# Climate Absolute Radiance and Refractivity Observatory (CLARREO)

## CLARREO Mission Overview

**January 2010**

**NASA Langley Research Center**
**Hampton, Virginia**

# CLARREO Mission Overview

- **Mission Purpose, Objectives, and Requirements**
- **Measurements and Instruments**
- **Spacecraft Bus and Observatory**
- **Launch Vehicle Strategy**

# Mission Objectives and Purpose

# CLARREO Goal and Objectives

## Mission Goal:

To provide accurate, broadly acknowledged climate records that are used to enable validated long-term climate projections that become the foundation for informed decisions on mitigation and adaptation policies that address the effects of climate change on society.

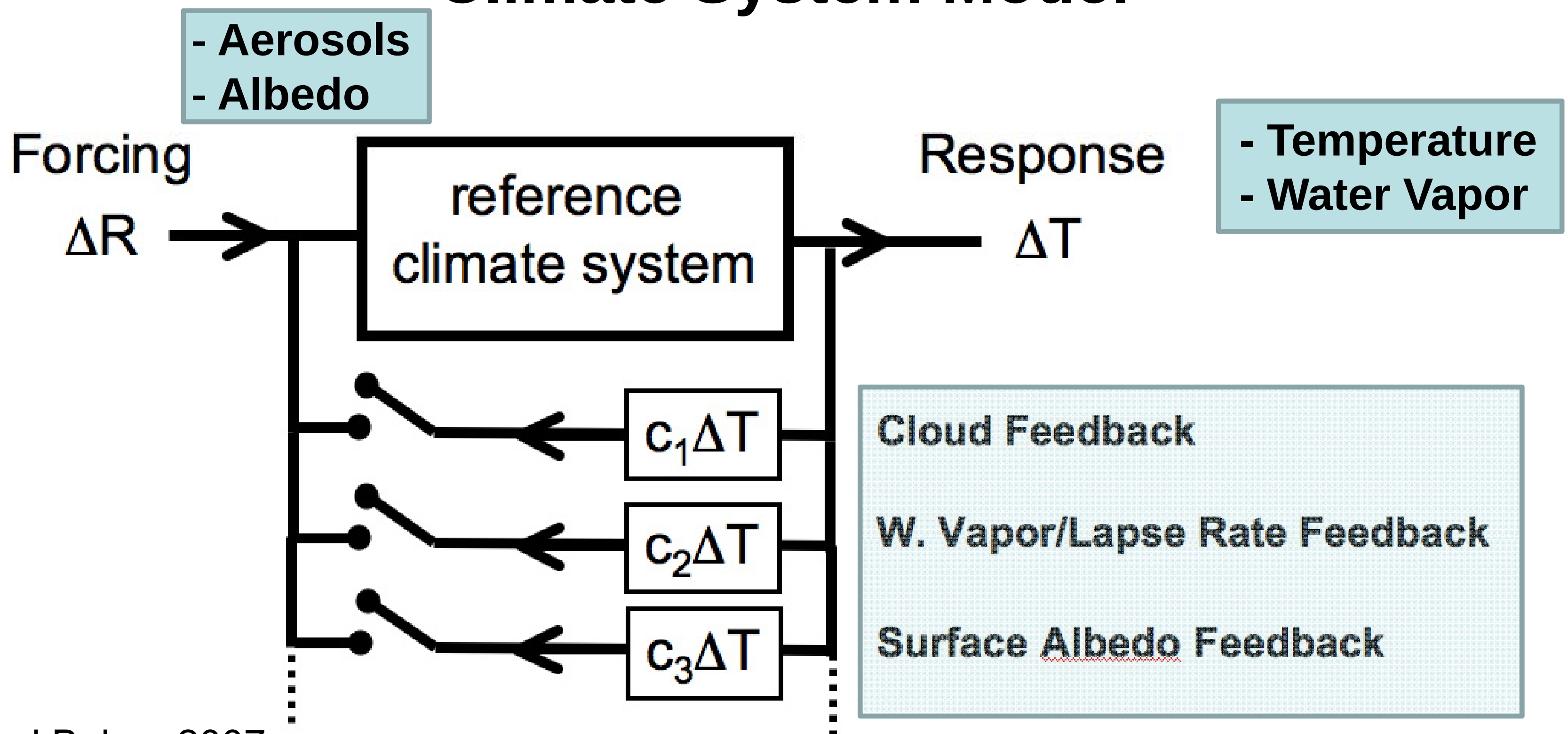
## Key Societal Objectives:

1. To establish a multi-decade benchmark climate record that is global in extent, accurate with rigorous traceability to international standards, and tested against independent methods.

2. To enable an operational climate forecast that is tested and broadly trusted through a disciplined strategy using state-of-the-art observations and mathematically-rigorous analytical techniques to establish credibility.

3. To enable the creation of decision structures that assimilate accurate data and forecasts into intelligible and specific products, promoting international commerce, societal stability and security.

# Climate System Model




Roe and Baker, 2007

***Reducing uncertainty in predictions of ΔT is critical for public policy affecting adaptation to changes in sea level and precipitation***

# CLARREO Science Goal and Requirements

**Overall Science Goal:**

Make highly accurate, global, SI-traceable decadal change observations sensitive to the most critical, but least understood, climate forcings, responses, and feedbacks.

**Specific Key Science Requirements:**

1. To measure the absolute spectrally resolved radiance in the infrared with high accuracy (0.1 K 3σ brightness temperature) by downward-directed spectrometers in Earth orbit.

2. To measure the absolute spectrally resolved nadir reflectance of solar radiation from Earth to space with high accuracy (0.3% 2σ). Solar radiation reflectance constitutes a powerful and highly variable forcing of the climate system through changes in snow cover, sea ice, land-use, aerosol, and clouds.

