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THE FUTURE OF HUBBLE SPACE TELESCOPE SCIENCE

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Abstract: The Hubble Space Telescope, HST, is a unique platform for new science. Each mission to HST is a complex dance of engineering, astronautics, and science that brings new scientific opportunities to the telescope. Through new instruments, new discoveries and new insights, HST's role as the premier space astronomical instrument will continue into the next millennium. The 1997 maintenance mission will give HST infrared eyes to peer far back in time and space as well as into the birth places of galaxies, stars and planets. It will multiply HST's spectroscopic grasp many fold to increase our knowledge of distant quasars and nearby planets. In many respects HST creates its own future through its revelations about our universe. This talk is a small selection of what lies ahead.

THE OPPORTUNITY

Unlike any previous large space instrument, HST presents the opportunity for continual improvement of its scientific capabilities. In this way HST is similar to major groundbased observatories that early recognized that new and more efficient instrumentation is the most practical and economic way of utilizing the large capital investment in a telescope and its support facilities. Up until now large space astronomy missions have been perpetually saddled to the horse they rode in on, the instrumentation they were launched with.

HST is also creating its own scientific opportunities. Its unprecedented ability to monitor the distant and early stages of the universe has presented new and startling observations, many of which do not fit into our conventional paradigm for the Universe. It is forcing us to rethink our concepts of the formation and evolution of the Universe and has presented us with such perplexing conundrums as a Universe younger than the stars and galaxies within it. These newly posed questions can only be answered by HST itself with new observations and new instruments. It is here that the wisdom of renewable instrument resources is particularly evident.

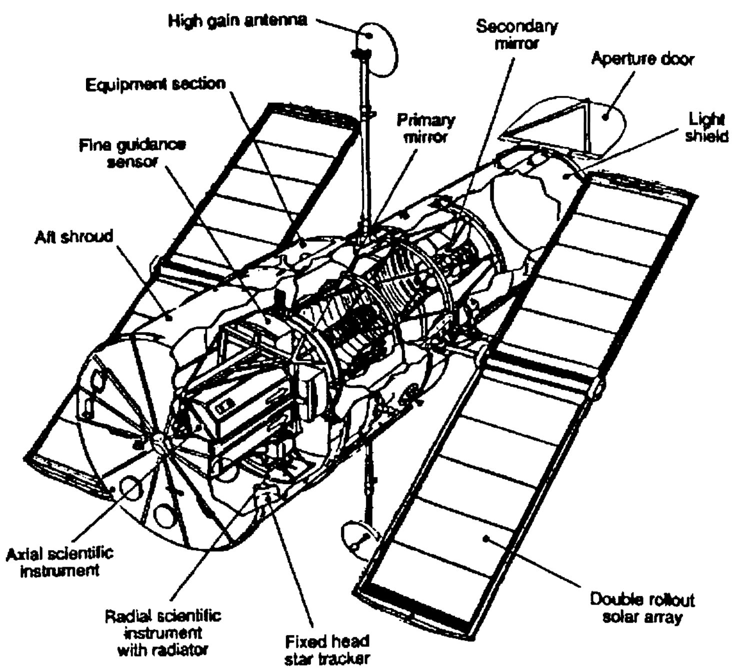
The technical opportunity

From the outset the Hubble Space Telescope design incorporated the opportunity to not only easily maintain key systems through on-orbit maintenance but also the opportunity to change out older astronomical instruments with more modern ones. This capability allows improvements in detectors and instruments to be used on the telescope and also allows the implementation of new instrumental capabilities. The upcoming maintenance mission utilizes both of those opportunities. The Space Telescope Imaging Spectrometer (STIS) contains modem CCD and MAMA detectors to improve the HST spectroscopy capabilities from the one dimensional format of the present spectrometers to a much more efficient two dimensional format. The

Near Infrared Camera and Multi-Object Spectrometer (NICMOS) will provide a totally new HST capability of infrared imaging and spectroscopy.

HST scientific instruments (S1s) reside in five different bays behind the optical focus of the telescope in a structure termed the aft shroud. There are four axial bays extending along the optical axis of the telescope and one radial bay extending radially from the optical axis. The Fine Guidance Sensors (FGSs) also occupy a second radial bay. In addition to their critical role in guiding the telescope, they also perform an important scientific mission of precision astrometry. Rather than being permanently installed in the bays the instruments are secured with latches that allow removal and substitution of instruments on-orbit by astronauts. Both of the new instruments, STIS and NICMOS are axial instruments, similar in outside dimensions to the COSTAR instrument installed during the first maintenance mission.

