

# Knowledge and the Universe

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# How do you know where the bus will take you?

For example...



How do you know the Sun will “recover” from an eclipse?



For example...

How often do you make decisions or draw conclusions?  
How important are they?  
How reliable are they?



NOT about what to do, but simply figure out what's true or correct



How often do you **make decisions** or draw conclusions?

How important are they?  
How reliable are they?



build knowledge

How often do you make decisions or draw conclusions?

How important are they?  
How reliable are they?

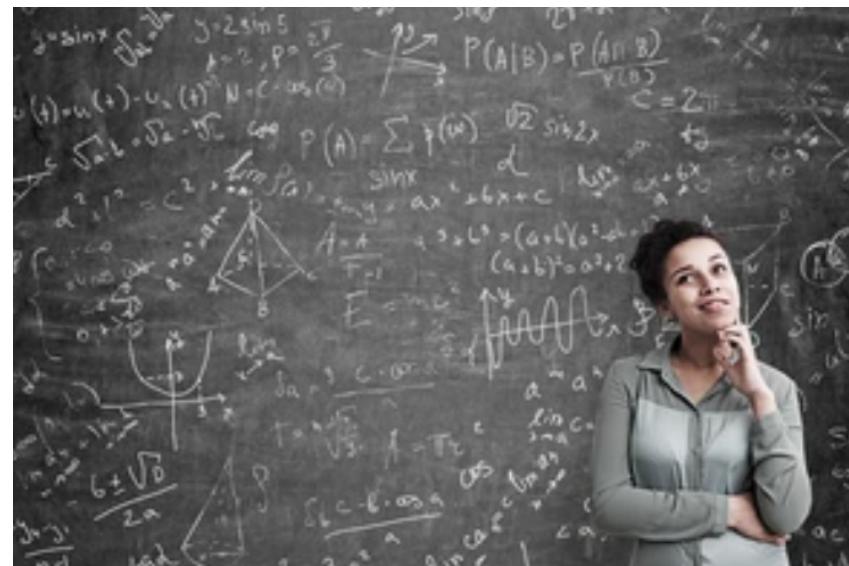


**Example 1.1 (Classes and pandemic.)** Is it safe to return to in-person classes while COVID-19 is still around? Think about how you would answer this question.

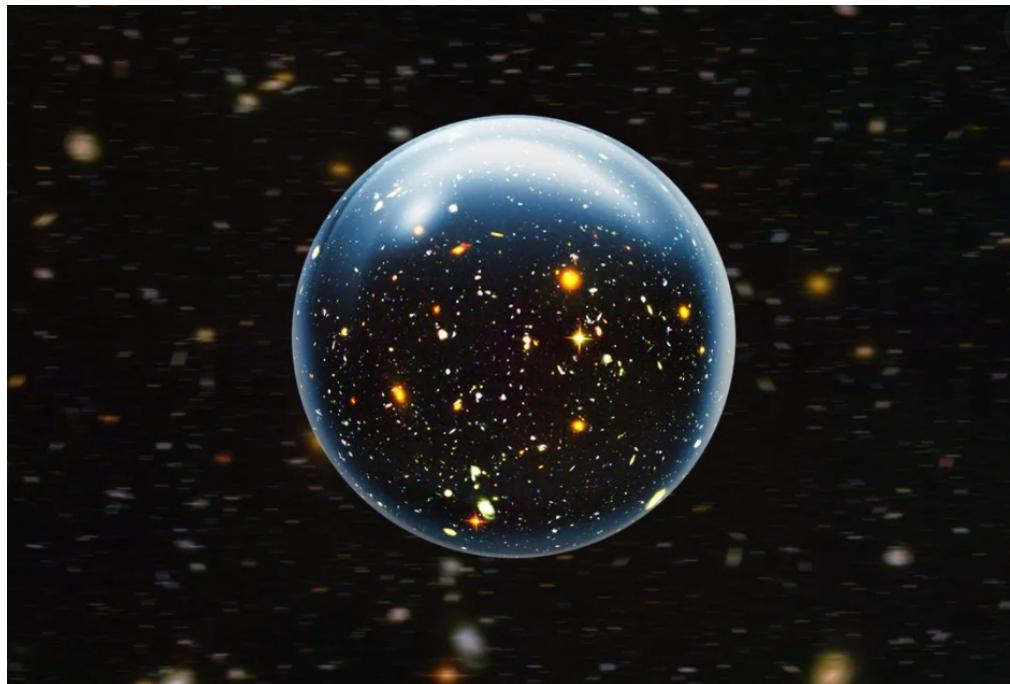
For example...



What about inferences in science?  
Are they different?  
Why?



**Example 1.2 (Curvature.)** Is it true that our Universe could be curved, like a surface of a ball? Think about what makes you believe/doubt this statement.



For example...

# The story about the process of science.



Freelance Revolution: Meet Kola...  
[forbes.com](https://www.forbes.com)



So, You Want To Be A Scientist?  
[careerbright.com](https://www.careerbright.com)



Scientists Rises, Pew Poll Shows ...  
[the-scientist.com](https://www.the-scientist.com)



research into medieval p...  
[theguardian.com](https://www.theguardian.com)



