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National Space Organization

From FORMOSAT-3/COSMIC to FORMOSAT-7/COSMIC-2 Mission

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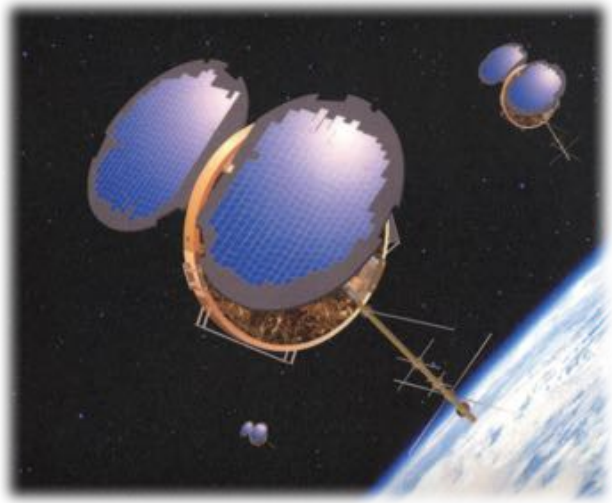
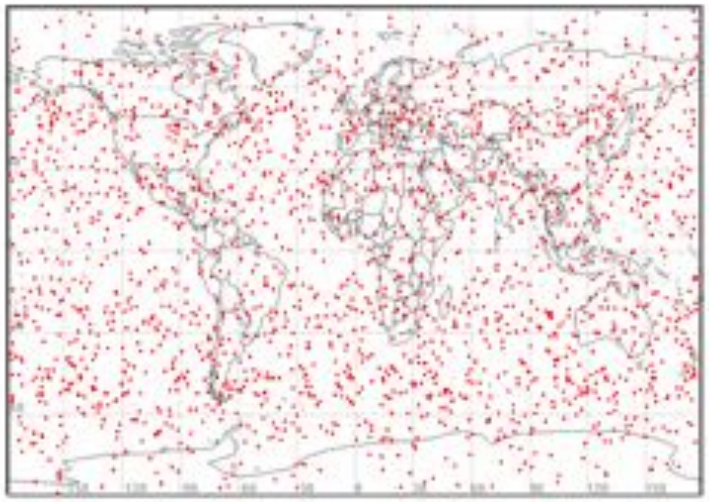
FORMOSAT-3/COSMIC



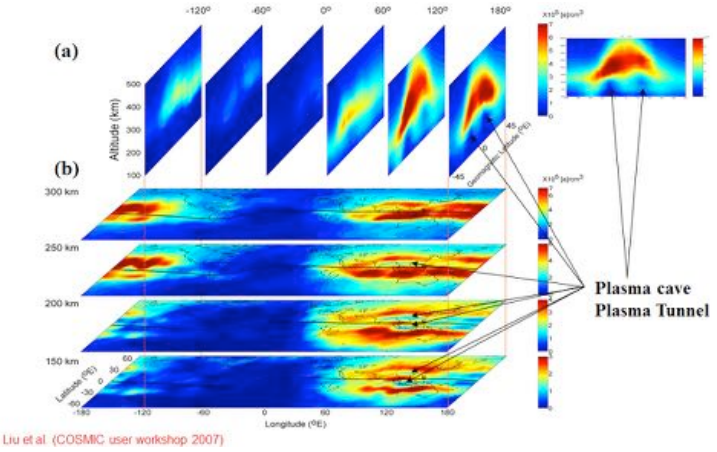
- The FORMOSAT-3 is the 3rd major space program at NSPO. It is known as Constellation Observing System for Meteorology, Ionosphere, and Climate, COSMIC, in the United States.
- An AIT-TECRO Agreement was implemented in May, 1999 to move forward with the COSMIC/FORMOSAT-3 Joint Program. UCAR is assigned to represent the U.S. and NSPO is authorized to represent Taiwan to jointly execute this mission.
- The 6 micro-satellites were successfully launched in April, 2006. This is the first time that six constellational weather satellites were successfully launched in cluster formation.
- The FORMOSAT-3/COSMIC Radio Occultation Constellation has been proven to have significant societal impacts and is appraised as the “Most Accurate and Stable Thermometer in Space”.

Taiwan Science Team Review FS3/C1 in 2008

- **High accuracy, precision and vertical resolution demonstrated.**
- **Significant positive impact on skill scores of operational NWP. Weather Centers started to incorporate FS3/C1 data into system.**
  - ✓ ECMWF: 8 months after launch
  - ✓ NCEP and UK Met Office: 13 months after launch
  - ✓ Meteo France: 17 months after launch
  - ✓ Central Weather Bureau: 39 months after launch
- **Discovery of new ionospheric features (e.g. Plasma caves, Nighttime mid-latitude summer anomaly, Plasma depletion bay, Ionospheric earthquake precursor)**



Providing 1500 soundings per day for weather forecasting system



Ionospheric plasma cave/tunnel

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Review of FORMOSAT-3 Satellite Anomaly

FORMOSAT-3 Anomaly	FORMOSAT-7 Enhancement
Computer resets	Enhancement on the total ionizing dose and single event upsets requirements
Bus GPS receiver anomaly	Data from TGRS as a backup
Attitude excursion	Enhancement on the attitude requirement
Propulsion parameter adjustment	On-site support from contractor
Solar array anomaly	Redundancy
Lost of communication	To take advantage of phoenix mode
Payload GOX bad signal noise ratio	JPL
Payload GOX reboot loop	JPL
Payloads TBB/GOX interference	---

