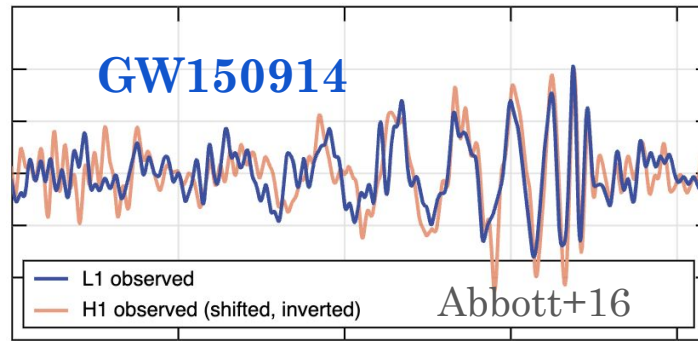




Gravitational-Wave (GW) Astrophysics

Lecture 1

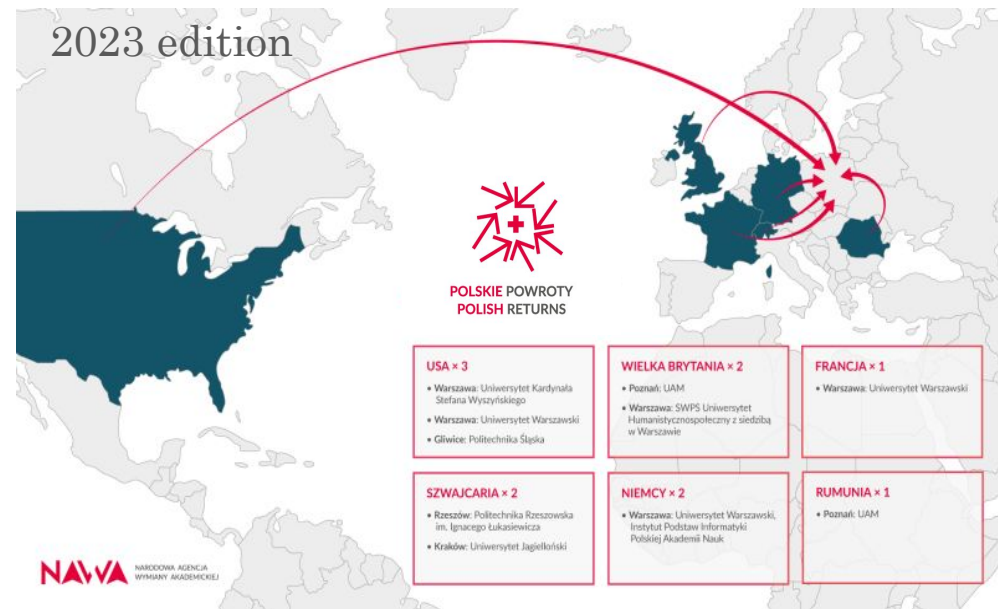
Marek Szczepańczyk
Department of Physics,
University of Warsaw

Warsaw, 06.09.2026

Return to Poland

- B.A., M.Sc., University of Warsaw
- Ph.D., ~5 years: Embry-Riddle Aeronautical University (Arizona)
- Postdoc, ~5 years: University of Florida
- Assistant Professor, present: University of Warsaw

<https://www.fuw.edu.pl/~mszczepancyk/>



Organization

The course is a practical introduction to Gravitational-Wave Astrophysics

Criteria to pass the course: oral exams

- Winter semester: project
- Spring semester: choose a GW source/effect, what are the detection prospects? (research project)

Supporting literature (theory):

- Slides: <https://www.fuw.edu.pl/~mszczepancyk/>
- Maggiore M., Gravitational Waves. Vol. 1: Theory and Experiments
- Maggiore M., Gravitational Waves. Vol. 2: Astrophysics and Cosmology
- Creighton J. & Anderson W., Gravitational Wave Physics and Astronomy
- And...

