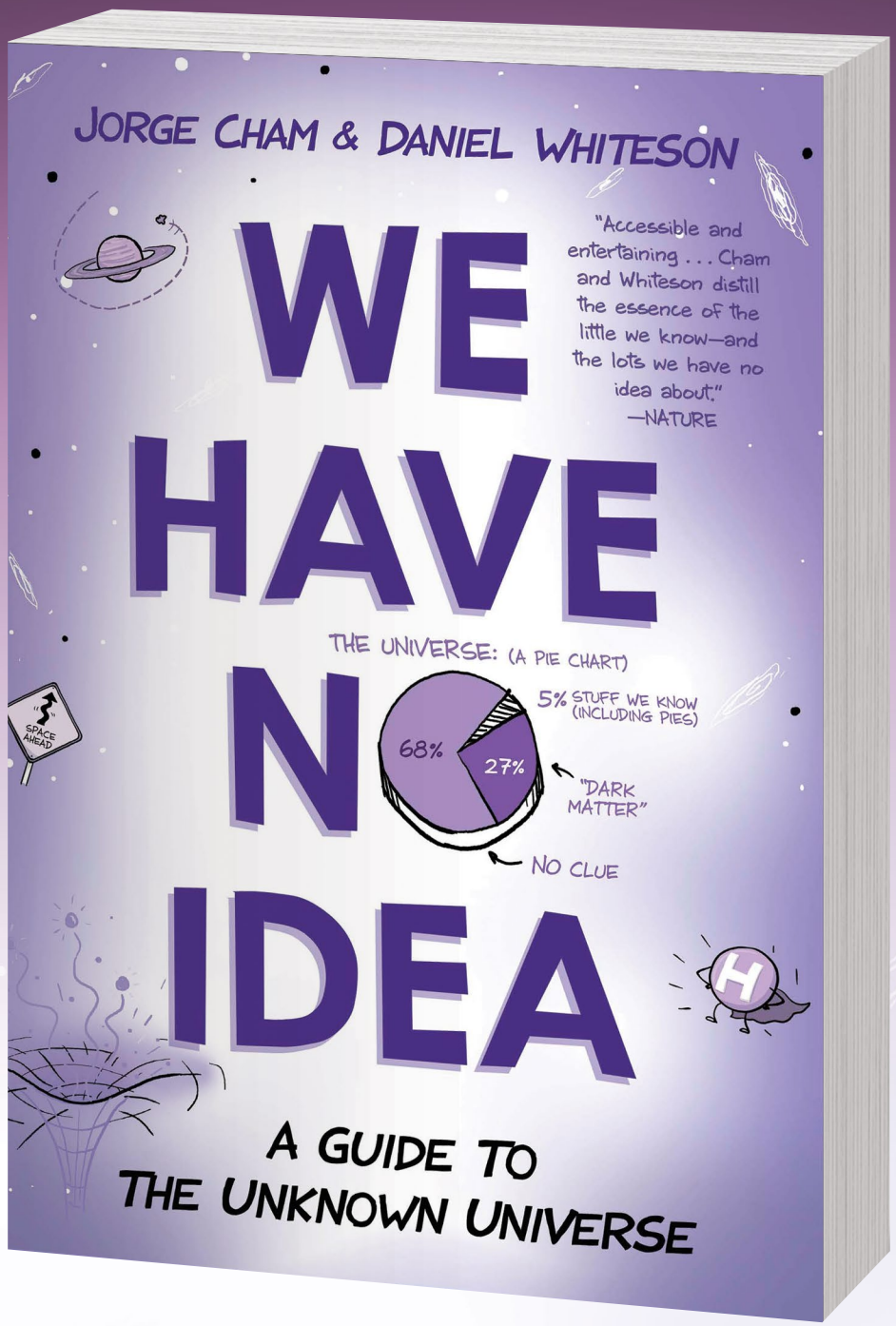
TEACHER'S GUIDE to

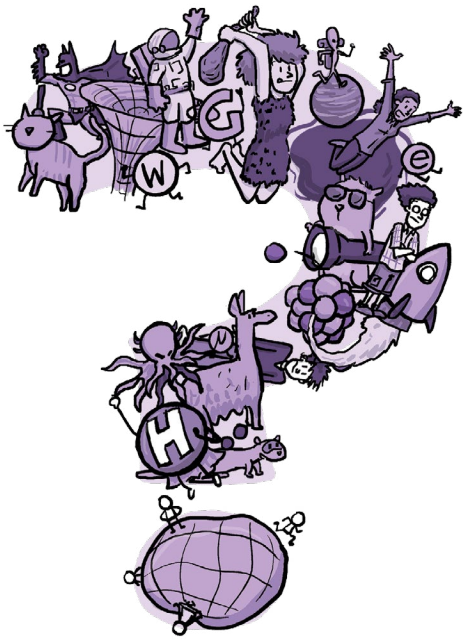


Penguin Random House
ACADEMIC MARKETING

In *We Have No Idea,* PHD Comics creator Jorge Cham and particle physicist Daniel Whiteson have teamed up to explore everything we *don't* know about the universe. Armed with their popular infographics, cartoons, and entertaining and lucid explanations of science, they offer the best answers currently available for questions that are still perplexing scientists.

This fully illustrated introduction to the biggest mysteries in physics also demystifies many complicated things we *do* know about, from quarks to gravitational waves and exploding black holes. With equal doses of humor and delight, Cham and Whiteson invite students to see the universe as a vast expanse of uncharted territory that's still theirs to explore.

DISCUSSION QUESTIONS



- What mystery about the universe would you most like to see scientists solve? Explain why.
- What unanswered questions about physics did you think already had answers? Why is it surprising that scientists don't have answers for them yet?
- Pick one of the questions from the book's table of contents. How would you explain the answer to a friend who hasn't read the book? (Please don't say "We have no idea!")
