Linear Mode Photon Counting HgCdTe Avalanche Photodiode Performance and LMPC CubeSat Status

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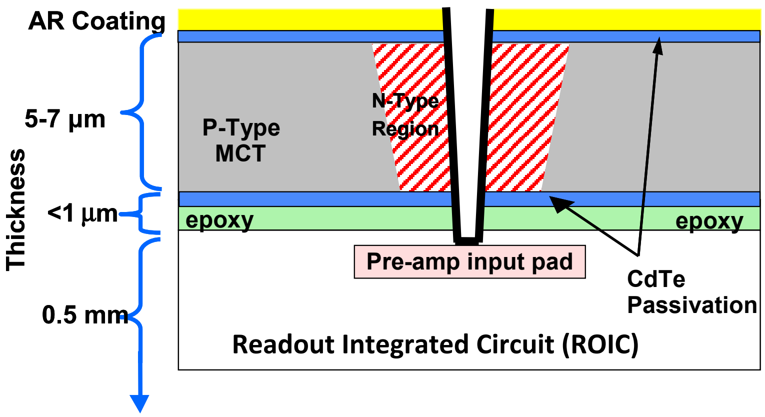
Outline

- Introduction – DRS HgCdTe e-APD
- 4x4 HgCdTe e-APD for CO_2 lidar
- 2x8 LMPC HgCdTe e-APD for the ACT-10 program
  - Major achievements
  - Measurement results
- In space technology validation with CubeSat
  - Aero-Cube 9 (AC-9) bus
  - Integrated Cooler Dewar Assembly
  - Electronics and Optics
  - Science experiments

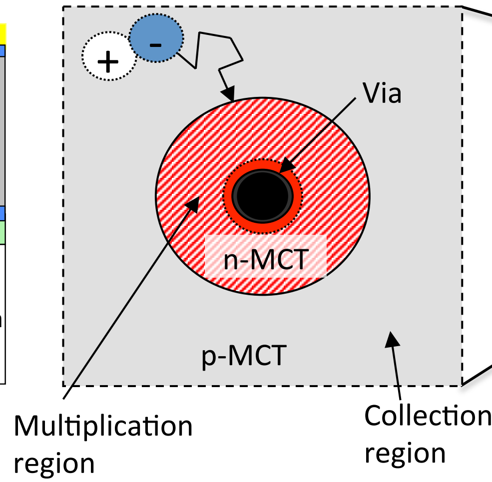
DRS HDVIP™ e-APD Architecture

Front-side illuminated, cylindrical diode geometry in 2x8 format

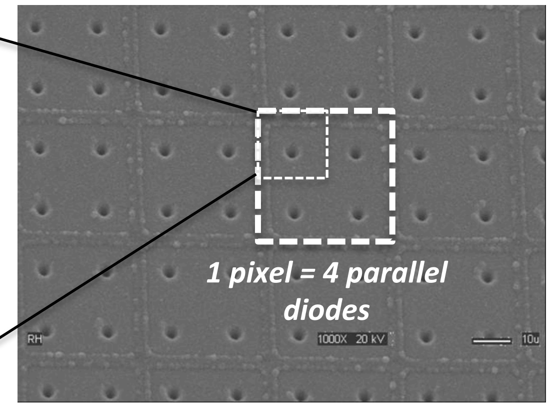
Diode Side View



Diode Top View

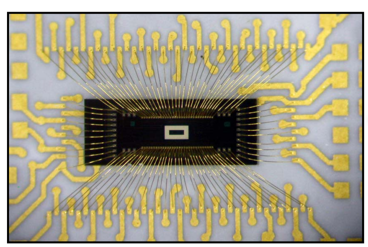


Array SEM Image



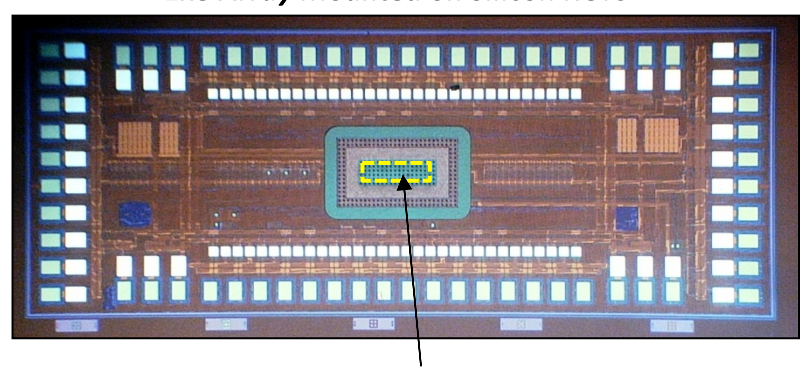
Ceramic Mounted in LN_2 Lab Dewar (80 K Operation)

ROIC Mounted on Ceramic Carrier



32 simultaneous outputs

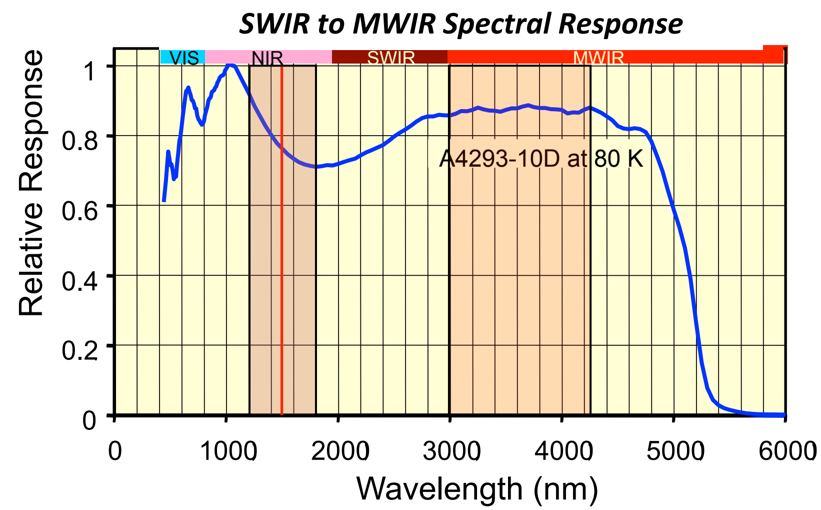
2x8 Array Mounted on Silicon ROIC

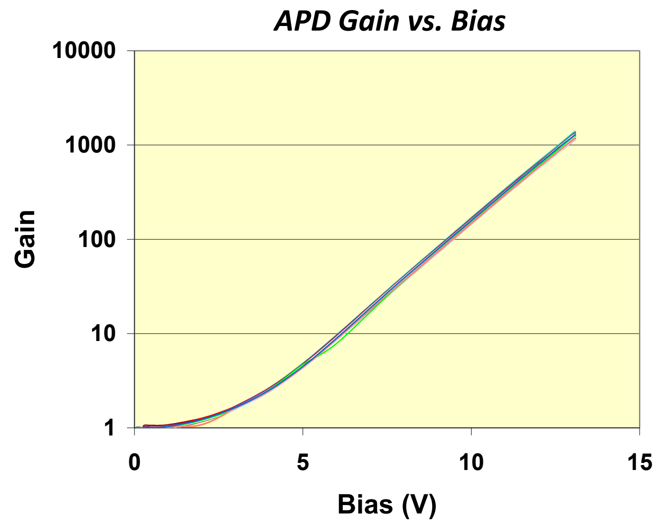


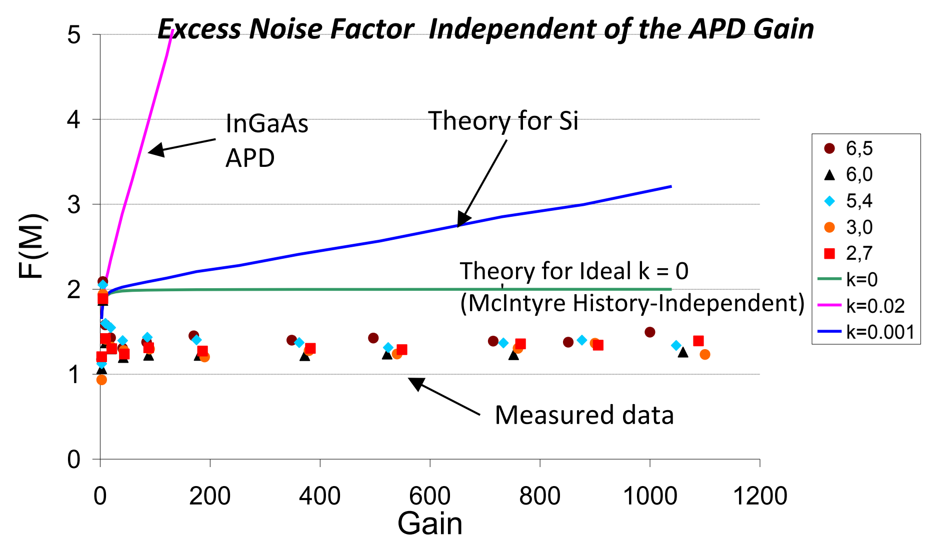
2x8 HgCdTe Pixel Array

Enabling Technology: HgCdTe e-APD

- High quantum efficiency
- Broadband spectral response (0.4 – 5 μm)
- High, stable, and uniform APD gain
  – Nearly noiseless single carrier gain (F ≈ 1.2-1.3)
- Low dark current
- High bandwidth
- Large dynamic range

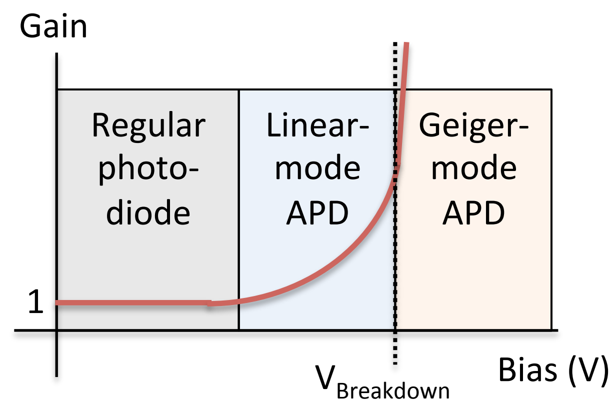


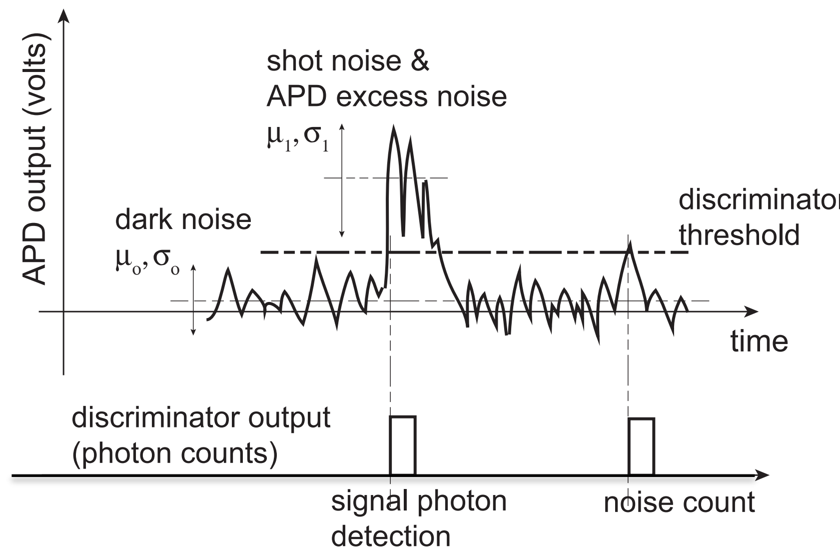




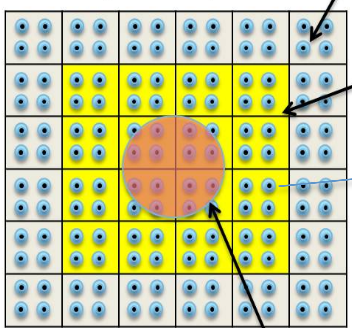
Linear Mode Photon Counting

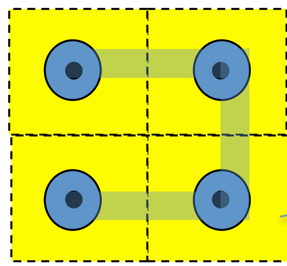
- An linear mode APD improves the detector sensitivity by multiplying primary photo-current to above the circuit noise.
- APD also introduces an excess noise due to the randomness of the gain.
- Si APD and InGaAs APDs have to operate in Geiger mode (non-linear) to attain the APD gain required to detect single photons
- Linear mode photon counting detection is possible if all of the followings occur simultaneously:
  - (a) Low circuit noise;
  - (b) High APD gain;
  - (c) Low APD excess noise;
  - (d) Low dark current;
  - (e) High electrical bandwidth;
  - (f) Wide linear dynamic range

