NASA's contribution to Ozone Research and Monitoring

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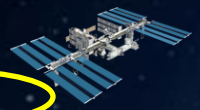
What DOES NASA support regarding Ozone research NOW?

- Continue to Observe Ozone and the Stratosphere from UV backscatter and Limb sounding
  - See earlier talks by Bhartia, Stolarski, Santee, Burrows
- Continued support of ground based networks for Ozone and related compounds
  - NDACC
  - AGAGE
  - SHADOZ
    - See earlier talks by Reimann and foursome on ground based talks
- Continued, though reduced level of effort relative to the past, aircraft observations of stratospheric processes.
  - See earlier talk by Kurylo
- Continued support of laboratory kinetics
  - See earlier talk by Burkholder
- Continued support of a data analysis program taking advantage of all of the above observations.
  - This includes the ACMAP program and science teams associated with each operating satellite.

Earth Science Missions



ISS Instruments

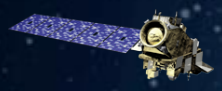
CATS, LIS, SAGE III

TSIS-1, OCO-3, ECOSTRESS, GEDI

CLARREO-PF, TSIS-2

JPSS-2 Instruments

RBI, OMPS-Limb



- Formulation
- Implementation
- Primary Ops
- Extended Ops

Landsat 9

PACE

GeoCARB

TROPICS (12)

MAIA

Sentinel-6A/B

NI-SAR

SWOT

TEMPO

GRACE-FO (2)

ICESat-2

CYGNSS (8)

NISTAR, EPIC
(DSCOVR / NOAA)

SMAP

Suomi NPP
(NOAA)

Landsat 7
(USGS)

QuikSCAT

SORCE,
TCTE (NOAA)

Terra

Landsat 8
(USGS)

Aqua

CloudSat

CALIPSO

GPM

Aura

GRACE (2)

OSTM/Jason 2
(NOAA)

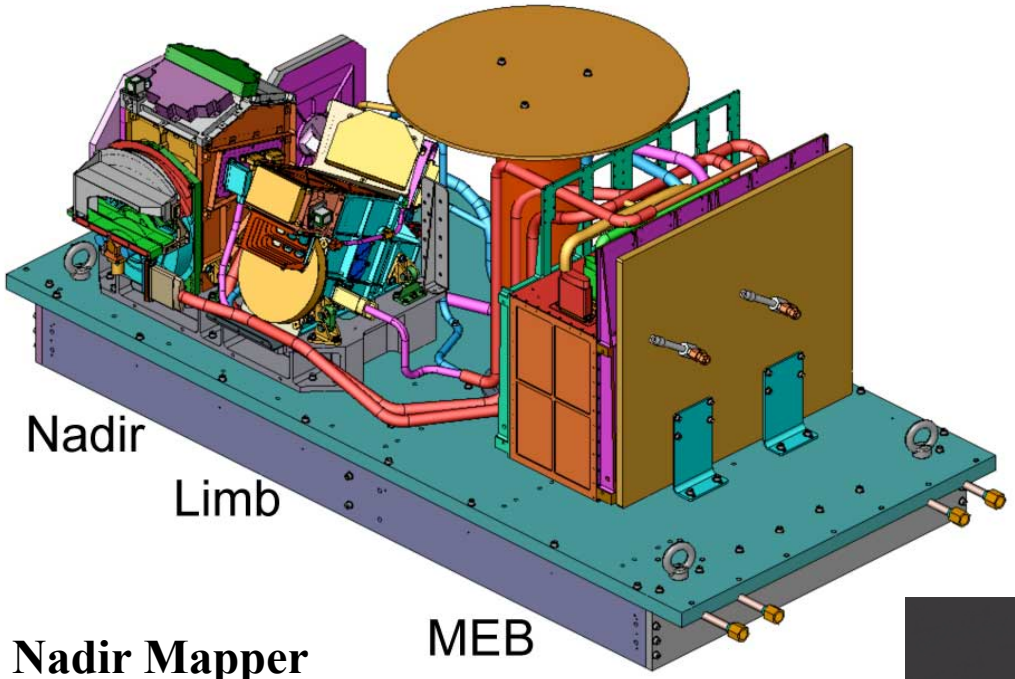
OCO-2

05.17.17

OMPS (on S-NPP)

Ozone Mapper Profiler Suite

Global daily monitoring of three dimensional distribution of ozone and other atmospheric constituents. Continues the NOAA SBUV/2, EOS-AURA OMI and SOLSE/LORE records.