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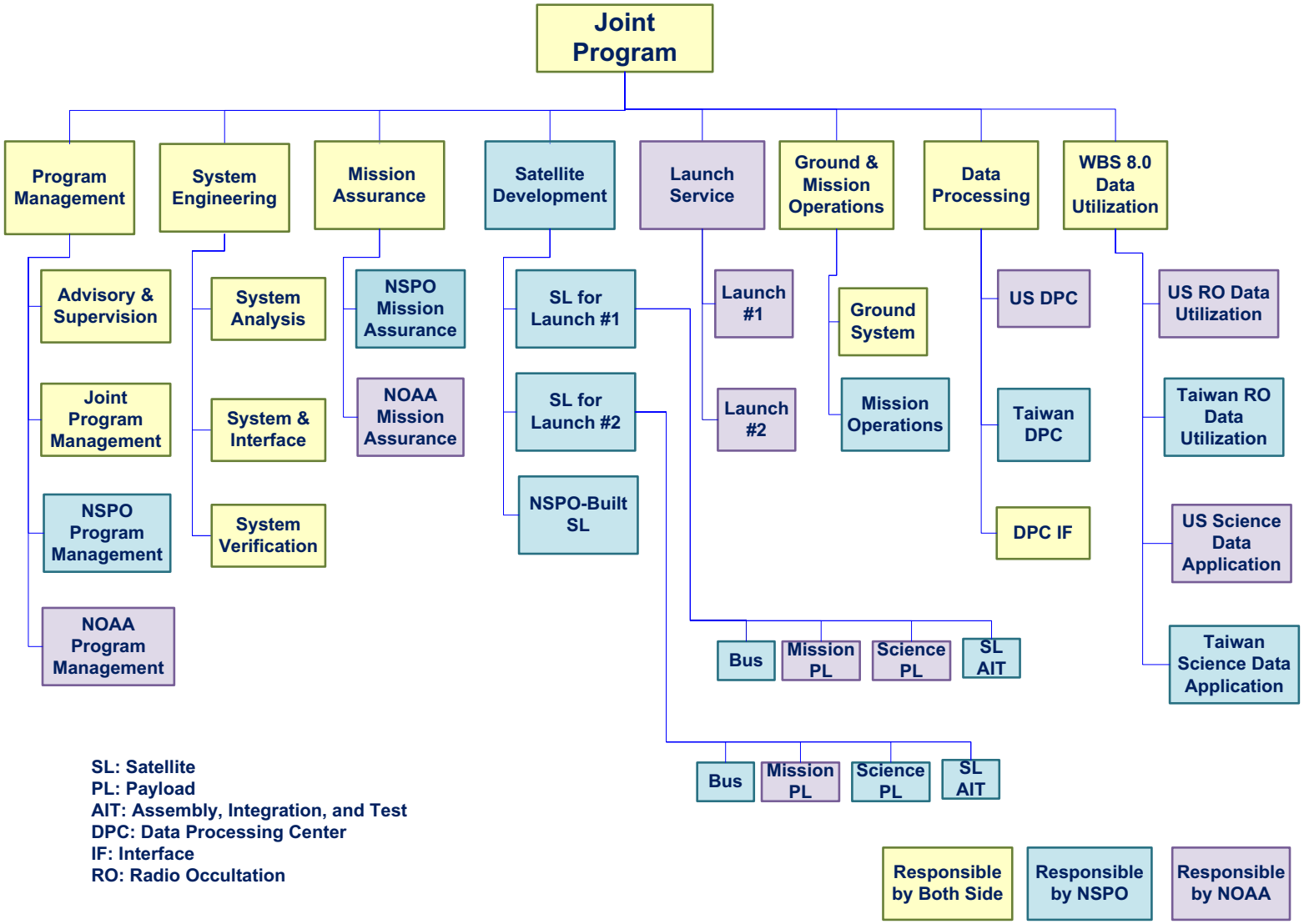
FORMOSAT-3/COSMIC Lessons Learned Review