- Why is it important to think and learn about the things we don't understand about a subject? Think of something you'd like to get better at (a subject in school, a sport or activity, a problem you're trying to solve). How would you go about figuring out the unknown unknowns—the things you don't know you don't know—of that particular subject or problem?

AUTHOR Q&A

How did you end up writing a book together?

Daniel is a particle physicist who does research at the Large Hadron Collider (LHC) in Geneva. He realized particle physics is hard to understand without visuals, because a lot of the concepts deal with such tiny or counterintuitive objects. So he reached out to Jorge, who draws the web comic Piled Higher and Deeper (also known as PHD Comics). Together, we made a comic and a video about the work being done at the LHC, which is probably most famous for discovering a particle called the Higgs boson. Once we made the one video, we realized we had a lot of questions about science that we wanted to try answering together. Rather than developing comics that explain existing scientific discoveries, we thought it would be fun to write a book discussing some of the biggest unsolved questions in the universe.

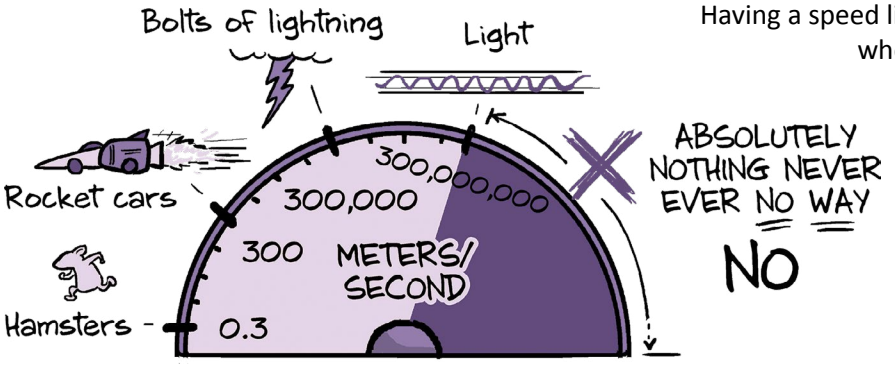
Why are you so interested in the things we don't understand about physics?

