PROSPECTS FOR SPACE TELESCOPE IN THE SEARCH FOR OTHER PLANETARY SYSTEMS

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ABSTRACT. The Hubble Space Telescope (ST) will be launched with five dedicated scientific instruments and a capability to do astrometric measurements with the fine guidance sensors. Four of these -- the Faint Object Camera, the Wide Field Camera, the Fine Guidance Sensors and the High Speed Photometer -- can be used in the search for extrasolar planetary systems. The Faint Object Camera will be able to directly detect planets around a few of the nearby bright stars. The Wide Field Camera and the Fine Guidance Sensors can be used astrometrically, both with an accuracy of about 2 mas per observation. The High Speed Photometer possibly can detect planets during occultation of stars by the moon and minor planets. The ST is expected to be launched in mid-1986 and these observations are the among the first planned with the instruments.

1.0 INTRODUCTION -- THE SPACE TELESCOPE OBSERVATORY

The cutaway view of the Hubble Space Telescope (ST) is shown in Figure 1. It is an f/24 Ritchey-Chretien with a primary mirror 2.4 meters in diameter. The electronics are arranged around the primary mirror; the science instruments and fine guidance sensors are arranged behind it. The field of view of the telescope is divided among the various instruments as shown in Figure 2. The five science instruments include the High Resolution Spectrograph (HRS), the Faint Object Spectrograph (FOS), the High Speed Photometer (HSP), the Wide Field/Planetary Camera(WF/PC), and the Faint Object Camera (FOC). Any two of the Fine Guidance Sensors (FGSs) are used for guiding and the third may be used as an astrometric instrument. Full descriptions of the instruments, their characteristics and observing capabilities are included in the book edited by Hall (1982).

The ST will be placed in low earth orbit, altitude about 500 km. It will have two major advantages over ground-based instruments. Because it will not have to contend with the earth's atmosphere, it will have a limiting magnitude of 28, increasing by a factor of 7 the distance to which man can see, and a possible resolution of 0.007

M. D. Papagiannis (ed.), The Search for Extraterrestrial Life: Recent Developments, 75–84.

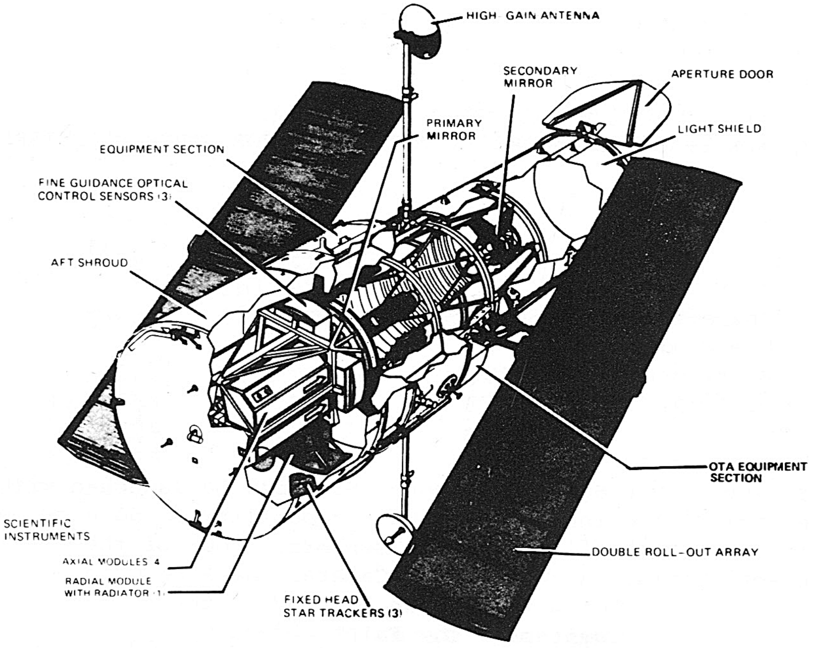

Figure 1. Cutaway view of the **Hubble** Space **Telescope**. The largest astronomical satellite ever orbited, the ST observatory carries five dedicated instruments and also has the capability to make astrometric measurements with the guidance sensors. Four of the six instruments, all but the spectrographs, will likely be used for planet search programs.

