CPEP and Gravitation

Lynn Cominsky
Sonoma State University

Proposing a new CPEP section

- Gravitation
- Inspired by ongoing NSF-funded work on behalf of LIGO (Laser Interferometer Gravitational-wave Observatory)
- First product would be a new poster highlighting LIGO and the (hopefully soon) discovery of gravitational waves
- Just in time for Einstein’s centennial of General Relativity in 2016

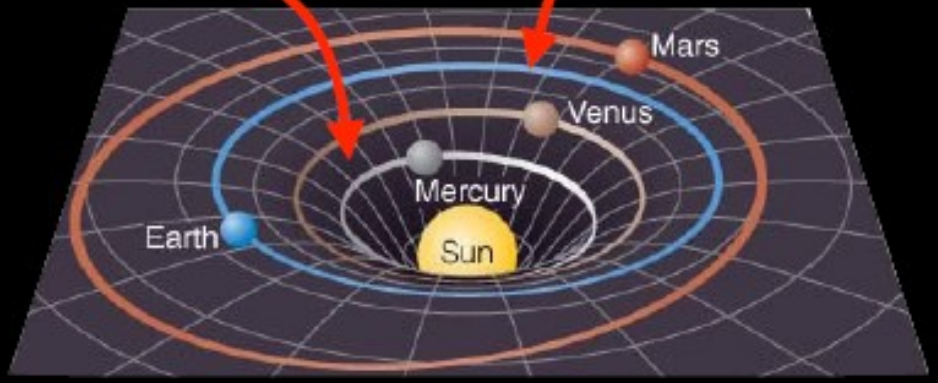
What are gravitational waves?

- Predicted by Einstein's General Theory of Relativity
- Compress and stretch spacetime
- Travel at the speed of light
- An entirely new way to view the Universe – once they are detected
- Very hard to detect! (None seen to date, earliest possible detections in 2016)

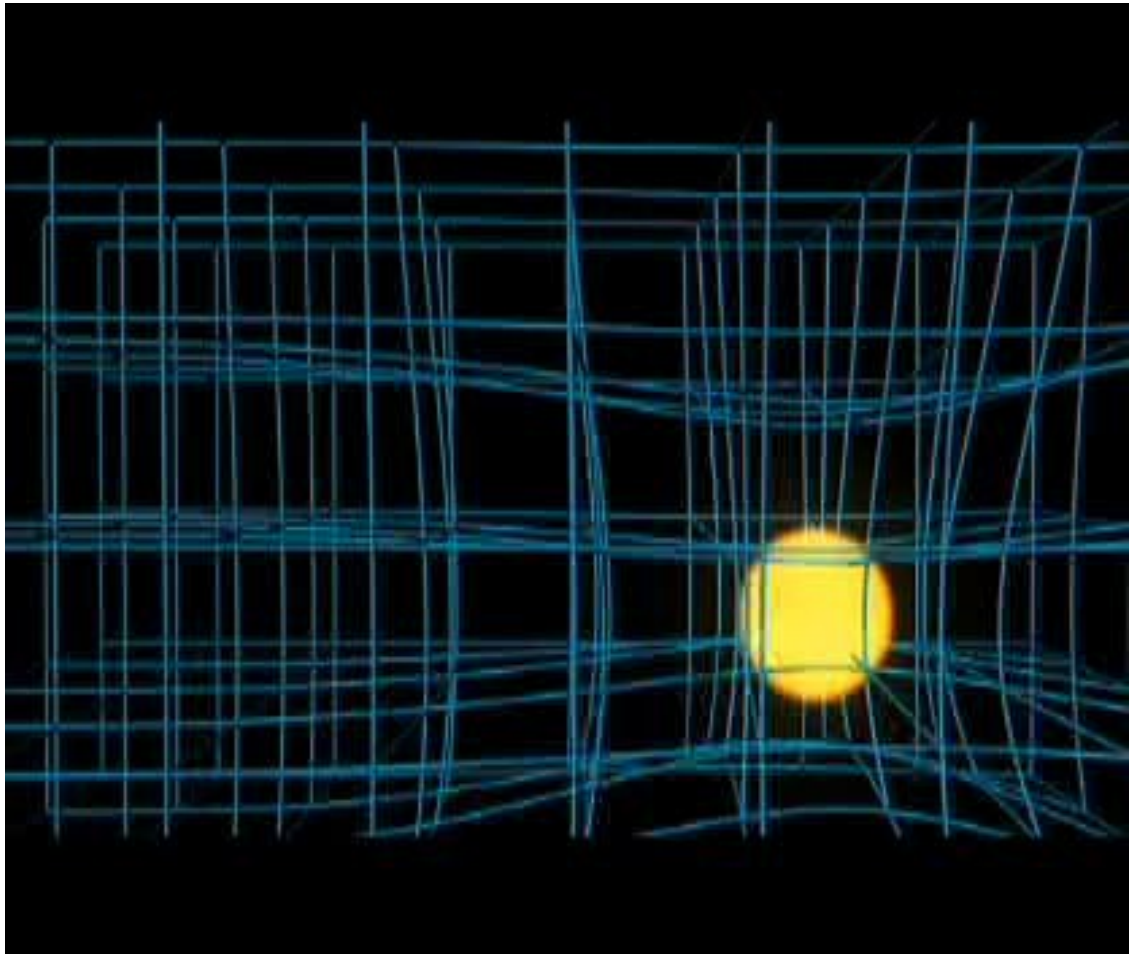
- In General Relativity matter tells space how to curve and space tells matter how to move

