HOW WE 'KNOW': MAKING DISCOVERIES IN MODERN PHYSICS

Lecture 1: The Language of Modern Physics

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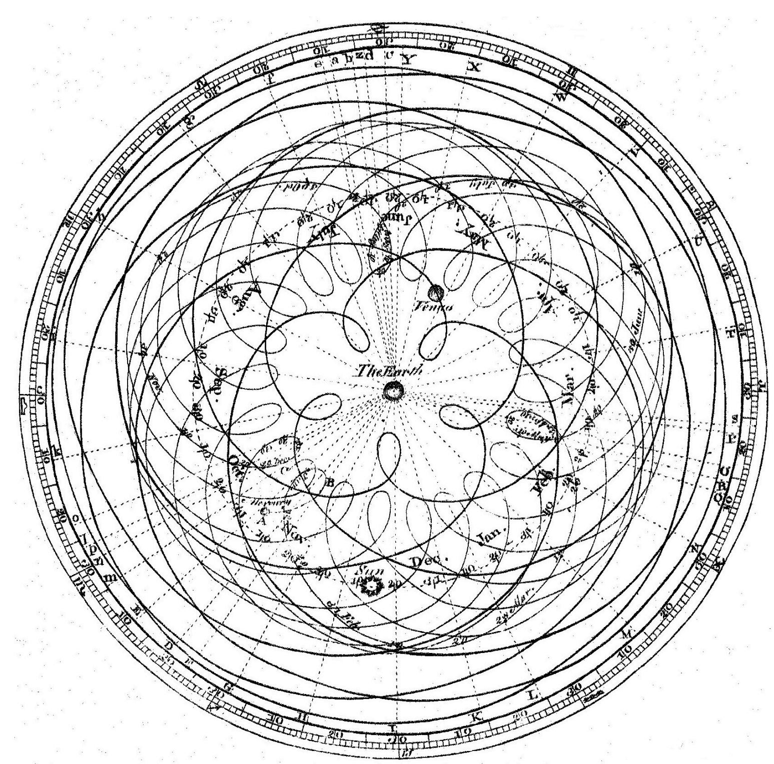
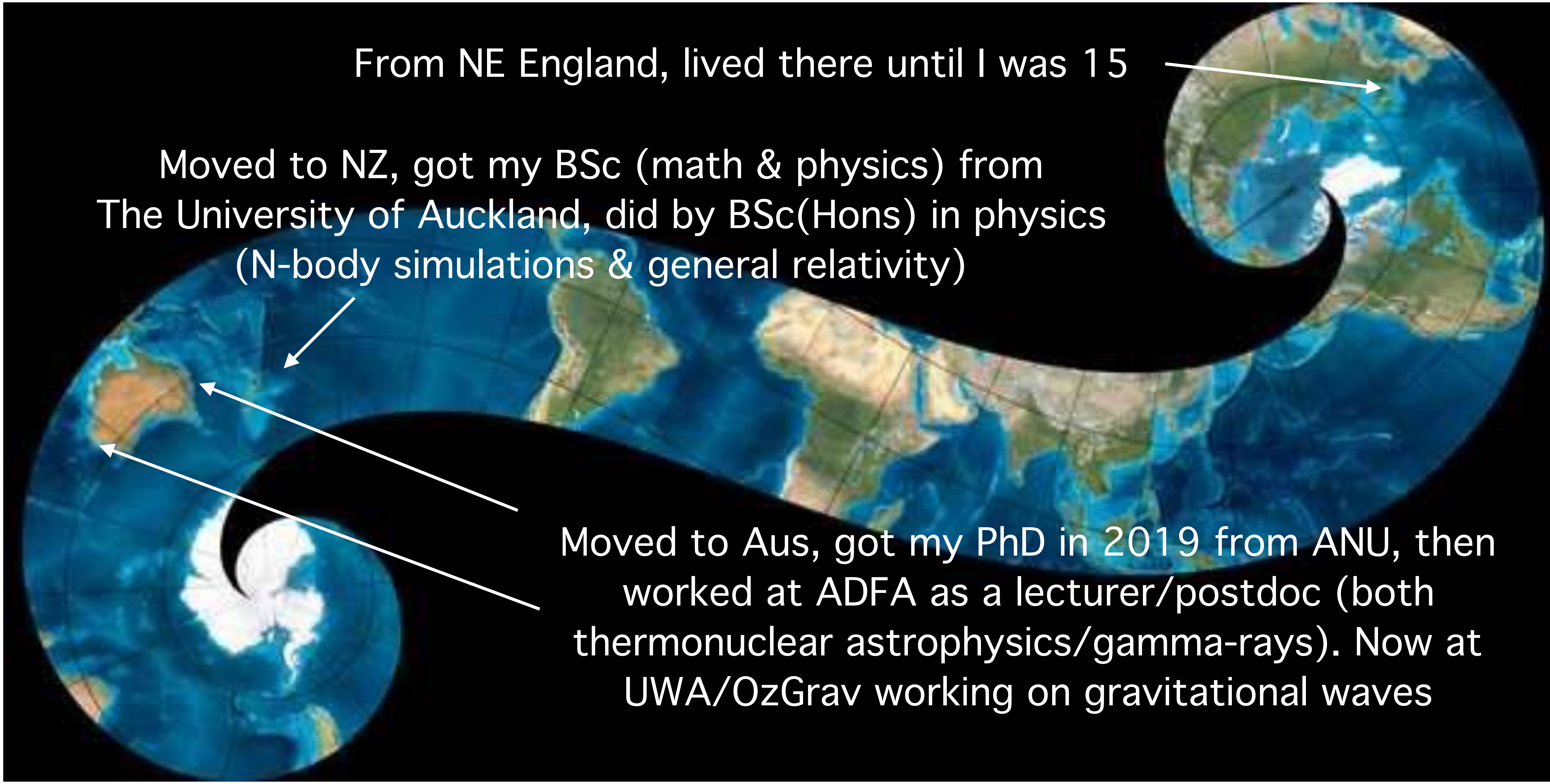


About me



Lots of disparate things, all connected by statistics/information theory and how we learn things from data

