



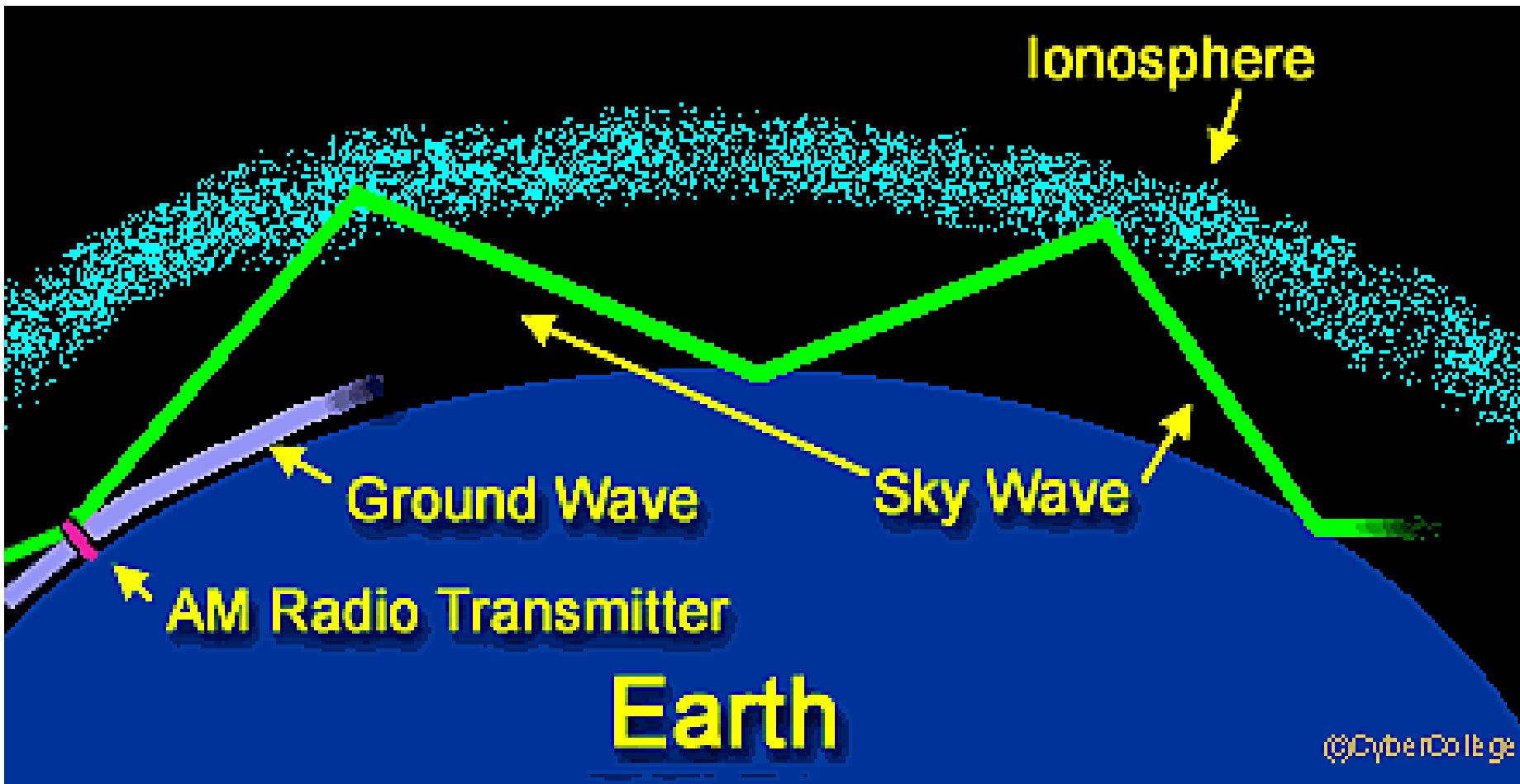
Canada - in Space

*Presented by
Don Kjosness, PhD
to*

*Engineering Student Society & EcoSat Program
University of Victoria*

July 6th, 2016

CANADA'S SPACE INTERESTS BEGAN WITH IONOSPHERIC STUDIES



Study of ionosphere critical to communications

Communications critical to Canada, particularly North

Aurora - visible indicator re communications performance

Shows status of earth's magnetosphere

FOUNDATION OF CANADA'S SPACE PROGRAM

Galileo named phenomenon "aurora borealis" after Roman goddess of morning; he thought luminescence due to reflected sunlight in atmosphere (17th century).

1839 - Sir Edward Sabine established **first magnetic observatory** (UofT) to study proposition by **Edmund Halley (1716)** that northern lights formed according to Earth's magnetic field.

Sabine first to determine magnetic disturbances occur worldwide, related to number/strength of sunspots.

1839 - Meteorological Service of Canada is set up, also at UofT.

CANADIAN SPACE PROGRAM DRIVERS

Canadian Space Program is ‘Driven by Needs’

Strong links between government, industry and universities

Strong export & international cooperation focus

Initial Drivers

Communications

Remote sensing

Many Innovations, including

Robotics

Optics

Advanced software

Advanced Science Instruments

Space-based Telescopes

Environmental monitoring

MAJOR CANADIAN FIRSTS

Distinguished history exploring space and developing scientific, commercial applications

3rd country to build & launch satellite

(Alouette 1 in 1962)

1st national domestic communications satellite network

(Telesat's Anik 1 in 1969)

1st high powered, direct broadcast satellite

(Hermes/CTS, 1976)

Robotics systems for Space Shuttle/Space Station

(Canada Arm (1982+))

Early adopter/developer of remote sensing satellites and technology

Landsat use starting in 1972

Designed & built Radarsat 1 & 2 (1995+)

CANADA'S WORLD-CLASS SPACE COMPANIES

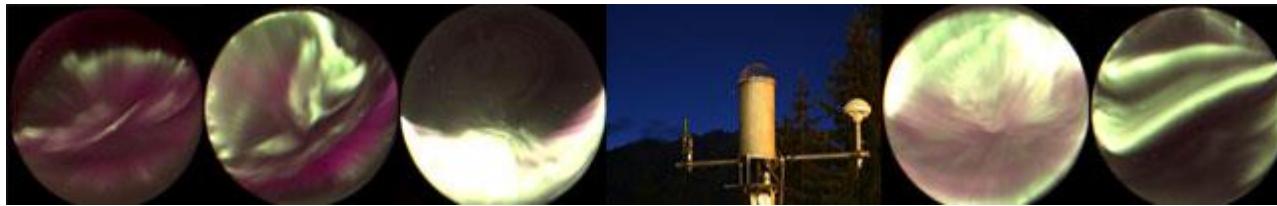
Developed world-class companies supplying Canadian/international customers
(Canada one of few countries who's companies export more than they sell domestically)

- **McDonald Detwiler & Associates (MDA; began @ UBC in late '60s)**
 - World leader in remote sensing & surveillance satellites and ground-based processing systems
 - Bought Canadarm from Spar Aerospace (Spar first Canadian prime contractor)
 - Developed and operated Radarsat 1 & 2
- **SED Systems (began @ UofS in 1965)**
 - Began with rocket and balloon upper atmospheric research
 - First ground-based, 3 axis real-time attitude control of civilian satellite in synchronous orbit
 - International supplier of satellite tracking, control and performance monitoring ground stations
 - Deep space tracking network for Rosetta/Philae lander which landed in 2015
- **COM DEV International (began in Cambridge Ontario, 1975)**
 - World leaders in space-qualified passive microwave equipment & optical subsystems
 - Equipment on over 950 satellites
- Many smaller firms also provide satellite systems and ground systems

CANADIAN SATELLITE PROGRAMS

	<i>Launched</i>	<i>Retired</i>	<i>Purpose</i>
Alouette 1	September 29, 1962	1972	Ionosphere research
Alouette 2	November 29, 1965	August 1, 1975	Ionosphere research
ISIS 1	January 30, 1969	1990	Ionosphere research
ISIS 2	April 1, 1971	1990	Ionosphere research
Hermes	January 17, 1976	November, 1979	Communications satellite
RADARSAT-1	November 4, 1995	March 29, 2013	Earth observation satellite
MOST	June 30, 2003	<i>In service</i>	Space telescope
SCISAT-1	August 12, 2003	<i>In service</i>	Earth observation satellite
RADARSAT-2	December 14, 2007	<i>In service</i>	Earth observation satellite
NEOSSat	February 25, 2013	<i>In service</i>	Monitoring of near-Earth objects
Sapphire	February 25, 2013	<i>In service</i>	Military space surveillance
BRITE	February 25, 2013	<i>In service</i>	Space telescope
CASSIOPE	September 29, 2013	<i>In service</i>	Ionosphere research, experimental telecommunications.
M3MSat	June 20, 2016	<i>Planned</i>	Communications satellite

EVOLUTION OF CANADA'S SPACE PROGRAM



Ground-based observations (now coordinated with satellites)



Sounding Rockets

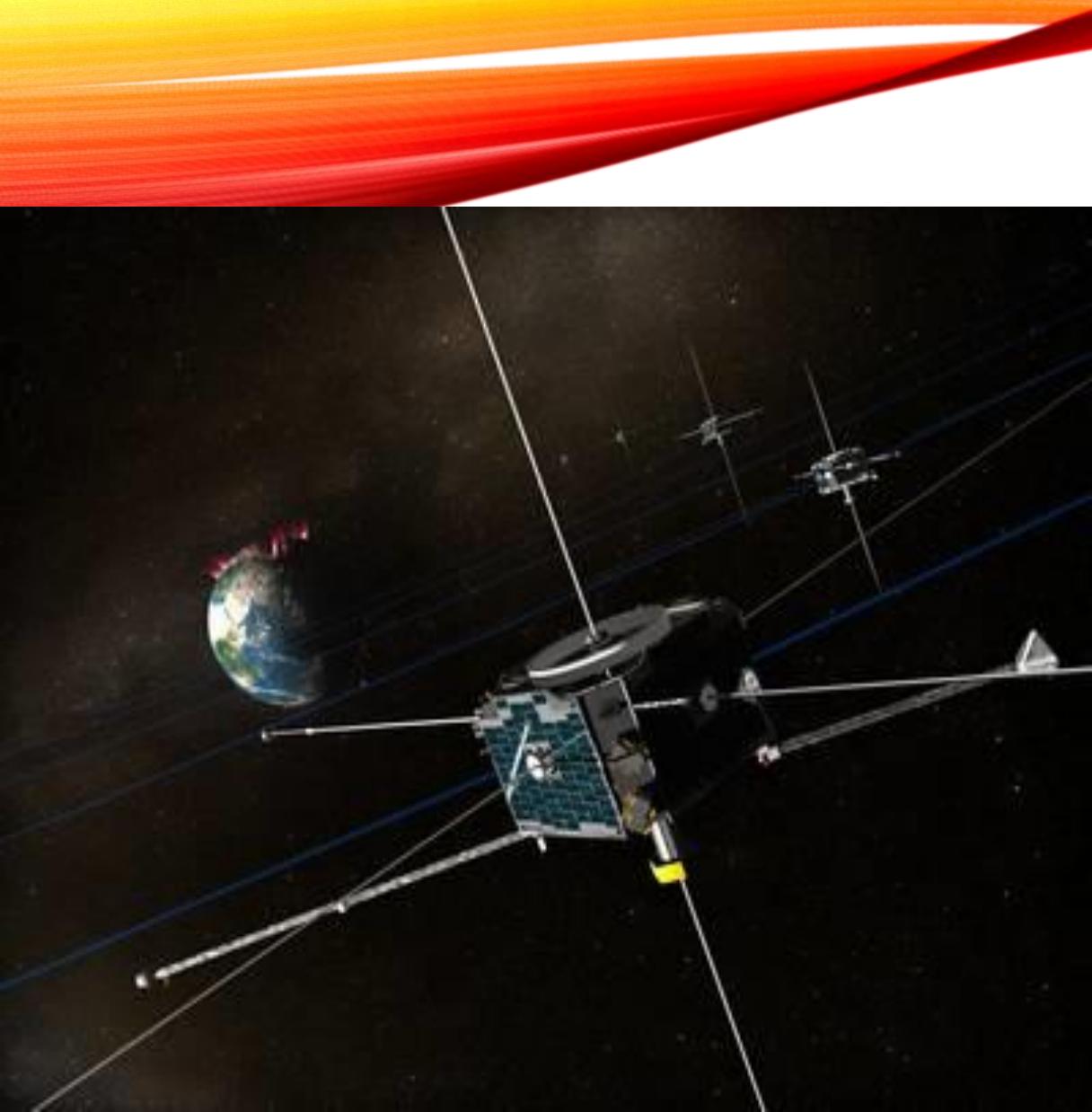
Balloons



Satellites



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*Canadian contributors - UofS, UNB, UofC,
Athabasca University, UofA, CSA, NRCan*

SATELLITE/GROUND-BASED PROGRAMS

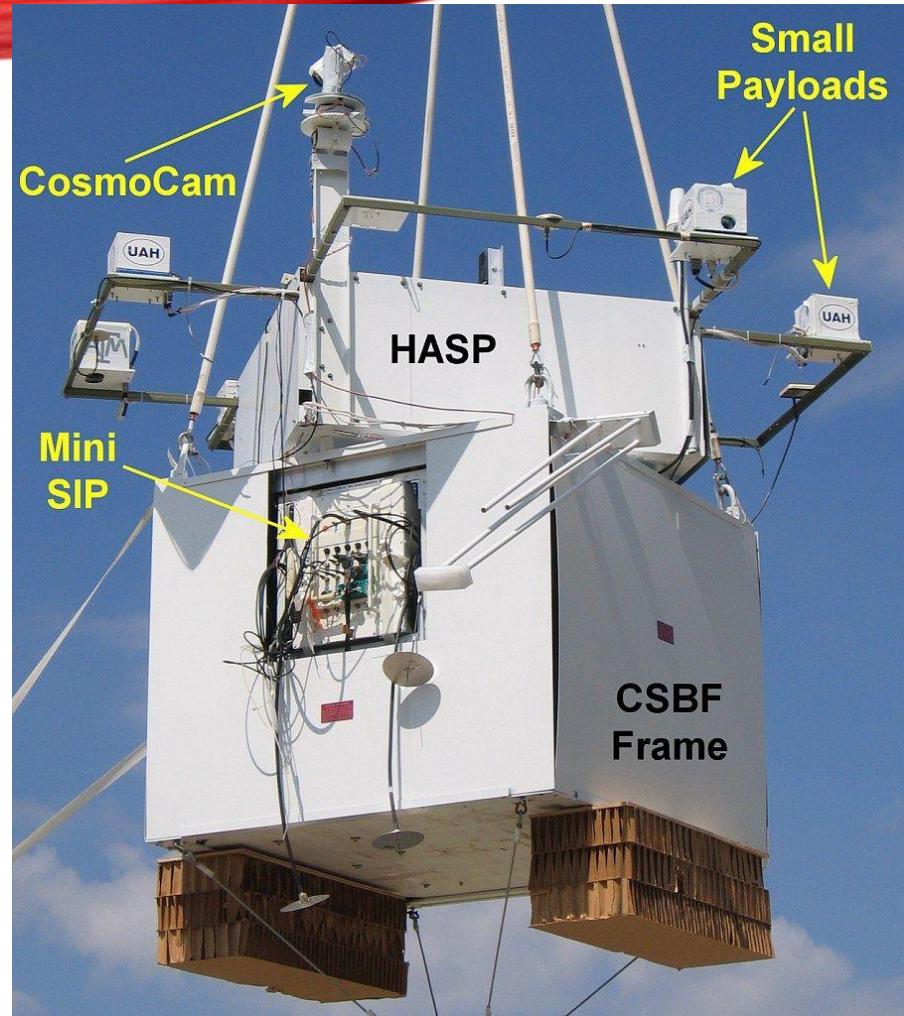
Ground-based began early 20th century - e.g. ground-based ‘all sky’ cameras, radars & radio propagation experiments by university researchers.

Ground-based observations ongoing but now coordinating with satellite-based observations.

