Waveforms

The 3rd event

LVT151012

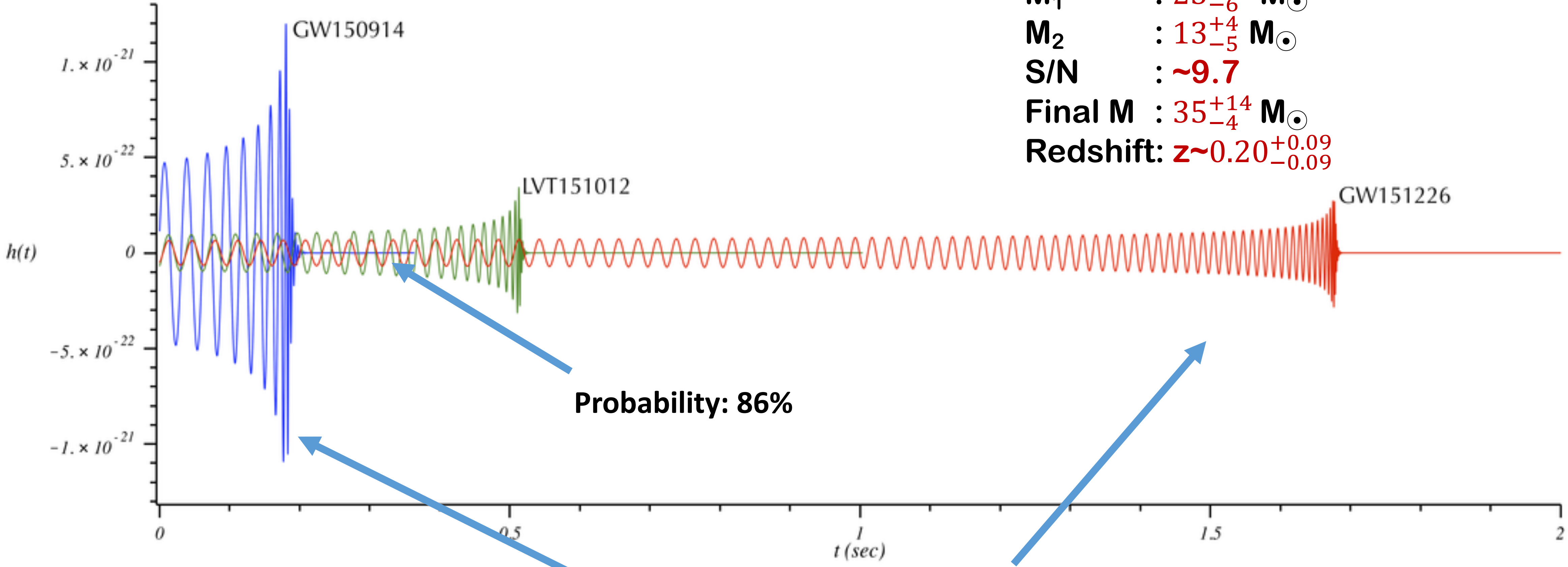
M_1 : 23^{+18}_{-6} $M_\odot$

M_2 : 13^{+4}_{-5} $M_\odot$

S/N : **~9.7**

Final M : 35^{+14}_{-4} $M_\odot$

