Astro FIt 2
Astronomy Fellowships in Italy

Marie Skłodowska-Curie Actions

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An introduction to compact objects from an observational point of view

Metsähovi Radio Observatory – 14 August 2018

Federico’s main research interests

Compact Objects (Black Hole, Neutron Star, White Dwarf):

1. Low Mass X-ray binaries (LMXBs)
Accreting black hole/neutron star in binaries

2. Cataclysmic Variable Stars (CVs)
Accreting white dwarf in binaries

3. Ultra Luminous X-ray Sources (ULXs)
Accreting black hole/neutron star in binaries

4. Magnetars
Isolated Neutron Stars, X-ray pulsars

Transient Low Mass X-ray Binaries

Main Collaborators: Russell, Stella, Koljonen, +many

LMXBs

NS or BH primary, accreting from a low mass companion ($M<M_\odot$)

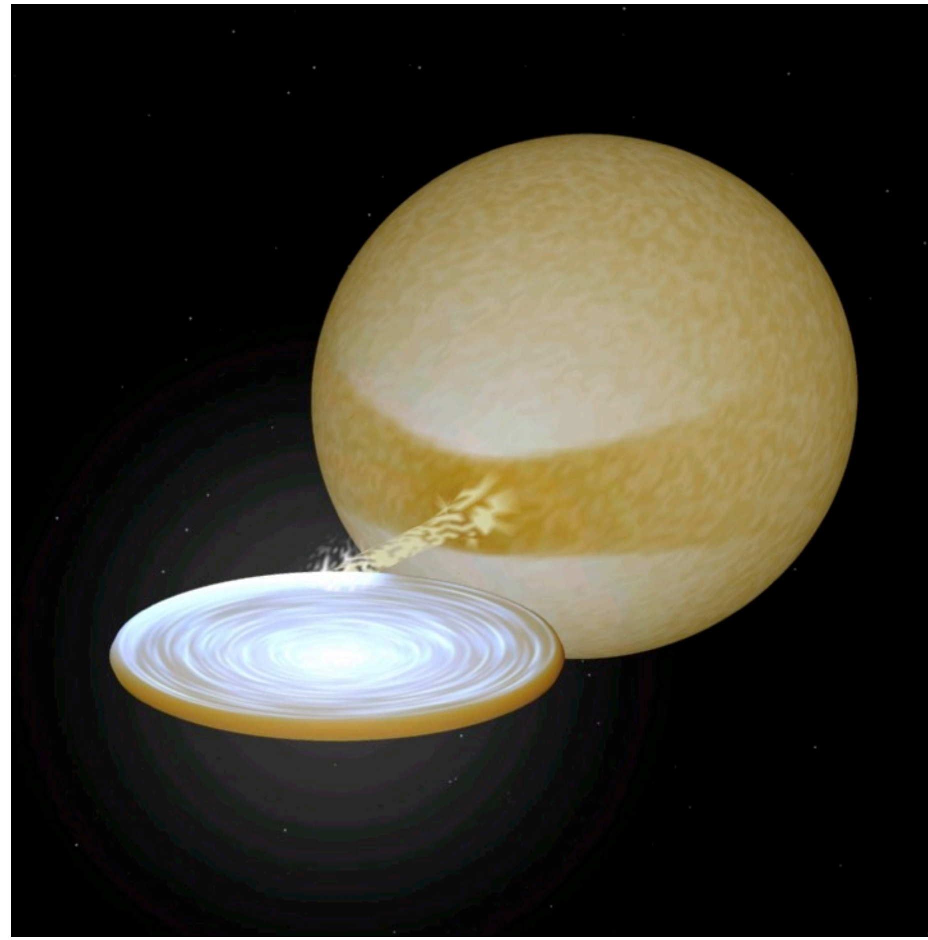
Transient LMXBs

Outburst

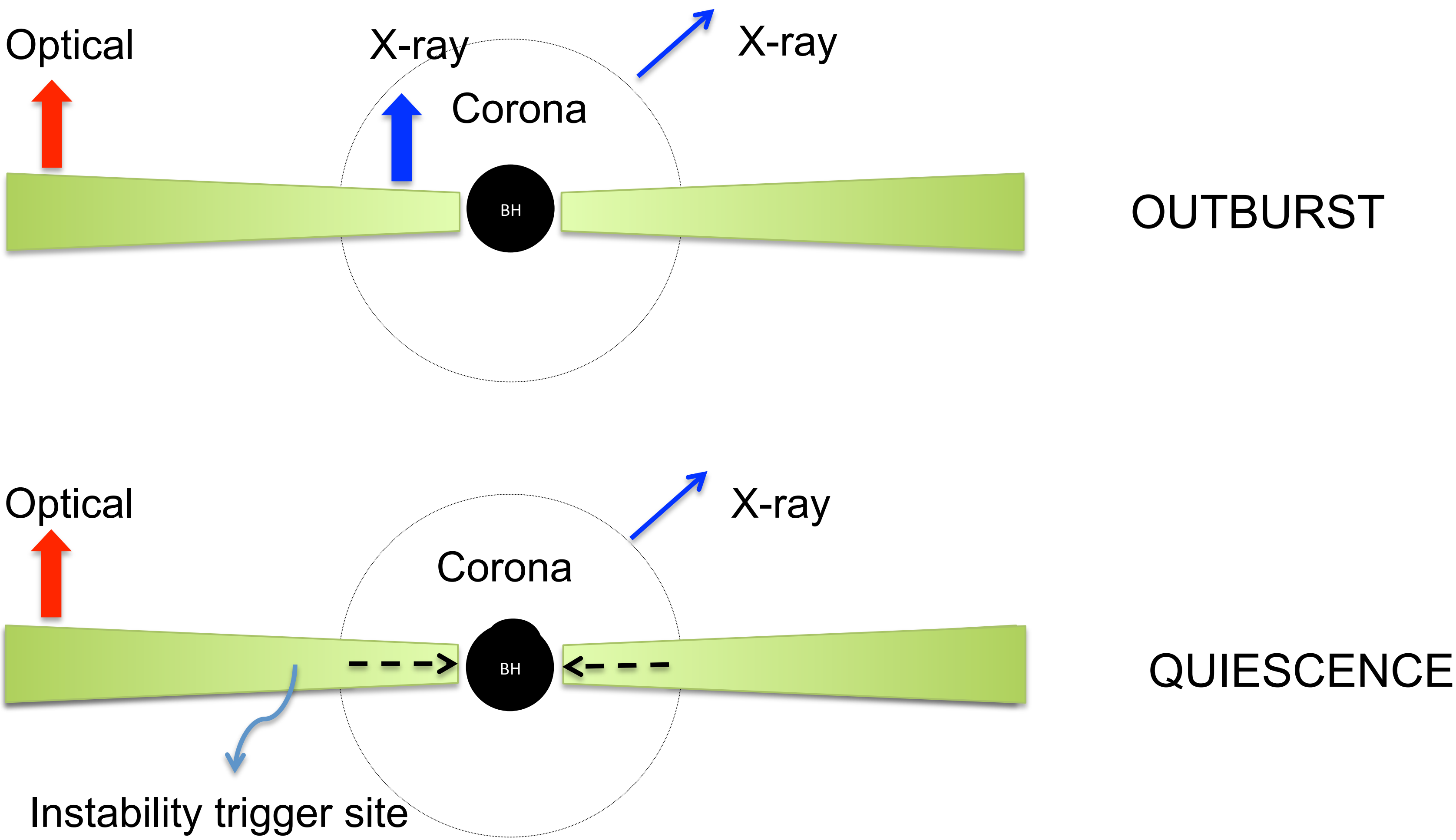
Lasting weeks to years
$L_X \approx 0.1\ L_{Edd}$

Quiescence

Lasting up to decades
$L_X \approx 10^{-8} - 10^{-4}\ L_{Edd}$



Disk Instability Model



Open questions

Several open questions, some of them are:

- What is the quiescent accretion disk structure?
- How close the disk is extending to the BH in quiescence?
- How exactly LMXBs go from quiescence to outburst?

→How can we constrain/test the disk instability model in LMXB?

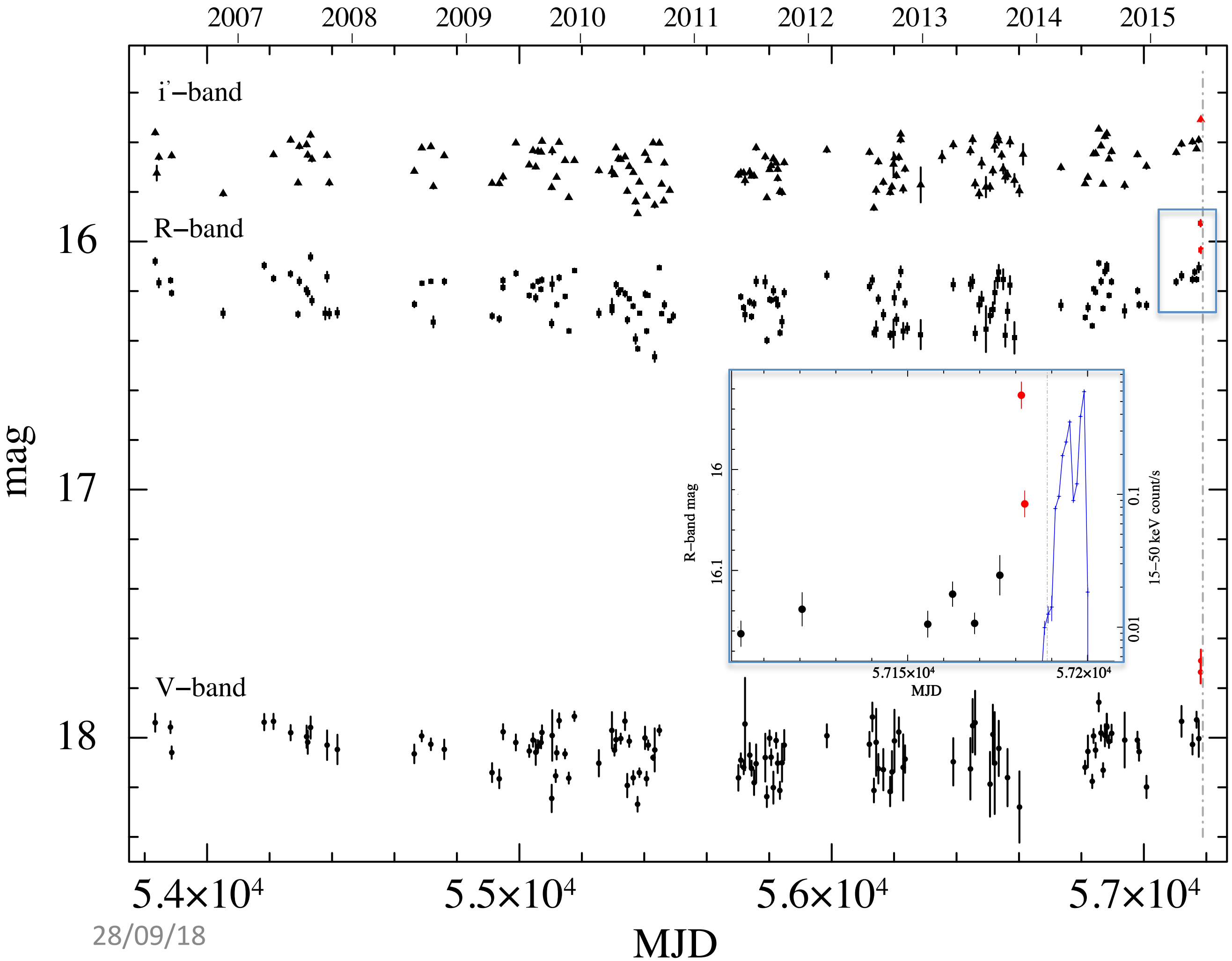
Long-term simultaneous optical and X-ray monitoring of transients

