Future large telescopes in space

prepared by R. Fosbury & R. Hook with input from P. Bèly,
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Motivation

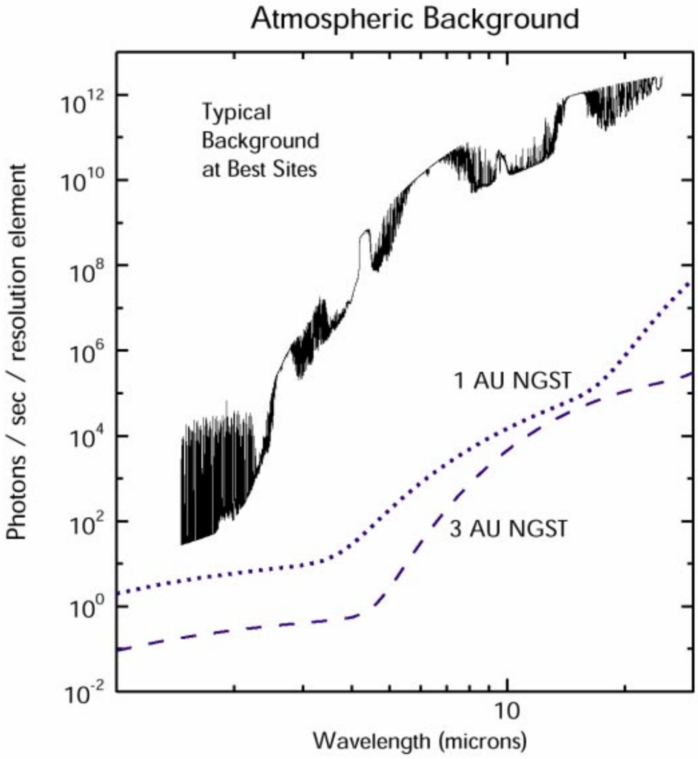
For those wavelength regions accessible from the ground, experience with HST has shown that the capabilities of ground- and space-based telescopes can be considered complementary rather than directly competitive. In addition to the obvious advantages of space:

- no atmospheric absorption/emission;
- no turbulence;
- greater stability—no changing seeing or gravitational loading;
- can be used 100% of the time—at least for certain pointings;

there are some more subtle differences which are likely to remain important. These include:

- that space can provide wider fields of high quality, stable imaging compared to active/adaptive optics on the ground—at all wavelengths;
- control of structures and optical surfaces only needs to compensate for thermal variations, not changing gravity vectors;
- no protection from weather is required, however, protection from solar heating, UV-degradation of materials and space debris is needed;
- passive cooling of IR telescopes, instruments and even detectors (working up to ~5µm) is possible.

Even in space, the environmental factors put significant constraints on the acceptable spacecraft location. The Zodiacal light is the limiting background for NGST in its core spectral range (1–5µm) and there would be a significant improvement in going from a one to a three AU orbit (see Figure).



A model atmospheric background for Mauna Kea compared with an optimum zodiacal light background at 1 AU and 3 AU. The primary mirrors are assumed to have 3% emissivity and temperatures of 273, 50, and 30 K, respectively. The background units are expressed as photons per second, 100% bandpass, and angular resolution element (λ/D) and are independent of telescope aperture.

Technology development and cost evolution

NASA clearly sees NGST as a model for the development of future large mirrors in space. The limitation of NGST to a deployed aperture of ~8m is set by the availability of low cost launchers and fairings with the energy to reach L2.

It is unlikely that we will have fairings much larger than the shuttle bay or the Ariane 5 /EELV size in the foreseeable future. This is roughly 4 to 4.5 metres in diameter and 10 to 15 metres long. Mass is also limited to 3 to 5 tons to a drift or L2 orbit.

If cost is no object, and one can use the largest shrouds and extra boosters, packaging and mass are the limiting factors and the practical limit seems to be about 100 square metres of primary mirror (i.e., about 11 metres in diameter). Note that this is close to the range envisaged for the Space Based Laser (SBL: http://www.afbmd.laafb.af.mil/ade/sblproject.htm), i.e., 11 to 13 metres. This is a little larger, but is for low earth orbit. If SBL goes ahead, it certainly would drive the entire business of space telescopes and launchers. But this would not fundamentally change the maximum size of telescopes that can be launched at one time.

For still larger space telescopes, the answer is likely to be a cluster or array of individually deployable ~10m telescopes, in line with what has been proposed for the individual interferometer modules of the Planet Finder (see below).

