**1 - Introduction to the gallery (brief version)**

Hello, my name is David DeVorkin, and I am the curator of this gallery. As you walk through the five rooms in this gallery, you'll find that as we acquire new tools for observing the universe, we discover new universes; indeed, new tools create new universes.

Each of these universes has tended to be larger and less human-centered, less personal. Notice, too, that there are no final answers, only better informed questions. And notice, especially in the final room, that astronomy benefits from a balance of ground-based and space-based telescopes.

Finally, also you'll notice that women have played a significant role in changing our view of the nature of the universe, and the roles have changed just as significantly over time.

**2 - Introduction to the gallery (extended version)**

Welcome to the Explore the Universe Gallery. My name is David DeVorkin, I am the curator of the gallery, and, together with about 70 other people, we built this gallery in the late 1990s, and it opened in September, 2001.

We wanted the title of the gallery to be an invitation to our visitors to participate as much as possible in the excitement of discovery, so as you walk through the gallery pondering the famous telescopes and the beautiful images of deep space, you'll see that as we Earthlings acquired new tools for observing the universe, in effect, we discovered new universes; indeed, new tools *create* new universes.

There was first the mind: our first tool, able to perceive itself and the universe around it. Of all the senses – touch, taste, hearing, smell, and seeing – only the last, seeing, could be used for exploring beyond Earth.

The gallery is separated into rooms, and these rooms are according to the instruments we have available over the past millennium. In the first and smallest room, you will encounter the visible universe: the universe revealed by the eye. It's a universe based upon man and then upon the Earth, and ever-improving instrumentation in this first universe reveals inconsistencies and anomalies with the universe of the Greeks.

Then, moving into the next, you will encounter the universe of the telescope. It confirms that the universe is not centered on man or on the Earth but on the Sun. It leads to studies of the distributions of the stars in the heavens and the question if stars are all there are, or are there systems of stars beyond the stars?

Then, we move into photography: adding the photographic plate to the telescope allows us to accumulate information over time and to see far fainter and far more subtle features of the universe, and here in the 20th century we will see that the questions posed in the 18th and 19th were answered in the 20th, and that, indeed, we're in a universe of galaxies. It's a new universe, one where there are cities of stars instead of stars alone.

And then we move from there into the world of spectroscopy, added to photography and added to the telescope, and we find that the universe is no longer static; it's expanding. And then finally we move into the digital age; that is the time that we all experience together today. And that gives us a new universe that we now are getting familiar with but is still as mysterious as when it was discovered, the "Dark Universe."

As you go through the gallery, there will be a number of themes that you might keep in mind, and these are some of them: first, the new universes that we talk about of course tend to be larger and less homo-centric (that means "less based upon man"). This doesn't mean that man is reduced in scope or stature but finds himself in a much larger and much more complex and far less personal universe. And then as you go through, you will encounter an astronomer named Edwin Hubble, and a little later in the gallery you will see a telescope named after him (the Hubble Space Telescope). And this is to remind us that throughout the last 400 years of the telescope there's been a changing relationship of the astronomical observer to the telescope, as telescopes got bigger and complex, people who built them and people who used them changed; look for those changes. Finally, at the end of the gallery, you will see that there are no final answers, no authoritarian statements, only better-informed questions, and that the answers change over time.

Throughout the final and largest section of the gallery you will see that astronomy benefits from a balanced synergy between ground-based and space-based observations. And then among the many other themes that you may pick up as you go through, notice that women have played significant roles in changing our view of the nature of the universe throughout the centuries, and that the role of women has changed just as significantly over time. Have fun!

**Ask astronomer Jay Pasachoff a question:**
**3 - What did Johannes Kepler find out about planetary orbits?**

**Interviewer**: Dr. Pasachoff, what did Johannes Kepler find out about planetary orbits, and how was Tycho Brahe involved?

**Dr. Pasachoff:** Tycho Brahe, in the late 1500s, made great pre-telescopic observations from an observatory he built on an island off the coast of Denmark. In 1601, he brought the observations and his entourage to Prague, where soon thereafter he was joined by a young astronomer, Johannes Kepler. Tycho Brahe soon died, and Kepler eventually took over the records of the observations. He tried to make sense of the positions of Mars in the sky against the background of stars, but he couldn't make sense with the circles in which people then thought they moved. It was only about 60 years since Copernicus had published his book that had the Sun at the center of what we now call the solar system, and not everyone was even convinced of that. Eventually, Kepler figured out that the planets moved around the Sun ("orbited" it, we say) in a kind of squashed circle called an ellipse. In 1609, in his book Astronomia Nova, "the New Astronomy," he came out with the first two of his laws of planetary orbits. The first is that the planets orbit the Sun in ellipses with the Sun at one focus, one of two points in an ellipse that define how far out of round it is. Kepler's second law governs how fast planets move in their orbits, going faster when they're closer in than when they're further away, with their speeds following a relation Kepler found. Ten years later, he came out with his third law, a harmonic law, in the book Harmonices Mundi, that links the distances of the planets from the Sun to how fast they go around the Sun.