3. To utilize Global Navigation Satellite Systems (GNSS) radio occultation as a source for another benchmark of the climate system. This technique is traceable to the international standard second and is an independent method complementing the spectrometers.

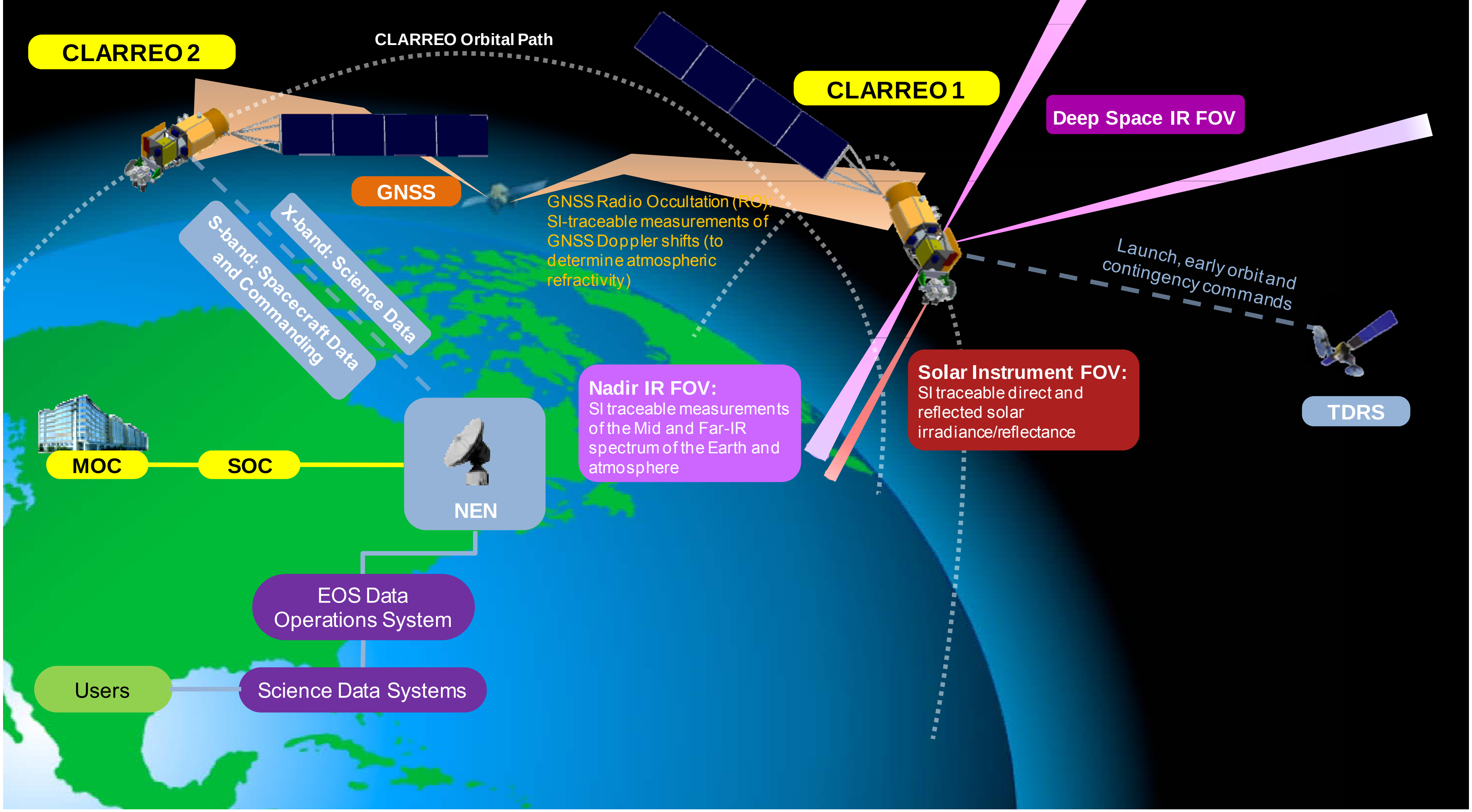
4. To use CLARREO as a high accuracy calibration standard for use by operational, climate relevant infrared and reflected solar instruments like CERES, CrIS, IASI, VIIRS and Landsat.

