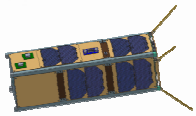
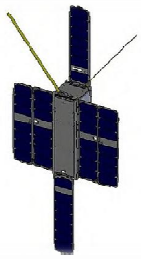
1st APSCO & ISSI-BJ Space Science School

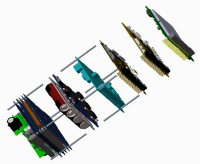


25th Oct 2016, Thailands

CubeSats: Tiny Satellite – A Big World



Prof Dr Shufan Wu
Shanghai Engineering Centre for Microsatellite
99 Haike Road, Pudong District
Shanghai 201203, China
shufan.wu@mail.sim.ac.cn



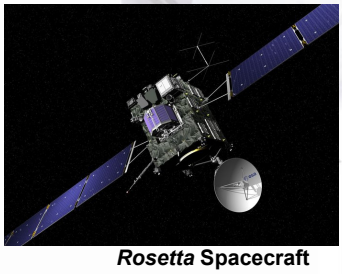
Outline

- *Satellite Development Trends: Smaller & Smaller*
- *CubeSat Technologies & Applications*
- *Space Business Set-ups with CubeSats*
- *SECM: Shanghai Engineering Centre for Microsatellites*
- *STU-2 mission: 3 CubeSats for multiple application*
- *Summary*

2014 top 10 Science Breakthroughs

http://www.technology.org/2014/12/19/journal-science-unveils-top-10-breakthroughs-2014/

The **Rosetta spacecraft** caught up with the comet known as 67P/Churyumov-Gerasimenko beyond Mars this August, and its preliminary results – along with the studies it will allow in the near-future–top this year's list of the most important scientific breakthroughs, according to the editors of *Science*



***Rosetta* Spacecraft**
(1900kg, 850W)

CubeSats: Although they've been blasted into space for more than a decade now, cheap satellites with sides that are just 10 centimeters squared, called CubeSats, really took off in 2014. Once considered educational tools for college students, these miniature satellites have started to do some real science, according to researchers.

***Philae* Spacecraft**
(100kg, 32W)

Developing Trends of Satellite

- **Development of small satellite**
  - ✓ Multi-functional **Minisat** (100-500kg) has been widely applied to high-requirement space mission
  - ✓ **MicroSat** (below 100kg) is beginning to play a very important role in high-requirement mission
  - ✓ **NanoSat** (<10kg represented by **CubeSat)** is opening a new revolution in space technology and industry

CubeSat Concept

- 1999: first proposed by professors from California State Polytechnical University and Stanford University
- 1U CubeSat : Volume:10×10×10cm^3, Mass <1.33 kg
- 2003: First CubeSat launched into orbit
- 2U/3U/6U/12U/… CubeSats
- 300+ CubeSats have been put into orbit worldwide
- 2014: CubeSats – one of the top 10 science breakthroughs in 2014

CubeSat: Tiny Satellite – Big World

Developing Trends of Satellite

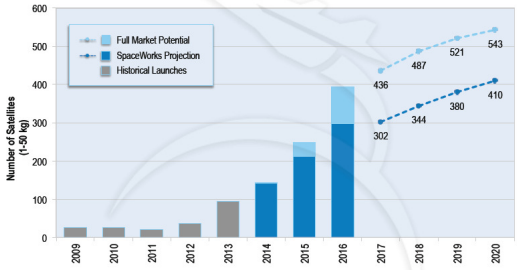
Cubesat Era

- ✓ Faster building time
- ✓ Lower cost of manufacture
- ✓ Easiness of mass production

- ✓ Ability to be launched in groups or 'piggyback'
- ✓ Minimal financial loss in case of failure

Nano/Microsatellite Launch History and Projection (1 - 50 kg)

Projections based on announced and future plans of developers and programs indicate between 2,000 and 2,750 nano/microsatellites will require a launch from 2014 through 2020

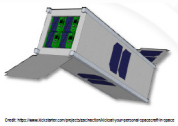


SpaceWorks *Released in **Feb 2014***

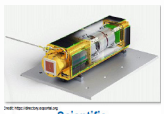
CubeSat is Changing the Economics of Space

Developing Trends of Satellite

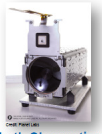
Technology
TechEdSat-4
Mass: 4 kg
Launched: 7/2014



Technology
KickSat-1
Mass: 5 kg
Launched: 4/2014

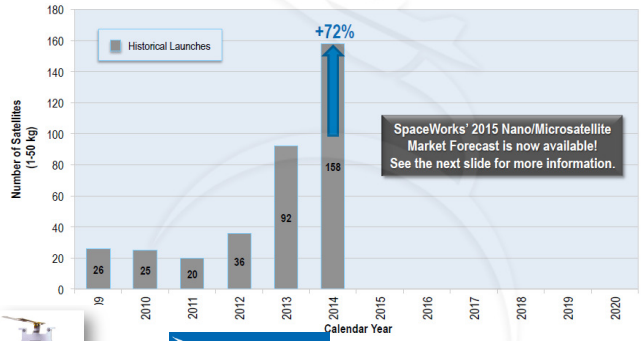


Scientific
SporeSat
Mass: 5 kg
Launched: 4/2014



Earth Observation
Flock-1b
Mass: 6 kg
Launched: 7/2014

The nano/microsatellite industry continues to thrive, with 158 satellites launched last year

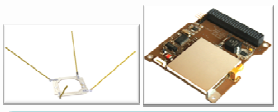


SpaceWorks *Released in Feb 2015*

2014 Updates

S. Wu, Oct 25th 2016, Thailand 7

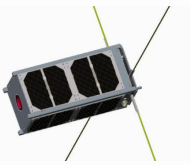
CubeSat Technology: Platform



NanoCom U482C half duplex UHF radio
GomSpace NanoCom ANT-1

AOCS
3-axis attitude stabilization & control

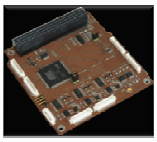
1 3-axis magnetometer
3 Magnetorquers
5 Coarse sun sensors
4 Fine sun sensors
3 Gyros
1 Y-axis momentum wheel
1 BD2/GPS dual mode receiver



