

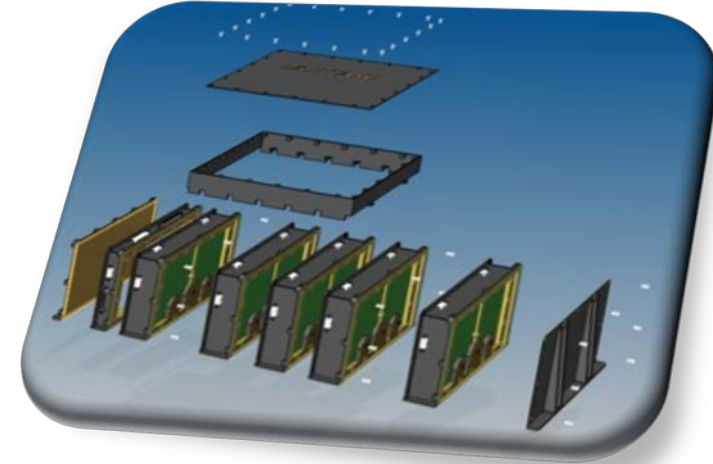
# MUSTANG Applications

## Modular Avionics

IEEE Space Computing Conference

Pasadena, CA July 30 – August 1 2019

Art Azarbarzin



**July 30 – August 1, 2019**

NASA Goddard Space Flight Center

**Electrical Engineering Division**





# Acronym List



ACE	Attitude Control Electronics	EGSE	Electrical Ground Support Equipment	IRAD	Internal Research and Development
ACS	Attitude Control System	EMI	Electromagnetic Interference	ISS	International Space Station
ADC	Analog to Digital Converter	ETU	Engineering Test Unit	JPL	Jet Propulsion Laboratory
ASIC	Application Specific Integrated Circuit	EVD	Engine Valve Driver	JTAG	Joint Test Action Group
BC/RT/BM	Bus Controller, Remote Terminal, Bus Monitor	FDC	Fault Detection and Correction	LCRD	Laser Communications Relay Demonstration
C&DH	Command and Data Handling	FPGA	Field Programmable Gate Array	LVDS	Low Voltage Differential Signal
CM	Control Module	GEDI	Global Ecosystem Dynamics Investigation	MAIA	Multi-Angle Imager for Aerosols
COMM	Communications	GB	Gigabyte	MB	Megabyte
DAU	Data Acquisition Unit	GPM	Global Precipitation Mission	Mbps	Megabits Per Second
DDR	Double Data Rate	GSFC	Goddard Space Flight Center	Mbit	Megabit
DSB	Data Storage Board	HK	Housekeeping	MCE	Mechanism Control Electronics
DTN	Delay Tolerant Networking	HM	Heater Module	MHz	Megahertz
DRAM	Dynamic Random Access memory	I2C	Inter-Integrated Circuit	MMS	Magnetospheric Multiscale Mission
EDAC	Error Correction and Detection	ICDU	Instrument Command and Data Handling Unit	MRAM	Magnetoresistive Random Access Memory
EDU	Engineering Development Unit	ILLUMA-T	Integrated LCRD LEO User Modem and Amplifier Terminal	MSFC	Marshall Space Flight Center
EEPROM	Electrically Erasable Programmable Read-Only Memory	IO	Input Output	MUSTANG	Modular Unified Space Technology Avionics for Next Generation



# Acronym List



mW	Milli Watt	S/C	Spacecraft
NASA	National Aeronautics and Space Administration	SAM	Solar Array Module
NICER	Neutron star Interior Composition Explorer	SERDES	Serializer/Deserializer
NVRAM	Nonvolatile Random Access memory	SM	Segment Module
O2O	Optical to Orion	SPARC	Scalable Processor Architecture
OCI	Ocean Color Instrument	SpW	SpaceWire
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem Mission	SRAM	Static Random Access memory
PROC	Processor	SSR	Solid State Recorder
PSE	Power System Electronics	SUROM	Startup Read Only Memory
OM	Output Module	TBR	To Be Resloved
PCU	Power Converter Module	Tbits	Terabits
PM	Power Module	TCC	Thermal Control Card
PMC	Power Monitor Card	TX	Transmit
PROM	Programmable Read Only Memory	XAUI	10 Gigabit Media Independent Interface)
RMAP	Remote Memory Access Protocol	UART	Universal Asynchronous Receiver/Transmitter
RX	Receive	WFIRST	Wide Field Infrared Survey Telescope

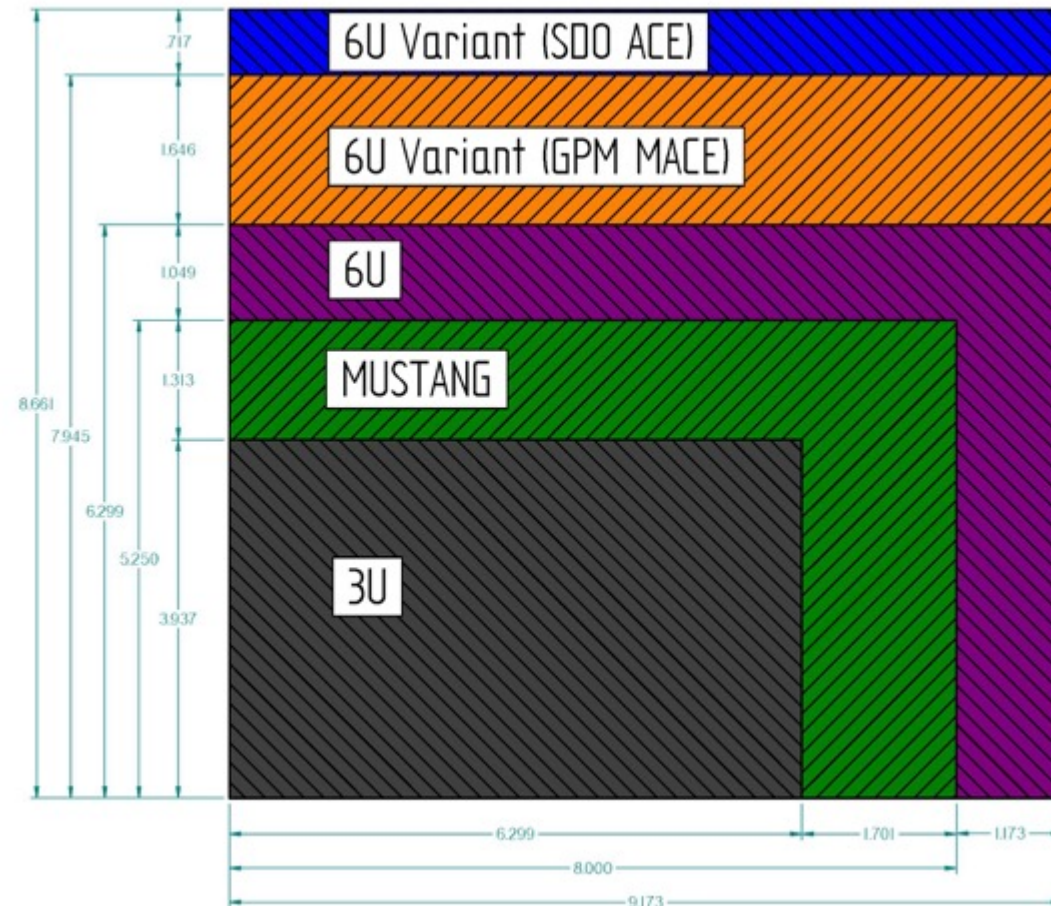


# What is MUSTANG?

(Modular Unified Space Technology Avionics for Next Generation)