The mass of the Sun curves the space around it

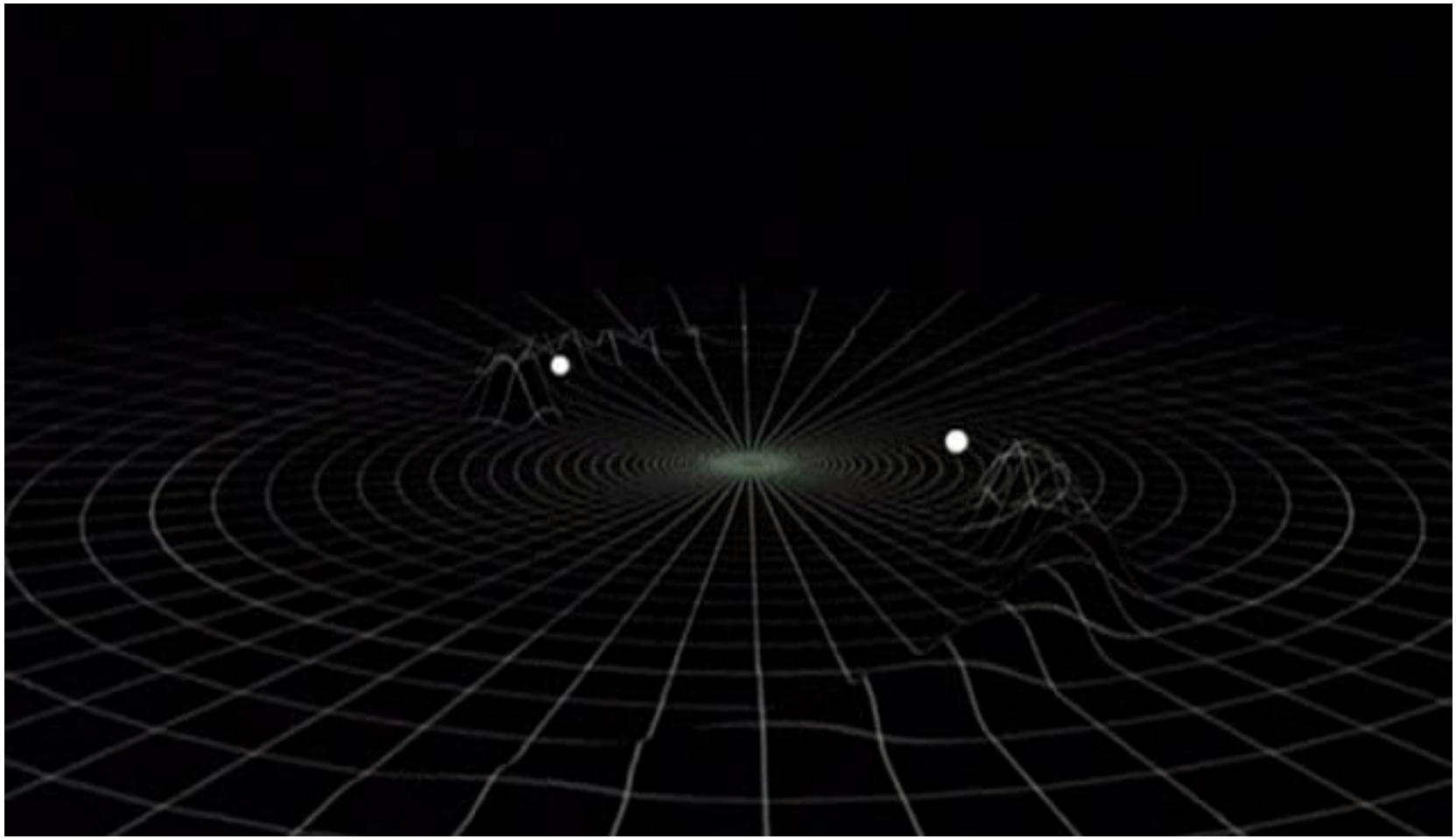
The planets follow the shortest path in the curved space

