Science AMA Series: I'm Christophe Galfard, a theoretical physicist and author of The Universe In Your Hand. I write and speak about the science of the universe, from black holes to our cosmic origins and nearly everything in between. AMA!

Christophe$_{G}alfard$[1]$andr/ScienceAMAs$[1]

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Abstract

Hello Reddit! My name is Dr. Christophe Galfard and I'm a theoretical physicist and author of The Universe In Your Hand. I hold a Ph.D. in Theoretical Physics from Cambridge University where my supervisor was the world-renowned Professor Stephen Hawking. I worked with him on black holes and the origin(s) of our universe for many years. While I'm no longer at Cambridge, I now spend pretty much all my time spreading scientific knowledge to the general public in [hopefully] entertaining ways. From the tiniest particles to the edge of our known universe as well as theoretical scientific attempts to unify all known forces in a Theory of Everything, I seek to help everyone understand the science of our world - as it is seen by today's scientists. How was our universe formed? Why do stars die and why do some of them become black holes? Our world is filled with mystery, excitement, and questions whose answers still escape the brightest minds to walk on Earth. My goal is to help everyone who wants to learn more about our universe and how it works in a way that anyone is able to understand and grasp. If you've ever had a question about the solar system, the Big Bang, dark matter, parallel universes, quarks, or anything else (science related!), now's the time. I will be back to answer your questions at 3 pm EDT, Ask me anything! Well, there are so many brilliant questions that I've left unanswered that I feel a bit bad about it, but it is time for me to wrap this up... I'll try to come back to answer some of these in the days to come. In the mean time, thank you so much for your questions, I've had a great time answering as many as I could! And don't ever forget to keep asking questions about our beautiful world! Christophe

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R/SCIENCE CHRISTOPHE_GALFARD

Hello Reddit!
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What are some discoveries in theoretical physics that we can reasonably look forward to over the next 20 years?

oskiwiiwii

Let's put it this way: there are two kinds of discoveries that could happen. The first type consists of theoretical breakthroughs. The other are experimental ones. So let's begin with a theoretical one, and I'll here mention one that may have something to do with my field of work: some kind of breakthrough in quantum gravity would be awesome. As you probably know, we today have two theories that are extraordinarily powerful at explaining our reality: Einstein's General Relativity, for the very big, and Quantum theory for the very small. But they don't match. To begin with, they don't use the same notions of space and time. To reconcile both is what a theory of quantum gravity is all about. Why would that be awesome? It would allow us to understand things we today can't, like the Big Bang and what happens at the heart of black holes. Now about experimental discoveries. I'll just list a few: - the

of The Universe In Your Hand. I write and speak about the science of the universe, from black holes to our cosmic origins and nearly everything in between. AMA! , *The Winnower* 3:e146141.15845 , 2016 , DOI: 10.15200/winn.146141.15845

nature of dark matter - the nature of dark energy - the existence of extra dimensions (very cool) - black holes in the lab (very cool) - discovering a new type of particle that does not fit within existing theories. - Proof of an initial cosmic inflation (and maybe the occurrence of many big bangs). I may think of some more soon, as I reply to other questions!

How much faith do you have in math itself, in terms of it's reliability to draw conclusions about the universe, cosmic origins, etc?

Here's where I'm coming from... I have a B.S. in Applied Math, with a focus on physics and physical chemistry. During my studies, I become more and more skeptical of physicists (particularly theoretical physicists) that made conjectures about the universe (or anything else) based solely on math, as opposed to stuff that can also be tested in a lab.

It just seems like there's so much speculation. I know...that's why it's called "theoretical". I get it. But even in undergraduate courses, we'd derive equations that were supposed to provide proof of what's going on in our physical universe. I could see what we derived, but I often doubted the conceptual implications.

And that was just a B.S. in Applied Math. I can't even imagine what everything looks like at the graduate level. I also wonder if I had gone to graduate school - would it have given me a stronger foundation and filled in the missing pieces, causing me to have more faith in those that talk about the universe, black holes, cosmic origins, etc., or...would I be even more of a skeptic.

tl;dr - How reliable are these maths? Are they reliable enough to make solid conjectures about black holes, cosmic origins, and other topics that theoretical physicists tackle.

