Exoplanets around LISA Verification Binaries

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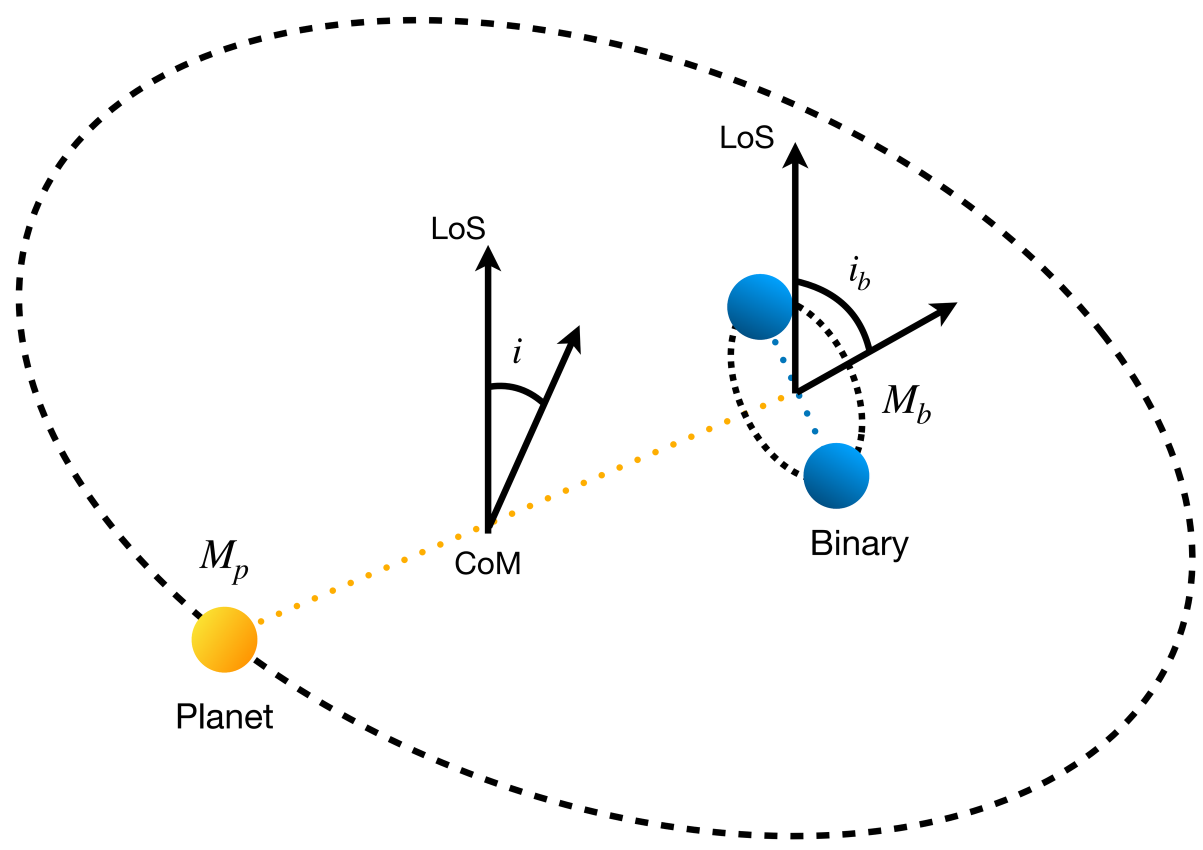