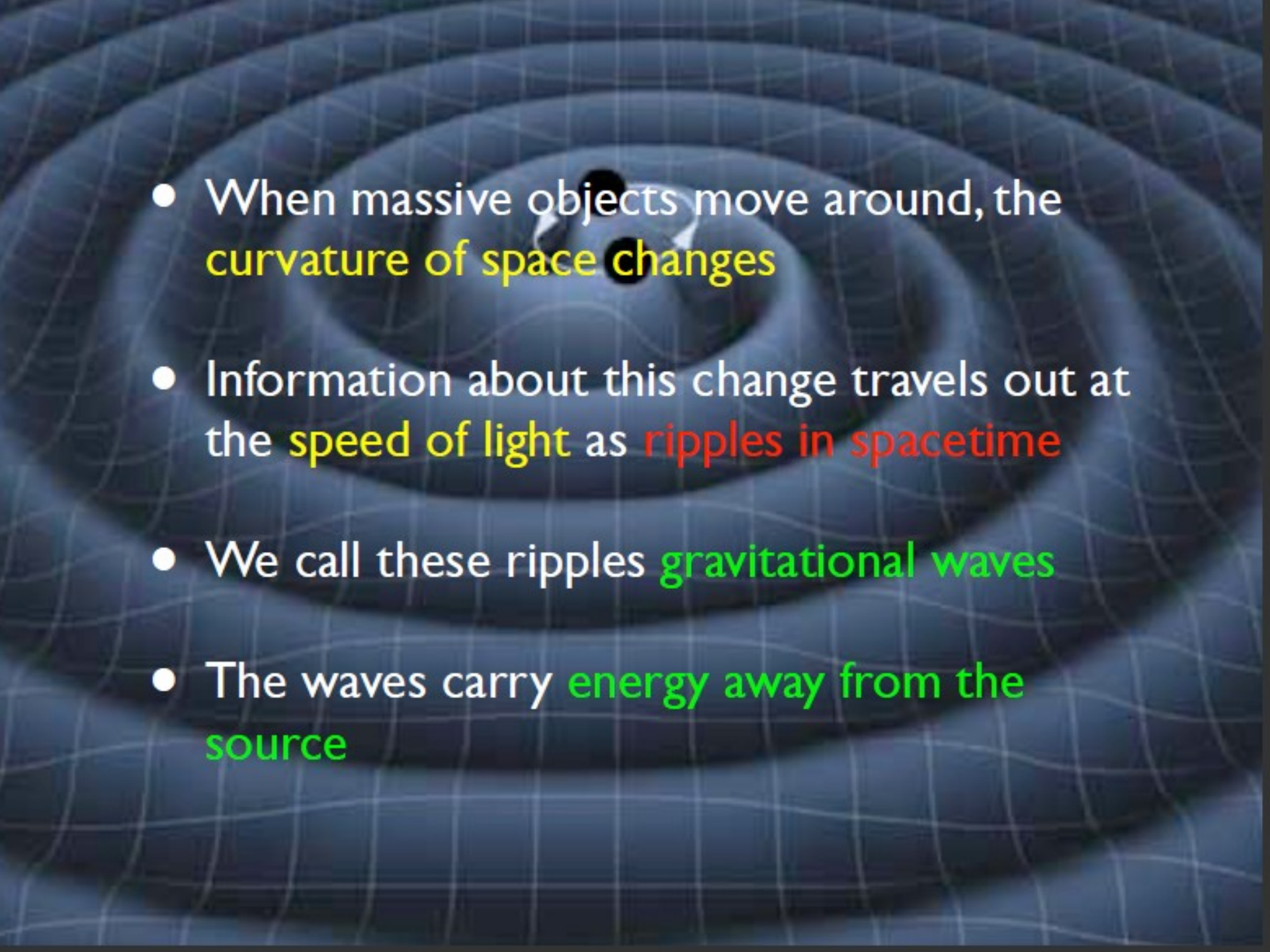


Spacetime curvature



Binary in spacetime



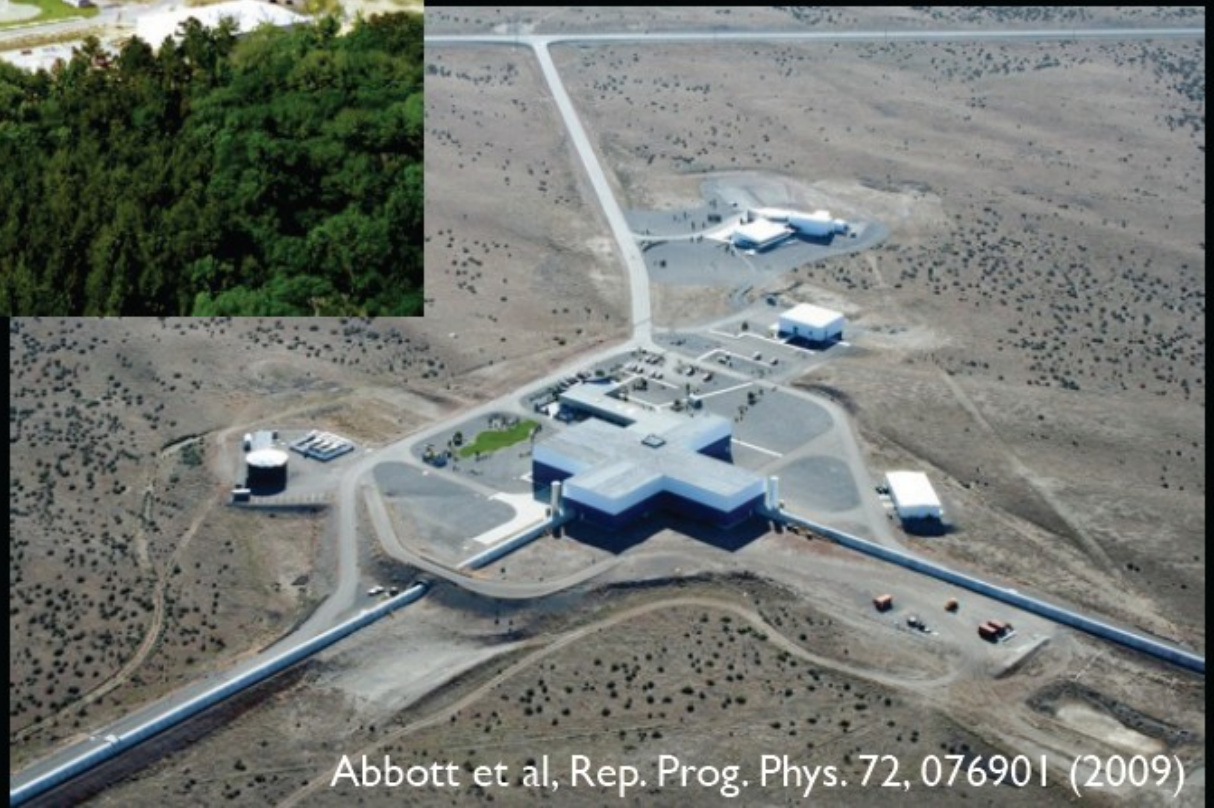


- When massive objects move around, the curvature of space changes
- Information about this change travels out at the speed of light as ripples in spacetime
- We call these ripples gravitational waves
- The waves carry energy away from the source

Gravitational Waves

- Experiments to detect GWs are currently being upgraded
  - LIGO (Hanford and Livingston) are now online and beginning engineering runs. By the end of 2015, they will begin the first science run. We hope to reach design sensitivity by 2017
  - Virgo (Italy) expected to come online in 2016
  - GEO (Germany) still operational (not as sensitive)
  - LIGO (India) – pending agreement, perhaps in 2020+