- A form factor for building future avionics/electronics small/mid size instruments and spacecraft
  - 5.25" x 8" (board size)
- No-backplane; enables size optimization for available volume and mix and match the portfolio of the card designs to meet the mission needs
  - 22 designs
- Circuits and designs can be re-laid out for larger Flagship class missions (and less frequent) that currently envision needing larger 6U cards
  - WFIRST (GSFC Mission) has re-laid out two boards worth of circuits into one 6U-220 in a Modular Form (GPM size boards shown in **orange**)



Note; Acronym list will be provided at the time of presentation



# MUSTANG General Status 6/25/2019



	MUSTANG design portfolio	Design Heritage	Programs Baselined	Design	Schematic	Layout	FPGA	EDU Assy Completion	EDU Test Completion	Comments
1	Processor (PROC)	IRAD	PACE/OCI/MAIA	100%	100%	100%	100%	✓ Complete	✓ Complete	6 Processors built and delivered (2 for MAIA); Processor #2 completed Vibe and Tvac. <b>Flight Unit under test</b>
2	Communication (COMM)	MMS, LRO, GPM/SDO	PACE	100%	100%	100%	80%	✓ Complete	✓ Complete	Flight build planned for Spring 2020
3	Housekeeping (HK)	MMS	PACE/OCI/MAIA	100%	100%	100%	100%	✓ Complete	✓ Complete	<b>Flight Unit under test</b>
4	Engine Valve Drive (EVD) &Deployment	MMS	PACE	100%	100%	100%	100%	✓ Complete	✓ Complete	Flight build planned for Spring 2020
5	Power Monitor Card (PMC)	MMS/GPM	PACE/WFIRST	100%	100%	100%	100%	✓ Complete	✓ Complete	
6	Output Module (OM) B2C	MMS/GPM	PACE/OCI/WFIRST	100%	100%	100%	NA	✓ Complete	✓ Complete	Flight Build on progress
7	Low Voltage Power Converter (LVPC) B2C and I2C	MMS	PACE/OCI/MAIA/WFIRST	100%	100%	100%	NA	✓ Complete	✓ Complete	<b>Flight Unit under test</b>
8	Segment Module (SM)	LRO, SDO, MMS, GPM	PACE	100%	100%	100%	NA	✓ Complete	✓ Complete	Flight build planned for Spring 2020
9	Solar Array Module (SAM)	MESSENGER/STEREO	PACE/WFIRST	100%	100%	100%	NA	✓ Complete	✓ Complete	
10	Data Storage Board (DSB)	MMS	PACE/MAIA	100%	100%	100%	100%	✓ Complete	✓ Complete	<b>Flight Unit under test</b>
11	Attitude Control System IO (ACS IO)	GPM	PACE	100%	100%	100%	100%	✓ Complete	✓ Complete	Flight build planned for Spring 2020
12	Mechanism (MCE)	GPM	PACE/OCI	100%	100%	100%	100%	✓ Complete	✓ Complete	Flight Build on progress
13	Deployment B2C and I2C	MMS	PACE/OCI	100%	100%	100%	NA	✓ Complete	✓ Complete	Flight build planned for Spring 2020



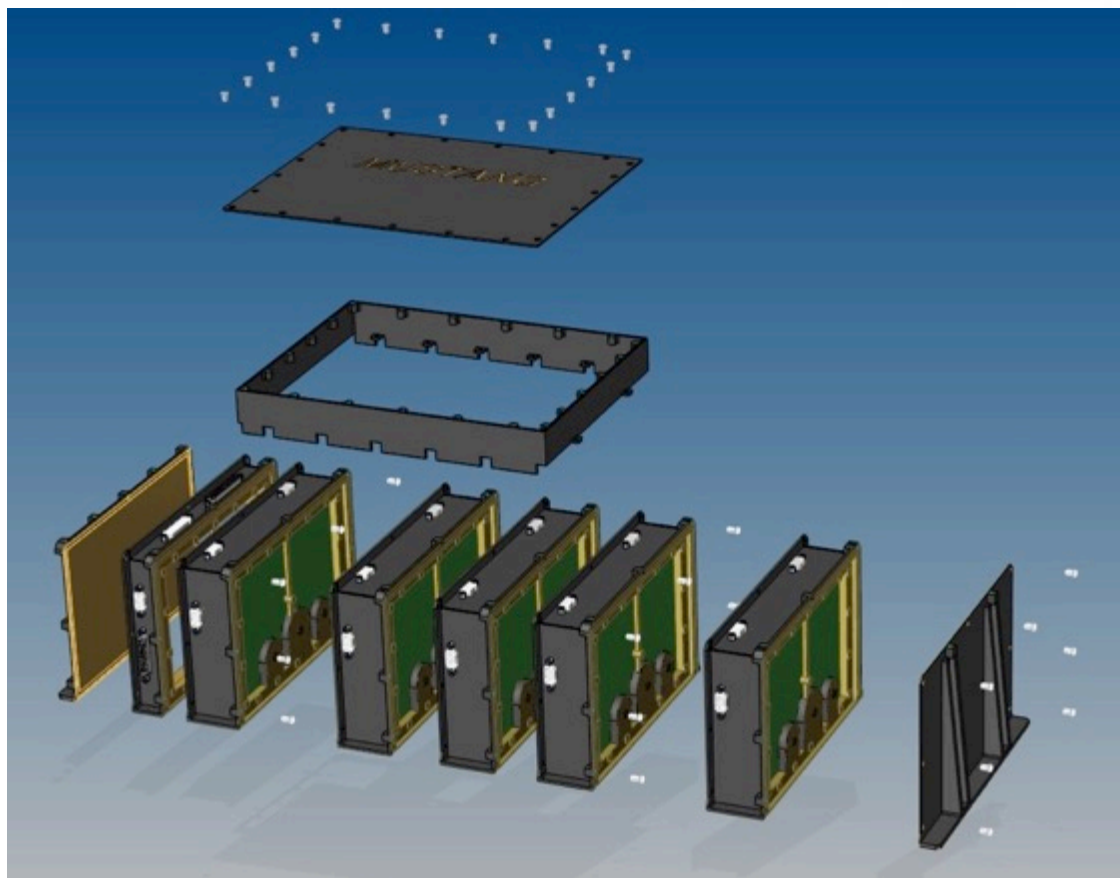
# MUSTANG General Status 6/25/2019 (cont'd)



