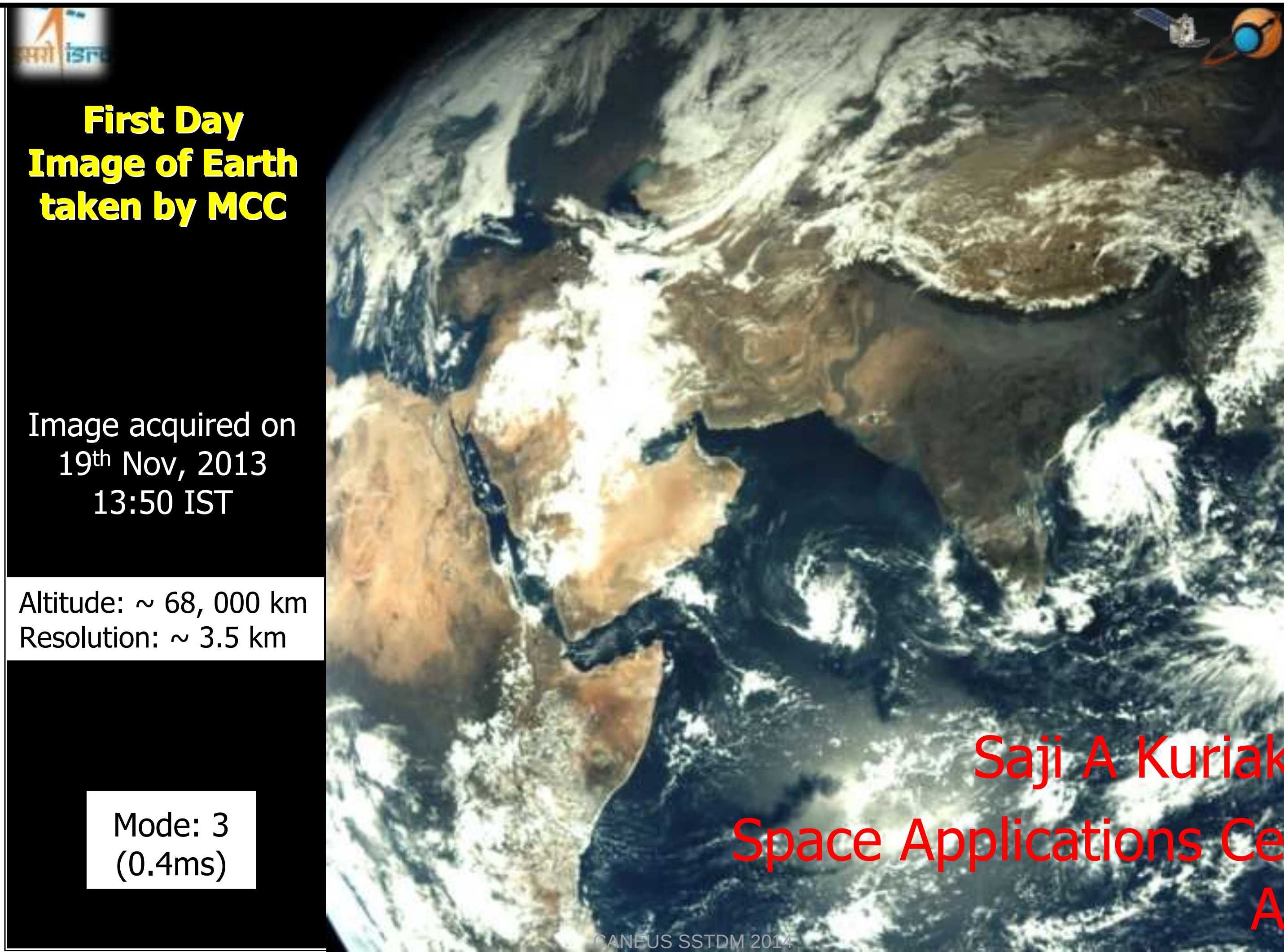
ELECTROOPTICAL PAYLOADS FOR EARTH AND PLANETARY OBSERVATION



Saji A Kuriakose, SEDA
Space Applications Centre, ISRO
Ahmedabad

Electro-optical Imaging Systems Developed By ISRO - Synopsis



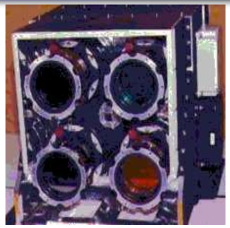


LiV HySI

CHANDRAYAN-1

Sensors developed to observe earth (land, ocean, atmosphere) and moon from space in various wavelength bands