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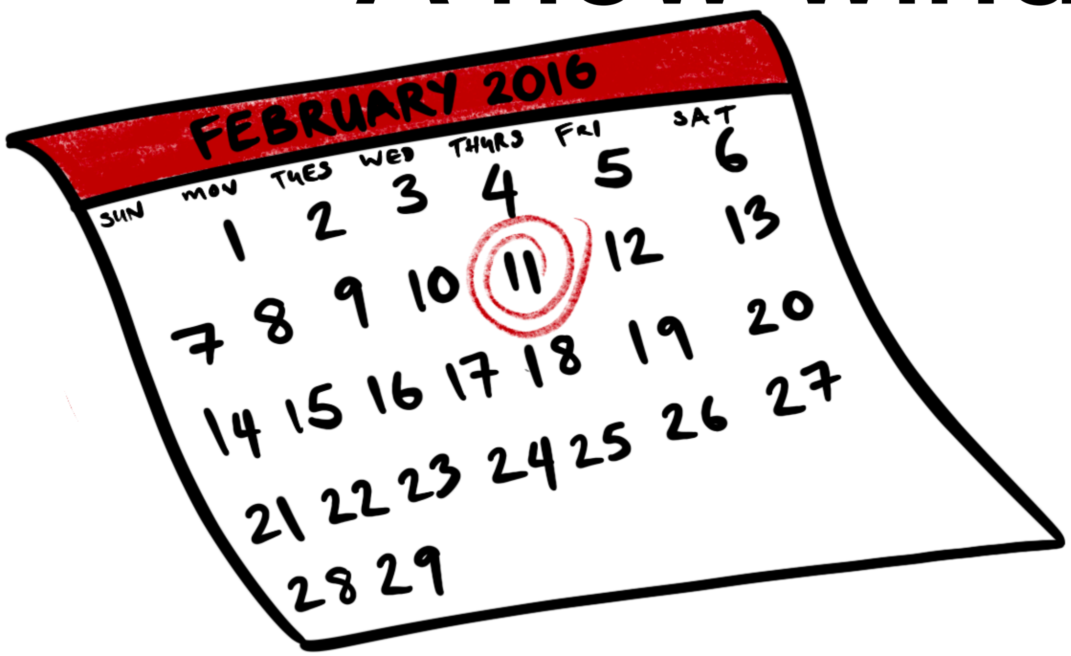
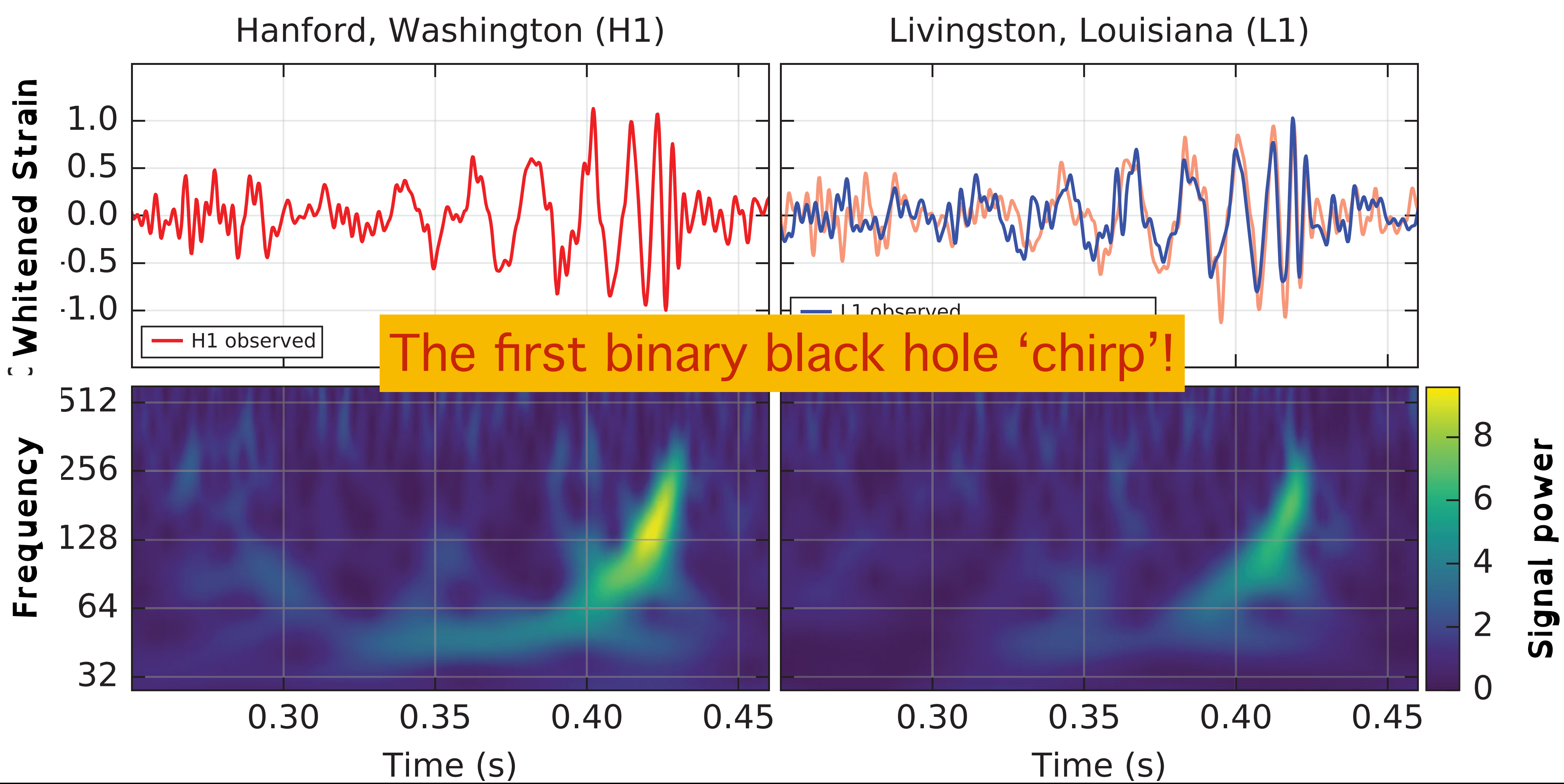
A new window into the universe



Where were you on 11 February 2016?

The LIGO collaboration hold a press conference at 3am AEST to announce the first detection of gravitational waves on September 14 2015



The first binary black hole ‘chirp’!

