

We should take comfort in two conjoined features of nature: first, that our world is incredibly strange and therefore supremely fascinating . . . second, that however bizarre and arcane our world might be, nature remains comprehensible to the human mind.

– Stephen Jay Gould

A Universe of Amplitudes

Dan Styer
Oberlin College
Department of Physics and Astronomy

Outline

- I. The amplitude framework
- II. How what we already know fits into the amplitude framework
- III. Evidence for the amplitude framework

I. The amplitude framework

What is it?

I. The amplitude framework

Answers the question:

“What is the probability of going from one state to another?”

The amplitude framework

1. Enumerate all ways of going from initial to final state.
2. Assign an amplitude (an arrow) to each way.
3. Add up all the arrows.
4. The probability is the square of the magnitude of this sum arrow.

The amplitude framework

Amplitude isn't a thing you can touch/feel/see, but instead a mathematical tool that allows us to calculate probabilities.

The amplitude framework

Different names for amplitude:

proclivity; propensity; push factor

A mix of the word influence and amplitude like ampluence?
inflitude?

The “betwixt and between index” due to the amplitude’s
property of being kind of an intermediate step.

The amplitude framework

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proclivity; propensity; push factor

A mix of the word influence and amplitude like ampluence?
inflitude?

The “betwixt and between index” due to the amplitude’s
property of being kind of an intermediate step.

~~That/which is Not/but/whispers of/What Is/~~

(That which is not but whispers of what is.)

The amplitude framework

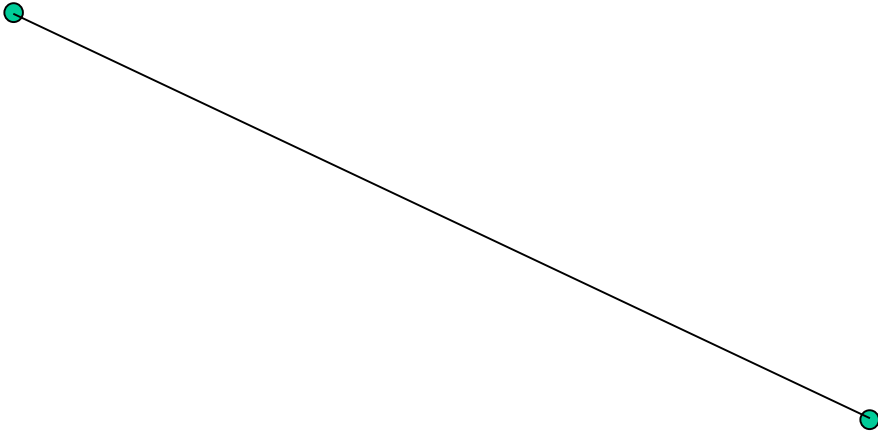
1. Enumerate all ways of going from initial to final state.