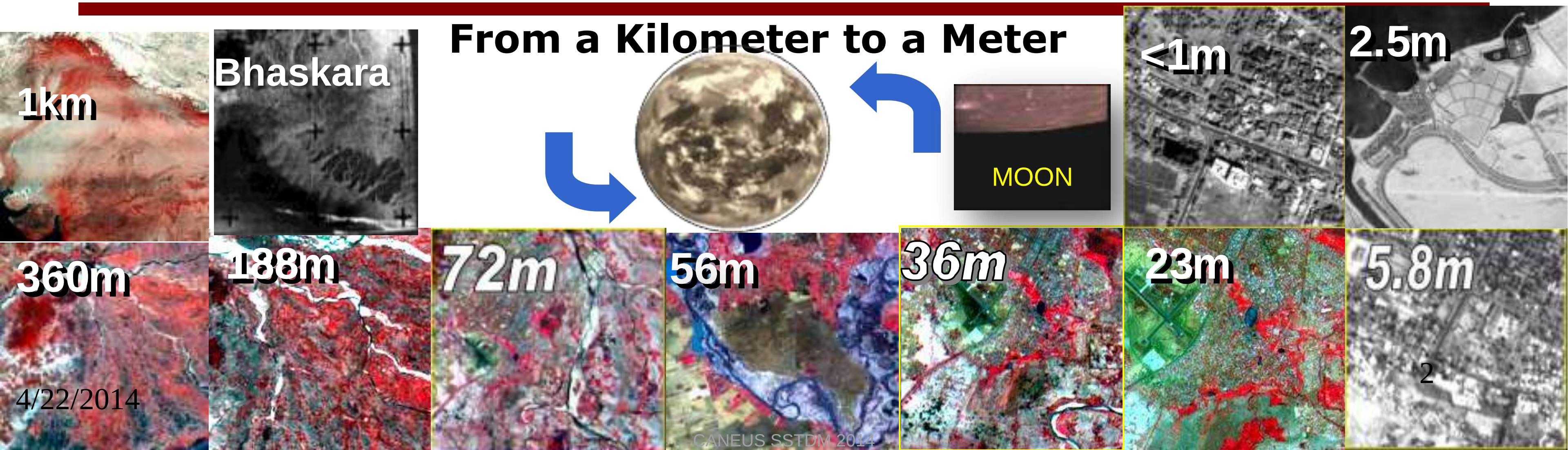
Bhaskara 1979



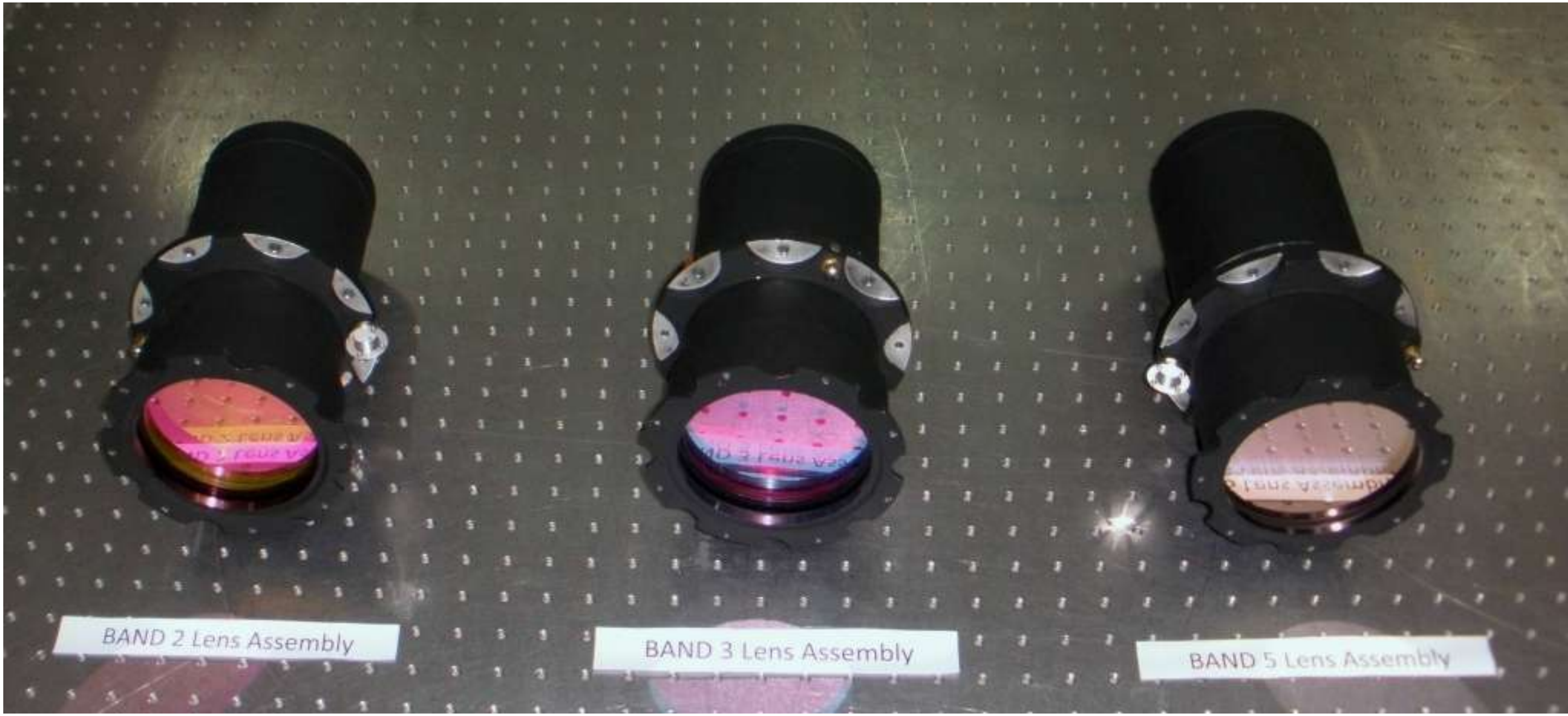
PANCAMERA


Cartosat-2B 2010

From a Kilometer to a Meter

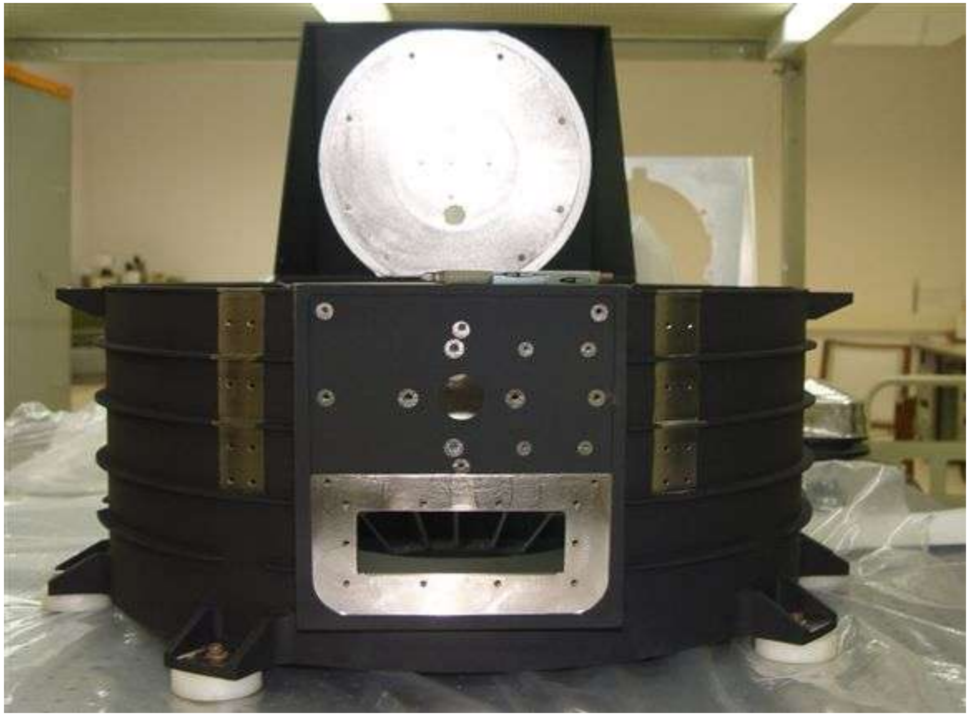


Optics


BAND 2 Lens Assembly
BAND 3 Lens Assembly
BAND 5 Lens Assembly

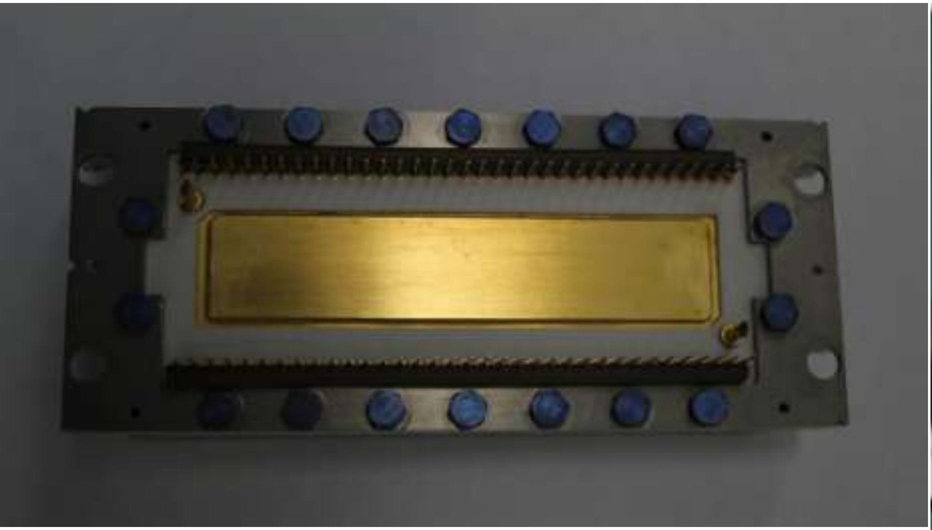
Mechanical structures

AWiFS

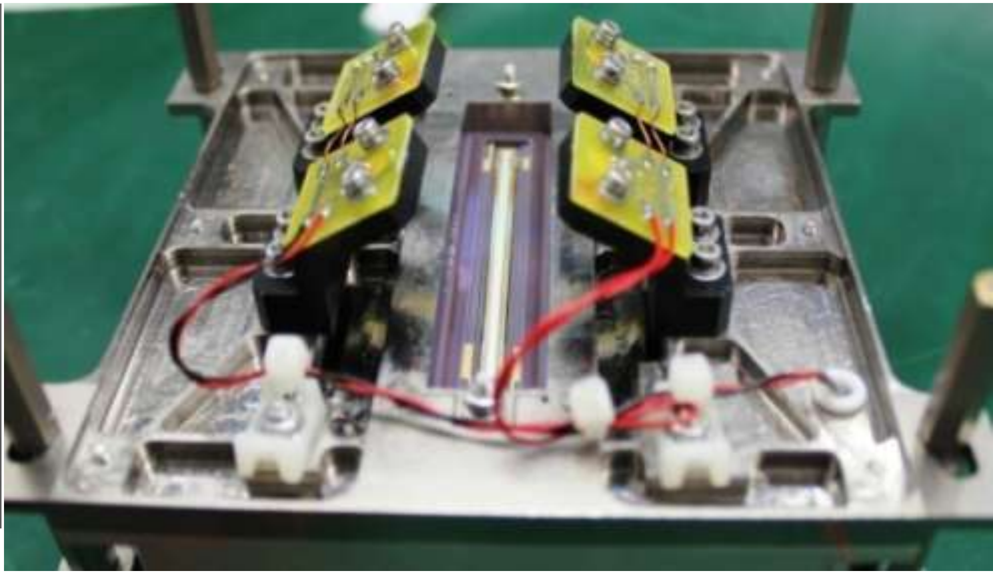


LISS IV

Detectors

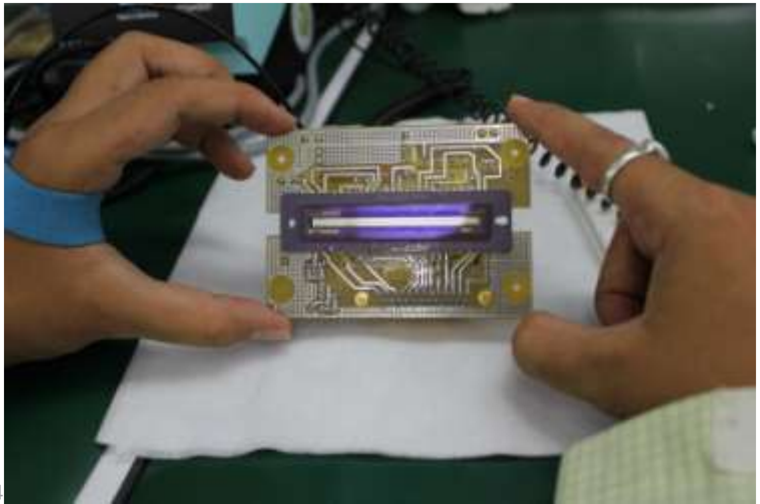


6K SWIR Detector



6K VNIR CCD (191A)

6K VNIR CCD (191A)



Payload Electronics

- detector drive signals (Bias and clocks)
- analog and digital processing of detector output
- On-board calibration electronics
- Timing and control signal generation
- Onboard data processing like Non Uniformity Correction (NUC)
- Power supply for all payload electronics systems
- Interface to data handling, Tele-command, Telemetry and Raw bus

Resource Monitoring

Bhaskara

- ✓ First Remote sensing camera on satellite
  - ➢ Spin stabilized satellite,
  - ➢ Super Vidicon TV cameras (area detector)
  - ➢ Mechanical & electronic shutters
  - ➢ High voltage circuitry (14KV)
  - ➢ Slow readout of Vidicon with precision current sources
  - ➢ Low noise video processing, 400Kbps data rate, contiguous pictures
  - ➢ Discrete components based CMOS logic, ADC etc.

IGOV-1Km, Swath-400Km
2 Bands

IRS-1A/B: Quantum jump in resource observation

- First operational satellite designed for resource monitoring
- Circular sun synchronous polar orbit, 3-axis stabilized satellite
- Resolution improved from 1Km to 36.5m, Data rate -26Mbps
- Solid state technology (2048 element, 13µ pixel CCD)
  - Better SNR & radiometric accuracy , reduced complexity
- Band wise modular architecture to survive single point failures.

- ✓ CCD based imaging technology mastered & quantization (7 bit) limited noise systems achieved
- ✓ Phased readout of CCD to minimize hardware
- ✓ LS/STTL devices used meet speed
- ✓ Non-space grade ICS like Op-amps, clock driver, ADC, analog switch used after in house qualification.
- ✓ S & X band Tx systems developed.

Development helped in understanding the sensitivities of band to band registration.

