The Marshall 100-Meter X-ray Beamline

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ABSTRACT

The Marshall 100-Meter X-ray Beamline is a user facility for x-ray and EUV optics and instrumentation calibration, located at NASA's Marshall Space Flight Center in Huntsville, Alabama. Also known as the Stray Light Test Facility, the Marshall-100 provides a range of focal plane detectors, x-ray sources, translation stages, cleanrooms, and high-vacuum level capability to the high-energy astrophysics community. Facility time is made available to Astronomy and Physics Research and Analysis (APRA) funded projects and is also available to the broader community upon request made to beamline management. The beamline has successfully been employed in the calibration of larger scope projects such as the Spectrum-Roentgen-Gamma Astronomical Röentgen Telescope X-ray Concentrator (ART-XC) telescope and the Small Explorer (SMEX) class Imaging X-ray Polarimetry Explorer (IXPE) Space Telescope. Additionally, the Marshall-100 is instrumental in supporting testing related to MSFC's high-angular resolution optics development program.

Keywords: X-ray Beamline, Stray Light Test Facility, X-ray Calibration

1. INTRODUCTION

The Marshall 100-Meter X-ray Beamline, also known as the Stray Light Test Facility, is an x-ray and EUV test facility for the evaluation of instruments ranging from student led research and development projects to Small Explorer (SMEX) space telescope missions. Located at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, the Marshall-100 is a horizontal-pipe class beamline facility. Its 100-meter-long beamline, large beam diameter and Instrument Chamber, high vacuum level capability, coupled with its complement of vacuum rated translation stages, x-ray sources, and detectors make it ideal for the characterization of grazing incident optical systems. Additionally, the facility's flexibility allows for the testing of collimators, grating spectrometers, detectors, and other hardware employed on both astrophysics and heliophysics x-ray observatories. The Marshall-100 is available to Astronomy and Physics Research and Analysis (APRA) funded projects with additional access available upon request to beamline management (listed in this manuscript). Its operation is supported thought NASA's Internal Scientist Funding Model (ISFM) and, along with providing support to the wider community, it plays a critical role in the testing of MSFC's own high-angular resolution, replicated nickel shell optics development program.[1]

To deliver the highly collimated, low angular divergent x-rays required for telescope calibration, horizontal beamlines like the Marshall-100 operate by positioning an x-ray source at one end of a large diameter vacuum tube and instrumentation at the other. Beamlines are generally on the order of 100 m long and, as the distance between the source to the instrument is increased, the incident rays on the optic become more parallel and the angular size of the source is decreased. Since a Wolter optical system behaves like a thin lens, a longer source-optic distance will better approximate the flight performance of the telescope. The world's foremost x-ray beamline is the X-ray and Cryogenic Facility (XRCF).[2] Also located at MSFC, the XRCF has a 540 m long

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baseline and was instrumental in the calibration of the Chandra X-ray Observatory[3] as well as the Einstein Observatory (High Energy Astronomy Observatory-2).[4] The XRCF was upgraded in the early 2000s and is now NASA's flagship cryogenic optical test platform, being used to qualify the James Webb Space Telescope temperature dependent performance[5] and is currently being prepared to calibrate ESA's Advanced Telescope for High-ENergy Astrophysics (Athena).[6,7] While the capabilities of the XRCF are unparalleled, its sibling facility, the Marshall-100, is a flexible calibration facility that can provide support to a wide range of test missions. This manuscript lists past programs that have employed the Marshall-100 and extensively details its capabilities as an x-ray test facility.

2. PROJECTS AND MISSIONS

Figure 1. The Marshall 100-Meter X-ray Beamline, located at Marshall Space Flight Center adjacent to Building 4487 and has a total line length of 101 m. Also known as The Stray Light Test Facility, this installation was constructed in 1963 and is used extensively both for MSFC internal optics development and the broader scientific community as made available through APRA.

