Hard X-ray Cataclysmic Variables

Domitilla de Martino

INAF Capodimonte Observatory Naples

Co-Is:
F. Bernardini, M. Falanga, J.M. Bonnet-Bidaud,N. Masetti, M. Mouchet K. Mukai

“The X-ray Universe 2014” – June 17, 2014

Outline

- Introduction:
  - CV types, magnetic fields and evolutionary links
  - Hard X-ray surveys: role in Galactic X-ray Source populations?
  - Emission and accretion properties

- X-ray follow-ups:
  - New members with XMM-Newton
  - Temporal and spectral properties

- Conclusions and future perspectives
  - What do we still need ?

CV sub-types

~ 1166 CVs known to date

Non-Magnetic CVs

Dwarf novae & Novalike

~80 % of all CVs

$B_{WD} << 10^5 – 10^6$ G

Magnetic CVs

Intermediate Polars & Polars

~20 % of all CVs

B_{WD} ~ 1 -> 230MG

Isolated Magnetic WDs

~10 % of all WDs

B_{WD} ~ 3kG -> 1000MG

High incidence of magnetism

Magnetic Cataclysmic Variables

Polars

Porb ≅ Prot (hrs)

B_{WD} > 10 MG

Polarized in optical/nIR

Intermediate Polars (IPs)

Prot (mins) < Porb (hrs)

B_{WD} < 10MG (?)

Unpolarized or weakly polarized

Bright in soft X-rays

(ROSAT era)

~ 100 system

Bright in hard X-rays

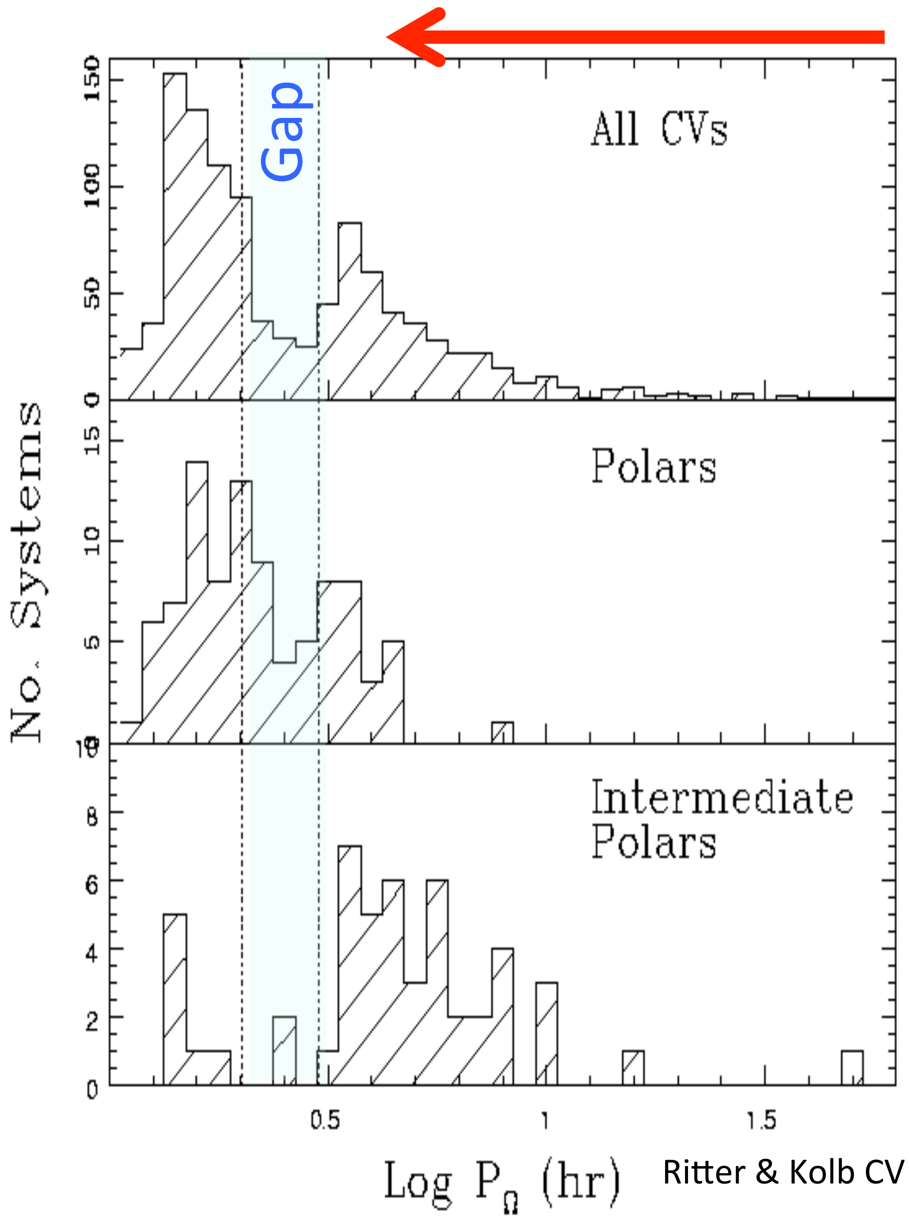
(INTEGRAL/SWIFT era)

~ 50 systems

Is there a relation between two types ?

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

Orbital Period Distribution



Ritter & Kolb CV Cat. 7.20v 2013

Binaries evolve towards short Porb

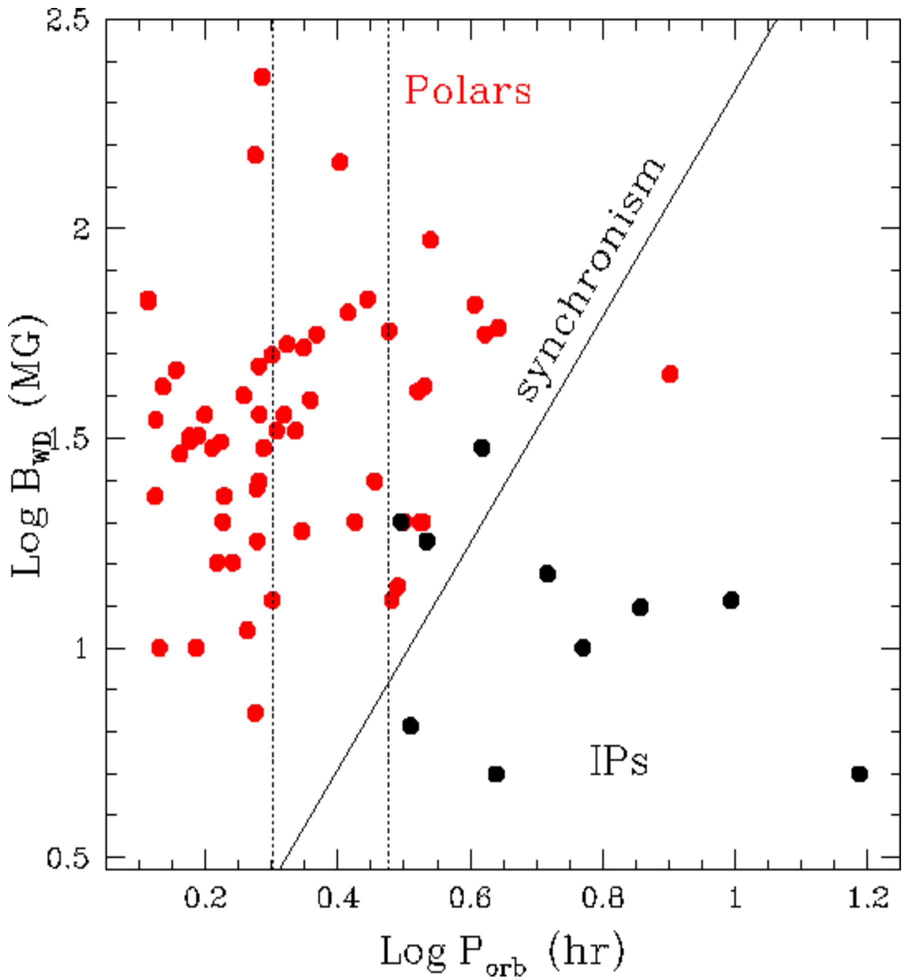
Angular Momentum Losses via:

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

- Most IPs are above gap
- Most Polars are below gap

IPs may evolve into Polars if similar B-fields

Orbital Period vs B-field



Adapted from Beuermann 1999

Synchronism

when torque of magnetostatic interaction of μ_{WD} and μ_{Sec} balances accretion:

$$G_{sync} = G_{accret}$$

$$\mu_{WD}\, \mu_{Sec} / a^3 \approx (dM/dt)\, R_{lobe,WD}^{\;2} / Porb$$

$$B \cong 8.2\, (dM/dt_{-10})^{1/2}\, (Porb/4h)^{7/6}\ MG$$

Polarised IPs may represent the progenitors of low-B Polars

Galactic faint X-ray source populations

- Galactic Center: Chandra 1Ms survey (Muno et al.2004; Ruiter et al. 2006; Hong et al. 2012):

  - Thousands faint sources resolved:
  - Hard Spectra: Power law Γ < 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):

