Albert Einstein Institute
Max Planck Institute for Gravitational Physics and
Leibniz Universität Hannover

Optical Cross Coupling in Space-Based Gravitational Wave Detectors

Marie-Sophie Hartig and Gudrun Wanner

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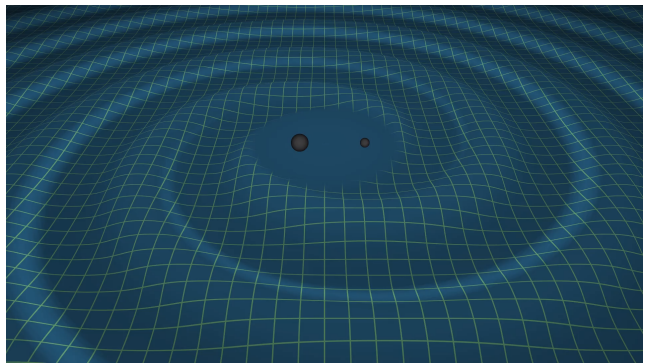
lisa pathfinder

What are Gravitational Waves?

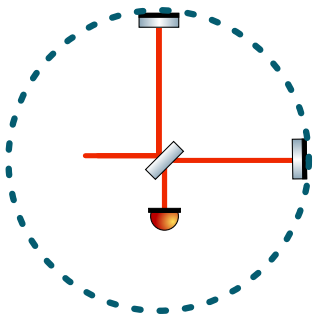
Gravitational Waves (GW) are 'ripples' in space time. They carry the information about their origins.

Sources of interest:
very massive accelerating objects



Credit: LIGO/T. Pyle

Ground-Based Gravitational Waves Detectors

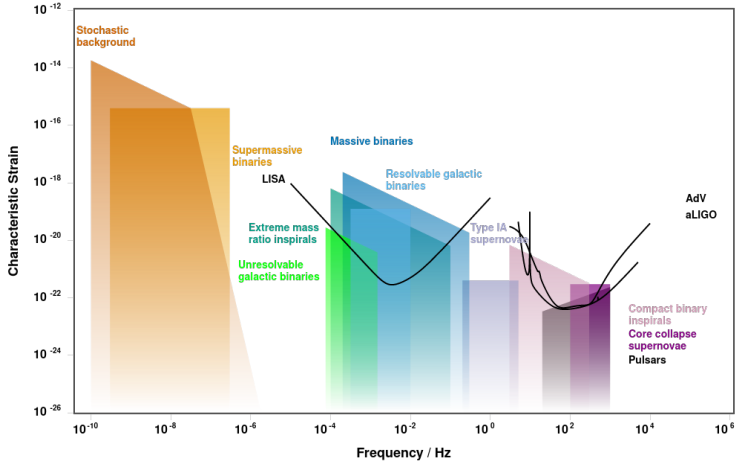


LIGO, Credit: LIGO Lab/Caltech/MIT

Virgo, Credit:
The Virgo Collaboration

Limits: size, seismic noise (traffic, tides, ...), ...

Why going to Space?

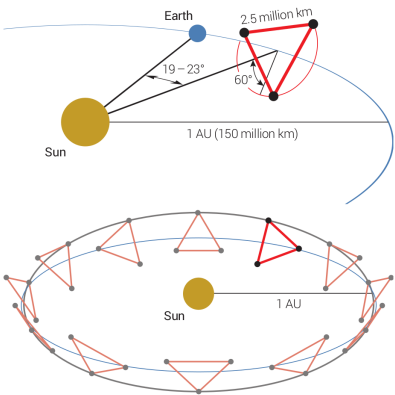


Source: `gwplotter.com`

⇒ earth-bound detectors cannot detect all sources

⇒ go to space: **LISA**

Laser Interferometer Space Antenna (LISA)



LISA is the first ever mission to study the entire Universe with Gravitational Waves.

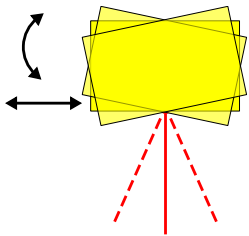
- ⇒ ESA mission with contributions from NASA
- ⇒ 3 spacecraft exchanging laser beams
- ⇒ follows behind the Earth in its orbit

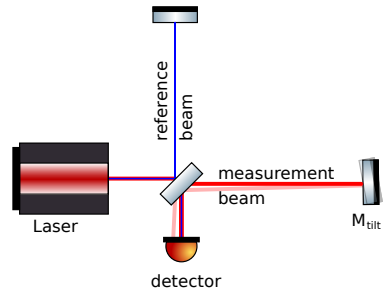
Planned launch: 2034

Investigated noise: Laser frequency noise, Clock noise, Tilt-To-Length Coupling, ...

