Ultra-long Period Radio Sources - Are they Magnetars?

Zorawar Wadiasingh (University of Maryland College Park / NASA GSFC)
Work with:
Paz Beniamini (Open University, Israel)
Alex Cooper (Oxford)
Jeremy Hare (NASA / GSFC)
George Younes (NASA /GSFC)
Kaustubh Rajwade (Oxford)
Andrey Timokhin (Zelona Gora)
Sam Lander (East Anglia)
Konstantinos Gourgouliatos (Patras)

July 9, 2024 — 17th Marcel Grossman Meeting

Ultra-long Period Radio Sources - Are they Magnetars?

Zorawar Wadiasingh (University of Maryland College Park / NASA GSFC)

Work with:
Paz Beniamini (Open University, Israel)
Alex Cooper (Oxford)
Jeremy Hare (NASA / GSFC)
George Younes (NASA / GSFC)
Kaustubh Rajwade (Oxford)
Andrey Timokhin (Zelona Gora)
Sam Lander (East Anglia)
Konstantinos Gourgouliatos (Patras)

I'll argue they are compatible with magnetars

July 9, 2024 — 17th Marcel Grossman Meeting

Short review: galactic ultra-long period magnetar (ULPM) candidates

Galactic ULPM candidates - 1E 161348–5055 in RCW 103

1E 161348–5055 - The magnetar CCO in RCW 103

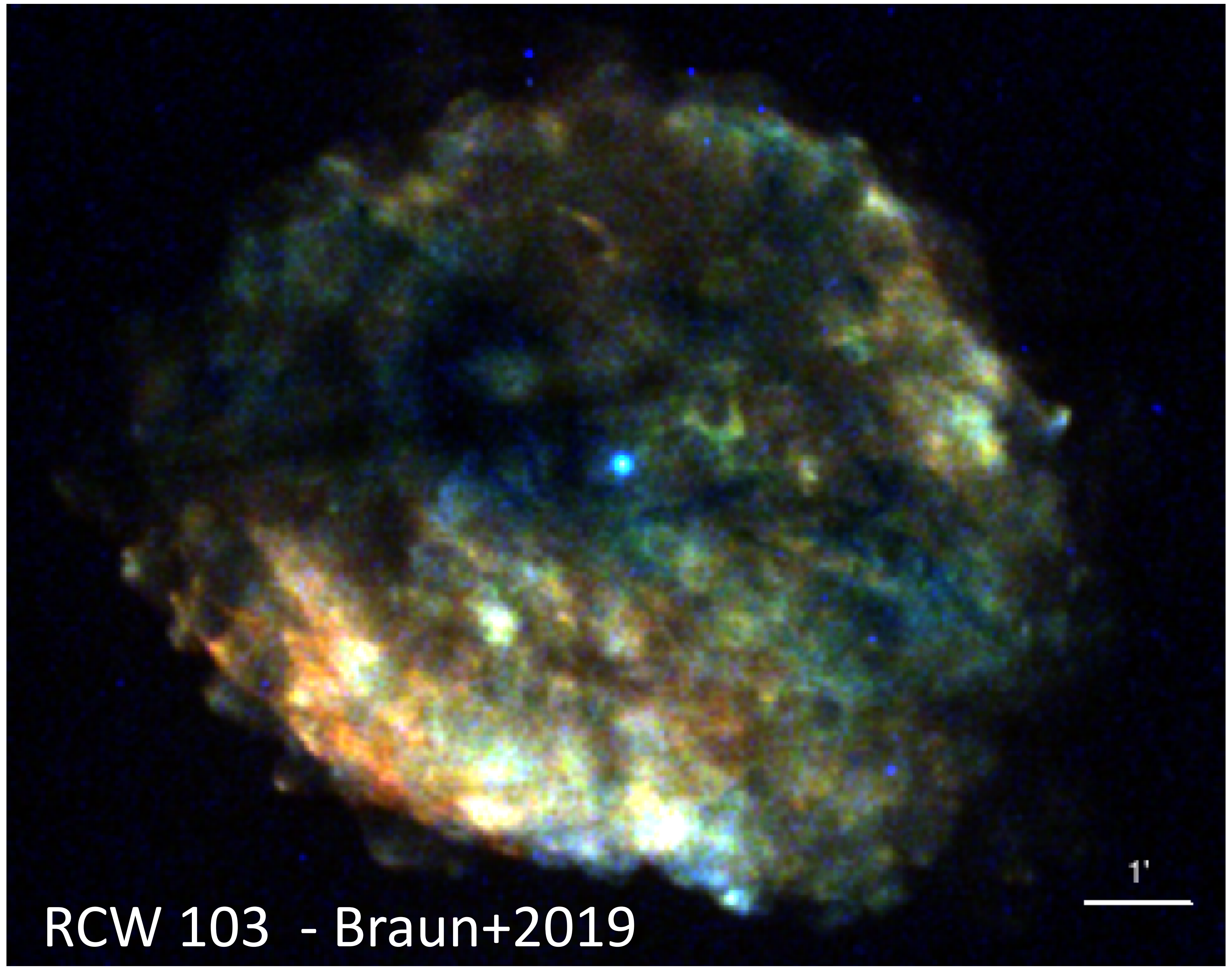
Pulsating (P ~ 6.7 hr) central compact object in SNR RCW 103:

1. Millisecond duration short X-ray bursts - similar to magnetars
2. Long-term outbursts and non-thermal hard X-ray emission
3. Proper motion ~ 170 km/s from *Chandra* imaging – Wide binary would have been disrupted
4. Companion hotter than M7 ruled out by HST observations – close binary should have been detected

} Magnetar-like phenomenology

Isolated magnetar nature of 1E 161348 seems most compatible with observations!

Credit: De Luca et al. 06, 08, Esposito et al. 11, D’Ai et al. 16, Rea et al. 16, Tendulkar et al. 17, Borghese et al. 18, Braun et al. 2019



RCW 103 - Braun+2019

Galactic ULPM candidates - 1E 161348–5055 in RCW 103

1E 161348–5055 - The magnetar CCO in RCW 103

Pulsating (P ~ 6.7 hr) central compact object in SNR RCW 103:

1. Millisecond duration short X-ray bursts - similar to magnetars
2. Long-term outbursts and non-thermal hard X-ray emission

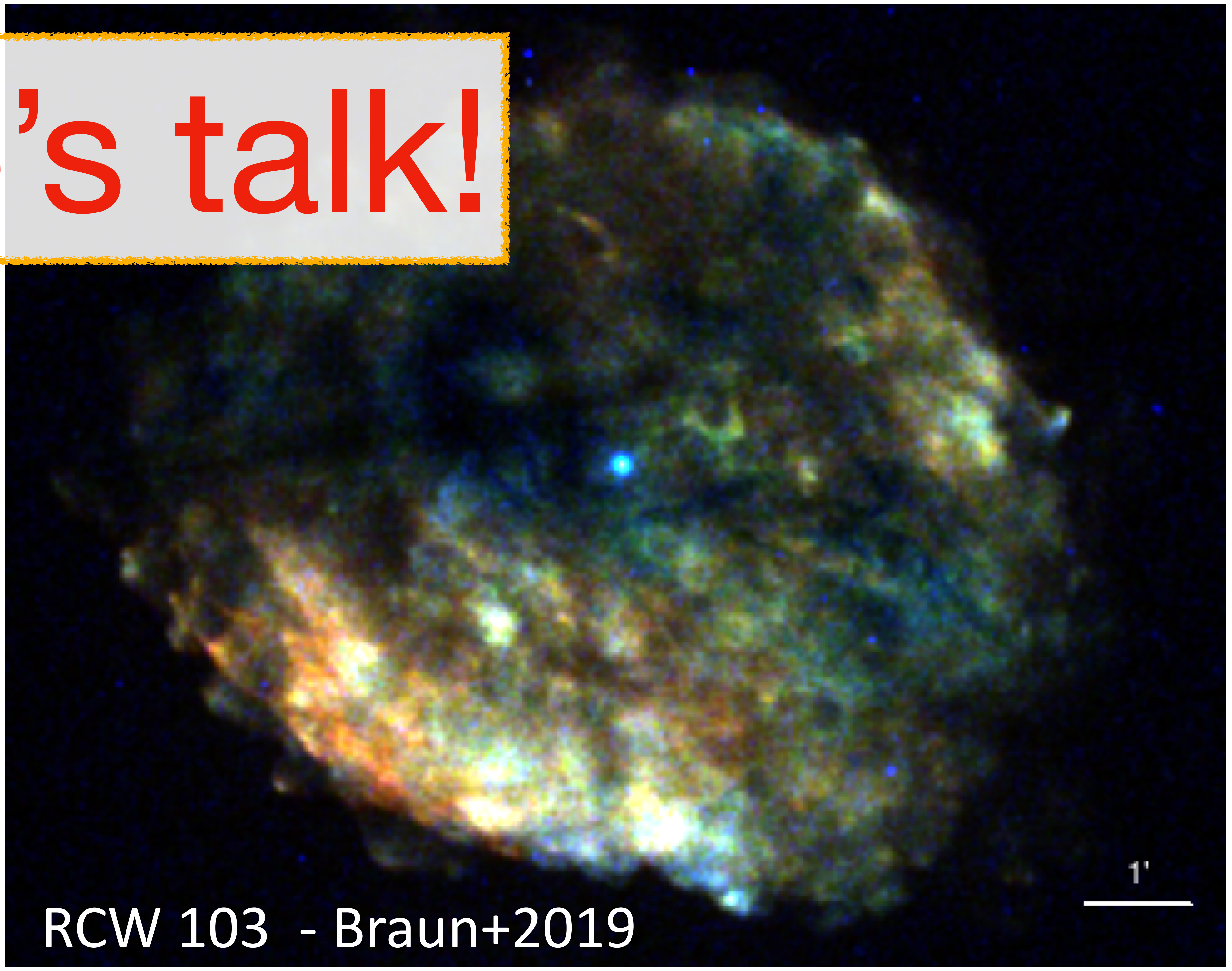
} Magnetar-like phenomenology

3. Proper motion ~ 170 km/s from *Chandra* imaging – Wide binary would have been disrupted
4. Companion hotter than M7 ruled out by HST observations – close binary should have been detected

See Alice Borghese's talk!

Isolated magnetar nature of 1E 161348 seems most compatible with observations!

Credit: De Luca et al. 06, 08, Esposito et al. 11, D'Ai et al. 16, Rea et al. 16, Tendulkar et al. 17, Borghese et al. 18, Braun et al. 2019



RCW 103 - Braun+2019

Persistent Hard Tail of The Ultra-long Period Magnetar in RCW 103

Rea+2016, De Luca+2006, D'Ai+2016 and earlier works

P = 6.67 hr

This existence of this object is one of the major reasons to believe ULPMs are real and common
(besides new radio candidates…)

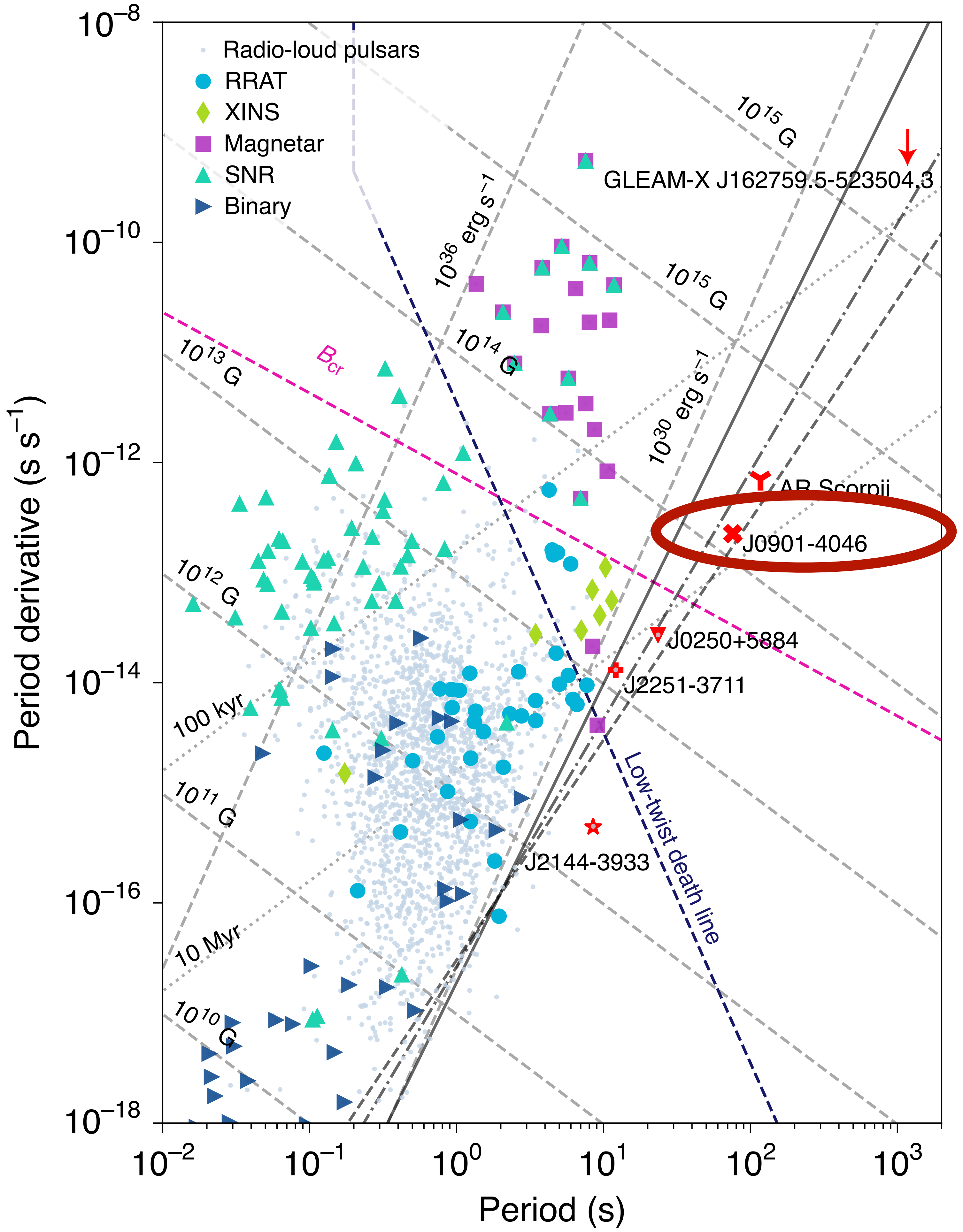
See Beniamini, Wadiasingh, & Metzger (2020)

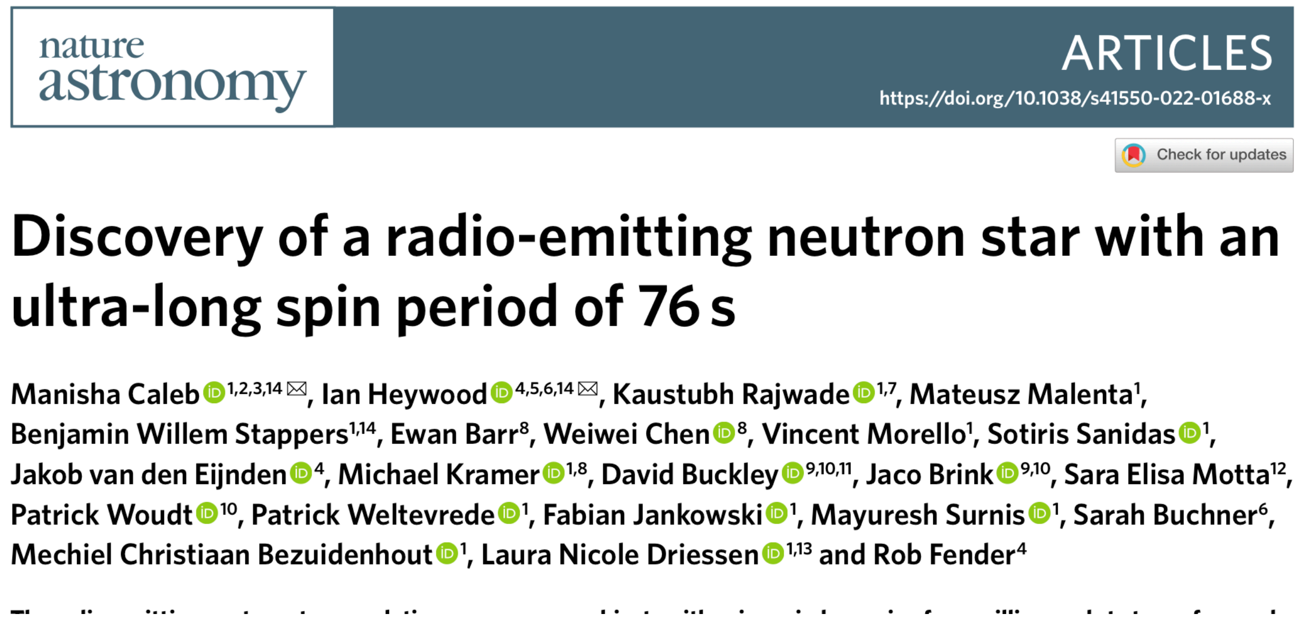
Galactic ULPM candidates - PSR J0901-4046

PSR J0901-4046 (formerly MTP0013)

P ~ 76 s pulsar, well-measured Pdot ~ 2x10^{-13} —> B_{pole} ~ 2x10^{14} G

1. Pulsar radio characteristics: high polarization fraction, PPA swings, variability in single pulses of flux and polarization
2. Very stable in timing — unusually stable for a magnetar
3. Only 328 pc away (YWM16) — implies many more exist
4. Lx < $10^{30.5}$ erg/s
5. harmonic spaced QPOs at O(10) Hz– consistent with the existence of NS crust, unlikely to be magnetospheric Alfvenic modes





nature astronomy

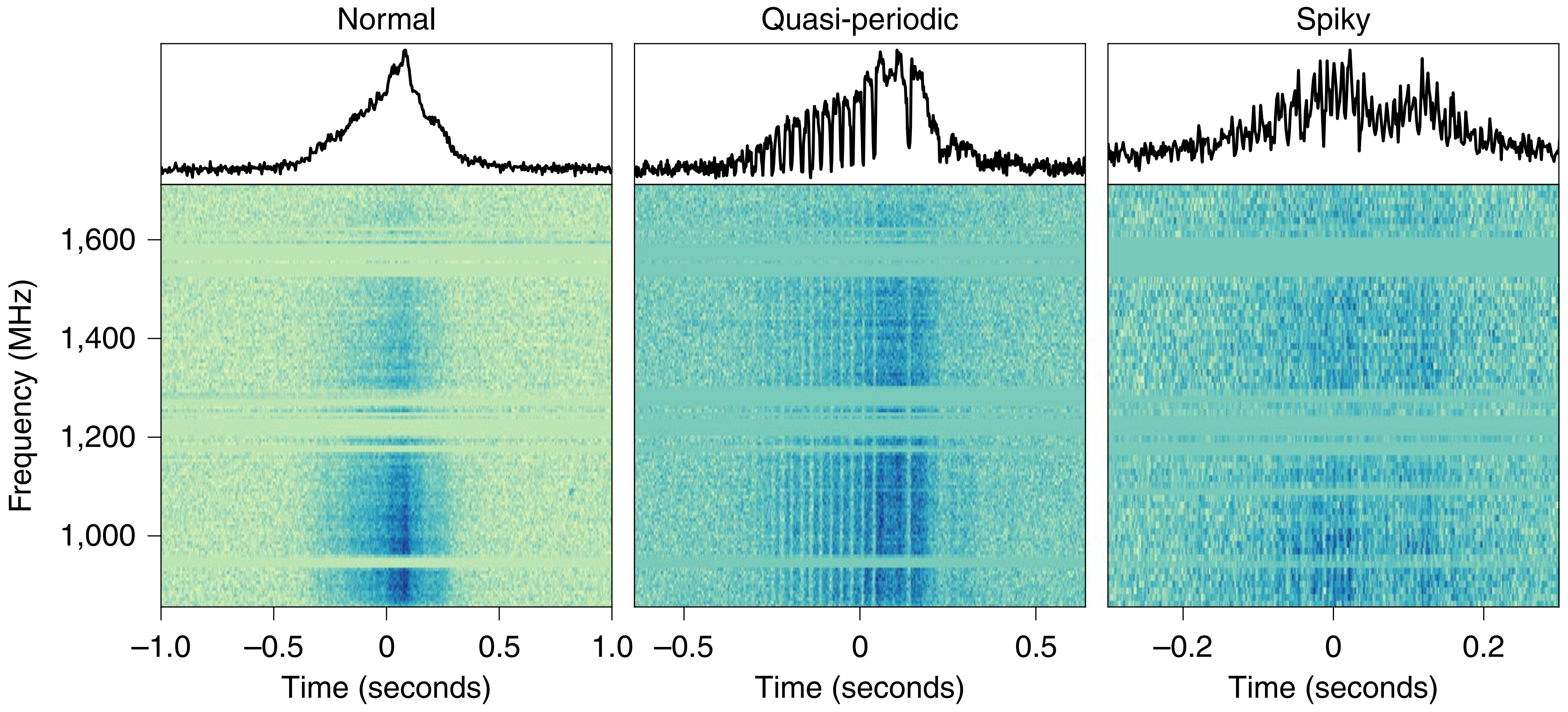
ARTICLES

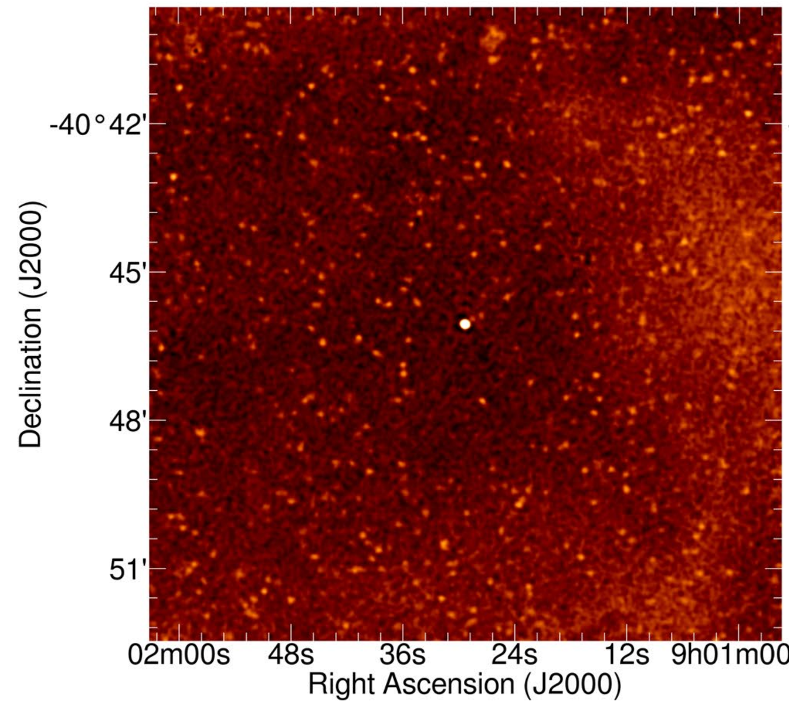
https://doi.org/10.1038/s41550-022-01688-x

Check for updates

Discovery of a radio-emitting neutron star with an ultra-long spin period of 76 s

Manisha Caleb[1,2,3,14], Ian Heywood[4,5,6,14], Kaustubh Rajwade[1,7], Mateusz Malenta[1], Benjamin Willem Stappers[1,14], Ewan Barr[8], Weiwei Chen[8], Vincent Morello[1], Sotiris Sanidas[1], Jakob van den Eijnden[4], Michael Kramer[1,8], David Buckley[9,10,11], Jaco Brink[9,10], Sara Elisa Motta[12], Patrick Woudt[10], Patrick Weltevrede[1], Fabian Jankowski[1], Mayuresh Surnis[1], Sarah Buchner[6], Mechiel Christiaan Bezuidenhout[1], Laura Nicole Driessen[1,13] and Rob Fender[4]





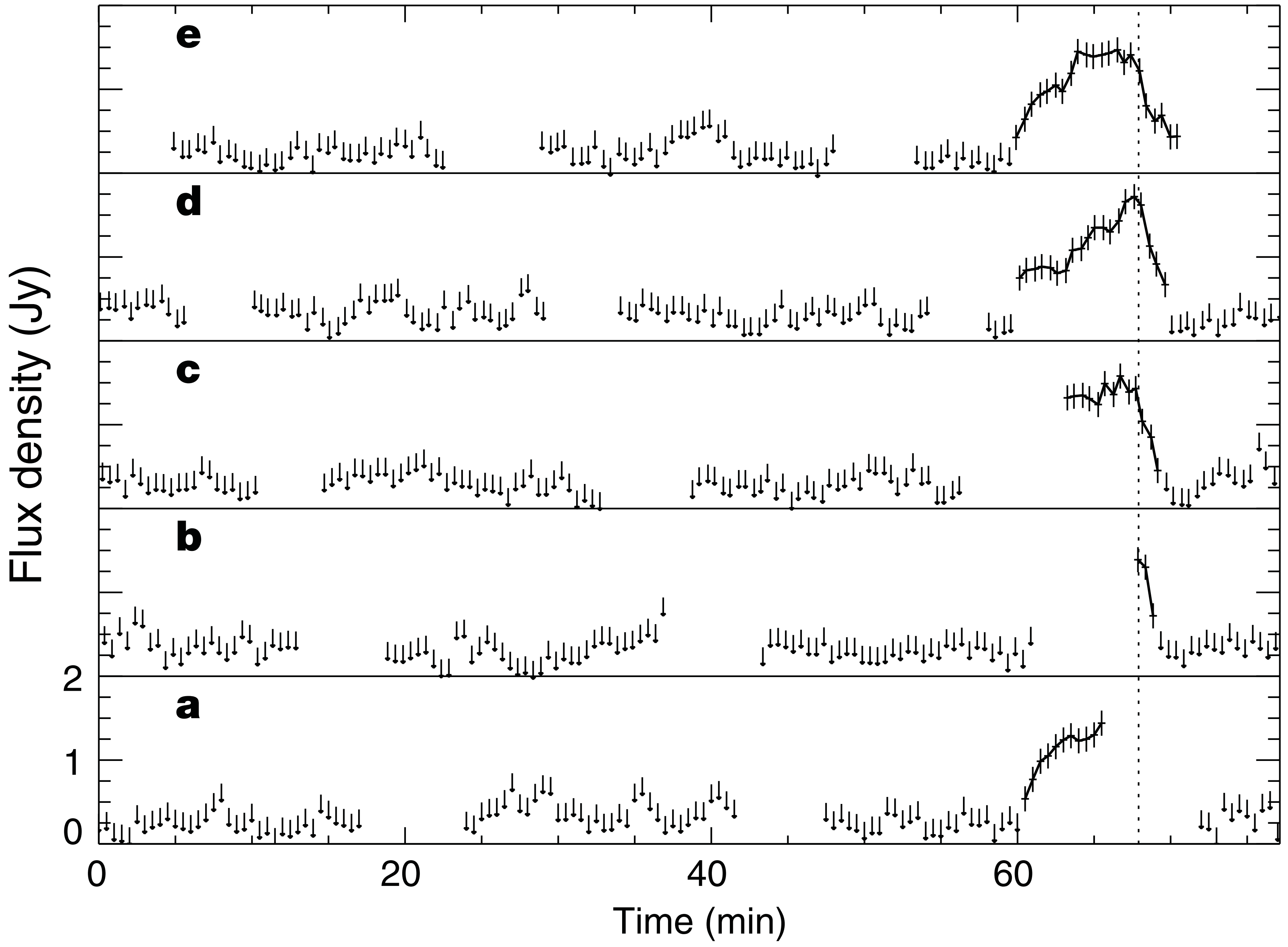
Credit: Caleb et al. 2022

Galactic ULPM candidates - GCRT J1745–3009

GCRT J1745–3009

The Galactic "burper". A P ~ 77 minute source discovered serendipitously by VLA

1. 10 minute wide "pulses"
2. $T_{brightness}$ >> 10^12 K for D > 70 pc
3. Optical observations rule out M type / brown dwarf nearby counterpart
4. If period is spin – cannot be rotation powered – suggestive of a magnetar origin



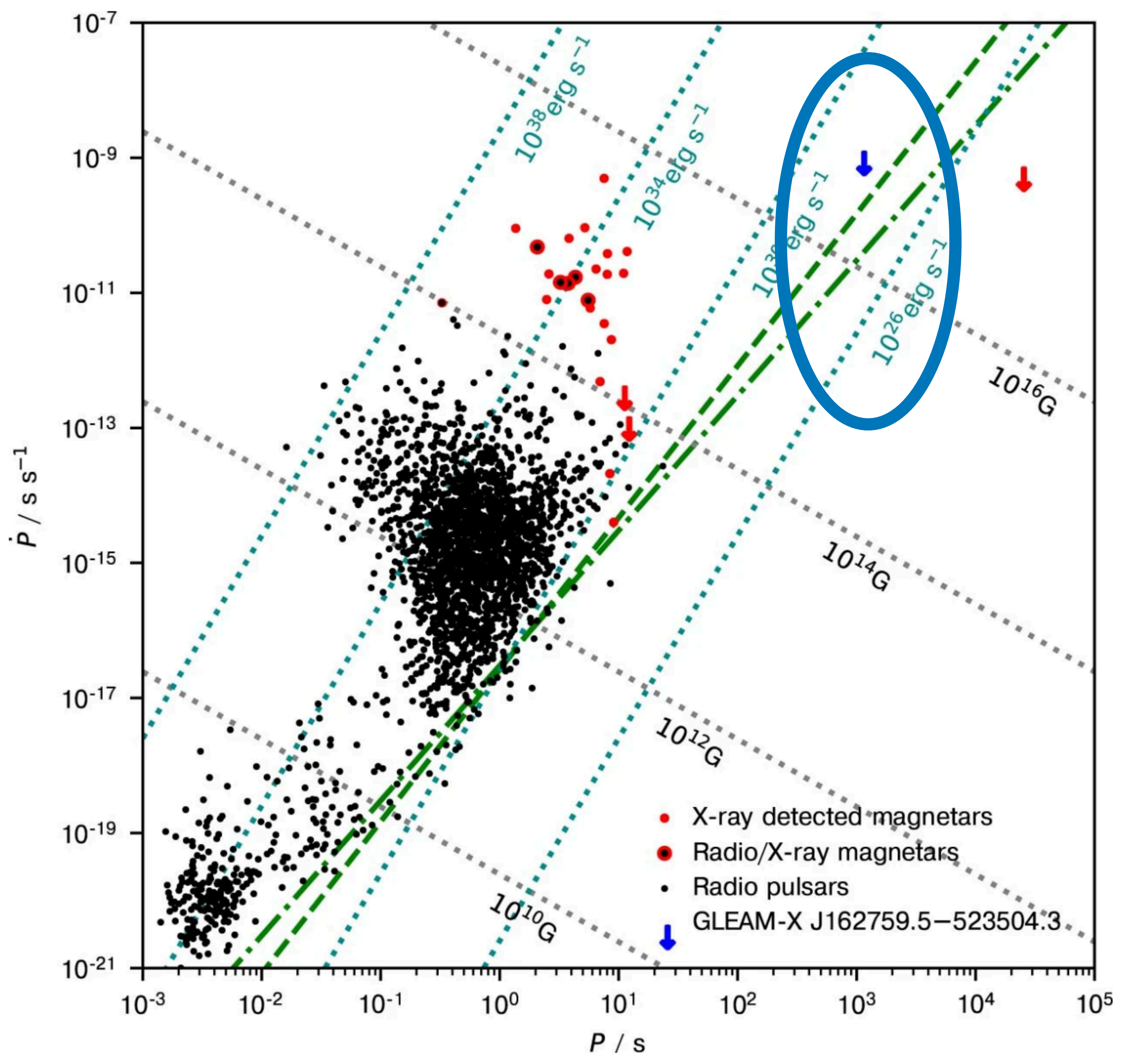
Credit: Hyman et al. 05,Kaplan et al. 08, Spreeuw et al. 09