Constructed in 1963, the Marshall-100 was originally designed to test stray light suppression systems for orbital optical telescopes, including the preliminary designs for the suppression system employed on the Large Space Telescope, now known as the Hubble Space Telescope.[8] The facility remains useful and available for optical light testing if requested. While not initially designed for x-ray calibration, the facility's long beamline, low operational pressure, and large Instrument Chamber makes it ideal for x-ray testing for which it is now primarily deployed. In the past it has been used in the development of sub-orbital x-ray telescope missions such as the science balloon mission High Energy Replicated Optics/ to Explore the Sun (HERO/HEROS))[9,10] and previous iterations of the sounding rocket mission Focusing Optics X-ray Solar Imager (FOXSI).[11] The Marshall-100 has also been used for pre-flight calibration of space-based missions such as the Astronomical Röentgen Telescope X-ray Concentrator (ART-XC) (13) mission. Additionally, the Marshall-100 was vital in the development and testing of the NASA Small Explorer-class mission, the Imaging X-ray Polarimetry Explorer Space Telescope (IXPE).[12] Launched December 9, 2021, IXPE (Principal Investigators: Weisskopf, Ramsey, O'Dell, Kaaret of MSFC) is a polarization sensitive x-ray telescope that required both polarized and unpolarized x-rays in its 2 to 8 keV bandpass for calibration.[13,14] As of the writing of this conference paper, the IXPE collaboration currently has 29 published science papers with additional papers currently under review and in preparation. An extensive list is given at the following website.*

More recently the facility has hosted the calibration efforts of several smaller scale missions and research projects. Miniature X-ray Optics (MiXO) is an on-going project managed by the Center for Astrophysics- Harvard & Smithsonian (SAO) to develop metal/ceramic hybrid lightweight Wolter-I optics (Principal Investigator:

*https://ixpe.msfc.nasa.gov/

Romaine of SAO). Developed through the Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) program, MiXO's goal is to develop low cost, SmallSat deployable, high-resolution optics for planetary science missions to study elemental abundance of airless planetary bodies.[15] In the spring of 2022, the Lunar Environment Heliospheric X-ray Imager (LEXI) team traveled to the Marshall-100 to do a full instrument calibration. With a forthcoming launch in 2024, LEXI (Principal Investigator: Wash of Boston University) is a wide field-of- view soft x-ray telescope utilizing slumped micropore (Lobster-eye) optics. Managed from Boston University, its scientific goal is to image emission from solar wind charge exchange in the Earth's Magnetosphere from the Moon's surface.[16] The SmallSat Solar Activity X-ray Imager (SSAXI) (Principal Investigator: Moore of SAO) was also calibrated at the Marshall-100 throughout the year of 2022 with a full telescope calibration taking place in the spring of 2023. SSAXI will launch from Poker Flat, Alaska as a sounding rocket mission in the spring of 2024.[17] Following up on the three successful previous missions FOXSI-4(principal investigator: Glesener of the University of Minnesota) was extensively calibrated at the Marshall-100 during 2022 and 2023.[18] FOXSI-4 will also launch from Poker Flat in the spring of 2024, during solar maximum, imaging solar radiation in the hard and soft x-ray to study energy release and particle acceleration in the corona. Additionally, the FOXSI-4 optics were designed and manufactured at MSFC.[19]

3. THE MARSHALL-100 FACILITY

The Marshall-100 is housed within MSFC Building 4487 on the Redstone Arsenal. The total actual length of the beamline is 101 m long, with the x-ray source room on the east side and the Instrument Chamber terminating on the west end of the facility. The vacuum tube that connects the source room to the Instrument Chamber is 93 m long and 1.3 m in diameter, widening to 1.5 m at the source end. A gate valve seals the source end of the beamline, allowing for the x-ray source to be changed while the beamline is maintained at a low vacuum level. The Instrument Chamber can accommodate large test articles, as it is 8 m long and 3 m in diameter. A 3 m wide dome door caps the Instrument Chamber allowing for the entire line to be pumped down. The dome door is attached to and removed from the beamline via a crane lifting operation.

The Instrument Chamber is housed within a class 10,000 cleanroom. The cleanroom is a staging area where test articles and holding fixtures are prepared for installation into the beamline. A 3-ton, overhead gantry crane is used for lifting heavier test articles into and out of the Instrument Chamber and its use is available upon request. The cleanroom is accessible through an access-restricted gowning antechamber and all personnel are required to wear provided 'bunny suit' coveralls while working in the class 10,000 cleanroom. NASA/MSFC cleanroom standards are maintained in the room to ensure high quality industrial hygiene, low particulate levels, and reduce foreign objects and debris. When pressurized to atmosphere and the dome door is removed, the entire beamline and Instrument Chamber is accessible to cleanroom gowned personnel and experimenters. Also, while vented, the beamline is kept at a positive pressure by pumping dry air into the beamline to prevent contamination and water condensation in the line.

