Quantum-Mania: Quantum Mechanics from Marvel's Ant-Man

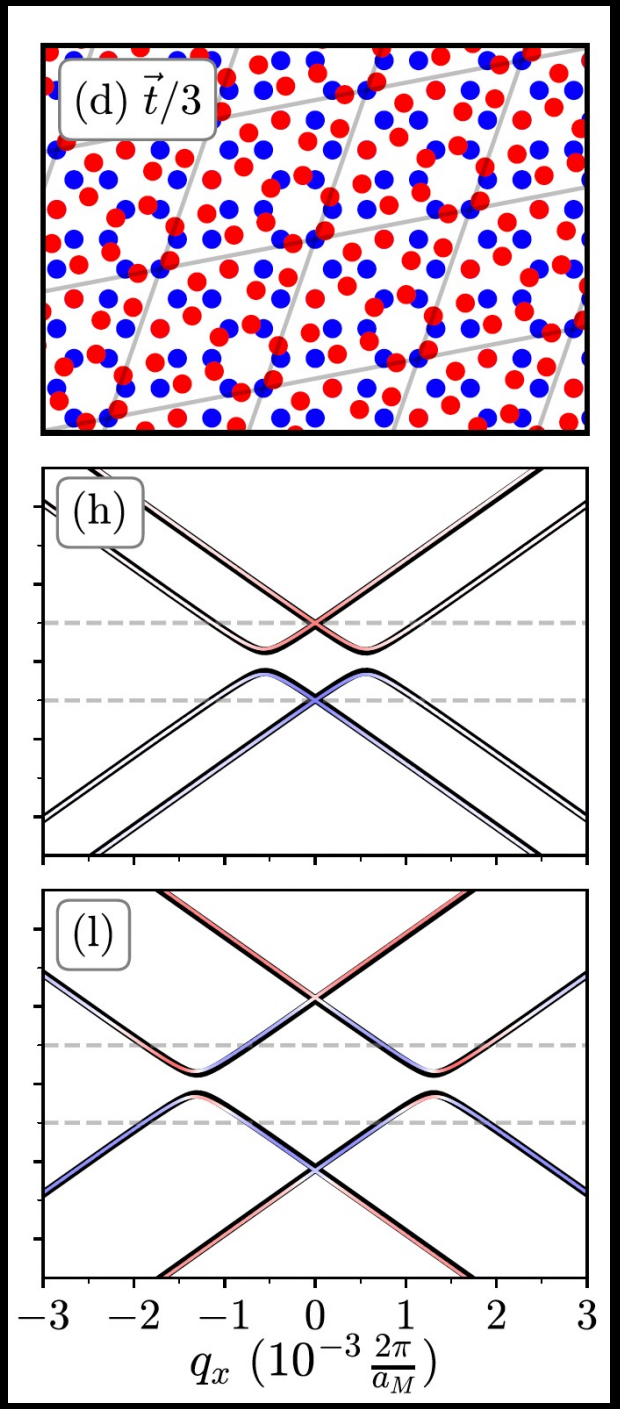
Spenser Talkington • UPenn Physics Department

Science Education Academy Philadelphia: Pop Science Talk

18 February 2023

Who am I?

