National Aeronautics and Space Administration

Cutting Edge Smartphone Technologies for the Warfighter on the Tactical Edge

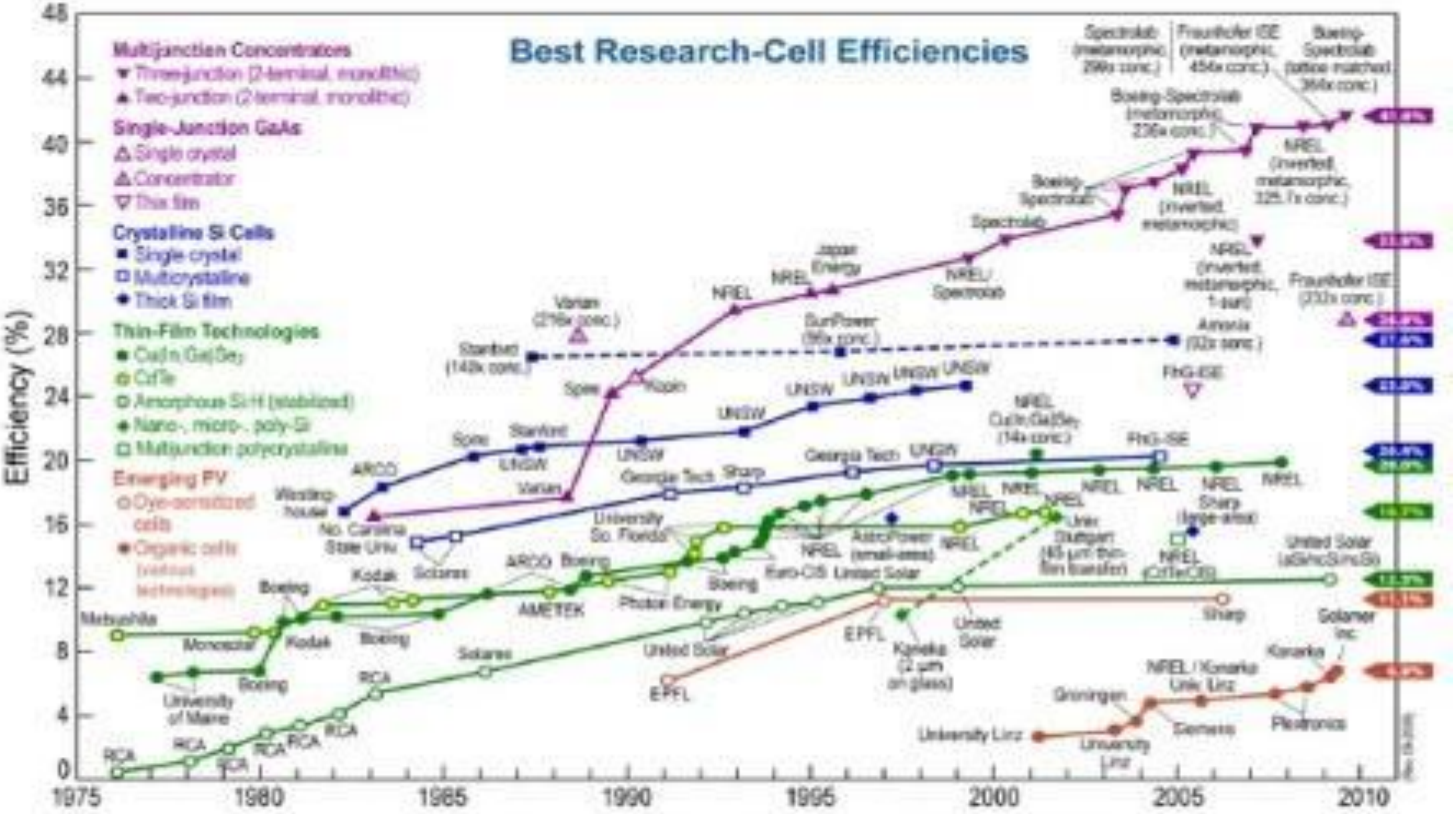
NASA Ames Research Center
Dr. Belgacem Jaroux, Associate Director of Engineering
Dr. John Hanson, Deputy Program Manager, EDSN

May, 2014

Overview

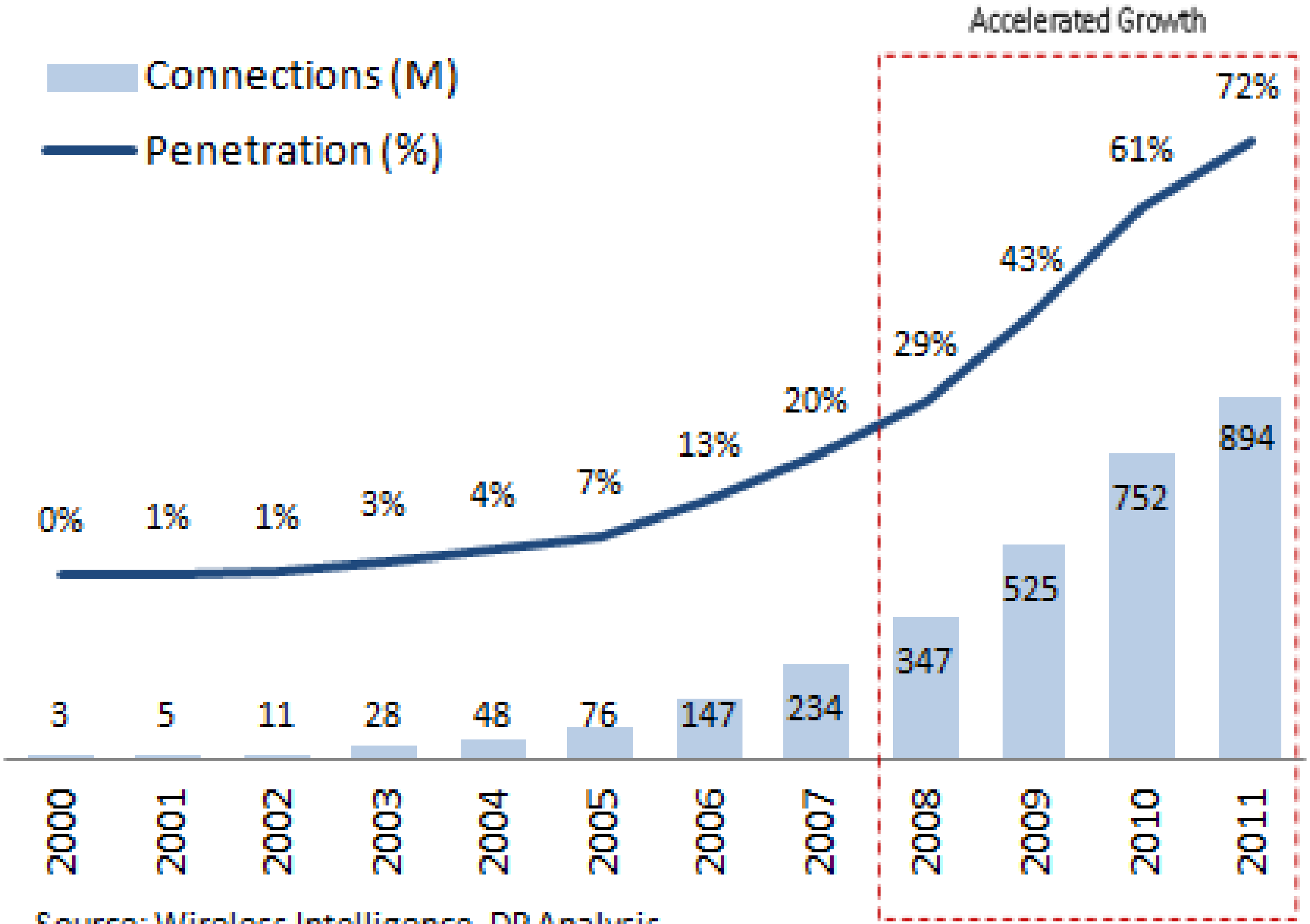
- **Motivation**
- **SmallSat Development at Ames**
- **PhoneSat Based Spacecraft**
- **Trends in COTS Space**

Solar Array Improvement



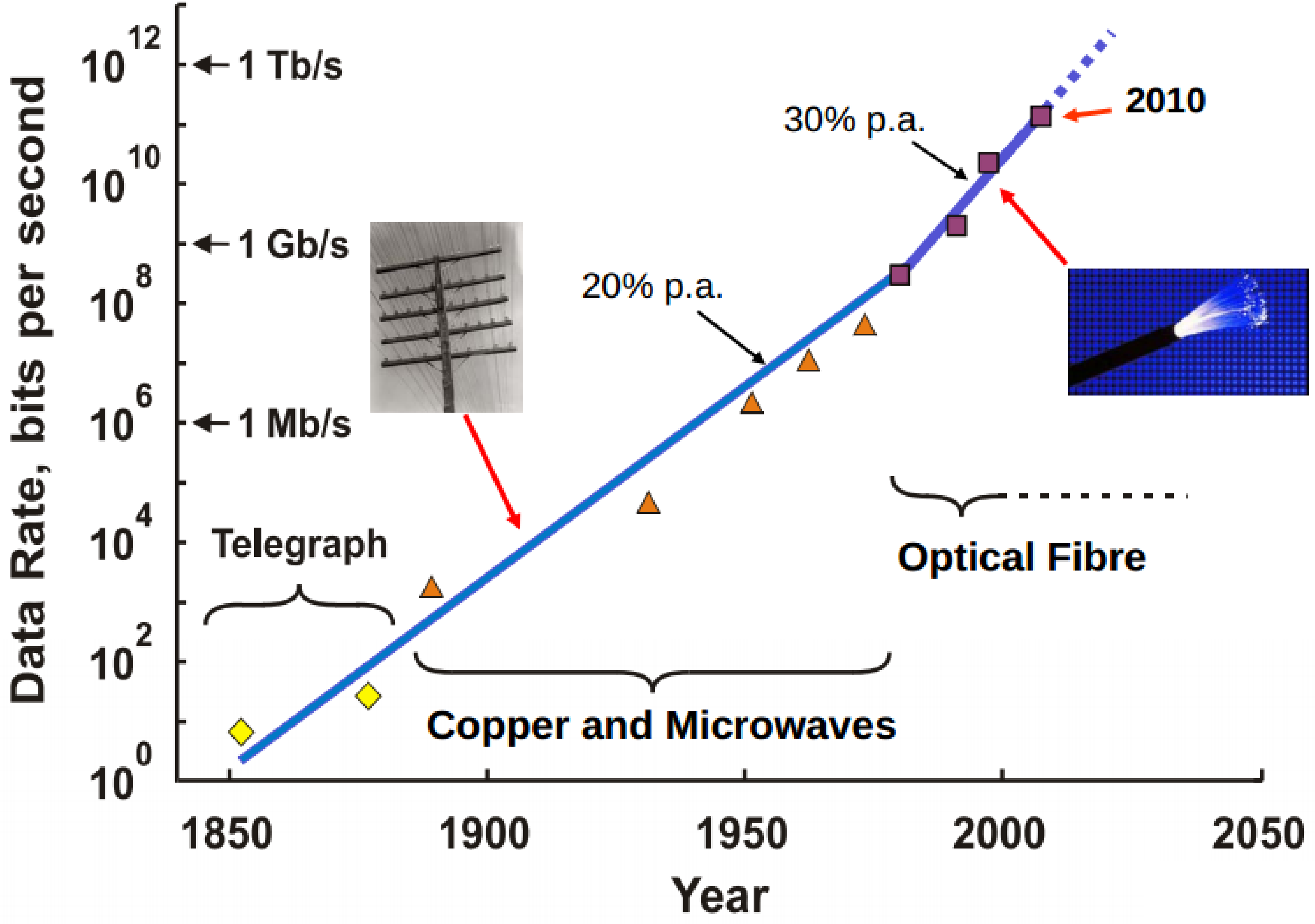
Best research cell efficiencies 1975–2009
(Kazmerski 2009)