TTC

platform

OBDH

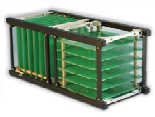


EPS

Structure

GomSpace NanoMind A712C

GomSpace P31US power supply system



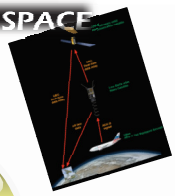
ISIS 2U cubesat structure

S. Wu, Oct 25th 2016, Thailand 8

CubeSat Technology: Payloads

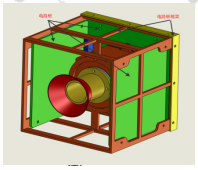
Gamalink

ADS-B

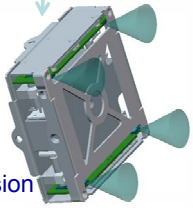


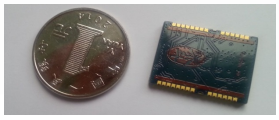
Optical Camera

Payloads



AIS





NANO SPACE

Cold-gas micro-propulsion

BD2/GPS dual mode GNSS

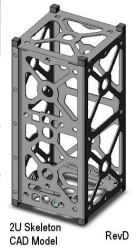
SATLAB

CubeSat Technology: Structure

Structure / Configuration:

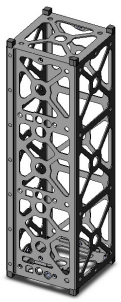
1U Skeleton CAD Model RevD

1U = 10x10x10 cm ~ 1KG
2U = 20x10x10 cm ~ 2KG
3U = 30x10x10 cm ~ 3KG
6U = 30x20x10 cm ~ 6KG
12U …

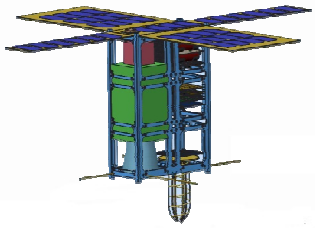


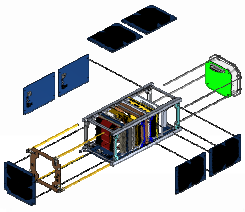
2U Skeleton CAD Model RevD

- PC104 stackable PCB are commonly used (90x96 mm boards)
- Sandwich of boards



3U Skeleton CAD Model RevD

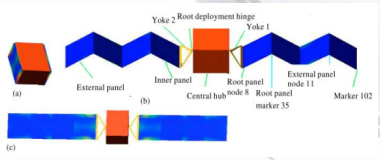


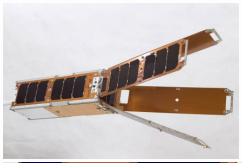


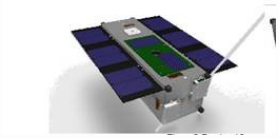
CubeSat Technology: Power (EPS)

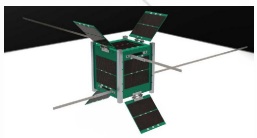
Deployable solar arrays (panels) can be purchased from

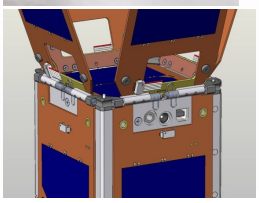
- ISIS (NL)
- Clyde Space (UK)
- Pumpkin (California, USA)



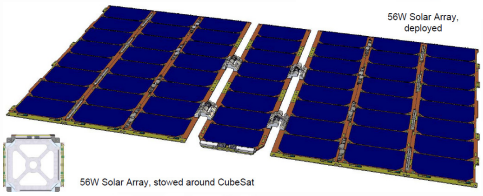








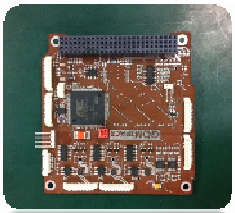
STRaND



56W Solar Array, deployed

56W Solar Array, stowed around CubeSat

CubeSat Technology: OBDH



CM-iTC

Computer-on-Module
75 x 65 x 8 mm

Atom E680 @1.6GHz	1000Mb Ethr*2
2GB DDR2	USB*6, COM*4
32GB microSD flash disk	HDA / Audio
SATA HDD interface	PCI Express
SDIO slot	GPIO, I2C, CANbus
RGB/LVDS/SDVO 1920x1080	0.2 to 7 watt

CM-T3730

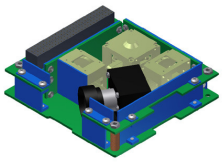
Computer-on-Module
66 x 44 x 7 mm

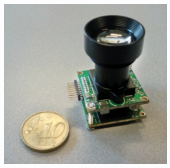
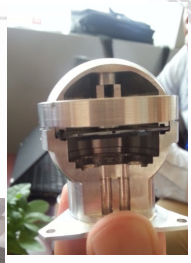
DM3730 @1000MHz	USB*3, COM*3
H.264, MPEG4 & WMV9 codecs	GPIO, SDIO/MMC
2D/3D hardware acceleration	WiFi & Bluetooth
64-256MB Mobile DDR	Audio mic & spkr
1-8 GB microSD flash disk	100Mb Ethr
TFT & STN LCD, PAL/NTSC TV	0.05 to 1.5 watt

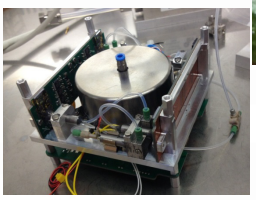
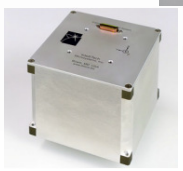
CubeSat Technology: AOCS

