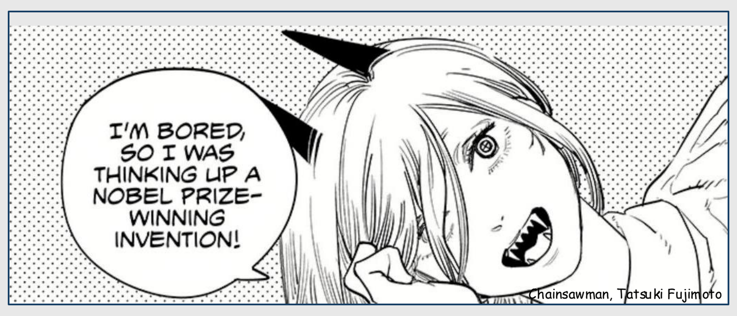
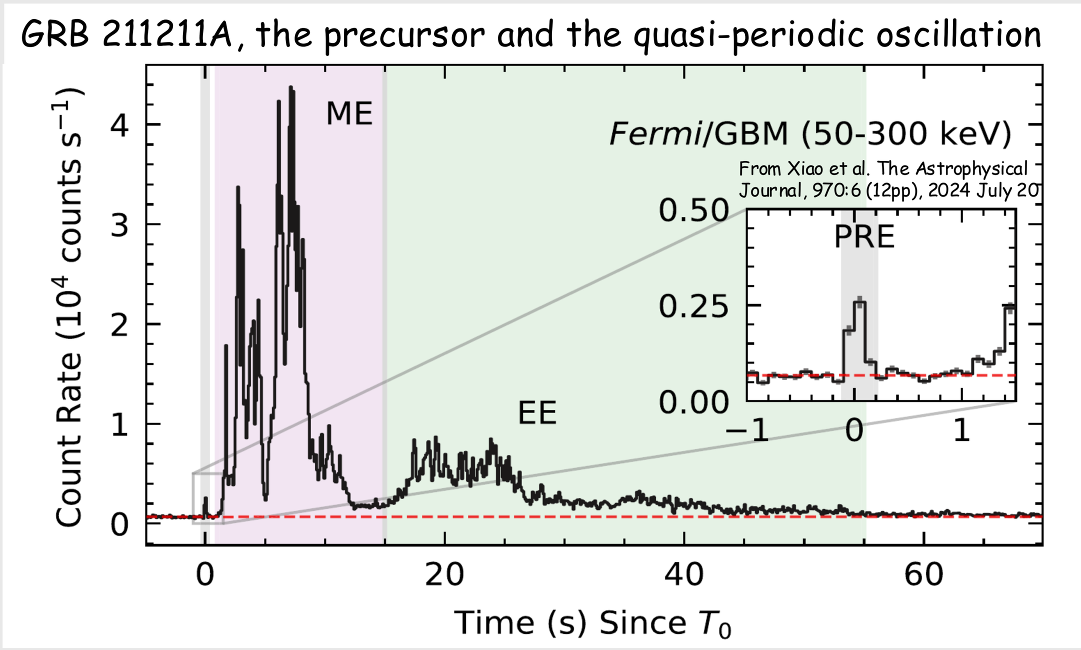
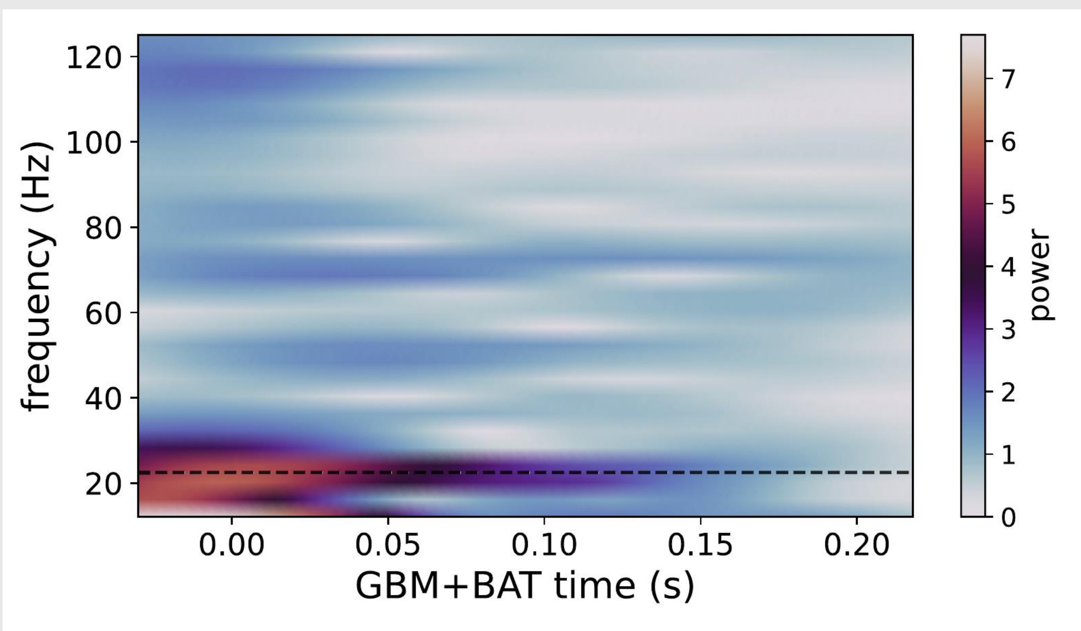
The Wibbly-Wobbly Precursor in a Merger Origin Long-Duration GRB

