Development of mirror modules for the ART-XC instrument aboard the Spectrum-Roentgen-Gamma mission

M. Gubarev[1], B. Ramsey[1], S.L. O'Dell[1], R. Elsner[1], K. Kilaru[1], J. McCracken[1],
C. Atkins, The Univ. of Alabama in Huntsville

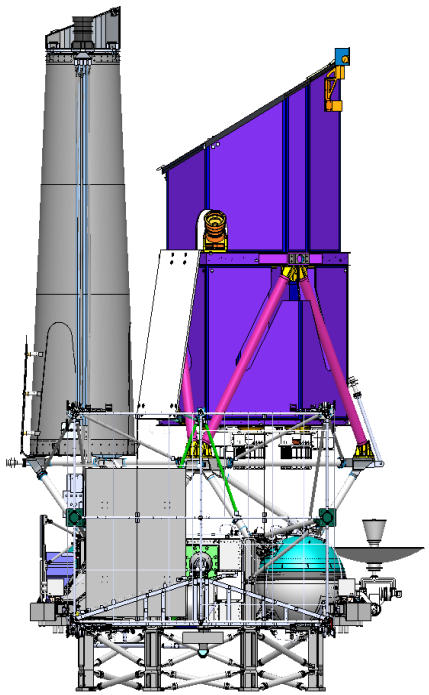
M. Pavlinsky[2], A. Tkachenko[2], I. Lapshov[2]

[1]NASA Marshall Space Flight Ctr., Huntsville, AL 35812, USA
[2]Space Research Institute, Moscow, Russia

ИКИ

SRG overview

ART-XC eROSITA



✓The Spectrum-Röntgen-Gamma (SRG) mission is a Russian-lead X-ray astrophysical observatory that carries two co-aligned X-ray telescope systems.

✓The primary instrument is the German-led **e**xtended **RO**entgen **S**urvey with an **I**maging **T**elescope **A**rray (eROSITA), a 7-module X-ray telescope system that covers the energy range from 0.2-12 keV.

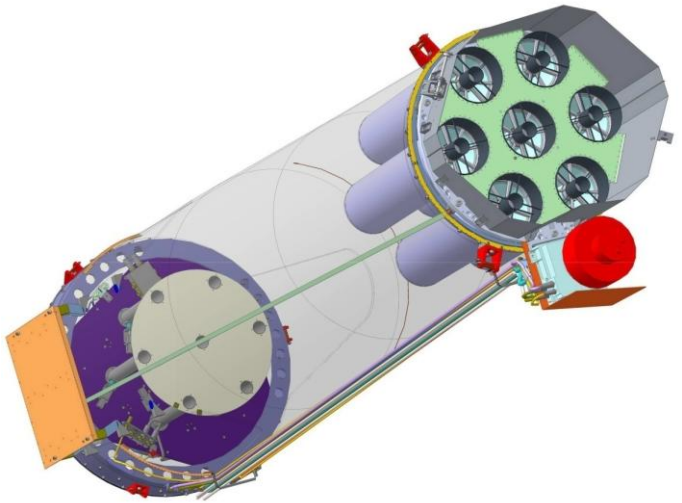
✓The complementary instrument is the **A**stronomical **R**oentgen **T**elescope – **X**-ray **C**oncentrator (ART-XC or ART), a 7-module X-ray telescope system that provides higher energy coverage, up to 30 keV.

Parameter	ART	eROSITA
Energy Range	**5-30 keV**	**0.2-12 keV**
Effective Area	**455 cm^2 at 8 keV**	**2500 cm^2 at 1 keV**
Field of View	**32 arcmin**	**1 deg**
System Angular Resolution (on axis)	**1 arcmin**	**15 arcsec**
Energy Resolution	**1.4 keV at 14 keV**	**130 eV at 6 keV**

ART optics

MSFC has designed and is fabricating
-four ART x-ray optics modules under an International Reimbursable Agreement between NASA and with IKI
-three + one spare ART-XC modules under Agreement regarding Cooperation on the ART-XC Instrument onboard the SRG Mission between NASA and IKI

Parameter	Value
Number of Mirror Modules	7=4+3
Number of Shells per Module	28
Shell Coating	> 10 nm of iridium (> 90% bulk density)
Shell Total Length, inner and outer diameters	580 mm, 50 mm, 150 mm
Encircled Half Energy Width	Less than 1 mm diameter, center of field of view Less than 2.5 mm diameter, 15 arcmin off axis
Mirror Module Effective Area	≥ 65 cm^2 at 8 keV (on axis)
Module Focal Length	2700±1 mm



