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Paper Session II-A - Hubble Space Telescope: The Image Restored

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Since the first servicing mission to Hubble Space Telescope (HST), astronomy has entered a new golden age. This paper will serve to give a small set of examples of the new imagery and the unexpected discoveries that have been made using the Wide Field and Planetary Camera 2 (WFPC2) built by NASA's Jet propulsion Laboratory. In addition, using these examples, the extrapolation to "what's ahead" will be discussed.

For the 1997 second servicing mission to HST, two new scientific instruments will replace two instruments currently on board. The Near-Infrared Camera And Multi-Object Spectrograph (NICMOS) will, for the first time, extend HST's vision to the near infrared (up to 2.5 microns wavelength). The new Space Telescope Imaging Spectrograph (STIS) will bring new spectrographic and imaging capabilities to Hubble at ultraviolet and visible wavelengths.

For the 1999 third servicing mission, a new Advanced Camera for Surveys (ACS) will be installed in HST to provide a wider field of view than the current cameras with higher pixel resolution detectors. In 2002, a new instrument is also slated for HST, but the type of instrument is yet to be selected.

For the distant future, the Next Generation Space Telescope (NGST) is in the early planning stages. Using a much larger aperture mirror than the current telescope, the NGST will bring the advantages of increased light-gathering power and greater angular resolution provided by the large aperture mirror.

One major goal of astronomy is the quest to learn of our origins. Science leads us from the origin of the universe to the origin of galaxies; from the origin of stars and planets to the origin of human life on Earth. The HST has shown the giant advantage of using a telescope above the turbulence and selective absorption of the earth's atmosphere. The NGST will push the resolution and faintness levels achievable to new limits.

THE ORION NEBULA MOSAIC

Located 1500 light-years away in our own spiral arm of the Milky Way Galaxy is a giant molecular cloud in the constellation of Orion. Most of this cloud is invisible from earth but ground-based studies at millimeter wavelengths have revealed its existence. On the earthward side of this cloud is an enormous bubble blown into the gas and dust by the birth of numerous massive hot stars.

The brightest part of this cloud is called the Orion Nebula. It is visible to the naked eye on cold northern hemisphere winter evenings. Figure 1 shows a spectacular color panorama of the center the Orion nebula. It is one of the largest pictures ever assembled from individual images taken with NASA's Hubble Space Telescope. The picture was seamlessly composite from a mosaic of 15 separate fields. It covers an area of sky about five percent the area covered by the full Moon.

The seemingly infinite tapestry of rich detail revealed by Hubble shows a churning turbulent star factory set within a maelstrom of flowing, luminescent gas. Though this 2.5 light-year wide view is still a small portion of the entire nebula, it includes almost all of the light from the bright glowing clouds of gas and a star cluster associated with the nebula. Hubble reveals details as small as 4.1 billion miles across.

An unusually large amount of HST observing time was devoted to making this panorama. This valuable time is justified because the nebula is a vast laboratory for studying the processes that gave birth to our own Sun and solar system 4.5 billion years ago. Many of the nebula's details can't be captured in a single picture-any more than one snapshot of the Grand Canyon yields clues to its formation and history. Like the Grand Canyon, the Orion nebula has a dramatic surface topography-of glowing gasses instead of rock—with peaks, valleys and walls. They are illuminated and heated by a torrent of energetic ultraviolet light from its four hottest and most massive stars, called the Trapezium, which lie near the center of the image.

Along with the Trapezium, this stellar cavern contains 700 hundred other young stars at various stages of formation. High-speed jets of hot gas spewed by some of the infant stars send supersonic shock waves tearing into the nebula at 100,000 miles per hour. These shock waves appear as thin curved loops, sometimes with bright knots on their end (the brightest examples are near the bright star at the lower left).

The mosaic reveals at least 153 glowing protoplanetary disks (first discovered with the Hubble in 1992, and dubbed "proplyds"). Proplyds are believed to be embryonic solar systems that will eventually form planets. (Our solar system has long been considered the relic of just such a disk that formed around the newborn Sun). The abundance of such objects in the Orion nebula strengthens the argument that planet formation is a common occurrence in the universe. The proplyds that are closest to the Trapezium stars (image center) are shedding some of their gas and dust. The pressure of starlight from the hottest stars forms "tails" that act like wind vanes pointing away from the Trapezium. These tails result from the light from the star pushing the dust and gas away from the outside layers of the proplyds. Besides the luminescent proplyds, seven disks are silhouetted against the bright background of the nebula. These dark objects allow Hubble astronomers to estimate the masses of the disks as at least 0.1 to 730 times the mass of our Earth.

