Hard X-ray Cataclysmic Variables

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CV sub-types

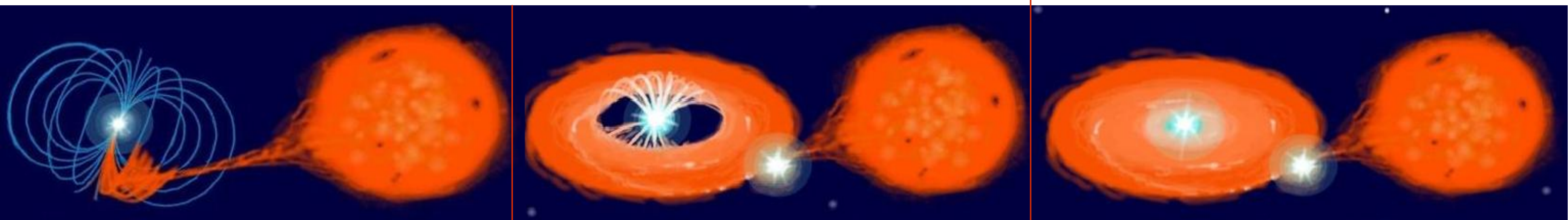
~ 1430 CVs known to date

Magnetic Cataclysmic Variables

~20 % of all CVs

Non MCVs

~80 % of all CVs



Polars	Intermediate Polars	Classical/Dwarf Novae

(Prototype AM Her) $B_{WD} \sim 1 - 230\text{x}10^6$ G

Synchronous Rotation

$P_{spin} = P_{orb}$ (hrs)

Asynchronous Rotation

P_{spin}(mins) $\ll P_{orb}$ (hrs)

P_{orb} (P) $< P_{orb}$ (IP)

~ 130 systems

Bright in soft X-rays

ROSAT era

~ 74 systems +30candidates

Bright in hard X-rays

INTEGRAL/SWIFT era

$B \ll 10^5$–10^6 G

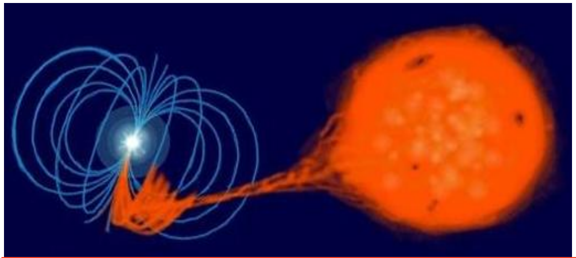
Energy Sources:

CN: nuclear burning

DN: through gravity

(For a review see B. Warner 1995)

Polars



Bright in soft X-rays

ROSAT era

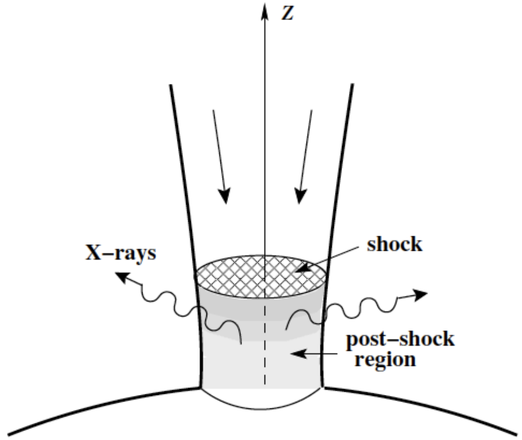
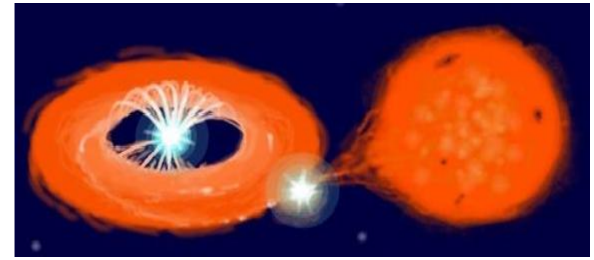


Fig. 1. A schematic view of the accretion flow onto the WD magnetic polar cap. The accreting gas falls quasi-radially towards the magnetic poles, forming a standing shock, below which the X-rays are emitted.