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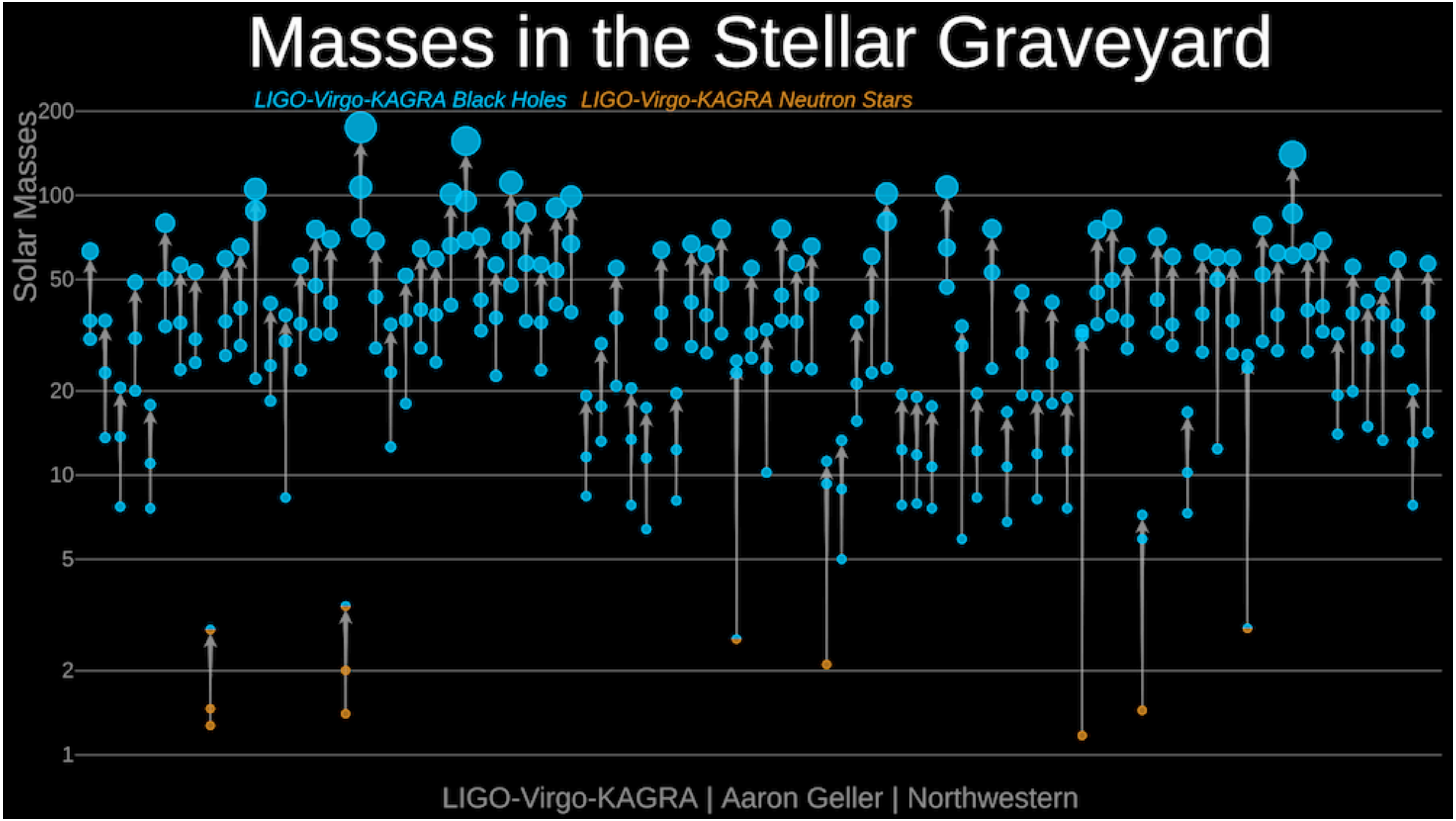
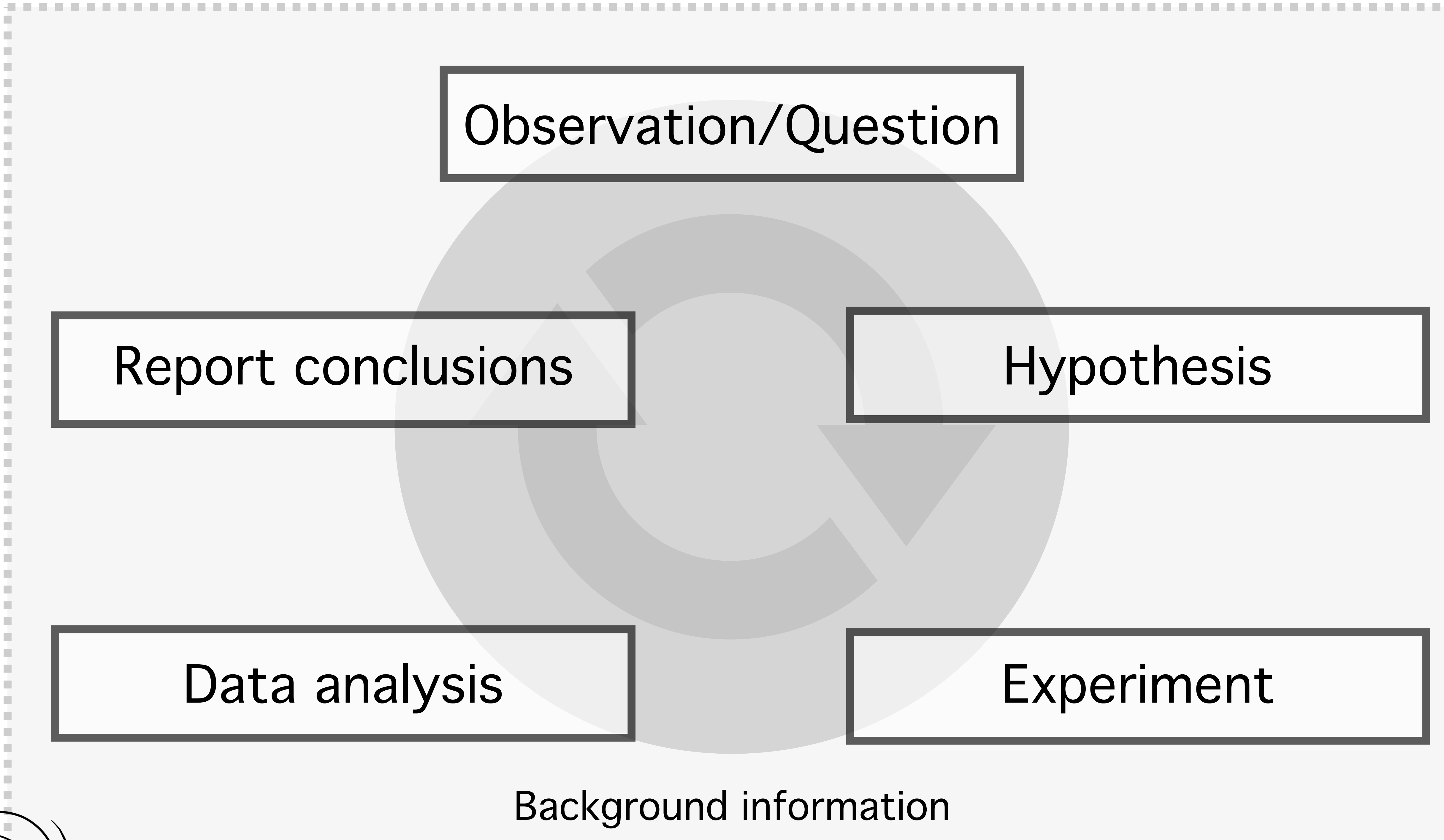

Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

About me

What happens during the mergers of compact objects (neutron stars, black holes and white dwarfs)?

- Where do compact objects come from? What sort of galaxies and environments do they form in? How old are they?
- What happens inside a neutron star in the moments after it merges?
- What other phenomena may be explained by compact object mergers?
- How do we connect the processes that happen on subatomic scales to what we observe on cosmological scales?
- How will we continue to detect these events with new detectors that work on different principles?
- How do we develop the next Australian gravitational wave detector?

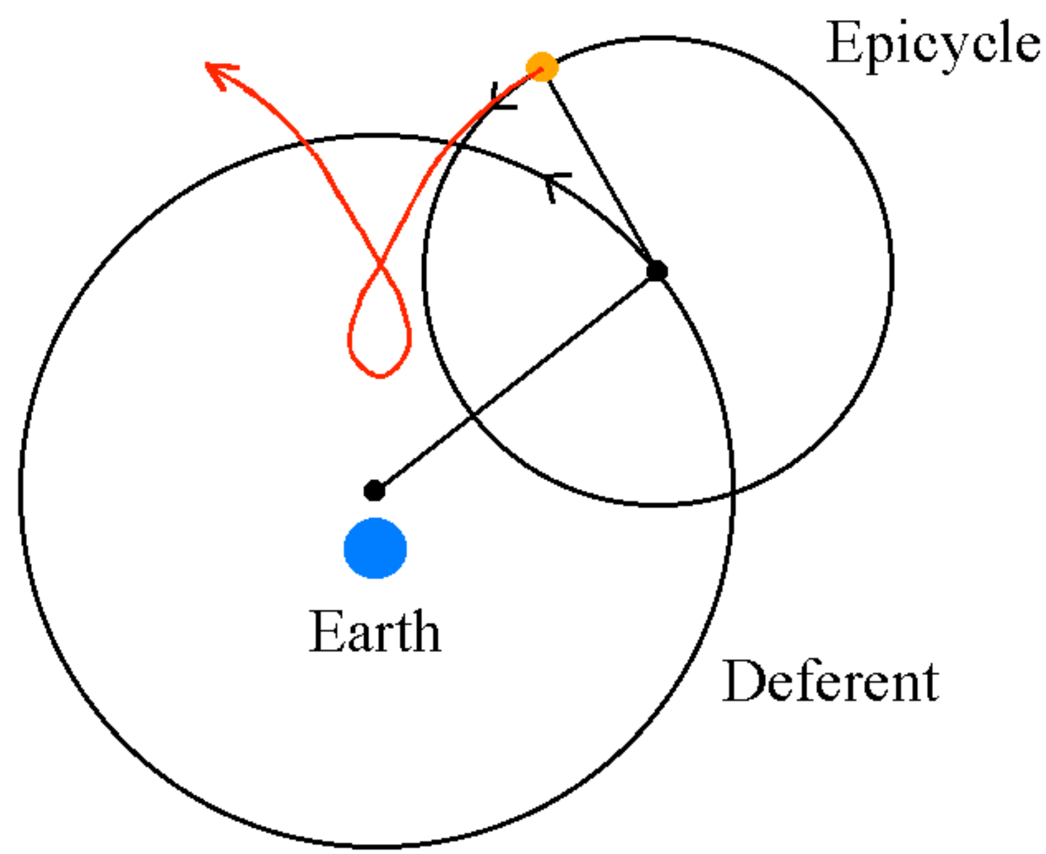
Physics and the scientific method



Frames of reference: Epicycles

Observation: Motion of the Planets in the night sky

Background Information: Earth is the centre of the Universe

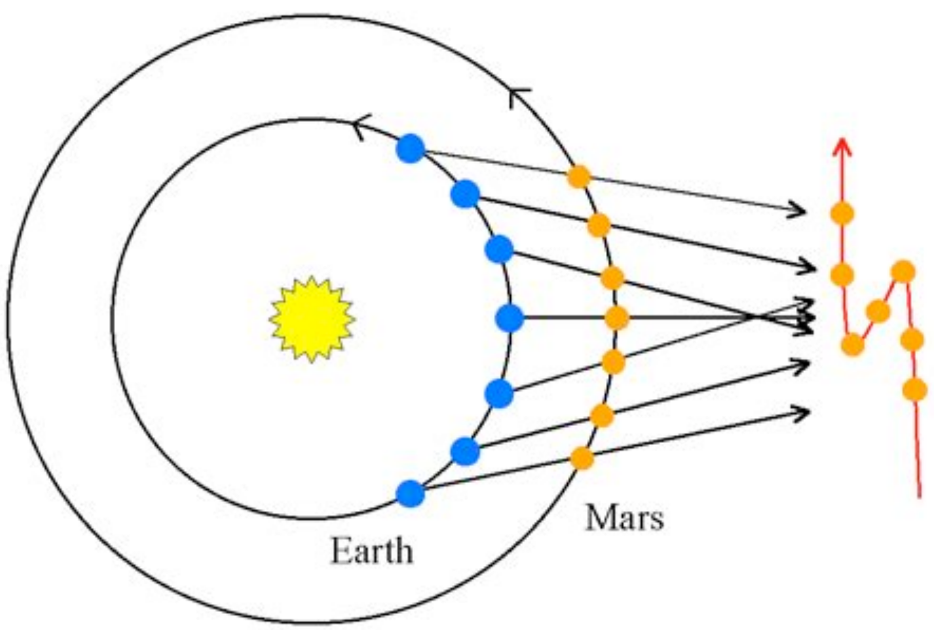


Ptolemy's Hypothesis: Planets orbit around the Earth in a large circle called the deferent, and move in a smaller circle (epicycle) at the same time