Galactic ULPM candidates - *GLEAM-X J162759.5–523504.3*

GLEAM-X J162759.5–523504.3

P ~1091 sec, Pdot < 10^-9 radio transient

1. Close to 100% linear polarization
2. Rapid (~0.5 s) variability suggesting compact object with brightness temperature > 10^16 K
3. Cannot be a rotation powered NS
4. Orders of magnitude more luminous than radio WDs
5. 2% duty cycle
6. Beyond pulsar death-line for standard pulsar field strength
7. WD disfavored (Beniamini, Wadiasingh+2023, Rea+2024)



Credit: Hurley Walker et al. 2022


nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > articles > article

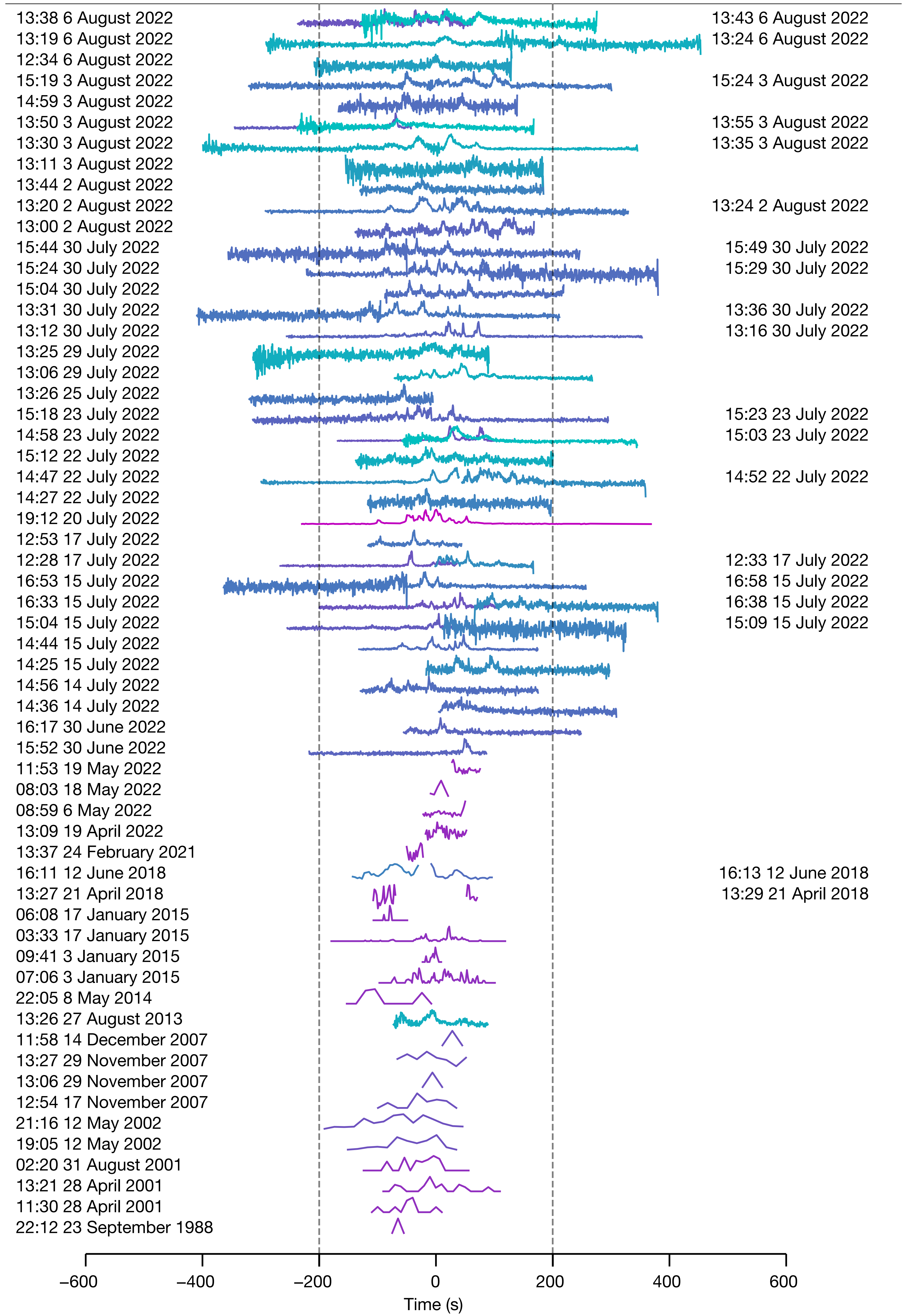
Article | Published: 26 January 2022

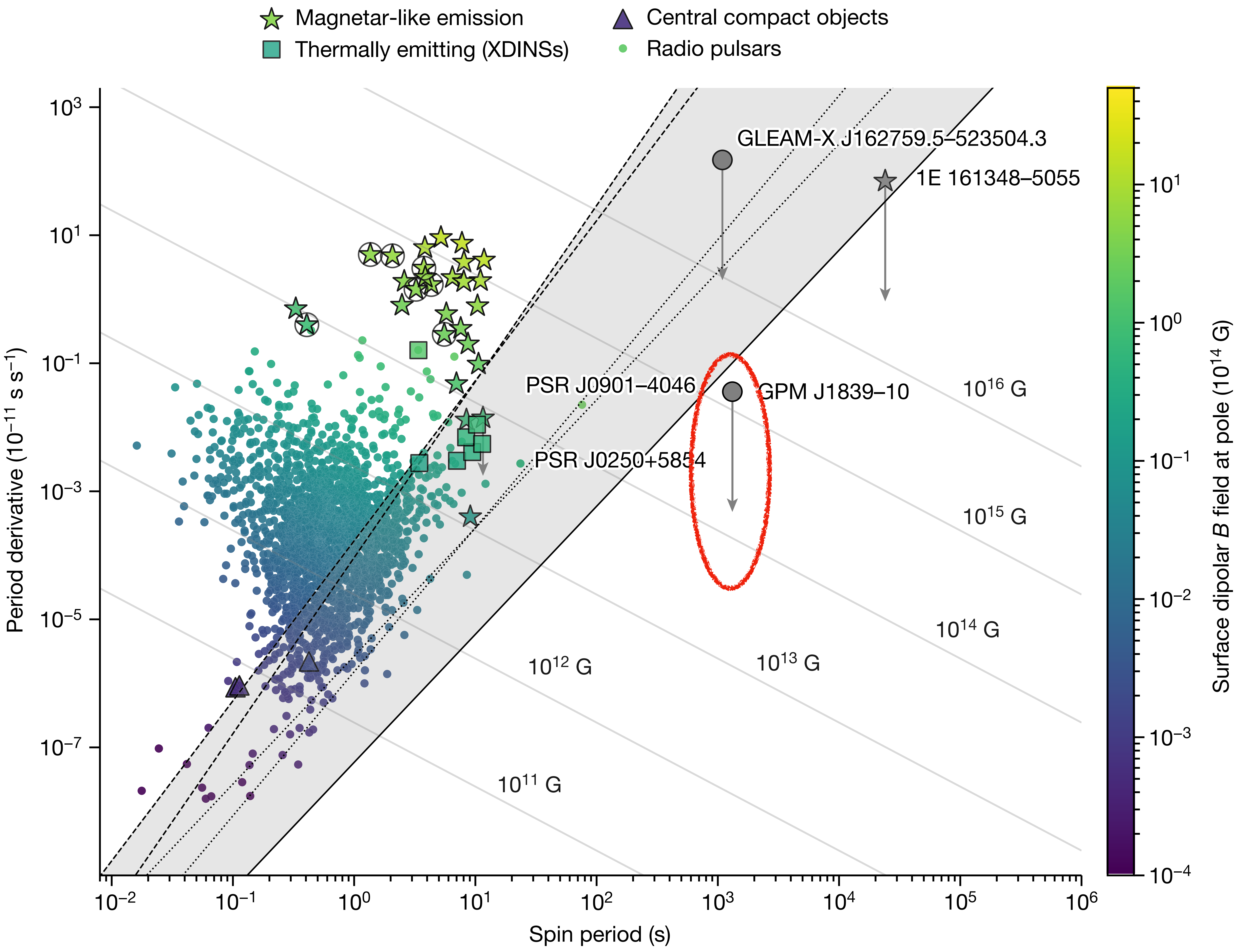
A radio transient with unusually slow periodic emission

N. Hurley-Walker ✉, X. Zhang, A. Bahramian, S. J. McSweeney, T. N. O'Doherty, P. J. Hancock, J. S. Morgan, G. E. Anderson, G. H. Heald & T. J. Galvin

Galactic ULPM candidates - ***GPM J1839-10 - Active for >30 years!***

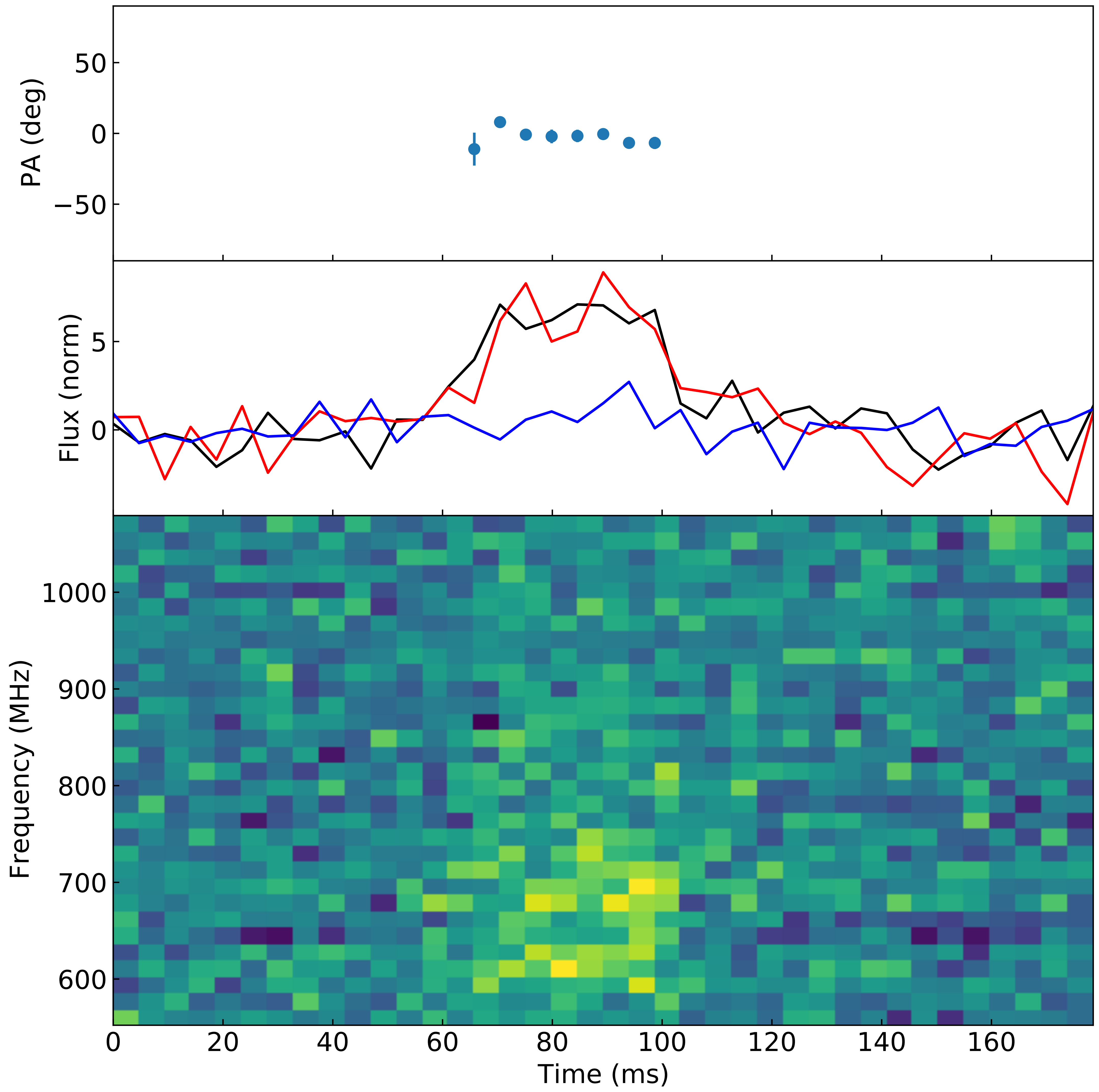
Credit: Hurley Walker et al. 2023



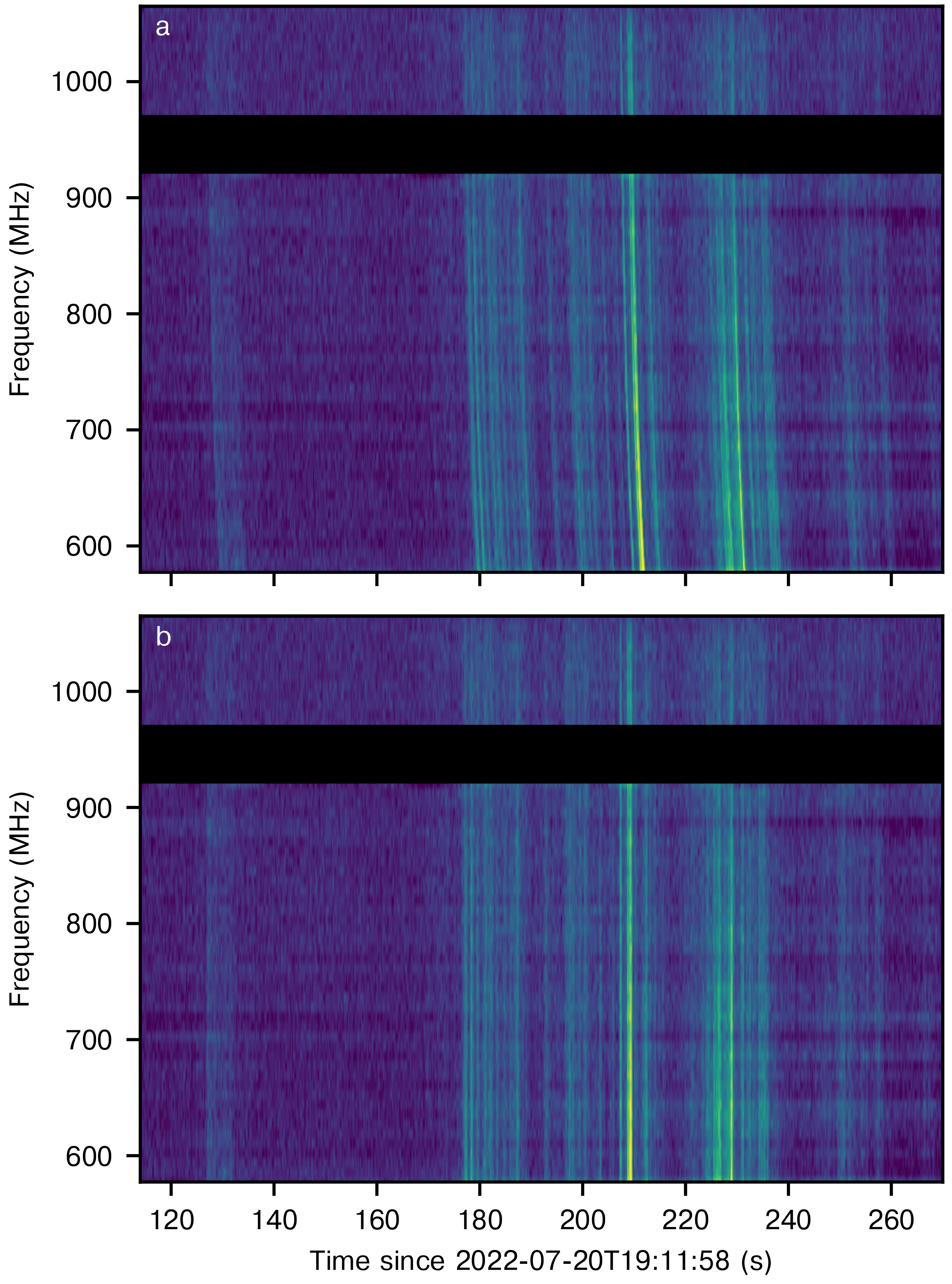


Galactic ULPM candidates - GPM J1839-10 - Millisecond Pulses and Flat PA — FRB like?!

Credit: Hurley Walker et al. 2023



Extended Data Fig. 6 | The polarization profile of a 30-ms burst observed with MeerKAT PTUSE. The RM is −531 rad m^{-2}. The top panel shows the measurements of the PA at different pulse phases. The middle panel shows the total, linearly polarized and circularly polarized flux densities as a function of time, represented by the black, red and blue lines, respectively. The bottom panel shows the dynamic spectrum of the burst. The start time of the plot is 19:35:43.228133 UTC 20 July 2022. The apparent steep spectrum is not intrinsic to the source but because of the misalignment of the coherent beam.

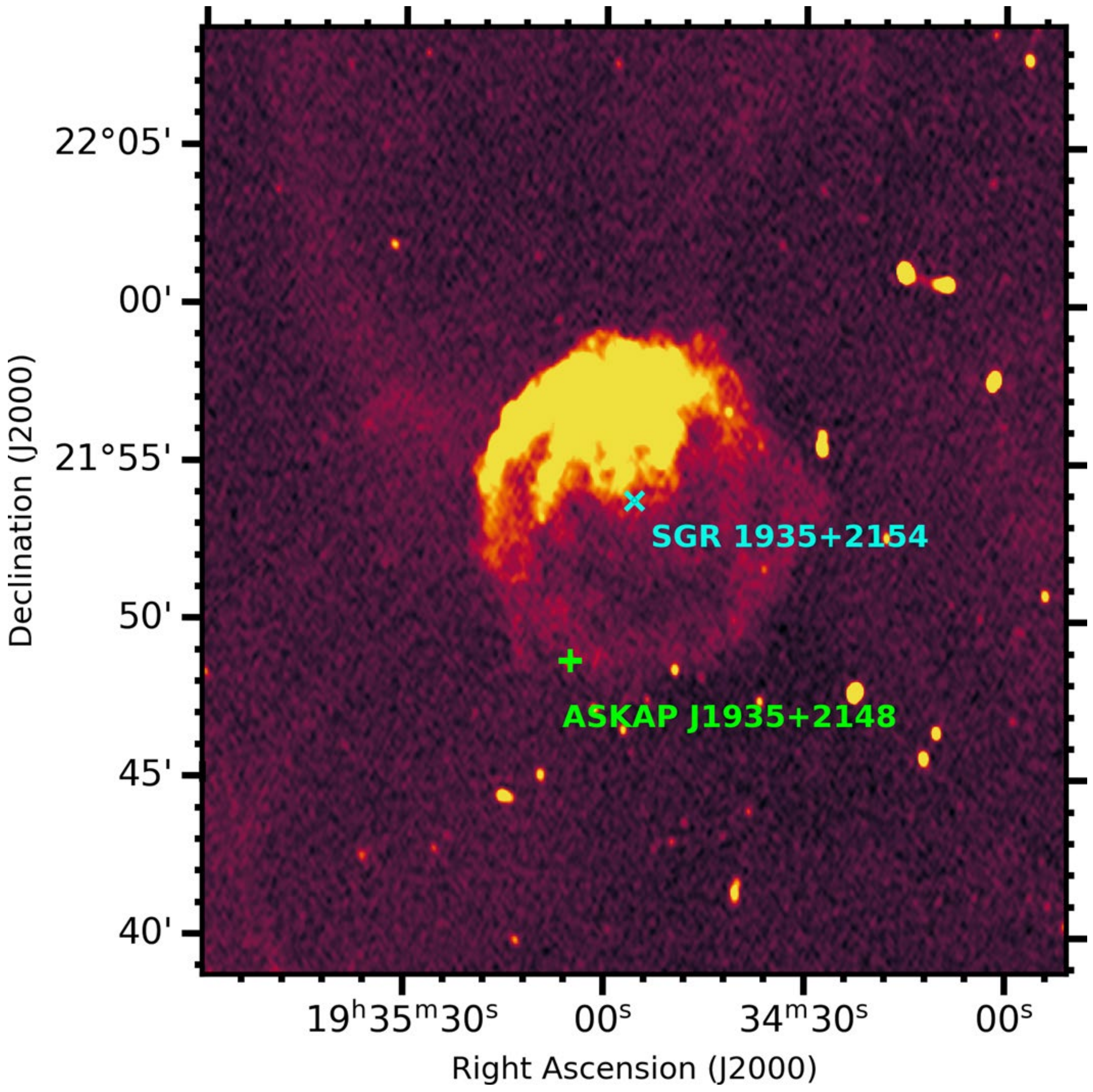


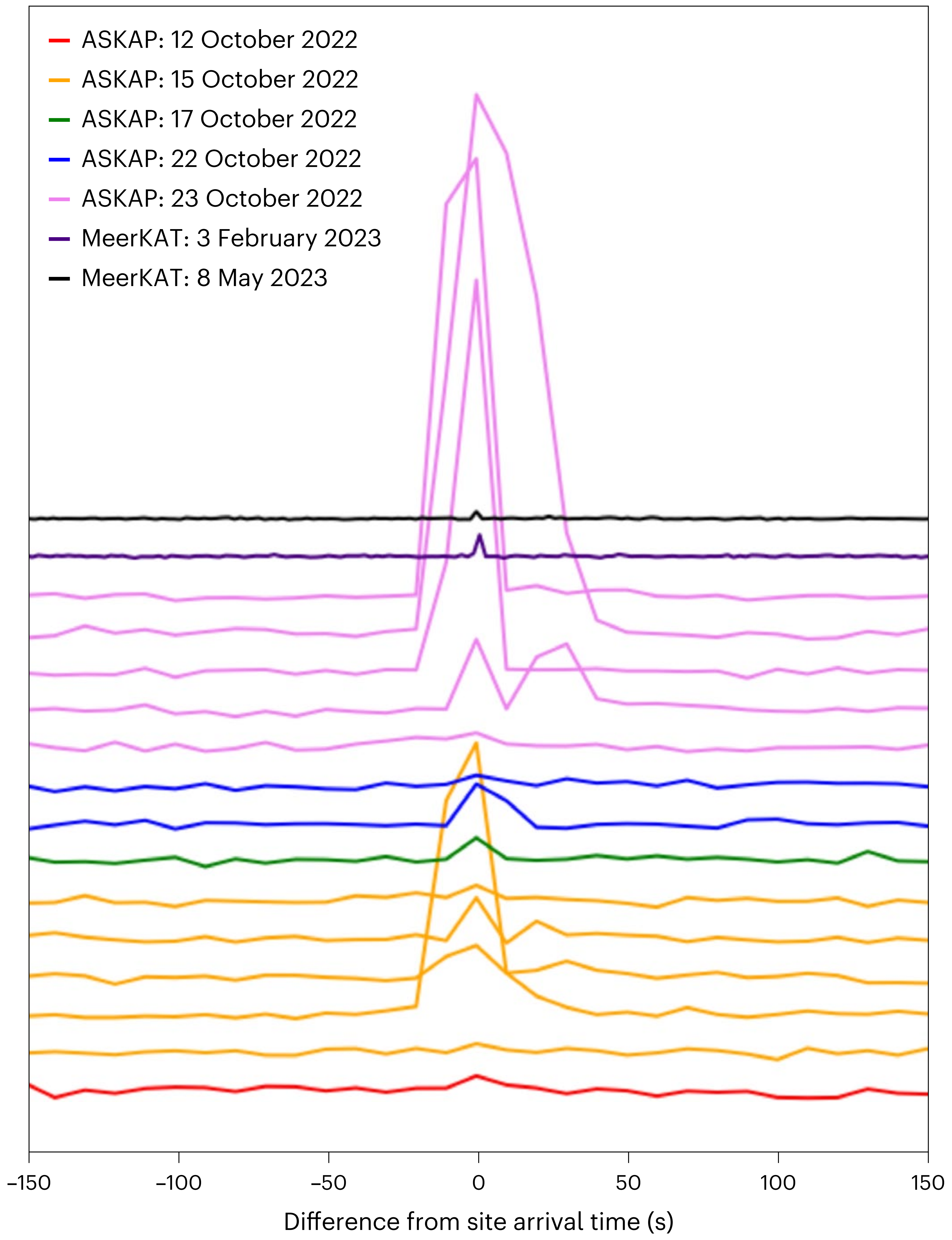
Extended Data Fig. 7 | Dynamic spectrum of the 19:12:33 20 July 2022 pulse detected with the APSUSE instrument on MeerKAT. The time resolution is 3.9 ms and the frequency resolution is 8.5 MHz. Strong interference signals have been removed in the 950-MHz band and at the band edges below 577 MHz and above 1,065 MHz. The data are shown before de-dispersion (**a**) and after de-dispersion (**b**).

