Intelligent Payload Module Update

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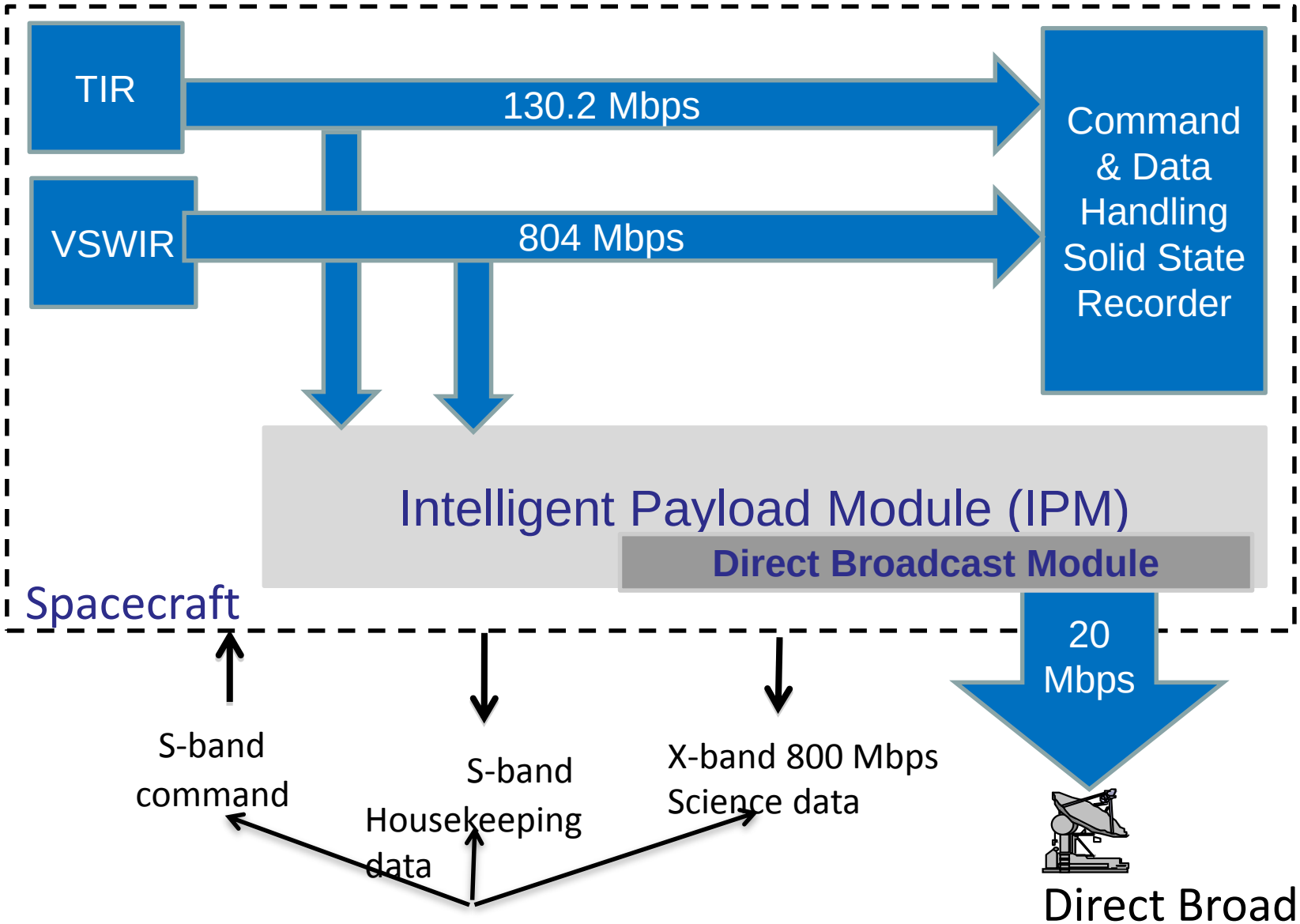
HyspIRI Symposium
Onboard Processing and Efficient Data Product Distribution Session
June 3, 2015

Original HyspIRI Low Latency Data Flow Operations Concept (Intelligent Payload Module)



To/From Alaska and Norway Ground Stations

Generalizing Revised IPM Definition

- Intelligent Payload Module (IPM) - Adapter for SensorWeb for high speed sensor data which is a combination of flight hardware and flight software that provides data subsets and/or higher level data products in near real time or realtime

- SensorWeb - a set of sensors (land, marine, air, space) and processing which interoperate in a (semi) automated collaborative manner for scientific investigation, disaster management, resource management, and environmental intelligence”.

  - More information at: http://sensorweb.nasa.gov

Key Intelligent Payload Module (IPM) Functionality

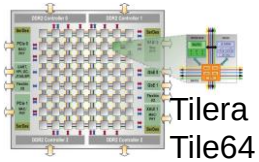
- Secondary onboard science data processor
- High performance onboard processing (radiation hardened/tolerant) that can handle 930 Mbps input instrument data rate
  - Multicore processors
  - Field Programmable Gate Array (FPGA)
- Rapid access to real time subsets of sensor data for low latency users
- Rapid access to real time or near real time science data products for low latency users
- Rapid customization and integration of onboard algorithms
- Utilize industry standard formats;
- Minimize mass, volume, and power;
- Provide user extensible image processing toolkit (WCPS);
- Support a heterogeneous series of orbital, sub-orbital and *in situ* platforms via SensorWeb coordination.

