Science and its imitators

Astronomy 101
Syracuse University, Fall 2021
Walter Freeman

October 19, 2021

Announcements: change in course format

As you know, we have had to seriously curtail the amount of printing we do for your class.

This will impact the way we do homework, lecture, labs, and possibly even quizzes.

For **lab**:

- You should bring **paper** and a laptop or tablet to lab (if you have one)
- You can access the lab materials electronically or print copies for yourself
- You will need paper to keep notes
- You'll get a grade based on a conversation with the lab TA while you are at lab
- You won't need to turn anything in or do anything after your lab

Announcements: change in course format

For **homework**, we will likely post questions electronically (as a PDF); you will answer them on your own paper and turn them in as before.

We will replace the **in-class tutorials** with lots of A/B/C/D questions plus tutorials that I will lead (like we did for the first part of the energy exercises).

Quizzes may continue as we have been doing them if we can print that many sheets. We may also switch to Blackboard quizzes that you will do in the auditorium. We'll let you know well in advance of the next quiz.

Announcements: papers

Remember that your first paper is due today unless you have asked for and gotten an extension.

Turn in a paper copy to your TA's mailbox *and* email a copy to `suast101projects@gmail.com`. The emailed copy is for our enduring record; the paper copy is what we will grade.

The nature of science

The discoveries of Kepler, Galileo, and Newton did more than explain the solar system.

They merged disciplines that had been separate since the time of the Greeks:

- Natural philosophy: "what is the truth of Nature?" (truth-seeking)
- Astronomy: "Where can I find Mars next week?" (practical applications)

Newton brought us into the age of *astrophysics* – possibly the first true *science*. What's that mean?

Properties of science: a reminder

Broad properties of science:

- **Empiricism:** the ultimate authority is what we measure about the world around us, not what we think.
- It is vitally important that the conclusions we *claim* come from our data actually do
- There's a whole field of math dedicated to data analysis: *statistics*. It has to be done honestly and well!

- **Self-skepticism:** someone making a scientific claim should actively search for things that might prove themselves wrong
- Potentially refuting arguments/evidence are a *good* thing

- **Universality:** the laws of nature apply in all places and times, and to all things (including humans)
- Since the laws of nature are universal, they form a coherent whole
- Any new finding must find its place within the framework of preexisting measurements and principles
- Very rarely previously-accepted things get overturned; more often they are *extended*

- **Objectivity:** scientific ideas, or the evaluation of them, should be independent of any particular human perspective
- Science is not about *you* (whoever you are)
- Criticism of other people's ideas isn't about them, either

Properties of science, in our story

Science – as a means of seeking truth – has a few fundamental properties:

- **Empiricism:** the ultimate authority is what we measure about the world around us, not what we think.
- The new scientific approach to mechanics started with Kepler, Sophie, and Tycho's observations of the planets, observations made by Galileo and Newton, and then built from there
- This is different from the old Greek natural philosophy, that valued *pure thought* over the dirty work of *measuring things*

- **Self-skepticism:** someone making a scientific claim should actively search for things that might prove themselves wrong
- Kepler was convinced planetary orbits were circles and tried *very hard* to make circular orbits work... until the data convinced him otherwise
- Tycho did *not* do this: when he observed a lack of stellar parallax, he didn't consider the possibility that the stars might just be very far (250,000 AU) away

Properties of science, in our story

Science – as a means of seeking truth – has a few fundamental properties:

- **Universality:** the laws of nature apply in all places and times, and to all things (including humans)
- Newton's big idea: $F = ma$ explains all motion, in space and on Earth, in the same way
- This was different from the previous belief that matter on Earth worked one way, and matter in space worked a different way

- **Objectivity:** scientific ideas, or the evaluation of them, should be independent of any particular human perspective
- Earth was no longer given a privileged place or special rules
- Just because Galileo threatened a dominant religious/political paradigm doesn't make him wrong!
- Understanding the sky from many different places on Earth is critical to knowing how it works

Principles that come from these:

These things are difficult and many honest scientists (meaning: anyone who talks about the natural world) slip up. These principles are safeguards to protect us from being too convinced of things that are not true. But it is possible to be a good, honest scientist, and make mistakes.

