HOW WE ‘KNOW’: MAKING DISCOVERIES IN MODERN PHYSICS

Lecture 2 Different views of uncertainty

Dr Fiona Panther | OzGrav-UWA | fiona.panther@uwa.edu.au

Today

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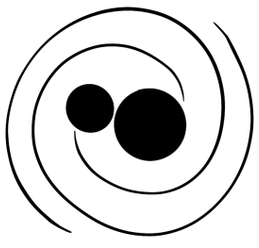
- Discovery of the CMB



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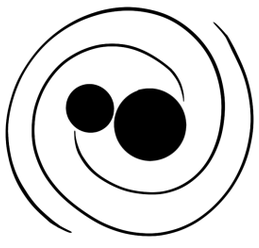
- Discovery of the CMB
- Frequentist statistics



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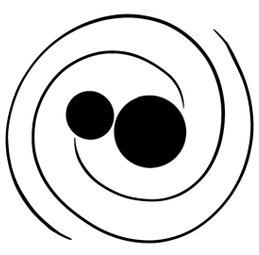
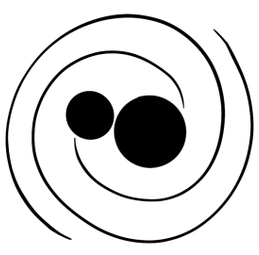
- Discovery of the Higgs boson



Today

- Discovery of the CMB
- Frequentist statistics
- Discovery of the Higgs boson
- Motivation for Bayes theorem and Bayesian inference

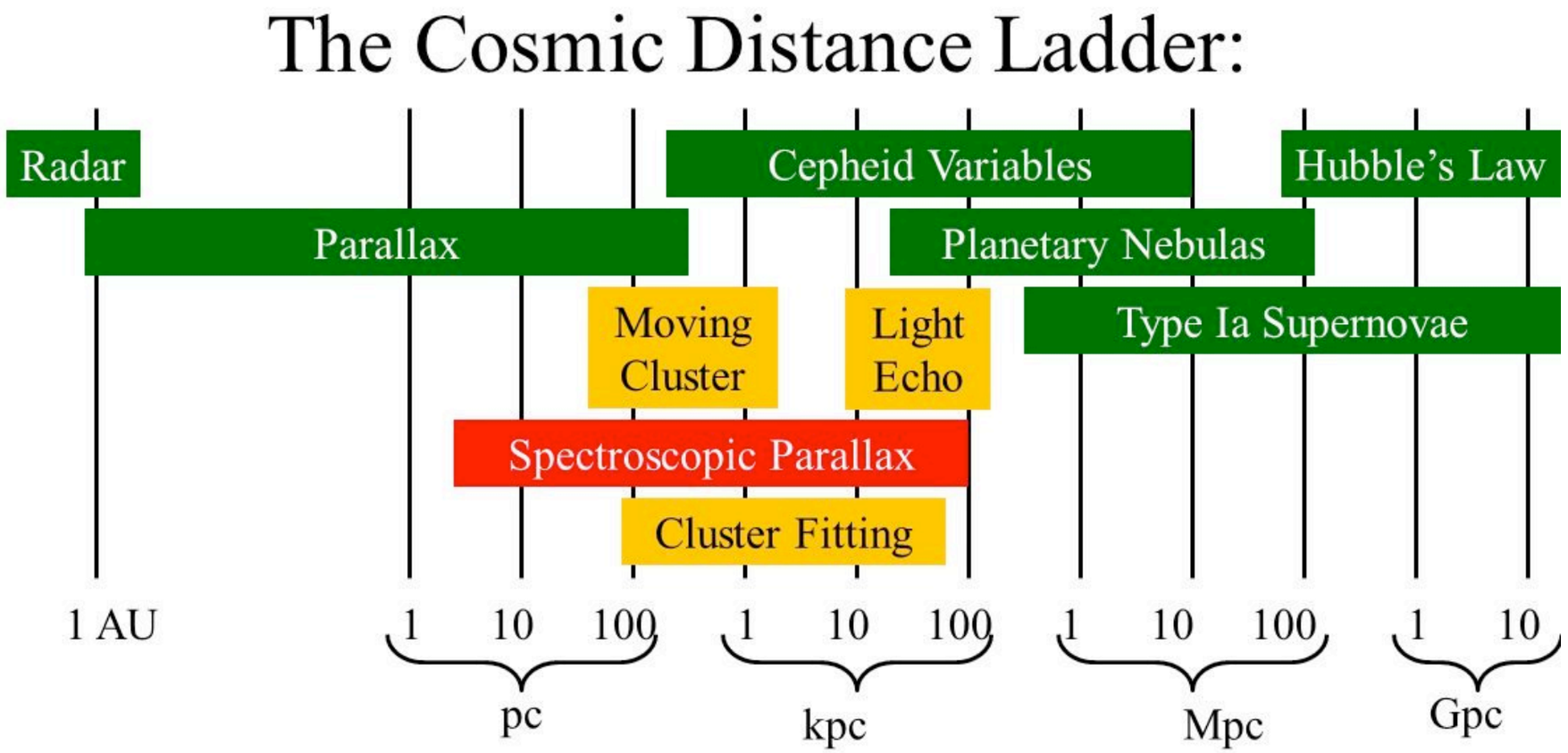


The Big Bang Theory

Slipher (1912): Galaxy spectra are redshifted - moving away from us
Friedmann: A valid solution to the Einstein field equations (general relativity) is that space-time is expanding

The Big Bang Theory

Hubble & Lemâitre: More distant galaxies are receding faster
Lemâitre: The universe has increased in size as time goes on - the universe used to be smaller.



The Big Bang Theory

Hubble combined the distance measurements with observations of redshift to find that more distant galaxies recede faster