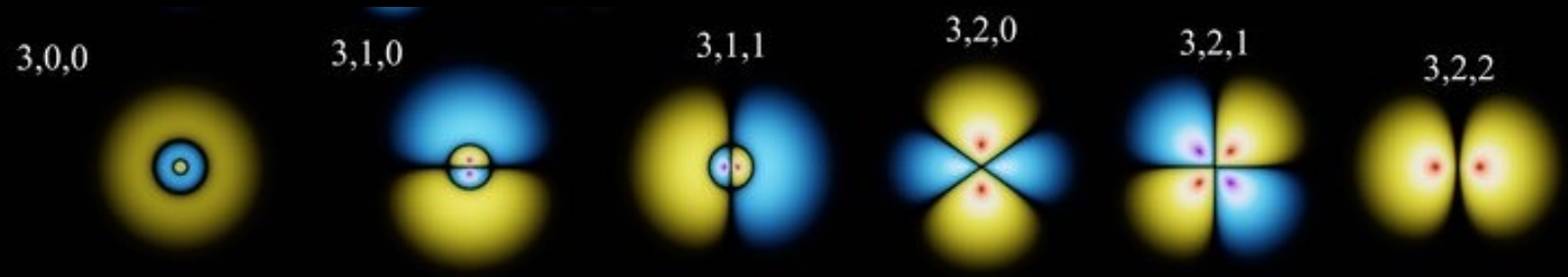
- Physics Graduate Student at UPenn
- Studying electronic materials using quantum mechanics
- Day-to-day work activities
  - Reading scientific papers
  - Talking about research with advisors, peers, and mentees
  - Calculating properties of materials and programming simulations
  - Writing up results
- Have volunteered with SEA for two years so far
- Fun fact: I have run eight marathons and plan to run two more this year



What Does Quantum Mean?

- What does it mean?
- Casual definition
  - Small things with probabilistic outcomes

