Ultra-long Period Magnetars

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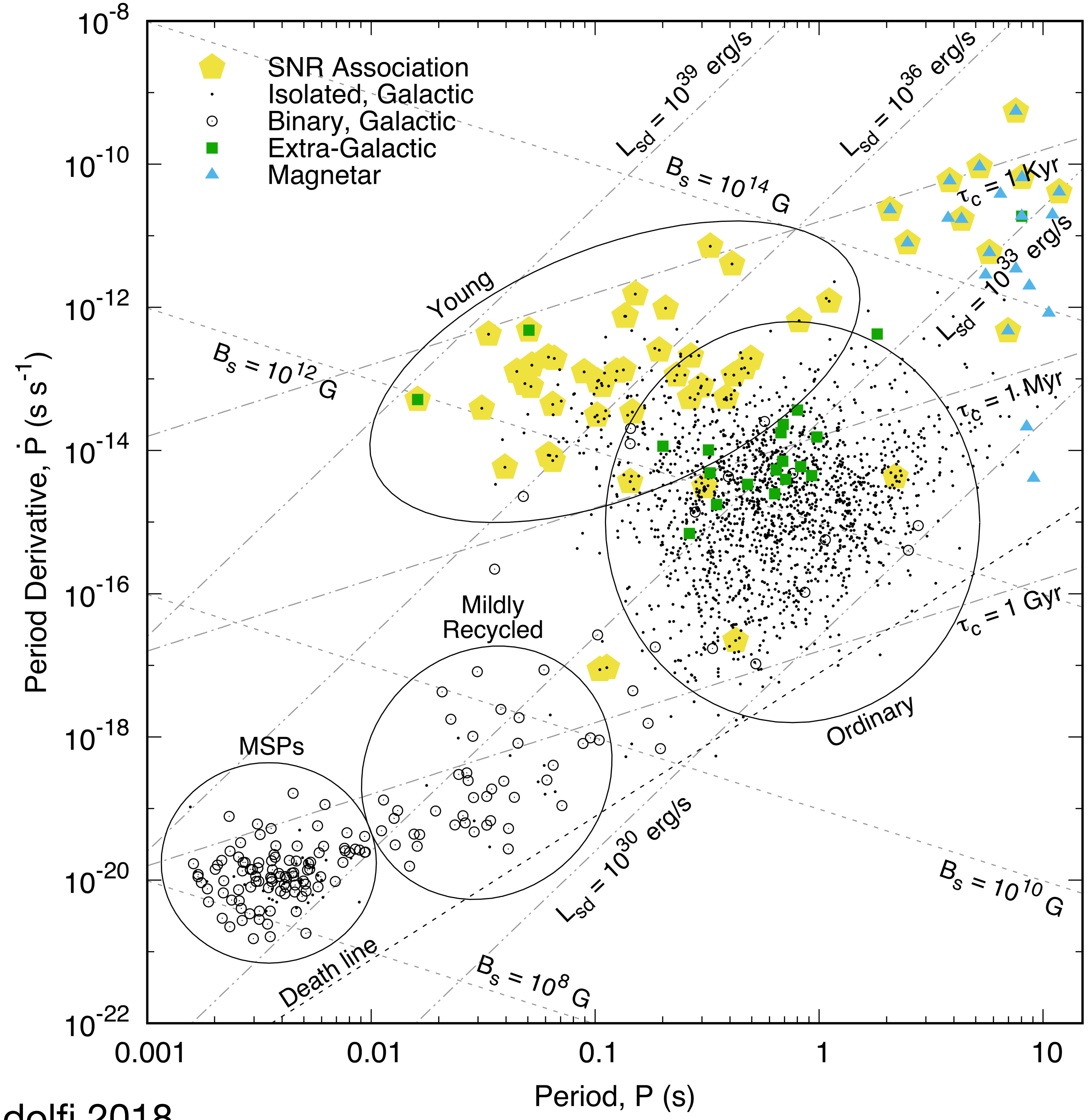
Alex Cooper (Oxford)
Andrey Timokhin (Zelona Gora)
Alice Harding (LANL)
Matthew Baring (Rice)
Jeremy Hare (NASA GSFC)
+ many others

Relativistic Magnetospheres, Les Houches School Workshop
Les Houches, France, April 9, 2025

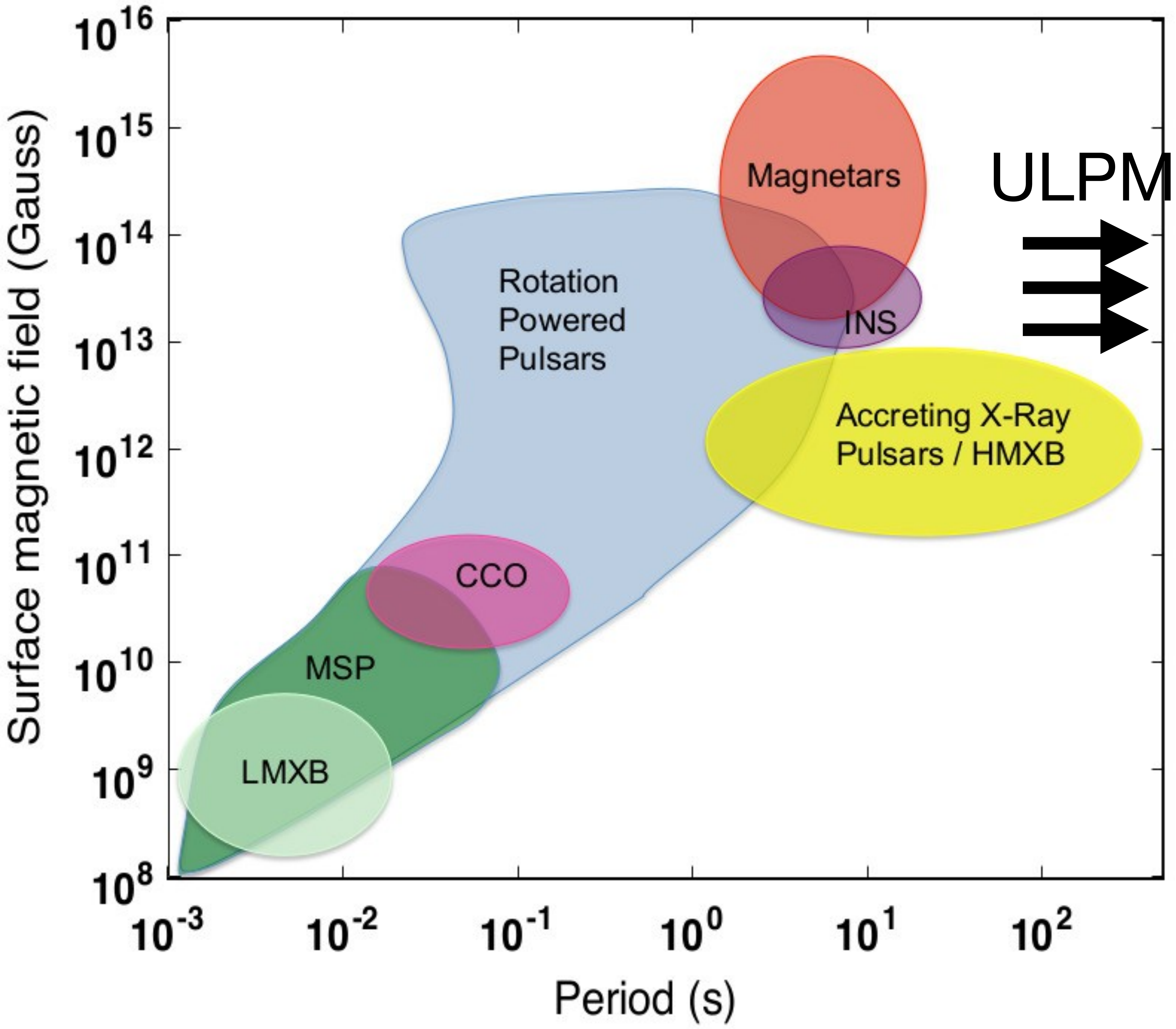
Outline

- Why and what
  - Why is this exciting
  - What: The zoo of long period radio transients and recent discoveries
- How
  - slow rotation magnetars, small twists, QED pair cascades, QED resonant Compton versus curvature photon gaps & death lines

The Neutron Star Zoo



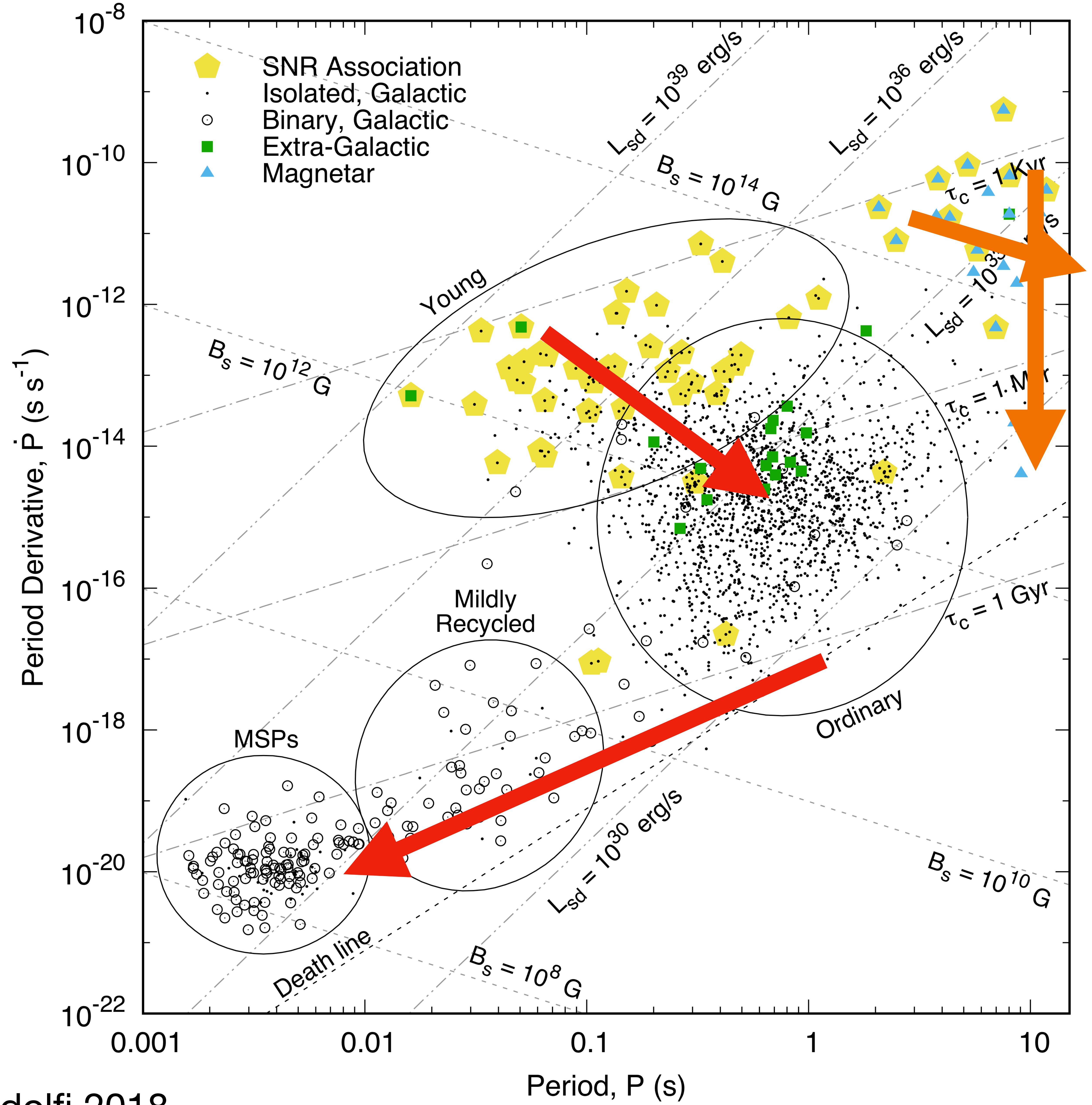
Ridolfi 2018



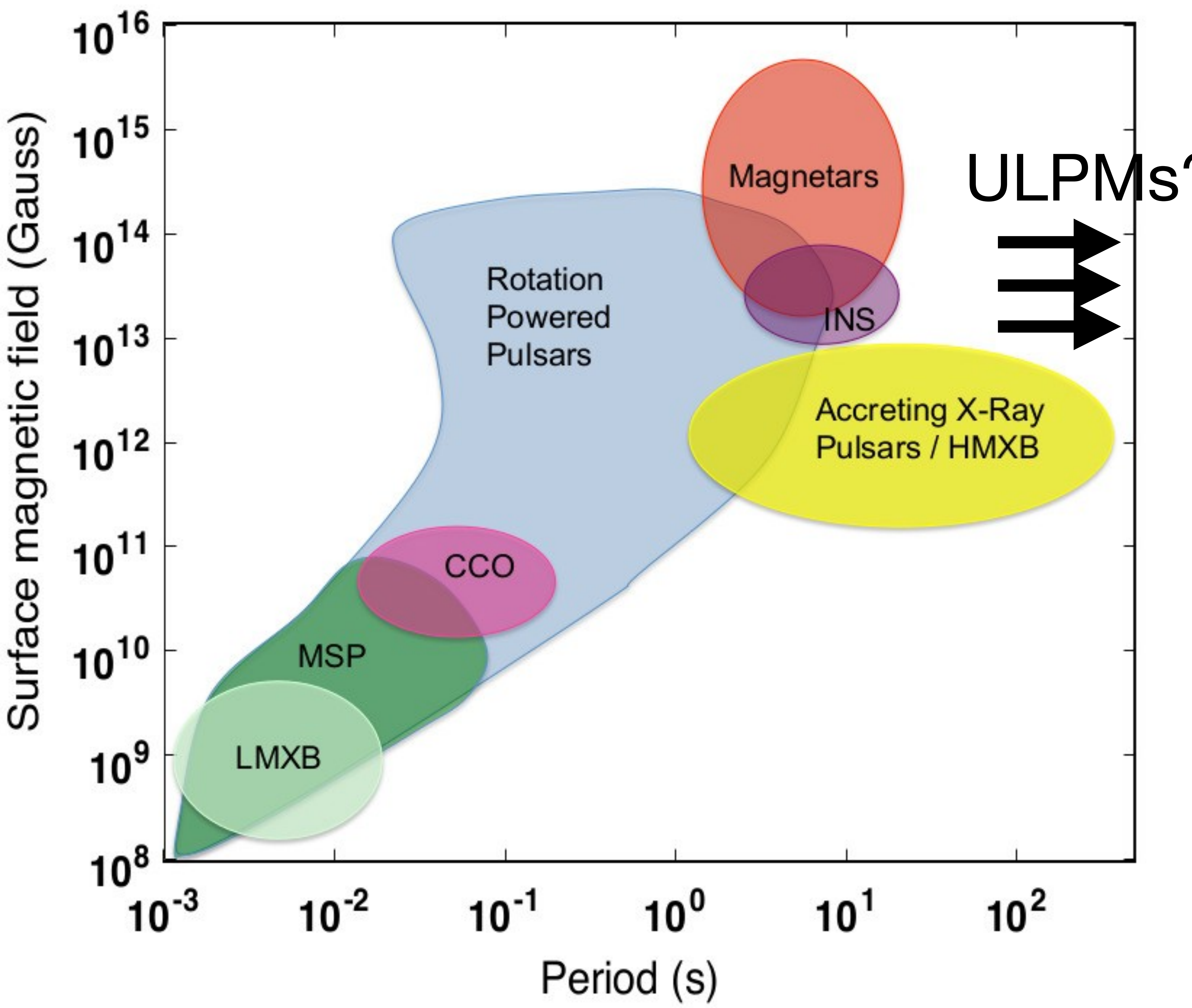
ULPMs?

Harding 2013

The Neutron Star Zoo

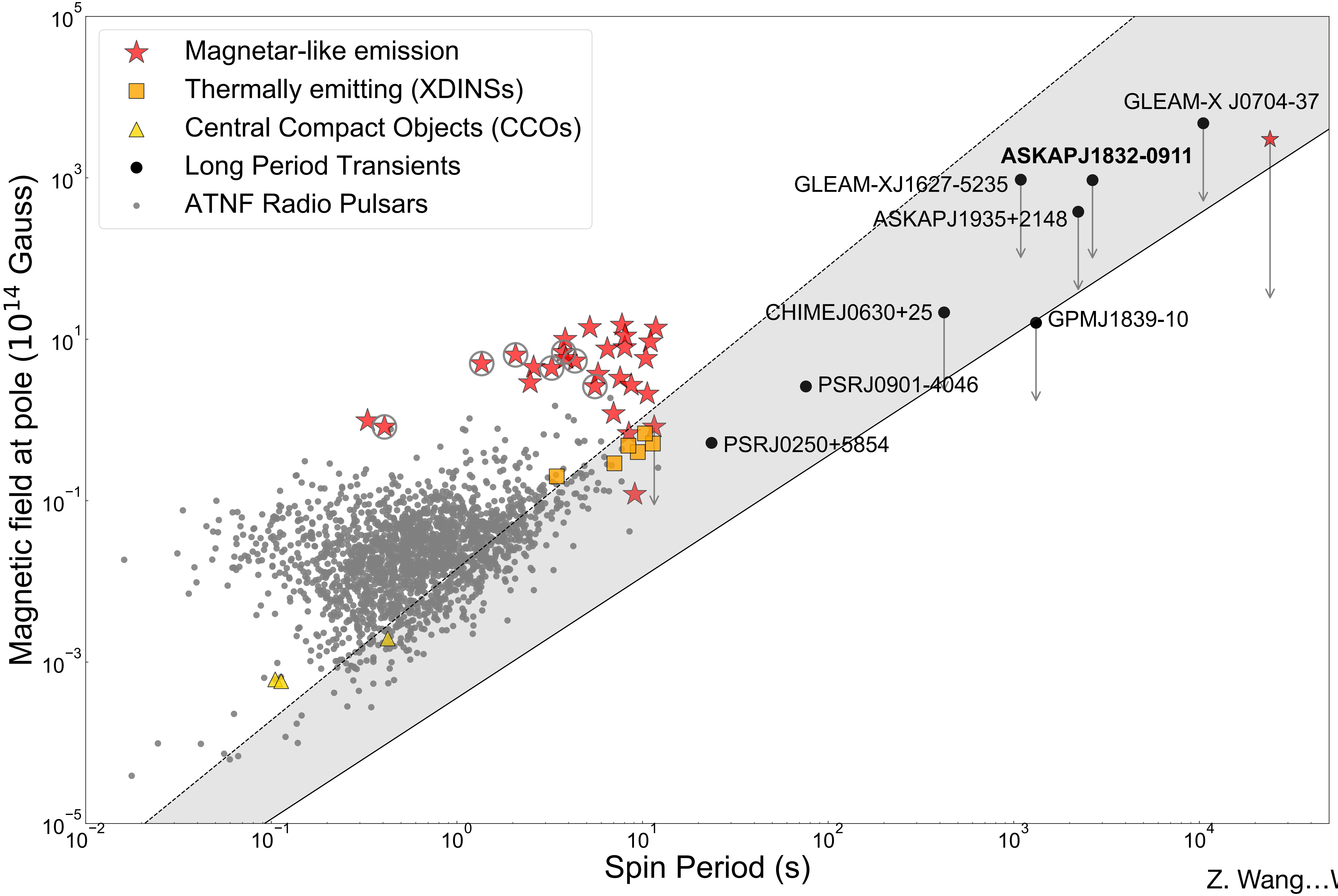


Ridolfi 2018



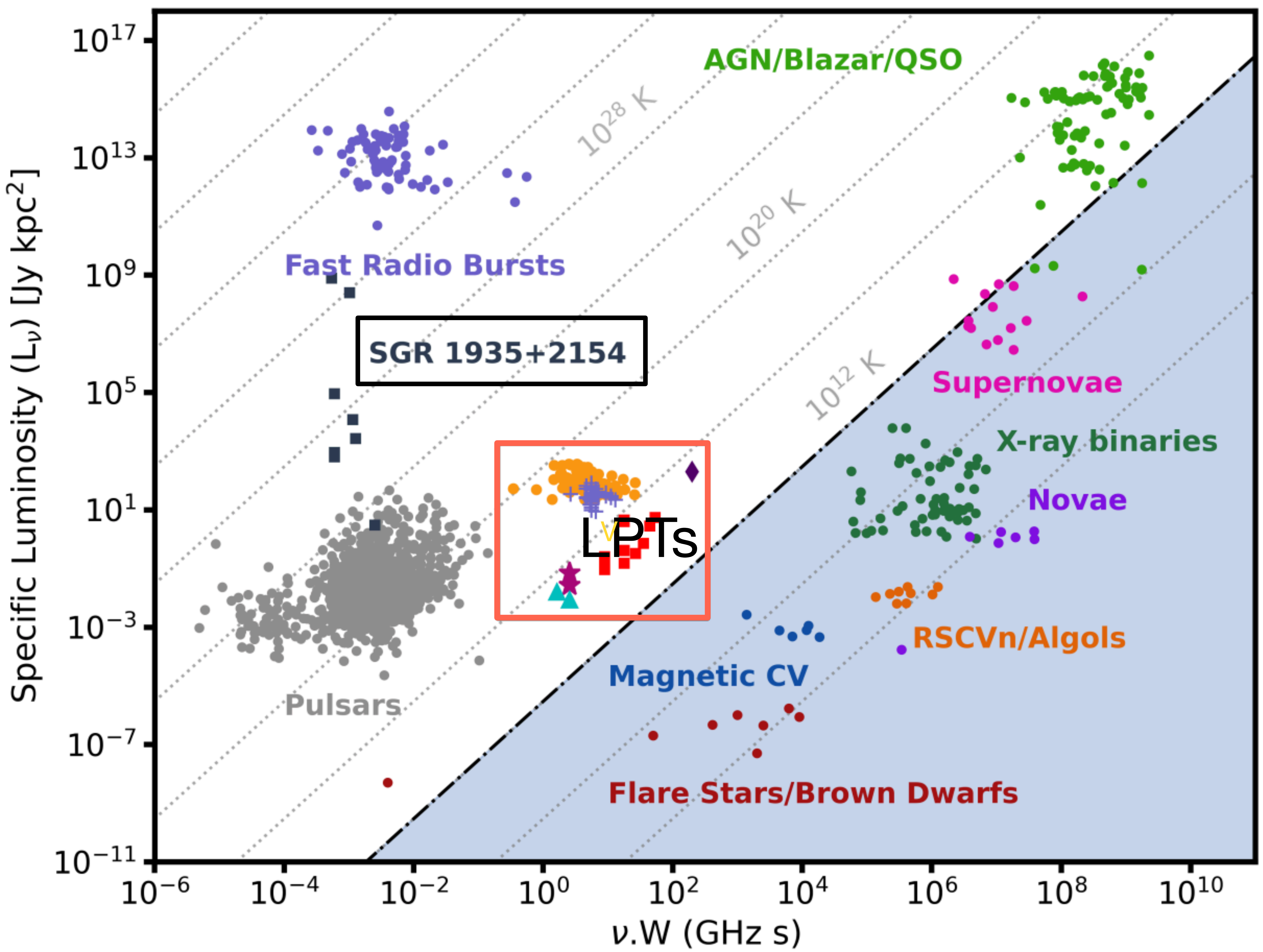
Harding 2013

The Neutron Star Zoo



Z. Wang…Wadiasingh+, 2025

The Expanding Coherent Radio Transient Phase Space



Caleb et al., 2024

Motivation: Why are they intriguing?

if they are magnetized neutron stars

- Facilities FRB generation and escape from inner magnetosphere, potential FRB progenitors ("low-twist" FRB model) (original motivation in **Wadiasingh**&Timokhin 2019; **Wadiasingh**+2020; Beniamini, **Wadiasingh**, Metzger+2020)
- New kind of common highly-magnetized neutron star (Beniamini, **Wadiasingh,** Hare+2023)
    - How do they form and spin down to long periods? Possibility: SN fall-back disks and magnetar winds (Beniamini, **Wadiasingh**, Metzger+2020; Beniamini, **Wadiasingh,** Hare+2023; Ronchi, Rea+ 2022)
- The objects are likely old! Implications for core field retention/evolution and superconductivity (Beniamini,**Wadiasingh**,Hare+2023; Lander 2024; Lander,Gourgouliatos,**Wadiasingh**,Antonopoulou 2024)
- Some pulses extremely bright in radio, exceeding 20-50 Jy, visible at extragalactic distances (N.B. LPRTs could have been discovered in the 1950s)
- Possible systems for test of QED processes, including pair cascades and photon splitting, mode switching and the vacuum resonance if ions are present in the magnetosphere (**Wadiasingh**+2020; Cooper&**Wadiasingh** 2024; Harding; **Wadiasingh,** Baring 2025)
- Interesting for electrospheres
- If involved in BNS/NSBH mergers, potentially greatly improves precursor detectability and EM torques imprints in GW waveform for 3G detectors (e.g., Cooper,Gupta, **Wadiasingh**+ 2023; Skiathas, Kalapotharakos, **Wadiasingh**+2025)

Note 1: 1E 161348–5055 in RCW 103

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

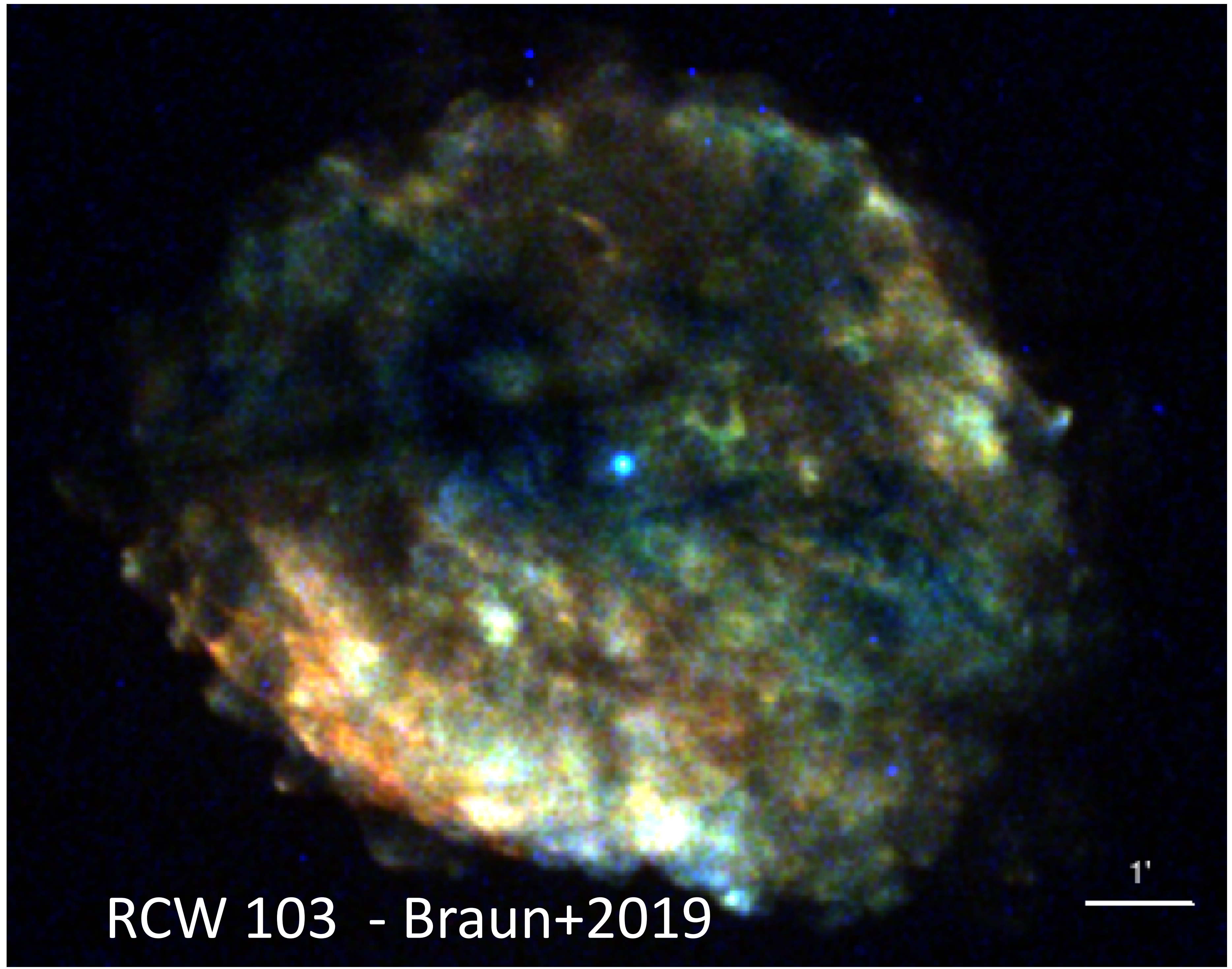
Pulsating (P ~ 6.7 hr) central compact object in SNR RCW 103:

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

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



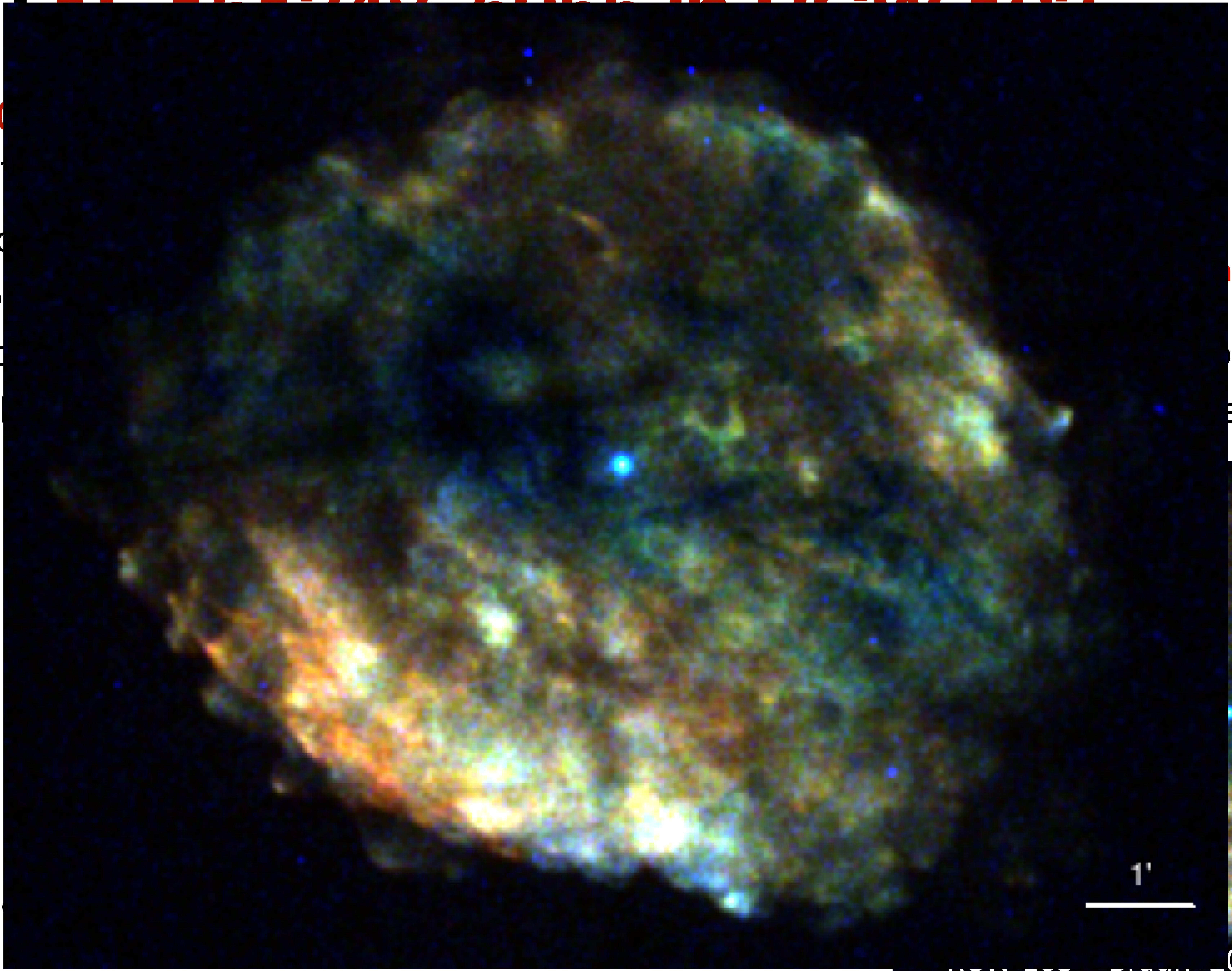
RCW 103 - Braun+2019

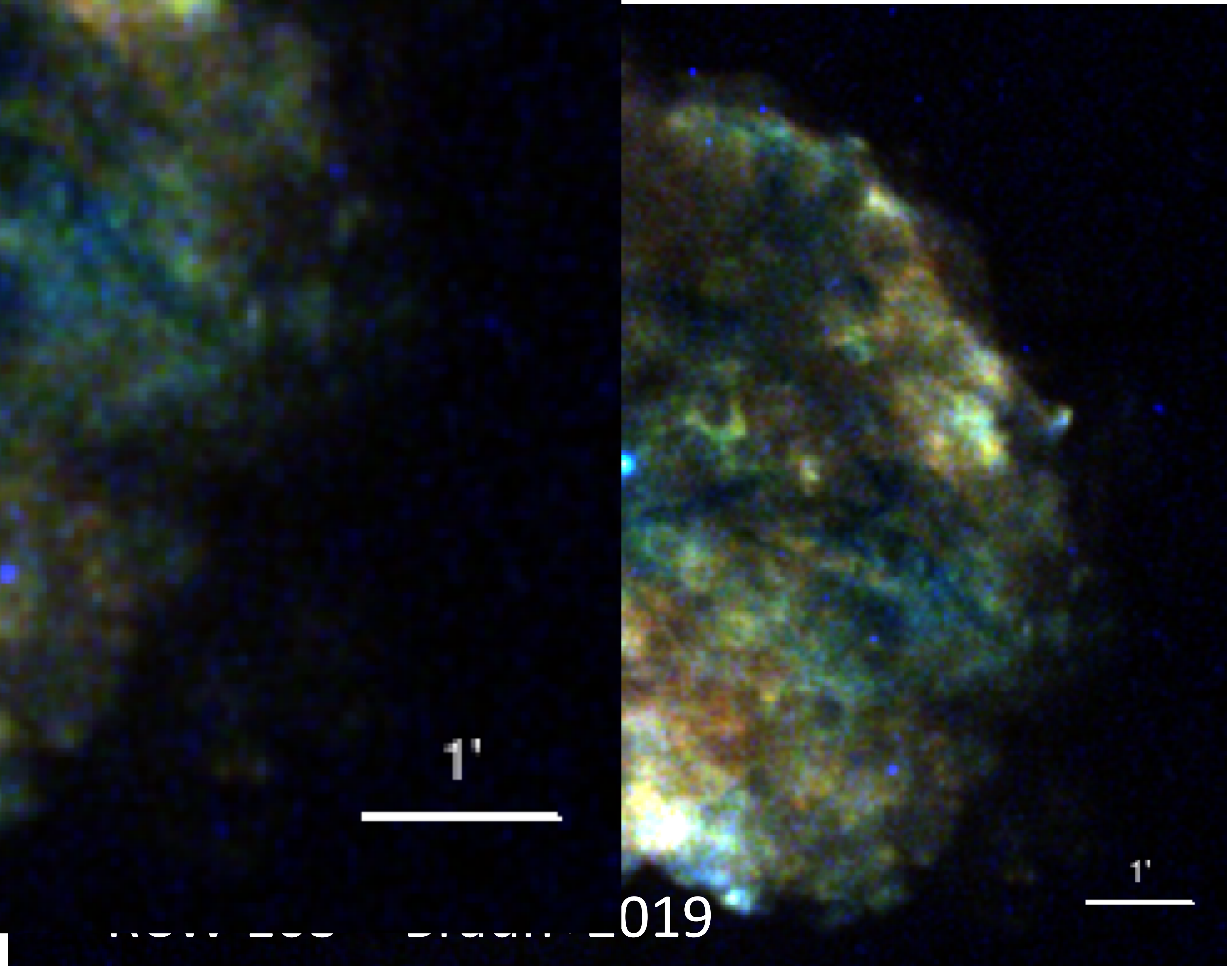
Note 1

1E 161348–5

Pulsating (P ~ 6.

