

Remote Measurement of Pollution—A 40-Year Retrospective: Part I—Temperature and Gaseous Species

An historical assessment of the RMOP
Report, NASA SP-285, at
(<http://ntrs.nasa.gov>)

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by

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Current Sensor Capabilities and their Historical Development

- Focus is on **remote sensing research at Langley Research Center (LaRC)**, as placed within the larger historical context of the many other concurrent developments of the NASA, NOAA, academic, and international communities.
- The current review (Part I) considers techniques for the measurement of **temperature and gaseous species from satellite platform**.
- *The findings are contained in a ~50-page, NASA Technical Memorandum that is under review, including **citations to many key papers**.*
- Part II will be prepared in 2011 and will focus on both passive and active measurements of particulates and clouds from satellite.

LaRC's Current Engineering Expertise Supports Earth Science

Capabilities

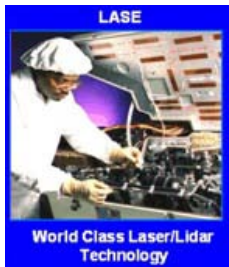
**Advanced Concepts
Development**

**Advanced Technology
Development**

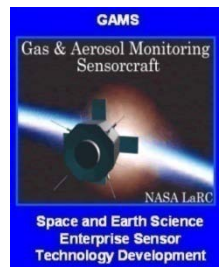
**Technology
Demonstration**

**Flight Systems
Development**

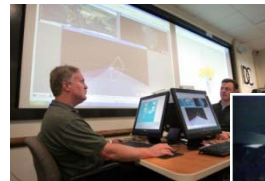
Areas of Expertise



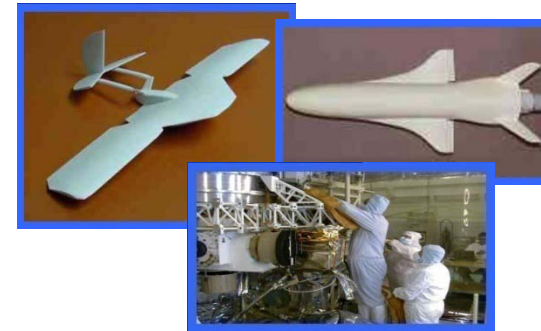
**Lidar/Laser
Systems**



**Sensor/Sensing
Systems**



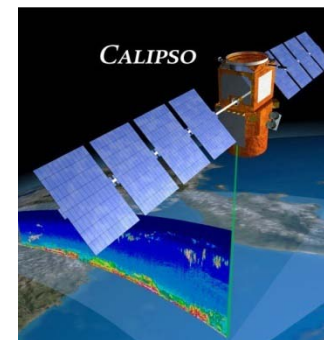
**Engineering
Environments**



**Fabrication and
Manufacturing**



Flight Systems



1940's



1971



Present

Aeronautics Focus

- Create model atmospheres, surface to 100 km.
- Passive sensing studies of Earth's CO₂ horizon for spacecraft attitude and reentry.
- Laser sensing of fluid flow in wind tunnels and turbulence in the atmosphere



Remote Sensing Application

- Satellite infrared limb emission sensors.
- Satellite measurements by solar occultation (SO).
- Satellite imagers and Gas Filter Correlation Radiometry (GFCR) techniques.

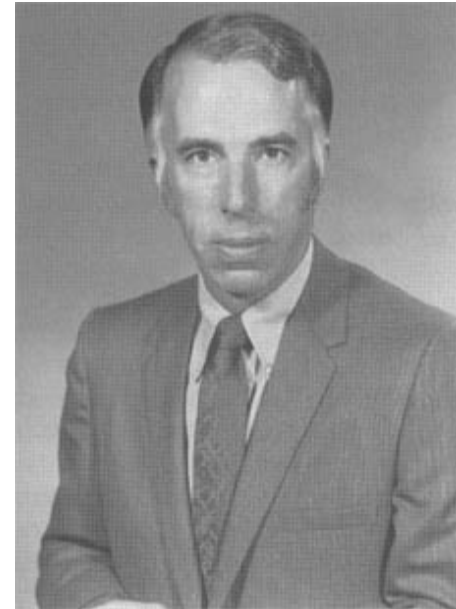
Sensors for the Next Decade

- Hyper-spectral imaging of troposphere
- limb scattering for lower stratospheric ozone
- SO via SAGE III from Space Station
- tunable lasers for column CO₂
- geostationary GFCR measurements for CO.