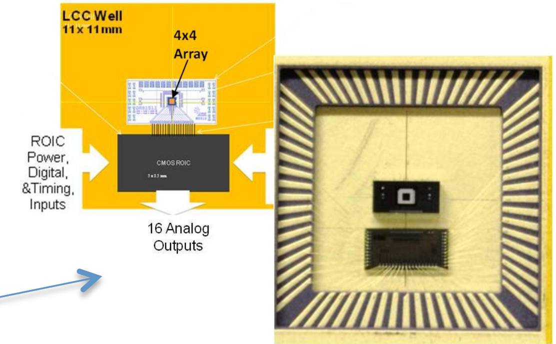


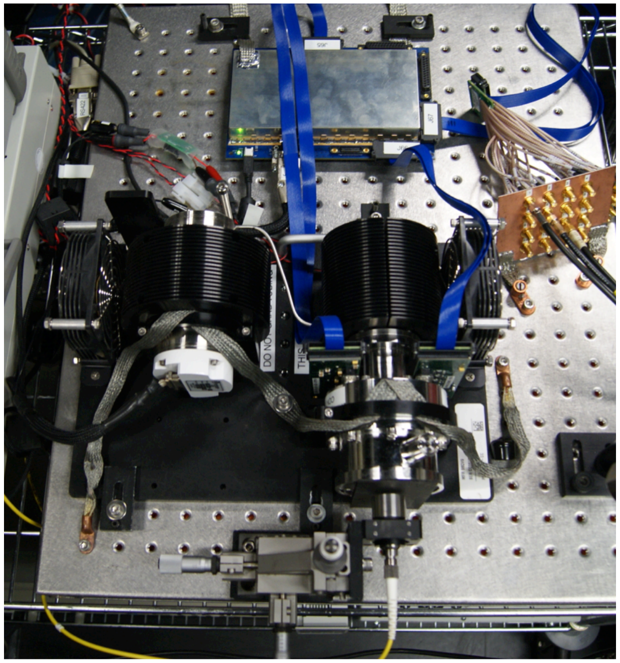


4x4 HgCdTe e-APD for CO_2 Lidar

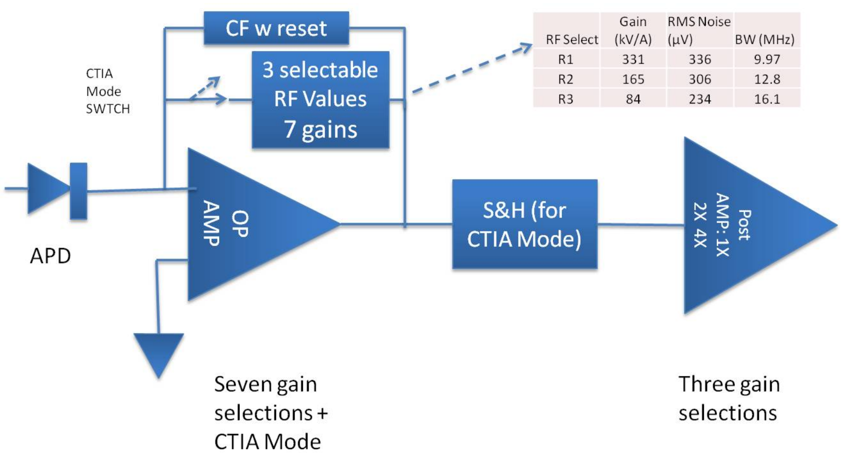








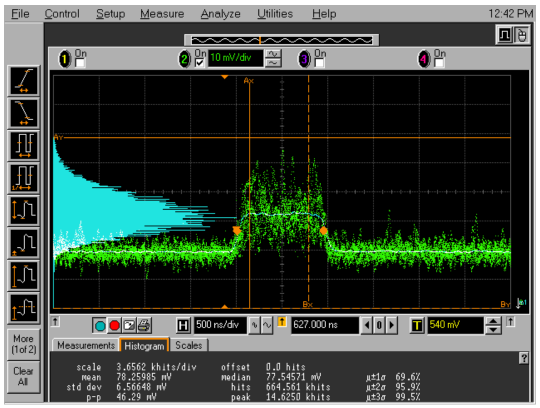
Custom CMOS ROIC, RTIA or CTIA mode of operation

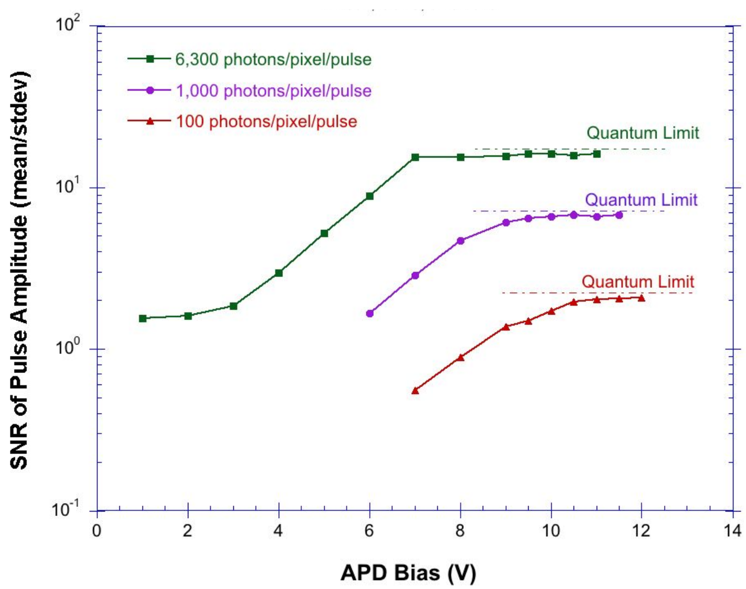


RF Select	Gain (kV/A)	RMS Noise (µV)	BW (MHz)
R1	331	336	9.97
R2	165	306	12.8
R3	84	234	16.1

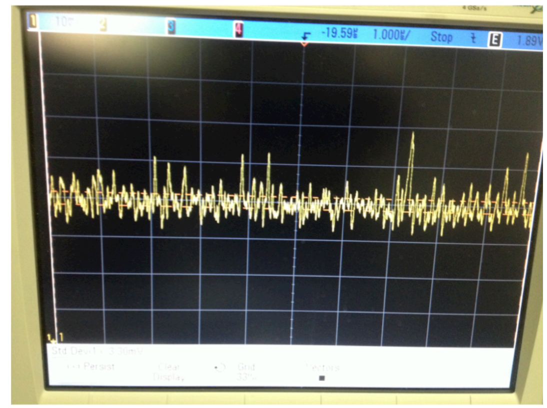
Performance of 4x4 HgCdTe e-APD

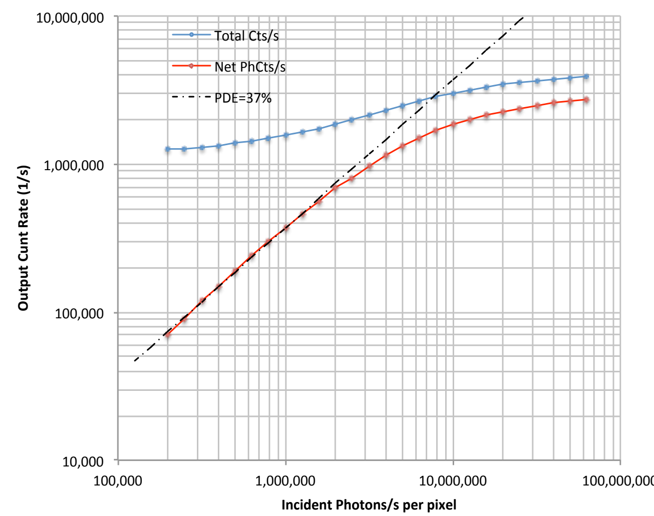
Analog Detection Performance





Single Photon Detection Performance





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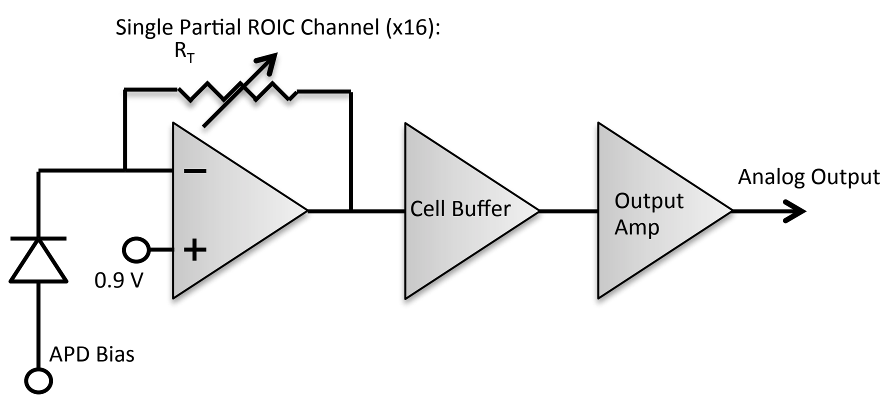
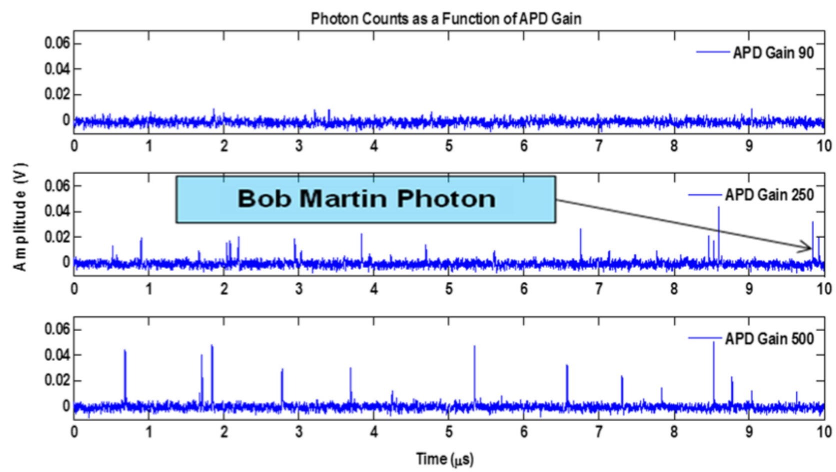
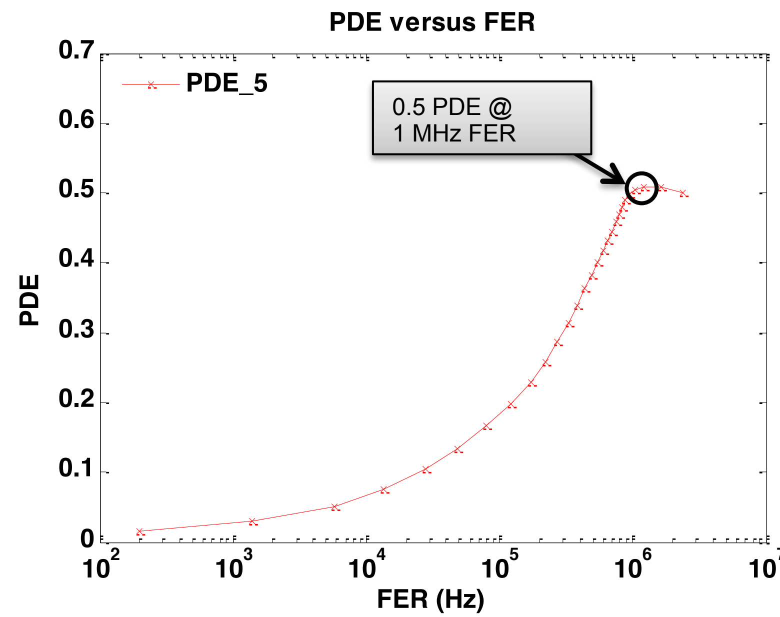
First LMPC HgCdTe e-APD Array

Beck *et al*. First reported a LMPC HgCdTe e-APD FPA at SPIE 8033, 2011.

- 4.2 µm cutoff HgCdTe
- 2x8 pixel read-out integrated circuit (ROIC) in 0.18 µm Si CMOS by ADIC







- 50% PDE at 1 MHz false event rate
- Linear analog output
- 8 ns minimum time between events
- 0.4 – 4.2 µm spectral response

J. D. Beck, R. Scritchfield, P. Mitra, W. Sullivan III, A. D. Gleckler, R. Strittmatter, R. J. Martin, *Proc. SPIE* 8033, 80330N (2011).

