Slide 1 - Intro:

- The Hubble Space Telescope is a revolutionary instrument whose design, technology, and serviceability have made it one of NASA's most transformative observatories. From determining the atmospheric composition of planets around other stars to discovering dark energy, and from verifying supermassive black holes to studying galaxies back near the beginning of time, Hubble has changed humanity's understanding of the universe.

- Thirty-five years after its launch in 1990, Hubble's images and science continue to inspire. This presentation will provide a brief history of the telescope, give an overview of the spacecraft's design, supply a summary of the space shuttle servicing missions, present the highlights of its incredible scientific discoveries, and discuss its future.

Slide 3 - The Beginnings:

- Lyman Spitzer proposed an orbiting, Hubble-like telescope 75 years ago.
    - Problem: Earth's atmosphere
        - Distorts light (this is why stars flicker)
        - Blocks or partially blocks certain wavelengths
    - Greater access to wavelengths of light
    - Better images

Slide 4 - A Real Possibility:

- With advocacy of astronomers like Nancy Grace Roman and John Bahcall, the Large Space Telescope Project approved in 1969
- NASA suggested a lifespan of 15 years, meaning instruments would need servicing.
- ESA teamed up with NASA to provide some funding (15 percent).
- Telescope later named after astronomer Edwin Hubble, who confirmed the existence of galaxies beyond our own and found they were moving away from us

Slide 5 - Under Development:

- Development began at a number of NASA centers and contractors.
- NASA planned to maintain and upgrade the telescope via servicing missions in orbit.
- Telescope was ready to launch in 1985 but the 1986 Challenger disaster grounded the shuttle fleet
- Engineers used the time, as with previous delays, to continue to work on and upgrade systems.

Slide 6 - On Its Way!:

- Liftoff! April 24, 1990
- Deployed into orbit around Earth via the shuttle's robotic arm on April 25, 1990
- Discovery and Hubble orbited Earth together for about two days in case problems occurred that required the astronauts to take corrective action.

Slide 8 - Hubble in Detail:

- First astronomical observatory in orbit around Earth that takes images in wavelengths from ultraviolet to near infrared
- Hubble is the size of a school bus.
- Orbits over 300 miles (482 km) above Earth's surface
- Circles Earth approximately once every 95 minutes, about five miles (8 km) per second
    - Fast enough to travel across the United States in about 10 minutes.
- Can resolve objects 1,000 times better than the human eye.
    - That's enough to see two fireflies separated by about 10 feet (3 meters) from roughly the distance between New York City and Tokyo.
- Hubble's nearly 8 foot (2.4 meter) primary mirror is smaller than those of many Earth-based observatories.
    - What makes Hubble so powerful is its position above Earth's atmosphere.
        - Offers Hubble a pristine view of the universe
        - Allows it to see wavelengths blocked or partially filtered by the atmosphere.

Slide 9 - Observatory Design:

- Powered by two solar arrays that convert sunlight into electrical energy that is stored in six batteries
- Turns with reaction wheels
    - Based on Newton's Third Law of Motion – for every action there is an equal and opposite reaction – turning a reaction wheel in one direction causes Hubble to react by turning the opposite way
- Gyroscopes (gyros) detect its rate and direction of motion.
    - The telescope has six gyros, but typical operations only use three of them.
    - Originally, the others served as backups, but gyros eventually wear out and fail.
    - Today, Hubble has three operational gyros but only uses one for operations.
        - One gyro has reliability issues, the other is in reserve.
- Fine Guidance Sensors (FGSs) act within the pointing and control system. They find and lock on to guide stars, keeping Hubble virtually motionless while observing.
- Two high-gain antennas transmit commands and data between the spacecraft and communications satellites.
- Three types of instruments:
    - Cameras (Advanced Camera for Surveys and Wide Field Camera 3)
    - Spectrographs (Cosmic Origins Spectrograph and Space Telescope Imaging Spectrograph)
    - Interferometers (Fine Guidance Sensors).

Slide 10 - Servicing:

- First space-based observatory designed for servicing by astronauts in orbit
- Shortly after deployment, found the primary mirror had an aberration that affected the clarity of the telescope's early images
    - Corrected on the first servicing mission in December 1993

- Hubble servicing missions involved intensive coordination between NASA's Kennedy Space Center in Florida, Johnson Space Center in Texas, and Goddard Space Flight Center in Maryland.
    - Preparations included astronaut training at all three centers.
        - Simulations of shuttle and telescope operations during the mission at Johnson and Goddard
        - Testing and preparing instruments and hardware for flight at Goddard
        - Preparing launch operations and the space shuttle for launch, flight, and landing at Kennedy.

Slide 11 - Servicing Missions:

- Five total servicing missions
    - Servicing Mission 1
        - The first opportunity to conduct planned maintenance on the telescope
        - Astronauts installed new instruments, including equipment that counteracted the flaw in Hubble's primary mirror.
    - Servicing Mission 2
        - Extended range of wavelengths Hubble can see with the installation of two new instruments and increased efficiency and performance
    - Servicing Mission 3A
        - Servicing Mission 3: split into two parts when Hubble's gyros started to fail. At that time, Hubble required at least three of its stabilizing gyros to conduct science. Hubble entered a state of dormancy called safe mode while the telescope awaited repairs. Gyros replaced during 3A along with some other components.
    - Servicing Mission 3B
        - Replaced Hubble's solar panels and installed the Advanced Camera for Surveys
    - Servicing Mission 4
        - Fifth and final serving mission
            - Left the observatory at the peak of its scientific capability, and prepared it for many years of further scientific discovery

Slide 12 - Observations:

- Space is a big place. Over its 35 years of nearly continuous observations, Hubble has only looked at one tenth of one percent of the sky.
    - Next slides represent a small sample of Hubble’s thought-provoking discoveries and images
    - They highlight some of Hubble’s greatest scientific achievements to date.

Slide 14 - Our Solar System:

- Hubble’s long presence in space and regular observations of the planets — Jupiter, Saturn, Uranus, Neptune, and Mars — give researchers the opportunity to study their ever-changing atmospheres and moons

- Among the items Hubble has observed:
    - Comet fragments striking Jupiter
    - Auroras Jupiter, Saturn, and Uranus
    - Changes in Jupiter's Great Red Spot
    - Changes in Saturn's ring system
    - Changes in Neptune's clouds
    - The atmosphere, surface features, and dust storms on Mars
    - Discovering water on Jupiter's moons
    - Discovering moons around Uranus and Neptune

Slide 15 - Tracking Evolution in the Asteroid Belt:

- Hubble helps shape understanding of the asteroid belt, made up of remnants from the formation of the solar system.
    - Studies interactions and composition of asteroids
- Image shows a binary asteroid, or two asteroids 300163 (2006 VW139) orbiting each other. They have comet-like features. This is the first known binary asteroid also classified as a main-belt comet.
    - Bright halo of material, called a coma
    - Long tail of dust

Slide 16 - Uncovering Icy Objects in the Kuiper Belt:

- Hubble observes outskirts of solar system/Kupier Belt
    - Found a moon around dwarf planet Makemake
    - Found several new moons around Pluto
    - Observations of Pluto and its moons helped NASA plan the New Horizon spacecraft's flyby of Pluto

Slide 17 - Exploring the Birth of Stars:

- Ability to see ultraviolet, visible, and near-infrared light enables study of several aspects of star formation
- Young stars shine brightly in ultraviolet light
- Visible light reveals the structure of star-forming clouds, the shock waves induced by jets from forming stars, and colorful ionized gas in the nebulae energized by young stars.
- Infrared light's longer wavelengths can pass through the cloud relatively undisturbed, revealing embedded objects like developing stars

Slide 18 - The Death Throes of Stars:

- Stars collapse in different ways after running out of fuel, depending on mass
    - Hubble observes planetary nebulae and supernova remnants.
        - Planetary nebulae get their name from early astronomers because they looked like planets through telescopes of the time. They're actually outer layers of a star thrown off by dying Sun-size stars *(see thumbs)*.

        - Supernova remnants are the aftermath of massive stars that exploded, as in this image of the Crab Nebula *(main image)*

Slide 19 - Finding Planetary Construction Zones:

- In 1992, Hubble was the first telescope to resolve protoplanetary disks (“proplyds”) around stars in the Orion Nebula.
    - Protoplanetary disks are dense gas and dust disks surrounding newly formed stars.
    - Hubble found proplyds around nearly 200 stars in the nebula.
    - Proplyds are the beginnings of the formation of planetary systems.
- First to image a forming planet in ultraviolet light

Slide 20 - Recognizing Worlds Beyond Our Sun:

- Hubble studies exoplanet atmospheres
    - First measurements of the atmospheric composition of an extrasolar planet as it passed in front of its star
    - Hubble’s observations have identified atmospheres that contain sodium, oxygen, carbon, hydrogen, carbon dioxide, methane, helium, and water vapor.
    - Hubble’s observations demonstrate that we can detect and measure basic organic components for life on planets orbiting other stars.

