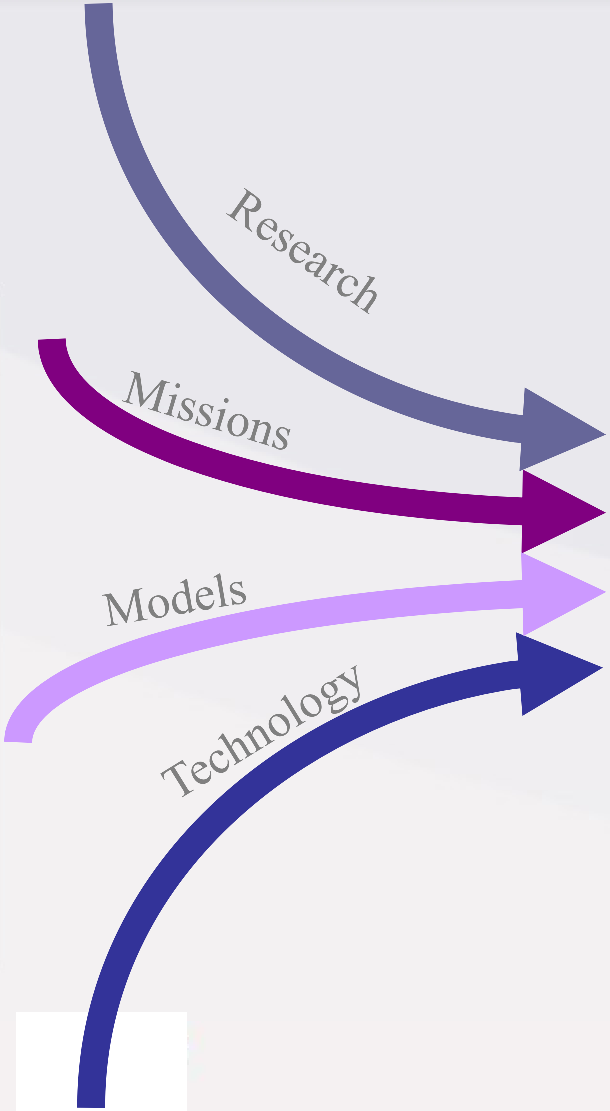
NASA Science Mission Directorate
Earth Science Division

NASA's Planned GHG Missions and Timelines

Ken Jucks, NASA Program Manager Upper Atmosphere Research Program; Program Scientist for Aura, OCO-2, OCO-3, CLARREO, ASCENDS, TEMPO (EVI-1), Earth Venture Instrument-2, ATTREX (EVS-1)

Focusing NASA Earth Science Assets on Answering Specific Questions



Carbon Cycle & Ecosystems (CO_2, CH_4)

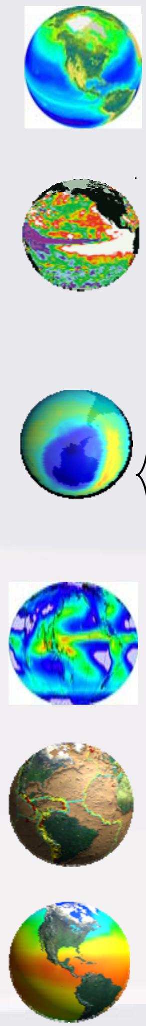
Climate Variability & Change (atmospheric constituent effects on climate)

Atmospheric Composition

Water &Energy Cycle (atmospheric water vapor)

Earth Surface & Interior (volcanic effects on atmosphere)