1. Millisecond
2. Long-term o
3. Proper motio
4. Companion





enology

ted

een detected

Credit: D
et al. 16,

019

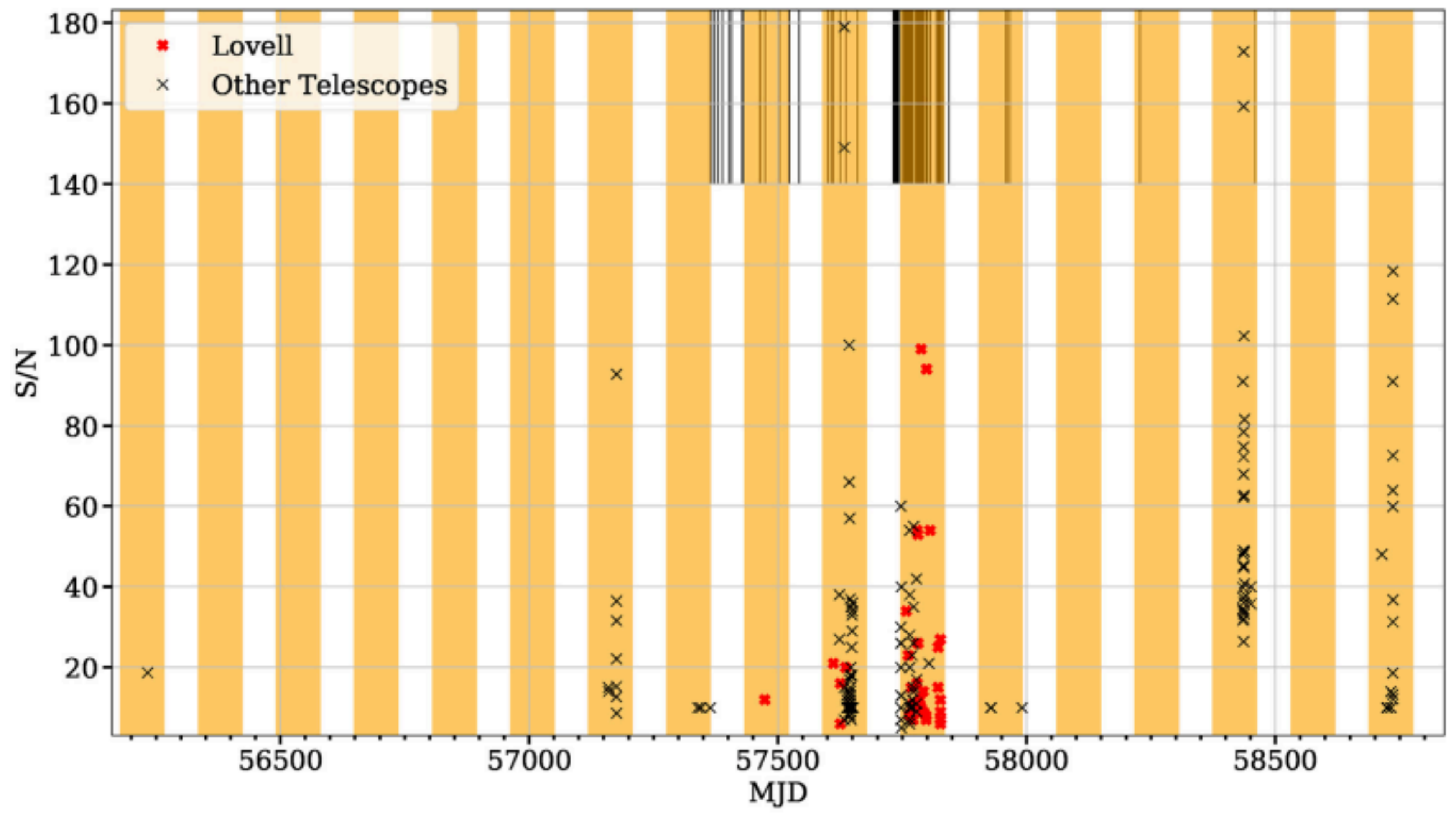
Note 2: Connection to FRBs

Magnetars are the prime candidate FRB sources, possible shared conditions for bright coherent emission

Secure long-term periodicity (16 days and 157 days) reported for two repeating FRBs - third one of ~120 days tentatively detected

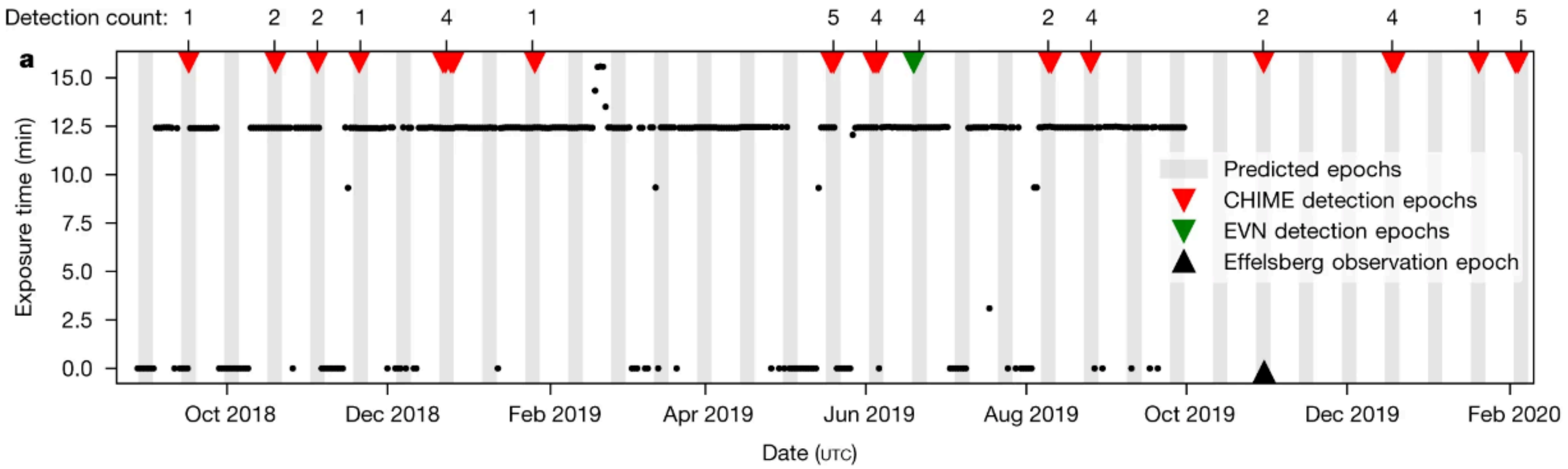
Precession, binarity, obscuration, or **long periods**

Long periods facilitate escape of FRBs from the inner magnetosphere



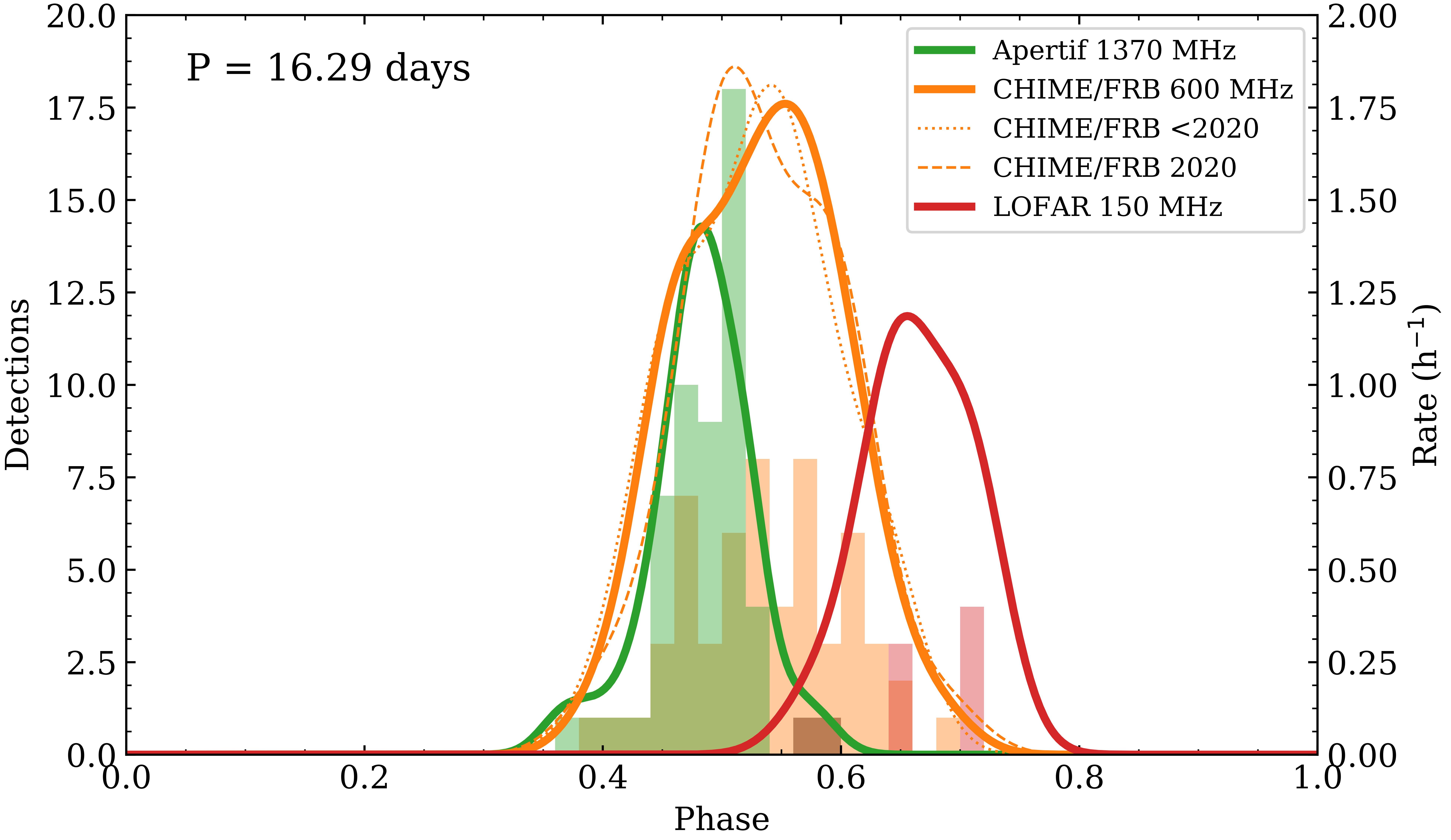
Rajwade et al. (2020)

e.g. Wadiasingh& Timokhin 2019
Wadiasingh et al. 2020,
Beniamini, Wadiasingh et al., 2020
Beniamini, Wadiasingh et al. 2023
Cooper & Wadiasingh 2024



CHIME/FRB Collaboration (2020)

Shrouding in a binary seems ruled out in FRB 180916



Pastor-Marazuela+ 2021, Nature, 2012.08348

Some observational highlights

Observations of long period transients

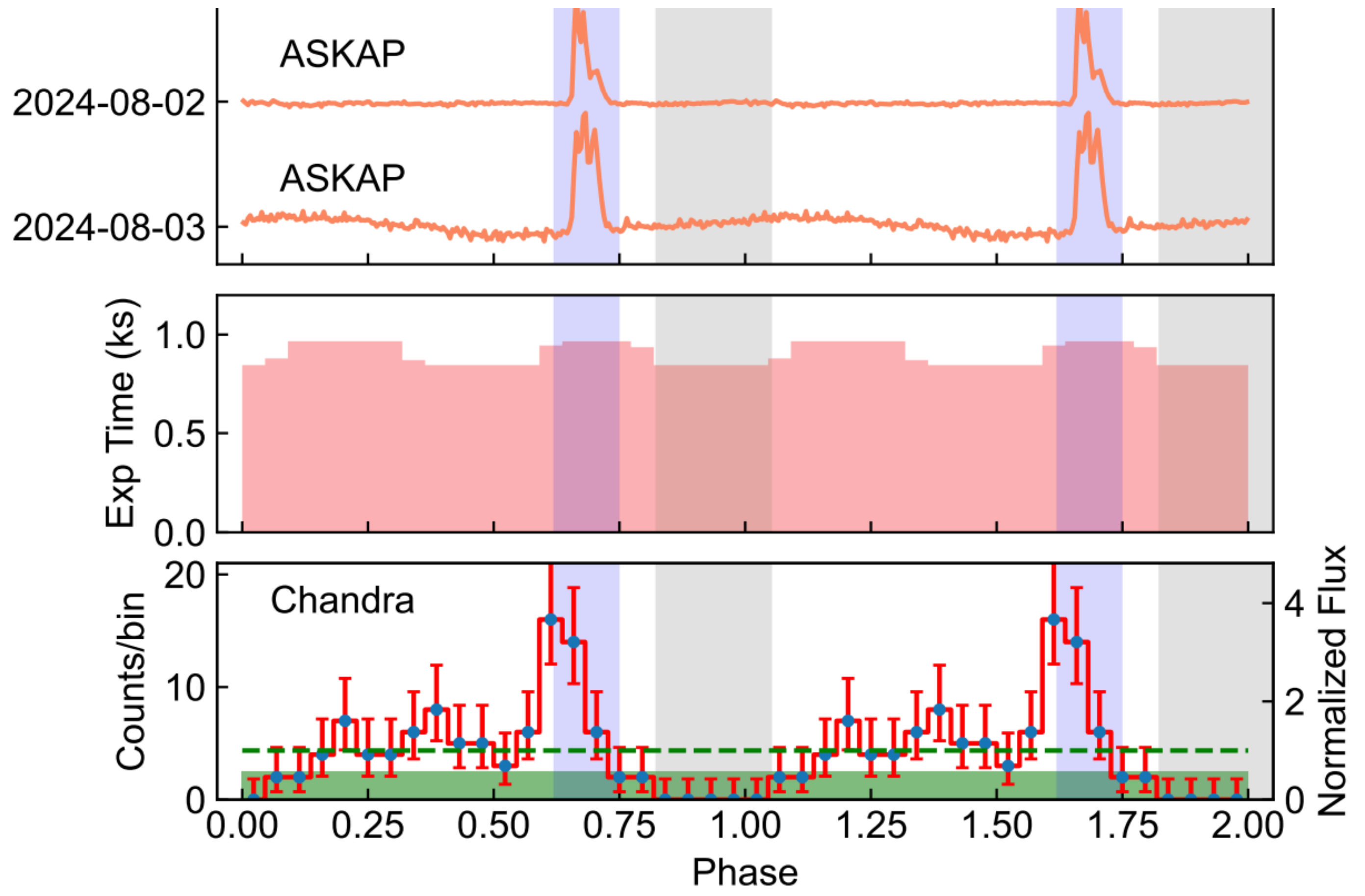
ASKAP J1935+2148: 54 minute period transient with 3 distinct emission states

CHIME J0630+25: 7 minute period transient, DM distance 170 ± 80 pc

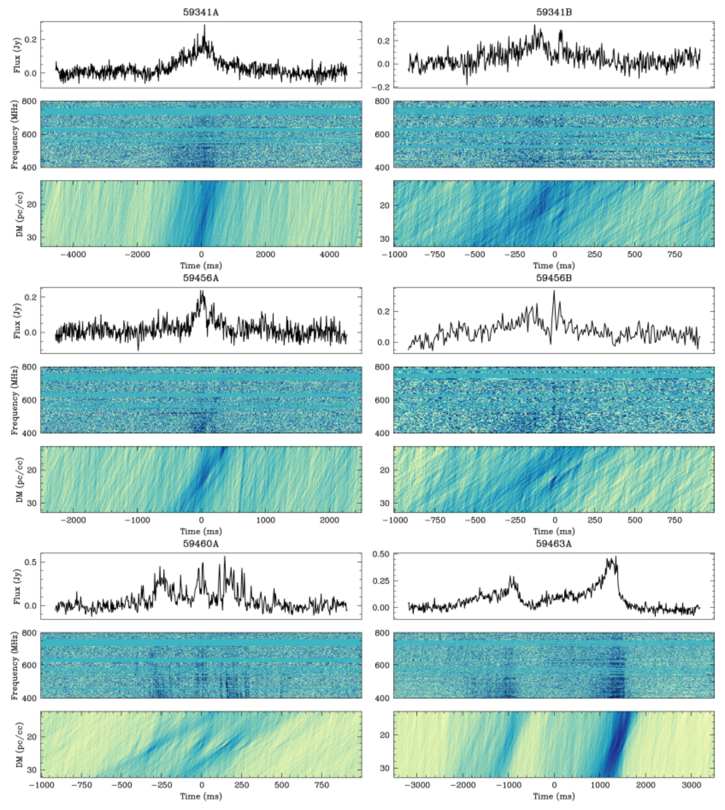
GLEAM-X J0704-37: 2.9hr period *binary* source with high Galactic latitude

ASKAP J1839-07: 6.5hr period source with interpulses

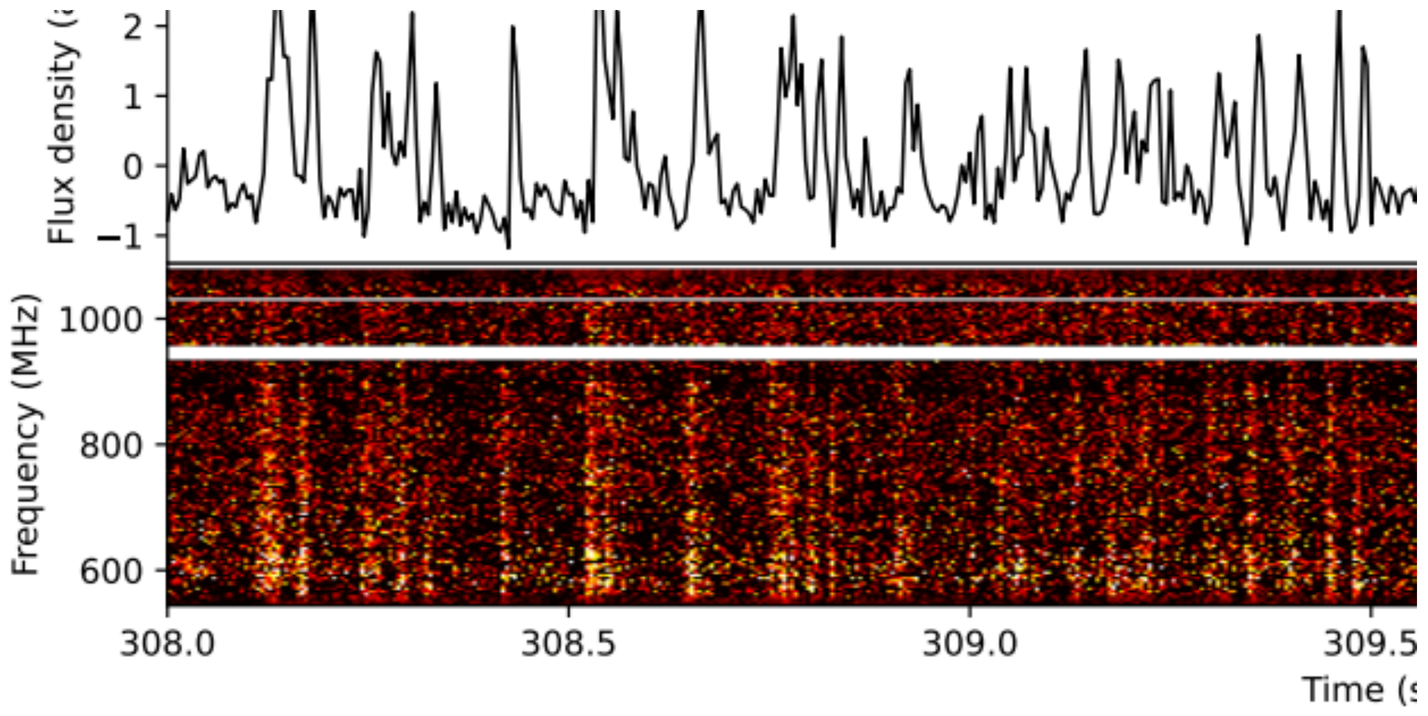
ASKAP J1832–0911: 44 min period with X-ray pulsations(!)



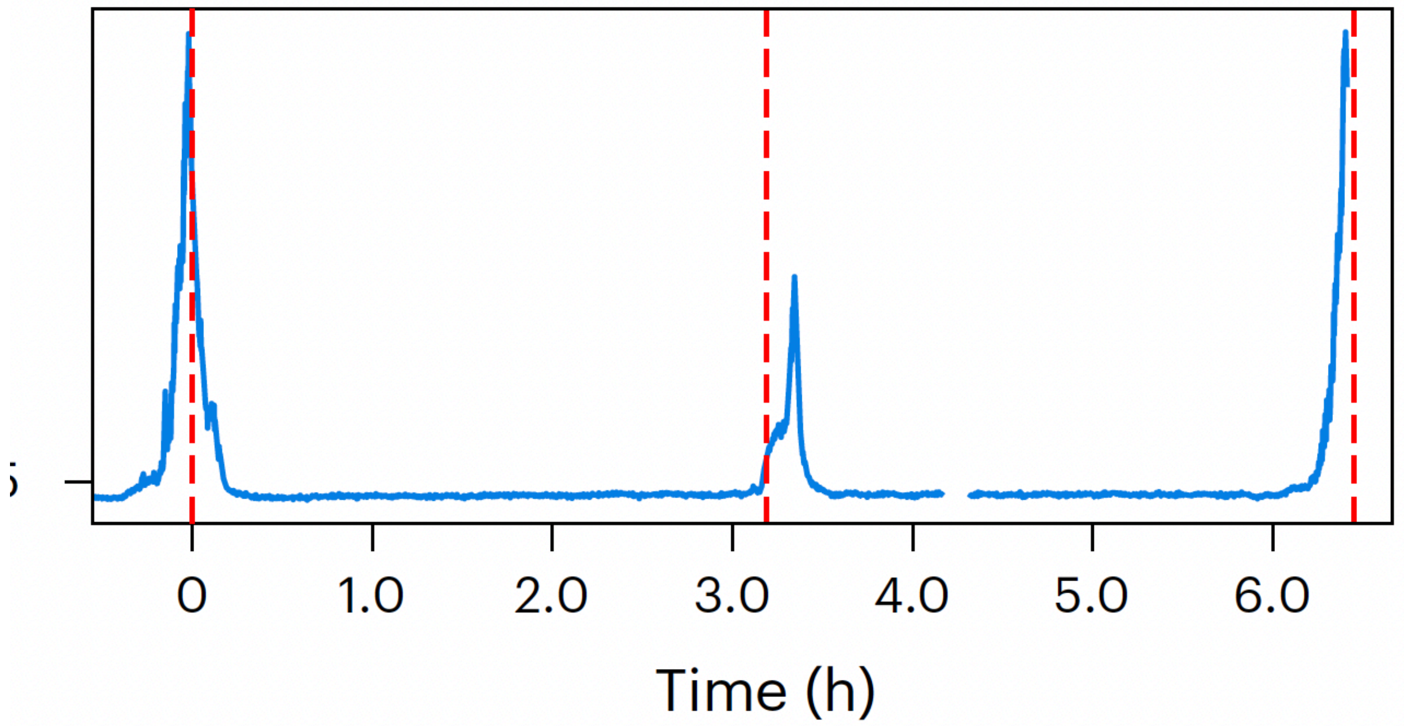
Wang et al., 2025 (ASKAP J1832)



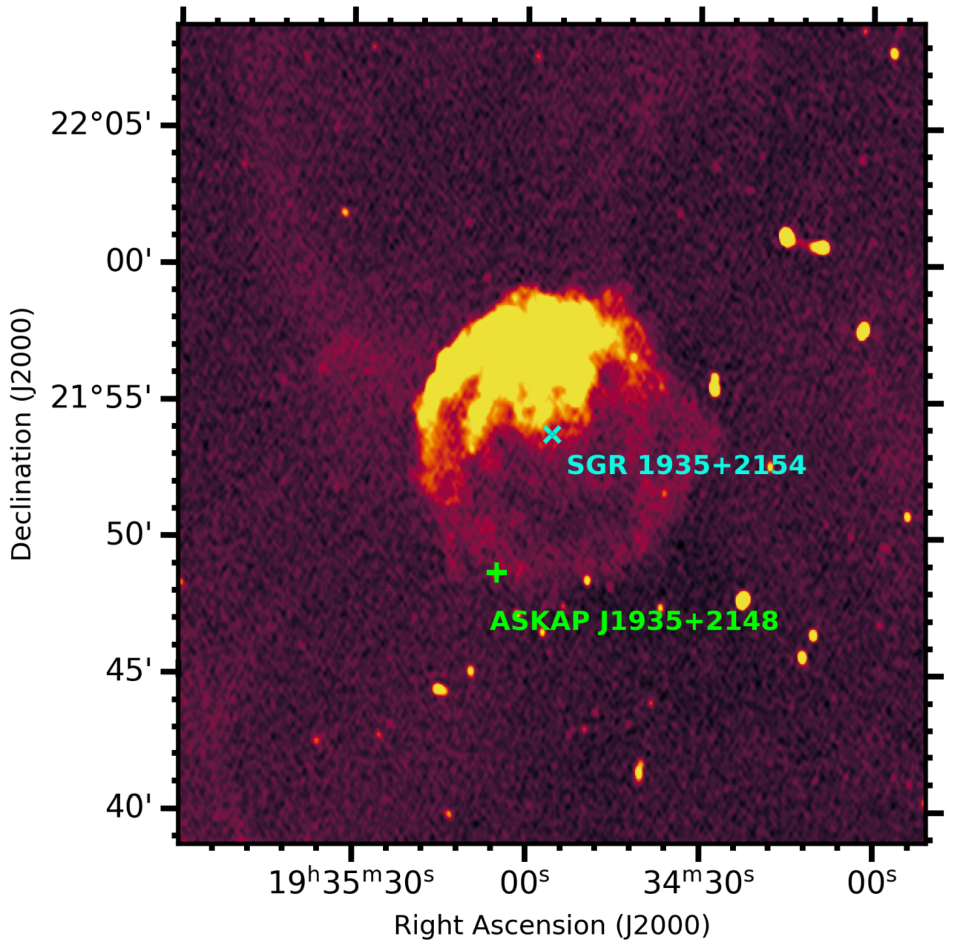
Dong et al., 2024 (CHIME)



Hurley-Walker et al., 2025 (GLEAM-X)



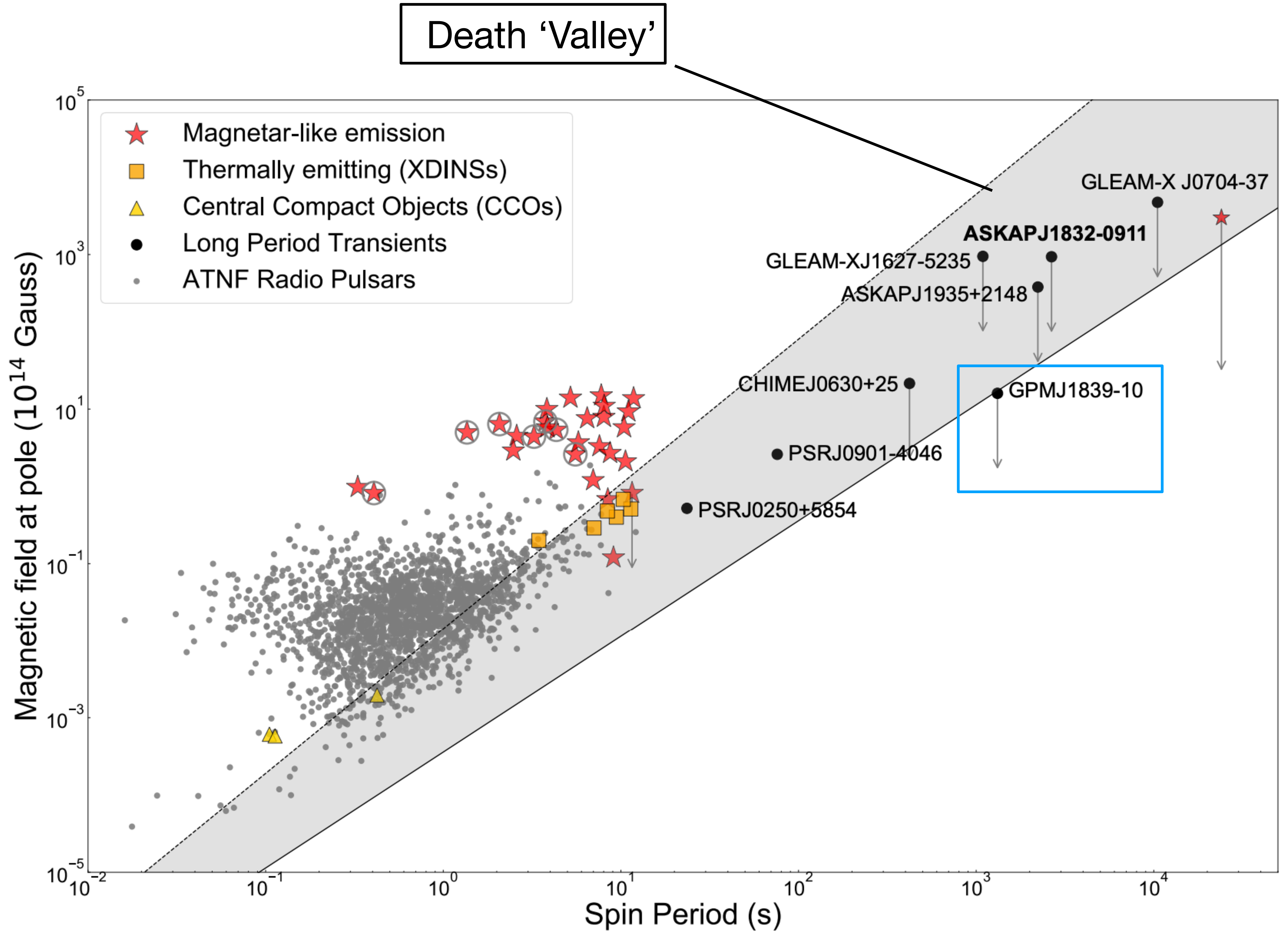
Lee et al., 2025 (ASKAP J1839)



Caleb et al., 2024 (ASKAP J1935)

Are they magnetars?

Source	GLEAM-X J1627	GPM J1839-10
P [min]	18.18	21
$\dot{P}$	$< 1.2 \times 10^{-9}$	$< 4.6 \times 10^{-13}$
Pulse [s]	30-60	30-300
Distance [kpc]	1.3±0.5	5.7±2.9
$F_{\nu,\mathrm{radio}}$ [Jy]	5-40	0.1-10
L_{radio} [erg/s]	$\approx 10^{28-31}$	$\approx 10^{28}$
$L_{\mathrm{spin-down}}$ [erg/s]	$\lesssim 1.2 \times 10^{28}$	$\lesssim 10^{25}$
$L_{\mathrm{X,0.3-10keV}}$ [erg/s]	$< 10^{32}$	$< 1.5 \times 10^{32}$
Duty cycle	$\approx$ 2 months	$\gtrsim$ 33 years



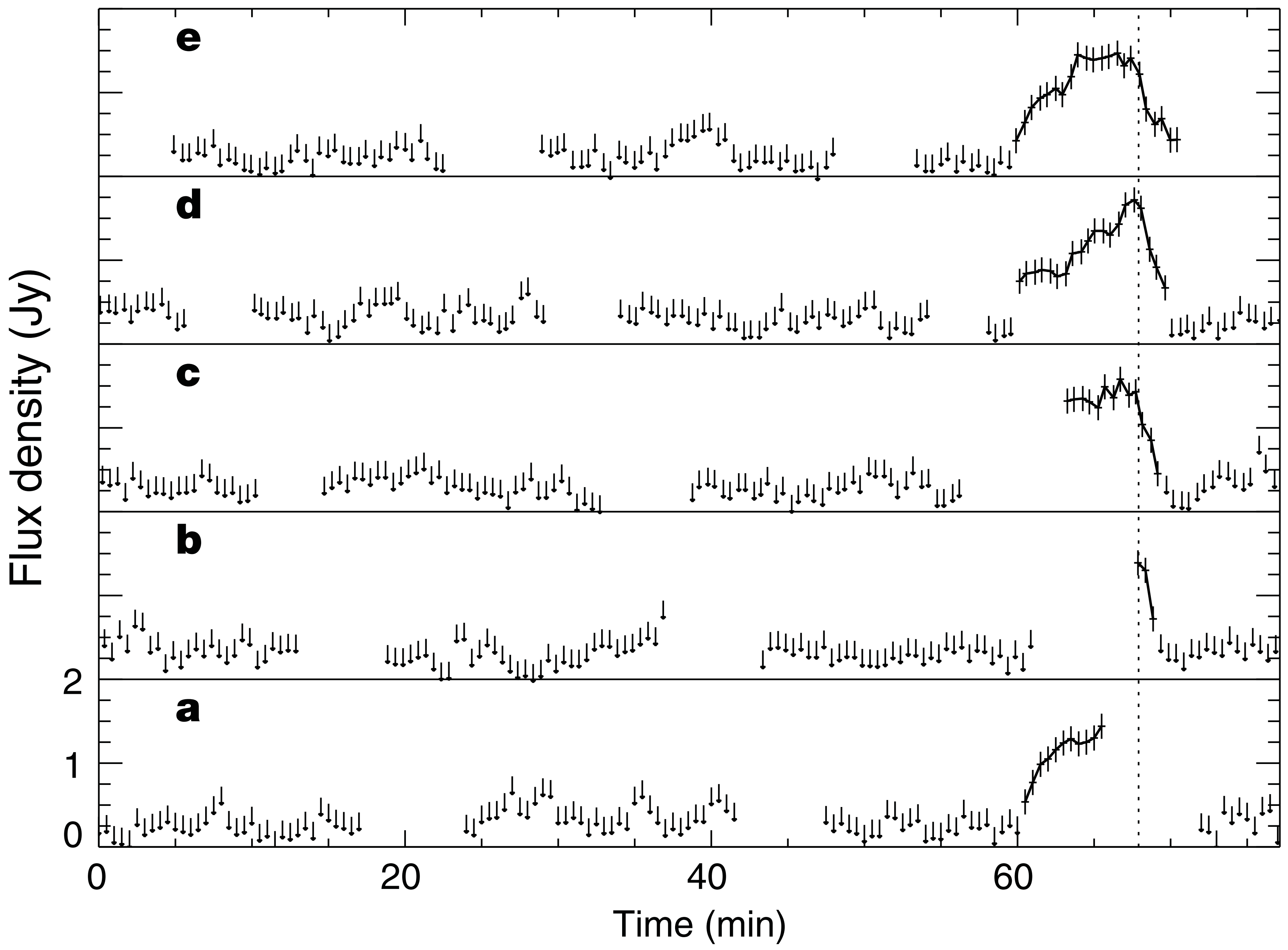
Z. Wang..

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

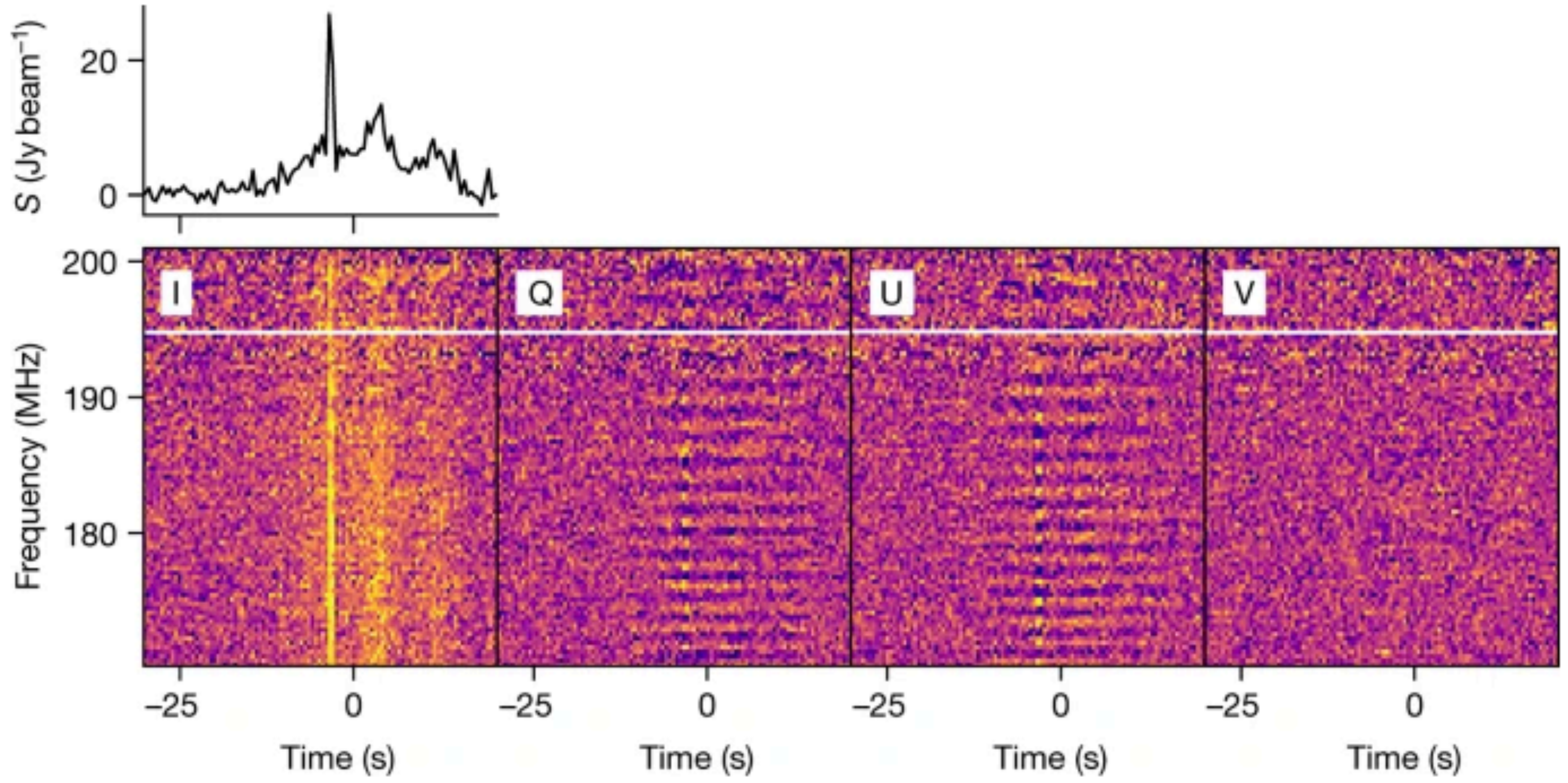
Galactic ULPM candidates - GLEAM-X J162759.5–523504.3

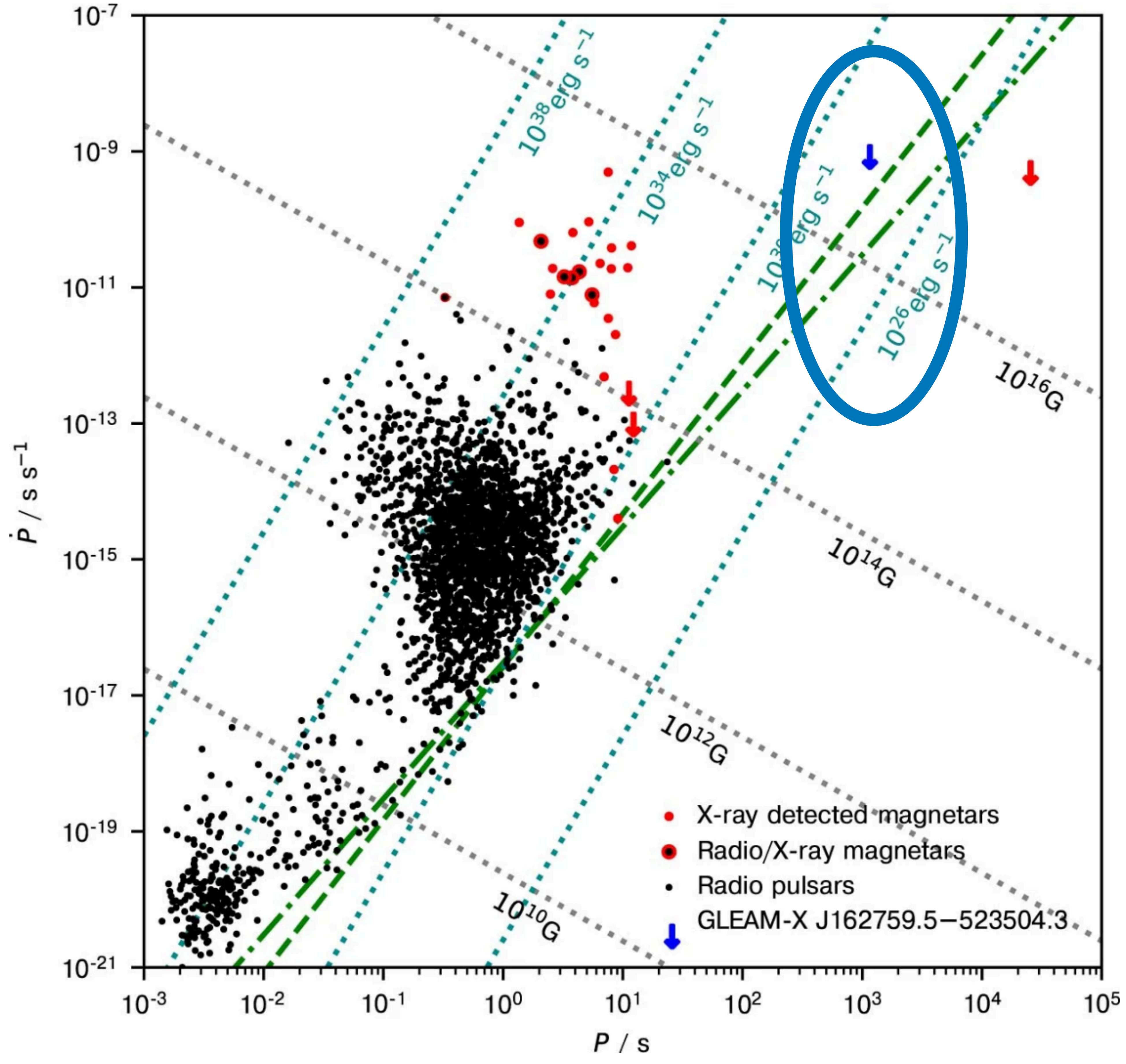
GLEAM-X J162759.5–523504.3

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

1. Close to 100% linear polarization, up to 40 Jy pulses
2. Rapid (~0.5 s) variability suggesting compact object with brightness temperature > 10^16 K
3. Cannot be a rotation powered NS
4. 2% duty cycle
5. Beyond pulsar death-line for standard pulsar field strength
6. WD can largely be ruled out (Beniamini, Wadiasingh, Hare+2023)
7. No multi-wavelength counterpart - most binary companions ruled out

