Hypotheses and Data

Visible and Invisible

Seen and Unseen

- There are scientific *hypotheses* (i.e. theories, models) and scientific *data* (i.e. evidence). What's the difference?

- **Empirical Data** = description of what has been *seen*, or *observed* in some way
- A **Hypothesis** describes unobserved objects, situations and processes that might be causes of the data.

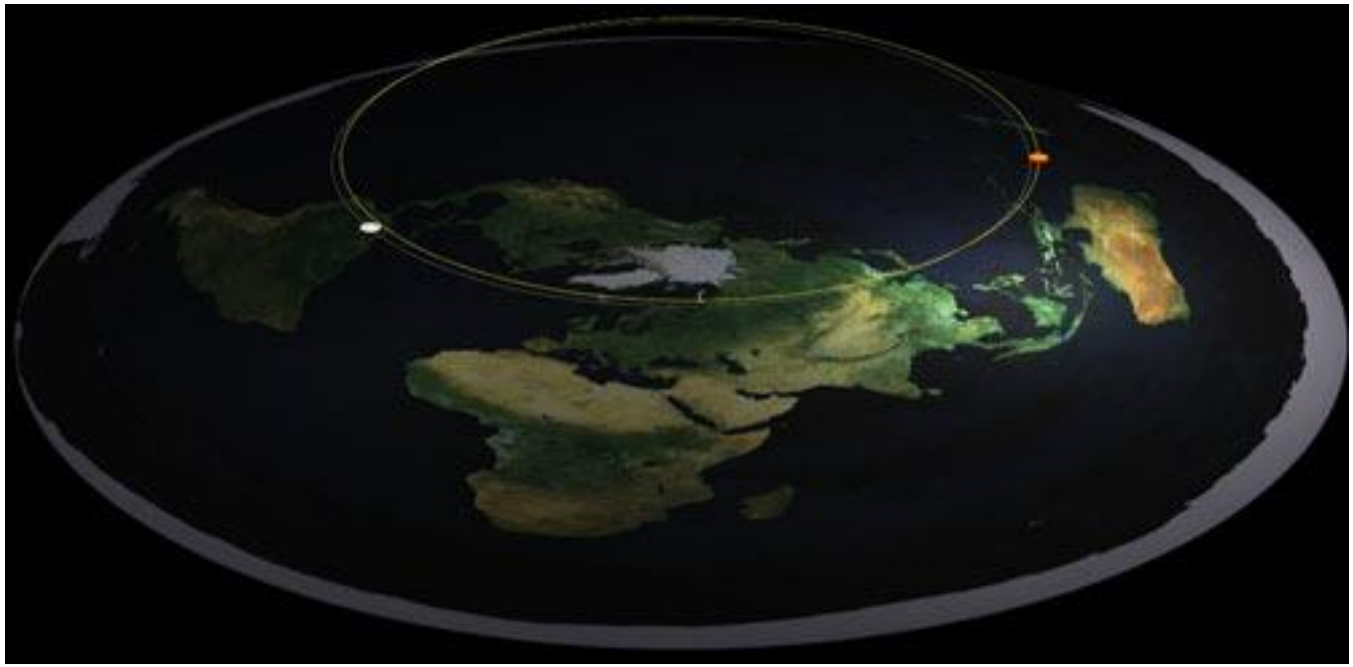
Certain and Uncertain

Data: Typically the data are fairly certain, since they have been observed. "Seeing is believing". (Exceptions?)

