# The hard X-ray population of accreting white dwarf binaries: the Swift role

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# Accreting WD Binaries

~ 1430 CVs  ~ 80 AM CVn  ~315 Symbiotic stars

**Cataclysmic Variables sub-types**

Non-Magnetic CVs

Dwarf novae & Novalike

~65-70% of all CVs

$B_{WD} << 10^5 – 10^6$ G

Magnetic CVs

Intermediate Polars & Polars

~ 30% of all CVs

$B_{WD} > 10^6$ G

Isolated Magnetic WDs

~13 % of all WDs

$B_{WD}$ ~ 3kG -> 1000MG

**High incidence of magnetism**

# Magnetic Cataclysmic Variables

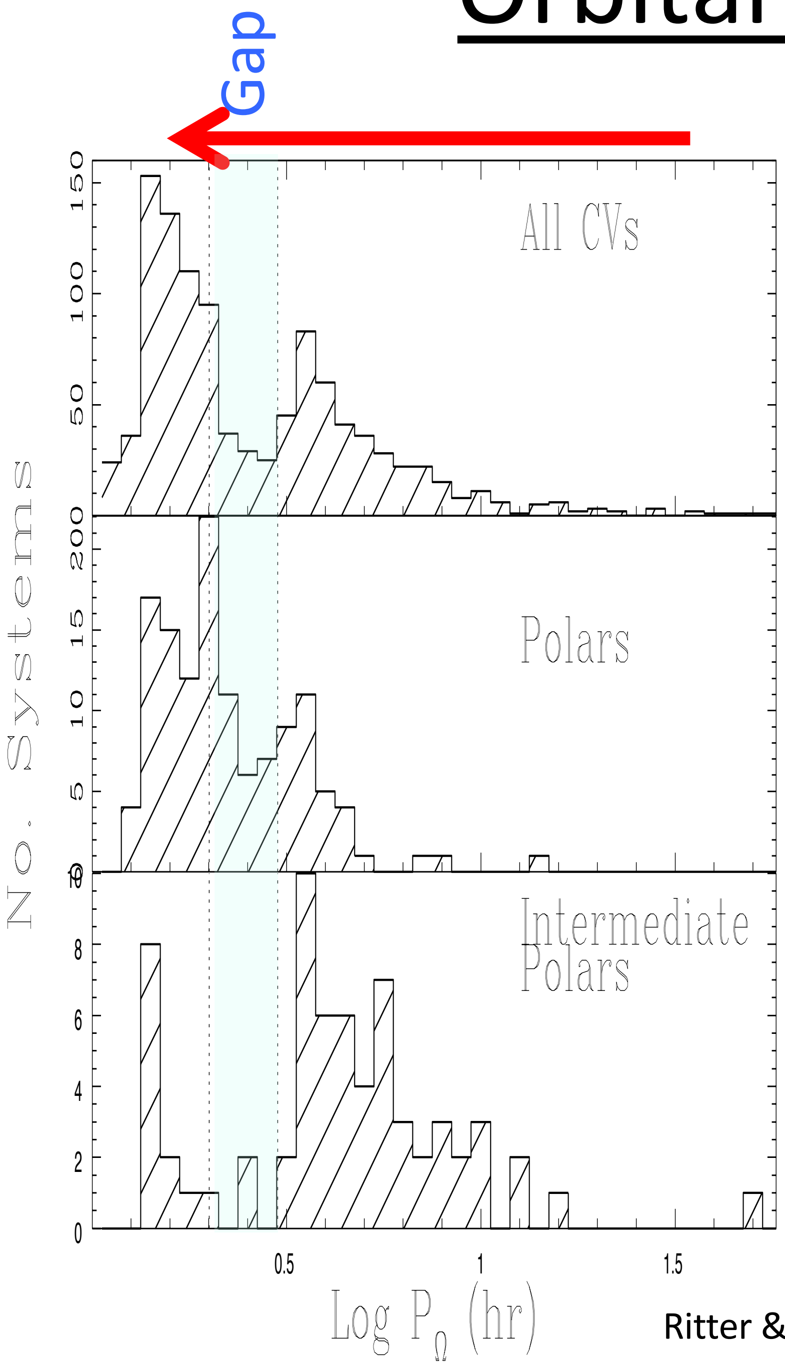
~ 30% of whole CV population

| Polars | Intermediate Polars (IPs) |
|---|---|
| Porb ≅ Prot (hrs) | Prot (mins) < Porb (hrs) |
| $B_{WD}$ ~ 10 – 230 MG | $B_{WD}$ < 10MG (?) |
| Polarized in optical/nIR | Unpolarized or weakly polarized |
| ~ 218 systems | ~ 74 systems + 79 candidates |
| Bright in soft X-rays (ROSAT era) | Bright in hard X-rays (INTEGRAL/SWIFT era) |

Is there a relation between two types ?

- Different B-fields?
- Same B but evolutionary link?

# Orbital Period Distribution




Binaries evolve towards short Porb

Angular Momentum Losses via:

- Magnetic Braking (MB) above CV 2-3h "gap"
- Gravitational Radiation +residual MB below

➢ Most Polars are below gap

➢ Most IPs are above gap

IPs may evolve into Polars if similar B-fields

Ritter & Kolb CV Cat. 7.24v

# Galactic faint X-ray source populations

**What role of CVs in X-ray populations?**

## Galactic Center (GCXE)

Chandra 1Ms

Suzaku 1.3Ms

INTEGRAL 12Ms

XMM-Newton 1Ms

NuSTAR 1.7Ms

≈88% of GCXE resolved faint **hard** sources

- Power law Γ <1–1.5 or KT ~ 20keV
- Fe lines (6.7-6.9keV)
- Lx ~ $10^{30}$ - $10^{34}$ erg/s
- Follows IR stellar emission of inner regions

→ mCVs likely dominate inner GC regions

(Muno+04, Uchiyama+11; Hong+2012,+14; Heard&Warwick13, Perez+15; Hailey+16; Hong+16)

## Galactic Ridge (GRXE)

RXTE 29Ms

Chandra 1Ms

XMM-Newton 2XMMi

Suzaku 3Ms

INTEGRAL 0.2-4Ms

≈70-80% of GRXE@6.7keV resolved in discrete **hard** sources

- Follows IR stellar emission
- Lx ~ $10^{32}$ – $10^{35}$erg/s & KT ~20keV

  → likely mCVs of IP-type
- Lx < $10^{32}$ erg/s & KT ~2-6keV

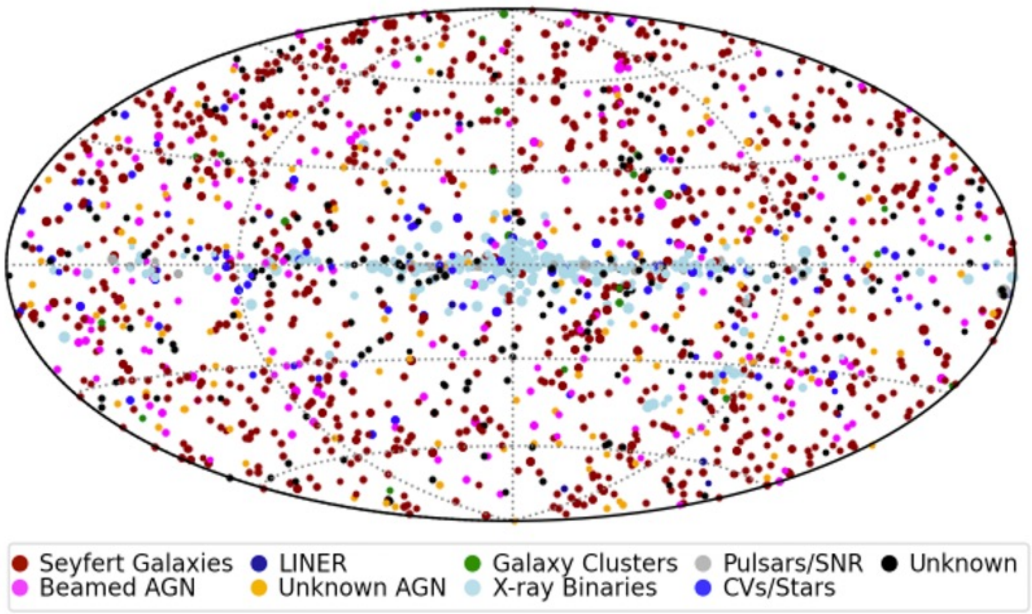
→coronally active binaries, CVs, Polars ?

