Canadian Contributions Studies for the WFIRST Instruments

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ABSTRACT

WFIRST-AFTA is the NASA's highest ranked astrophysics mission for the next decade that was identified in the New World, New Horizon survey. The mission scientific drivers correspond to some of the deep questions identified in the Canadian LRP2010, and are also of great interest for the Canadian scientists. Given that there is also a great interest in having an international collaboration in this mission, the Canadian Space Agency awarded two contracts to study a Canadian participation in the mission, one related to each instrument. This paper presents a summary of the technical contributions that were considered for a Canadian contribution to the coronagraph and wide field instruments.

Keywords: WFIRST, EMCCD, Integral Field Spectrograph, LOWFS, Relative Calibration System, Fine Guidance Sensor, Coronagraph Instrument, Wide Field Instrument

1. INTRODUCTION

The Wide-Field Infrared Survey Telescope – Astrophysical Focus Telescope Asset (WFIRST-AFTA) mission is the NASA's highest ranked mission that was identified in the 2010 National Academy of Science decadal survey: New World, New Horizon. Its 2.4-m telescope aperture combined with its exquisite image quality and it field-of-view 90 times larger than Hubbles's ACS and 200 times larger than WFC3/IR will give scientists access to a set of high-quality data to attempt to answer top modern scientific questions. The mission has entered its formulation phase at the beginning of 2016 with an expected launch date in 2025.

The mission science objectives will be achieved using two main instruments, the Wide Field Instrument (WFI) and the Coronagraphic Instrument (CGI). The WFI has an image plane composed of 18 H4RG detectors that covers a FoV of 0.281 deg^2. An 8-position element wheel will include six filters ranging from 0.76 μm to 2.0 μm, a dark channel and a grism channel to do slitless spectroscopy between 1.35 μm and 1.89 μm. The WFI will also include a separate Integral Field Channel (IFC) based on an image slicer that is baselined to provide spectra over the 0.6 μm to 2.0 μm waveband over two FoVs. One FoV will be optimized for the supernovae survey while the second FoV will be optimized for galaxy characterizations. The CGI will aim at detecting faint companions at unprecedented contrast levels to enable the detection of old evolved planet in reflected light and enabling an overlap of indirect detection techniques and direct imaging for the first time.

The tremendous amount of data that will be collected by WFIRST and its quality makes the mission very appealing to Canadian scientists. The top recommendation of the Canadian decadal survey, the LRP2010, was for an involvement in a survey mission that can shed new light on the mystery of dark energy, which was reaffirmed in its 2015 mid-term review. WFIRST was identified as a mission that would fulfill this goal. A Canadian involvement in the WFIRST mission would not only allow our scientists to have access to the data but also to beneficiate from the socio-economic

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advantages that come with an involvement in a world-class observatory that will find clues to answer the top scientific questions of our time in astrophysics.

In this context, the Canadian Space Agency has awarded two contracts in 2014 to evaluate possible Canadian contributions to the mission: one on contributions to the WFI and one on the coronagraph instrument (CGI). The main goal of these studies is to provide recommendations on the technologies that Canada could provide based on their alignment with Canada's space policy framework and their technological maturity. This paper presents brief summaries on the work and recommendations that issued from these studies.

2. CORONAGRAPH INSTRUMENT CANADIAN CONTRIBUTION STUDY

2.1 Coronagraph Instrument Description

The direct detection of exoplanets and the study of their atmospheres is a great technological challenge due to the proximity of the planet to its host star and the brightness difference between the two bodies. Current ground-based systems are searching for young gaseous companions that are self-luminous in the near-infrared due to the remaining heat from their formation. These instruments can find companions with a limiting brightness ratio of the host star over the planet, or contrast, in the order of $10^5 – 10^6$. Old, evolved planets have come to equilibrium with the radiation they absorb from their host star and deep space. Hence, they do not have significant heat left and their imaging depends on the detection of the light from their host star they reflect. Detecting this reflected light requires a significant improvement in contrast. For example, detecting a Jupiter twin would require a contrast of the order of 10^9 between the star and the planet.

WFIRST will be the first mission to reach this contrast level. For the first time, evolved planets similar in size and in orbit to the ones in our Solar system will be detected and their atmosphere will be studied. Planets detected with indirect techniques will be imaged allowing their orbit to be fully constrained and their mass determined with unprecedented accuracy. Debris disks around nearby stars will be imaged with an unprecedented contrast and they will be probed closer to their host star than they have ever been to gain crucial information on the interaction of planets with the debris disks during their formation and discriminate between different planet formation models.

The most efficient and mature coronagraphs that have been selected for WFIRST [1] are the Shaped-Pupil Coronagraph (SPC) [2]and the Hybrid Lyot Coronagraph (HLC) [3]. Different set of masks will be available for each of those two coronagraphs to yield optimal performances in different wavebands. The masks will be located in two focal planes and two pupil planes with relay optics in between. A filter wheel will also be used to select the waveband.

In addition to the set of coronagraph masks, the CGI will use two deformable mirrors (DM) and a fast steering mirror (FSM). It will use the feedback from a low-order wavefront sensor (LOWFS) to stabilize the image and correct for low order aberrations to ensure optimal positioning and image quality on the coronagraphic occulting mask. The imaging focal plane array will also be used to provide information on speckle locations and the deformable mirrors will be used to cancel these speckles. A flip mirror will be used to direct the image towards either an imaging camera or the integral field spectrograph (IFS). A second filter wheel is placed in the imaging camera path with a polarization beamsplitter. A lens can also be deployed in this path to image the pupil on the detector. Post-processing speckle suppression techniques will then be used to further lower the detection threshold. The IFS will be used to acquire spectra of the detected companion and provide information that can be also be used to reduce the speckle noise. EMCCDs are currently the baseline for both the imaging FPA and the IFS FPA. A schematic representation of the coronagraph instrument is shown in Figure 1.

