GeoTRACE Science Advisory Team: Jack Fishman, John Burrows, Jeremy Hales, Paul Crutzen, Guy Brasseur

GeoTRACE Industry Partners:

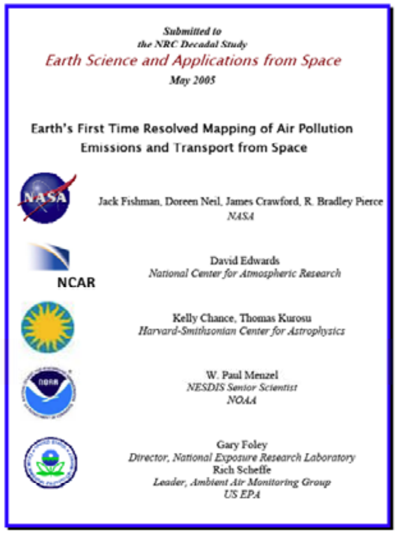
Ball Aerospace, CSC, The Weather Channel, Hughes, PanAmSat, Space Systems Loral, Lockheed Martin

GeoTRACE Formulation:

Alan Little, Doreen Neil, Joan Howard, Eric Ramberg, Pamela Rinsland, Tom Shykula, Elvin Ahl, Bonnie Allen, Robert Averill, L. B. Bush, William Brune, M. D. Canright, Robert Estes, Jack Fishman, James Gleason, Larry Gordley, Dana Gould, A. G. Hagemann, Gary Halama, Robert Hess, Sean Kenny, James Leitch, Jonathan Miles, James Miller, Don Robinson, Marilee Roell, Glen Sachse, Dean Sparks, Jr,. Shelley Stover, Kevin Vipavetz, Gary Wilson

GeoTRACE is a proposed NASA mission to measure air pollution for the first time in the way that weather is observed:

***every hour, from space, across the entire continent*.**



Submitted to
the NRC Decadal Study
Earth Science and Applications from Space
May 2005

Earth's First Time Resolved Mapping of Air Pollution
Emissions and Transport from Space

Jack Fishman, Doreen Neil, James Crawford, R. Bradley Pierce
NASA

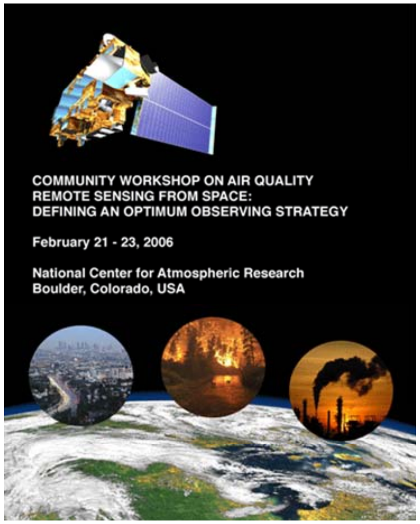
David Edwards
National Center for Atmospheric Research

Kelly Chance, Thomas Kurosu
Harvard-Smithsonian Center for Astrophysics

W. Paul Menzel
NESDIS Senior Scientist
NOAA

Gary Foley
Director, National Exposure Research Laboratory
Rich Scheffe
Leader, Ambient Air Monitoring Group
US EPA