Key Players for Langley

- **Edgar Cortright**, LaRC Director (1968-75), created its atmospheric science organization.
- **J. Don Lawrence, Jr.**, served as AESD/ASD Division Head 18 yrs.
- **Charles Mathews** of LaRC led NASA Office of Applications from 1972.
- Langley was already focused on stratospheric ozone and its related species because of the associated implications to the SST and national policy. *Thus, Don Lawrence quickly recognized that any atmospheric measurements would need to be of excellent quality, requiring careful calibration and independent validation.*



Dr. Edgar Cortright

Direction and Context for the Remote Measurement of Pollution (RMOP) Workshop

The Workshop was convened in 1971 at LaRC, following the MIT SCEP Report of 1970 and when NASA was emphasizing its Applications Programs.

- Environmental issues of the time included regional-scale transport of pollution, acid rain, degradation of coastal estuaries, and effects of emissions from SST aircraft.
- NASA Director of Meteorology, Morris Tepper, and the AAFE Program Mgr, Jules Lehmann, directed Langley to conduct the Workshop.
- There were 3 key RMOP Panels: Gaseous Species (**Will Kellogg**), Particulates (**Verner Suomi**), and Water Pollution (**Gifford Ewing**).

The RMOP Report was used as a blueprint for NASA's Applications programs for the following two decades.

RMOP Gas Species Panel Members

(Persons in red would be directly associated with successful satellite instruments.)

William Kellogg, NCAR, Chair

Tony Barringer, Environmental Measurements, Inc.

Jacob Becher, Old Dominion Univ.

C. Barney Farmer, JPL

John Gille, Florida State Univ.

Gary Grew, NASA Langley

Philip Hanst, APCO Technical Center

Allen Lefohn, Div. of Physics and Chemistry, EPA

Claus Ludwig, General Dynamics Corp.

John Ludwig, Office of Air Programs, EPA

William Matthews, SCEP Report and MIT

Donald Pack, Air Resources Lab, NOAA

Ted Pepin, Univ. of Wyoming

James Russell, III, NASA Langley

Harold Yates, NESS, NOAA

Objectives of the RMOP Retrospective

This review focuses on **temperature and species profiles and distributions** as measured from a satellite platform for studies **at regional to global scales**.

Co-located temperature profiling from satellites (from TIROS to Nimbus, AIRS, IASI, and RO-GPS) was reviewed by William Smith, Sr., at the 8th History Symposium.

A major theme is the trade-off between obtaining **good accuracy** and having the necessary **spatial resolution** (e.g., see Houghton, Taylor, and Rodgers, *Remote Sounding of Atmospheres*, 1984).