Slide 21 - Seeing Light Echoes:

- Light echoes
    - As light travels from stellar outburst into space, as in this image of V838 Monocerotis, it bounces off and illuminates existing but unseen layers of dust around the star, like a flashlight shining off fog.

Slide 22 - Tracing the Growth of Galaxies:

- Hubble looks back at galaxies throughout time.
    - Takes time for light to travel through immense space. Because of this, the light arriving at Hubble from distant universe has traveled for billions of years and shows us galaxies as they appeared then.
    - Even closer objects are seen as they were in the past. Light from the Sun is about eight minutes old when it reaches Earth, meaning see it as it was eight minutes earlier.
- Image is the Hubble Ultra Deep Field, which contains an estimated 10,000 galaxies in roughly the area of sky seen through the eye of a needle held at arm’s length.

Slide 23 - Galaxy Details and Mergers:

- Gravity pulls galaxies together causing them to interact.
- Hubble shows that many galaxies interact with one another, that mergers are common, and that galaxies grow and evolve by merging.

Slide 24 - Monster Black Holes are Everywhere:

- Before Hubble supermassive black holes were theoretical.
- Hubble found supermassive black holes live in the centers of most galaxies.

Slide 25 - Homing in on Cosmic Explosions:

- Hubble explores the origins of gamma-ray bursts (GRB), explosions so intense they can emit more energy than the Sun over its entire 10-billion-year life, as well as supernovae.
- Because of Hubble astronomers now categorize GRBs into two types:
    - Long GRBs (where the initial burst lasts two seconds or longer), stemming from the explosive, supernova deaths of massive stars.
    - Short GRBs (where the burst lasts less than two seconds), associated with the collision of either two neutron stars or a neutron star and a black hole.
- Hubble has ringside seat to watch supernovae in progress

Slide 26 - Discovering the Runaway Universe:

- Hubble refined measurements of the expanding universe and found that the expansion of the universe is, mysteriously, speeding up.
    - We call the force behind this accelerating expansion dark energy.
        - Found by studying objects like Type 1a supernovae, which explode with a known brightness, making it possible to judge distance to galaxies containing them, like judging the distance to car headlights on a dark road.
        - Discovery won Nobel Prize in Physics in 2011

Slide 27- Focusing in on Gravitational Lenses:

- Hubble can see objects even farther away than its resolution allows by using gravitational lenses in space.
    - Gravitational lenses happen when immense gravity — like that from a cluster of galaxies — bends, distorts and magnifies light from objects even further away, beyond the cluster.

Slide 28 - Shining a Light on Dark Matter:

- More than 80% of the universe's mass is stuff we have never seen.
- Hubble observes dark matter by the way its gravity affects visible objects.
- Hubble observations help astronomers build maps of the location and properties of the densest concentrations of matter.
- Image shows both visible (normal) matter and invisible dark matter
    - Dark matter is highlighted with a bluish-purple glow

Slide 29 - Mapping the Cosmic Web:

- After the Big Bang, the universe evolved into a web of filaments and vast sheets, largely made of dark matter, which shape the structure of the universe today.
- This cosmic web forms the large-scale backbone of the universe.
- Hubble's dark matter observations can help identify and define this structure.

    - This image shows the massive galaxy cluster MACS J0717, where four separate galaxy clusters collided. The repeated collisions in MACS J0717 are the result of a 13-million-light-year-long stream of galaxies, gas, and dark matter – known as a “filament” – pouring into a region already full of matter.

Slide 30 - Hubble’s Future is Bright:

- Hubble is in great shape.
    - Redundancies exist in all critical systems except a few. In those cases, alternate operational scenarios and associated software have been developed (or are under development) to work around a possible failure.
    - The Hubble team anticipates continuing to do exciting, extraordinary, and prize-winning science through the end of the decade and into the next.
- Currently partners with James Webb Space Telescope and other observatories
- Will partner with the Nancy Grace Roman telescope once launched.
- Will continue to advance science while looking for the unknown
- As Lyman Spitzer dreamed in the 1940’s, Hubble is still poised to continue to “uncover new phenomena not yet imagined.”

Slide 31 - For More Information:

- Find out more about Hubble and see more Hubble images!
- Follow Hubble on social media for new discoveries!