Kepler was a great mathematician, in addition to being a great astronomer, and he later used the newly-invented logarithms to calculate a book of tables, the Rudolphine tables, which came out in 1627. These tables could be used for calculating the positions of the planets in the sky more accurately than ever before. Kepler's productive period overlapped with that of Galileo, but the two astronomers, uh, lived in very different parts of Europe and they did not collaborate, though they corresponded a bit.

**4 - What is this man doing?**
This man is observing the stars and planets with a pointing device called an armillary sphere. The rings and dials represent the astronomer's coordinate system for mapping the sky, similar to latitude and longitude on the Earth.
This man is looking through two slits at an object in the sky. When he gets the object lined up through the slits correctly, he can read the object's position on the dial. What can this man learn by accurately measuring the positions of stars and planets in the sky? Before accurate measurements were made, people thought the objects in the sky all orbited around the Earth. Once accurate measurements were made, however, a mathematician named Kepler was able to use the data to show that the Earth and other planets orbit around the Sun.

**5 - Where are Pluto, Neptune and Uranus?**
You've probably heard that the International Astronomical Union demoted Pluto to the status of a dwarf planet in 2006. But that's not why Pluto is missing from these models! These are models of the Universe from before the invention of telescopes. What objects in the Universe can you see without a telescope, with just your eyes? There's the Sun, the Moon, the stars, the occasional comet or meteor, and five planets: Mercury, Venus, Mars, Jupiter, and Saturn. People in ancient times had no idea there were other planets in our solar system. That's why you don't see Pluto, Neptune, Uranus, or other objects in the Universe in these models.

**Ask astronomer Owen Gingerich a question:**
**10 - Did Galileo use the telescope to prove that the Earth moves around the Sun?**

**Interviewer**: Dr. Gingerich, did Galileo use the telescope to prove that the Earth moves around the Sun?

**Dr. Gingerich**: You'll hear the statement over and over that Galileo "proved" the Copernican system. Wrong! What Galileo found were some spectacular observations that made the Copernican system seem much more reasonable. Among other things, the telescope revealed satellite systems around other planets. That doesn't really prove anything, but it does make the Copernican system seem more reasonable. And it was persuasive, but it was not actually proof. What is considered proof didn't come until the 19th century. One important effect of the Earth moving around the Sun is that, from these different vantage points, the nearby stars look to have slightly different positions. This is called the "annual stellar parallax." It's the same sort of effect you get by closing one eye and then the other eye, as you look at something closer against the distant background, and you'll see the object jump back and forth.

**Ask astronomer Owen Gingerich a question:**
**11 - What are some of the telescope's greatest contributions to astronomy?**

**Interviewer**: Over its 400 years of use in astronomy, what would be some of the telescope's biggest contributions to our understanding of the nature of the universe?

**Dr. Gingerich**: First of all, Galileo's observations of the Moon, showing the mountains and the valleys, proved that the Moon was a rather Earth-like object. And that was a giant step toward refuting the ancient, Aristotelian cosmology, which said the heavens were perfect and of totally different substances and quite unlike the Earth. Another was the discovery of the very large size of our own Milky Way system; how distant the stars were, how they were arranged in this large, flattened disc with the center of the galaxy where we now understand, again using telescopes, from the swift motion of those stars near the nucleus of our galaxy, that there's a giant black hole there. This understanding of the structure of the Milky Way is very significant. And the great jump to more distant galaxies, to understand that they were island universes of their own, a million or more light years away. This is work that was particularly associated with the name of Edwin Hubble and the 100-inch telescope on Mount Wilson; a telescope, parts of which you can see in this very gallery.

**12 - Who invented the telescope?**

Actually, it wasn't Galileo. Galileo was the first to build a telescope and use it to observe the heavens. But he didn't come up with the idea for the telescope by himself. The credit for inventing the telescope is given to Hans Lippershey. In 1608, he applied for a patent on the instrument and published his design. Other instrument makers, mostly opticians, were building similar devices at the same time, and no patent was granted to Lippershey.

So why is Galileo's name associated with the telescope? Descriptions of Lippershey's design soon spread across Europe. In 1609, Galileo pointed a telescope he had built to the heavens and became the first astronomer to observe the stars, planets, and other things in the sky with a telescope. This is why Galileo's name is linked with the invention of the telescope: because he made many important discoveries in astronomy using his telescopes, and because he wrote about his discoveries so that others could build on the work he did.

**13 - How did Herschel make his map of the Milky Way?**

William Herschel was a great observer. He built large telescopes so that he would be able to see dimmer objects and to see further into the universe. He wanted to know the location of everything that was in the universe: the stars, the nebulae, the planets. So he set out to make a map of the stars in the Milky Way Galaxy.

He constructed the map by counting the stars in 683 views of the night sky in his 20 foot telescope, the one that's here in the exhibit. Collectively, they covered the range of directions away from the Earth. In some directions, a field of view in his telescope would have many stars, and in other directions a field of view would have relatively few stars. From this, Herschel deduced that the Milky Way has a flat shape.

One thing that Herschel assumed when making the map was that he could see to the edge of the Milky Way. He found that the Sun is near to the center of our galaxy. But this assumption was wrong; Herschel didn't realize that dust between the stars in the Milky Way would dim the light of the more distant stars, so that they couldn't be seen. The Milky Way actually extended farther than he could see, and today we know that the Sun is not at the center.