# building knowledge

## The story about the process of science.



Freelance Revolution: Meet Kola...  
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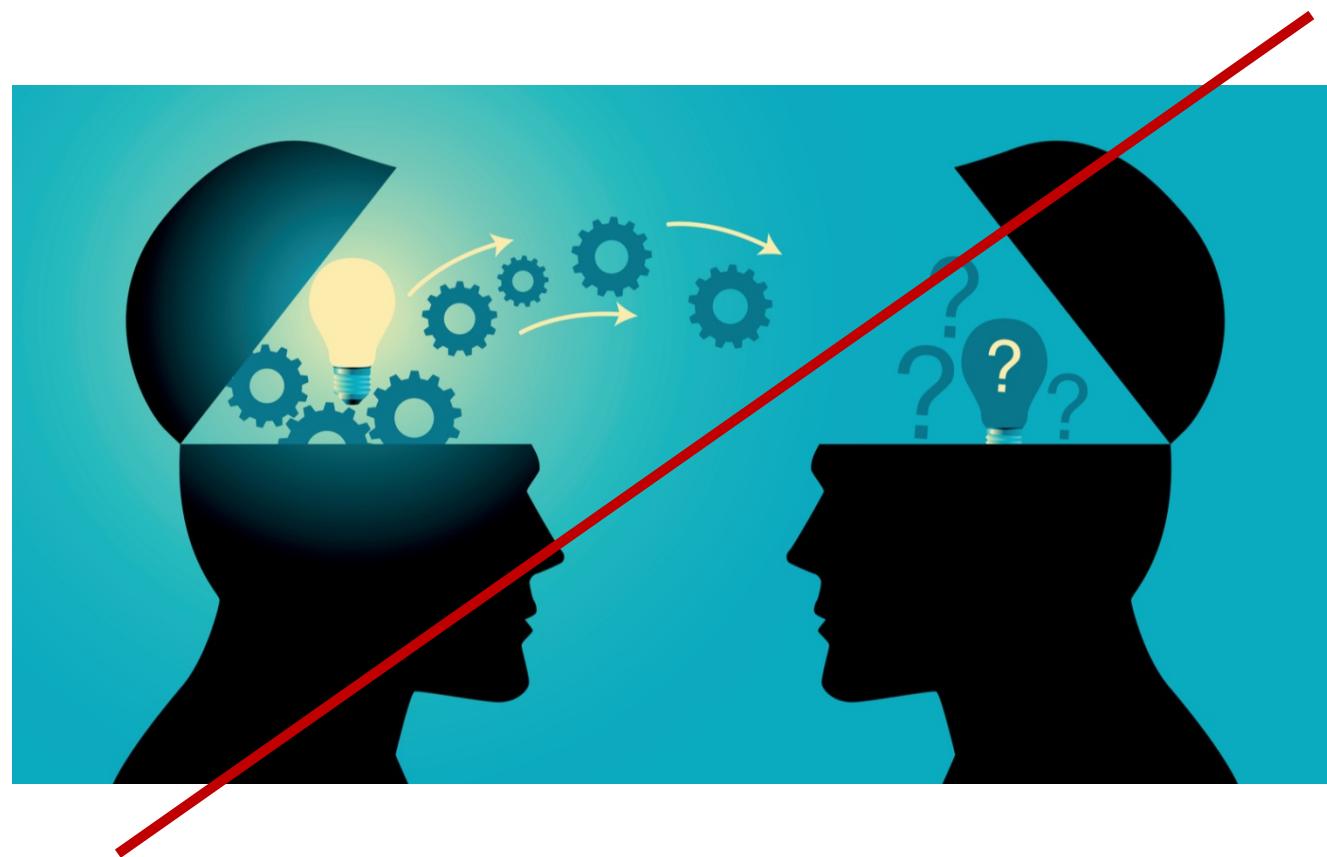
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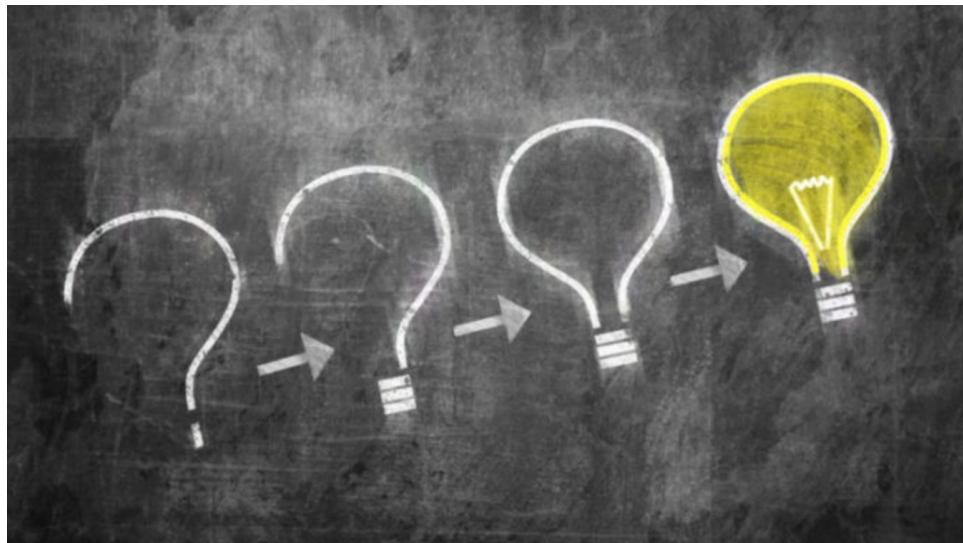


The story about the process of **building knowledge**.



The story about the process of **building knowledge**.

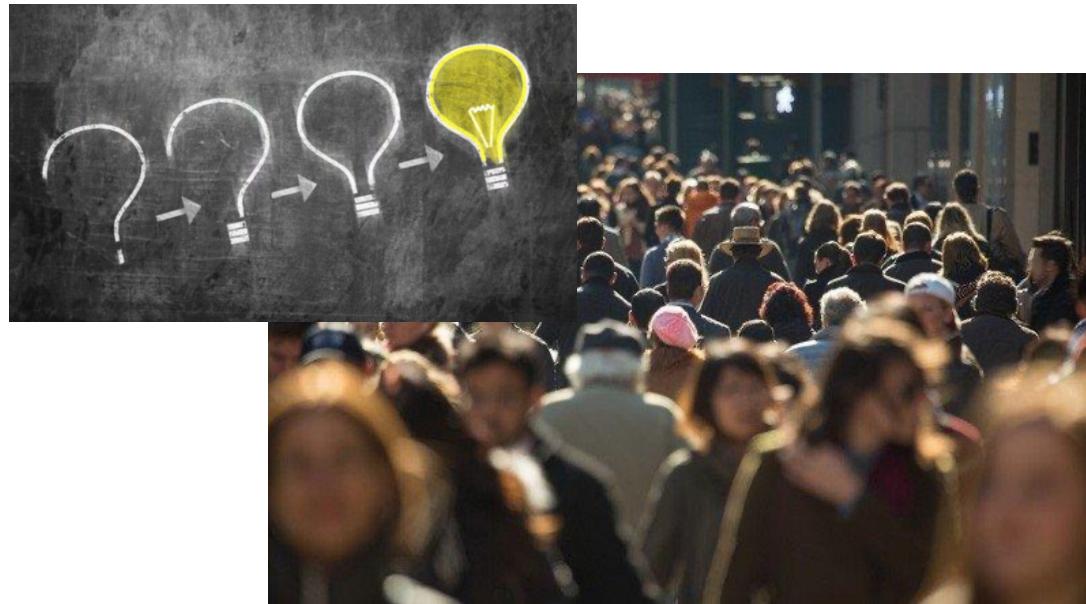
Question



Answer  
Knowledge  
Belief

human

The story about the process of building knowledge.



Tools for building knowledge

Experience

Experiment

Observation

Common sense

Tools for building knowledge

Questions

Likelihood

Intuition

Common sense

## Tools for building knowledge

Evidence

Questions

Likelihood

Intuition

# Tools for building knowledge

**Evidence**

**Questions**

**Likelihood**

**Common sense**  
+  
**Intuition**



What is “intuition”?