IPM as an Evolving Platform Integrating HW and SW Components

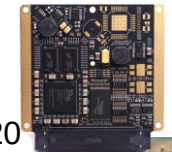
- IPM is a platform which integrates an evolving set of hardware and software components

HW Components

SpaceCube 1.0



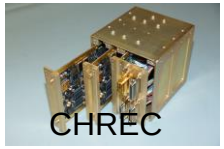
Tilera Tile64 TileGX



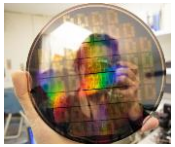
Zynq ZC7020

SpaceCube 2.0 PowerPC Virtex5

IPM 1.0

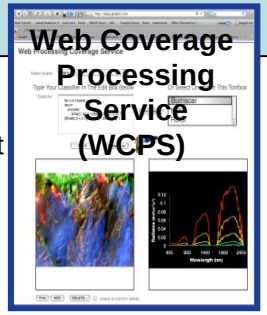


CHREC Space Processor Cubesat ARM/Zynq FPGA



Processors with nano-material

2005 2010 2015 2020



SensorWeb Enablement (SWE) OGC Standards

Geocorrection For Airborne Platform (GCAP)

Atmospheric Correction

AESOP automated parallelization

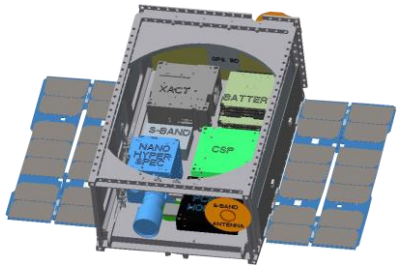
Automated High Level Synthesis of FPGA circuits and Linux API

SW Components

IPM Weight	5-20 lbs		<1 lb
IPM Power	20 – 80 watts	<10 watts	<2-3 watts
IPM Clock	100 Mhz – 800 Mhz		>300 Mhz
Data Throughput	50 kbps – 1 Gbps		>10 Gbps

Broad Range of Supported Platforms

Contract MD 500C



Cubesat

ISS Optical Window

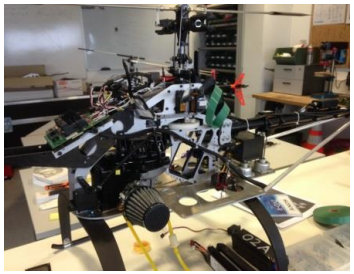
USFS King Air B200

Intelligent Payload Module

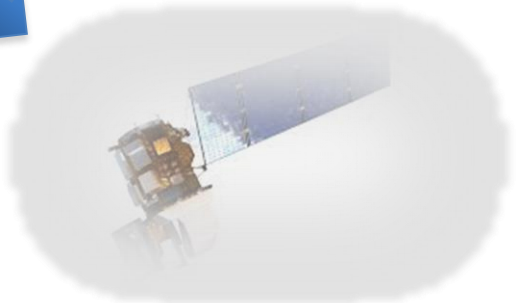
HyspIRI

USFS Cessna Citation

NASA Cessna 206H



Rotorcraft Drone



Landsat 9

Basic SensorWeb Architecture

Data Processing Node

Data Distribution Service

Data Distribution Service

Web Processing Service (WPS)

Data Aggregation Service

Sensor Data Products

Internet

SWE Node

SWE Node

SWE Node

In-situ Sensor Data Node

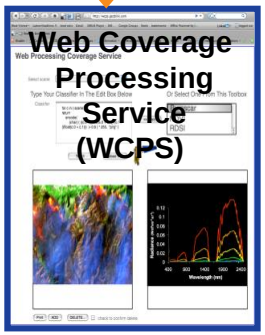
UAV Sensor Data Node

Satellite sensor data product

Sensor Planning Service (SPS)

Web Notification Service (WNS)

Sensor Observation Service (SOS)



Identity Management Service (OpenID 2.0)

SensorWeb Enablement (SWE)
OGC Standards

GSFC SensorWeb Components (Ground)

SensorWeb Toolkit Subsystem	Type	NTR	How long in operation	TRL	Developed Under	Note
SensorWeb Reference Architecture	Arch	GSC-5025286	7 years +	9	AIST-05	Active on EO-1
Campaign Manager (GeoBPMS)	WfCS	GSC-16267-1	5 years	9	AIST-05	Active on EO-1
Campaign Manager Client	WfCS	GSC-5027514	2 years	7	AIST-05	Not used
Identity Management Services	Security	GSC-16268-1	5 years	9	AIST-05	Active on EO-1
EO-1 SPS 0.3 (GSFC)	SPS	GSC-16271-1	5 years	9	AIST-05	Active on EO-1
EO-1 SOS	SOS	GSC-16272-1	5 years	7	AIST-05	Active on EO-1
OGC Publish/Subscribe Basic	WNS	GSC-16270-1	5 years	9	AIST-05	Active on EO-1
WCPS	WCPS	GSC – 16273-1	3 years	9	AIST-08	Active on EO-1
Weka to WCPS Translator	WCPS	GSC-16274-1	3 years	7	AIST-08	Not used
Flood Dashboard	DADM	GSC-16275-1	3 years	9	EO-1	Active Namibia, Central America, others
GeoSocial API	WfCS	GSC-17162-1	0 years	6	AIST-QRS11	Namibia, Central America, others
Flood Vectorization Topojson	WCPS	GSC-17169-1	0 years	6	TBS	Demo mode
Geo-Registration of Multi-Source Image Data	WCPS	GSC-16862-1	0 Years	6	TBS	Demo mode

