CARBO: The Carbon Balance Observatory

Charles E. Miller, Christian Frankenberg, James K. Wallace, Shannon Zareh, Amy Mainzer, Andre Wong, Annmarie Eldering, Dejian Fu, Mayer Rud, Yuri Beregovski, Daniel Wilson, Cynthia Brooks, Daniel Jaffe

IWGGMS-14, Toronto
10 May 2018

CARBO Programmatic Overview

Jet Propulsion Laboratory
California Institute of Technology

- Funded by Instrument Incubator Program (IIP)
  - NASA's Earth Science Technology Office (ESTO)

- Institutions:
  - JPL – Instrument Design/Build
  - University of Texas, Austin – Silicon Immersion Grating
  - Caltech – Data Reduction

- **Goal**: develop new instrument to measure atmospheric CO2, CH4, CO and enhanced SIF that is smaller, lighter, less expensive and more capable than the OCO instrument series.

CARBO Team

Jet Propulsion Laboratory
California Institute of Technology

C Miller
PI

J K Wallace
Proj Mgr

S Zareh
Deputy PM

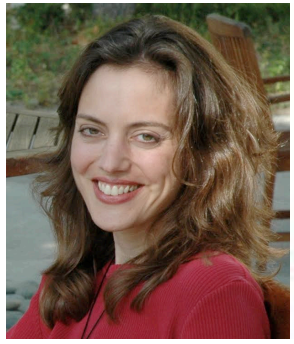
D Jaffe
Gratings

D Wilson
Gratings

A Eldering
Science

C Frankenberg
Science

D Fu
Science



A Mainzer
Science

J McGuire
Optics

P Sullivan
Detectors

Not Pictured: Mayer Rud (optics), Yuri Beregovski (optics), Xu Wang (optics), Ayan Chakrabarty (optics), Andre Wong (detectors), C Brooks (gratings)

CARBO Targets Gaps in the CEOS Carbon from Space Strategy

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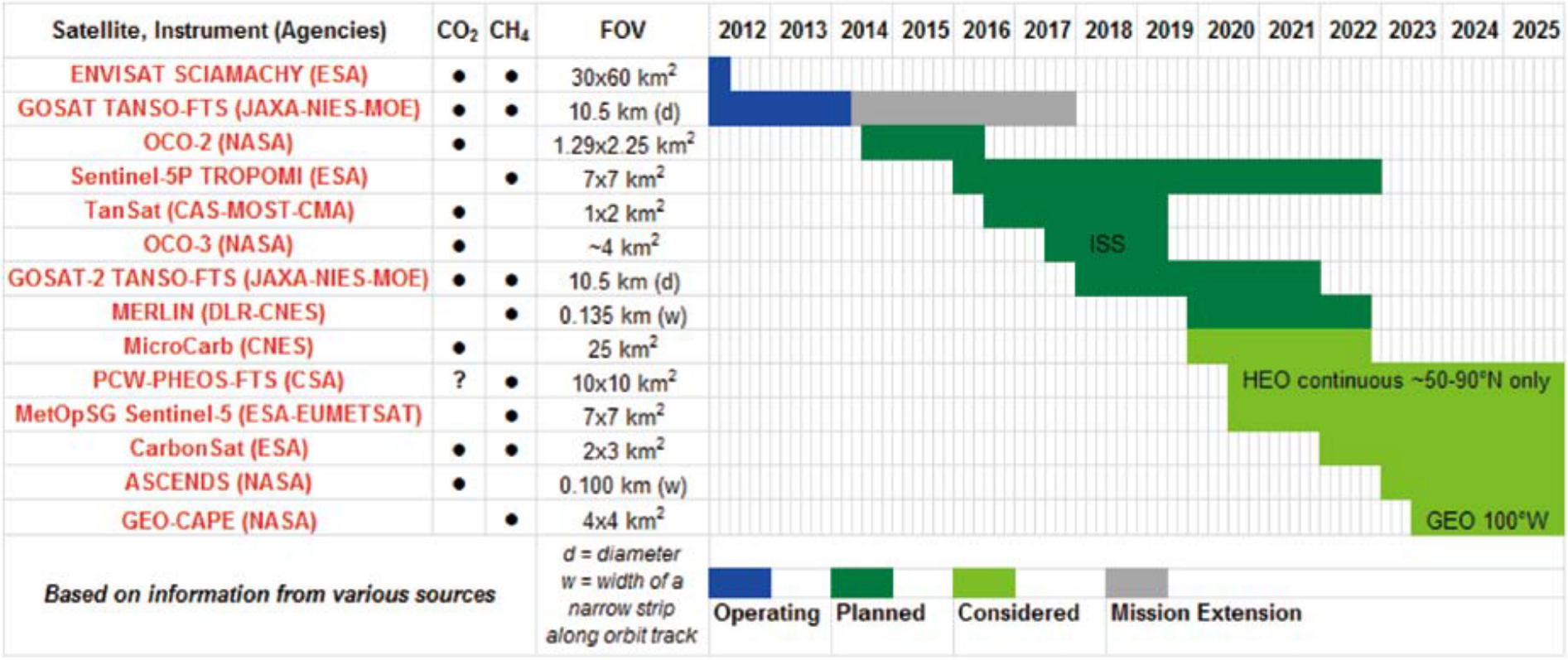