(Revnivtsev+06,07,09; Sazonov+06; Yuasa+12; Warwick+14;Nobukawa+16; Perez+2019)

# The Hard X-ray Surveys

**The complementary role of SWIFT & INTEGRAL**

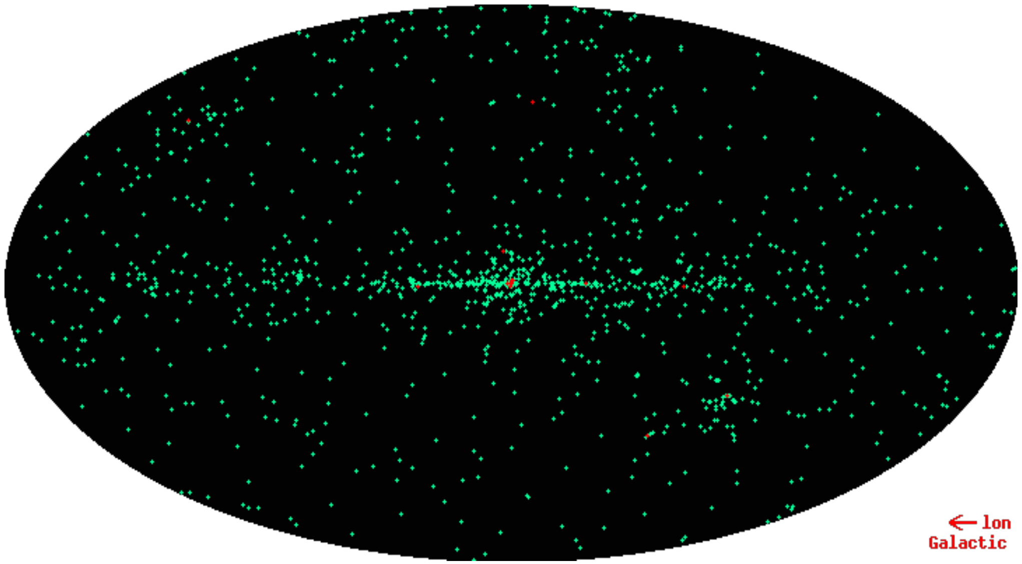
## SWIFT/BAT 157-month Sky




**Sensitivity ~ 8E-12 cgs for 90% of the sky**
**Uniform coverage**
**1891 sources detected in 14-195keV**

Oh et al. 2018, Swift Sept. 2024

## INTEGRAL/IBIS 17yrs Sky

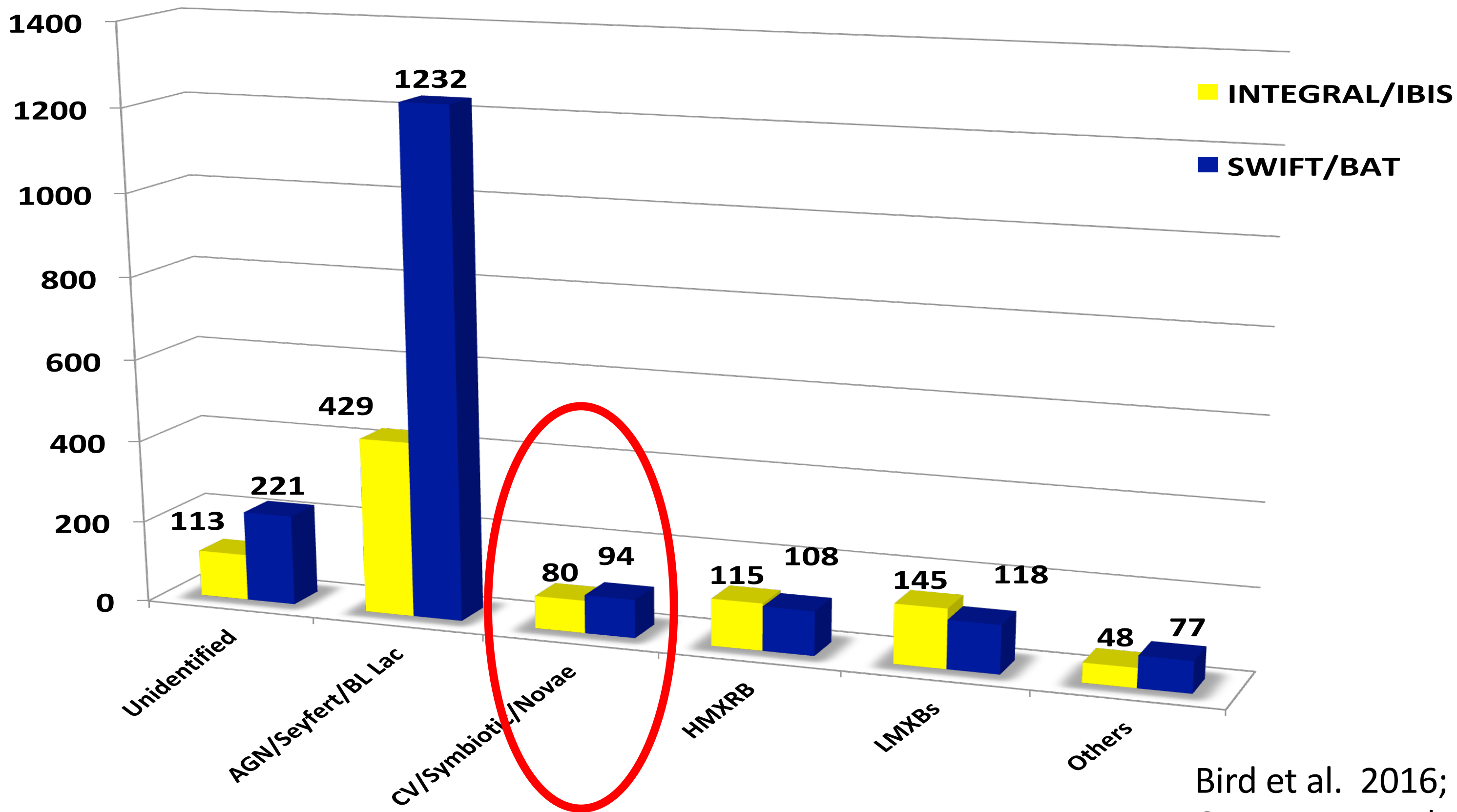



**Sensitivity ~ 2.6E-11 cgs for 90% of the sky**
**Deep coverage of Galactic Plane**
**929 sources detected in 17-100 keV**

Krivonos et al. 2022, Cat 2024

# The Hard X-ray Surveys

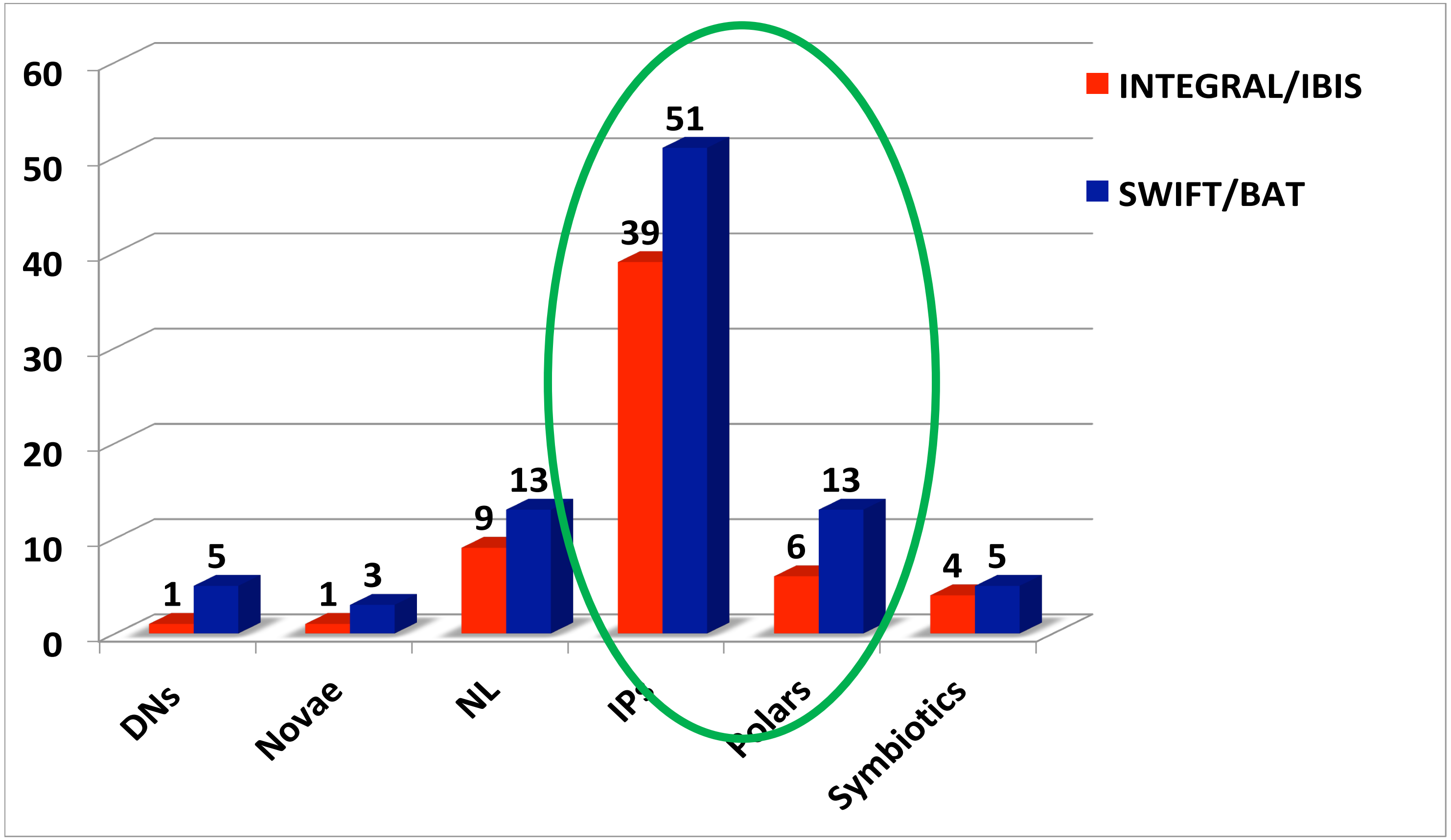
- INTEGRAL/IBIS and SWIFT/BAT changed our view of X-ray sky
- Dominance of extragalactic sources
- ~ 25 % of Galactic X-ray sources are CVs
- Efficient  for some CV types




Bird et al.  2016;   Krivonos et al. 2022
Cusumano et al. 2014;  Oh et al. 2018 Swift+24

