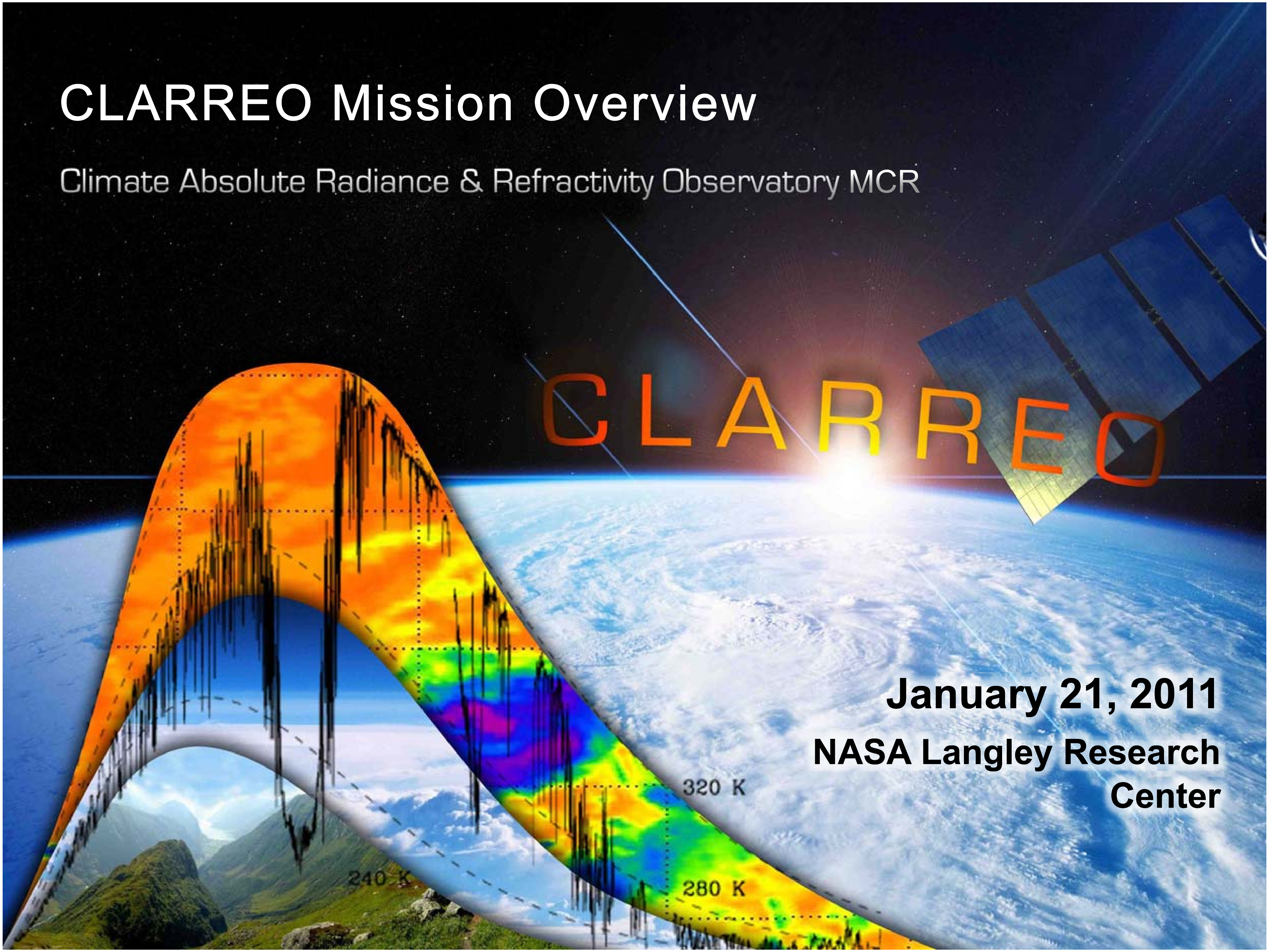
CLARREO Mission Overview

Climate Absolute Radiance & Refractivity Observatory MCR



January 21, 2011

NASA Langley Research Center

This package contains a top-level overview of the CLARREO mission as of January 21, 2011.

For the latest news on the CLARREO mission or for contact information, please visit the mission web site at:

http://clarreo.larc.nasa.gov/

Contents

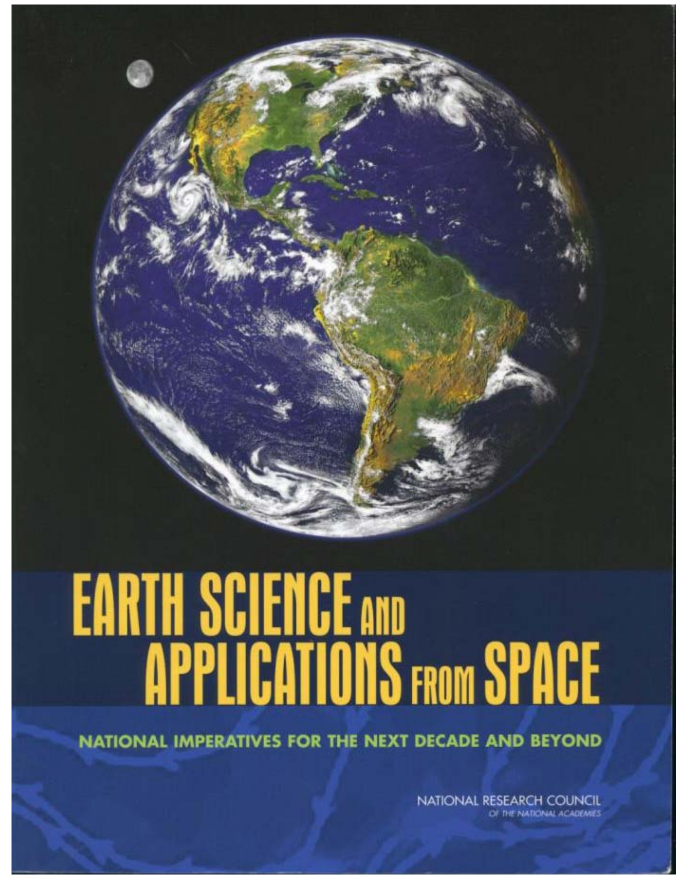
1. CLARREO Background

Mission Origins

CLARREO = Climate Absolute Radiance and Refractivity Observatory

- **CLARREO was recommended as a top priority for NASA by the National Academy of Science**
  - The 2007 Decadal Survey of “Earth Science and Applications from Space” identified CLARREO as one of the four high-priority “Tier 1” earth science missions

- **CLARREO will be the cornerstone of the long-term climate observing system**
  - Trend detection (decadal scale)
  - Improvement and testing of climate predictions
  - Calibration of operational and research sensors



CLARREO is the Next Step in Climate Observation

Mission Benefits and Objectives

Societal Benefits

- **Enable knowledgeable policy decisions based on internationally acknowledged climate measurements and models through:**
  - Observation of high accuracy long-term climate change trends
  - Use the long term climate change observations to test and improve climate forecasts

Science Objectives

- **Make highly accurate and SI-traceable decadal change observations sensitive to the most critical but least understood climate radiative forcings, responses, and feedbacks**
  - Infrared spectra to infer temperature and water vapor feedbacks, cloud feedbacks, and decadal change of temperature profiles, water vapor profiles, clouds, and greenhouse gas radiative effects
  - GNSS-RO to infer decadal change of temperature profiles
  - Solar reflected spectra to infer cloud feedbacks, snow/ice albedo feedbacks, and decadal change of clouds, radiative fluxes, aerosols, snow cover, sea ice, land use
  - Serve as an in-orbit standard to provide Reference Intercalibration for broadband CERES, and operational sounders (CrIS, IASI), imagers such as VIIRS, AVHRR, geostationary

A Mission with Decadal Change Accuracy Traceable to SI Standards

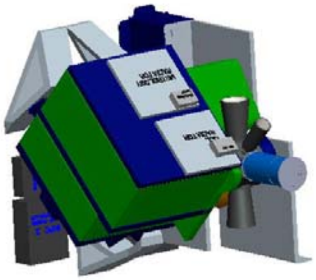
2. Science Measurements

Science Measurement Summary

- **As outlined in the Decadal Survey, CLARREO will make the following science measurements:**
  - Solar reflected spectra: SI traceable relative uncertainty of 0.3% (*k*=2)*
  - Infrared emitted spectra: SI traceable uncertainty of 0.1K (*k*=3)*
  - Global Navigational Satellite System Radio Occultation: SI traceable uncertainty of 0.1K (*k*=3)*
- **For each measurement CLARREO will acquire:**
  - At least five (5) years of data to establish an initial climate benchmark
  - At least one (1) year of overlapping data between two like instruments for measurement verification
- **To accomplish these measurements CLARREO will fly:**
  - Two infrared spectrometers
  - Two solar reflected spectrometers
  - Two GNSS radio occultation instruments

The term “k” refers to Coverage Factor as defined in NIST TN 1297.

