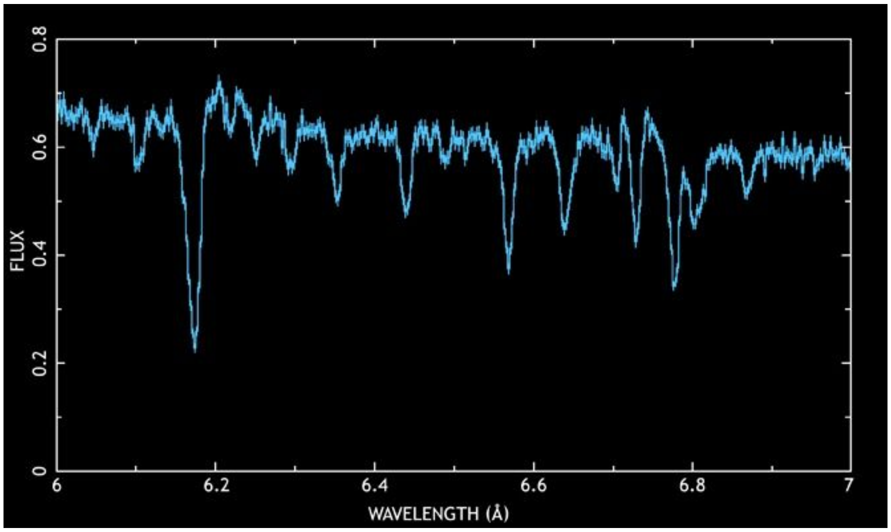
Satellite Data Results - Level 3

Black Holes -> X-ray -> Spectrometer -> Nested



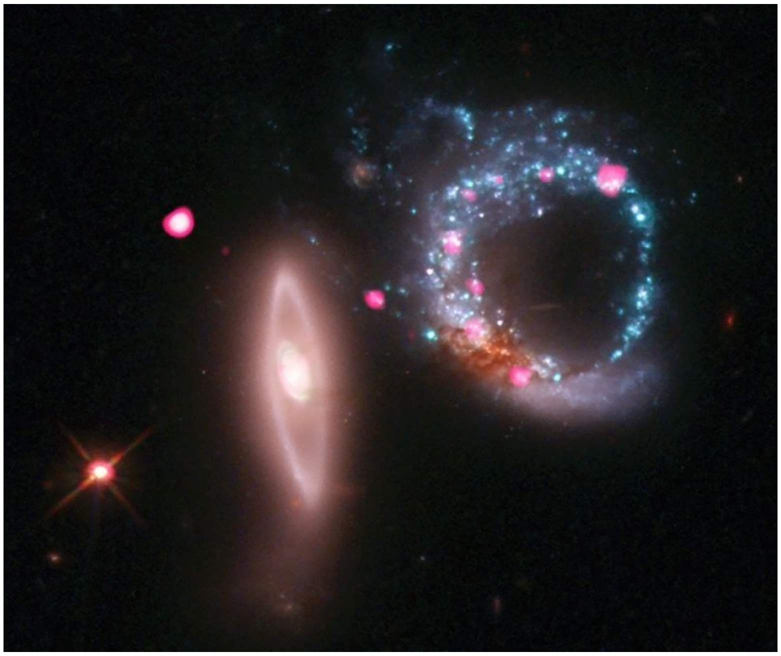
The data your satellite produces might look like this real data from the Advanced CCD Imaging Spectrometer (ACIS) and the High Energy Transmission Grating Spectrometer (HETGS) on the Chandra satellite. Chandra has nested X-ray mirrors that resemble glass barrels; they are designed this way so that incoming X-rays just graze the mirrors so they can be focused. The HETGS is an assembly that is swung into position behind the mirrors where it can intercept the reflected X-rays. The X-rays are diffracted by HETGS, which changes their direction an amount dependent on the energy of the X-ray, just like a prism separates light into its component colors. The ACIS, located at the focal point of the telescope, can then detect the location of the X-ray as well as measure its energy.

The above spectrum, a graph of intensity of energy over wavelength, is of a binary star system called GRO J1655-40, which consists of a black hole pulling matter in the form of hot gas from its companion, a normal star. Most of this material is spiraling toward the black hole, creating a disk around it, though about 30% of the matter is being blown away. The dips in the spectrum show that ionized atoms of elements like oxygen and nickel in the gas around the black hole are moving away from the black hole in a high-speed wind. Magnetic forces in the disk of gas around the black hole are largely responsible for the phenomena in this case, as it is magnetic fields that are driving the winds in the disk, and magnetic friction that is heating up the inner part of the disk to the point that it emits X-rays. Understanding magnetic fields is important, and can increase our understanding, not just of star-sized black holes, but supermassive ones and even planet-forming disks around young sun-like stars.

Learn more about Chandra: https://chandra.si.edu/

Image Credit: NASA/CXC/U.Michigan/J.Miller et al

Black Holes -> X-ray -> Camera -> Nested
Galaxies -> X-ray -> Camera -> Nested



The data your satellite produces might look like this real data from the Chandra X-ray Observatory Advanced CCD Imaging Spectrometer (ACIS) (in pink) and the Wide Field Planetary Camera 2 (WFPC2) on the Hubble Space Telescope with its blue, visible-light, and infrared filters represented as blue, green, and red, respectively. Known as Arp 147, this pair of gravitationally interacting galaxies consists of an elliptical galaxy (left, near center) that collided with a spiral galaxy, distorting it into a ring. The dusty reddish knot in the lower left part of the ring was probably the location of this galaxy's original nucleus. The ring of blue stars indicates a region of intense star formation, which was probably the result of shock waves caused by its close encounter with the elliptical galaxy.

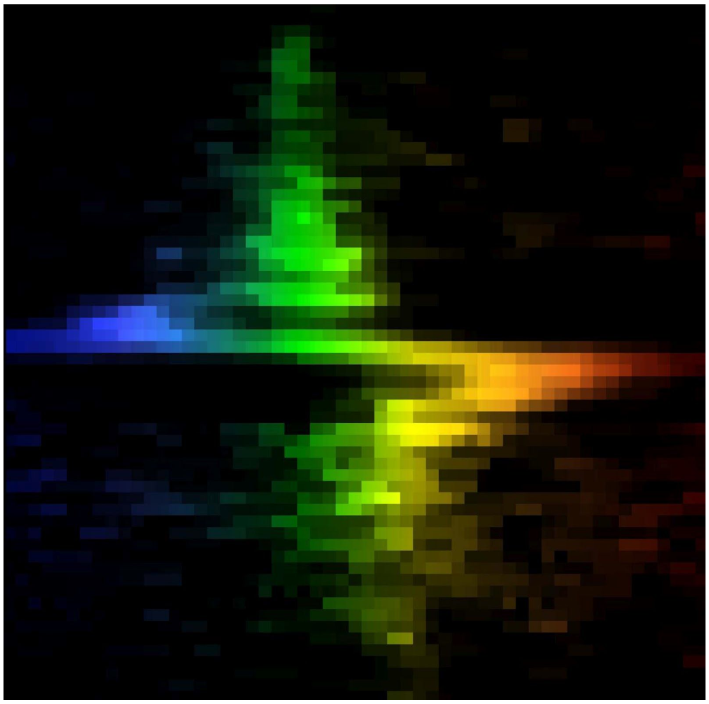
Some of these new stars have sped through their evolutionary cycle in just a few million years, exploding as supernovae and leaving neutron stars and black holes behind. Neutron stars and black holes that have companion stars can become bright sources of X-rays; nine of these (in pink) are scattered around the blue ring. They are so bright in X-rays that they must be black holes, likely with masses ten to twenty times that of the Sun.

An X-ray source was also detected in the nucleus of the red elliptical galaxy on the left, possibly a poorly-fed supermassive black hole. Other objects unrelated to Arp 147 are also visible: a foreground star in the lower left part of the image, and a background quasar visible as the pink source above and to the left of the red elliptical galaxy.

Learn more about Chandra: https://chandra.si.edu/

Image Credit: X-ray: NASA/CXC/MIT/S.Rappaport et al, Optical: NASA/STScI

Black Holes -> Optical -> spectrometer -> Single Primary
Galaxies -> Optical -> spectrometer -> Single Primary



The data your satellite produces might look like this real data from the Hubble Space Telescope's Space Telescope Imaging Spectrograph (STIS). STIS is an imaging spectrograph that has the ability to simultaneously produce spectra (graphs of intensity of light over a range of wavelengths) from many points across an object like a galaxy. This spectra is of the center of the galaxy M84. The S-shape in the spectrum indicates the presence of a rapidly swirling disk of material around a central supermassive black hole. The change in wavelength, shown by a swing to the left at the top of the spectrum, is from gas in the black hole's disk that is moving towards us. Near the middle of the spectrum, gas both approaches and moves away at high speeds, which means it is orbiting close in to the black hole. Below that is a swing to the right, showing gas that is moving away from us.

This data can be used to calculate the mass of the black hole. Just as the mass of the Sun can be calculated using the laws of Newton and Kepler, the rotation speed of gas around the black hole can be used to measure the black hole's mass. STIS measured the velocity of the gas within 26 light years of the black hole to be 880,000 miles per hour (400 kilometers per second) and the black hole was calculated to be about 300 million times the mass of the sun.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: Gary Bower, Richard Green (NOAO), the STIS Instrument Definition Team, and NASA

Black Holes -> Optical -> spectrometer -> Segmented
Galaxies -> Optical -> spectrometer -> Segmented

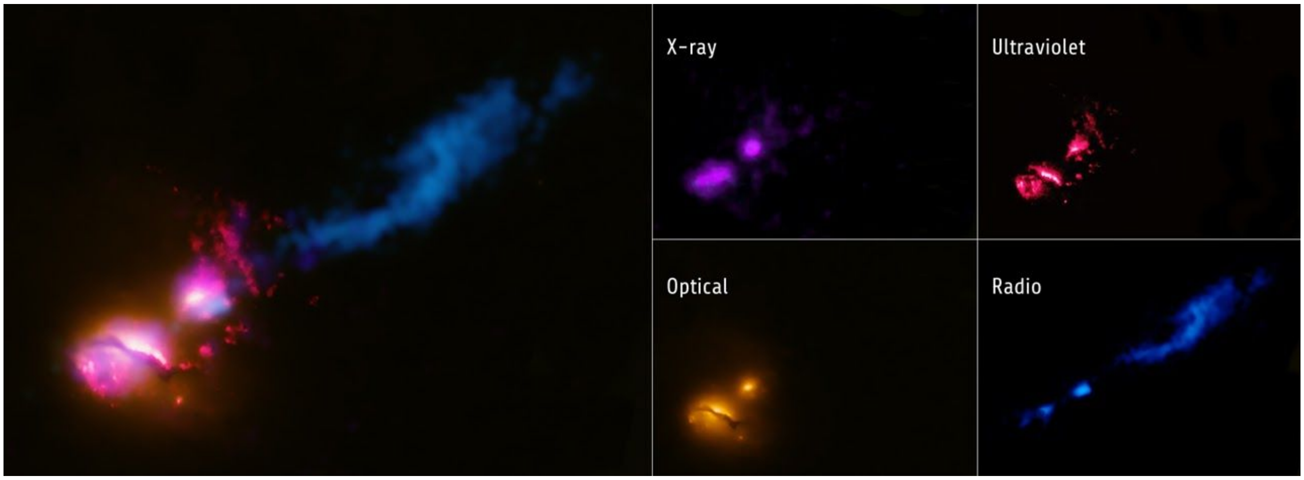
Your satellite is cutting-edge! Real data from a large, visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. An example is the James Webb Space Telescope, an infrared telescope with a giant segmented mirror 6.5 meters (21 feet, 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though designed to see primarily in the infrared, Webb can detect red and orange visible light, and Webb's segmented, deployable design could be used to build a telescope optimized for visible light.

