THE POTENTIAL ROLE OF SMALL SATELLITES, CUBESATS, CONSTELLATIONS, AND HOSTED PAYLOADS IN DESIGNING THE FUTURE EARTH OBSERVING SYSTEM ARCHITECTURE

COMMITTEE ON EARTH SCIENCE AND APPLICATIONS FROM SPACE (CESAS)
September 17-19, 2014
NAS Building, 2101 Constitution Ave NW, Washington, DC

Perspectives on SmallSats and CubeSats

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Dr. Peter Pilewskie

Designing the Future
Earth Observing System Architecture Agenda

10:45	Discussion with Bryant Cramer, former Associate Director of the USGS and former NASA ESD Deputy Director (tentative)
11:30	Discussion with Walter Scott, Digital Globe and Committee
12:15	Lunch
1:15	Earth Science with Hosted Payloads and Small Sat Constellations Lars Dyrud, Draper Laboratory
2:00	Discussion with Bill Swartz, PI RAVAN, Johns Hopkins Applied Physics Laboratory
2:45	Break
3:00	Perspectives on SmallSats and CubeSats Tom Sparn and Peter Pilewskie University of Colorado/Laboratory for Atmospheric & Space Physics (LASP)
4:00	Discussion with John Scherrer, Project Manager for CYGNSS, Southwest Research Institute
4:45	Roundtable Discussions: Committee and Guests
5:30	Adjourn for the Day

Perspectives on SmallSats and CubeSats Outline

1. Current State of Small Satellite Technology
2. Examples of SmallSat/CubeSat implementations
3. Disaggregation of LEO Earth Observing Systems (EOS) using SmallSat Capability
4. Science impacts and implication of using SmallSats on EOS
5. Risk Assessment for EOS using SmallSats and CubeSats
6. Issues with proliferation of small spacecraft

Tipping Point for Successful Design of Disagrigated Critical LEO Earth Observing Space Systems

Small and Medium missions
Start of Large Mission
First CubeSat Launch
75 th CubeSat Launch
~ 167 th Cubesat launched
~ 352 th Cubesat launched
~ 585 th Cubesat launched
~ 655 th Cubesat launched

DMSP BLOCK 5B
Solar Mesosphere Explorer
DMSP BLOCK 5D
UARS
SeaWiFS, TRMM
TERA, Landsat 7, QuickSCAT,ACRIM
NMP/EO-1
Jason 1, Meteor 3M-1/Sage III
AQUA, GRACE, ADEOS II (Midori II)
ICESat, SORCE
AURA
CALIPSO, CloudSat, Hydros
JASON-2
SAC-D/Aquarius
Suomi NPP
Landsat 8
TCTE
SMAP, GPM, OCO-2, SAGE III
Jason-3
ICESat-II, CYGNSS
JPSS-1, GRACE FO
TEMPO, PACE
HyspIRI, SWOT
L-band SAR
ACE
JPSS-2, ASCENDS
GEO-CAPE
3D , GACM, GRACE-2

1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048

Current State of Small Satellite Technology
Small Satellite Class Definitions

LASP experience
In Building and flying
Satellite Systems

"CubeSat"

Satellite Class	Mass Range
Small satellite	100 and 500 kg (220 and 1,100 lb),
Micro satellite	10 and 100 kg (22 and 220 lb)
Nano satellite	1 and 10 kg (2.2 and 22.0 lb).
Pico satellite	0.1 and 1 kg (0.22 and 2.20 lb),
Femto satellite	10 and 100 g (0.35 and 3.53 oz)

- Many Nano-satellites are based on the "CubeSat" standard
  - Consists of any number of 10 cm x 10 cm x 10 cm units
  - Each unit, or "U", usually has a volume of exactly one liter
  - Each "U" has a mass close to 1 kg and not to exceed 1.33 kg
    - (e.g. a 3U CubeSat has mass between 3 and 4 kg)
- Micro-satellites, such as the LASP Micro Bus (LMB), are larger and more capable but often share common avionic components with Nano-satellites

We are in the "Age of "U"

Projection Estimates for Small Satellites

- 2013 Projection estimated:
  - 93 nano/microsatellites would launch globally in 2013;
    - *92 nano/microsatellites actually launched*
  - An increase of 269% over 2012

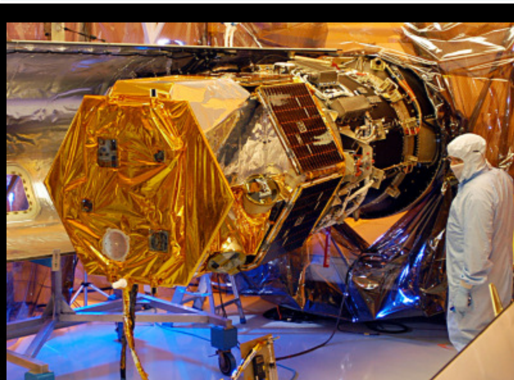
- 2014 Projection: A significant increase in the quantity of future nano/microsatellites needing a launch.
  - 260 nano/microsatellites
  - An increase of 300% over 2013