The new infrared camera NICMOS will enable astronomers to see into the dusty disks of proplyds. The camera will allow us to look where we think new planets may be forming and to test theories of star and planetary formation.

Technical information: Components of this color mosaic are 45 separate images taken with the WFPC2. The images of the Orion nebula were taken in blue, green and red between January 1994 and March 1995. Light emitted by oxygen is shown as blue, hydrogen emission is shown as green, and nitrogen emission as red light. The overall color balance is close to that which an observer living near the Orion nebula would see. The irregular borders produced by the HST images have been smoothed out by the addition of images from the European Southern Observatory in Chile obtained by Bo Reipurth and John Bally, these being about 2% of the area shown here and lying at the top left corner.

Credit: C.R. O'Dell (Rice University), and NASA

GAS PILLARS IN M16-EAGLE NEBULA

Another dark molecular cloud further away than Orion but still on our side of the Milky Way galaxy is located in the constellation of Serpens.

Figure 2 shows eerie, dark pillar-like structures that are columns of cool interstellar hydrogen gas and dust that are also incubators for new stars. The pillars protrude from the interior wall of a dark molecular cloud like stalagmites from the floor of a cavern. They are part of the "Eagle Nebula" (also called M16-the 16th object in Charles Messier's 18th century catalog of "fuzzy" objects that aren't comets), a nearby star-forming region 7,000 light-years away.

The pillars are in some ways akin to buttes in the desert, where basalt and other dense rock have protected a region from erosion, while the surrounding landscape has been worn away over millennia. In this celestial case, it is especially dense clouds of molecular hydrogen gas (two atoms of hydrogen in each molecule) and dust that has survived longer than their surroundings. The erosion is caused

by a flood of ultraviolet light from hot, massive newborn stars. This process is called "photo evaporation." This ultraviolet light is also responsible for illuminating the convoluted surfaces of the columns and the ghostly streamers of gas boiling away from their surfaces, producing the dramatic visual effects that highlight the three-dimensional nature of the clouds. The tallest pillar (left) is about a light-year long from base to tip.

As the pillars themselves are slowly eroded away by the ultraviolet light, small globules of even denser gas buried within the pillars are uncovered. These globules have been dubbed "EGGs." EGG is an acronym for Evaporating Gaseous Globules, but it is also a word that describes what these objects are. Forming inside at least some of the EGGs are embryonic stars-stars that abruptly stop growing when the EGGs are uncovered and they are separated from the larger reservoir of gas from which they were drawing mass. Eventually, the stars themselves emerge from the EGGs as the EGGs themselves succumb to photo evaporation.

The picture was taken on April 1, 1995 with the Hubble Space Telescope Wide Field and Planetary Camera 2. The color image was composed by combining three separate images taken in the light of emission from different types of atoms. Red shows emission from singly ionized sulfur atoms. Green shows emission from hydrogen. Blue shows light emitted by doubly ionized oxygen atoms.

Credit: Jeff Hester and Paul Scowen (Arizona State University)

AN HOURGLASS NEBULA AROUND A DYING STAR

When Sun-like stars get old, they become cooler and redder, increasing tremendously in size and energy output. These starts are called red giants. Most of the carbon (the basis of life) and particulate matter (crucial building blocks of solar systems like ours) in the universe is manufactured and dispersed by red giant stars. When the red giant star has ejected all of its outer layers, the ultraviolet radiation from the exposed hot stellar core makes the surrounding cloud of matter created during the red giant phase glow: the object becomes a planetary nebula. A long-standing puzzle is how planetary nebulae acquire their complex shapes and symmetries, since red giants and the gas/dust clouds surrounding them are mostly round. Hubble's ability to see very fine structural details (usually blurred beyond recognition in ground-based images) enables us to look for clues to this puzzle.

Figure 3 is an image of MyCnl8, a young planetary nebula located about 8,000 light-years away. It was taken with the Wide Field and Planetary Camera 2. This Hubble image reveals the true shape of MyCn18 to be an hourglass with an intricate pattern of "etchings" in its walls. This picture was composed from three separate images taken in the light of ionized nitrogen (represented by red), hydrogen (green), and doubly-ionized oxygen (blue). The results are of great interest because they clear up the poorly understood ejection of stellar matter that accompanies the slow death of Sun-like stars. In previous ground-based images, MyCn18 appears to be a pair of large outer rings with a smaller central one.
The fine details seen here in the HST image are blurred out by the turbulence in the Earth's atmosphere.