Adjacent to the class 10,000 cleanroom is the computer room, which houses the computers used to control and record data from the facility's x-ray tubes, stages, detectors, and housekeeping monitors. Additional workspace for both MSFC personnel and visiting experimenters is available in the computer room. The room itself, while accessible in street clothing, is a 100-K cleanroom. The computer room is located next to a loading dock, which allows larger test articles to be driven to the beamline. A double door, under positive pressure, opens into the class 10,000 cleanroom, giving ingress and egress for test articles. Hermetically sealed, electronic feedthrough flanges are attached to the beamline both in the class 10,000 cleanroom and in the computer room, allowing for cabling of test articles and detectors under vacuum when required.

To facilitate x-ray transmission, the Marshall-100 is required to achieve a high vacuum of 10^{-5} Torr or better. After the test articles have been positioned in the beamline and the Instrument Chamber dome door has been sealed, the evacuation of the beamline is completed in stages. Three Strokes Vacuum rotary piston roughing pumps, each with connected blowers and liquid nitrogen cooled getters, are in an enclosed room near the center of the line. Working in unison the roughing pumps can evacuate the entire line to 10^{-3} Torr in approximately 1.5 hours before being sealed off from the line with gate valves. Two 'Torr Master 250' cryopumps from CVi Inc., operated in closed-cycle with compressed helium, are mounted to the line in the source room. Once the beamline is at 10^{-3} Torr, these cryopumps are used to take the facility down to the high-vacuum regime. Operating in

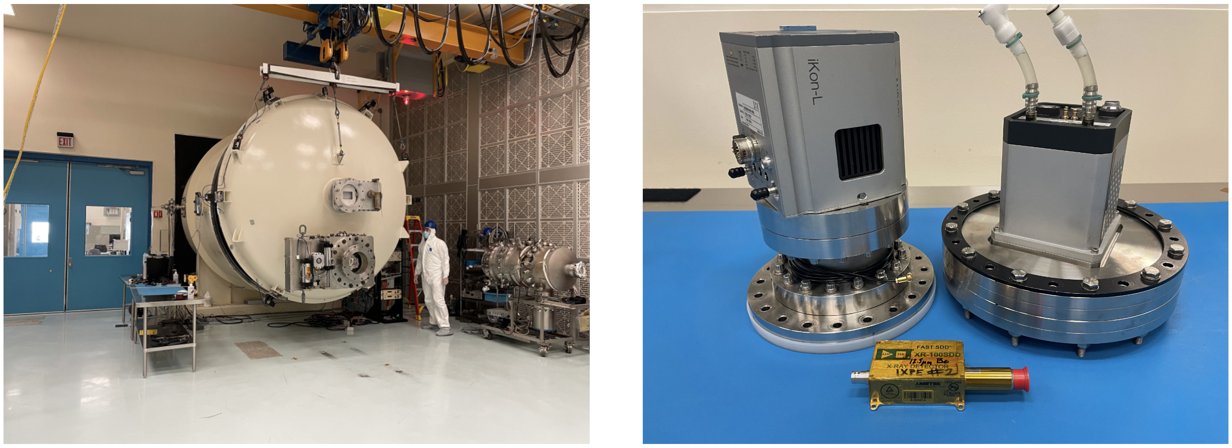

Figure 2. Left: The Marshall-100 class 10,000 cleanroom. Located within the cleanroom, the Instrument Chamber is 3 m in diameter and has a length of 8 m. Right: Available Bellhousing detectors (Section 5.1) include the Andor iKon-L CCD camera (2048-by-2048-pixel array with 13.5 μm pitch) and the Andor Marana-X sCMOS camera (2048-by-2048-pixel array with 6.5 μm pitch.) Between the cameras is the Amptek Fast-SDD Ultra High-Performance Silicon Drift Detector with 50 mm^2 collecting area.

this mode, the Marshall-100 can go from atmospheric level to 10^{-5} Torr in 4 hours and can achieve 10^{-6} Torr in 6 hours. The hold time at this vacuum level is 1 to 3 weeks depending on loads placed on the system. A third cryopump, the larger CVi 'Torr Master 900,' is mounted on to the top of the Instrument Chamber. Cooled with a closed compressed helium system and a liquid nitrogen shroud, operating this cryopump allows the beamline to be pumped down to 10^{-7} Torr. However, running in this mode will exhaust the 1000-gallon liquid nitrogen tank in approximately 2 days and is not generally used unless ultra-high vacuum levels are needed. Additional pumping support is provided by a 10 inch Varian turbo pump that is attached to the line in the source room. This pump can be used to take the line from rough vacuum to 10^{-5} Torr in several hours. It is not necessary for normal operations of the facility but is used to reduce the gas load on the cryopumps. Beamline pressure is displayed in the computer room, the class 10,000 cleanroom, and the x-ray source room.