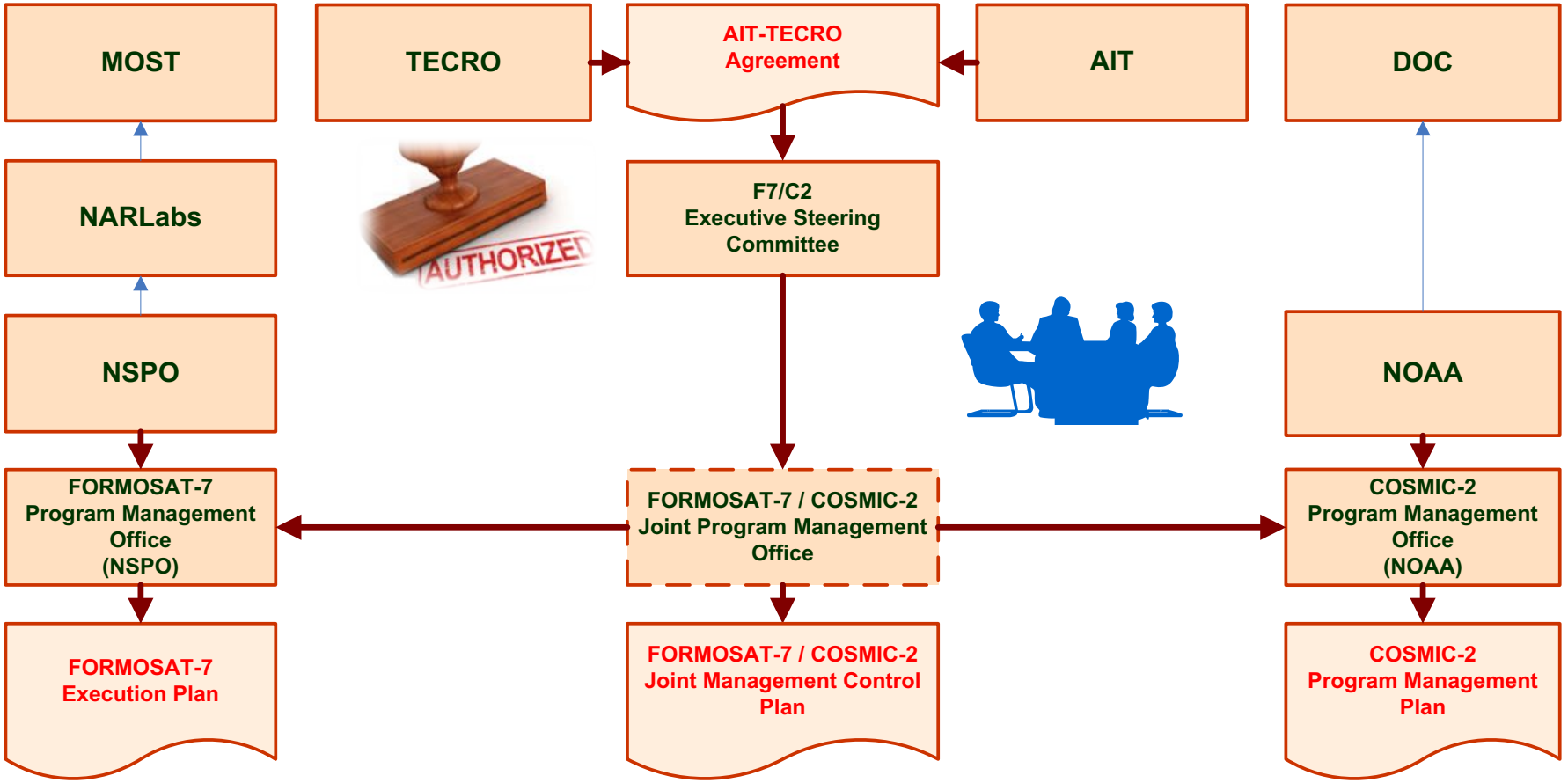
Participating parities include NOAA, MOST(NSC), NSPO, UCAR, JPL, BRE, NRL, and Taiwan science team. Held at UCAR in 2009.

Areas	Lessons Learned
Mission	• S-band frequency selection: to minimize the radio interference with other satellite program. • RFI among payload: passive payload is preferred. • Secondary payload determination: The secondary payload should meet the level 1 requirement and be endorsed by system engineer on interfaces.
Program	• Procurement practice on Taiwan side • Patent right for constellation deployment
Data Processing Center	To elaborate the description on the firmware change (for mission operations, for users' application)
Mission Payload	More thorough test procedures, longer test time, more budget allocation.

FORMOSAT-7/COSMIC-2 Joint Program



FORMOSAT-7/COSMIC-2 Supervision



- AIT-TECRO Agreement was signed in 2010.
- The first Executive Steering Committee meeting was held in 2011.
- The Implementing Arrangement #1 defining the Launch#1 was signed in 2013.

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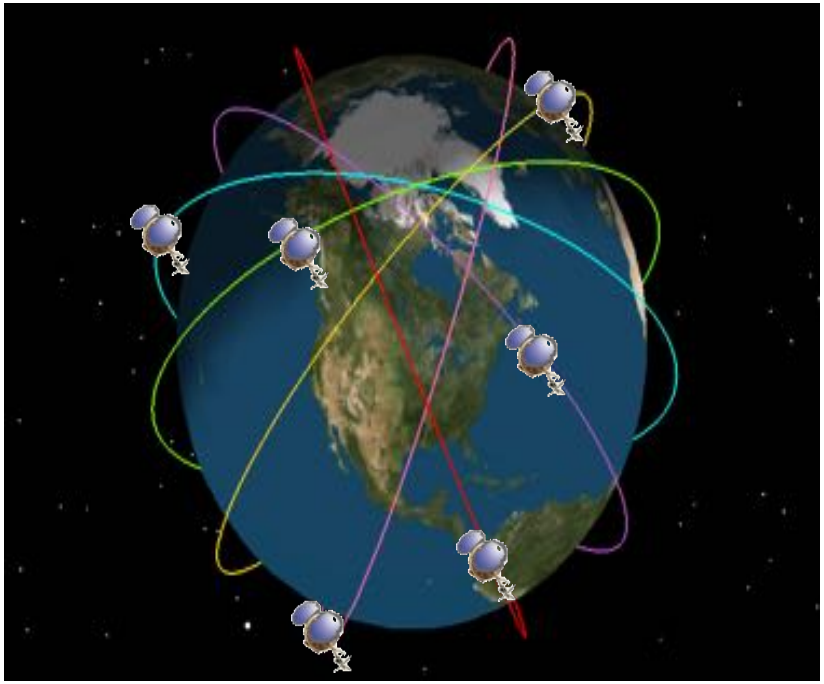
FORMOSAT-3 and FORMOSAT-7 Constellation



FORMOSAT-3/COSMIC

GPS Radio Occultation

Constellation of 6 microsatellites

1500~2000 occultation per day

80% observations available within 3 hr

FORMOSAT-7/COSMIC-2

GPS+GLONASS Radio Occultation

Constellation of 12 small satellites

8000 occultation per day

45-min data latency (median) for Launch#1

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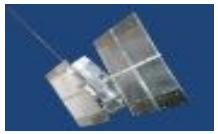
FORMOSAT-7/COSMIC-2 Key Parameters

