Galactic Neutron Stars

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The Problem

- LIGO(+VIRGO+GEO etc.) wants to detect CW emission from a (isolated) neutron star
- Such a NS would need to be:
  - Nearby: $h \sim 1/d$
  - Quickly rotating: $h \sim 1/P^2$, + finite band, noise curve
  - Elliptical: $h \sim \varepsilon$
- Current analysis on known objects gives only upper limits (e.g., Abbott et al. 2009)
- Are there any unknown objects that would be better targets?

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  - Ne
  - Qu … curve
  - Elliptical: h~ε

Are there any indications of "missing"/ unusual populations?

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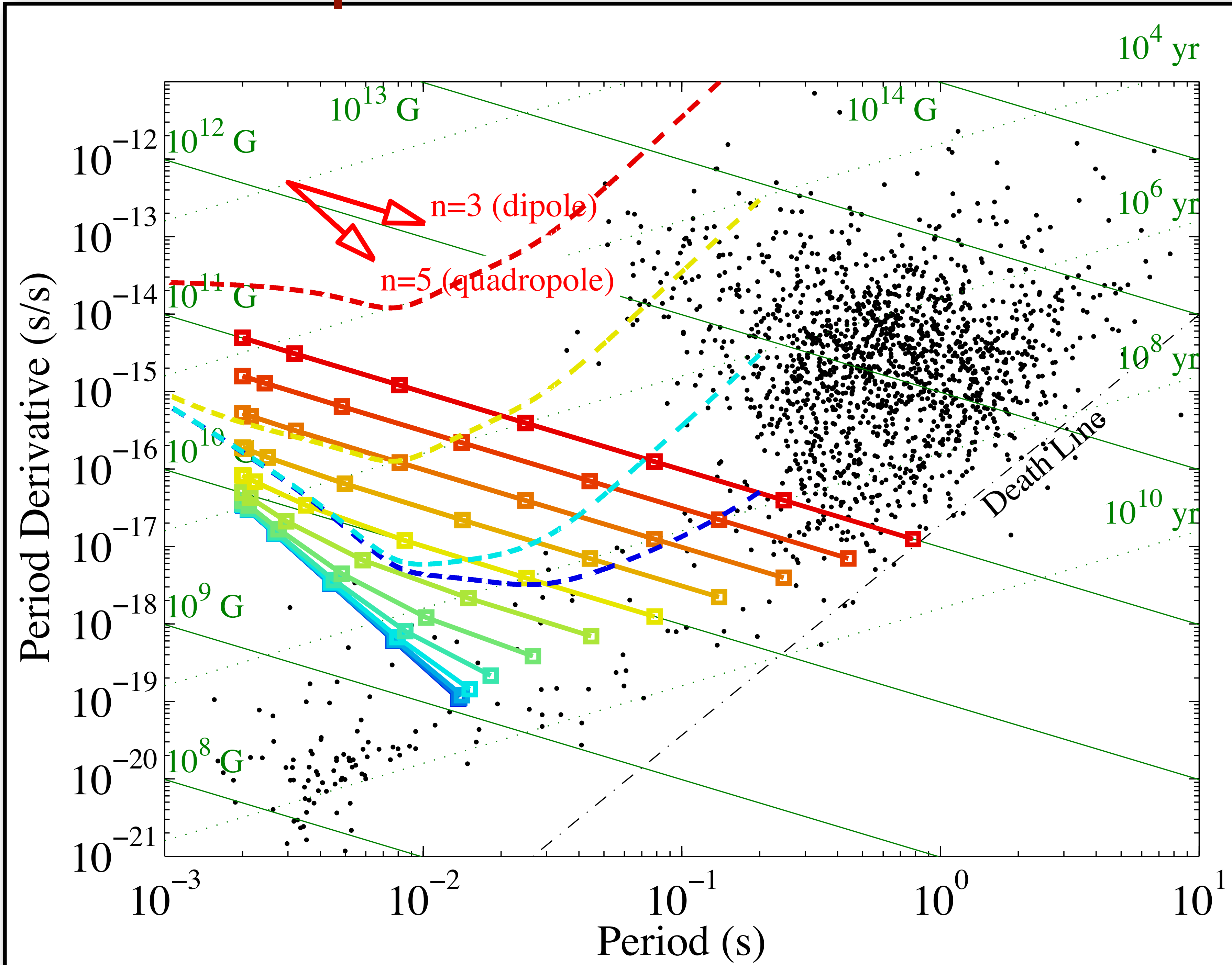
- Are there any unknown objects that would be better targets?

Which Populations?



See Wade et al. (2012)

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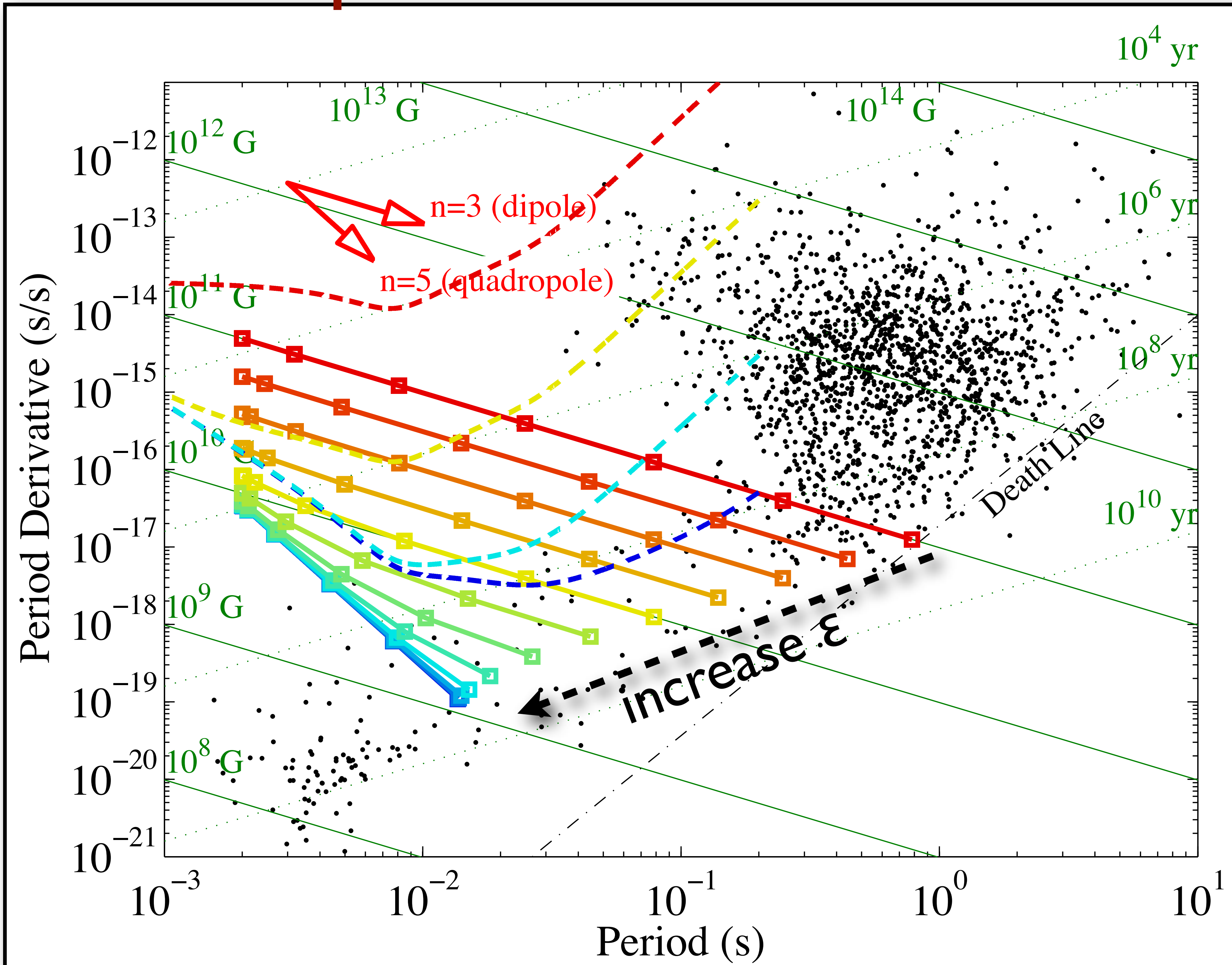