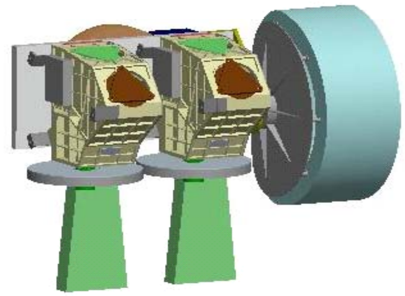
Science Instruments



Infrared (IR) Instrument Suite

Fourier Transform Spectrometer

- Systematic error less than 0.1K (*k=3)*
- 200 – 2000 cm^{-1} contiguous spectral coverage
- 0.5 cm^{-1} unapodized spectral resolution
- Nadir pointing, systematic within 0.2°
- GIFOV: 25 km
- Consecutive earth view orbit samples ≤ 200 km
- NeDT < 10 K (1 σ)



Reflected Solar (RS) Instrument Suite

Two Grating Spectrometers with Gimbal-mounted (1-axis)

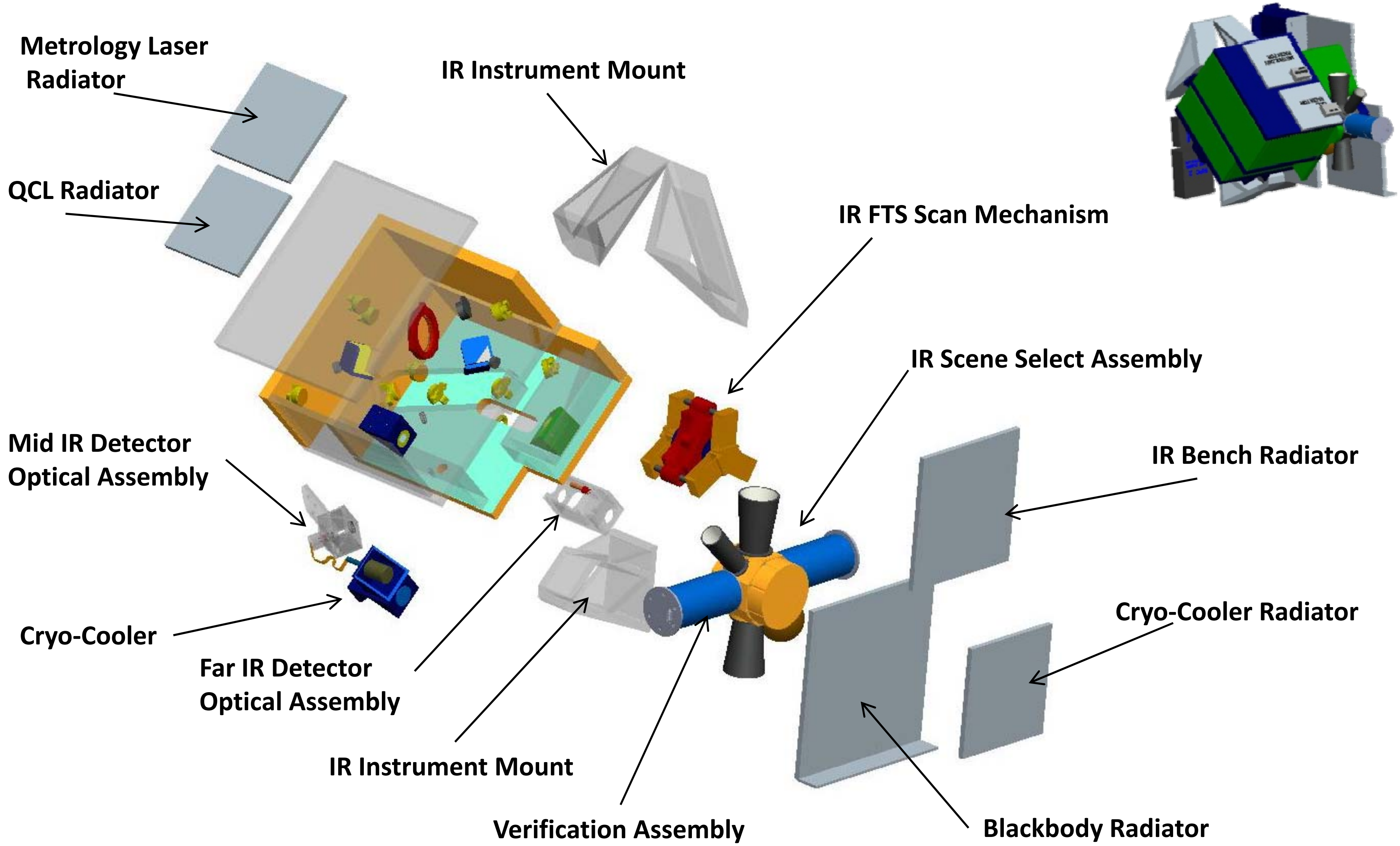
- Systematic error less than 0.3% (*k*=2) of earth mean reflectance
- 320 – 2300 nm contiguous spectral coverage
- 4 nm sampling, 8 nm resolution
- GIFOV < 0.5 km by 0.5 km
- Swath width ≥ 100km @600 km
- Nadir viewing > 90% of the time
- S/N ratio > 33 for λ < 900 nm, S/N ratio > 25 for λ > 900 nm
- Polarization sensitivity < 0.5% (*k=2*) for λ < 1000 nm, < 0.75% (*k=2*) for λ > 1000 nm

GNSS Radio Occultation Receiver

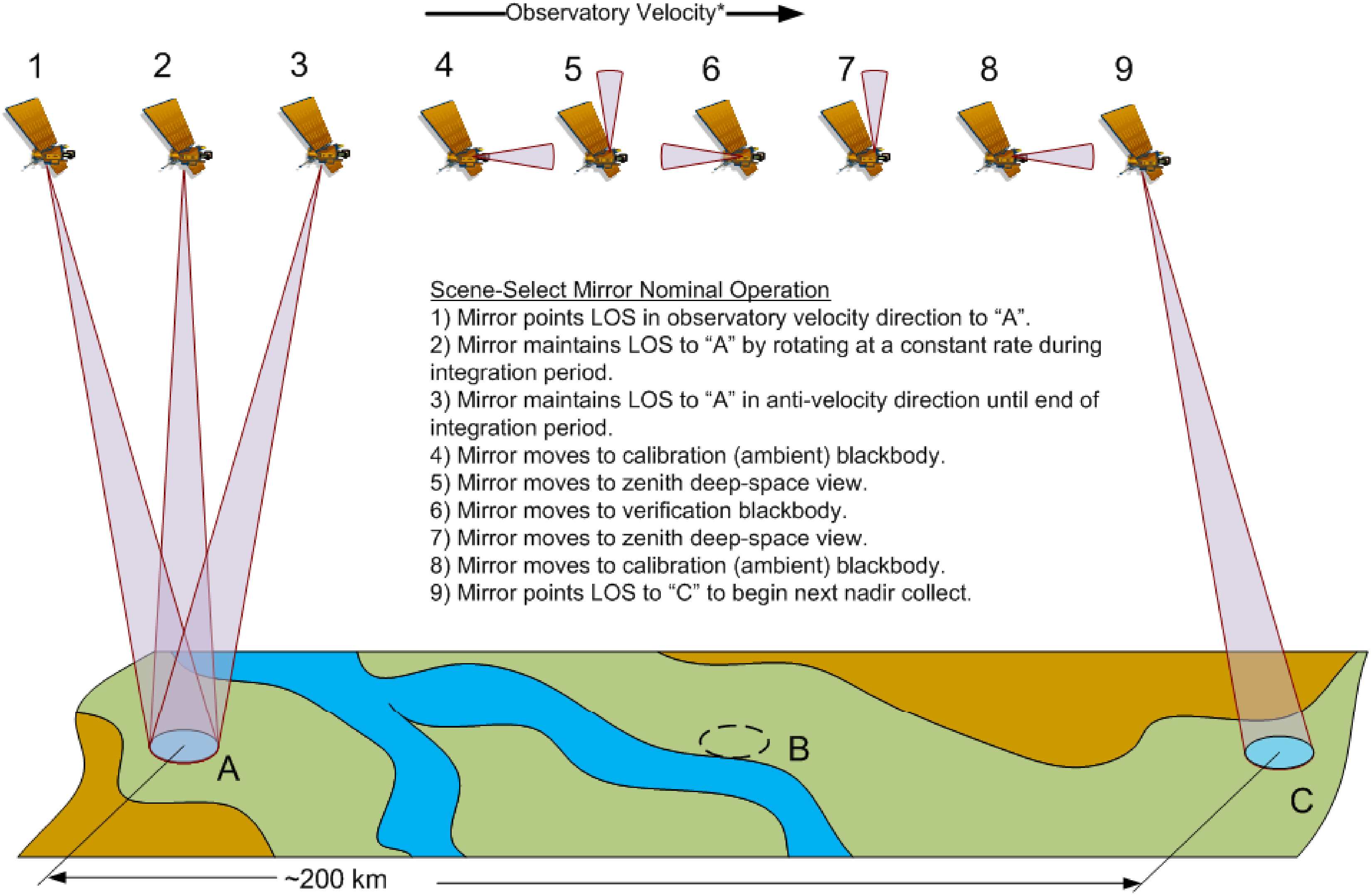
GNSS Receiver, POD Antenna, RO Antennae

- Refractivity uncertainty 0.03% (*k=1*) for 5 to 20 km altitude range
- Sampling for annual mean 10 degree latitude zones (1000 occultations/day)

