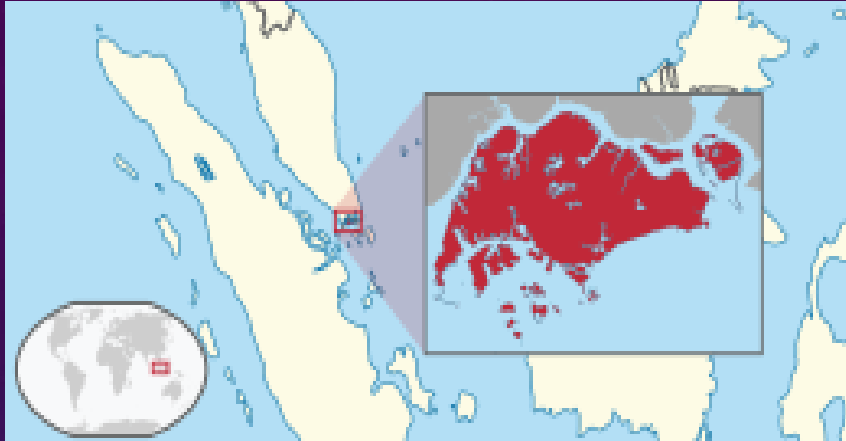


SMALL SATELLITES MISSIONS @ NTU SINGAPORE

AMAL CHANDRAN
ASSISTANT PROFESSOR
ASSOCIATE DIRECTOR, SARC, SCHOOL OF EEE
NANYANG TECHNOLOGICAL UNIVERSITY

SINGAPORE



- Area of 720 km²
- Population of ~ 5.5 Million
- No natural resources.
- 37th globally in GDP.
- 74% of GDP from service industry, 25% from industry
- Has the two top ranked universities in Asia.



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NTU ranks 11th in world rankings, highest position ever by a Singapore or Asian university

Published on: 08-Jun-2017

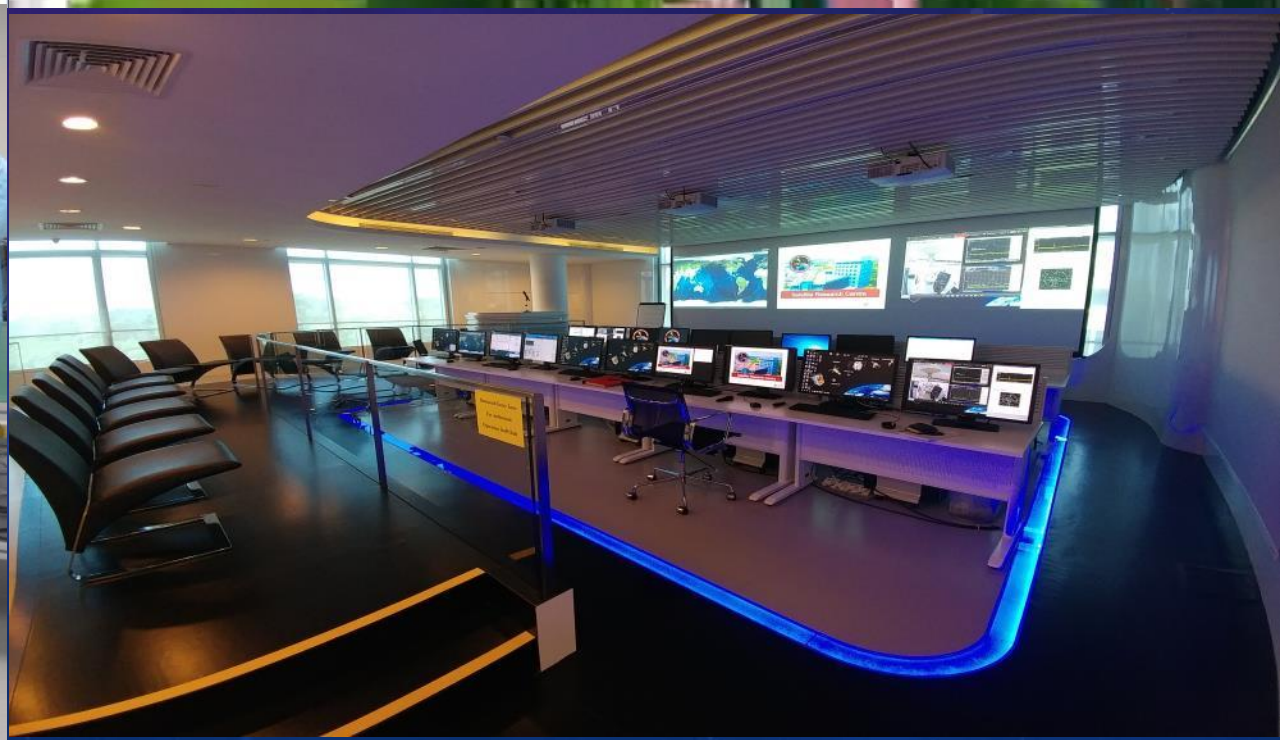
The meteoric rise of Nanyang Technological University, Singapore (NTU Singapore) in the last five years continues as NTU climbs to 11th place in the latest Quacquarelli Symonds (QS) global league table of top universities released today.

This makes NTU the highest ranked university in Singapore as well as in Asia.

The 11th position is NTU's best performance ever, after it leapt 26 places to 13th place in the world in 2015 and maintained that position last year.



Satellite Research Centre



SINGAPORE IN SPACE

- First homegrown satellite XSAT (built at NTU) launched in 2011.
- Has 12 satellites now in the UN database.
- None of our satellites are registered.
- Singapore is not a COSPAR member

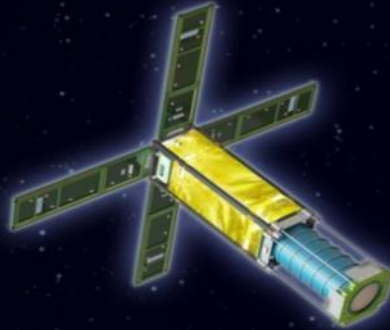
International Designator	Name of Space Object	State/Organization	Date of Launch	Status
[1998-067KX]	[AOBA-VELOX 3]	[(for Singapore)]	[2017-01-16]	[in orbit]
[2015-077B]	[KENT RIDGE 1]	[(for Singapore)]	[2015-12-16]	[in orbit]
[2015-077C]	[ATHENOXAT 1]	[(for Singapore)]	[2015-12-16]	[in orbit]
[2015-077A]	[VELOX C1]	[(for Singapore)]	[2015-12-16]	[in orbit]
[2015-077D]	[TELEOS 1]	[(for Singapore)]	[2015-12-16]	[in orbit]
[2015-077F]	[VELOX 2]	[(for Singapore)]	[2015-12-16]	[in orbit]
[2015-077E]	[GALASSIA]	[(for Singapore)]	[2015-12-16]	[in orbit]
[2014-034E]	[VELOX 1]	[(for Singapore)]	[2014-06-30]	[in orbit]
[2014-033U]	[POPSAT HIP1]	[(for Singapore)]	[2014-06-19]	[in orbit]
[2013-066Y]	[VELOX PII]	[(for Singapore)]	[2013-11-21]	[in orbit]
[2011-022B]	[ST 2]	[(for Singapore)]	[2011-05-20]	[in GSO]
[2011-015C]	[X-SAT]	[(for Singapore)]	[2011-04-20]	[in orbit]

SaRC - Satellite Research Centre



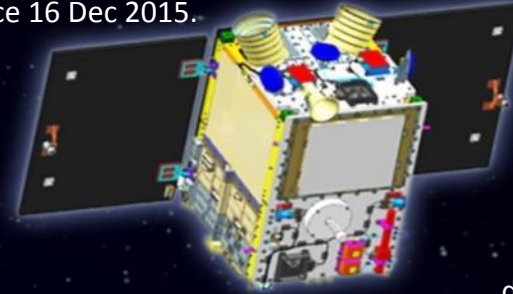
VELOX-I

World first zigbee network in space



VELOX-CI

A climate research satellite using radio occultation.
In orbit since 16 Dec 2015.



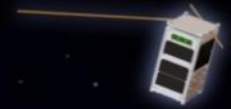
VELOX-II

Inter-satellite communication demonstrating anywhere anytime up and down link.
In orbit since 16 Dec 2015.



AOBA VELOX-III

Pulse plasma thruster demonstration satellite.
Launched in ISS 16 Jan 2017.



VELOX-PIII

The smallest satellite with iPhone size, 193g. In orbit since 30 June 2014.



VELOX-PII

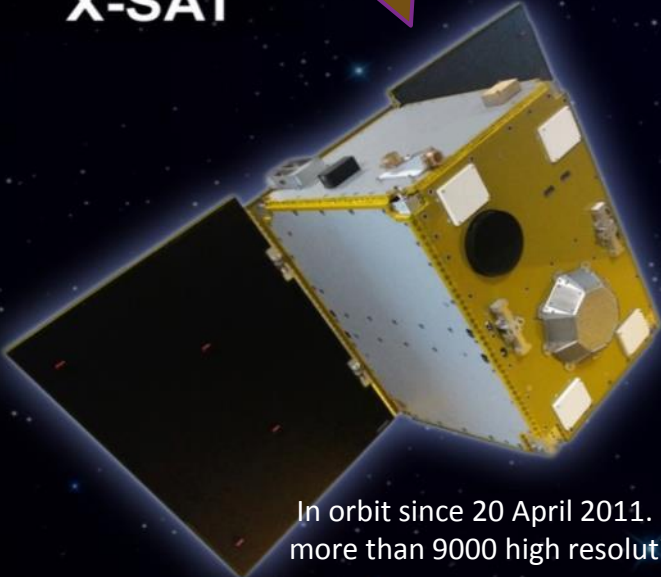
The first student built satellite.
In orbit since 21 Nov 2013.



X-SAT

Celebrated its 6th year anniversary

In orbit since 20 April 2011. It captures more than 9000 high resolution images.



