00:10

Six months ago, i watched with bated breath as nasa's insight lander descended towards the surface of mars. Two hundred meters, 80 meters, 60, 40, 20, 17 meters. Receiving confirmation of successful touchdown was one of the most ecstatic moments of my life. And hearing that news was possible because of two small cube sets that went along to mars with insight. Those two cube sets essentially livestreamed insight's telemetry back to earth, so that we could watch in near-real time as that insight lander went screaming towards the surface of the red planet, hitting the atmosphere of mars at a top speed of about 12,000 miles per hour. Now, that event was livestreamed to us from over 90 million miles away. It was livestreamed from mars.

01:14

Meanwhile, the two voyager spacecraft -- now, these are these two almost unbelievably intrepid explorers. They were launched the same year that all of us here were being introduced to han solo for the first time. And they are still sending back data from interstellar space over 40 years later.

01:37

We are sending more spacecraft further into deep space than ever before. But every one of those spacecraft out there depends on its navigation being performed right here at earth to tell it where it is and, far more importantly, where it is going. And we have to do that navigation here on earth for one simple reason: spacecraft are really bad at telling the time. But if we can change that, we can revolutionize the way we explore deep space.

02:09

Now, i am a deep space navigator, and i know you're probably thinking, "what is that job?" well, it is an extremely unique and also very fun job. I steer spacecraft, from the moment they separate from their launch vehicle to when they reach their destination in space. And these destinations -- say mars for example, or jupiter -- they are really far away. To put my job in context for you: it's like me standing here in los angeles and shooting an arrow, and with that arrow, i hit a target that's the size of a quarter, and that target the size of a quarter is sitting in times square, new york.

02:49

Now, i have the opportunity to adjust the course of my spacecraft a few times along that trajectory, but in order to do that, i need to know where it is. And tracking a spacecraft as it travels through deep space is fundamentally a problem of measuring time. You see, i can't just pull out my ruler and measure how far away my spacecraft is. But i can measure how long it takes a signal to get there and back again. And the concept is exactly the same as an echo. If i stand in front of a mountain and i shout, the longer it takes for me to hear my echo back at me, the further away that mountain is. So we measure that signal time very, very accurately, because getting it wrong by just a tiny fraction of a second might mean the difference between your spacecraft safely and gently landing on the surface of another planet or creating yet another crater on that surface. Just a tiny fraction of a second, and it can be the difference between a mission's life or death.

03:56

So we measure that signal time very, very accurately here on earth, down to better than one-billionth of a second. But it has to be measured here on earth. There's this great imbalance of scale when it comes to deep space exploration. Historically, we have been able to send smallish things extremely far away, thanks to very large things here on our home planet. As an example, this is the size of a satellite dish that we use to talk to these spacecraft in deep space. And the atomic clocks that we use for navigation are also large. The clocks and all of their supporting hardware can be up to the size of a refrigerator. Now, if we even want to talk about sending that capability into deep space, that refrigerator needs to shrink down into something that can fit inside the produce drawer.

04:48

So why does this matter? Well, let's revisit one of our intrepid explorers, voyager 1. Voyager 1 is just over 13 billion miles away right now. As you know, it took over 40 years to get there, and it takes a signal traveling at the speed of light over 40 hours to get there and back again. And here's the thing about these spacecraft: they move really fast. And voyager 1 doesn't stop and wait for us to send directions from earth. Voyager 1 keeps moving. In that 40 hours that we are waiting to hear that echo signal here on the earth, voyager 1 has moved on by about 1.5 million miles. It's 1.5 million miles further into largely uncharted territory. So it would be great if we could measure that signal time directly at the spacecraft.

05:45

But the miniaturization of atomic clock technology is ... Well, it's difficult. Not only does the clock technology and all the supporting hardware need to shrink down, but you also need to make it work. Space is an exceptionally harsh environment, and if one piece breaks on this instrument, it's not like we can just send a technician out to replace the piece and continue on our way. The journeys that these spacecraft take can last months, years, even decades. And designing and building a precision instrument that can support that is as much an art as it is a science and an engineering.

06:29

But there is good news: we are making some amazing progress, and we're about to take our very first baby steps into a new age of atomic space clocks. Soon we will be launching an ion-based atomic clock that is space-suitable. And this clock has the potential to completely flip the way we navigate. This clock is so stable, it measures time so well, that if i put it right here and i turned it on, and i walked away, i would have to come back nine million years later for that clock's measurement to be off by one second.

07:05

So what can we do with a clock like this? Well, instead of doing all of the spacecraft navigation here on the earth, what if we let the spacecraft navigate themselves? Onboard autonomous navigation, or a self-driving spacecraft, if you will, is one of the top technologies needed if we are going to survive in deep space. When we inevitably send humans to mars or even further, we need to be navigating that ship in real time, not waiting for directions to come from earth. And measuring that time wrong by just a tiny fraction of a second can mean the difference between a mission's life or death, which is bad enough for a robotic mission, but just think about the consequences if there was a human crew on board.

07:47

But let's assume that we can get our astronauts safely to the surface of their destination. Once they're there, i imagine they'd like a way to find their way around. Well, with this clock technology, we can now build gps-like navigation systems at other planets and moons. Imagine having gps on the moon or mars. Can you see an astronaut standing on the surface of mars with olympus mons rising in the background, and she's looking down at her google maps mars edition to see where she is and to chart a course to get where she needs to go?

08:21

Allow me to dream for a moment, and let's talk about something far, far in the future, when we are sending humans to places much further away than mars, places where waiting for a signal from the earth in order to navigate is just not realistic. Imagine in this scenario that we can have a constellation, a network of communication satellites scattered throughout deep space broadcasting navigation signals, and any spacecraft picking up that signal can travel from destination to destination to destination with no direct tie to the earth at all.

08:57

The ability to accurately measure time in deep space can forever change the way we navigate. But it also has the potential to give us some pretty cool science. You see, that same signal that we use for navigation tells us something about where it came from and the journey that it took as it traveled from antenna to antenna. And that journey, that gives us data, data to build better models, better models of planetary atmospheres throughout our solar system. We can detect subsurface oceans on far-off icy moons, maybe even detect tiny ripples in space due to relativistic gravity.

09:37

Onboard autonomous navigation means we can support more spacecraft, more sensors to explore the universe, and it also frees up navigators -- people like me -- to work on finding the answers to other questions. And we still have a lot of questions to answer.

09:57

We know such precious little about this universe around us. In recent years, we have discovered nearly 3,000 planetary systems outside of our own solar system, and those systems are home to almost 4,000 exoplanets. To put that number in context for you: when i was learning about planets for the first time as a child, there were nine, or eight if you didn't count pluto. But now there are 4,000. It is estimated that dark matter makes up about 96 percent of our universe, and we don't even know what it is. All of the science returned from all of our deep space missions combined is just this single drop of knowledge in a vast ocean of questions. And if we want to learn more, to discover more, to understand more, then we need to explore more.

10:57

The ability to accurately keep time in deep space will revolutionize the way that we can explore this universe, and it might just be one of the keys to unlocking some of those secrets that she holds so dear.

11:11

Thank you.

11:12

(applause)