Advanced Technology in Small Packages Enables Space Weather Nanosatellites

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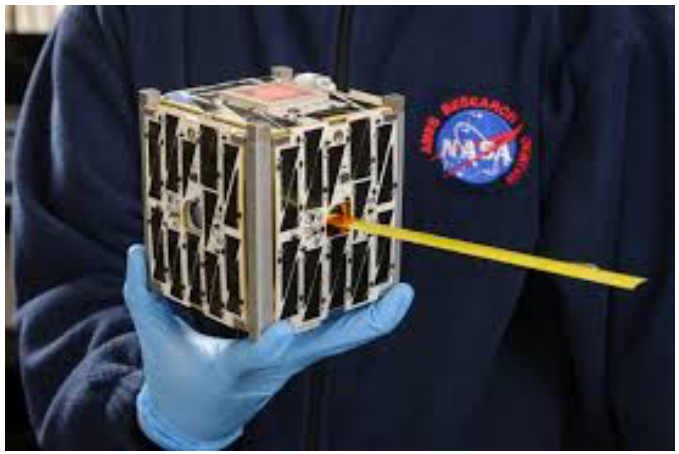
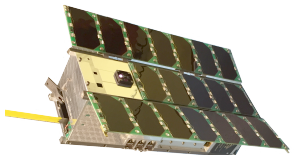


MinXSS CubeSat

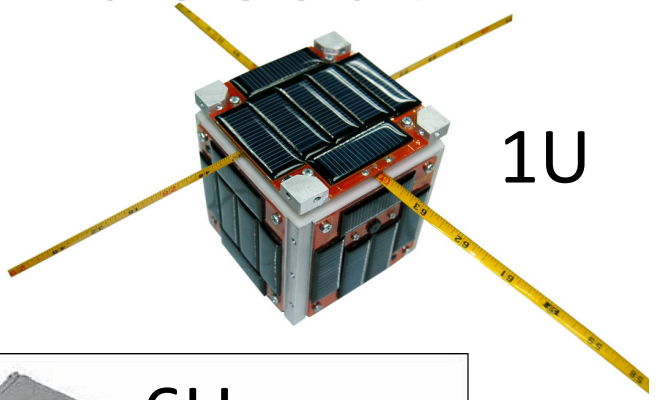
Outline

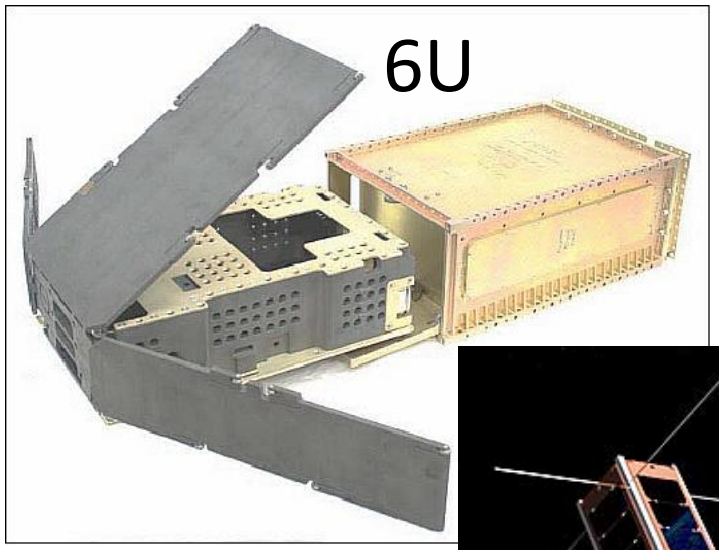
- NRC 2016 Report about CubeSats
  - *Achieving Science with CubeSats: Thinking Inside the Box*
- Nanosatellite Technology is mature
  - Nanosatellite: 1-10 kg satellite
  - CubeSat Unit (1U): 10cm x 10cm x 10cm
  - Most NSF/NASA Science CubeSats are 3U (4 kg) or 6U (12kg)
- Example: CU's MinXSS CubeSat
  - MinXSS overview
  - Solar science with MinXSS
  - Space weather studies with MinXSS
- Compact Instrument for Space Weather Operations

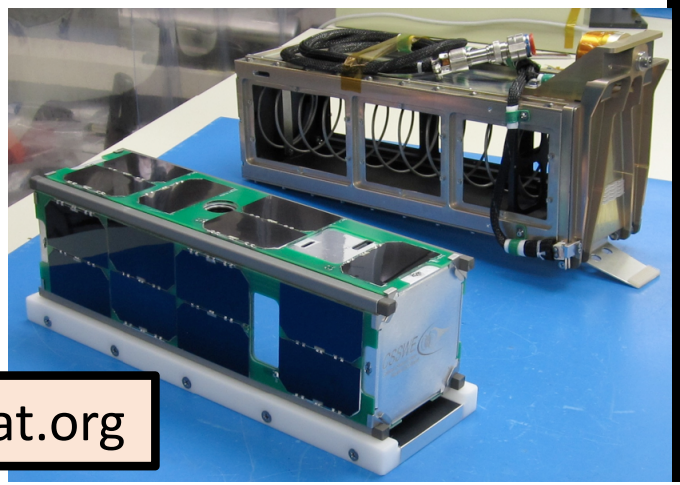


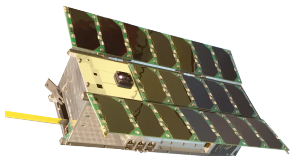
What is a Nanosatellite / CubeSat?

- Nanosatellite is in the mass range of 1 to 10 kg. The CubeSat is a special case.
- CubeSat "unit" of 1 liter (10 cm x 10 cm x 10 cm) was defined by Cal Poly (Jordi Puig-Suari) & Stanford (Bob Twiggs) in 1999
- Dispenser encapsulates satellite to ease interface to launcher
- The Unit (U) is scalable with standard 3U, 6U, 12U, & 27U dispensers
- Commercial parts are used to enable fast, low-cost development for a short-life mission









http://www.cubesat.org

2016 NRC Report

1999 CubeSat concept started

2003 First CubeSat launch

2006 NASA First Technology CubeSat

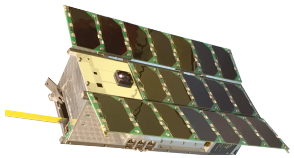
2008 NSF Geoscience CubeSat program starts