Arch- Architecture
WfCS – Workflow Chaining Service
SPS – Sensor Planning Service
WCPS – Web Coverage Processing Service
WNS – Web Notification Service
DADM – Data Aggregator and Display Mashup

JPL SensorWeb Components (Ground)

SensorWeb Toolkit Subsystem	Type	NTR	How long in operation	TRL	Developed Under	Note
Intelligent Payload Module	WfCS	JPL-45445	6 years	9		Active on EO-1
	WfCS	JPL-48148	6 years +	9		Active on EO-1
MODIS-based Flood Detection, Tracking and Response	WfCS	JPL-48149	4 years	9		Active
Change based satellite monitoring using broad coverage targetable sensors	WfCS*	JPL-48147	7 years	9		Active on EO-1
EO-1 SPS 2.0	SPS	JPL-48142	5 years +	9		Active on EO-1
WPS Software Framework	WPS	JPL-45998	6 years	9		Active on EO-1
Autonomous Hyperspectral Data Processing/Dissemination	WfCS*	JPL-48123	7 years	9		Active on EO-1

Arch- Architecture
WfCS – Workflow Chaining Service
SPS – Sensor Planning Service
WNS – Web Notification Service
WCPS – Web Coverage Processing Service

DADM – Data Aggregator and Display Mashup
* - Noncompliant with OGC Standards

IPM SensorWeb Internal SW Components (Onboard)

SensorWeb Toolkit Subsystem	Type	NTR	How long in operation	TRL	Developed Under	Note
Intelligent Payload Module	WfCS	GSC-16867-1	Assorted		AIST-11	
- cFE command in integrated into IPM	-Til		6 months	7		Active Bus helo
- cFE telemetry out integrated into IPM	-Til		6 months	7		Active Bus helo
- cFE CFDP integrated into IPM	-Til		6 months	7		Active Bus helo
- WCPS integrated into IPM	-Til		6 months	7		Active Bus help
- GCAP single processor	-Til		6 months	6		Active Bus helo
- GCAP parallel processed on multicore	- Til		6 months	6		Active on testbed
- FLAASH Atmospheric Corr, one proc	- Til		6 months	5		Active on testbed
- FLAASH Atmospheric Corr, parallel	- Til		6 months	4		Active on testbed
- Spectral Angle Mapper	- Til		6 months	6		Active Bus helo
- Instrument data ingest	- FPGA			3		Helo/cubesat
- FLAASH AC	- FPGA			3		Helo/cubesat
- GCAP	- FPGA			3		Helo/cubesat

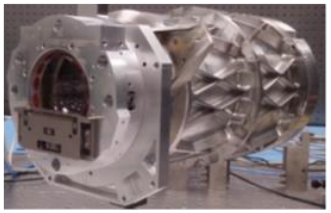
Arch- Architecture
WfCS – Workflow Chaining Service
SPS – Sensor Planning Service
WNS – Web Notification Service
WCPS – Web Coverage Processing Service

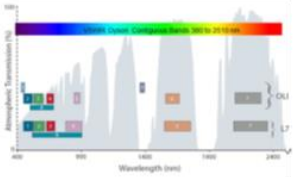
DADM – Data Aggregator and Display Mashup
- - Noncompliant with OGC Standards

Til – on Tilera multicore
GCAP – Geocorrection for Airborne Platforms

Revised Mission Concept for ISS or Smallsat

SpaceCube 2.0 Version of IPM – Combined dual PowerPC's and FPGA. Previous versions of SpaceCube on ISS now, SpaceCube 2.0 on ISS FY16 for DoD





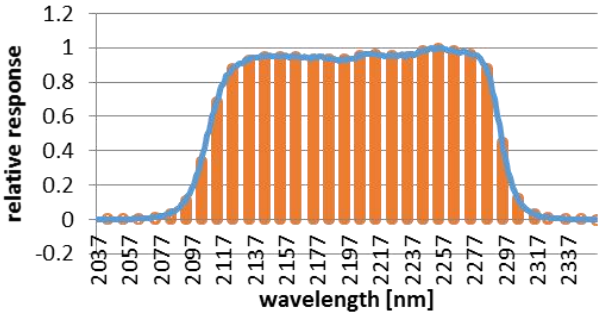
Imaging Spectrometer Data Via LVDS

- 1.2 Gbps data rate
- 1200 cross track pixels
- 13 bits per pixel
- 306 Spectral Bands
- 240 frames per second

Output via 100 Mbps Wifi to ISS

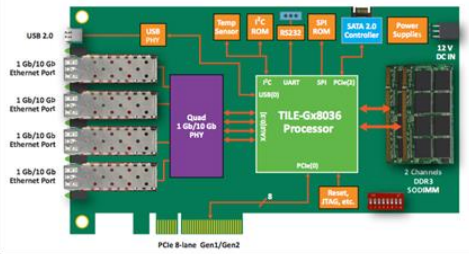
- Perform Level 1 Radiometric Correction
- Perform convolution of up to 48 bands synthesized into 1 band
- Need 8 Landsat bands generated
- 48 Bands have weighting factor and are added to form one Landsat band 12 bit value embedded in 16 bit word
- Each of the Landsat bands can use some of the same 48 bands as the other Landsat bands
- Majority of processing in FPGA

Hyperion / OLI SWIR2 Band Comparison
In-Band Band-Average RSR



Note: Validation approach for generation of Landsat bands and contents of convolution look up table to be determined by science team.