Above is a spectrum of the black hole at the center of the galaxy M84 from the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope. The spectrum describes the motion of gas that swirls around the black hole. Telescopes like Hubble have already made amazing scientific discoveries; astronomers are very excited to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: Gary Bower, Richard Green (NOAO), the STIS Instrument Definition Team, and NASA

Black Holes -> Optical -> Camera -> Single Primary
Black Holes -> UV -> Camera -> Single Primary
Galaxies -> UV -> Camera -> Single Primary



The data your satellite produces might look like this real data from the Hubble Space Telescope. Optical data from the Wide Field Planetary Camera 2 (WFPC 2) is in orange, and ultraviolet data from the Space Telescope Imaging Spectrograph (STIS) is in red. These data are combined with an X-ray image from Chandra (purple) and radio observations from the Very Large Array and MERLIN (blue). The object pictured, known as 3C 321, is actually a system that contains two galaxies in orbit around each other. A powerful jet from a supermassive black hole at the heart of one of the galaxies (lower left) is blasting the edge of the other galaxy (above and to its right); the impacting jet is disrupted and deflected (upper right), much like a stream of water from a hose would be if it hit a wall at an angle. The jet struck the companion galaxy relatively recently, less than about a million years ago. The violence of this, as well as the high-energy radiation produced by it, could greatly affect any planets in its path, damaging their atmospheres; however, the jet could also trigger a burst of star formation in its wake, which could one day mean new planets.

Each wavelength shows a different aspect of this event. The X-ray data provides evidence that each galaxy contains a rapidly growing supermassive black hole at its center. The Hubble ultraviolet data shows large quantities of warm and hot gas in the vicinity of the galaxies, indicating the supermassive black holes in both galaxies have had a violent past. Hubble's visible light image shows the glow from the stars in each galaxy. A bright spot in the radio image shows where the jet struck the side of the galaxy, about 20,000 light-years from the main galaxy, dissipating some of its energy. The radio data also shows that the jet stretches some 850,000 light years past the galaxy it impacted.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: X-ray: NASA/CXC/CfA/D.Evans et al.; Optical/UV: NASA/STScI; Radio: NSF/VLA/CfA/D.Evans et al., STFC/JBO/MERLIN

Black Holes -> Optical -> Camera -> Segmented
Black Holes -> UV -> Camera -> Segmented
Galaxies -> UV -> Camera -> Segmented

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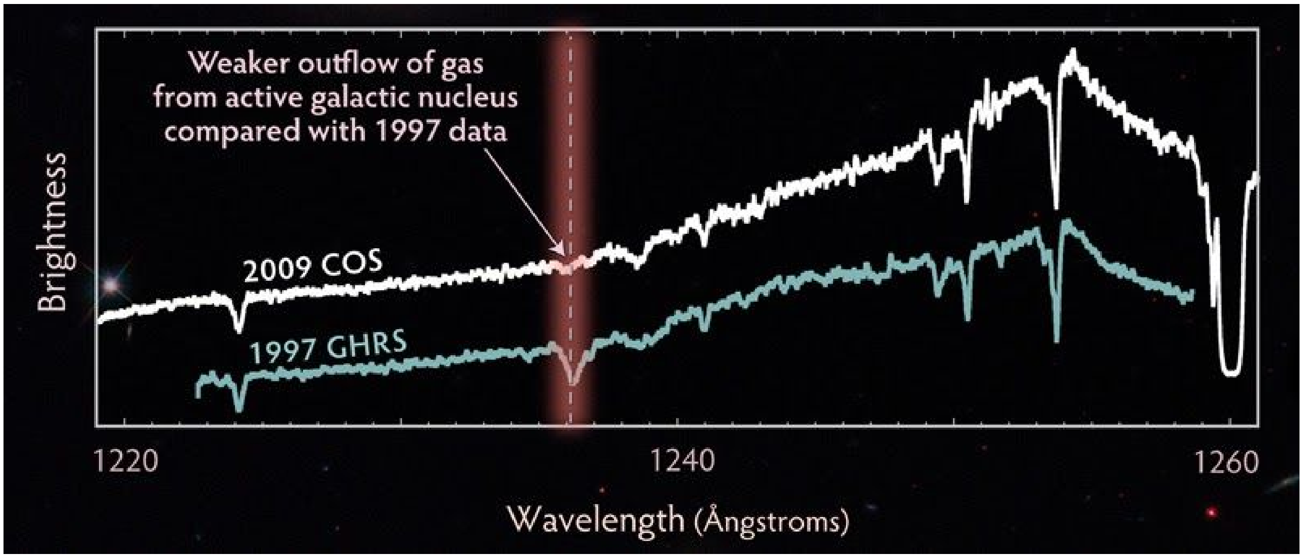
Above is a multiwavelength image of 3C 321, including optical and ultraviolet data from the Hubble Space Telescope's Wide Field Planetary Camera 2 (WFPC 2) and Space Telescope Imaging Spectrograph (STIS), respectively. 3C 321 is a system of orbiting galaxies; a jet from the black hole at the center of one of them is blasting the other. Visible wavelengths show the glow from the stars in the galaxies (in orange), and large quantities of warm and hot gas in the vicinity are visible in the ultraviolet (in red). (Additional radio data in blue traces the path of the jet, and X-ray data from Chandra in purple highlights the presence of supermassive black holes at the center of both galaxies.) Telescopes like Hubble have already made amazing scientific discoveries; astronomers are very excited to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: X-ray: NASA/CXC/CfA/D.Evans et al.; Optical/UV: NASA/STScI; Radio: NSF/VLA/CfA/D.Evans et al., STFC/JBO/MERLIN

Black Holes -> UV -> Spectrometer -> Single Primary
Galaxies -> UV -> Spectrometer -> Single Primary



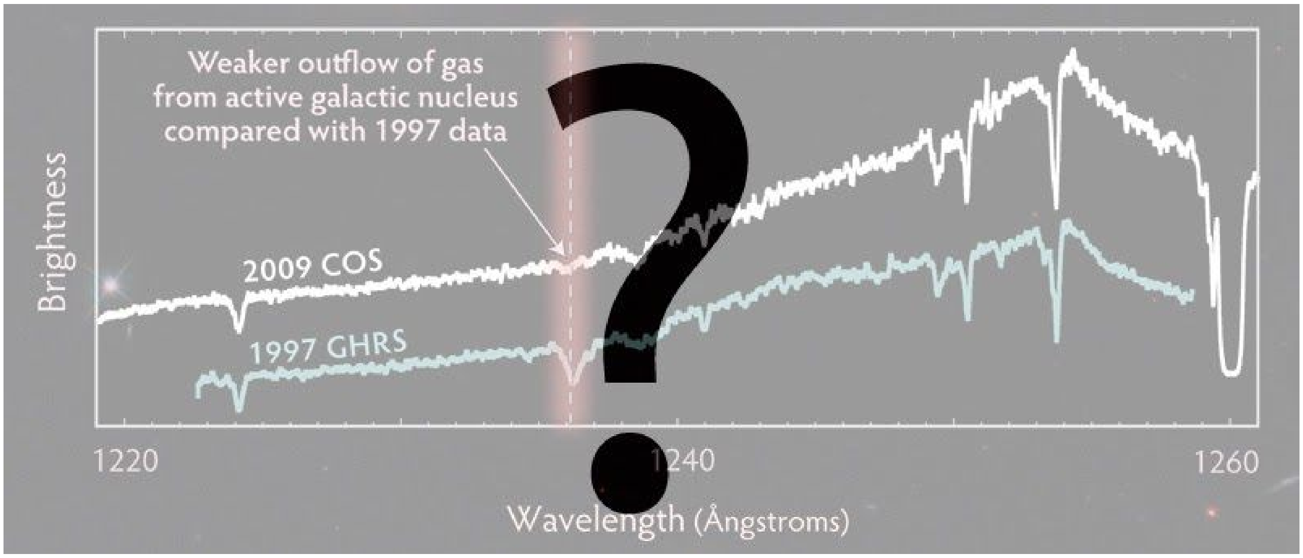
The data your satellite produces might look like this real data from the Cosmic Origins Spectrograph (COS) onboard the Hubble Space Telescope. These spectra show the intensity of light over ultraviolet wavelengths of Markarian 817, a spiral galaxy with a supermassive black hole at its center, that is explosively expelling matter into space at 9 million miles an hour. When observations from COS in 2009 (top) were compared with data from the Goddard High Resolution Spectrograph (GHRS) taken in 1997 (bottom), scientists learned that a hydrogen gas cloud present in 1997 had disappeared, likely in an outflow of material from the galaxy.