2010 NSF First CubeSat launch

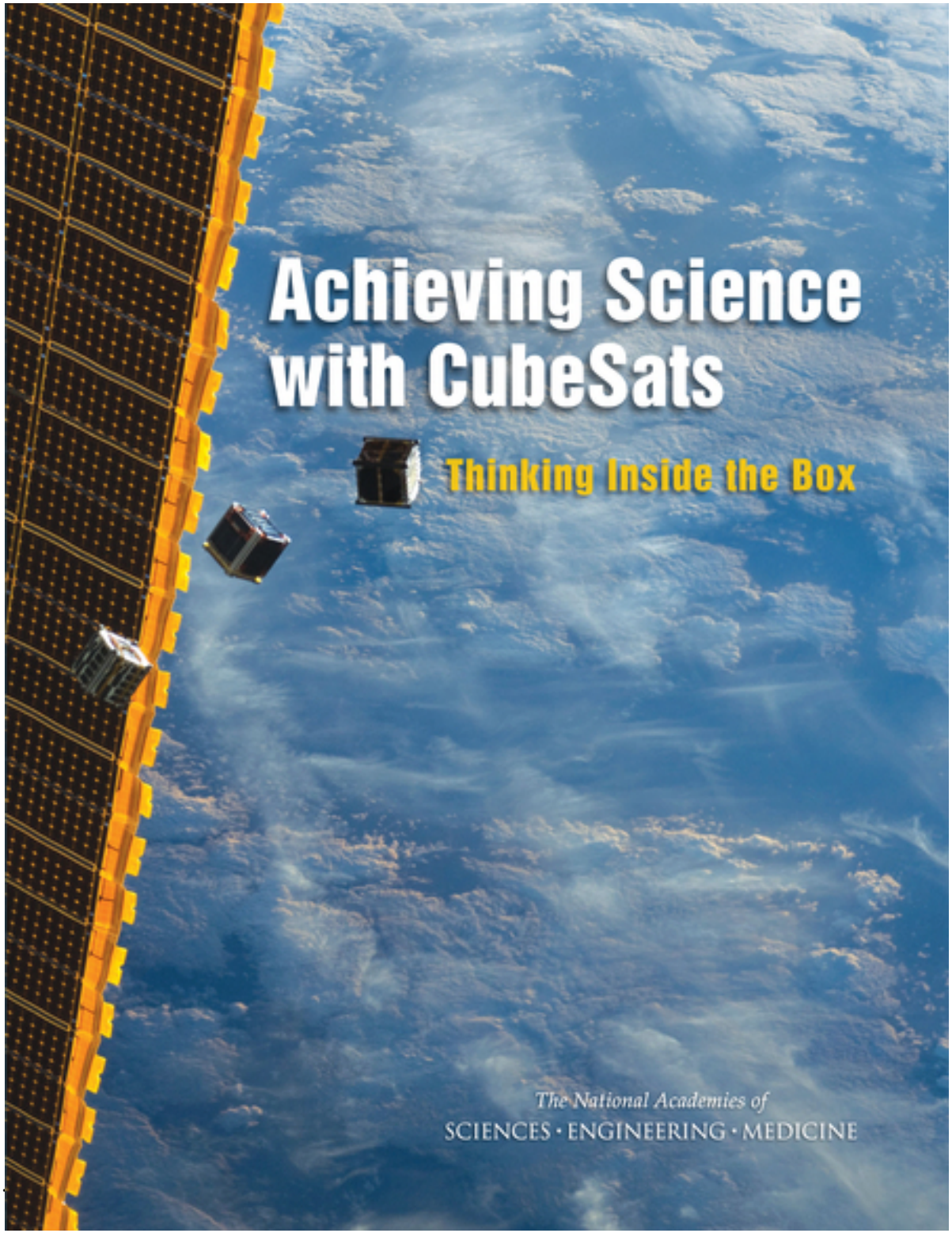
2014 NASA Science CubeSat program starts

2016 NASA First Science CubeSat deployed (MinXSS-1)

- The time is right for science from CubeSats !

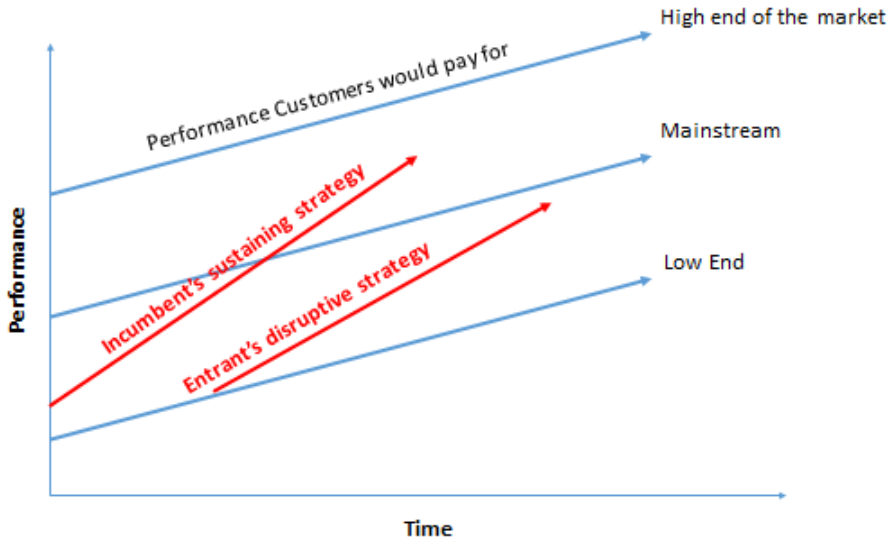


Book is now available at Target



CubeSats are Disruptive Technology

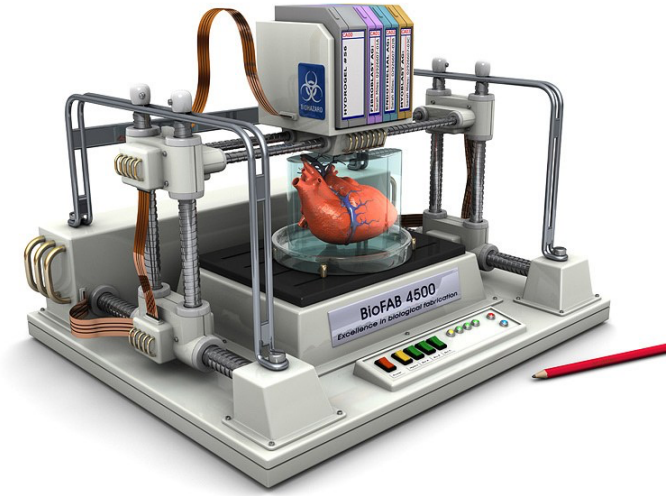
- Has poor performance at start
- Is cheaper than status quo
- Targets underserved users
- Has rapid growth at low cost
- Advances with new technology



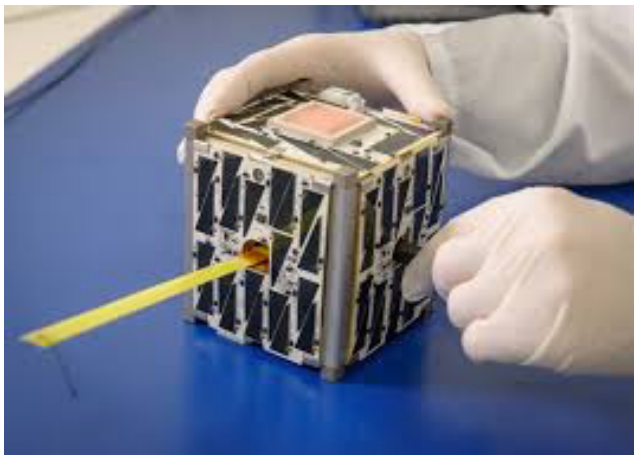
From *Achieving Science With CubeSats*

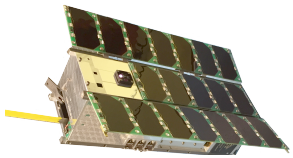
Smart Phones as
Mobile Internet & Digital Camera