We like to look out into the universe and think about the possible crazy things that could be revealed to us. Most popular science books focuses on answers—explaining what we do know. Many grand mysteries of the universe have been cracked open by science, from the makeup of matter on Earth to the nature of the stars in the sky. But future scientists may be wondering, "What's left for me to discover?"

The answer is, well, almost *everything*. Science has always been about exploration, about sailing into the ocean of the unknown and trying to learn new things. There are big open questions that actually do have answers. We just don't know them yet. In fact, we only know what's going on in about five percent of the universe at this point.

What are the benefits of explaining science with illustrations as well as words?

There are two reasons. First, physics is a very visual subject. We are seeking to explain the structure and organization of the universe, and that is often better done with diagrams and pictures. Second, *cartoons* are a great way to do it because they are not intimidating or self-important and they can make the subject feel more accessible. Drawing a scientific concept is a great way to make sure you're explaining it in an understandable way.

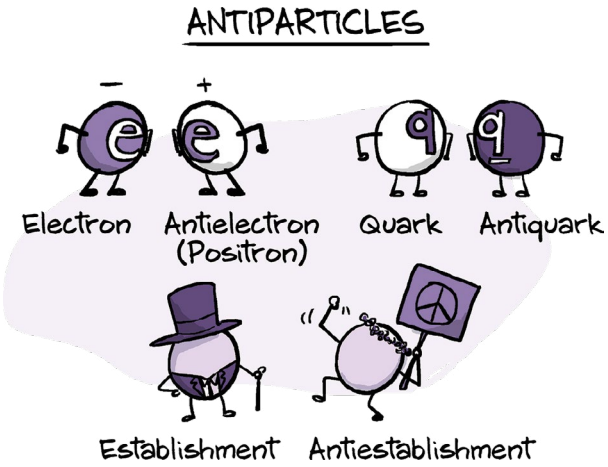


Did you write about any subjects that seem like they would be simple but turned out to be surprisingly complex and mysterious?

A lot of people know that the universe has an unbreakable speed limit. It's a key part of everyone's favorite physics equation, the "c" in $E=mc^2$. (In case you're curious, c, the universe's speed limit, is 300,000,000 meters per second.) But why can't anything move faster than light? Nobody knows! It seems deceptively simple that light has a set speed that nothing else can exceed, but it gets very complicated when you consider the ramifications of it. Having a speed limit actually throws into question the whole idea of time, causality, and any kind of consistent order of events in the Universe.

Did anything that seems complex and mysterious turn out to be fairly simple?

Dark matter is something that people have heard of, and which sounds complicated and mysterious. But the little we know about it is actually pretty simple. We know it's there, and we know how much of it there is. That's about it! It turns out that there is a lot of it (five times as much as there is of our kind of matter) and that it is all around us, in huge blobs that envelop each galaxy.

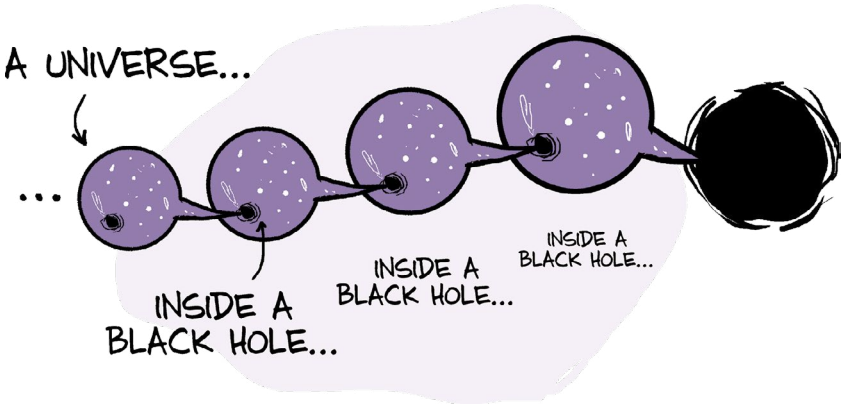


What were you most surprised and excited to learn we have no idea about?