SF___SF

That is a very pertinent question. Let me put it this way: we (humans) started in the dark, from scratch. We figured out that Nature obeys some laws. And we found out that one, only one, tool could help us understand these laws. Mathematics. That being said, there is a huge difference between mathematics and physics. I've met many mathematicians who would pull their hair at the way physicists used the maths. But we do not have any other tool! None! That may well change in the future, but today, that's it. Still, we have that, and the mathematical physics has allowed us to discover a universe, a reality, far bigger and more beautiful than was thought. Now about assumptions: it is very hard to understand the universe as it is, in its entirety. So what physicists do is that they try to find some principles to which they believe Nature abides. Many of the principles put forward over the ages have turned out to be wrong. But some seem to be right. And these assumptions have mathematical implications that led to experimental discoveries. Let me give you an example: to study the universe as a whole, to try to mathematically describe it, you can assume that it looks the same wherever you are. On a very large scale that is. If you don't, then your equations do not lead to a universe that looks like ours. If you do, then it does (I am being very schematic here). And you can then have a look at what that implies. This means imposing a certain symmetry upon our universe. The same can be done for particles, in the quantum realm. New symmetries have led to the discoveries of new particles. So yes, the mathematics used are reliable. So reliable that they can tell you the mass and electric charges of particles with an accuracy of more than one part in a billion even before those said particles are discovered. That being said, one of the beauty of (real) science is that no assumption is taken for granted. They will always be put into question, in light of new discoveries. Still, as far as I know, mathematical physics and mathematical physics only has ever allowed mankind to discover something about our reality that was beyond our senses.

Recently one of my favorite astrophysicists (Neil deGrasse Tyson) commented on how he thought the

chances of our universe being a simulation was 'Very High' which is pretty much opposite of what many others in the field believe (from what I have read).

Where do you stand on the thought? And do you have any other 'out there but scientifically plausible' theories on the meaning/purpose/etc of our known universe?

SuspiciousDroid

I actually love this question! I do not know whether Neil said that or not, so let's just see what it would mean for us and forget about the probability of it being the case. My take is that it wouldn't make much difference: were we to discover we live in a simulation, the question would then be about the meaning of the world that created that simulation. And I do not know about any meaning or purpose of our known universe. Which, from my point of view, makes it an even more beautiful place: we are free to create that purpose for ourselves!

I have a question about the profession itself.

As someone *really* into physics, I'm considering going for a degree in theoretical physics, but I am worried about actually getting a job somewhere. Just what are the possible career paths for someone with this degree?

Also why is there no repulsive gravitational force? Every other force (strong, weak, electromagnetic) can be both attractive and repulsive. So why not gravity?

Thanks a lot!

harry353

First of all, you should go into physics for the sake of it! Now it so happens that once you have that degree, many private companies may contact you to do something different altogether.

About no repulsive gravitational force: dark energy acts as one. What it is however, is not yet known.

Thank you for doing this AMA, Dr. Galfard! Since the expansion of our universe is accelerating will there ever be a point where a photon will seem to reverse direction because the space between two points is expanding faster than the speed of light? Is there a limit to the rate of expansion of the universe?

jmwilli25

Thank you for your question. The way things move in our universe is very tricky. It depends on who's looking at them. But in the vacuum of outer space, a photon always shoots straight ahead (and straight ahead, if the path is curved, may not be a straight line) at the speed of light. Now the expansion of the universe, as you may know, is not something that acts on the velocity of the objects themselves. Rather, it is a process that stretches the distances. So to get from one point in our universe to another, very, very far away, light will have to shoot through a path whose length increases with time. As far as I know, there is no limit to the theoretical rate of expansion of the universe, so extremely far apart points may well have the distance separating them increase at a rate faster than the speed of light. That, by the way, does not contradict Einstein's light-speed velocity limit: it means that those two points will never, ever be able to communicate with each other. A photon sent by one to the other would have to cross a distance that stretches faster than the photon an fly. It would still shoot ahead, though.