After CEOS Strategy for Carbon Observations from Space (2014)

Recent Concepts:

- ARRHENIUS
- AIM-North

The Million Dollar Question

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Smallsats @ ~$1M/unit

Exploiting Large Format FPAs (>1M) & Digital Electronics

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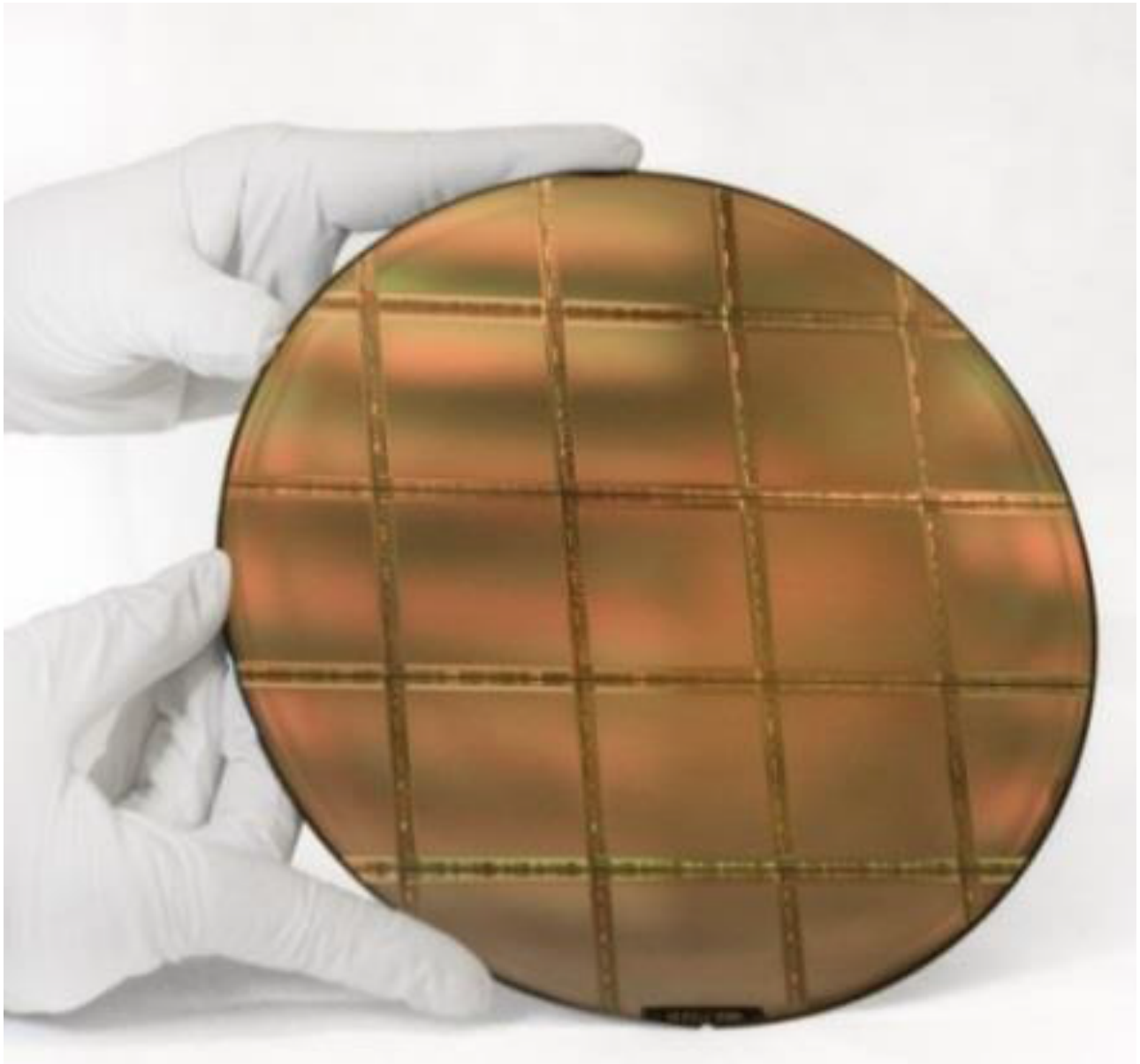
Improved Performance

