GeoCarb Mission Update

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GeoCarb: Built on Strong Partnerships

GeoCarb Mission: Overview

The GeoCarb Mission is designed to collect observations of the column averaged concentrations of carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO), and solar induced fluorescence (SIF) from geostationary orbit (GEO) at a spatial resolution of 5-10 km over the Americas between 50º North and 50º South Latitudes as a hosted payload on a commercial communication satellite.

The Goal of the GeoCarb Mission *is to provide observations and demonstrate methods to realize a transformational advance in our scientific understanding of the global carbon cycle.*

Science Hypotheses

Baseline Mission

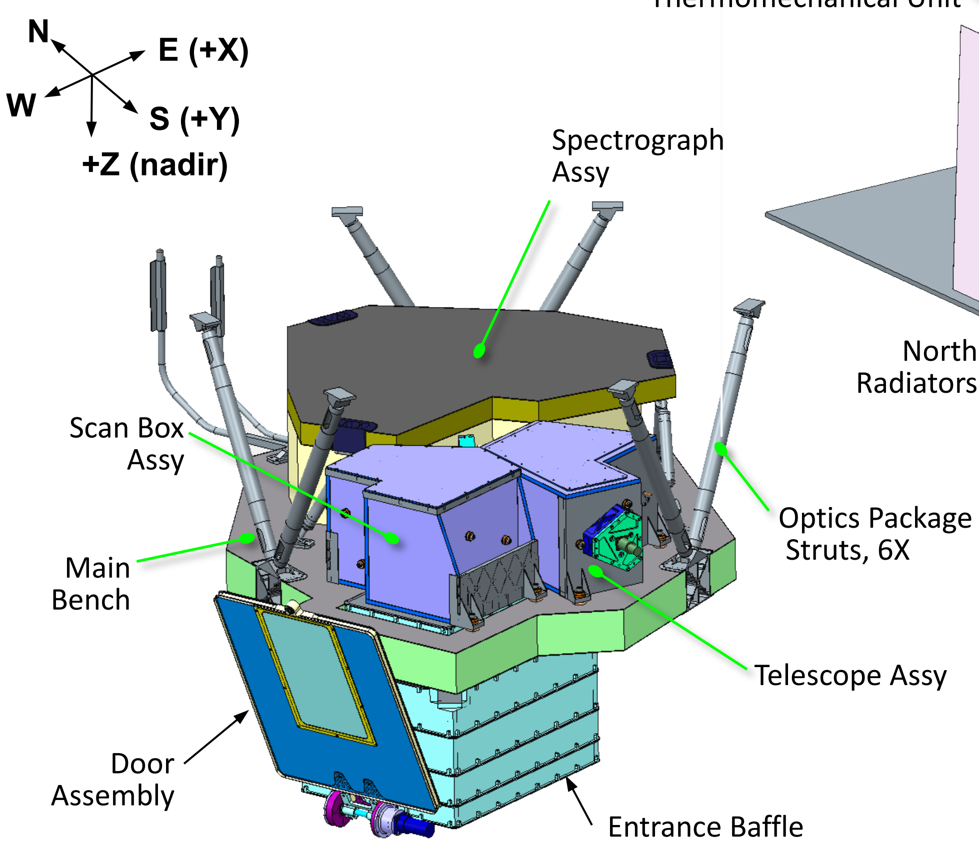
Threshold Mission

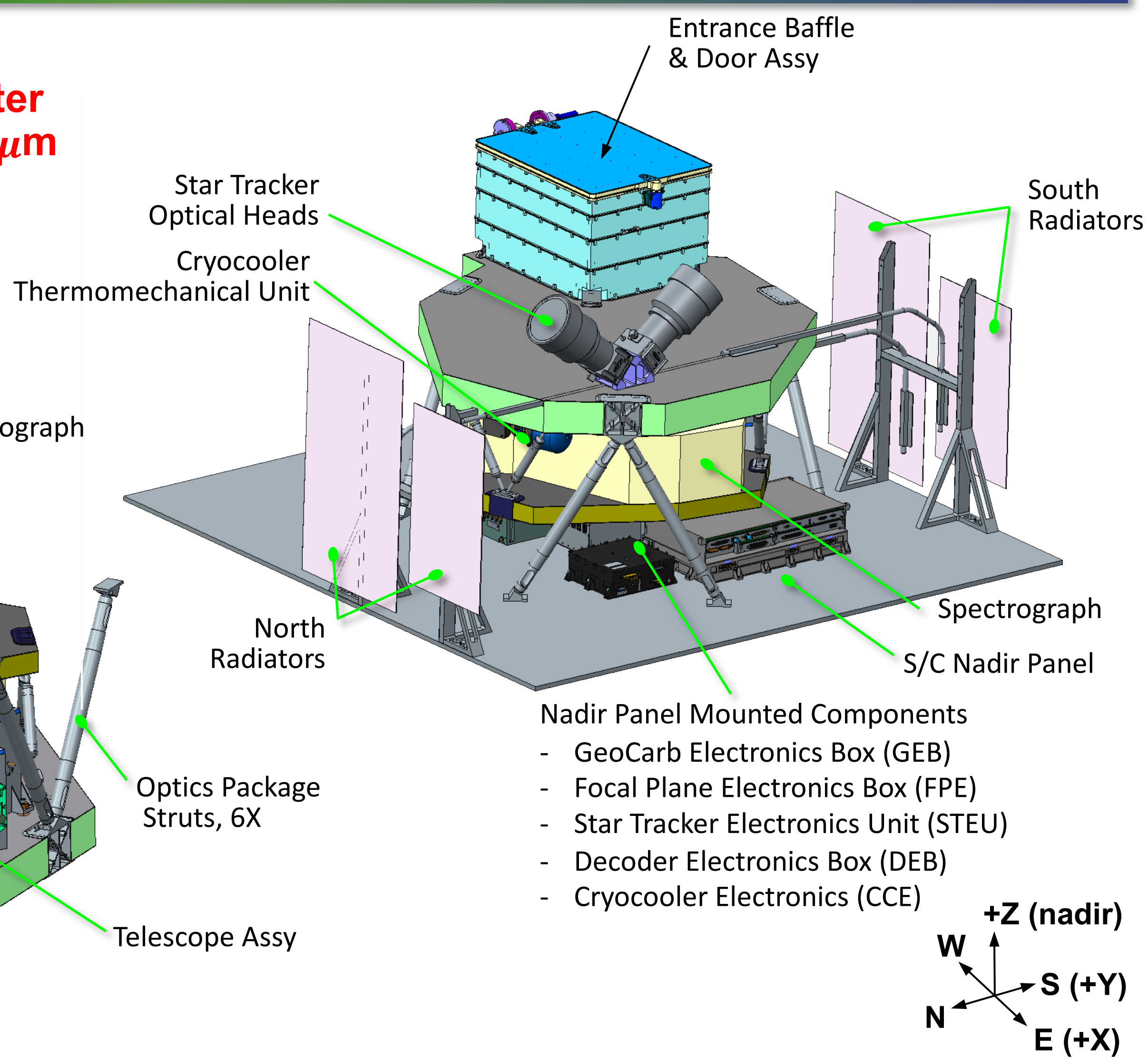
1. The ratio of CO_2 fossil source to biotic sink for CONUS is ~4:1
2. Variation in productivity controls spatial patterns of terrestrial sinks
3. Amazonian ecosystems are a large (~0.5-1.0 GtC/y) net sink for CO_2
4. Larger cities emit less CO_2 emission per capita than smaller ones
5. Amazonian ecosystems are a large (~50-100 MtC) net source for CH_4
6. The CONUS methane emissions are a factor of 1.6 ± 0.3 larger than in EDGAR and EPA databases