VELOX II

Inter-Satellite Data Relay System (IDRS)

Communicate with higher orbit satellites
Demonstrate the uplink and downlink capability over:

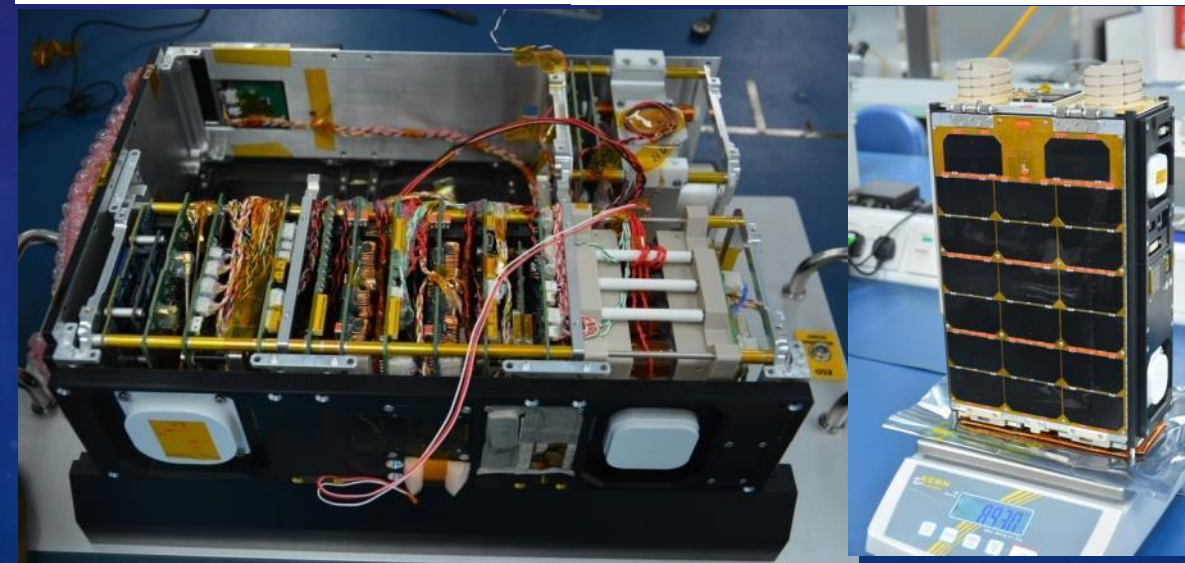
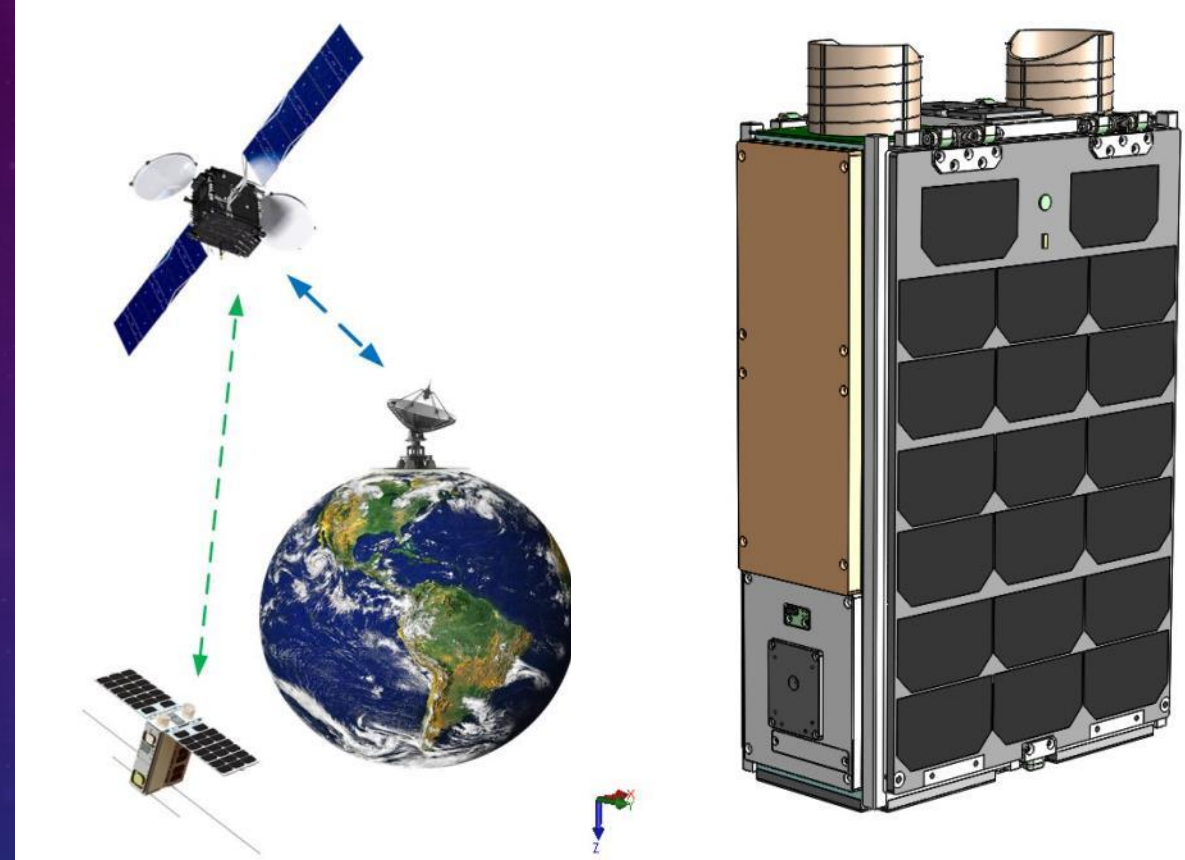
1. Asia region
2. Africa region
3. America region

Achieve:

- 350kB data downlink per experiment
- 1MB data uplink per experiment
- Firmware upgrade demonstration on payload

COTS GPS Payload

- Radio occultation (RO)
- Precision orbit determination
 - Verify implemented orbit propagator
- Relative navigation research (together with VELOX-CI)
- Update orbital parameters on-the-fly



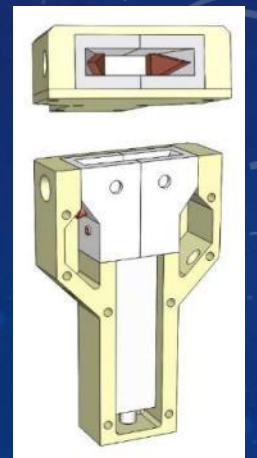
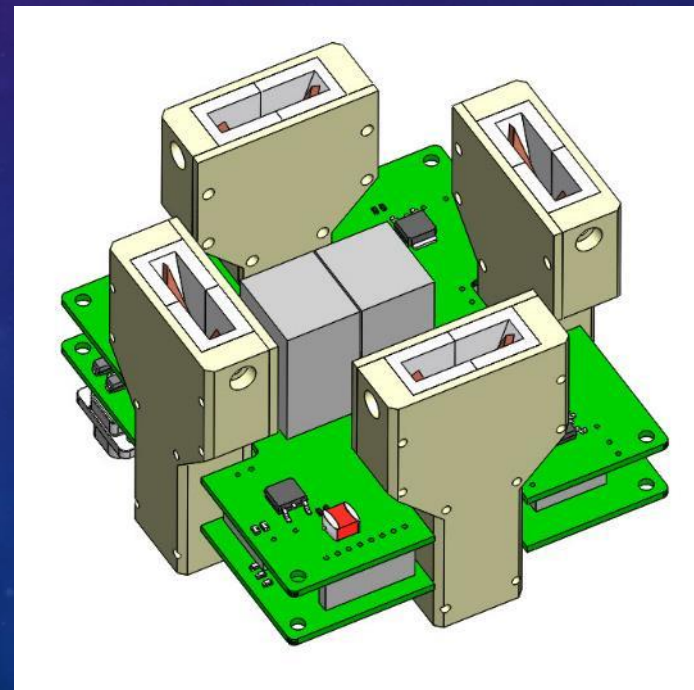
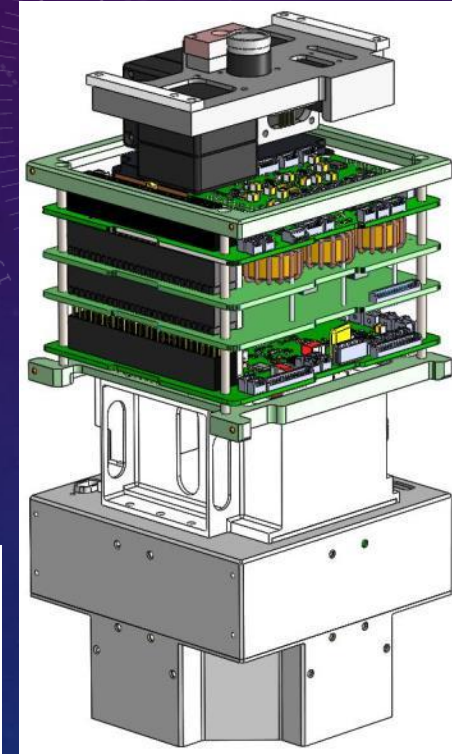
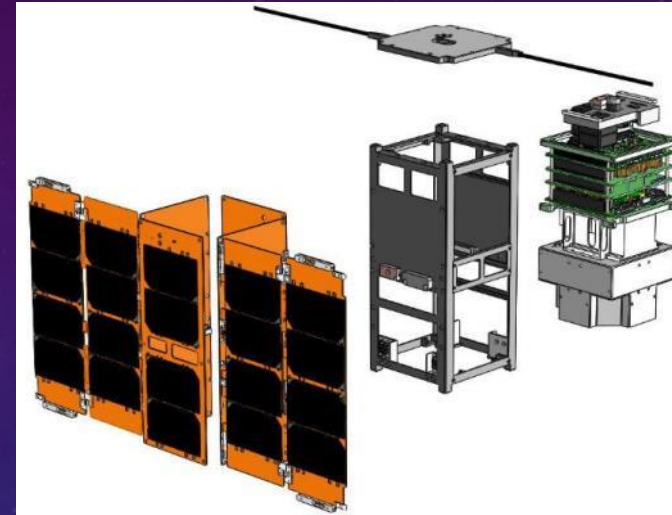
AOBA VELOX-IV