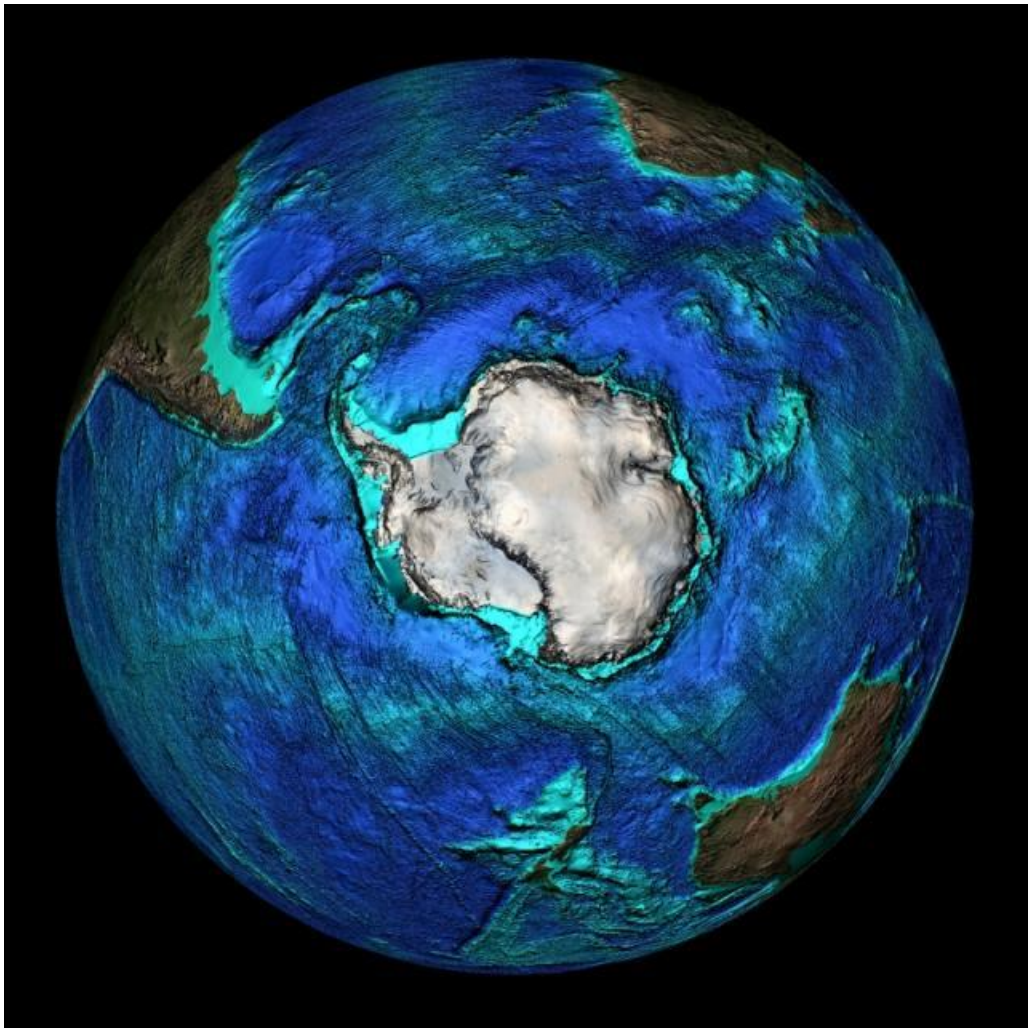
Hypothesis: Typically, a hypothesis is somewhat uncertain, since is not directly verifiable by observation. (Exceptions?)

- For example, consider two people arguing about the shape of the earth in the 5th century B.C.
- Sally says that the world is round, like a ball. Her friend Mike says that it's flat like a plate.
- Are these hypotheses, or data?
- They're *hypotheses*, since one cannot see the shape of the earth without going up into space.