GeoCarb aims to fundamentally advance our understanding of how the carbon cycle behaves on regional scales.

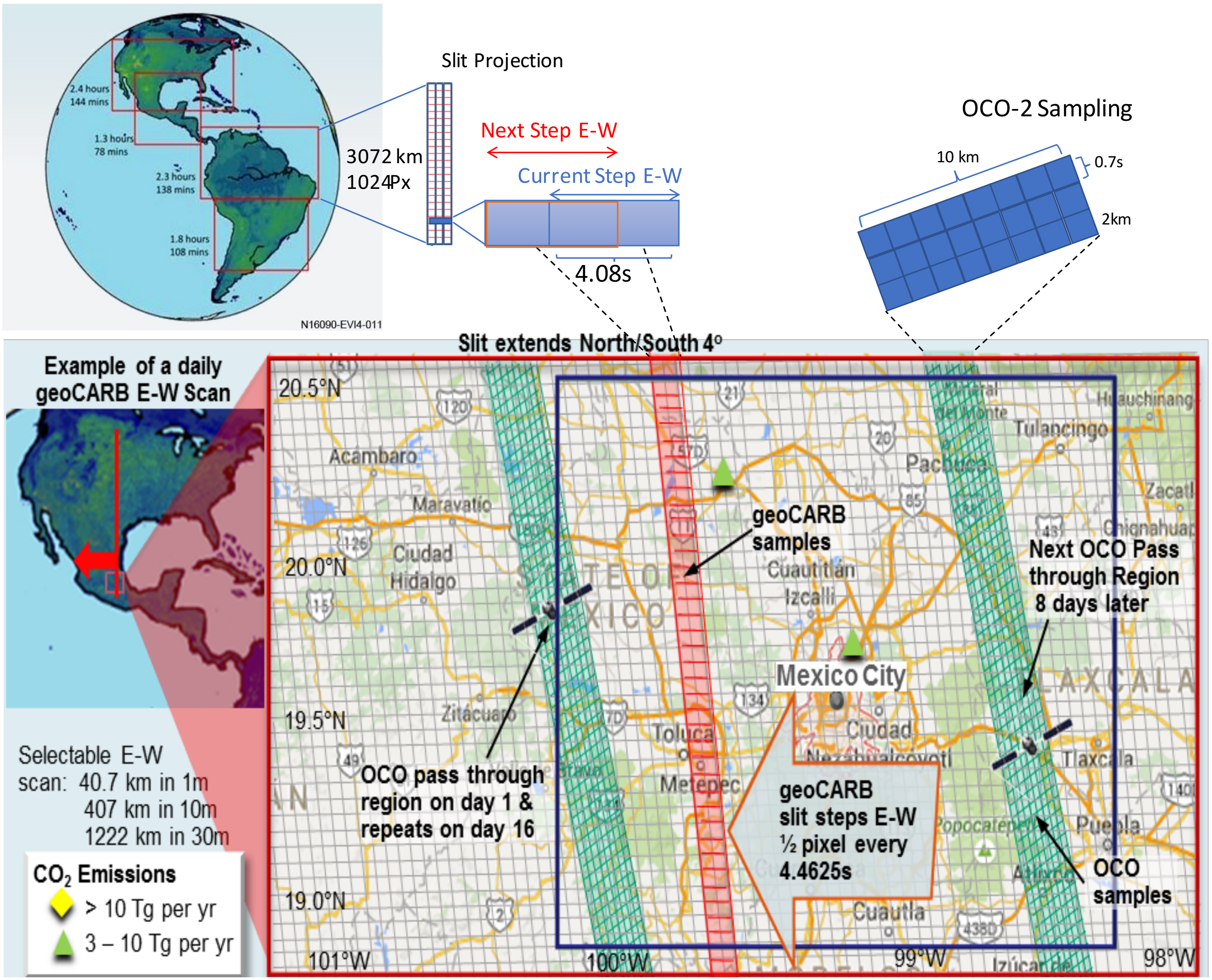
Instrument Overview

Single slit, 4-Channel IR
Scanning Littrow Spectrometer
Bands: 0.76μm, 1.61μm, 2.06μm and 2.32μm

