Science and its imitators

Astronomy 101
Syracuse University, Fall 2018
Walter Freeman

October 18, 2018

"[T]he imagination of nature is far, far greater than the imagination of man (sic). For instance, how much more remarkable it is for us to be stuck – half of us upside down – by a mysterious attraction, to a spinning ball that has been swinging in space for billions of years, than to be carried on the back of an elephant supported on a tortoise swimming in a bottomless sea.

For instance, I stand at the seashore, alone, and start to think.

There are the rushing waves, mountains of molecules, each stupidly minding its own business, trillions apart, yet forming white surf in unison.

Ages on ages, before any eyes could see, year after year, thunderously pounding the shore as now.

For whom, for what? On a dead planet, with no life to entertain.

Never at rest, tortured by energy, wasted prodigiously by the sun, poured into space. A mite makes the sea roar.

Deep in the sea, all molecules repeat the patterns of one another till complex new ones are formed. They make others like themselves, and a new dance starts.

Growing in size and complexity: living things, masses of atoms, DNA, protein... dancing a pattern ever more intricate.

Out of the cradle onto the dry land, here it is standing: atoms with consciousness, matter with curiosity.

Stands at the sea, wonders at wondering: I, a universe of atoms, an atom in the universe."

–Richard Feynman (again), from *The Value of Science* (1955)

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- Lab 6 prelab will be finished tonight and posted, and put in the Clinic
- Paper 2 will be assigned today

Paper 2

You have two options for this paper:

- Scientific ethics: write about a case where scientific ethics ran off the rails, or an issue where scientific inquiry must navigate an ethical minefield

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- Archaeoastronomy: write about the astronomical practice of a historical culture of your choice

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)

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- Truth in precision
- Synergy between truth-seeking and practical observation
- Synergy between theory and experiment
  - Theory: "Use things we've already observed to design a model"
  - Exp't: "Carefully choose observations to make to inform/test models"

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- Body of supporting evidence grows
- Continually seek to expand the *scope* of the model with more observations

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- What about gravity very close to big things?
  - Scope of Newton's gravity had to be modified
  - Newtonian gravity only right for small accelerations
  - Einstein: "I think I have a new model"
  - Newtonian gravity still correct within its scope

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- Scientific explanations are not anthropocentric – they don't give humans (or Earth) a special role

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The natural, non-anthropocentric view *does* influence our outlook, though...

Scientific integrity

"But this long history of learning how not to fool ourselves–of having utter scientific integrity–is, I'm sorry to say, something that we haven't specifically included in any particular course that I know of. We just hope you've caught on by osmosis.
The first principle is that you must not fool yourself–and you are the easiest person to fool. So you have to be very careful about that. After you've not fooled yourself, it's easy not to fool other scientists. You just have to be honest in a conventional way after that.

...

I'm talking about a specific, extra type of integrity that is not lying, but bending over backwards to show how you are maybe wrong, that you ought to have when acting as a scientist.

...

One example of the principle is this: If you've made up your mind to test a theory, or you want to explain some idea, you should always decide to publish it whichever way it comes out. If we only publish results of a certain kind, we can make the argument look good. We must publish both kinds of results."

–Feynman, commencement address at Caltech, 1974

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 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:

- Confirmation bias / placebo effect
- Ulterior motives: young-earth creationism, climate science, politicization
- Profit motive: vaccines causing autism
- Publication bias (jellybeans!)
- Artificially limited scope (some psych studies)

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

What would you like to talk about?

- Astrology
- Economics and integrity
- Ghosts and such
- Homeopathy vs. desensitization therapy
- Climate change
- Genetically-modified crops and statistics
- Vaccination
- ESP / telepathy
- Exterrestrial life
- Radioactive medicine
- Drug testing
- Medical marijuana
- Scientific integrity more broadly
- Something else...