Reduced Complexity

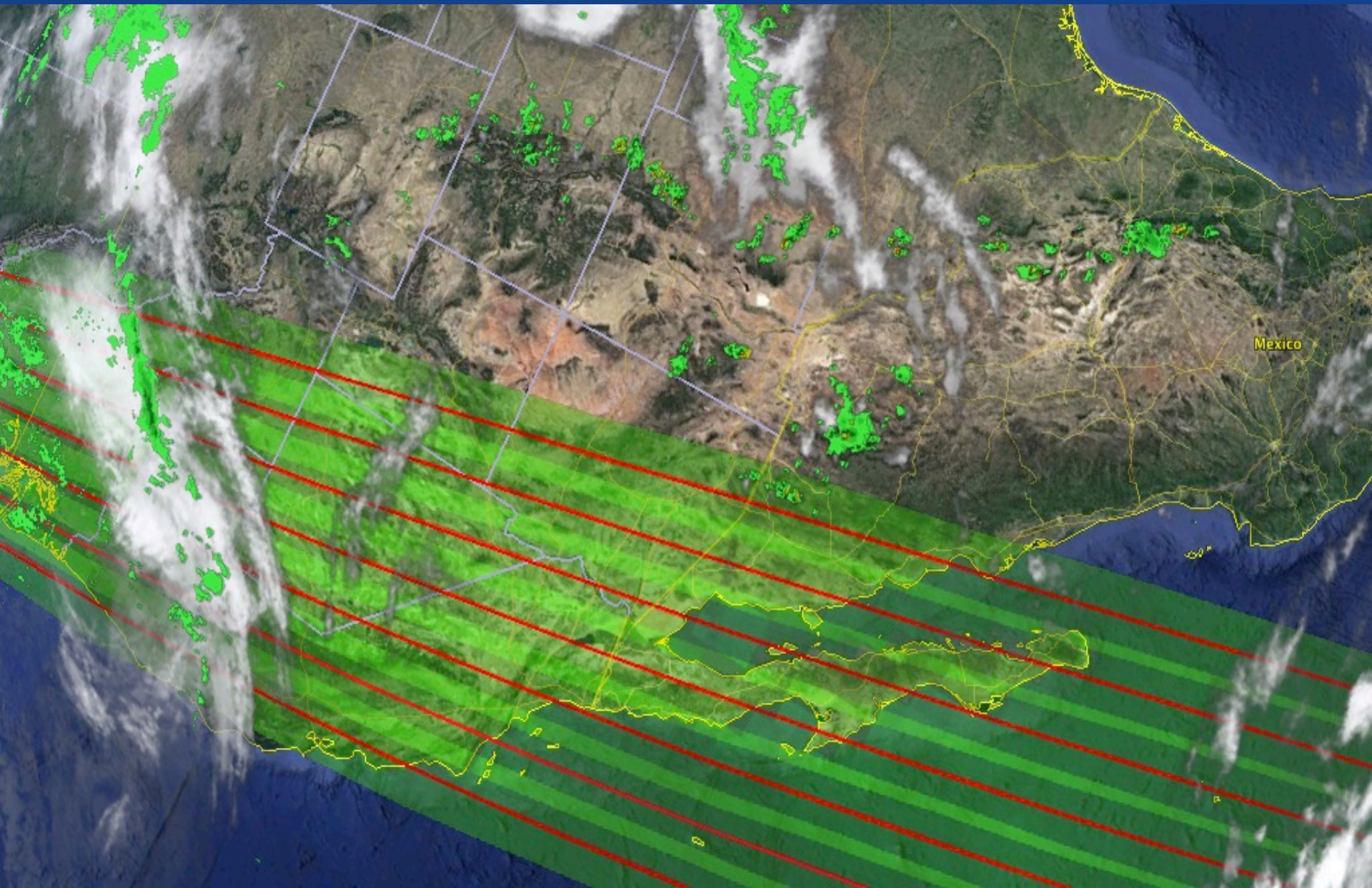
Reduced Mass & Power



CARBO Instrument Requirements

- Science Requirements
  - Measure column-average dry air mole fraction (X) of CO2, CO, CH4 and SIF with single sounding precisions of
    - XCO_2: < 1.5 ppm
    - XCO: < 5 ppb
    - XCH_4: < 7 ppb
    - SIF: < 10% error
  - Spatial and temporal coverage
    - Spatial sampling ~2km on the ground from LEO (~700 km)
    - Instantaneous FOV: 10 deg < FOV < 30 deg
    - Global coverage
    - Revisit frequency: < 7 days
    - Sun Synchronous orbit (fixed LST)