Telecom Improvement in India

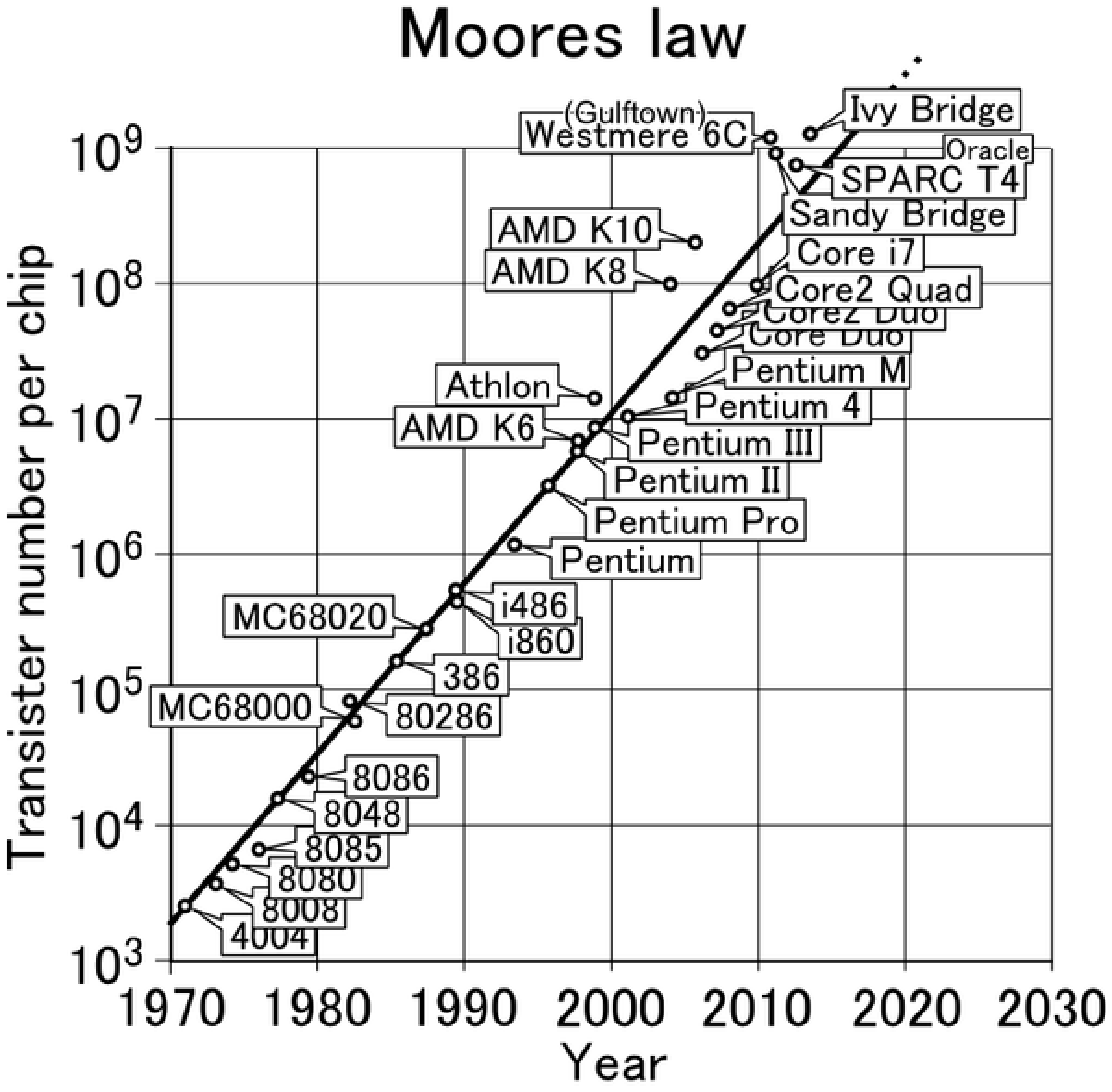


Source: Wireless Intelligence, DP Analysis

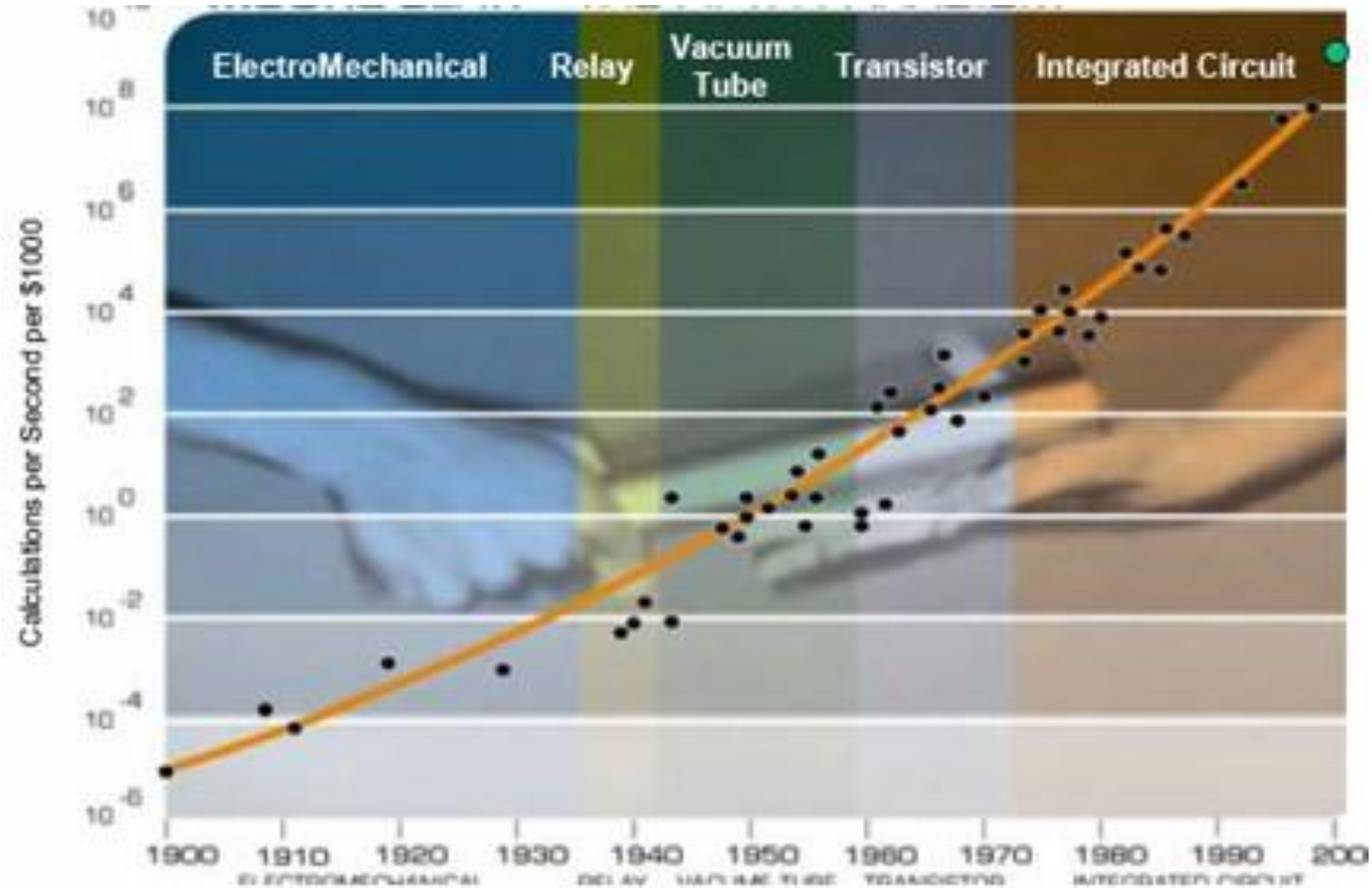
Backhaul Progress over 125 Years



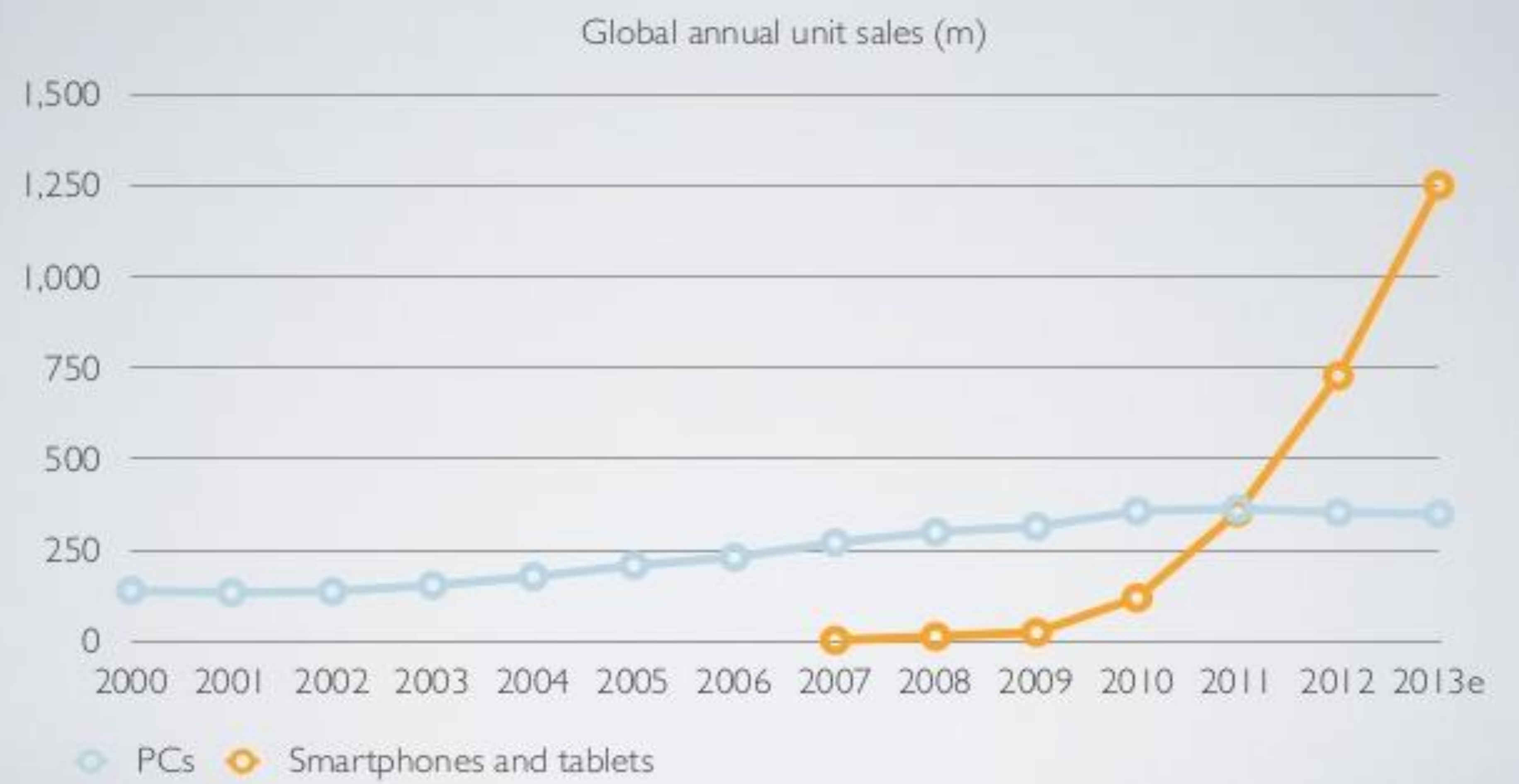
Moores Law


Moores law
Transister number per chip
Year
10^9
10^8
10^7
10^6
10^5
10^4
10^3
1970
1980
1990
2000
2010
2020
2030
(Gulftown)
Westmere 6C
Ivy Bridge
Oracle
SPARC T4
Sandy Bridge
AMD K10
AMD K8
Core i7
Core2 Quad
Core2 Duo
Core Duo
Pentium M
Athlon
Pentium 4
AMD K6
Pentium III
Pentium II
Pentium Pro
Pentium
i486
i860
MC68020
386
MC68000
80286
8086
8048
8085
8080
8008
4004