- Magnetometers
- Magnetorquers
- Wheels
- MEMS Gyro
- Accelerometers
- Sun Sensor
- Star Tracker
- GPS/BD Receiver
- Micro-Propulsion
- …





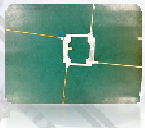




MAI-100, 200, 300, 400

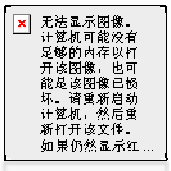
CubeSat Technology: TMTC

- UHF/VHF for TM/TC
- S-band for TC/TM/payload data downlink
- X-band for payload data downlink
- Dual bands solutions (e.g. VHF/UHF – UHF/VHF or UHF/S-Band) prevent demanding (mass and volume) Diplexer onboard
- Antennas: Patches and/or “tape measure”

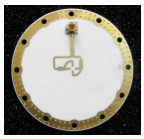


Microhard MXH S-Band on PCB designed to fit on CubeSat

10 cm

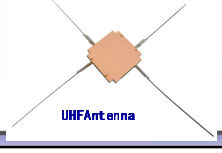


S-Band Transmitter



Patch Antenna

UHF Transmitter



UHFAntenna

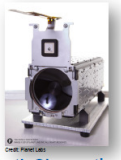
CubeSat Application

- The Important Way of Development for Engineering Training and Space Education
- The Important Platform of New Technology and New Concept Demonstration
- The Development of Hot Spots in the Field of Counter Space
- New Force of the Exploration for Tactical Application
- CubeSat has found Applications in all space sectors

CubeSat Application

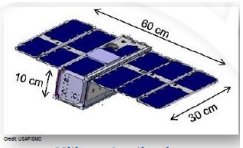
- Education
- Technology Demonstratio
- Earth Observation
- Science
- Communication
- Data Collection
- In-orbit Inspection/Servi
- Deep Space Exploration
- Military
- …

Education
ArduSat
Mass: 1 kg
Launched: 8/2013



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

Technology
SwampSat
Mass: 1.2 kg
Launched: 11/2013



Military Application
SENSE-1
Mass: 5 kg
Launched: 11/2013

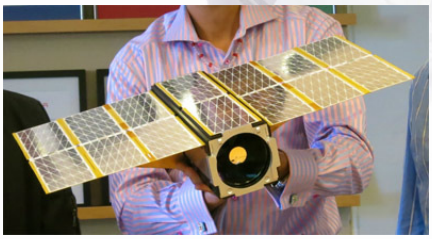
Scientific Research
Phonesat 1.0
Mass: 1 kg
Launched: 4/2013

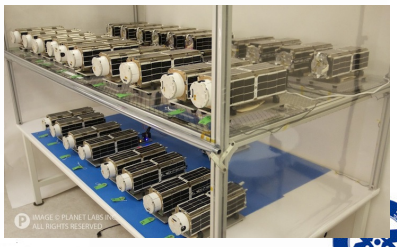
➔ **2014: CubeSats – one of the top 10 science breakthroughs in 2014**

CubeSat: Earth Observation

Planet Labs:

- 97 CubeSats launched by 2014, the largest quantity ever contributed by a commercial company
- 3U size (30x10x10 cm), ca 5 kg, provide a resolution of 3-5m Earth imagines, for commercial applications
- Targeting to be a constellation of few hundred satellites



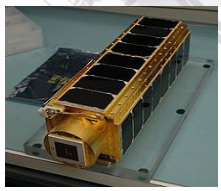


CubeSat: Sciences

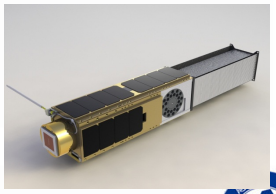
Microgravity/biology

- **GeneSat-1** (NASA Ames Research Center)
  3U CubeSat, launched on 16 December 2006 by a Minotaur I
  Payload: a bacteria growth experiment (E. coli (Escherichia))

- **PharmaSat** (NASA ARC)
  launched on 19 May 2009 by a Minotaur I
  Payload: an experiment to measure the influence of microgravity upon yeast resistance to an antifungal agent



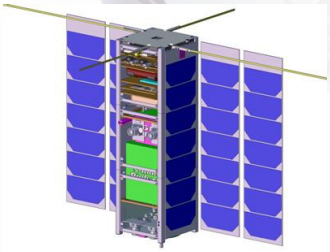
- **O/OREOS** (NASA ARC)
  launched on 19 November 2010
  by a Minotaur IV
  Payload: 2 experiments
  - to test how microorganisms survive and adapt to the stresses of space
  - to monitor the stability of organic molecules in space



CubeSat: ESA Ops-Sat mission

ESA: Ops-Sat, a 3U CubeSat for IOD of Operational software

- 3U CubeSat
- 600km SSO
- Incl: 97.8 deg



OPS-SAT Team at the end of the study

Space Mission Operations – Designing for the Future

23 February 2012

As the computational power available both on Earth and on spacecrafts is growing, new ways of operating space missions can be implemented. The European Space Operations Centre (ESOC) in Darmstadt (D) is working towards that goal by developing new procedures and innovative software applications, continuously enhancing Europe's capabilities and efficiency in space operations.