Of course, it is also possible to be dishonest: to intentionally warp the process of science to convince people of things that are not true.

Principles that come from these:

Empiricism: A model is only valid within the realm of data against which it has been checked.

- Precision: is the law of gravity valid to one part in a billion? One part in a trillion?
  - "Equivalence" (all objects fall at the same rate in a vacuum): holds to one part in 10^{17}
  - Universal gravitation: **Not quite true in regions of strong gravity!**
  - Conservation of energy: seems absolutely solid, from fragments of an atom to black holes
- Scope and scale: Is Newtonian mechanics valid for very fast things? Things as large as a galaxy? Things as small as an atom?
  - Very fast things: **not quite**, since close to the speed of light space and time get mixed up
  - Very large things: Yes, things as large as galaxies and beyond (but this requires dark matter)
  - Very small things: **no**, since quantum mechanics changes definitions of "position"

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- Universality helps with this, but we have to be careful
  - We don't need to drop every rock off a cliff to understand projectile motion...
  - ... but it's hard to know exactly what limits we have to probe

Principles that come from these:

Self-skepticism: It's the duty of the claimer to search for experiments that they can do to possibly prove themselves wrong.

- "Neutrinos faster than light"
- The caution of LIGO after their Nobel Prize-winning discovery
- Particle physicists and their "one in a million" rule

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- The most powerful evidence for an idea is an experiment that will produce something unexpected if you're right, but can conclusively disprove your idea if you're wrong
- In 1917 Einstein proposed a radical new way of thinking about gravity
- ... and calculated from it two things, one of which could be tested the next time there was an eclipse
- If Einstein was wrong, we'd know it immediately.

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- These experiments need to be as diverse as possible: this is hard, since you have to check things you're not familiar with

There's an entire discipline of mathematics designed to, in an objective way, examine what results mean: statistics.

But it's only as honest as the people wielding it: `https://xkcd.com/882/`

Science: a powerful, corruptible tool

This synergistic enterprise has been behind a vast amount of progress for humanity in the last 350 years.

As with anything powerful, this process can be corrupted.

Your second paper will involve analyzing an incident where it has been.

Let's look at how that can happen.

Common fallacies

Please feel free to chime in with your own examples.

I'd like to spend much of the time today "off script" – talking about your examples, rather than my slides.

I'll also be steering clear of any topics that are "hot-button". Feel free to write about these in your papers! But I won't be using them as examples here: climate change, creationism, vaccination, drug laws...

Two notes

"Scientific integrity" is not a reference to the usual sort of integrity – to being a good, honest person.

It is possible to do horrible things in the process of research, but do research that is well-grounded and draws correct conclusions.

It is also possible to be an honest, diligent scientist and make mistakes, and come to incorrect conclusions because of flaws in the application of the scientific process. (I have done this myself.)

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There is a difference between a flawed process of science and simply being wrong. We aren't talking about math errors or physics mistakes here. But a sound process of science catches its own mistakes through self-skepticism and transparency.

There is a difference between a flawed process of science and being a terrible person, too. We aren't talking about experiments that hurt their subjects, either.

Cherry-picking and biased data

One example of how this goes wrong: **cherry-picking.**

A strict definition: **Using limited, biased data that will give you a biased result**, accidentally or intentionally

Example: the "fifth force", a proposed modification to $F_g = \frac{GMm}{r^2}$

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of the gravitational force nearby to analyze them

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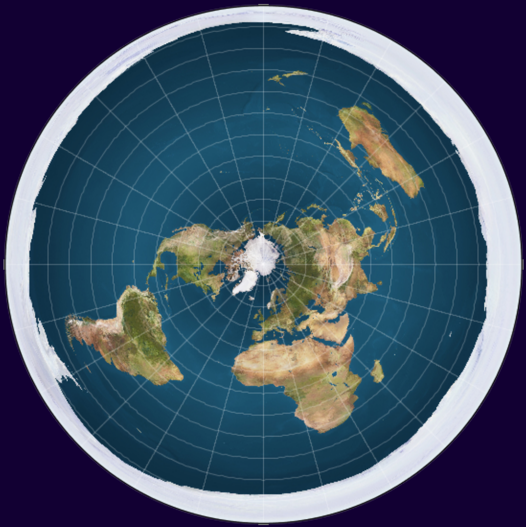
- Once this was realized and corrected, the signal went away
- Nobody meant to deceive anyone here

Cherry-picking, examples



PeteSvarrior, for the Flat Earth Wiki; cc-by-sa.

