Search for Wormhole Candidates in Astrophysical Binary Systems via Radial Velocity Analysis

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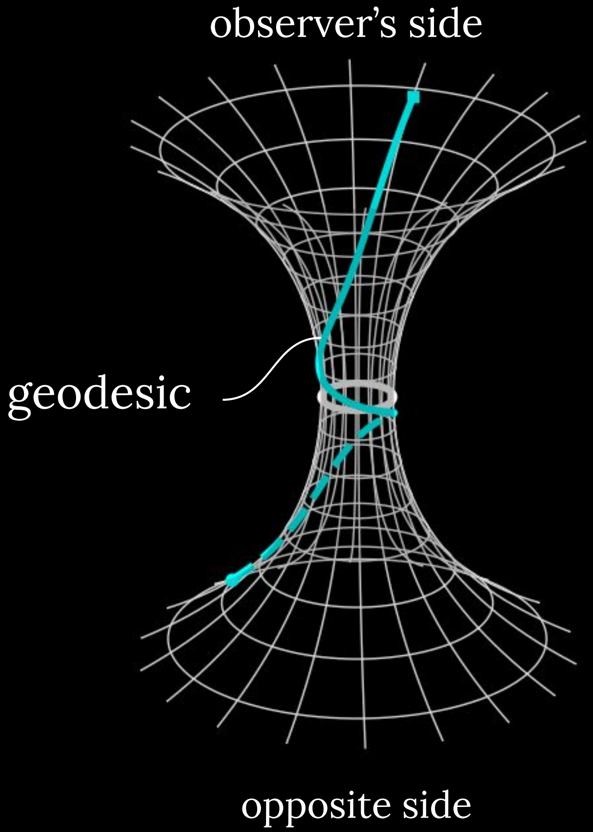
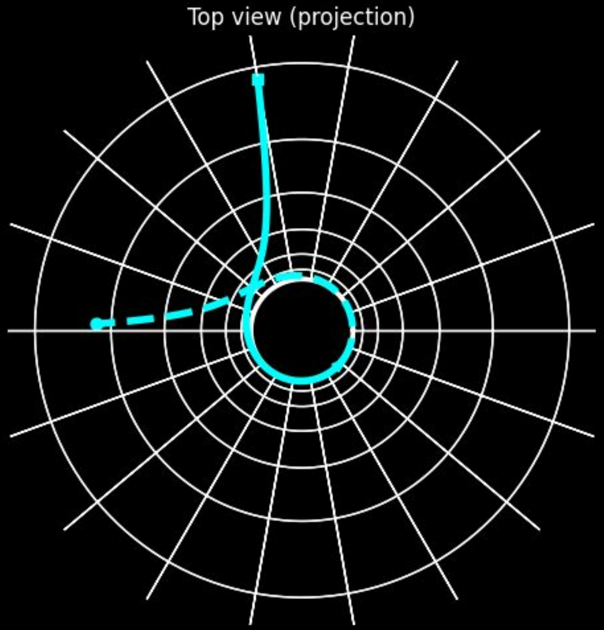
1. Wormholes in spacetime





2. NEC violation

Morris M. S., Thorne K. S./Am. J. Phys./1988

Clearest example – Morris–Thorne wormhole:

$$ds^2 = -e^{2\Phi(r)}dt^2 + \left(1 - \frac{b(r)}{r}\right)^{-1} dr^2 + r^2 d\Omega^2$$

traversable throat requires exotic matter:

$$p + \rho c^2 < 0.$$

3. Dark energy and exotic matter

ΛCDM: Λ – cosmological constant

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R - 8\pi G\Lambda g_{\mu\nu} = 0$$