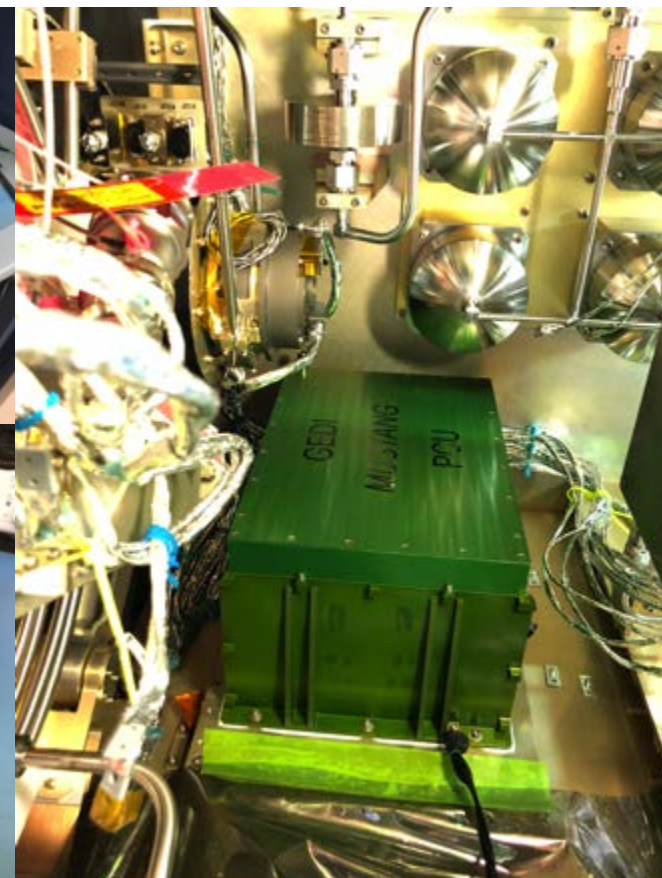
	MUSTANG design portfolio	Design Heritage	Programs Baselined	Design	Schematic	Layout	FPGA	EDU Assy Completion	EDU Test Completion	Comments
14	Dark Star	IRAD	OCI/GEDI	100%	100%	100%	NA	✓ Complete	✓ Complete	
15	Digital I/O (M1)	LCRD/SpaceFrame	PACE/OCI	100%	100%	100%	100%	✓ Complete	✓ Complete	Generic FPGA code for testing complete. Application specific depends on mission.
16	Thermal Control Card (TCC)	TIRS	PACE/OCI	100%	10%	100%	100%	✓ Complete	✓ Complete	Flight build planned for Spring 2020
17	Heater Module (HM)/I2C	MMS	OCI/MAIA/WFIRST	100%	100%	100%	NA	✓ Complete	✓ Complete	Flight Unit under test
18	PPT Controller	MESENGER	*	100%	100%	100%	NA	✓ Complete	✓ Complete	* Designed for WFIRST
19	PPT Power Card	MESENGER	*	100%	100%	100%	NA	✓ Complete	✓ Complete	* Designed for WFIRST
20	OM I2C	MMS	PACE/WFIRST	100%	100%	100%	NA	✓ Complete	✓ Complete	
21	Application Specific DarkStar	IRAD	OCI	100%	100%	100%	NA	✓ Complete	✓ Complete	Flight build planned for Spring 2020
22	ISS Power Convertor Unit (120 to 28 V plus distribution) 2 modules PM and CM	NICER	GEDI/ILLUMA-T/O2O	100%	100%	100%	NA	✓ Complete	✓ Complete	Flight Unit for GEDI on ISS since Nov 2019
	<b>Future Plans</b>									
	DTN Card(Integrating DSB & Proc designs)									
	Processor upgrade with HPSC chiplet upgrade									
	High Voltage Card									
	Custom ADC (for multi-channel Instruments)									



# GEDI Flight PCU with EMI cover (operating on ISS since Nov 2018)



**GEDI Flight Unit**





# MUSTANG Processor Card Features (Dual Leon 3)



## – GR712RC Dual-Core LEON3FT SPARC V8 Processor ASIC (200 MIPS)

- Memory controller for SRAM, PROM, MRAM, and parallel IO (FPGA)
- 6 UARTS, GPIO, 6 SpW ports - 2 with RMAP, 1553 BC/RT/M
- 1.8V Core Voltage

## – RTG4 Catch all FPGA

- FLASH memory controller with onboard EDAC
- Time Management and Distribution with external clock input
- 2 additional SpW ports with RMAP
- Watchdog and other FDC
- LEON3 Core for CFDP
- 10 Mb ETHERNET Core available with IPLEON3
- **Up to 20 LVDS/RS422 Discrettes**
- 1.2V FPGA Core Voltage

## – General

- Up to 32 MB SRAM (16 MB Shared SRAM with FPGA)
- 8-16 GB FLASH, 8 MB MRAM (EEPROM functionality), 64K PROM
- **Daughter card capability with custom functionality**