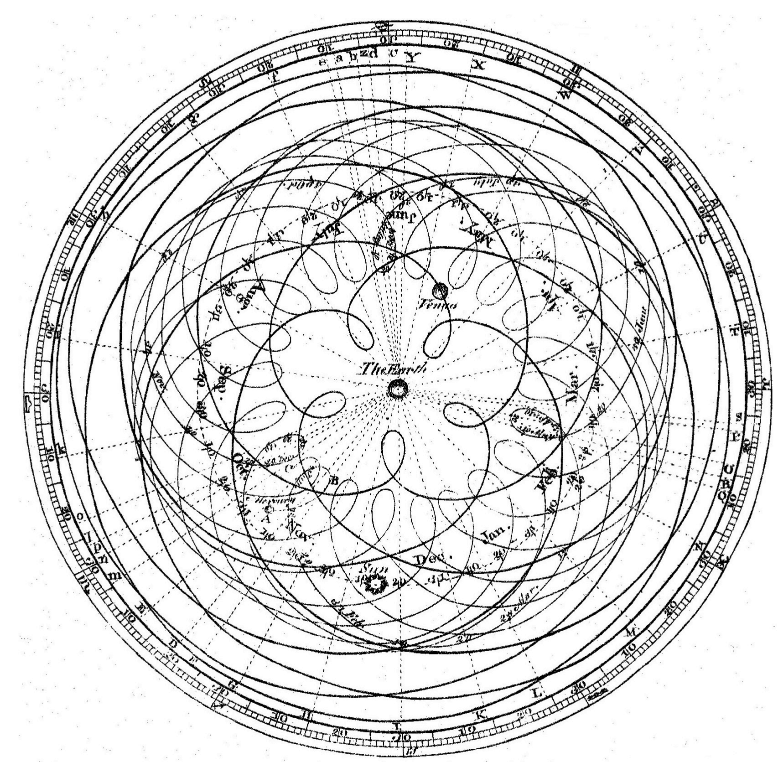
Frames of reference: Epicycles

Ptolemy's conclusion from experiment (observation of the planets) went largely unchallenged for hundreds of years - required new background information and a change in our 'Frame of Reference'

Reality: heliocentric



Mis-specified model: geocentric



Occam's Razor: The simplest solution that explains all observations is preferred

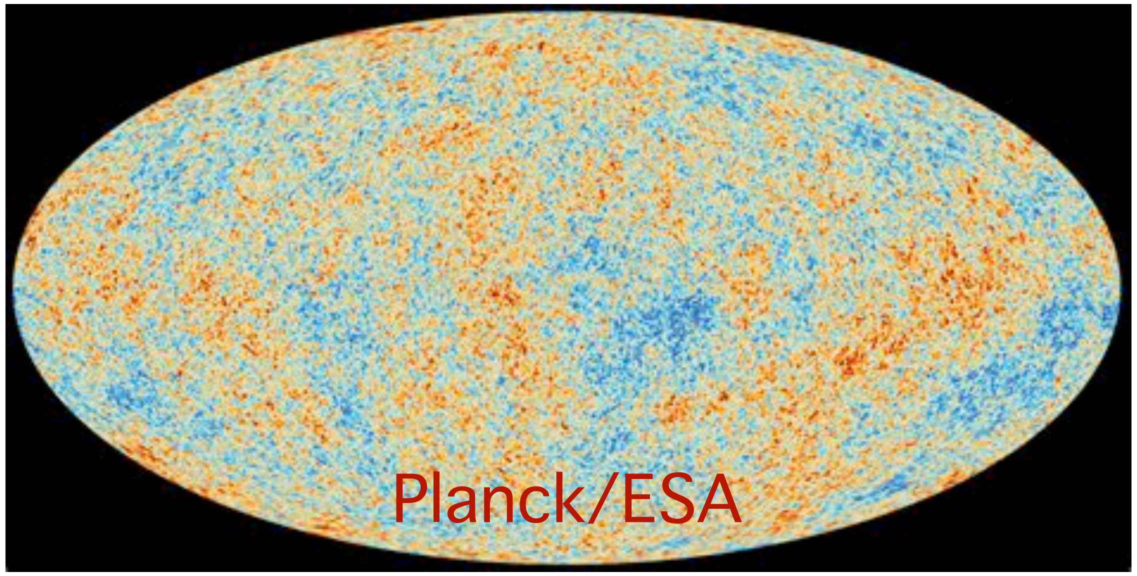
Confirmation Bias: BICEP2

Easy to dismiss this cautionary tale: we know better now, and we have more background information than ever. How do we still come to the wrong conclusion?

In 2014, a large team of scientists studying the polarisation of the cosmic microwave background with the BICEP2 telescope announced to the world they had discovered evidence of small gravitational wave ripples in their observations

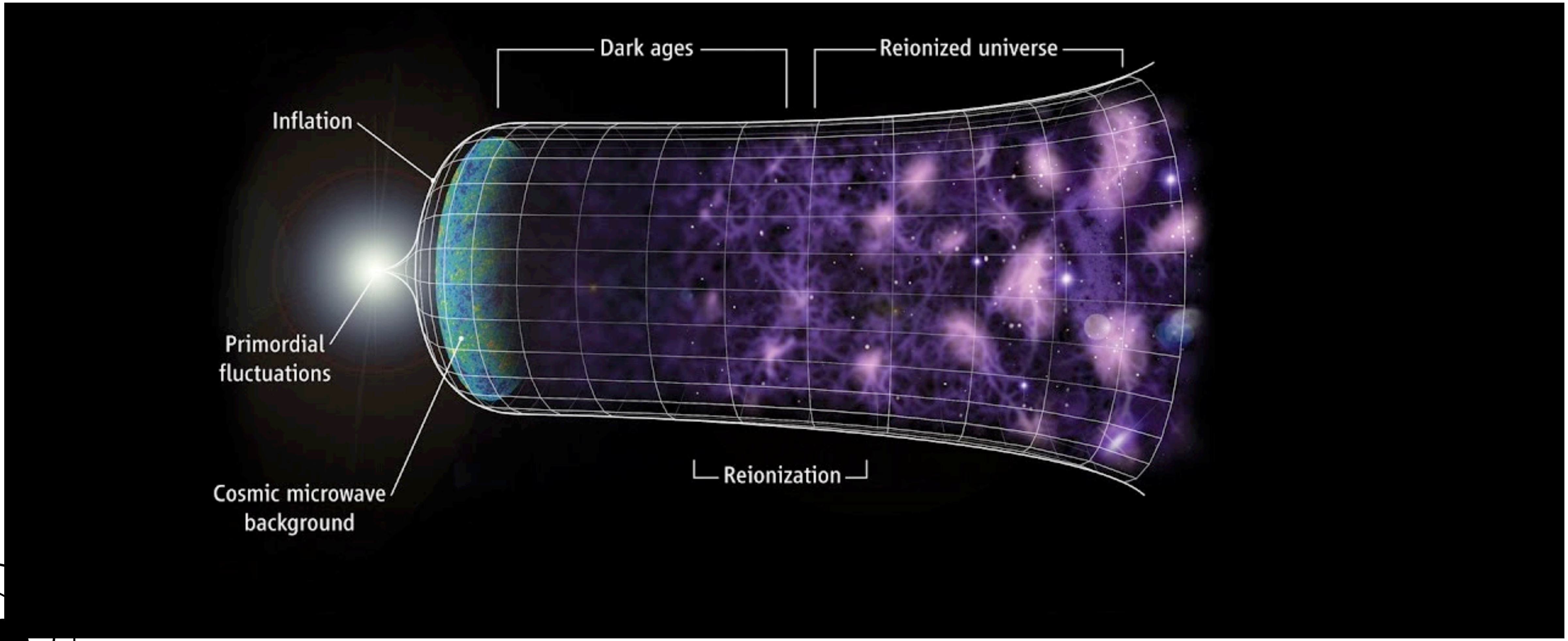
Several months later, it was found that the signal was actually due to interstellar dust in our own Galaxy mimicking the signal the scientists were looking for

