Didicosm

Greg Egan

1

"Look!" Charlotte's father commanded her, gesturing up at the sky with a sweep of his hand that encompassed every speck of light above them.

He'd dragged her out of bed and driven for more than an hour, finally stopping beside an empty plot of land far from the center of the city. She could see the Milky Way stretching from horizon to horizon, and at any other time she might have marveled at the sight. But she still didn't understand why they'd come here. Her mother was sick; they should not have left her alone.

"I know what the stars look like," she replied. "I want to go home."

"But you need to understand," her father declared. "The stars we can see are just a drop in the ocean. Beyond the horizon, there are more stars, more galaxies. On and on forever. Worlds without end." He raised his face toward the zenith, swaying.

"I don't care," Charlotte retorted.

"An infinity of worlds," her father insisted. "Some of them must be home to a family just like ours." He looked down; even in the starlight, she could see his eyes piercing her. "But some of them won't be quite the same. There must be worlds where your mother's not sick at all."

"I don't care," Charlotte repeated, angrier than ever now. Her actual mother in her actual house was actually sick, and they should never have left her.

"Do you accept it, though?" her father asked. "You need to accept it. Somewhere she's living a better life, with people beside her just like us."

"I want to go home," Charlotte pleaded.

"Not until you understand that I'm telling you the truth," her father replied.

Charlotte wanted to protest that he was starting to scare her, but she was afraid that the accusation would only make things worse. Would he leave her by the side of the road and drive away, if she didn't say what he wanted to hear? Until this moment, that would have been unthinkable, but he was not himself anymore.

"I believe you," she said, as calmly as she could. "You wouldn't say it if it wasn't true."

"Thank you!" He beamed at her and squatted down to embrace her. Then he led her back to the car.

"You'll be strong, won't you?" he asked, as he tugged his seatbelt across his chest.

"Yes," Charlotte replied. *Strong about what?* She was the one facing up to her mother's condition. But all that mattered right now was keeping him happy.

On the drive home, her father barely spoke, but he couldn't stop smiling. Charlotte was sure that she'd never been up at this hour before, but whenever her eyelids began to droop she felt a protest from deep in her body, as sharp and urgent as if she'd stopped breathing, and she snapped back into full wakefulness again.

Back at the house, she drank a glass of water, then her father tucked her into bed. When he turned out the light and left the room, she checked the time on her watch. How long would it take him to fall asleep? She heard the toilet flushing, water running, footsteps, doors creaking. After a while, the crack beneath her door became fully dark, which meant there were no lights on in any of the rooms nearby.

Charlotte decided to wait twenty minutes, using the light button on her watch sparingly because she knew how quickly it could run down the battery. Each time she checked, she wondered if it would be better to close her eyes and fall asleep, hoping that in the morning everything would be normal again. But when her watch finally showed ten to three, and she stood on the brink of abandoning her plan, she pictured her father staring down at her beneath the wild sky, and she knew she had no choice.

She climbed out of bed and crossed the room, carrying her pillow and blanket. She'd begged her parents to give her a phone for her eighth birthday, but they'd laughed off the idea and refused to commit to it even at nine or ten. She turned the handle of her bedroom door and opened it, just wide enough for her to squeeze out into the corridor, bringing the bedclothes along with her. The house was in darkness, but her eyes sketched the space ahead of her in slabs of gray, imbued with a strange granularity that shifted and flowed with each step she took.

When she entered the living room, she couldn't see the small table that held the phone at all, but she knew where it was and she headed toward it, navigating by the larger masses of the couch and the armchairs. On TV, whenever people tried to walk quietly their floors squeaked, but she knew there was concrete beneath the carpet, and her bare feet were silent; the real danger would be if she knocked something over.

When she was sure she was close to the table, Charlotte reached out slowly with her free hand. Her fingers touched nothing but air; she drew back, turned slightly, and tried again. When the side of her hand brushed something rough but pliable, she almost panicked from sheer surprise, but then she remembered the vase full of flowers from her grandmother that her father had left on the table the day before.

She moved her hand away and lowered it, until it made contact with the table. She let it rest there for a while, as hints of the objects in front of her slowly swam up out of the grayness, revealing the white handset resting in its charging cradle.

When she lifted the handset, the small display window and the keyboard lit up. She lay down on the floor and made a tent with her blanket, then held her pillow over the side of her head to help muffle the sound even more. She'd thought of calling the emergency number, but she couldn't trust a stranger to understand why she thought she needed help. Her grandmother would understand, but her hearing wasn't great; even face-to-face Charlotte struggled sometimes to make herself clear. And her grandmother didn't have a car of her own.

She scrolled down through the contacts and found an entry for her uncle, Nate. He was always helping her parents with jobs around the house. But what if he was angry with her for calling so late? What if he thought she was playing some kind of prank?

The phone went dark. Charlotte shook it; nothing happened. She touched a key, blindly; the phone lit up again, showing a 3 in the window. She deleted it, then hit the up and down keys to be sure that Nate was still selected. Then she hit the key with the green handset icon, and heard the flurry of tones from the number being called.

After six rings, someone grunted irritably, "Yes?"

"Uncle Nate?"

There was a silence, then he replied, "Charlotte?" He sounded more disbelieving than annoyed. But then his voice changed abruptly. "Is something wrong?"

Charlotte repositioned the pillow to be sure she couldn't be heard and recounted the trip her father had made her take. Nate let her speak uninterrupted, only asking a single question at the

end. "Your Mum wasn't up when you got home?"

"No." Charlotte didn't want to tell him that she was afraid to go into her parents' room to try to rouse her, but he seemed to understand that she couldn't do that.

Nate said, "I'm going to come over right now, and have a talk with your Mum and Dad, just to make sure everything's all right." He paused for a moment, then confessed, "I don't know if you should go back to bed, or go and wait in a neighbor's house."

Charlotte said, "I'll go back to bed." She did not believe for a moment that her father was planning to harm her, but she was sure that his strange behavior would only grow stranger if he caught her sneaking out of the house.

"All right. I'll be there very soon. Okay?"

"Yes."

Charlotte took the phone away from her ear; it was dark again. She lay still, listening, picturing her father standing beside the tent, ready to upbraid her for her betrayal. But when she pulled the blanket aside there was no one. She stood up slowly, making sure she could see the cradle clearly before she tried to replace the handset.

In her room, she spread the blanket over her bed, but she couldn't bring herself to climb in and pretend to be asleep. If her father found her sitting in the dark, she would just have to make up some excuse. Maybe she could tell him she'd been thinking about the stars.