DRS Technologies

Major Achievements under the ESTO ACT-10 Program

1. Reproduced the LMPC HgCdTe e-APD arrays with high yield and improved performance
2. Reduced false event rate (FER) due to the light emission by the preamplifiers (ROIC)
   - Photons emitted from Si CMOS transistors in saturation as hot carriers traversing the pinch-off region, photon emission rate is ~10^4 greater at 77 K compared to 300 K
   - *Solution: Add metal layer between the APD and ROIC.*
3. Increased APD Gain by decreasing the junction diameter
4. Improved cold shield assembly to reduce noise from ambient thermal emissions
5. Improved photon detection efficiency (PDE)

2011 Limitation to be Addressed	2011 LMPC FPA	2014 FPA	
		A8327-8-2 (Cu + V_{Hg} doped)	A8327-14-1 (V_{Hg} doped)
1.) FER at 50% PDE	> 1 MHz	151 kHz	151 kHz
2.) Maximum APD Gain	470	1910	1100
3.) Maximum PDE	0.50	0.72	0.66

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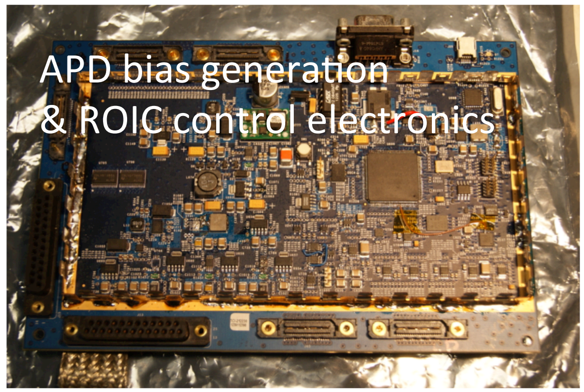
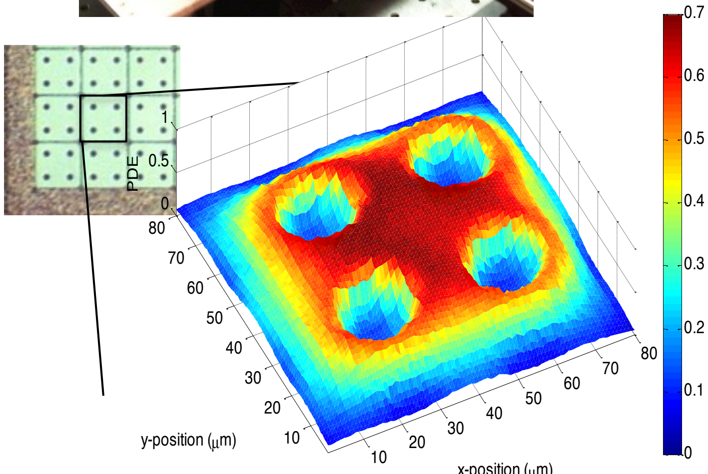
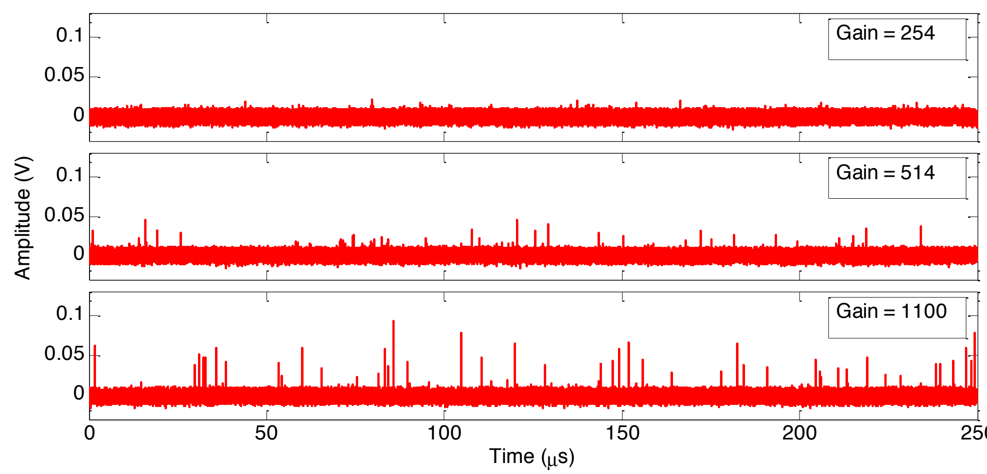
LMPC HgCdTe e-APD Delivered to NASA GSFC



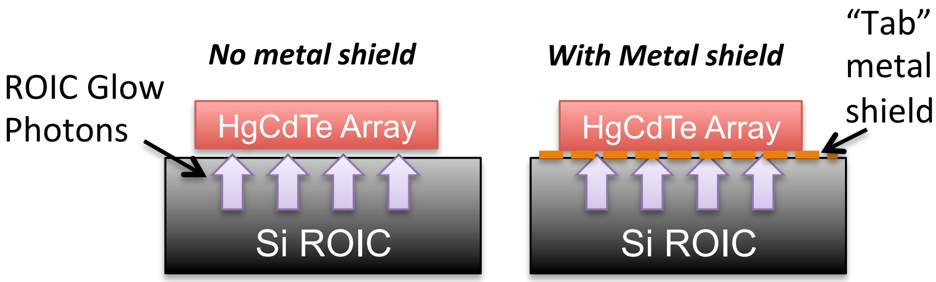
- Two units assembled and tested by DRS, one delivered to GSFC and currently being tested
- 2x8 ROIC from earlier programs, 20 µm active area and 64 µm pitch
- LN2 cooling system for lab use.



PDE vs. position

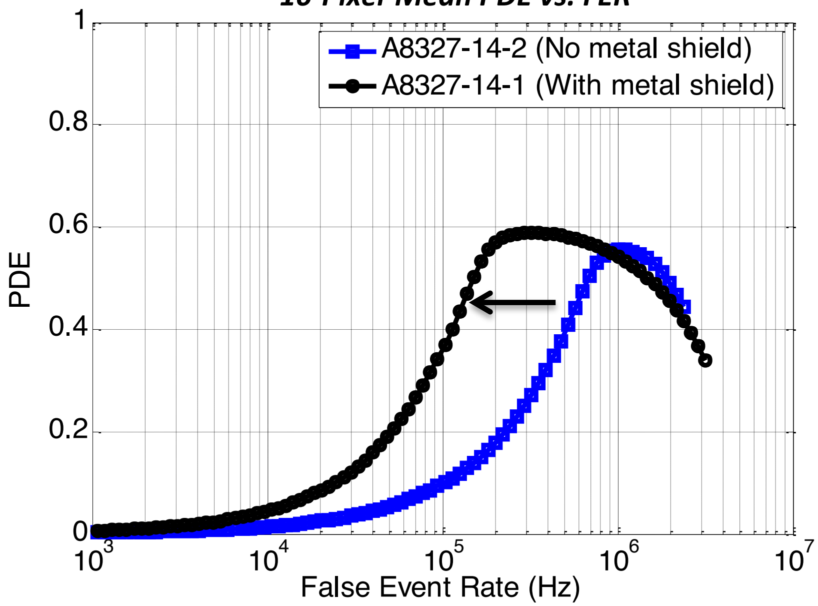


Blocking Photons Emissions from ROIC

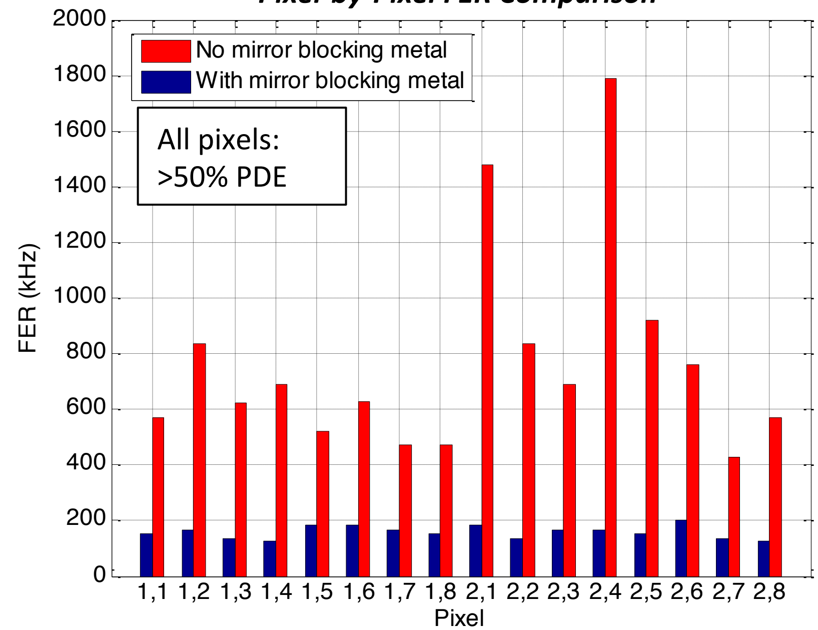


FER ≤ 200 kHz for every pixel with blocking metal layer, a 1/5 reduction.
Multiple metal layers are expected to decrease FER to diode limit (< 20 kHz).

