Commercially Hosted Orbiting Carbon Observatory

Robert Thompson

LMU|LA
Loyola Marymount
University

Outline

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- Trade Study Results
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- Ground Segment Concept
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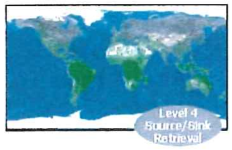
- Schedule
- Summary
- Conclusion



Project Purpose

- Determine feasibility of a commercially hosted carbon monitoring satellite constellation
- Provide alternative architecture to meet scientific goals of NASA's failed Orbiting Carbon Observatory (OCO) mission
  - Failed launch February 2009
    - Failure under investigation
  - Intended to provide global map of CO_2 concentration
- Provide initial analysis to OCO project team

Analysis Methodology

Pre-Phase A: Concept Studies

Purpose
To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected

Typical Activities and Products
(Note: AO projects will have defined the deliverable products.)

- Identify missions and architecture consistent with charter
- Identify and involve users and other stakeholders
- Identify and perform tradeoffs and analyses
- Identify requirements, which include:
  - Mission,
  - Science, and
  - Top-level system.
- Define measures of effectiveness and measures of performance
- Identify top-level technical performance measures
- Perform preliminary evaluations of possible missions
- Prepare program/project proposals, which may include:
  - Mission justification and objectives;
  - Possible ConOps;
  - High-level WBSs;
  - Cost, schedule, and risk estimates; and
  - Technology assessment and maturation strategies.
- Prepare preliminary mission concept report
- Perform required Pre-Phase A technical activities from NPR 7120.5
- Satisfy MCR entrance/success criteria from NPR 7123.1

Reviews
- MCR
- Informal proposal review

Background-Mission Statement

Mission Statement

Replace the failed OCO satellite and make precise, time-dependent global measurements of atmospheric carbon dioxide (CO_2) from sensors hosted on commercial earth orbiting satellites.

Mission Statement

- Where are the sources of carbon dioxide?
- What natural processes absorb carbon dioxide from human emissions?
- Will those processes continue to limit increases in atmospheric carbon dioxide?
- Will they stop or even reverse and accelerate the atmospheric increases?
- Is the missing carbon dioxide being absorbed primarily by land or the ocean?
- Why does the increase in atmospheric carbon dioxide vary from one year to the next while emission rates increase uniformly?
- How will carbon dioxide sinks respond to changes in Earth's climate?
- What are the processes controlling the rate at which carbon dioxide is building up?

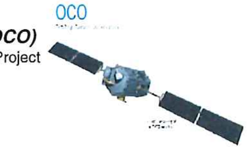
Carbon Dioxide's Role in Global Climate Change?

- One of many gases that trap heat near the earth's surface
- Is a critical component of the earth's atmosphere
- Most abundant greenhouse gas (.03%)
- Since the dawn of the industrial age, the concentration of CO_2 has
  - increased by about 25%
  - from about 280 parts per million to over 370 parts per million.
- Has numerous man-made and natural sources

Background-Relevant Programs

OCO

Orbiting Carbon Observatory (OCO)
- NASA Earth System Science Pathfinder Project
- Designed to determine atmospheric CO_2
- Initiated in 2003, Failed launch in 2009
- Approximately $300M



Commercially Hosted IR Payload (CHIRP)
- US Air Force R&D Project
- Designed to host an experimental wide field of view (WFOV) IR payload in GEO
- Initiated in 2008
- $65 million project including launch
- Slated to launch to 2010/2011

Background-Relevant Programs

Global Positioning System Wide Area Augmentation System (FAA)

- Currently enhancing GPS signal in Alaska
- WAAS payload hosted on Intelsat spacecraft
- Launched in 2005

Automatic Identification System hosted payload (US Coast Gaurd)

- Currently enhancing ship tracking
- Payload hosted Orbcomm spacecraft
- Launched in 2008

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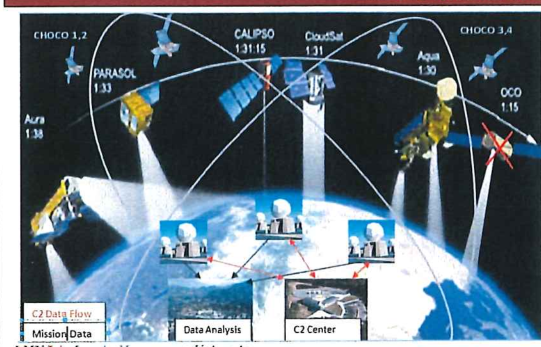
CHOCO Architecture Overview