Nadir Mapper

Grating spectrometer, 2-D CCD

110 deg. cross track, 300 to 380 nm spectral, 1.1nm FWHM bandpass

Nadir Profiler

Grating spectrometer, 2-D CCD

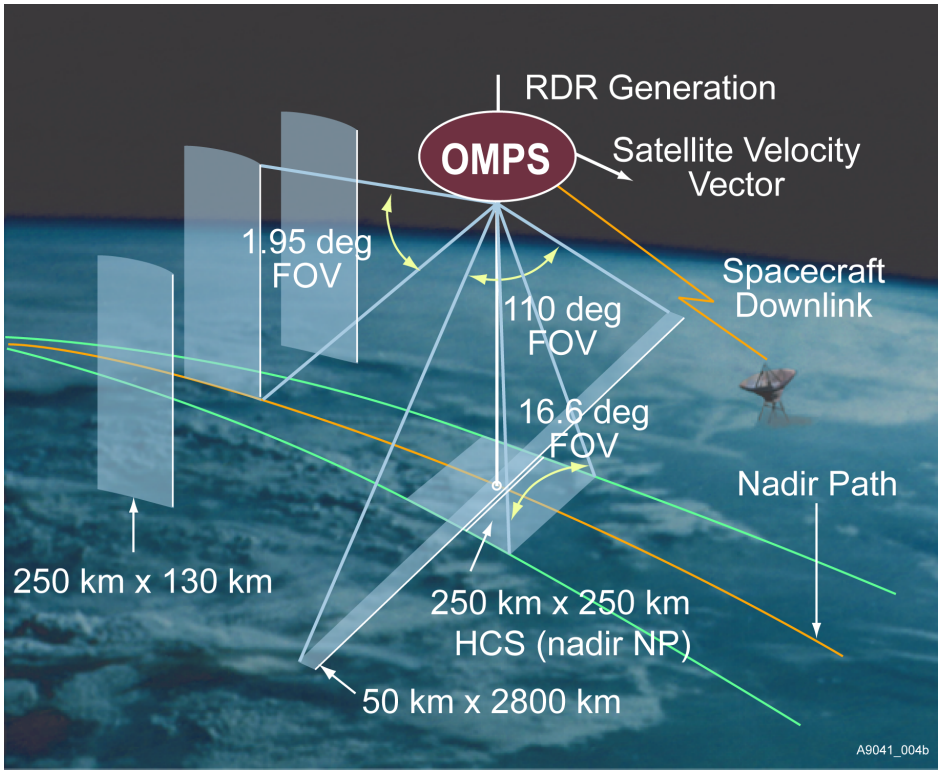
Nadir view, 250 km cross track, 270 to 310 nm spectral, 1.1 nm FWHM bandpass

Limb Profiler

Prism spectrometer, 2-D CCD

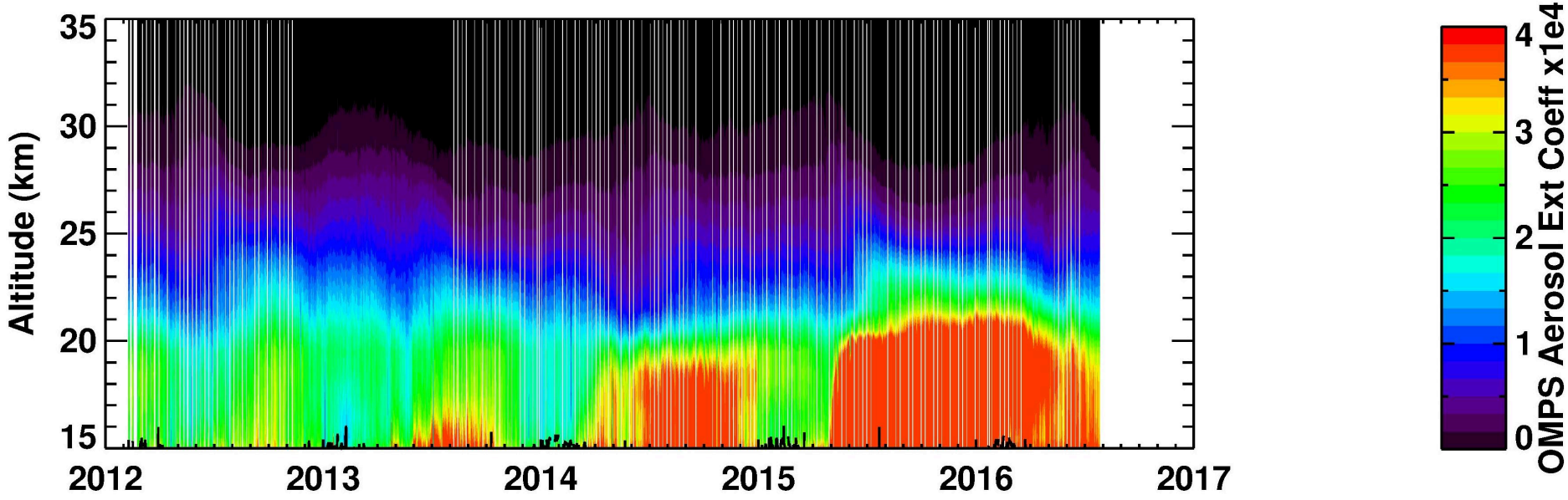
Three vertical slits, -20 to 80 km vertical, 290 to 1000 nm spectral

The calibration systems use pairs of working and reference solar diffusers.