Built Jointly with Kyutech, Japan

Mission Objective

Technology demonstration of attitude and orbit control by pulsed plasma thrusters (PPT) and low light camera for future Lunar-Horizon Glow observation mission

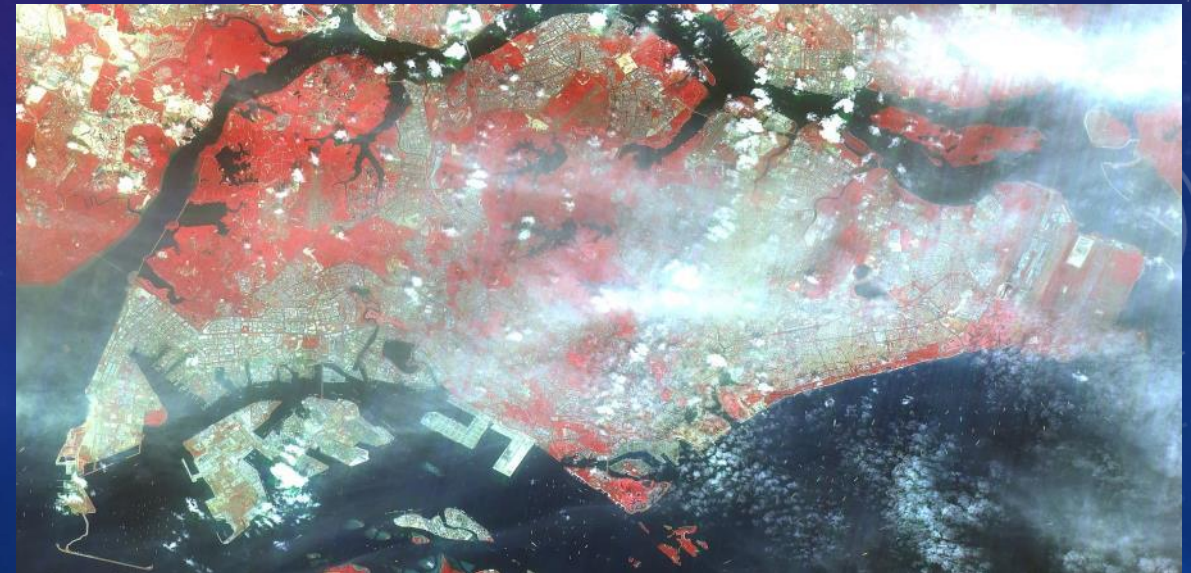
- Momentum dumping of 0.0001 Nms for short axis in 1 hour
- Orbit maneuvering of $\Delta V=60\text{m/s}$ by PPT in 1 year
- Capturing images of Earth horizon while entering eclipse, and night view images of Earth
- + Capturing the Earth-rim image with upper-atmosphere luminous phenomena such as aurora from the eclipse side



SARC MILESTONES

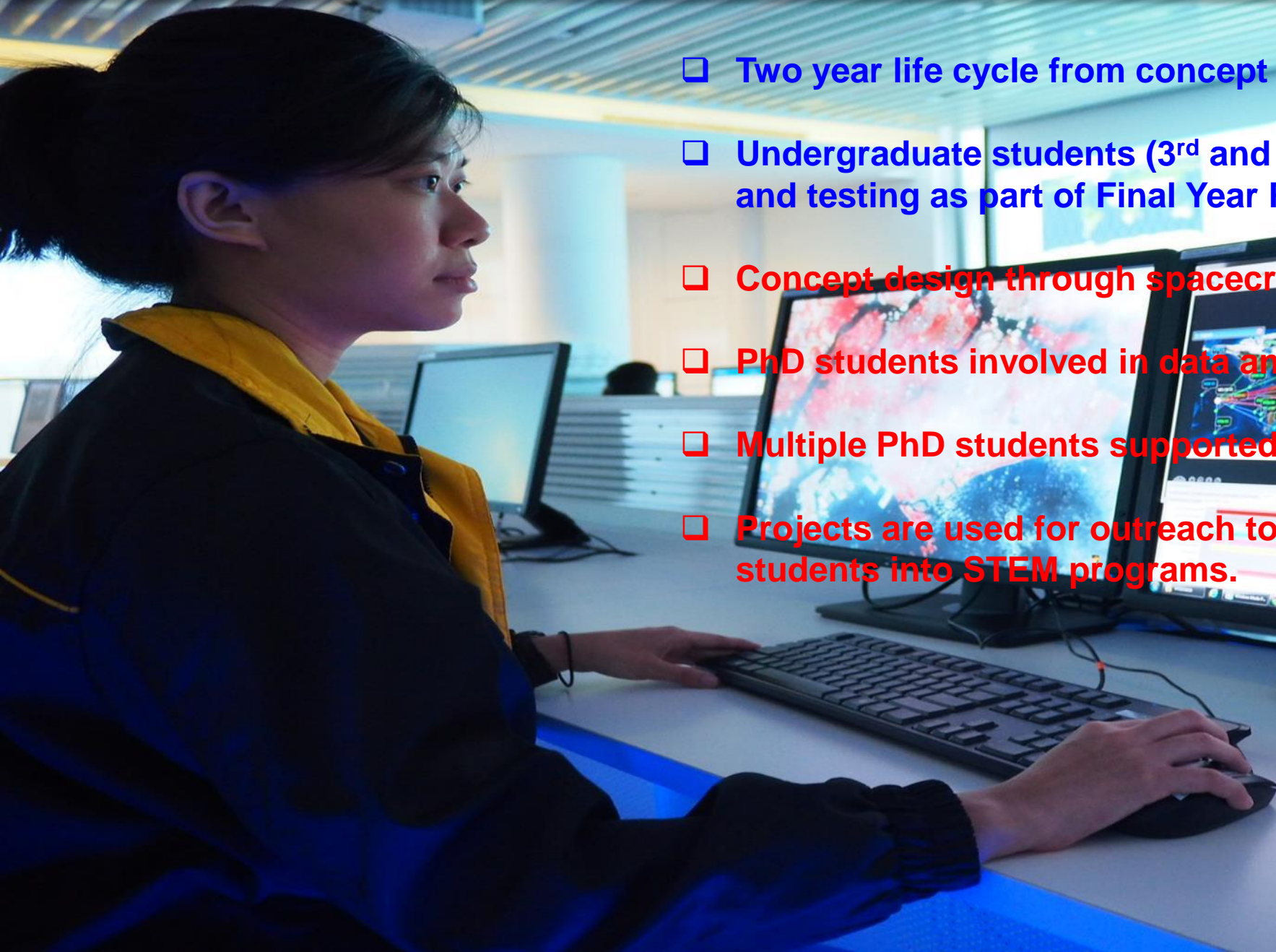
No	Satellites	Size	Main Mission	Launched
1	XSAT	105 Kg	Imaging	20 April 2011
2	VELOX-P1I	1 U	Satellite Control	21 Nov 2013
3	VELOX-I	3 U	Imaging	30 June 2014
4	VELOX-P1II	0.5 U	Intra-Satellite RF communication	30 June 2014
5	VELOX-CI	135 Kg	GPS Radio Occultation	16 Dec 2015
6	VELOX-II	6 U	Inter-Satellite Communication	16 Dec 2015
7	AOBA-VELOX-III	2U	Pulsed-plasma Thruster	16 Jan 2017 ISS

- Satellite ranging from 0.2 kg to 135 kg micro-satellites
- All deployed and worked successfully.
- SaRC knows how to design, build, test & operate small satellites.



Student training at SaRC

- ❑ Two year life cycle from concept design to launch.
- ❑ Undergraduate students (3rd and 4th year) involved in building and testing as part of Final Year Project.
- ❑ **Concept design through spacecraft design class**
- ❑ **PhD students involved in data analysis and retrieval.**
- ❑ **Multiple PhD students supported for technology R&D**
- ❑ **Projects are used for outreach to high schools to get local students into STEM programs.**



Teaching with MOOC's

- Launch a MOOC to appeal to not just Singapore but a global audience
- Teaching will be hands on with space kits.
- Selected payloads can be launched on rides of opportunity



- Selected MOOC students will be invited to annual summer workshops along with selected high school teams.
- Promote diversity and STEM education through participation in annual summer workshops

The International Satellite Program in Research & Education (INSPIRE)