Moore’s Law Has Been at Work for More than 100 Years

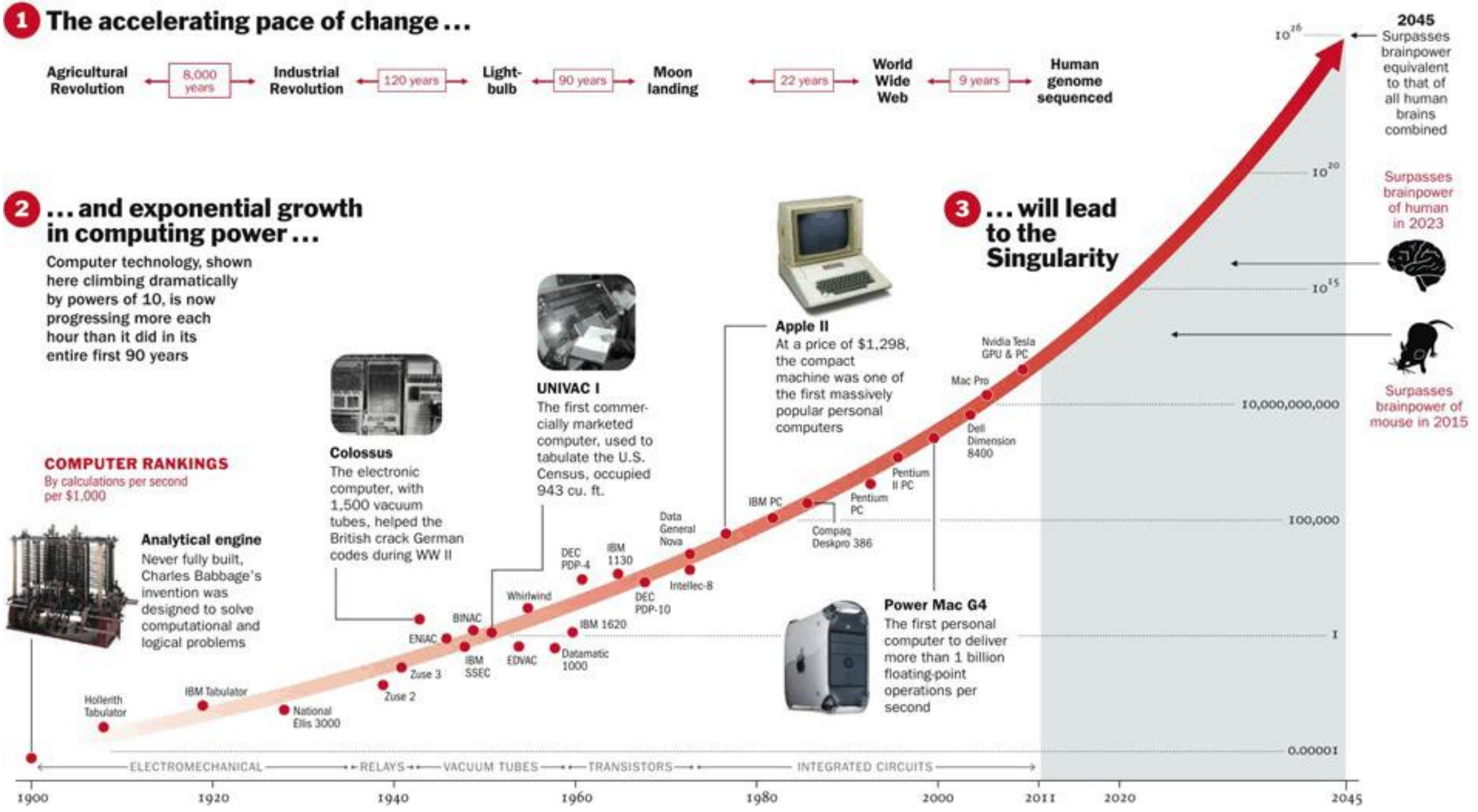


Computing Platform Growth



Source: Enders Analysis

How do we apply COTS advances in mobile computing power and features to space?



1 The accelerating pace of change . . .

2 . . . and exponential growth in computing power . . .

Computer technology, shown here climbing dramatically by powers of 10, is now progressing more each hour than it did in its entire first 90 years

3 . . . will lead to the Singularity

COMPUTER RANKINGS
By calculations per second per $1,000

Analytical engine
Never fully built, Charles Babbage's invention was designed to solve computational and logical problems

Colossus
The electronic computer, with 1,500 vacuum tubes, helped the British crack German codes during WW II

UNIVAC I
The first commercially marketed computer, used to tabulate the U.S. Census, occupied 943 cu. ft.

Apple II
At a price of $1,298, the compact machine was one of the first massively popular personal computers

Power Mac G4
The first personal computer to deliver more than 1 billion floating-point operations per second

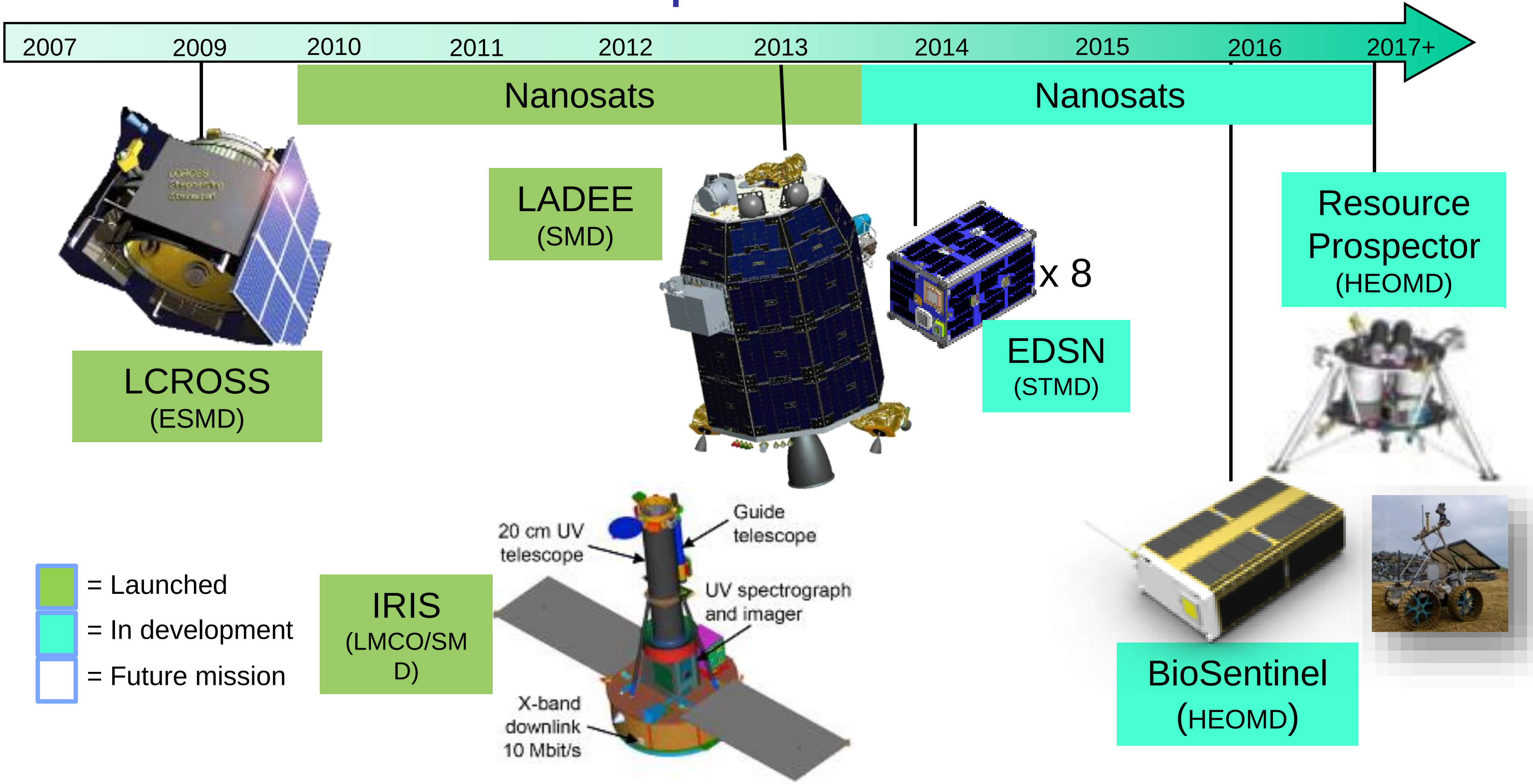
2045
Surpasses brainpower equivalent to that of all human brains combined

Surpasses brainpower of human in 2023

Surpasses brainpower of mouse in 2015

http://vak1969.com/2014/01/30/

ARC Small Spacecraft Timeline



Nanosats

Nanosats

LCROSS
(ESMD)

LADEE
(SMD)

EDSN
(STMD)

x 8

Resource Prospector
(HEOMD)

BioSentinel
(HEOMD)

IRIS
(LMCO/SMD)

🟩 = Launched
🟦 = In development
⬜ = Future mission

NASA-ARC continues a history of manifesting cost efficient (< $250M) , increasingly-capable Small Satellites

ARC NanoSat Product Timeline

2006 2008 2009 2010 2011 2012 2013 2014 2015 2016+

2006
- GeneSat
  3U bus

2008
- PreSat*
  3U bus
- NanoSail-D1*
  3U bus

2009
- PharmaSat
  3U bus

2010
- O/OREOS
  3U bus
- NanoSail-D2
  3U bus

2011
- PhoneSat1
  1U – SubOrbital Test

2012
- TechEdSat
  1U bus

2013
- TechEdSat-3
  3U bus
- SporeSat
  3U bus
- EDSN
  (8) x 1.5U bus
- PhoneSat 1 & 2ß
  1U bus
- ORS^2
  6U bus

2014
- EcamSat
  6U bus
- PhoneSat2
  1U bus
- TechEdSat-4
  6U bus

2015
- formulating
  T6U-1
  6U bus

2016+
- T6U-2
  6U bus
- T6U-3
  6U bus
- BioSentinel
  Cis-Lunar 6U bus

🟩 = Launched
🟦 = In development
☐ = Future mission
* = Launch Vehicle did not reach orbit

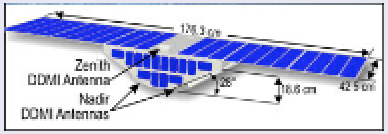
NASA-ARC continues a history of manifesting cost efficient, increasingly-capable CubeSats

EDSN (x 8)

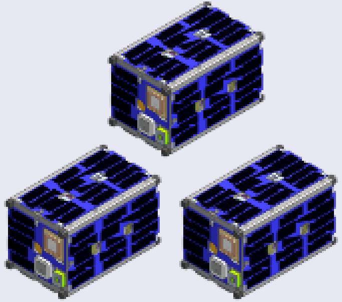
SmallSats for Science Missions

Earth Science

CYGNSS

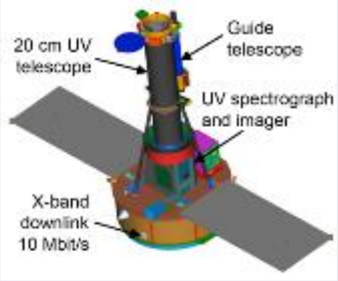


EDSN

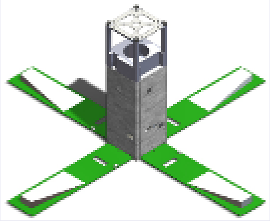


Heliophysics

IRIS

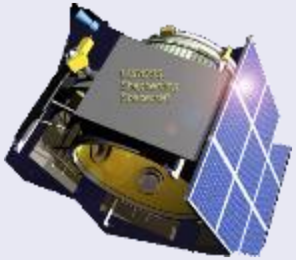


HiMARC



Planetary Science

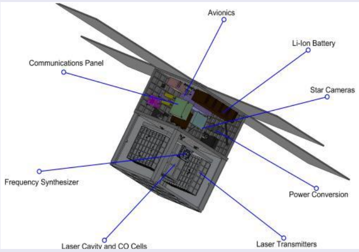
LCROSS



LADEE

Astrophysics

STAR

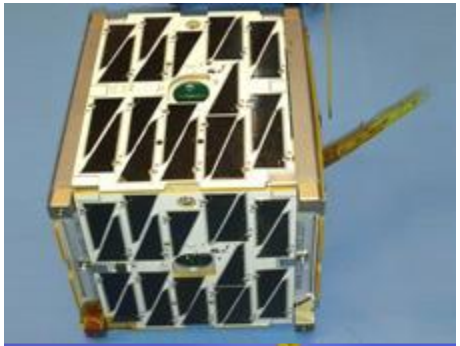


TESS

Small Satellites are a disruptive capability for NASA Science: Allowing greatly smaller systems that provide Significant Science Return for smaller costs, and higher risks.