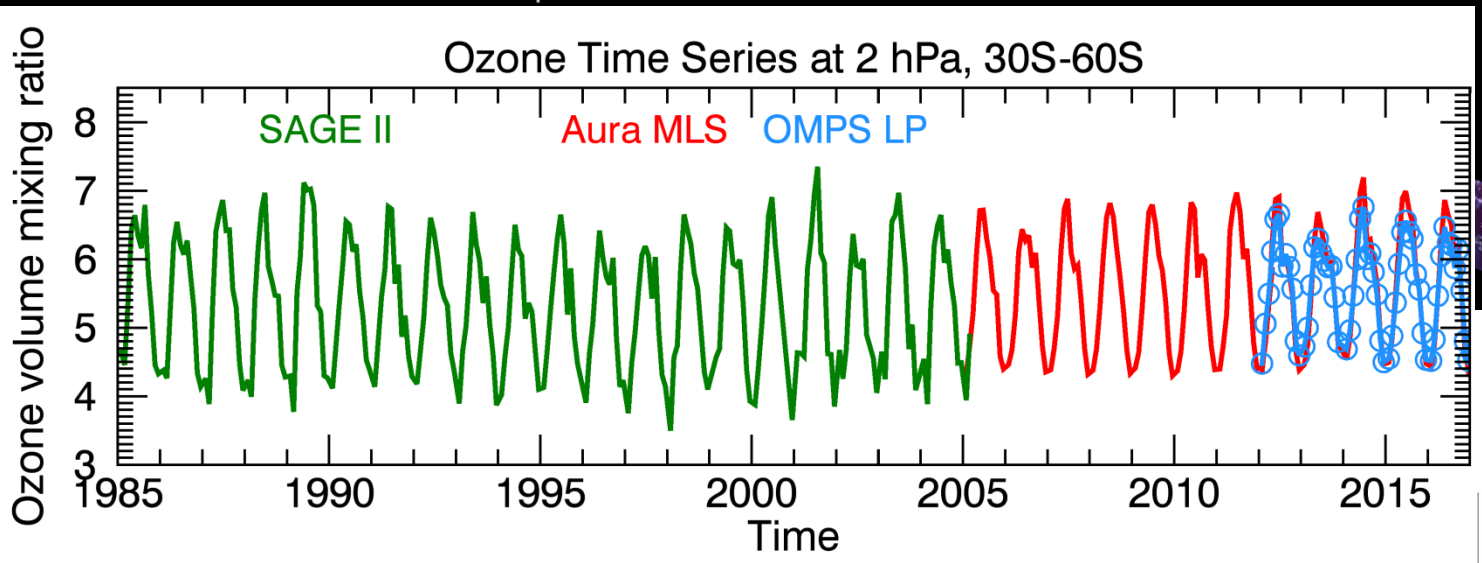


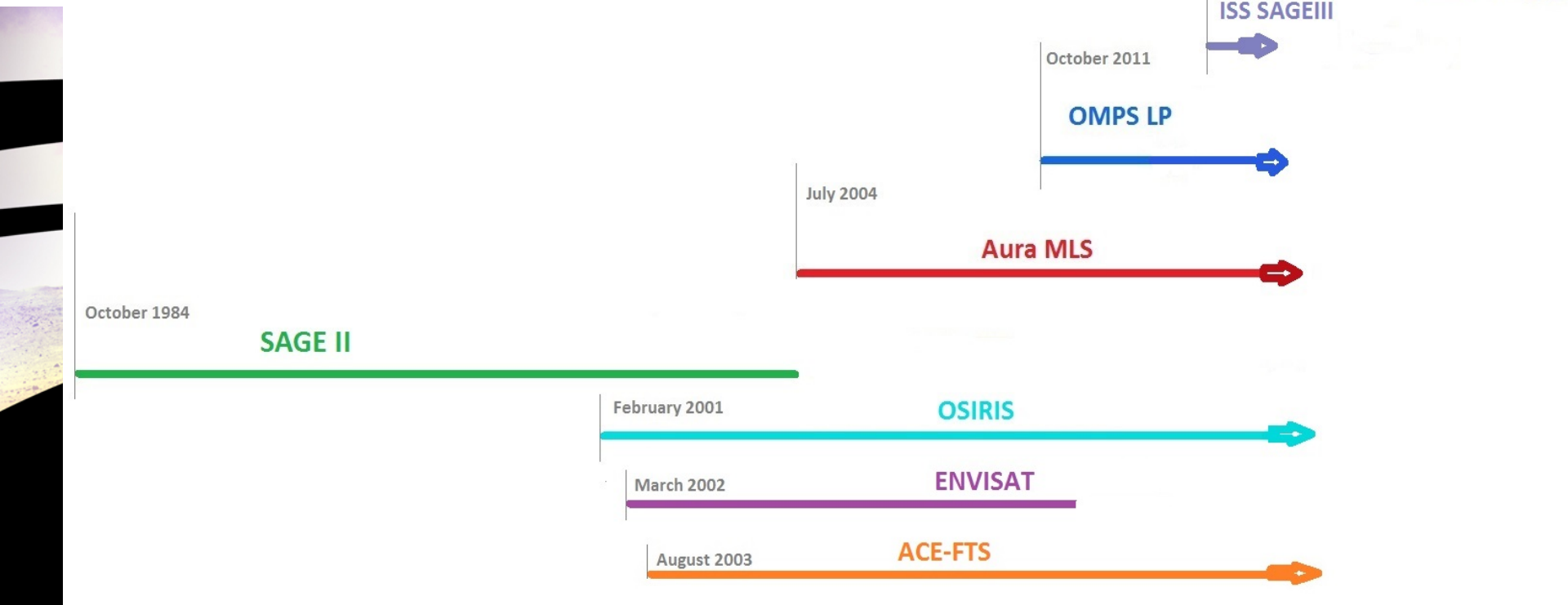
L. Flynn

OMPS-Limb Aerosols, key science product



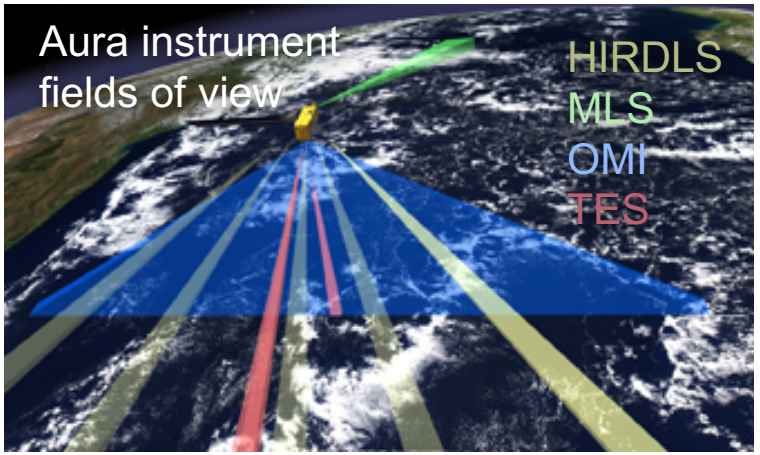
OMPS Limb Profiler continues NASA ozone

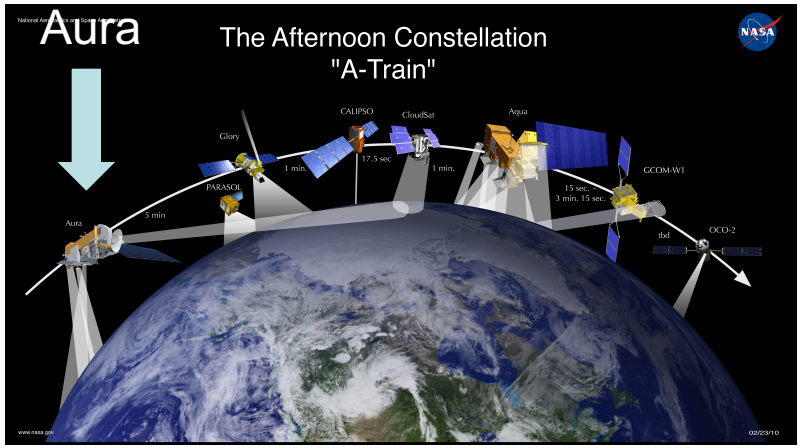




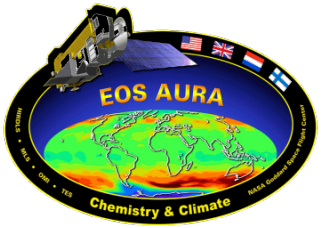
EOS Aura

- Launched VAFB, July 15, 2004
- Orbit: Polar: 705 km, sun-synchronous, 98° incl., ascending 1:45 PM equator crossing time.
  - Aura follows Aqua in the same orbit by <7 minutes. Orbit position moved closer to Aqua to improve science – crossing time unchanged.
- Main science objectives: stratospheric ozone recovery; air quality; climate change
