Detectability of General-Relativistic Apsidal Precession in Short-Period Transiting Giant Planets to Be Discovered by the Roman Galactic Bulge Time Domain Survey (GBTDS)

Shreesham Pandey[1,*]

Department of Physics, Kirori Mal College, University of Delhi, New Delhi 110007, India

[*]E-mail: shreeshampandey@gmail.com

A survey-specific Monte Carlo forecast combining 1PN orbital precession with the GBTDS high-cadence window function

Motivation

- GBTDS: six 72-day high-cadence seasons (3 early + 3 late in the 5-yr mission), 12.1-min cadence in F146 — roughly 440 days of high-cadence photometry total.
- Survey forecast to yield ≈ 60,000–200,000 transiting planets from ≈ 59 million monitored bright bulge stars.
- 1PN general relativity predicts apsidal precession of eccentric orbits, already targeted for single hand-picked planets (HD 80606b, WASP-14b) via transit-timing methods.
- No prior study forecasts this signal for the population GBTDS itself will deliver — using GBTDS's own real season structure.

Research Question

For GBTDS's expected short-period (1–10 day), eccentric transiting giant planets, what fraction show a 1PN GR apsidal-precession transit-duration signature distinguishable (SNR ≥ 3) from the survey's own photometric timing precision?

Why This Is A Gap

No prior survey-wide GR-precession forecast exists; GBTDS's real season schedule has never been used for this; result has direct bearing on any future Roman mission-extension case.

Broader Significance

Sets a GR-test precision floor for GBTDS; connects to relativistic orbital dynamics work (blanets in Kerr/Schwarzschild spacetimes), extended here from the AGN-disk regime to transiting exoplanets.

Physics

$$\Delta\varpi = \frac{6\pi G M_\star}{c^2 a(1-e^2)} \quad \text{(1PN precession rate)}$$

$$T_{14}(\omega) = T_0 \frac{\sqrt{1-e^2}}{1+e\sin\omega} \quad \text{(eccentric transit duration, Winn 2010)}$$

$$\Delta T_{14} \approx \frac{dT_{14}}{d\omega}\,\dot\omega_{\rm GR}\,B \quad \text{(accumulated drift over baseline } B\text{)}$$

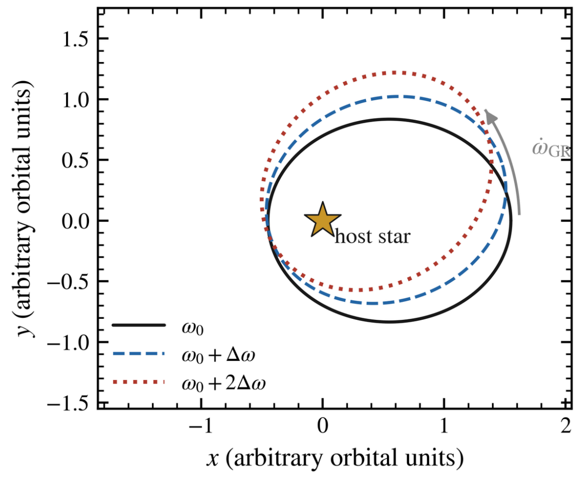

Fig. 1 — 1PN apsidal precession of an eccentric close-in orbit; three orbital phases (ω_0, $\omega_0+\Delta\omega$, $\omega_0+2\Delta\omega$) around the host star, arrow marks precession direction $\dot\omega_{\rm GR}$.

Abbreviations & Symbols

GR — general relativity · 1PN — first-post-Newtonian · SNR — signal-to-noise ratio · GBTDS — Galactic Bulge Time Domain Survey · F146 — Roman's near-infrared filter
P — period · e — eccentricity · ω — argument of periastron · T_{14} — transit duration · $M_\star$ — host-star mass · $M_\odot$ — solar mass

Selected References

Blanchet, Hébrard & Larrouturou (2019), A&A 627, A70; Antoniciello et al. (2021), MNRAS; Pál & Kocsis (2008), MNRAS 389, 191; Miyazaki et al. (2021), AJ 161, 84; Wilson et al. (2023), ApJS; Roman GBTDS mission docs — roman.gsfc.nasa.gov, roman-docs.stsci.edu.

GBTDS Window Function

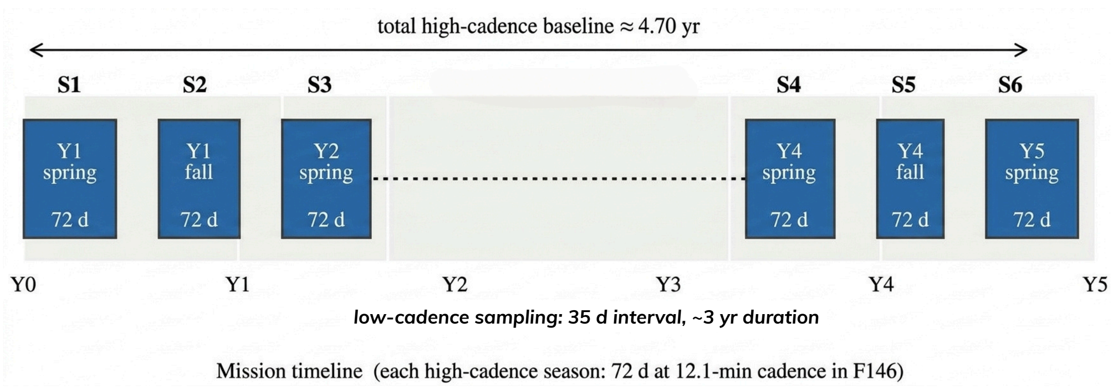

Fig. 2 — adopted 6-season mission timeline (S1–S6), 3 seasons early + 3 late, ≈ 4.70 yr total baseline, low-cadence (35-day) sampling in between. Season schedule not yet finalized by the mission; this is a representative proxy.