Organization

Overview of Gravitational Waves

Astrophysics (Winter semester 2026/27)

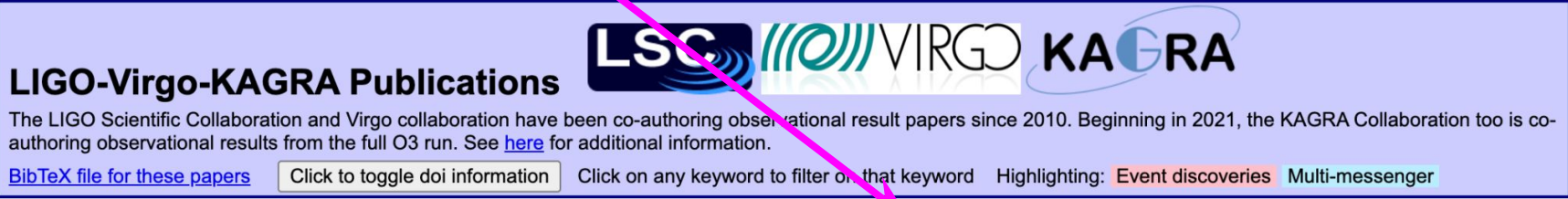
- General Relativity and linearized theory
- Gravitational-wave sources
 - Generation: quadrupole formula and examples
 - Compact binaries: black holes and neutron stars
- Gravitational-wave detectors
 - Interferometry
 - Detector network
- Gravitational-wave data analysis and searches
 - Model-dependent (matched filtering)
 - Model-independent (burst)

Future of the field (Spring semester 2026/27)

- The next decade of Gravitational-Wave Astrophysics
- The next-generation detectors
 - Cosmic Explorer
 - Einstein Telescope
- Special gravitational-wave sources detected so far
 - Gravitational-wave lensing
 - Binary neutron stars
 - Special compact objects
 - Core-collapse supernova
 - Pulsar glitches
 - Quasi-normal modes

Literature (status of the field)

- LIGO-Virgo-KAGRA papers: <https://pnp.ligo.org/ppcomm/Papers.html>
- The field is evolving quickly: Science Summaries

<div>  </div>						
Release Date	Title	Keywords (clear filter)	Science Summary	Journal citation	arXiv Preprint	Public Report
Oct 28, 2025 <i>*Recent*</i>	GW241011 and GW241110: Exploring Binary Formation and Fundamental Physics with Asymmetric, High-spin Black Hole Coalescences (by LSC, Virgo and KAGRA)	O4 CBC LVK	summary	Astrophys. J. Lett. 993, 21 (2025)	2510.26931	P2500402
Oct 20, 2025 <i>*Recent*</i>	Directional search for persistent gravitational waves: Results from the first part of LIGO, Virgo, and KAGRA's fourth Observing Run (by LSC, Virgo and KAGRA)	O4 Stochastic LVK	summary	Submitted to PRD	2510.17487	P2500380
Sep 10, 2025 <i>*Recent*</i>	GW250114: Testing Hawking's area law and the Kerr nature of black holes (by LSC, Virgo and KAGRA)	O4 CBC GW250114 LVK	summary	Phys. Rev. Lett. 135, 11405 (2025)	2509.08054	P2500421
Sep 10, 2025 <i>*Recent*</i>	Black Hole Spectroscopy and Tests of General Relativity with GW250114 (by LSC, Virgo and KAGRA)	O4 CBC GW250114 TGR LVK	summary	Submitted to PRL	2509.08099	P2500461
Sep 9, 2025 <i>*Recent*</i>	GW230814: investigation of a loud gravitational-wave signal observed with a single detector (by A. G. Abac et al. (LSC, Virgo and KAGRA))	O4 GW230814 LVK	summary	Submitted to ApJL	2509.07348	P230814
Sep 9, 2025 <i>*Recent*</i>	Directed searches for gravitational waves from ultralight vector boson clouds around merger remnant and galactic black holes during the first part of the fourth LIGO-Virgo-KAGRA observing run (by LSC, Virgo and KAGRA)	O4 CW LVK	summary	Submitted to PRD	2509.07352	P2500256
Sep 4, 2025 <i>*Recent*</i>	GWTC-4.0: constraints on the cosmic expansion rate and modified gravitational-wave propagation (by LSC, Virgo and KAGRA)	O4 CBC LVK	summary	Submitted to ApJL	2509.04348	P2400152
	Upper Limits on the Isotropic Gravitational-Wave Background from	O4				