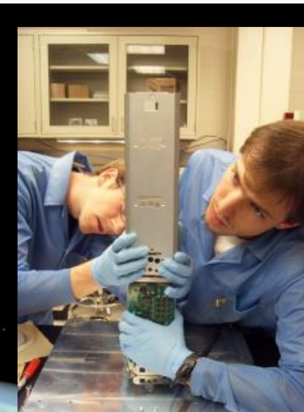
- 2015 – 2016 Projection:
  - Currently 650 future nano/microsatellites (1 – 50 kg)
  - Currently 48 future (2014+) picosatellites (< 1 kg)
  - An increase of 134% over 2014 (reaching maximum capacity of launch availability)

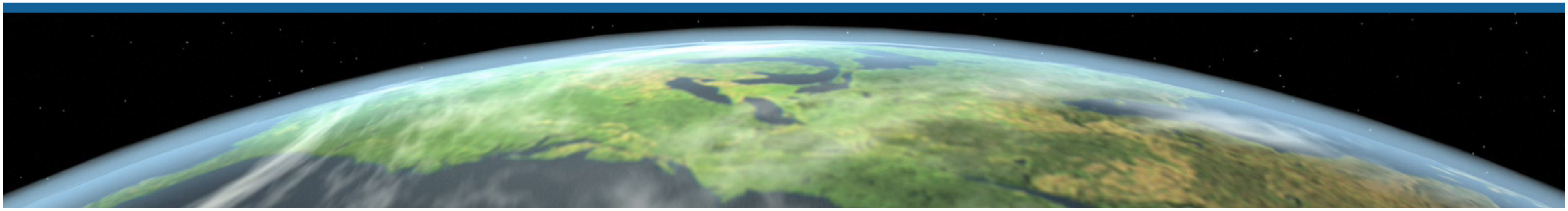
Acknowledgment:
Many statistics and data are provided by the SpaceWorks Enterprises, Inc. (SEI) Satellite Launch Demand Database (LDDB) • The LDDB is an extensive database of all known historical (2000 – 2013) and future (2014+) satellite projects with masses between 0 kg and 10,000+ kg

Characteristics of SmallSat's

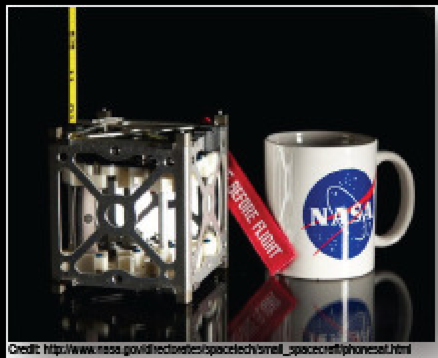
Small Satellites	Micro Satellites	Cube/Nano Satellites
$20M-$80M	$3M-$18M	$100K-$2M
Robust Propulsion	Limited Propulsion	Very limited Propulsion
Redundancy available	Selective Redundancy	Single String
Very Accurate Pointing	Accurate Pointing	Good Pointing
Substantial Launch Vehicle	Shared Ride or Small Launch Vehicle	Shared Ride in many readily available P-POD
High Data Capability	High Data Rate	Low Data Rate
Very Large Apertures	Large Apertures	Small Apertures



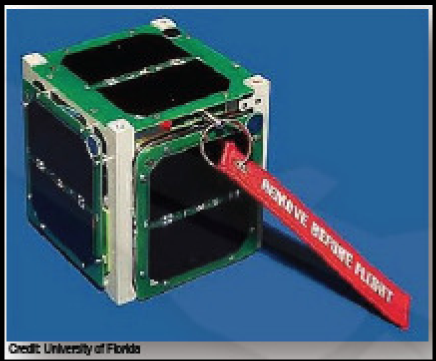




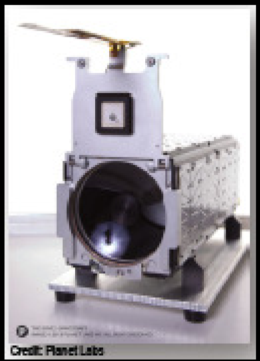
Nano Satellite/CubeSat Applications and Associated Examples



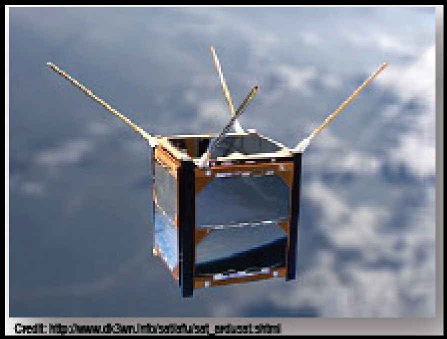
Scientific Research
Phonesat 1.0
Mass: 1 kg
Launched: 4/2013



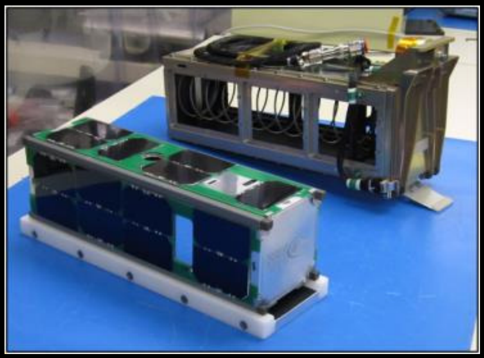
Technology
SwampSat
Mass: 1.2 kg
Launched: 11/2013



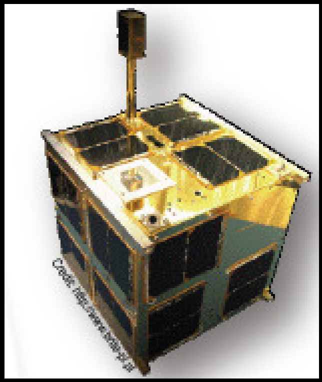
Earth Observation
Dove 2
Mass: 5.5 kg
Launched: 4/2013