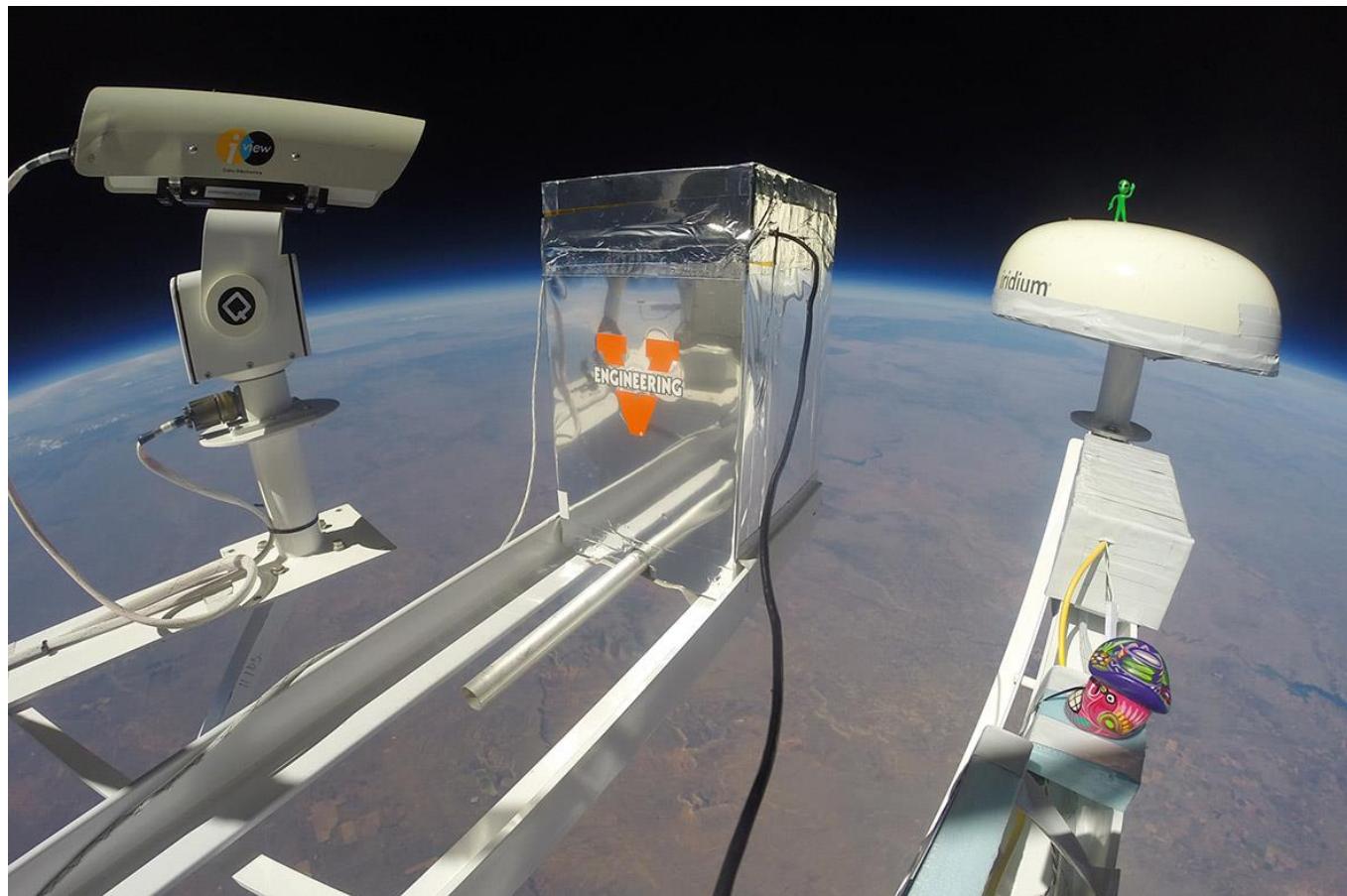
THEMIS: NASA launched constellation of 5 smallsats (February 2007); coordinated with 20 ground-based, automated, all-sky cameras across Arctic Circle (Canada & USA). Cameras took pictures every 3 seconds over 2 year missions (140 million pics).

- Satellites carry identical electric, magnetic & particle detectors to study aurora. Satellites in coordinated orbits. Every four days, they line up along Earth's magnetic tail to track disturbances in magnetosphere.

- Satellites look for macroscale interactions during sub-storms; compare to observations from ground stations.



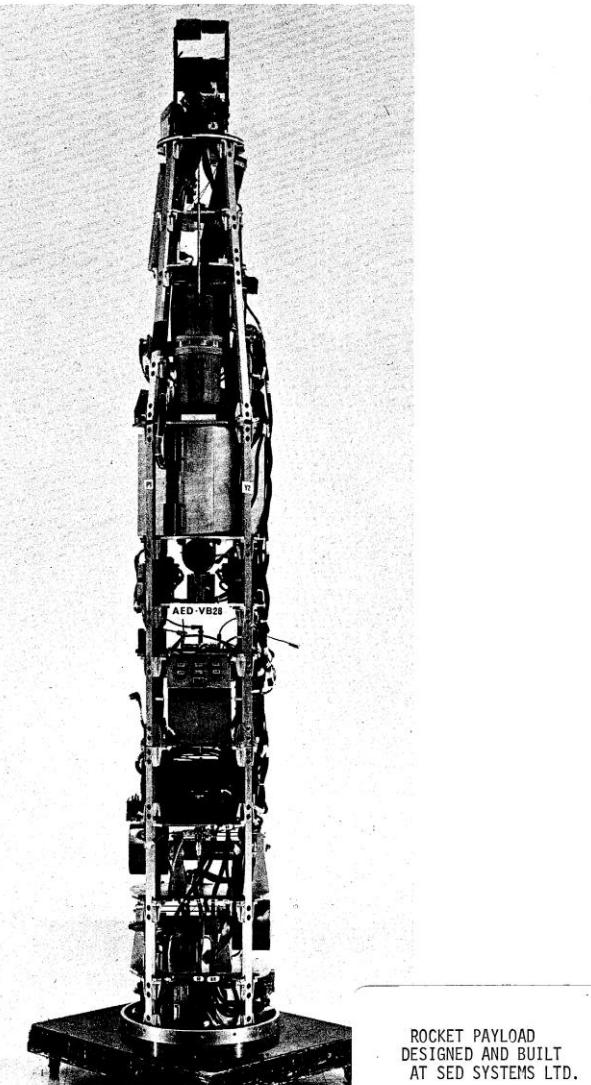
Piggy-back
Student
payload
from
Mid-'80s



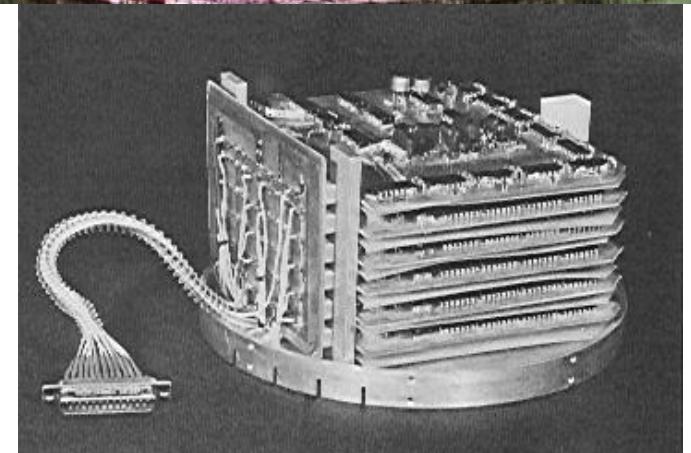
BALLOONS

Similar 'student participation' concept as for Space Shuttle 'Getaway Specials'

SOUNDING ROCKETS



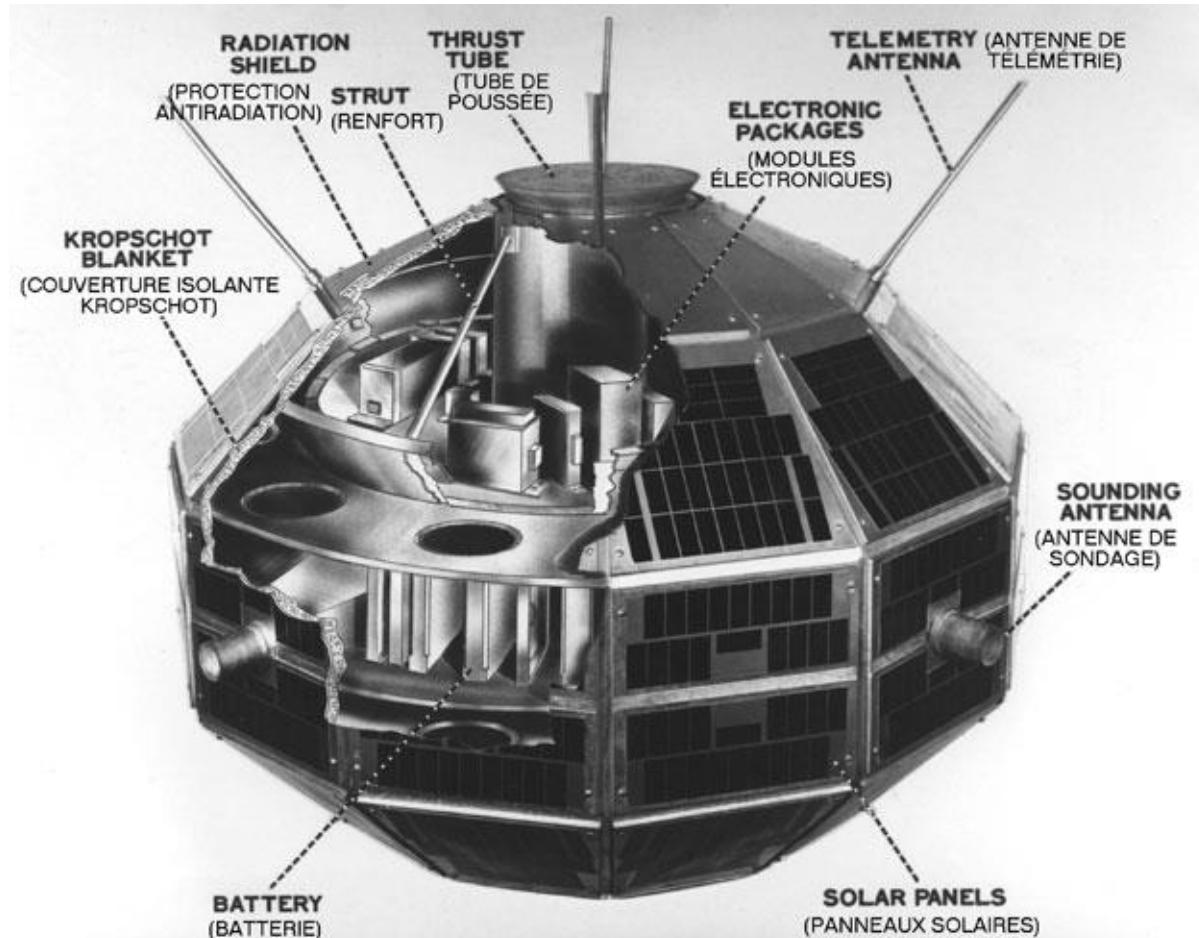
SED Systems & Bristol Aerospace -
major Canadian participants with NRC
(began in '50s)



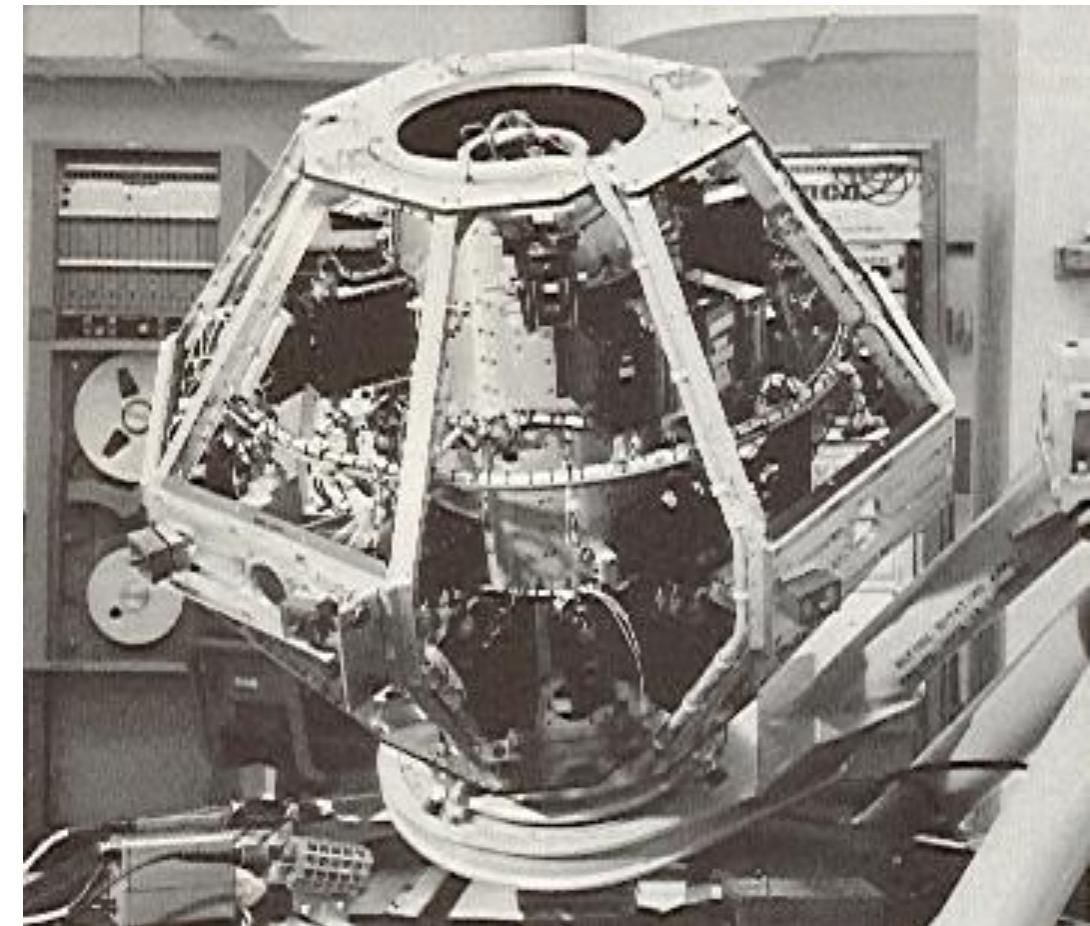
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FIRST SCIENCE SATELLITES

Ionospheric Top Side Sounders



Alouette - 1962



ISIS - 1969

COMSATS



Early experiments and deployments in Arctic & Remote areas

Leader in ComSats & Ground Systems

- Satellite systems & subsystems
- Ground Control & In-orbit Performance Monitoring Systems
- Remote & Urban Communications
- Forerunner to ‘direct to home’

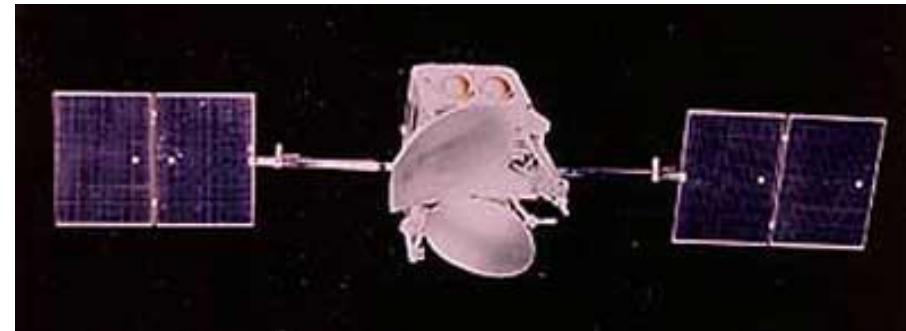
Pioneered applications

- e.g. entertainment, Internet, Telemedicine, Education

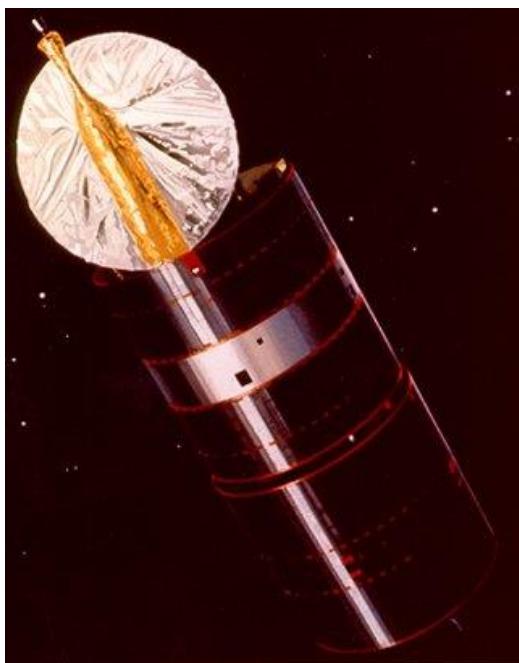
Major international sales



Anik A (3)



Anik B (1)



Anik C (3) & D (2)



Anik F (4)



Anik E (1)



Anik G (1)