Occasional radiometric jump & blooming at few places understood & corrected in subsequent payloads

The overall data quality was very good

IRS-1C/D

Three tier imaging capability

- WiFS : Coarse resolution (188m) & wide swath(700Km)
- LISS-3: Medium resolution (23.5m in VNIR,70m in SWIR),swath:140Km
- PAN: High resolution (5.8m) & swath 70Km)

Challenges

- ➢ WiFS
  - ✓ Indigenous lens design & development
- ➢ Dark signal issues, large signal levels & data rate matching
  - ✓ Resolved by combination of optical along track alignment and line sampling
- ➢ PAN-First time development of 3mirror off-axis un-obscured reflective telescope
  - ✓ Swath achieved with three 7µm pixel, 4000 element CCDs
  - ✓ Steering mechanism (±26◦) for faster revisit & stereo
  - ✓ Optical bias of CCDs to improve the charge transfer
  - ✓ FTTL for high speed logic , Data rate increased (85Mbps)
  - ✓ In house qualified high-speed Op-amps (GBW: 350MHz), ADC (20Msps) & precision switch, etc. to meet speed

IRS-1C/D

LISS-3

- 6K element high capacity low noise CCD developed for (VNIR)
  - ✓ **Challenges in electrical interfacing to realize proper PAM signal met**
- First time, SWIR band realized with InGaAs detector (2100 element, 26 μ pixel, staggered)
  - ✓ **Complex detector- development a challenge**
  - ✓ **Vidicon mode of operation-new CE to meet complex signal processing**

LISS-III

- Blooming problems avoided with large dynamic range detectors
  - ✓ **Caused overdrive of signal processors at high illumination resulting in phase reversal of Op-amp and high current conditions**
  - ✓ **Resolved by incorporating anti-blooming control at CCD and high-speed clipping circuits in video chain**
- BBR and thermo-mechanical stability
  - ✓ **Structures of PAN & LISS-3 realized by milling them from large Invar forgings with weight reduction techniques**

The spacecraft was considered best in civilian remote sensing

RESOURCESAT-1

Follow on of IRS-IC/D
PAN enhanced to Multi-spectral (LISS-4)
LISS-3 (SWIR) improved to 23.5m ground resolution
AWiFS realized with 70m ground resolution, 4 bands (B2,B3,B4, B5) and 10 bit radiometric data

- Improved urban planning
- Mapping
- National security
- Crop discrimination & yield
- Precision Farming
- Forestry
- Disaster management

RESOURCESAT-2

LISS-4

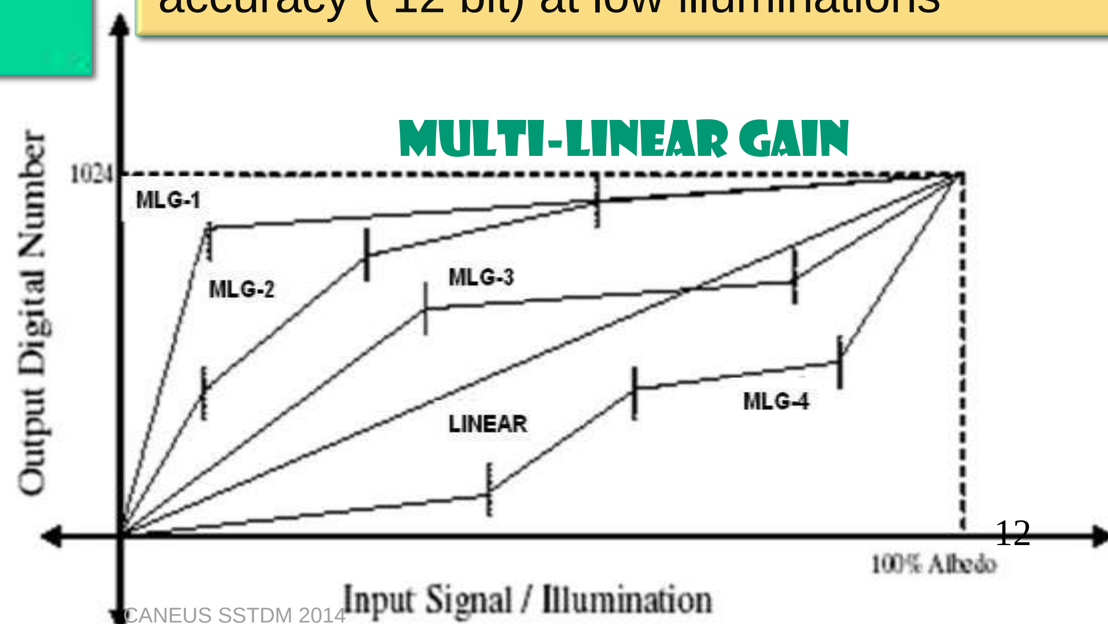
✓Improved contrast, 100% albedo with single gain
✓Full 70Km data (23Km in RS-1) Transmitted

Data compression (Tx-105Mbps)

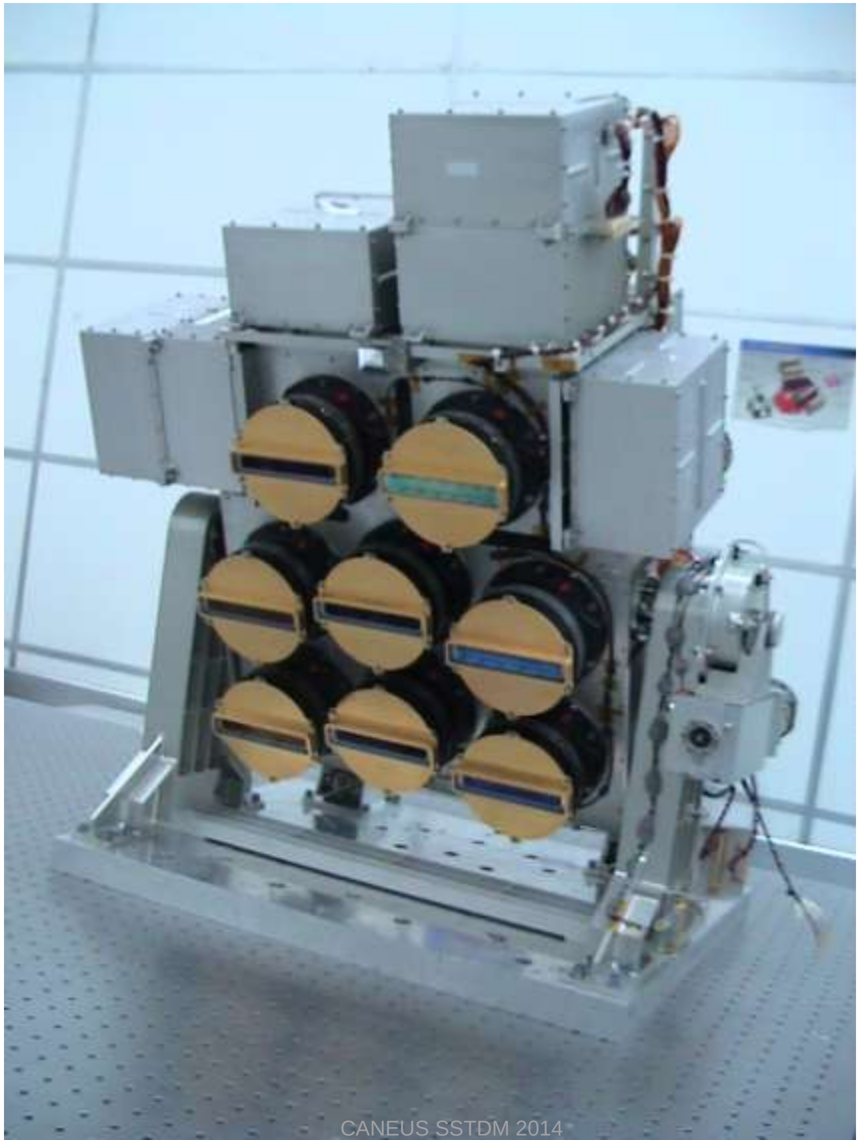
✓DPCM for LISS-4 and LISS-3 with 10 bit radiometric resolution
✓MLG (AWiFS) to enhance radiometric accuracy (12 bit) at low illuminations

Miniaturization

RESOURCESAT	1	2
Total Cards	131	46
Packages	29	12
Volume (in^3)	11296	3082
Weight (Kg)	107	32
Power (W)	223	180



OCEANOGRAPHY SENSORS



OCM -1/2

- ✓ Spatial footprint:360m-Best in its class
- ✓ Swath 1420 Kms, 2 day repeativity
- ✓ 8 spectral bands
- ✓ Large FOV (±43◦) met with telecentric lens

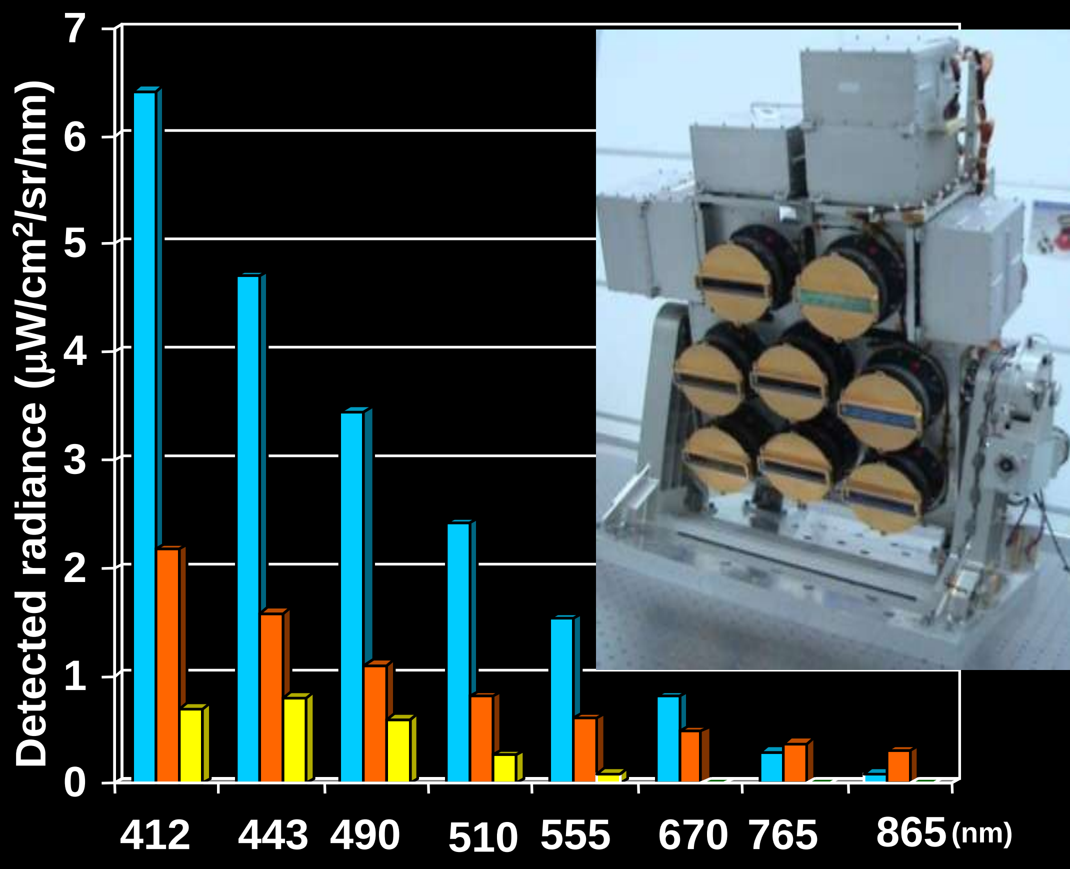
- ✓ Sea & land imaging
- ✓ Large dynamic range & low signal from sea
- ✓ Large atmospheric path radiance (ocean -20%, atmosphere-80%), radiance contamination due to sun-glint
  - ➢ Narrow spectral bandwidth
  - ➢ 6K detector with large charge handling capacity + exposure control & anti-blooming control
  - ➢ Atmosphere correction - B7 & B8
- ✓ Sun glint (season & global)
  - ➢ Dealt by ±20º tilt mechanism
  - ➢ Light weight structure
  - ➢ NESR< $1.08 \mu W.cm^{-2} sr^{-1} \mu m^{-1}$ @1x1Km2 resolution