## – Mass: 0.986 Kg

## – Power: 12.6W full card. Can be tailored to lower power per application depending on clock frequency and IO needed.

## – Volume: 2"W x 7.24"H x 9.605"D







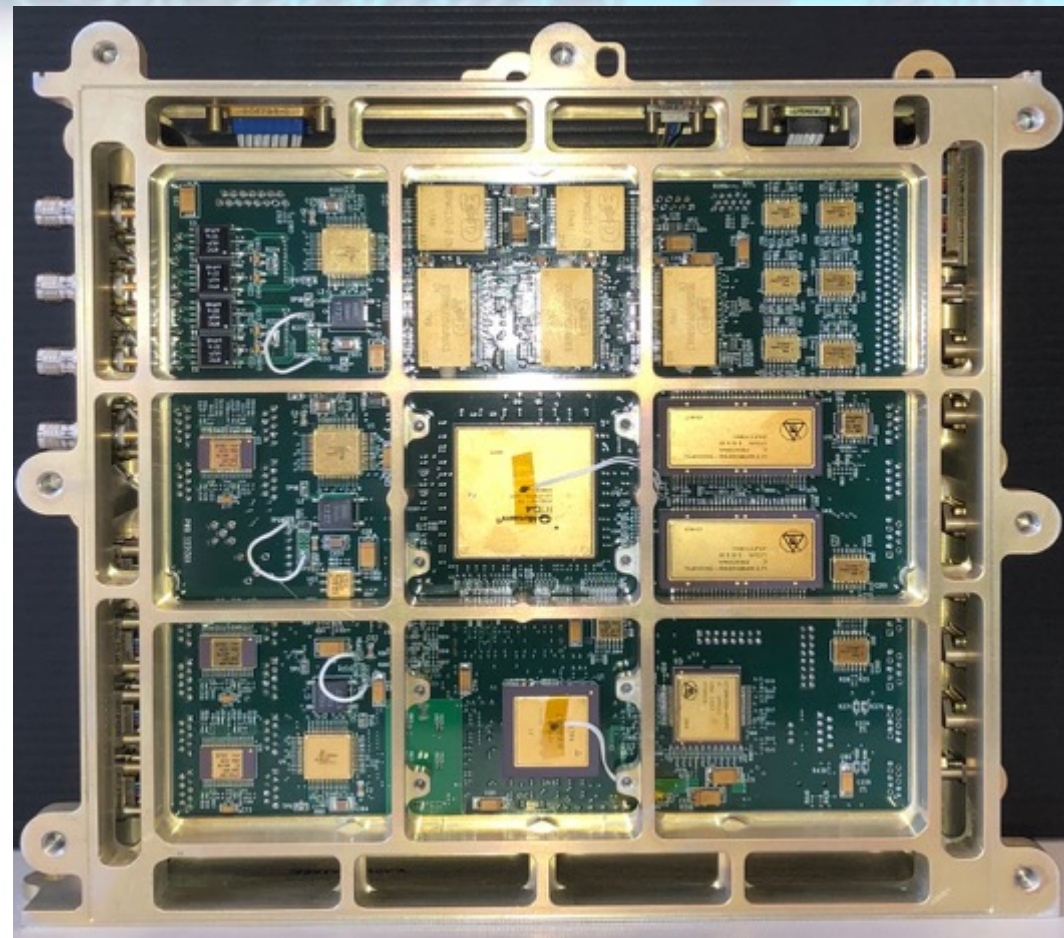
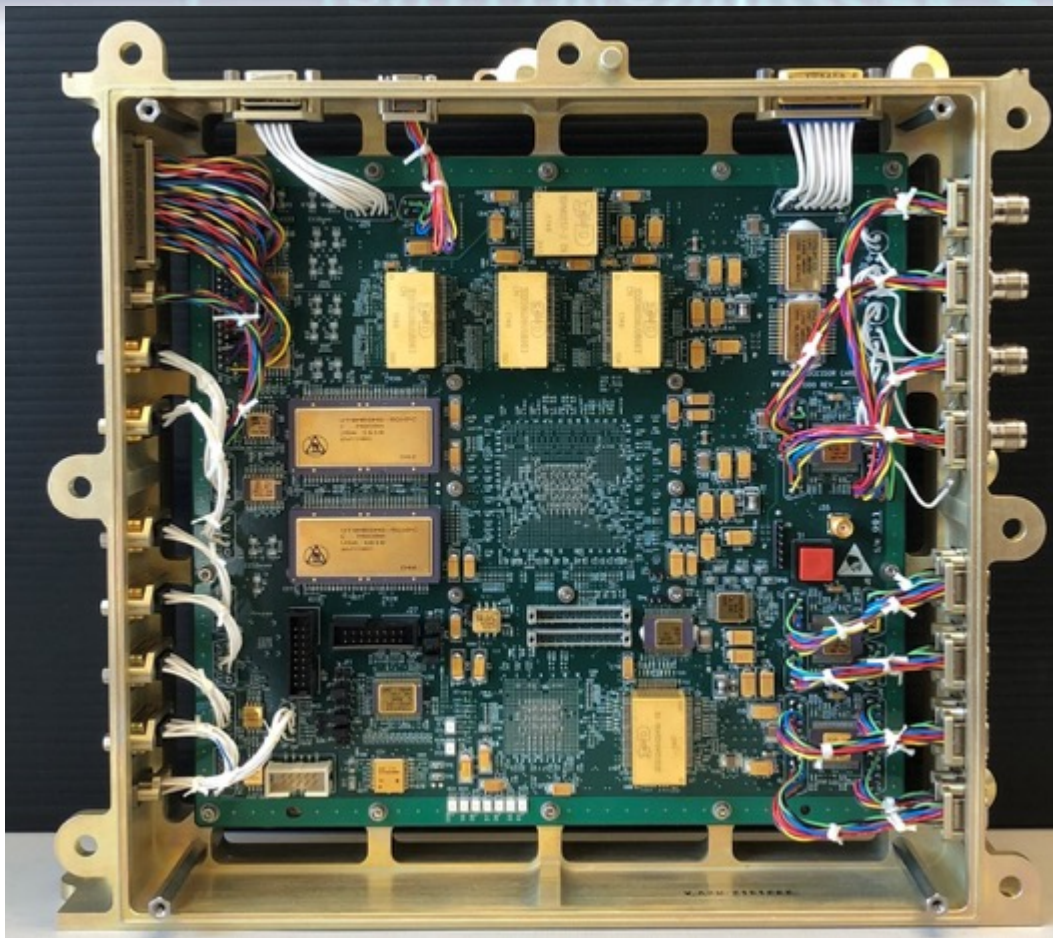
# MUSTANG Processor Design upgraded for WFIRST Mission



- Quad Leon 4 ASIC (MUSTANG + size module form factor)- Board size 6U-220
    - 3 Engineering Board assembled tested; 1 delivered to the JPL Coronagraph Team to be used in the Instrument for a tech Demo on WFIRST Observatory (2 more deliveries planned for JPL)
  - MUSTANG Team is planning on lifting the Quad Leon 4 design/layout and create an upgraded version of MUSTANG Processor Card
  - WFIRST Processor Board features listed below
- 
- Processor: GR740, Quad Core LEON4 SPARC V8 Processor and 250MHz-Rev 1
  - FPGA: RTG4
  - SUROM 64KB
  - SDRAM 256MB(+128MB FEC)
  - DDR2 4GB(+2GB FEC)
  - MRAM 2X16MB
  - Oscillator QT194(50MHz)+QT2020
  - Peripherals:
    - SpaceWires: 20(8 GR740,12 RTG4)
    - 1553B: 1(1 GR740)
    - RS422: 16 TX and 16RX
    - UART: 3 (2 GR740,1 RTG4)
    - Debug ports: SPW Debug port and RTG4 JTAG