The Faulkes Telescope Project (part of the LCOGT):
Ongoing optical monitoring of 40 LMXBs (Lewis et al. 2008)

Combined with all sky monitoring X-ray data (BAT, MAXI)
and pointed observations

Our Results on V404 Cyg

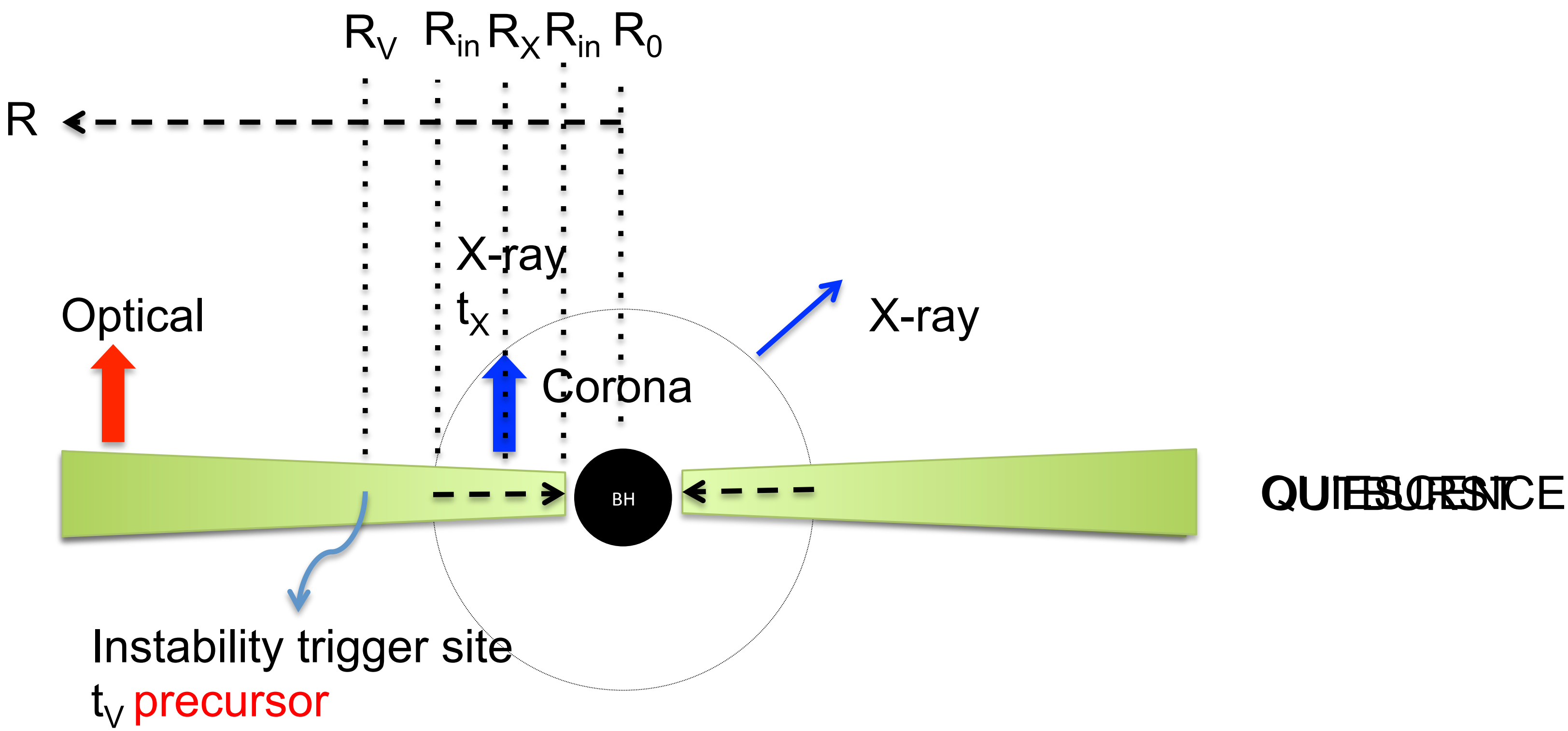
V404 Cyg is a transient LMXB with a 9 $M_{\odot}$ black hole
Multiple outburst, well known distance, low absorption: Perfect Target



• Optical precursor

Optical rises 7 days before X-ray

Disk Instability Model



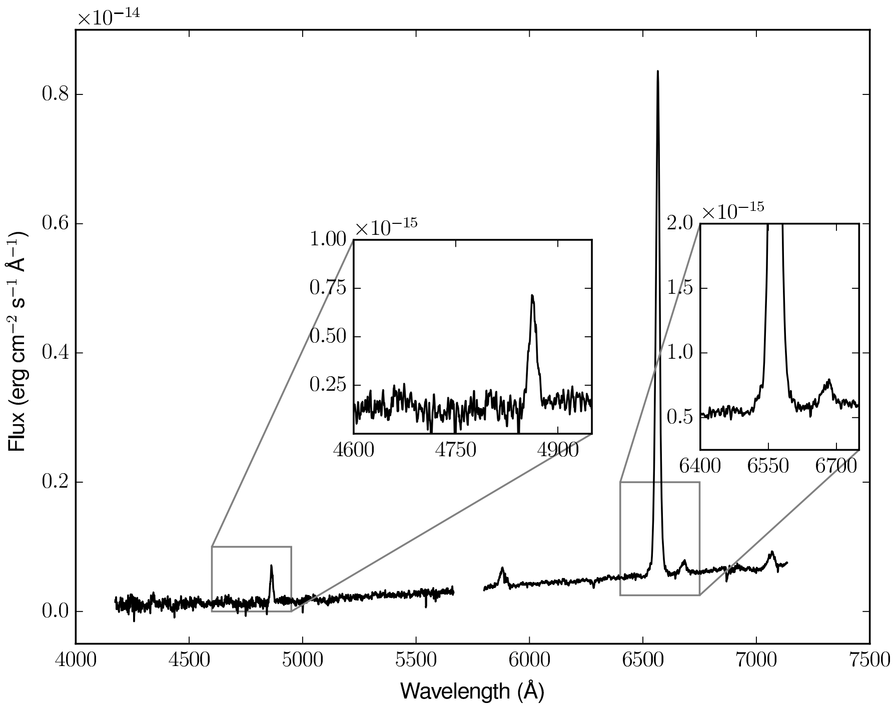
A delay of 7 days according to the DIM corresponds to:
$t_{vis} = \Delta t_{V\text{-}X} = 7$ days → $R_V = 300 – 800\ R_s$ → $R_{in} < 800\ R_s$
Without truncation the maximum delay is 1 day only.

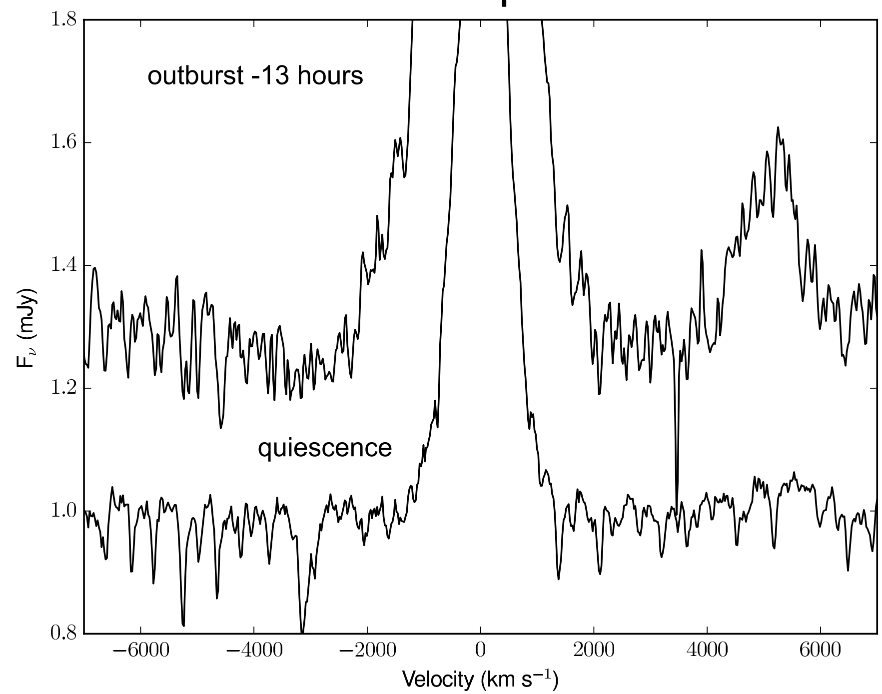
This calculation require assumptions (R_X, Temp)
But we also get a direct measure from Hα

Optical Spectrum

Luckily V404 Cyg was observed 13 hours before its outburst

Hα is x7 quiescence





$R_{in} = 0.5(c \sin(i)/v_{in})^2$, i = 67 degrees

Quiescece: $v_{in} \leq 1500$ km/s → $R_{in} \geq 17000$ Rs
Pre-outburst: $v_{in} \geq 2468$ km/s → $R_{in} \leq$ 6200 Rs (factor of 3 lower than quiescence)

Summary

- Simultaneous optical and X-ray monitoring is a powerful tool
- We observed the exact transition from quiescence to outburst
- We measure a 7 days X-ray delay
- Data can be interpreted in the framework of the disk instability model (truncated disk)
- We can put constrain on the disk instability model (Temp, R_{in})
- We measured R_{in} shrinking between quiescence and immediately before outburst
- Future: Pipeline to automatically update our monitoring on transients

