Remarks for the Bahcall Committee
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Increasing Hubble's Capability with New Instruments

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Summary

HST's unparalleled capability to address the foremost questions in astrophysics can be increased by factors of 10 or more with installation of one or more instruments during a post SM 4 mission. As an example, I discuss an instrument optimized for surveys for galaxies at redshifts between 6 and 10, the era of first galaxy formation and reionization of the Universe. This instrument, "High-z", would have a discovery efficiency 17 times greater than WFC3, Hubble's premier optical-IR camera that is scheduled for installation during a servicing mission in 2004/2005.

Introduction

First, I wish to thank the committee for giving me an opportunity to speak to you. By way of introduction, I am a Professor at the Johns Hopkins University, and an Astronomer at the Space Telescope Science Institute. I was a co-investigator and one of the four original team members who wrote and won the proposal for the Faint Object Spectrograph, whose PI was Richard Harms. After Hubble's launch and discovery of spherical aberration in the primary mirror, I urged Riccardo Giaconni to form a "tiger team" to look for ways that would correct the spherical aberration, and especially to look for solutions that would solve the problem for all of HST's instruments. With Riccardo's blessing, Bob Brown and I co-chaired what came to be called the "Strategy Panel". Two key recommendations were: 1) "*Continue WFPC II development for the first servicing mission (in 1993).* [and] *Assure the proper alignment of the spherical aberration correction*." 2) "*Develop the COSTAR to repair FOC, HRS, and FOS on the first servicing mission (in 1993)*." After NASA adopted the Strategy Panel's recommendations, I became the Project Scientist for COSTAR, working with the Project Engineer and team leader, Jim Crocker, to insure the success of the tightly time-lined COSTAR. Installation of COSTAR and the WFPC II in 1993 led to the complete restoration of Hubble's intended capabilities. In 1995 I led a team that proposed and won "The Advanced Camera for Surveys" (ACS), an instrument that has increased Hubble's survey capability by a factor of 10 in the blue and near infrared.

Programmatics

I will begin with a few "programmatic considerations." If there is a post SM 4 mission and a new instrument, I feel strongly that the instrument should be selected in a peer reviewed, open competition. There is enough time to select and build an instrument for a servicing mission in 2009, provided that NASA acts in a timely way and selects an instrument no later than January of 2005. I think that some of the costs of a final mission and instrument could be offset in at least two ways. One way would be to open the Midex or Discovery competitions for an SM 5 instrument. This would have the advantage of using Explorer money to put an instrument in a premier 2.4-m telescope, and would serve a broader community than most Explorer missions. There would be a disadvantage in that funding for a new instrument would not be guaranteed, depending instead on the outcome of review and selection as an Explorer. The second cost offset depends on NASA's decision about how Hubble will end its life. If public safety dictates that Hubble cannot be allowed to end with an uncontrolled reentry, we must either fly a Shuttle mission or an expensive robotic mission to retrieve the telescope, or attach a propulsion system that would allow a controlled reentry or a boost into a high stable orbit at end of life. A mission in 2009 should allow time to develop a propulsion system that could be attached to Hubble during the mission. The cost of the mission is then a cost that would have been incurred in any case. I also think there is great value-added to the cost of a mission to Hubble and the risk taken by a Shuttle crew if we are willing to invest 15 to 20% of the mission cost in an instrument that brings significant new capabilities to Hubble. Finally, I note that a servicing mission in 2009 would largely fill the gap between HST and a plausible launch of JWST sometime between 2013 and 2015.