2005 Decadal Survey White Paper



COMMUNITY WORKSHOP ON AIR QUALITY
REMOTE SENSING FROM SPACE:
DEFINING AN OPTIMUM OBSERVING STRATEGY

February 21 - 23, 2006

National Center for Atmospheric Research
Boulder, Colorado, USA

2006 Community Workshop Consensus Report

GeoTRACE **Approach**

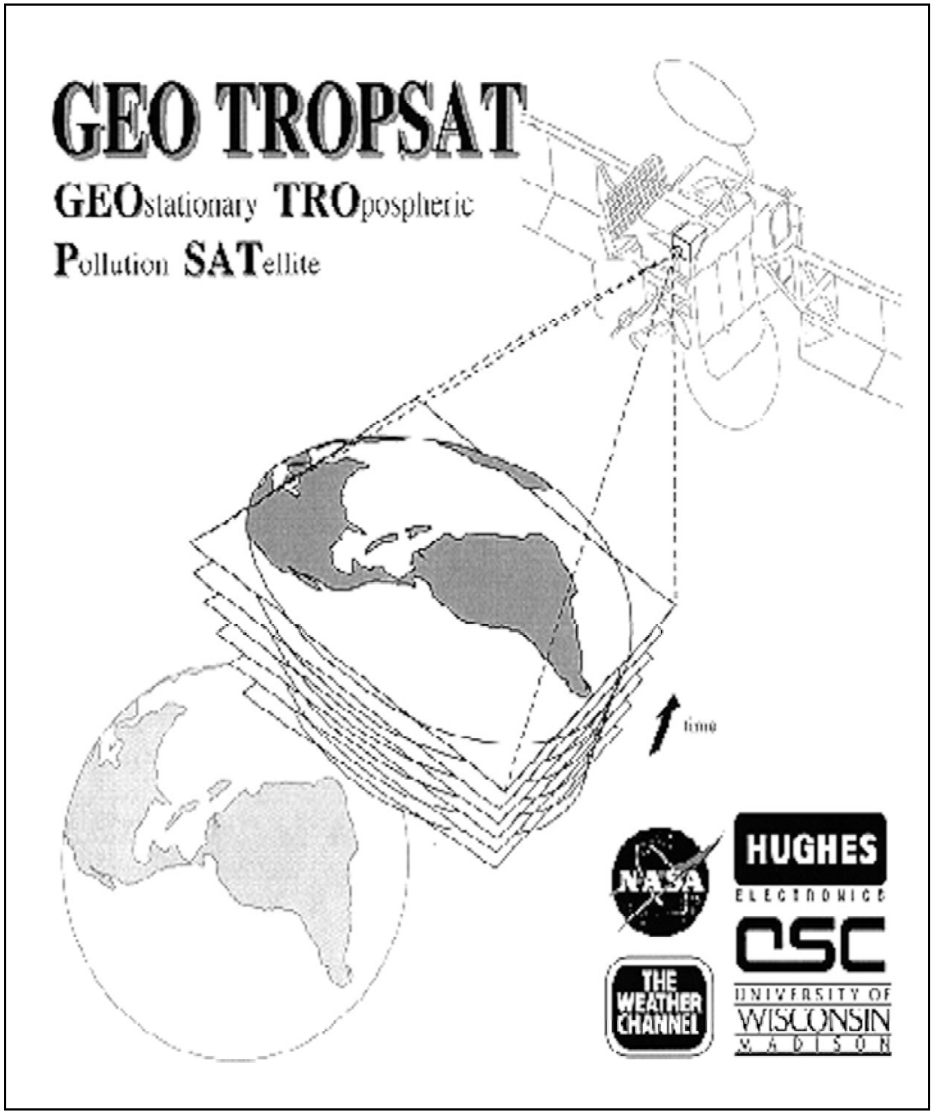
- Employ the same robust trace gas measurement techniques presently used in low Earth orbit to deliver unprecedented time-of-day resolved chemical weather.

- Simultaneous measurements of O3, aerosols, CO, NO2, SO2, and HCHO for documenting and interpreting the profound variability of tropospheric chemistry.

- GeoTRACE's time-of-day distribution of principal constituents remains the missing piece of the integrated observing strategy for tropospheric chemistry, highlighted by the international Integrated Global Atmospheric Chemistry Observations Theme Report on Atmospheric Chemistry as <u>#1 objective</u> for the decade (2004).

- The model of international sharing of geostationary weather data provides the framework for global coverage of chemical weather.

GEO TROPSAT (1996) proposed to ESSP-1 rated “outstanding science” and invited to submit a Step 2 proposal.