3D Printers



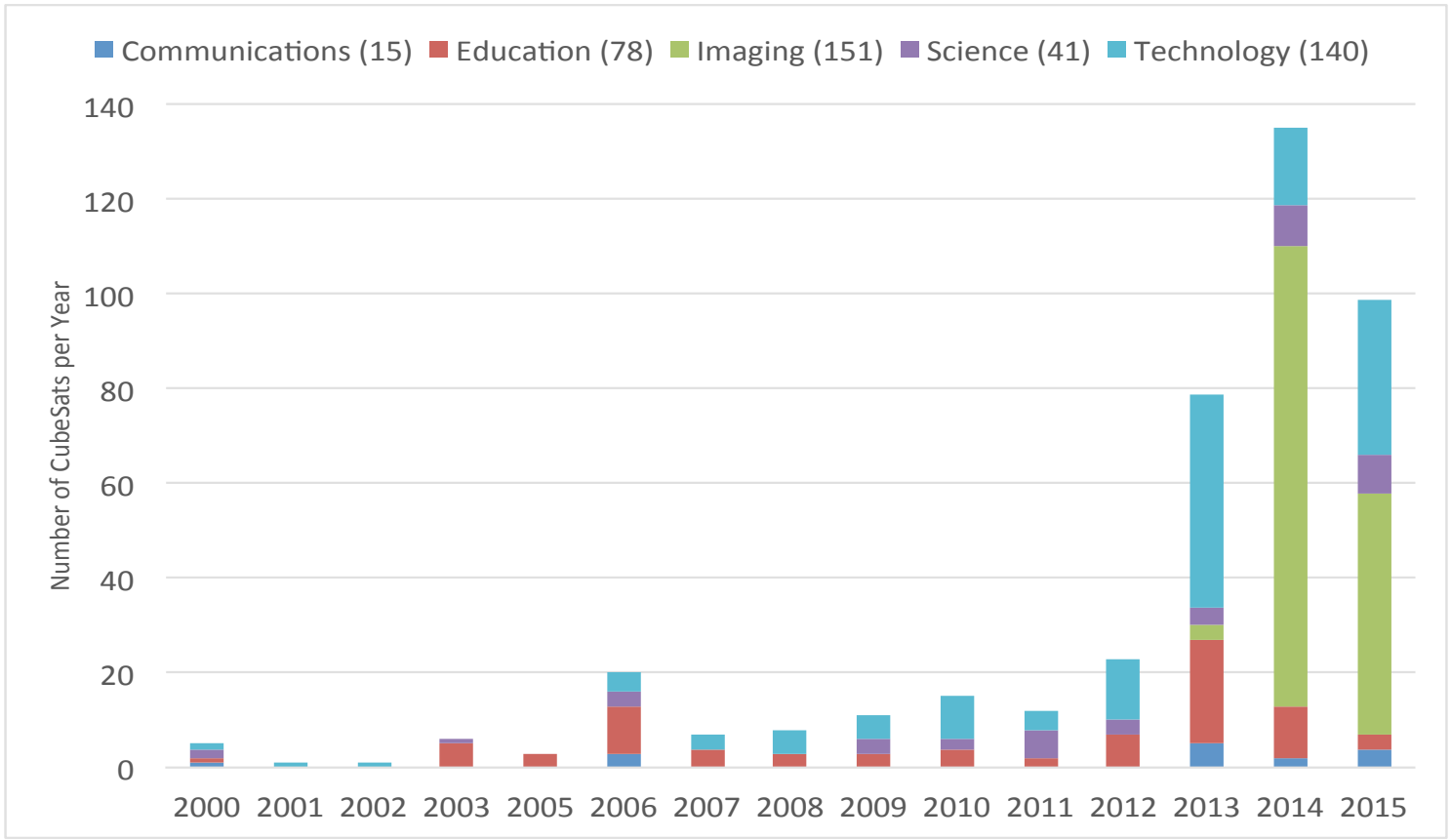
CubeSats

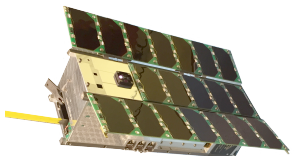




Number of CubeSat Missions

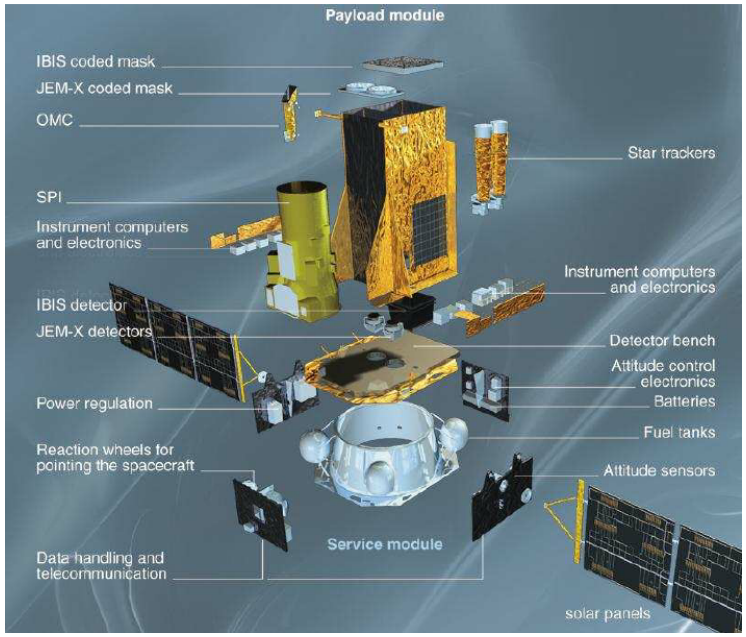
- As of April 2017, there have been 614 CubeSats launched
  - NRC Report: 92% of science CubeSats have been successful (67% success for all)
  - Swartwort (*J. Small Sat.*, **2**, 213-233, 2013) provides an overview of the first 100 CubeSat missions
  - https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database#database





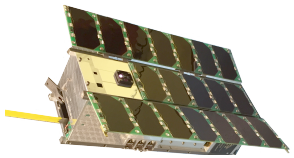
Spacecraft 6 Ps

- Payload
  - instrument
- Pointing
  - attitude control
- Phone
  - communication, radio
- Power
  - solar cells, battery, voltage regulation
- Processor
  - command & data telemetry
- Propulsion
  - navigation



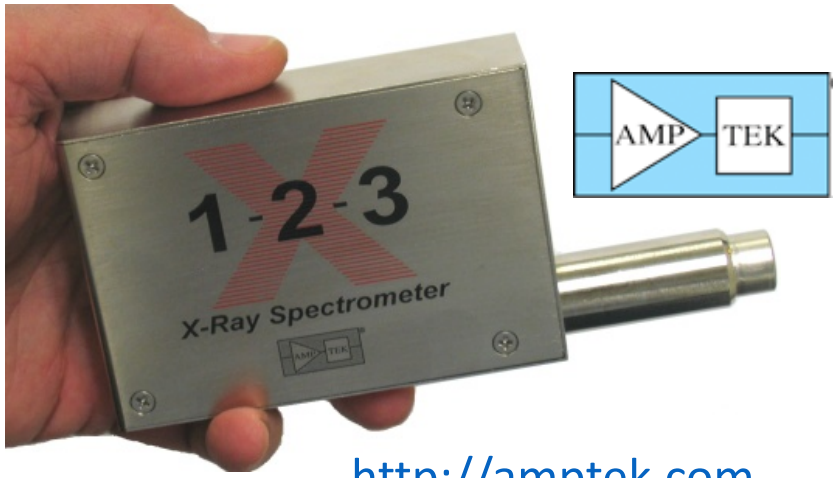
INTEGRAL Spacecraft
Exploded View
as example

NASA Ames: Small Satellite Technology State of the Art
https://www.nasa.gov/centers/ames/engineering/state-of-the-art



Examples of Mature CubeSat Technology

- Amptek miniature X-ray spectrometer
  - X123: 0.2U, 0.2kg, 2.5W
  - Energy range of 0.5-100 keV with 0.15 keV resolution

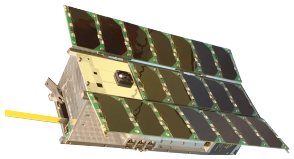


http://amptek.com

- Blue Canyon Technologies (BCT) Attitude Determination and Control System (ADCS)
  - XACT: 0.5U, 1kg, 2W
  - In-flight performance of 8 arc-sec stability

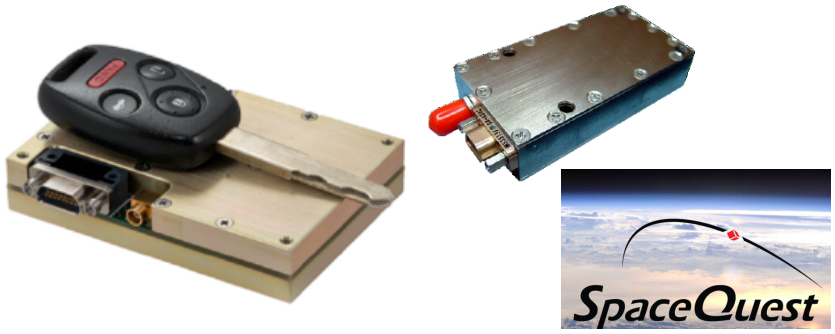
BCT XACT 0.5U
Star Tracker
Coarse Sun Sensor
Magnetometer
Reaction Wheels
Torque Rods

http://bluecanyontech.com



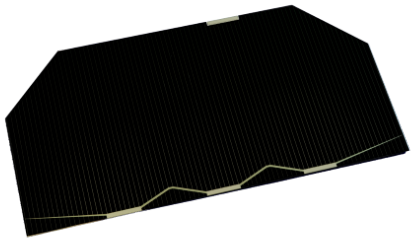
Examples of Mature CubeSat Technology

- SpaceQuest miniature radios
  - TRX-U UHF transceiver: 0.1U, 0.14kg, 8W
  - TX-2400M S-band transmitter: 0.04U, 0.07kg, 5W



http://www.spacequest.com/

- AzurSpace 30% efficient triple-junction solar cell
  - 3G30C: 0.001U, 0.003kg
  - Flight heritage; 8cm x 4cm size fits CubeSat format well