which is equivalent to the field with EoS p=-ρ

Alternatively one can assume a dynamic dark energy with EoS

$$p = w\rho c^2$$

$$w < -1 \longrightarrow p + \rho c^2 < 0$$

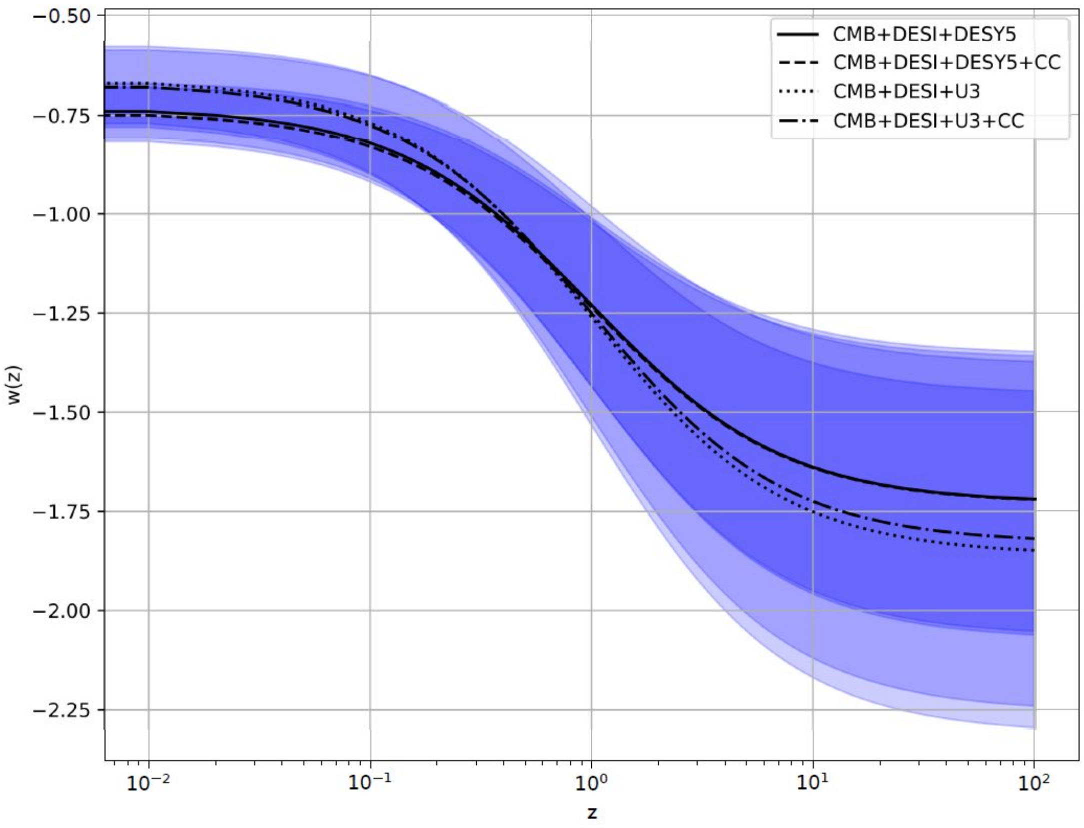
Caroll et al./Phys.Rev.D/2003

4. DESI DR1/DR2

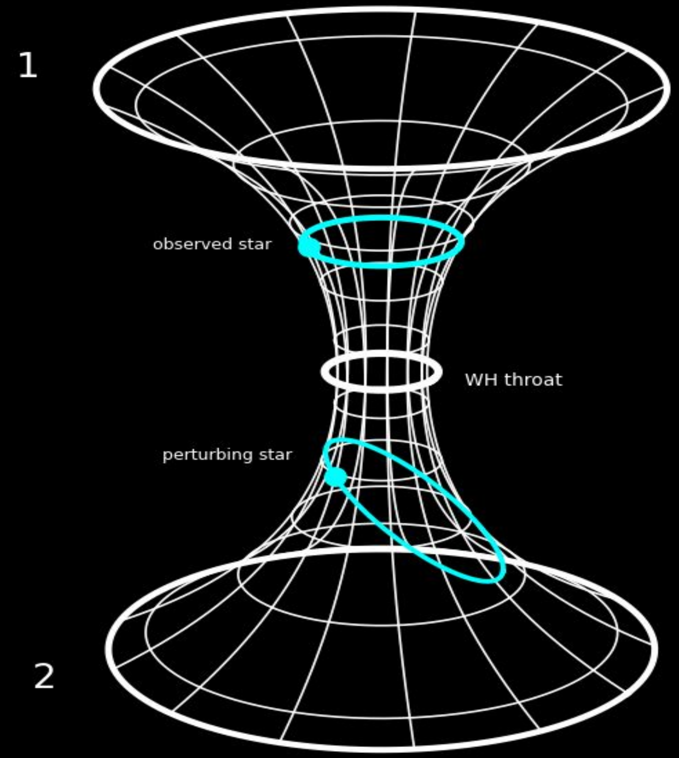
DESI Collaboration/JCAP/2025
Giarè et.al/Phys.Dark Univ./2025

