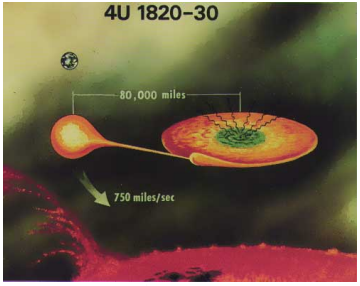
Joint NICER/IXPE Workshop 2024

First detection of X-ray polarization in the UCXB 4U 1820-30 with IXPE

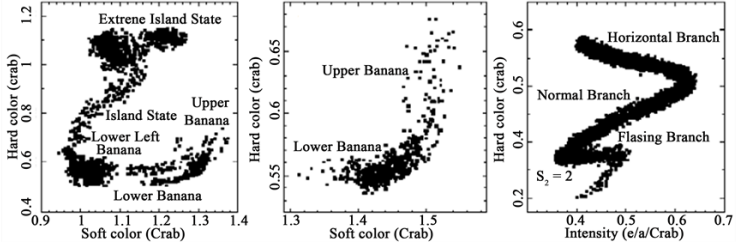
Alessandro Di Marco
on behalf of the IXPE Science Team
alessandro.dimarco@inaf.it

INAF-IAPS

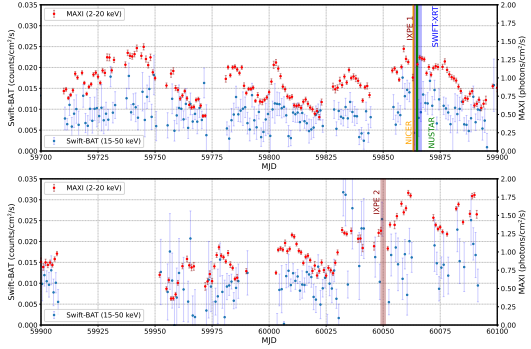
A. Di Marco, F. La Monaca, J. Poutanen et al.,
ApJL 953, L22, 2023
eprint arXiv:2306.08476



- Binary systems having a NS ($B < 10^{10} G$) and a companion star ($M < M_{\odot}$)
- Accreting matter via Roche lobe overflow (similar to BH)
- Classified in:
  - Z-sources with luminosities 0.1–1 L_{Edd}
  - Atoll-sources with luminosities 0.01–0.1 L_{Edd}

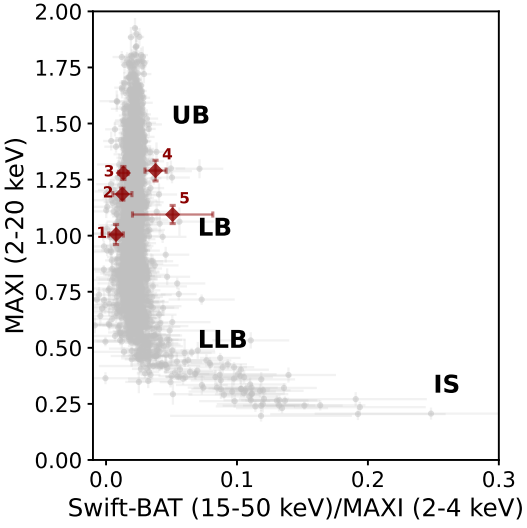


The NS LMXB 4U 1820–303



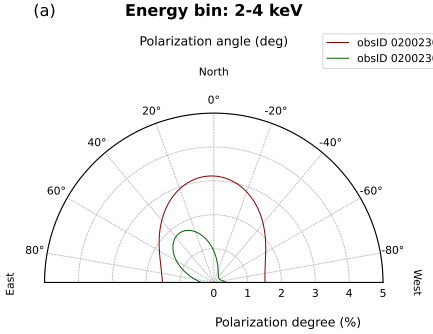
- LMXB consisting of a He WD accreting on to an ultracompact NS
- First identified source of type I X-ray bursts (bursts only around the flux minima)
- Orbital period of 685 s producing a $\sim 2\%$ peak-to-peak modulation
- Superorbital period of $\simeq 170$ days

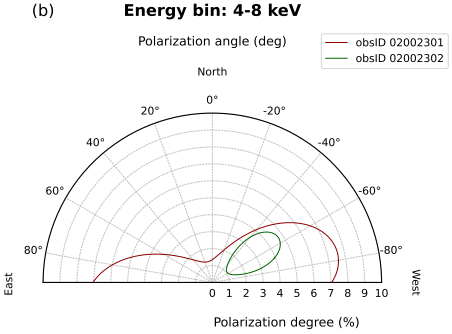
- Previous tentative to measure of X-ray polarization
  - ➥ PD $< 4.7\%$ at 2.6 keV and $< 10.8\%$ at 5.2 keV (99% CL) by OSO-8 ApJ 280(1984)255