According to one theory for the formation of planetary nebulae, the hourglass shape is produced by the expansion of a fast stellar wind within a slowly expanding cloud that is more dense near its equator than near its poles. What appears as a bright elliptical ring in the center, and at first sight might be mistaken for an equatorially dense region, is seen on closer inspection to be a potato shaped structure with a symmetry axis dramatically different from that of the larger hourglass. The hot star thought to eject and illuminate the nebula is therefore expected to lie at its center of symmetry. However, the star is clearly off center. Hence MyCn18, as revealed by Hubble, does not fulfill some crucial theoretical expectations.

Hubble has also revealed other features in MyCnl8 that are completely new and unexpected. For example, there is a pair of intersecting elliptical rings in the central region that appear to be the rims of a smaller hourglass. There are the intricate patterns of the etchings on the hourglass walls. The arc-

like etchings could be the remnants of discrete shells ejected from the star when it was younger, flow instabilities, or the result of a narrow beam of matter impinging on the hourglass walls. The hypothesis of an unseen companion star and accompanying gravitational effects may be necessary to understand the structure of MyCnl8.

Credits: Raghvendra Sahai and John Trauger (JPL), the WFPC2 science team, and NASA

HUBBLE'S DEEPEST-EVER VIEW OF THE UNIVERSE UNVEILS MYRIAD GALAXIES BACK TO THE BEGINNING OF TIME

Figure 4 shows several hundred never-before-seen galaxies. They are visible in this deepest-ever view of the universe, called the Hubble Deep Field (HDF). Besides the classical spiral and elliptical shaped galaxies, there is a plethora of other galaxy shapes and colors that are important clues to understanding the evolution of the universe. Some of the galaxies may have formed less than one billion years after the Big Bang.

Representing a narrow keyhole view all the way to the visible horizon of the universe, the HDF image covers a speck of sky l/30th the diameter of the full Moon (about 25% of the entire HDF is shown here). This field is so narrow that just a few foreground stars in our Milky Way galaxy are visible. These few stars are vastly outnumbered by the menagerie of far more distant galaxies. Some of these galaxies are nearly as faint as 30th magnitude, or nearly four billion times fainter than the limit of human vision. (The relatively bright object with diffraction spikes just left of center may be a 20th magnitude star.) Though the field is a very small sample of sky area, it is considered representative of the typical distribution of galaxies in space because the universe, statistically, looks the same in all directions.

The image was assembled from many separate exposures (342 frames total were taken, 276 have been fully processed to date and used for this picture) with the WFPC2, for ten consecutive days between December 18 to 28, 1995. This picture is from one of three wide-field CCD (Charged Coupled Device) detectors on the WFPC2.

This true-color view was assembled from separate images taken in blue, red, and infrared light. By combining these separate images into a single color picture, astronomers will be able to infer—at least statistically—the distance, age, and composition of galaxies in the field. Bluer objects contain young stars and/or are relatively close, while redder objects contain older stellar populations and/or are farther away.

Credit: Robert Williams and the Hubble Deep Field Team (STScI) and NASA

Both new second-generation instruments slated for the February 1997 servicing mission will be used in this area of cosmological research. The NICMOS will be able to take infrared images of even more distant and young galaxies than those seen here. Such galaxies have their light shifted into the near infrared part of the spectrum by the extreme Doppler effect due to the expansion of the Universe.

A recent discovery by Hubble is the unexpected numbers of blue galaxies at very faint magnitude limits. Are these dwarf blue galaxies at relatively close distances? Alternatively, are they distant ultraviolet giant galaxies Doppler shifted so they appear blue? STIS with its superb detectors and efficient spectrographic optics will be an effective tool to probe these faint blue galaxies.

Acknowledgments: Thanks to the scientists who have generously shared their data. Special thanks to Ann Jenkins for her technical writing and editorial skills. Thanks, too, to Jim Barcus and Eva Doyle for making the published version possible.