HERMES (CTS) – 1ST HIGH POWERED DBS

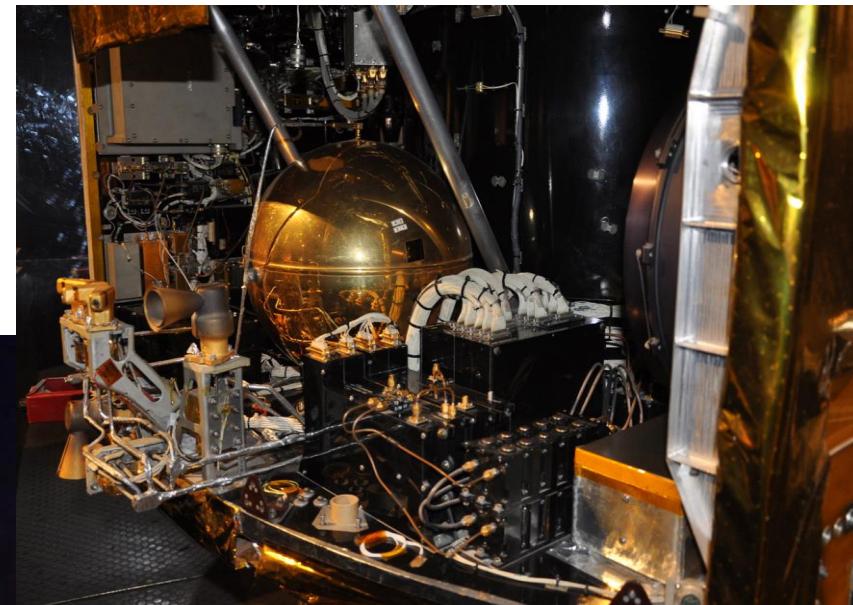


*200 watt, Ku band Travelling
Wave Tube*

30" steerable parabolic antennas

*Joint Canada-NASA
experiment*

Operated 1976-1980



*First real-time, ground-based 3-
axis attitude control of civilian
synchronous orbit satellite*

Closed loop computer control

1976 STATE OF THE ART SATELLITE CONTROL



HP2100 Ground Control Computers



Xerox Sigma 9 Real-time Simulation Computer

*Hermes
Satellite
Ground Control
Centre - Ottawa*

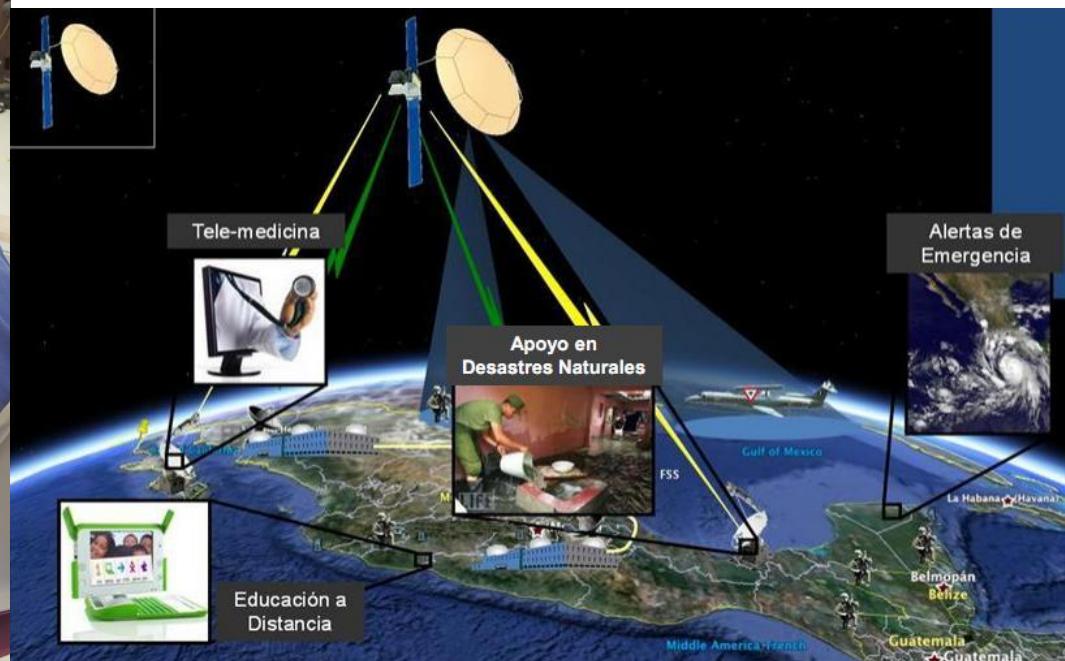
GCAP Real-time Status Display

	084-14 30 13	ENC	B	CTS	GCAP	ORB	SLT	SX	SY	SZ	ENCOR	B	R2	414
	12:25:43		75	00:0000		101.6	0.99	-0.03	-0.17		IX	94.2	Y1	0.523
CMD														
GCAPF	0	ALPHA	S	350.29	WX RGP	-10.00	ALPHA	E	0.00	P1	0.625	Y4	0.523	
STIND	0	DELTA	S	-1.53	WY RGP	-9.91	DELTA	E	0.00	P2	0.625	Y1	0.414	
GMODE	0	SSE	P/R	10	WZ RGP	-10.02	NES	A/B	0.01	P3	0.600	Y2	0.523	
CTRLM	0	NSS	ID	1	RGP		MHL	SPD	3710.	P4	0.600	Y3	0.414	
AEFLG	0	SX		0.9853	SY	-0.0266	SZ		-0.1606	R1	0.414	Y4	0.392	
***** ATTEN *****														
AEREF	0.00	MNADT	0.100		SCN A	0.0	SCN B	0.0						
ASREF	180.0	MAXNX	512		CRS A	0.0	CRS B	2.0						
IGNAE	0.03	AWAIT	5.0		EPR A	0	EPR B	1						
ALFOB	2.0	CMAT	30.0		SPR A	0	SPR B	0						
VDB	0.30	REDT	1.00											
		WYSMD	1.00		NSSID	1	WLSPD	3709.0						
					NA	62.0	WLCPH	156.0						
					NB	54.0								
					WYEDR	2.123								
NR_AB	00	WYSDR	-0.00											
NR_B	95	WXZDR	0.01											

GCAP - Ground Control & Procedures

SED Systems

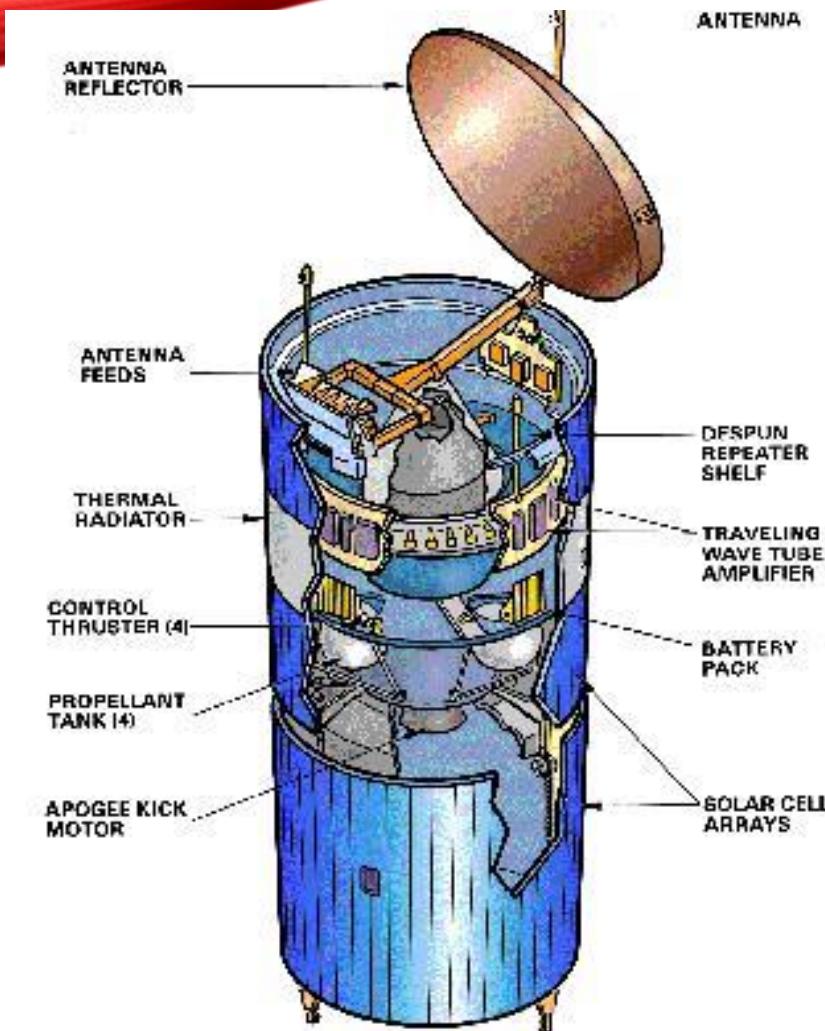
2016 STATE OF THE ART SATELLITE IN-ORBIT PERFORMANCE MONITORING SYSTEMS



Mexsat system @ SED Systems

COMMON PLATFORMS

- Pioneered with balloons/rocket payloads/larger satellites
- Common platforms and systems
 - Save development time & effort
 - Reduce schedule, costs & risks
 - Improve reliability
 - Free up development budget for new systems, sensors, payloads
- Common platform systems include
 - Structures
 - Power systems
 - Telemetry & Command systems & attitude sensors
 - Attitude control
- Meet needs of Shuttle and many launch rockets for common launch interfaces
- Enables development of Micro/Nano satellites
 - Creates opportunities for new suppliers/university scientists to participate
 - Often ‘single mission’ satellites which can provide access to more launch vehicles
 - Low-cost, rapid development.



HS 376
SPACECRAFT CONFIGURATION

EARLY EXAMPLE OF STANDARDIZED SATELLITE PLATFORM

Hughes HS376 Comsat

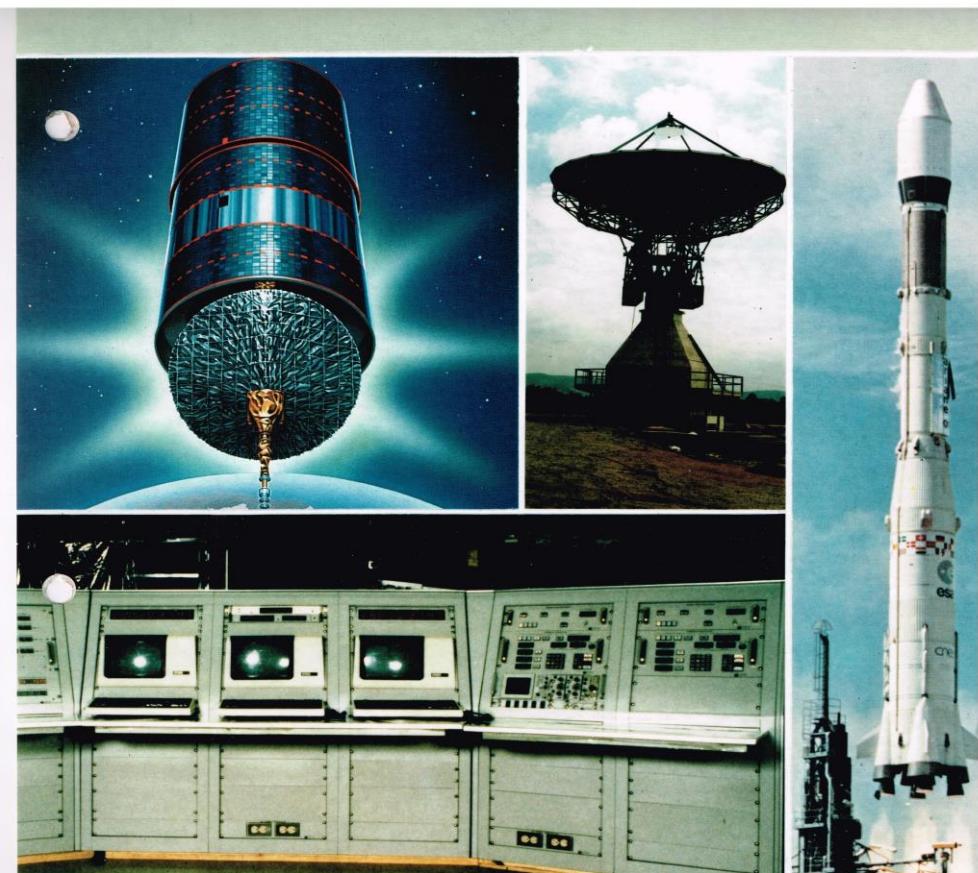
Used for 15+ major international programs

- '70s through '90s
- e.g. Anik C, Anik C, Brazilsat, PanAm Sat, Satellite Business System, Westar, etc.

Supports many different Comsat frequencies

- e.g. C band, Ku band, Ka band

Many Shuttle and Ariane rocket launches



Mission Requirements Document

BRAZILSAT A1/A2 (1986-2003)

First international satellite primed by Canada

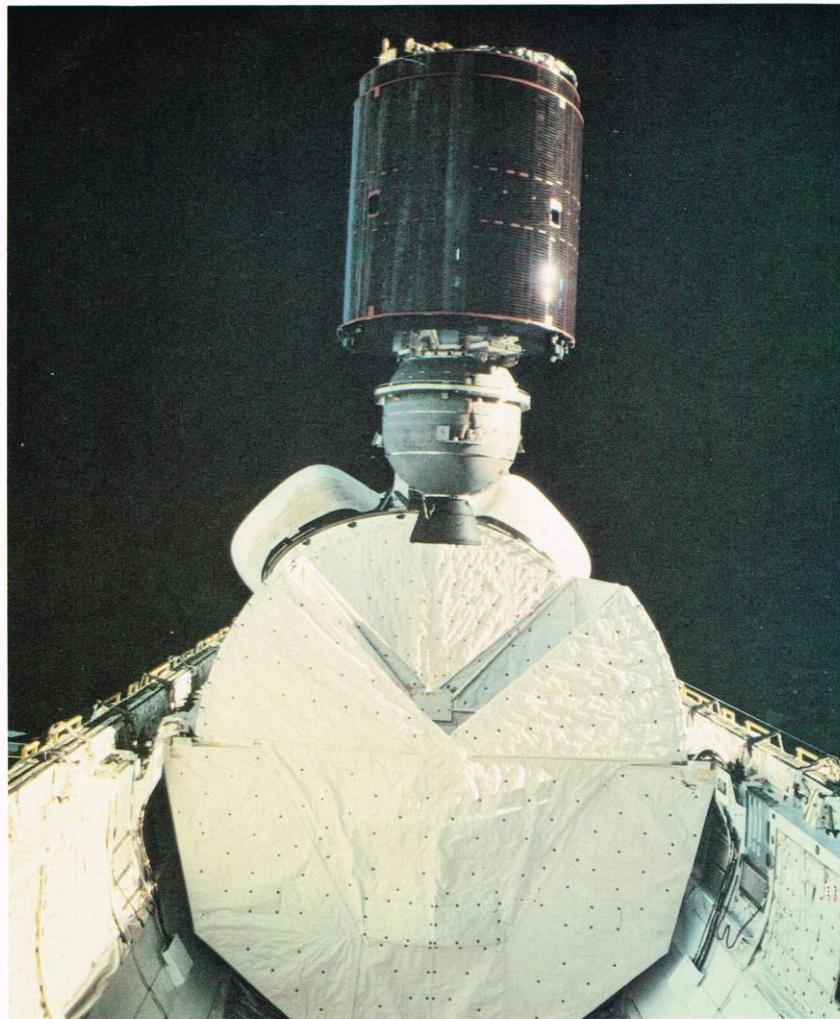
Based on HS 376 Bus

Team

- Prime Contractor: Spar Aerospace
- Spacecraft: Hughes Aircraft, Spar Aerospace
- Ground Control/Monitoring System: SED Systems, Hughes Aircraft

