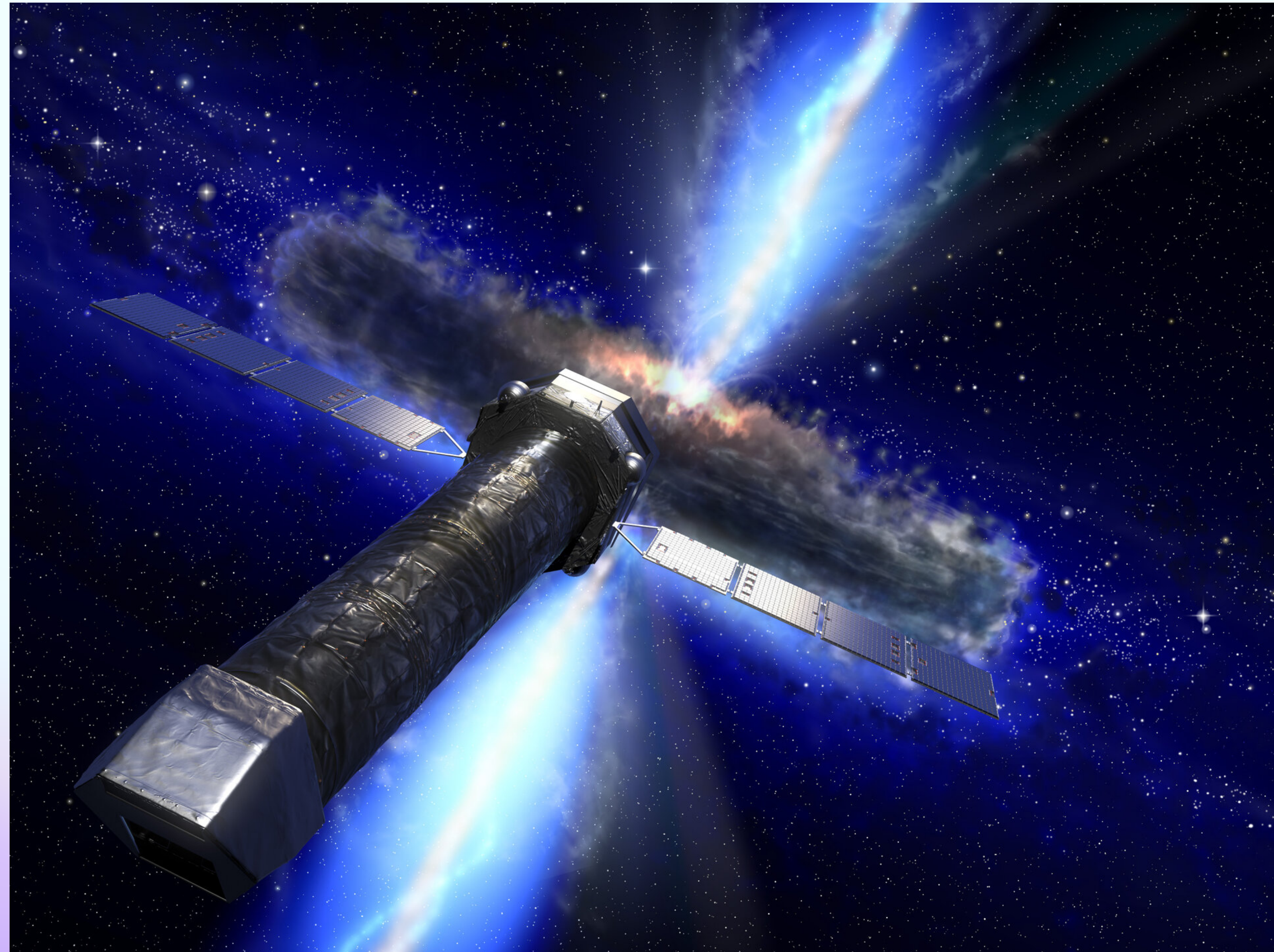
- 2030
- 2-8 keV
- 5x IXPE

# Looking to the future

NewAthena

0.1-12 keV

High-resolution



# Key Take Home Message

- Combined polarimetric and high resolution spectroscopic observation of highly magnetised isolated neutron stars will provide invaluable insights

Thank you!