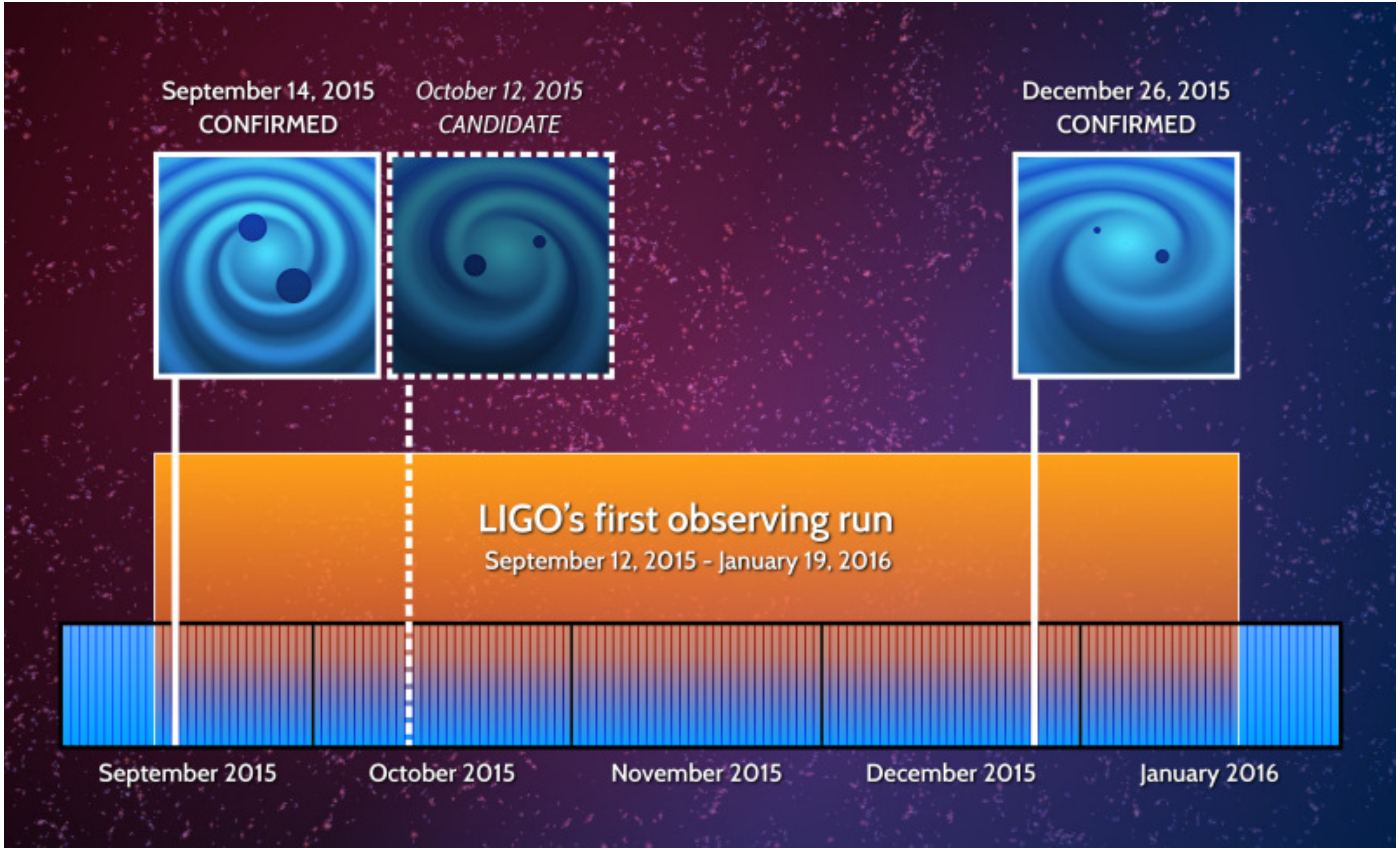
Redshift: $z \sim 0.20^{+0.09}_{-0.09}$



Probability: 86%

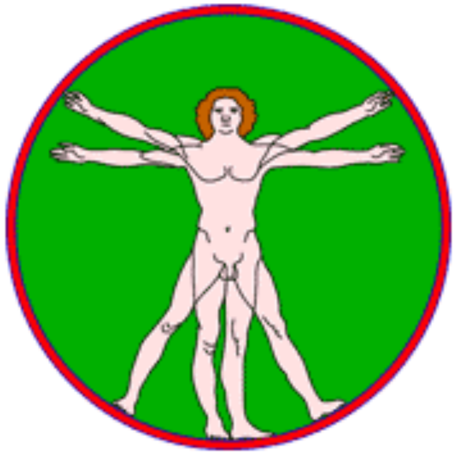
Probability: 99.9999%

