Polarisation Prediction for LISA via Intensity Interferometry

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1. Introduction

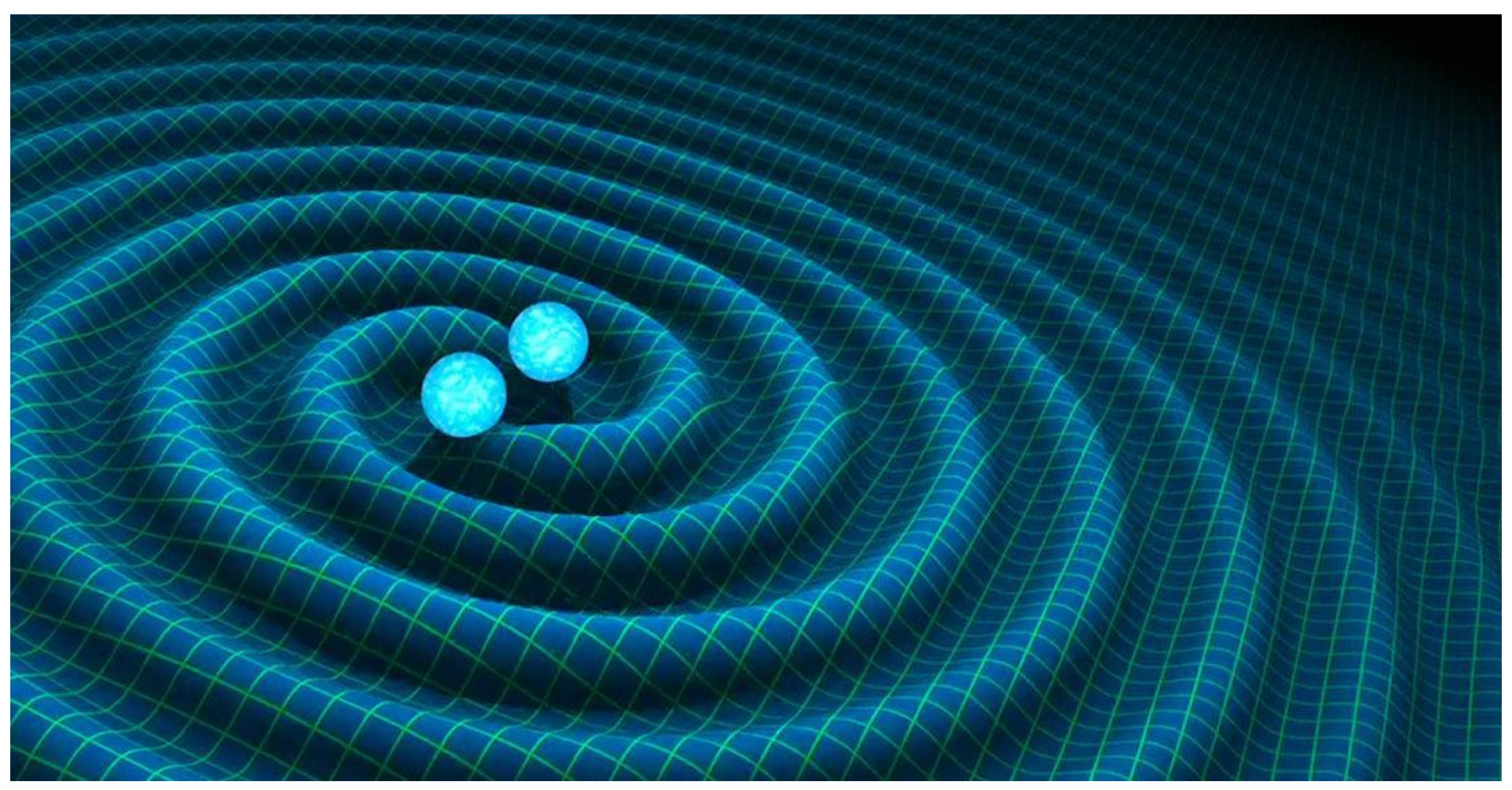
Certain close binary-star systems in the Galaxy will be detected via gravitational waves by LISA. If the orientation on the sky of any of these LISA verification binaries[1] were to be inferred from its electromagnetic signal, gravitational wave predictions could be extended to include polarisation amplitudes. We propose a novel strategy for doing this, using intensity interferometry for the Cherenkov Telescope Array.[2]

[1] Stroeer A., Vecchio A., 2006, Classical and Quantum Gravity, 23,S809

[2] Dravins D., LeBohec S., Jensen H., Nuñez P. D., 2013, Astropar-ticle Physics, 43, 331