Here's a map of a flat earth from the Flat Earth Wiki (ugh).

The distances are more or less right for the Northern Hemisphere...

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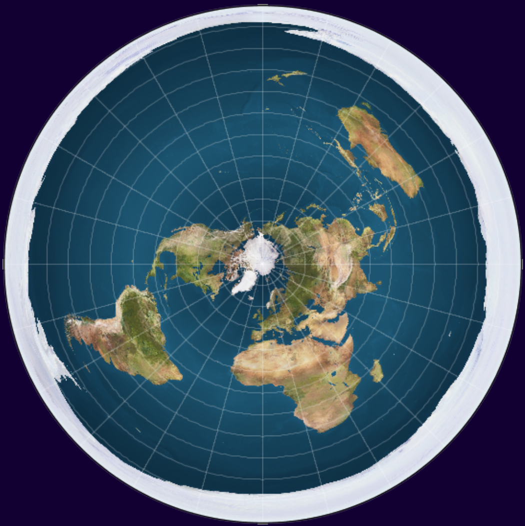


PeteSvarrior, for the Flat Earth Wiki; cc-by-sa.

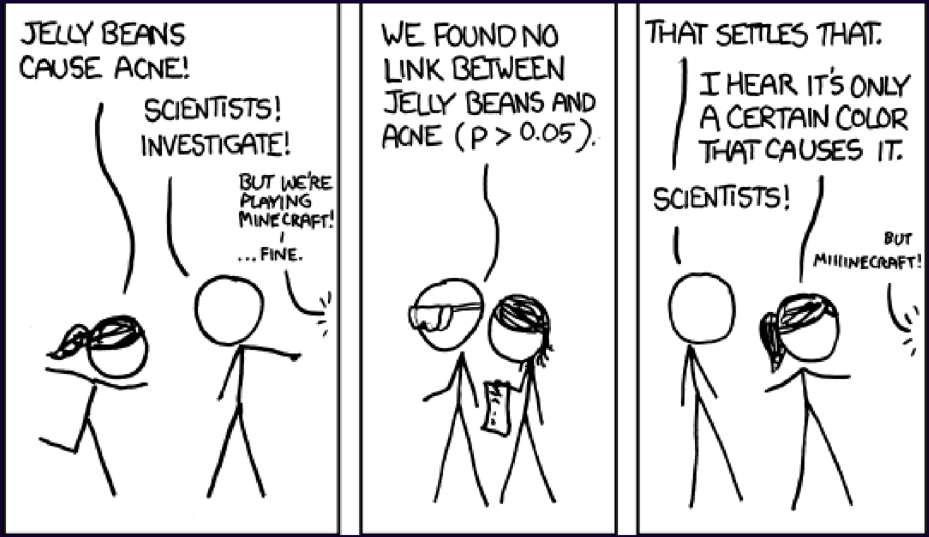
Here's a map of a flat earth from the Flat Earth Wiki (ugh).

The distances are more or less right for the Northern Hemisphere...

They're completely absurd for the Southern Hemisphere!