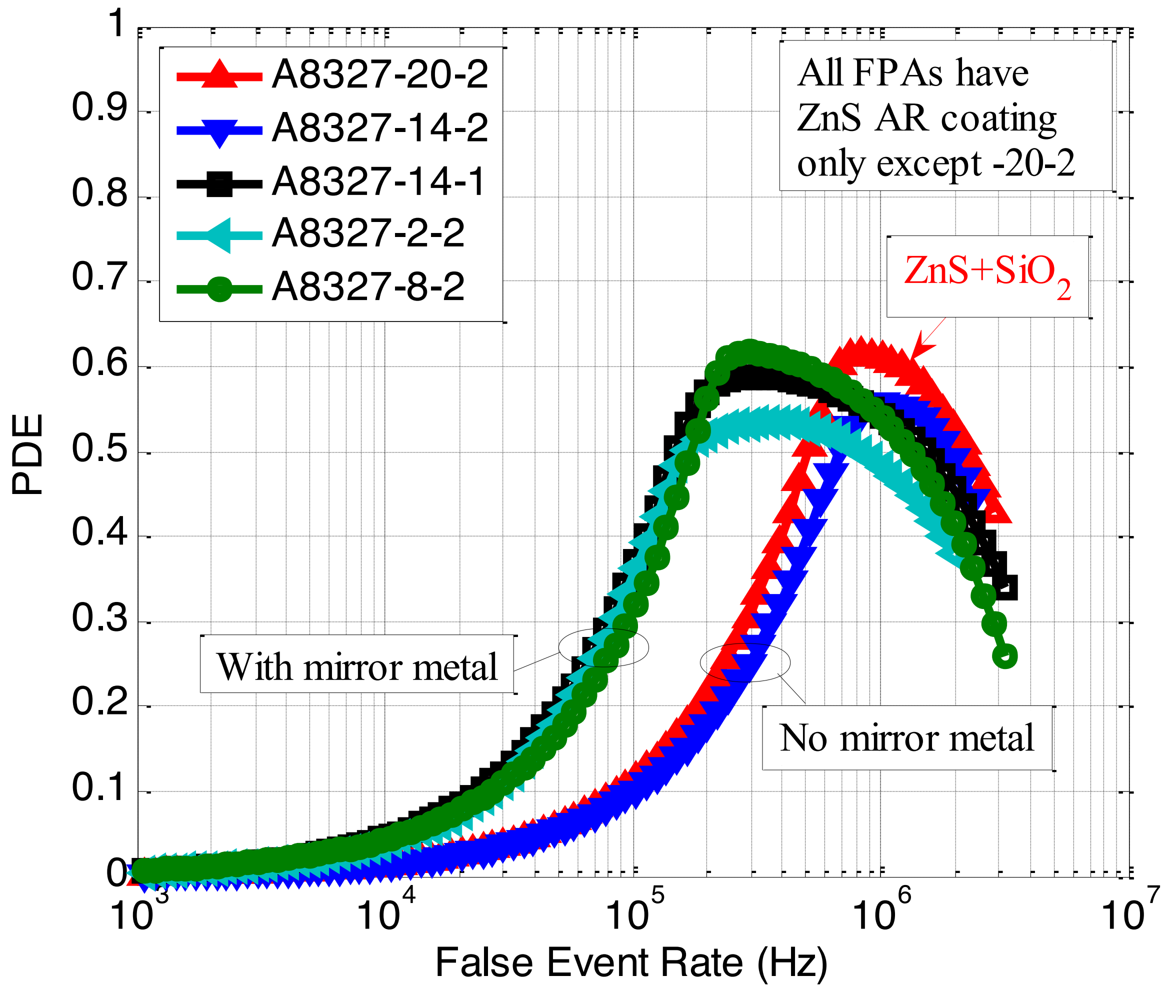
16-Pixel-Mean PDE vs. FER



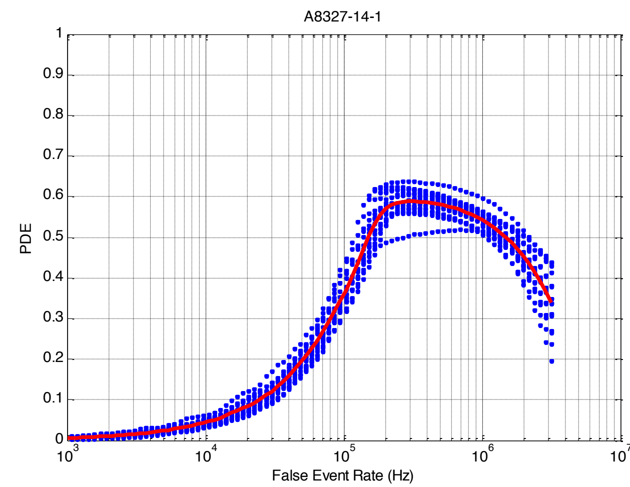
Pixel-by-Pixel FER Comparison

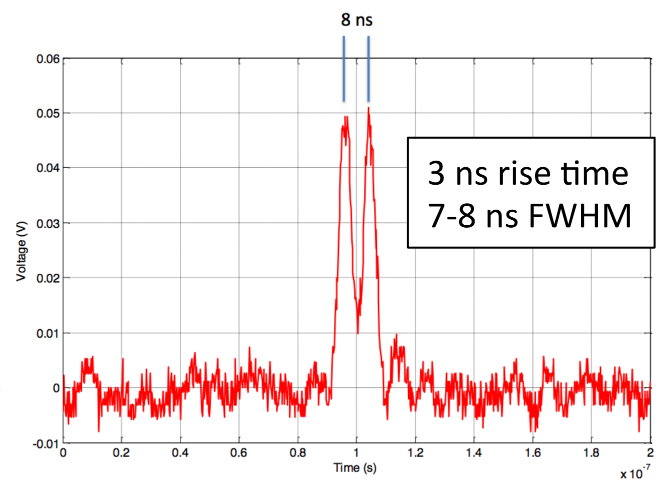


PDE vs. False Event Rate



Individual Pixel Data





LMPC HgCdTe e-APD Performance Summary

Parameter	Specification	Oct. 2014 Status	Notes
Size and form factor	2x8 pixel array, 20 µm dia, 64 µm pitch	Demonstrated	Form factor can be changed if funds available for a new ROIC
Photon Detection Efficiency 0.9 to 4.2 µm	> 40% (> 50% goal)	> 50% (> 65% demonstrated)	From optical input to the analog outputs
Dark count rate	< 500 kHz (<100 kHz goal)	< 200 kHz demonstrated	Including detector dark current, ROIC and system noise
Pulse pair separation	≤ 10 ns (< 6 ns goal)	8 ns demonstrated	ROIC stray capacitance limiting bandwidth
Timing jitter	< 1.0 ns rms (< 0.5 ns rms goal)	~1.4 ns rms (1.1 ns rms demonstrated)	Improvement with smaller pitch APDs expected.
Excess Noise Factor	< 1.4	1.2-1.25 (1.3-1.4 in 2011 Array)	Decreased diode junction width
Outputs	Analog and Digital (optional)	Demonstrated	Linear mode multi-photon resolution with analog outputs
Housing	LN2 Dewar (80K) with window, f/1.5 to f/4.9	Demonstrated	May be housed in an existing long lifetime space cryo-cooler
Simultaneity of Specifications	All specifications met at the same time	Demonstrated	

LMPC CubeSat Status

Funded by ESTO In-space Validation of Earth Science Technologies (InVEST) Program, 2013-2016

Principal Investigator
Dr. Renny Fields, The Aerospace Corporation

Co-Investigators
Mr. Jeffrey Beck, DRS Technologies
Dr. James Abshire, Goddard Space Flight Center
Dr. Xiaoli Sun, Goddard Space Flight Center

Objectives:

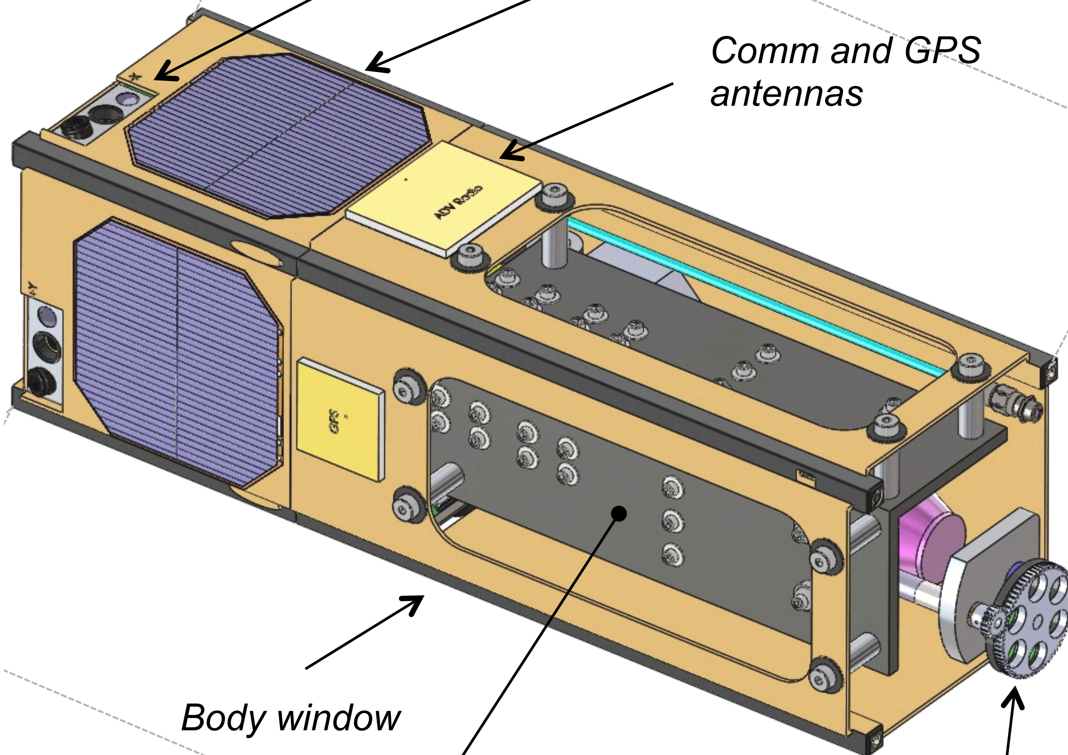
- **Monitor LMPC HgCdTe e-APD performance in space, including radiation damage, responsivity, and SNR.**
- **Demonstrate one-way laser uplinks to CubeSat, e.g. CO_2 lidar measurements and laser communications**

CubeSat Bus Mechanical Design and Electrical Architecture

LMPC CubeSat Bus: AeroCube-9 (AC-9)

Complete assembly (wings not shown)

- 3U CubeSat (<5 kg)
- 3-axis stabilized
- 0.1-degree pointing accuracy
- LMPC cryocooler and Dewar hard mounted to an angle bracket that also serves as the radiator and mounting points within the satellite.
- The satellite body has cutouts for the radiator to see space
- A warm filter wheel indexes to the appropriate filter.



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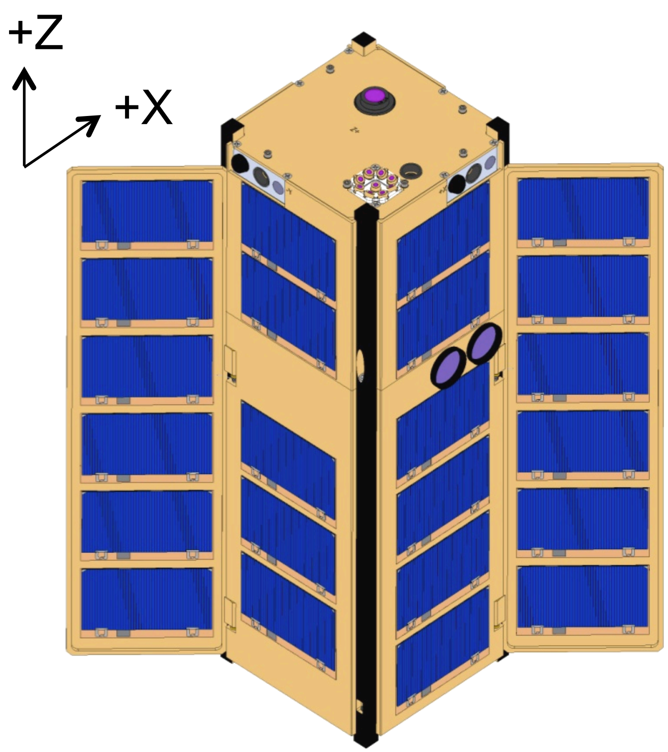
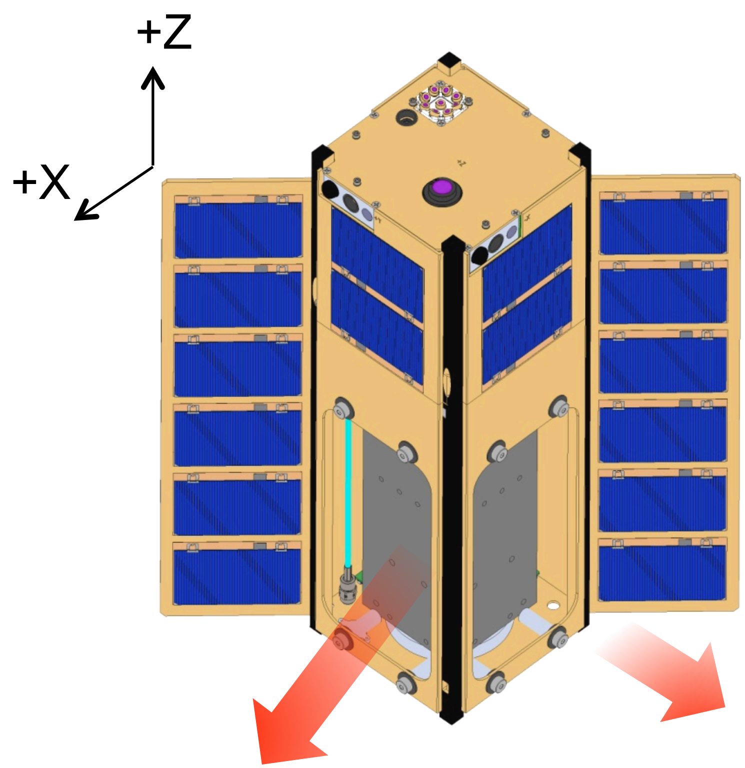
LMPC Bus

Assembly (wings shown)



<u>Sun view</u>
Solar cells needed to run cryopump



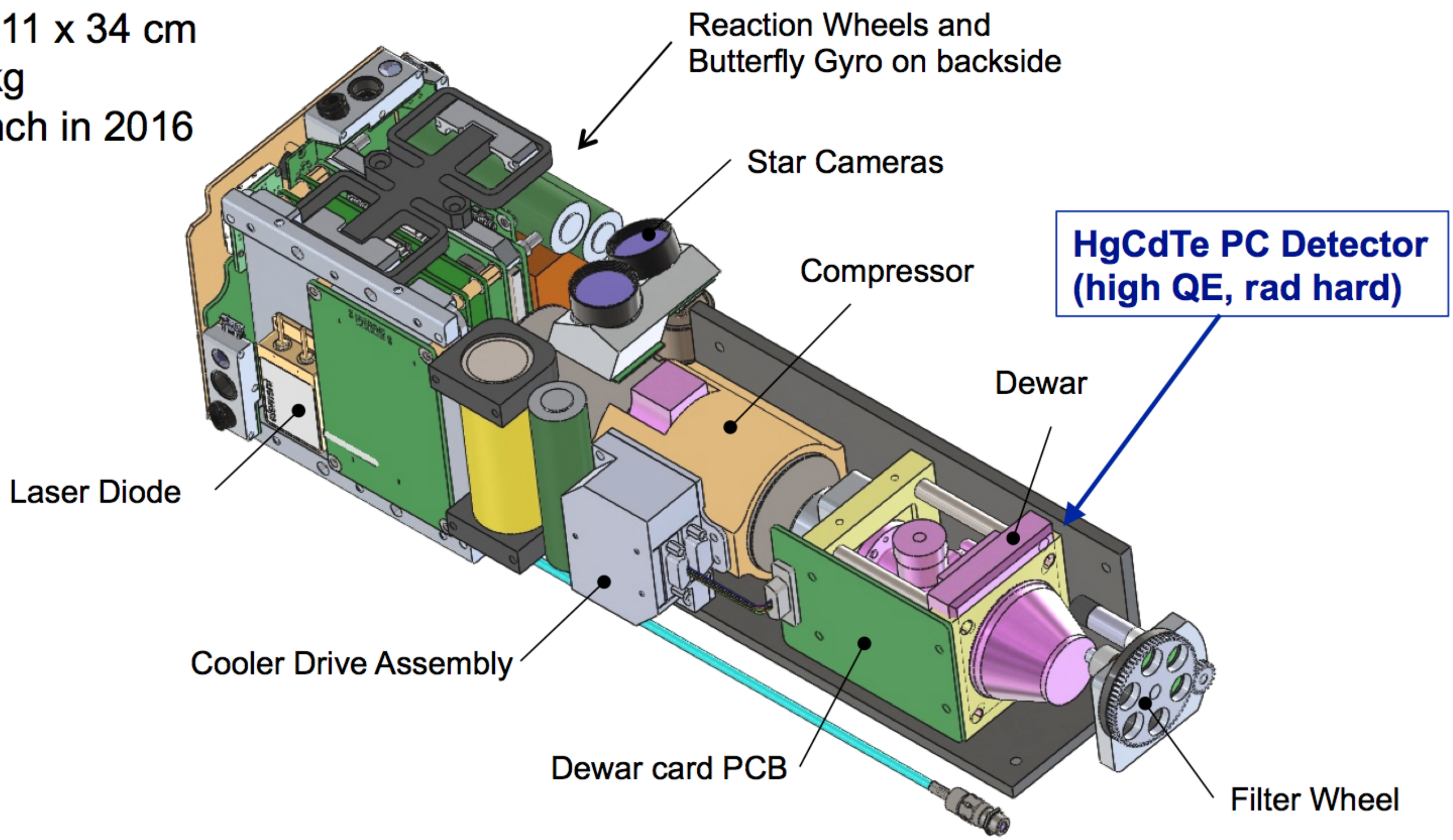
<u>Anti-sun view</u>
LMPC cryopump radiator has direct view to space through two windows – no heat straps

