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CANADIAN PARTNERSHIP IN JWST (AND ASTROSAT)

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ABSTRACT

The James Webb Space Telescope (JWST) is planned to be the most-powerful-ever facility-type space telescope, to be launched in 2014 with minimum lifetime of 5 years, and 10 year goal. The major partner is NASA, with the others being ESA and CSA. JWST will operate 3 instruments in the wavelength range ∼0.8 to 5 microns, and one in the range 5-27 microns. The telescope will be diffraction-limited upwards from 2 microns, with primary mirror diameter approximately 6.5m, collecting area about 8 times that of HST, and comparable spatial resolution. It will offer low to moderate spectral resolution and filter imaging sensitivity unmatchable from the ground, and open up major discovery space in the 5-27 micron range, where it is many orders of magnitude more sensitive than possible from the ground. JWST will be complementary to ground-based 30m class telescopes. Canada has guaranteed access to 5% of JWST observing time, plus GTO time on 3 of the instruments. Canada is providing the redundant fine guidance cameras, and one science instrument for JWST. This paper describes details of Canada's partnership in JWST.

I also note and describe Canada's participation in the ISRO Astrosat orbiting observatory, which will provide guaranteed access to co-aligned telescope observations through a range of X-ray energies to UV-optical, and operate in the same timeframe as JWST.

The paper concludes with a few notes on future space observatory facilities that are very desirable as part of the next decadal plan.

1. OVERVIEW

Initially conceived as the next generation telescope to follow HST, in the mid-1990s, JWST has evolved as summarised in the abstract (see figure 1). The entire telescope will operate at cryogenic (∼40K) temperatures, orbiting the L2 point where it is shielded and passively cooled from the Sun, Earth, and Moon with a large 5-layer sunshade. Table 1 summarizes the 4 science instruments and their capabilities. NASA has an extensive web page on the project, with links to the ESA and CSA pages. The NIR instruments are designed to be limited in sensitivity only by the zodiacal light background, and the mid-infrared instrument (MIRI) is cooled further to 7 K by an on-board cryo-cooler, to achieve similar sensitivity. There are coronagraph capabilites on the 3 imaging instruments, and the spectrograph has a programmable multi-slit capability as well as fixed slits and an IFU.

The JWST instruments are designed to enable detailed investigations in four science theme topics: a) first light and re-ionization; b) assembly of galaxies; c) star-formation; d) planets and the origin of life. These themes are common to science drivers for 30m ground-based telescopes, and while they provide a performance benchmark, it is understood and expected that JWST will enable a very broad base of investigations, and that by the time of operations, there will be new and different topics to be pursued. The infrared capability of JWST will certainly make major progress in observing first light objects in the universe, and in star and planet formation. With its unprecedented sensitivity, JWST will also certainly make major unanticipated discoveries, and provide deep surveys that require follow-up work with ground-based and other concurrent facilities. Access to JWST for new investigations will be a key to maintaining a place in the forefront of astronomy for the decade of its operation. (Gardner et al 2006) gives a thorough discussion of the JWST design and science capabilities. (Thronson et al 2009) is a conference proceedings that describes how JWST science investigations also require other concurrent facilities.

Figure 2 shows a comparison of JWST with 30m ground-telescope capabilities. While details may be arguable, depending on the level and field size of AO on the ground, but the main point is to show the two facilities are very complementary, and being a partner in both will put Canadian astronomers in an excellent (and essential) position to do leading research during the next decade.

This paper will not dwell in further detail on the science capabilities of JWST, which are broad and well-documented. Instead, I will focus on the Canadian aspect of the partnership, how it is working, and how it will be part of the next decade of Canadian astronomy.