- Space Segment
  - 8 total hosted payloads on 8 Iridium NEXT satellites
    - 2 planes (0 degrees and 180 degrees)
  - 4 hosted payloads in each plane
    - 2 primary CO2 sensors
    - 1 secondary CO2 sensor
    - 1 O2 sensor
- System Control Segment
  - Modification of 4 Iridium Telemetry Tracking And Control (TTAC) stations
  - Modification of Iridium Satellite Network Operations Center (SNOC)
- Mission Data Analysis Segment
  - Modification of 2 gateways for mission data acquisition
  - Modification of OCO Ground Data System at JPL for CHOCO data processing

CHOCO Architecture



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Trade Study Summary

- **#1 Orbit (LEO, MEO, GEO)**
  - LEO Iridium NEXT constellation chosen primarily for availability, SNR
  - MEO unable to identify suitable host constellation
  - GEO unable to meet required Signal to Noise Ratio (SNR)
- **#2 Host Spacecraft Class (microsat, smallsat, medium, enterprise)**
  - Trade narrowed to smallsat due to outcome of Trade #1
- **#3 Payload design (new, modified OCO, original OCO)**
  - Modified payload chosen due to heritage, ability to meet host limitations
  - Original OCO payload ruled out due to mass & power constraints
  - New payload ruled out due to cost and schedule risk for new development

Trade Study Summary cont.

#4 Sensor location (nadir deck, side deck, integrated into satellite bus)

- Nadir deck chosen based upon pointing, thermal, integration benefits
- Side deck ruled out due to impact on satellite structure interference issues
- Integration into satellite ruled out due to impact on spacecraft baseline

#5 Data Rate (10mbps, 150mbps, 500mbps)

- Data rate of 10 mbps chosen based upon limitations of communications subsystem
- 150mbps ruled out due to technical/programmatic risks of building dedicated comm
- 500mbps ruled out due to inability to fit within host spacecraft allocations

#6 Spacecraft Data Interface (modified S/C C&DH, separate electronics)

- Separate payload interface electronics chosen to minimize impact on host S/C
- 150mbps ruled out due to technical/programmatic risks of building dedicated comm

 # 7 Ground System (New or modified existing)

- Modified ground data system chosen to leverage prior investment
- Modified gateways and C2 center chosen to leverage prior investment

Key Mission Requirements

1.01	**General Mission Requirement**
	Global persistent space-based measurements of atmospheric carbon dioxide (CO2).
1.02	**Payload Compatibility**
	High commonality with the OCO payload
1.03	**Measurement Approach**
	Dry air mole fraction X_{co2} within .4% or 1.4ppmv.
1.04	**Measurement Accuracy**
	1% when averaged over regional scales (1000km x 1000 km) and monthly time scales
1.05	**Calibration Approach**
	An independent calibration shall be used to correct regional-scale systematic biases.
1.06	**Launch**
	Ariane 5 and Zenit 3 launch vehicles
1.07	**Early-orbit operations**
	60 day early-orbit operations phase of the commercial host spacecraft.
1.08	**Orbit**
	80° N and 80° S latitude, at a minimum.
1.09	**Lifetime**
	5 years

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Key Performance Requirements

2.01	**Spectral Resolution-CO2 band 1**
	The system shall be capable of resolving greater than 1000 bands between 1.591um and 1.621um
2.02	**Spectral Resolution-O2**
	The system shall be capable of resolving greater than 1000 bands between .738um and .772um
2.03	**Spectral Resolution – CO2 band 2**
	The system shall be capable of resolving greater than 1000 bands between 2.042um and 2.081um
2.04	**Spatial Resolution -**
	Sample area shall not exceed 3km²
2.05	**Signal to Noise Ratio**
	The signal to noise ratio shall be greater than or equal to 2600 for the 1.591μm – 1.621μm CO_2 band
2.06	**Revisit Rate**
	8 hours.
2.10	**Link Budget**
	The system shall maintain a link budget margin of 3 db at 95% environmental conditions
2.11	**Data rate**
	The system shall require a data rate no greater than 12.5 mbps

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Key Physical Requirements

4.01	Mass
	50 kgs
4.02	Dimension
	30 cm in width, 40 cm in height, and 70 cm in length
4.03	Power
	less than 200 watts (peak) 50 watts (nominal) of power
4.05	Physical interface adapter
	Fit on a single open panel within center of gravity margins of the host spacecraft
4.06	Electrical interface adapter
	electrical and RF interface adapter
4.09	Field of view
	unobstructed host satellite fields of view
4.10	RFI/EMC
	Radio Frequency and Electromagnetic Compatibility (RFC/EMC) with host spacecraft.