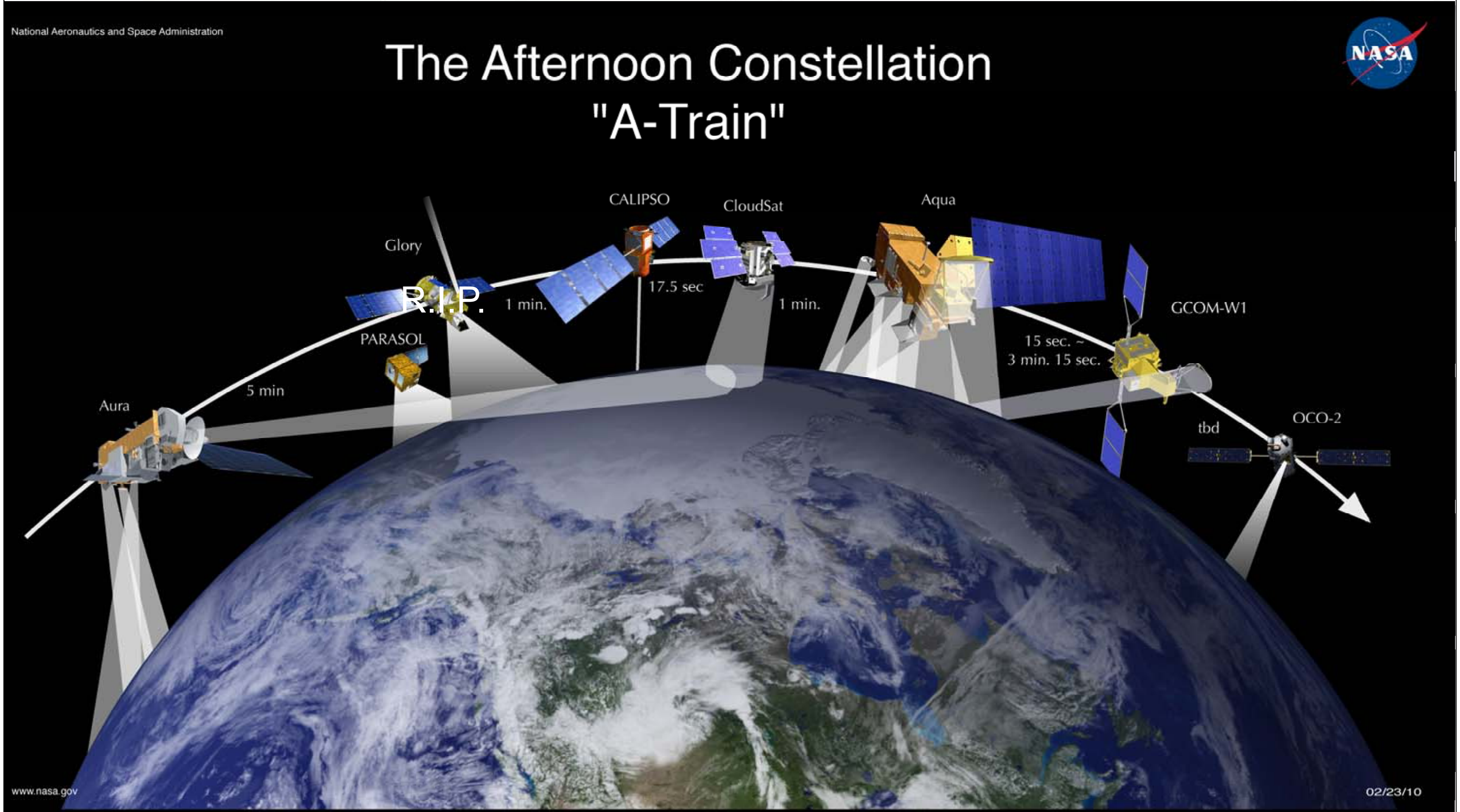
Weather (effects on air quality)