Gavin P Lamb, Liverpool John Moores University, UK

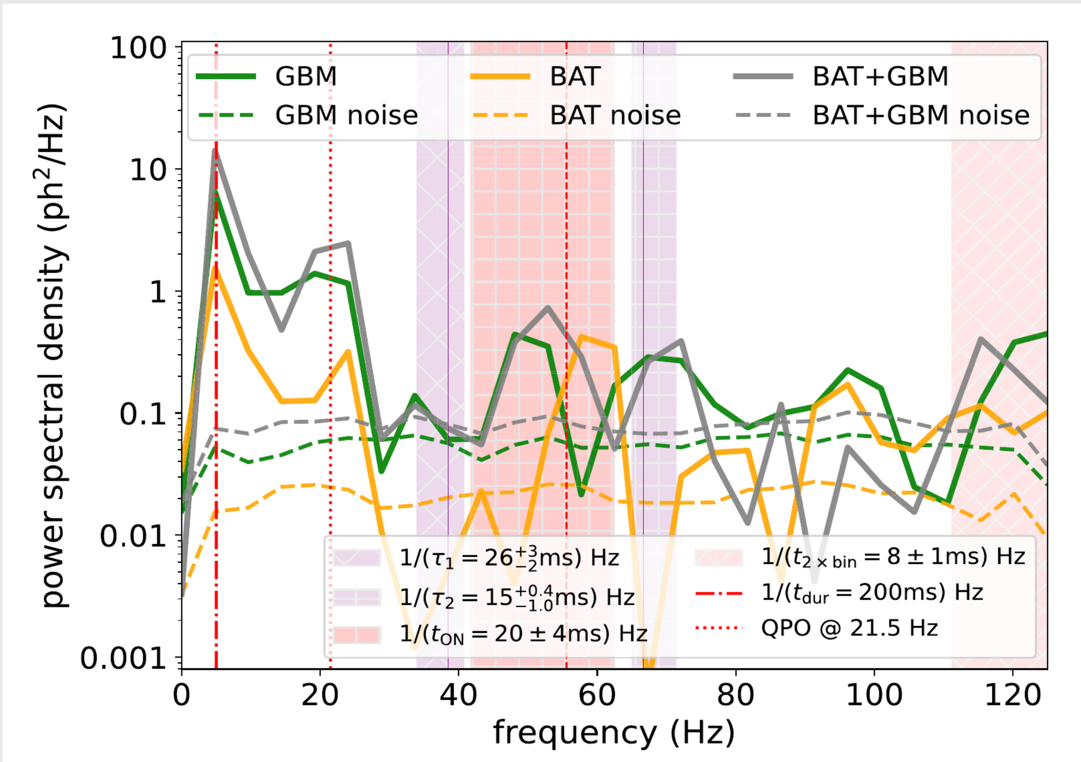




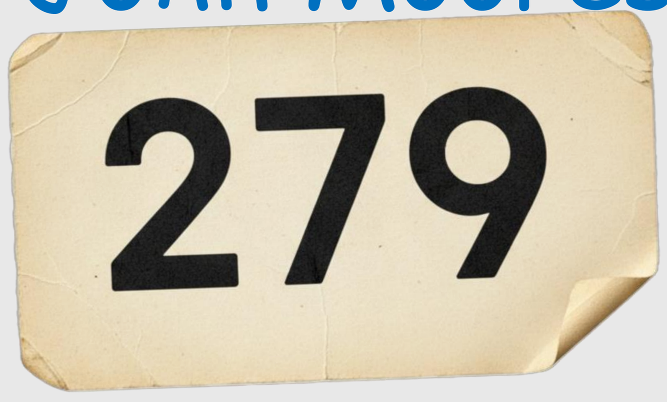
The prompt GRB emission of GRB 211211A – the precursor is shown in the zoom-in. The precursor leads the main burst by ~1 s and has a duration ~0.25 s



The combined precursor Fermi-GBM and the Swift -BAT signal for the 'all' data analysed between 10 and 125 Hz via an STFT. The colour-map indicates the relative power density at the given time. The dashed black line indicates the location of the quasi-periodic 22.5 Hz signal from Xiao et al. (2024).



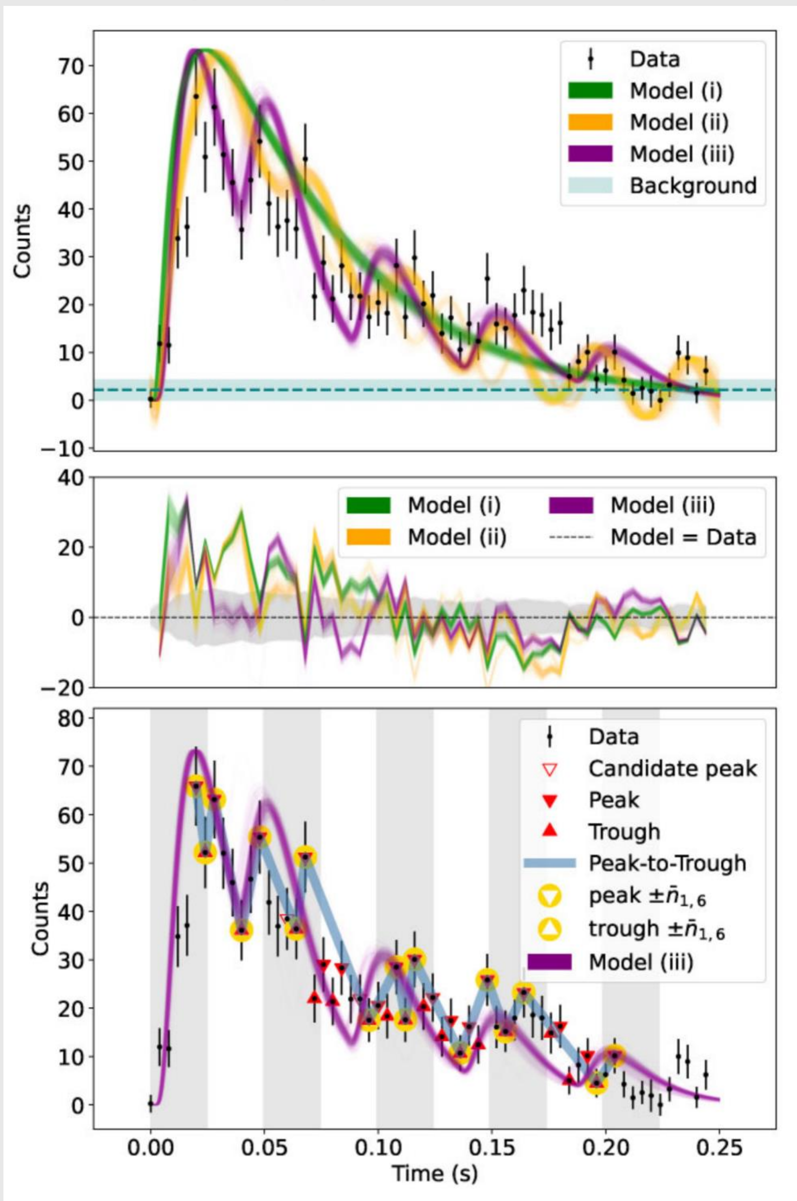
The PSD via Welch's method of the Swift-BAT, the Fermi-GBM n_a and n_1, and the sum of the data. The noise trace is that of the background data for a duration of 10spreceding the precursor. The vertical lines and shaded panels indicate various time-scales within the data: at ~ 5 Hz the red dash–dotted line corresponds to the precursor duration, t_{dur} = 0.2 s; the 21.5 Hz line is the candidate QPO; the shaded grid-hatched region at ~ 55 Hz is the approximate 'ON' cycle duration for the engine; and the red cross-hatched region corresponds to the twice the sampling frequency. The two purple shaded regions are the model (iii) pulse rise and decline time-scales, with the shaded region at 38 Hz given by τ_1 = 26+/-3 ms, and at 67 Hz the τ_2 = 15+/-1 ms. Note also that the MVT found by Xiao et al. (2024) was 15 ms ≡ τ_2 .