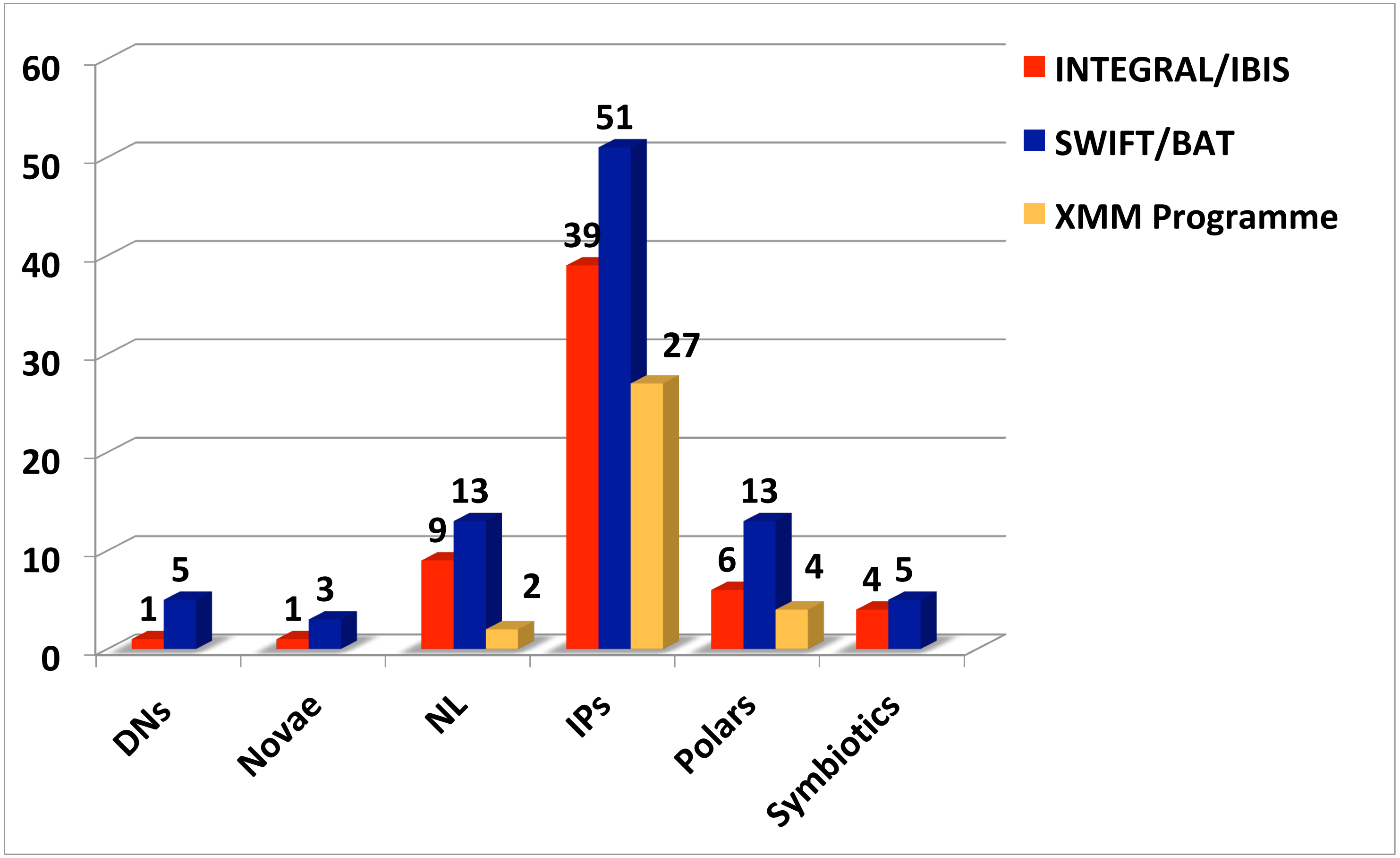
# What type of hard CVs

- IPs doubled in number with INTEGRAL/SWIFT detections!
- Hard X-ray Polars discovered
- Novalike CVs – many still disputed to be mCVs



# What type of hard CVs

- Classification requires optical and deep X-ray follow-ups
- XMM-Newton programme: new identifications



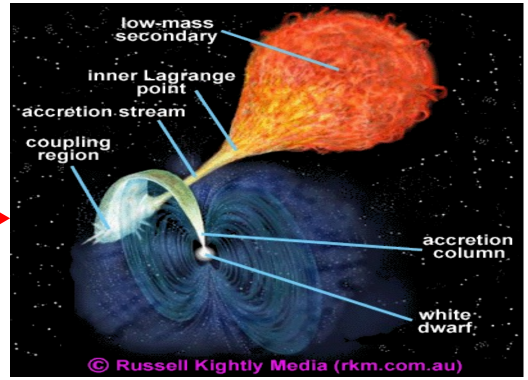
# Identifying new mCVs:
# Search for X-ray pulses with XMM-Newton

- X-ray Power Spectra: Accretion mode diagnostic :

$\omega \approx \Omega$ → Polars

$\omega - \Omega$ → Stream-fed IP

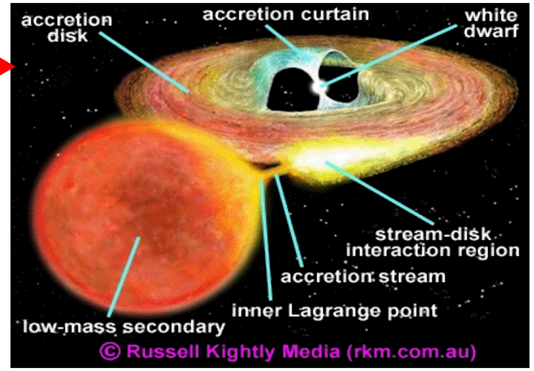
NO DISC →




$\omega$ → Disc-fed IP

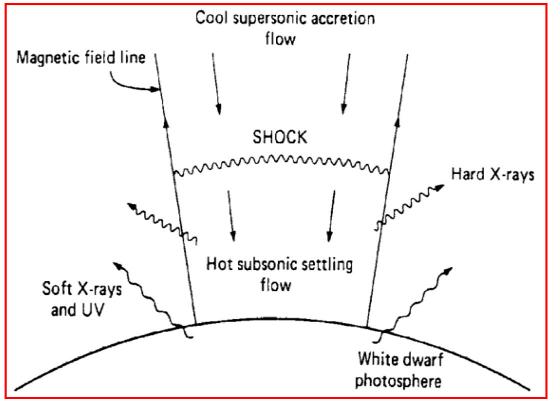
$\omega$ , $\omega$-$\Omega$ → Disc-overflow (Hybrid)

YES DISC →




- Energy dependent X-Ray/UV/Optical pulses:
  - Geometry and B-field complexity
  - Sites of Primary & Reprocessed radiation
  - Absorption effects
- X-Ray spectra:
  - Accretion region: Pre-Shock, Post-Shock, spot at disc rim
  - WD irradiation and WD mass

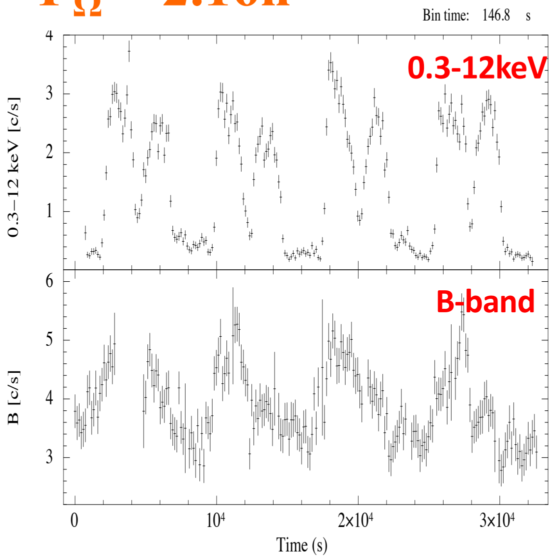
# X-ray light curves of hard Polars




$$P_\omega = P_\Omega$$

SWIFTJ2218.4-1925

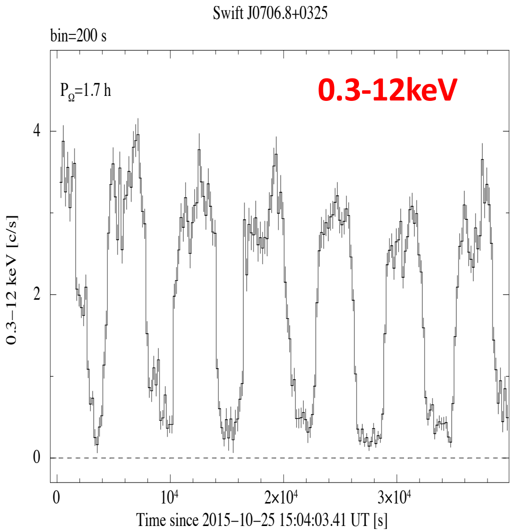
$P_\Omega = 2.16h$




(Bernardini et al. 2014)

SWIFT J0706.8+03

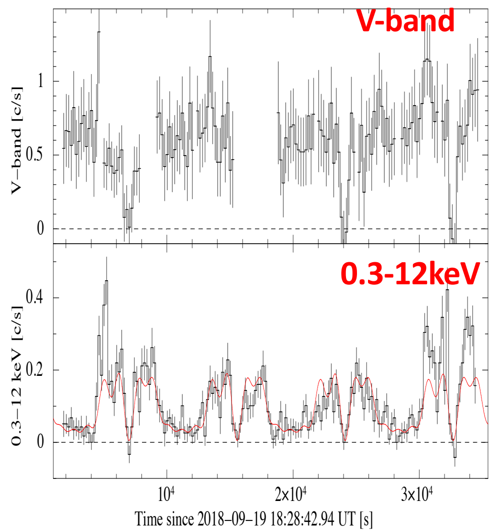
$P_\Omega = 1.70h$




(Bernardini et al. 2017)