Education
ArduSat
Mass: 1 kg
Launched: 8/2013



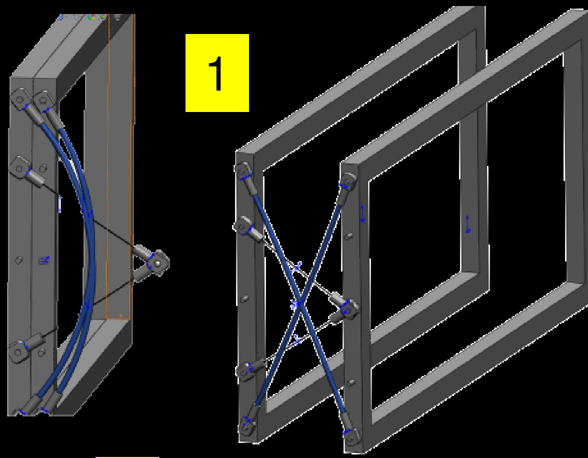
Weather Monitoring
CSSWE
Mass: 5 kg
Launched: 09/2012



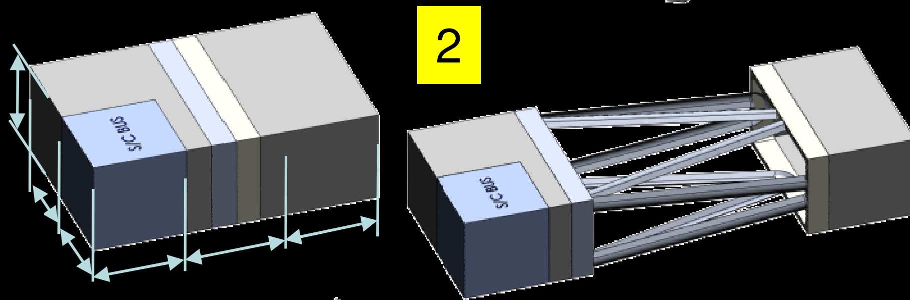
Astronomy
BRITE-PL
Mass: 7 kg
Launched: 11/2013

Examples of Concepts to expand the capabilities of Cubesat Nano/Microsatellites

1. Tension / Compression Members
2. 8 element carpenter tape deployment
3. Long Tension / Compression Members
4. Precision Rails (miniature linear bearings and guides)
5. Modified Carpenter Tape Hinge Deployment



1



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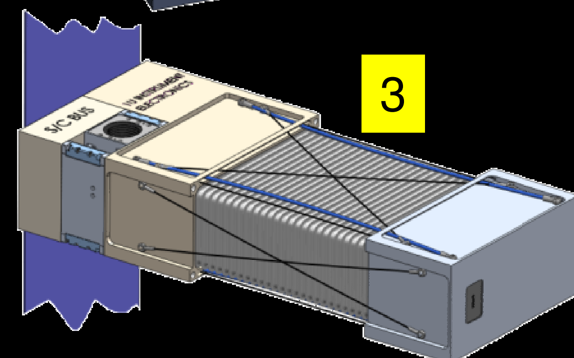

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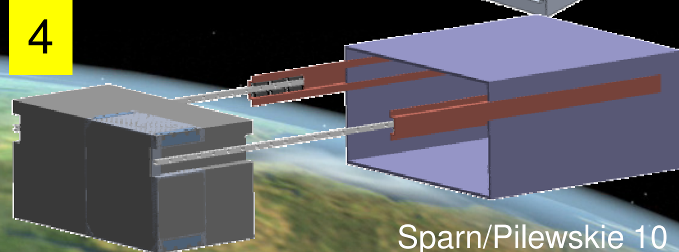

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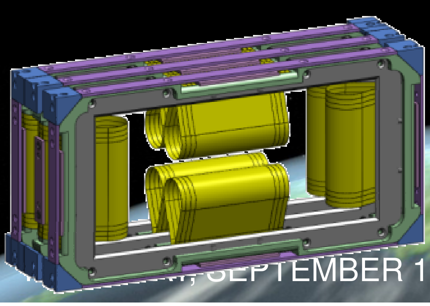

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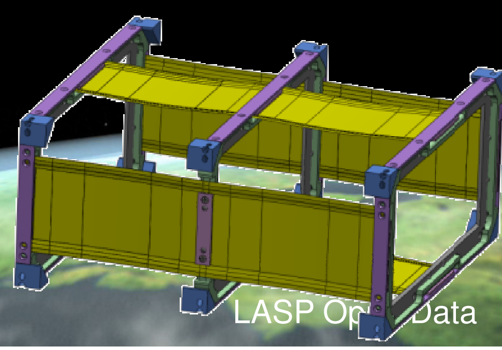
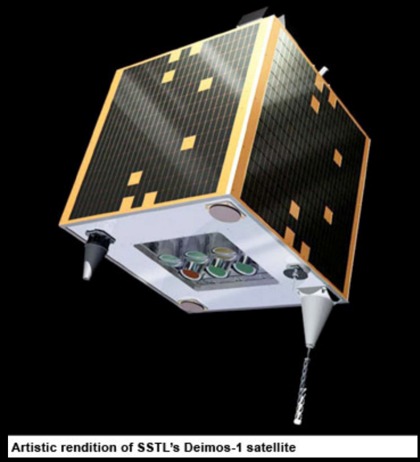