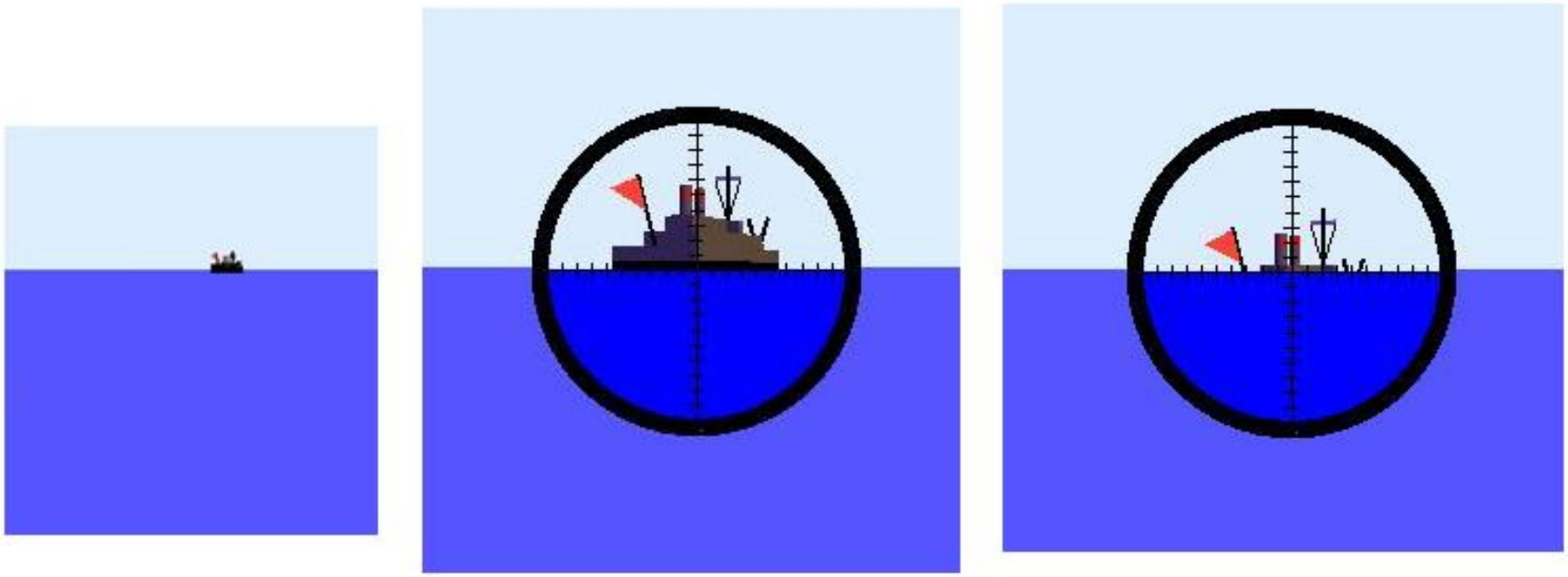
Flat earth hypothesis



Round earth hypothesis



What are some relevant data?



A ship that sails into the distance appears to sink. Is it sinking?

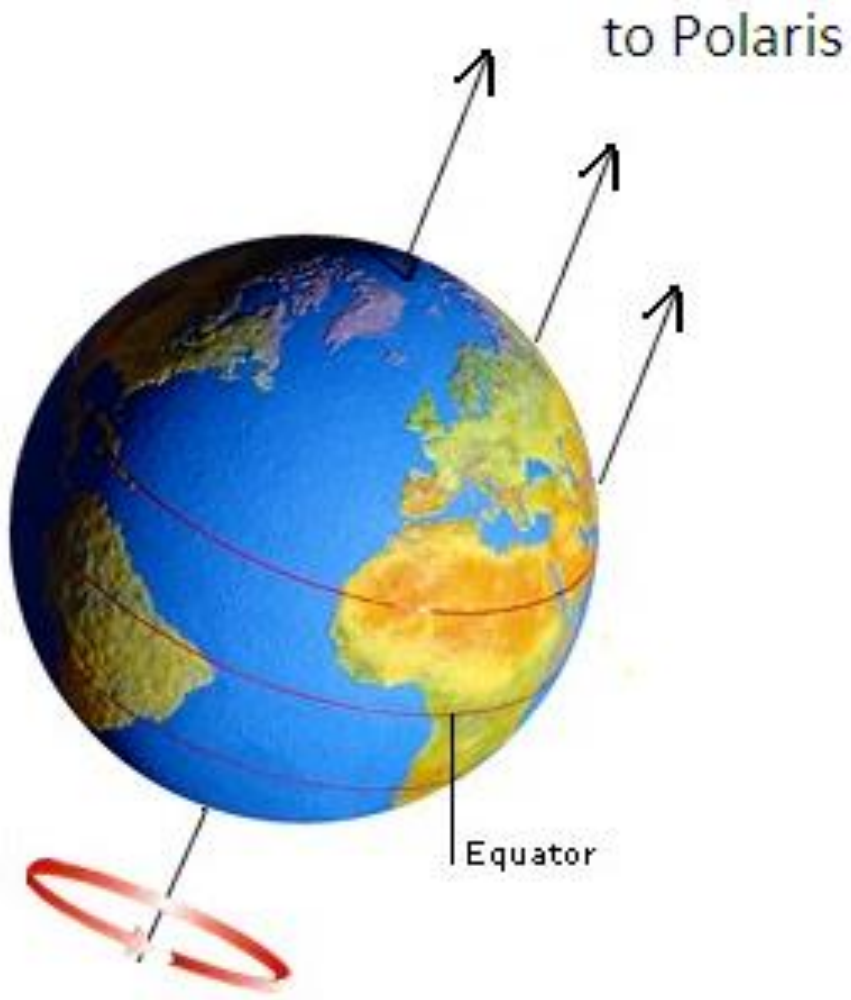
More data

- The earth throws a curved shadow on the moon during a lunar eclipse.

More data

- Polaris, the pole star, appears higher in the sky as you travel north. (At the equator, it is on the horizon.)