Rea et al. (2022) & Lyman et al. (2025)





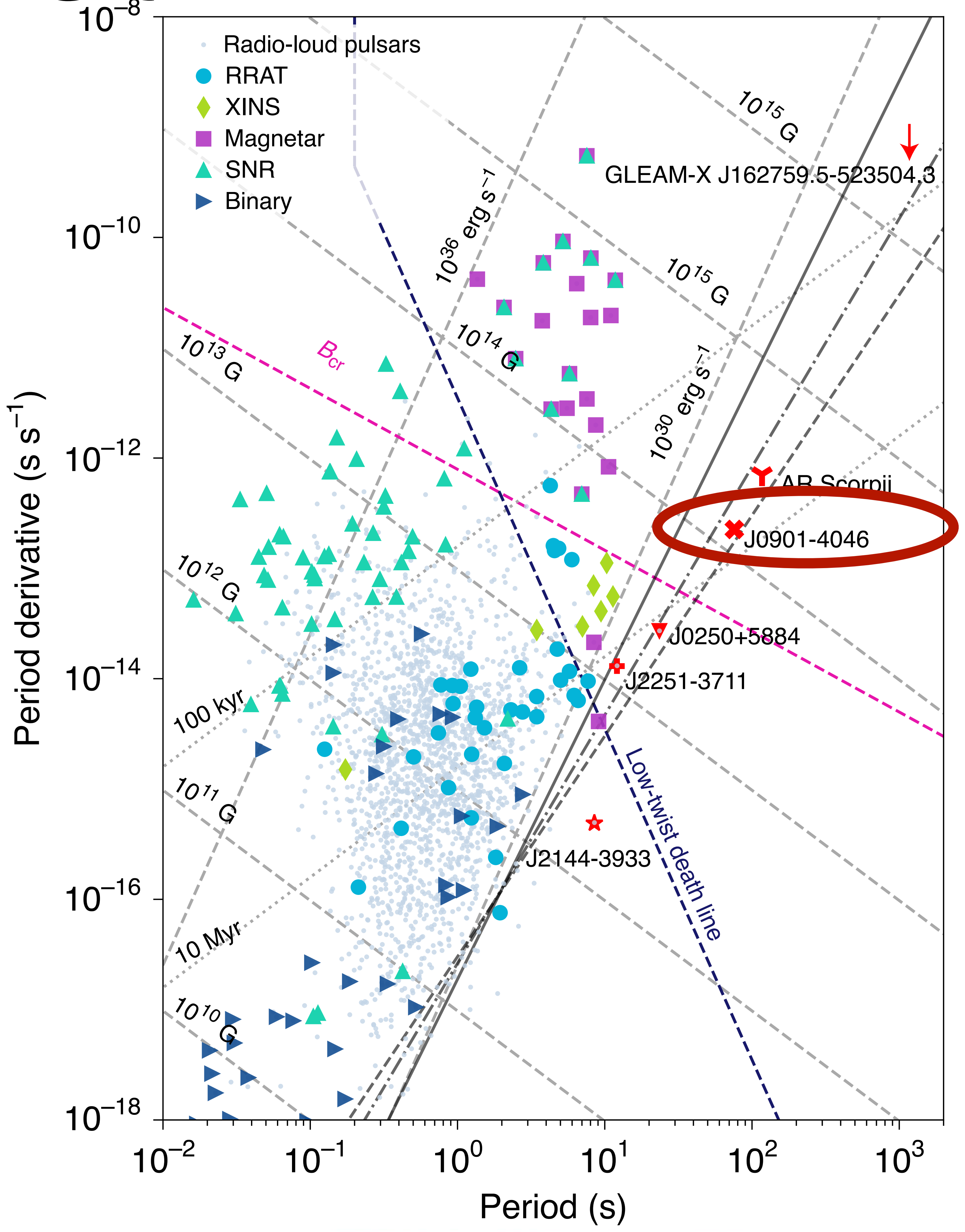
Credit: Hurley Walker et al. 2022

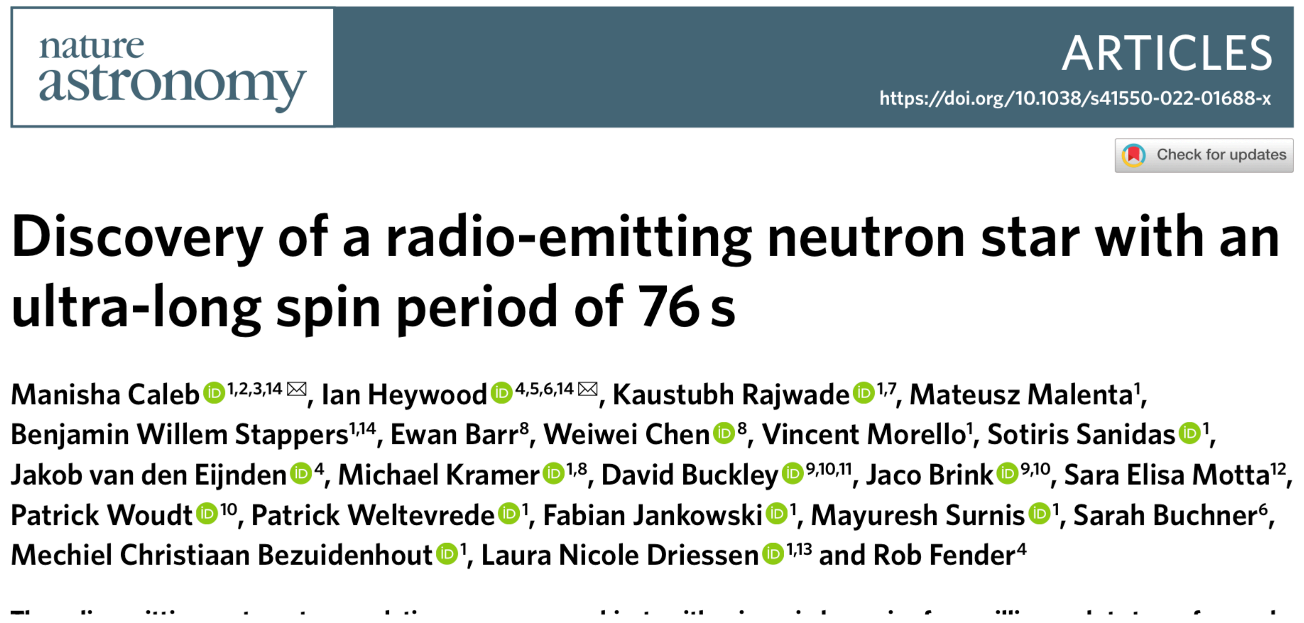
Galactic ULPM candidates - PSR J0901-4046

PSR J0901-4046 (formerly MTP0013)

P ~ 76 s pulsar, well-measured Pdot ~ 2×10^{-13} —> B_{pole} ~ 2×10^{14} G, age > 5 Myr

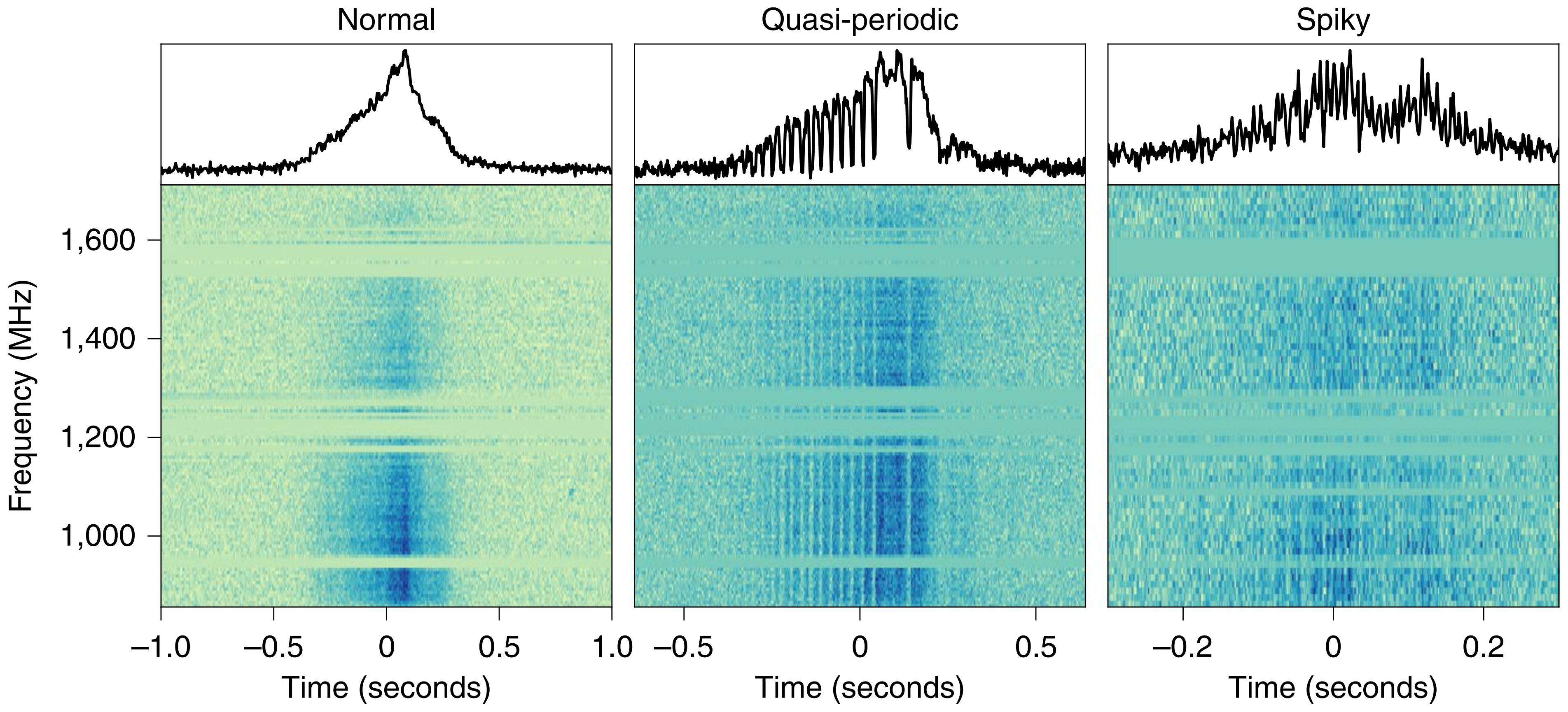
1. Pulsar radio characteristics: high polarization fraction, PPA swings, variability in single pulses of flux and polarization
2. Very stable in timing — unusually stable for a magnetar
3. Only 328 pc away (YWM16) — implies many more exist
4. Lx < $10^{30.5}$ erg/s
5. harmonic spaced QPOs at O(10) Hz–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

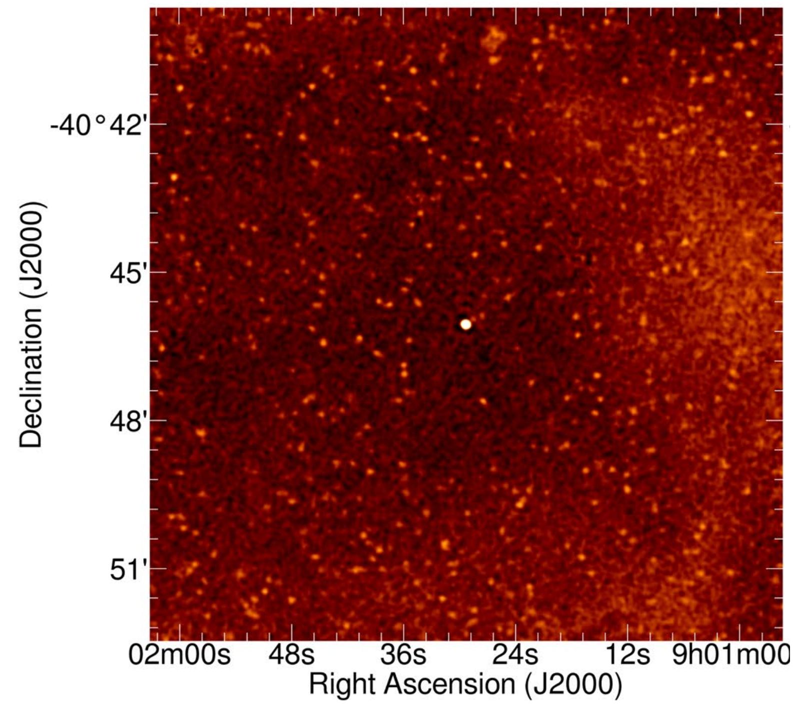



nature astronomy
ARTICLES
https://doi.org/10.1038/s41550-022-01688-x

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

Manisha Caleb, Ian Heywood, Kaustubh Rajwade, Mateusz Malenta, Benjamin Willem Stappers, Ewan Barr, Weiwei Chen, Vincent Morello, Sotiris Sanidas, Jakob van den Eijnden, Michael Kramer, David Buckley, Jaco Brink, Sara Elisa Motta, Patrick Woudt, Patrick Weltevrede, Fabian Jankowski, Mayuresh Surnis, Sarah Buchner, Mechiel Christiaan Bezuidenhout, Laura Nicole Driessen and Rob Fender





Credit: Caleb et al. 2022

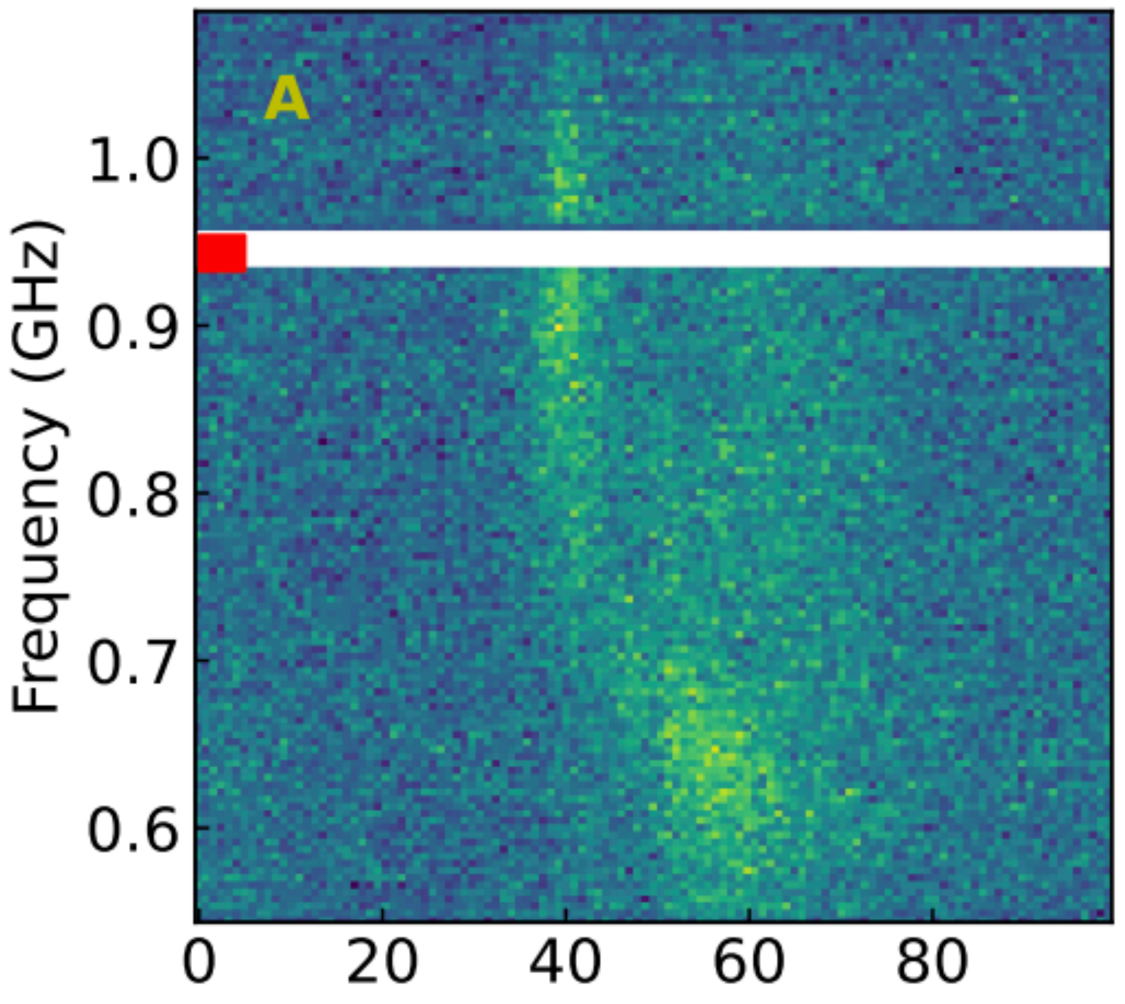
Observations of long period transients - GPM J1839-10

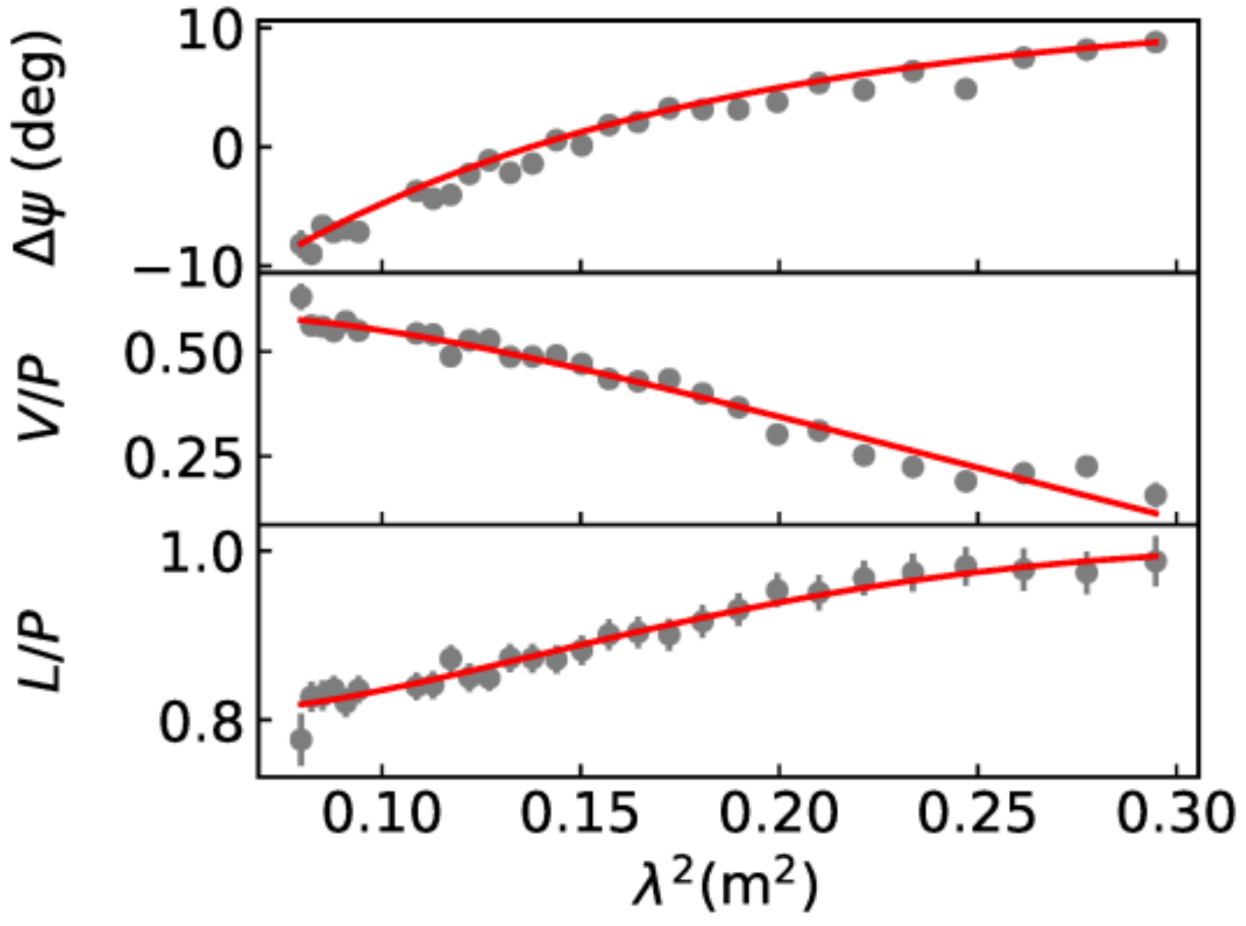
GPM J1839-10, with pulses dating back decades

21 minute period, 30-300s pulses with rich substructure, FRB-like drifting and linear-to-circular polarisation conversion

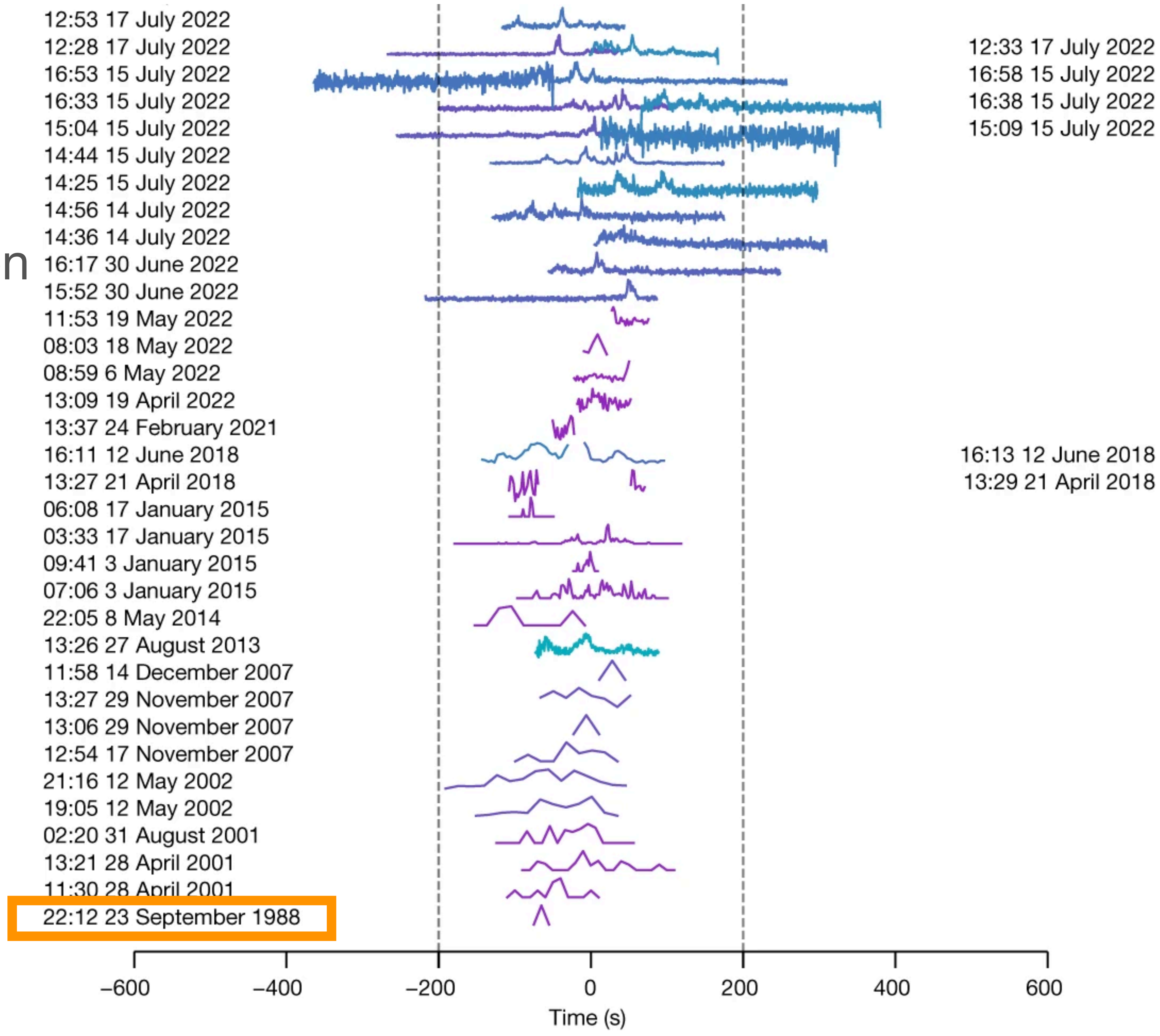
Strong spin period derivative < 3 x 10^{-13} s/s

No multi-wavelength counterpart



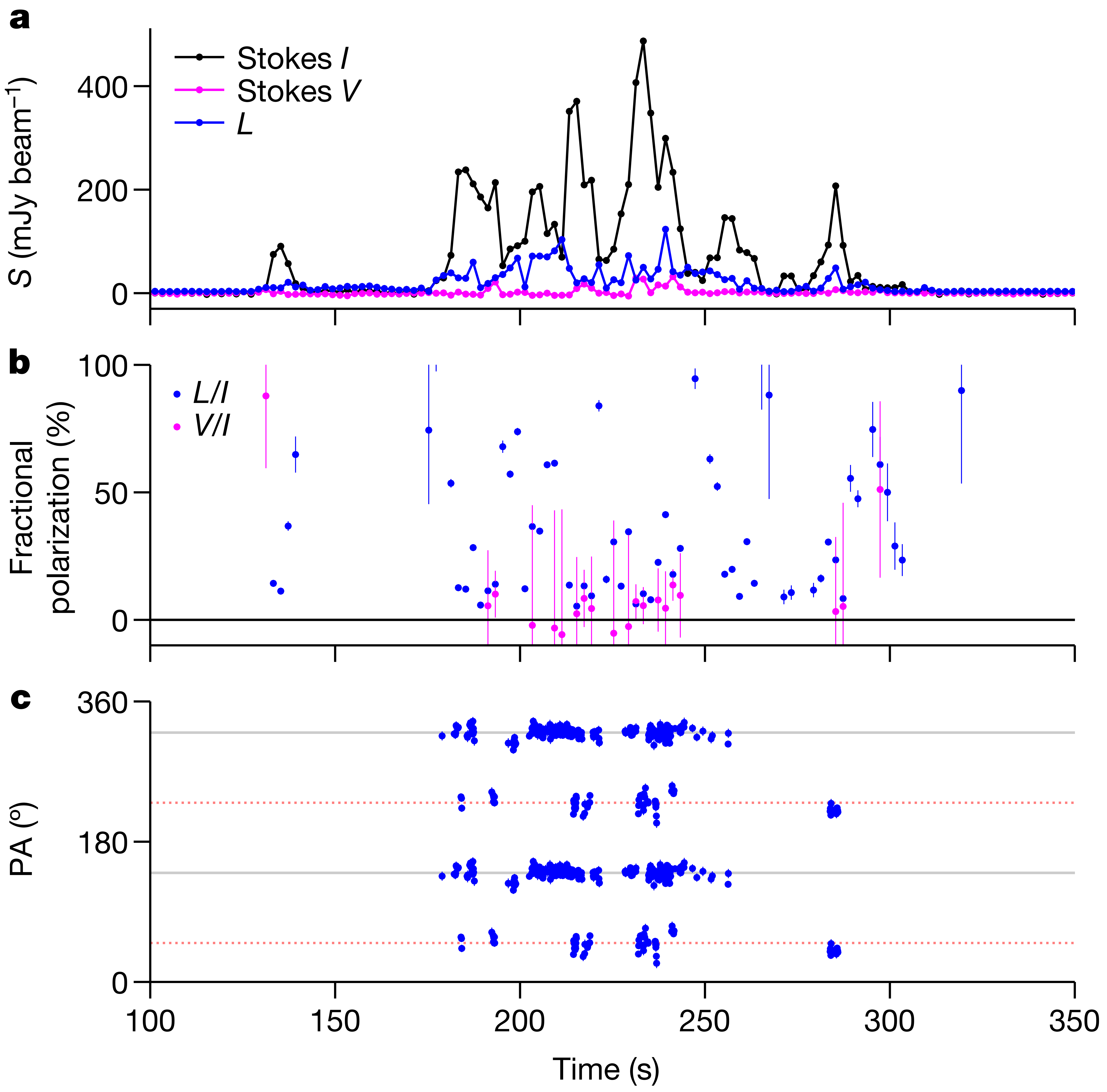


Men et al., 2025



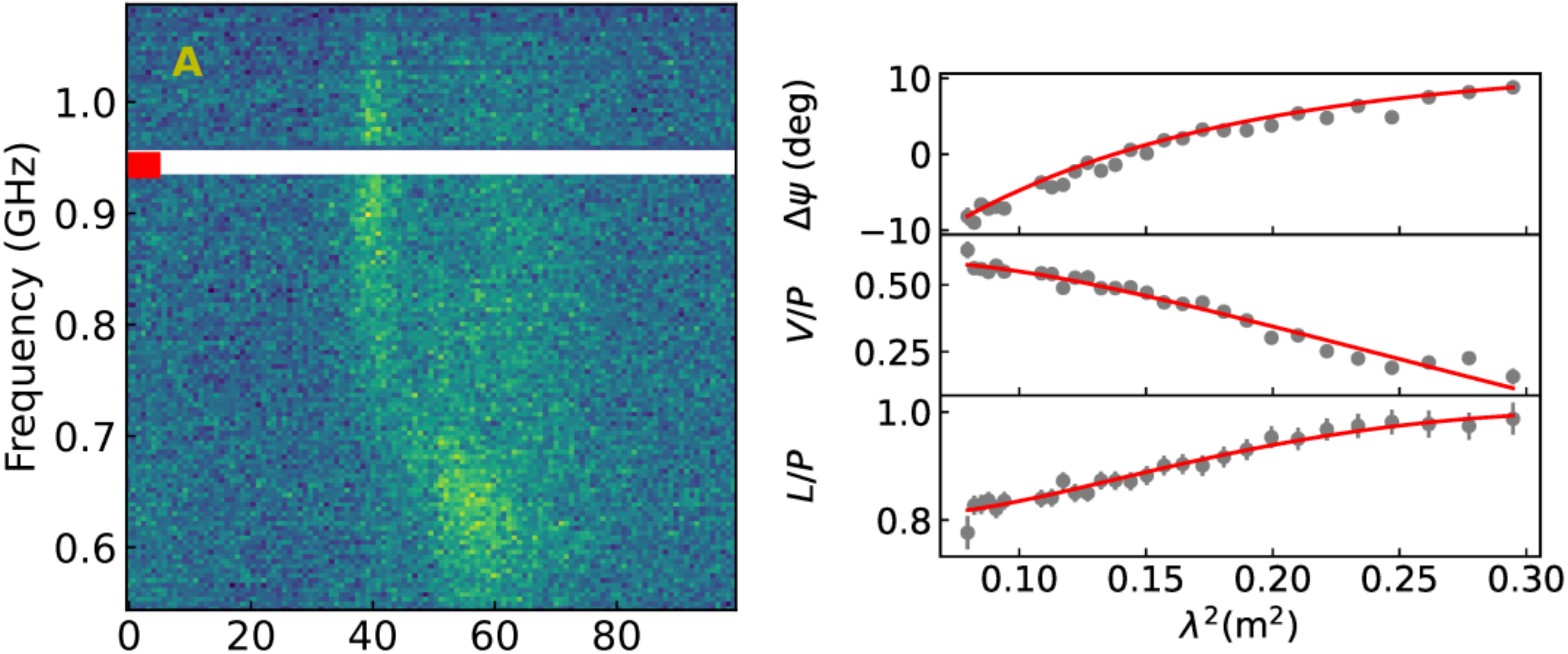
Hurley-Walker et al., 2023

Observations of long period transients - GPM J1839-10



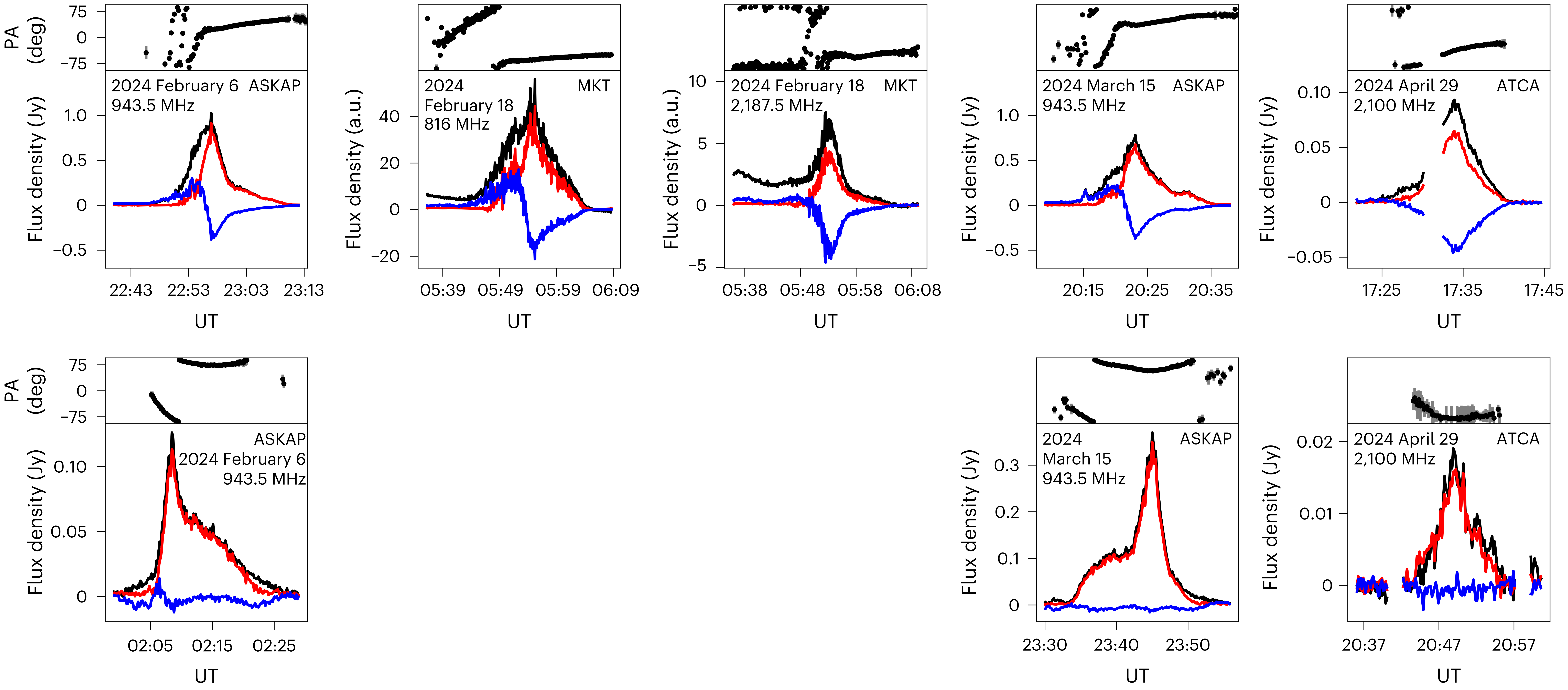
Hurley-Walker et al., 2023

Observations of long period transients - GPM J1839-10



Men et al., 2025

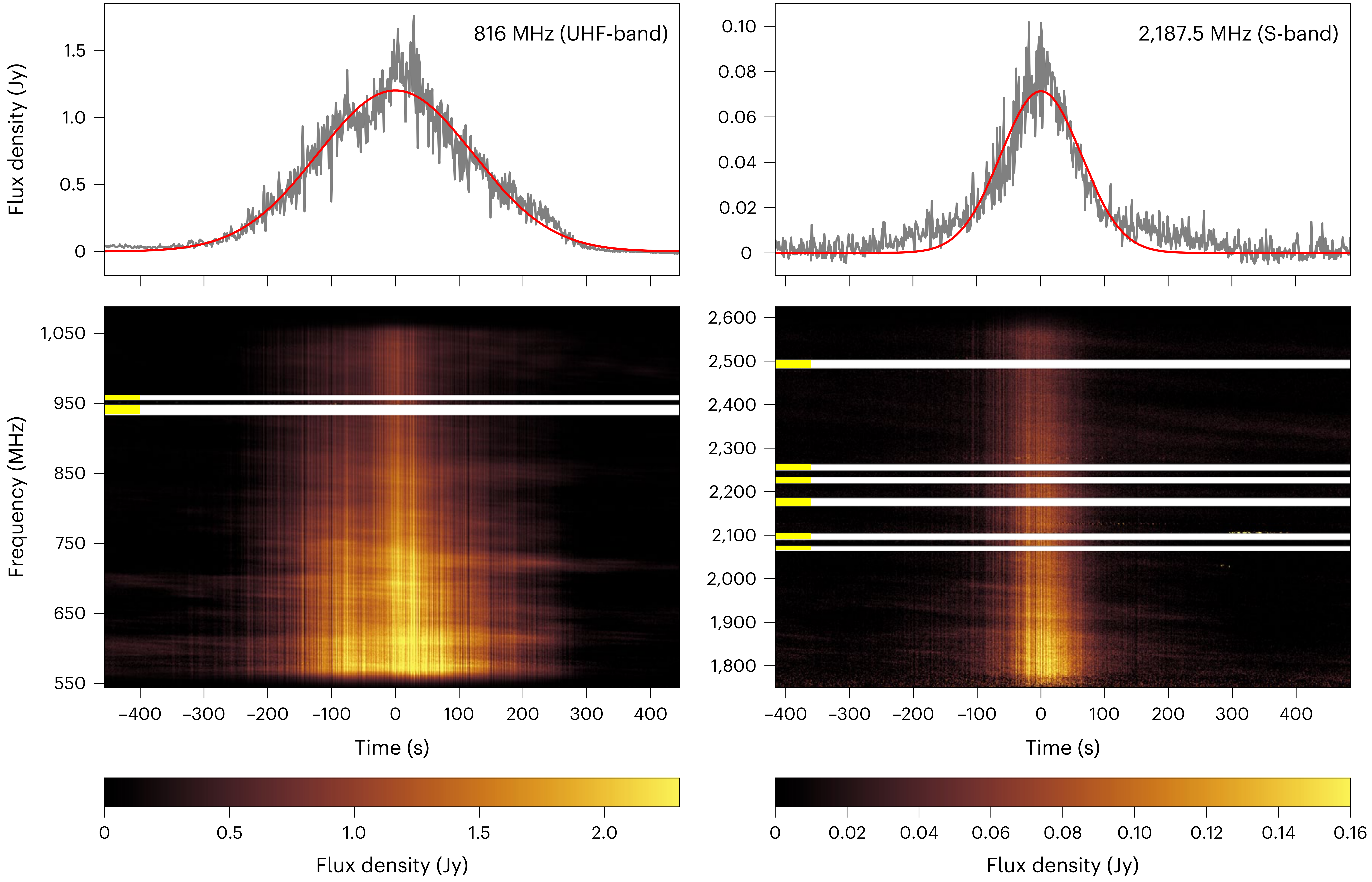
A 6.45 hr LPRT with an interpulse - ASKAP J1839-07