Infrared Instrument Concept



Infrared Instrument Operations



Scene-Select Mirror Nominal Operation

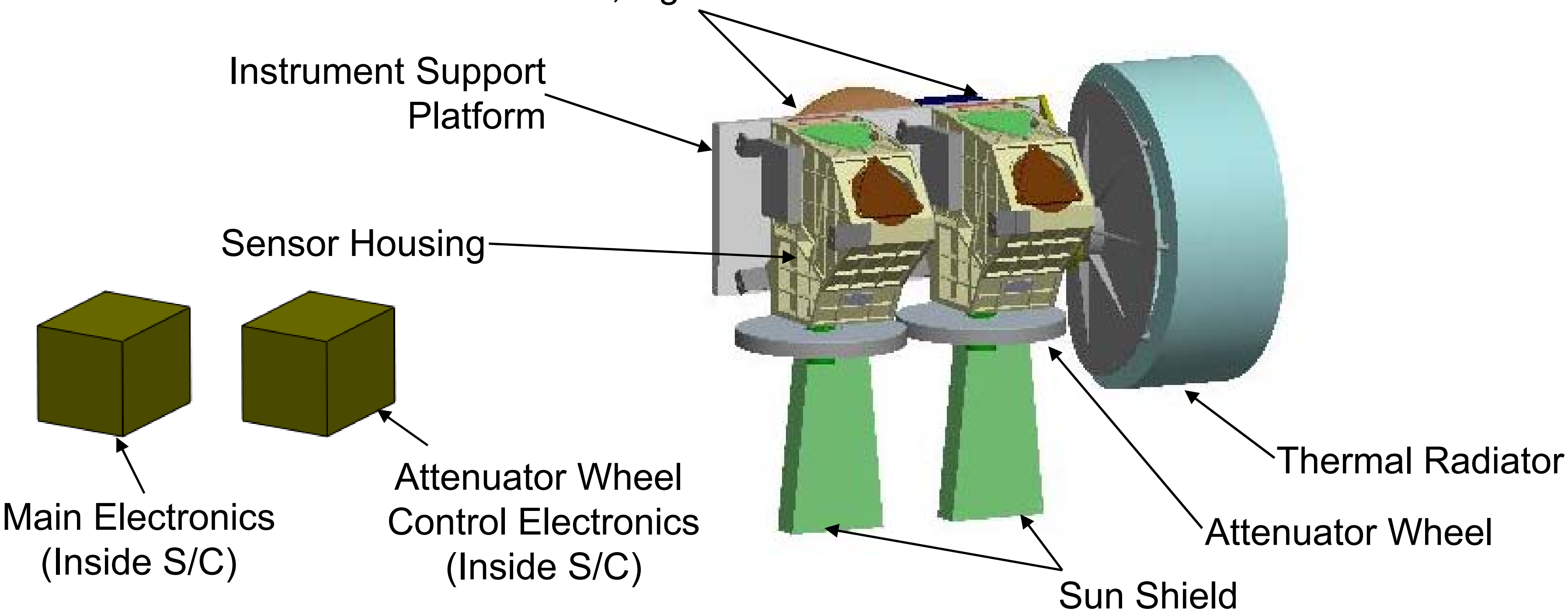
1) Mirror points LOS in observatory velocity direction to “A”.
2) Mirror maintains LOS to “A” by rotating at a constant rate during integration period.
3) Mirror maintains LOS to “A” in anti-velocity direction until end of integration period.
4) Mirror moves to calibration (ambient) blackbody.
5) Mirror moves to zenith deep-space view.
6) Mirror moves to verification blackbody.
7) Mirror moves to zenith deep-space view.
8) Mirror moves to calibration (ambient) blackbody.
9) Mirror points LOS to “C” to begin next nadir collect.

*Prior to Yaw Flip

Earth views alternate with verification system views

Reflected Solar Instrument Concept

2x Optical Packages
- Blue Channel 320-640nm, silicon detectors
- Red/NIR Channel 600-2300nm, HgCdTe detectors



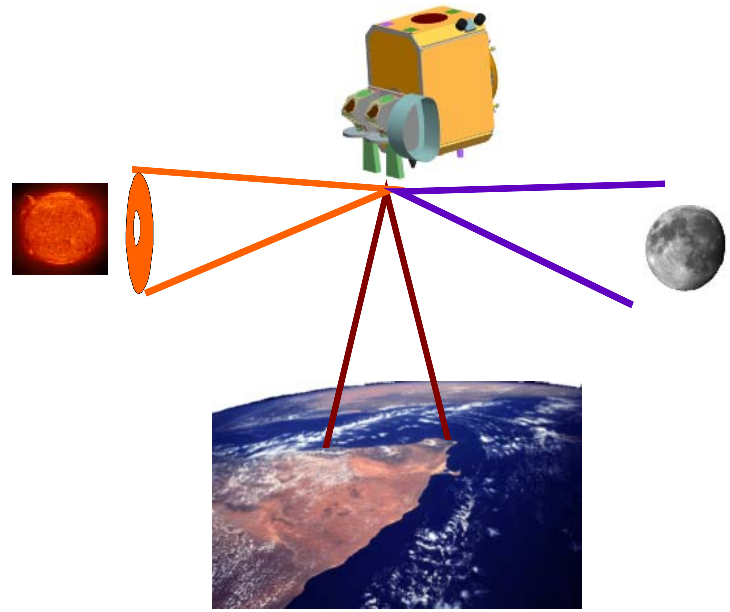
- Commonality of design of two optical packages aids in calibration
- All-aluminum materials including telescope optics with Offner design
- Cooled focal planes tailored for each spectral region

  250 K for Silicon

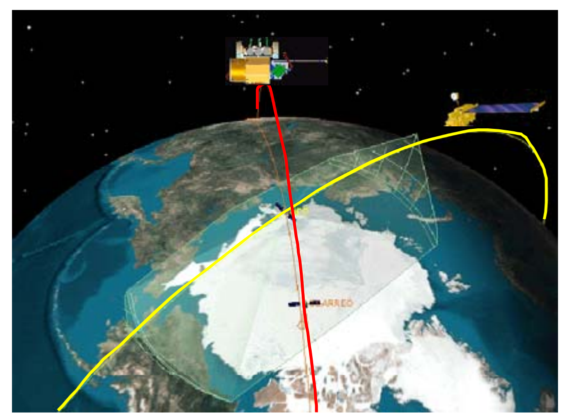
  200 K for HgCdTe

Reflected Solar Instrument Operations

- **Reflectance retrieval, calibration and inter-calibration requirements lead to three basic operating modes**
  - Nadir Data Collection (>90% data collection time)
  - Solar Calibration
  - Inter-calibration of other on-orbit assets



- **Verification of calibration drives the need for lunar views**



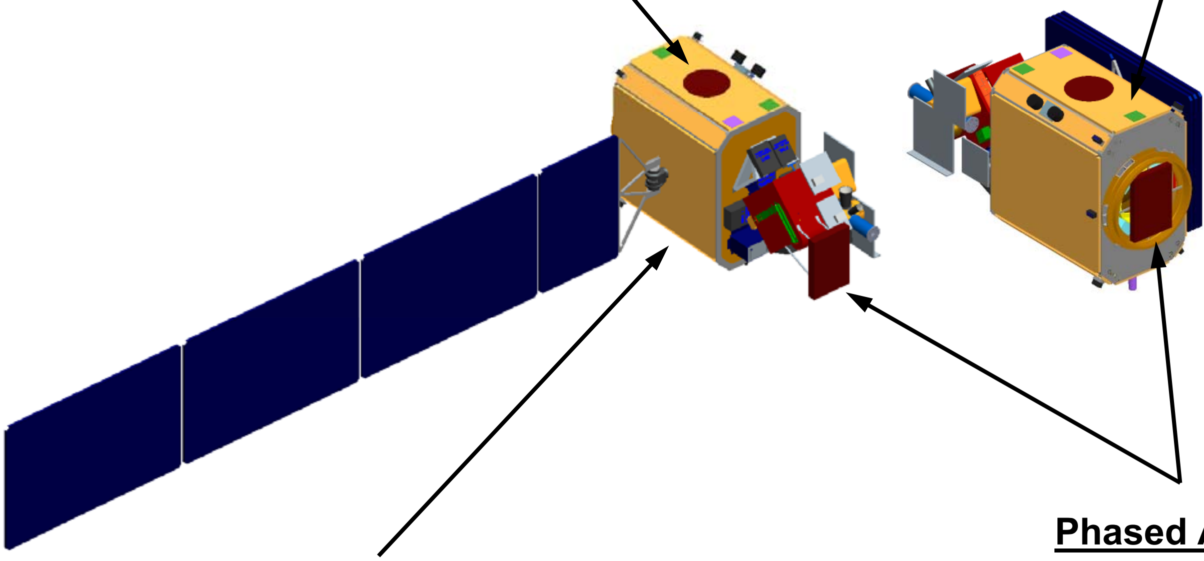
Three basic operating modes for RSS instrument

Radio Occultation Instrument Concept

POD Choke Ring Antenna
Located on zenith deck of spacecraft for views to GNSS satellites

Receiver – RF receiver with additional capability for radio occultation processing (located inside spacecraft bus)

Ultra-stable Oscillator
Provides high-precision time reference for zero-differencing (inside Bus)



Laser Retro Reflector
Located on nadir side of spacecraft for precise orbit determination (POD) validation using Satellite Laser Ranging

Phased Array RO Antennas
Located on ram and wake faces with fields-of-view (FOV) oriented towards the Earth's limb to view GNSS constellation Earth-occulting satellites (rising and setting)

Calibration to SI Standards

- **Calibration Characterization at climate accuracy and time scales**
  - Pre-launch characterization, testing, and calibration
    - Instrument builder site
    - Independent site calibration
    - SI traceable transfer radiometers, sources (e.g. NIST SIRCUS system)
  - Spacecraft Integration testing and calibration (vacuum chamber)
  - In orbit characterization, testing, and calibration
    - On orbit sources, verification of source accuracy
    - Earth viewing, solar, lunar & calibration operations schedules
    - Aircraft instrument under-flights
    - Future absolute calibration of the moon using high altitude balloon (30km) would provide an additional verification (5, 10, or even 20 yrs from now)
    - Engineering unit or instrument spares for ground testing anomalies.