Powerful winds caused by streams of charged particles in the disk of matter around the black hole are responsible for blowing material away. Some of it becomes intergalactic gas, while some of it rains back onto the galaxy. The material being expelled contains atoms of elements like carbon, nitrogen, and oxygen, and the signatures of these elements are contained in spectra. Astronomers can use these spectra to understand the motion of the outflowing material, including how much of it escapes and how much is recaptured by the galaxy. The composition, location, and dynamics of the winds that distribute the material can also be determined.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA, ESA, and the Hubble SM4 ERO Team

Black Holes -> UV -> spectrometer -> Segmented



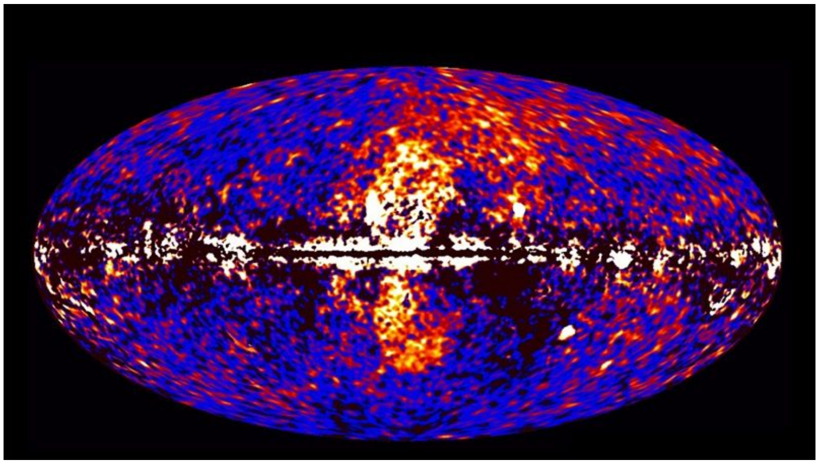
Your satellite is cutting-edge! Real data from a large, ultraviolet space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. An example is the James Webb Space Telescope, an infrared telescope with a giant segmented mirror 6.5 meters (21 feet, 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb's segmented, deployable design could also be used to build a telescope optimized for ultraviolet light.

Shown above is 2009 data from the Cosmic Origins Spectrograph (COS) onboard the Hubble Space Telescope, compared with older Goddard High Resolution Spectrograph (GHRS) data from 1997. Both spectra show the intensity of light over ultraviolet wavelengths of Markarian 817, a spiral galaxy with a supermassive black hole at its center, that is explosively expelling matter into space at 9 million miles an hour. An ultraviolet telescope with a large, segmented mirror and sensitive detectors could further refine these data results with more detailed spectra. Telescopes like Hubble have already made amazing scientific discoveries; astronomers are very excited to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: NASA, ESA, and the Hubble SM4 ERO Team

Galaxies -> Gamma ray -> Scintillator
Black Holes -> Gamma ray -> Scintillator



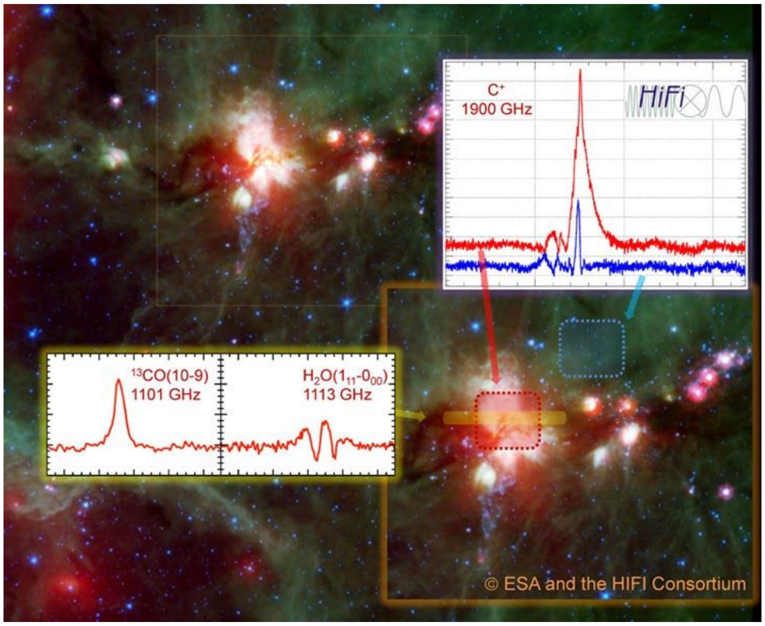
The data your satellite produces might look like this real data from the Large Area Telescope (LAT) onboard the Fermi Gamma-ray Space Telescope. This gamma-ray, all-sky map shows a previously unseen large-scale structure that was discovered by Fermi in 2010. Visible on this image as a dumbbell shaped feature (in yellow/orange) emerging from the galactic center, extending 25,000 light-years north and south from the plane of the Milky Way, are what appear to be large gamma-ray emitting bubbles.

These bubbles were previously undetected, partly because of a fog of gamma rays that appears throughout the sky. The fog happens when particles moving near the speed of light interact with light and interstellar gas in the Milky Way. However, the LAT team was able to detect these giant features due to the LAT's high resolution (which was the highest of any gamma-ray detector at the time) and their continued efforts to refine their models to remove the effects of the gamma-ray fog from their data.

Scientists now are conducting more analyses to better understand how the never-before-seen structure was formed. The bubble emissions are much more energetic than the gamma-ray fog and also appear to have well-defined edges. The structure's shape and emissions suggest that it was formed as a result of a large and relatively rapid energy release - the source of which remains a mystery. One theory is that the bubbles are a remnant of a past eruption from a supermassive black hole at the center of our galaxy. While there is no evidence that the Milky Way's black hole has a jet today, it may have in the past. Another theory is that the bubbles may have formed as a result of gas flowing out from a burst of star formation, perhaps the one that produced many massive star clusters in the Milky Way's center several million years ago.

Learn more about Fermi: https://imagine.gsfc.nasa.gov/observatories/learning/fermi/

Image Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.



The data your satellite produces might look like this real data from the Heterodyne Instrument for the Far Infrared (HIFI) on the European Space Agency's Herschel satellite, a far-infrared and submillimeter mission that at the time of its launch in 2009, was the largest telescope to be put into space. This spectrum, or graph of intensity over a range of wavelengths, is some of the first data produced by Herschel, and was a test of its capabilities.

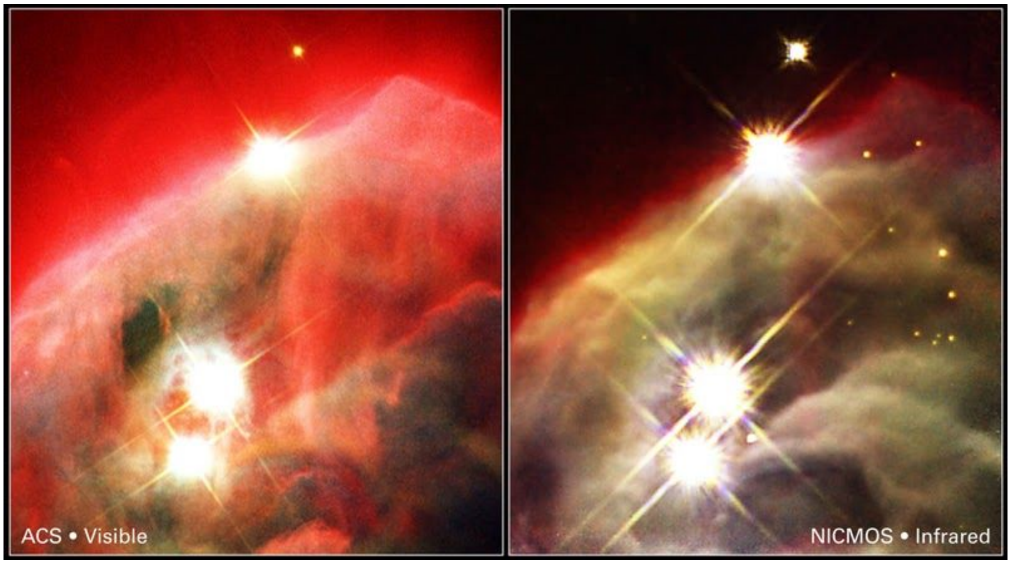
The image (which was captured by the infrared Spitzer Space Telescope) and the HIFI spectra show the first object observed by HIFI - DR 21, a star-forming region in our Milky Way about 6000 light years away. In the image, emission from large molecules glows green due to the nearby, newly-formed massive stars.

The blue and red boxes on the inset image (which itself is outlined in orange) show an area that has been surveyed for ionized carbon. A new star is present within the red box. The spectrum of that region (the red line in the top graph) shows the presence of a powerful wind that is ripping the gas cloud apart. By contrast, the region in the blue box has not yet been disturbed by this star (the blue line in the top graph). The yellow stripe through the red box shows where HIFI found evidence of carbon monoxide (far side of red spectrum at left) and water molecules (near side). The large width of the carbon monoxide peak and the shape of the water spectrum indicate that this material is part of a massive outflow from the newly formed star.

Learn more about Herschel: http://www.esa.int/esaSC/120390_index_0_m.html

Image Credit: ESA and the HIFI Consortium, (background) NASA/Sptizer

Star Formation -> IR -> Camera -> Single Primary
Star Formation ->Optical -> Camera -> Single Primary



The data your satellite produces might look like this real data from the Advanced Camera for Surveys (ACS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) onboard the Hubble Space Telescope. The visible light image at left and the near-infrared image at right give slightly different views of the star-forming region known as the Cone Nebula (NGC 2264). The four large, bright stars are visible in both infrared and visible light images because they are in front of the nebula. The smaller yellow stars are, however, visible only in infrared light because they are either behind the nebula or embedded in it. Infrared light is needed in order to study stars that are hidden by dusty clouds that are opaque to visible light, particularly because it is in these regions that stars are born. The Cone Nebula is so dense that NICMOS can only see half a light-year deep into the seven light-years-long nebula. It is in the thickest dust that the youngest stars are forming.