2nd Revised Mission Concept for ISS or Smallsat

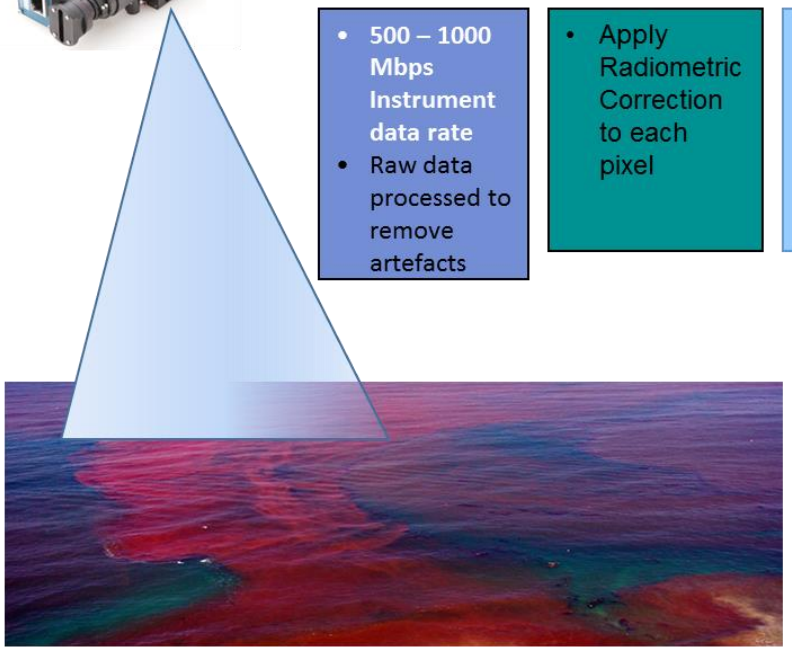


Onboard multicore processor or single Linux Processor

FPGA Onboard Accelerator

Level 0	Level 1R	Atmospheric Correction	Geometric Correction	Level 2 Classification
• **500 – 1000 Mbps Instrument data rate** • Raw data processed to remove artefacts	• Apply Radiometric Correction to each pixel	• Convert radiance to reflectance	• Tag each pixel with correct location information	• Run Web Coverage Processing Service to run algorithm against data (e.g. spectral angle mapper, vectorizer)

Downlink RT Algal Bloom Maps to Users on Bay 10 Mbps



Bench Functionality Checklist

Date	Description	Multi core	FPGA	L0	L1R	AC	L1G	WCPS	LandS Convol	cFE/ CFS	WCPS	Free wave IO		Comment
6/XX/12	IPM Testbed HW integrated with cFE, Freewave IO Wifi	√								√				Tilera Tile64 Hello World
8/XX/12	Spectral Unmixing Parallel Bench Test							√						Speed test with parallelized algorithm
9/XX/12	GCAP Parallelized Test						√							Speed depending on how many Til cores used
8/14/13	B23 Rooftop test of IPM with ChaiV640	√		√	√						√			Imaged GSFC with IPM system
8/23/13	SpaceCube 1.5 test with AC	√	√			√								Ran FLAASH on Virtex5 on PowerPC
8/XX/14	Portion of FLAASH AC on FPGA of ZC702 performance benchmark		√											Fast Fourier Transfer installed on FPGA of Zynq

√ **Passed**

Flight Functionality Checklist

Date	Description	Multi core	FPGA	L0	L1R	AC	L1G	WCPS	LandS Convol	Rad Tol	Small Pkge	No EMI	Low Power	Comment
	IPMv1 Complete/ChalV640 Box Complete													
03/23/13	IPM-AMS Flight Ogden	√		√	√		√	√						
03/28/13	IPM-GIIHT Langley	√		√	√		√							
10/15/13	IPM Flight GIIHT - Langley	√		√	√		√							
7/7/14	Approval for Bussmann Helo Flights													
7/16/14	IPM-Chai Flight 1 Bussmann Helicopter	√		√	√		√	√				√		No image, EMI
7/23/14	IPM-Chai Flight 2 Bussmann Helicopter	√		√	√		√	√				√		
9/19/14	IPM-Chai Flight 3 Bussmann Helicopter	√		√	√		√	√				√		Image, no EMI, lost frames
1/20/15	IPM-Chai Flight 4 with Zynq based processor	√		√	√		√	√				√		Prove no lost frames
4/13/15	IPM-Chai Flight 5 with Zynq based processor	√	√	√	√			√				√		1st FPGA use
5/5/15	IPM Chai Flight 1 on Cessna 206H Langley to PEARL	√	√	√	√		√	√						1st Langley Flight to PEARL