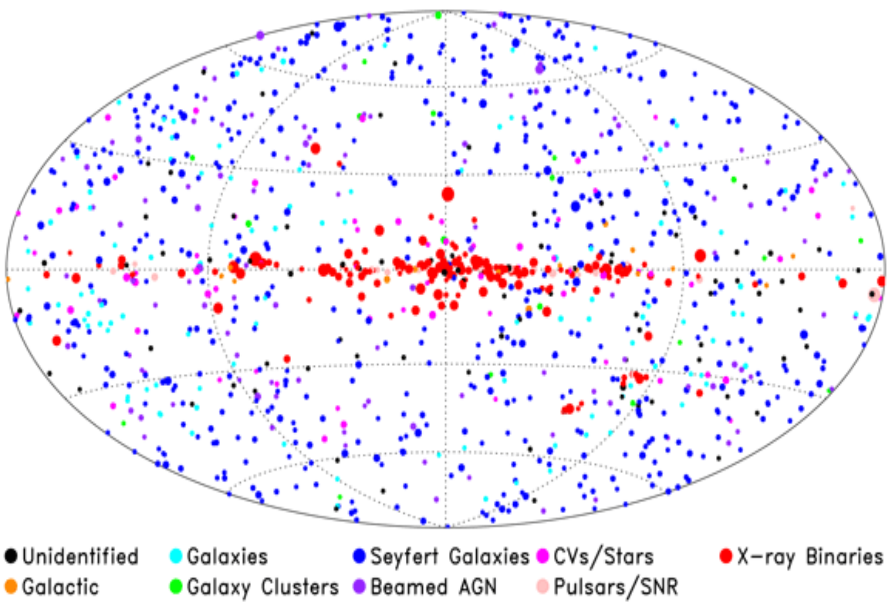
A Census of Hard X-ray Magnetic Cataclysmic Variables

Main Collaborators: De Martino, Mukai, Falanga

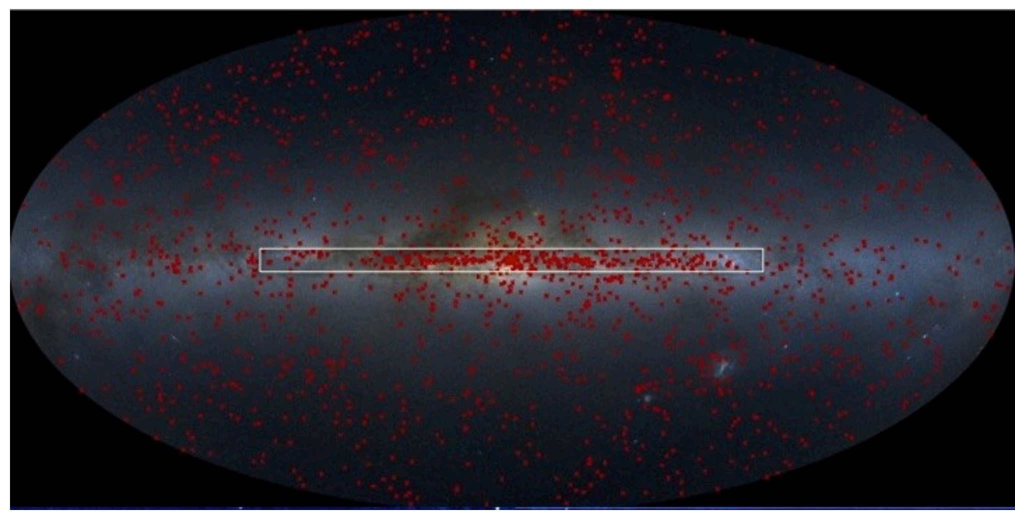
Hard X-ray catalogs

- 20% of galactic sources are Cataclysmic Variables
- Accreting white dwarf from low mass companion
- 25% of all CVs are magnetic systems

BAT

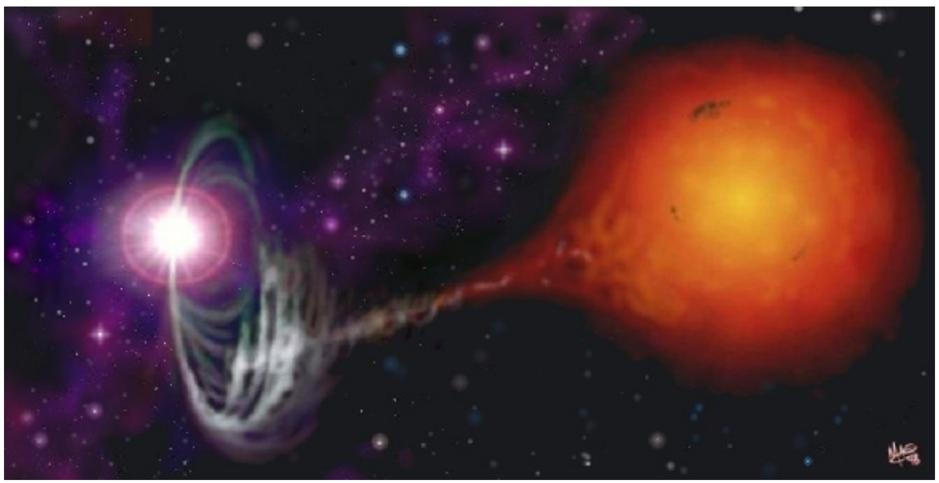


IBIS/ISGRI+BAT

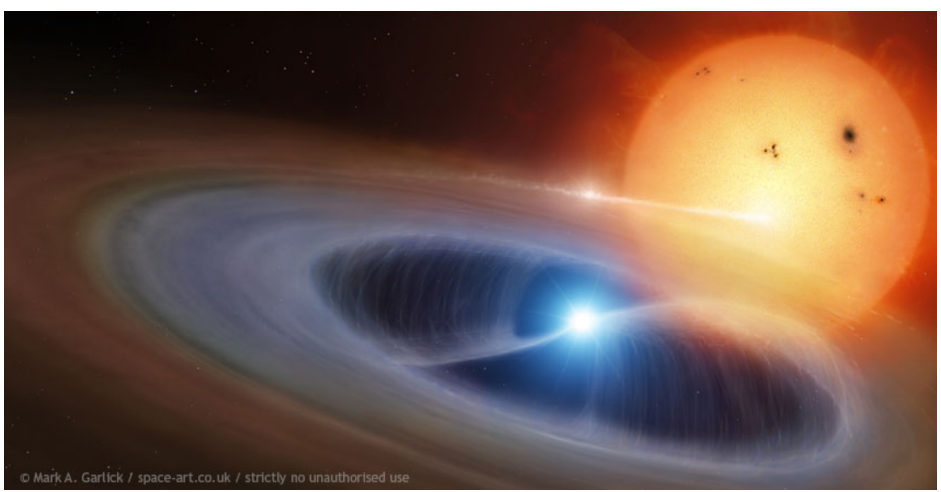


Magnetic CVs

- If the magnetic field is strong enough to regulate the accretion flow the system is defined Magnetic



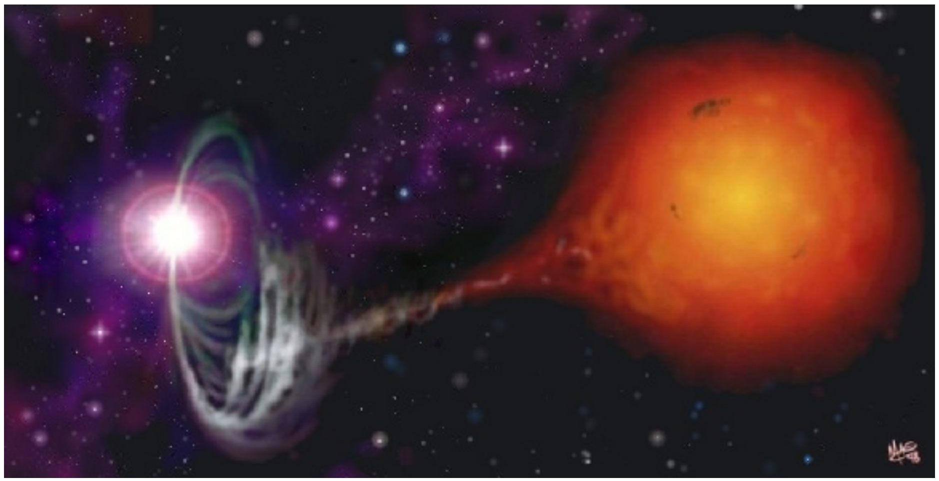
Polars
$B=10^{7}$-10^{8} G



Intermediate Polars (IPs)
$B \leq 10^{6}$ G (?)

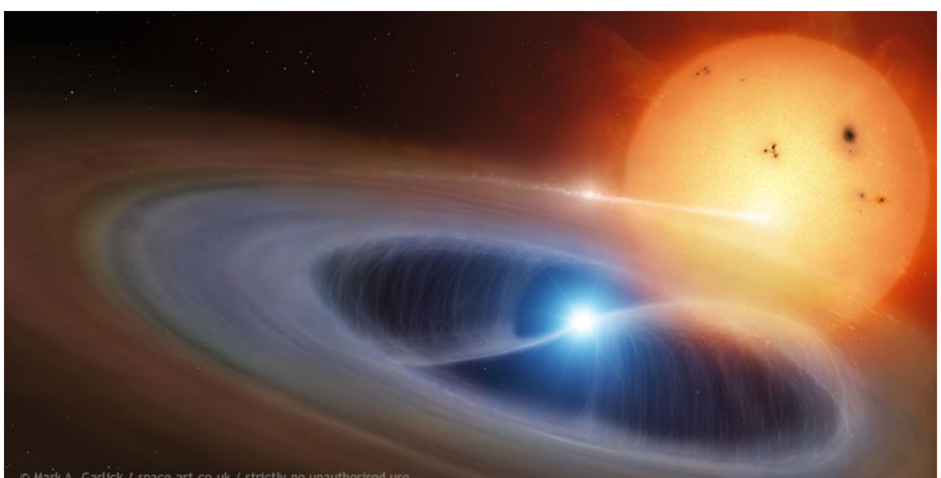
Polars and IPs

- Accretion: intense X-ray and Optical emission
  Periodic emission at spin and orbital period



Polars

$P_{spin} = P_{orb}$ [hrs]