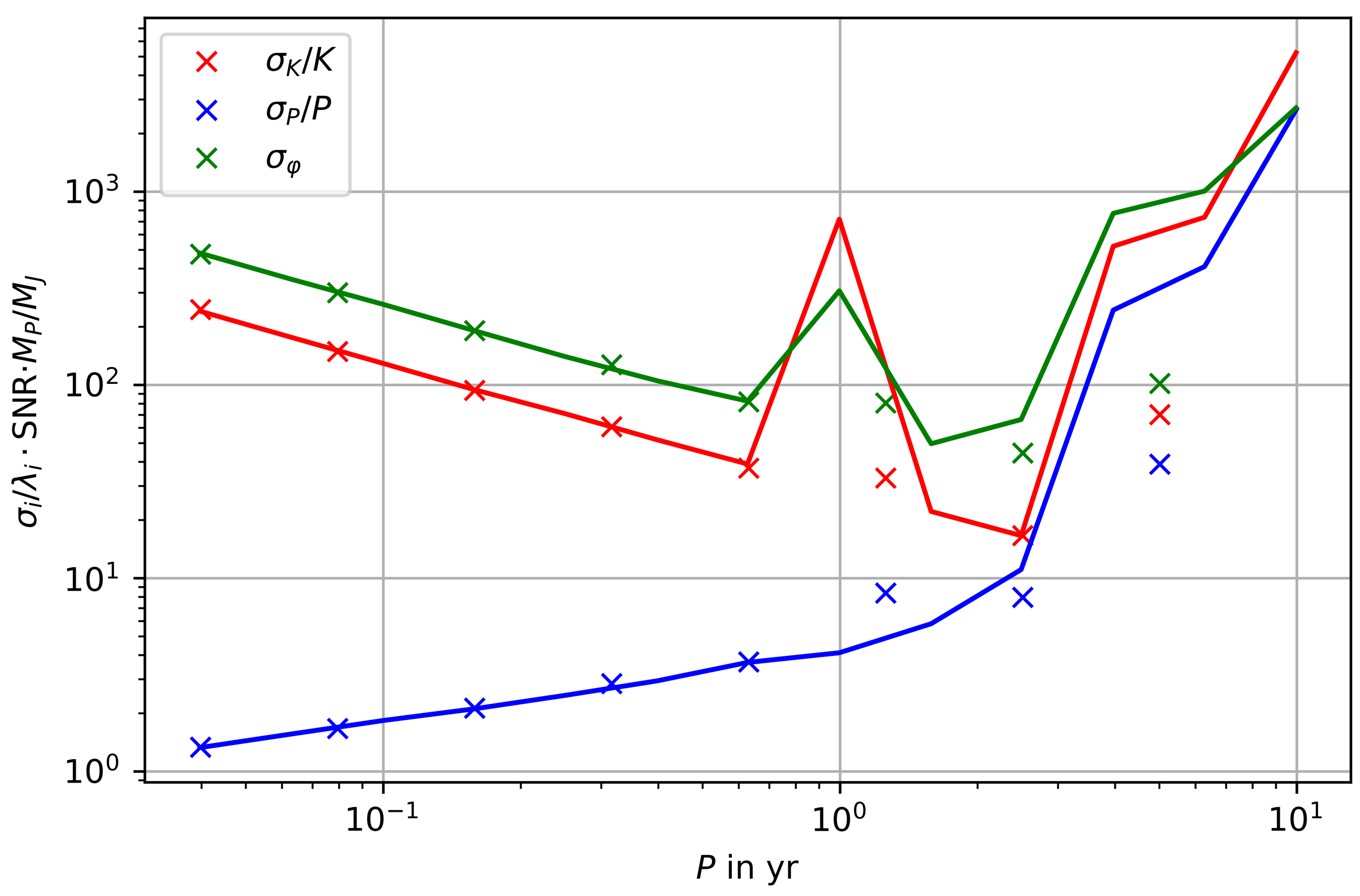
Laser Interferometer Space Antenna as an Exoplanet Detector