- initial

- final

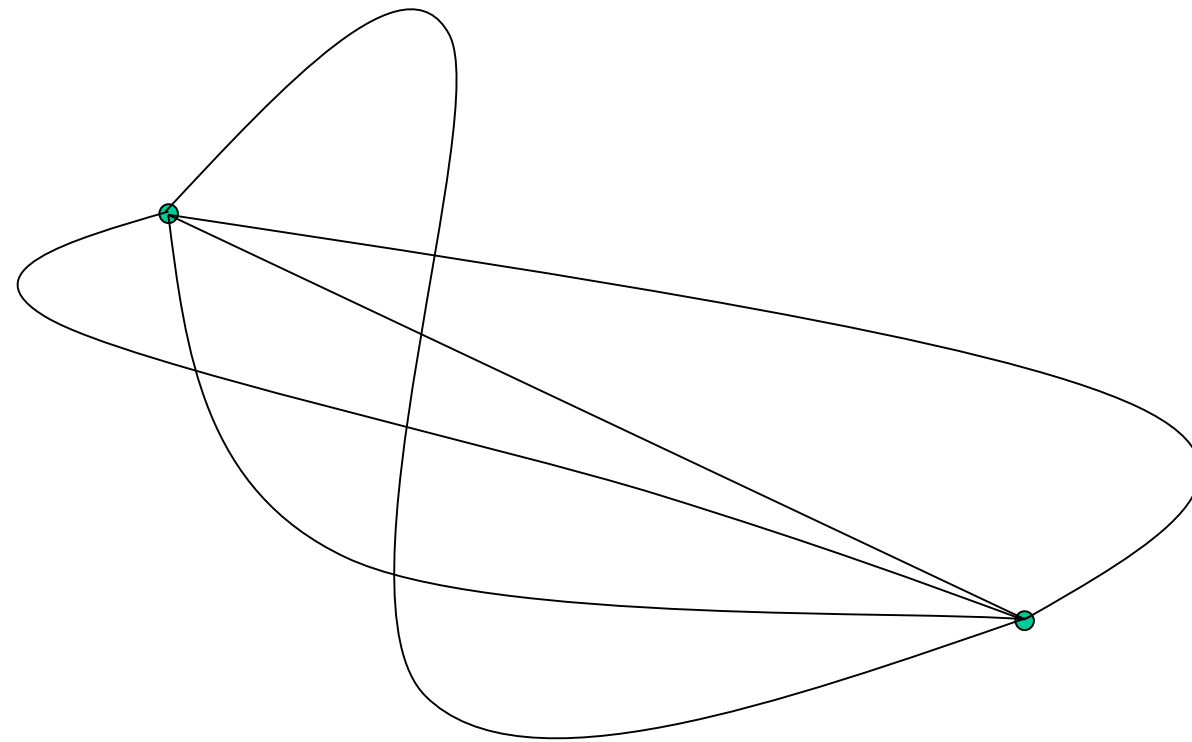
The amplitude framework

1. Enumerate all ways of going from initial to final state.



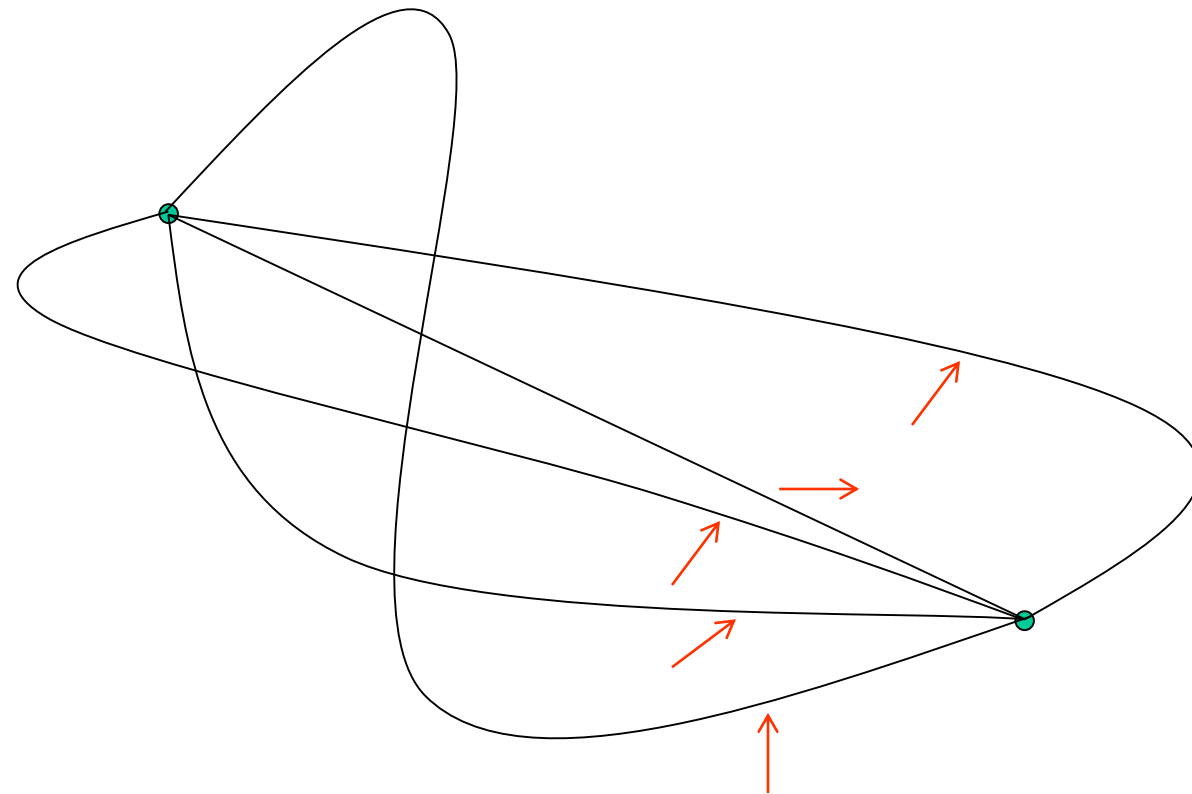
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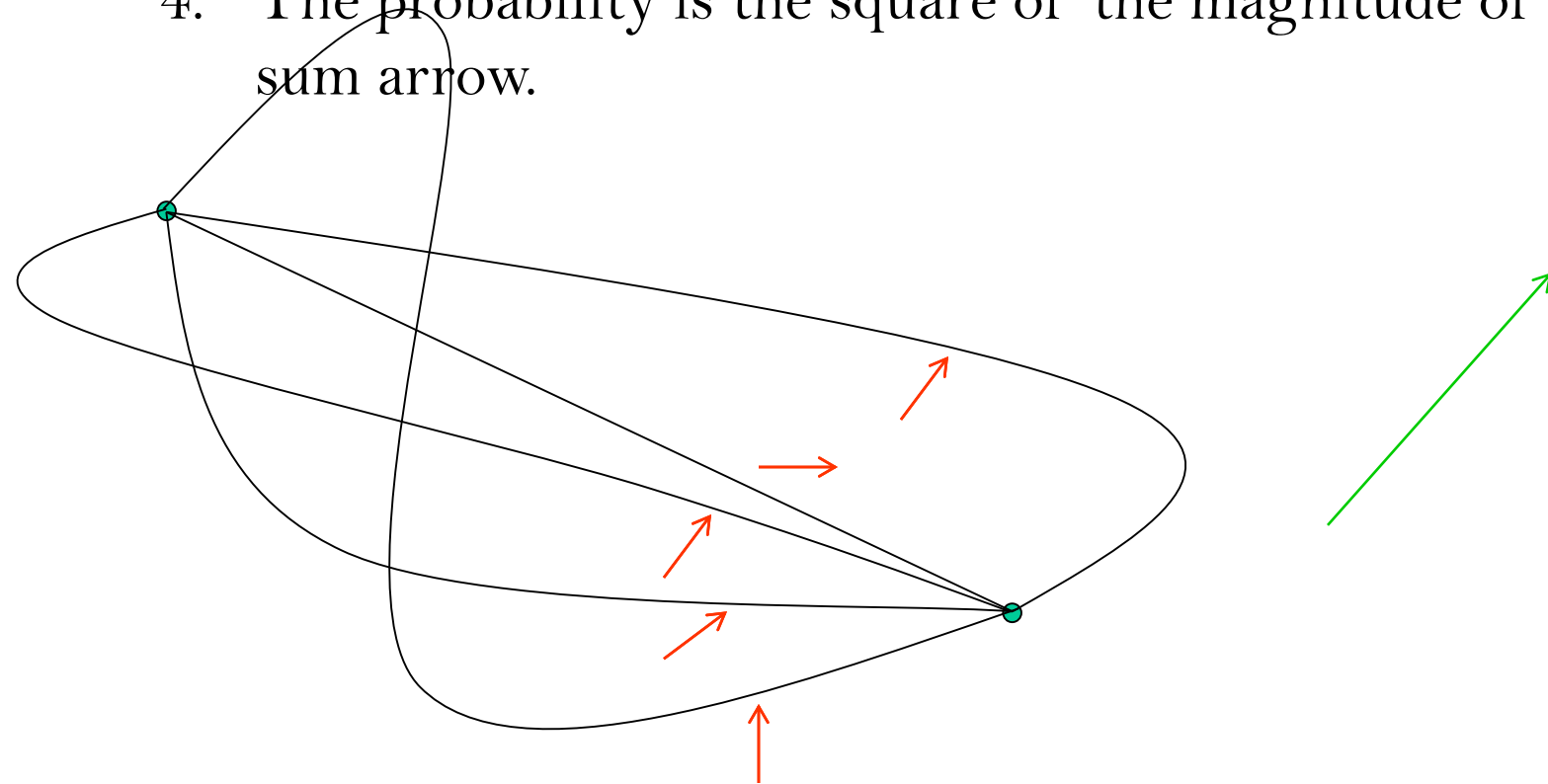
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The amplitude framework

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Is the framework correct?

No experiment can prove that the framework is correct, because even if you showed that it works in a million situations, tomorrow I could find a new situation in which it doesn't work.

So I can't prove that it's correct ... no one can.

What I can do is show you some of the millions of situations in which the framework's been tested, and never yet failed.

II. How does what we know
fit into the
amplitude framework?

Four pillars of quantum mechanics

- quantization
- probability
- entanglement
- interference



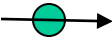

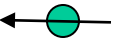
Quantization

What it is: The spin projection on a vertical axis is either $m_z = +m_B$ or $m_z = -m_B$.

Metaphor: As if a person were either tall or short, never in between. Either rich or poor, never in between.

Probability

What it is: If the value of m_z is $+m_B$, then m_x has no value.

Amplitude picture: An atom with spin up 
has amplitude  for having spin right 
and amplitude  for having spin left  .

Probability

Metaphor: A mountain is high or low, but it is neither rich or poor – the concept of wealth doesn't apply to mountains.

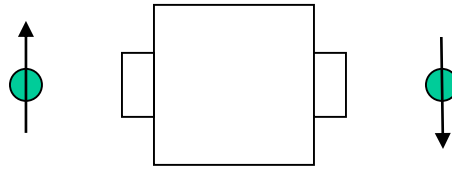
A corporation can be rich or poor, but it is neither high nor low – the concept of height doesn't apply to corporations.

Entanglement

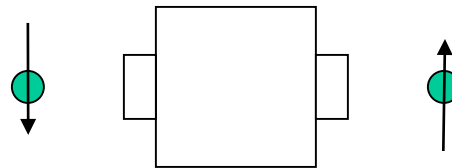
What it is: Two distant objects can have associated actions, even though they cannot affect each other.
(Correlation without causality.)

Entanglement

Amplitude picture: An entangled state has amplitude \rightarrow for having spins “up down”



and amplitude \leftarrow for having spins “down up”



(There is no good way to picture this state using classical ink.)

Entanglement

Metaphor, word, phrase, story, picture: ?

Entanglement

Metaphor, word, phrase, story, picture:

“spooky action at a distance”

– A. Einstein

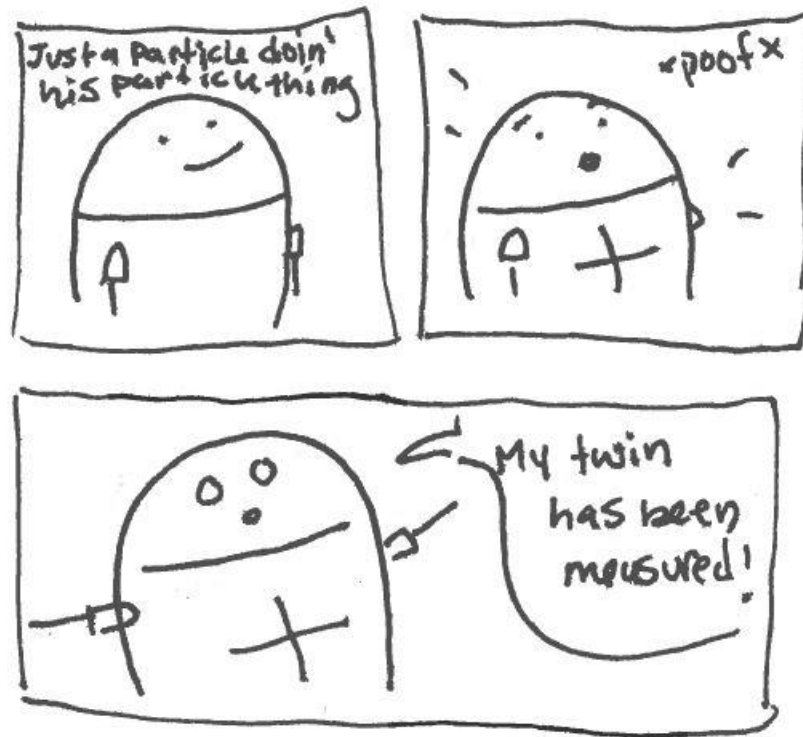
Entanglement

Metaphor, word, phrase, story, picture:

I personally would call it “twinepathy” which is what my twin sister and I joke we have when we say the same thing at the same time.