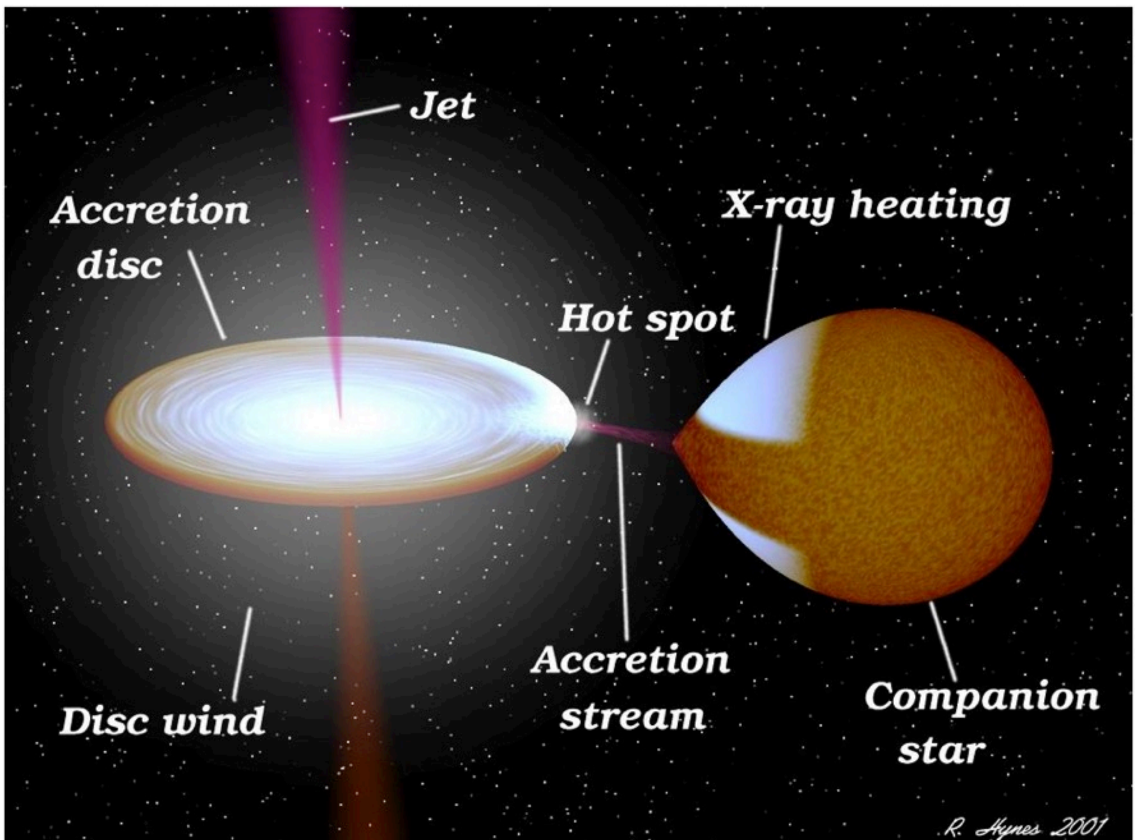


Intermediate Polars (IPs)

P_{spin} [min] < P_{orb} [hrs]

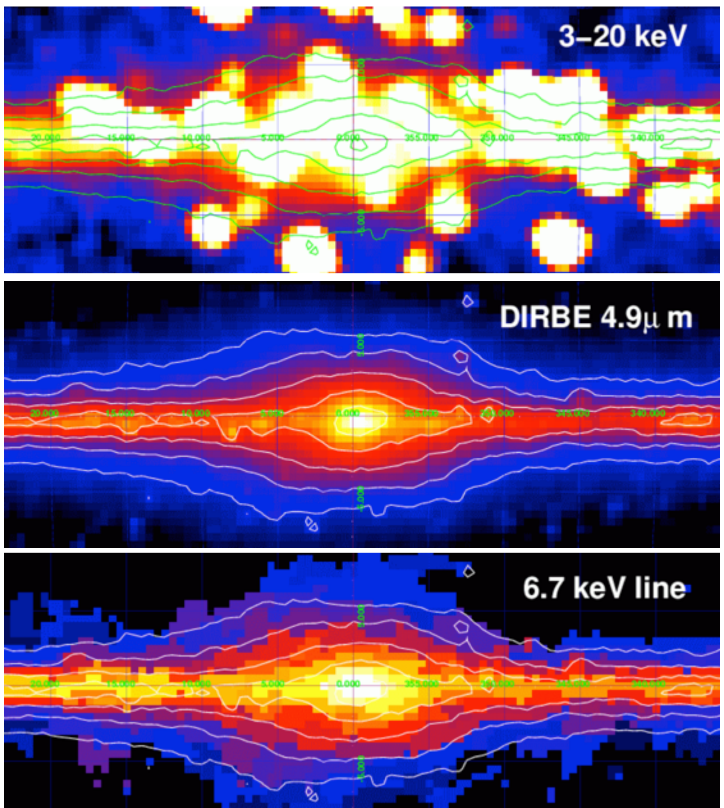
Importance of AWDs

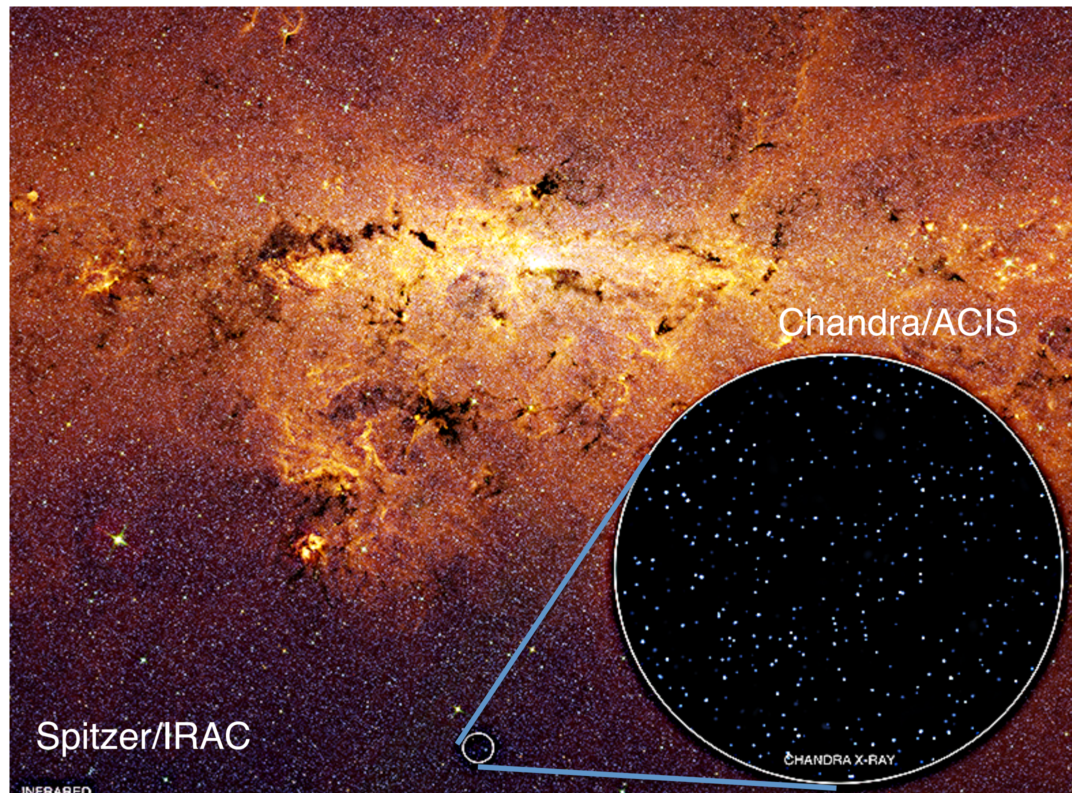
- Close-by, numerous (~1300 CVs), variable
  Universality of accretion at all scales
  AWD perfect laboratory



Why do we study magnetic CVs?

- Galactic "diffuse" X-ray emission: hard sources
  Majority should be mCVs at $10^{30}<L_X<10^{34}$ erg/s
  What are those with $L_X \sim 10^{29-30}$ erg/s ?

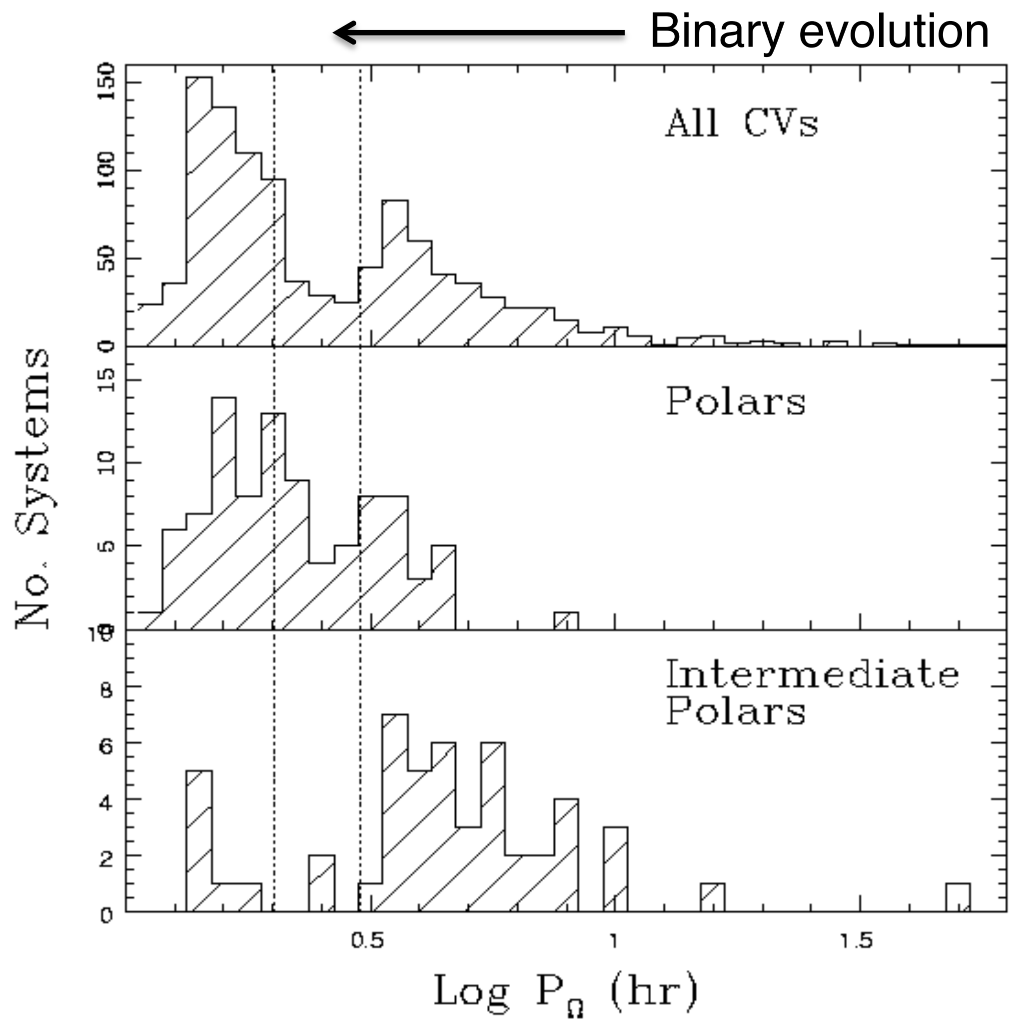




Revnivtsev 2006,2009, Hong 2012, Hailey 2016 + more

Why do we study magnetic CVs?