Figure 1. THE HUBBLE SPACE TELESCOPE



The science opportunity to learn about our universe

The goal of the Hubble Space Telescope is no less than the accurate measurement of the size, shape, content, age, history and future of the Universe. This quest is akin to the great voyages of discovery that mapped our globe during the renaissance of intellect from the dark ages of unquestioned dogma. Those voyages showed the vast content of our world and showed that it extended far beyond the small regions of the earth known at the time. They also confirmed that the world was round, not the flat geometry one perceives in a local view of our environment. Also, as in all great voyages, they raised new and more sophisticated questions about our world along with some of the tools to find the answers.

HST has been on its voyage of discovery for 6 years now. As in many great voyages it had a very rocky start with problems stemming from the very nature of large and vast projects. Also, as in great voyages, a few stood apart from the doom sayers to find the answers and fix the problems. Now we have a telescope that routinely does what no other telescope can do. Each week new and sometimes bizarre objects are seen that dazzle our mind and stretch our ability to understand. There are, however, observations that individually do not make front page news, but when taken collectively are fundamentally changing our view of the Universe. They may also be leading us to the conclusion that our view of the Universe, crafted through the individually successful disciplines of elementary particle physics and general relativity, is wrong and that one our both of these great achievements in physics may also be wrong. At this point the HST observations are leading us toward a Universe of low enough density and fast enough expansion to be significantly younger than the oldest stars in our own Galaxy. This is an absurdity which would show us the folly of our view. It is the opportunity for new exploration that HST creates for itself and it is a large part of the question that the new instruments of HST will address.

THE NEW SCIENCE

There is neither the space nor the time hereto list and describe the new scientific programs of STIS and NICMOS. Suffice it to say that these observations span the space from our nearest planets to the most distant reaches of the Universe. In fact these are just the observations planned by the builders of the instruments and which represent a small minority of the planned observations. The majority of the observations will be made by General Observers (GOS) competing for the available time on the instruments. Instead I will try to describe the observations which are directly involved in Cosmology, the science to take the measure of the Universe. These are observations which directly apply to the possible absurdity of an Universe younger that its content.

The voyage of cosmology

We have made some very remarkable and startling conclusions about our environment, the Universe, since the voyages of Columbus, Magellan and others. We have confirmed that we are not the center of our system of planets, moon, and sun. We revolve around our sun, third one out, and certainly not the biggest of the lot. Our sun is indeed one of “billions and billions” of other stars that make up a galaxy. Again we are not at the center but in the suburbs of our galaxy, the Milky Way. Indeed it is only in this century that we have formed and observed the concept of a galaxy. Since then we have learned that there are “billions and billions” of galaxies of which ours is only one. Perhaps most remarkable of all we have learned that the observable Universe is expanding and has an origin in time marked by the Big Bang. The Universe then has a definable age. The concepts of general relativity have also shown that it is possible for the Universe to be not flat, in a way somewhat analogous of the earth not being flat. Our quest is then to measure these most fundamental aspects. How fast are we expanding? This number we call the Hubble constant Ho. How much is in the universe? A number we call the density parameter!& What is its shape?

A parameter we call the curvature. What is its age? This is a number derivable from the others.