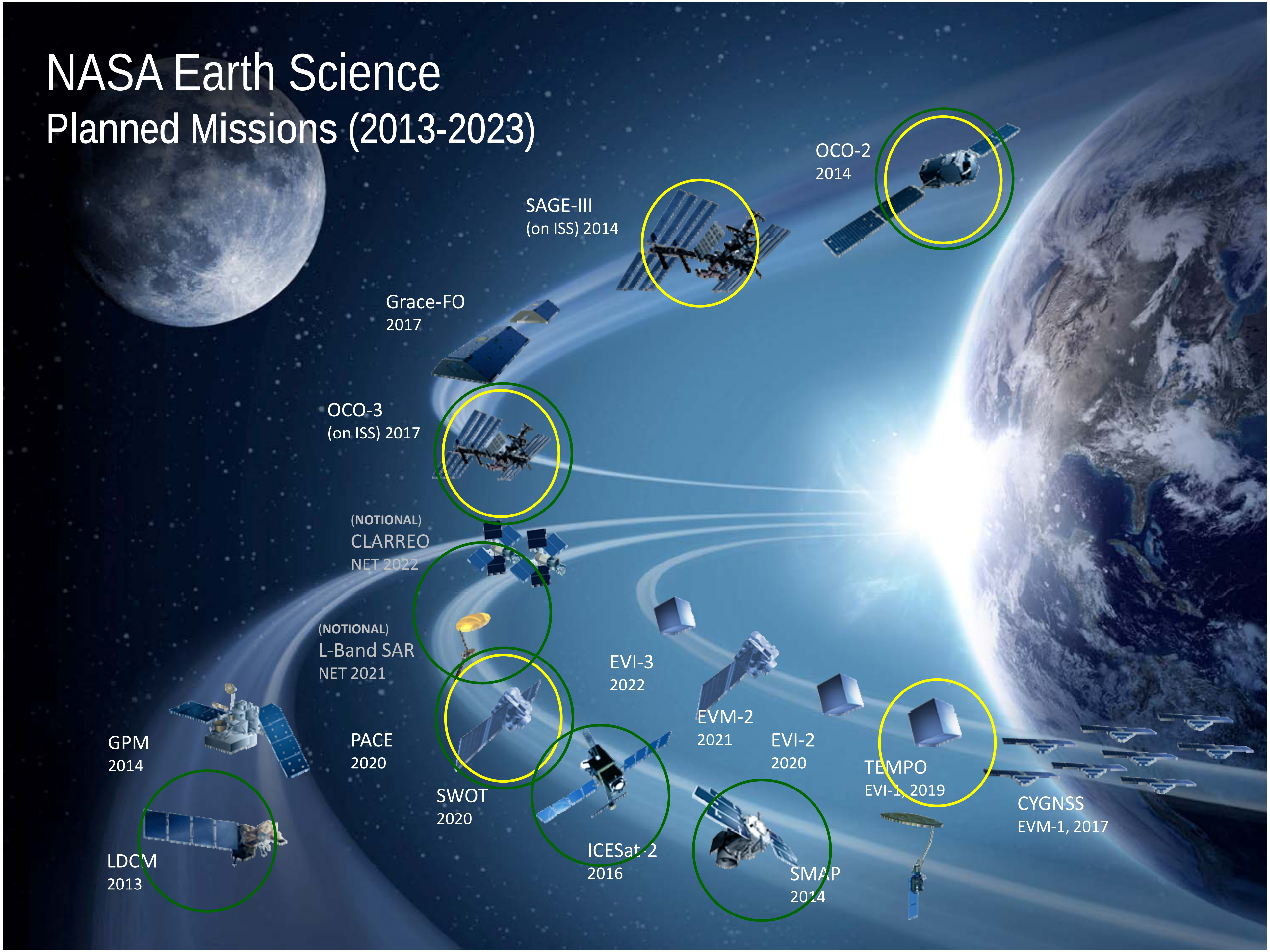


- How is atmospheric composition changing?
- What chemical & physical processes are important for air quality, radiative transfer and climate?
- What trends in atmospheric constituents and solar radiation are driving global climate?
- How do atmospheric trace constituents respond to and affect global environmental change?
- How will changes in atmospheric composition affect ozone and regional-global climate?

NASA's Existing Earth Science Fleet

NASA Earth Science satellite observations



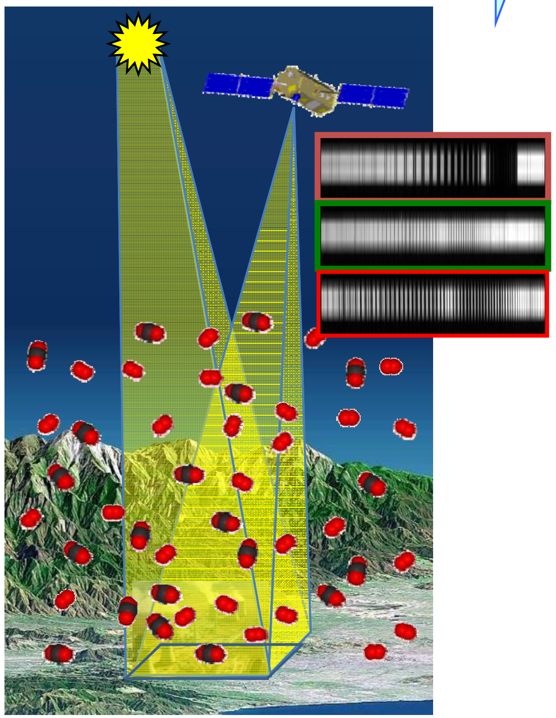

NASA Earth Science
Planned Missions (2013-2023)
OCO-2
2014
SAGE-III
(on ISS) 2014
Grace-FO
2017
OCO-3
(on ISS) 2017
(NOTIONAL)
CLARREO
NET 2022
(NOTIONAL)
L-Band SAR
NET 2021
EVI-3
2022
EVM-2
2021
EVI-2
2020
TEMPO
EVI-1, 2019
CYGNSS
EVM-1, 2017
GPM
2014
PACE
2020
SWOT
2020
ICESat-2
2016
SMAP
2014
LDCM
2013