- *The launch of the **Laser Interferometer Space Antenna (LISA)** is currently planned for 2037.*
- *With the first ever detection of **gravitational waves** (GW), namely GW150914, GW astronomy has officially become a key part in **multi-messenger astronomy**.*
- *Recent years have seen the investigation of a **novel detection method** for exoplanets around GW emitting binary star systems.*
- *This technique[1] is conceptually similar to that of radial velocity measurements, where **the orbital motion of an exoplanet induces a detectable Doppler shift in the GW frequency of the binary system**, rather than its electromagnetic spectrum.*
- *Dozens of galactic binaries have been identified as so called "LISA verification binaries"; **loud, galactic, ultracompact GW sources with electromagnetic counterparts**.[2]*
- *The diagram shows the geometric setup of a compact binary with a circumbinary planet.*



*We investigate whether the **presence of an exoplanet** could leave a **detectable imprint** for LISA measurements in the **GW emission** of verification binaries!*

Methods and Analysis



- *The **Fisher information approach** lets us predict the **recoverable uncertainties of system parameters** σ_i and correlations $\mathrm{cov}(i,j)$ over the detector lifetime by assuming stationary Gaussian noise characterised by a **noise spectral density** $S_n(f)$ in the limit of **high** SNR.*
- *One can calculate the **Fisher matrix** by numerically performing the integration for a **nearly mono-chromatic signal** by $\Gamma_{ij} = \frac{2}{S_n(f_0)} \int_0^{T_{\mathrm{obs}}} \partial_i h(t) \partial_j h(t) \mathrm{d}t$ and then by taking **the inverse** of the Fisher information to recover the expected **covariance matrix** in the parameters λ_i, and λ_j.*
- *Panel shows **relative uncertainties** in the determination of the **planet's period** P, **it's initial phase** φ_0 and the parameter $K = \frac{2\pi G^{1/3}}{P} \frac{M_P}{(M_b+M_P)^{2/3}} \sin i$ related to the **minimum mass** for LISA, **normalized by the SNR** and **exoplanet mass** (solid lines), **if we have no prior information about the system.***
- *The **uncertainties scale as** $\sigma_i \propto \mathrm{SNR}^{-1}$ killing the explicit dependence on the strain sensitivity $S_n(f)$.*
- *LISA is unable to detect Jupiter-like circumbinary planets with no prior information about the source position, **which is not the case for verification binaries** (see next panel).*