Galactic ULPM candidates - *ASKAP J1935+2148 - mode changing source*

P = 54 mins bridges the gap

Credit: Caleb et al. 2024, Nature Astronomy

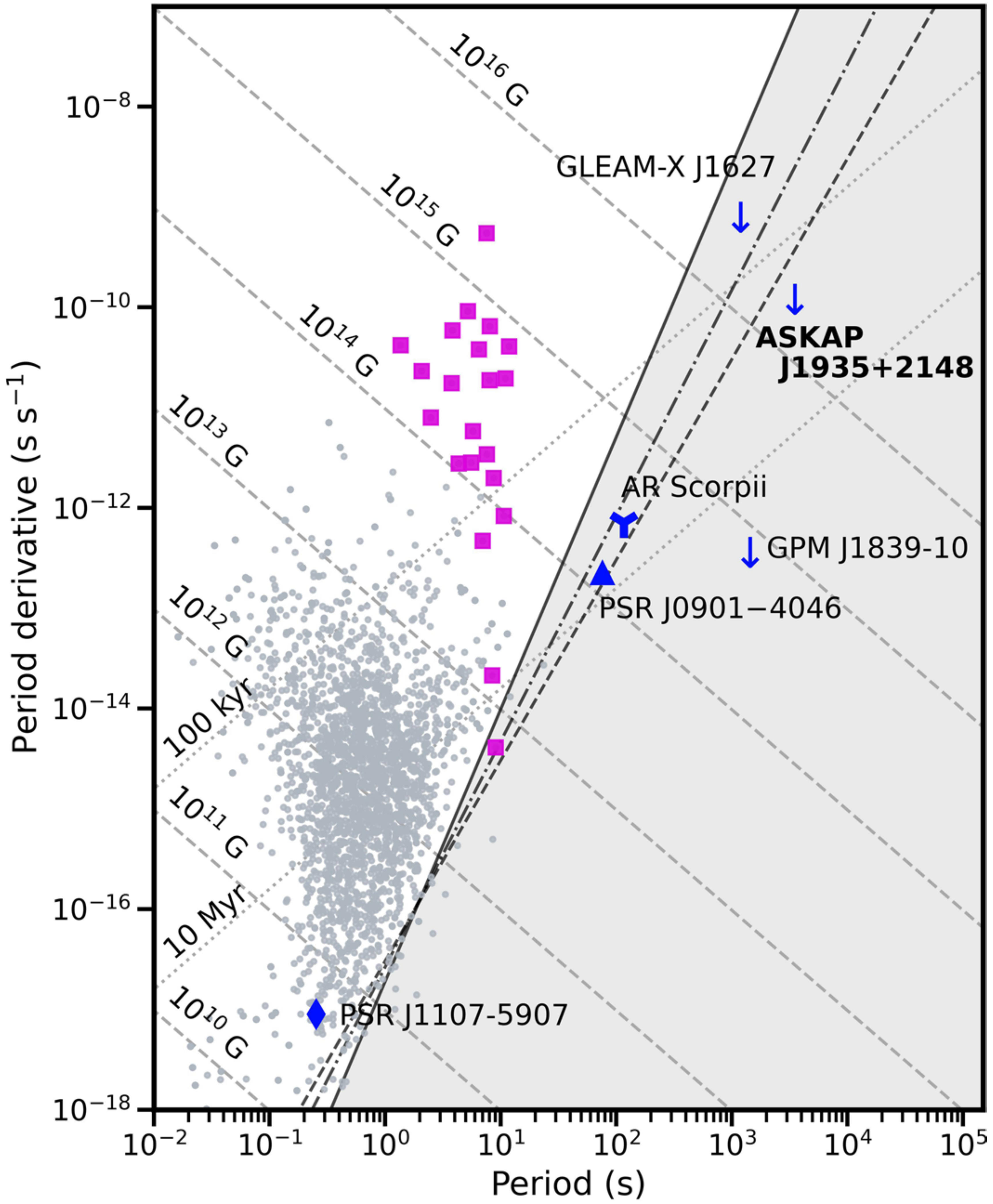


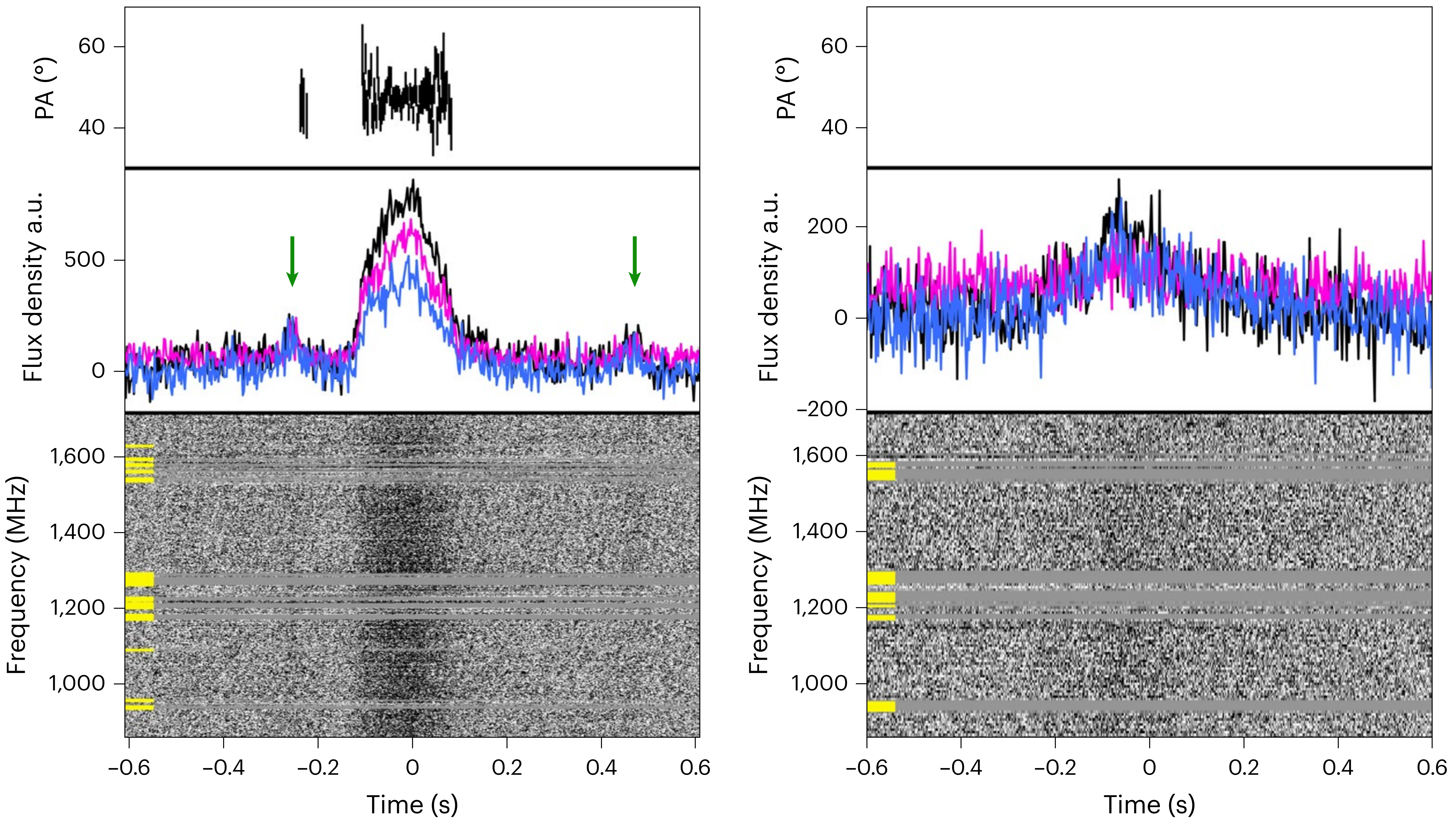


Galactic ULPM candidates - *ASKAP J1935+2148 - mode changing source*

P = 54 mins bridges the gap

Credit: Caleb et al. 2024, Nature Astronomy





Galactic ULPM candidates - ASKAP J1935+2148 - mode changing source

P = 54 mins bridges the gap

Credit: Caleb et al. 2024, Nature Astronomy

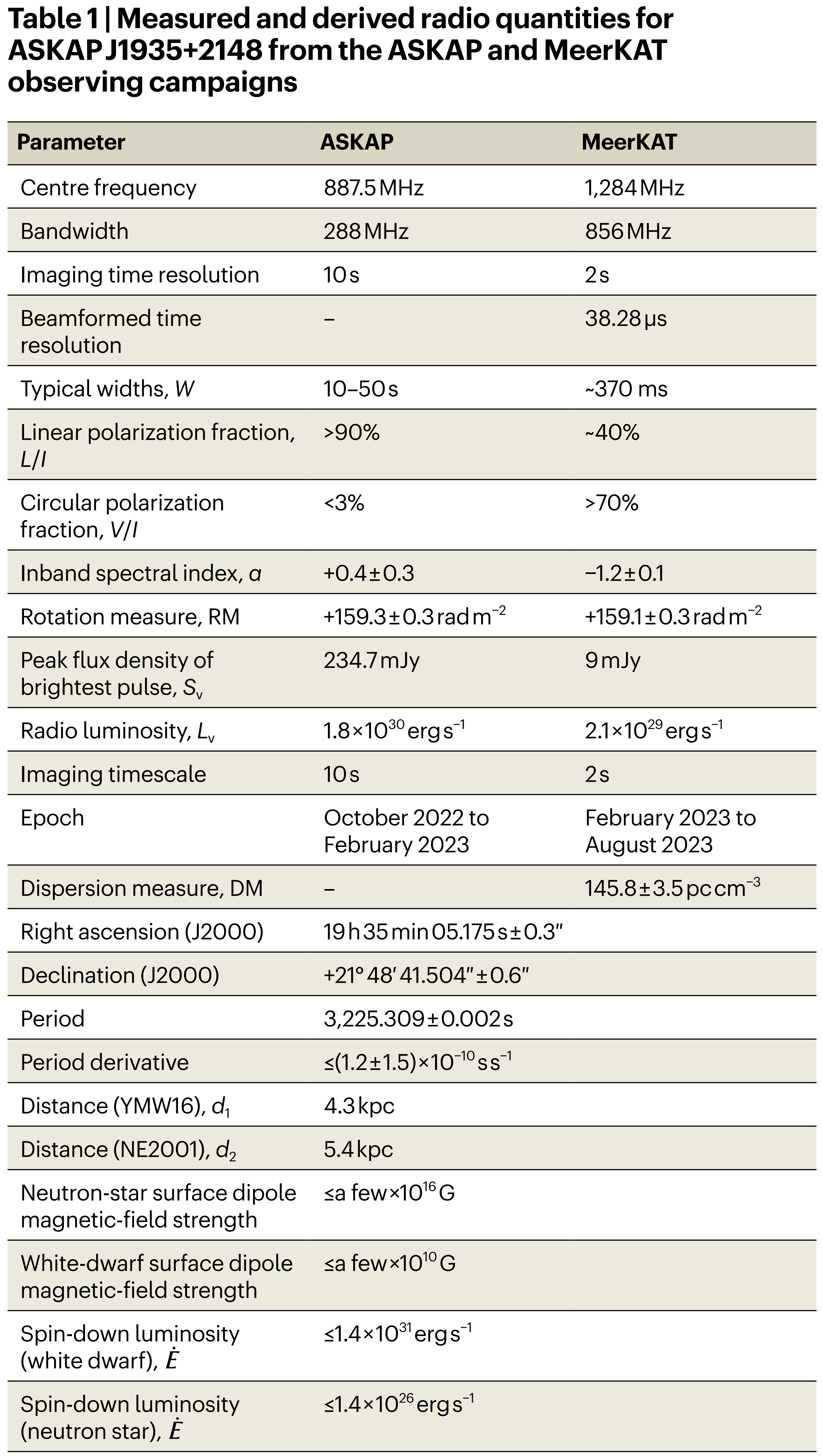
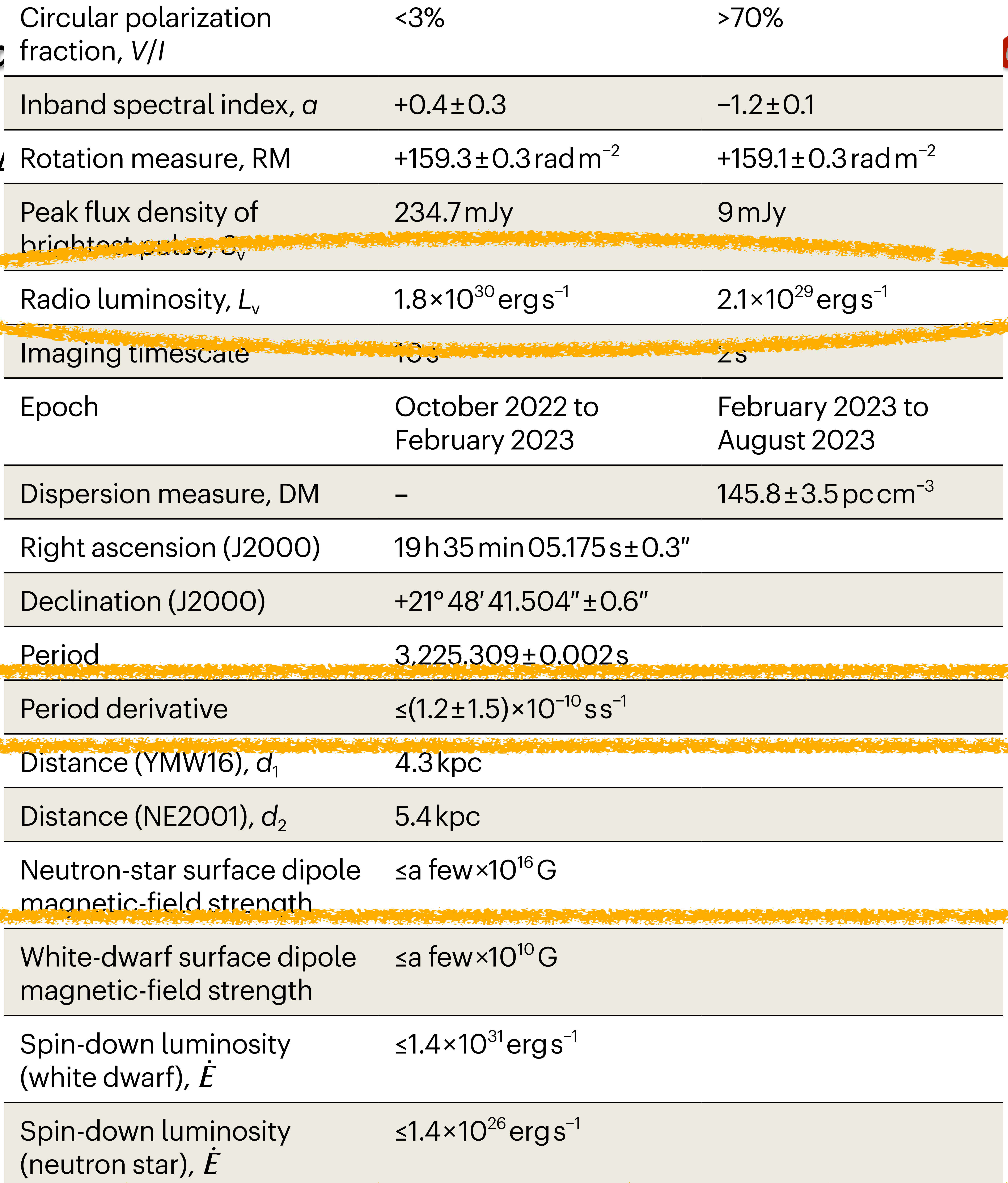


Table 1 | Measured and derived radio quantities for ASKAP J1935+2148 from the ASKAP and MeerKAT observing campaigns

Parameter	ASKAP	MeerKAT
Centre frequency	887.5 MHz	1,284 MHz
Bandwidth	288 MHz	856 MHz
Imaging time resolution	10 s	2 s
Beamformed time resolution	–	38.28 μs
Typical widths, W	10–50 s	~370 ms
Linear polarization fraction, L/I	>90%	~40%
Circular polarization fraction, V/I	<3%	>70%
Inband spectral index, α	+0.4±0.3	−1.2±0.1
Rotation measure, RM	+159.3±0.3 rad m^{-2}	+159.1±0.3 rad m^{-2}
Peak flux density of brightest pulse, S_ν	234.7 mJy	9 mJy
Radio luminosity, L_ν	1.8×10^{30} erg s^{-1}	2.1×10^{29} erg s^{-1}
Imaging timescale	10 s	2 s
Epoch	October 2022 to February 2023	February 2023 to August 2023
Dispersion measure, DM	–	145.8±3.5 pc cm^{-3}
Right ascension (J2000)	19 h 35 min 05.175 s±0.3″	
Declination (J2000)	+21° 48′ 41.504″±0.6″	
Period	3,225.309±0.002 s	
Period derivative	≤(1.2±1.5)×10^{-10} s s^{-1}	
Distance (YMW16), d_1	4.3 kpc	
Distance (NE2001), d_2	5.4 kpc	
Neutron-star surface dipole magnetic-field strength	≤a few×10^{16} G	
White-dwarf surface dipole magnetic-field strength	≤a few×10^{10} G	
Spin-down luminosity (white dwarf), $\dot{E}$	≤1.4×10^{31} erg s^{-1}	
Spin-down luminosity (neutron star), $\dot{E}$	≤1.4×10^{26} erg s^{-1}	

Galactic ULPM canc anging source

Credit: Caleb et al. 2024, Nature A



Circular polarization fraction, V/I	<3%	>70%
Inband spectral index, α	$+0.4 \pm 0.3$	-1.2 ± 0.1
Rotation measure, RM	$+159.3 \pm 0.3\ \mathrm{rad\,m^{-2}}$	$+159.1 \pm 0.3\ \mathrm{rad\,m^{-2}}$
Peak flux density of brightest pulse, S_ν	234.7 mJy	9 mJy
Radio luminosity, L_ν	$1.8 \times 10^{30}\ \mathrm{erg\,s^{-1}}$	$2.1 \times 10^{29}\ \mathrm{erg\,s^{-1}}$
Imaging timescale	10 s	2 s
Epoch	October 2022 to February 2023	February 2023 to August 2023
Dispersion measure, DM	–	$145.8 \pm 3.5\ \mathrm{pc\,cm^{-3}}$
Right ascension (J2000)	19 h 35 min 05.175 s ± 0.3″	
Declination (J2000)	+21° 48′ 41.504″ ± 0.6″	
Period	3,225.309 ± 0.002 s	
Period derivative	$\leq (1.2 \pm 1.5) \times 10^{-10}\ \mathrm{s\,s^{-1}}$	
Distance (YMW16), d_1	4.3 kpc	
Distance (NE2001), d_2	5.4 kpc	
Neutron-star surface dipole magnetic-field strength	$\leq$ a few $\times 10^{16}$ G	
White-dwarf surface dipole magnetic-field strength	$\leq$ a few $\times 10^{10}$ G	
Spin-down luminosity (white dwarf), $\dot{E}$	$\leq 1.4 \times 10^{31}\ \mathrm{erg\,s^{-1}}$	
Spin-down luminosity (neutron star), $\dot{E}$	$\leq 1.4 \times 10^{26}\ \mathrm{erg\,s^{-1}}$	

Aside: these seem bright enough (1-20 Jy @ 1 GHz at 3-5 kpc) to detect in nearby galaxies —> observers please find them!

Source Densities

GLEAM-X J1627 and PSR J0901-4046 age limits

Various arguments all imply these are old objects

- Source density
- Spin-down age
- Timing stability (PSR J0901-4046 is as stable as >>100 kyr old pulsars)
- Cooling age based on models or empirical distributions and X-ray limits
- Proper motion and galactic offset (GLEAM-X object)

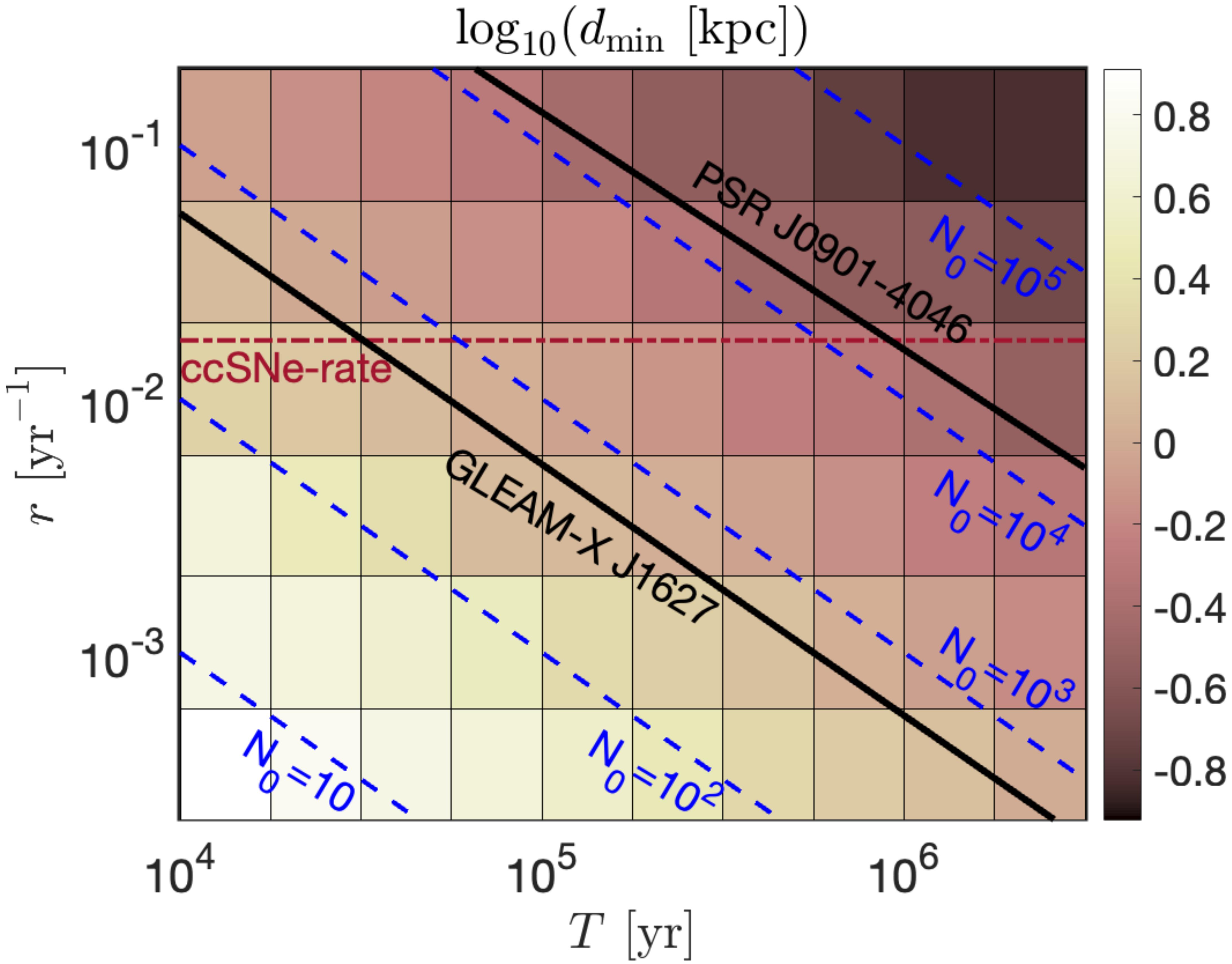
GLEAM-X J1627 and PSR J0901-4046 age limits

Various arguments all imply these are old objects

- Source density
- Spin-down age
- Timing stability (PSR J0901-4046 is as stable as >>100 kyr old pulsars)
- Cooling age based on models or empirical distributions and X-ray limits
- Proper motion and galactic offset (GLEAM-X object)

GLEAM-X and MTP0013 (PSR J0901-4046)

- Source density estimate using Monte Carlo technique similar to Faucher-Giguere & Kaspi 2006 (birth and propagate sources in the plane with the Galactic potential and a kick velocity distribution…)
- Implies ~10^3 GLEAM-X like objects and ~few x 10^4 PSR 0901-4046 like pulsars in the Galaxy
- Implies minimum age to not exceed CCSNe rate

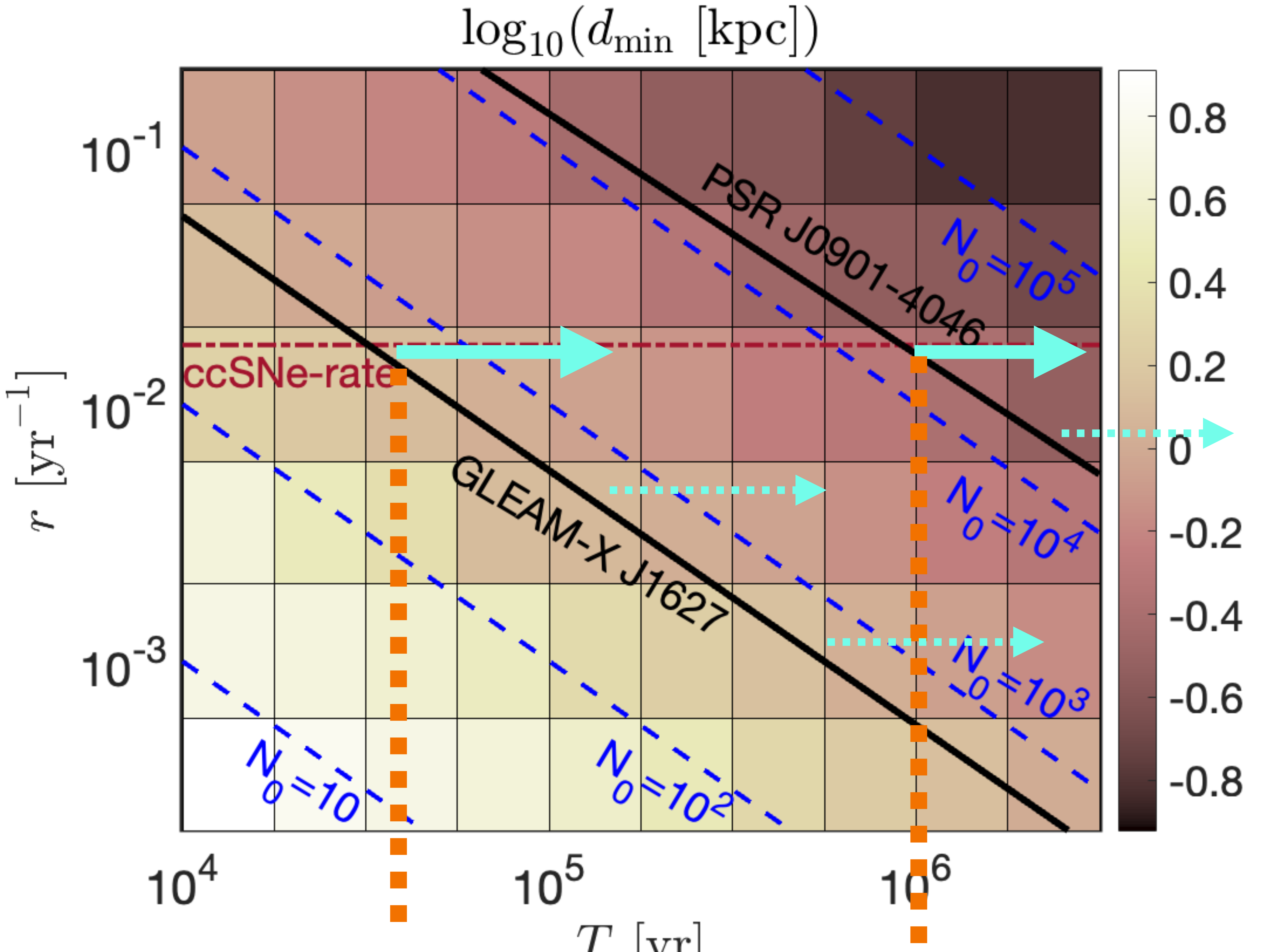


Beniamini, Wadiasingh, Hare+ 2023

See also Rea+2024

GLEAM-X and MTP0013 (PSR J0901-4046)

- Source density estimate using Monte Carlo technique similar to Faucher-Giguere & Kaspi 2006 (birth and propagate sources in the plane with the Galactic potential and a kick velocity distribution…)
- Implies ~10^3 GLEAM-X like objects and ~few x 10^4 PSR 0901-4046 like pulsars in the Galaxy
- Implies minimum age to not exceed CCSNe rate

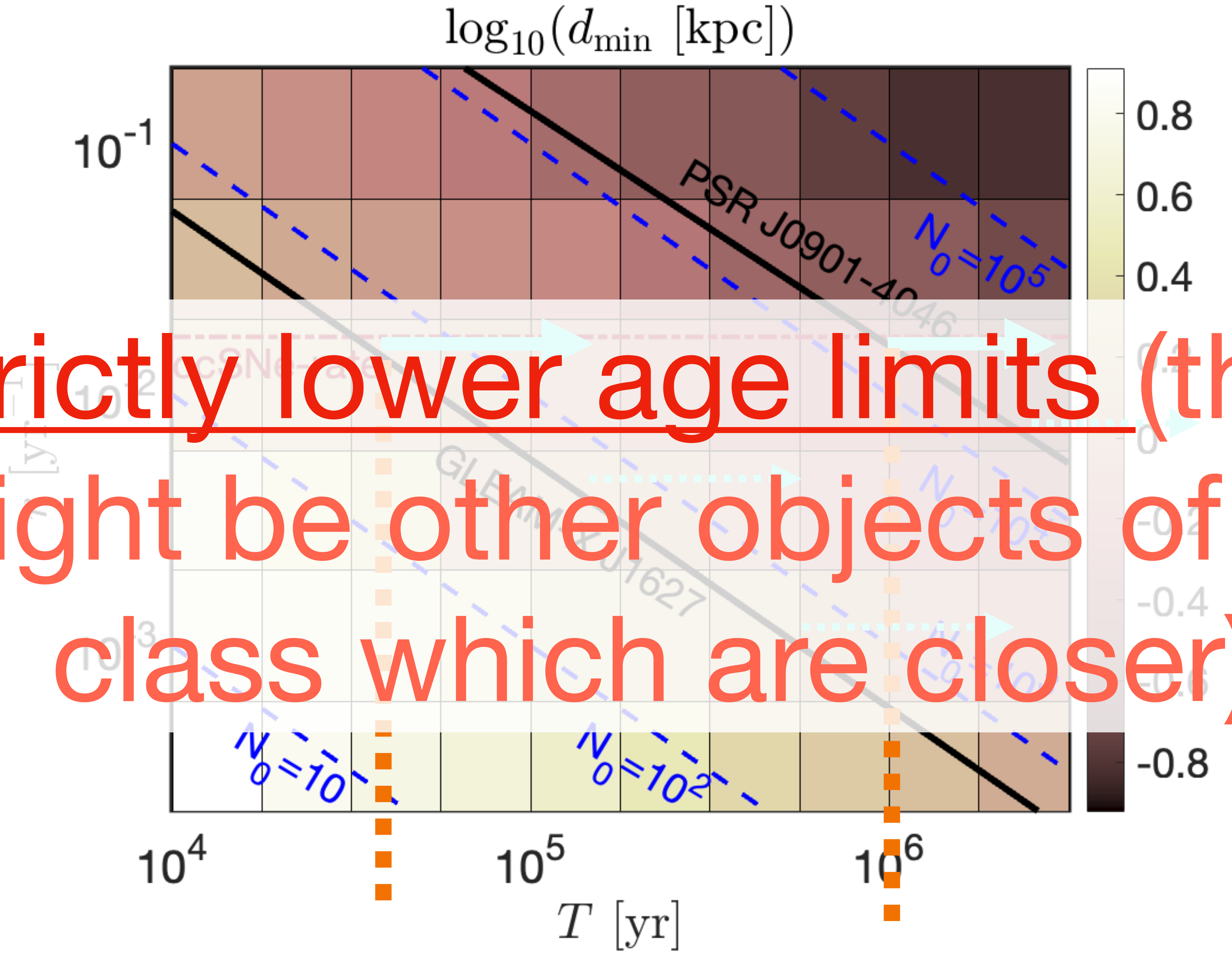


Beniamini, Wadiasingh, Hare+ 2023

See also Rea+2024

GLEAM-X and MTP0013 (PSR J0901-4046)

- Source density estimate using Monte Carlo technique similar to Faucher-Giguere & Kaspi 2006 (birth and propagate sources in the plane with the Galactic potential and a kick velocity distribution…)
- Implies ~10^3 GLEAM-X like objects and ~few x 10^4 PSR 0901-4046 like pulsars in the Galaxy
- Implies minimum age to not exceed CCSNe rate



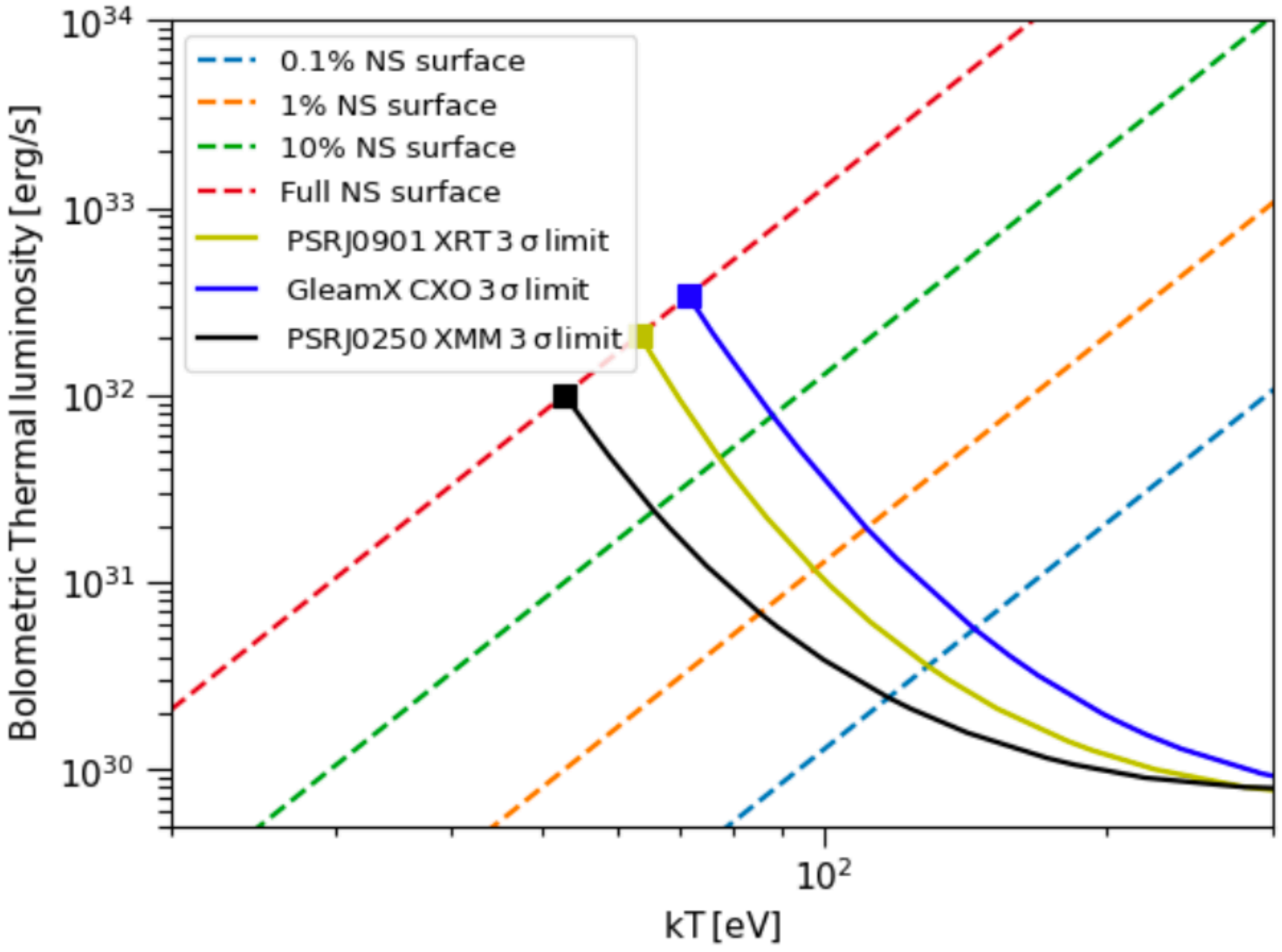
Strictly lower age limits (there might be other objects of the class which are closer)