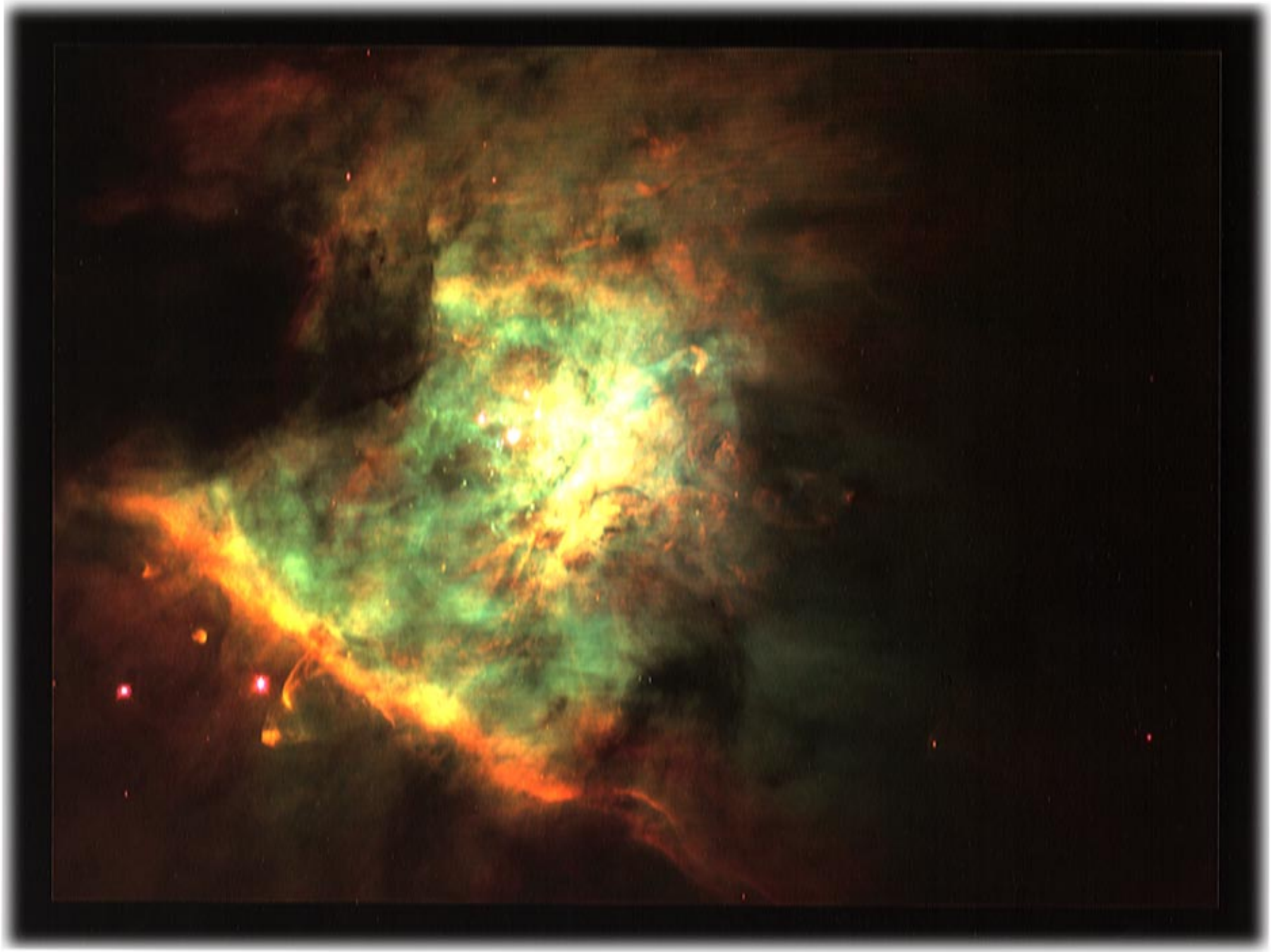


Fig. 1

Orion Nebula

Operated for NASA by AURA

esa european space agency

Orion Nebula

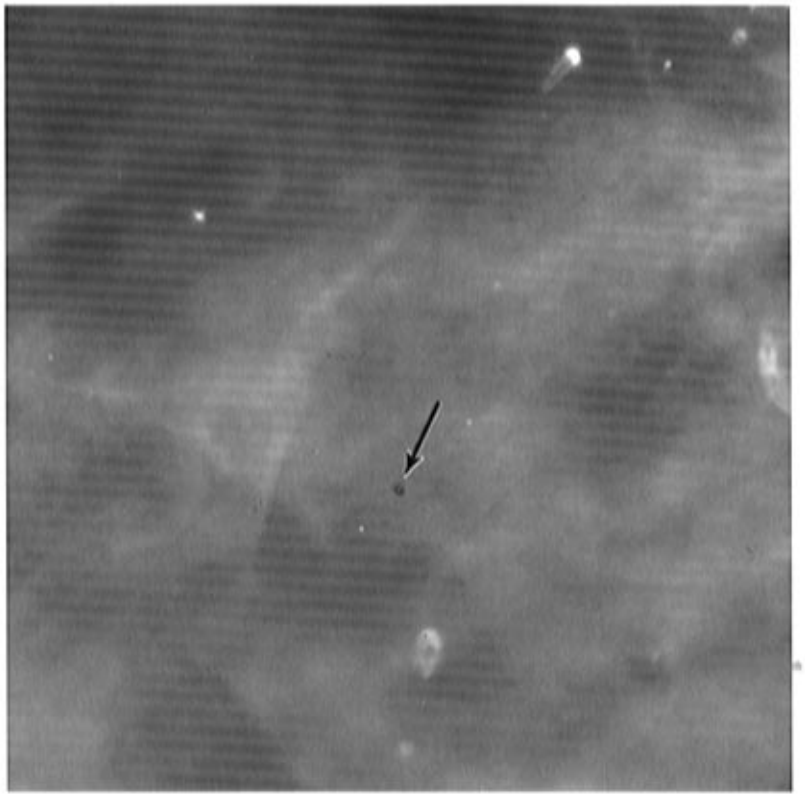
The Orion Nebula is a region filled with hot gas and dust, the raw materials for building new stars. It is located in the area of the sword of Orion the Hunter, a constellation named by ancient Greeks that dominates the northern hemisphere winter sky. The Nebula appears as a fuzzy starlike area visible even without a telescope on clear, dark nights. The Nebula is nearby; it is 1,500 light years away in our spiral arm of the Milky Way Galaxy.

Crucible of Creation

Four of the Nebula's hottest and most massive stars lie near the center of the image. Light from these stars illuminates the Nebula's "cavern" just as flashlights light up a cave. The cavern contains 700 other young stars at various stages of formation. Some of the infant stars send jets of hot gas into the Nebula at 100,000 miles per hour. These jets appear as thin curved loops, sometimes knotting at the end where they hit denser material. The brightest examples are near the reddish star in the image's lower left.

Planets Under Construction

The Orion Nebula also contains 153 glowing disks thought to be infant solar systems *(see detail image, right)*. Many of the Nebula's young stars are embedded in the middle of pancake-shaped disks of dust and gas. Astronomers think the disks, called protoplanetary disks or proplyds, may be an early stage of planet formation. Our solar system probably formed out of just such a disk 4.5 billion years ago.



About the Image

