Constraints on the space density of CVs and implications for evolution models

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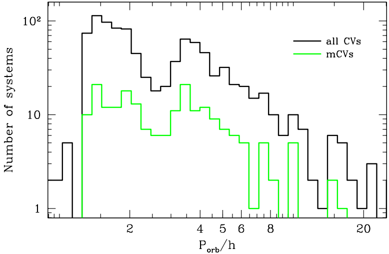
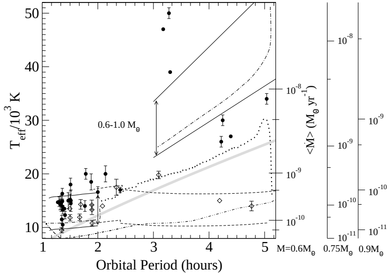
Very basic basics of CV evolution

Angular momentum loss drives mass transfer and orbital evolution

$\Rightarrow P_{orb}$ is an indication of the evolutionary state of a CV





Townsley & Gänsicke 2009

Disrupted MB model

- motivated by non-magnetic CV P_{orb} distribution
- 2 AML mechanisms: GR and MB.
- MB operates only at $P_{orb} \gtrsim 3\,\mathrm{h}$
- $\tau_{GR} >> \tau_{MB}$

How about the mCVs?

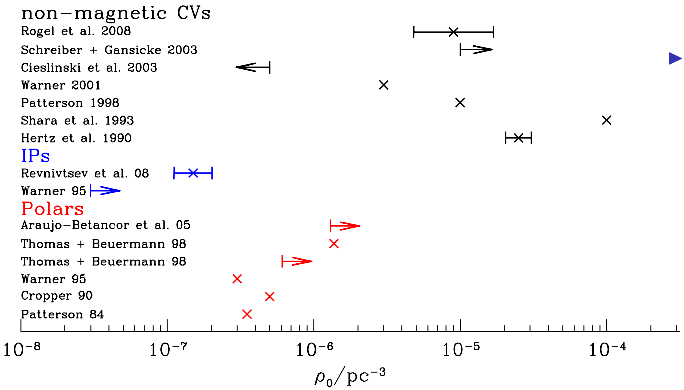
- also form in Common Envelope
- Also lose orbital AM; evolve in P_{orb}
- The period histogram is similar
- $\Rightarrow$ the same except for needing to form a magnetic WD?

No MB in polars?

- B-field stops the stellar wind escaping
- Observational support: low T_{eff} at long-P_{orb} (maybe at all periods)
- $\Rightarrow$ $\tau_{GR} \sim a^{-4} \Rightarrow$ very long for long-P_{orb} polars

Why/how to measure CV space density (again)?

Existing CV space density measurements:



- Basic prediction of theory
- $\frac{\rho_1}{\rho_2} \simeq \frac{\tau_1}{\tau_2}$, but:
  - Large disagreements
  - Large uncertainties
  - Difficult to quantify errors

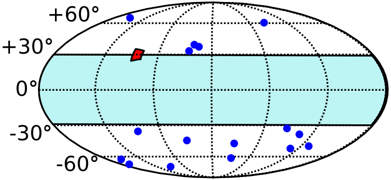
X-ray flux-limited sample the best to use:

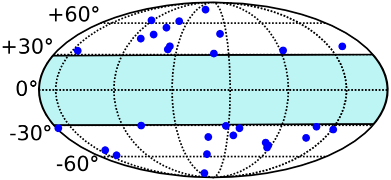
- No volume-limited sample and CVs differ a lot in luminosity $\Rightarrow$ Selection effects
- Systematic errors probably dominate

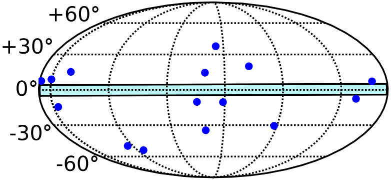
$\Rightarrow$ Need a simple, well-defined sample to deal correctly with all errors