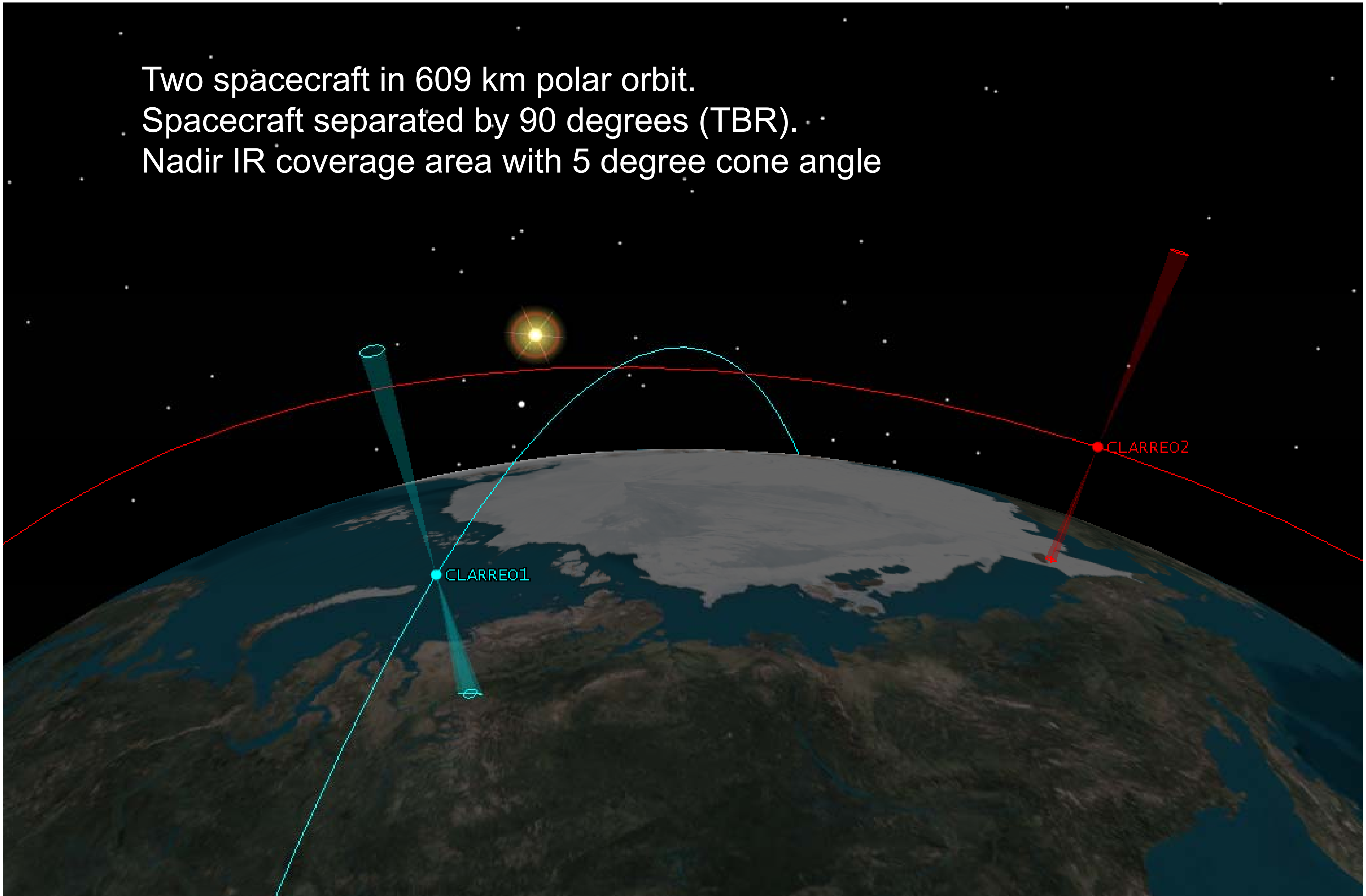
# CLARREO Mission Description

| **Launch Requirements** | |
|---|---|
| Nominal Orbit | LEO |
| Altitude (Km) | 609 |
| Inclination | 90° |
| Design Operational Life | 3 years |
| Estimated Launch Readiness Date (LRD) | NET 2016-19 |
| CBE Instrument Size | Variable |
| Launch Site Requirement (East or West Coast) | West |
| **Science and C&D Handling** | |
| Science Downlink Format | CCSDS |
| Science Data Downlink Frequency | X Band |
| Science Data Rate (Gb/day) | 314 Gb/day |
| Instrument Housekeeping Telemetry | S-Band & X-Band |
| Instrument Housekeeping Telemetry Data Rate (Gb/day) | ~ 1 Gb/day |
| Onboard Data Storage (Gb) | ≥ 314 Gb |
| **Payload Mass** | |
| Payload Mass Allocation (w/contingency) | 295 kg |
| Mass Margin | 30 percent |
| NTE Payload Mass (kg) | 384 |
| **Payload Power** | |
| Payload Orbit Average Power Allocation (W) | 405 W |
| Payload Peak Power Allocation (W) | 618 W |
| Power Margin | 30 percent |
| NTE Orbit Average Payload Power (W) | 527 |
| Bus Voltage (V) | 28 |

| **Mechanical Interface** | |
|---|---|
| Mechanical Interfaces | Individual specified interfaces for each payload element |
| Field Of View (FOV) | Infrared Instrument FOV = 2.4°<br>- (Pointed either nadir, zenith, or 45° from zenith)<br>Reflected Solar Instrument FOV = 500m, with 100 km swath<br>- (Pointed either nadir or off-nadir up to 120°)<br>GNSS-RO Instrument<br>- Occultation antennas (2) centered 65° w.r.t. nadir, ±10° in nadir-ram/wake planes, ±45° out of plane<br>- Precise Orbit Determination (POD) antenna, ±75° cone w.r.t. zenith |
| **Attitude Control** | |
| Pointing Knowledge (1 sigma) | < 0.1 degree or 360 arc sec |
| Pointing Accuracy (1 sigma) | < 0.1 degree or 360 arc sec |
| Jitter | < 0.1 degree or 360 arc sec over 0.1 second |
| ACS | 3-axis stabilized - reaction wheels and magnetic torque rods |
| GPS Receiver | Minimum 1 |
| Star Trackers | Minimum 1 |
| **Instrument Thermal Requirement** | |
| Thermally Isolated | Yes |
| **Propulsion** | 5 years Mission Capability |
| **Observatory Environmental & Facility (driven by Instrument)** | |
| NASA Risk Classification | Class C |
| EMI/EMC | GSFC 7000 |
| Vibe | GSFC 7000 |
| Thermal Vacuum | GSFC 7000 |
| Radiation | GSFC 7000 |
| Clean Room Class | 10K |
| Special Facility Needs | None |

Mission Goal: To provide accurate, broadly acknowledged climate records that are used to enable tested and trusted long-term climate projections that become the foundation for informed decisions on mitigation and adaptation policies that address the effects of climate change on society.