- Formal definition
  - Counting eigenstates

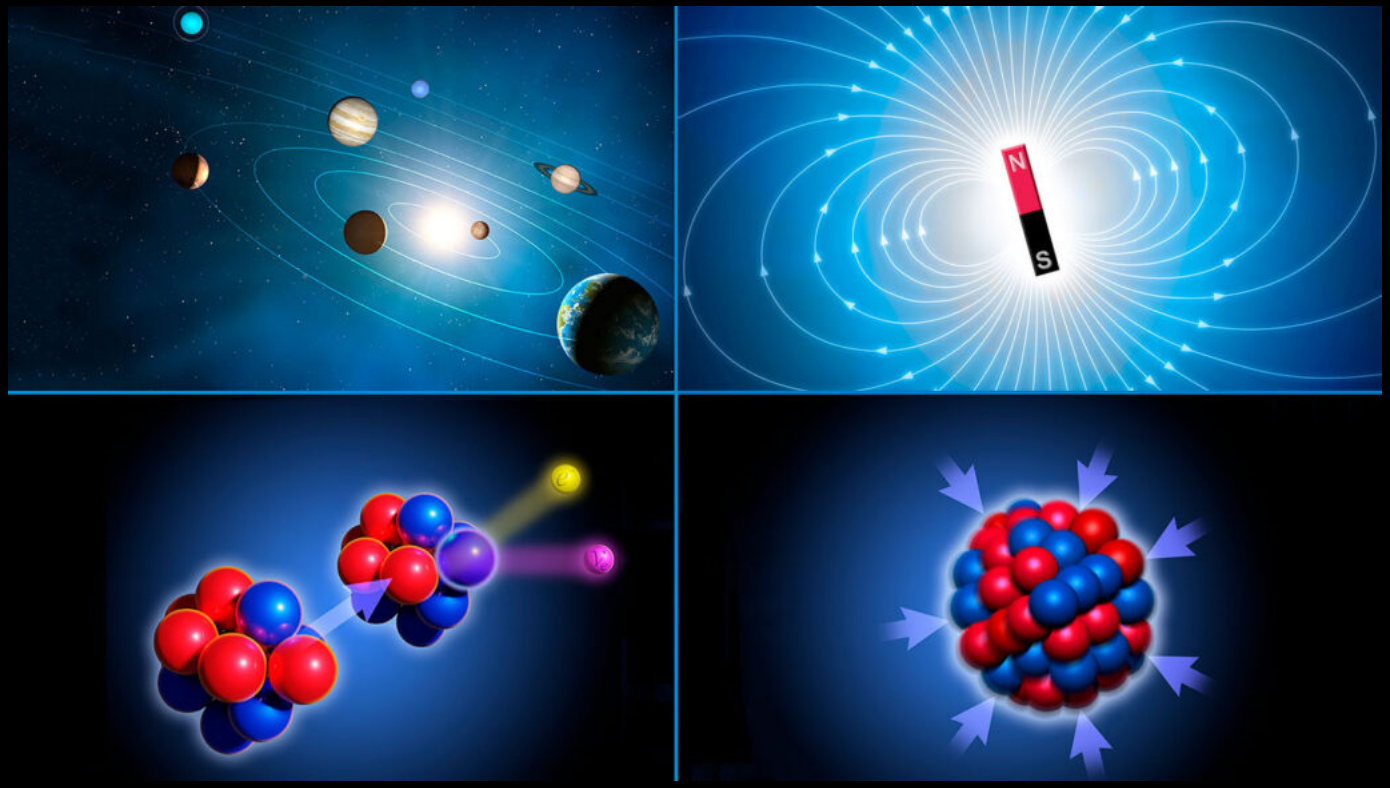


The Quantum Realm

- “… it’s a place outside time and space beneath ours…”
- What is the proton?

Thinking Like a Physicist 1

- Ask: “what are the symmetries and what acts on what?”



Thinking Like a Physicist 2

Thinking Like a Physicist 2

- Ask: “what stays the same”
- Often
  - Momentum
  - Energy
  - Mass
  - Angular Momentum
  - Charge
  - …

Probability and the Schrödinger Equation

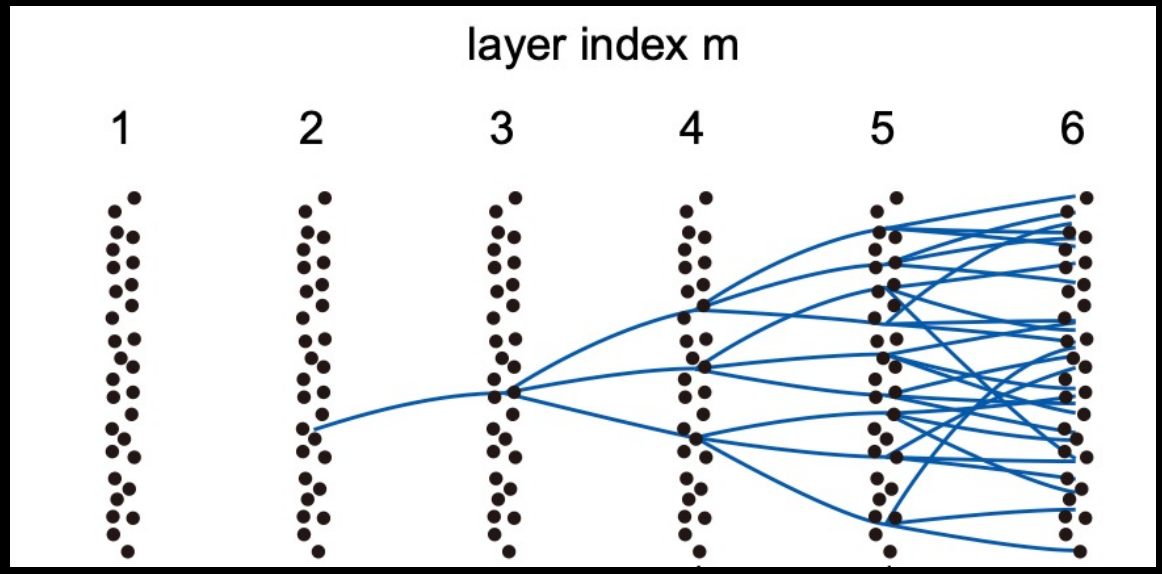
- Outcomes in quantum mechanics are probabilistic
- Schrödinger equation gives the possibilities ψ for a system described by H