Trying our best to model the precursor!!!

Three simple models:
(i) A single pulse following a Norris et al. (2005) FRED-like profile
(ii) A pulse plus a sinusoid – oscillation on-top of a single pulse
(iii) Multiple consecutive pulses, as (i), with a damped amplitude
See equations 14, 15 & 16 in the paper (scan the QR code)

Use a peak/trough finding algorithm (based on Li & Fenimore 1996)

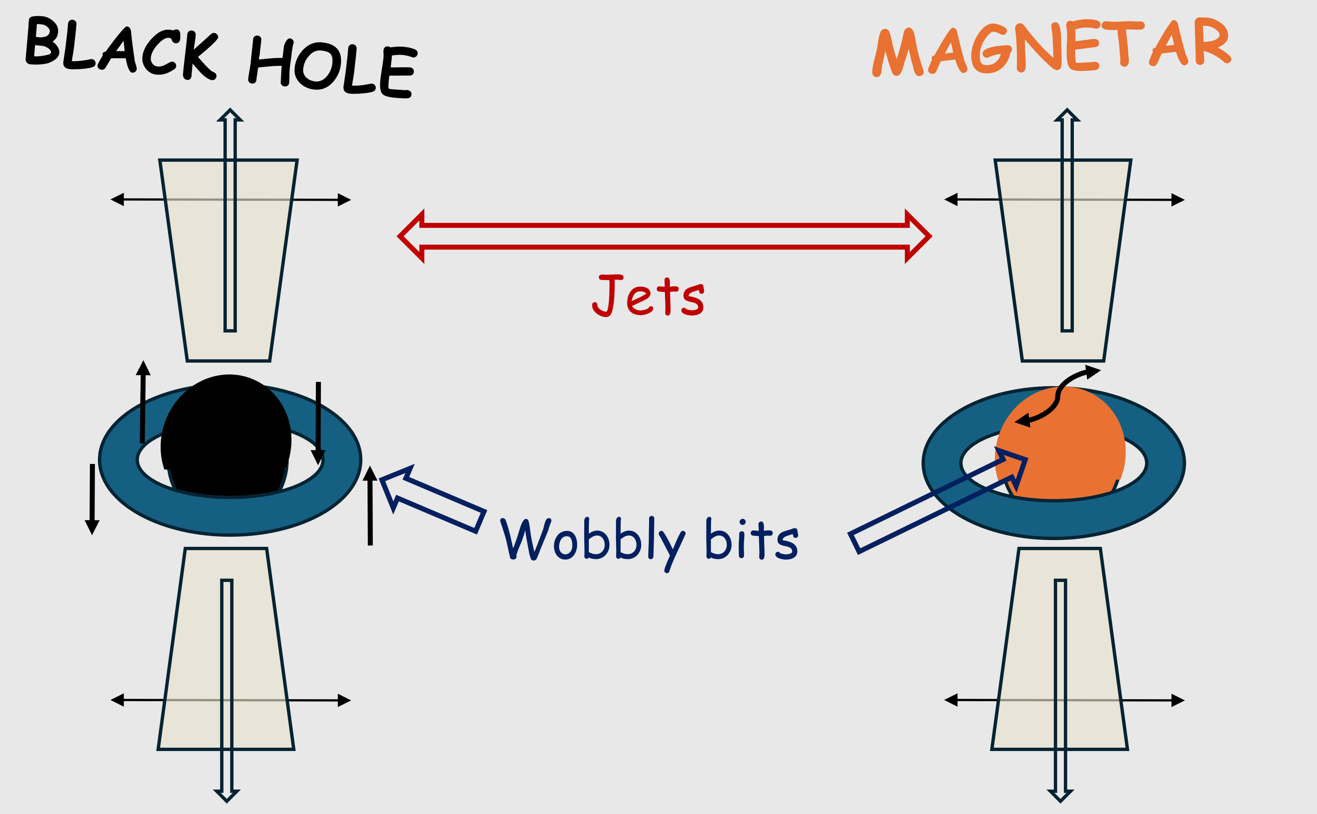


Model	τ_1 (ms)	τ_2 (ms)	x	ν_ω (Hz)