Sensor detected radiance =

Raleigh path radiance (molecular scattering) +

Aerosol path radiance (aerosol scattering) +

Water leaving radiance x Atmospheric transmittance

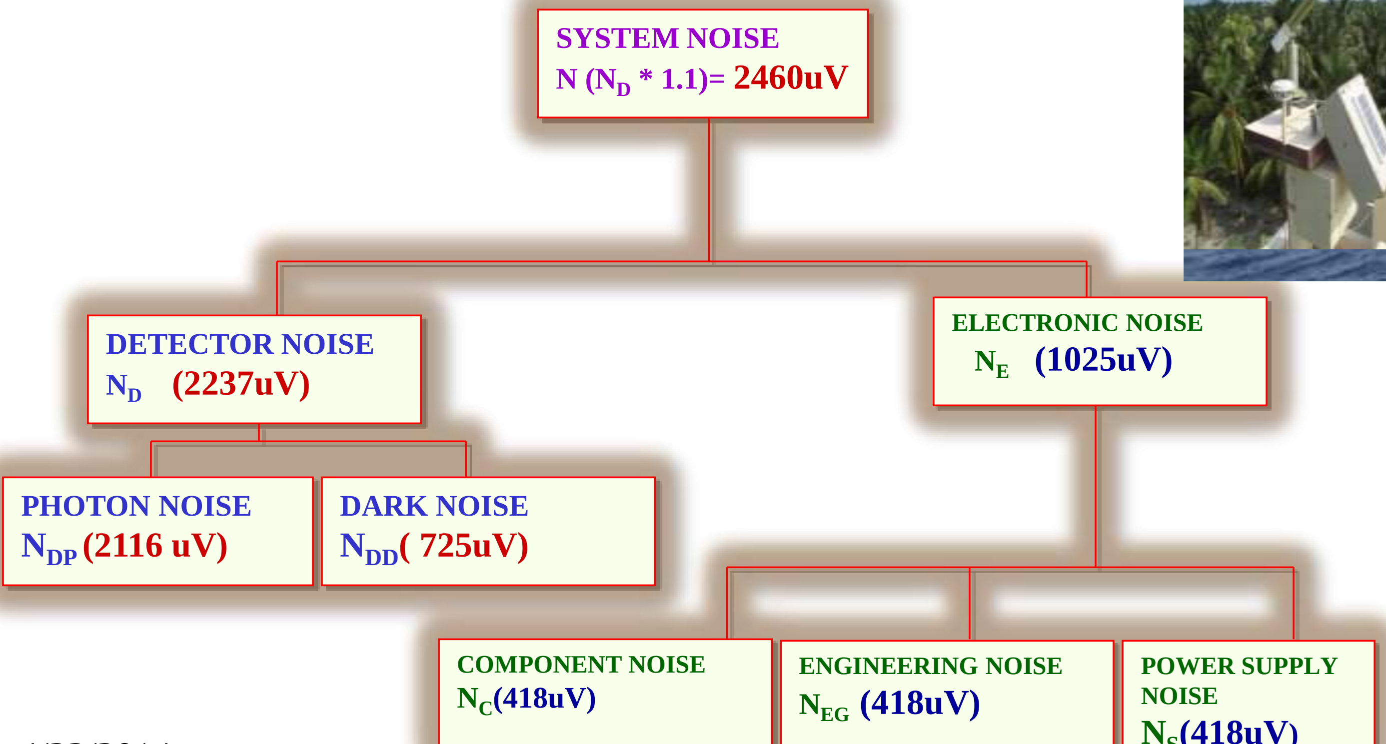


✓ True 12 bit digitization (first time)

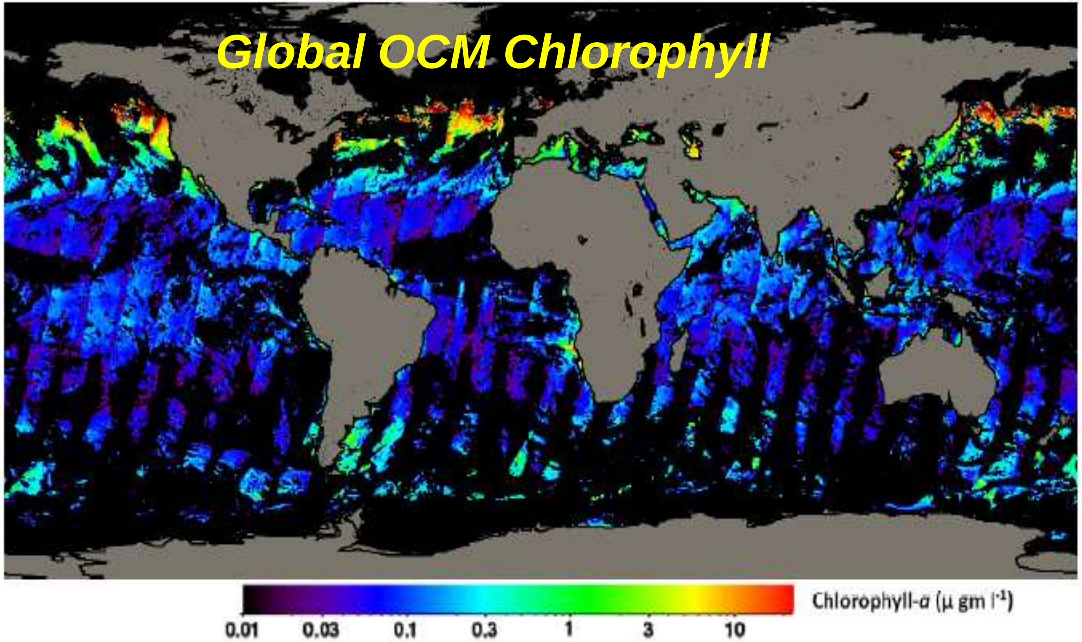
- Noise modeled, apportioned & controlled
- Achieved photon noise limited performance
- Band wise separate lens, filter, detector and electronics to maximize performance
- Lens barrel material selected to compensate CTE of Lens back focal length

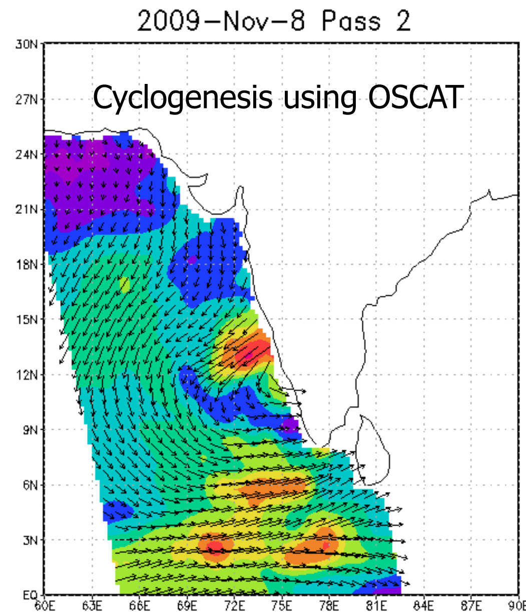
✓ On-board calibration

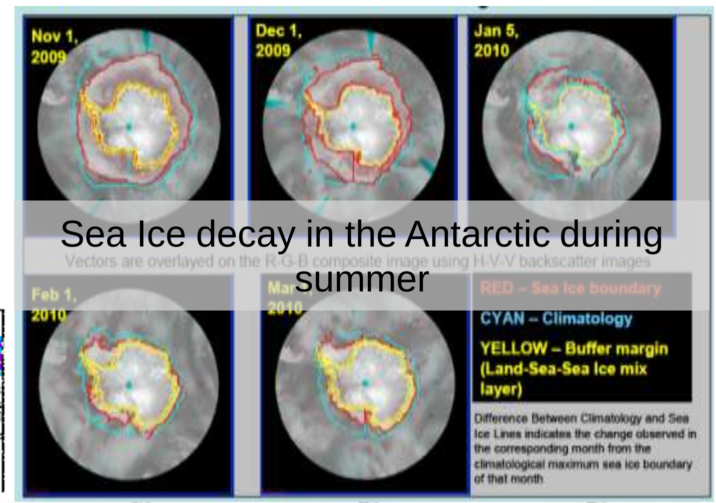
- Low noise current controlled LED source
- Exposure selection for 16 levels
- NIST traceable uniform source for radiometric calibration on ground
- In-situ ocean measurements for validating sensor calibration after launch.