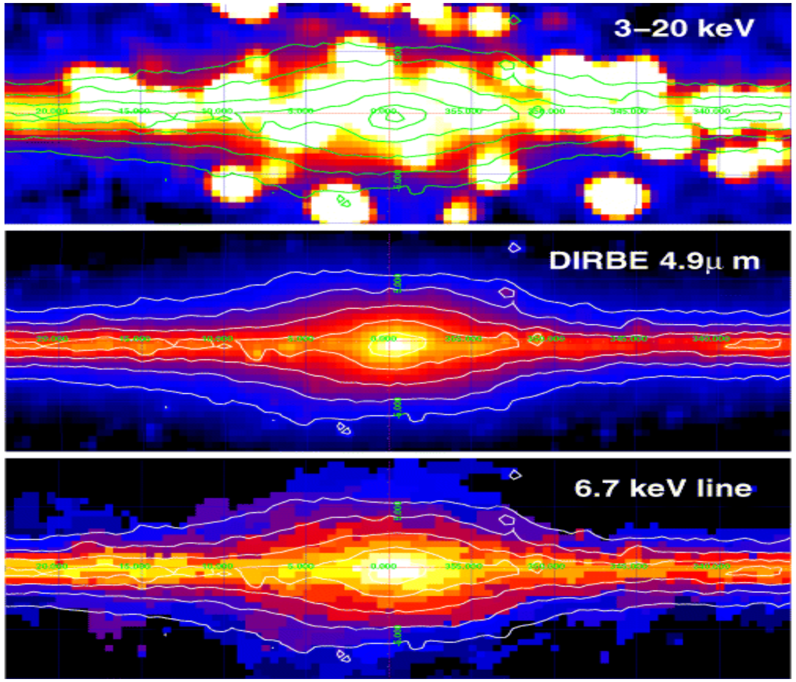
RXTE, Chandra, INTEGRAL, Suzaku surveys

(Revnivtsev et al. 2006,2009; Sazonov 2006; Yuasa et al. 2012 Warwick et al. 2014)

- ~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

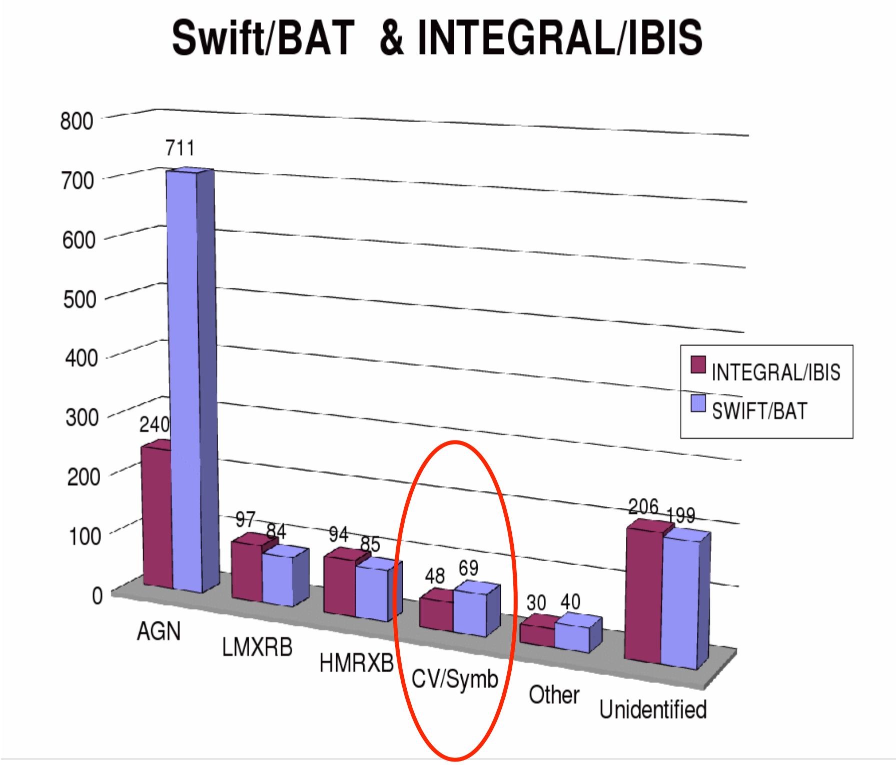
MCVs purported as dominant hard low-Lx population

Revnivtsev et al. 2006

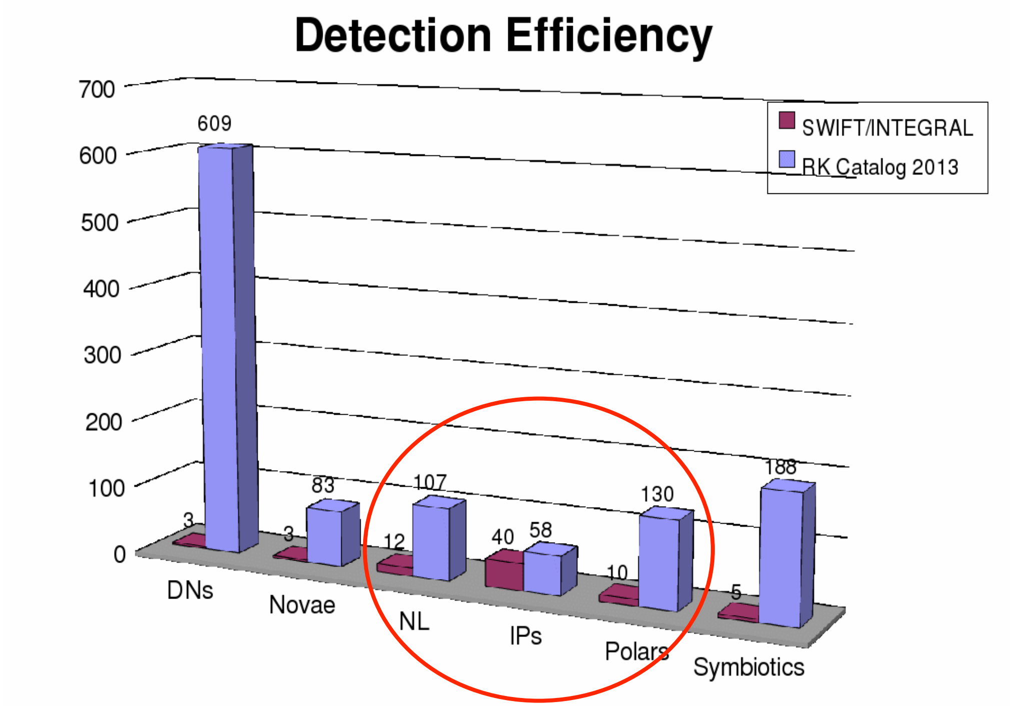


The Hard X-ray Surveys

- INTEGRAL/IBIS and SWIFT/BAT changed our view of X-ray sky
- 20% of Galactic X-ray sources are CVs
- Efficient only for some CV types



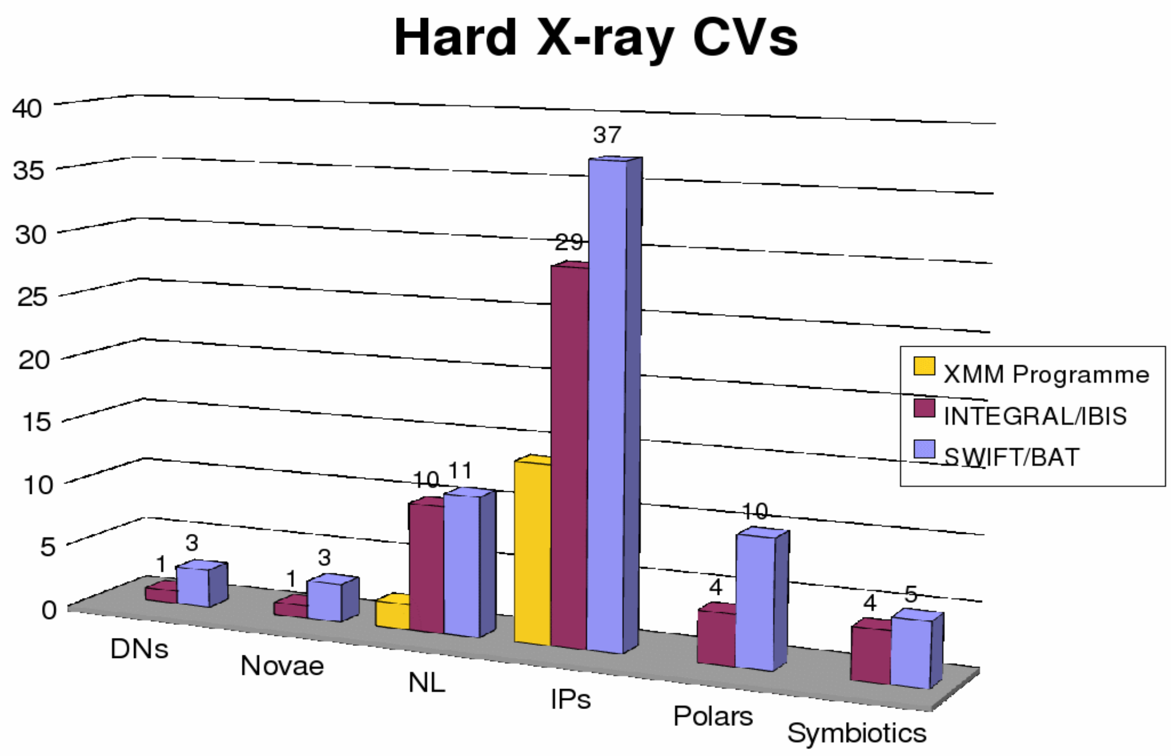
Bird et al. 2010; Krivonos et al. 12
Cusumano et al. 2010; Baumgartner et al. 2013