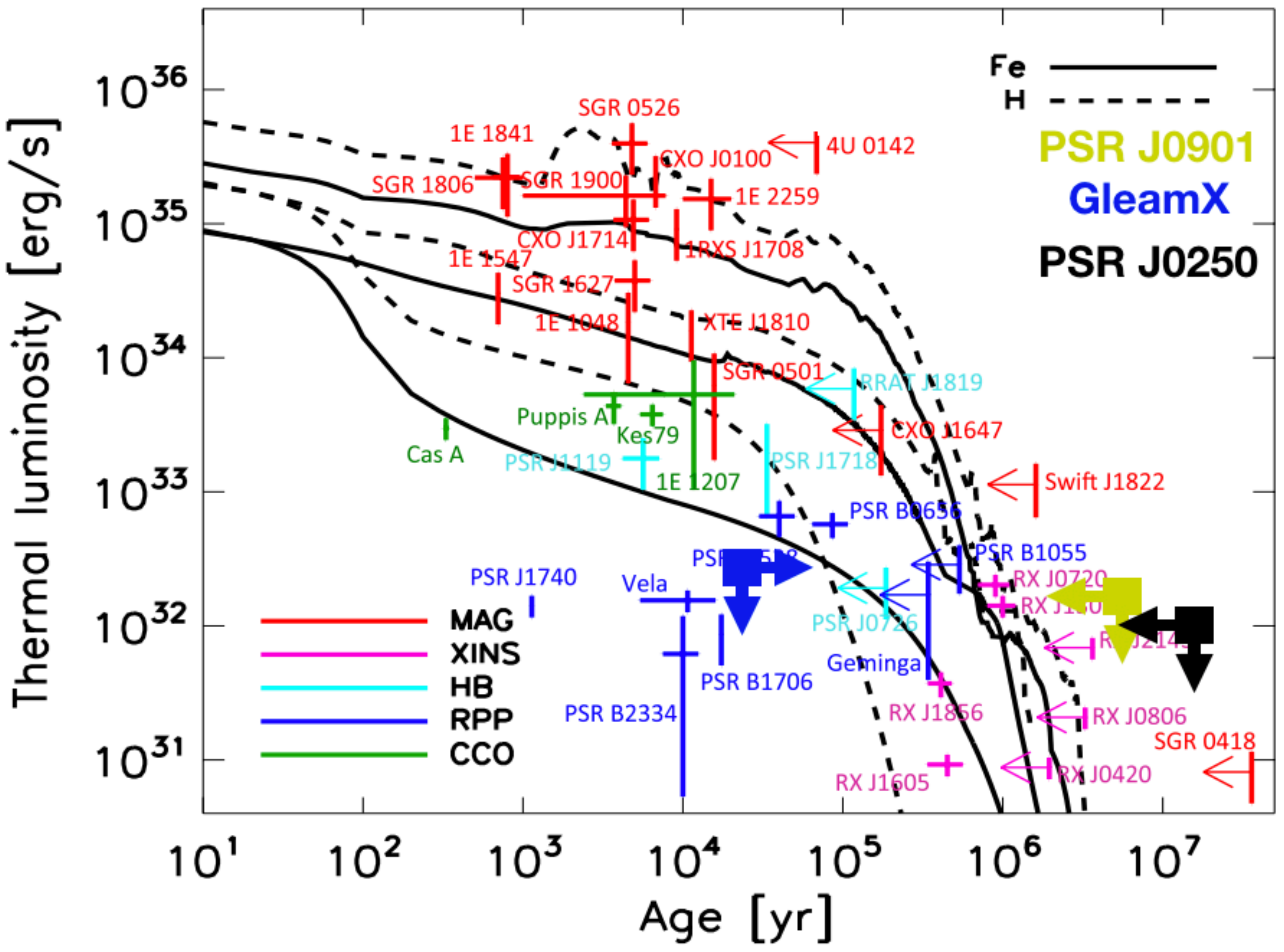
Beniamini, Wadiasingh, Hare+ 2023

See also Rea+2024

Age constraints from X-ray limits and cooling models

somewhat less well constrained due to mass and composition dependence



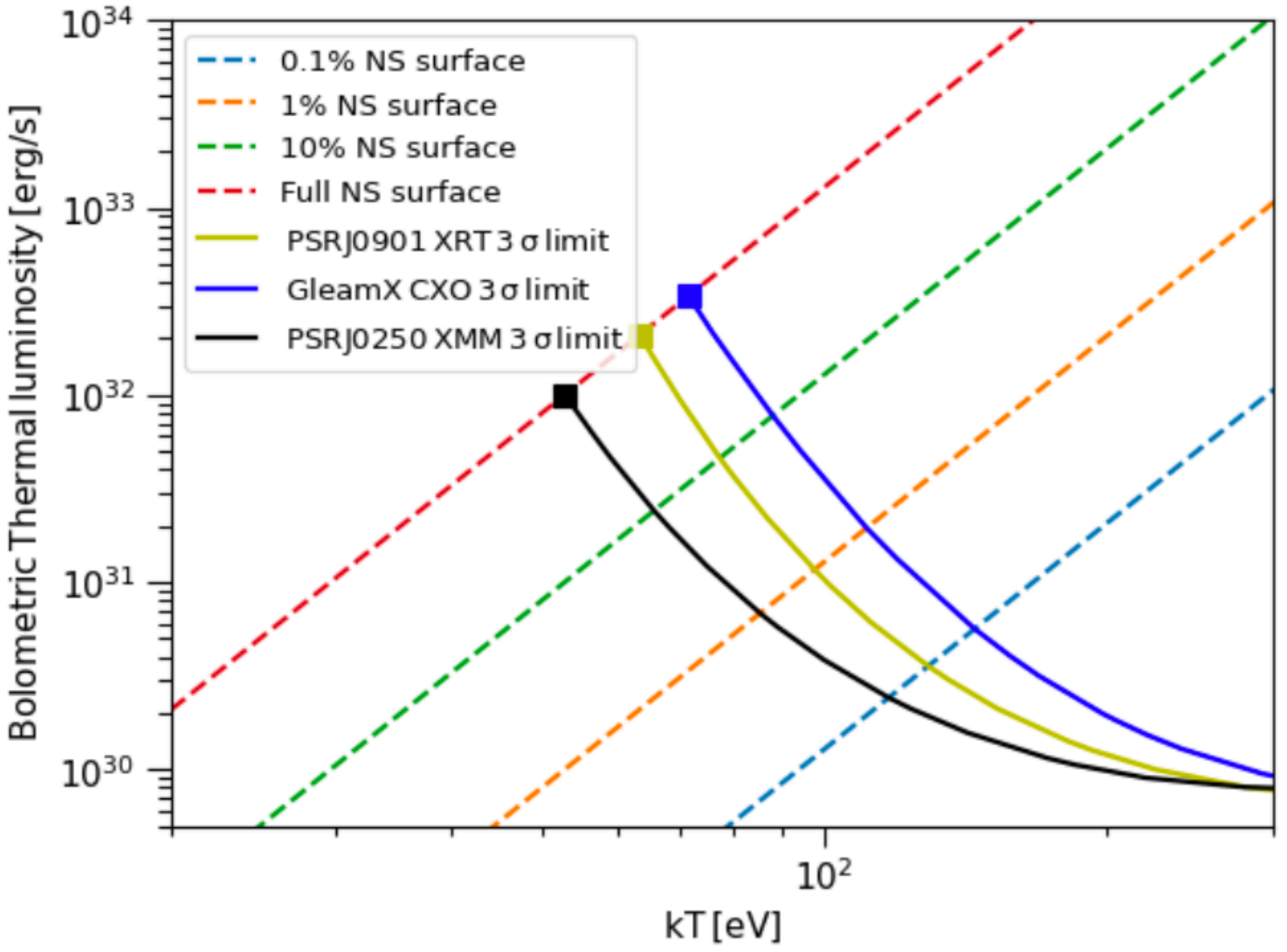


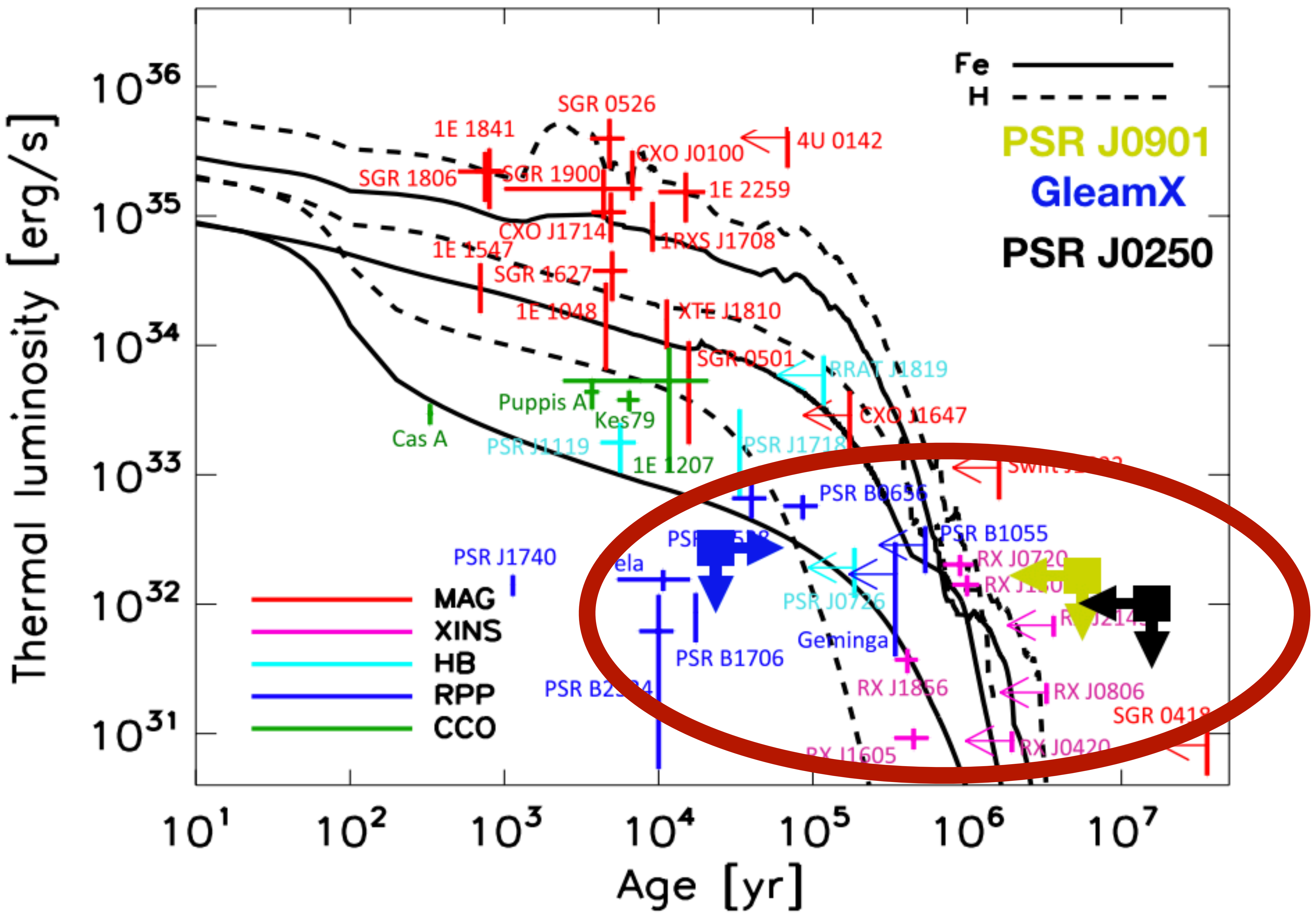
Beniamini, Wadiasingh, Hare+ 2023

See also Rea+ 2024

Age constraints from X-ray limits and cooling models

somewhat less well constrained due to mass and composition dependence



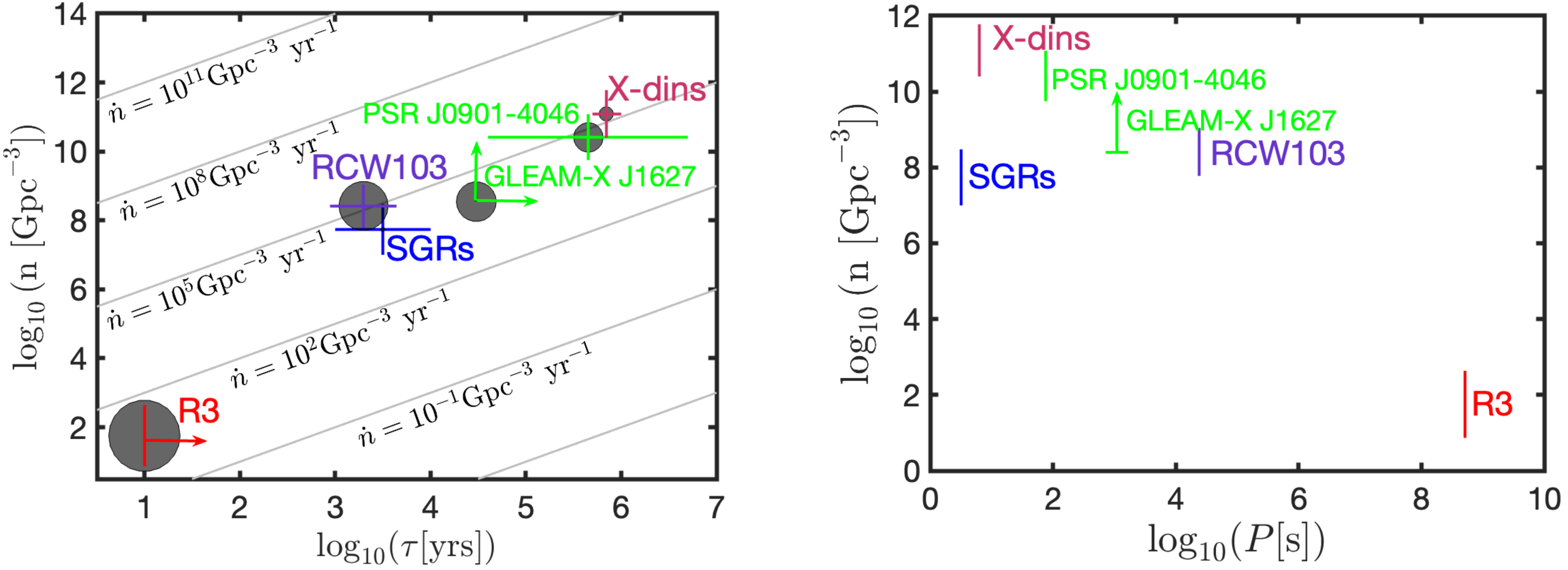


Beniamini, Wadiasingh, Hare+ 2023

See also Rea+ 2024

Combined age limits

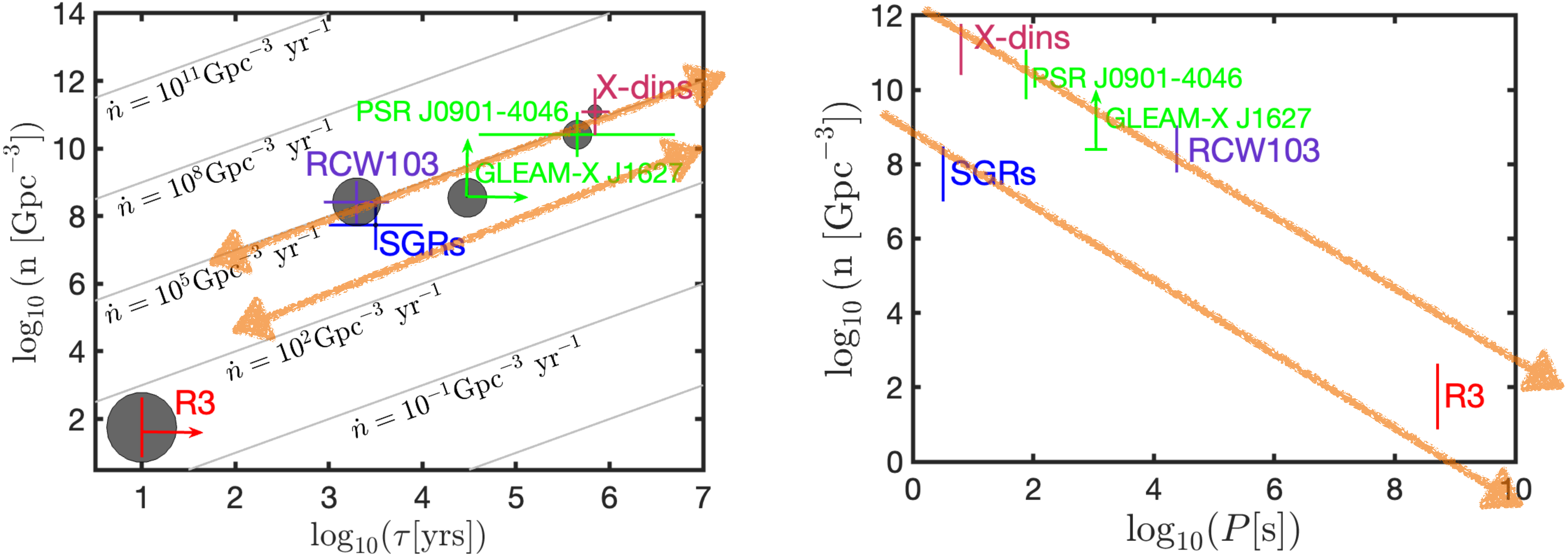
Various arguments all imply these are old objects



Beniamini, Wadiasingh, Hare + 2023

Combined age limits

Various arguments all imply these are old objects



Beniamini, Wadiasingh, Hare + 2023

Are they highly-magnetized neutron stars (“magnetars”)?

The definition of a “magnetar” here is magnetically-powered highly-magnetized NS

Power source options - Gravitational power?

given luminosities ~10^28 - 10^32 erg/s

- Gravitational power?
  - accretion power (e.g. fallback disk)
  - tight binary companion (WD +stellar comp, NS+ stellar comp)
  - double degenerate system (NS+WD, WD+WD, etc)
- Problem: requires synchronization of orbit in binary cases -> still requires a highly magnetized neutron star ! (Pizzolato, Colpi, de Luca+ 2008)
  - even then, orbital power could be too low for longer P
  - strongly disfavored for the CCO in RCW 103 with HST observations (Tendulkar+2017)
  - disfavored for GPM J1839-10 too based on its stable timing and P~ 20 mins
- Problem: radio duty cycles are very narrow of ULPM candidates, 0.1-5%
  - also no underlying pulsed emission like eclipsing compact pulsar systems
- Problem: Coherent radio emission requires strong electric fields

Arguments for highly magnetized NS and why WDs are disfavored for long period radio sources

- Millisecond duration sub-structure and high brightness temperature of this sub-structure — requires relativistic plasmas (require voltage to pull charges from a surface a NS >> WD)
- Pulses too narrow compared to Ar Sco
- Too slow to be rotationally-powered isolated WDs
- luminosity — they are orders of magnitude brighter than any known WDs, even in binaries
  - we know of thousands of WDs in Gaia and other surveys, none have showed this behavior and those that do are in binaries (e.g. Pelisoli+2024)
- Source densities and power source — too common and luminous to be WDs given WD birth rates and known magnetic field distributions
- Binary interactions and orbital power? Again too slow to explain luminosities

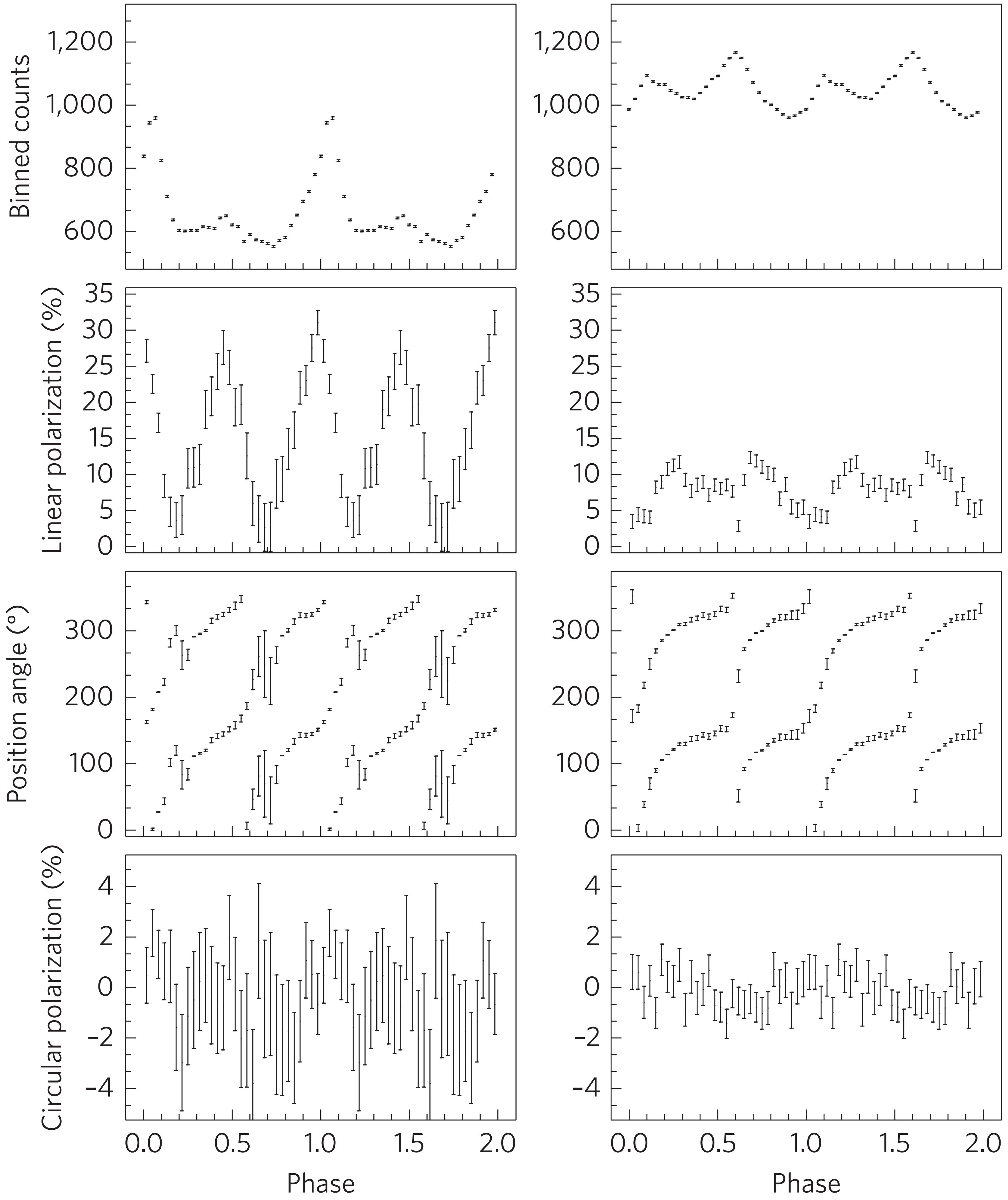
Ar Sco (white dwarf pulsar) versus ULPs

phenomenologically

- 2 minute spin period versus 20-50 minutes
- Pulse duty cycle large (20-40%) compared to ULPs (ASKAP J1935 - 10^-4 duty cycle!)
- only 116 pc away compared to kpc for ULPs
- orders of magnitude lower luminosity
- obvious optical counterpart and binary companion

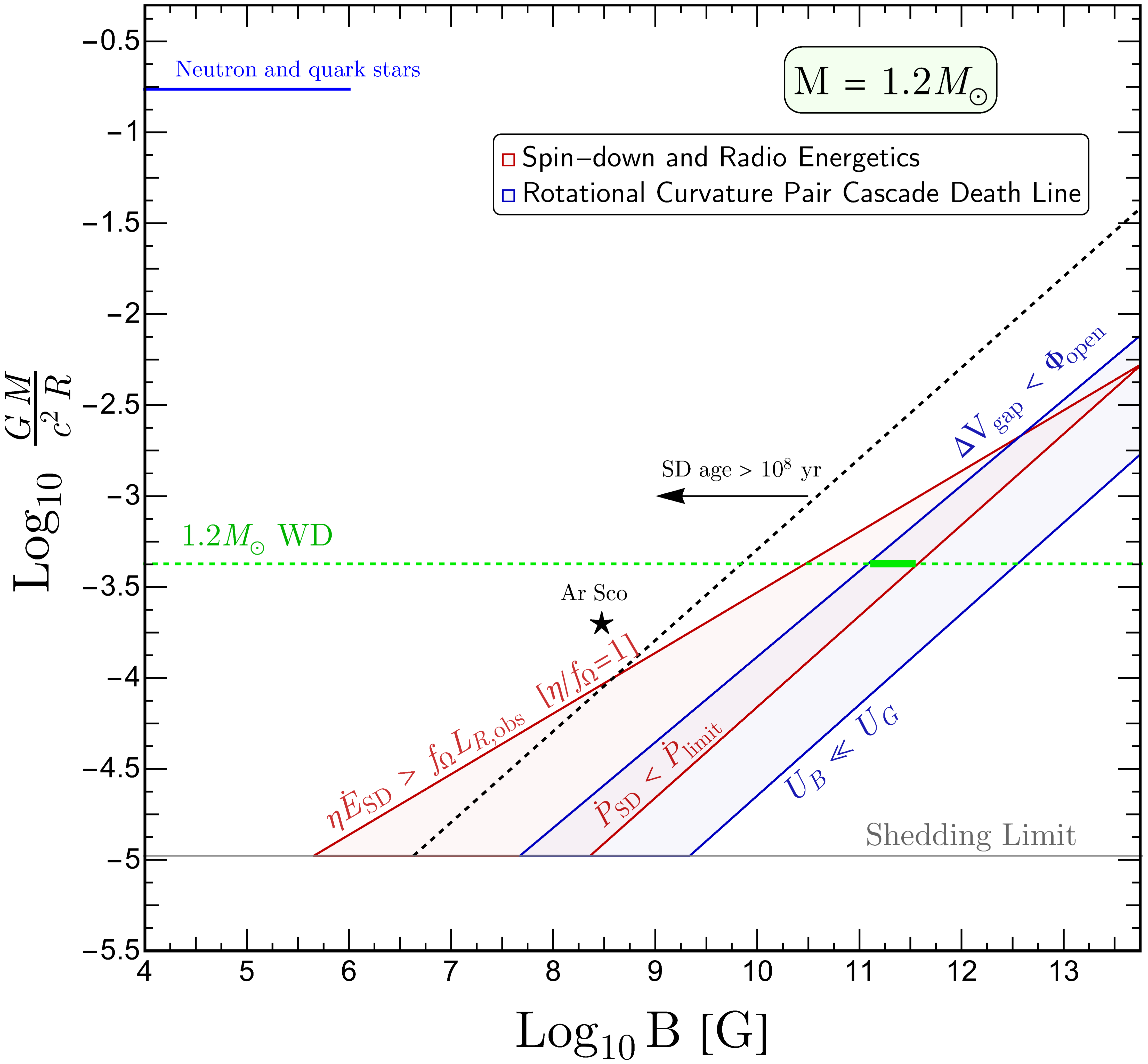
Credit: Buckley et al. 2017

Ar Sco optical polarized photometry



Rotation-powered WD?

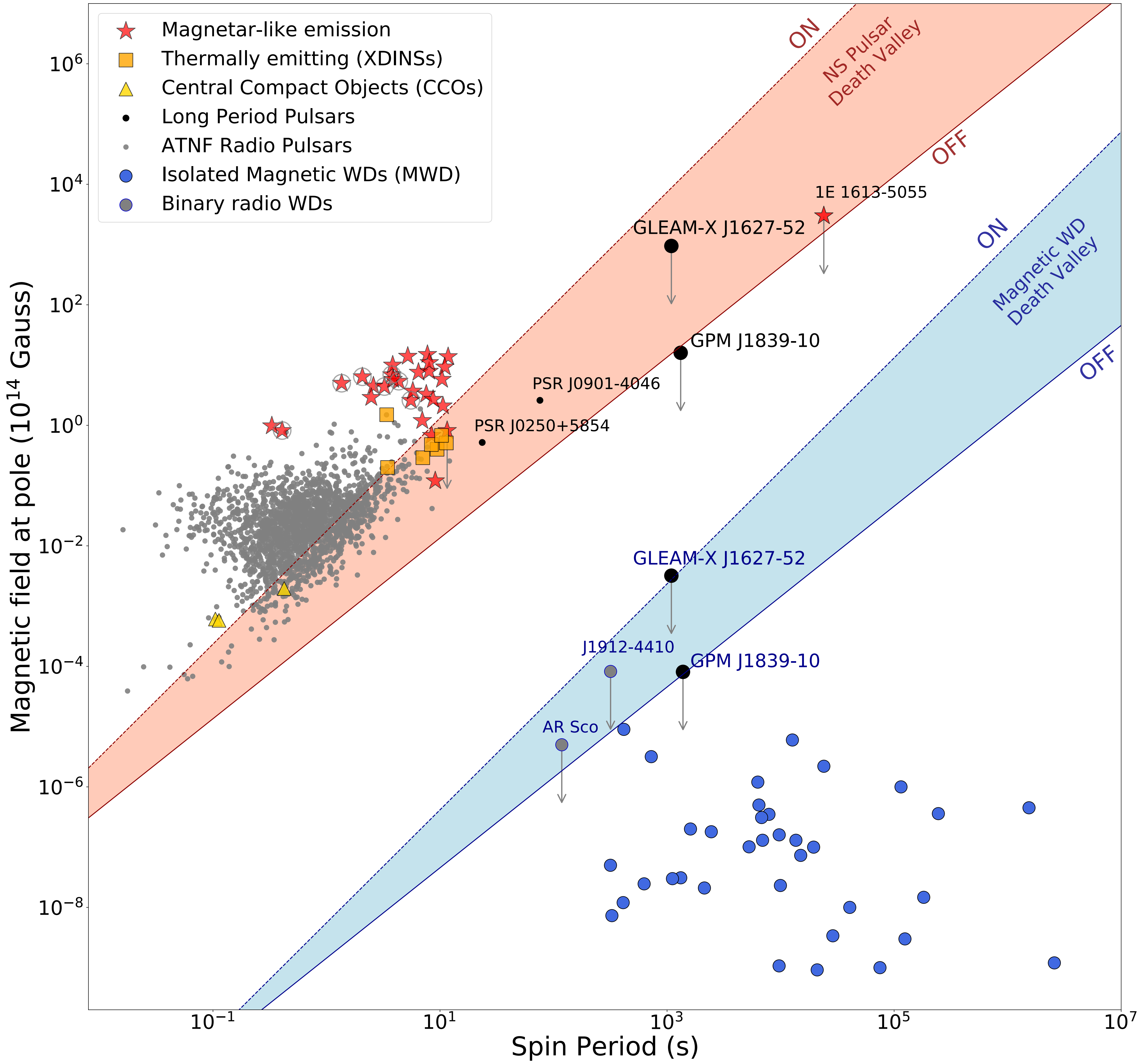
seems largely ruled out for GLEAM-X J1627 based on Pdot and optical limits



Beniamini, Wadiasingh, Hare+2023

Rotation-powered isolated WD?

seems largely ruled out for GPM J1809-10 too



Credit: Rea et al. 2024

Population synthesis experiments find isolated WD scenarios cannot explain high radio luminosity

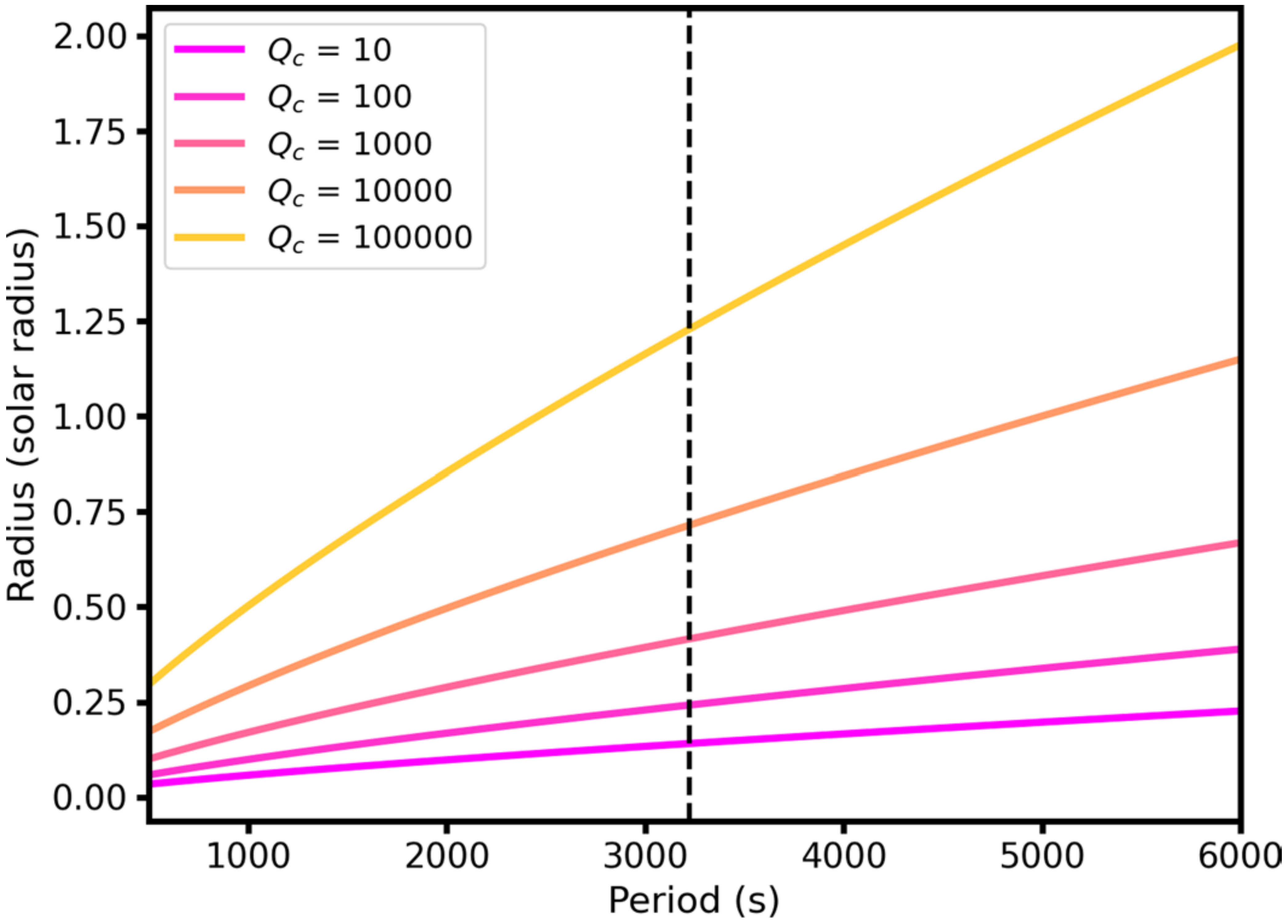
On the other hand, NS scenarios require revisions on field evolution

Rotation-powered isolated WD?

definitely ruled out for ASKAP J1935+2148 with P = 54 mins

Caleb+2024,
Beniamin, Wadiasingh, Hare+2023

$$R \gtrsim 4 \times 10^{9} \left(\frac{Q_c}{10}\right)^{4/17} P_3^{13/17} B_9^{-8/17} \quad \mathrm{cm}$$



Extended Data Fig. 5 | Constraints on the radius of a source, in units of solar radii, for various assumed rotational periods. Q_c is the ratio of the field curvature radius to the stellar radius with the value inversely proportional to the size of the star. Q_c is typically assumed to be 10 for WDs but is larger in reality. The vertical line denotes the period of ASKAP J1935 + 2148. Even in the most conservative case of $Q_c = 10$, we are able to rule out a white dwarf origin scenario. More details in Methods.