2PCB J0658-1746

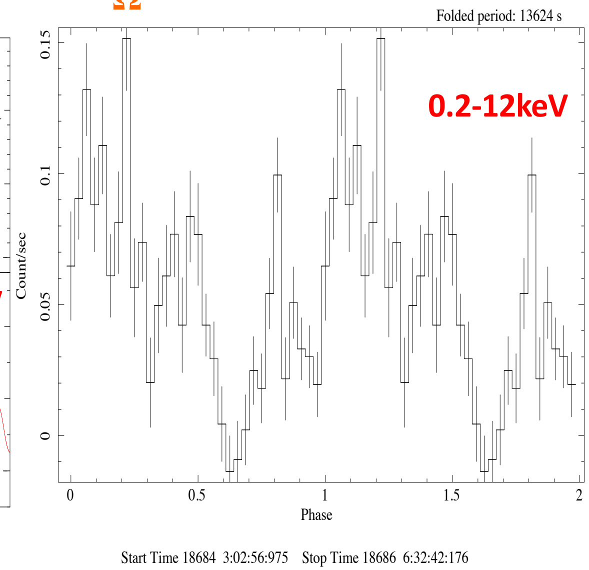
$P_\Omega = 2.38h$




(Bernardini et al. 2019)

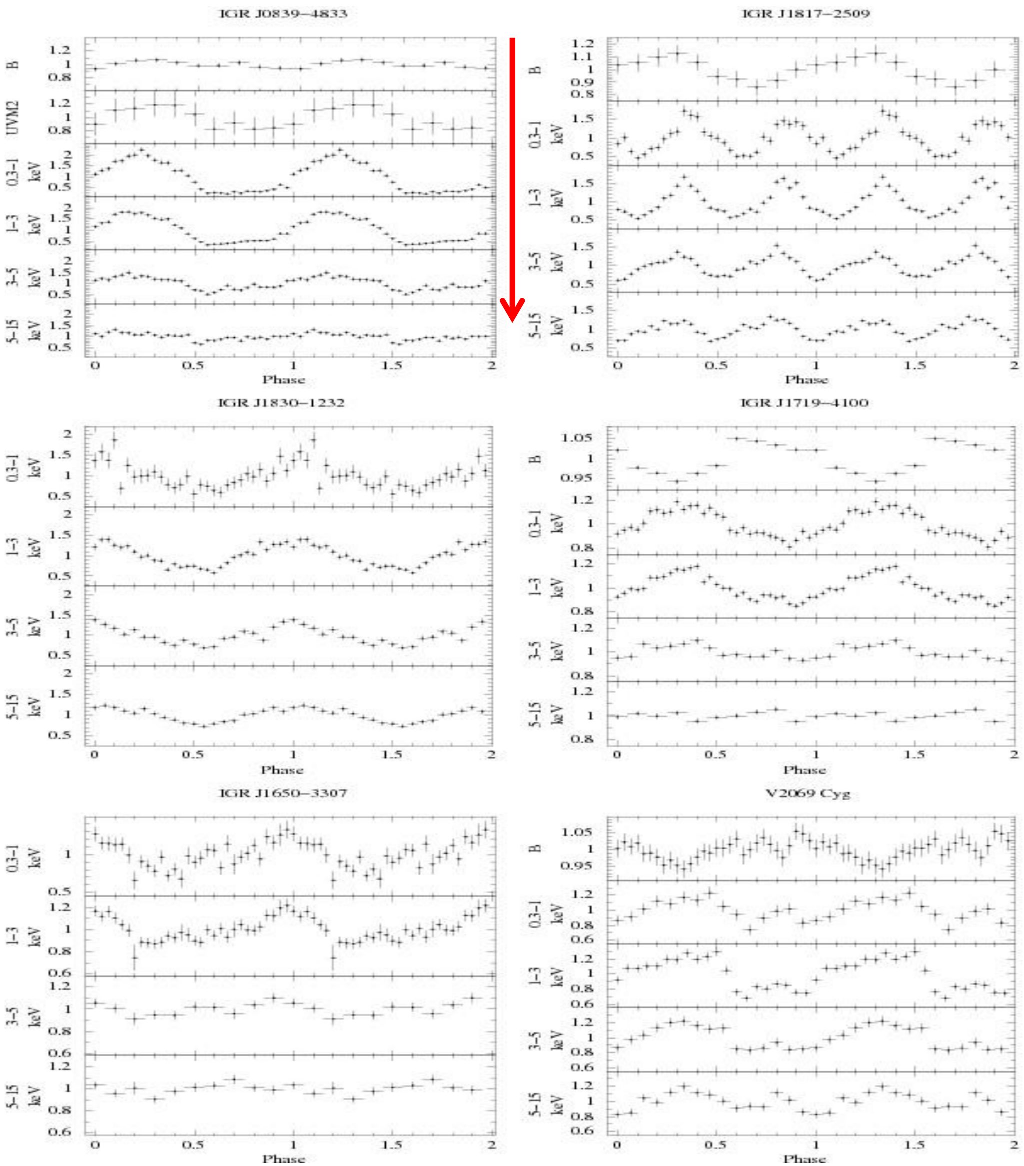
SWIFTJ2341+764

$P_\Omega = 3.71h$




(DdM et al. 2025)

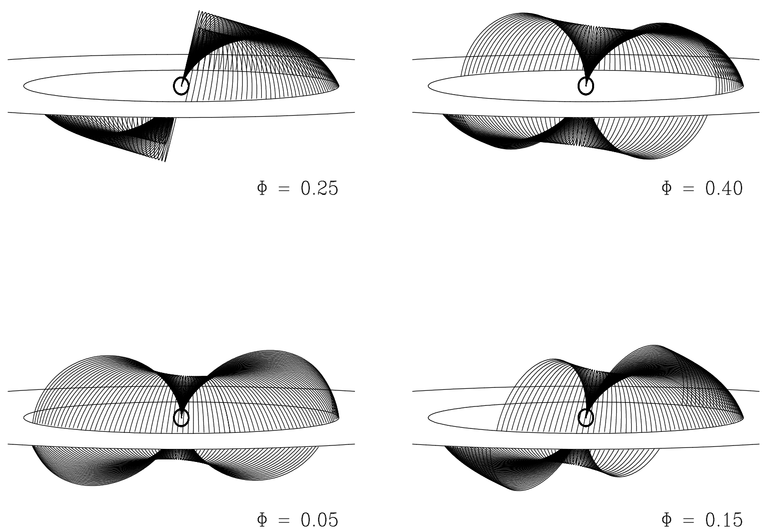
# Energy dependent spin pulses in IPs




Bernardini et al. 2012→2018 + DdM in prep.

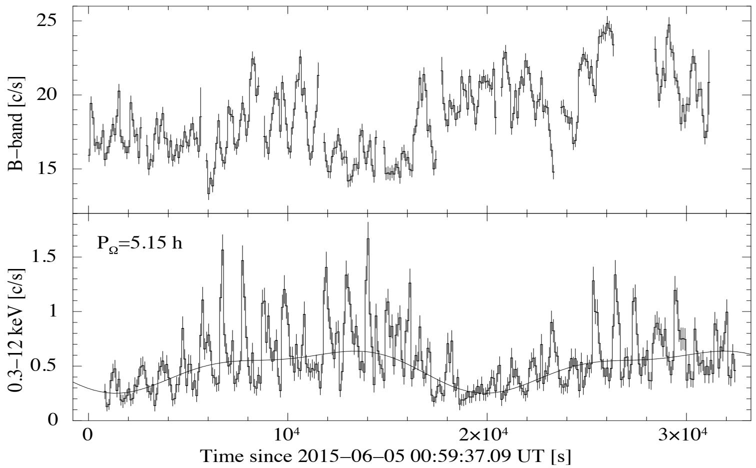
- Amplitudes decrease with energy
  → Photoelectric absorption
- Shapes may change with energy
  → multiple emission components

Accretion Curtain Geometry
(Rosen+89,Ferrario+93):

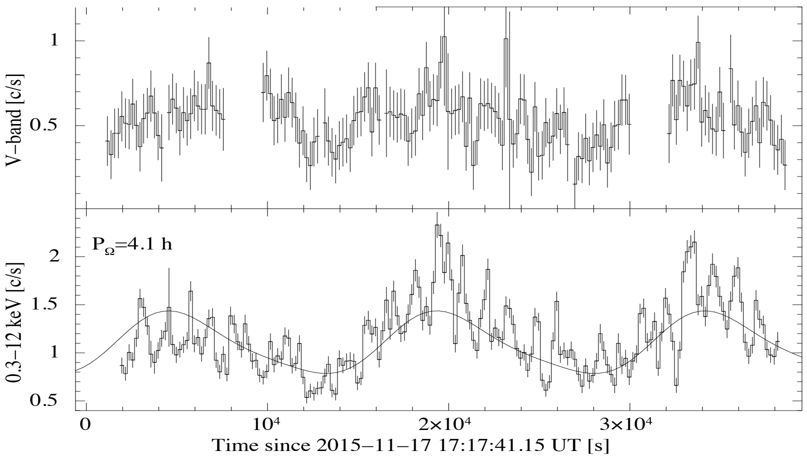


# X-ray multiple periodicities in IPs

$P_\Omega$ = 5.2h
$P_\omega$=1033.5s
$P_{\omega-\Omega}$ =1093.4s   Swift J0927.7-6945




$P_\Omega$ = 4.1h
$P_\omega$=1265.6s
$P_{\omega-\Omega}$ =1373.8s   Swift J2113.5+5422




## X-ray orbital modulation is not uncommon

- 13 systems so far

(Parker et al.2005; Bernardini et al. 2012; 2017, 2018, Rawat et al. 2024)

- Amplitudes from 3-4% up to ~ 100%
- Amplitudes decrease at higher energies
- No relation with dM/dt but high inclinations (i>60deg)