2. PARTNERSHIP HISTORY AND LESSONS LEARNED

Canadian participation in JWST was a major goal of the last LRP, and as such, was kept as a high priority to accomplish. The Canadian participation was initiated by Simon Lilly, who established Canada as a potential partner via an extended series of discussions among the three agencies who now are the JWST partners. Simon and I were on the early science working groups where the eventual suite of instruments and partner roles were decided. There have since been several adjustments of scope and hardware details, but the plan for CSA to provide the redundant guider cameras and the tunable filter imager were agreed early on, and have been held to. Figure 3 shows the special CSA logo for the project, and figure 4 shows the engineering model of the whole

CSA instrument with associated test optics for thermal vacuum testing.

JWST required a number of new technologies to be developed for its operation (beryllium mirrors, low noise large array IR detectors, mirror support systems, microshutter arrays, low temperature parts and mechanisms throughout, etc). On the Canadian side, we had to develop the capability for a space-qualified tunable etalon system working over a factor 3 in infrared wavelengths at cryogenic temperatures. The inevitable delays, problems, and changing accounting rules have raised the formal JWST cost by a factor of several - of the CSA hardware and software as well as NASA's, and the project is now the largest item in both NASA and CSA's space science budgets. Nevertheless, the high priority of the project has kept it from being scrapped or descoped by all concerned. The science requirements indeed require the full capability as designed, and are sufficiently compelling to maintain. These are all essential elements of how the facility development has remained on track through budget problems and delays. It is widely expected that JWST will be a vehicle for major astronomy discoveries for its lifetime, and well beyond. Within Canada, there have been budget and contract issues that have been troublesome, and the project now is overseen by a Senior Project Advisory Committee (SPAC) drawn from various government and academic departments, which was triggered when the cost exceeded $100m. In addition to the CSA contractors, both HIA and Universite de Montreal have provided significant technical work towards the design and testing of the instrument components, and performance modelling.

There are a number of lessons that may be learned regarding participation in such large projects, from the JWST experience. To refer to a few, first, the makeup of the CSA contract management team is very important: this group needs to interface with the contractors, foreign agency and contractor managers, science and operations team participation, as well as CSA internal budget and protocol issues. It took years, and some significant interface problems to get all that working, including a very visible and unfortunate stop-work episode due to CSA prime-contractor issues. Second, in working with high-tech hardware from the US, ITAR is a major issue, and all concerned need to spend significant effort making sure the rules (not always sensible ones in our context) are followed. Third, the detailed effort involved over years should not be underestimated - my own participation in JWST regularly involves some 8 telecons per week, and physical meetings of various groups 1-2 times per month, all extended over many years. At this point - still 5 years from launch - we still have significant worries, but those are normal in this type of project. We have not learned all the lessons yet, but I do commend the commitment and dedication on the part of CSA to maintain and complete this very large and high-profile project. I feel that the connection between astronomy and CSA as a result is in very good health, but needs to be nurtured for the future of JWST and all future such efforts, whether large international, or Canadian-led. Overall, we have good working relations and mutual respect between CSA, NASA, and ESA, but for future collaborations, any major partner will want to be sure that the considerable extra trouble and overhead of an international partnership is worth what is being brought to the mission.

3. OPERATIONS PHASE AND THE FUTURE

Looking ahead to the operations phase, currently scheduled to begin a few months after a mid-2014 launch, we (CSA) intend to keep Canadian operations scientists at STScI for the duration of the mission, directly supporting our instrument and those who would use it. Currently there are four such scientists in place, under contract through HIA, with CSA funds. One aspect of operations where both NASA and CSA have not planned ahead sufficiently is the work of preparing for full support of the instruments. This involves interfaces for proposal preparation, exposure tools, visibility tools, dither patterns development, calibration files for filters and wavelength settings, and after observation, data pipeline processing to remove instrumental signatures, and delivery of useful and reliable data products. We are currently struggling to get all this ready to support cycle 1 observations, even although it is five years ahead. There are added complications when several instrument modes are possible: in the case of the TFI this includes various coronagraph observations, use of the non-redundant mask, and simultaneous observations with NIRCAM, as originally intended.