Microsatellite Applications and Associated Examples

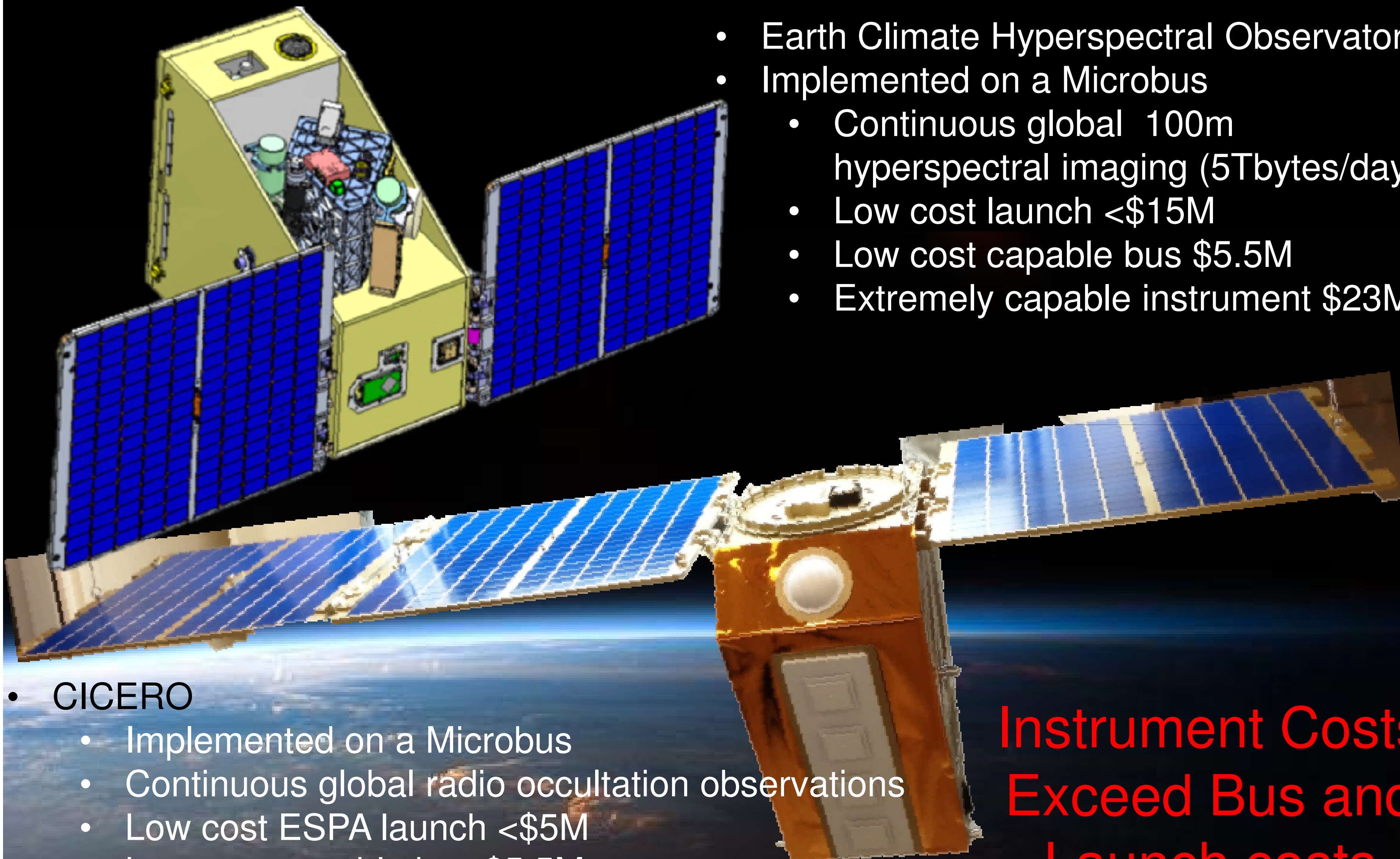

STPSAT-3 with TCTE



SSTL-100


LASP Micro Bus (LMB)
TOMC (concept)

Micro Satellites Capabilities and Cost



- Earth Climate Hyperspectral Observatory
- Implemented on a Microbus
  - Continuous global 100m hyperspectral imaging (5Tbytes/day)
  - Low cost launch <$15M
  - Low cost capable bus $5.5M
  - Extremely capable instrument $23M

- CICERO
  - Implemented on a Microbus
  - Continuous global radio occultation observations
  - Low cost ESPA launch <$5M
  - Low cost capable bus $5.5M
  - Extremely capable instrument $7M