No apparent optical / binary counterpart

Lee, Caleb… **Wadiasingh** +2025

A 6.45 hr LPRT with an interpulse - ASKAP J1839-07



No apparent optical / binary counterpart

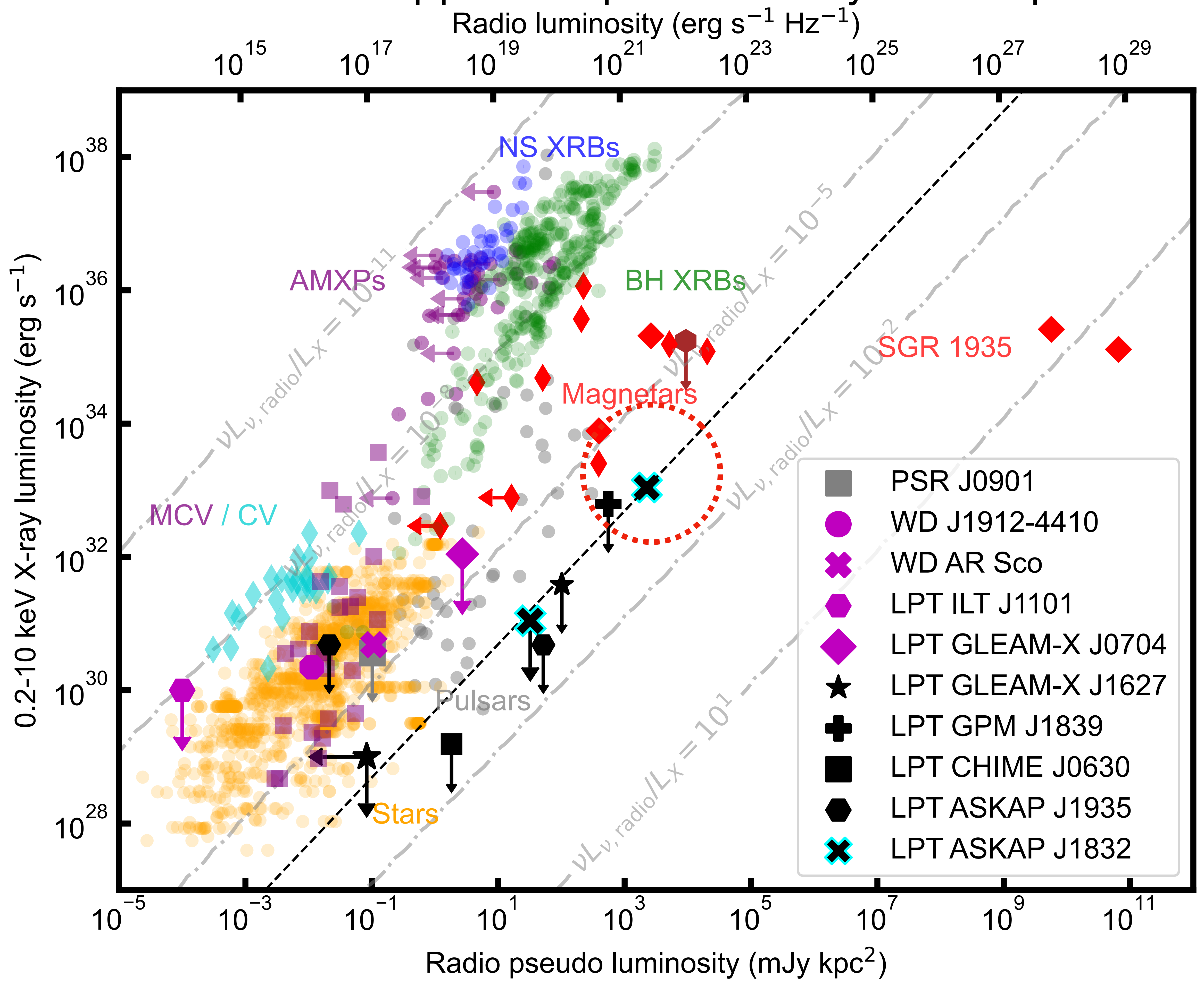
Lee, Caleb… **Wadiasingh** +2025

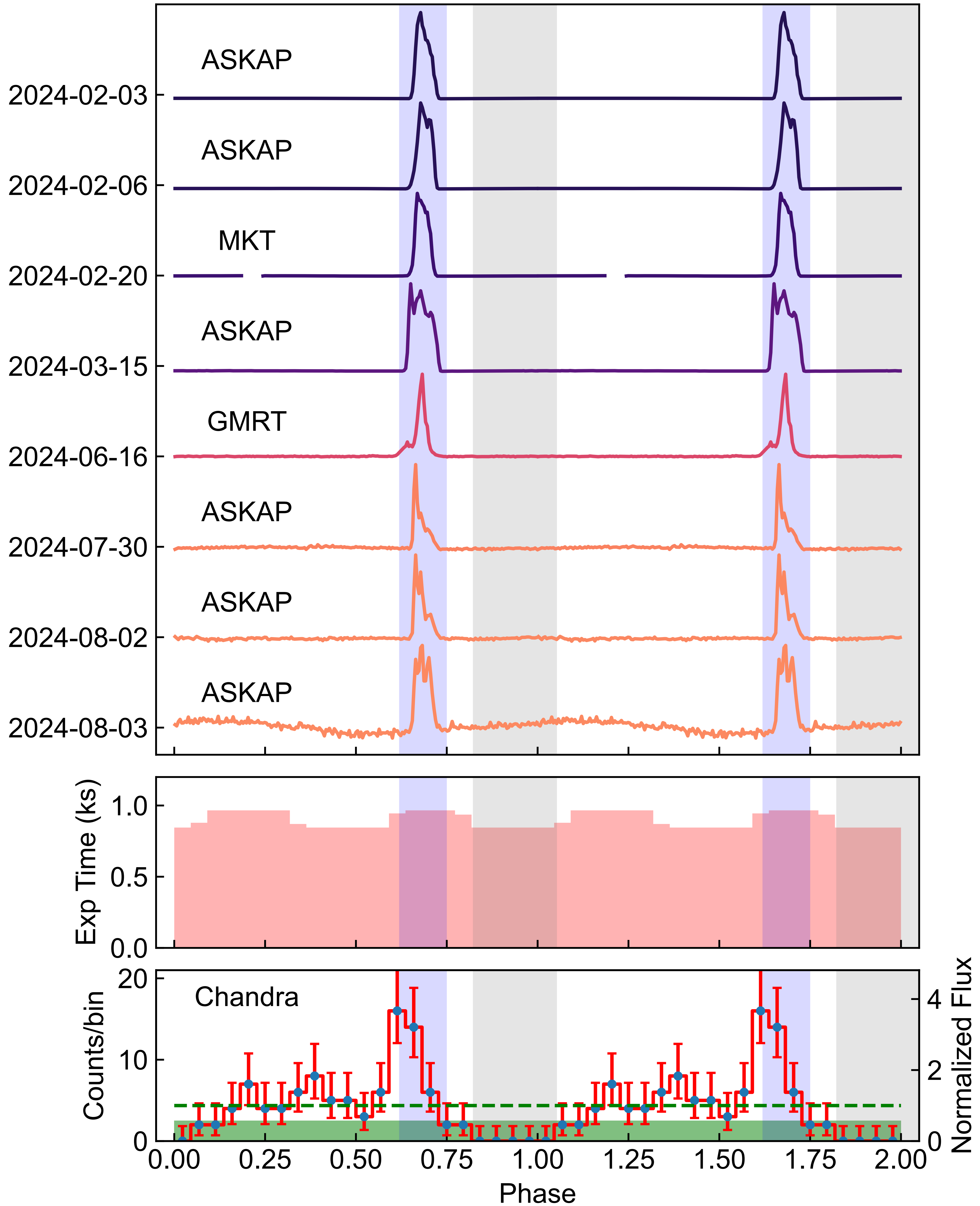
Observations of long period transients - ASKAP J1832-0911

10^33 erg/s radio and X-rays - highly efficient radio

Some radio pulses 20 Jy!

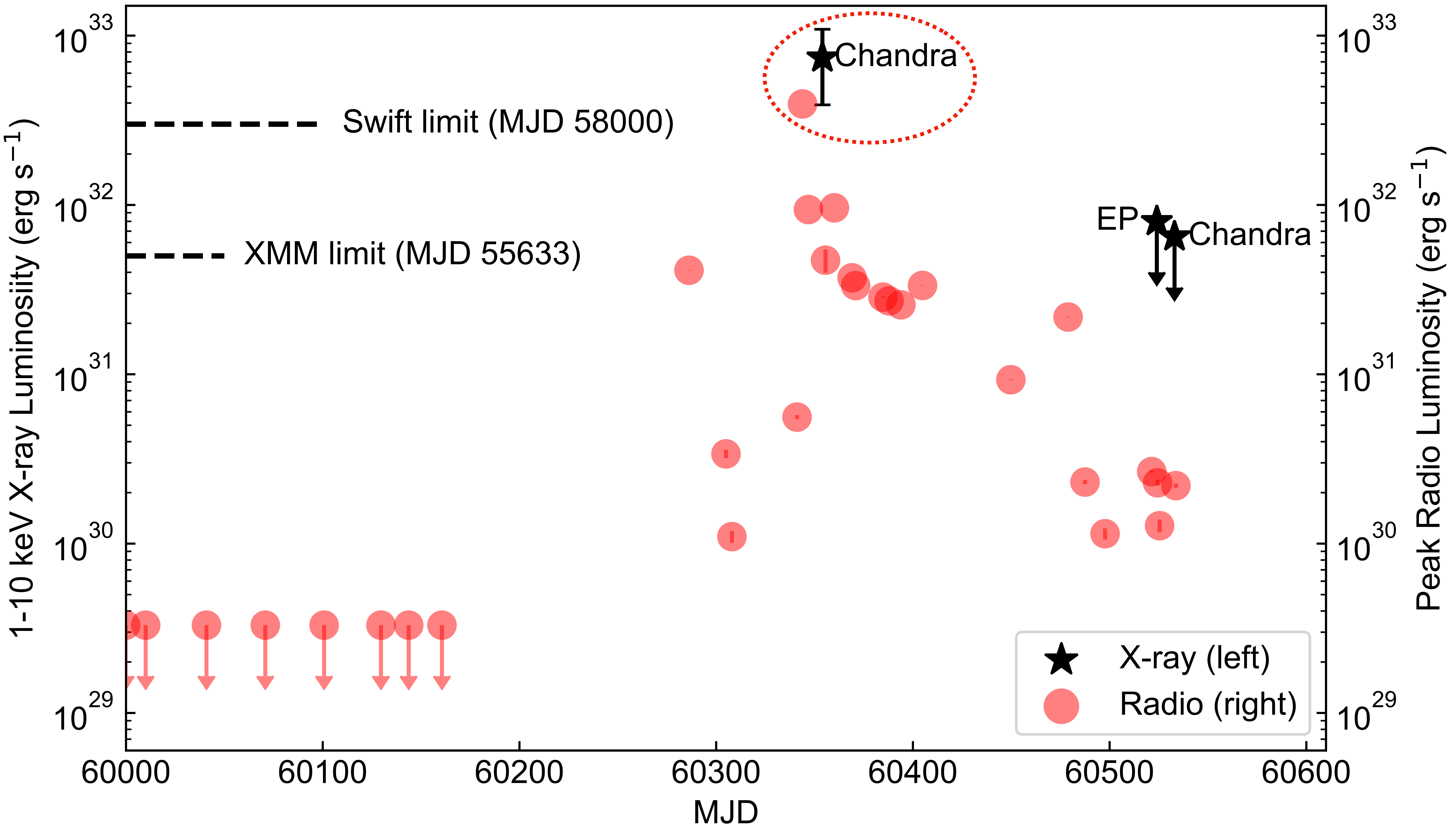
No apparent optical / binary counterpart





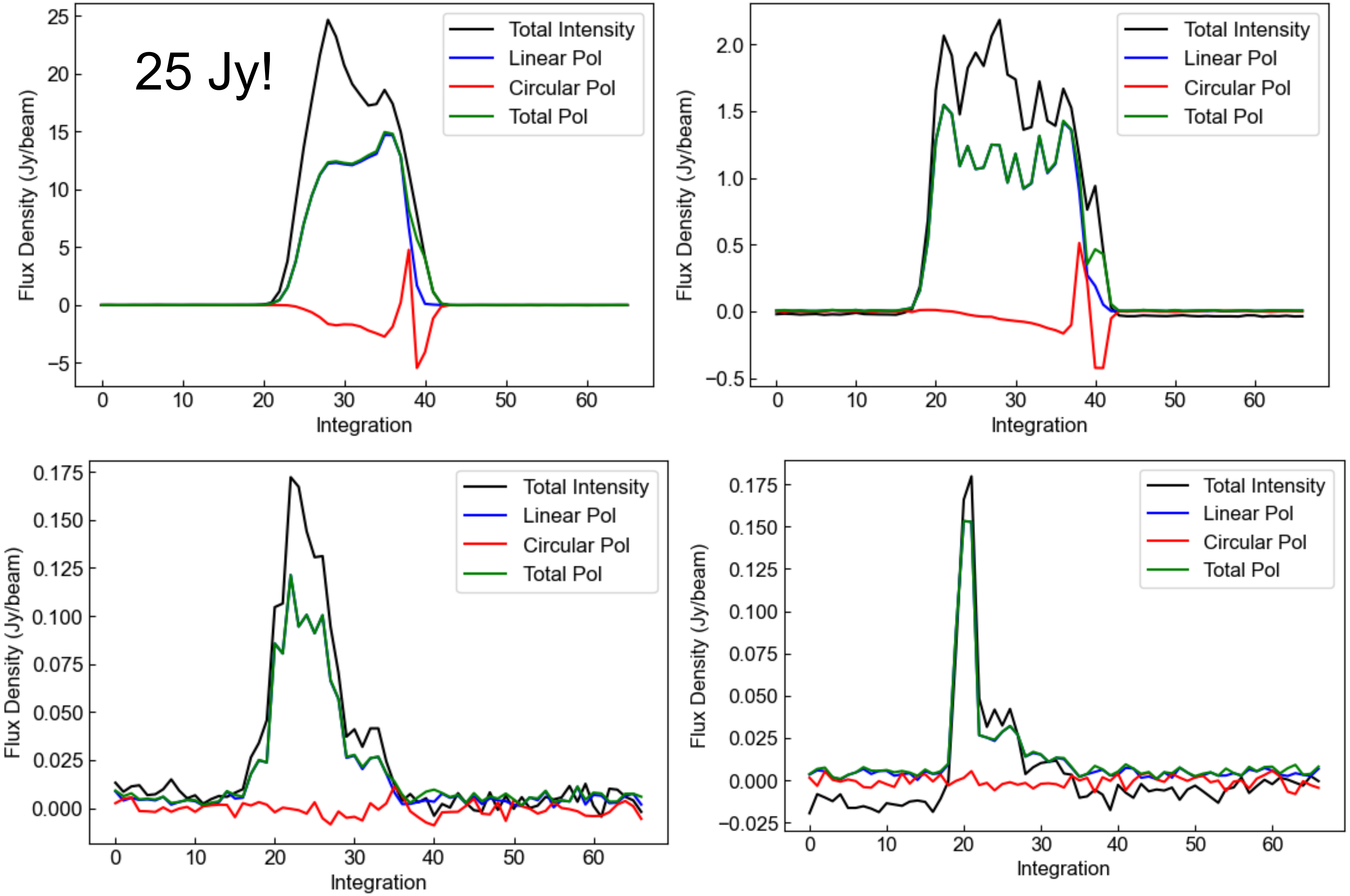
Ziteng Wang,Rea,…,**Wadiasingh** et al. 2025

Observations of long period transients - ASKAP J1832-0911



Ziteng Wang,Rea,…,**Wadiasingh** et al. 2025

Follow-ups of ASKAP J1832-0911



Ziten Wang, Rea,…Wadiasingh et al. 2025

Variable pulse morphology, polarisation properties, radio spectral index…

How might they exist?

Many possible mechanisms to spin down magnetars to long periods

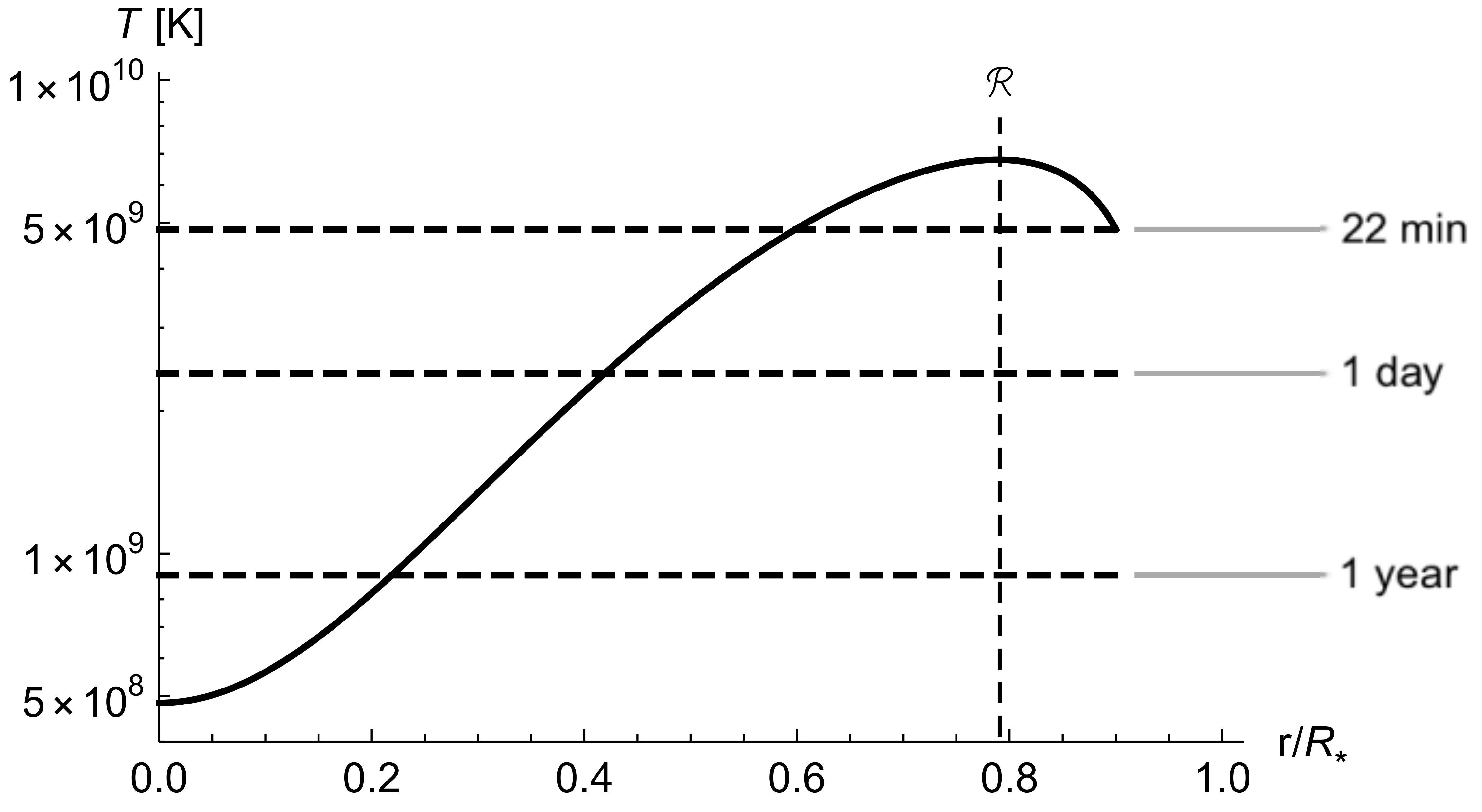
There is much phenomenological evidence for epochs of enhanced spindown in Galactic magnetars.

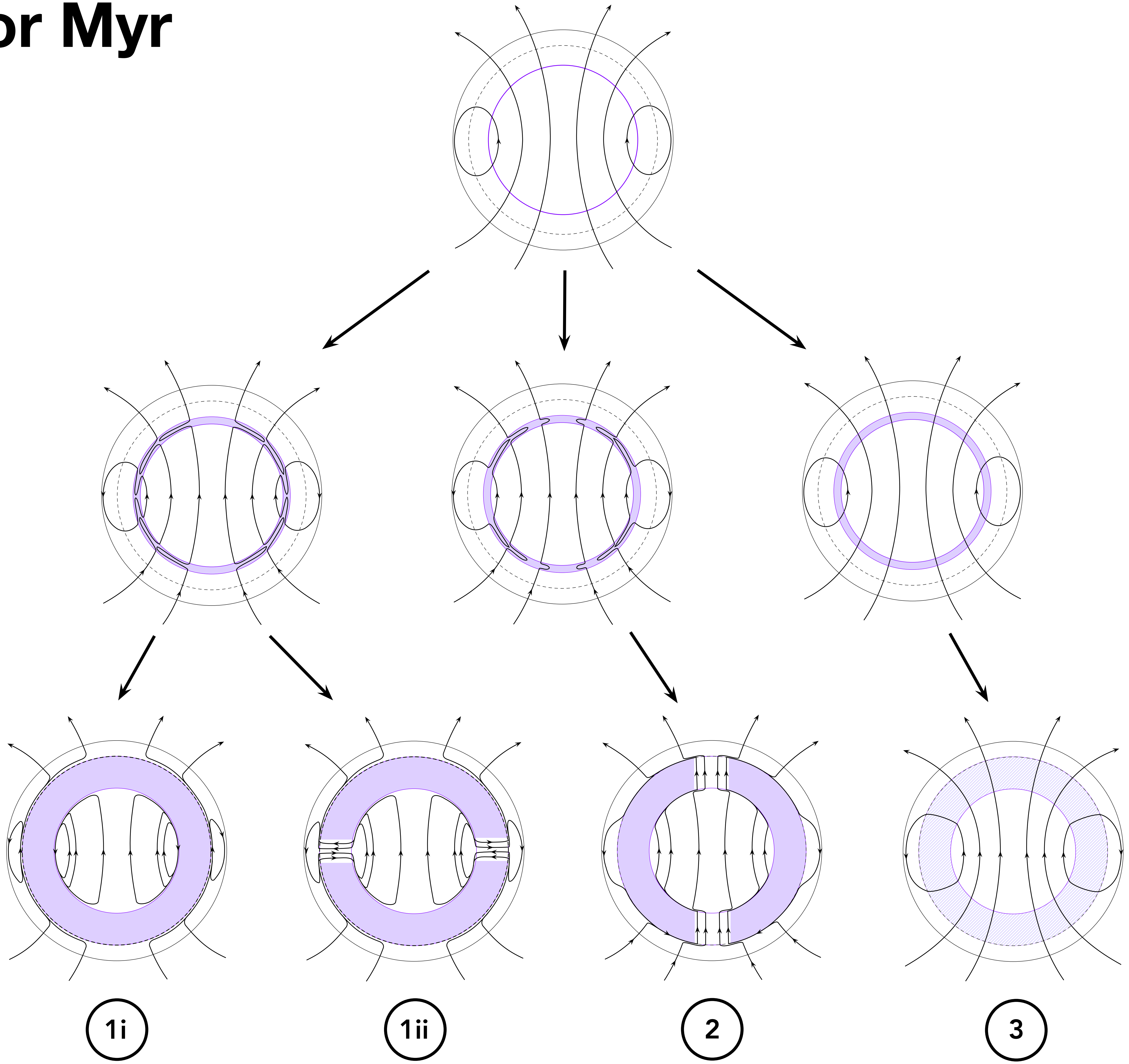
Physical mechanisms for attaining long periods:

- Fallback disks (Beniamini, **Wadiasingh**, Metzger+2020; Xu+2021; Ronchi, Rea+ 2022, Beniamini, **Wadiasingh,** Hare+2023;)
- Enhanced spindown from monopolar particle winds and opening of magnetic flux (Beniamini, **Wadiasingh**, Metzger+2020)
- Giant flare kicks (Beniamini, **Wadiasingh**, Metzger+2020)
- 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

Core Fields and Superconductivity

Survival of >10^15 G fields for Myr

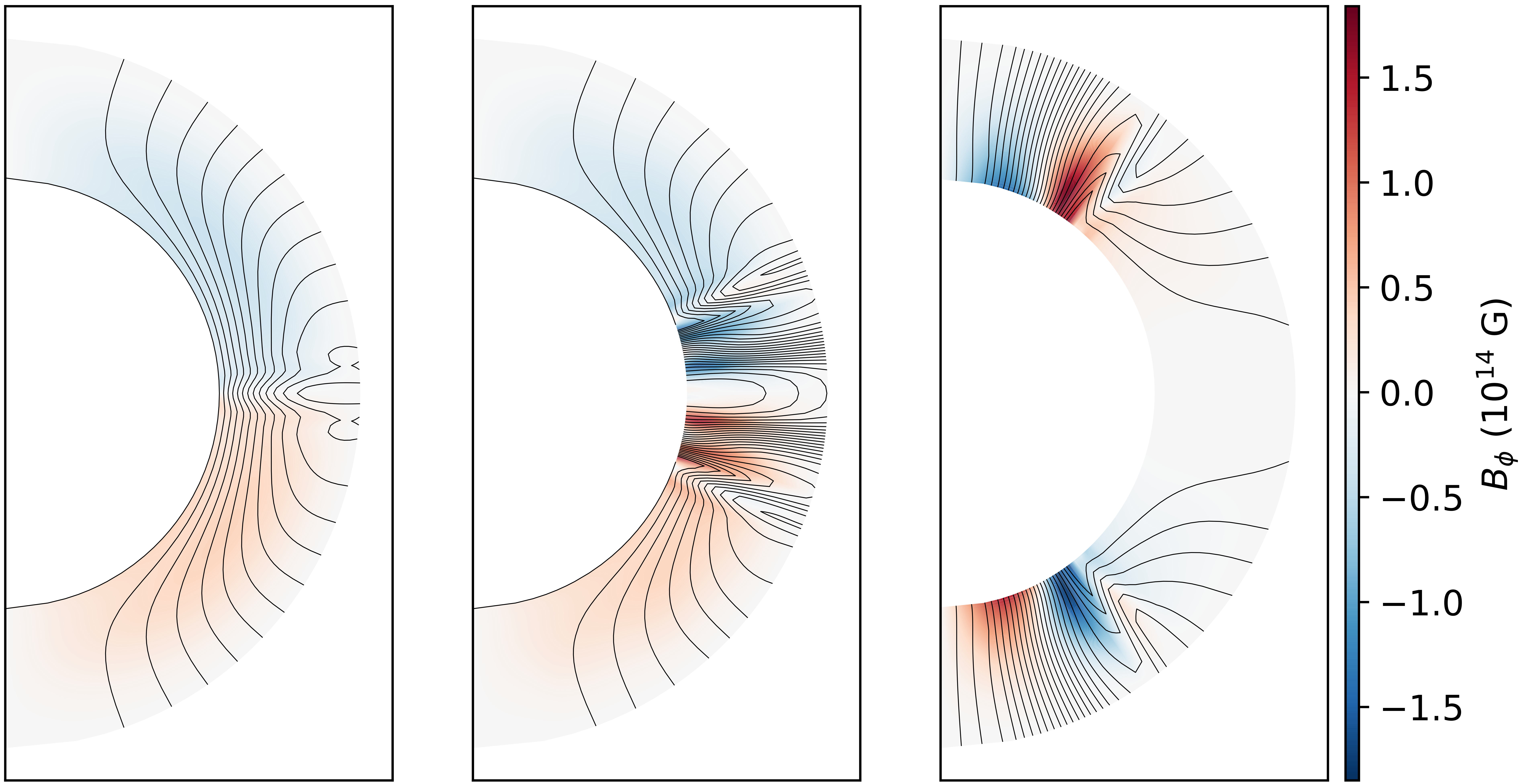




Ho+2018;
Beniamini,**Wadiasingh**,Hare+2023;
Lander 2024;
Lander,Gourgouliatos,**Wadiasingh**,Antonopoulou 2024

Core Fields and Superconductivity

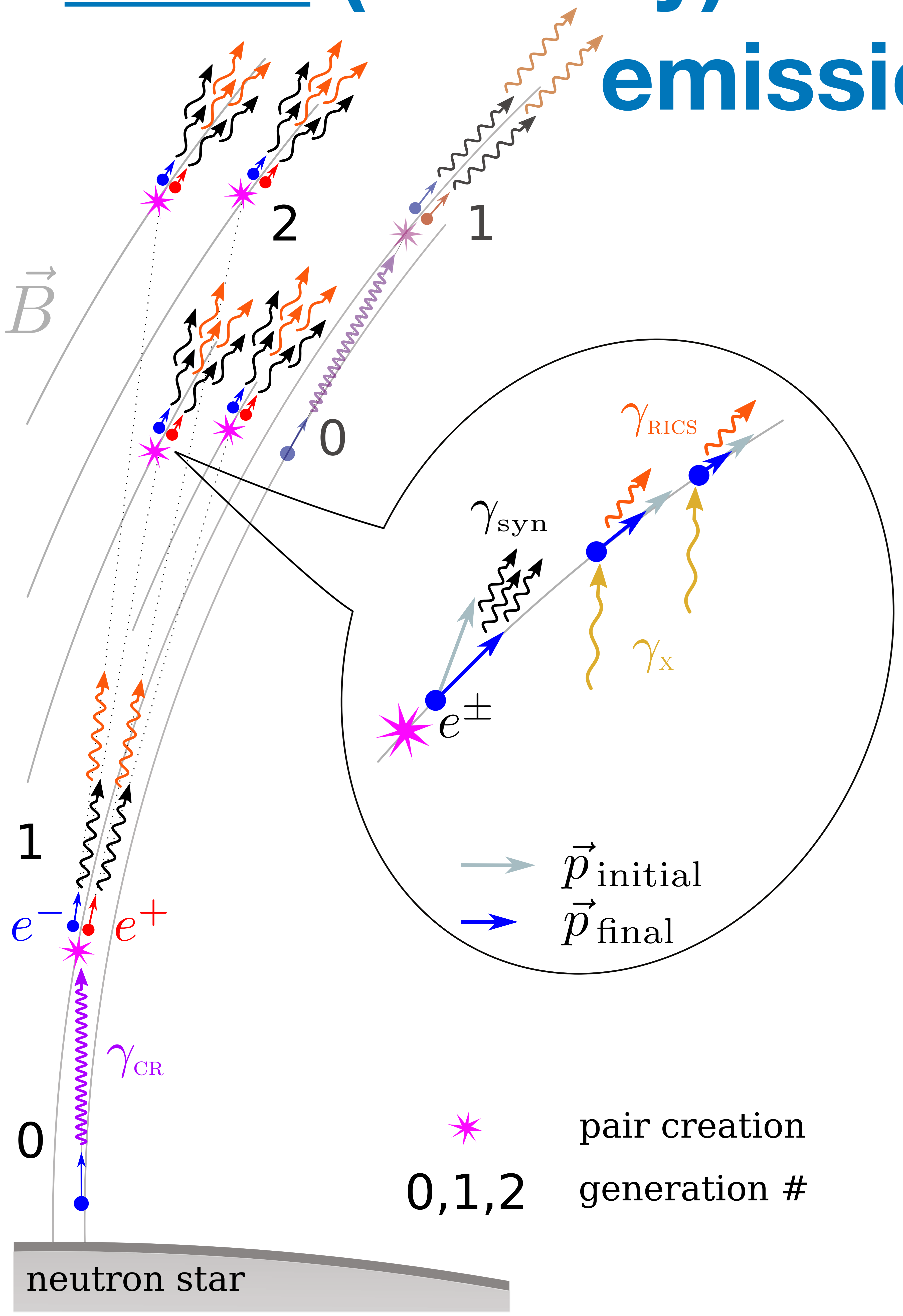
Survival of >10^15 G fields and activity for Myr



Lander,Gourgouliatos,**Wadiasingh**,Antonopoulou 2024

How might the radio emission be produced?

We <u>know</u> (broadly) what is required for pulsar-like radio emission: pair cascades



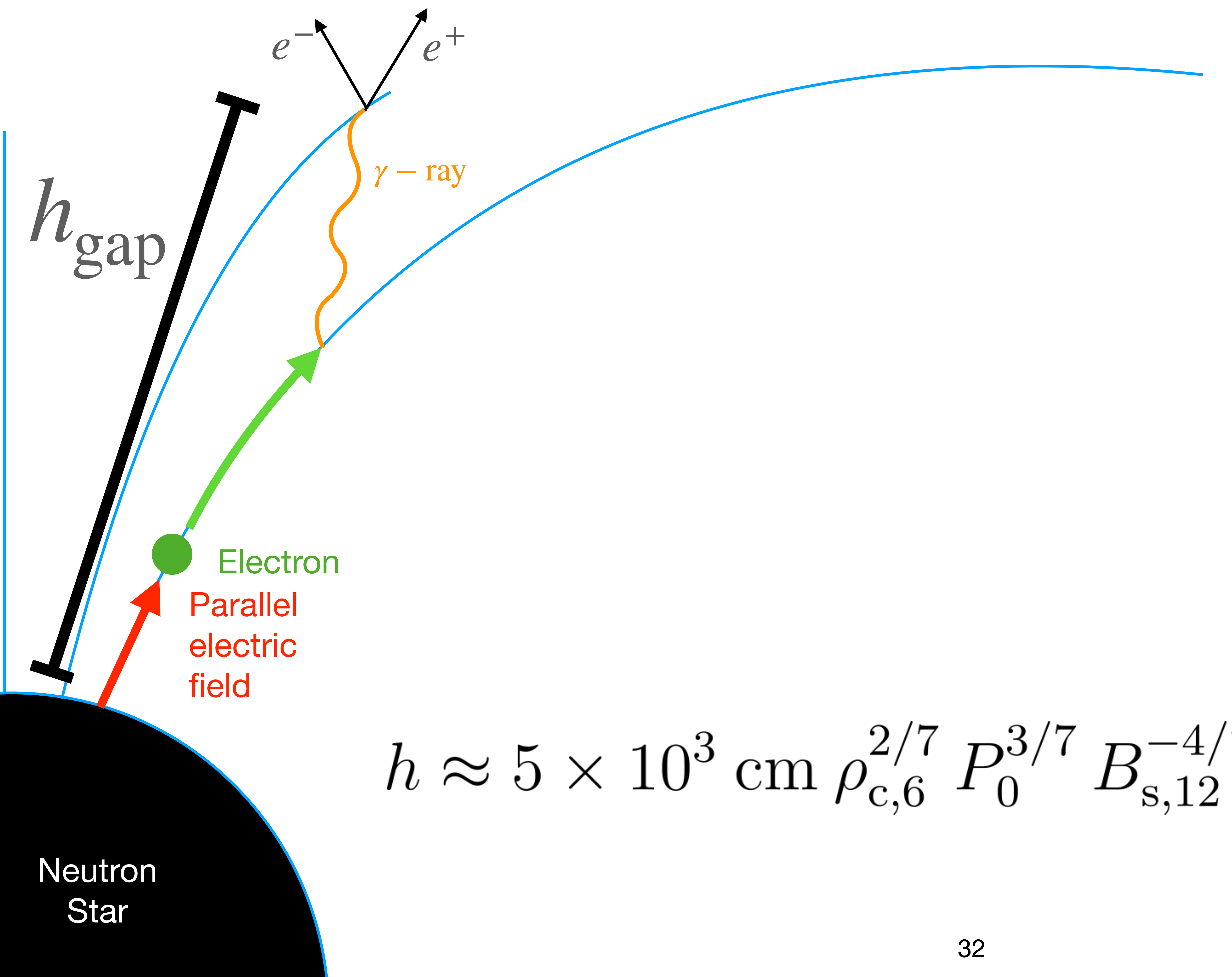
$$\gamma + B \to e^+ + e^-$$

Pairs are produced in the ground Landau state in magnetar high-B regime

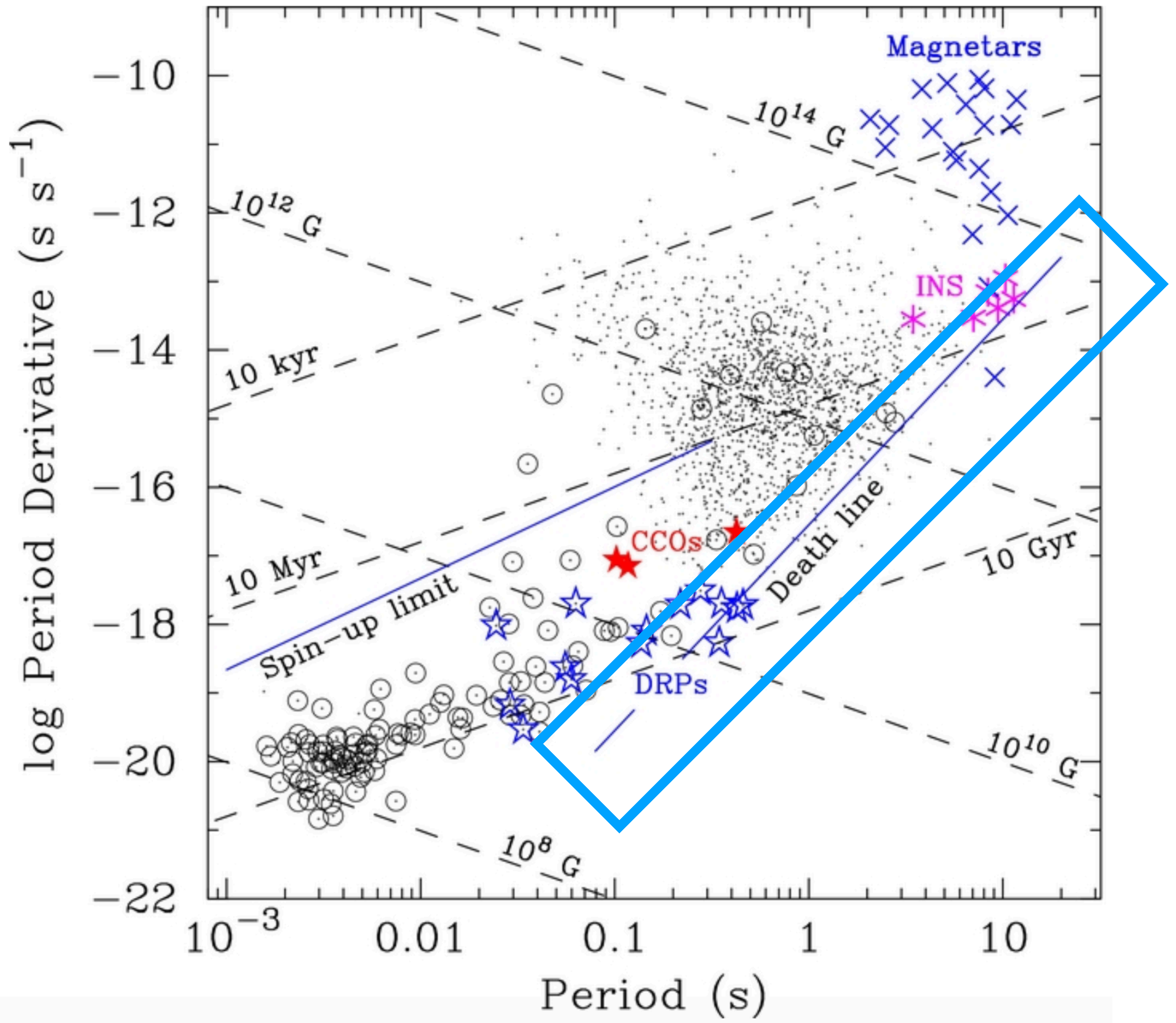
e.g., Sturrock (1971), Baring & Harding (1997), Baring & Harding (2001), Timokhin (2010), Timokhin & Arons (2013) Timokhin & Harding (2015, 2019)

The Pair Curvature Death Line

- Computing the unscreened gap height allows luminosity estimates

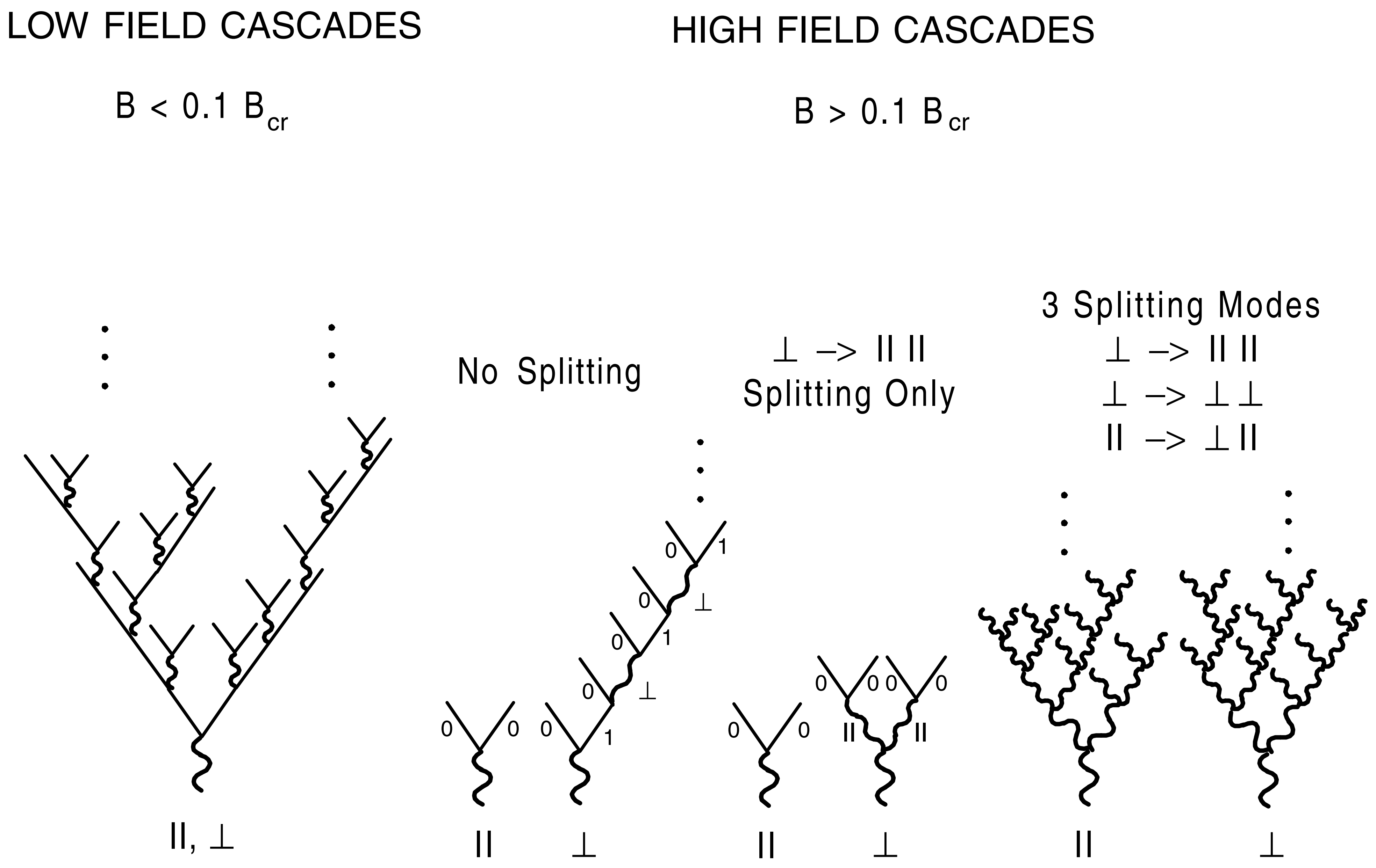


$$h \approx 5 \times 10^3 \text{ cm } \rho_{c,6}^{2/7}\, P_0^{3/7}\, B_{s,12}^{-4/7}$$



How are magnetar pair cascades different?