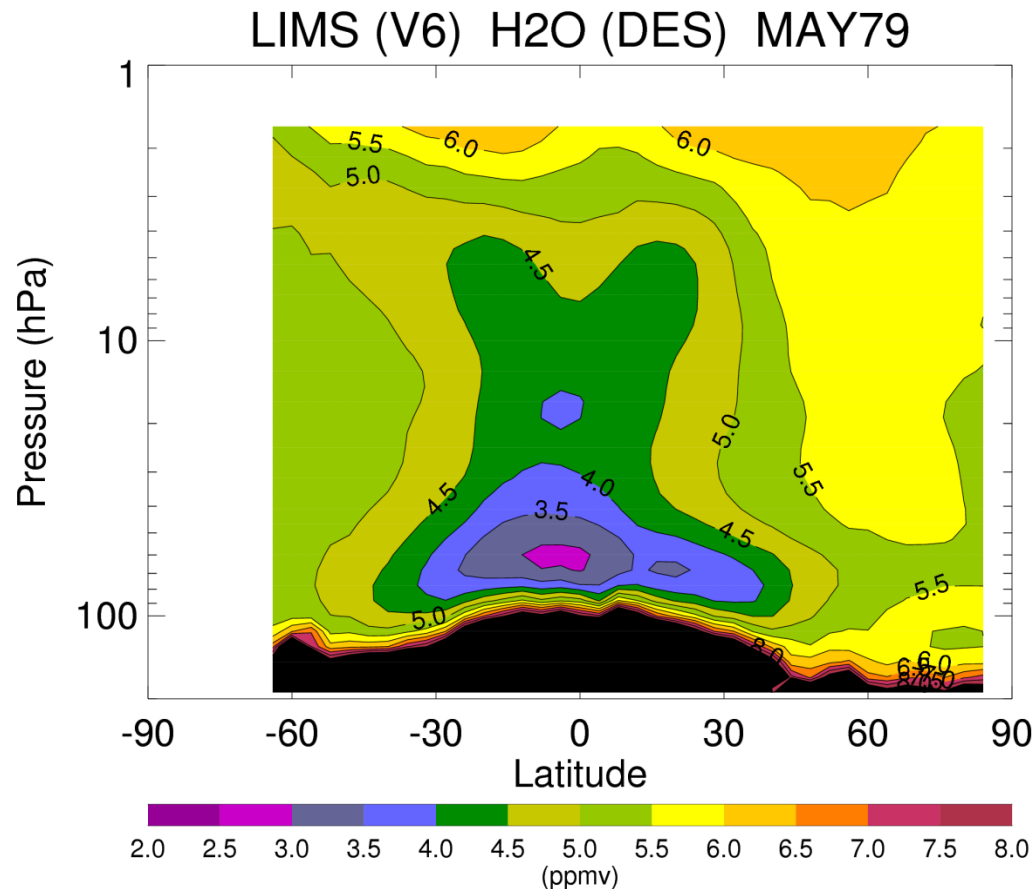
Ultimately, the selection for a spaceflight opportunity was based on **scientific goals and sensor performances**.

Satellite infrared instruments for **temperature and species**

- Nimbus 4 (1970)—primarily UV and **IR nadir** imagers and sounders (e.g., Backscatter Ultraviolet (BUV) and **Selective Chopper Radiometer (SCR)**).
- Nimbus 5 (1972)—**SCR** plus first microwave imagers and sounders.
- Nimbus 6 (1975)—**first IR limb emission profiler—Limb Radiance Inversion Radiometer (LRIR) (J. C. Gille)** plus High Resolution Infrared Sounder (HIRS), **Pressure Modulator Radiometer (PMR)**, and Scanning Microwave Spectrometer (SCAMS), which were the precursors to the NOAA sensors on TOVS.
- Nimbus 7 (1978, the “pollution patrol satellite”)— **Limb Infrared Monitor of the Stratosphere (LIMS) (J. C. Gille and J. M. Russell III)**, **Stratospheric and Mesospheric Sounder (SAMS)**, SBUV/Total Ozone Mapping Spectrometer (TOMS).
- TIMED (2001 to present)—**Sounding of the Atmosphere using Broadband Emission Radiometry or SABER (J. M. Russell III and M. G. Mlynczak)** for the stratosphere through lower thermosphere. *Operations extended through 2012.*

Zonal mean distribution of stratospheric H₂O from LIMS

(Industry partner Honeywell Radiation Center)



Information content of retrievals of radiances and transmittances

Morris Tepper (top) and Don Lawrence (bottom) co-sponsored **Workshop on Inversion Methods in Atmospheric Remote Sounding** in December 1976.

Trade-offs between measurement **accuracy** and the desired **spectral and spatial resolutions** are defined.