FORMOSAT-7/COSMIC-2	*First Launch*	*Second Launch*
Mission Objectives	To be achieved after Full Operational Capability: ◆ 8,000 atmospheric sounding profiles per day ◆ 45-min data latency for neutral atmosphere and 30-min data latency for ionosphere and space weather	
Constellation	6 SC to low-inclination-angle orbit (mission altitude 520 km)	◆ 6+1 SC to high-inclination-angle orbit (mission altitude ~800 km)
GNSS RO Payload	TGRS	TGRS
Scientific Payload	US furnished IVM and RF Beacon Instrument	Taiwan furnished
Launch Vehicle	Falcon Heavy rideshare; ESPA Grande Ring	Compatible with Falcon 9, Falcon Heavy, and EELV with a 5-m fairing
Launch Schedule (as a goal)	2018	TBR
Communication Architecture	Via Ground Station	

Mission Architecture



GLONASS-FDMA

High-inc

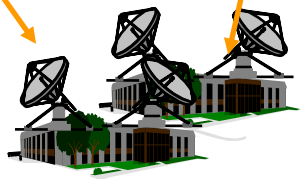
GPS

NSPO-Built S/C

FORMOSAT-7/ COSMIC-2

Low-inc

TT&C stations (Taiwan)



TT&C stations (overseas)

Fiducial Network

Launch Vehicles

Satellite Operations and Control Center

US DPC

Taiwan DPC

Users

Researchers

Data Products

	Data Products
Neutral Atmosphere	• Bending angle profile • Refractivity profile • Temperature profile • Geopotential height profile
Ionosphere and Space Weather	• Total Electron Content (TEC) • Electron Density Profile (EDP) • Scintillation amplitude index(S_4) • Scintillation phase index (S_f)

Launch#1
FORMOSAT-7 Mission Satellites

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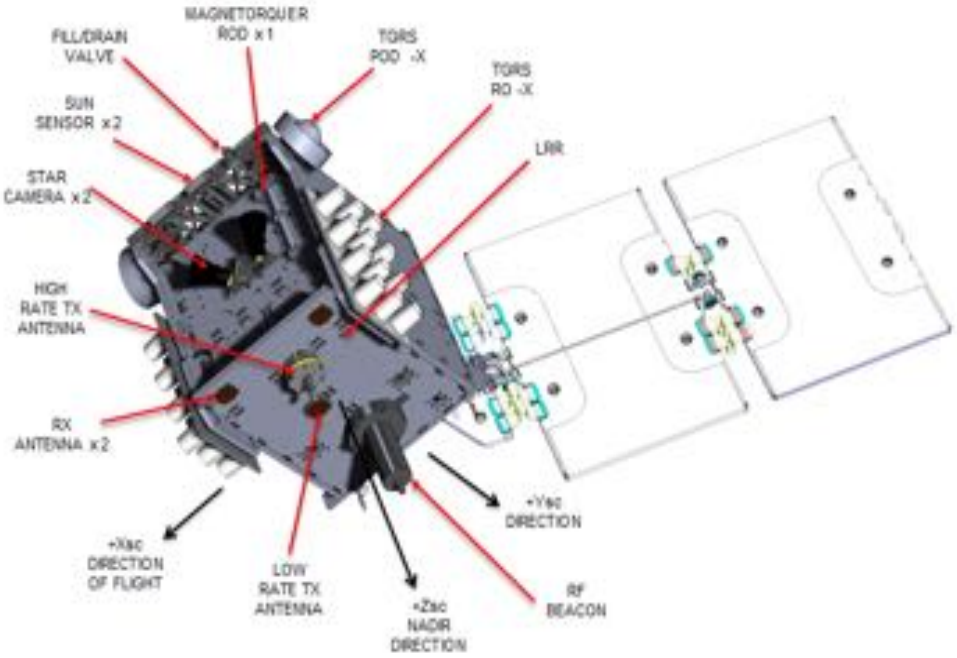
Shape	cuboid unilateral load solar array
Size	100 x 125 x 125 cm^3
Mass	300 kg (per satellite)
Communications Capabilities	S band, upload speed 32kbps ,download speed 2 Mbps
Payload Support	data capacity 2Gbits, load 39.4 kg, power supply 95W

Mission Payload	TGRS (TriG GNSS Radio occultation System)	To measure the phase and group delay of GPS and GLONASS signals.
Science Payload	IVM (Ion Velocity Meter)	To measure electric field perpendicular to the magnetic field and ion motion parallel to the magnetic field
	RFB (Radio Frequency Beacon)	To measure total electron content and ionospheric scintillation.