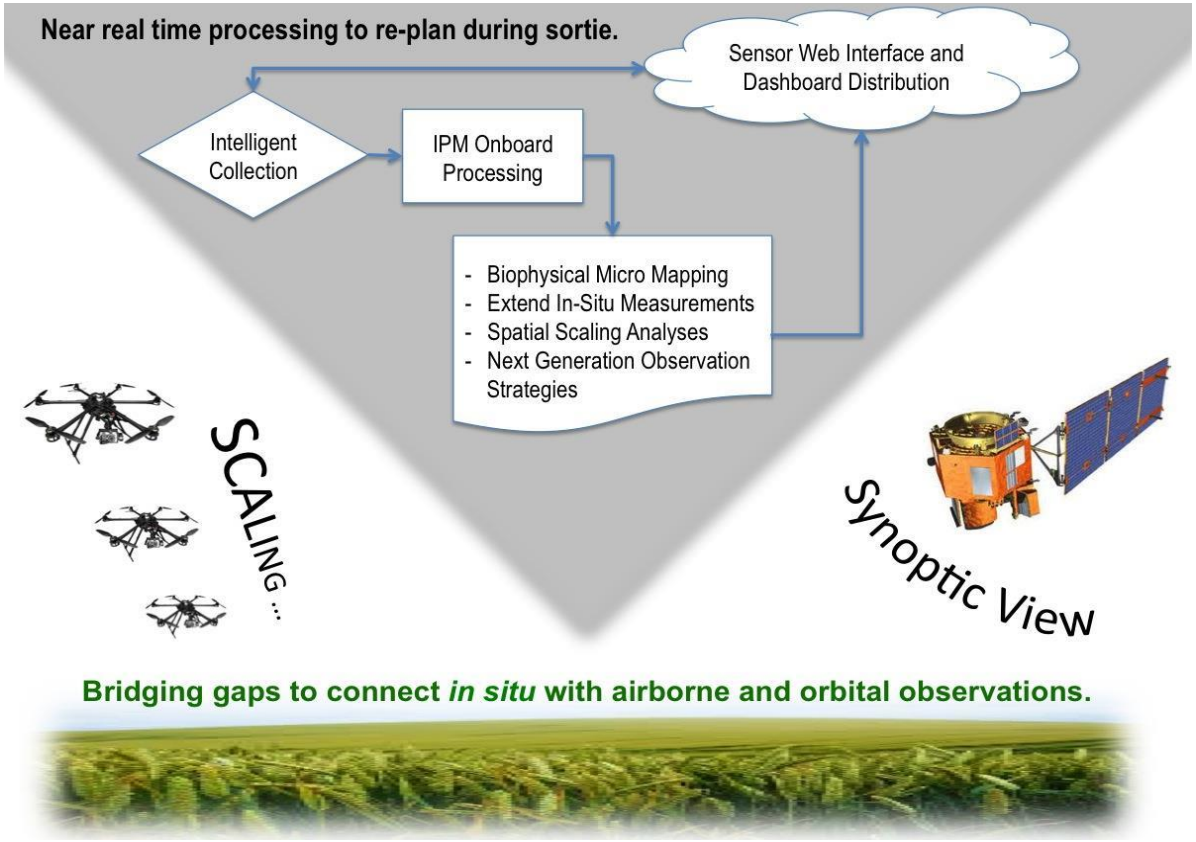
√ Passed √ Delayed to Future Flights √ Planned

Flight Functionality Checklist

Date	Description	Multi core	FPGA	L0	L1R	AC	L1G	WCPS	LandS Convol	Rad Tol	Small Pkge	No EMI	Low Power	Comment
5/29/15	IPM Chai Flight 2 on Cessna 206H	√	√	√	√	√	√	√				√		Langley to PEARL
6/20/15	IPM-Chai Bussmann Flight 2 to PEARL	√	√	√	√	√	√	√				√		PEARL Flight
7/15/15	IPM-Chai Flight 7 with Zynq based processor	√	√	√	√	√	√	√				√	√	More FPGA stuff- Manassas
7/15/15	Mini UAV Flight Barcelona (Enric)	√									√	√	√	TBD
8/10/15	IPM-Chai Bussmann flight 8 to PEARL	√	√	√	√	√	√	√				√		Algae detection
8/20/15	IPM-Chai Flight 3 with Zynq based processor from Langley to PEARL	√	√	√	√	√	√	√		√	√	√	√	PEARL Leaf on – some processing on FPGA

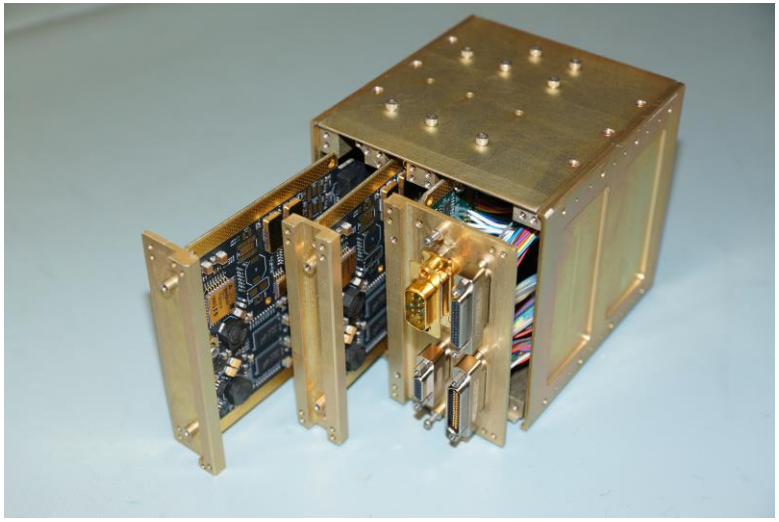
√ Passed √ Delayed to Next Flight √ Planned