Monte Carlo Setup

- N = 200,000 synthetic systems; $M_\star$ ~ U(0.35, 1.1) $M_\odot$; P ~ log-U(1, 10) d; e ~ Rayleigh(σ = 0.12, e < 0.6); ω ~ U(0, 2π); F146 ~ U(15,21); R_p ~ U(0.7, 1.3) R_{Jup}.
- Photometric precision anchored to 1 mmag/15-min bright-star benchmark, rescaled to 12.1-min cadence and magnitude.
- Detection statistic $SNR_{GR} = \Delta T_{14}/\sigma_{T14}$, threshold $SNR_{GR} \geq 3$.

Key Result

- 0.02% of simulated systems reach SNR ≥ 3
- 1.06 s median predicted GR duration shift
- 75.4 s median achievable timing precision.

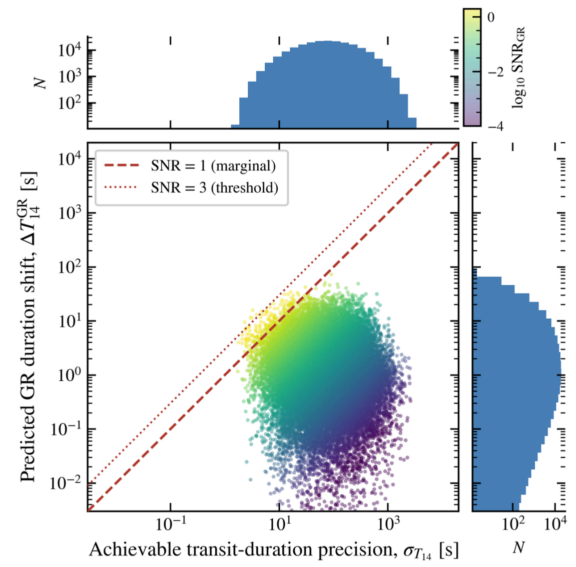

Fig. 3 — predicted GR duration shift vs. achievable timing precision (main panel, log–log, colored by $\log_{10} SNR_{GR}$) with marginal histograms on top/right; legend marks SNR=1 and SNR=3 lines; nearly the whole population falls below threshold. N = 2×10⁵.

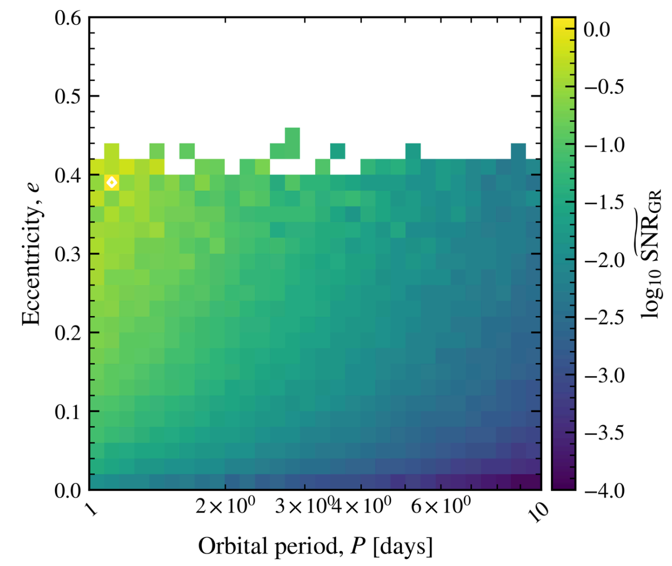

Fig. 4 — median SNR_{GR} across (P, e) parameter space; white SNR=1 contour; detectability confined to P ≲ 2 d, e ≳ 0.3.

Discussion

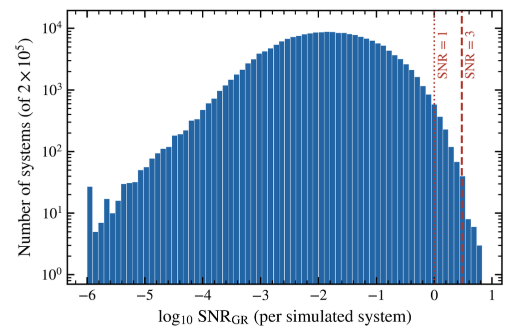

Fig. 5 — histogram of $\log_{10}(SNR_{GR})$ across the full population; peak sits ~2 orders of magnitude below SNR=1, thin tail crosses threshold.

Consistent with prior finding that period-based transit timing alone can't reveal GR precession on realistic survey baselines. Marginal-SNR systems cluster at P≈1.0–1.3 d, e≈0.19–0.53, $M_\star$≈0.36–0.95 $M_\odot$. A mission extension scales ΔT_{14} linearly while σ_{T14} improves only as √N, so extension would materially help. Combining GBTDS with decade-plus ground-based follow-up (as for HD 80606b) could push select systems to detectability.

Conclusion

GR apsidal precession is not a broadly accessible GBTDS transit-timing observable for the survey's core short-period giant-planet catalog, but a narrow extreme subpopulation approaches marginal detectability, motivating targeted follow-up and mission-extension planning.