Terrestrial Ecology Missions

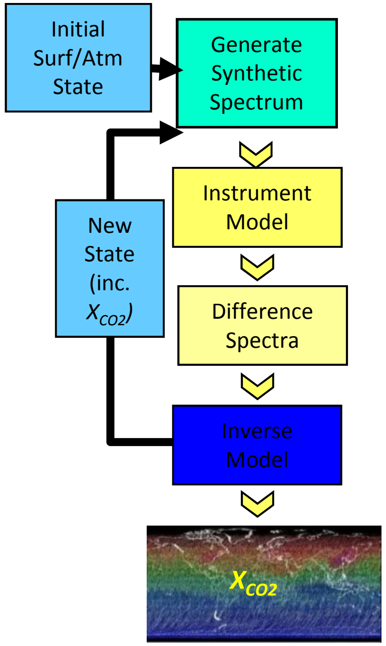
Mission	Point of Contact	Status
SNPP-VIIRS	**Chris Justice**, James Gleason	Current
LDCM	**Jeff Masek**, James Irons	Current
ICESAT-II,	**Amy Neuenschwander**, Mark Caroll	Phase A-D
SMAP	Eni Njoku	Phase A-D
OCO-2	David Crisp	Phase A-D
BIOMASS	Sassan Saatchi	Phase A
L-Band-SAR (formerly DesDynI-R)	**Ralph Dubayah**, Paul Rosen	Pre-Phase A
HyspIRI	**Simon Hook**, Rob Green	Pre-Phase A

OCO-2 Key Science Objectives

- OCO-2 is the first NASA mission designed to make space-based measurements of atmospheric carbon dioxide (CO_2) with the precision, coverage, and resolution needed to:
  - Quantify CO_2 emissions on the scale of a large U.S. state or average-sized country
  - Find the natural “sinks” that are absorbing over half of the CO_2 emitted by human activities
- To accomplish these objectives, OCO-2 will:
  - **Record** spectra of CO_2 & O_2 absorption in reflected sunlight



  - **Retrieve** variations in the *column averaged CO_2 dry air mole fraction, X_{CO2}* over the sunlit hemisphere



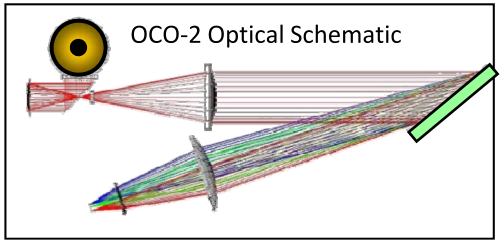
  - **Validate** measurements to ensure X_{CO2} accuracy of 1 - 2 ppm (0.3 - 0.5%)

OCO-2 Mission Concept

Payload

Science Instruments:

- The single instrument incorporates three co-bore-sighted, high resolution, imaging grating spectrometers
  - O_2 A-band @ 760 nm
  - Weak CO_2 band @ 1610 nm
  - Strong CO_2 band @ 2060 nm
- Resolving Power ~20,000
- High Signal-to-Noise Ratio
- Collects 8 cross-track soundings at 3 Hz across a narrow (10.6 km wide) swath


OCO-2 Optical Schematic

Implementation

Launch Date: **Late 2014**

Lifetime: **2 years (consumables for 5 years)**

Mission Cost :**$438M (reserve incl.)**

Payload Cost :**$140M + 30% reserve**

Partners: **JPL**

Mission Class: **C, with selected redundancy**


OCO-2 Instrument


OCO-2 Spacecraft


Delta II Launch Vehicle

Mission Architecture

- Orbit: **A-Train 705 km Sun-Synchronous, 1:30pm LTDN**
- Repeat: **16 day nadir + 16 day glint**
- Downlink: **Alaska Satellite Facility (2 downlinks/day)**
- Science Data: **92 Gbits/day**
- Launch Vehicle: **ULA Delta-II 7320-10**