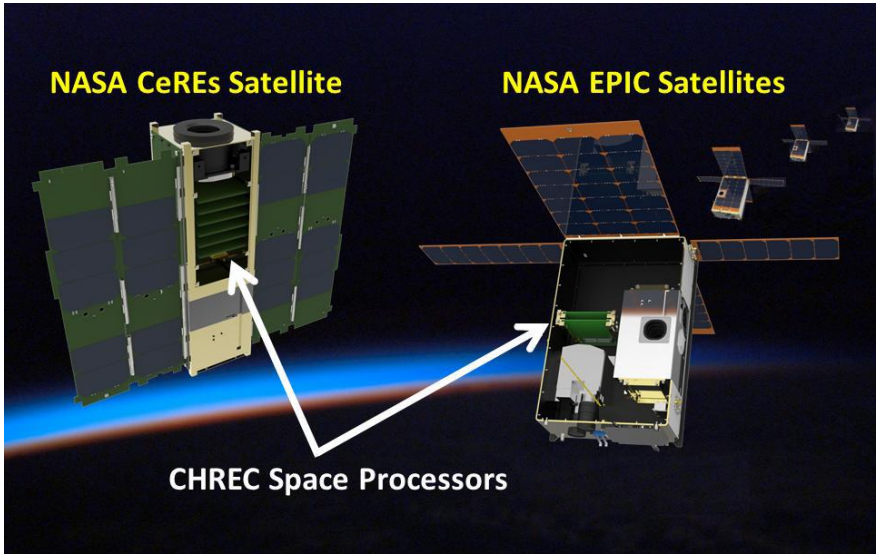
IPM Enabled Hexacopter Flights



IPM enables image aided navigation depending on realtime measurement

CSP in ISS and Cubesat





- CSP/SpaceCube Tech Demo ISIM (Space Station)
  - ✓ 2 CSP's, SpaceCube 1.0, 1.5, 2.0
  - ✓ Delivered to DoD early FY15 and launched early FY16
  - ✓ Gary Crum/587
- Compact Radiation BElt Explorer (CeREs) is part of NASA's Low-Cost Access to Space program
  - ✓ 3U Cubesat
  - ✓ 1 CSP
  - ✓ Delivery to GSFC early 2015, Launch 2016

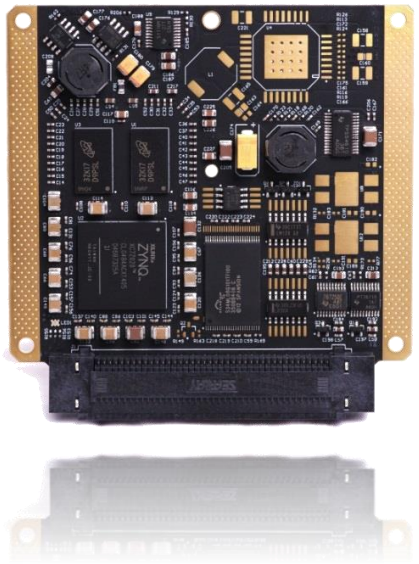
ZC702 – Zynq (ARM/FPGA Processor) Proxy for COTS+RH+FTC CHREC Space Processor (CSP)

COTS

- Zynq-7020 hybrid SoC
  - Dual ARM A9/NEON cores
  - Artix-7 FPGA fabric + hard IP
- DDR3 memory

RadHard

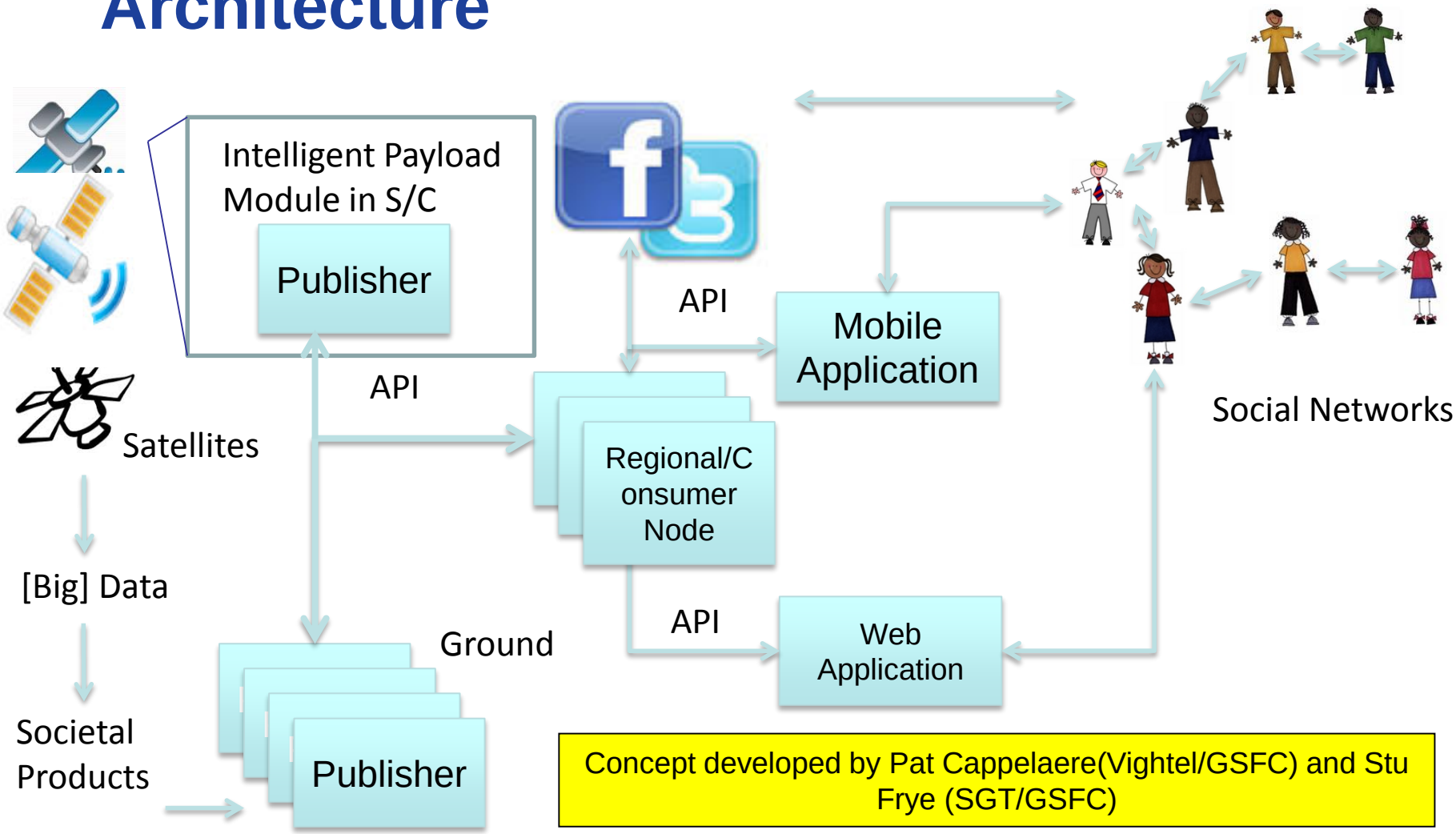
- NAND flash
- Power circuit
- Reset circuit
- Watchdog unit