2. Gravitational Waves

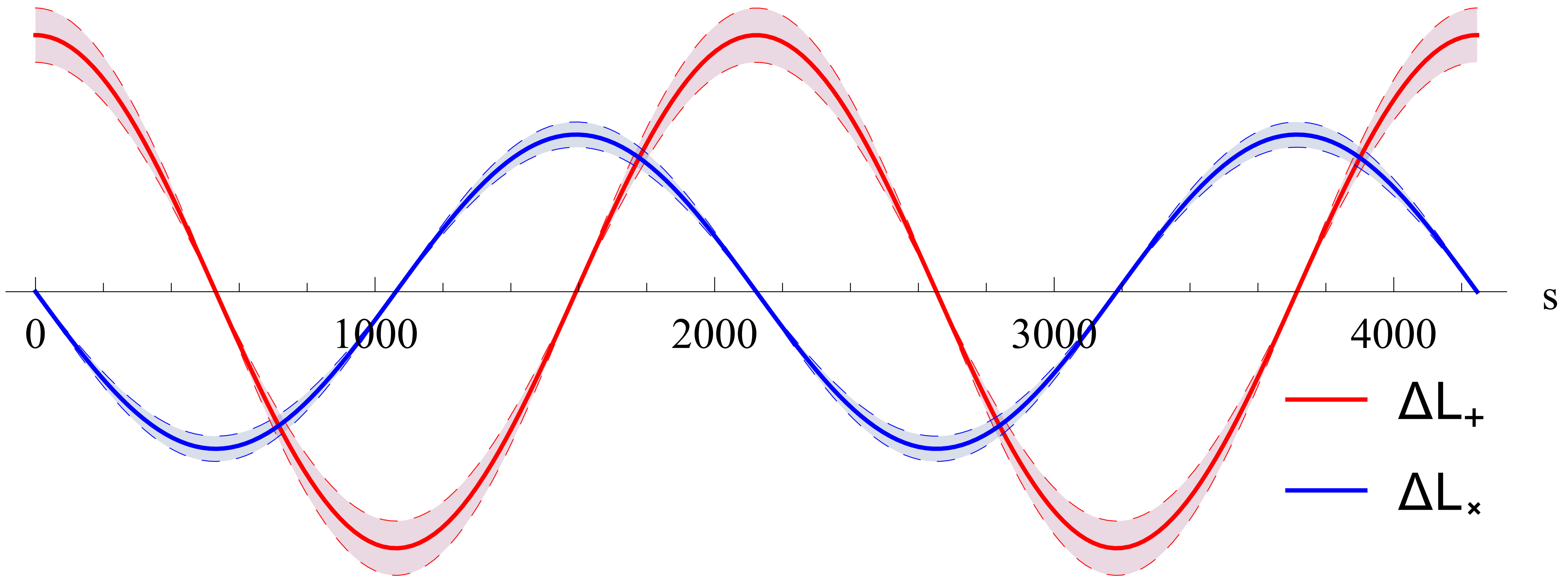
Predicting a gravitational wave signal requires knowledge of all parameters that characterise the source and its orientation with respect to the detector. For LISA verification binaries, all the parameters are already known — *except* the orientation on the sky, which cannot be determined yet via direct imaging. The intensity interferometry method provides the missing ingredient for a prediction of the polarisation amplitudes.



Artist's impression by R. Hurt (Caltech-JPL)