# WFIRST Processor Board; Quad Leon 4

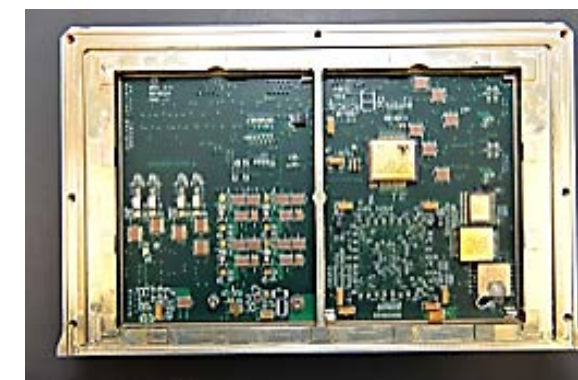
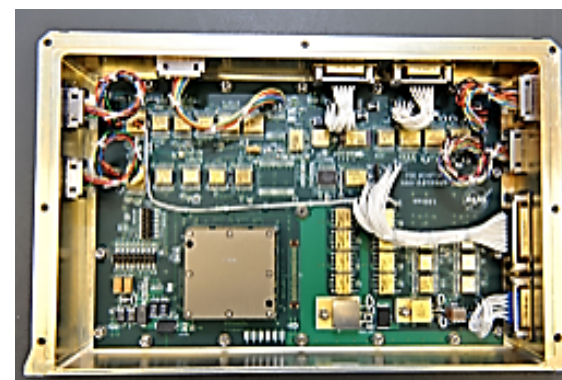




# Digital I/O Card Features (SERDES 3.125 Gbits)



- Unbuffered SERDES, from RTG4
  - 16 pairs xmit, 16 pairs rec.
  - Each pair capable of 3.125 Gbits
  - Each set of 4 pairs can be used in XAUI mode (10G Ethernet)
- LVDS and/or RS422
  - 20 pairs in / 20 pairs out
  - Splits between LVDS and RS422 every 4 pairs (one chip handles 4 pairs)
  - LVDS 100 MHz, RS422 10 Mbps
- LVDS using repeaters
  - High speed LVDS from RTG4
  - 36 pairs in, 18 pairs out, 200 MHz rate
- DDR2 memory, Two independent banks, 128Mx32, 4 Gbit
- SRAM memory, 8Mx32, 256 Mbit
- MRAM memory, 4Mx32, 128 Mbit
- RTG4 150 FPGA
- Mass; 1.070 Kg
- Volume; 2.5"W x 7.24"H x 9.605"D
- Power; 8W

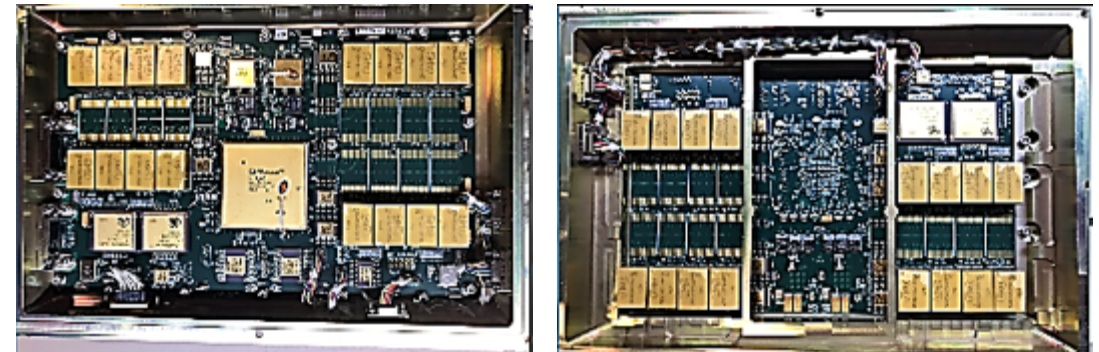




# Data Storage Board Features (3.5 Tbits Storage using Flash)



- Up to 3.5 Tbit (448 Gbyte) Flash SSR
  - Sizeable in 512 Gbit (64 GB) banks
- 7 banks of 64 GB
  - 8 3D-Plus Flash stacks per bank
  - 8 Flash die per stack
  - 8 Gbit per die
  - Independently powered or in groups (TBR)
- 8 MB Rad-Hard MRAM
  - Sizeable in 16 Mbit (2 MB) banks
- Interfaces
  - 4 SpW interfaces, buffered
  - 4 1-3.125 Gbps SerDes interfaces (unbuffered)
- Power
  - Internally derived 2.5V and 1.2V
- Mass: 1.3 Kg
- Power Consumption: 3.7W for fully populated board
- Volume: 2"W x 7.24"H x 9.605"D





# MUSTANG utilization for GSFC in-house work



- GEDI PCU 6 Modules (120V to 28V convertor) operating on ISS since Nov 2018: 1 EDU + 1 Flight Unit
- Illuma-T PCU (copy of GEDI PCU with 3 modules) in production; 1 EDU + 1 Flight Unit
- O2O PCU (Orion) (identical to Illuma-T) – share EDU with Illuma-T + 1 Flight Unit
- OCI Instrument; Avionics CDR complete and flight build in progress
  - ICDU (7 module assembly)
    - 2 EDUs delivered to flight software team
    - 1 ETU used for box qualification (delivery on target in April 2019)
    - 1 Flight Unit (delivery Fall 2019)
  - MCE (4 module assembly) (1 EDU, 2 ETUs and 1 Flight)
  - DAU (4 MUSTANG modules delivered to custom box) – 1 EDU, 1 ETU, 1 Flight
- PACE spacecraft bus – EDU build complete and delivered (preparing for flight build)
  - C&DH Unit (5 Modules) 1 EDU; DTN implementation
  - C&DH-ACE (7 Modules) 1 ETU and 1 Flight
  - PSE (Power Subsystem Electronics) 12 Modules; 1 ETU + 1 Flight