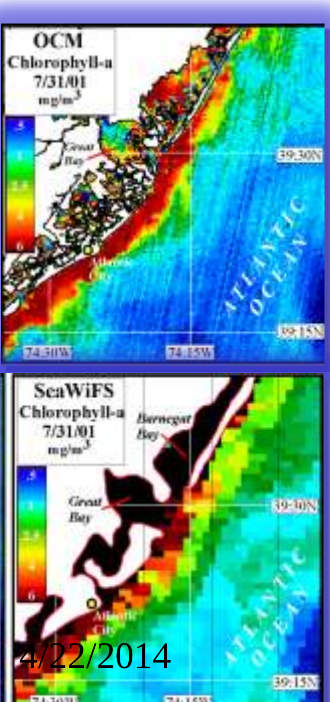
Kavaratti site (in-situ) data



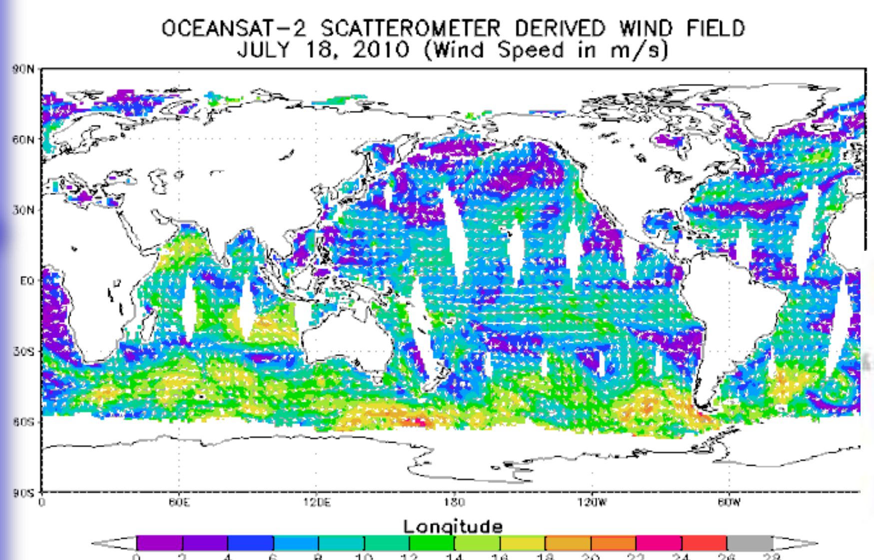




Sea Ice decay in the Antarctic during summer



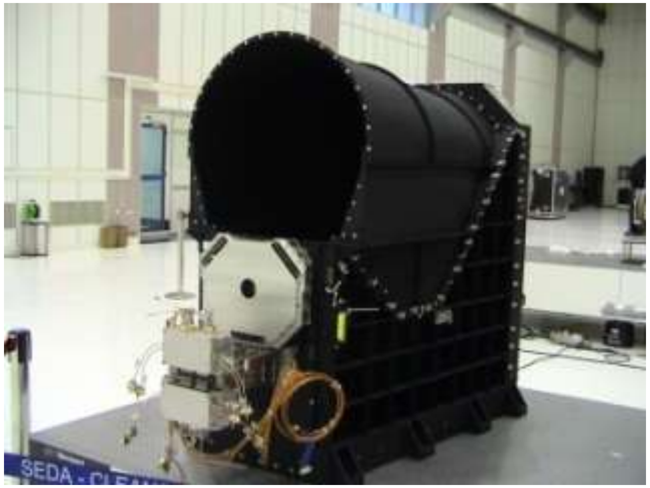
OCM & SeaWiFS



Oil Spill Detection -Gulf of Mexico

CARTOGRAPHY SENSORS

TES



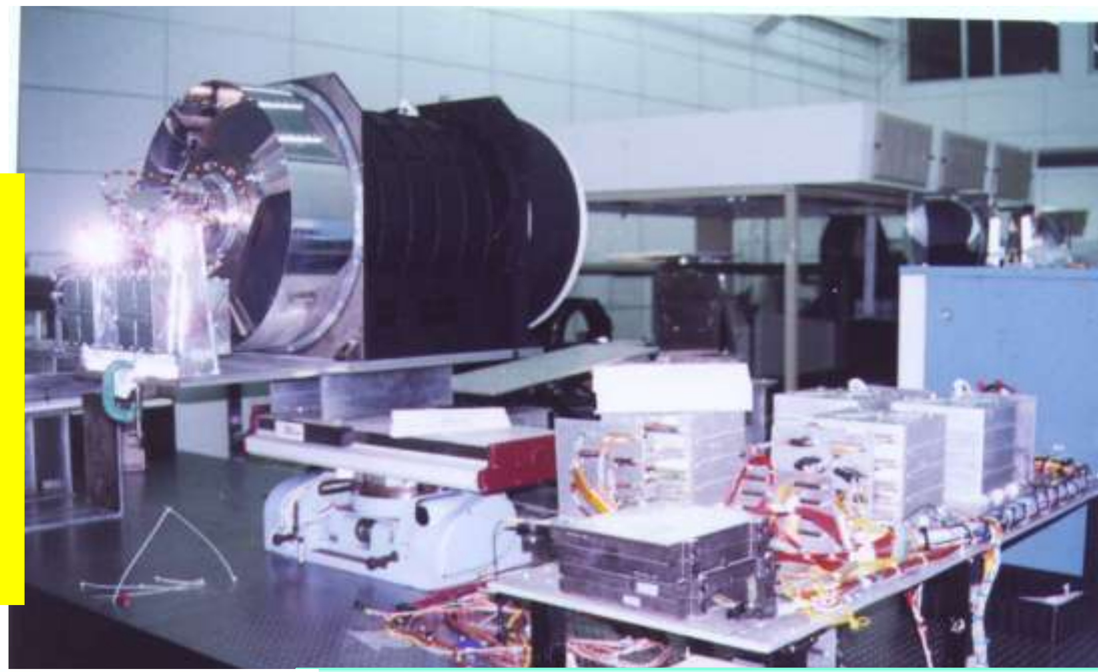
Cartosat 1

Cartosat 2

TES

IGFOV (m) @560Km : 1
Swath(Km) >14
SNR @ Saturation >128
SWR @ Nyquist >0.16
Data rate(Mbps) : 2*85

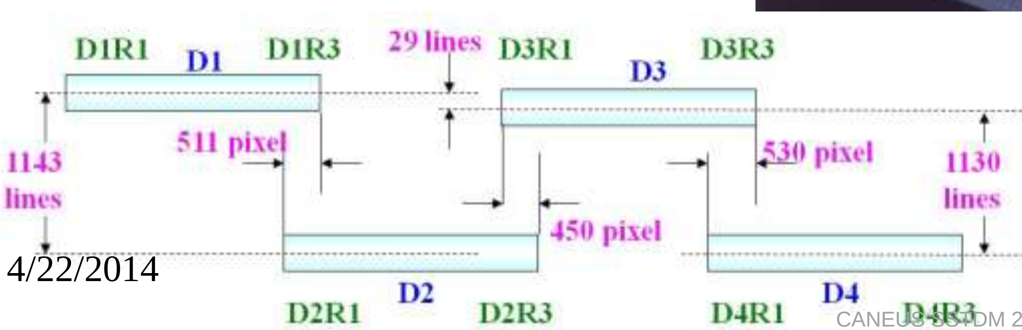
Challenges associated with HR sensors
(a) Signal strength
(b) Large focal length requirements
(c) Diffraction limit of optics
(d) Large data rate
(e) Platform stability



✓ High resolution Camera

- 560mm on-axis RC telescope (F/7)
- Required speed 6x PAN met by velocity reduction + IRS- PAN camera electronics
- First time complex satellite slewing technology tried

Short development time - 1 year



CARTOSAT-1

- ✓ First Real time stereo imaging
- ✓ Two fore & aft. PAN cameras (500- 850 nm)
- ✓ Better than 2.5 m resolution
- ✓ Swath 27.5 km for stereo and 55 km for monoscopic mode
- ✓ across track tilt to give better revisit

New technologies

- ✓ 500mm dia TMA optics for large FOV(±1.08º)
  - ➢ Mirrors polish:λ/80 accuracy
  - ➢ Iso-static mirror mounts
  - ➢ Matching of mechanical/ thermal/ opto-mechanical properties
- ✓ Light weighted Invar structure (EO module weight 250Kg)
- ✓ 12000 element CCD, Focal plane CCD drive Electronics near to detector
- ✓ Video processor - processing within 200ns, (100% albedo). Digital double sampler designed with 12Bit ADC(40Msps) & current feedback Op-amps
- ✓ Digital logic, 105MHz Tx -First time ECL logic for timing & interface
- ✓ Transmission limit of 105Mbit/s, onboard 3.2:1 data compression (338 Mbit/s)

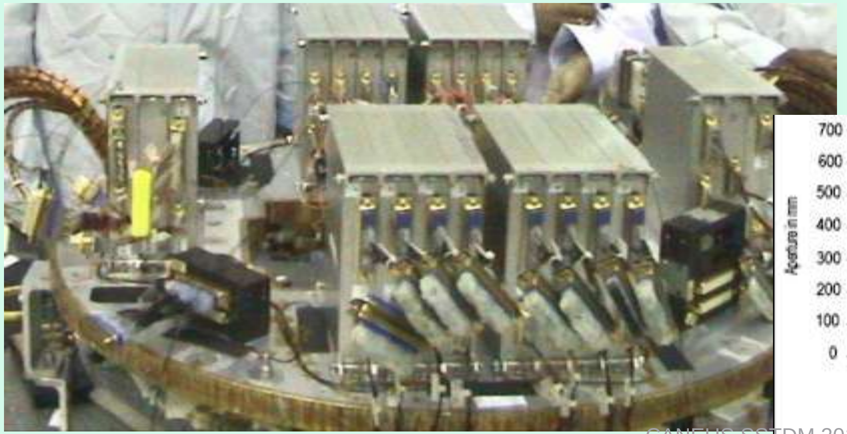
The data products software development was a major milestone. Best quality Digital elevation data realized in the world.