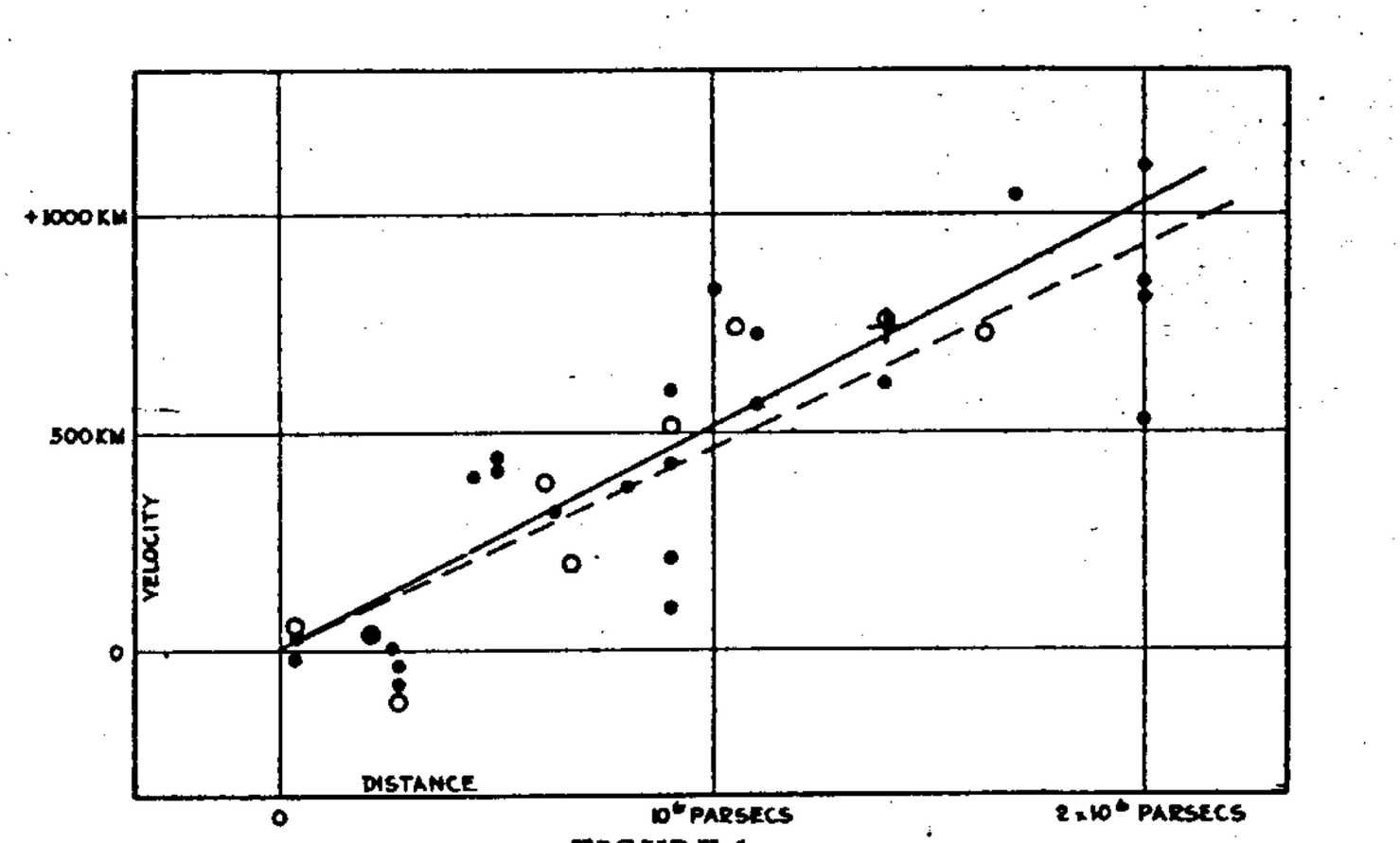
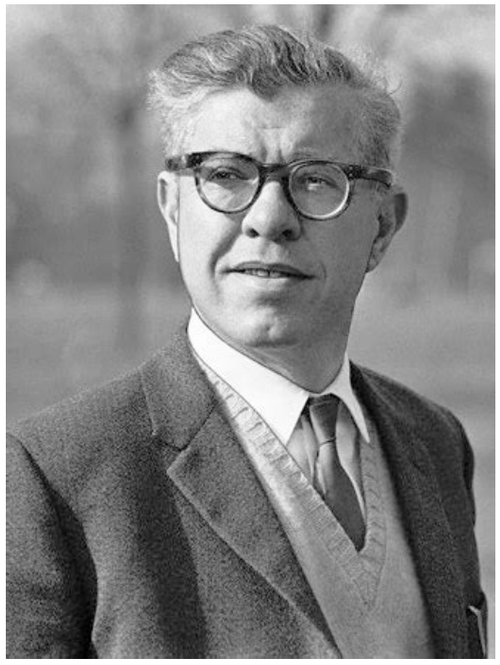


FIGURE 1

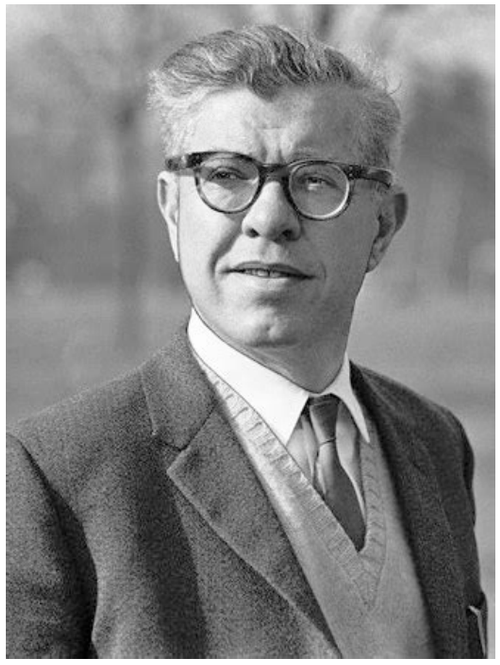
The Big Bang Theory



Fred Hoyle (+ Bondi and others): steady state universe

Georgi Gamow (+ many others): ‘Big Bang’ theory

The Big Bang Theory

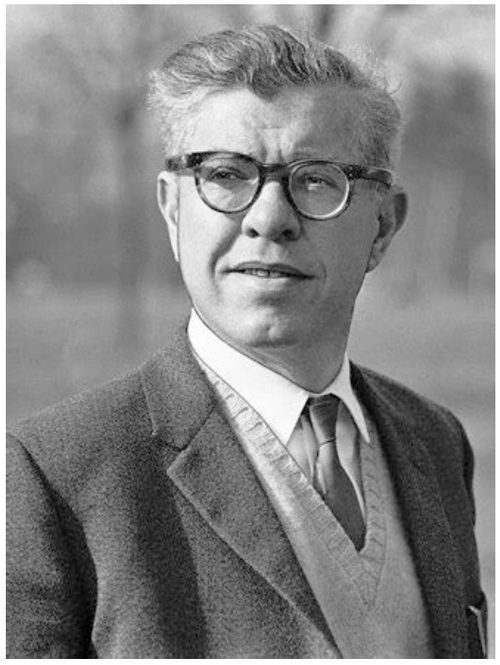


Fred Hoyle (+ Bondi and others): steady state universe

- The density of matter in the expanding universe remains unchanged due to a continuous creation of matter
- The perfect cosmological principle: the observable universe is practically the same at any time and any place.

Georgi Gamow (+ many others): ‘Big Bang’ theory

The Big Bang Theory



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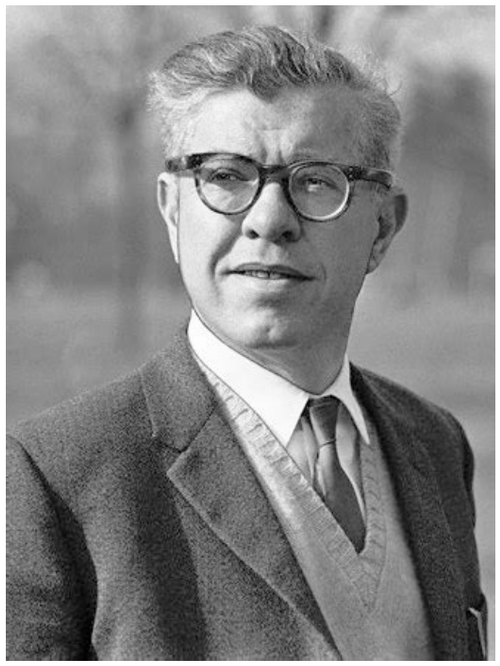
Georgi Gamow (+ many others): 'Big Bang' theory

- Universe begins in a 'singularity' (Hawking) and expands
- All matter is created at the beginning - no creation of matter after the Big Bang

The Big Bang Theory

Fred Hoyle



- Many accounts say that Hoyle coined the term to be derogatory, but Hoyle himself denied it was meant that way
- May have been disparaging at the time - Hoyle later changed his mind about the Big Bang theory

The Big Bang Theory

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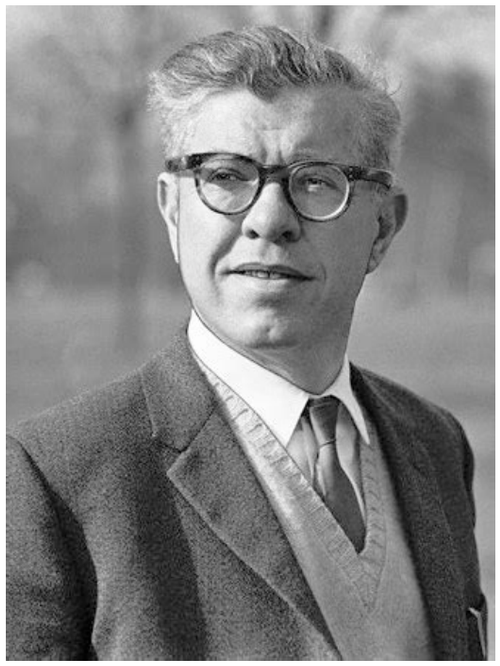