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|---|---|---|---|---|---|
| CLARREO Architecture Top-Level Diagrams | | | DRAFT | SCaN | CLARREO |
| Title: CLARREO Mission High-Level Operational Concept Graphic | | | | GNSS | Users |
| Figure/Table/Type: OV-1 | Date: 9/24/2009 | Version: 1 | Figure: 3 | Science Data Processing Center | |

# Measurements and Instruments

# CLARREO Measurement Concept & Instrument Suite

## Key Measurement Concept :

Make climate measurements that are SI traceable

### Infrared Measurements

- One infrared interferometer
- On-orbit calibration and verification systems
- Primary measurement is nadir benchmarking
- Inter-calibration at nadir only

### Reflected Solar Measurements

- One suite of grating spectrometers
- Nadir benchmarking approx. 95% of duty cycle
- Sun and lunar views for calibration
- Inter-calibration requires off-axis pointing

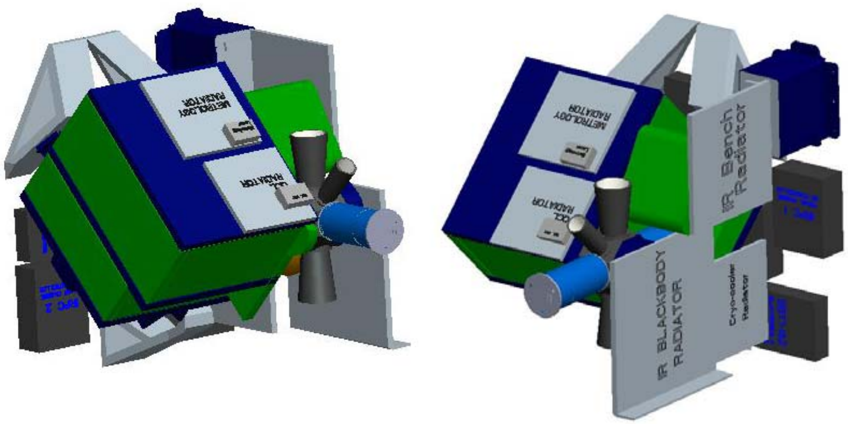
### GNSS Radio Occultation (RO)

- One GNSS-RO system
- Fore and aft occultation antennas
- Zenith antenna for precise orbit determination

**Payload Suite**

| Instrument | Observatory I | Observatory II |
|---|---|---|
| Infrared Spectrometer | FTS | FTS |
| | 5 to 50 micron | 5 to 50 micron |
| | Nadir | Nadir |
| Reflected Solar Spectrometer 1 | Grating | Grating |
| | 320-640 nm | 320-640 nm |
| | Gimbal-mounted | Gimbal-mounted |
| Reflected Solar Spectrometer 2 | Grating | Grating |
| | 600-1200 nm | 600-1200 nm |
| | Gimbal -mounted | Gimbal -mounted |
| Reflected Solar Spectrometer 3 | Grating | Grating |
| | 1150-2300 nm | 1150-2300 nm |
| | Gimbal -mounted | Gimbal -mounted |
| GNSS Radio Occultation System | POD | POD |
| | 1 Receiver | 1 Receiver |
| | 3 Antennas | 3 Antennas |

# Infrared Instrument Suite




**Baseline Instrument Package:**

- *FTS, calibration-verification system, thermal management hardware, support structure, and electronics*
  - Mass: 85 kg CBE
  - Average Power: 158 W CBE
- *Instrument Dimension: ~42x65x70 cm$^3$*
- *Data Rate: 224 kb/sec*
- *Data Volume: 19.3 Gb/day*

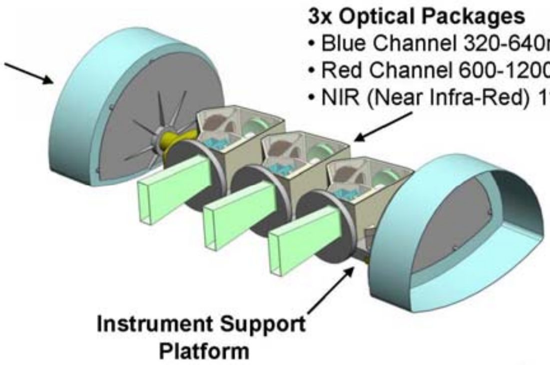
**Instrument Description:**

- *A Fourier Transform Spectrometer (FTS) for SI traceable measurements of the Mid and Far-IR spectrum of the Earth and atmosphere using two detectors within a single instrument*
- *Utilizes one ambient black body and deep space as on-orbit calibration sources.*
- *Utilizes one phase-change cell equipped blackbody and an emissivity monitoring system*
- *Uncooled pyroelectric detector for the Far-IR and an actively cryocooled MCT detector for the Mid-IR*

**Characteristics:**

- *Spectral Range: ~ 5-50 $\mu$m (200-2000 cm$^{-1}$)*
  - ~5 to 15 $\mu$m (actively cooled MCT)
  - ~15 to 50 $\mu$m (Pyroelectric)
- *Unapodized Resolution: 0.5 cm$^{-1}$*
- *Radiance Scale Accuracy: 0.1 K 3$\sigma$*
- *FOV: ~2.4 deg*
- *GIFOV: ~24 km*
- *Integration Period: ~ 8 seconds*

# Reflected Solar Instrument Suite




**Baseline Instrument Package:**

- *Three spectrometers, thermal management, and electronics*
  - Mass: 75 kg CBE
  - Average Power:  99 W CBE
- *Instrument Suite Dimension: ~185x58x91cm$^3$*
- *Data Rate: Up to 160 Mb/sec (compressed)*
- *Data Volume: Up to 130 Gb/day (compressed)*

**Instrument Description:**

- *A trio of pushbroom hyperspectral imagers with high spatial and spectral resolution for SI traceable direct and reflected solar irradiance measurements*
- *Calibration of detectors obtained through precision apertures -neutral density filters rotated via filter wheels*
- *Field of regard (FOR) needed for Solar-Lunar Calibrations, Intercalibrations, and Benchmarking achieved with two-axis gimbal*