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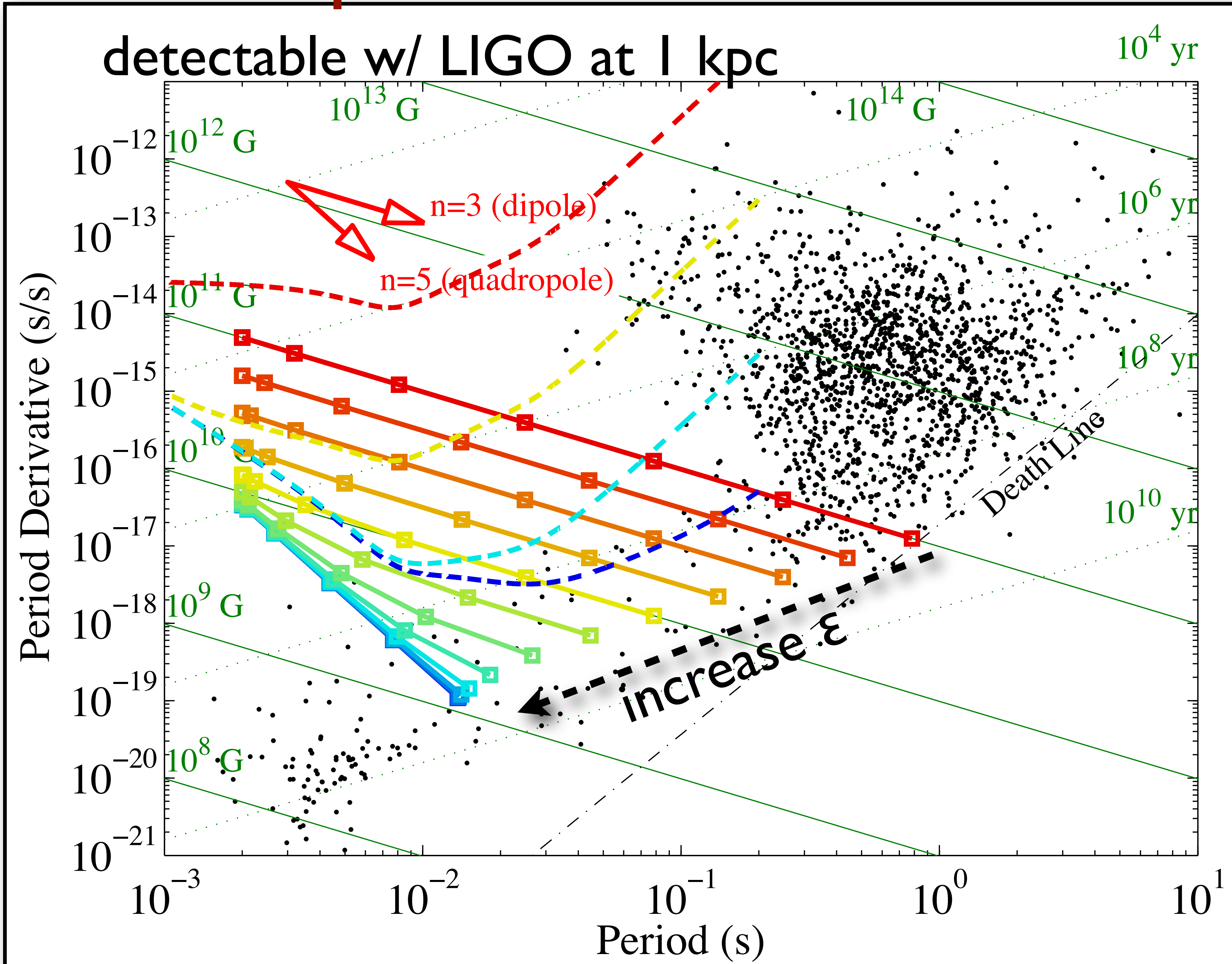

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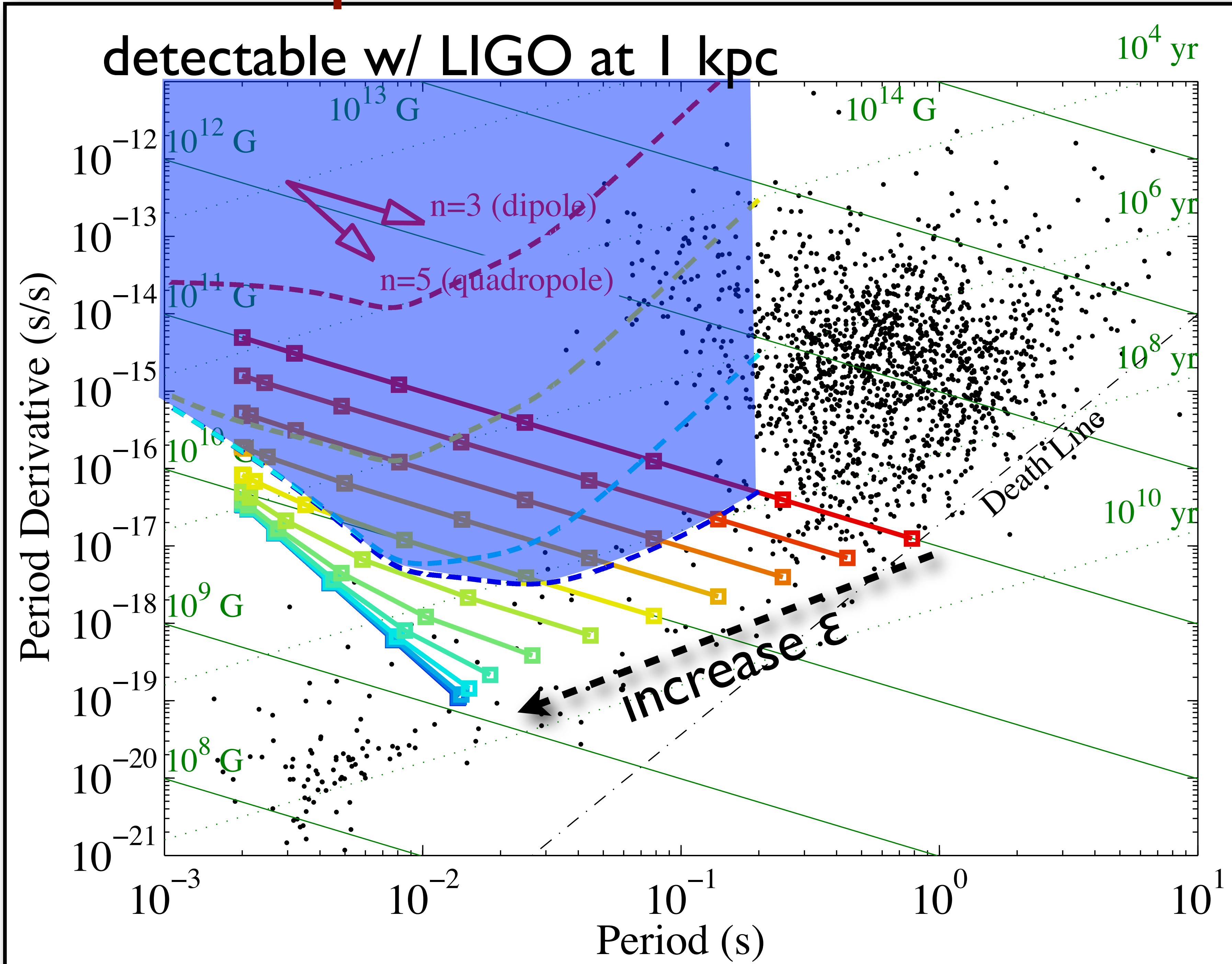