With her eyes growing ever more adapted to the darkness, the room took on a strange kind of clarity. She was used to most of the details being lost in shadow if she looked out from her bed, and to the way everything instantly appeared in its proper place if she switched on the light, but while it had been years since she'd even half-believed that her familiar possessions might be moving around of their own accord at night, or melting into odd new shapes when she couldn't quite see them, she felt like a documentary maker with a special camera, finally capturing their true nocturnal behavior, and the actual view impressed her as much as any imaginary alternative. It was not that she couldn't have guessed what she'd see; it was the fact that she could see it at all.

Charlotte thought she heard a car pull up in the street, but her window faced the back yard so she had no way to be sure. The knocking on the door left no doubt; she waited, tensed, for her father to come stomping down the corridor.

But he didn't. No lights came on, no doors opened. Nate was knocking firmly and persistently, without making it sound like he was trying to smash the door down. Charlotte knew her mother's medication left her drowsy even in the daytime, and at night she might easily sleep through this. But it was harder to believe that her father could do the same.

She turned on her bedroom light, then walked out and headed for the entranceway; her father could hardly blame her for responding when he'd ignored the sound for so long. When she opened the front door, Nate smiled at her uneasily.

"Are you all right?"

"Yes," Charlotte replied. "I don't know why Dad didn't get up."

Nate followed her into the living room. "You stay here," he said. "I don't want you to worry. Your Dad's been under a lot of stress, and what he did was pretty weird, but if I can talk to him, I bet he'll understand why it scared you, and he'll come and say sorry and give you a big hug."

"Okay."

He squeezed her shoulder then headed down the corridor. "Phillip?" she heard him call. He knocked on the door of her parents' room. "Beth? It's just Nate. I know it's the middle of the night, but Charlotte was worried, so she gave me a call."

Charlotte couldn't hear any response.

Nate announced, almost jokingly, "Don't freak out guys, but I'm coming in."

She heard the bedroom door open, then a moment later she could tell that the light had been switched on. The house remained silent; if her father was rebuking Nate for the intrusion, he was doing it in a whisper so as not to wake her mother. Then she heard Nate say quietly, "Ambulance please."

Charlotte ran down the corridor and into the room. Nate was standing beside the bed; he

turned and tried to block her way, but once she'd slipped past him he made no attempt to drive her out. She'd already seen all there was to see.

Both her parents were lying in bed, in poses no different than if she'd snuck in on them early on a Sunday morning. Her mother was frowning and screwing up her eyes, as if the light was painful to her even in her dreams, but her father's face was expressionless.

Nate was still talking to the operator on his phone; he put his fingers to the side of her father's throat.

"No," he said. "I can't feel anything."

* * *

2

After Charlotte's mother died, her grandmother moved in to help Nate take care of her. Her grandmother slept in her parents' old room, while Nate stayed in the spare room—the one that Charlotte's mother had always told her would belong to Charlotte's own baby brother, one day.

At school, everyone gazed at her with pity, and seemed to know as much about her father's death as she did. "He overdosed on her mother's painkillers," Charlotte heard people telling each other when they thought she wasn't listening. But if any of them knew why her father had taken the pills, they were whispering the answer when she was entirely out of earshot.

Nate was kind to her, finding jokes that made her smile whenever he saw an opening, but never pushing her with anything except her homework. Her grandmother hugged her a lot, cooked her favorite meals, and made sure she was in bed by nine. Charlotte felt like she was bobbing up and down in the middle of the ocean, while these two well-meaning adults joined hands in a ring around her and tried to make her feel that she was paddling in a safe, shallow pool.

She'd never asked her mother why she thought her father had taken his own life. Charlotte had told the police everything she could recall him saying to her, sitting in the kitchen the morning after, with Nate and her mother beside her. Nate could make no sense of it either; he just talked about the stress of her mother's illness on all of them.

It was almost two years later when Charlotte finally found a clue. Nate was spending the weekend at his girlfriend's house. Charlotte's grandmother had dozed off in her armchair, and Charlotte was bored with everything the TV, the computer, and the books in her own room could offer her. She'd taken books from the shelves in the living room before, but they'd usually turned out to be dull and impenetrable. When her mother was alive, she'd told her that maybe she'd enjoy some of them when she was older. "*Anna Karenina* isn't a children's book." Even at ten, when Charlotte tried the first page again, she had to agree.

But the sky was gray, and she had nowhere else to be, so she kept going, from book to book, shelf to shelf. They weren't all novels; there were history books and science books too. She read a few pages of *The Elegant Universe*, *The Fabric of Reality*, *The God Equation*. She knew these had belonged to her father, so she forced herself to keep staring at the words, hoping they might reveal something about his state of mind.

The fourth book had a creased spine and pages coming loose, as if her father had read through it many times. She took it into the kitchen so she could place it flat on the table, instead of risking more damage by holding it up in front of her face.

She opened it and began reading the introduction.

* * *

At this very moment, countless light-years away, on a planet that looks exactly like the Earth, a person who looks, thinks, and acts just like you is reading exactly the same sentence as the one you are reading right now.

You might find this claim shocking, amusing, or preposterous, but it is not the product of whimsy or imagination. It is an inevitable consequence of the best understanding modern science can offer us, when it comes to the nature, the history, the shape, and the size of the universe we inhabit.

* * *

Charlotte kept going until she started to sink into the morass of words, unsure how much of

her confusion was down to her lack of vocabulary and how much was the fault of the writer. But she could understand enough to be sure that her father had been swayed by the book in some way.

She wasn't ready for *Anna Karenina*, and she wasn't ready to make complete sense of this either. But she would learn. The book was here in her hands now, a witness she could question again and again. Whatever it had to say about her father's death, it was only a matter of time before she deciphered it.

* * *

3

The line in the bookstore was nowhere near as long as Charlotte had expected, for an author touring six countries on the coattails of a blockbuster movie. She'd made Vince wait outside, to give herself a chance to gather her thoughts while she stood in the queue, but when she approached the desk there were only two people ahead of her, and neither of them seemed interested in chatting with the man once they'd acquired the signature that would add a few dollars to the resale value of their first edition of *The Science of Doctor Imbroglio*.

When Charlotte's turn came and she placed her own tattered paperback in front of him, Derek Linderman laughed. "That's a blast from the past! How old were you when this came out?"

"Eight," she said. "It belonged to my father."

"But he handed it on to you, once you were old enough?"

Charlotte said, "Not exactly. He took his life not long after he read it."

"Oh." Linderman frowned. "I'm sorry to hear that."