- We want understand their evolution
  What is the link between Polars and IPs?



Credit de Martino

Open questions

- Galactic “diffuse” emission (buldge, disc, center)
  What are the source producing it exactly?
  Is there a still uncovered population of low-L CVs?

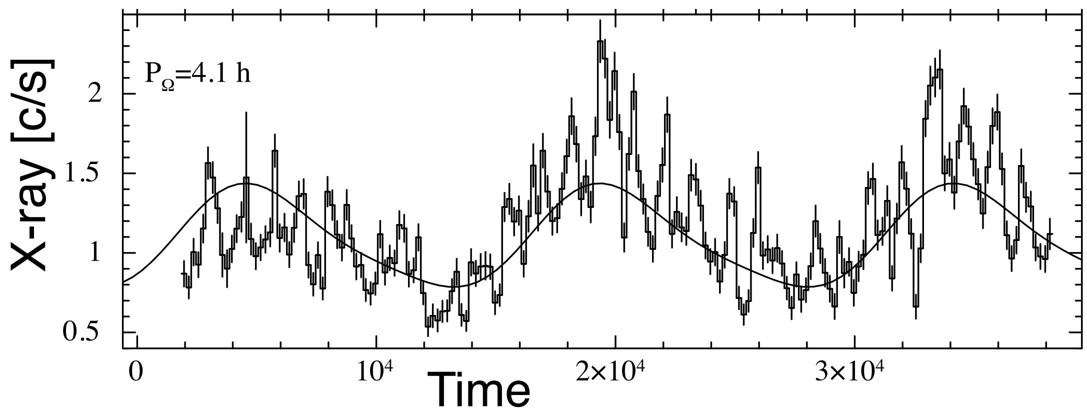
- Binary evolution
  Do long-period IPs evolve into Polars if similar B?

- Magnetic CVs
  Why are they hard X-ray emitters?
  What is the true population of mCVs?

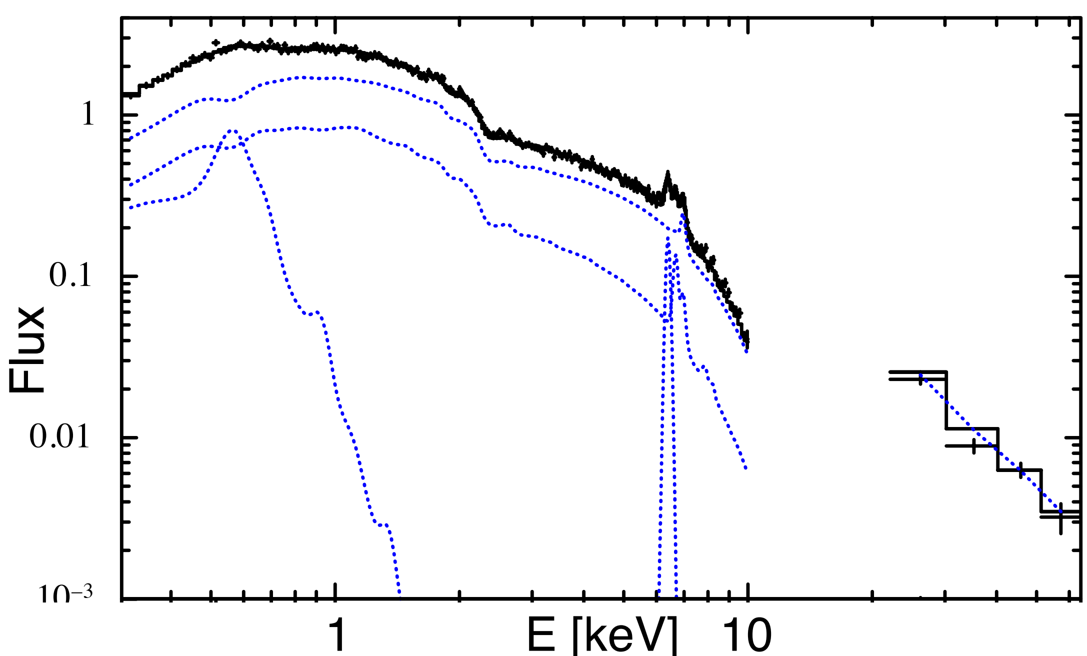
→ Volume (or at least flux) limited sample of mCV

XMM-Newton program

- Opt. follow-ups provide suitable candidates
- Unambiguous identification resides in the X-rays



