APPROACHES AND STRATEGIES FOR BRINGING RECENT SCIENTIFIC DISCOVERIES INTO THE CLASSROOM

Michael Cowley (MQ / AAO)

Image credit: VASAVA

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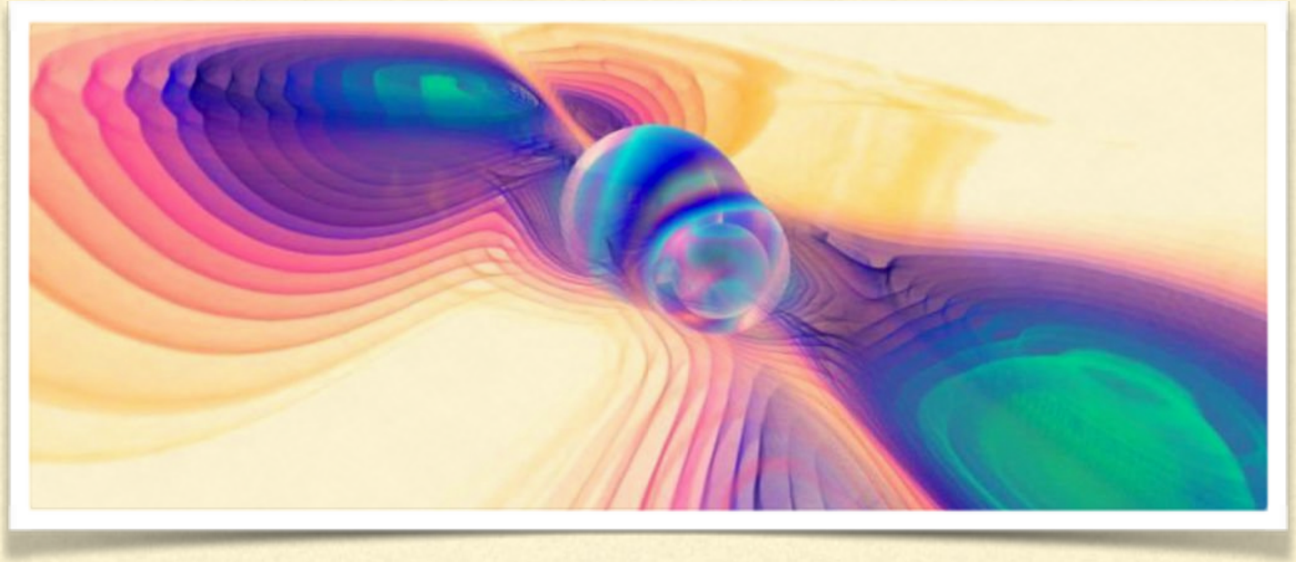
Australian Government
Department of Industry, Innovation and Science

AAO

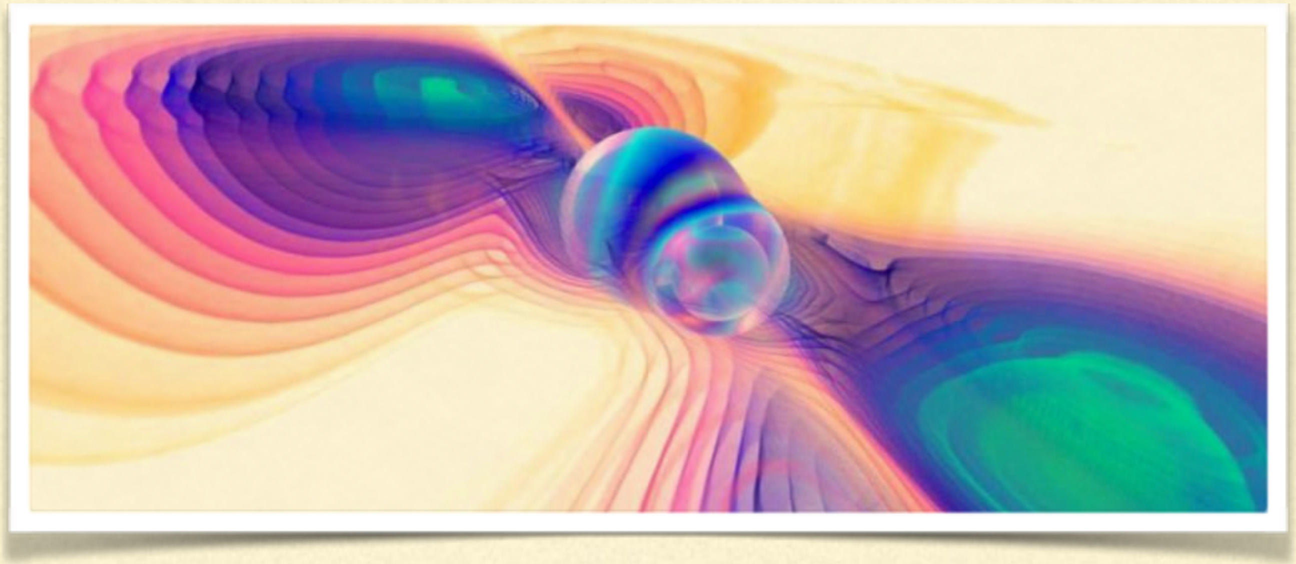
GRAVITATIONAL WAVES & THE HIGGS BOSON

Gravitational waves



On September 14, 2015, the Laser Interferometer Gravitational-wave Observatory (LIGO) received the first confirmed gravitational wave signals. Now known as GW150914 (for the date on which the signals were received in 2015, 9th month, day 14), the event represents the coalescence of two black holes that were previously in mutual orbit. LIGO's exciting discovery provides direct evidence of what is arguably the last major unconfirmed prediction of Einstein's General Theory of Relativity.

GRAVITATIONAL WAVES



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9.2.4 TRANSMISSION OF LIGHT

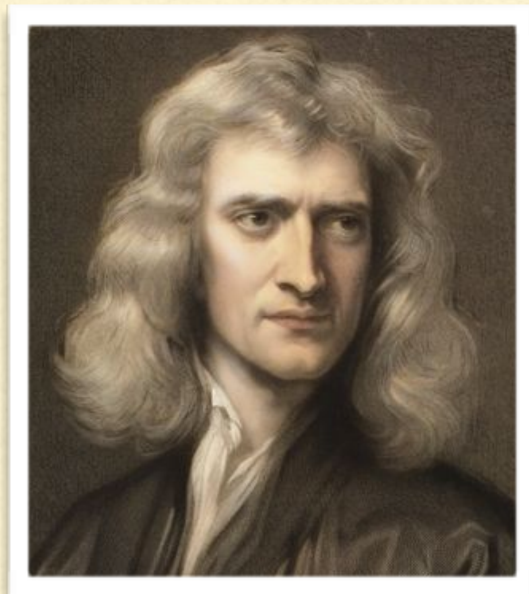
9.2.1 GRAVITATIONAL FIELDS

8.2.1 THE WAVE MODEL

9.7.6 STELLAR EVOLUTION

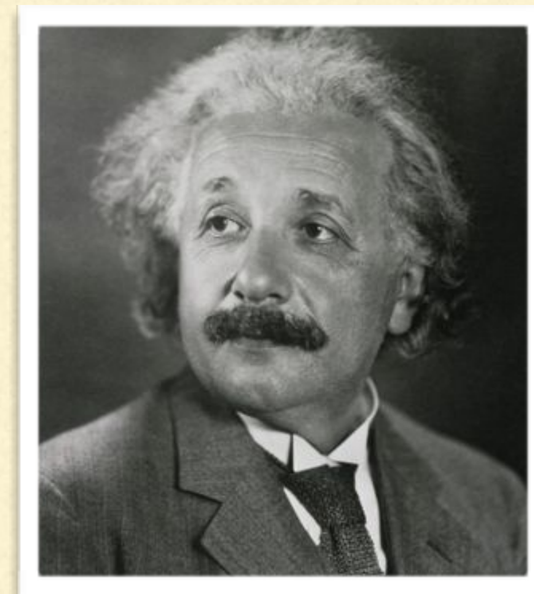
7.1.2 PRACTICE OF PHYSICS

THE NATURE OF GRAVITY



Newton

- "Action at a distance" - an object can be moved without being physically touched by another object
- Newton's Law offered no prospect of identifying any mediator of gravitational interaction

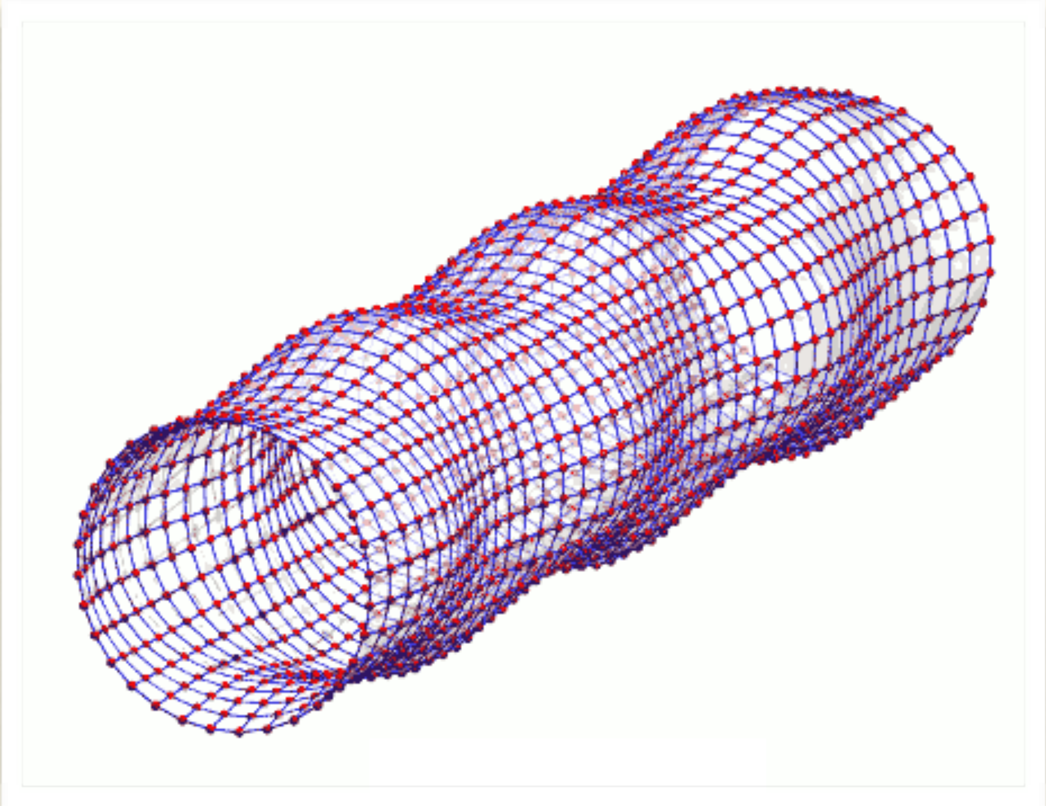


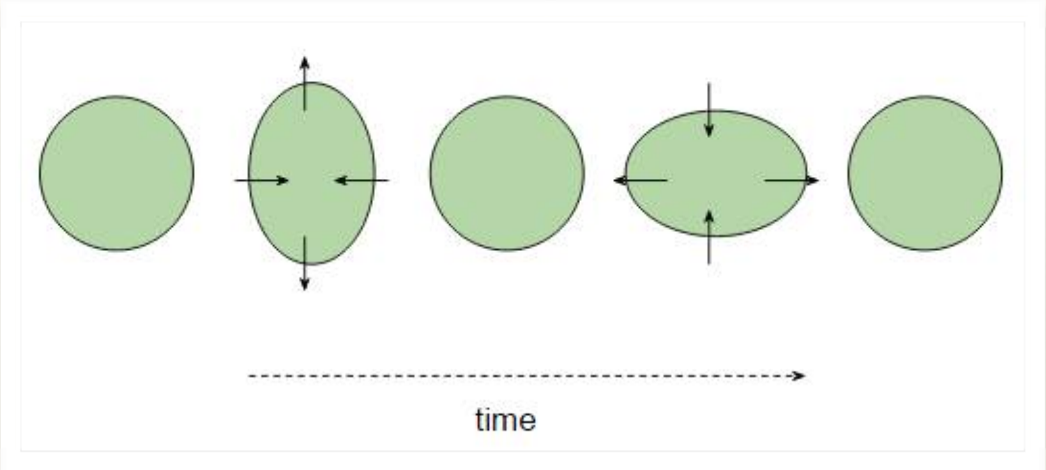
Einstein

- Gravitational interaction is mediated by the deformation of space-time geometry
- Matter acts upon space-time geometry, deforming it, and space-time geometry acts upon matter

Gravitational Waves

- They are "ripples in spacetime"
- Generated by any object where its acceleration is not spherically or cylindrically symmetric
- These ripples travel at the speed of light
- When they pass through space, they compress in one direction and stretch in another





8.2.1	THE WAVE MODEL

9.2.1	GRAVITATIONAL FIELDS

Image credit: Einstein Online

HOW MUCH DO THEY SQUEEZE AND STRETCH SPACE?