Ariane Rocket Launch

8 years design life target, operated for 17 years



EXAMPLE HS 376 LAUNCH

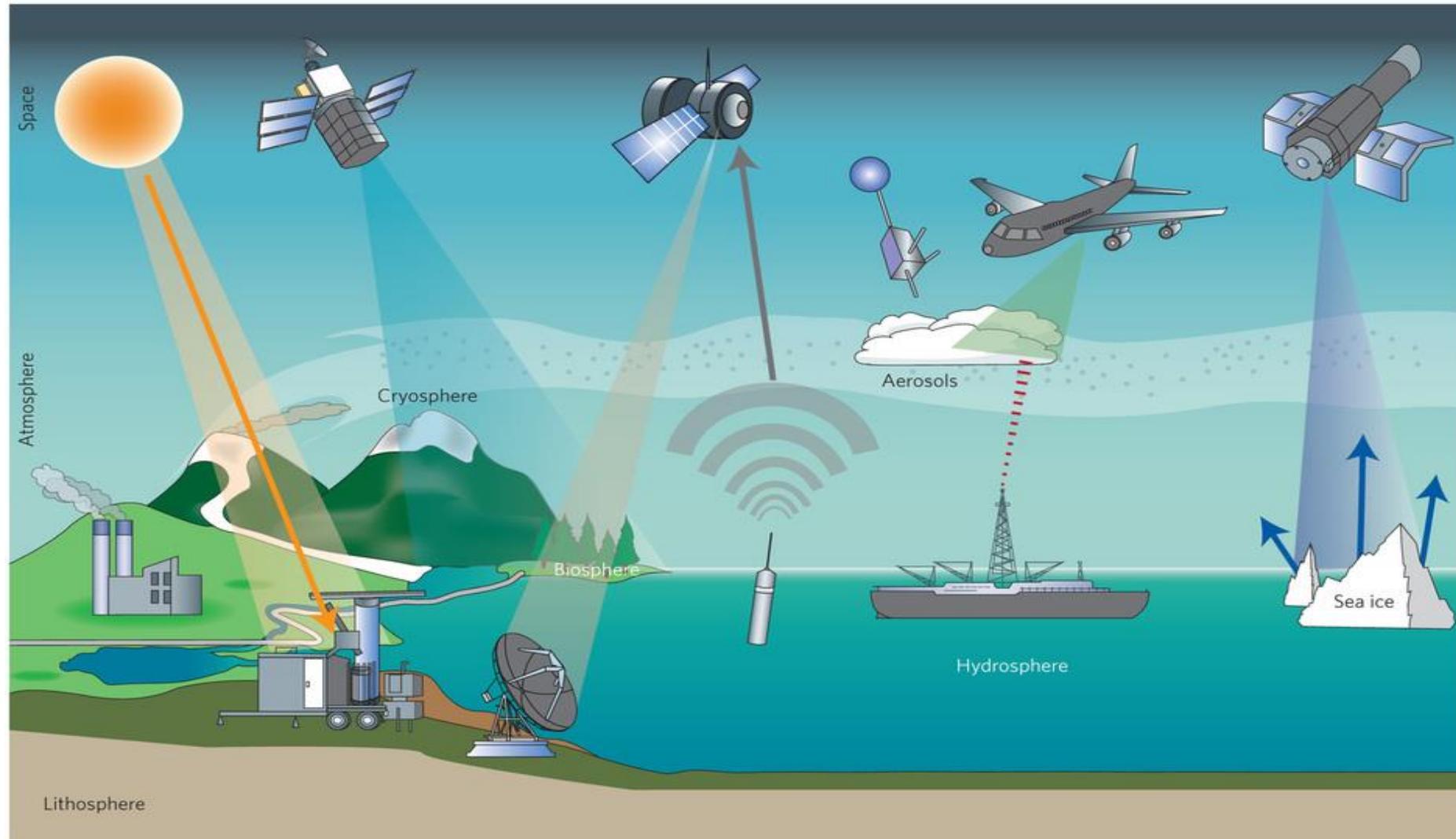
Dual Shuttle launch (November 1982)

Satellite Business Systems satellite (foreground)

Anik C
(rear launch container)

SED Systems - supplied Satellite Integration & Test Systems for many HS376 projects

REMOTE SENSING & SURVEILLANCE



Canada was 1st non-US user of Landsat

MDA - leader in ground collection & processing for many international remote sensing satellites

Custom processing applications for Canadian & international customers

Other surveillance systems for civilian and military uses



FIRST EARTH RESOURCES SATELLITE - LANDSAT

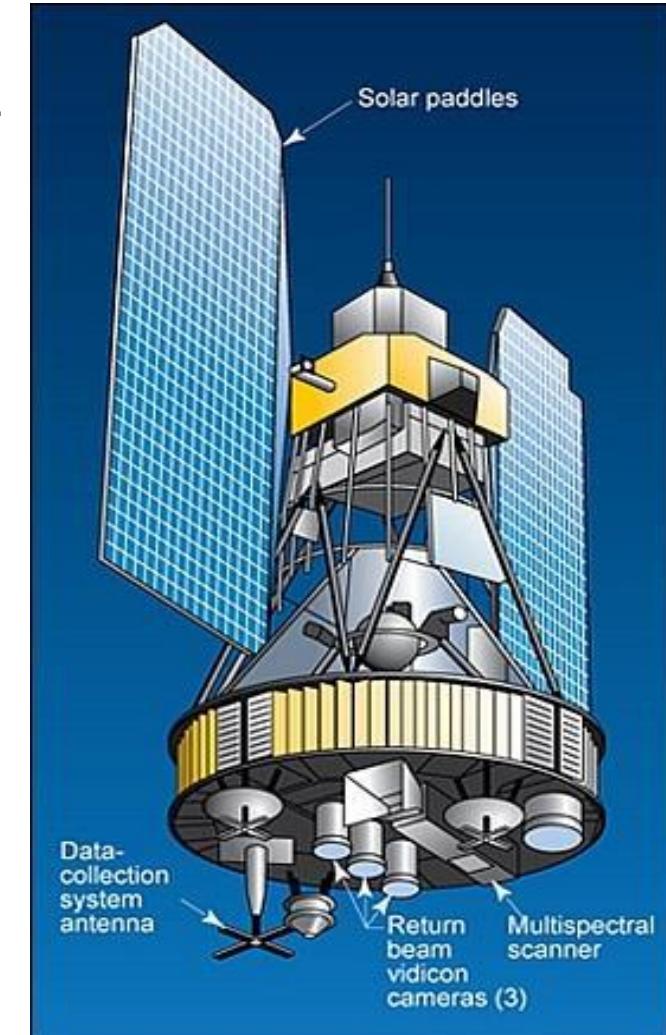
*Landsat 1 -
1972*

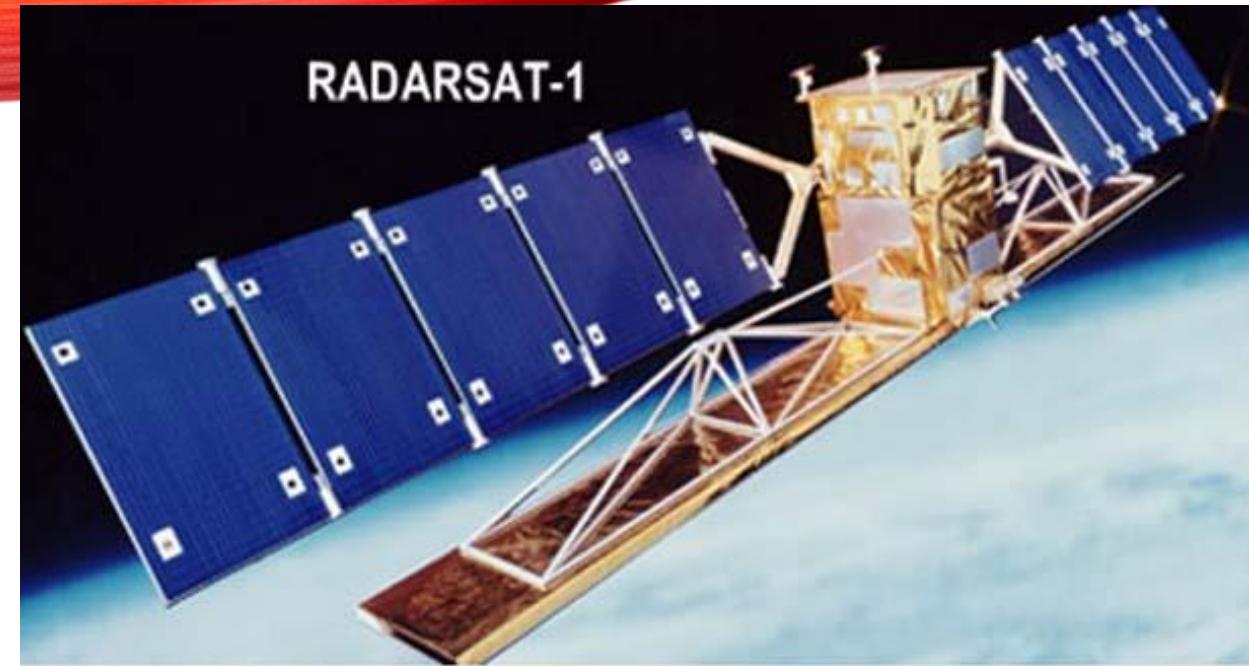
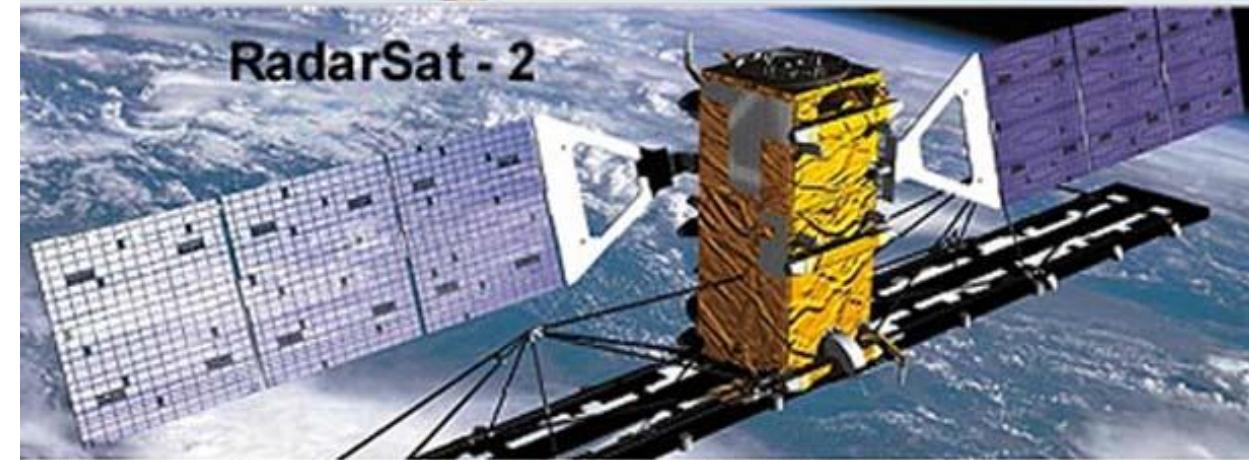
Prince Albert Satellite Station (PASS)

1958 - built to track aurora

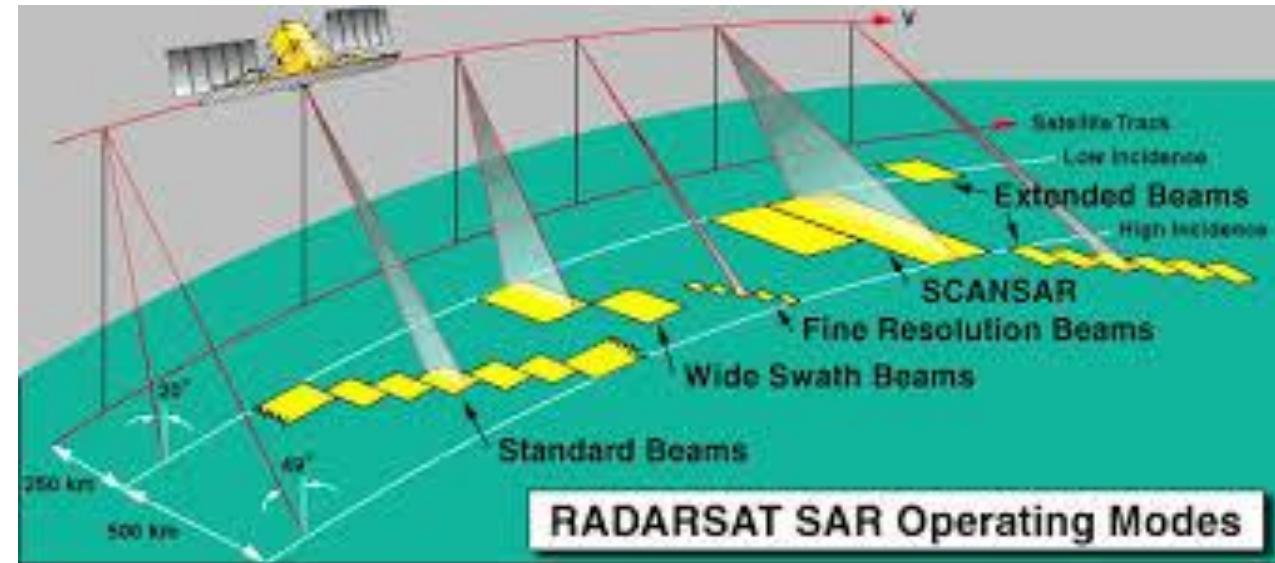
1971 - modified to track
Landsat & later many other
satellites