# Tools for building knowledge

Evidence

Questions

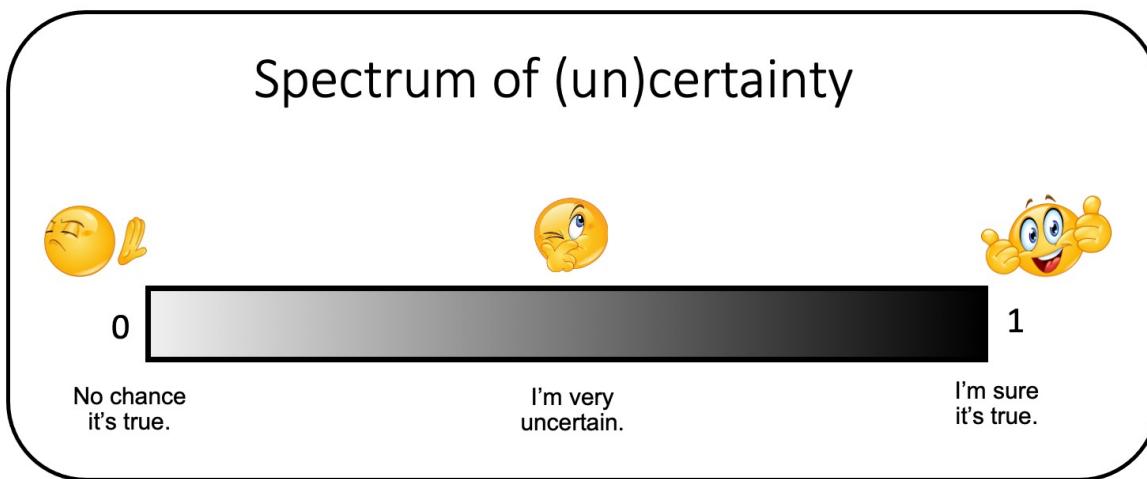
Likelihood

Prior knowledge



What is ``likelihood''?

We're gonna call that *probability*.



# Tools for building knowledge

Evidence

Questions

Probability

Prior knowledge



What does it mean to be “uncertain”?  
Is that a bad thing?!



What does it mean to be “uncertain”?  
Is that a bad thing?!

Uncertainty is a natural part of life & science.

But we'd like to quantify it!

Does that mean there is no Truth??

Does that mean there is no Truth??



The Moon formed, somehow.



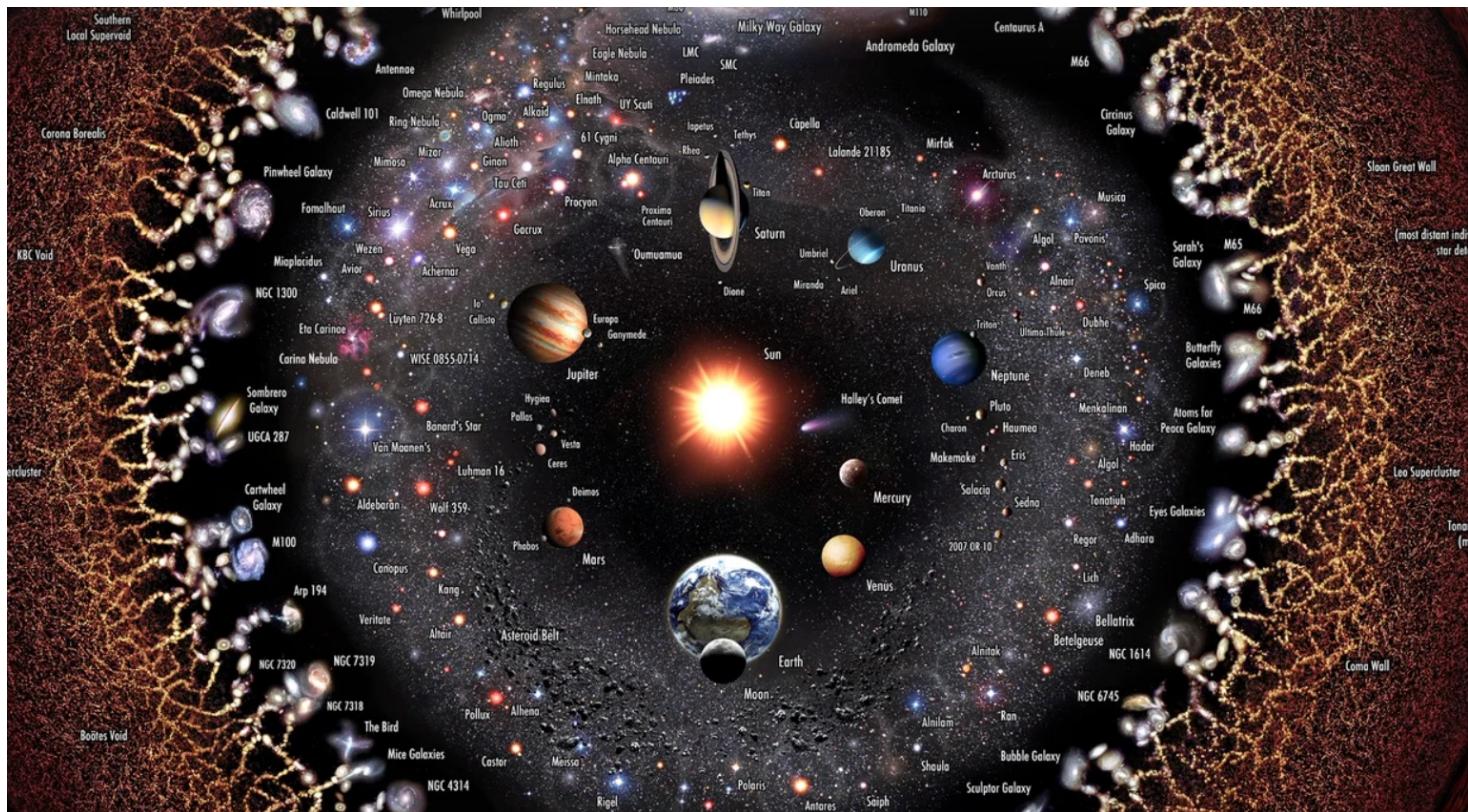
Either he has coronavirus or he doesn't.

**Example 1.3 (Comfort with uncertainty.)** Think of a situation where you had to make a choice, but the evidence you gathered made it only 80% likely that you're right. Is this enough? Can you think of situations where it is, and situations where it isn't? What do you think is the probability/level of certainty that is enough for scientists to announce a discovery?



Announcement of the discovery of the Higgs  
Boson particle, CERN 2012

**Example 1.4 (Compare theories.)** Think of two theories mentioned in this course, and discuss how their uncertainty/probability compares. Which one would you be less surprised if it gets refuted? Why?



**Example 1.5 (A safe bet.)** Imagine you're making a bet on the heads/tails result of a coin flip. How much money would you put on that bet? Imagine instead that you're making a bet that it will not rain tomorrow. How much money would you put this time? Finally, imagine that you are a National Science Foundation officer, deciding whether to fund a new CMB experiment, whose team claims that they would discover gravitational waves from the Big Bang, based on a theoretical prediction; they are asking for 50 million dollars. Would you be willing to make that bet?