GEO TROPSAT

GEOstationary TROpospheric Pollution SATellite

NASA

HUGHES ELECTRONICS

OSC

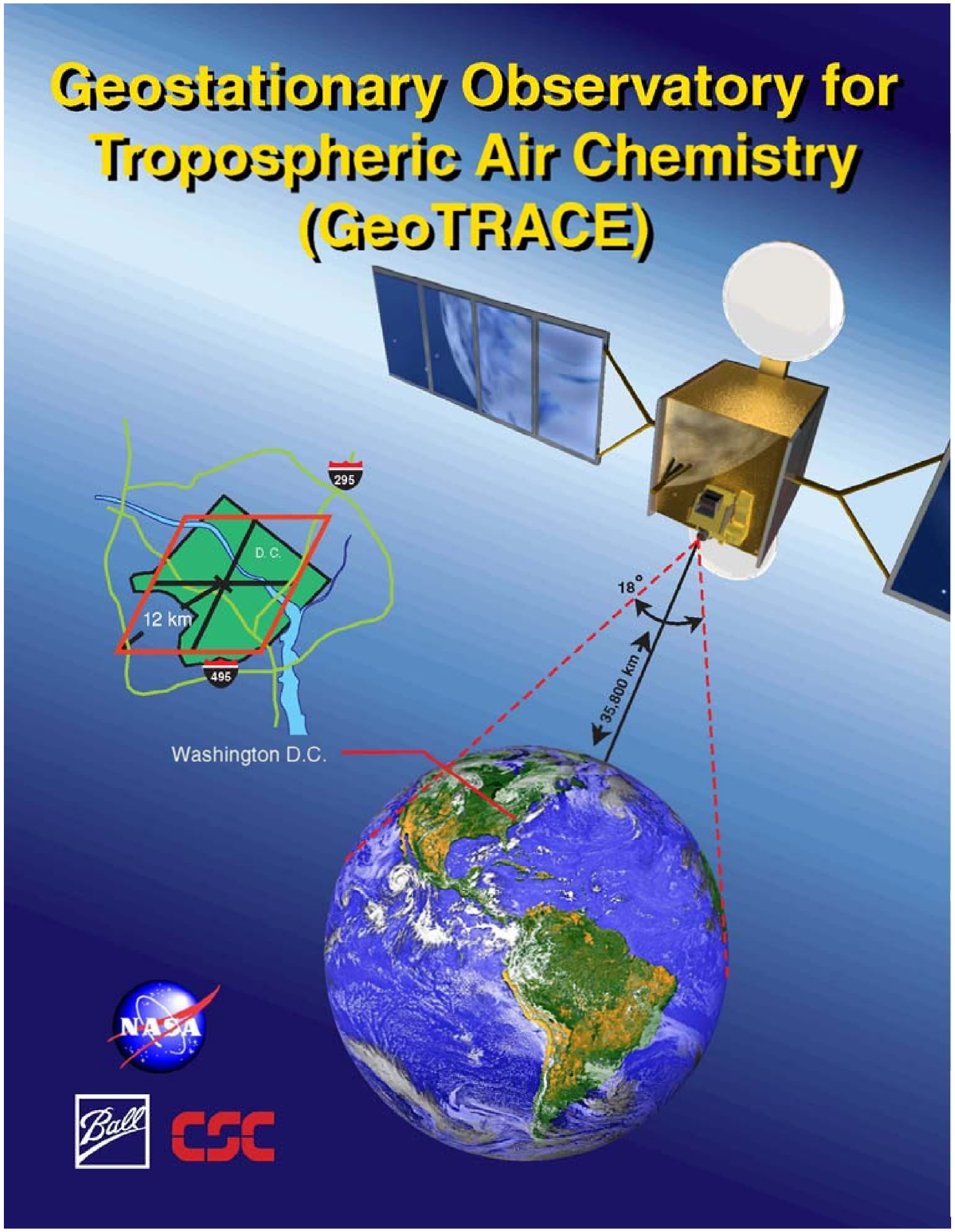
THE WEATHER CHANNEL

UNIVERSITY OF WISCONSIN MADISON

Remote sensing from geostationary orbit: GEO TROPSAT, a new concept for atmospheric remote sensing. Alan D. Little, Doreen O. Neil, Glen W. Sachse, Jack Fishman, and Arlin J. Krueger, Proc. SPIE 3221, 480 (**1997**), DOI:10.1117/12.298116

NASA CDTM - 10012
Pre-Phase A Study Report for the Geostationary Tropospheric Pollution Satellite (GEO TROPSAT) Mission.
A. D. Little, D. O. Neil, Editors

GeoTRACE (1999) proposed to NMP-EO1, rated “outstanding” in all evaluation criteria.