Orbital Sciences Antares A-ONE

21 April, 2013

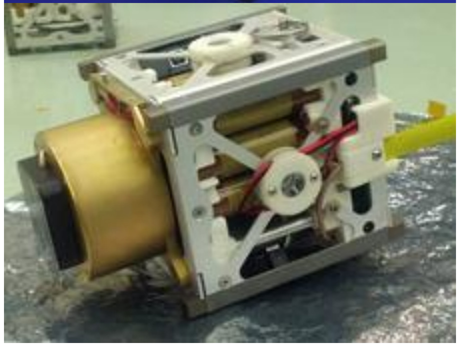


PhoneSat 2.0ß

“Alexander”

PhoneSat 1

“Graham”

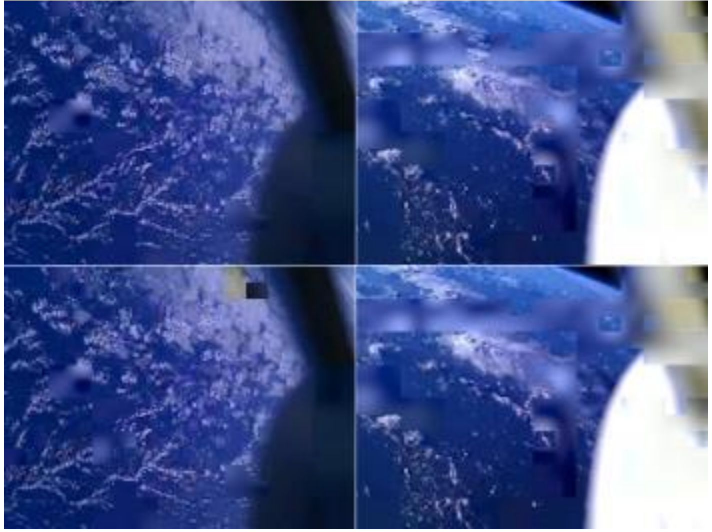


PhoneSat 1

“Bell”

Iridium modem experiment

- Demonstrated smartphone can operate as satellite CPU
- Onboard image selection and downlink via beacon packets
- Packet reception by amateur radio community



Orbital Sciences Minotaur ORS-3

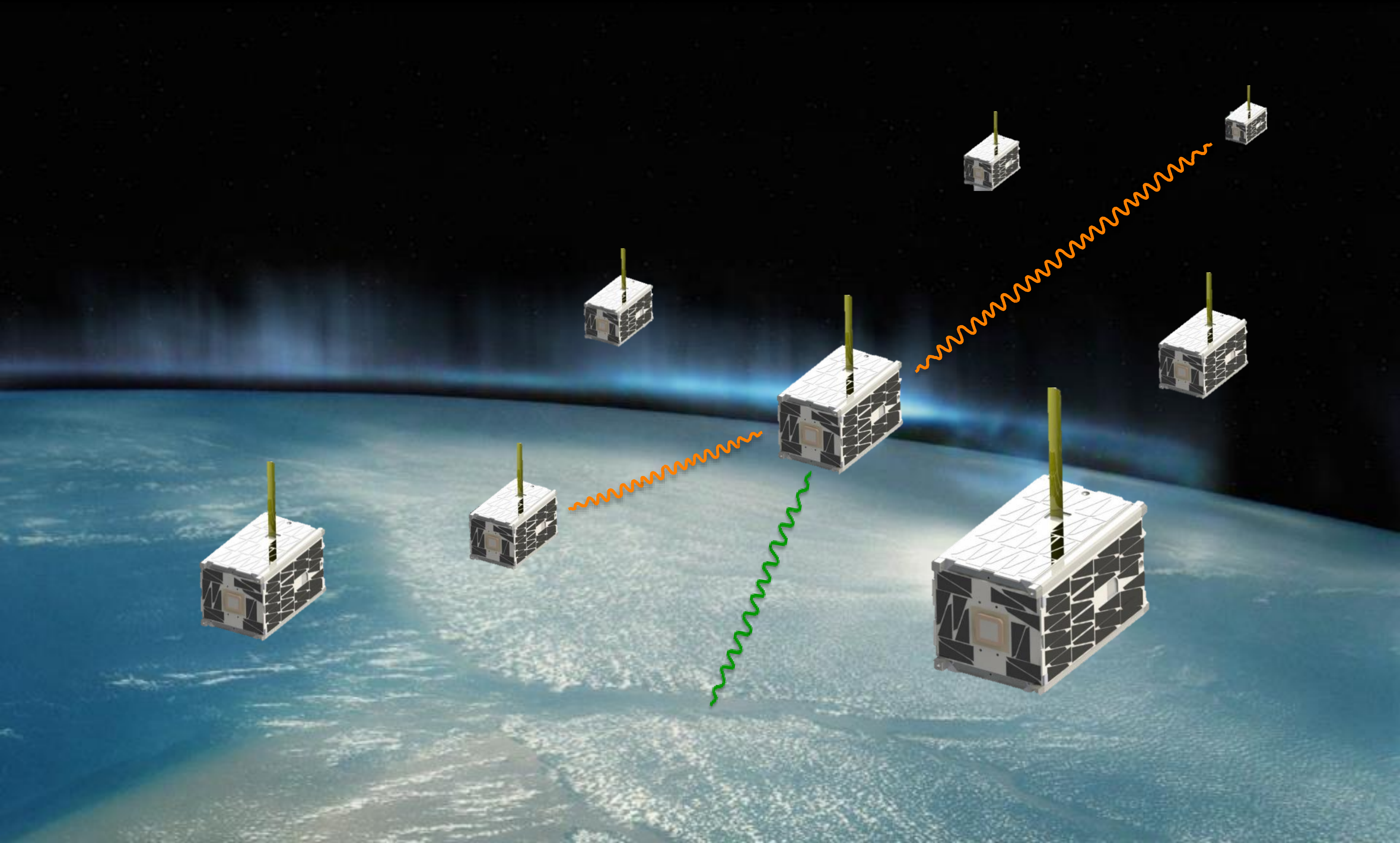
20 November, 2013 PhoneSat 2.4 (PhoneSat 2 on ELaNa 4 launch)

SpaceX Falcon 9 CRS-3

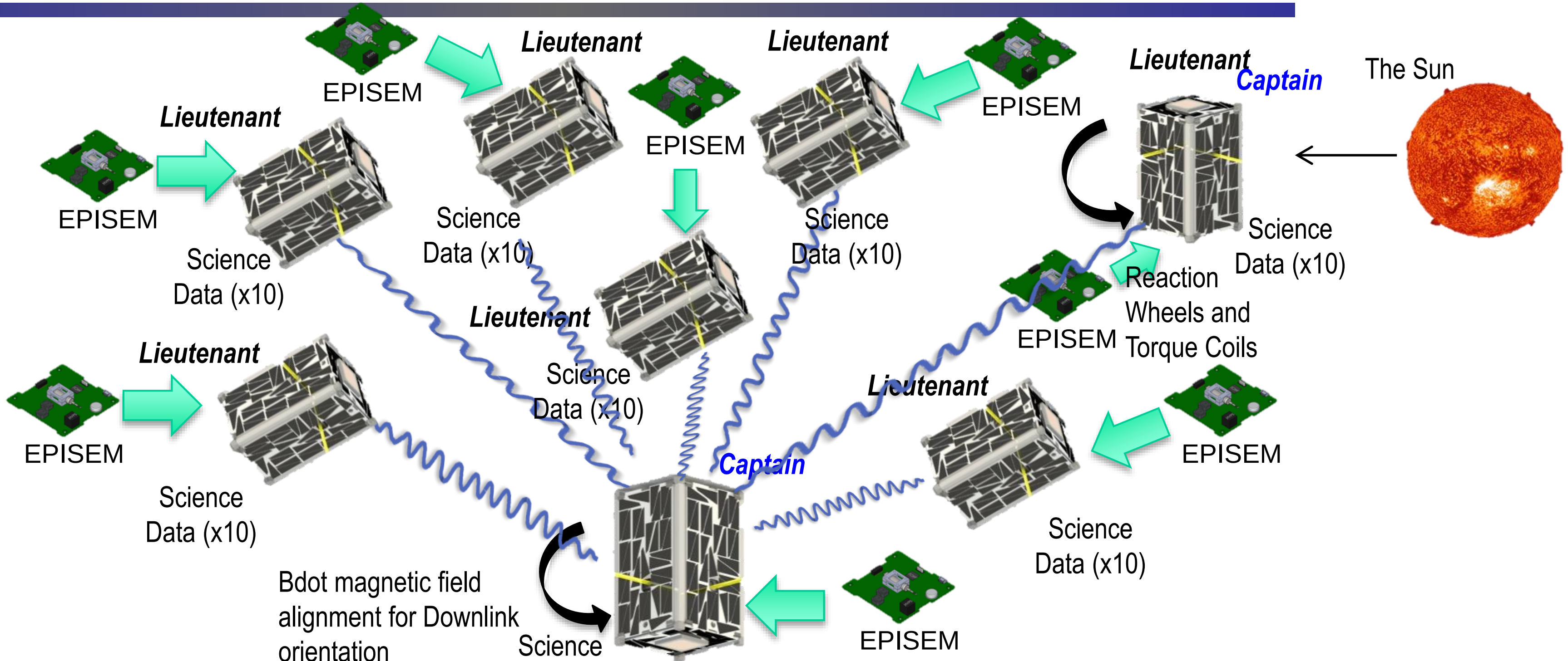
18 April, 2014 PhoneSat 2.5 (PhoneSat 2 on ELaNa 5 launch)

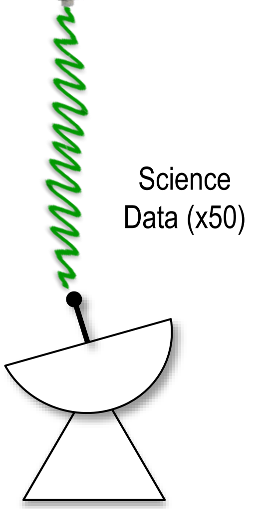
- Demonstrated ADCS
- Detumble and magnetic alignment using magnetorquers and magnetometer
- Calculated coarse sun vector using currents from solar panels
- Pointing using reaction wheels
- Attempted S-band communication

SmallSat Network Demonstrations



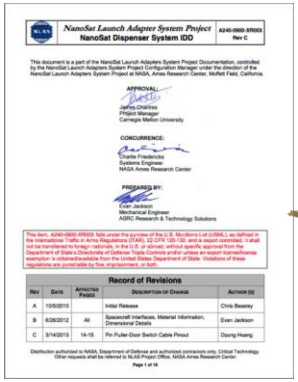
EDSN Mission





Operations are autonomous
No uplink/commanding required

- 10x one-way space-to-space data transfer (Crosslink)
- 5x one-way space-to-ground data transfer (Downlink)
- Transfer 50x science measurements via Crosslink
- Transfer 50x science measurements via Downlink
- 1 pointing maneuver demonstration



NanoSat Launch Adapter System Project NanoSat Dispenser System IDD	A240-0900-XR003 Rev C

This document is a part of the NanoSat Launch Adapters System Project Documentation, controlled by the NanoSat Launch Adapters System Project Configuration Manager under the direction of the NanoSat Launch Adapters System Project at NASA, Ames Research Center, Moffett Field, California.