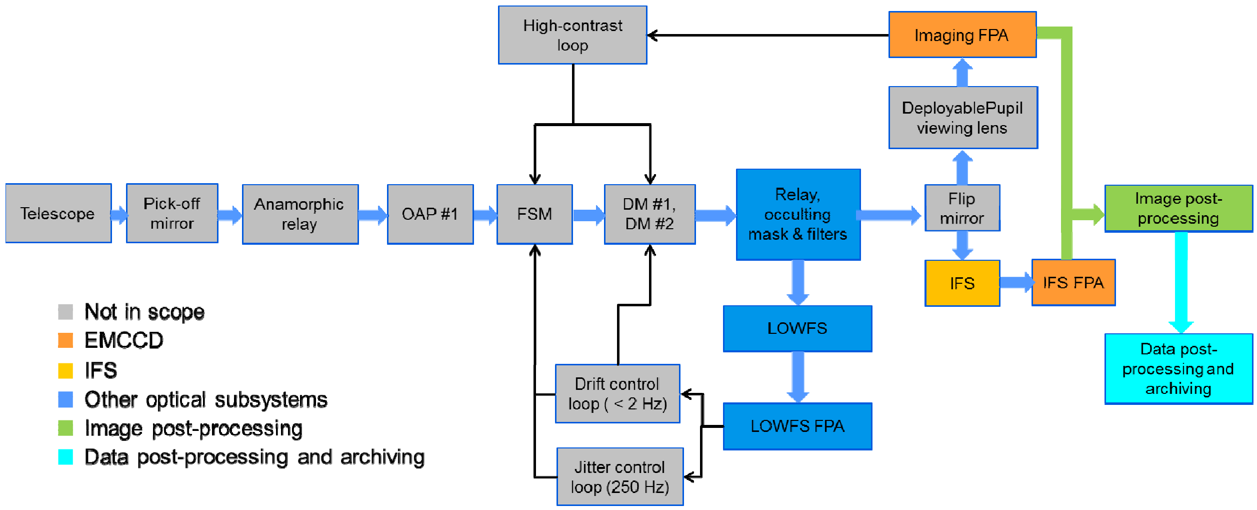

Figure 1: CGI block diagram with potential Canadian contributions identified

2.2 Potential Canadian Contributions

ABB has joined forces with five universities/companies/institutes to explore the best contributions that Canada could make to the WFIRST CGI, the potential scientific yield of such a contribution and the potential impact on the Canadian industry. The project was separated in two phases. Six potential contributions were identified for the phase 1 of the project. These contributions were:

- The EMCCD: the company Nüvü Camēras has developed the most sensitive EMCCD available on the market in the photon counting mode. So far, this camera is the only one that has met all the current WFIRST CGI sensitivity requirements [4]. Two such cameras are baselined in the WFRST CGI, one in the imaging channel and one in the Integral Field Spectrograph (IFS) channel.
- The IFS: The IFS will be used to acquire the spectrum from the companions to characterize their atmosphere. Canada has been highly involved on the development of the GPI IFS. It has led the optical system development and integration. Canada also has a strong heritage in the development of optical systems for space applications.
- Image post-processing: Canada has also been in charge of the development of the data reduction pipeline for GPI to transform the raw data collected by the IFS to a calibrated companion spectrum [8]. Speckle suppression techniques can also be used in this step to further improve the signal-to-noise ratio of the detection. Canada is an international leader in this field (see [4], [6], and [7]).
- Data processing and archiving: This contribution consists in housing the released data pipeline reduction routines, as opposed to developing them in the previous contribution, and housing a mirror site for archiving the mission data. CADC in Victoria specializes in this type of service of international observatories and missions. This contribution could take the form of:
  - An external mirror site,
  - Value added data products, WFIRST Cache,
  - Support to software development teams,
  - Science teams support.

  As a worked example of a possible data processing contribution, study team members also worked on an architecture for a GPI-like data pipeline.
- The Low-Order-Wavefront-Sensor (LOWFS): The LOWFS is used to measure evolving aberrations and transmit the information in closed loop to a fine steering mirror and deformable mirrors to stabilize the host star in the coronagraph instrument in motion and in focus, and maximize its rejection by the coronagraph. A

LOWFS based on a pyramid wavefront sensor (PWFS) is proposed. This builds on newly acquired Canadian expertize in PWFS and combines the Canadian expertize in adaptive optics and high-contrast imaging.

- The wheels: The CGI will use eight wheels to switch between different coronagraph configurations and switch filters. This is an opportunity to build on the heritage of the Canadian contribution to JWST, the NIRISS element wheel.

The three options to be pursued in the second phase of the study were the EMCCD, the IFS and the LOWFS. The EMCCD and the IFS were selected based on the Canadian recognized expertize and past heritage while the LOWFS was selected to explore in more details the potential of the proposed solution but likely has a technological maturity too low to be a contribution to the WFIRST mission.

While image processing is also a recognized Canadian expertize, it would most likely take the form of the funding of scientists and post-doctoral fellows that would participate in the Science Investigation Teams (SIT). It was judged that too little was known at the moment on the speckles of the WFIRST CGI, and that little more would be learned by continuing the investigation of this option in the second phase of the study. A similar conclusion was also reached for the data processing and archiving. More information on the final data product would be necessary to pursue the investigation in the second phase. The wheels option was not pursued given that preliminary information pointed towards requirements significantly more demanding than for the NIRISS element wheel which made it doubtful that its heritage could be reused.

2.3 EMCCD Contribution

The EMCCD proposed for WFIRST is a flight version of the Nüvü Camēras commercial product that meets all the WFIRST CGI detector requirements. The baseline is to integrate the commercially available CCD201-20 from e2v with the Nüvü Camēras controller that includes cold proximity electronics, the warm electronics and the harness connecting them, mounted in a mechanical assembly. The power supply is also included to provide a complete solution. The EMCCD package will interface mechanically with the bench, and thermally with the cold strap connected to the passive radiator. It would include the two flight systems, the one in the imaging channel and the one in the IFS. The main requirements for the EMCCD are given in Table **1**. The EMCCD contribution with the main interfaces with the coronagraph instrument identified is shown in Figure **2**.