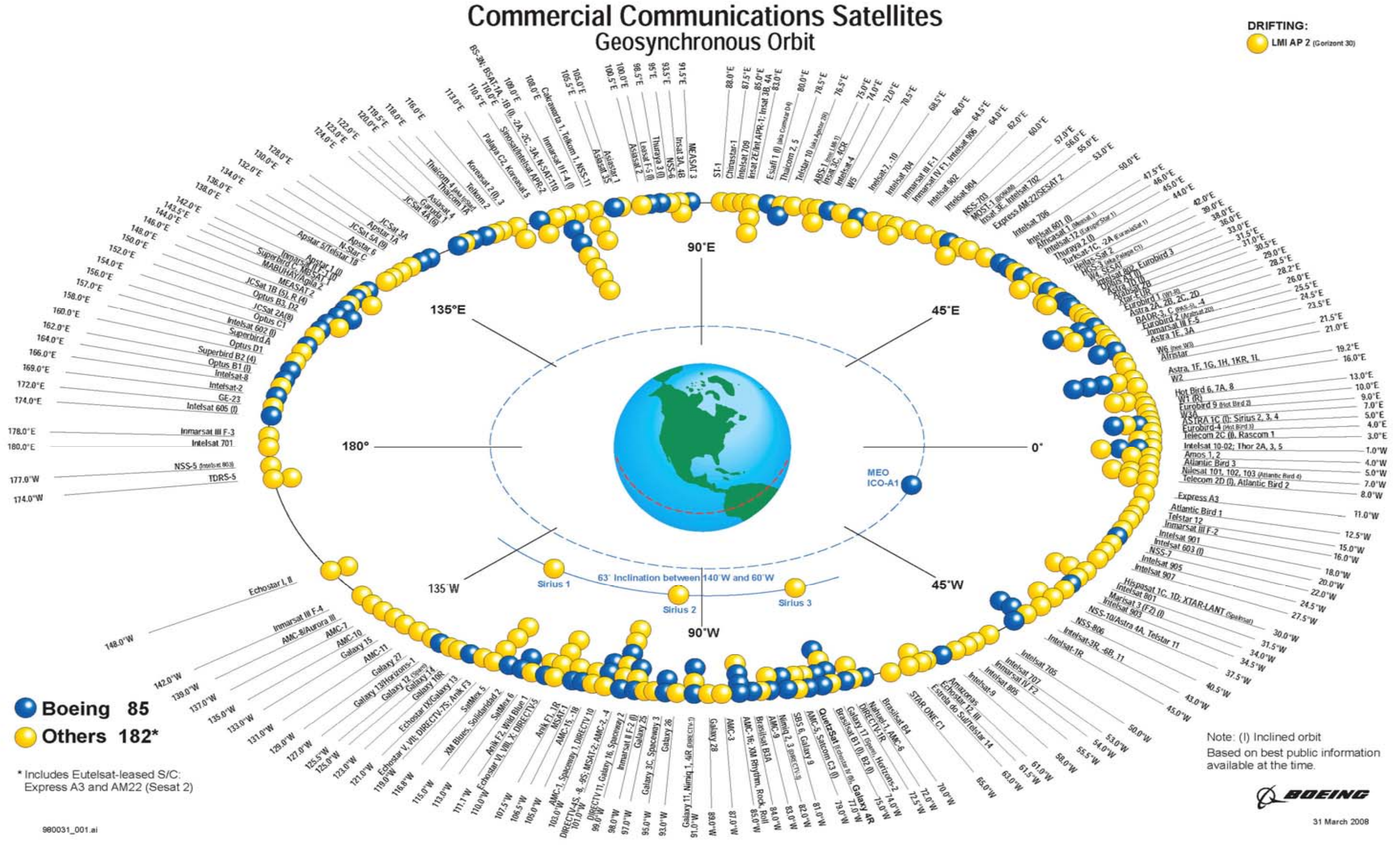


Commitment letters to the project from Hughes, Pan Am Sat, Space Systems Loral, and Lockheed Martin to fly GeoTRACE on commercial communications satellites.

Commitment letter from Hughes to fly GeoTRACE on (government-owned) TDRS-J ($39-43M)

Note:
TDRS-J Soars into Night Sky
December 4, 2002

Neil Jan 2005



Notes: Each commercial vendor has a similar diagram highlighting their brand. Key points for NASA are that the regulated slots in GEO are limited, of high value to industry . Over active markets, satellites are replaced more frequently than their design life to add new capability, providing additional opportunities for access to space.

GeoTRACE has science goals similar to the atmospheric portion of GEO-CAPE

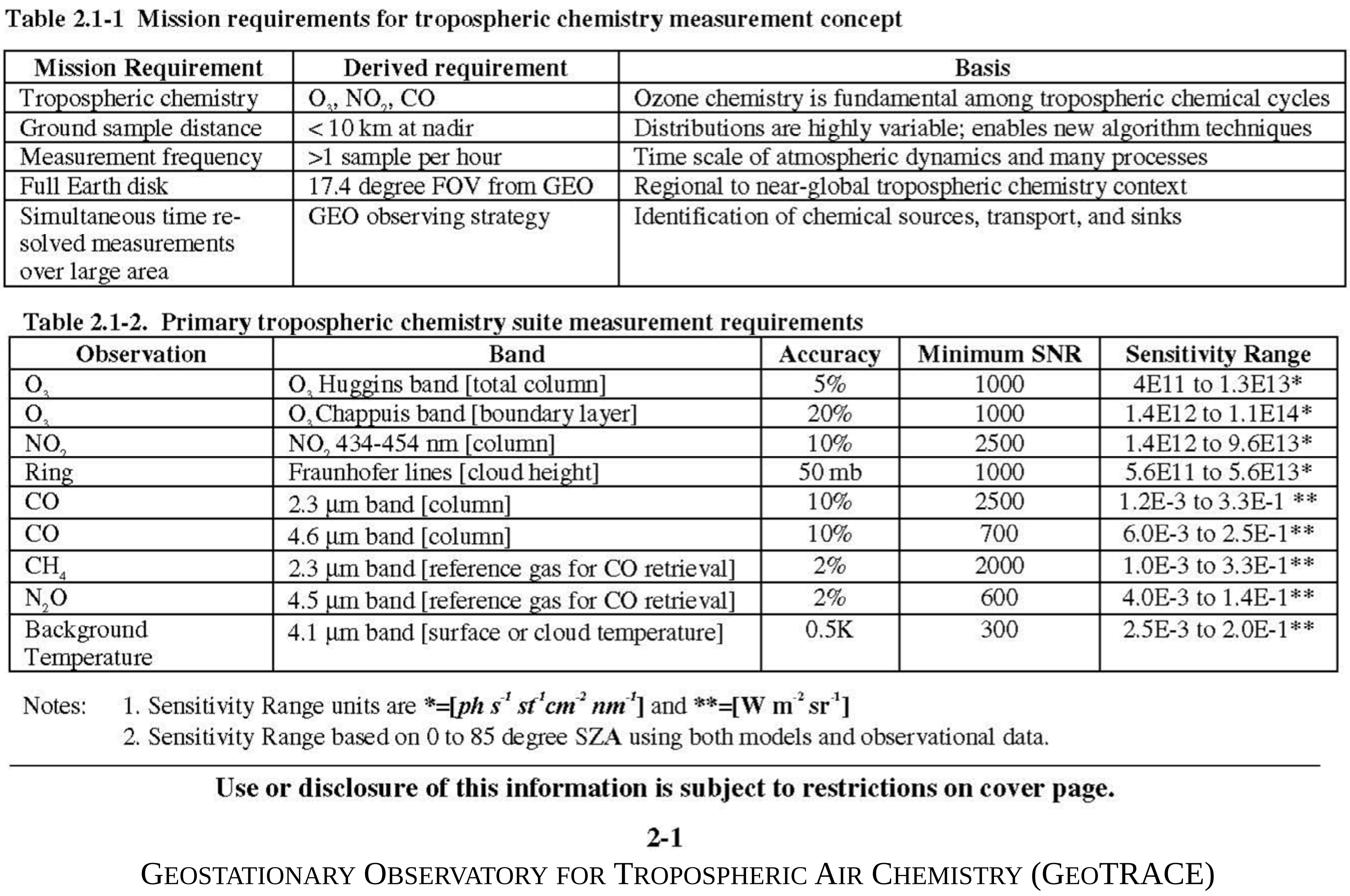


Table 2.1-1 Mission requirements for tropospheric chemistry measurement concept

Mission Requirement	Derived requirement	Basis
Tropospheric chemistry	O_3, NO_2, CO	Ozone chemistry is fundamental among tropospheric chemical cycles
Ground sample distance	< 10 km at nadir	Distributions are highly variable; enables new algorithm techniques
Measurement frequency	>1 sample per hour	Time scale of atmospheric dynamics and many processes
Full Earth disk	17.4 degree FOV from GEO	Regional to near-global tropospheric chemistry context
Simultaneous time resolved measurements over large area	GEO observing strategy	Identification of chemical sources, transport, and sinks