# Tools for building knowledge

**Evidence**

**Probability**

**Prior knowledge**

## Tools for inference

Evidence



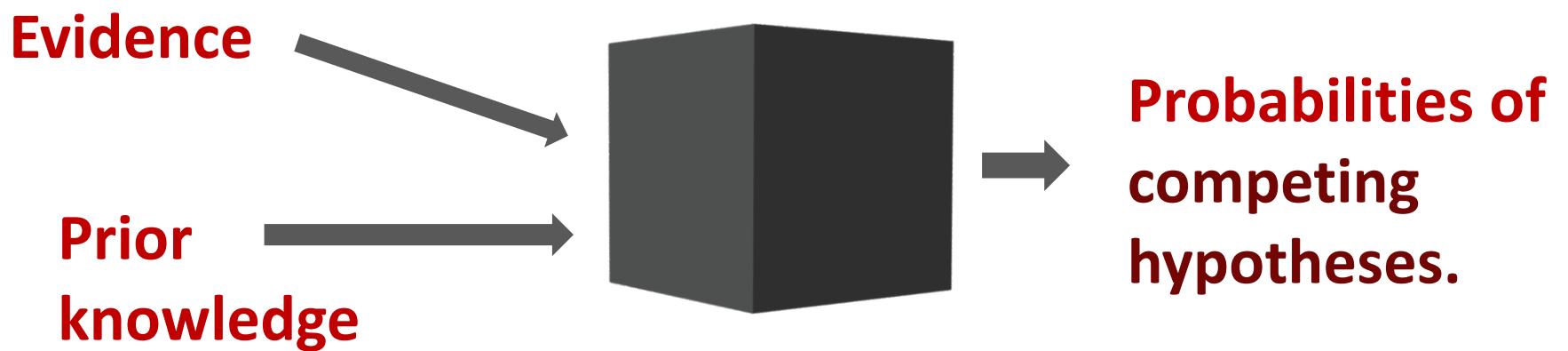
Probability



Prior knowledge

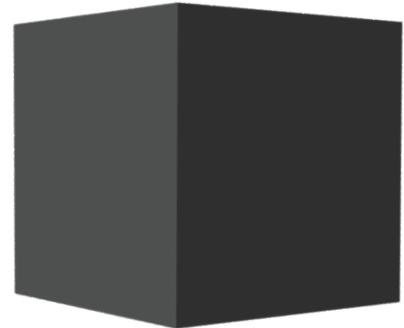


# Probabilistic inference

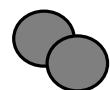
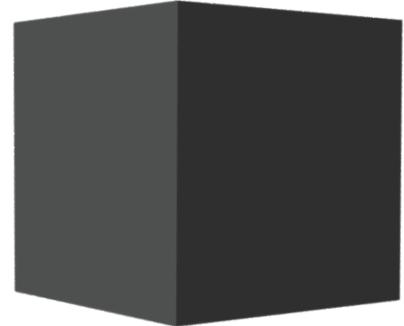


Probabilistic inference

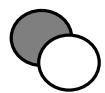
What's in the box?



# What's in the box?

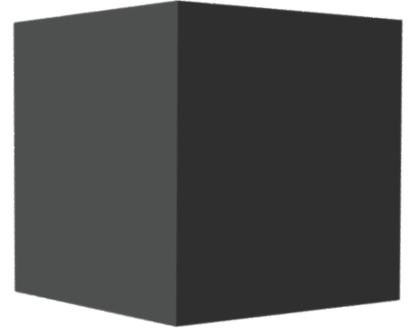


*Hypothesis 1 – GG – Both balls are grey.*

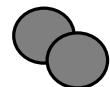


*Hypothesis 2 – GW – One ball is grey, one ball is white.*

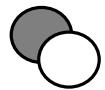
# What's in the box?



Priors:

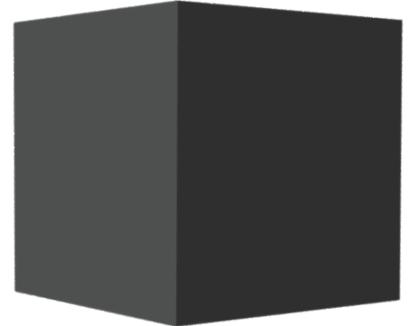


$$P(GG) = 0.5$$



$$P(GW) = 0.5$$

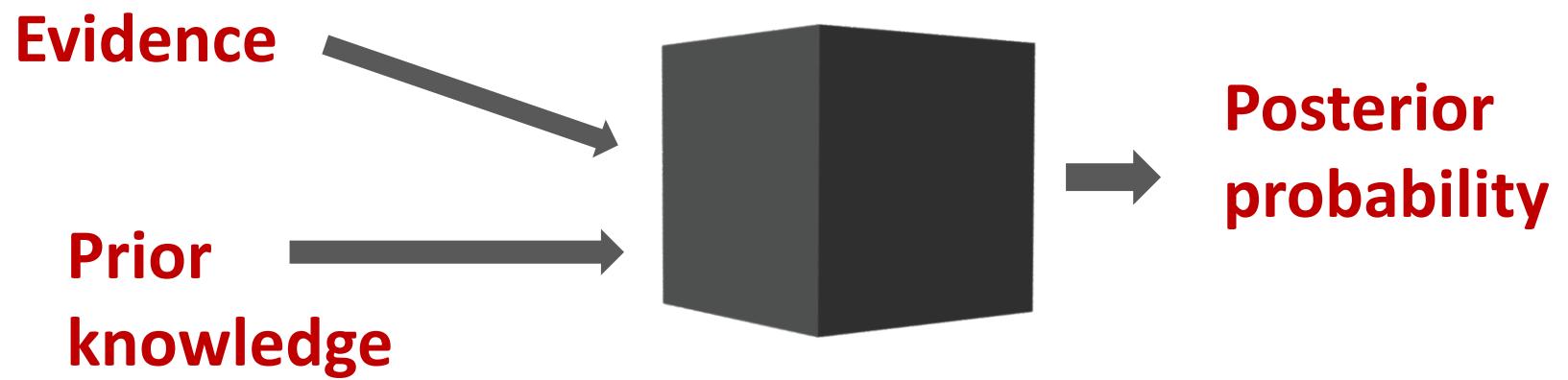
# What's in the box?