Achievement to challenges on FORMOSAT-7

Transmitting antenna: 4
Receiving antenna: 10
FOV constraints: antennas, IVM sensors, star cameras, sun sensors, thrusters, solar array



Launch#1
FORMOSAT-7 Mission Satellite Status

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Test Phase	PFM	FM2	FM3	FM4	FM5	FM6
AIT – ASSEMBLY VERIFICATION TESTS						
Payload I&T	SSTL	NSPO	NSPO	NSPO	NSPO	NSPO
ISFT - Integrated Systems Functional Tests	SSTL	SSTL/NSPO	SSTL/NSPO	SSTL/NSPO	SSTL/NSPO	SSTL/NSPO
AMB – Ambient Tests	SSTL	SSTL	SSTL	SSTL	SSTL	SSTL
SEET – System End to End	SSTL	NSPO	NSPO	NSPO	NSPO	NSPO
Ground Segment Compatibility Test (NEET)	NSPO	NSPO	NSPO	NSPO	NSPO	NSPO
EVT – THERMAL						
TC – Thermal Cycling	SSTL	SSTL	SSTL	SSTL	SSTL	SSTL
TV – Thermal Vacuum	RAL	NSPO	NSPO	NSPO	NSPO	NSPO
EVT – EMC RADIATED						
EMC CE & CS	SSTL	N/A	N/A	N/A	N/A	N/A
EMC RE – Radiated Emissions	Astrium P/NSPO	N/A	N/A	N/A	EMI	N/A
EMC RS – Radiated Susceptibility	Astrium P/NSPO	N/A	N/A	N/A	EMI	N/A
EVT – DYNAMIC TESTS						
Separation Shock	Astruim P/RAL	N/A	N/A	N/A	N/A	N/A
Acoustic	Structure (Q)	N/A	NSPO(PF)	N/A	N/A	N/A
Random Vibe	Astruim P/RAL(PQ)	NSPO(PF)	NSPO(PF)	NSPO(PF)	NSPO(PF)	NSPO(PF)
Quasi Static (Sine Vibe)	Astruim P(PQ)	N/A	N/A	N/A	N/A	N/A
MOI	SSTL	N/A	N/A	N/A	N/A	N/A
Mass/CoG	SSTL/NSPO	NSPO	NSPO	NSPO	NSPO	NSPO

- **Satellite assembly, integration and test has been completed in May 2016. All 6 six satellites sit in NSPO's facility.**

Launch#1
Launch Vehicle Interfaces

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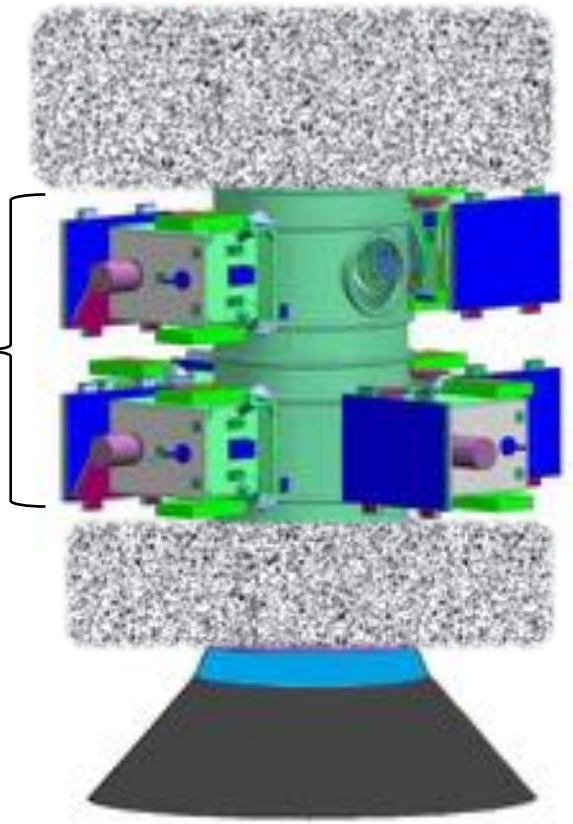
- **Six satellites will be placed on the Integrated Payload Stack of Falcon Heavy**

Concept of Falcon Heavy from Launch Comlex-39A CCAFS



Launch#1
Ground Stations

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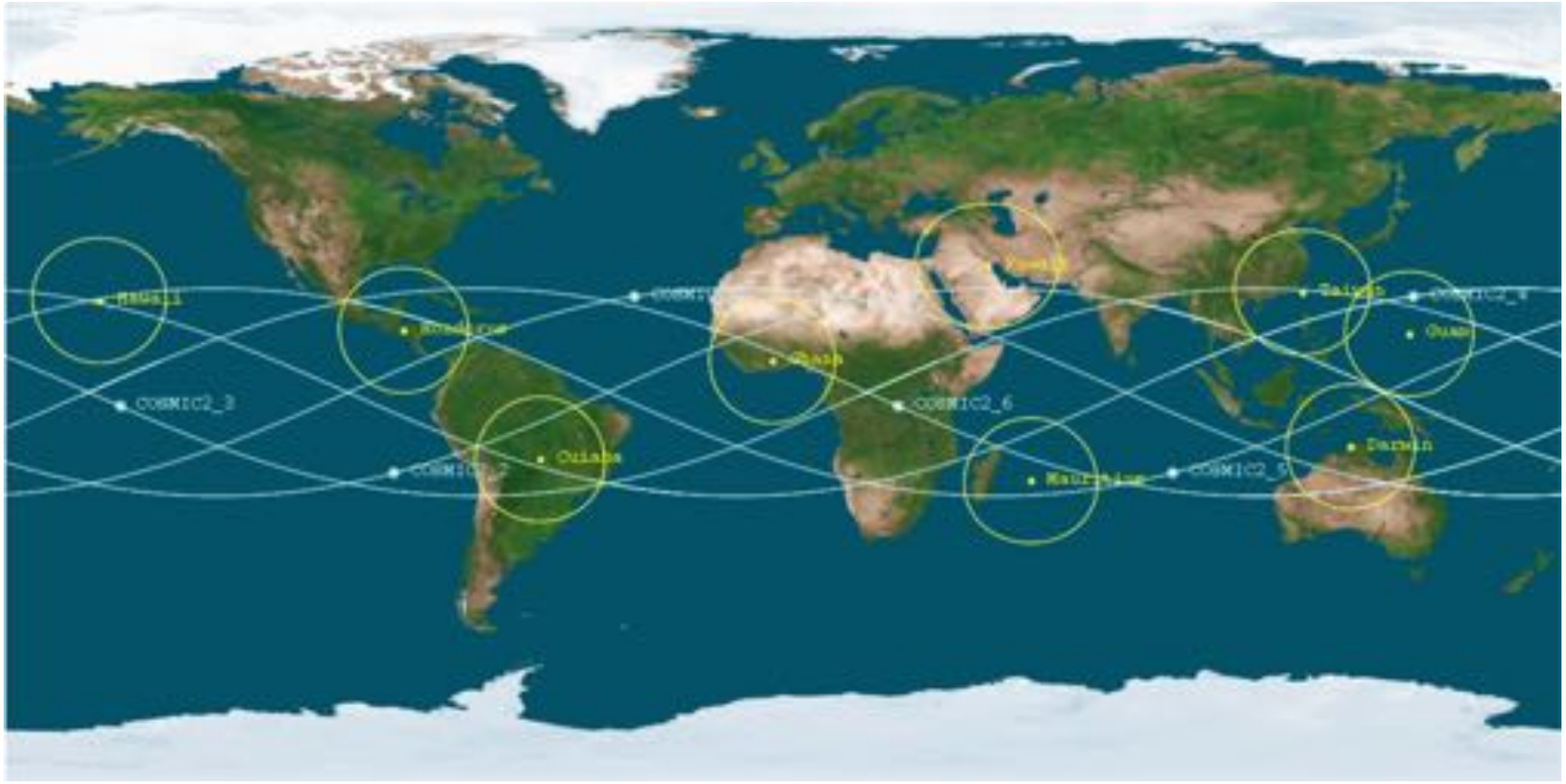