- Red points report the state of the source along our coordinated observations:
  1. 2022 October 11: NICER, IXPE, and Swift-XRT
  2. 2022 October 12: Swift-XRT, NuSTAR
  3. 2022 October 13: Swift-XRT
  4. 2023 April 15: IXPE, Swift-XRT, NICER, NuSTAR and ATCA
  5. 2023 April 16: IXPE, Swift-XRT, NICER and NuSTAR
- **Source was in the Lower Banana state during all the observations**
- Data of the two IXPE observations were performed when the source was at the maximum of the superorbital period

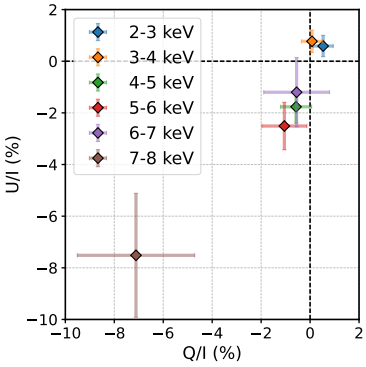
- No significant polarization in 2-8 keV

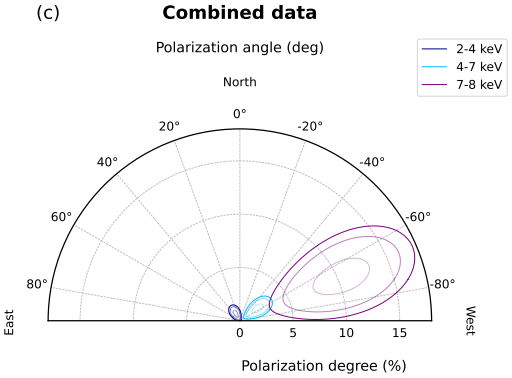




- Contours are at 99% C.L.
- Contour regions in both the energy bins are compatible
- Because of this and the HR compatibility we can combine the two data sets

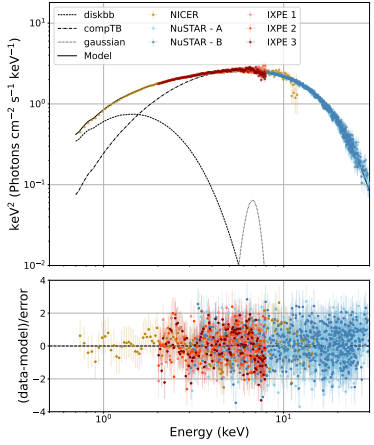
4U 1820–303: polarization as a function of the energy





- An energy trend is well visible
- Energy bin 7–8 keV highly significant (99.99%CL)
- Grouping in 3 bins: 2–4 keV, 4–7 keV and 7–8 keV detection significance is 99.99997% CL
- PA rotation of 90 deg at 96% CL at $\simeq$4 keV

Best model **diskbb + Gaussian (broad) + CompTB** assuming thermal comptonization ($\delta = 0$), seed photons having bbody distribution ($\Gamma = 3$) and large comptonized fraction ($logA = 5$)



TBABS(DISKBB + COMPTB + GAUSSIAN)		
TBABS	N_H	$0.144^{+0.011}_{-0.010}$
DISKBB	T_{in}	$0.517^{+0.034}_{-0.036}$
	NORM	1840^{+520}_{-360}
COMPTB	kT_s	0.717 ± 0.046
	α	0.926 ± 0.013
	kT_e	$2.919^{+0.016}_{-0.008}$
	NORM	0.05429 ± 0.00044
GAUSSIAN	LINEE	6.63 ± 0.086
	SIGMA	$0.564^{+0.013}_{-0.012}$
	NORM	$0.00203^{+0.00059}_{-0.00049}$
$\chi^2/\text{dof} = 1835.25/1780 = 1.03$		
F_{diskbb}/F_{tot}=0.114		
F_{compTB}/F_{tot}=0.884		
$F_{gaussian}/F_{tot}$=0.002		

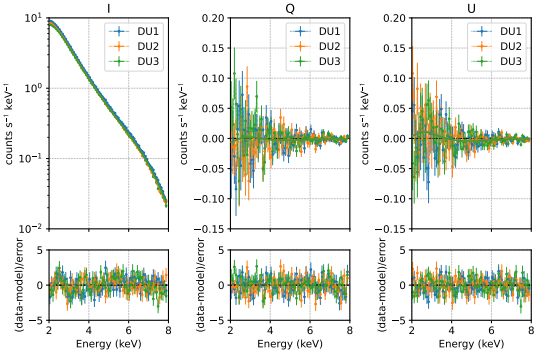
Errors are at 90% CL

- Spectral I parameters frozen from the previous fit

- Trying different XSPEC polarimetric models, assuming unpolarized iron line:
  1) TBABS(GAUSSIAN + **polconst***(DISKBB + COMPTB))
     - ➥ $\chi 2/\mathrm{dof} = 740.37/664 = 1.115$
  2) TBABS(GAUSSIAN + **pollin***(DISKBB + COMPTB))
     - ➥ $\chi 2/\mathrm{dof} = 703.94/662 = \mathbf{1.063}$