What's something about the universe that most people don't know about but should?

happygloomy

That we can understand it. That we know much more about it than we used to. That it has a readable history: we can for instance read in the stars what the story of our planet is (by comparing it to other planets' histories). That we should all stick together to try and understand it and protect ourselves, because away from the shelter that our home planet provides, it is a very, very violent place.

How do you deal with the fact that there probably is a limit to what we can figure out? That although we know so much, we probably even haven't scratched the surface of understanding the nature of reality? I love physics and want to pursue a degree in it, but this bothers me.

And also, how do you think consciousness arises from non-conscious objects? If we're made of cells which are made of molecules, which are made of atoms and so forth.. how can we experience a self? It just seems like magic. Can science ever answer this question?

theoman333

Every epoch has its limits. We, today, know much, much more than any of our ancestors. But our knowledge has its limits too, and it is my belief that this will remain true forever. Had we already figured out every thing, I would strongly advise you against pursuing a degree in physics. But we haven't, and that's what makes science so exciting. And about consciousness, well, I do not believe I am qualified to answer that question. Still, as far as I know, as of today, we know more about our universe than we know about our brains. So there may be nice scientific breakthroughs to be made there too.

Greetings, Dr. Galfard. Thanks so much for doing this. My question is as follows:

How likely or unlikely do you think it is that dark matter and or dark energy could be explained by a theoretical remodeling of General Relativity, or perhaps even by a brand new theory of gravitation all together?

Two4ndTwois5

First of all, let me say this: dark matter and dark energy were 'found' using General Relativity (actually, Newton is enough for dark matter). Had we not that theory, we wouldn't have found these mysteries. So I would answer your question this way: if we somehow figure out, in the years to come, that dark matter and dark energy actually do not exist, then it would imply that General Relativity needs remodeling.

What made you pursue physics? What was that one spark that made you say "I'm going to be a physicist"? Also, how much work is it to be a physicist? I've always wondered that.

TetraxZ

Personally, I don't see anything more intellectually satisfying than trying to unravel the laws of nature. The fact that we have inherited from our ancestors a way to do it (that's physics), is a wonderful gift. I wanted to learn what was known, and maybe a bit more. I wanted to figure out how the universe was born, how we came to exist and all that. We've only been able, as a species, to try and answer these questions for about a century.

Hi Dr. Galfard. I've always felt that once you get to a certain level of knowledge where you become an expert, you lose some of the wonder of the world, since it can all be explained with science. What's out there in the universe that still brings you that wonder and makes you feel like a kid again?

jrm20070

Hi jrm20070, well, I agree with the suggestions given below by BNNJ and theoman333 !

Hello Dr. Christophe Galfard, i have two question regarding the expansion of the Universe. In a "TED-talk" i heard some physicist say that the expansion of the Universe isnt slowing down like it should be (if the driving force was the big bang) but its even accelerating. My questiond: Is this true? and how do you mesure such a thing, since we cant even observe the edge of the Universe?

Best regards, Christian.

Szogun1

Hi Szogun1, let me add some things to what cypherpunks replied below. First of all, yes, it is correct indeed: the expansion of our universe does seem to have accelerated recently (5 billion years ago). That very unexpected discovery earned Perlmutter, Schmidt and Riess the 2011 Nobel Prize in Physics. And they indeed figured that out by looking at the light that was emitted by far away exploding stars. But not any stars, special ones, ones that we believe we know how they explode. They are white dwarfs that swallow the matter from a nearby giant stars. When they reach 1.4 times the mass of the Sun, boom, they blow up. And they always blow up in the exact same manner, so by comparing the light from this explosion as it arrives here on Earth to what we expect it to be near the explosion, these scientists were able to tell how far the stars were and how much of the universe's expansion their light had to travel before reaching the Earth. That is how they 'saw' that our universe's expansion started accelerating about 5 billion years ago.

What is the current tendency of scientists in your field and/or you regarding what might be outside our Universe?