- Resonant inverse Compton scattering (RICS, effectively cyclotron absorption+ immediate emission) channel photons can compete versus the curvature radiation
- Radiative losses can be catastrophic in the RICS channels
- Photon splitting can suppress pair production efficiency
- Pairs produced are largely in the ground Landau state, so do not effectively radiate synchrotron photons to continue a cascade
- Non-resonant scatterings are suppressed



Baring & Harding (2001)

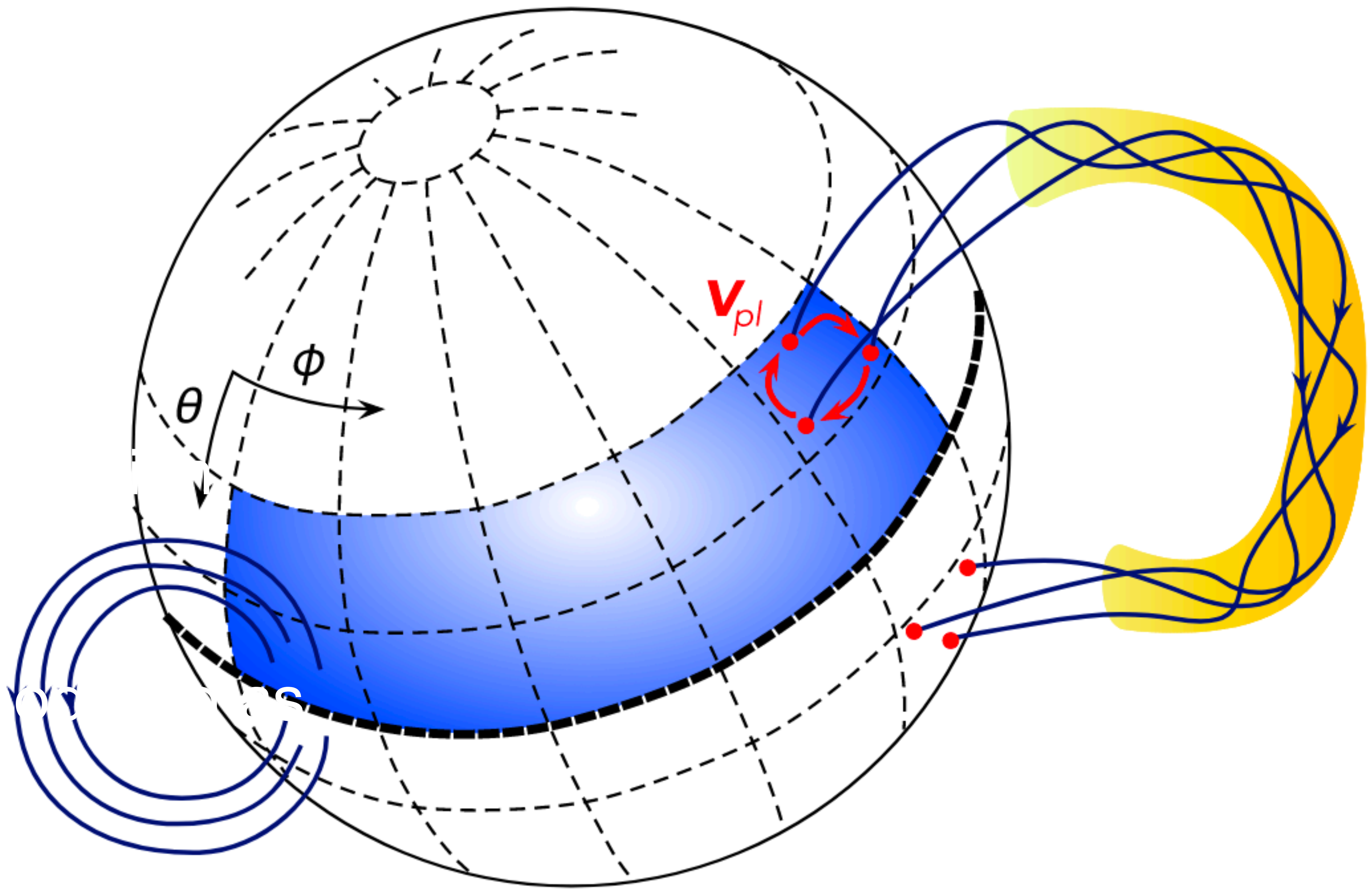
Ingredient 1: Plastic Flow powered twists

- At B > 10^{15} G **plastic flow** (magnetic stress driven 'continental drift') dominates crustal evolution, and can twist the magnetic field

See e.g. Lander 2019; Gourgouliatos & Lander 2021; Lander 2023

$$\psi \equiv \frac{B_\phi}{B_{\rm dp}} < 1$$

Twists require charge similarly to rotation — Analogous to preexisting "low-twist" model for FRBs proposed by Wadiasingh & Timokhin 2019, Wadiasingh+2020

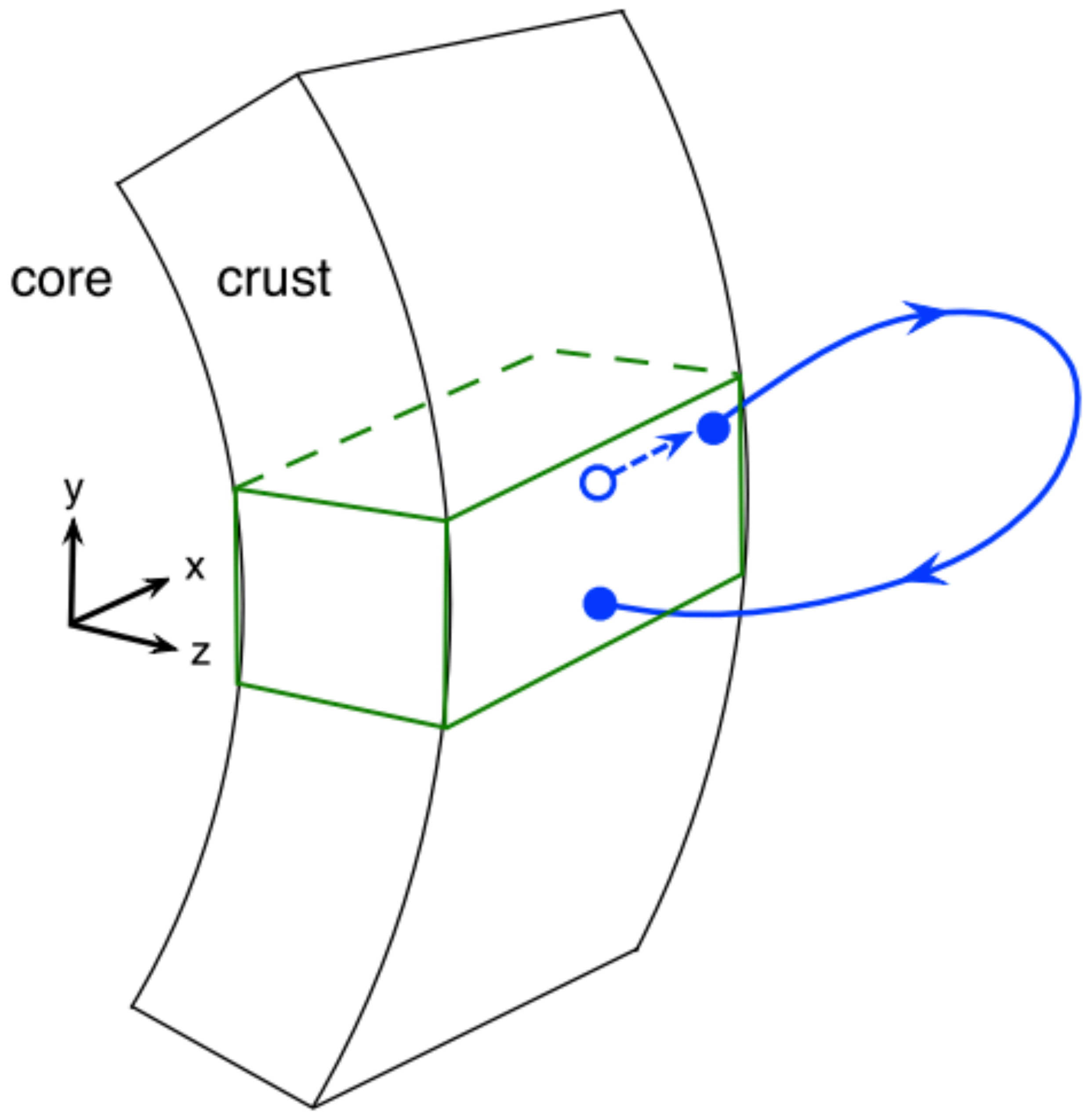


Lander et al., 2023

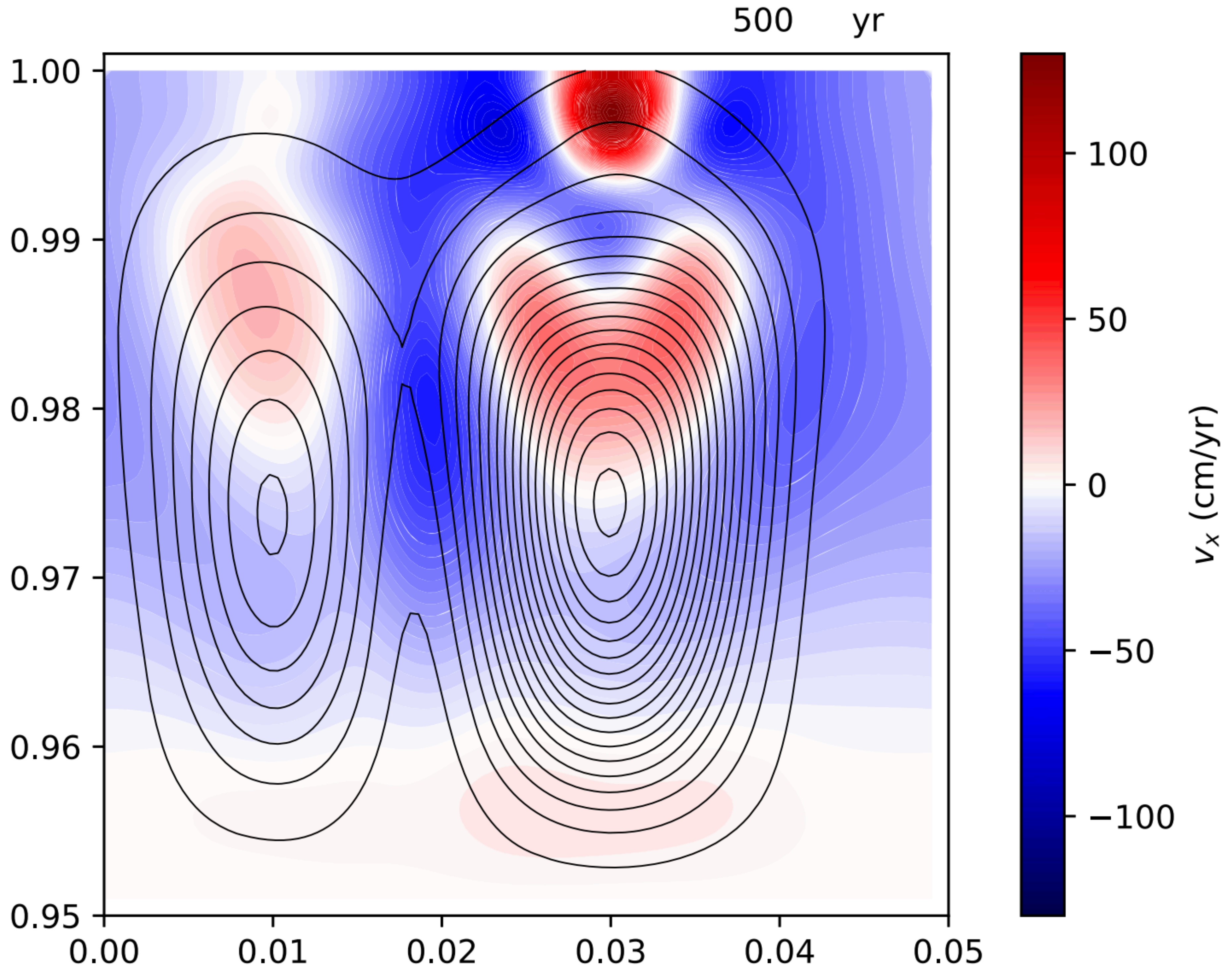
Ingredient 1: Plastic Flow powered twists

- At B > 10^{15} G **plastic flow** (magnetic stress driven 'continental drift') dominates crustal evolution, and can twist the magnetic field

- Lander et al (2019) show that plastic flow of 1km^2 patches has velocities of **1-100 cm/yr** for months to decades



Cooper & Wadiasingh (2024)



Lander, 2019

Ingredient 1: Plastic Flow powered twists

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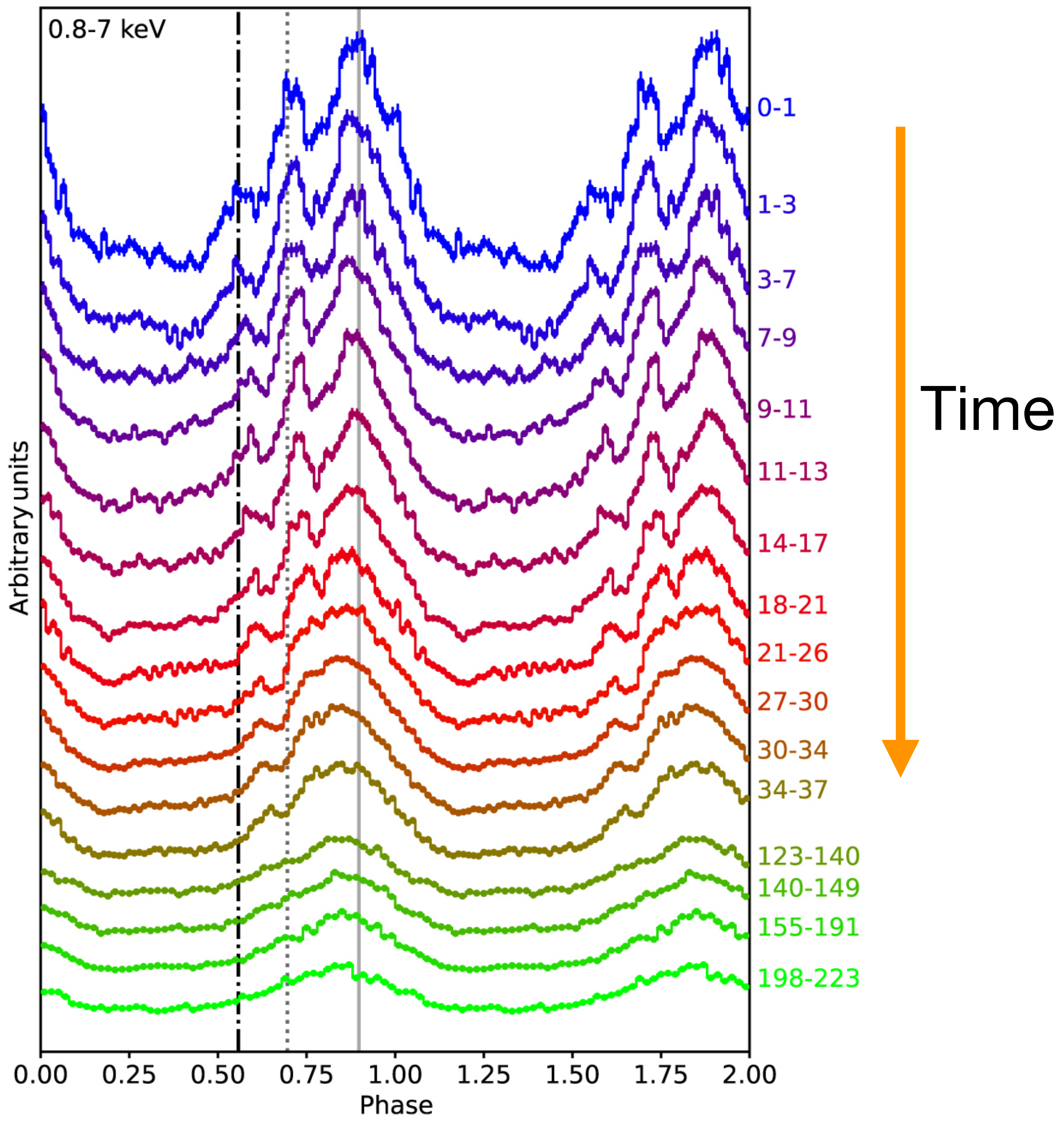
- Lander et al (2019) show that plastic flow of 1km^2 patches has velocities of **1-100 cm/yr** for months to decades
- Younes et al. (2022) posit a connection between X-ray magnetar pulse peak migration plastic flow, requiring 10^6 cm/yr

See also Younes et al. (2025)

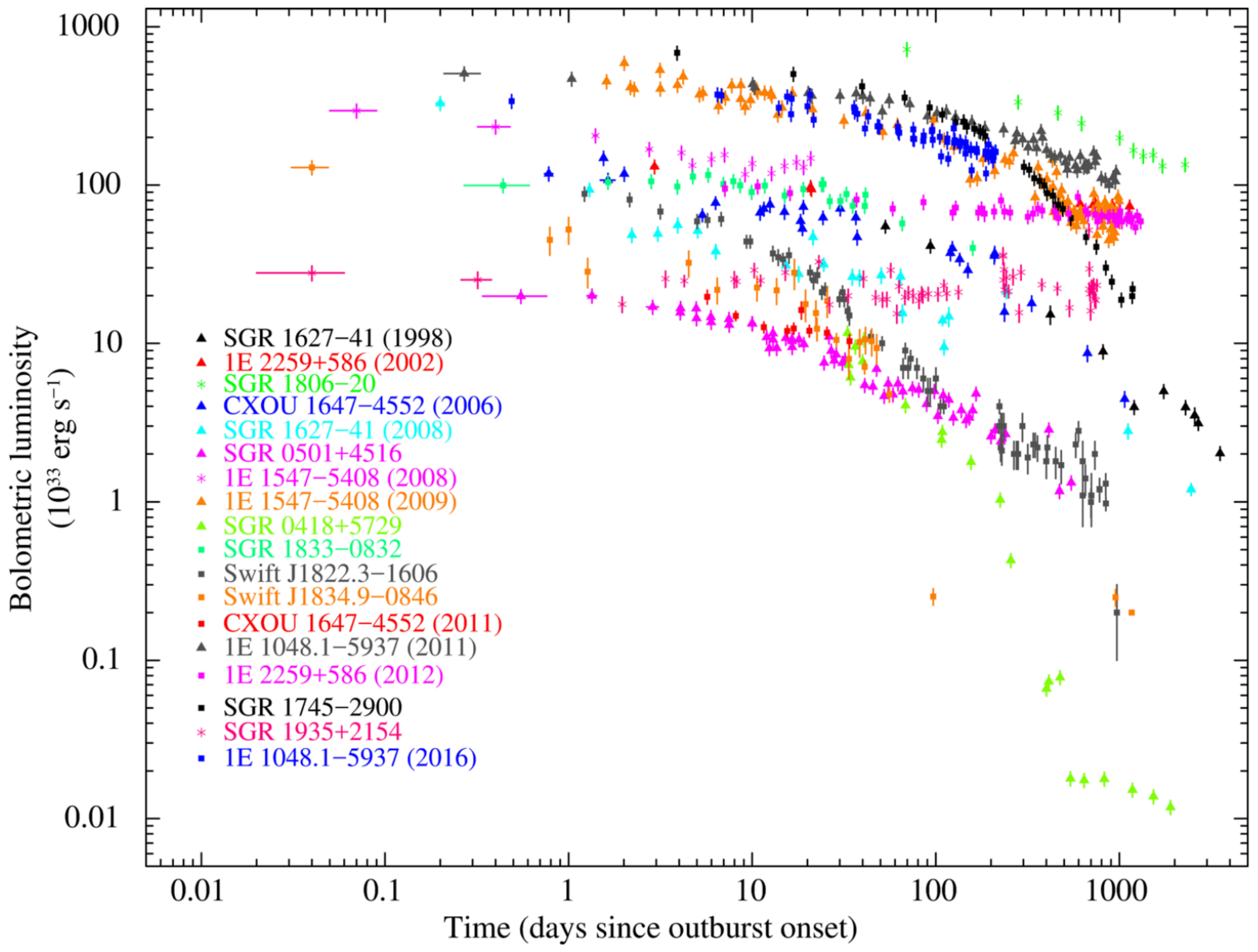


Younes+ 2022

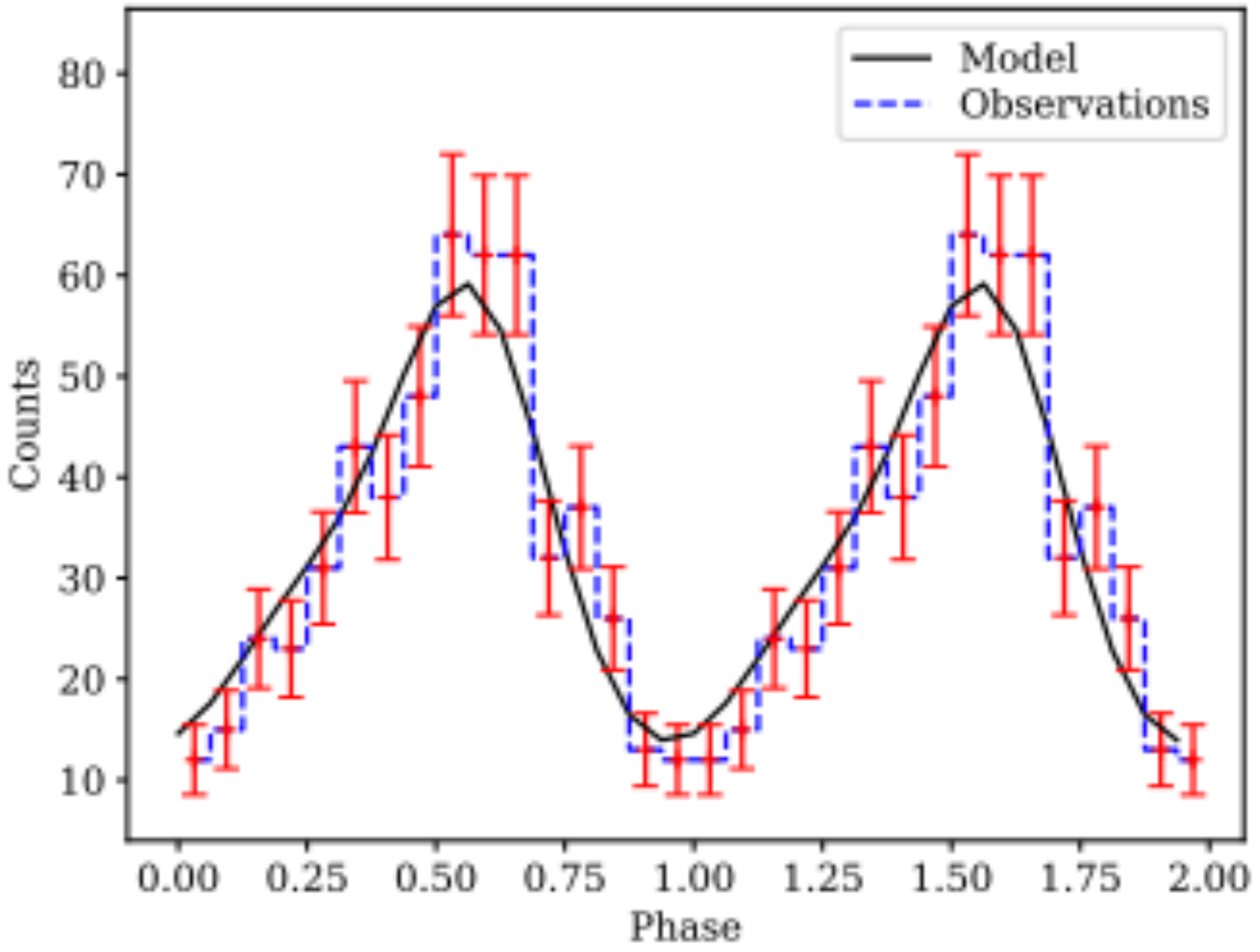
Cooper & Wadiasingh (2024)

Ingredient 2: Twist-induced radio emission

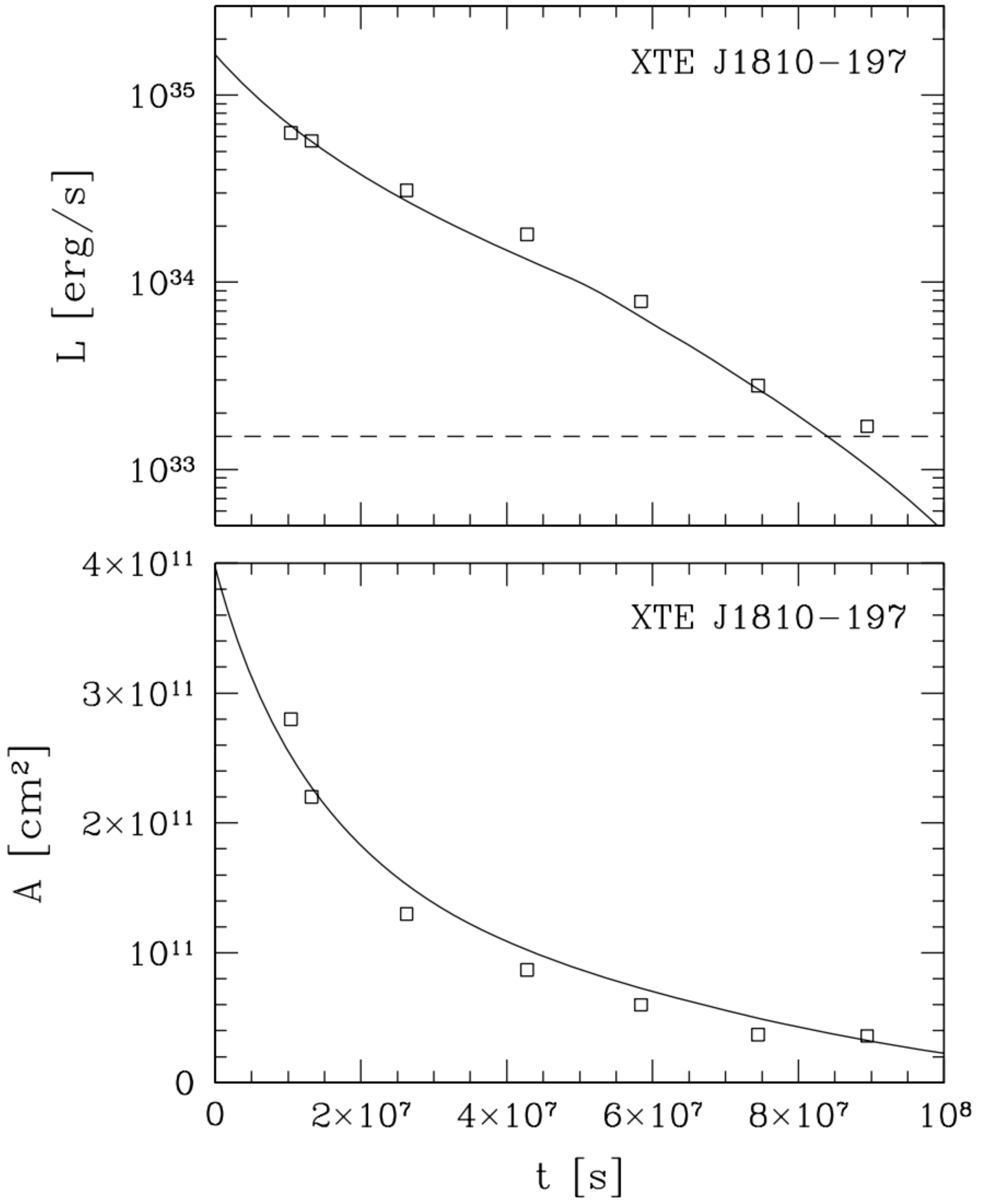
- Persistent magnetar activity can be described by twisted magnetic fields



X-ray magnetars in outburst (Coti Zelati+ 2018)



Pulse fit with twisted field (Igoshev+ 2021)



Long-term twist evolution (Beloborodov, 2013)

Ingredient 2: Twist-induced radio emission

- Persistent magnetar activity can be described by twisted magnetic fields

Rotation: $$\rho_{\mathrm{GJ}} \approx \frac{2B}{cP}$$

Twist: $$\rho_{\psi} \approx \frac{B \sin^2(\theta_{\mathrm{fp}})\Psi}{4\pi R_{\mathrm{NS}}}$$

- Twists require charge similarly to rotation

Analogous to preexisting “low-twist” model for FRBs proposed by Wadiasingh & Timokhin 2019, Wadiasingh+2020

Crustal density and temperature gradients also drive magnetic field evolution

Alternative: Thermoelectrically induced small twists

$$\frac{\delta \vec{B}}{\delta t} = -c\nabla \times \left(\frac{(\nabla \times \vec{B}) \times \vec{B}}{4\pi q n_e} + \frac{c\nabla \times \vec{B}}{4\pi\sigma_{con}} - \frac{S_e}{q}\nabla T \right).$$

dB/dt orthogonal to both gradients > twisted component

Positive feedback loop: dT/dx != 0 > Twist > Particle acceleration > Hotspot heating > dT/dx != 0

Cooper & Wadiasingh (2024)

Ingredient 2: Twist-induced radio emission

- Persistent magnetar activity can be described by twisted magnetic fields

$$\rho_{\rm GJ} \approx \frac{2B}{cP}$$

$$\rho_{\psi} \approx \frac{B \sin^2(\theta_{\rm fp})\Psi}{4\pi R_{\rm NS}}$$

Analogous to preexisting "low-twist" model for FRBs proposed by Wadiasingh & Timokhin 2019, Wadiasingh+2020

- Twists require charge similarly to rotation

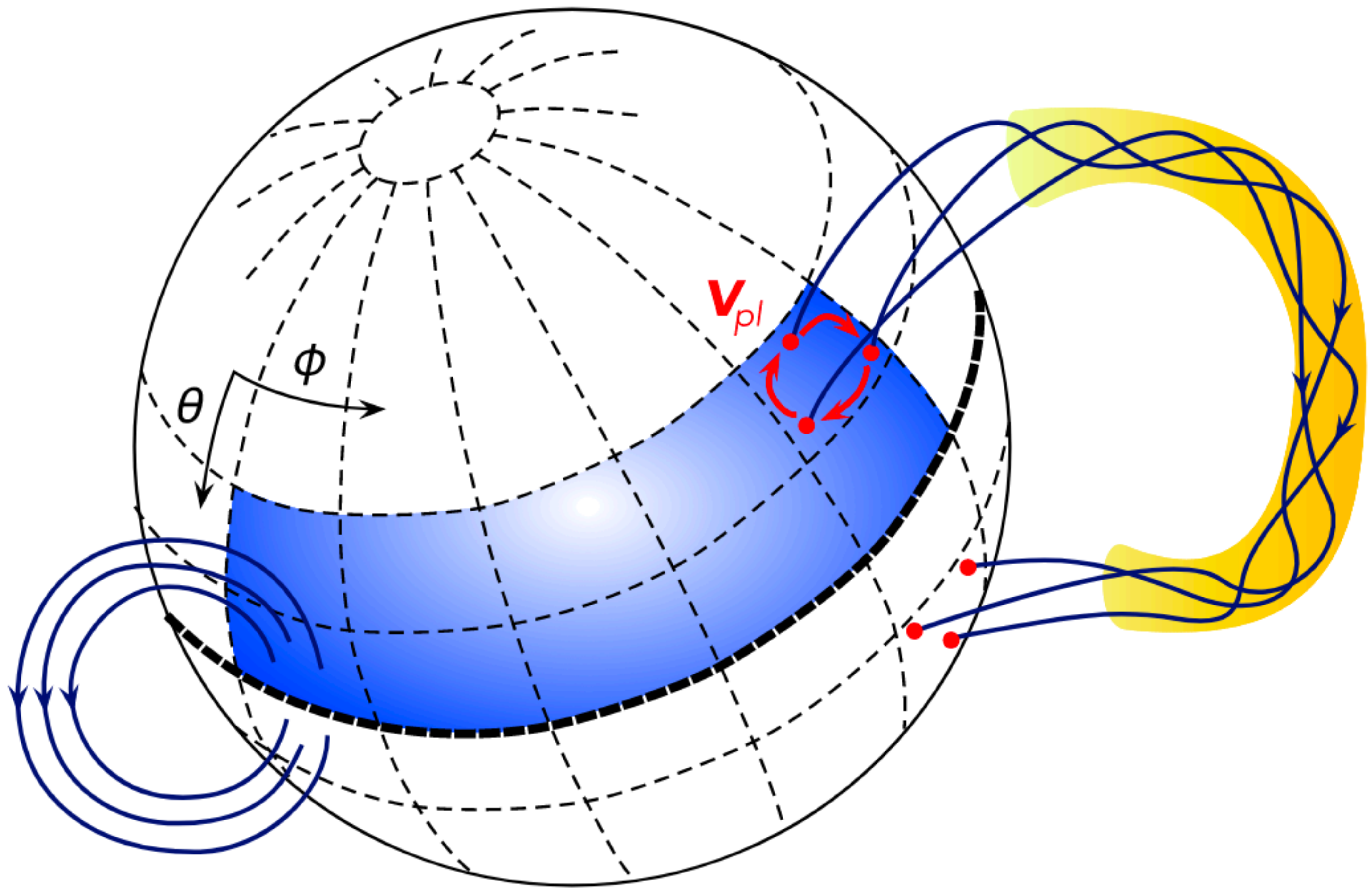
$$\Psi_{\rm crit} \equiv \Psi(\rho_{\psi} = \rho_{\rm GJ})$$

Broadband radio emission (e.g. Timokhin 2010, Timokhin & Arons 2013, Philippov et al., 2020, Benáček+2024,2025)

If $\rho_{\psi} > \rho_{GJ}$ → Twist dissipation → Acceleration gaps → Pair production → Broadband radio emission