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Key Programmatic Requirements

5.01	**Cost**
	$350M
5.02	**Schedule**
	Fully operational by December 2015, first sensor launched by December 2014
5.03	**Systems Engineering Philosophy**
	NASA systems engineering handbook
5.04	**Test Philosophy**
	Comply with the commercial host spacecraft product assurance requirements
5.05	**GSE Requirement**
	Include necessary ground support equipment for development and operations.
5.06	**Facilities Usage**
	Maximize usage of existing commercial facilities for development and operations

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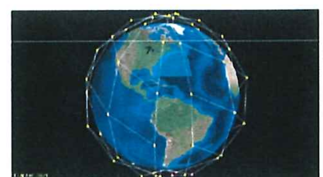
Iridium NEXT Constellation Overview

System

Constellation :	66 Satellites in 6 planes of 11
Orbit:	Polar at 780 km
Inclination:	86.4°
Period:	111 minutes per orbit
Launch:	2013 – 2016
Mission Life:	15 years to beyond 2030
Risk Mitigation:	6 in-orbit spares + 6 hanger spares



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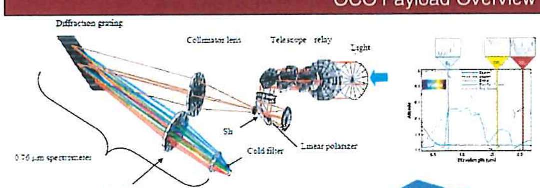
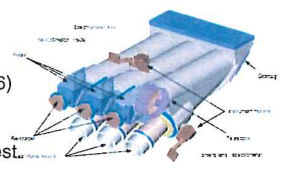
OCO Payload Overview



Type: Grating Spectrometer
Colorbands: 3 (1.61, .76, 2.06)
Mass: 150kg estimated
Power: 500W avg. estimated
Volume:40h x 90w x 70l cm est.



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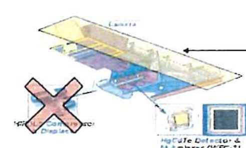
CHOCO Payload Restrictions

Payload Sensors

Missions:	4 types (others under consideration)
Payload Weight:	50 kg
Payload Dimension:	30 x 40 x 70 cm
Payload Power:	50 W average (200 W peak)



Due to weight, power and volume constraints each IRIDIUM satellite will host only a single sensor shown in the highlighted area, also the HIRDLS Compressor & Displacer Cooling subsystem will be replaced by 2 L3 B1500 tactical cryocoolers

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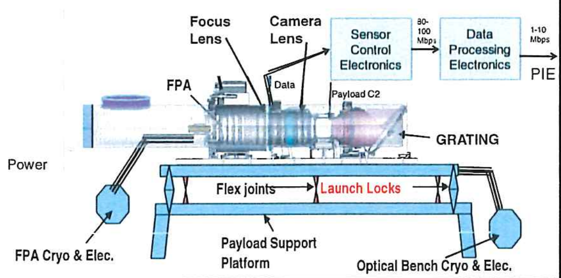
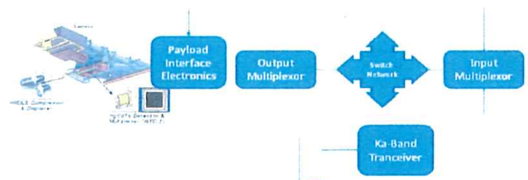
OCO Payload Overview



CHOCO Payload Overview - Key Interfaces



Type: Grating Spectrometer
Colorbands: 1 per sensor
-CO_2 1.61, O_2 .76 , CO_2 2.06
Mass: 50kg estimated
Power: 170W avg estimated
Volume: 30h x 40w x 70l cm est.