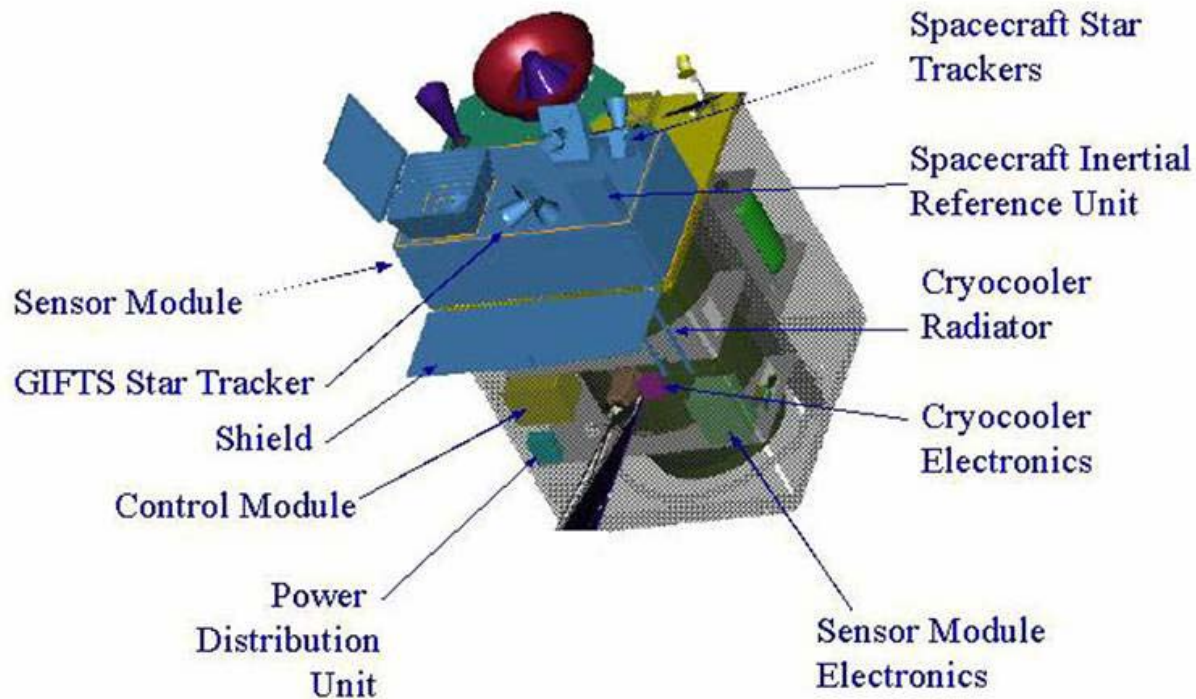
Sensitive detectors, accurate instrument pointing, and co-located temperature profiles are required. NASA supported obtaining **higher quality, spectral line parameters**, which led to a reprocessing of LIMS data in 2002.



SABER

Sounding of the Atmosphere using Broadband Emission Radiometry

(With John Hopkins University Applied Physics Lab and industry partner, Space Dynamics Lab, of Utah State University)