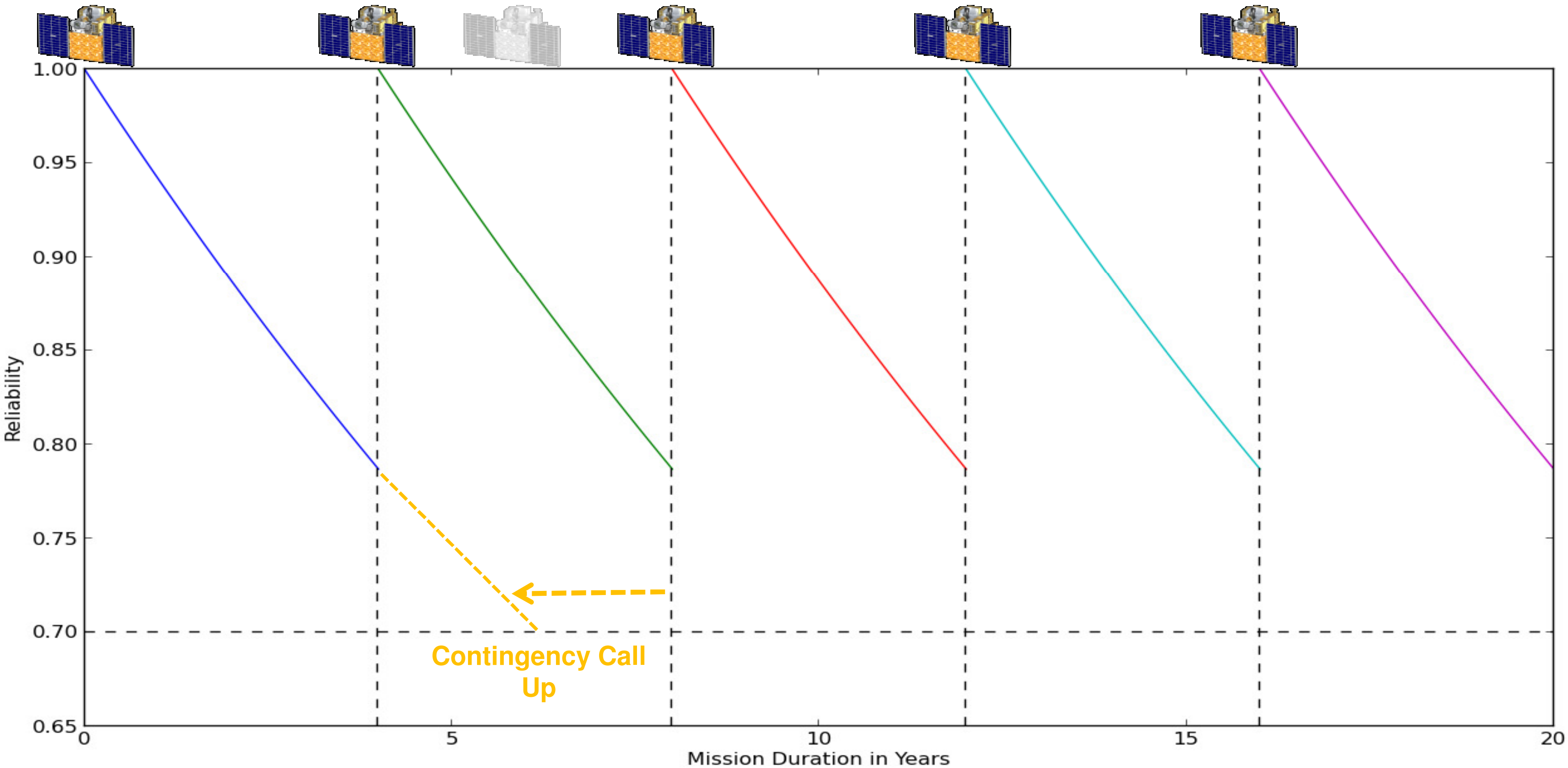
Instrument Costs Exceed Bus and Launch costs

Risk Assessment for EOS using SmallSats and CubeSats

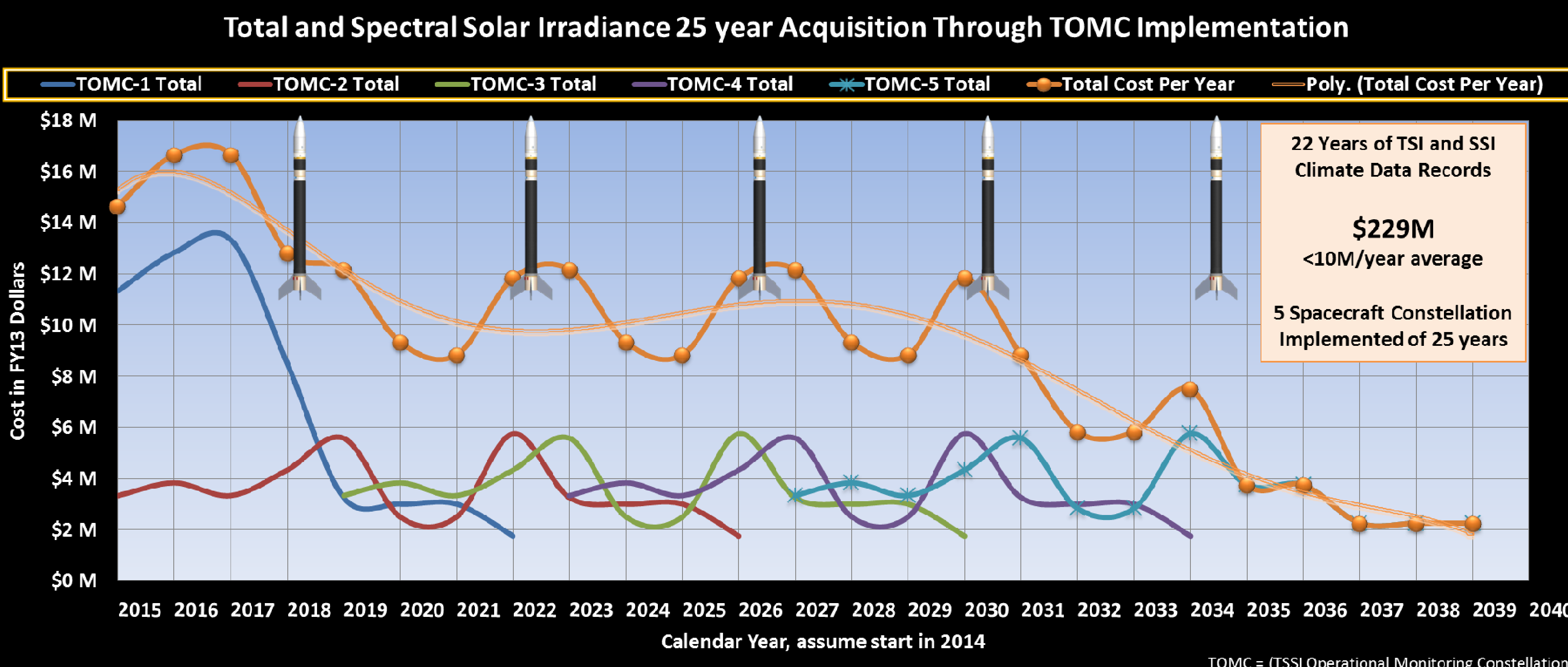
- For current Earth Observing systems, the chief risks are most often not technical they are programmatic
  - Financial risk due to large systems costs and continuity of funding issues
  - Continuity risks due to schedule drivers of complex systems integration
- Disaggregation reduces single year cost impacts and growth
- System risk due to catastrophic failure is reduced by overlapping "constellation" of measurements
- Continuity risk reduced by having overlapping space systems