(Long-exposure photograph, about 2 hours)


to Polaris
Equator

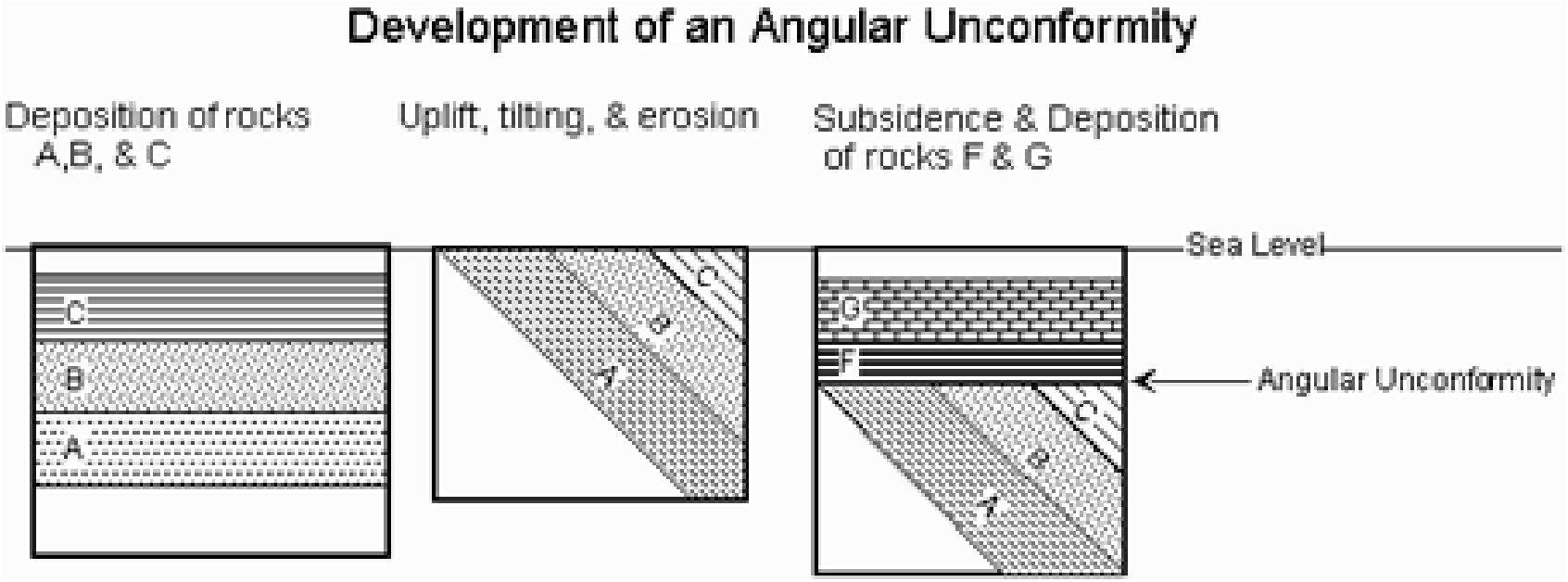
Data are *observable*

- Note that these are all matters that are directly *observable*.

  (Although they may involve other theoretical terms, such as “north”.)

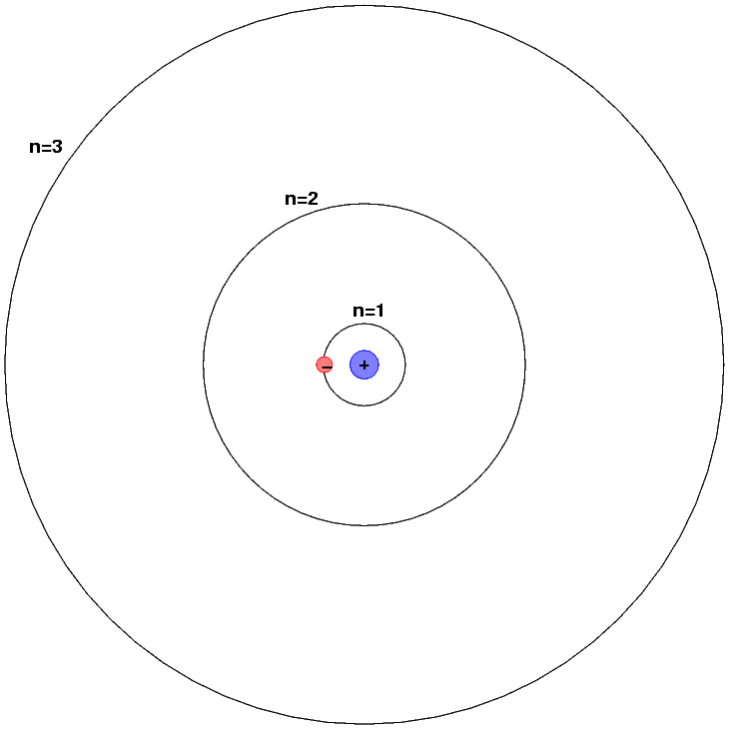
Geological data
(the Hutton angular unconformity)