➔ Localised absorbing material at the disc rim

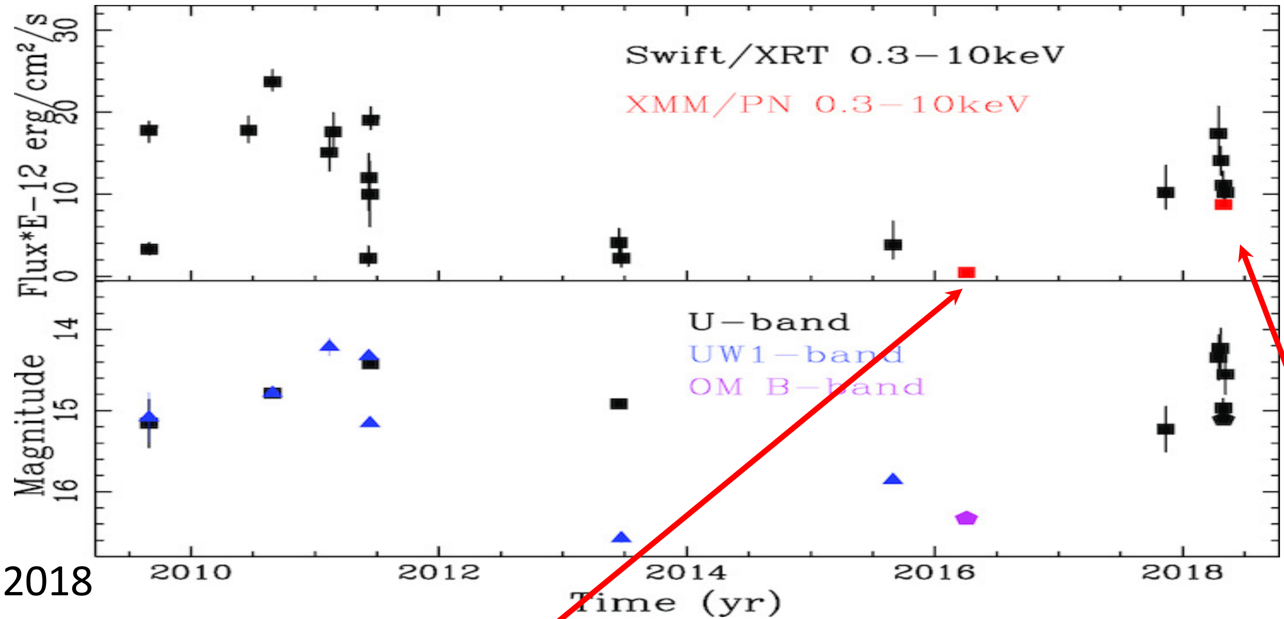
## X-ray beat periodicity in many IPs (~20%)

- X-ray beat can reach $A_{\omega-\Omega}/A_\omega$ ~ 1

➔ Disc-overflow accretion configuration

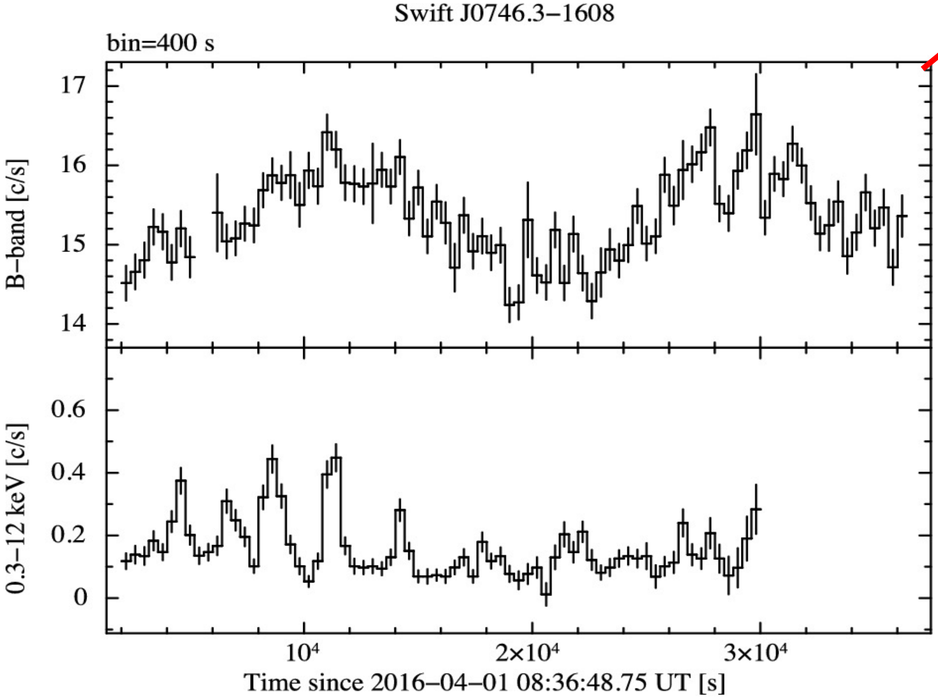
# Swift role to catch high and low states