The High-z Instrument

"High-z" is an axial optical/IR instrument designed to make highly efficient surveys for galaxies at redshifts between 6 and 10, which, in WMAP cosmology, corresponds to look back times of 12.6 to 13 Gyrs. This is an era when the Universe was being reionized (possibly the second time) by star formation and AGNs in the first generations of galaxies. In broad terms, High-z would have a 4K × 4K optical camera, optimized for the highest possible throughput in the Sloan i and z bands, and a 4K × 4K IR camera designed for high throughput in the J and H bands. The High-z IR camera would have *twice* the resolution of the WFC 3 IR camera and a *3.6 times larger* areal field of view. The High-z optical camera would have a *2.4 times larger* areal field of view than the optical Wide Field Camera 3 (WFC 3), and would have *7 times higher* sensitivity in the crucial z-band. The combination of High-z's overall optical design, larger fields of view, and higher sensitivity would make it *17 times faster than WFC 3* for surveys searching for, i-band, z-band, and J-band dropouts.

We have an optical design for High-z that is based on the proven optical design for the ACS Wide Field Camera. The optical camera would be based on the successful ACS WFC, which is producing fabulous images as we speak, and the design for the IR camera would be grounded in the experience gained with the WFC 3 1K × 1K IR camera. High-z would be based on proven designs and technology from HST instruments and from other missions. A quick but thorough look at the overall instrument showed that this instrument can be built. I will be happy to answer questions that the committee may have about the instrument, and provide details to the committee as needed.

High-z Science

The high efficiency of the High-z instrument would enable astronomers around the world to address a broad range of present and future outstanding questions in astrophysics. As examples of science that could be done with High-z, I list three broad themes.

1. The Formation and Evolution of Galaxies

Surveys for i-band, z-band, and J-band dropouts would identify galaxies at redshifts between 6 and 10. Galaxies at these redshifts are reionizing the Universe, and are among the first generation of galaxies. The surveys would establish luminosity functions, luminosity densities, and morphologies of this first generation of galaxies.

Deep ACS images of clusters of galaxies at redshifts up to z = 1.23 reveal that ellipticals were already in place at less than half the age of the Universe. The colors of the ellipticals suggest that many formed at redshifts between 2 and 3. Deep NIR/IR surveys would illuminate the formation and evolution of clusters and cluster galaxies.

Spiral galaxies are present at redshifts up to 1, but appear to be missing at redshifts higher than 2. High-z would enable efficient, multi-color NIR/IR surveys that could reveal the build up of spiral bulges and disks. Put another way, what is presently missing and cannot be provided from the ground is the morphological evolution of galaxies at redshifts between 1 and 2.5. Large area IR surveys with High-z's resolution and sensitivity would provide the data needed to compare optical restframe images of galaxies during their formative periods with nearby galaxies.

2. Strong and Weak Lensing

The distribution and nature of dark matter is an outstanding problem. Deep ACS g,r,i,z images of strongly lensing clusters are allowing us to measure the distribution of dark matter in clusters with unprecedented precision. Extending the surveys to J and H and deepening the surveys with High-z's NIR sensitivity will enable better mass distributions to larger radii in more clusters.

Background galaxies near the critical radius can be magnified by factors up to ~20. The high magnification allows us to study otherwise unobservable galaxies. Searching for lensed i,z, and J-band dropouts is a powerful way to find the faintest galaxies out to z = 10.5

High sensitivity and a stable PSF combined with superb spatial resolution and a large field of view enable weak lensing studies of the dark mass distribution in the halos of clusters and in the field.

3. Supernovae and Dark Energy

Wide field IR surveys are needed to find and utilize Type Ia supernovae at redshifts $z > 1$, a period of cosmic expansion history which can provide unique constraints on the nature of dark energy and is only accessible from Space." Surveys with ACS have already found and typed (via ACS Grism spectra) substantial numbers of supernovae at $z \sim 1$ (and higher). At higher redshifts the peak of the restframe luminosity and the spectral features needed to classify the supernova shift into the J and H bands. High-z would enable HST to find and type (via an IR Grism) large numbers of supernovae at redshifts between 1 and 2. If WFC 3, ACS, and High-z were operated in parallel for 6 months, a few hundred Type Ia supernovae at redshifts between 1 and 2 could be found, typed, and measured for light curves. These would enable us to make substantial progress towards constraining the equation of state of dark energy and its time derivative, crucial clues in the quest to understand the physics of dark energy.