Iceklimber

There is a funny thing about the word "universe". It is made out of "uni", which means "one" and "verse" which means "turned into". So universe basically means "turned into one". By definition, there hence is nothing outside. That being said, "atom" means "that which cannot be cut". Yet we today know they can. So let's define our Universe as everything that may have been, is, or one day will be within our reach, whatever the technology, known or unknown. Then it is true that some research has led to the existence of other universes. There are several types of such universes. Some rely on the existence of extra dimensions. Dimensions that are not the ones we know: neither left right up down in front or behind. Nor time. You'd need another word to point someone in that direction. But were you to be able to travel along that (or these) direction, you may end up in another universe. Within this scenario, there is, indeed, something outside our universe.

Another type is due to quantum effects. In such "many world" scenarios, every time there is an interaction in the world of the very small, every time a quantum state has to chose between different possibilities, as many 'parallel universes' are created, where all these possibilities become realities.

But there is a catch: we've yet to find proofs of the existence of either of these, and the second one will most probably forever remain beyond our experimental reach, so it may not be science...

What do current theories and evidence say regarding whether space-time is continuous or discrete (e.g. loop quantum gravity)?

Where do you fall on the issue?

hexachoron

I personally don't see how space-time can be continuous. There has to be some quantum effects down there and that also should apply to space-time. Now, whether loop quantum gravity is correct or not about it, time will tell! All the theories we have so far are not yet able to make predictions that can be experimentally checked. Let's hope that will change soon.

Have you come across the sum of all integers equalling -1/12 thing? Is that equals sign a little bit bogus? I think it's only equal in the context of other infinities. How many dimensions are there? If I'm interested in this stuff, in what area should I do my M Sc? Mathematicians seem a bit clueless in comparison to physicists to me, but it really is the math that I'm interested in. Thanks

ruorgimorphu

Hi there, here's a link to a post by David Berman (who is very good, by the way). It will answer your questions: https://plus.maths.org/content/infinity-or-just-112

Can you give a 'real world' example as to the scale of the entirety of the observable universe? If the Sun was a penny, etc..

pw0803

Tricky. The universe is huge. But let me put it this way: imagine you are living in the future and that mankind has colonized every single star in the universe. You'd then have friends everywhere and you'd want to give them a call. When you use a mobile phone, your voice is basically turned into light and travels at the speed of light. To reach a friend on the Moon, your voice would have to travel for one second. So you'd get a reply 2 seconds later. To reach the Sun, your call would take about 8 and a half minutes. To reach the closest star after the Sun, it would take more than 4 years. To reach the Andromeda Galaxy, our largest galactic neighbor, 2 million years. To reach the edge of the visible universe, 13.8 billion years.

To put it another way: the Sun is, say, to make it easy, 1 million kilometers in diameter. Light can shoot through that distance in 3 seconds. The visible universe is 27 billion light years wide. So whatever you start with for the Sun, be it a penny or anything else, you'd have to multiply that by about (roughly) a million billion (off the top of my head).

Other than the fact of red shift, is there any other supporting evidence for the big bang? Doesn't the fact that you have to make up things like dark energy and super expansion seem to suggest there are more problems with the theory of a big bang than by suggesting that light loses energy over the huge distances it travels.?

Just2bad

There are many supporting evidence for the Big Bang. The red-shift is evidence for our universe's expansion, not for the big bang itself. But it does suggest that since the universe is expanding, it must have been smaller in the past (I'm here talking about the visible universe, the universe we can see using light). Using such a logic, you reach a moment in our past when the energy of everything we

today see was packed into a much tighter volume. So tight that it was opaque to light, meaning light could not travel through it. If you now run time forward, it means that there was a moment in our universe's past history when it turned from opaque to transparent. And that should show in the sky. And it does. That is what scientists have called the cosmic microwave background. It's existence was predicted before it was detected (in 1965, by Penzias and Wilson). To learn more about it, you can read this: http://science.nasa.gov/astrophysics/focus-areas/what-powered-the-big-bang/

What is something concerning space and physics that you can't wrap your head around? Many things are so hard to understand to me...

KrishaCZ

Pretty much everything about our universe is very hard to visualize. That is where maths become useful. Let me give you an example: if I ask you to picture infinity in your mind, you'd be in trouble. But there is a symbol for it in mathematics, the 8 (horizontal), which allows you to 'think' it. In physics, maths are used to picture things, to manipulate them, sometimes without having to picture them in our minds. Where words are at a loss, maths come in very handy.