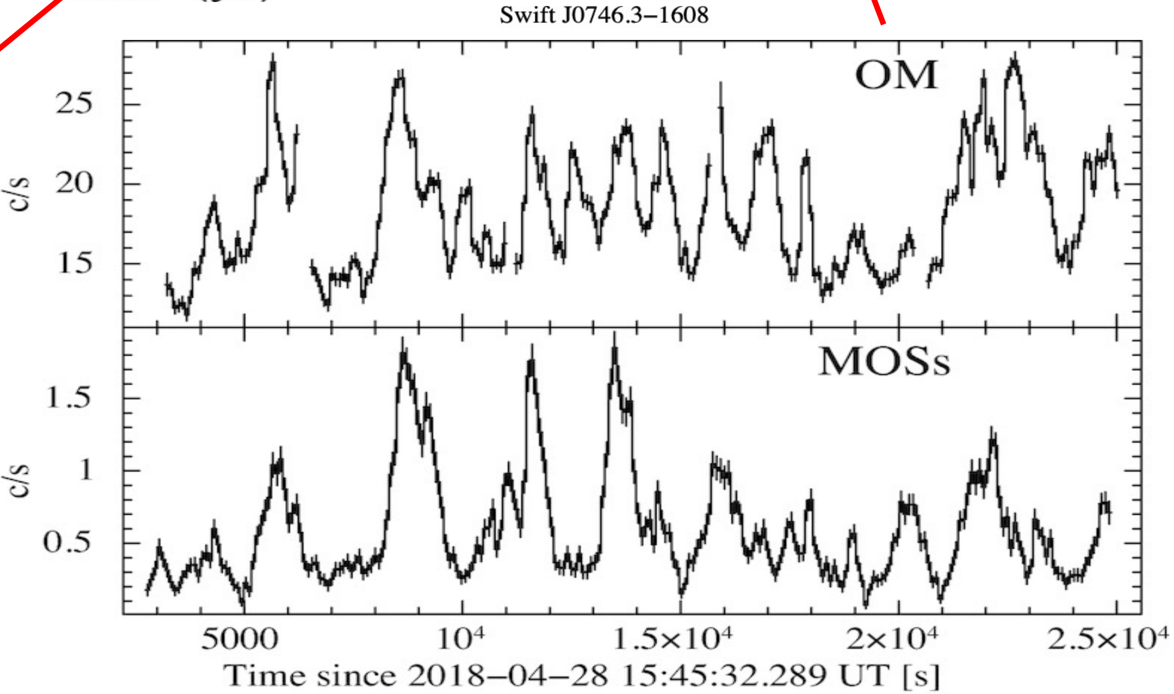
$P_\Omega = 9.38$ h
$P_\omega = 2300$ s



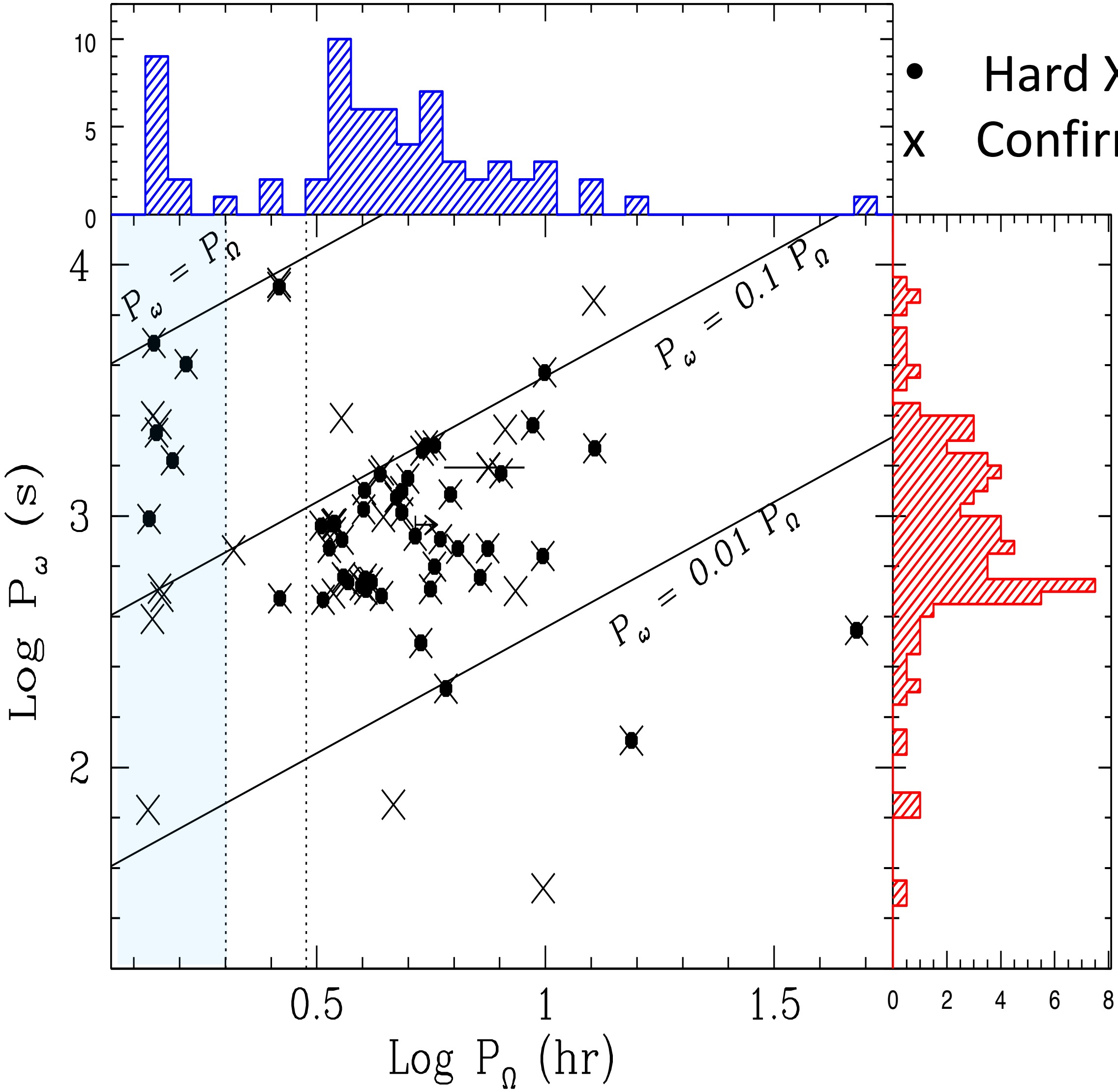

**Rare in IPs**

Bernardini et al. 2017, 2018



# The confirmed IP sample




- • Hard X-ray IPs : 56
- x Confirmed IPs : 74

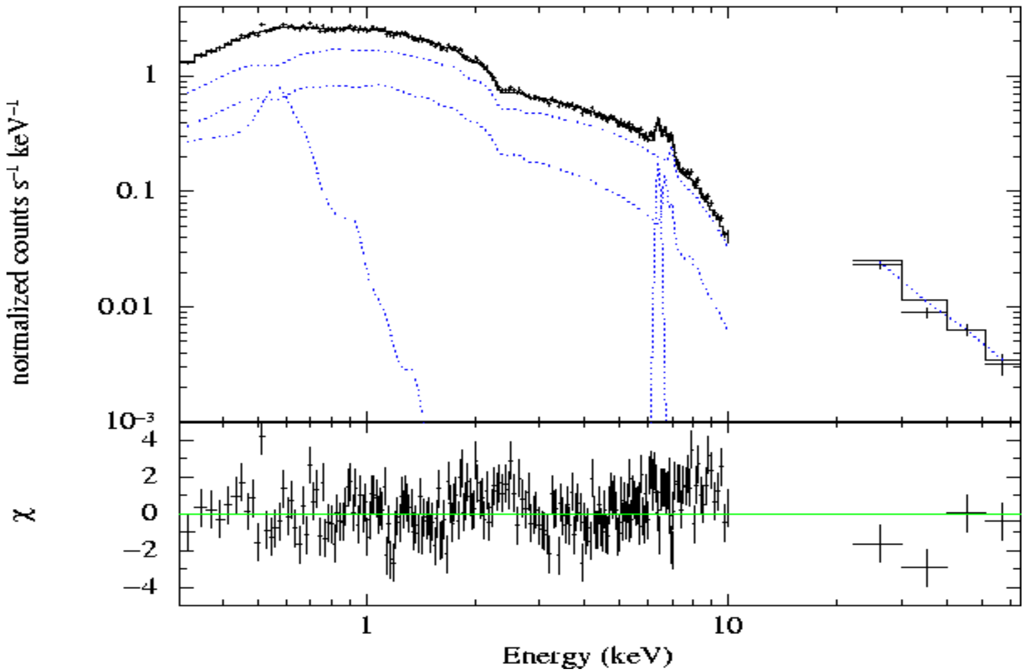
- $P_\omega$: few hundreds –few thousands sec
- Most at $P_\Omega > 3h$ - many (10%) at > 6h
- Clustering at $P_\omega/P_\Omega \approx 0.05$- 0.1
- ~ 14% below 2-3h gap (50% are hard)
- Weakly desynchronized at $P_\Omega <$ 2-3h should NOT exist!!
  or
  Low-B and old systems will never reach synchronism

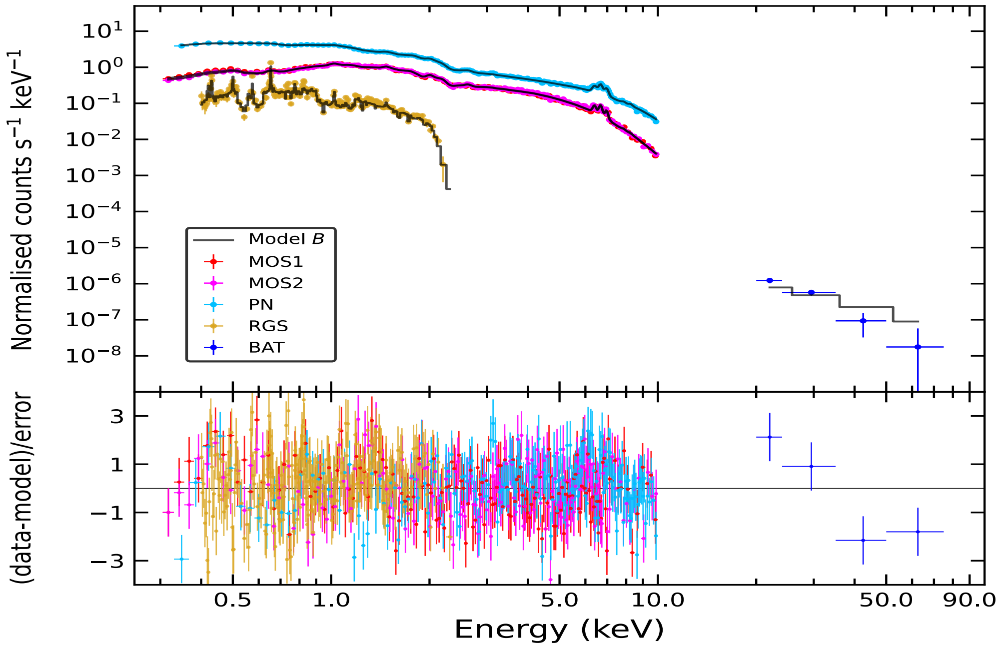
Updated from de Martino et al. 2020

# Broad-band Spectra: combining XMM-Newton + Swift/BAT or INTEGRAL/IBIS

Spectra are thermal and complex:

- Multi-T plasma : $T_{low} \approx 0.16$keV ...... $T_{high} \approx 30\text{-}50$ keV — Post-shock
- Cool absorbers : total ($N_H \sim 10^{20} - 10^{21}$ cm$^{-2}$ ) — Interstellar
  partial ($C_F \sim 40\text{-}60\%$; $N_H \sim 10^{22} - 10^{23}$ cm$^{-2}$ ) — Pre-shock
  additional partial ($C_F \sim 40\text{-}70\%$; $N_H \sim 10^{23}$ cm$^{-2}$ ) — Outer disc rim (Bulge)
- Fe Ka @ 6.4keV: EW ~ 100-250 eV — Reflection Pre-shock/WD



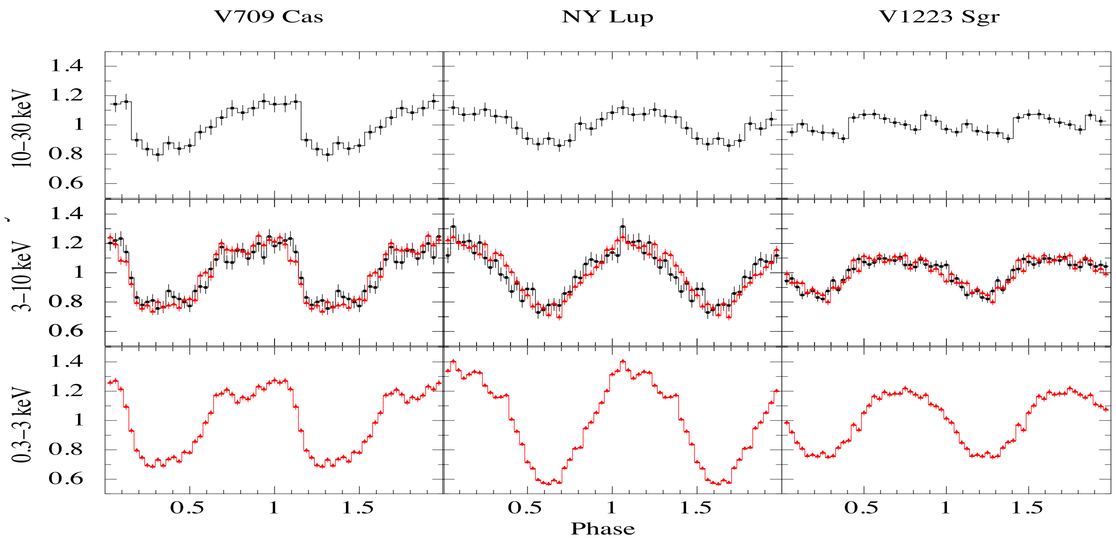



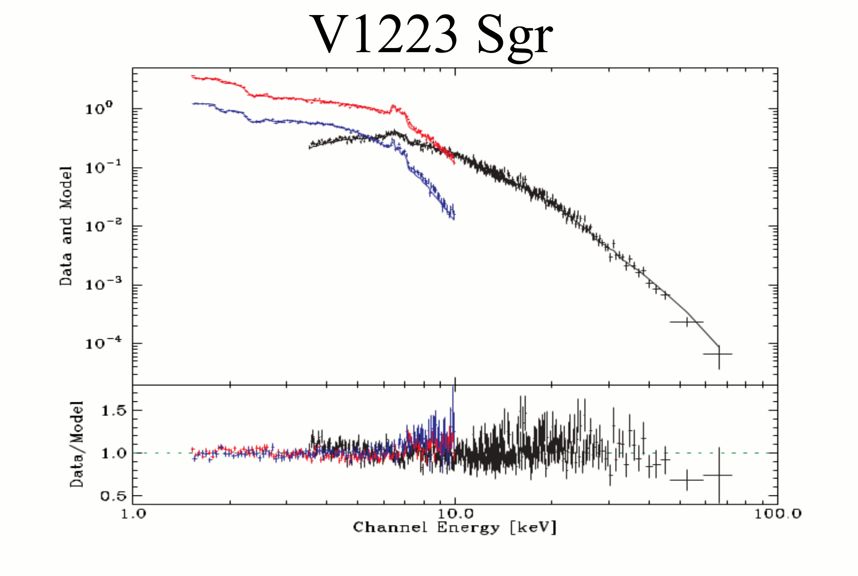

Bernardini+12; Rawat+24

# Evidence of reflection continuum

SWIFT/BAT & INTEGRAL/IBIS unable to disentangle

Joint XMM-Newton / NuSTAR observations of bright IPs




| | | | |
|---|---|---|---|
| Rel_ref | ~0.45 | ≥ 1.0 | ~ 0.7 |
| H_shock | ~ 0.2Rwd | < 0.05 Rwd | ~ 0.05 Rwd |
| EW(6.4keV)= | 105eV | = 132 eV | =90eV |

phabs∗pwab(reflect∗mkcflow+Gaussian)