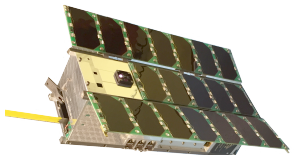
AZURSPACE SOLAR POWER GMBH

http://www.azurspace.com/

- sparkfun Li-poly battery
  - PRT-08483: 0.02U, 0.04g
  - 2 Amp-hr, 3.7 V; excellent in-flight performance

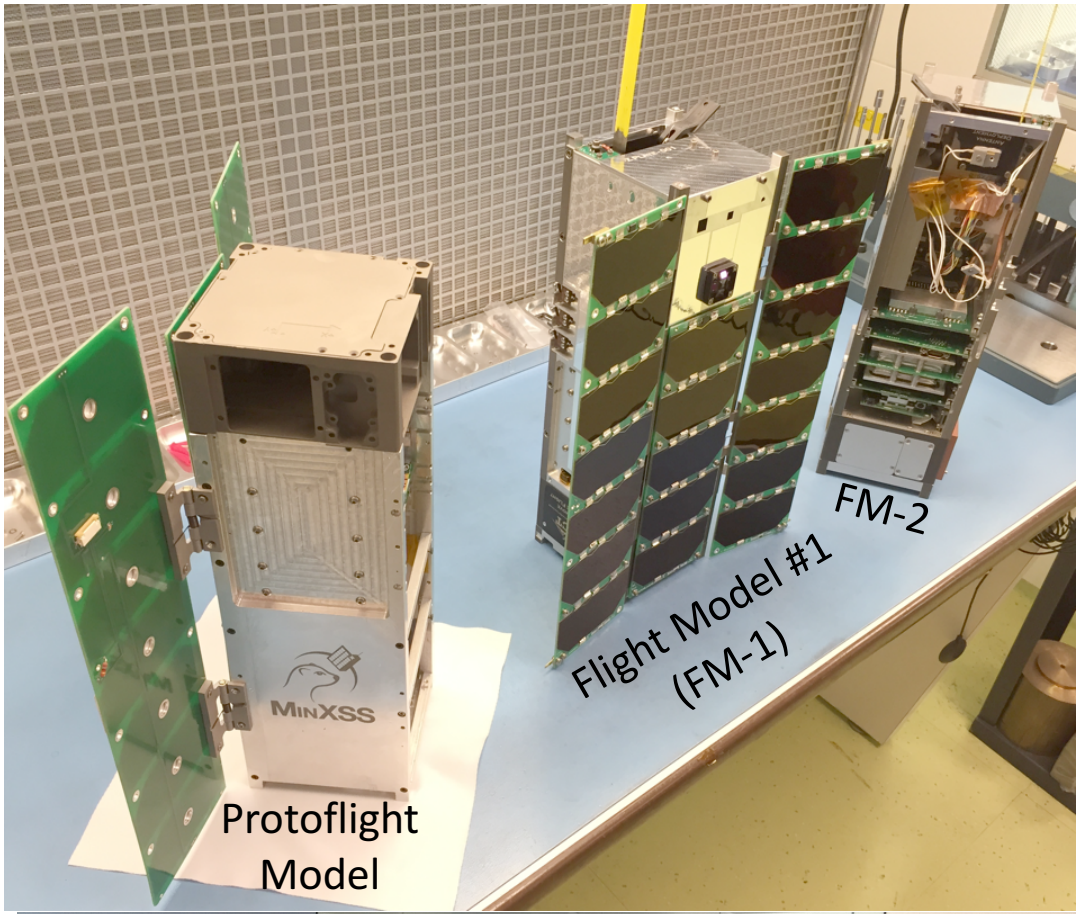
sparkfun START SOMETHING

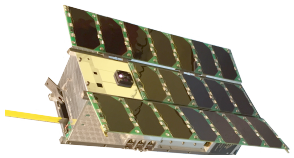
https://www.sparkfun.com



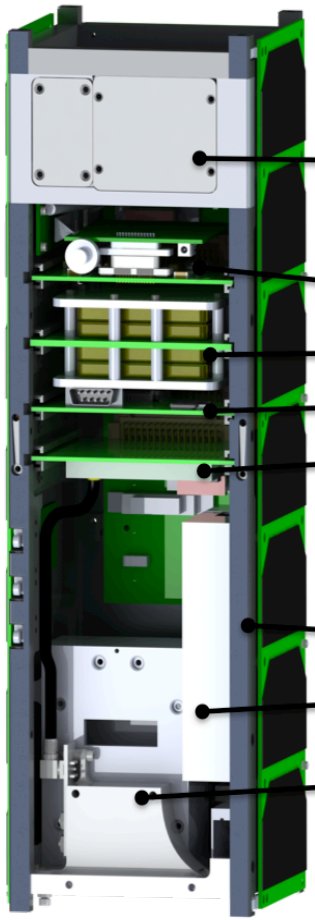
NASA MinXSS CubeSat Mission

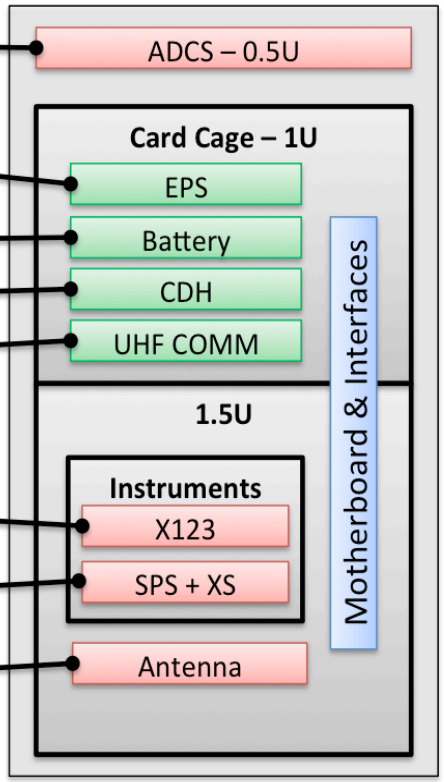
- Miniature X-ray Solar Spectrometer (MinXSS) CubeSat mission goal is to explore the solar irradiance soft X-ray (SXR) spectral variability and its impact on Earth's upper atmosphere
- MinXSS-1 deployed from ISS in May 2016 and re-entry is expected in May 2017
- MinXSS-2 launch is in Oct 2017 to SSO 500 km altitude for a 5-year mission
- MinXSS is a student class project at the University of Colorado and funded by NASA