*The result/data: The ball that was removed from the bag is grey.* 

  $P(G|GG) = 1$

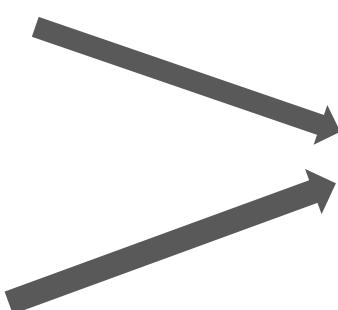
  $P(G|GW) = P(W|GW)$



# What's in the box?

**Likelihood**

(probability of given evidence,  
under my hypothesis)

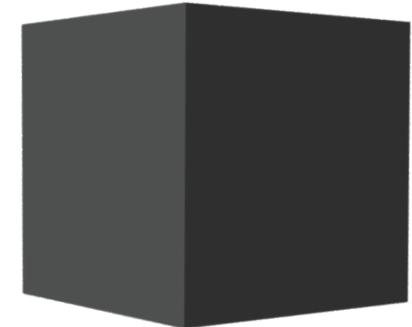


**Prior**

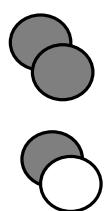
(probability of my hypothesis,  
before considering evidence)

**Posterior**

(probability of my  
hypothesis, taking into  
account priors &  
evidence)



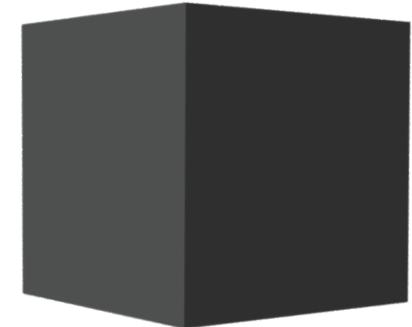
# Inference Box



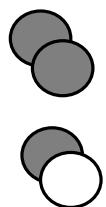
Hypothesis	Prior	Likelihood	$h = \text{Likelihood} \times \text{Prior}$	Posterior
GG	0.5	1	$1 \times 0.5 = 0.5$	?
WG	0.5	0.5	$0.5 \times 0.5 = 0.25$	?

$$\text{Posterior(GG)} = 0.5 / (0.5 + 0.25)$$

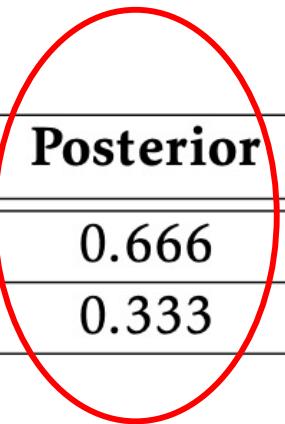
$$\text{Posterior(GW)} = 0.25 / (0.5 + 0.25)$$



## Inference Box

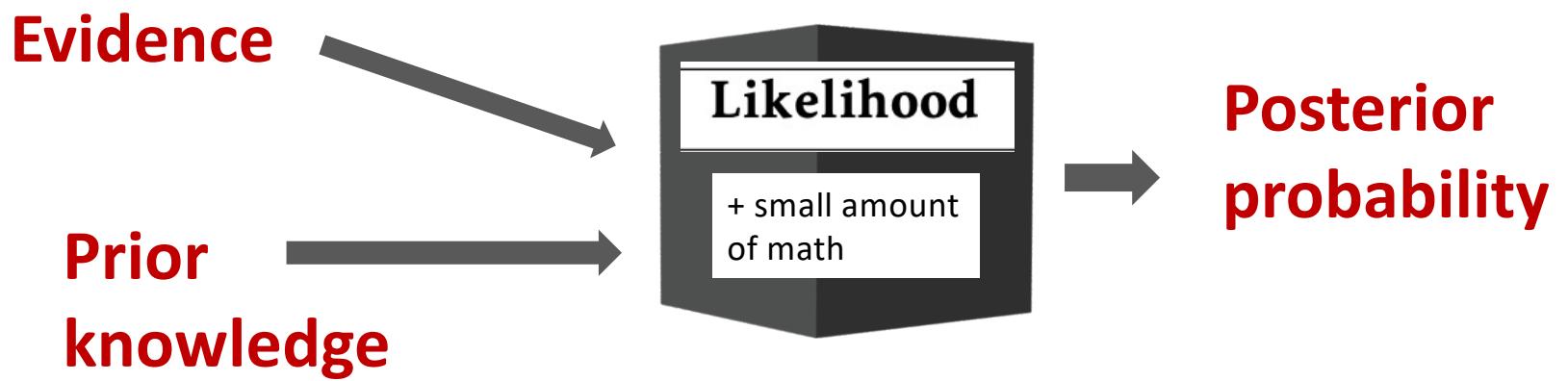


Hypothesis	Prior	Likelihood	$h = \text{Likelihood} \times \text{Prior}$	Posterior
GG	0.5	1	0.5	0.666
WG	0.5	0.5	0.25	0.333

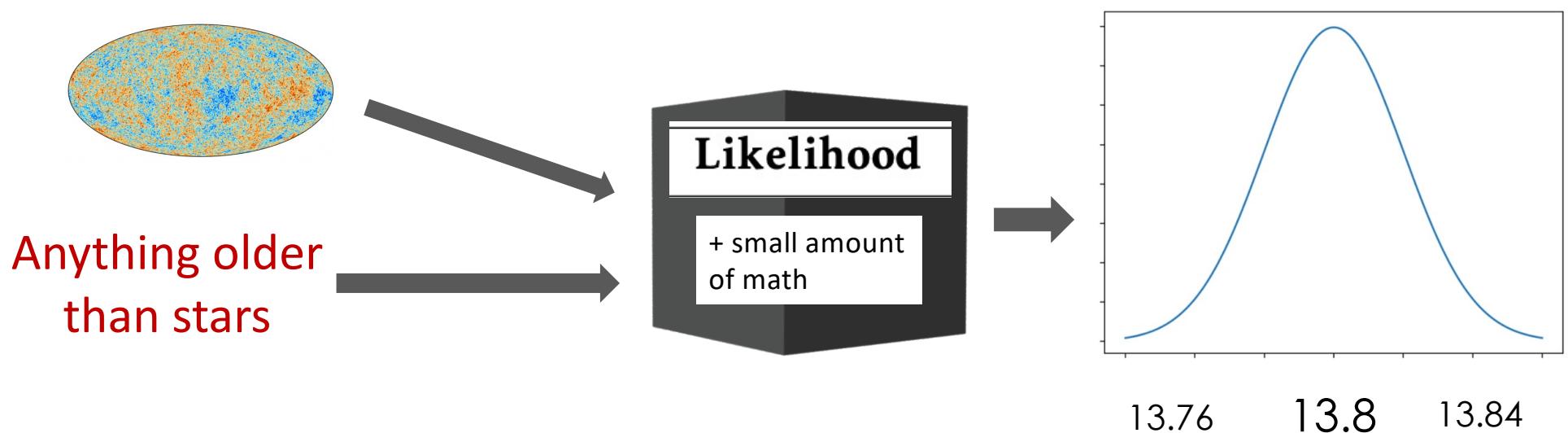


$$\text{Posterior(GG)} = 0.5 / (0.5 + 0.25)$$

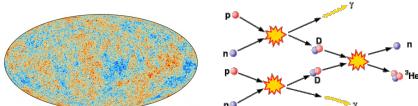
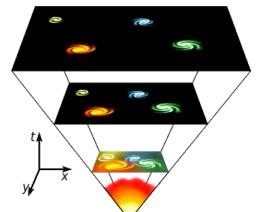
$$\text{Posterior(GW)} = 0.25 / (0.5 + 0.25)$$