Table 1: EMCCD main performance requirements

Specification	**Requirement**	**Notes**
Active pixels	1024 x 1024	
Pixel pitch (μm)	13 x 13	
Effective read noise (e-)	0.2	Achieved using EM gain
Dark current (e-/pix/sec)	$1x\ 10^{-4}$	@165K, IMO
Clock induced charge @ 5σ threshold (e-/pix/frame)	0.0018	10 MHz horizontal frequency; 1MHz vertical frequency; EM gain = 1000
QE (%)	88	@ 660nm, 165K
	68	@ 770nm, 165K
	28	@ 890nm, 165K

The main challenge in the EMCCD development is to find the space qualified equivalent of the components currently used in the commercial product. All critical parts were identified in a space qualified variant during a preliminary study. Two main elements were identified to be at a lower maturity level. First, the high speed of the clock generation (10 MHz) combined with its shaping is a first for space operating systems. Space qualified operational amplifiers that delivered the required current could not be found but could be replaced by two operational amplifiers used in parallel. There is a low risk that this solution will not work which can be mitigated by lowering the pixel read frequency from 10 MHz to 8 or 5 MHz for example. This would come at the cost of increasing the clock-induced charges (CIC).

Nüvü Camēras is currently under contract with the Canadian Space Agency to conduct this technological maturation activity. The controller board will be designed and manufactured with all the electronic components having space qualified versions. The main goal of this activity is to demonstrate that the noise level can be reached with the new electronics in a TVAC environment representative of the WFIRST thermal environment.

The second technological element needing a maturation activity is the detector. The baselined CD201-20 from e2v has not been space qualified. However, another EMCCD, the CCD97, has been tested in radiation and showed similar behaviors to CCDs: the dark current increased and charge transfer efficiency decreased. Also, the ability for low light imaging after exposure to radiation remains to be demonstrated. Protons in particular can have a detrimental impact by generating traps preventing the charge transfer to take place. Mitigation mechanisms for this effect still have to be developed. Activities to increase the maturity of this element have been conducted [9], and are presented in this conference [10], [11].

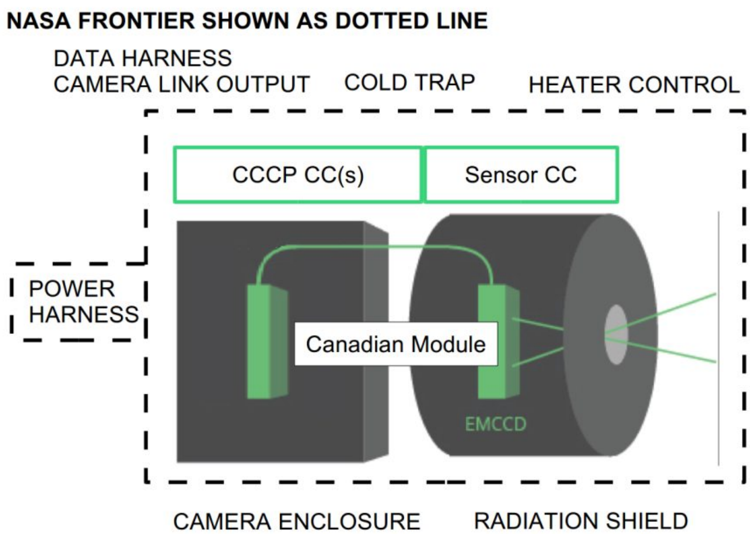

Figure 2: Illustration of the Canadian EMCCD module with the main interfaces with WFIRST CGI identified in white. The CCD Controller for Counting Photons (CCCP) and the sensor modules are shown.

The EMCCD is driven in IMO and its operating temperature is set to 165 K to obtain the required dark current level (10^{-4} electron/pixel/s). A thermal analysis was conducted to evaluate if the current passive radiator can cool the detector to this temperature. It was found that the detector temperature is at the limit of what can be achieved with the current radiator so parasitic heat loads will need to be carefully controlled. Similar performances were obtained for the two orbits that were considered at the time of the study, L2 and GEO, given the small size of the Earth within the radiator FoV. However, the passage of the Earth in the passive radiator FoV in GEO will induce thermal instability. Simulations demonstrated that the detector temperature will vary by 4°C peak-to-peak due to Earth while the detector stability requirement is to remain within 1°C. It was demonstrated that this could be made compliant by using a heater to stabilize the temperature.

2.4 Integral Field Spectrograph

Spectra from companions will be acquired by using a lenslet-based IFS. This type of IFS is currently used in high-contrast imaging instruments such as the Gemini Planet Imager [12] and SPHERE [13]. It spatially samples the focal plane image before dispersion which maximizes the speckles spectral correlation and allows for optimal speckle suppression when post-processing techniques based on this correlation are used.

The main requirements that were used as input to the study are given in Table **2**. A conceptual design was made to estimate performances, mass, and volume of the system. Cost estimates, technological readiness and the development schedule were also based on this conceptual design. It was assumed that the CCD201-20 EMCCD from e2v which has a pixel pitch of 13µm was to be integrated.