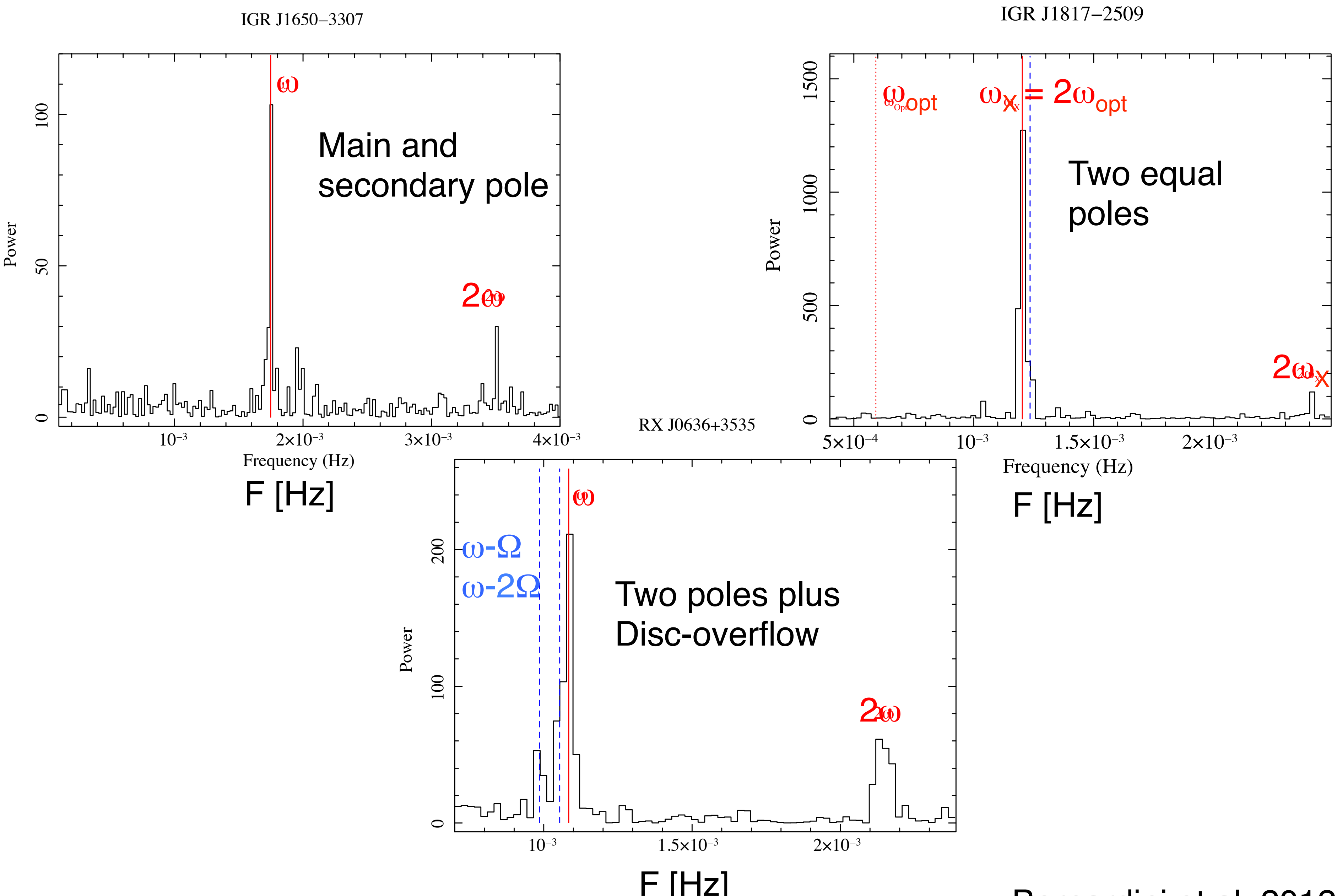
P_{spin} , P_{orb}



Multi-T optically thin
6.4 keV Fe-line

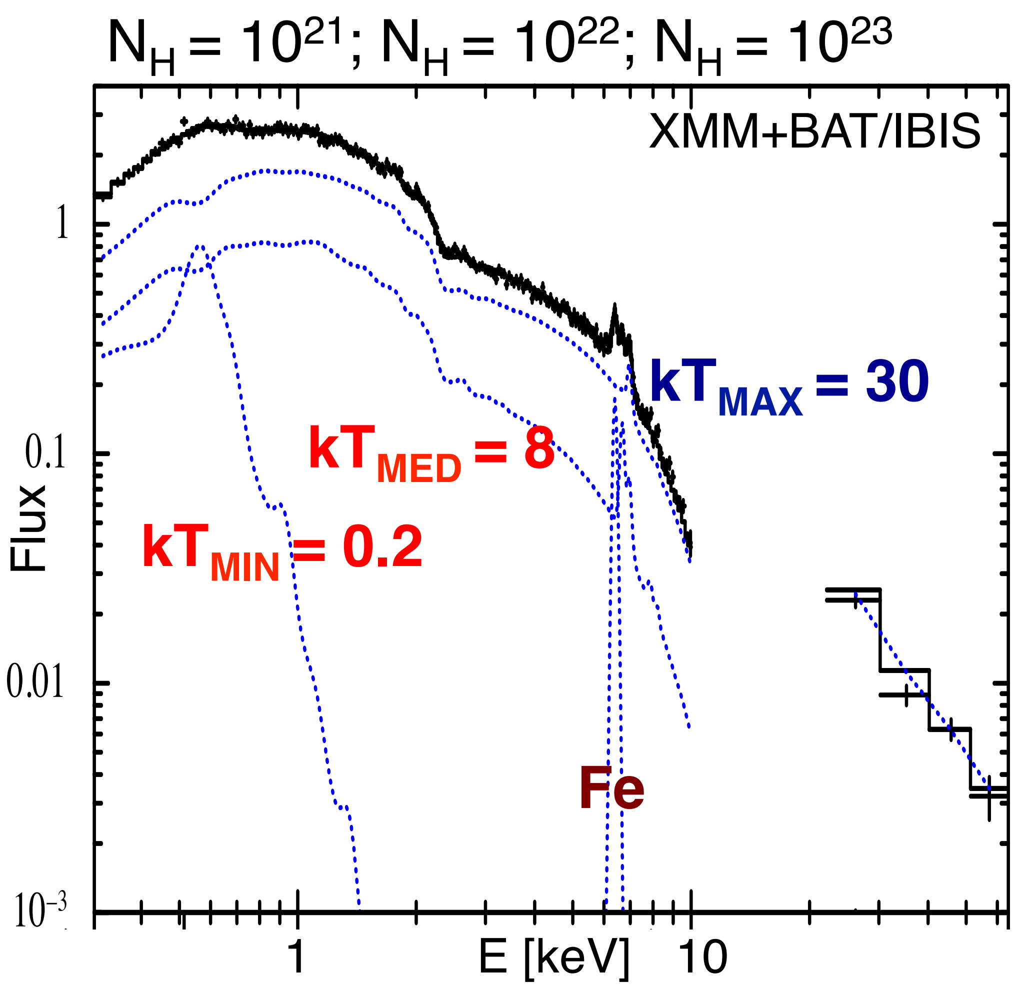
Bernardini et al. 2012--2017

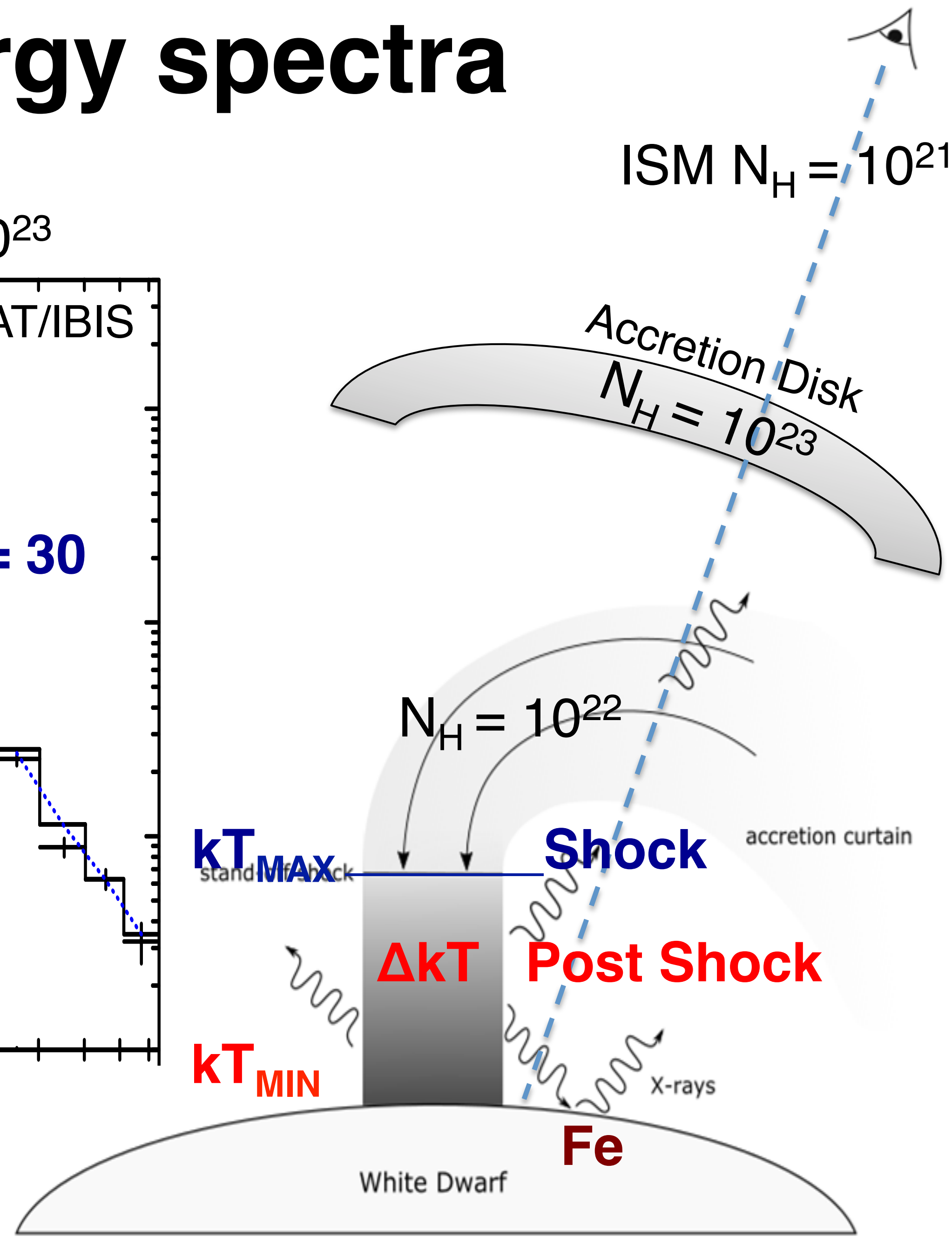
X-ray power spectra of IPs



Bernardini et al. 2012

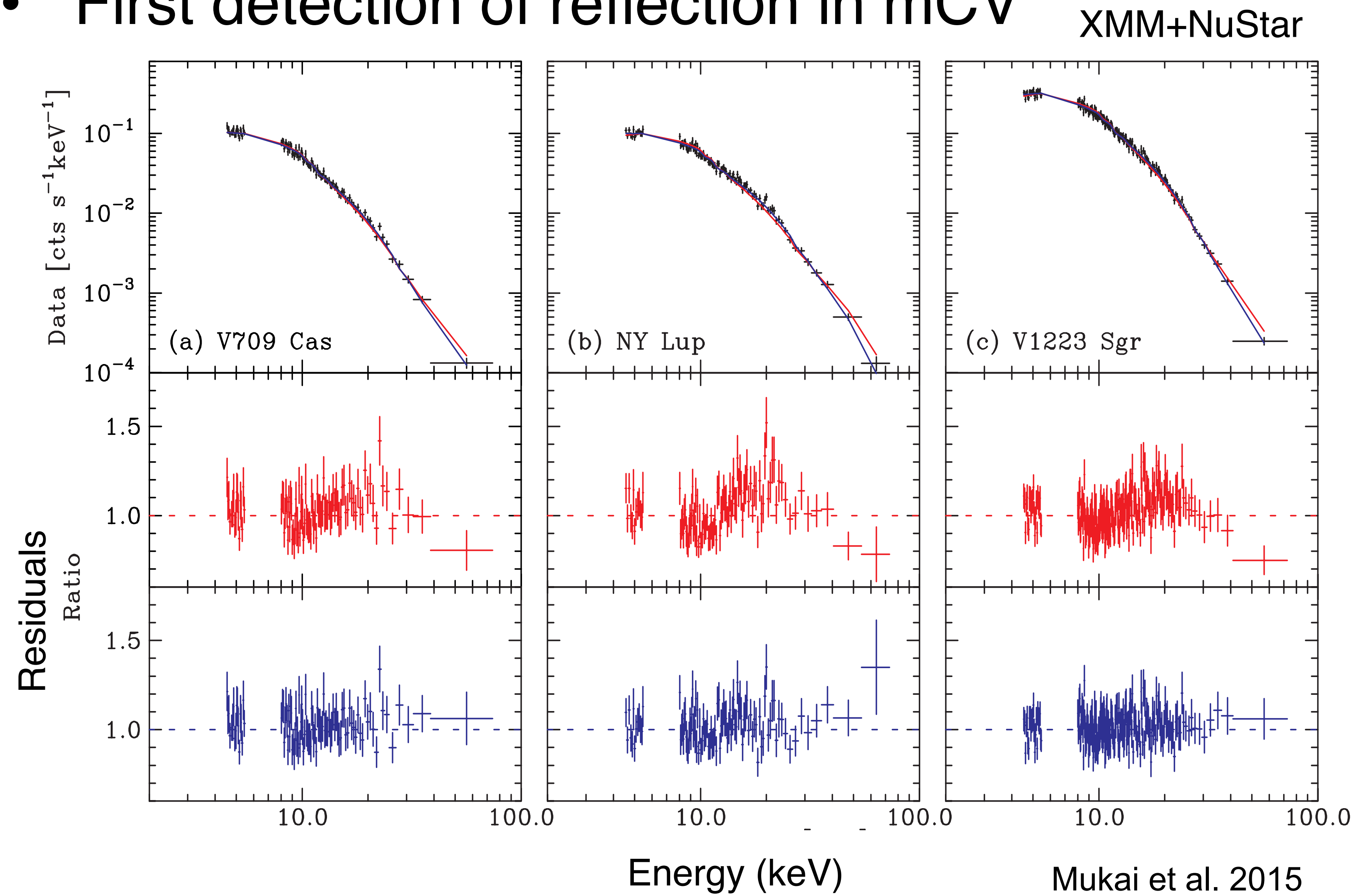
Broad-Band energy spectra





Some specific result

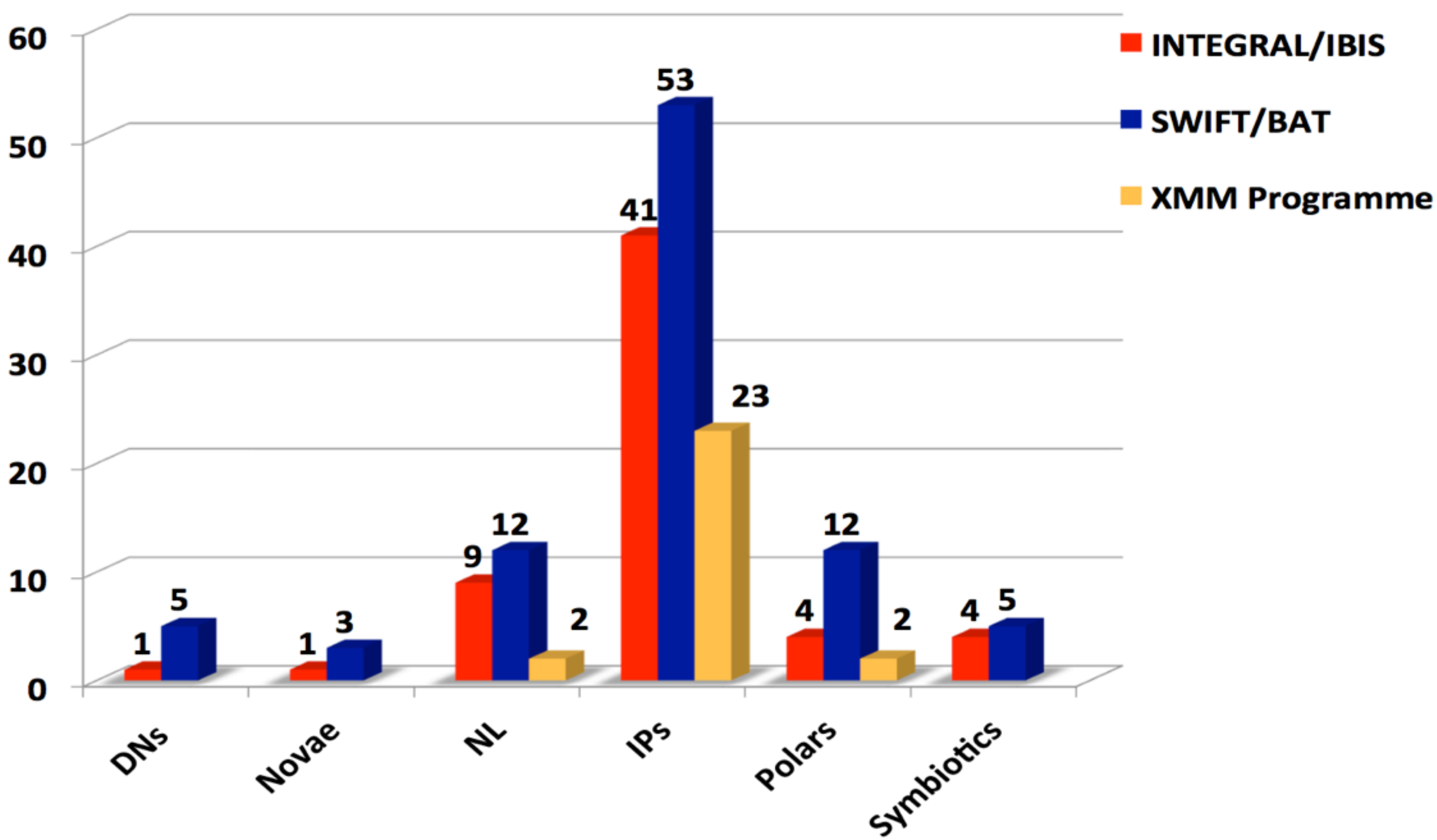
- First detection of reflection in mCV



Mukai et al. 2015

General results of the program