The Cone resides in a turbulent star-forming region, located 2,500 light-years away in the constellation Monoceros inside our own Milky Way galaxy. Radiation from hot, nearby young stars (not shown) has slowly eroded the nebula over millions of years.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: (NICMOS image) NASA, the NICMOS Group (STScI, ESA), and the NICMOS Science Team (University of Arizona). (ACS image) NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA

Star Formation -> IR -> Spectrometer -> Segmented
Star Formation -> IR -> Camera -> Segmented

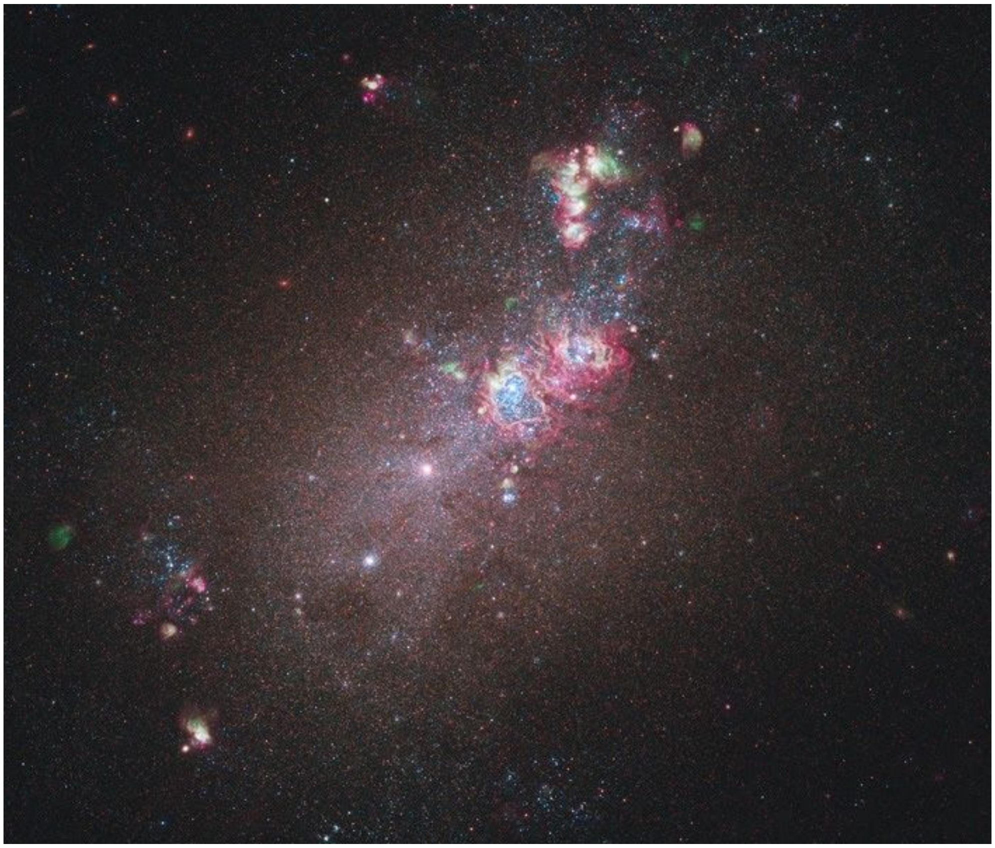
Your satellite is cutting-edge! Real data from a large, infrared space telescope with a segmented mirror does not yet exist, though it will in the near future. An example is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet, 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Hubble can see a small portion of the near-infrared part of the electromagnetic spectrum, but a larger mirror and longer infrared wavelength capabilities are needed to see deep into the thick dust clouds where stars are being born. With its superior imaging and spectroscopic abilities, Webb will give astronomers their closest look yet at star formation.

The above image is from a computer model that represents astronomers' best ideas about the star formation process within a dusty nebula. Redder colors indicate thicker dust. The pinwheel near the center is a protostar, perhaps 10,000 years old. Protostars arise when a dense knot of dust less than a light-year across collapses, but the details of the process are not well known. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: NCSA/NASA/A. Kritsuk and M. Norman (UC San Diego) and A. Boley (Univ. of Florida)

Star Formation -> UV -> Camera -> Single Primary



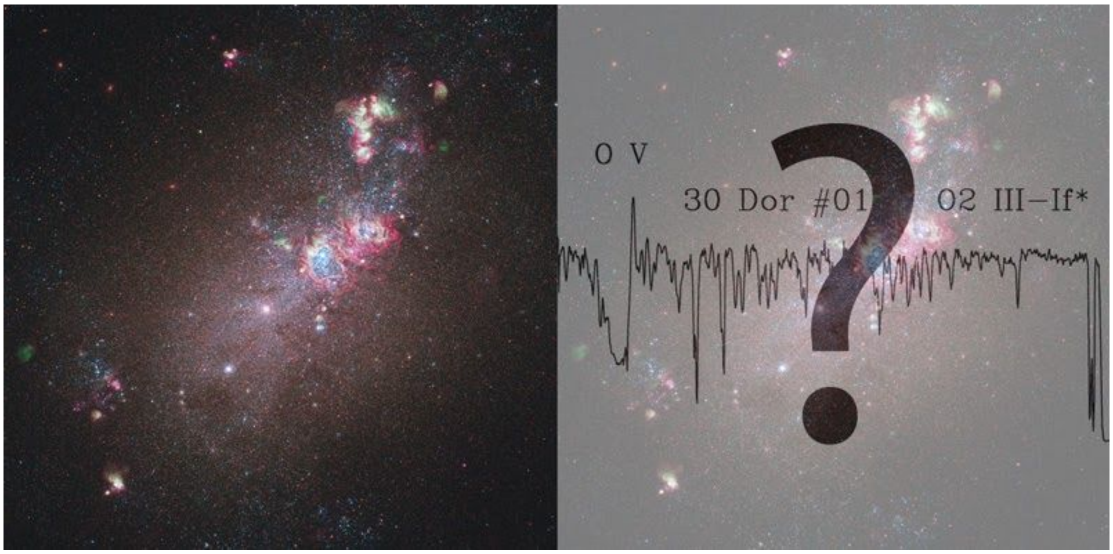
The data your satellite produces might look like this real data from the Wide Field Camera 3 (WFC3) onboard the Hubble Space Telescope. This image of nearby dwarf galaxy NGC 4214 uses both ultraviolet and visible-light filters. The regions of star formation in this galaxy glow because of the strong ultraviolet light emitted from young stars. Hot winds from these young stars blow out into the surrounding gas at millions of miles an hour, which causes bubbles to form. One example of this is near the center of the galaxy, where a giant gas bubble surrounds hundreds of massive blue stars, each more than 10,000 times brighter than our Sun. The bubble will increase in size as the most massive stars in the center reach the ends of their lives and explode as supernovae.

Though NGC 4214 is small and irregularly shaped, it is nearby and thus provides a unique view of star formation in galaxies other than the Milky Way. The visible-light filters reveal the light from older star populations and the overall structure of the galaxy, and can also be used to detect the presence of specific gases such as hydrogen, nitrogen, and oxygen.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration

Star Formation -> UV -> Camera -> Segmented
Star Formation -> UV -> Spectrometer -> Segmented
Star Formation -> Optical -> Camera -> Segmented
Star Formation -> Optical -> Spectrometer -> Segmented
Galaxies -> UV -> Spectrometer -> Segmented



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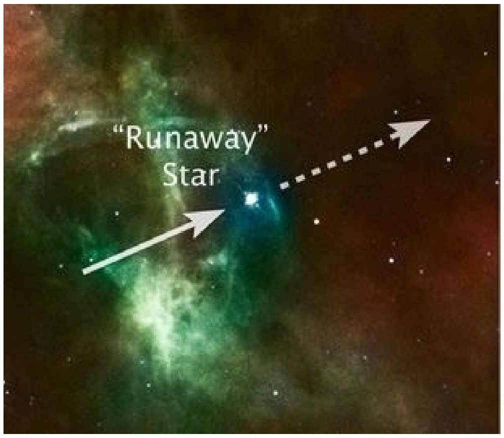
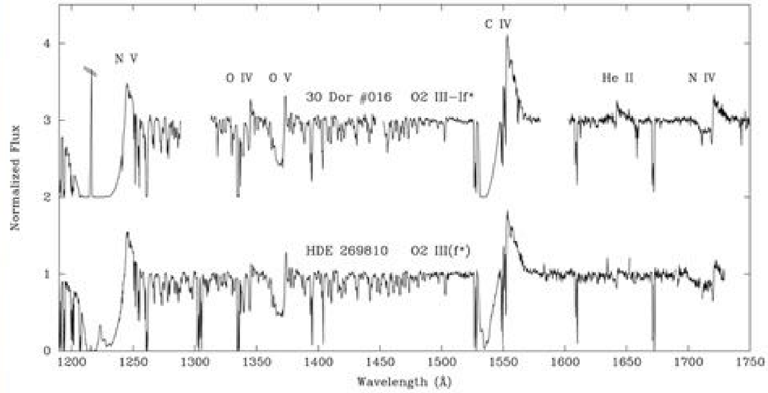
At left is an ultraviolet/visible light image of star formation in the small, nearby dwarf galaxy NGC 4214, which was captured by Hubble's Wide Field Camera 3 (WFC3). The regions of star formation in this galaxy glow because of the strong ultraviolet light emitted from young stars. A telescope with a much bigger mirror would reveal things never-before-seen and make unprecedented discoveries. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: (left and right) NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration (spectrum, right) NASA, ESA, and C. Evans, et al. (from The Astrophysical Journal, vol. 715, p. L74, 2010)





The data your satellite produces might look like this real data from the Hubble Space Telescope. On the left is an image taken by Hubble's Wide-Field Planetary Camera 2 (WFPC 2) and on the right are spectra from the Cosmic Origins Spectrograph (COS) and the Space Telescope Imaging Spectrograph (STIS). These ultraviolet spectra, or graphs of intensity of energy over wavelength, compare two stars, both in the Large Magellanic Cloud, an irregular galaxy near to our own. The top graph is COS data of a massive star called 30 Dor 016 and the bottom one is STIS data of a similar star, HDE 269810. Both of these stars are "runaway" stars - stars that are seen traveling at high speeds and have been ejected from their birthplaces.