$$\hat{H}\psi = E\psi$$

- E is the energy which generates time translation

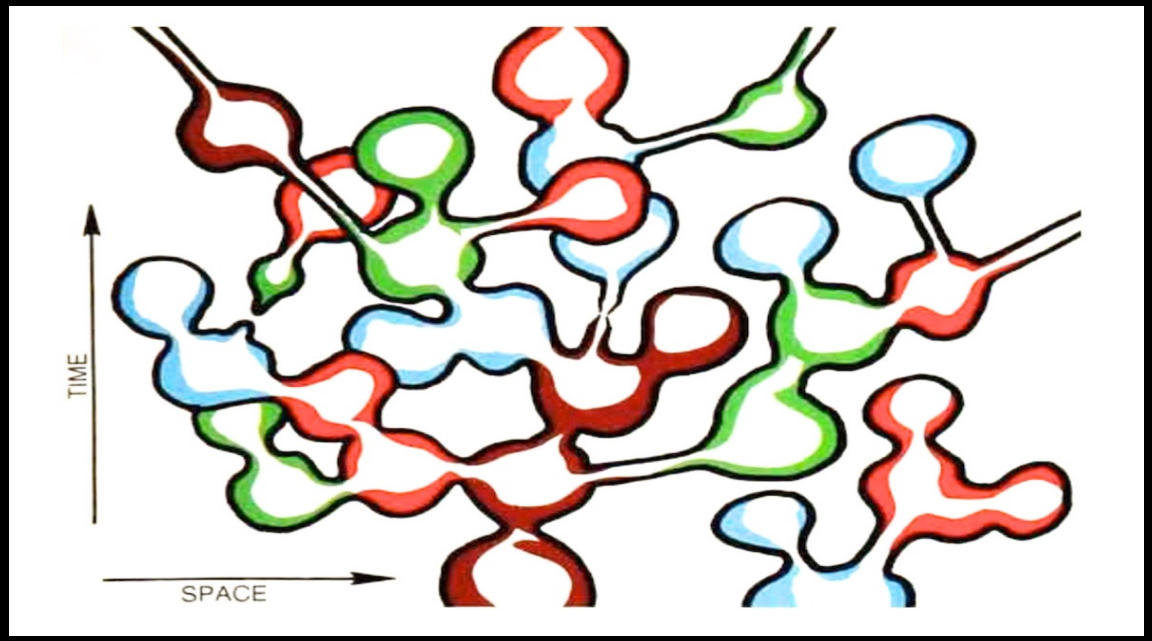
Probability Storm

- Multiple outcomes at once?
  - No!
- The possibility of another you
  - If the universe is infinite
  - Or in some versions of multiverse
- Particles can duplicate in avalanches
  - e.g. the quantum breakdown model