Table 2: IFS main requirements

Requirement	**WFIRST Value**		
Band center wavelength, λ_c (nm)	660	770	890
λ_{min} (nm)	600	700	810
λ_{max} (nm)	720	840	970
Coronagraph PSF sampling by lenslets at λ_c [# of lenslets/(λ_c/D)]	3.3	3.9	4.6
FoV (in λ_c/D)	14.5	12.4	10.7
FoV (radius in arcsec)	0.82 x 0.82		
Lenlets spatial filter holes diameter (µm)	25-30		
Magnification	1X		
Spectral resolution (2 px)	70 ± 5		
Spectrophotometric precision	0.06 mag		
Operating temperature (K)	290		

A contributor to the spectrophotometric error is the contamination between spectra that can be controlled by the spectrograph F-number. The conceptual design was based on an F/10 system that is estimated to be at the most aggressive end of the acceptable F-numbers for the system. This was chosen to have more conservative estimates by designing a conceptual system that is potentially more aggressive than necessary. Two conceptual design approaches were investigated, a refractive and a reflective approach. The latter was selected for its smaller volume to yield a given optical performance. The resulting conceptual design is shown in Figure **3**.

The system was evaluated to be a low risk contribution. The elements with less heritage are the lenslet array and focal plane masks assembly. Increasing the maturity of this assembly was evaluated to be a low R&D effort.

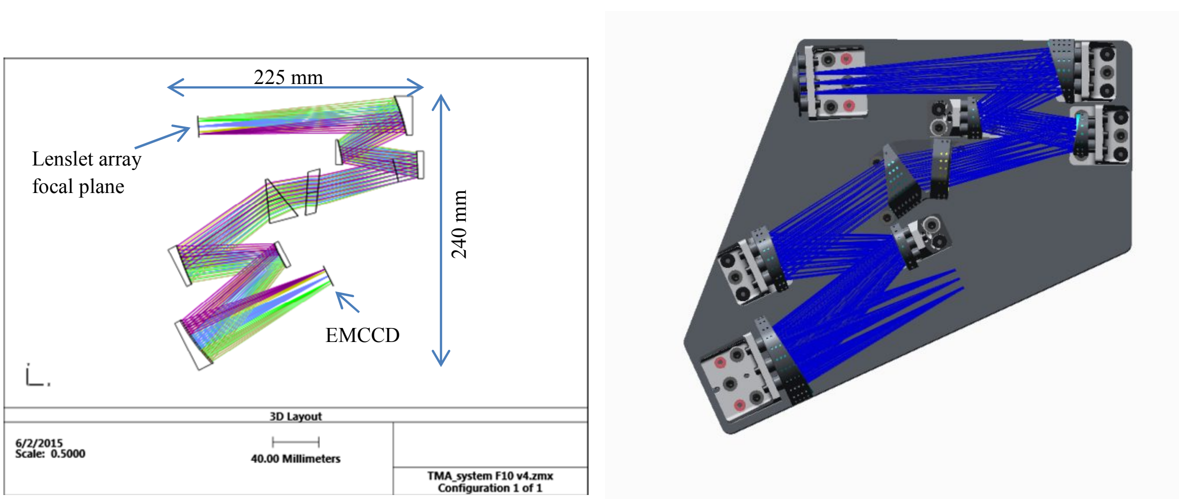

Figure 3: Illustration of the IFS conceptual design presented in the Canadian contribution study

2.5 Low-Order Wavefront Sensor

The LOWFS is used to monitor slowly varying low-order aberrations to compensate them in real-time with the fine steering mirror or the deformable mirrors to yield optimal host star light rejection with the coronagraph. The high accuracy required for the LOWFS points toward a phase sensor to avoid the noise propagation associated with slope and curvature sensors when computing phase. The current baseline for the phase sensor is to use a Zernike WFS in which a phase shift is introduced to a section of the star light incident on the occulter with a phase mask. This has the disadvantage of having a chromatic dependancy given that the induced phase shift is spectrally dependant.

Table 3: LOWFS main requirements

Requirement	Value	Comment
LOS (drift and jitter)	0.4 mas	
Low order WFE sensing	~10 pm	at slow rate (> minutes)
Sensitivity	High	
Linearity	High	

The pyramidal wavefront sensor has been demonstrated to act as a phase sensor for small abberrations when no modulation is used [15]. It has been proposed in the first phase of this study to use the P-WFS as a LOWFS that is achromatic and that does not necessitate lenses between the occulting plane and the detector. The proposed concept is based on a pyramid made from the intersection of lenslets [16] and is shown in Figure 4. A reflective coating is applied on the pyramid to use it in reflection and avoid chromatic aberrations. The power on each pyramid facet allows to reimage the pupils on the detectors. The pyramid is also cut to fit within the occulting zone of the coronagraph occulting mask.

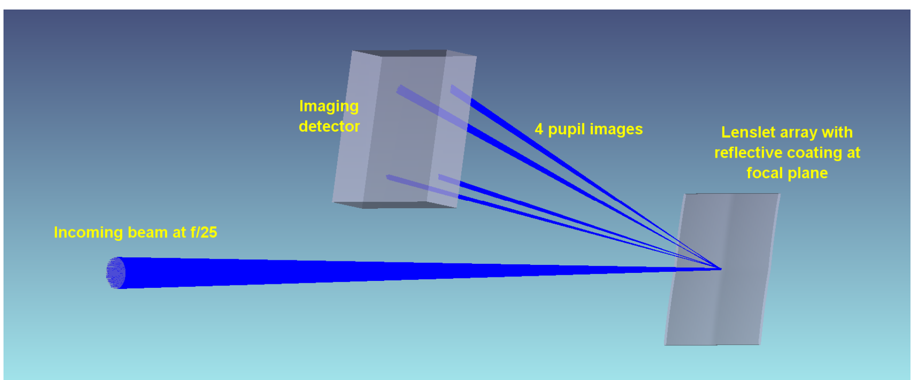

Figure 4: Illustration of the LOWFS concept based on the intersection of four reflective lenslets

As mentionned above, this contribution is at a very low stage of maturity, TRL2, so it is not considered as a viable potential Canadian contribution to the WFIRST mission. However, the concept has some merit and is also based on the P-WFS which is a technology currently being developped in Canada Hence, it was further investigated through simulations in the second phase of the study to better evaluate its potential.