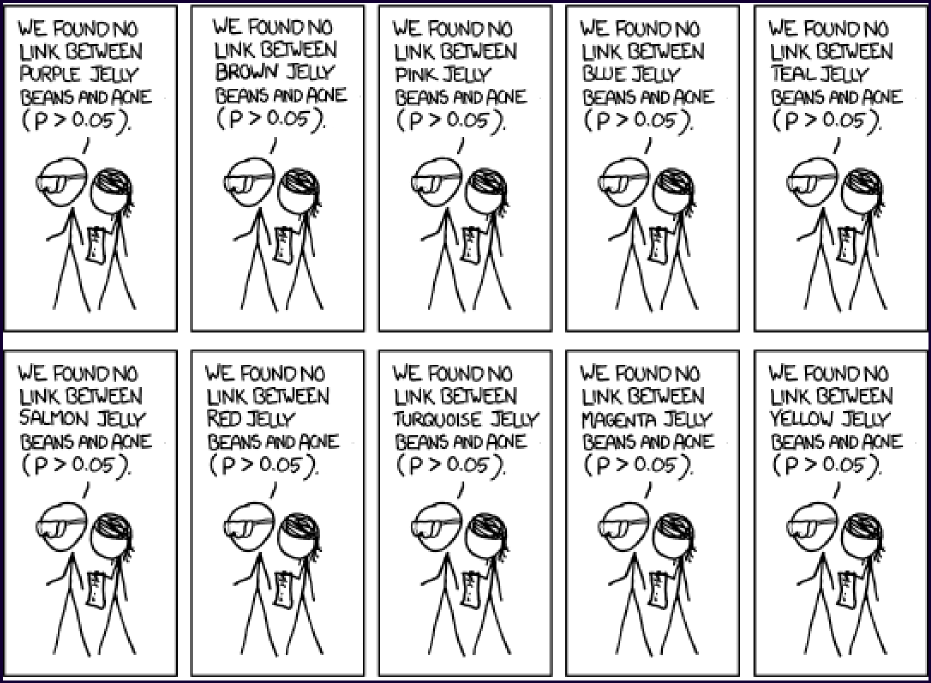
Clearly no Flat Earthers asked any Argentinians how far it was to New Zealand...

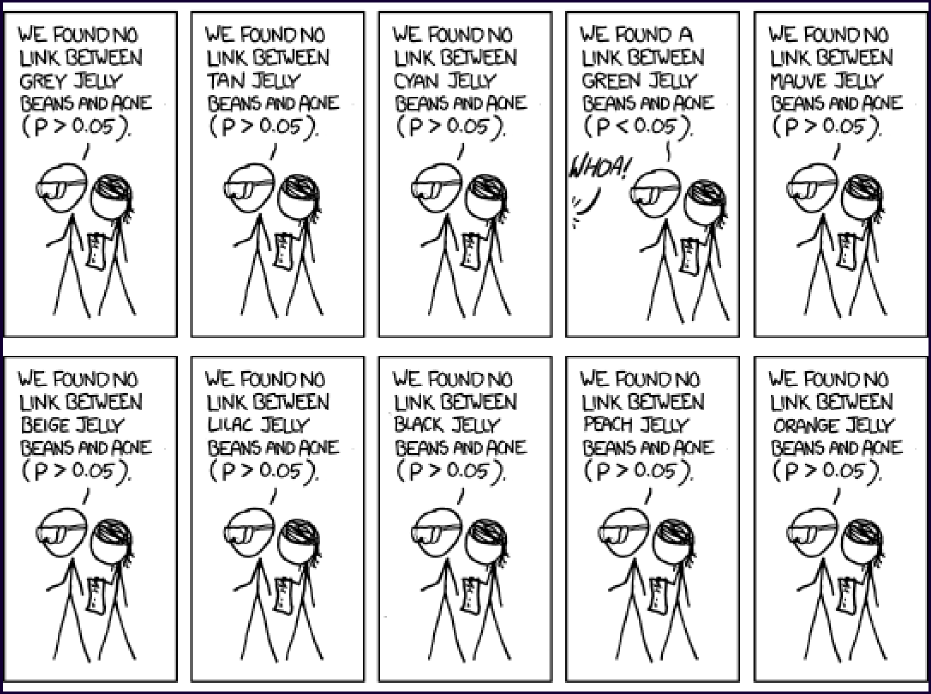
Cherry-picking, examples: reporting bias



$p > 0.05$: "whatever we found, there's more than a 5% chance that it is just a coincidence"