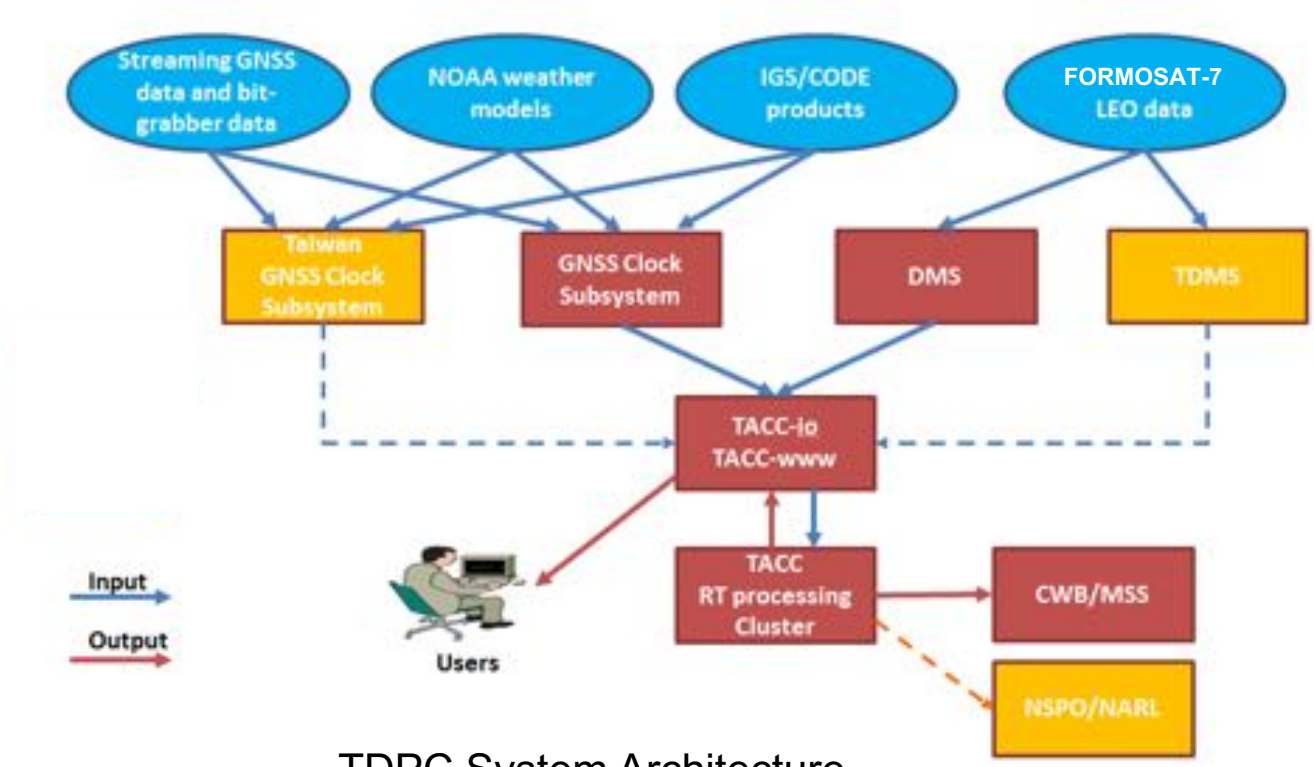
- 9 ground stations to support 30~45-min (median) data latency.