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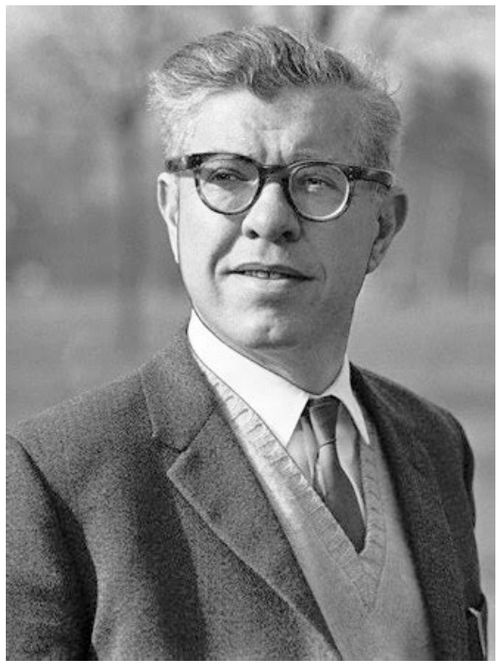

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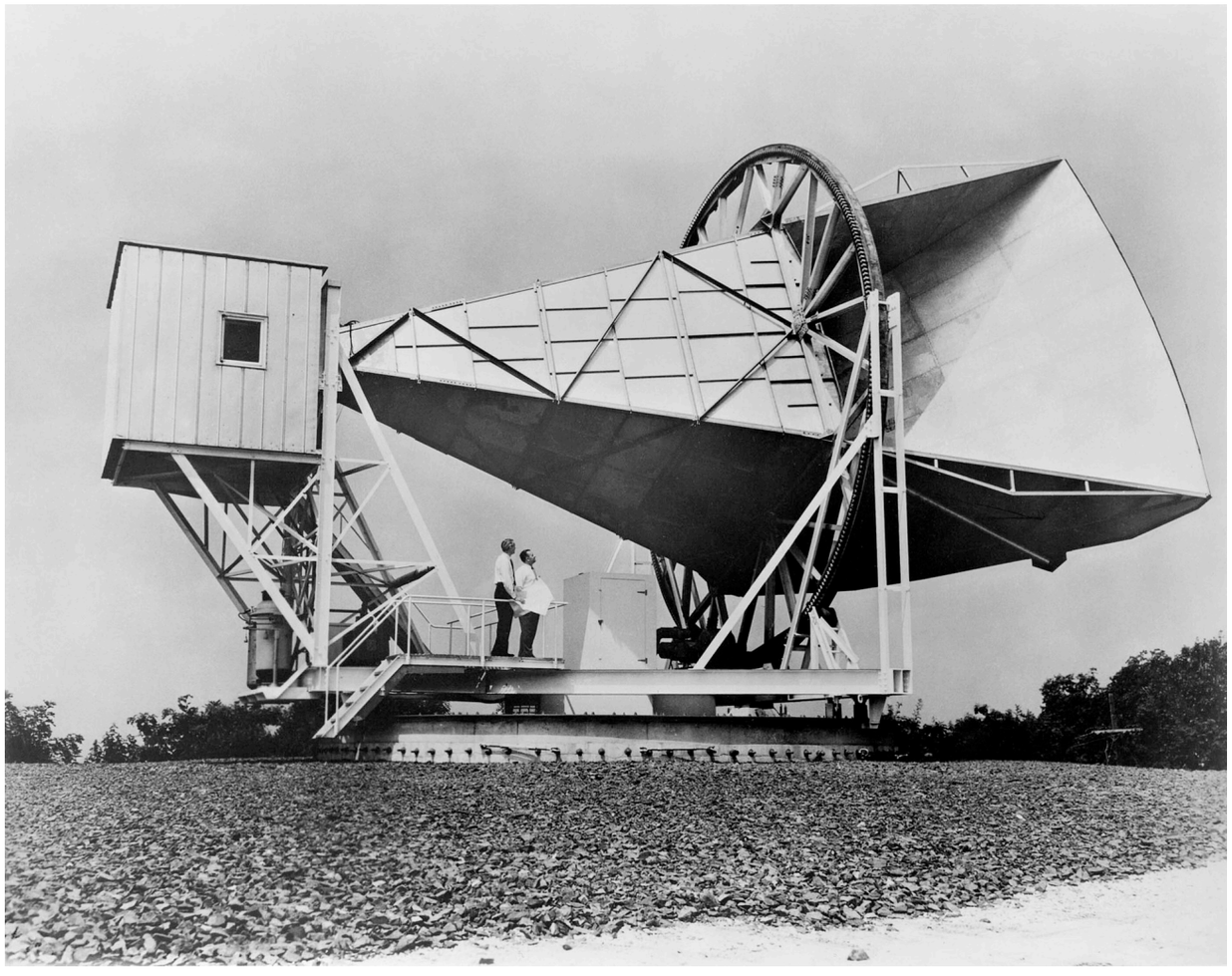
We now come to the question of applying the observational tests to earlier theories. These theories were based on the hypothesis that all the matter in the universe was created in one bigh bang at a particular time in the remote past. It now turns

Penzias, Wilson and the pigeons

A major prediction of the Big Bang origin of the universe is the existence of the ‘Cosmic Microwave Background’ - residual thermal energy left over from the Big Bang



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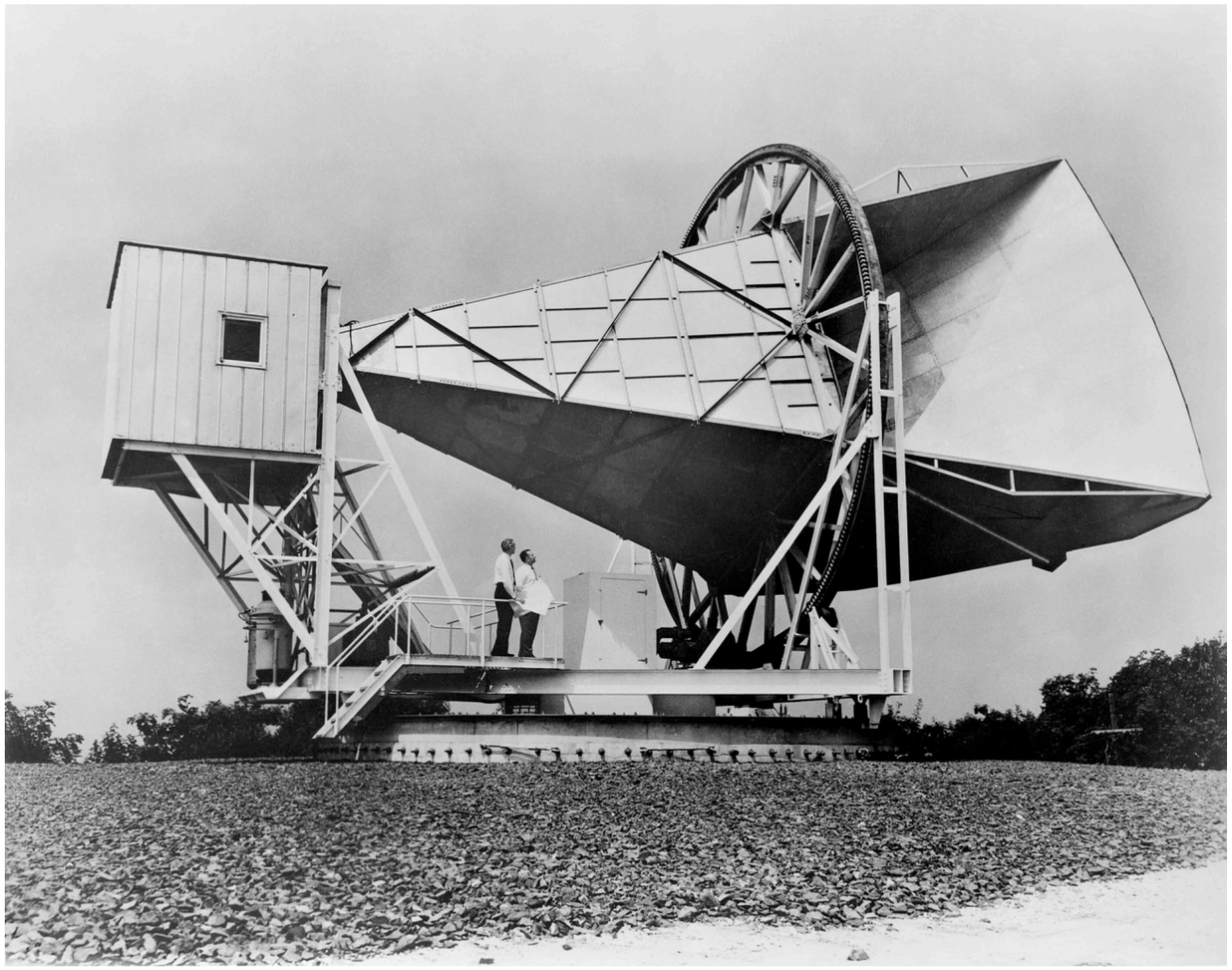

Radio astronomers measure noise and signal in terms of ‘temperature’. This is because noise often comes from thermal sources inside the experiment.