Confirmation Bias: BICEP2



The CMB is polarised - two polarization modes (E and B)

B-mode polarisation can be caused by ripples from the rapid expansion of the Universe during inflation



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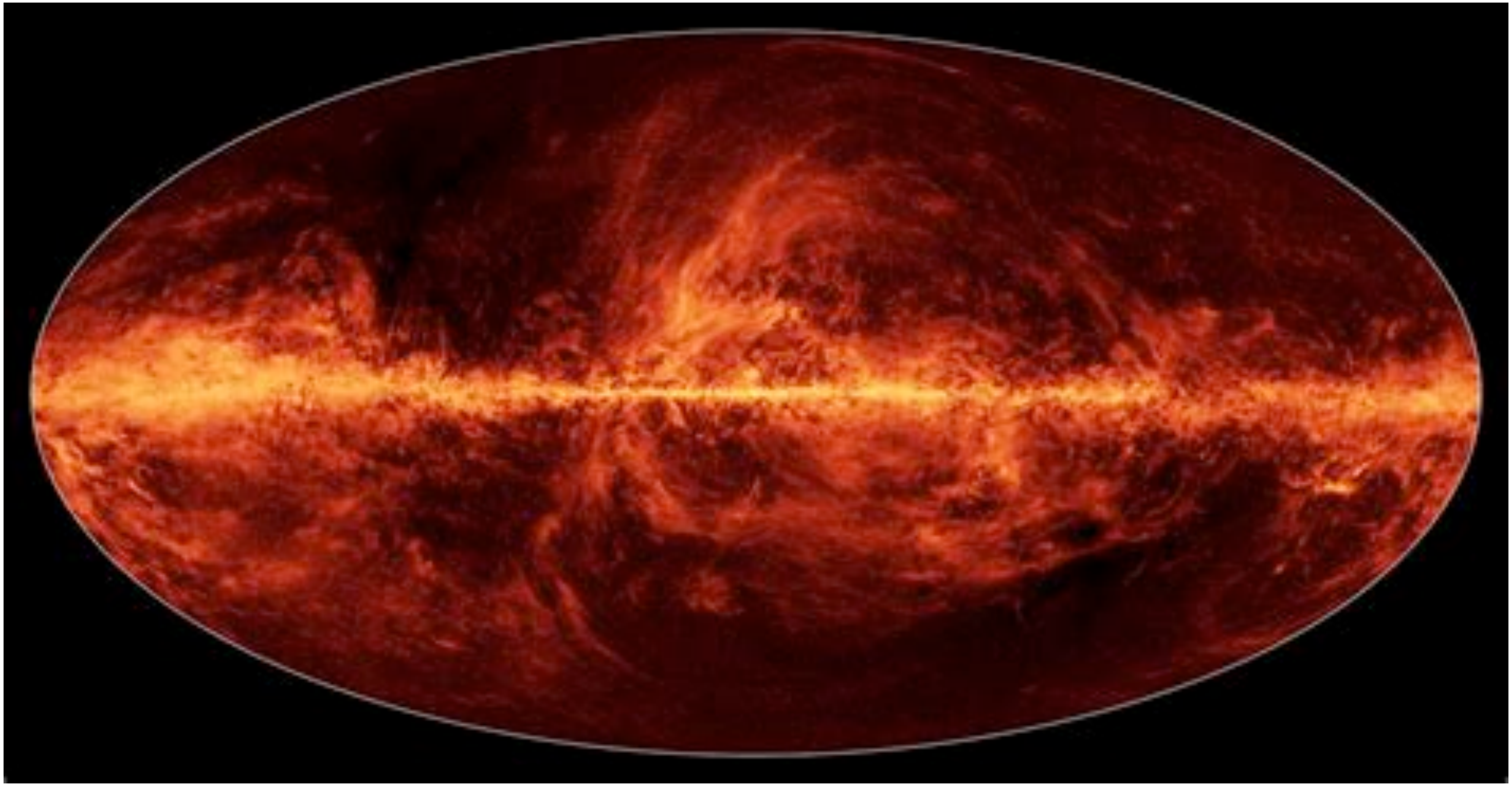
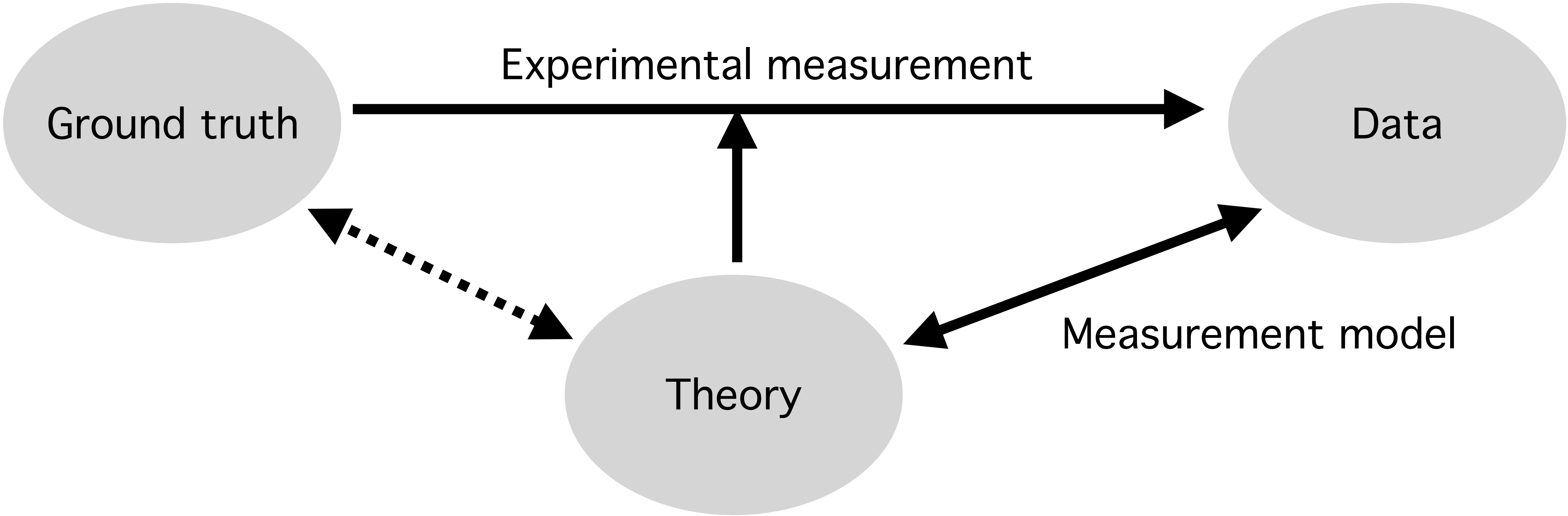
Confirmation Bias: BICEP2