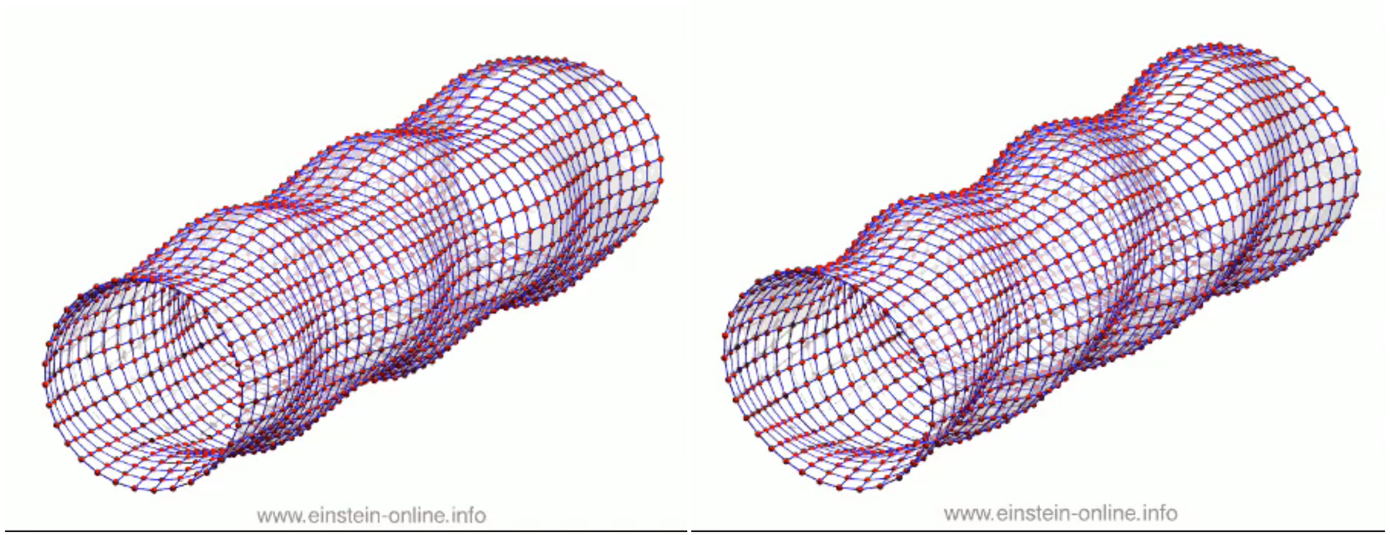
LIGO Timeline



WHAT ARE GRAVITATIONAL WAVES

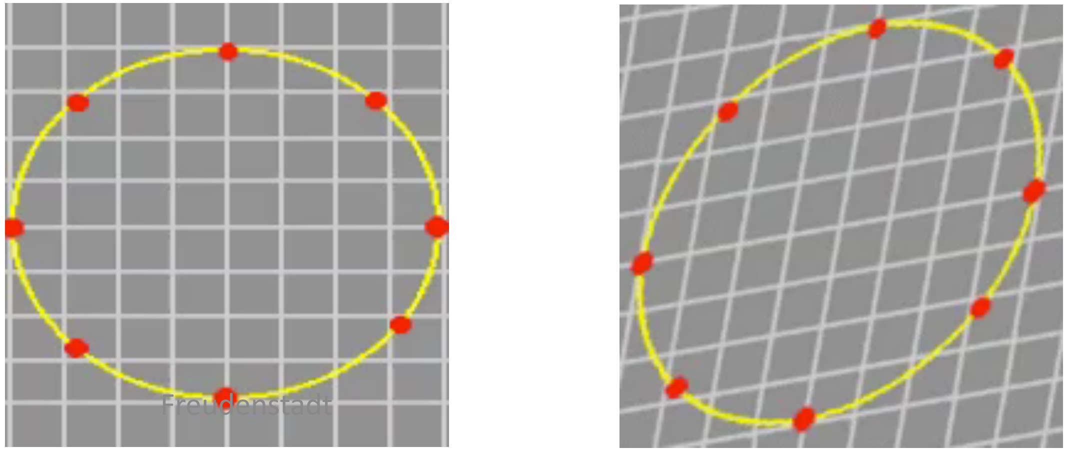
They produce **tidal deformations** on massive bodies.