- As expected by model independent analysis (PCUBE), XSPEC favors a not constant polarization
  - ➥ F-test result 17.13 with probability 5.6×10^{-8}

- Assuming two different polarization components to diskbb and compTB:
  1) TBabs(gaussian + **polconst***diskbb + **polconst***compTB)
     - ➥ $\chi 2/\mathrm{dof} = 724/662 = 1.094$
  2) TBabs(gaussian + **polconst***diskbb + **pollin***compTB)
     - ➥ $\chi 2/\mathrm{dof} = 699/660 = 1.057$
  3) TBabs(gaussian + **polconst***diskbb + **polpow***compTB)
     - ➥ $\chi 2/\mathrm{dof} = 697/660 = \mathbf{1.054}$



- The χ^2 test slightly favors a solution with a diskbb having constant polarization and a compTB having a power-law polarization behavior

Spectro-polarimetric analysis: a polarization to each component II

Polarimetric components		`polconst*diskbb + polconst*comptb`	`polconst*diskbb + pollin*comptb`	`polconst*diskbb + polpow*comptb`
`diskbb`	PD (%)	9.8 ± 4.2	$8.1^{+7.1}_{-6.8}$	$3.2^{+3.0}_{-2.9}$
	PA (°)	32 ± 13	-59^{+13}_{-26}	43 ± 35
`comptb`	PD / A_1 (%)[a]	5.31 ± 0.24	5.7 ± 2.4	$0.46^{+9.63}_{-0.46} \times 10^{-3}$
	$A_{\rm slope}$ (% keV^{-1})	–	-1.9 ± 0.6	–
	$A_{\rm index}$	–	–	$-4.9^{+1.6}_{-2.6}$
	PA / ψ_1 (deg)[a]	-63 ± 11	38 ± 7	-63 ± 7
	$\psi_{\rm slope}$ (deg keV^{-1})	–	0 (f)[b]	–
	$\psi_{\rm index}$	–	–	0 (f)[b]
	χ^2/dof	$724/662 = 1.094$	$699/661 = 1.057$	$697/661 = 1.054$

Errors are at 90% CL.

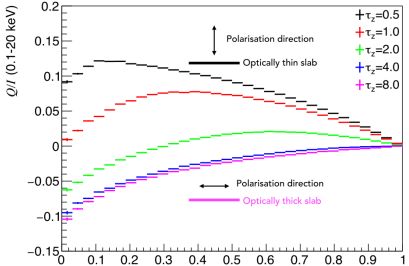
[a]For the `pollin` and `polpow` models, A_1 and ψ_1 refer to the PD and PA values at 1 keV.

[b]We fixed the slope and the index of the PA at zero.

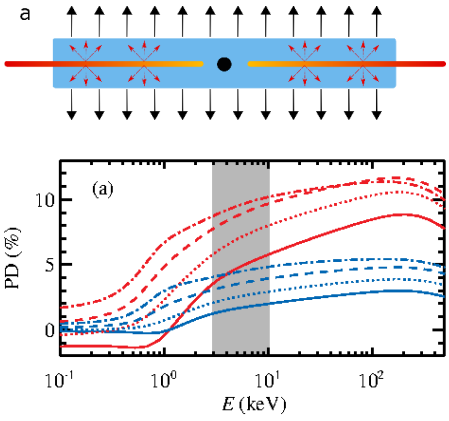
- χ^2/dof favors `pollin` and `polpow` for `compTB` with a constant PA

- Polarization detection at 99.995%, up to 99.99997% when polarization is energy resolved
- **Clear detection of polarization increasing with energy up to 10% in the 7–8 keV energy bin** (values higher than other atoll sources observed by IXPE)
- Disk component needs to be polarized
- **Energy spectrum dominated by Comptonization** as in the hard state, thus we can study the corona properties

- PD increasing with energy is associated with a corona with slab geometry, where PD can reach $10\% - 20\%$ for an optical thin corona, but in our case $\tau > 10$ that it could imply PD of few % (Sunyaev & Titarchuk, 1985); **some non-standard corona geometry is slightly required**
- Reflection component not well constrained
  - ➥ Flux contribution $< 5\%$ with respect to the total
  - ➥ Maximum PD for a reflection component $\simeq 20\%$ (Matt+ 1993 and Poutanen+ 1996) $\rightarrow$ maximum PD at level of 1%



[Tomaru+ 2024]



- From Poutanen et al., (ApJL 949, L10, 2023) a PD increase with energy is expected for slab geometry in the presence of relativistic outflows
- Similar expectation from Gnarini et al. (MNRAS 514, 2561, 2022)
- **Inclination should be higher to explain such a fast increase of PD**
- For more details about this work:
  Di Marco A., La Monaca F., Poutanen, J. et al.
  ApJL 953, L22, 2023 (eprint arXiv:2306.08476)