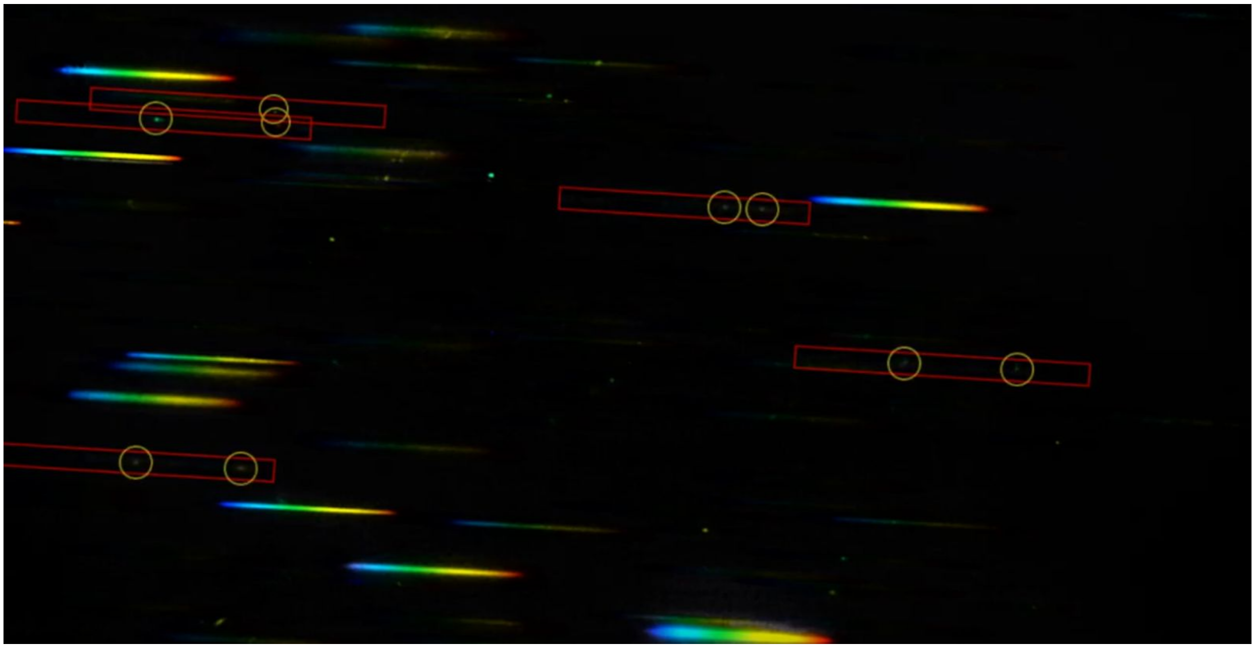
30 Dor 016, shown in the Hubble image above, is about 90 times more massive than our sun, and is whipping through space at 250,000 miles (400,000 kilometers) an hour. It appears to already have traveled some 375 light-years from its place of birth, a star cluster called R136, located deep in the 30 Doradus (or Tarantula) Nebula. This star is very young, only 1-2 million years old, and it appears to have been kicked out of its birthplace by a group of even bigger sibling stars. Astronomers can tell the star is moving quickly because features in the spectra of 30 Dor 016 show that its stellar winds are blowing at very fast speeds, the fastest yet seen for a runaway star.

Runaway stars can be created in a few ways. A star can be ejected from its birthplace by an encounter with one or two heavier siblings, or a star may get a 'kick' from a supernova explosion. Because the R136 star-forming region is so young, the cluster's most massive stars haven't gone through their life cycles and exploded as supernovae yet, so most likely 30 Dor 016 was ejected through interaction with other stars.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: (image) J. Walsh and Z. Levay, ESA/NASA (spectra) NASA, ESA, and C. Evans, et al. (from The Astrophysical Journal, vol. 715, p. L74, 2010)

Star Formation -> Optical -> Spectrometer -> Single Primary
Early Universe -> Optical -> Spectrometer -> Single Primary



The data your satellite produces might look like this real data from the Hubble Space Telescope. Astronomers have used Hubble's highly-sensitive Wide Field Camera 3 in its "grism spectroscopy mode" to find bursts of star formation in small and distant galaxies.

A grism is a combination of a grating and a prism, and it splits up the light from a galaxy into its constituent colours, producing a spectrum. In this image, the continuum of each galaxy is shown as a "rainbow."

Astronomers can look at a galaxy's spectrum and identify light emitted by the hydrogen gas in the galaxy. If there are stars being formed in the galaxy then the intense radiation from the newborn stars heats up the hydrogen gas and makes it glow.

All of the light from the hydrogen gas is emitted in a small number of very narrow and bright emission lines. For dwarf galaxies in the early Universe the emission lines are much easier to detect than the faint, almost invisible, continuum.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA and ESA. Text Credit: STScI

Early Universe -> Optical -> Spectrometer -> Segmented

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The above shows real data from the Hubble Space Telescope. Astronomers have used Hubble's highly-sensitive Wide Field Camera 3 in its "grism spectroscopy mode" to find bursts of star formation in small and distant galaxies.

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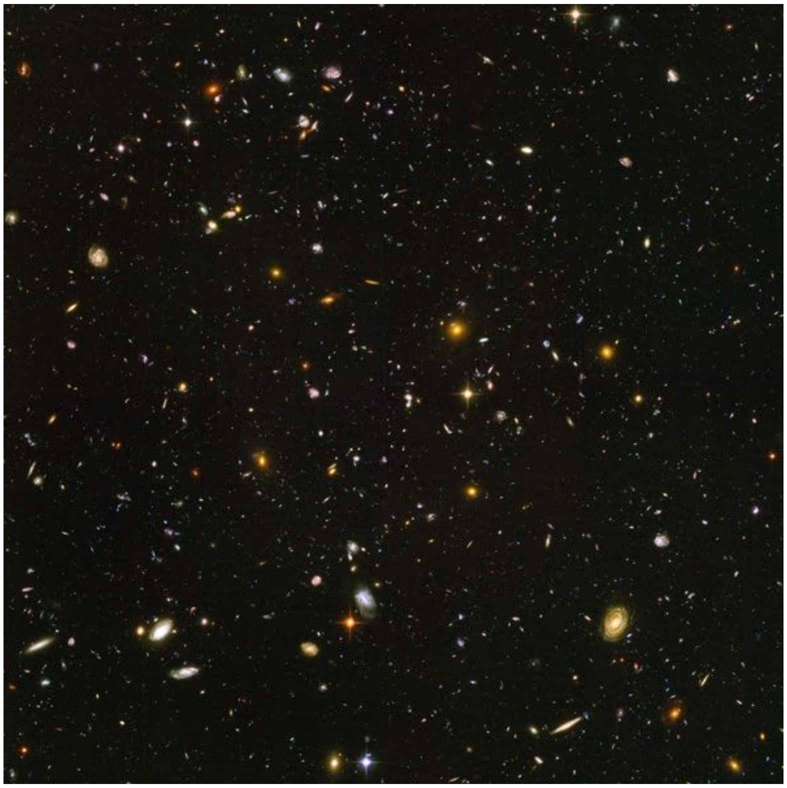
Image Credit: NASA and ESA. Text Credit: STScI

Early Universe -> Optical -> Camera -> Single Primary



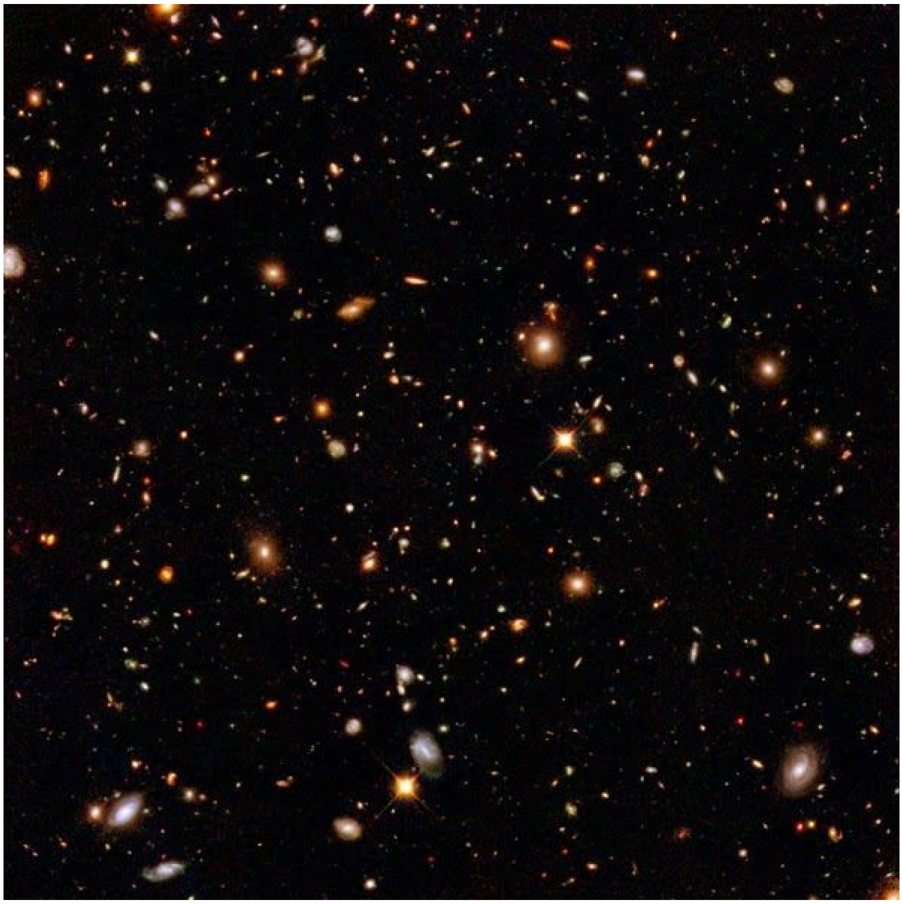
The data your satellite produces might look like this real data from the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope. This image is known as the Hubble Ultra Deep Field (HUDF) and is a million-second-long exposure that reveals the the most distant galaxies ever to be seen in visible light, offering insights into what types of objects existed in the universe long ago. This tiny patch of sky - much less than the area the full moon covers on the sky - reveals over 10,000 galaxies, many of which existed when the universe was only a fraction of its present age. A wide range of galaxies of various sizes, shapes, and colors are present here, some of them oddly shaped, and some apparently interacting with each other. Their strange shapes are a far cry from the majestic spiral and elliptical galaxies we see today. These oddball galaxies chronicle a period when the universe was more chaotic and order and structure were just beginning to emerge.

This HUDF image is visible-light, though Hubble also captured a spectacular infrared view of the same field of galaxies.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

Early Universe -> IR -> Camera -> Single Primary



The data your satellite produces might look like this real data from the Near Infrared Camera and Multi-object Spectrometer (NICMOS) on the Hubble Space Telescope. This image is known as the Hubble Ultra Deep Field (HUDF) and is a million-second-long exposure that reveals the the most distant galaxies ever to be seen in visible light, offering insights into what types of objects existed in the universe long ago. This tiny patch of sky - much less than the area the full moon covers on the sky - reveals over 10,000 galaxies, many of which existed when the universe was only a fraction of its present age. A wide range of galaxies of various sizes, shapes, and colors are present here, some of them oddly shaped, and some apparently interacting with each other. Their strange shapes are a far cry from the majestic spiral and elliptical galaxies we see today. These oddball galaxies chronicle a period when the universe was more chaotic and order and structure were just beginning to emerge.