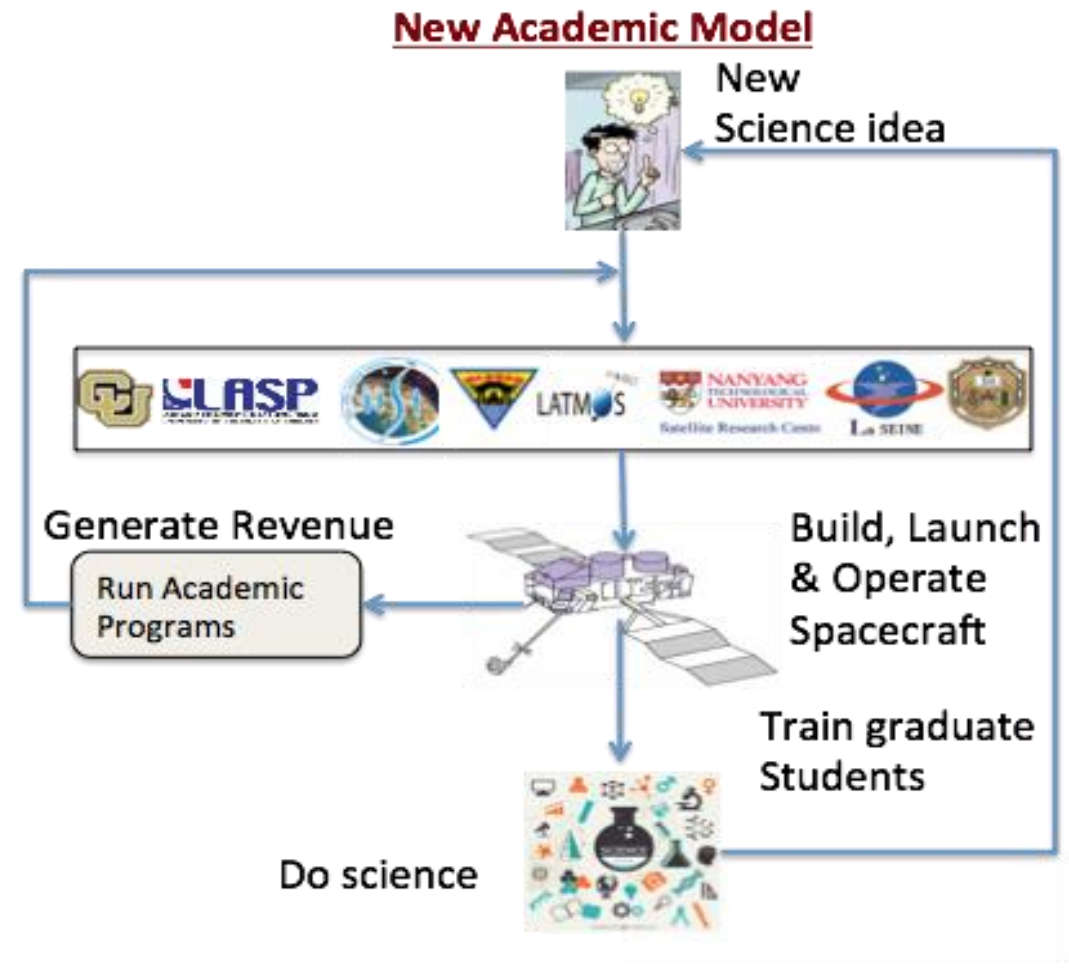
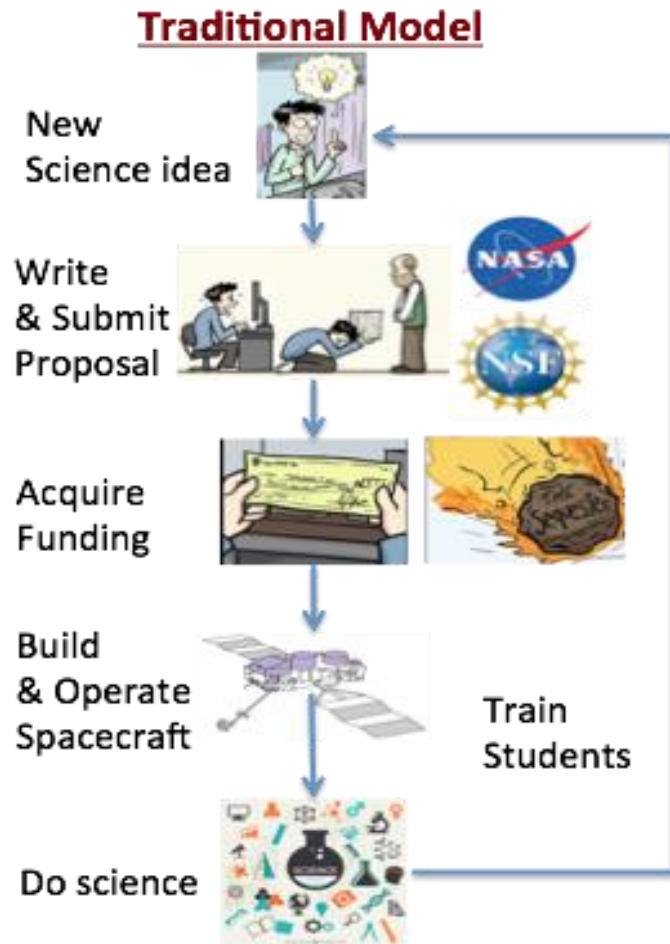
A partnership between **IIST (ISRO's flagship University)** and **CU Boulder (The largest NASA funded University)** has acted as a catalyst to form an international consortium of Universities doing research in space science and engineering. Under the INSPIRE Consortium, three launches are to be provided in 2019, 2021 and 2023 on board ISRO PSLV.

INSPIRESat-1 – Funded and built by **CU Boulder**, **IIST** and **NCU Taiwan** with support from NTU

INSPIRESat-2/IDEASSAT Funded by **National Space Organization of Taiwan (NSPO)**
Built by NCU Taiwan with support from CU Boulder and IIST

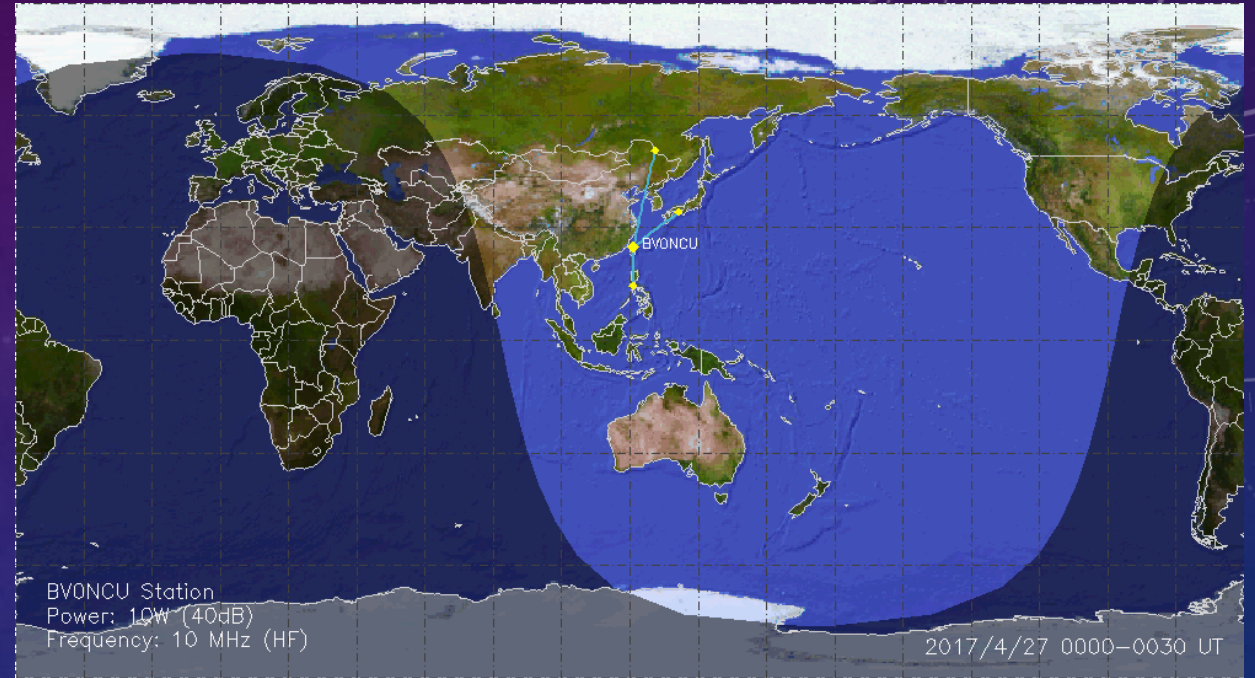
INSPIRESat-3 Funded by **NTU Singapore**
Built jointly by NTU, CU Boulder, IIST and NCU.

A new model for satellite development

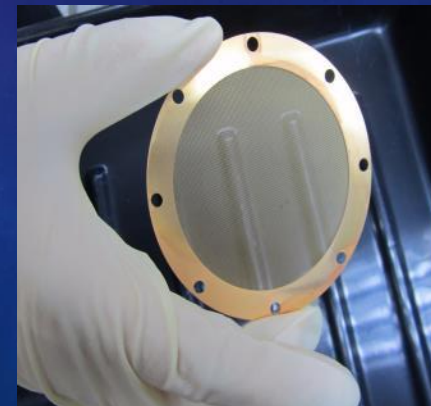
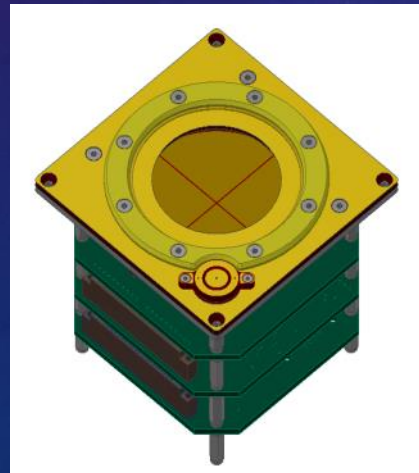
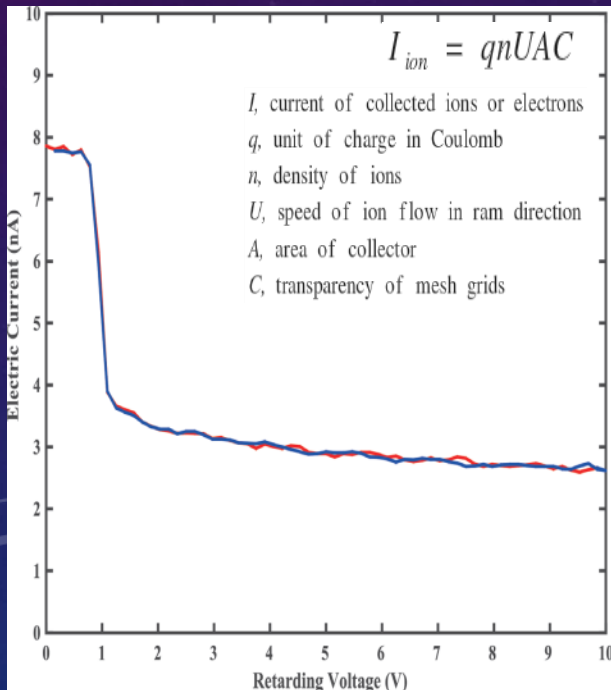