MinXSS Design Overview

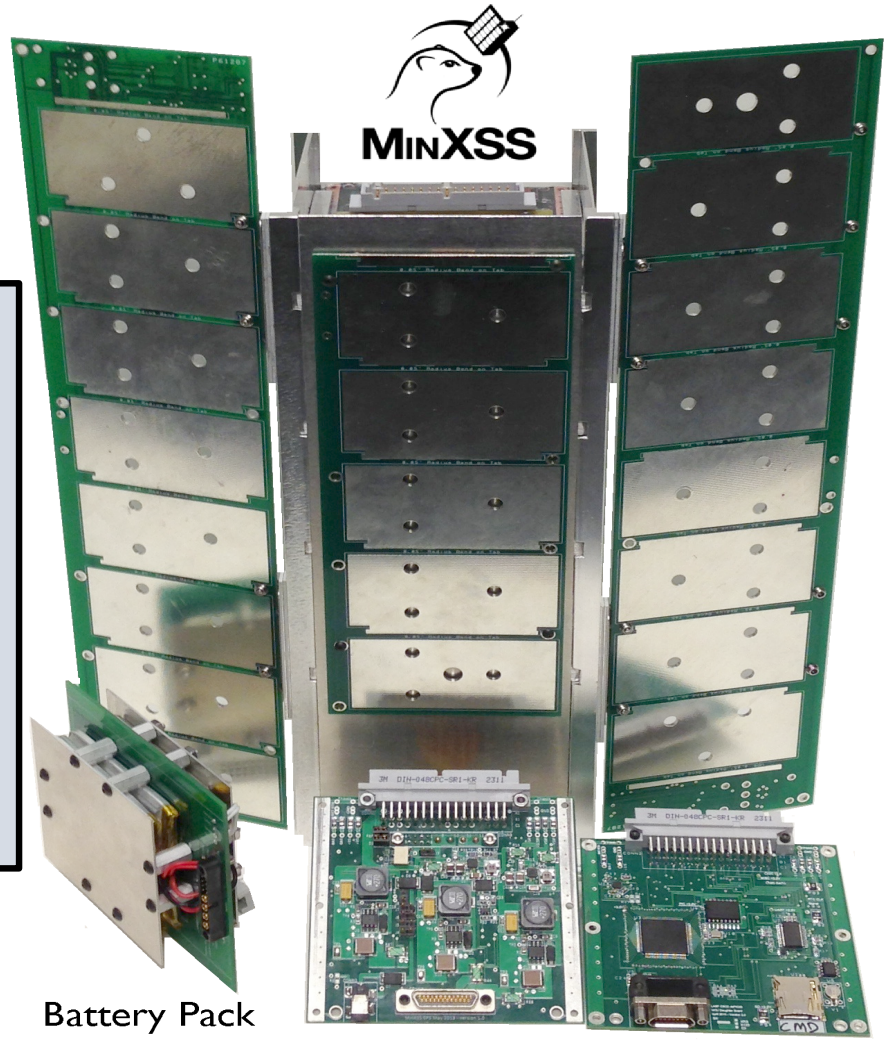




Volume
3U

Mass
3.51 kg

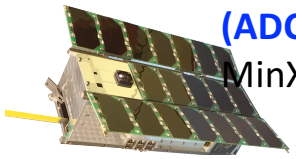
Power
Avg. 8.3W
Peak 25W



Key

Structure	Motherboard
Daughterboard	Other HW

Acronyms: Command & Data Handling (CDH), Electrical Power System (EPS) with **AzurSpace solar cells** and **sparkfun Li-poly battery**, Communications (COMM, Li-1 UHF Radio), **Attitude Determination & Control System (ADCS, BCT XACT),** Solar Position Sensor (SPS), X-ray Position Sensor (XPS), **X123 is Amptek X-ray spectrometer**. MinXSS does not have propulsion.

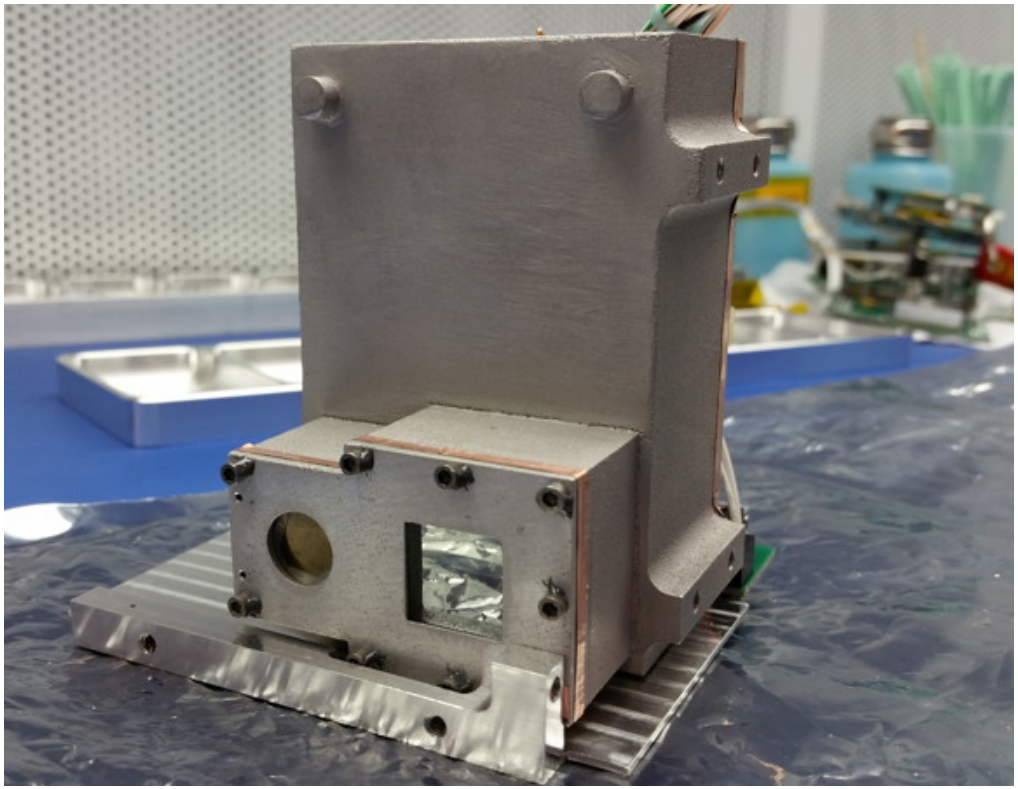


Science Instruments: X123 & SPS-XP

X-ray Spectrometer
(primary instrument)

Amptek X123-SDD

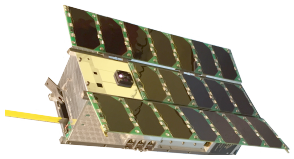
Solar Position Sensor & X-ray Photometer