Geological hypothesis



This hypothesis involves the claim that the land mass has been lifted thousands of feet up out of the ocean, tilted, eroded and then lowered into the ocean again. (Has anyone observed this?)

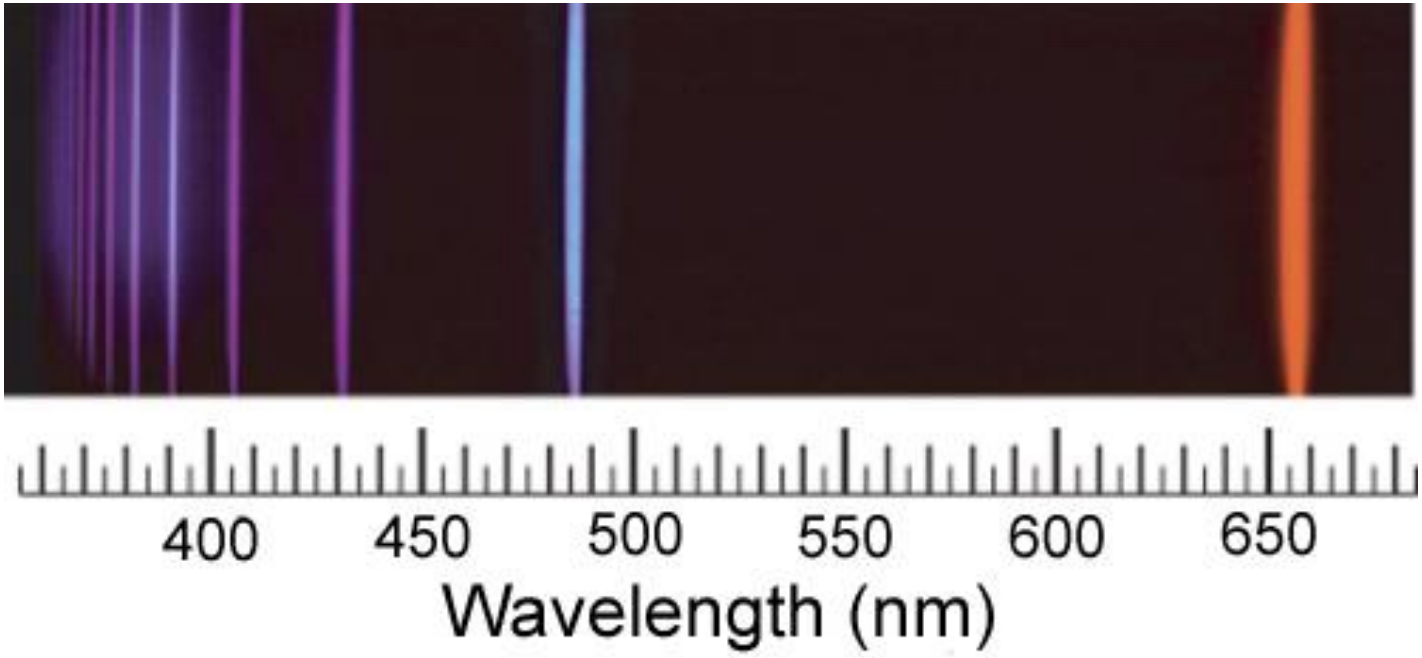
A hypothesis in physics



- A hydrogen atom is thought to have one electron orbiting one (much heavier) proton. The electron can exist in different orbits, or energy levels, n = 1, 2, 3 etc. (Can we *see* this structure in a sample of hydrogen?)