LMPC has a nominal sun-pointing orientation to keep its radiator cold

LMPC CubeSat

IDCA payload and avionics assemblies

- 11 x 11 x 34 cm
- 4.5 kg
- Launch in 2016



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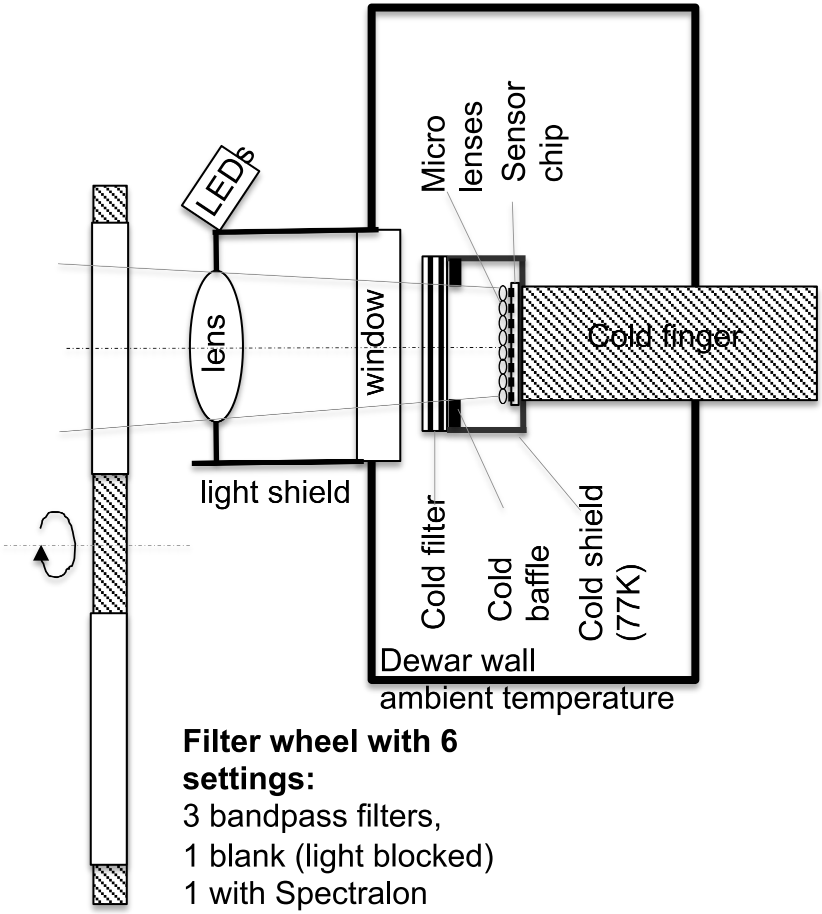
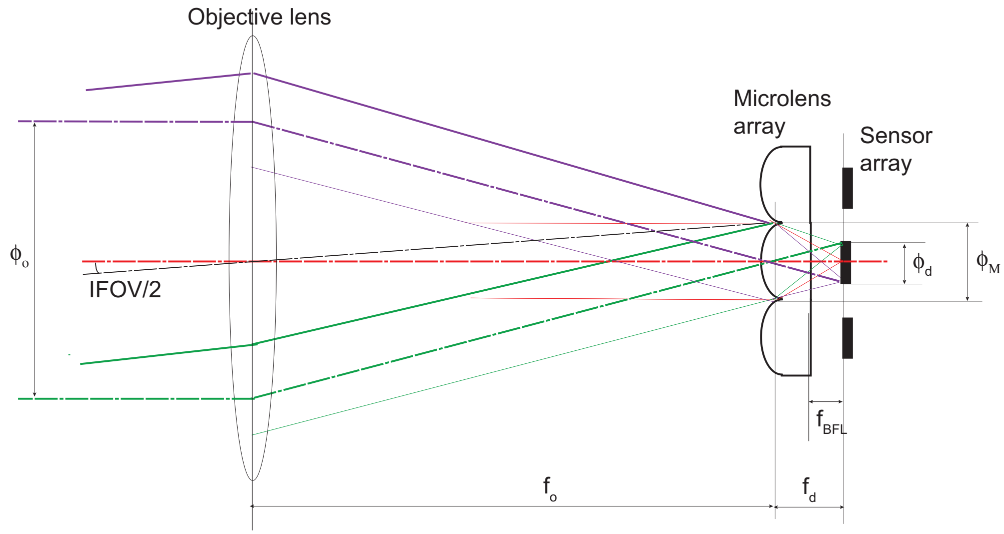
LMPC CubeSat Optics



Filter wheel with 6 settings:
3 bandpass filters,
1 blank (light blocked)
1 with Spectralon
1 open

Microlens array to improve fill factor



$$\frac{\phi_o}{f_o} = \frac{\phi_d}{f_d}, \quad f_M/\# = f_d / \phi_M, \qquad IFOV = \frac{\phi_M}{f_o} = \phi_M \frac{\phi_d}{\phi_o f_d} = \frac{\phi_d}{\phi_o f_M/\#},$$

$$or, \ \phi_o = \frac{\phi_d}{IFOV \ f_M/\#}$$

- Objective lens diameter 6 mm
- F/6.8, iFOV = 1.5 mrad, 2x8 pixels
- Double cold filters, 1.0 to 2.07 μm passband

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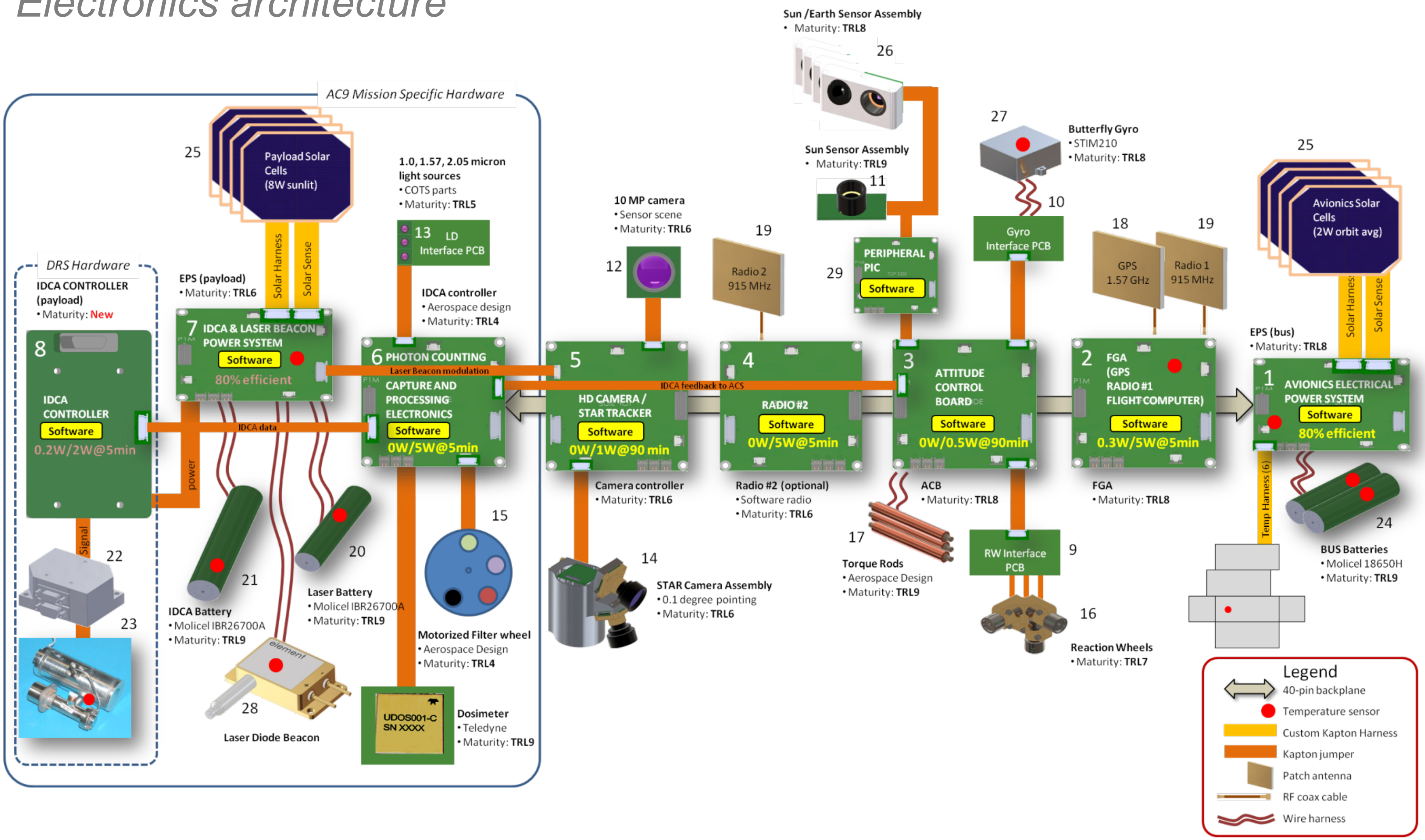
LMPC CubeSat Electronics

Electronics architecture



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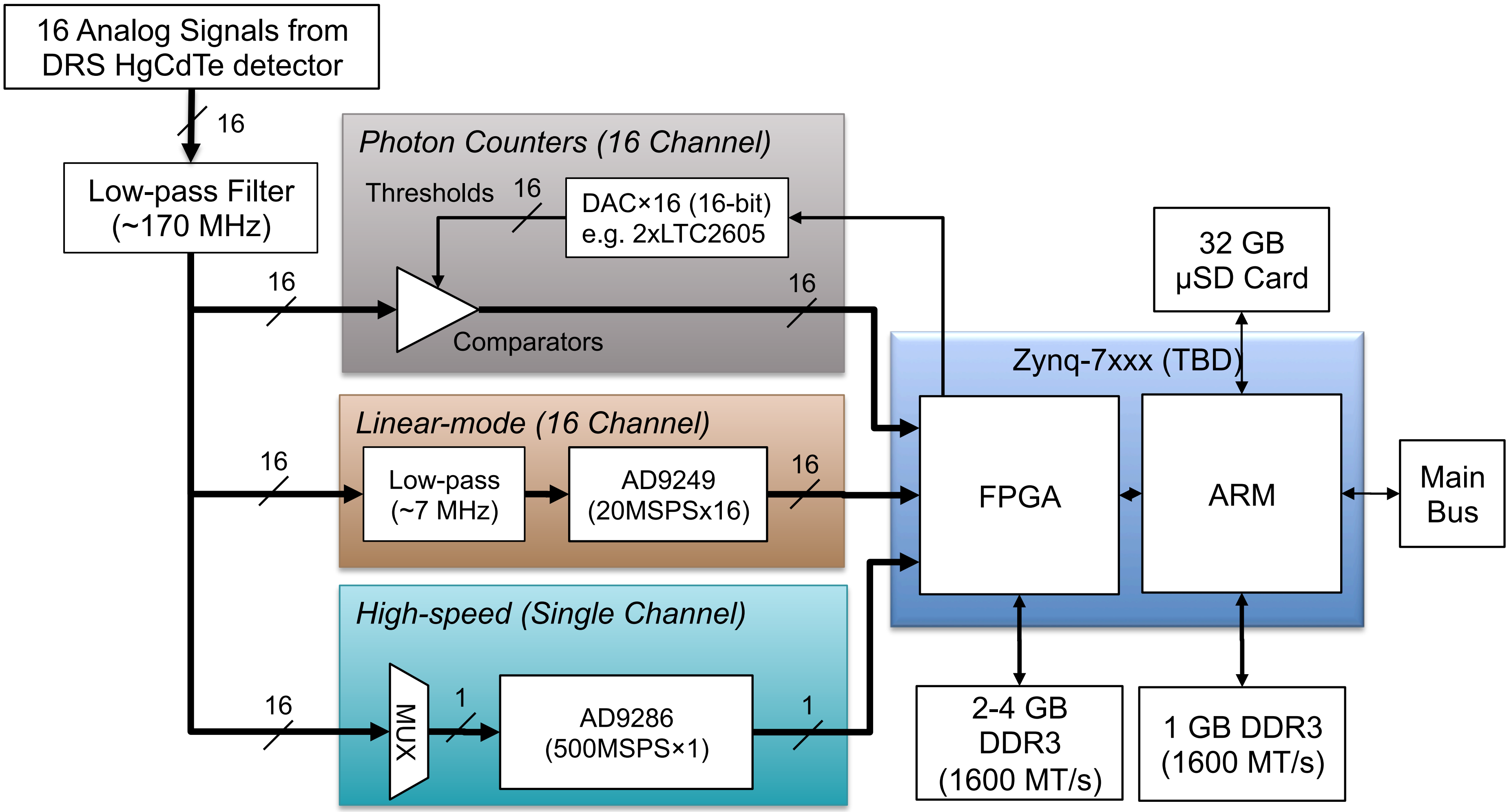
LMPC Payload Signal Processing



