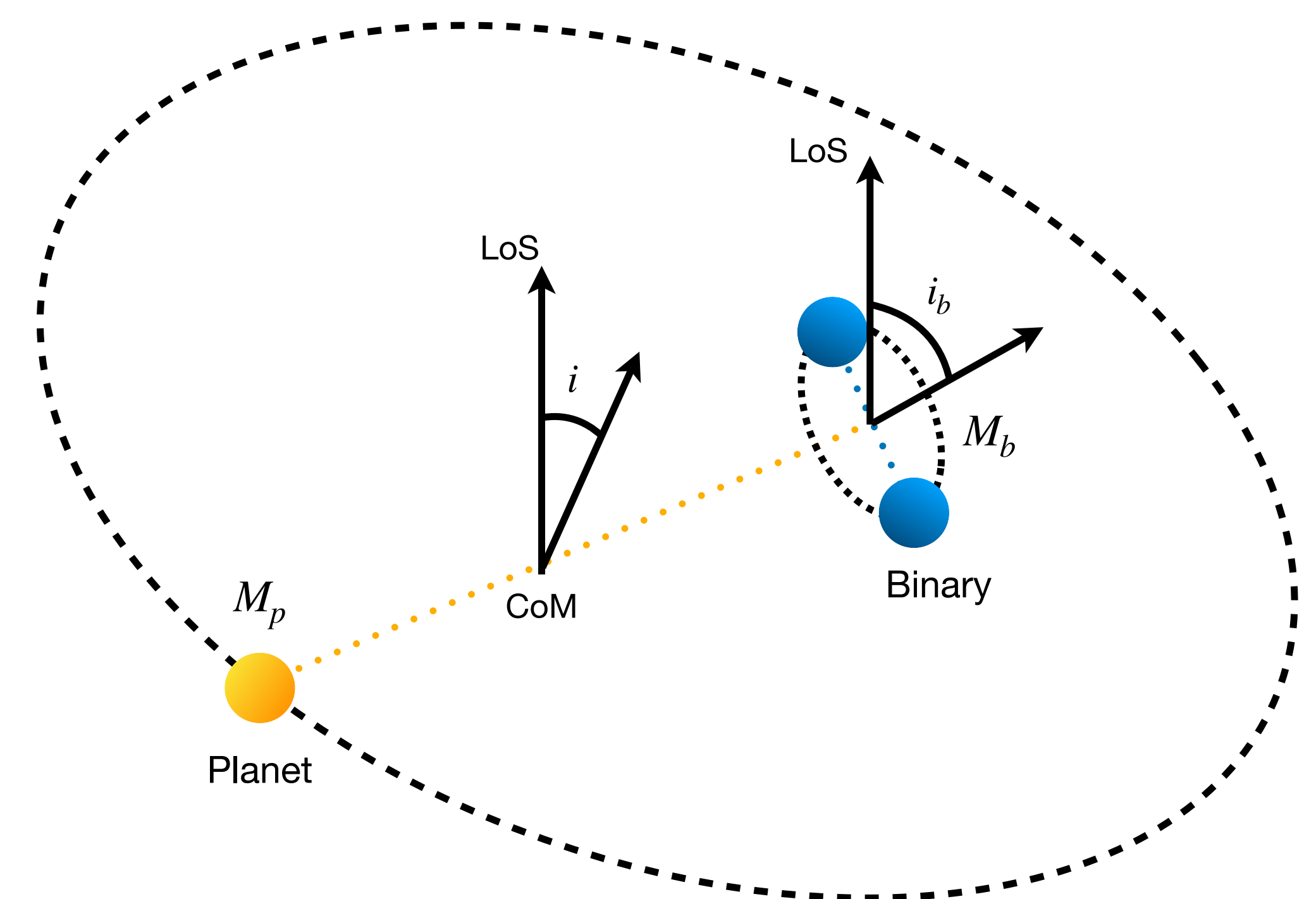


Exoplanets around LISA Verification Binaries

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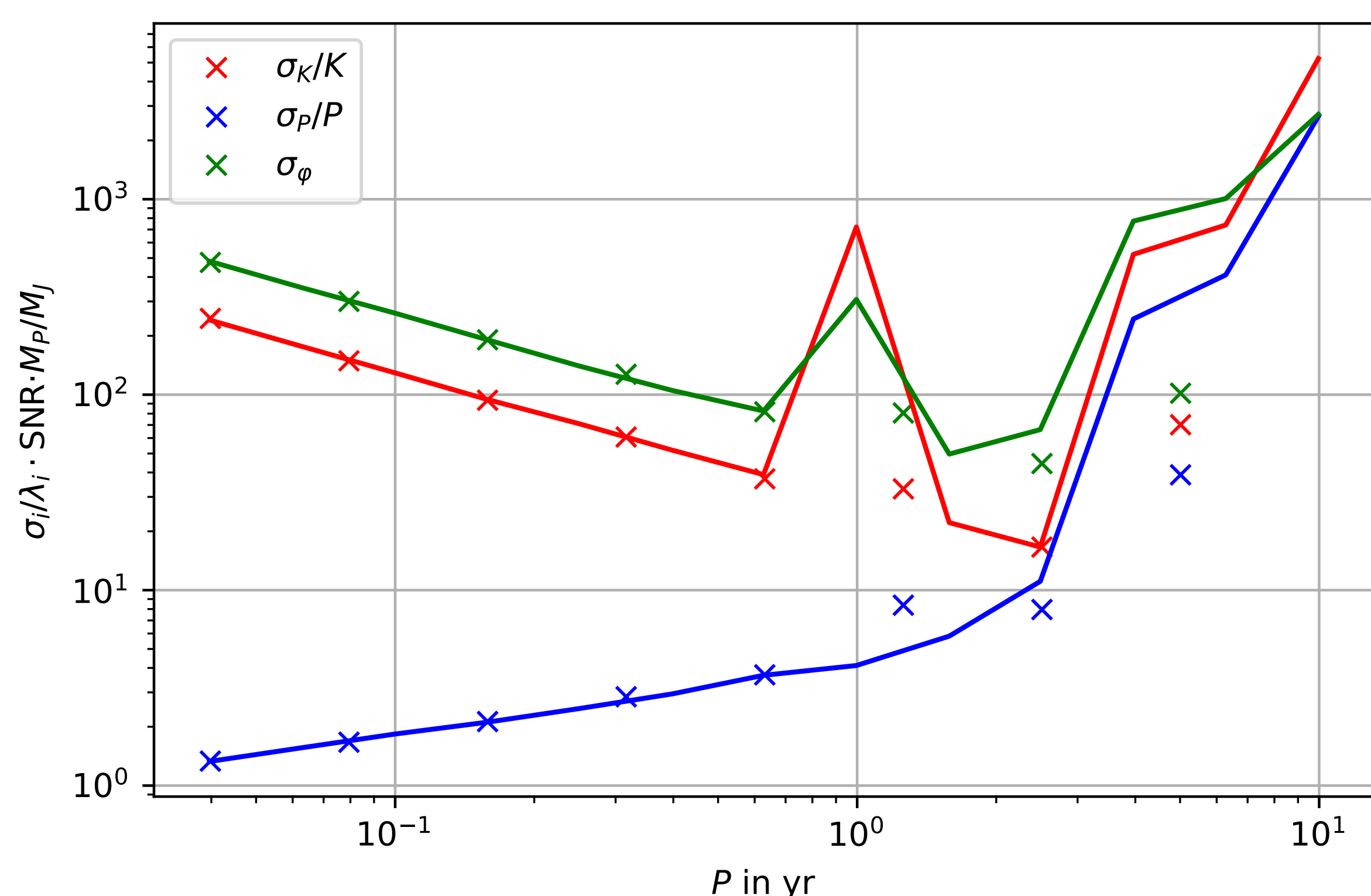
Laser Interferometer Space Antenna as an Exoplanet Detector

- 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 $\text{cov}(i, j)$ 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 monochromatic signal** by $\Gamma_{ij} = \frac{2}{S_n(f_0)} \int_0^{T_{\text{obs}}} \partial_i h(t) \partial_j h(t) dt$ 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 , **its 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** $\sigma_i \propto \text{SNR}^{-1}$ 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).