Entanglement

Metaphor, word, phrase, story, picture:



Entanglement

Metaphor, word, phrase, story, picture:

Entanglement makes my brain confused
in an interesting way!

Entanglement

Metaphor, word, phrase, story, picture:

two parts of a whole

Theology: Holy Trinity

“Batter my heart, three-person’d God”

– John Donne

Entanglement

Metaphor, word, phrase, story, picture:

Einstein's Spookiness,
Schrödinger's Entanglement,
Both make me confused.

Entanglement

Metaphor, word, phrase, story, picture:

What do you call a college couple that spends so much time together they no longer have an independent sense of self as every action of one affects the other?

Entangled!

Entanglement

Metaphor, word, phrase, story, picture:

I think a potential alternate name for entanglement could be quantum community?

I know it's a bit syrupy, but being in a co-op has really made me think a lot about the relationships we build in community, and I think this functions a bit like that.

Entanglement

Metaphor, word, phrase, story, picture:



Entanglement

Metaphor, word, phrase, story, picture:

Go to poem.

Entanglement

Metaphor, word, phrase, story, picture:

“Once you’ve shared certain experiences with a person, it’s impossible to get them out of your life. Things that affect them affect you, and vice versa.”

Entanglement

Metaphor, word, phrase, story, picture:

“Once you’ve shared certain experiences with a person, it’s impossible to get them out of your life. Things that affect them affect you, and vice versa.”

But we know that entanglement comes through probabilities, not through cause and effect.

Entanglement

Metaphor, word, phrase, story, picture:

A haiku in Japanese:

見えるとも
事実も変わる
侘寂だ。

Even when it is visible,
Reality ^{also} changes.
How wabi-sabi.

Entanglement

Metaphor, word, phrase, story, picture:

A haiku in Japanese:

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事実も変わる
侘寂だ。

Even when it is visible,
Reality ^{also} changes.
How wabi-sabi.

Wikipedia: Wabi-sabi is a concept in traditional Japanese aesthetics constituting a world view centered on the acceptance of transience and imperfection.

Entanglement

Metaphor, word, phrase, story, picture:

A haiku in Japanese:

見えるとも
事実も変わる
侘寂だ。

Even when it is visible,
Reality ^{also} changes.
How wabi-sabi.

Why “transience and imperfection”?

How about “magic and sacredness”?

Entanglement

Metaphor: Love

Entanglement

Metaphor: Love

Lovedancing

The quantum mechanical affair

Romeo and Juliet



Entanglement

Metaphor: Love

Entanglement means that the two particles cannot be described independently. It reminds me (in a silly way) of an overly dependent relationship between two lovers!

Entanglement

Metaphor: Love (Walt Disney version)

Entanglement

Metaphor: Love (Walt Disney version)



“A Wrinkle in Time”
movie released:
9 March 2018

Entanglement

Metaphor: Love (Walt Disney version)



“A Wrinkle in Time”
movie released:
9 March 2018
production company:
Walt Disney Pictures

Dull sublunary lovers' love
 (Whose soul is sense) cannot admit
Absence, because it doth remove
 Those things which elemented it.

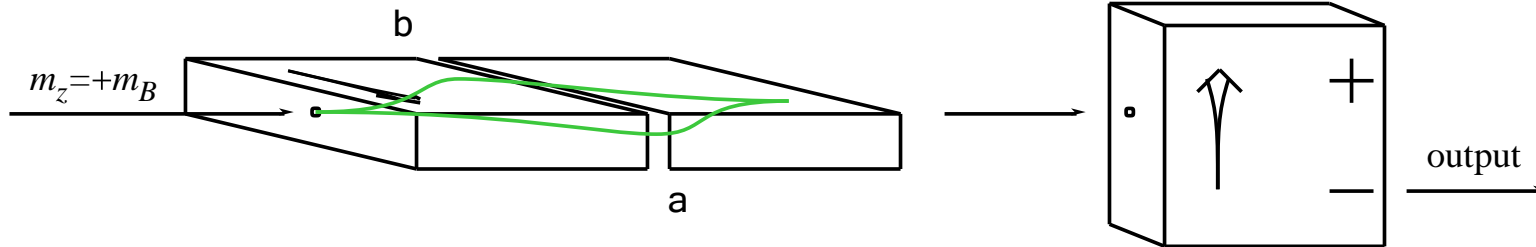
But we by a love, so much refined,
 That ourselves know not what it is,
Inter-assured of the mind,
 Care less, eyes, lips, and hands to miss.

Our two souls therefore, which are one,
 Though I must go, endure not yet
A breach, but an expansion,
 Like gold to airy thinness beat.

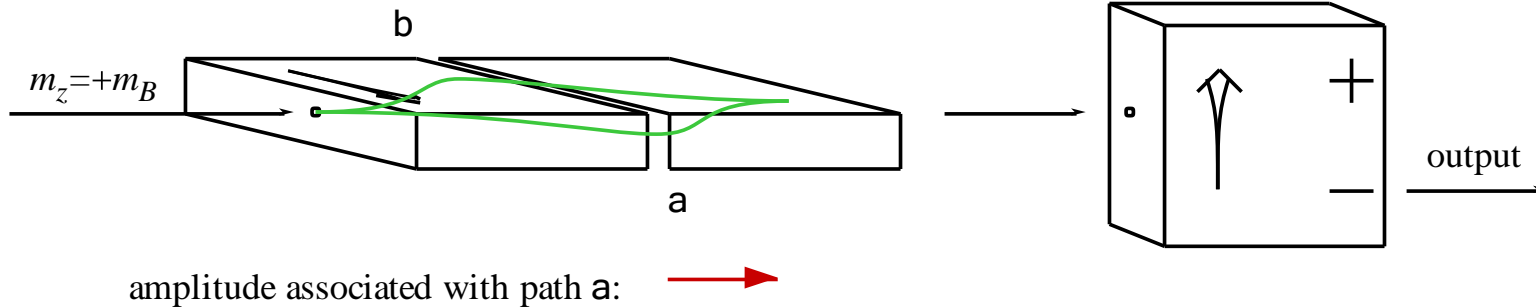
--- John Donne (1611 or 1612)

A Valediction: Forbidding Mourning

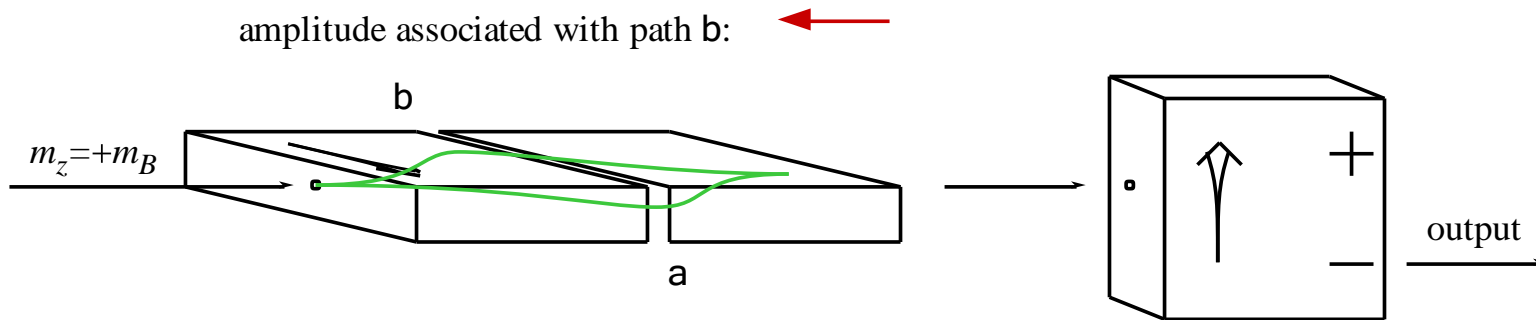
Interference



Interference



Interference



Interference

Words and phrases:

The atom takes both paths.