$$w(z) = w_0 + w_a \cdot \left(1 - \frac{1}{1+z}\right)$$

**Moiseev, Sazhina//JETP 2025. – 168*



5. Model independent wormhole search strategy



$$\Delta a = \mu \left(\frac{R}{r_p} - \frac{R}{r_a} \right) \frac{1}{r_1^2}$$

Dai, Stojkovic/Phys.Rev.D/2020 and other

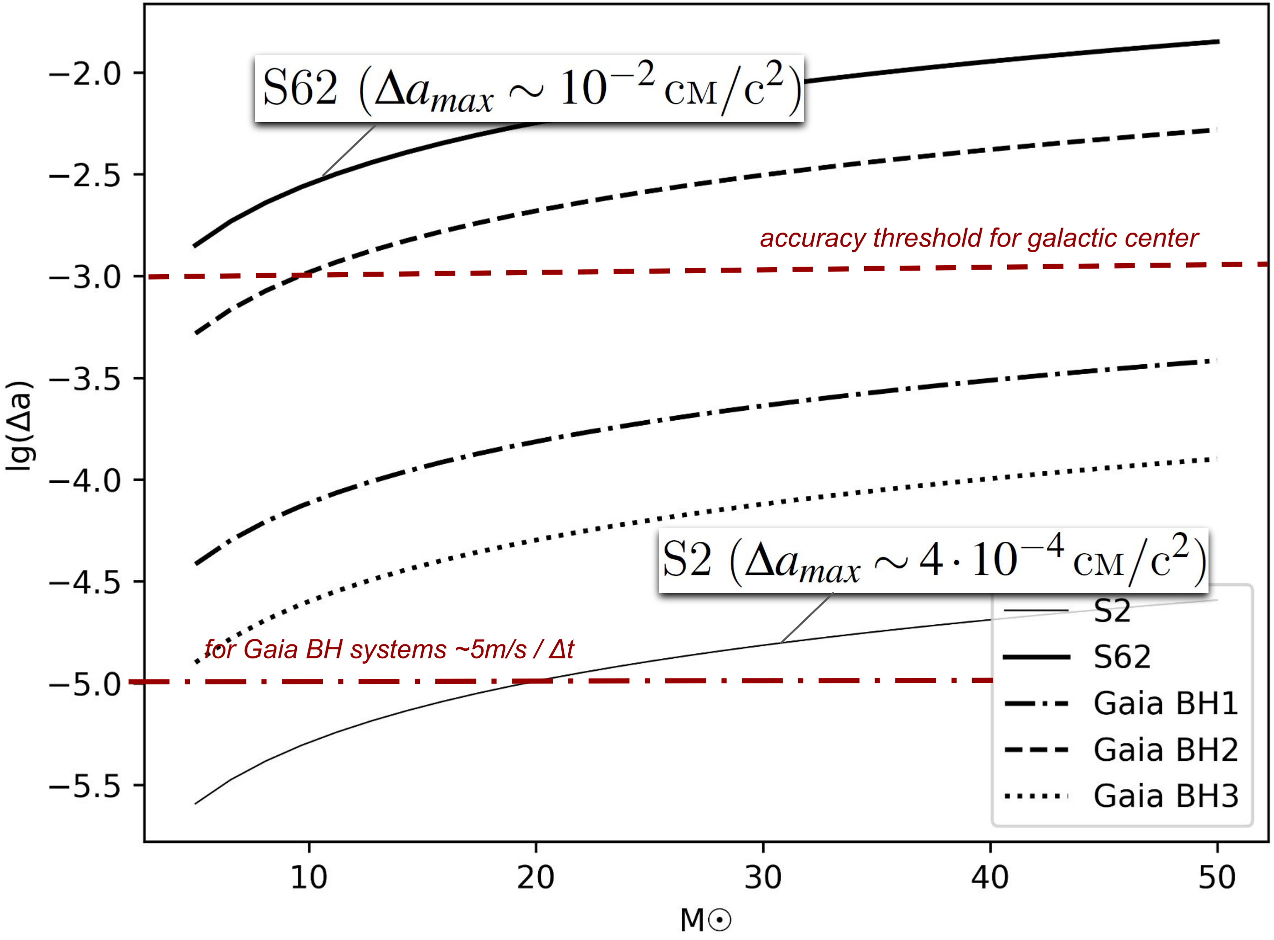
6. Dormant black hole binaries with luminous companions (dBH-LC)

Name	M_{BH} ($M_\odot$)	M_{LC} ($M_\odot$)	P_{orb} (days)	e	Type
GC NGC3201 #12560	≥ 4.36	$0.81^{+0.05}_{-0.05}$	$166.88^{+0.71}_{-0.63}$	$0.610^{+0.020}_{-0.020}$	MS
GC NGC3201 #21859	≥ 7.68	$0.61^{+0.05}_{-0.05}$	$2.24^{+0.01}_{-0.01}$	$0.070^{+0.04}_{-0.04}$	MS
VFTS 243	≥ 8.70	$25.0^{+2.3}_{-2.3}$	$10.40^{+0.01}_{-0.01}$	$0.017^{+0.01}_{-0.01}$	MS
HD 130298	$8.80^{+3.5}_{-1.5}$	$24.2^{+3.8}_{-3.8}$	$14.63^{+0.01}_{-0.01}$	$0.457^{+0.007}_{-0.007}$	MS
Gaia BH1	$9.78^{+0.18}_{-0.18}$	$0.93^{+0.05}_{-0.05}$	$185.59^{+0.05}_{-0.05}$	$0.454^{+0.005}_{-0.005}$	MS
AS 386	≥ 7.00	7^{+1}_{-1}	$131.27^{+0.09}_{-0.09}$	0	Giant
Gaia BH2	$8.93^{+0.33}_{-0.33}$	$1.07^{+0.19}_{-0.19}$	$1276.70^{+0.6}_{-0.6}$	$0.518^{+0.002}_{-0.002}$	Giant
Gaia BH3	$32.70^{+0.82}_{-0.82}$	$0.76^{+0.05}_{-0.05}$	$4253.1^{+98.5}_{-98.5}$	$0.7291^{+0.0048}_{-0.0048}$	Giant
2M05215658+4359220	$3.30^{+0.80}_{-0.70}$	$4.4^{+2.2}_{-1.5}$	$82.20^{+2.50}_{-2.50}$	$0.005^{+0.003}_{-0.003}$	Giant
Gaia ID 3425577610762832384	$3.60^{+0.80}_{-0.50}$	$2.66^{+1.18}_{-0.68}$	$877^{+2.0}_{-2.0}$	$0.05^{+0.01}_{-0.01}$	Giant

Physical parameters of dBH-LCs observed through radial velocity or astrometric measurements.

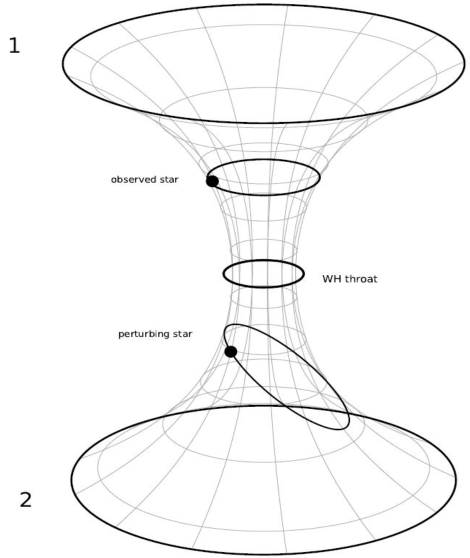
Li et al./A&A/2026

7. Preliminary estimates



Moiseev, Sazhina//JETP 2025. – 167.