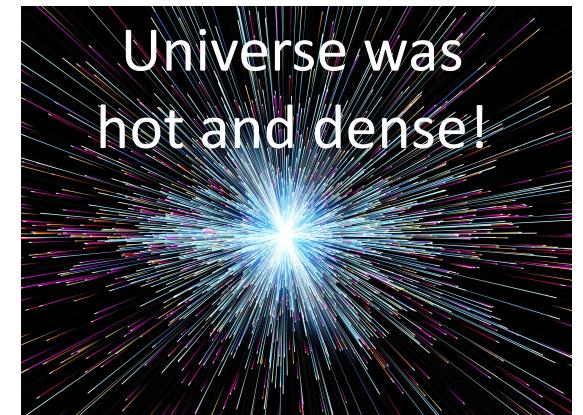
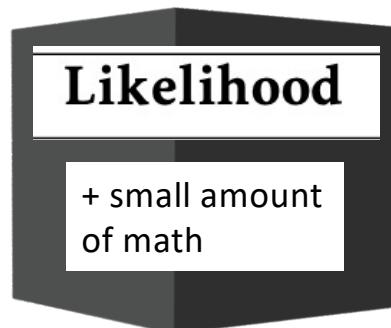
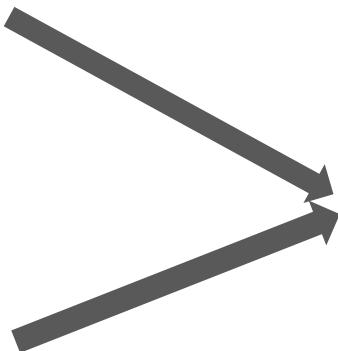
# Example 1: Age of the Universe (in billions of yr)



## Example 2: The Big Bang Theory



Universe was  
probably always  
the same...

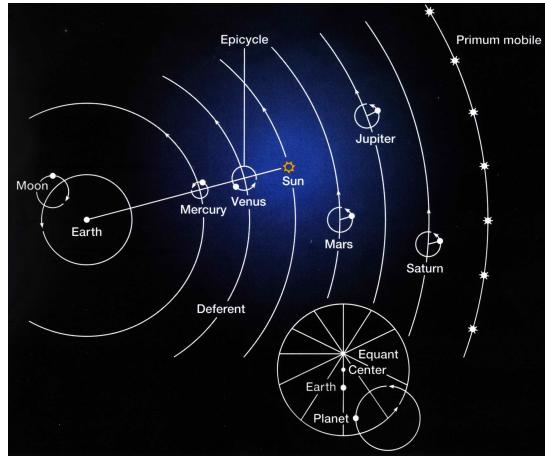


**Example 1.7 (Unfair coin?)** Imagine that someone gives you to pick one of 10 coins, without looking. And after you take one, she tells you that out of the 10, one was with double heads. You flip your coin, still without looking. It comes up heads. After that one flip, what is the probability that this is that unfair? How many times in a row do you need to get heads before you are fairly sure that you've drawn an unfair coin?



<https://docs.google.com/spreadsheets/d/1YDfMtfwLxTGRFfGtqhcWpylKRqTFsyAxF8unY7JtRPI/edit?usp=sharing>

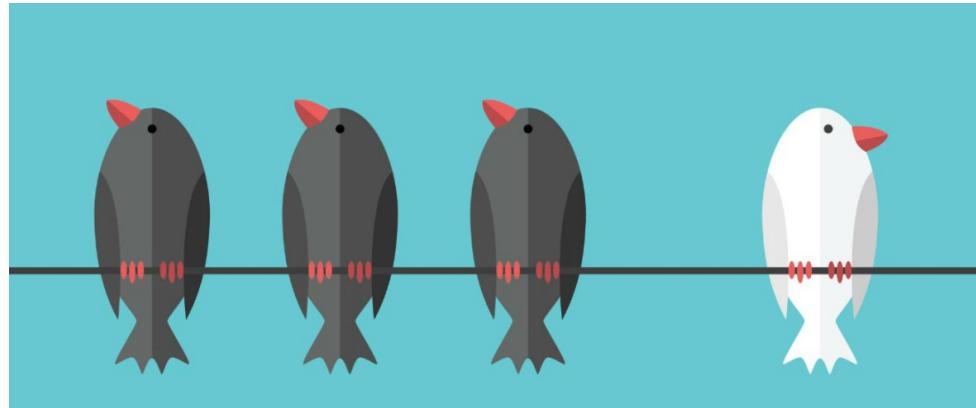
# What made the decision??



# Let's talk about priors!



**Example 1.10 (Good priors.)** Can you think of an example situation where a prior assumption is helpful?



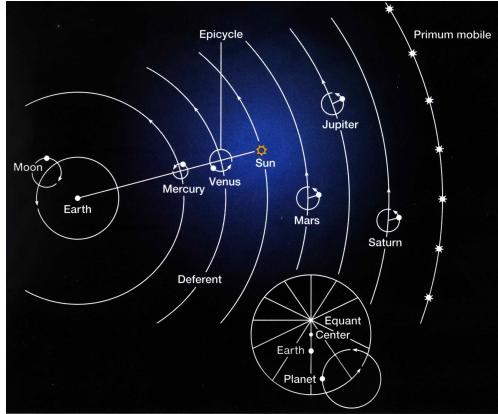
## Let's talk about priors!

**Example 1.9 (Bad priors.)** Can you think of an example situation where a prior assumption causes a problem?

How do you make sure prior is not a problem?

How do you make sure prior is not a problem?

Ensure that you also consider evidence.



## Shifting paradigms

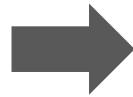
**Example 1.12 (Shifting paradigms.)** Think of a discovery you learned about in this class that shifted your understanding of the Universe. How uncomfortable are you with this new knowledge? Why do you believe it, or why do you still doubt? What would make you convinced?



## Changing minds

**Example 1.11 (Changing minds.)** Consider something you have always believed to be true. Think about why, and what it would take to change your mind. This example can be something from life or from science.

# When do paradigms shift and minds change?



And when do paradigms/minds remain fixed,  
in spite of evidence?

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in spite of evidence?