Intermediate Polars

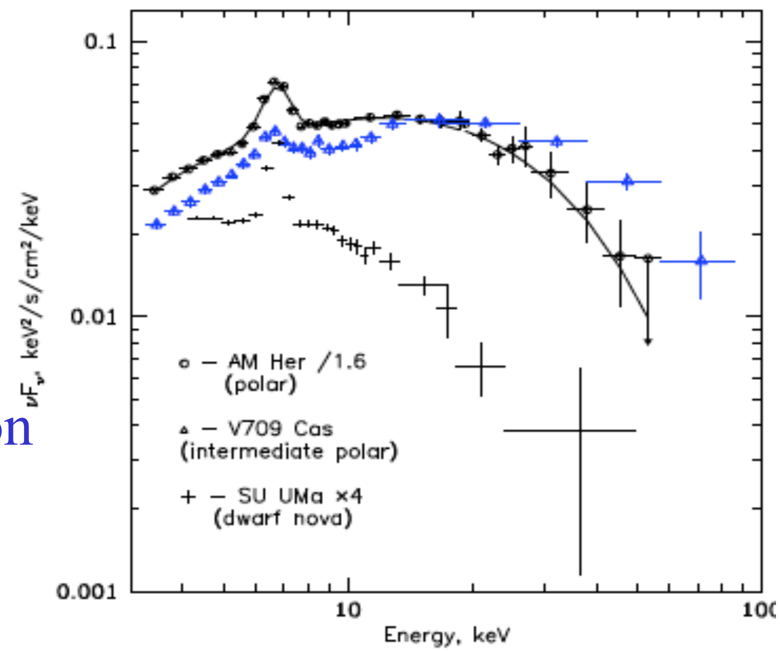


Bright in hard X-rays

INTEGRAL/SWIFT era

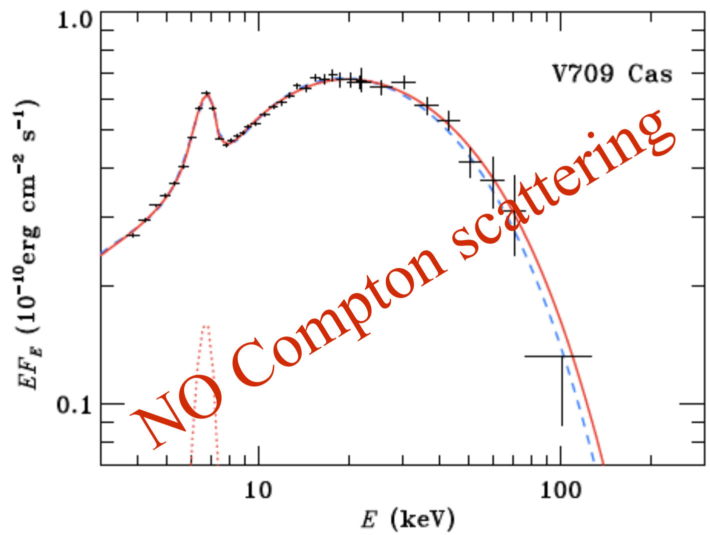
Bremsstrahlung

Cyclotron cooling supress the bremsstahlung high temperature emission



(Revnivtsev et al. 2008)

Multi temperature post-shock spectrum



(Suleimanov et al. 2008)

What Cooling mechanism?