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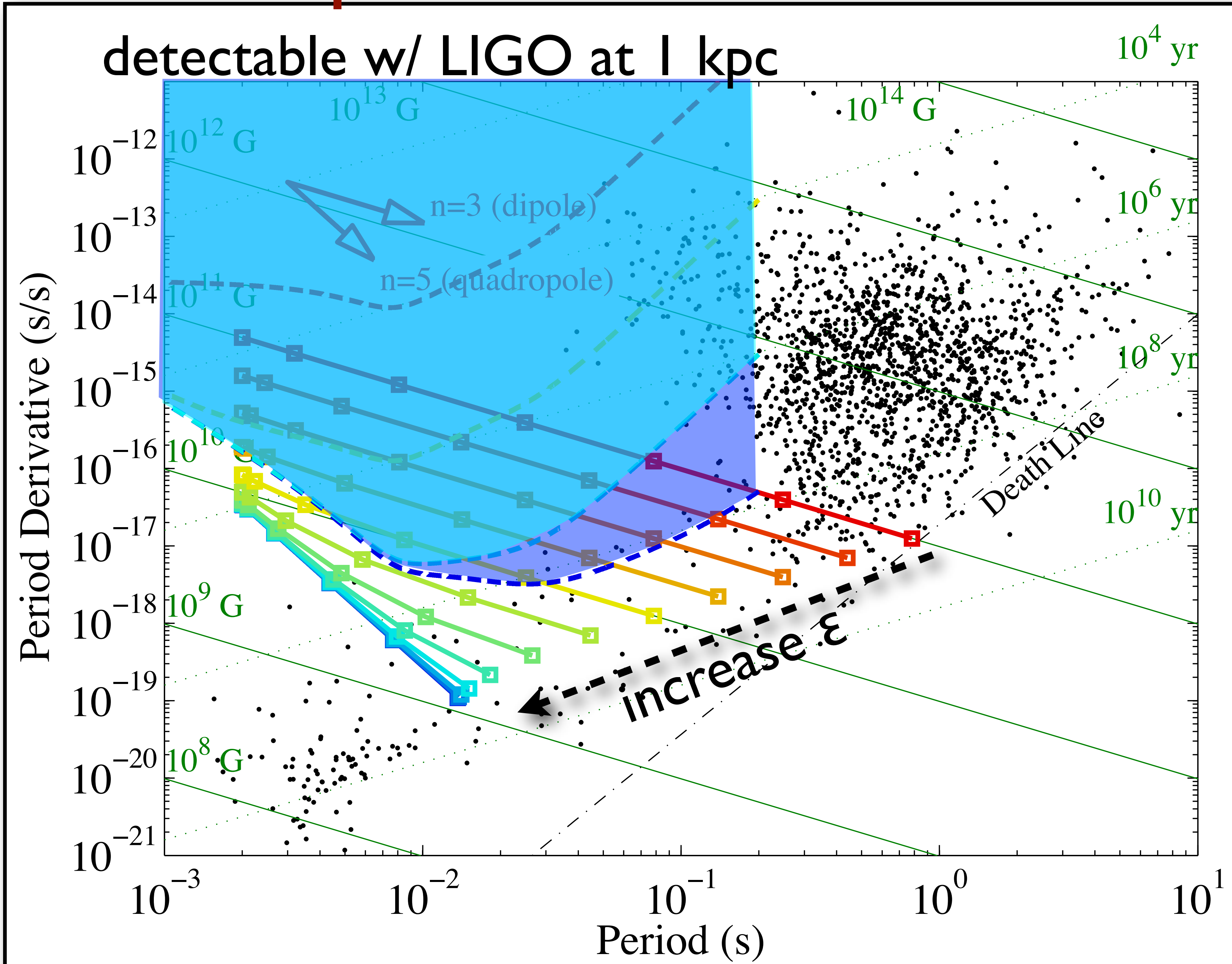

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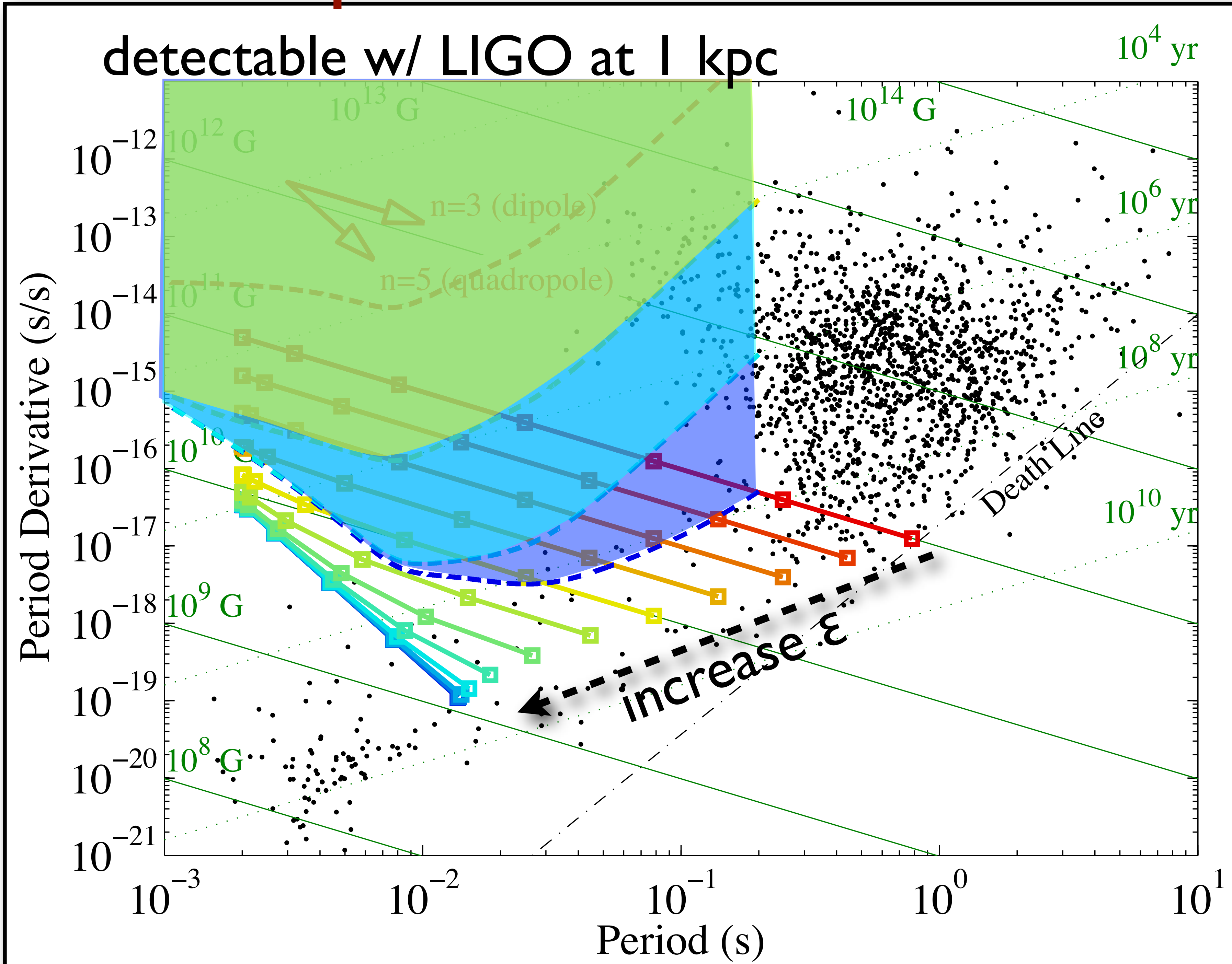

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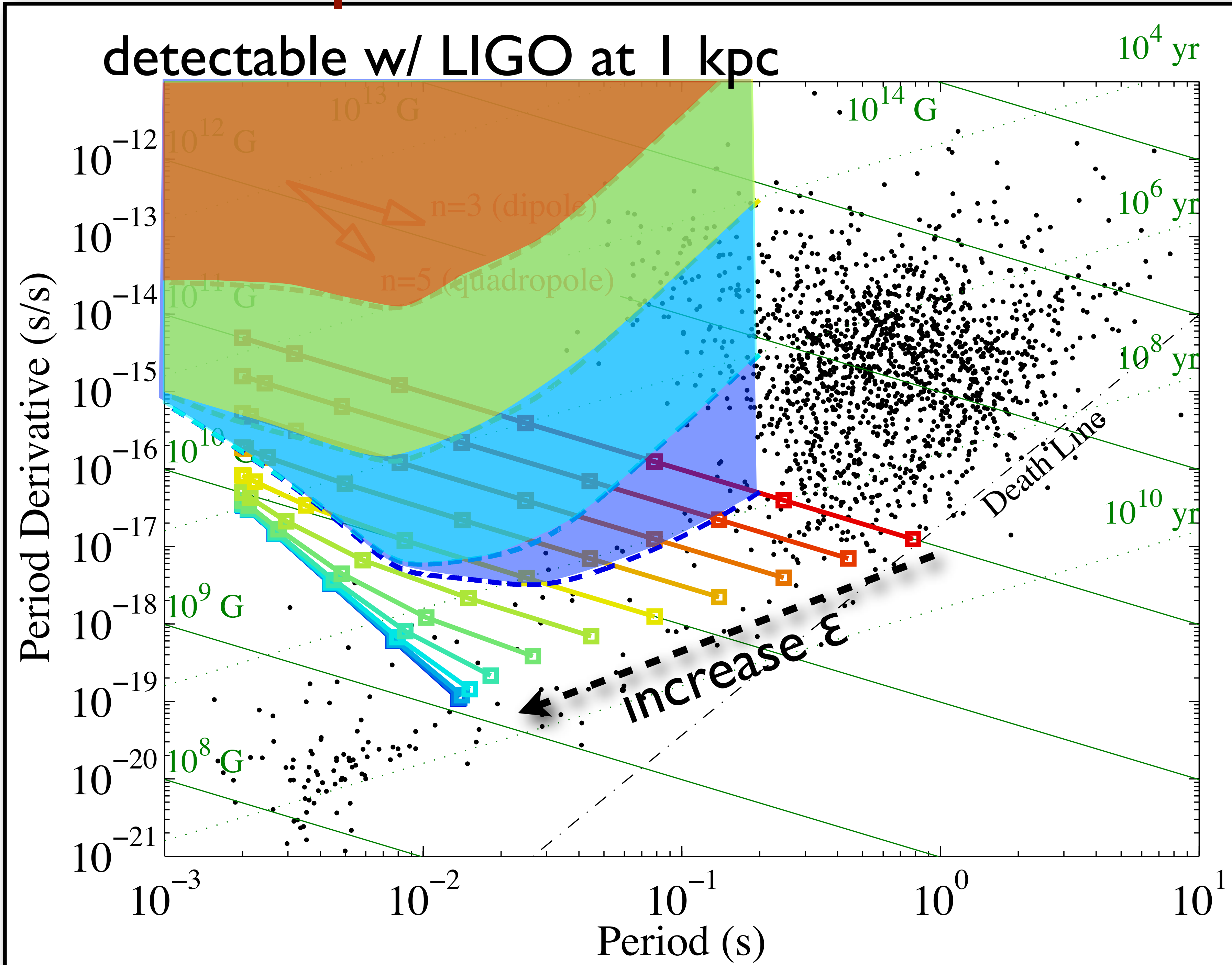

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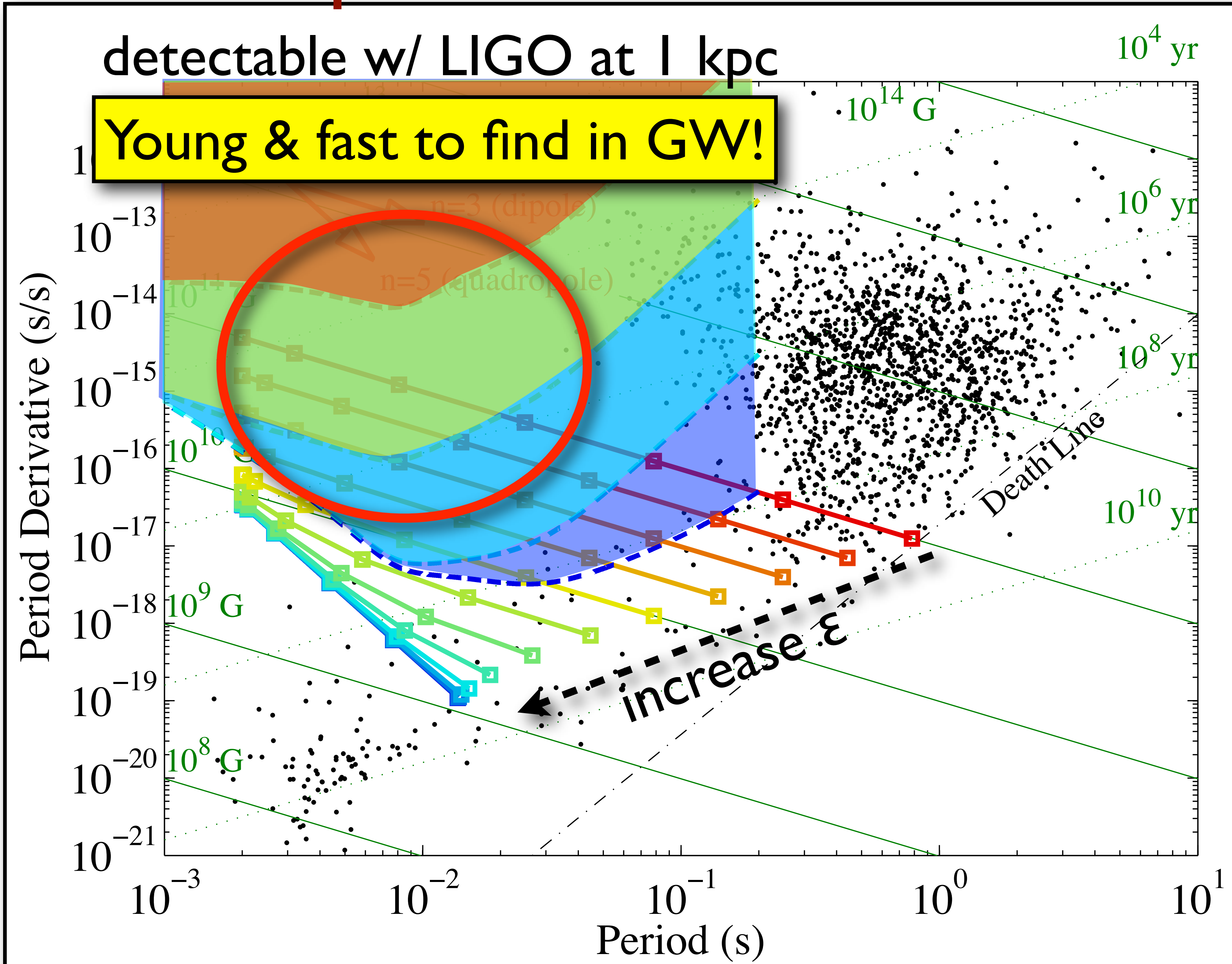