Traceability to SI Standards is Key to Decadal Change Accuracy

3. Mission Concept

Mission Implementation

- **Lead Center: Langley Research Center**
  - Project Management; Science; Systems Engineering; Spacecraft; Payload; Infrared Instrument Suite; GNSS-RO; System Integration; Mission Operations; Science Data Processing

- **Supporting Center: Goddard Space Flight Center**
  - Reflected Solar Instrument Suite; Science support; Science Data Processing support

- **Category 1 mission, as defined in NPR 7120.5D (NID NM 7120-81)**

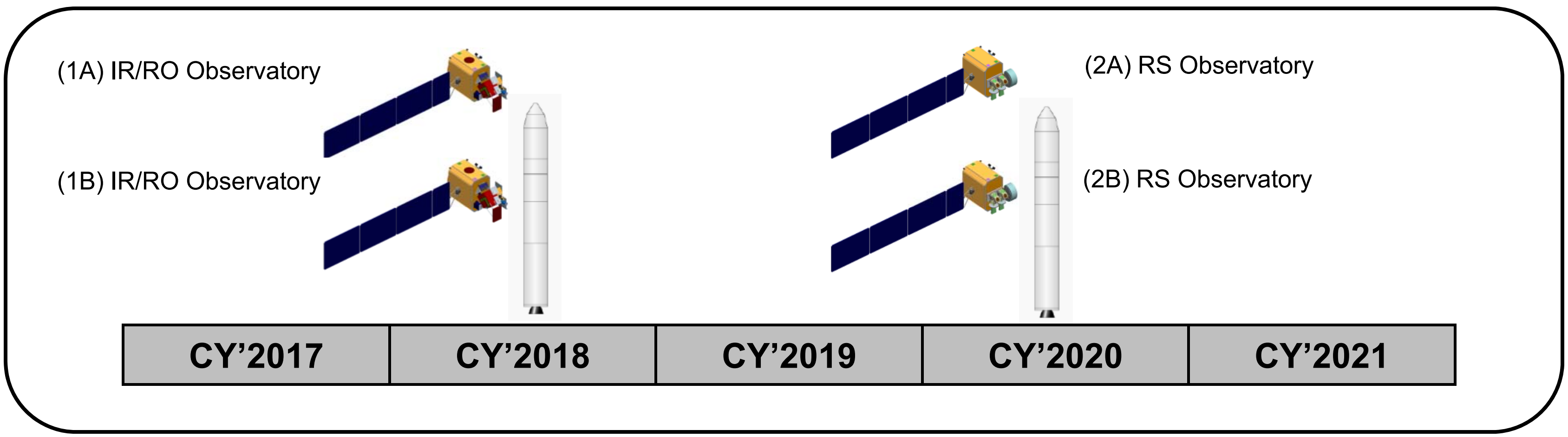
- **Class C payload risk classification, as defined in NPR 8705.4**

Mission Concept

- **Three instruments (two of each)**
  - Infrared (IR) Spectrometer
  - Reflected Solar (RS) Spectrometer
  - Global Navigation Satellite System-Radio Occultation (GNSS-RO)

- **Four observatories, two dual-manifested launches on Minotaur IV+ vehicles**
  - July 2018: Two Infrared (IR) Observatories, each with GNSS-RO
  - May 2020: Two Reflected Solar (RS) Observatories

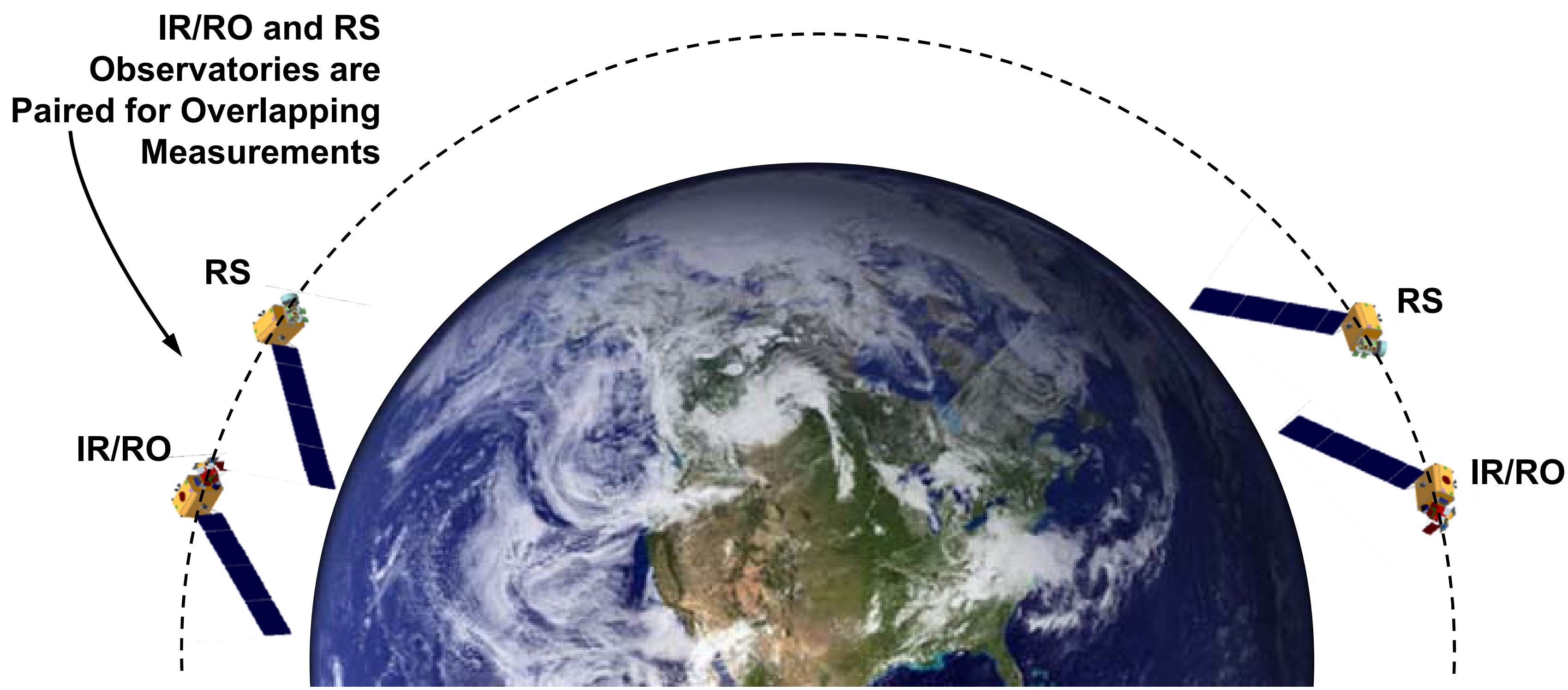
- **609 km polar orbits (90° inclination)**



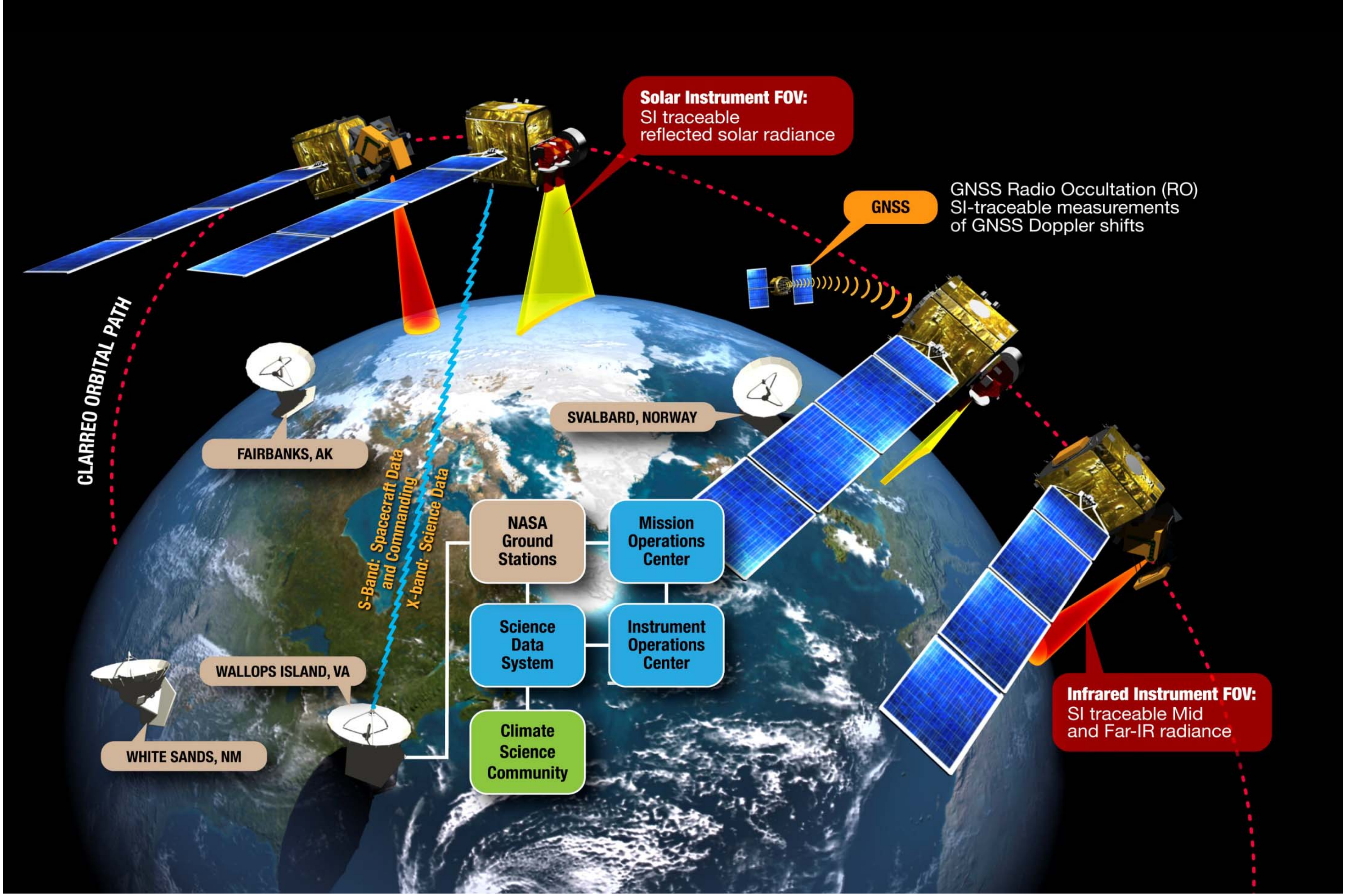
CLARREO Orbit Selection

Orbit Parameters:

- Mean Altitude = 609 km (61-day ground track repeat cycle)
- Period = 5812.4 ± 0.25 secs (orbit maintenance requirement)
- Inclination = 90°
- RAAN = 0° or 180° (for reference inter-calibration)



CLARREO Mission Overview



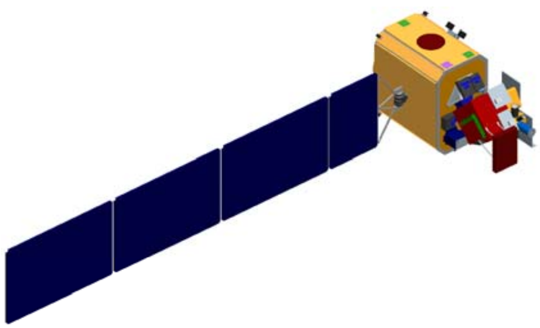
4. Observatory Concepts

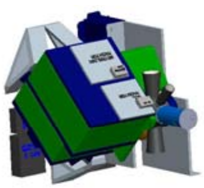
Observatory Summaries

IR/RO Observatory

CBE Mass: 389 kg

CBE Power: 437 W





Infrared (IR) Instrument

- FTS
- CBE Mass: 76 kg
- CBE OA Power: 124 W
- Data Rate: ~228 kbps
- Data Volume: 26 Gb/day

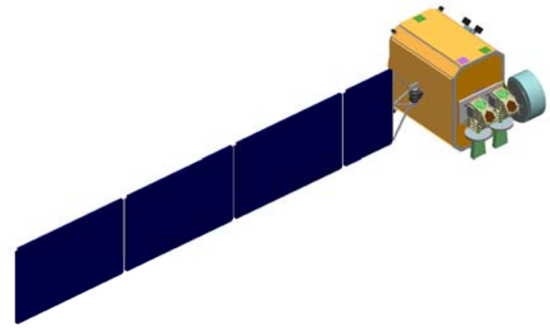
GNSS-RO Instrument

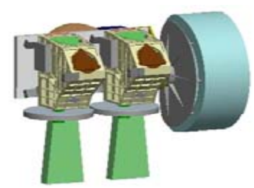
- GNSS Receiver / Antennas
- CBE Mass: 18 kg
- CBE OA Power: 35 W
- Data Rate: ~119 kb/s
- Data Volume: 13 Gb/day

Reflected Solar Observatory

CBE Mass: 381 kg

CBE Power: 400 W





Reflected Solar (RS) Instrument

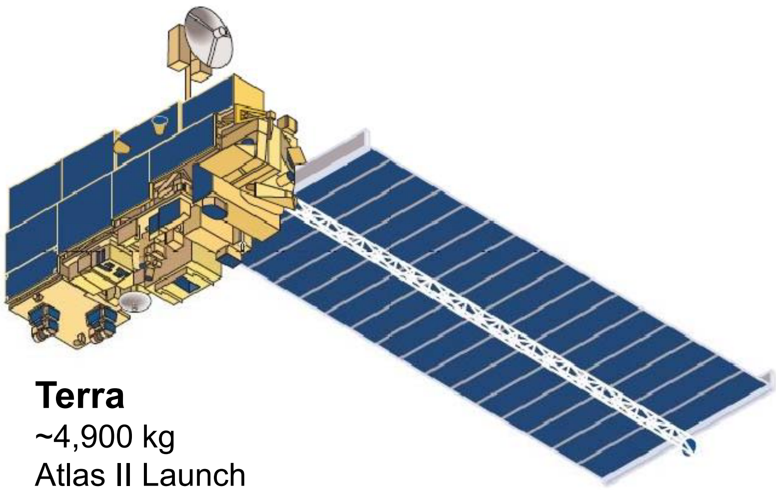
- Two Grating Spectrometers
- CBE Mass: 69 kg
- CBE OA Power: 96 W
- Data Rate: 1.3 to 325 Mbps
- Data Volume: 89 Gb/day

Gimbal for RS Instrument

- Single-axis of rotation
- CBE Mass: 14 kg
- CBE OA Power: 17 W
- Data Rate: ~10 kb/s
- Data Volume: 370 Mb/day

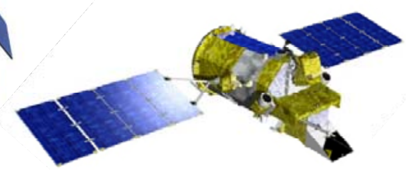
CLARREO Observatory Comparison

The CLARREO observatories are relatively small among other Earth science spacecraft

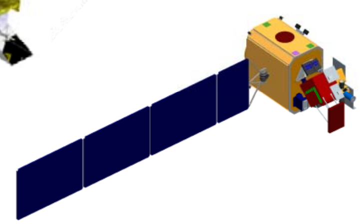


Terra
~4,900 kg
Atlas II Launch

Icesat
~1,000 kg
Delta 2 Launch



Glory
~500 kg
Taurus XL Launch



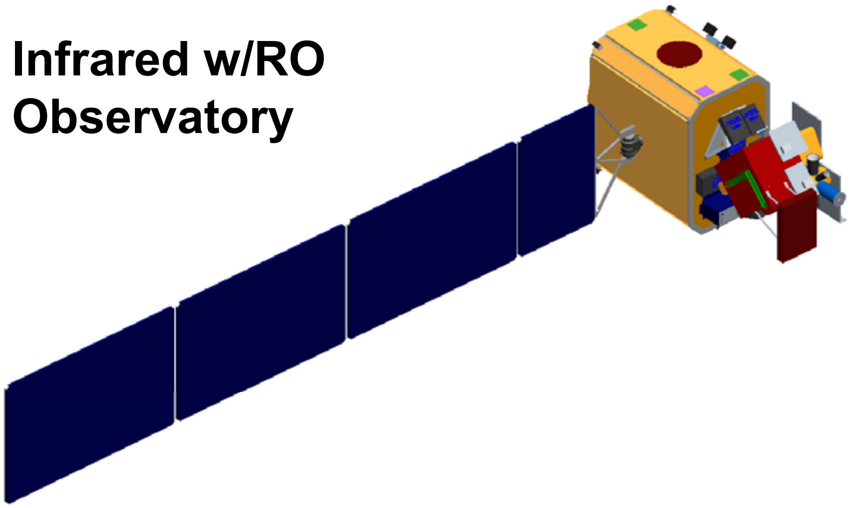
CLARREO
~460 kg x 2
Minotaur IV+ Launch

SORCE
~290 kg
Pegasus XL Launch

Note: Images are not perfectly to scale

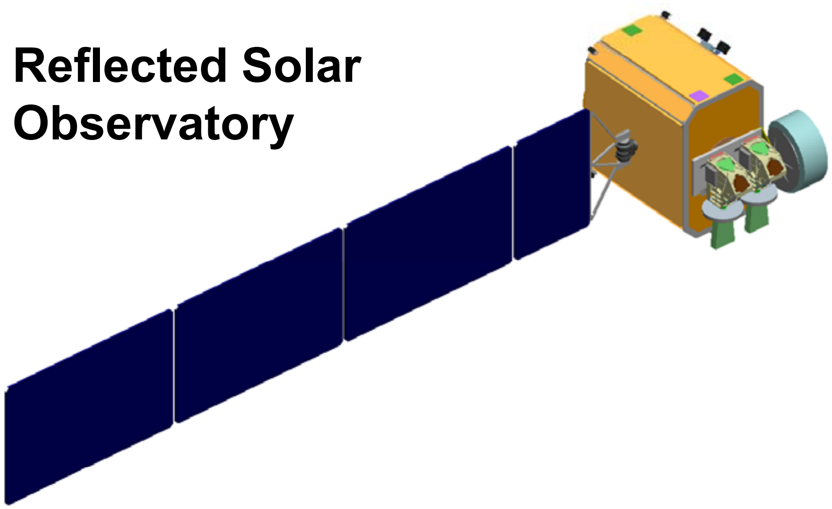
Observatory Concept Mass Summaries

Infrared w/RO Observatory



IR OBSERVATORY MASS BUDGET	CBE (kg)	Cont. (%)	Allocation (kg)
Payload	94	30%	122
Spacecraft[1]	279	15%	319
Observatory Dry Mass Total	373	18%	441
Propellant	16	0%	16
Observatory Wet Mass Total	389	-----	457