The CARBO Sampling Strategy



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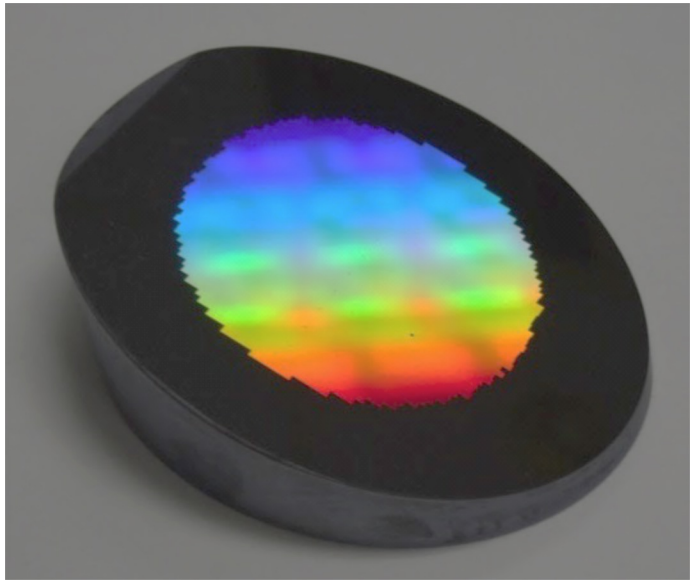
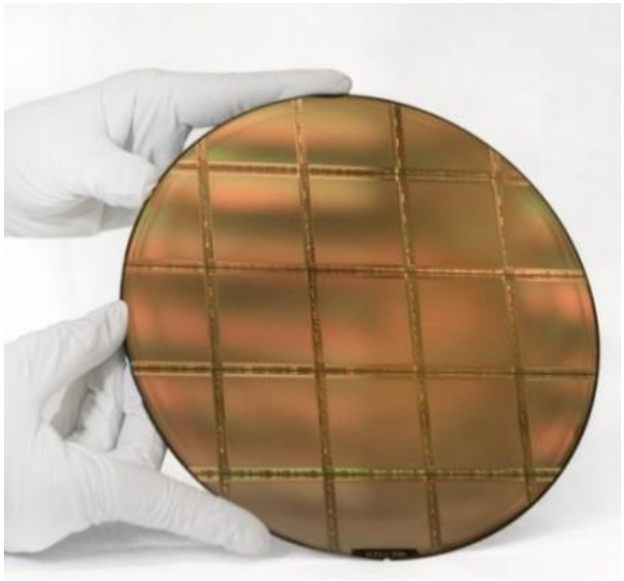
Key CARBO Design Elements

- Immersion Gratings:
  - Significant reduction of instrument size
  - Large reduction in anamorphism
  - Reduced polarization sensitivity
  - Use large format FPAs effectively



- Large format digital detectors:
  - Increased performance
  - Reduced mass, power
  - Reduced complexity
  - Operational flexibility



CARBO Will Deliver Enhanced SIF

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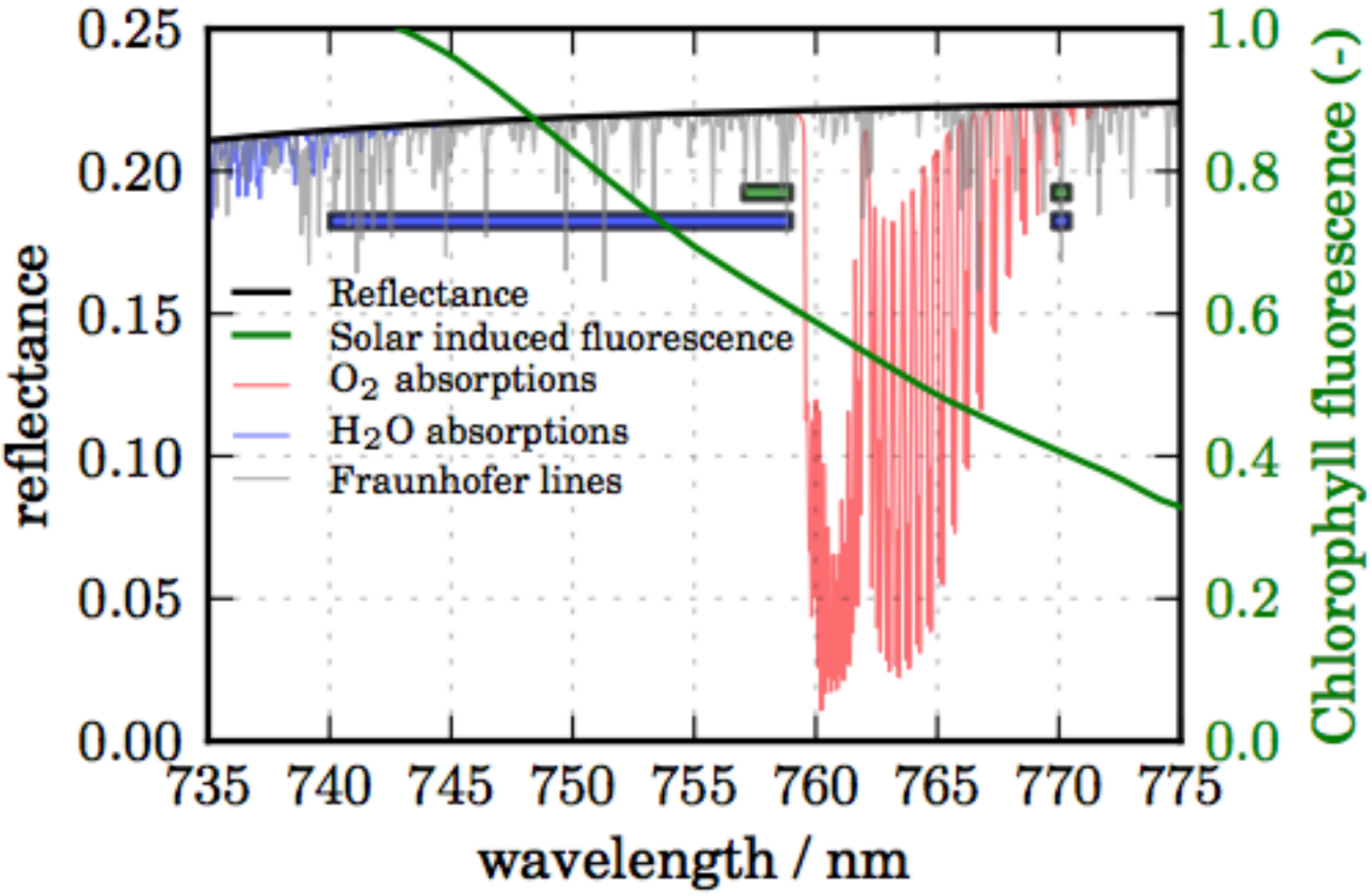