"Our time is distinguished by wonderful achievements in the fields of scientific understanding and the technical application of those insights. Who would not be cheered by this? But let us not forget that human knowledge and skills alone cannot lead humanity to a happy and dignified life. Humanity has every reason to place the proclaimers of high moral standards and values above the discoverers of objective truth. What humanity owes to personalities like Buddha, Moses, and Jesus ranks for me higher than all the achievements of the enquiring and constructive mind. What [they] have given us we must guard and try to keep alive with all our strength if humanity is not to lose its dignity, the security of its existence, and its joy in living."

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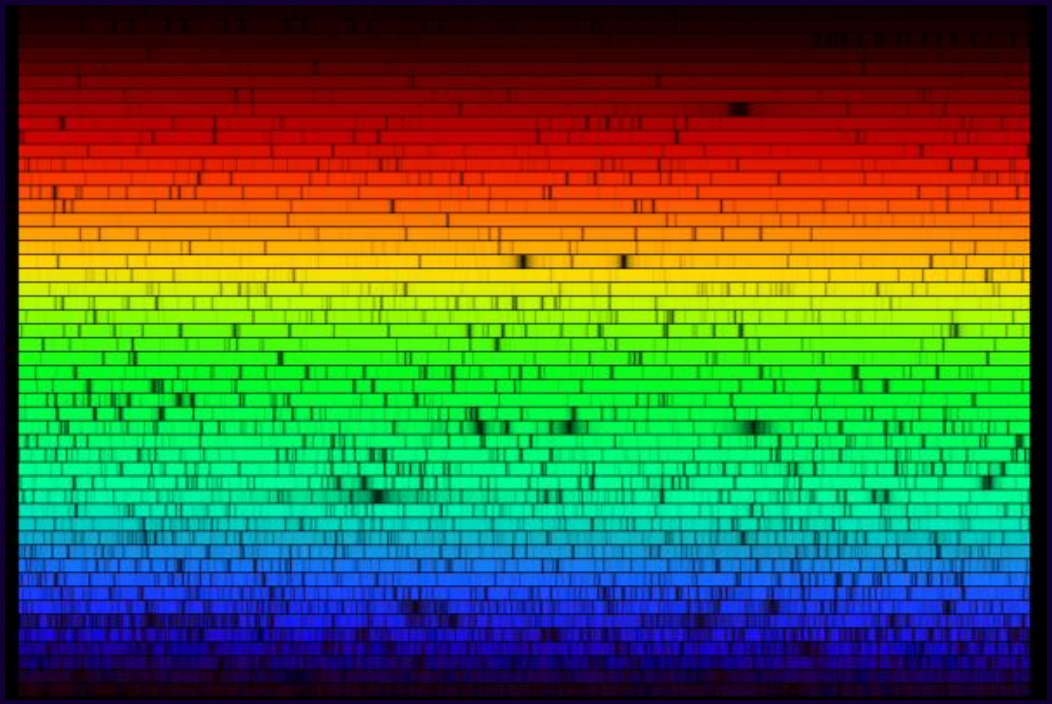
"Tell your son to stop trying to fill your head with science, for to fill your heart with love is enough!"

–Richard Feynman, 1981



This is a “picture” of the Sun. What can we learn from it?

How much of the light in this room can you see?

A: All of it
B: Most of it
C: Around a quarter of it
D: Not much of it at all

How much of the sound in this room can you hear?

A: All of it
B: Most of it
C: Around a quarter of it
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Sounds can have a spectrum of frequencies and wavelengths, and we can only perceive a piece of that spectrum.