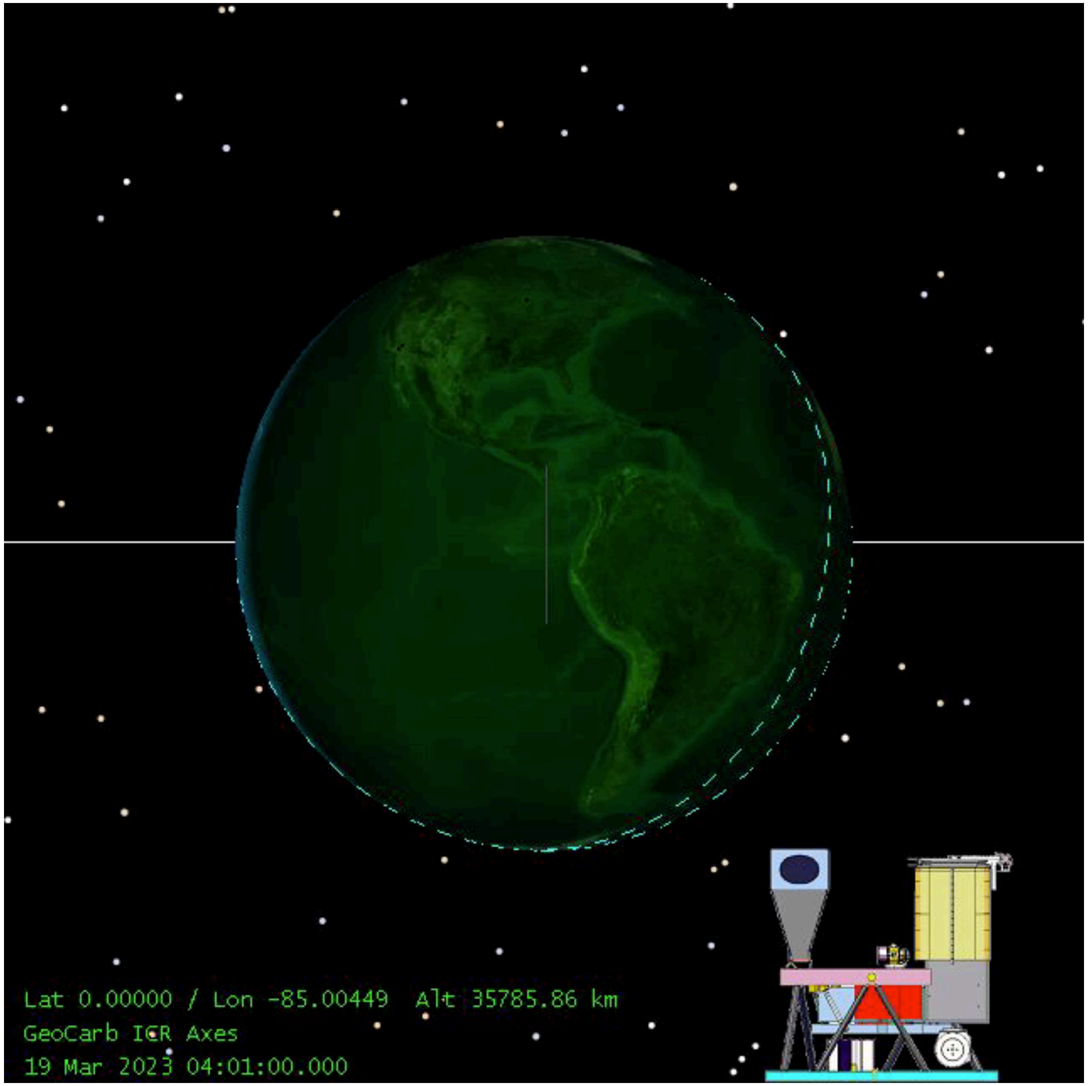




Mexico City: OCO-2 and GeoCarb

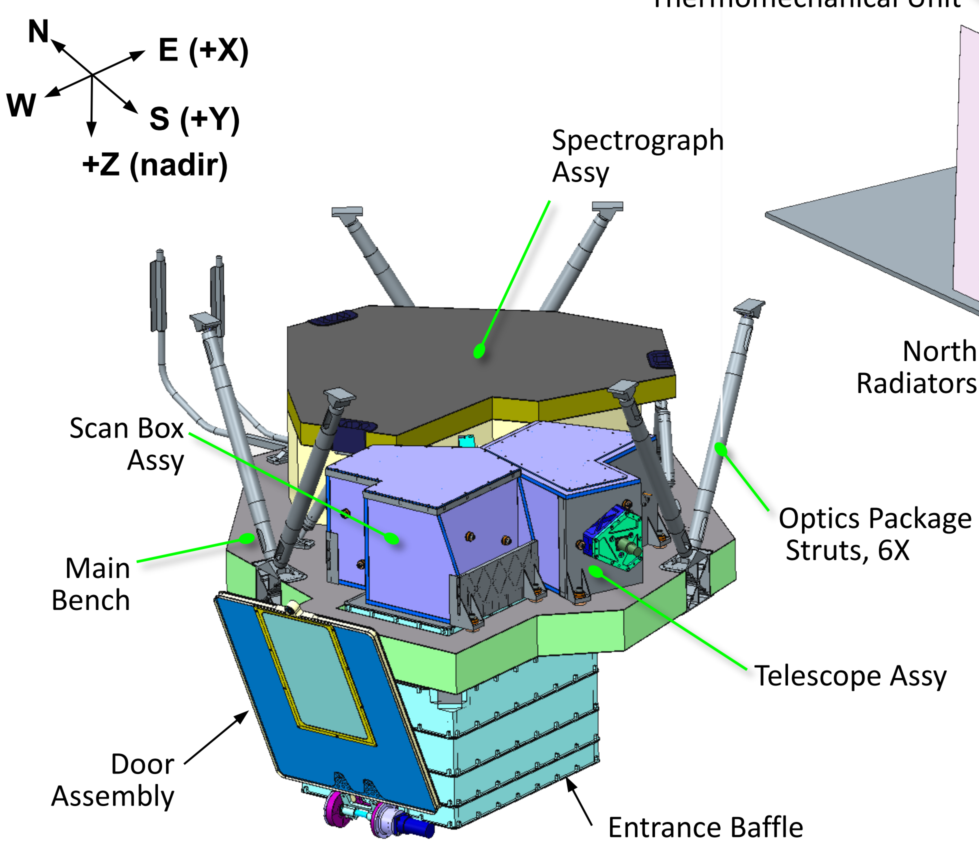


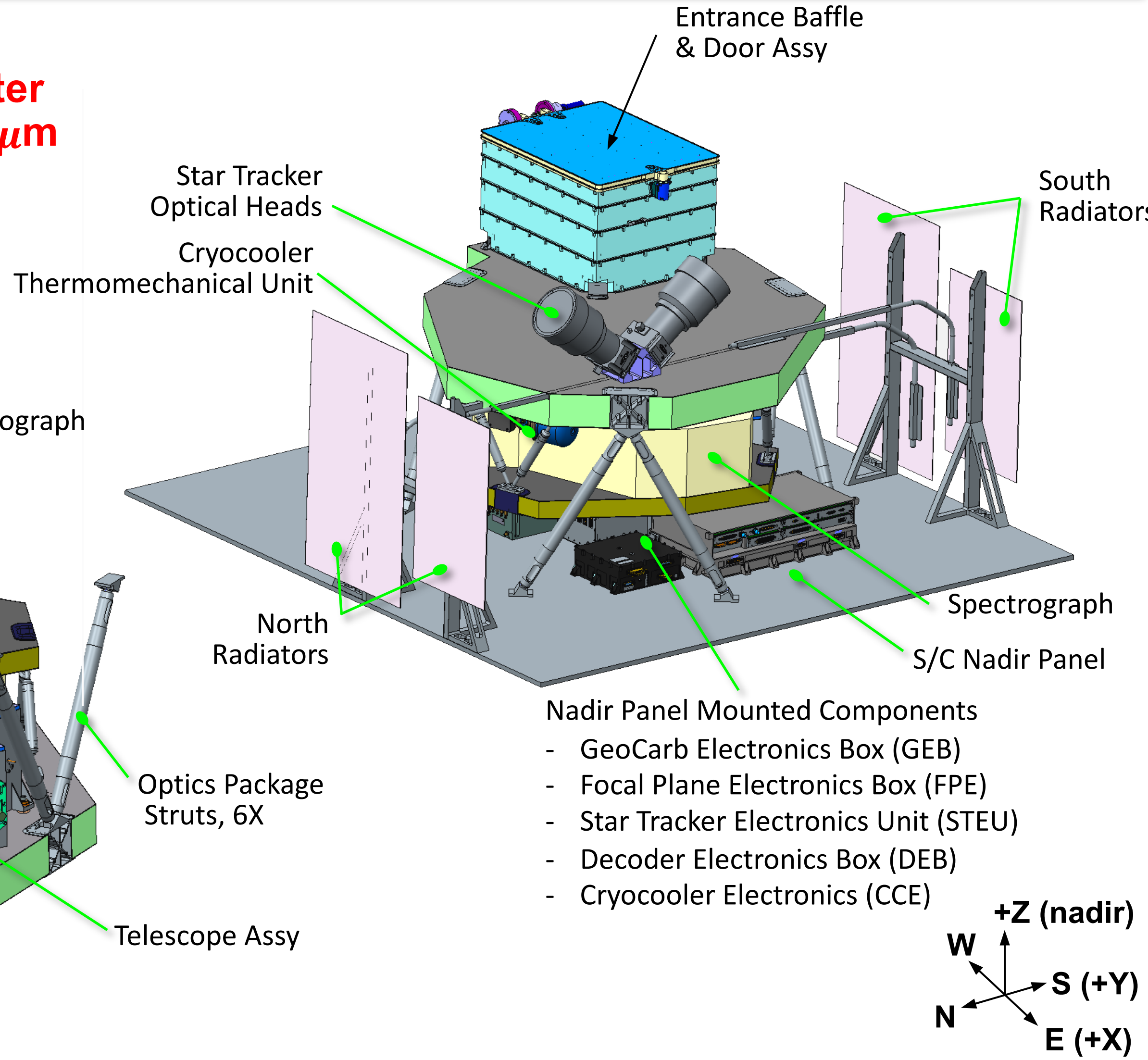
A Day in the Life of GeoCarb



Simplified Instrument Overview

Single slit, 4-Channel IR Scanning Littrow Spectrometer
Bands: 0.76μm, 1.61μm, 2.06μm and 2.32μm





Instrument Design Changes

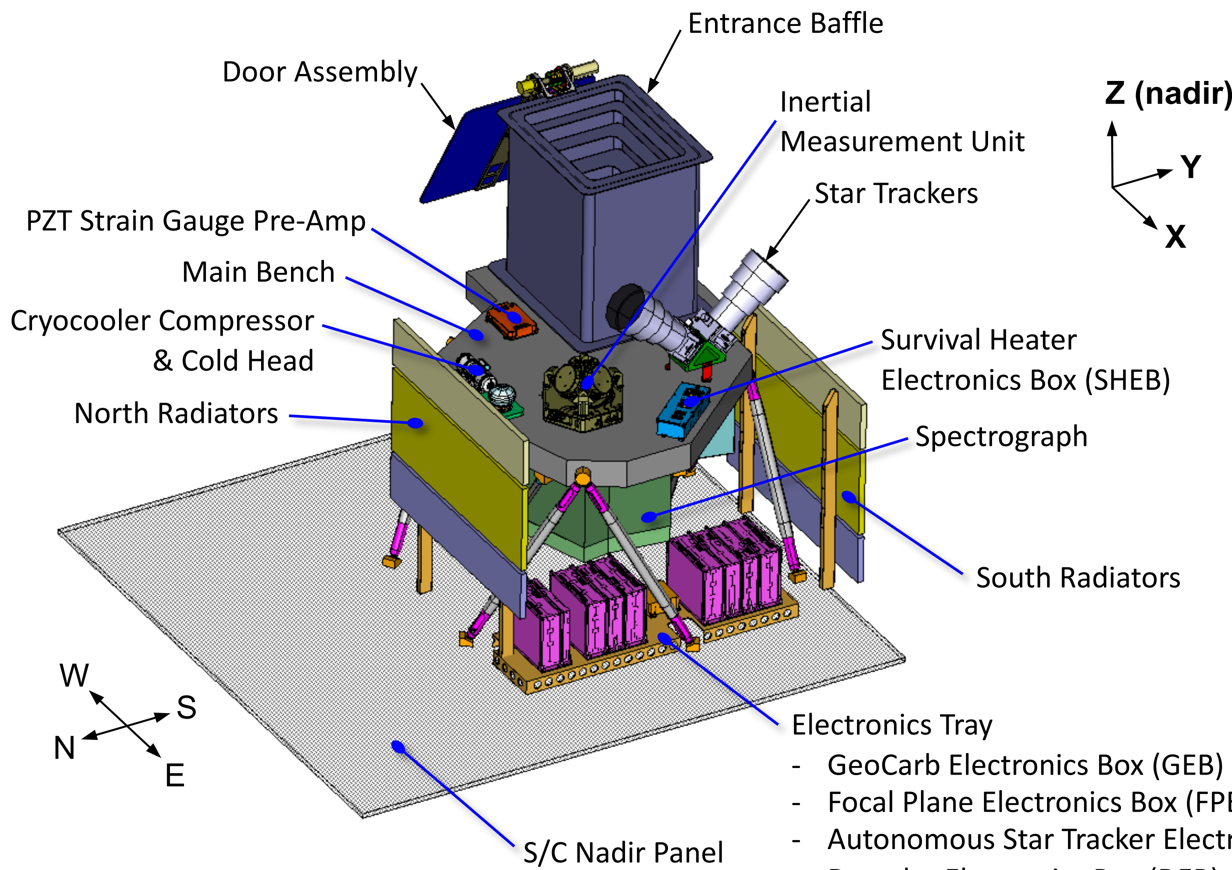
- **Based on analyses and trades, the following changes were made to the Baseline Instrument at PDR:**
  - Modified ISS
    - Image Stabilization System (ISS) modified to use scan mirror fed by star tracker rather than active mirror fed by IMU
  - Removed Calibration Drum Assembly
    - Removal of cal drum mechanism and structure
  - Reduced Optical Aperture for system
    - Reduced optic substrate size of optics (varies by optic)
  - Remove SHEB
    - Use mechanical thermostats for survival heaters
  - Change from PID thermal control
    - Reduction in FSW complexity
  - Removed FPA thermal sensor
    - Redundant sensor, removes wires, reduces parasitics
  - Removed redundant power harness to S/C
    - SES agrees with minimal impact
  - In addition, the above changes allowed for electronics box reductions:
    - Combination of Mech 2 and Bridge board
    - Removal of 1 and ½ boards: Mech 2 and PZT driver circuits
    - Allowed for reduction of one whole row of boards (slots)

