Recognizing pseudoscience

Physics 211
Syracuse University, Physics 211 Spring 2019
Walter Freeman

April 11, 2019

Announcements

Today's class is an interlude, designed to ensure you're prepared for the paper.

We'll also discuss Exam 3 and the exciting new black hole image!

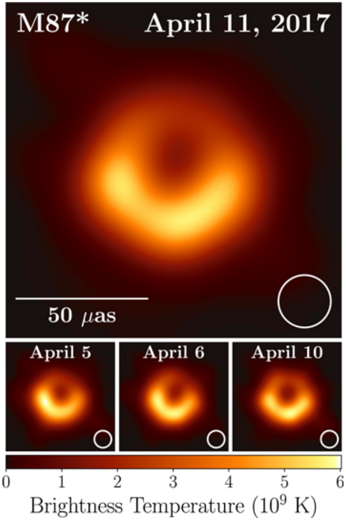

Image of the black hole seen by the Event Horizon Telescope – a telescope the size of Earth!

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- The tumbling spaceship short answer problem is just the demo we did in class, with the person on the spinning platform – except, instead of starting at rest, the spinning object ends at rest.
- The "show me how conservation of momentum and the work-energy theorem come from Newton's laws" problems were direct copies of problems from recitation.
  - Often students don't take "Explain..." or "Discuss..." problems as seriously as "Calculate..." ones during recitation and on homework
  - This is a mistake; these are often some of the most crucial to actually *understanding* the physics

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However, since people found this material challenging and the content of the exam unexpected, we're going to give you a second shot:

- The final exam won't be truly "comprehensive".
- Instead, the distribution of material will be something like:
  - Unit 4 (torque and rotational dynamics): 50%
  - Unit 3 (conservation of momentum and energy): 35%
  - A mix of other topics: 15%

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- We will look at your grade separately on the Unit 3 material, and based on how well you do on it, will give you points back on Exam 3:
  - If you do better on the momentum/energy material on the final than you did on Exam 3, your Exam 3 grade will go up
  - If you don't do better on that material on the final than you did on Exam 3, then nothing else happens (i.e. this can't hurt you).

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- We'll determine how to calculate this once we see the Exam 3 grades. (We decided to do this just a few hours ago.)

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This exam was hard. We didn't expect you to have had such a rough time with it, and it sounds like many of you had trouble with the focus on conceptual understanding rather than calculation.

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Also remember: **regardless** of your grades, we support you. If you need support or assistance, whether that's with our subject or with anything else at Syracuse, we're on your side no matter what.

Black holes

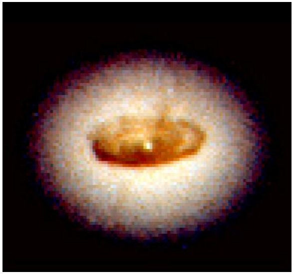
A black hole is a place where matter is so dense that its gravity becomes strong enough that light can't escape.

The black hole is surrounded by a boundary called the *event horizon*, which delinates the region from which light can't escape.

Anything that gets near a black hole orbits it, like the planets orbit the Sun. But:

- Friction between these bits of dust does negative work on them, reducing their velocity
- This reduces their kinetic energy, so gravity pulls them closer to the black hole
- This does positive work on them (see our exam!), speeding them back up.
- As they get closer and closer, they get hotter and hotter, and glow brighter and brighter

The event horizon can be surrounded by a glowing disk of gas at millions of degrees.



(Hubble image of a very bright accretion disk)

(Artist's rendering, if the BH didn't bend its own light)

Black holes

There are two types of black holes:

- Ones that form from the dead cores of huge stars (mass of a few times that of our Sun)
- Ones that form from the junk that falls to the center of a galaxy (mass billions of times larger)

This recent image is of a supermassive black hole around 50 million light years away, at the core of a galaxy called M87.

This is exciting because it's an image of the *actual event horizon*, not just the *accretion disk*.