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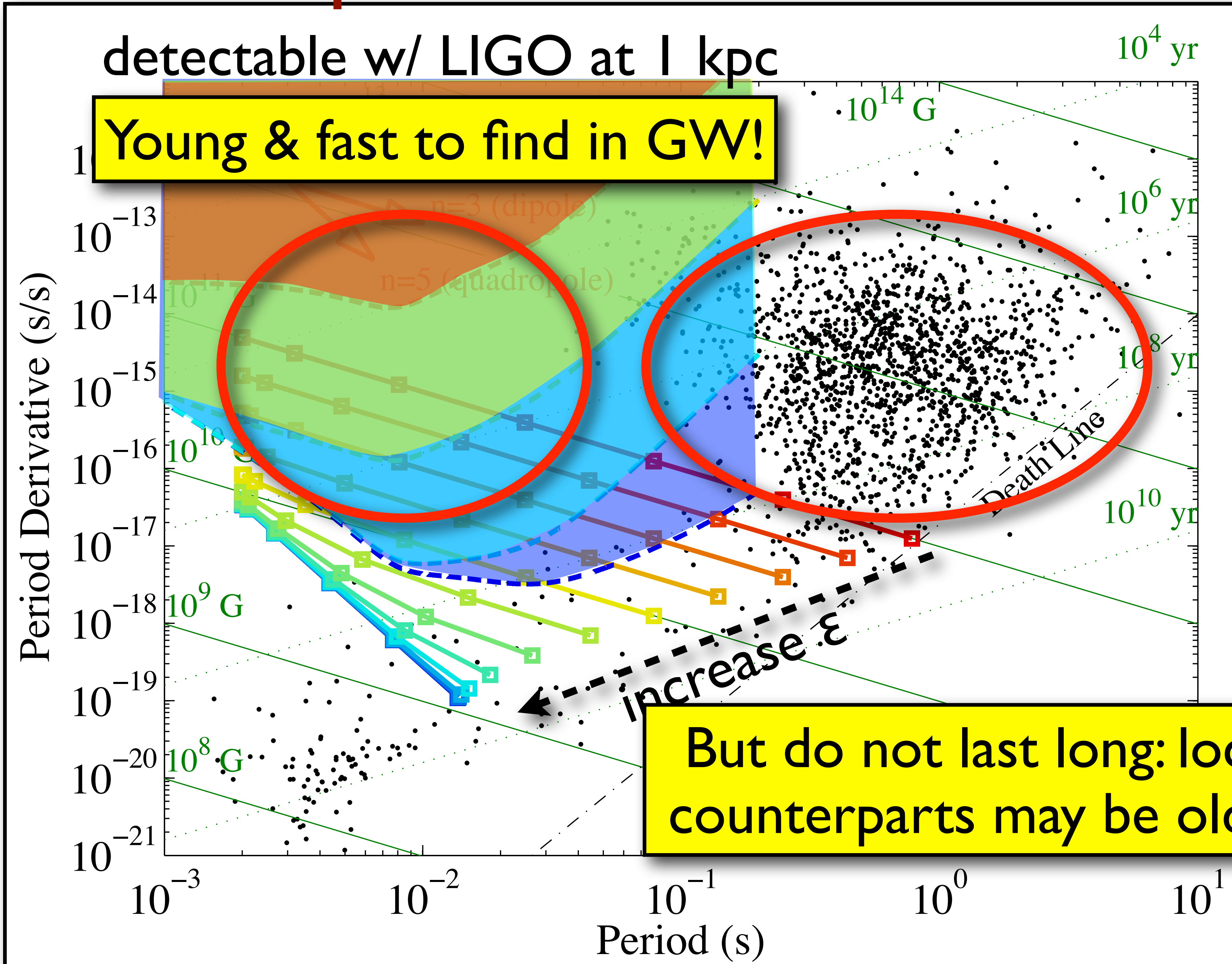

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- Finding: 0 found from accretion; 7.5±0.5 found from cooling

What We Know from X-rays

- *ROSAT* All-Sky Survey (>0.05 count/sec):
  - Soft X-rays (0.1-2.4 keV)
  - Efficient way to find young/energetic/nearby neutron stars

[red box] =no radio

Pulsars (non-thermal, P<400 ms)	INS (thermal, P>3 s)
v. young! Crab (48.4 s^{-1})	RX J1856.5-3754 (3.64 s^{-1})
Vela (3.4 s^{-1})	RX J0720.4-3125 (1.64 s^{-1})
PSR B0656+14 (1.92 s^{-1})	RX J1605.3+3249 (0.90 s^{-1})
Geminga (0.54 s^{-1})	RX J0806.4-4123 (0.38 s^{-1})
PSR B1055-52 (0.35 s^{-1})	RX J1308.6+2127 (0.29 s^{-1})
old! PSR J0437-4715 (0.20 s^{-1})	RX J2143.0+0654 (0.18 s^{-1})
old or young? Calvera (0.08 s^{-1})	RX J0420.0-5022 (0.14 s^{-1})
PSR J0538+2817 (0.06 s^{-1})	No Beaming!
PSR B1951+32 (0.07 s^{-1})	

Kaplan (arXiv:0801.1143); Kaplan and van Kerkwijk (2009, ApJ, 705, 798);
Zane et al. (2011, MNRAS, 410, 2428)

Non-Detection of Accreting NS

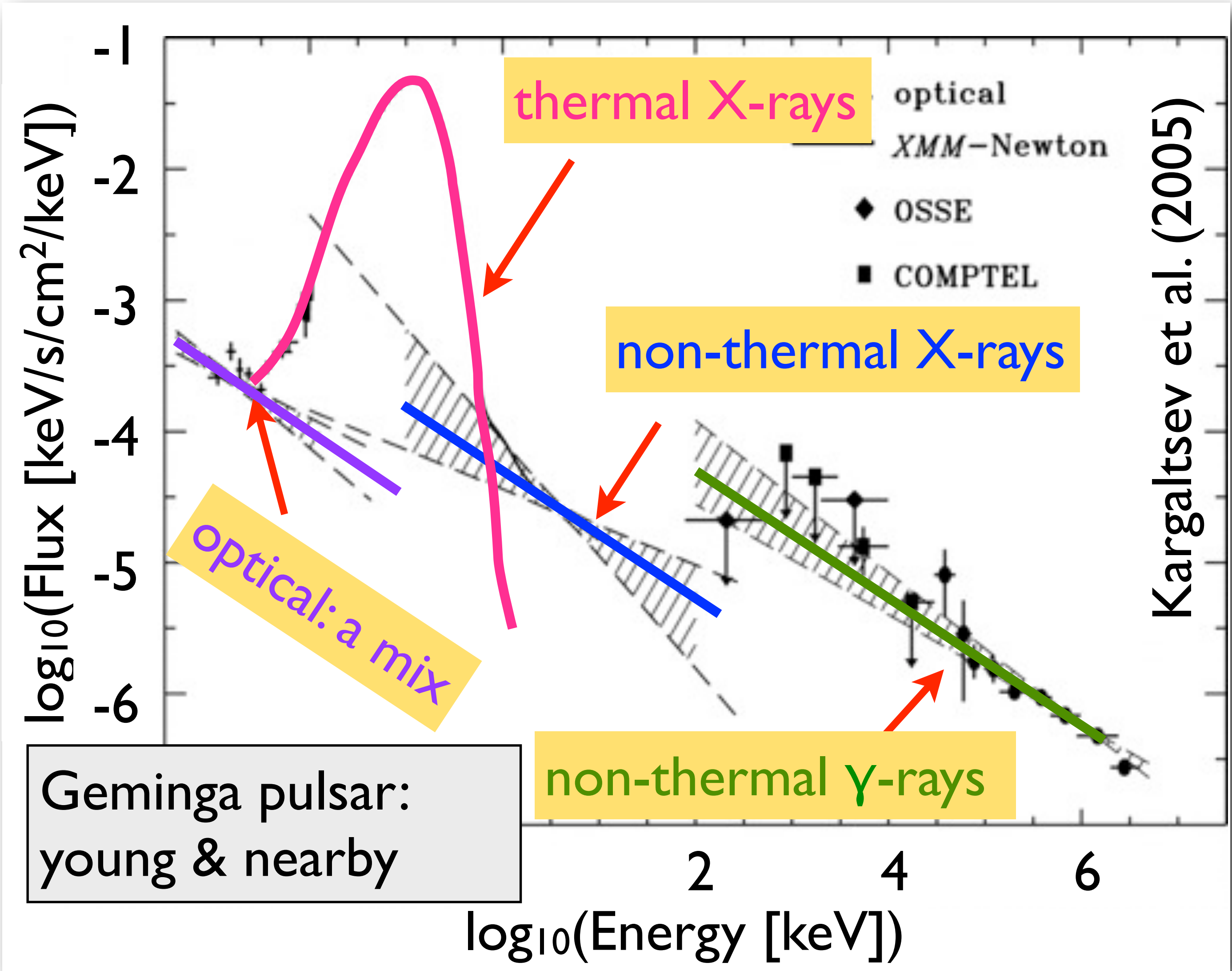
- Perna et al. (2003, ApJ, 594, 936):
  - Inclusion of realistic velocity distribution ($L \sim \dot{M} \sim 1/v^3$)
  - And accretion suppressed wrt Bondi
    - Weak B of ISM
    - Strong B of NS
  - Revised expectation consistent with 0 found