A preliminary result is that the truncated pyramid that fits in the occulting mask acts as a spatial filter that smooths the pupil images on the detector. Nevertheless, the simulations showed that the mean error was of 0.06 mas for a photon noise limited image after 500 Monte Carlo runs.

As a follow-on activity, Université Laval has received a Flights and Fieldwork for the Advancement of Science and Technology (FAST) grant from the Canadian Space Agency to build a balloon compatible system that can be used to test high-contrast imaging technologies. The LOWFS will be further developed through this grant with a goal to test it on the balloon bench.

3. WIDE FIELD INSTRUMENT CANADIAN CONTRIBUTION STUDY

3.1 Wide Field Instrument Description

The WFIRST WFI will be the one used for the HLS and galactic bulge survey. It is composed of two main optical paths. First, the wide field detector path is composed of two fold mirrors F1 and F2, and of a tertiary powered mirror M3. F2 will be adjustable in tip, tilt and focus. It has a filter wheel with 8 positions, six of which are occupied by filters, one that hosts a grism to do slitless spectroscopy and one port used for dark acquisitions. The focal plane is composed of 18 H4RG sensor cold arrays (SCAs) and 18 associated sensor cold electronics (SCEs). Guide windows on the detectors will be used to track stars and guide the observatory. An auxiliary guider (AG) will also be present for cases where the sensor guiding will not be optimal such as during the grism observations.

The second path goes to an integrate field channel (IFC). This channel will be used to acquire hyperspectral data of two different FoV, one of 3”x3”, and one of 6”x6”.

The WFI will also include a Relative Calibration System (RCS). This sub-system will include all the necessary sources to calibrate the IFC and the wide field channel detectors. All the sub-systems are shown in Figure 5.

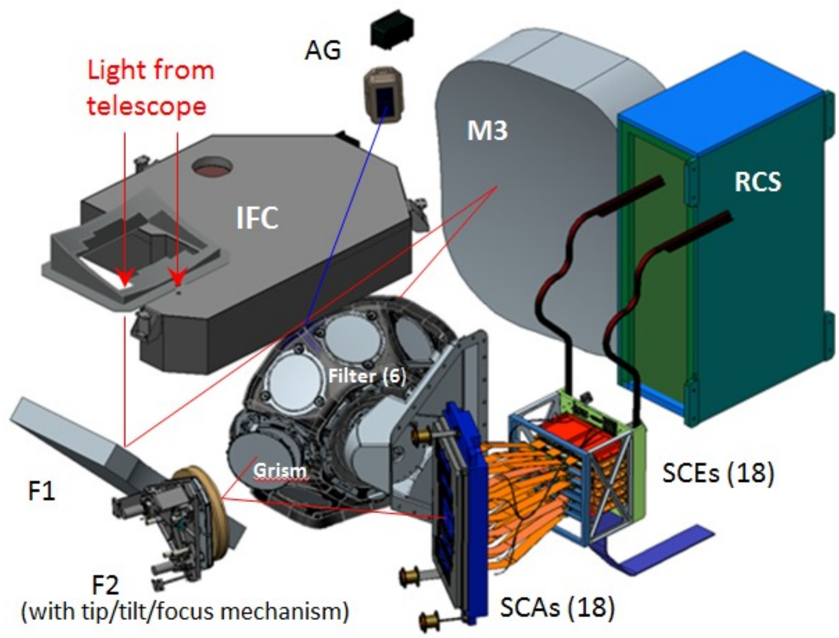

Figure 5: WFIRST WFI main sub-systems (from [17])

3.2 Potential Canadian Contributions

In this study we considered three potential Canadian contributions to the WFI in some detail:

1. Integral Field Channel (IFC)
2. Fine Guidance Sensor Processor
3. Calibration projection optics for the Relative Calibration System.

These potential Canadian contributions are described in the next few sections.

In terms of the concept developments we found that the IFC field of view could be readily expanded allowing for redundancy and for an improved photometric redshift survey. For the calibration system we assessed the challenging flat fielding requirement and made some progress on how these requirements may be achieved. The calibration sub-system could naturally form part of the IFC contribution. For the WFIRST Fine Guidance Sensor we found that the current concept of image processing within the WFI instrument command and data handling unit may not be optimal and a standalone processor may be desirable. Moreover, we showed that a stand-alone processor may enable unique science, Kuiper Belt Objects (KBO) detection via occultations, and may also enable guiding on QSO's during grism observations. The latter would be a major savings in mission cost compared to the alternative of a stand-alone auxiliary guider with its additional optics, detectors and electronics.

All three contributions that were studied in detail were found to be viable contributions, but it must be kept in mind that other contributions, not studied in detail, may also be feasible and indeed desirable. For example data processing / archiving contributions were also considered as part of this project, but it was decided not to pursue such a contribution at this point only because the overall WFIRST project is not yet at the level of maturity that concrete contributions could be defined.

Also in the area of calibration other potential contributions outside of the contribution of the specific hardware considered in the report were considered in the study as follows:

1) Simulations/studies for flow down of science to calibration requirements
2) The fielding of hardware for absolute calibration
3) Development of secondary spectro-photometric standard star catalogs
4) Potential contributions to detector characterization

3.3 Integral Field Channel Contribution

We reviewed possible alternative designs for the WFI IFC concept presented in SDT2015 [18] and eventually settled on a variant of this design – namely a doubling up of the SDT2015 concept as shown in Figure 6. This achieves redundancy and increases the FoV for the galaxy redshift survey. This will give a better sample of redshift-determined galaxies for the HLS observations, leading to reducing statistical uncertainty for cosmology, which is one of the major goals of the WFIRST mission. Using back to back optical benches to mount each side of such an IFC model (as shown in Figure 7) provides some flexibility since each can be tested / characterized separately as they are built up. Environmental testing would of course be done with the complete assembled unit.

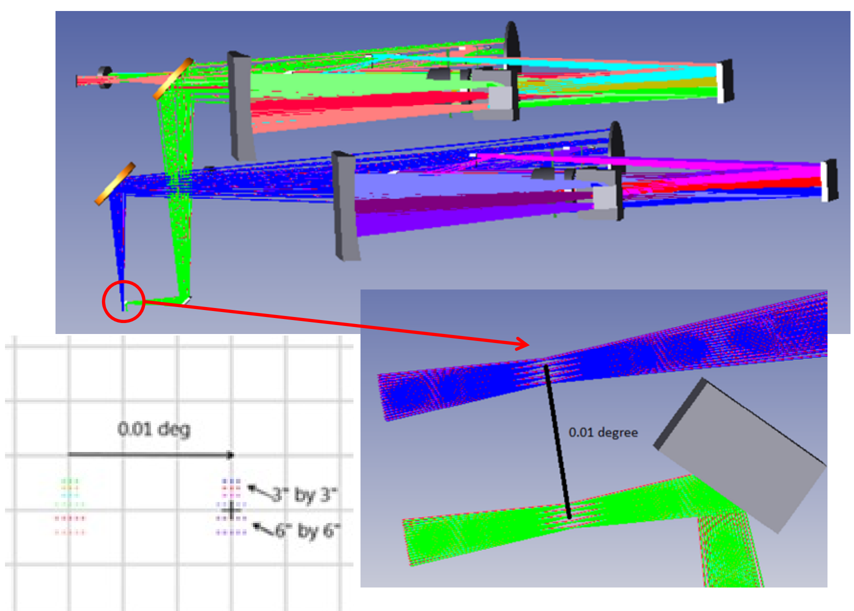

Figure 6: Illustration of the part 2 IFU concept. Redundancy and FoV increase are achieved by using 2 sets of IFUs similar to the one presented in [18].

3.4 Relative Calibration System Contribution

As preliminary study of the calibration hardware which will be needed for the WFIRST WFI, we considered primarily the delivery optics for the calibration light into the Wide Field Channel (WFC) and the IFC. The proposed calibration contribution builds on the current WFIRST WFI calibration concepts which would make use of the RCS. The RCS would consist of a variety of illumination sources feeding an integrating sphere. The RCS would be mounted external to the instrument and would use fiber-optics to supply calibration light from the integrating sphere to various key points within the instrument.

The WFIRST WFC and IFC calibration requirements were reviewed and the most challenging requirement was identified as the flat-fielding calibration function for both the WFC and the IFC focal planes. The primary purpose is to obtain linearity measurements at different fluence levels (photons/sec) on the detectors. While this illumination does not have to transit all the optical elements in the instrument, it does have to be uniform and much more importantly this uniformity has to be stable to the <0.1% level over the life of the mission. A concept for the projection optics was developed as shown in Figure 8, showing the location of the projectors in the IFC optical path, and Figure 9, showing the projector concept.

Figure 9 also shows the results of a ray trace simulation of the uniformity performance obtained from three of these projectors. Three are sufficient to obtain good uniformity on the IFC detector(s). We are recommending early prototyping to confirm the stability of this flat field can be maintained to the required precision over the lifetime of the mission.

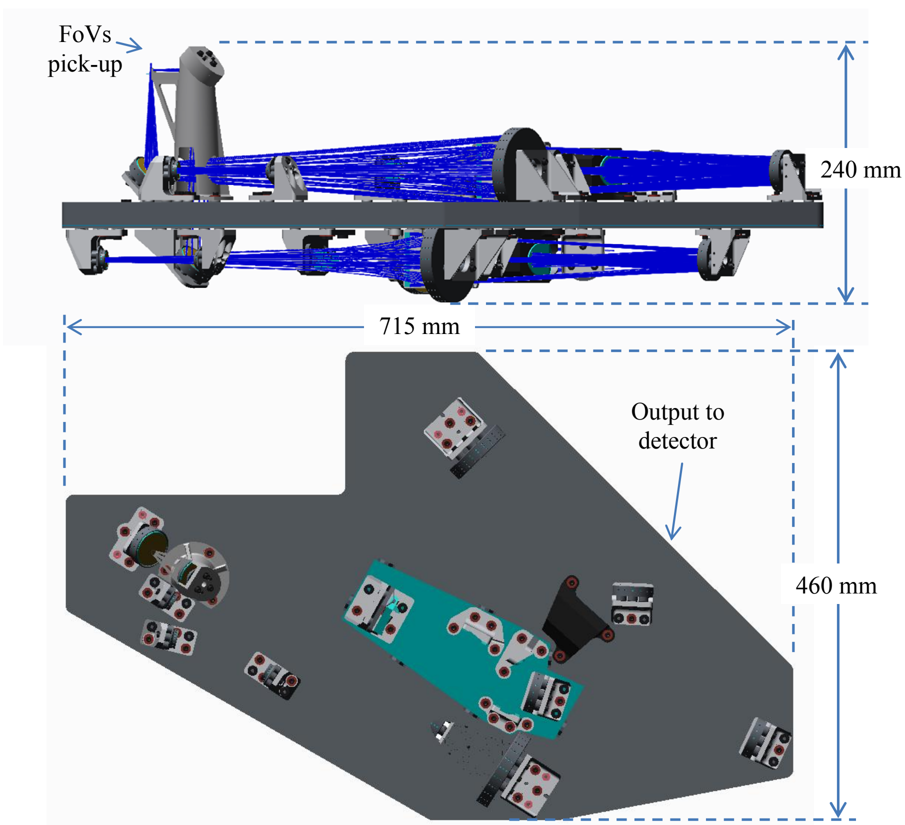

Figure 7: Opto-mechanical concept for the proposed IFU solution.

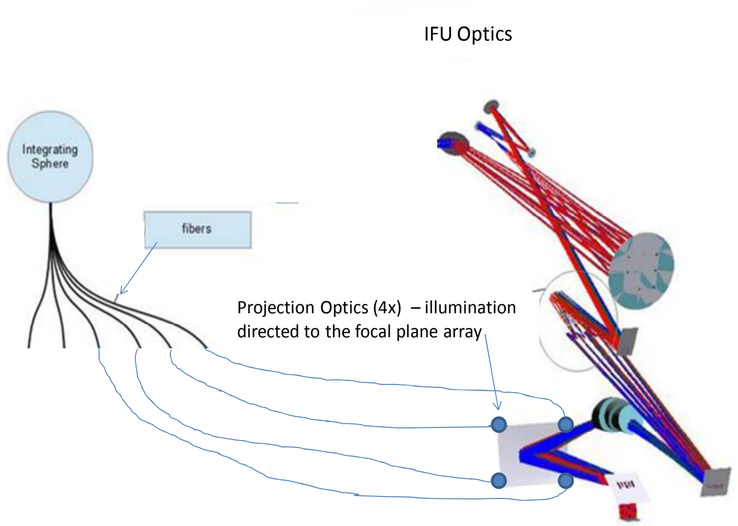

Figure 8: Flat-Field Calibration Delivery Optics Concept

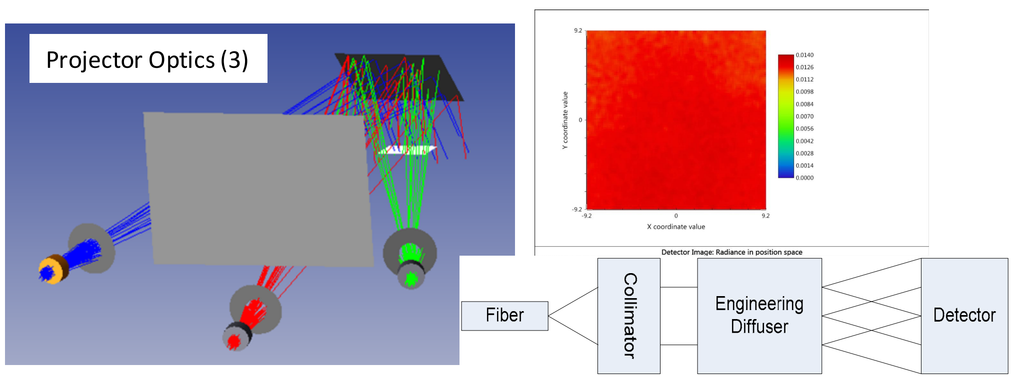

Figure 9: Flat-Field Calibration Delivery Optics Concept Details

Another component of the calibration delivery optics concept developed for the IFC is spectral calibration of the illumination output of the RCS. The RCS illumination will be used to calibrate the WFI through its filters and by using the IFC this light can be monitored for any spectral changes which might otherwise be mis-interpreted as changes in the filter band-passes of the main instrument. Moreover by injecting the RCS illumination in between the slit mirrors multiple spectra will be formed by the IFC spectrograph, providing a precise wavelength calibration of the individual image slices. The concept is shown in Figure 10.

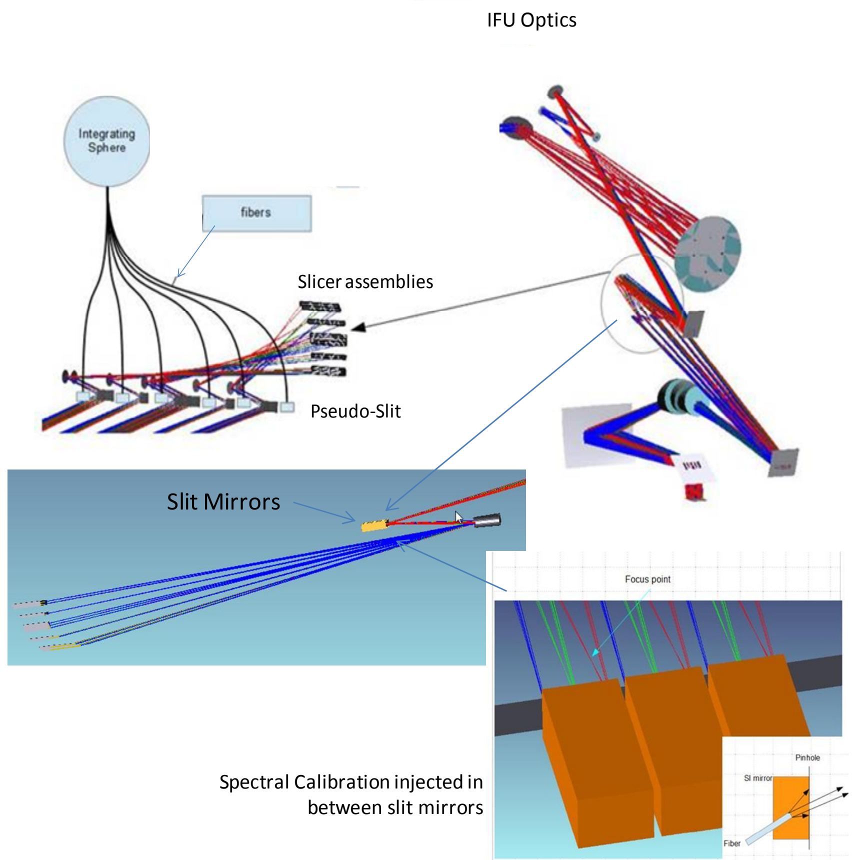

Figure 10: Spectral Calibration Delivery Optics Concept Details

3.5 Fine Guidance Sensor Contribution

The concept examined for the WFIRST Fine Guidance Sensor in this work builds on the currently proposed WFIRST Guider architecture, which makes use of the on-chip detector guide window readout capability of the H4RG multiplexers used for the main imager. There will be 18 of these 4k x 4k detector arrays covering 0.28 deg^2 of sky in the WFI focal plane. This large area ensures that there are typically at least 4 and as many as 18 stars within the field of view that are bright enough for use as guide stars, no matter which WFI bandpass filter is in use [19].