The NICMOS attack

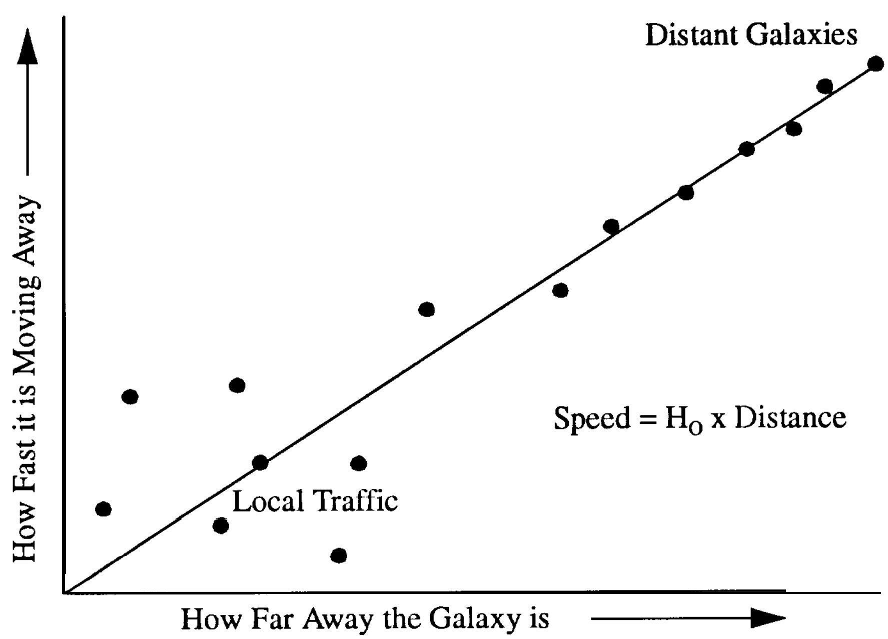
Since I am the NICMOS Principal Investigator I will spend more time in this area because I understand it more. I will, however, try to talk about at least one principal area that STIS attacks.

NICMOS has a fundamental advantage over current HST instruments in observing cosmological phenomena. This advantage comes from the concept of the redshift. Our expanding universe produces the observable phenomena that the more distant an object is from us the greater its velocity away from us. Motion away from us shifts all of the radiation to lower frequencies or redward. The greater the velocity, the greater the redshift. We will exploit this in a moment for other purposes, but for now it says that more distant objects will have more of their light in the NICMOS infrared region and less in the ultra-violet and optical region. Since NICMOS will detect radiation in the region where distant objects emit the most it will have and advantage in sensitivity.

The Hubble Constant

Let us return to the statement above that the further away from us something is the faster it is moving away. The quantitative statement of this fact is that an objects speed due to the expansion of the universe is some number times its distance. That number is called the Hubble constant (H_0) after Edwin Hubble whose name is also attached to the telescope.