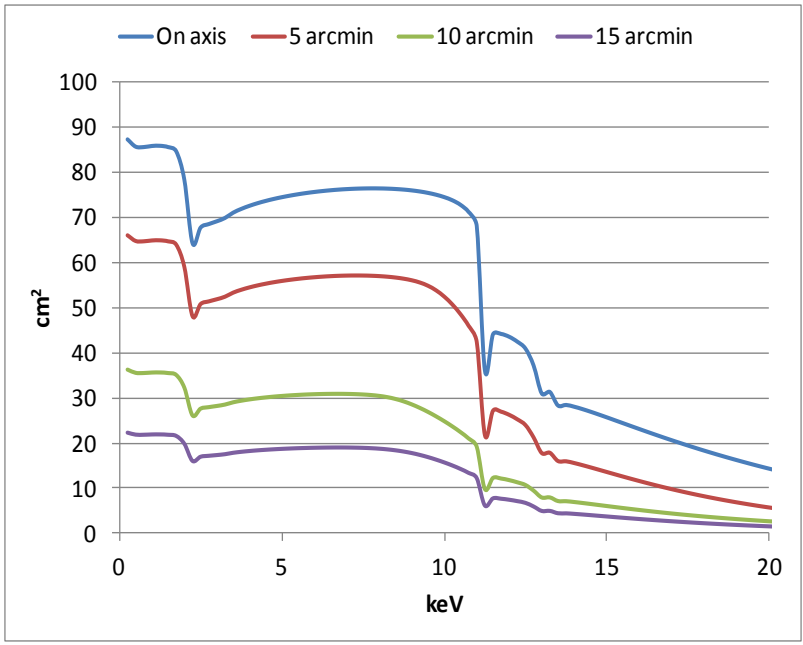
ART optics

MSFC is utilizing electroformed-nickel replication (ENR) to fabricate four ART X-ray mirror modules.

In this process a thin nickel or nickel-alloy mirror shell is electroformed onto a figured and super-polished electroless-nickel-plated aluminum mandrel, from which it is subsequently separated in chilled water by differential thermal contraction.

Wolter I prescription for ART mirrors. The goal angular resolution for the ART mirror module is 30 arcseconds HPD.

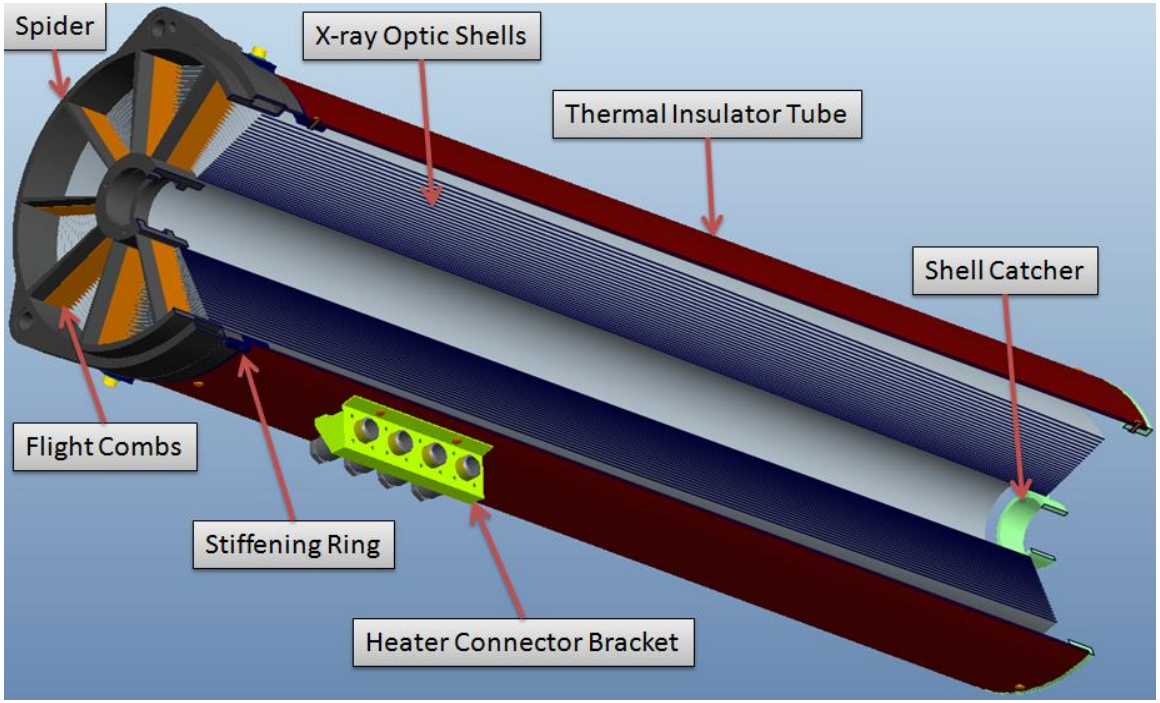
The science-derived effective area requirement for the optics is > 65 cm^2 at 8 keV on axis