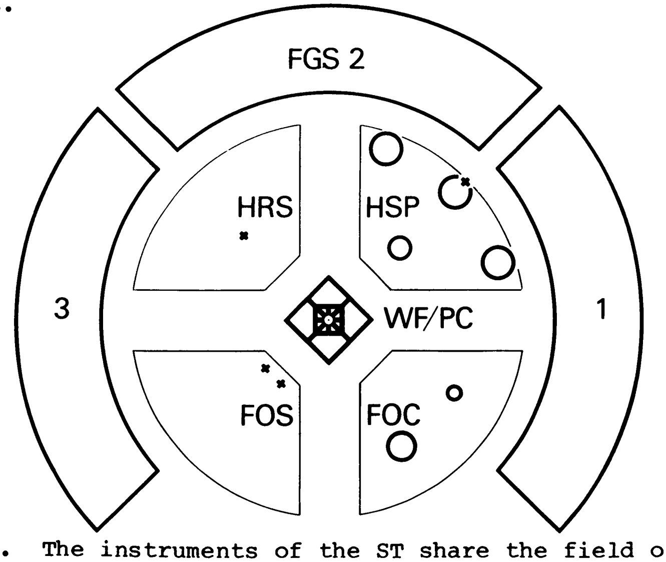

Figure 2. The instruments of the ST share the field of view. The Wide Field/Planetary Camera is at the center, the other dedicated scientific instruments share the field around it, and the Fine Guidance Sensors operate in three-quarters of the outer annulus. The small circles are the apertures of the various instruments.

arcsec. A simulation of the increased resolution of the satellite over ground-based instruments is illustrated in Figure 3. The wavelength range for observations is from 1150 to 11,000 angstroms, from just beyond Lyman alpha into the infrared.

The ST observatory has been designed as a modular system which can be serviced in orbit. This allows the replacement of electronics or science instruments or any one of the guidance sensors by a crew from the space shuttle without returning the satellite to earth. This modularity emphasizes the care which has gone into making the Space Telescope a versatile satellite able to support a wide variety of programs and observations.

The ST will be administered in the same way as all other large observatories. The observing time will be awarded by the director of the Space Telescope Science Institute (ST ScI) according to the recommendation of a telescope allocation committee. Proposals for observing time will be solicited by the ST ScI and reviewed by the committee. The major exception to this is the guaranteed time to the teams of scientists which have been responsible for the construction of the science instruments and for building the astrometry software system. Together the teams will receive 100% of the observing time on the telescope for the first two months available, then a declining percentage for the next 28 months. Beyond the guaranteed time for the instrument teams, none of the specific observations to be made with the telescope are yet known, although a few key programs may be suggested at the time of proposal solicitations. The other exception to the peer review process will be the director's discretionary time, less than 10% of the total time available, allocated by the ST ScI director for scientific support activities or targets of opportunity, such as supernovae.

2.0 PLANET SEARCH PROGRAMS FOR THE ST SCIENCE INSTRUMENTS

Based on the planning by the teams for their guaranteed time and discussions of instruments (Hall, 1982), there are no plans to use either of the spectrographs in planet search programs and they will not be further discussed here. All of the other instruments may be used and are discussed in separate sections below.

2.1 Planet Search with the Faint Object Camera

The FOC may be used in the direct detection of major planets around other stars. The f/96 optical relay system of the instrument is shown in Figure 4. This is used in conjunction with a compact Cassegrain assembly to provide imaging at f/288. In this mode of operation there is also available a coronographic finger of width 0.8 arcsec with an apodizing mask which removes light scattered from the secondary mirror, its spider, and the primary mirror supports. The detector for this mode of the FOC is an imaging detector in photon counting mode. The system measures the x,y coordinates of each arriving photon and stores them in an array which can be read out non-destructively during