8. Velocity perturbations



$$\Delta a = \mu \left(\frac{R}{r_p} - \frac{R}{r_a} \right) \frac{1}{r_1^2}$$

$$\tau_{\text{pulse}} \sim \left(\frac{r_p}{r_a} \right)^2 T$$

$$\Delta v \sim \tau_{\text{pulse}} \cdot \Delta a = 2\pi \left(\frac{r_p}{r_a} \right)^2 \sqrt{\frac{A^3}{G(M+m)}} \cdot \frac{GmR}{r_1^2} \left(\frac{1}{r_p} - \frac{1}{r_a} \right)$$

9. Line-of-sight velocity

$$\Delta v = 4\pi \frac{G^2 M m}{r_1^2 c^2} \sqrt{\frac{A^3}{G(M+m)}} \left(\frac{r_p}{r_a}\right)^2 \left(\frac{1}{r_p} - \frac{1}{r_a}\right) \equiv \frac{\mathrm{const}}{r_1^2}$$

$$\vec{v} = \vec{v}_0 + \Delta v \cdot \vec{e}$$

$$v^o = [\vec{v}^{observer}]_z = [R_z(\Omega) R_x(i) (\vec{v}_0 + \Delta v \cdot \mathrm{sign}(-\dot{r}_1) \cdot \vec{e})]_z$$

10. Radial velocity perturbations simulated for Gaia BH1

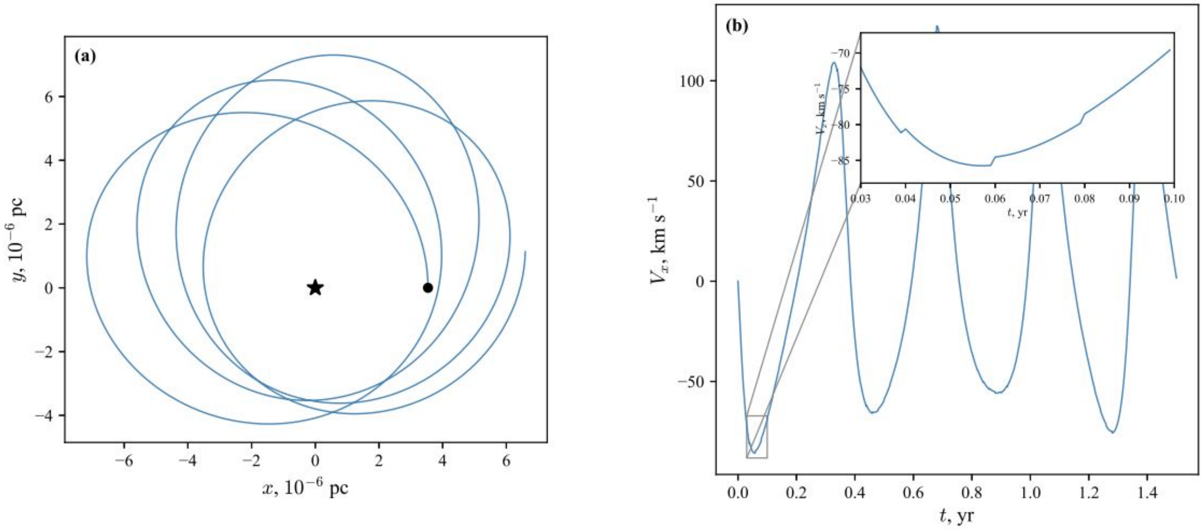


Figure 3: *Left*: integrated trajectory of the star in the orbital plane. *Right*: x-component of the stellar velocity. The inset demonstrates how small the sought perturbations are even when artificially amplified by a factor of 1000 in the simulation.

11. Perturbation template

$$v(t) = v^o(t) + n(t)$$

$$r(t) = v(t) - v_0(t) = s(t) + n(t)$$

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$$u(t) = \frac{1}{W} \sum_{k=0}^{N-1} (a_k - \bar{a})\,\delta(t - t_k), \quad a_k = \frac{C}{r_1^2(t_k)}$$