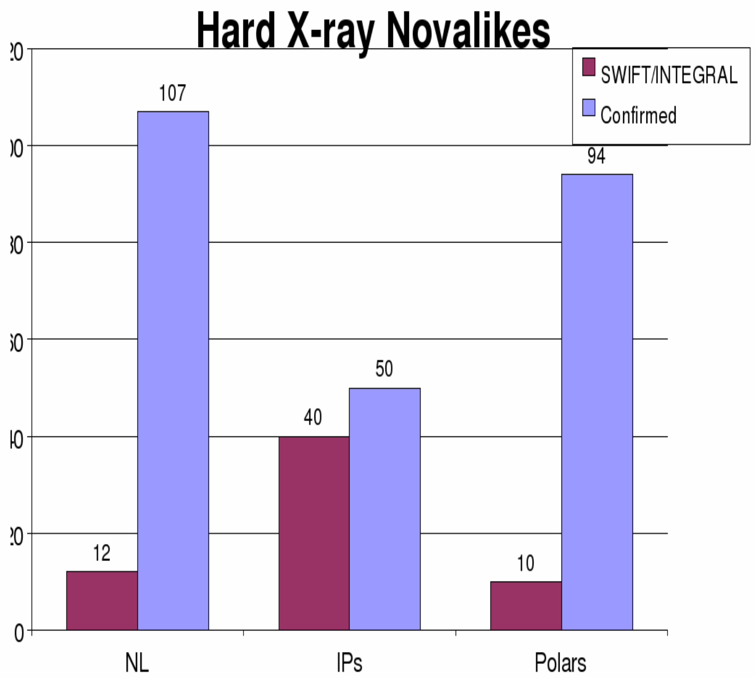


Ritter & Kolb Cat. 7.20v 2013

What type of hard CVs

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





XMM-Newton Programme

23 CV Candidates: 19 IPs confirmed + 1 LMXB + 2 NL + 1Polar

X-ray Power Spectra of IPs :

- Accretion mode diagnostic : ω → Disc
  - $\omega - \Omega$ → Direct (no disc) accretion
  - ω and ω-Ω → Disc overflow (Hybrid)

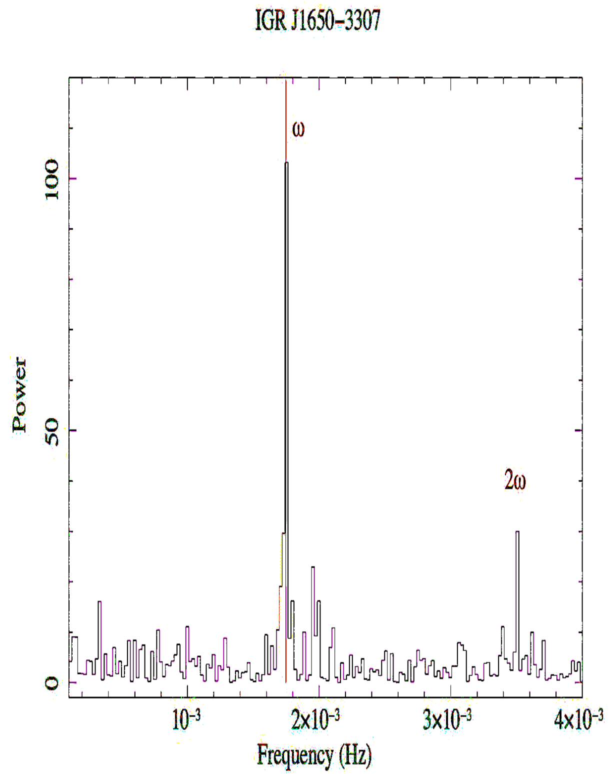
Energy dependent X-Ray/UV/Optical pulses:

- Geometry and B-field complexity
- Sites of Primary & Reprocessed radiation
- Absorption effects

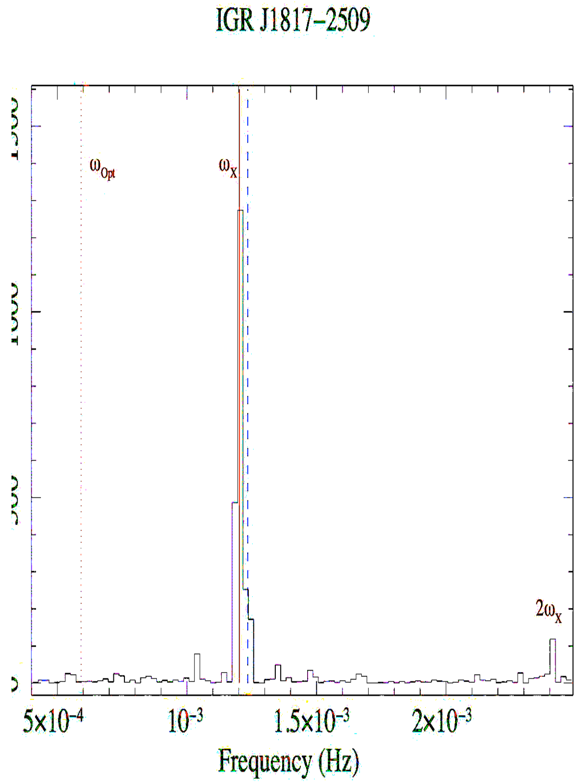
X-Ray spectra:

- Accretion region: Pre-Shock, Post-Shock
- WD irradiation and WD mass

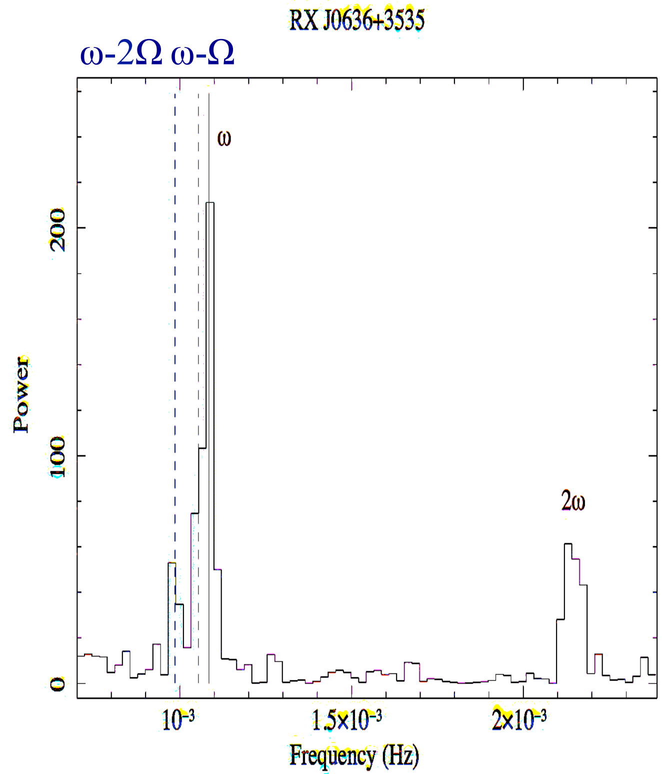
A few examples of X-ray Periodicities



Main and secondary pole



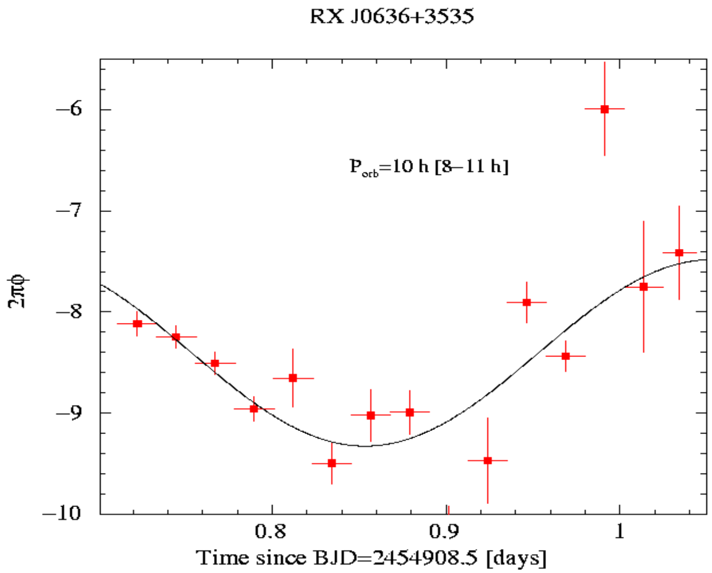
Two equal poles

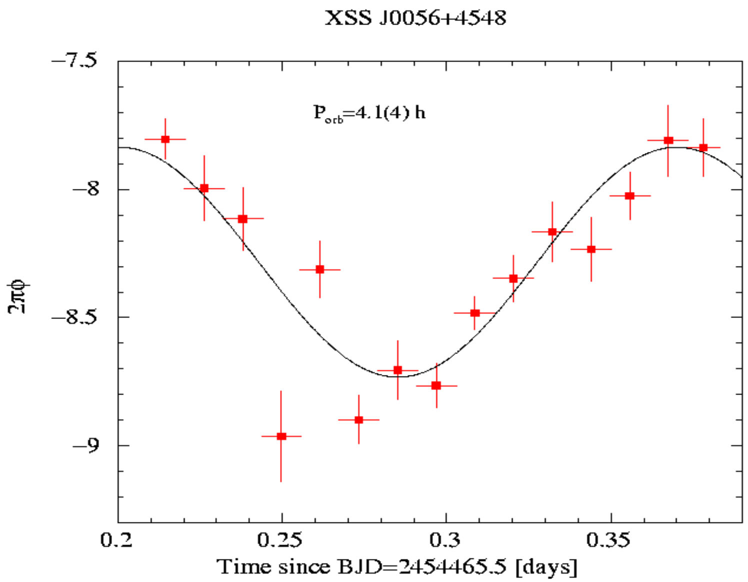


Two poles hybrid

(Bernardini et al. 2012)