- Four Instruments:
  - HIRDLS (High Resolution Dynamics Limb Sounder, Univ. Of Col/NCAR./ Oxford U. K.)
  - MLS (Microwave Limb Sounder, JPL)
  - OMI (Ozone Monitoring Instrument, Netherlands/ Finland)
  - TES (Tropospheric Emission Spectrometer, JPL)
- Level 1 mission success requirements have LONG been met
- Celebrated 13 year anniversary in July!!
- Main data validation program is complete. Some residual validation activities are ongoing.
- Spacecraft in reasonable shape
  - Fuel sufficient for ~2022 or later orbit lowering





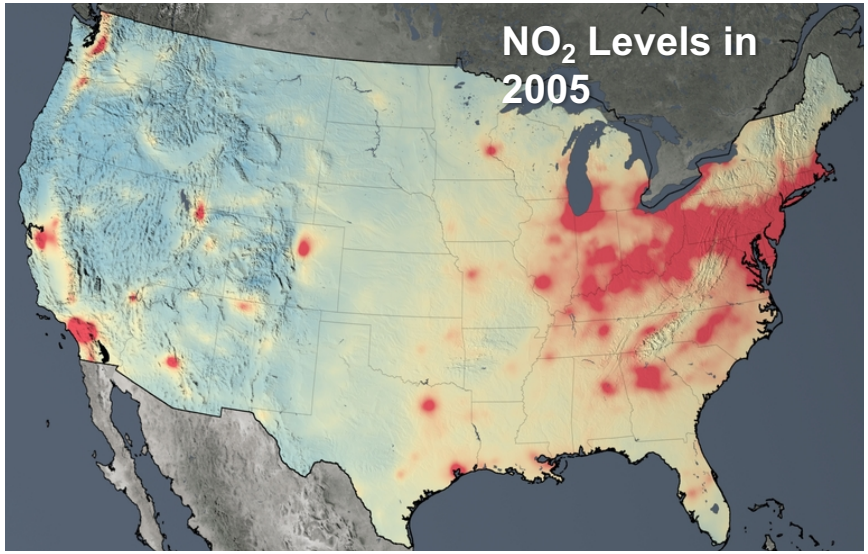
EOS Aura (cont)