Magnetically-powered isolated WD?

can be ruled out based on source density and energetics

Argument goes as follows:

1. Total energy observed released ~10^37-10^39 erg over a few months
2. Can keep this activity up at most ~50-100 yrs for a 10^8 G WD (1% of WD population have magnetic fields > few times 10^8 G),
    - even shorter for 10^6 G WDs
3. Observed ULP source densities though demand a high formation rate
4. This demands a magnetized WD formation rate significantly larger than known WD formation rates — reductio ad absurdum!

$$\frac{\dot{r}}{\dot{r}_{\rm WD}} \gtrsim 200 B_8^{-2} R_{8.5}^{-3} f_{\Omega} \eta^{-1} L_{R,31.5}.$$

Beniamini, Wadiasingh, Hare+ 2023

How to get a neutron star to such a long period?

Many possible mechanisms to spin down magnetars to long periods

There is much phenomenological evidence for epochs of enhanced spindown in Galactic magnetars.

Physical mechanisms for attaining long periods:

- Fallback disks
- Enhanced spindown from monopolar particle winds and opening of magnetic flux
- Giant flare kicks
- Regular magnetic dipole spin-down persisting on a long-lived strong field
- Some or all of the above operating over the lifetime of the object

Beniamini+2020; Ronchi, Rea+2022

Phenomenological evidence for enhanced spin-down

Enhanced spin-down associated with GFs and strong bursting behavior

- SGR 1900+14: $x_p \equiv \frac{\Delta P}{P} \sim 10^{-4}$ after 1998 GF
- SGR 1806-20: Increased $\dot{P}$ since 2004 GF. Up to 2012, P increased by extra 2% compared to pre-GF extrapolation (Younes et al. 15).
- Kinematic age constraints of these magnetars suggest further $\dot{P}$ enhancements in their past (Tendulkar et al. 12)
- 1E 2259+586 : Anti-glitch of $x_p \sim 10^{-6}$ in ~100 days (Archibald et al. 13)

Simplest phenomenological model

If $x_p = const$ then $P_f = P_0 \exp\left(N_p x_p\right) \rightarrow P_f \gg P_0$ for $N_p > x_p^{-1}$

- With $E_{GF} \sim 4\times10^{44} erg$ and $x_p \sim 10^{-4}$, a significant increase of P requires a magnetic energy reservoir of > $4\times10^{48} erg$ or internal field $B_{int} > 5\times10^{15} G$
- Compare to SGR 1900+14: $B_{dip} = 7\times10^{14} G$ and recall that B_{int}~10 B_{dip} inferred from X-rays
- Small population of highest B magnetars could plausibly evolve to ULPMs

Beniamini, Wadiasingh, Metzger 2020

Physical mechanisms for enhanced spin-down

Charged particle winds

- Mass–loaded charged wind with $L_{pw} > L_{dip}$ opens up B lines beyond

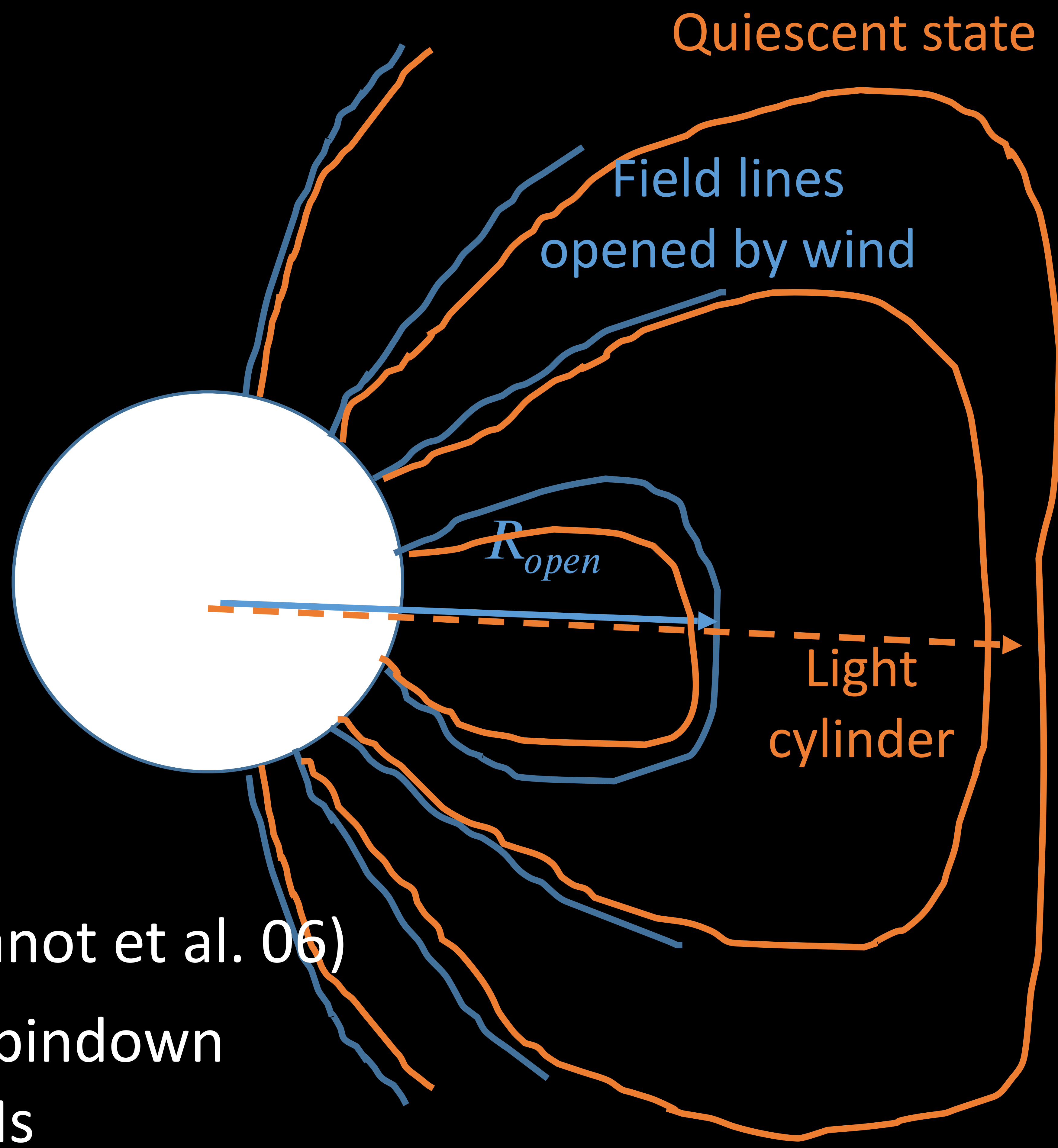
$$R_{open} \sim R_{NS} \left(\frac{B_{dip}^2 R_{NS}^2 c}{L_{pw}} \right)^{1/4}$$ (Thompson & Blaes 98, Harding et al. 00)

- Spindown scales as open flux squared -> Enhanced spindown $\dot{P} \propto P$
- $P_f = P_0 \exp(\frac{t}{\tau})$ with

$$\tau = \frac{I c R_{\rm open}^2}{B_{\rm dip}^2 R_{\rm NS}^6} = \frac{I c^{3/2}}{B_{\rm dip} R_{\rm NS}^3 L_{\rm pw}^{1/2}} = 5 \times 10^7 B_{\rm dip,15}^{-1} L_{\rm pw,40}^{-1/2} \ {\rm s}$$

$$P_{\rm f} = P_0 \exp\left[\frac{E_{\rm B} \Delta t_{\rm pw}}{E_{\rm f} \tau}\right] = P_0 \exp\left[0.7 \frac{B_{\rm int,16}^2 B_{\rm dip,15} E_{\rm pw,42}^{1/2} \Delta t_{\rm pw,2}^{1/2}}{E_{\rm f,44}}\right]$$

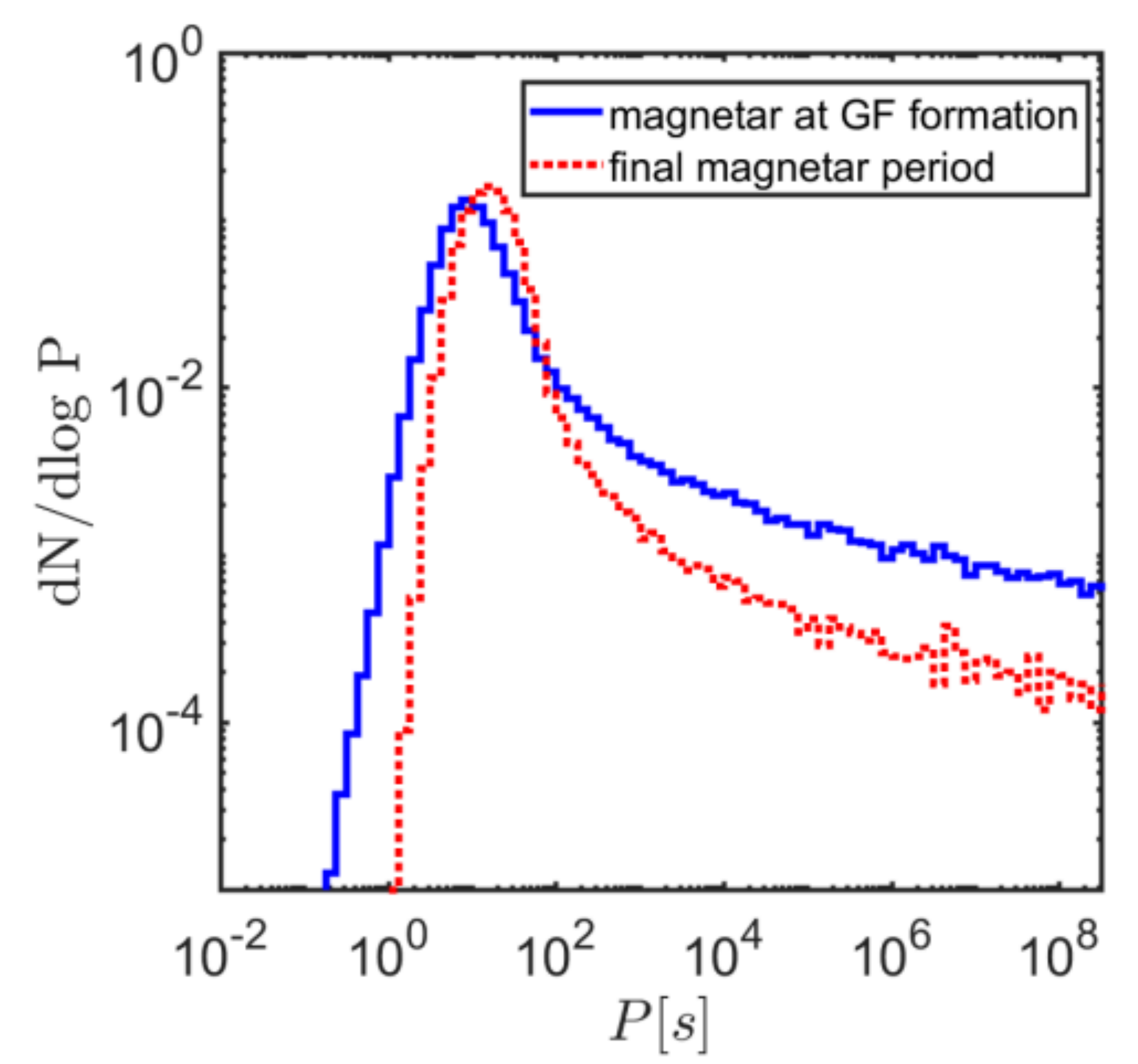
- Outflows with $E_{kin} \sim E_f$ inferred from 1806-20 GF (Gelfand et al. 05, Granot et al. 06)
- Pulsating tail of GF require mass-loaded wind – longer duration favors spindown
- Exponential sensitivity to physical conditions —> small fraction of ULPMs



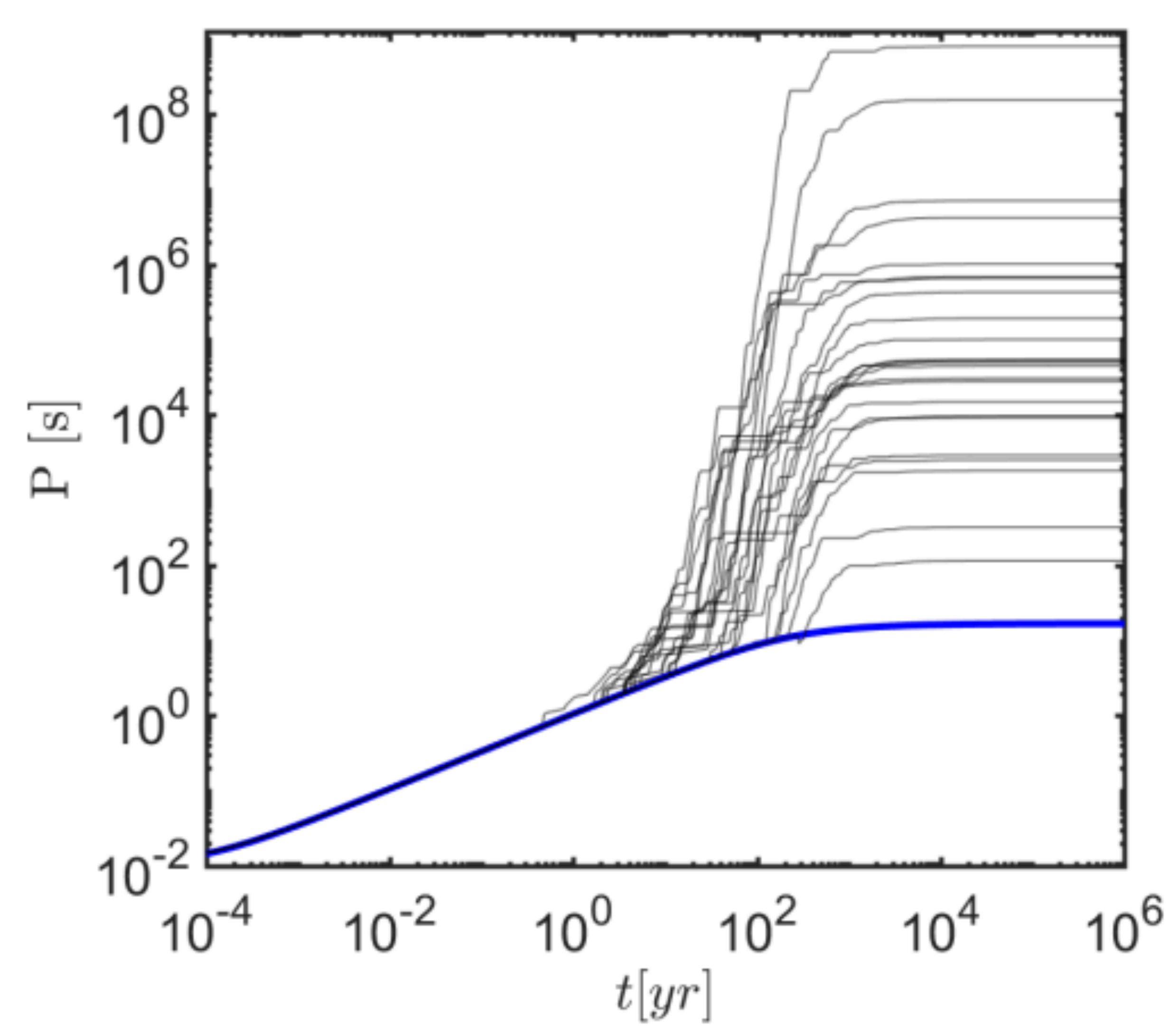
Physical mechanisms for enhanced spin-down

Charged particle winds

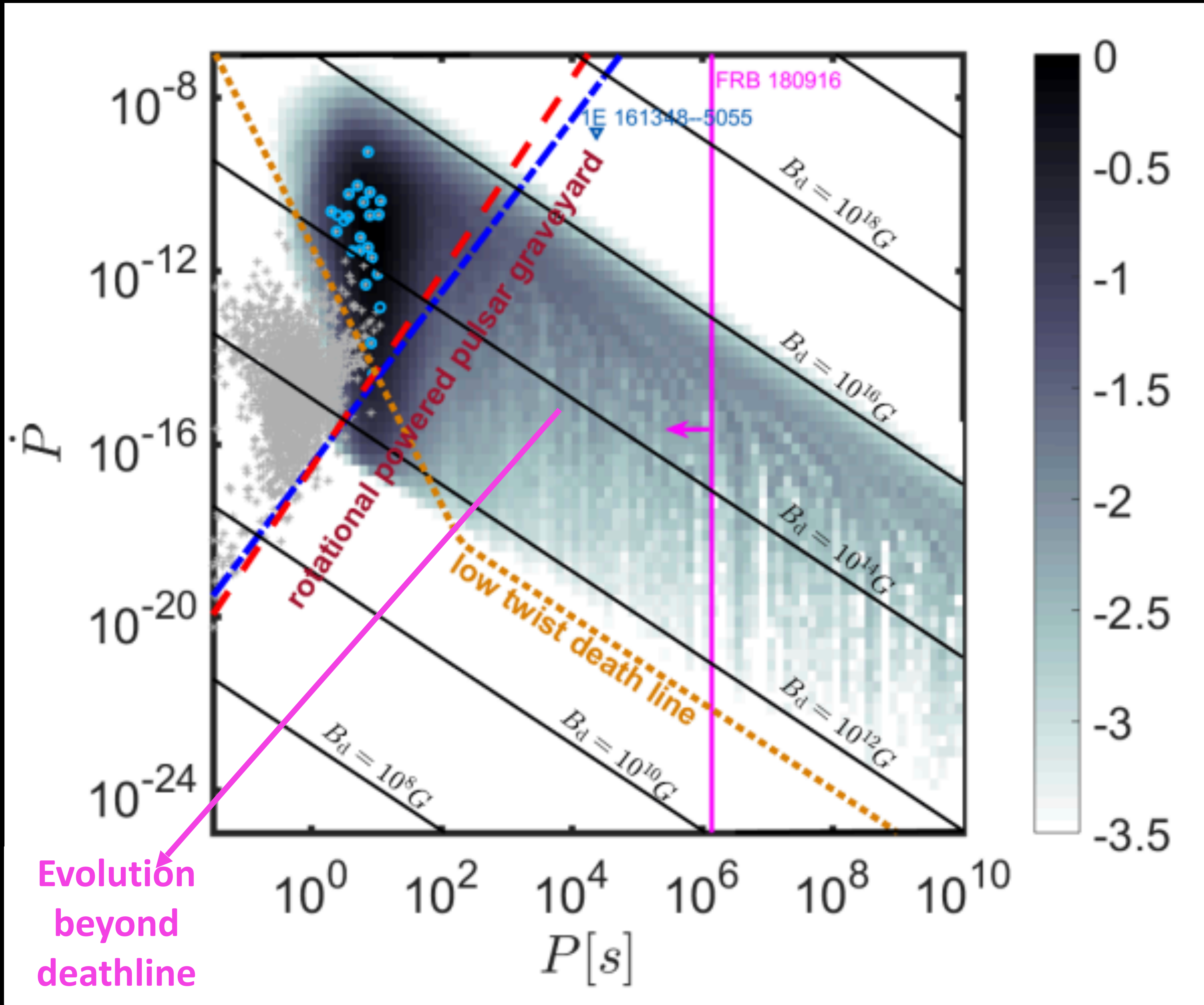
- Monte Carlo proof of concept:



Flat P distribution at large P



Example P evolutions



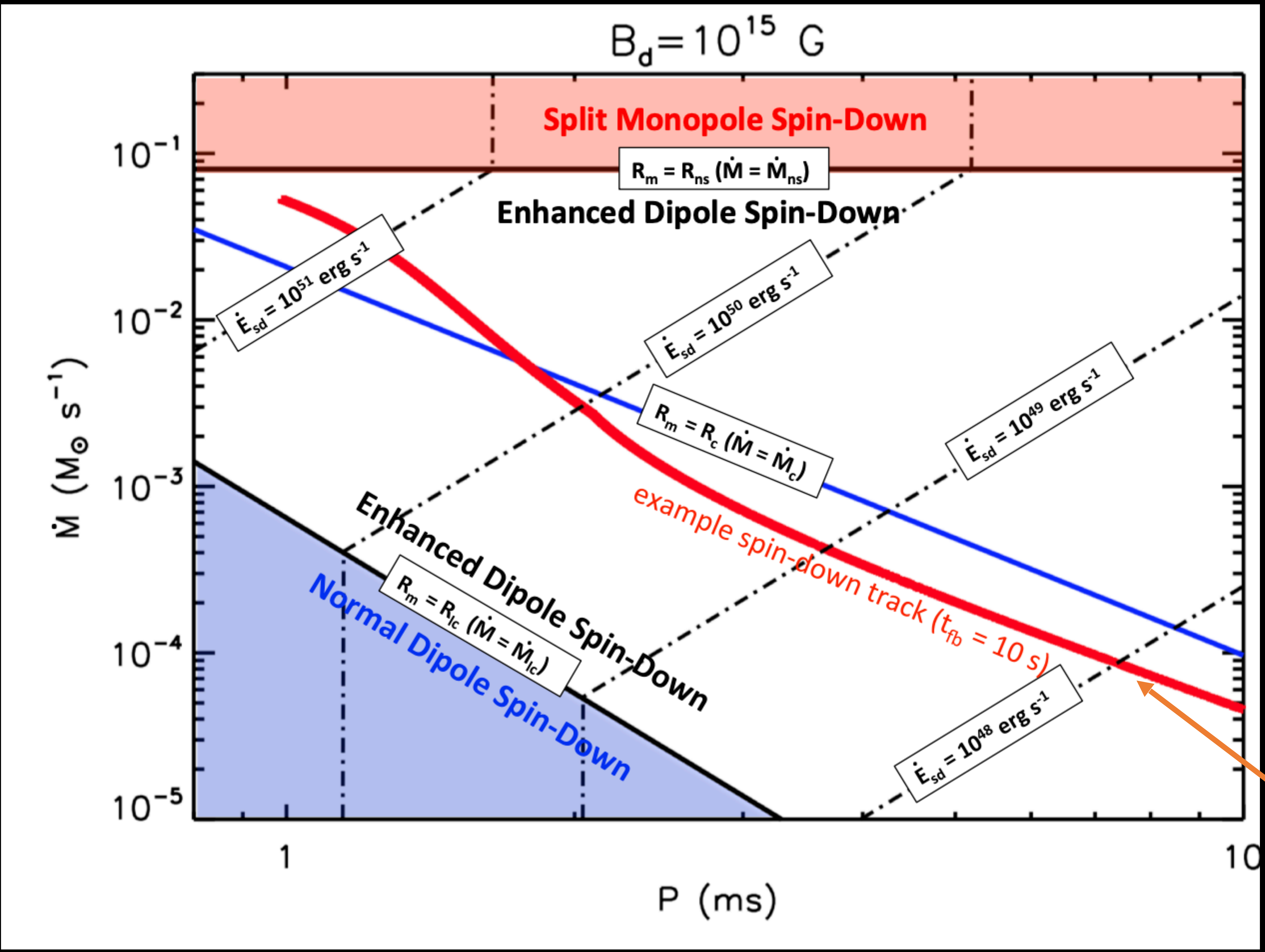
Evolution beyond deathline

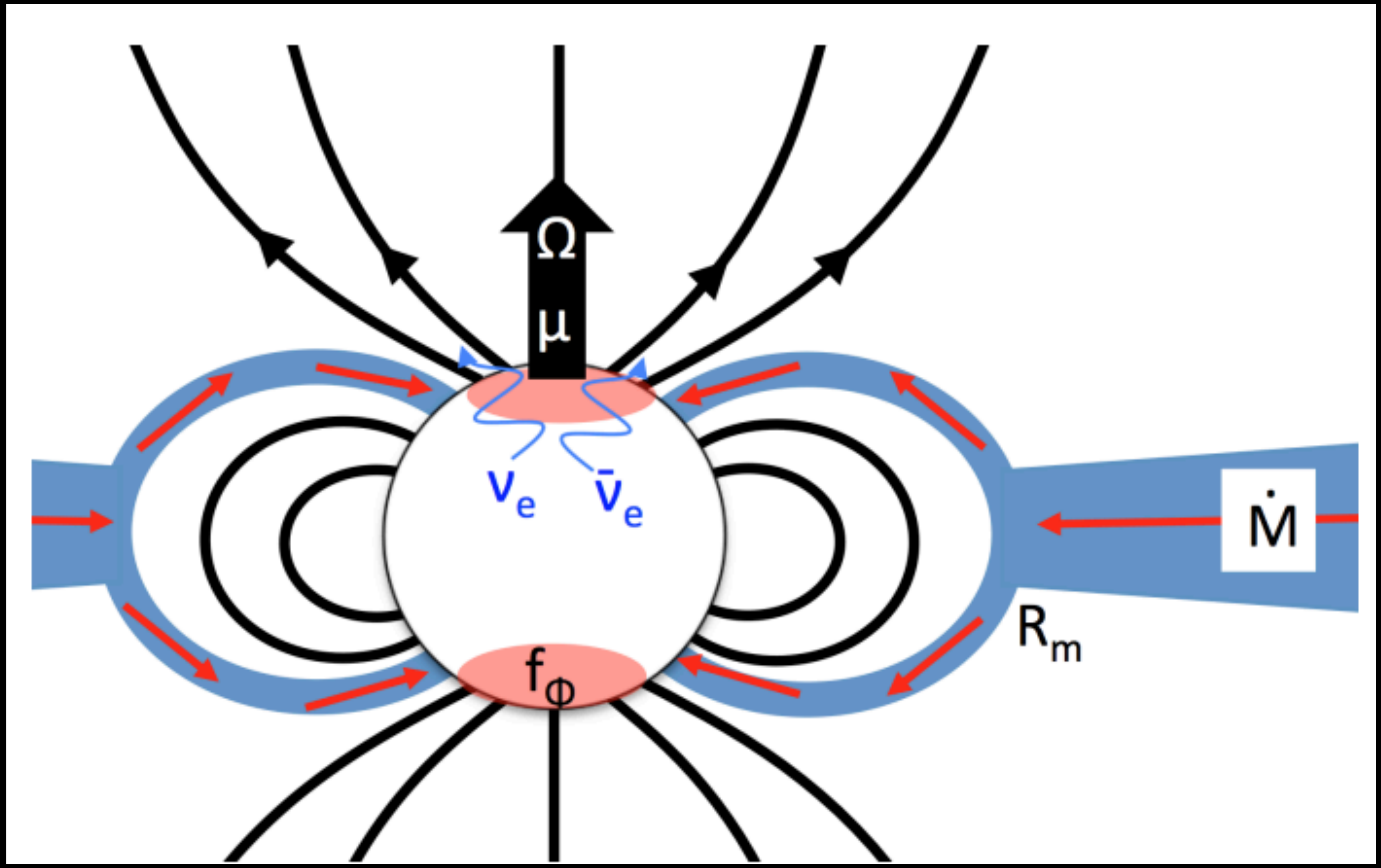
Beniamini, Wadiasingh, Metzger 2020

Physical mechanisms for enhanced spin-down

Fallback accretion

- RCW103 – sub-energetic SN remnant: consistent with more fallback (Braun et al. 2019)
- Fallback accretion alters magnetar evolution by adding rotational energy sink/reservoir and enhancing spindown by opening up field lines