The telescope operations will follow very closely the processes in place for HST, and we expect to have Canadians on the review panels. There will be no archive outside of NASA, as modern data distribution processes do not need any, but CADC are discussing ways to work with NASA and STScI to enhance data products and distribution. I note also that the Canadian 5% is a guaranteed minimum - with competitive proposals and collaborations, we can exceed that. It's a model that we used and that worked well with our 5% partnership in FUSE.

One matter that underscores the difference between NASA and CSA cultures is the role of the science team. In the NASA system, the selected instrument team (essentially the PI) has the full responsibility to run industrial contracts and deliver the instrument. CSA however, award and run the hardware contract themselves, and the (formally purely advisory) role of the science team has taken years to establish within this paradigm. There is still a lack of detailed information on contract details, test plans, and schedules, while the essential role of making science-based trades and changes in 'requirements' as instruments, electronics, detectors, optics, etc evolve, has been hard to establish. Another arena of potential issues is the calibration and test of hardware by science and operations people - the hardware contract has not dealt with this well in the case of JWST, and the CSA instruments pass directly to NASA on completion. On the other hand, the Astrosat-UVIT hardware (see details below) was handed over completely to the science team after fabrication, for 8 weeks of calibration and characterization before delivery, and this has worked very well. CSA is currently undergoing re-organization, in which the present managerial separation between hardware fabrication and science operations will disappear, and should allow better integration of science team participation.

On the science team front, there has been some very useful and collegial cross-fertilization of instrument science team members across the JWST project. We have Canadians on 2 of the other 3 instrument teams, and have some US scientists on the Canadian team. This has much to commend it, and from the Canadian side has allowed our scientists to participate in the instrument development and science planning, including collaborations between teams, as well as access to significant GTO time and investigation planning. In general, being a partner in the project has allowed Canadians to participate actively in all aspects of JWST development and planning (particularly via membership in the international Science Working Group, close interaction with the other science team leaders, and membership on key committees such as the JSTAC), and effectively to 'punch well above our weight'. This aspect of partnership is worth noting, especially as it is sometimes noted that we can always apply for observing time (as long as it is the policy set by the real partners) at no cost to CSA. In spite of the increased CSA costs over the original agreed budget, our share of the full cost of JWST is some 2.5%, while our formal partnership is set at 5%.

It is worth noting the importance of enrolling a science team for such projects. The incentive ultimately is the guaranteed observing time that allows scientists to make first discoveries with the new telescope. For some it is also the ability to influence the instrument design and capability as it is built, and for others the chance to design the calibration and commissioning activities (plus choose the first targets for these). The makeup of the team should include all these skills and motivations, and the committment to devote a significant amount of time in the years just before and after launch. Finally, the team has to work together over many years (the average number in my exeriences is 13!), so may span different stages of a research career.

CSA have supported the (low level) travel needs of the various Canadians on science teams, as well as travel and partial salary recovery for HIA activities in JWST. This is intended to continue as needed through operations phases. CSA also supports the TFI principal investigator, Rene Doyon at Universite de Montreal, and their activities. At this stage there is no plan for CSA to support general participation in JWST science by individual astronomers in Canada, as has also not been the case for other space facility science, including FUSE, in which Canada was also a partner.

A final point on JWST is the enormous public outreach potential, that needs to be developed more extensively in Canada. STScI is already bringing to bear their outreach office that has been so successful with HST. JWST is superlative in so many ways, and promises discoveries that will change our thinking forever. As partner in this enterprise, Canada can, and should, get much more recognition and publicity within the country. Canada is providing the official historian for JWST - Robert Smith from the University of Alberta, who wrote the HST history, attends all major meetings and will publish a book on the whole project once it is launched.