FTC = Fault-Tolerant Computing

- Variety of mechanisms
  - External watchdog unit to monitor Zynq health and reset as needed
  - RSA-authenticated bootstrap (primary, secondary) on NAND flash
  - ECC memory controller for DDR3 within Zynq
  - ADDAM middleware with message, health, and job services
  - FPGA configuration scrubber with multiple modes
  - Internal watchdogs within Zynq to monitor behavior
  - Optional hardware, information, network, software, and time redundancy

Publisher/Consumer/GeoSocial API Architecture



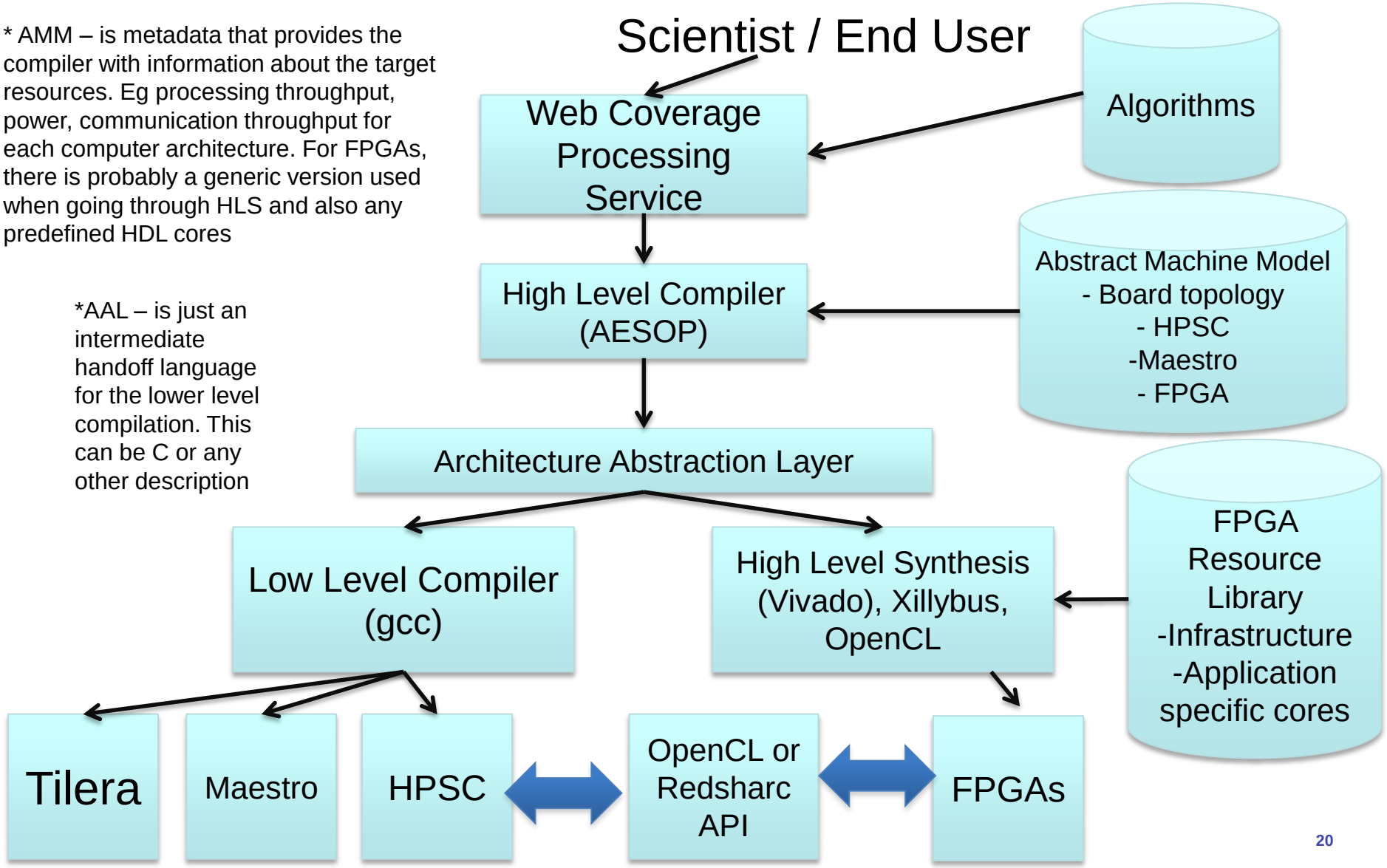
Concept developed by Pat Cappelaere(Vightel/GSFC) and Stu Frye (SGT/GSFC)