Pouch Cove, Nfld. station
later added to better cover
east coast/Atlantic



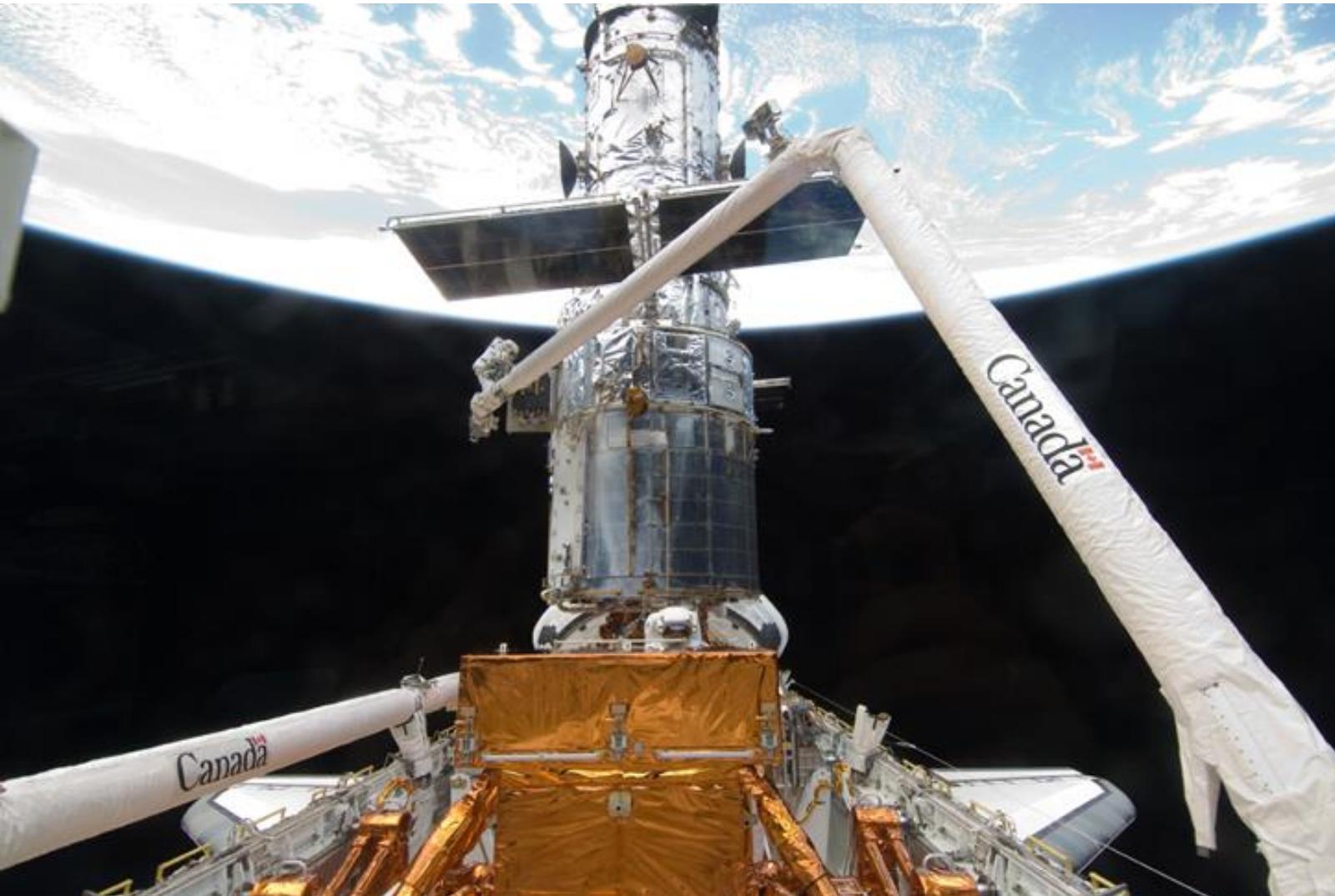
RADARSAT-1**RadarSat - 2**

Images Captured From Canadian Space Agency Site

RADARSAT

Radarsat 1 (1995) & 2 (2007)
- MDA designed, built & operated

Night time/cloudy skies tracking of arctic ice & other environmental activities



SPACE ROBOTICS

Canadarm first launched on Shuttle in 1982

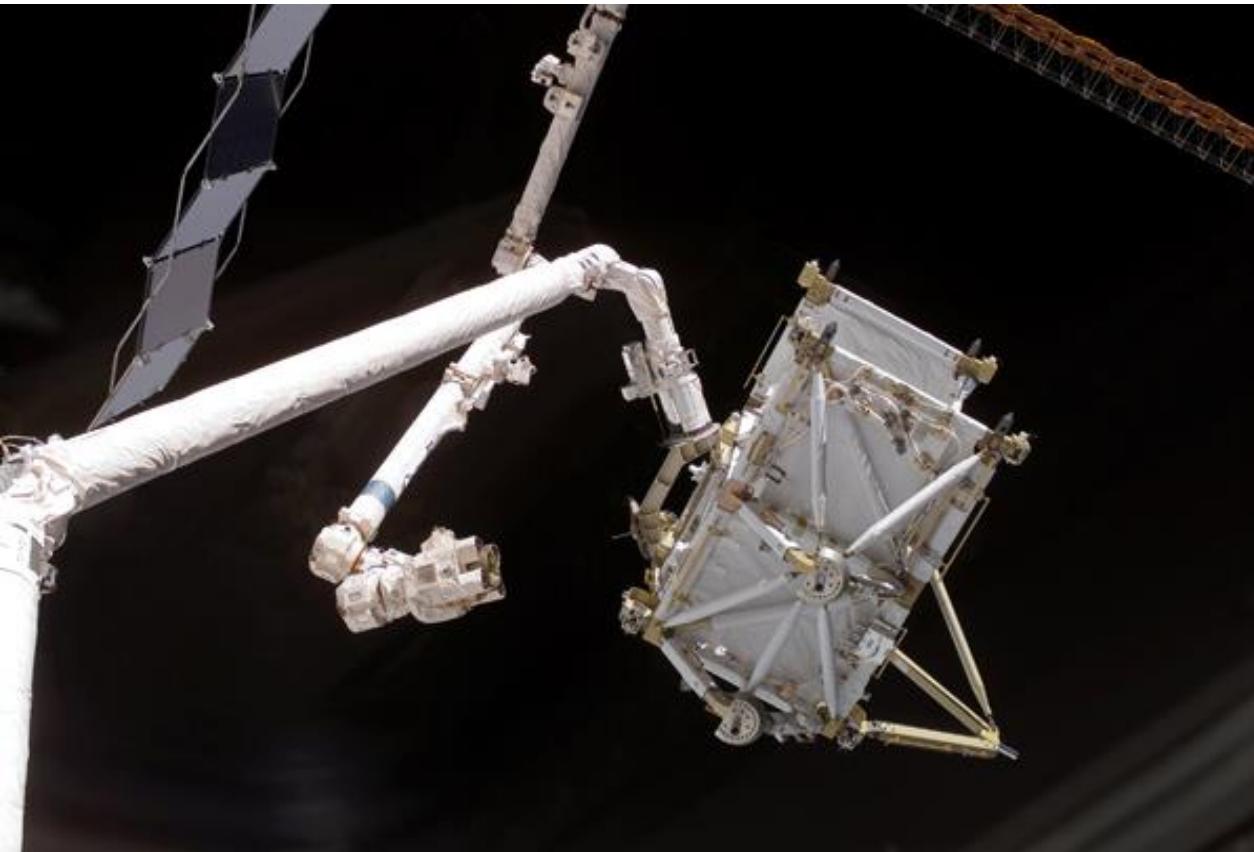
Canada's ongoing contribution to International Space Station

Spinoffs in medicine, industry, mining, other space programs

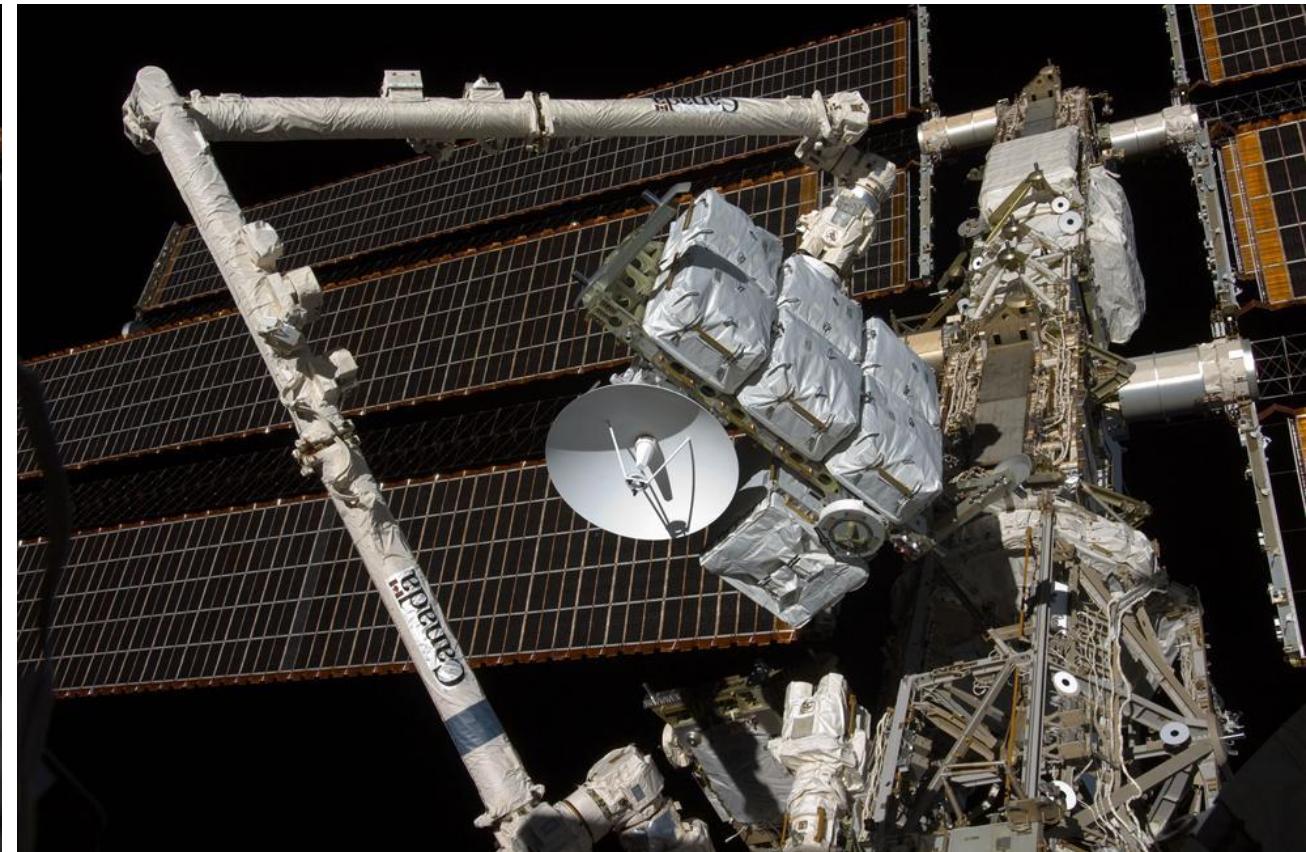
Developed by Spar, now MDA

Launched Hubble in 1990; serviced Hubble 4 times

ROBOTICS - SPACE STATION



Discovery's Canadarm holds ISS' P5 truss for hand off with Canadarm2 - 2011



Integrated Cargo Carrier moved on Canadarm2 - July 2009

CANADA'S PARTICIPATION IN INTERNATIONAL SPACE SCIENCE PROGRAMS

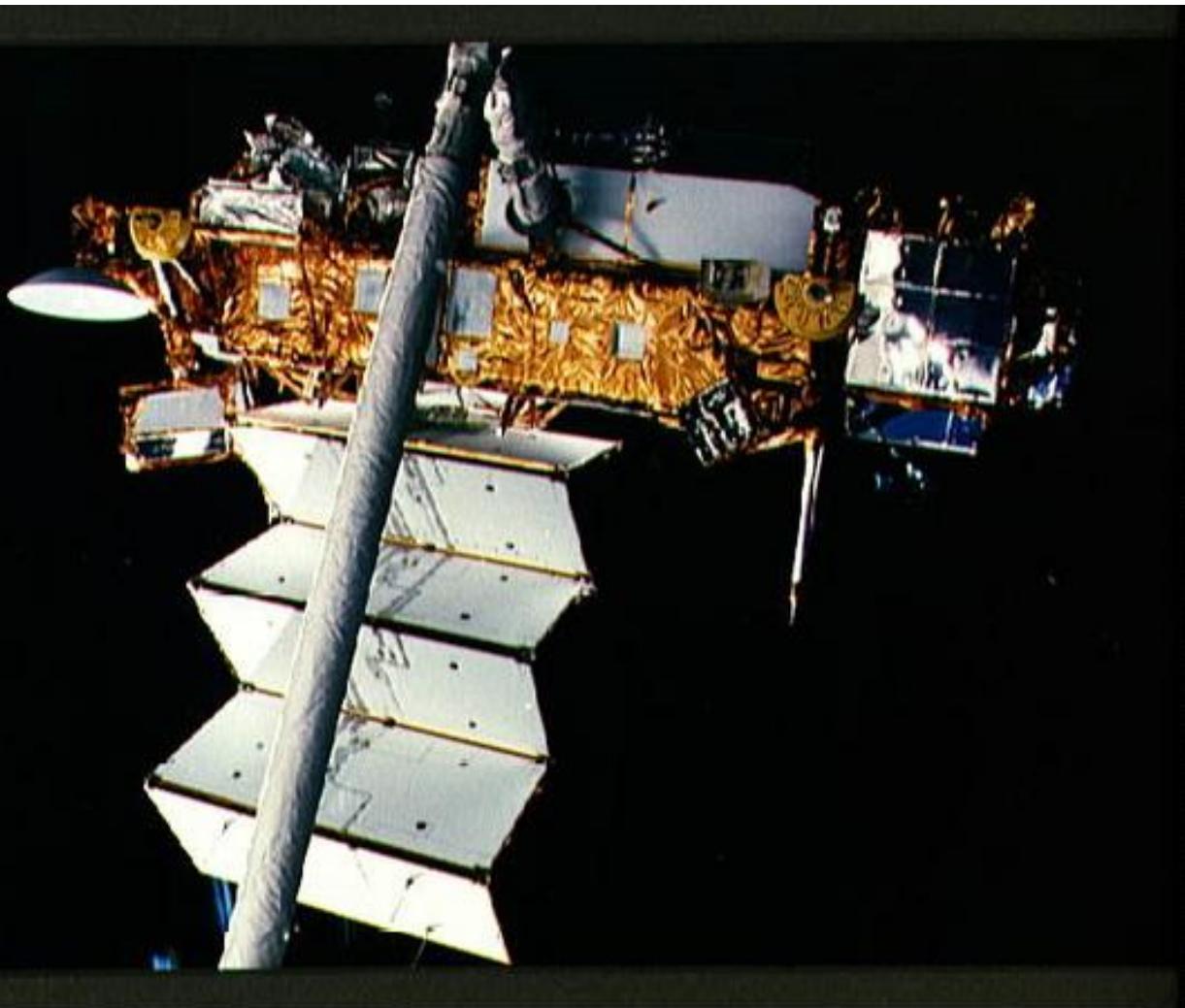
Name	Country	Primary Agency	Launch Date	Canadian contribution	Notes
FUSE	USA	NASA	1999	Fine Error Sensor	COM DEV
Terra	USA	NASA	1999	MOPITT (Measurements of Pollution in The Troposphere)	PI: Jim Drummond; COM DEV
Odin	Sweden	SNSB	2001	OSIRIS (Optical Spectroscopic and Infrared Remote Imaging System)	PI: Doug Degenstein, University of Saskatchewan ; Routes
Envisat	Europe	ESA	2002	ESA collaboration	
CloudSat	USA	NASA	2006	Radar components	COM DEV
THEMIS	USA	NASA	2007	Automated ground observatories	
Phoenix	USA	NASA	2007	Meteorological station	First Canadian component on Mars; confirmed snow on Mars
Herschel	Europe	ESA	2009	HIFI Local Oscillator Source Unit	COM DEV
Planck	Europe	ESA	2009	ESA collaboration	PI: J. Richard Bond, University of Toronto and Douglas Scott, University of British Columbia
Proba-2	Europe	ESA	2009	Fiber Sensor Demonstrator	MPB Communications Inc.
SMOS	Europe	ESA	2009	ESA collaboration	
Curiosity	USA	NASA	2011	APXS instrument	
Swarm	Europe	ESA	2013	Electric Field Instrument (EFI)	COM DEV
Astrosat	India	ISRO	2015	Precision detectors for the twin UV and visible imaging telescopes (UVIT)	PI: John Hutchings
Astro-H	Japan	JAXA	2016	Hard X-ray Telescope	
OSIRIS-REx	USA	NASA	2016	OSIRIS-REx Laser Altimeter (OLA)	First Canadian component on a sample return mission
JWST	USA	NASA	2018	Fine Guidance Sensor /Near Infrared Imager and Slitless Spectrograph (FGS/NIRISS)	PI: John Hutchings, Herzberg Institute of Astrophysics
					06.07.16

ON-GOING PARTICIPATION - SPACE-BASED ATMOSPHERIC SCIENCE

Canada has participated in many upper atmospheric/aurora monitoring satellites.

Examples are discussed following.

Canadarm Launching UARS in 1991

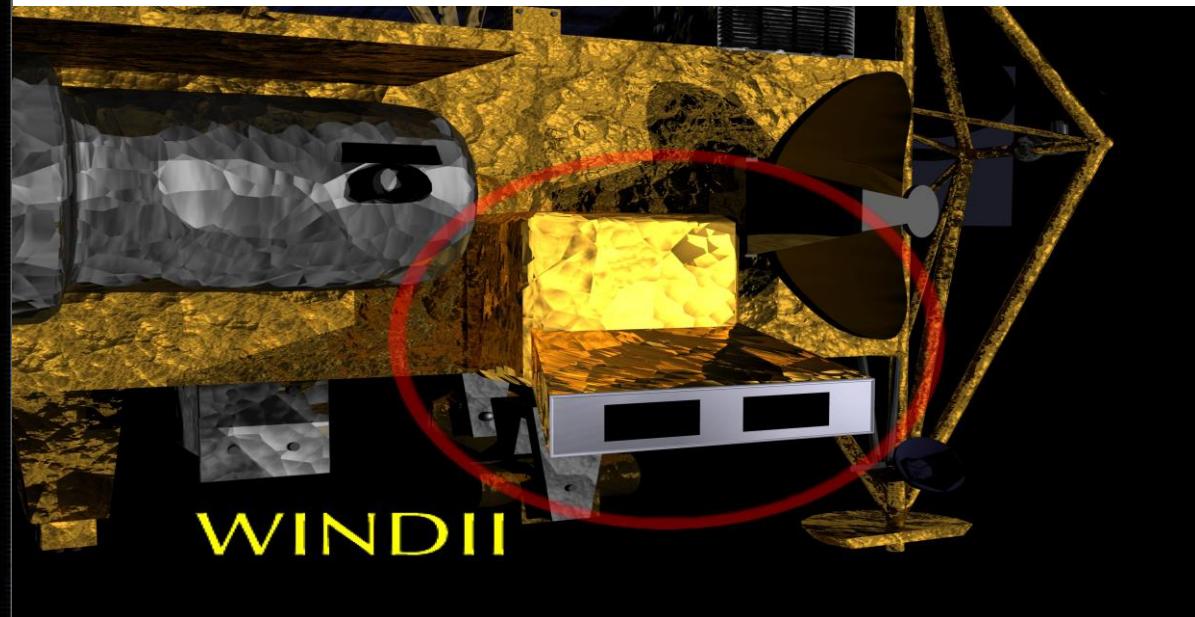


WINDII

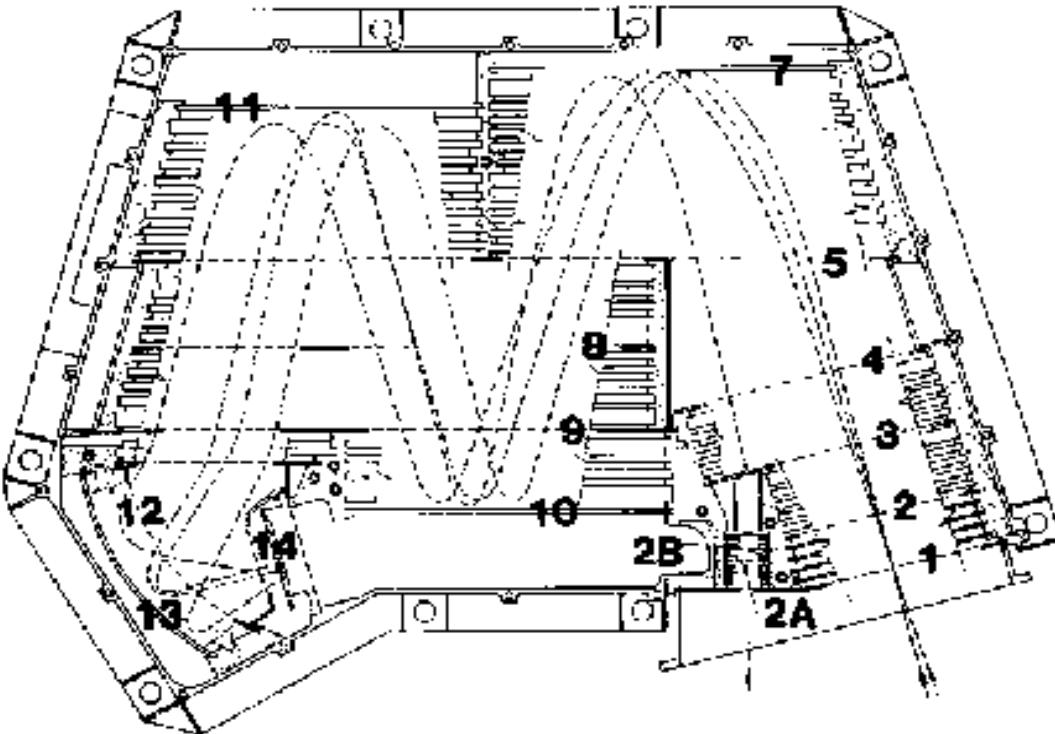
Canada's WINDII instrument flew on Upper Atmospheric Research Satellite (UARS, 1991-2004)