… and deform periodically the spacetime geometry

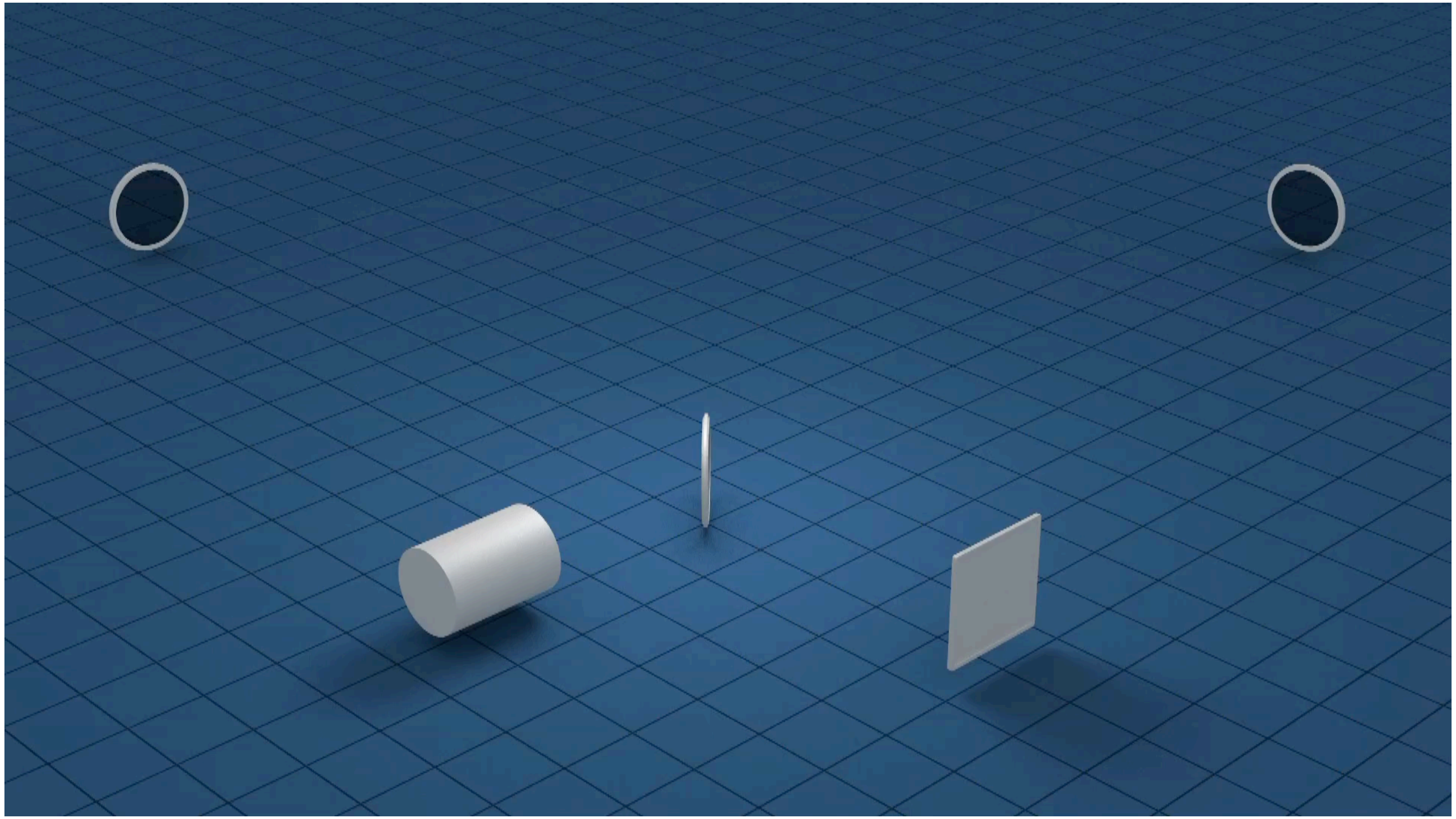
$$\Delta L \sim h * L$$



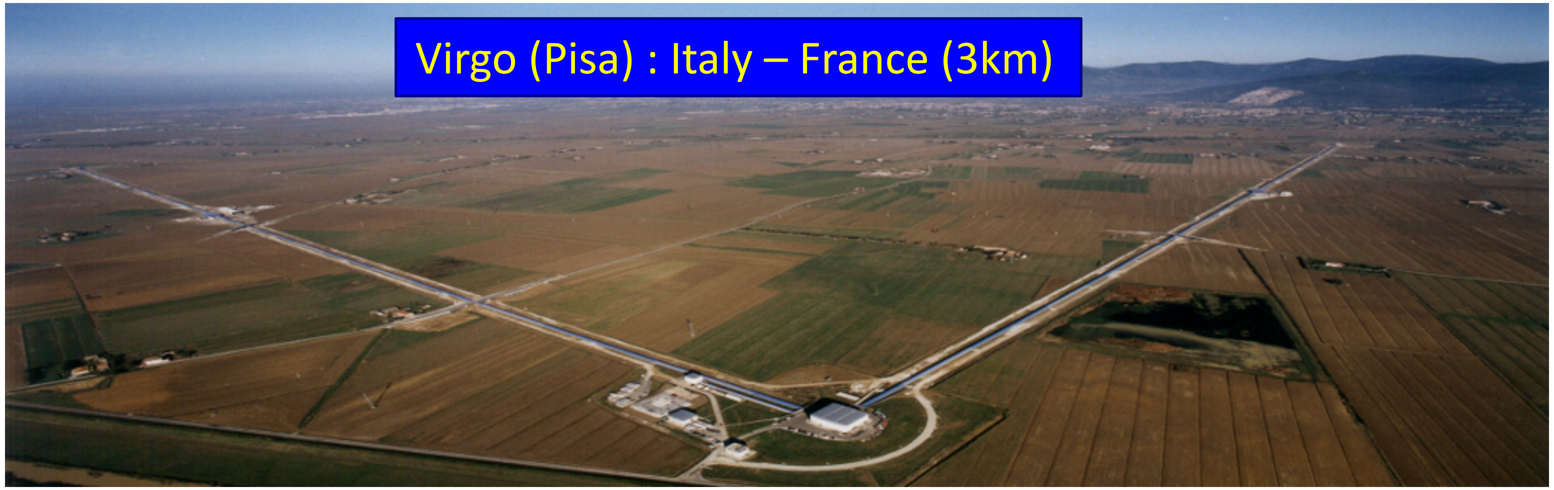
GRAVITATIONAL WAVE DETECTORS

Rainer Weiss

Roland Drever



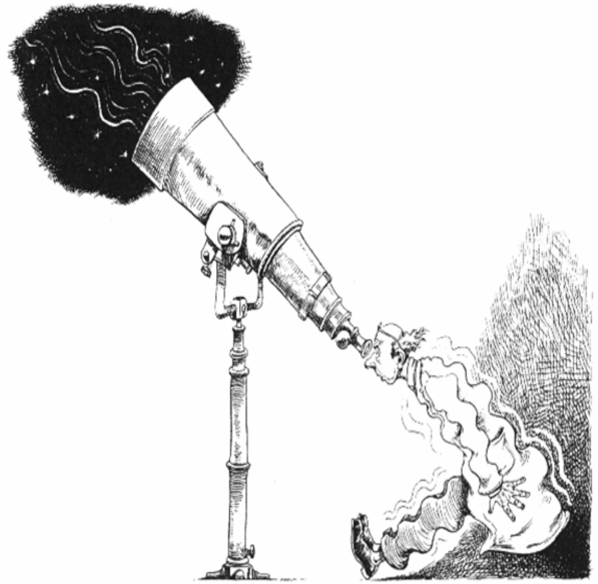
THE FLAGSHIP DETECTORS



1960-70 & the Golden Decade

- **1957: Pirani**-Bondi+… demonstrate that gravitational waves carry energy
- **1960-** : Black Holes– (**Finkelstein**, Kruskal, **Wheeler**,…)
- **1963**: **1st** & **only** solution of Einstein equations describing rotating black holes (Roy Kerr)
- **1960-70** : Post-Newtonian Approximations (Chandrasekhar)
- **1963**: Peter & Mathews: gravitational radiation from binary systems
- **1965-…**: First Equations of State for Neutron Stars (not yet detected!)
- **1966-…:** Kip Thorne and collaborators engaged in the systematic study of gravitational wave sources
- **1965-**… J. Weber builds the first resonant GW detector
- **1967**: Detection of the 1st pulsar Jocelyn Bell Burnell & Antony Hewish
- **1960+: Zel'dovich** and collaborators «Relativistic Cosmology »