CHOCO Payload Mass Budget

Component	Mass (kg)	Mass Contingency	Contingency %	Total Mass
Optical Assembly	17	0.85	5	17.85
Cryocooler	3.5	0.035	1	3.535
Cryocooler Electronics	2	0.02	1	2.02
Focal Plane Array Electronics	2.5	0.025	1	2.525
Data Processing Electronics	7	0.7	10	7.7
Payload Interface Electronics (PIE)	5	0.5	10	5.5
Payload Bench	6	0.6	10	6.6
Thermal Protection/Blankets	1	0.05	5	1.05
Cabling	2	0.1	5	2.1
Totals	46	2.88	Allocated=50kg	48.88

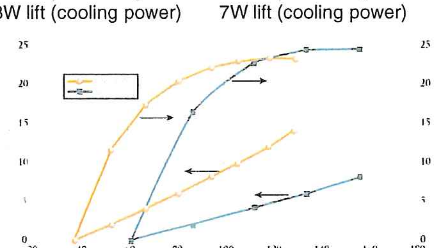
CHOCO Payload Power Budget

Component	Average Power (Watts)	Peak Power (Watts)
Optical Assembly	1	1
Cryocooler	36	120
Cryocooler Electronics	40	45
Focal Plane Array Control Electronics	15	15
Data Processing Electronics	50	75
Payload Interface Electronics (PIE)	25	25
Totals	167	281
Host Spacecraft Allocation	Avg power = 50 (Watts)	Peak power=200 (Watts)

CHOCO Thermal Considerations

Focal Plane Temp = 77K
30W input average
3W lift (cooling power)

Electronics Temp = 120K
40W input average
7W lift (cooling power)



Mission Data Analysis Segment Overview

- **Level 0:** Data from the sensors fed through the Ka band cross-links network to Iridium ground stations at Tempe, USA or Svalbard, Norway
- **Level 1:** Data may sent to appropriate data centres for processing, calibration, quality control, converted to a standard format and archived
- **Level 2:** Calibrated data passed to the primary users on relevant time scales
- **Level 3:** Where value is added value from data, products may be sold to commercial enterprises
- **Validation:** Iridium offers a unique possibility to validate data in real-time by using remote platforms on the Earth's surface and in the atmosphere for in situ calibration

Risks

Risk ID	Risk Item	Risk Score
1	Hosted payload deck design	4
2	Interface Electronics	6
3	Payload/Spacecraft Integration	6
4	EMC/EMI	6
5	Interface Control Document (ICD) development	5
6	Thermal Management	4
7	Pointing precision	8
8	Cabling	8
9	Data processing	8
10	Payload Weight	12
11	Spacecraft schedule	6
12	Payload Power	20

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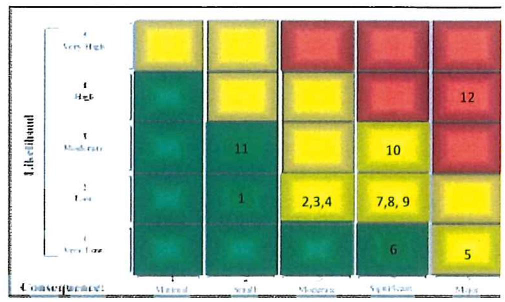
Risk Summary



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Technology Readiness Assessment Summary

CTU #	Critical Technology Unit (CTU)	TRL	Rationale
1	Sensor Optics	6	The sensor optics for the CHOCO concept are the same as the OCO sensor optics that were tested in a thermal vacuum chamber and calibration chamber before the flight failure
2	Focal Plane Array	9	The Focal plane array for the CHOCO concept is the Hawaii 1kx1k chip that has flown on previous IR missions
3	Sensor Electronics	6	The sensor electronics for the CHOCO concept are the same as the OCO sensor electronics that were tested in a thermal vacuum chamber and have undergone vibration testing
4	Interface Electronics	4	The proposed interface electronics for the CHOCO concept are based upon the CHIRP sensor payload Interface (SPI) that has developed an engineering model which has been tested under a laboratory environment.
5	Cryocooler	7	The CHOCO cryocooler is assumed to be the same L3 tactical cryocooler that has flight heritage on RHESSI and has been flight proven through successful mission operations on other spacecraft
6	Communications subsystem	3	The CHOCO sensor communication subsystem responsible for accepting data from the sensor electronics and compressing, storing, and forwarding the data to the Iridium NEXT communications payload is a newly developed CTU whose components have been developed but has not been tested at a CTU level. The analytical and experimental function have been developed as a proof of concept for other IR sensing spacecraft.
7	Hosted Payload Deck	4	The hosted payload deck for CHOCO is based upon the CHIRP design. Similar components therefore have been developed and validated in a laboratory environment.