Calculated effective area of ART x-ray optics module

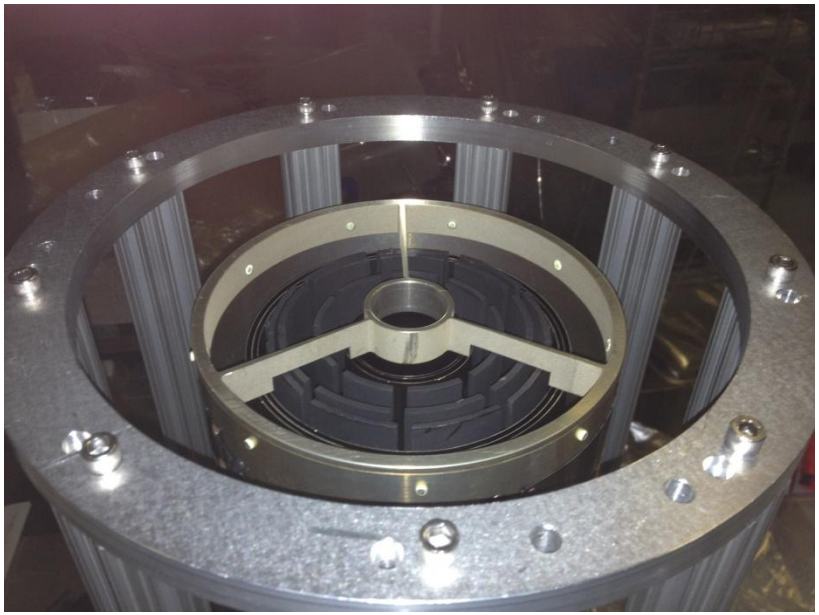
Mechanical design

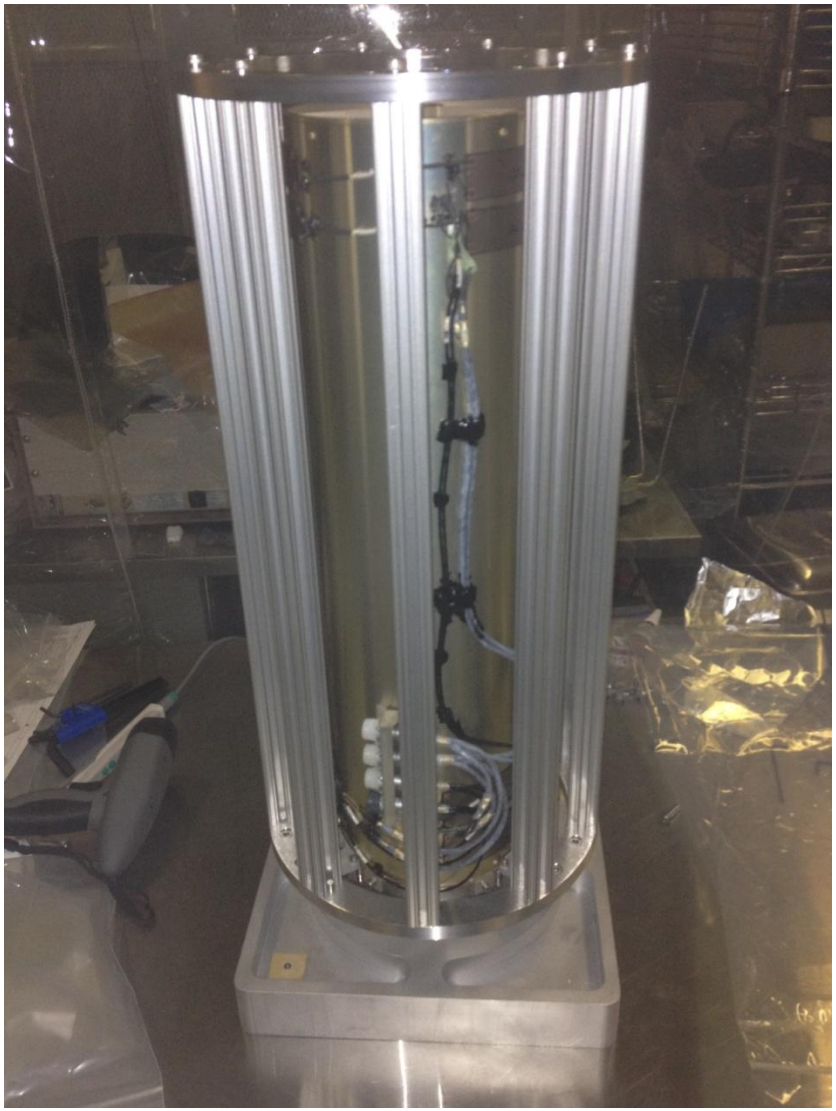
- One spider design allows to increase the thickness of outer shells (250 – 350 micron)
- Estimated weight margin is 1kg
- The mechanical stress estimates are conservative ; the margin is 1.7 (requirement is 1.5.)
- Heaters are provided by the IKI