Looking Ahead



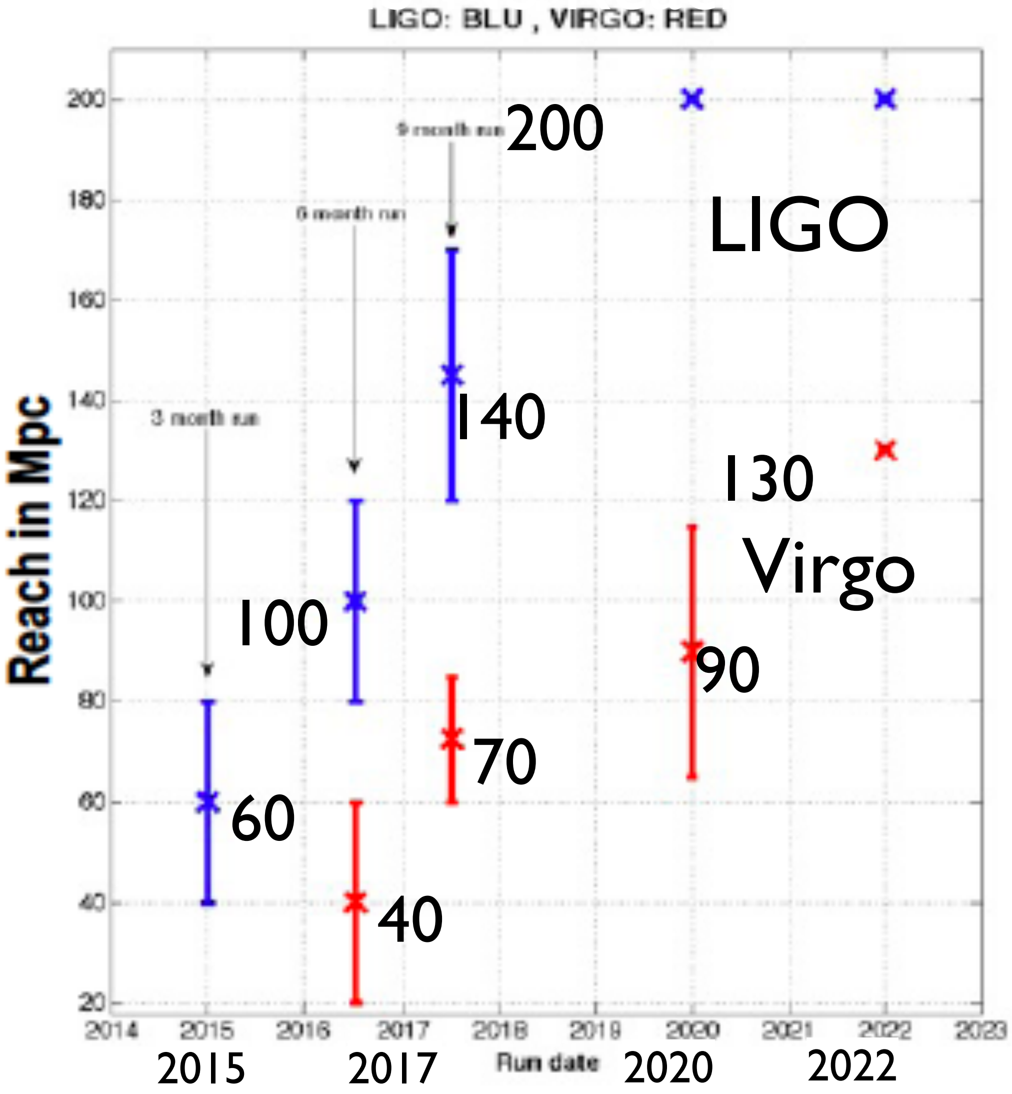
LIGO: PLAN

Second generation interferometers to begin science operations:

- Advanced LIGO (2 interferometers) – 2015
- Advanced Virgo (1 interferometer) – 2016

Approximate run schedule:

- **Advanced LIGO:**
  ~ 3 month run in 2015,
  ~ 6 month run in 2016-17
  ~ 9 month run in 2017-18
- **Advanced Virgo:**
  ~ 6 month run in 2016-17
  ~ 9 month run in 2017-18
- *Modification of run schedules is likely as we learn more about the instruments*



From V. Kalogera

SCIENCE OBJECTIVES

Cosmology: Exploring black hole seeds

*The origin and evolution of BHs that seem to populate galactic cores is **one of the unsolved problems in modern cosmology**.*

Cosmography: Measuring the Universe with standard sirens

One of the most spectacular aspects of compact binary signals is that their amplitude is completely determined by GR, without the need for any complicated astrophysical modelling of their environments.

Fundamental physics: Testing gravity with black holes

*Nearly a hundred years after its formulation, GR continues to be the preferred theory of gravity. **However, the theory is yet to be tested in strong gravitational fields that occur in the vicinity of BH horizons**. Gravitational wave observations of compact binaries could facilitate many such tests*

SCIENCE OBJECTIVES

Astrophysics: Catching supernovae in their act

It is expected that the gravitational collapse and the ensuing explosion can be fully understood ***only by studying the deep interiors of the proto-neutron star that forms in the process****, which is inaccessible to electromagnetic observations.*

Modelling SNe involves inputs from almost all branches of physics and current simulations of the process are far from complete.