Table 2.1-2. Primary tropospheric chemistry suite measurement requirements

Observation	Band	Accuracy	Minimum SNR	Sensitivity Range
O_3	O_3 Huggins band [total column]	5%	1000	4E11 to 1.3E13*
O_3	O_3 Chappuis band [boundary layer]	20%	1000	1.4E12 to 1.1E14*
NO_2	NO_2 434-454 nm [column]	10%	2500	1.4E12 to 9.6E13*
Ring	Fraunhofer lines [cloud height]	50 mb	1000	5.6E11 to 5.6E13*
CO	2.3 μm band [column]	10%	2500	1.2E-3 to 3.3E-1 **
CO	4.6 μm band [column]	10%	700	6.0E-3 to 2.5E-1**
CH_4	2.3 μm band [reference gas for CO retrieval]	2%	2000	1.0E-3 to 3.3E-1**
N_2O	4.5 μm band [reference gas for CO retrieval]	2%	600	4.0E-3 to 1.4E-1**
Background Temperature	4.1 μm band [surface or cloud temperature]	0.5K	300	2.5E-3 to 2.0E-1**

Notes: 1. Sensitivity Range units are *=[$ph\ s^{-1}\ sr^{-1} cm^{-2}\ nm^{-1}$] and **=[$W\ m^{-2}\ sr^{-1}$]
2. Sensitivity Range based on 0 to 85 degree SZA using both models and observational data.

Use or disclosure of this information is subject to restrictions on cover page.

NMP GeoTRACE featured mature instrument concepts, operating scenario, access to space

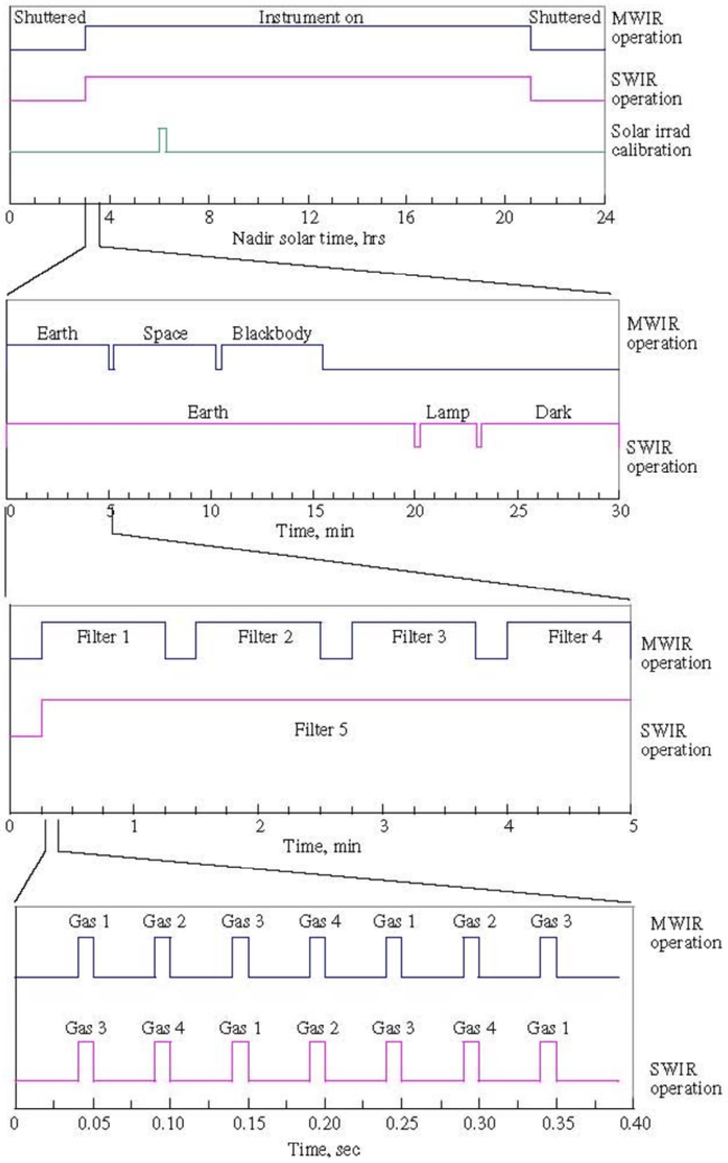
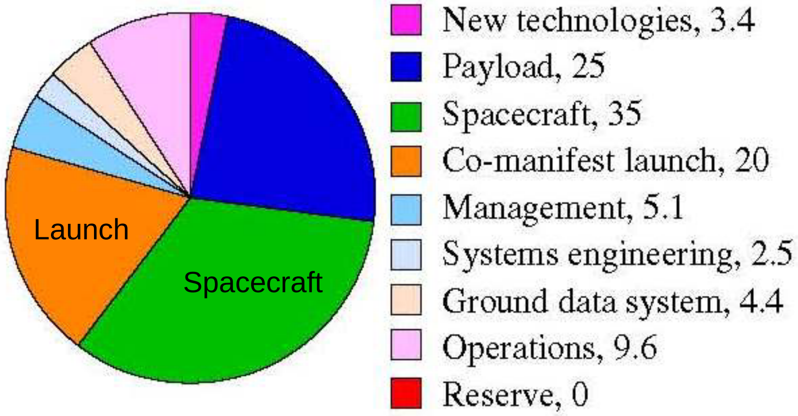