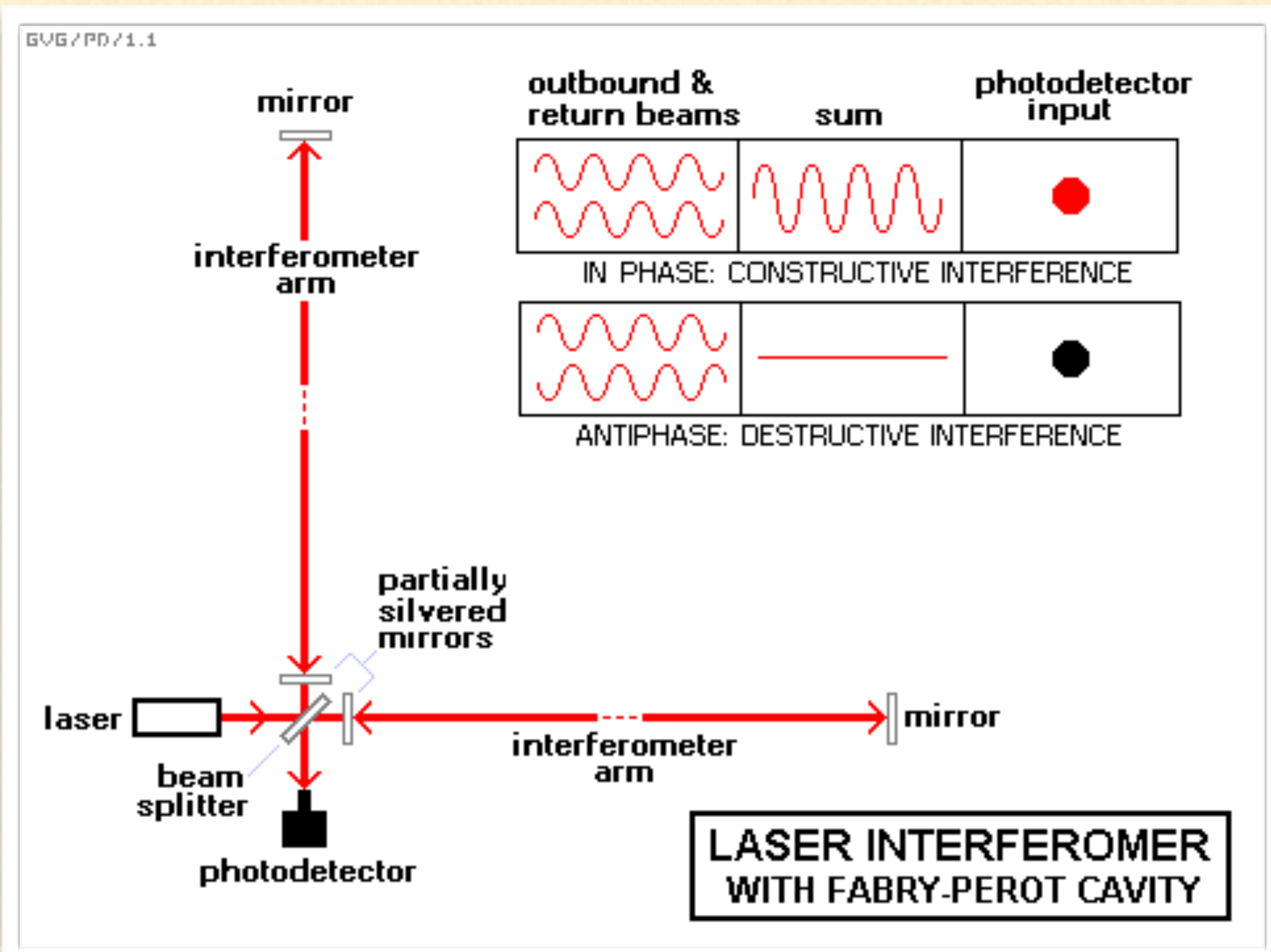
Two neutron stars (weighing a collective total of 1 million Earth masses) orbiting each other 1,000 times a second would only generate a gravitational wave signal that displaces distance by 1/1,000th of the diameter of an atomic nucleus (~10^{-18} meters)

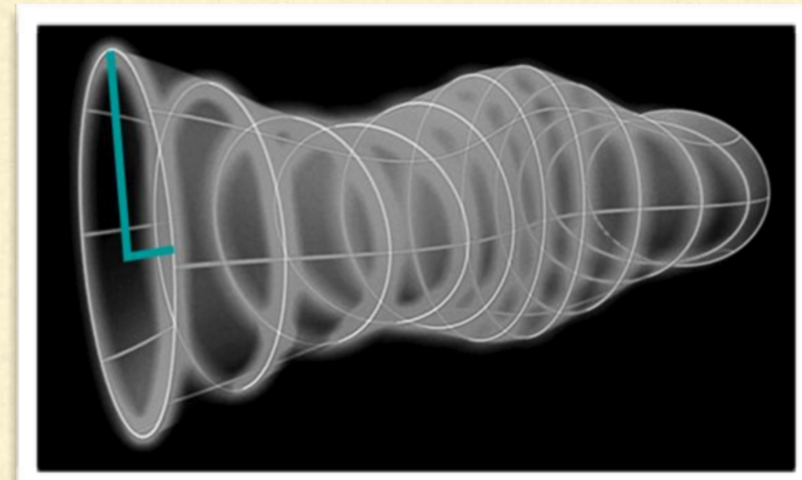
Start with…

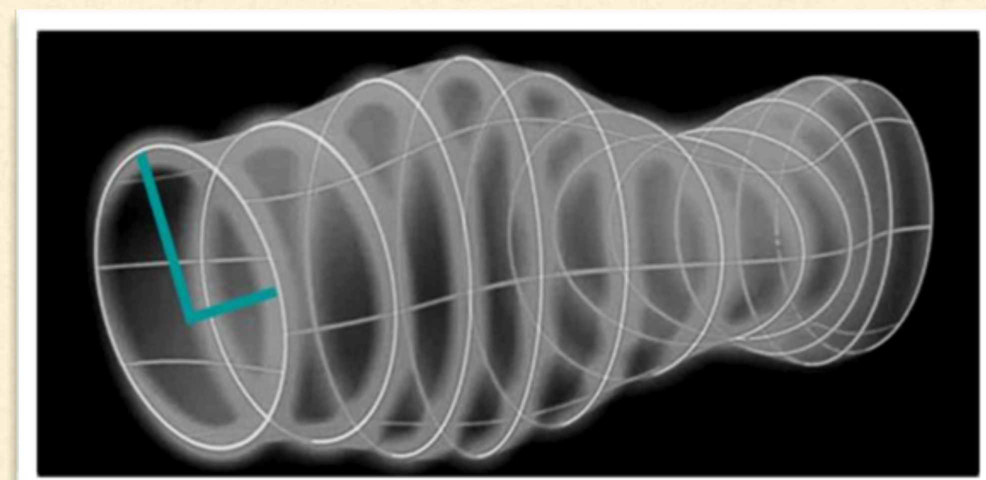
	One meter
÷10,000	*Human hair, about 100 microns*
÷100	*Wavelength of light, about 1 micron*
÷10,000	*Atomic diameter, 10^{-10} meter*
÷100,000	*Nuclear diameter, 10^{-15} meter*
÷1,000	*LIGO sensitivity, 10^{-18} meter*

…BUT, HOW DO YOU DETECT A ONE BILLION BILLIONTH OF A DIFFERENCE IN LENGTH?

WITH LASERS AND THE MICHELSON INTERFEROMETER





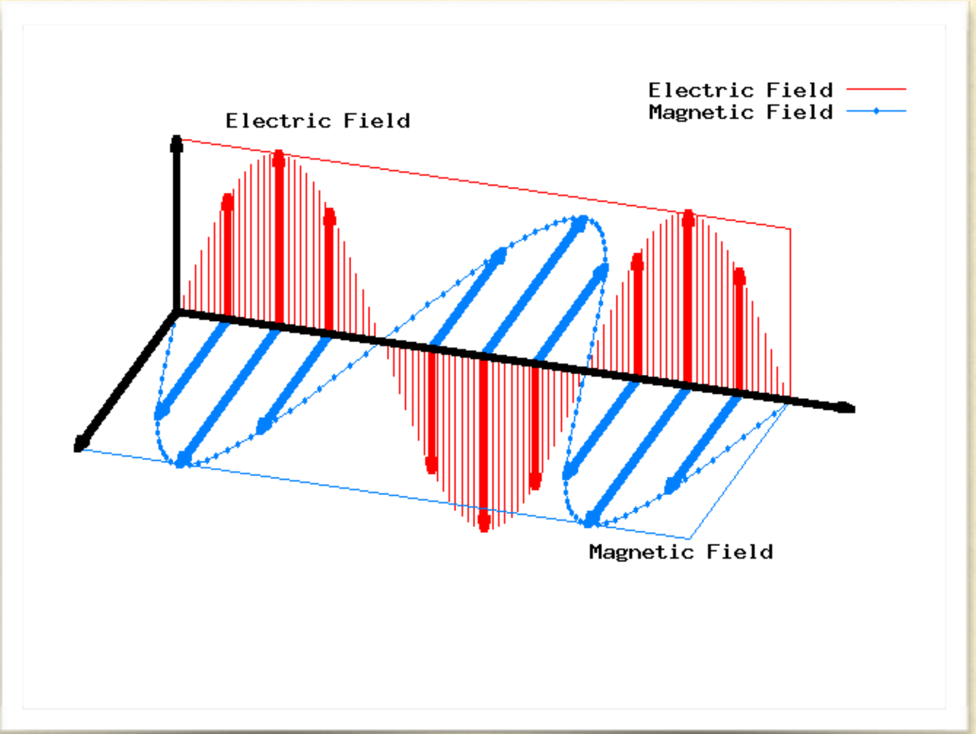


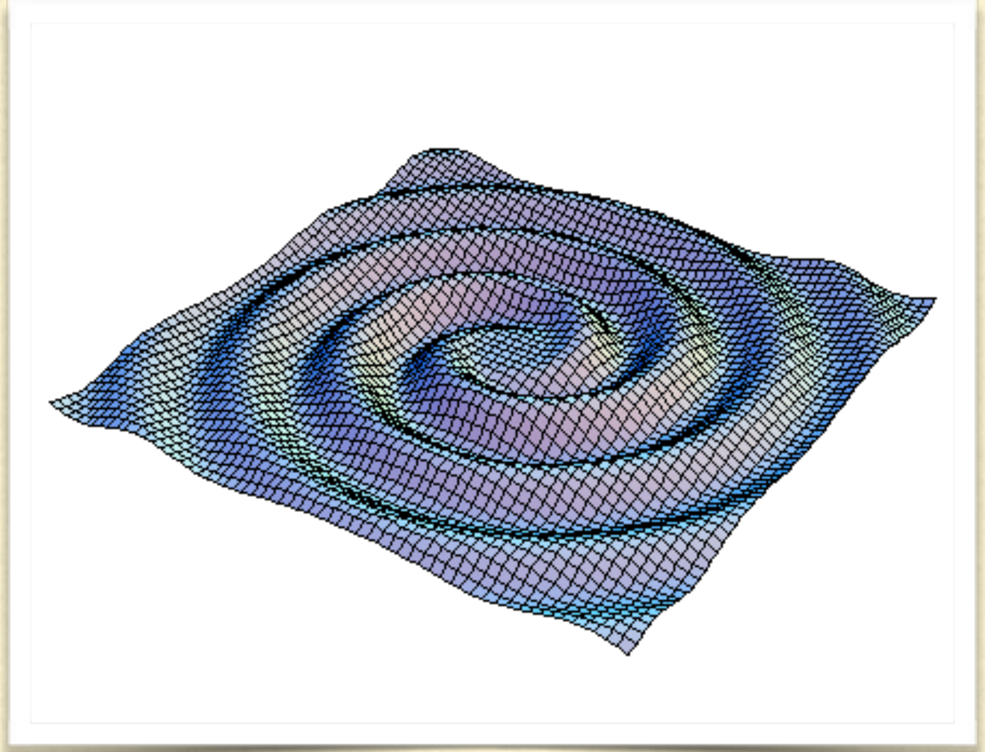
7.1.1 THE HISTORY OF PHYSICS
9.2.4 TRANSMISSION OF LIGHT
9.2.1 GRAVITATIONAL FIELDS

Image credit: Einstein Online

INTO THE CLASSROOM

- The physics of waves is relevant to both gravitational waves and the interferometer
- Many properties of EM waves, such as amplitude, frequency and polarisation are also relevant to gravitational waves
- A tabletop interferometer is an ideal demonstration to complement the discussion of these topics



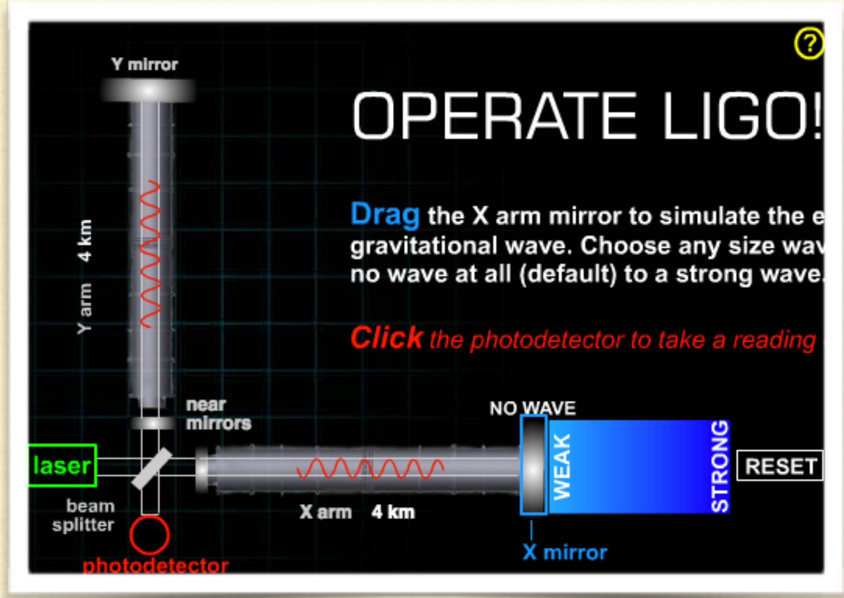


7.1.1	THE HISTORY OF PHYSICS	9.2.4	TRANSMISSION OF LIGHT	9.2.1	GRAVITATIONAL FIELDS

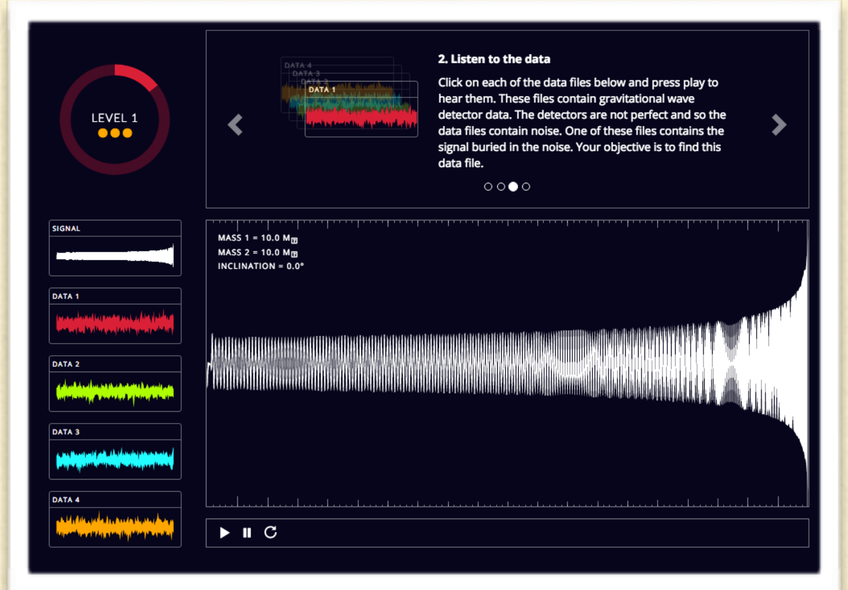
Image credit: Abramovici et al. 1992

INTERFEROMETER SIMULATIONS

- **Simulations** can help understanding
- They can help visualise mathematical concepts and physical phenomena
- However, they're not necessarily a replacement for "real" demonstrations