This is accounted for by measuring the amount of signal from a calibrated, terrestrial source like a dewar of liquid helium

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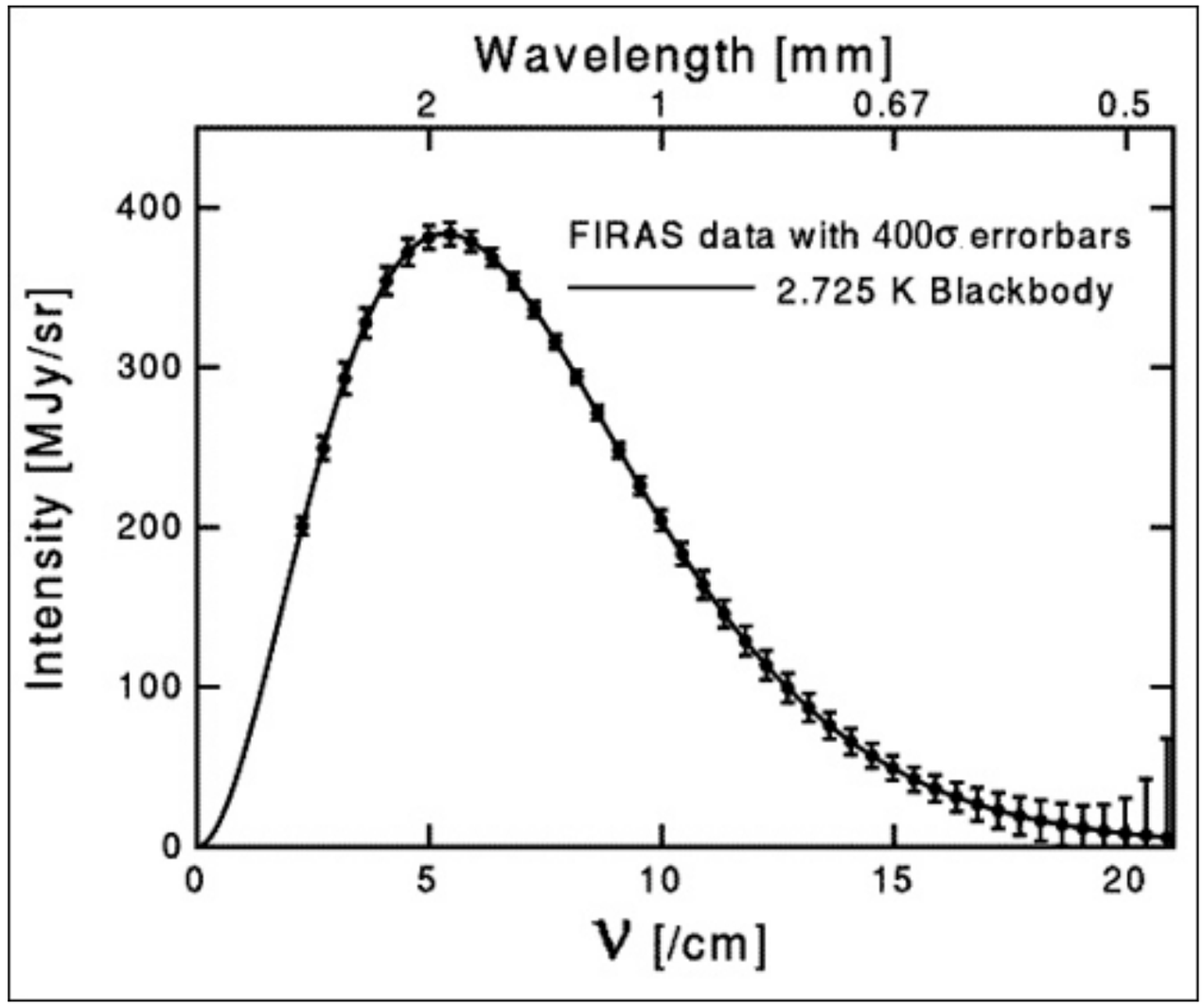
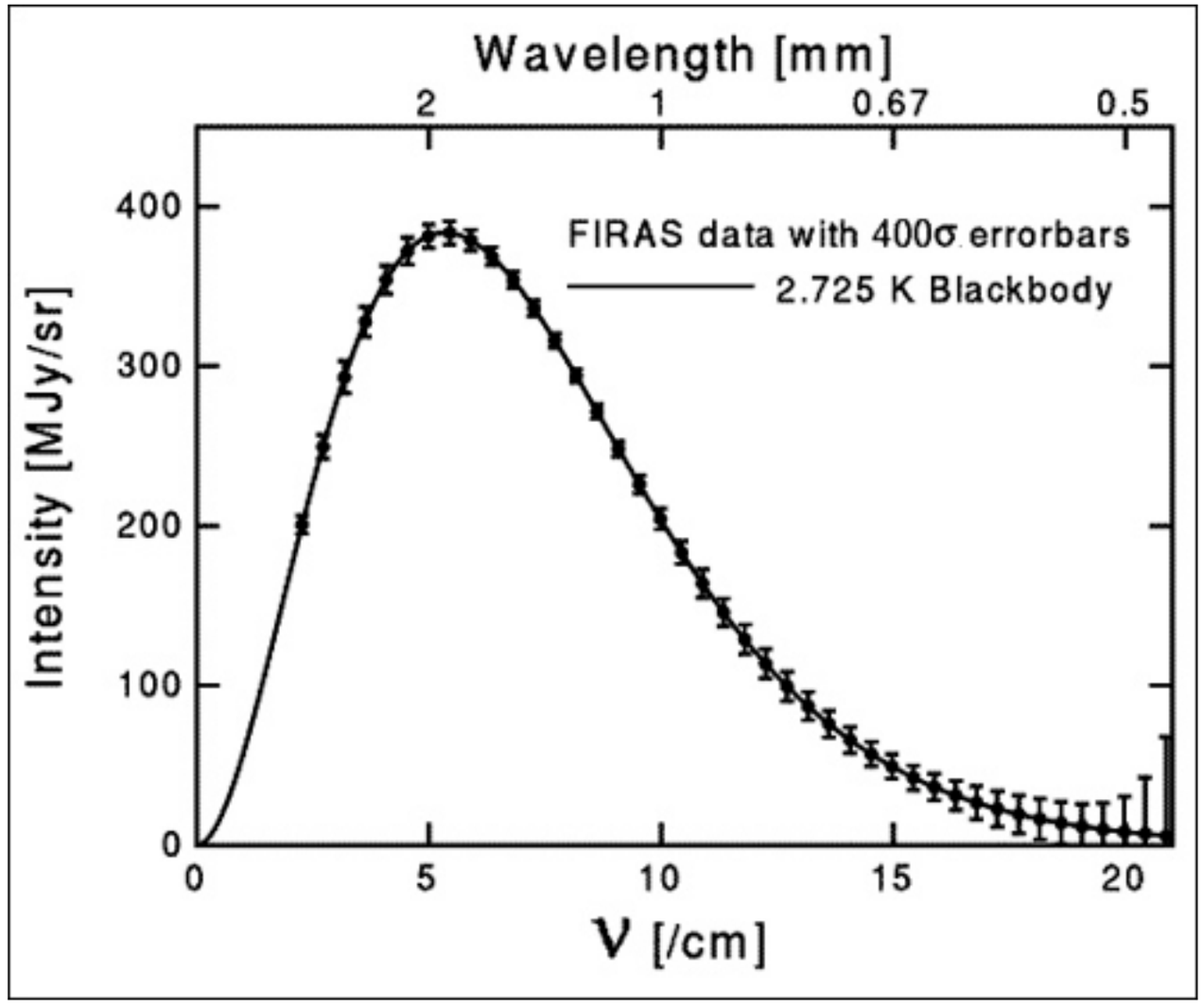


Penzias, Wilson and the pigeons

- Penzias and Wilson noticed there was still a source of noise that was much larger than expected, coming from all directions

- They even cleaned the telescope - evicting some nesting pigeons, and removing the ‘white dielectric material’ they had left behind

- Nothing removed the excess of noise at 2.7 Kelvin.