A few examples: Orbital period search





Orbital dependence of pulse phases

↓

Porb can be estimated

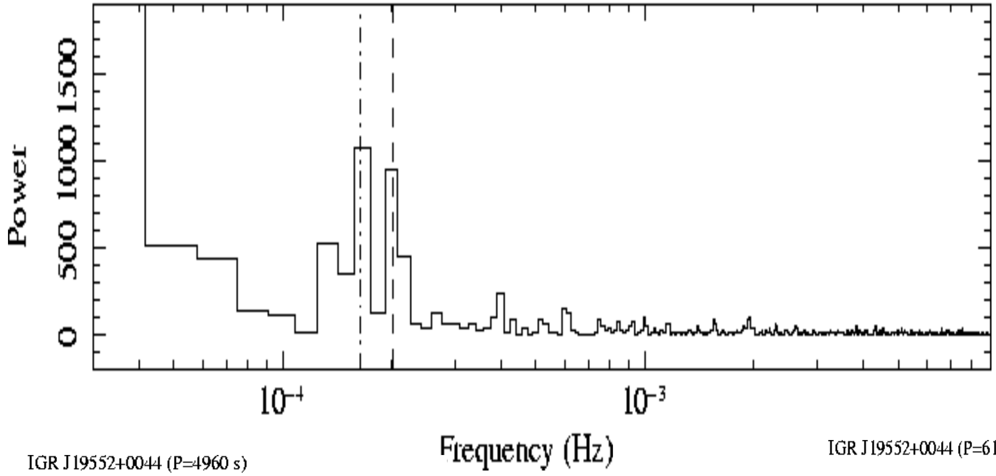
Bernardini et al. 2012

A “Paloma analogue” below the gap

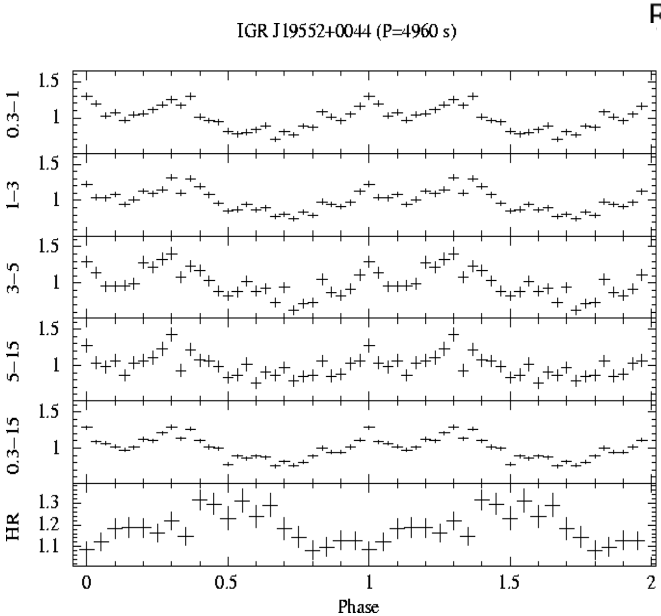
Porb =1.69hr   Pspin=4960sec

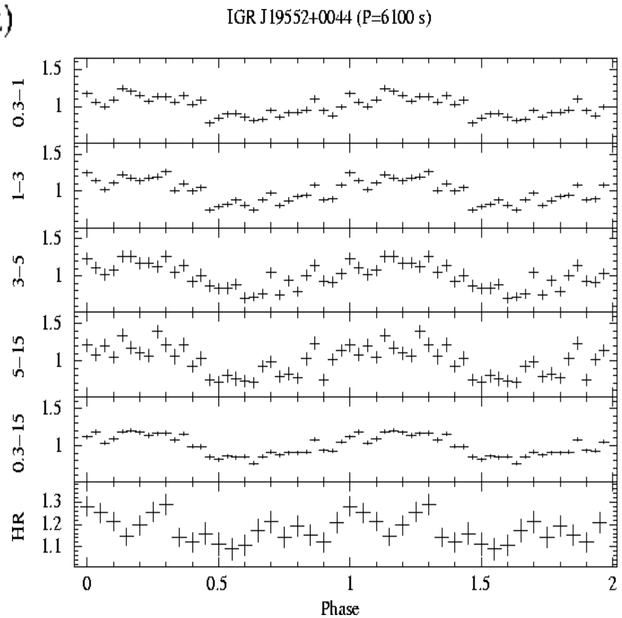
Porb/Pspin ~ 0.8

IGR J19552+0044

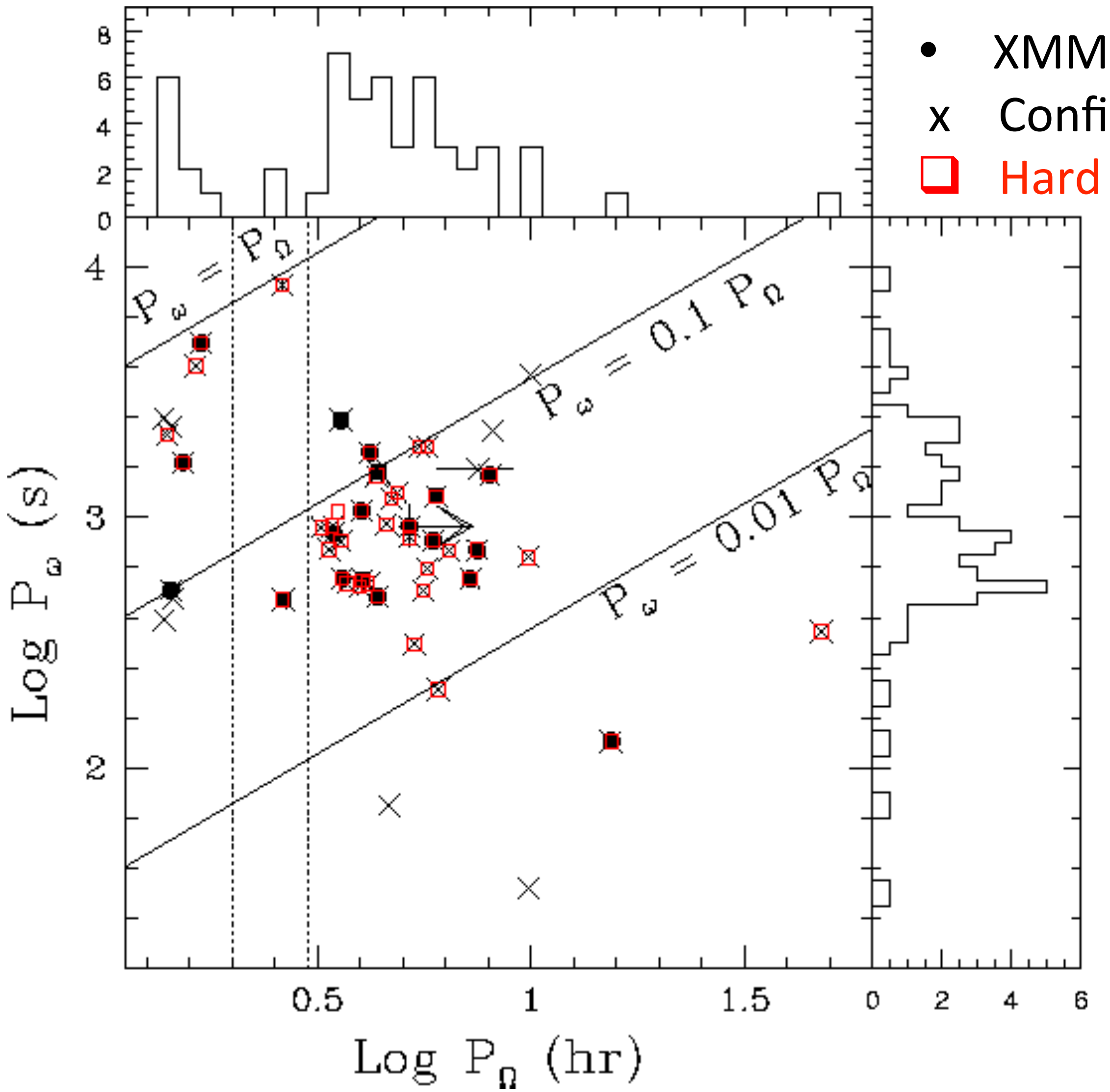


Bernardini et al. 2013





The confirmed IP sample

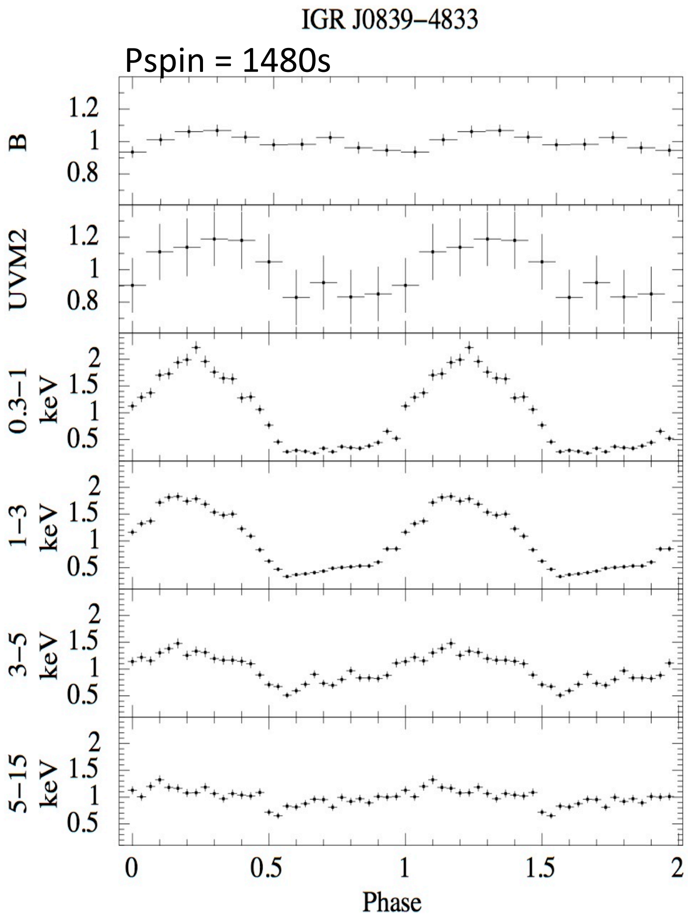


Update of Bernardini et al. 2012, 2013

- XMM programme
- x Confirmed IPs
- ❑ Hard X-ray IPs

- P_ω: hundreds – thousands sec
- Most at P_Ω > 3hr
- Clustering at $P_\omega/P_\Omega \approx 0.05$- 0.1
- Weakly desynchronized at P_Ω < 2-3hr