Simplified Instrument

- **Optical redesign: reduction of SNR from smaller aperture area - <u>doubled stare time to meet SNR reqts</u>**
  - SNR has margin in all channels, despite the presence of increased noise from thermal glow
  - Areal coverage rate retained by removal of double sampling
- **Removal of Secondary Solar Calibration Drum: redundancy to assess changes in primary diffuser – <u>already planned lunar observations will be sufficient</u>**
  - Lunar observations will be used to assess changes in the calibration over time. This methodology has been demonstrated by OCO-2. Working with lunar cal experts to adapt the OCO-2 approach for GeoCarb sampling
- **Removal of IMU: expected pointing knowledge is reduced by ~0.1km, but it <u>still meets MDRA requirements</u>**

We meet all Level 1 requirements and satisfy the mission hypotheses with the Replanned Project, though with some reduced margin

GeoCarb: Baseline Instrument PDR



Electronics Tray
- GeoCarb Electronics Box (GEB)
- Focal Plane Electronics Box (FPE)
- Autonomous Star Tracker Electronics (ASTE)
- Decoder Electronics Box (DEB)
- Cryocooler Electronics (CCE)

Heat Pipes not shown

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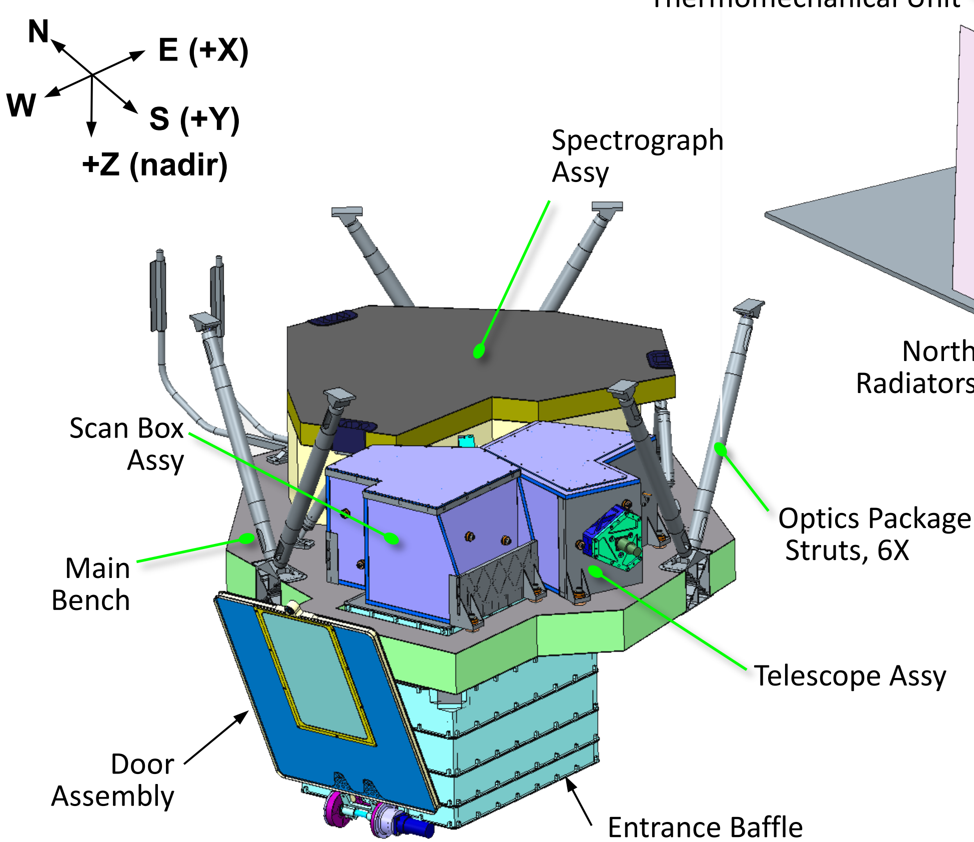
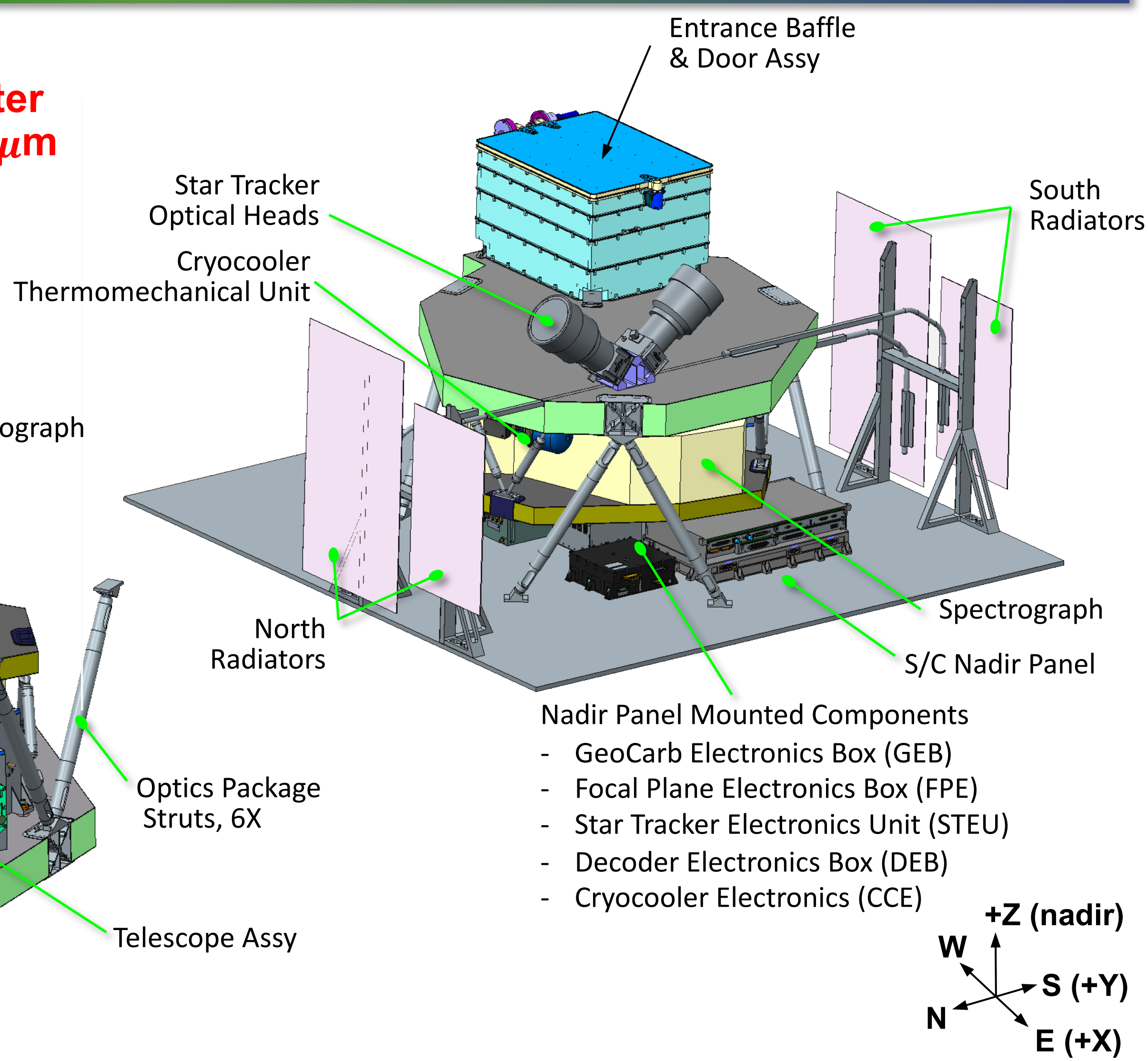
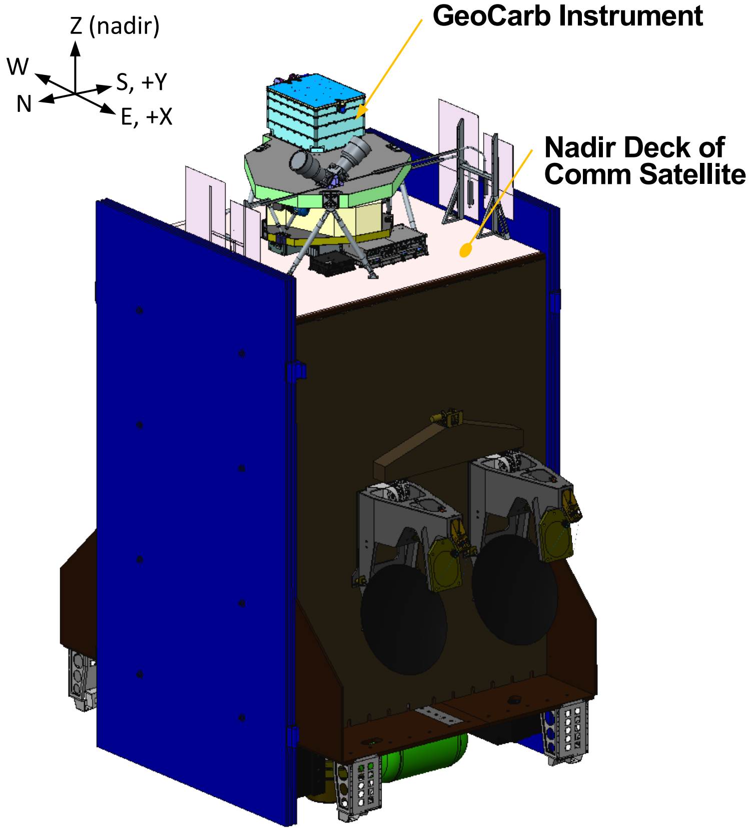