# MUSTANG utilization for Collaboration with other NASA Centers



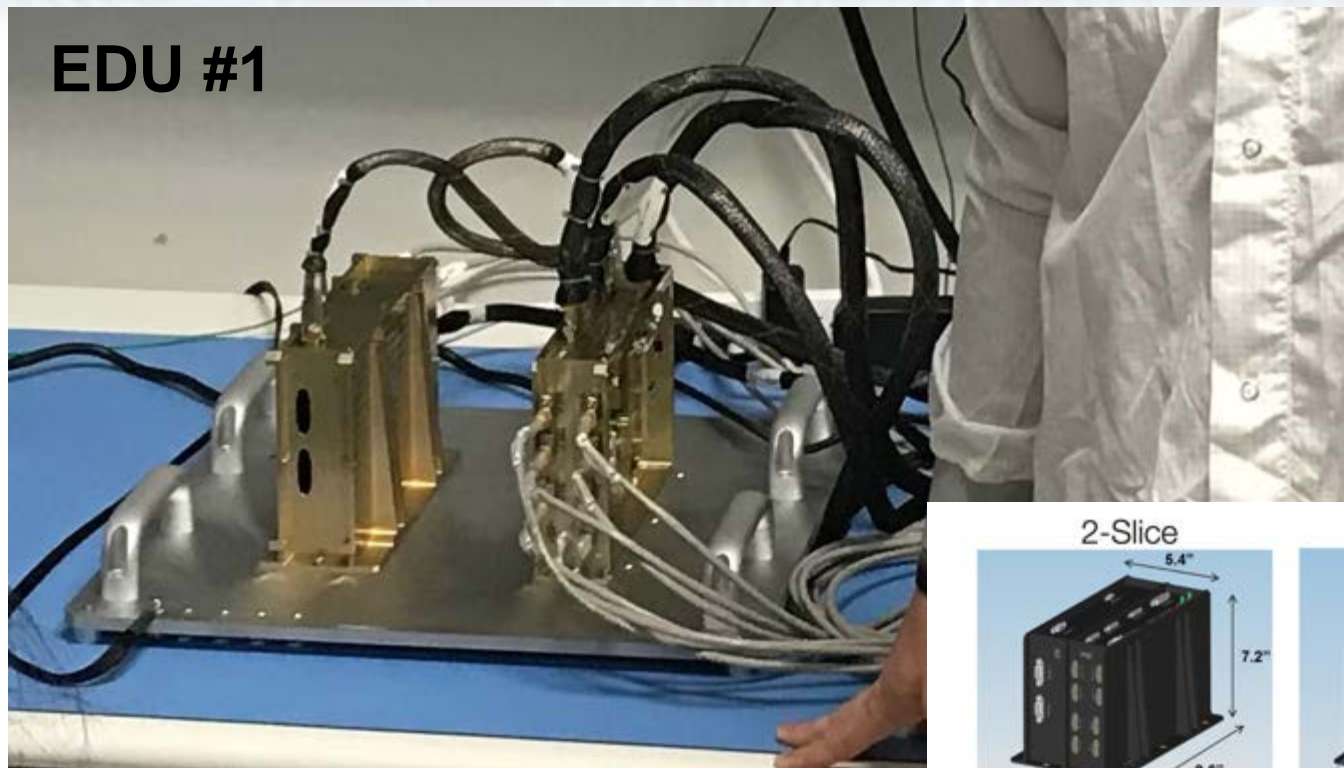
- MAIA Instrument Electronics – Collaboration with JPL
  - 2 EDUs plus 2 EGSEs
    - EDU#1 delivered July 2018 (2-Module Unit) Processor/Data Storage plus EGSE #1
    - EDU#2 delivered September 2018 (5-Module Unit) including Processor/Data Storage plus EGSE #2
  - 1 Flight Unit plus 1 EGSE; Flight Build completed and under test, EGSE 90% complete
    - 2-Module delivery and 3-Module delivery plus EGSE #3; October 2019 (on target)
- Lunar Platform Lander (renamed VIPER) - Collaboration with MSFC (tentative launch date 2023) a tech demo
  - MUSTANG hardware was selected- criteria; lower power, best fit for available volume, “Extendability” (modular feature) and comparable cost (copies of existing designs)
  - 1 ETU plus 2 Flight Units
    - 18 modules (2 boxes) to manage power subsystem, power distribution and flight data system
    - Total of 54 modules to deliver