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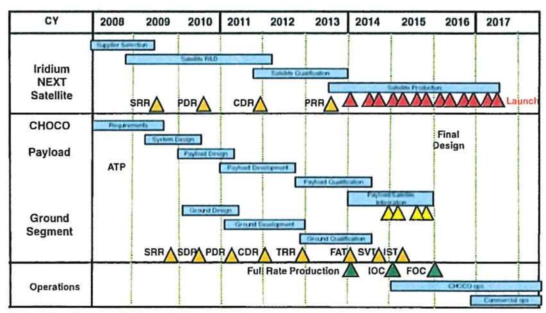
CHOCO Schedule



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CHOCO Cost Estimate

Item	Element	Proposed
1	PROGRAM MGT & SEIT (10% of overall cost)	$25,000,000
2	SPACE SEGMENT	
2.1	CHOCO Sensor Modifications (NRE)	$30,000,000
2.2	Hosted Spacecraft Interface	$10,000,000
2.3	Sensor Procurement ($20,000,000 x 8 sensors)	$160,000,000
2.4	Spacecraft Accommodation (NRE)	$10,000,000
2.5	Spacecraft transponder fees (4 satellites * 3 years)	$10,000,000
2.6	Impact on spacecraft lifetime	$5,000,000
	Total Space Segment (Sum of 2.1-2.6)	$225,000,000
3	GROUND SEGMENT	
3.1	Ground Segment Development	$20,000,000
3.2	Satellite Operations (5 years)	$15,000,000
	Total Ground Segment	$35,000,000
	TOTAL PRICE with All Demonstrations (Sum of 1 +2 + 3)	$285,000,000

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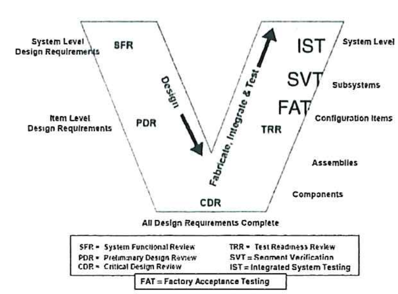
Verification Approach Model



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Mission/Performance Requirements Verification Approach

1.01	**General Mission Requirement**
	Demonstration
1.02	**Payload Compatibility**
	Analysis
1.03	**Measurement Sensitivity**
	Test
1.04	**Measurement Accuracy**
	Test
1.05	**Calibration Approach**
	Demonstration
1.06	**Launch Vehicle Compatibility**
	Analysis
1.07	**Early-orbit operations**
	Demonstration
1.08	**Orbit**
	Analysis
1.09	**Lifetime**
	Analysis

2.01	**Spectral Resolution-CO2 band 1**
	Test
2.02	**Spectral Resolution-O2**
	Test
2.03	**Spectral Resolution – CO2 band 2**
	Test
2.04	**Spatial Resolution -**
	Test
2.05	**Signal to Noise Ratio**
	Test
2.06	**Revisit Rate**
	Analysis
2.10	**Link Budget**
	Analysis
2.11	**Data rate**
	Analysis/Test

Physical/Programmatic Reqts Verification Approach

4.01	Mass
	Inspection
4.02	Dimension
	Inspection
4.03	Power
	Test
4.05	Physical interface adapter
	Inspection
4.06	Electrical interface adapter
	Test
4.09	Field of view
	Inspection
4.10	RFI/EMC
	Test

5.01	**Cost**
	Inspection
5.02	**Schedule**
	Demonstration
5.03	**Systems Engineering Philosophy**
	Inspection
5.04	**Test Philosophy**
	Inspection
5.05	**GSE Requirement**
	Test
5.06	**Facilities Usage**
	Inspection

Summary

- CHOCO concept is technically feasible
- Overall medium technical risk
  - Payload power, Payload weight, On-board processing, & electronic interfaces are key risks
  - Power allocation will have to be studied/negotiated
  - Medium-High technology readiness level
- $300 Million estimated cost
  - Overall medium-low cost risk
  - Easily adjusted by changing the number sensors
- Overall medium-low schedule risk

Ethics Considerations

- Is the investment worth the return?
  - From a utilitarian perspective resources are used to cause the most good for the greatest number of people
  - Concept designed to maximize mission utility vs cost
- Acceptable to skirt national space transportation policy?
  - Ethical to follow precedence and ask for a waiver
- Ethical to use commercial assets to further gov't need?
  - NASA project less troublesome than defense mission.
  - Justified based upon protection of commercial and civilian population interests

Conclusion

"Understanding the complex changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity."

Earth Science and Applications from Space-Urgent Needs and Opportunities to Serve the Nation Congressional Report

Hosted carbon monitoring satellite concept is one potential option to meet this challenge that takes into consideration:

- Technical constraints
- Fiscal constraints
- Schedule constraints
- Ethical considerations
- Quality considerations
- Lessons learned

Questions?

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