Interferometry

The smallest angular size you can make out in a picture is given by:

$$\theta = \frac{\text{wavelength of light}}{(\text{size of lens})}$$

So, to get a detailed picture, you need to measure very short wavelengths with a very big aperture (lens/mirror size).

Your "aperture" is just the region over which you can correlate the *phase* (whether a wave is going up or down at any given time) at different points.

If you can do that by another means (by making a machine that detects phase as well as the presence of light), you can count different observing stations as part of the same aperture.

This process is called "interferometry" or "synthetic aperture imaging".

Interferometry

This gets harder as the frequency goes up, since the wave switches from "up" to "down" faster.

Also: frequency is inversely proportional to wavelength.

Remember that we need a combination of *large aperture* and *short wavelength* (meaning high frequency) to get a detailed picture.

The Very Large Array, a synthetic aperture radio "telescope", in New Mexico. The telescopes are on railroad tracks to allow operators to customize the aperture shape.

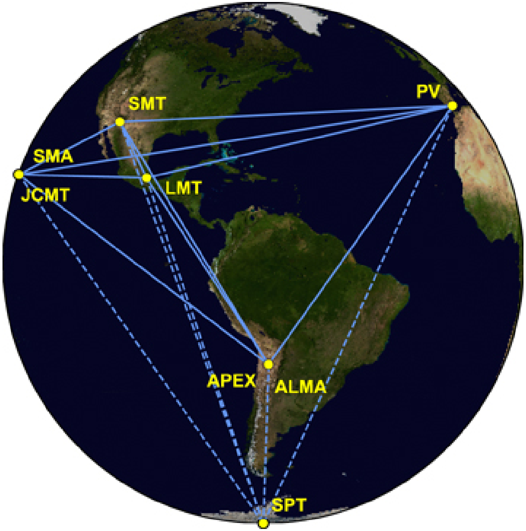
The problem:

- The very shortest wavelengths (x-rays, γ-rays) don't bend in lenses or bounce off mirrors well
- Mid-range wavelengths (like light) are long enough that it's hard to make a clear picture without a physically huge aperture, but have frequencies too fast to do interferometry
- Radio waves have a slow enough frequency to do interferometry, but have too long of a wavelength to get a clear picture even with an enormous synthetic aperture

The Event Horizon Telescope

The solution, allowing the Event Horizon Telescope to observe extremely fine detail: (Remember: we want a large aperture and short wavelength/high frequency)

- Combine data from radio telescopes across the hemisphere
- This gives an enormous synthetic aperture
- Develop very accurate ways to measure and correlate phase over long distances (timing equipment)
- Measure at very high frequencies (a few thousand times FM radio)
- You now have a radio telescope the size of Earth, measuring very short wavelengths