4. THE SOURCE ROOM

On the east end of the beamline is the x-ray source room which houses all x-ray sources, controls, and alignment tools. A 15 inch, nomadic gate valve separates the beamline from the source room fixturing, allowing for the venting of source room equipment while maintaining vacuum in the beamline. A 2 m long 'source pipe' connects the beamline's 15 inch gate valve to the x-ray source staging vacuum chamber known as the Crystal Box. The source pipe is pumped down to high vacuum with its own dedicated Drivac vacuum pump and adds a small extension to the total length of the beamline. An Optical Blocking Filter (OBF) is mounted within a manual gate valve on the source pipe, directly in front for the Crystal Box. The OBF, manufactured by Luxel, is made of 537.2 nm thin polyimide film with 52 nm of aluminum deposited on it, allowing for the transmission of x-rays while remaining opaque to optical and UV light. The thin-film filter can only withstand 1 Torr of pressure differential and is only used when the source can generate optical light contamination. The source pipe also contains the Marshall-100 laser alignment system. The system consists of a retractable mirror that can be inserted and removed from the beam path. Orthogonal to the mirror is a vacuum viewport. A 660 nm red laser is pointed through the viewport and, when on, will reflect off the mirror and produce a diverging beam that propagates down the length of the beamline. When incident upon an x-ray optic, this beam allows for the test optic to be coarsely aligned and focused while being installed into the beamline, ensuring proper positioning prior to pump down.

Connected to the end of the source pipe is the Crystal Box. All x-ray sources used at the Marshall-100 are staged from this vacuum chamber. It is designed to accommodate the easy exchange of x-ray tubes, the alignment of the tubes once installed to eliminate scatter off the beam-pipe walls, and the positioning of filters into the beam path of the rays. Additionally, polarized x-rays can be produced via Bragg diffraction, making the Crystal Box essential to IXPE calibration effort.

Table 1. X-ray sources currently available for use at the Marshall-100.

Tube Brand	Anode	Line (keV)	Max Voltage (kV)	Max Current (mA)
TruFocus 6050	Mo	2.3 l, 17.5 k_a	50	1
Be window	Rh	2.7 l, 20.2 k_a	50	2
	Ti	4.5 k_a	50	2
	Fe	6.4 k_a	50	1
	Cu	0.9 l, 8.1 k_a	50	1
TFX3110EW	W	8.4 l, 59.3 k_a	110	2.5
TruFocus-10-2-AL	Al	1.5 k_a	8.5	0.5
Manson Source	*variable*	*variable*	10	1

The Crystal Box is a cylindrical vacuum chamber with a diameter of 16 inches and a height of 15 inches. Its scroll pump and turbo pump allow for the quick evacuation of the chamber with pressure being read out by a cold cathode gauge. Pressure and temperature housekeeping are all read out by a LabVIEW routine on the source room computer. Additionally, x-ray source settings are read out and controlled through this LabVIEW routine which can be operated remotely via the computer room at the detector end of the beamline. X-ray tubes are mounted to the Crystal Box and must be interchanged manually. For unpolarized source operations, tubes are mounted in-line to the beam-pipe. All 'low-flux' tubes currently available at the Marshall-100 are listed in Table 1 with their characteristics. The most used tubes are the TruFocus 6050 series. The TruFocus 6050s are all beryllium window sealed sources and are used when the testing requirement bandpass is between 2 to 50 keV, or with characteristic line emission ranging from 2.3 to 17.5 keV. When high energy x-rays are required, the beryllium window sealed TFX3110EW, with a tungsten anode, can achieve Bremsstrahlung emission up to 110 keV with a maximum characteristic line emission of 59 keV. Lower energy x-ray line emission is provided by the Trufocus-10-2-AL, with an aluminum anode giving 1.49 keV K_a line emission. The Marshall-100 also has a facility Manson low energy x-ray source. The Manson source has a variety of interchangeable anodes and can be used to achieve line emission less than 1 keV. Both the Trufocus-10-2-AL and the Manson source are windowless and are exposed to ambient pressures. These windowless tubes require high vacuum states ($\sim 10^{-5}$ Torr) to prevent damage. Also, when in operation these tubes will produce large amounts of UV and optical light requiring the use of the OBF to prevent light contamination. Regardless of the source being used, the physical x-ray emitting spot size of each tube is estimated to be on the order of ~ 100 μm or smaller, providing a sub arc-second source at 100 m.