This HUDF image is near-infrared, though Hubble also captured a spectacular visible-light view of the same field of galaxies.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA, ESA, and R. Thompson (Univ. Arizona)

Early Universe -> Optical -> Camera -> Segmented
Galaxies -> Optical -> Camera -> Segmented

Your satellite is cutting-edge! Real data from a large, visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. An example is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet, 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb will be able to detect red and orange visible light, and Webb's segmented, deployable design could be used to build a telescope optimized for visible light.

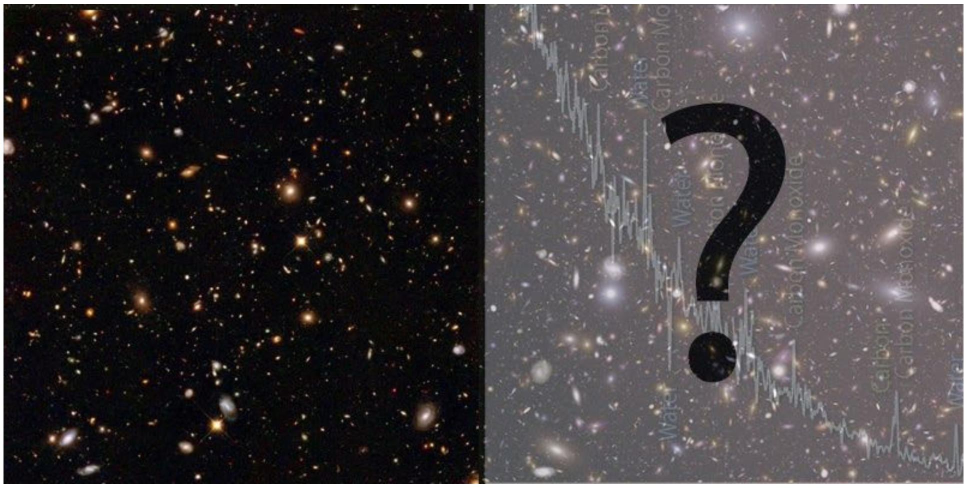
With its superior imaging and spectroscopic abilities, Webb will be able to look further back into the past than ever before, to see the first stars and galaxies that formed in the early universe. Because Webb is optimized for the infrared, it will be able to see the part of the spectrum where the most distant and earliest galaxies shine. Hubble sees "toddler" galaxies - Webb will see newborns.

The earliest galaxies were small dwarfs, smaller even than the galaxies that Hubble has seen (above left, visible-light view) in its Ultra Deep Field. (Above right shows simulated data.) One way astronomers think galaxies grew was by colliding and merging with other small galaxies, and over billions of years these mergers built up the giant galaxies we see today. Mergers triggered pulses of star formation that created the elements necessary for planets, and ultimately, life. Astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

Early Universe -> IR -> Camera -> Segmented
Early Universe -> IR -> Spectrometer -> Segmented
Galaxies -> IR -> camera -> Segmented
Galaxies -> IR -> Spectrometer -> Segmented



Your satellite is cutting-edge! Real data from a large, infrared space telescope with a segmented mirror does not yet exist, though it will in the near future. An example is the James Webb Space Telescope, an infrared telescope with a giant segmented mirror 6.5 meters (21 feet, 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) With its superior imaging and spectroscopic abilities, Webb will be able to look further back into the past than ever before, to see the first stars and galaxies that formed in the early universe. Because Webb is optimized for the infrared, it will be able to see the part of the spectrum where the most distant and earliest galaxies shine. Hubble sees "toddler" galaxies - Webb will see newborns.

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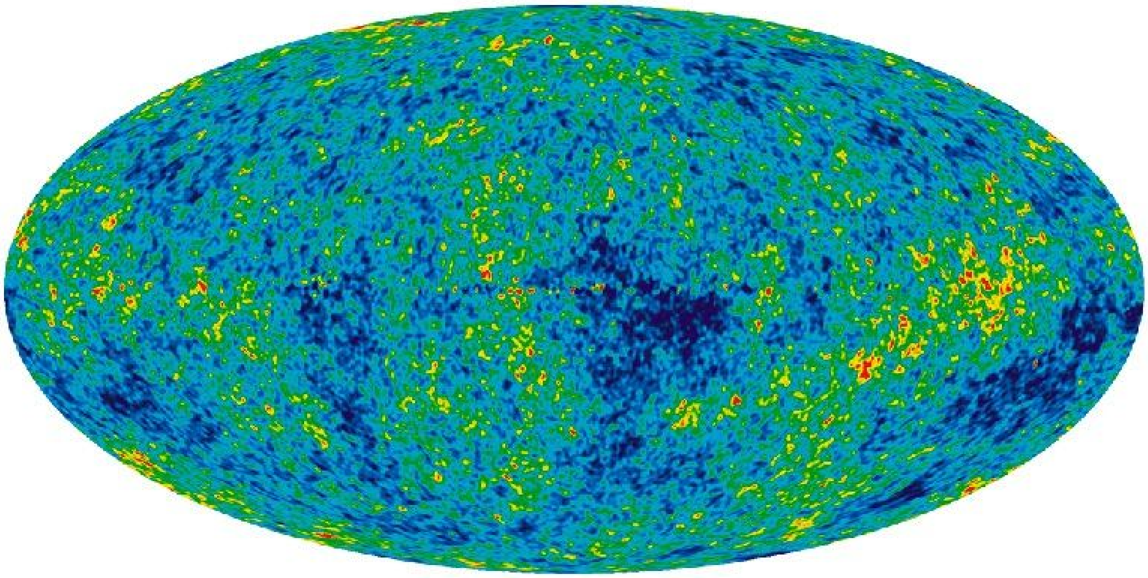
Image Credit: (left) NASA, ESA, and R. Thompson (Univ. Arizona)
(right) NASA (overlay) ESA/Herschel/SPIRE "Nearby Galaxies" consortium

Early Universe -> Microwave -> Radiometer



The data your satellite produces might look like this real data from the Wilkinson Microwave Anisotropy Probe (WMAP), a cosmology satellite that was launched in 2001. Though its predecessor, COBE, had several instruments, WMAP's only instrument is a pair of radiometers. WMAP's goal is to measure the temperature differences in the cosmic microwave background (CMB) radiation, the radiation released after the Big Bang but long before the formation of galaxies, when the universe was less than 400,000 years old. These "anisotropies", or temperature differences, are used to measure the universe's geometry, content, and evolution, as well as to test the Big Bang Theory.

The above detailed, all-sky picture of the infant universe was created from seven years of WMAP data. The image reveals 13.7 billion year-old temperature fluctuations (shown as color differences) that correspond to the seeds that grew to become the galaxies.

Learn more about WMAP: http://map.gsfc.nasa.gov/

Image Credit: NASA / WMAP Science Team

Galaxies -> IR -> camera -> Single Primary
Galaxies ->Optical -> camera -> Single Primary

The data your satellite produces might look like this real data from the Advanced Camera for Surveys (ACS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) onboard the Hubble Space Telescope. Both images show a face-on view of the spiral galaxy, M51, also known as the Whirlpool. At left, visible light reveals the galaxy's curved arms, pink star-forming regions, and bright blue star clusters.

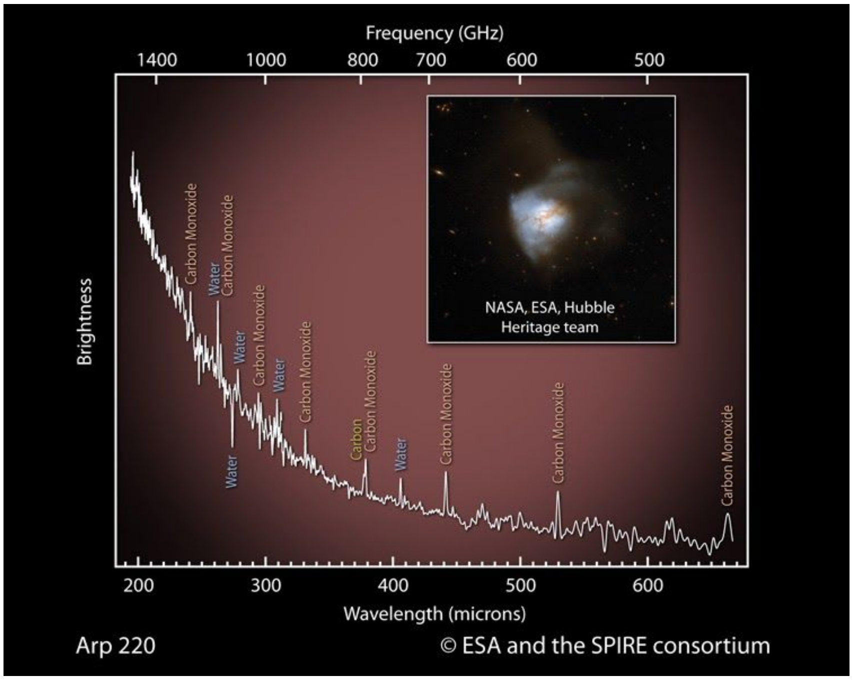
In the near-infrared image at right, most of the starlight has been removed, revealing the Whirlpool's skeletal dust structure. The red color in the near-infrared image traces the dust, which is punctuated by hundreds of tiny clumps of stars, each about 65 light-years wide and never-before-seen. These star clusters cannot be seen in visible light because of the opaque, dense dust that surrounds them. Despite these tiny clumps, the dust largely lies in smooth lanes, something that surprised astronomers, who had expected to see large, 100-300 light-year-wide dust clouds. In this case, an encounter with another galaxy may have prevented giant clouds from forming.