Radiative losses by Cyclotron & Bremsstrahlung for B>1MG

Frad ≈ ρ^a Te ^{b}

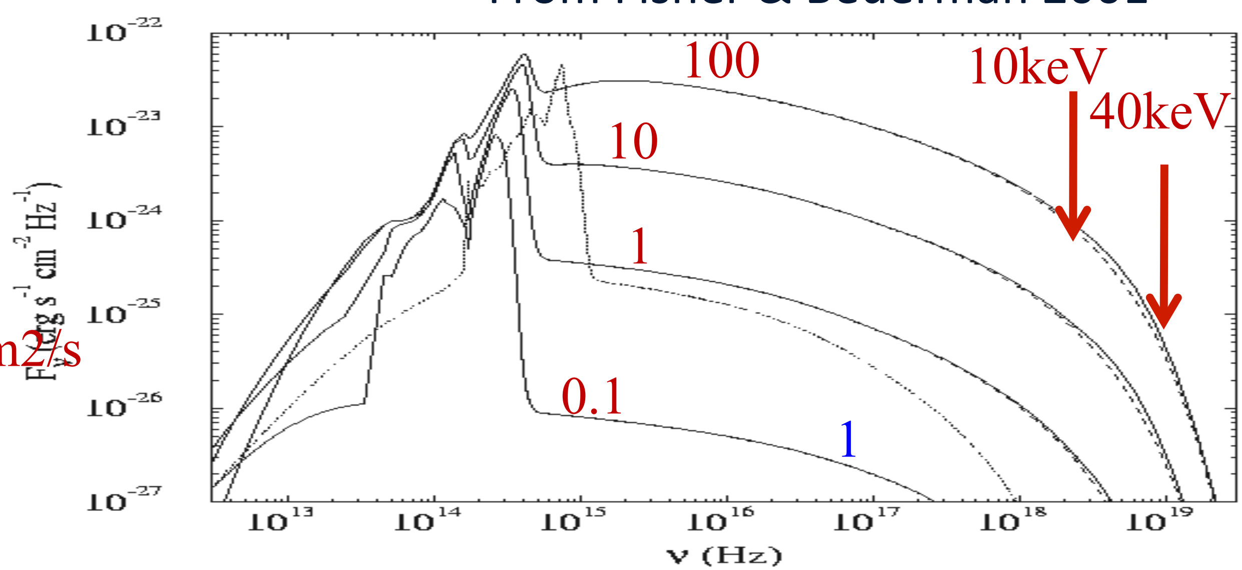
One-fluid plasma in low B and high flow rates
(Fisher & Beuermann 2001; Beuermann 2003)