Figure 2. MEASURING THE HUBBLE CONSTANT

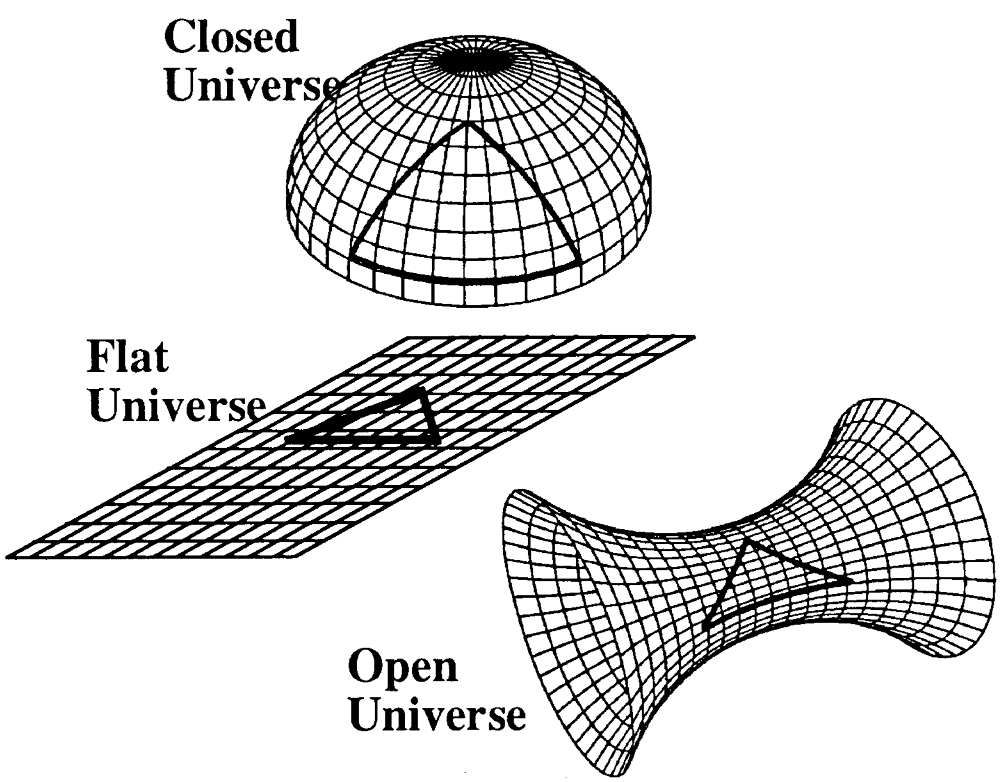


The value of the Hubble Constant is one of the holy grails of astronomy. In one sense it is not a constant in that it does change with time, however, so slowly that we simply say the number measured now is what we are looking for. That is why we call it Ho rather the H. The subscript o stands for now. The concept for measuring the Hubble Constant is very straight forward, measure the speed and distance for a large number of galaxies and find the average of the values of Ho. As usual though in practice it is more difficult. A reasonable analogy is trying to find the average speed on the Bee Line expressway to the Cape by observing from Orlando. The random local traffic confuses the signal. You have to look at cars far away to find the real flow. Our problem in astronomy has been to find the distance to galaxies far enough away to determine the true flow rather than the local traffic. NICMOS will be able to measure the distance to galaxies that are not tied up in local traffic by measuring the distribution of their infrared emission from their stars. This should provide a true breakthrough in this number. Figure 2 above depicts the process we are talking about.

Space Warp

Measurement of the Hubble constant, as spectacular as it is, is just the first step in our quest. The Hubble constant tells us how fast the universe is expanding now, but we also want to know its shape, history and future. Lets look at the shape next. In some ways we want to know if the road is straight or curved. For the Bee Line we know that it is very, very straight except for a few kinks. For the Universe we are not sure. Shape is the very essence of cosmology for we know from Einstein and General Relativity that space itself can be curved and warped. There are really only three basic choices called closed, open, and flat.

Figure 3 OPEN, CLOSED, AND FLAT UNIVERSES

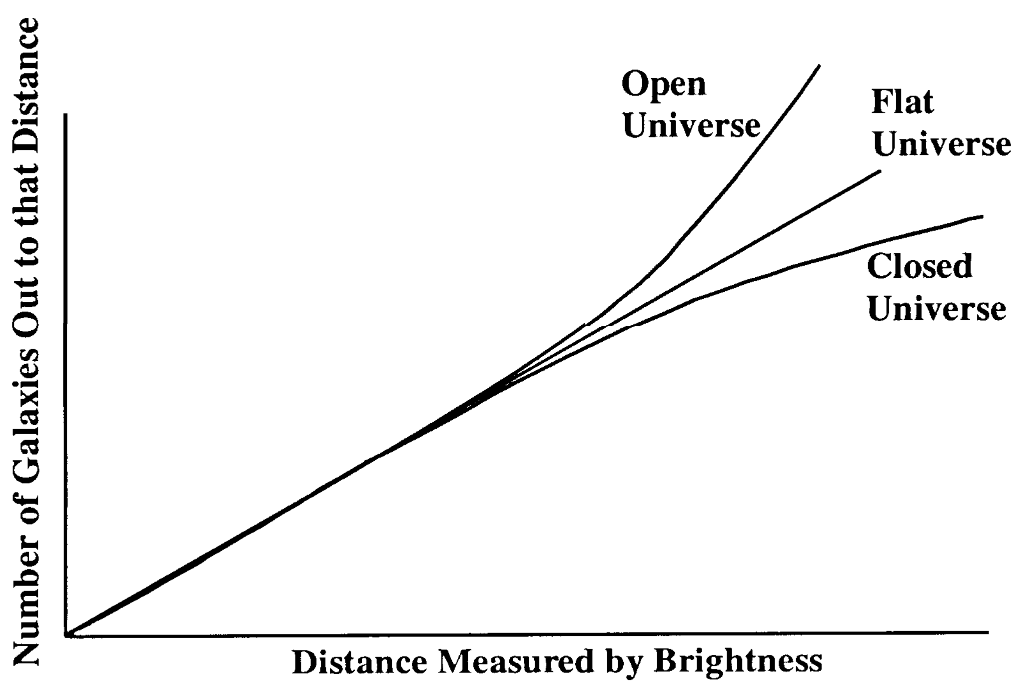


Each of these choices has a profound significance for the future of our universe however. In a closed universe the universe will eventually fall back on itself to the conditions that occurred at the instant of the big bang. In an open universe the universe will continue to expand forever, becoming a very cold large empty place. The flat universe says that we will just stop expanding at an infinite time from now never expanding further but also never falling back to its original state. The curvature we talk about is in four dimensions but we have examples in three dimensional space shown above.