Cherry-picking, examples: reporting bias




WE FOUND NO LINK BETWEEN GREY JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN TAN JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN CYAN JELLY BEANS AND ACNE (P > 0.05).
WE FOUND A LINK BETWEEN GREEN JELLY BEANS AND ACNE (P < 0.05).
WHOA!
WE FOUND NO LINK BETWEEN MAUVE JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN BEIGE JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN LILAC JELLY BEANS AND ACNE (P > 0.05).
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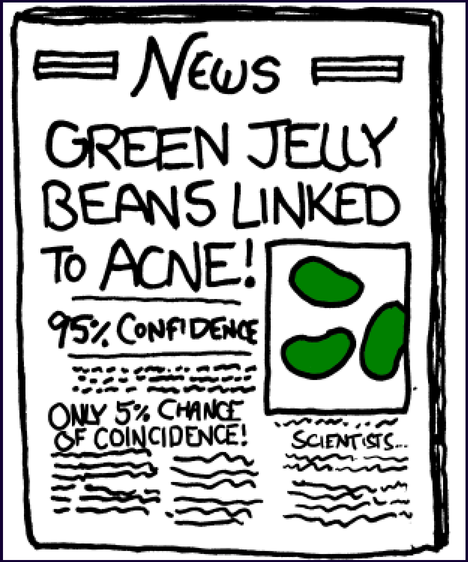

xkcd #882, by Randall Munroe: cc-by-nc.

Laundering data through statistics: dangerous!

Reporting only an interesting/profitable/exciting piece of data, and ignoring the rest, leads to flawed conclusions!

This is particularly worrying in medical research.

Other sorts of biased data

The US Army Air Forces bombed Nazi Germany using large aircraft during World War II.

Many aircraft were hit by enemy fire but returned to airfields in England.

A B-17 "Flying Fortress" that nearly lost its tail after a collision with a German fighter. This aircraft, still able to fly, returned to an Allied airfield in Algeria with no crew injured, including the tail gunner!

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The USAAF did an assessment of these aircraft to see where they were being hit: on the fuselage, on the wings, on the tail, but not in the engines or the nose.

Should the USAAF add extra armor to...

- A: The locations where the returning aircraft had been hit
- B: The locations where the returning aircraft had *not* been hit
- C: All locations on the aircraft equally?

Do you have any favorite examples of biased data causing flawed conclusions?

Common fallacies: ad hominem arguments

An ad hominem argument is one that condemns someone else's argument because of *who* they are, not the content of their logic.

A few types (paraphrased):

Conspiracy-type reasoning (false allegations of ulterior motives):

- "NASA faked the moon landings because they wanted to cover up the fact that their rockets didn't work"
- "The anti-smoking campaign is there to make money, and also something something Nazis" (`http://www.smokingaloud.com`)
- "They just *say* that fluoride helps dental health but it's really a Communist plot"

Arguments based on status or identity:

- "That person is an esteemed expert; we must trust them without question!"
  - Four out of five dentists recommend such-and-such brand of toothpaste...
- "That person is a nobody; how could they have any good ideas?"
- "That person is a member of race/religion/gender/political party XYZ, how could they have anything right to say?"

Ad hominem arguments

Ad hominem (Latin: "against the person") arguments fail the scientific standard of *objectivity*: claims should be evaluated based on data and logic, not on who is making them.

False claims of ulterior motives are a common sort of *ad hominem* attack.

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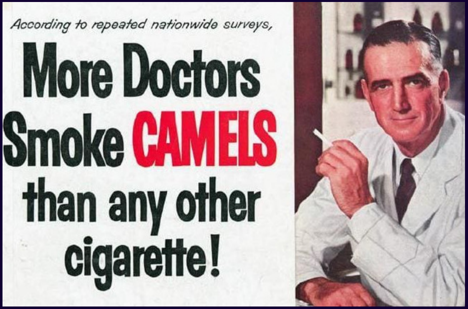
False claims of ulterior motives are a common sort of *ad hominem* attack.

... and using "argument from authority" is the reverse: well, if these doctors say that they smoke Camels, they must be safe... right?

Sometimes deliberately deceptive people really *do* have ulterior motives. This can be a warning sign that someone is being deceptive...