Mission Constellation Estimated Reliability

- Mission estimated reliability at four years is 0.78, dropping to 0.74 at year 5.
- The design goal of maintaining the mission reliability above 0.70 is achieved with a good margin.

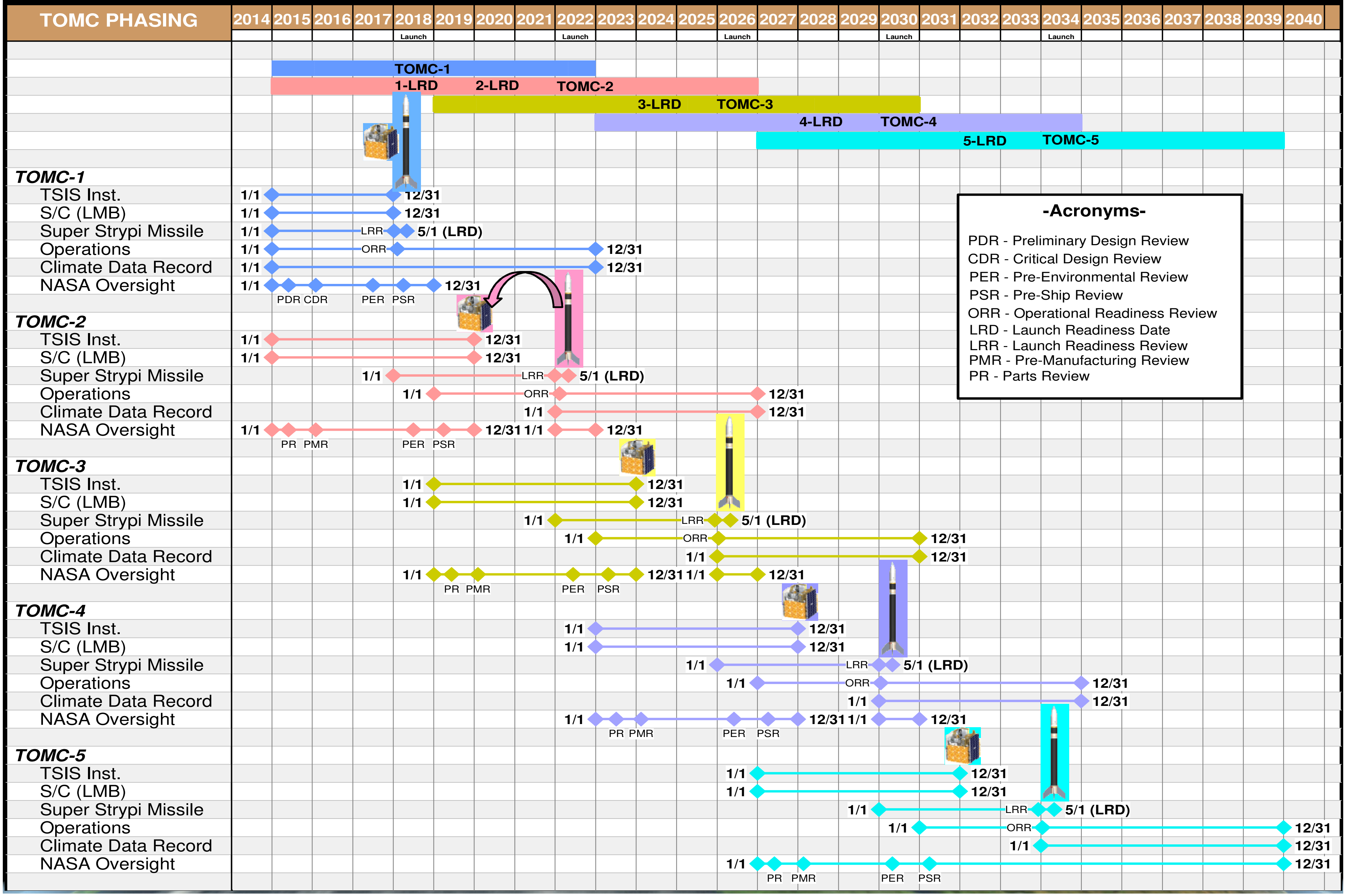


Implementation Cost Profile



- Earliest launch possible in 2018 if funding starts in FY 2015.
- Funding higher in first 3 years to establish hardware programs.
- Production of instruments, spacecraft and launch vehicle sustained over program.
- 25 years of CDR data production and archiving and operations.