Lecture 1

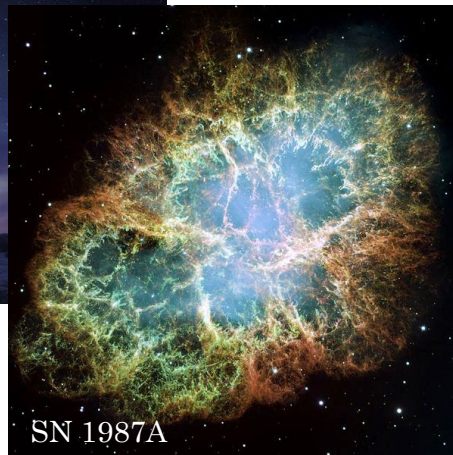
Introduction to GW Astrophysics

“Conventional” and “Gravitational-Wave” Astronomy

“Conventional” or time-domain Astronomy:

observing Universe using electromagnetic waves (e.g. visible light), cosmic rays or neutrinos.

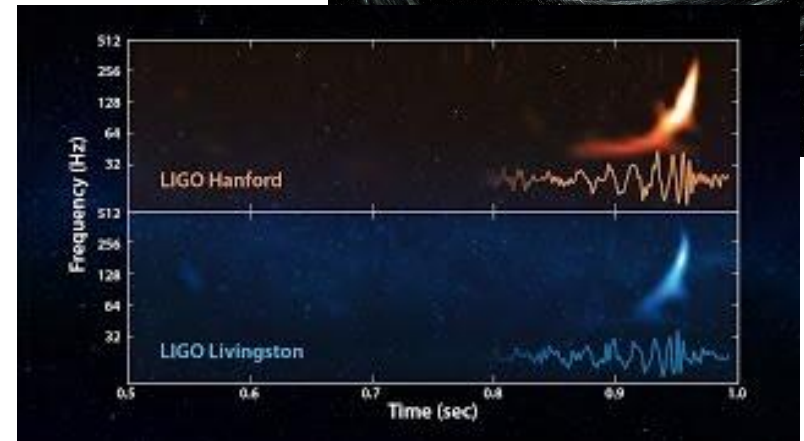
Looking at the Universe



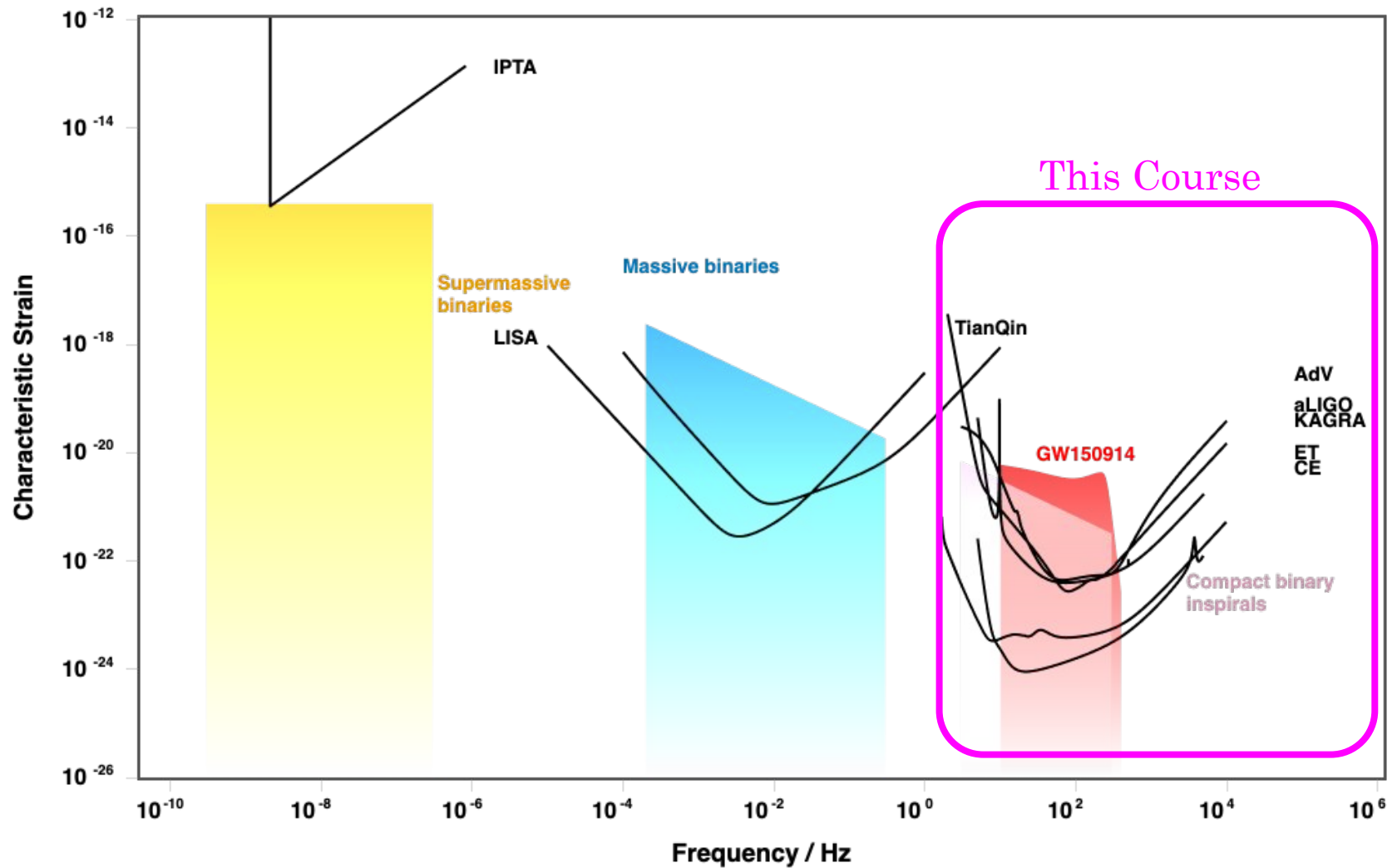
“Gravitational-Wave” Astronomy: observing Universe using gravitational-waves, the “ripples of spacetime”.