Near monochromatic x-ray sources are often required during the calibration of a test article. This is accommodated with the insertion of a thin foil metallic filter in front of the source. A thin foil filter made of the same element, or of an element one atomic number less than the tube anode is used to isolate the characteristic x-ray line emission from the Bremsstrahlung continuum. Manufactured by the Lebow Company,[†] the Crystal Box filter stage can hold up to 6 filters and is mounted directly in front of the low flux x-ray tubes. Alignment of the x-ray tubes is achieved with a manual X-Y micrometer flange positioner to ensure the x-ray beam is co-aligned with the beampipe, preventing scatter of the pipe's internal walls.

The Crystal Box also acts as a polarized x-ray source for the Marshall-100.[20] This is achieved through Bragg diffraction off a crystal internal to the chamber with x-rays from an unpolarized source that are incident onto the crystal. While a large percentage of the rays are absorbed by the crystal, the x-rays that are linearly polarized perpendicular to the crystal surface plane and that have a wavelength that satisfies the Bragg condition for the crystalline lattice spacing will reflect. The result is a monochromatic polarized beam that is reflected 90 degrees from the incident beam. The Crystal Box currently has three crystals mounted on a Zaber transition-rotation

[†]https://lebowcompany.com

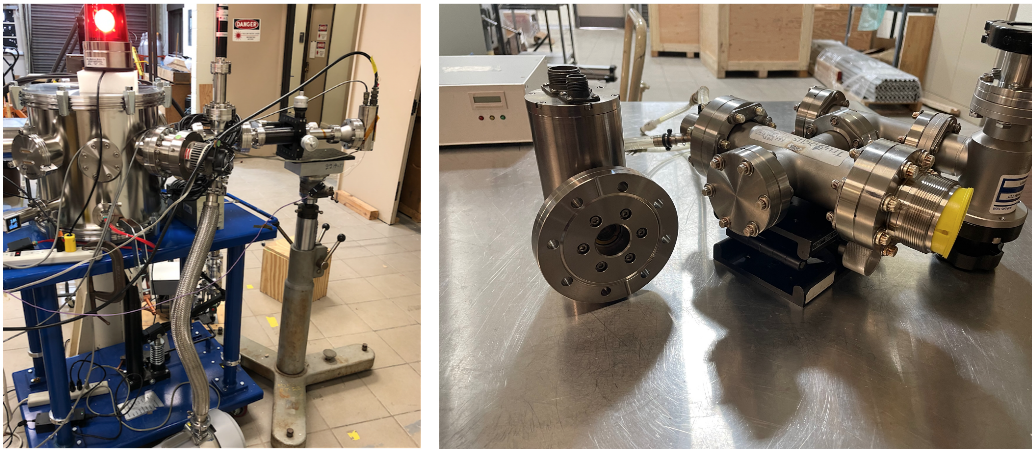

Figure 3. Left: The Crystal Box mounted unpolarized x-ray source. Right: TrueFocus 6050 and the Trufocus 30kV/30mA x-ray tubes.

stage which positions the crystals into and out of the beam. All crystals and corresponding x-ray tubes are listed in Table 2. Bragg diffraction is inherently inefficient, requiring that high flux x-ray tubes be used and the Trufocus 30kV/30mA tubes were acquired to ensure sufficient flux rates.

Table 2. Crystal Box polarized X-ray source characteristics.

Trufocus 30kV/30mA Anode	Line (keV)	Max Voltage (kV)	Max Current (mA)	Crystal
Rh	2.7	30	30	Ge(111)
Ti	4.5	30	30	Si(220)
Fe	6.4	30	30	aSi(400)

5. THE INSTRUMENT CHAMBER

The Instrument Chamber houses both motion stages and facility detectors, all of which are controlled directly through the computer room. 6-axis motion of the test article is provided by the PI-USA Hexapod H-850. With a maximum load capacity of 80 kg, the hexapod can linearly translate ± 50 mm on the X and Y axis while translating ± 25 mm in the Z axis, all with sub-micron repeatability. For rotating about the X and Y axes the Hexapod has $\pm 15°$ of motion, the range increasing to $\pm 30°$ when rotating about the Z axis with rotation repeatability being on the order of 2 seconds of arc. Often being used as a translation stage for a Wolter x-ray optics, the Hexapod is positioned in the Instrument Chamber so the optic is fully illuminated by the beam and the detector placed at the projected focus at the end of the beamline. The Hexapod is controlled through a specialized LabVIEW routine that allows for programmable motions that are synchronized with detector measurements, making both finding the focal position and the alignment of the optic uncomplicated.