"Does it feel like a step up, or down," she wondered, "going from half-baked cosmology seeped in treacly spirituality, to trying to spin a handful of buzzwords from a very dumb movie into some kind of pseudo-scientific framework that will explain away all of its plot holes?"

Linderman flinched slightly, but then some mechanical response kicked in. "My passion has always been to bring science to the widest possible audience—"

Charlotte burst out laughing. She'd just noticed that the poster in front of her showed Linderman himself tricked up to look like the movie's protagonist, right down to the top hat, rimless sun glasses, and ridiculous padded pectorals.

Linderman said, "Look . . . I'm truly sorry if your father found something in here that disturbed him." He slid the copy of *Everything Happens!* back across the desk toward her. "The message of the book was a positive and hopeful one. But I can't control people's responses."

"You could have tried not making overblown claims," Charlotte retorted. "Starting with the title."

"The publisher insisted—"

"Yeah, I've read the whole thing; it wasn't the publisher who dialed up the bullshit to 11."

Linderman glanced around; Charlotte wasn't sure if he was searching for a bookstore employee to come and rescue him, or checking that there were no witnesses to the conversation who might testify in a class action against him. Either way, no one was paying the slightest attention to the two of them.

"The science is what it is," he insisted. "The universe is spatially flat, within the error bars of every measurement we've made. So the null hypothesis must be that it goes on forever."

"*Must* be?" Charlotte spat back. "There are no less than *six kinds* of finite flat space that would work just as well."

"None of which we have evidence of inhabiting."

"None of which we'd expect, if they were large enough."

Linderman shook his head stubbornly. "You can dream up as many hypothetical properties for the universe as you like, but if they're undetectable, no one has any reason to believe in them."

Charlotte was incredulous. "You're really going to lecture me about undetectable properties, after claiming there are *infinite copies of the Earth* beyond the cosmic horizon? Okay . . . it's fun to write about infinities. Every child gets a kick out of Hilbert's Hotel. But you

couldn't portray it as just an amusing possibility; you had to pretend that it was all more or less a done deal, then play guru and ramble on about the supposed human implications."

"All of them good!" Linderman protested.

"Really? And if someone ends up dead, because they believe they're just stepping aside for the perfect life they're living elsewhere . . ." Charlotte broke off, struggling to retain her composure.

"I'm very sorry about your father," Linderman replied. "And I respect your right to have strongly held views on why it happened. But I honestly don't think this conversation is getting us anywhere."

He looked past her; another reader was approaching, eagerly holding up a copy of *Imbroglio*.

"You're right," Charlotte admitted. "It isn't." She picked up her father's book, then turned and walked away.

Outside, Vince had been pacing back and forth beside the entrance. "Are you all right?" he asked Charlotte.

"Yeah."

"Did you get what you'd come for?"

"No." Charlotte saw the worry on his face and touched his shoulder reassuringly. "I don't know what I expected. He was probably just thinking 'lawsuit, lawsuit!' all the time he was talking to me. But even if I'd gone in there with a document waiving any right to damages, how could he apologize? It's not like it's one line in one book where he went too far; it's his whole modus operandi. If he renounced sensationalism, it would be the end of his career."

They walked down to the coffee shop on the corner and found a table. "Don't you have a lecture soon?" she asked Vince, when they'd placed their orders.

He shrugged. "I can catch up online. What about you?"

"I think I'm going to have to write off the whole afternoon." She held up her hands; they weren't actually shaking, but they felt as if they were.

Vince was quiet for a moment, then he asked tentatively, "Now that you've spoken to him, do you think it will be easier?"

"To do what?"

"To accept that you can't . . . fix this."

"I accept that Linderman's never going to change," Charlotte replied. "Not this version of him, anyway."

Vince smiled, but he wasn't prepared to be brushed off with a joke. "I'm not a grief counselor," he said. "I don't know how you should deal with this."

"I don't either," Charlotte confessed. "But they've already found a cure for the cancer that killed my mother, so . . ."

Vince was taken aback. "And it would be up to you, if they hadn't?"

"I might have gone into medical research," she said. "But even if I had nothing to contribute, at least I'd know there were hundreds of people trying."

"Aren't there hundreds of cosmologists trying to figure out if the universe really is infinite?"

Charlotte said, "Maybe. Dozens, at least. But they might not reach an answer for centuries. I just wish more of them would acknowledge that they genuinely don't know yet, instead of acting like they need to anoint the infinite case as a kind of interim champion."

"Hmm." Vince was tactful enough to keep some thoughts to himself, but Charlotte couldn't blame him if the question running through his head right now was: *Does it really matter?*

"My father was depressed and delusional," she said, as the cart rattled up with their orders. "If he hadn't used Linderman's nonsense to rationalize what he did, he might have just picked something else. But even if that book didn't kill him, it's part of a whole corrosive trend, where bad pop science clickbaits its way into the wider culture. Remember when random celebrities would proclaim that there was a 90 percent chance the universe was a simulation? Or when people with actual political power believed that AI was on the verge of bootstrapping itself to superintelligence? The more grandiose the claim, the more traction it gets. And it all relies on a sleight of hand where the most naïve extrapolation possible gets passed off as a triumph of Occam's Razor."

"So . . . you're going to change your major to philosophy of science, and try to kick some sense into the field?" Vince suggested.

"I'm not that masochistic." Charlotte stirred her hot chocolate to disperse the sediment that had settled at the bottom, then took a long swig.

"But you're masochistic enough to stick with cosmology, when the problem you're obsessed with could take centuries to solve?"

"Yes," she agreed.

"What's the holdup, anyway?" Vince joked. "Can we see the backs of our heads with a telescope? No we can't. Case closed."

Charlotte said, "It's more like: can we see the same set of temperatures on two different circles in the cosmic background radiation?"

"Why circles?"

"Because the light that's reaching us now from any particular time in the past started out on a sphere. A year ago, it would have been a sphere one light-year in radius, and so on. The expansion of the universe messes with the size of the sphere, but it doesn't change the shape. The cosmic background radiation all comes from the moment when the universe cooled from plasma to atoms, making it much more transparent, so what we observe isn't a snapshot of the whole sea of hot gas, it's just the portion that happened to lie on a certain sphere. But if the universe is finite, and smaller than that sphere, the sphere will wrap around and intersect itself, along a set of circles. What look like different parts of the sphere, as we see it in the sky, will really be the same bits of hot gas, with exactly the same temperature."

"But we've looked for these circles, and we haven't found them?"

"Right."

"Then . . . what is there left to do? Improve the resolution and try again?" Vince caught himself. "But if the sphere's just not big enough to intersect itself, that won't help."