$$t_k = t_0 + kT$$

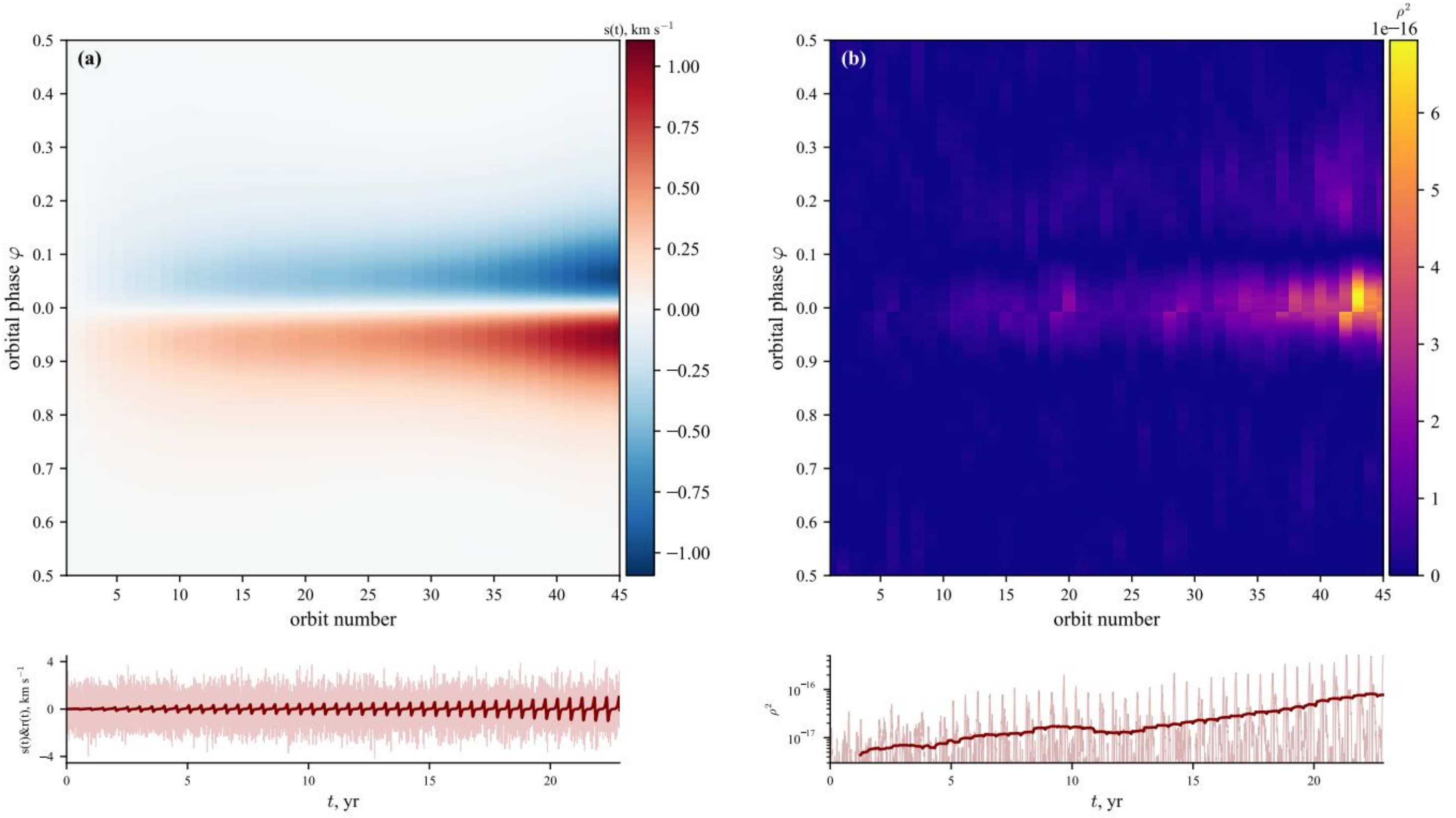
12. SNR

Allen et al./Phys.Rev.D/2012

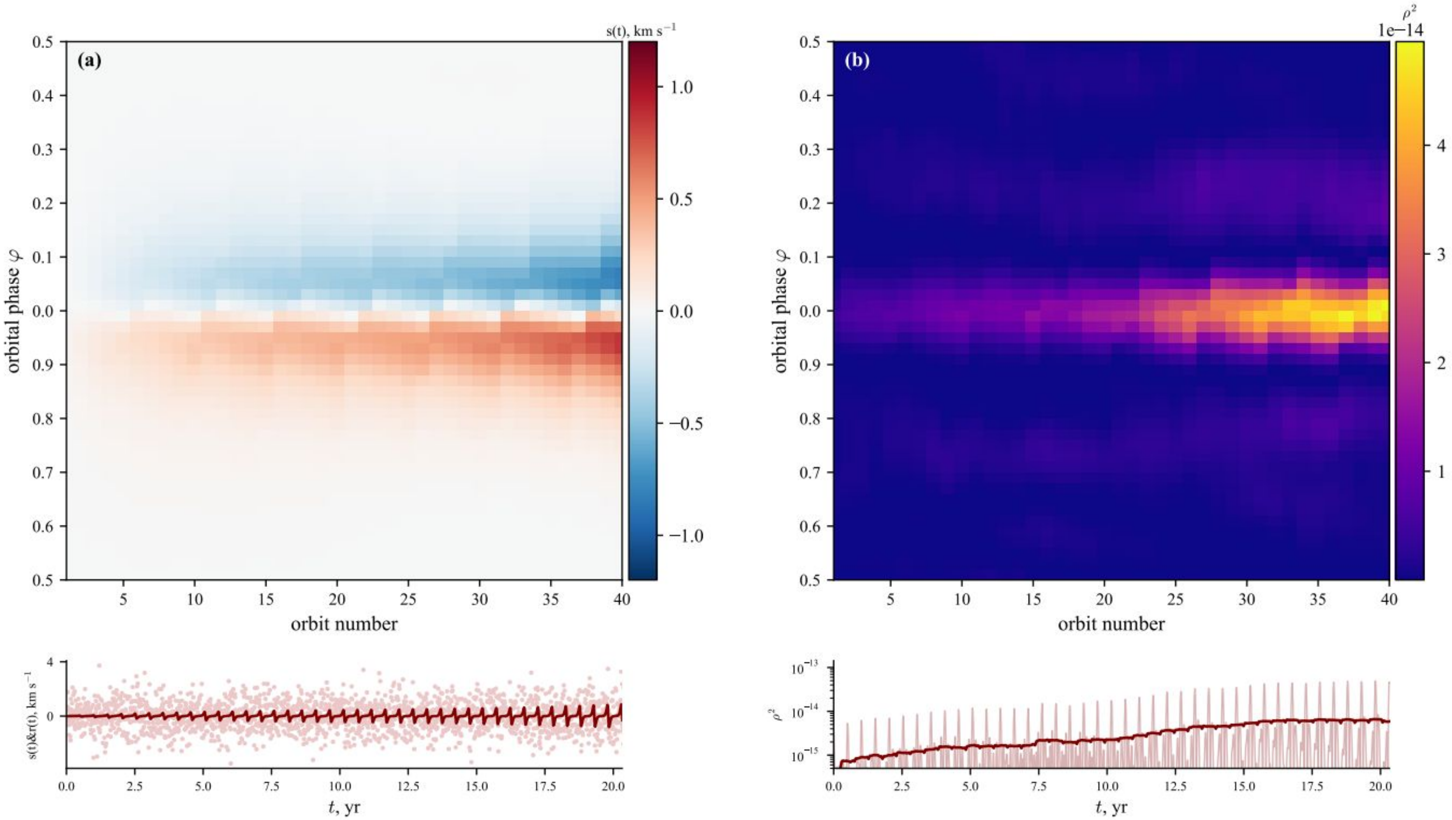
$$\mathrm{SNR}(t_0) = \frac{\int_0^\infty \frac{\tilde{r}(f)\,\tilde{u}^*(f)}{S_n(f)}\, e^{2\pi i f t_0}\, df}{\left[\int_0^\infty \frac{|\tilde{u}(f)|^2}{S_n(f)}\, df\right]^{1/2}}$$