Bremsstrahlung is primary & Cyclotron is secondary

Systems with moderately low field and high dm/dt can be hard X-ray sources

B=30 MG; dm/dt=100,10,1,0.1 g/cm2/s
B=100MG dm/dt=1 g/cm2/s

From Fisher & Beuerman 2001

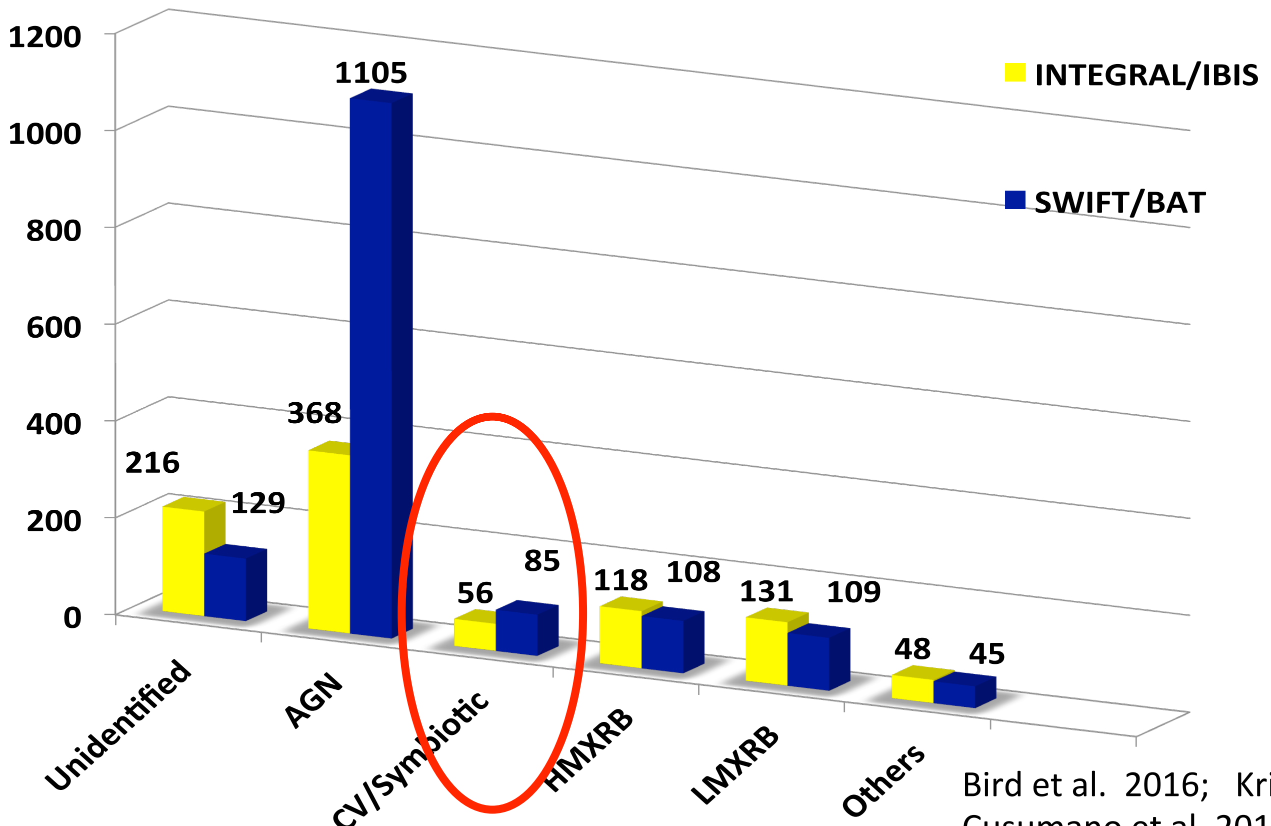


The model based on Cropper et al (1999)

- Mass continuity equation $$\rho v = a, \quad g / s / cm^2$$
- The momentum equation $$\frac{d}{dz}(\rho v^2 + P) = -\frac{GM_{wd}}{R_{wd}}\rho$$
- The energy equation $$v\frac{dP}{dz} + \gamma P\frac{dv}{dz} = -(\gamma - 1)\Lambda$$
- Ideal-gas law $$P = \frac{\rho kT}{\mu m_p}$$
- The cooling rate $$\Lambda = \left(\frac{\rho}{\mu m_p}\right)^2 \Lambda_N(T)$$
- The cooling function $\Lambda_N(T)$ from Sutherland & Dopita (1993)

The Hard X-ray Surveys

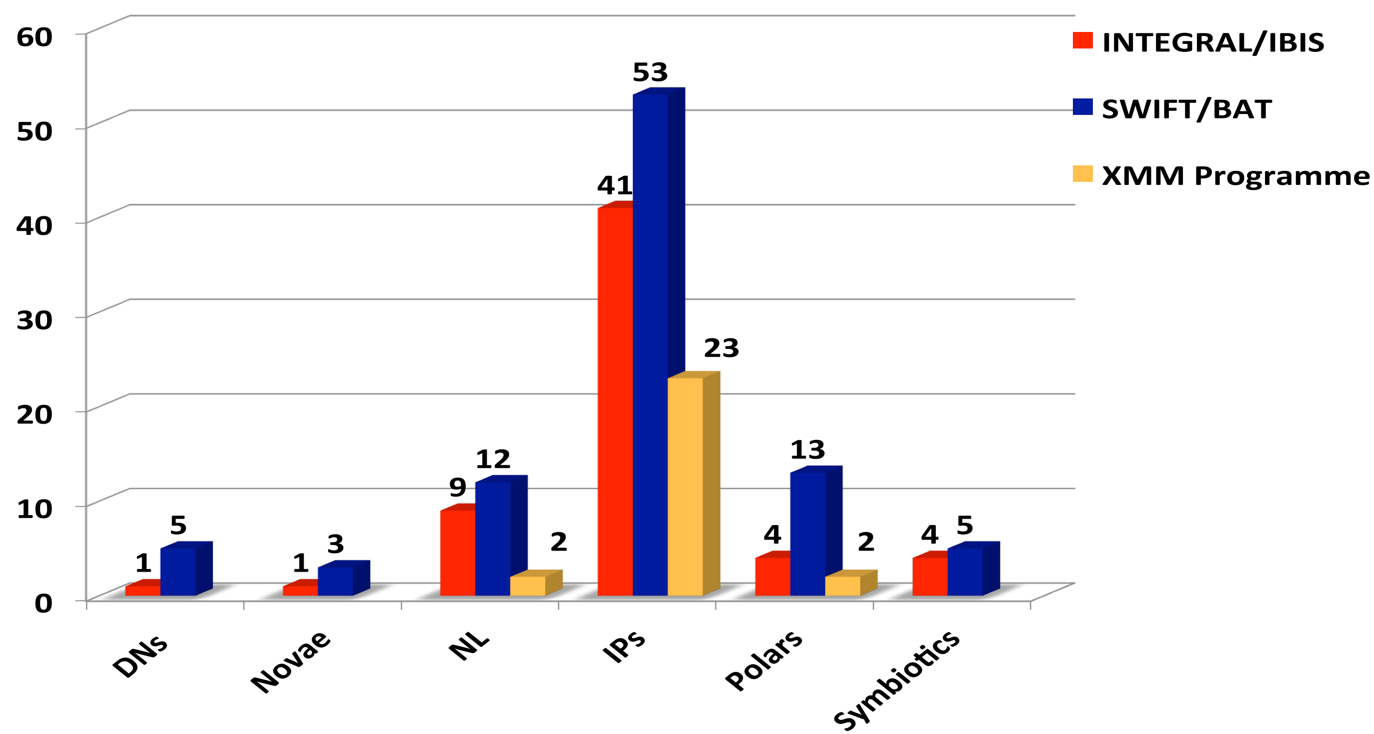
- INTEGRAL/IBIS and SWIFT/BAT changed our view of X-ray sky
- ~ 25 % of Galactic X-ray sources are CVs
- Efficient only for some CV types