- 41/50 detected by INTEGRAL/SWIFT
- 4/9 below gap are hard and weakly desynchronised

Energy dependent pulses



Bernardini et al. 2012

➢ Energy dependent Spin pulses:

- Amplitude decreases with energy
→ Photoelectric absorption from cool material

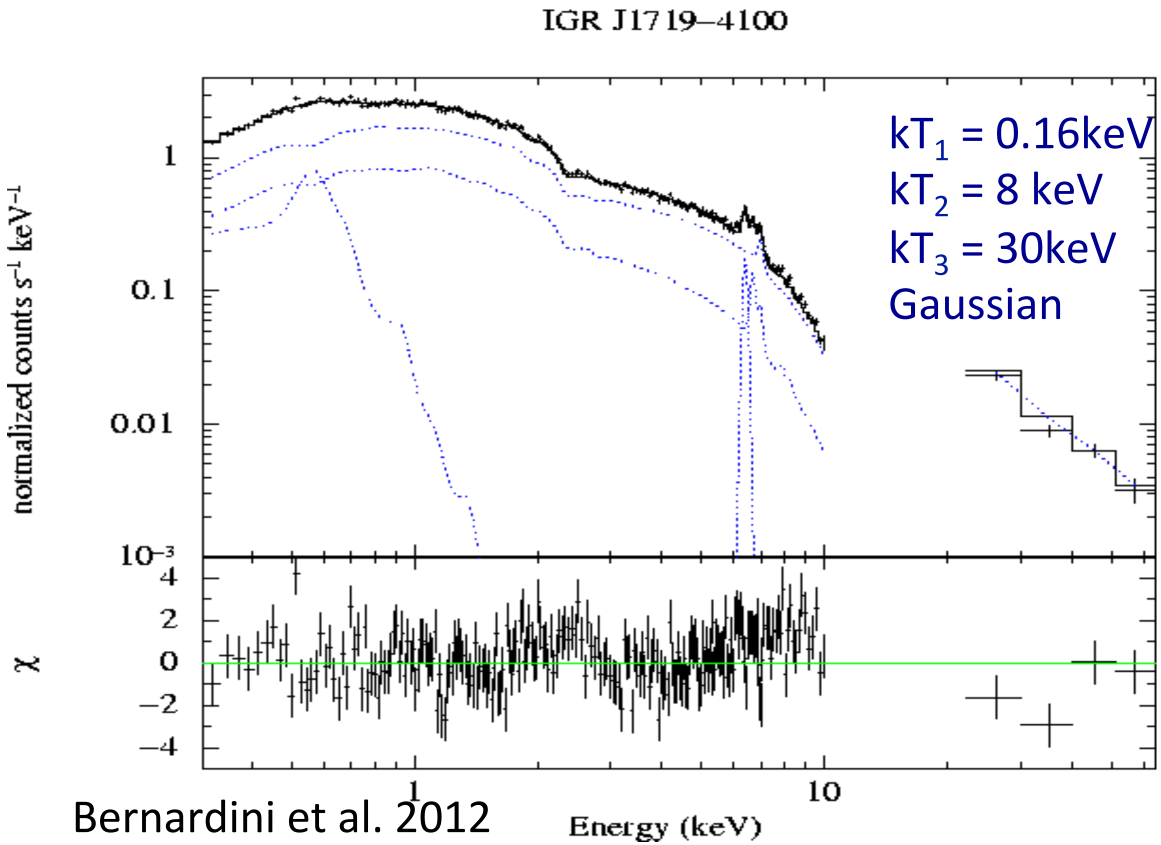
- Shapes change with energy
→ Additional emission components

→ Multi-component spectra

Broad-band Spectra

Spectra are thermal and complex:

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



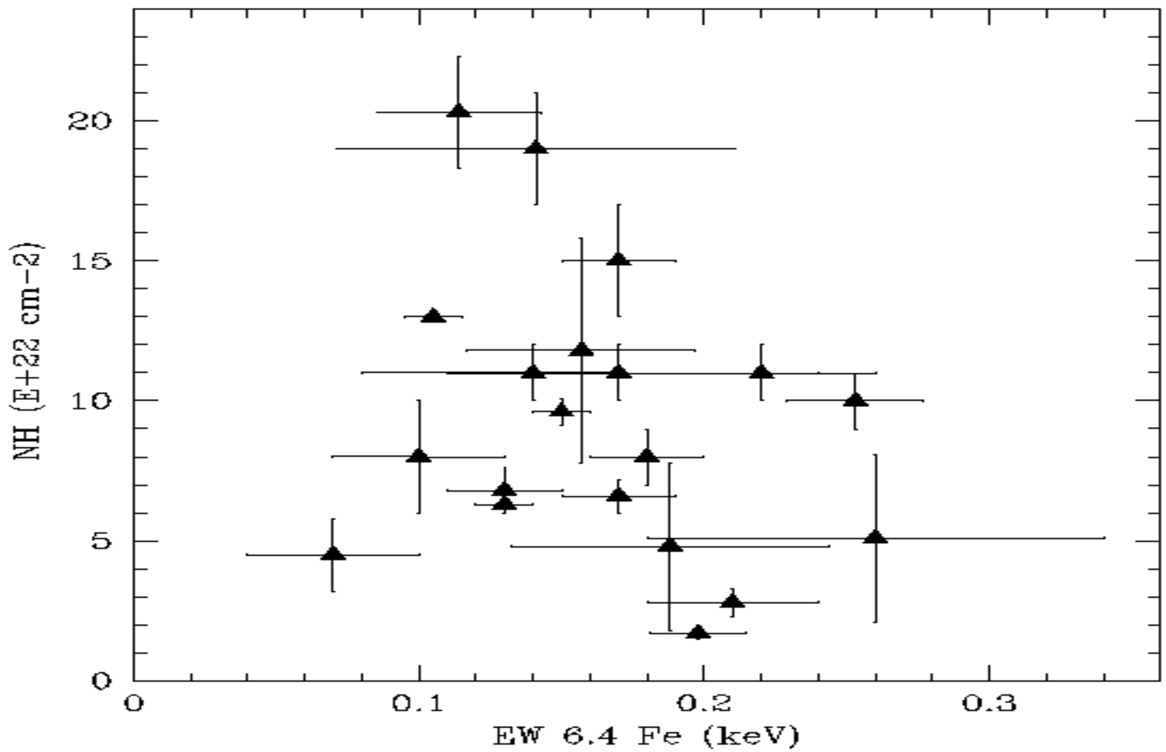
Bernardini et al. 2012

Broad-band Spectra

Gaussian @6.4keV: EW ~ 100-250 eV

→ Reflection from cold neutral matter should be important but reflection component not required in most cases.