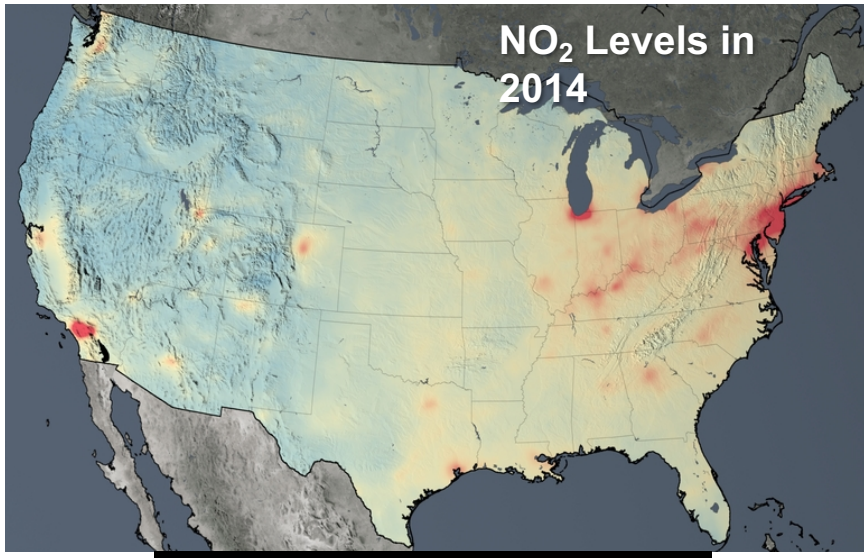


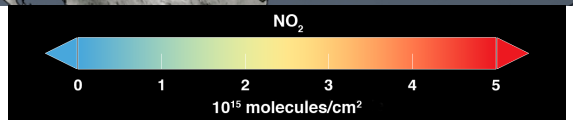
- Instrument status shows various status of “health”.

- HIRDLS is no longer operating
  - The chopper motor froze in 2009. Test to unfreeze have been unsuccessful
  - The team is still working to produce retrievals of more difficult species like CH4.
- TES is still operating with a lower duty cycle.
  - The FTS mirror carriage freezes often, significantly affecting the science return.
  - The metrology laser, a key component, was not working for months, but currently works..
  - TES will be decommissioned very soon, per the Senior Review recommendation.
- MLS has now lost two channels, one (the THz channel) was expected.
  - Otherwise, all systems are operating nominally with only small effects associated with age.
- OMI still has a blockage over a portion of it’s field of view.
  - This blockage is now changing with time.
  - Data within these footprints are not scientifically useful, and flagged.

Aura's Ozone Monitoring Instrument (OMI) Nitrogen Dioxide (NO_2) Data Show the Clean Air Act is Working!







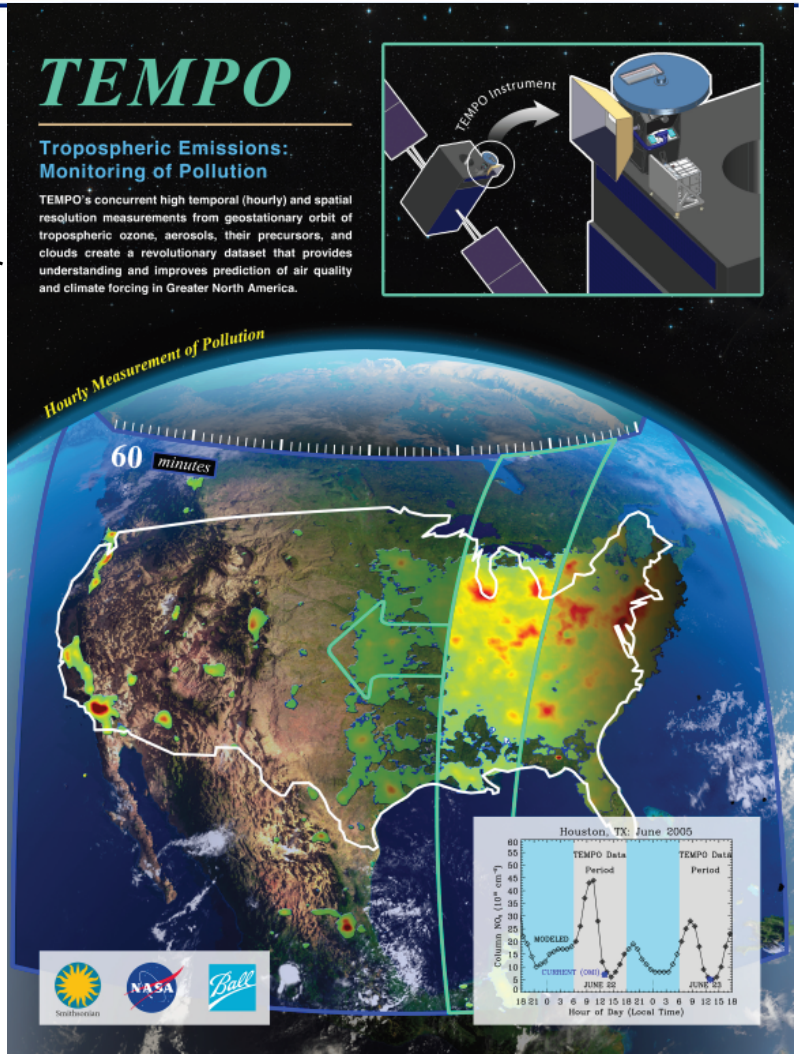
NO_2 is a common pollutant from power plants & automobiles. It damages ecosystems via acid deposition & eutrophication and is a precursor to atmospheric particulates & ozone, which damage our lungs. Ozone also affects plants, such as reducing crop yields. Pollutant emission controls have led to a dramatic reduction in NO_2 (20-60%) and, subsequently, ozone (~15%) over the US from 2005 to 2014.