The theory the BICEP2 scientists used to describe how dust in between stars in our galaxy underestimated the contribution to the B-mode signal

Information and uncertainty

In physics, we want to reconstruct the ground truth - some series of facts about our universe, from our observations.



In the scientific method, to create an experiment we have to come up with a hypothesis or theory to test. This informs how we build our experiment.

We try to make sure our model is a good representation of reality by using background information. We use the data our experiment generates to see how well our model fits our data

Information and uncertainty

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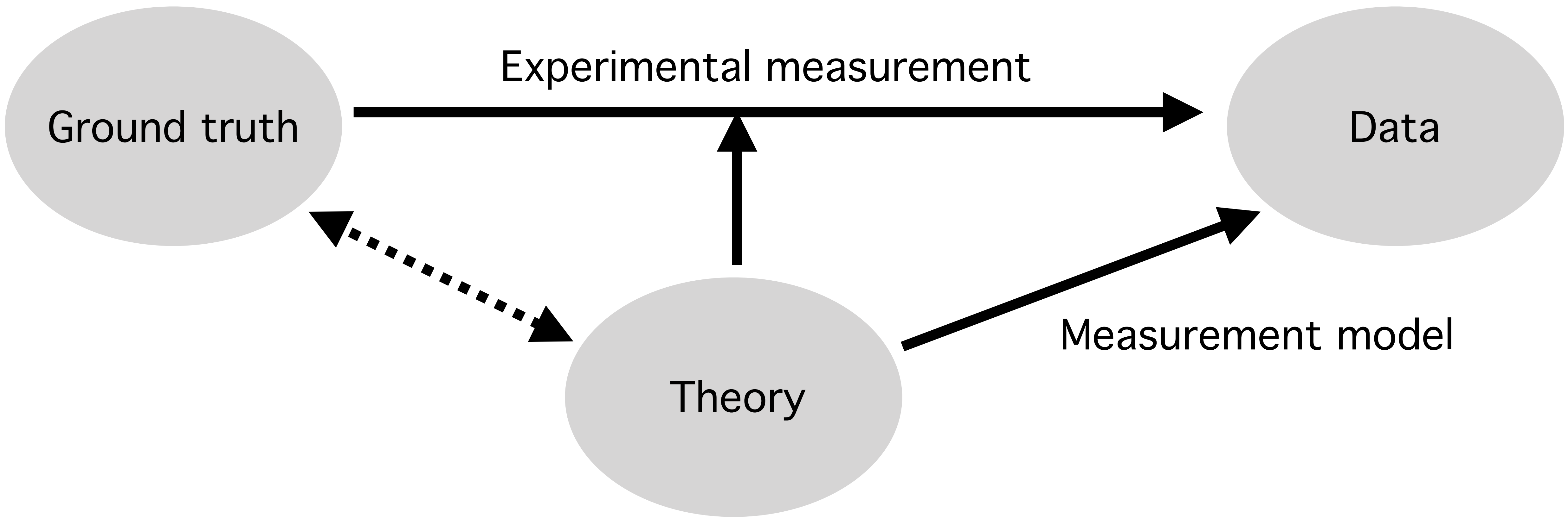

We report our results in the context of our theory, and hope that it represents the ground truth