CARBO Radiance Simulations

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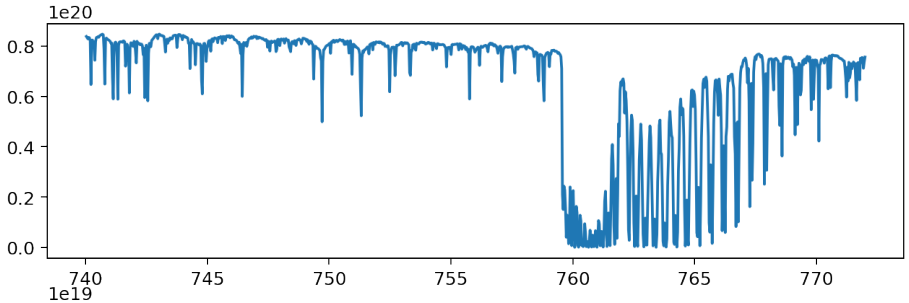
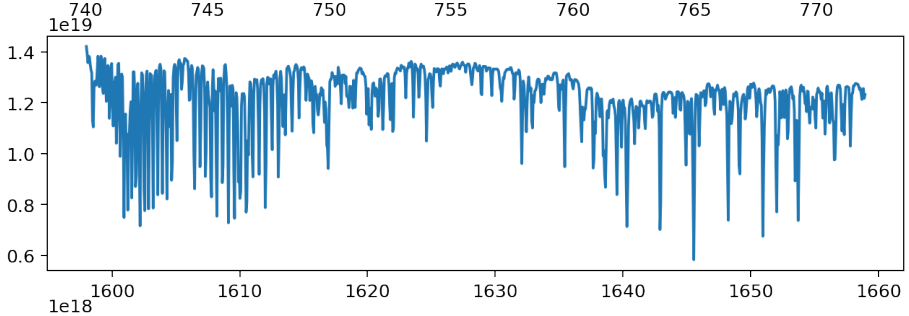
Ch 1



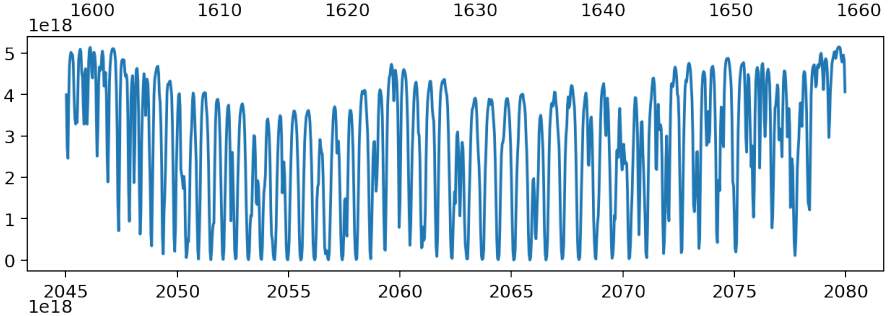
SIF, O2 A-band

Ch 2



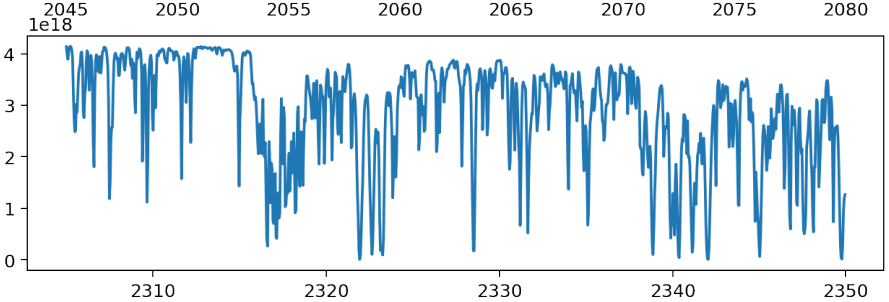
CO2, CH4

Ch 3



CO2

Ch 4



CH4, CO

Glass Immersion Grating (Ch 1)