Wind Imaging Interferometer for upper atmospheric winds (80-300 kms); Doppler Michelson Interferometer

Canadian Astronautics Ltd.; York University



SUPRATHERMAL MASS SPECTROMETER (SMS)

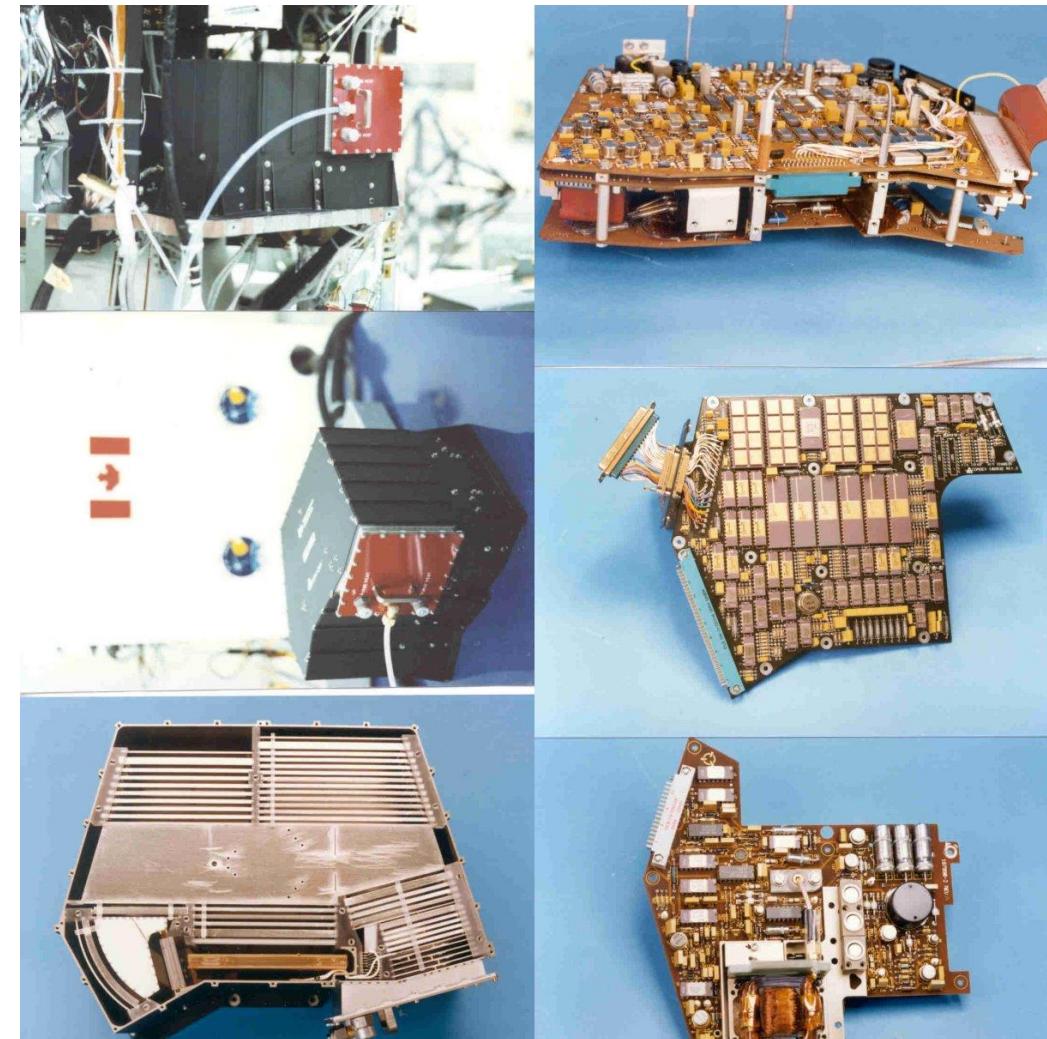


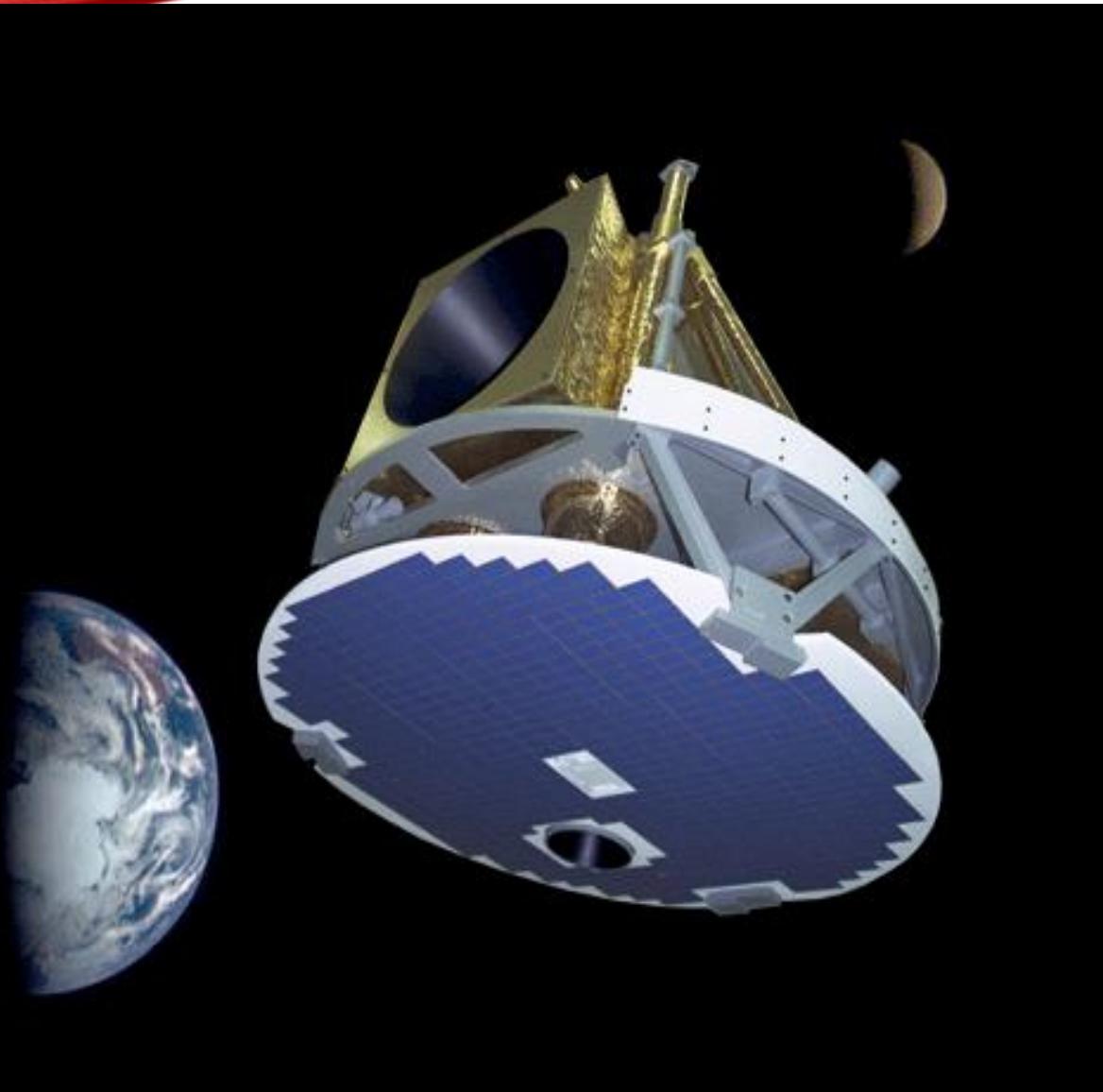
INCIDENT IONS

Bennett-type ion mass spectrometer. Measures mass composition & energy/velocity measurements of thermal/suprathermal ions in auroral and polar ionosphere.

Launched
1991, still
operating

Japanese
Akebono
satellite





SCISAT

Designed to make observations of atmosphere.

Main instruments

- Optical Fourier transform infrared spectrometer
- ACE-FTS Instrument
- Ultraviolet spectrophotometer MAESTRO.
- Devices record spectra of sun, as sunlight passes through Earth's atmosphere to analyze chemical elements of atmosphere/ozone layer depletion.

Goal: Atmospheric Chemistry Experiment (ACE) - measure and understand chemical/dynamical processes controlling distribution of ozone in upper troposphere and stratosphere. Approach is *solar occultation* technique.

Relatively small - 150kg, 5 ft. diameter

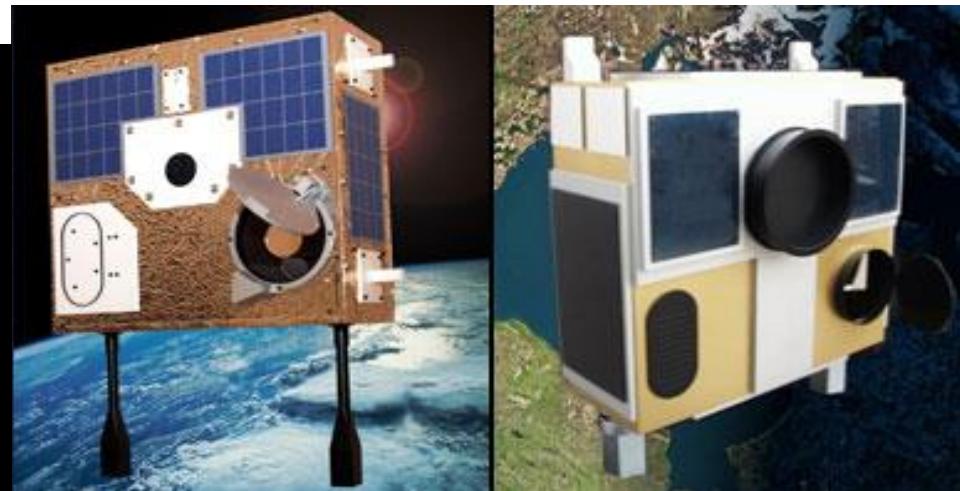
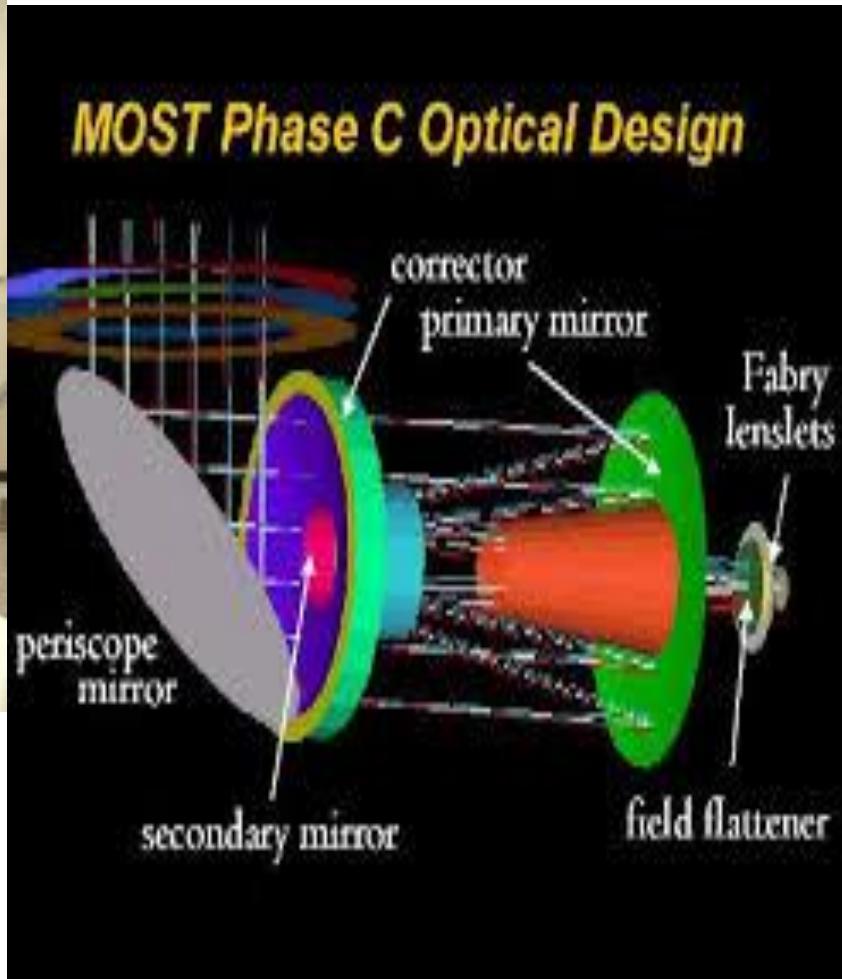
Launched 2003, still operating

SPACE-BASED ASTRONOMY & COMET LANDERS

In addition to its own programs, Canada is active in a number of international missions that:

- search for planets*
- near earth objects/space debris*
- land on comets*

CANADA'S PLANET HUNTER - “MICROVARIABILITY AND OSCILLATIONS OF STARS” (MOST)



Focus on **asteroseismology** (study star light variations, up to 60 days at a time)

Lifetime 2003 to 2014

Smallsat technology - 57.3 lbs

Microsatellites Systems Canada; supported by UofT, UBC

SAPPHIRE

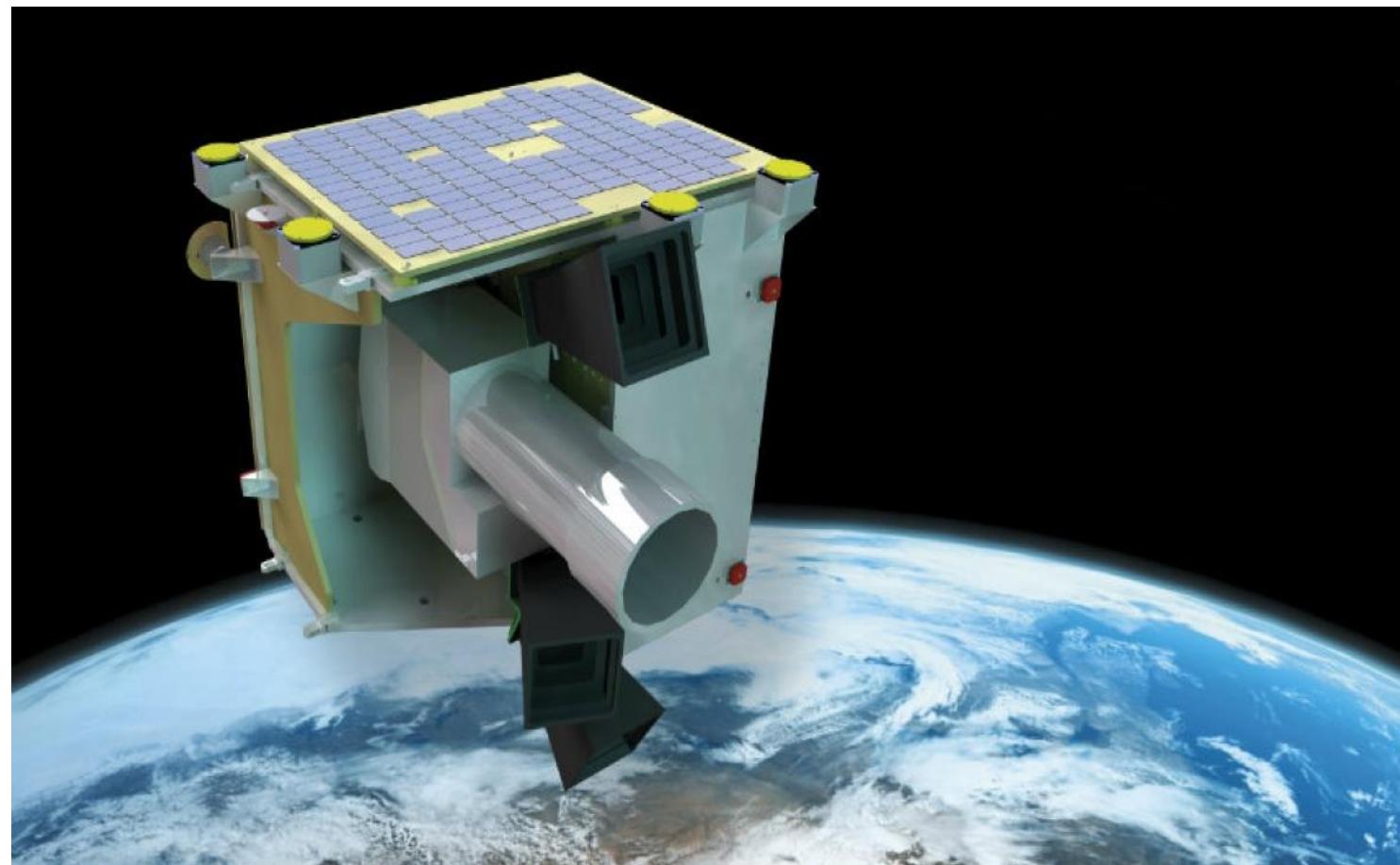
DND's '*space situational awareness satellite*'

- contributing sensor to the U.S. Space Surveillance Network. Data in international catalogue used to help prevent collisions in space -
- help safeguard over a trillion dollars of critical space assets: satcoms, weather, earth observation satellites, GPS, etc.