The lines in these drawing represent the path someone would take in each universe if they thought they were going in a straight line. In the closed universe they would eventually come back to the same point just as someone walking a “straight line” on our earth would eventually go all the way around the earth and be back where they started. In the flat universe the paths would be quite familiar to us as they are the same as our usually assumed flat geometry. In the open universe the straight and narrow paths diverge and will never come back to the same point. In this universe space is not closed but goes on forever.

How do we figure out what our universe looks like? A key here is how much volume there is in each universe. As we look further and further away we are looking at a larger and larger volume of the universe. However, the increase in volume with distance is different for each type of universe. The closed universe has the smallest increase, the flat universe is in the middle and the closed universe has the greatest. If we believe that there is a uniform density of galaxies in the universe, we should see more galaxies at large distances in the open universe and fewer galaxies in the closed universe. This is a standard technique call the number magnitude plot. Figure 4 below is a vary exaggerated view of the concept.

Figure 4. NUMBER OF GALAXIES VS DISTANCE



In practice there are many other factors that enter this method which must be dealt with. Among them are limitations on sensitivity and detecting galaxies at distances where all of the flux has been shifted to the infrared. This is where NICMOS on HST provides a great advantage over previous instruments. We will extend this study to distances that will provide a good measure of the curvature.

The STIS Attack

STIS, the Space Telescope Imaging spectrometer has several fundamental roles in the cosmological voyage to determine the parameters of our Universe. Some of the key observations are a measurement of the degree of curvature or warp of space and a measurement of what is warping it.

What Warps Space?

Mass warps space. The degree of curvature and the type of warp depends on the amount of mass present in the Universe. If there is enough mass space will form a closed shape or a closed Universe. In this space the Universe will eventually collapse upon itself. If there is not enough mass the Universe will expand forever in an open Universe. For just the right amount of mass it will be just balanced so that it slows down to no expansion at infinite time, the flat Universe. These are the Universes discussed earlier and depicted in Figure 3 above. One of the primary STIS observations centers on the determination of the mass in the Universe. Often distant galaxies are to faint to see but their presence is detected by the absorption of light from very distant quasars. Galaxies between us and a quasar will absorb the quasar light at particular frequencies associated with the hydrogen atoms in the galaxy. Detection of this absorption requires sensitive spectroscope y in the optical and ultraviolet region. STIS greatly increases our ability to detect intervening galaxies through greater efficiency and spectral coverage. These measurements of the number and velocity of galaxies between distant quasars and us will give a much more accurate determination of the amount of observable mass in the Universe. We will then compare this mass with the amount of mass required to match the slowing of the expansion of the Universe to determine the amount of unseen or dark matter in the Universe.

How old are we?

A remaining key question we will discuss is how old is the Universe? How long has it been around and what is its future? Combinations of previous HST observations, ground based observations and the future HST observations with STIS and NICMOS will give us a much better answer to these questions than before. If there is no mass in the Universe it will continue to expand at a constant rate because there would not be any way to slow it down. In this case it would be easy to determine that age by simply asking how long it took to expand to the present size at this constant velocity. Its just like seeing a car on the Bee Line 30 miles from Orlando going 60 miles an hour and saying it left Orlando half an hour ago.

The real case it is not as easy. Since we exist and we know of other planets, stars, and galaxies we then know that the Universe is not empty. The expansion of the Universe must,therefore, be slowing down and we see it expanding at a slower pace than it did previously. Since it was traveling faster in the past the Universe must be younger than we would predict by looking at the velocity now. We can predict the slowing down from our determination of the expansion now, H_o, the density of matter in space, Ω_0, and its geometry characterized by its curvature. It is our best estimate of each of these factors which lead us to a Universe that is about 8-10 billion years old. On the other hand the oldest stars in our galaxy are about 13-15 billion years old. This brings us right back to our original dilemma of a Universe younger than the stars in it.

This apparent absurdity is not discouraging. It is tremendously exciting. It is how we make fundamental, new insights into the nature of our environment, the Universe. New discoveries point out the flaws of our current thinking. Now is truly a time of new discoveries with HST and the time is nearly upon us in which STIS and NICMOS will serve as the new flagships in our voyage of discovery.