Listening to the Universe

Aurore Simonnet/LIGO/Caltech/
MIT/Sonoma State



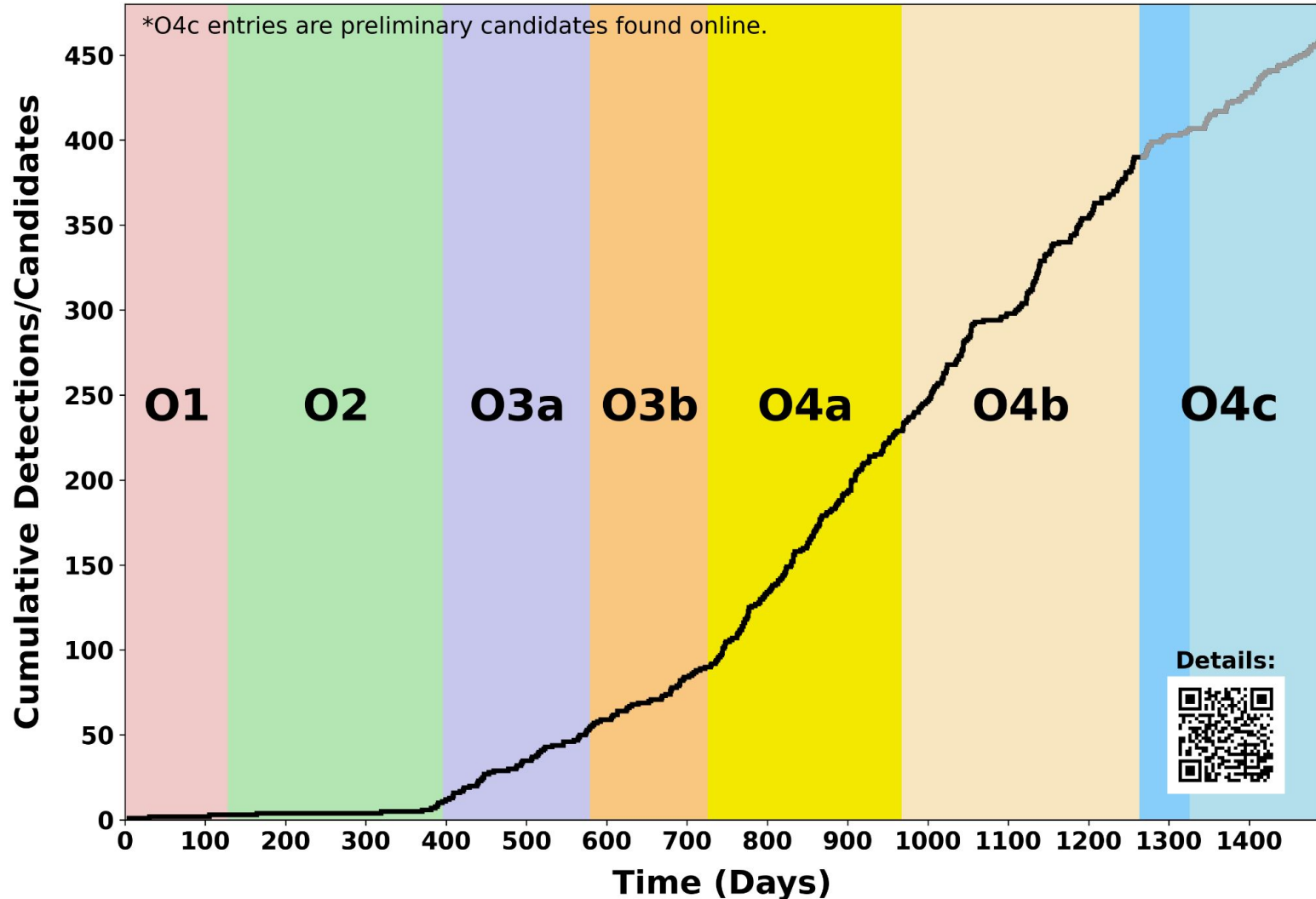
GW Spectrum



<http://gwplotter.com/>

Observing Run 4

O1 (3) + O2 (8) + O3a (44) + O3b (35) + O4a (139) + O4b (161) = 390, O4c* = 68, Total = 458