Origin: WD photosphere, pre-shock material (or both)



- No correlation of EWs with N_H high density absorber
- 5 cases max EW @ spin min WD photosphere favoured

Fe 6.4keV vs Reflection: XMM-Newton/NuStar AO13 programme (PI: K. Mukai)

Broad-band Spectra

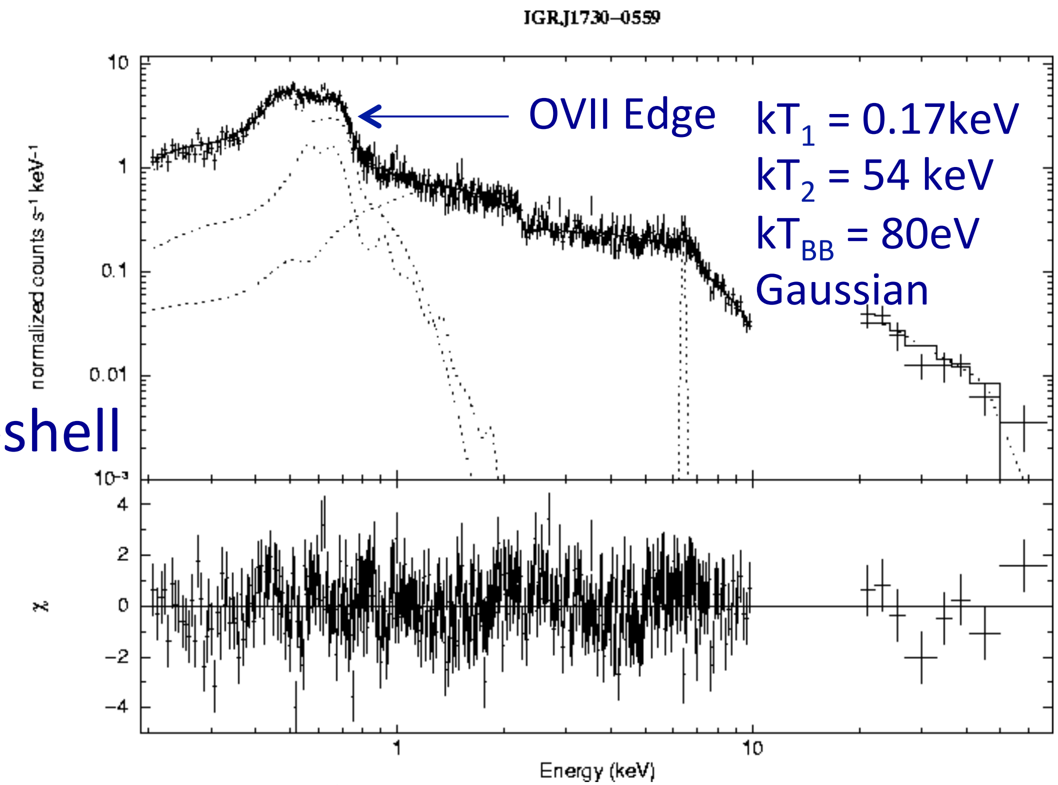
Spectra are thermal and complex:

- Multi-T plasma : $T_{low} \approx 0.14$keV ...... $T_{high} \approx 30\text{-}40$ keV — Post-shock
- Cool absorbers : total ($N_H \sim 10^{20} - 10^{21}$ cm^{-2}) — Interstellar
  partial ($C_F \sim 40\%$; $N_H \sim 10^{22} - 10^{23}$ cm^{-2}) — Pre-shock
- Gaussian @6.4keV: EW ~ 100-250 eV — Pre-shock/WD

In a few cases (3 so far) also:

- Absorption edge: ~ 0.74keV OVII K-shell

→ Warm absorber



de Martino et al. 2008

Broad-band Spectra

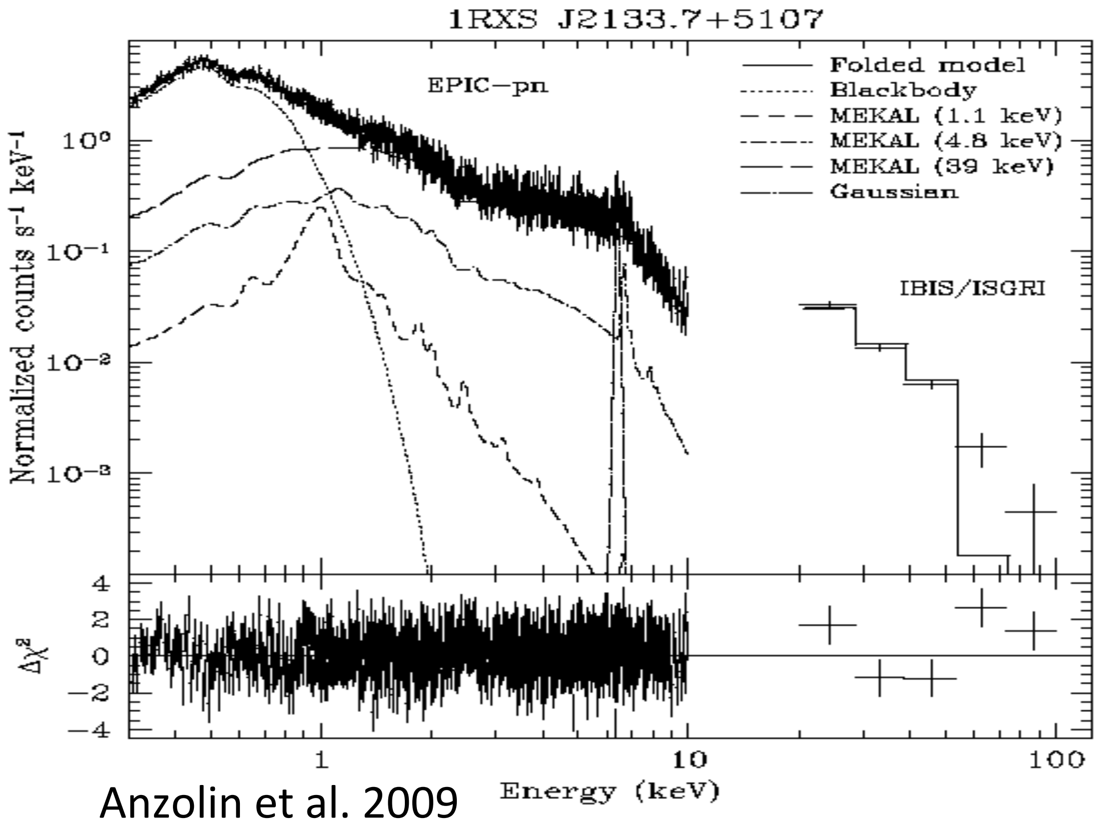
Spectra are thermal and complex:

- Multi-T plasma : $T_{low} \approx 0.14$keV …… $T_{high} \approx 30\text{-}40$ keV — Post-shock
- Cool absorbers : total ($N_H \sim 10^{20} - 10^{21}$ cm^{-2}) — Interstellar
  partial ($C_F \sim 40\%$; $N_H \sim 10^{22} - 10^{23}$ cm^{-2}) — Pre-shock
- Gaussian @6.4keV: EW ~ 100-250 eV — Pre-shock/WD

And in many cases also:

- Blackbody: kT ≈ 30-90 eV

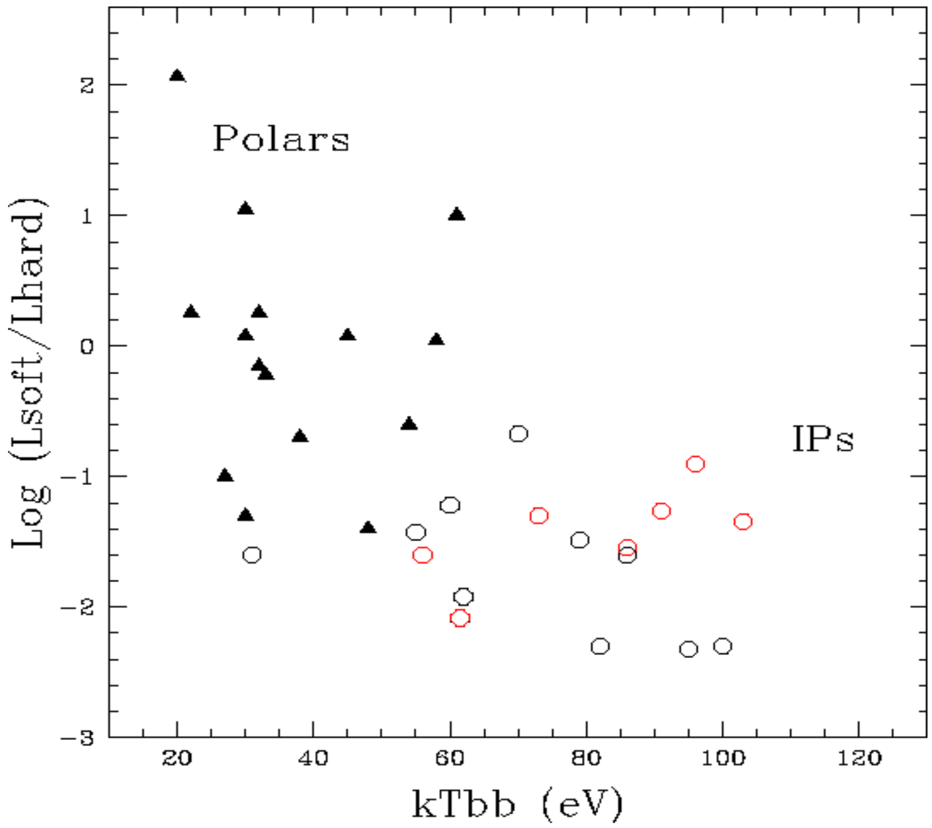
→ Reprocessing at WD surface



Anzolin et al. 2009

Soft X-ray view of MCVs

- Increasing number of IPs (17/50) with a soft BB component
  → Reprocessing at WD as most Polars