Bird et al. 2016; Krivonos et al. 2012
Cusumano et al. 2014; Oh et al. 2018

What type of hard CVs

- Novalike CVs include magnetics – many disputed to be mCVs
- IPs doubled in number with INTEGRAL/SWIFT detections!
- Still unidentified hard X-ray mCV candidates from optical spectroscopy



Galactic faint X-ray source populations

- Galactic Center: Chandra 1Ms survey

(Muno et al.2004; Ruiter et al. 2006; Hong et al. 2012;2014):

- Thousands faint sources resolved:
- Hard Spectra: Power law $\Gamma < 1 - 1.5$ (or KT ~ 25keV) & Fe line (6.7keV) in a few
- Lx ~ 10^{30} - 10^{33} erg/s (1-8kpc)
- Variability: Periodic (≈ 1.3 – 3.4hr)

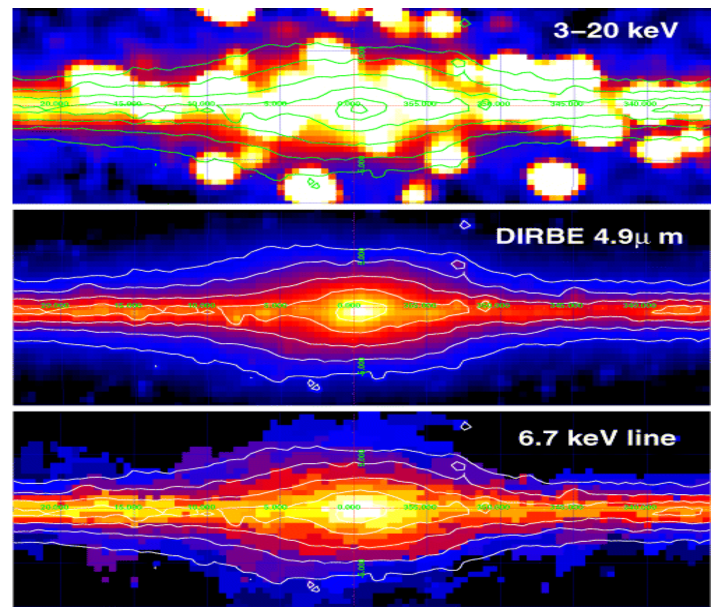
- Galactic Ridge X-ray Emission (GRXE):

RXTE, Chandra, INTEGRAL, Suzaku, NuSTAR, XMM-Newton

(Revnivtsev et al. 2006,2009; Sazonov 2006; Yuasa et al. 2012 Warwick et al. 2014; Perez et al 2015; Haley et al. 2016)

- ~80% of diffuse X-ray emission @ 6.7keV resolved in discrete sources
- Lx ~ $10^{32} - 10^{35}$ erg/s → CVs most magnetic
- Lx < 10^{32} erg/s → coronally active binaries, non-mCVs?

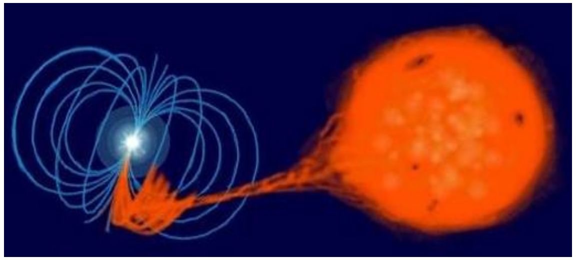
Revnivtsev et al. 2006



MCVs purported as dominant hard low-Lx population

Is there a relation between the two types ?