Host Spacecraft

- **Working with SES to ensure maximum compatibility of GeoCarb with candidate host spacecraft**
  - Enveloping candidate spacecraft environments
    - Mechanical, thermal, EMI/EMC, and contamination
  - Accommodate 100V spacecraft busses
  - Simplifying instrument to spacecraft interfaces
  - Simplifying satellite integration and test operations
  - Streamlining the instrument concept of operations

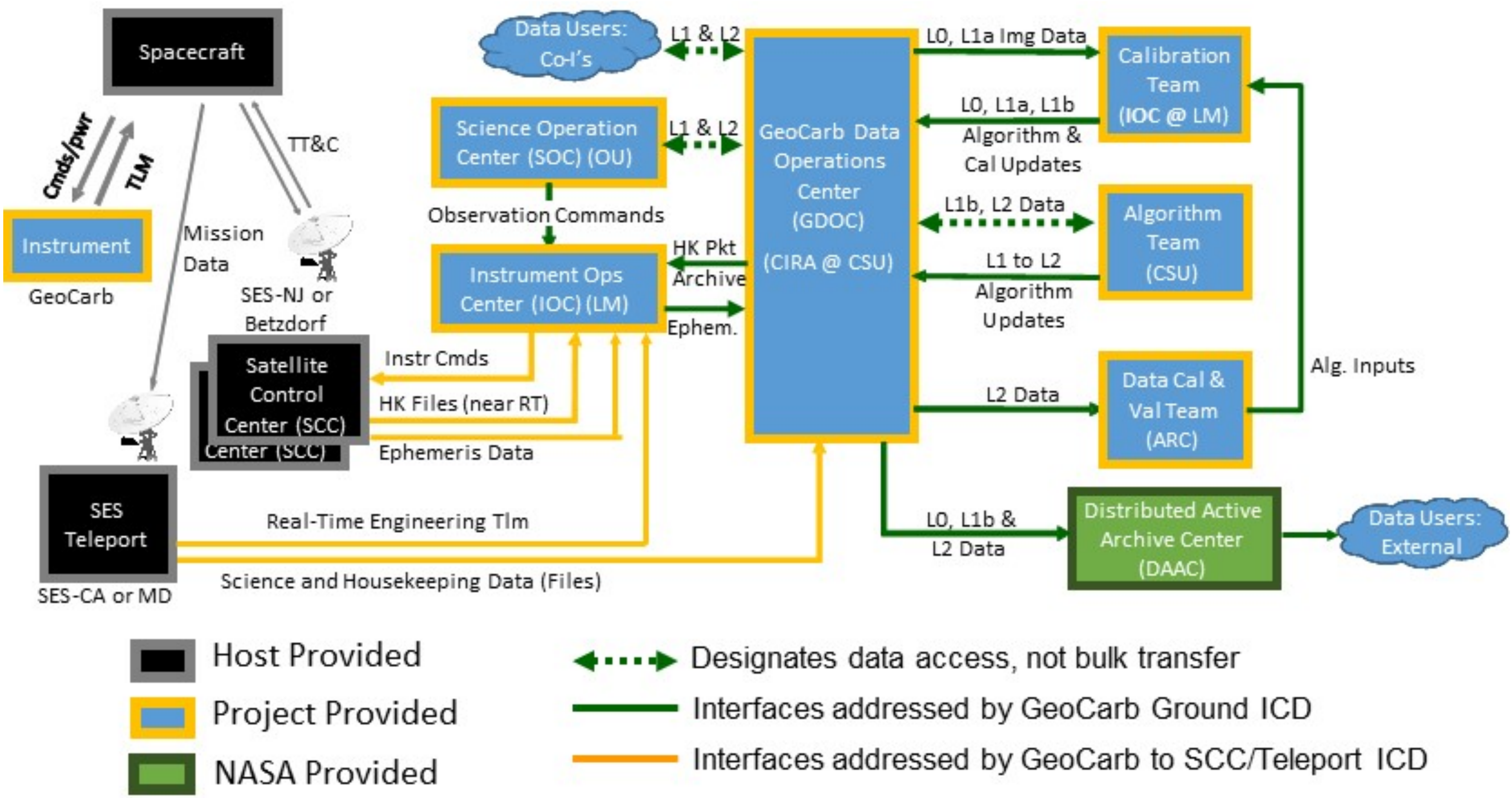


Launch Services: Currently June 2023 to 103º West

- **Launch services are provided by SES**
  - Procured and managed by SES separately from the Spacecraft contract
    - SES has recent experience with a variety of commercial launch vehicles:
      - SpaceX (Falcon 9)
      - Ariane 5 ECA
      - Soyuz
      - Proton Breeze M
  - Launch services include:
    - All applicable licensing and permitting
    - TIMs and applicable reviews
    - Launch site integration and testing
    - Launch and early orbit support