**Characteristics:**

- *Spectral Range: 320 – 2300 nm*
  - ~320 to ~640 nm (“Blue”)
  - ~600 to ~1200 nm (“Red”)
  - ~1150 to ~2300 nm (“NIR”)
- *Spectral Sampling: ~2 – 4 nm*
- *Range of pointing: 120 degrees*
- *Swath Width: ~100 km cross-track*
- *Spatial Sampling :~0.5 km at Nadir*

# GNSS Radio Occultation Instrument

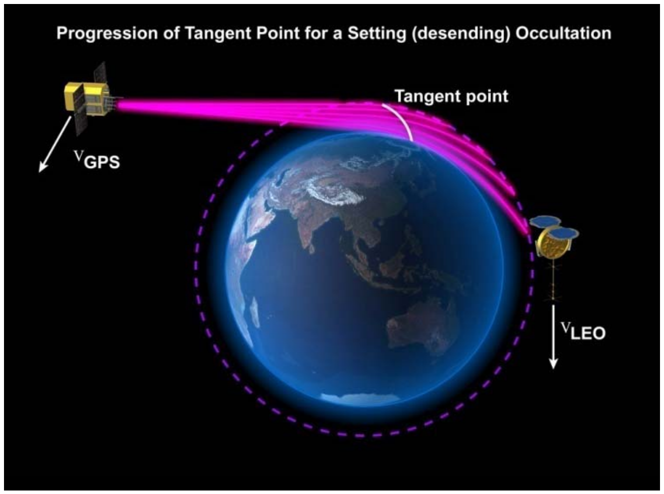



Figure from “COSMIC Update and Highlights” C. Rocken, UCAR

**Baseline Instrument:**

- *Receiver, antennas, and cabling*
  - Mass: 16 kg CBE
  - Average Power: 32 W CBE
- *Dimensions:*
  - Receiver: ~19x12x23 $cm^3$
  - POD Antenna: ~31 cm dia. x 4 cm (cone)
  - RO (Ram-Wake) Antennas: ~48x87x2 $cm^3$
- *Data Rate: 112 kb/sec*
- *Data Volume: 10 Gb/day*

**Instrument Description:**

- *GNSS (Global Navigation Satellite Systems) receiver using radio occultation (RO) to measure atmospheric refractivity through Doppler shifts*
- *Traceable to international standards (time)*
- *Used to derive atmospheric pressure, temperature, and water vapor concentration*

**Instrument Subsystems:**

- *One GNSS receiver*
- *One zenith facing, choke ring, precise orbit determination (POD) antenna*
- *Electronically steerable phased array ram and wake RO antennas*

**Instrument Operations:**

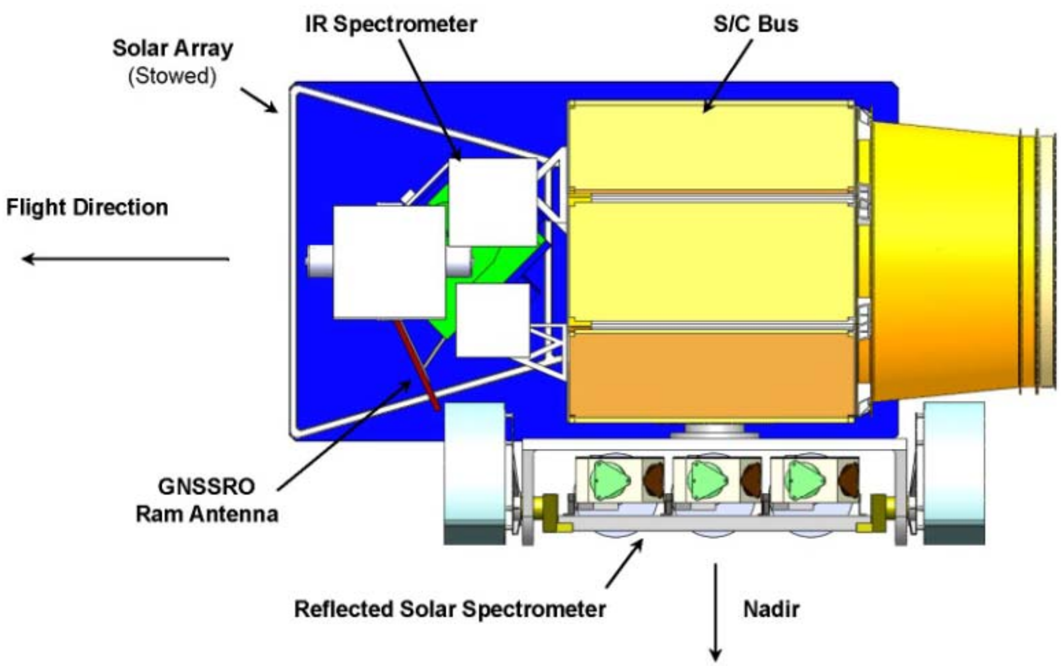
- *Number of occultations : ~2000/day/observatory*
  - 1000 each from GPS and Galileo
- *Rising and Setting Occultations*
  - Ram/Wake antennas provide both options with observatory yaw flip
- *Clock corrections on ground if necessary*