Types of (Isolated) Neutron Stars

Type	Energy Source	E.G.	B(G)	Age	P	Close?	R	O	X	γ	Bad for GW?	Refs.
Young Pulsar	Spin (+heat)	PSR B0656	$\sim 10^{12}$	$<10^{7}$	30ms-8s	<300 pc	✓	✓	✓	✓	spin-down quickly	
INS	Heat (+B)	RX J1856	$\sim 10^{13}$	$<10^{6}$	3s-10s	<200 pc	✕	✓	✓	✕	spin-down quickly++	Kaplan (arXiv: 0801.1143); Kaplan & van Kerkwijk (2009, ApJ, 705, 798)
Recycled Pulsar	Spin	PSR J0437	$\sim 10^{9}$	$>10^{8}$	<20 ms	<200 pc	✓	✓	✓	✓	spherical?	
Calvera	Spin? Heat?	Calvera	$<10^{12}$	?	59 ms	yes?	✕	✕	✓	✕	?	Rutledge et al. (2008, ApJ, 672, 1137); Zane et al. (2011, MNRAS, 410, 2428); Halpern (2011, ApJ, 736 L3)
Magnetar	B	SGR 1900+14	$>10^{14}$	$<10^{4}$	2s-10s	no	✓/✕	✓	✓	✓	spin-down quickly+++, far	Mereghetti (2008, A&A Rev., 15, 225)
CCO (Anti-magnetar)	Heat	Cas A	$\lesssim 10^{11}$	$<10^{4}$	~200 ms	no	✕	✕	✓	✓	born with long P?	Halpern & Gotthelf (2010, ApJ, 709, 436); Halpern & Gotthelf (2011; ApJ, 733, L28)

Young Pulsars

- Examples: Vela, Crab, Geminga
- P < 400 ms
- Rotation-powered (+heat), B~10^{12} G
- Radio, IR, optical, UV, X-ray, γ-ray



Isolated Neutron Stars

- Example: RX J1856.5-3754
- P = 3-10s
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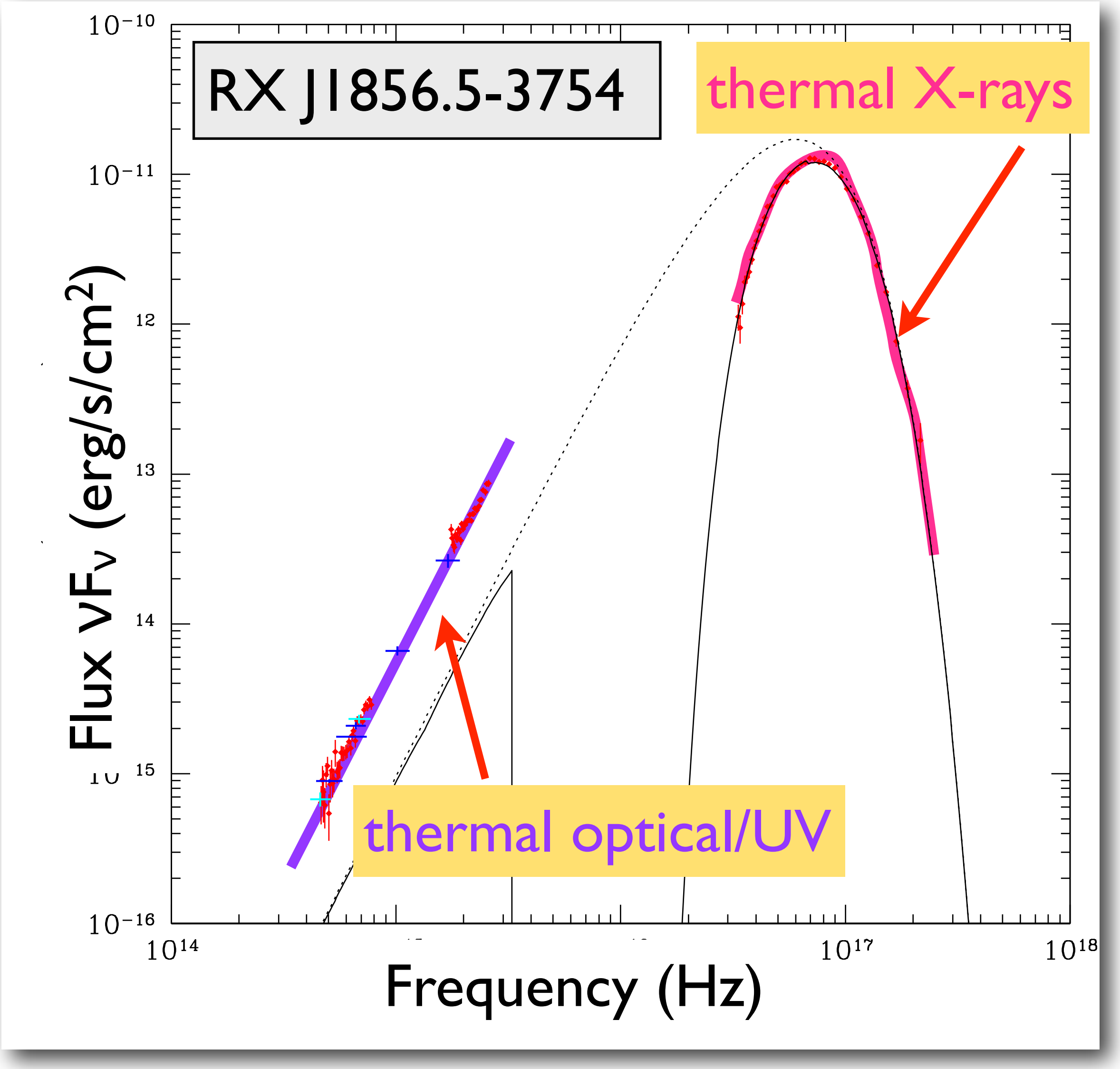
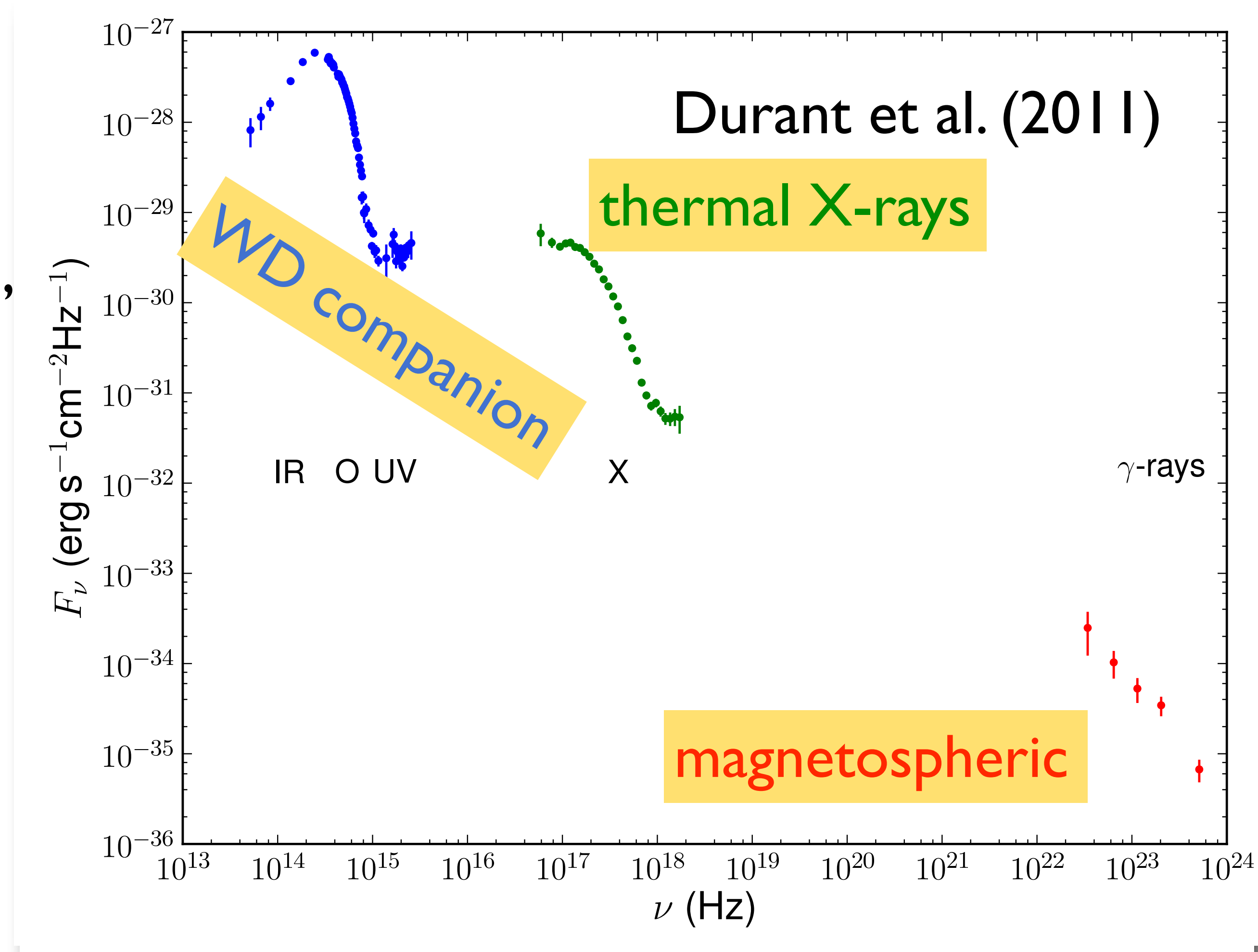