This spectacular panorama *(front)* is one of the largest pictures ever assembled using NASA's Hubble Space Telescope. The mosaic contains some 45 separate images taken in blue, green and red light between January 1994 and March 1995. Astronomer C. Robert O'Dell of Rice University matched and combined the images to look as they would to someone living near the Nebula.

Definitions

Nebula: *a cloud of interstellar gas and dust, seen either as a luminous patch of light or a dark cloud against a bright background. The term was coined to describe objects that appeared fuzzy when viewed through early telescopes.*

Nuclear Fusion: *two or more light nuclei join together to form a heavier nucleus, releasing energy in the process.*

Protoplanetary Disks/Proplyds: *disks thought to be made of 99% gas and 1% dust; appear around young stars; may evolve into planetary systems like our own.*

Light Year: *the distance light travels in a year (6×10^{12} or 5 trillion 900 billion miles).*

Fast Facts

Age

The four bright central stars are less than a million years old. The Nebula is the same age or younger.

Location

In the constellation Orion the Hunter in the northern hemisphere.

Distance from Earth

1,500 light years

Size

2.5 light years across, covering an area of sky about 5% the area covered by the full Moon.

Electronic Addresses

You can get images and other information about the Hubble Space Telescope using the Internet.

Using ftp or gopher, connect to ftp.stsci.edu and find files and directories in /pubinfo.

Using the World Wide Web (Mosaic, NetScape, Lynx, and other browsers), use URL http://www.stsci.edu/public. html and follow links from there.

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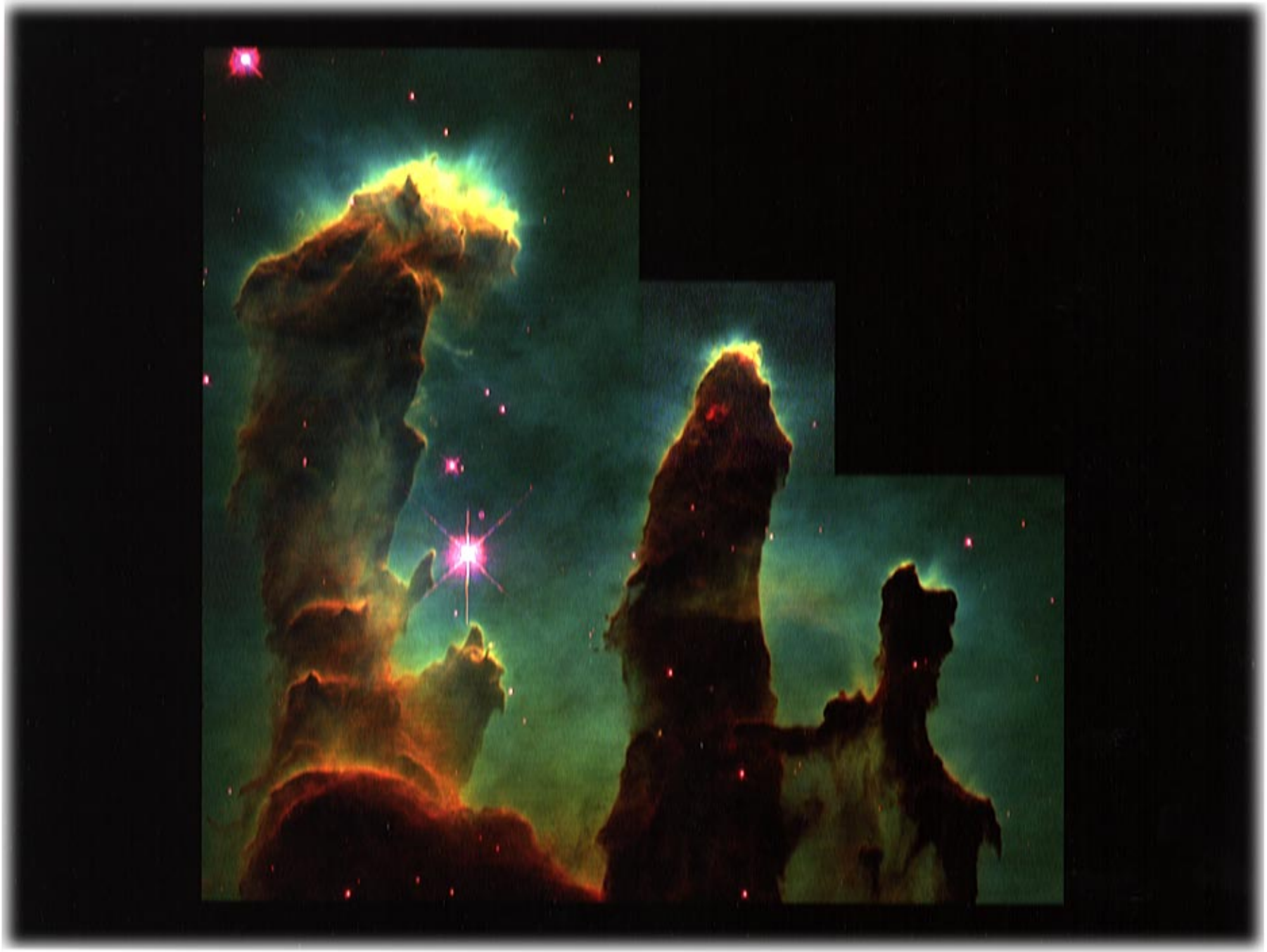
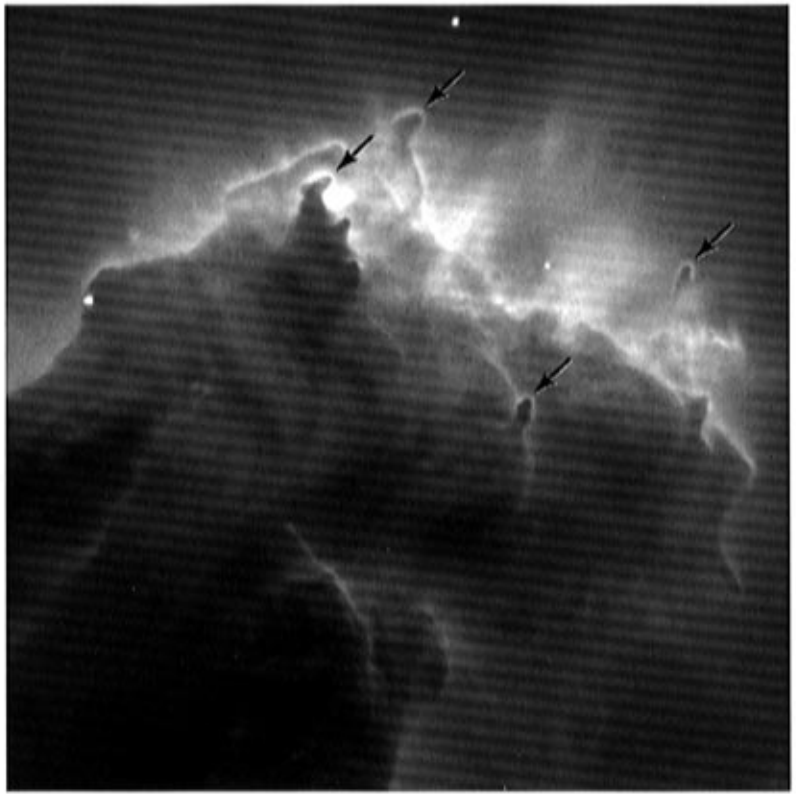