(i)	10^{+1}_{-1}	56^{+2}_{-2}	–	–
(ii)	13^{+1}_{-1}	55^{+2}_{-2}	$0.52^{+0.06}_{-0.06}$	$24.29^{+0.60}_{-0.45}$
(iii)	$\mathbf{26^{+3}_{-2}}$	$\mathbf{15^{+0}_{-1}}$	$\mathbf{0.56^{+0.02}_{-0.02}}$	$\mathbf{20.13^{+0.14}_{-0.08}}$
log $\mathcal{B}$	(i)	(ii)	(iii)	
(i)	0	−9.248	−22.357	
(ii)	0.248	0	−13.109	
(iii)	**22.257**	**13.109**	**0**	

Log Bayes factor

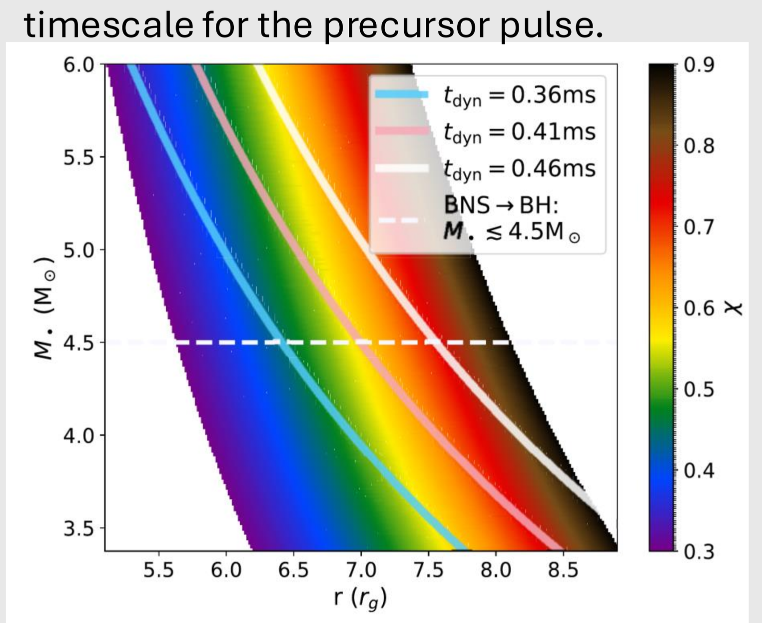
Model (iii) is the winner!*

*but it is entirely phenomenological (we made it up)