4. UVIT/ASTROSAT AND BEYOND

Another significant facility with CSA partnership is the Indian space agency (ISRO) Astrosat observatory. This observatory is due for launch in early 2011 for a 5-10 year mission, and contains the following instruments: hard X-ray coded-mask telescope, 3 large area proportional counter X-ray detectors, a soft X-ray imaging telescope, an all-sky monitor hard X-ray instrument, and two 40cm telecopes with filters and gratings covering FUV, NUV and optical wavelengths. All but the sky monitor are co-aligned and operate simultaneously, offering unique broad multi-wavelength capability. The UV-optical telescopes have 1"-1.5" resolution over half-degree fields, a factor of ∼4 better than GALEX, the current UV orbiting telescope, which appears close to final failure now. There are no other UV imaging telescopes currently in development. HST has much higher resolution but fields that are more than 100 times smaller. The LAXPC is more sensitive than the RXTE, with larger energy range. Figure 5 shows the full observatory and spacecraft.

CSA is providing the photon-counting detector systems for the UV-optical telescopes. Canada is guaranteed 5% of observing time, plus UVIT team time, and again has been very involved in the overall design and operation of the facility. This unique facility promises to be a valuable resource for Canadian astronomers during the coming decade. As noted above, the science team has negotiated a much stronger role in UVIT than is the case for JWST. On the other hand, dealing with ISRO, who are not used to running international facilities, has been a new challenge. Different lessons have been learned with this collaboration, but again, we have gained mutual respect and trust that can only be good for future partnerships. As one of the increasingly major global economies, with a large space program and funding for astronomy, India is a good community in which to have developed working collaborations.

The two space telescope partnerships I have described have a large range of cost to CSA, but both represent significant new research opportunities, as well as high-tech capability developed by Canadian companies. The partnership between the science community, CSA, and industry is an essential mix for future facilities. The CSA-sponsored Discipline Working Group reports have noted a number of exciting future space projects of high interest to Canadian astronomy, and already CSA is acting on two of them: wide field UV-opt-NIR imaging, and hard X-ray imaging. The LRP should strongly endorse studies and follow-up of these and other future missions. Many of these future facilities will be comparable in cost to our part in JWST, and we need to support CSA in seeking the budget that will enable them.

REFERENCES

Gardner J.P., et al, 2006, Space Science reviews, 123, 485
Thronson H.A., Stiavelli M., Tielens A.G.G.M., 2009, Astrophysics in the next decade, Springer

TABLE 1:JWST instrument capabilities

Instrument	Mode	FOV	Wavelength(μ)	mas/pixel	Resolution	Limit(nJy) [a]
NIRCAM[b]	Shortwave	Two 2.2'	0.6-2.3	32	4,10,100	11
	Longwave	Two 2.2'	2.4-5.0	65	4,10.100	
NIRSPEC	MOS	3'	0.6-5.0	100	100	132
			1.0-5.0		1000	
	Longslit	5 sizes	1.0-5.0		100,1000,3000	
	IFU	3"	0.7-5.0		2700	
TFI[b c]	Full imaging	2.2'	1.5-2.5,3.2-4.9	65	100	126
Guider	Full imaging	Two 2.3'	0.8-5.0	69	1	6
MIRI[b]	Imager	1.9'x1.4'	5-27	110	4-6	$\geq$700
	Slit spectrum	5"x0.6"	5-11	110	100	
	IFU	$\sim$5"	4 over 5-27	200-470	3000	

[a] For S/N=10 in 10,000 sec
[b] Also coronagraph mode for smaller FOVs
[c] Also non-redundant mask imaging