Reflected Solar Observatory



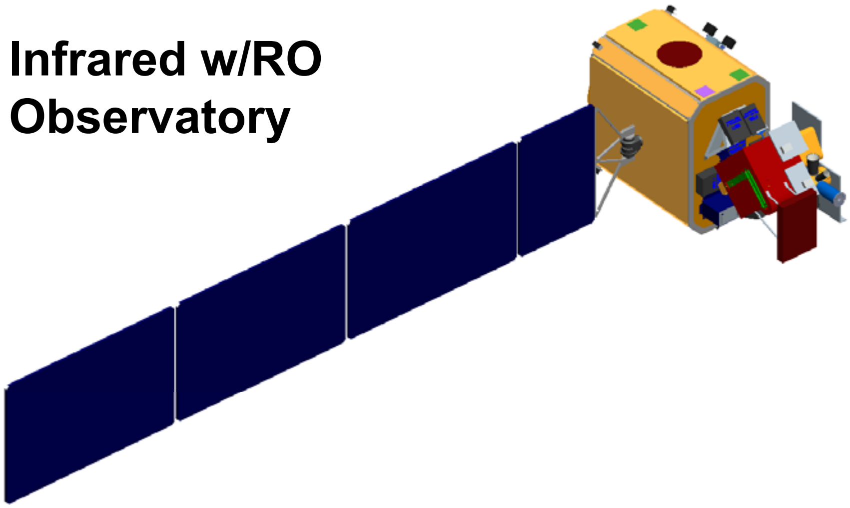
RS OBSERVATORY MASS BUDGET	CBE (kg)	Cont. (%)	Allocation (kg)
Payload	84	29%	108
Spacecraft[1]	282	15%	322
Observatory Dry Mass Total	366	18%	430
Propellant	16	0%	16
Observatory Wet Mass Total	381	-----	445

Notes:

1. Spacecraft mass include 6 kg for separation system components that stay with the bus

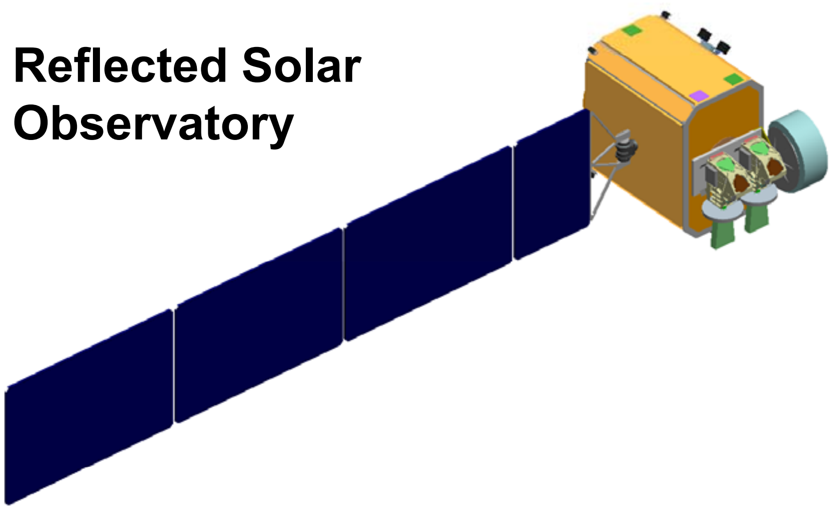
Observatory Concept Power Summaries

Infrared w/RO Observatory



IR OBSERVATORY POWER BUDGET	CBE (W)	Cont. (%)	Allocation (W)
Payload	159	30%	207
Spacecraft	278	10%	307
Observatory Power Total	437	17%	513
Available System Power (4.9 m^2 array) = 668 W			
Available Power Growth	53%	-----	30%

Reflected Solar Observatory



RS OBSERVATORY POWER BUDGET	CBE (W)	Cont. (%)	Allocation (W)
Payload	113	30%	147
Spacecraft	287	10%	317
Observatory Power Total	400	16%	463
Available System Power (4.9 m^2 array) = 668 W			
Available Power Growth	67%	-----	44%

Observatory Concept Delta-V Budget

Observatory Delta-V Budget

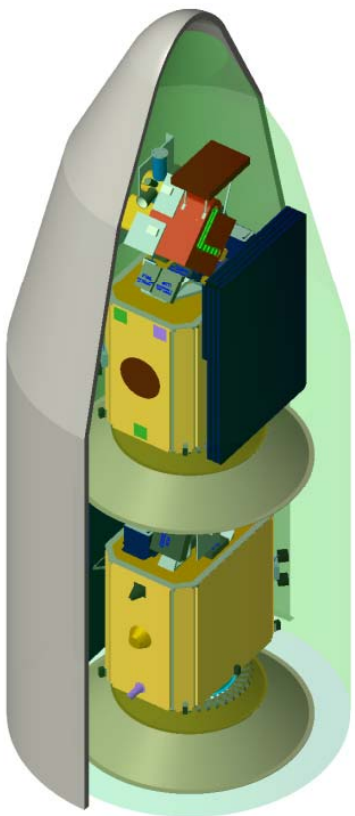
IR/GNSS-RO and RS Observatories	ΔV (m/s)	Hydrazine (kg)
Correction for Minotaur IV+ orbit insertion errors	40.1	10.6
In-plane transfer (pending Phase A trade studies)	2.7	0.7
Collision avoidance	0.3	0.1
Orbit inclination station keeping for 5 years	0.0	0.0
Orbit altitude (period) station keeping for 5 years	16.2	4.2
Controlled de-orbit	0.0	0.0
TOTALS	**59.3**	**15.6**
Hydrazine capacity (ATK 80389-1 spherical tank) = 22.5 kg		
Tank propellant margin = 44%		

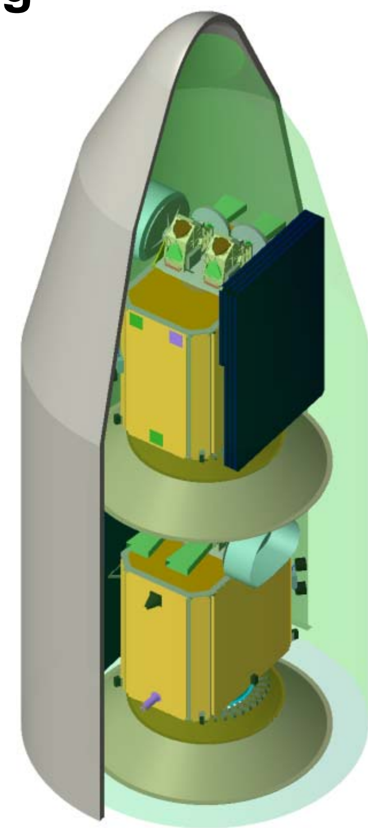
Notes:

1) **Minotaur IV+ insertion errors are 3-sigma values for altitude and inclination errors combined**
2) **Specific impulse = 210 s**
3) **Propellant calculated using 550 kg observatory NTE mass**
4) **In-plane transfer based on a 30-day, 180° change in true anomaly**