INSPIRESAT-1 SCIENCE OBJECTIVES

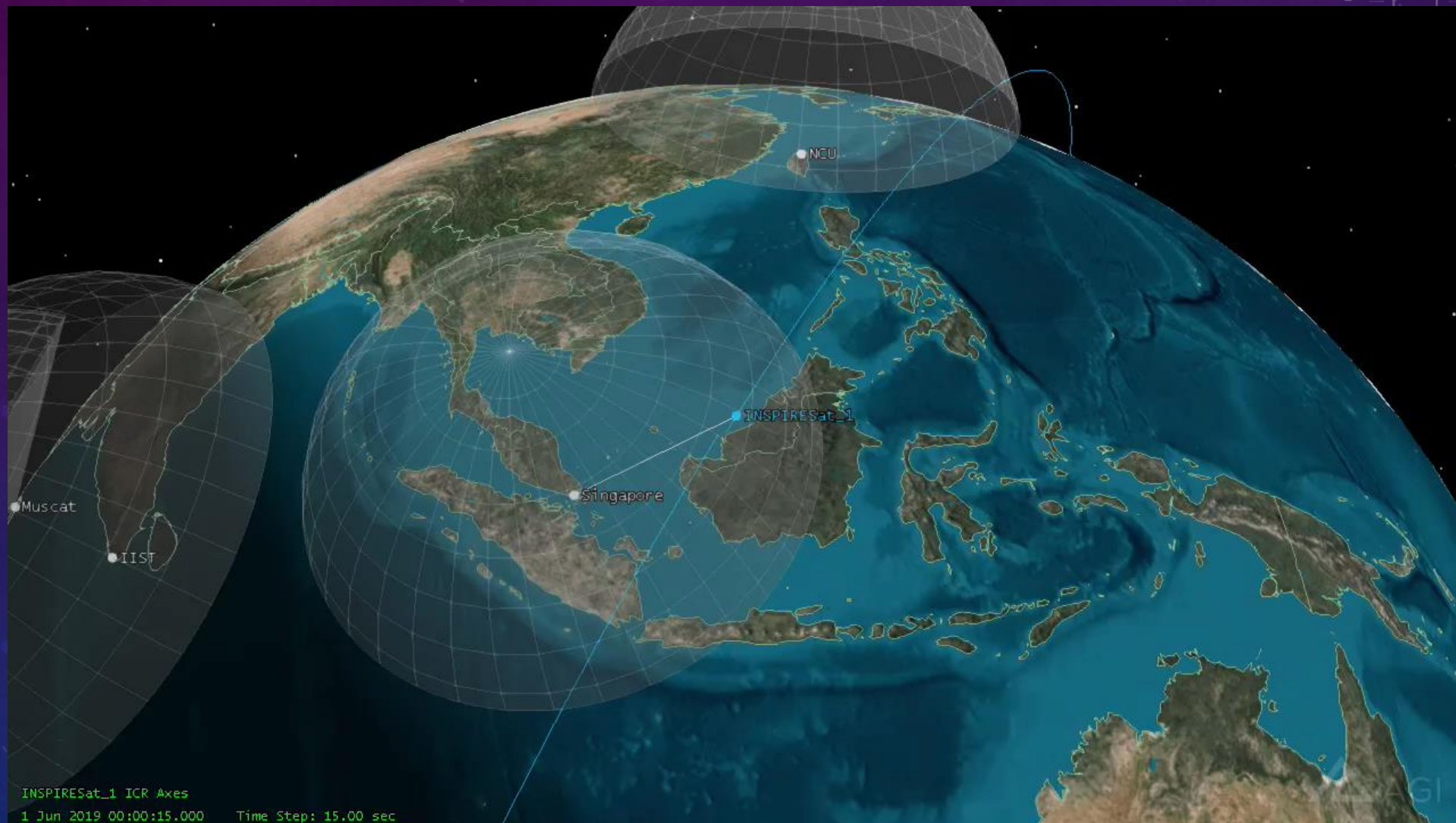
1. Observe occurrence and evolution of equatorial Plasma bubbles.
2. Observe Midnight Temperature Maximum features.
3. Observe Ion/electron temperatures, density and velocities



GIF courtesy of Chi-Ting Liao

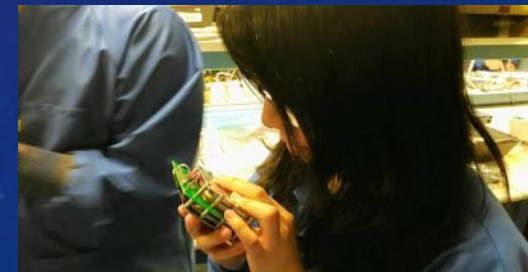


INSPIRESAT-1, IDEASSAT (INSPIRESAT-2) MISSION DESIGN

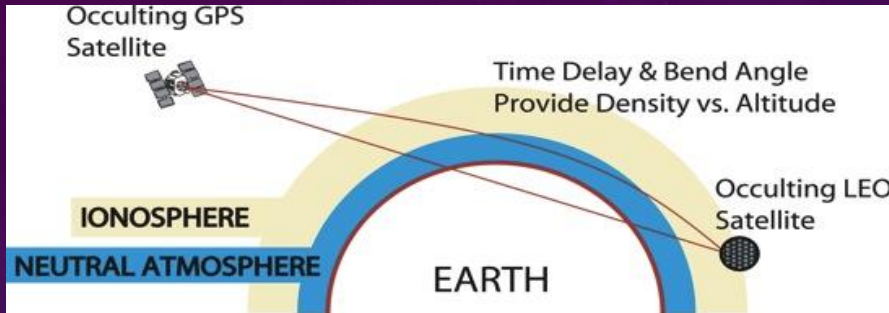


INSPIRE – BENEFITS TO NTU & SINGAPORE

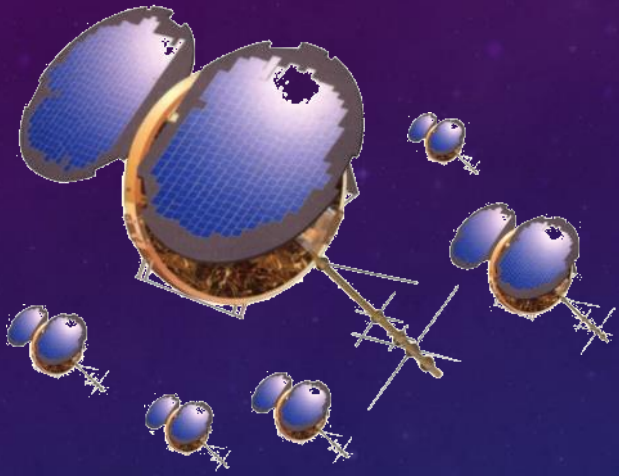
- Provides access to space for participating Universities
- Can be used to raise *Technology Readiness Level* of prototype technologies.
- Develops an innovative hardware oriented ‘hands-on’ curriculum for teaching spacecraft engineering and instrumentation.
- Distributing cost of a satellite mission among partners makes missions affordable.
- INSPIRE acts as a forum for bringing together students, engineers and scientists.
- Builds a collaborative attitude in future international space leaders.
- Helps to learn from best practices, shared knowledge and expertise
- Develop space data dissemination expertise.



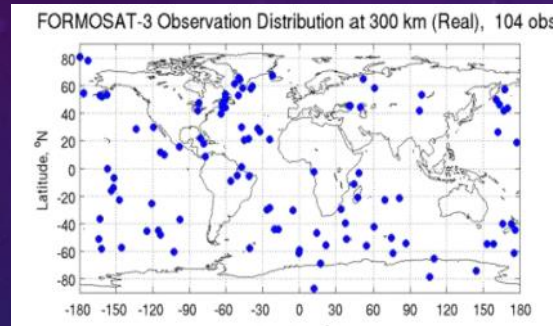
RADIO OCCULTATION



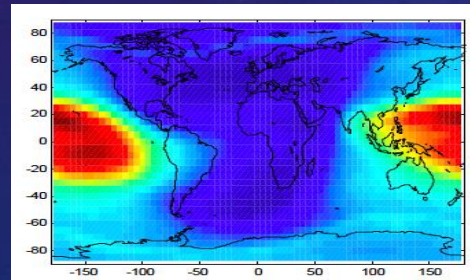
1. Total Electron Content Measurements
2. Vertical profiles of atmospheric temperature
3. Vertical profiles of water vapour.