Mukai et al. 2015; Shaw et al. 2020

- Large shock height -> low Reflection amplitude & strong hard X-ray modulation
- Small shock height -> large reflection amplitude & weak hard X-ray modulation

# Hard X-ray view of MCVs

IPs dominate hard X-ray detected CVs

**QUESTION**:
**Do hard IPs host massive WDs?**

From proper hard X-ray tail modeling masses can be inferred

$kT_{shock} = 3/8\ G\ M_{WD}/R_{WD}\ \mu\ m_H$

# Hard X-ray view of MCVs

## Using combined XMM-Newton + Swift/BAT or INTEGRAL/IBIS

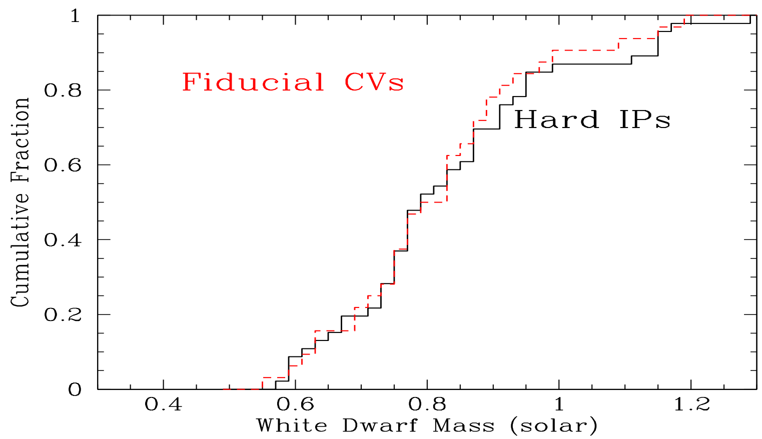
**Do hard IPs host massive WDs?**

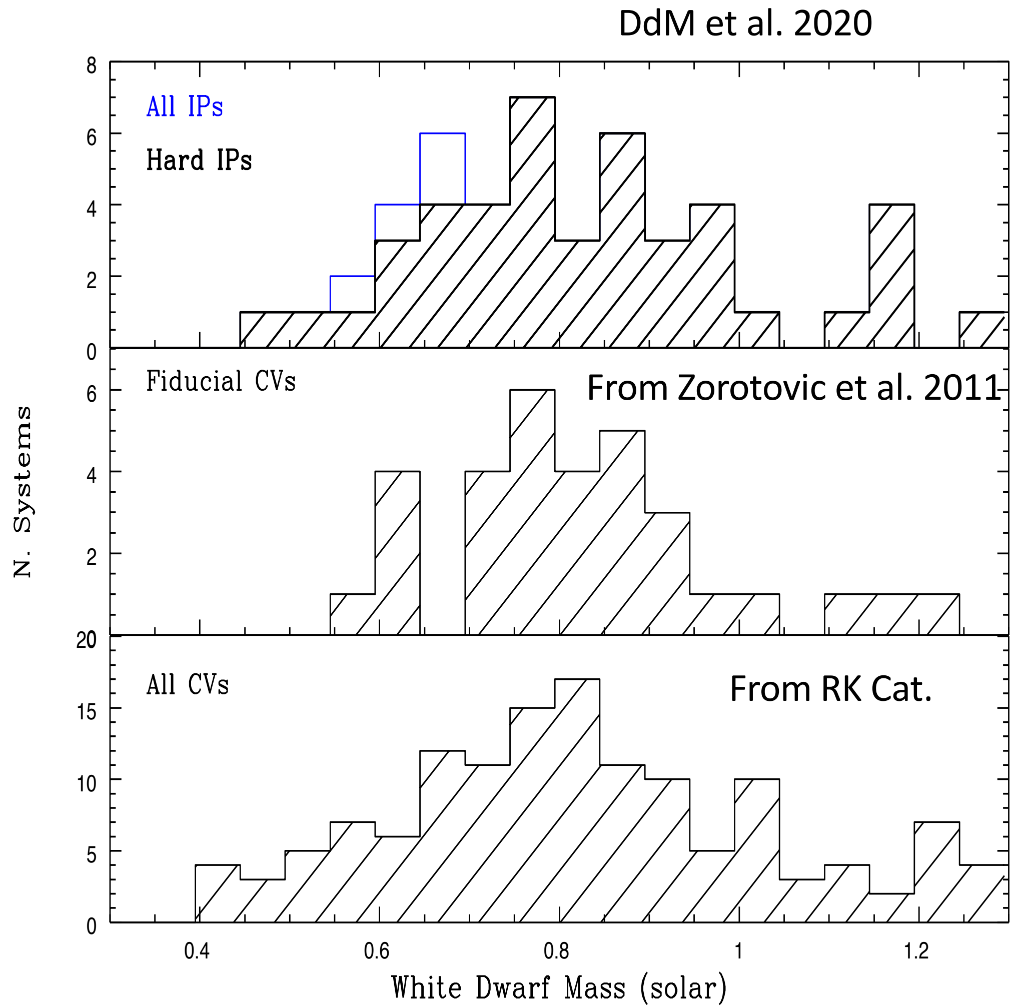
$$kT_{shock} = 3/8\ G\ M_{WD}/R_{WD}\ \mu\ m_H$$

$$\langle M_{IPs}\rangle = 0.84 \pm 0.17\ M_\odot$$

$$\langle M_{Fid}\rangle = 0.82 \pm 0.15\ M_\odot$$

$$\langle M_{CVs}\rangle = 0.83 \pm 0.23\ M_\odot$$

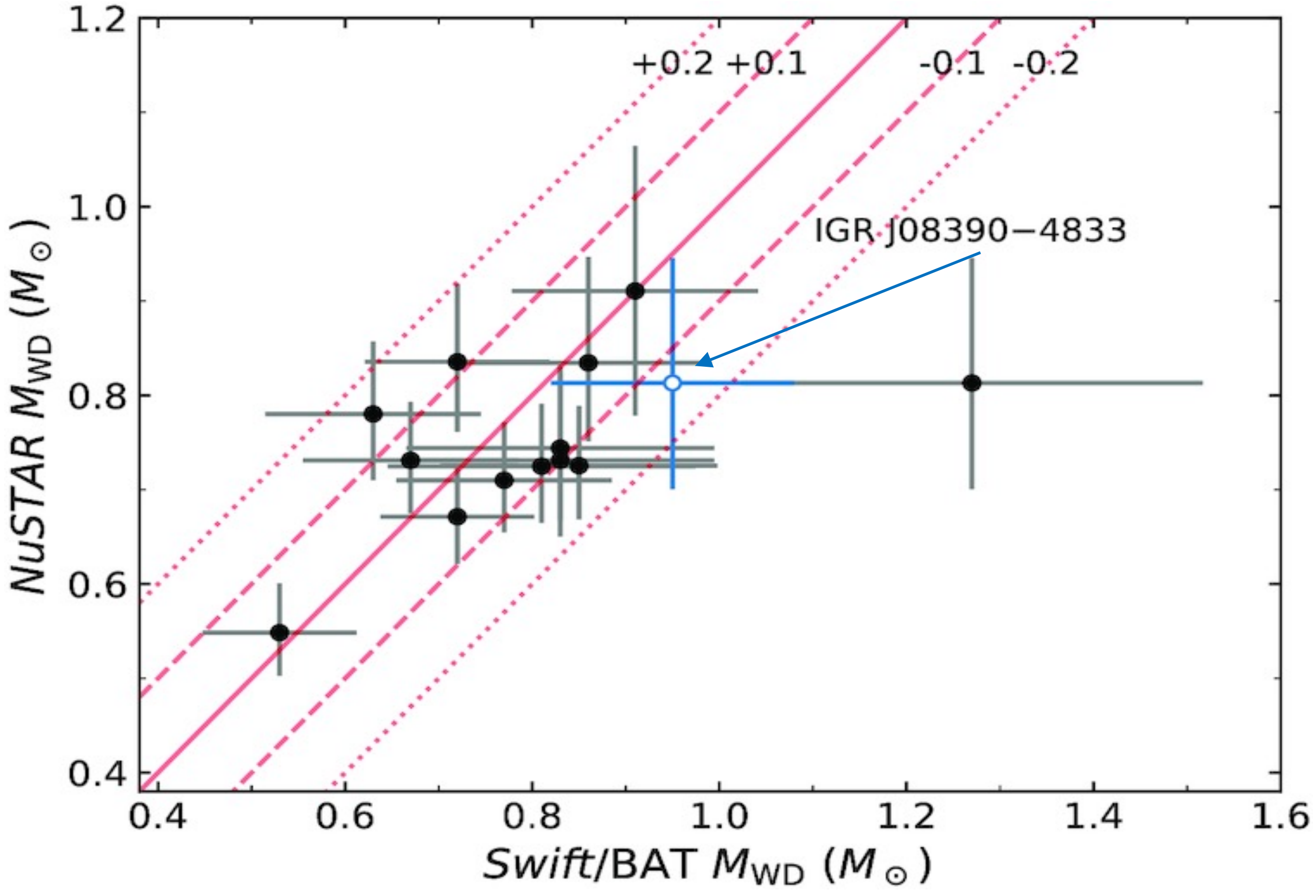



**WD IP masses not so different from non-magnetic WD CVs**

# Hard X-ray view of MCVs

NuSTAR sample confirms Swift/BAT results !