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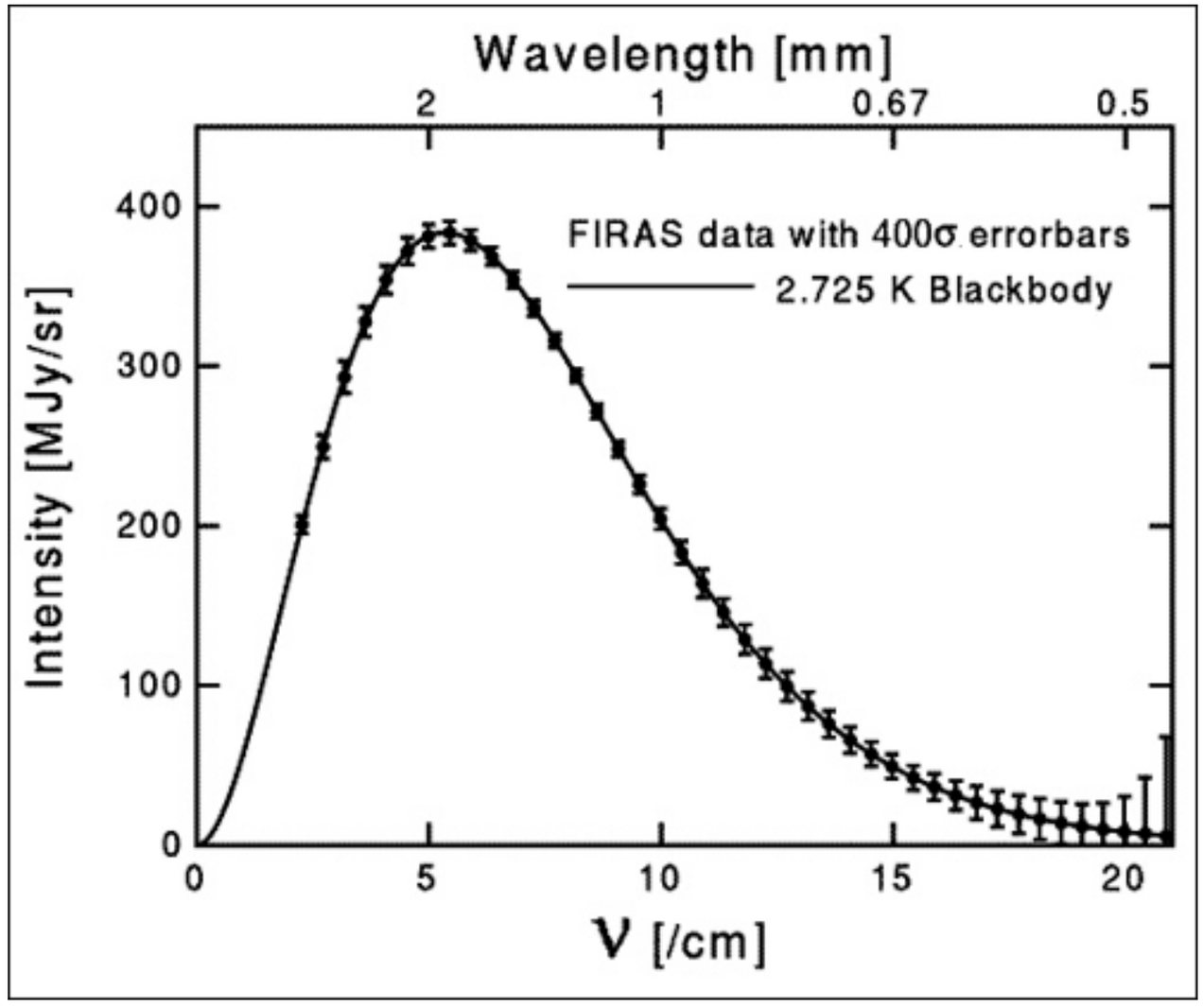
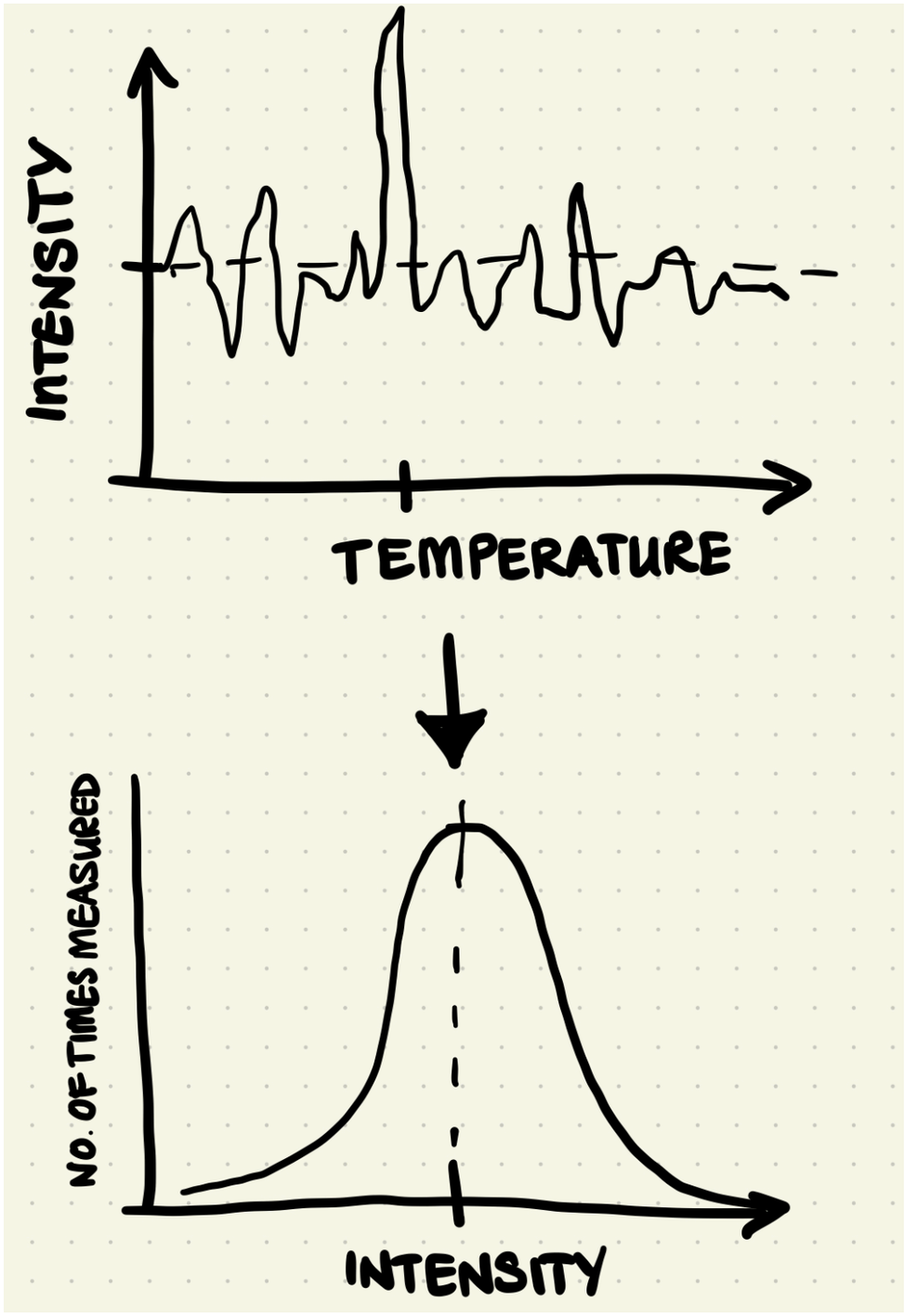


- They discussed this with another experimental group who were trying to detect the Cosmic Microwave Background with a similar set up. Dicke, the head scientist, remarked that their work had been scooped!