OPS-SAT is a small spacecraft designed by ESA CDF to provide a platform for in-orbit validation of these new concepts developed by ESOC. OPS-SAT will carry a number of experiments that will require a combination of changes to on-board and ground-software and will test

CubeSat – Solar Sail

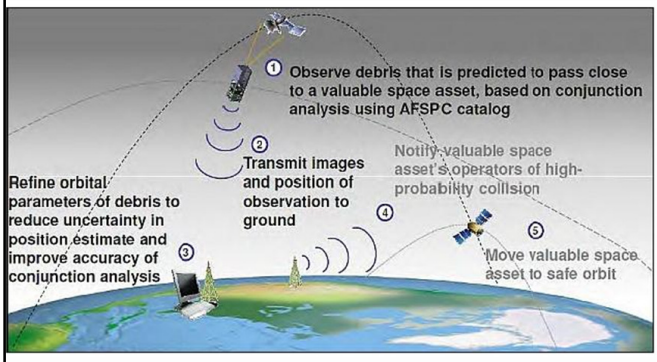
Small solar sail payload: NanoSail-D

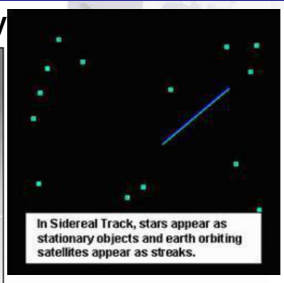
Micro sat-FASTSAT:	500 kg
Triple-CubeSat :	4kg
A solar sail developed area:	10m^2
Launch time:	2010 year

- ✓ The first time of nanosat launched by microsat
- ✓ Capability by using only the solar radiation pressure onto the sail as a propulsion means

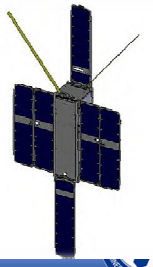
CubeSat - STARE

STARE: **Lowrence Livermore National Laboratory**





3U cubesat platform



The objectives of the program include: observer objects that are predicted to pass close to a valuable space asset based on conjunction analysis using the AFSPC (Air Force Space Command) catalog: transimt images and positions of observations to the ground.

CubeSat – US Airforce/Army

Civil | Military | Satellite Telecom | Earth Observation | Venture Space

05/11/10 12:00 PM ET

Air Force To Buy 2 Cubesats To Monitor Space Weather

By Turner Brinton

ShareThis

WASHINGTON — The U.S. Air Force in June plans to issue a request for proposals to deliver two fully integrated cubesats for monitoring environmental conditions in space, according to a May 10 posting on the Federal Business Opportunities website.

The Air Force Space and Missile Systems Center, Los Angeles, will be seeking a contractor to design, build, test and deliver two experimental satellites with Space Environmental Monitoring payloads, the posting said. Cubesats are standardized satellite platforms that measure 10 centimeters on a side and weigh about a kilogram. The term is sometimes used to describe the so-called 3U variant that is the size of three 10-centimeter cubes connected end to end.

The service plans to issue a draft request for proposals May 25, the posting said. In a November request for information, the Air Force said the satellites would be required to fly at an altitude of 400 kilometers for a one-year mission and deorbit within five years.

Civil | Military | Satellite Telecom | Earth Observation | Venture Spa

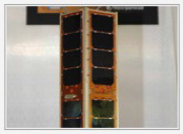
Mon, 9 August, 2010

U.S. Army Poised To Return to Satellite Operating Business

By Turner Brinton

ShareThis

WASHINGTON — After a 50-year hiatus from satellite development, the U.S. Army has gotten back in the game with plans to launch several tiny satellites this September and next fall that will demonstrate communications and remote sensing capabilities, a service official said.



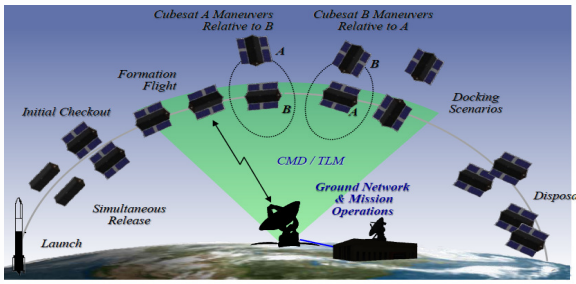
SMDC-ONE technology demonstrator. Credit: U.S. Army SMDC photo by John Cum

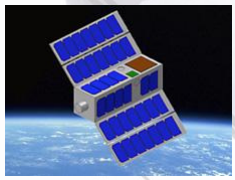
Enlarge Image

Enabled by electronics technology advances that allow more capability to be crammed into ever-smaller packages, the Army envisions one day building and operating its own satellites to support forces in the field, said John London, director of nanosatellite technology programs at Army Space

CubeSat Application - CPOD

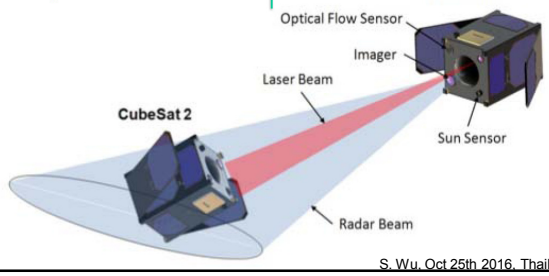
NASA Cubesat Proximity Operations Demonstration (CPOD)

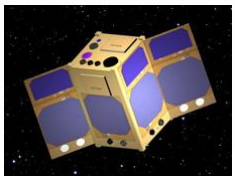




3U cubesat platform

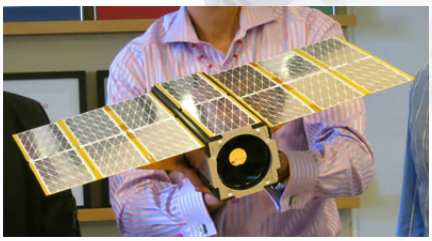
Optical communication and sensor demonstration



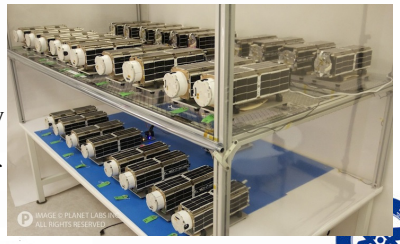


1.5U cubesat platform

CubeSat - Planet Labs



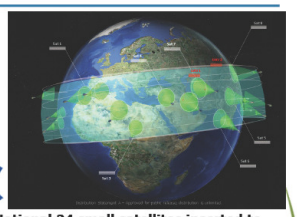
Flock-1:28 constellation of satellites, launch from the international space station. Each satellite is only (30 x 10x 10 cm), their image resolution is 3 to 5 meters. “Flock -1”satellites will capture imagery of Earth for use in humanitarian, environmental and commercial applications.