Mission Operations

- Schedule spacecraft bus and payload activities.
- Coordinate ground station pass plan.
- Send command and load to the satellite through TT&C stations.
- Monitor and trend the state of health of satellites.
- Conduct the constellation deployment

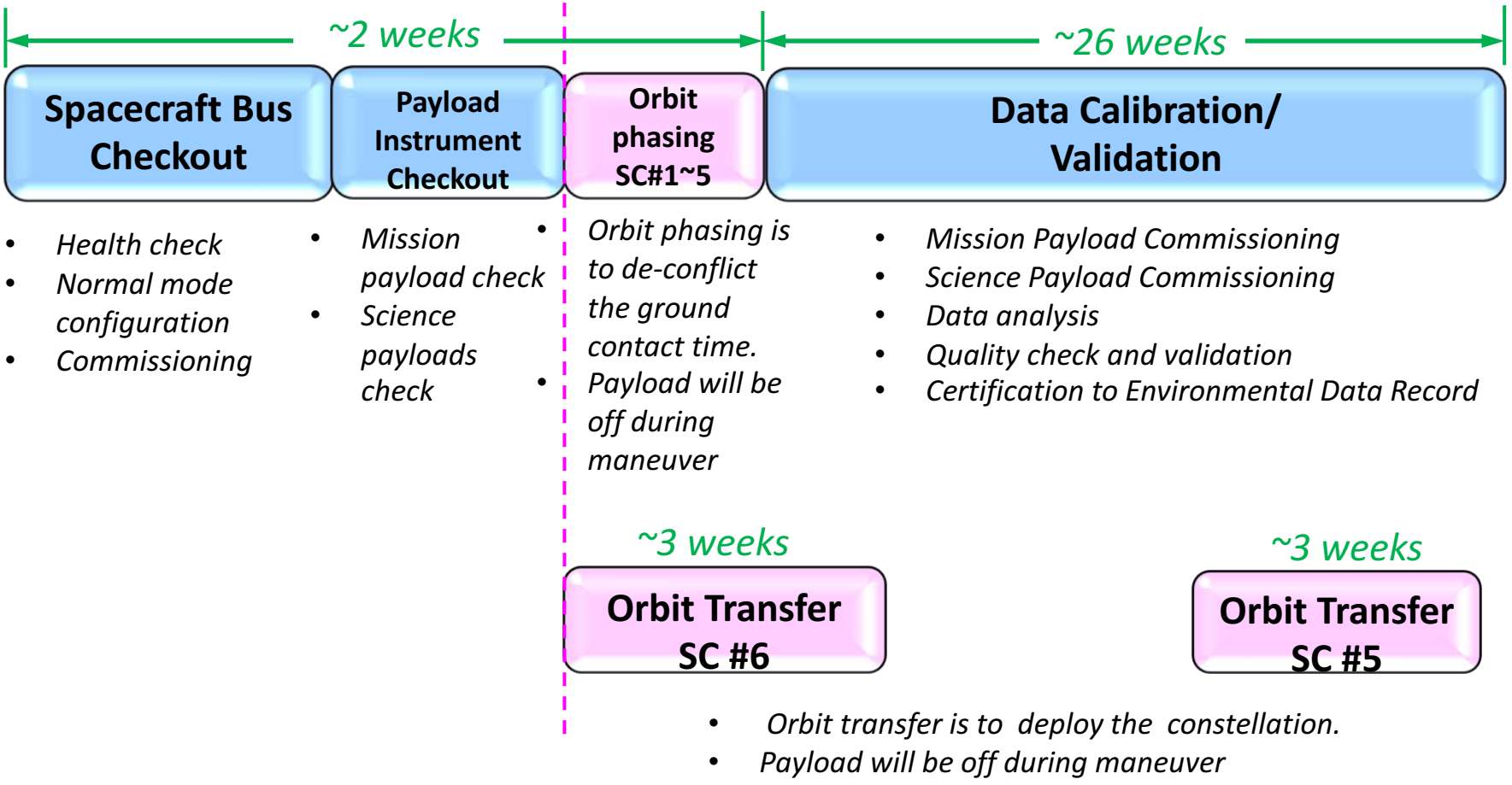
Data Processing Center

- Data is available on a full and open basis and assessable to users through data processing center.
- Two Data Processing Centers: one in the U.S. one in Taiwan. USDPC and TDPC have passed the readiness review.