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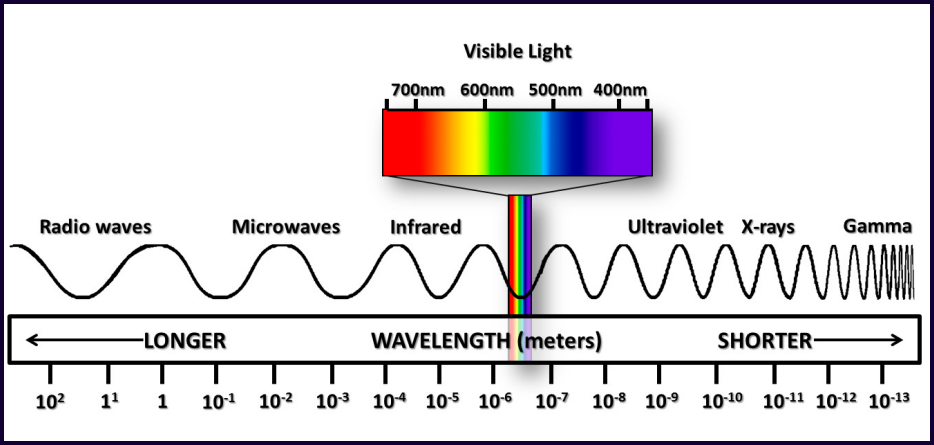
In the same way *light* has a spectrum of frequencies/wavelengths, and our eyes only perceive a tiny fraction of that spectrum.
When we say "light", we mean *all* wavelengths, not just the ones we can see!

The electromagnetic spectrum



There is an enormous range of “colors” of light out there!

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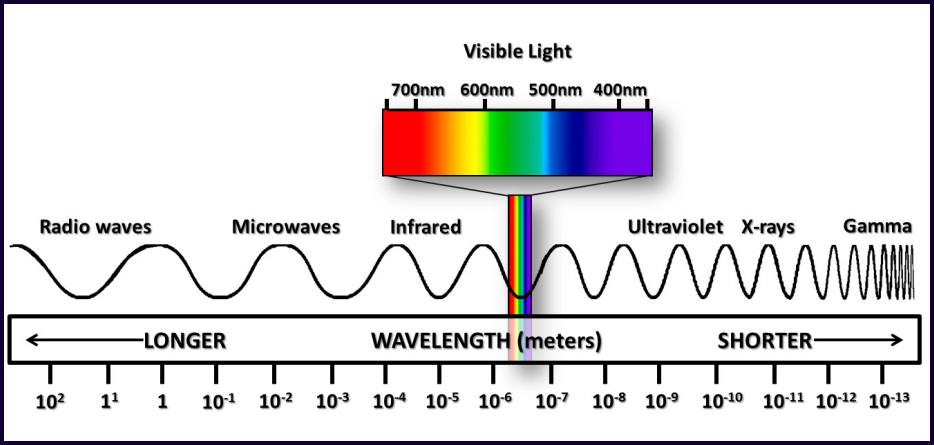

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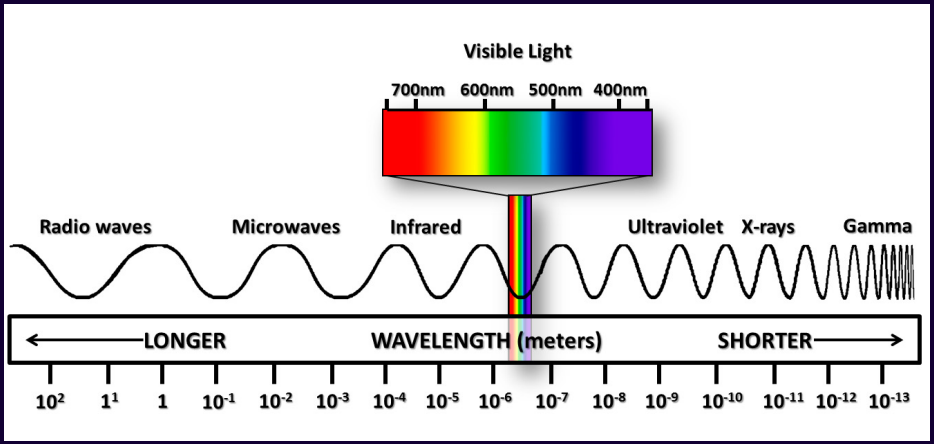