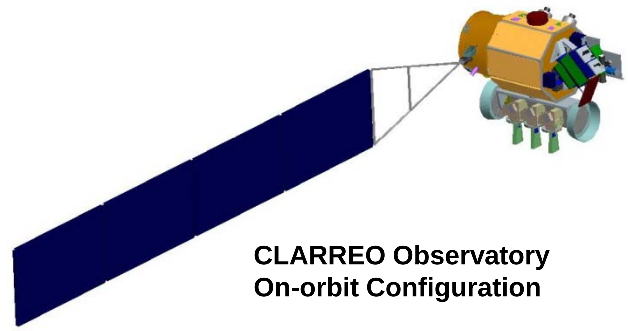
# Spacecraft Bus and Observatory

# Spacecraft Requirements and Drivers

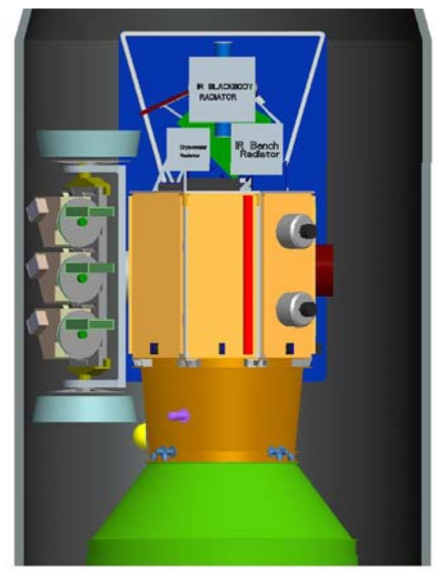
- **Mission Orbit:**
  - The spacecraft will be in nearly circular polar orbits at 609 km (+/-200m) altitude, 90 degree inclination angle (+/-0.1) degree and 90°separation in longitude of ascending node between observatories – beta angle in 90 degree orbit drives solar array design
- **Mission Lifetime:**
  - The mission lifetime shall be a minimum of 3 years
  - Operational consumables for 5 years of life
  - Post-mission orbit lifetime: <25 years – Controlled de-orbit drives propulsion system
- **Payload:**
  - Instrument Field of Regard's (FOR's) –drives instrument location and solar array design
- **Launch Vehicle:**
  - Minotaur IV+ Launch Vehicle launch capability, fairing diameter and CG offset limits – drives instrument location, mass of spacecraft, and solar array design
- **Mission Success:**
  - Spacecraft Reliability allocation –drives redundancy, mass and costs

# CLARREO Observatory Concept



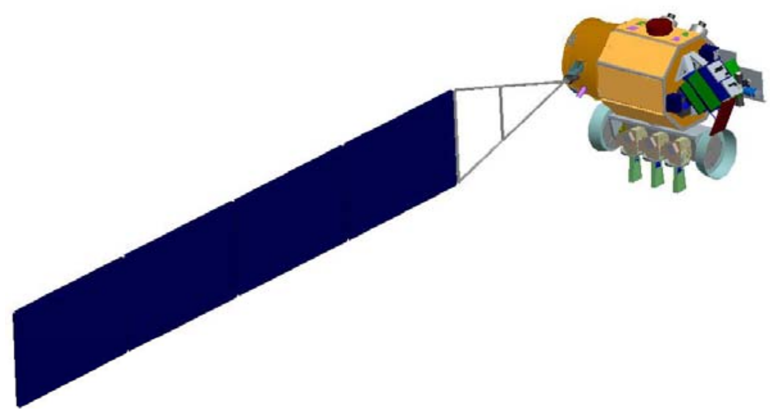
CLARREO Observatory
On-orbit Configuration




CLARREO Observatory (stowed configuration in Minotaur IV+)

# Spacecraft Bus Subsystems

- *Electrical Power System*
  - 158 A-Hr Li-ion battery capacity
  - 28V Direct Energy Transfer Power Bus
  - Deployable, 10.0 $m^2$ (1060W EOL)
- *Command and Data Handling*
  - Central Electronics Processor
  - Provide C&DH, Communications, Thermal, Propulsion and payload command and telemetry interfaces (SSR, C&DH computer)
- *Communications System*
  - X-Band for downlink for stored engineering and payload data
  - S-band for command uplink and telemetry downlink
  - Data Volume: 314 Gbits/day
- *Attitude Determination & Control System*
  - 3-axis stabilized attitude control system
  - Star trackers, IMU's, CSS, Magnetometers
  - Reaction Wheels and Magnetic Torque Bars
  - GPS for Orbit determination
- Propulsion System
  - Monopropellant – Hydrazine blowdown system
  - 4 +4 22 N Thrusters for orbit maintenance and controlled re-entry
- Thermal System
  - Thermal control using radiators and MLI
- Mechanical/Structural System
  - Aluminum sheet over aluminum honeycomb panels