$$S_{\mathrm{obs}} = \int_0^{t_{\max}} |\mathrm{SNR}^2(t)|\, dt$$

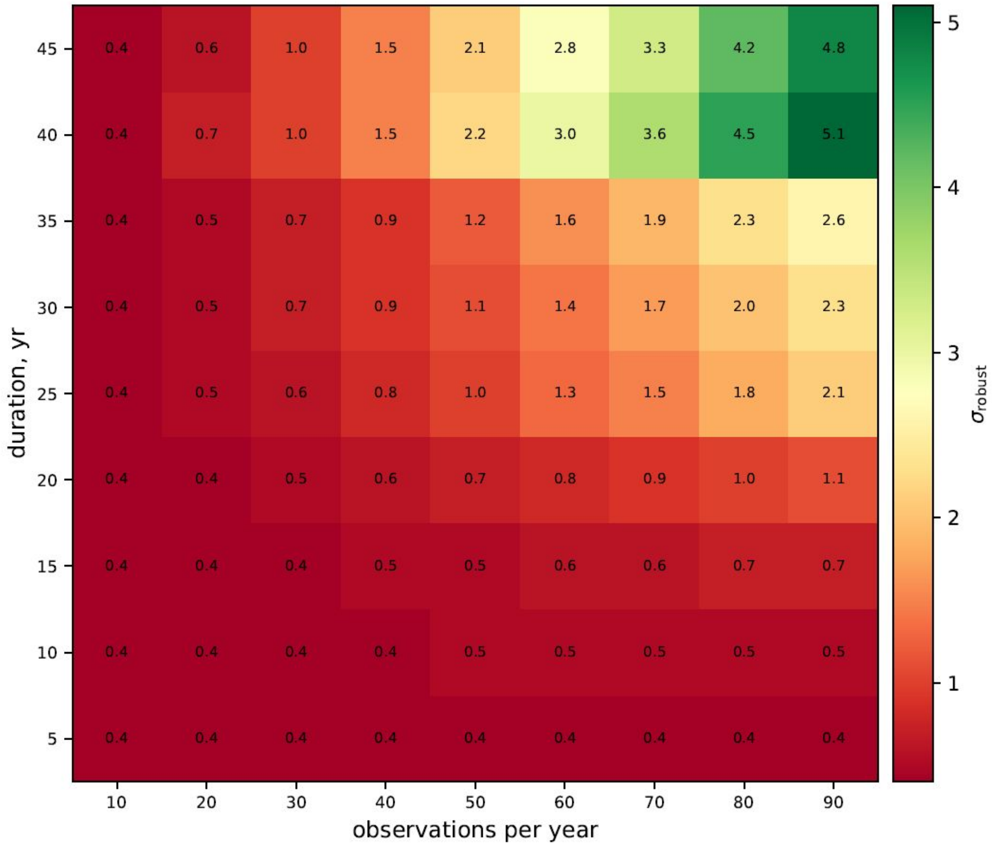
13. Model response



14. Discrete observations



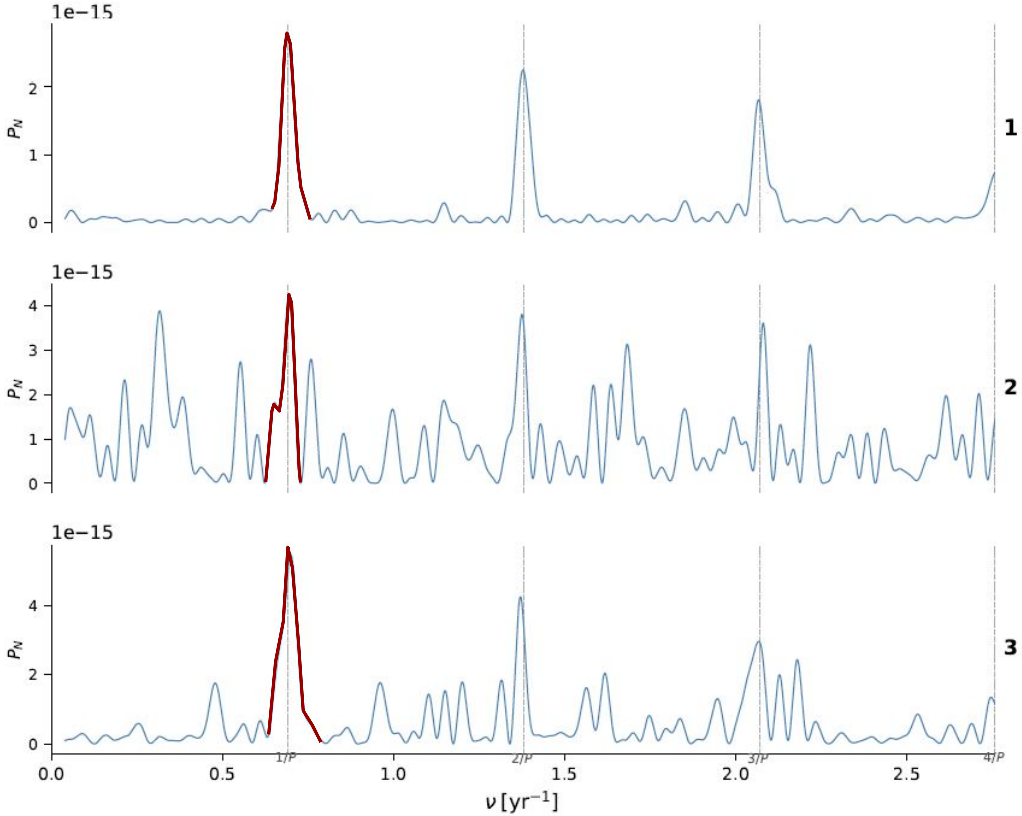
15. Observational strategy



- $M = M_{\mathrm{WH}} = 5 - 50 M_{\odot}$;
- $e_1 = 0 - 0.95$
- $C = 10^{-22} - 5 \cdot 10^{-20}$;
- $i = 0^{\circ} - 180^{\circ}$
- $\Omega = 0^{\circ} - 360^{\circ}$