"No. And you can't look back further in time with ordinary radiation, because the plasma before then just scattered it all."

"So, no ordinary radiation. Which leaves . . . what? Gravitational waves? Neutrinos?"

Charlotte laughed. "Exactly. You should drop history and come over to astrophysics."

Vince said, "We can detect both of those, can't we? With some effort."

"We can detect them if they're energetic enough: neutrinos from the sun, gravitational waves from colliding black holes. The cosmic neutrino background dates from about one second after the Big Bang, compared to hundreds of thousands of years for the microwaves, but it's been redshifted down to an even colder temperature, and the energy's nine or ten orders of magnitude less than neutrinos from the sun."

"Okay, I get it." Vince leaned back in his chair. "Instead of looking for flashes in a cubic kilometer of ice, or a mine full of weird expensive liquid, you'd need something the size of the moon."

"Or a completely different method," Charlotte added.

"Right." Vince hesitated. "But what if you find a better method, and there are still no matching circles? What if you spend forty years on this, and the universe still turns out to be larger than anyone can measure?"

"I can live with that," Charlotte replied. "As long as I did my best to push the search forward—instead of letting people get away with pretending that the question is settled and there's nothing to be found—I'll be satisfied that it wasn't a waste of time."

* * *

4

Charlotte sat down with her laptop half an hour before the interview and read through her notes one more time. She knew the proposal itself backward, but the notes translated the vision in her head into the specialist jargon she needed to use if she wanted to be taken seriously.

When Dr. Kassovitz called, she forced herself to wait three seconds before answering, taking to heart the advice she'd read that most people found a faster response disconcerting.

Kassovitz was softly spoken, and he put her at ease even as he moved briskly through the

pleasantries and urged her to begin.

"If you're willing to supervise my doctorate," she said, "I'd hope to be able to explore the prospects for estimating local variations in the cosmic neutrino background prior to recombination." The microwave background could only reveal details of the state of the universe four hundred thousand years after the Big Bang—but the distribution of matter, then, was shaped in part by the presence of neutrinos that had been traveling freely for hundreds of millennia, but were still packed together so tightly that their gravity alone could leave a mark. "Follin *et al* have already shown that we can infer the overall neutrino density from the phase shifts in acoustic waves in the plasma, but I believe there's scope to refine their approach to extract more information."

"Such as?" Kassovitz pressed her. "I mean, you can't hope to image the neutrino sources themselves."

"No, of course not." Any point on the sphere of plasma that they could actually observe would have been bathed in neutrinos that had traveled for four hundred thousand years from their own sphere-of-last-scattering, when the plasma had become transparent to neutrinos a mere second after the Big Bang. But untangling their individual routes would be impossible. At most, what might be discernible would be a very rough history of the total flux of neutrinos that had flowed through each region, exerting a gravitational tug on the plasma waves whose paths they'd crossed. "What I'd hope to detect would just be a statistical signature."

"For?"

Charlotte gathered up her courage. "Correlations in the neutrino sources that would play the same role as matching circles, in the absence of any direct imagery."

Kassovitz smiled; it took Charlotte a moment to convince herself that it was more an expression of delight than disbelief.

"You're not looking for an easy time, then," he mused. "Even neutrinos can only expand the horizon by about 3 percent. Do you really want to gamble on that being enough to make a difference?"

"There are hints that we might be close already," Charlotte replied. Though no matching circles had been found in the microwave background, there was a curious *absence* of features beyond a certain length scale, as if the universe might be too small to contain them. "But the experience would be valuable, regardless," she stressed. Learning to deal with the contamination and distortion of the microwave background, and learning how to model its properties under different assumptions, would arm her for a career in cosmology whether or not her own hypothesis survived.

Kassovitz pushed her for more details, on both the concepts she'd already mastered and those she hoped to come to grips with in the course of her dissertation. As they hacked their way through the weeds, she kept waiting for him to step back and ask her why she cared enough about the size of the universe to be willing to devote several years of her life to a very small chance of gleaning a few more clues.

He never did. But by the time the interview was over, Charlotte realized that this wasn't a sign that he was lukewarm about the topic himself. It was simply obvious to him that the question was worth pursuing, and he didn't need to be convinced that she shared this view.

* * *

5

Vince's flight into Munich was delayed for three hours. Charlotte dozed off in the arrivals lounge, but she'd told her phone to be persistent about waking her once the plane actually reached the gate, and it didn't let her down.

When she spotted Vince emerging from customs he looked like he'd had his own share of broken sleep, but there was a grin on his face and a spring in his step as he strode forward, scanning the crowd until their eyes met.

"Welcome to Germany!" Charlotte said, embracing him before he'd had a chance to take off his backpack, so she ended up with her hands pressed against a water bottle and what felt like a stack of T-shirts. "Have you got luggage to pick up?" she asked, as they separated.

"No. I thought I'd buy the bulky winter stuff here, instead of trying to find it in Sydney in December."

"That makes sense," Charlotte conceded, though he still risked freezing en route to the apartment. "How was the flight?"

He shrugged. "It's a metal tube. You sit in it." He leaned down and kissed her, still smiling. "It's so good to see you."

"You too."

Vince took out his phone. "Should I book us a ride?"

"No, there are trains every ten minutes."

"Okay." He hesitated. "But when am I going to get to use my joke about Nietzsche complimenting his ride-share driver?"

"Just give it a decent burial."

As they stepped onto the walkway, Charlotte felt a twinge of guilt: she'd been picturing the reunion for weeks now, imagining both of them gleeful and energetic as they bombarded each other with repartee and kick-started their old rapport. But she was so tired she could barely think.

"How's the thesis going?" Vince asked.

"Gah."

"Okay, that can wait till tomorrow." He put an arm around her shoulders. "I'm sorry I'm so late; the engineers had to fix something in Singapore. Maybe the hot towel dispenser was broken. I should have texted you to go home and get some sleep."

Charlotte laughed. "I couldn't not be here when you first set foot in the country."

"Yeah, but how cool would it be if you woke up in the morning and I was lying beside you, like I'd teleported straight into bed?"

When they reached the apartment they moved about quietly, so as not to wake Charlotte's flatmate, Lucy.

"I really can't have a shower?" Vince whispered. "Because honestly, I stink."

"I don't care," Charlotte replied. "I've got the whole day off tomorrow; we can sleep until she leaves, then we'll have the place to ourselves."

As they climbed into bed together for the first time in eighteen months, Charlotte let herself take comfort at the thought that she wasn't alone here anymore, with nothing but the work, and other people to whom all that mattered was the work. But then in the darkness, pressed against the warmth of Vince's body, she heard the work protest: fine, but don't let him steal too much time.