Antimatter is such a tangible mystery, so it seems like we should understand it a lot better than we do. Antimatter particles are a lot like regular matter particles, just with a different set of characteristics. We have a theory for them, we've seen them in the lab, and we can create them. But there's one thing we don't know about them: why is there more matter than antimatter in the universe? Why aren't we all made out of antimatter instead of matter? We have no idea, and the answer could totally change our understanding of the universe.

If you could ask the universe one question and be guaranteed an answer, what would it be?

We'd love to know what happened before the Big Bang. We know something about what happened in the earliest moments of the universe, and what we do know is pretty weird. But what came before, and what caused the Big Bang to happen? The answer would tell us so much about how our universe works, and even how it will end. Is our entire universe contained inside a black hole in another universe? Are we caught in an infinite loop of Big Bangs followed by Big Crunches as the universe expands and contracts over and over? The exciting thing is that there is very likely an answer to these questions, and the evidence needed to reveal it might be within our grasp if only we had the tools.



Where else can we learn about how little we know?

We are launching a podcast called "Daniel and Jorge Explain the Universe!" where we will take this same light-hearted and down-to-Earth approach to other big questions in science. You can also find explainer videos Jorge made with Daniel and others at **http://phdcomics.com/tv**.

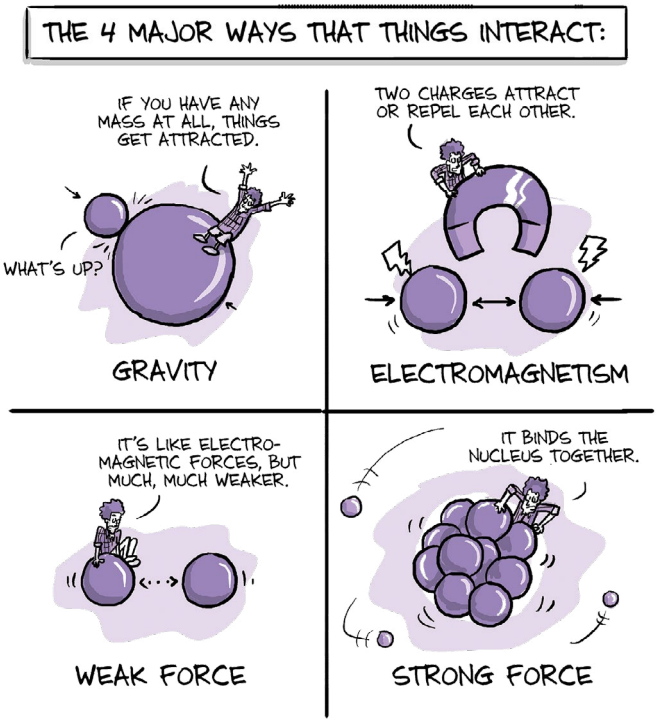
Does it seem likely that any of the mysteries you describe in the book will be solved anytime soon?

There are two fascinating areas of study that seem likely to yield some interesting results. One is dark-matter experiments. We don't know what dark matter is, and it's astounding that most of the matter in the universe is a mystery. It would be wonderful to discover whether it's made of particles and what those particles are like. Scientists are using big underground dark-matter detectors like LUX and XENON to try to figure this out. The next few years will tell us if dark matter is a discoverable particle.

The other exciting area right now is space observation. Observatories like the James Webb telescope are going to give us such an amazing view of the early universe. Almost every single time humanity has built a new telescope and looked out into space, they've found something crazy—something they didn't expect, something they didn't initially understand, something that made no sense, that upended our view of what's out there. We're very excited to see what the James Webb telescope discovers.

CLASSROOM ACTIVITIES

1 Imagine you've been hired by your local newspaper to illustrate articles about science. Find an article in the news about an exciting new science finding. Draw an illustration that explains the main concept visually. Remember that your drawing doesn't have to be complicated—in fact, the simpler it is, the better!