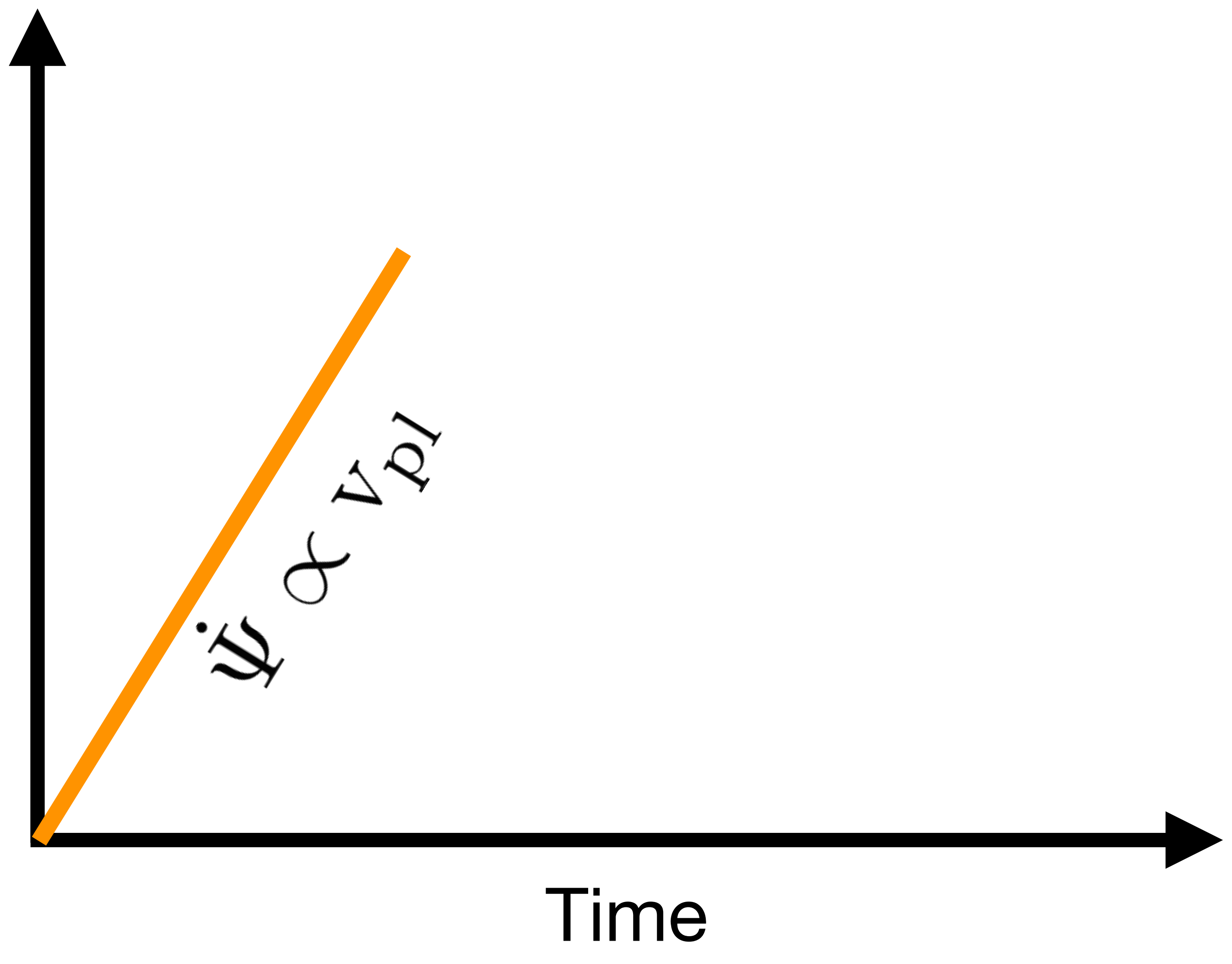
Model: Five steps

(1) Plastic flow twists field lines in ~km² patches



Lander 2023

$$\Psi = \frac{B_\phi}{B_0}$$



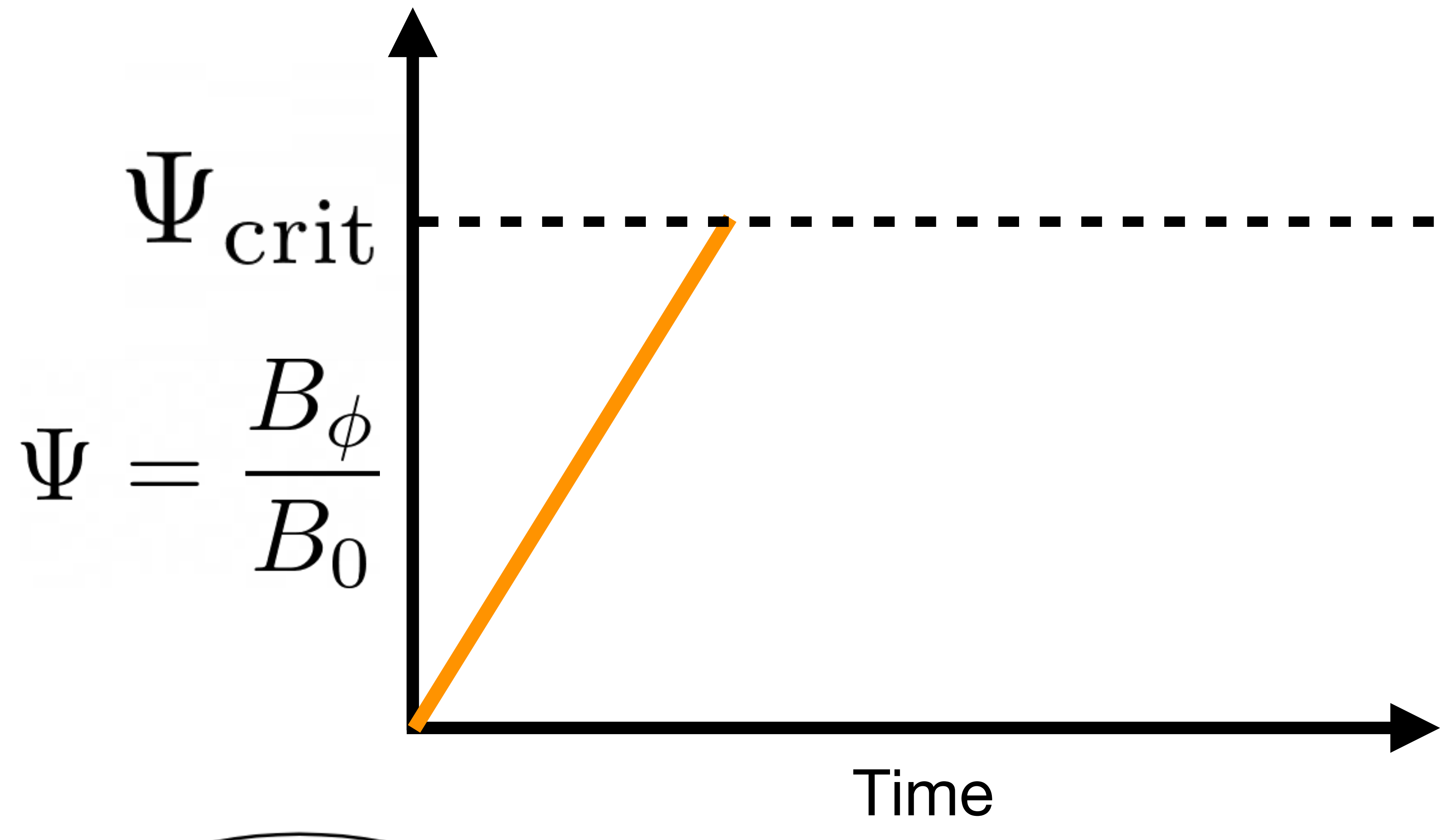
Model: Five steps

(1) Plastic flow twists field lines in ~km² patches

(2) Twist current requirements exceed GJ current

$$\rho_\psi > \rho_{GJ}$$

$$\Psi_{\rm crit} \approx 10^{-4}\, P_{\rm NS,3}^{-1}\, \theta_{\rm fp,-1}$$



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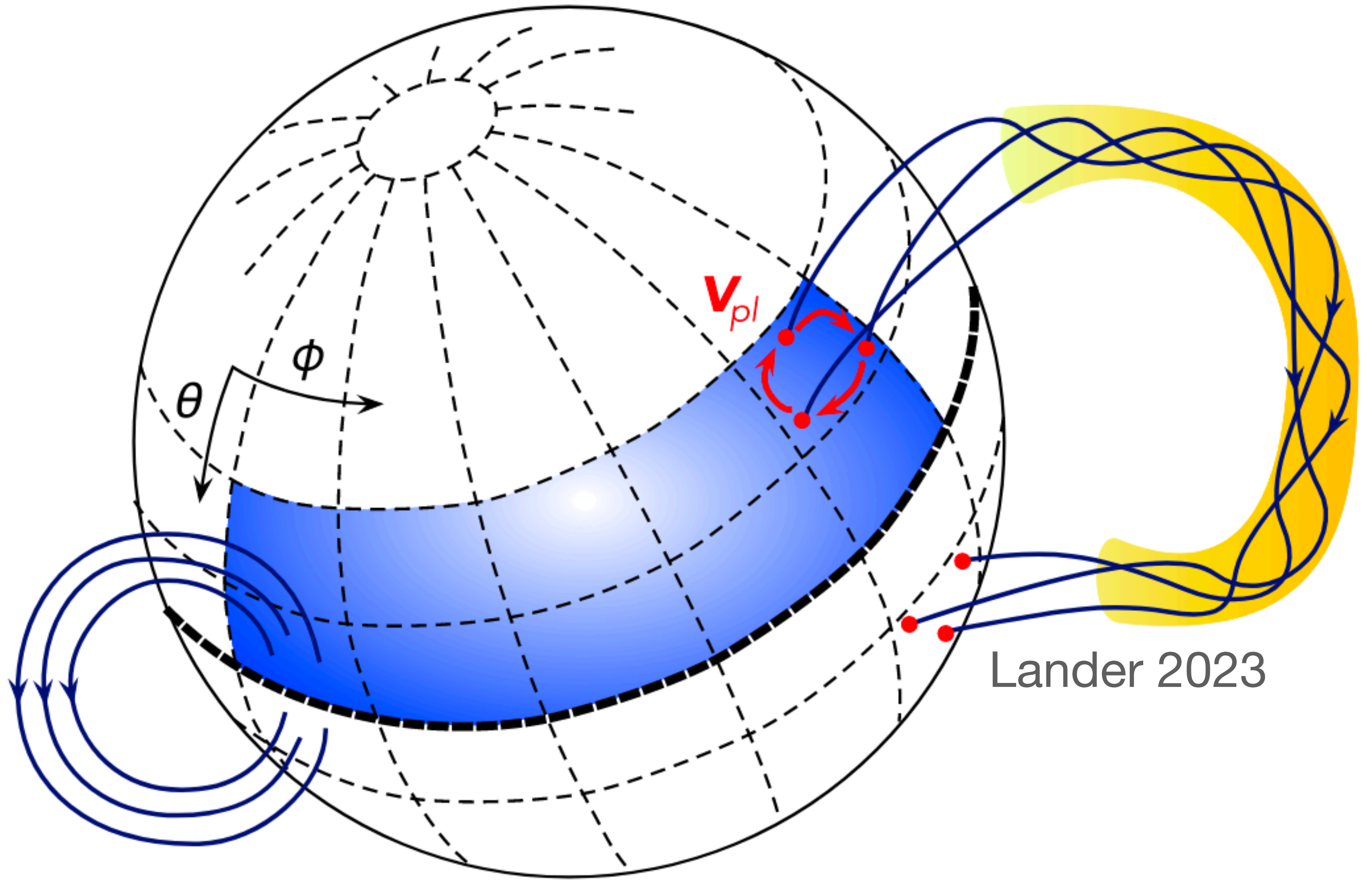


Lander 2023

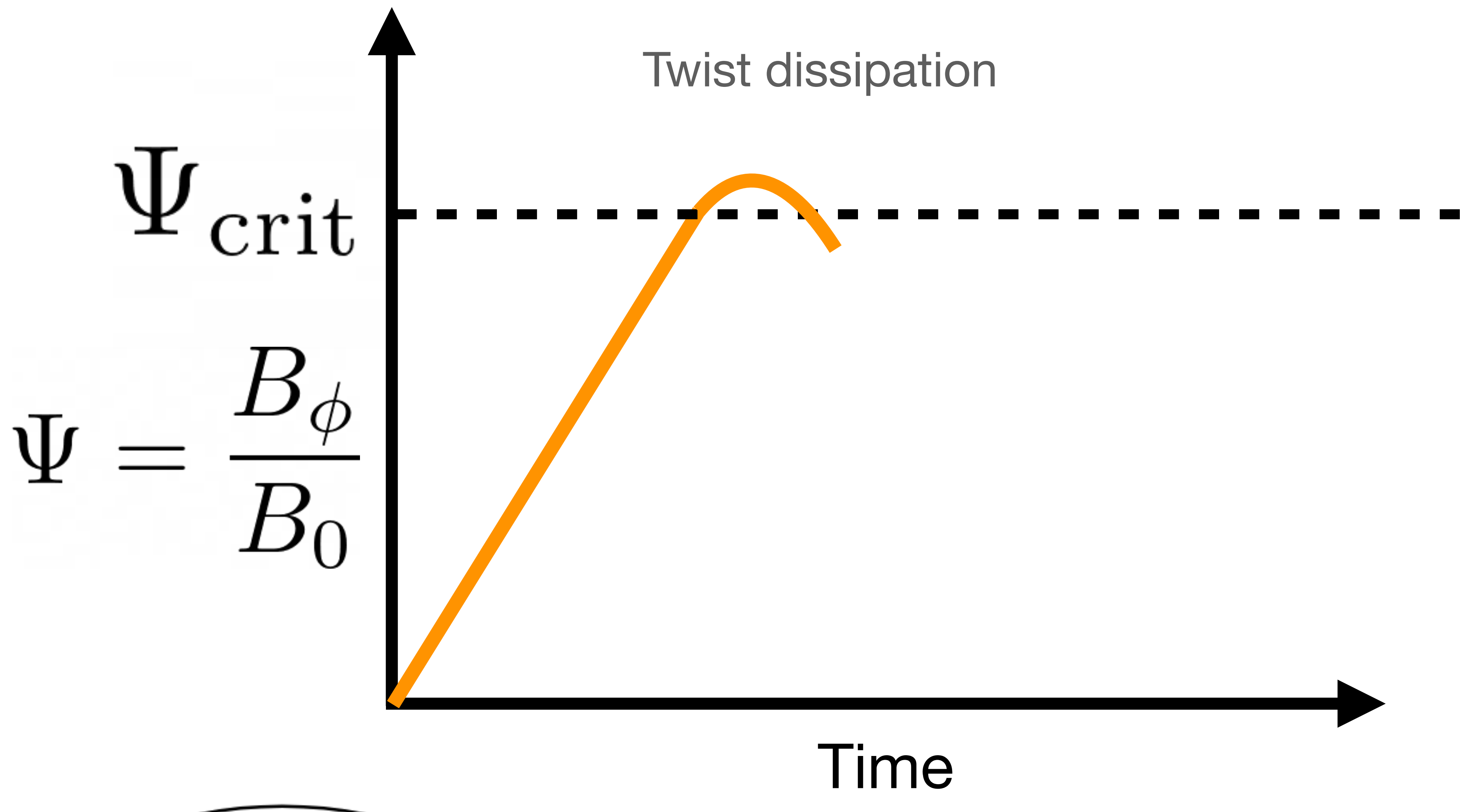
Cooper & Wadiasingh (2024)

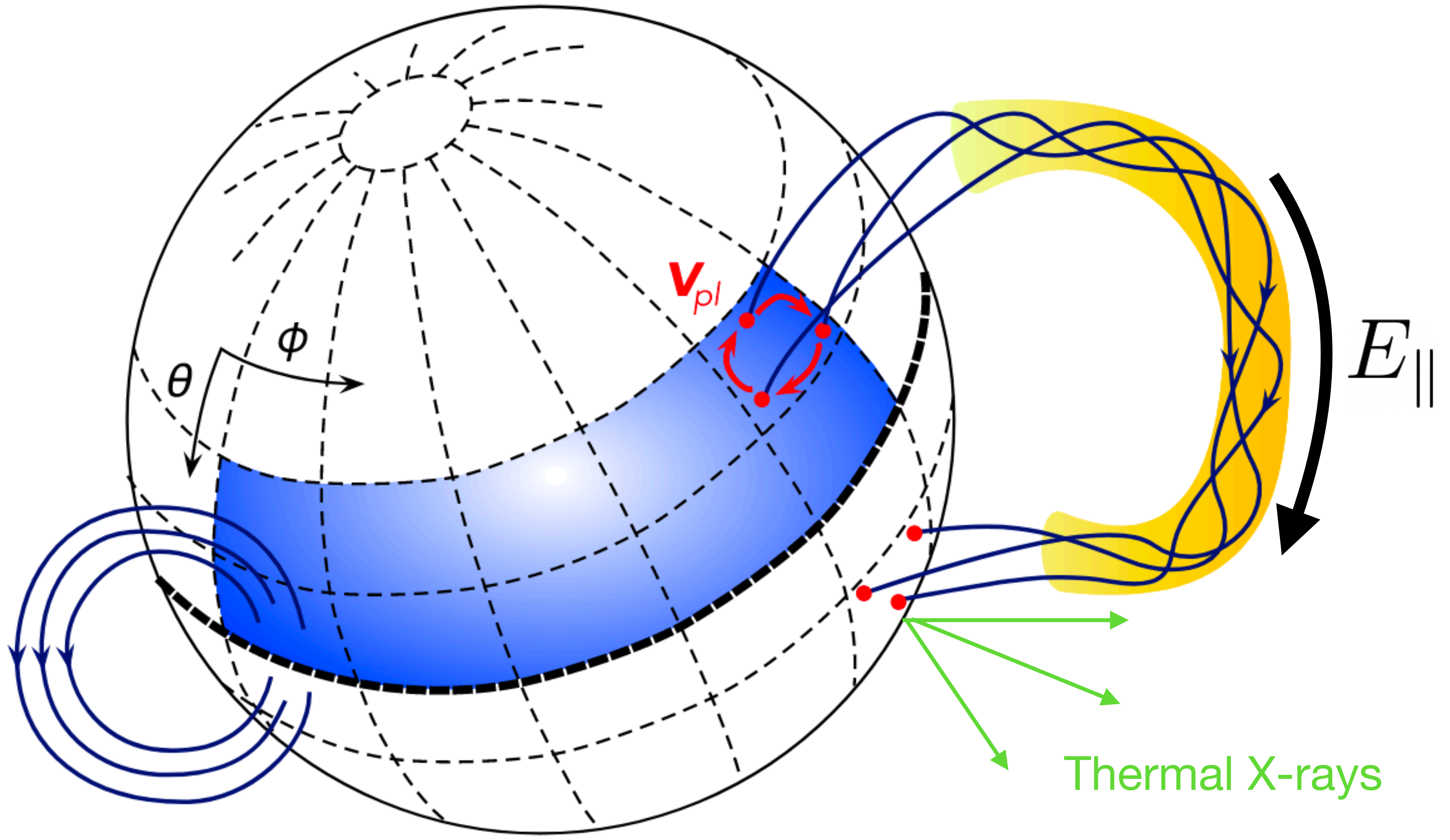
Model: Five steps

(1) Plastic flow twists field lines in ~km² patches

(2) Twist current requirements exceed GJ current

(3) Voltage increases rapidly accelerating particles
   (a) Particles bombard surface producing thermal UV/X-ray counterpart





Cooper & Wadiasingh (2024)

Model: Five steps

(1) Plastic flow twists field lines in ~km² patches

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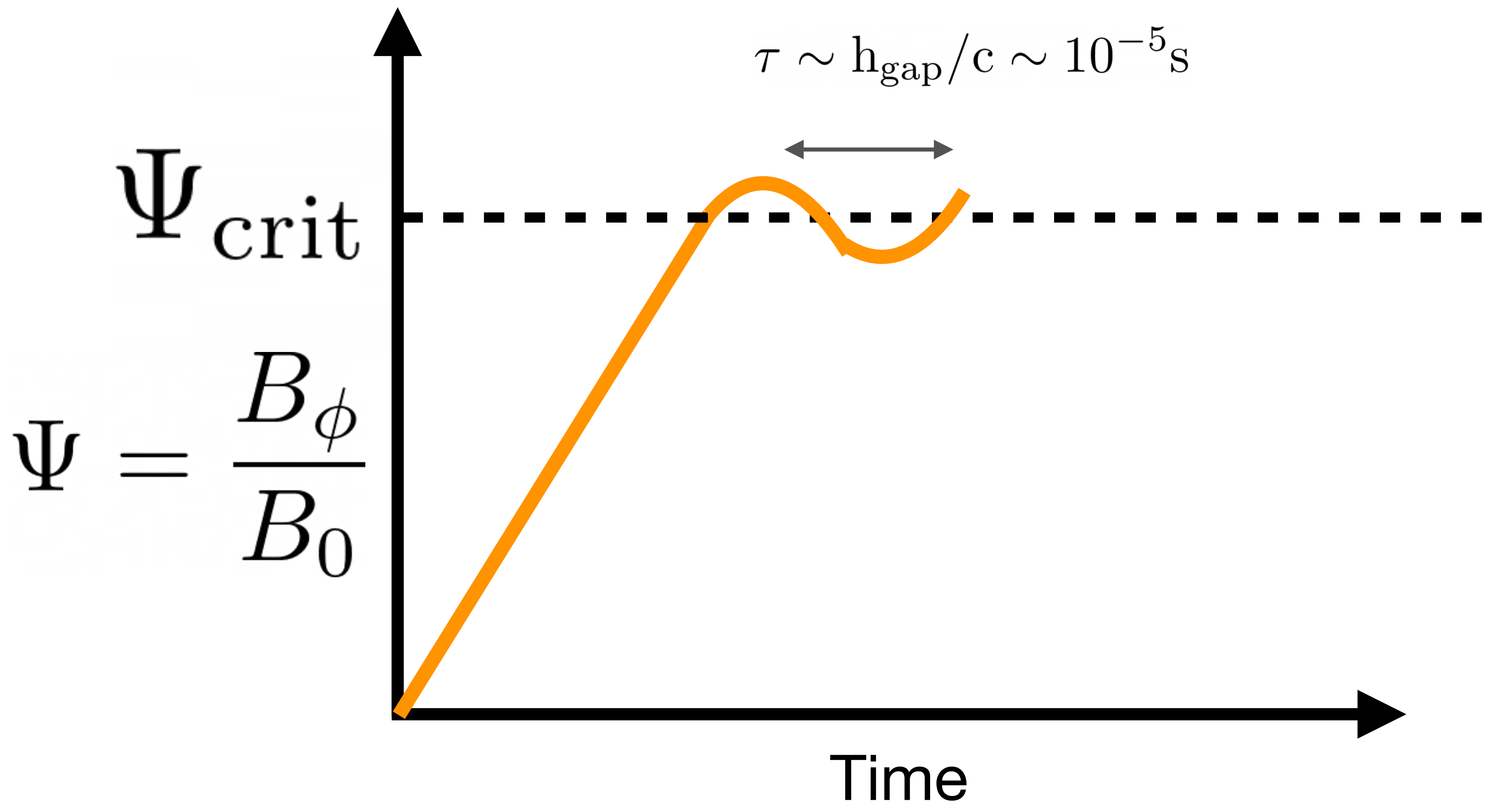
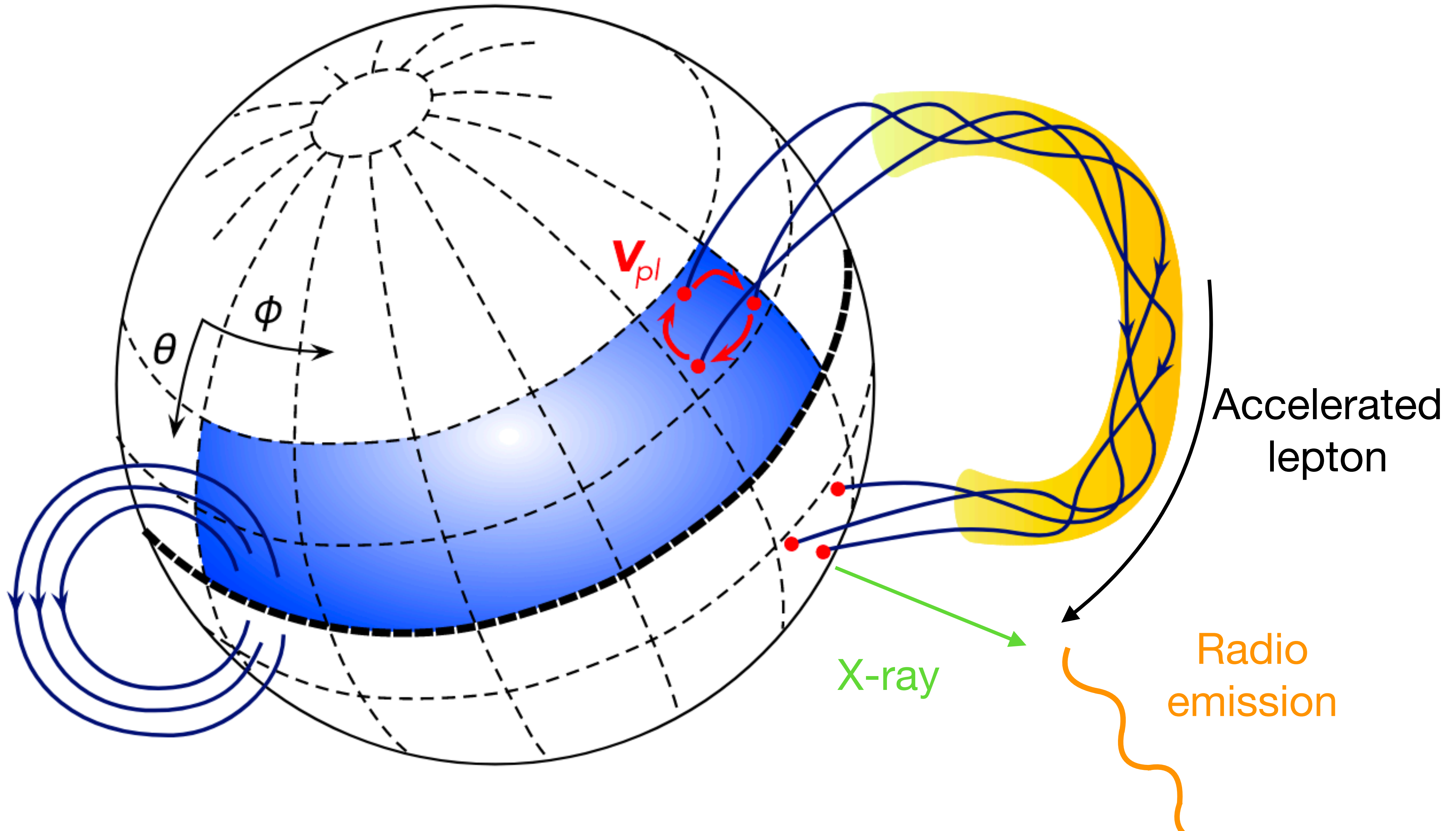
(4) Particles produce pairs via **RICS or curvature** photons, screen E-field, emitting radio waves





Cooper & Wadiasingh (2024)

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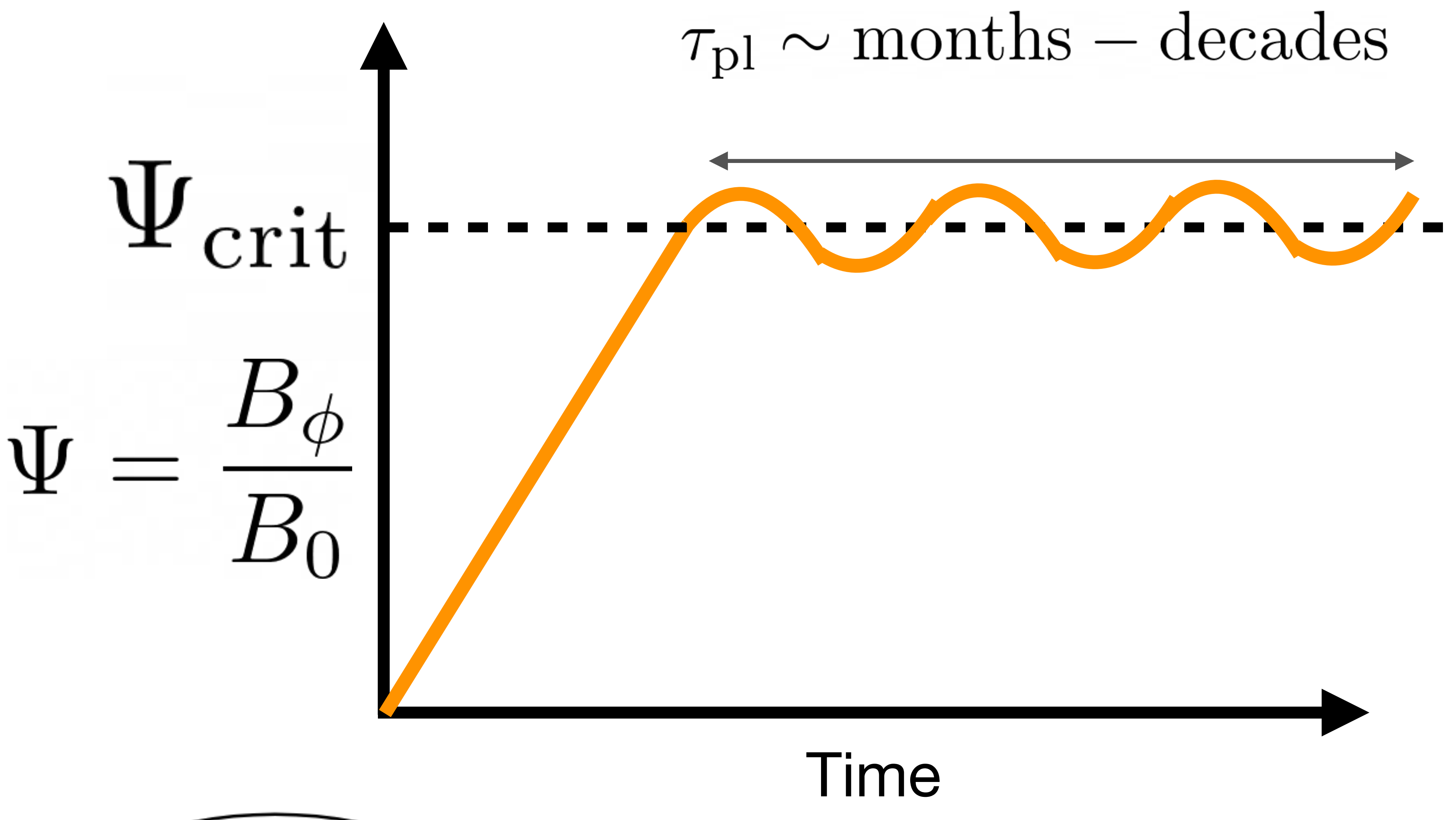
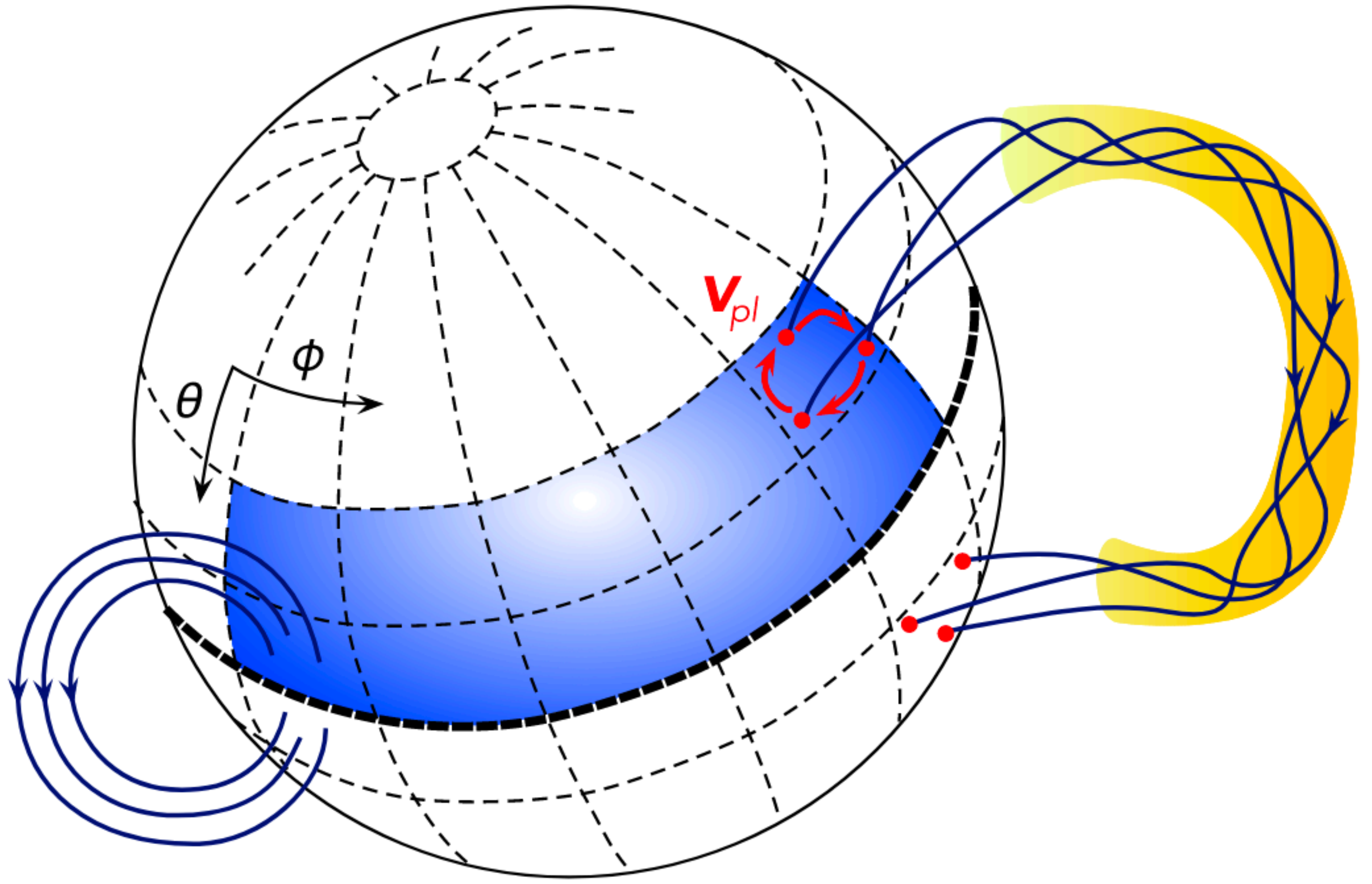
(a) Particles bombard surface producing thermal UV/X-ray counterpart

(4) Particles produce pairs via **RICS or curvature** photons, screen E-field, emitting radio waves

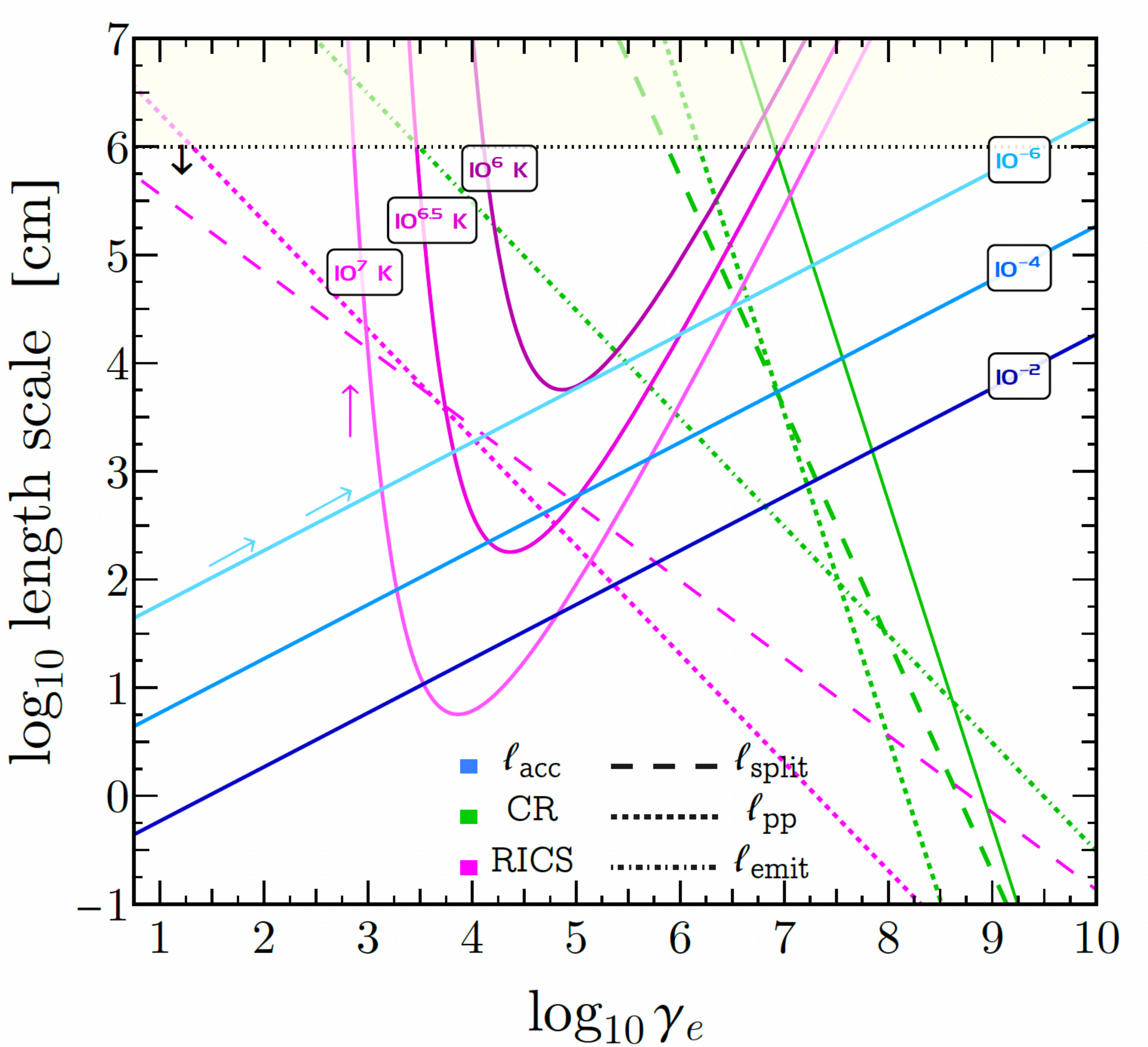
(5) Twist oscillates around critical value, with stable dissipation as long as plastic motion continues





Cooper & Wadiasingh (2024)