LIGO Livingston Observatory



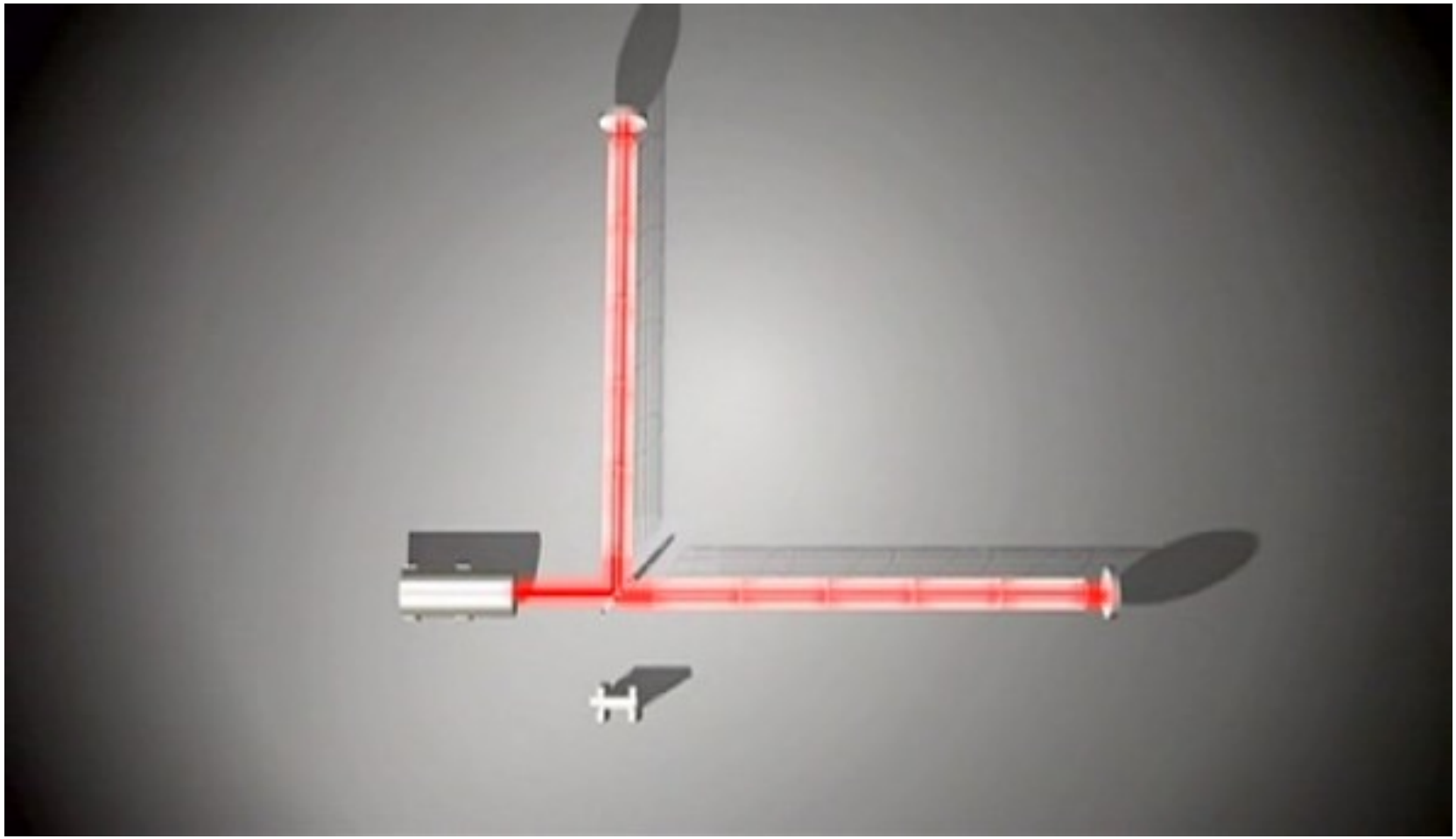
LIGO Hanford Observatory

Abbott et al, Rep. Prog. Phys. 72, 076901 (2009)

Virgo
Near Pisa, Italy

GEO600
Hannover,
Germany

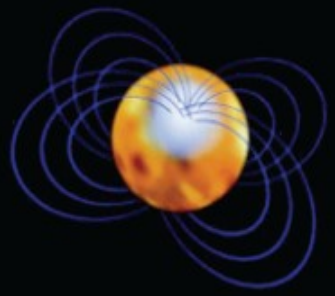
How LIGO works



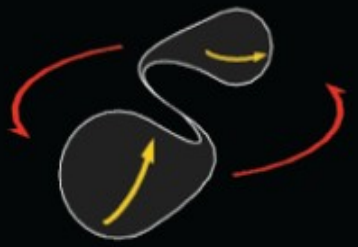
Einstein’s messengers,
National Science Foundation video