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# Launch Vehicle Strategy

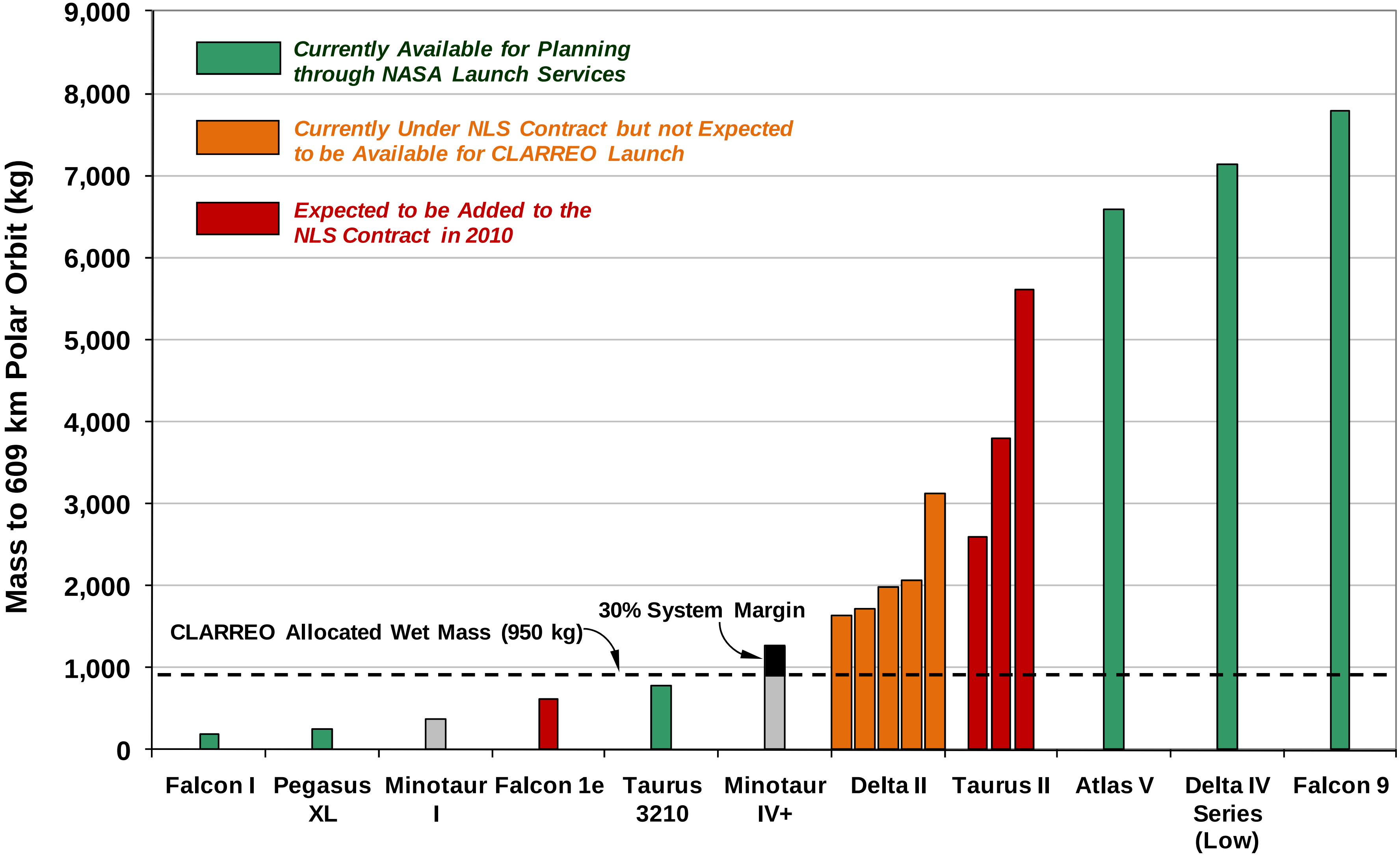
# Launch Vehicle Trades

**Pre-Phase A trade studies evaluated multiple launch vehicle options to identify the most cost-effective access-to-space solution.**

## Options Considered

- **Individual launches**
  - Falcon 1 and 1e
  - Pegasus XL
  - Taurus XL
  - Minotaur I and IV+
  - Taurus 2
  - Falcon 9
- **Single launch with dual manifest on an EELV (Atlas V or Delta 4) using the Dual Satellite System (DSS) currently under development**
- **Evaluation for Pre-Phase A focused mainly on the costs of the different options**