CARTOSAT-2

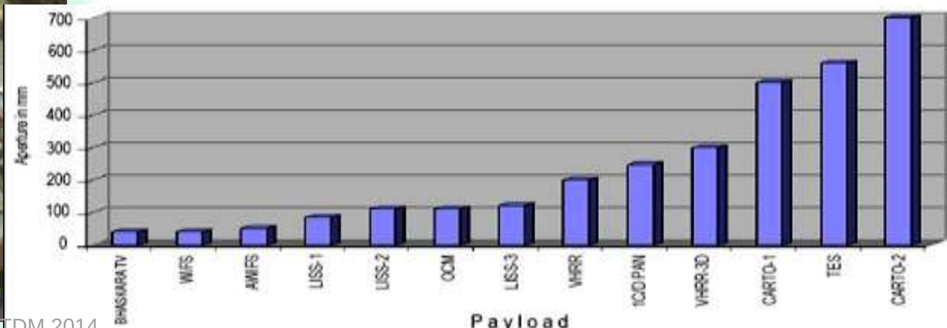
- ✓Indigenous large mirrors (50% light weighted 700mm dia)
- ✓Light weight CFRP structure(39Kg) & kinematic mirror mount
- ✓Compact f/8 system-Ritchey-Chretien on-axis Telescope
- ✓Model for telescope performance developed. Assembled in 1g conditions to meet operations in zero gravity
- ✓Stresses minimized, optics surface finish of $\lambda/50$ maintained
- ✓Thermal control of large size P/L – difficult task (better thermo-mechanical performance)
- ✓Agile spacecraft- designed around payload

- ✓ Better than 1m resolution
- ✓ 10 Km swath
- ✓ Step & stare technology
- ✓ Linear push broom array
- ✓ 10 bits

- ✓ Carto-2-Jan 2007
- ✓ Carto- 2A-April 2008
- ✓ Carto- 2B July 2010



Growth of Aperture

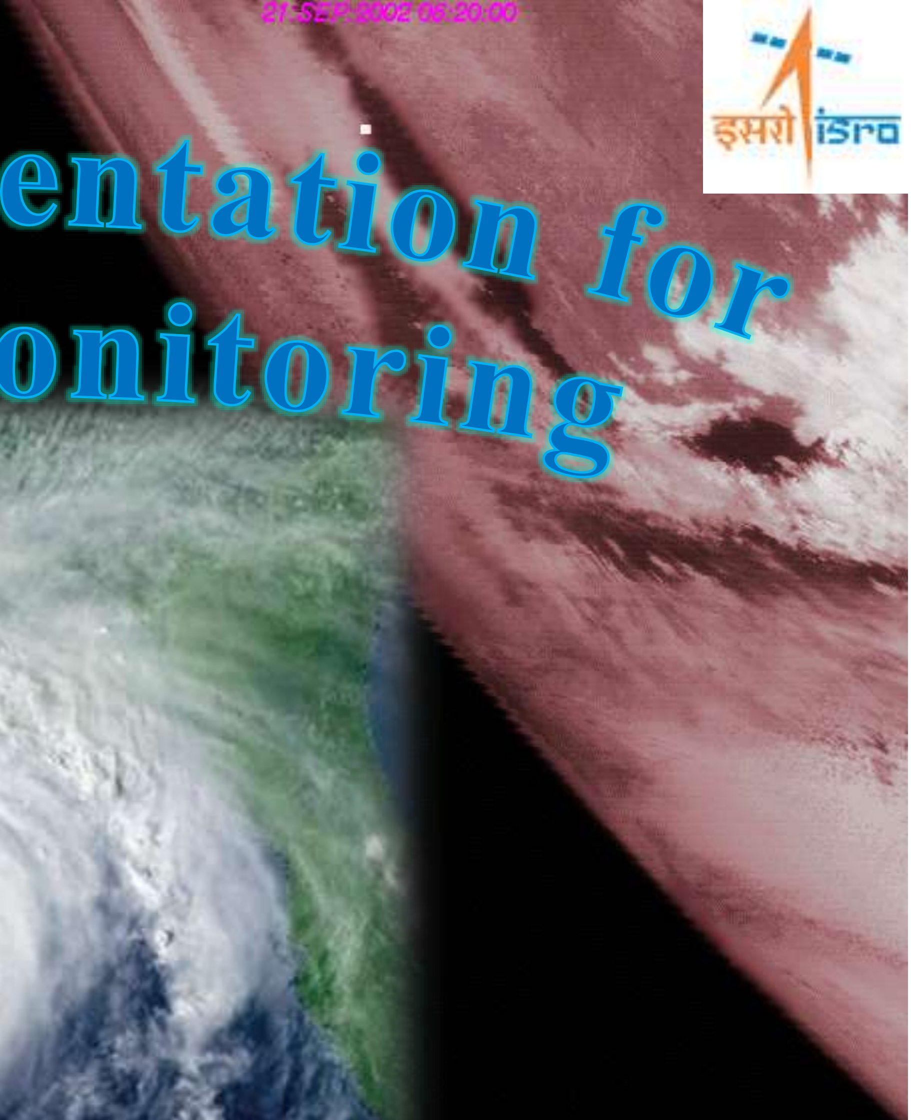


Cartosat-2 image of Mobil (USA)

Cartosat-2 image of Karnataka Vidhana Soudha

Cartosat-2B- Pentagon USA

Space Instrumentation for Weather monitoring



Weather monitoring- INSAT 2A/2B/2E/3A & Kalpana

Very High Resolution from GEO orbit

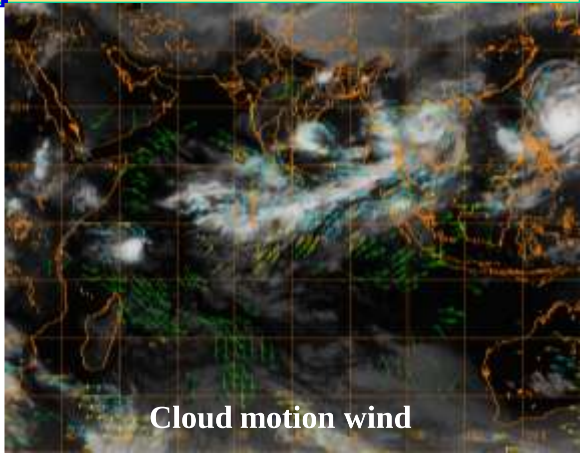
✓ Large spectral range, multi-band
- ➢ Reflective telescope + dichroic beam splitters
- ➢ Oversampling (electronics)- improve contrast at Nyquist

✓ Long dwell time
- ➢ Multiple detectors used

✓ Large FOV – 24◦ x18◦ (full globe +)
- ➢ Whiskbroom configuration with 2 Axis electro-mechanical scanning
- ➢ Programmable scanning -selected area
- ➢ Complex, accurate, synchronous scan mechanism developed for long life
- ➢ Select materials & torque for Thermo-mechanical stability

✓ IR detector -Cooling
- ➢ Passive cooler realized- 90K

•Cloud picture
•Sea surface temperature
•Wind
•Vertical temperature profile
•Vertical humidity profile and its horizontal positional distribution
•Total Ozone and its vertical profile
•Aerosol density and its vertical profile
•Trace constituents and their vertical profiles


Cloud motion wind

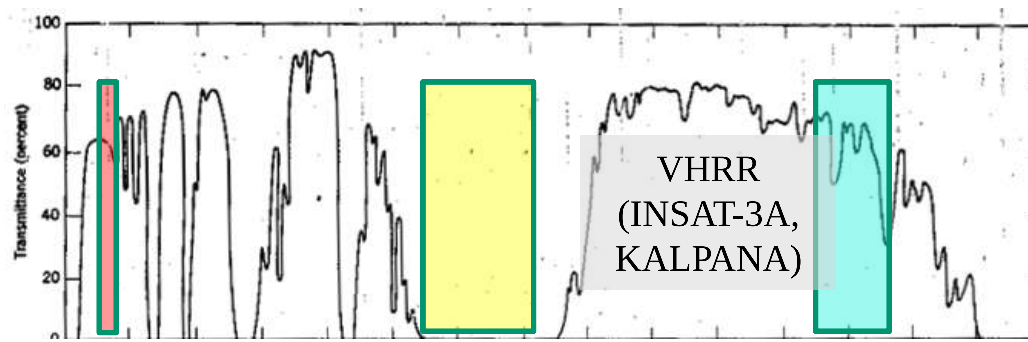
Development of coolers, temperature sensor integration for very low temperature operation was an uphill task

Challenges in weather monitoring instruments

✓Large background
- ➢ Cold view beyond earth
- ➢ Black body view
- ✓High resolution ADC
- ➢ 14 bit dynamic range & accuracy achieved by ingeniously using 10 bit ADC

✓Small signals (pA, nV)
- ➢ Very low noise bridge preamplifiers
- ➢ High gain trans-impedance amplifiers

Data processing & display of VHRR data achieved after accounting for
✓scan mirror position
✓Spacecraft attitude
✓Sensor non-uniformities
✓Earth's sphericity & oblateness



Vis
0.55-0.75um

WVP
5.7-7.1um

Thermal IR
10.5-12.5um

NEdT/SNR:	6 @2.5%Albedo	0.5K(@300K)	0.25K (@300K)
Dynamic Range:	100% Albedo	WVP and TIR: 4K-340K	
Spatial Resolution:	2 Km	8 Km	8 Km

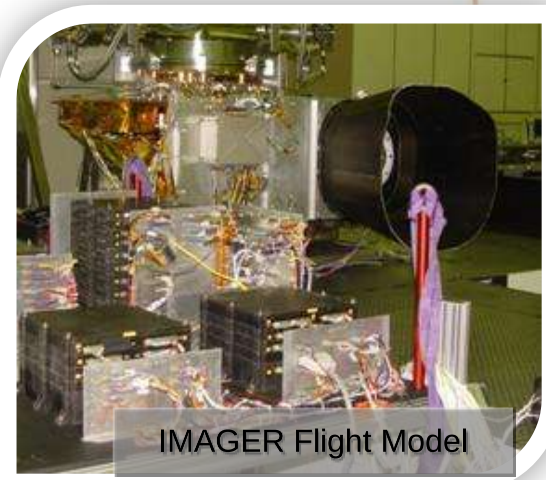
- INSAT-3A /2E upgraded with SWIR channel (1Km resolution) for monitoring cloud, snow delineation, forest fire detection etc.
- INSAT 2E, 3A & Kalpana additionally have water vapour channels