Defining a metric for a realistic cost comparison between space and groundbased developments is difficult for the very reason that the telescopes have different performance characteristics. For the foreseeable developments on the ground of high resolution imaging, it seems safe to assume that the large (in a relative sense!) area surveys with exquisite image quality such as those envisaged for NGST (with a foretaste provided by HDF) can only be done from outside the atmosphere.

We can already see, from current 8–10m projects, that the costs of large ground and space-based projects are converging. The NGST cost per unit aperture area is only about an order of magnitude larger than for VLT while the ratio for HST/NTT was closer to 10^3. The procurement plan for NGST, with late construction and early technology development, means that it is unlikely that the cost per unit area of space telescope will drop much further unless it is possible to exploit the economies of scale which would result from the SBL programme.

In the more distant future, alternatives to the deployable, segmented mirror technologies could be considered. Very large structures, deployed using methods akin to the current strategies for, e.g. the NGST sunshield, might provide filled aperture telescopes suitable for spectroscopy to extremely faint limits at a cost considerably lower than for a similar capability at a site subject to gravitational acceleration. Also, the developments in station-keeping required for the individual elements of space interferometers may make it feasible to construct large 'filled apertures' from free-flying segments.

A digest of useful URLs describing NASA and ESA astronomical space missions

NASA Missions

ORIGINS	General— main NASA site `http://origins.jpl.nasa.gov/`

Precursor missions

SIRTF	The Space InfraRed Telescope Facility, planned launch Dec 2001. Final NASA Great Observatory, 0.85m telescope, 3-180µm. 5 year lifetime. `http://www.jpl.nasa.gov/sirtf/home.html`
WIRE	The Wide Field IR Explorer, an infrared survey mission for launch in March ’99. `http://www.ipac.caltech.edu/wire/`
FUSE	The Far-UV Spectroscopic Explorer, high-resolution UV spectroscopy (90-120nm). Launch late ’98. `http://origins.jpl.nasa.gov/missions/fuse.html`
SOFIA	Stratospheric Observatory for Infrared Astronomy. 2.5m telescope in modified Boeing 747-SP. First flights in 2001. `http://origins.jpl.nasa.gov/missions/sofia.html`

First generation Origins missions

DS3	Space Interferometry test mission: Deep Space 3. A ‘free flying’ optical interferometer in space. A test-bed for future missions. Launch in 2001. Also known as the New Millennium Interferometer. `http://origins.jpl.nasa.gov/missions/ds3.html`
SIM	The Space Interferometry Mission. Positional measurements at micro-arcsec levels, synthesis imaging. Launch around 2005. `http://origins.jpl.nasa.gov/missions/sim.html`

NGST	The Next Generation Space Telescope. An 8m segmented mirror optical/near IR observatory. Baseline wavelength range 1-5um. Launch in 2007. ESA (via F-mission?) and Canadian collaboration.
	`http://ngst.gsfc.nasa.gov (Main NASA site)`
	`http://www.pha.jhu.edu/~papovich/QSO/node2.html`
	`http://www.astrsp-mrs.fr/www/ngst.html (French Site)`
	`http://www.ast.cam.ac.uk/HST/ngstinfo.html (UK Site)`
	`http://ecf.hq.eso.org/ngst/ngst.html (ECF site)`

Second generation Origins mission

TPF	The Terrestrial Planet Finder. A higher performance interferometer intended for imaging (detection) and spectral analysis of the light from earth-like planets around nearby stars. Launch around 2011 at the earliest. `http://origins.jpl.nasa.gov/missions/tpf.html`

Third generation

PI	The Planet Imager. A proposed later mission with huge arrays (5x4x8m) of free-flying large aperture interferometers to image the surfaces of earth-like planets around nearby stars. Mostly speculation at present. Earliest possible launch 2015+. `http://origins.jpl.nasa.gov/missions/pi.html`

ESA missions

Overview	`http://astro.estec.esa.nl/SA-general/Projects/projects.html` general overview of projects and links to missions

Missions under development

XMM	`http://astro.estec.esa.nl/XMM/xmm.html`
Integral	`http://astro.estec.esa.nl/SA-general/Projects/Integral/integral.html`
FIRST	`http://astro.estec.esa.nl/SA-general/Projects/First/first.html`
PLANCK	`http://astro.estec.esa.nl/Planck/`

Proposed future missions

IRSI	The infra-red space interferometry cornerstone candidate `http://astro.estec.esa.nl/SA-general/Projects/IRSI/`
GAIA	Interferometric astrometry. `http://astro.estec.esa.nl/SA-general/Projects/GAIA/gaia.html`
XEUS	Large area X-ray. `http://astro.estec.esa.nl/SA-general/Projects/XEUS/mission.html`

The NASA Origins timeline: