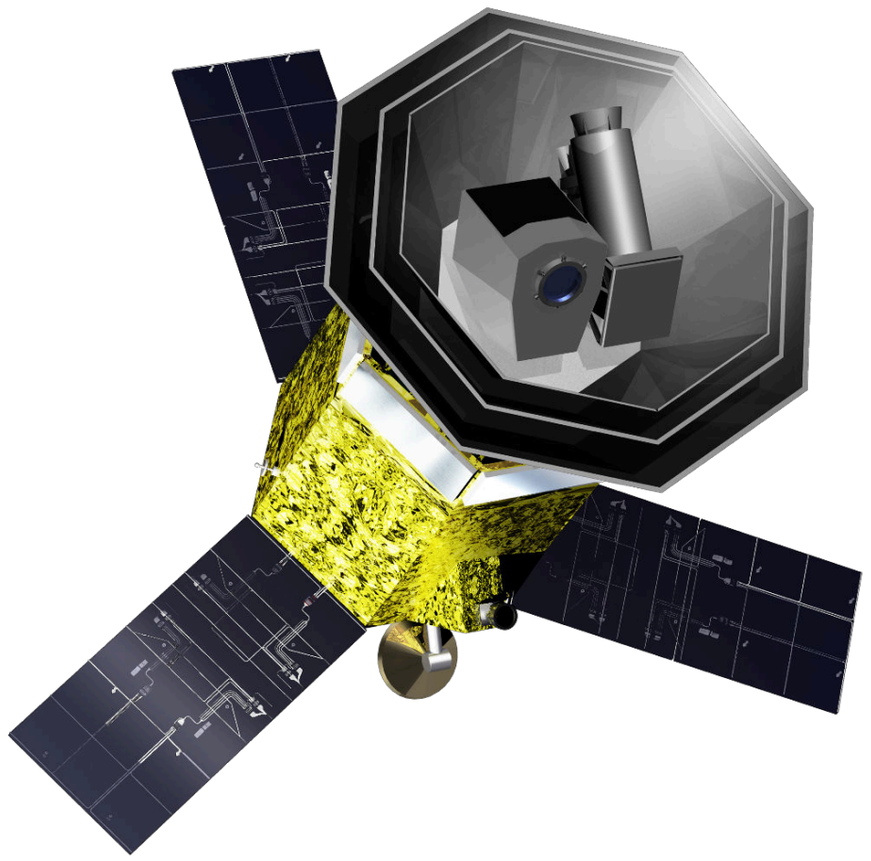
Canadian LiteBIRD Status

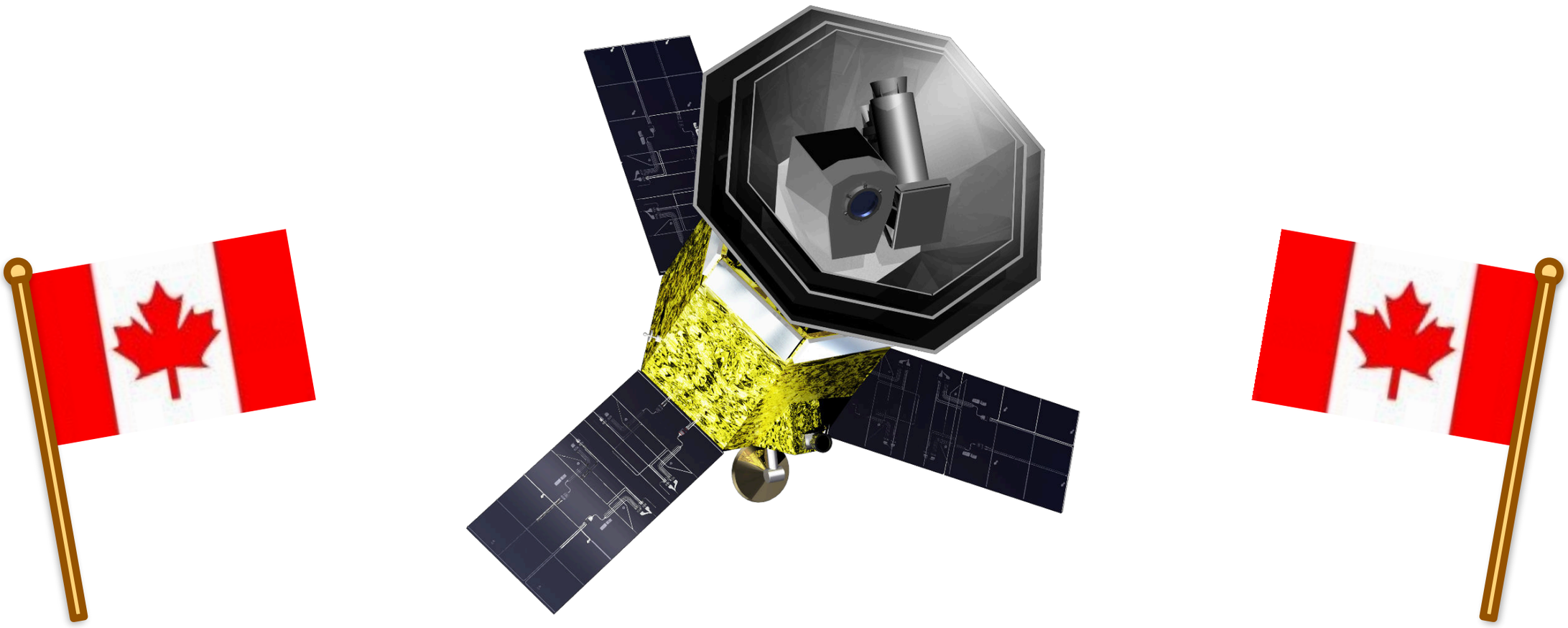


Douglas Scott

on behalf of Canadian LiteBIRD Team

LiteBIRD Kickoff Symposium
ISAS, Tokyo, July 2019

Canadian LiteBIRD Status



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Overview

- Technology contribution: DfMux readout
- Organization of effort in Canada
  – Three separate CSA-funded development lines
- Outlook for mission status funding and Canadian science involvement

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See poster for more details!

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  Digital frequency multiplexing

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Overview

- Technology contribution: DfMux readout
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  Canadian Space Agency
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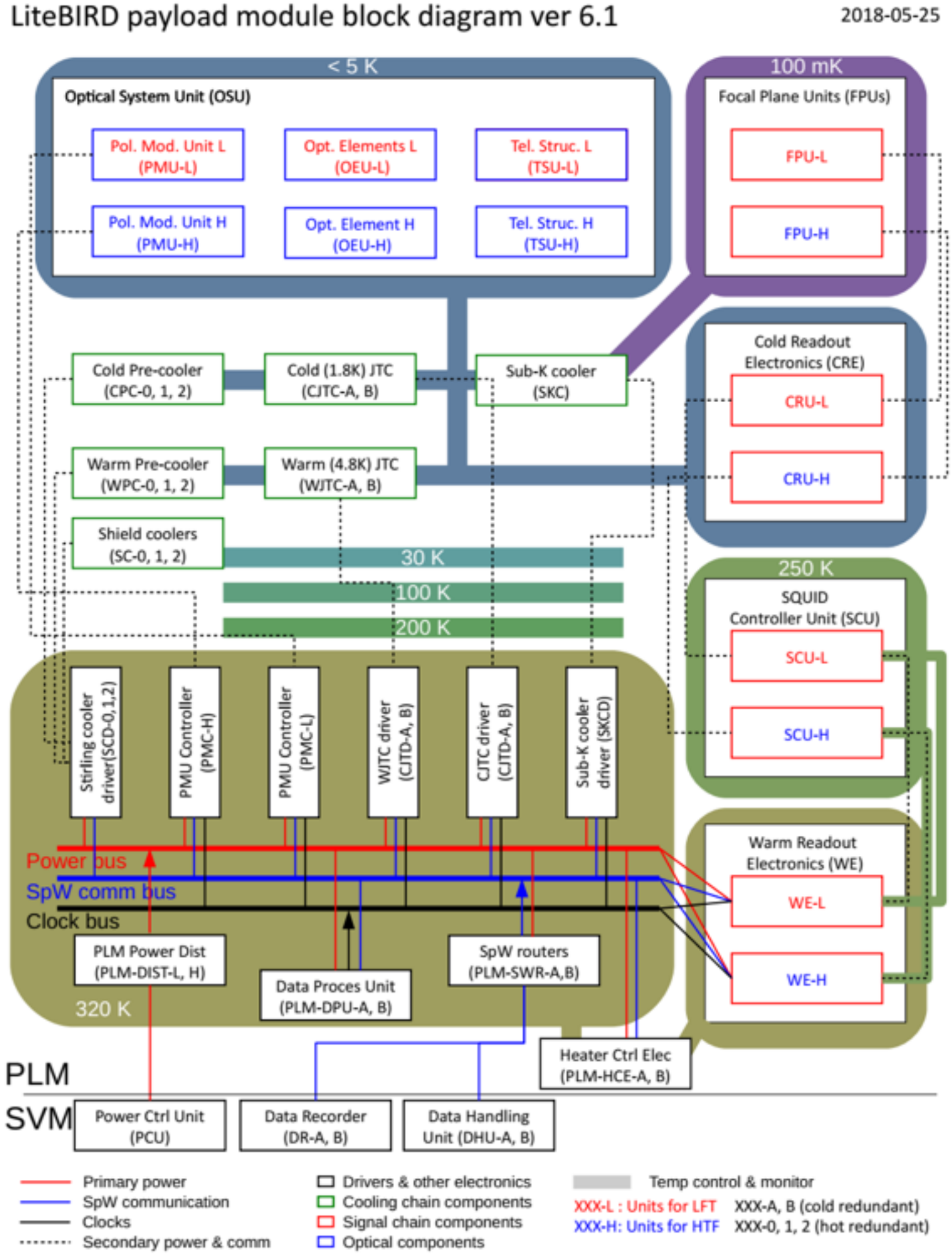
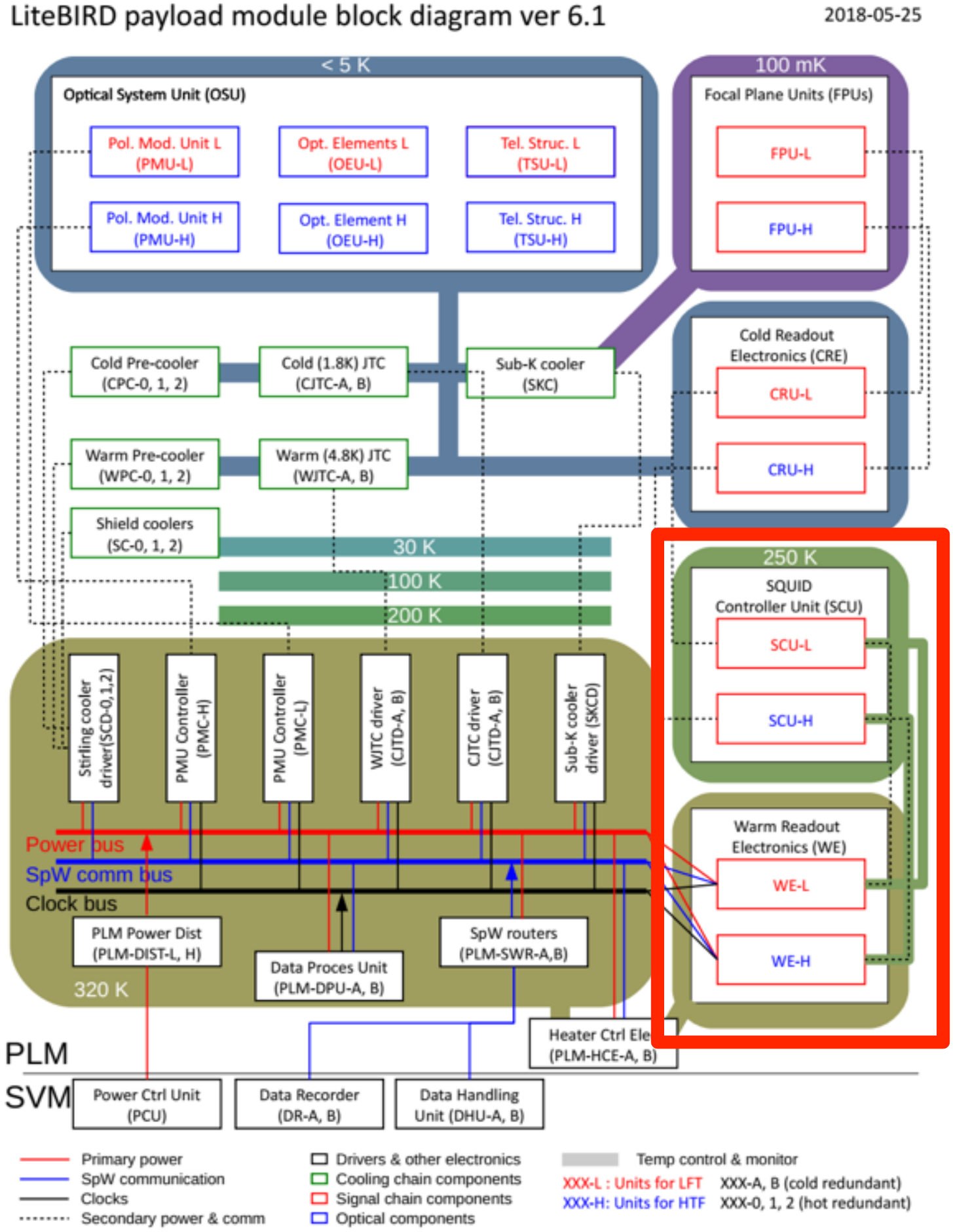
See poster for more details!

Payload Block Diagram



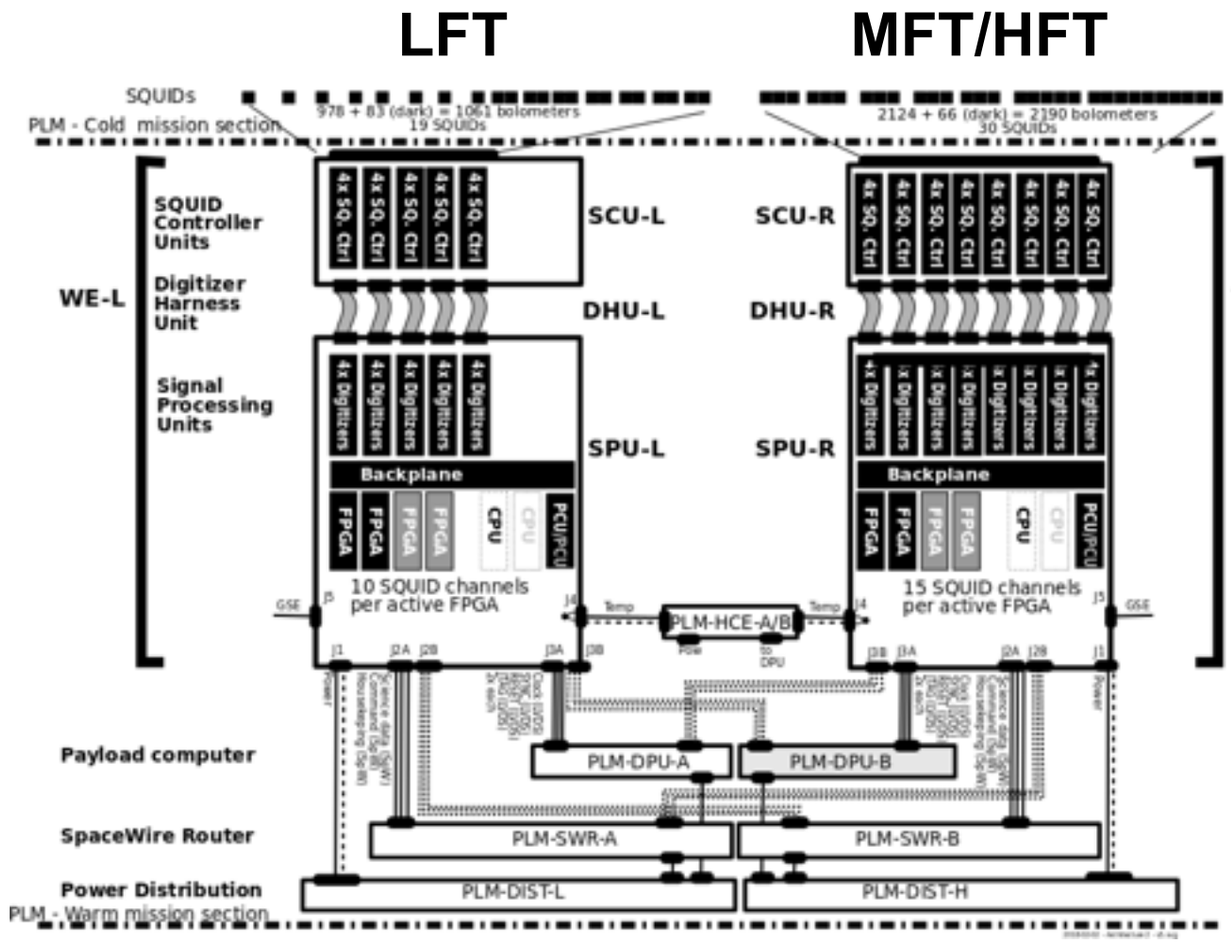
Payload Block Diagram



LiteBIRD Readout System

- Frequency Multiplexed Readout
  - USA: cold components
  - Canada: warm electronics (WE)

- Based on system deployed for South Pole Telescope (SPTpol & SPT3g), EBEX, and POLARBEAR/Simons Array



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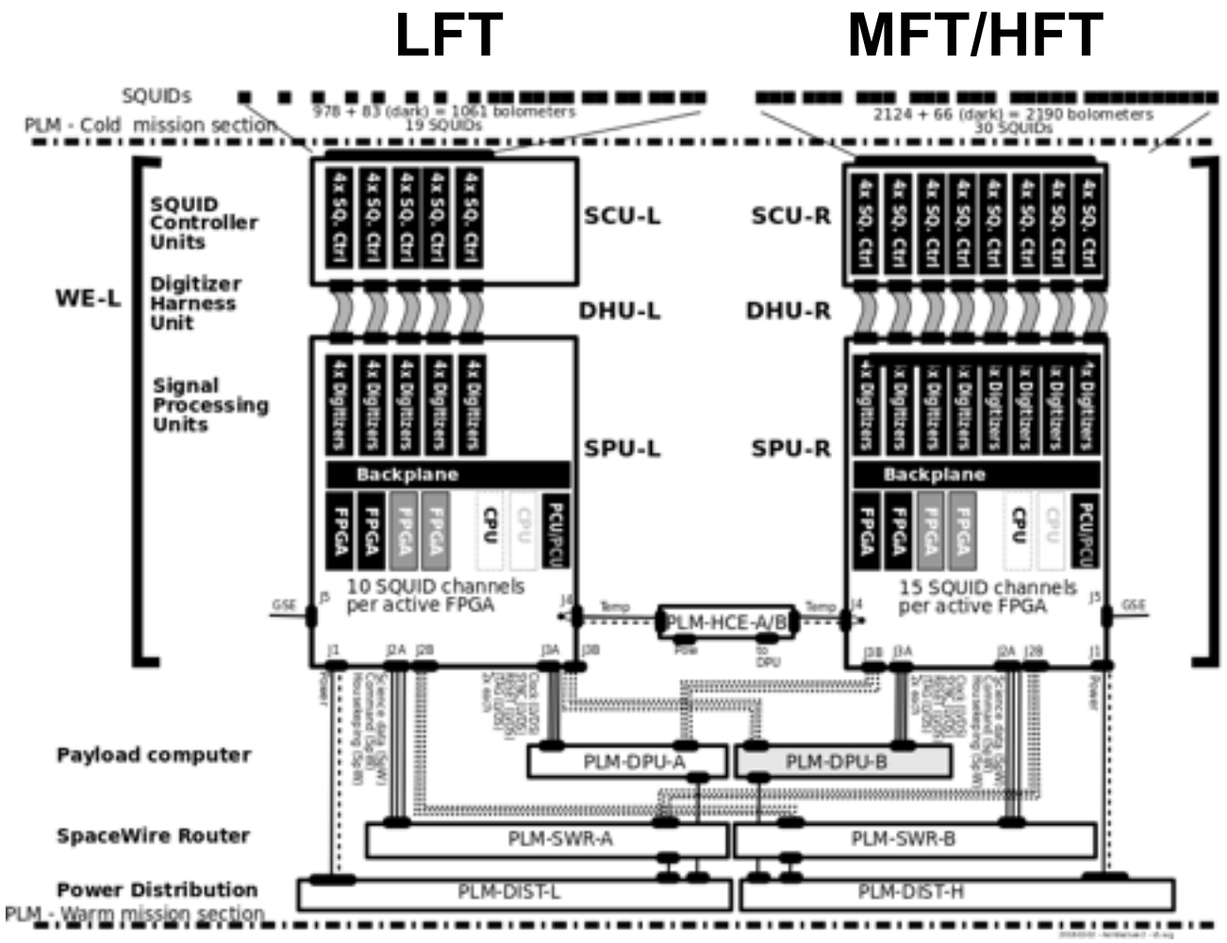
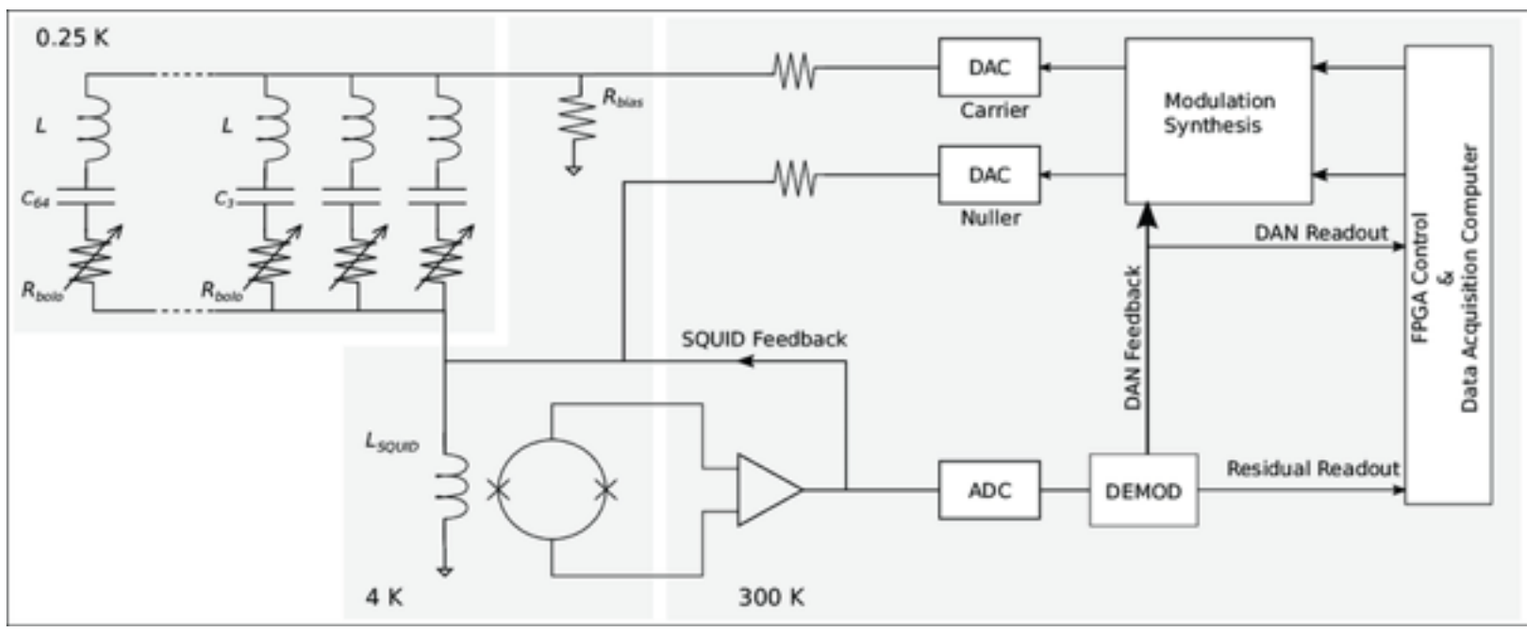
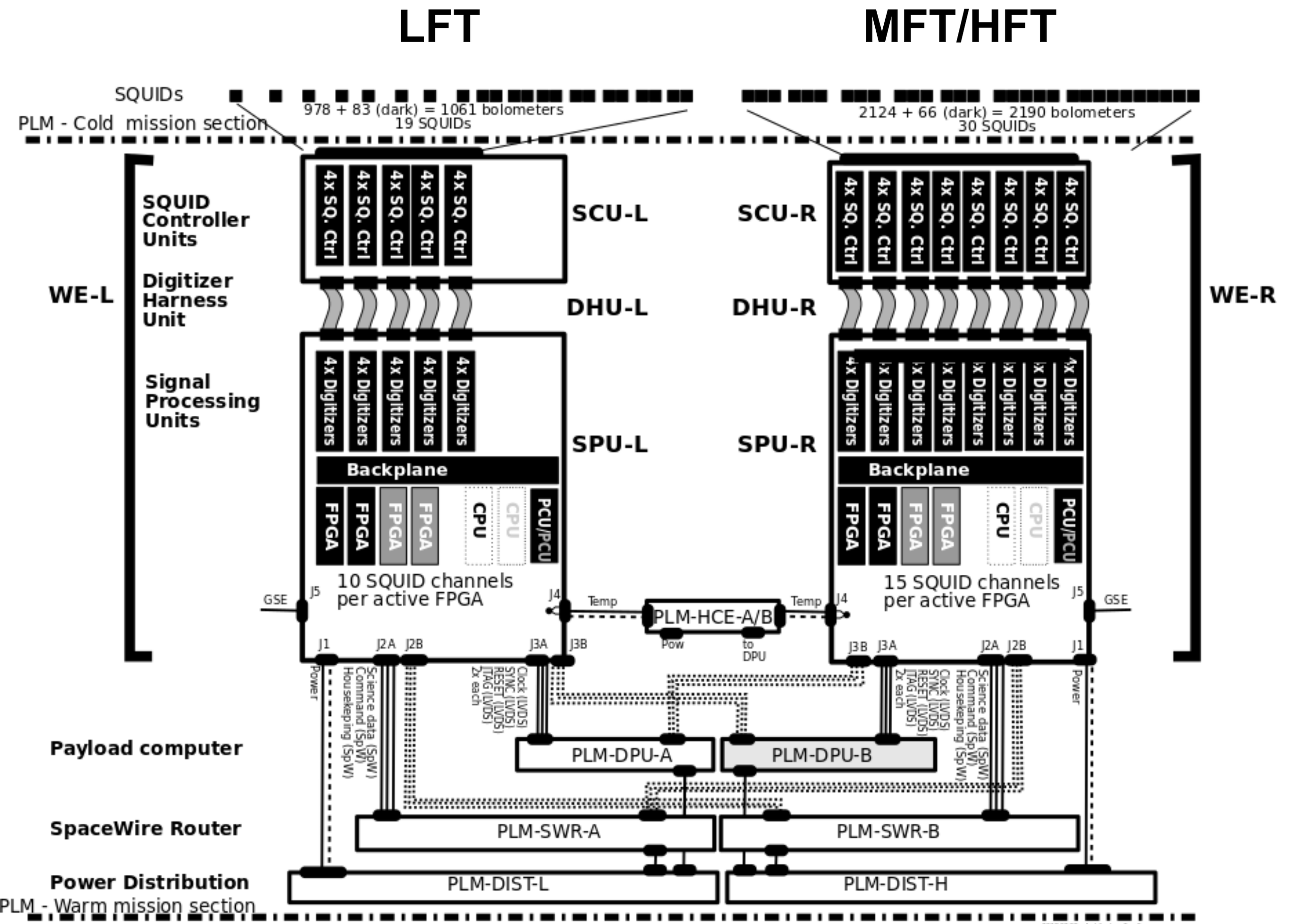
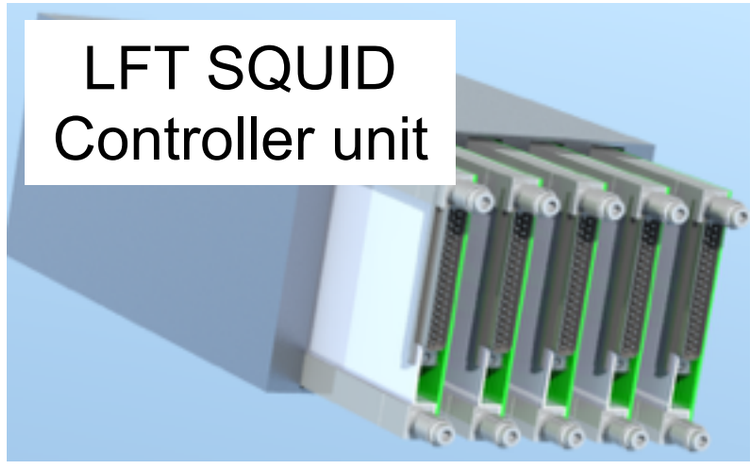




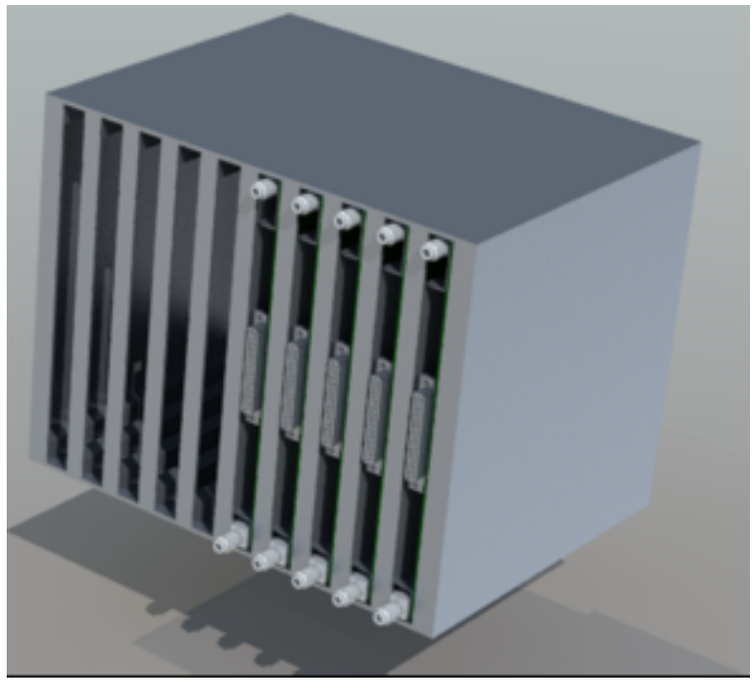
This circuit diagram shows how the frequency multiplexing for one SQUID module is implemented (an inductor/capacitor component selects each channel).

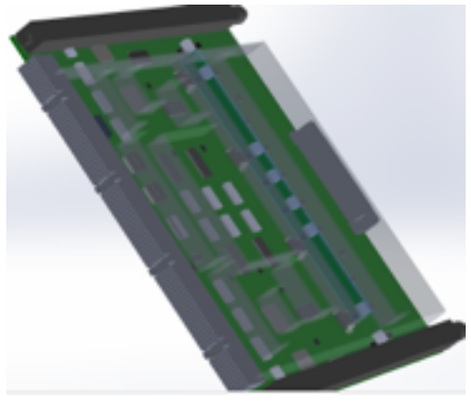

LFT
MFT/HFT
SQUIDs
PLM - Cold mission section
978 + 83 (dark) = 1061 bolometers
19 SQUIDs
2124 + 66 (dark) = 2190 bolometers
30 SQUIDs
SQUID Controller Units
Digitizer Harness Unit
Signal Processing Units
WE-L
WE-R
SCU-L
SCU-R
DHU-L
DHU-R
SPU-L
SPU-R
4x SQ. Ctrl
4x Digitizers
Backplane
FPGA
CPU
PCU/PCU
10 SQUID channels per active FPGA
15 SQUID channels per active FPGA
GSE
J1
J2A
J2B
J3A
J3B
J4
J5
Temp
PLM-HCE-A/B
Pow
to DPU
Power
Science data (SpW)
Command (SpW)
Housekeping (SpW)
Clock (LVDS)
SYNC (LVDS)
RESET (LVDS)
JTAG (LVDS)
2x each
Payload computer
PLM-DPU-A
PLM-DPU-B
SpaceWire Router
PLM-SWR-A
PLM-SWR-B
Power Distribution
PLM-DIST-L
PLM-DIST-H
PLM - Warm mission section

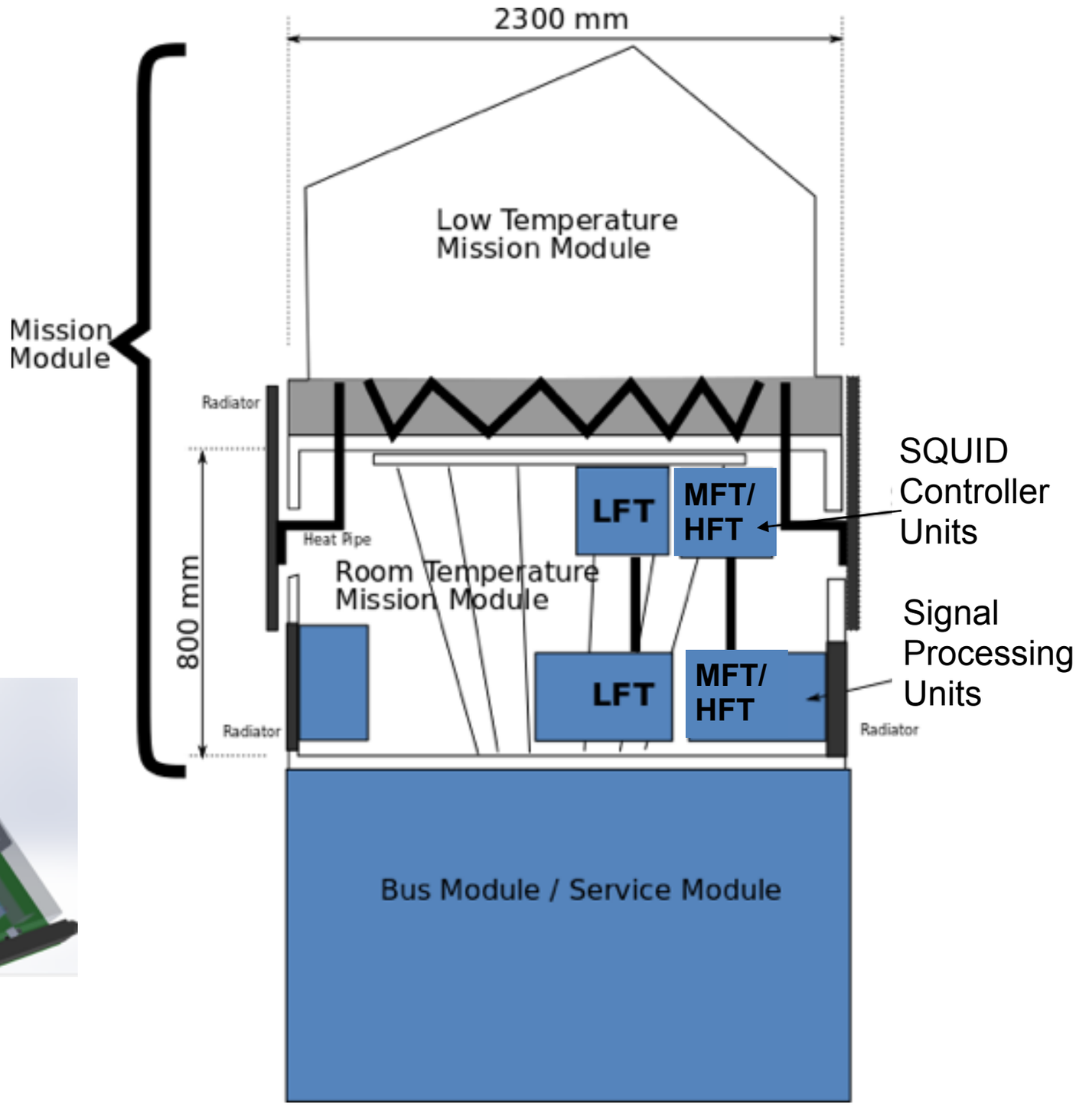
WE Units
(one pair for each telescope)



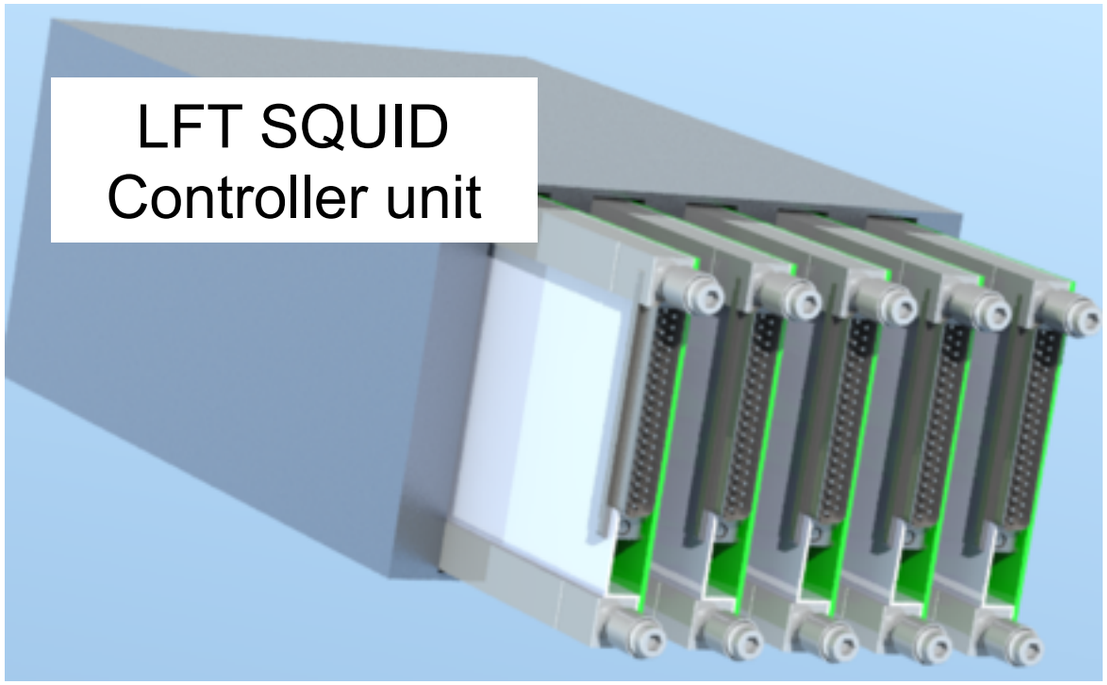
LFT Signal
Processing unit

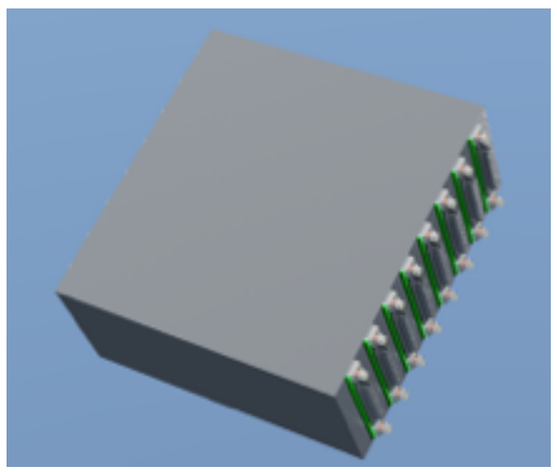






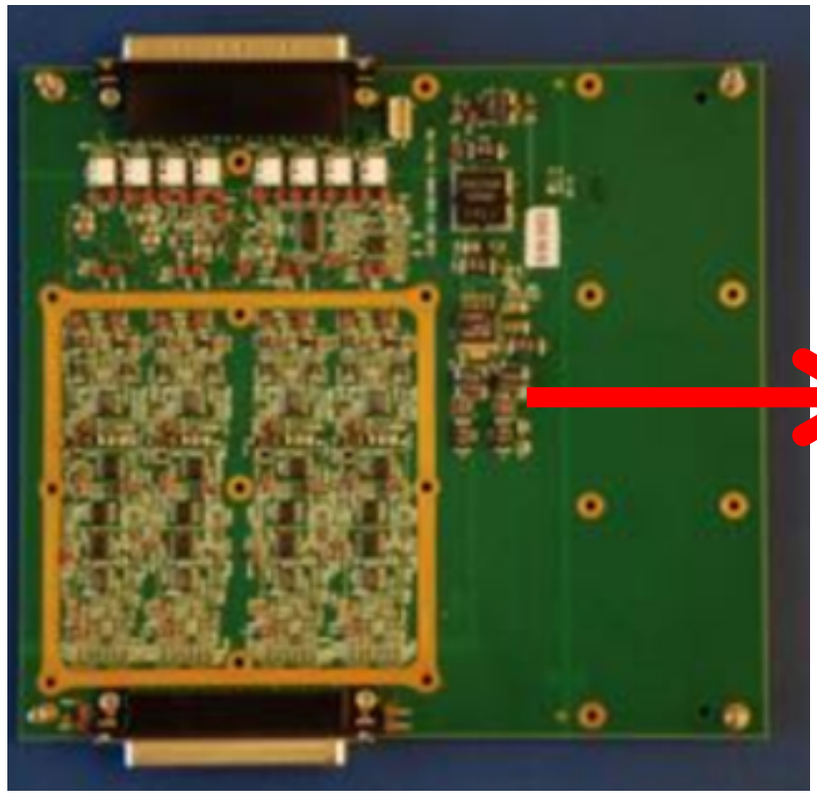
SQUID Controller Unit & Assembly



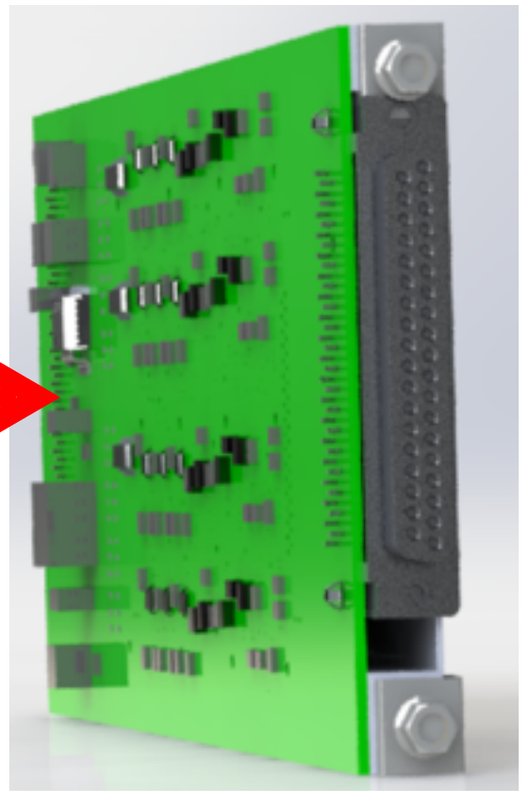


HFT
SQUID
Controller
unit

STDP SQUID
Controller



SQUID Controller
Assembly



- 4 SQUID channels per board
- Same design as previously (TRL5) – mostly needs re-layout
- Heat sinking through the guides and enclosure
- Powered via digitizer assemblies

Multiplexed readout requirements

- Synthesize bias combs
- Tune the detailed operation of the squid
- Digitize the output waveforms
  (before processing the MHz carrier signals into slow ~100 Hz detector timestreams for downlink)

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- Tune the detailed operation of the squid
- Digitize the output waveforms
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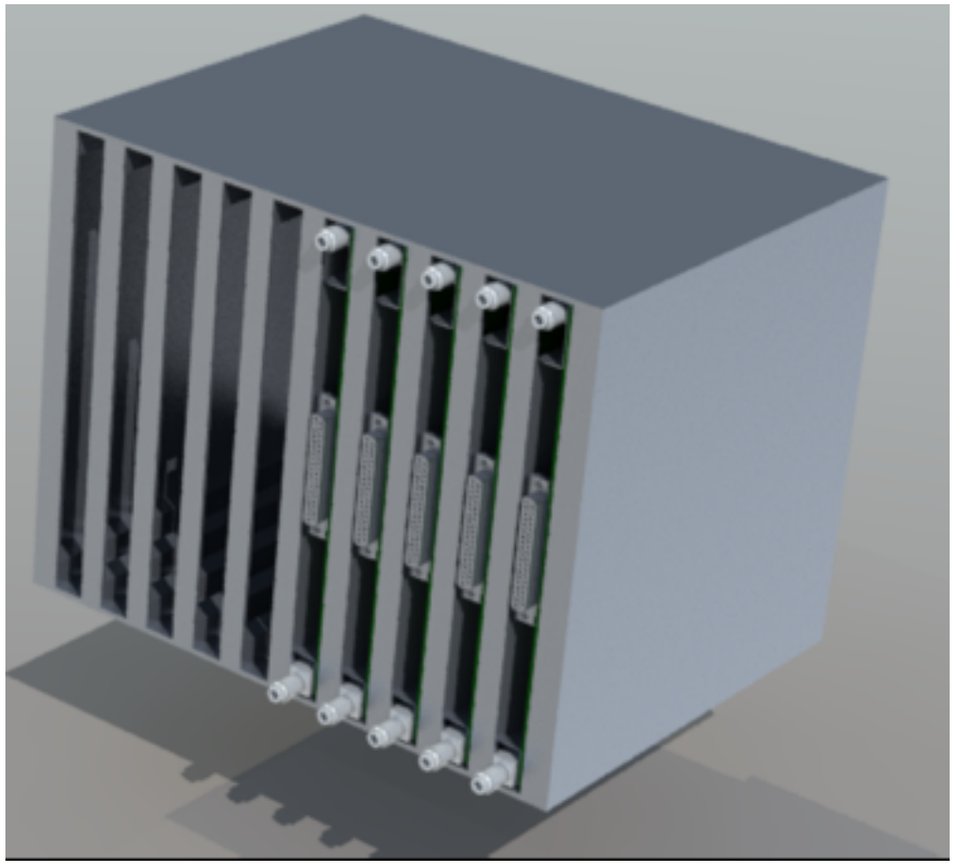
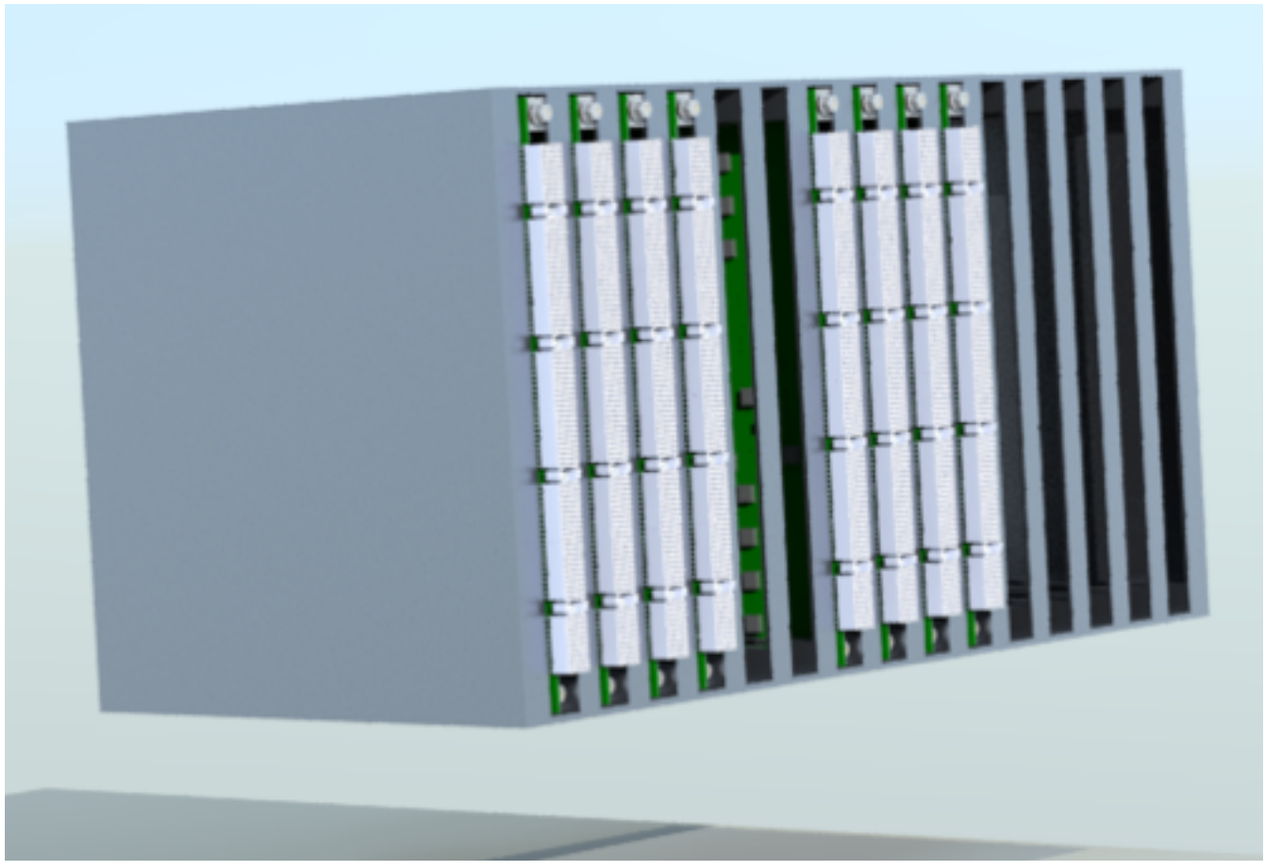
- And for the experts…

Signal Processing Unit



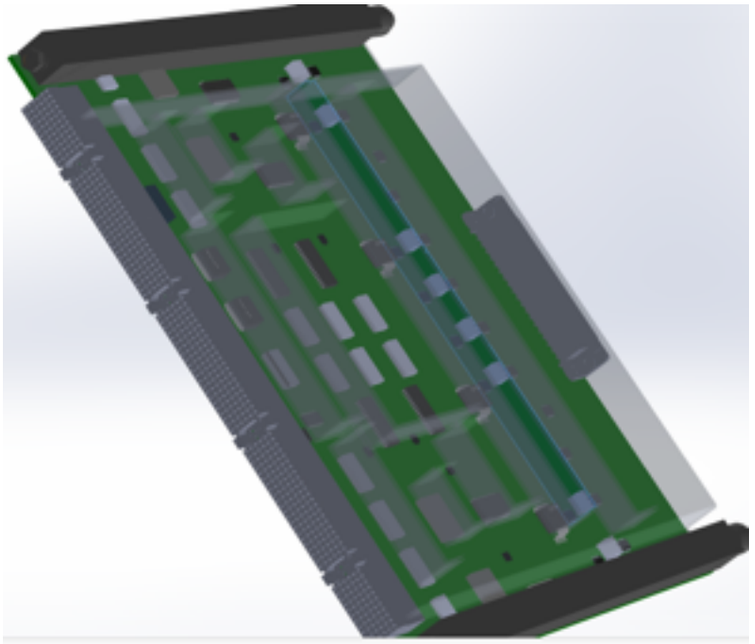


- 6U enclosure with backplane that includes
  - Signal Processing Assemblies (aka FPGA boards)
  - Digitizer Assemblies (DAC/ADC boards)
  - Power Conditioning assembly
  - Instrument controller (TBD)

Digitizer Assembly

Mezzanine (2 channels)

Digitizer Assembly (4 channels)



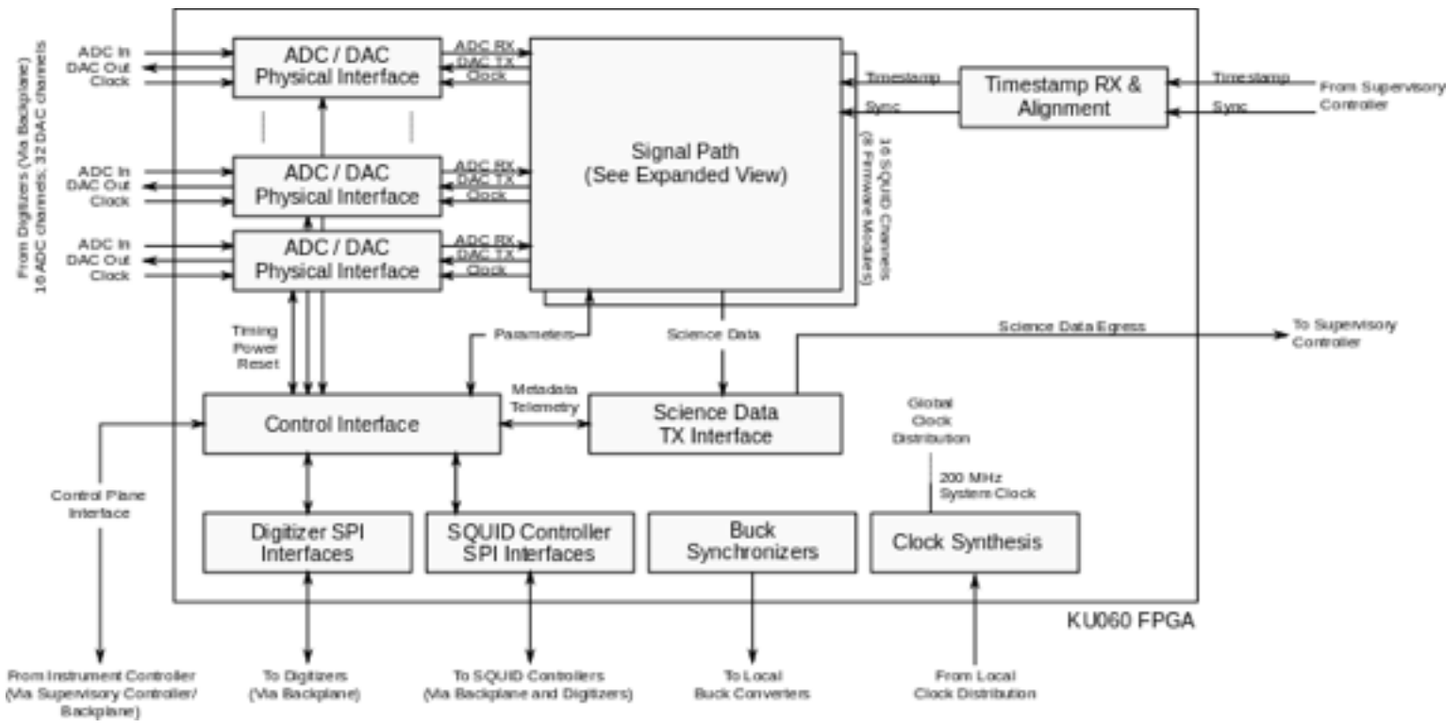
- Update of Mezzanine board (TRL5)
  - 4 SQUID channel/board
  - 6U format with heat-sinking/shield
  - May include use of a lower power DAC
  - Update buffers to FPGA (cross-strapping)

Signal Processing Assembly (aka FPGA board)

- Interfaces the Digitizer's ADC/DAC and processes/captures/compress the data
- 6U format
- Based on the Xilinx Kintex Ultrascale XQRKU060
  - Compatible with total integrated dose (TID) requirements
  - **Need to implement single-event upset (SEU) mitigation (1-2 events/hour) in firmware**
- Heat extraction is a challenge

Firmware

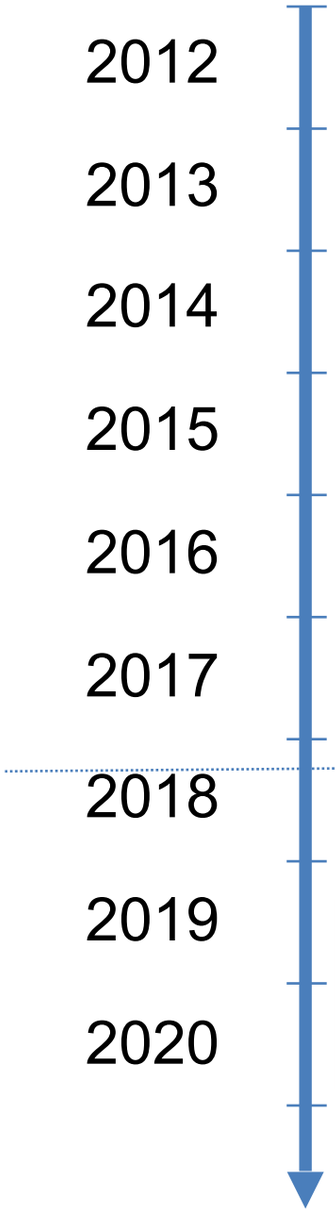
- Based on firmware developed previously
- Use FFT-based demodulator (used in SPT3g)
- Adds LiteBIRD control and data compression
- Add SEU mitigation (TMR, Scrubbing)



Other Assemblies

- **Power Conditionning Assembly (PCA)**
  - Filters and protects the power
  - Generates low-voltage for the other Assemblies
- **Backplane Assembly**
  - Distributes power from PCA to other boards
  - Connects digitizers to FPGAs

Funded Canadian LiteBIRD Activities



2012-2014: **Space Technology Development Program** (STDP)
Developed path-to-flight hardware and firmware

McGill UNIVERSITY COM DEV

2018: **Mission Contribution Study** (MCS) – 8 months
Explore Canadian contribution to mission instrumentation

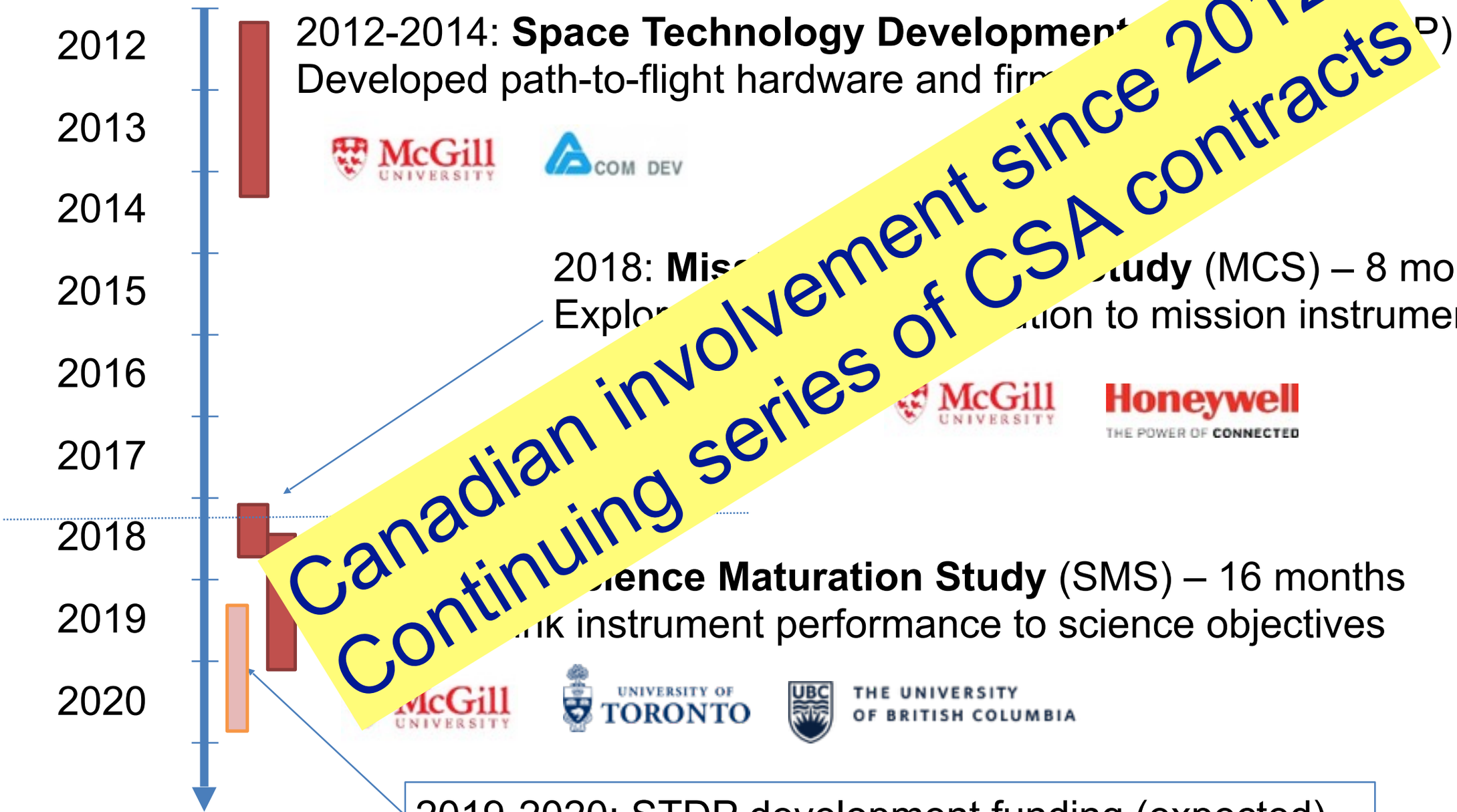
McGill UNIVERSITY Honeywell THE POWER OF CONNECTED

2018-2019: **Science Maturation Study** (SMS) – 16 months
Formally link instrument performance to science objectives

McGill UNIVERSITY UNIVERSITY OF TORONTO THE UNIVERSITY OF BRITISH COLUMBIA

2019-2020: STDP development funding (expected)
For path-to-flight signal processing unit development.

Funded Canadian LiteBIRD Activities



Canadian involvement since 2012
Continuing series of CSA contracts

Canadian LiteBIRD STUDY Team

McGill University

- **Matt Dobbs** (faculty)
- Jean-Francois Cliche (Engineer)
- Graeme Smecher (Engineer)
- Joshua Montgomery (student)

Honeywell Aerospace

(industrial contractor)

- Neil Rowlands (Project Scientist)
- + Project engineers

University of Toronto

- **Renée Hložek** (faculty)
- **Dick Bond** (faculty)
- Simran Nerval (student)
- Victor Chan (student)

University of British Columbia

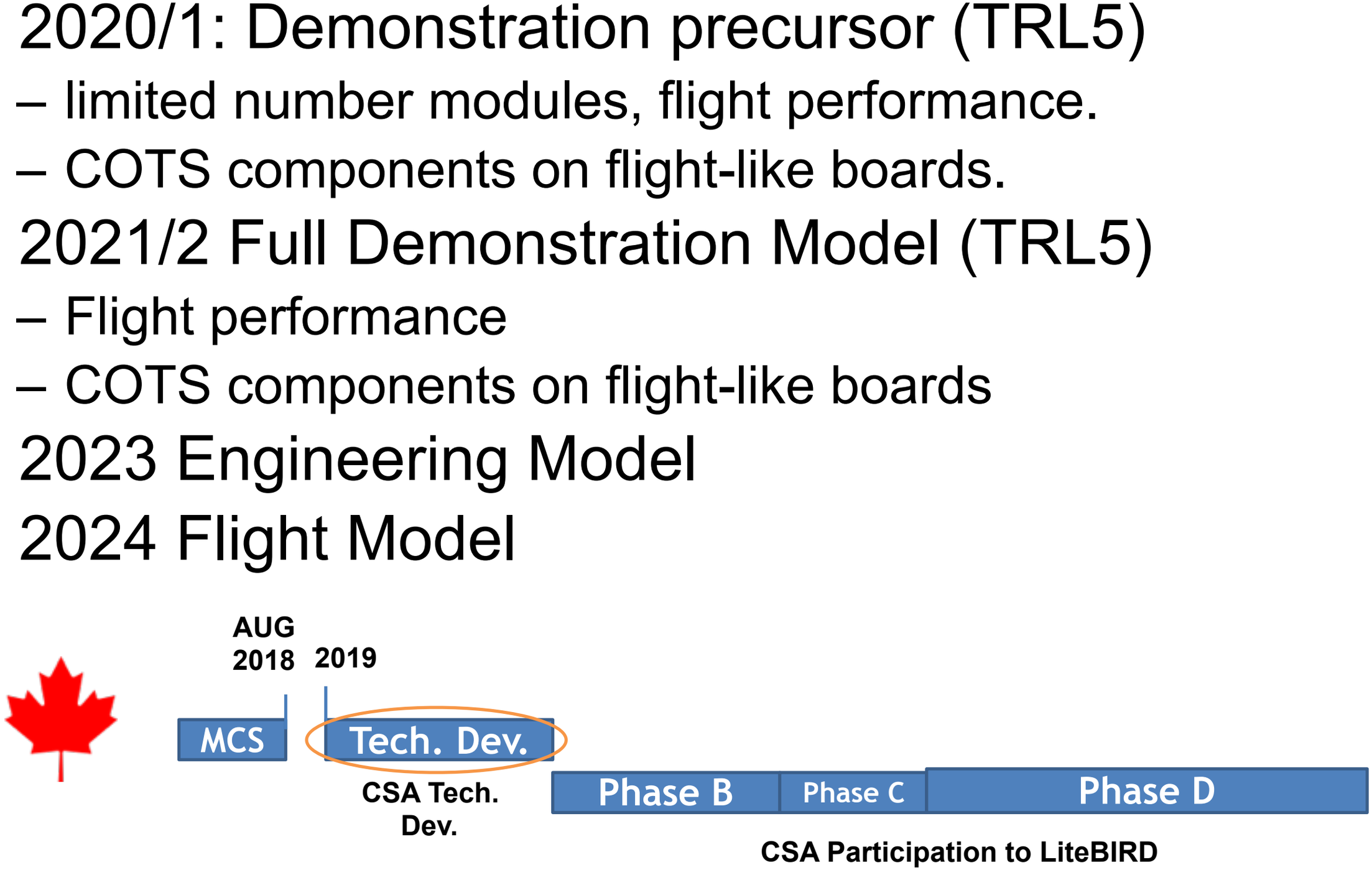
- **Douglas Scott** (faculty)

Mission Studies

- Funded by the Canadian Space Agency (CSA)
- Lead: McGill University
  - Key Engineers: J.-F. Cliche (PM) & Graeme Smecher
- Major Subcontractor
  - Honeywell Aerospace
    - Formerly COM DEV Canada (JWST Canadian Contributor)
- Objectives:
  - Analyse requirements for bolometer warm readout system
  - Preliminary design and risk analysis
  - Measure and simulate performance of readout electronics
  - Assess science goals, requirements and capability in Canada
  - Relate noise and crosstalk to science data quality
  - Provide project lifecycle costing for Canadian LiteBIRD science
- Recently completed mission contribution study (MCS) and presently in midst of study to determine science outcomes and contributions (SMS)

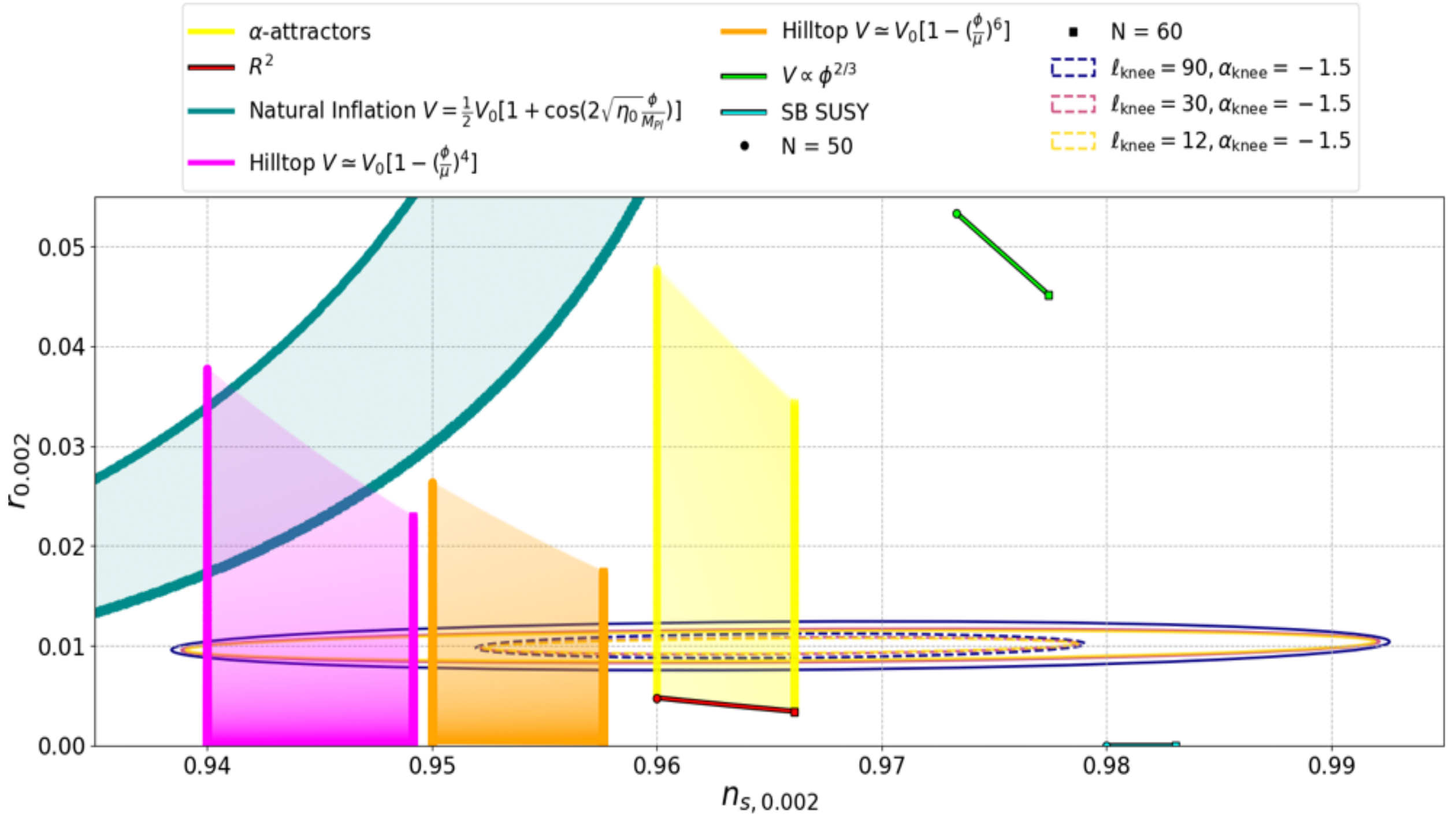
Example Canadian Deliverable Timeline

- 2020/1: Demonstration precursor (TRL5)
  - limited number modules, flight performance.
  - COTS components on flight-like boards.
- 2021/2 Full Demonstration Model (TRL5)
  - Flight performance
  - COTS components on flight-like boards
- 2023 Engineering Model
- 2024 Flight Model



Canadian LiteBIRD science investigations

Start by studying how cross-talk in the electronic systems will affect the systematic errors in our science measurement



How does the LiteBIRD noise model impact models of inflation?

Image from Simran Nerval

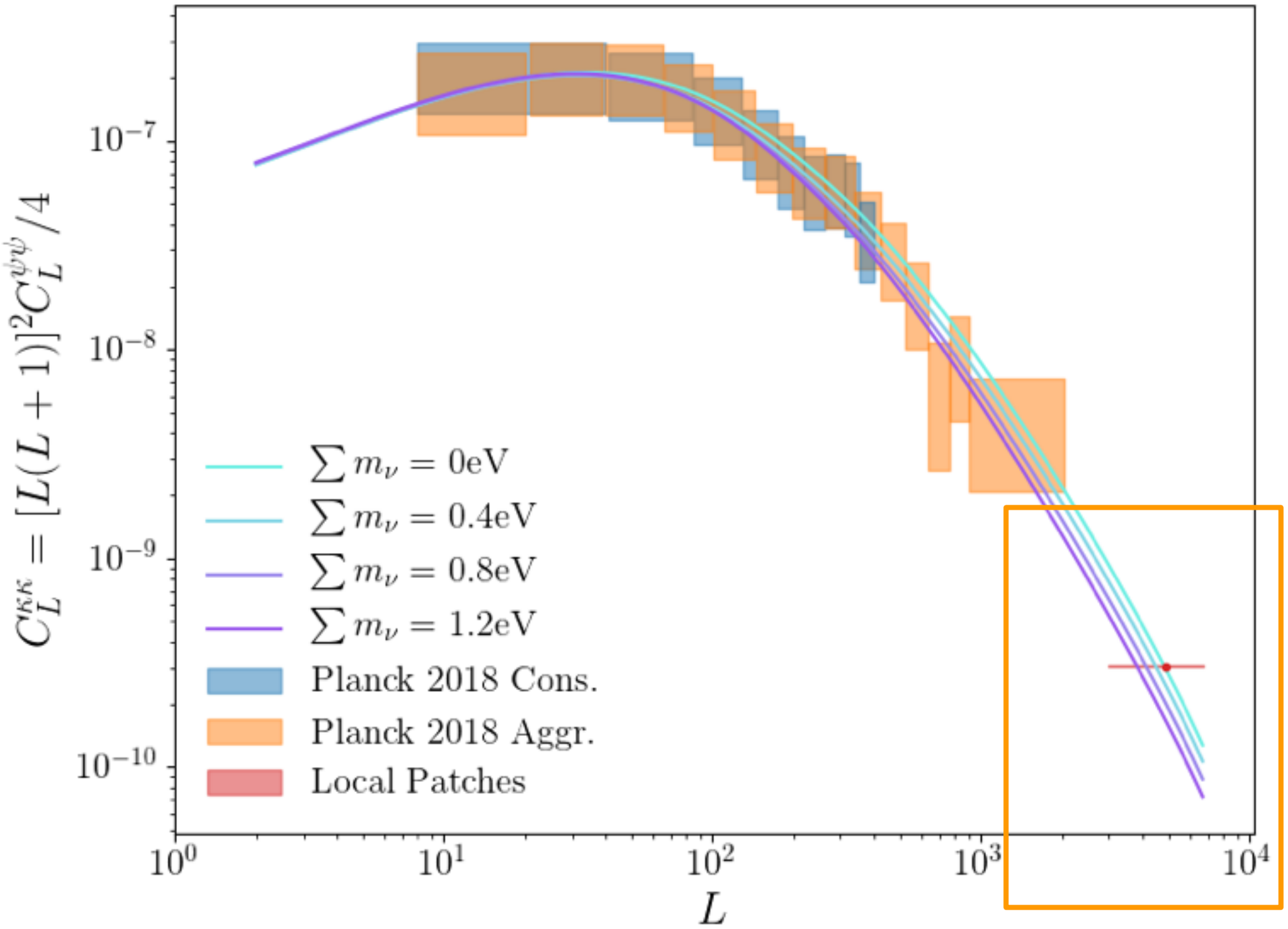
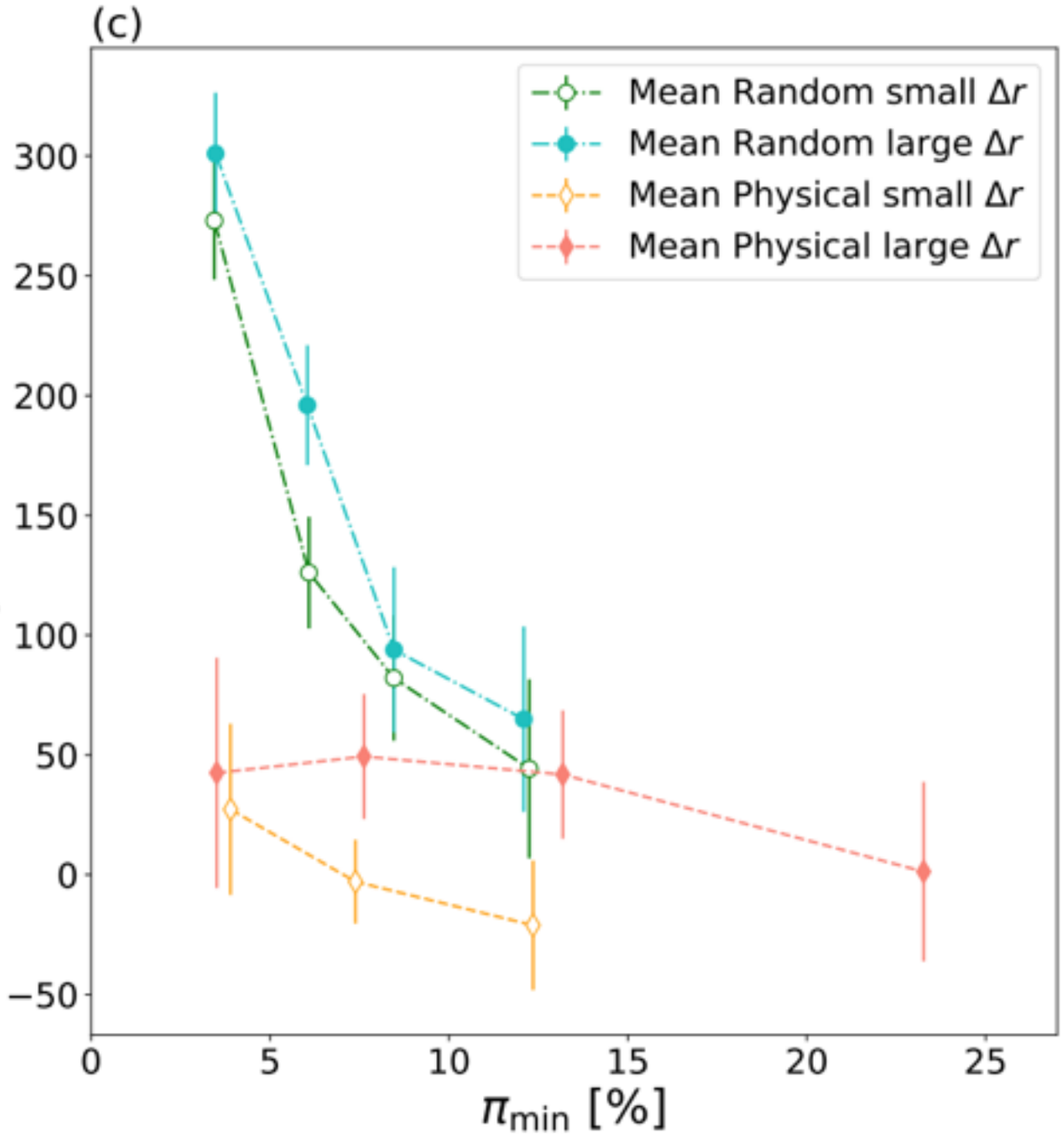
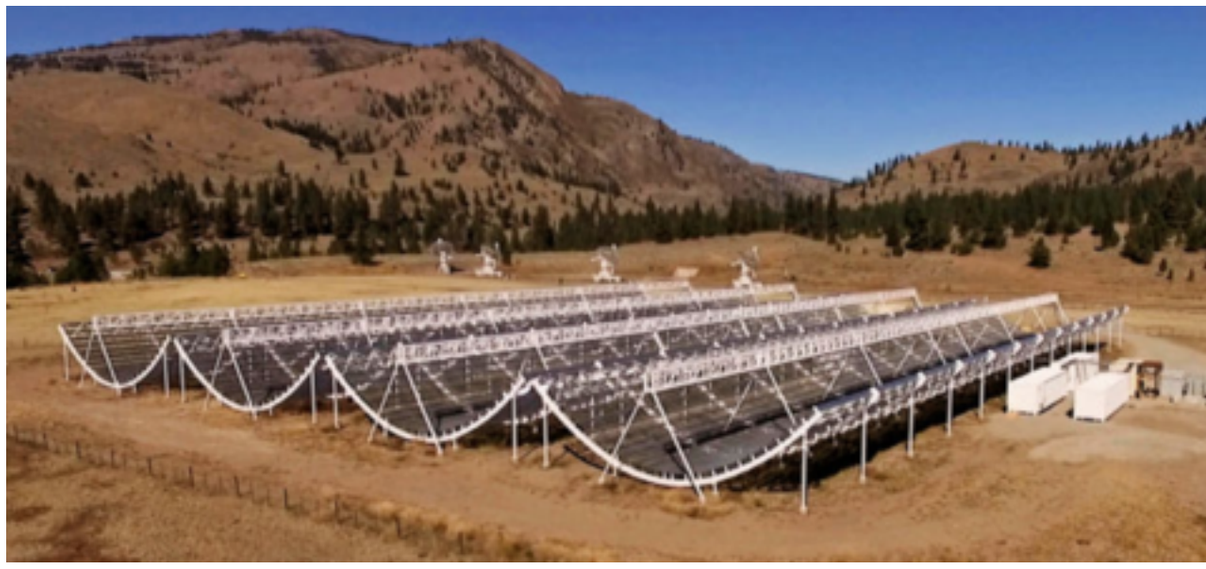


Image from Victor Chan

Can we use high-resolution small-scale measurements from e.g. Simons Observatory to estimate the lensing potential and delens the large scale *B*-modes from LiteBIRD?

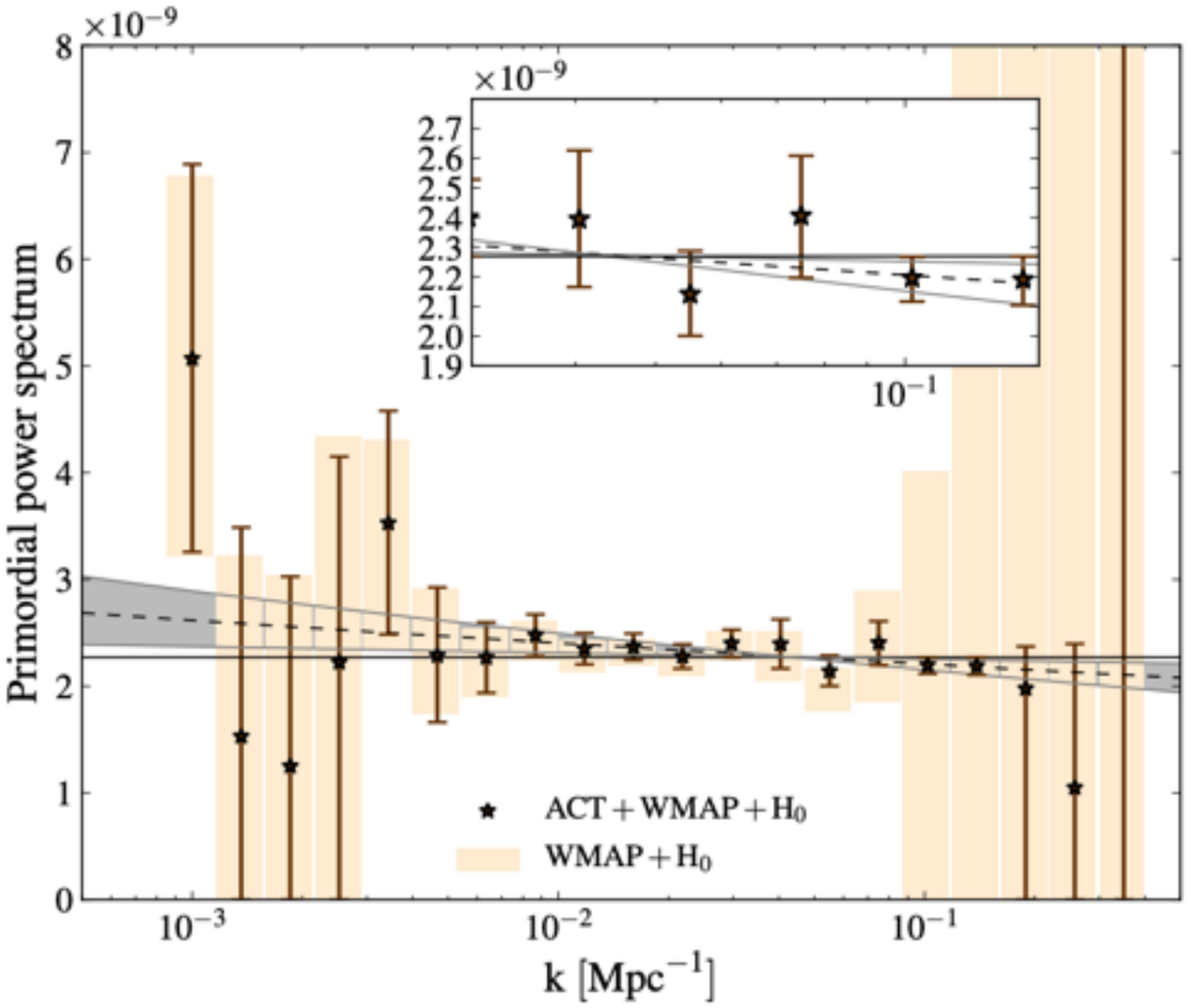


Vernstrom et al. 1905.02410

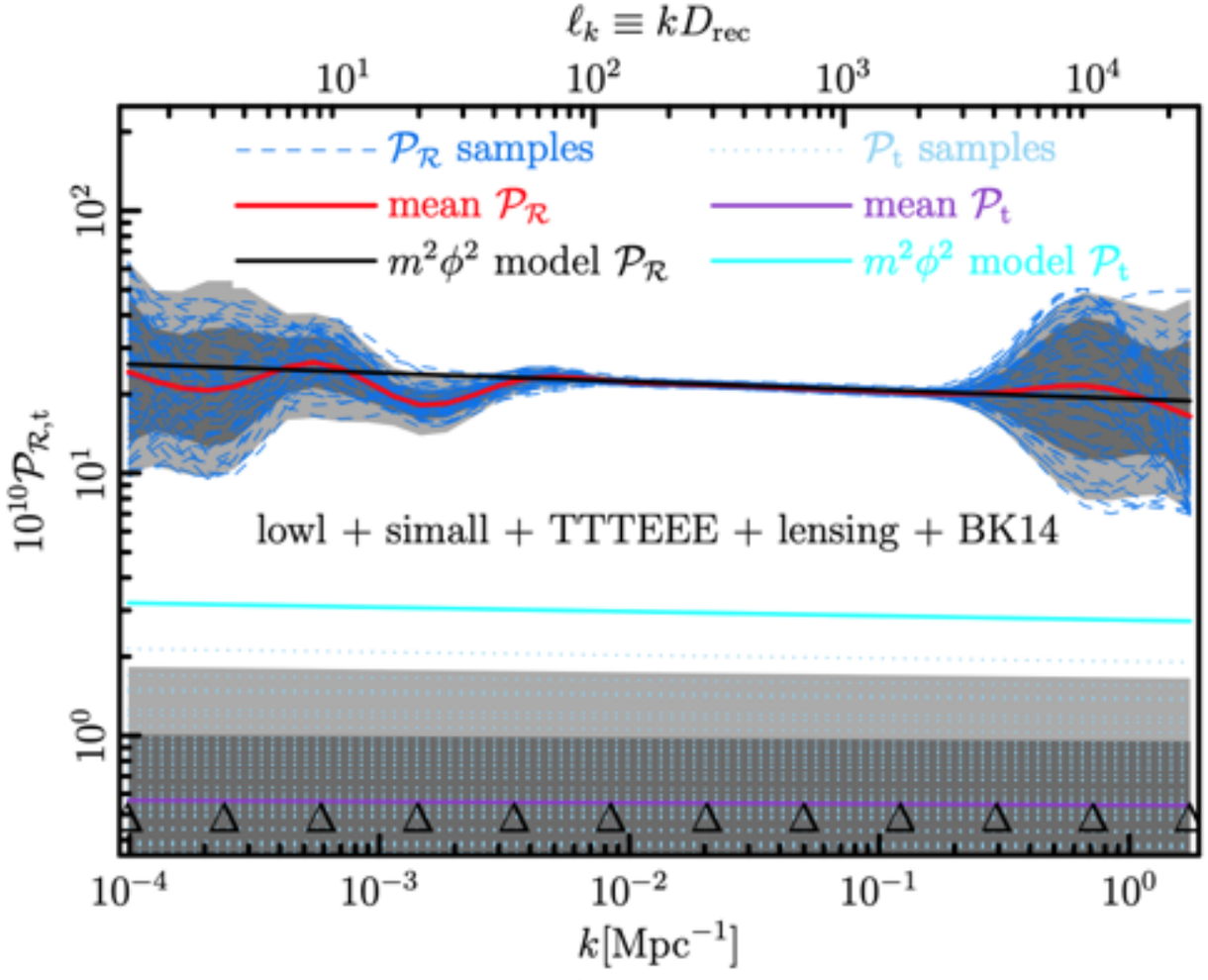


CHIME (Canadian Hydrogen Intensity Mapping Experiment)

Can we cross-correlate independent measurements of the polarisation fraction from radio maps with LiteBIRD to learn more about our own Galaxy?



Hlozek et al. 2012

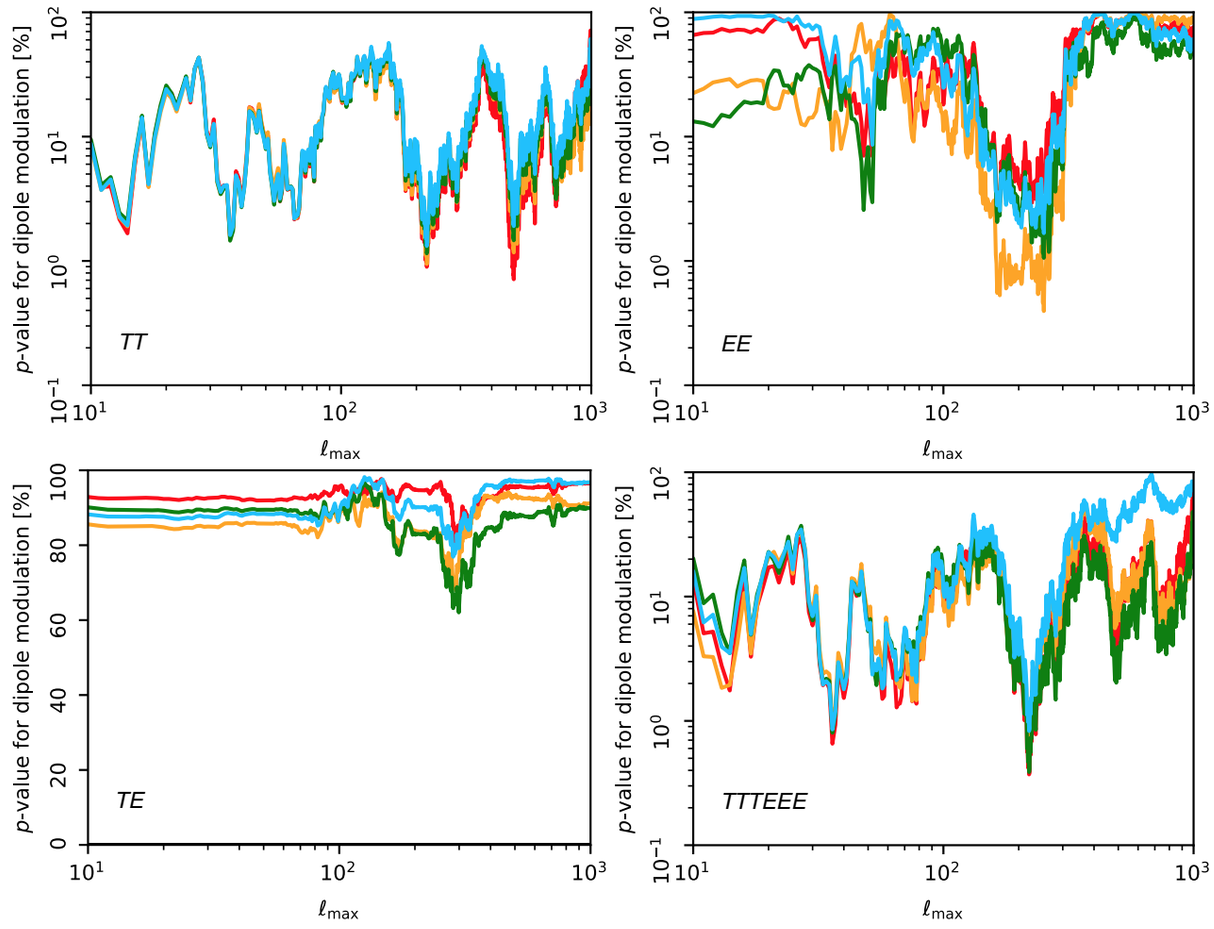


Planck 2018

With exquisite large-scale *B* modes, can we check for consistency of the power on large scales across the sky?

Can we reduce the uncertainty on the model-agnostic *P*(*k*) reconstruction on large scales?

Is the Universe lop-sided?
(i.e. is there a significant hemispheric asymmetry?)



Planck 2018 Tests of dipole modulation of power, including polarization

Planck's polarization sensitivity was not high enough to effectively test large-scale power modulation

With LiteBIRD we should be able to test several large-scale curiosities in *T* data, with independent *E* data

Canadian LiteBIRD contributions

- Canadians have been members of almost all previous CMB experiments

- Canada brings expertise in several areas (multiplexed TES readout, data analysis, cosmological interpretation, Galactic astrophysics, …)

- We are honoured and excited to be part of the next major step for CMB in space …

INTRODUCING LIGHTBIRD

By Franca Posted 15. February 2019 In Brands, Faces, News, Packshots, Press

LIGHTBIRD is a new eyewear brand founded by designer Corrado Rosson, which will premiere at this year's MIDO trade show. The 100% Made in Italy brand comes to the market as a start-up with innovative eyewear models that embody a world full of values for people who are willing to share the same lifestyle.

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→Large-scale Integrated *TEB* Inflationary Relic Detector

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with the help of Italy, France, USA, Canada, …

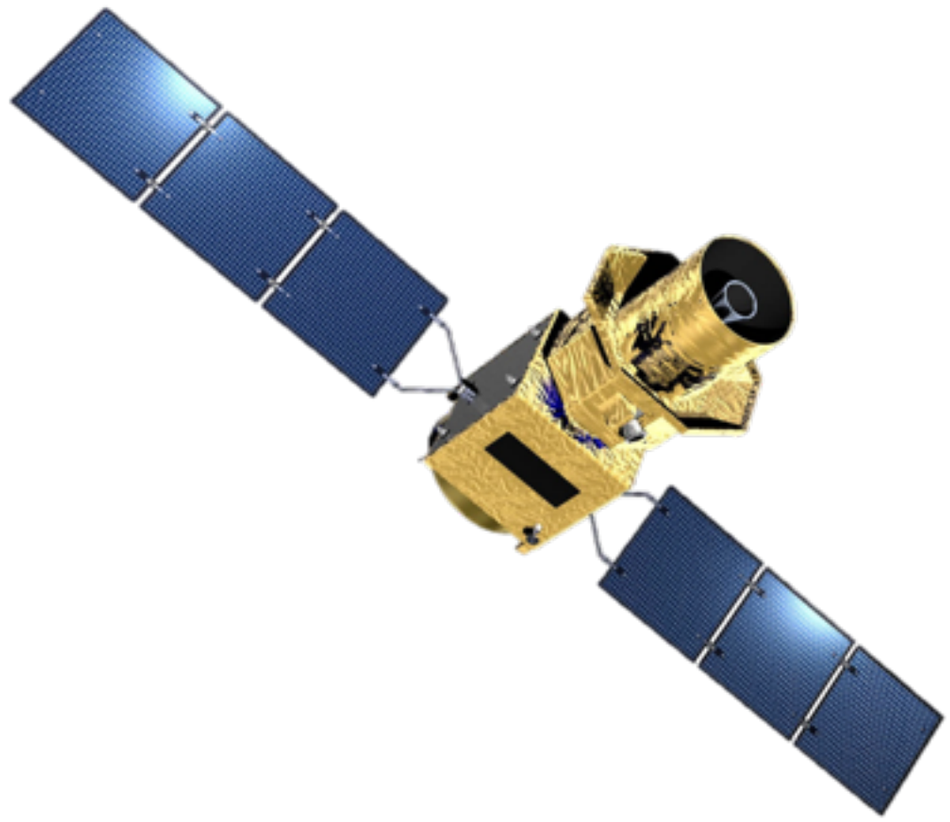
Measure *T*, *E*, *B*

Look at large-scales

→**Large-scale Integrated *TEB* Inflationary Relic Detector**

Extra slides

Canadian LiteBIRD Status

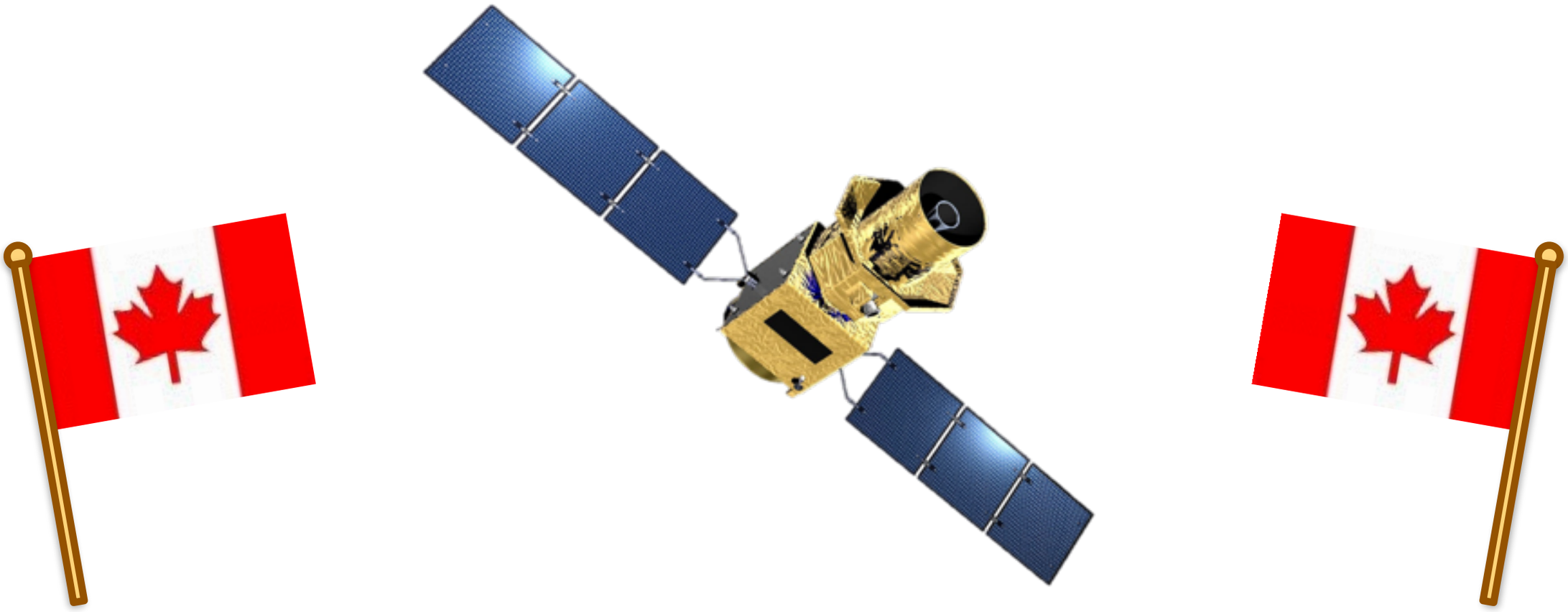


Douglas Scott

on behalf of Canadian LiteBIRD Team

LiteBIRD Kickoff Symposium
ISAS, Tokyo, June 2019

Canadian LiteBIRD Status



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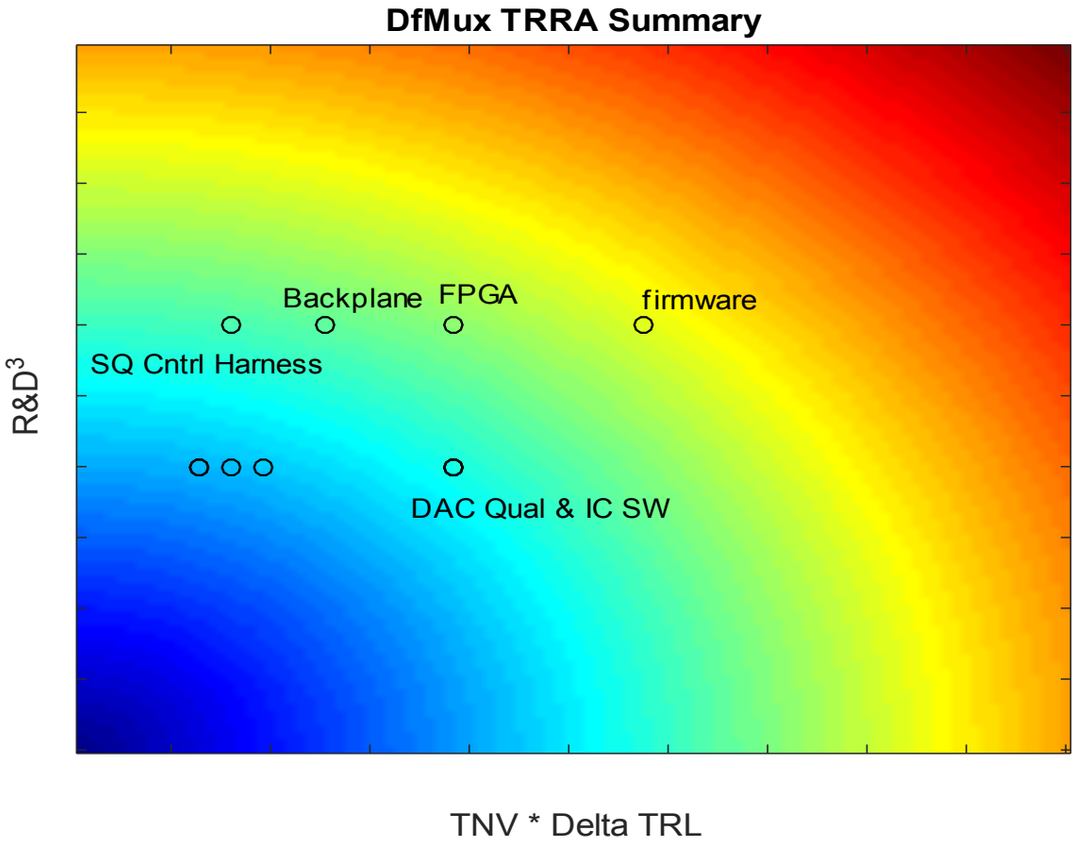
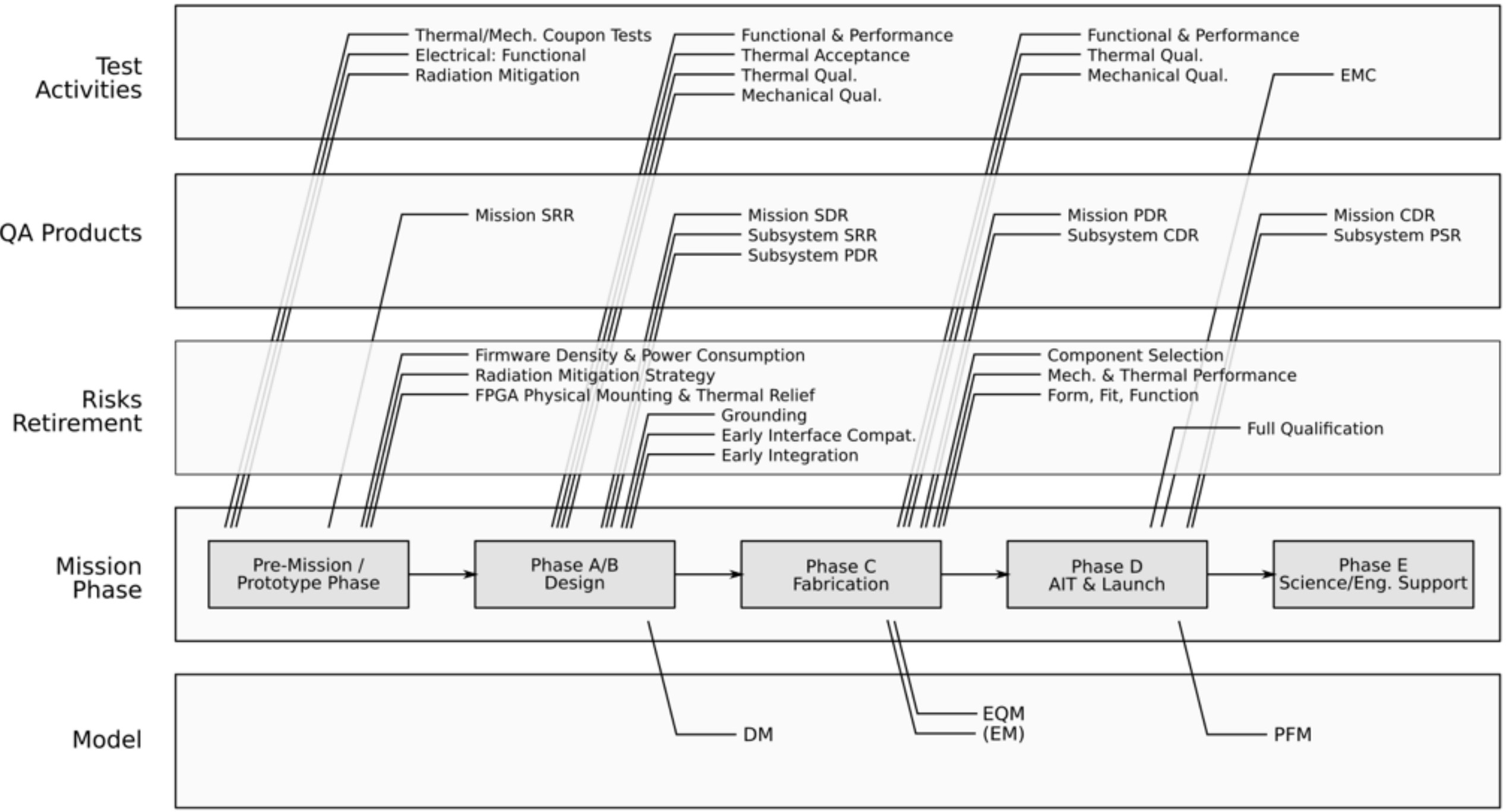
TRRA Summary



TRRA Product Structure Element		TRRA Results									Next Steps		
			TRL			R&D3 Uncertainty	TNV Value	TNV Weighting	TNV*DTRL	Risk	Propososed Development Activities		
PBS ID	Product Breakdown Structure Name	CTE	Previous TRL	Current TRL	Target TRL						Current Activity	TRL Target for Next Activity	Technology Demonstration
1	HFT & LFT Equipment												
1.1	SQUID Controller Unit	N	5	5	6	0.4	5	1.20	0.192	0.44		repeat TRL 5	prototype
1.2	Signal Processing Unit												
1.2.1	Enclosure	N	8	4	6	0.4	1	0.40	0.128	0.42		assist TRL 5	prototype
1.2.2	Digitizer Assembly												
1.2.2.1	Analog to Digital Converter	N		5	6	0.4	4	1.00	0.16	0.43		repeat TRL 5	prototype
1.2.2.2	Digital to Analog Converter	N		4	6	0.4	5	1.20	0.384	0.55		component qual?	EM
1.2.3	Backplane Assembly	Y		4	6	0.6	3	0.80	0.256	0.65		TRL5	prototype
1.2.4	Signal Processing Assembly												
1.2.4.1	Primary FPGA	Y		4	6	0.6	5	1.20	0.384	0.71		TRL4	prototype
1.2.4.2	Signal Processing Firmware	Y		3	6	0.6	5	1.20	0.576	0.83		TRL4	prototype
1.2.4.3	Supervisory FPGA & Firmware	N		6	6	0.4	2	0.60	0	0.40		TRL6	EM / EQM
1.2.5	Instrument Controller Assembly												
2.2.2.1	CPU	N		6	6	0.4	2	0.60	0	0.40			
2.2.2.2	Boot Loader Software	N		6	6	0.4	2	0.60	0	0.40			
2.2.2.3	Application Software	Y		3	6	0.4	3	0.80	0.384	0.55		TRL4	DM
2.2.2.3	Operating System Software	N		6	6	0.4	2	0.60	0	0.40			
1.2.6	Power Conditioning Assembly	N		3	6	0.4	3	0.80	0.384	0.55		TRL4	EM
1.3	SQUID Controller Harness	Y		5	6	0.6	4	1.00	0.16	0.62			prototype
1.4	Digitizer Harness	N		4	6	0.4	1	0.40	0.128	0.42		TRL6	EM / EQM

Development Approach



Summary

- Mission Contribution Study and Costing complete.
  - Need to investigate cost reduction scenario in parallel with international efforts.
    - Most of cost is in large number of models (pre-DM, DM, EM, FM).
- Technology development for pre-DM going forward this spring.
  - no near-term slow-down
- Mission status decision planned for 2020/2021.
  - Close contact between JAXA/ESA/NASA and CSA essential.