The atom has an amplitude to take either path.

Interference

Words and phrases:

Atoms are not like solid marbles, they are like air.
So they can go through different branches at the same time.

quantal schizophrenia

Interference

Words and phrases:

No matter how much I try to wrap my head around it, the fact that the atom goes through BOTH branches at the same time is so weird that I can't think of a word for it. Maybe something like the atom "ghosts" through the apparatus?

Interference

Words and phrases:

The atom ninjas its way through the box.

(It only works in the dark, when you're not looking,
and the process is steeped in deception.)

The atom ambivates through the box.

The atom shows duplacity.

Interference

Words and phrases:

I cannot compete with “ambivate” because it sounds funny and technical at the same time. You could say the atom wigwags.

Interference

Words and phrases:

In Daoism there is a noun that describes when a status is embedded in its opposed status so that they both exist at the same place together – different places at the same time. It's sort of like an atom going through both branches at the same time.

Interference

Words and phrases:

Two roads diverged in a wood and I —
I took the one less traveled by

- Robert Frost

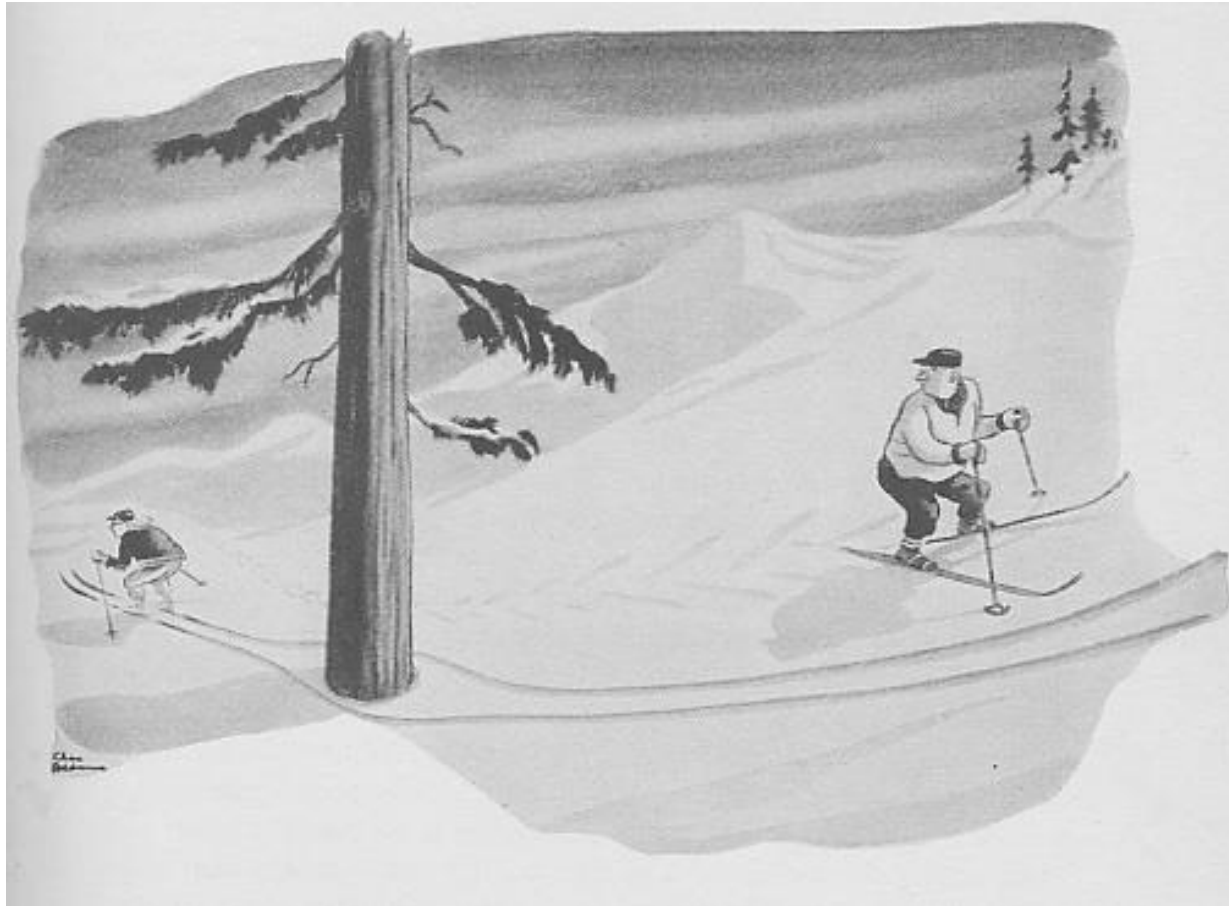
Interference

Words and phrases:

Two roads diverged in a wood and I —
I took both

- not Robert Frost

Interference



Charles Addams (1940) “Downhill Skier”

III. Evidence for the amplitude framework

We've done detailed experiments here on Earth to support the amplitude framework. But what about far away?

We can't touch or manipulate matter that's far underground, or in the planets or stars, all we can do is look at it.

Nevertheless, we can learn a lot by looking.

For example, spectra of glowing gases:

Hydrogen:



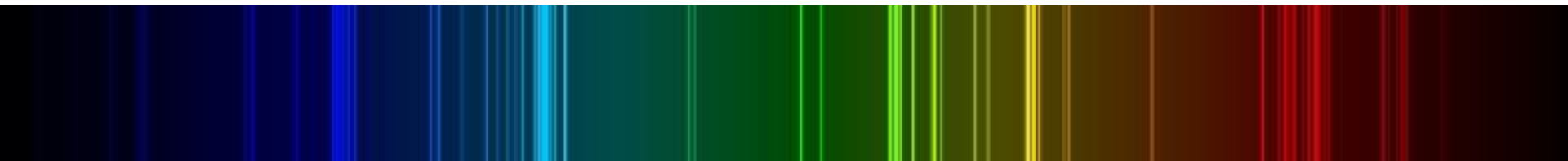
Hydrogen:



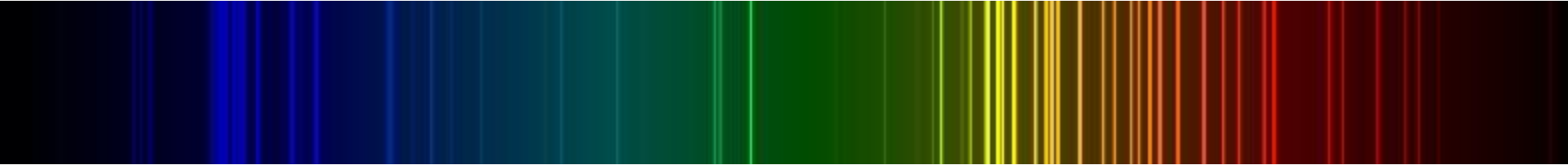
Helium:



Nitrogen:



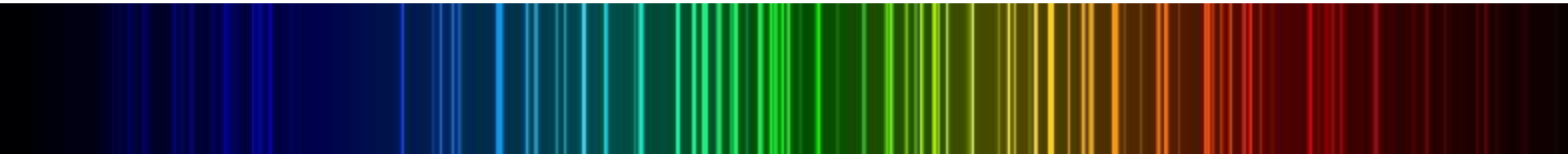
Neon:



Argon:

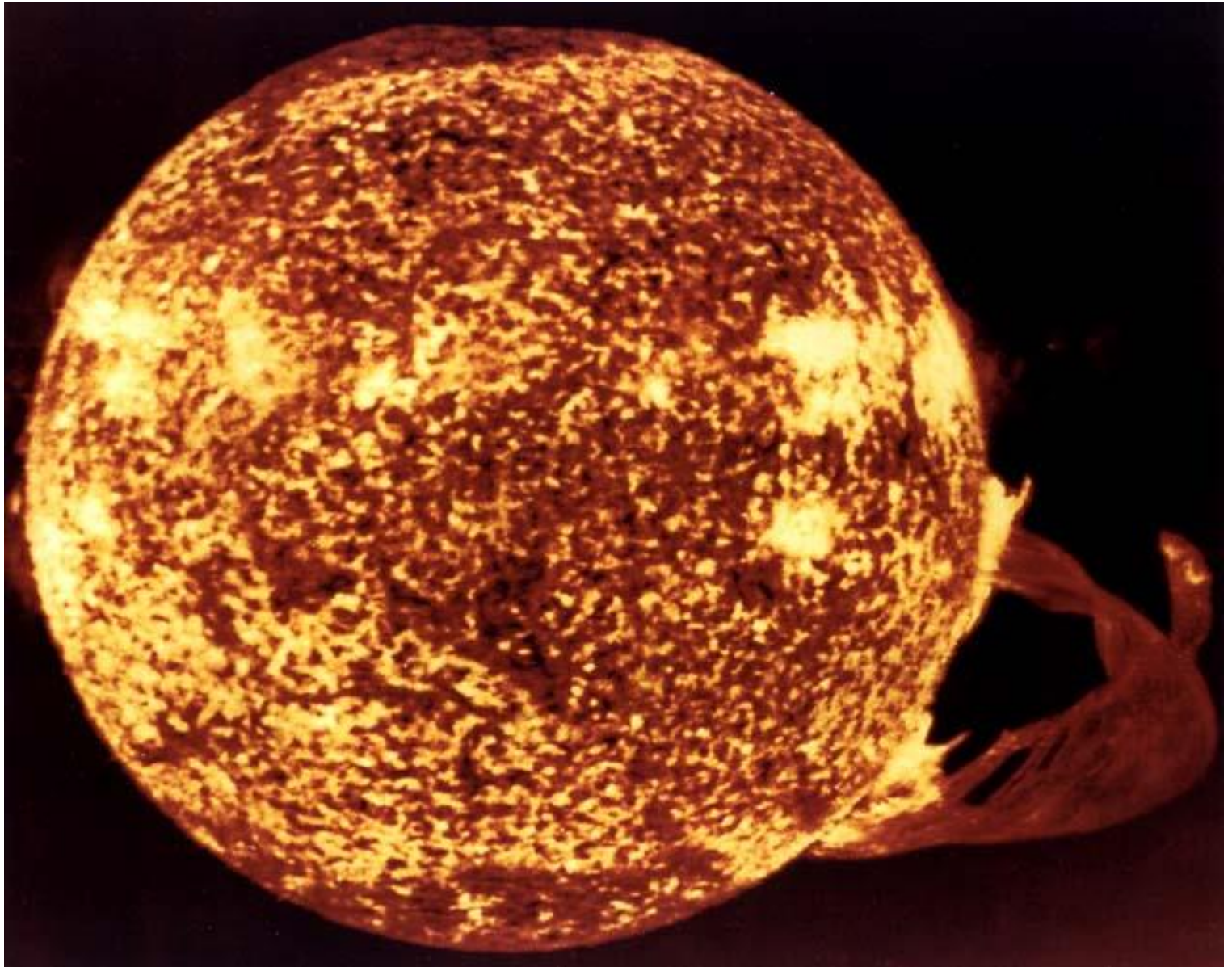


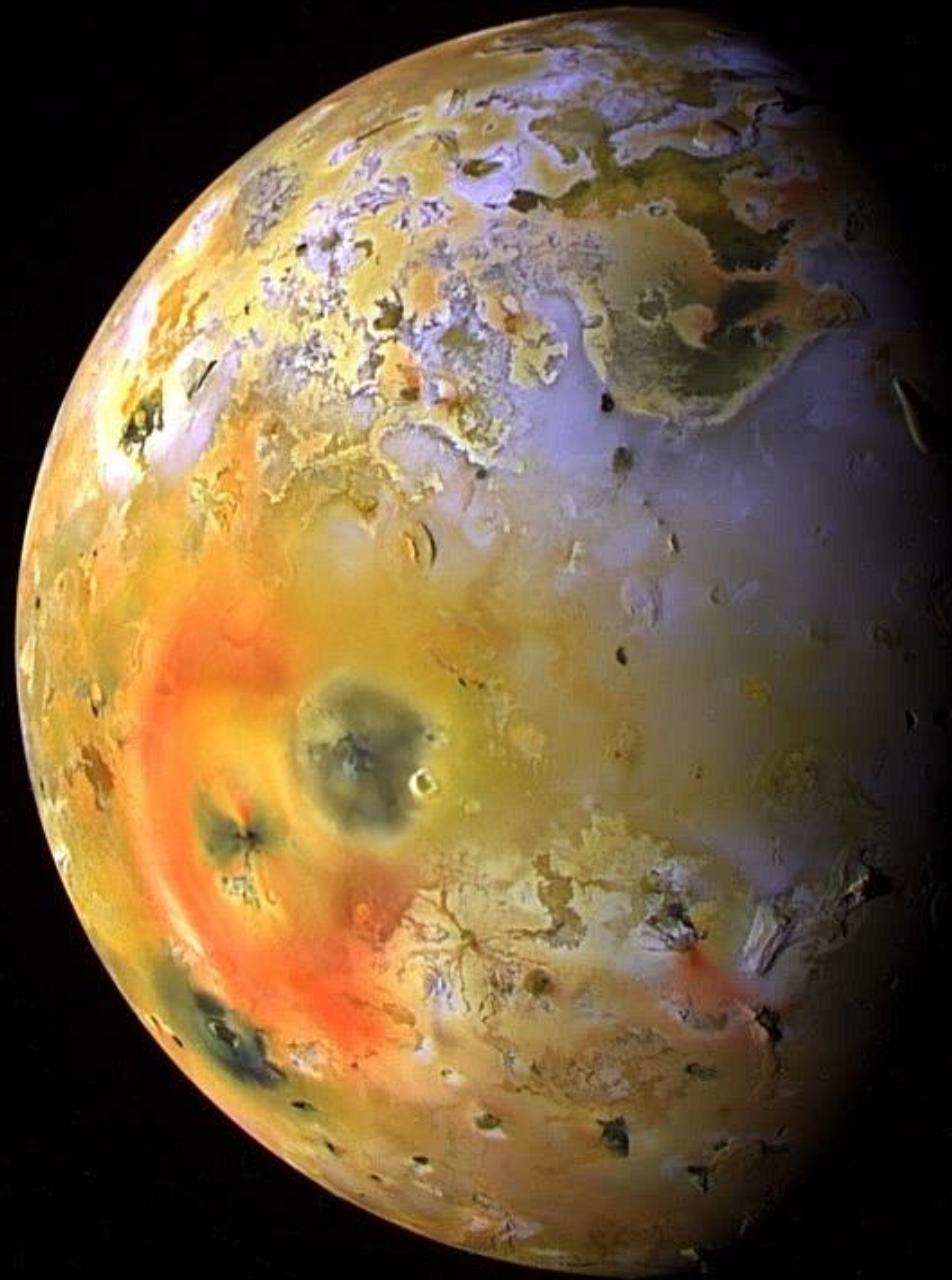
Xenon:

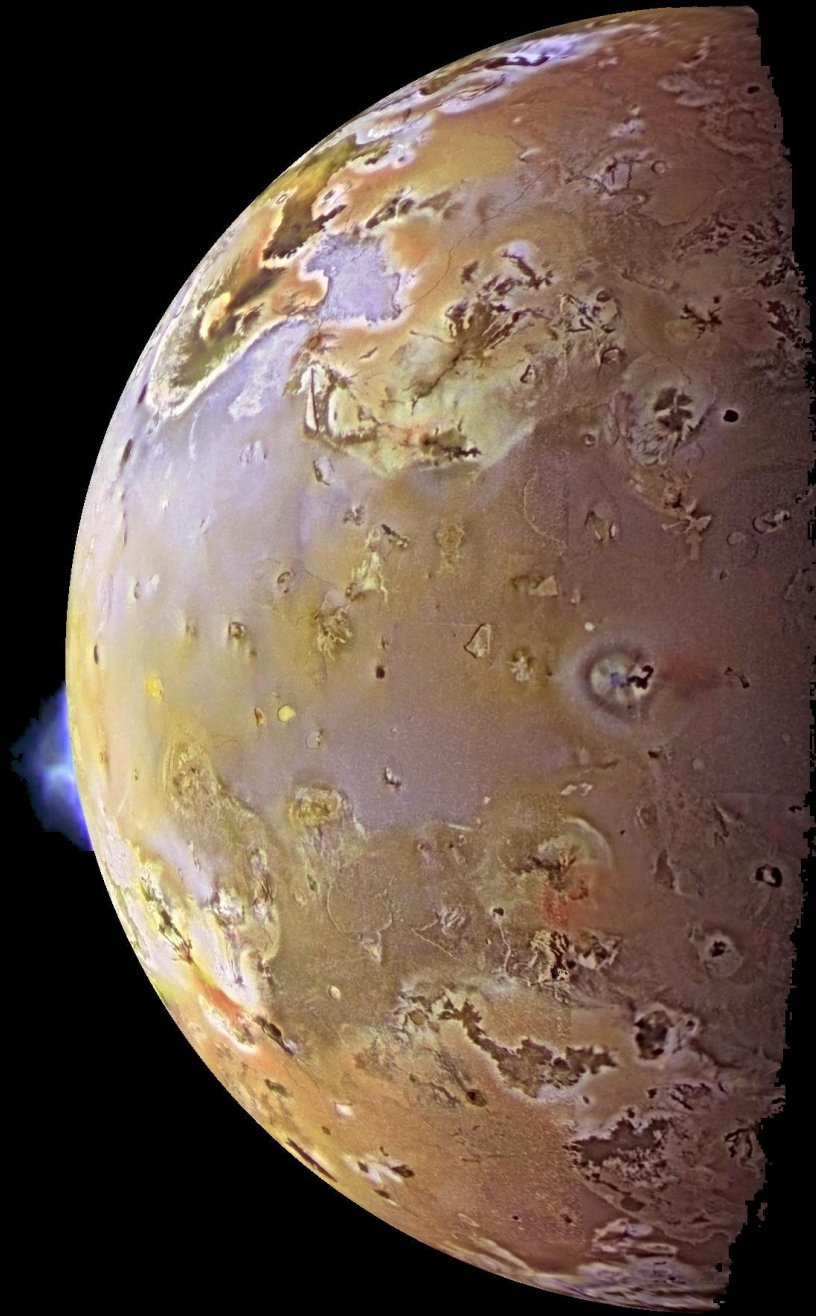


In fact, quantum mechanics was discovered through a path completely different from the path used in this course to explicate quantum mechanics.

Quantum mechanics was discovered (or invented) to explain how light was emitted from or absorbed by glowing atoms.







Okay, so quantum mechanics seems to hold within our solar system.

But what about outside the solar system?



Cone Nebula

HST • ACS

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI),
G. Hartig (STScI) and the ACS Science Team • STScI-PRC02-11b

Our galaxy consists of about 100 billion stars – fifteen for every man, woman, and child on Earth – plus numerous nebulae. Not every star has been checked in detail, but every one that has been checked is made up of atoms obeying the rules of quantum mechanics.

But what about outside our galaxy?