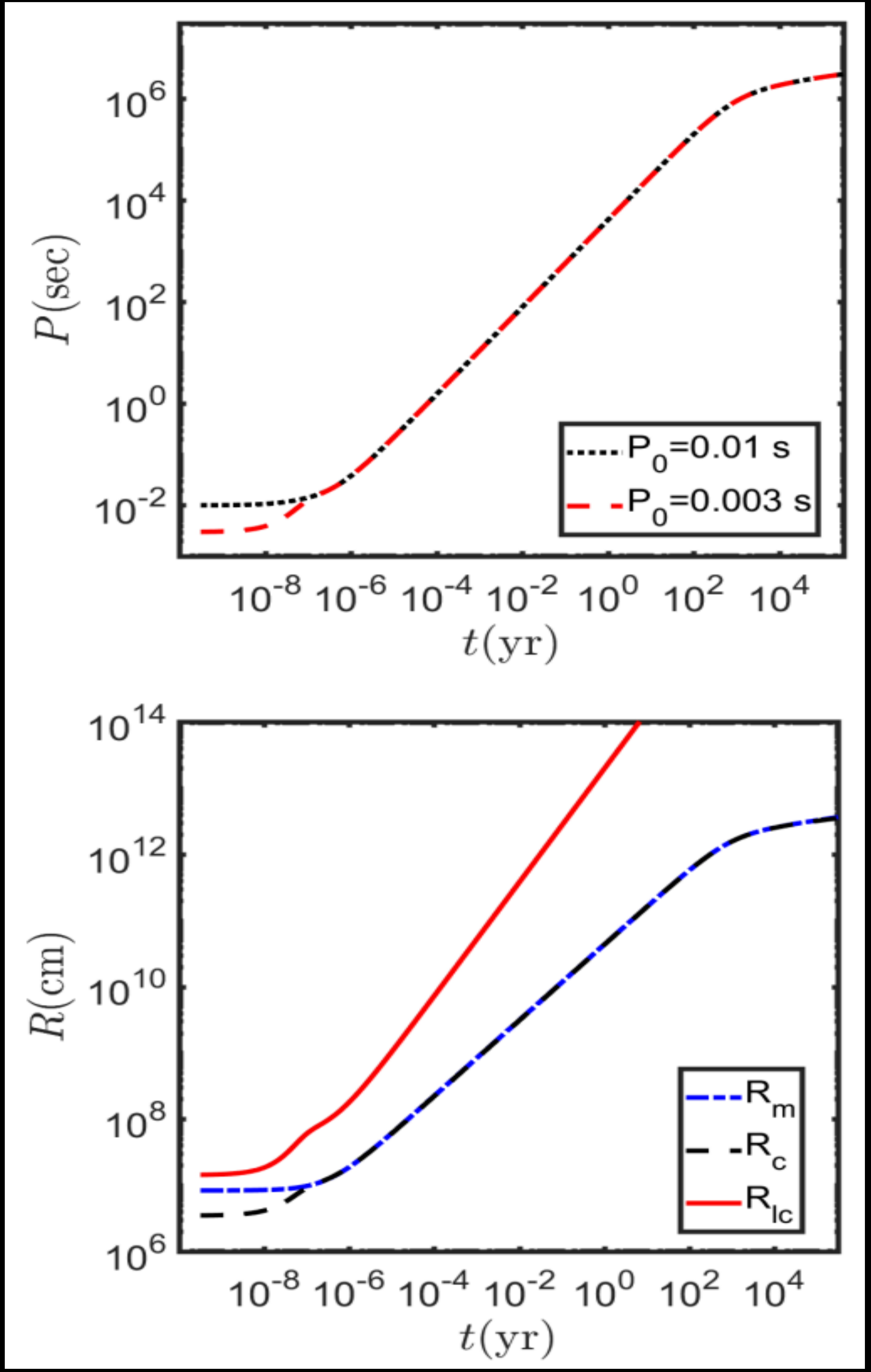
Rough equilibrium between co-rotation and Alfven radius

Metzger, Beniamini, Giannios 2018

Physical mechanisms for enhanced spin-down

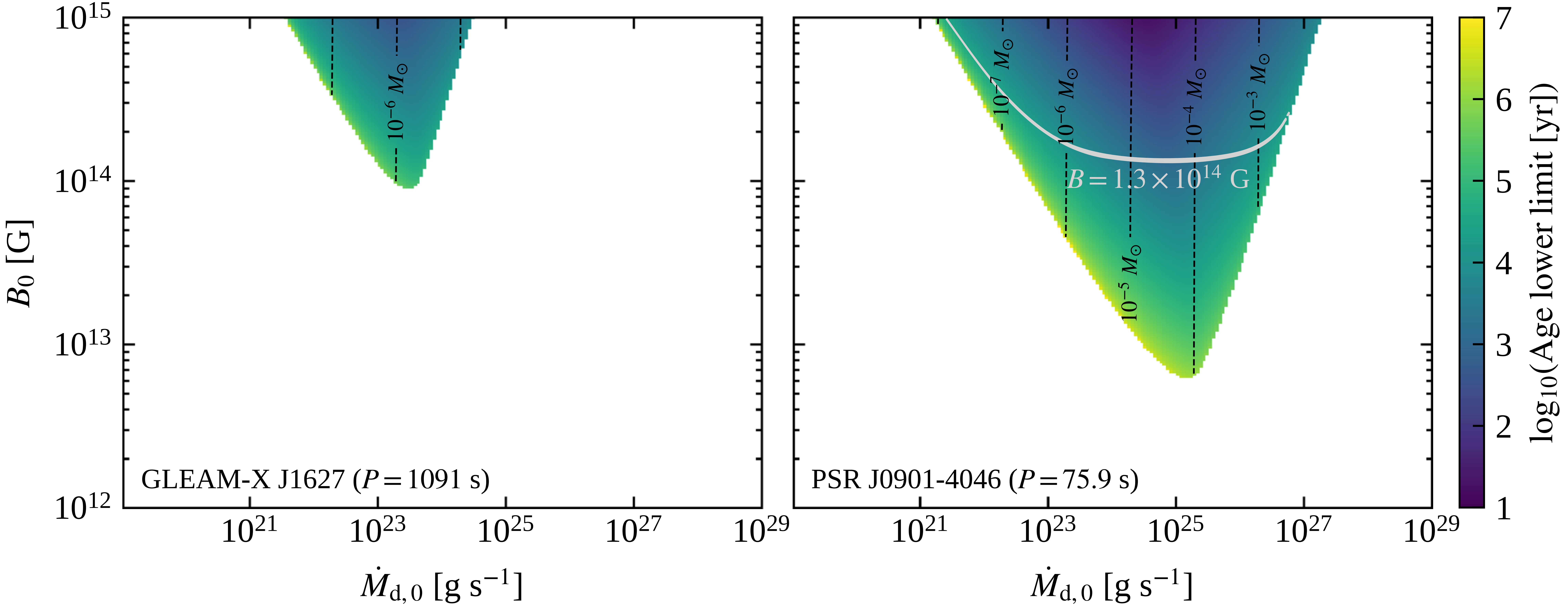
Fallback accretion

- P exponentially increases until $R_m \sim R_c$ and evolves as $t^{3\zeta/7}$ afterwards, where $\dot{M} \propto t^{-\zeta}$
- Large ζ expected for high $\dot{M}$ RIAFs
- ζ cannot be too large to avoid early disk disruption
- Maximum period set by time it takes magnetic field to decay (relative to initial fallback time)
- Accretion can lead to ULPMs under plausible conditions
- Bimodality of magnetar periods can be related to bimodality in SN properties



Beniamini, Wadiasingh, Metzger 2020

Fall-back disk mechanism requires high B, also favors older sources



Credit: Ronchi, Rea+ 2022

Implications for Magnetothermal Evolution Models

- Magnetar-strength fields must survive for Myr timescales! Challenging for standard magnetothermal evolution models. Magnetothermal evolutionary models of magnetars are nonlinear and path dependent

- Cannot be an uncommon track or finely-tuned for field evolution

- Interesting prospect for the M81 globular cluster FRB

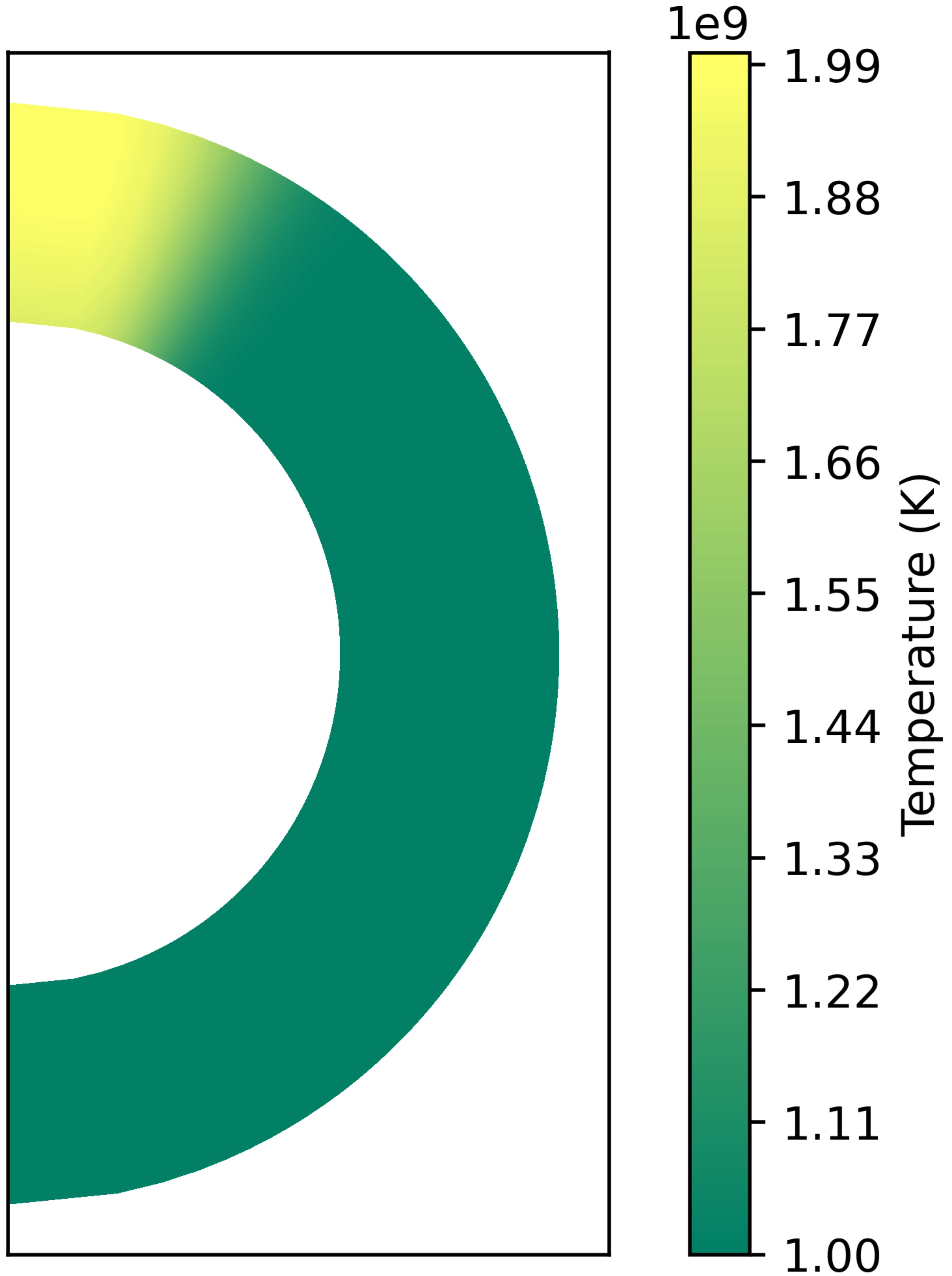
- Evolutionary tracks of PSR J0901-4046 like objects is likely totally different from standard X-ray magnetars

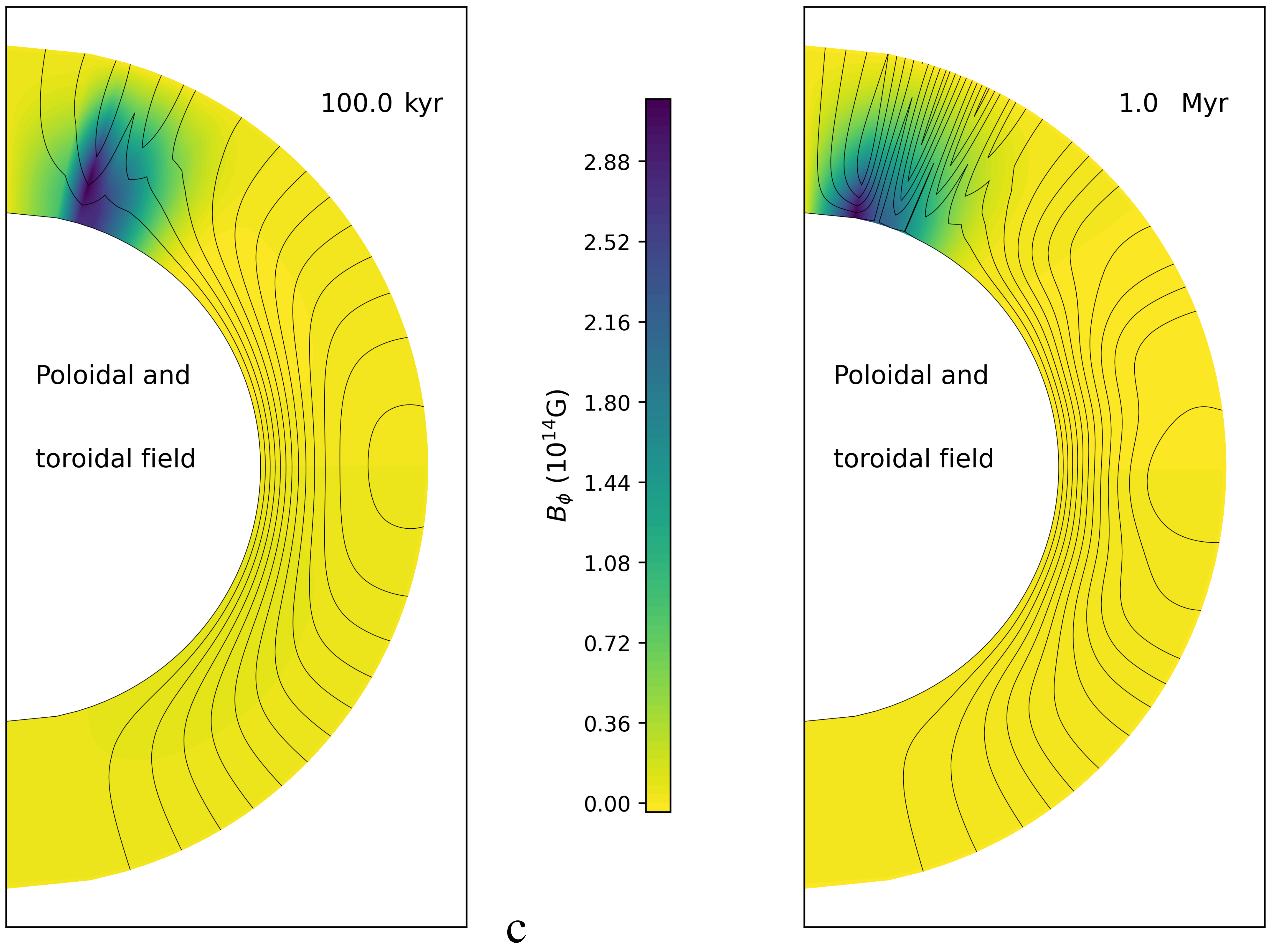
- Possibility: strong residual crust field in a "Hall attractor" which is commensurate with longer crust Ohmic decay timescales (Gourgouliatos and Cumming 2013, 2014)

- Possibility: Strong core field. Neutron+proton superfluidity can also suppress ambipolar diffusion in the core (e.g. GR92, Glampedakis et al. 2011, Graber et al. 2015) —> "solenoidal" part decays faster, so the remaining field will be largely poloidal with low-twist

- Possibility: Superconductivity Meissner effect in the core (Lander+)

Meissner effect and thermoelectric action?



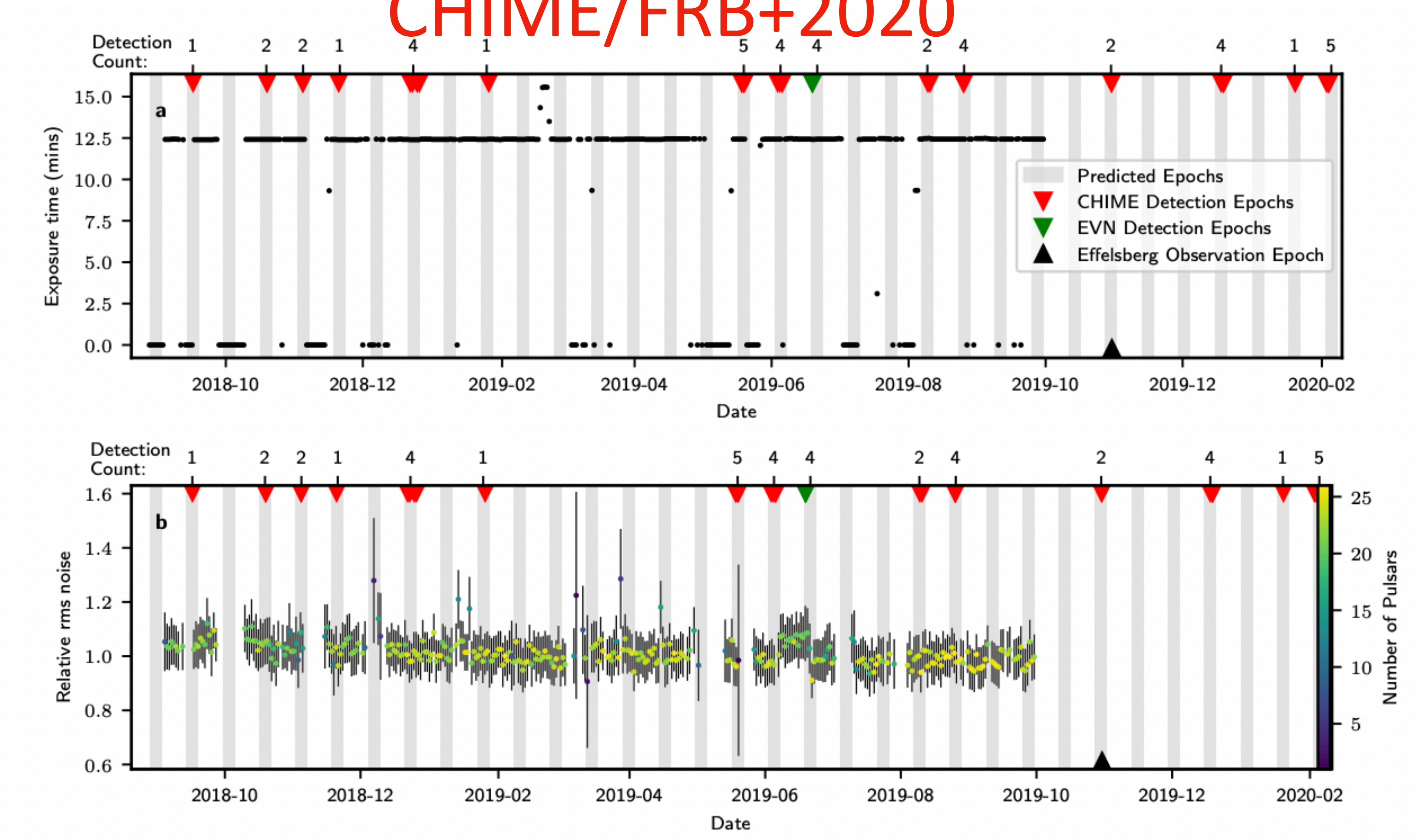


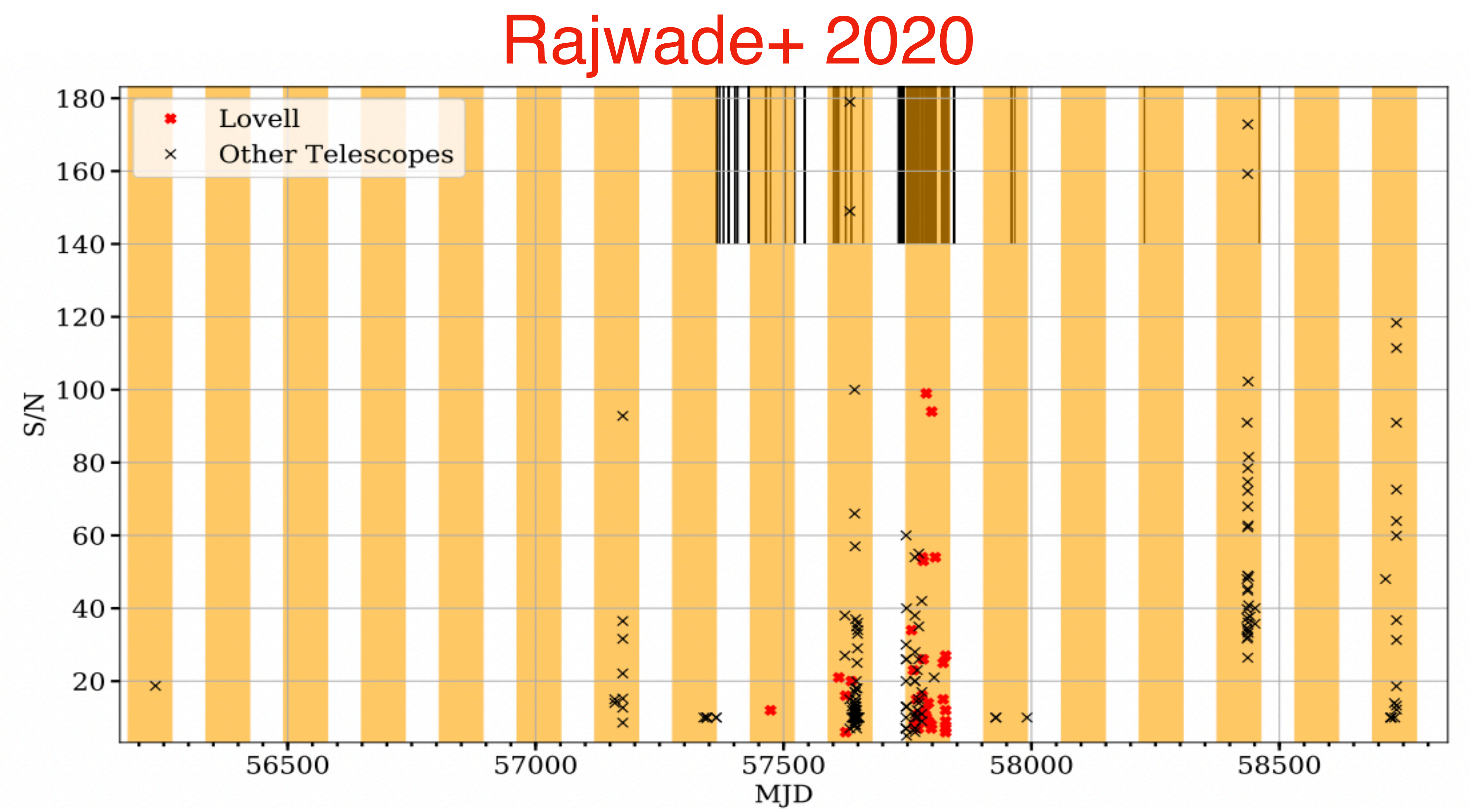
Credit: Gakis & Gourgouliatos 2024

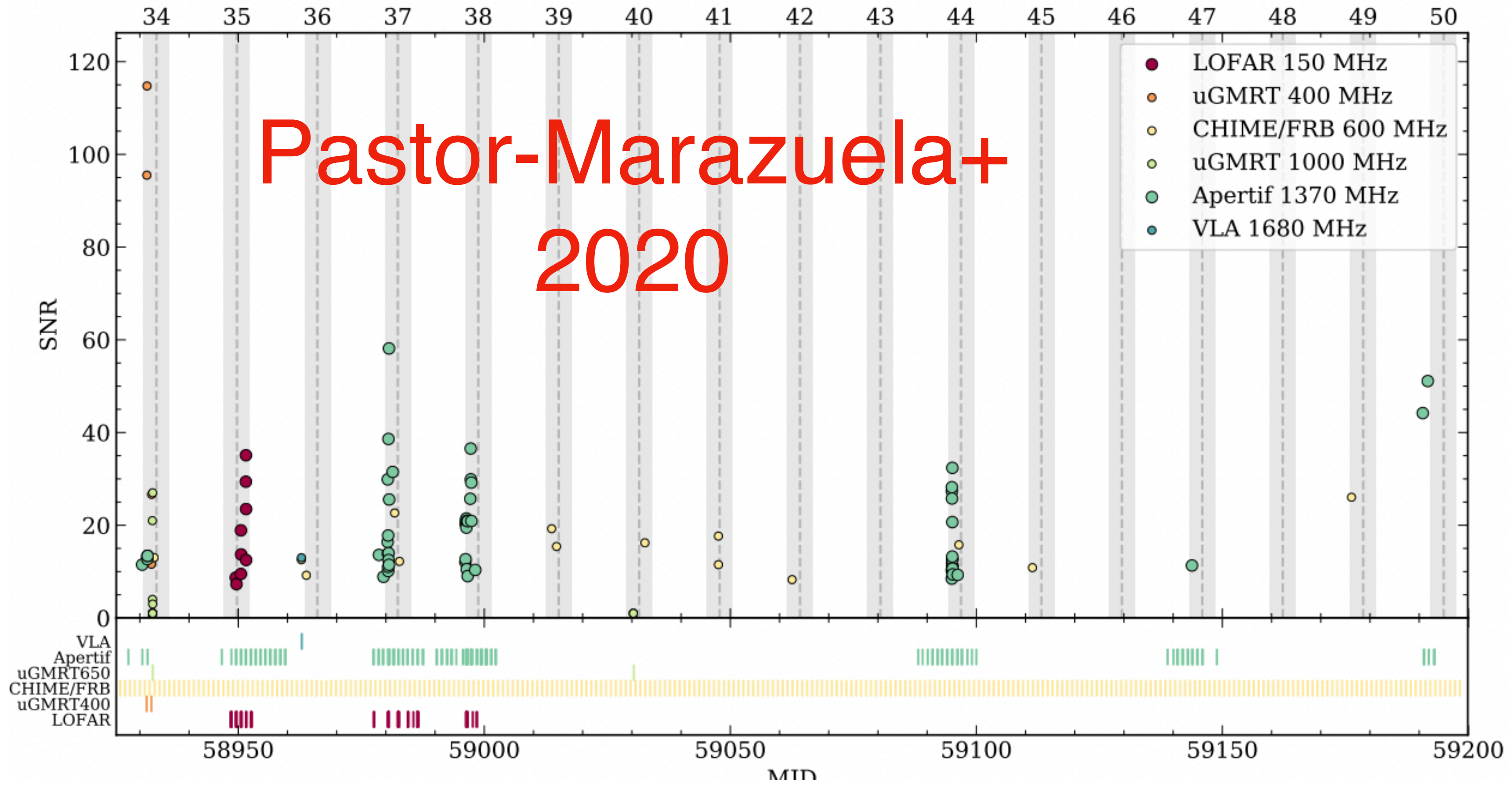
FRB Connections?