Figure 3.1-4. (IR) Instrument Timeline provides the level of functional detail necessary to set operational concepts, and specify data rates and mission systems (ie, pointing).

(a) Allocation of Costs with dedicated spacecraft



(b) Allocation of Costs with Hosted Payload Access to Space

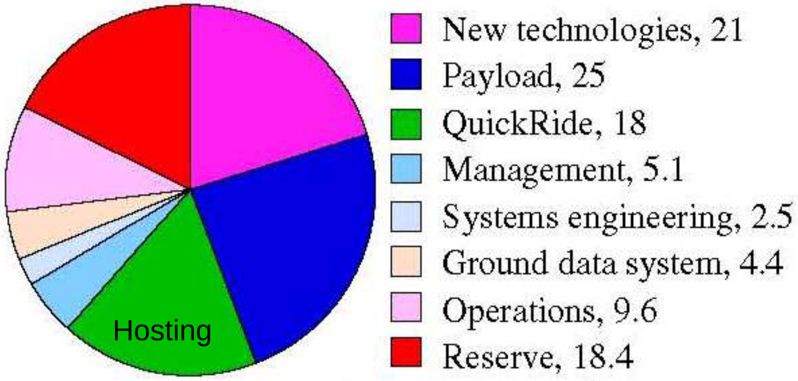


Figure 3.3-1. Cost allocations (in M$) show that hosting provides more new technology validation than dedicated spacecraft implementations.

GeoTRACE cost escalations and fidelity

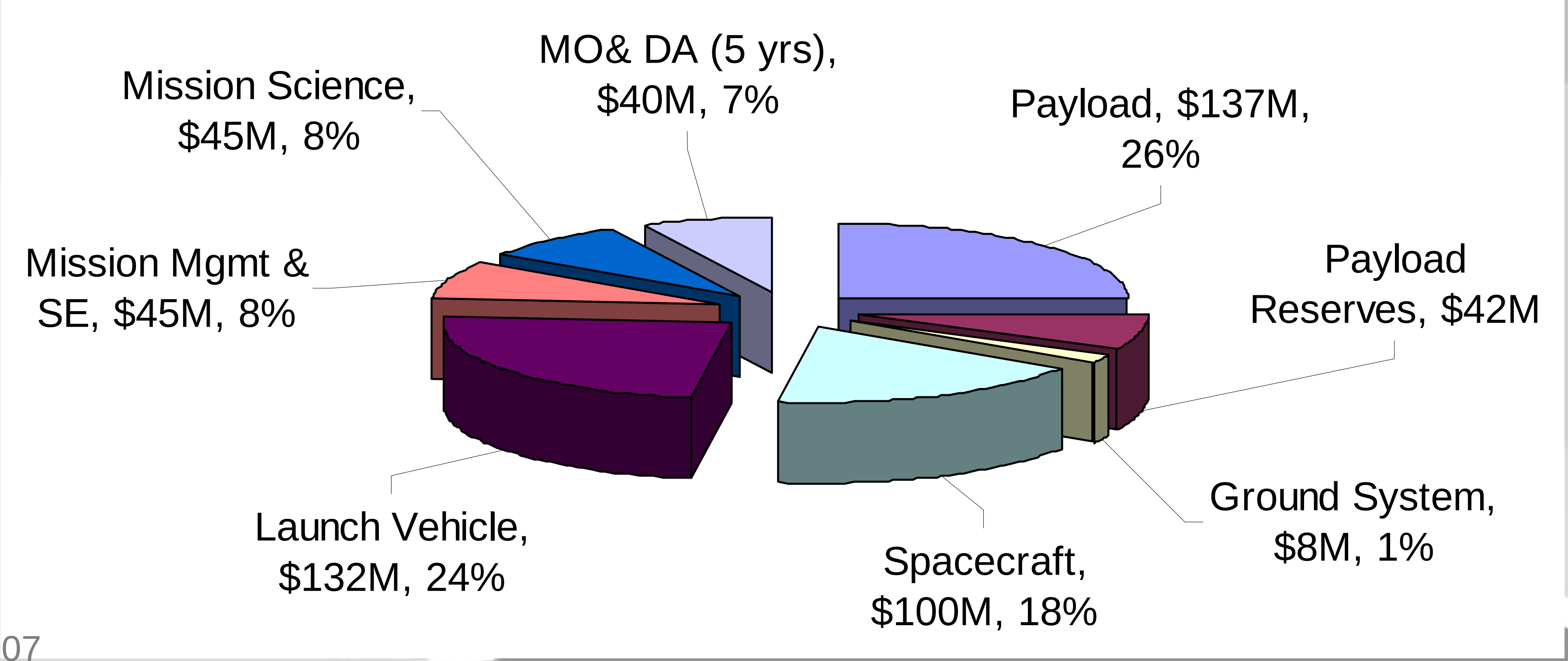
Solicitation	**Year**	**Cost (Millions)**	**Escalated Cost (Millions) for 2008 Start** [2]	**Comments:** See Note 1
ESSP-1	1996	$90	$116	First design study on instruments-basic Step-1 proposal of 12 pages
NMP-3	1999	$120	$148	Detailed industry partner work on instruments; Step-2 effort funded, full program development; Center management signoff; SAIC (independent) and RAO (GSFC) cost comparisons.
ESSP-3	2001	$140	$161	Step 1 effort. Escalated NMP-3 numbers; also brought in RAO (GSFC) estimates.