**20 - What was Henrietta Swan Leavitt's great discovery?**

Henrietta Swan Leavitt began working at the Harvard College Observatory in 1893. The director of the observatory, Edward Charles Pickering, hired women as "computers" to do the computational work. The women were responsible for things like measuring the brightness and position of stars and categorizing spectra.

Such data from observations is an astronomer's treasure, and these women "computers" got the first look at the photographic plates. With the wealth of data at her fingertips, in 1908, Leavitt made a remarkable discovery. She found that for a certain class of variable stars, called Cepheid variables, there was a relationship between the star's brightness and its period of variation. From the observations of a star's apparent brightness and its period of variation, a star's distance could be determined.

Astronomers took this new tool for calculating the distances to stars and used it to answer some of the big questions in astronomy at the time. When Edwin Hubble discovered a Cepheid variable in the Andromeda Galaxy in 1923, astronomers had some of the first evidence that the "spiral nebulae" they observed were separate galaxies, "island universes" outside of our own Milky Way.

**21 - How does this blink comparator work?**

Before the digital era, astronomers used instruments like this blink comparator to look for changes in the stars from night to night. To do so, they would expose a photographic plate to get an image of an area of the sky one night, and then come back and take another photographic plate of the same area on a later night.

The two images of the same star field could then be loaded into the blink comparator. The images would be carefully aligned and then projected onto the same view, and then the lights behind each photographic plate blinked on and off, back and forth, so that the two different views could be compared. Anything that changed would jump out: pulsate if it was a change in brightness, shift if it was a change in position. This method made it possible to quickly find anything that changed in the sky. Push the button on the blink comparator here in the gallery and see if you can pick out the variable star; it's the dot that appears bigger in one image than the other, corresponding to the changes in its brightness.

The blink comparator was used to locate variable stars, novae, asteroids, comets, and even Pluto. To study the variable stars and novae, astronomers would look for a star that changed in brightness, and to discover asteroids, comets, and Pluto, they looked for a star that appeared to move from one location to another.

**22 - Do astronomers today use blink comparators?**

Astronomers today no longer use photographic plates to record images of the sky. They use digital detectors called CCDs (charge-coupled devices), similar to commercial digital cameras, but more sensitive. They can display the images on their computers and use their data analysis software to "blink" the images for the same effect as a blink comparator. More often, though, the software actually does the tedious work of picking out the differences between the aligned images, which the astronomer validates.

Astronomers can now get through many images in a short amount of time, whereas it could take their counterparts in the early 1900s several hours to examine one plate pair. This digital method is used today to search for near-Earth objects that could possibly strike the Earth.

**30 – Who used this instrument?**

Starting in 1895, this instrument was used by hundreds of astronomers, who attached it to the great 36-inch telescope at Lick Observatory near San Jose, California. They used it to take spectra, rainbow fingerprints that can reveal how hot stars are and how fast they are moving toward us or away from us. Many students trained using this instrument. One of the first women to use it, and to earn her PhD with it, was Phoebe Waterman. Phoebe was trained at Vassar College and worked at Mount Wilson Observatory before she returned to graduate school at UC Berkeley in 1910. There she quickly distinguished herself and convinced her teachers that she was capable of using one of the largest telescopes in the world. The Observatory director, W. W. Campbell, trusted that Phoebe could handle the monster telescope alone, and she successfully employed it to confirm how stars should be classified by their spectra, one of the critical foundations of astrophysics.

After graduation, Phoebe became a staff astronomer at Cordova, Argentina, but on the journey there she met Otto Haas, and fell in love. Within the year they decided to be married, and so Phoebe moved to Philadelphia in 1914. She would have loved to return to astronomy, but in those days, unless a woman was single or married to an astronomer, she could not be a professional astronomer. However, Phoebe continued to be active in astronomical matters. She joined the American Association of Variable Star Observers and was an observer and patron for many years. She also shared her love of astronomy with her sons and grandchildren throughout her life. This Museum's public observatory, located just outside the building, is named in Phoebe's honor.

**40 - What am I looking at?**

You're looking at a false-color video image that shows what the Explore the Universe gallery, and everything in it, would look like if your eyes were sensitive to infrared light. Similar technology is used in night-vision goggles. Infrared is light with a longer wavelength than the visible light that our eyes can detect, and any object that has a temperature emits infrared.

Look at yourself in the video display screen and notice which parts of your body are the coldest. They should be colored blue or green. Hot spots show up red. Why do you think these parts of your body are the coldest? Here's a hint: your body warms itself up as the blood circulates.

Since infrared light can indicate the temperature of objects, what do you think will happen if you rub your hands together? How about if you drag your shoes across the carpet?

Here are some other things to try. Notice the glass case to on your right side as you're looking at the screen. Can you see infrared light from your body reflecting off the glass? Even though infrared is invisible to our eyes, infrared is still light and still acts like light. Infrared light can reflect off some surfaces that aren't shiny enough to reflect visible light and can even pass through some materials that block visible light. If you're carrying a plastic shopping bag, stick your hand inside and see if it's visible in the infrared. What about a paper bag or a cloth one?