Recycled (ms) Pulsars

- Example: PSR J0437-4715
- P < 100 ms
- Rotation powered, B~10^9 G, old
  - Thermal emission in X-rays from heated polar caps?
- Visible at radio, optical, UV, X-ray, γ-ray
- *Fermi* is finding many, L_γ related to $\dot{E}$ (Abdo et al. 2009, 2010, ...)

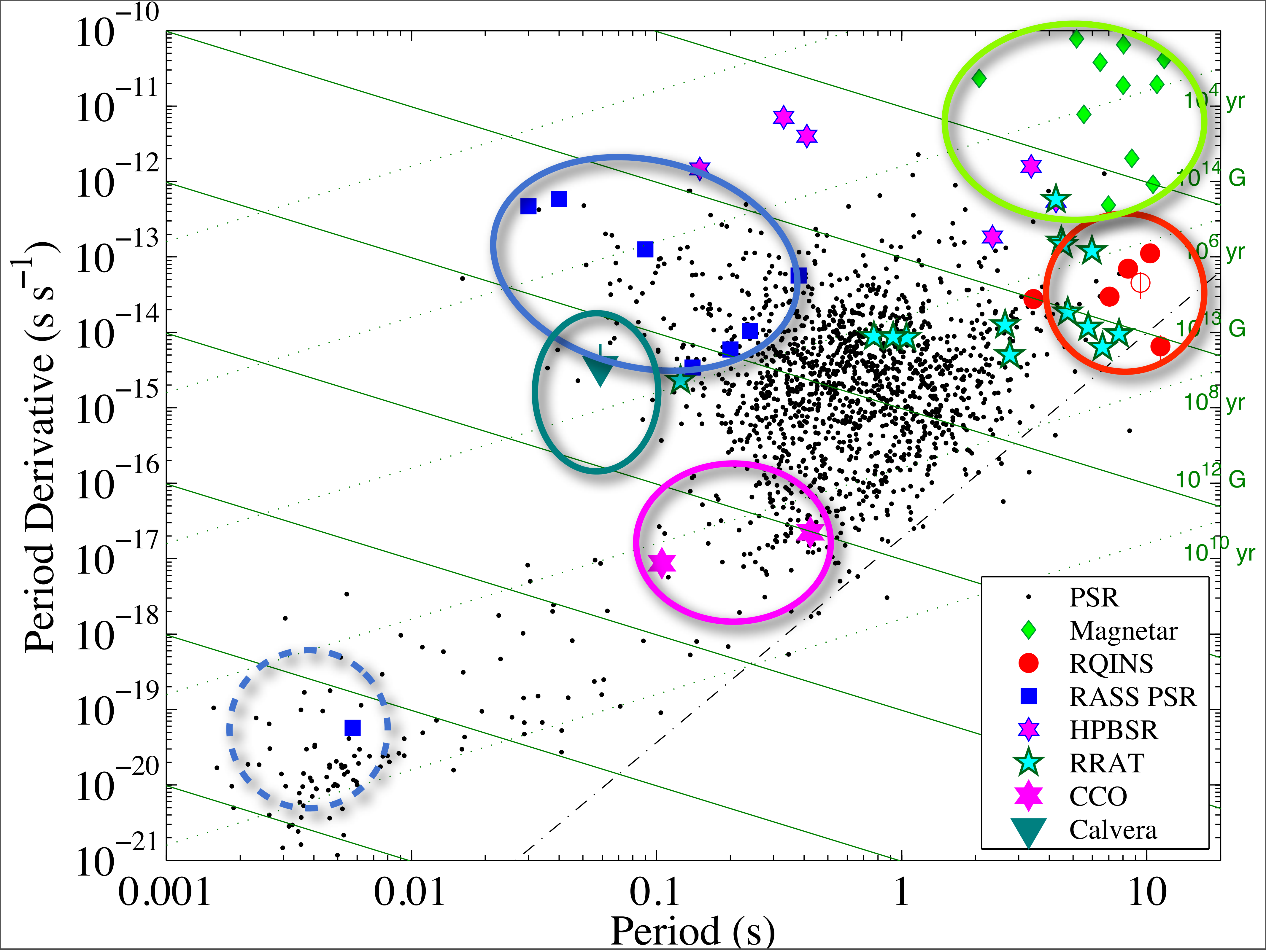


Calvera

- Discovered by Rutledge et al. (2008) in search for more INS
- Spectrum from Shevchuk et al. (2009)
  - $kT_{BB} \approx 250$ eV, but not a good fit
- P=59 ms (Zane et al. 2011)
  - $B < 10^{12}$ G (Halpern 2011)
- Visible at X-ray
- Rotation powered(?)/residual heat(?),
  - Distance unknown, consistent with ~1 kpc
  - Escaped Central Compact Object (CCO)?
  - Mildly recycled pulsar (analog of Geminga)?

