Key science with the Great Observatories

We asked participants in the "Making the Most of the Great Observatories" workshop, held in Pasadena in May 2006, to identify key science areas that need to be tackled by Great Observatories, particularly those investigations that rely on observations by at least two Observatories and those that support observing programs by future space-based Great Observatories or large ground-based telescopes. This document (based extensively on David Weinberg's compilation) summarizes the results of that process. This should not be taken as an official endorsement of these programs by any of the Great Observatories.

Planets and planetary systems

- Monitoring campaigns of atmospheric/auroral phenomena in Solar System gas giants.
- Detailed studies of Kuiper belt objects – binarity, masses, albedo, composition
- Concerted campaigns to probe the composition and structure of Solar System comets.
- Probing the physical properties of extrasolar planets through spectroscopic and photometric observations of eclipsing systems.
- Statistics and structure of planetary disks around sub-solar mass stars.
- Determine the lower mass limit for the IMF (i.e. can sub-Jupiter mass objects form in isolation from a parent "star"?).

Stars

- Beyond T dwarfs – search for brown dwarfs with temperatures below ~600K
- UV spectroscopy of [Fe/H]<-5 stars – using metallicities to constrain the first epoch of Galactic star formation.
- Systematic study of interacting binaries, particularly searching for likely progenitors of Type Ia supernovae.
- Age, composition and evolutionary history of Galactic Bulge globular clusters
- Astrophysics of jets and outflows – a systematic coordinated study of a well-defined, representative sample of Galactic evolved binaries.
- Coordinated cross-observatory observations of the Galactic Centre.
- Probing the low-mass IMF in young star clusters.
- Mass-loss and winds in massive stars.
- Dynamics of star clusters – mass segregation, stellar evolution and neutron star/BH progenitors.

Star Formation

- What is the interplay between molecular cloud structure and star formation?
- Is the physics of massive star formation similar to that of low-mass star formation?

- What are the physical mechanisms of proto-stellar accretion and proto-stellar outflows?
- What is the stellar IMF and is it universal?

Most of these issues could be addressed through complementing the current suite of observations of the Orion Nebula cluster through concerted observations of an additional star-forming region (Eta Carinae, 30 Doradus); there was strong consensus among interested parties that a major multi-wavelength survey was a high priority.

Galaxies and galaxy formation

- Probing the physics of stellar/supernova feedback – multi-wavelength studies of star-forming galaxies.
- Investigating the star-formation and chemical enrichment histories of local galaxies by studying resolved stellar populations (largely addressed on HST through the cycle 15 ANGST and ANGRRR programs).
- Investigating the relation between dark matter and galaxies through strong lensing studies.
- Probing the nature and source(s) of the extragalactic radiation background at UV/optical/IR wavelengths (resolved sources, fluctuation analysis, absolute measurements); archival data may be sufficient for this program.
- What physical mechanisms determine the joint distribution of galaxy stellar mass, star formation rate & history, morphology and environment as a function of redshift?
- What causes the downsizing of star formation and AGN activity at low redshift?

AGN and related phenomena

- What is the role of AGN feedback in galaxy formation and cluster evolution?
  - X-ray/UV studies of winds and outflows.
  - Deep X-ray images of clusters and individual elliptical galaxies.
  - Multi-wavelength studies of AGN hosts.
  - Large area galaxy/AGN surveys.
  - Stronger constraints on the black hole mass/velocity dispersion and BH mass/bulge mass relations.
- What causes the downsizing of star formation and AGN activity at low redshift?
- Multi-wavelength studies aimed at probing the physics of relativistic jets.
- Deep multi-wavelength surveys aimed at probing the location and physical state of obscuring material in AGNs.

Clusters, the inter-galactic medium and cosmology

- Investigating the relation between dark matter and galaxies through weak lensing maps of clusters and large-area weak lensing maps.

- Probing the epoch of reionization and the source of ionizing photons through detailed studies of high-z galaxies and QSOs, particularly He II reionization.
- Searching for the missing baryons through UV and X-ray emission/absorption observations of galaxy groups and clusters.
- High accuracy (<5%) determination of H_0 through observations of Cepheids in distant galaxies, closer alignment of Cepheid and SN Ia distance scales and geometric distance estimates to nearby galaxies (X-ray echoes in M31, masers in other galaxies). This is addressed partly through Cycle 15 *Hubble* programs.
- What is causing cosmic acceleration?

- High-z and ground-based supernova searches.
- Detailed investigations of supernovae systematics.
- Space-based calibration of ground-based weak lensing surveys.
- Calibration of cluster masses through X-ray and weak lensing observations.
- Detailed imaging surveys of nearby clusters to calibrate mass indicators for observations of high redshift clusters.
- Use Spitzer to compile a catalogue of high redshift ($z > 1$) clusters.

There was general consensus that there is little justification for acquiring new deep fields with the present suite of Great Observatory instruments. The combination of the HDF, UDF, GOODS, GEMS, COSMOS, Lockman Hole, the Extended Groth Strip, Bootes and SWIRE provide good sampling in terms of area and sensitivity, although some gaps in wavelength coverage remain. The strongest case for a new large-scale program centered on pushing one of the Chandra Deep Fields deeper, on the grounds of:

a. Reaching low-luminosity AGN in z~1-2 galaxies, to understand AGN/galaxy formation physics;
b. Reaching X-ray emission from star formation in z~1 galaxies;
c. Getting better statistics on "typical" sources to allow more accurate determinations of obscuring column densities;
d. Completing observations that will not be repeatable or surpassable for decades (until the next generation X-ray satellite).

General comments

- There are no obvious key scientific questions that are currently ignored by the Great Observatories. All of the projects highlighted during the workshop build on past science programs.
- Archival research will become increasingly important in the near future. It is imperative that the Great Observatories provide efficient cross-linking between their individual data archives.
- All time assignment committees (ground- and space-based) should bear in mind the limited cryogenic lifetime of *Spitzer* and potential lifetime issues for *Hubble*.
- Several projects proposed at the workshop were comparable in scale to the initial *Hubble* key projects. *Spitzer*'s schedule, however, does not allow sufficient time for formal selection of officially sanctioned, large, multicycle programs by the appropriate oversight committees. The onus is therefore on the astronomical

community to devise successful co-operative strategies for proposing important science.

- There was strong (but not unanimous) sentiment for examining means of streamlining the proposal process for projects that require medium to large allocations on two or more Great Observatories. The available options are being explored.