Qualification Unit

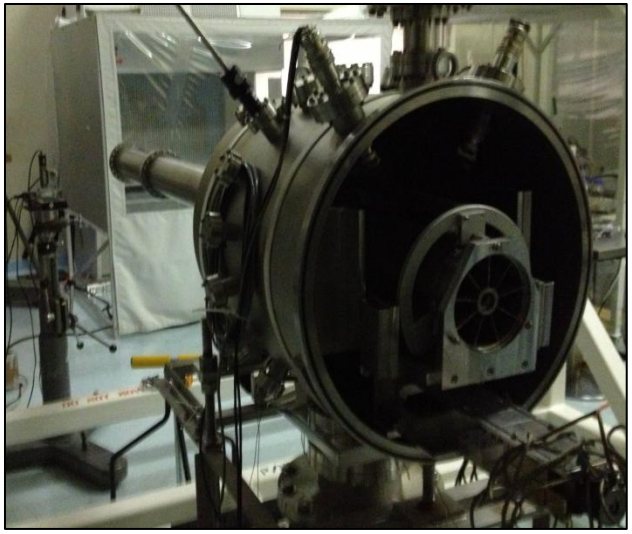
- ✓Three inner shells (1,2,4)
- ✓Three outer shells (25,26,27)
- ✓Three mass simulators to replace missing shells (diameters are 74, 101.3 and 126.4 mm)
- ✓Spider has the same design as for the flight modules





Qualification Unit

The ART-XC qualification module was x-ray tested before, during and after environmental testing. Measurements of on-axis effective area and point spread function were taken before any environmental testing, and then after each of the thermal, acoustic, vibration and shock tests. In addition, after the final test, a more comprehensive set of calibration data were taken.



Test	Effective Area (cm^2)	Error (cm^2)
Initial	13.56	0.35
Post thermal test	13.01	0.47
Post acoustic test	13.81	0.38
Post vibration test	13.49	0.38
Final (post shock)	13.71	0.38

There is no evidence for any change in the the ART-XC qualification unit due to the environmental tests performed.