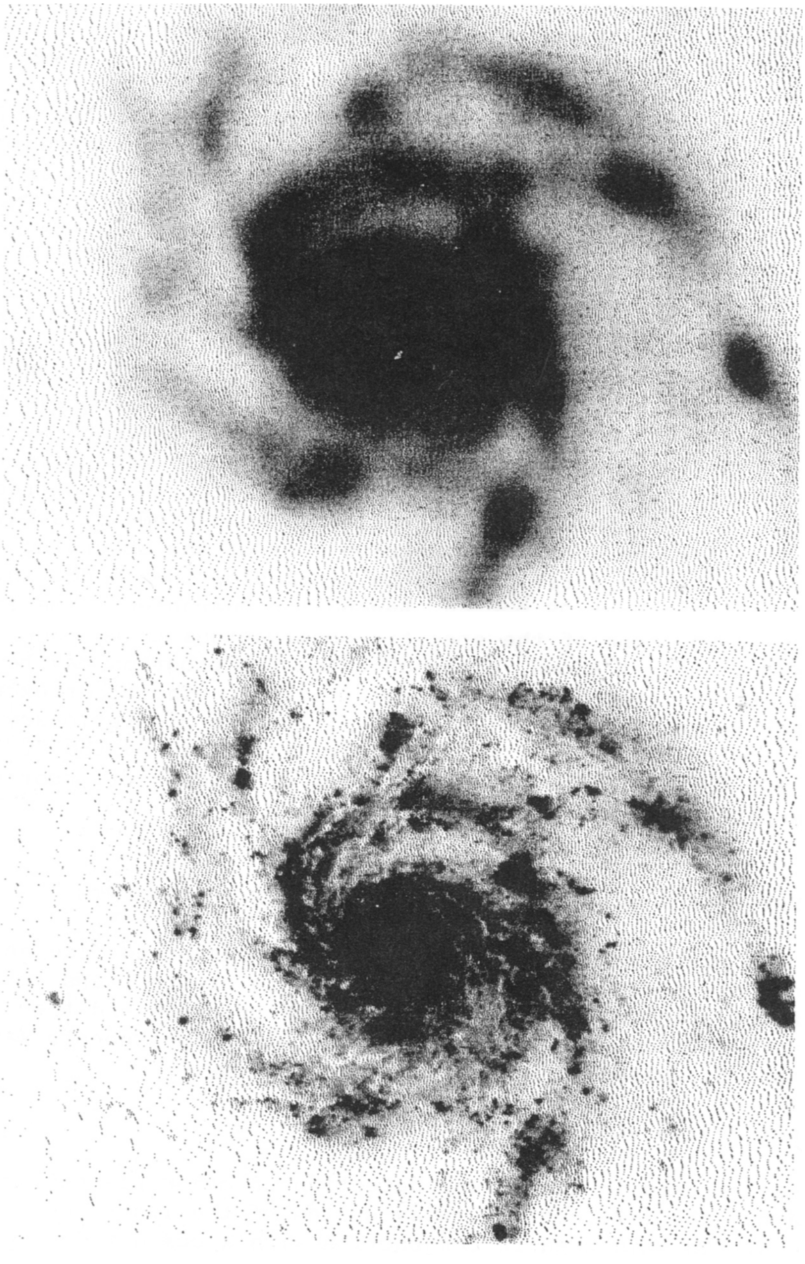

Figure 3. A simulation of the increased resolution of the ST. The top image represents a spiral galaxy seen with the 5-meter Hale telescope; the lower image the same galaxy as seen by the Space Telescope. The simulation was prepared from a digitized image from the 5-meter. (used with permission of the author, John L. Tonry, Institute for Advanced Study; previously published in Scientific American)

the exposure. The coronograph is used with an occulting mask which stops scattered light from within the detector. In the f/288 coronographic mode, the FOC has a resolution of 0.007 arcsec, a field of view of 3.8 by 3.8 arcsec, and is capable of measuring over a dynamic range of at least 16.7 magnitudes, a factor of 2×10^{-7}, for 1 arcsec separation. For confirmation a second observation would have to be taken with the ST rotated about its optical axis. The limit in the direct detection of planets with the ST is the light scattered by dust on the optics of the telescope, particularly the primary mirror. If at launch the mirror and optics meet the specifications currently set by NASA, this should not be a problem. A simulated image from the FOC illustrating a detection is shown in Figure 5.

In coronographic mode the FOC may detect major planets around nearby bright stars. It will not detect earth-size planets, but the unambiguous discovery of any planet would be considered a major contribution to SETI.