Nuclear Physics: Probing neutron star cores

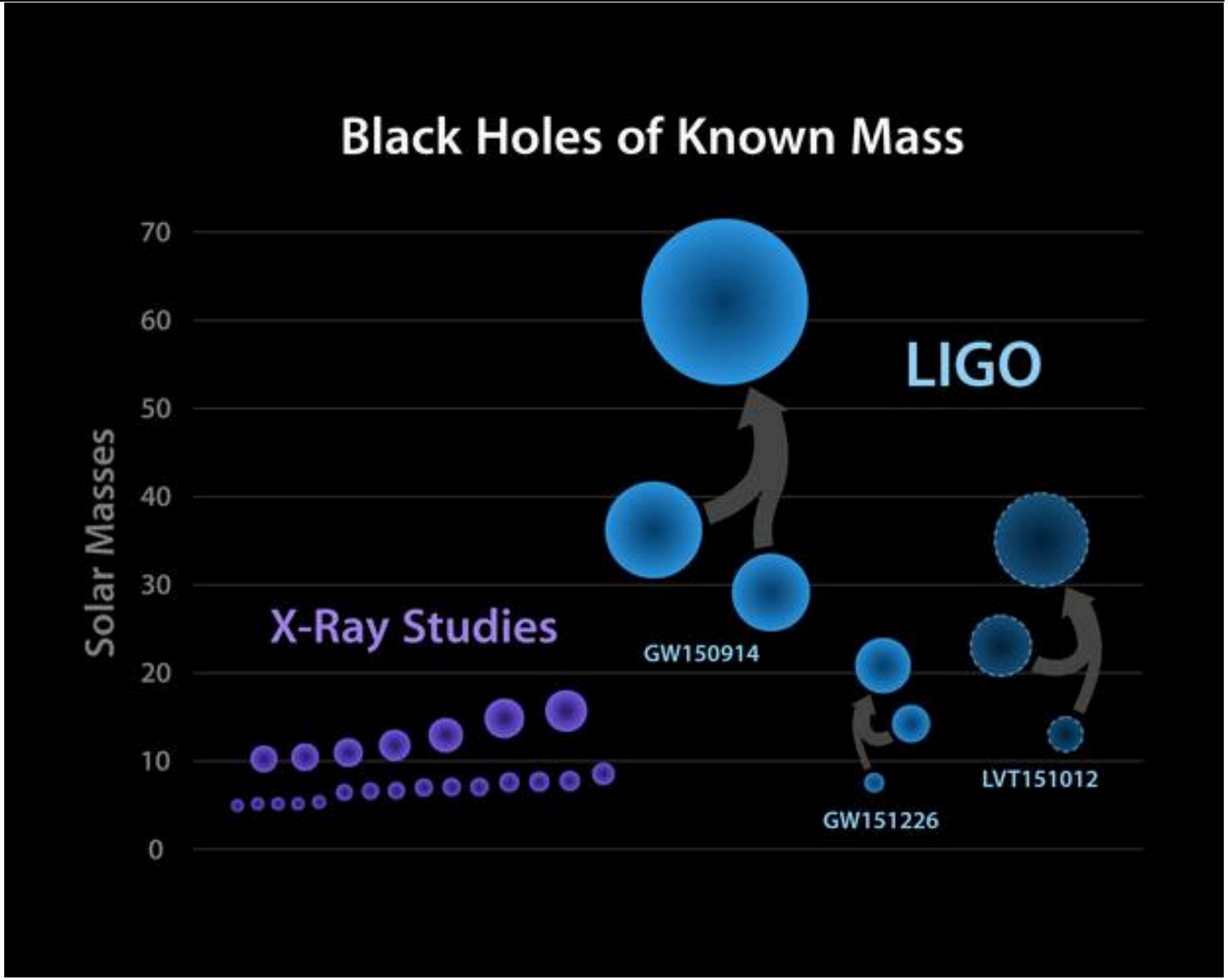
Neutron star cores are laboratories of extreme conditions of density, gravity and magnetic fields. The structure and composition of NS cores have largely remained unresolved even half-century after pulsars were first discovered. Their cores could be host to unknown physics and might be composed of quark-gluon plasma, hyperons or other exotica.