NGC4594



NGC891

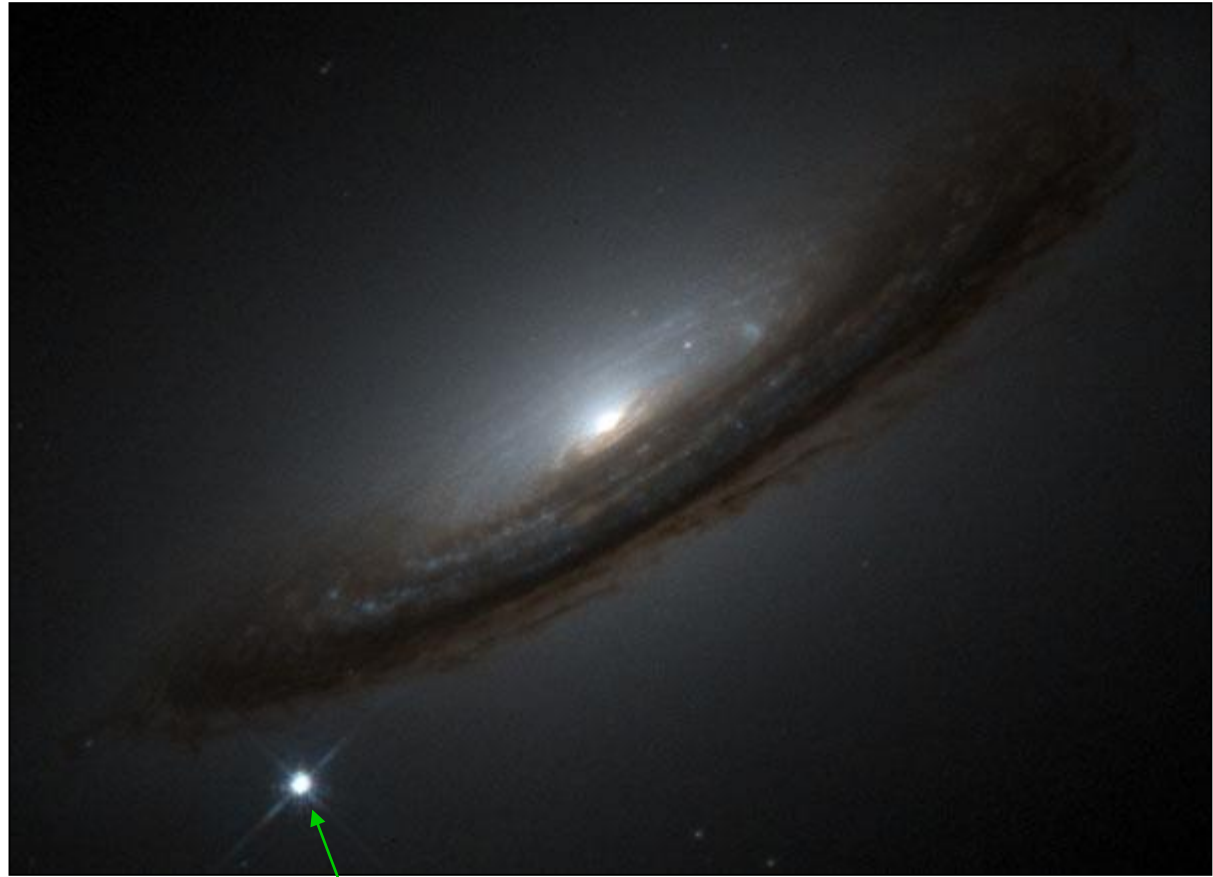


NGC5866

NGC4526

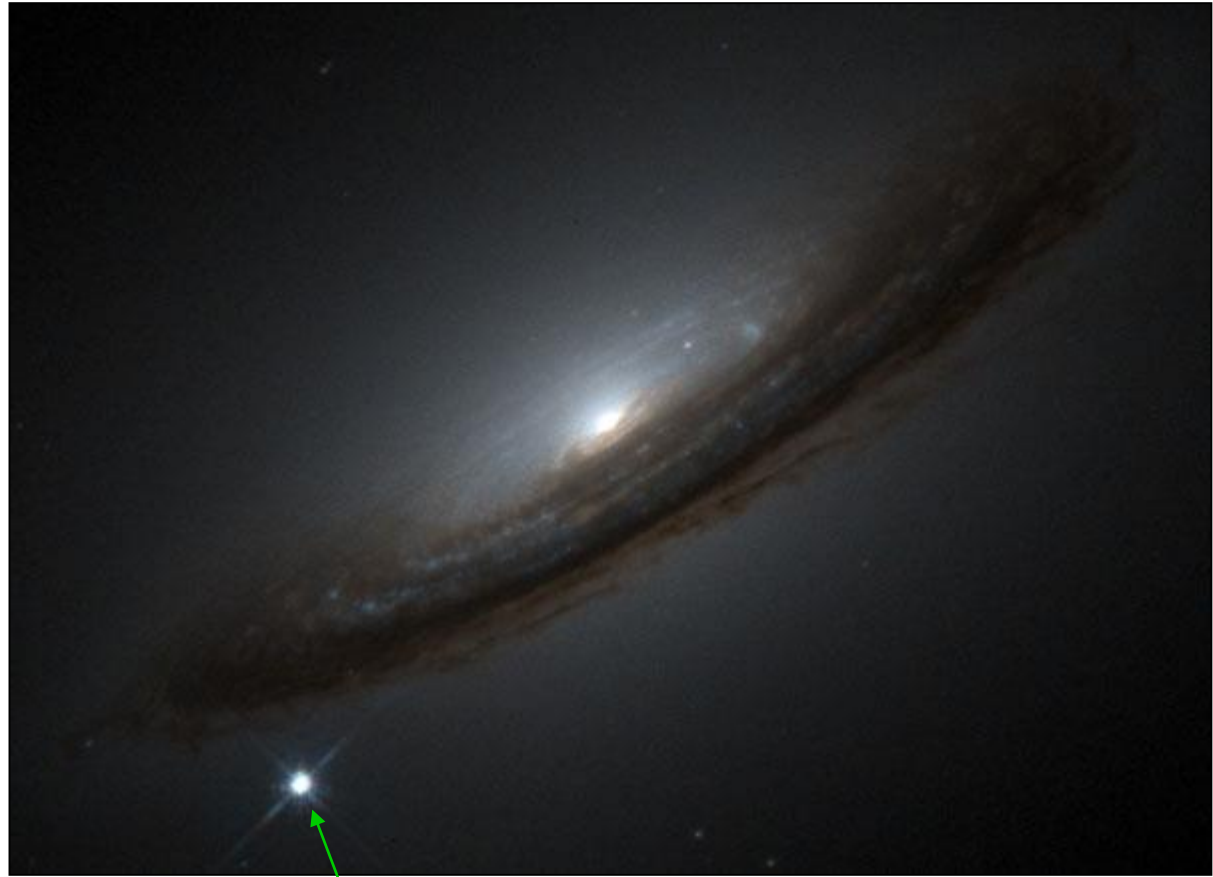


NGC4526

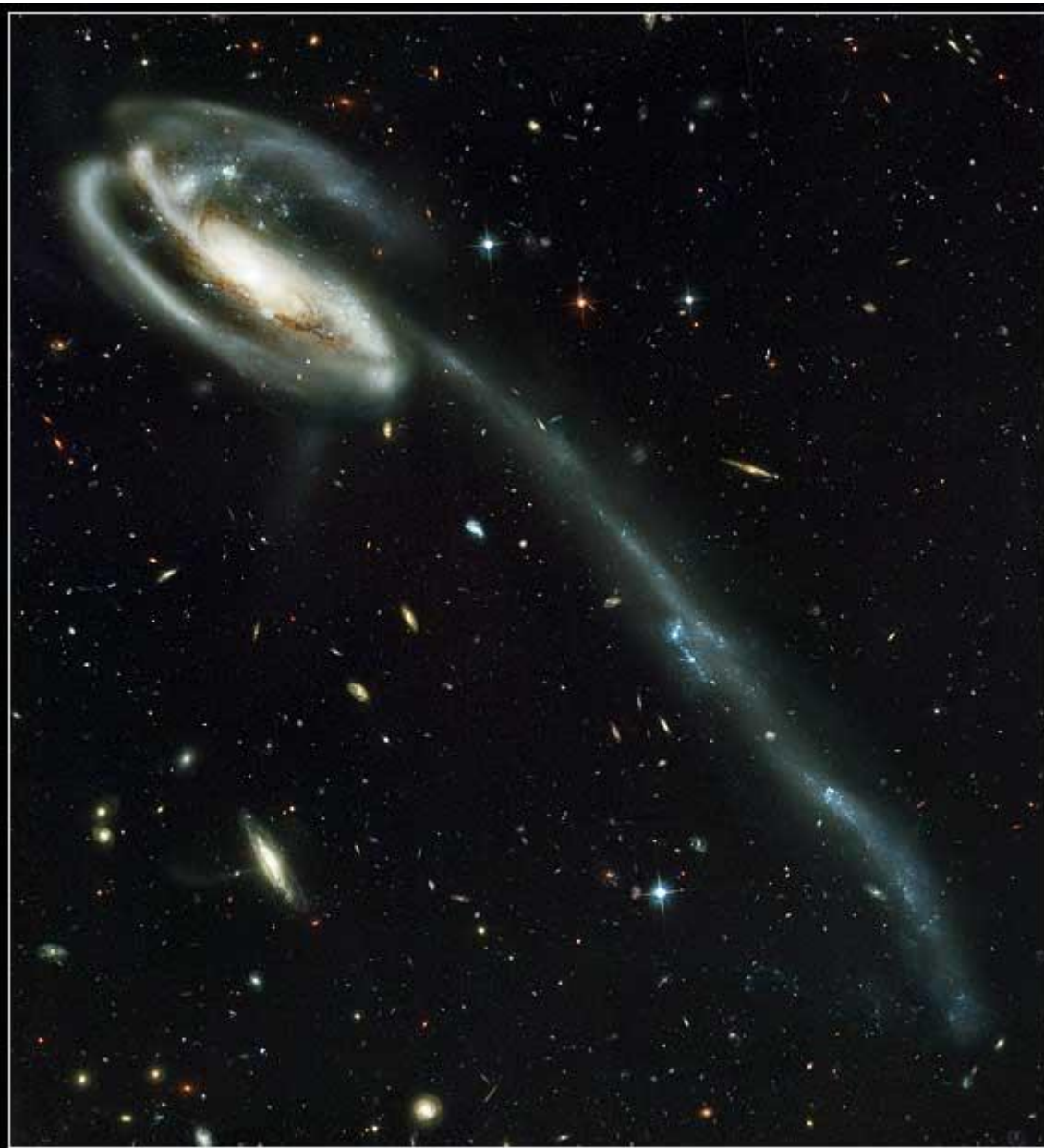


What's this?