LMPC CubeSat Science Experiments

	Experiment	Frequency	Purpose
1A	Radiation	Once per week	Dark current measurement on array, impact of radiation
1B	SNR	Once per week	SNR from on board source vs. time on orbit
2	Moon image	Once per lunar month	Radiometric calibration of sensitivity vs. time
3	Earth Image	Once per week	Radiometric sensitivity to relevant earth emissions
4A	Array track	Once or twice	Demonstrate ACS control to single pixel
4B	CO_2 measurement	Once	Measure response at CO_2 band
4C	Comm	Once or as needed	Demonstrate a communications link
4D	Altimetry	Once	Demonstrate LIST collections

LMPC CubeSat Science Experiments

Experiment 1 – Dark current measurement

Goal

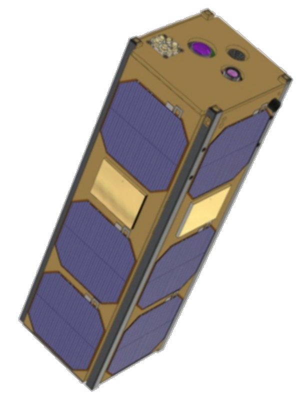
- Trend DRS FPA noise (dark current) throughout mission

Frequency

- Once per week

Data

- FPA dark counts per second
- FPA temperature



Expected result

- Dark current will increase throughout mission
- Dark current will increase with detector temperature
- Radiation damage anneal at near room temperature

Filter Wheel = OPEN (pos 1); LEDs = OFF; ACS = point to deep space + solar panels to sun

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LMPC CubeSat Science Experiment

Experiment 2 – Response to on board LEDs

Goal

- Calibrate and trend FPA response using internal LEDs at discrete frequencies of interest (1.06, 1.57, 2.05 µm)

Frequency

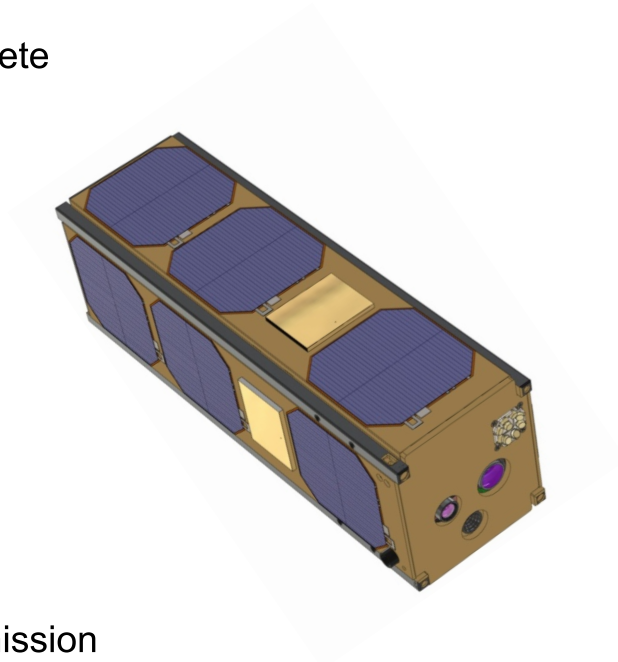
- Once per week individually pulse each LED

Data

- Record photon counts and pulse waveforms from each LED
- FPA temperature

Expected result

- Signal to noise ratio (SNR) remains constant throughout the mission
- SNR vs. temperature stays the same trend



Filter Wheel = CLOSED (pos 3); LEDs = ON; ACS = solar panels to sun

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LMPC CubeSat Science Experiment

Experiment 3 – Image moon (standard radiometric source)

Goal

- Calibrate and trend FPA response

Frequency

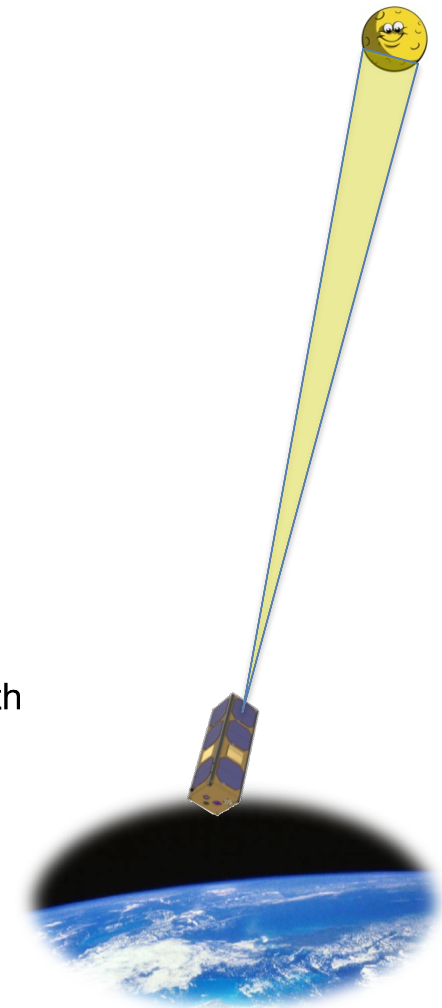
- Once per lunar month

Data

- Record raw data from FPA during lunar transit
- FPA temperature

Expected result

- Detector sensitivity stays constant but dark count rate increases with temperature and time



Filter Wheel = alternate 1064, 1572, 2050 Filter (pos 4,5,6); LEDs = OFF; ACS = point to moon

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LMPC CubeSat Science Experiment

Experiment 4 – Image sunlit earth

Goal

- Demonstrate FPA as an earth weather sensor by imaging the earth and cloud cover as a time varying scene. Correlate with corresponding camera images.

Frequency

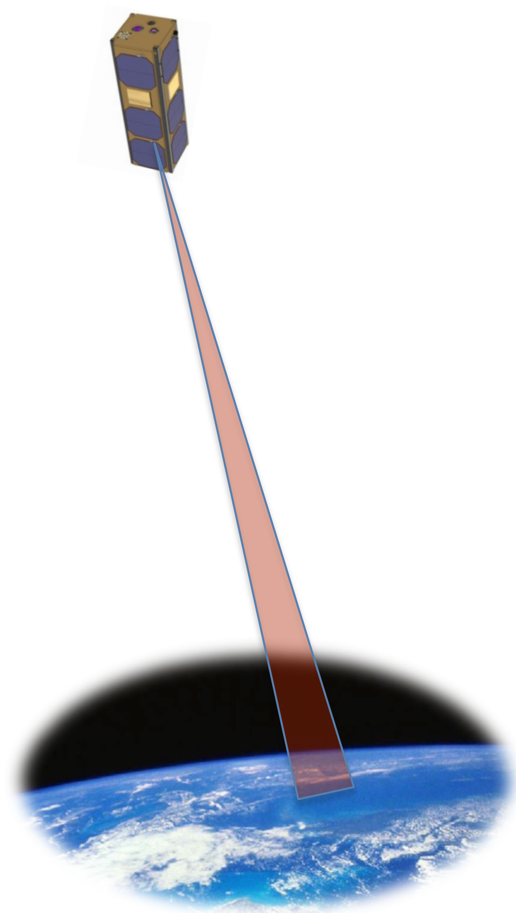
- Once per week

Data

- Record raw data from FPA during imaging of earth scene
- FPA temperature
- Corresponding visible imagery

Expected result

- Observe scene change at three wavelength as those from other Earth orbiting satellite images



Filter Wheel = alternate 1064, 1572, 2050 Filter (pos 4,5,6); LEDs = OFF; ACS = point nadir

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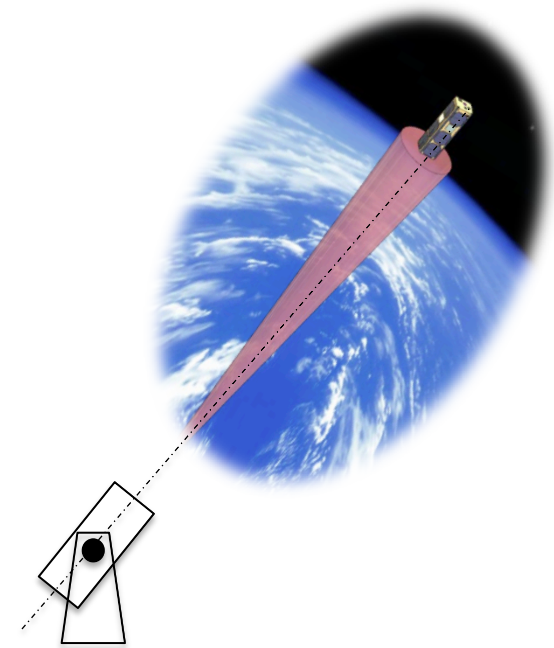
LMPC CubeSat Science Experiment

Experiment 5 – Detecting ground laser light

Goal

- Demonstrate FPA can track a source and feed back to satellite ACS. Source can be a ground laser or a star (point source). Ground sources may be any of three lasers: 1064, 1572 or 2050 nm. Use onboard laser beacon for ground telescope pointing aid.



Frequency

- As needed to support science experiments

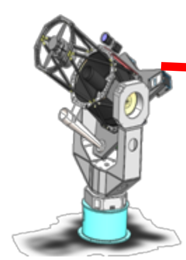
Data

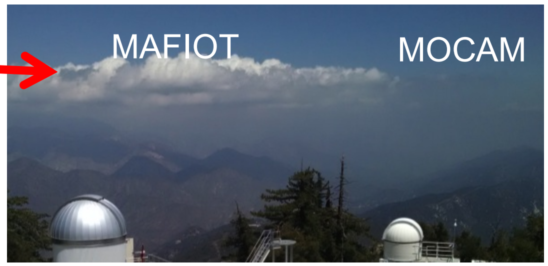
- ACS data demonstrating lock onto point source
- FPA temperature
- Corresponding visible imagery

Expected result

- LMPC record ground laser signals

Detector calibrations;
One-way CO_2 lidar demonstration;
Laser communication demonstration





Filter Wheel = alternate 1064, 1572, 2050 Filter (pos 4,5,6); LEDs = OFF; ACS = track a point source

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Technology and Laboratory Operations, 2014

Conclusions

- Successful demonstration of a new detector technology under the ESTO ACT-10 program, 2012-2014.
  - An emerging infrared photon detector array technology for 0.4-5 μm wavelength range.
  - 80-90% quantum efficiency, 500-1000 avalanche gain, near zero excess noise, and linear output.
  - Radiation tolerant to typical Earth orbit environment based on the proton radiation test result in 2013.
- A CubeSat in-flight demonstration with an Integrated Dewar Cooler Assembly is currently being developed under the ESTO InVEST program and will be launched in 2016.