System Data Flow Block Diagram

Organization and External Interface View



Ground ICDs are preliminary at PDR, baselined at CDR

Significant Accomplishments Since PDR

- **Project**
  - **Project Re-planned in order to increase cost reserves by $5.8M**
    - Instrument simplified
    - Science prioritization
    - Ground system processing reductions and optimization
    - Completed assessment and impact on Level 1 & 2 requirements
    - Updated concept of operations
    - Revised project plan to increase project cost reserves
  - Conversion of LM subcontract to Firm Fixed Price to reduce risk of future cost growth (in process)
  - Host management strategy is a) to assure SES a mass not to exceed 176kg (roughly 25% growth over proposal mass); b) to assume a cost by SES not to exceed 25% growth over proposal.
- **Science:**
  - **Significant improvement in end-to-end modeling**
    - Improved model used for in-depth study of scene inhomogeneity, instrument calibration/characterization, and error budgets
    - Level 2 retrievals coupled to performance results from the instrument model
- **Instrument**
  - Instrument simplified to achieve to reduce risk, mass and cost
  - Slit homogenizer baselined
  - Still meets Level 1 requirements
  - Engineering progress continues to mature the instrument baseline
- **Ground System**
  - Determined cost savings from the reduction in data rate due to the instrument descope
  - Exploring cost reduction opportunities through the use of cloud-based and existing NASA computing resources – retrieval timing tests, throughput (in process)

Significant Changes

Item	PDR CBE/MEV	DPDR CBE/NTE	% change
Instrument Mass (CBE/MEV)	186 kg / 213 kg	157 kg / 176 kg	-16% / -17%
Instrument Power (CBE/MEV)	406 W / 538 W	393 W / 521 W	-3% / -3%
Data Rate	18.7 Mbps	9.3	-50%
Unencumbered Cost Reserves	$7M	$21.3M	+304%
Funded Schedule Reserve	71 days	71 days	0%

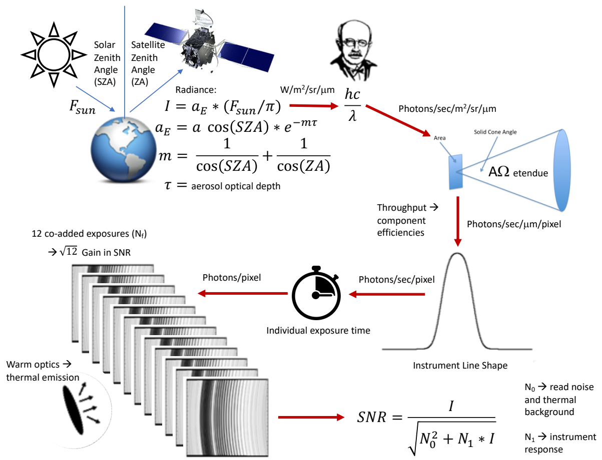
Replanned efforts have significantly increased the financial health and key contingencies of GeoCarb while maintaining performance that satisfied the Level 1 Requirements and Mission Objectives

Key Level 1 Requirements

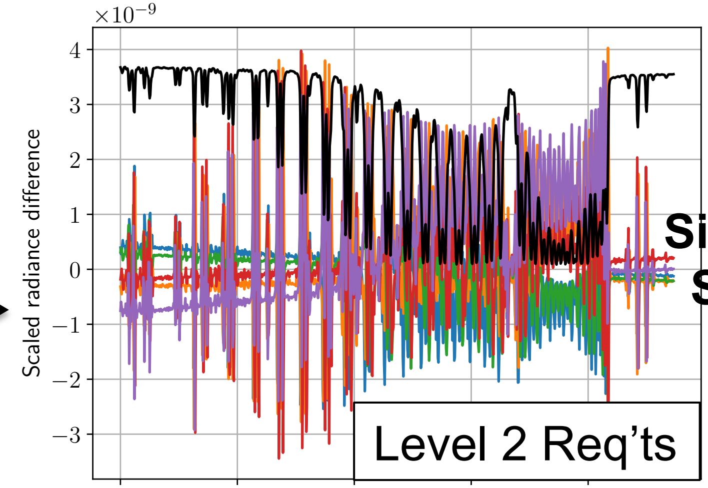
Req ID PLRA	Project Level 1 Requirements	Baseline	Threshold	Expected
4.1.1.a / 4.1.2.a	Retrieve estimates of the column-averaged dry air mole fractions XCO2, XCH4, XCO and SIF from space-based measurements over cloud-free scenes	XCO2, XCH4, XCO, SIF	XCO2, SIF	XCO2, XCH4, XCO, SIF
4.1.1.b.a / 4.1.2.b.a	The bias corrected, clear-air, multi-sounding GeoCarb retrieval estimates for XCO2 will demonstrate multi-sounding precision better than	<0.3%	<0.6 %	0.2%
4.1.1.b.b / 4.1.2.b.b	The bias corrected, clear-air, multi-sounding GeoCarb retrieval estimates for XCH4 will demonstrate multi-sounding precision better than	<0.6%	N/A	0.4%
4.1.1.b.c/ 4.1.2.b.c	The bias corrected, clear-air, multi-sounding GeoCarb retrieval estimates for XCO will demonstrate multi-sounding precision better than	< 10% or 12 ppb (whichever is greater)	N/A	8%
4.1.1.c 4.1.2.c	Retrieval estimates of solar induced fluorescence (SIF) with NESR ($W/m^2/\mu m/sr$)	<0.75	<1.0	<0.5
4.1.4.a	Geostationary orbit longitude	85º W ±20˚	N/A	103º W
4.1.4.c	Space-based measurements shall have spatial resolution at the sub-satellite point (single sounding)	< 60 km^2	<100km^2	< 60 km^2