Do you think the theory of Relativity is flawed and thus can be challenged? Is there any time when the theory of Relativity is preventing scientists from getting the "answer"? (I'm not a science person, I apologize if these questions sound dumb)

wingchauusa

I wouldn't say that the theory of relativity is flawed no. A better term might be incomplete. And that it is. We've known that for about half a century now, thanks, for instance, to the work of Roger Penrose and Stephen Hawking. They showed that if you rely on General Relativity, then there must have been a time and space in the past when and where there was so much energy everywhere that the very notions of space and time used by general relativity don't work anymore (that's the Big Bang). These are the "singularity theorems" of Penrose and Hawking. They also apply to black holes. So, in a sense, General Relativity is very humble: it predicts its own downfall. That is one of the reason why scientists are today trying to find a quantum theory of gravity. Such a theory would not abide to Penrose and Hawking's theorems and may not lead to a breakdown.

If "nothing" can "get out" of a black hole, including light,

how does the rest of the universe "feel" its gravity?

denizen42

Actually, it is not true that nothing can get out. That was what was believed before Hawking's 1976 discovery of black hole radiation. Nothing can get out of a black hole if you only consider gravity. But if you include quantum effects, then it is not true anymore.

About your second question: gravity weakens with the distance, so if you are far away enough from a black hole, you won't feel its pull at all.

What is up with this "dark energy/matter?" Is there an "Explain it like I'm 5 version of it? It feels like there is a "we know it is there, but we don't know it actually is."

nauticalfiesta

You're right: there are many clues pointing to the fact these things exist, but we still do not know what they are. In short: dark matter is a type of matter that has some gravitational effect. It was noticed at the beginning of the 20th century that stars in galaxies where moving far too fast to be held within their home galaxy by the gravity created by the stars and dust we see. They basically should fly away, like a marble made to spin too fast in a salad bowl. But they obviously don't. Si it was suggested back then that there should be some kind of invisible matter, matter that does not interact with light but with has a gravitational effect, responsible for this. Dark matter. Many independent experiments have led to the same conclusion, with no indication yet as of what that matter may be made of (all the matter we know interacts with light). Dark energy is something else altogether: it is responsible for the accelerated expansion of our universe. But we don't know what it is either... Let's hope new young physicists will figure that out for us!

What are some good starting books for people interested in physics?

Swantik

Well, if I may, mine! "The Universe in Your Hand" is the title.

http://www.amazon.com/gp/product/1250069521/ref=s9_simh_gw_g14_i1_r?ie=UTF8&fpl=fresh&pf_rd_m=ATVPDKIKX0DER&pf_rd_s=desktop-1&pf_rd_r=0WWG2QGZK0QK0VFX6D9H&pf_rd_t=36701&pf_rd_p=2437869742&pf_rd_i=desktop

If we theoretically made a hole straight down the center of the earth and someone jumped down (pretending they wouldnt get burned up by the earths core) would that person eventually slow down and stop near the center? Or would the fly out the other side?

Larroux

The person would fall to the other side and stop at exactly the same height he or she jumped in the first place (assuming there's no air friction), before falling down again, going back and forth. But with friction, he or she would not reach the same height and end up, after a while, at the center of the Earth, like a marble left to fall from the top of a salad bowl.

Does gravity react instantaneously or is it bound by the speed of light? And, if the latter, does it react at the speed of light or just close to? For example, say an object was flying across a planet parallel to the tangent line though close enough to be affected by the gravity, and, despite its impossibility, was going exactly C, would it not being affected by any of earth gravity until after it stopped? What would happen?

skilletzx

Gravity travels at the speed of light. Nothing carrying information of sorts can travel faster, and gravity carries some information (like about the mass of the object that creates it). For objects traveling at the speed of light, or close to, nearby a moving object you'd need to use the special rules of general relativity to figure out how gravity would affect the object. And remember: before the Earth was built, the matter it is now made had already been around for a while, so it already had a gravitational impact.