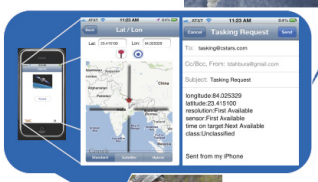
Minosat Application – SeeMe

SeeM

DARPA SeeMe goal: To enable mobile individual US warfighters access to on-demand relevant space-based tactical information



Notional 24 small satellites inserted to LEO, +/-10 deg latitude with goal of <90 min revisit



SeeMe constructs:

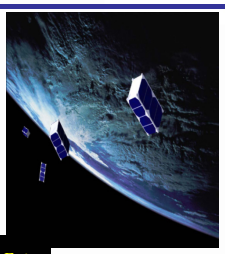
COTS-based, production capable, low-cost satellite bus.
+
Non-traditional high-performance membranes and apertures.
+
Aircraft-like rapid launch systems and logistics.

NIIRS 5.5 level imagery to of US military in the field

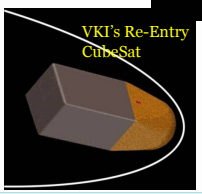
Fast Response Ability

CubeSat Constellation: QB50

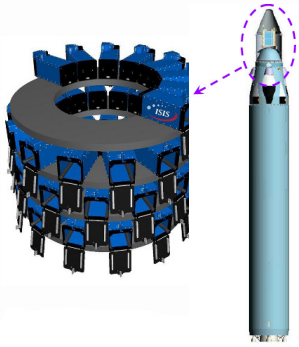
QB50 Project: 2012 launched by Von Karmen Institute, founded by EU FP7 Frame work

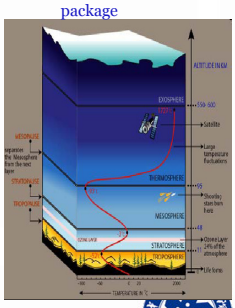


Gossamer-1 Solar Sail demonstration package



VKI's Re-Entry CubeSat



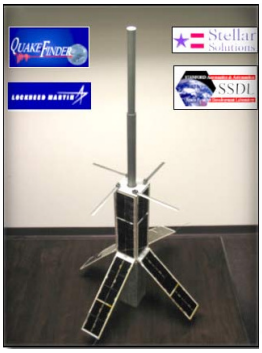


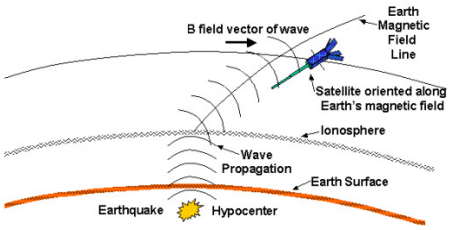
With 50 2U & 3U CubeSats, to perform in-orbit, multi-point, in-situ Earth atmosphere measurements at 90-320km level

QuakeSat 1 – 4.5kg NanoSat for Earthquake Detection

QuakeSat 1 – 3U CubeSat for Earthquake Detection

- 3U，4.5kg
- near polar orbit 700-900 kilometers
- Lifetime: 1 year (planned), 1.5 years (reached)
- Sensor: single axis, search coil type magnetometer with multiple frequency bands, detecting extremely low frequency electromagnetic (ELF) waves





QuakeSat-1 successufly demonstrated the detection of ELF waves from earth quakes.

Space Business Set-Ups

Since 2010，in Silicon Valley, many SME have emerged in Space business, focusing mainly on NanoSat/CubeSat technologies and their applications

- www.nanoracks.com
- http://planet-labs.com
- http://www.skyboximaging.com
- http://www.nanosatisfi.com
- http://www.dauriaspace.com

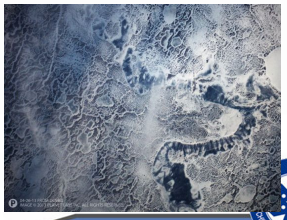
Similarly, SEMs are also emerging in Europe, dedicated to CubeSat/NanoSat business:

- **GOMSpace（2012, DM）**
- **ISIS（2012, NL）**
- **Clyde Space（UK）**
- **Berlin Space Technologies（DE）**
- **Tekever SPACE（PT）**
- **NanoSpace（Sweden）**
- ……

Space Business: Planet Labs

- In 2010 — Start up by 3 physicians from the NASA Ames Research Center, aiming to provide cheap Earth imagines with low cost NanoSat technologies
- 3U CubeSats: size ca 10cm x 10cm x 30cm，mass ca 5kg，imagine resolution 3-5 meter
- 2013: Two experimental CubeSat Dove-1/2 launched in April , Dove-3/4 in November
- 2014: totally 93 launched, and 26 were lost by the Antares failure in Oct 28th 2014
- In just nine days, Planet Labs built and delivered 2 satellites to be on-board the SpaceX CRS-5 launch campaign, which replicated the 26 lost CubeSats.