http://www.einsteinsmessengers.org/

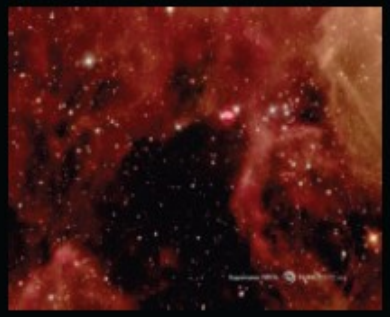
Sources of Gravitational Waves



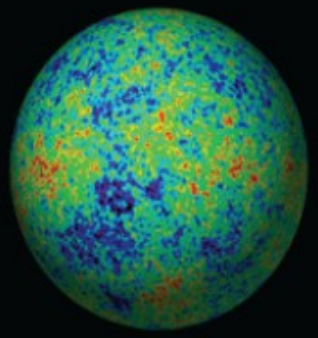
Continuous Sources:
spinning neutron stars



Compact binary coalescence (CBC):
inspiral, merger and ringdown of black holes and neutron stars

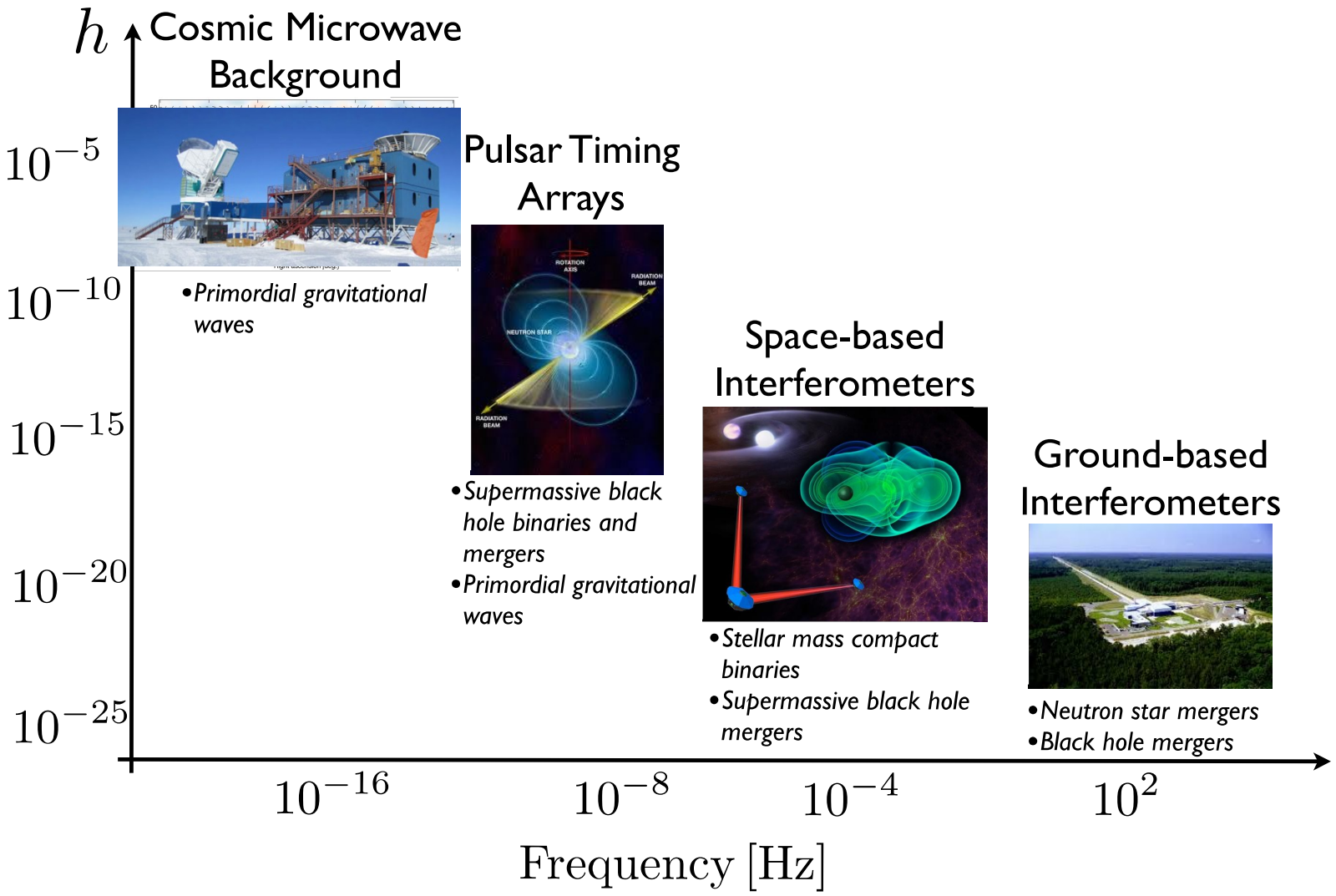


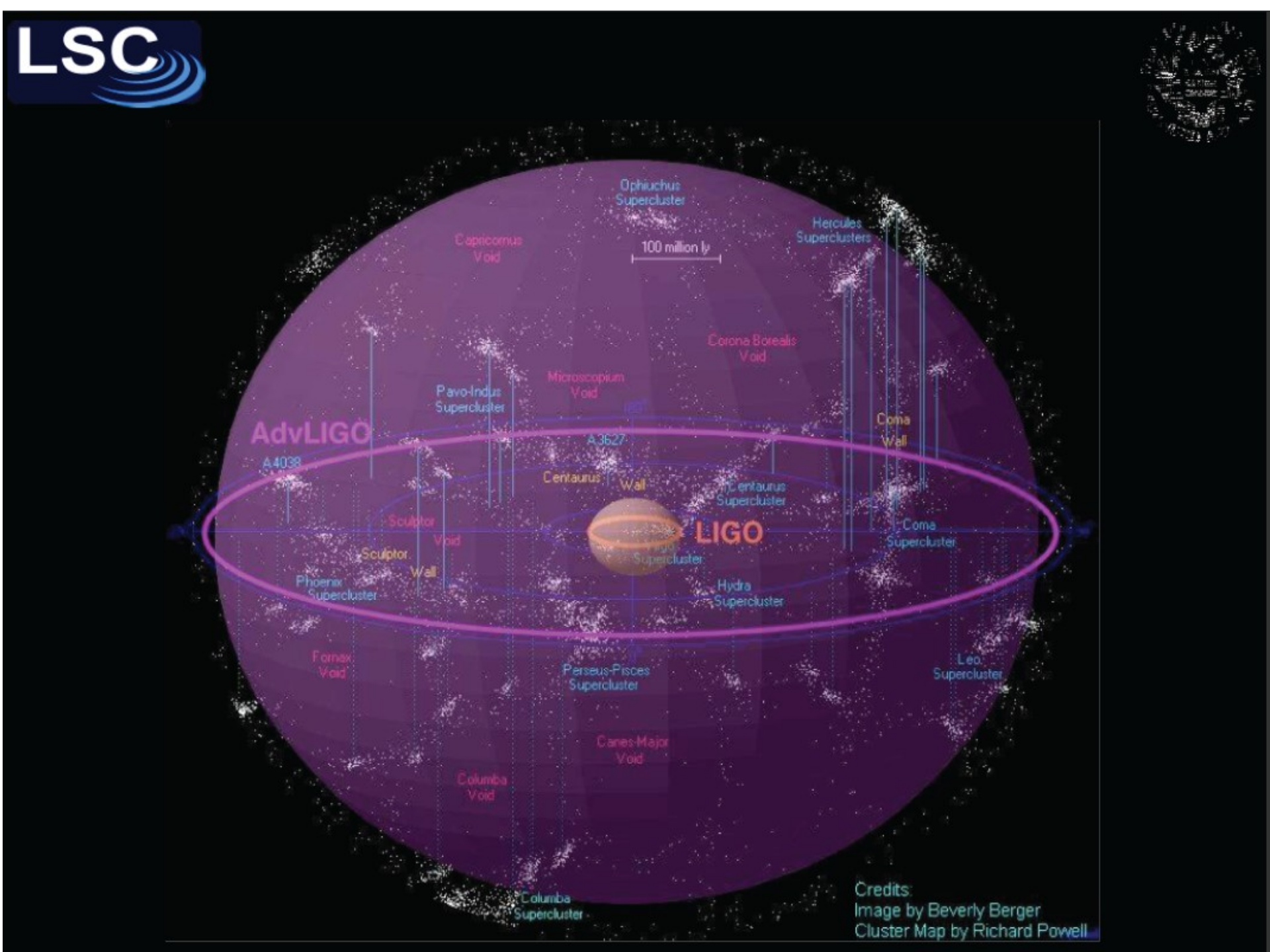
Short bursts:
supernovae, unmodeled transient sources