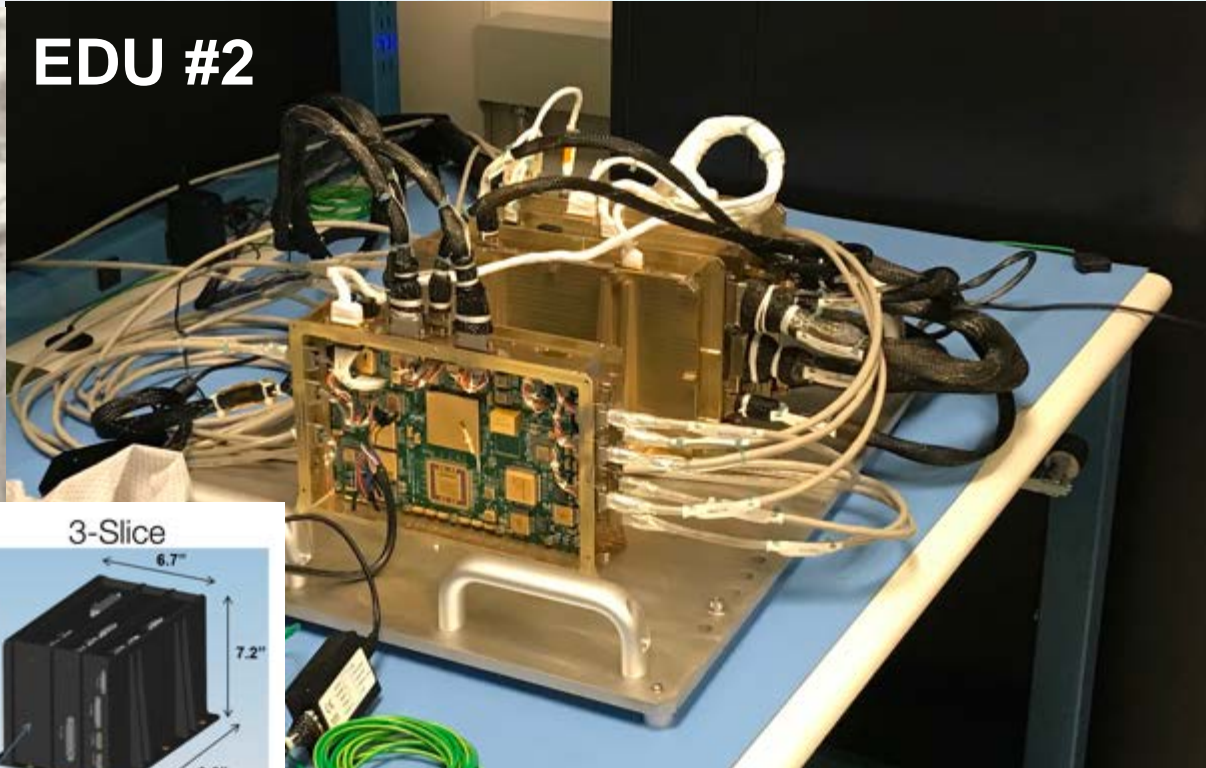
# MAIA hardware deliveries



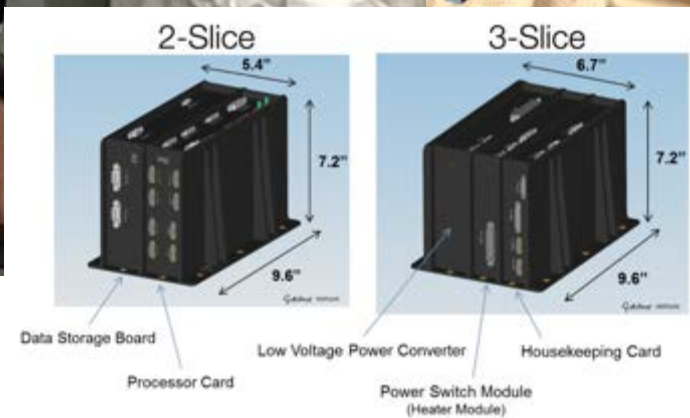
EDU #1



EDU #2

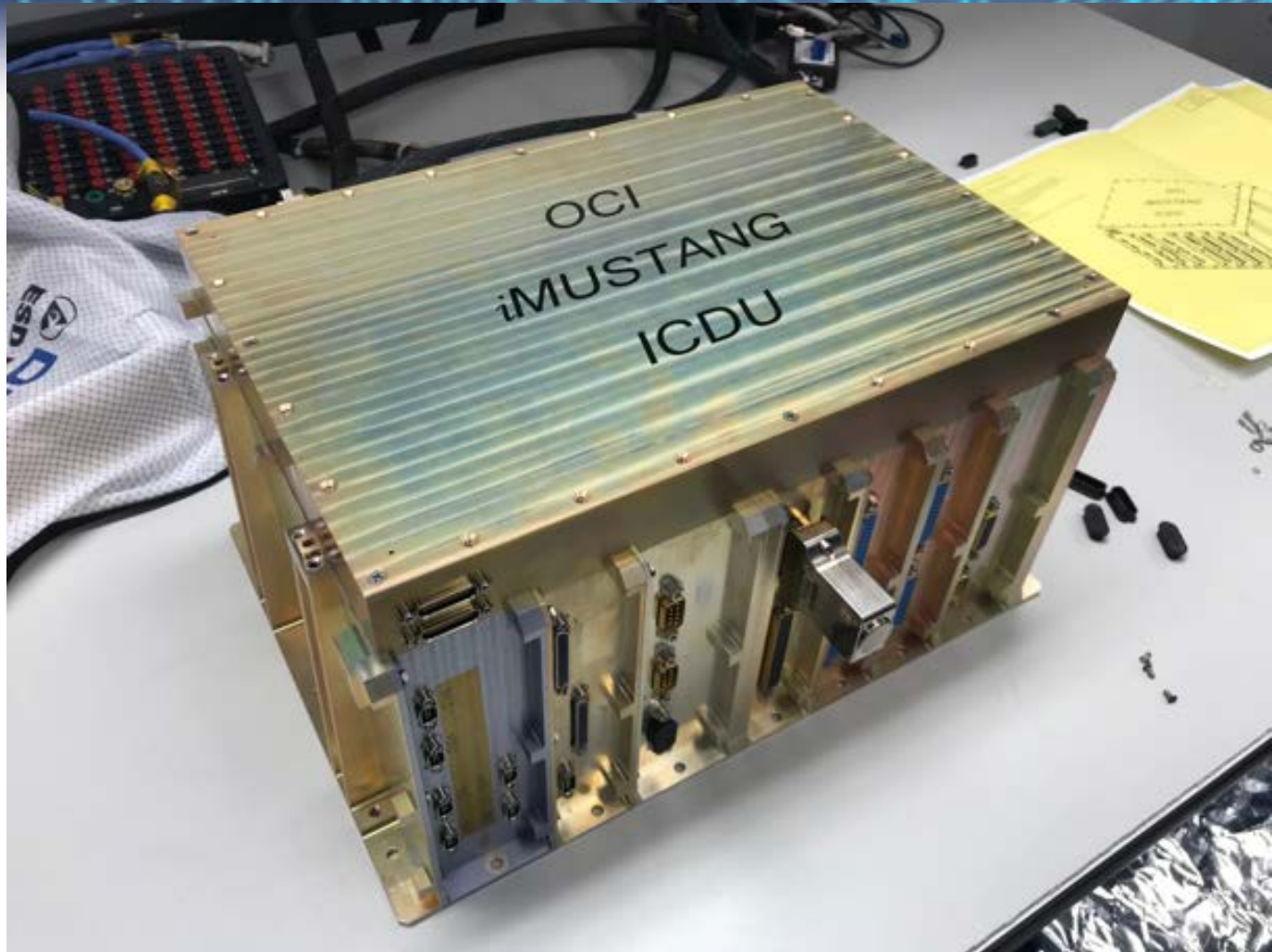


Flight Units

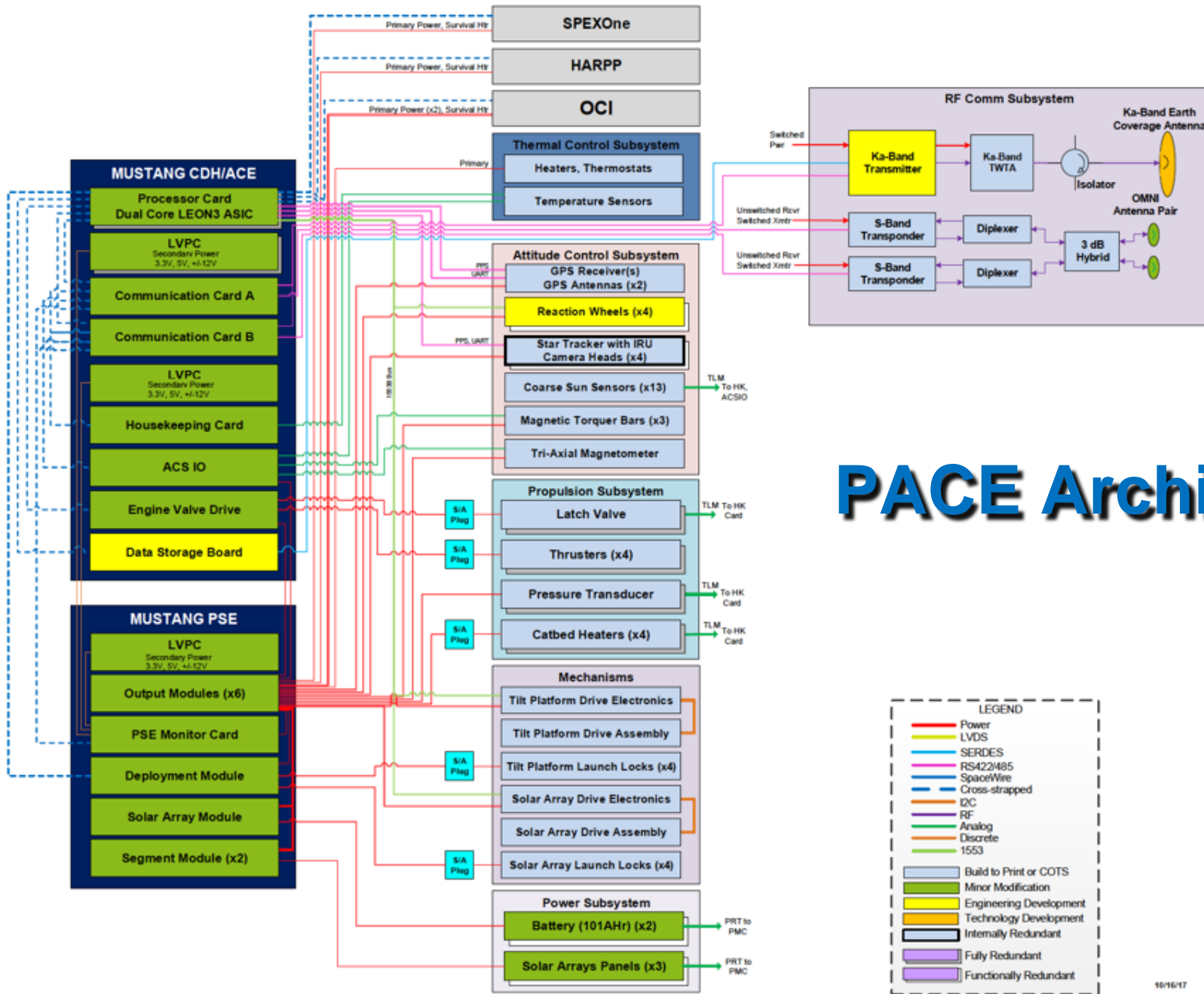




# MUSTANG OCI Instrument C&DH Unit (ICDU) (OCI is main Instrument for the PACE Mission at Goddard)







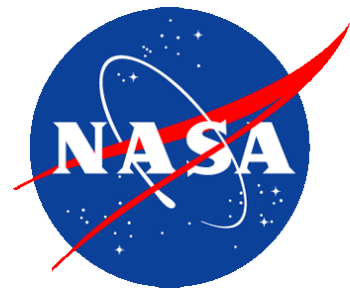
# PACE Architecture



# Summary



- MUSTANG modular Avionics can be used for fast development by mix and matching hardware
- There flexibility to adapt the interfaces without relaying out the board
- Adaptability for adjusting voltages for Application Specific Card
- Adaptability for power distribution with different power requirements
- Also the flexibility of combining the modules in any order that fits the available volume



*To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.*



# Back-up Charts



# MUSTANG Production



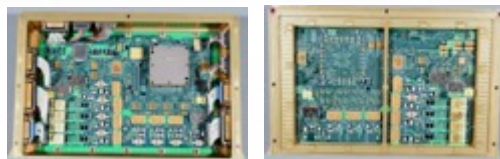
- MUSTANG will produce over 132 Boards for PACE Mission and MAIA Instrument including delivered EDUs & ETUs
  - 20 Boards for OCI Instrument
  - 100 Boards for PACE spacecraft (including Mechanism and Instrument Tilt platform)
  - 12 Boards for MAIA
- Mechanical and Electronics assemblies produces at multiple manufacturing houses in several States and ahead of schedule to avoid "Bottlenecks" during production cycle