http://www.amnh.org/explore/science-bulletins/astro/documentaries/gravity-making-waves/interactive-operate-ligo/
Interactive LIGO Interferometer



http://www.blackholehunter.org/
Search for gravitational waves

7.1.2	PRACTICE PHYSICS	9.2.4	TRANSMISSION OF LIGHT	9.2.1	GRAVITATIONAL FIELDS

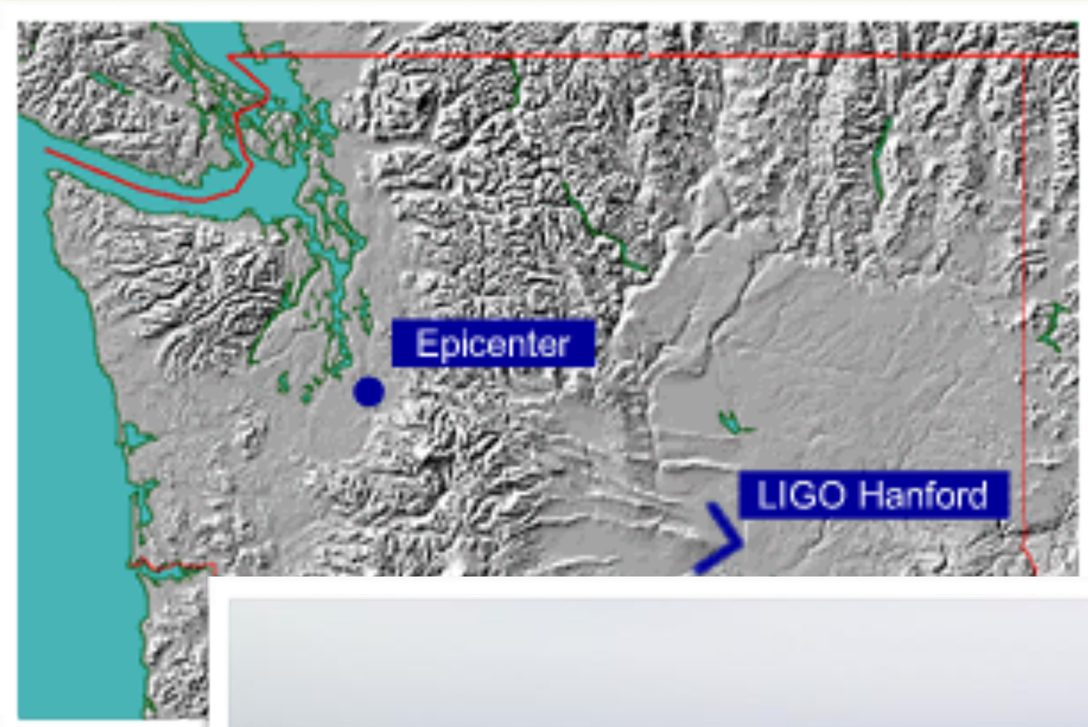
LIGO - A GROUND BASED INTERFEROMETER

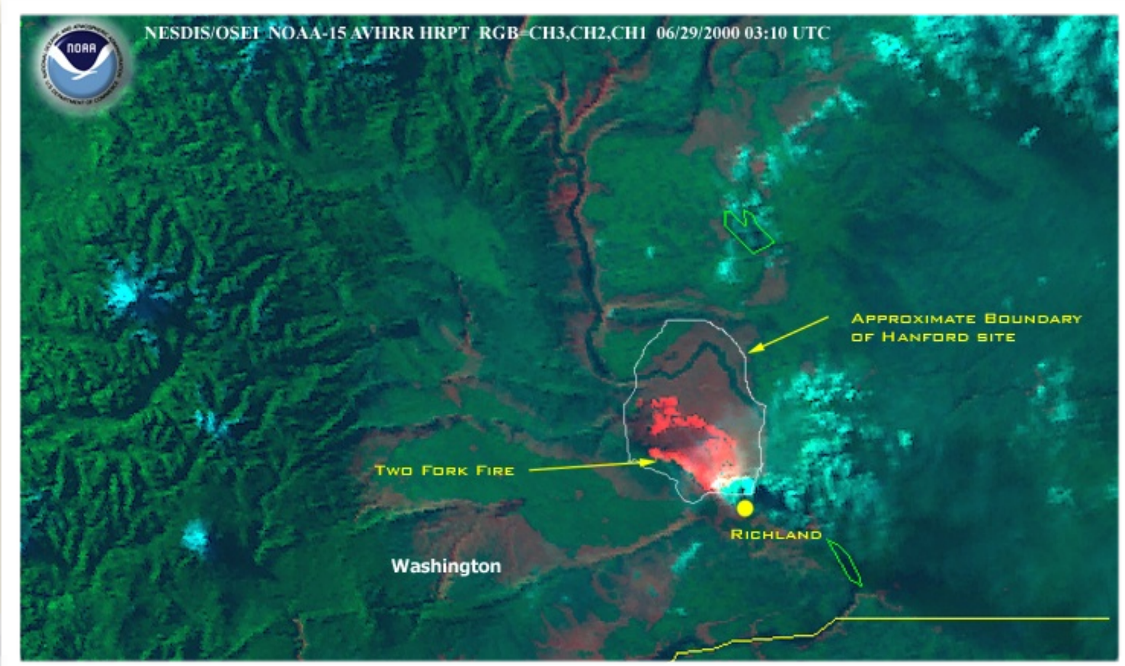
Louisiana

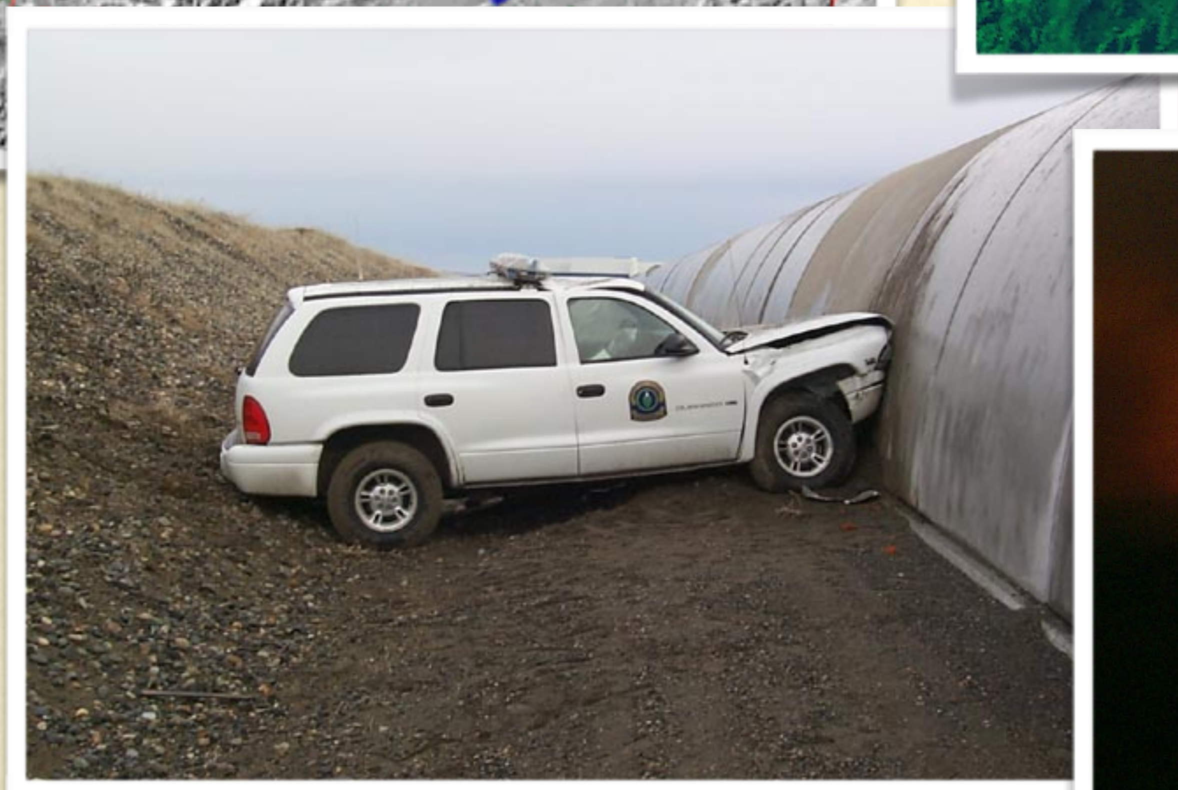
Washington

Multiple interferometers are needed to confidently detect and locate the sources of gravitational waves