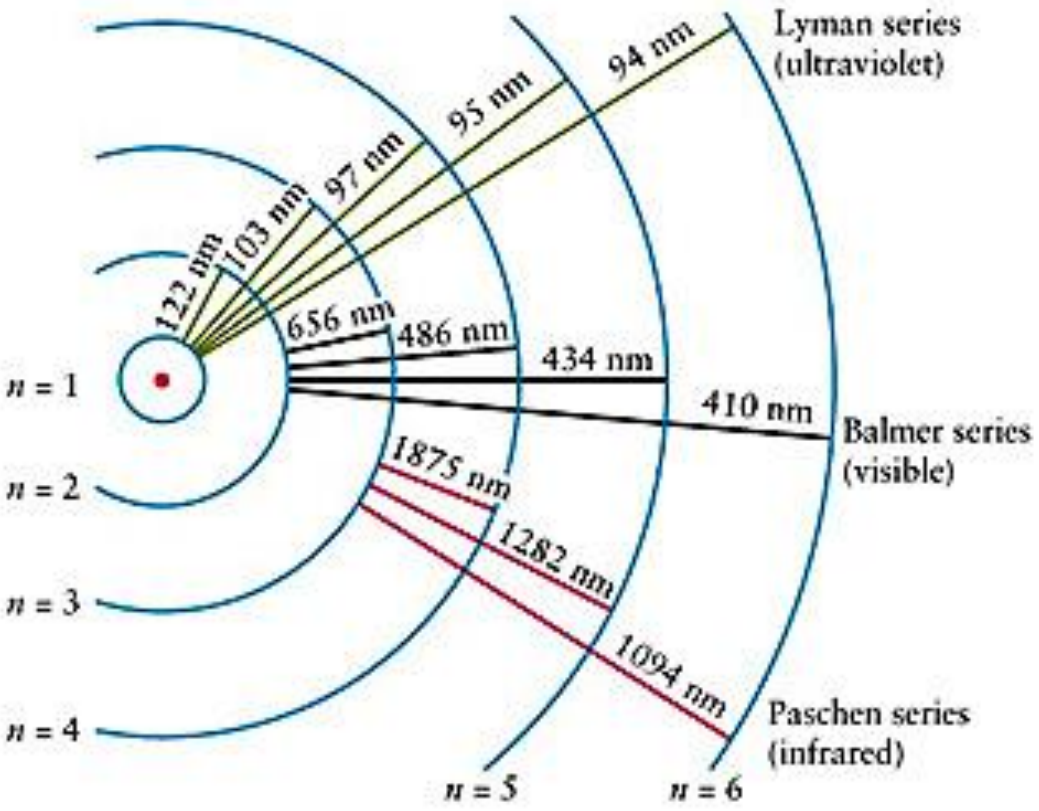
Supporting data

- The “Balmer series” of spectral lines for the hydrogen atom is shown below. Visible light emitted by hydrogen atoms is composed of certain precise wavelengths.



How the model predicts the data

- When an electron drops from a higher to a lower orbit, it releases energy in the form of a photon. The energy E of the photon is a function of its wavelength λ. ($E = hc/\lambda$)



Empirical Statements

- An empirical statement is a claim that, if true, could in principle be observed.
- Thus, some empirical statements are false. E.g.:
  - "The sun rose today at 3.14pm"
  - "As he addressed Parliament last Tuesday, Mr. Trudeau rose slowly into the air, with no visible means of support"

Predictions

- *A prediction is an empirical statement*, but it is not necessarily observed to be true.

- A prediction is an empirical statement that is logically derived from a theory or hypothesis.
- Thus a prediction describes what a believer in that theory *expects* to see.

Predicts ≈ Explains

"Quantum mechanics predicts that the light emitted by energised hydrogen will contain just a few, sharply-defined, wavelengths"

General format:

<Theory> predicts <data>

When a theory *predicts* some data, we usually think that the theory *explains* the data as well, or potentially explains the data at least.

A hypothesis in biology

- American geneticist Dr. Eugene McCarthy proposed in 2013 the hypothesis that humans are a hybrid between chimpanzees and pigs, after a boar mated with a chimp a few million years ago.

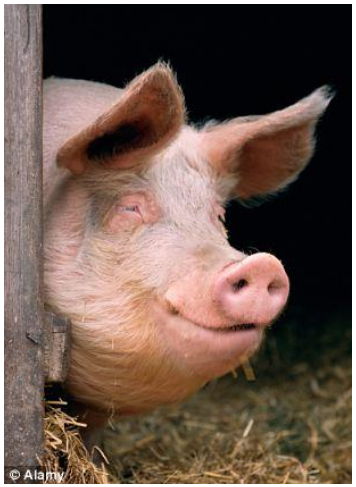
Evidence

- Humans are supposed to belong to the order primates, but they have dozens of characteristics not shared by any other primates, e.g.:
  - Naked skin
  - layer of subcutaneous fat
  - Lightly pigmented eyes
  - Protruding, cartilaginous nose
  - Narrow eye opening
  - Many pig-like skeletal features
  - Diverticulum at cardiac end of stomach
  - Multipyramidal kidneys