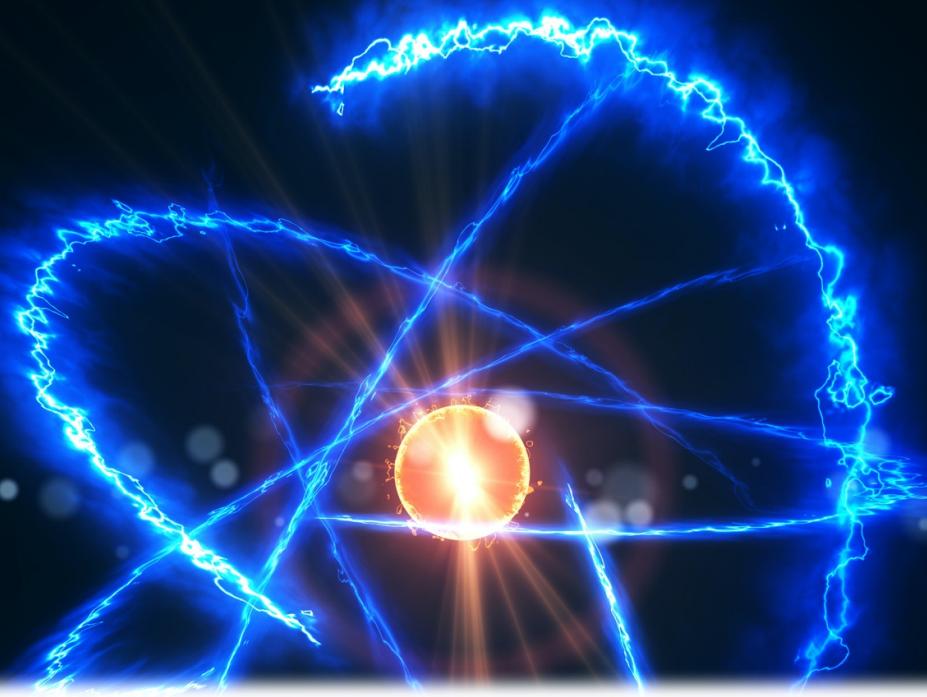


And when do paradigms/minds remain fixed,  
in spite of evidence?



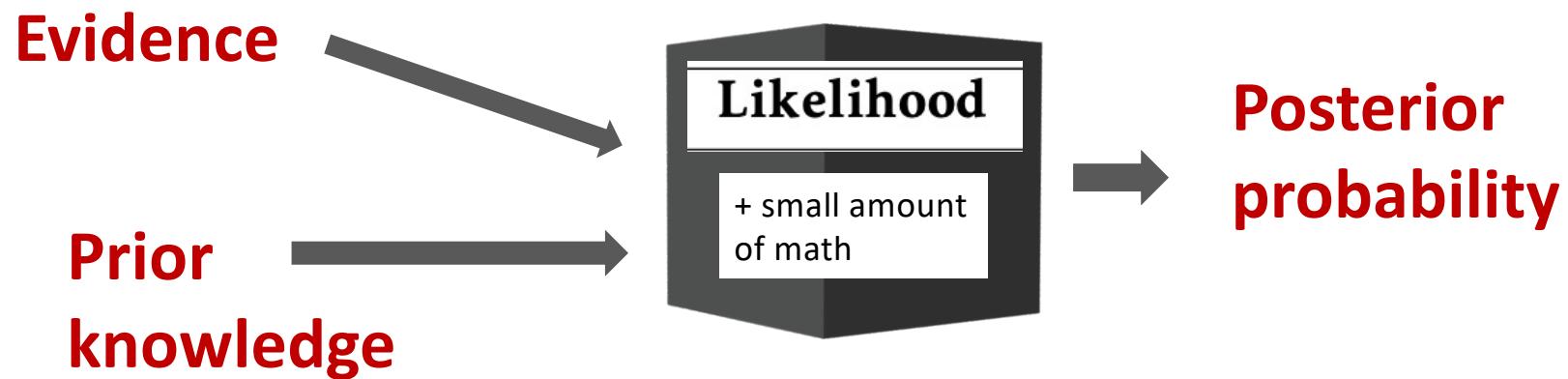
Never the case!!!

How would you approach a person with  
different beliefs?

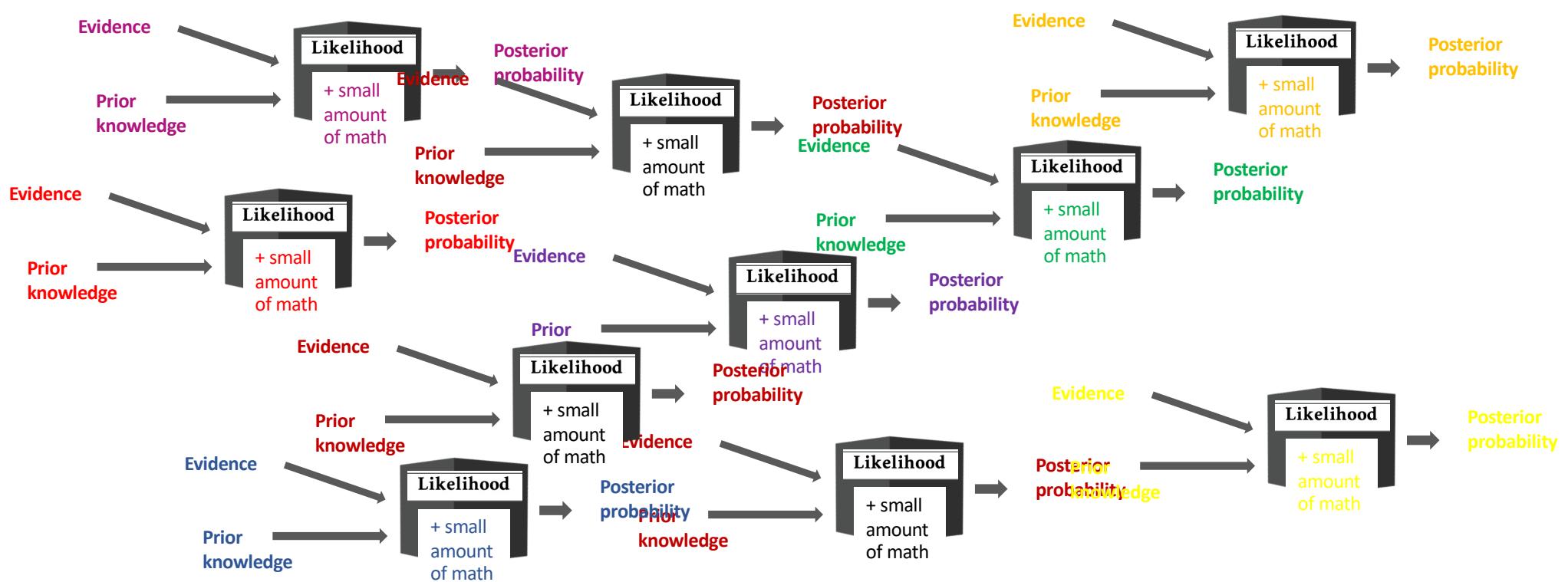


*If this is how it works, what is then **scientific** about scientific inference?*