Sapphire monitors space objects in orbits between 6,000 and 40,000 kms

Smallsat, launched 2013, 148 kg

MDA, supported by Com Dev International & Surrey Satellite Technology's bus (began with Oscar)





NEOSAT

Launched February 25, 2013

Near-Earth Object Surveillance Satellite

First space telescope dedicated to detecting & tracking asteroids/satellites.

Scan space near Sun to pinpoint asteroids that may pass close to Earth.

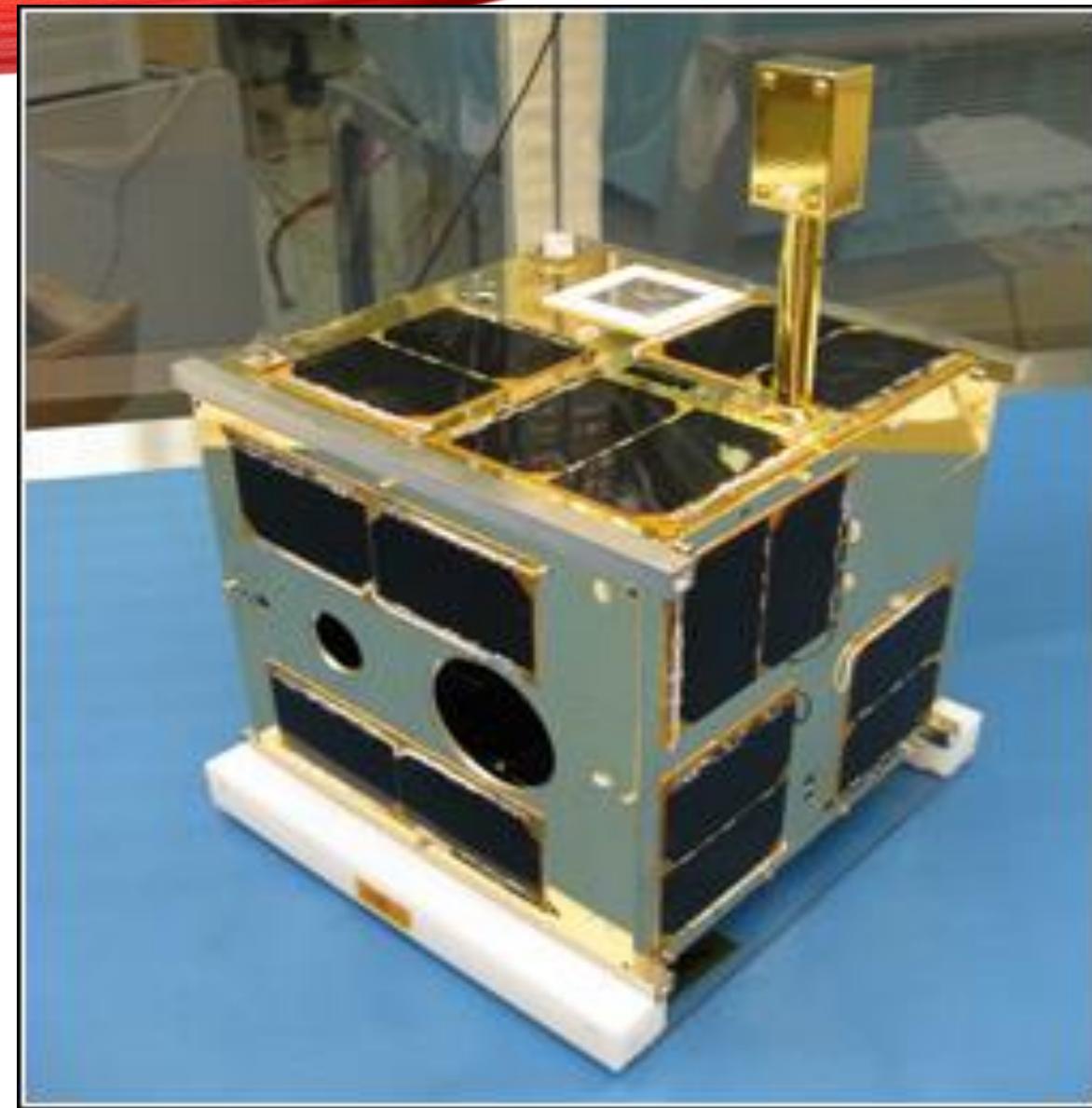
Sweep skies in search of satellites & space debris (part of Canada's commitment to keeping orbital space safe).

Industry-leading technology Canada already demonstrated with success of MOST.

First implementation of Canada's generic microsatellite bus

Suitcase sized

SPECTRO Analytical Systems, MicroSat Systems Canada



BRITE CONSTELLATION

Bright Target Vibration Explorer (BRITE) - first launch 2013

Fleet of nanosatellites to study brightest stars – look for mysteries hidden from world's largest telescopes

Study **true vibrations** of stars not visible from earth due to turbulent atmosphere

Learn about structure/evolution of bright, massive stars including ‘blue stars’ which are precursors to super novae. Seismically probe stars by vibration analysis

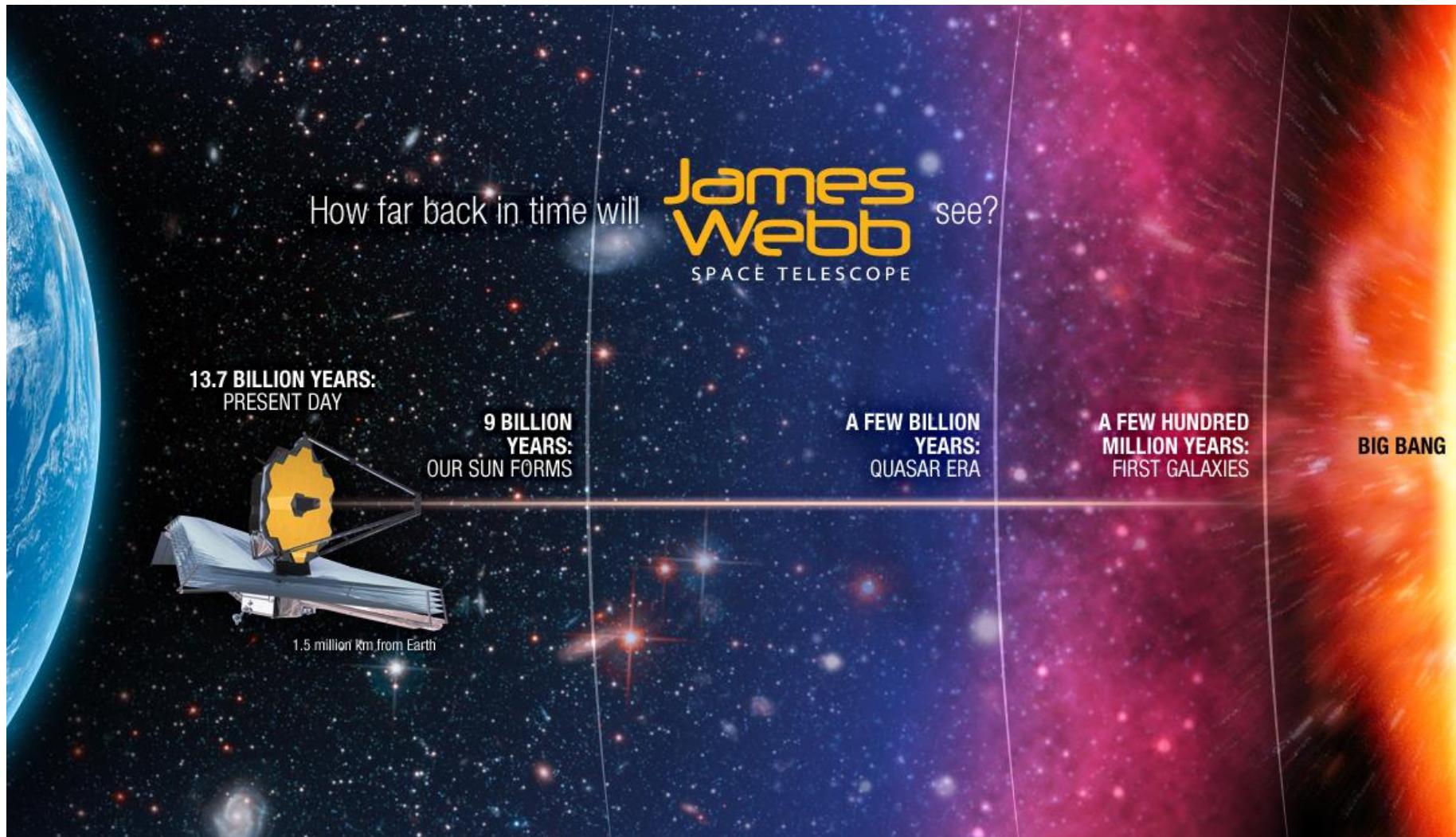
6 satellites - 2 from Canada (others - Austria & Poland); complement MOST

20 cm cubes, 8 kg

First space astronomy mission done with nanosats

UTIAS; supported by UBC, UofT

JAMES WEBB SPACE TELESCOPE



6.5 metre, segmented, foldable mirror (Hubble 2.5m)

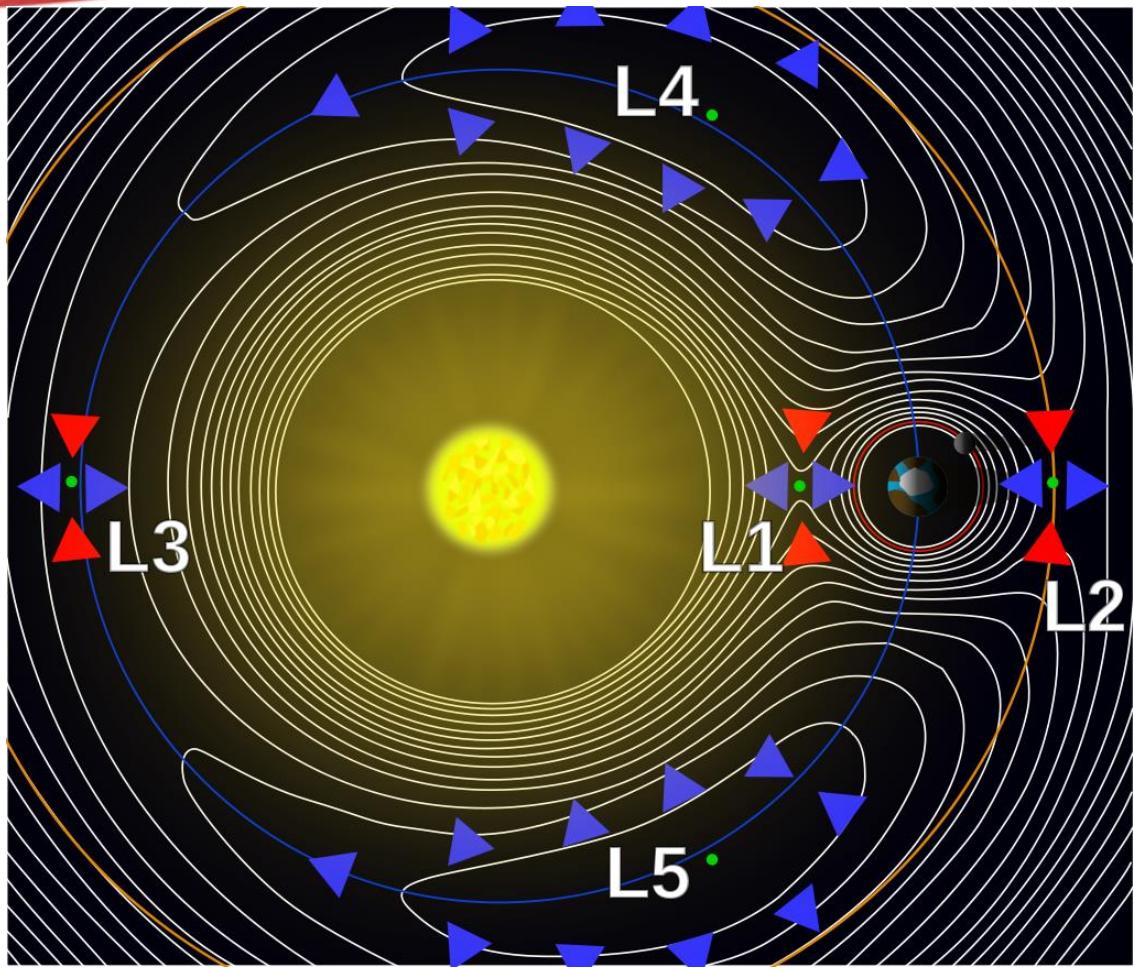
Launch in 2018 to Earth-Sun **Lagrange 2** point (1,500,00 km from Earth)

Visible to mid-infrared light

Large sunshield keeps mirror/four science instruments below 50 K (-220 °C; -370 °F)