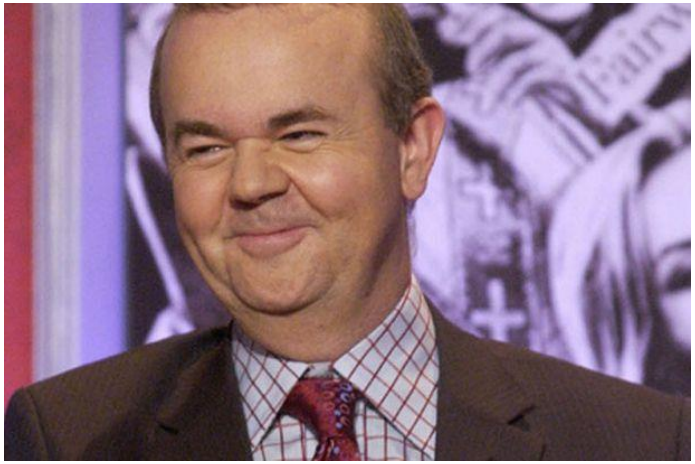
- These are all features of pigs! McCarthy's theory *predicts* that humans should have many porcine features.

More evidence

Chief Wiggum



Daisy



Ian Hislop

(Can you tell which ones are human?)

Data or hypothesis?

- When you suck on a straw whose lower end is immersed in pop, the pop moves up the straw.
- When you drink pop through a straw, the pop moves up the straw to prevent a vacuum from forming, since nature abhors a vacuum.
- When you drink pop through a straw, you create a drop in air pressure in the straw, above the pop. The outside air pressure then pushes the pop up the straw.

Data or hypothesis?

- When magnesium is burned in air, it combines with oxygen in the air to form magnesium oxide.
- When magnesium is burned in air, it forms a white solid that is heavier than the original metal.
- When magnesium is burned in air, the phlogiston in the metal is driven off to leave a white ash.

What data are appealed to here?

- In the late 17th and early 18th centuries there were two competing theories of mechanics, the Cartesian and the Newtonian theories. The older Cartesian theory (developed by René Descartes) saw the universe as full of particles that interact only by colliding with each other. There was no vacuum on this account. Nor was there a gravitational force, as such. The motions of the planets around the sun were explained as the result of a vortex (whirlpool) of swirling fluid, with the rotating sun at the centre, like the whirlpool created when a bathtub is drained. The planets are swept around by this vortex, which explains why they all orbit the sun in (roughly) the same plane, and in the same direction. The earth has its own mini-vortex, which sweeps the moon in its orbit around the earth. The earth's vortex also explains, Descartes said, why heavy bodies fall to the earth when released, e.g. why apples fall from trees. (The tiny swirling particles of the vortex are forced outward by their rotation, and get pressed against the boundary with the sun's vortex. This pressure gradient forces large bodies like apples inward, towards the earth.)

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A hypothesis becomes data!

- Interestingly, the “motions of the planets around the sun” are treated as data here.

- Can one really *see* these motions?

- No. All one sees are dots of light moving through the constellations.
- This is itself a hypothesis (the Copernican hypothesis) but by the time of Descartes it was well established, and so treated as data.

Find the *theoretical* claims

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Hypotheses *explain* data

- Why do scientists bother with hypotheses? Why not just write down lots of data?

- Hypotheses describe how the world works. They describe causes, mechanisms, structures, etc. They *explain why* things happen the way they do.
- We like to know these things.

Hypotheses *predict* data

- The newer theory of Isaac Newton saw the universe as mostly empty, i.e. a vacuum. The planets orbit the sun due to the sun pulling on the planets, across millions of miles, by the force of gravity. Newton postulated that the gravitational force obeyed a simple mathematical formula, the 'inverse square law', and in this way mathematically predicted some aspects of their motions very accurately. (The Cartesians couldn't match this feat.) In particular, Newton derived Kepler's laws of planetary motion, which were well accepted by this time. On the other hand, Newton's laws did not entail that the planets will all orbit the sun in the same direction. Newton regarded this fact as resulting somehow from how the universe began, rather than from natural law. Newton explained the falling of apples using his force of gravity. (The earth has its own gravity, though it's much weaker than the sun's.)