Planet Labs联合创始人，克里斯(ChrisBoshuizen)、辛德勒(schingler)、以及马歇尔(Marshall)



Space Business: GOMSpace

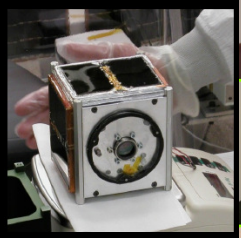
GOMSPACE • Founded by 3 young graduates from AAU-CubeSat

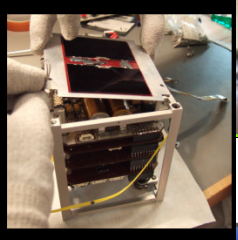
GomSpace Short History

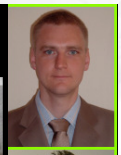
University spin-off
- Based on research from Aalborg University 2001-2007
- Founded in September 2007
- A Danish private limited company

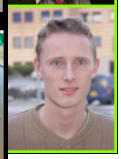
Based on experience with small satellites
- AAU-Cubesat flown in 2003 (top figure)
  - One of the first Cubesats to fly
  - Camera mission
  - Reference project for many university missions since
- AAUSAT-II launched in 2008 (bottom figure)
  - Gamma ray detector payload
  - Still operating

Company focus areas
- Subsystems for nano-satellites
- Complete nano-satellite platform solutions
- Novel applications of nano-satellites
- Consulting work with domain relevance



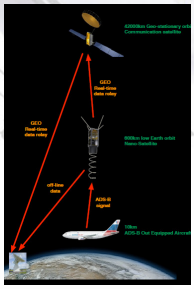






Space Business: GOMSpace

• Fast development: from 6 staff in 2012 to 20+ full-time staffs currently



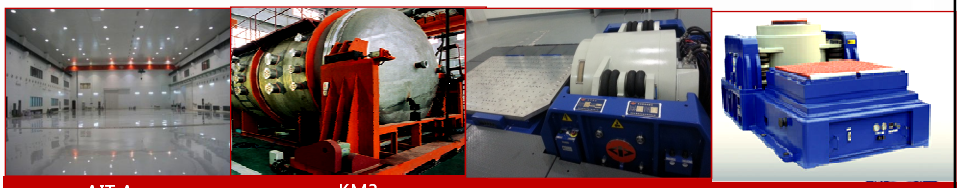
CubeSat Space Business in China

- No CubeSat has been launched in China before Sept 2015
- QB50 project triggered the CubeSat technology
- The government has decided to open the space sector to private investment for civil space application (the National congress meeting)
- NanoSat and CubeSat become very active in several universities and companies in China
- So far, very few private SME dedicated to NanoSat and CubeSat have been founded
- Market is huge, Entrance threshold is low for CubeSat/NanoSat, Policy is open for private space investment Science
- In Sept 2015 China has seen the first bunch of CubeSats to be launched into Space -- 1 CubeSat on LM-6 & 3 CubeSats on LM-11…

SECM: Shanghai Engi Centre for MicroSat

- **SECM was founded on Sep.15, 2003**
  - Founded by Chinese Academy of Sciences (CAS) and Shanghai City Government
  - To build a technical platform and innovation base for micro/small satellites

- **Located in Pudong of Shanghai**
  - ✓ Offices: ~ 15,000 m²
  - ✓ AIT area: ~12,000 m²
- **Able to manufacture 20+ satellites simultaneously**



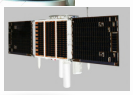
AIT Area | KM3 | 20T Vibration table | 10T Vibration table

SECM: Mission Accomplished

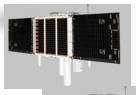
Commni-cationu | Micro/Nano Satellite | Navigation

2003 · CX-1(01)

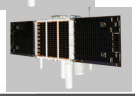
2008 · CX-1(02)



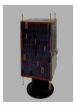
2011 · CX-1(03)



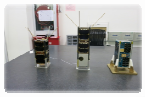
2014 · CX-1(04)



2008 · BX-1



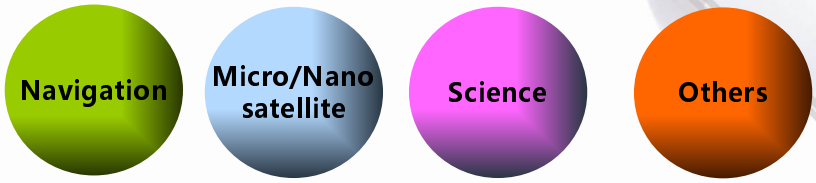
2015 · STU-2 (TW-1) 3 CubeSats



2015 · Nav-1

Over past 10 years, SECM has launched into orbit 9+ micro/small satellites, accumulated 30+ orbit-year of satellite operation.

SECM Missions Ongoing



Nav-1 (2015) [ca.900kg]
Nav-2 (2016)

BX-2 (2016) [50kg]
STU-1 (2U CubeSat)
SoftwareSat (3U)

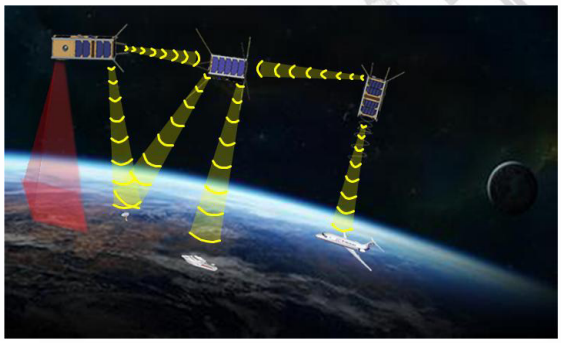
TanSAT(2016, 600kg)
DMaHS(2016, 1800kg)
QUESS (2016, 500kg)
SVOM (2021, 950kg)
……

STU-2 Mission Requirements

- Monitoring sea ice status in polar regions
- Gaining the maritime traffic information via AIS receiver
- Monitor civil aircraft traffic information via ADS-B receiver
- New technology demonstration & validation of Micro-propulsion, dual-band GPS-BD receiver, and Gamalink
- Demonstration of autonomous rendezvous (RVD) flight

STU-2 Mission Configuration

- 3 Cube Satellites to carry different payloads
- 2 Ground Stations (UHF band) in Shanghai and Nanjing of China
- 1 Data Receiving Station (S-band) in Shanghai
- Orbit: SSO, 480km, 8:00am
- Launch: Sept 25th 2015
  Jiuquan, China