TOMC Implementation Plan



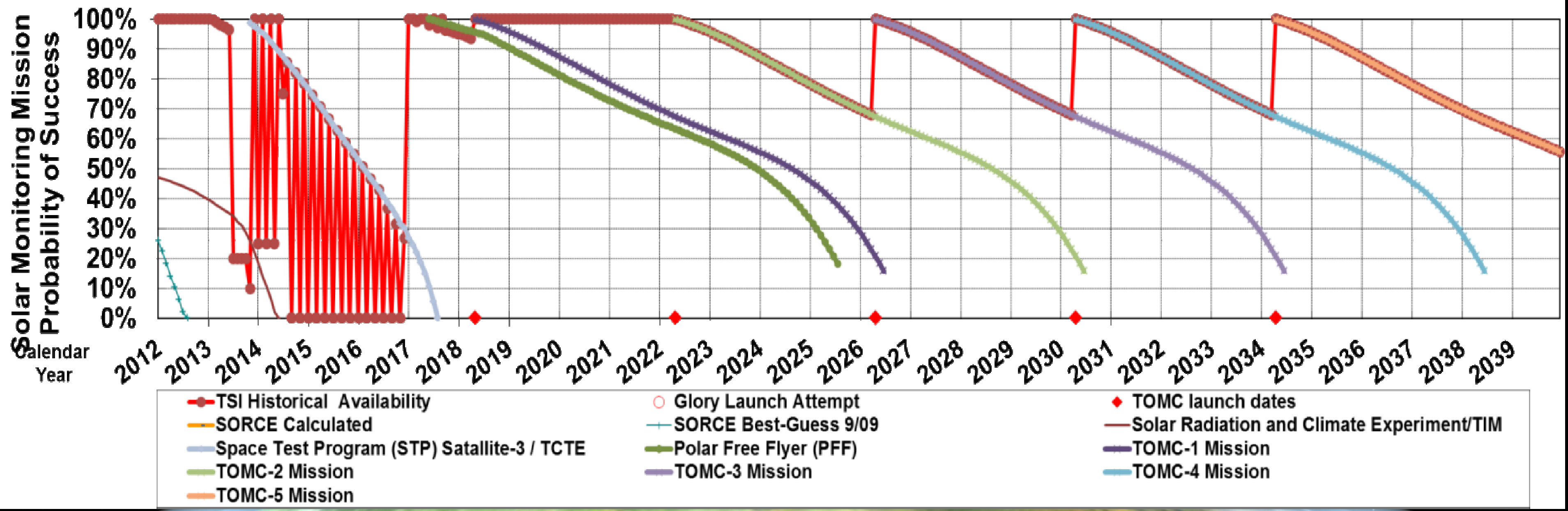
Why Take a risk?

- The TSIS instruments represent a substantial investment in design, calibration and implementation. ($49M)
- Copy costs for existing instruments are much lower and calibration facilities are developed and in-place. ($5.5M/TIM 6.5M/SIM copy cost)
- Larger expenditure does not guarantee successful launch.
  - Challenger loss (Sparten Halley)
  - Glory loss (Glory/TIM instrument)

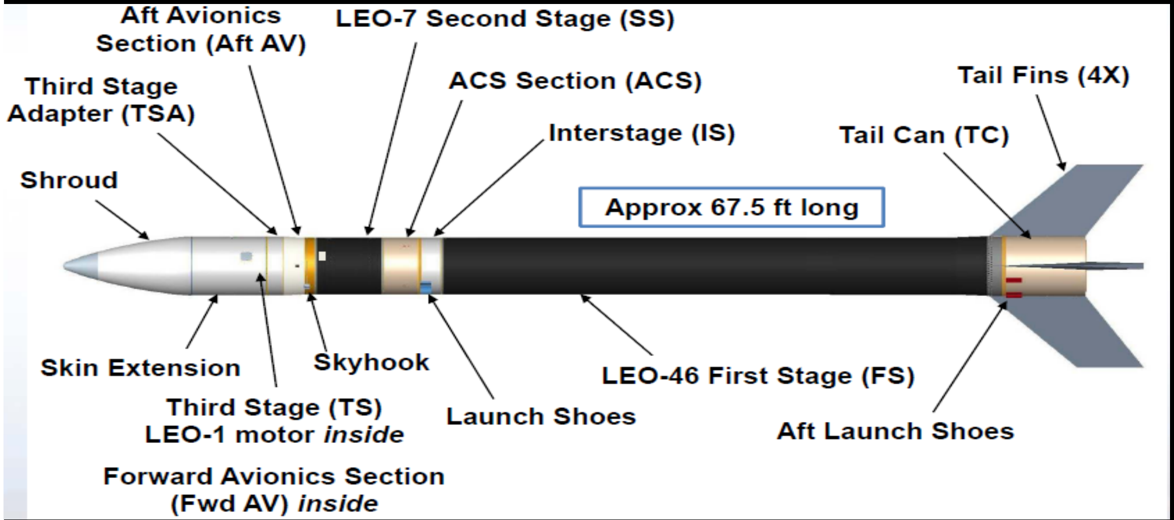
Solar Irradiance Climate Data Record (CDR) Availability Risk

(TOMC Provides 22+ years CDR)

- A constellation of multiple overlapping space missions provide a reliable operational system to monitor data.
- Funding risk is reduced because of low yearly expenditure.
- A large number of potential de-scopes provide planned flexibility for the future.