Backup Slides

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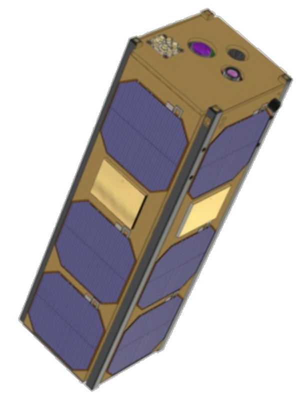
Paper B4P5

Science Experiments

LMPC Mission

Experiment 1A – Dark current measurement



Goal

- Trend DRS FPA noise (dark current) throughout mission

Frequency

- Once per week

Data

- FPA dark counts per second
- FPA temperature

Expected result

- Dark current will increase throughout mission
- Dark current will increase with detector temperature

Filter Wheel = OPEN (pos 1); LEDs = OFF; ACS = point to deep space + solar panels to sun

LMPC Mission

Experiment 1B – Signal to noise ratio measurement

Goal

- Calibrate and trend FPA response using internal LEDs at discrete frequencies of interest (1.06, 1.57, 2.06 μm)

Frequency

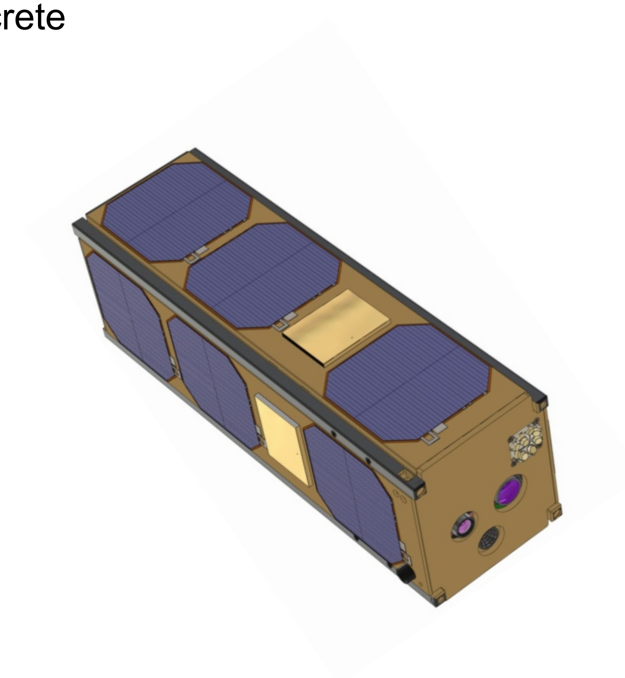
- Once per week individually pulse each LED

Data

- Record photon counts and pulse waveforms from each LED
- FPA temperature

Expected result

- SN will decrease throughout mission
- SN will decrease with detector temperature



Filter Wheel = CLOSED (pos 3); LEDs = ON; ACS = solar panels to sun

LMPC Mission

Experiment 2 – Image moon (radiometric source)

Goal

- Calibrate and trend FPA response

Frequency

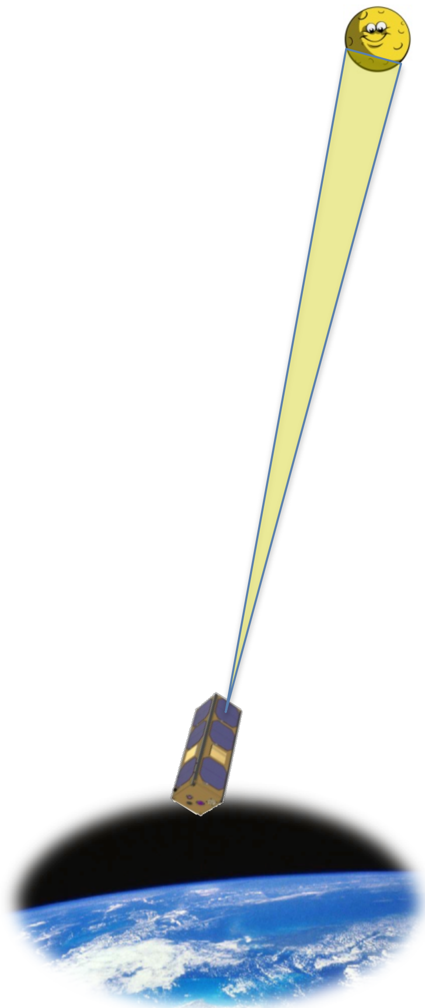
- Once per lunar month

Data

- Record raw data from FPA during lunar transit
- FPA temperature

Expected result

- Calibrate detector sensitivity.



Filter Wheel = alternate 1064, 1572, 2050 Filter (pos 4,5,6); LEDs = OFF; ACS = point to moon

LMPC Mission

Experiment 2 – Image moon (radiometric source) - continued

Assumptions

- Receiver lens diameter: 4-5 mm
- Receiver optics : 50% transmission
- FPA: 50% Quantum efficiency
- Optical bandpass filter widths: 1 nm FWHM
- Detector dark count rate: 100 KHz

Radiometry

- Spectral irradiance of the entire lunar disk outside Earth's atmosphere:
  $0.0026 W/m^2 \mu m$ at 1064 nm; $0.0014 W/m^2 \mu m$ at 1572nm
- Optical power on each detector pixel:
  - At 1064 nm: $0.0026 W/m^2 \mu m * (1 nm) * [pi\ (4mm/2)^2] * 50\% / 4.4^2$
    = 0.84 pW (2.3 MHz rate at output)
  - At 1572 nm: $0.0014 W/m^2 \mu m * (1 nm) * [pi\ (4mm/2)^2] * 50\%$
    = 0.45 pW (1.8 MHz rate at output)
- Signal Margin = ~20x (13dB) above the average dark count rate

LMPC Mission

Experiment 3 – Image earth

Goal

- Demonstrate FPA as an earth weather sensor by imaging the earth and cloud cover as a time varying scene. Correlate with corresponding camera images.

Frequency

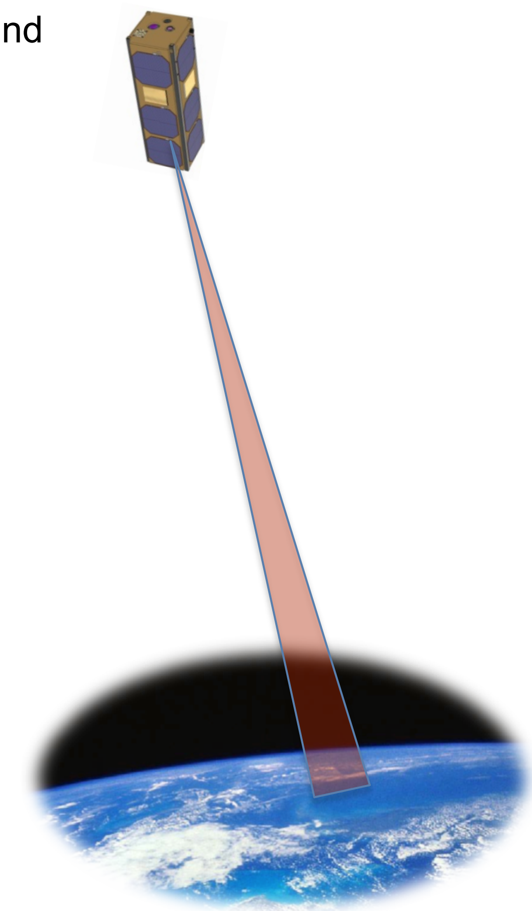
- Once per week

Data

- Record raw data from FPA during imaging of earth scene
- FPA temperature
- Corresponding visible imagery

Expected result

- Observe scene change. Confirm with visible camera images.



Filter Wheel = alternate 1064, 1572, 2050 Filter (pos 4,5,6); LEDs = OFF; ACS = point nadir

LMPC Mission

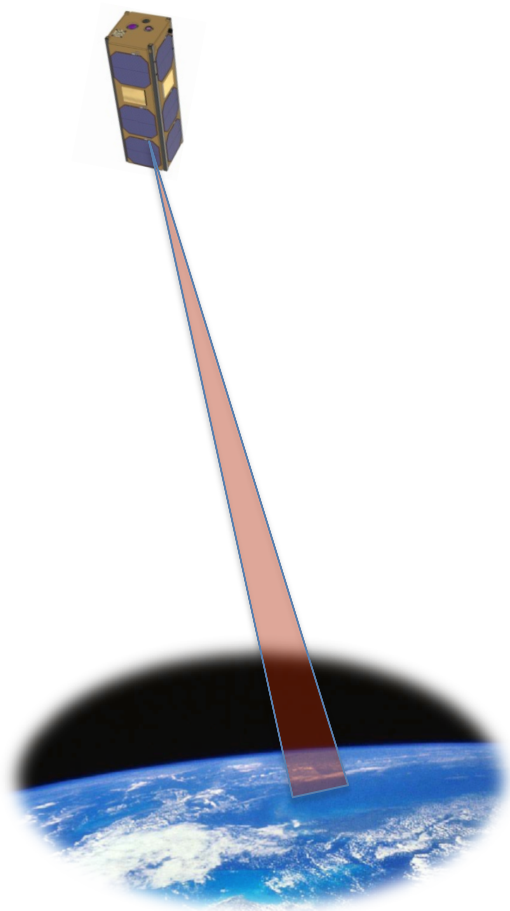
Experiment 3 – Image earth - continued

Assumptions

- AC-9 pointed nadir
- Extended source (clouds) over entire FOV
- Altitude: 600km with Albedo = 100%
- Receiver lens diameter: 4 mm
- Receiver optics: 50% transmission
- FPA: 50% Quantum efficiency
- Optical Bandpass filter bandwidth: 1 nm FWHM
- Detector dark count rate: 100 KHz

Radiometry Calculation:

- Solar irradiance of sunlit clouds above Earth atmosphere:
  0.68 W/m^2 nm at 1.06 and 0.27 W/m^2 at 1.570 um
- Scene area seen by receiver with 2 mrad IFOV (spatial resolution)
  600 km*2mrad = 1.2 km
- Optical power on each detector pixel
  - At 1064 nm: $0.68 W/m^2 nm/pi*(2mrad)^2 (1nm)[pi (4mm/2)^2]*50\%$
    = 5.4 pW (15 MHz detected photon rate)
  - At 1572 nm: $0.27 W/m^2 nm/pi*(2mrad)^2 (1nm)[pi (4mm/2)^2]*50\%$
    = 2.2 pW (8.7 MHz detected photon rate)
- Signal Margin = 15x to 8.7x (12 to 9.4dB)



LMPC Mission

Experiment 4A – FPA feedback to ACS

Goal

- Demonstrate FPA can track a source and feed back to satellite ACS. Source can be a ground laser or a star (point source). Ground sources may be any of three lasers: 1064, 1572 or 2050 nm. Use onboard laser beacon for ground telescope pointing aid.

Frequency

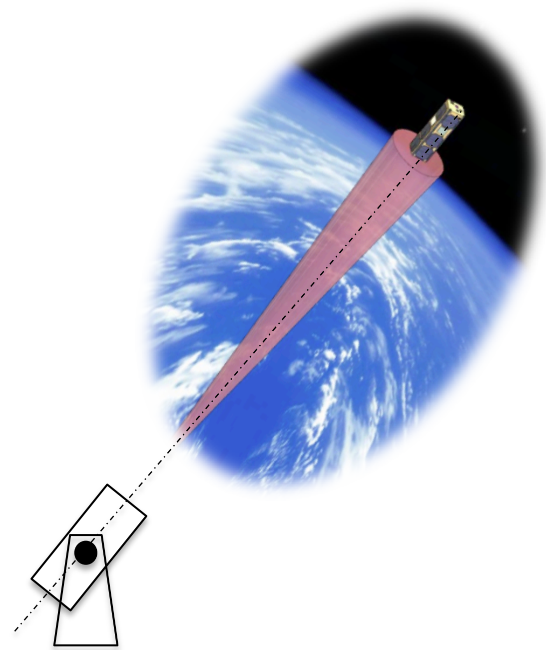
- As needed to support science experiments

Data

- ACS data demonstrating lock onto point source
- FPA temperature
- Corresponding visible imagery

Expected result

- LMPC will maintain pointing based on payload feedback



Filter Wheel = alternate 1064, 1572, 2050 Filter (pos 4,5,6); LEDs = OFF; ACS = track a point source

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LMPC Mission

Experiment 4B – Measure CO_2 absorption

Goal

- Measure CO_2 absorption in atmosphere column from a 1572 nm laser ground source (ASCENDS mission). Use onboard laser beacon for ground telescope pointing aid.