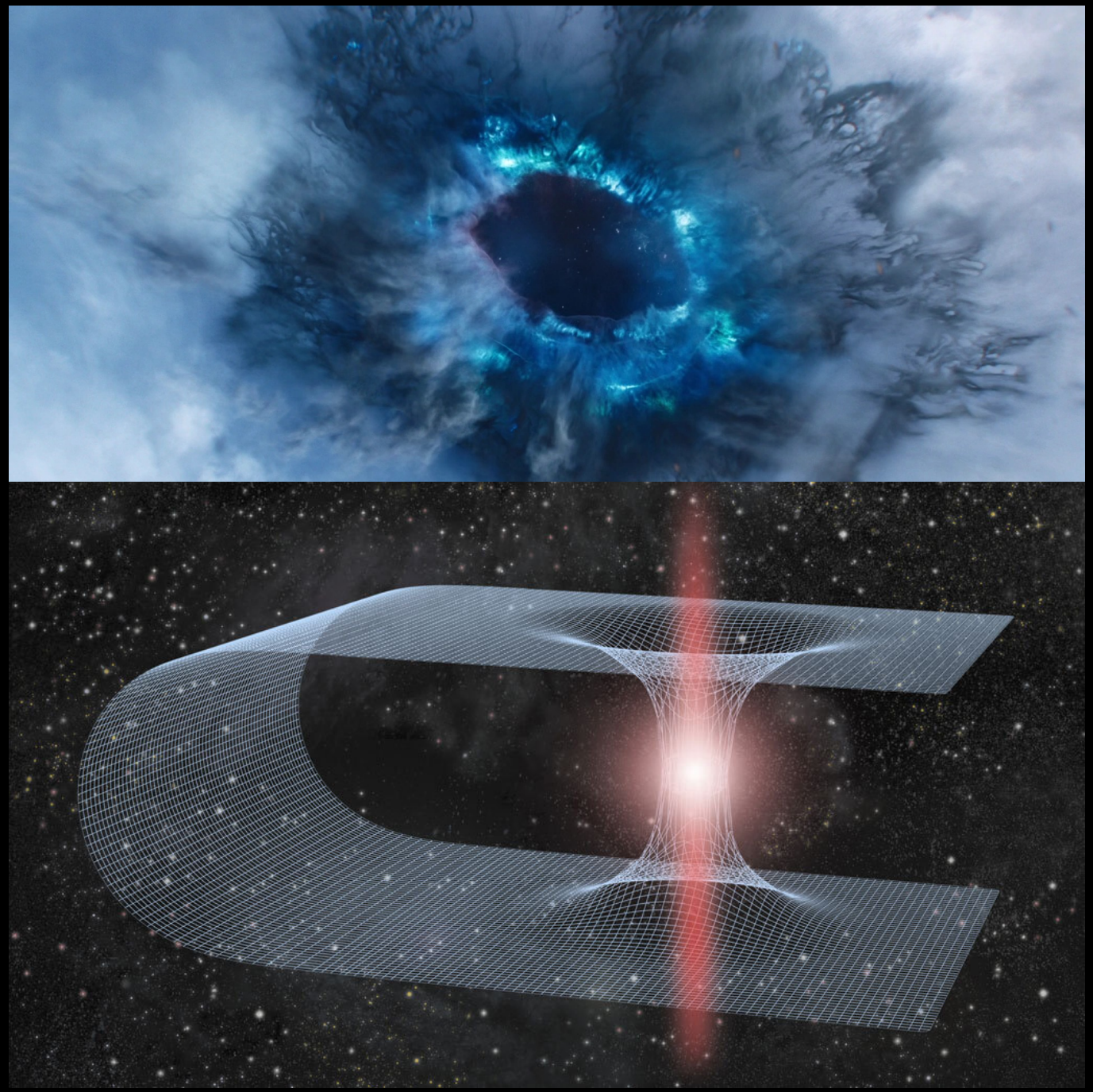
The Multiverse

- Multiple universes?
- Quite possibly!
  - Many-worlds hypothesis
  - From inflation
    - Quantum fluctuations at the beginning of time lead to multiple universe bubbles
    - Developed at UPenn!



Wormholes

- Can we shortcut between distant places?
- Sure, why not?
  - No one told us if the long distance was the shortest distance between the places
  - This is the “topology” of space
- But it costs a lot of energy