  - Mechanical housing; Minnesota & Maryland
  - Bare Board fabrication houses in multiple States; Colorado, California, Texas & Arizona
  - Electronic Assemblies
    - Irvine Electronics – California
    - Cobham – Colorado
    - Genesis Engineering Solution – Maryland
    - GSFC in-house assembly (ISO certified; operated by the certified contractor-partner)
    - Other potential assemblies houses to be used;
      - Flextronics (CA)



# MUSTANG Cards



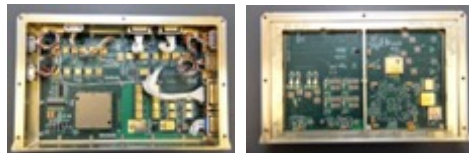
**Engine Valve Driver Card**



**Digital IO Card**



**PSE Monitor Card**



**Output Module Card**



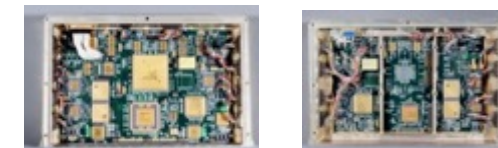
**Housekeeping Card**



**Communication Card**



**Processor Card**



**Data Storage Board  
(not fully populated)  
Full capacity 3.5Tb**

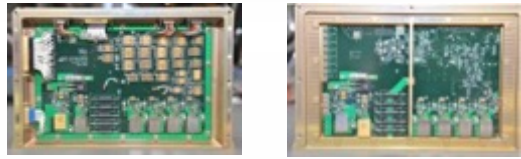




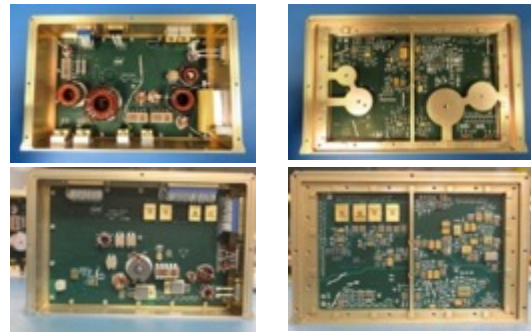
# MUSTANG Cards



**Deployment Card**



**Power Converter Unit (PCU) –  
Used in ISS  
Applications  
(Power Module – PM &  
Control Module – CM)**



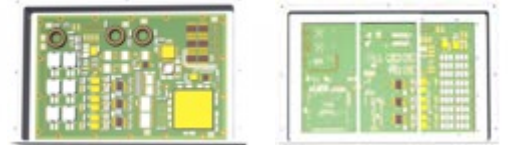
**Segment Module**



**Heater Module**



**Mechanism Control Card**



**Dark Star Power Converter Card**



**Low Voltage Power Converter Card**

