HST++ Summary

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Abstract. At this meeting HST++ has earned its place on NASA's Origins theme 2003 roadmap as the large UV/optical mission. The strategic high ground HST++ should occupy is wide-field high-resolution imaging and ultraviolet spectroscopy. Key projects include the evolution of the intergalactic medium, the first generation of stars in the Local Group, and the expansion of the Universe.

1. The Discovery Space for HST++

The first speakers at this meeting stressed to us that the astrophysical landscape is sure to change by the time of the launch of the Hubble Space Telescope's successor. A clear vision of the discovery space of a new mission complements the quest for key projects in an important way. Dimensions of the discovery space include:

- ultraviolet spectroscopy 2.5 mag beyond the Cosmic Origins Spectrograph (COS)
- optical imaging 2.5 mag beyond the Advanced Camera for Surveys (ACS)
- spatial resolution of a few milli-arcseconds
- a field of view larger than ACS, sampled with at least a billion pixels

This description assumes an 8 meter effective diameter collecting area. Instrumental gains beyond this are possible, if science drivers are identified, and detector development (for example) is pursued. Discussion suggested that the extraordinary richness of the atomic spectrum in the ultraviolet was an additional feature of the discovery space.

2. The Astrophysics Facility Landscape in 2015

HST+++ will complement facilities such as the Atacama Large Millimeter Array (ALMA), the Next Generation Space Telescope (NGST), the Giant Segmented Mirror Telescope (GSMT), and the Space Interferometry Mission (SIM). The scientific emphasis of the first three of these will be galaxy formation in the young Universe and star and planetary system formation. The SIM mission

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(and GAIA) will measure fundamental astronomical distances and motions, and lay down an accurate map of our Galaxy.

An ultraviolet/optical mission in the 2015 time frame would be very complementary with these facilities, and fill a major void in our understanding of the evolution of the intergalactic medium (IGM), including

- determining the equation of state of the baryonic Universe
- surveying hot gas (10^5–10^7 K)
- measuring its large scale structure
- discovering how galaxies interact with this environment
- tracing the chemical evolution of both light elements, such as deuterium, and heavy elements in all their phases.

A wide field optical instrument could have a major impact on cosmology by studying

- weak lensing
- supernova cosmology

However, the 2000 decadal survey Astronomy and Astrophysics in the New Millennium expects these problems to be substantially addressed from the ground by means of the Large Synoptic Survey Telescope (LSST), which is slated to furnish a digital survey of the sky each week. Its science drivers include:

- a weak lensing mass map of the Universe
- 100,000 supernovae per year in the redshift interval 1–2
- a survey of Earth crossing asteroids
- 10,000 primordial trans-Neptunian objects

3. "Killer Apps" for HST++

3.1. The Intergalactic Medium

We were encouraged on the first day to find some "killer applications" for the new mission. A good case was put to us in a series of presentations for identifying the large scale structure of the IGM at z < 1.65. The outcomes would include:

- complete knowledge of the evolution of Lyα forest and its large scale structure. This would require many QSO spectra to give many sight lines through the IGM. The new mission would fill the void in our understanding at redshifts less than the critical value (1.65) for Lyα to enter the window in which the UV penetrates to the ground.
• tracing the evolution of damped Lyα systems to low redshifts. These systems, thought to evolve into normal galaxies, are the major baryon concentrations for all redshifts.

• understanding the chemical evolution of the IGM to the present day

• the correlation of this Lyα cloud structure to galaxies

The redshift survey required to accomplish the last of these goals could effectively be executed from the ground by the next generation multi object spectrograph (Barden 2002).

3.2. Understanding the Galaxy’s Hot Corona

There is a strong suggestion from highly ionized clouds, and from the physics of high velocity clouds and the Magellanic Stream, that the Galaxy is bathed in a hot corona of low density gas at temperatures at $10^5 - 10^7$ K. Indeed, this phase of the IGM may be pervasive and amount to a global baryon reservoir.

To study the Galaxy in sufficient detail to establish this model requires that we maximize the number of sight lines for absorber spectroscopy and the spectroscopic resolution with which these sight lines are probed. This discovery of the Galaxy’s environment and its ecology seems from the discussion at this meeting to be a second killer application for HST++. Its requirements on the mission are broadly compatible with the first, but spectroscopic resolution trades would need to be made carefully.

4. Stellar Populations “Killer Apps” for HST++

Stellar populations have proved a rewarding field with HST. There is a tendency, however, to try to win the war one island (or galaxy) at a time.