GOES-R XRS PCB with ASIC & Diodes

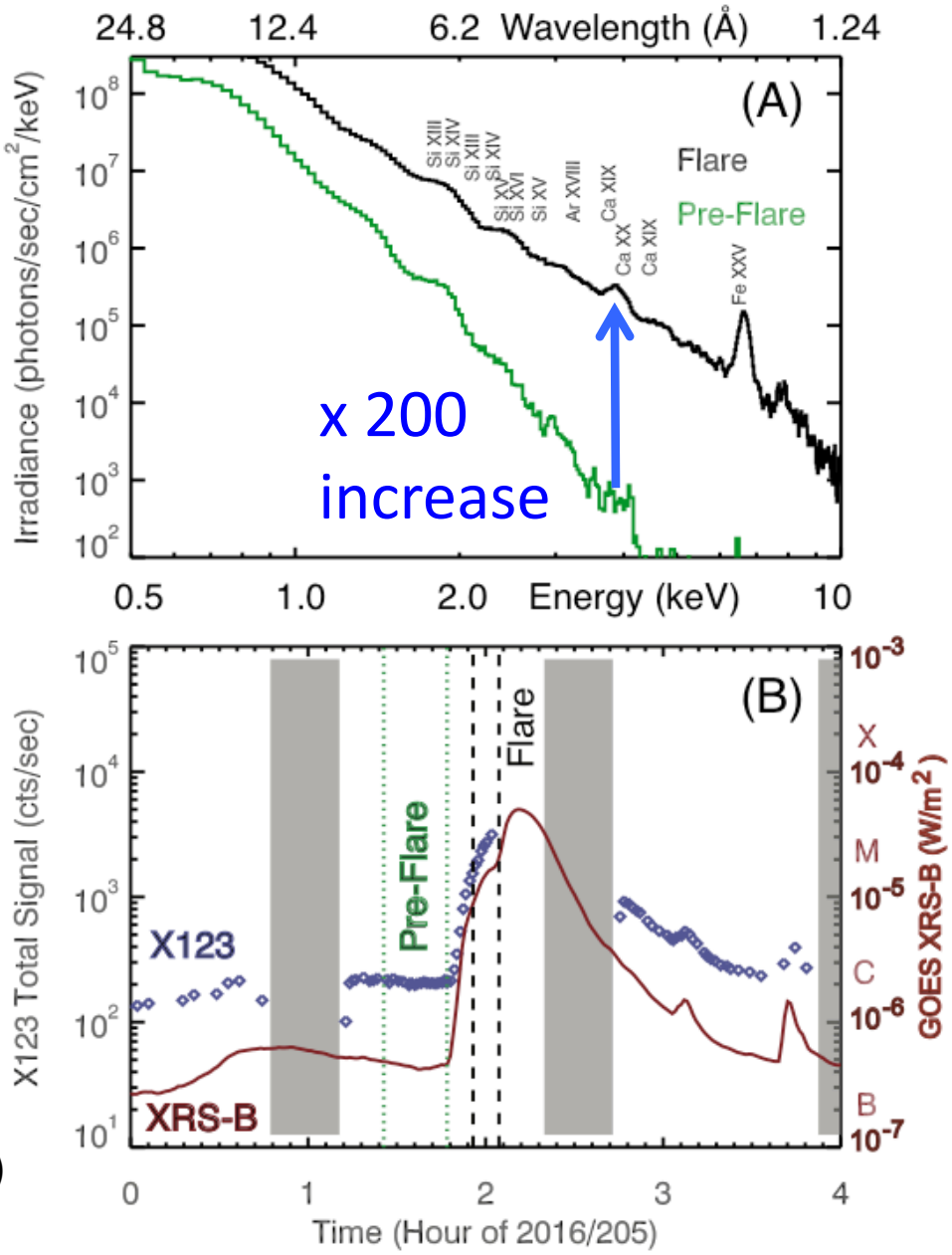
Student-built SPS-XP Power Board

Student-designed Housing: **3D Printed**

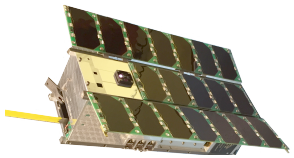


MinXSS Solar Science: Studying Flare Energetics

- **M5.0 flare on 23-Jul-2016**
  - SXR irradiance increases during this flare by a factor of 4-200 relative to the pre-flare level
  - Emission includes Bremsstrahlung continuum along with many hot coronal lines
- MinXSS X123 data have 10-sec cadence but with data gaps during orbit eclipse periods

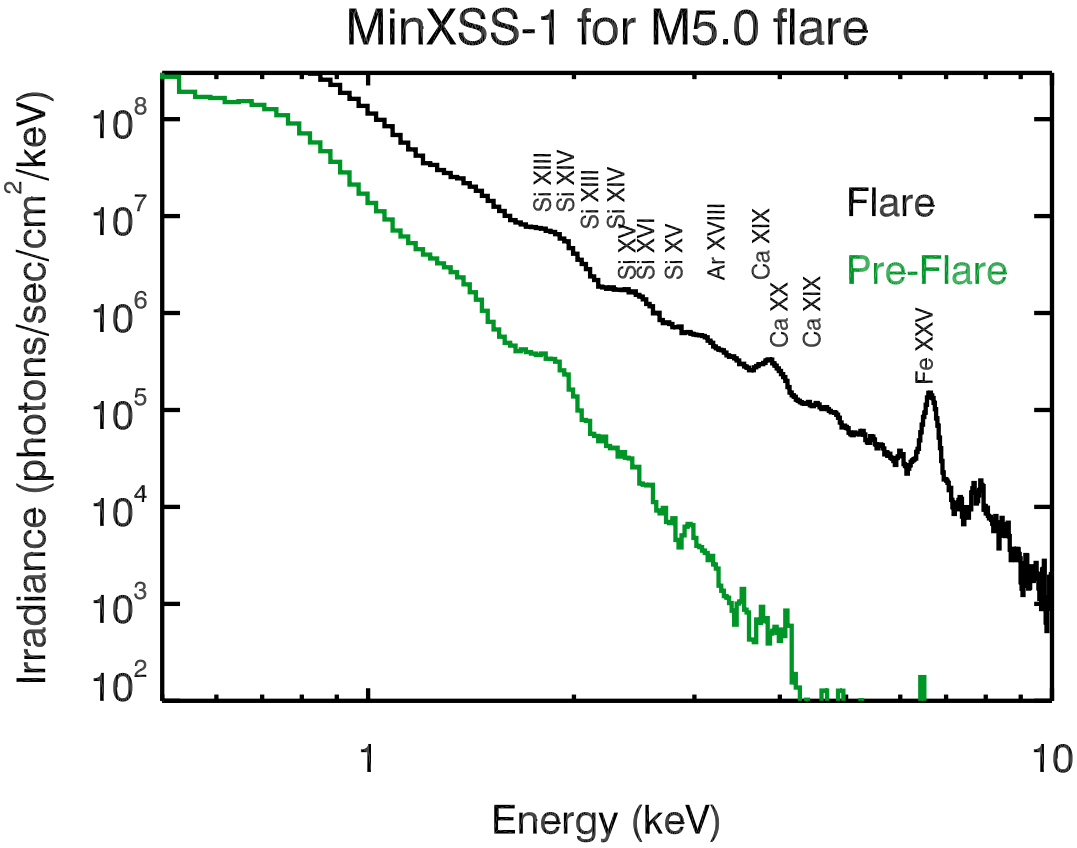


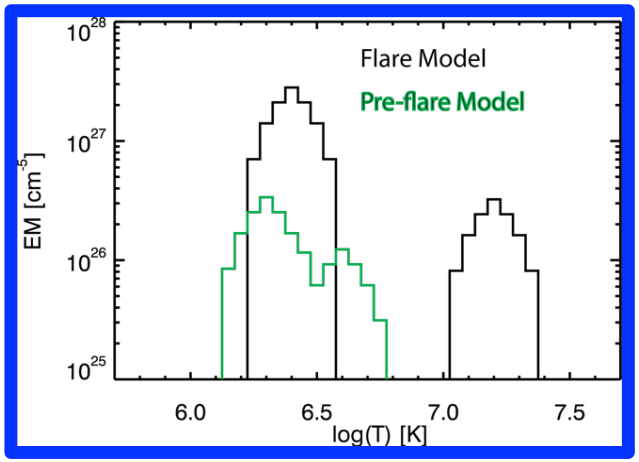
Figures from Woods *et al*. (*ApJ*, 2016)



MinXSS Solar Science: Studying Flare Energetics

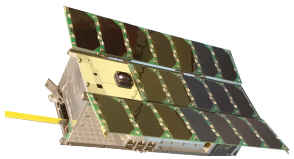
- **Plasma Diagnostics**
  - **Temperature**
    - Harder spectra (e.g. flare) have hotter temperatures
      - Pre-flare: 2-4 MK
      - Flare: 2-15 MK
    - Multiple temperature components can be derived with SXR spectra
  - Low First Ionization Potential (low-FIP) ions like Fe, Ca, and Si provide indication of **composition**
    - Pre-flare: coronal (2.1)
    - Flare: photospheric (1.2)