OCO-2 in the A-Train

Spacecraft

Launch Mass CBE: **495 kg,** JPL DP Margin: **10%**

Required Power CBE: **587 W, (815 W capability)**

P/L Data Rate: **3 Mbps**

Downlink Data Rate: **150 Mbps X-band**

Stabilization: **3-axis**

System Pointing: **Control = 6 mrad, 3σ/axis**

Knowledge = 1.7 mrad, 3σ/axis

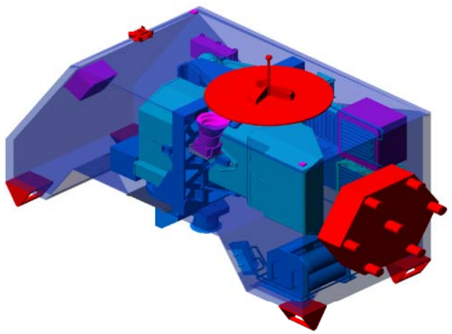
OCO-3* Project Overview

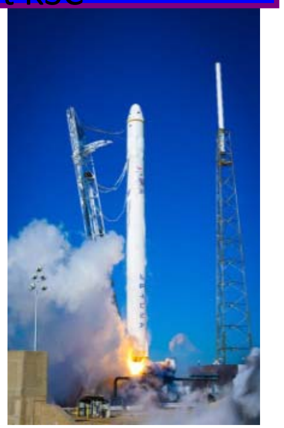
OCO-3 is a NASA-directed Climate Mission on the International Space Station

- OCO-3 will collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO_2) dry air mole fraction, X_{CO2}, with the precision, resolution, and coverage needed to improve our understanding of surface CO_2 sources and sinks (fluxes) on regional scales (≥1000 km).
    - Measurement precision and accuracy requirements same as OCO-2
    - Operation on ISS allows latitudinal coverage from 51 deg S to 51 deg N
    - Additional pointing mirror assembly allows for glint and nadir data collection, and enhanced target

Salient Features:

- High-resolution, three-channel grating spectrometer (JPL)
- Deployed on the International Space Station
- Payload Delivery Date: Sep 2016 at KSC





*Proposed Mission

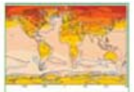
ASCENDS Mission/Measurement Quad Chart

Science Objectives

CO_2 measurements: day and night, all seasons, all latitudes

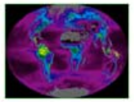
Inventory of global CO_2 sources and sinks

Connection between climate and CO_2 exchange



Improved climate models and predictions of atmospheric CO_2

Identification of human-generated CO_2 sources and sinks to enable effective carbon trading



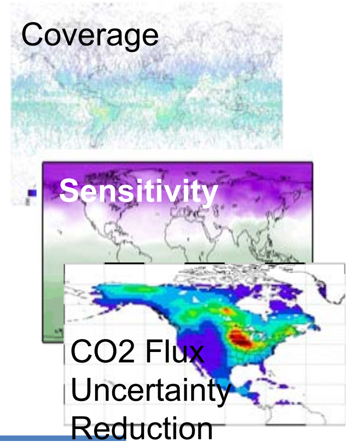
Closing of the carbon budget for improved policy and prediction

These objectives have not changed since the Decadal Survey was published.

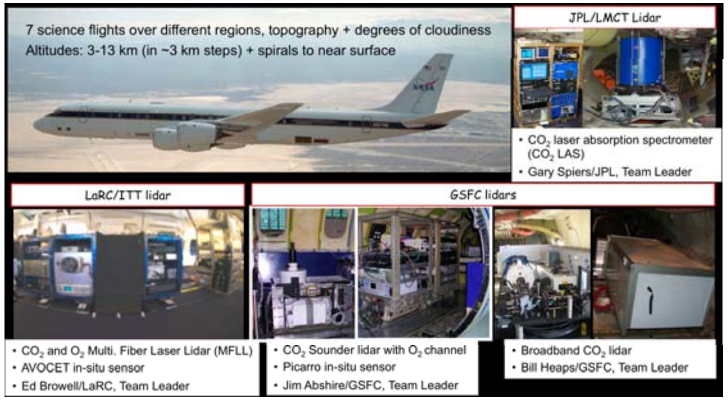
Modeling Support

Observational System Simulation Experiments (OSSEs)

- Relate science objectives to measurement requirements
- Provide information needed for instrument and mission design trade studies
- Demonstrate the complementarity of space-based active and passive greenhouse gas capabilities