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Record of Revisions

Rev	Date	Affected Pages	Description of Change	Author (s)
A	10/5/2010		Initial Release	Chris Beasley
B	6/26/2012	All	Spacecraft Interfaces, Material Information, Dimensional Details	Evan Jackson
C	3/14/2013	14-15	Pin Puller-Door Switch Cable Pinout	Dzung Hoang

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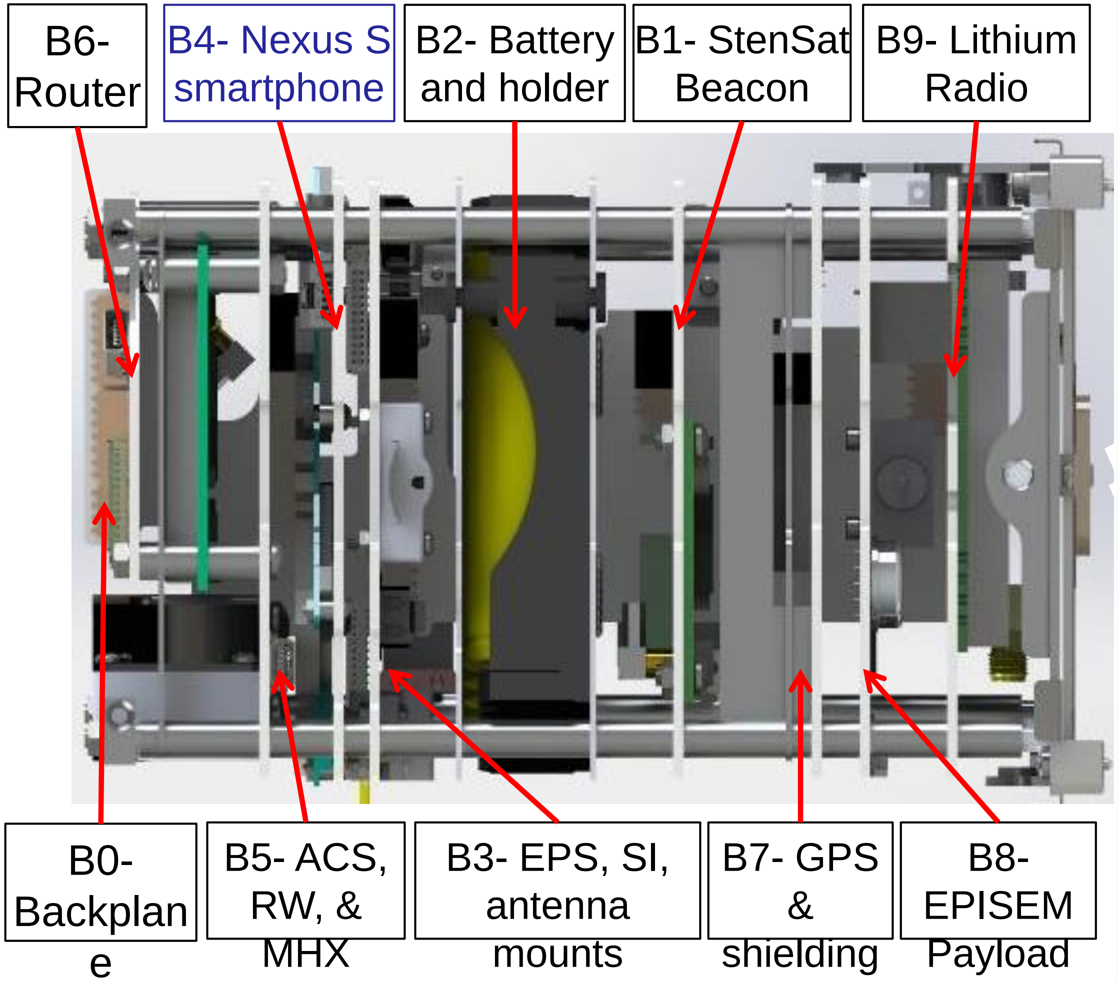
Page 1 of 16

NLAS Interface Definition Document

8x EDSN Satellites integrate into 2x NLAS Dispensers

Overview of Design



B6- Router

B4- Nexus S smartphone

B2- Battery and holder

B1- StenSat Beacon

B9- Lithium Radio

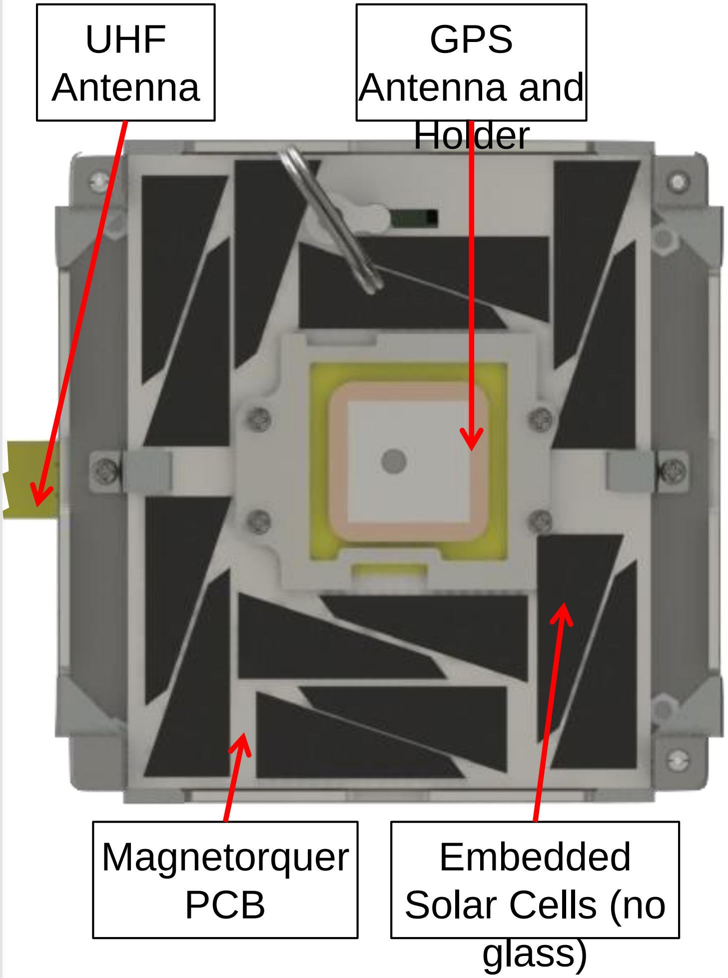
B0- Backplane

B5- ACS, RW, & MHX

B3- EPS, SI, antenna mounts

B7- GPS & shielding

B8- EPISEM Payload



UHF Antenna

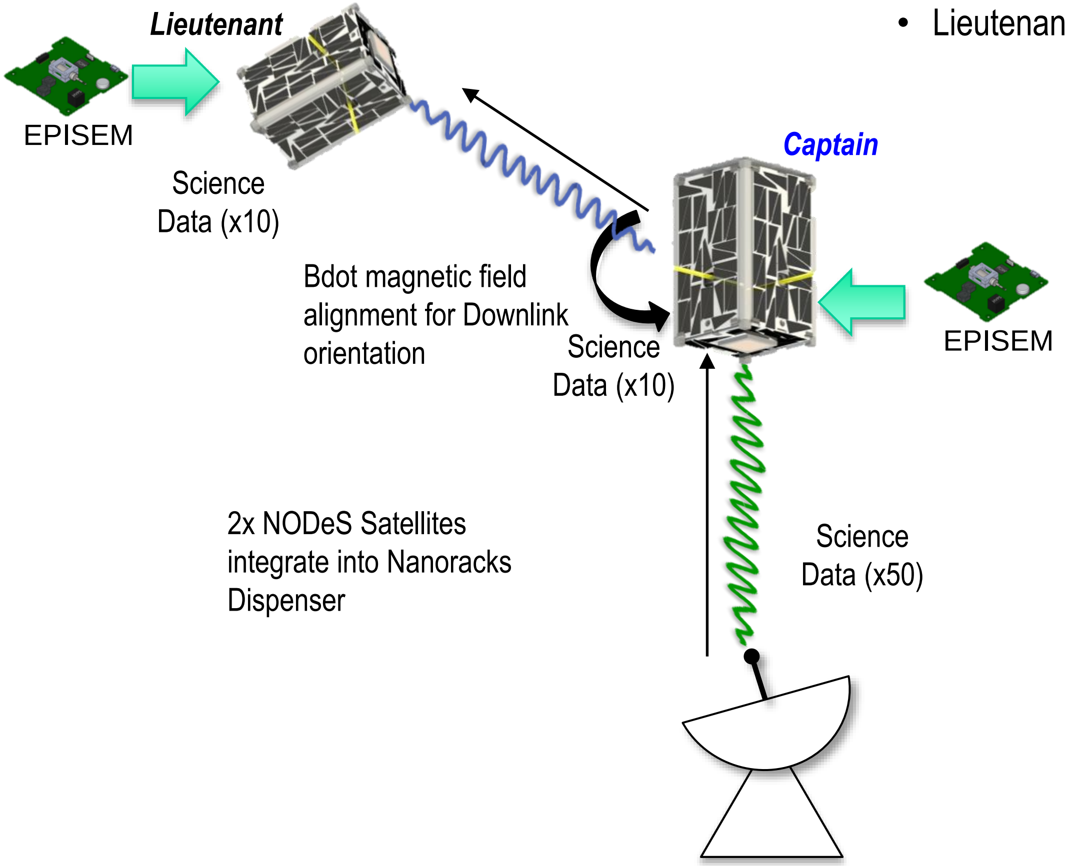
GPS Antenna and Holder

Magnetorquer PCB

Embedded Solar Cells (no glass)

Spacecraft Commanding through the Network

- Downlink session initiated
- Command sent from ground station to Captain
- Crosslink session initiated
- Command sent from Captain to Lieutenant
- Lieutenant Executes Command



Lieutenant

EPISEM

Science Data (x10)

Bdot magnetic field alignment for Downlink orientation

Captain

Science Data (x10)

EPISEM

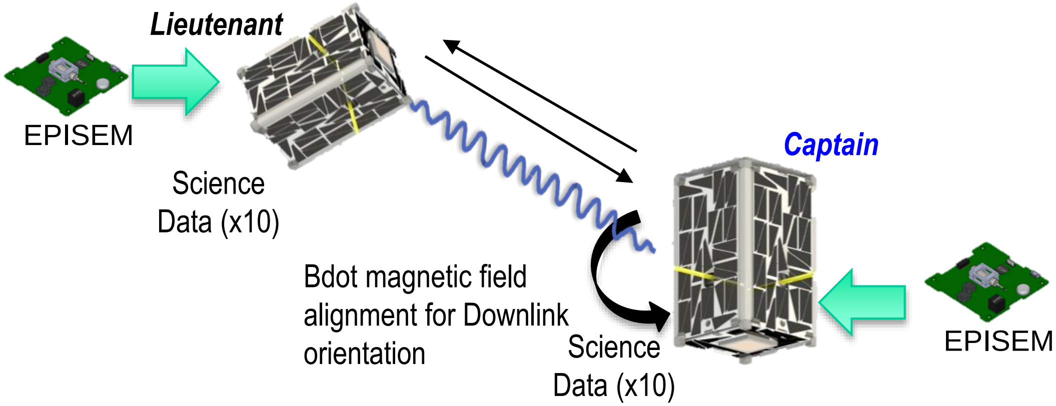
2x NODeS Satellites integrate into Nanoracks Dispenser

Science Data (x50)

NODeS Mission

Network Autonomy: Negotiated Captaincy

- New minor cycle start
- Spacecraft get GPS data
- Captain initiates negotiation



2x NODeS Satellites integrate into Nanoracks Dispenser

TechEdSat: A CubeSat launched from ISS

- **Launched to ISS on July 2012 via JAXA's HTV in the cubesat carrier**
- **Then it was mounted to the Multi-Purpose Experiment Platform (MPEP) to go out JAXA's ISS airlock**
- **The Japanese Experiment Module's Remote Manipulator System positioned the MPEP for satellite deployment, and the satellites were deployed**
- **NASA-ARC / San Jose State University Project / Swedish National Space Board**

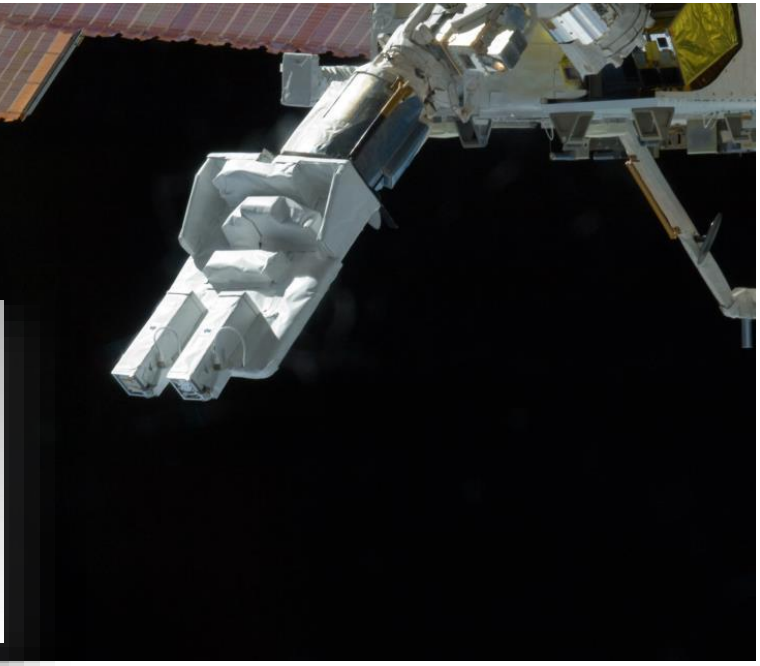
ISS Deployment:

October 4, 2012

Over 1000 Orbits now

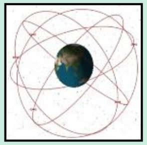
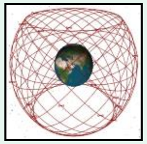
>500kb+ data downlinked

1U TechEdSat spacecraft
•100 x 100 x 113.5 mm
•1.2kg



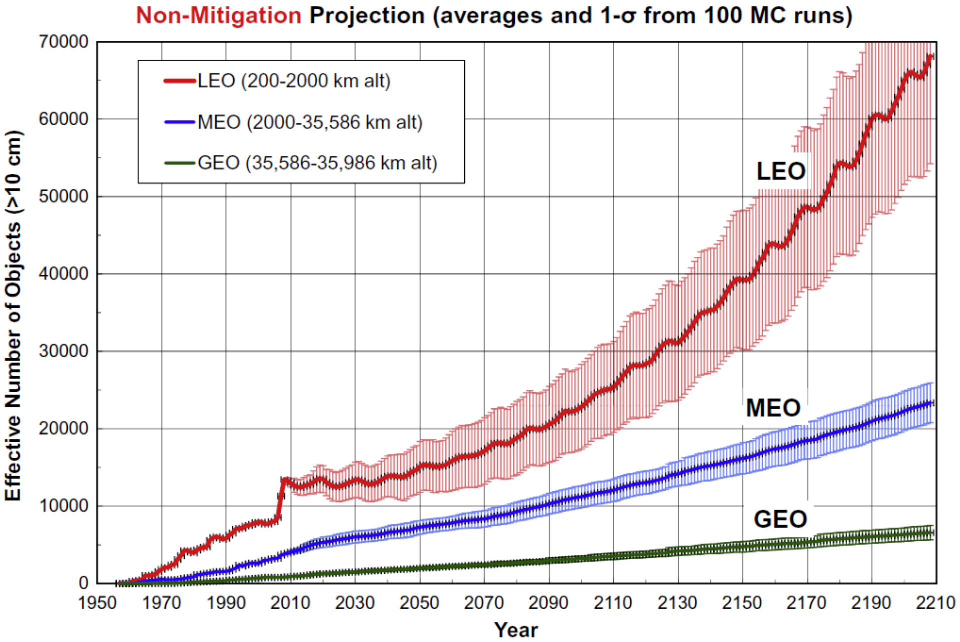
Space Debris causes significant cost for satellite operations. Simulations predict an increasing risk of collisions with satellites.

Cost increase for maintaining different satellite constellations for 20 years due to debris impact

Constellation type	*Today's increase in replenishment cost*
Government 5 satellites @$750M ea 	4%, $700M
Commercial 20 satellites @250M ea 	9%, $1400M
Commercial 70 satellites @$50M ea 	14%, $700M

Source: W. Ailor (Aerospace Co.), IAC 2010, IAC-10.A6.2.10, 7p.

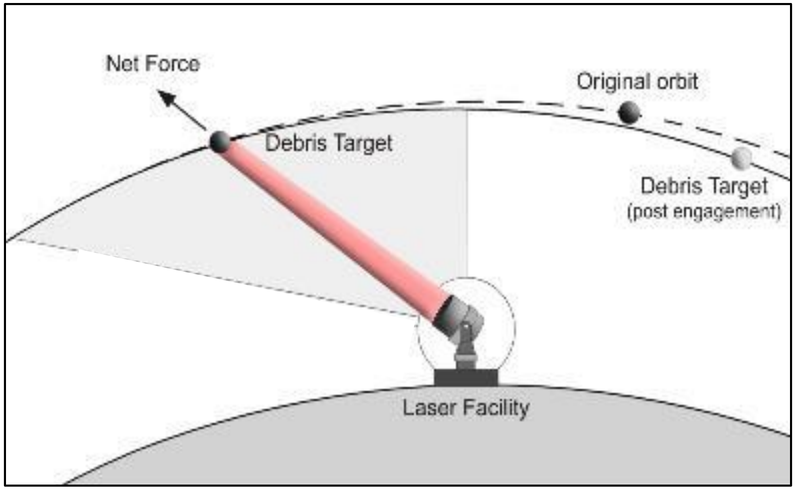
Projected number of debris objects over time



Source: J.-C. Liou (NASA Debris Office), Advances in Space Research 47(2011), p.1865-1876

Challenge: Find cost effective measures to protect satellites and(!) stabilize the debris e

LightForce provides collision avoidance on warning, not de-orbit of individual debris objects

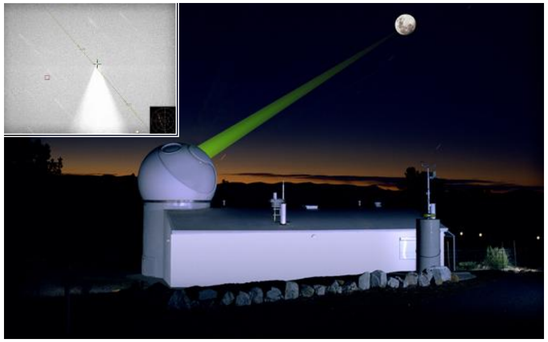


Concept:

1. Potential collision detected by USSTRATCOM, data relayed
2. Laser engages, photon pressure changes in-track velocity of debris
3. Repeat at each pass over ground station until collision is mitigated

LightForce: small orbital changes induced by photon pressure from ground-based lasers, just big enough to avoid collisions

\+



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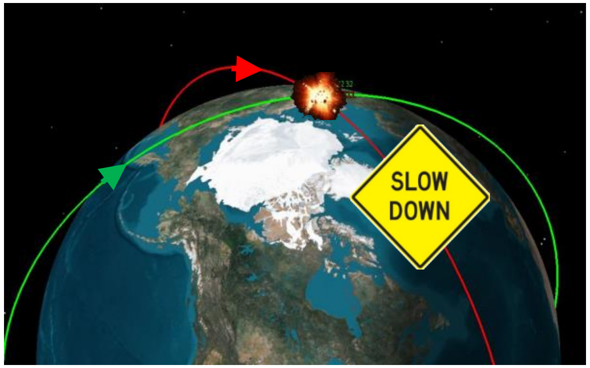


Industrial 10 kW laser

Laser debris ranging station

Collision Avoidance

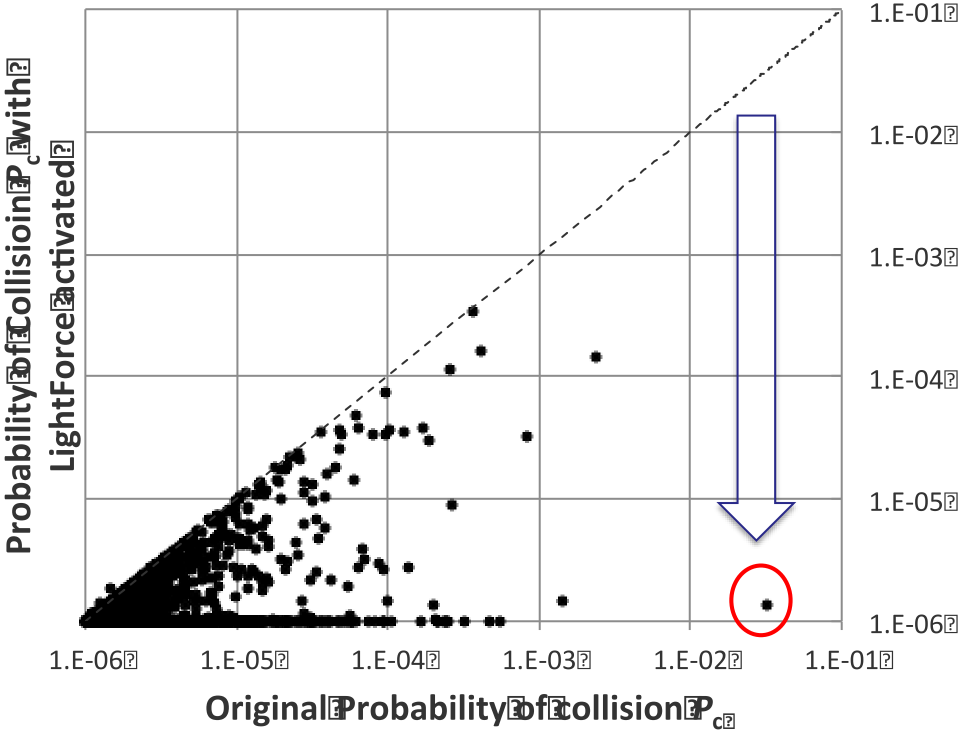
Performed an end-to-end simulation of LightForce to assess the effect on probability of collision for high-risk

1) TLE orbital data refined

2) All-on-all conjunction analysis performed, probability of collision for conjunctions determined

3) LightForce is activated and probability of collisions are re-evaluated

4 LightForce stations with 20 kW each



Additional results indicate that LightForce would be an efficient tool: 80+% reduction of expected number of collisions using only 2

National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

Modulating Retro-Reflectors could overcome the comm bottleneck for Cubesats in LEO

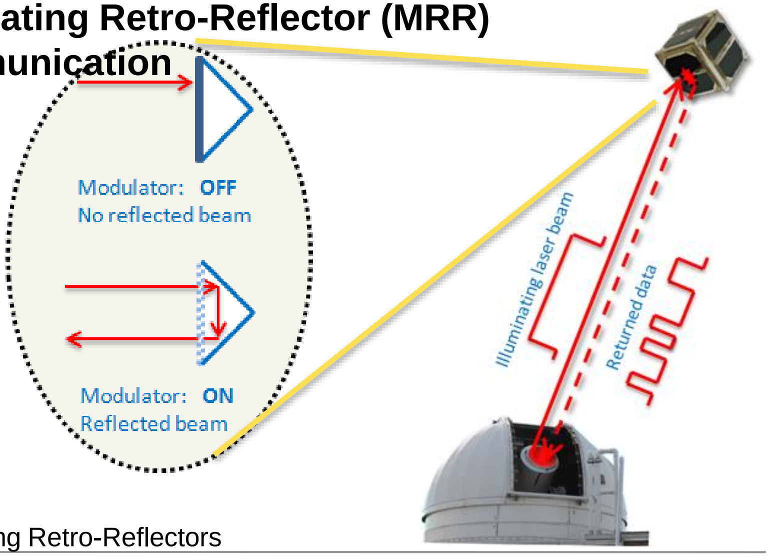
Background

- CubeSats have a very little capacity to download data in spite of their setting aside most of the power consumption for communications
- Optical communications have the potential to break that bottleneck, both in regard to data rate and spectrum management.
- However: standard laser comm approaches need high accuracy pointing.