Information and uncertainty

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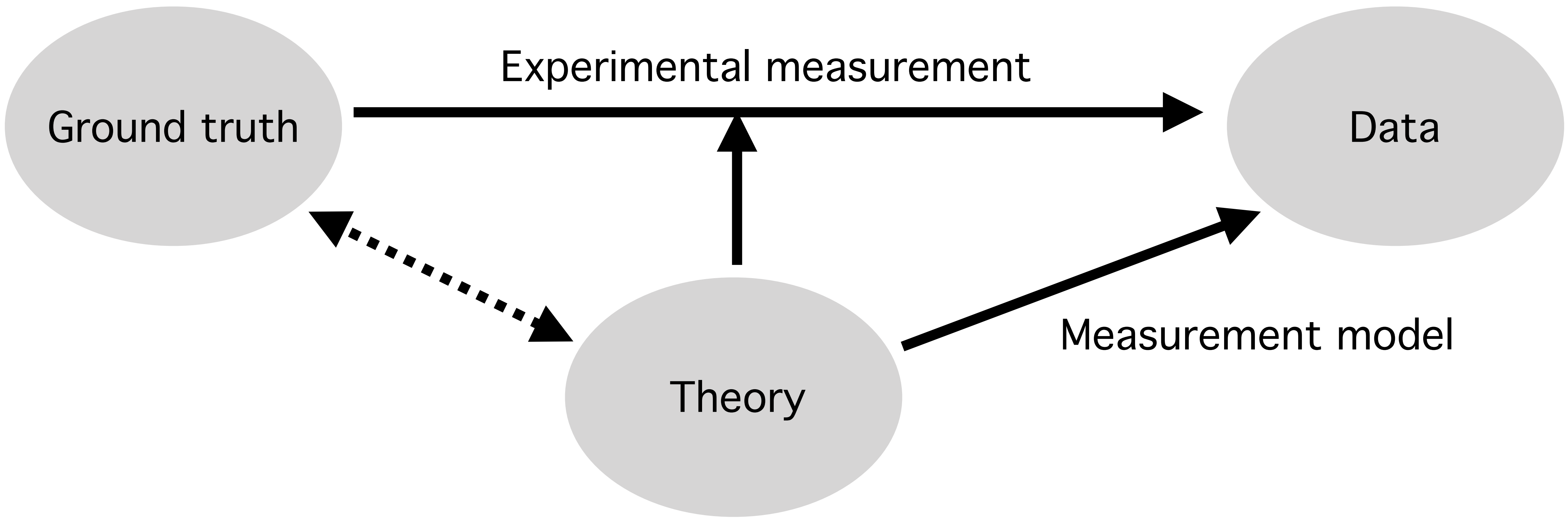
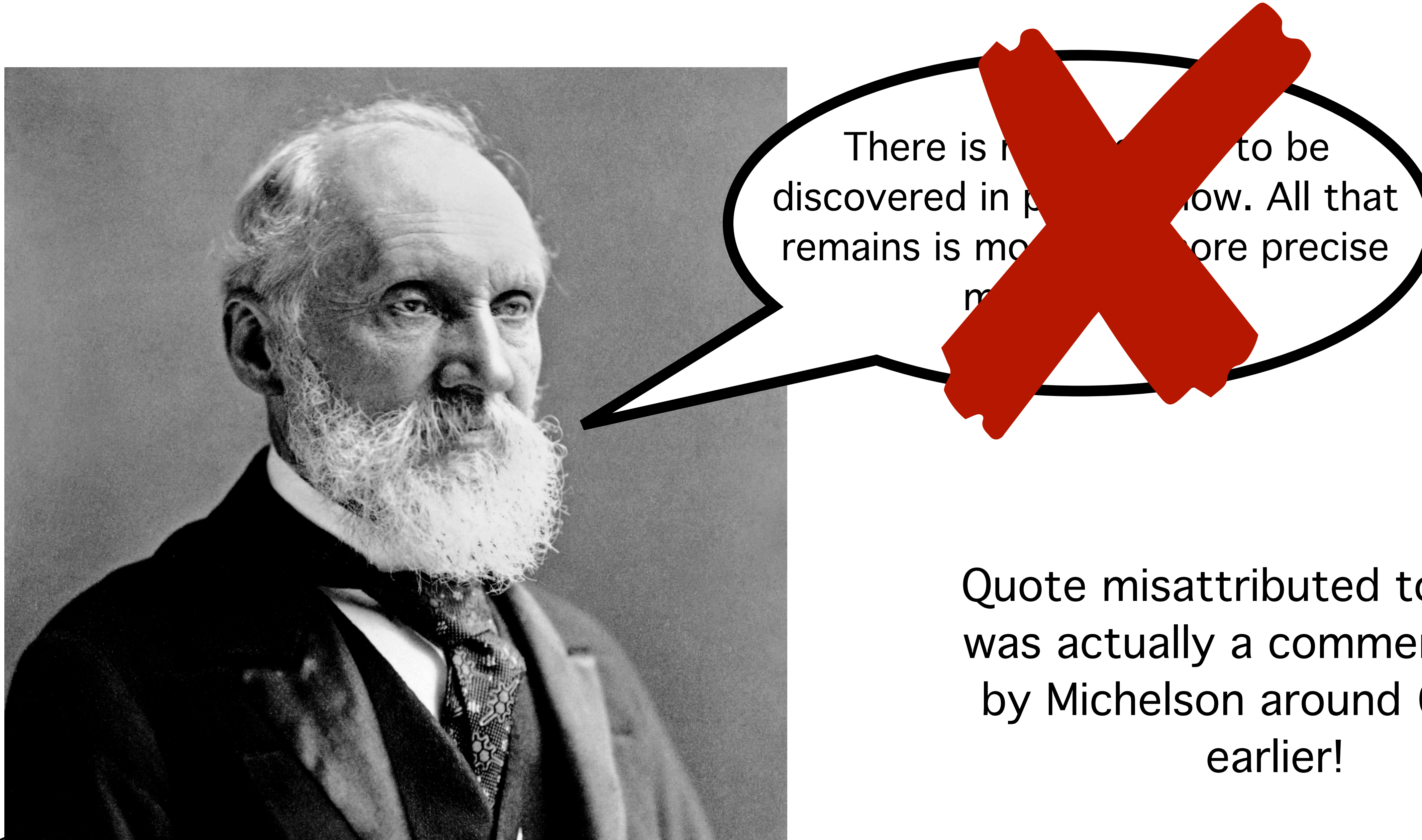


Uncertainties can arise in any part of this process:

- Noise processes in experimental measurements
- Systematic error in measurements
- Theory misses an aspect of the ground truth that is important

The pursuits of modern physics: what we want to know



Lord Kelvin

Quote misattributed to Kelvin, was actually a comment made by Michelson around 6 years earlier!

The pursuits of modern physics: what we want to know

Almost every Nobel prize in physics requires one (or both) of these two physics theories

Quantum Mechanics

Description of the universe at the scale of atoms and subatomic particles

Energy, momentum of a system bound together by forces comes in discrete packets called quanta

Predictions of theory are not absolute - can only give probability of an event occurring

Relativity

Description of how gravity manifests: matter tells space how to curve and space tells matter how to move

Time as a dimension has the same priority as space - spacetime

There is no absolute observer - passage of time in one reference frame may be percieved differently by another

The pursuits of modern physics: what we want to know

Anything new, anything true, anything interesting - Vladimir Kostic

- How did the Universe come to be the way it is today?
- How does matter behave at physical extremes (pressure, temperature, close to speed of light, gravity)
- What is dark matter and dark energy?
- How accurately can we measure things when quantum mechanics gets in the way?

In the past few years: gravitational waves (predicted in 1915), observation of a black hole event horizon, discovery of the Higgs boson

In the next 10-50 years*: discovery of dark matter particle/physics beyond standard model