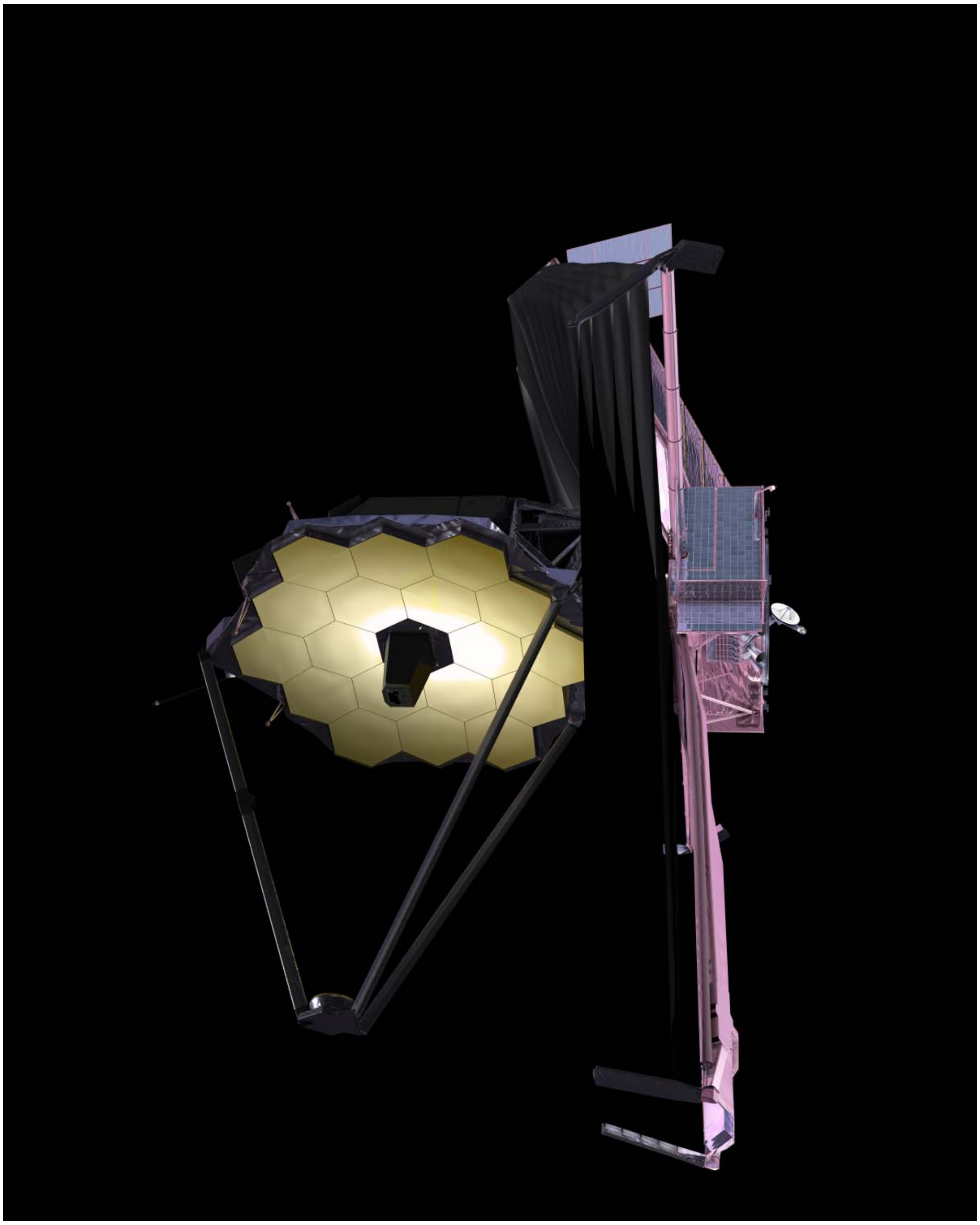

Fig. 1.— Final design of JWST

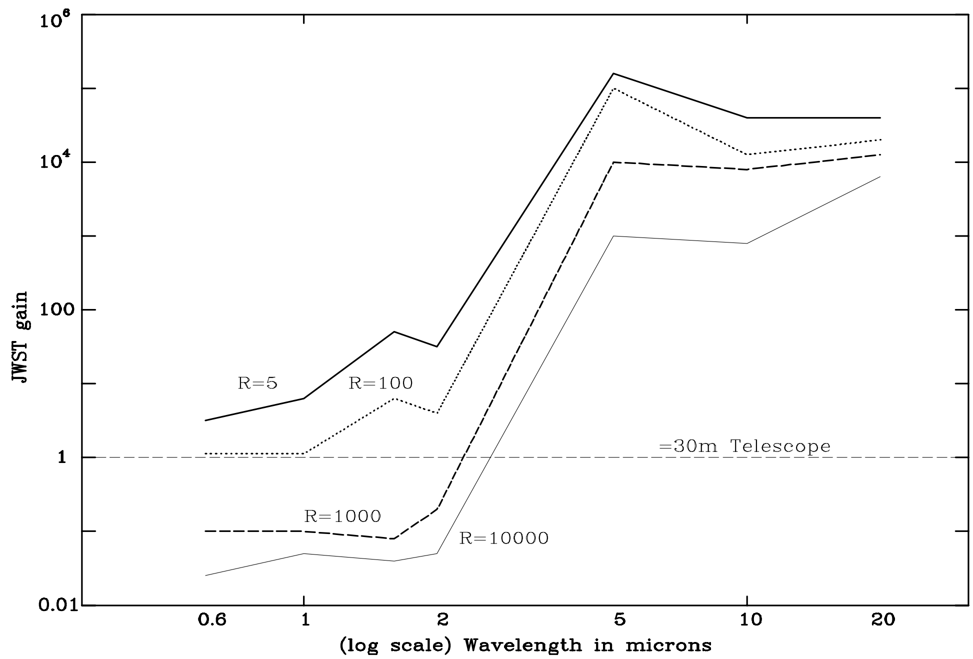

Fig. 2.— Observing sensitivity of JWST compared with 30m ground-based telescope over JWST wavelength range. The TMT will not operate at the longer wavelengths and the low R comparisons assume reasonable levels of TMT AO performance.