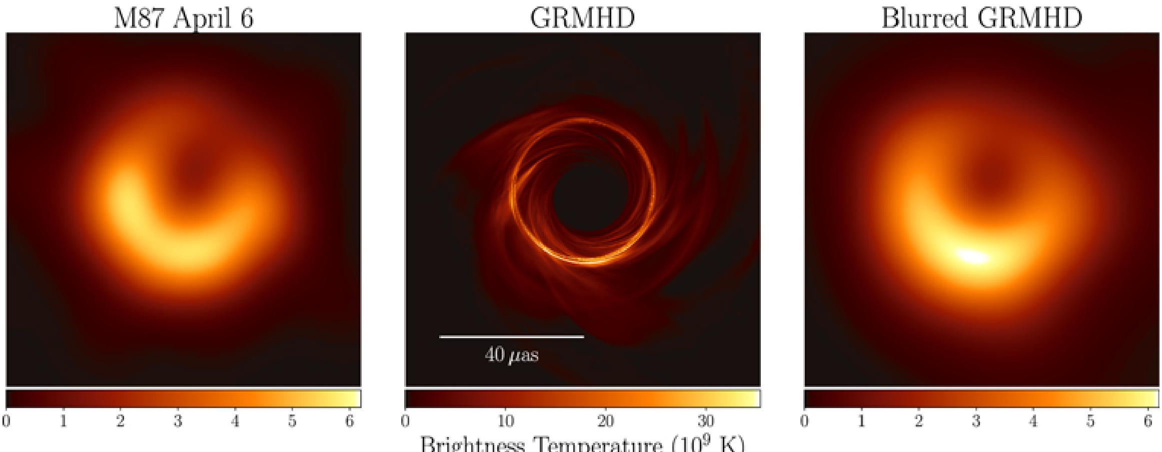


The Event Horizon Telescope

Since this is a synthetic aperture, doing the data processing is hard.

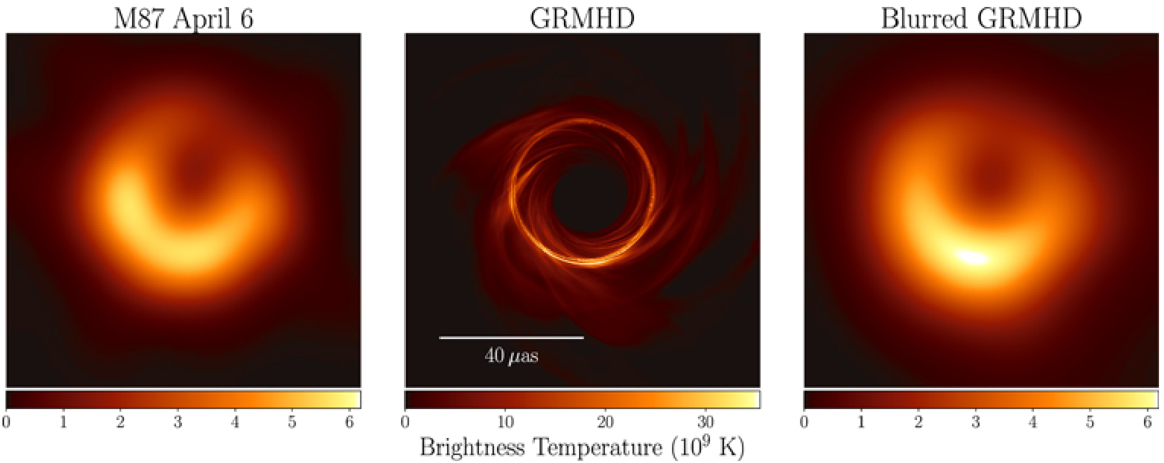
Imagine using a camera with the whole lens blacked out, except for a few tiny pinholes, and that's constantly spinning!

Some very clever folks had to develop new math and algorithms for image analysis and reconstruction to do this... but here's the result:



(Left: Image from the Event Horizon Telescope. Center: Simulation of what it would look like. Right: The simulation, blurred to match the resolution of the EHT.)

Why this is a big deal



We've never seen a black hole before.

The light coming from the region near the event horizon is bent by the gravity of the black hole itself. (This is why the central region is black.)

This gives us a picture of both the gas falling into a black hole, *and the gravity around a black hole.*

Recognizing pseudoscience/flawed science: overview

Previously, we had a class devoted to the properties of science. We studied:

- The broad traits of good science that make it such a powerful way to learn about our world
- An example of what those traits look like
- An example of what it looks like when they go awry in one specific case: cherry-picking

Today we'll discuss, specifically, how this goes wrong. We'll look at other flaws and abuses of the scientific process and how to recognize them, and discuss ideas for your papers.

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. (Examples?)

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.

Properties of science

Broad properties of science as a means of seeking truth:

- **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

First, some definitions

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- **Deliberate deception:** a claim made by someone who knows it is false, but who uses scientific language and trappings to lie more convincingly.
  - Examples: tobacco/cancer denialism; "scientific racism"...
- **Honest mistakes:** a claim made by someone believing it is true, following what they believe to be sound logic, but making an honest error that leads them to a false conclusion.
  - Examples: The US Army survey of aircraft damage

Common fallacies

Let's explore some common ways that these principles get violated. This isn't an exhaustive list!