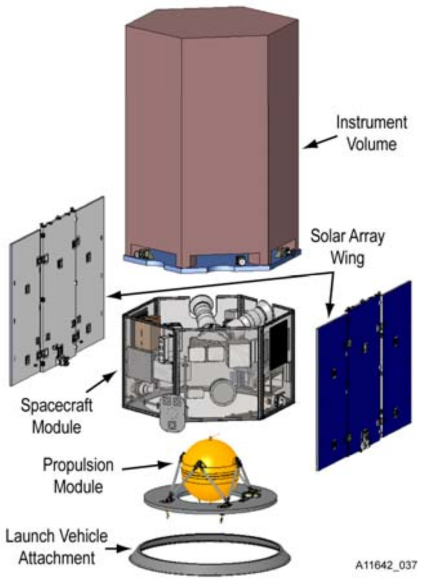


Aircraft/Technology Development



- ESTO investments continue to expand the options for achieving ASCENDS objectives
- Aircraft flights advance technology readiness of candidate ASCENDS instrument concepts

Mission Development



Mission Studies confirm that plausible candidate instruments can be accommodated on RSDO spacecraft with
- •Total mass: ~1600 kg
- •Payload mass: < 500 kg
- •Total power: < 2000 W
- •Payload power < 1100 W

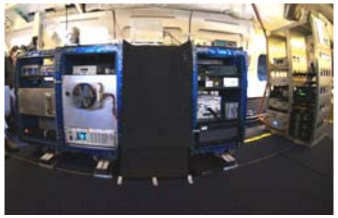
This system can be launched into a 450 km circular orbit by
- •A dedicated Falcon 9 or
- •as part of a dual spacecraft launch on an Atlas V.

Winter 2013 ASCENDS DC-8 Airborne Campaign

(19 February – 7 March 2013)

JPL/LMCT Lidar

LaRC/Exelis Lidar



GSFC CO2 Lidar Sounder

GSFC Broadband CO2 Lidar

Implementation

- **Flight Test Candidate ASCENDS Instruments:** **LaRC/Exelis IM-CW CO_2 Lidar (MFLL); GSFC CO_2 Lidar Sounder; JPL CO_2 LAS; GSFC Broadband CO_2 Lidar (shown above installed on DC-8)**
- **Conduct Eight DC-8 Flight Tests from NASA Dryden Palmdale Base:**
  - **Engineering Flight; CA Central Valley Flights (day & night); RRV Flight**
  - **Three long-range flights over snow surfaces east of Rocky Mountains**
  - **Long-range flight over Pacific with sampling over CA/OR coastal forest**

Objectives

- **Advance testing of CO_2 & O_2 measurements under day and night conditions.**
- **Assess CO_2 & O_2 measurements over Railroad Valley (RRV) with GOSAT overpass.**
- **Obtain reflectance and CO_2 & O_2 measurements over fresh and aged snow surfaces.**
- **Evaluate CO_2 & O_2 measurement performance in presence of thin cirrus clouds.**
- **Obtain reflectance data from ocean surface with high wind speeds (~10 m/s) and assess CO_2 & O_2 performance over tall coastal forest conditions.**
- **Evaluate derivation of XCO_2 from combination of CO_2 & O_2 measurements.**

Team’s Proposed FY2013/FY2014 Plans

- Write the draft ASCENDS White Paper and vet with community.
- HQ evolve thinking on how to implement the mission.
- Evolve candidate ASCENDS instruments toward Phase A
  - Early technology maturation funding will reduce implementation risk
- Refine ASCENDS mission design studies (To support future AO process)
- Conduct independent cost analyses for instrument candidates
- Continue ASCENDS Science Working Group activities to support white paper review
  - Hold public workshop to review/vet White Paper
  - Development of Level 1 requirements
- Prepare for ASCENDS future release of AO (in what ever form that ends up being)

Earth Science Decadal Survey Venture Line

EVS:
Sustained Sub-Orbital Investigations

Every 4 years

EVM:
Complete, self-contained, small missions,
Every 4 years

EV-Instrument:

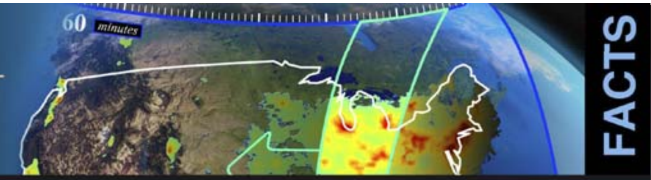
Full function, facility-class instruments
Missions of Opportunity (MoO)

Every 18 months

- Regular, frequent EVI solicitations specifically allow NASA's ESD to develop capable instruments for flights on NASA or partner missions