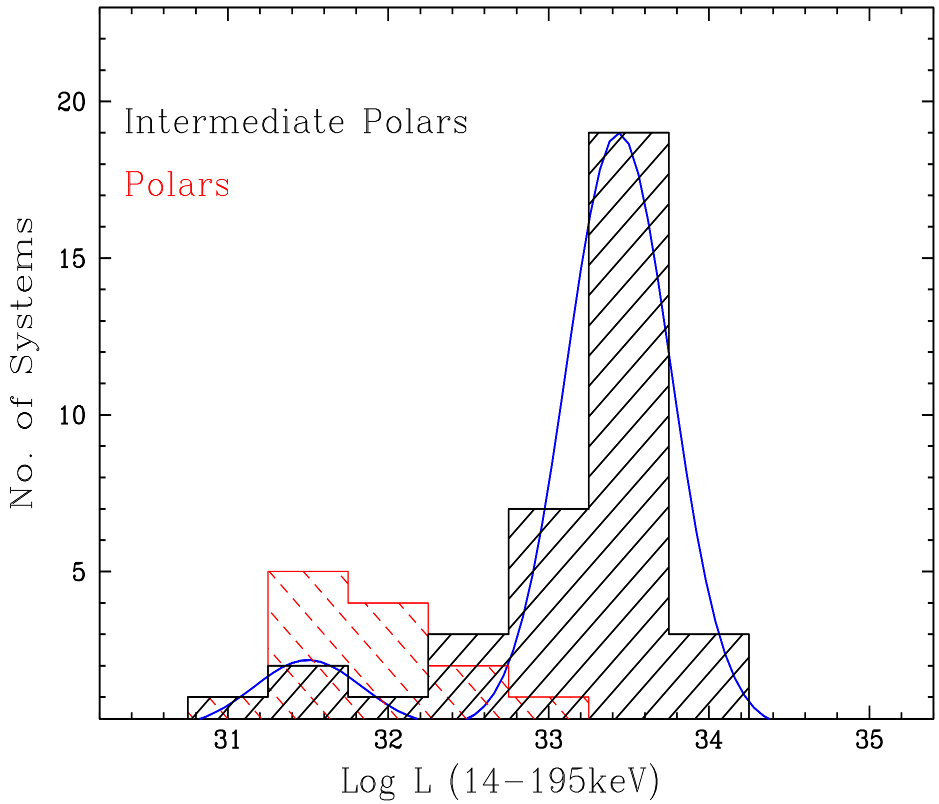

Shaw et al. 2020

$\langle M_{mCVs} \rangle = 0.77 \pm 0.10\ M_{\odot}$

# Hard X-ray Luminosities using Gaia

**Swift/BAT sample [14 – 195keV]**

Fx > 8 x $10^{-12}$ erg/cm$^2$/s




DdM et al. 2020

**37 IPs** @ d ≤ 1.8kpc (10% accuracy)

- <Lx> ~ 1.3 x $10^{33}$ erg/s
- 4 IPs at Lx ≤ 1 x$10^{32}$ erg/s
  with 3 below the 2-3h gap

**Bimodality ?**

Expected ~10 IPs at Lx< 1 x$10^{32}$ erg/s within 350pc (Pretorius&Mukai 2014)

**11 Polars @** d ≤ 500pc:

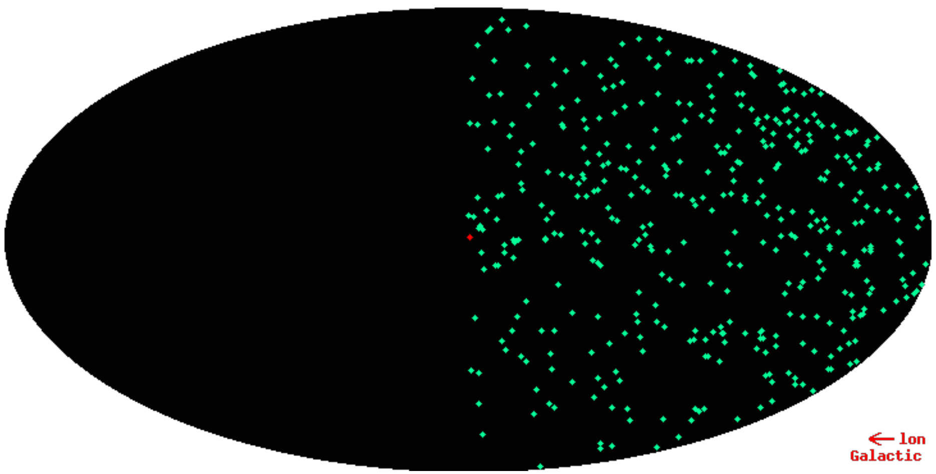
- <Lx> ~ 8 x $10^{31}$ erg/s

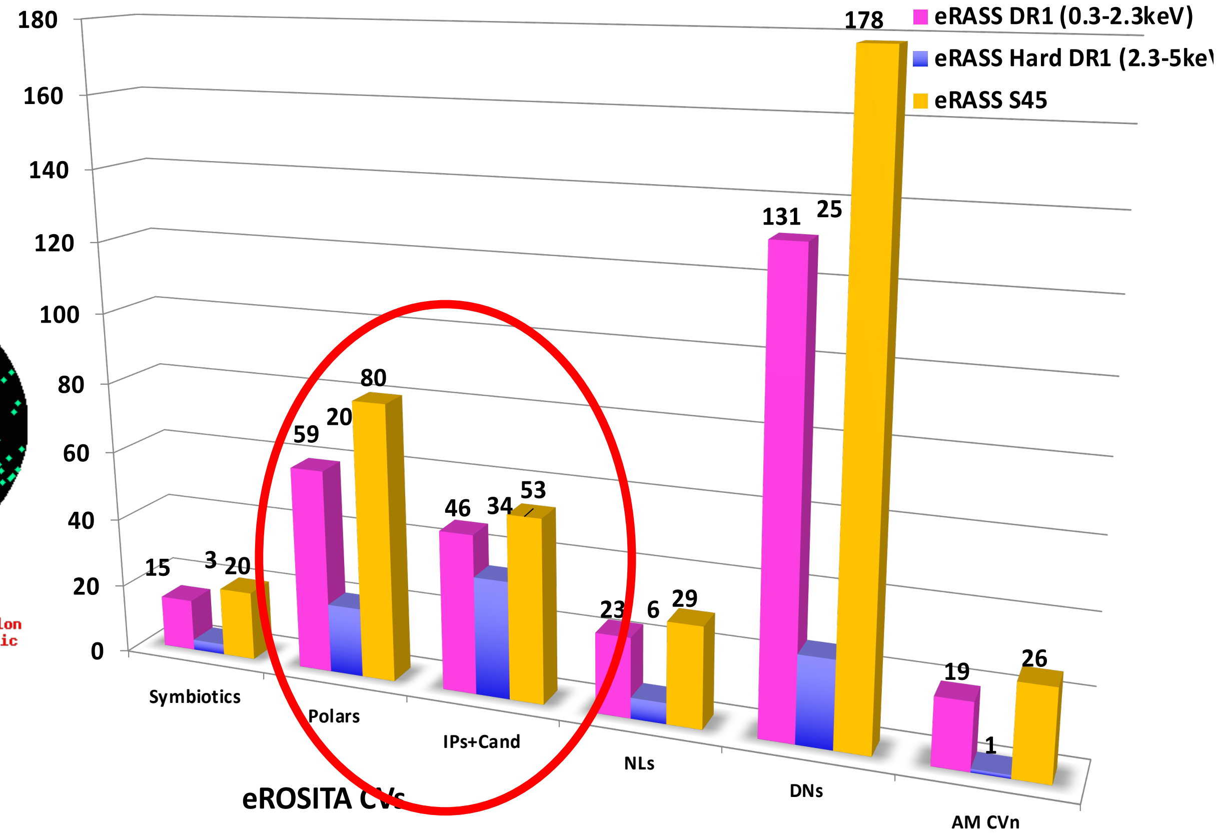
Need to push the limit to faint systems

# eROSITA CVs

**416 CVs detected in eRASS DR1 (0.2-2.3keV)**
**100 detected in eRASS DR1 hard (2.3-5keV)**

Magnetic CVs dominate in hard X-rays




Schwope et al. 2024

# Conclusions

- Hard X-ray CVs: mainly mCVs of IP type doubled thanks to INTEGRAL/SWIFT
- New IPs below gap doubled – most weakly desynchronised - not expected if similar B-fields as Polars
- New systems populate very long (>6h) Porb ≈10% of IP population .- evolved donors
- Faint X-ray sources to be discovered to verify bimodality in Lx
  → push new identifications to survey limits - eROSITA
- Hard X-ray mCVs:
  - WD mass is a key ingredient but not crucial
  - Hard moderate low B & high dm/dt – bremsstrahlung cooling dominate

This work could not have carried out  without the contribution of  our Colleague and Friend

Maurizio Falanga @ ISSI Bern-Bejing

we will miss him !

Thanks!