**41 - What is a pigeon doing here?**

**Interviewer**: You must be wondering why this pigeon is here. Well, we've brought her here to explain it for herself.

**Pigeon**: Actually, I'm here to complain about my cousin from New Jersey.

**Interviewer**: Your Jersey cousin?

**Pigeon**: Yeah, my cousin from New Jersey. She's been on my couch for months now because she was evicted from her nest in New Jersey.

**Interviewer**: Why'd that happen?

**Pigeon**: Well, you know, it was a great place. She moved down there, it was close to the ocean, right off the Garden State Parkway, she loved it, lots of people there. Well, one day, these scientists move in, and you know scientists, they just kept complaining about her.

**Interviewer**: Why were they complaining?

**Pigeon**: Well, you know, first it was the noise, they kept saying they heard all this noise and it was interfering with their equipment, and they kept complaining to her landlord about the noise. And then after she was quiet, they started complaining that her droppings were interfering with their equipment. I don't understand how that could happen, but sure enough, she got evicted.

**Interviewer**: Gosh, that's a horrible thing to happen.

**Pigeon**: Well, you know the funny thing about it? It wasn't her fault anyway. The scientists found out that she wasn't making the noise, it was something called the big bang. And she got evicted for it anyway! Now the scientists, they win the Nobel Prize, but my poor cousin's stuck sleeping on my couch and I gotta go complain to people about it!

**Ask astronomer John Mather a question:**
**42 - What did COBE tell us about the birth of the Universe?**

**Interviewer**: Dr. Mather, what is the significance of what you and your colleagues discovered with the COBE satellite?

**Dr. Mather:** Okay, well, we discovered three things. Number one, we showed that the Big Bang Theory was probably right, that the big bang happened 13.7 billion years ago. Number two, we found the material in the early universe that led to the existence of galaxies today; these are found as hot and cold spots in the heat radiation that's left over from the big bang. And the third thing we found was that the universe is brighter than we thought; the stars and galaxies have been busy doing things we didn't know about ever since they were made. So, in a nutshell, three huge discoveries that have really changed the way that we look at the universe and shown us the next direction to go.

**Ask astronomer John Mather a question:**
**43 - What are you working on now?**

**Interviewer**: Dr. Mather, you've won the Nobel Prize, and that is a remarkable achievement for anyone in a lifetime, but you're still working; what are you doing now?

**Dr. Mather:** Well, now I'm working on the James Webb Space Telescope, which is the planned successor for the Hubble Space Telescope. It's to be bigger, more powerful, observe infrared that can't be seen from the ground or with the Hubble Space Telescope, so that we can look farther back in time towards the beginning of the universe; see the first stars and the galaxies that were born; see how galaxies are assembled out of little pieces, probably; see how stars are made in galaxies, even close to home here; and, ideally with luck, learn how planets are made; and even, we have some small chance of studying the atmospheres of planets around nearby stars to see if any of them could eventually be like Earth.

**Ask astronomer Caty Pilachowski a question:**
**44 - How does someone get to use a big telescope?**

**Interviewer**: Dr. Pilachowski, how does someone get to use a big telescope like this one?

**Dr. Pilachowski:** It starts with an idea. An astronomer will generally be working on a particular problem for a while, and there'll be a particular set of observations that they need to make further progress on the problem. They'll write a proposal; it's a few pages long, it includes the information about what the science they want to do is, why it's important, what they'll learn, and a lot of technical details. The proposal is submitted to the National Observatory, typically six months in advance of the observing run, and the proposals are reviewed by a committee. They select the top ones, and if it doesn't work, astronomers try again. They keep trying until they get that telescope time they need for their research.

**Interviewer**: Can anyone use the telescope?

**Dr. Pilachowski:** Actually, yes! This telescope is pretty amazing that way. It was one of the first big telescopes built that allowed any astronomer with a great idea to get access to telescope time. Before this telescope was built, you had to be at an institution that had its own facility, but this one is a national facility. And what this did was it allowed any astronomer at any institution, any university in the country, who had a good idea to be able to get telescope time and do their science and compete with every other astronomer in the country. It made it possible for astronomy to blossom, transformed the field. This is still a telescope where anybody with a good idea can come to get their observations

**Ask astronomer Caty Pilachowski a question:**
**45 - What's it like to observe at the Mayall telescope?**

**Interviewer**: Dr. Pilachowski, what's it like to observe at the Mayall 4-meter? Do you get to look through the telescope?

**Dr. Pilachowski:** The telescope is actually behind the wall behind me, through the glass windows that you might see in the picture, and I'm working on a computer. The observing process is very much done on computers. I use computers to give instructions to the instrument (when to open the shutter, when to close the shutter, how long to integrate), and then I use the computer to look at the data that are taken by the instrument. We don't look through the telescope, per say, with our eyes. The basic functions are like a digital camera that any museum visitor might be using to take pictures; we take pictures with digital cameras and then analyze them with the computer.