Polars



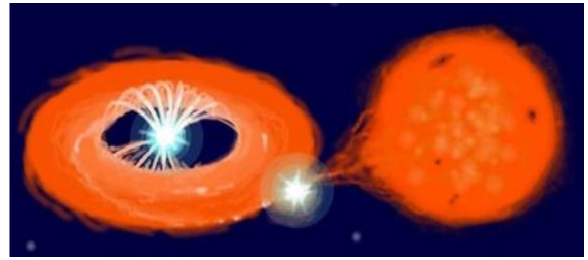
~ 130 systems

Bright in soft X-rays

Polarized in optical/nIR

ROSAT era

Intermediate Polars



~ 74 systems +30candidates

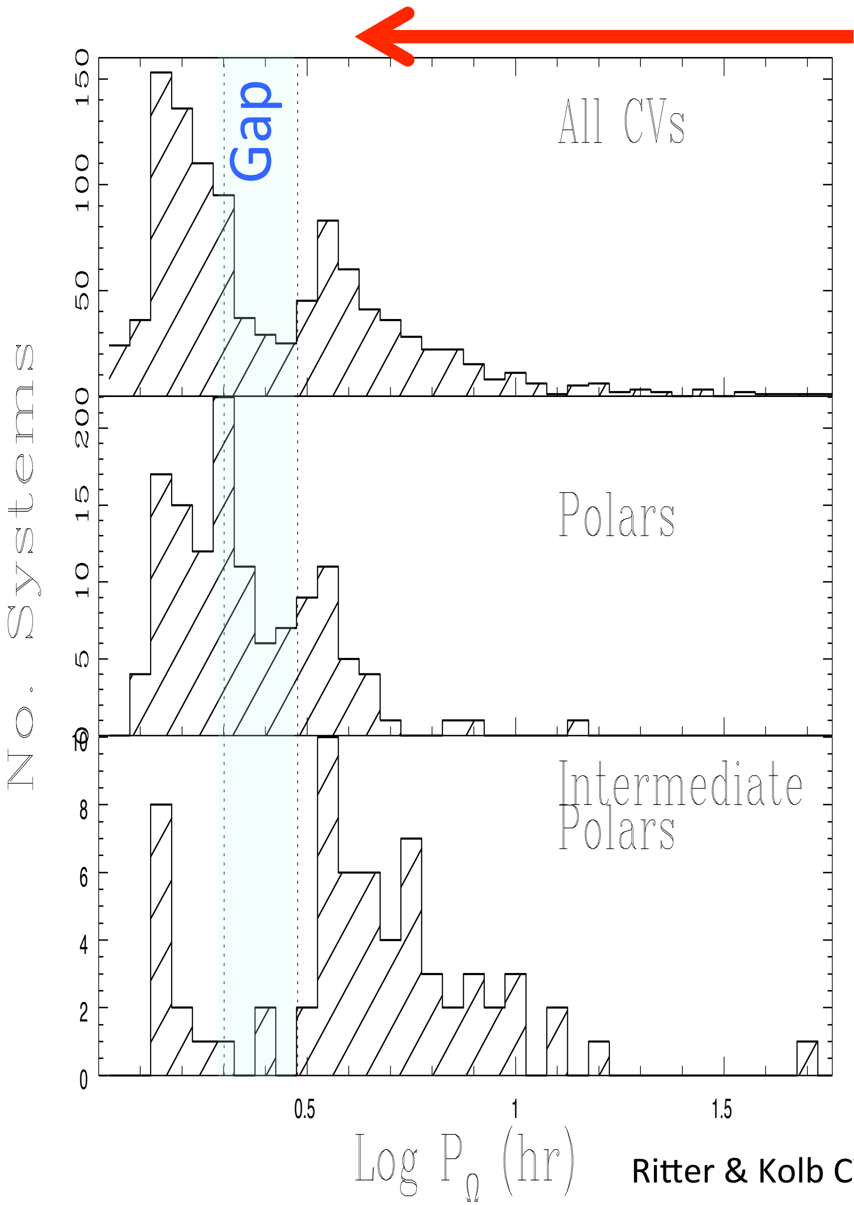
Bright in hard X-rays

Unpolarized or weakly polarized

INTEGRAL/SWIFT era

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

Orbital Period Distribution



Binaries evolve towards short Porb

Angular Momentum Losses via:

- Magnetic Braking above CV 2-3h "gap"
- Gravitational Radiation below "gap"

➢ Most IPs are above gap

➢ Most Polars are below gap

IPs may evolve into Polars if similar B-fields

Ritter & Kolb CV Cat. 7.24v

INTEGRAL/XMM-Newton Programme

29 CV Candidates: 23 IPs confirmed + 1 LMXB + 3 NL + 2Polars

- X-ray Power Spectra of mCVs :

- Accretion mode diagnostic : $\omega \approx \Omega \rightarrow$ Polars

$\omega \rightarrow$ Disc-fed IP

$\omega - \Omega \rightarrow$ Stream-fed IP

ω and ω-$\Omega \rightarrow$ Disc-overflow (Hybrid)

- 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, bulge at disc rim
- WD irradiation and WD mass

Hard X-ray view of MCVs

IPs dominate hard X-ray detected CVs

Using Anzolin+08,09, Brunschweiger09 Tomsick 16, Hayley+16; Suleimanov+16, Bernardini+12,+13,15,17; Shaw+18,Wada+18

Do hard IPs host massive WDs?

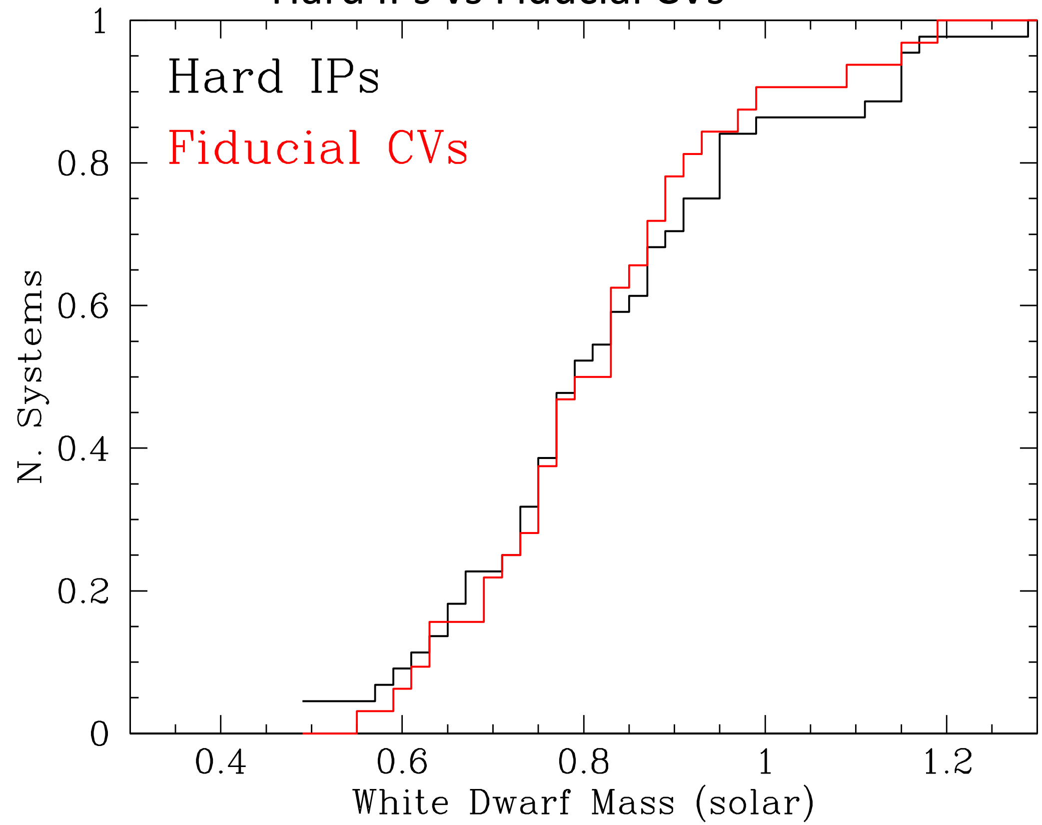
$kT_{shock} = 3/8\ G\ M_{WD}/R_{WD}\ \mu\ m_H$