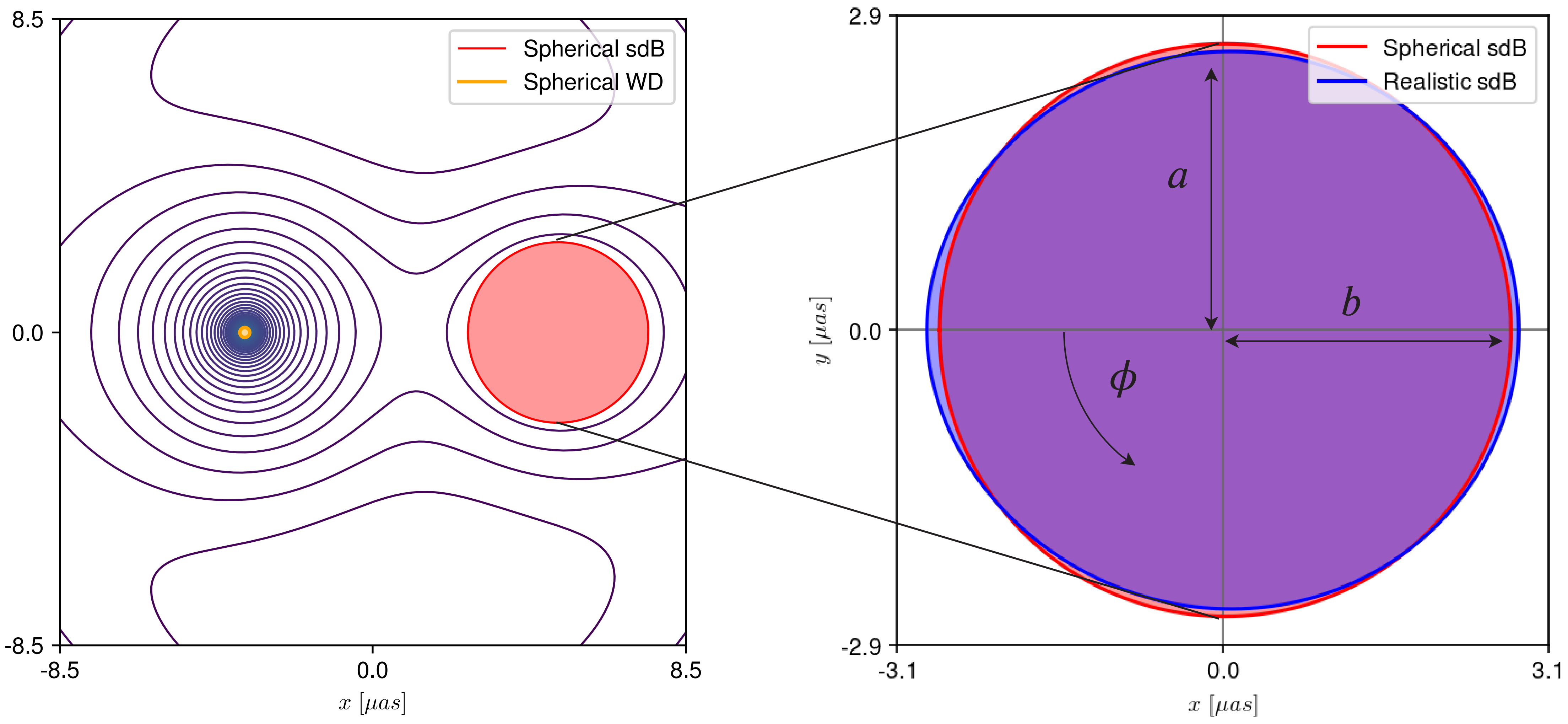
3. Predicting the Polarisation Amplitudes

Here,we show a simulated prediction of a gravitational wave strain. The observed strains ΔL_+ and $\Delta L_\times$, corresponding to two polarisations, depend on the orientation of the detector arms (known) and the orientation of the source (to be separately measured). A determination of the latter to within a few degrees yields an uncertainty of $\sim 10\%$ in the gravitational wave strain for CD-30 11223.