**Ask astronomer Caty Pilachowski a question:**
**46 - What research are you doing now?**

**Interviewer**: Dr. Pilachowski, what are you working on now?

**Dr. Pilachowski:** My interest right now is trying to understand where the elements came from, all those elements in the periodic table: Carbon, Aluminum, Sodium, Iron, Barium, Praseodymium. Where did they come from? We know that they were formed in stars, but the detailed processes are sometimes hard to understand. Here at the Mayall, I began work on understanding the origin of heavy elements, things like Europium and Barium, and I've now taken that work to try to understand some of the lighter elements. I'm particularly looking at stars in globular clusters. These are immense collections of stars that formed a long time ago and have stayed together because of their neutral gravity. These systems of dense balls of stars seem to be able to create unusual mixtures of elements. We don't know why and we don't know how, so we're investigating particular elements that seem to be created in odd ways in these star clusters to try to figure out where these elements are coming from.

**Ask astronomer Jay Pasachoff a question:**
**48 - How do astronomers today use Johannes Kepler's findings?**

**Interviewer**: Dr. Pasachoff, how do astronomers today use Johannes Kepler's findings about planetary orbits?

**Dr. Pasachoff:** Planets go around the Sun in a certain period of time, known as the "period" of its orbit. In 1619, Johannes Kepler came out with his third law of planetary orbits, a law in a book called Harmonichus Mundi, the Harmony of the Worlds. His third law linked the square of the period of a planet's orbit with the cube of its distance from the Sun. He had to do a lot of math at a time before calculators, before slide rules, to get that result. Imagine what Kepler could've done with the computers we have today!

In any case, from Kepler's third law, we figured out how distant the planets are from the Sun proportional to each other. For example, from Mars' 2-year period of revolution around the Sun, we can calculate that Mars is one and a half times further away from the Sun than Earth is. We needed a distance for any two objects in the solar system, such as the distance to Venus that we got from the rare transits of Venus across the Sun (an event that last happened in 2012 and won't happen again until 2117), to then figure out all the other distances in the solar system.

Now, NASA has a wonderful spacecraft aloft, originally called the Kepler spacecraft after Johannes Kepler. Uh, it looked at over 100,000 stars all the time to find planets going around other stars, so-called "extra-solar planets" or "exoplanets." It has found over 1,000 exoplanets, and has thousands more candidate exoplanets to check out. When it does find exoplanet candidates, it can time their periods of revolution around their parent stars. From those periods, scientists on Earth use Kepler's third law to find the sizes of their orbits. They are looking especially to find hundreds of Earth-

size and smaller planets in or near the "habitable zone," the region around a star in which water could be liquid, ice, or gas, and so potentially support life. The spacecraft's goal was also to determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets. So Kepler's laws of planetary orbits from 1609 and 1619 are finding important uses in the 21st century.
The original Kepler mission functioned from its 2009 launch until 2013, when the system used for accurate pointing failed. From 2014 onward, a K2 so-called "second light" Kepler mission is operating, with the spacecraft using an alternative pointing method to look at different regions of the sky, still searching for and finding exoplanets.

**49 - Why can I see right through this telescope mirror? (brief version)**
You're standing in front of the Hubble Space telescope back-up mirror, and you've asked, "Why is it called a mirror when you can see through it?" Well, it was built to be a mirror, but it was not completely finished. It was built perfectly to the proper specifications, but it lacks only the thin aluminum skin that is deposited in a vacuum tank after the glass is shaped and polished to the proper optical shape. So why doesn't it have this aluminum skin? Well, this mirror was built by Kodak in the 1980s to back up the mirror made by the Perkin Elmer Corporation that would fly on the Hubble Space Telescope in 1990. When the Perkin Elmer mirror was accepted by NASA, the Kodak mirror was packed away unfinished. For sensitive mirrors, the aluminum coating should be as fresh as possible. And so this one was never coated.

**50 - Why can I see right through this telescope mirror? (extended version)**
Hello! You're standing in front of the Hubble Space Telescope backup mirror, and you've asked the question, "Why do we call it a mirror if we can see right through it?" Well the short answer is that the mirror was built to the proper specifications, but it was never quite finished. It was never coated with a thin aluminum skin to make it reflective. This question was posed when we were building the gallery by the designer of the gallery, who looked at it and said, "Why is it a mirror?" She felt we needed to explain the situation better to our visitors. That's why we've added a little space mirror on the right panel of the exhibit. You can see that the space mirror is half-coated with aluminum and the structure behind it, of course, is rendered invisible. Of course there's a story behind why it was never coated to look and act like a mirror. NASA contracted with two premier optical firms to produce the flight mirror and its backup. Perkin-Elmer built the flight mirror, and Kodak the back-up. If something catastrophic happened to the Perkin-Elmer mirror, the Kodak mirror would be available and the mission would not be delayed. But nothing did happen, so the Perkin mirror was flown in 1990 as the Hubble primary mirror, and the Kodak mirror was placed in storage. Well, as is well known, within a few months of launch, the Perkin-Elmer mirror was found to be seriously flawed, enough to cause a real uproar. As the exhibit labels point out here, astronomers and NASA engineers soon found a solution, and after the first servicing mission in 1993, Hubble's eyesight was corrected and it began returning fabulous crystal clear images of stars and galaxies in the deep universe. But what of the back-up mirror, which was in fact made perfectly to the

proper specifications? It remained in storage because it was unlikely that NASA would ever want to build another space telescope of this design.
So the Hubble back up mirror was brought to the Museum and placed in the Explore the Universe gallery in 2001 where you see it here. The Kodak mirror was never finished. Although it was ground and polished and figured to a fraction of a wavelength of light, and is one of the most perfect large optical mirrors in existence, NASA never asked for it to be coated with a thin skin of reflective aluminum. And so it remains, 99 percent complete but lacking its mirror skin. But in some way, this makes it an even more interesting artifact for exhibit here in the gallery. You can see how a space mirror is really built. You can see how it was built up out of slats of glass, set in square grids, and covered by a thin glass shell. Only in this way was the mirror's weight kept under a ton, and light enough, yet rigid enough, to be flown into space.