* * *

6

They spent the afternoon shopping, then joined some of the other students for a small dinner party that Eiji and Alice had offered to host, to welcome Vince.

"What did you do in Australia?" Alice asked him, as she moved around the table pouring drinks.

"I was a high school teacher," he replied. "History, French, and German . . . like a Swiss army knife. I had to work in a rural town for three years, straight after graduating, to have some of my student debt waived. But now I'm hoping to survive by teaching English here, until Charlotte gets her doctorate."

"Hoping?"

Charlotte said, "He already has a job lined up in a language school." Apparently the students were mostly newly arrived foreigners, who needed English as a third or fourth language.

"So all of you are physicists?" Vince asked.

Christoph laughed and held up his hands, palms toward each other, then brought them together until they almost touched.

"Astrophysicists?" Vince guessed. "Cosmologists?"

"Keep going," Christoph urged him.

"How much more specialized can you get?"

Eiji said, "We're all collaborating on a couple of proposals for NuWave."

"And it's definitely going to be launched now?"

Charlotte said, "It's still not certain, but the proposals from all the would-be investigators will form part of the case to the funding bodies."

"And could influence the final design," Maya added. "That's why we're all under so much stress right now. It's six weeks to the deadline for our last chance to sway the ESA and JAXA to adopt the choice of instruments we want."

"I see." Vince looked at Charlotte oddly, as if he was hurt that she hadn't spelled this out to him earlier. "So what do you need to submit?"

"A solid argument that our preferred version of NuWave would have a good chance of finding something new," Eiji explained. "Which basically means simulating various scenarios for the early universe, and simulating the probe and its instruments, then showing that in the end we could actually distinguish the different scenarios—to a high degree of certainty—by analyzing the data we collect."

"It sounds more like a drug trial than astronomy," Vince joked.

"Even Galileo couldn't just look at the rings of Saturn and see them for what they were," Maya replied. "If we could travel anywhere in time and space, check everything out firsthand, and come home with a 3D movie to prove it, that would be glorious . . . but in reality we're stuck here, looking at shadows through fog."

Christoph said, "Four kinds of fog, at least. There are other microwave sources, in the foreground, that we need to characterize and subtract from our measurements. There's the Sunyaev-Zeldovich effect, where the cosmic microwaves interact with electrons in galactic clusters. There's gravitational lensing, which messes with the angular distribution and the brightness. And my own speciality is the Sachs-Wolfe effect, where all the gravity wells the microwaves have encountered since they were emitted modify their spectrum."

"I'm more familiar with the Strachey-Woolf effect," Vince replied, deadpan.

"The what?" Christoph peered at him uncertainly.

"It's a geometrical theorem about the Bloomsbury Group: they lived in squares, painted in circles, and loved in triangles."

Maya laughed, but the others were bemused. Charlotte said, "You'll have to excuse him, he's from the humanities."

Back in the apartment, Vince was subdued.

"Are you still jet-lagged?" Charlotte asked.

"Probably," he replied. "I wish you'd told me you were under all that pressure, with the deadline."

"I didn't want to make a big deal of it."

"Okay." He sat on the bed. "But everything hangs on this, doesn't it? If NuWave doesn't get funded, or if it gets launched without the instruments you need, you might never get the chance to test your theory."

"'Never' is a big word," Charlotte replied.

"Not for another twenty or thirty years, then."

"That could be right," she conceded.

Vince said, "So whose legs do I need to break to make it happen?"

"You can't threaten the ESA on your own," Charlotte explained. "They won't accept anything unless it's in triplicate."

"You've met my brothers."

"I'm glad you're here," Charlotte said. "I think I might have been going a bit crazy."

"I hope it's not the Sunyaev-Zelda-Fitzgerald effect." Vince caught himself. "Sorry, that's not even funny. Poor Zelda. I really am jet-lagged."

"So just sleep now, for as long as you need to."

"Hmm." Vince started taking his shoes off. "You have to work tomorrow, don't you?"

"Yes." The language school wouldn't be open until January; he was going to be at a loose end until then.

"I could go sight-seeing," he said. "But after tomorrow, we need to figure out how to make this work. If I'm just going to be under your feet, there's no point in me being here."

Charlotte was stung for a moment. But she could understand how it would feel if he came all this way only to find that they could barely spend any time together.

"You want to help out with the submissions?" she suggested.

"Umm . . . you know most of it's over my head?"

Charlotte said, "You're still a thousand times better at languages than Google Translate, and a hundred times better than I am. If you're willing to proofread and polish what the team produces . . . you never know, one euphonious turn of phrase in the appropriate idiom might be just what it takes to get us over the edge."

Vince laughed. "I don't believe that for a moment, but I'll do my best."

* * *

7

Charlotte was in the back yard helping Mabel give her new puppy a flea bath when she heard her phone ringing.

"Can you get that?" she yelled out to Vince. She was up to her elbows in suds, but if the call was the one she'd been waiting for, she couldn't bear the idea of it going to message.

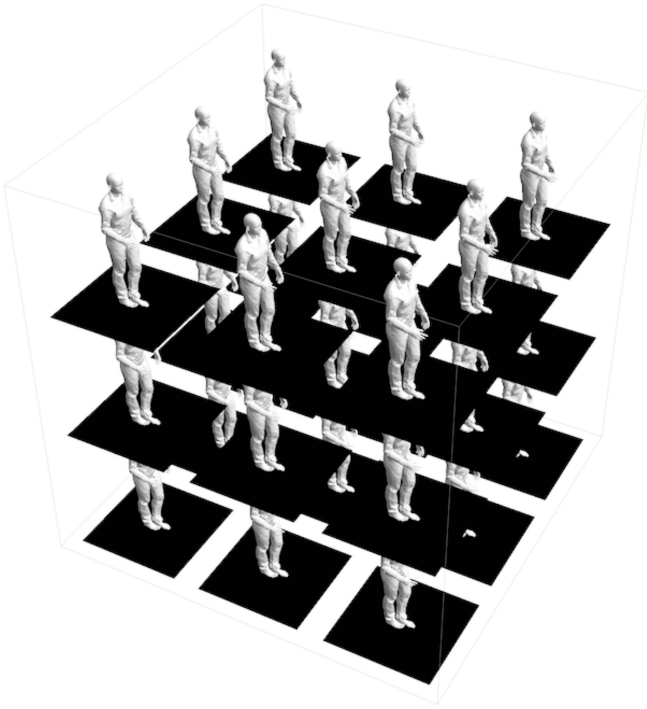
"Okay!" he yelled back.