The ability to probe the dust structure of a galaxy is important, as it provides astronomers with invaluable information on how the gas and dust collapse to form stars. Although Hubble is providing amazing views of the internal structure of galaxies such as M51, the upcoming James Webb Space Telescope (with its giant, segmented mirror) will show us even more detail about dusty galaxies, much further into the infrared part of the electromagnetic spectrum.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: (ACS) NASA, ESA, S. Beckwith (STScI), and the Hubble Heritage Team (STScI/AURA) (NICMOS) NASA, ESA, M. Regan and B. Whitmore (STScI), and R. Chandar (University of Toledo)

Early Universe -> IR -> Spectrometer -> Single Primary
Galaxies -> IR -> Spectrometer -> Single Primary



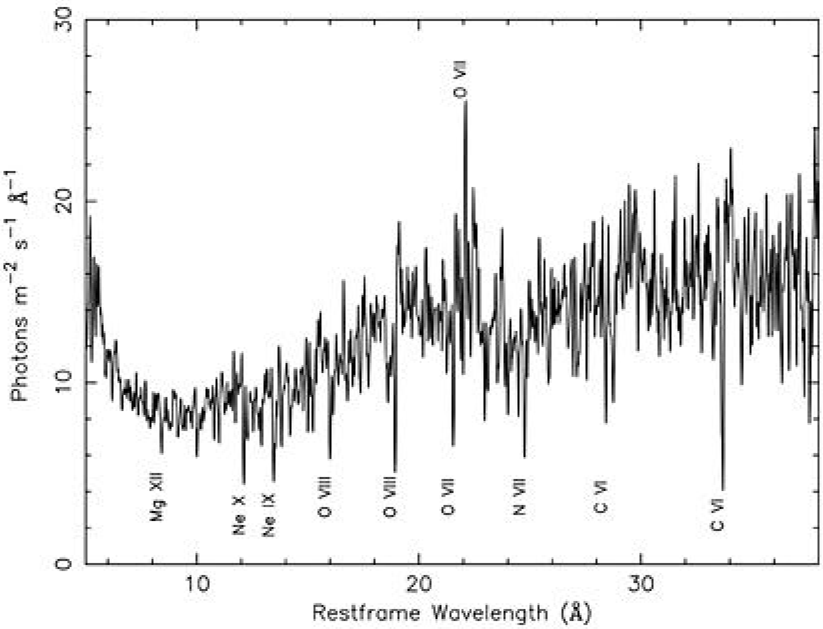
The data your satellite produces might look like this real data from the Spectral and Photometric Imaging Receiver (SPIRE) instrument on the European Space Agency's Herschel Space Telescope, a far-infrared and submillimeter mission that at the time of its launch in 2009, was the largest telescope to be put into space. This spectrum, or graph of intensity over a range of infrared wavelengths, shows the presence of carbon monoxide (CO) and water (H_2O) in the galaxy Arp 220. Located 250 million light years away, Arp 220 has very active star formation that was triggered when two large spiral galaxies collided. When two galaxies collide, though the stars in the galaxy are extremely unlikely to collide with each other, the gas and dust in the galaxy get compressed and heated by the collision. This compression and heating causes more star formation, which can be detected by looking for emission by particular molecules like CO and H_2O.

Over billions of years, mergers of small galaxies can result in the giant galaxies we see today. Studies of Arp 220 are important for understanding distant galaxies and galaxy formation in the early universe.

The inset optical image of Arp 220 was made with the Hubble Space Telescope.

Learn more about Herschel: http://www.esa.int/esaSC/120390_index_0_m.html

Image Credit: ESA/Herschel/SPIRE "Nearby Galaxies" consortium and NASA/ESA/STSci (inset).

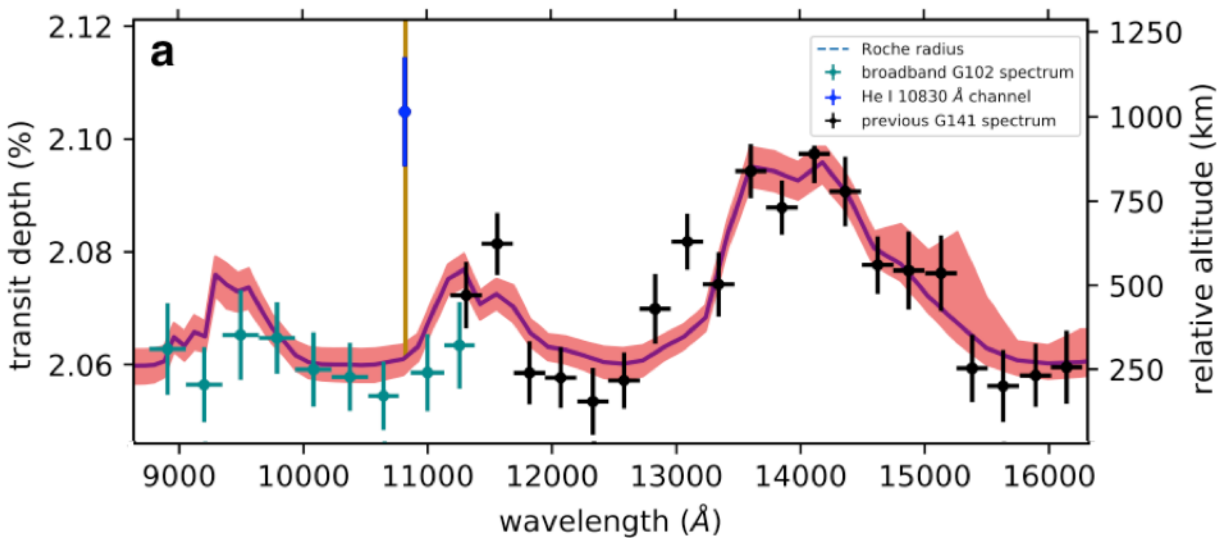


The data your satellite produces might look like this real data from the High Resolution Camera (HRC) and the Low Energy Transmission Grating Spectrometer (LETGS) on the Chandra satellite. Chandra has nested X-ray mirrors that resemble glass barrels; they are designed this way so that incoming X-rays just graze the mirrors so they can be focused. The LETGS is an assembly that is swung into position behind the mirrors where it intercepts the reflected X-rays. The X-rays are diffracted by LETGS, which changes their direction an amount dependent on the energy of the X-ray, just like a prism separates light into its component colors. The HRC, located at the focal point of the telescope, can then detect the location of the X-ray on the detector and also measure its energy.

This X-ray spectrum (or graph of intensity of light over wavelength) is of the central region of the galaxy NGC 5548, and it gives astronomers information about the gas around the giant black hole in the center of the galaxy. The deep valleys in the spectrum (called absorption lines) are produced when warm (few million degree) gas absorbs X-rays of specific energies from hotter gas close to the central black hole, and are due to the presence of elements like carbon, nitrogen, oxygen, neon and magnesium. A peak in the spectrum due to emission from oxygen is also identified. The lines are slightly shifted to shorter wavelengths because the gas is moving away from the black hole at about a million kilometers per hour.

Learn more about Chandra: http://chandra.si.edu/

Image Credit: NASA/SRON



The data your satellite produces might look like this real data, captured by the Wide Field Camera 3 (WFC3) on the Hubble Space Telescope. WFC3 was used in a mode that allows spectroscopy to examine the atmosphere of exoplanet WASP-107b in the infrared.

In 2018, a PhD student from the UK, Jessica Spake, led an international team of astronomers who looked at the infrared spectrum of this planet and for the very first time, discovered helium in the atmosphere of a planet outside the Solar System. Not only is this significant scientifically, but it also was a “proof-of-concept,” that looking at spectra in the infrared would be an effective way to study exoplanets. The James Webb Space Telescope, optimized for infrared light, will have the ability to examine exoplanet atmospheres in greater detail than ever before.

WASP-107b is about the size of Jupiter but with only 12% of its mass. The large amount of helium detected indicates an extensive upper atmosphere. In the spectra shown above, the teal points were the ones observed by Spekke et al in the infrared, while the black are from a previous study at different wavelengths. The points are fit against a model (the red line) that assumed features in the spectrum were due to water. The bright blue line shows the detection of helium, and the gold is from a later model of the line. This is what makes scientists think that there is helium extending above the water layer in the atmosphere. The helium model also indicates that helium is being stripped away from the planet.

Learn more about the Hubble: http://hubblesite.org/

Image credit: J. J. Spake, D. K. Sing, T. M. Evans, et al.

Exoplanets -> IR -> Spectrometer -> Segmented
Exoplanets -> IR -> Camera -> Segmented

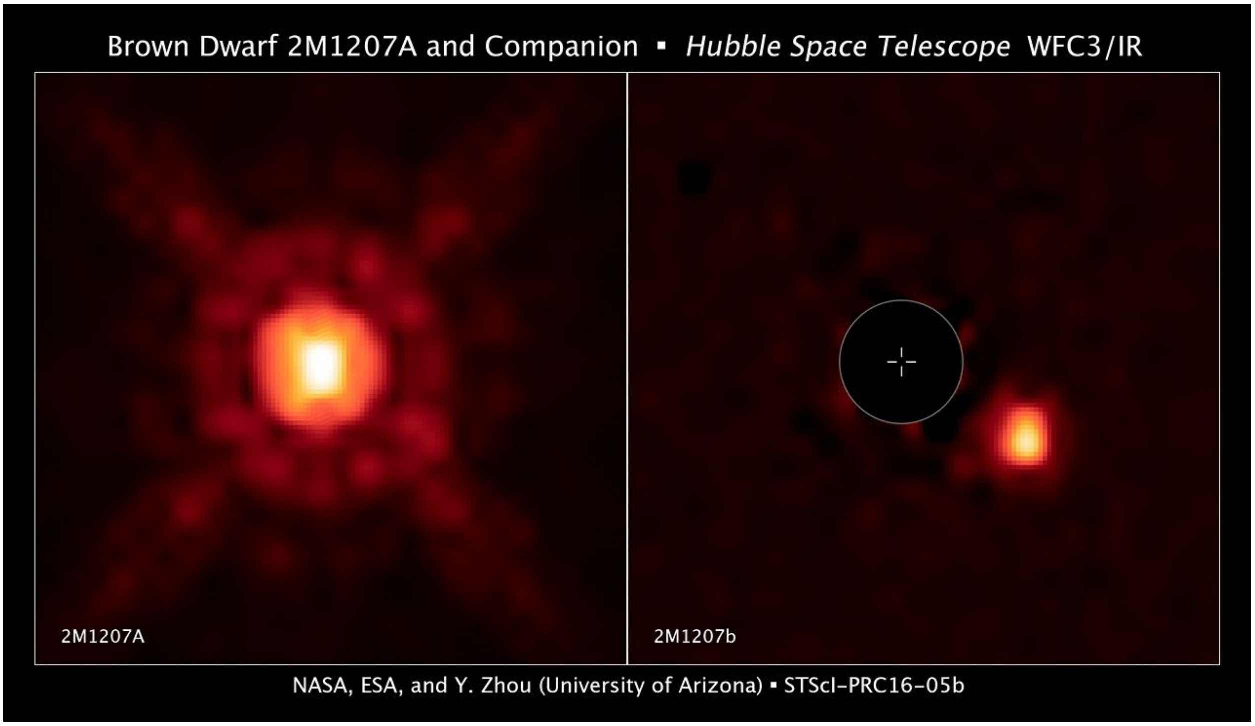
Your satellite is cutting-edge! Real data from a large, infrared space telescope with a segmented mirror does not yet exist, though it will in the near future. An example is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet, 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) As an infrared telescope, Webb will be able to unravel the birth and early evolution of stars and planets by peering into the hearts of dense and dusty cloud cores where star formation begins. Webb's superior imaging and spectroscopy capabilities will allow us to study stars as they are forming in their dusty cocoons. It will also be able to study planet-forming disks around stars and study organic molecules that are important for life to develop.