SENSITIVITY VS. NOISE







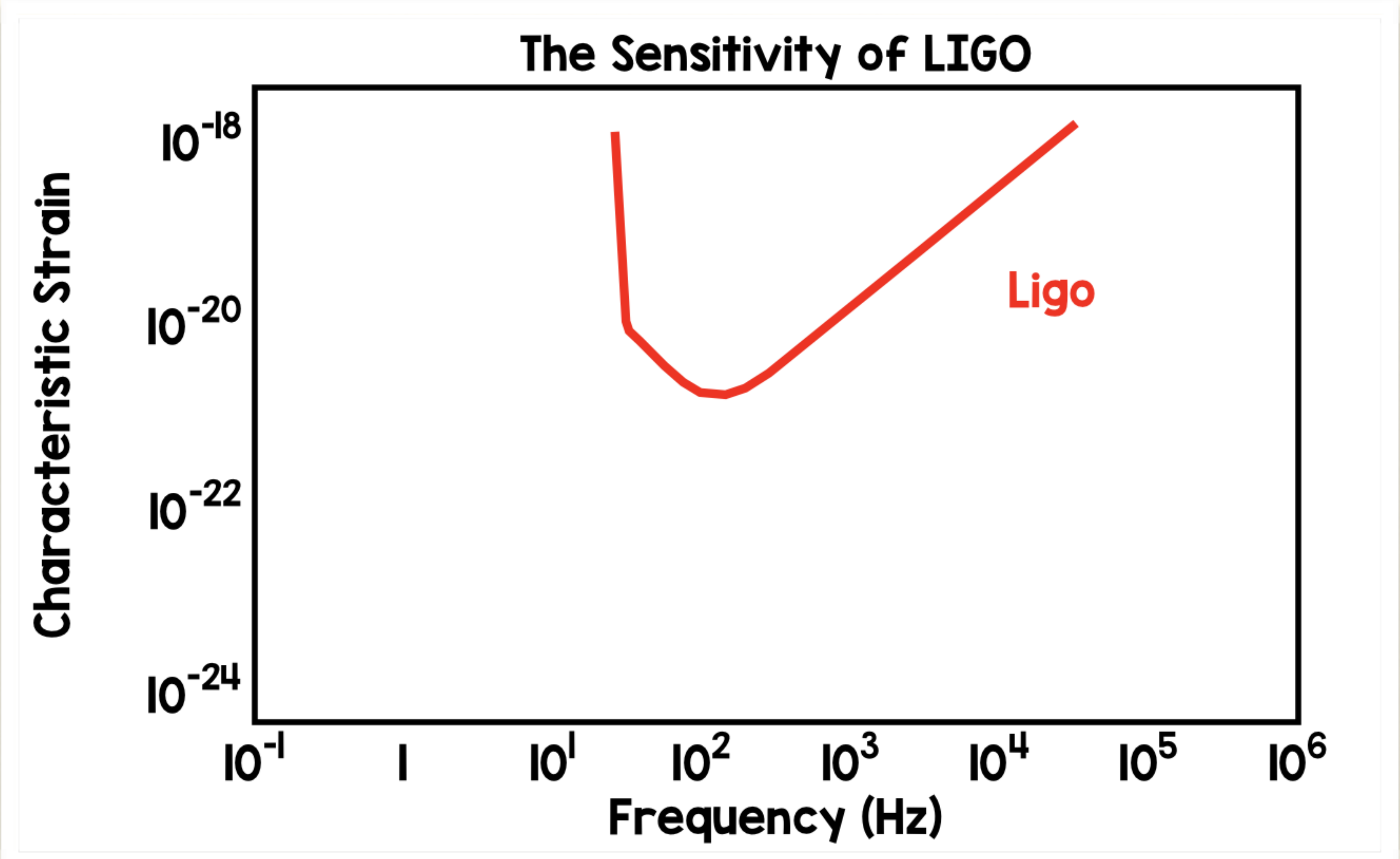
7.1.3	APPLICATIONS OF PHYSICS

9.2.4	TRANSMISSION OF LIGHT

9.2.1	GRAVITATIONAL FIELDS

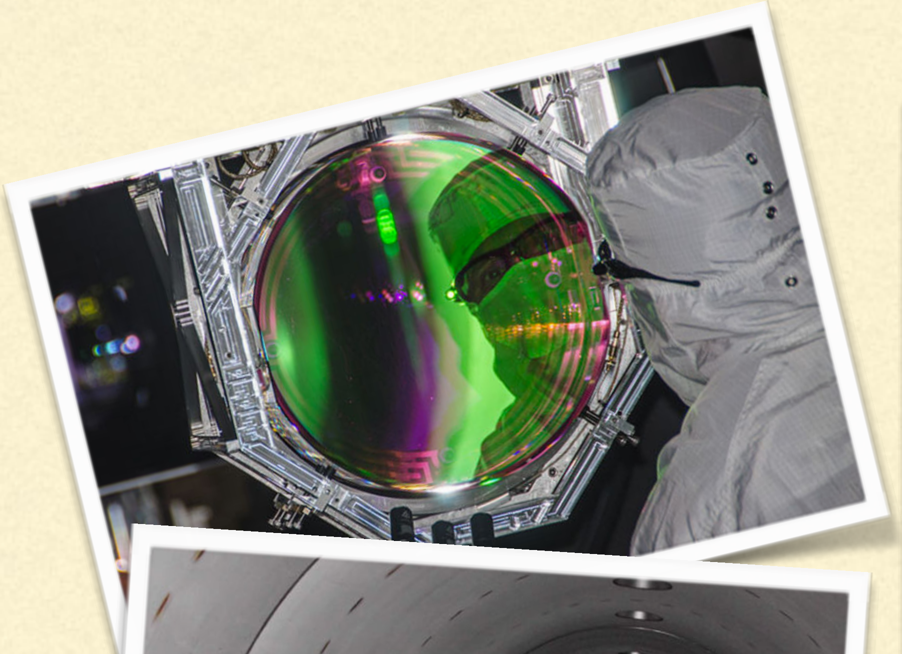
LIGO VERSION 1.0

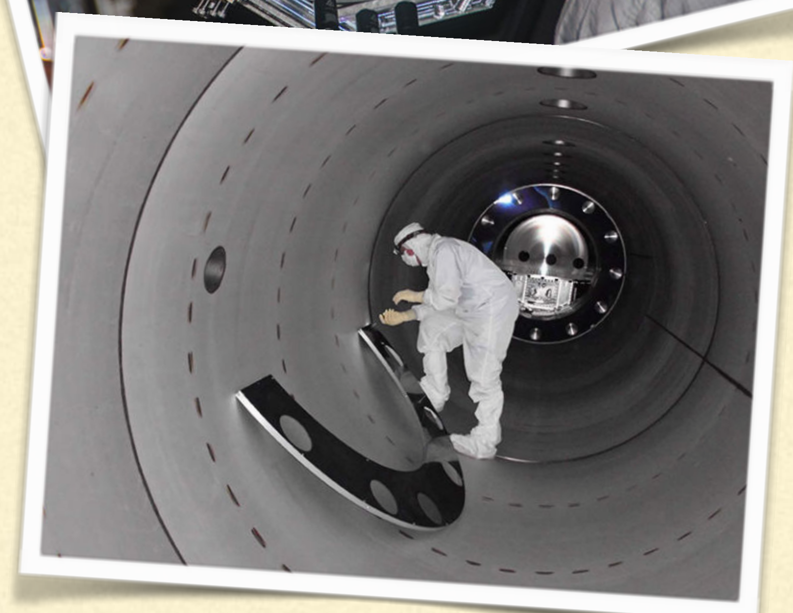
- Built: 1994 - 2002
- Initial run: 2002 - 2010
- Detections: 0
- Expected: 1 to 1/10,000 per yr
- Best case: 8
- Worst case: 10,000 yrs for 1

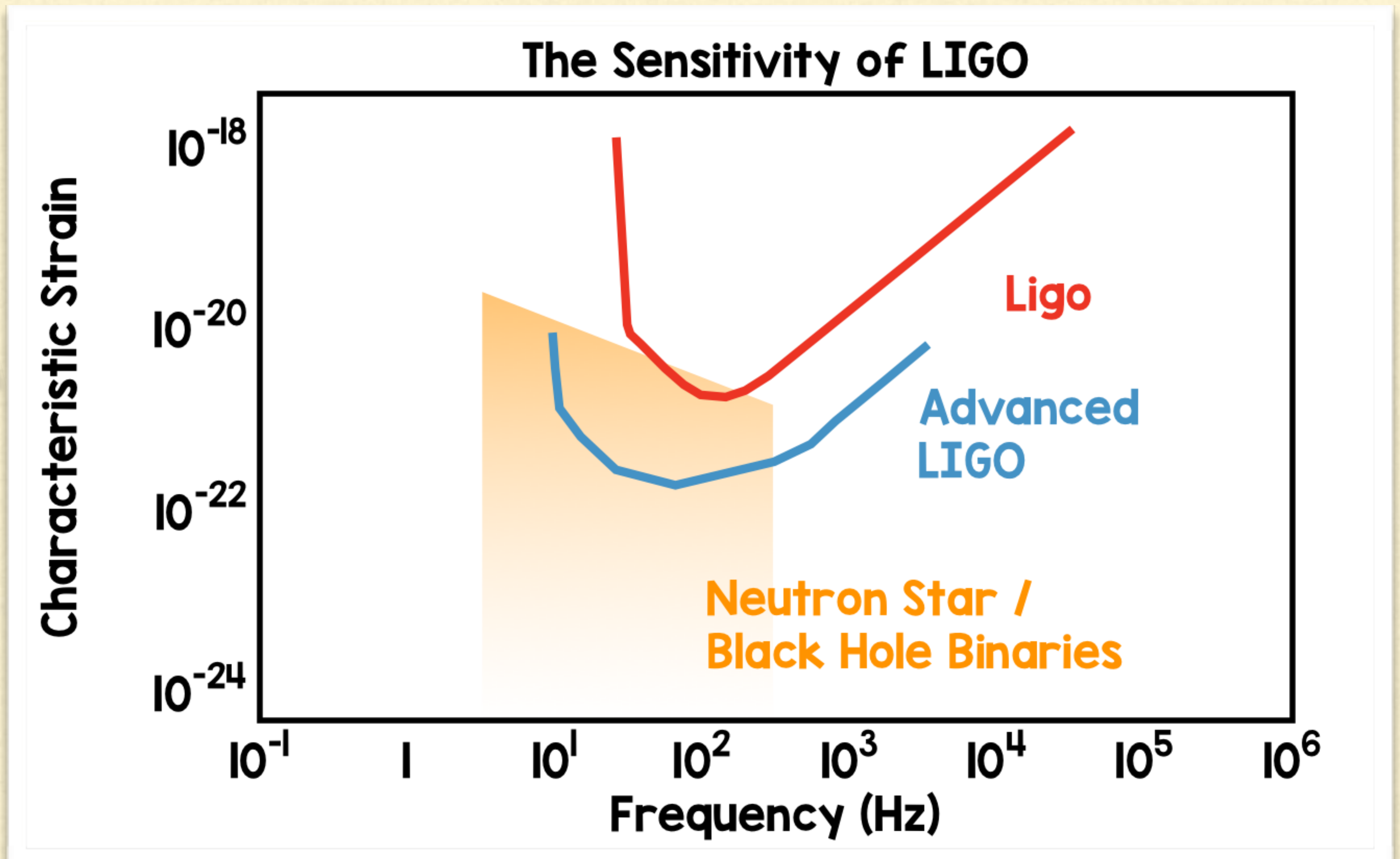


7.1.3 APPLICATIONS OF PHYSICS | 9.2.4 TRANSMISSION OF LIGHT | 9.2.1 GRAVITATIONAL FIELDS

ADVANCED LIGO







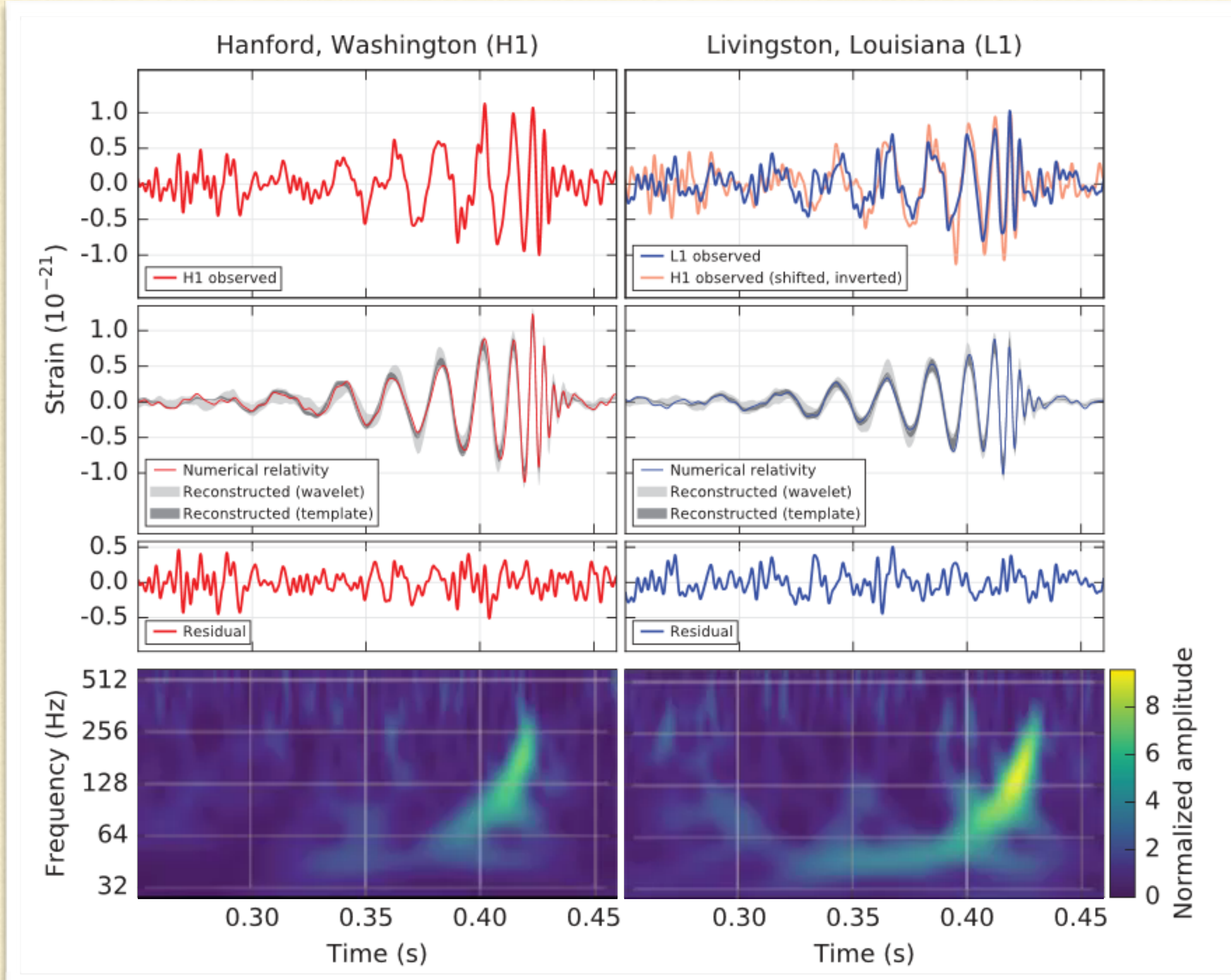
From 2010 - 2015, LIGO received a $205 million upgrade to its interferometers

7.1.3	APPLICATIONS OF PHYSICS

9.2.4	TRANSMISSION OF LIGHT

9.2.1	GRAVITATIONAL FIELDS

LIGO'S DETECTION



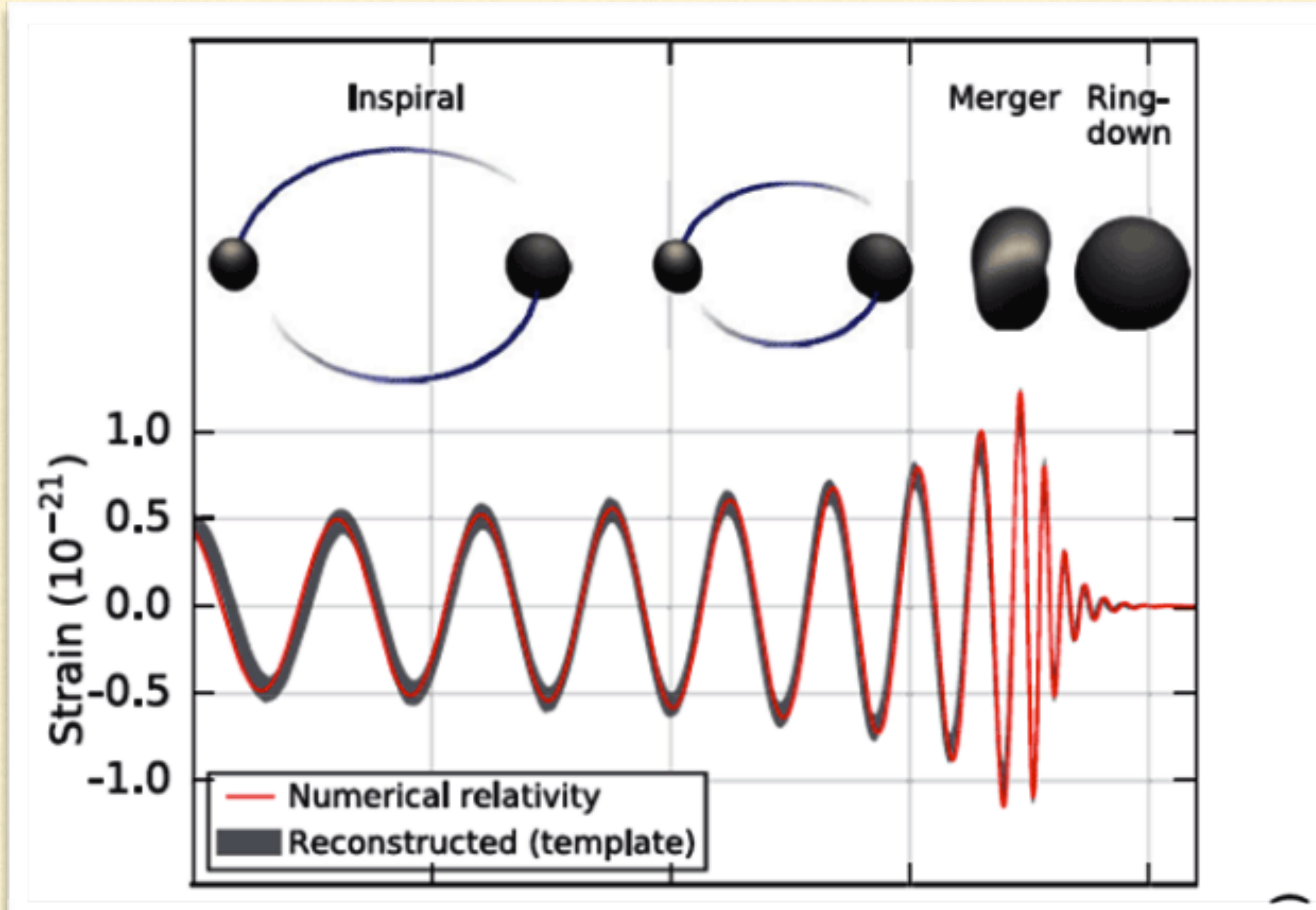
9.2.4	TRANSMISSION OF LIGHT

9.2.1	GRAVITATIONAL FIELDS

Image credit: Abbot et al. 2016

LIGO'S DETECTION

- Two massive black holes merging
- 36 and 28 times the mass of the Sun
- Estimated 1.3 billion light years away
- Combined mass of the final black hole is 62 solar masses
- 3 Suns worth of mass was lost in gravitational wave energy