Other Types of NS

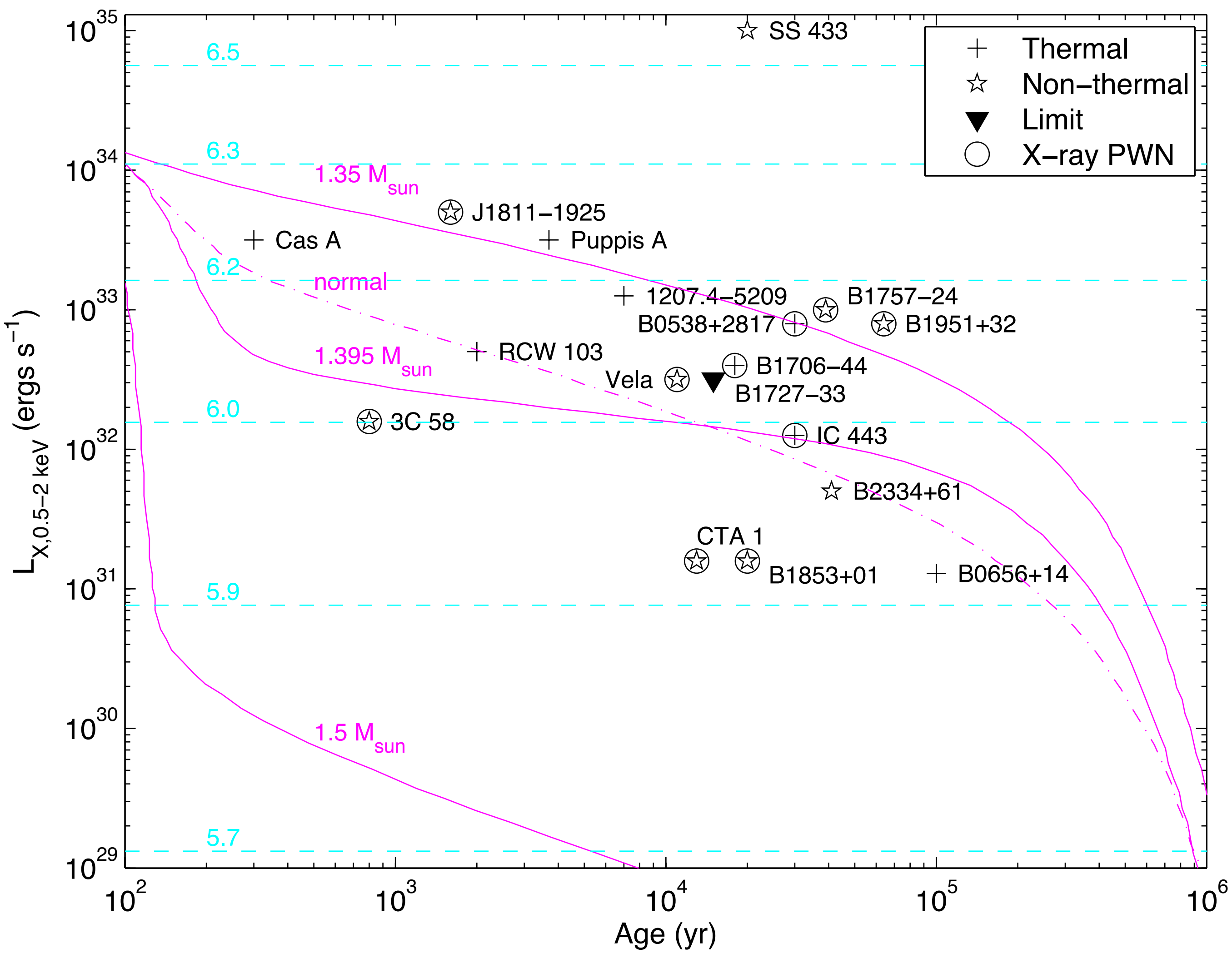
- Magnetars (2s-10s):
    - B decay, $B \gtrsim 10^{14}$ G
    - Visible at radio, IR, optical, UV, X-ray, γ-ray
- CCOs (100ms-500ms):
    - Pavlov et al. (2004); de Luca (2008) for reviews
    - Compact Central Objects (in young SNRs)
    - Residual heat, $B < 10^{11}$ G (anti-magnetars): Halpern & Gotthelf
    - Visible at X-ray
- No local examples of either, but young: could influence old population



Period Derivative (s s^{-1})
Period (s)
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
0.001
0.01
0.1
1
10
10^4 yr
10^{14} G
10^6 yr
10^{13} G
10^8 yr
10^{12} G
10^{10} yr
PSR
Magnetar
RQINS
RASS PSR
HPBSR
RRAT
CCO
Calvera

What Else Should Be There?

- Kaplan et al. (2004, 2006): X-ray search for young NSs in supernova remnants
- Tight limits on 15 (of 45) SNRs, factor of ~10 below normal cooling
- Accelerated cooling + low B→invisible?
  - Would then be in accreting sample
- Or something else (high v, BH, SN Ia, ...)



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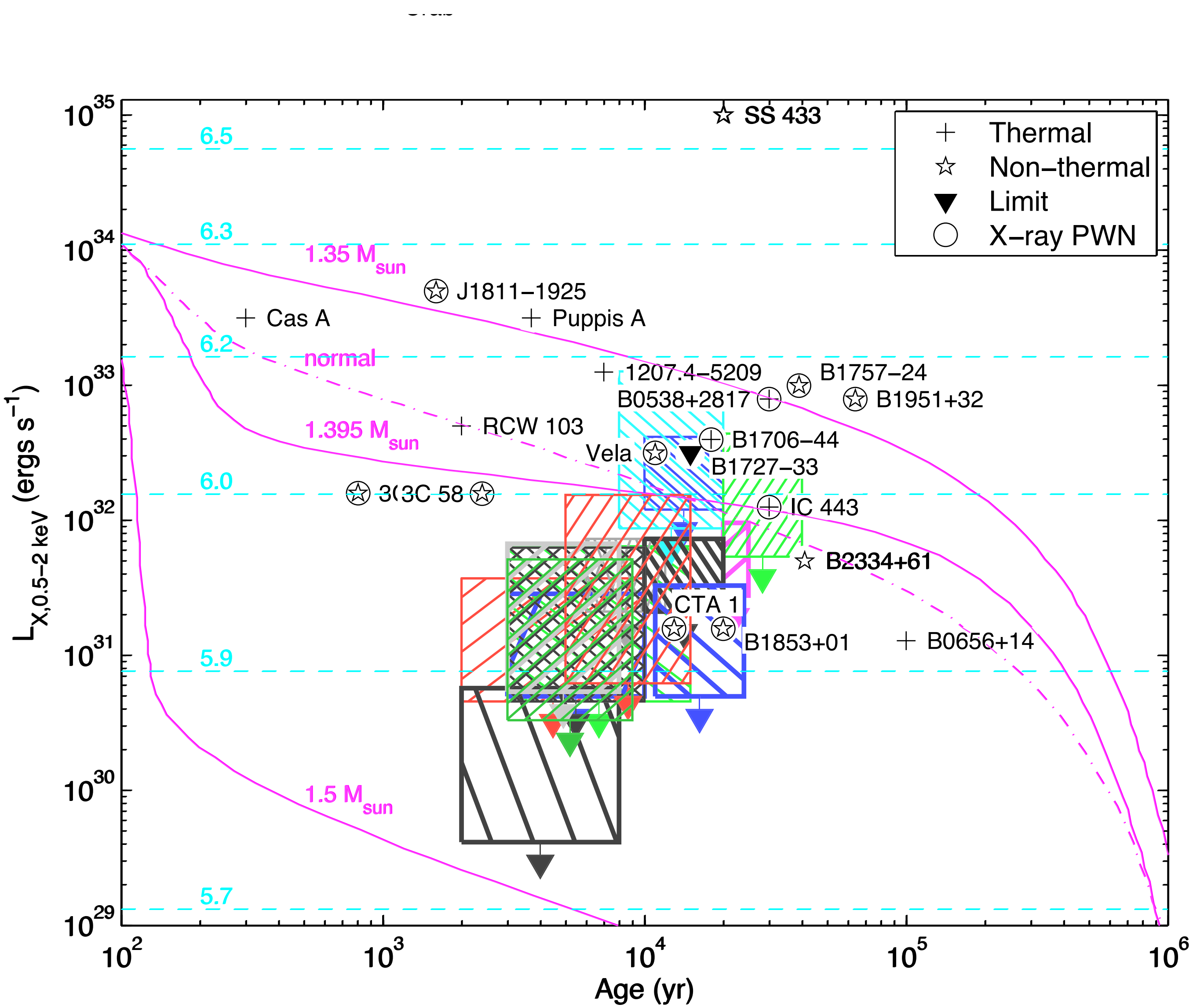

Populations

- INS: 20%-40% of pulsars (visibility augmented by B decay); Kaplan & van Kerkwijk (2009)
  - Young sources ~consistent with enhanced (x3?) SN rate locally (Popov et al. 2005, 2006, ...); but double counting (Keane & Kramer, Gill & Heyl)?
- CCOs: 10%-20% of SNRs (based on sample of Kaplan et al. 2004)
- There should still be other NSs out there (accreting, cooling, ...)
  - *ROSAT* searches (Rutledge et al.; Turner et al.; Agüeros et al.) could have found some, but only found Calvera
  - ≲30 total remaining in *ROSAT* (Turner et al. 2010)
  - Deeper *XMM* searches (Pires et al. 2009) identified candidate(s)
  - *eROSITA* will conduct soft X-ray survey with x10 sensitivity of *ROSAT* (launch in 2012/13), expand population to >100
  - But ISM + Stefan-Boltzmann make it hard to find nearby, cool objects
  - Will help find distant, hot objects instead
- We can't find invisible objects, but wide diversity apparent in what is found