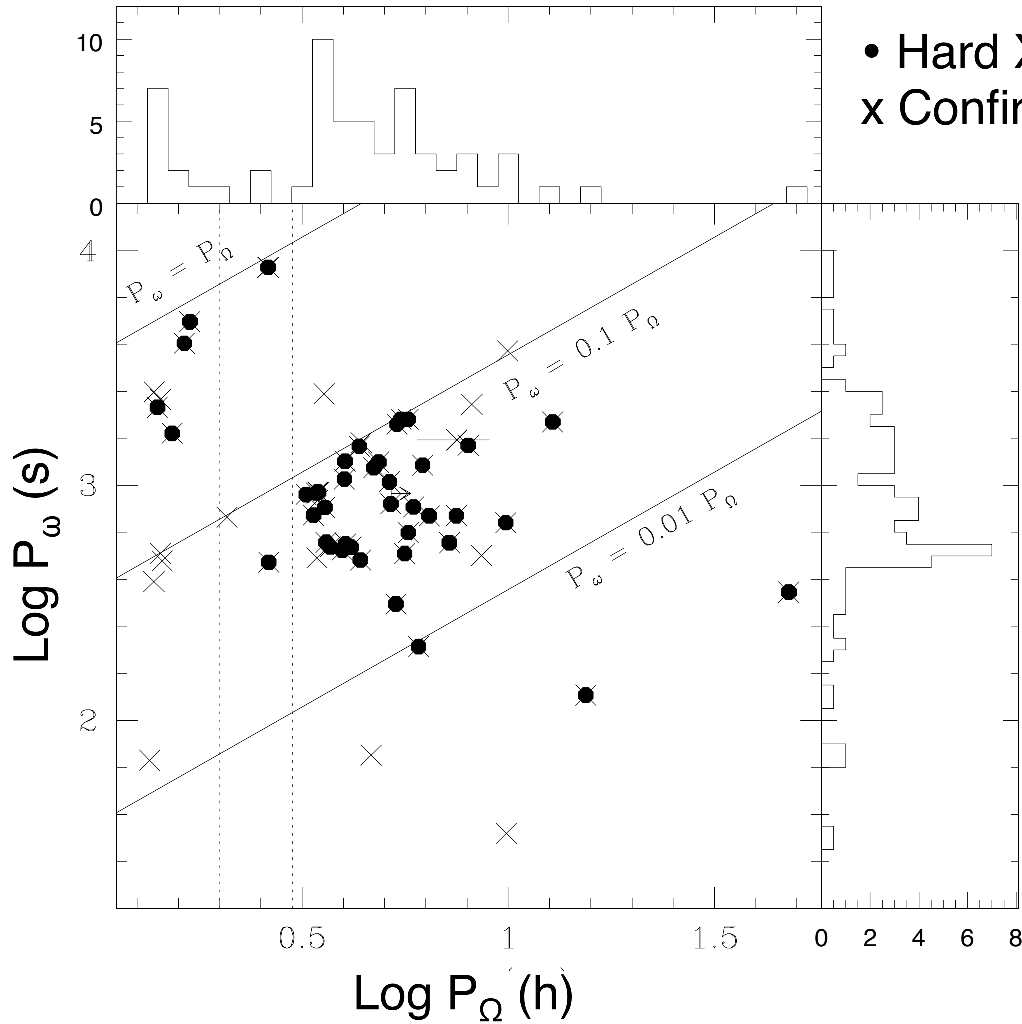
- How many CVs are out there?
  23 IPs + 2 Polar + 3 NL + 1 LMXB (transitional)



Bernardini et al. 2012 to 2018 - Credit de Martino

General results of the program

- What did we learn about IPs?



• Hard X-ray Ips = 55
x Confirmed IPs = 74

P_ω: hundreds – thousands seconds

Most at P_Ω > 3hr

Clustering at $P_\omega/P_\Omega \approx 0.05$- 0.1

Weakly desynchronized at P_Ω < 2-3hr

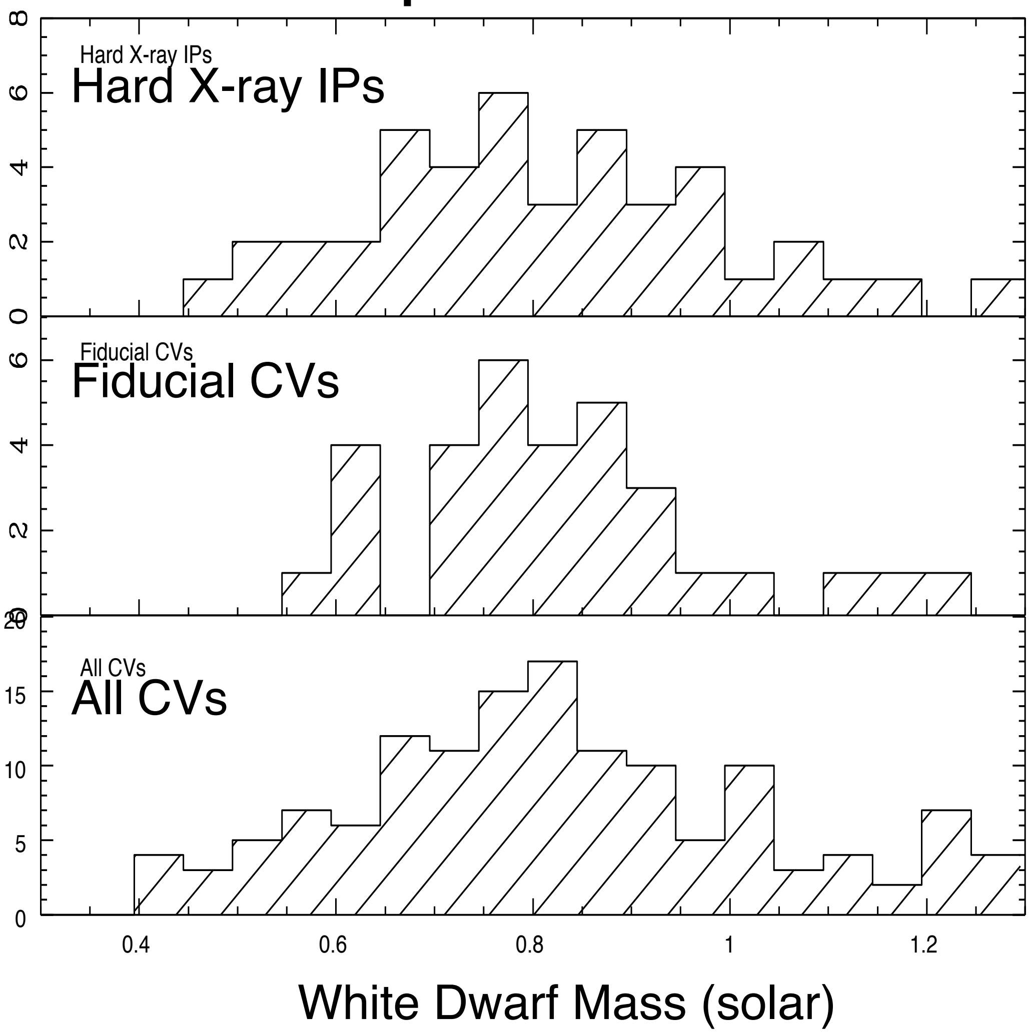
~ 15% below gap (50% are hard)