INSAT-3D Challenges

- Improvements in Imager resolution
- 18 narrow IR channels in sounder (measurement of vertical profile of CO_2, water vapour, Ozone etc.) Hardware was realized in same volume

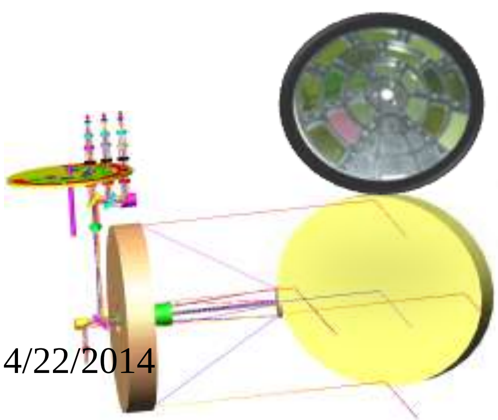
New technologies

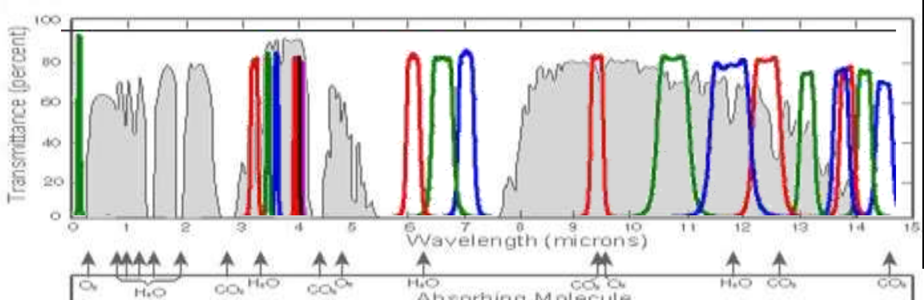
- ✓ Filter wheel at 200K & shaft at 0-40◦C
- ✓ 14 bit ADC to meet large dynamic range
  - Realized chain noise, referred to detector- 3 nV/√Hz
- ✓ Black-body temperature measured with 0.1◦C accuracy
- ✓ Large electronics hardware miniaturized

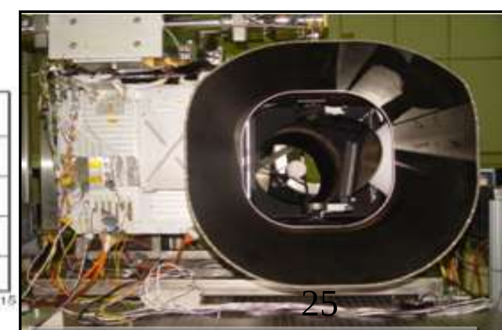


IMAGER Flight Model

Channels	Resolution
Visible, SWIR	1 km
MIR, TIR-1, TIR-2	4 km
Water Vapor	8 km







SOUNDER Flight Model

MINIATURE SENSORS DEVELOPMENT

MINIATURISED MULTISPECTRAL CAMERA (IMS-1)

Design for small satellite

- Small volume, low weight & power
- Size & weight limit
- Focal length – Resolution
- Aperture –SNR & Contrast
- Power limits
- Camera speed
- Transmission data rate,
- Thermal control aspects, etc.

MISSION GOALS

Space craft altitude : 632 Km
Resolution : 37 m
Swath : 151 Km
Spectral bands : 4 (VNIR)

Power: 13.2 W

✓**Indigenously Developed compact Lens**
✓**Indigenously Developed 4K, Four Port CCD**
✓ **FPGA & AFE (instead of video processor) based miniature camera electronics – First time**

IMPROVEMENTS OVER TIME

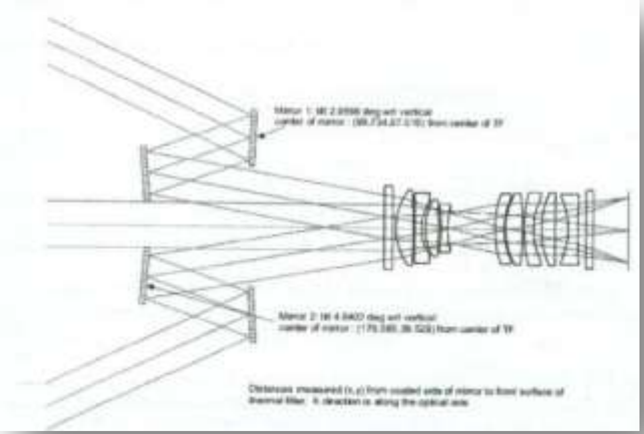
	LISS-2A & 2B (1985)	IMS-1 MX (2007)	NAN0-PL (2010)
			
Size (mm3)	2 X (505 X 504 X 450)	311 X 250 X 167	120 X 140 X 130
Weight (Kg)	150	5.8	1

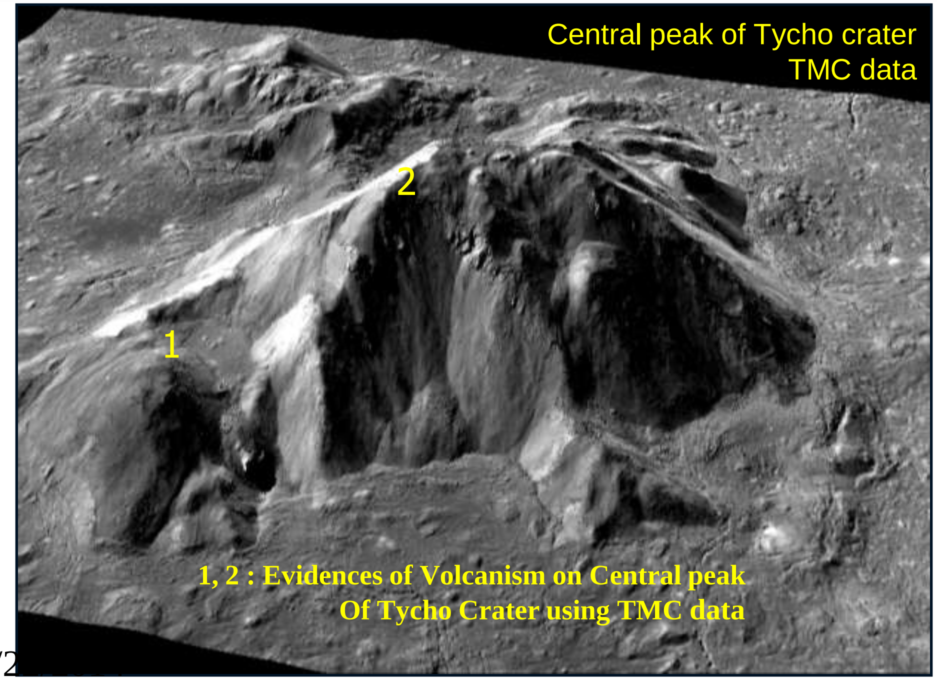
Terrain mapping camera for moon mission

Design Challenges

- ✓ Miniature stereo triplets, B/H = 1 &FOV : ±25◦ (5m)
- Single lens + fold Mirrors (innovative optical field compressor)
- ✓ Low power (20W), small volume & low mass (8Kg)
- Honeycomb with CFRP Face sheets
- APS with On-Chip Digitizer, FPGA based logic

YAW	= 450 mm
ROLL	= 362 mm
PITCH	= 255 mm
Weight	< 6.3 kg
Power	< 1.8 W



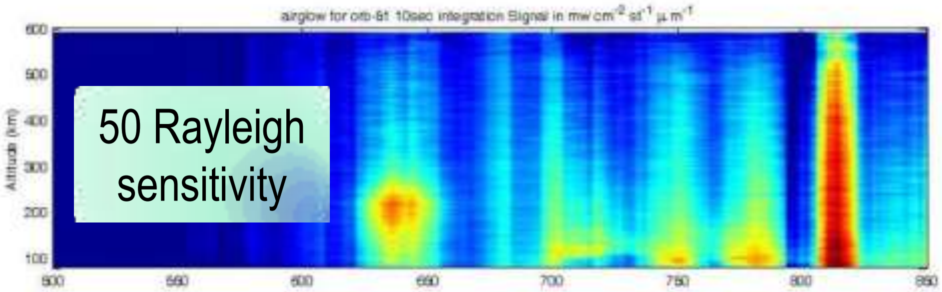


Spectral range	– 0.5 to 0.75 um
Gain / Exposure	– 4 each
Quantization	– 12 bit
MTF	-- >15%
SNR - >80 (@ 1.2 mW/ cm2/str/um)	
>300 (@ 14 mW/ cm2/str/um)	
Datarate	– 16.286Mbps/chain

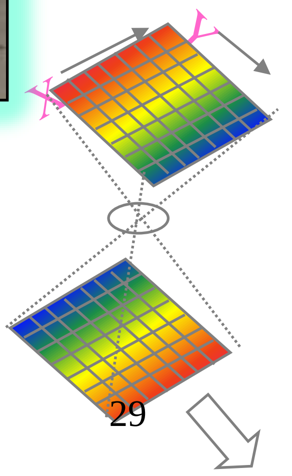
Hyper Spectral Imaging Payload – Mineral/ chemical mapping of lunar surface & air glow measurement

First time

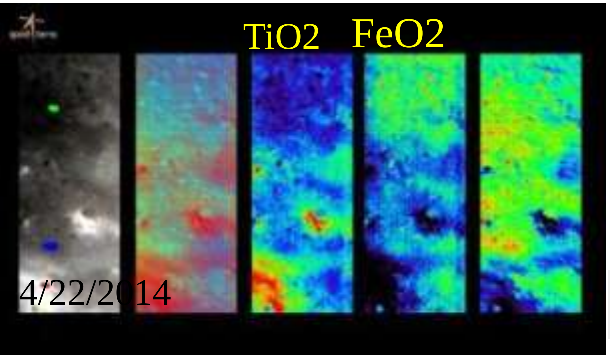
- ✓ **64 bands, 15nm spectral band**
- ► Optics - wedge filter based spectral dispersion & wide band lens for simplicity & compact size
- ► Spectral bandwidth by pixel binning
- ► Active Pixel Sensor-256x 512 pixs with on-chip digitizer for low power & weight + FPGA based camera electronics & Tray packages
- ► Structure using CFRP-Honeycomb