Observatory Launch Configurations

Dual-manifest Configurations in Minotaur IV+ Fairing

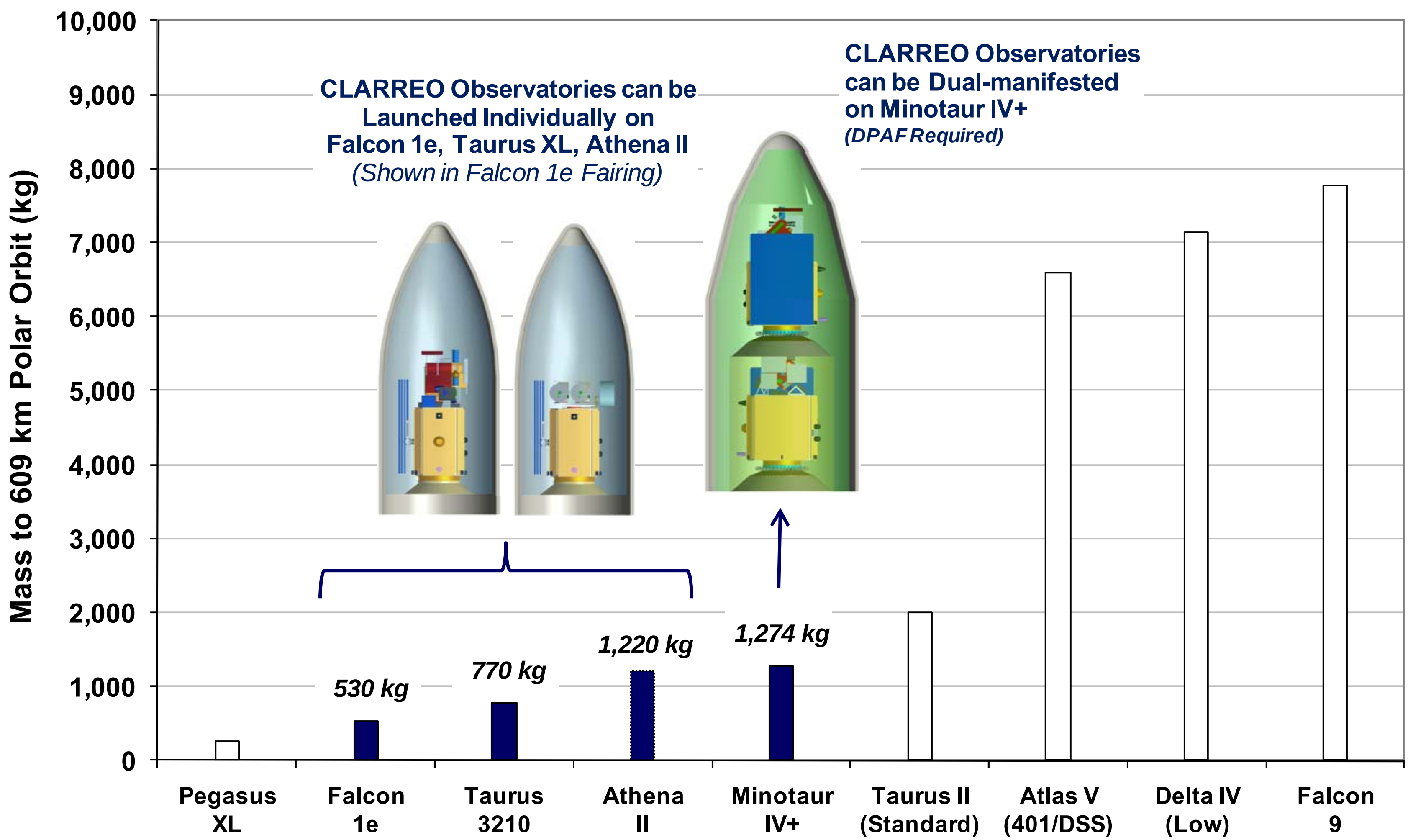




2018 Dual Infrared/RO Observatory Launch

2020 Dual Reflected Solar Observatory Launch

Launch Vehicle Flexibility



5. Spacecraft Bus Concept

Spacecraft Bus Requirements

The Infrared Observatory and Reflected Solar Observatory will use a common spacecraft bus meeting the following top-level performance requirements

Orbit Definition:

Orbit Period: 5812.4 +/- 0.25 s (609 km +/- 200m)

Inclination: 90 +/- 0.1 degree

Spacecraft Reliability:

The CLARREO spacecraft bus shall have a reliability of no less than 0.70 at 5 years

Consumables Lifetime:

The CLARREO spacecraft bus shall have sufficient consumable resources to last 5 years

Decommissioning Policy:

The CLARREO spacecraft bus shall comply with NPR-8715.6 for decommissioning

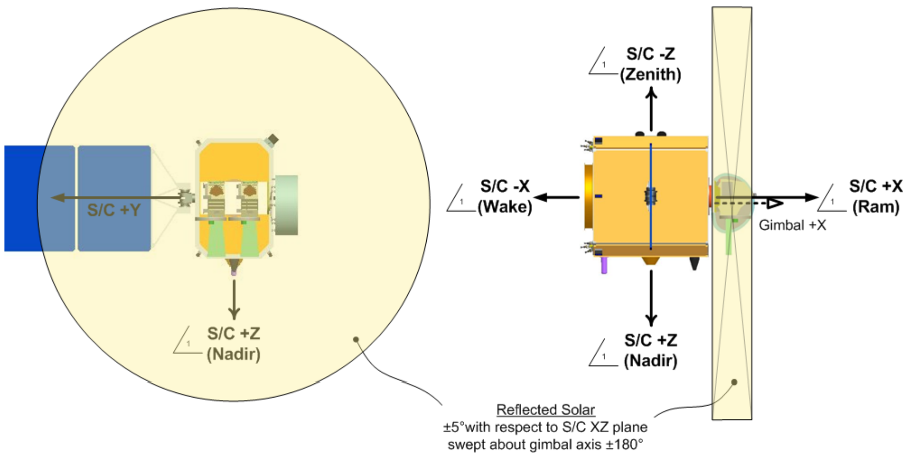
Launch Vehicle:

The spacecraft bus shall be compatible for a dual manifested launch on a Minotaur IV+ launch vehicle

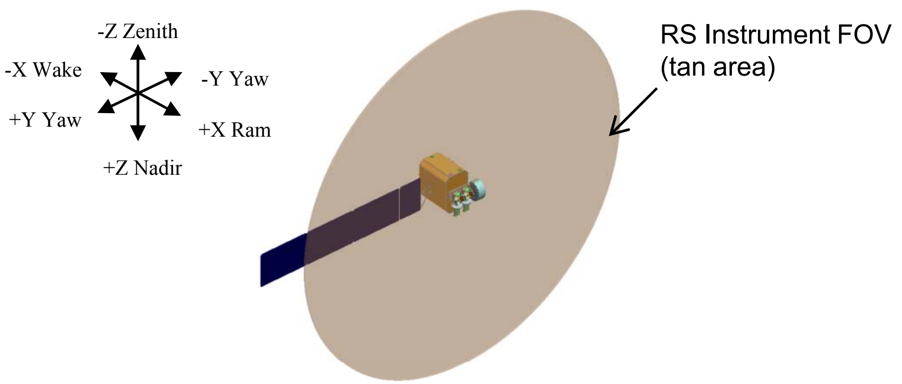
Payload:

The spacecraft shall accommodate the payload mass, power, data rate/volume and Fields of Regard

Reflected Solar Observatory Drivers



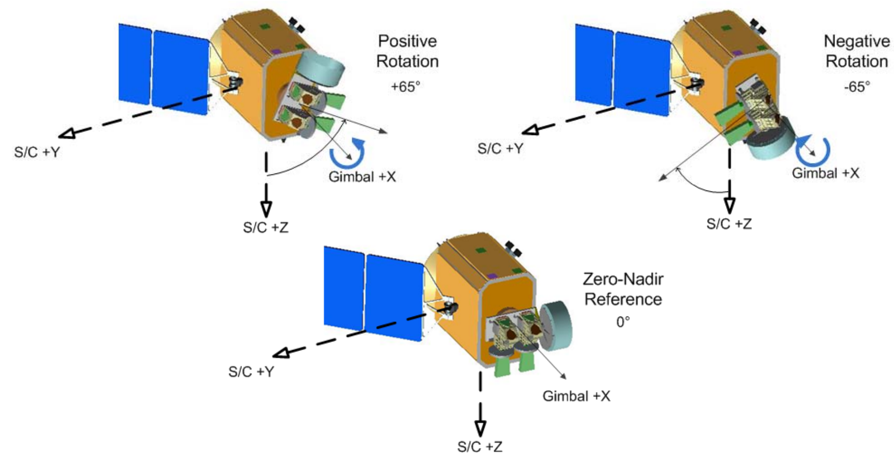
Side view of RS Observatory showing FOV



Iso view of RS Observatory showing FOV

Key Drivers for Reflected Solar Observatory

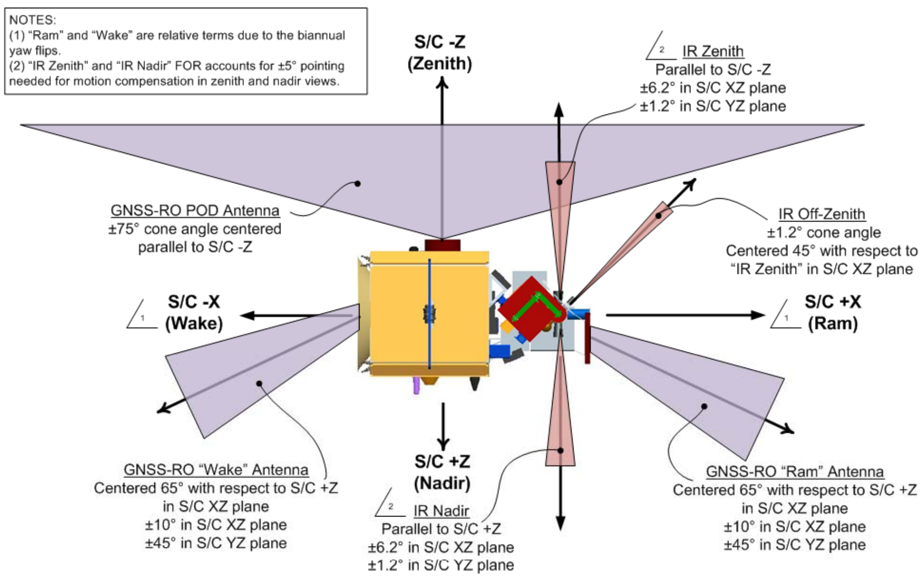
RS Reference Inter-calibration operations
- Require S/C yaw maneuver before and after gimbal slew and data collection