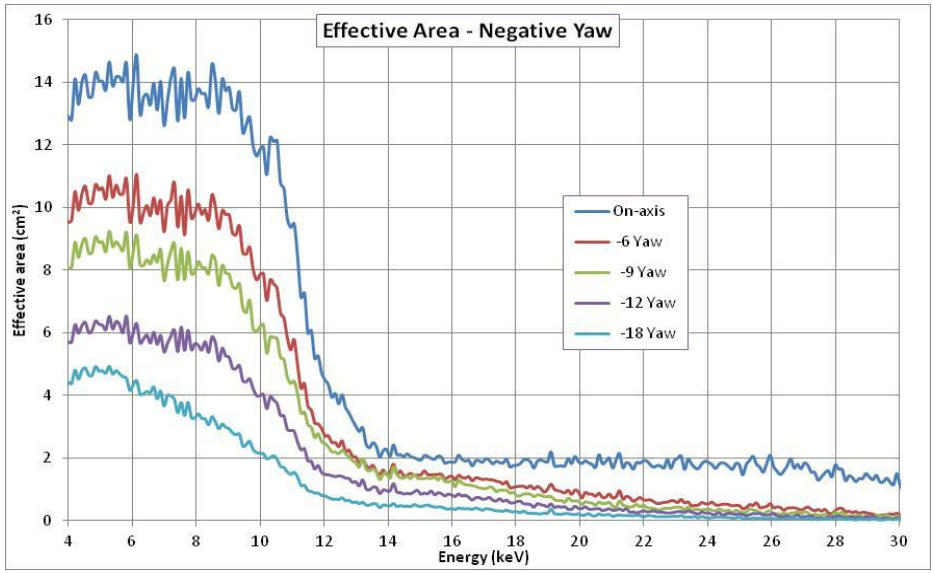
Qualification Unit

Half-Power Diameter (HPD) was calculated at each stage of test and the results varied between 31 and 33 arcsec with no statistically significant change or trend

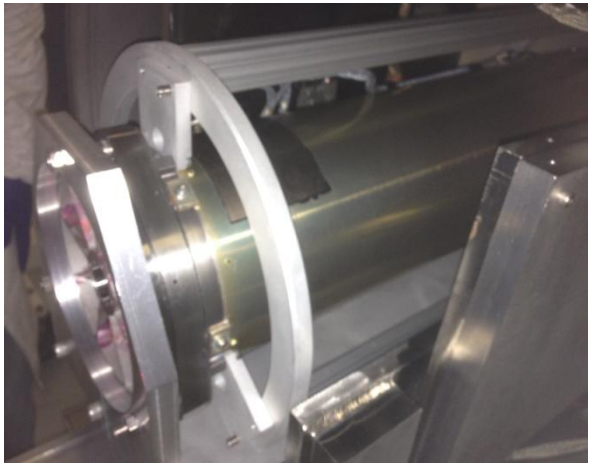
the measured resolution exceeds requirements by a factor of two.

the true (zero-g) resolution is probably nearer 25 arcsec, when gravity effects are subtracted in quadrature.

The measured focal length of the qualification module at the 104m source to optics distance was measured to be 2773 mm (nominal 2772 mm).



Measured effective area of the engineering unit is consistent with the 65 cm2 goal for the flight units.