Tilt-To-Length Coupling

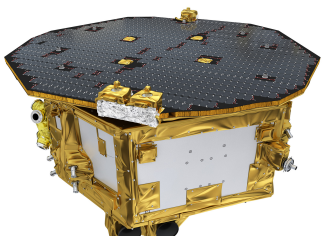
Tilt-To-Length Coupling (TTL) =
Cross coupling of lateral and angular jitter into the length measurement





TTL in Space Missions

TTL coupling was a major noise source in the LISA Pathfinder Mission!



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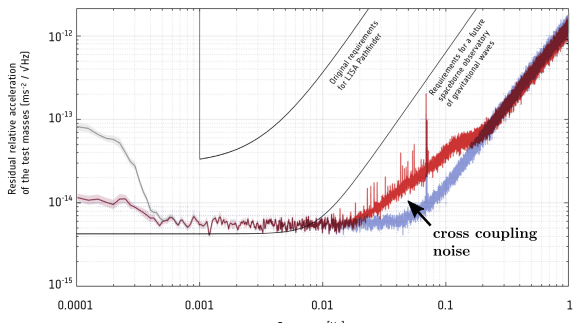

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Further reading: https://doi.org/10.1103/PhysRevLett.116.231101

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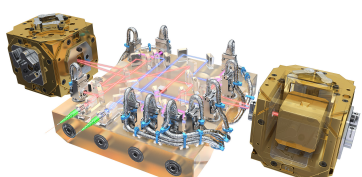

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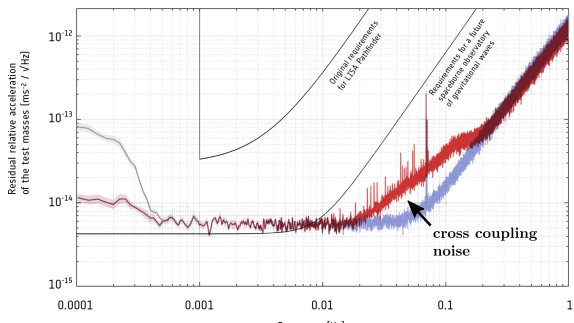

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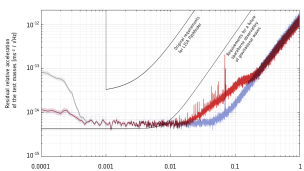
Analytic Model

Subtraction strategy:

Fit cross coupling noise (acceleration noise) and subtract it from measurements:

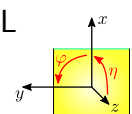
$$\Delta g_{\mathrm{x-talk}} = C_1\ddot{\varphi}[t] + C_2\ddot{\eta}[t] + C_3\ddot{y}[t] + C_4\ddot{z}[t] + C_5\overline{y}[t] + C_6\overline{z}[t] + \delta_{\mathrm{ifo}}\ddot{x}_1[t]$$



Disadvantages:
no physical interpretation of coefficients, models not unique, coefficients vary

Suppression strategy:

Find analytic TTL model. Realign components for a suppression of the TTL effect.

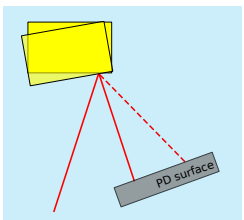


Further reading: https://doi.org/10.1088/1742-6596/840/1/012043

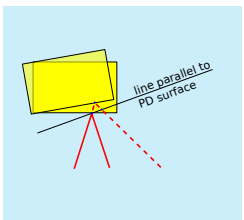
... it's complicated

Geometric effects:

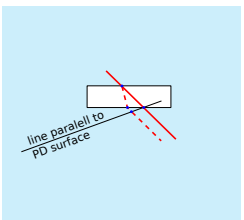
Lever Arm Effect



Piston Effect

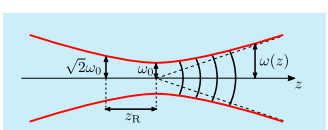


Transm. Comp.

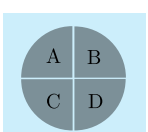


Other ("non-geometric") effects:

Gaussian Beams



Detector Shape

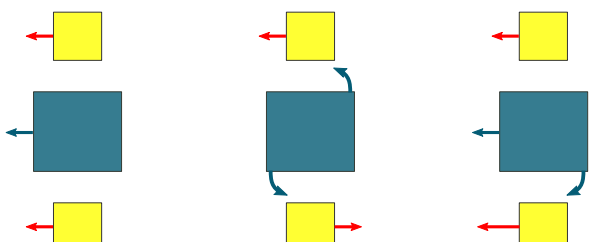


... and many more.

Status of Investigations

- ✓ Full analytic 3D model
- ✓ Verification of model against numerical results
- ☐ Verification of model against real data from an LPF experiment dedicated to test TTL (ongoing...)

Experiment:



Acknowledgments

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