Facts about Selected Investigation

TEMPO



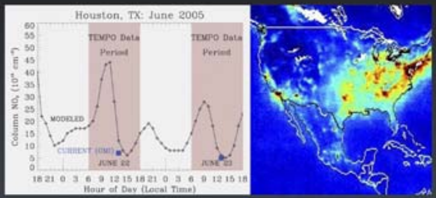
Tropospheric Emissions: Monitoring of Pollution

PI: Dr. Kelly Chance,
Smithsonian Astrophysical Observatory

TEMPO's concurrent high temporal (hourly) and spatial resolution measurements from geostationary orbit (GEO) of tropospheric ozone, aerosols, their precursors, and clouds create a revolutionary dataset that provides understanding and improves prediction of air quality (AQ) and climate forcing in Greater North America (GNA).

SCIENCE OBJECTIVES

- Collect simultaneous high temporal and spatial resolution measurements of pollutants over GNA.
- Measure the key elements in tropospheric ozone chemistry & aerosol cycles.
- Observe aerosols & gases for quantifying and tracking evolution of pollution.
- Integrate observations from TEMPO and other platforms into models to improve representation of processes.
- Serve as the North American geostationary component of an international constellation for air quality monitoring.
- Determine the diurnal instantaneous radiative forcings associated with pollutants and other climate agents on the continental scale.



TEMPO maps hourly changes in North American air quality.

SCIENCE TEAM captures global expertise in air pollution science, UV-Visible measurements, and image navigation and registration.

Kelly Chance, (PI)	SAO	Xiong Liu, (DPI)	SAO
James Carr	Carr Astro	Ronald Cohen	UC Berkeley
David Edwards	NCAR	Jack Fishman	St. Louis U.
David Flittner	LaRC	Jay Herman	UMBC
Daniel Jacob	Harvard	Scott Janz	GSFC
Joanna Joiner	GSFC	Nickolay Krotkov	GSFC
James Leitch	Ball	Randall Martin	SAO
Doreen Neil	LaRC	Michael Newchurch	UAH
R. Bradley Pierce	NOAA	Robert Spurr	RT Solutions
Raid Suleiman	SAO	James Szykman	EPA
Omar Torres	GSFC	Jun Wang	U. Nebraska

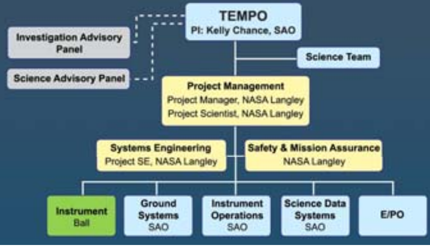
INVESTIGATION OVERVIEW

TEMPO is an innovative use of a well-proven technique, able to produce a ground-breaking dataset. It is led by PI Dr. Kelly Chance, SAO, who for over 30 years has been at the forefront of atmospheric composition and pollution remote sensing. Dr. Chance and the Science Team have extensive expertise in algorithm development for GOME-1 & 2, SCIAMACHY, OMI and OMPS. The PI is supported by the NASA Langley team, which brings project management and space flight instrument development expertise (CALIPSO, CERES, SAGE III) with emphasis on hosting science payloads on a variety of platforms. The TEMPO imaging grating spectrometer is designed and built by Ball (with heritage in building OMPS and SAGE III) to take advantage of a GEO host spacecraft. Image navigation and registration is led by Carr Astronautics (GOES-R). Science data processing capitalizes on operational algorithms used with current LEO instruments. TEMPO will launch at a prime time to be the U.S. component of a global GEO constellation for pollution monitoring.

UNIQUE CAPABILITIES

- Demonstrated space-based chemical suite sensitive to key elements of tropospheric air pollution chemistry.
- Hourly daylight observations from geostationary orbit capture diurnal cycle of emissions & chemistry.
- Order of magnitude improvement in spatial sampling to resolve gases at urban scales and improve emissions inventory.
- Multi-spectral observations are sensitive to ozone in the lower-most troposphere, reducing uncertainty in air quality predictions by 50%.
- Geostationary orbit allows multiple observations per day, increasing the probability of viewing a clear-sky scene.

INVESTIGATION ORGANIZATION provides clear lines of authority with accountability and ownership.



The low-risk, high heritage TEMPO grating spectrometer is a well established instrument to provide trace gas and aerosol measurements.