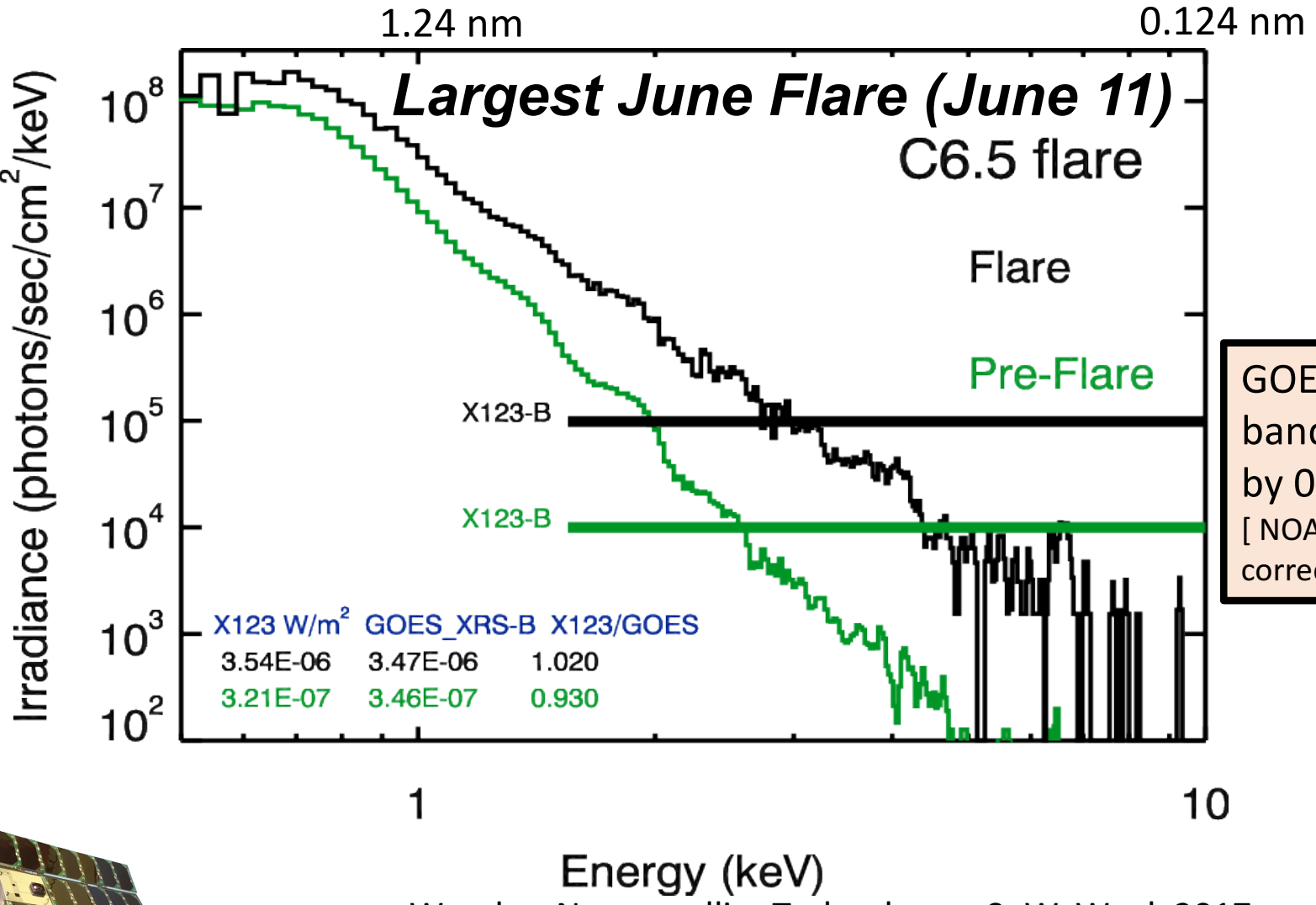
Two-temperature model fits for MinXSS spectra

Figure from Woods *et al*. (*ApJ*, 2016)

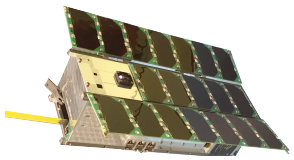


MinXSS Contribution for Space Weather

- GOES X-Ray Sensor (XRS) has been reference for X-ray flare detection and flare classification since the 1970s.
- MinXSS X123 can provide a spectral calibration for GOES XRS



GOES XRS-B 1-8 Å band is divided by 0.7 (or x 1.42)
[NOAA's calibration correction]



MinXSS Contribution for Space Weather

- The X123 integrated band over 1-8 Å is lower than the GOES-15 XRS-B for lower levels. This difference is related to the GOES-15 XRS-B background level and choice of reference spectrum for the GOES XRS data processing algorithm.

MinXSS X123 validates the GOES XRS calibration.

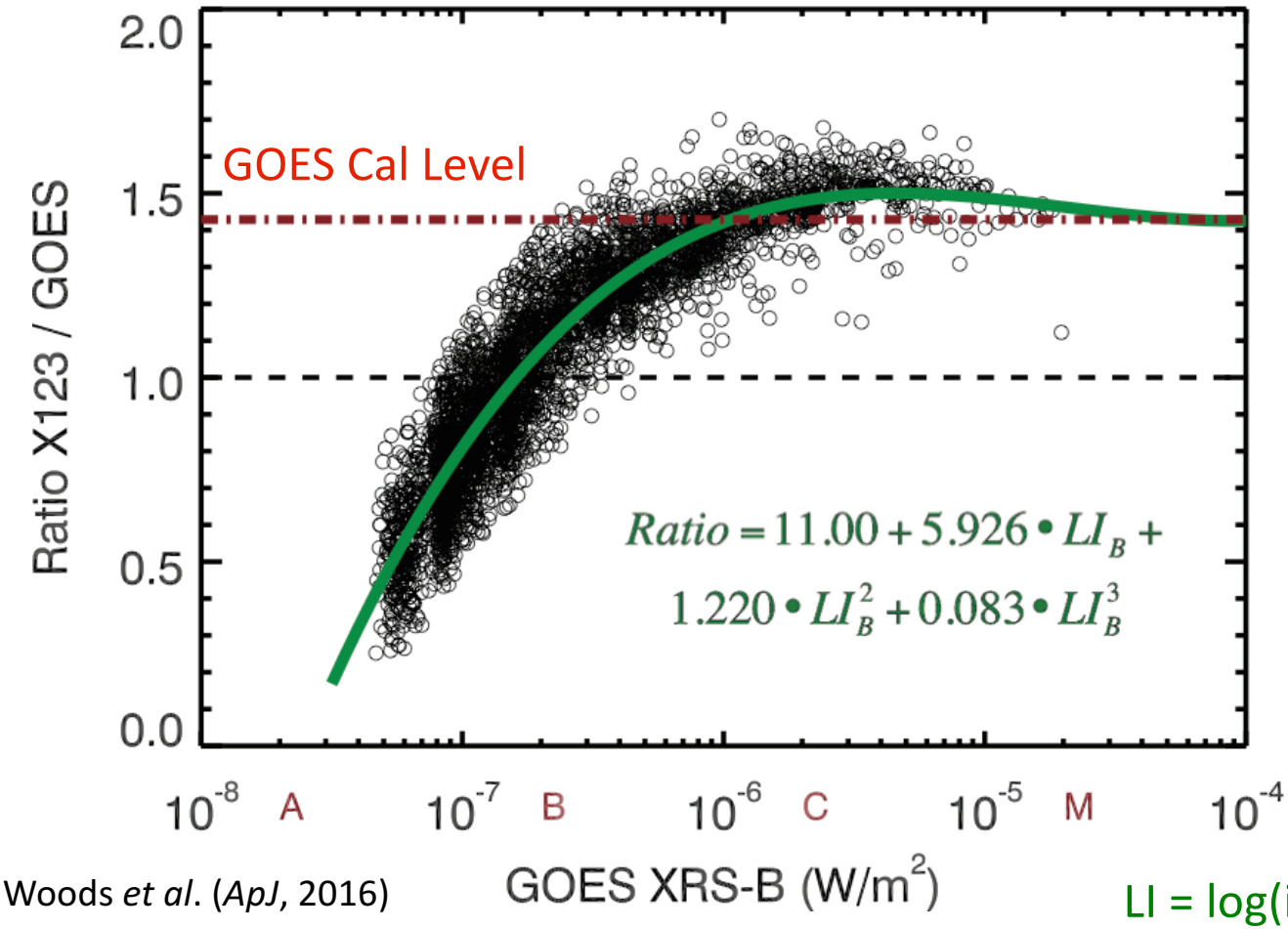
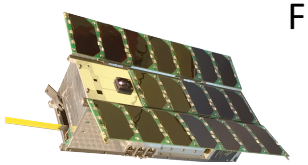


Figure from Woods *et al*. (*ApJ*, 2016)