Gravity and Black Holes

- Distance, time and gravity = stress and energy

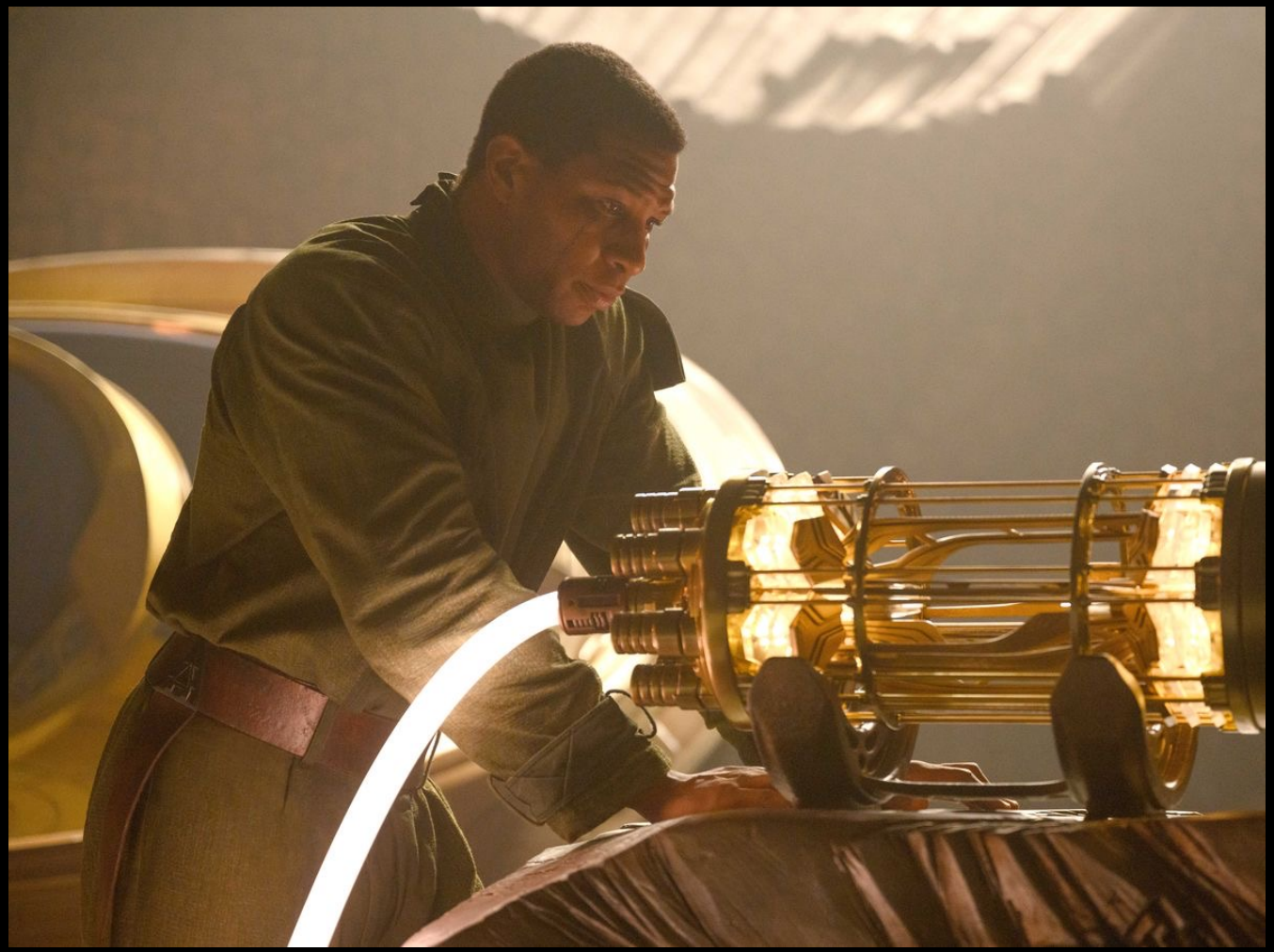
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G_N T_{\mu\nu}$$

- If the energy density becomes too large a black hole forms
  - Gravity is strong enough to trap light!
  - Hence they are dark

Messier M87 Black Hole

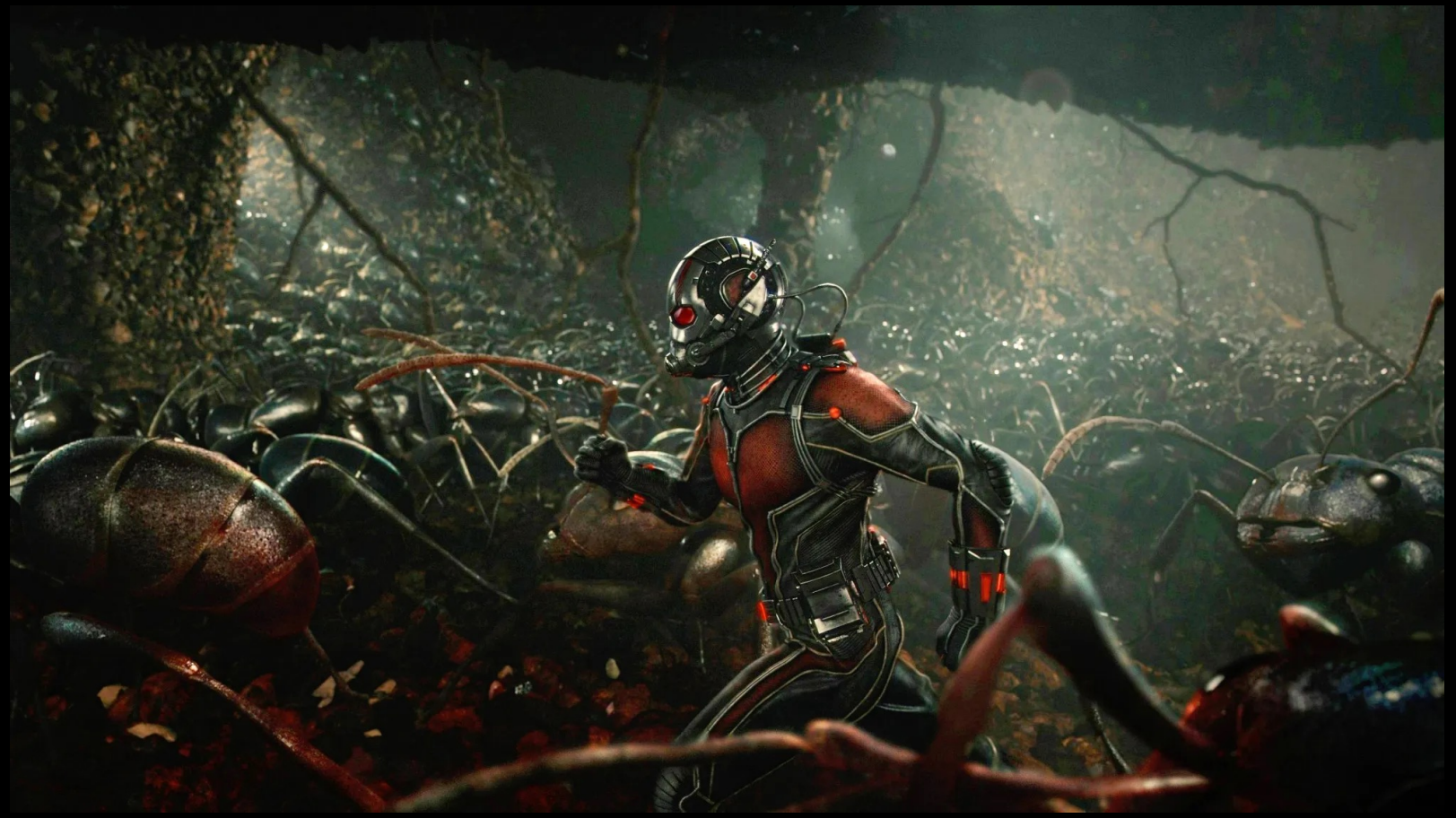
“Time, it’s not what you think it is”

- What is it?
- General Relativity
  - Time is a length which can be found from the energy density
- Quantum Mechanics
  - Time evolution is generated by energy
    - High energy -> High frequency
    - Low energy -> Low frequency