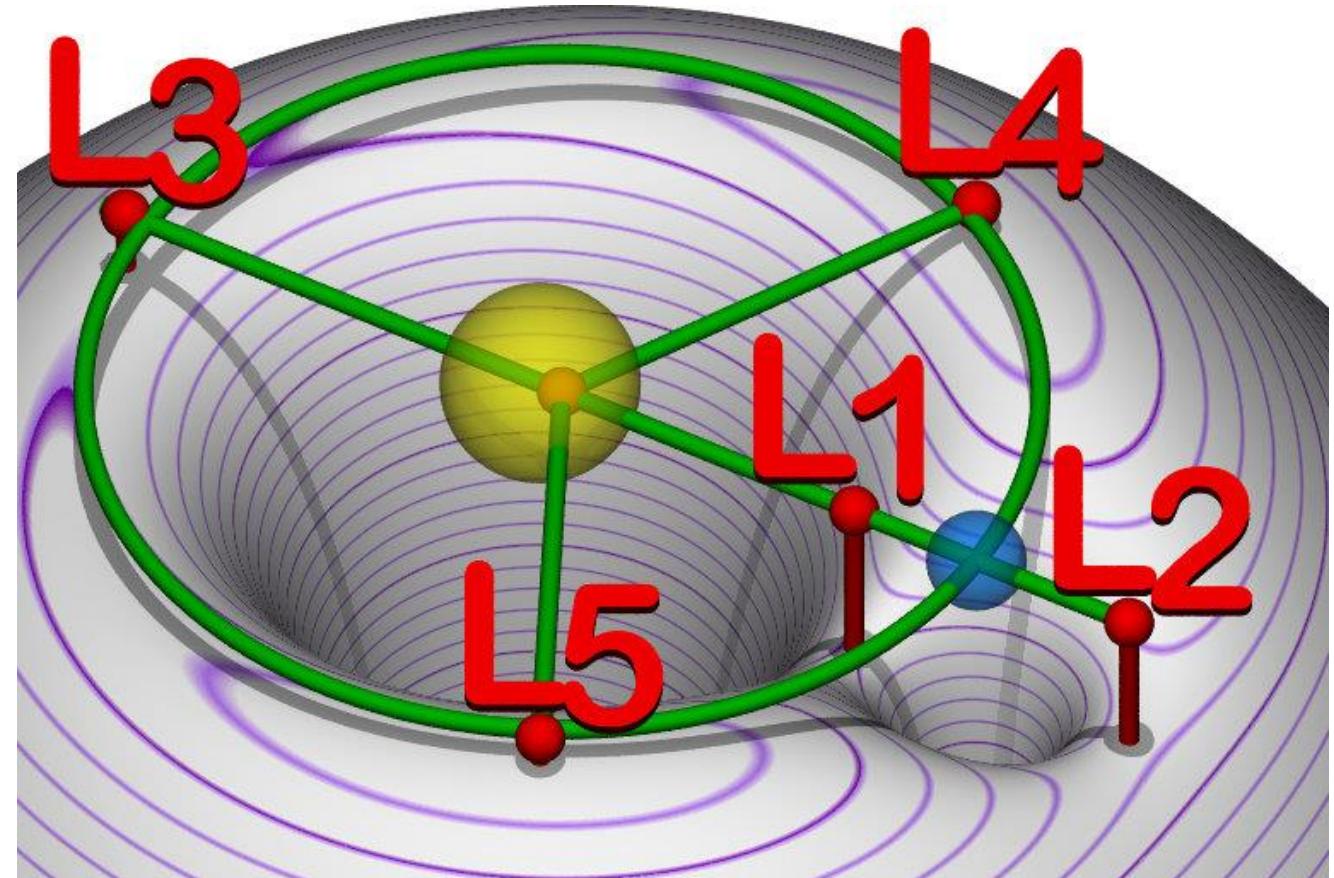
Canada providing '**Fine Guidance Sensor**'; one science instrument - **Near-Infrared & Slitless Spectrograph (NIRISS)**

COM DEV International;
Universite de Montreal & NRC



WEBB @ LAGRANGE POINT L2

Location in space where 2 large bodies provide gravity balance to allow spacecraft to maintain position



ROSETTA SPACECRAFT & PHILEA COMET LANDER - DEEP SPACE TRACKING NETWORK

Tracking stations - Australia, Spain, Argentina

European Rosetta Mission with Philea lander

2004 launch, 2014 Philea landing

35m antennas (500 tonnes); X-band

SED Systems



Comet 67P/Churyumov-Gerasimenko (510 million kms)

MICROSATELLITES

Canada actively developing & deploying of micro-satellites

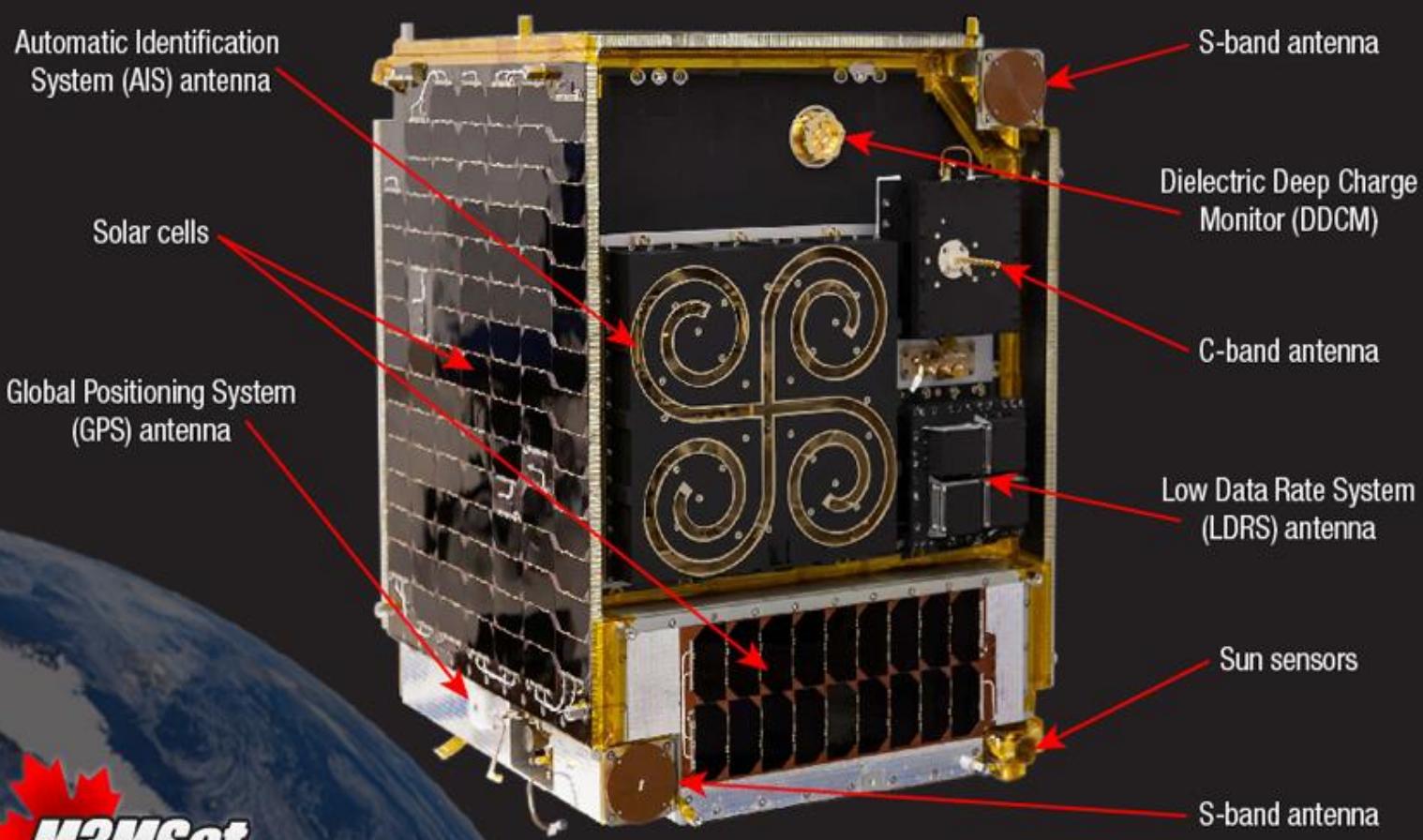
Reduced costs/program schedule & access to ‘standardized systems’ expand opportunities for scientific teams & smaller companies to participate in space program

Satellites often ‘single purpose’ in nature

A number of examples shown earlier

Following recent examples illustrate current/future opportunities

MARITIME MONITORING AND MESSAGING MICRO SATELLITE



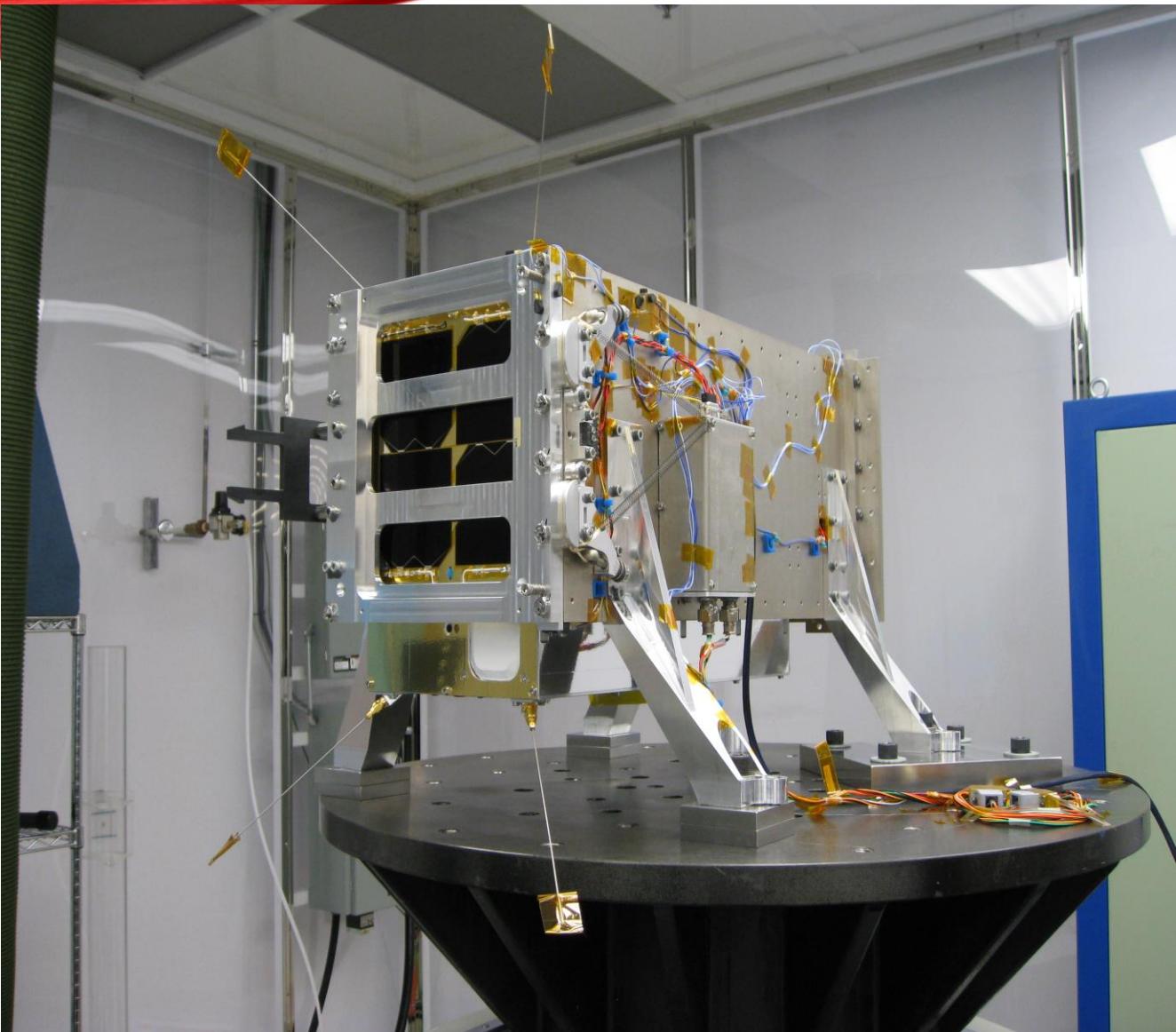
Testing Automatic Identification System (AIS) technology - transmits information on ships' identity, heading & speed.

Testing new microsatellite-based technologies to help develop standardized satellite buses

Launched into polar orbit on June 21st

Structure weighs 85 pounds, size of refrigerator

COM DEV International; UofT, U Waterloo (funders CSA/Defence Research & Development Canada



GHGSAT (CLAIRE)

Mission - global reference for remote sensing of GHG/air quality gas (AQG) emissions from industrial sites

- Novel technology enables GHG/AQG measurement, better accuracy at fraction of cost of comparable alternatives.
- Owners able to monitor all facilities, anywhere in world, with common technology, near-real-time.
- Significantly improved emissions information enable industries to better measure, control, and ultimately reduce emissions of GHGs and AQGs.
- First satellite, *Claire*, launched into Polar Orbit on June 21st

Measures 2 key gases - carbon dioxide, methane

Microsatellite, size of microwave

GHGSAT is Quebec-based, private sector company

THE BUSINESS OF SPACE

Space program provides many, emerging opportunities for engineers & scientists to

- pursue careers*
- help develop new science, programs, applications & companies.*

The key is to understand ‘value proposition’ & ‘value chain’ that connects ‘needs’ with ‘end users’ (i.e. government or industry groups fund the work).

Relevant technologies cover virtually all areas of science & technology.

SPACE AS A BUSINESS

Comsat Business Model is primarily based on providing high speed, high volume, easy to access ‘Point A’ to ‘Point B’ real-time connectivity

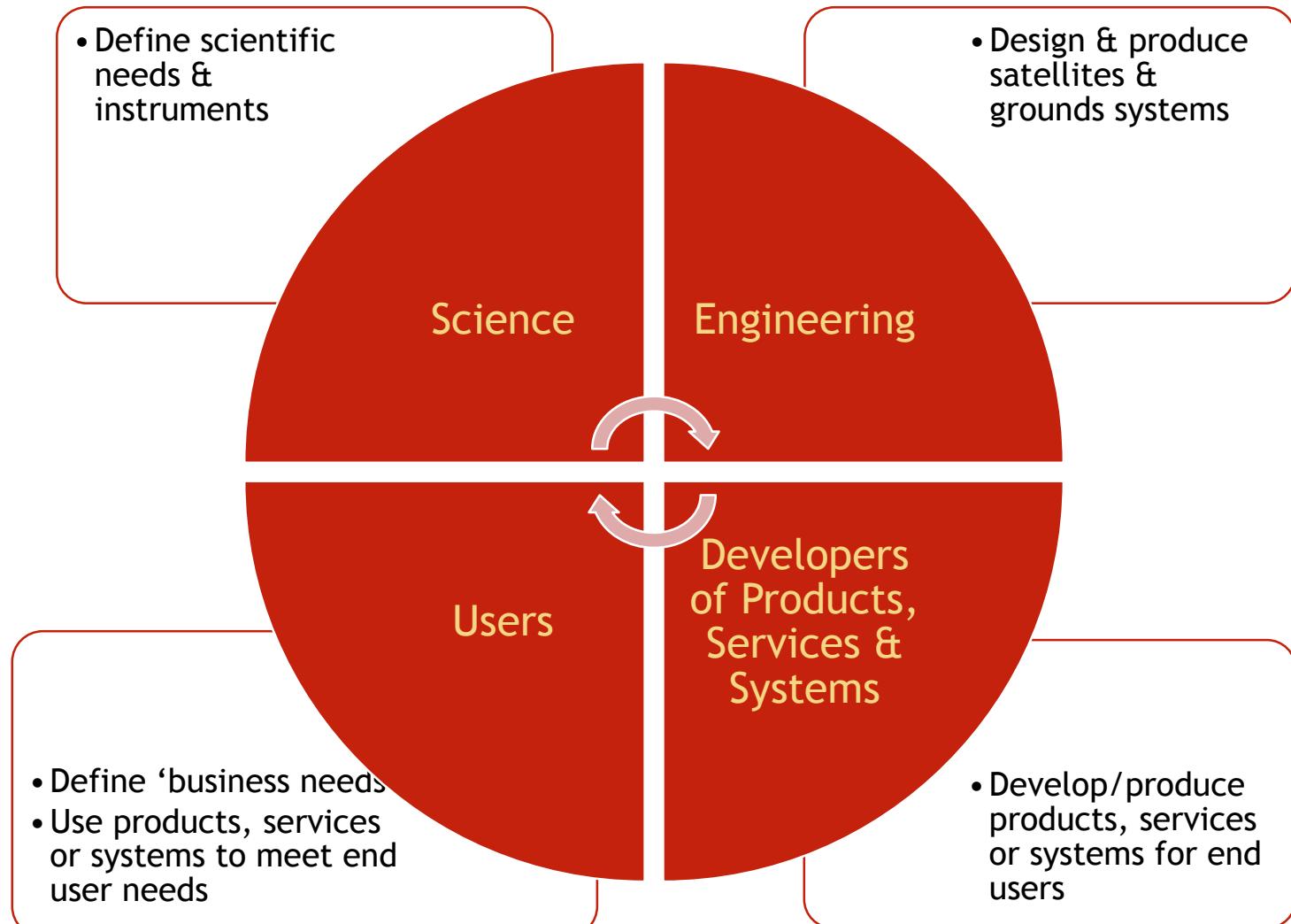
Other satellite Business Models based on Value Chain illustrated below

Data Collection

***Data Analytics –
process/analyze date,
turn raw data into
information***

***Package & Deliver
Actionable
Information to ‘End
Users’ (the real ‘value’
for government, industry
customers)***

SPACE BUSINESS TEAM



ECOSAT ROLE



Ecosat is great fit/natural link with emerging Canadian/international micro-sat/nanosat trend

Excellent training ground for students interested in space-related careers (science, engineering, software, etc.)
- perhaps create new Coop Programs with industry

Companies in Canada & beyond need motivated people with real interests related to space program

Emerging micro-sat/nanosat opportunities are basis for new, small companies re technology/applications

Excellent opportunity for UVic scientists/engineers to pursue new science opportunities/commercial deployments
- e.g. ocean monitoring, environmental monitoring, etc.



UV image from Hubble



Visible Light Image

The background of the image is a photograph of the Aurora Borealis (Northern Lights) in a dark night sky. The aurora is visible as green, swirling, and flowing light forms against the black background. There are also some small white stars scattered across the sky.

Thank you

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