A methodology to rapidly discover, obtain and distribute satellite data products via social network and open source software

Next Generation IPM Multicore/FPGA Integrated Architecture

* AMM – is metadata that provides the compiler with information about the target resources. Eg processing throughput, power, communication throughput for each computer architecture. For FPGAs, there is probably a generic version used when going through HLS and also any predefined HDL cores

*AAL – is just an intermediate handoff language for the lower level compilation. This can be C or any other description

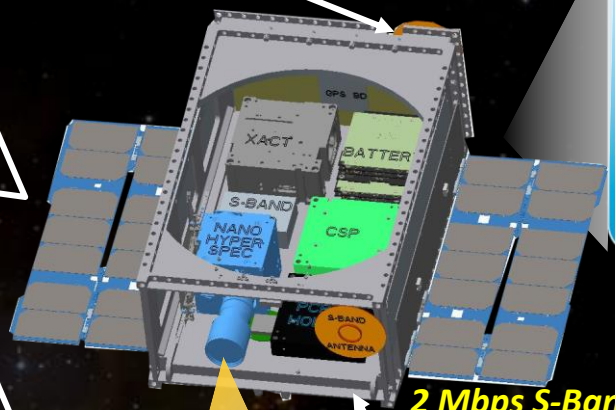


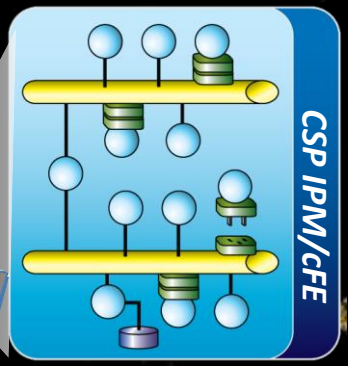
IPM Enables Hyperspectral Cubesat Concept

TDRSS

1 kbps Multiple Access On Demand or 12 kbps Single Access S-band CCSDS Command/Telemetry/Locate

Launched from ISS via CSLI at 400 km altitude, 51.6 deg inclination

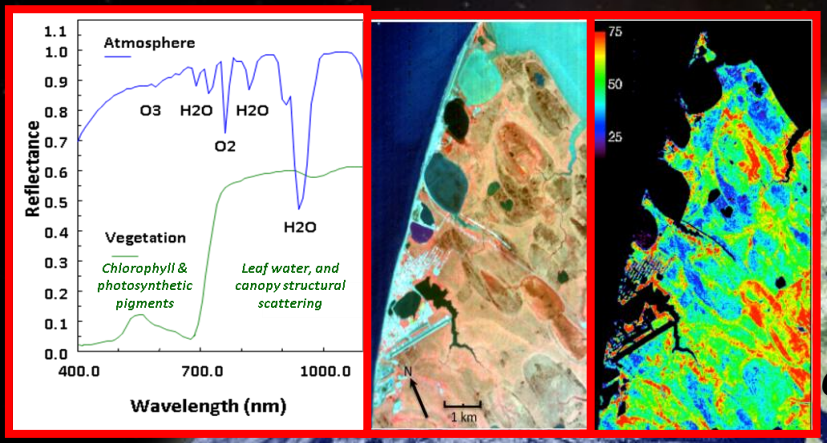




Onboard Processing

1 kbps Multiple Access On Demand or 12 kbps Single Access S-band CCSDS Command/Telemetry/Locate

2 Mbps S-Band instrument Data & Data Products



White Sands Ground Station

Wallops Ground Station

Closed IONet

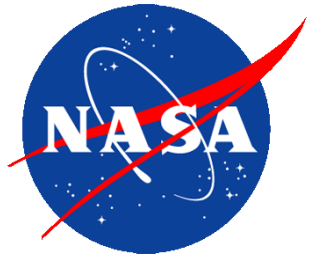
Open IONet

FFT Benchmark Tests with Various CPU Processors and FPGA

Processor	Cores	FFTW 1 band 128 x 256 time (Msec)	Clock rate (Mhz)	Power Consumption (watts)	Program mability
TileGX	1	21.3			+
TileGX	4	10.0			+
Maestro	1	187	200	14 watts	+
Maestro	8	55	200	14 watts	+
ZynqARM	1	8.7	667	3 watts	0
ZynqARM	2	6.9	667	3 watts	0
XeonPhi	1	9.0			+
XeonPhi	171	0.221		225 watts	+
FPGA	NA	1.5	100	<3 watts	-

Processor Comparison

Processor	MIPS	Power	MIPS/W
MIL-STD-1750A	3	15W	0.2
RAD6000	35	15W	2.33
RAD750	300	15W	20
LEON 3FT	75	5W	15
LEON3FT Dual-Core	250	10W	25
BRE440 (PPC)	230	5W	46
Maxwell SCS750	1200	25W	48
SpaceCube 1.0	3000	7.5W	400
SpaceCube 2.0	6000	10W	600
SpaceCube Mini	3000	5W	600


NASA