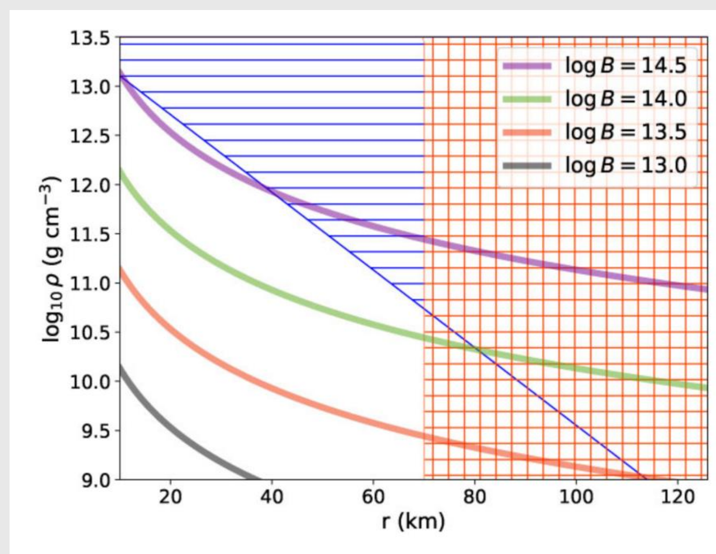


A thick accretion disc forms around a spinning black hole. Turbulence or a large disc radius results in a long accretion timescale, t_{acc} > 2s. At early times, the inner disc is torn via a Lense-Thirring mechanism that invokes a precession of the inner component. Periodic or episodic accretion of this torn inner disc results in the on-off cycle required to produce the observed periodicity within the precursor. Differential precession within the torn inner disc leads to the signal dampening. The width of the torn inner disc sets the timescale for the precursor pulse.

A new magnetar can wobble and precess, but at very high frequencies, too high for our observations. However, a quasi-periodic oscillation can occur due to magnetohydrodynamic processes within the disc.
Alfven waves can produce oscillations within the disc with a lower-frequency at a relevant range. The Alfven waves will lose energy in a non-linear way, particularly in highly turbulent discs – as expected following a merger of neutron stars.



The viable parameter space for the radius (in gravitational radiii) of the 22 Hz QPO via Lense-Thirring precession and the required black-hole mass and spin (colourmap). The white dashed line indicates the upper-limit for a neutron star binary merger, above which, one component is a black hole



The required magnetic field strengths (contours), radius and disc density that can result in Alfven wave oscillations at 22 Hz. The blue lined region marks an impossible density region for a disc, and the orange hatched region is the Alfven limit.

CONCLUSIONS: Both of these processes are viable for the periodicity within GRB 211211A's precursor. However, **we favour black-hole Lense-Thirring** as no evidence of a long-lasting magnetar in GRB 211211A has been found (Schroeder et al. The Astrophysical Journal, 998:93 (11pp), 2026 February 10). **Checkout our paper for a few other possibilities**

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **540,** 2727–2744 (2025)
https://doi.org/10.1093/mnras/staf89
Advance Access publication 2025 May 31

Prompt periodicity in the GRB 211211A precursor: black-hole or magnetar engine?

Gavin P. Lamb[1★] Thomas Baxter[1] Conor M. B. Omand[1] Dimple[2] Zoë McGrath[1] Cairns Turnbull[1] Eric Burns[3] Hamid Hamidani[4] Ilya Mandel[5,6] Kim L. Page[7] Stephan Rosswog[8,9] Nikhil Sarin[9,10] Andrew Blain[6] Laurence Datrier[11] Shiho Kobayashi[1] Andrew Levan[12] Rhaana Starling[7] Benjamin Gompertz[2] Nusrin Habeeb,[7] Khang Nguyen[1] and Nial Tanvir[7]

[1]Astrophysics Research Institute, Liverpool John Moores University, IC2 Liverpool Science Park, 146 Brownlow Hill, Liverpool L3 5RF, UK
[2]School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[3]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA
[4]Astronomical Institute, Graduate School of Science, Tohoku University, 6-3, Aramaki Aza-Aoba, Aoba-ku, Sendai 980-8578, Japan
[5]School of Physics and Astronomy, Monash University, Wellington Road, Clayton, Victoria 3800, Australia
[6]ARC Centre of Excellence for Gravitational Wave Discovery – OzGrav, Level 9, AMDC Building
Swinburne University of Technology, Hawthorn VIC 3122, Australia
[7]School of Physics and Astronomy, University of Leicester, University Road, Leicester LE1 7RH, UK
[8]Hamburger Sternwarte, University of Hamburg, Gojenbergsweg 112, D-21029 Hamburg, Germany
[9]The Oskar Klein Centre, Department of Physics, Stockholm University
[10]Nordita, Stockholm University and KTH Royal Institute of Technology
[11]California State University, Fullerton, Department of Physics, 800 N
[12]Institute for Mathematics, Astrophysics and Particle Physics, Depart
Gelderland, NL

LIVERPOOL JOHN MOORES UNIVERSITY

THE ROYAL SOCIETY