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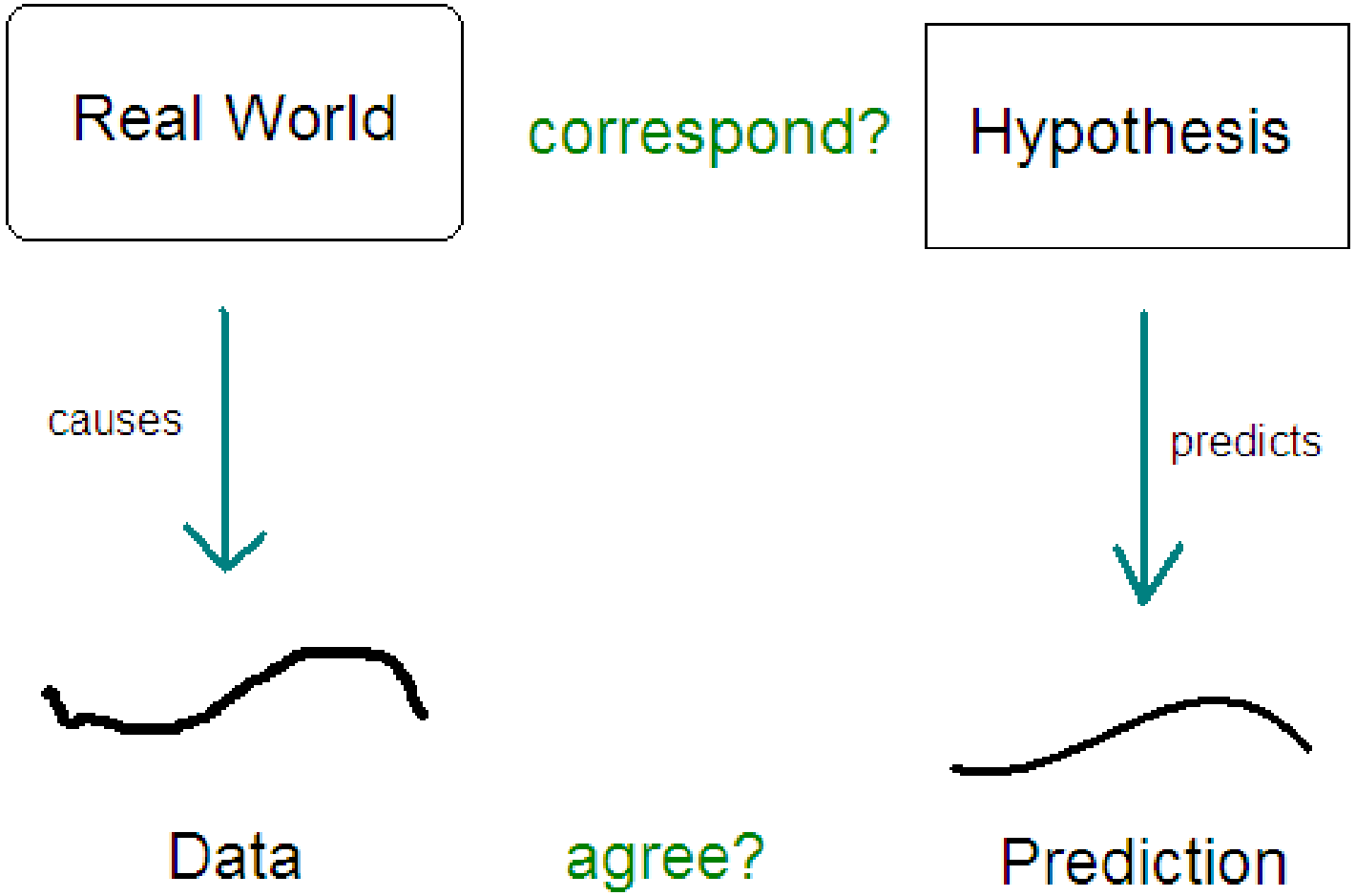
theoretical claim observed data prediction relation


Real World
correspond?
Hypothesis
causes
predicts
Data
agree?
Prediction

Why can't scientists just make stuff up?

- A hypothesis isn't considered "empirically adequate" unless its *predictions* match the real *data*.
- A hypothesis isn't considered to be a good explanation, or likely to be true, unless it is empirically adequate.

Alternative hypotheses

- Hypotheses are (almost) never certain, since it is always possible to think up alternative hypotheses to explain the available data.
  - The earth may really be flat, for example, but light rays curve near the earth's surface, causing the illusion of a round earth!
- How do we judge between competing hypotheses that predict the same data?