High Reliability Low Cost Access to Space



Low Cost Rocket Design
Super Strypi

- Super Strypi heritage from Sounding Rockets and Missile defense systems
- Three-stage solid propellant motor stack.
- Fin & spin stabilized vehicle, with attitude control system.
- Optimized motor design: exceeds payload objectives.
- Maximize performance & minimize cost by simplifying design & manufacturing process.
- Meet quick response launch requirement.

Evolved Expendable Launch Vehicle Secondary Payload Adapter, or ESPA ring.

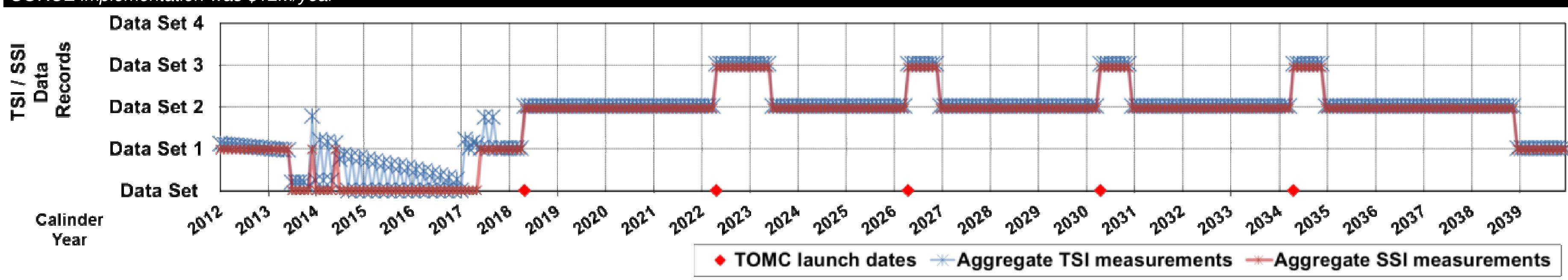
ESPA allows up to six secondary satellites, up to 400 pounds each, to "share a ride to space" on Delta IV or Atlas V launch vehicles while carrying a large primary satellite.

TOMC Cost Benefit Analysis

($229M / 22+ years CDR)

$1.3B Investment **$37M / year**	NPOESS Implementation $184M for TSSI **$26M / year**	PFF Implementation $120M for TSSI **$24M / year**	TOMC Implementation $229M for TSSI **$10M / year**

SORCE implementation was $12M/year



$M FY13$	Start up Year	Year	Year	Launch Year	Year	Year	Year	Launch Year	Year	Year	Year	Launch Year	Year	Year	Year	Launch Year	Year	Year	Year	Launch Year	Year	Year	Year	Year	Year	total Space Systems
Relative Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	5
Calendar Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	
Space Assets	12.33	13.33	12.33	3.00	6.00	3.50	3.00	3.00	6.00	3.50	3.00	3.00	6.00	3.50	3.00	3.00	3.00	-	-	-	-	-	-	-	-	**90.50**
Launch Cost	1.00	2.00	3.00	5.00	2.00	2.00	2.00	4.00	2.00	2.00	2.00	4.00	2.00	2.00	2.00	4.00	2.00	2.00	2.00	3.00	-	-	-	-	-	**50.00**
Operations	0.33	0.33	0.33	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.00	1.00	1.00	**32.50**
Data Systems	0.33	0.33	0.33	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	**42.00**
NASA Oversight	0.66	0.66	0.66	1.33	0.66	0.33	0.33	1.33	0.66	0.33	0.33	1.33	0.66	0.33	0.33	1.33	0.33	0.33	0.33	1.00	0.25	0.25	0.25	0.25	0.25	**14.51**
Total Cost Per Year	**14.66**	**16.66**	**16.66**	**12.83**	**12.16**	**9.33**	**8.83**	**11.83**	**12.16**	**9.33**	**8.83**	**11.83**	**12.16**	**9.33**	**8.83**	**11.83**	**8.83**	**5.83**	**5.83**	**7.50**	**3.75**	**3.75**	**2.25**	**2.25**	**2.25**	**229.51**

- The TOMC implementation is less than half the cost of large missions, with a system level reliability as implemented (t*hrough a constellation of small low-cost spacecraft*) higher than large missions.

Issues With Proliferation of Small Spacecraft

1. Each spacecraft requires a uplink/downlink frequency allocation
2. Each spacecraft becomes “orbit debris” and occupies a potential orbital slot
3. Capability limited based on the laws of physics and there is a general “push” to reduce requirements
4. There will be more “failures” due to the implementation cost/risk choice. Although the system reliability will remain the same or better than large mission approach