"Keep still," Mabel urged Samson in her most soothing tone, but the dog seemed unconvinced that the drenching was an act of affection.

Vince emerged from the house, carrying Charlotte's phone. "Alice says the final data is significant at seven sigmas for the individual topology, though it drops to six in the context of testing for all the platycosms."

"What's a platycosm?" Mabel asked.

"When two platypuses love each other very much . . ." Vince began, but he saw Charlotte's warning look and stopped. "Do you want to talk to Alice?" he asked. "I can put it on speaker."



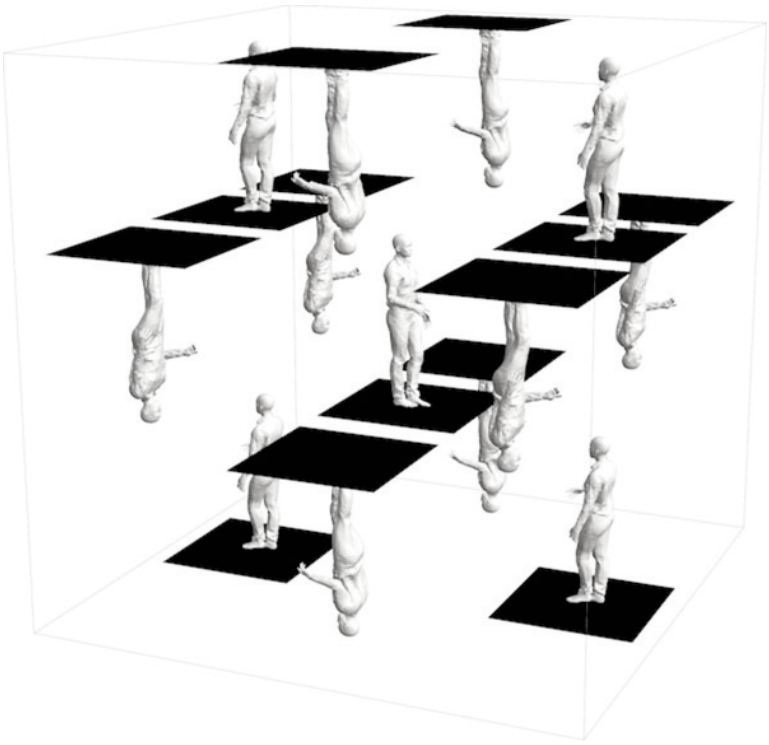
"Thanks."

He placed the phone on the table beside the basin they were using as a dog bath. Charlotte kept her grip on Samson; Vince couldn't really take over, since they didn't have another pair of gloves, and Mabel couldn't control the squirming puppy by herself.

"Alice, that's fantastic!" Charlotte shouted, unsure if she was close enough to be heard.

"Absolutely," Alice replied. "About the best we could hope for. I'm still shocked, though. I always thought the 3-torus would win out in the end."

"It really wasn't a bug, then? We didn't screw up?" The whole team had been so surprised by



the results that they'd been waiting for an independent group to perform their own analysis and see if they arrived at the same conclusion.

"No," Alice confirmed. "The only topology that explains the actual correlations is a didicosm."

Mabel laughed, at yet another strange word. Alice said, "Hi, Mabel."

"Hi. I'm washing the fleas off Samson."

"That sounds like fun."

Charlotte said, "So we'll hit publish?"

"In a couple of days; we're just making sure the paper incorporates the second analysis properly. And the university is putting out a press release—"

"Will they run it past you?" Charlotte asked anxiously.

"Yes, that's the policy." Alice hesitated. "Are you okay to do some media, if we get requests that fit with your timezone?"

"You're first author," Charlotte replied.

"Sure, but it's your thesis that spelled out the method that got us here. And you know what journalists are like: the story needs to start with NuWave getting the green light fifteen years

ago, and why they picked one design over the other."

Charlotte said, "Okay."

When Alice hung up, Vince moved the phone out of range of insecticide splatter. "Are you all right?" he asked Charlotte.

"Of course," she replied. Her head was pounding, and her mouth was dry, but she'd probably just inhaled too much of the flea wash. "Stop wriggling," she begged Samson, afraid she was going to lose her grip on him and he'd end up rolling wet on the grass.

"I don't understand," Mabel complained. "What happened?"

Charlotte said, "We think we know how big the universe is. And the shape of it." *The universe? Really?* Arguing about the best way to ask these questions beside a blackboard strewn with equations back in Munich had been one thing, but receiving the answers beneath a clear blue sky in a suburban back yard was utterly surreal.

"What shape is it?" Mabel asked.

"A weird one," Charlotte admitted. "Once I get my hands dry, I'll try to explain it."

* * *

8

"Maybe the easiest thing is to start with what I call the chessboard view," Charlotte told the program's host, Natalie. "If the universe was a three-dimensional torus, it would look like an infinite grid of cubes with a copy of you in every cube. A bit like being in a room with mirrored walls, except the images of you aren't reversed, and they're all facing the same way as you are."

The graphics team had produced a set of illustrations, and the producer brought the first one up as an inset for Charlotte to see as she spoke; even though they weren't going out live, this gave her a sense of the flow of her exposition as the audience would encounter it.

"But the universe isn't actually a torus," Natalie prompted her. "That was the big shock, wasn't it? If it wasn't going to be infinite Euclidean space, the next simplest thing would be a torus."

Charlotte flinched a little at this supposed ranking, but she conceded, "What we found was the topology we were least expecting. The classical name for it is the Hantzsche—Wendt manifold, but the mathematician John Conway called it the didicosm. For the didicosm, you need to treat the grid of cubes as a kind of three-dimensional chessboard, with alternating black and white cubes, and now there are only copies of you in the cubes with the same color."

* * *

The illustration changed to conform to her description. "What's more, most of the images of you have been rotated through 180 degrees. The ones you reach if you take two steps in any direction, passing through a cube of the opposite color, are oriented just like you are, but the ones you reach if you take a kind of bishop's move and jump into a cube of the same color that you share an edge with, are rotated by half a turn around one of the three axes of the grid."

"This isn't the kind of thing you could actually see through any telescope, though, is it?" Natalie asked.

"No. Light and neutrinos that have traveled since the Big Bang have barely had time to cross more than one cube. So we couldn't just hunt for a pattern laid out like this; we really had to squeeze the data for every possible hint."

"And the universe isn't this chessboard, anyway," Natalie stressed. "It's just . . . which part, exactly?"