Frequentist stats and significance

‘We observe an excess of intensity at 2.7 Kelvin. How likely is it that this arises from noise alone??’

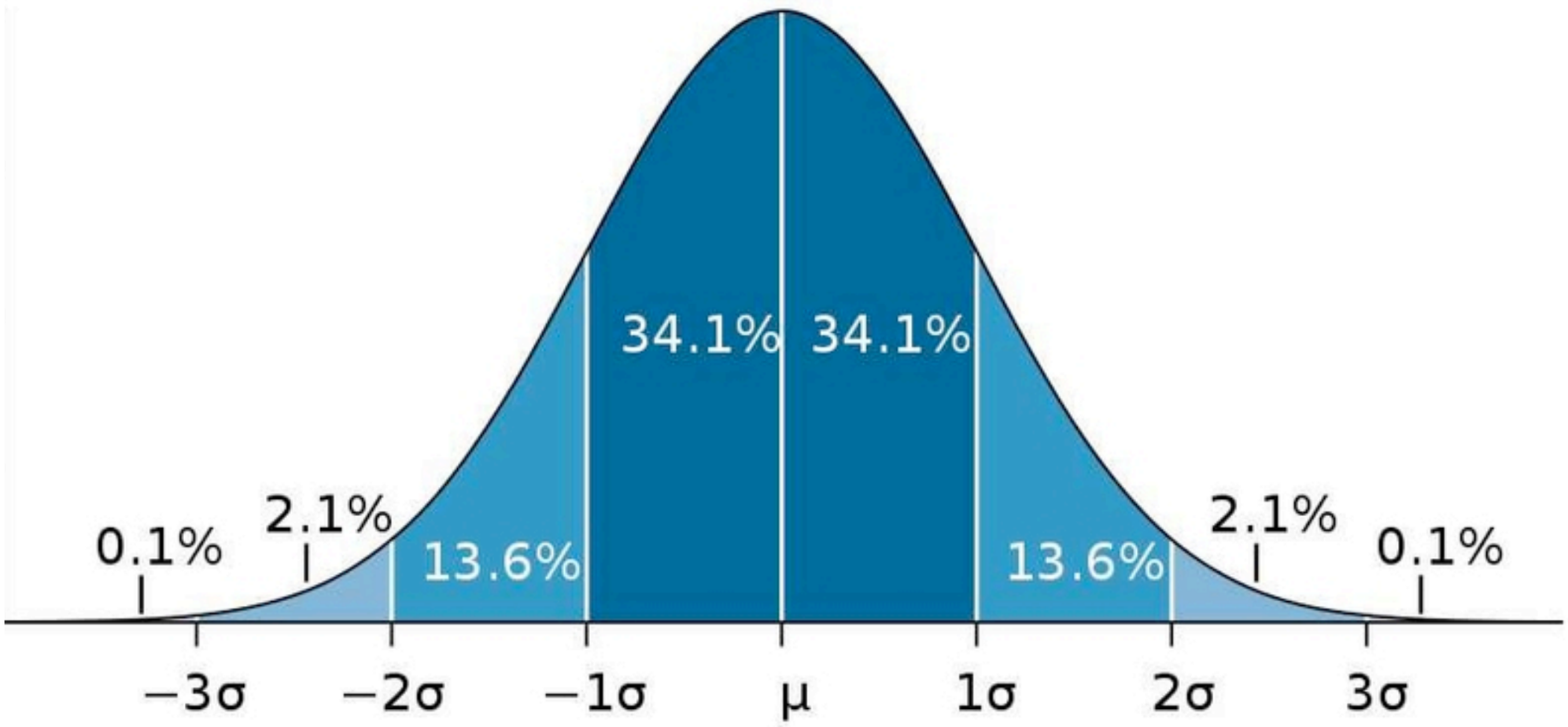


e.g. Measure intensity of noise temperature at different temperatures

Count how many times you see each intensity value in your data - only see high values such as the one at 2.7 Kelvin very rarely, so not consistent with noise

Frequentist stats and significance

Significance: how far from the mean noise level is the measurement?

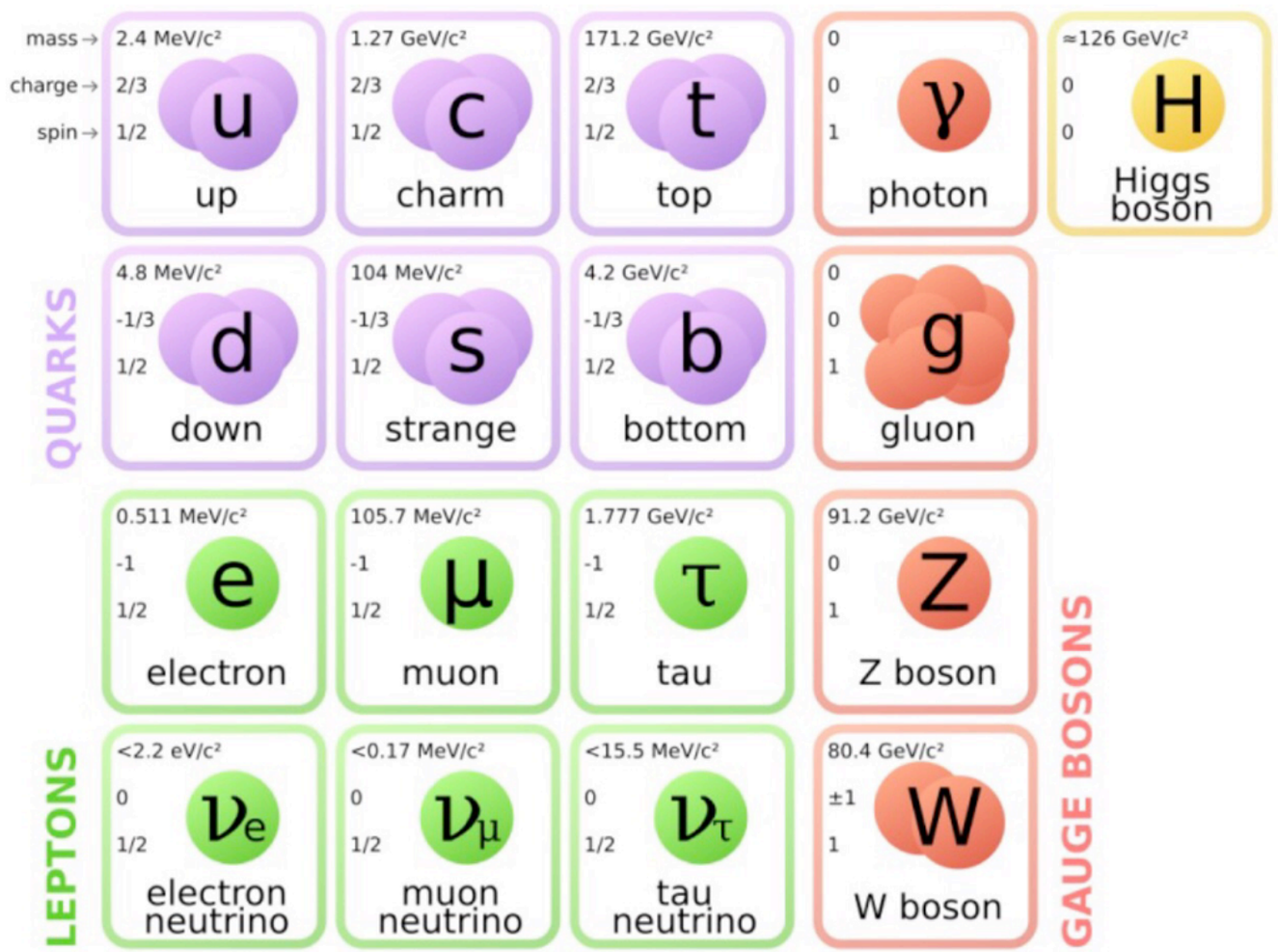


Some notes:

- The result in a frequentist analysis is a point estimate
- Confidence interval: if you repeat the experiment many times, the true value of the parameter will lie within the defined range X% of the time

Standard Model

Describes the quantum building blocks of the universe and how they interact with one another



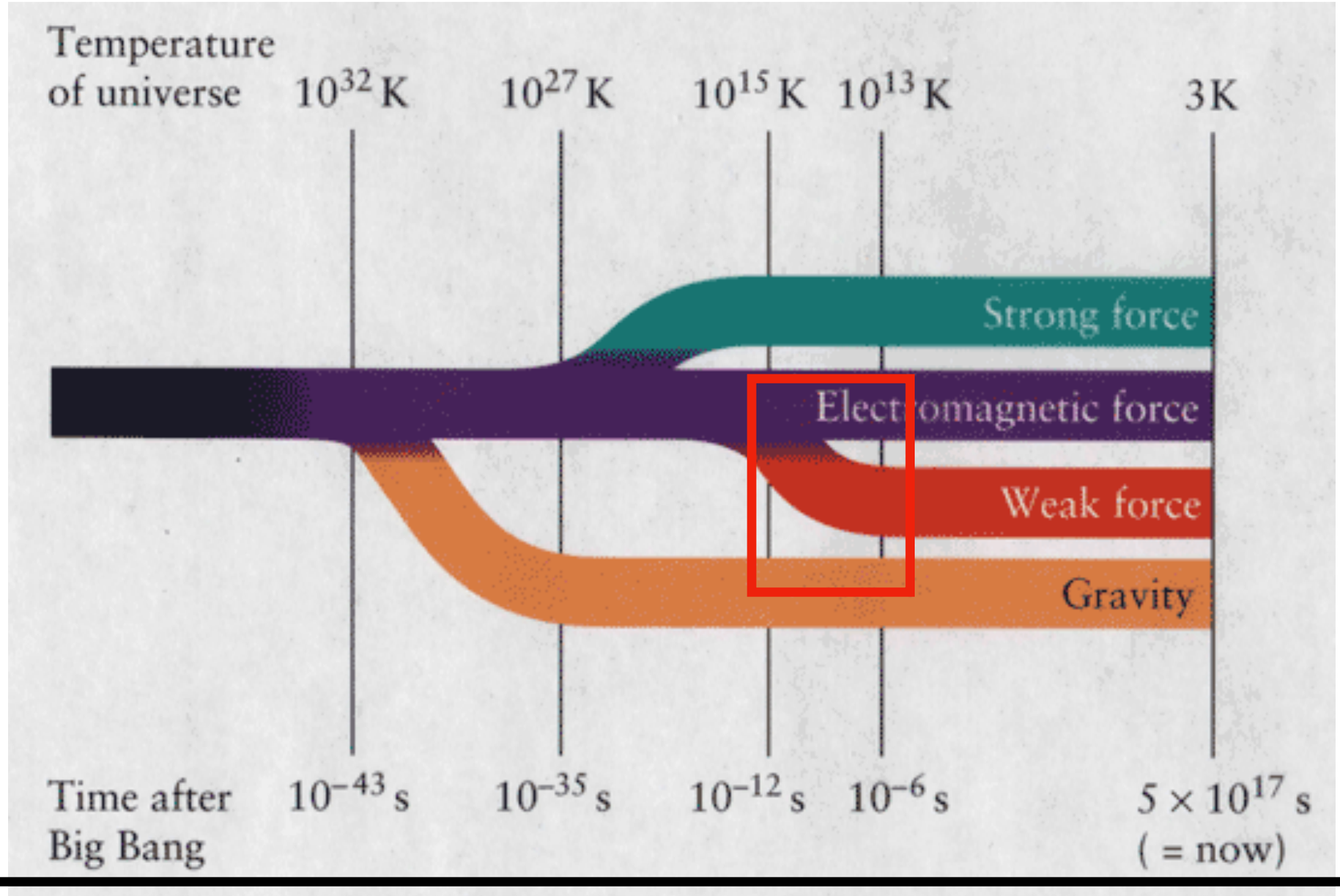
MASS

Classical definition: how much matter there is in something

Einsteinian definition: how much inertia something has (how much force do you need to apply to make something accelerate)

Some force carrying particles are observed to have non-zero masses - how?