2.2 Planet Search with the Wide Field Camera

The Wide Field/Planetary Camera operates in two modes, as a Wide Field Camera or a Planetary Camera. As the Wide Field Camera it may be used for the astrometric detection of major planets around nearby stars. The schematic of the WF/PC is shown in Figure 6. Upon entering the camera, the beam is broken into four by a shallow pyramid. Each of the four beams passes through a Cassegrain reimaging telescope and onto a solid state CCD silicon detector. One of the facets of the pyramid has a low reflectance spot, 1.38 arcsec in diameter, providing a reduction of more than 7 stellar magnitudes, which may be used to observe a bright nearby star against a background of faint reference stars. The astrometric accuracy is expected to be 0.002 arcsec across one of the CCDs, which covers an area of 1.3 by 1.3 arcmin.

Others at this meeting have discussed the detection capabilities of astrometric searches with various levels of accuracy, so we will not go into further detail here. The only other information necessary to find the range of detections possible with the WF/PC (see section 3 below) is the length of time for the observations. The WF/PC can be used over the full wavelength range of the ST and reaches magnitude 18 with a signal to noise of 100 in an exposure of about 10 secs.

2.3 Planet Search with the High Speed Photometer

The HSP is unique among the ST instruments because it has no moving parts. It provides photometric observations with 27 different filter/aperture combinations by using magnetically focused image dissectors. One of the recent realizations about the HSP is that in some cases it can be used in the detection of planetary systems. The HSP is exceptional because it can operate with a very fast sampling rate (10^5 hertz) over a large dynamic range, 20 magnitudes, with an accuracy as good as 0.001 mag. This gives it the capability to detect planets during occultations of their primary stars. This will be pos-

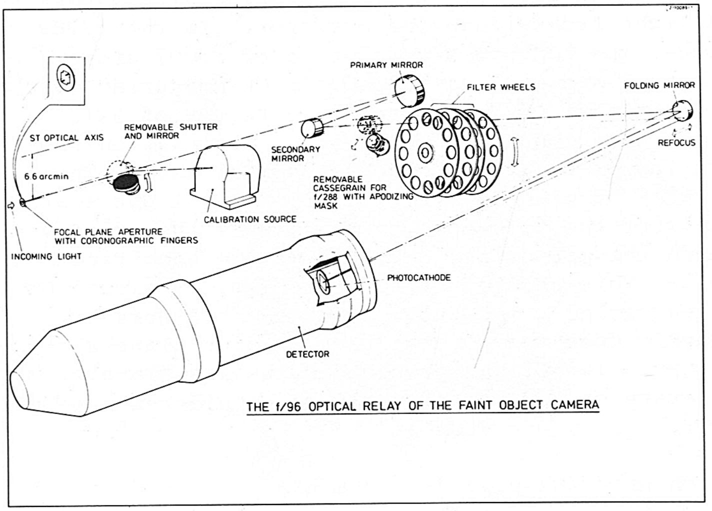

Figure 4. The Faint Object Camera f/96 Optical Relay System. This can be used in f/288 coronographic mode for the direct detection of planets.