Approach

- Modulating Retro-Reflectors send laser beams right back to their source independent from their orientation
- Minimal pointing requirements at the spacecraft
- Minimal power requirements at the spacecraft
  --> complexity shifted from the spacecraft to the ground station

Modulating Retro-Reflector (MRR) Communication



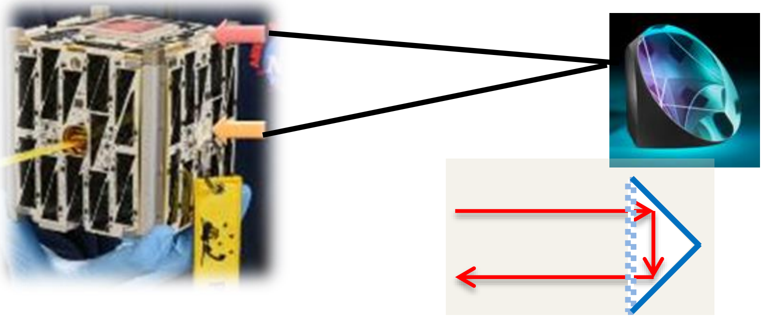
Modulator: **OFF**
No reflected beam

Modulator: **ON**
Reflected beam

Modulating Retro-Reflectors
as main communication system on CubeSats

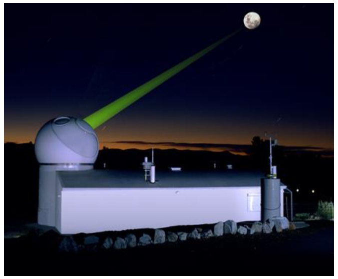
First Steps

- PhoneSat 2.4 and 2.5 carry passive (non-modulating) retroreflectors
- Proof-of-concept of laser tracking of LEO Cubesats
- Sensors at the ground stations pick up reflections from the retro-reflectors



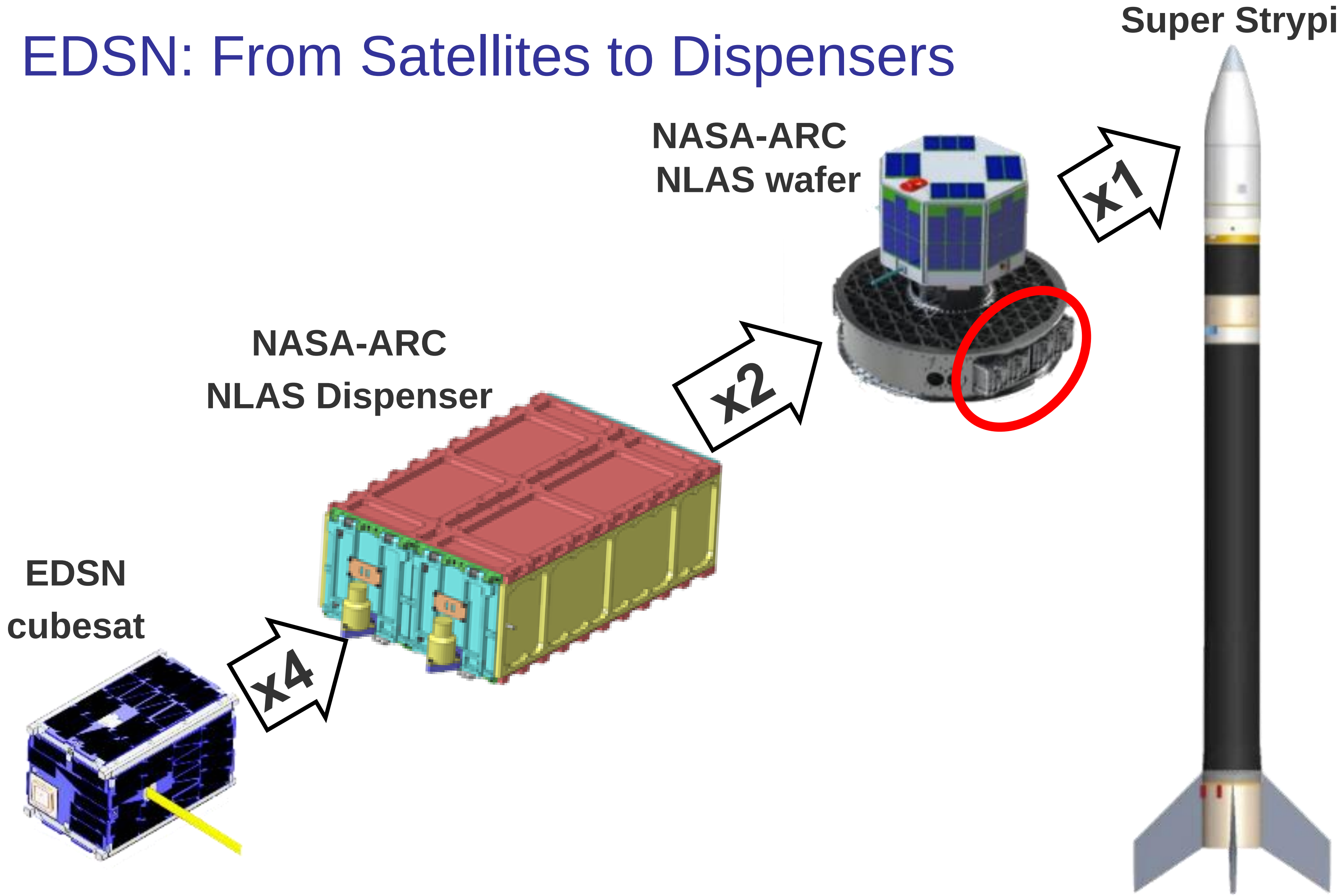
Laser Ground Station candidates

Air Force Reasearch Lab's Starfire Optical Range



EOS Space Systems, Mt Stromlo (AUS) site

EDSN: From Satellites to Dispensers



Super Strypi

NASA-ARC NLAS wafer

NASA-ARC NLAS Dispenser

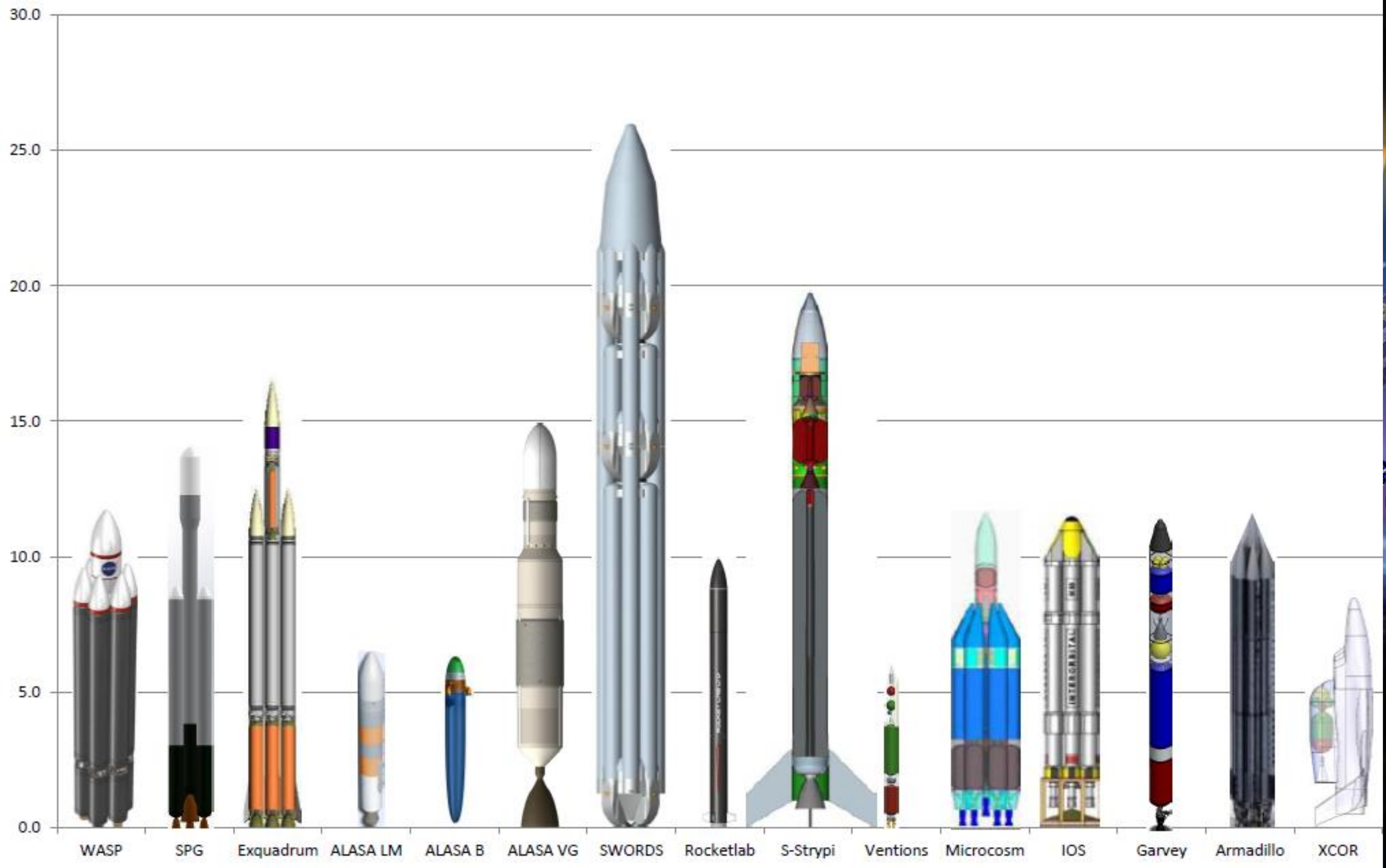
EDSN cubesat

CNAT PROBLEM ADDRESSED:

No lightweight cheap avionics solution

National Aeronautics and Space Administration

Axiom: Million Dollar Rockets Need Major Reduction in Avionics Cost



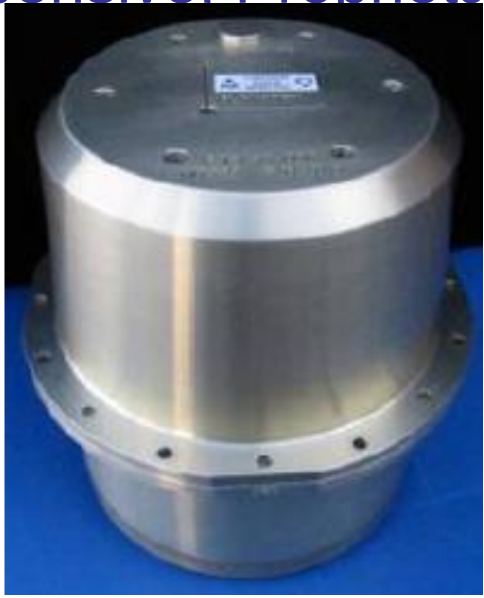
Existing Launch Vehicle Avionics: Large, Heavy, Expensive, Proprietary

Super

Strypi

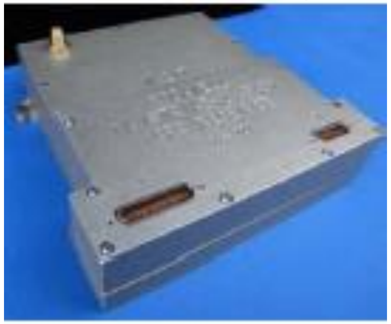
AVIONICS $10M?

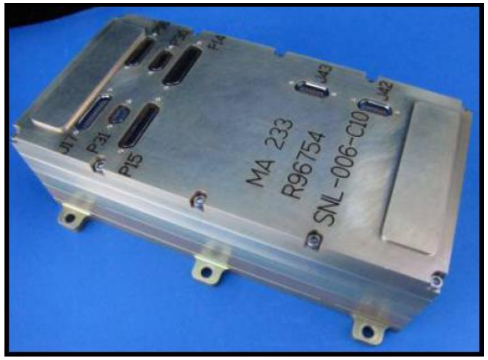
Raptor HG9900 IMU 7.Kg



Rockwell-Collins NavStrike

3.3 GPS Receiver, 0.5 Kg





IMPACCT-2K Flight Computer, 1.4 kg

LADEE M5 Avionics $20M?