Samples and calculation

3 complete X-ray flux-limited surveys (from ROSAT and BAT):



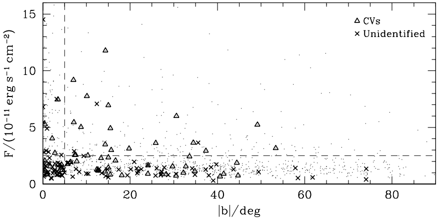




- RBS (0.5–2.0 keV, $F_X \gtrsim 10^{-12} \mathrm{erg\,cm^{-2}s^{-1}}$)
- NEP (0.5–2.0 keV, $F_X \gtrsim 10^{-14} \mathrm{erg\,cm^{-2}s^{-1}}$)
  - 20 non-magnetic CVs
  - 24 mCVs (6 IPs)

  IPs have hard X-ray spectra $\Rightarrow$ ROSAT not good
- BAT (14–195 keV, $F_X \gtrsim 2.5 \times 10^{-12} \mathrm{erg\,cm^{-2}s^{-1}}$)
  - 15 IPs

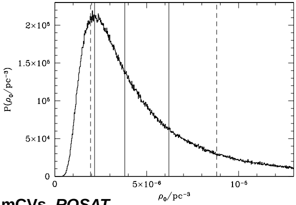
All 3 samples have identifications for all sources



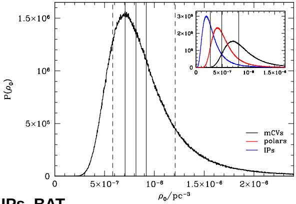
Use $1/V_{max}$ and Monte Carlo code

Best estimate space densities

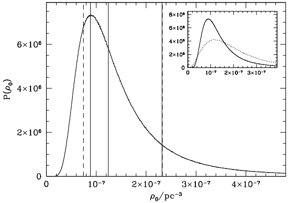
non-magnetic



mCVs, *ROSAT*



IPs, BAT



Simulation gives a PDF of ρ

(Do it separately for different samples for sub-types ρ)

non-magnetic CVs:

$$\rho_0 = 4^{+5}_{-2} \times 10^{-6}\,\mathrm{pc}^{-3}$$

mCVs:

- All mCVs: $\rho_0 = 8^{+4}_{-2} \times 10^{-7}\,\mathrm{pc}^{-3}$
- For polars and IPs separately:

  $\rho_{polar} = 5^{+3}_{-2} \times 10^{-7}\,\mathrm{pc}^{-3}$

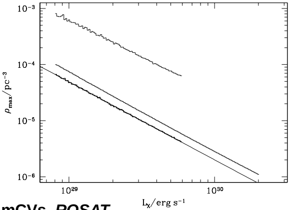
  50% duty cycle lowstates doubles ρ_{polar}
- Long-period IPs from BAT:

  $\rho_{IP,lp} = 1^{+1}_{-0.5} \times 10^{-7}\,\mathrm{pc}^{-3}$
- Low precision, but reliable
- Measurements apply only to detected population

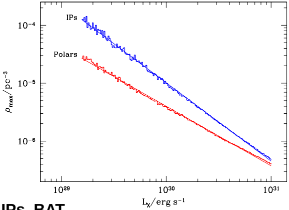
Pretorius & Knigge (2012); Pretorius, Knigge & Schwope (2013); Pretorius & Mukai (2014)