Fig.

Eagle Nebula

Operated for NASA by AURA



Eagle Nebula

The three columns of dust and gas in this Hubble Space Telescope image are located in the Eagle Nebula. The Nebula contains hydrogen and microscopic dust particles, the raw materials for building new stars. The Eagle gets its name because to some the Nebula resembles the bird of prey with outstretched wings and talons bared.

Uncovering New Stars

Off the top of this picture, there are young, hot, massive stars that shine very brightly. The stars' powerful radiation heats the surrounding gas, making it glow. This intense radiation is responsible for sculpting the columns; it erodes more tenuous gas in the columns through a process called photoevaporation. The erosion reveals denser gas globules surrounding newly formed stars *(see close-up, right)*. Scientists call them "Evaporating Gaseous Globules" or EGGs.

Star Birth

Stars are born when clouds of dust and gas collapse because of gravity. As more and more material falls onto the forming star, it finally becomes hot and dense enough at its center to trigger the nuclear fusion reactions that make stars, including our Sun, shine. Photoevaporation in the Eagle Nebula has cut newly forming stars off from the cloud feeding them. While some of the EGGs are large enough to eventually become stars, others may never make it.

About the Image

The Eagle Nebula was photographed by Jeff Hester and Paul Scowen of Arizona State University using the Wide Field and Planetary Camera 2 on board NASA's Hubble Space Telescope on April 1, 1995. The color picture is made up of three separate color images: red shows light from sulfur atoms in the cool gas at the edge of the clouds, blue shows light from ionized oxygen atoms in the hot, evaporated halos, and green shows light from hydrogen atoms.

Definitions

Nebula: *a cloud of interstellar gas and dust, seen either as a luminous patch or light or a dark hole in a bright background. The term was coined to describe objects that appeared fuzzy when viewed through early telescopes.*

Nuclear Fusion: *two or more light nuclei join together to form a heavier nucleus, releasing energy in the process.*

Photoevaporation: *a process where intense light from hot stars eats away the surface of dense clouds.*

Light Year: *the distance light travels in a year (6×10^{12} or 5 trillion 900 billion miles)*

Fast Facts

Age
The Eagle Nebula is two million years old, the EGGs will live for another 10-20,000 years.

Location
In the constellation Serpens, the Serpent, alongside the southern Milky Way

Distance from Earth
7,000 light years

Size
Our Solar System would fit comfortably inside an EGG. The right column is about one light year from top to bottom.

Electronic Addresses

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Using ftp or gopher, connect to ftp.stsci.edu and find files and directories in /pubinfo.

Using the World Wide Web (Mosaic, NetScape, Lynx, and other browsers), use URL http://www.stsci.edu/public. html and follow links from there.