Microphysics

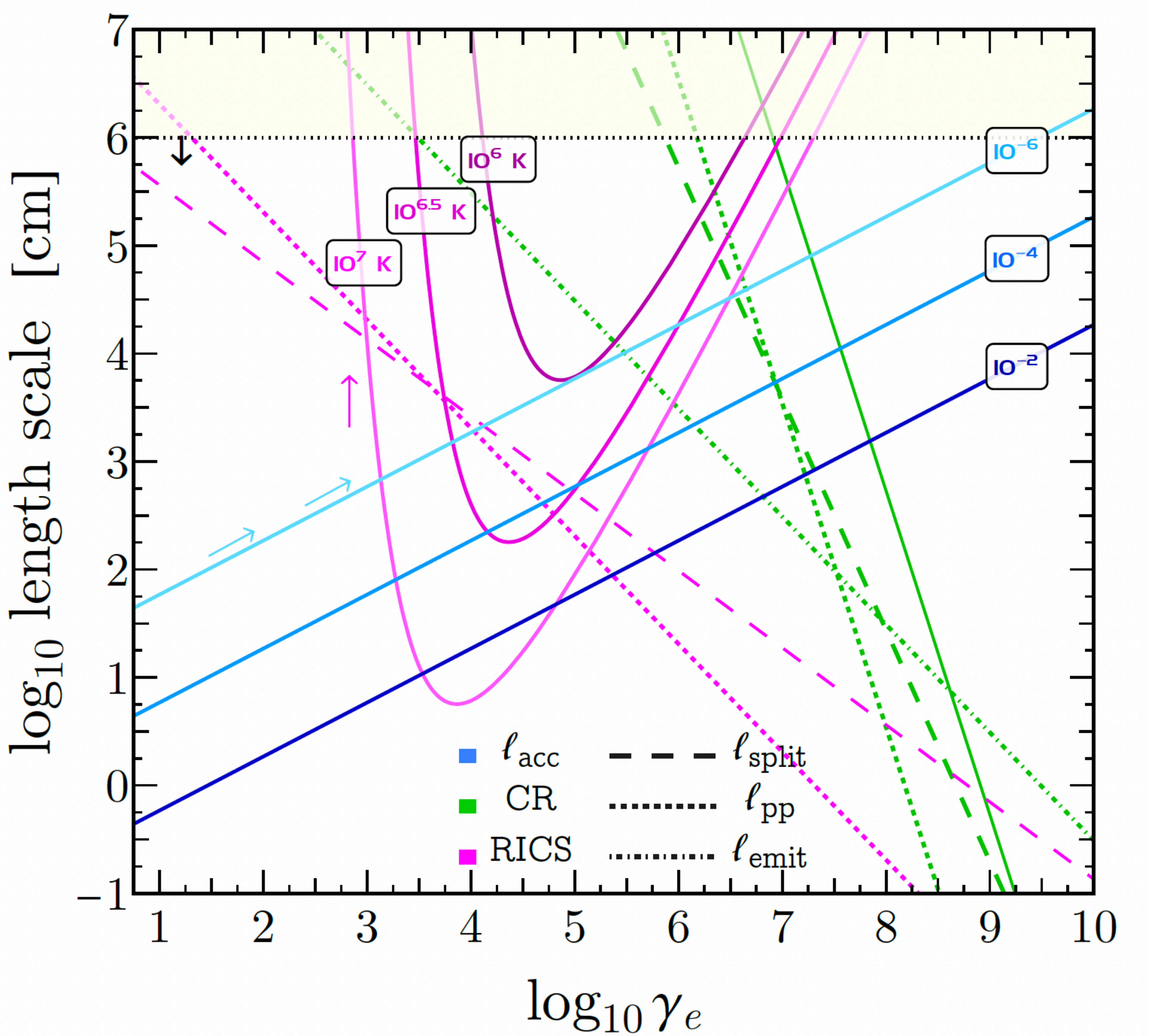


Particles accelerated as they cross gap height

Cooper & Wadiasingh (2024)

Microphysics

For high temperatures they produce gamma-rays via RICS of thermal photons, which produces pairs



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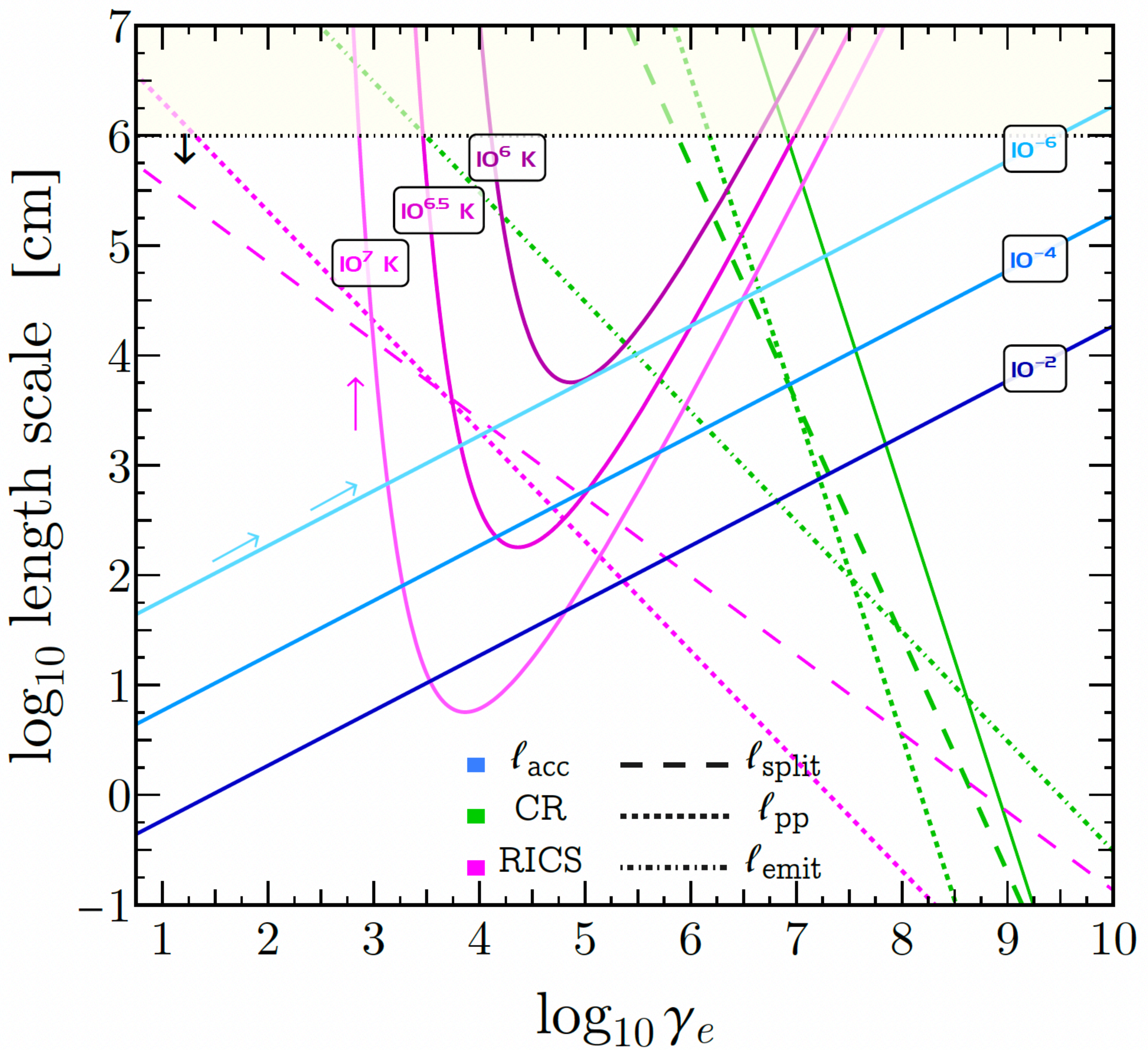


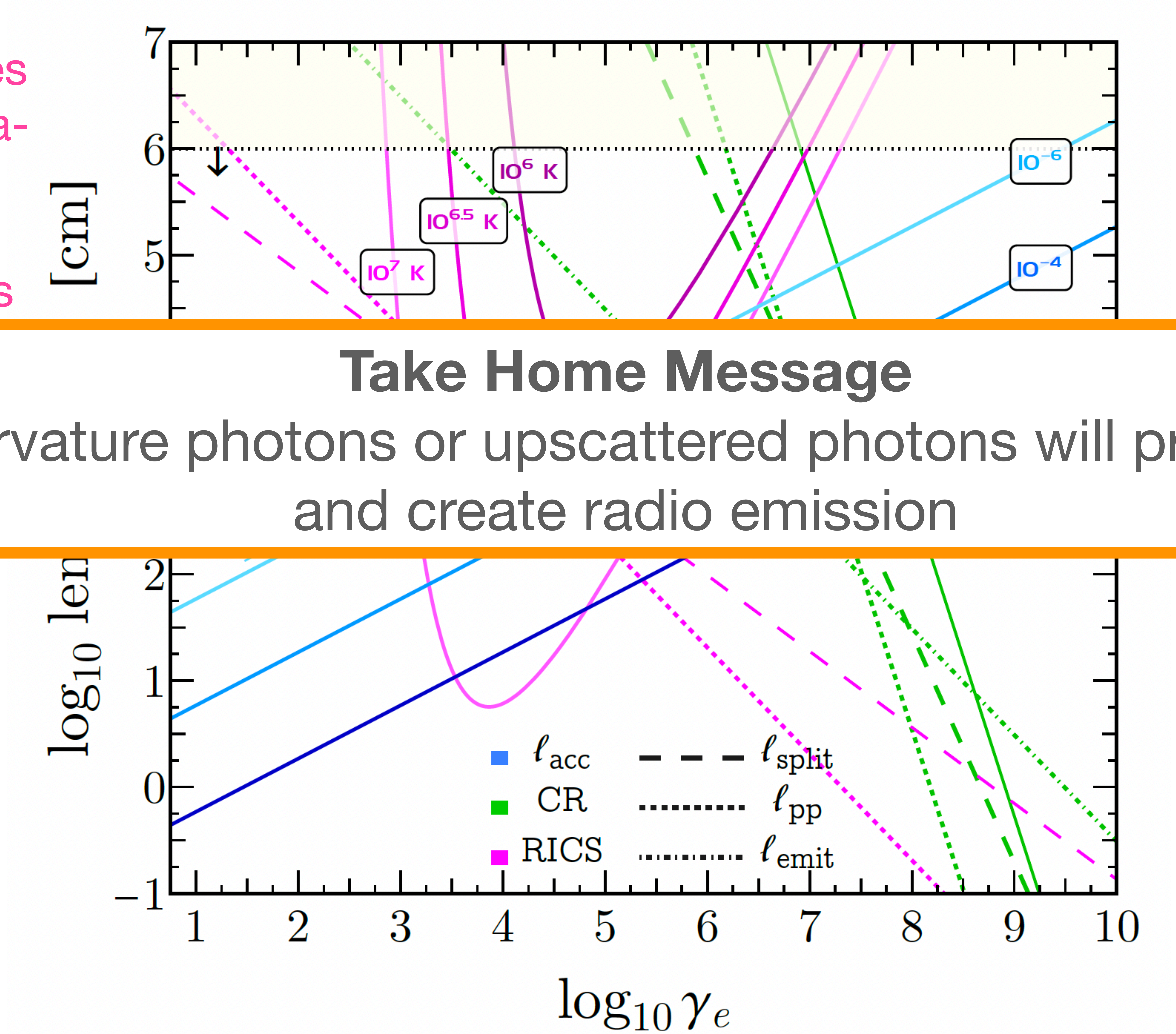
Particles accelerated as they cross gap height

If they 'miss' RICS tail, they produce gamma-ray curvature photons which produces pairs

Cooper & Wadiasingh (2024)

Microphysics

For high temperatures they produce gamma-rays via RICS of thermal photons, which produces pairs



Particles accelerated as they cross gap height

If they 'miss' RICS tail, they produce gamma-ray curvature photons which produces pairs

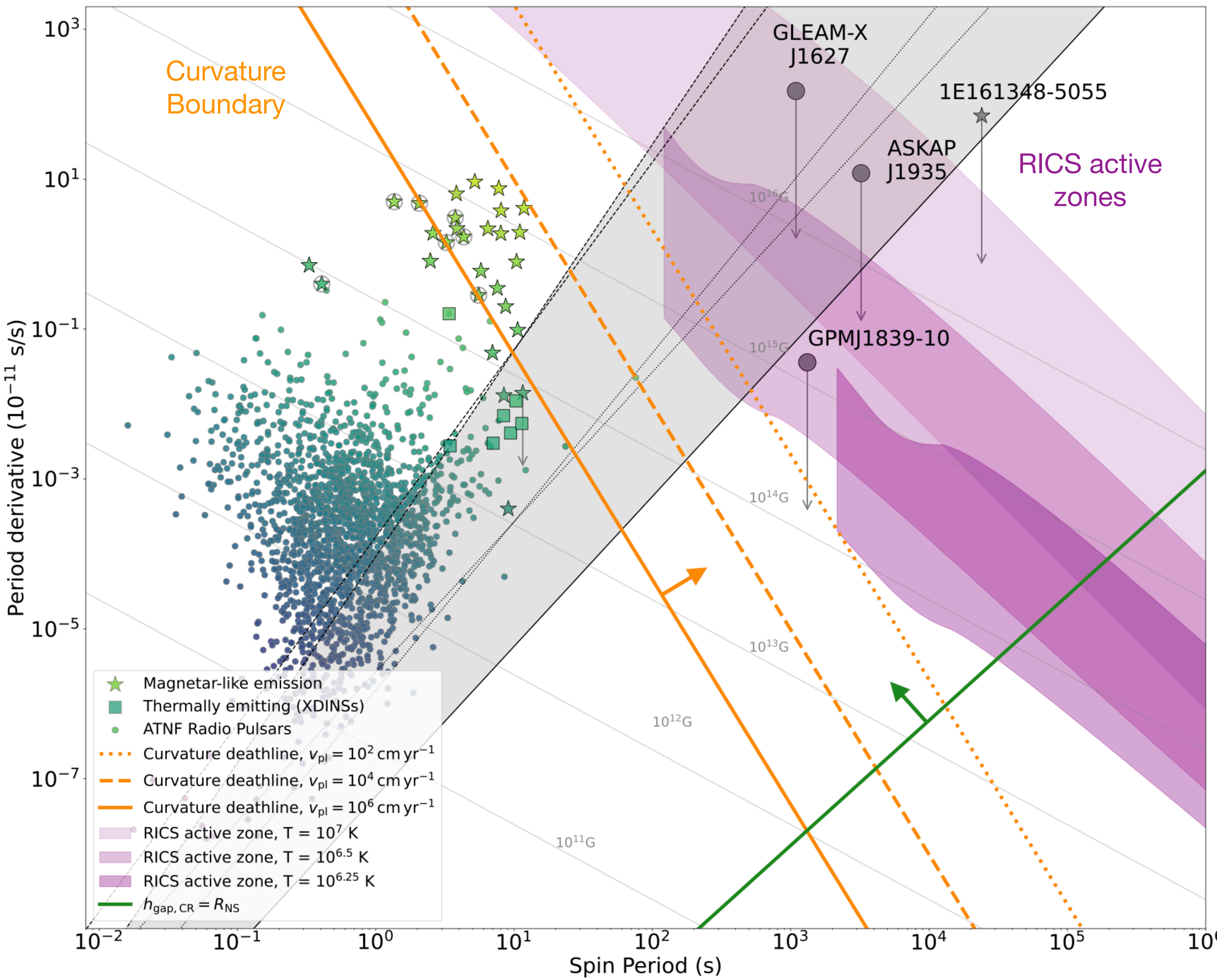
Take Home Message

Either curvature photons or upscattered photons will produce pairs and create radio emission

Cooper & Wadiasingh (2024)

Model Predictions

- Microphysics defines allowed parameter space



Cooper & Wadiasingh (2024)

Predictions

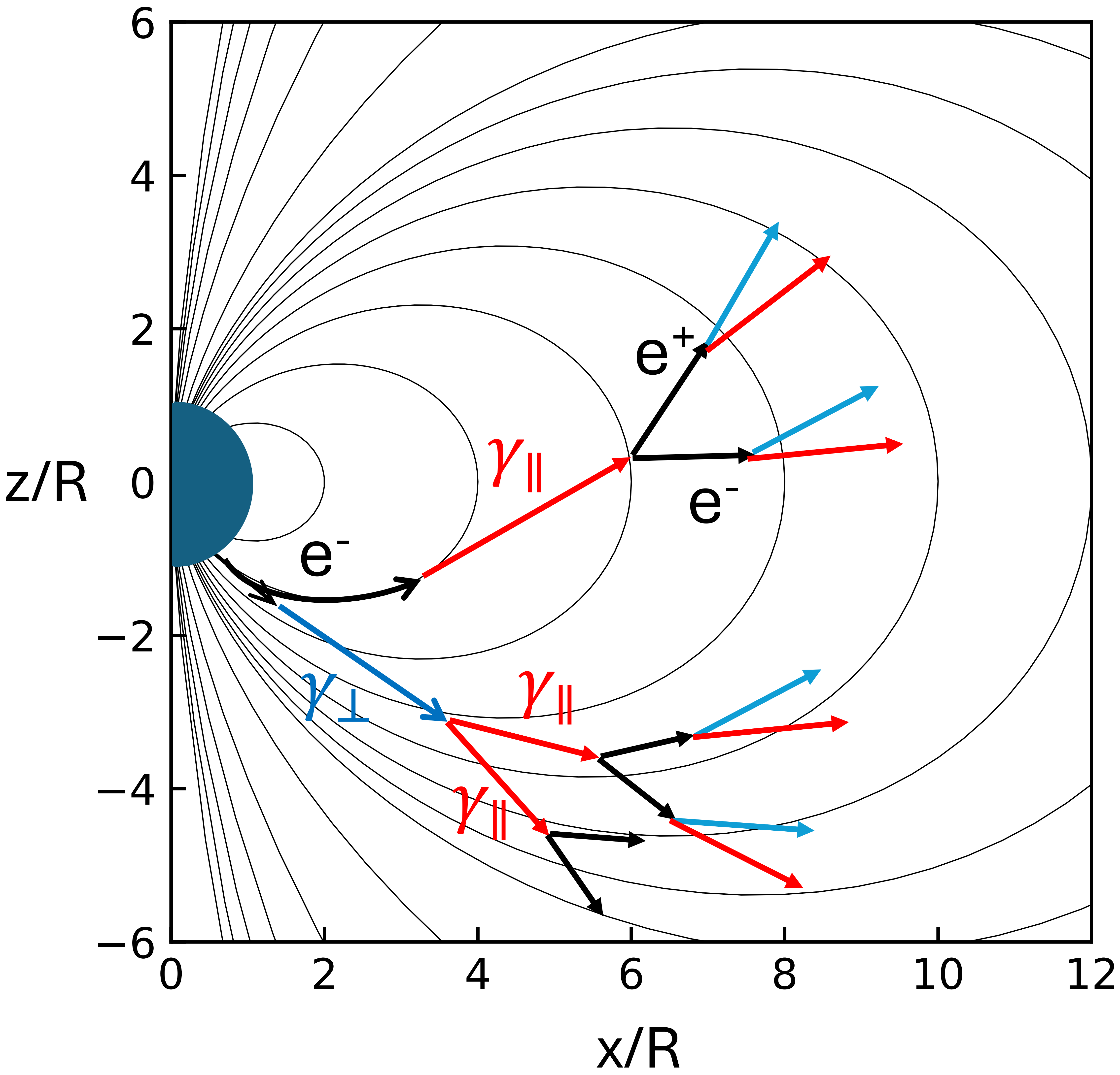
- Minimum period depending on v_{pl} or T

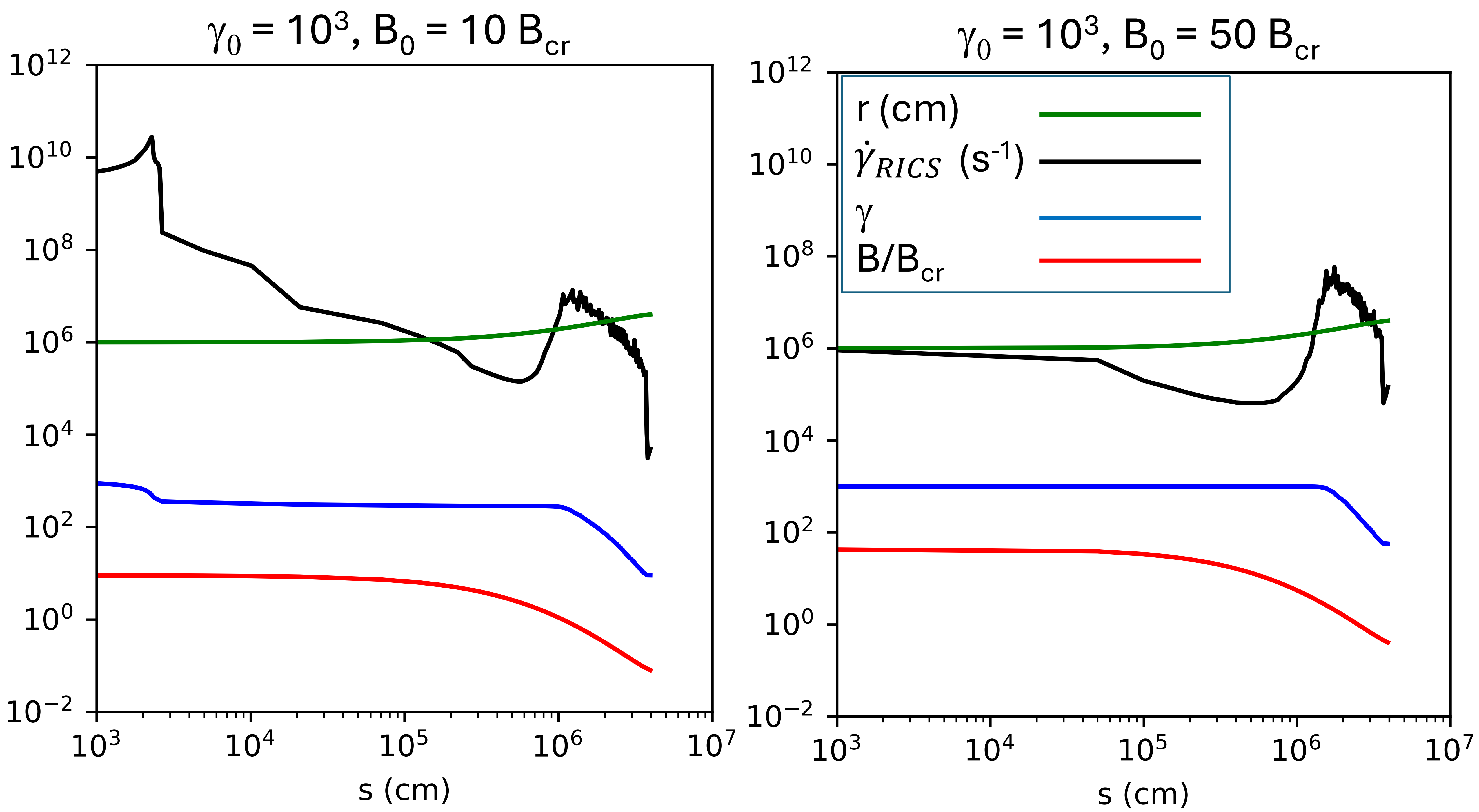
$$P_{\rm RICS} \gtrsim 120\ (T/10^{6.5}{\rm K})^{-5}\,{\rm sec}$$

$$P_{\rm curv} \gtrsim 150\ ({\rm v_{pl}}/10^3\,{\rm cm\,yr^{-1}})^{-7/6}\,{\rm sec}$$

Cooper & Wadiasingh (2024)

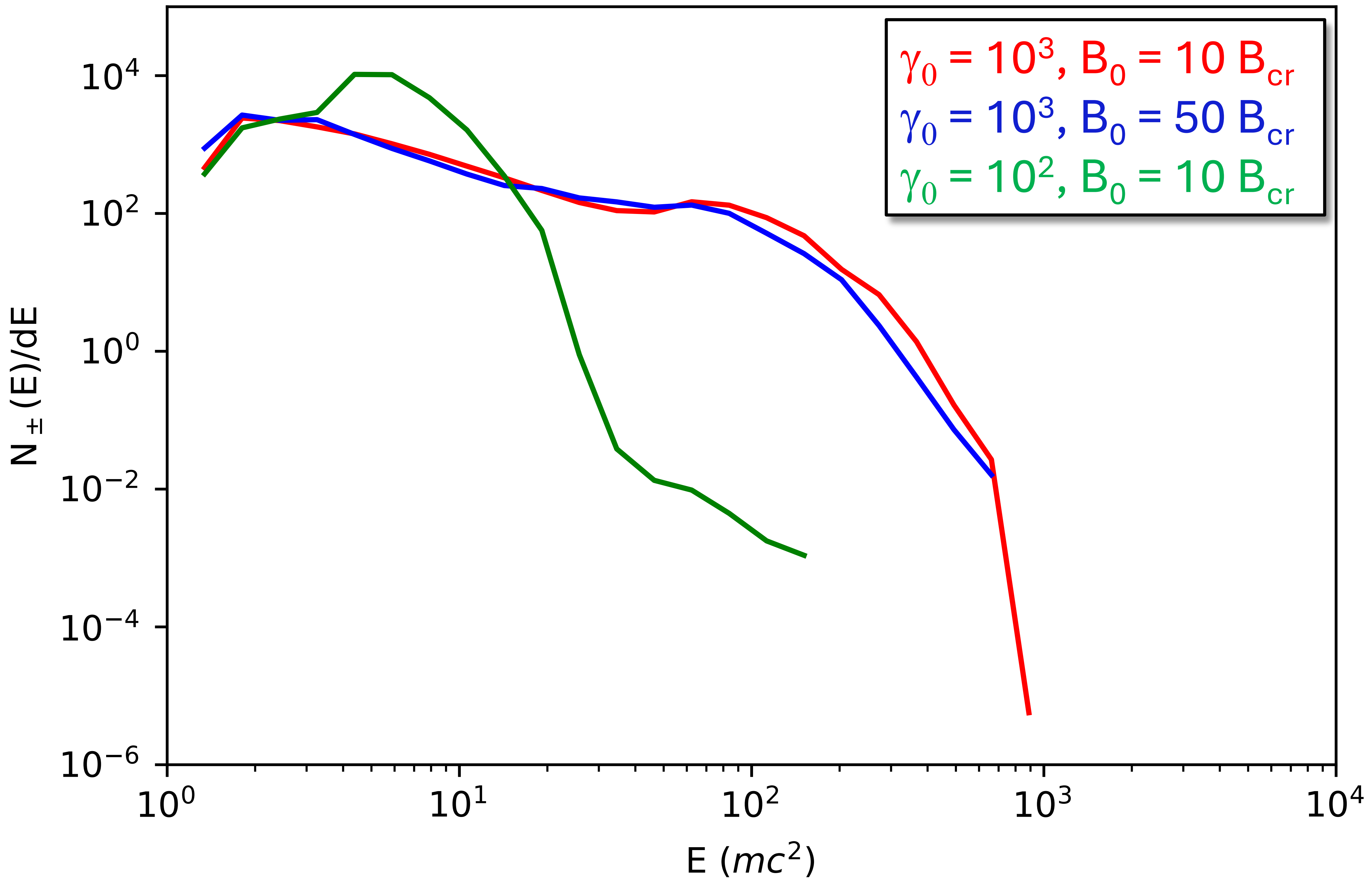
More accurate magnetar RICS cascades with photon splitting

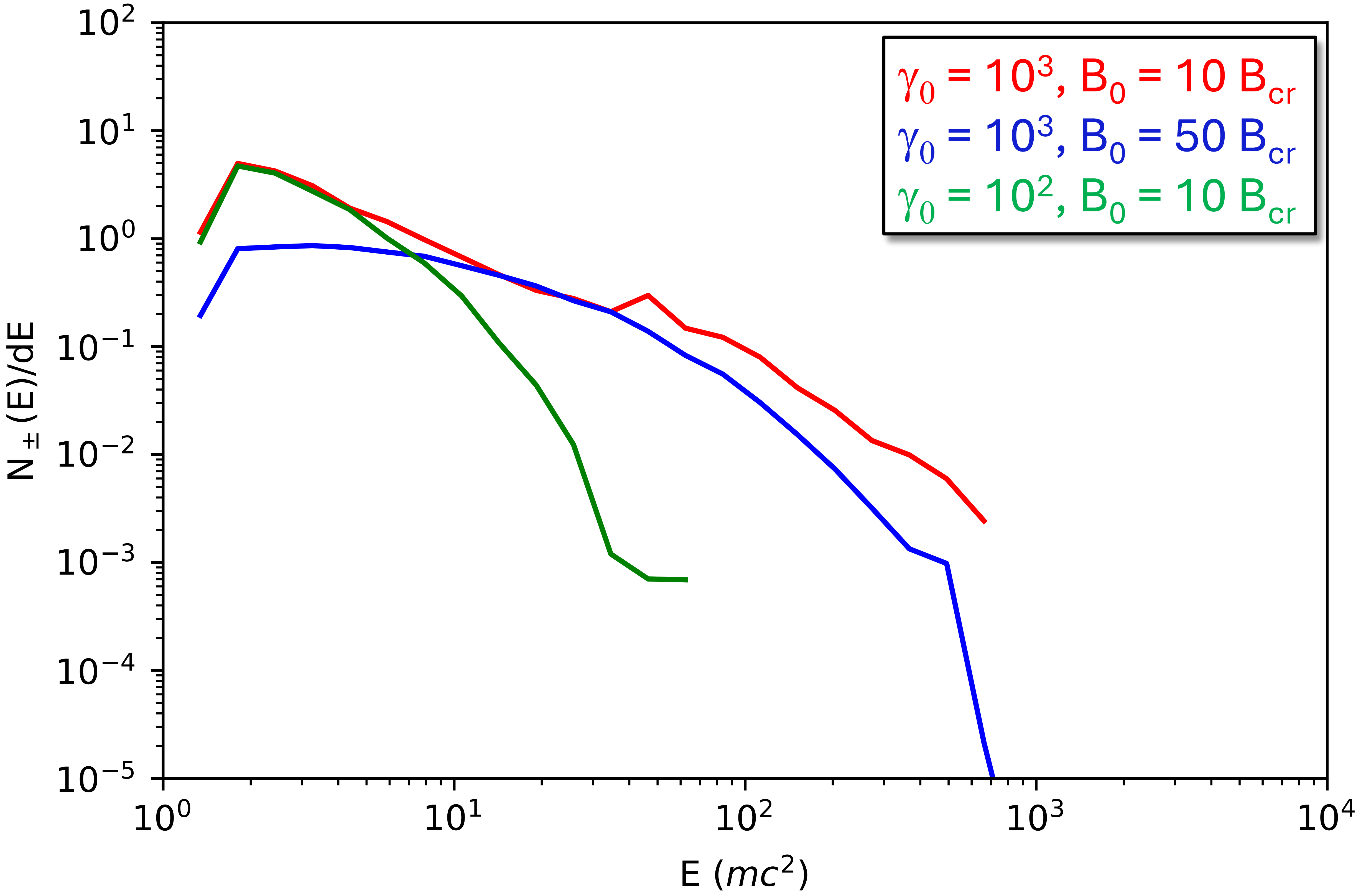




Harding, Wadiasingh, Baring+ 2025 in prep

More accurate magnetar RICS cascades with photon splitting





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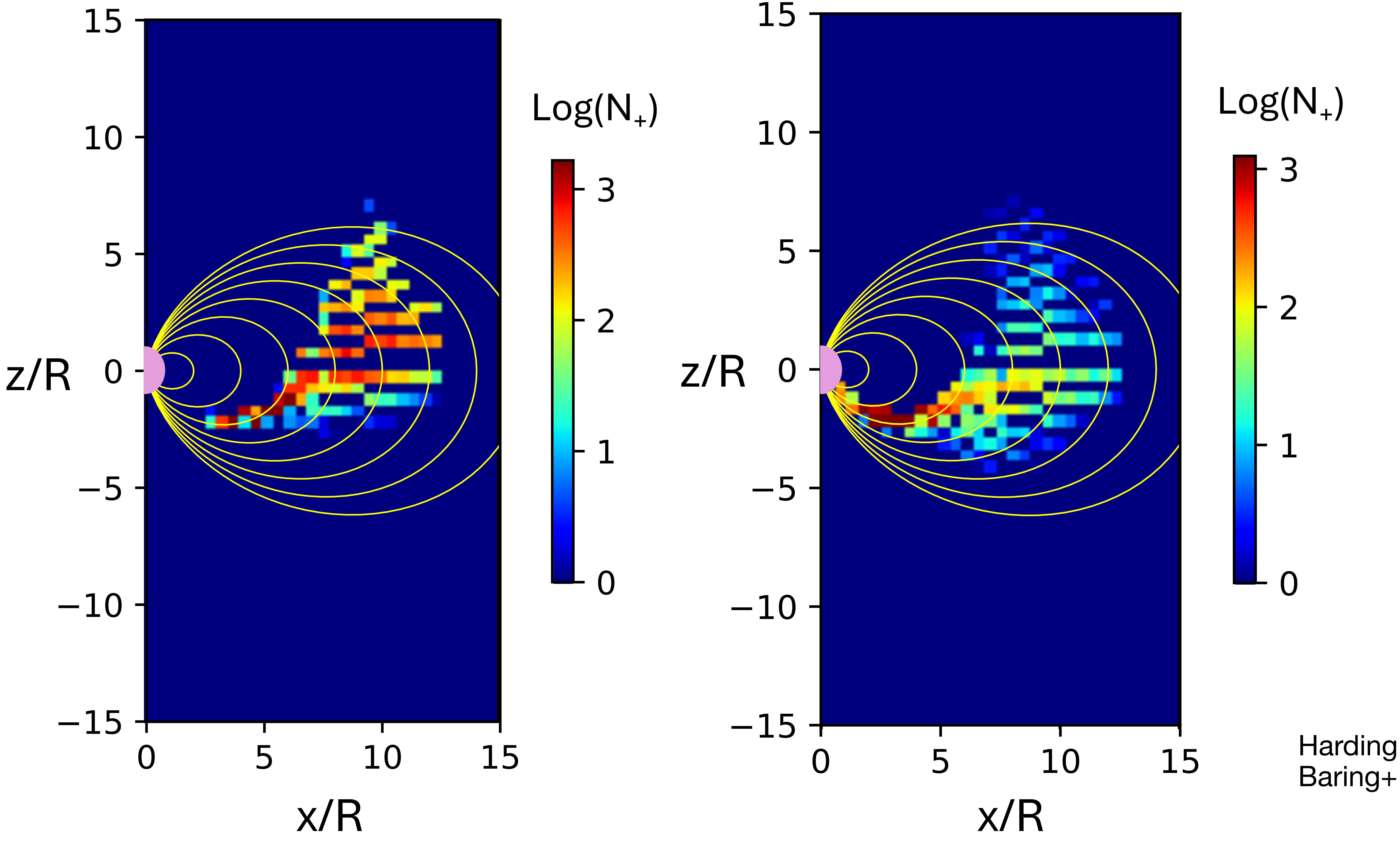

Harding, Wadiasingh, Baring+ 2025 in prep

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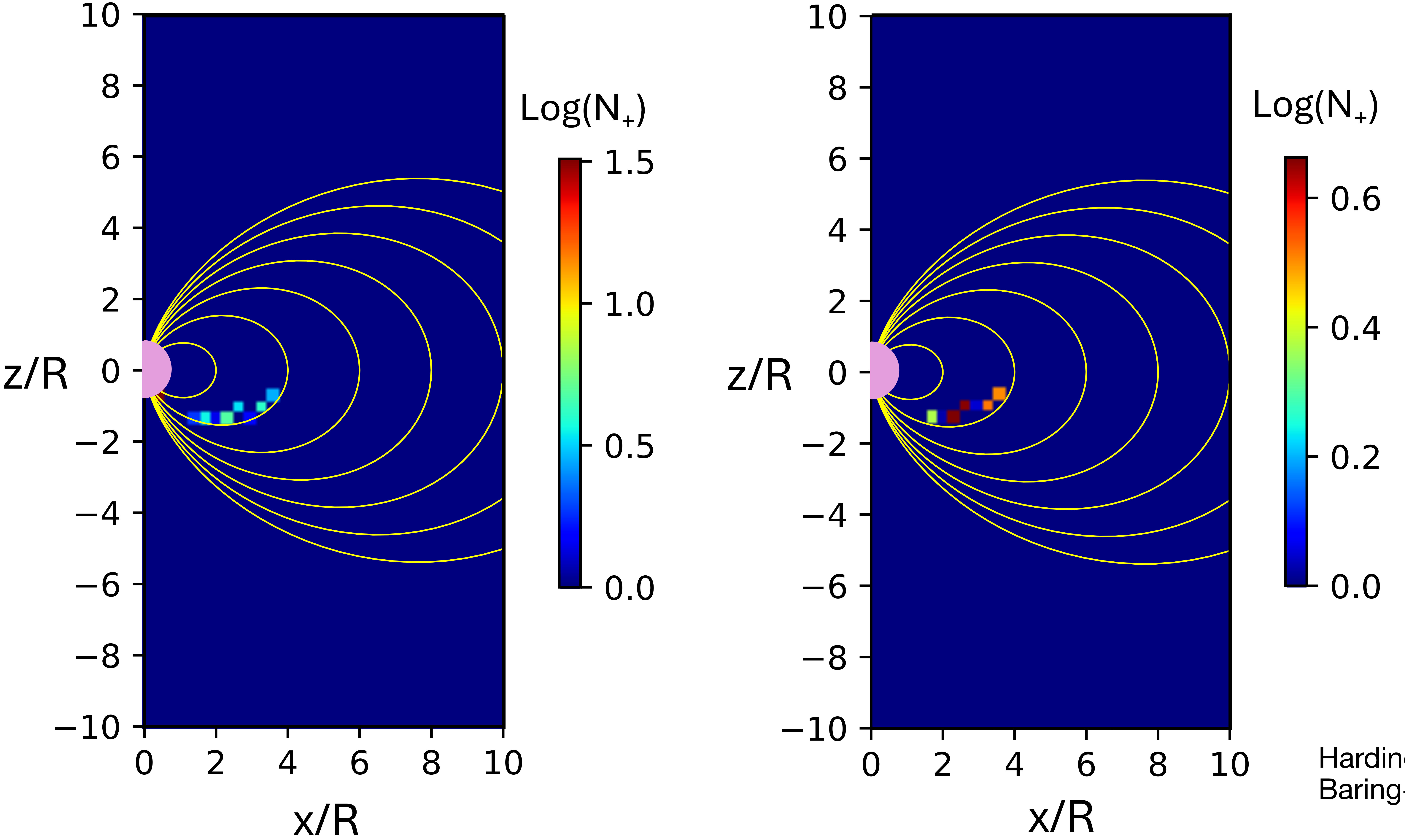