On April 12, 2016, President Obama used OMI NO_2 data to explain how pollution affects our planet: https://www.youtube.com/watch?v=LKe5FdKIn_Is

Lamsal, L.N., et al., *U.S. NO_2 trends (2005-2013): EPA Air Quality System (AQS) data versus improved observations from the Ozone Monitoring Instrument (OMI)*, Atmos. Environ., doi:10.1016/j.atmosenv.2015.03.055, 2015.

Hourly atmospheric pollution from geostationary Earth orbit

PI: Kelly Chance, Smithsonian Astrophysical Observatory
Instrument Development: Ball Aerospace
Project Management: NASA LaRC
Other Institutions: NASA GSFC, NOAA, EPA, NCAR, Harvard, UC Berkeley, St. Louis U, U Alabama Huntsville, U Iowa, RT Solutions, Carr Astronautics
International collaboration: Mexico, Canada, Cuba, Korea, UK, ESA, Spain, Netherlands



Selected Nov. 2012 as NASA's first Earth Venture Instrument

- NASA will arrange hosting on commercial geostationary communications satellite with launch expected NET 11/2018

Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality

- UV/visible grating spectrometer to measure key elements in tropospheric ozone and aerosol pollution
- Distinguishes boundary layer from free tropospheric & stratospheric ozone

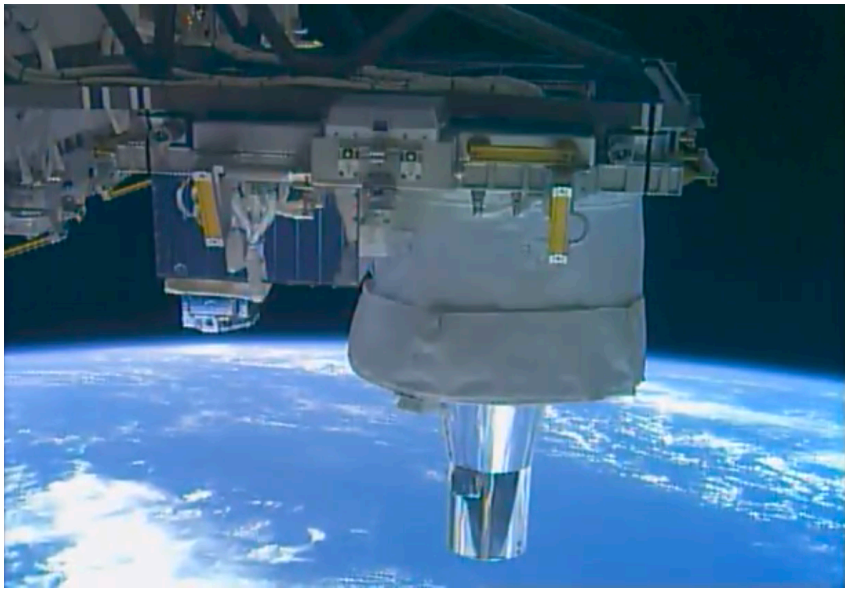
Aligned with Earth Science Decadal Survey recommendations

- Makes many of the GEO-CAPE atmosphere measurements
- Responds to the phased implementation recommendation of GEO-CAPE mission design team