$<M_{IPs}> = 0.83 \pm 0.19\ M_\odot$

$<M_{Fid}> = 0.82 \pm 0.15\ M_\odot$

$<M_{CVs}> = 0.82 \pm 0.24\ M_\odot$

Hard IPs vs Fiducial CVs

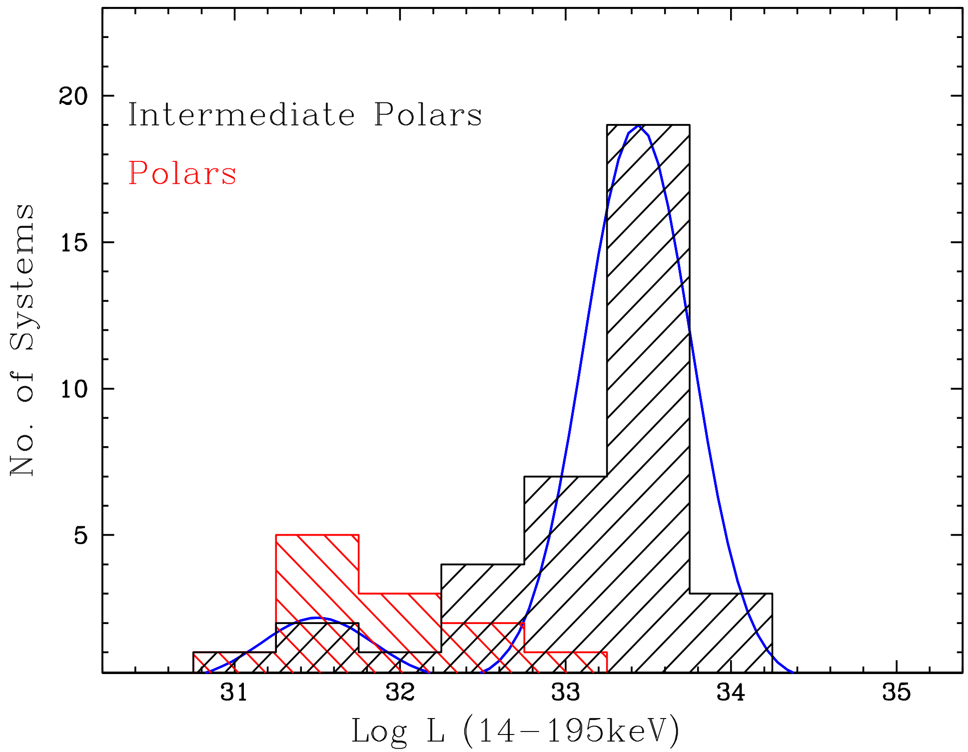


K-S test give probability of 98.1% that distributions are from the same parent population

Hard X-ray Luminosities using Gaia DR2

Hard X-ray sample [14 – 195keV]

$F_x > 7.3 \times 10^{-12}$ erg/cm^2/s



IPs:

- $\langle L_x \rangle \sim 1.3 \times 10^{33}$ erg/s up to $\sim$ 1.8kpc
- High Lx IPs at d > 300pc
- 4 IPs at $L_x < 1 \times 10^{32}$ erg/s within $\sim$ 200 pc with 3 below the 2-3h gap

Bimodality

Polars:

- $\langle L_x \rangle$ 8×10^{31} erg/s up to $\sim$ 520 pc
- Low Lx: Polars, short Porb IPs

(see Reis et al. 2013; Pretorius& Mukai 2014)

What we still need:

Near Future:

- ➢ Census of hard X-ray CVs : population study - space density
  - Ongoing XMM-Newton identification programme
  - Searches of new systems in 3XMM (Extras project funded by EU)
- ➢ Polarimetric surveys of mCVs

Bit Far Future:

- ➢ iXPE to probe accretion geometry through X-ray polarization
- ➢ Theseus will allow monitor of large sample of CVs over a broad range
- ➢ e-ROSITA will find thousands of hard X-ray CVs : follow-ups
- ➢ eXTP will study faint mCVs over a broad-band range
- ➢ ATHENA will trace post-shock plasma (Oxygen, Fe, Si, Mg, S) ;
  warm and cool absorbers;
  WD mass via Grav. Redshift of 6.4keV fluorescent line