"Two adjacent cubes. You can pick any two you like; as long as they share a face, it makes no difference. If you could travel far enough that it looked as if you were leaving that box, you'd just find yourself moving inward from the border, at a different location." Charlotte smiled in anticipation, and the producer played the clip of her and Mabel examining the shoebox that Charlotte had marked up to show how the various parts of the boundary would need to be connected. Unlike the 3-torus, where all three pairs of opposite faces were matched in the simplest possible way, here one pair was matched directly, another was matched with a 180-degree twist, while the other two faces were each joined back to *themselves* with a 180-degree twist and a slide.

"That really is bizarre, isn't it?" Natalie suggested. "I mean, how does a slab of space get joined up like that?"

"Maybe it doesn't need to 'get joined up,'" Charlotte replied. "There's no reason to think it started out in a different form."

"But then, how did it come into existence with that particular shape in the first place?" Natalie pressed her.

"We don't know how *anything* comes into existence!" Charlotte protested. "Whatever we'd found, the same question would apply."

"That's true," Natalie conceded, though she still seemed bemused, and Charlotte couldn't blame her. Every member of the team had had their own doubts about the peculiar topology.

They finished the interview chatting about the progression of ever more arcane methods of extracting information from the microwave background, from COBE to WMAP to Planck to LiteBIRD to NuWave. "What's next?" Natalie asked. "What more can we discover?"

"Maybe there's a chance to rule cosmic inflation in or out," Charlotte mused. "I don't know how, but someone's sure to come up with a new idea eventually."

When the call ended, she rose from her seat and wandered through the house, trying to convince herself that she hadn't said anything too foolish.

Mabel was at school, but Vince was in the living room; they'd both taken a fortnight's leave, so Charlotte could deal with the madness and Vince could keep everything else from falling apart. "How did it go?" he asked.

"All right, I think."

He gestured at the screen of his laptop, smiling. "'The Gang that Slew Infinity,'" he read, as Charlotte walked around to take a look for herself. The article began with an array of sixty photos, including all the theorists behind the didicosm result and the people who'd designed and

built the instruments that flew on NuWave. "It does point out that there are far too many collaborators to share a Nobel Prize, but you're mentioned as one of the possible—"

Charlotte put her hands over her ears and started humming. Vince said, "Okay, okay! Forget about Stockholm. The real question is: will Dev Patel do a cameo in the movie?"

Charlotte sank onto the couch beside him. "When Edwin Hubble realized that the Milky Way was just one galaxy out of billions, no one rioted in the streets, and no one burned him at the stake. But I wonder how he felt, just sitting around at home afterward. Was it no big deal? Or did he keep pinching himself?" Even invoking the comparison felt hubristic, but she needed to anchor the whole thing to some kind of precedent. The discovery was a shock, but there'd been shocks like this throughout history.

"I'll hunt down a biography," Vince promised. "The ideal birthday present for the woman who proved we really can't have everything."

* * *

9

"Just imagine a world," Linderman enthused, "where instead of a PlayStation, every teenager has their own universe in a shoebox!"

Vince said, "Turn it off."

"No." Charlotte felt sick, but she needed to keep watching.

"It doesn't work like that," Mabel whispered to Samson.

"No, it doesn't," Charlotte agreed.

"We couldn't ask for starker evidence, really," Linderman continued, while the interviewer on the split screen nodded encouragingly. "What NuWave revealed might as well have been instructions from some alien Ikea assembly sheet. To build your pocket universe, step one, join tab A to tab B. And now we're sitting in someone's bedroom, like a fish tank! One of millions of fish tanks—and that's on just one planet, in the infinite parent universe."

"How do you know the parent universe is infinite?" the interviewer asked. "Couldn't that be a pocket universe as well?"

"Of course," Linderman replied. "We could well be three or four levels down. But my point is, you have to get to the top eventually: a universe that arose under natural conditions. Of course an artificial universe will be finite, but the universe where it all began won't suffer from the same constraints."

"Thank you, Professor Linderman," the interviewer concluded. "Derek Linderman's new book, *Our Shoebox Universe*, will be out next month from Oxford University Press." Then the evening news moved on to a local story about a quoll sanctuary.

"OUP did ask me to write a book on the NuWave results," Charlotte admitted. "I said I didn't have time, but I hoped Alice might do it. She went with a different publisher, though, and I don't think she's finished the manuscript yet."

Vince said, "When she does, who do you think will be taken more seriously? Someone who actually worked on the project, or a washed-up hack who's on record predicting that NuWave would find no evidence of a finite universe at all?"

"I know who'll sell more copies and get more coverage," Charlotte replied glumly.

"Can we have a quoll?" Mabel pleaded.

"No," Vince said. "It would probably fight with Samson. And they're endangered, so I'm pretty sure it would be against the law."

"They won't fight, they'll be friends!" Mabel insisted.

"I should have led with 'against the law,' shouldn't I?" Vince realized.

Charlotte tried to calm herself. Every scientific discovery was fodder for some kind of self-serving spin; if it hadn't been Linderman, it would have been someone else. All she could do was talk honestly about the results; everything else was out of her hands.

* * *

10

Charlotte climbed out of bed as quietly as she could, but when she picked up her shoes Vince stirred and raised his head.

"Are you okay?" he asked.

"I can't sleep," she replied. "I'm going for a drive."

"It's almost one o'clock!"

"I know."

Vince sat up. "You can't let these idiots get to you. Do you want to talk about it?"

"I'm okay," she said. "I just need to get out of the house for a while."

"All right." He could hardly offer to come with her and leave Mabel all alone.

Charlotte drove out to the field where her father had taken her, almost thirty years before. She couldn't remember how the sky had appeared to her then, but it had been close to the same hour and the same time of year, so except for the greater light pollution from the old-style streetlamps, it could not have been too different.

As she gazed up at the Milky Way, she tried to imagine how her father would have responded if he'd been armed with the truth: that the galaxies did not stretch on forever, and a mere quadrillion worlds or so were far too few to offer any prospect of even the crudest recurrence of his circumstances. If he abandoned his family, there'd be no substitute, living the life he'd always wanted them to have. There was only the one, flawed version, and it was up to him to disown it or embrace it.

But if it was too late for him, she couldn't even count on her belated victory to sway anyone who needed it right now. Linderman was just the noisiest objector in a growing chorus; the shape the NuWave data had revealed was too strange to believe in as a product of nature. The saner voices called it an error in the instruments or the analysis; the rest claimed it was proof that the universe was an artifact.

Either way, nothing was settled. After thirty years of effort, she had been rewarded with more than she'd ever dared hope for. But she had still failed.