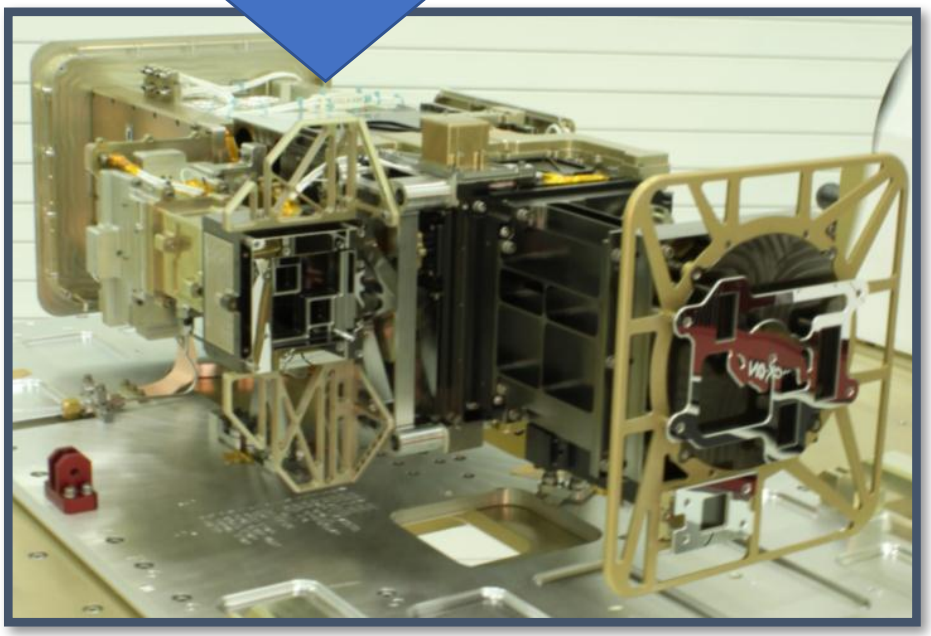
LI = log(irradiance)



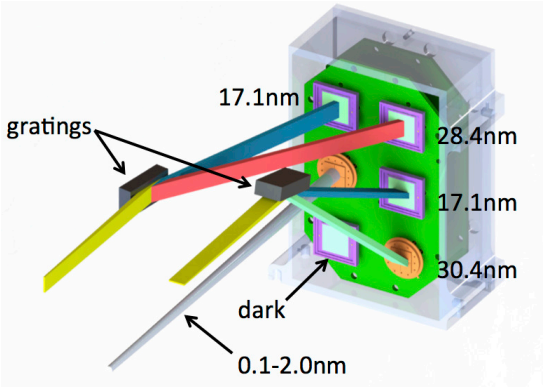
Smaller Packages Can Also Benefit Larger Missions

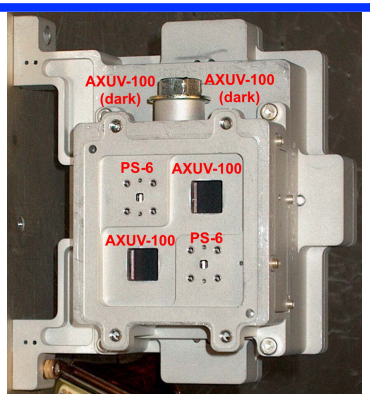
- GOES-R EXIS → 2U instrument, ***SEEDS***

Solar Eruption Early Detection System



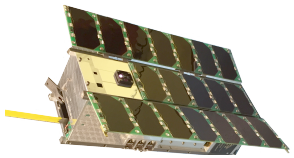
SEEDS is a re-packaging of GOES-R XRS to have one X-ray channel and four EUV channels.





- SEEDS incorporates low-power, low-noise ASIC electrometer from GOES-R EXIS. This ASIC also flown on MinXSS.
- Compact instrument provides 50% of EXIS channels with factor of 50 reduction in size / mass / power / data

EXIS & SEEDS Comparison			
	EXIS	SEEDS	
Mass	29 kg	0.6 kg	÷50
Power	31 Watts	0.4 Watts	÷80
Data Rate	9,700 bps	150 bps	÷60
Cadence	3 sec XRS 30 sec EUVS	3 sec X-ray 3 sec EUV	÷ 1 ÷ 3



Four Key Flare Phases Measured with SEEDS

- **Gradual Phase = Soft X-Ray (SXR)**
  - **Provides flare magnitude & location**
  - GOES-R XRS heritage design
- **Impulsive Phase = He II 304 Å**
  - **Provides warning for eruptive flares**
  - Compact version of GOES-R EUVS-A
- **Coronal Dimming = Fe IX 171 Å**
  - **Proxy for CME velocity & mass**
  - Key result from SDO EVE, but not learned in time to be implemented on GOES-R EXIS
- EUV Late Phase = Fe XV 284 Å
  - **Used for coronal dimming correction**
  - Key result from SDO EVE

Flare Phase	C	M	X
Gradual Ph.	100%	100%	100%
Impulsive Ph.	56%	90%	100%
Coronal Dim.	13%	39%	67%
EUV Late Ph.	5%	22%	39%

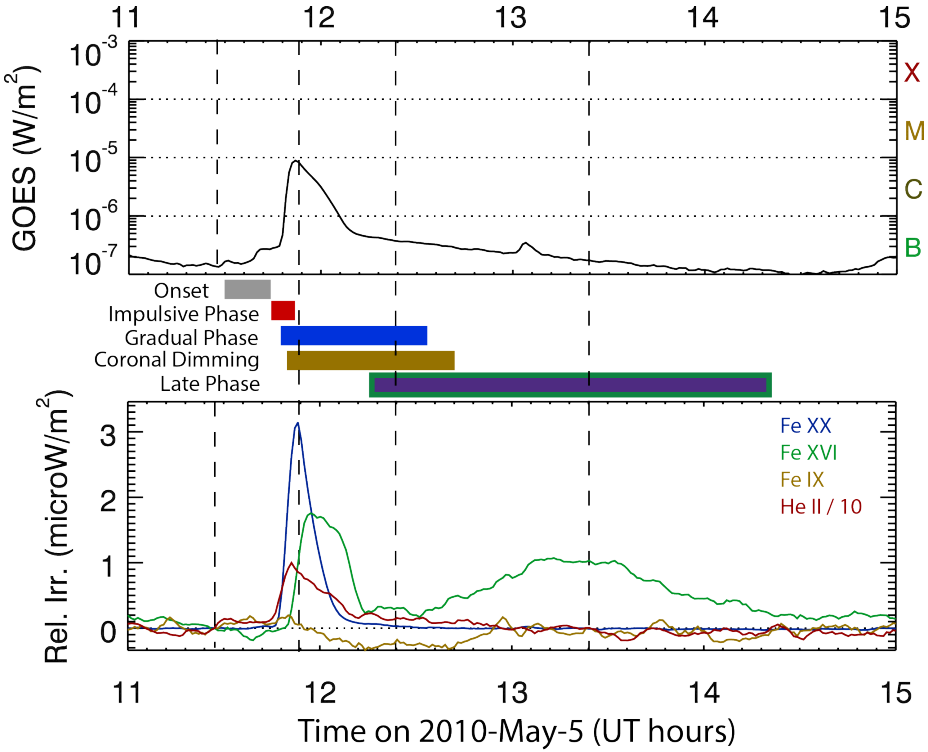
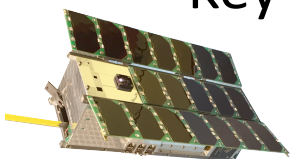


Figure is from Woods *et al*. (*ApJ*, 2011).
Table values are from Hock (PhD Thesis, 2012).



Summary

- NRC 2016 Report about CubeSats
  - *Achieving Science with CubeSats: Thinking Inside the Box*
  - The time is right for science from CubeSats !
- Nanosatellite Technology is mature
  - Every type of spacecraft subsystem has been developed and most have been demonstrated in flight.
  - Science-motivated CubeSats have had 92% success rate !
- Example: CU's MinXSS CubeSat
  - MinXSS-1 has had a very successful 1-year mission.
  - MinXSS has provided new calibration / validation for GOES XRS !
- Compact instruments could be used for Sp Wx Operations