LIGO-G2302098 (f244d4f6), updated on 25 May, 2026

Credit: LIGO-Virgo-KAGRA Collaboration

Rapidly evolving field

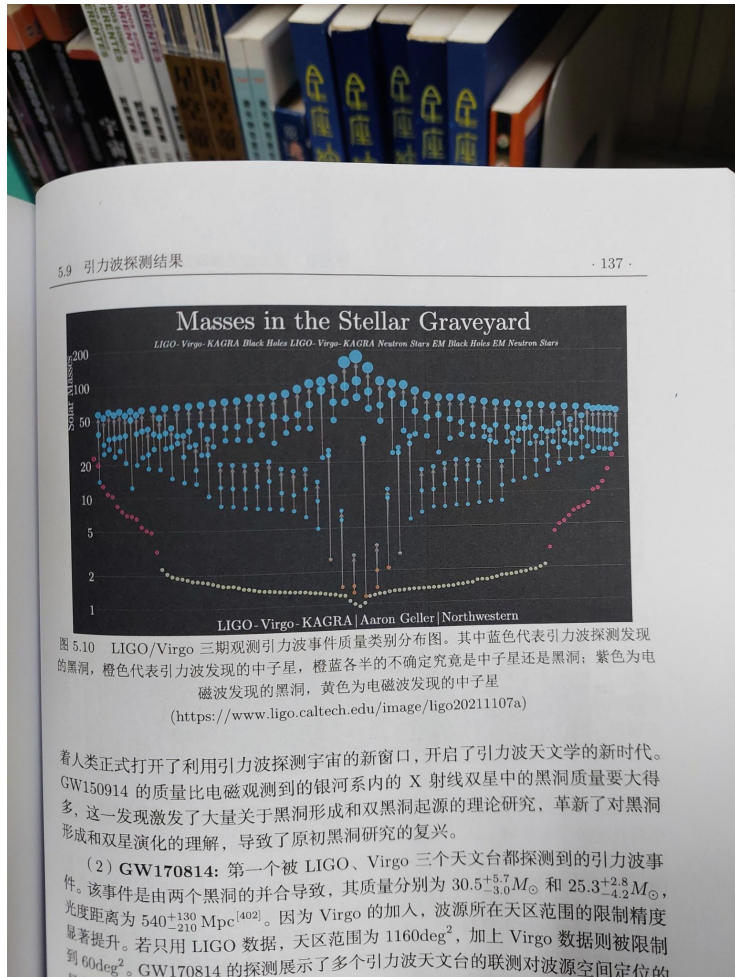
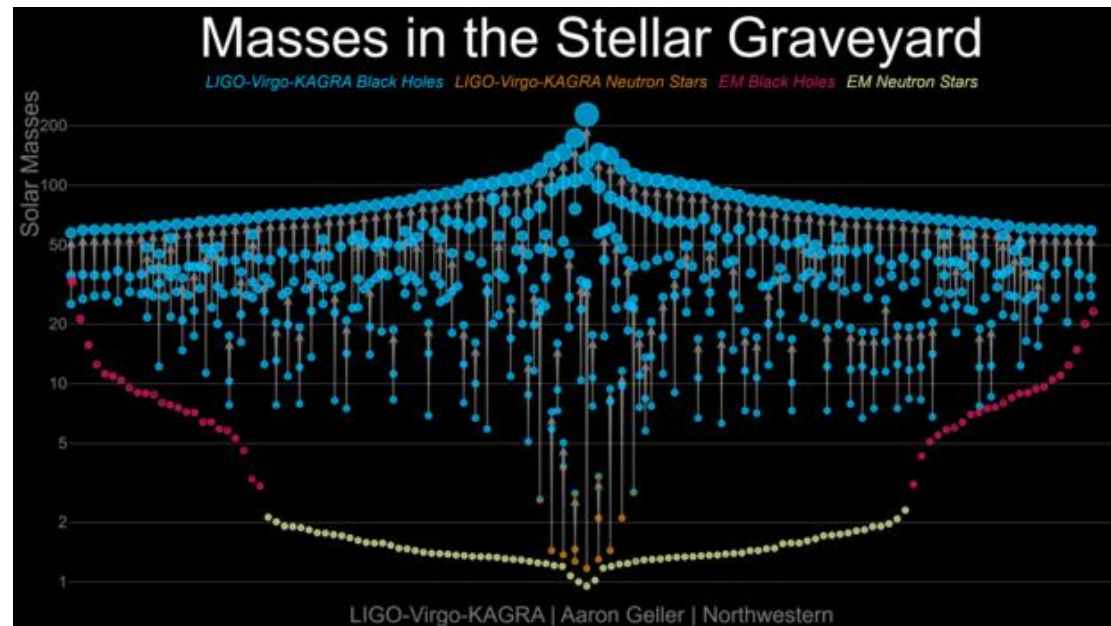
GW Catalog:

O1 + O2 + O3

Books are getting outdated quickly...

GW Catalog:

O1 + O2 + O3 + O4a



Einstein Equation and Experimental Gravitation

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

- *Space-time tells matter how to move; matter tells spacetime how to curve* J. Wheeler
- Einstein Equation:
 - Solving it analytically/numerically, or
 - **Let the Nature solve it for us**
- An abundance of gravitational-wave sources are to discover, but only handful are precisely modelled.

Gravitational Waves

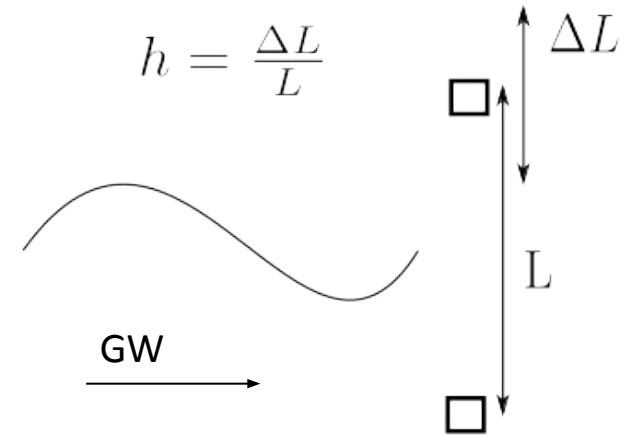
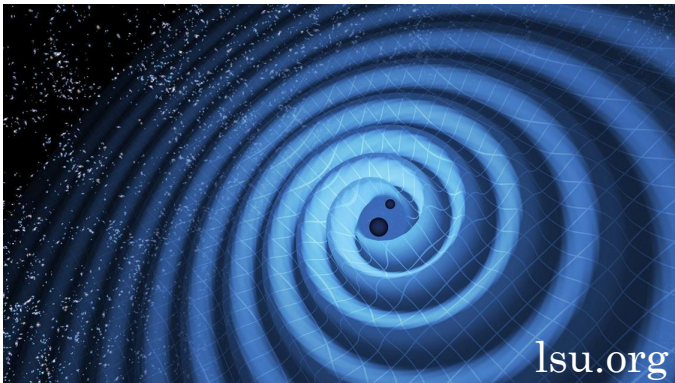
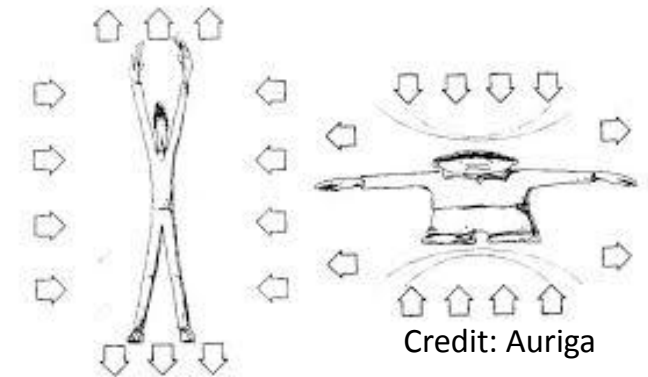
1916 – Gravitational Wave solution, linear approximation:

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

h – GW strain

14.09.2015 – Detection of Gravitational Waves!

GWs passing through two objects change distance between them.



Credit: Auriga