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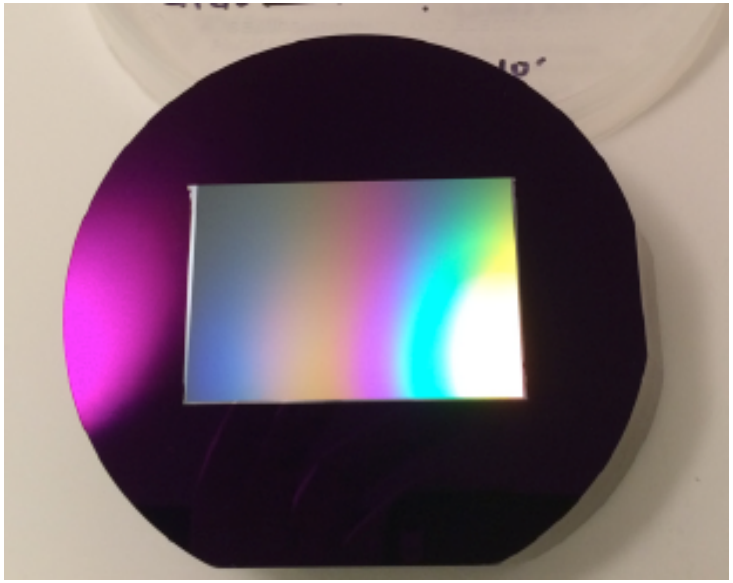
JPL will fabricate glass immersion grating for SIF/O2 channel

- New e-beam lithography machine has been commissioned
- Resources and personnel ready to begin



Silicon Immersion Grating (Ch 2)

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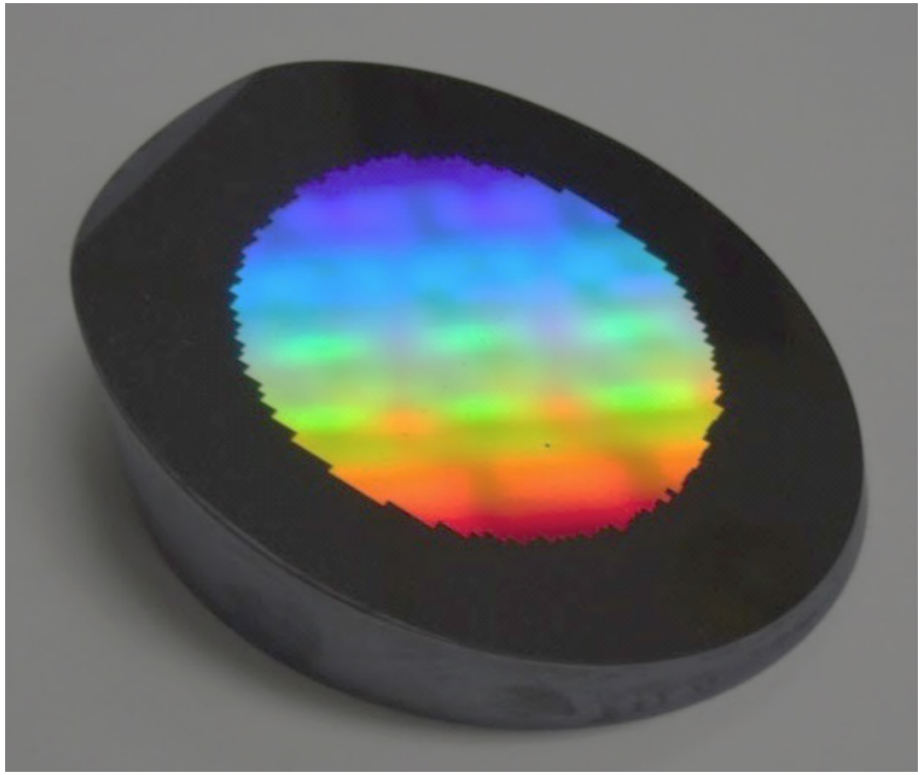

Cindy Brooks
Univ Texas

Dan Jaffe
Univ Texas

University of Texas team members will fabricate silicon immersion grating for CO2/CH4 channel

- JPL e-beam lithography will be used to write the grating
- UT processes & tests final Si component

Engineering Si Immersion Grating Exceeds Required Performance

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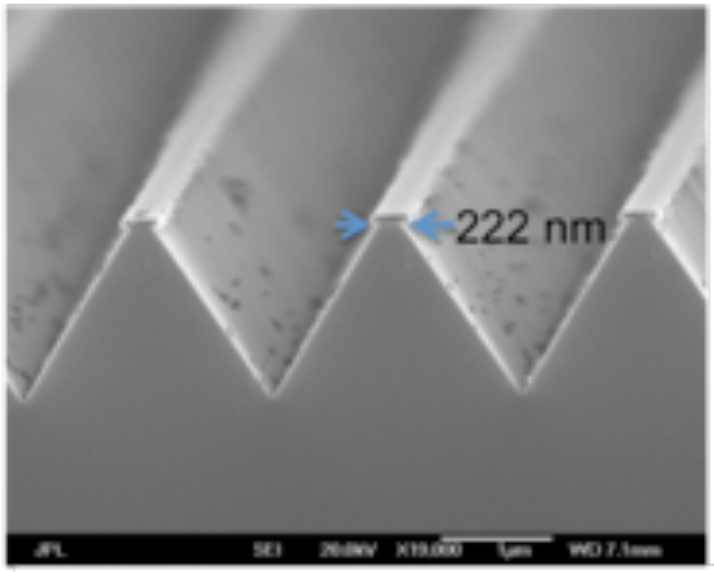