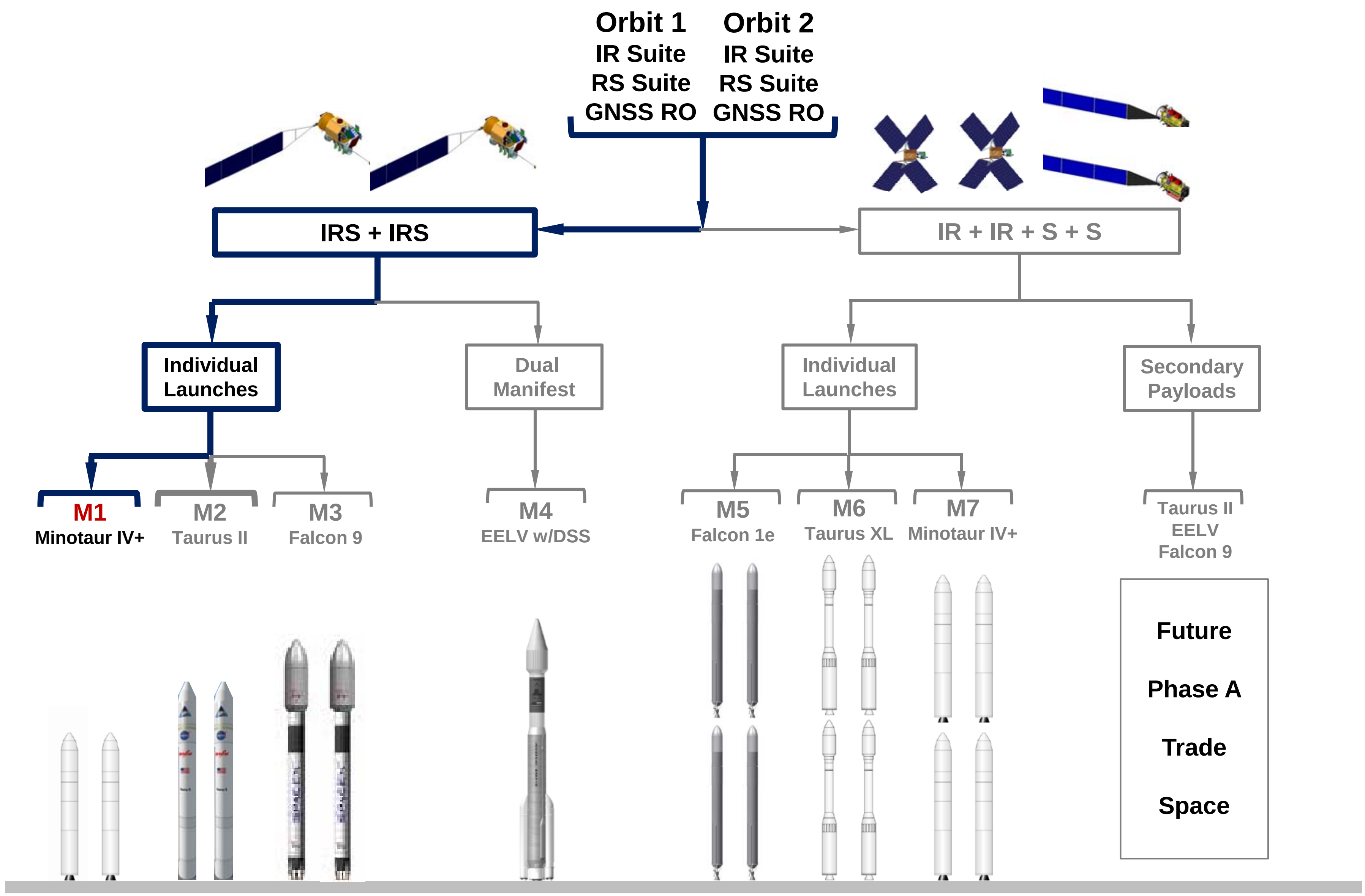
# CLARREO
## Launch Vehicle Options

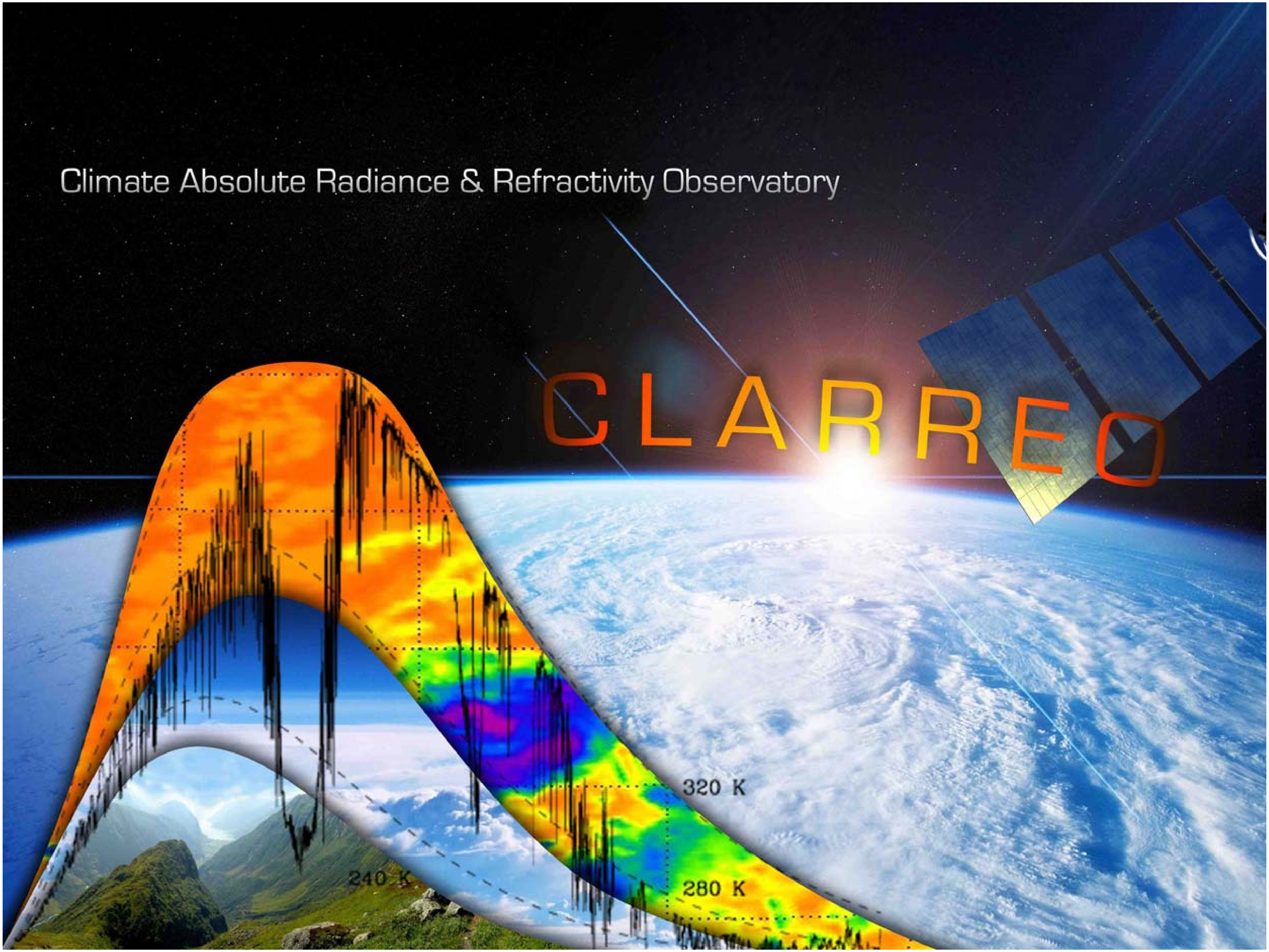


# Mission Architecture Strategy for MCR

- **The three most cost competitive and viable mission architectures available when future launch vehicles are included in the trade space are:**
  - Launch two observatories as a dual-manifest on a single EELV
    - Derivative concept is to replace the EELV with a Falcon 9 if the Falcon 9 proves to have polar orbit capability and dual-manifest capability
  - Launch two observatories individually on two Minotaur IV+ vehicles
    - Derivative concept is to replace the Minotaur IV with a Falcon 9 if the Falcon 9 proves to have polar orbit capability
  - Launch four observatories with one spectrometer (IR or RS) on four Falcon 1e launch vehicles (assumes that the Falcon 1e cost < Minotaur IV cost)
- **Based on current data, the Minotaur IV+ appears to be the most cost-effective solution, but launch vehicle trade studies will continue to be conducted in Phase A**

# Mission Architecture Decision Tree





Climate Absolute Radiance & Refractivity Observatory
CLARREO
320 K
280 K
240 K