$$Z_{\mathrm{obs}} = \frac{S_{\mathrm{obs}}}{\sigma_{\mathrm{robust}}}$$

16. LS periodogram

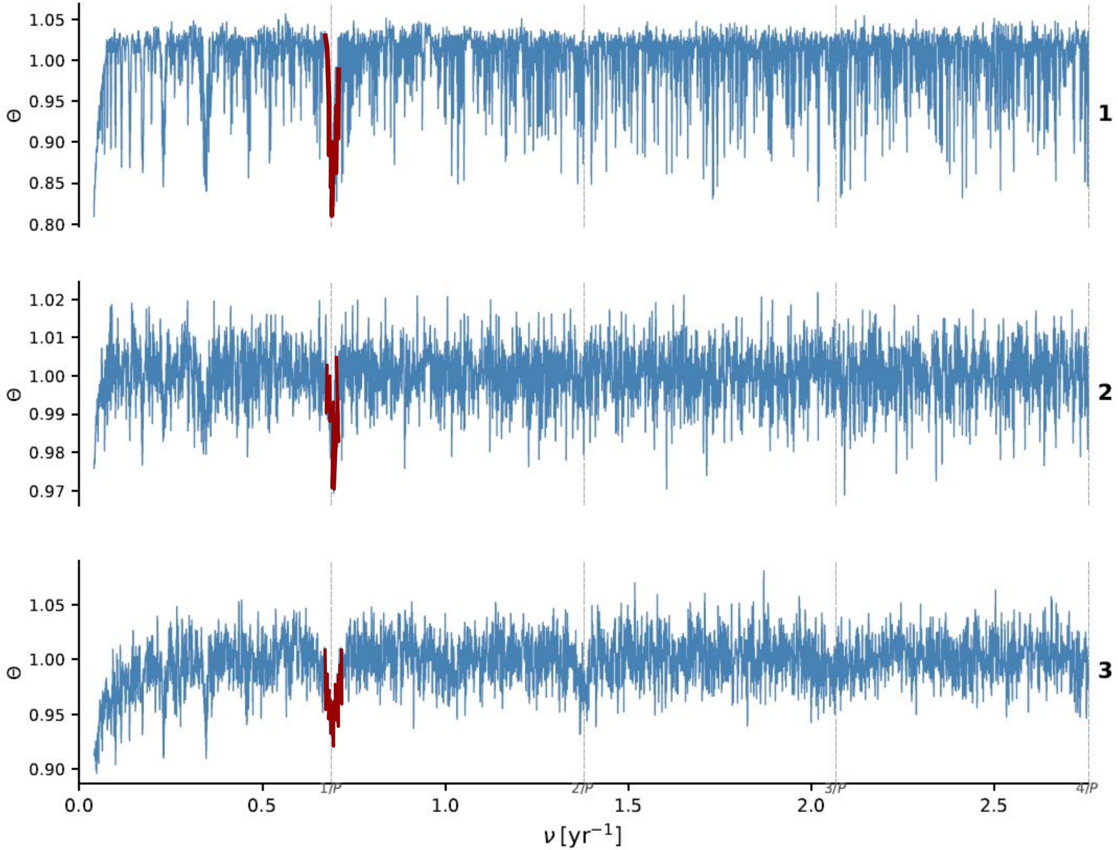


Noise 1 km/s

Noise 4 km/s

Noise 1 km/s
100 obs./yr

17. Abbe–Lafler–Kinman statistic

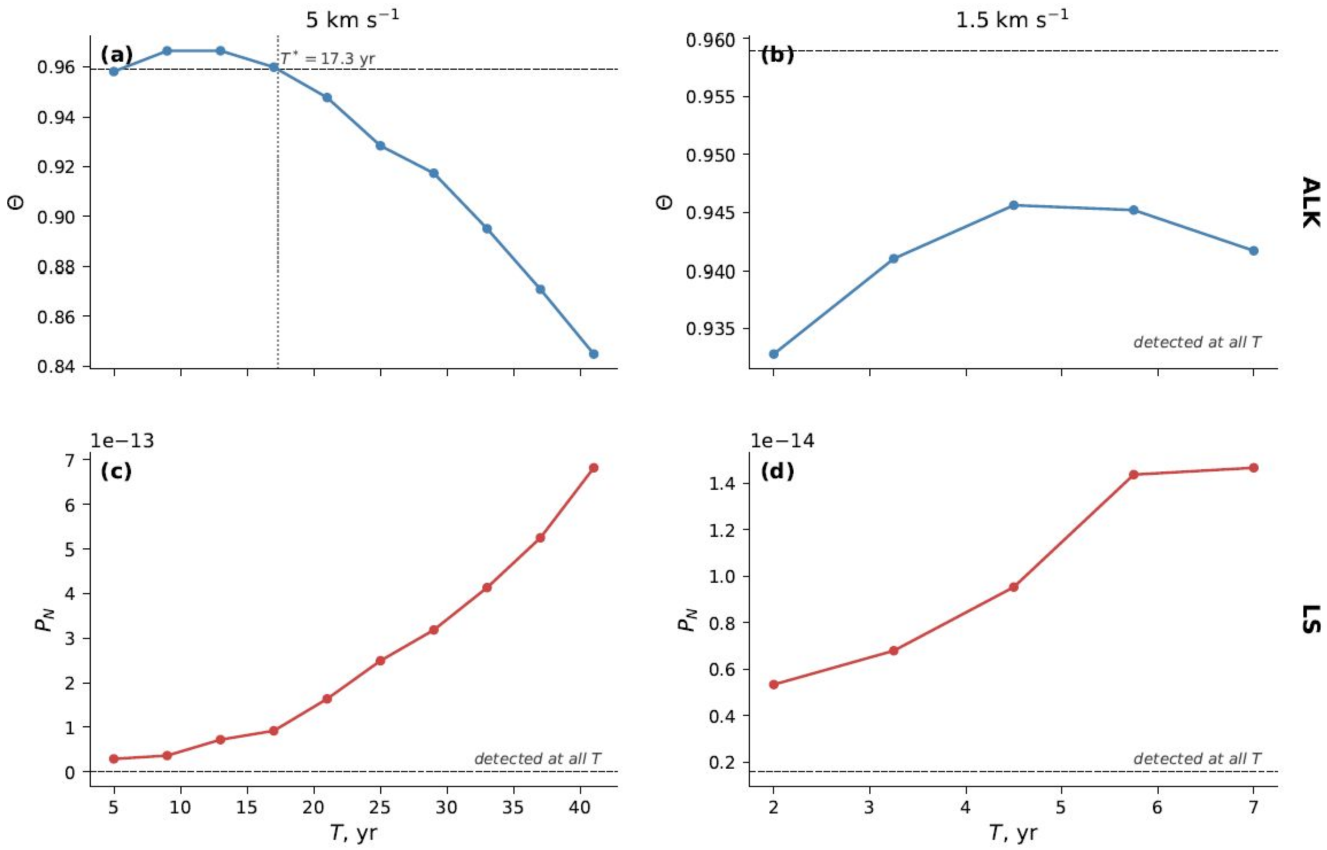


Noise 0.3 km/s

Noise 1 km/s

Noise 0.5 km/s
100 obs./yr

18. Spectral and non-parametric analysis



19. Results

1. A method for detecting traversable wormholes in wide binary systems via anomalous perturbations in the radial velocity of the companion star has been developed; an analytical expression for the perturbation amplitude has been derived, a signal template has been constructed, and a detection statistic based on the matched filtering method has been developed.
2. Numerical simulations of 500 synthetic systems demonstrate that, for a radial-velocity measurement precision of ~ 1.5 km/s, the effect can be detected over an observational baseline of 30–40 years; the LS spectrum and the ALC statistic serve as independent verification tools and reduce the required observation time to ~ 15 years.
3. A concrete observational program has been substantiated and formulated: monitoring of dBH-LC systems with a cadence of ~ 80–100 radial-velocity measurements per year.

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