AN EXAMPLE: Stellar Mass BHs in the Universe

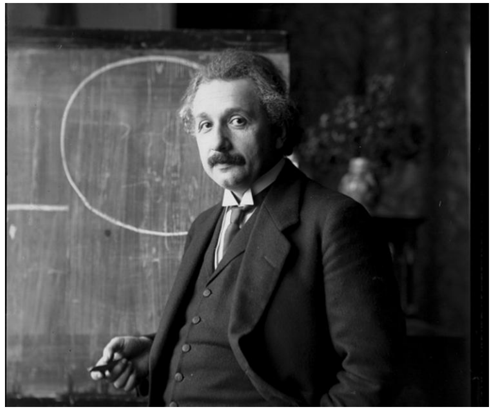
GW150914
SNR =24
Net spin of BBH~0
Final spin of BH ~ 70% max

GW151226
SNR =13
Net spin of BBH~29% max
Final spin of BH ~ 75% max

LVT151012
SNR =10
Net spin of BBH~0
Final spin of BH ~ 70% max



eLISA : The Laws of Nature



Confronting General Relativity with experimental measurements of gravity is one of the most important objectives of fundamental physics.

eLISA will map the spacetime around astrophysical BHs, yielding a battery of precision tests of GR in an entirely new regime.
These have the potential to uncover hints about the nature of quantum gravity, as well as enabling measurements of properties of the universe on the largest scales.

The nature of gravity in the strong-field limit is so far largely unconstrained, leaving open several outstanding questions.

- Does gravity travel at the speed of light?
- Does the graviton have mass?
- How does gravitational information propagate: Are there more than two transverse modes of propagation?
- Does gravity couple to other dynamical fields, e.g., massless or massive scalars?
- What is the structure of spacetime just outside astrophysical black holes?
- Do their spacetimes contain horizons?
- Are astrophysical black holes described by the Kerr metric, as predicted by GR?

The Very Near Future… (2015-2020)

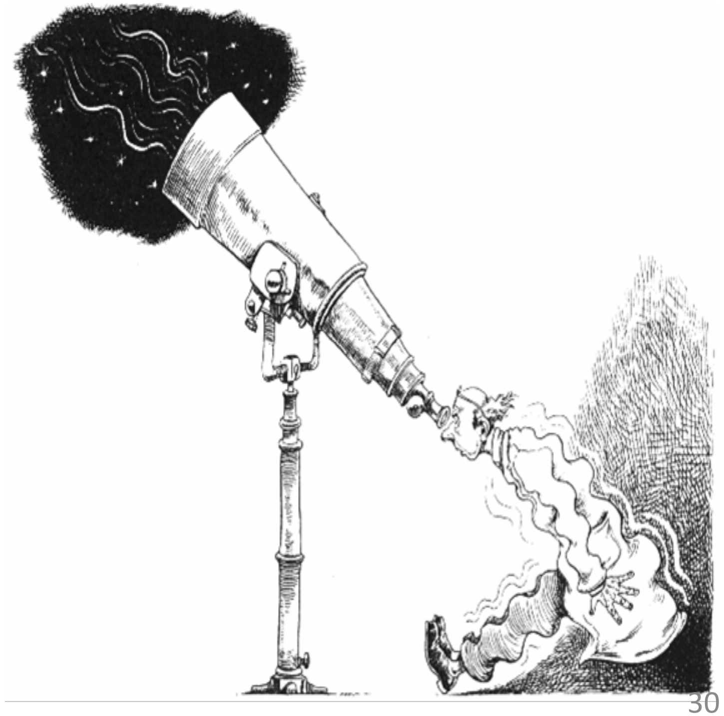
2015 :	Adv LIGO commissioning and science runs
2016-17:	Adv Virgo joins science runs
2017:	CMB: first measurement of Ω_{GW} at z~1000 ★ ????
2014+ :	PTAs pool data, increase number of MSPs
2015:	iKAGRA science run
2015:	LISA Pathfinder launched
2015-20:	PTAs get their first nHz detection ★
2016-20:	Adv IFOs get first 100 Hz detection ★
2017:	eLISA confirmed by ESA for 2028 launch
2018:	KAGRA data at Advanced Level sensitivity
2018:	ET approved in Europe, construction begins 2020
2020:	INTIGO data at Advanced level sensitivity

B.F.Schutz

BLACK-HOLE COLLISIONS WERE EXPECTED – BUT IS THERE ANYTHING ELSE OUT THERE;

GRAVITATIONAL WAVES OPENED A NEW WINDOW IN TO THE UNIVERSE

IT’S UP TO US TO “LISTEN” ITS SECRETS



THANK YOU