“End to End” Simulator

Instrument Performance Model

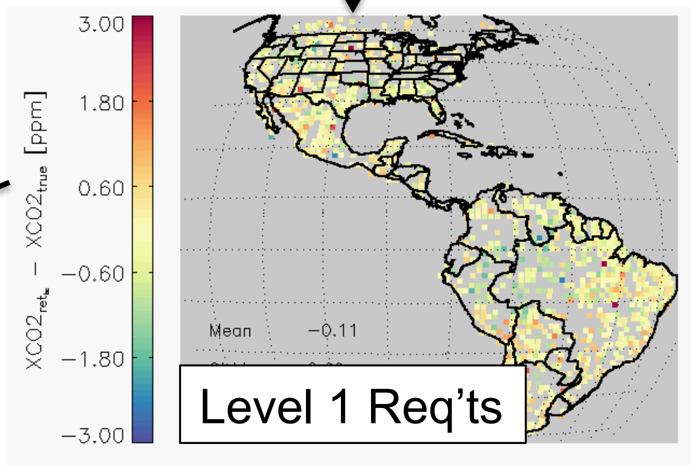


Level 3/4 Req’ts

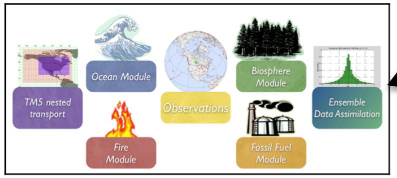


Simulated Spectra

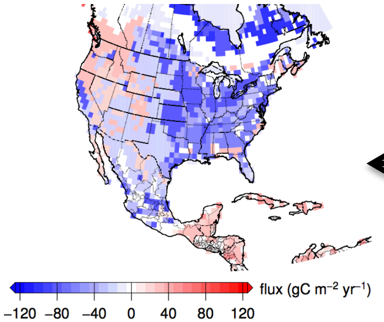
Synthetic Retrievals



Atmospheric inversion model



Inferred fluxes



Mission Objectives

Use of the Simulation System

- **Propagate instrument characteristics into L2 retrieval errors**
  – Trace L1 requirements (e.g., XCO_2) downward to instrument performance requirements (Level 3-4)
    - Radiometric Calibration
    - Spectral Calibration
    - Polarization response knowledge
    - Image navigation and registration
  – Separate random and systematic error effects
  – Examine different error effects on data quality filtering
  – Value of the Slit Homogenizer
- **Propagate L2 retrieval errors into flux estimates**
  – Trace L1 requirements upward to Science Objectives
  – Examine data throughput impacts on Science Objectives

Slit Homogenizer Status

- **Low risk approach for SH development**
  - Leveraging from ESA Sentinel-5
    - ILS distortion simulation algorithms
    - One of the SH vendors (WinLight) fabricated Sentinel 5 SH
    - Same test laboratory (ITO)
  - Two vendors (LightMachinery and WinLight) have developed prototype SH
    - Both have heritage developing SH or similar optical elements for flight
    - Using 2 vendors to develop SH prototypes reduces risk
      - Prototypes are being tested at ITO, will inform flight model selection
  - Schedule risk is mitigated by identifying key SH decision points in the IMS
    - We will design and procure 3 SH depths (and associated fold mirrors) if prototype testing is not available to finalize SH geometry
    - Decision on single SH design needed by Oct 2019 to not impact instrument schedule
  - Flight slit homogenizer environmental testing by January, 2020 (prior to integration and prior to CDR)
- **We have a backup plan in-place should the SH be undesirable**
  - Backup plan (install a standard slit with a flat fold mirror) is low-cost and may be implemented late (Jan 2020)
  - Meets threshold mission requirements

PI Assessment

- **Successful project-wide Re-plan reduced costs and risks across all segments.**
- **Reduced instrument complexity, mass, and data-rate while meeting all Level 1 Requirements**
- **Host management strategy is a) to assure SES a mass not to exceed 176kg (roughly 25% growth over proposal mass); b) to assume a cost by SES not to exceed 25% growth over proposal. Hosting uncertainties are being further mitigated through:**
  - Regular interaction with our preferred host SES and other potential candidate hosts
  - Incentivize LM to have mass below 176kg (in process)
- **Science segments are proceeding more quickly than anticipated due to close collaboration with other missions (e.g. OCO-2/3) and well established teamwork, which enables speedy closure for opportunities and changes**
- **PI assesses GeoCarb budget as "yellow" due to cost reserves being smaller than 25% (21.9% at D-PDR). This is an acceptable level of risk for a Class D project; however, the PI decided (1 May 2019) to Convert the LM contract to a Fixed Price Contract to reduce further the risk of cost growth.**

Summary

- **The GeoCarb Project has matured significantly during Phase B**
  - A revised PLRA better reflects the scientific goals of the mission
  - The instrument design is far better than preliminary design maturity
  - Scientific algorithms are well beyond typical missions at this stage
  - Program-wide Replan - significant reductions in instrument complexity, mass and data rate, which decreases hosting costs
  - Conversion of LM contract to FFP reduces risk of future cost growth
  - Working with SES and GEOshare to identify additional launch opportunities
- **Medium risk, but Extremely High Reward!**
  - The scientific outcomes will be unprecedented as we revisit the western hemisphere land masses every day – the information we will provide on the carbon cycle in the Amazon and in North America will be revolutionary
  - We will demonstrate the feasibility of a PI-led commercially hosted payload mission with a focus on Earth Science

GeoCarb has made great progress in all mission segments and through wise team-wide decisions after PDR. We are ready to proceed to Phase C/D. KDP-C is 18 July!!

Science Team Posters at IWGGMS

- Atmospheric Variations in Column Integrated CO2 On Synoptic and Seasonal Time Scales Over the U.S. (Wang)
- The Ability of GeoCarb to Constrain the Interannual Variability of Carbon Gases over the Amazon (Weir)
- Progress in Atmospheric Carbon Monitoring Using NASA's Goddard Earth Observing System (GEOS) Model and Data from the OCO and GOSAT Missions (Weir)
- Characterization of OCO-2 and ACOS-GOSAT Biases and Errors for Flux Estimates (Kulawik)
- Simulation-retrieval Experiments over the Western Hemisphere with the GeoCarb Greenhouse Gas Retrieval Algorithm (McGarragh)
- Seasonal and Diurnal Opportunities for XCH4, XCO2, and XCO for the Amazonian Rainforest Region Allowing Sampling and Validation (Chatfield)
- Comparison between MOPITT and OCO-2 Flux Inversions: Analyze of CO-CO2 Correlation (Peiro)
- Characterizing and Mitigating the Impact of Model Transport Errors on CO2 Flux Estimates in the Assimilation of XCO2 Data from OCO-2 (Jones)
- NASA's Carbon Cycle OSSE Initiative - Informing future space-based observing strategies through advanced modeling and data assimilation (Ott)

See You at Launch!!!!!

ありがとうございました

THANK YOU