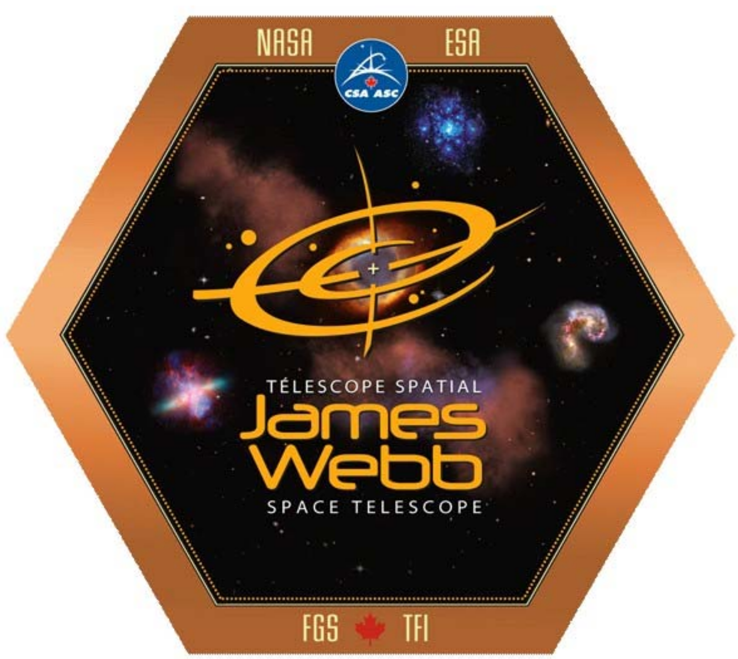

Fig. 3.— CSA logo for JWST

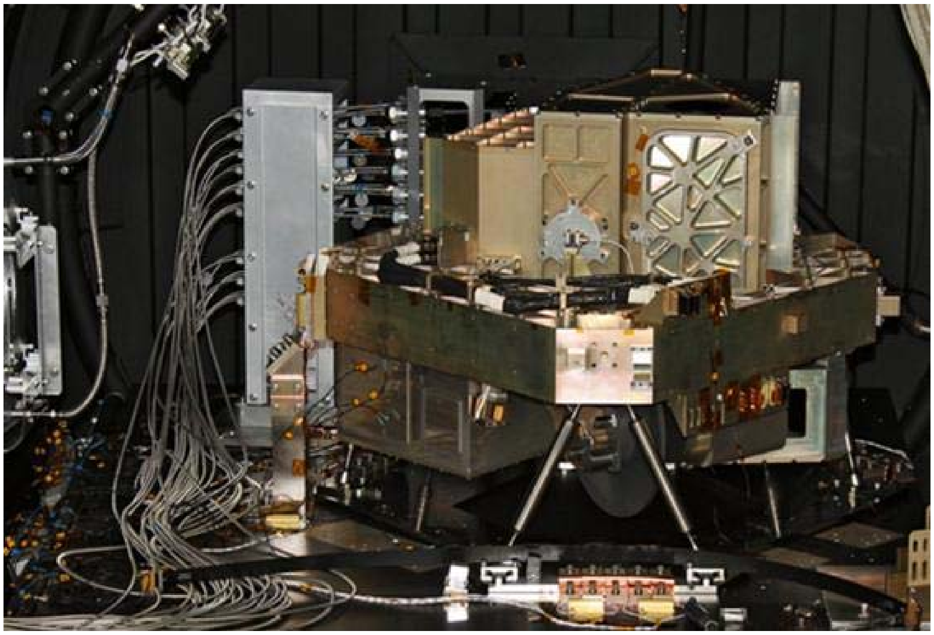

Fig. 4.— The engineering model unit of the combined guider + TFI instruments set up for thermal vacuum test January 2010

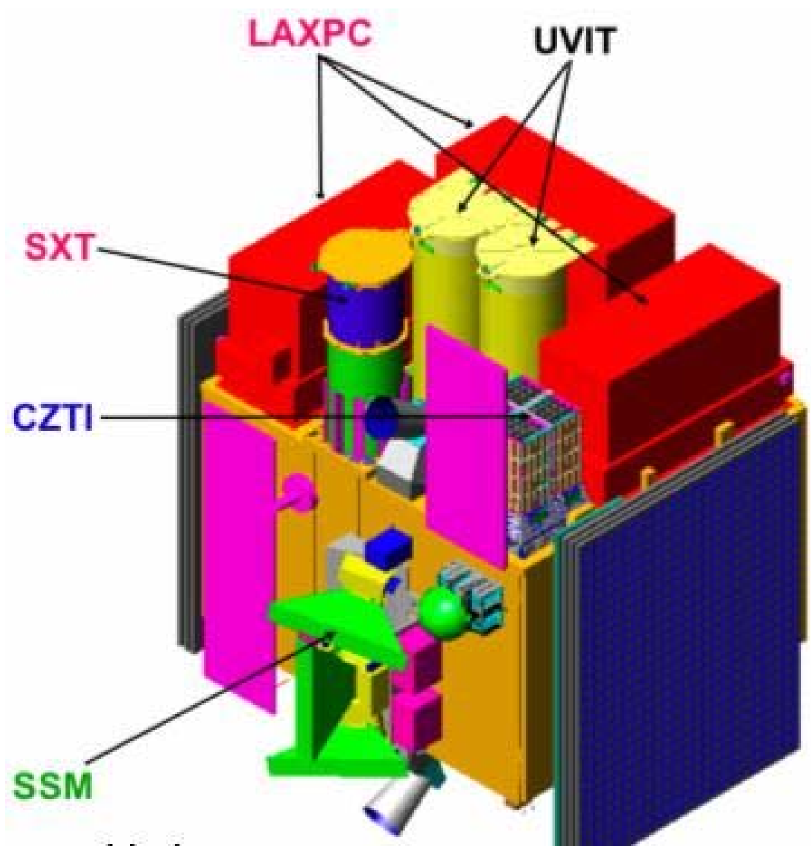

Fig. 5.— Astrosat observatory with the five instruments labelled: LAXPC - large area proportional counters; CZT - coded mask hard X-ray imager; SXT - soft X-ray imaging telescope; SSM - scanning X-ray sky monitor; UVIT - UV-optical imaging telescopes.