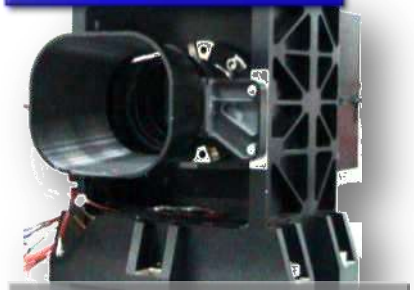
Wedge filter



Power :2.6W
Weight:2.9Kg



CHANDRAYAN-1



IMS-1

NEW SENSORS UNDER DEVELOPMENT & TECHNOLOGY CHALLENGES

Cartosat 2C/D

Challenges

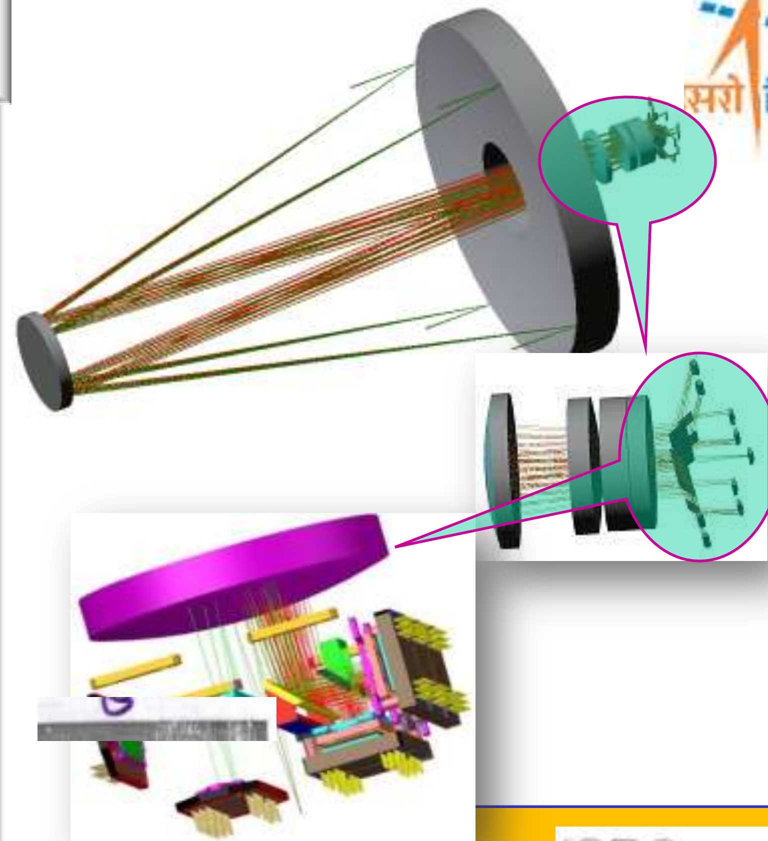
PAN -0.67 m . MX 1.5m imagery,

Optics & structure same as in Carto-2/2A/2B

High Data Rate

Radiometric improvements

- ❑Multi-line TDI detectors
- ❑Optical butting -large swath with short detectors
- ❑Improved FOV
- ❑strip filters for spectral selection
- ❑Low power, high speed focal plane electronics
- ❑Data rate – 3.2 Gbps
- ❑Sync. of satellite movement with TDI detector
- ❑On-board radiometric correction
- ❑Thermal handling – 200W at focal plane
- ❑Development of test bench & data archival



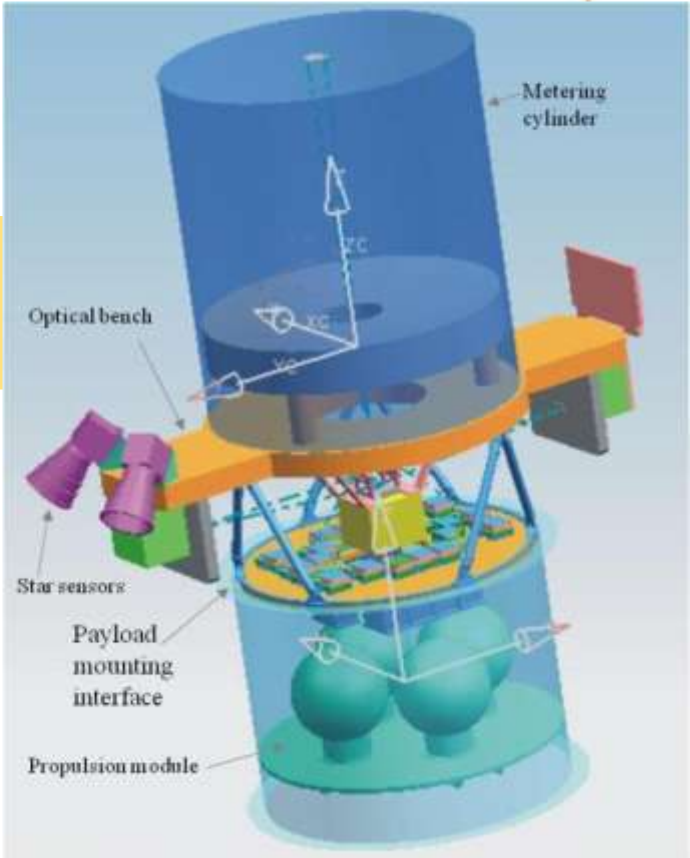
Cartosat-3 Mission

PAN	: 0.25 m (400 – 950 nm)
Mx (VNIR)	: 0.5m, 4 Bands
MIR	: 5m (3- 5 µm)
Swath	: 16 Km@ 450 Km Alt.

Challenges

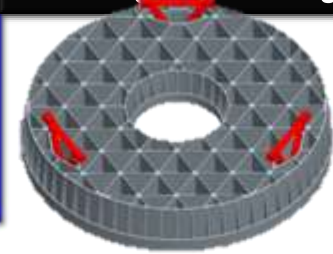
Payload Size: 1.3m Dia* 2.1m
Payload Weight : 550Kg
Payload Power : 1275 W

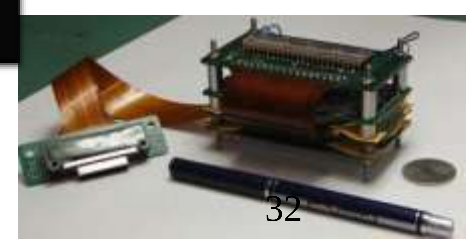
- Agile & stable platform
- High data rates (~41Gbps & 1.6 Tb SSR)
- Variable Compression
- 8-PSK modulation, Ka / X band Tx
- Precise bus control system
- Programmable Integration time w.r.t altitude
- Speed increases by 10 fold
  - Focal plane electronics, 400 signal processors & high capacitance drive
- Higher power requirements (>950W)
  - Focal plane heat removal- heat Pipes/ SIL Pad etc. Power converter design
- On-board focusing
- High speed ground checkout system



CARTOSAT-3 SPACECRAFT PAYLOAD

Mirror -light weighted to 70 Kg from 420 Kg





0.2 Kg, 1.9" X 3.5" X 2.4"

GISAT challenges

- **Surveillance, Monitoring of transient phenomena (cyclones, tsunami etc.)**
- **Continuous spectral discrimination & parameter extraction of vegetation, soil/vegetation, rock/soil ,inland & coastal water**

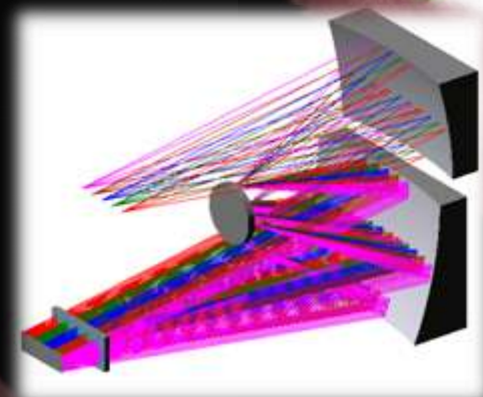
Meteorology and night time imaging

✓ Imaging & spectroscopy for land, ocean & atmosphere studies

✓ Very high resolution (50m VNIR, 1.5Km LWIR) imaging

✓ Very high resolution Imaging spectrometers in VNIR, and SWIR

✓ Versatile scanning modes



➢Optics FOV ~ 1◦, S/C slewing to cover earth disc

➢Spectral range from 0.4 to 12.5 um

➢ High density focal plane

➢Calibration using cold and planetary view

➢24K VNIR, 512x 256 VNIR , 1000x 256 SWIR, 320x 256 LWIR detectors for higher scan speed

➢Convex grating based spectrometers

➢Long life active coolers

➢ 7 scan modes including arbitrary scan for irregular area

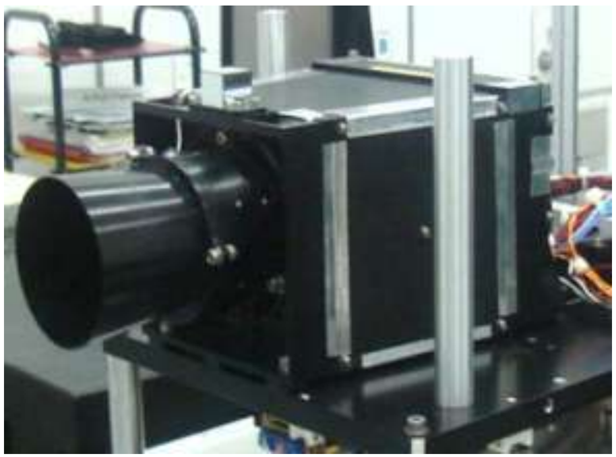
➢Compact focal plane electronics.

➢Photon noise limited system SNR

➢Versatile Formatter design (CCSDS, Space packet protocol) & MIL-STD-1553 interface

Mars Orbiter Mission Payloads

- Methane Sensor for Mars (MSM)
- Thermal Infrared Imaging Spectrometer (TIS)
- Mars Colour Camera (MCC)



MCC

MSM

TIS

Thanks