Time Dilation

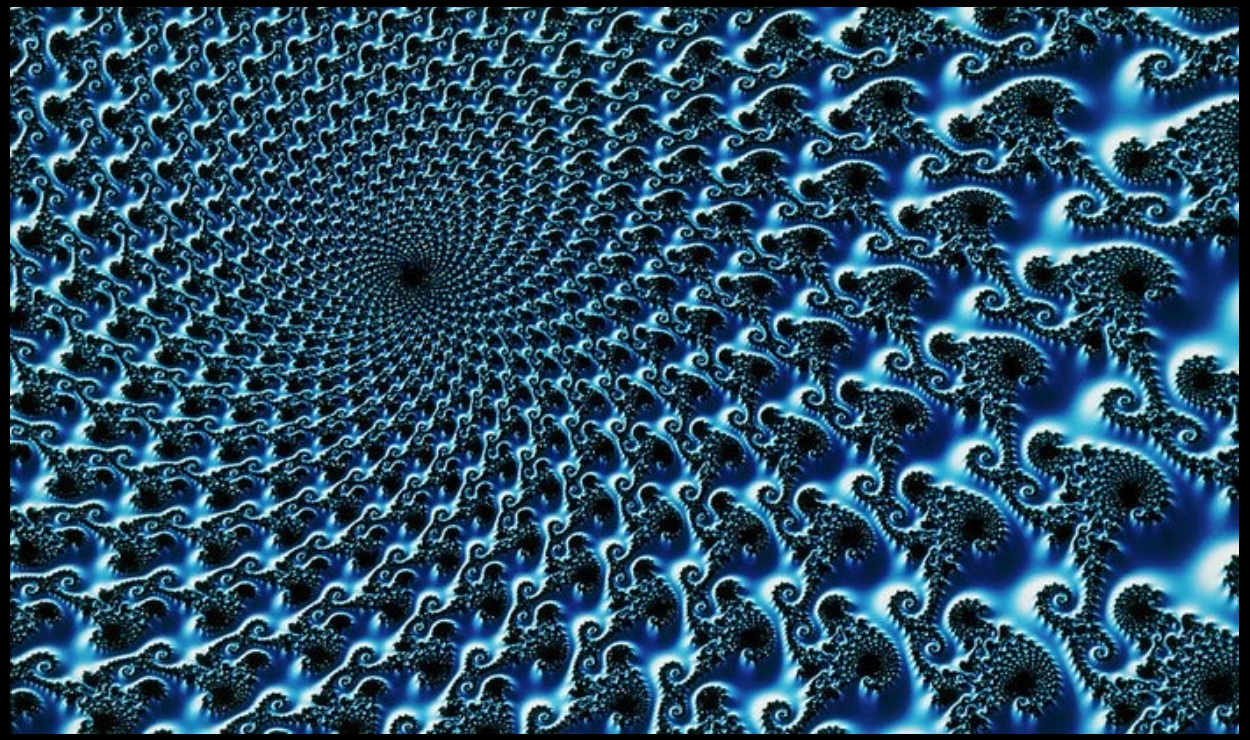
- “While we got here quickly, the ants traveled much more slowly and had thousands of years to evolve…”
- Fast moving observers experience less time
  - Special relativity



$$t_{\text{ants}} = \frac{t_{\text{heroes}}}{\sqrt{1 - v_{\text{heroes}}^2 / c^2}}$$

Fractals

- Fractional dimensional structures
- Shown in the transition to the quantum realm
- Can exhibit a conformal structure
- Associated with scale invariance such as that at a phase transition
  - Such as water boiling
  - Many different bubble sizes



What Can You Do in Physics?

- Develop new technologies
  - Quantum computing
- Explain fundamental mysteries
  - What is dark matter?
- Many open questions and frontiers

Career Outlook

- 4-6 year PhD program
- Lots of freedom
- Can work anywhere in the world
- Low pay
- Good job opportunities after
  - Salary and connections less than if one worked straight after bachelors

Parting Thoughts

- “If we knew where the ride would take us it wouldn’t be a ride”
- “Make mistakes, take chances, and there is always room to grow”
- “My whole life happened because I messed up” and then got back up