NGC4526



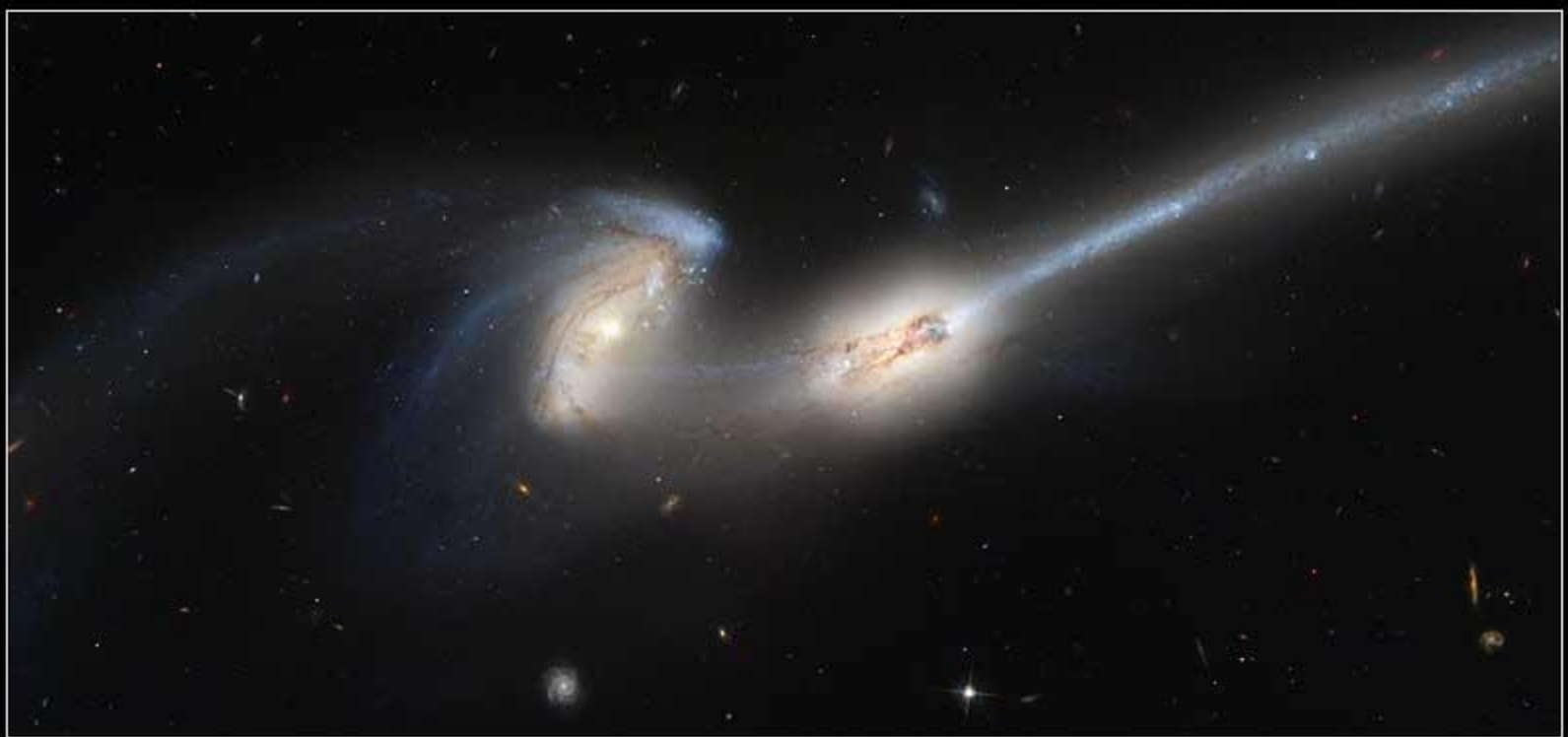
Supernova 1994D



Tadpole Galaxy • UGC 10214

HST • ACS

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI),
G. Hartig (STScI) and the ACS Science Team • STScI-PRC02-11a



The Mice • Interacting Galaxies NGC 4676

HST • ACS

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI), G. Hartig (STScI) and the ACS Science Team
STScI-PRC02-11d





We are privileged to live in a Universe as various,
as arresting, and as beautiful as our own.

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And we are privileged to be engaged in the ongoing
process of discovering more about that Universe.

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For the past several weeks, you've been a part of this process. There's no need to stop. Try looking at "Physics World" at

<http://physicsworld.com/cws/channel/news>

Or look at the "Astronomy Picture of the Day" at

<http://apod.nasa.gov/apod/>

Or use your home computer to look for gravity waves

<http://einstein.phys.uwm.edu>

Or participate in research by classifying galaxies at

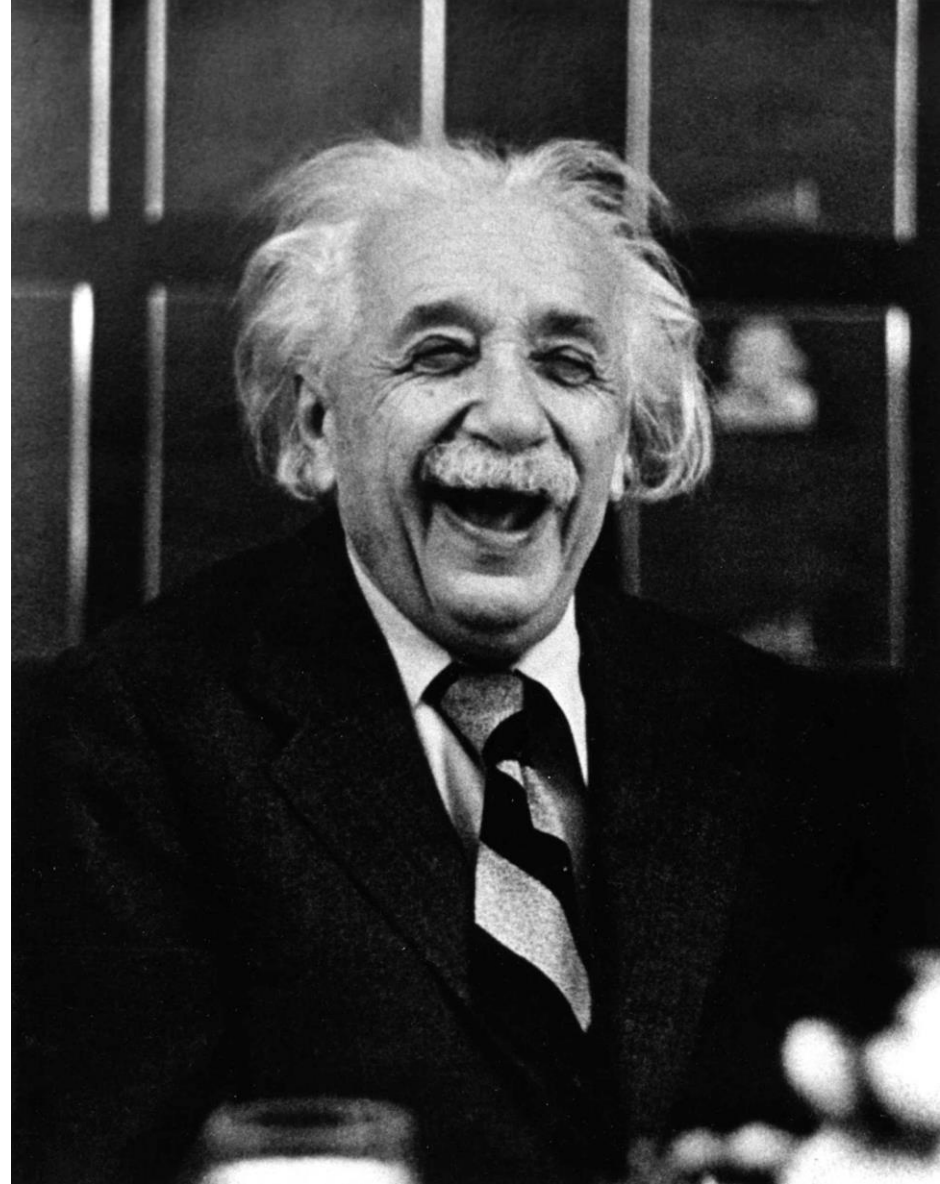
<http://www.galaxyzoo.org/>

Or, if you're an amateur astronomer, make a significant research contribution by looking for supernovae:

<http://snews.bnl.gov/amateur.html>

The important thing is not to stop questioning. ...
Never lose a holy curiosity. ...
Don't stop to marvel.

– Albert Einstein, 1954





Goodbye and fare well.