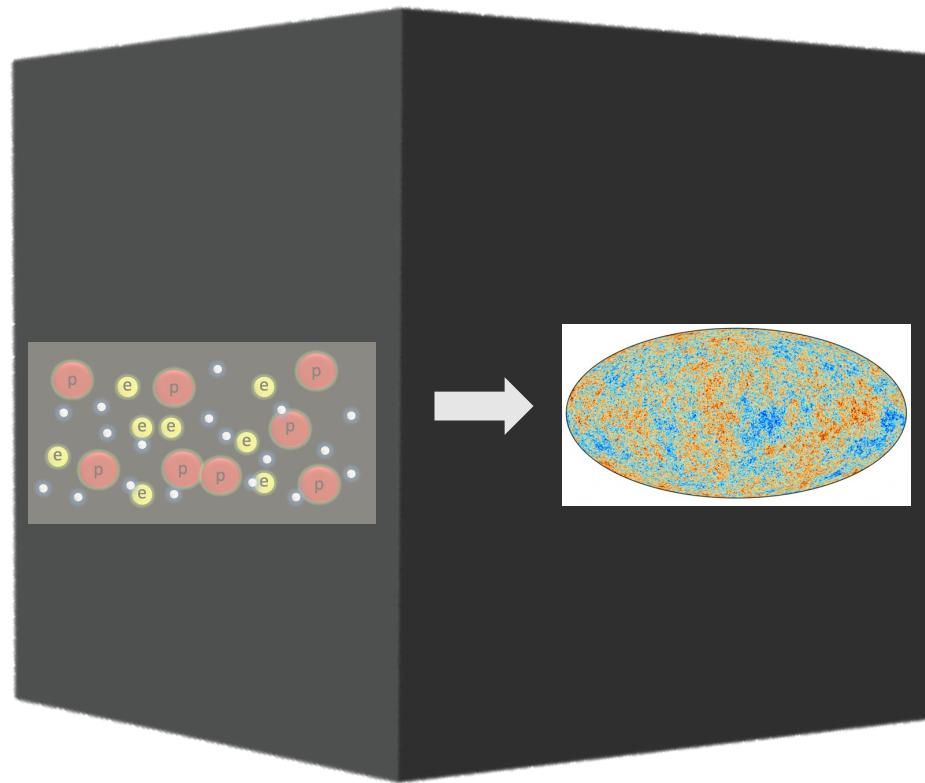
1. We stick to this---no hiding evidence.



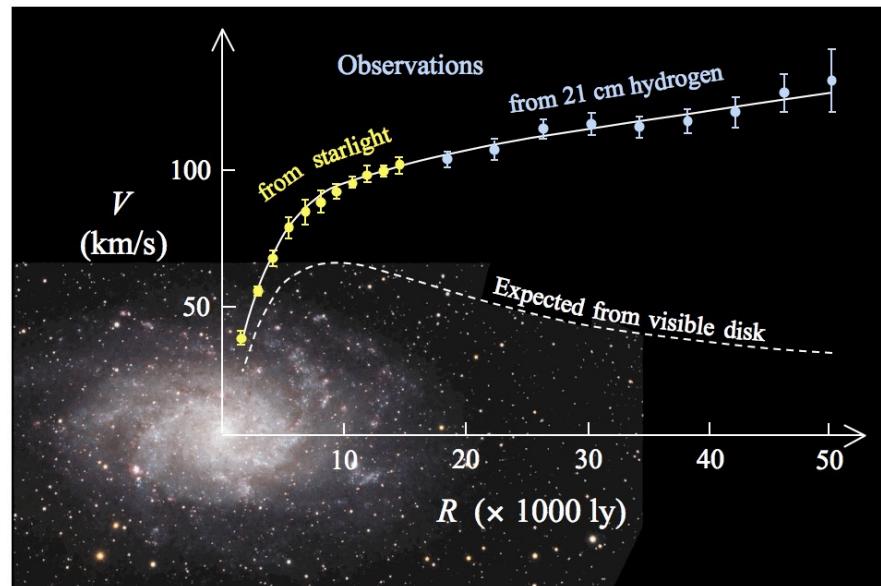
## 2. We check each other---reproducible science.



### 3. Likelihood of data, given a theory.

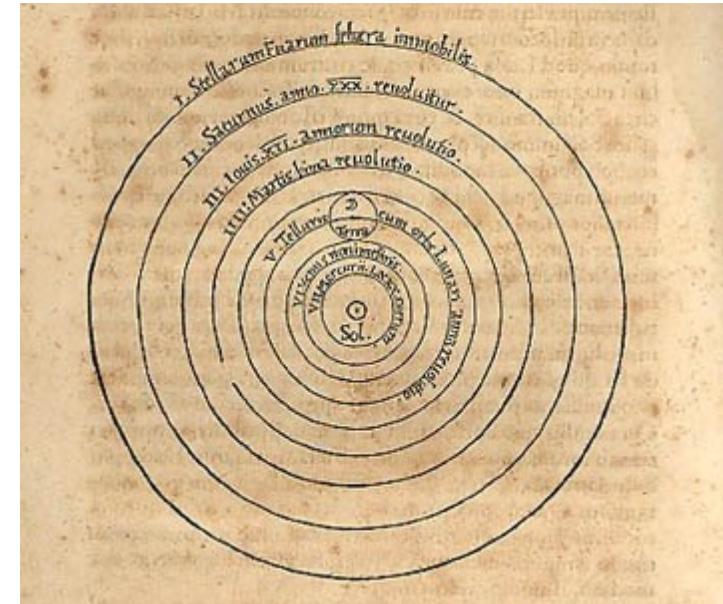
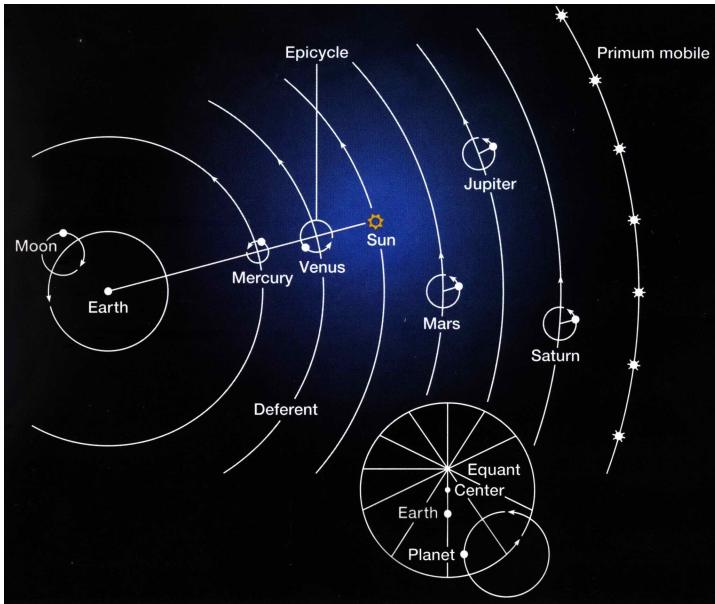


## 4. A sense of what is possible ( = list of all competing hypotheses)



Modified Gravity vs. Dark Matter?

# Also, in life and science: Preference for simplicity (Occam's razor)



Heliocentric vs. Geocentric system?



THE END...

# Key definitions

- **Probability** = certainty that a statement is true.
- **Probabilistic inference** = a systematic way to *infer* an answer that is most **probable** (given all the prior knowledge and all the evidence) and quantify the remaining level of uncertainty.
- **Prior** is the probability that a certain hypothesis is correct *before* (or prior to) considering any evidence, or data.
- **Likelihood** is the probability that a certain outcome (or data) would result *if* a certain hypothesis is true.
- **Posterior** is the probability that a hypothesis is true *after* considering all the information/evidence/data/experiments, and all the priors, and taking into account all the **competing hypotheses**.