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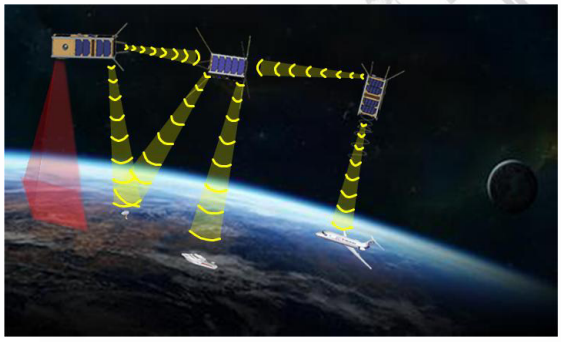
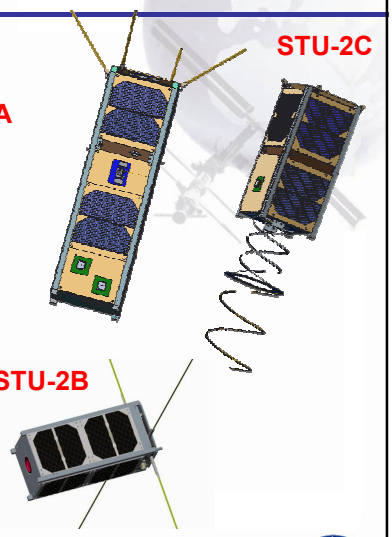


Satellites Configuration

- STU-2A: 3U CubeSat
  - ✓ Gamalink
  - ✓ Camera
  - ✓ GPS/BD Receiver
  - ✓ Micropropulsion
  - ✓ S-band transmitter
- STU-2B: 2U CubeSat
  - ✓ Gamalink
  - ✓ AIS receiver
  - ✓ GPS/BD receiver
- STU-2C: 2U CubeSat 1.9kg
  - ✓ ADS-B Receiver
  - ✓ GPS/BD receiver



Project Schedule

Phase A/B
1. Mission Analysis & Design
2. System design
3. SRR, PDR

Phase B/C
1. Procurements
2. Subsystem testing
3. Ground electrical testing
4 … …

AIT & Launch
1. AIT,
2. Testing
3. Launch campaign
4. LEOP & operation

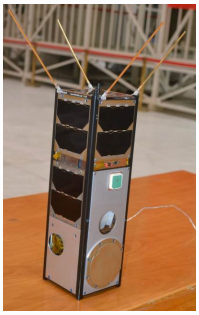
Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept

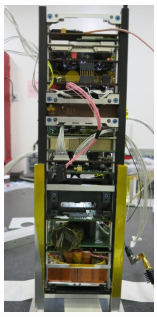
2014 2015

Earth Observation and Marine/Air Traffic Monitoring with a Multiple CubeSat Constellation

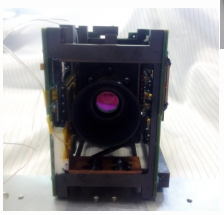
STU-2A CubeSat

Body mounting solar panel, 3-axis attitude stabilization and control based on momentum wheels and star tracker, UHF TT&C, and S-band transmitter. ……