COSMIC 1 & 2
416 kg satellite constellation that demonstrated the use of GPS RO for weather forecasting and use in data assimilation models

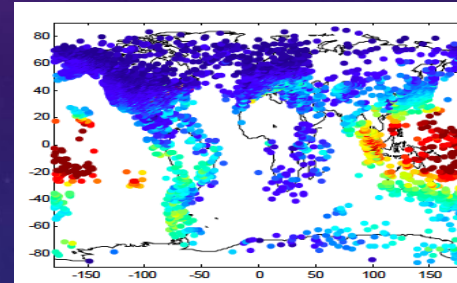


Background model

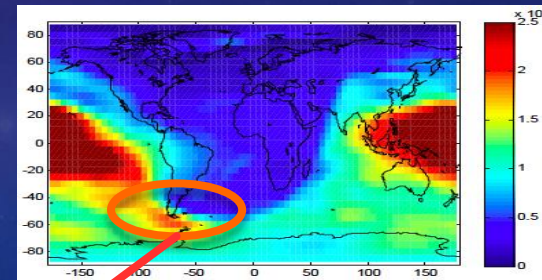


Electron density structure missed in the background model

Ground based TEC

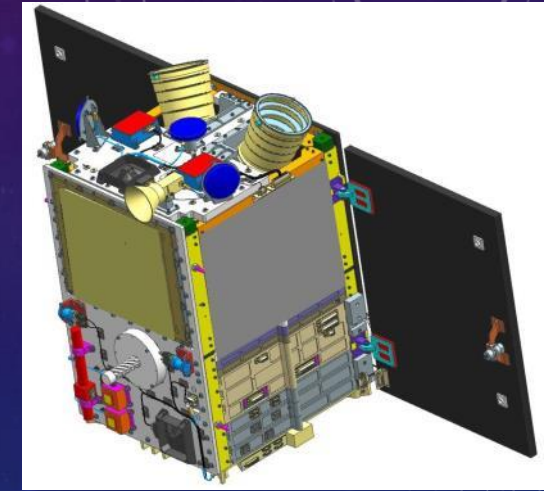
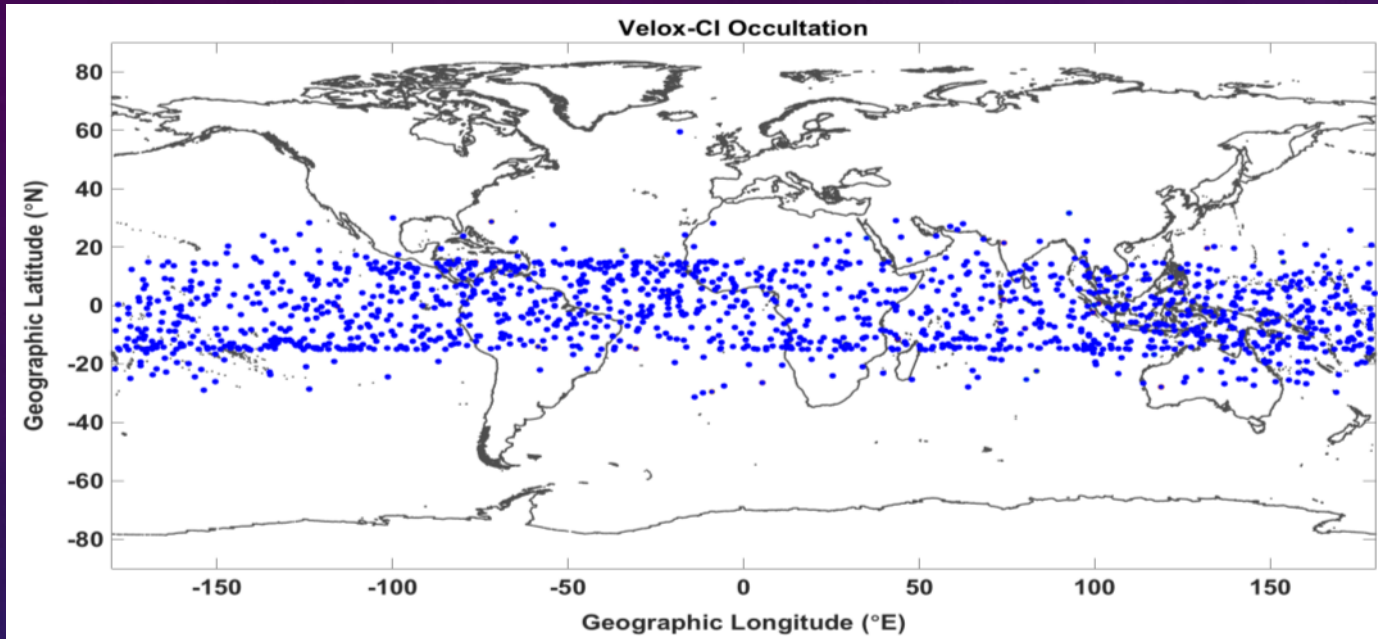


Data Assimilation



Lemur-2 from SPIRE
4 kg 3U cubesat. A constellation of SPIRE satellites are expected to provide commercial weather data

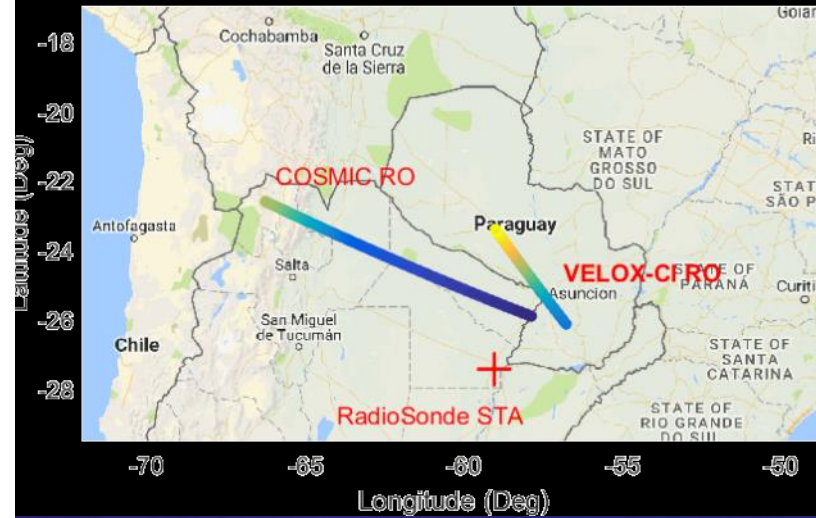
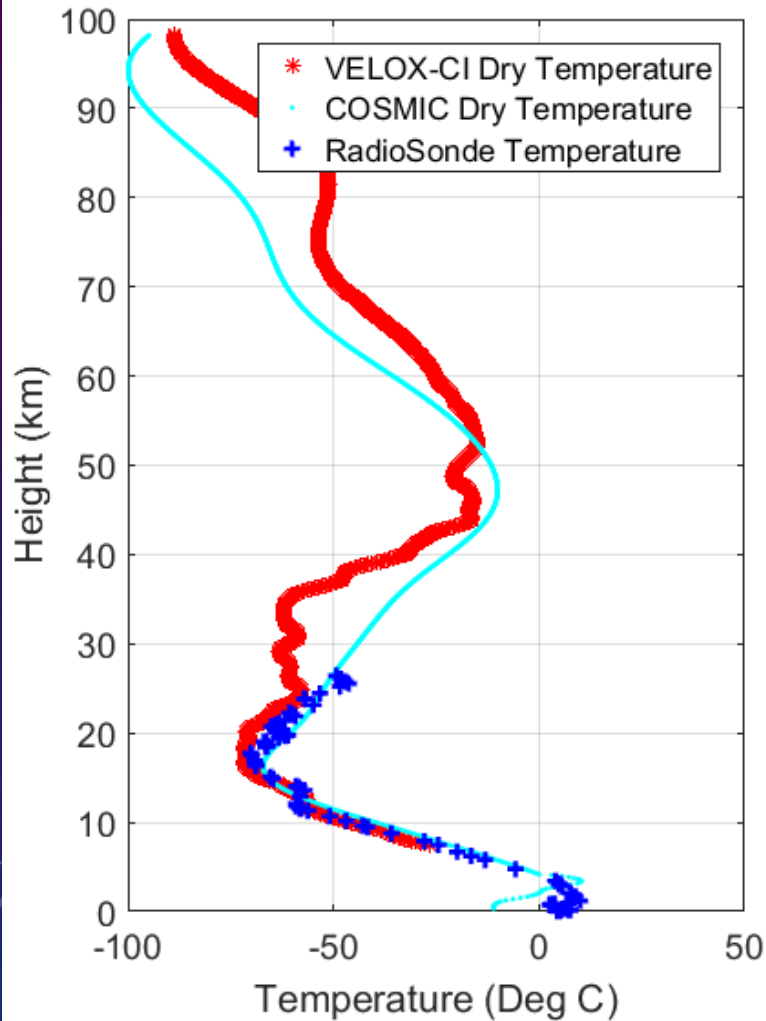
RO EXPERIENCE AT SARC



- Total mission data collected **2.48 GB**.
- **194** missions which covered **340** orbits.
- Map showing over **1,600** radio occultation events.