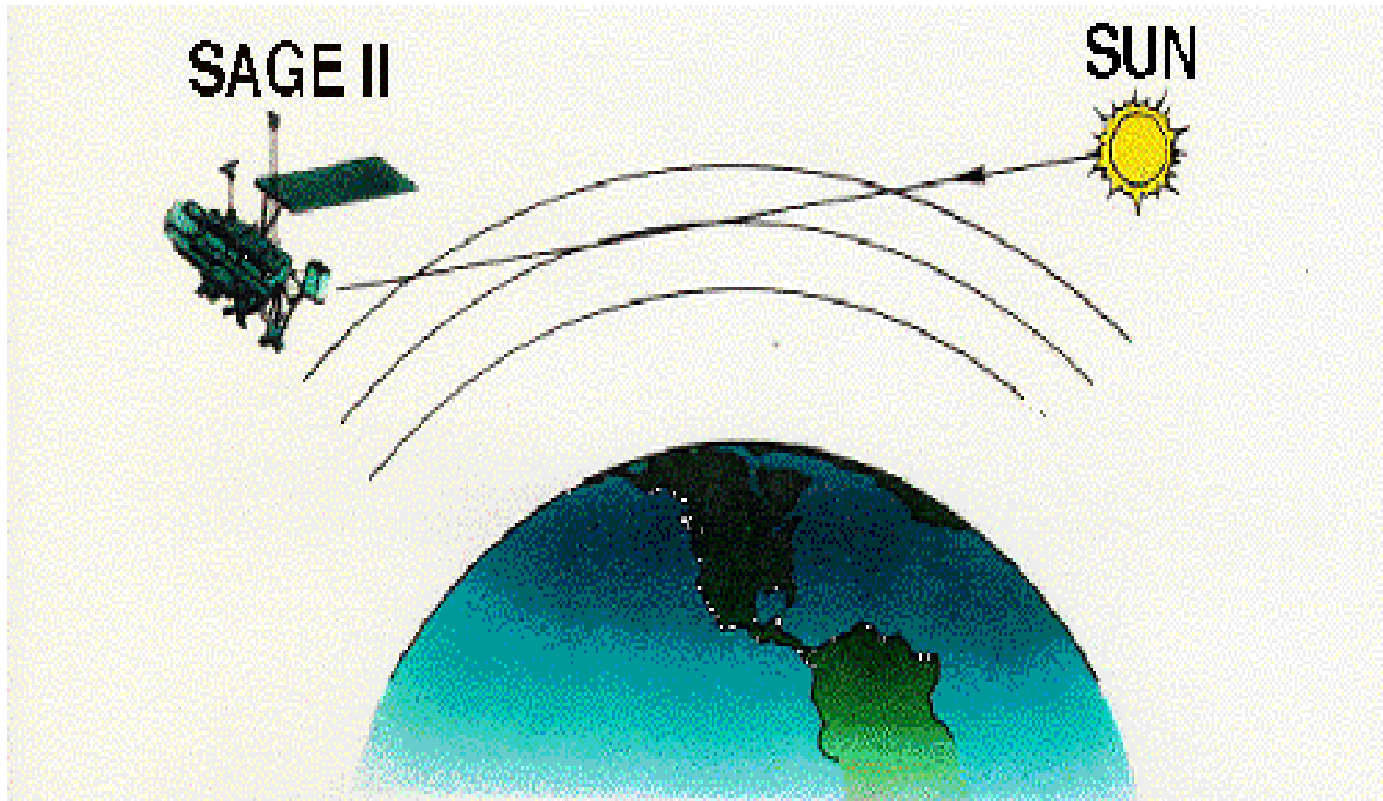


Satellite Solar Occultation Instruments

- Apollo-Soyuz Test Project (1975)—**first solar occultation transmission—Stratospheric Aerosol Monitor (SAM)** (T. J. Pepin)
- Nimbus 7 (1978)—**Stratospheric Aerosol Measurement II (SAM II)** (M. P. McCormick)
- Atmospheric Explorer Mission B (AEM-B in 1979)—**Stratospheric Aerosol and Gas Experiment (SAGE)** (M. P. McCormick)
- Earth Radiation Budget Satellite (ERBS in 1984)—**SAGE II** (M. P. McCormick)—operated successfully until 2005, *providing the trends in O₃ over a 21-yr period.*
- Earth Observing System (EOS in 2001)—**SAGE III** (M. P. McCormick) on Meteor 3 for polar measurements of stratospheric clouds and ozone via occultation and limb scattering techniques.

Measurement geometry for SAGE II

(Industry partner Ball Aerospace)



GFCR and Broadband Radiometry Experiments

- Space Shuttle (STS-2 in Nov 1981 and STS-41G in Oct 1984 and later on STS-59 and STS-68 in 1994)—**Measurement of Air Pollution from Satellites (MAPS)** (H. G. Reichle, T. Barringer, and C. Ludwig)—Sounder for tropospheric CO.
- Upper Atmosphere Research Satellite (UARS in 1991)—**Halogen Occultation Experiment (HALOE)** (J. M. Russell III). **HCl, HF, NO, and CH₄ were measured via GFCR techniques.** *The LaRC-built HALOE instrument operated flawlessly for 14 years.*
- **Four UARS instruments used limb techniques** for obtaining their gas profiles—HALOE, MLS, ISAMS, and CLAES.
- **AIRS and TES** on NASA's EOS satellites rely on **multi-channel spectral selectivity** for the profiling of temperature and gas species; **HIRDLS (J. Gille and J. Barnett)** is a successor of LIMS and ISAMS and employs high vertical resolution, limb radiometry.