KEY INSTRUMENT CHARACTERISTICS

Requirements		Comment
Field of Regard	GNA	Mexico City to Canada tar sands & Atlantic to Pacific
Imaging Time	1 hr	1250 scan positions with 2.8 sec integration
Footprint N/S	2.0 km	Native pixel achieved by 44 cm telescope effective focal length
Footprint E/W	4.5 km	
Spectral Range	290-690 nm	1,024 spectral channels matched to 2k focal plane
Spectral Resolution	0.6 nm	Achieved by spectrometer design
Spectral Sampling	0.2 nm	

Heritage-based grating spectrometer efficiently achieves the requirements derived directly from the Science Traceability Matrix.

Species	λ Band nm	SNR Reqs	SNR Predict	EOL Margin
SO_2	305-345	1297	1820	40%
H_2CO	327-354	487	2094	330%
NO_2	423-451	1233	1910	55%
$C_2H_2O_2$	433-457	1350	2331	73%
O_3 (UV)	303-345	1122	1635	46%
O_3 (Vis)	546-648	958	1254	31%
AOD	354, 388	1000	1596	60%

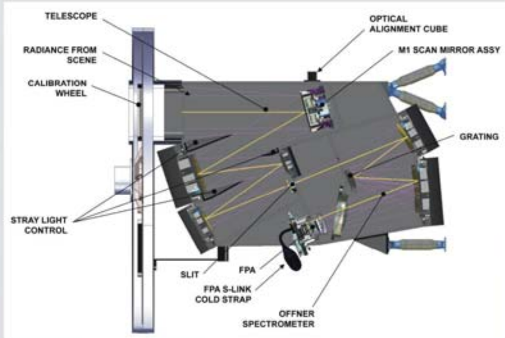
Substantial margins for predicted signal-to-noise ratios are the foundation for a low-risk program.

INSTRUMENT COMPLEMENT

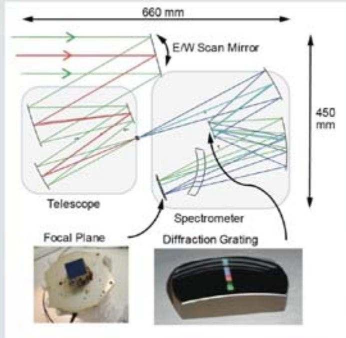
TEMPO moves high heritage LEO hardware to GEO following a low-risk build philosophy. The high design maturity of the TEMPO spectrometer is leveraged from LEO-proven heritage from OMPS, SAGE III, and SBUV, as well as from GEO studies and risk reduction activities. This, coupled with substantial performance margins, results in a low-risk, compact configuration ideally matched to deliver a high value science product.

Requirements	TEMPO		
	Current Best Estimate	Contingency	Maximum Expected Value
Mass (kg)	92	17%	107.9
Average Power (W)	81.6	22%	99.4
Downlink Rate (Mbps)	8.95		
Volume (l x w x h)	1.02m x 1.07m x 0.96m		

The low resource requirements for TEMPO can be accommodated by any of the commercial GEO buses over GNA, ensuring flexibility to selection of a host platform.

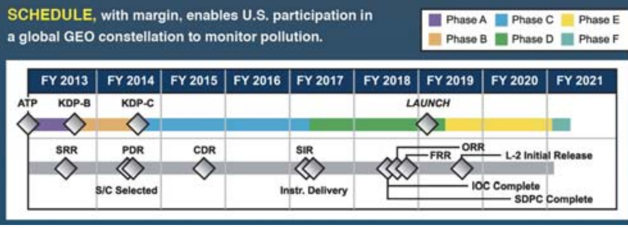


UV-Visible spectrometer: High heritage assemblies deliver innovative science using a low-risk approach.



The optical subsystem leverages Ball's heritage designs. Ball internal efforts have characterized the proposed focal plane and diffraction grating, reducing the implementation risk.

SCHEDULE, with margin, enables U.S. participation in a global GEO constellation to monitor pollution.



Proposed Total Mission Cost:
RY Lifecycle Cost: $93,216,782
FY14 Lifecycle Cost: $90,000,000

Recap

- NASA is currently operating and developing many missions relevant to Greenhouse Gases, Atmospheric processes, and Carbon Cycle processes
- There are still many missions NASA, and the US Earth Science research community would like NASA to do faster. Given current available budgets, this is not possible.
- The primary route right now to get new mission concepts developed is through the Venture Class solicitations.
  - There is little guarantee that this avenue will get YOUR favorite measurement done from space any time soon either.