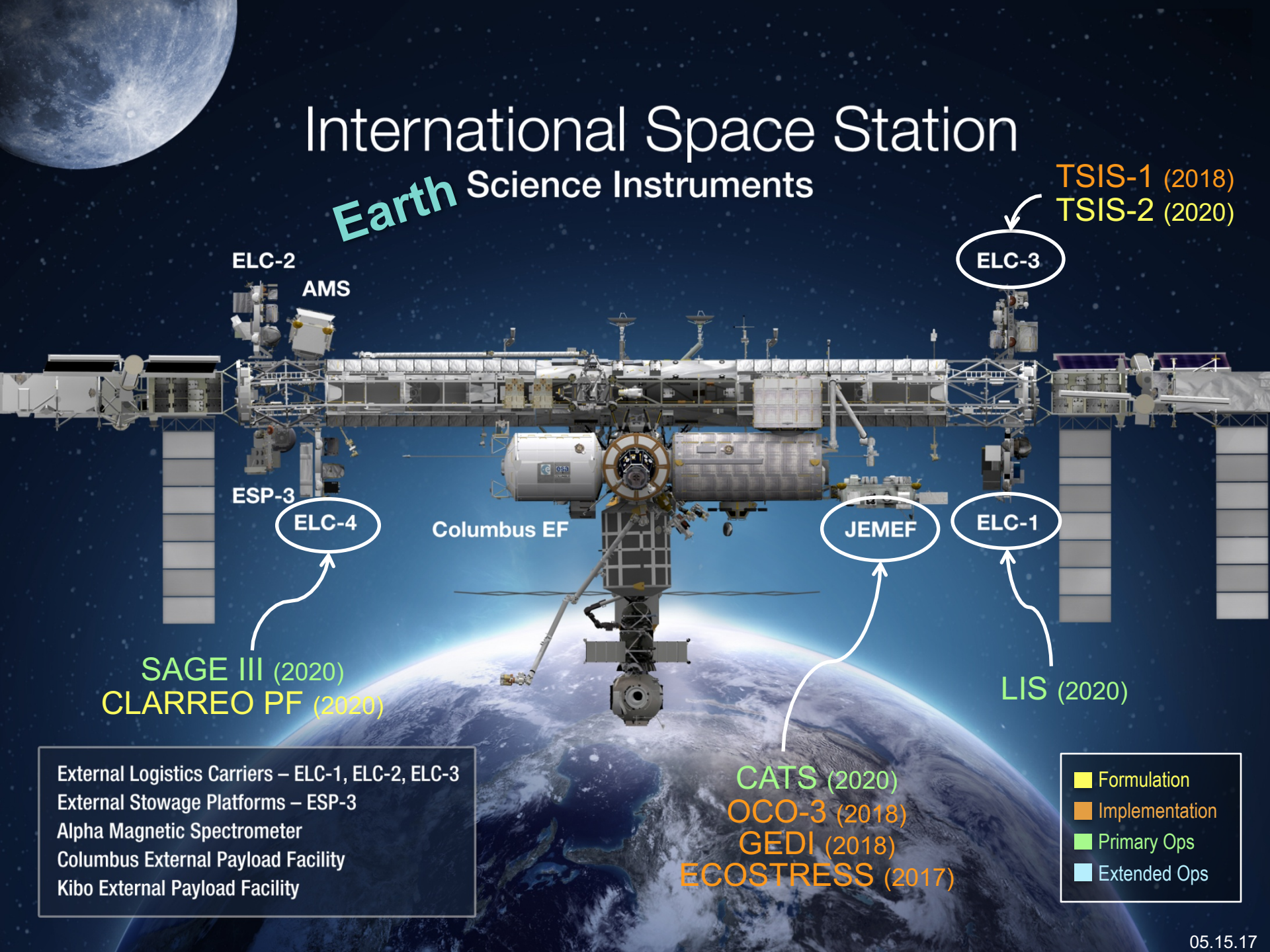
North American component of an international constellation for air quality observations

SAGE III/ISS Status

- SAGE III/ISS is the second SAGE III instrument flown
- The first was on the METEOR 3M spacecraft 2001-2005
- SAGE III/ISS is currently in the early stage of commissioning
- Anticipate the Solar Occultation data set will start April 1, 2017
- Initial validation ends with the public release of data no later than mid August 2017
- Produces profiles of Ozone, aerosol, H_2O, and NO_2



- Launched February 19, 2017
- Installed March 7, 2017
- First light March 15, 2017
- SAGE III/ISS is enabled by significant ESA contributions


International Space Station
Earth Science Instruments
TSIS-1 (2018)
TSIS-2 (2020)
ELC-3
ELC-2
AMS
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
SAGE III (2020)
CLARREO PF (2020)
LIS (2020)
CATS (2020)
OCO-3 (2018)
GEDI (2018)
ECOSTRESS (2017)
External Logistics Carriers – ELC-1, ELC-2, ELC-3
External Stowage Platforms – ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility
Formulation
Implementation
Primary Ops
Extended Ops
05.15.17