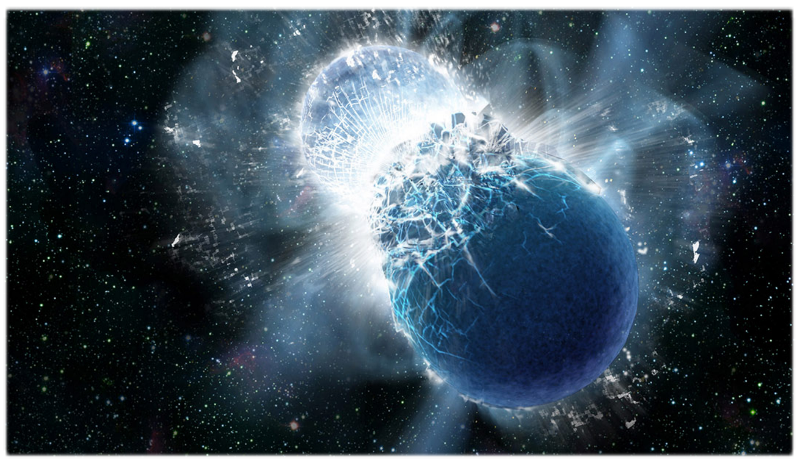
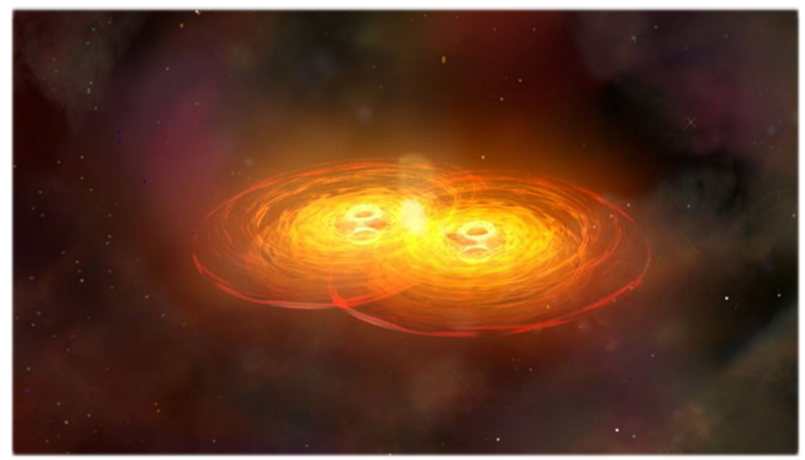
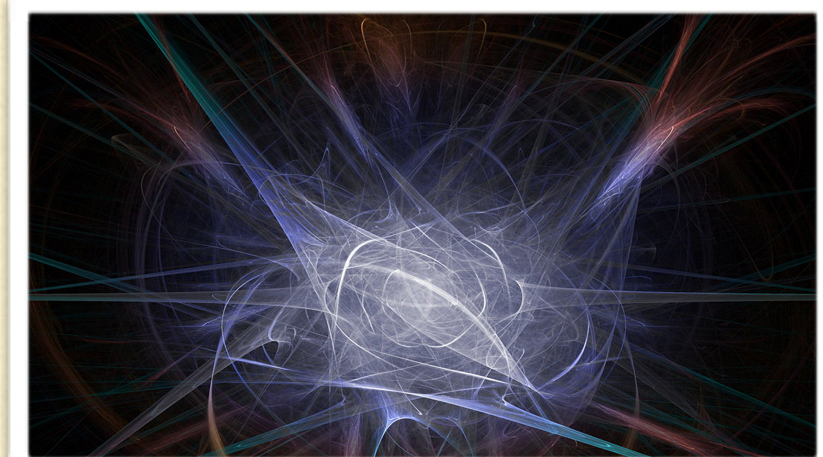
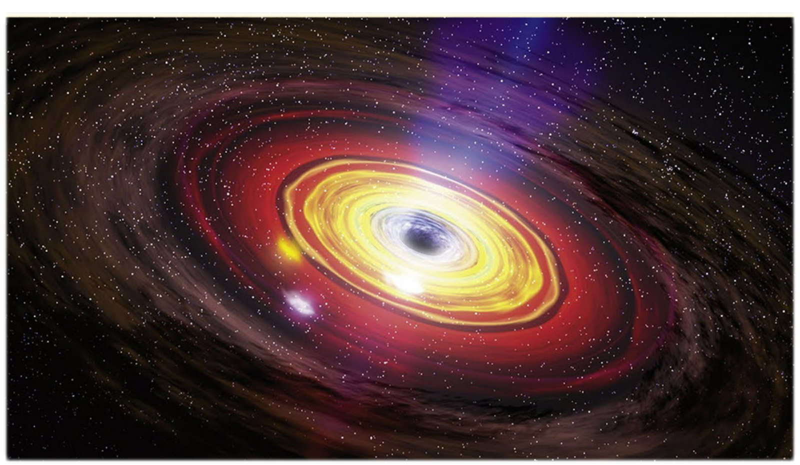
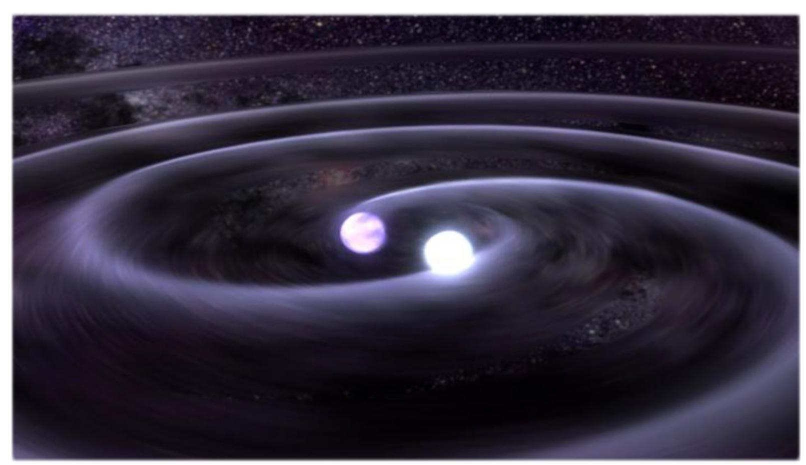


9.2.4	TRANSMISSION OF LIGHT	9.2.1	GRAVITATIONAL FIELDS	9.7.6	STELLAR EVOLUTION

Image credit: Abbot et al. 2016

FUTURE DIRECTIONS

Gravitational Wave astronomy is a new way to look at the universe. It has the potential to allow us to explore fundamental physics, examine the weirdest objects in the universe and peer back to the universe's earliest moments.

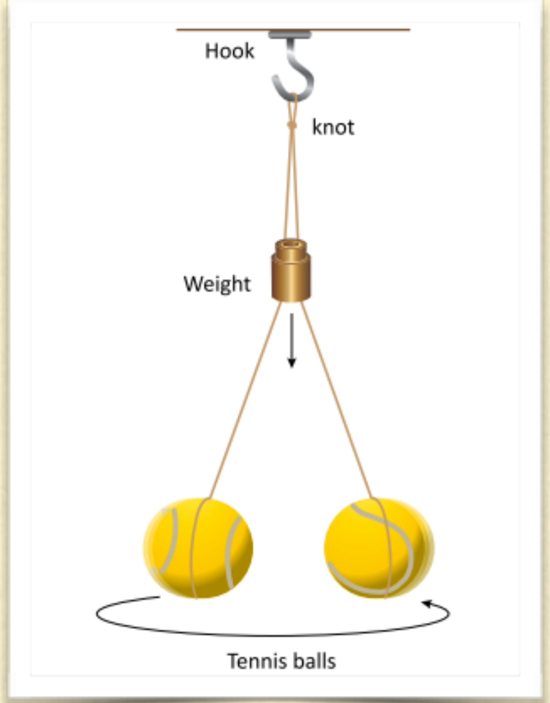







7.1.4	IMPLICATIONS

7.1.5	DEVELOPMENT IN PHYSICS

GRAVITY ACTIVITIES

Activity 1: Coalescing Black Holes
Brief overview: Students interact with a demonstration of orbiting spheres that have an increasing orbital frequency as they coalesce.
Duration: 30 min
Essential Question: What happens when two black holes spiral in towards each other?
Grades: 7 – 12

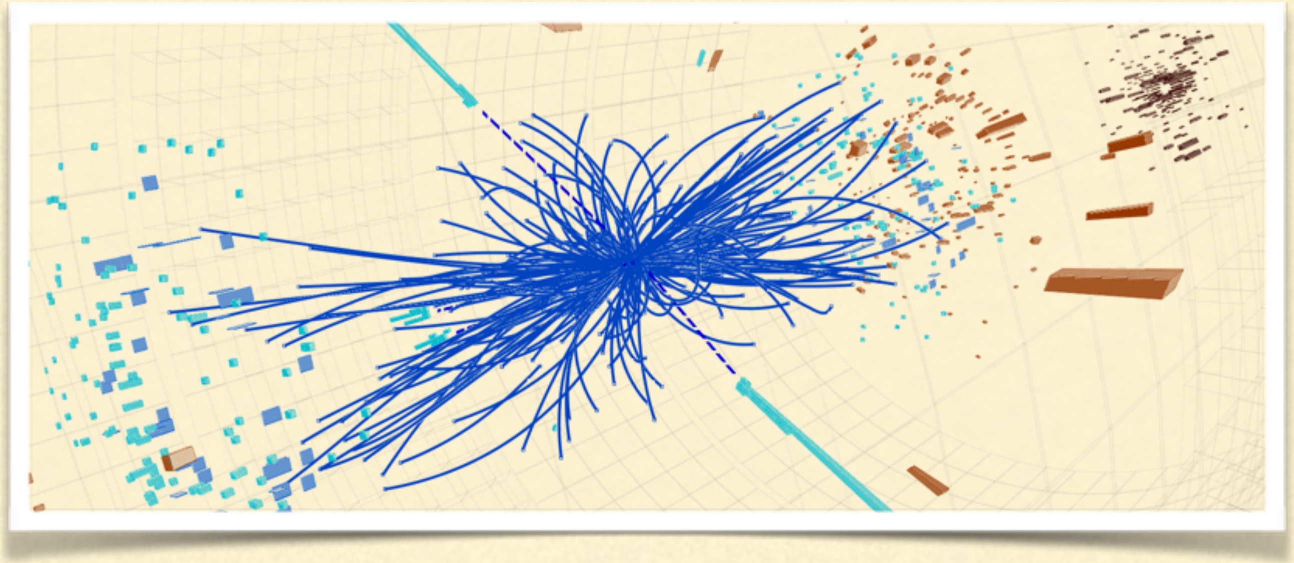


Activity 2: Warping of Spacetime
Brief overview: Students explore the behaviour of two orbiting spheres in spacetime.
Duration: 30 min
Essential Question: How do binary black holes warp spacetime?
Grades: 7 – 12

7.1.10	MATTER

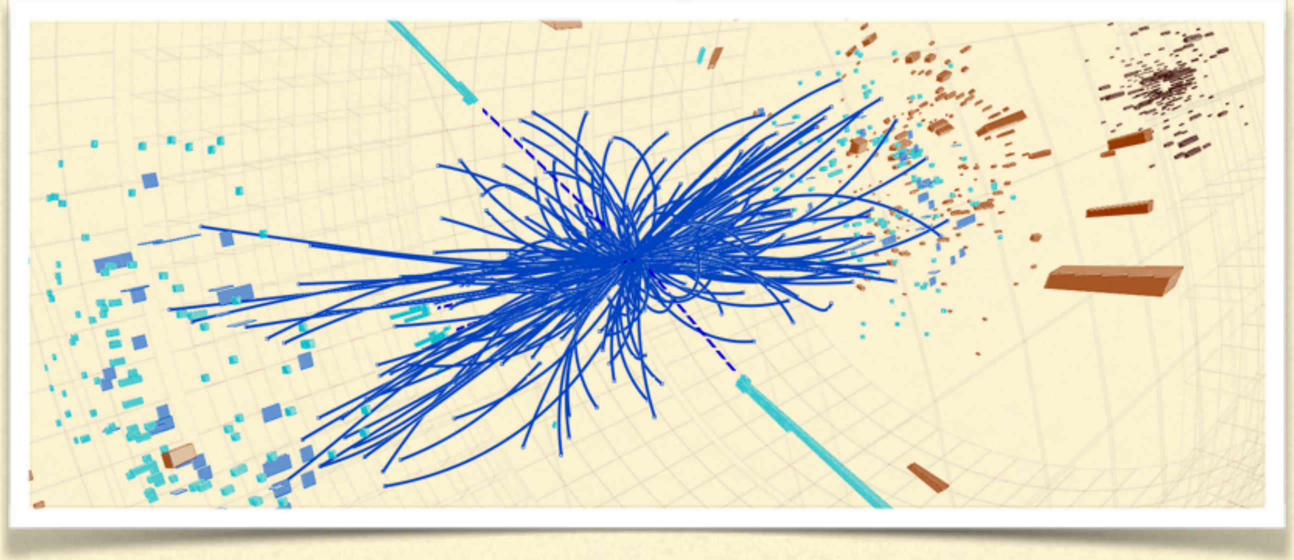
9.2.1	GRAVITATIONAL FIELDS

HIGGS BOSON



On 4 July 2012, the ATLAS and CMS experiments at CERN's Large Hadron Collider announced they had each observed a new elementary particle. This particle is crucial to particle physics theory and consistent with the Higgs field, which was first predicted to exist in the 1960s. The presence of this field explains why the fundamental particles that make up matter have mass.