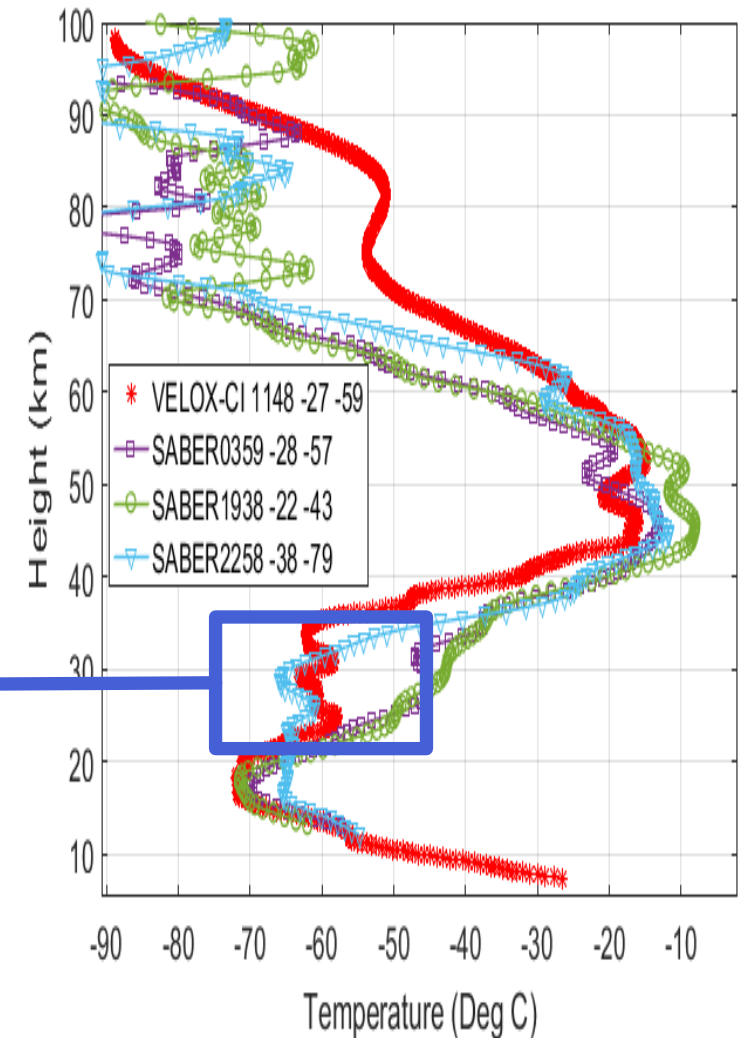
VELOX-CI RO PERFORMANCE

Courtesy of Dr. Bingxuan Li



Indications of possible Gravity Wave activity

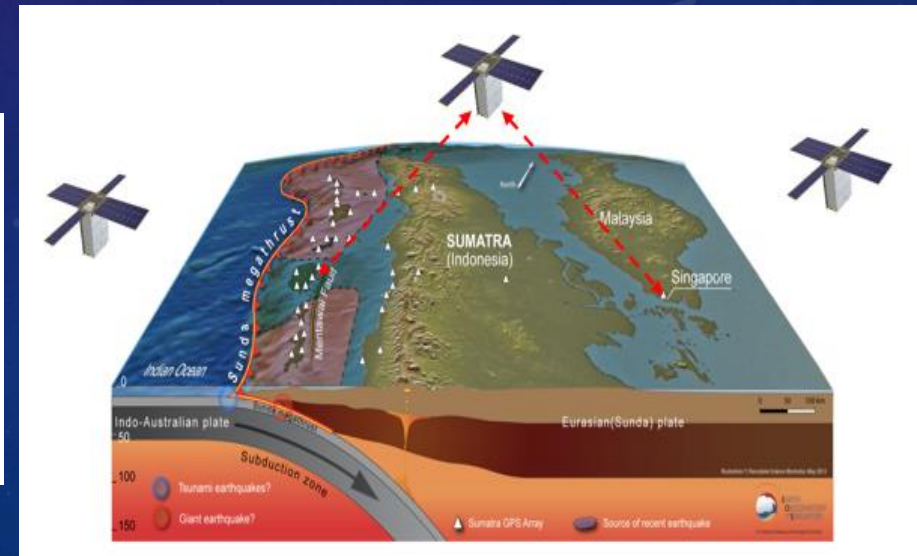
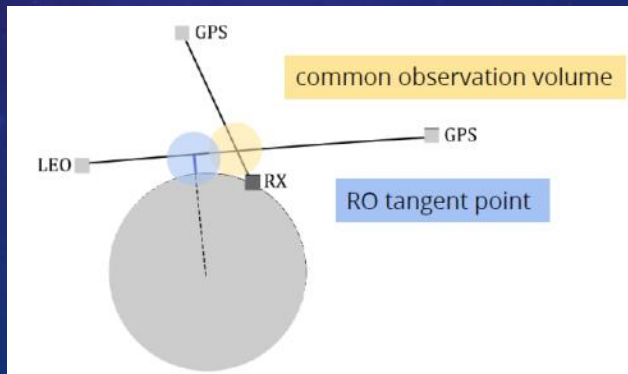
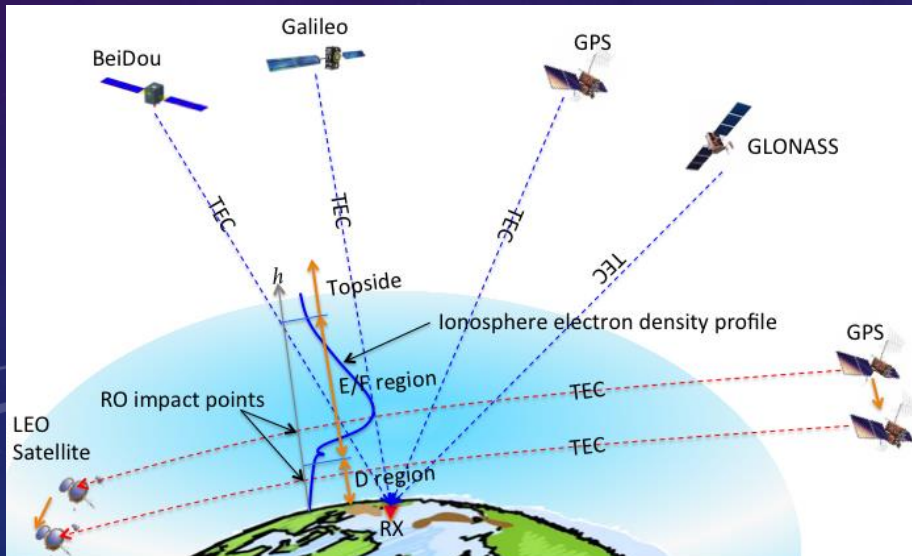
Comparison with SABER instrument on-board NASA TIMED satellite



REGIONAL IONOSPHERIC MAPPING AND AUTONOMOUS UPLINK (RIMAU) CONSTELLATION

- RIMAU is proposed to be an equatorial constellation carrying the compact ionosphere probe and a GPS radio occultation payload.
- RIMAU-Sat-1 can demonstrate common volume TEC measurements with ground based GPS receivers.
- CIP will provide information of fine-scale ionospheric structure. A constellation (8 satellites) can provide continuous common volume measurements and provide an unprecedented opportunity to map the ionosphere regionally.

(More ground based receivers/occultation points → higher resolution mapping)



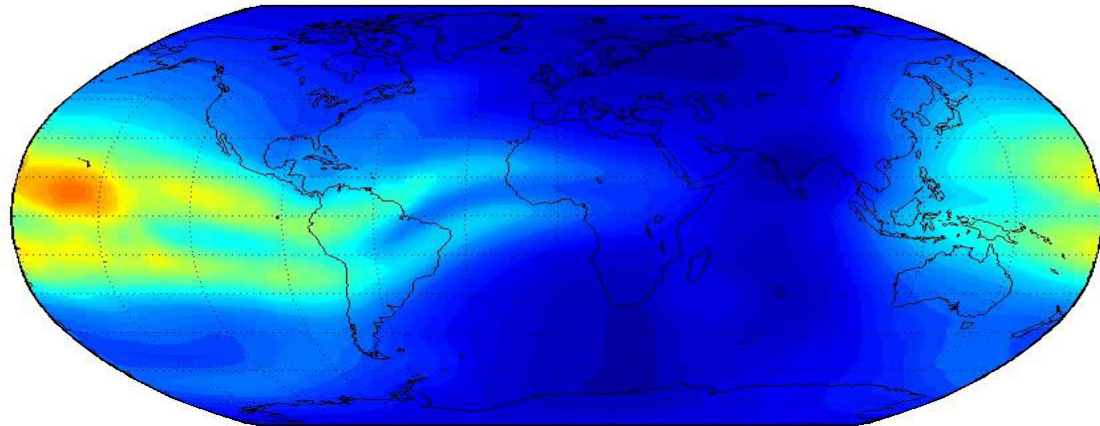
Ionosphere Weather and Irregularity

Solar and Geomagnetic Activities

(solar radiation, high-latitude E , *aurora*, *joule heating*)

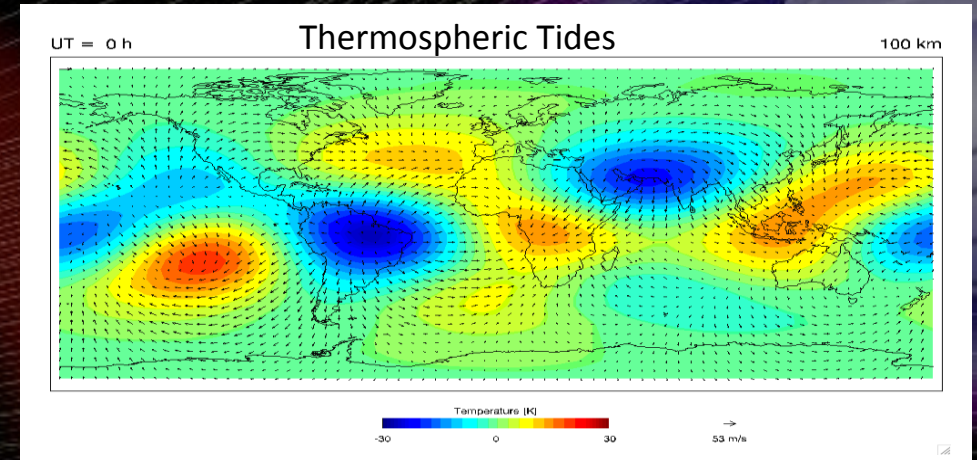


Assimilation 2013 072 00:0
Min: 2.7113 Max: 77.1236



Lower Atmospheric Perturbations

(thermospheric tides, planetary waves, gravity waves)



The Way Forward in Singapore

– Understand ionosphere weather and plasma irregularity

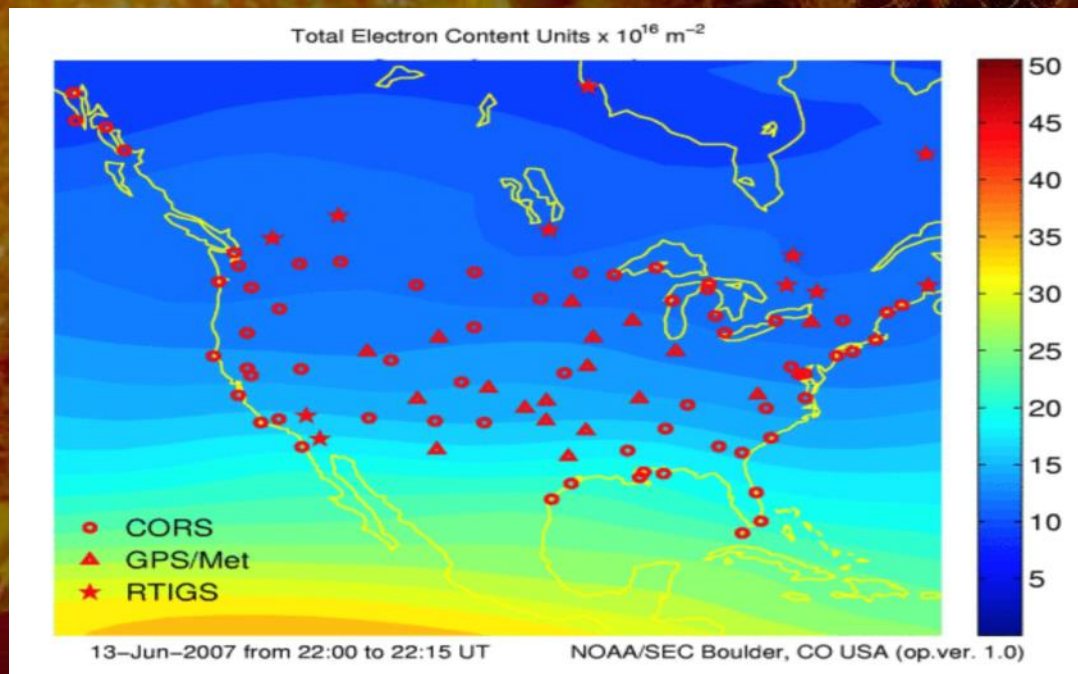
– Numerical Modeling and Observational System