Observed FRB periodicity

Two prolific repeaters R1 (FRB 121102) and R3 (FRB 180916)


CHIME/FRB+2020

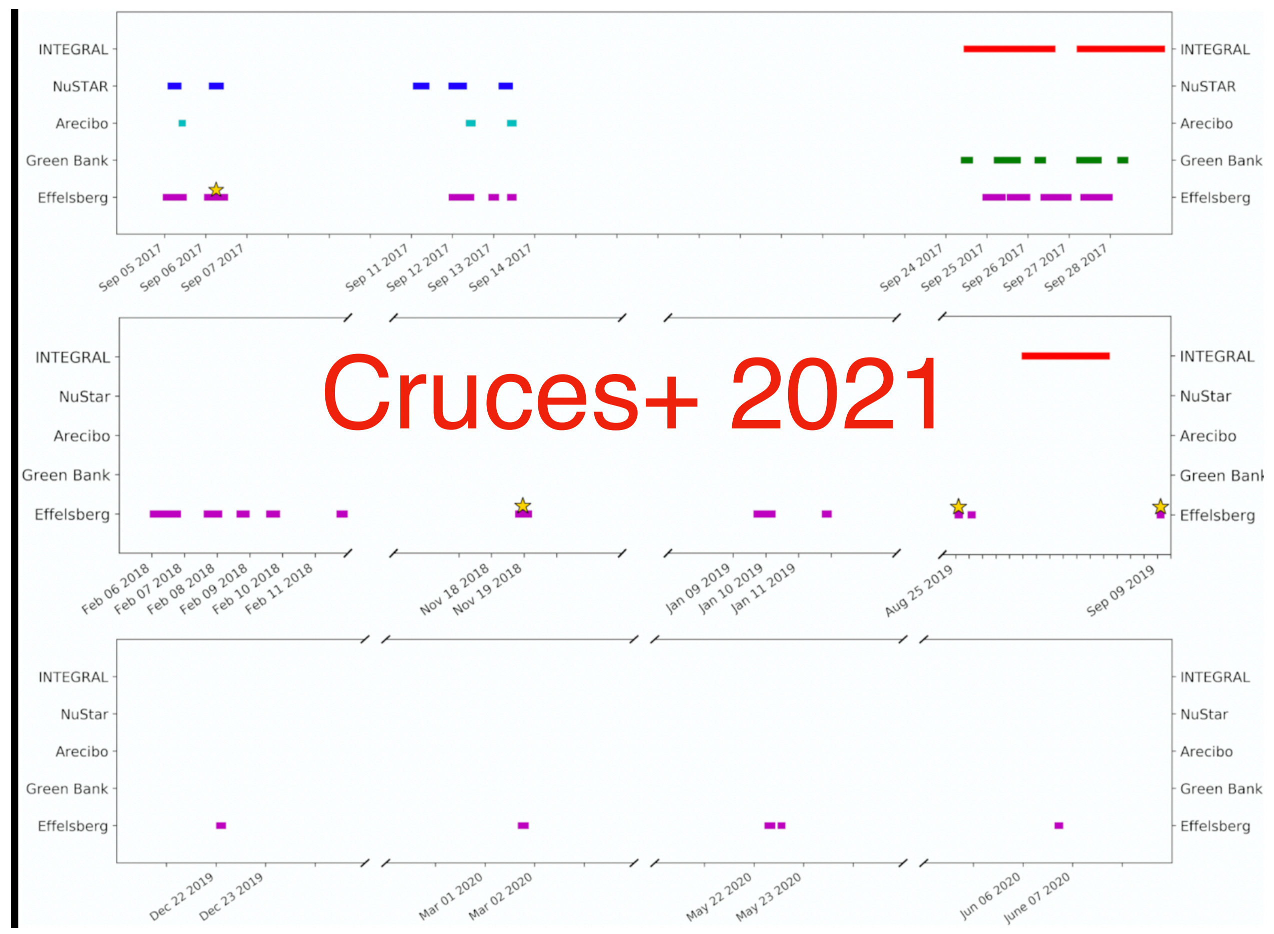

Rajwade+ 2020


Pastor-Marazuela+ 2020

No aliasing ;
periodicity persists in continued monitoring / other bands

Potential explanations:
binarity (orbital period)
precession
rotation

FRB 121102 – 160 day periodicity, day active phase


Cruces+ 2021

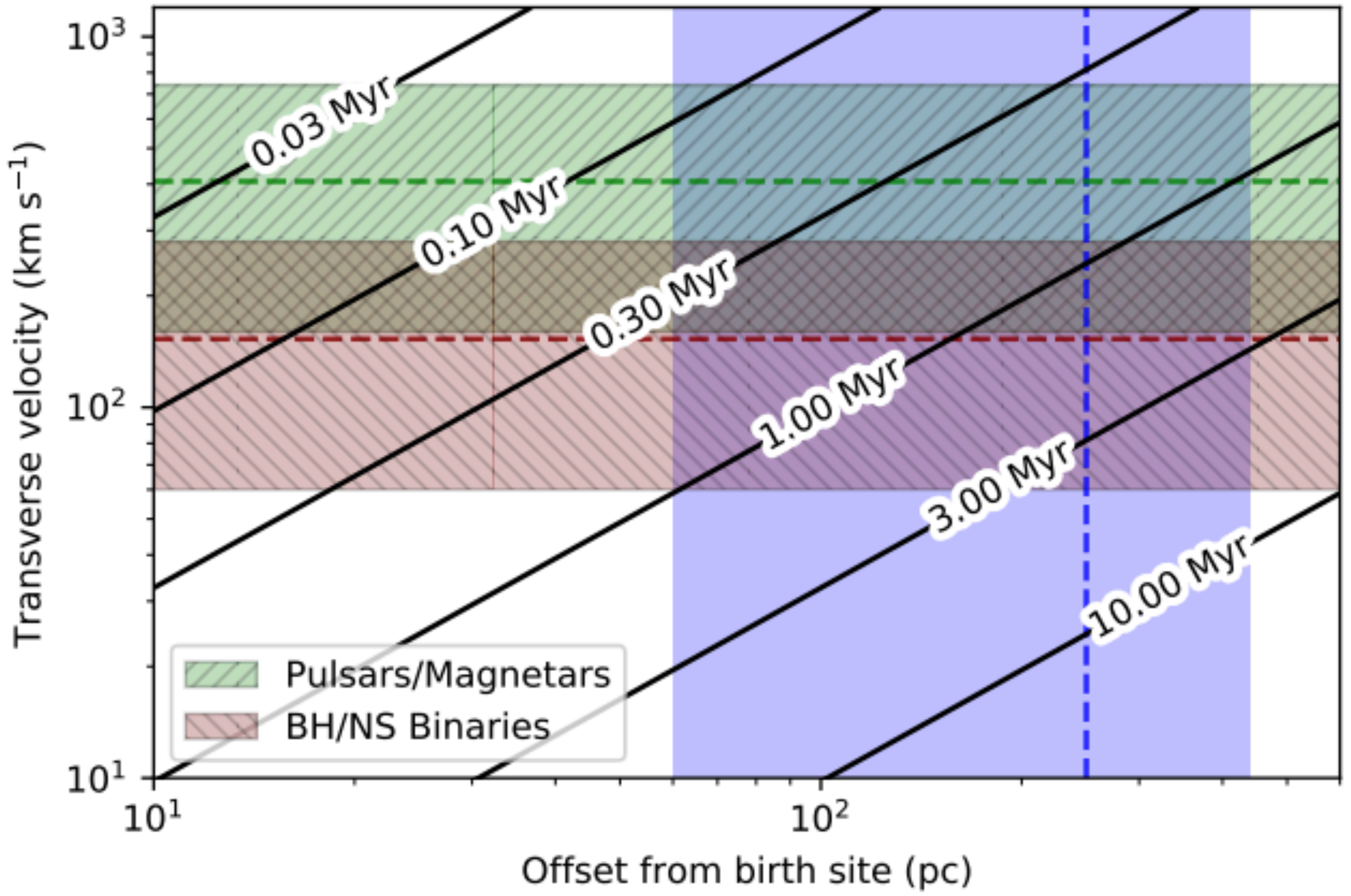
I’ll advocate for the long period scenario

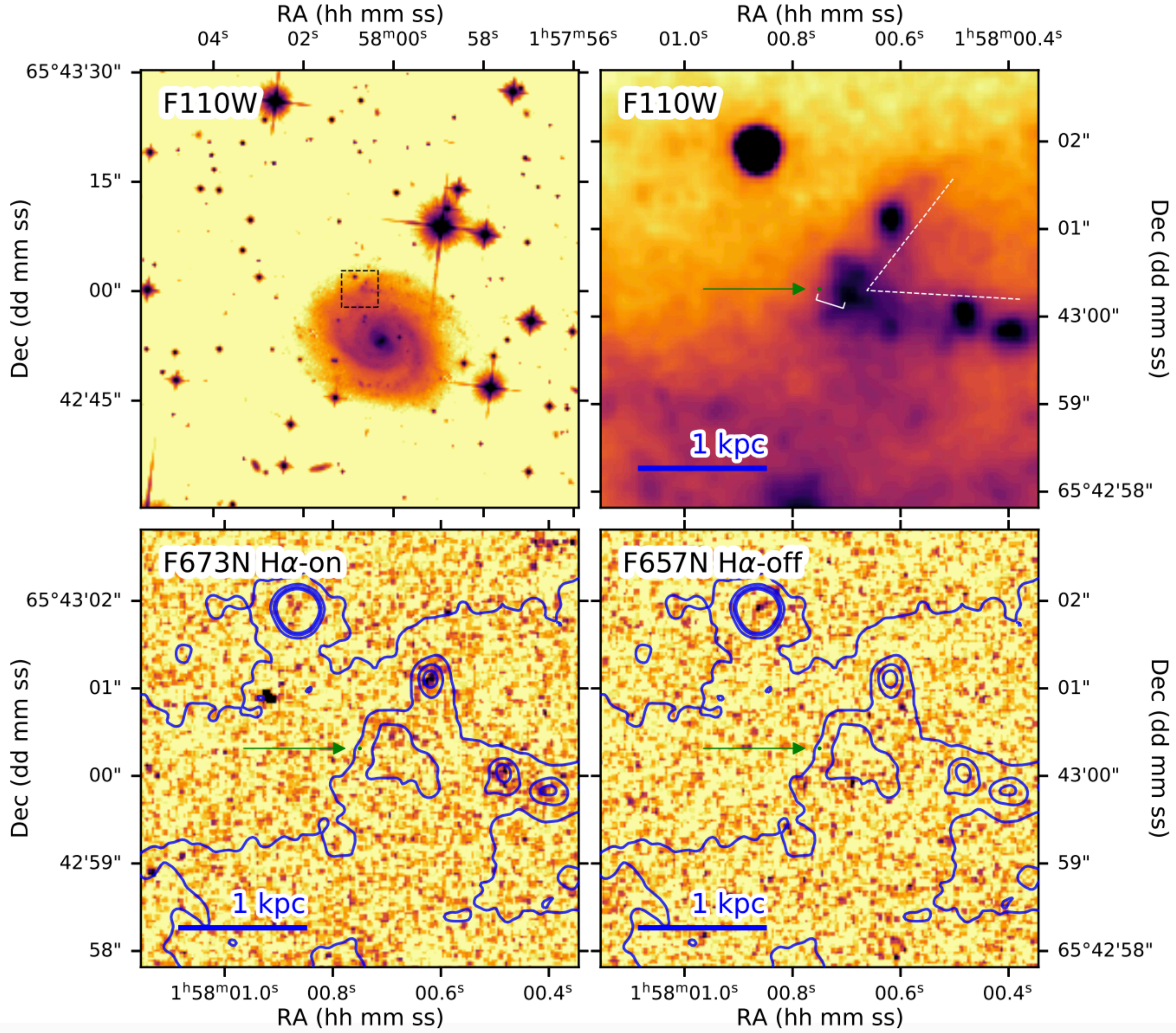
Challenges for other models

Precession predictions

- High temperature -> Young age (challenged by offset from star-forming environment, Tendulkar et al. 21 for R3)
- Significant changes in polarization (but R1 polarization quite stable)
- Underlying shorter period (ruled out for R1, Zhang et al. 18, Li et al. 2021)
- Precession inversely related to deformation -> many more FRBs should have longer periods (and activity might anti-correlate with period)

Tendulkar et al. 21



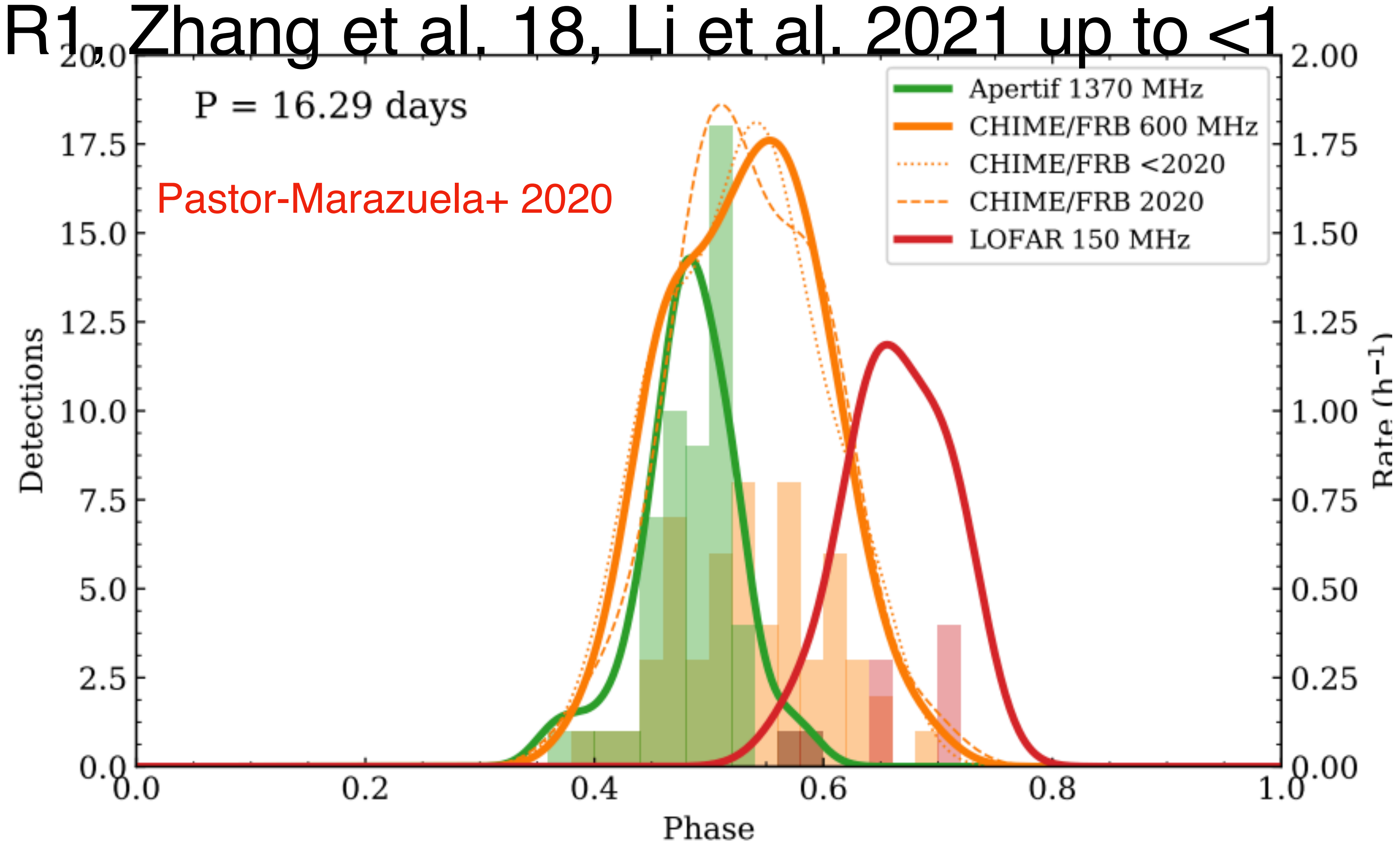


Challenges for other models

Shrouded binary models

- Shrouding preferentially obscures low frequency bursts. In eclipsing pulsars

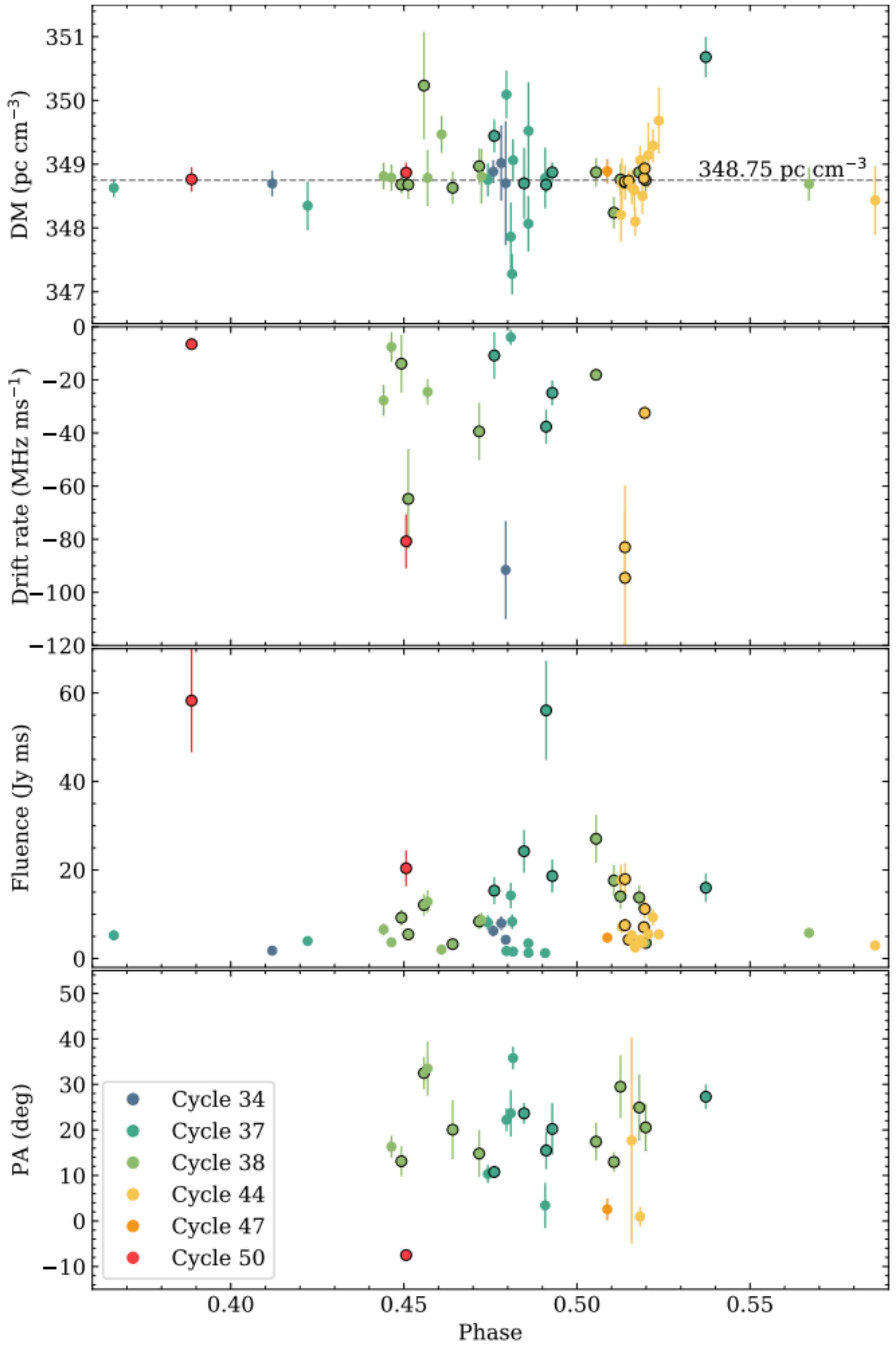
  Opposite is observed! eclipse fraction ∝ *ν^(-0.4)*
- Bright O/B type companion ruled out for R3 (Tendulkar et al. 21)
- DM changes within active phase -> *but ΔDM < 0.1 pc/cm^3*
- Low frequency spectral cutoff *(unobserved)*
- Strong flux/fluence modulation with phase — where are the weak bursts? *(unobserved)*
- Underlying shorter period (ruled out for R1, Zhang et al. 18, Li et al. 2021 up to <1 ks)



Pastor-Marazuela+ 2020

- Large and fluctuating RM which should lead to significant depolarization at low frequencies and RM sign reversal (Beniamini, Kumar & Narayan 22)

Pastor-Marazuela+ 2020

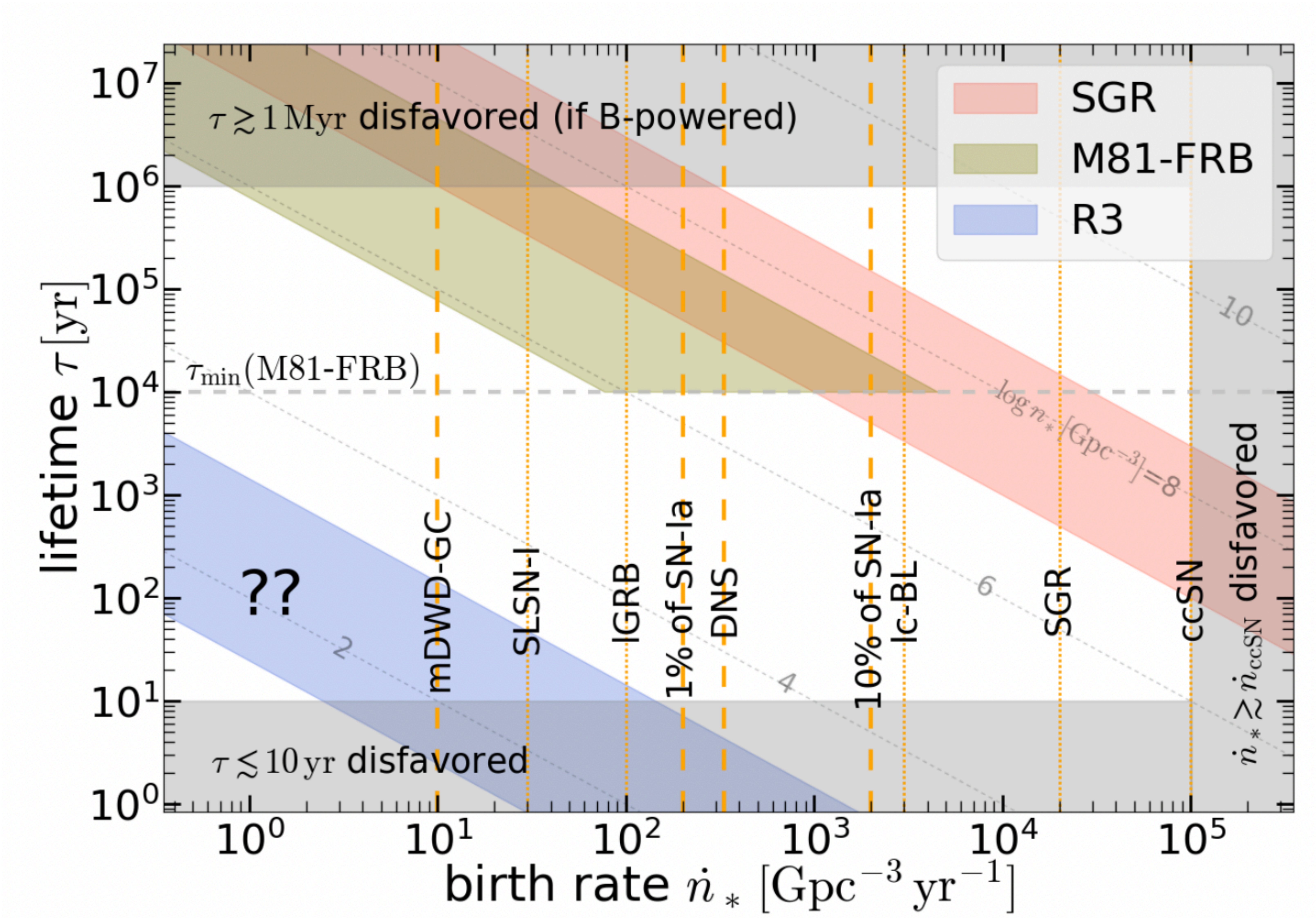


Source densities

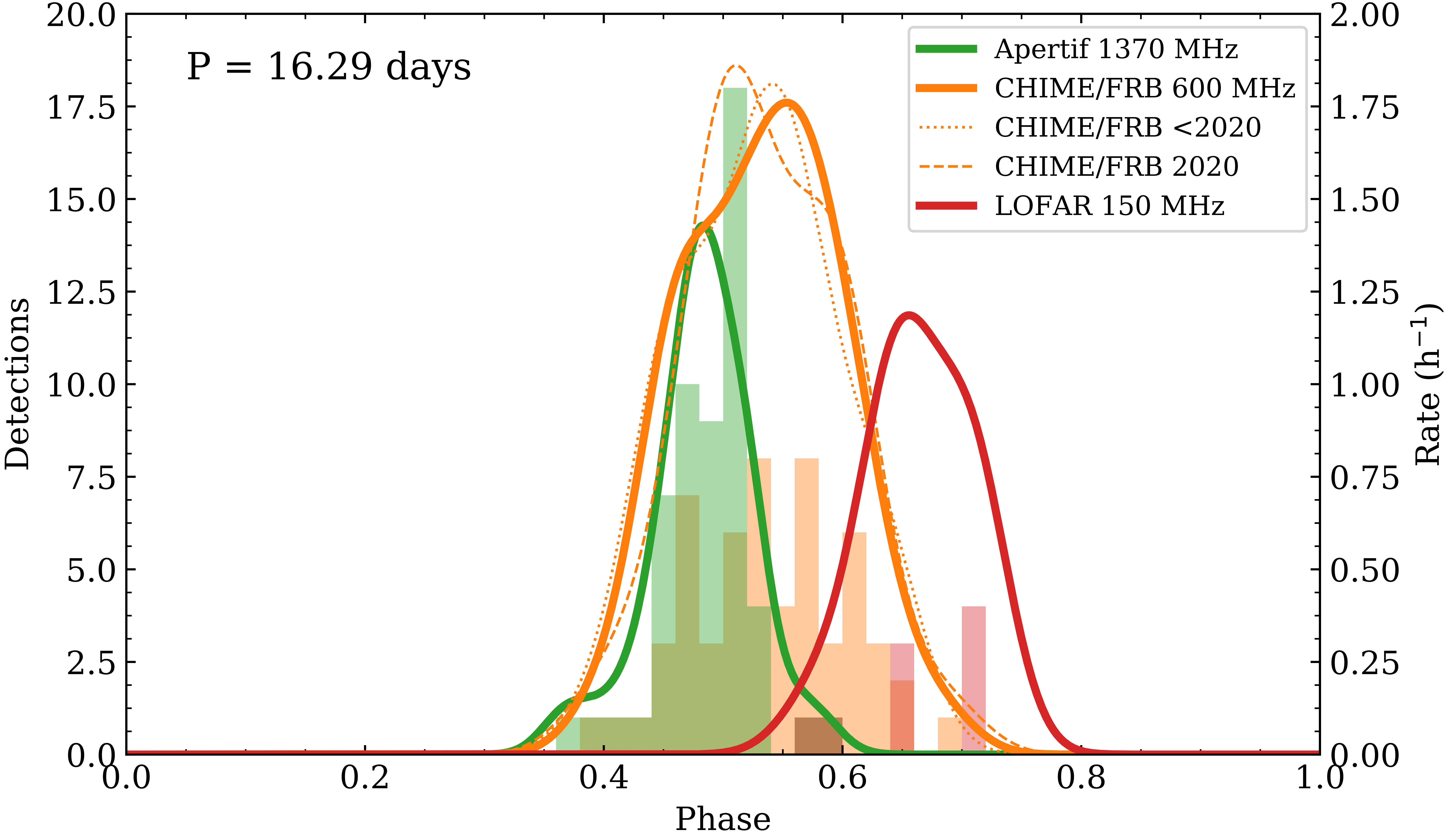
- R3 birth rate < 10^-3 ccSNe rate (Nicholl et al. 16)
- R3 source density 10^-7 to 10^-5 compared to Galactic magnetars (Lu, Beniamini, Kumar 21)

Rarity favors somewhat ‘exotic’ explanation

And yet some basic features of ULPMs observed even in Galactic objects…



Shrouding in a binary seems ruled out in FRB 180916



Pastor-Marazuela+ 2021, Nature, 2012.08348

If magnetars can survive for Myr ages, **then** Pulsar Revival in NSNS/NSBH mergers is an exciting possibility

Pre-merger emission in NSNS/NSBH coalesces

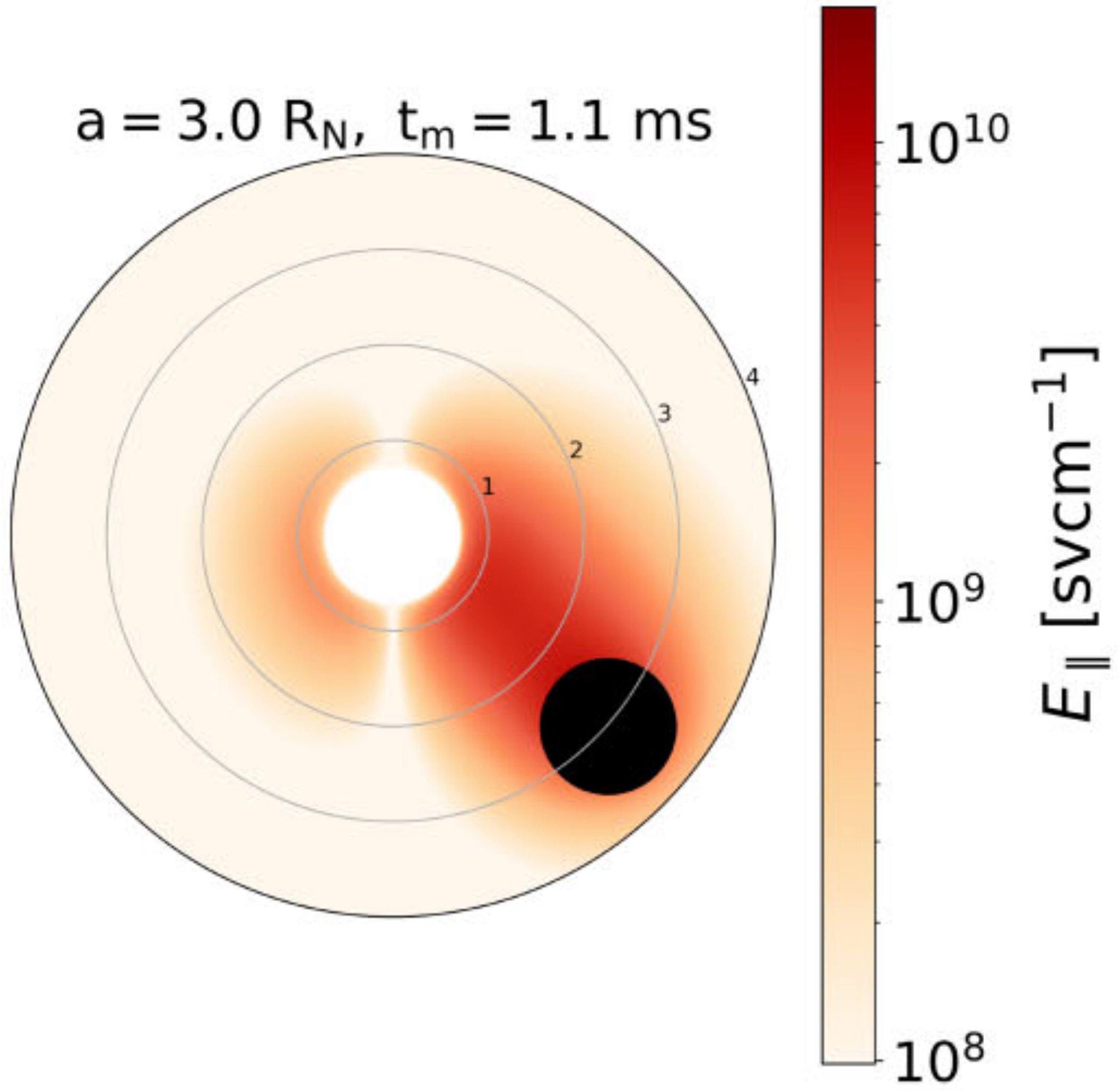
Considered in many works with different mechanisms and assumptions

Reconnection: Zhang (2020), Lai (2012), Most & Philippov (2020,2022)

Resonant crust scattering: Tsang+(2012), Suvorov & Kokkotas (2020)

Wind driven shocks: Medvedev & Loeb (2013), Sridhar+(2021)

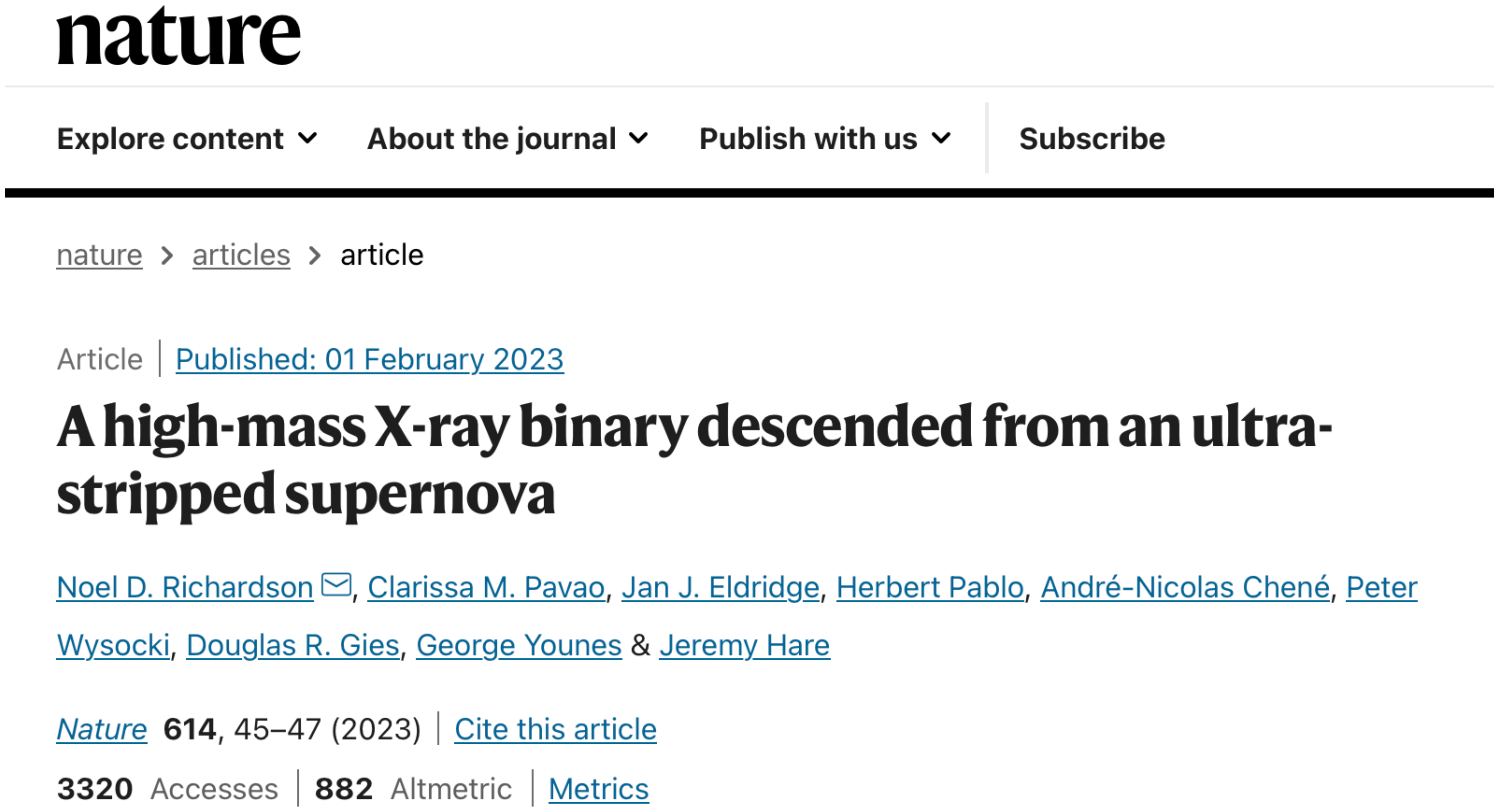
Pulsar revival: Lipunov & Panchenko (1996), Lyutikov (2019), **this talk** — Cooper, Gupta, Wadiasingh+ (2023)



Cooper, Gupta, Wadiasingh + 2023

Q: Any realistic prospect for a magnetar to be involved in a BNS merger?