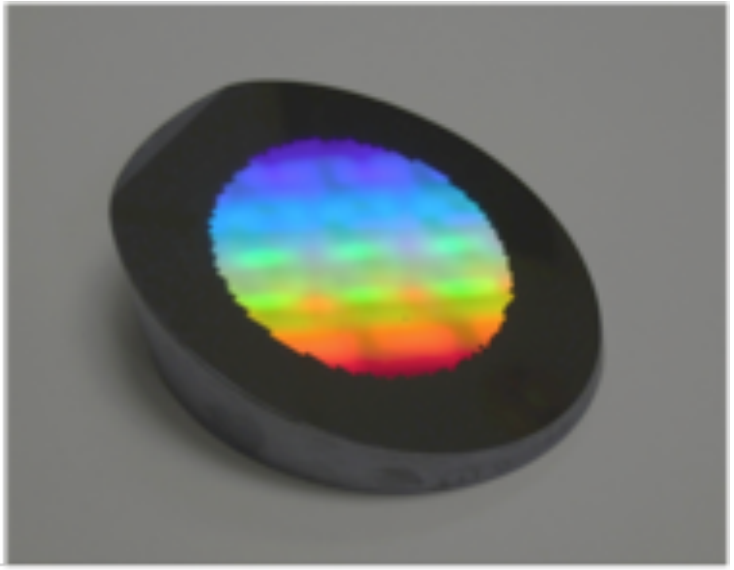

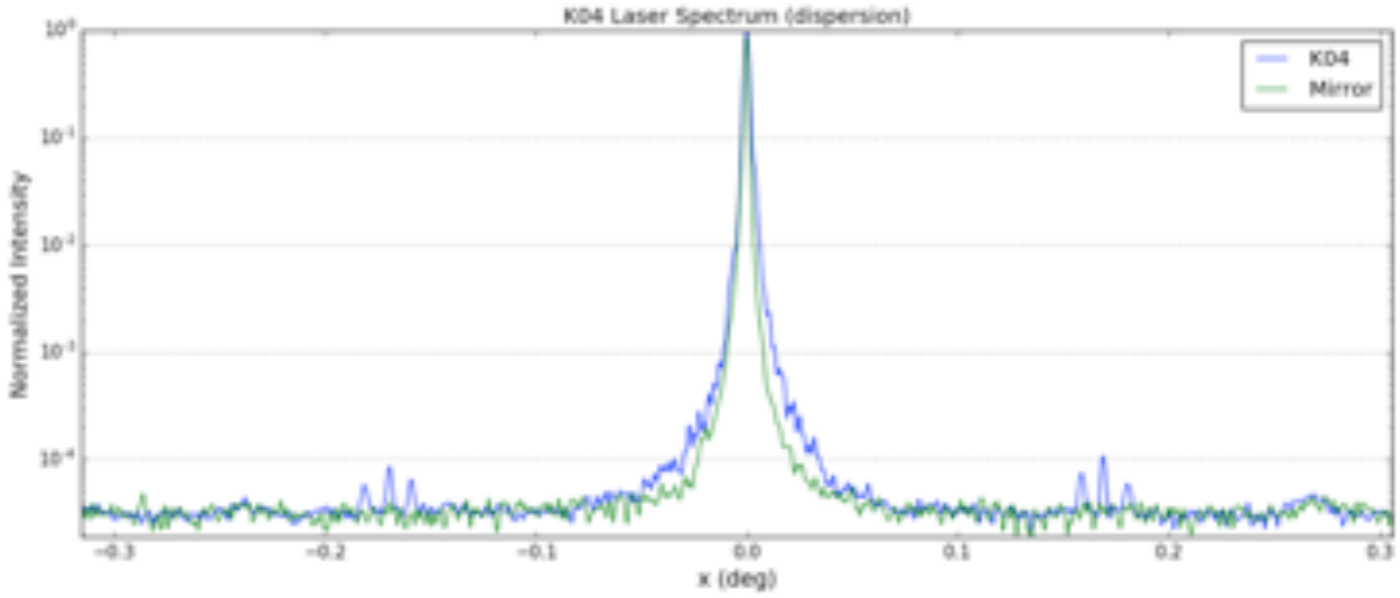

CARBO Optical Design Meets Required Performance

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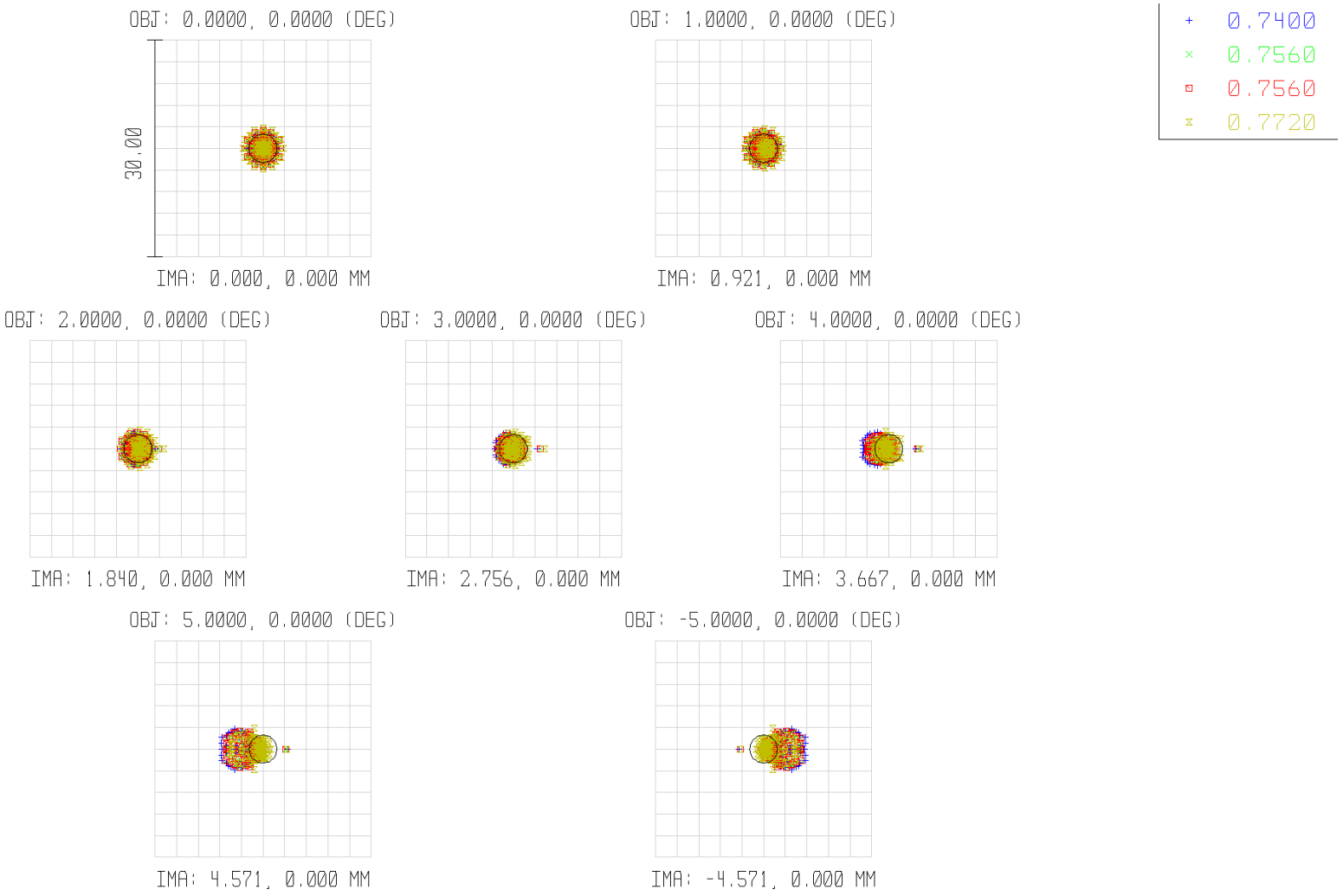
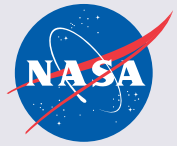


CARBO Summary

- **CARBO design meets OCO-like performance requirements in a package that is smaller, lighter, and includes CH4, CO and enhanced SIF and contiguous global mapping with ~5-day revisit**
- **CARBO design opens the potential for smallsat constellation deployment**
- **The CARBO-IIP instrument could be used for airborne science and OCO-2/OCO-3/GeoCARB validation after IIP completion (late 2019)**

ESAS 2017 Reconfirms the High Priority of the CARBO Science



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- ***Thriving on Our Changing Planet A Decadal Strategy for Earth Observation from Space***, the 2017-2027 decadal survey for Earth science and applications from space ("ESAS 2017") released January 2018

- Observing System Priority:
  - Targeted Observable: Greenhouse Gases
  - Science: CO2 and CH4 fluxes and trends
  - Explorer Class ($350M cap)

- CARBO will be ready for the Explorer opportunities

- The CARBO-IIP instrument could be used for airborne science and OCO-2/OCO-3/GeoCARB validation after IIP completion (late 2019)

CO2 & CH4 Measurements Ranked Most Important in ESAS 2017

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Science/Applications Value:

- Improved measurements of atmospheric CO2 and methane from space, combined with mapping of surface properties, would allow us to better understand and quantify the sources and sinks of CO2 and methane. This spans the interests of multiple panels and is central to the carbon cycle integrating theme.

Earth Science/Application Objective E-2a:

- Quantify the fluxes of CO2 and CH4 globally at spatial scales of 100-500 km and monthly temporal resolution with uncertainty <25% between land ecosystems and atmosphere and between ocean ecosystems and atmosphere.

Importance: Most Important

Observational Approach:

- Global observations of CO2 and methane at horizontal resolution of a few km and daily revisit with sufficiently high precision to constrain regional budgets of surface fluxes on a weekly time scale. This might be achieved with SWIR spectrometers that observe the atmospheric column with sensitivity down to the surface (p. 3-67)