Stochastic sources:
gravitational wave background from the big bang

GW Spectrum


h
Cosmic Microwave Background
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
•Primordial gravitational waves
Pulsar Timing Arrays
ROTATION AXIS
RADIATION BEAM
NEUTRON STAR
RADIATION BEAM
•Supermassive black hole binaries and mergers
•Primordial gravitational waves
Space-based Interferometers
•Stellar mass compact binaries
•Supermassive black hole mergers
Ground-based Interferometers
•Neutron star mergers
•Black hole mergers
10^{-16}
10^{-8}
10^{-4}
10^{2}
Frequency [Hz]


LSC
Ophiuchus Supercluster
Capricornus Void
100 million ly
Hercules Superclusters
Corona Borealis Void
Microscopium Void
Pavo-Indus Supercluster
AdvLIGO
A3627
Coma Wall
A4038
Centaurus Wall
Centaurus Supercluster
LIGO
Sculptor Void
Coma Supercluster
Sculptor Wall
Phoenix Supercluster
Hydra Supercluster
Fornax Void
Perseus-Pisces Supercluster
Leo Supercluster
Canes Major Void
Columba Void
Columba Supercluster
Credits
Image by Beverly Berger
Cluster Map by Richard Powell

Resources for Physics teachers

- GWs address much broader questions than just astronomy + lots of physics in the experimental design
- At present, not many resources exist that are suitable for college or AP high school physics students
- I have received NSF funding to develop these types of resources for training lower-division (especially Community College) teachers as well as web-based resources for students
- The first new product would be a poster about waves and gravity that could be distributed (sold) by CPEP

Physics Resource website

- Two new classroom units that describe LIGO science and LIGO technologies
  - text, illustrations, conceptual and numerical exercises, multimedia resources such as animations and simulations, interactive computer applications, and homework problems
  - links to useful existing materials for calculus-based physics classes in college or high school
  - information about opportunities for LIGO-related student internships, REU programs and transfer opportunities to universities with LIGO-related research
  - Linked to ligo.org – *would also like to create a new CPEP section on gravitation*

Educator Professional Development

- Our first course – LIGO: Waves & Gravity is offered July 16 – Aug 6, 2015
- Can sign up for academic or continuing education credit through Sonoma State University
- Advertised through many channels but we could still use additional enrollment

Other things SSU can help with:

- Online Cosmology curriculum for general education college students – being distributed by Kendall Hunt publishers
- Big ideas in Cosmology – 18 chapters of online material
- LIGO: Waves & Gravity will use four of these chapters: Light, Classical Gravity, Special Relativity and General Relativity

Big Ideas in Cosmology

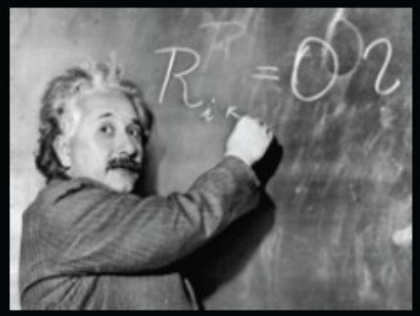
- Demo here

Next steps?

- There are other LIGO Scientific Collaboration members (e.g., Jocelyn Reed from CSU Fullerton) who would also like to get involved with CPEP – how do I get them involved?
- I am investigating what to do with our left over NASA posters and resources – possible to distribute (or sell?) through CPEP? I won't know the answer to this for about a year, due to the transition in NASA STEM education

Backups Follow

Fundamental questions that gravitational-wave observatories can answer



Is General Relativity the correct theory of gravity?

What is the nature of one of the four fundamental forces?

How many black holes are there in the universe?

Do black holes really have no hair?

How do the first generations of stars live and die?

How do stars and galaxies evolve?

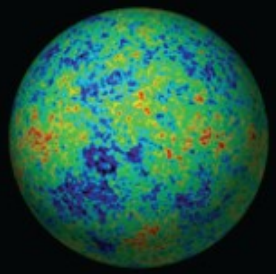
Fundamental questions that gravitational-wave observatories can answer

How does core collapse power a supernova?

What is the mass of the neutrino?

What is the nuclear equation of state of neutron stars?

What is the engine that powers short gamma-ray bursts?



What new physics lies beyond the microwave background?

What happened in the earliest moments of creation?