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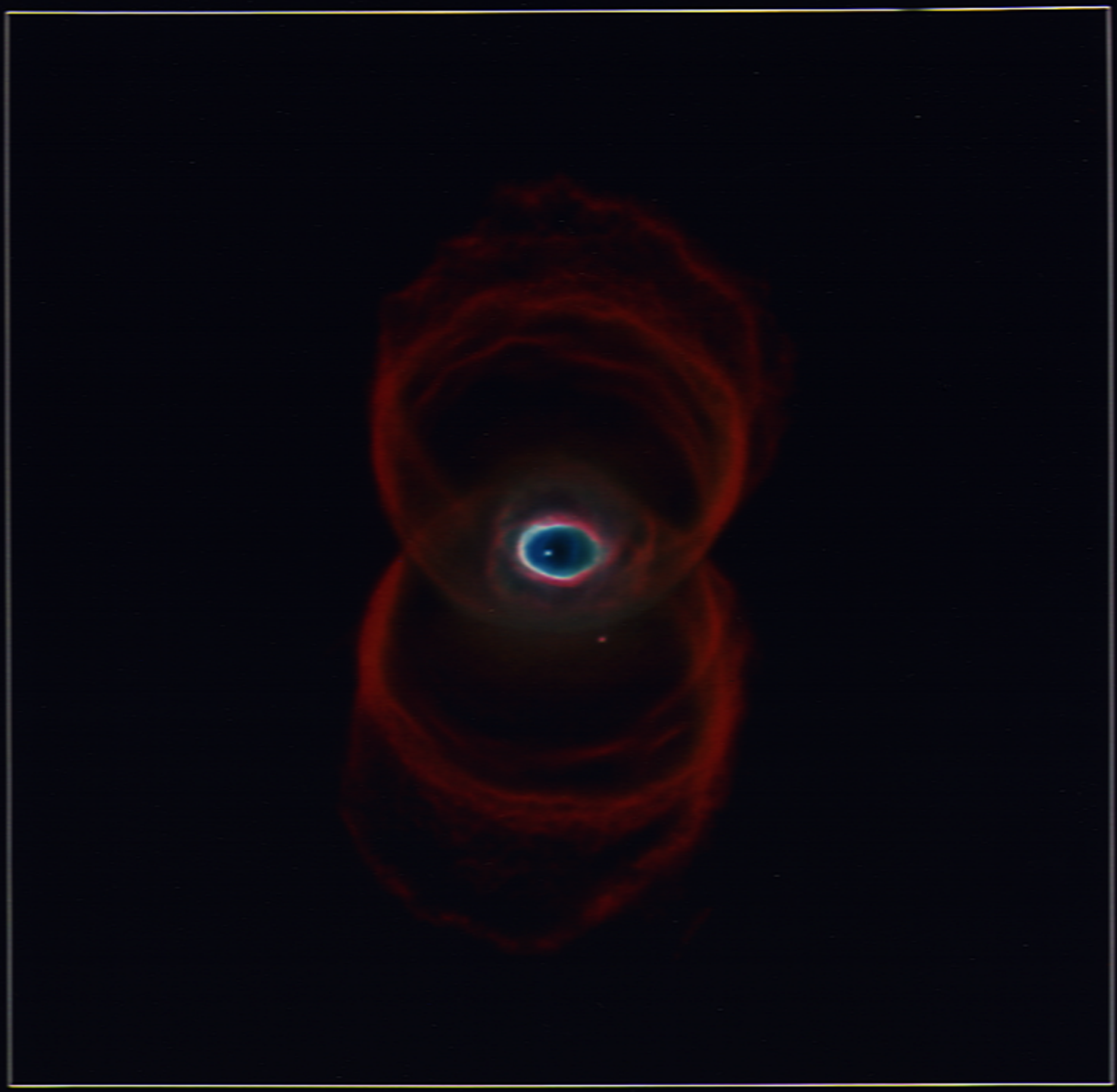

Hourglass Nebula · MyCn18

Hubble Space Telescope · WFPC2

PRC96-07 · ST ScI OPO · January 16, 1996 · R. Sahai and J. Trauger (JPL), WFPC2 Science Team, NASA

Fig. 3

Hubble Deep Field

Hubble Space Telescope • WFPC2

PRC96-01a • ST ScI OPO • January 15, 1995 • R. Williams (ST ScI), NASA

Fig. 4