The GoldHelox Solar X-Ray Telescope Testing Progress Report

J. Barnes[a], P. W. A. Roming[b], J. W. Moody[a], R. S. Turley[a], P. F. Eastman[a], T. Lloyd[a], D. Eldredge[a], A. L. Raines[a], C. Reily[c], J. Kegley[c], J. Keidel[c], J. McCracken[c], K. Whitley[c], E. Wright[c], M. Baker[c], J. Carpenter[c], G. Chavers[c], H. Haight[c], B. Hale[c], T. Hill[c], D. Javins[c], J. Norwood[c], R. Siler[c], J. Tucker[c], D. Watson[c], and R. Takahashi[a]

[a]Brigham Young University Dept. of Physics and Astronomy, Provo, UT, USA
[b]Penn State University Dept. of Astronomy and Astrophysics, 555 Davey Lab, University Park, PA, USA
[c]X-Ray Calibration Facility, Marshall Space Flight Center, Huntsville, AL, USA

ABSTRACT

The GoldHelox Solar X-Ray Telescope underwent several tests during the years of 1997-1999, and continues through the testing phase of the project. The instrument itself, a solar telescope to ride on board the Space Shuttle, is designed to photograph the sun in soft x-ray wavelengths between 171Å to 181Å. Critical to its success, many tests are required to insure safety, robustness, and overall accuracy of the telescope during its mission. Among these are shake table tests, optical tests, vacuum integrity, and thermal analysis. This paper describes the GoldHelox project including its current status as a mission, the tests performed on the instrument to date, and the tests pending.

Keywords: GoldHelox, X-ray Telescope, MSFC, XRCF

1. INTRODUCTION

Early in 1989 four Brigham Young University students set out with an ambitious goal to photograph the sun in the soft X-Ray wavelengths. Originally designed to be carried aloft by balloon, their proposed plan included a telescope to image the sun and all of the optics necessary to isolate a single wavelength range. After a successful balloon flight test the plan expanded undergoing several revisions, including a delivery mode change from a high altitude balloon to the space shuttle. Three prototypes were built, the final being what is now known as the GoldHelox project, Gold representing the color of the sun, and Helox, meaning the sun (helios) in X-ray light. The telescope is designed to image the sun onto standard 35mm film in the wavelength range of approximately 171Å to 181Å. To do so the telescope will ride in a NASA Get-Away-Special (GAS) canister on board the space shuttle under the NASA Hitchhiker program.

The intention of the GoldHelox research team is to image the sun in rapid sequence and obtain new solar data to help answer the following questions:

- What phenomena cause the initial energy release in a solar flare?
- What is the initial structure of solar flares?
- What relationship exists between coronal mass ejections, microflares and high resolution upper transition region magnetic structures?
- What effect does the impulse phase of solar flares have on the transition region between the chromosphere and the corona?

Further author information: (Send correspondence to J. Barnes)
J. Barnes: E-mail: jbarnes@wigner.byu.edu
P. W. A. Roming: roming@astro.ps.edu
J. W. Moody: jmoody@byu.edu
R. S. Turley: turley@physics.byu.edu
P. F. Eastman: eastmanp@byu.edu
C. Reily: cary.reily@msfc.nasa.gov
J. Kegley: jeff.kegley@msfc.nasa.gov

In *X-Ray Optics, Instruments, and Missions III*, Joachim E. Trümper, Bernd Aschenbach, Editors, Proceedings of SPIE Vol. 4012 (2000) • 0277-786X/00/$15.00

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

With the exception of a handful of minor parts to be optimized and machined, all of the mechanical structure of GoldHelox is complete. The mirrors have been manufactured and coated and the non-flight electronics have been built and tested. Progress continues on the flight version and the final version of the control software. Eleven years after its conception, GoldHelox is nearly ready to fly.

With the payload package design nearly finished, the project has moved on to the performance testing phase. The instrument has already undergone a stress analysis test, a system component test of the electronics, optics, and vacuum integrity, and a system integration test at Marshall Space Flight Center (MSFC) in which the telescope successfully imaged a point source while under vacuum. These tests have affirmed that the overall design of the telescope can accomplish its purpose.

In the course of the tests, several weaknesses as well as strengths have been discovered. The mirror alignment procedure must be improved to assure the designed resolution of 2.5 arcsec is realized. Currently, the best resolution obtained is on the order of 25 arcsec. The electronics packaged within GoldHelox performed most of its tasks flawlessly, exceeding many expectations, but there are some potential problems with voltage leakage which have led to modifications in the high voltage shielding throughout the telescope.

Ongoing activities include film exposure calibration, thermal analysis, and safety certification. After these final tests are completed, and the paperwork has been certified by NASA, the GoldHelox telescope will be prepared for flight.

2. THE GOLDHELOX PROJECT OVERVIEW

2.1. Organization

GoldHelox is an undergraduate college student project under the control of senior and graduate students. The work force is divided into mechanical, electrical, optical, public relations, technical writing, and systems integration teams. Students from several different majors combine in their various specialties in each of the teams bringing a cross-discipline approach to the mission. Because of this multi-disciplined organization, GoldHelox has proven to be a practical source of learning for all of the students involved, preparing them for the real life situations they will encounter after graduation.

A unique aspect of the project is that it is completely managed by students. Although faculty advisors are in place, they only aid students, both undergraduate and graduate, in handling the progress of the mission and in acquiring funding. Since the beginning in 1989 approximately 300 students have participated in the project, many of these presenting their work in professional venues. Most of these students donate their time without pay, receiving publishing opportunities and research credit instead.

A severe challenge is that when the students graduate, they inevitably leave a void in knowledge and skills creating the need for recruiting and retraining newer members. We have learned the necessity for good documentation that is well written and referred to often.

A major advantage of the format of GoldHelox is the cost. The direct instrument costs are nearing $250,000, which is a fraction of the cost of other X-ray telescopes. It must, however, be noted that indirect costs, particularly the testing support from Marshall Space Flight Center, exceeds this amount. Our low cost is only possible through the gracious support that professionals particularly at NASA and other interested organizations such as Utah State University and Weber State University have given and continue to give to the project.

2.2. Optical System

The GoldHelox telescope is a modified Ritchey-Chretien style with a 3.5 inch diameter primary mirror and a 0.88 inch diameter secondary mirror.[1] These mirrors are multilayer coated alternating Molybdenum and Silicon twenty times in thicknesses of 40Å and 65Å respectively. They are specifically designed for normal and near normal incidence reflection at 171Å to 181Å. This combination enhances reflection in the desired wavelengths and rejects reflection at others. The reflectivity in this wavelength window is approximately 0.35.[2] A one micron aluminum filter rests in the pathway of the sunlight just before the detector to reject optical, ultraviolet light, and x-ray side bands. The transmission of this filter between 171Å and 181Å is approximately 0.40.

The detector is a standard micro channel plate assembly (MCP) operating in the usual manner with 300V sustained on the MCP and 1800V placed on the phosphor coated fiberoptic screen. The MCP has a pore diameter of

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

10μm and a pore center to center distance of 12μm situated at a 12 deg bias angle. To expose the film, the potential on the back of the MCP and the phosphor screen are both raised by 700V. The film is Kodak Technical Pan black and white 35mm film.

The field of view of the telescope is 40 arcmin, with a spatial resolution predicted to be 2.5 arcsec. The sun fills approximately half of the area of this field. The telescope holds upwards of fifty or more feet of film allowing for several exposures to be taken relatively close in time so that fast temporal changes in the sun dynamics can be studied. The flight matrix has not yet been finalized, and as details emerge from further tests, and as mission constraints are finalized, the experimental procedure will solidify. One current plan is for sequences of five short exposures each substantially less than a second to be taken one second apart, followed by a twenty-five second wait. This pattern would then be repeated for 10 minutes during each of four orbits.[3]

2.3. Mechanical System

The foundation of the telescope is an aluminum sealed container. This container will maintain one atmosphere of pressure and houses the electronic components required for the mission. The telescope itself is attached to the top of the sealed container and is free to rotate in azimuth and altitude to center the sun in the frame. It capable of moving 35 deg from normal, however, it will only be required to move less than a degree while in flight. Motion in both axes is accomplished by stepper motors. A sun sensor is mounted on the side of the telescope tube for solar acquisition and tracking. A sealed film container is attached to the back of the telescope tube. This also contains the hardware necessary for advancing the film. The film container maintains atmospheric pressure during the flight. See 1).

A circular polished aluminum plate is located at the top end of the telescope tube to reflect the sunlight that does not enter the aperture. This is to help maintain thermal stability and also to be a safety containment shield, keeping small parts inside the canister should any break free during launch. The telescope tube is fabricated from a magnamite graphite prepeg tabe reinforced with graphite fibers laid 41 deg from vertical making thermal expansion along the telescope tube equal to zero.[1] This protects the image quality by keeping the focus fixed while the temperature varies throughout the experiment.

2.4. Electrical System

The electronics on board GoldHelox consist of a processor, memory, a low voltage power converter, and a high voltage converter. Each of these items reside in the sealed container. The power for the telescope is provided by the space shuttle electrical system. Although a link to the ground may be established during the flight, the telescope itself will be able to work on its own, with the possible exception of the initial power up which will be done by command from the astronauts or ground.

The processor controls all of the main functions of the telescope including power up, sun tracking, MCP exposure, and film advance. The software for these functions is loaded into processor memory. A power up sequence is provided to condition and prepare the MCP for use. In this phase, the MCP voltages are each stepped up to operating voltages in small increments over the course of 100 minutes. The voltages are held for an additional 10 minutes at which time the camera is ready for exposure. Before each set of exposures is taken a light sensor on the telescope is used by the processor to determine a rough alignment in the direction of the sun. After this, a fine-tuning sensor is used to center the solar image on the film. When the MCP is conditioned and the sun is centered, the processor directs the high voltage power converter to change the voltages on the back of the MCP and at the phosphor screen. The higher voltages are relaxed again after the exposure is finished. The film then advances and another exposure is ready to begin. The final part of the electrical system is approximately a half dozen temperature sensors placed on the telescope and inside the sealed container. The telescope can be powered down and stowed Safety routines are triggered in the event that these sensors indicate a problem.

3. TESTS

Four major areas of testing either have been implemented, or are being implemented on GoldHelox: vibration analysis, full systems test, exposure and other ongoing tests such as film calibration, and thermal analysis. A description of each of these follows.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

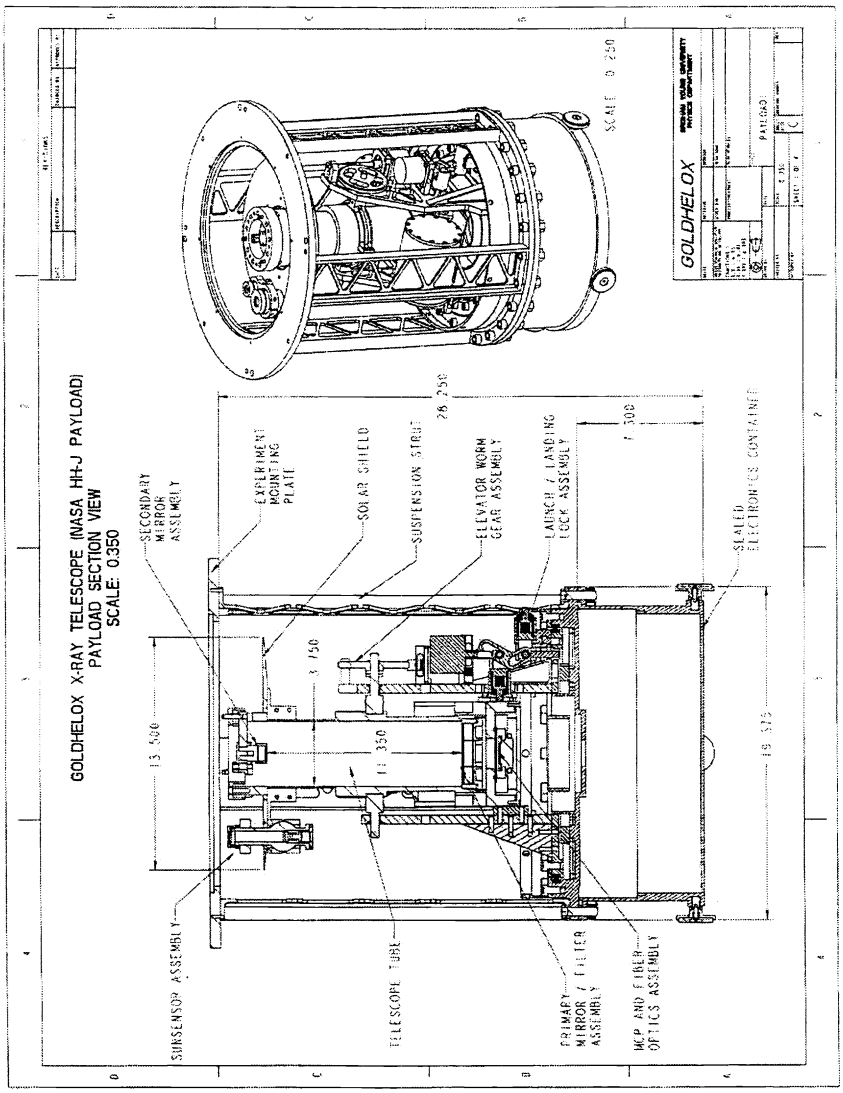


Figure 1. A schematic for the GoldHelox telescope.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

3.1. Tests Early in the Project

Before completion of the mechanical structure, several tests were performed. These aided in the design of the optical system of the telescope, and also gave an indication of the detection capabilities. One such test exposed the MCP to an off-band x-ray source to give a rough value of the voltages required to image x-rays.[4] This gave early indications of the exposure times necessary. With this as a guide, the procedure has been inverted to find the MCP voltages necessary to match a predetermined exposure time. Other tests were done to optimize the filter and the computer configuration and software.[5]

3.2. Vibration Analysis

The payload is required by NASA to remain intact at vibrational forces up to 15g. The lowest natural frequency allowed by NASA is 50Hz. The GoldHelox mechanical team tested the assembled payload on a shake table at Weber State University in Ogden, Utah in the fall of 1997. The first test was largely successful with only two small parts fracturing. After redesigning and replacing these parts, the payload passed NASA specifications. In a subsequent test the first mode was discovered to be between 75Hz and 100Hz. On this test, however, the full range of frequencies was not able to be tested, therefore a retest is currently planned.

3.3. Full System Test

A full systems test began July 16, 1998 in the X-Ray Calibration Facility (XRCF) at MSFC and lasted five weeks. XRCF houses a large vacuum chamber originally designed and built for testing the AXAF space x-ray observatory, now known as Chandra. The facility includes a 75 foot long large chamber roughly the size of the space shuttle cargo bay, connected to another 1700 feet of tubing at the end of which is an x-ray source building. This entire chamber is capable of obtaining vacuum ranges of 10^{-7} torr.

Prior to arrival at MSFC, two XRCF engineers inspected the GoldHelox telescope at Brigham Young University to determine the tools that would be necessary during the testing. Plans were also made for a bakeout of the instrument parts in preparation for entering the vacuum environment. These plans were carried out at MSFC three weeks prior to the test by three GoldHelox team members and the XRCF staff.

One week before testing the telescope the optics were aligned by focusing and centering the image onto the MCP plane (See fig. 2). To do this GoldHelox was placed on a cart level with the XRCF source tube. A flat mirror was placed in the still open vacuum chamber approximately 400 feet away. A HeNe laser was situated behind the telescope shining onto the mirror and reflecting onto the telescope face. A divergent or spreading lens in the beam followed by a collimating lens created a final beam of parallel light which was the width of the primary mirror. A video camera detector was set at the MCP plane broadcasting the image on a small television. The focus of the telescope was adjusted until the smallest image possible appeared in the center of the screen.

Difficulties emerged from this alignment procedure. First was the fact that the mirror, the telescope, and the laser were not optically isolated from vibrations. Also, the heat of the Huntsville summer as it warmed the exposed XRCF tube from the outside was apparent in the beam and continually shifted the focus spot on the camera. Another issue was that the optics used to expand and collimate the laser beam were not the quality that should be used in the flight alignment. A final difficulty arose from the inability to exactly pinpoint the MCP plane by measurement. All of these problems have since been addressed, and an alignment procedure developed that includes improved optics, optical isolation, and elimination of the problem of finding the MCP plane. The solution is to replace the MCP with a mechanical replica that has a reflective surface and use additional optics and reflections to determine the best focus. This new alignment procedure is current being tested.

On July 11, just a few days before the test began the main processor failed requiring a delicate replacement in the early hours of the morning. MSFC opened up one of its electronics stations in a nearby building and a new processor chip was soldered into place. July 14, with the electrical team leader's departure scheduled for 7am the following morning, the payload was transferred into the vacuum chamber. After a lunch break the final wires were connected to the GoldHelox computer link, and the MCP was wired into place. One minor short was corrected, and the film was installed into the canister. At 5am, July 15, the GoldHelox team members left the vacuum chamber and pump down finally began (See fig. 3).

Evacuation took two days during which the computer link to GoldHelox was tested and a separate link between the test computer and Brigham Young University was established. The GoldHelox electrical team leader was then

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

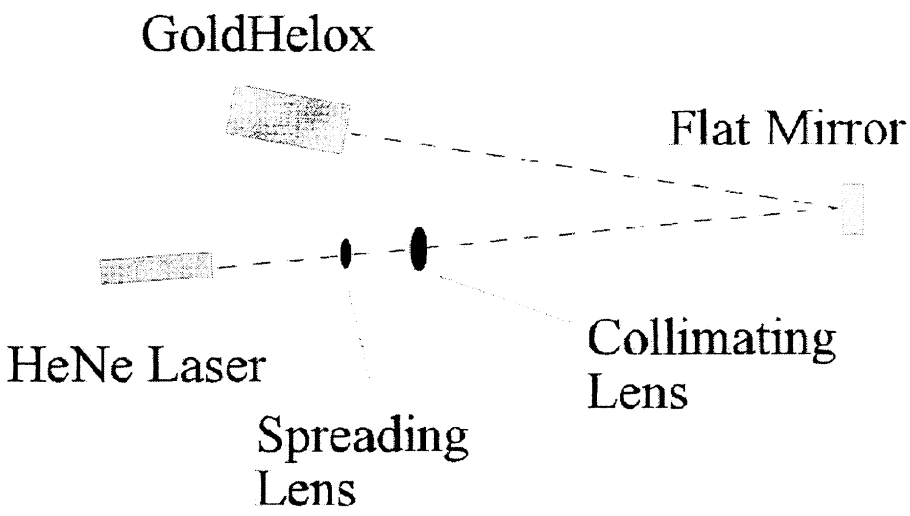


Figure 2. A summary of the telescope alignment setup.

able to monitor the progress of the test from Provo. A Penning cathode source with an aluminum anode was used to create the x-ray beam and a 0.1μm aluminum filter was installed at the source end to act in the place of a filter on GoldHelox.

The test procedure was to expose the film to the x-ray light at different exposure times of 1, 5, 10, 20, 30, 40, 50, and 60 minutes at each of three different angular positions of the telescope; 0 deg, 6 arcmin, and 12 arcmin from normal with the x-ray beam. This allowed the GoldHelox research team to get a feel for the effects of different exposure times, as well as ensuring that at least one of these sets landed on the MCP plane in the desired position.

The film was developed at maximum contrast levels fearing that the low level flux from the XRCF source and other uncertainties in the alignment would lead to low detections. The results were impressive. The x-ray source was clearly detected, and varied in intensity with exposure time as expected (See Fig. 4). This verified the general accuracy of the optical design, multilayered mirror coatings, telescope sensitivity in the detection window, and collimation. Although the spot size was a factor of ten greater than the optimal value of 2.5 arcsec, this was a minor issue in light of the overall success of the test and was not unexpected given the previously mentioned alignment difficulties. For all concerned, it was a great moment

There were several electronic failures that were surmounted or ignored that damaged portions of the computer during the tests. These failures gave us valuable information on how to better shield the computer from the high voltage power converter. Fortunately these problems did not compromise the testing. We have redesigned the mission to include a ground link in the event that a similar problem arises during flight.

Another important issue is identifying the cause and prevention of so called hot spots on the MCP. At least two hot spots are present on all of the exposures from the test. While this could have been a manufacturer defect, we presume that better care and handling of the MCP will reduce the risk of this happening again in the future.

3.4. Ongoing Tests

Currently underway are similar tests familiarizing the GoldHelox optical team with the use of the MCP and the film development procedure. Questions still remain about the efficiency of the telescope, the optimal film exposure times and development procedure, as well as a reduction in the likelihood of extraneous spots on the images. The experimental profile will be finalized upon the completion of these tests.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

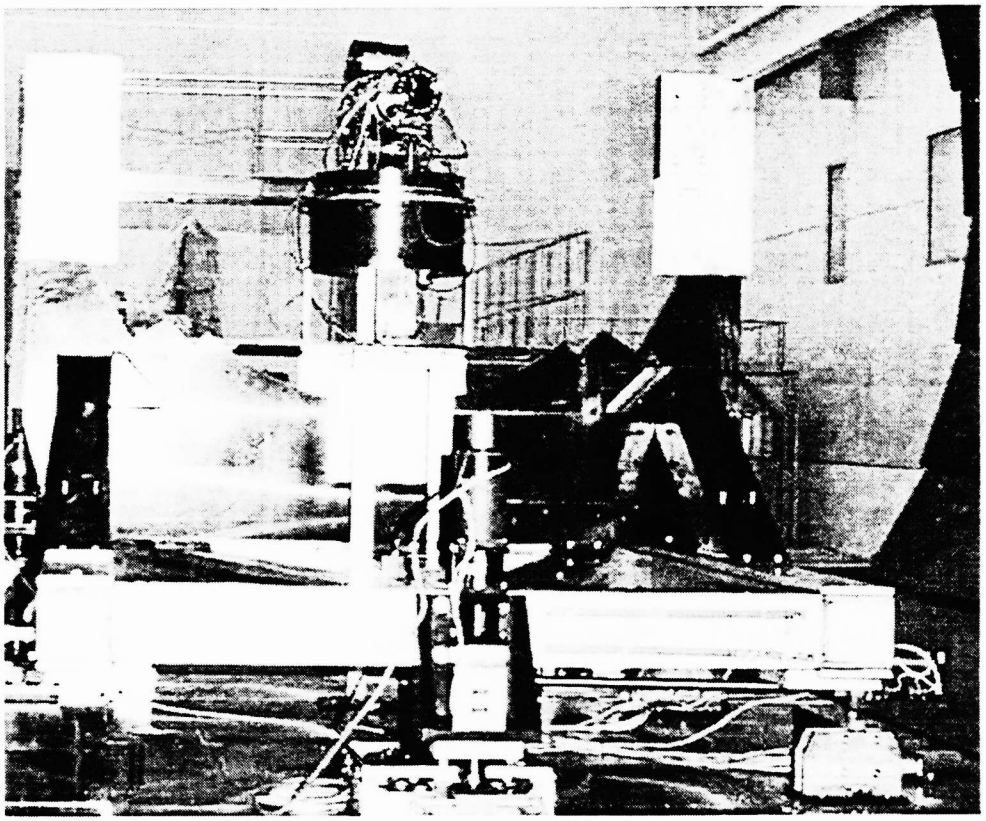


Figure 3. The telescope on the test bed in the XRCF vacuum chamber just prior to pump down.

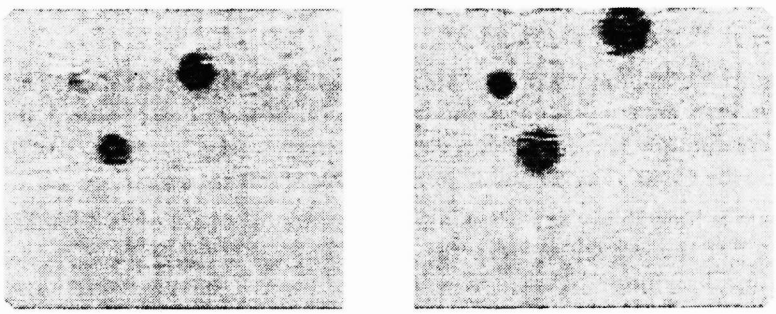


Figure 4. Two exposures from the test at XRCF taken at different angles with respect to the source. The spot on the top right corner is the source beam.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms

Thermal analysis for mission integrity and safety has begun. A class at Brigham Young University, under the direction of Dr. Jerry Bowman is performing the analysis which will be completed by mid April. The results of this test will be reported at a future date.

4. CONCLUSION

The GoldHelox Solar X-ray telescope testing is nearly completed. The remaining tests are currently underway. GoldHelox is tentatively slated to fly with the IEH-4 package in approximately a year to take advantage of the solar maximum. With a major purpose of educating Brigham Young University students, the project has already been and will continue to be a success. The entire payload has been designed from the beginning to be completely reusable even at other wavelengths and so may experience more than this one flight. This illustrates the ability of students, who when left to their imagination and with encouragement from supportive faculty and others, do real science in the early years of their career. Working as a model in conjunction with other institutions doing the same type of work the GoldHelox concept can be established as an invaluable method for reducing costs, expanding students abilities and opportunities, and doing research.

ACKNOWLEDGMENTS

We are thankful for the efforts of Utah State University, Weber State University and NASA for all of the support we have received from them. Specifically, we thank the MSFC Photo Lab and Wiring Shop for providing their services. We are particularly grateful for a generous financial gift from Dr. John Gunter. Last of all, we are grateful for the students who have been part of the project.

REFERENCES

1. D. S. Durfee, J. W. Moody, K. D. Brady, C. Brown, B. Cambell, M. K. Durfee, D. Early, E. Hansen, D. W. Madsen, D. B. Morey, P. W. A. Roming, M. B. Savage, P. F. Eastman, and V. Jensen, "Goldhelox: A soft x-ray solar telescope," *Journal of X-Ray Science and Technology* **4**, pp. 1–9, 1994.
2. T. W. B. Jr., S. Mrowka, and M. C. Hettrick, "Molybdenum-silicon multilayer mirrors for the extreme ultraviolet," *Appl. Opt.* **24**, pp. 883–886, 1985.
3. M. K. Spute, M. L. Hintz, P. W. A. Roming, T. Lloyd, R. S. Turley, J. W. Moody, A. Raines, T. J. U. Jr., P. F. Eastman, and V. Jensen, "Nasa g-133 'goldhelox': A project update," *Journal of X-Ray Science and Technology* **7**, pp. 215–223, 1997.
4. M. L. Hintz, D. S. Olsen, and J. W. Moody, "Imaging soft x-rays using a microchannel plate," 1996.
5. M. Williams, E. Hansen, A. Reyes-Mena, and D. D. Allred, "The transmittances of thin polymer films and their suitability as a supportive substrate for a soft x-ray solar filter," in *EUV, X-Ray and Gamma-Ray Instrumentation for Astronomy II*, *SPIE* **1549**, pp. 147–154, 1991.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 03/27/2014 Terms of Use: http://spiedl.org/terms