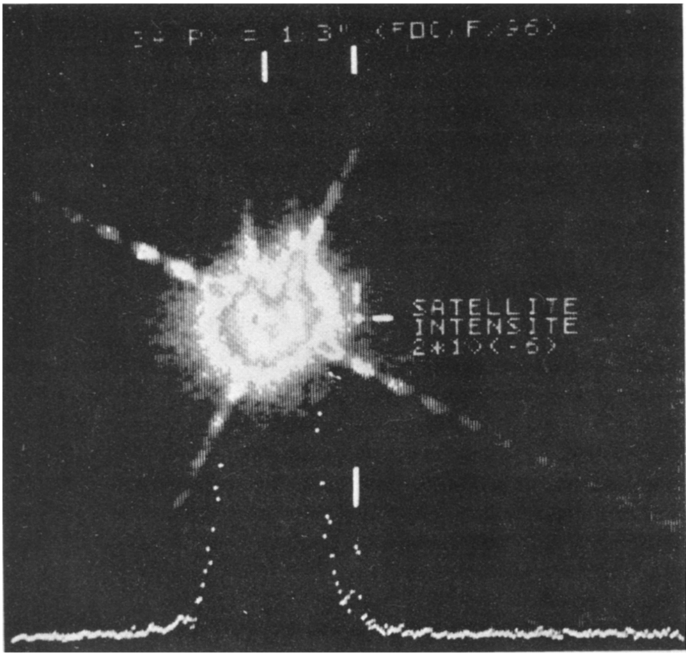

Figure 5. A simulation of a direct detection of a planet with the FOC. The planet is 2x10^{-7} times fainter than the central star and separated by 1 arcsec.

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sible marginally during lunar occultations, but is more likely during occultations by minor planets. This method of detection is included here for completeness. Because of the difficulty in predicting minor planet occultations, it will be used seldom for planned observations with the ST, but may happen serendipitously.

2.4 Planet Search with the Fine Guidance Sensors

When the ST is in normal operation it is stabilized by guide stars, one in each of any two of the three FGSs. This means that the third FGS can be used to make astrometric observations. The schematic of the FGS is shown in Figure 7. It contains two white light interferometers using Koesters prisms, one for each coordinate. The sensor does not move physically within the FGS, but the optical assembly called the star selector is capable of directing the light from anywhere within the field of view of the sensor (see Figure 2) into the interferometers.

The FGS has the largest field of view of any instrument on the ST. Each sensor covers an area nearly one-quarter of an annulus whose outer diameter is 28 arcmin and width is 4.3 arcmin, a total area of 69 square arcmin. But the FGS can observe only one star at a time. During the time of observations and slew time to the next star, the sensor must be stabilized by the guide stars so that any error in the tracking which would affect the astrometry should be noticeable. The observations take about one minute per star and can be used as bright as 4th and as faint as 17th visual magnitude. The slew time between stars is a few seconds. The accuracy of the relative positions from FGS measurements is 0.002 arcsec, the same as that for the WF/PC. However, the extra field size is an advantage in establishing a reference frame.

3.0 OBSERVING TIME ON THE SPACE TELESCOPE

In the sections above we have discussed the possibilities of finding planetary systems using various instruments on the ST. All four of them are capable of doing this. However the same characteristics which make the ST so useful for planet search programs are the same ones which make it desirable for so many other programs in astronomy, everything from determining the fundamental reference frame to the structure of quasars. A recent poll by the ST ScI of the astronomical community showed that planned requests for observing on the ST would oversubscribe it by a factor of 15. In effect the ST has many capabilities in planet search beyond that of ground based systems -- the greatest limitation will be the amount of available observing time.

To get a realistic estimate of the accuracy of any planet search program using the ST requires not only an estimate of the instrumental accuracy, discussed for all of them above, but also an estimate of the amount of observing time available. This can be done using the following:

$$t = T * f(sci) * f(inst) * f(sch) * f(*)$$

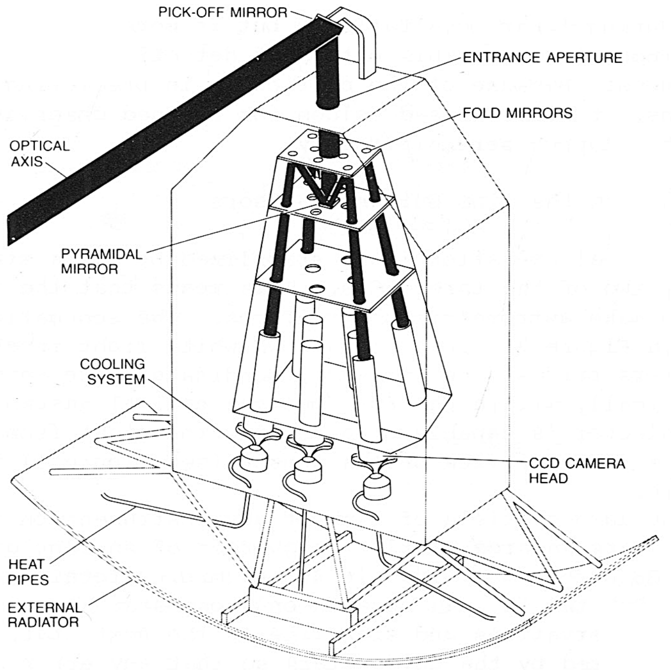

Figure 6. A schematic of the Wide Field/ Planetary Camera. The Wide Field mode of this instrument may be used for astrometric detection of planetary systems. The image from the ST falls onto a shallow four-faceted pyramid, which divides the beam into four. These are imaged on individual CCD chips. The best astrometry is if only one chip, 1.3 arcmin square, is used. (illustration from "The Space Telescope," J. N. Bahcall and L. Spitzer, copyright 1982 by Scientific American, Inc. and reprinted with permission)

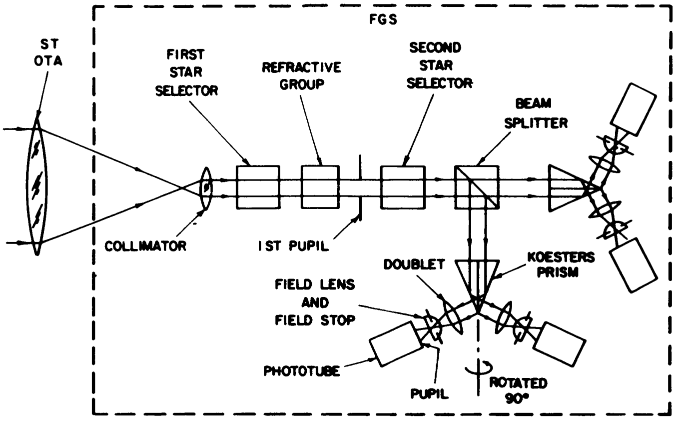

Figure 7. A schematic of a Fine Guidance Sensor. The star selectors can pick out light from anywhere within the field of view of the sensor. The position is measured using the Koesters prism interferometers, one in each coordinate.

where t is the time available per star per year
T is the length of a year
f(sci) is the fraction of time on the ST available for scientific observations
f(inst) is the fraction of that time available for the instrument in question
f(sch) is the fraction of the instrument's time available for a planet search program
f(*) is the fraction of the time available for each star on the program, nominally 1/n where n is the number of stars.

If T(obs) is the amount of time needed for one observation, then

$$N = t/T(obs)$$

is the number of observations per year per object and the estimated annual accuracy for the position of the object is

$$\sigma_{yr} = \sigma_o / N$$

if the error of the observations, σ_o, is Gaussian.

As an example, consider an observation using the FGS for a program of 10 stars, which each are observed with 9 reference stars, so that an observation of a target and reference stars in one set takes 10 minutes. For the Space Telescope, the fraction of time which will be spent actually gathering scientific data is estimated to be about 35%. For the estimate of the fraction of science time using the FGS for observations we use simply 1/6 of the available time, since there are six instruments. The fraction of time on planet search as opposed to other programs -- parallaxes, binary star measurements, proper motion studies, etc. -- is approximated at 20%. Combining all of these together

$$t = 525{,}960 * 0.35 * 0.17 * 0.20 * 0.10 = 589 \text{ min/star/yr}$$

$$N = 589/10 = 60$$

$$\sigma_{yr} = 0.25 \text{ milliarcsec/star/year}$$

Of course many of the numbers are speculation now, and estimates vary widely. The example above is perhaps optimistic.

4.0 SUMMARY

The Space Telescope has the capability to directly detect planets with the Faint Object Camera and perhaps with the High Speed Photometer. It also has the capability to perform astrometric searches for major planets about the nearby stars using the Wide Field Camera and the Fine Guidance Sensors. Any discovery would be the first major step in our understanding of the formation of stars and planetary systems, as well as in the search for extraterrestrial intelligence. The major limit to searching for extrasolar planetary systems with the Space Telescope will be the amount of observing time available because of its popularity for other types of astronomical programs as well. While it is not the ideal instrument with which to conduct a survey for planetary systems, it will pave the way for later dedicated programs.

REFERENCE

Hall, D. N. B. (1982) Proceedings of Special Session of Commission 44, IAU 18th General Assembly, Patras, Greece.

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