**Ask astronomer Vera Rubin a question:**
**51- What made it possible for you to make the discovery?**

**Interviewer:** What made it possible for you to make the discovery of the flat rotation curve?

**Dr. Rubin:** That's easy, I was working with Kent Ford, who was an instrument maker, an instrument builder, and he had just made an image tube that could be used for, um, a telescope so that you could record much fainter things. So, I was always interested in the outsides of galaxies because, among other things, nobody else seemed to be interested in them, so it was really the new instrumentation that I was using that made it possible to get rotation curves of galaxies pretty far out.

**Ask astronomer Vera Rubin a question:**
**52 - Is being a woman today in astronomy an issue for you?**

**Interviewer:** Is being a woman in astronomy an issue, today, for you?

**Dr. Rubin:** No. Being a woman in astronomy is not an issue for me today because I think I've done enough astronomy and astronomers are pleased with it and I'm very well accepted. But I think it can be an issue for younger women, and it perhaps can be an issue for even more senior women. I think you have to be lucky and have colleagues that are interested in your work and the fact that you're a woman doesn't matter. But I think sometimes women find themselves in situations where that does not happen. And we all hope that those kinds of things are disappearing, and it will make less and less difference to the younger women as they advance in the discipline.

**Ask astronomer Margaret Geller a question:**
**53 - What led you to study the large scale structure of the Universe?**

**Interviewer:** What led you to study the large scale structure of the universe? And also, what led you to produce the wonderful visual that we display here in the museum?

**Dr. Geller:** Well I've always, I guess I was attracted to science by an interest in patterns in nature, and I guess I was very fortunate to discover the largest patterns we know. And I felt compelled to share those. I think people are fascinated by the patterns that we see in nature, and human beings are wired up to recognize patterns and to interpret them. And in many ways that's what science is really about.

**Ask astronomer Margaret Geller a question:**
**54 - How did you make this map?**

**Interviewer:** Dr. Geller, how did you make this map?

**Dr. Geller:** Making the map, is a kind of an interesting process. We start out with pictures of the sky, and in those pictures we identify distant, fuzzy objects: galaxies like our own Milky Way. So then we know two positions on the sky, and then we want to know how far away the galaxies are. And in the case of the maps we see, these galaxies are hundreds of millions of light years away from us. So that means it took the light from them hundreds of millions of years to reach the telescope that takes the image. In essence, we sort of cheat to figure that out; what we do is we measure how fast they're moving. So we spread the light from each galaxy out into its colors, and that gives us a spectrum. And in that spectrum we see a pattern of features, of lines, which tell us what the galaxy is made of. And in essentially all galaxies, with very few exceptions, these lines are shifted to longer, redder wavelengths than what we would see in a laboratory on Earth. And that shift to longer wavelengths tells us that the galaxies are moving away from us. Then we use the discovery made in the late 1920s by Edwin Hubble that galaxies appear to recede from us with velocities proportional to their distances. So once we know the velocity, we have an idea of the distance. That's how we make the map.

**Ask astronomer Margaret Geller a question:**
**55 - What questions are there still about the largest structures?**

**Interviewer:** Dr. Geller, what questions do astronomers still ask about the largest structures in the universe?

**Dr. Geller:** There is still the issue of how large the largest irregularities in the universe are, and there is still a lot of argument about that. The map that you see covers a tiny, tiny fraction of the universe. I'd like to say that it covers a fraction of the universe smaller than the fraction of the Earth covered by the state of Rhode Island. And today we have much larger maps which reach much deeper into the universe, and they show this same kind of structure, with these very thin structures where the galaxies are, and huge, dark regions where the galaxies aren't. And that structure persists throughout the universe. These kinds of structures that we saw are typical of all the surveys that have been made. And, I mean, the map you're looking at has thousands of galaxies in it; now there are surveys that have a million galaxies, and they show the same kinds of patterns. In the Sloan Digital Sky Survey, which is a larger survey, which goes about five times deeper than our map, there are apparent structures which are larger, but how many and how frequent that is nobody really knows.