When she pulled into the driveway, Vince was standing on the porch in the dark. For a second, her chest tightened. Had something happened to Mabel? But he would have called her, surely.

"Is everything all right?" she asked him, as she came up the steps.

He said, "It is now."

* * *

11

"We have a loving creator," Pastor Finlay told Charlotte. "And He has left the signs of His handiwork in the sky. It's thanks to you that we've finally deciphered them, so it's only fitting that we ask you to lend your endorsement to our mission to spread His good news."

"I can't help you with that," Charlotte said. "And . . . I don't mean to be rude, but my office hours are for my students."

"Well, I've studied your findings as much as anyone," Finlay replied.

"That's very diligent of you. But my own interpretation—"

"I gather you don't accept that nonsense from Linderman?"

Charlotte said, "No, but—"

"Teenagers with fish tanks!" Finlay was horrified. "Our Lord's one creation, consecrated with the Holy Fold—"

"The what?"

Finlay produced his own copy of the shoebox model. For some reason, the usual letters indicating the matchings had been replaced with ones from the Hebrew alphabet. "I gather that the actual folding can only be performed in five dimensions. I believe we will find the whole construction foreshadowed in the scriptures, but that's still a matter of ongoing research."

"Of course," Charlotte replied. "But you'll have to excuse me now, there are students waiting."

"Let me leave my card," the pastor insisted.

Serena had been waiting in the hall. "Did you hear any of that?" Charlotte asked her, as she entered the office.

"I think I got the gist of it."

Charlotte composed herself. "Anyway, sorry . . . what can I help you with?" Serena was in the final year of her bachelor's degree, but they'd been discussing possible topics for a master's thesis for a while.

"I have an idea," she said tentatively. "Something I started looking into recently."

"Okay. Regarding . . . ?"

"The topology of the universe."

Charlotte didn't reply, but her expression must have changed, because Serena suddenly looked like she wanted to flee.

"To be honest," Charlotte said, "I'm so tired of hearing what the topology means, or why we got it wrong, that I'm probably not the best person for this. I'll talk to some other people in the department and find you another adviser."

"I understand," Serena said. She rose to her feet, but then she hesitated. "I can't not tell you, though," she declared reluctantly. "I'm sorry. It would just be wrong. If you think it's rubbish, I won't bother you again, but—"

Charlotte stopped her. "Okay. Go ahead." Unless she was going to retire from the job entirely, she had no right to curl up into a ball and refuse to listen to any sensible response that her claims provoked. "But if you're going to lecture me on how the NuWave team failed to treat Silk damping properly, I'll get Alice on the line to set you straight."

Serena looked horrified. "I'm not objecting to your analysis! I haven't learned a tenth of what I'd need to assess it properly."

"All right." That hadn't stopped half of the critics, but it made a pleasant change. "So what's your objection?"

Serena said, "I have no objection. I've just been trying to understand if there's a reason why the topology turned out to be a didicosm, and not one of the other possibilities."

"Short of alien Ikea."

"Well, yes."

Charlotte said, "Go on."

"I found a paper," Serena said, "from about twenty years ago. It gives an account of inflation using a model of quantum gravity, rather than invoking a new inflation particle. The initial state involves a kind of loop down at the Planck scale, which can't increase in size as the volume of the universe grows. In that paper, they assumed the universe was infinite and simply connected, so these loops just got diluted away. But if the universe was, say, a 3-torus, there'd be these loops running all the way around it, and if *they* couldn't grow, neither could the universe. It would be like trying to inflate a doughnut-shaped balloon encased in shower-curtain rings."

Charlotte smiled at the image, but she wasn't sure where this was going. "The didicosm isn't simply connected either; there are plenty of non-trivial loops."

"I know," Serena said, "but there's a difference. The didicosm has a finite homology group; it's the only platycosm with that property." On the whiteboard, she sketched a series of loops that crossed the shoebox, one following the other, and showed how the combined loop could be untangled into something much simpler. "In the homology group, this amounts to saying that the fourth power of the loop I called x is trivial. And you get the same result if you swap x and y. So there are only sixteen different loops in total."

Charlotte recalled reading this, long ago; it had been amusing, but she'd never thought of it as physically relevant. "A string that wraps around a didicosm would still restrain it." The homology group was a mathematical abstraction, where you pretended that the order in which you went around a sequence of loops could be changed at will. It encoded useful information about the topology of the space, but an actual piece of string didn't play by those rules.

Serena reached into her backpack and brought out her notebook. "A classical piece of string, sure. But this is quantum gravity. If I've understood the paper correctly, the probability for the space wrapped up in these loops tunneling out into the inflationary phase will be suppressed by the size of its homology group. For an infinite homology group, that means literally zero chance. For a finite one, it just tells you how long you'd have to wait. So if you take a random tangle of these loops at the Planck scale, the only macroscopic space they can possibly give rise

to is a didicosm."

Charlotte accepted the notebook from her; there was a printout of the quantum gravity paper, heavily annotated, slipped in behind the front cover.

They sat for a while, going over the calculations together. "This isn't my area," Charlotte admitted. "But you seem to be on the right track. Are the authors . . . ?"

"They're still active," Serena said. "I didn't try to contact them yet. I wanted to talk to you first."

"Maybe you can write a new paper with them, extending their results to this case."

Serena's face lit up. "That would be fantastic!"

"What if I email them and make the introductions?"

"Thank you."

When Serena left, Charlotte sat for a while, trying to clear her head. Maybe this would come to nothing; the particular model of quantum gravity was obscure, and she wasn't aware of any other results that lifted it above its competitors. But maybe the didicosm was not as "unnatural" or "arbitrary" as it had been portrayed. Maybe it really was the only shape the universe could have taken.

When Charlotte arrived home, Vince was cooking dinner, and Mabel was in the back yard playing with Samson. Charlotte greeted them, then sat in the kitchen where she could watch them both.

She had to stop thinking of the NuWave results as a failure. Even if nothing was settled, even if people kept disputing them for another thirty years, she had helped to open the door for the next generation to continue searching for the truth.

Vince groaned. "I've burned the potatoes," he muttered.

Charlotte walked over and kissed him.

"What was that for?" he asked.

"For reminding me," she said, "that I live in the best of all possible worlds."

Greg Egan's latest novel, Scale, *is a political thriller set on a version of Earth where people come in seven wildly different sizes, and his latest collection of stories is* Sleep and the Soul. *He can be found at @gregeganSF on Twitter and https://mathstodon.xyz/@gregeganSF on Mastodon.*