Answer: depends on delay time distribution and field decay timescale, but possible yes



Article | Published: 01 February 2023

A high-mass X-ray binary descended from an ultra-stripped supernova

Noel D. Richardson, Clarissa M. Pavao, Jan J. Eldridge, Herbert Pablo, André-Nicolas Chené, Peter Wysocki, Douglas R. Gies, George Younes & Jeremy Hare

Nature **614**, 45–47 (2023) | Cite this article

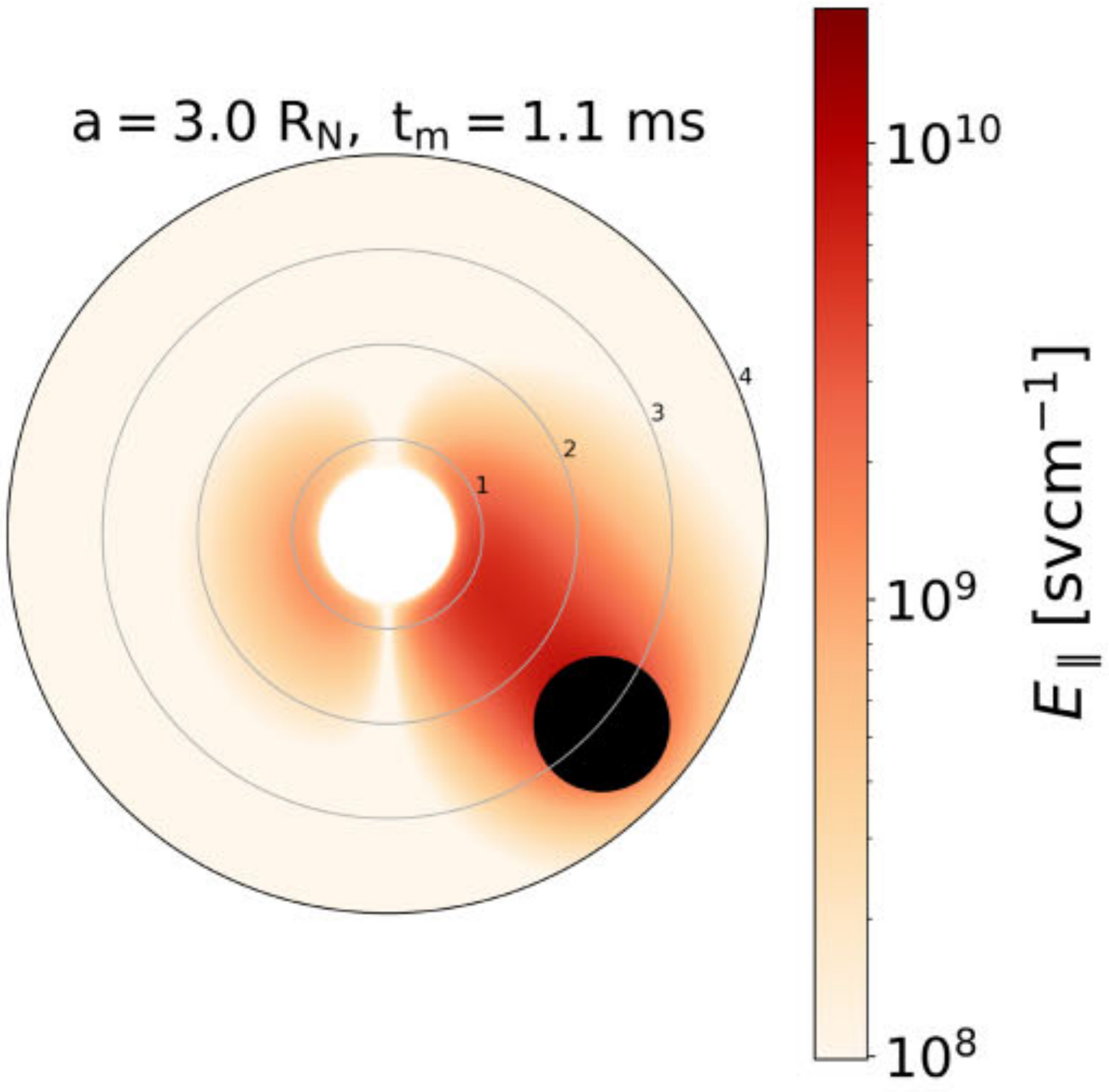
3320 Accesses | **882** Altmetric | Metrics

Richardson et al. 2023

SGR 0755-2933 is an **old long period magnetar** in a circular system that will eventually form a DNS system

Setup

Conductor + magnetized NS + classical pulsar models for pair luminosity



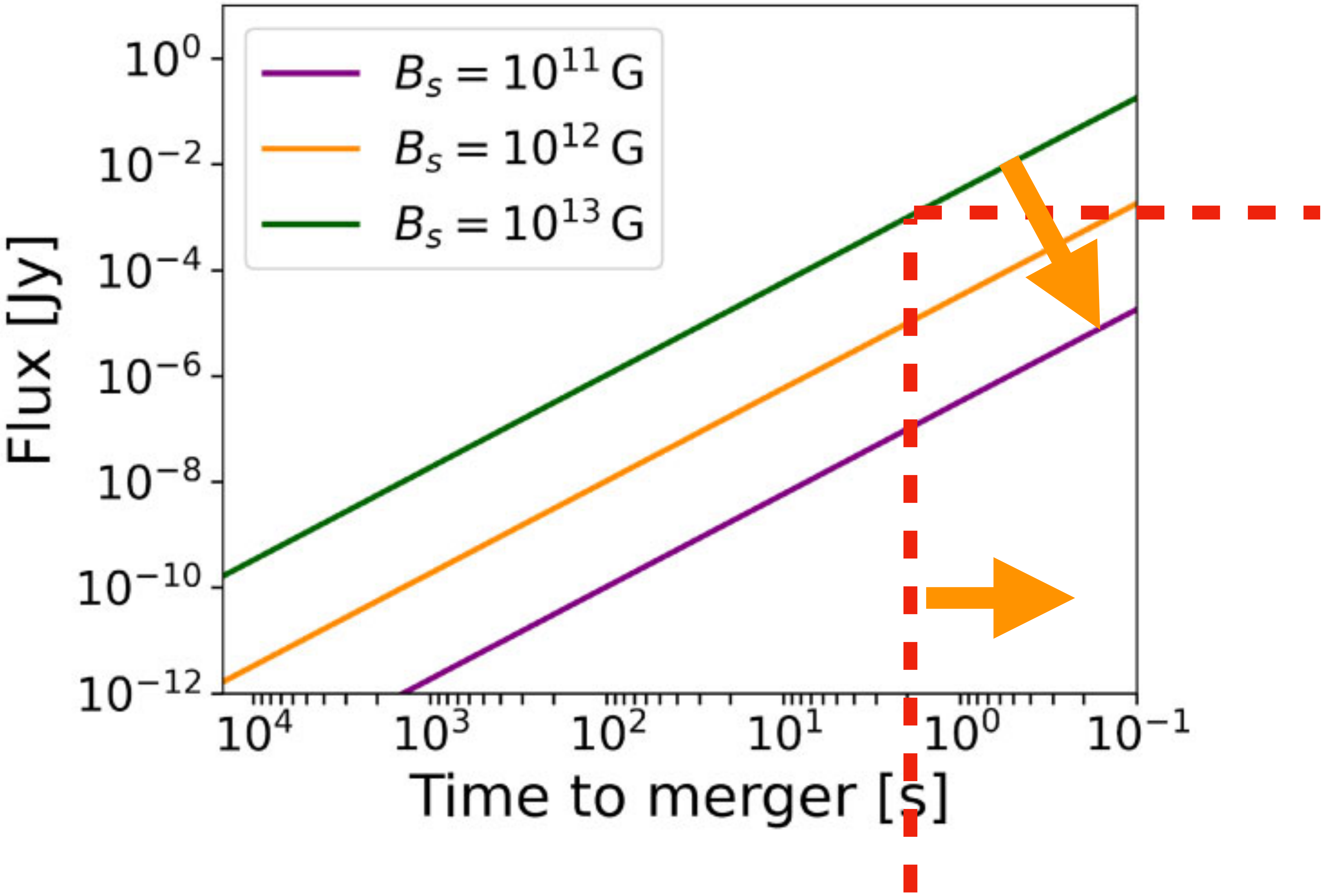
Cooper, Gupta, Wadiasingh + 2023

Details and ignorance of the coherent emission mechanism are captured by a dimensionless efficiency parameter η

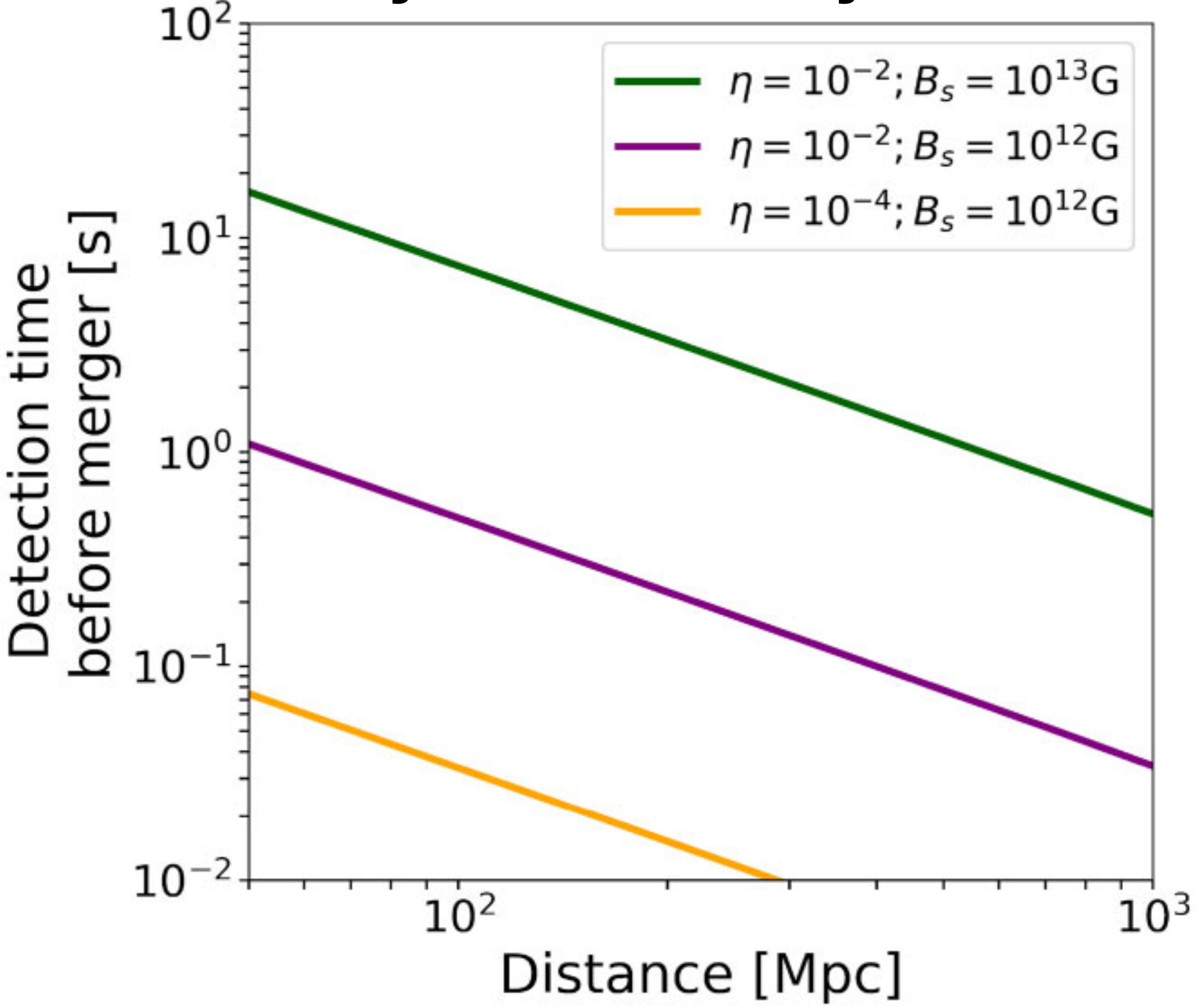
Time to merger

tens of seconds prior to merger potentially tenable

100 Mpc merger



1 mJy ms sensitivity threshold

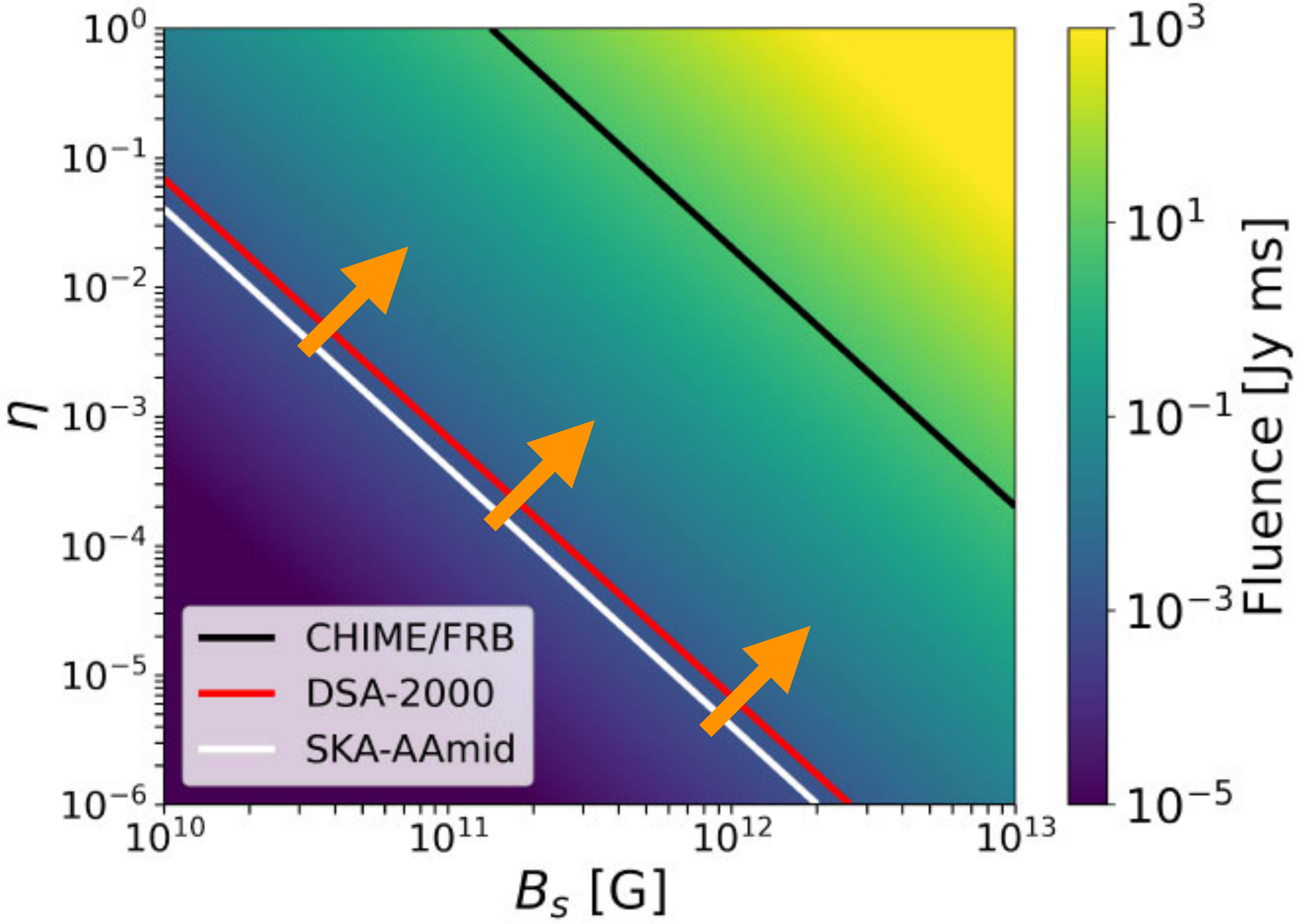


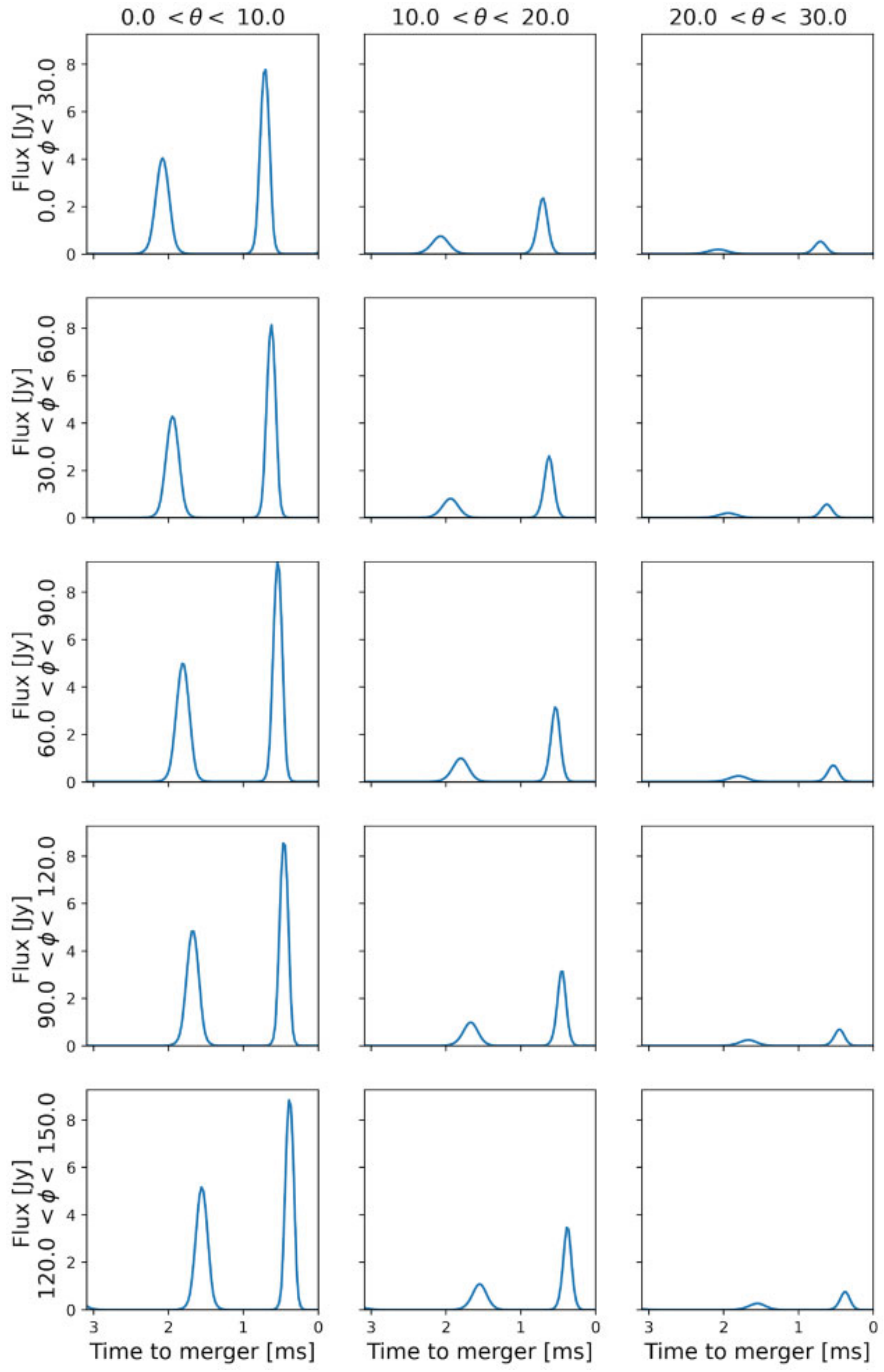
Cooper, Gupta, Wadiasingh + 2023

Fluence

in last 3 ms

Cooper, Gupta, Wadiasingh + 2023





Optimistic Rate Estimates

based on a Poynting-flux scaling rather than voltage scaling

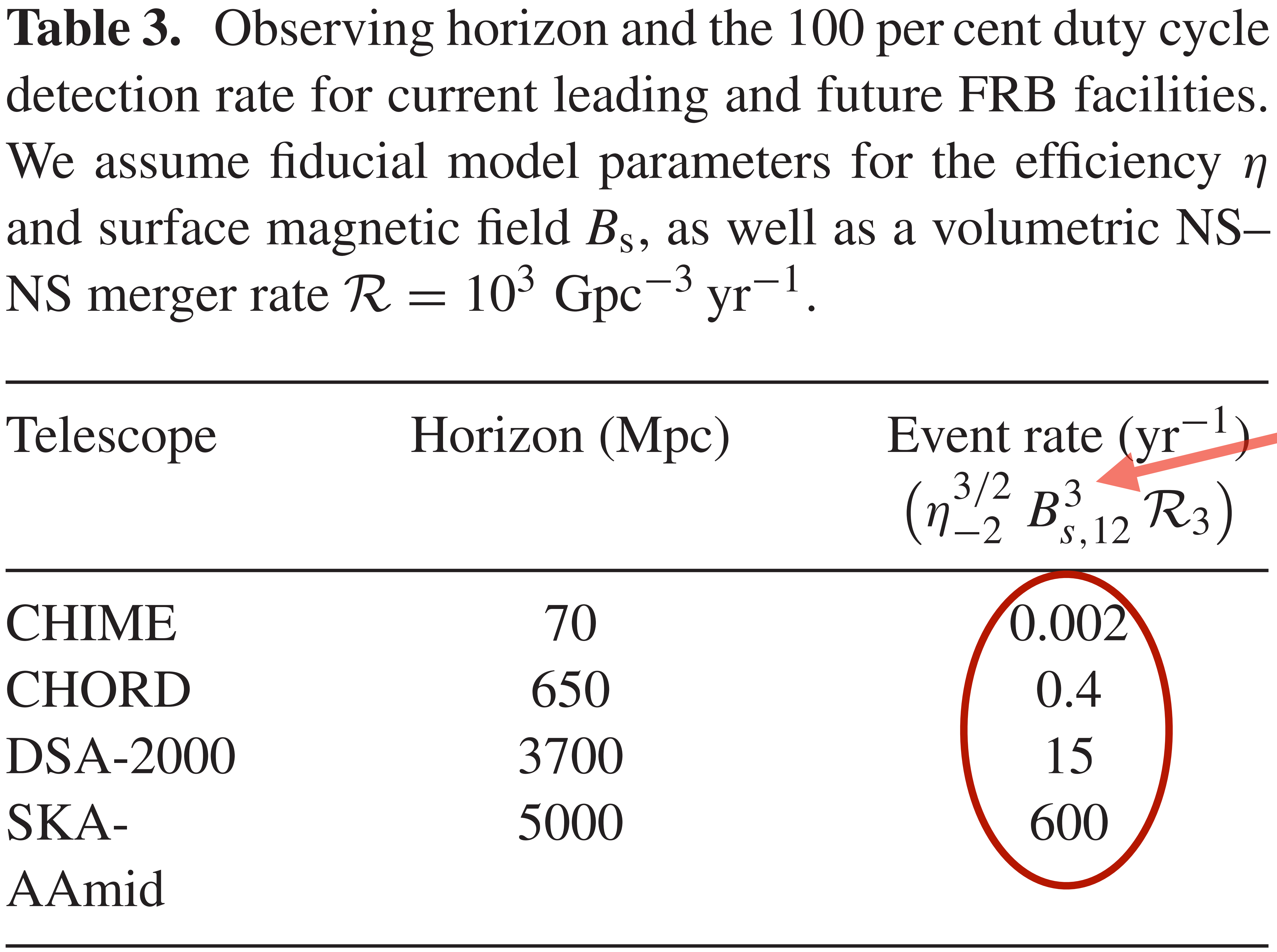


Table 3. Observing horizon and the 100 per cent duty cycle detection rate for current leading and future FRB facilities. We assume fiducial model parameters for the efficiency η and surface magnetic field B_s, as well as a volumetric NS–NS merger rate $\mathcal{R} = 10^3$ Gpc^{-3} yr^{-1}.

Telescope	Horizon (Mpc)	Event rate (yr^{-1}) $\left(\eta_{-2}^{3/2} B_{s,12}^{3} \mathcal{R}_3\right)$
CHIME	70	0.002
CHORD	650	0.4
DSA-2000	3700	15
SKA-AAmid	5000	600

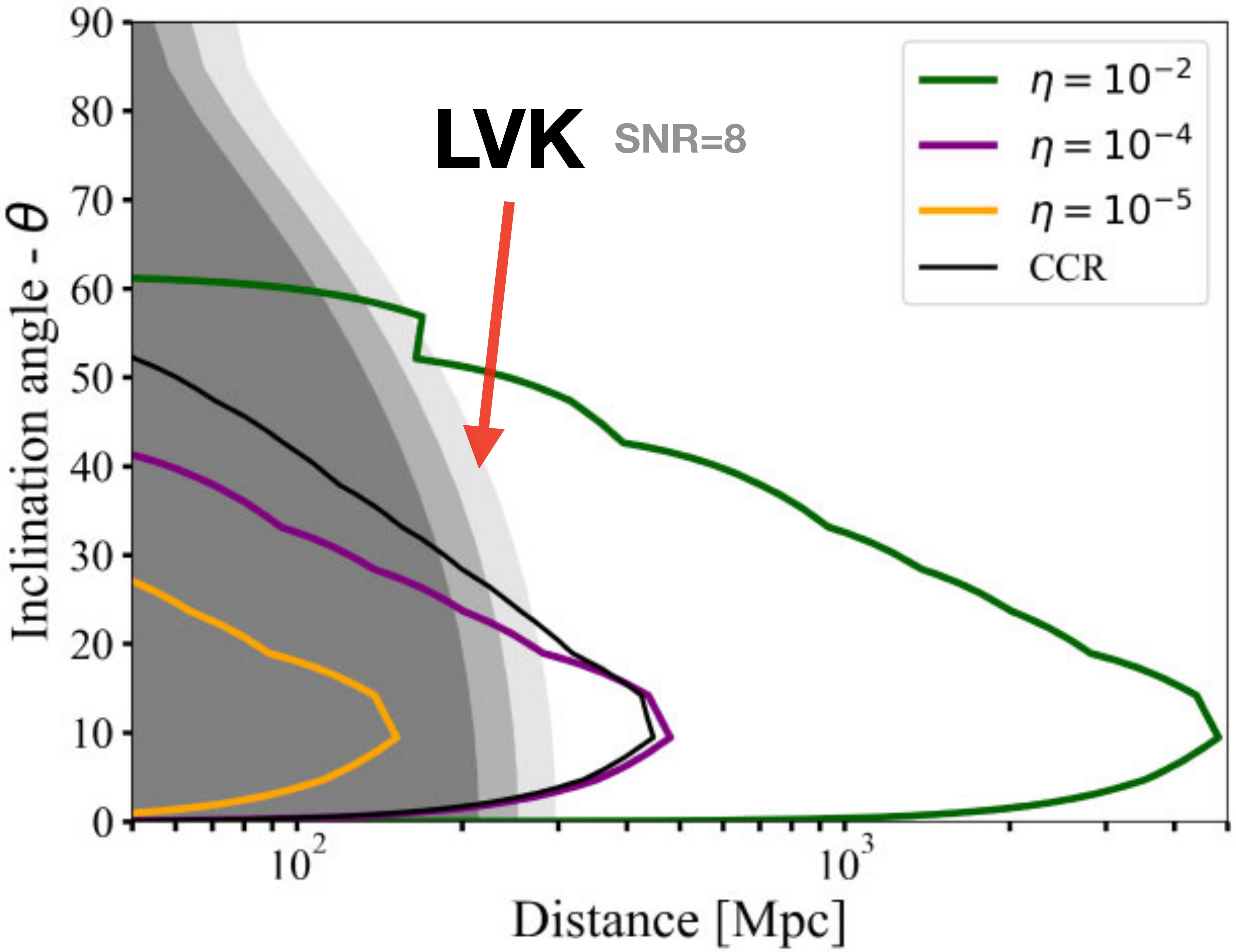
Cooper, Gupta, Wadiasingh + 2023

Rate can be much higher if a significant fraction of mergers involve magnetars

Alternatively: rate goes as $B^{3/2}$ for voltage scaling

GW Joint dectability

based on a Poynting-flux scaling rather than voltage scaling



B=10^{12} G here

Horizon scales as $B^{1/2}$ or B for magnetars depending on voltage or Poynting-flux scaling

Cooper, Gupta, Wadiasingh + 2023

Open Questions

that hopefully will be answered in the next decade

- How many ultra long period pulsars (magnetars) are out there? How are they related to FRBs?
- Are there some binaries? Is that related to formation, or emission?
- What is their galactic latitude distribution? How old are they?
- Can we find ULPMs in nearby galaxies?
- Are magnetars involved in compact object coalesces? If so, at what rate? Does the radio mechanism follow a Poynting flux or voltage scaling?