Please feel free to chime in (in person or on Slack) with your own examples. We'll be going back over the Slack logs from class today; people making suggestions will get extra credit on Exam 3.

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...

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.

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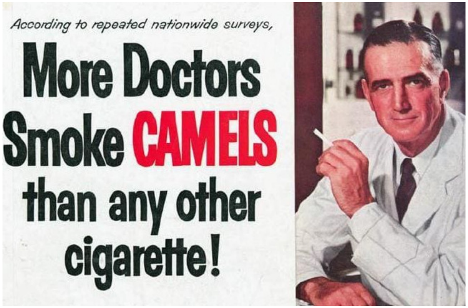
... and using "argument from authority" is the reverse: well, if these doctors say that they smoke Camels, they must be safe... right?

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



Ad hominem arguments

Do you have any favorite examples of *ad hominem* arguments being used to support flawed scientific claims?

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–*The New York Times*, 1920

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"*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

Statistical dishonesty

Statistics is the mathematical discipline that lets us turn empirical data into conclusions.

It lets us turn a collection of "maybes" and "probablys" and "unlikelys" into "almost certainlys".

Statistics is immensely powerful. But:

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- It is a subtle, complex field of math (you can get PhD's in it)
- It is a lot of work and only someone intimately familiar with data is really equipped to analyze it
- It is absolutely essential if science is going to look to empirical data as the highest authority

A great many flawed scientific processes come down to flawed statistics. Some common statistical fallacies:

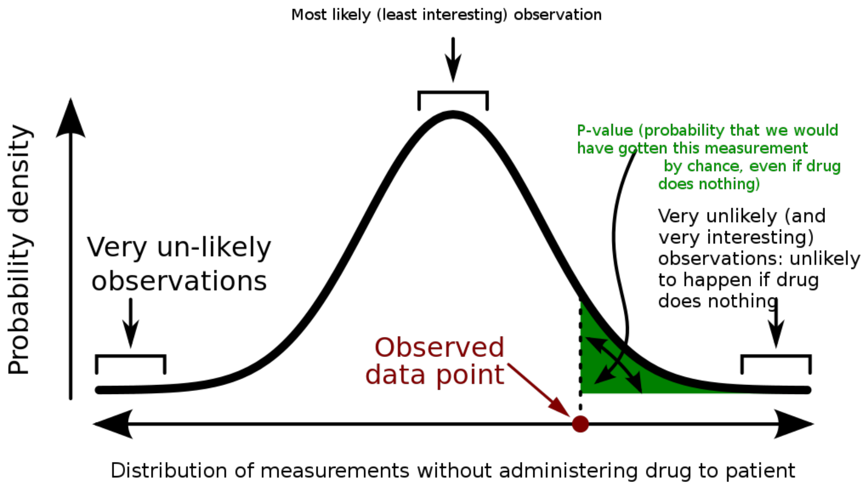
- "Garbage in, garbage out": flawed, stinky data $\rightarrow$ statistical analysis $\rightarrow$ incorrect but nonstinky conclusions!
- Correlation implies causation
- Incorrect use of statistical inference (statistics is hard)
- Some types of cherry-picking:
  - "P-hacking"
  - Publication bias

Statistical inference done honestly

Suppose we want to test if a new drug (or a chemical in food) has any effect.