55/74 detected by INTEGRAL/SWIFT

Bernardini et al. 2017

General results of the program

- Why IPs have harder X-ray spectra?
  -> Other parameters than M_{WD} play a role



kT_{shock} => M_{WD}

$<M_{IPs}> = 0.81 \pm 0.18\ M_\odot$

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

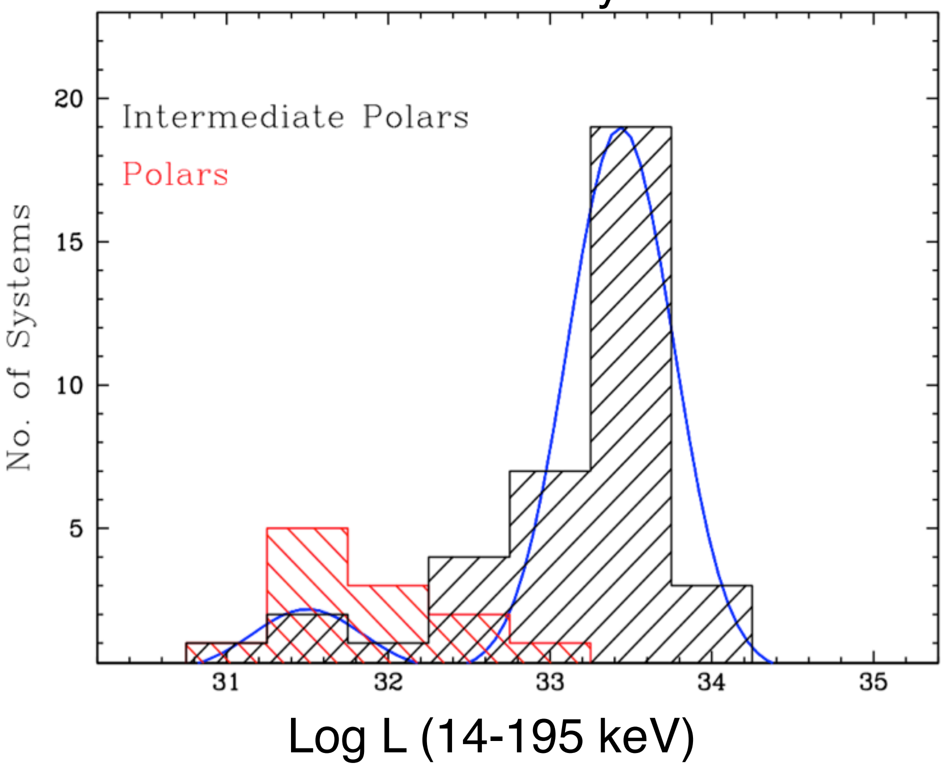
$<M_{CVs}> = 0.82 \pm 0.24\ M_\odot$

Made using: Anzolin 08,09, Brunschweiger 09, Tomsick 16, Bernardini et al. 12,13,15,17. Credit de Martino.

General results of the program

- Is there a still uncovered population of low-L IPs?
- What is the CV and mCV space density?

Bimodality



IPs: <Lx> ~ 1.3×10^{33} erg/s (up to 1.8kpc)

4 IPs at Lx < 10^{32} erg/s
with 3 below the 2-3h gap

Polars: <Lx> ≤ 8×10^{31} erg/s (up to 520 pc)

Low Lx: Polars, short-P_{orb} IPs

Conclusions and Perspectives

- XMM program is an ongoing project
- Hard X-ray CVs are dominated by mCV of IP-type
- They increased by 50% thanks to hard surveys
- Hard magnetic CVs have:

  M_{WD} consistent with other CVs

  Maybe harder because moderate B & high dm/dt

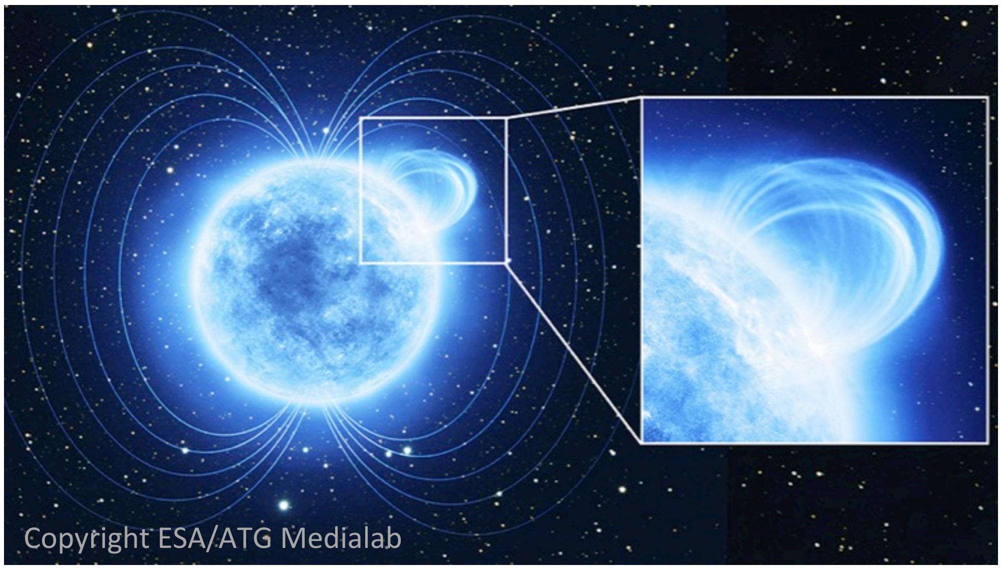
- Near Future: census of hard X-ray CVs

  XMM-Program + Extras -> flux limited sample

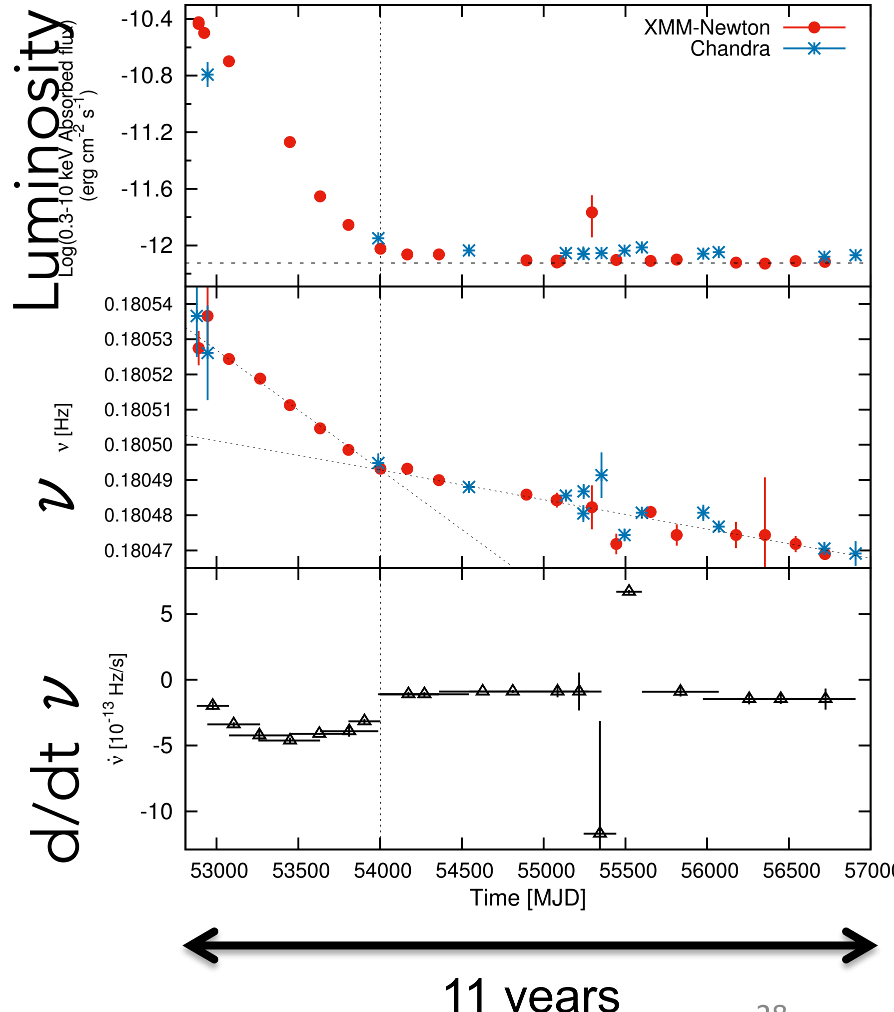
  Unveil the true population of faint sources

  Widen our knowledge of CVs and binaries

Evidence for Magnetospheric Twist in Magnetar Outbursts



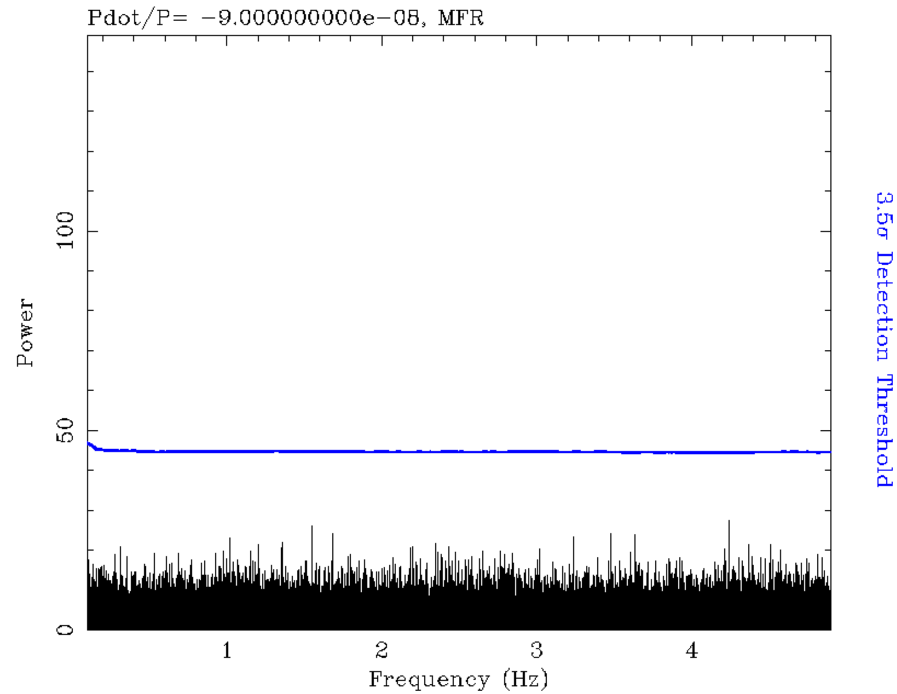
Pintore, Bernardini et al. 2016



Main Collaborators: Israel, Stella, Pintore +many

Ultraluminous X-ray sources

Accreting Black Hole/Neutron Star with High Mass companions in other galaxies



Future:

- **XMM-Newton Large Program: How many Neutron Stars?**
- **Unveil the nature of the companion star**

Main Collaborators: Israel, Rodriguez, Koljonen, +many


Roma – *Via Appia Antica*


Napoli – *Pizzeria*


Abu Dhabi – *Camel Festival*

Thanks!
Grazie!
Kiitos!