Upper limits on hypothetical fainter populations

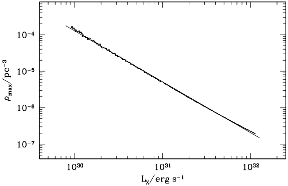
non-magnetic



mCVs, *ROSAT*



IPs, BAT



Non-detections constrain sizes of undetected populations

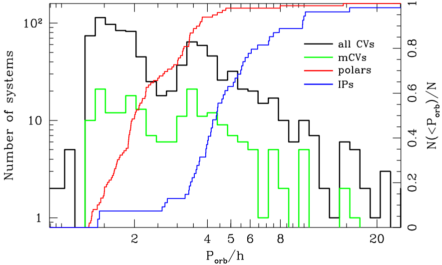
- Assume all systems in the 'hidden' population have the same (faint) L_X
- Find ρ that predicts 3 detected faint systems (detecting 0 is then a 2-σ result)
- Non-magnetic:
  $\rho < 4.82 \times 10^{-5} (L_X / 10^{29}\,\mathrm{erg\,s^{-1}})^{-1.48}\,\mathrm{pc^{-3}}$
  $\Rightarrow \rho = 10^{-4}\,\mathrm{pc^{-3}}$ requires $L_X \lesssim 8 \times 10^{28}\,\mathrm{erg\,s^{-1}}$ (that's pretty faint)
- IPs:
  $\rho < 1.02 \times 10^{-5} (L_X / 10^{30}\,\mathrm{erg\,s^{-1}})^{-1.35}\,\mathrm{pc^{-3}}$
- Polars:
  $\rho < 4.01 \times 10^{-6} (L_X / 10^{30}\,\mathrm{erg\,s^{-1}})^{-1.03}\,\mathrm{pc^{-3}}$
- long-period IPs, BAT band:
  $\rho < 5.15 \times 10^{-6} (L_X / 10^{31}\,\mathrm{erg\,s^{-1}})^{-1.40}\,\mathrm{pc^{-3}}$

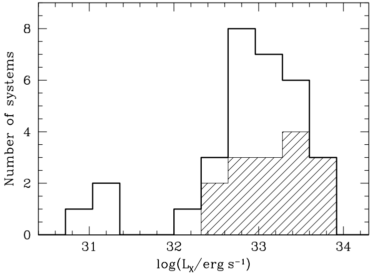
Pretorius & Knigge (2012); Pretorius, Knigge & Schwope (2013); Pretorius & Mukai (2014)

Evolutionary relationship between IPs and polars

P_{orb} histogram of mCVs similar to non-magnetic CVs

But almost all IPs are long-P_{orb}, almost all polars short-P_{orb}





- Short-period polars can form at short period. But where do long-period IPs go
- IP might synchronize when $\dot{M}$ drops at 3 h

Do IPs evolve into polars?
(e.g. Chanmugam & Ray 1984)

- Would imply $\rho_{polar,sp}/\rho_{IP,lp} \simeq \tau_{GR}/\tau_{MB}$ (expect theoretically $\tau_{GR}/\tau_{MB} \gtrsim 5$)
- $\frac{\rho_{polar,sp}}{\rho_{IP,lp}} = 3^{+3}_{-1}$ (Ratio $\gtrsim 10$ within 2-σ)

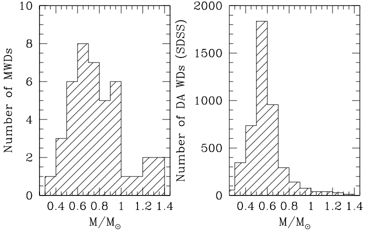
Do IPs just stay IPs?
(e.g. Norton et al. 2008)
Faint IP population:

- $10^{-7}\,\mathrm{pc}^{-3} < \rho_{faint} < 5 \times 10^{-6}\,\mathrm{pc}^{-3}$
- Similar in size to short-period polar population

Data can't distinguish these 2 options for now (but best bet probably a combination)

Intrinsic fraction of magnetic WDs

Formation of mWDs to do with binary evolution?