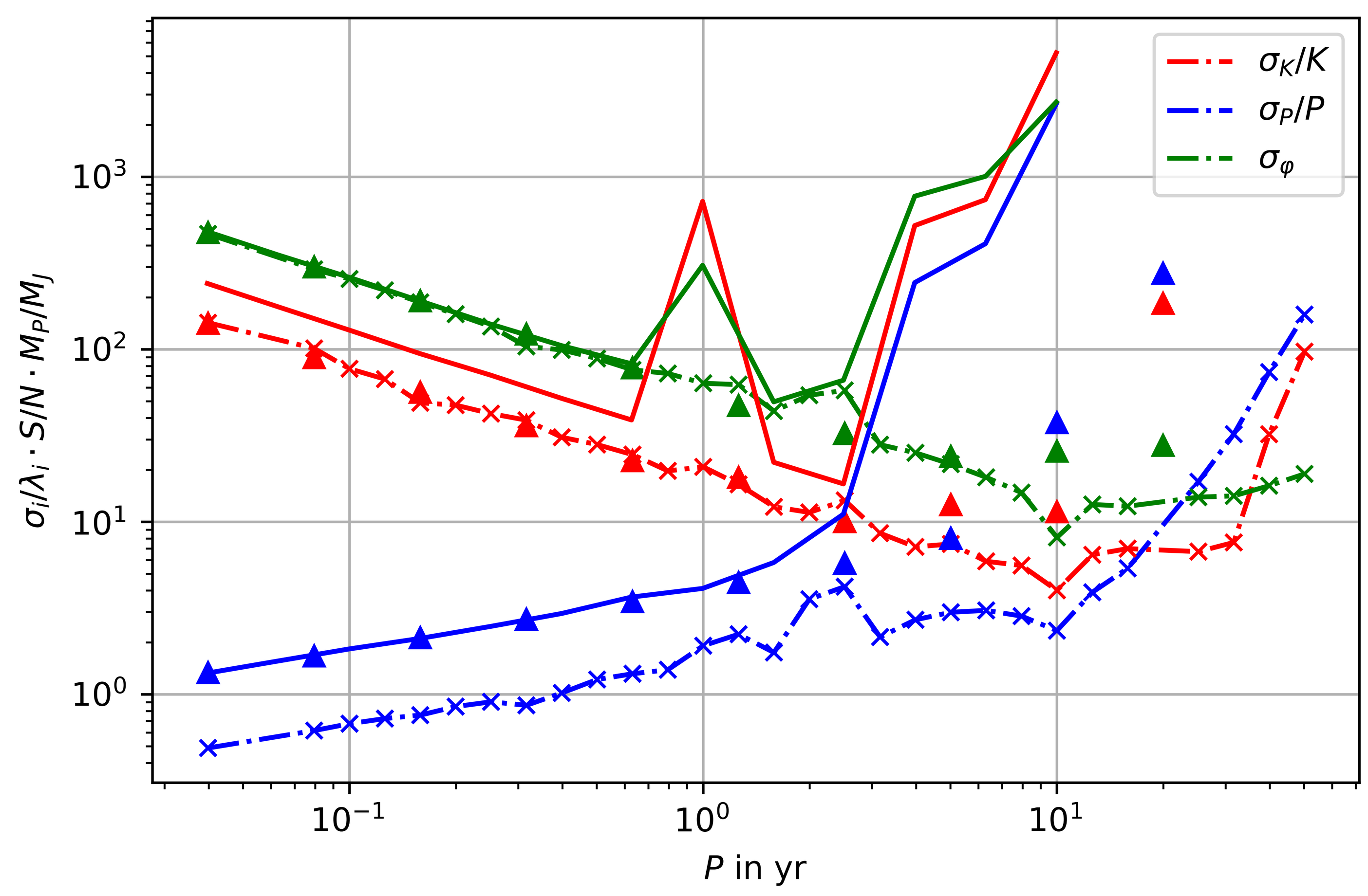
Challenges and Inclusion of Doppler Tracking

Challenges:

- *One needs high signal-to-noise ratios SNR $\gg$ 1 of the binary in order to observe the signal of an exoplanet, strongly reducing the number of candidate systems.*
- *As with classical RV techniques, this method is strongly biased to favor massive planets with orbital periods P comparable to the nominal mission life-time.*
- *As space-borne missions orbit the sun next to Earth, planets with periods comparable to a multiple of one year cant be resolved because of a high correlation with the detectors orbit. For verification binaries, this degeneracy vanishes.*

Doppler Tracking Missions to Uranus and Neptune:

- *Recent years have seen numerous publications underlining the importance of a **space mission** to the **ice giants** in the upcoming decade that involve a 10 yr cruise time. The cruise time can be **utilized to search for GWs** by observing the **Doppler shift** caused by them in their **radio link**.[3]*
- *Panel shows the uncertainties in determination of P, φ_0, K for random sources by LISA (solid lines) an ice giant Doppler tracking mission **for verification binaries** (dashed), and with LISA (triangles). Naturally, the SNR will be **much lower** for the Doppler tracking mission than for LISA.*



*Thus, **prospective ice giant missions** with sufficient Doppler tracking capabilities can help constrain exoplanet parameters **along with LISA**, around verification binaries.*

References

[1] Tamanini, N. Danielski, C. 2019 The gravitational-wave detection of exoplanets orbiting white dwarf binaries using LISA, *Nature Astronomy*
[2] Kupfer, T et al. 2018: LISA verification binaries with updated distances from Gaia Data Release 2, *MNRAS*
[3] Soyuer D. et al. 2021: Searching for gravitational waves via Doppler tracking by future missions to Uranus and Neptune, *MNRAS*

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