The Parker X-Y Stage is used for facility detector positioning and is installed at the end of the beamline. Its maximum load capacity is 100 kg and can move 91 cm in the X direction and 76 cm in the Y direction with 0.1 μm resolution. Connected to a water/ethylene glycol external chiller, a detector mounting plate is attached to the Parker Stage that is kept at 10° C. Mounted directly to this plate is the facility's Charge-Coupled Device (CCD) camera and Fast-Silicon Drift Detector (SDD), with additional space for other instrumentation. The facility CCD x-ray camera is the Andor Technology's Andor DW436. This vacuum capable CCD camera's operational temperature is $-45°$ which is achieved using an internal ThermoElectric Cooling chiller that is heat sunk directly to the mounting plate. The camera has its own optical blocking filter and shutter system. The CCD chip itself is a 2048 X 2048 array of 13.5 μm pixels that are read out directly by Andor's provided software. Capable of running in single photon counting mode, the Andor DW436 is generally used to characterize the point spread function of a test optic and has a 5 MHz pixel readout speed.

Mounted directly underneath the CCD camera is the Amptek, Ultra High-Performance, XR-100 Fast-SSD, a single pixel detector with fast count rate and high energy resolution. With a 50 mm^2 collimated collecting area that is sealed with a 12.5 μm beryllium window, this detector has a usable energy bandpass from 1.5 to 20 keV and an energy resolution of 122 eV FWHM at 5.9 keV. More importantly, the response between Amptek Fast-SDD is cross calibrated, and the capable count rate of the detector is 1,000,000 counts per second. An Amptek XR-100 Fast-SDD with a C1 (silicon nitride) window, with a collecting area of 17 mm^2, is also available when measurements bellow 1.5 keV are required. Using the Parker Stage, a mounted Amptek SDD can be positioned at the focus of the test optic. A cross calibrated Amptek Fast-SDD can be mounted directly at the input of the x-ray optic allowing for measurements of the effective area to be determined in real time. This measurement is expedited by the Amptek Fast-SDD's high count rate and low deadtime, allowing for higher input flux illuminated on the optic and reducing test time. When a test article has a high energy bandpass, an Amptek XR-100 CdTe detector, with a collecting area of 25 mm^2, is also available, allowing for effective area measurements up to 100 keV. The Amptek detectors are vacuum compatible and have similar form factors, allowing for the interchange of detectors. More information on the Amptek detectors can be found on the company's website[‡].

Figure 4. SSAXI mounted mirror module on the facility's hexapod. The Parker Stage, with the facility's CCD camera and focal plane SDD, positions detectors in the focal plane. The red laser light is used to facilitate coarse alignment and focusing the test article.

Table 3. Facility translation stages and x-ray detectors.

Vacuum capable translation stages	
PI-USA Hexapod H-850	6-axis linear and rotational stage. Linear range of $\pm$50 mm. Rotational range of $\pm 30^\circ$. 80 kg load capacity.
Parker Linear Stages	X-Y linear stage. Linear range of 90 by 76 cm. 100 kg load capacity.
Facility x-ray cameras and single pixel detectors	
Andor DW436	Vacuum capable CCD camera, 2048 X 2048 array of 13.5 μm pixels with 5 MHz readout speed.
Andor iKon CCD	Externally mounted CCD camera, 2048 X 2048 array of 13.5 μm pixels with 5 MHz readout speed.
Andor Marana X sCMOS	Externally mounted CMOS camera, 2048 X 2048 array of 6.5 μm pixels with 310 MHz readout speed.
Amptek XR-100 Fast-SSD	Single pixel silicon drift detectors with with 50 mm^2(Be window) and 17 mm^2(C1 window) collection areas. Energy bandpass less than 20 keV.
Amptek XR-100 CdTe Detector	Cadmium Telluride Detector with 25 mm^2 collection area. Energy bandpass greater than 20 keV.