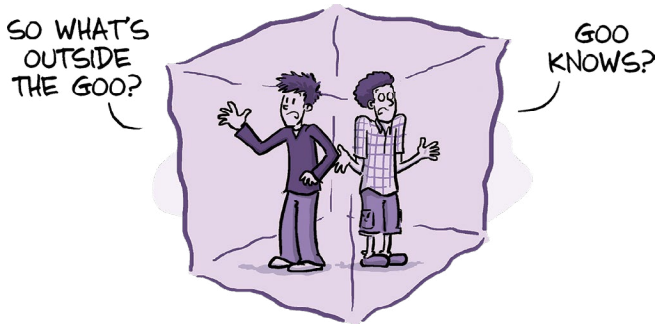
2 Team up with a classmate to create a science comic together. First, each of you should write four sentences on your own explaining a topic you recently learned about in class. Then give your written description to the other person. Divide a piece of paper into four boxes and illustrate each of the four sentences you received from the other person, then hand it back. Does seeing your words translated into images make you think of a better way to explain your topic?

3 Metaphors are a powerful way to explain complicated scientific concepts, by comparing something complicated and unfamiliar to something that's easy to understand. Pick one of the following concepts, research how it works, then come up with a metaphor to describe it to someone who doesn't know anything about it.

Dark matter	**Black holes**	**Text messages**	**Zippers**
Gravity	**Electricity**	**Bicycles**	**Toilets**

Example: Space is not emptiness. It's a physical thing, like a huge blob of thick goo that we're all stuck inside. Normally, we can all move around in the goo without any problems, just like we can move around a room full of air without noticing the air particles. But under special circumstances, this goo can bend, ripple, and stretch. You can think of gravity as the bending of space: if there's a big object in the goo, like a giant bowling ball, it distorts the space around it, squishing the goo and drawing other objects toward it.

4 We have no idea what dark matter is. The world's smartest scientists, stumped, have asked you to come up with your own theory about what it could be. Is it the inverse of our universe, with strange dark-matter versions of Earth, the sun, you, and all your friends? Is it a giant invisible plant that operates as a single hive mind? Matter that's made entirely of emotions? Anything is possible! Think about what life would be like in your theoretical dark matter universe. Then think about how might we go about testing whether or not your theory is right.



5 You are a famous particle physicist, and you've been studying the fundamental particles of matter. Until now, we only knew of these twelve particles:

THE "FUNDAMENTAL" MATTER PARTICLES

	1st GENERATION	2nd GENERATION	3rd GENERATION	CHARGE
QUARKS:	UP u	CHARM c	TOP t	+2/3
	DOWN d	STRANGE s	BOTTOM b	-1/3
LEPTONS:	ELECTRON e	MUON M	TAU T	-1
	ν_{ELECTRON} ν_e	ν_{MUON} ν_m	ν_{TAU} ν_t	0

SOME MASS → MORE MASS → EVEN MORE MASS

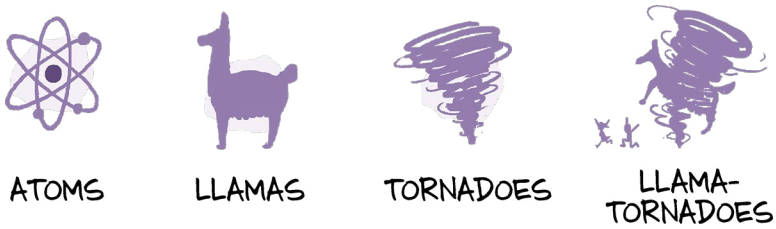
But you've just discovered some even more fundamental particles, the things that these other particles are made of. Now you have to describe them.

What are you going to name your particles? As you can see above, there are no real rules for what you should call it.

What are your particles' charges? Whatever they are, you have to be able to combine them to create the quarks and leptons listed above. The charge of the bigger particle is the sum of the smaller particles that make it up. (For example, a proton is made up of two ups and a down quark, with charge = ⅔ + ⅔ – ⅓ = +1. A neutron is made of one up and two down quarks, with charge = ⅔ – ⅓ – ⅓ = 0.)