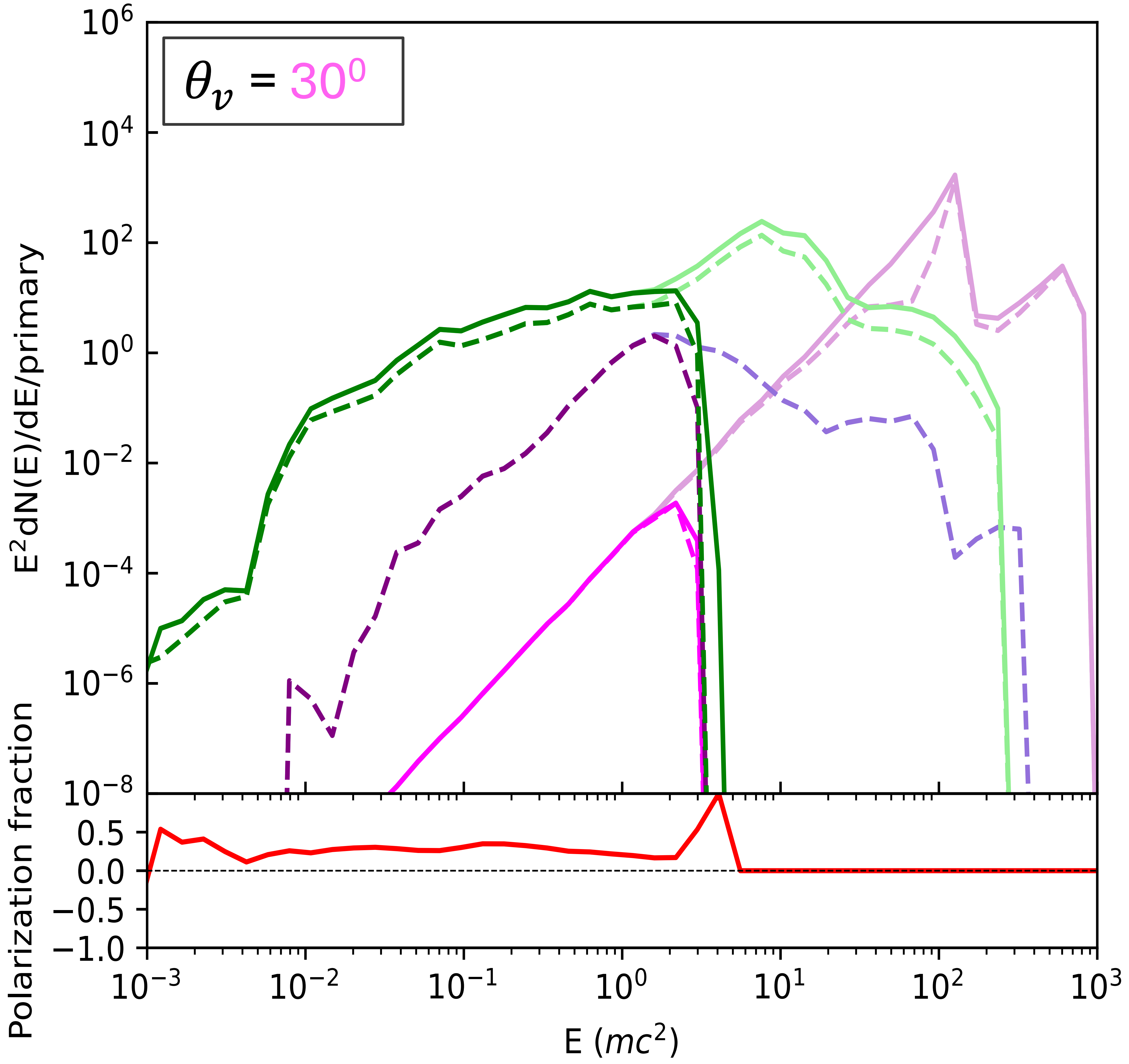
Harding, Wadiasingh, Baring+ 2025 in prep

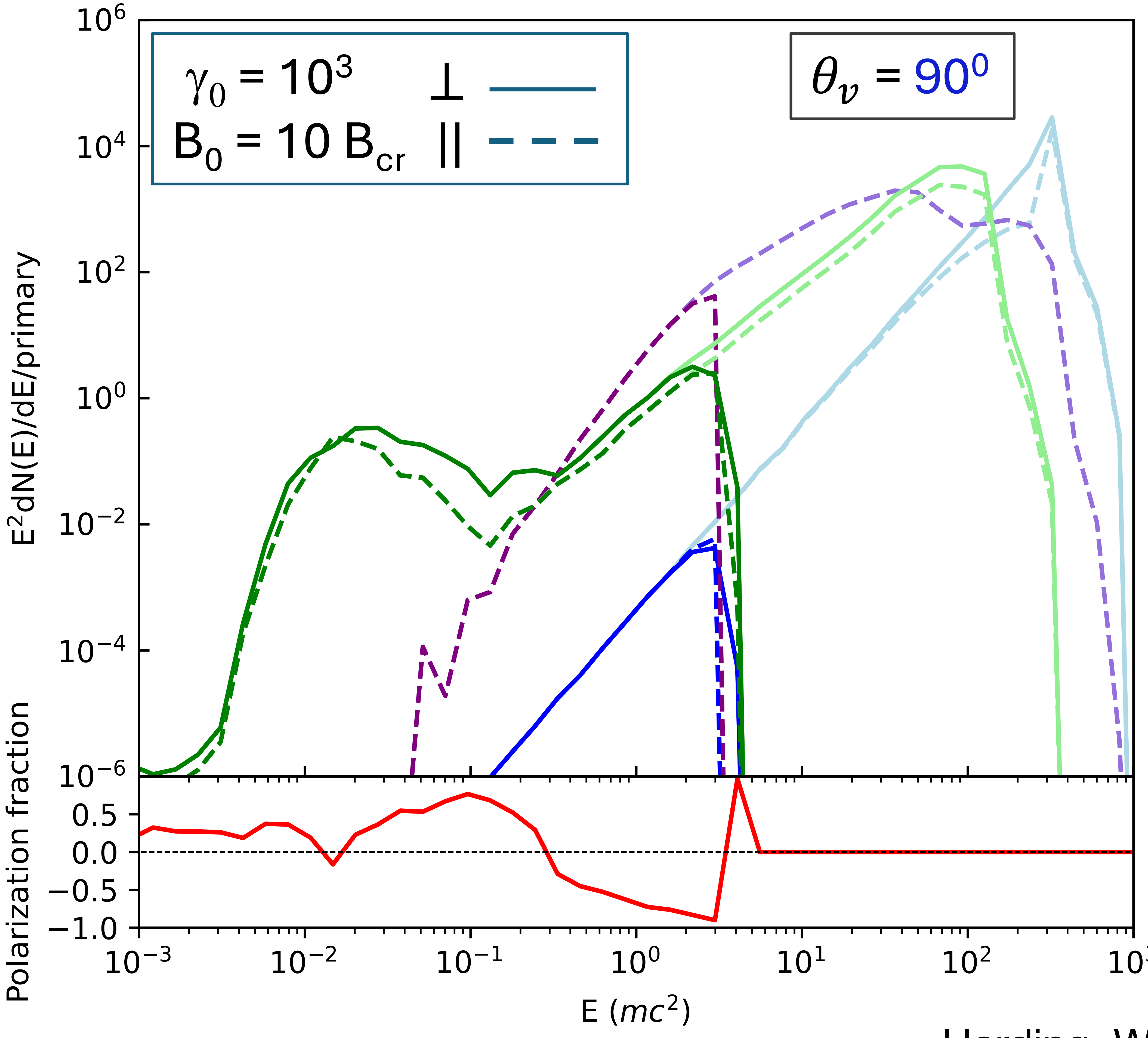
More accurate Magnetar RICS cascades with photon splitting

$r_{\max} = 4$	No RICS losses γ_0			RICS losses γ_0		
$B_0/B_{\rm cr}$	10	10^2	10^3	10	10^2	10^3
10	3	4	5	3	6	4
	9×10^{-8}	4.8×10^4	2.7×10^4	9×10^{-8}	15	62
50		5	5		4	5
		7.8×10^3	7.8×10^3		5	20
$r_{\max} = 6$						
10		6	6			
		4×10^4	2.4×10^4			

Harding, Wadiasingh, Baring+ 2025 in prep

More accurate Magnetar RICS cascades with photon splitting





Harding, Wadiasingh,
Baring+ 2025 in prep

Observational Outlook

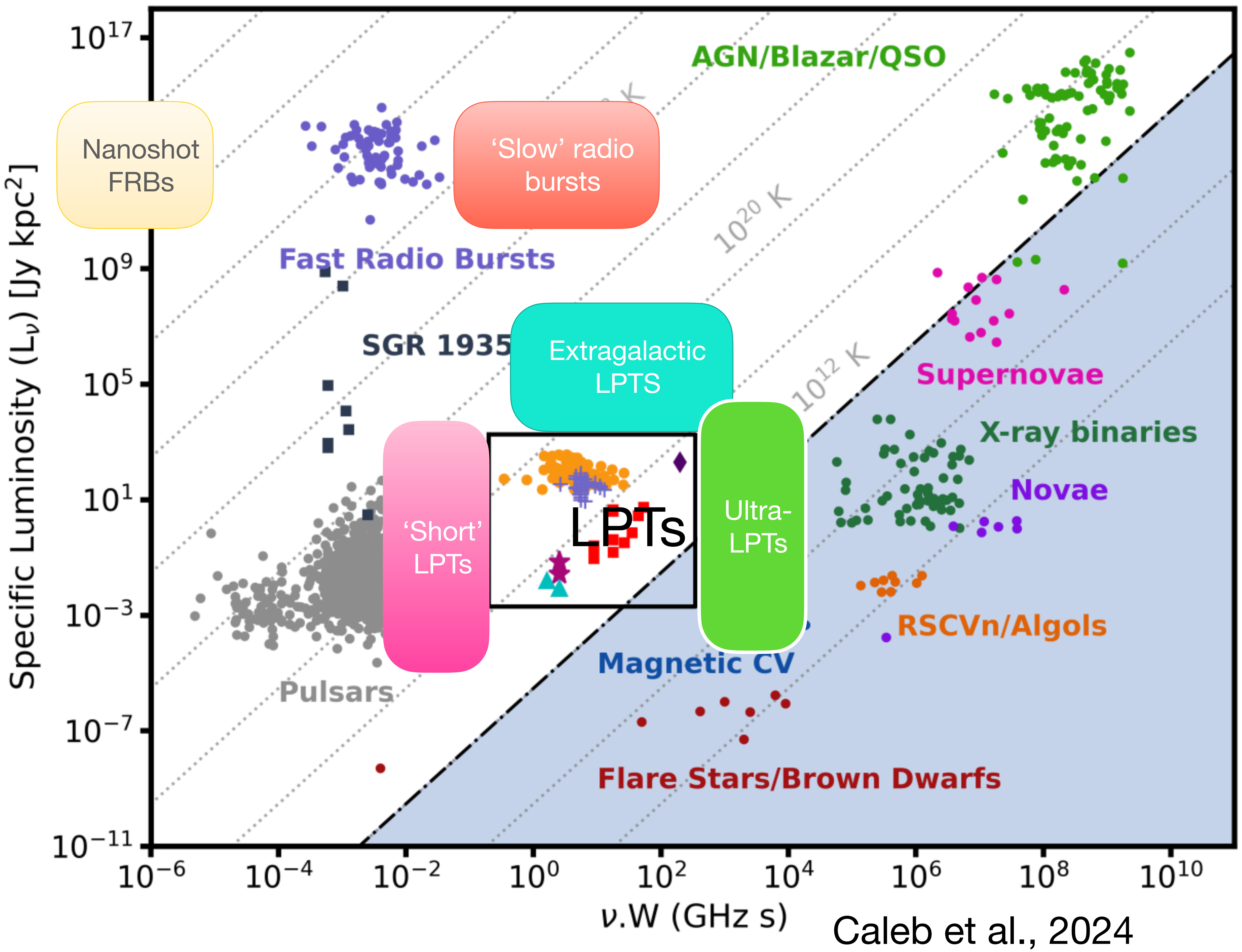
Many more LPTs will be found given current discovery rate

Extra-galactic LPTs will be uncovered

Sensitive X-ray/optical observations of nearby and high latitude sources crucial

New sources will bridge the gap between pulsars and LPTs

see e.g., Wang et al. 2025, 41sec pulsar appears to not rotationally powered)



Caleb et al., 2024

Cooper & Wadiasingh (2024)

Mechanisms for Producing ULPMs - enhanced spin-down

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

Beniamini, Wadiasingh, Metzger 2020

Physical mechanisms for enhanced spin-down

Charged particle winds

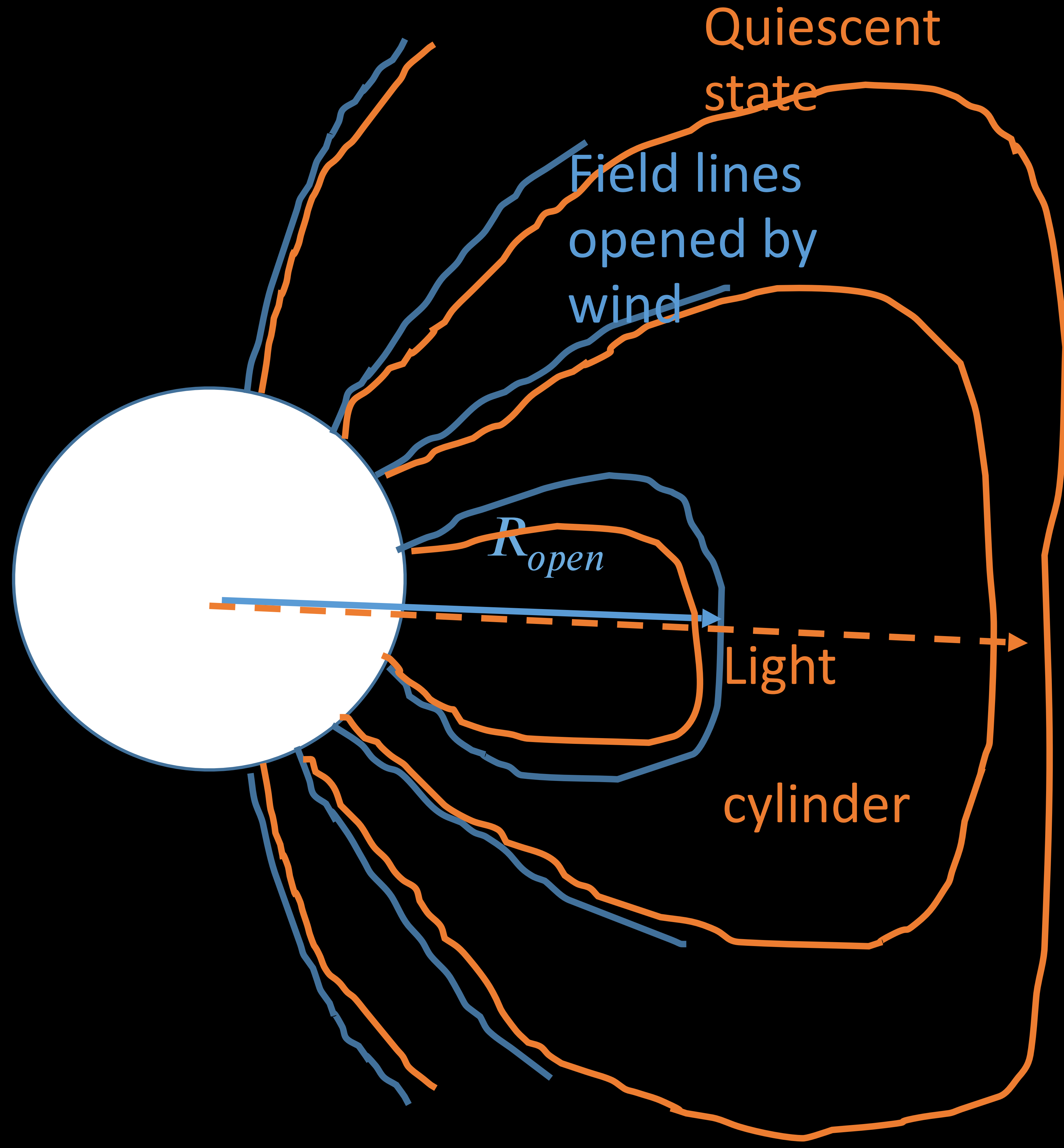
- Mass–loaded charged wind with $L_{pw} > L_{dip}$ opens up B lines beyond

$$R_{open} \sim R_{NS}\left(\frac{B_{dip}^2 R_{NS}^2 c}{L_{pw}}\right)^{1/4}$$ (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 $\tau = \frac{IcR_{\rm open}^2}{B_{\rm dip}^2 R_{\rm NS}^6} = \frac{Ic^{3/2}}{B_{\rm dip} R_{\rm NS}^3 L_{\rm pw}^{1/2}} = 5 \times 10^7 B_{\rm dip,15}^{-1} L_{\rm pw,40}^{-1/2}$ s

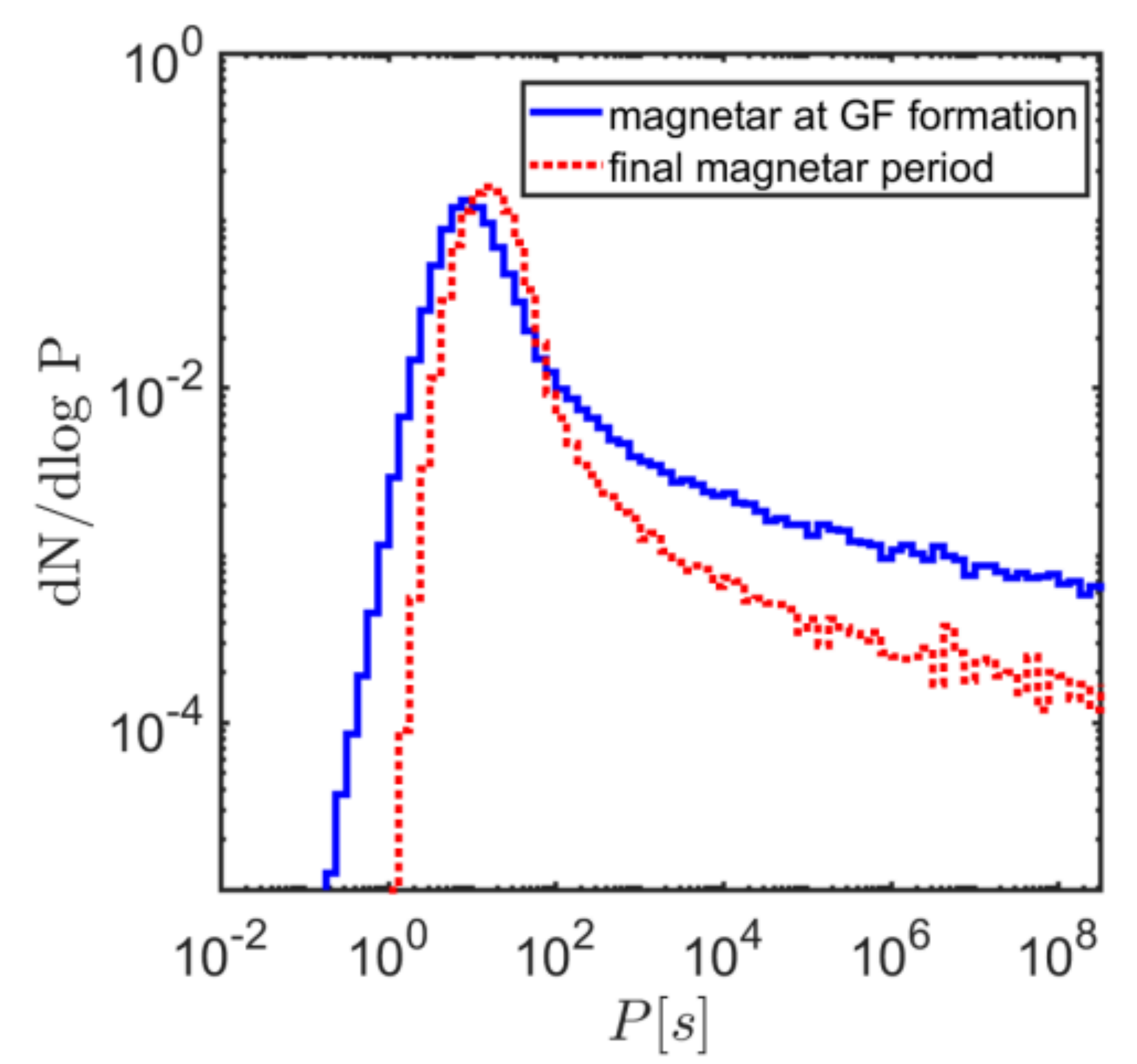
$$P_{\rm f} = P_0 \exp\left[\frac{E_{\rm B}\Delta t_{\rm pw}}{E_{\rm f}\tau}\right] = P_0 \exp\left[0.7 \frac{B_{\rm int,16}^2 B_{\rm dip,15} E_{\rm pw,42}^{1/2} \Delta t_{\rm pw,2}^{1/2}}{E_{\rm f,44}}\right]$$



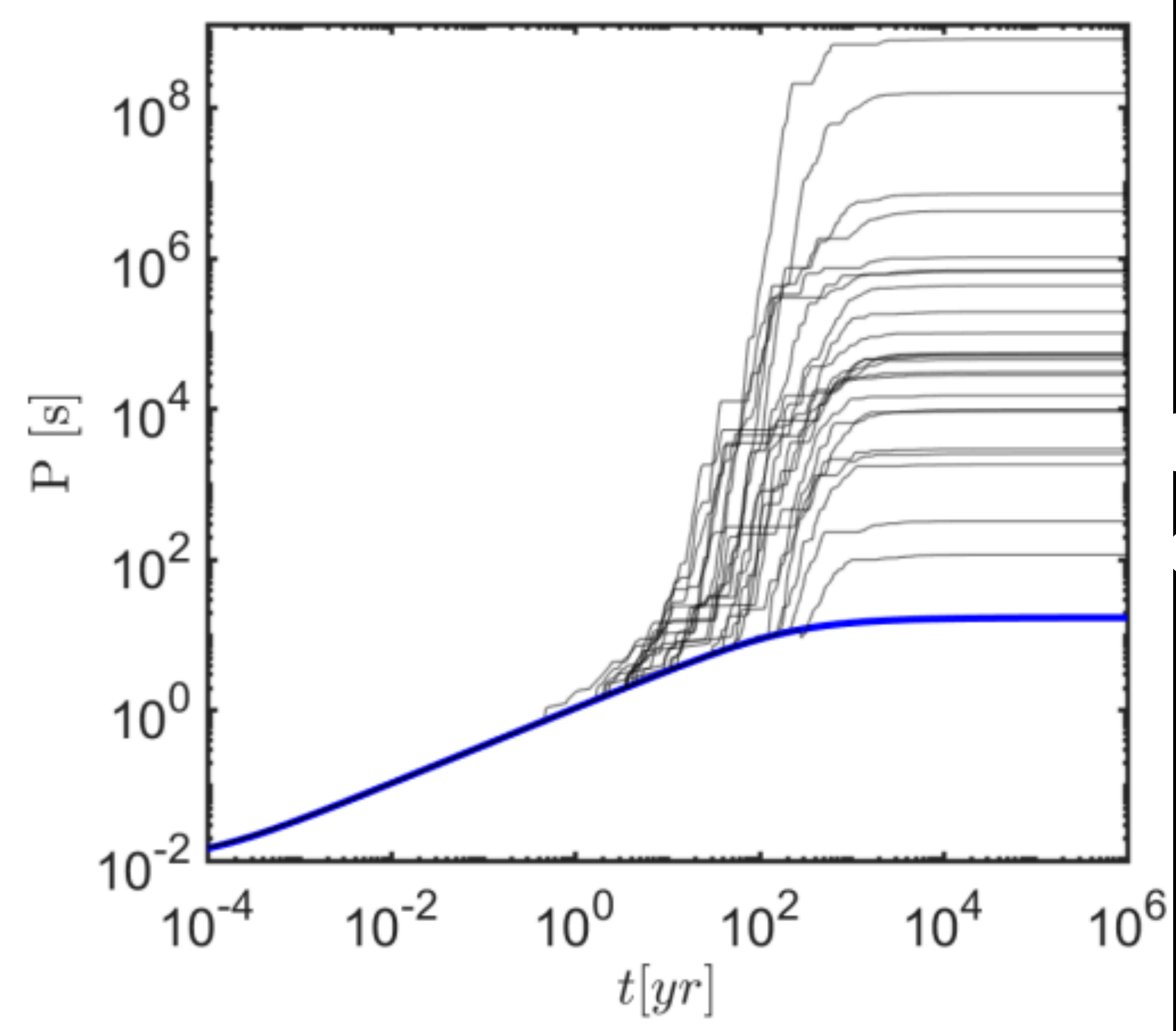
Physical mechanisms for enhanced spin-down

Charged particle winds

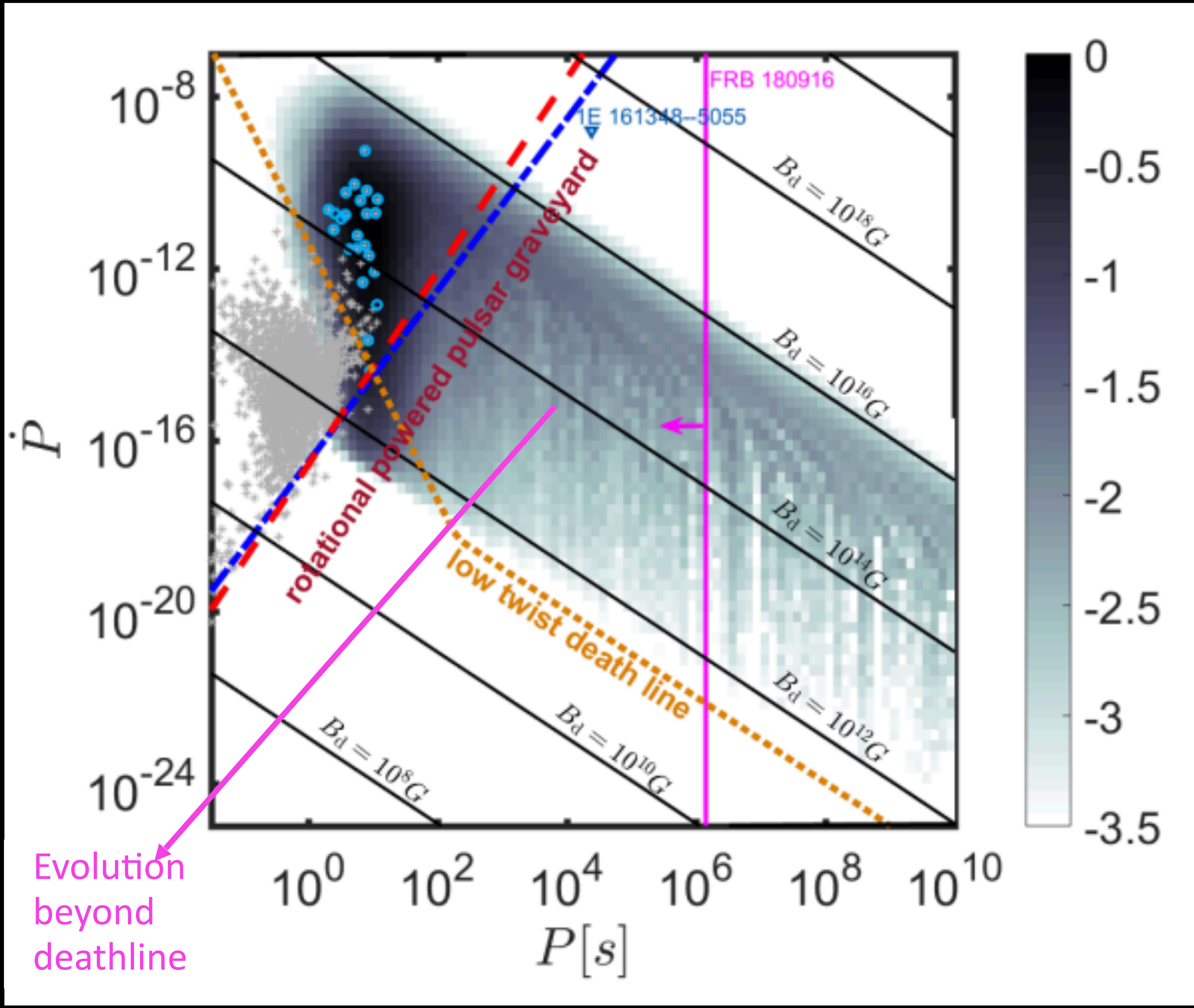
- Monte Carlo proof of concept:



Flat P distribution at large P



Example P evolutions



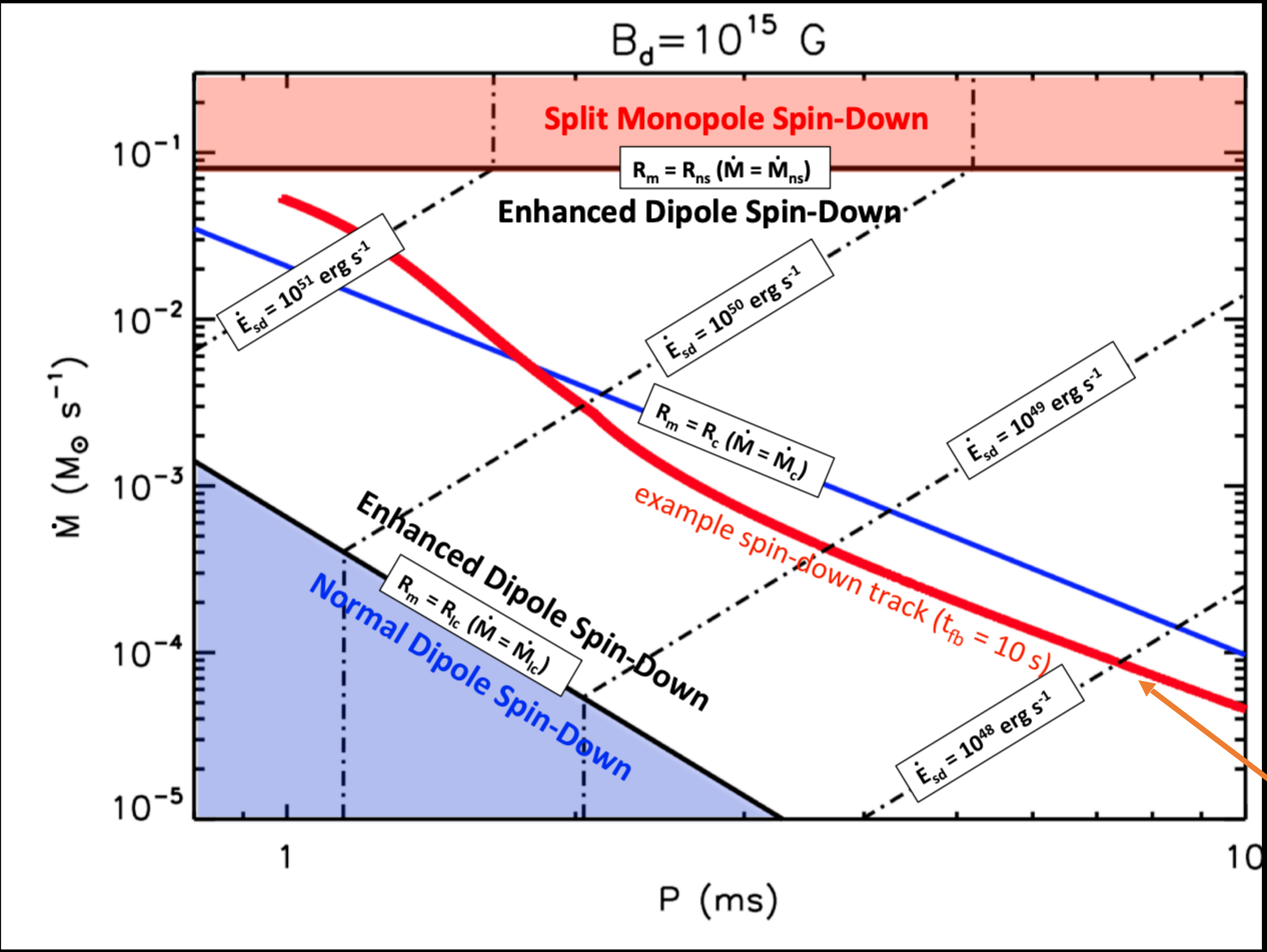
Beniamini, Wadiasingh, Metzger 2020

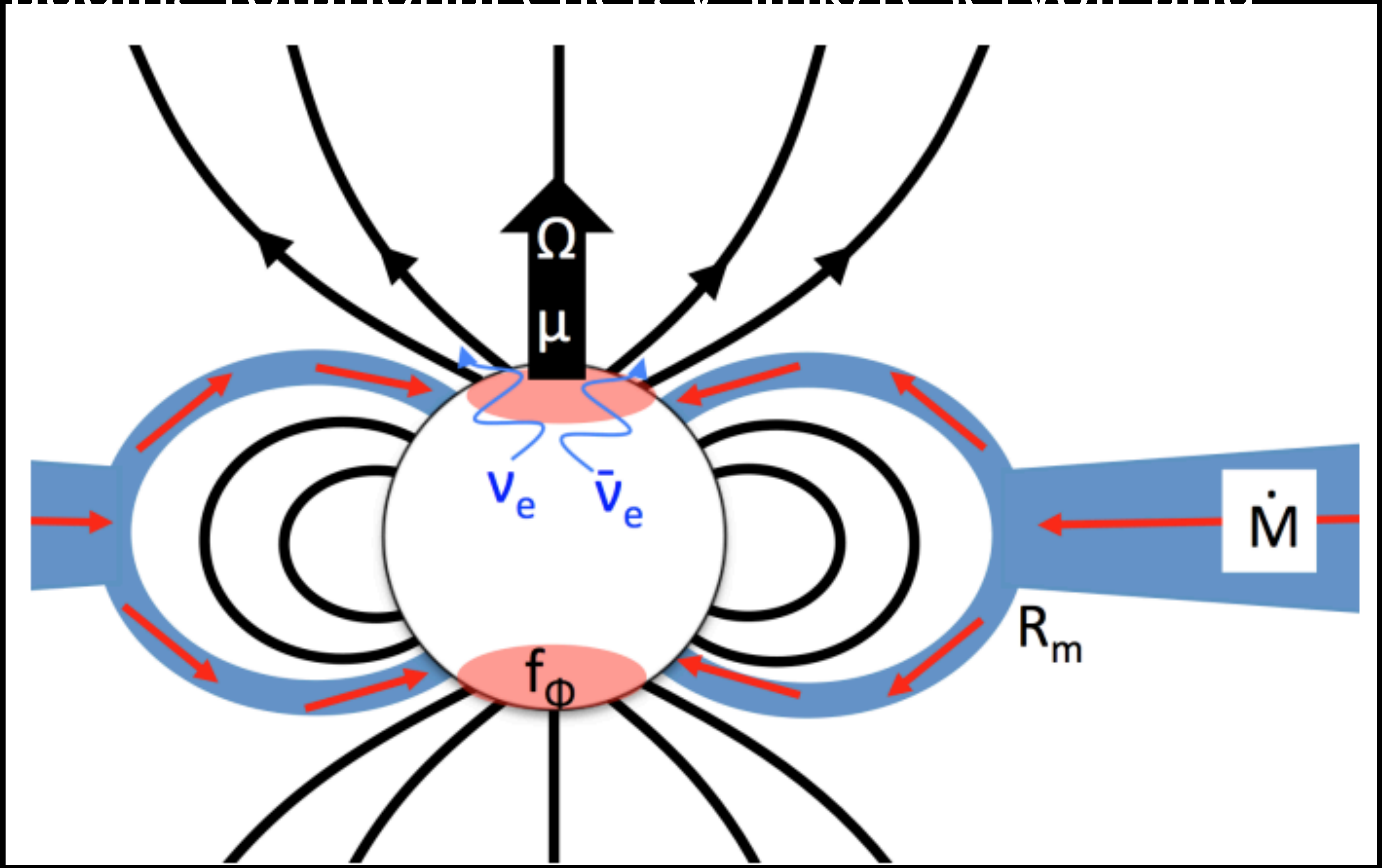
Physical mechanisms for enhanced spin-down

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





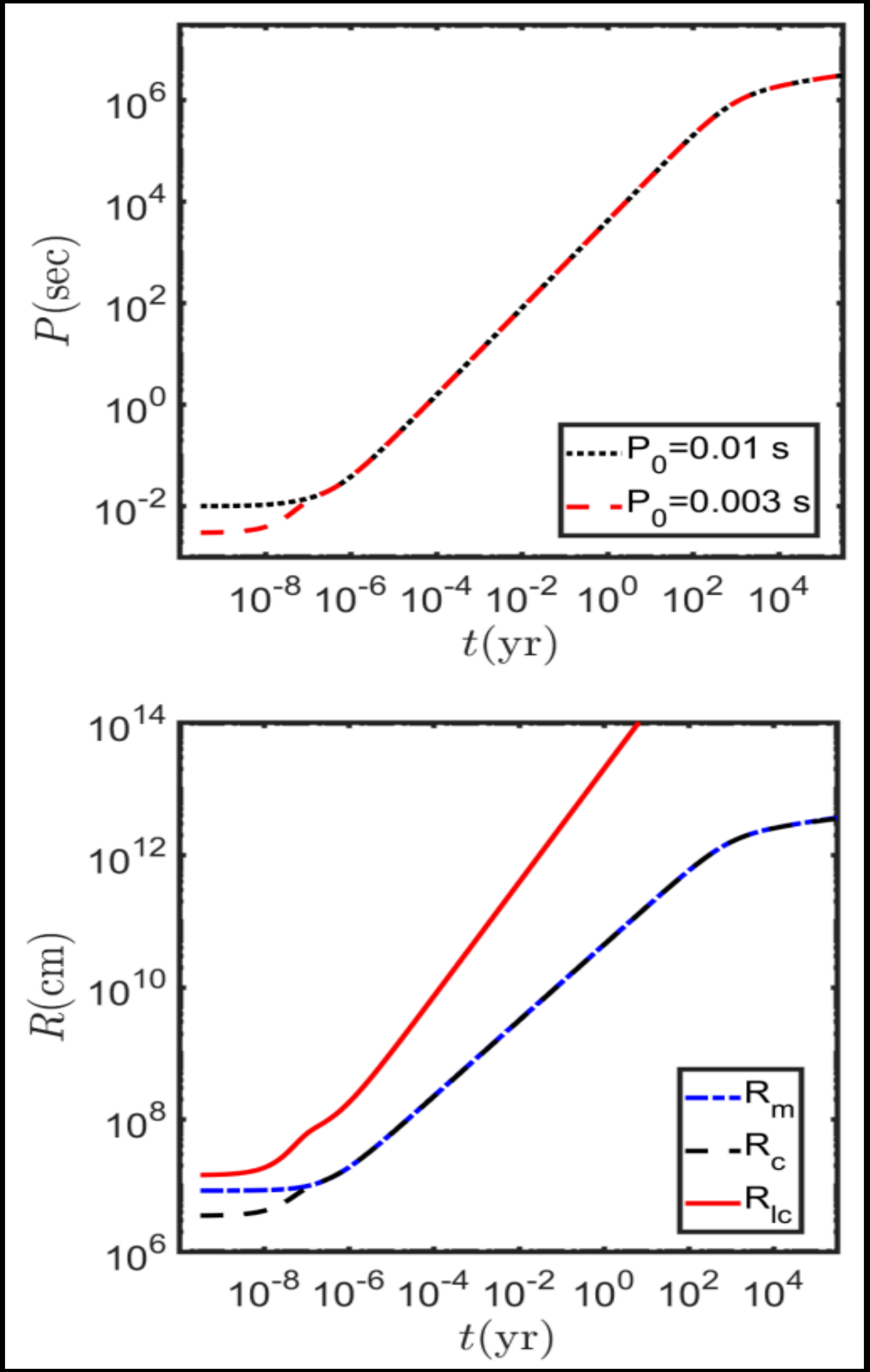
Rough equilibrium between co-rotation and Alfven radius

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)



Beniamini, Wadiasingh, Metzger 2020