‡https://www.amptek.com

5.1 The Bellhousing

Measurements in the Instrument Chamber require the installation, and subsequent removal, of the Instrument Chamber's dome door, a process that requires a crane operation. The Marshall-100 also needs to be completely repressurized to gain access to the Instrument Chamber and then must be re-evacuated to make an additional measurement. While this is relatively fast, this operation can be time prohibitive when characterizing multiple test articles in a day. When quick turnaround is required, the external Bellhousing can be utilized. The Bellhousing connects directly to the Instrument Chamber's dome door via a pneumatic gate valve sealed specialized flange. The internal diameter of the flange is 292 mm and is concentric to the beamline. All test optics that are inserted into the Bellhousing must have a diameter less than this to be fully illuminated. Once attached, the Bellhousing opens near the center, allowing access to the optical mounting platform on the Newport transition/rotational stage. The linear transition stage has 150 mm of motion (0.1 mm resolution) along the optical axis of the beamline, allowing for the focusing of the test article. The rotational stage has two degrees of motion in both the tip and the pan with 1 minute of arc of resolution. The Bellhousing is pumped with the use of an external scroll pump and Drivac turbo pump, with a pump down time from atmosphere to $\sim 10^{-5}$ Torr of 30 minutes.

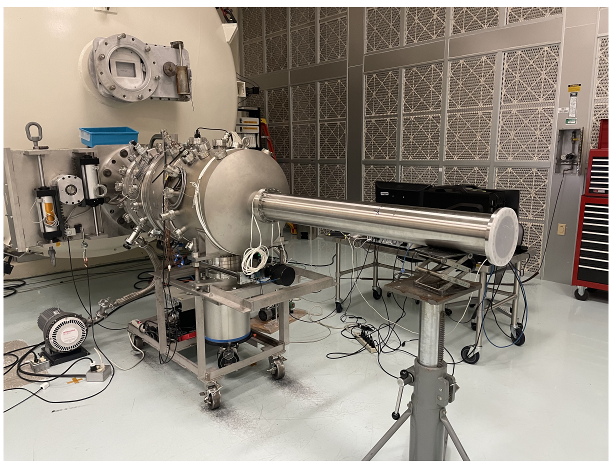

Figure 5. The external bellhousing allows for the quick testing of smaller articles without the repressurization of the beamline.

The output port of the Bellhousing is a 160 conflat flange and is 1422 mm away from the gate valve input. Additional 160 conflat tubing can be added to the output for test optics with longer focal length. The focal length extension tubing length ranges from 100 mm to 1500 mm but can be adjoined to accommodate focal lengths of approximately 4 m. Currently the bellhousing has two x-ray camera options for characterizing the point spread function of an optic. The Andor iKon CCD camera is an external version of the same camera used within the Instrument Chamber on the Parker Stage with an identical detector plane chip (2048-by-2048-pixel array with 13.5 μm pitch, operational temperature is $-45°$ C, and readout speed of 5 MHz). When higher plate scale resolution is required, the new Andor Marana X sCMOS (Scientific Complementary Metal-Oxide Semiconductor) external camera is now also available for use at the Marshall-100. The Andor Marana X sCMOS, with an operational temperature of $-45°$ C, has a detector pitch of 6.5 μm but with the same pixel grid as the Andor iKon CCD, lowering its collecting area to 13.3 mm by 13.3 mm. The Marana-X sCMOS has a very fast readout rate of 310 MHz at its high dynamic range (16-bit) setting. The spectral response of a test article within the Bellhousing can be measured by removing the external camera and replacing it with a 1 mm thick beryllium vacuum window. An external Amptek Fast SDD or CdTe can then be positioned at the focal position of the test optic for effective area measurements for energies greater than ~ 3 keV.

6. SUMMARY

The Marshall 100-Meter X-ray Beamline is affordable, adaptable, and capable of calibrating high-angular resolution optics and optical assemblies. It also possesses unique capabilities not found in other x-ray beamlines, such as polarized x-ray light sources. It is able to support x-ray optic and instrumentation research and development, as well as the end-to-end calibration of x-ray telescopes. More importantly, it is a user-friendly facility with a team that prides themselves in making the beamline's extraordinary capabilities available to the entire community. The Marshall-100 is advertised to all successful APRA funded projects and is supported through NASA's Internal Scientist Funding Model (ISFM). Additional community support to other NASA Centers, Universities, and Industry is also available through contact with the authors.

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