Note 1: None of the above include the “full cost” for a dedicated s/c and launch. Each mission allocated costs to accommodate non-recurring engineering changes, plus operating and bandwidth lease costs to the owner/operator.

Note 2: Escalation is from NASA New Start Inflation calculator at NASA Cost Estimation web site. http://cost.jsc.nasa.gov/bu2/inflation/nasa/inflateNASA.html

Science from GEO is highly affordable.

- The Decadal Survey estimated GEO-CAPE would cost $550M.
- Forty two percent of this cost is spent on the launch (24%) and spacecraft (18%).
- Hosted payload spacecraft and launch costs could be
  reduced by an order of magnitude. ($232 M to $23 M or less).
- If similar savings were obtained for GEO-CAPE, the hosted payload solution
  saves nearly half of the total mission cost.



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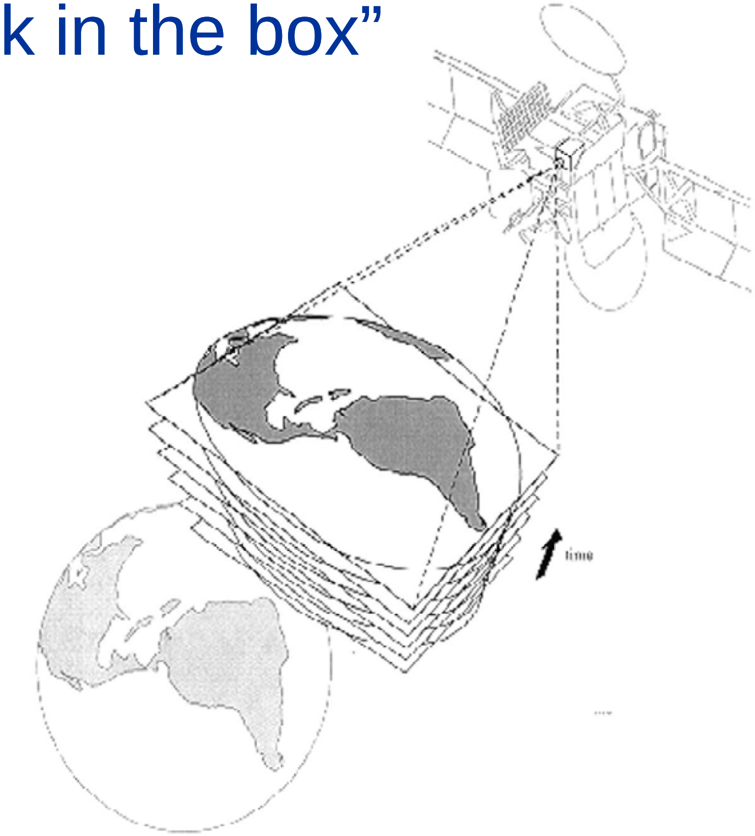
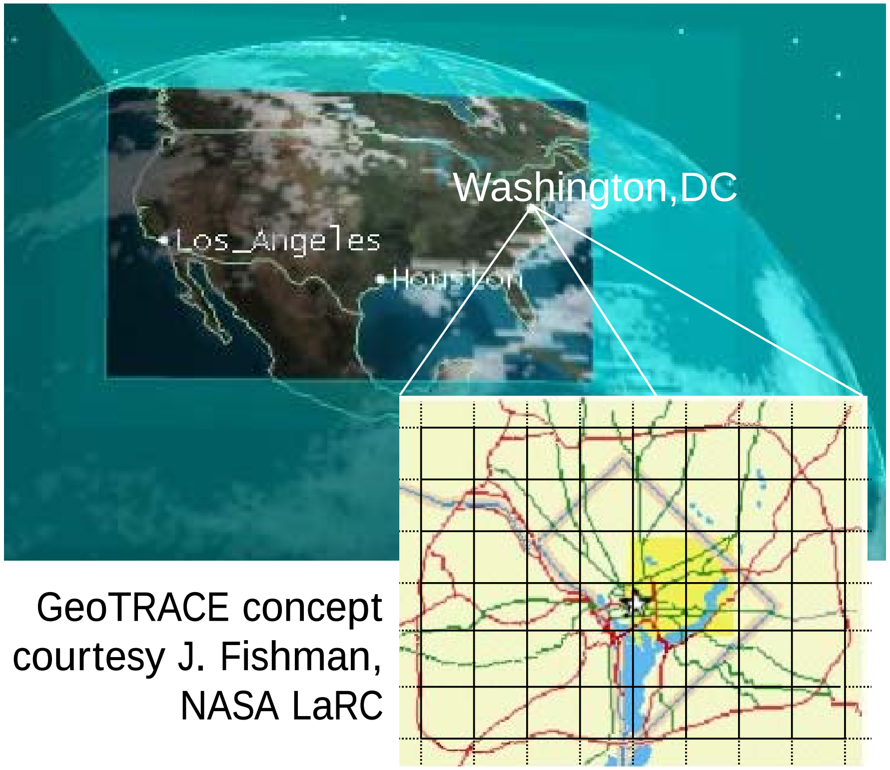
NMP GeoTRACE observing strategy
“disk in the box” simplifies pointing requirements, shrinks instrument size, reduces risk