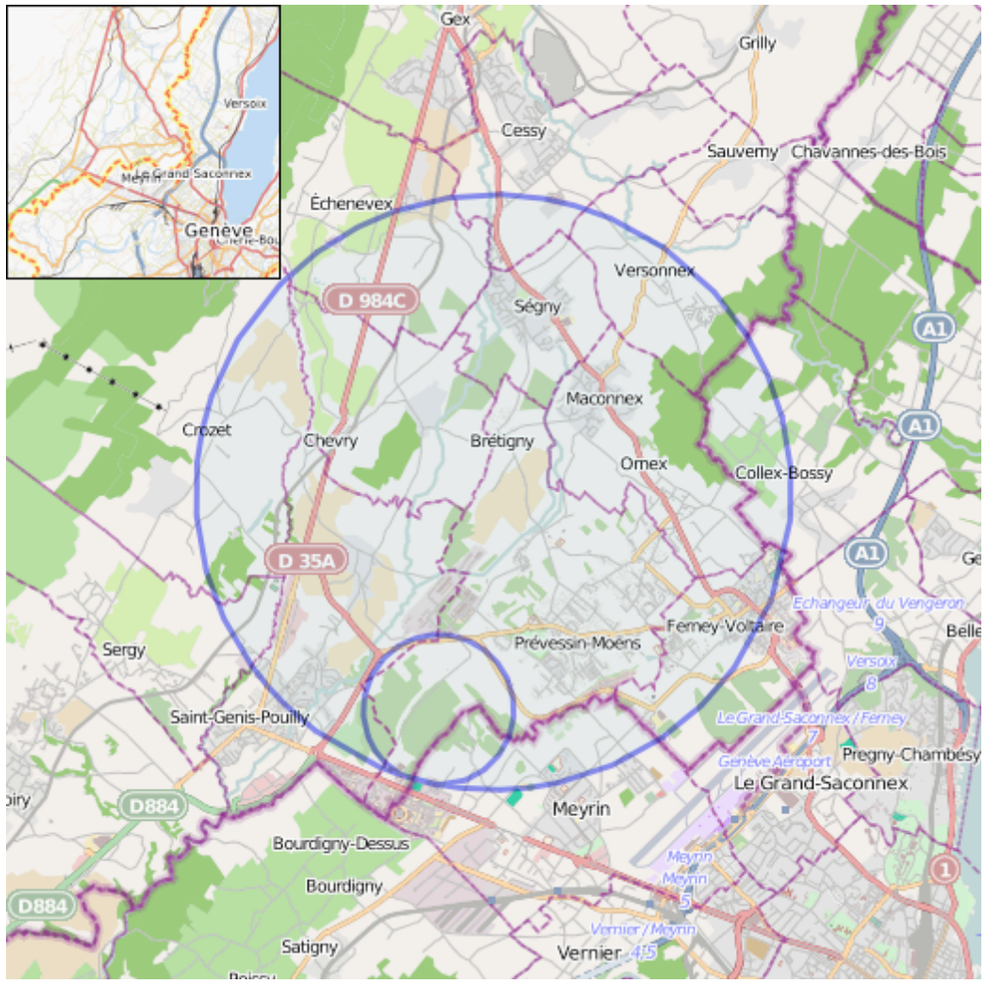
Higgs Boson

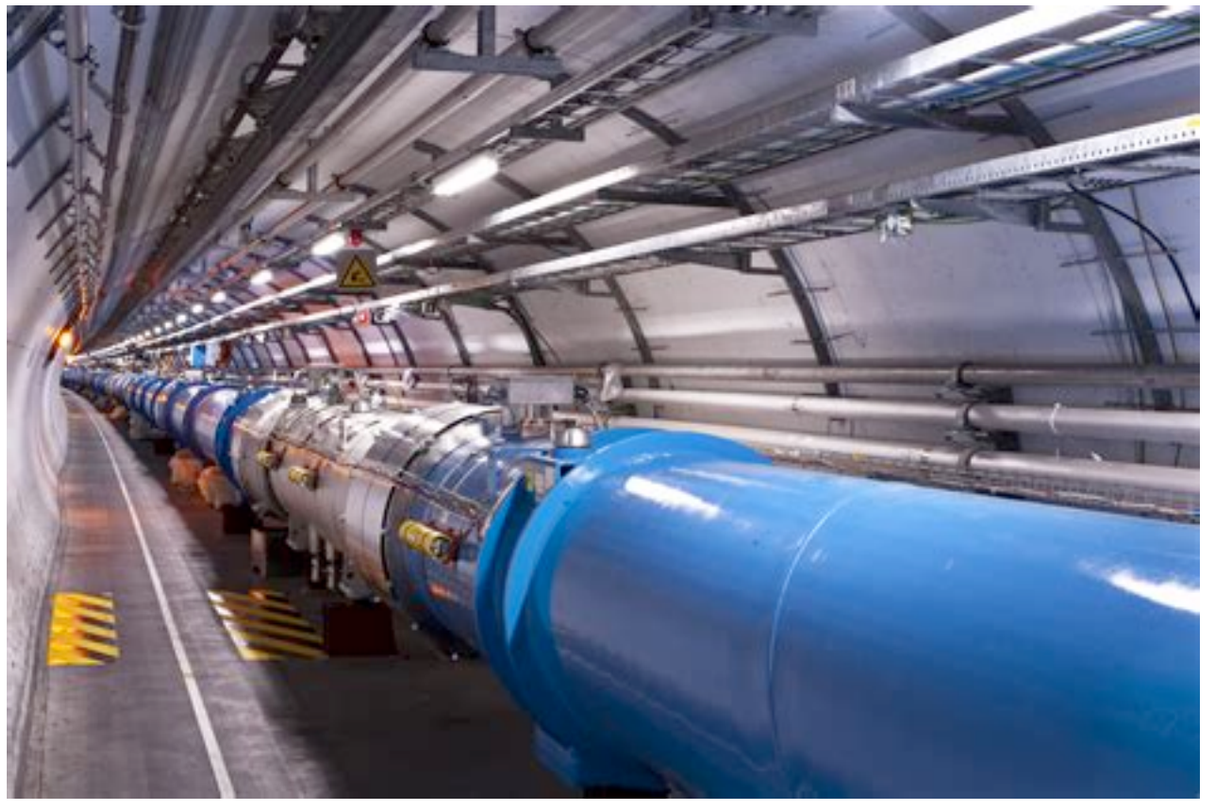


Branching occurs due to a process called ‘symmetry breaking’ - the Higgs field couples to the fields responsible for the weak force (which mediates radioactive decay), giving them the property of mass

The Large Hadron Collider

Protons (also lead nuclei) are accelerated by superconducting magnets and are smashed together inside detectors - recreates conditions a few seconds after the Big Bang (density, temperature) and can access physics of phase transitions





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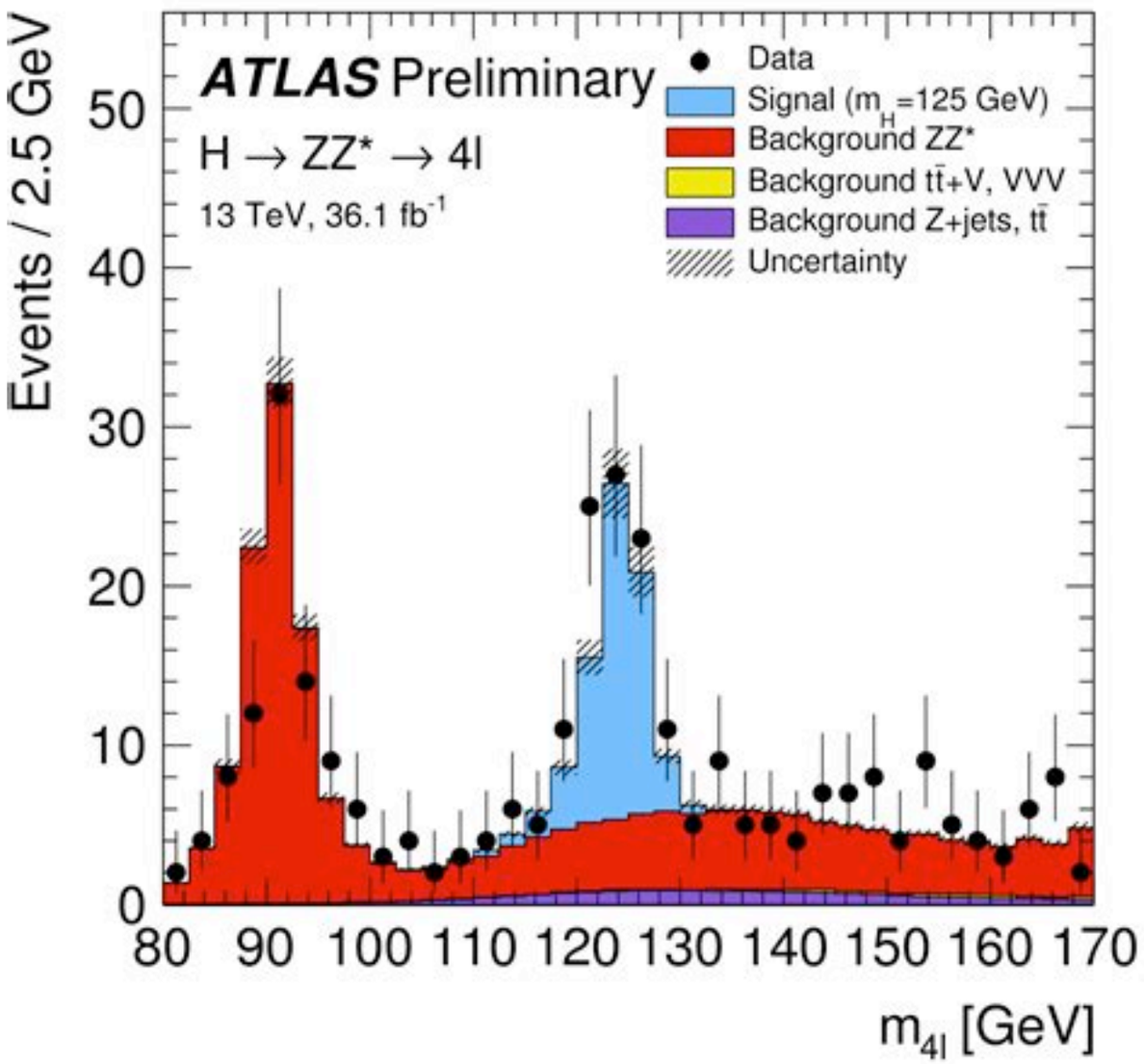
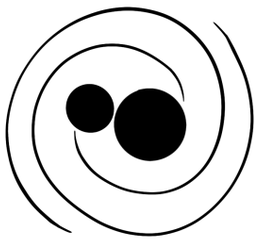


Measure an excess of decays associated with a particle with a mass energy of around 125 GeV (significance of 5 sigma) close to the mass predicted by theory

The 5-sigma significance is the threshold for rejecting the ‘null hypothesis’ (that the event is just noise processes)

Asking better questions with Bayes theorem



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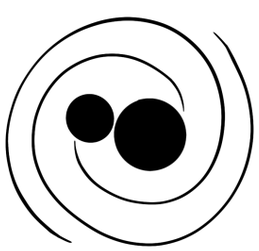

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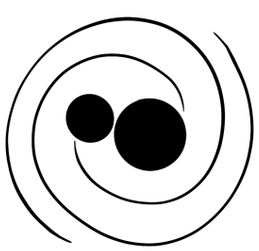

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- Next lecture: how we actually do this