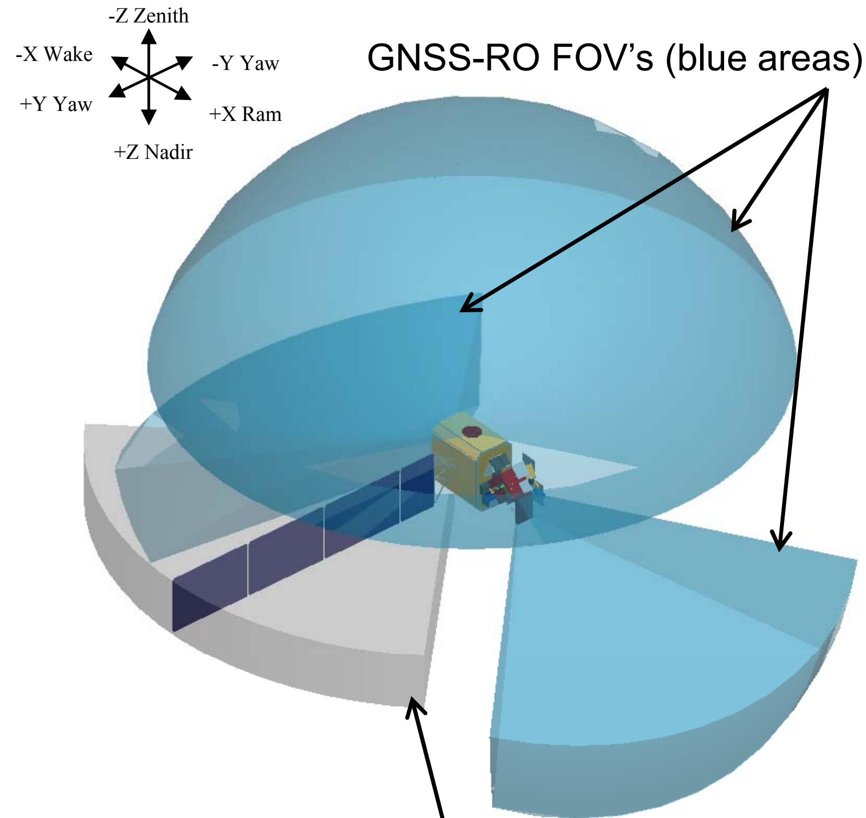
RS Instrument / gimbal motion relative to spacecraft

IR/RO Observatory Drivers

Key Drivers for IR/RO Observatory



Side view of IR/GNSS-RO Observatory showing FOV's



- Solar array range of motion (gray area)
  - Clears payload FOV's
  - AD&CS components sized to handle torque from array

Iso view of IR/RO Observatory showing FOV's

Common Spacecraft Bus Subsystems

Electronic Power System

- 83 A-Hr Li-Ion battery capacity
- 28V Direct Energy Transfer Power System
- Deployable, 4.9 m^2 (1262W EOL)
  single, two-axis articulating four panel array

Command and Data Handling

- Central Electronics Processor (C&DH / AD&CS)
  Provide C&DH, Comm., Thermal, Propulsion, AD&CS and payload command and telemetry interfaces
- SSR: 128 Gbits/day (Includes contingency, margin & encoding)

Communication

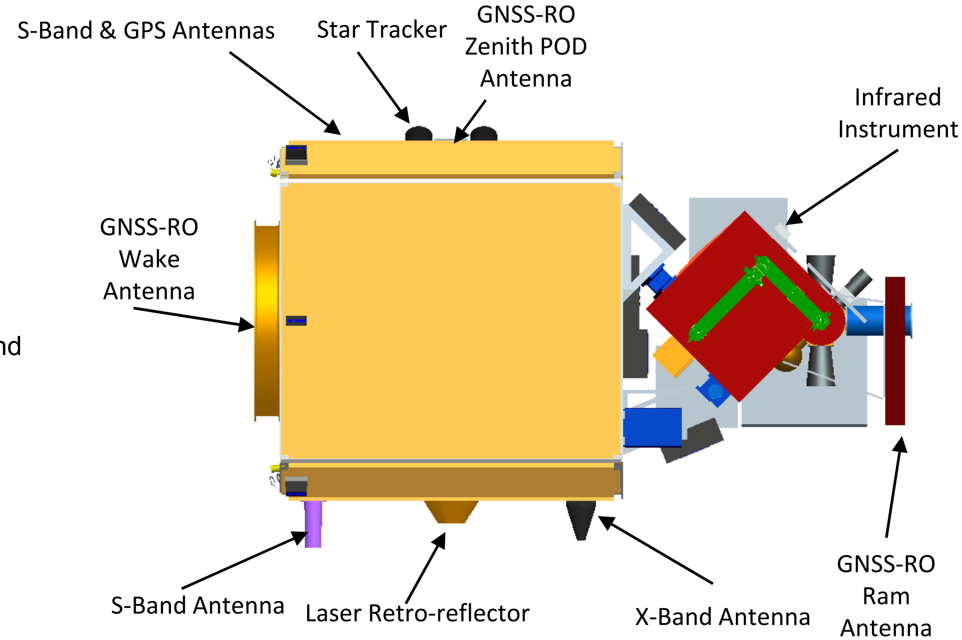
- X-band downlink for science and engineering data
- S-Band for command uplink and H/K telemetry downlink

Attitude Determination & Control

- 3- axis stabilized attitude control system
- Star trackers, IMU, Coarse Sun Sensors, Magnetometer
- Reaction wheels, Magnetic Torque Bars
- GPS for orbit determination

Propulsion

- Monopropellant – Hydrazine blow down system
- 59.9 m/s estimated delta V budget (15.6 kg propellant)
- 4 + 4 2 N thrusters for injection dispersion, collision avoidance, and orbit maintenance



CLARREO IR/GNSS-RO Observatory
(Side view with S/A removed)

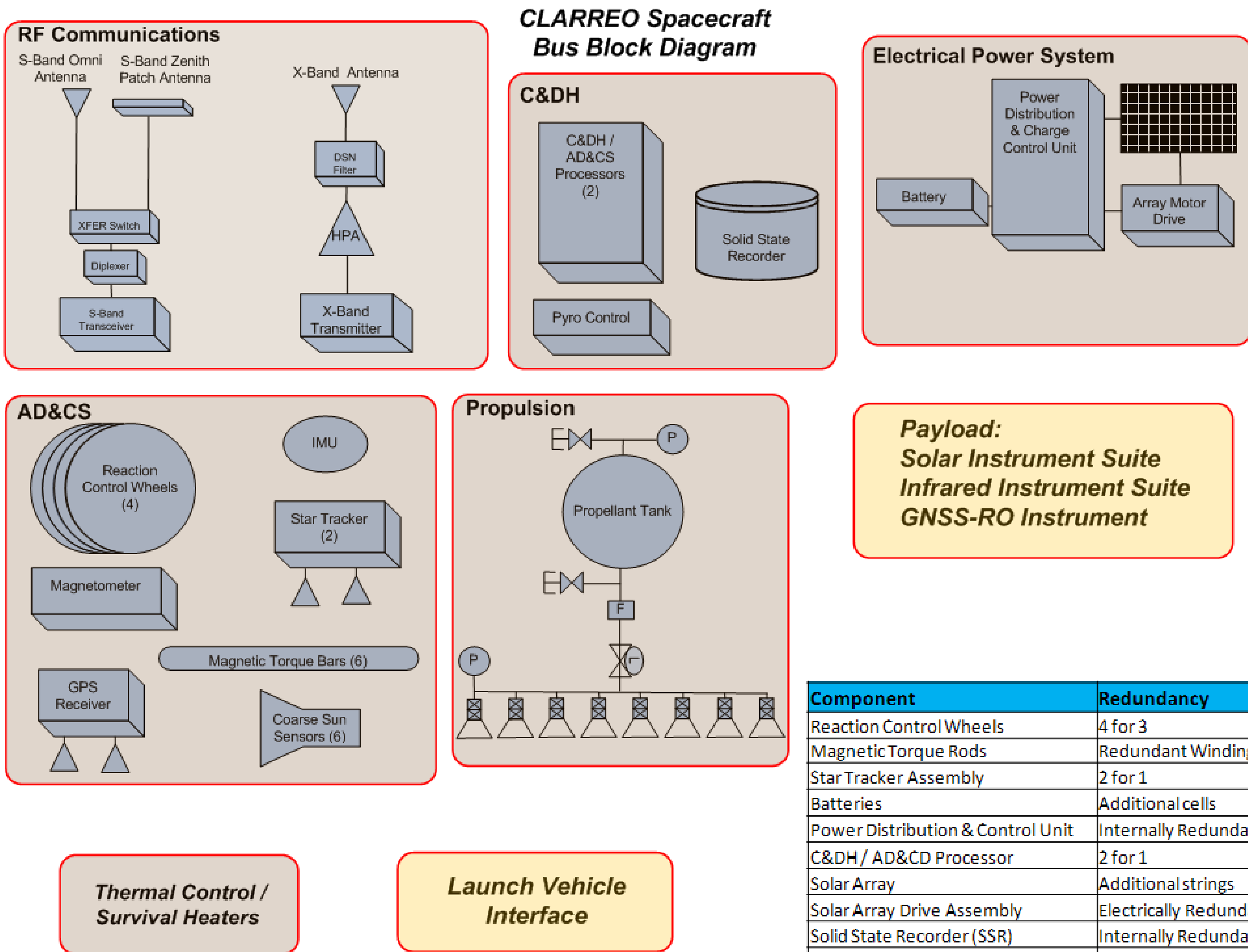
Thermal

- Bus thermal control using radiators, heaters and MLI
  - RS and GNSS-RO electronics rely on S/C bus for thermal control
- Passive bus thermal control using radiators and MLI

Mechanical / Structural

- Al sheet over Al honeycomb panels

Spacecraft Bus Block Diagram



Component	Redundancy
Reaction Control Wheels	4 for 3
Magnetic Torque Rods	Redundant Windings
Star Tracker Assembly	2 for 1
Batteries	Additional cells
Power Distribution & Control Unit	Internally Redundant
C&DH / AD&CD Processor	2 for 1
Solar Array	Additional strings
Solar Array Drive Assembly	Electrically Redundant
Solid State Recorder (SSR)	Internally Redundant
Thrusters	8 for 4

6. Mission Status

Mission Status

- **CLARREO successfully completed its Mission Concept Review (MCR) on November 17, 2010**

- **The next mission milestone is to complete Key Decision Point -A (KDP-A) planned for February/March 2011**

- **Following KDP-A the mission team will commence Phase A activities leading to a mission System Requirements Review (SRR) planned for early to mid-2012**