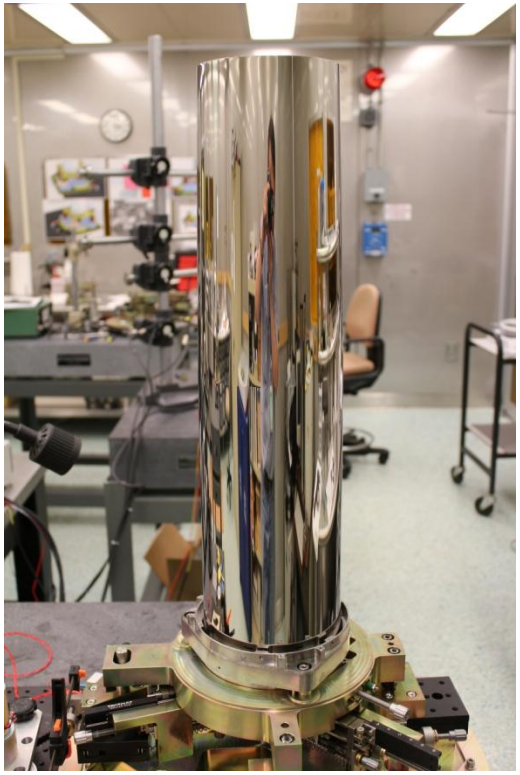


Flight Units Status

	MODULE 1	MODULE 2	MODULE 3	MODULE 4	MODULE 5	MODULE 6	MODULE 7	MODULE 8
1	M1 S03	M1 S05	M1 S06	M1 S07	M1 S12	M1 S13	M1 S14	M1 S1
2	M2 S01	M2 S06	M2 S08	M2 S14	M2 S16	M2 S17	M2 S10	M2 S18
3	M3 S07	M3 S08	M3 S09	M3 S10	M3 S06	M3 S05	M3 S11	M3 S04
4	M4 S04	M4 S07	M4 S09	M4 S10	M4 S15	M4 S03	M4 S16	M4 S14
5	M5 S03	M5 S06	M5 S07	M5 S09	M5 S12	M5 S10	M5 S04	M5 S11
6	M6 S04	M6 S05	M6 S07	M6 S10	M6 S08	M6 S09	M6 S11	
7	M7 S03	M7 S04	M7 S05	M7 S06	M7 S10	M7 S11	M7 S09	M7 S07
8	M8 S01	M8 S03	M8 S04	M8 S05	M8 S07	M8 S06	M8 S02	M8 S08
9	M9 S02	M9 S01	M9 S05	M9 S08	M9 S03	M9 S06	M9 S09	M9 S07
10	M10 S03	M10 S04	M10 S01	M10 S06	M10 S05	M10 S07	M10 S09	M10 S10
11	M11 S01	M11 S02	M11 S04	M11 S06	M11 S10	M11 S09	M11 S11	M11 S08
12	M12 S03	M12 S01	M12 S04	M12 S05	M12 S07	M12 S08	M12 S10	M12 S06
13	M13 S01	M13 S03	M13 S05	M13 S04	M13 S09	M13 S10	M13 S12	M13 S06
14	M14 S02	M14 S03	M14 S07	M14 S06	M14 S08	M14 S04	M14 S10	M14 S11
15	M15 S02	M15 S03	M15 S04	M15 S05				
16	M16 S01	M16 S02	M16 S06	M16 S11				
17	M17 S02	M17 S01	M17 S06	M17 S11				
18	M18 S02	M18 S03	M18 S04	M18 S01				
19	M19 S05	M19 S04	M19 S06	M19 S03				M19 S01
20	M20 S02	M20 S05	M20 S04	M20 S01	M20 S03	M20 S09	M20 S10	
21	M21 S03	M21 S01	M21 S04	M21 S06				
22	M22 S05	M22 S03	M22 S04	M22 S01				
23	M23 S01	M23 S03	M23 S02	M23 S05	M23 S07	M23 S06		
24	M24 S03	M24 S04	M24 S05	M24 S02				
25	M25 S03	M25 S09	M25 S07	M25 S08				
26	M26 S08	M26 S07	M26 S06					
27	M27 S06	M27 S08	M27 S09	M27 S13				
28	M28 S02	M28 S04	M28 S01					

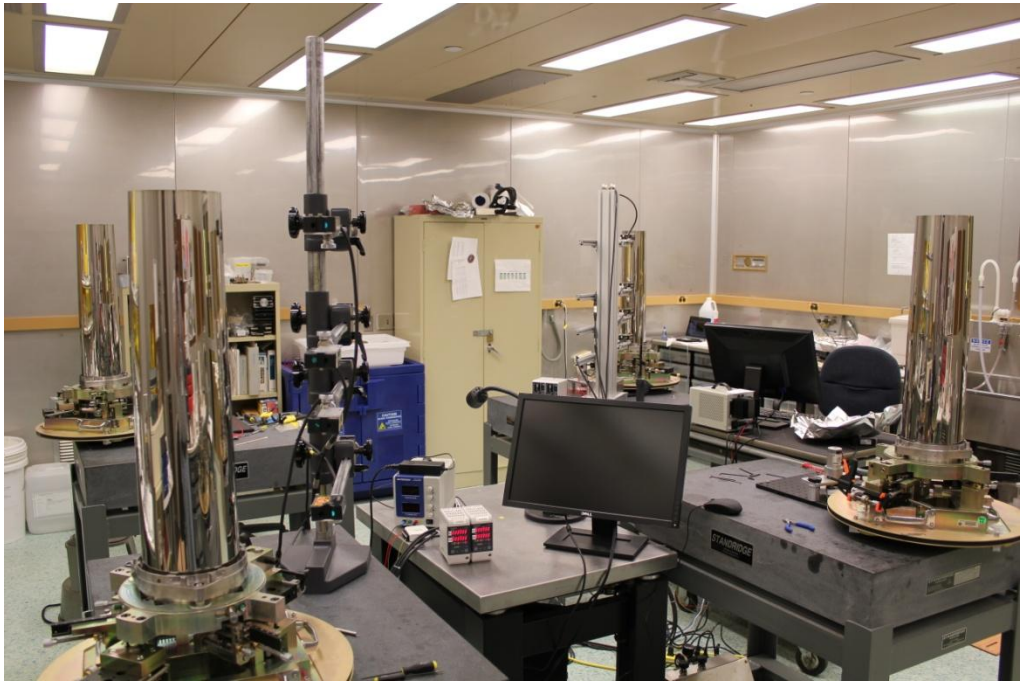
accepted

integrated



Future

- Calibrations will be start in in September
- First four modules will be delivered to Moscow in November
- Three modules will be delivered to Moscow in January



Conclusions

- MSFC is developing eight x-ray mirror modules for the ART-XC instrument on board the SRG Mission.
- The Engineering Unit tests are successful
- MSFC is on schedule to deliver flight units in the November of 2013 and January 2014.