

Final Report

High Resolution X-ray Imaging

NAG5-5020

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NAG5-5020 covered a period of 7.5 years during which a great deal of progress was made in x-ray optical techniques under this grant. We survived peer review numerous times during the effort to keep the grant going.

In 1994, when the grant started we were actively pursuing the application of spherical mirrors to improving x-ray telescopes. We had found that x-ray detectors were becoming rapidly more sophisticated and affordable, but that x-ray telescopes were only being improved through the intense application of money within the AXAF program. Clearly new techniques for the future were needed.

We were successful in developing and testing at the HELSTF facility in New Mexico a four reflection coma-corrected telescope made from spheres. We were able to demonstrate 0.3 arcsecond resolution, almost to the diffraction limit of the system. The community as a whole was, at that time, not particularly interested in looking past AXAF (Chandra) and the effort needed to evolve.

Since we had reached the diffraction limit using non-Wolter optics we then decided to see if we could build an x-ray interferometer in the laboratory. In the lab the potential for improved resolution was substantial. If synthetic aperture telescopes could be built in space, then orders of magnitude improvement would become feasible. In 1998 NASA, under the direction of Dr Nick White of Goddard, started a study to assess the potential and feasibility of x-ray interferometry in space. My work became of central interest to the committee because it indicated that such was possible.

In early 1999 we had the breakthrough that allowed us build a practical interferometer. By using flats and hooking up with the Marshall Space Flight Center facilities we were able to demonstrate fringes at 1.25keV on a one millimeter baseline. This actual laboratory demonstration provided the solid proof of concept that NASA needed. As the year progressed the future of x-ray astronomy jelled around the Maxim program. Maxim is a set of two major x-ray astronomy missions based on the concepts I developed and demonstrated under this SR&T grant. The first Maxim is to image the sky at 100micro-arcsecond resolution. That is one thousand times higher resolution than Hubble. The full Maxim has the ultimate goal of imaging the event horizon of a black hole in an active galactic nucleus (AGN). This will require 0.1 micro-arcsecond resolution — one million times higher than Hubble! Nonetheless, using the techniques developed under this grant, it has become possible. Maxim Pathfinder is now in the NASA planning for a new start in approximately 2010. The full Maxim is carried as a vision mission for the post 2015 timeframe.

Finally, this grant is the evolved version of the SR&T grant we carried during the 1980 s and up to 1994. At that point in time this grant was also working on x-ray optics, but concentrating on x-ray spectroscopy. The techniques developed by 1990 were not chosen for use on Chandra or XMM-Newton because they were too new (timing is everything). During the last year, however, the Constellation-X mission (the successor to Chandra) recognized the need for better spectroscopy techniques and tapped our expertise. We were able to support the initial work on Con-X through this program. It now appears that the off-plane mount will be used in Con-X, increasing performance and decreasing cost and risk.

During these last seven years the grant has also provided support for two graduate students. Dennis Gallagher is now active in the space program as a senior engineer at Ball Aerospace, and Scott Sarlin is a senior systems scientist for Boeing in Los Angeles.

The details of all this can be found in the publications we have written during the period of performance of the grant. We close with that list.

The following publications have been supported in full or in part by NAG5-5020

1. Gallagher, D., Cash, W., Green, J. C., A Search for an X-Ray Scattering Halo Around Scorpius X-1 , *Ap. J.* , **439**, 976-982, 1995
2. Cash, W., X-ray Diffraction Gratings , *Proceedings of the International School of Space Science*, 1995
3. Cash, W., X-ray Interferometers , *Proceedings of the International School of Space Science*, 1995
4. Gallagher, D., Cash, W., Jelsma, S., Farmer, J., Sub-Arcsecond X-ray Telescope for Imaging the Solar Corona in the 0.25-1.25keV Band , , *Proc. Soc. Photo-Opt. Instr. Eng.* , **2805**, 121-132, 1996
5. Cash, Webster, High Resolution X-ray Imaging , *The Next Generation of X-ray Observatories*, edited by MJL Turner and MG Watson, University of Leicester Report XRA97/02, pp 147-152, 1997
6. Cash, Webster, X-ray Interferometry: Exciting Science and Feasible Technology , *Proceedings of the 16th IEEE Instrumentation and Measurement*, ed. V. Piuri and M. Savino, IEEE Press, 1123-1128, 1999
7. Cash, W., High Resolution X-ray Imaging in *Small Missions for Energetic Astrophysics*, S. P. Brumby editor, American Institute of Physics Press, 44-57, 1999
8. Cash, W., High Uniformity Collimator for X-ray Proximity Lithography , *Proc. Soc. Photo-Opt. Instr. Eng.* , **3767**, 59-66, 1999
9. Shipley, A., Cash, W., Osterman, S., Joy, M., Carter, J., Development of a Grazing Incidence X-ray Interferometer , *Proc. Soc. Photo-Opt. Instr. Eng.* , **3786**, 291-299, 1999.
10. Kahn, S. K., Paerels, F. B., Rasmussen, A., Schattenburg, M. L., Ricker, G. R., Bautz, M. W., Doty, J. P., Prigozin, G. Y., Nousek, J. A., Burrows, D. N., Hill, J. E., Cash, W. C., Large Area Reflection Grating Spectrometer for the Constellation-X Mission , *Proc. Soc. Photo-Opt. Instr. Eng.* , **3765**, 94-103, 1999.
11. Shipley, A., Cash, W., Joy, M., Grazing Incidence Optics for X-ray Interferometry , *Proc. Soc. Photo-Opt. Instr. Eng.*, **4012**, 456-466, 2000.
12. Joy, M., Shipley, A., Cash, W., Carter J., Zissa, D., Cuntz, M., Experimental Results from a Grazing Incidence X-ray Interferometer *Proc. Soc. Photo-Opt. Instr. Eng.*, **4012**, 270-277, 2000.
13. Cash, W., White N., Joy, M., The Maxim Pathfinder Mission: X-ray Imaging at 100 Micro-Arcseconds , *Proc. Soc. Photo-Opt. Instr. Eng.*, **4012**, 258-269, 2000.
14. Windt, D., Cash, W., and Kahn, S., The Scattering of X-rays by Interstellar Dust on the Micro-Arcsecond Scale , *Ap. J.*, **528**, 306-309, 2000.
15. Cash, W., Shipley, A., Osterman, S., and Joy, M., Laboratory Detection of X-ray Fringes with a Grazing-Incidence Interferometer , *Nature*, **407**, 160-162, 2000.
16. Cash, W., High Uniformity Collimator for X-ray Proximity Lithography , *Proc. Soc. Photo-Opt. Instr. Eng.* , **4144**, 228-237, 2000
17. Cash, W., White, N., and Joy, M., The Maxim Pathfinder Mission: X-ray Imaging at 100 Micro-Arcseconds , ASP Proceedings, in press, 2001

18. Cash, W., X-ray Interferometry , IAU Symposium 205, Galaxies and Their Constituents at the Highest Angular Resolutions, Schilizzi et al editors, ASP Press, 457-462, 2001
19. Cash, W., A Twisted Look at the X-ray Sky , *Nature*, **411**, 644-647, 2001.
20. Cash, W., Shipley, A., and McEntaffer, R. L., X-ray interferometry: ultra-high-resolution astronomy , *Proc. Soc. Photo-Opt. Instr. Eng.*, **4506**, 127-135, 2001.
21. Shipley, A., and Cash, W., Alignment of a Grazing Incidence X-ray Interferometer , *Proc. Soc. Photo-Opt. Instr. Eng.*, **4444**, 17-28, 2001.