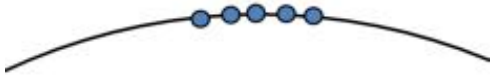


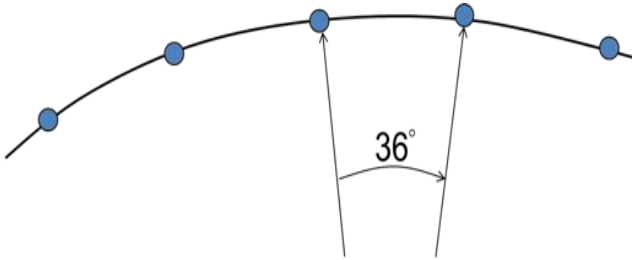
TDPC System Architecture

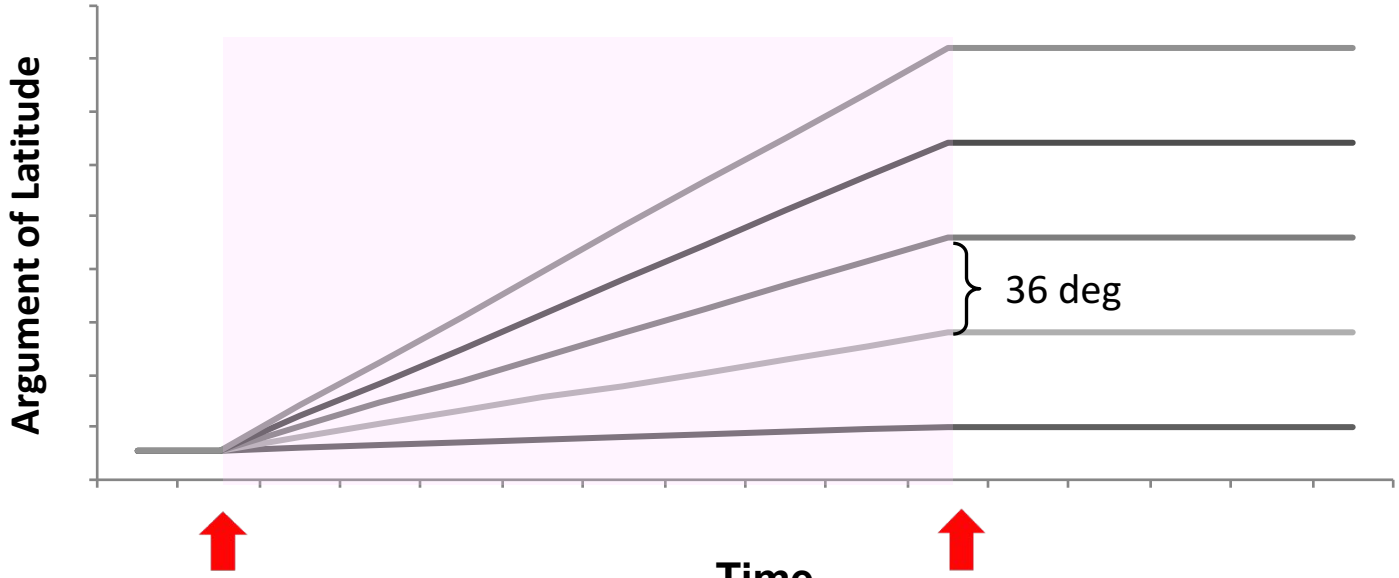
Timeline after Launch



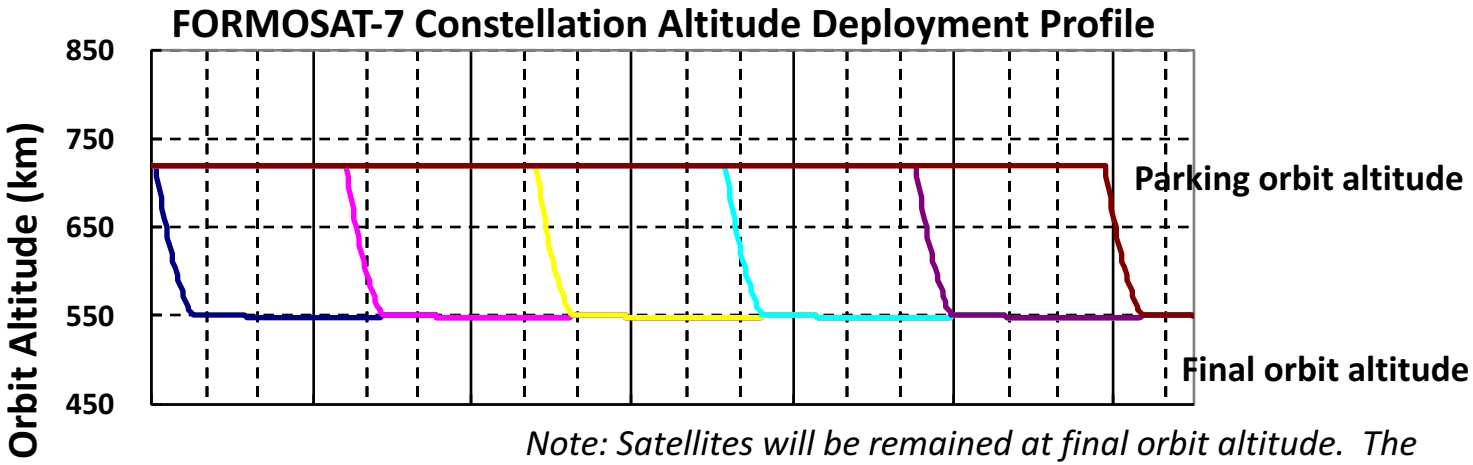
Orbit Phasing







Constellation Deployment



Note: Satellites will be remained at final orbit altitude. The maintenance will be activated as the orbit is decayed to below 520 km.

- **Constellation Deployment takes advantage of J2 effect (perturbation because of a nonspherical earth)**
- $$\Delta \Omega / \Delta t = k \cdot (a_A^{-3.5} - a_B^{-3.5}) \cdot \cos i$$

  Ω: Right ascension of ascending node; t:time
  k: constant; a: semi-major axis; i: inclination

- **Constellation deployment to final orbits will take ~19 months**
- **Every ~108 days, the operations team will maneuver a spacecraft from parking orbit to mission orbit**

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Initial Operational Capability (IOC)

IOC	Milestone	Estimated Accomplished at
Satellite IOC	✓ Complete Satellite's health check ✓ Satellite in normal operations	*Launch + 1 months*
Neutral atmosphere IOC	✓ Initial TGRS products available for operational use	*Launch + 7 months*
Mission constellation IOC	✓ Satellites in deployed constellation ✓ Sufficient ground stations are deployed to meet latency requirements. ✓ Complete neutral atmosphere data validation	*Launch + 20 months*

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- **FORMOSAT-3 satellites have provided data for 11 years.**
- **This is the 10th COSMIC Data Users' Workshop.**
- **FORMOSAT-7 Launch#1 is almost ready.**
- **The International Conference on GPS Radio Occultation (ICGPSRO) will be held in September 2018 in Taiwan.**