**Ask astronomer Tony Tyson a question:**
**56 – Why did you build this camera?**

**Interviewer:** Dr. Tyson, why did you build this camera?

**Dr. Tyson:** Dark matter remains a deep mystery. By the 1970s, we knew that galaxies are held together by the gravitational attraction of invisible dark matter. But what is dark matter, and how is it distributed in our Universe? If we could somehow see this invisible, transparent stuff, that would advance our understanding of its physical nature. Einstein showed that light from a background source bends around a foreground mass. If the background source is a galaxy, this creates a mirage, a sort of distorting the shape of the galaxy. In the 1970s I attempted to detect this with photographic plates, but they were not sensitive enough. The solution was a new detector, the charge-coupled device, invented at Bell Labs. Applying CCDs to astronomy, I built CCD cameras of increasing size, and undertook early sky surveys. Discovering a population of distant galaxies, the so-called "faint blue galaxies." This is just what was needed to make images of dark matter: a backdrop of millions of distant galaxies. We made maps of dark matter clumps from the cosmic mirage distortions of these background galaxies. After developing weak-lensing mass mapping, we needed to survey an even larger volume of the Universe. To do this, we had to build a camera with a mosaic of CCDs and put it on a wide-field telescope. This survey capability is called "throughput." I teamed up with Gary Bernstein and Bob Lee to build a wide-field camera with four large CCDs. We named it the "Big Throughput Camera."

**Ask astronomer Tony Tyson a question:**
**57 – How did it contribute to the discovery of dark energy?**

**Interviewer:** Dr. Tyson, how did this camera contribute to the discovery of dark energy?

**Dr. Tyson:** The Big Throughput Camera on the Blanco 4-meter telescope was the most powerful sky survey capability at that time. The National Observatory agreed to host the Big Throughput Camera, opening this new survey strategy to the entire astronomy community. Two groups of astronomers applied to use the Big Throughput Camera to search for supernovae. They needed a wide and fast sky survey. The idea was first to find the supernova as it explodes, using the wide-field Big Throughput Camera. And then quickly, before it fades, use the Hubble Space telescope and other telescopes to learn about its spectrum and distance, so that the expected deceleration of the expansion of the Universe could be measured.

Gary Bernstein, Dave Whitman and I supported these community Big Throughput Camera observing rounds. Both supernova survey teams were finding many supernovae each night. When they analyzed their data eventually, they found something amazing; instead of decelerating, the Universe was in fact accelerating. What causes this late-time acceleration? This new mystery of our Universe is called "dark energy." So we live in a Universe composed mostly of dark matter and dark energy. What is the physical nature of this dark universe? The solution to these twin mysteries will likely revolutionize our understanding of physics.

**Ask astronaut John Grunsfeld a question:**
**60 – When did you first want to become an astronaut?**

**Interviewer:** When did you first want to be an astronaut? Was it before you were an astronomer, or after you became an astronomer?

**Dr. Grunsfeld:** I decided that I wanted to be an astronaut roughly at about the age of six or seven. This was a time where there was kind of a serendipity of a couple of different things. First of all, most obvious, it was the early 1960s, Gemini program, early Apollo program, these were extremely exciting times, especially for a young boy. Perhaps equally as important, this was when regular families like mine got televisions, so on television I got to see the Gemini astronauts training for long-duration flights, and the various medical tests and things they did, the isolation training for the long hours in the space capsule. For many years I played with my friends, played astronauts, wore mock space helmets, eventually becoming a Star Trek fan. But through all these years, there was never a career path to be an astronaut, so it was always the kind of dream of wanting to be President, or any of these other things considered almost truly impossible. But as I continued through school, I had a love of science. At first it was to be a paleontologist; I think if there's two things every child loves, it's dinosaurs and space. Somehow that gets trained out of us. But I was fascinated, growing up in Chicago, by all the fossils in the limestone on the lake shore of Chicago. And so science always played a role. And as I got older I became more interested in astronomy and astrophysics. When I went to MIT for college, immediately I jumped into the space business. Always in the back of my mind, though, was this desire not just to build instruments to go into space, which was my career, but to go there myself. And so, after I got my PhD in Physics at the University of Chicago, having flown an experiment on the space shuttle, I sent in my application and felt like, 'If I don't apply, the outcome is known. If I do apply, you know, there's always a chance.' About six months later I got a call, asking me if I wanted an interview, and I thought, 'Well, they must interview thousands of people.' Turns out I'd been narrowed down to a group of less than a hundred. Finally, in 1991, they called and said, "We'd like you to come to Houston and be an astronaut."

**Ask astronaut John Grunsfeld a question:**
**61 – How many times have to been to HST, and how will this visit be different?**

**Interviewer:** Dr. Grunsfeld, how many times have you visited the Hubble Space Telescope, and how will this visit be different?

**Dr. Grunsfeld:** I've been to the Hubble Space Telescope two times in my career as an astronaut, the first time in 1999, the second time in 2002. This time I'm going to be very excited to see my old friend, the Hubble Space Telescope, but this one will be a little bit different, because after the 2002 mission, and the tragic loss of Space Shuttle Columbia, the Hubble Mission was canceled. And so for many years, we worked on how to keep Hubble going as long as possible, and perhaps visit it with a robotic spacecraft. But here I am, ready to go to launch, to visit Hubble one more time, and I'm just gonna be thrilled to see the telescope. But also, after we're done fixing the telescope, I'll know that this is probably, almost certainly, the last time that people will ever see the Hubble, until it reenters sometime a decade and a half from now.