Updated from Anzolin et al. 2008

But with differences:

- L_{soft}/L_{hard}(Polars) > L_{soft}/L_{hard}(IPs)

  Cyclotron cooling important at high B :
  $L_{BB} \approx L_{cyc} + L_{hard}$ with $L_{cyc} > L_{hard}$

- Wide range kT_{bb} -uncomfortable high!

  kT_{BB} α (dM/dt) $f^{-1/4}$

- $f_{IPs} \sim 10^{-6} - 10^{-5} << f_{Polars} \sim 10^{-4} - 10^{-3}$

- 7 out of 17 soft IPs found polarised
- Good low-B Polar progenitor candidates

Hard X-ray view of MCVs

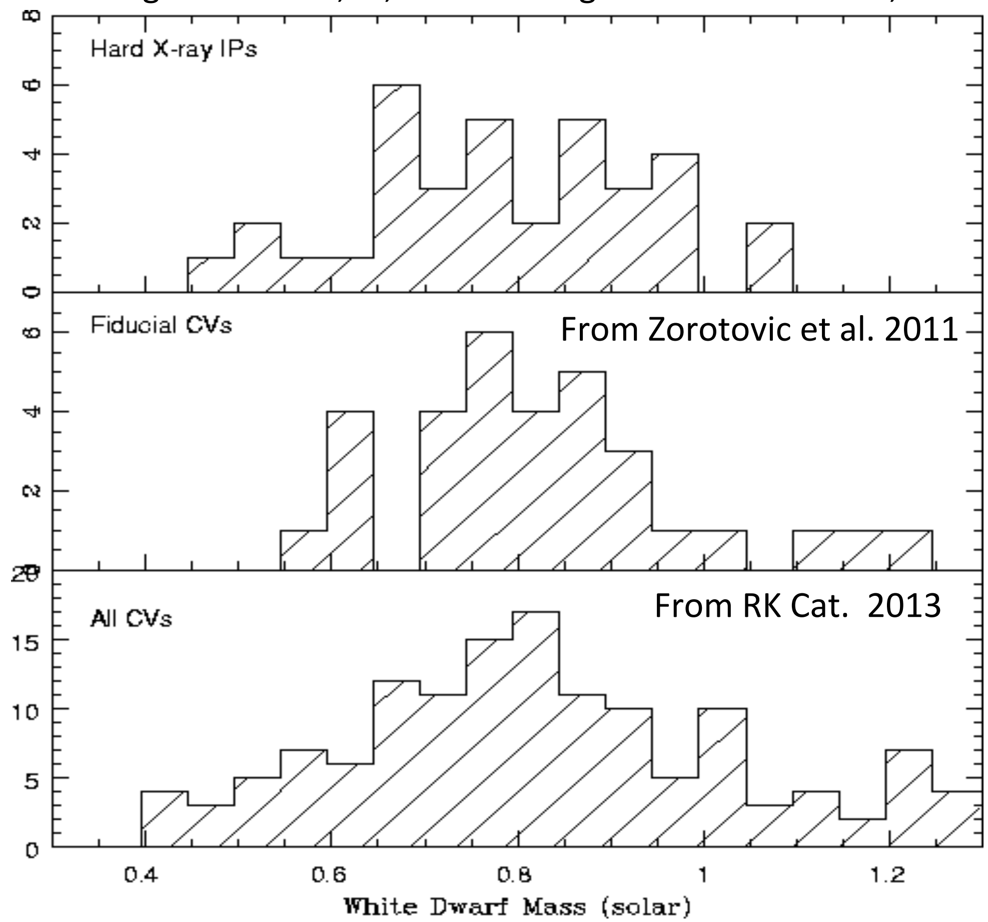
IPs dominate hard X-ray detected CVs in INTEGRAL and Swift surveys

Do they host massive WDs?

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

$<M_{IPs}> = 0.78 \pm 0.16\ M_\odot$
$<M_{Fid}> = 0.82 \pm 0.15\ M_\odot$
$<M_{CVs}> = 0.82 \pm 0.24\ M_\odot$

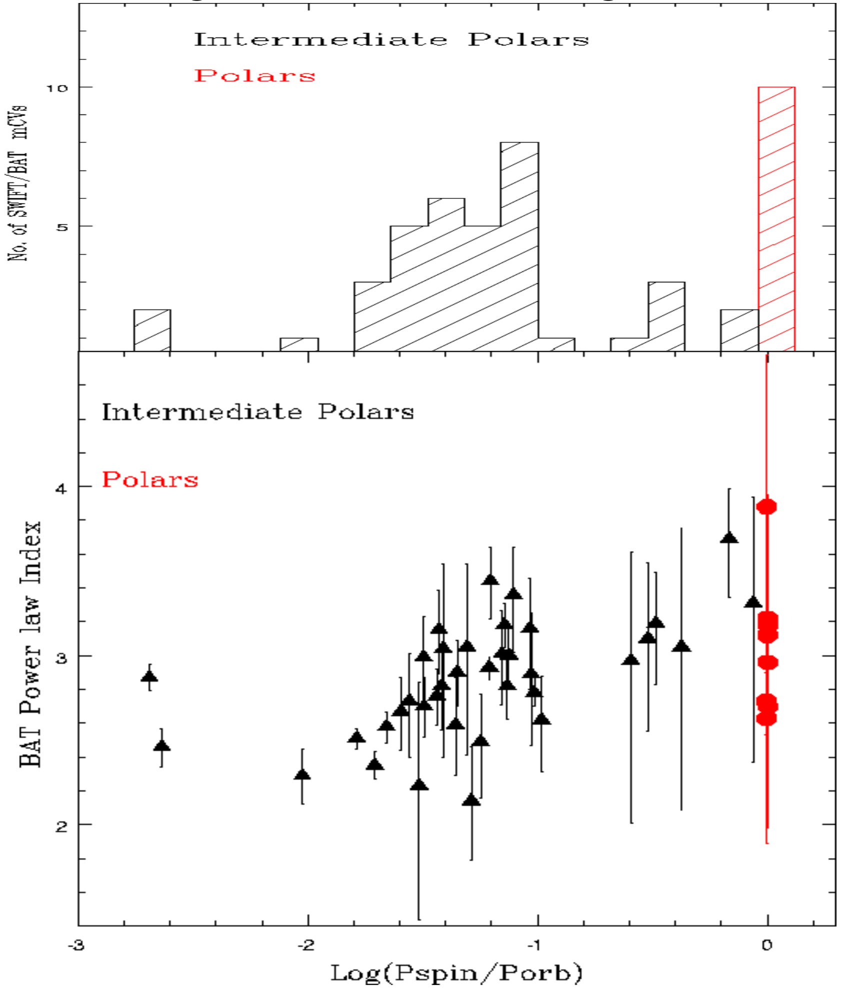
Using Anzolin+08,09, Brunschweiger09 Bernardini+12,+13



IP masses not different from other CVs

Why hard sources?

Using SWIFT/BAT Cat. Baumgartner+13



Hardness vs Spin/Orbit ratio

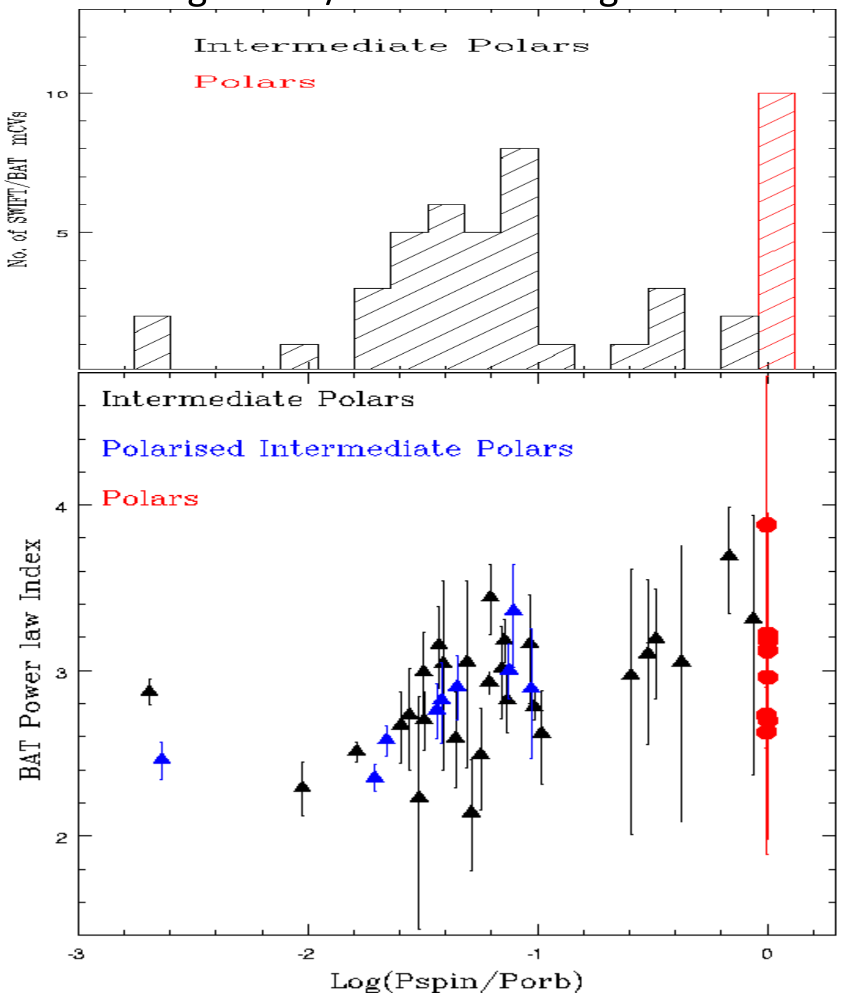
Spin/Orbit ratio as a proxy of B strength

(Scaringi et al. 2010)

- Large spread in $P_{\omega}/P_{\Omega} \sim$ 0.02-0.1 range
- Weakly desynchronised are also hard

Why hard sources?