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"[A]fter the rocket quits our air and really starts on its longer journey, its flight would be neither accelerated nor maintained by the explosion of the charges it then might have left. To claim that it would be is to deny a fundamental law of dynamics, and only Dr. Einstein and his chosen dozen, so few and fit, are licensed to do that.... That Professor Goddard, with his "chair" in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action and reaction [Newton's third law], and of the need to have something better than a vacuum against which to [push] – to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools."

–*The New York Times*, 1920

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–*The New York Times*, 1920

"*Further investigation and experimentation have confirmed the findings of Isaac Newton in the 17th Century and it is now definitely established that a rocket can function in a vacuum as well as in an atmosphere. The* Times *regrets the error."*

–*The New York Times*, 1969

Ignoring refuting evidence

Self-skepticism is a hallmark of sound science. Good scientists report:

- Any experimental evidence that might conflict with their proposal
- All of the possible flaws that *they* thought of in their claim
  - ... and how they considered them
- Any tests that anyone *else* could do to try to disprove them
- All the things that make them uncertain about their result
- The limits of their conclusions

Most good scientific writing spends much of its time doing the above. You should only try to convince other people you are right once you have tried very hard, yet failed, to prove yourself wrong.

Any claimant that spends most of their time talking *up* their conclusions is likely suspect.

Ignoring potentially refuting evidence

Ignoring or failing to search for refuting evidence is a common trait of faulty scientific process. This can either be:

- Ignoring refuting evidence altogether, even if it's widely known
- Dismissing refuting evidence out of hand, without considering it in any real way
- Failing to think of potentially refuting evidence and search for it

Do you have any favorite examples of flawed scientific claims that fail to address potentially refuting evidence?

`https://wiki.tfes.org/Flat_Earth_-_Frequently_Asked_Questions`

Manufacturing a controversy

We've discussed some of the common features of people *advancing scientific claims* incorrectly, negligently, or dishonestly.

Sometimes dishonest people aren't trying to *advance* something they know to be false, though.

They're more interested in convincing people to *reject* something that is true.

To do that, they only need to create doubt. This is commonly done by *manufacturing a controversy*.

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(This is a common tactic to erode trust in *anything*, not just science – common in politics and negative advertising)

Manufacturing a controversy

Do you have any favorite examples of manufactured controversies?

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Consider again the tobacco industry:

- "Secondhand smoke doesn't cause health problems; those studies are wrong"
- "Are you really sure that secondhand smoke causes health problems? Maybe it was building ventilation!"

One of these is a far easier sell than the other!

The industry's strategy does not require winning the debates it manufactures. It is enough to foster and perpetuate the illusion of controversy in order to muddy the waters around scientific findings that threaten the industry. Thus it offers reassurance to smokers, helping them to rationalize and repress their health concerns. Furthermore, claims of "not proven" resonate with friendly or naive journalists and governments, and provide an excuse for not taking strong governmental or societal action against tobacco.

–Yussuf Saloojee and Elif Dagli, "Tobacco industry tactics for resisting public policy on health" Bull. World Health Organ. 78(7): Genebra, July 2000.

Sensationalism

Two things are both true:

- Some scientific findings can dramatically change our lives and our perspective on the world, and are compelling and exciting
- Whether a scientific claim is true or not doesn't depend on whether it's exciting or not (objectivity)

Scientists thus have twin duties:

- They should engage with society in sharing the excitement and interest of their findings. Science communication is vital (and many of us are bad at it; the astronomers do better than the physicists!)
- They should separate this excitement from the task of evaluating the validity of claims

Sensationalism

Beware of any sort of scientific claim that conflates the evidence that it is true with why you should be excited by it, or that seems to be hyped by its claimant.

Good scientists do hold press conferences, because many discoveries are exciting!

But these happen only in the context of:

- a vast amount of self-skepticism applied to their results first
- objective, sober presentation of the *evidence* for their conclusions

Science vs. pseudoscience

Often people adopt the trappings of science to give nonscientific ideas a veneer of validity. This is called "pseudoscience" – fake science.

Science

- Universal models
- Natural principles
- Testable predictions
- Not anthropocentric
- Replicable results
- Self-skepticism

Pseudoscience

- Singular events
- Supernatural explanations
- Untestable predictions
- Different rules for people
- Results defy replication
- Self-promotion