Frequency

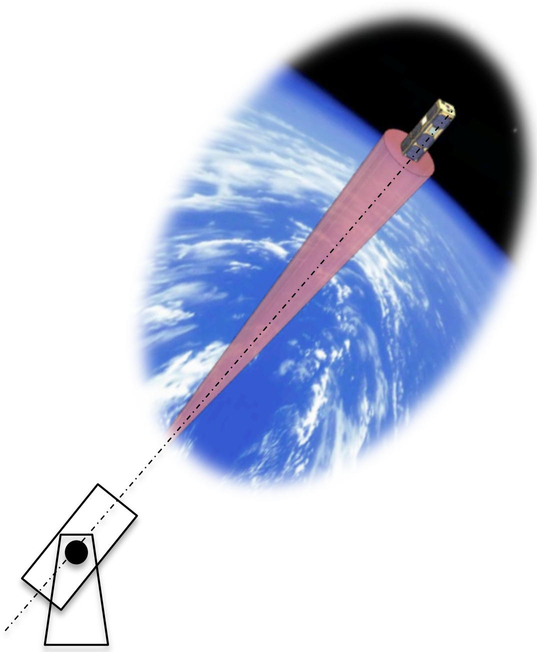
- Once

Data

- Record raw data from FPA during illumination
- ACS data demonstrating lock onto ground source
- FPA temperature
- Corresponding visible imagery

Expected result

- CO_2 absorption will vary depending on atmosphere thickness



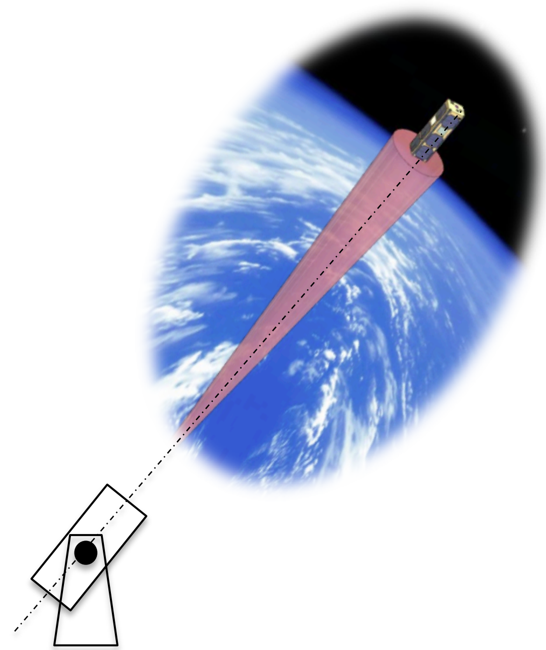
Filter Wheel = 1572 Filter (pos 6); LEDs = OFF; ACS = track ground source

LMPC Mission

Experiment 4B – Measure CO_2 absorption - continued

Assumptions

- CubeSat points to ground station to within 2x2 array of pixels (4 mrad)
- Ground station laser: 1572 nm, 25 uJ/pulse, 1us FWHM, 10 kHz, (airborne CO_2 Sounder transmitter)
- Laser Beam divergence = 1.8 mrad
- Ground telescope pointing: 0.3 mrad
- Range: 1000 km
- Receiver diameter: 4 mm
- Receiver optics : 50%
- FPA: Quantum efficiency: 50%
- Background and dark noise: 1 MHz



Radiometry:

- Total laser signal attenuation (propagation losses)
  $[\,4\text{mm}/(1.8\text{mrad}*1000\text{km})]^2 *50\% = 2.5\text{e-}12$
- Received laser pulse energy per pulse on each detector pixel
  25uJ*2.5e-12 = 3.1e-17 J/pulse
  (120 detected photons/pulse at 1572 nm)
- Minimum detectable signal of the detector: 4 photons/pulse
- Signal Margin: 30x (15dB)

LMPC Mission

Experiment 4C – Optical communication link

Goal

- Demonstrate one-way (uplink) optical communication at low data rates. Use onboard laser beacon for ground telescope pointing aid.

Frequency

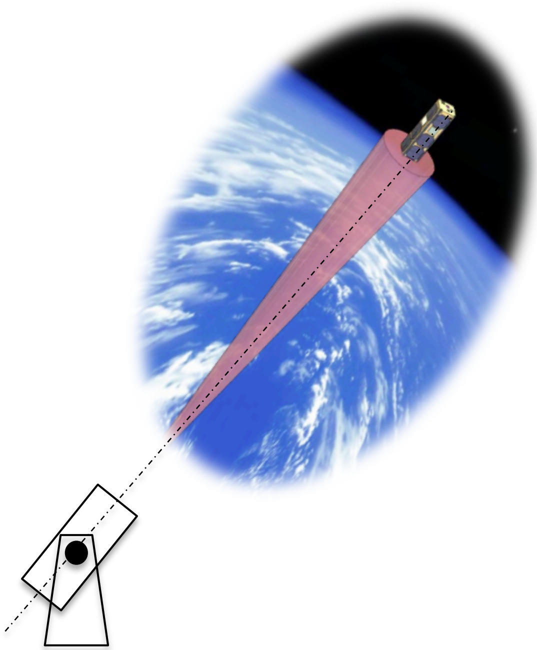
- Once

Data

- Raw data from FPA comprising a message that is stored
- ACS data demonstrating lock onto ground source
- FPA temperature
- Corresponding visible imagery

Expected result

- LMPC will detect very low uplink power



Filter Wheel = 1572 Filter (pos 5); LEDs = OFF; ACS = track ground source

LMPC Mission

Experiment 4D – Receive LIST signals

Goal

- Measure optical signals similar to those expected for LIST. Use onboard laser beacon for ground telescope pointing aid.

Frequency

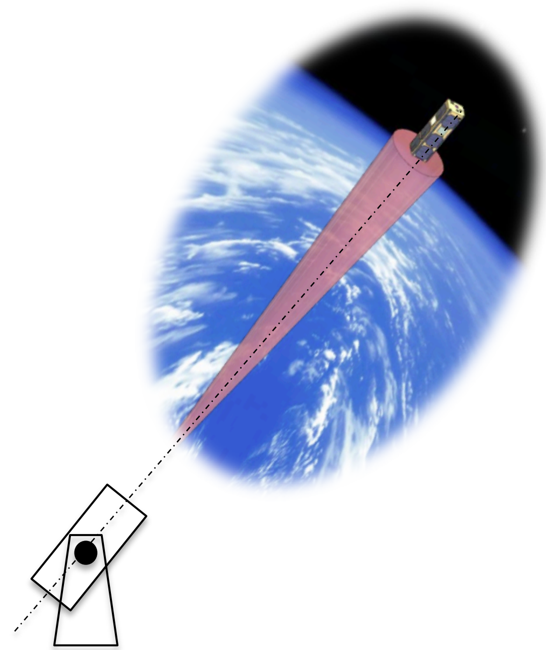
- Once

Data

- Record raw data from FPA during illumination
- ACS data demonstrating lock onto ground source
- FPA temperature
- Corresponding visible imagery

Expected result

- LMPC will receive LIST signals



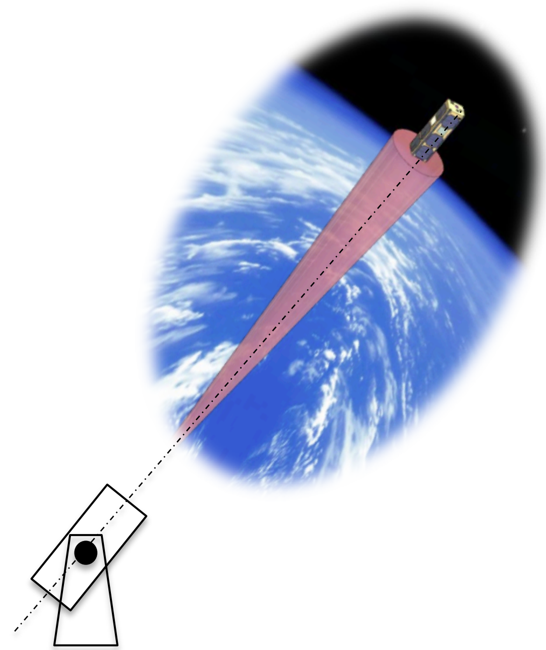
Filter Wheel = 1064 Filter (pos 4); LEDs = OFF; ACS = track ground source

LMPC Mission

Experiment 4D – Receive LIST signals - continued

Assumptions

- CubeSat points to ground station to within 2x2 array of pixels
- Ground station laser: 1064 nm, 0.5-3 ns pulse width, 25 uJ/pulse, 10 kHz.
- Laser Beam divergence = 1.8 mrad
- Ground telescope pointing: 0.3 mrad
- Range: 1000 km
- Receiver diameter: 4 mm
- Receiver optics : 50%
- FPA: Quantum efficiency: 50%
- Background and dark noise: 1 MHz



Radiometry (for a 25 uJ/pulse transmitter):

- Total laser signal attenuation (propagation losses)
  $[\,4mm/(1.8mrad*1000km)]^2 *50\% = 2.5e\text{-}12$
- Received laser pulse energy per pulse on each detector pixel
  25uJ*2.5e-12*50% = 3.1e-17 J/pulse
  (83 detected photons at 1064 nm)
- Assuming the minimum detectable signal: 4 photons/pulse
  Signal Margin: 21x (13dB)

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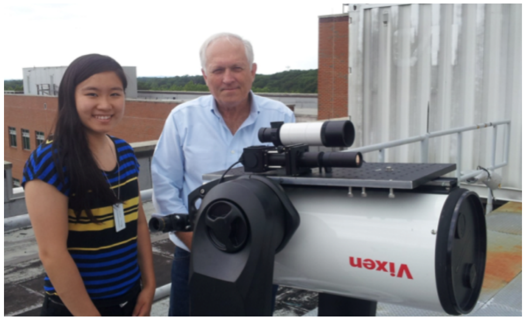
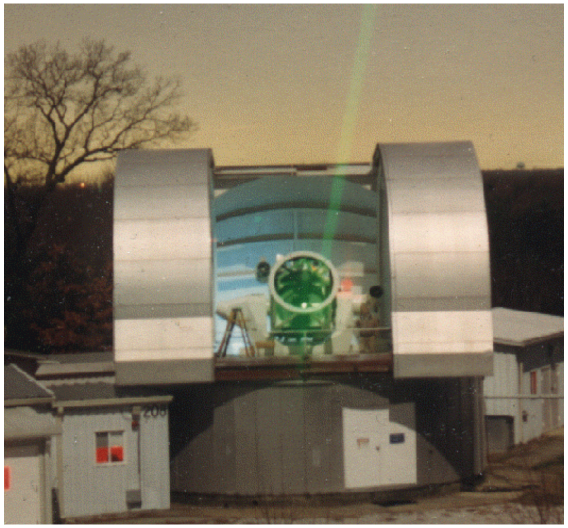
LMPC Mission

Optical ground station resources

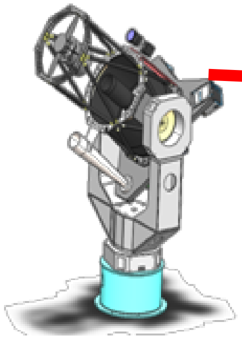
Modified commercial telescope
(Vixen-VMC200L)

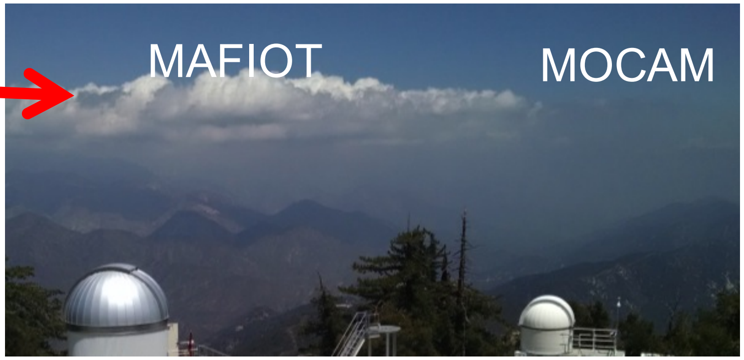


1.2 meter Telescope Facility at
Goddard's Geophysical and
Astronomical Observatory (GGAO)



Mt Wilson Observatory
operated by Aerospace Corp.





Payload Signal Processing Electronics

LMPC Payload

Raw snapshot capture

- Capture raw, full-rate ADC output from a single, preselected channel in short, intermittent bursts.
  – Trigger event could be pulse detection, countdown timer, etc.
  – e.g. Capture 1 μsec window centered around each of the last fifty events on input channel 7.
- Requires a small high-speed memory, but can be subdivided to serve multiple purposes
  – e.g. 64 windows of 512 samples
  – e.g. One window of 32768 samples
- Store data at leisure for download to ground or on-board software analysis.
  - To manage downlink volume, most data-processing must be on-board.
  - FPGA limited to simple real-time processing. Most analysis will be performed by regular software running on ARM.
  - ARM will run a GNU/Linux environment with full access to common applications and utilities. (e.g. C++ and/or Python libraries.)

LMPC Payload

Example Analysis Concept: Pulse spectrum estimation

- Real-time data triggering and capture by FPGA:
  - Monitor a preselected input channel using high-speed ADC (500 MHz).
  - Detect input pulses. (i.e. Oscilloscope-style trigger.) For each pulse, store a window of 1,024 samples, centered on rising edge.
  - Continue storing windows until timeout or 10,000 capture events.
    - Note: Number of windows and window size are examples only. Maximum sizes are limited only by memory capacity.
- Post-capture analysis by ARM software:
  - Read each stored capture window.
  - Perform FFT and compute magnitude.
  - Noncoherent accumulation of output spectrum over all windows.
  - Store final output spectrum for later download.

LMPC Payload

Pulse counting and histograms (Real-time analysis)

- Histogram can operate in linear mode or Geiger mode.
  - Geiger mode is driven by photon-counter electronics.
  - Linear mode can be driven by either ADC.
    - Adjustable thresholds to estimate photon count from peak height.
  - Both configurations measure count rate (counts per unit time).
- Can accumulate data in real-time for all channels simultaneously.
- Start first time interval a fixed delay after command or event.
  - – e.g. Command from ground station, RTC, or flight computer
  - – e.g. Internal timer, capture histogram once every three seconds
- Each histogram bin is the accumulation of count events within a given time interval.
  - – Interval can be adjusted from 2 nsec to 10+ sec.
  - – Any number of histogram bins up to 64k (?)

LMPC Payload

Laser communication receiver (Real-time analysis)

- Receive On-Off-Keyed laser communication signals from any selected channel.
- Real-time tracking and demodulation up to 250 MBaud.
  - Note: This is the upper limit set by capture hardware.
    Link budget and channel conditions may further limit maximum rate.
- Timing tracking, packet detection, FEC, and other logic can be recycled from AC7.