MAPS

Measurement of Air
Pollution from
Satellites

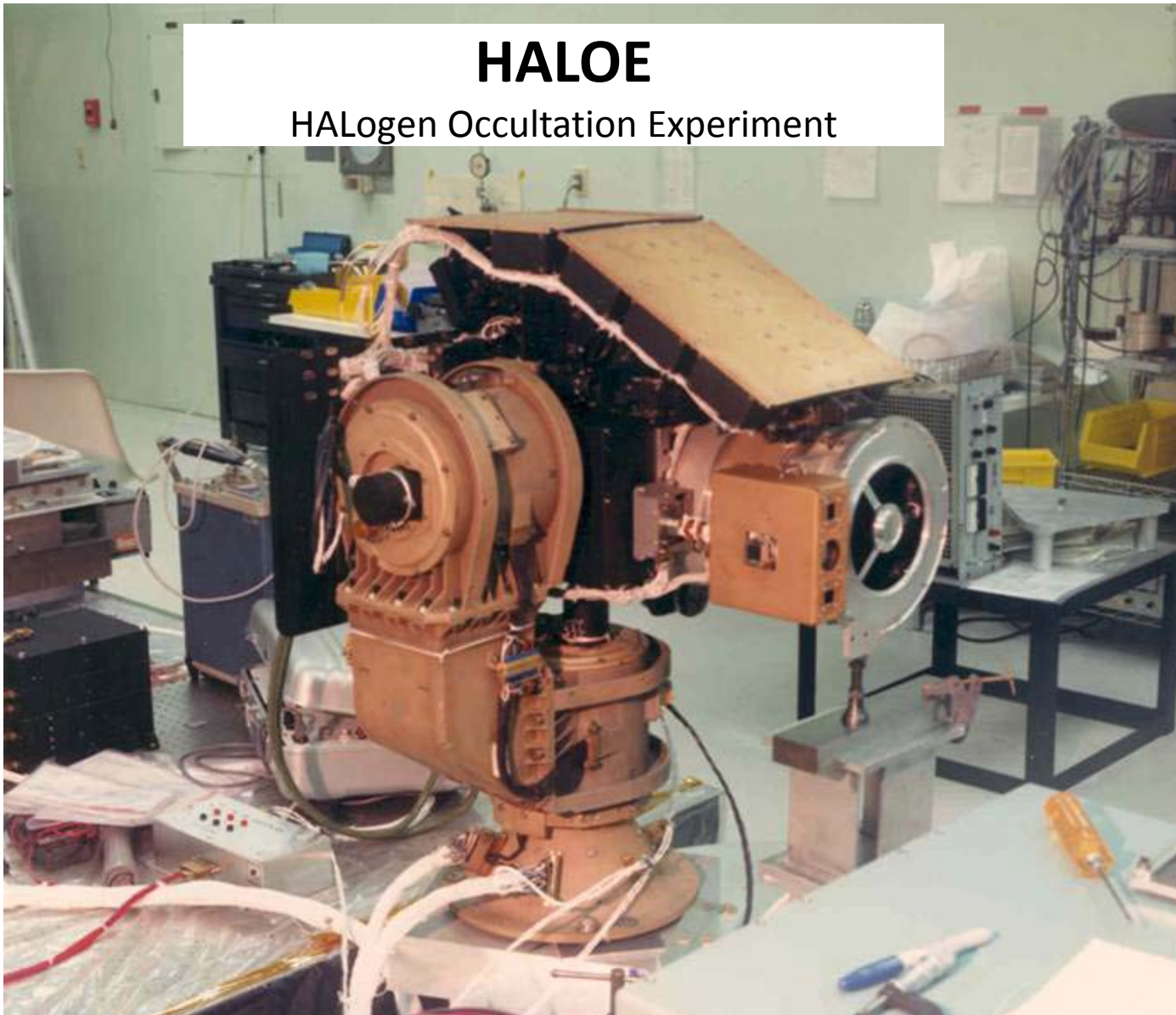
Industry partners
TRW and
Barringer Research



Flown four times on the Shuttle and with its initial flight on STS-2 in 1981, MAPS was NASA's first-ever space-based, tropospheric remote sensor. It also was on Mir in 1994. MAPS measured distributions of CO and is the precursor to MOPITT on EOS Terra.

HALOE

HALogen Occultation Experiment



Flown on the UARS spacecraft from Sept 12 1991 - Nov 21 2005



Summary

Better accuracies, spatial and spectral resolutions, and long-term measurement stability are still the technology goals, *as identified at the RMOP Workshop*.

- The RMOP report of 1971 was an early precursor to the current Decadal Plan for NASA's Earth Sciences from the National Research Council (NRC) Report of 2007.
- The original RMOP blueprint for sensor development within the AAFE Program was continued in the mid-1990s via NASA's New Millenium Program (NMP), Instrument Incubator Program (IIP), and Earth System Science Pathfinder (ESSP).
- Langley's Science and Engineering Directorates are continuing to develop remote sensors for use on environmental satellites.

E. Remsberg contributed to LIMS, HALOE, and SABER during his career, 1971-2010.