Tout et al. 2008

- If only stellar evolution, mWD fraction same in
  - isolated WDs ($\simeq$10%; Kawka et al. 2007)
  - CVs ($\simeq$20% of known CVs; Ritter & Kolb)
  - detached WD/red dwarf binaries (no mWDs)
- Maybe mWDs all form through CE evolution (Tout et al. 2008)
  - Smaller final orbital separation
    $\Rightarrow$ stronger B-field
  - Single mWDs result of merger; ones that don't merge mCVs

    $\Rightarrow$ Real intrinsic difference in fraction of mWDs

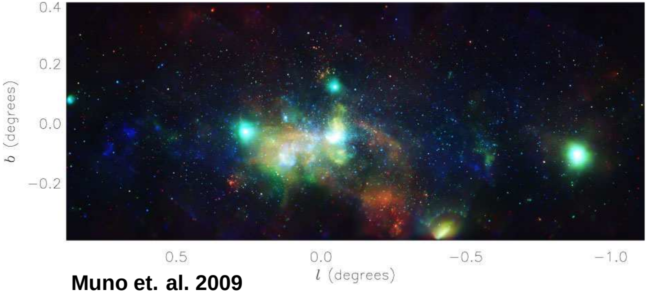
Are mWDs really more common in CVs than in the field?

- mCVs: $8^{+4}_{-2} \times 10^{-7}\,\mathrm{pc}^{-3}$
- non-magnetic CVs: $4^{+6}_{-2} \times 10^{-6}\,\mathrm{pc}^{-3}$ (Pretorius & Knigge 2012)
- So, $\log(f_{mCV}) = -0.8^{+0.3}_{-0.4}$, i.e $f_{mCV} \simeq 16\%$
- only good to within about a factor of 2
  (perhaps systematic bias as well)

$\Rightarrow$ Fractions are the same, within the errors

X-ray source populations

Do IPs dominate Galactic X-ray Source Populations?



Muno et. al. 2009

Chandra GC survey:

- $2^\circ \times 0.8^\circ$
- $\simeq$ 9000 sources ($L_X \gtrsim 10^{31}\,\mathrm{ergs}^{-1}$ at 0.5–8.0 keV)
- Uncertain source classification

- X-ray sources in the Galactic Centre: $\rho_{X,GC} \sim 6 \times 10^{-4}\,\mathrm{pc}^{-3}$
- stellar density 1590$\times$ higher than solar neighborhood
- 1 X-ray source per $\sim$100,000 stars in the GC
- our ρ_{IP} implies 1 IP per $\sim$200,000 stars in solar neighborhood

$\Rightarrow$ Consistent, because numbers are only good to withing a factor of $\sim$2

IPs can account for most of the X-ray source population in the Galactic Centre (also in the Milky Way as a whole, in globular clusters)

Conclusions

- ρ is a basic prediction of CV evolution theory $\Rightarrow$ important to constrain it observationally
- Flux-limited X-ray samples maybe the best way to measure it
- We use the complete samples from RBS and NEP, construct one from *Swift*/BAT
- non-magnetic CVs: $4^{+6}_{-2} \times 10^{-6}\,\mathrm{pc}^{-3}$
- mCVs: $8^{+4}_{-2} \times 10^{-7}\,\mathrm{pc}^{-3}$ (for detectable systems)
  - IPs and polars separately: $\rho_{polar} = 5^{+3}_{-2} \times 10^{-7}\,\mathrm{pc}^{-3}$ and $\rho_{IP} = 3^{+2}_{-1} \times 10^{-7}\,\mathrm{pc}^{-3}$
- Some implications for evolution of CVs
  - Non-magnetic: $\rho_0 = 10^{-4}\,\mathrm{pc}^{-3}$ implies $L_X \lesssim 8 \times 10^{28}\,\mathrm{erg\,s}^{-1}$ for dominant population
  - ρ_{IP} high enough to explain observed number of bright ($L_X \gtrsim 10^{31}\,\mathrm{ergs}^{-1}$) Galactic Centre X-ray sources
  - Fraction of strongly magnetic WDs not clearly higher in CVs than in the single WD population
  - $\rho_{polar,sp}/\rho_{IP,lp}$ consistent with long-P_{orb} IPs becoming short-P_{orb} polars. Also possible that short-P_{orb} IP population is big enough (IPs evolve into IPs), despite very small observed number
- To improve on this, we need similar but deeper CV samples with good distances $\Rightarrow$ *Gaia*; also *eROSITA* and further follow-up of BAT sources