SAGE III/ISS O_3 Profile

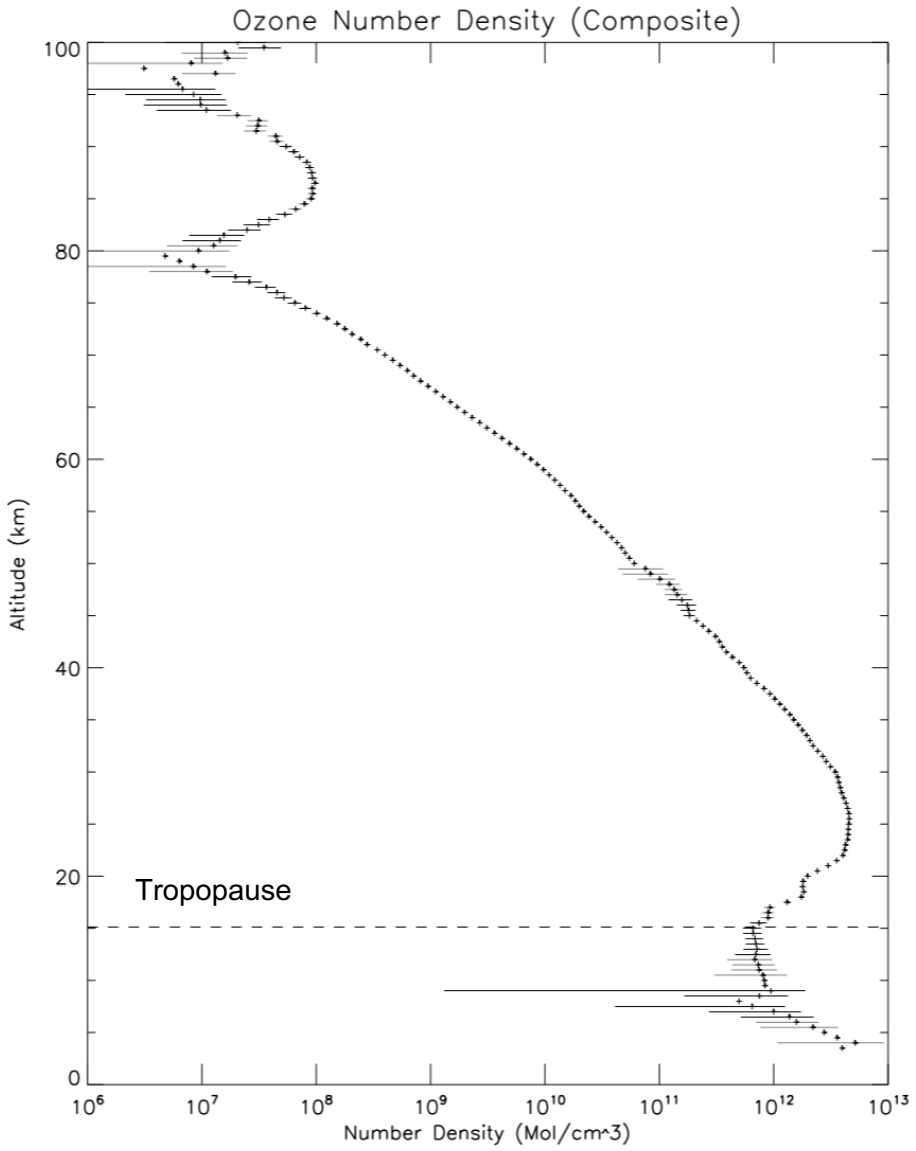
SAGE III product development proceeding well

- O_3 profiles span the entire mesosphere, stratosphere and most of the troposphere* with 1Km vertical resolution throughout.
- O_3 density varies by 6 full orders of magnitude over this altitude range.
- Uncertainty estimates in individual profiles at the stratospheric peak are typically 0.5%.

- Further improvements in overall data quality forthcoming prior to public release.

* As clouds permit

October 2, 2017



What is NASA planning for future Ozone/stratosphere observations?

- NASA will continue to operate Aura and SAGE-III as long as the NASA Senior Review process determines that it is returning science quality observations relative to the financial commitment to continued operations.
  - In early 2023, Aura will run out of fuel for orbit adjustment above the amount needed for successful deorbit of the satellite.
  - There is a chance NASA could allow the orbit to drive after that if the science return is considered appropriate.
  - SAGE-III allocation on the ISS is also contingent on the ISS location is not allocated to another project from one of the many International partners for the "I"SS.

What is NASA planning for future Ozone/stratosphere observations?

- NASA is committed to continuing the Limb portion of OMPS on the NOAA JPSS satellites starting with JPSS-2. NOAA will fund the nadir instruments from JPSS-1 onward.
- There are no current plans for limb sounding satellites beyond Aura that will obtain key observable like HCl, N_2O, or CH_4.
  - It is unlikely that the Current Decadal Survey (release due by end of 2017) will recommend a continuation of such observations
  - The only other possible route for NASA to support such observations in the future will be through a competitive proposal being selected through an Earth Venture solicitation, OR, we are directed to do so from the Executive/Legislative branches of the US Government.

Non-Space observations that will continued to be supported by NASA

- Because of the lack of guarantee of space observations for key stratospheric parameters, ground-based observations that form long term data sets must continue to be supported.
  - AGAGE **IS** NASA's primary response to the mandate for monitoring and understanding long term observations of Ozone Depleting Substances.
  - NDACC observations are the only way to ensure long term understanding in changes of stratospheric parameters like HCl, temperature, and maybe even water vapor. Not overly useful for stratospheric transport related tracers.
    - SAGE-III does get H_2O, but that is not guaranteed for long term.
- Because of the continued need to validate tropospheric ozone profiles, ozone lidar and ozonesondes will most likely maintain continued support.

One major caveat to everything I said…

The draining swamp **MAY** have other ideas than I do!