Minotaur, Pegasus, Taurus

IMU: Honeywell SIGI 10 Kg

Avionics > Nano LV Payloads

Game-Changing Breakthroughs Sought by Ames

Enable use of Tactical/Industrial IMUs in NanoLVs

Challenge: excessive noise & drift rate in MEMS COTS IMUs

Possible Solution: Apply optimal estimation and multi-sensor diversity to estimate and remove high drift rates and scale errors

Payoff: Credit-card size, <$2K ea. for gyro/accel/magnetometer triads & <2K ea. GPS

Exploit Small-Footprint Cellphone Processors, cubesat GPS

Challenge: adapt to limited serial I/O options available on ARM-based cellphone boards

Possible Solution: Common compact I/O interface board for NanoLVs, qualify for ascent-to-orbit environments

Payoff: Dirt-cheap hardware, broad software/OS support, 200x200 mm footprint, vary small mass

Software Functional Standardization via Model Based Software Development & Parameterization

Challenge: diversity of NanoLV GNC design solutions

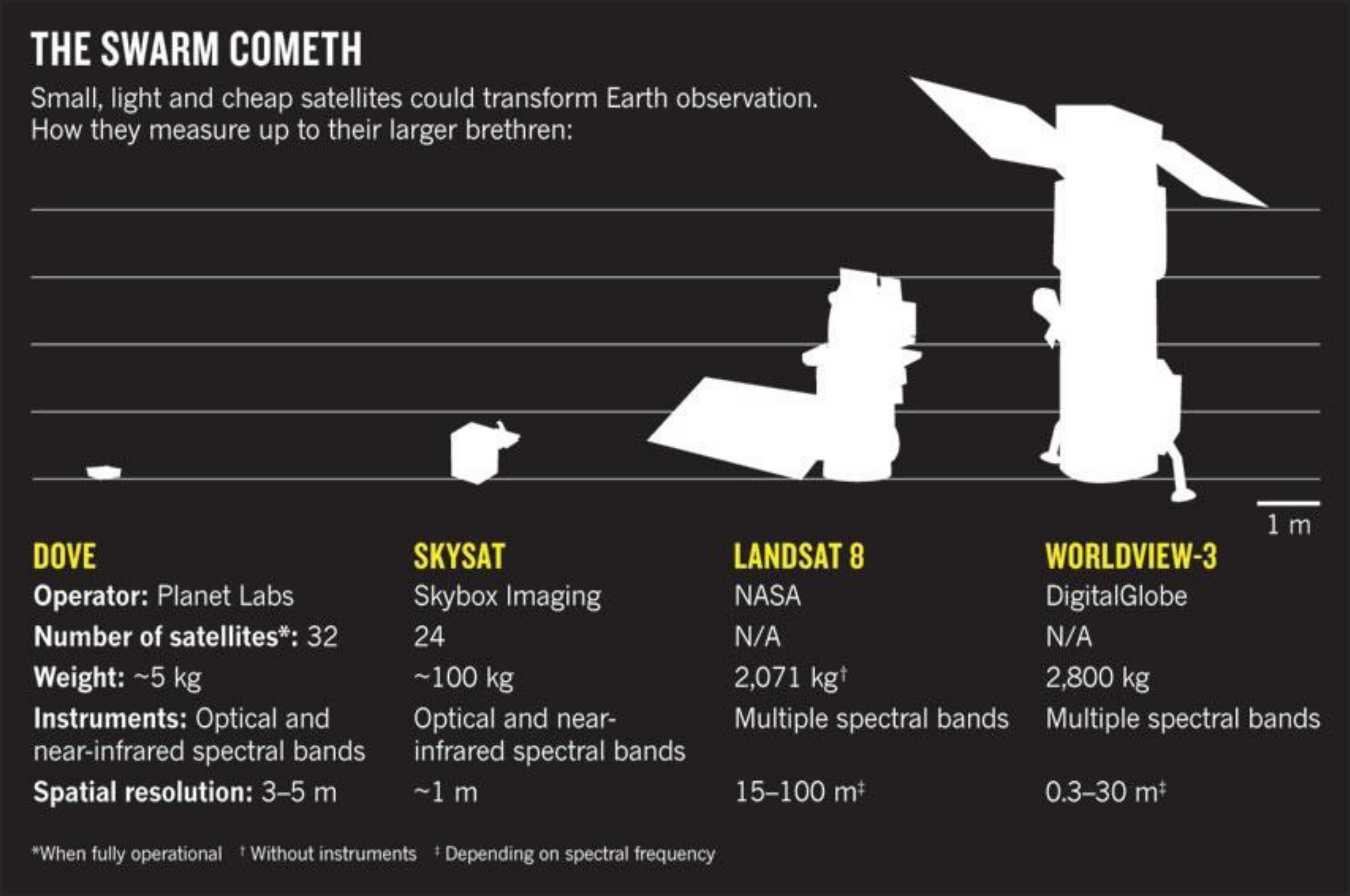
Guiding Idea: Primary software functions are common to all NanoLVs

Possible Solution: Common Functional Architecture, design-specific parameter scripts, model-based gain tuning, generate code on top of flexible comms middleware

Payoff: common toolset for all contenders, Ames support of transition

Trends in Government Space

- **Gov’t as the purchaser of data, not missions**
- **HW will be transparent to govt -> PL & Skybox**



THE SWARM COMETH

Small, light and cheap satellites could transform Earth observation. How they measure up to their larger brethren:

	DOVE	SKYSAT	LANDSAT 8	WORLDVIEW-3
Operator:	Planet Labs	Skybox Imaging	NASA	DigitalGlobe
Number of satellites*:	32	24	N/A	N/A
Weight:	~5 kg	~100 kg	2,071 kg†	2,800 kg
Instruments:	Optical and near-infrared spectral bands	Optical and near-infrared spectral bands	Multiple spectral bands	Multiple spectral bands
Spatial resolution:	3–5 m	~1 m	15–100 m‡	0.3–30 m‡

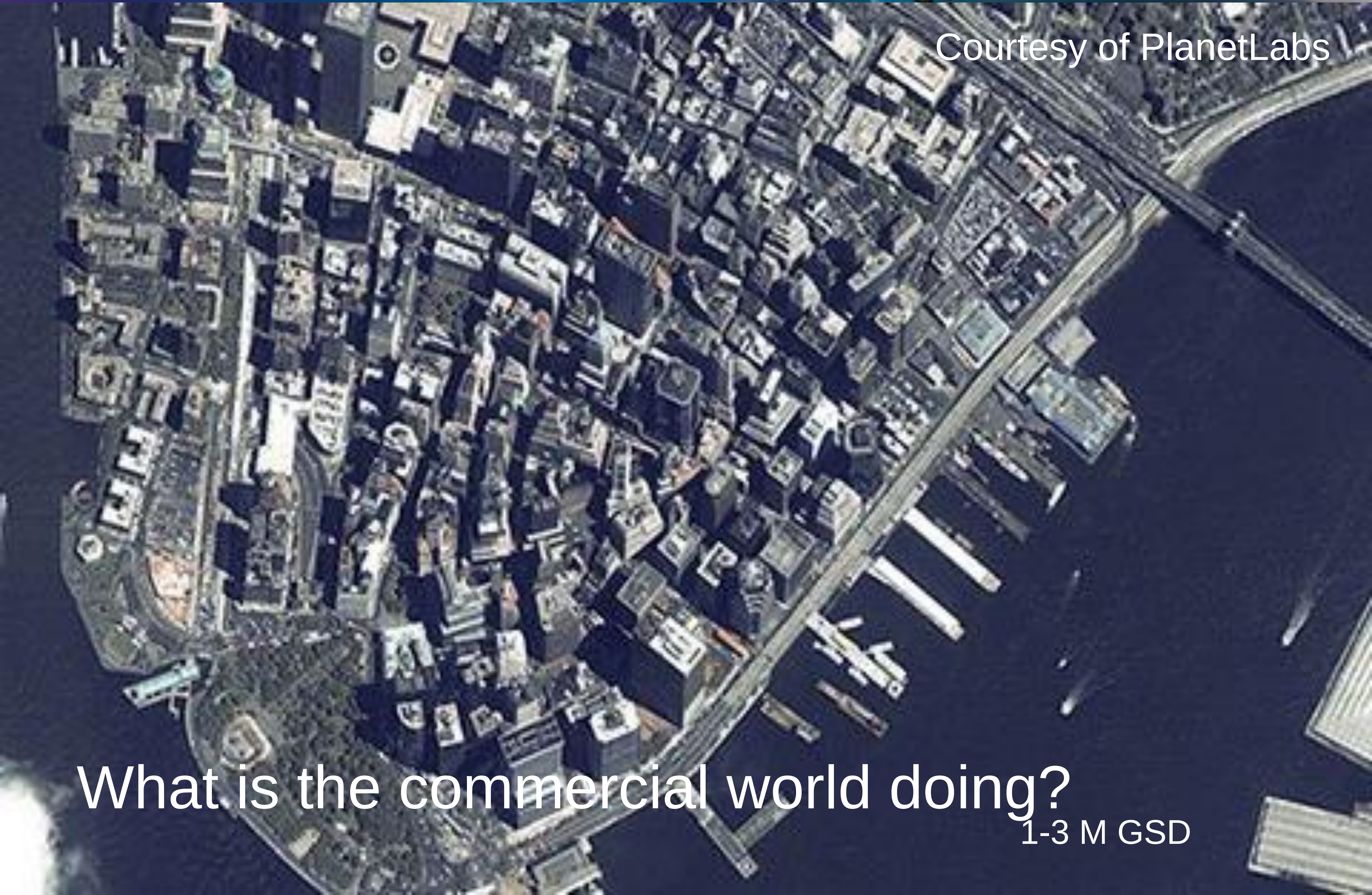
*When fully operational † Without instruments ‡ Depending on spectral frequency

Courtesy http://www.nature.com/news/many-eyes-on-earth-1.14475

What is the commercial world doing?

Courtesy Skybox

Images and Full Motion Video in Near Real Time



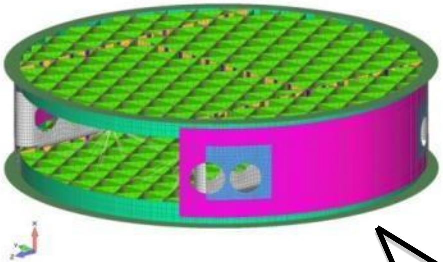
Courtesy of PlanetLabs

What is the commercial world doing?

1-3 M GSD

Questions?

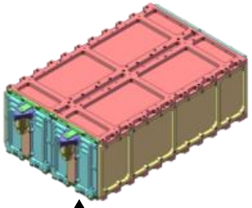
Integrated Payload Stack (IPS)



NASA/ARC

NLAS
(X2)

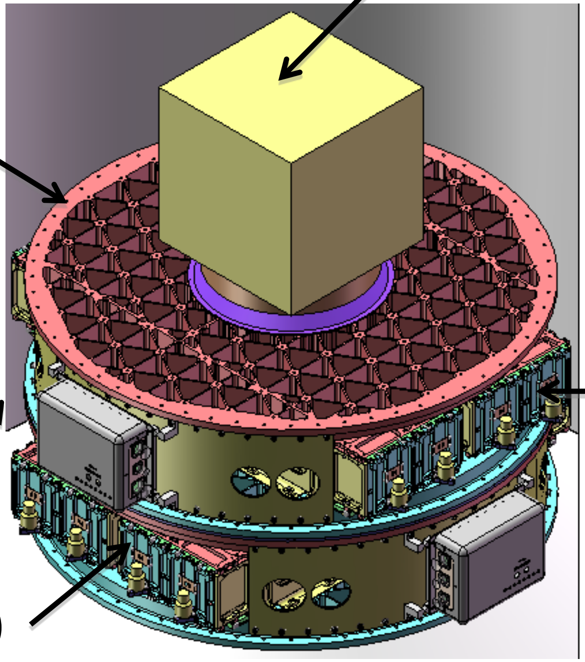
TBD Spacecraft **(STP)**



NASA/ARC

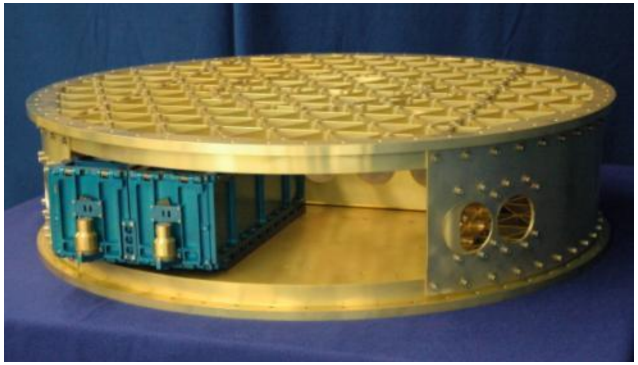
ORS

NRO



NASA/ARC
6U Dispenser

NRO P-PODs (x8)



Mission

- First flight demo with NASA, ORS, STP and NRO spacecraft
  - 45° , 450 km circular orbit from Kwajalein Atoll
  - Planning ILC April 2011

**May be NLAS dispensers*