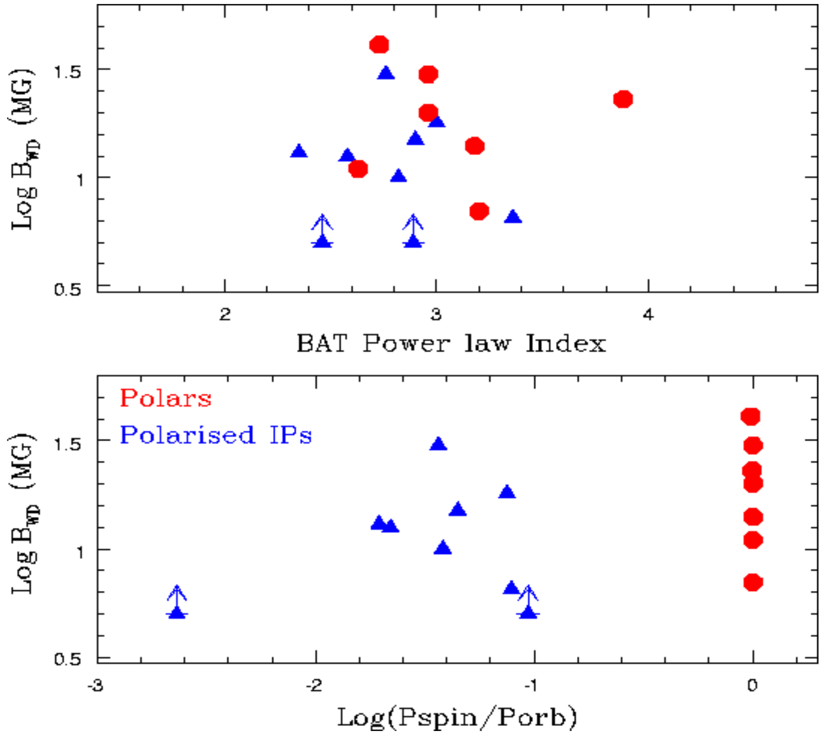
Using SWIFT/BAT Cat. Baumgartner+13



Hardness vs Spin/Orbit ratio

Spin/Orbit ratio as a proxy of B strength
(Scaringi et al. 2010)

- Polarised hard IPs and Polars



Magnetic field is not the only parameter

What Cooling mechanism?

Radiative losses by Cyclotron & Bremsstrahlung for B>1MG

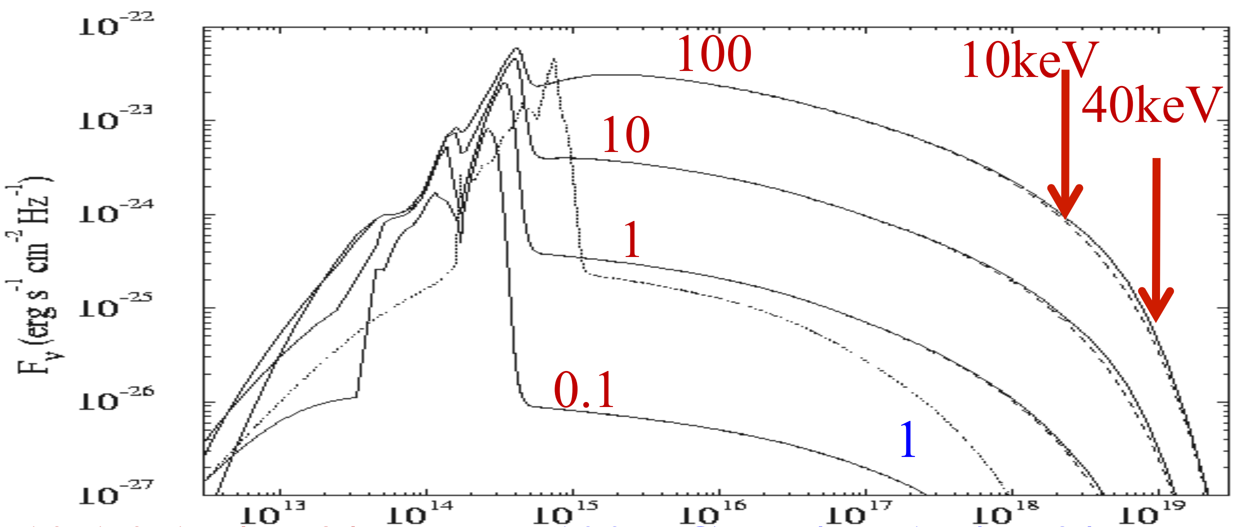
$F_{rad} \approx \rho^{a} T_e^{\,b}$

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

Bremsstrahlung is primary & Cyclotron is secondary

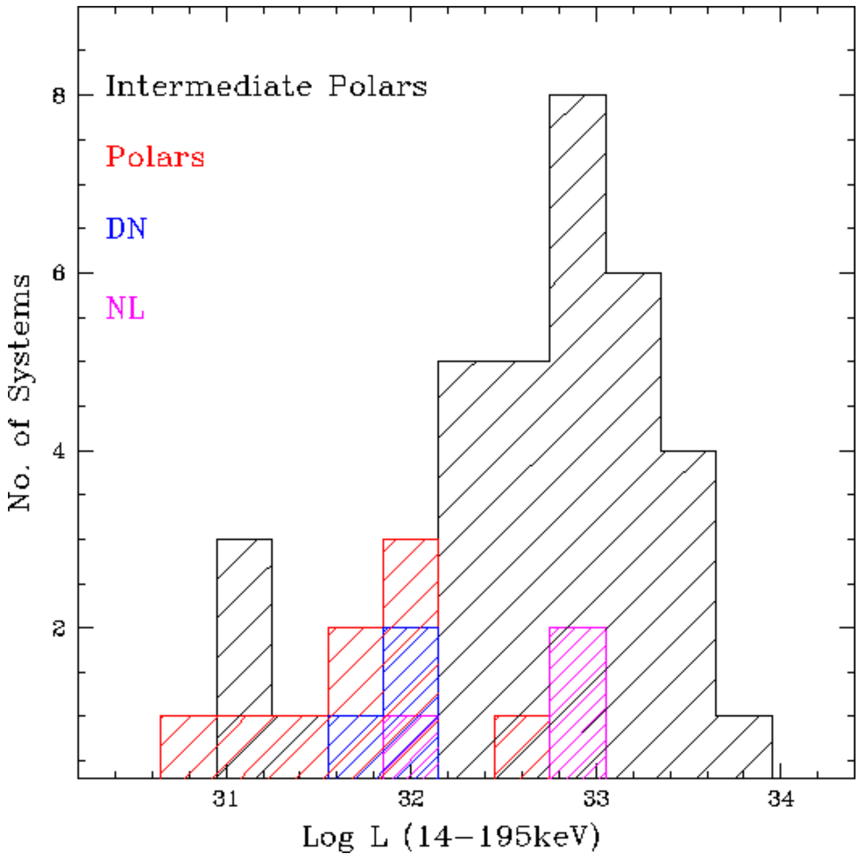
Systems with moderately low field and high dm/dt can be hard X-ray sources

From Fisher & Beuerman



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

Hard X-ray Luminosities



- IPs: <Lx> ~ 8×10^{32} erg/s (up to ~1kpc)
- Polars: Lx ≤ 2×10^{32} erg/s (up to 300pc)
- Too few non magnetics
- Low Lx : Polars, short Porb IPs or even DNs ?
- Need to improve distances (Gaia)

What we still need:

Near Future:

- Census of hard X-ray CVs :
  - Ongoing XMM-Newton identification programme
  - Searches of new systems in 3XMM (~ 190 CVs detected)
- Modelling of hard X-ray continuum above 10keV:
  - higher sensitivity spectra above 10keV to model reflection
  - Spin phase resolved spectra (Fe 6.4keV vs Refl.) to locate reflector

  Nustar+XMM-Newton programme for AO13
- Polarimetric survey of IPs

Far Future:

- e-ROSITA will find thousands of hard X-ray CVs requiring follow-ups
- ATHENA+ will map Fe complex including Grav. Redshift (Fe 6.4keV)

Conclusions

- Hard X-ray CVs dominated by mCVs of IP type

- Increase by 50% IP members thanks to INTEGRAL/SWIFT

- IPs found to share similar BB component as the Polars

- Hard mCVs have:
  - wide range of B-fields but not higher than 30-40MG
  - WDs are not so massive
  - Hard mCVs because of moderate B & high dm/dt

- Faint X-ray sources to be identified