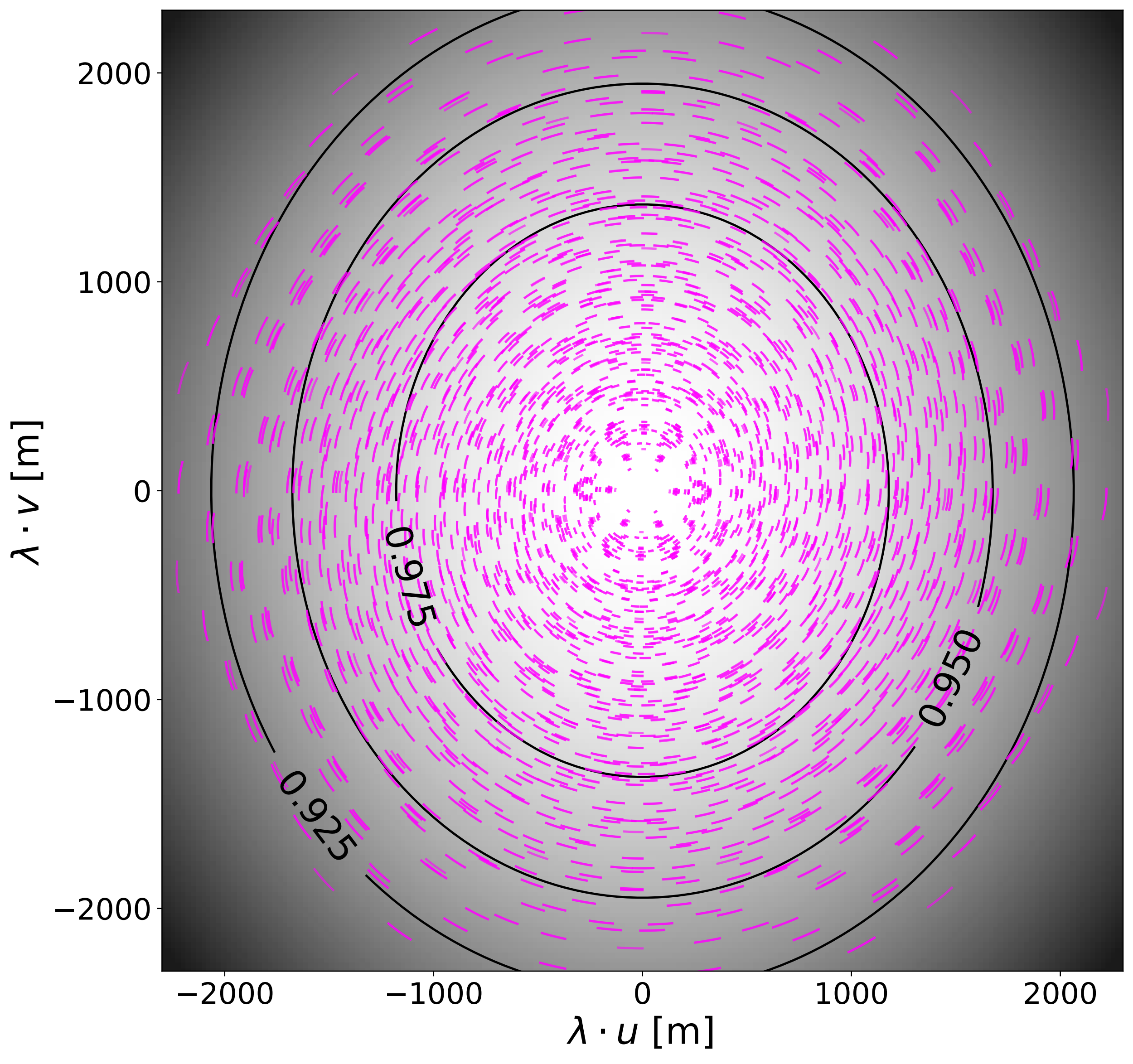


4. Tidal Effects

Here we consider the brightest LISA verification binary CD-30 11223, which consists of a hot helium star and a much fainter white dwarf. Due to tidal interactions, the shape of the larger star is distorted. According to the Roche potential, the stellar surfaces are not spherical but follow a tear-drop-shaped equipotential line. The actual value of the surface potential is found through the requirement that the enclosed mass be equal to the observed stellar mass. For this system we obtain a deviation of $\sim 6\%$ from unity on the ratio of the two semi-axes a and b. By measuring the elongation direction we can infer the orientation of the orbital plane which allows for predicting the polarisation of the gravitational waves emitted by the binary.



5. Intensity Interferometry



The main idea behind intensity interferometry involves *temporally* correlating the light signals received by a pair of telescopes, in order to deduce *geometric* properties of a light source. The measured intensities in both telescopes $\langle I_1 \rangle$ and $\langle I_2 \rangle$ (averaged over a timescale, characteristic of the setup) can be cross correlated, leading to a profile $\langle I_1 \cdot I_2 \rangle(\mathbf{B})$ depending on the baseline $\mathbf{B}$ between the telescopes. Assuming a chaotic and extended light source, one can relate the time correlation of the intensity fluctuations $\langle \Delta I \rangle = \langle I - \langle I \rangle \rangle$, to the Fourier magnitude of the source distribution $\Sigma(\mathbf{r})$ in the spectral plane:

$$\langle \Delta I_1 \cdot \Delta I_2 \rangle = \langle I_1 \rangle \langle I_2 \rangle |\gamma_{12}|^2$$

Here we see the coverage on the Fourier magnitude plane by the Cherenkov Telescope Array (CTA) South for an exposure time of 30 minutes. The Earth's rotation helps us sample the plane efficiently. We can compute the observation time required to get a sufficient signal to noise ratio to measure the variations of $|\gamma_{12}|^2$. With currently available photon-detectors, the integration time needed would be several months. If larger arrays of photon detectors (SPADs or superconducting nanowires) become available, the observing time would decrease dramatically. On the other hand, using the Very Large Telescope in combination with CTA, the required integration time becomes of the order of days.