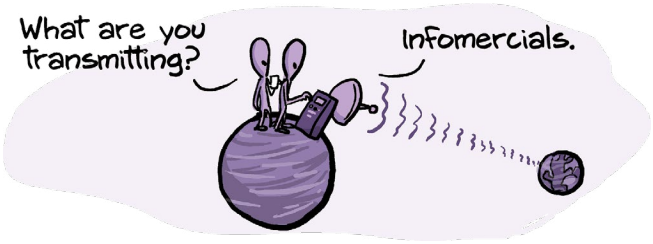
How do your particles hold together? For example, the Hydrogen atom is a proton and electron held together using electromagnetism (which uses photons to communicate). And protons are quarks held together by the strong force (which uses gluons to communicate). How are your particles held together?

NOT THE FUNDAMENTAL UNITS OF THE UNIVERSE:



ATOMS LLAMAS TORNADOES LLAMA-TORNADOES

6 What message would you want to send to any aliens who might be out there listening to us? Write a message that you would broadcast out into the unknown universe. What would you tell them about life on Earth? How would you convince them not to view us as a potential threat?



7 You want to know how likely it is that anyone will hear your message. We can use the Drake equation to estimate the number of intelligent species we could potentially talk to (N):

$$N = n_{stars} \times n_{planets} \times f_{livable} \times f_{life} \times f_{intelligent} \times f_{civ} \times L$$

This number changes as we learn more about the universe. Plug in three sets of guesses for the following variables to see how many alien civilizations we have the potential to contact in each scenario:

n_{stars}: The number of stars in the galaxy (our current guess is 100 billion)

$n_{planets}$: The average number of Earth-like planets per star (right now our guess is 0.2, but there could be more!)

$f_{livable}$: The fraction of those planets that could support life (between 0 and 1)

f_{life}: The fraction of livable planets that actually develop life (between 0 and 1)

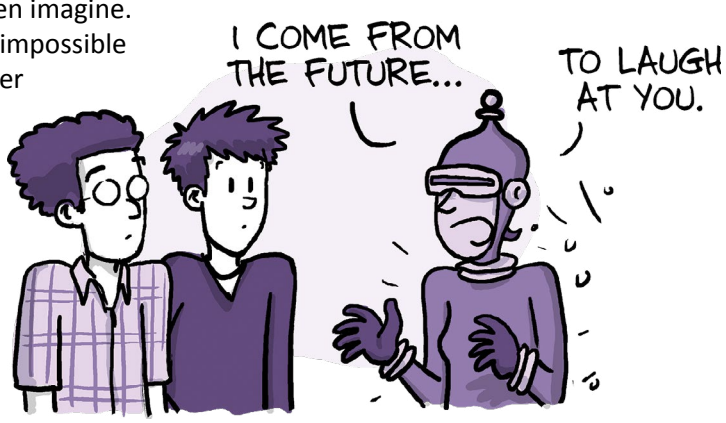
$f_{intelligent}$: The fraction of planets with life that develop intelligent life (between 0 and 1)

f_{civ}: The fraction of intelligent species that develop technological civilization and can send messages or spaceships into space (between 0 and 1)

L: The probability that they are around at the same time as we are (choose a percentage between 0 and 100, then divide your number by 100).

8 The universe is stranger than scientists can even imagine. Luckily, science fiction writers love to imagine impossible scenarios beyond our current understanding. Consider one of the following open questions about physics:

- What happens inside a black hole?
- What is the most basic element of matter?
- How many dimensions are there?
- Is time travel possible?
- Can we control gravity?
- Are we alone in the universe?
- What happened before the Big Bang?



Come up with a premise for a science fiction novel about a future where we've answered one of these questions. What did the answer turn out to be? How does this knowledge change life on Earth (or beyond)?

RESOURCES AND REFERENCES

Check out PHD comics here: **http://phdcomics.com**

Learn about the Large Hadron Collider here: **https://home.cern/topics/large-hadron-collider**

Watch Jorge's science explainer videos here: **http://phdcomics.com/tv**

Listen to Jorge and Daniel's podcast here: **danielandjorge.com**