HIGGS BOSON



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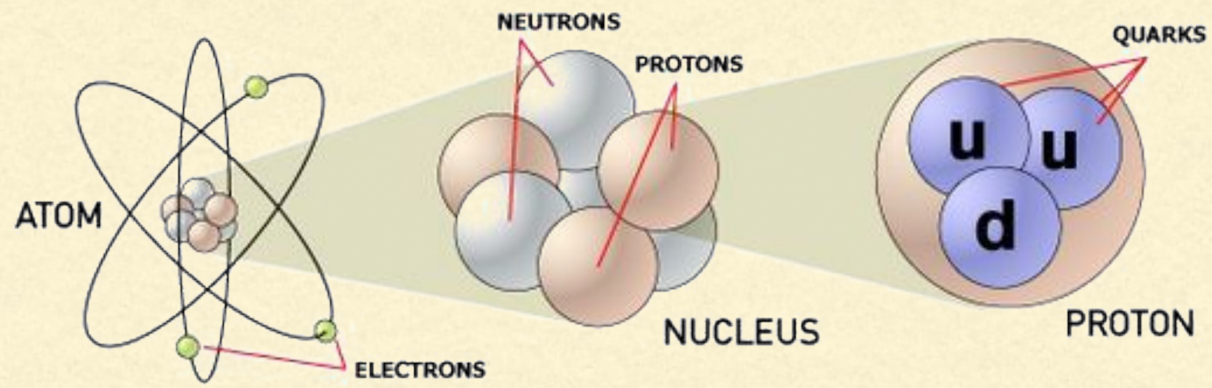
7.1.10	MATTER	7.1.6	DYNAMICS	7.1.2	PRACTICE OF PHYSICS

WHAT'S THE MATTER?



- The nucleus of an atom is made up of neutrons and protons
- Different combinations of the up and down quark make up the neutron and proton
- Therefore, to make up matter, you only need the electron, up quark and the down quark

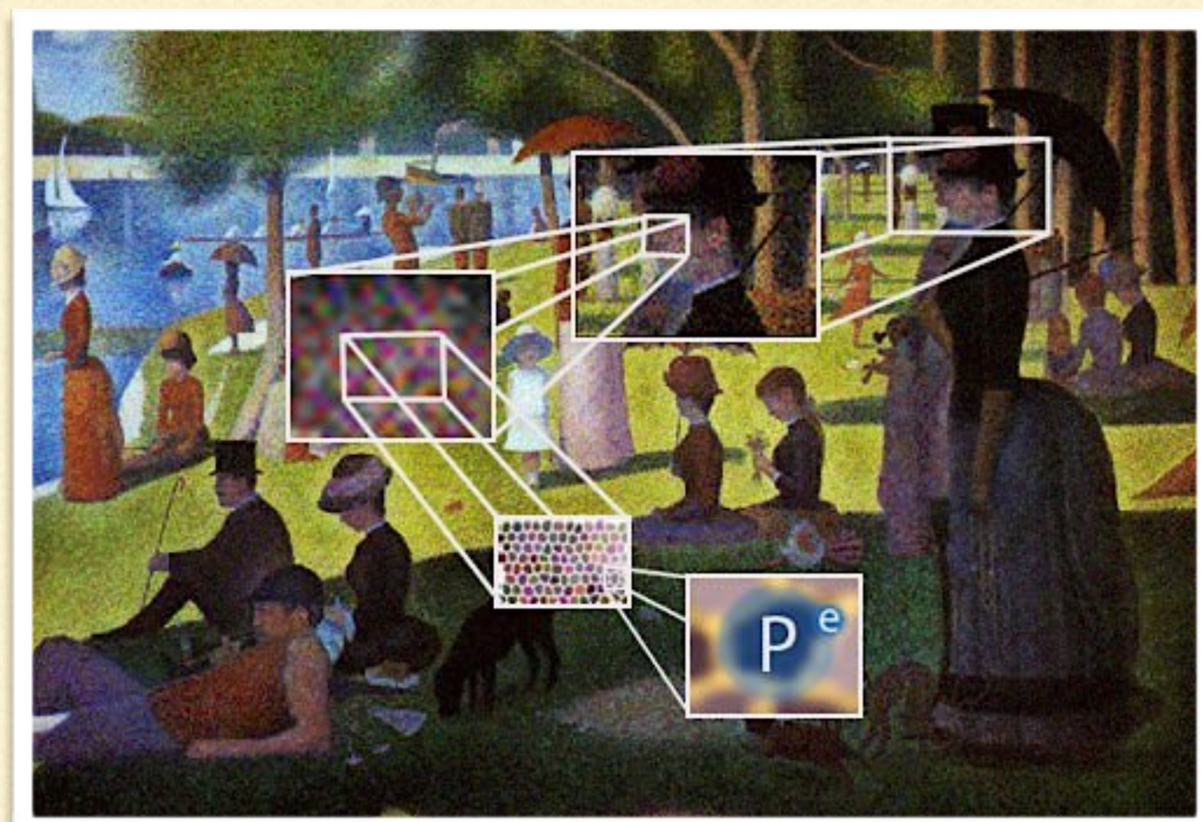
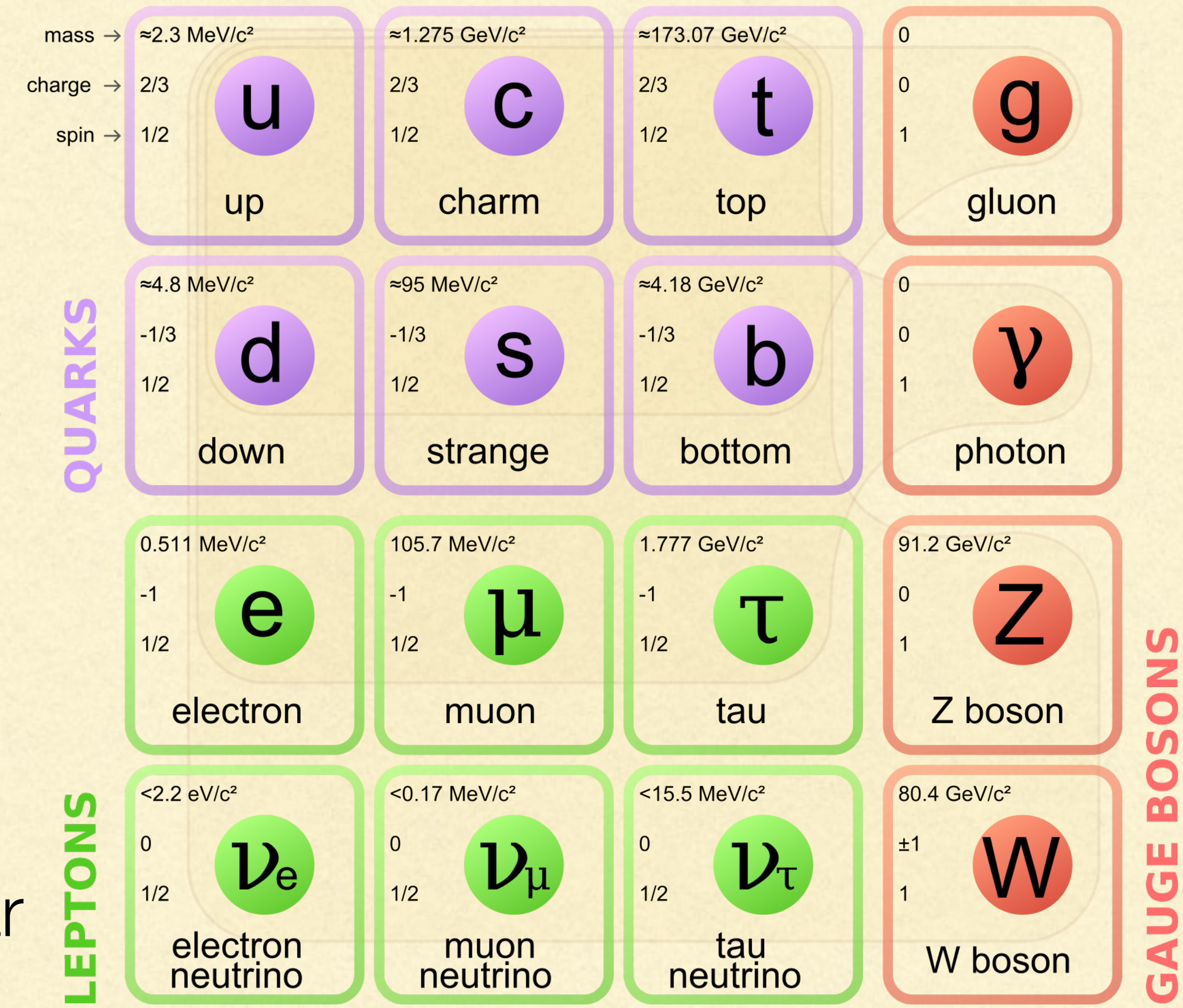


Image credit: Universe Adventure

STANDARD MODEL

- In addition to the electron, up quark and down quark, physicists have discovered many other elementary particles
- All matter is composed of the fermions (quarks and leptons)
- While bosons provide three forces: electromagnetism, strong nuclear and weak nuclear



7.1.10	MATTER	7.1.6	DYNAMICS

Image credit: Fermilab

STANDARD MODEL

- Allows us to mathematically describe all observed physical processes in the Universe (except for gravity)
- When first formulated, it was discovered the bosons has zero mass
- This presented a problem as experiments showed not all bosons have zero mass
- To make the equations work, physicists added an extra boson into the mix - the Higgs

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu\partial_\nu W^-_\mu - M^2W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu\partial_\mu A_\nu - \frac{1}{2}\partial_\mu H\partial_\mu H - \frac{1}{2}m_h^2H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac{1}{2}(H^2+\phi^0\phi^0+2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + A_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - \frac{1}{2}g^2W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2s_wc_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3+H\phi^0\phi^0+2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_h[H^4+(\phi^0)^4+4(\phi^+\phi^-)^2+4(\phi^0)^2\phi^+\phi^-+4H^2\phi^+\phi^-+2(\phi^0)^2H^2] - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2W^+_\mu W^-_\mu[H^2+(\phi^0)^2+2\phi^+\phi^-] - \frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2+(\phi^0)^2+2(2s_w^2-1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2s_wA_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac{1}{2}ig^2s_wA_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2-1)Z^0_\mu A_\mu\phi^+\phi^- - g^1s_w^2A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial+m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial+m_u^\lambda)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial+m_d^\lambda)d^\lambda_j + igs_wA_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)] + \frac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2-1-\gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\frac{4}{3}s_w^2-1-\gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1-\frac{8}{3}s_w^2-\gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_jC^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)] + \frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_jC_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar{u}^\lambda_jC_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_jC^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_jC^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}^\lambda_ju^\lambda_j) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}^\lambda_jd^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5u^\lambda_j) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5d^\lambda_j) + \bar{X}^+(\partial^2-M^2)X^+ + \bar{X}^-(\partial^2-M^2)X^- + \bar{X}^0(\partial^2-\frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2Y + igc_wW^+_\mu(\partial_\mu\bar{X}^0X^- - \partial_\mu\bar{X}^+X^0) + igs_wW^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+Y) + igc_wW^-_\mu(\partial_\mu\bar{X}^-X^0 - \partial_\mu\bar{X}^0X^+) + igs_wW^-_\mu(\partial_\mu\bar{X}^-Y - \partial_\mu\bar{Y}X^+) + igc_wZ^0_\mu(\partial_\mu\bar{X}^+X^+ - \partial_\mu\bar{X}^-X^-) + igs_wA_\mu(\partial_\mu\bar{X}^+X^+ - \partial_\mu\bar{X}^-X^-) - \frac{1}{2}gM[\bar{X}^+X^+H + \bar{X}^-X^-H + \frac{1}{c_w^2}\bar{X}^0X^0H] + \frac{1-2c_w^2}{2c_w}igM[\bar{X}^+X^0\phi^+ - \bar{X}^-X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-] + igMs_w[\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+X^+\phi^0 - \bar{X}^-X^-\phi^0]$$

$$gMW^+_\mu W^-_\mu \boxed{H} - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu \boxed{H}$$

7.1.10	MATTER	7.1.6	DYNAMICS	7.1.7	ENERGY	7.1.2	PRACTICE OF PHYSICS

HIGGS MECHANISM

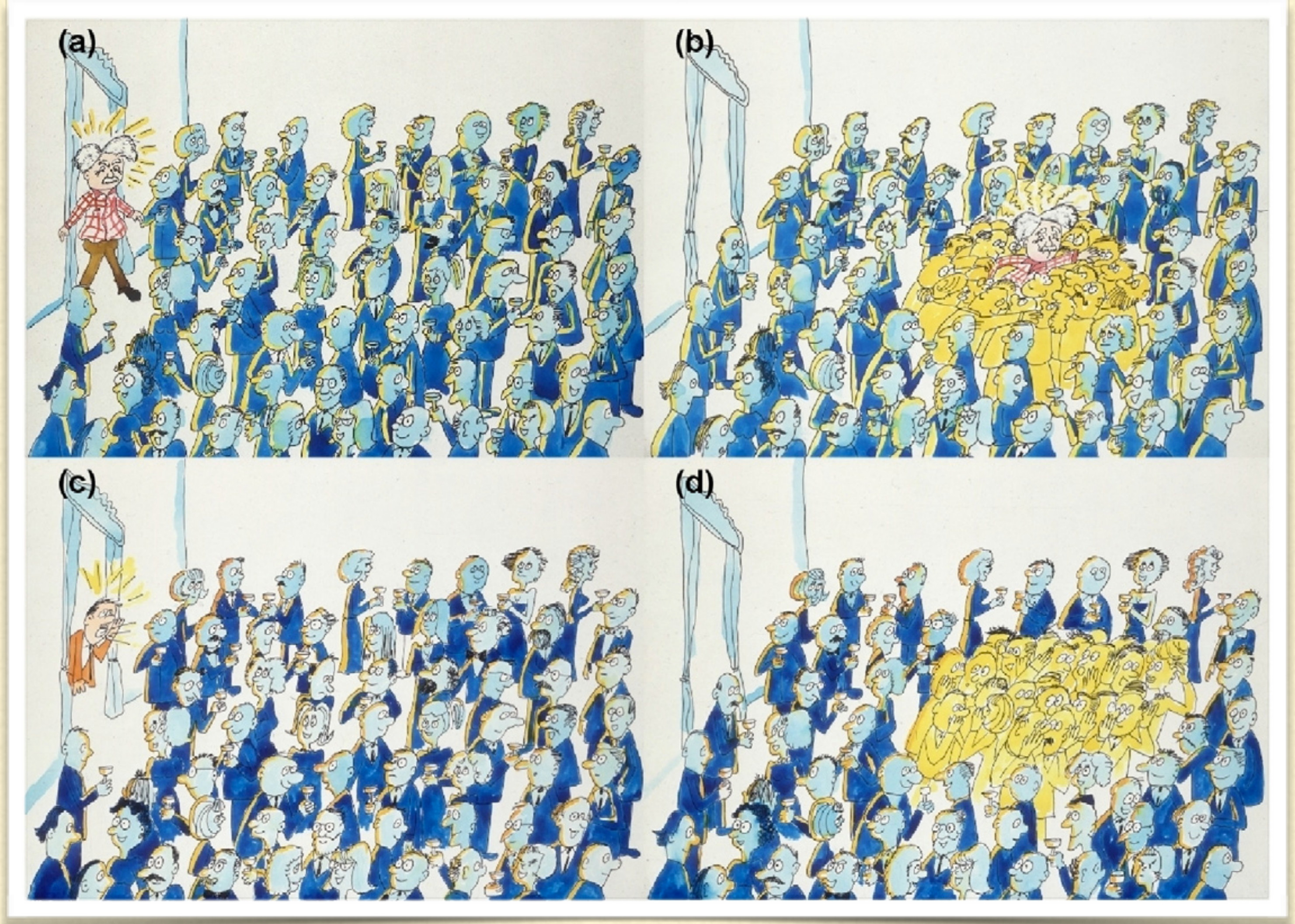
The Higgs mechanism generates mass through its interaction with other particles. This is difficult to visualise, so many use metaphors to explain…

- Some use food, suggesting the Higgs field is like molasses, slowing particles that flow through it

- Others use people, where a crowd represents the Higgs field and a passing celebrity is an interacting particle

HIGGS: THE CROWD METAPHOR

- In panels (a) and (b) you can see how Einstein (a particle) enters a room with physicists (the Higgs field) and gets slowed down by his colleagues wanting to talk to him (he couples to the Higgs field and attains mass)
- Panels (c) and (d) explain how the Higgs field itself attains mass (Higgs boson) by coupling to itself: If a rumour propagates through the room, the physicists (Higgs field) form a local crowd intensively chatting (self coupling)



METAPHORS: FRIENDS OR FOE?