The above image is from a computer model. Represented is a protostar deep within the cold, turbulent cocoon of a molecular cloud which hosts a dusty disk where brown dwarfs or planets may one day form. Webb will be able to make observations of stars with dusty disks and young solar systems in the near- and mid-infrared, hunting for planets and probing the regions interior to the dust ring for structures like an inner asteroid belt. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Learn more about the James Webb Space Telescope: http://jwst.nasa.gov/

Image Credit: NCSA/NASA/A. Kritsuk and M. Norman (UC San Diego) and A. Boley (Univ. of Florida)

Exoplanets -> IR -> Camera -> Single Primary



The data your satellite produces might look like this real data from the Wide Field Camera 3 aboard the Hubble Space Telescope. Though primarily an optical telescope, Hubble has some ability to detect infrared light.

This image shows a near-infrared-light view of a brown dwarf (left) located 170 light-years away from Earth. It is no more than 30 times the mass of Jupiter, making it too small to sustain nuclear fusion to shine as a star.

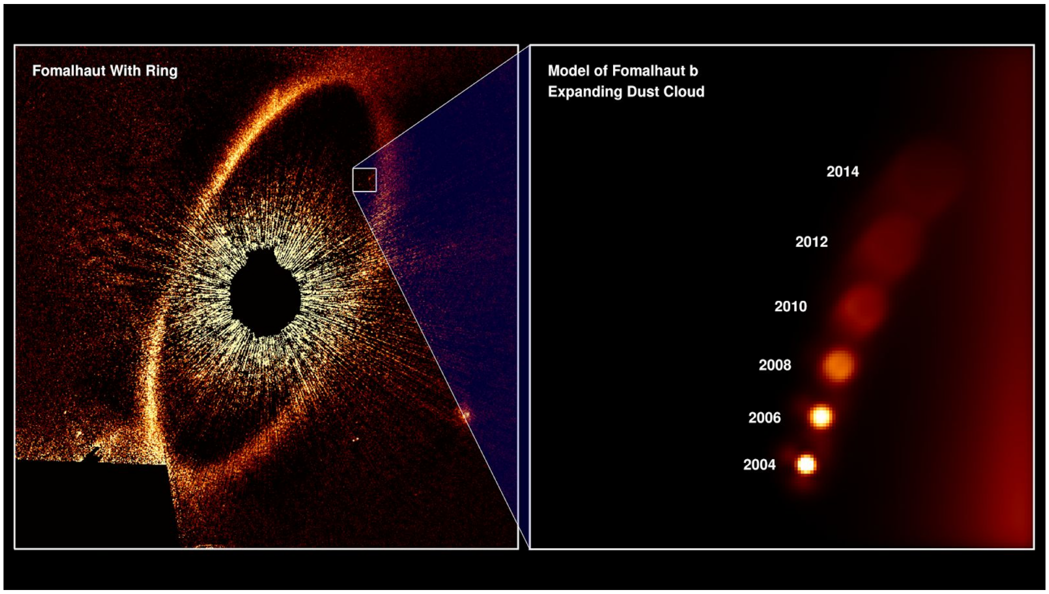
But when the glow of the brown dwarf is subtracted from the image, a smaller and fainter companion object becomes visible (right). No more than four times the mass of Jupiter, this companion is dubbed a super-Jupiter. It has an estimated diameter as big as 40 percent greater than Jupiter's diameter. This world is 8 billion kilometers from the brown dwarf, nearly twice the distance between our Sun and the planet Neptune.

Because the planet is only 10 million years old, it is so hot it may rain molten glass and iron in its atmosphere. Hubble has measured fluctuations in the planet's brightness that suggests the planet has patchy clouds as it completes one rotation every 10 hours.

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA, ESA, and Y. Zhou (University of Arizona), Text source: STScI

Exoplanets -> Optical -> Camera -> Single Primary



The data your satellite produces might look like this real data from the Space Telescope Imaging Spectrograph (STIS) onboard the Hubble Space Telescope. This image (left) is an updated view of Fomalhaut b from 2012, an object previously thought to be an exoplanet… but the latest Hubble data and modeling show that it may not be one after all!

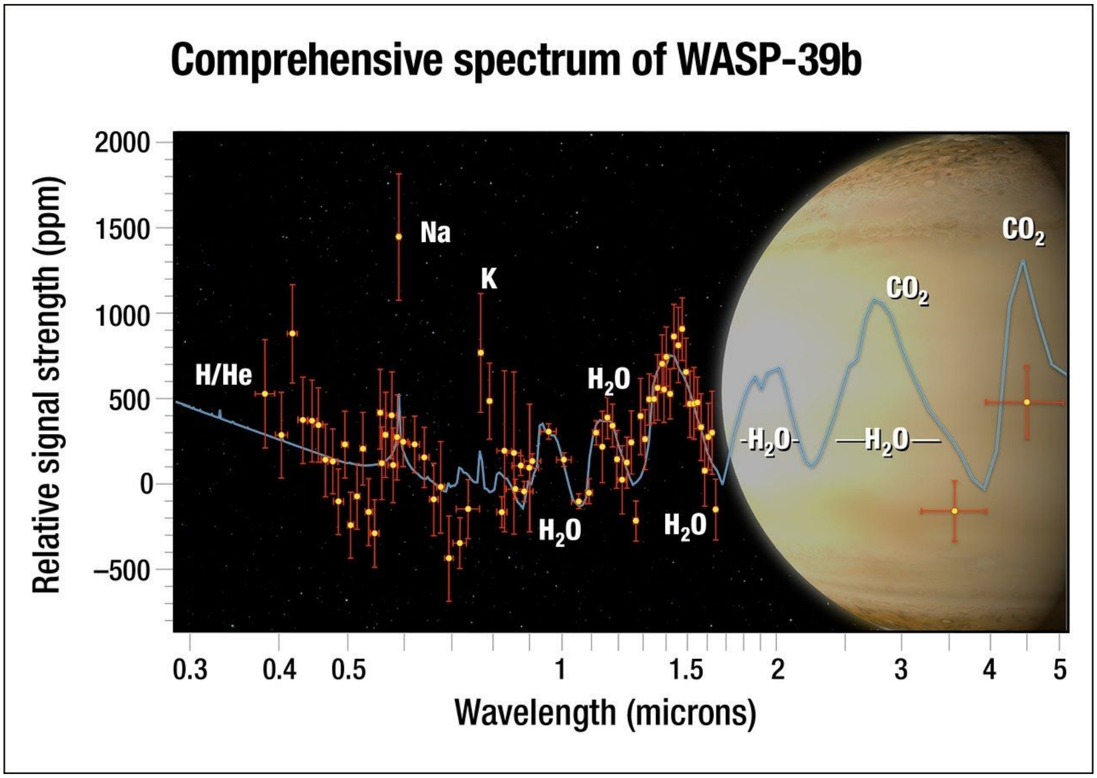
The first image of this object was captured by Hubble in 2004, and at the time, was thought to be the first visible-light snapshot of a planet. There were several subsequent observations, but by 2014, the planet candidate faded below Hubble's detection. The best interpretation is that the object wasn't ever a fully formed planet at all, but an expanding cloud of dust from a collision between two minor bodies, each about 125 miles across. The diagram at the right is based on a simulation of the expanding and fading cloud. The cloud, made of very fine dust particles, is currently estimated to be over 200 million miles across. Smashups like this are estimated to happen around Fomalhaut once every 200,000 years. Therefore, Hubble was looking at the right place at the right time to capture this transient event.

"The Fomalhaut system is the ultimate test lab for all of our ideas about how exoplanets and star systems evolve," said George Rieke of the University of Arizona's Steward Observatory. "We do have evidence of such collisions in other systems, but none of this magnitude has been observed in our solar system. This is a blueprint of how planets destroy each other."

Learn more about the Hubble: http://hubblesite.org/

Image Credit: NASA, ESA, and A. Gáspár and G. Rieke (University of Arizona)Text partially sourced from STScI

Exoplanets -> Optical -> Spectrometer -> Single Primary



The data your satellite produces might look like this real data, which is actually a spectrum made using a combination of data from several wavelengths and instruments. The spectrum includes optical data from the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope and the ground based Very Large Telescope's (VLT) optical instrument FORS2, combined with infrared data from the Spitzer Space Telescope's InfraRed Camera Array (IRAC), and the Hubble Space Telescope's Wide Field Camera 3 (using a spectroscopy mode).

This spectrum is notable because it is a comprehensive view of WASP-39-b's atmosphere. In fact, as of 2018, it is the most complete spectrum of an exoplanet's atmosphere possible using the day's technology. (The infrared James Webb Space Telescope will excel at in-depth studies of exoplanet atmospheres and will certainly be a tool astronomers use to learn even more detail.)

Spectra are created by essentially dissecting starlight filtering through the planet's atmosphere into its component colours, which can tell scientists about an atmosphere's composition. In the case of WASP-39b, the team found clear evidence for water vapour in its atmosphere, and though that was expected, the surprise was how much water was present - three times as much as Saturn has. This suggests that the planet formed farther out from the star, where it was bombarded by icy material.

Credit: NASA, ESA, G. Bacon and A. Feild (STScI), and H. Wakeford (STScI/Univ. of Exeter)

Exoplanets -> Optical -> Spectrometer -> Segmented
Exoplanets -> Optical -> Camera -> Segmented

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