Hi! Thanks for doing this, I found your book in an airport bookstore and couldn't put it down the whole

trip! I greatly enjoy this realistic sci-fi genre that is emerging with books like yours and The Martian so I am just wondering, who else do you think does a good job of entertaining or even storytelling while teaching "99% real" science? Second, I was hoping to hear your point of view on the non-existence of an observer-independent reality, which John Wheeler said "can no longer be upheld," and what that means for you. Thank you so much!

new_to_cincy

At last someone who's read my book! (It's only been out 3 days in the US though...) Thank you for your comment! I haven't read it yet, but I think Carlo Rovelli's Seven Brief Lessons on Physics is very good, as well as Janna Levin's Black Hole Blues. Now, about Wheeler's take: that's a difficult one. It so happens that the laws of quantum physics are so different from the ones our intuition makes us believe the world obeys that it is always very tricky to try and understand them out of our everyday experiences. That being said, I believe that Wheeler's point of view, although rather controversial at the time, is actually held by most today. Every time we (or anything really) interacts with the very small (and we do that all the time), we have an impact on it. Nature seems to work this way. And I'm pretty certain that is also the case in the very big. Albeit not for quantum related reasons.

Dr. I have a crippling anxiety that the universe will collapse any second and this keeps me up at night. Are my fears unfounded? Also, if it was collapsing would it be instantly or over time to collapse?

Rangider

Well, you can rest easy. It is not going to happen. There is not a single indication anywhere neither in the present nor in the past that this could happen. And as far as we know, our universe obeys some laws. These laws cannot be broken. And none of them allows any such thing.

Hi Dr. Galfard, first off, I would like to thank you for your efforts in educating the public about the beautiful universe that we're in right now. There's just so much to learn about the nature of reality! Okay, moving on to my question. Is it proven that there is life thriving on other planets? If so, what is the ratio of livable planets to the non-livable ones?

ThatEngineCadet

Many thanks for your comment! And no, it is not proven that there is life anywhere at all but on Earth. Even though many believe (or hope, or fear) that life our universe in teeming with it, we are yet to find a single occurence of it somewhere else. That being said, we are at the beginning of that search. The first exoplanet (that's a planet orbiting a star that is NOT the Sun) was discovered only 22 years ago. Since then, we've had confirmation of about 2000 more, no more than a dozen of which may be suitable for life as we know it. And we are just about to have the technology to figure out what their atmospheres are made of... You can look at this : http://phl.upr.edu/projects/habitable-exoplanets-catalog

Would you mind explaining how 'The Big Rip' would occur, and the likelihood of its occurrence? Also, what do you think the end of the universe will be?

spaghetti335

Let's put it this way: the universe we live in seems not only to expand but that this expansion accelerates. So here is what that means: the expansion means that the distances between two very far apart object increases. The 'very far apart' bit is important, because locally (around the Earth, say),

gravity is stronger. You need huge expanses of emptiness for expansion to occur. There's no expansion between the Earth and the Moon, nor the Earth and the Sun, nor within our galaxy, nor in between our galaxy and our galactic neighbors. Distances have to be bigger. That being said, this expansion is accelerating, so it may one day (in the very very distant future) be stronger than gravity, even locally. That's where the Big Rip comes in. If the expansion of distances was unbounded, it would ended tearing everything apart. That's the Big Rip. Is that likely? I dont' know! (but I'd rather doubt it).

Do you think we will ever have the tools to stop quantum mechanics from interfering with observations of wave functions?

ZedMcgee

No, I don't think so. I think that interaction is an inherent part of the laws of nature. We just have to accept it and try to understand it better.

Would you rather live on Mars or Venus(above the clouds of death)?

dcred123

Mars. Venus is hell.

Are you going to answer any of the above questions?

XbattlefieldX

I'll try!

What made you choose theoretical physics over the numerous other fields within physics? I'm a Berkeley-Bound physics major exploring my options.

imsmartiswear

Intellectually, I think it is the most challenging. But that is a personal point of view. You may find something else more appealing and you'd be right to!

This may be off topic, and I am only a layman just now getting into science and physics, but...In the theory of multiverses, the idea is that there are universes that exist almost exactly as this one, but one small detail is different. And the chain builds for each one of the universes. This creates an infinite amount of universes, correct? Which means, in the grand scheme of things, not only is anything possible, but everything exists?

bigbluewolverine

Yep, you got it.