Positive: Metaphors allow a student to build on existing knowledge and help them understand something quickly and intuitively

Negative: This intuition can be misleading and hinder the development of a deeper understanding in the future

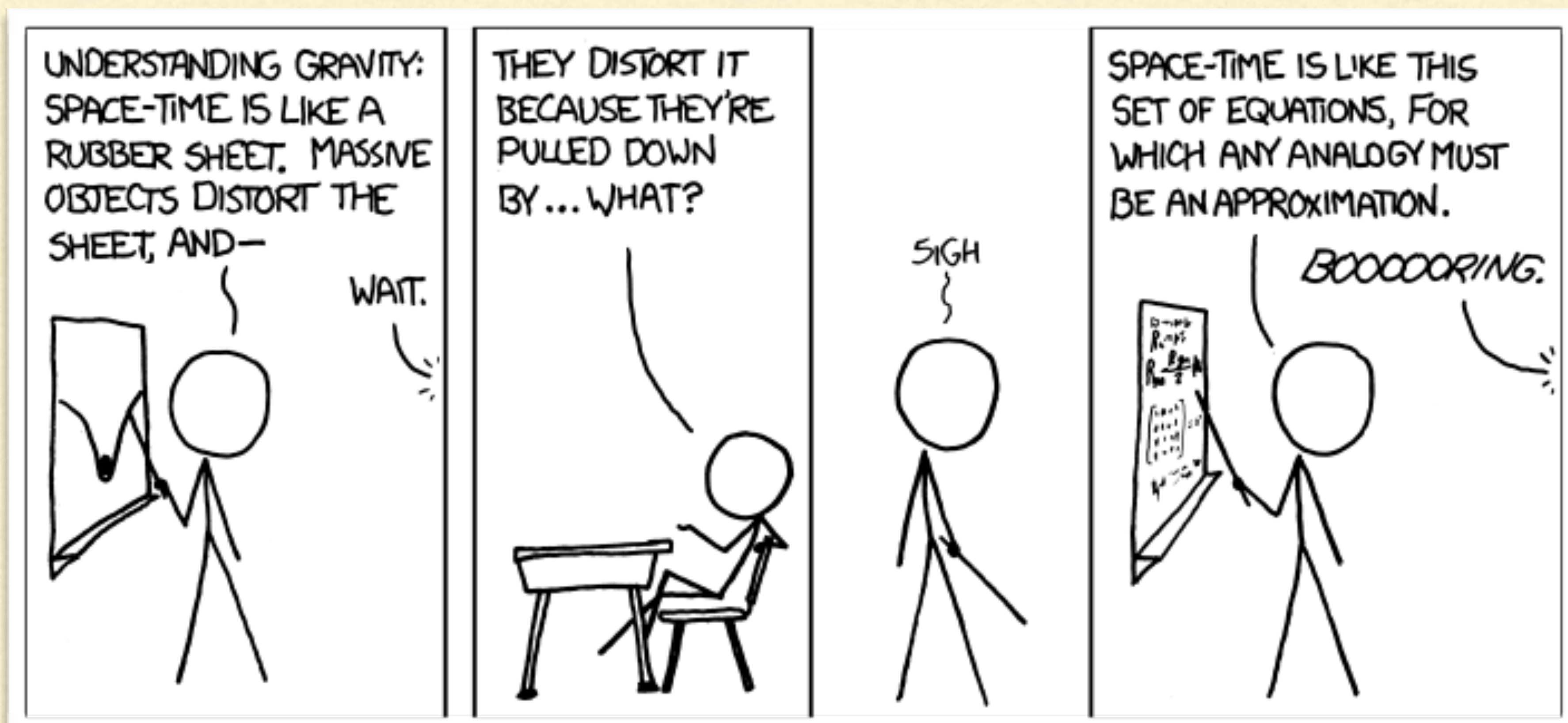


Image credit: XKCD

METAPHORS: FRIENDS OR FOE?

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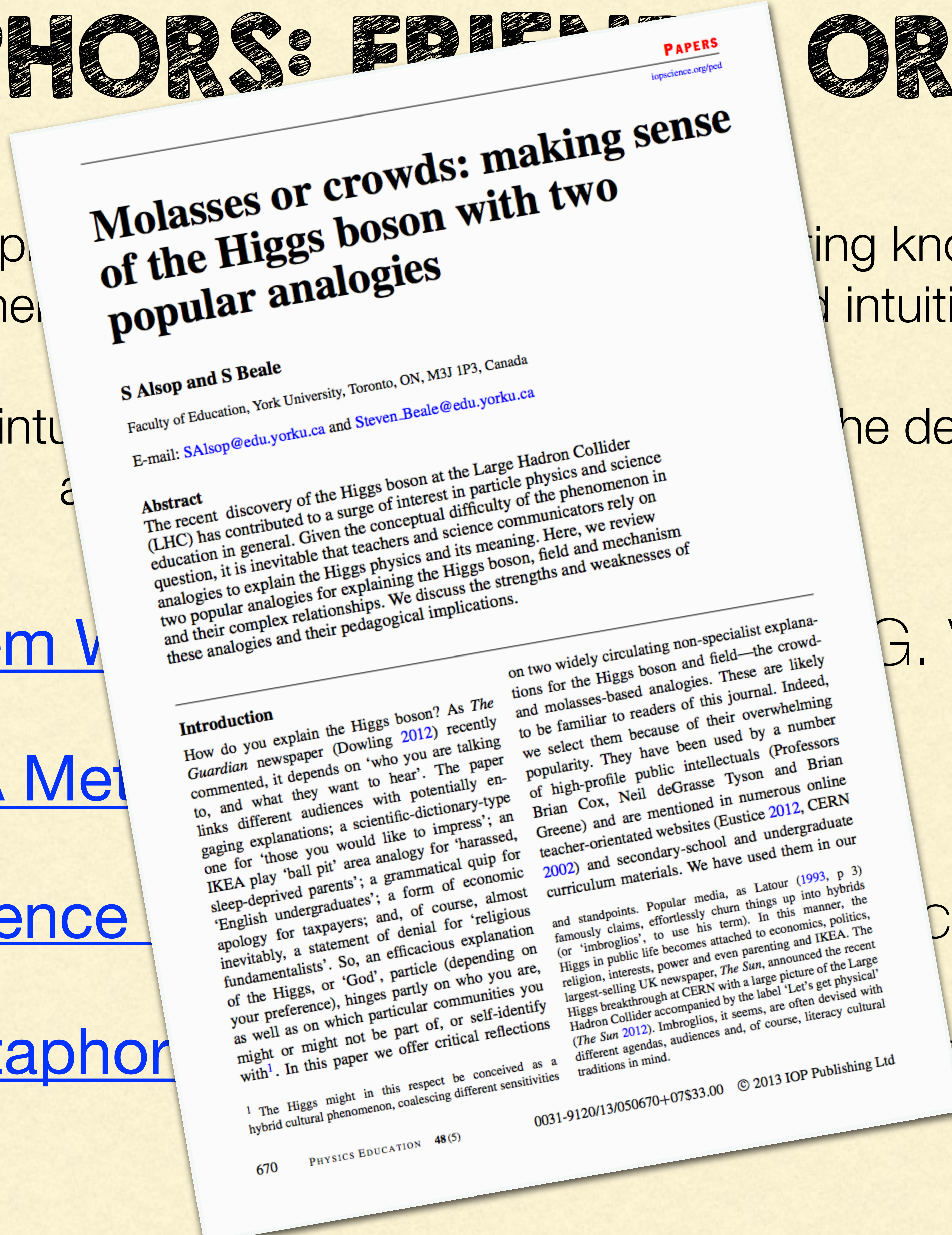
The Problem With Metaphors by Thomas G. Vincent

A Metaphor Too Far by Philip Ball

In Defence of Metaphors by Caleb A. Scharf

Metaphorical Thinking by Robert Root-Bernstein

METAPHORS: FRIE OR FOE?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Molasses or crowds: making sense of the Higgs boson with two popular analogies

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Abstract
The recent discovery of the Higgs boson at the Large Hadron Collider (LHC) has contributed to a surge of interest in particle physics and science education in general. Given the conceptual difficulty of the phenomenon in question, it is inevitable that teachers and science communicators rely on analogies to explain the Higgs physics and its meaning. Here, we review two popular analogies for explaining the Higgs boson, field and mechanism and their complex relationships. We discuss the strengths and weaknesses of these analogies and their pedagogical implications.

Introduction
How do you explain the Higgs boson? As *The Guardian* newspaper (Dowling 2012) recently commented, it depends on 'who you are talking to, and what they want to hear'. The paper links different audiences with potentially engaging explanations; a scientific-dictionary-type one for 'those you would like to impress'; an IKEA play 'ball pit' area analogy for 'harassed, sleep-deprived parents'; a grammatical quip for 'English undergraduates'; a form of economic apology for taxpayers; and, of course, almost inevitably, a statement of denial for 'religious fundamentalists'. So, an efficacious explanation of the Higgs, or 'God', particle (depending on your preference), hinges partly on who you are, as well as on which particular communities you might or might not be part of, or self-identify with[1]. In this paper we offer critical reflections on two widely circulating non-specialist explanations for the Higgs boson and field—the crowd- and molasses-based analogies. These are likely to be familiar to readers of this journal. Indeed, we select them because of their overwhelming popularity. They have been used by a number of high-profile public intellectuals (Professors Brian Cox, Neil deGrasse Tyson and Brian Greene) and are mentioned in numerous online teacher-orientated websites (Eustice 2012, CERN 2002) and secondary-school and undergraduate curriculum materials. We have used them in our

[1] The Higgs might in this respect be conceived as a hybrid cultural phenomenon, coalescing different sensitivities and standpoints. Popular media, as Latour (1993, p 3) famously claims, effortlessly churn things up into hybrids (or 'imbroglios', to use his term). In this manner, the Higgs in public life becomes attached to economics, politics, religion, interests, power and even parenting and IKEA. The largest-selling UK newspaper, *The Sun*, announced the recent Higgs breakthrough at CERN with a large picture of the Large Hadron Collider accompanied by the label 'Let's get physical' (*The Sun* 2012). Imbroglios, it seems, are often devised with different agendas, audiences and, of course, literacy cultural traditions in mind.

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Positive: Metap … ing knowledge and help the … intuitively

Negative: This intu … he development of a

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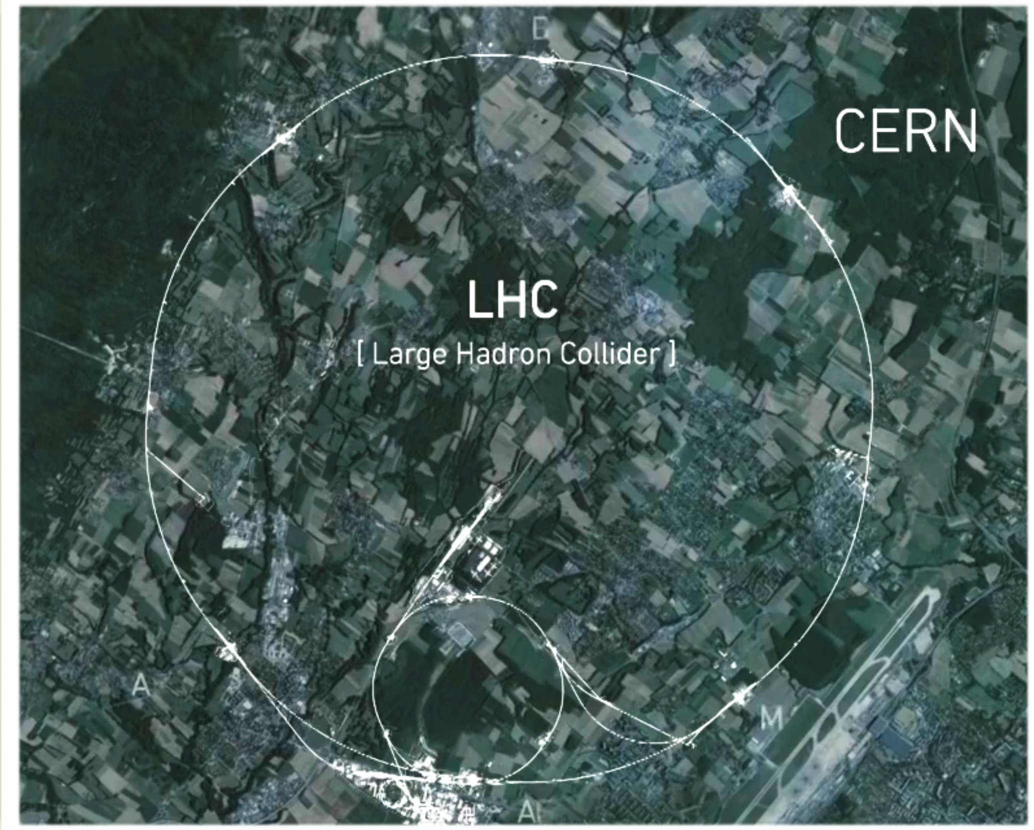
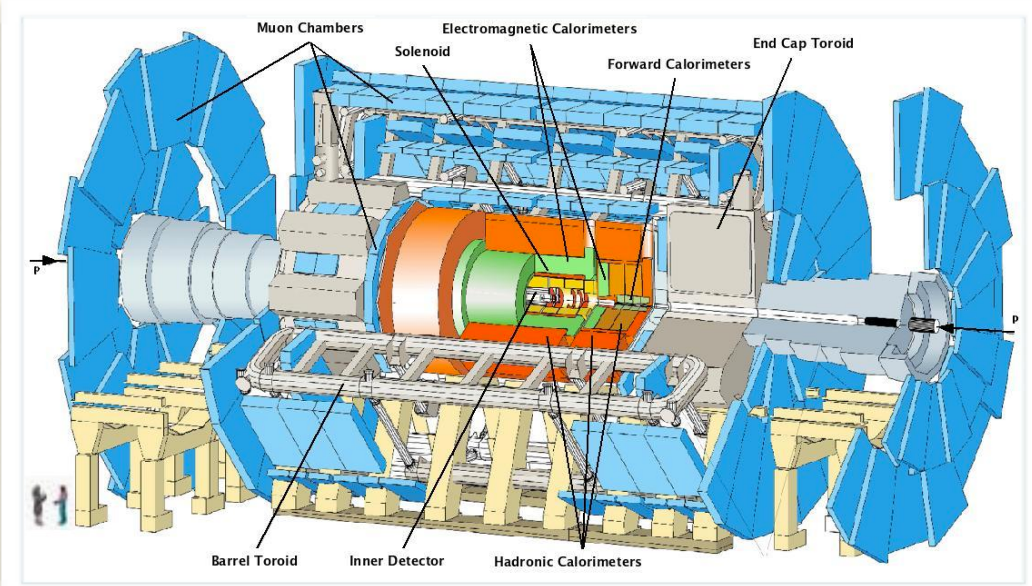
THE LARGE HADRON COLLIDER