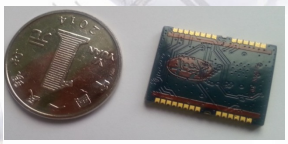




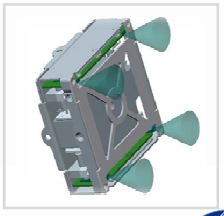
STU-2A:
2.9kg/2.9W



Camera

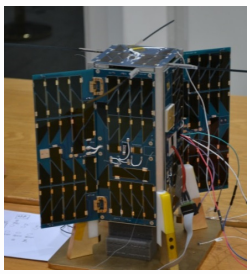


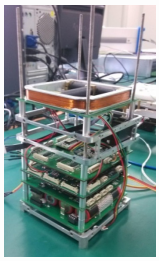
BD/GPS



Propulsion

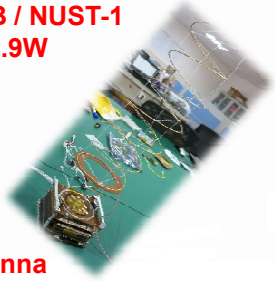
STU-2B/2C CubeSats





STU-2B / NUST-1
2.2kg/2.9W

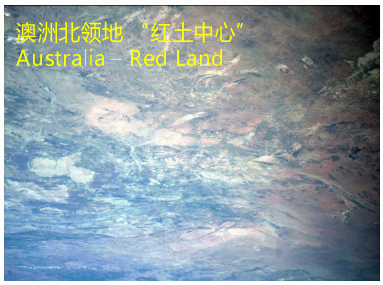
AIS Receiver

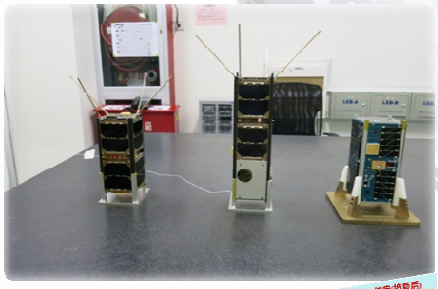


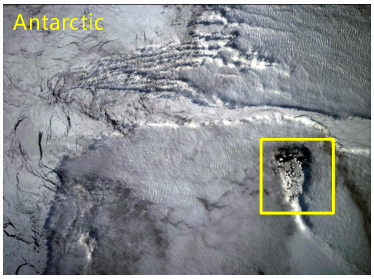
ADS-B Antenna

STU-2C:
1.9kg/2W

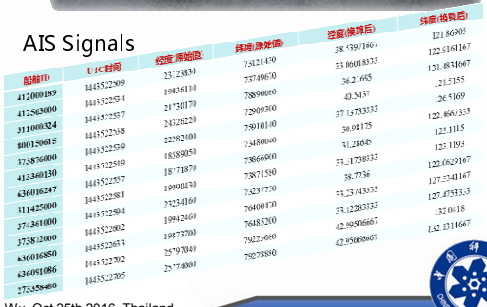
Preliminary In-Orbit Results





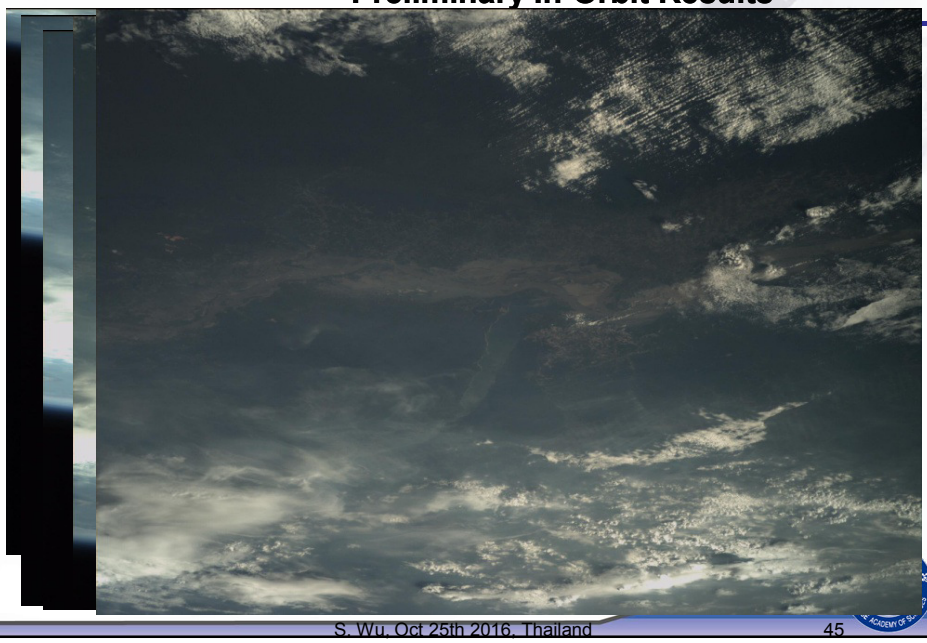


AIS Signals



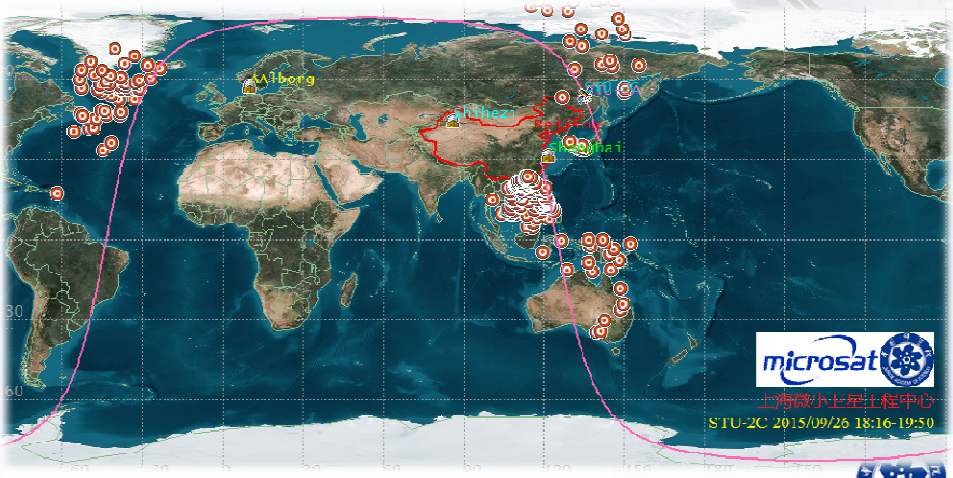
Preliminary In-Orbit Results

Preliminary In-Orbit Results



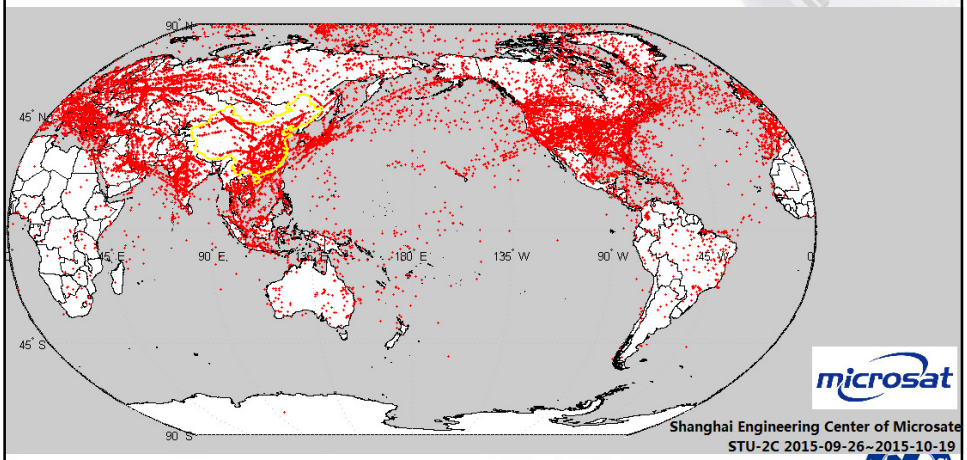
Preliminary In-Orbit Results

On Sept 26th, within one orbit, ADS-B collected >51k signals from ADS-B



Preliminary In-Orbit Results

ADS-B Received Data from Sept 26, till Oct 19 2015, STU-2C has collected multi-millions signals from 17455 aircraft, see their distribution



Summary

- CubeSats: Tiny Satellite – a Big World
- CubeSats: A good basis for Space Technology R&D/IOD
- CubeSats: Low threshold for Space Business
- CubeSats: Enter into all space application sectors
- CubeSats: promote Commercial space sectors
- CubeSats: Emerging many new companies and entrepreneurs

- ***SmallSat: has changed the Space Economics since 1980s***
- ***CubeSat: is a new wave to reshape Space Economics***
- ***Space is unlimited: the application market is huge***


Thanks!
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