Correct thing to do:

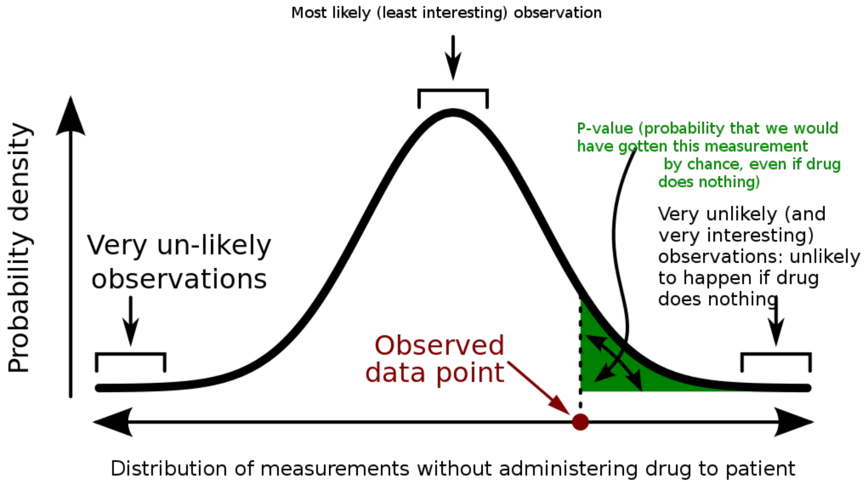
- Make lots of measurements of how people react to the drug
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
- Get excited if their average is very different from the center of the curve (maybe drug made that happen?)
  - (Statistics gives us tools to quantify "very different")



Statistical inference gone wrong, I: cherry-picking

Classic cherry-picking:

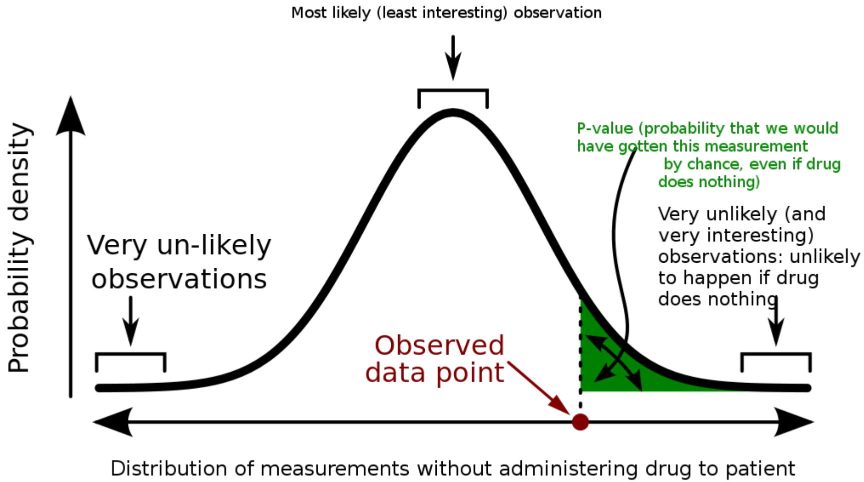
- Make lots of measurements of how people react to the drug
- Forget about the ones close to the center (they are boring!)
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
- Even if the drug does nothing, you'll get a distribution looking like the green portion
- Notice that their average is very different, get excited!



Statistical inference gone wrong, II: biased data

Biased data (the survivorship bias from Exam 2 is an example):

- Make lots of measurements of how people react to the drug
- Fail to measure the ones on the left-hand side (they're dead)
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
- We removed the left-hand side, so the average shifts right
- Notice that their average is very different, get excited!



Statistical inference gone wrong, III: publication bias

If the measurements are entire *studies*, we often unintentionally cherry-pick them in *meta-analyses* (studies averaging many studies together)