- 27 kilometers in circumference
- Supported by 10,000 scientists and engineers from over 85 countries
- Several decades to build
- Accelerate protons to 99.99% the speed of light
- Whips them clockwise and anticlockwise before colliding



- Collisions are detected by ATLAS (A Toroidal LHC ApparatuS)
- Width 46m, Diameter 25m, weighs 7 million kg and contains 3000km of cable
- Capable of detecting 6 hundred million collisions per second
- Generates 1 petabyte (1000 terabytes) of raw data per second



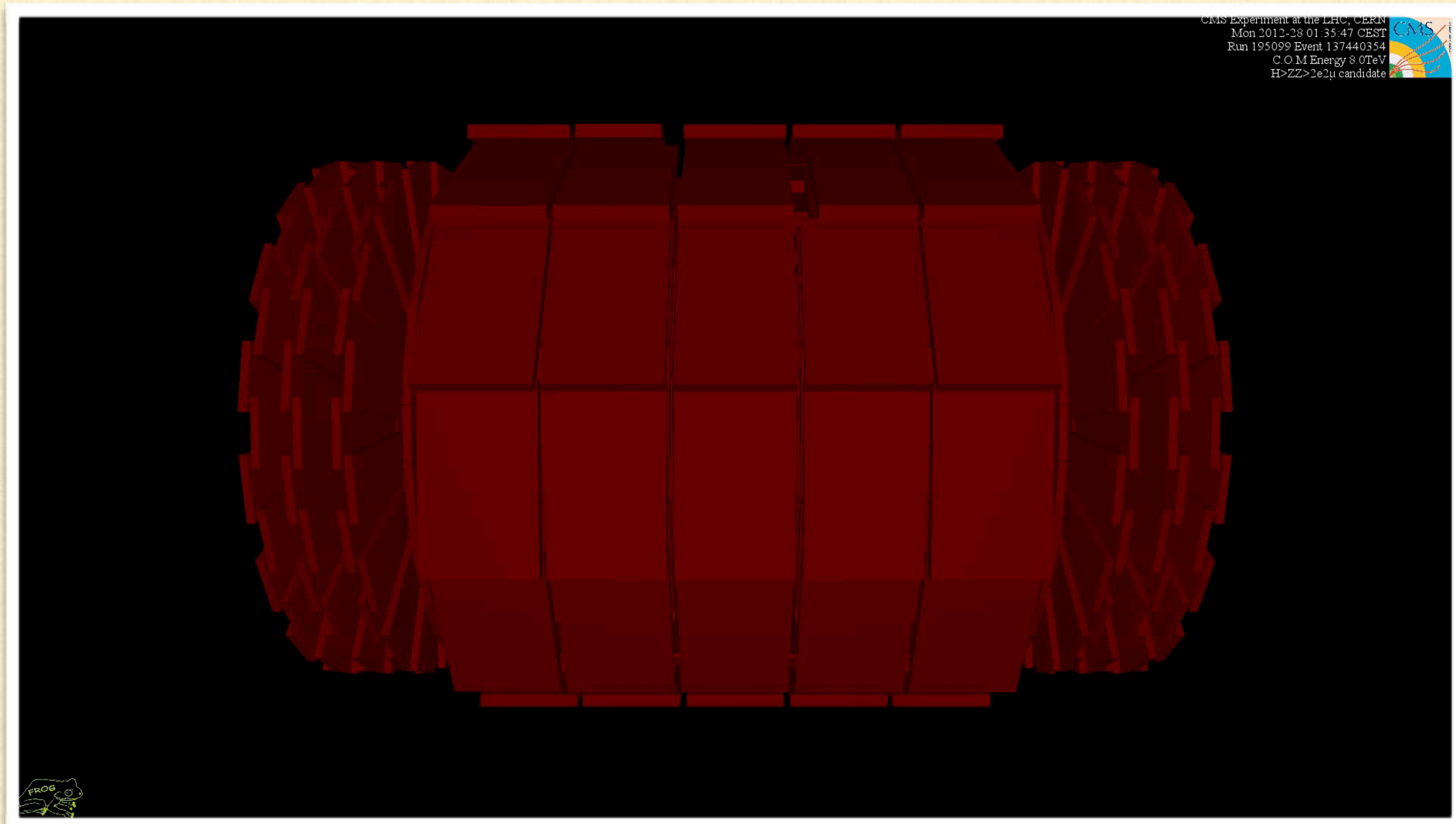
7.1.10	MATTER	7.1.6	DYNAMICS	7.1.7	ENERGY

CMS DETECTOR

Peter Higgs stands on the cavern floor at CMS (Compact Muon Solenoid), with the detector open for maintenance behind him (Image: Maximilien Brice/CERN)

7.1.10	MATTER
7.1.6	DYNAMICS
7.1.7	ENERGY

THE COLLISION!

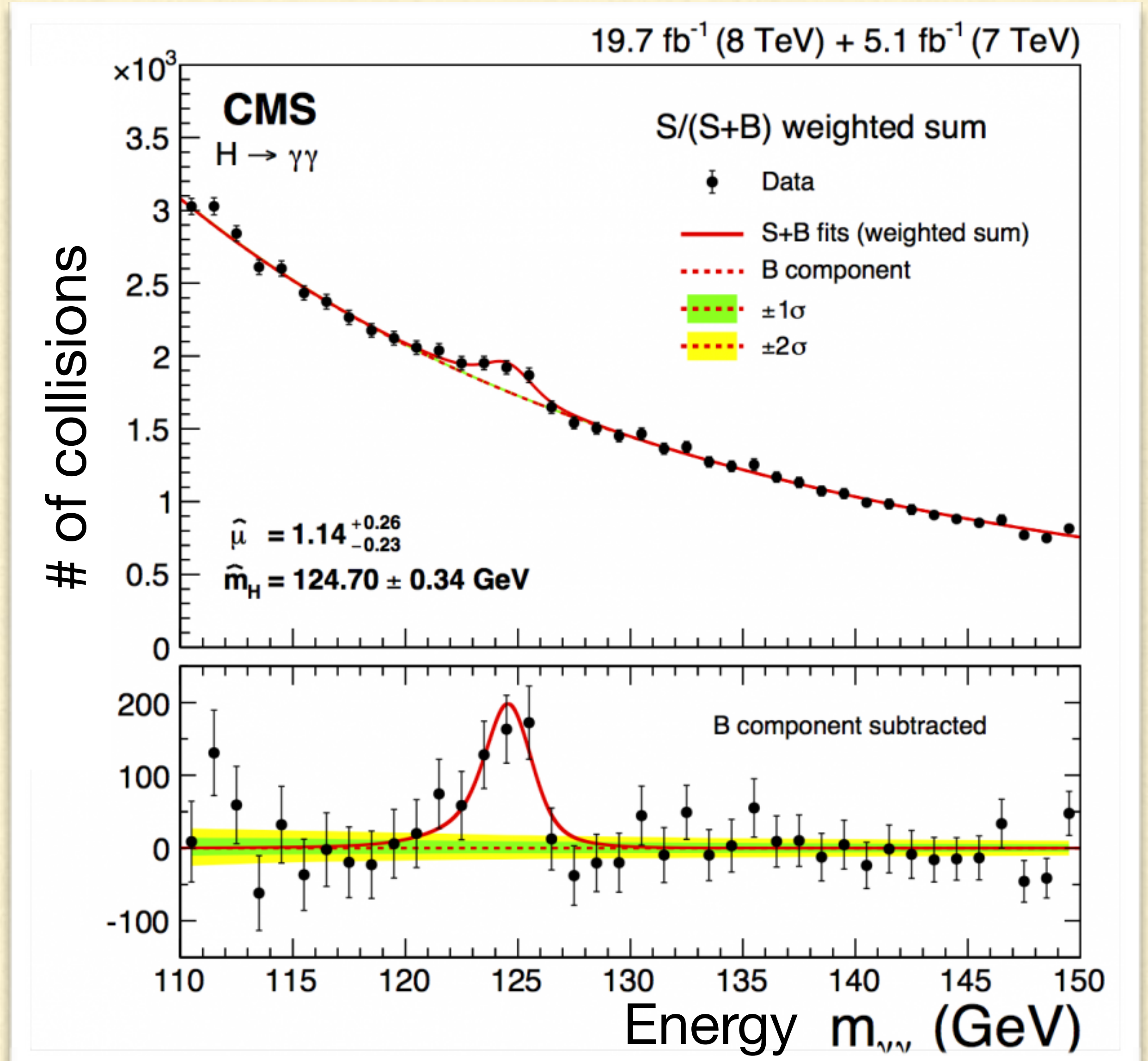


In this simulation, protons are collided. Lines denote other particles, and energy deposited is shown in blue (Image: CMS)

7.1.10	MATTER	7.1.6	DYNAMICS	7.1.7	ENERGY

DETECTING THE HIGGS

- Don't actually "see" the Higgs boson; see the decays of it (i.e., the transformation of boson energy into two photons)
- These decay products (the two photons) are what the detectors are looking for
- The detectors count proton-proton collisions for which two photons are produced (y-axis)
- They also measure the energy of these photons (x-axis)
- The bump corresponds to an "excess" of decay particles that may reveal a Higgs boson at an energy from 115 to 135 GeV (mass/energy)

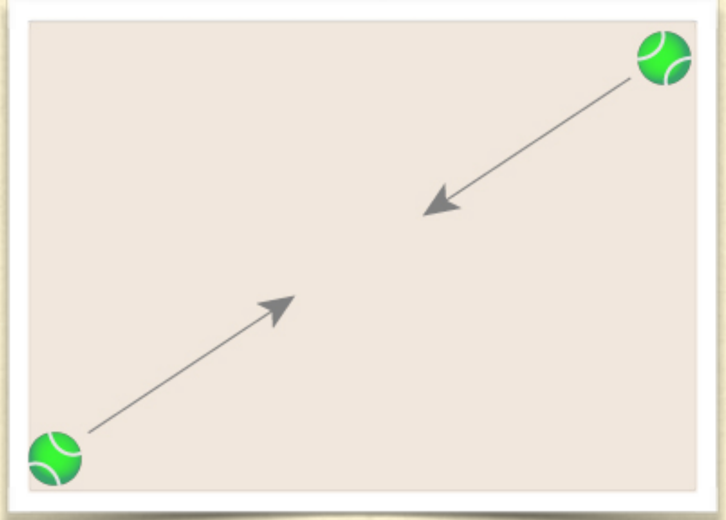


7.1.10	MATTER	7.1.6	DYNAMICS	7.1.7	ENERGY	7.1.2	PRACTICE OF PHYSICS

CLASSROOM ACTIVITIES

Activity 3: What's in the Box?
Brief overview: Students attempt to determine the content of a box by making various types of observations.
Duration: 30 min
Inquiry Focus: Inferring—drawing a conclusion about a hidden object in a closed box based on its sound, motion, weight and other observations.
Grades: 7 – 10

Activity 4: Colliding Particles
Brief overview: Students are introduced to some of the factors involved in producing particle collisions, such as the ones that occur in the Large Hadron Collider
Duration: 30 min
Inquiry Focus: modelling of complex scientific experiments
Grades: 10 – 12



TOPICS FOR DISCUSSION OR WRITING EXERCISES

- Compare the impact of the discovery of Higgs boson to another “game changer” (e.g. heliocentric solar system, theory of evolution by natural selection) in the history of science. How are they similar? In what ways are they different?
- The Higgs boson confirms the Standard Model, but scientists say it could also lead to its revision or possibly even its replacement. In this light, discuss the role of models in science.
- More than forty years elapsed between the time Peter Higgs first proposed his theory and the announcement of the Higgs boson’s discovery. Gives specific examples of how this lengthy process illuminates the scientific method in action.
- Some people argued that learning more about the fundamental laws of nature wasn’t enough to justify spending billions of dollars that might be better spent in other ways. Do you agree with the their line of thought? Give arguments for or against.
- Should the governments fund other expensive science projects (e.g. space exploration) even if the “practical” benefits are not immediately obvious?

7.1.2	PRACTICE OF PHYSICS	7.1.4	IMPLICATIONS FOR SOCIETY	7.1.5	CURRENT ISSUES

RESOURCES

http://web.science.mq.edu.au/~mcowley/open_afternoon/