- Nowcast Capability

- Combine available satellites and ground-based instruments

- Ground/LEO Common Volume

- South-East Asia TEC Map through Data-assimilation



US-TEC by NOAA-SWPC

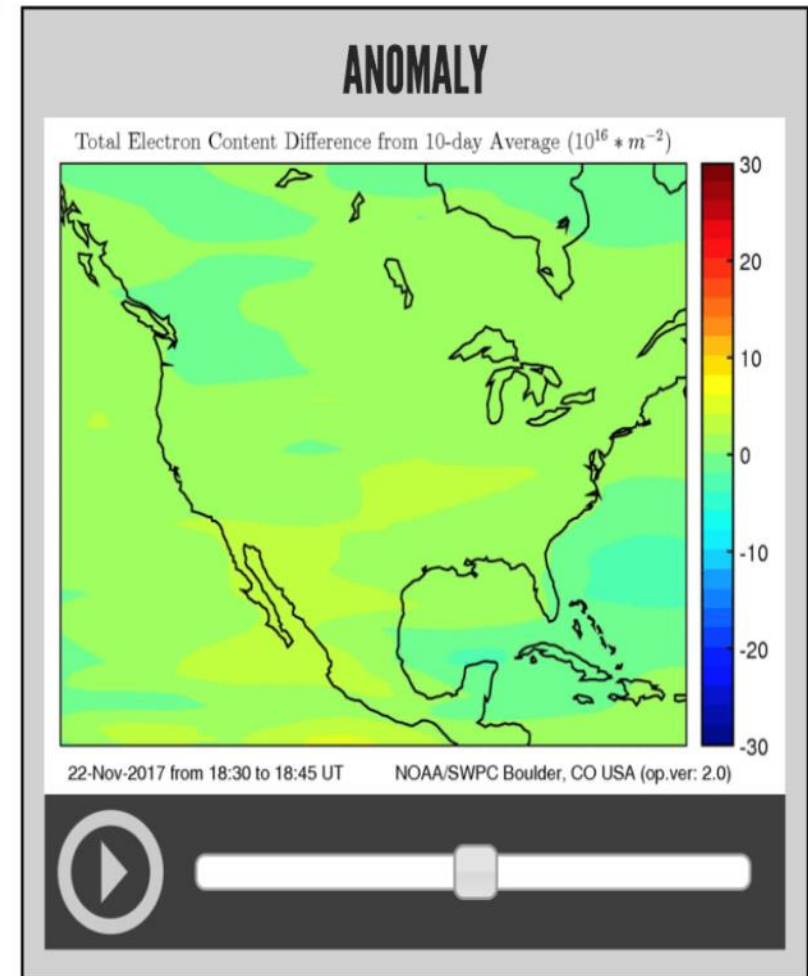
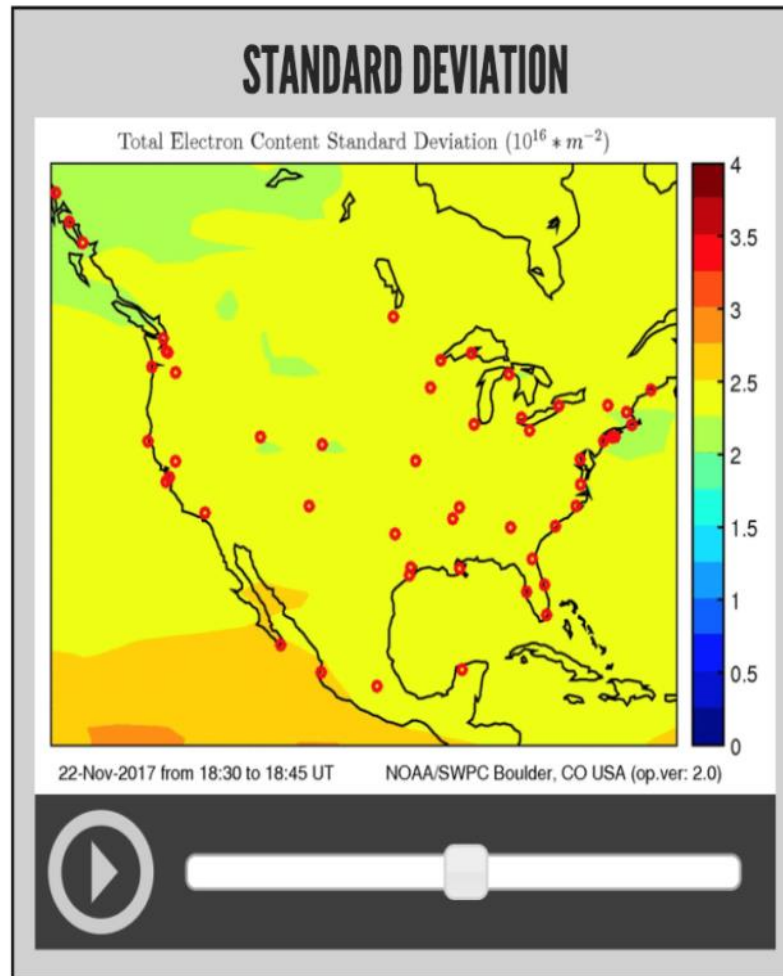
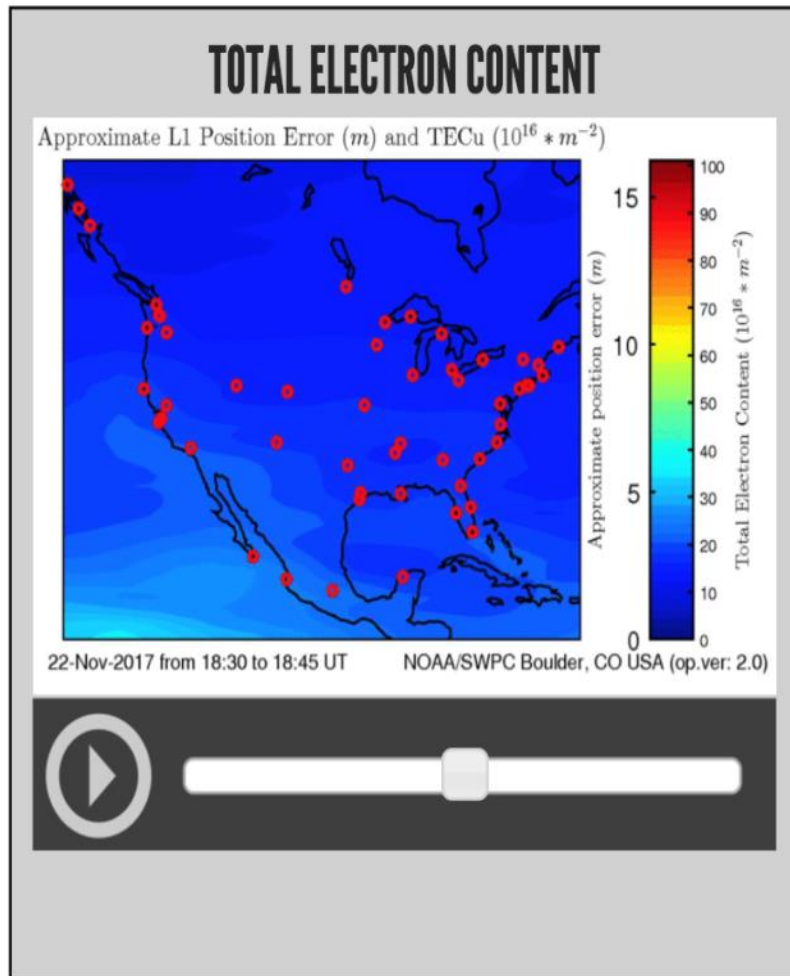
- Positioning and Navigation community
- Collaboration between SWPC, NGS, FSL, and NGDC
- Kalman filter over CONUS + ground-based GPS data, IRI background model, solve for receiver biases
- 15-minute cadence with 15 to 30 minute latency
- 2 - 3 TEC unit accuracy ($\sim 34 - 48$ cm delay at L1 frequencies)

Available GPS Ground Stations at the Neighborhood

1. International GNSS Service (IGS) Network

U.S. TOTAL ELECTRON CONTENT

<http://www.swpc.noaa.gov/products/us-total-electron-content>



3. Asia Oceania Space Weather Alliance (AOSWA) – LAPAN and other universities

Role of SaRC in Singapore Space Sector

A self sustaining
Space Industry

- ❖ Interest middle and high schoolers in STEM

- ❖ Have them enroll in Engineering and Physics at Universities
- ❖ Develop a curriculum to be able to train students.

- ❖ Create an eco-system for students to be employed after graduation.

- ❖ Help the government craft policy to invest in space technologies and bring in space industry.
- ❖ Demonstrate societal and economic benefits to investing in space

- ❖ Act as incubators for space startups.
- ❖ Retain the trained workforce.