In operation there will be a 16x16 pixel window around each selected guide star (up to one per detector array) each of these read out at high rate while the rest of the image performs the long duration science exposures. This guide window data has to be processed to provide centroid (guide star position) information to the spacecraft attitude control system to stabilize the line of sight. Based on JWST FGS experience we find that this level of image processing would produce a significant computational load if it is performed in the WFI instrument command and data handling unit (ICDH). An alternative concept of a stand-alone guider processor was developed as shown in Figure 11.

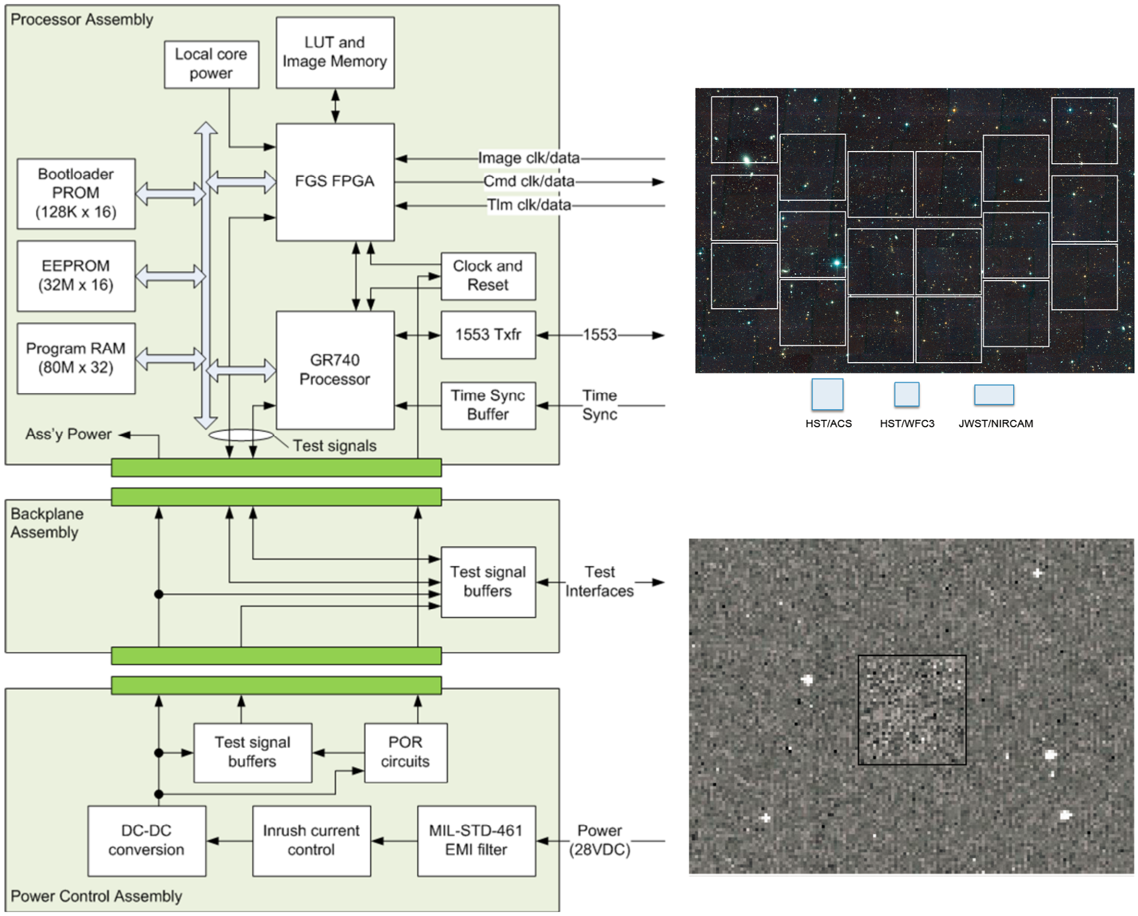

Figure 11: FGS Processor Architecture (left), WFI Focal Plane (right top) and on-detector guide window example from [20] (right bottom)

In addition to the benefit of off-loading the Guider image processing from the WFI ICDH we found two other potentially significant advantages to a standalone FGS Processor. The first enables an additional science objective for the mission, namely the ability to detect serendipitous KBO occultations. We estimate that as many as 30 KBO detections could be made per year by the WFIRST Guider during normal operations, if the guide window image data can be sampled at ~20 Hz.

The second advantage would be the ability to guide on quasi-stellar objects (quasars) during grism mode observations. In the grism mode the WFI filter is replaced by a grism which disperses the light from every object in the WFI focal plane. Normal stars have a continuum spectrum which becomes a line in such images, whereas QSO's have emission line spectra and thus would remain as near point sources. A preliminary assessment of the QSO brightness and statistics seems to show that they are sufficiently numerous for the purpose of guiding in grism mode. Additional sampling (like that required for KBO detections) and additional image processing would be required to optimize the signal to noise ratio. These performance advantages come about because of the processing power that would be available with a stand-alone processor. The alternative solution to guiding during grism mode observations is to add an auxiliary guider to the WFIRST payload, a significantly greater complication to the mission than a standalone Guider processor.

4. CONCLUSION

There is a strong interest from the academic and industrial community in Canada for a participation in WFIRST. Multiple options for a contribution for both the CGI and the WFI were presented. These options were selected based on the maturity of the technology in Canada, the business potential they enable, their expected socio-economical impact and their alignment with Canadian key technologies. Follow-on activities have been accomplished or are underway to increase the maturity of some of these options. These activities have been briefly presented.

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