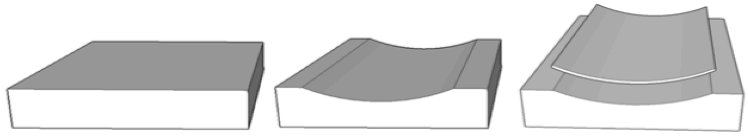
Lightweight and Diffraction-Limited X-ray Telescopes

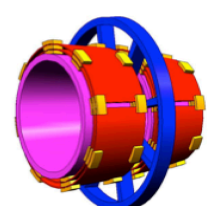
William W. Zhang
NASA Goddard Space Flight Center
Greenbelt, MD 20771
(Submitted on 25 March 2013 to NASA Astrophysics Roadmap team)

X-ray astronomy has been progressing by leaps and bounds since its beginning with a small collimated Geiger counter aboard a sounding rocket in the early 1960's. Its major milestones have included the first satellite (*Uhuru* in 1970), first imaging telescope (*Einstein* in 1979), culminating in the four major telescopes simultaneously in operation at the present time: Chandra, XMM-Newton, Suzaku, and NuSTAR. Of the four important properties that characterize the capability of a telescope, i.e., ***angular resolution***, ***photon collection area***, ***energy bandwidth***, and ***spectral resolution***, these four telescopes each capitalizes on one or two of them, none on all of them. . The fondest hope of x-ray astronomers is to have all these four qualities realized in a single telescope or observatory. The first three of the four qualities can be addressed by the development of lightweight diffraction-limited x-ray optics.

The construction of an x-ray telescope consists of three key elements: (1) fabrication of the grazing incidence optical elements, (2) coating of the optical elements with an X-ray reflective layer, and (3) alignment and integration of the elements into a mirror module. For future large area X-ray optics, the use of segmented mirrors in modular housings is dictated by cost, mass and size considerations. We envision a development program for segmented X-ray mirrors that is based on the following key technological components: (1) stress-free, single crystal silicon mirror substrates; (2) high speed, deterministic optical surface polishing; (3) atomic layer deposition for X-ray reflective layer coating; and (4) nano-machining of the precision alignment components. These processes, well established within industry, are currently the most promising for constructing high angular resolution X-ray mirrors. This program will adapt and refine each of these industrial processes toward making ***lightweight*** and ***diffraction-limited*** x-ray optics.



Fabrication of lightweight diffraction-limited mirror segments using single crystal silicon: polish first and then lightweight



Alignment and integration using nano-machined spacers (shown in yellow)

We envision the following "way stations" over the next three decades. Each of these notional missions would incorporate the best imaging spectrometer or gratings system available at the time to achieve unprecedented spectral resolution:

1. ~2020: an Explorer-class mission with 1" angular resolution and an effective area matching that of the XMM-Newton: ~0.5 m^2 at 1 keV.
2. ~2030: a probe-class mission with 0.1" angular resolution with approximately 1 m^2 effective area at 1 keV.
3. ~2040: a strategic mission with diffraction limited imaging (~0.05") at 1 keV with 3 m^2 effective area at 1 keV, and 0.1" and 0.1 m^2 at 100 keV.

All of these missions can be implemented with currently (~2012) existing launch vehicles.