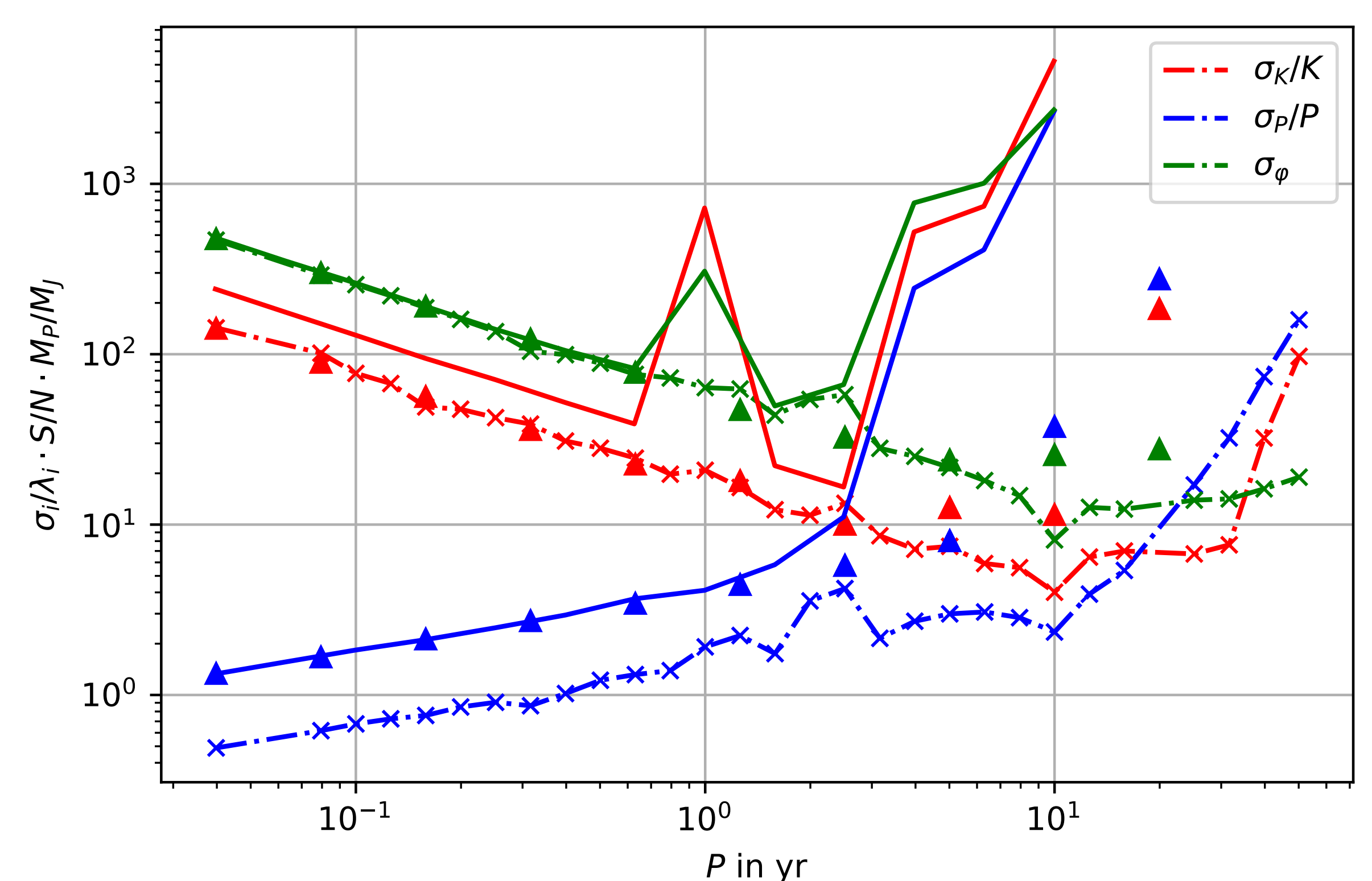
Challenges and Inclusion of Doppler Tracking

Challenges:

- One needs high signal-to-noise ratios $\text{SNR} \gg 1$ 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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