4.1. Galaxy Formation

A clear theme, such as galaxy formation needs to be developed and strategic outcomes targeted, such as

• the quest for the predicted dark halos which were unfilled or lightly filled with baryons

• the nature of the first generation of stars and its initial mass function (IMF)

• forming stellar halos by accretion

Each of these areas calls for wide field imaging with resolution several times that of HST. The frequency and characteristics of star streams like that discovered by Ibata et al. (2001) in M31 will teach us a great deal about stellar halo formation. The resolution of HST++ would open much of the Local Supercluster to such studies.
4.2. The Hubble Constant

Cepheids in Coma will be accessible to HST++. Coma's peculiar velocity has been estimated at \( \sim 1\% \) of its redshift, thus cutting secondary distance indicators out of the classical extragalactic distance scale (see Kennicutt, Mould, & Freedman 1995). If HST++ can extend its Cepheid distance measurements to a few times the Virgo distance, the SN Ia zero-point will be verified within 5 years with a sample of 50 or more SN Ia hosts.

With the aid of SIM to accurately define the Cepheid zero-point, the error budget \( \delta H/H_0 \) can be reduced to approximately 2\%. The principal outcome of this work will be a constraint, not so much on the age of the Universe, which will have been measured with Planck, as much as on the dark energy. This results from measuring both \( \Omega \delta^2 \) from the cosmic microwave background, and \( \delta H \) separately. Together these should yield a determination of the equation of state of the Universe, \( \delta w \approx 0.01 \). The HST Key Project aimed to find how fast the Universe is expanding; HST++ can tell us why the Universe is expanding.

5. The Relation Between HST++ and GSMT

5.1. Where HST+++ Will Complement GSMT

There are many instances to illustrate how the legacy of HST will be extended by the combined efforts of the next generation of telescopes.

- Star formation histories in Virgo can be studied in Main Sequence Population I (to \( 10^8 \) years) with HST++, and in its intermediate age and old population on the Asymptotic Giant Branch (\( 10^8 - 10^{10} \) years) with GSMT.

- The Universe at \( z = 6 \). The molecular clouds will be studied with ALMA; the star formation rate from H\alpha with NGST. The kinematics of galaxy formation and assembly will require GSMT. Finally, the Lyman continuum is a subject for HST++.

- The large scale structure of the IGM at \( z < 1.65 \). HST++ will probe the intergalactic medium densely with many lines of sight. The relationship between the structure in the Lya forest and the galaxies will require a deep redshift survey at optical wavelengths. GSMT can provide that survey with its seeing-limited multi-object spectrograph.

5.2. Where GSMT Will Supersede HST

There are also instances where GSMT can complete work commenced with HST. An example is the evolution of the fundamental plane. The evolution of M/L from \( z = 0.5 \) to 1.5 has been clearly delineated by van Dokkum et al. (2001) and Kelson et al. (2000a,b). Structural parameters have been from HST and kinematics from Keck. Extension of this work to \( z = 2 \) to 3.5, where evolution is fastest can be accomplished observing both structure and kinematics from GSMT, using the conventional Mg lines at \( 517 \) nm redshifted to \( 1.6 - 2.3 \mu \).
5.3. Extending the Stellar Populations Laboratory

Detailed star formation histories will be accessible with HST++ for M31 and for galaxies in the nearest groups. The prototype work is that of Holtzman et al. (1996) with HST/WFPC2 on the star formation history of the LMC. In all Local Group galaxies, the full star formation history is on display. Their color-magnitude diagrams (CMDs) show the number of stars formed each Gyr in the Hertzsprung gap. One simply has to count the stars as they cross. A basic assumption here is that the IMF is robust. This is verified by HST studies of local dwarfs, although one should be wary that it may be inapplicable to Population III.

Figure 1. WFPC2 CMD of a field in the LMC from Holtzman et al. (1996). Information on the star formation history is provided by the stars crossing the Hertzsprung gap between the main sequence and giant branch.
6. The Importance of Resolution for HST++

An 8 meter HST++ does not cross any critical resolution thresholds for galactic nuclei. However, it is worth keeping in mind that the resolution standard for astronomical facilities will rise in the next decade.

6.1. Resolving Stars

There are a number of interesting applications of this resolution in stellar astrophysics.

- the hot O VI inner disk in CVs
- surface features of cool stars
- globular cluster cores
- star formation

Star formation applications are addressed in Beckwith's review (this volume).

6.2. Black Hole Environments

Probing the physics of black hole environments may call for comparable resolution from the ultraviolet to millimeter wavelengths.

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<th>Resolution</th>
<th>λ</th>
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<td>HST++ (4 m)</td>
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<tr>
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7. Organization

There is much to be gained from a coordinated ground-based science co-program. This should be designed at the outset. The recent Committee of Research in Astronomy & Astrophysics emphasized such coordination (Augustine et al. 2001). The new National Astronomy and Astrophysics Committee is intended to encourage the necessary NSF/NASA cooperation. Internationally, the Inter-Agency Consultative Group can assist by effecting NASA/ESA cooperation.

References


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