- Different scientists do experiments on how people react to the drug
- Nobody publishes the ones close to the center (they're boring, back to the drawing board!)
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
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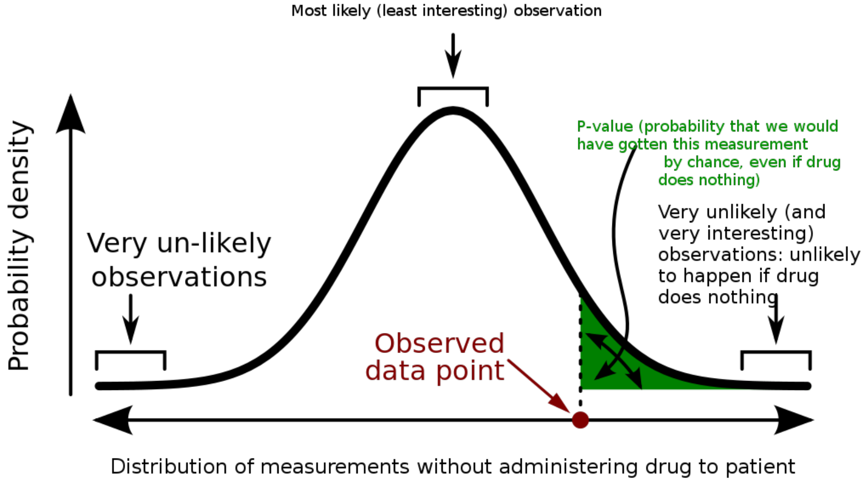

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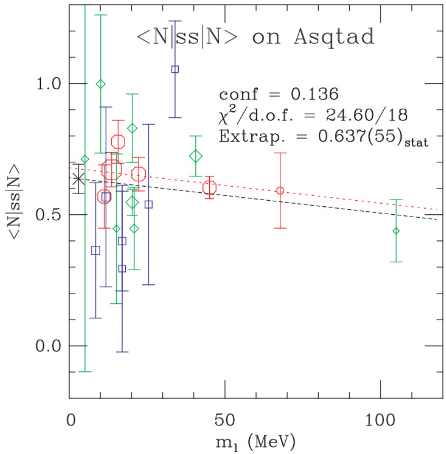
The above example about drug studies is real: publication bias is a serious problem in drug development! (See `https://www.nejm.org/doi/full/10.1056/NEJMsa065779`)

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?

(Post to Slack for extra credit)

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

Ignoring the rest of science: "island claims"

Natural laws are universal: the laws of physics are the same everywhere and at all times.

This means that a new idea doesn't just have to fit together with the evidence used to support it, and a few bits of potentially refuting evidence.

It has to play nice with **all** other data, from centuries of experience.

If you're proposing a new fundamental law of physics, it has to get along with everyone else.

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- We see nuclear reactions that don't seem to conserve momentum; what happened?

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It has to play nice with **all** other data, from centuries of experience.

If you’re proposing a new fundamental law of physics, it has to get along with everyone else.

- We see nuclear reactions that don’t seem to conserve momentum; what happened?
- The following things are mutually inconsistent; what do we do?

Ignoring the rest of science: "island claims"

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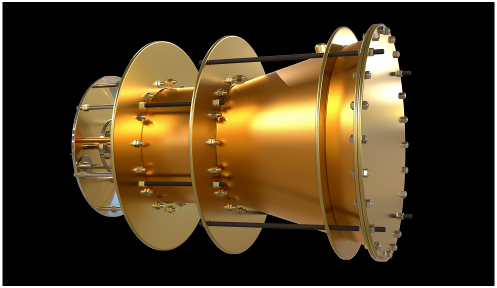
- The following things are mutually inconsistent; what do we do?
  - Electromagnetism (very well tested in the lab)
  - The independence of space and time
  - A universe that fundamentally makes sense (we all agree on how things will happen, etc.)

Ignoring the rest of science: “island claims”

If you’re proposing a new machine, then there needs to be a plausible explanation for how it works.



“The EM-Drive”, not actually a rocket engine

People claimed this is a rocket motor that uses no fuel (reaction mass), only an energy source.

They acknowledged that it seemed to violate Newton’s third law / the conservation of momentum, but had no explanation for how it actually *did* work. But they claimed it produced a tiny fraction of a newton of thrust.

(It didn’t. It was interference between the machine and the measuring equipment. It’s hard to measure a tiny force on a huge thing in the context of lots of microwaves.)

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

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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

Now let's talk about that black hole :)
`https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT`
`https://arxiv.org/abs/1802.05783`