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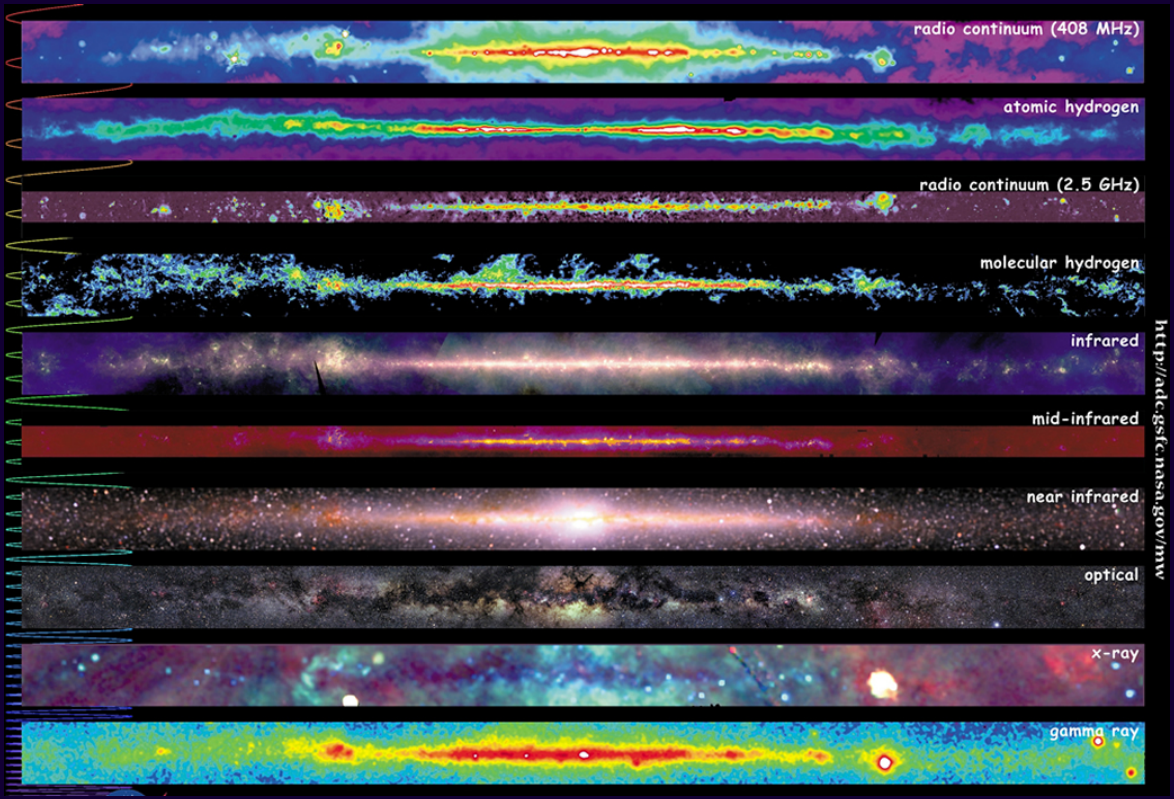
We can learn far more about what's going on in the orchestra if we have the whole spectrum, rather than just a piece!


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw

An illuminating story

In the late 19th century, the laws of electromagnetism looked like this:

- Electric fields exert a force on electric charges
- Magnetic fields exert a force on *moving* electric charges

We know this thanks in large part to the work of Michael Faraday, who famously wasn't good at algebra and drew pictures of fields.

Where do these fields come from?

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- ... which makes a magnetic field ...
- ... which makes an electric field further away ...
- This leads to a traveling electromagnetic disturbance: an *electromagnetic wave*.

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Maxwell calculated that these electromagnetic waves traveled at around 300 million meters per second.

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Independently, light had been measured to travel at 300 million meters per second some years prior.

So ... if this electromagnetic wave travels at the speed of light, perhaps it *is* light?

In the history of science, sometimes theory gets ahead of experiment – like in the discovery of the nature of light.