**Ask astronaut John Grunsfeld a question:**
**62 – What is your responsibility during this mission?**

**Interviewer:** Dr. Grunsfeld, what is your specific responsibility during the mission?

**Dr. Grunsfeld:** On this mission to the Hubble Space Telescope, STS-125, Servicing Mission 4, I'm the lead space walker on the mission. I'm also responsible for all of the Hubble systems when it's attached to the shuttle, the lead payload system specialist. As the lead space walker, and the most experienced Hubble space walker ever I suppose, my job is to make sure that all the space walks are conducted properly, that we solve the problems that we encounter, and that we fix everything we can on the telescope that we're supposed to fix. I'm also the chief safety officer on board for the space walks, and I'll use my experience and my judgment and my experience as an astronomer to help train the spacewalking crew.

**Interviewer**: Dr. Grunsfeld, what will be the most difficult operation or procedure during the servicing mission?

**Dr. Grunsfeld**: On this mission to the Hubble, we have a couple of categories of things we're doing. The first is to install new scientific instruments: the new Wide Field Camera 3, and the Cosmic Origins Spectrograph. We're also going to install some somewhat routine equipment that just keeps the telescope running, like new gyros, new batteries, and new fine guide sensors. We're going to try and repair two instruments that have failed that were never designed to be fixed on orbit. One is the Space Telescope Imaging Spectrometer, and the other is the Advanced Camera for Surveys. Now what's certainly the most difficult repair, I think, is gonna be the Advanced Camera for Surveys, because it involves cutting through a metal grid, removing 36 tiny screws to get a cover plate off, and then pulling four circuit cards out from the electronics box, and then reinstalling new electronics and new power supplies. In principle, both the STIP and ACS repairs are similar, it's just, for the ACS repair, I can't actually see the whole worksite. It's around the corner of the instrument. And then having to peer around the corner in order to get access to it was just a little bit challenging in training. We've been able to successfully do it, but I think this is gonna be the one where everybody holds their breath the longest.

**Ask astronaut John Grunsfeld a question:**
**63 – What are you taking on this historic flight?**

**Interviewer**: I know that astronauts typically take things that are symbolic of their flights up with them. What are you taking on this historic flight?

**Dr. Grunsfeld**: This is an incredible flight to the Hubble Space Telescope, and of course we're taking lots of gear to fix the telescope, but I'm also allowed to take somewhat small personal items on a special entrance. And on this flight, I'm taking a basketball from the University of Chicago, circa 1909, Edwin Hubble used (playing basketball as point guard) to win the National Championship. He was not only an incredible astronomer but a terrific athlete, a great example of a well-rounded guy. I also have the pleasure of taking one of Brad Washburn (famous American explorer of Alaska and the world, a pioneer of aerial photography, a pilot, and a Director of the Boston Museum of Science for many years), one of his favorite cameras. It's a Zeiss Icon Maximer B, which he used in a famous ascent of Mount Lucenia, in Alaska, in which he carried this camera through thick and thin as they were trying to survive. And finally, at the very end, he had to give up the camera, hung it on a tree, so that at least their story could be known after they perished, which at this point they thought they might. Three days later they were rescued, and were able to go back on horseback and get the camera.

**Interviewer**: How did you get the basketball?

**Dr. Grunsfeld**: I got the basketball from the University of Chicago. I explored a number of interesting Hubble items as a University of Chicago graduate (that's where I got my PhD in Physics), and the University of Chicago put their best brains together to think about, what Hubble item could we carry to celebrate this famous scientist, to reunite this item with the Hubble Space Telescope (Hubble's namesake). And they didn't come up with some technical item, or perhaps one of his notebooks. The astronomers, the physicists, decided that something Hubble loved, his other passion of sports, would be the perfect item, and I came up with the basketball. And the University of Chicago was National Champion in basketball for three years running, 1908, 1909, and 1909-1910. So, the 1909 basketball.

**Ask astronaut John Grunsfeld a question:**
**64 – Why does the Wide Field Camera have all these holes in it?**

**Interviewer**: Dr. Grunsfeld, why does the Wide Field Camera have all these little holes in it, and what does that tell us about the environment that the Hubble Space Telescope is in?

**Dr. Grunsfeld**: In 2009, we visited the Hubble Space Telescope to do a series of upgrades and repairs, including putting a new super duper camera, the Wide Field Camera 3, in the Hubble Space Telescope. When we pulled out the old camera, the Wide Field Camera 2, we noticed that the surface of the wide radiator was covered in tiny dings. These dings are caused by micrometeorite damage, some of which are micrometeorites left over from the debris that formed the solar system. Others are due to man-made objects: bits of paint from old satellites, bits of metal that are orbiting the Earth and slowly spiraling in.

During space walks, or EVAs (Extra Vehicular Activity), we worry a lot about these little micrometeorites. If one of them were to hit one of us or the space shuttle, it could cause a lot of damage. To help study the micrometeorites, scientists at the Johnson Space Center have cut out circles the size of dimes and quarters from the white radiator in order to study the micrometeorites that are embedded in the paint. It didn't look that bad when we left it on orbit, uh, the little dings are actually very, very small, some of them were even hard to see.

I hope you enjoy the exhibit, and, even better, I hope you enjoy the wonderful images that the Hubble Space Telescope is taking today!