NMP GeoTRACE
“disk in the box”



ESSP- 3 GeoTRACE
“box on the disk”



GeoTRACE concept courtesy J. Fishman, NASA LaRC

Washington DC: 48 pixels within the I-95 beltway

<u>All</u> GeoTRACEs are hosted payloads.

Neil 2008

NASA Precision Pointing State of Practice

NASA spacecraft precision pointing capability

Instrument	Footprint km	Spacecraft	Orbit, km	Footprint in µrad	**pointing accuracy, µrad**	**pointing stability (jitter)**
NASA Hubble	**(space)**	**Hubble**	**600**	**--**	**0.04**	**0.028 µrad/ 24 hours**
GEOCAPE color	**0.25 x 0.25**	**--**	**35786**	**7**	**1.75**	**0.07 µrad/ 80 sec**
NASA Chandra	**(space)**	**Chandra**	Highly eccentric (10,000 – 140 000 km)	**--**	**145**	**1.2 µrad/ 10 sec**
GEOCAPE Chem	**7.3 x 7.3**	**--**	**35786**	**205**	**38**	**50 µrad/ 2 sec**
GOES-R	**4 x 4 (sounder)**	**Commercial**	**35786**	**112**	**21**	**83 µrad/ 2 sec**

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Earth Observation Pointing State of Practice

NASA atmospheric chemistry and ocean color pointing capabilities

Instrument	Footprint km	Spacecraft (s/c)	Orbit, km	Footprint in µrad	pointing accuracy µrad	pointing knowledge µrad	pointing stability
MOPITT (chem)	22 x 22	**Terra**	705	31196	727 **s/c + instr 3 axis, 3 σ**	436	1040 µrad/ 1 sec
OMI (chem)	24 x 13	**Aura**	705	34029	4198 **s/c + instr 3 axis, 3 σ**	421	402 µrad/ 6 sec
GLI (color)	1 x 1	**ADEOS2**	803	1245	2909 **s/c + instr 2 axis, 3 σ**	388	11 µrad / 1 sec
CALIPSO	0.1 x 0.1	**Proteus**	705	142	1396 **s/c + instr 3 axis, 3 σ**	1047	5.2 µrad / 4.7 msec
GEOCAPE Chem	7.5 x 7.5	--	35786	205	37 1 σ	--	50 µrad / 2 sec
GEOCAPE color	0.25 x 0.25	--	35786	7	2 1 σ	--	0.07 µrad / 80 sec

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Government Payloads in orbit on Commercial Spacecraft

Hosted Payload Examples	Year Flown	Payload Type	Estimated Integration Complexity	Arrangement Type	Sponsor	Operator	Mfr	Spacecraft
Marisat	1976	Comms	Dedicated		DoD	Intelsat & Comsat		Marisat-F2
Fleetsat	1970s	Comms	High	2 year + options	Navy	Comsat		
Ku- band demonstrator	1980s	Comms demo	Moderate	2 yrs Gov't then commercial	Canadian Gov't	Telesat		Anik B
LEASAT	1990	Comms	Dedicated	7-year lease then commercial	DoD & Australian Defence	Intelsat & Hughes	Hughes?	LEASAT 5
WAAS	1996	Navigation	Mod-High	10-yr Lease	FAA	Inmarsat		POR
WAAS	1997	Navigation	Mod-High	10-yr Lease	FAA	Inmarsat		AOR-W
X-ray Imager on solar array yoke	2000	Imager	Low			NOAA	SS/L	GOES 11/L
X-ray Imager on solar array yoke	2001	Imager	Low	Interagency	NASA/MSFC	NOAA	SS/L	GOES 12/M
Ka-band demonstrator	2002	Comms demo	Low-Moderate	FFP Demo	U.S. DTH & Can. Gov't	Telesat	Lockheed	Nimiq-2
UHF Payload	2003	Comms			Australian Defence	Singtel Optus	SS/L, Mits-ubishi	Optus-C1
Cell Saver Demonstration	2004	Demo	Low			Loral Skynet	SS/L	Telstar-14
Thermal Coating Experiment	2004	Demo	Low			Loral Skynet	SS/L	Telstar-14
Radiation Dosimeter	2004	Sensor	Low			Loral Skynet	SS/L	Telstar-14
Onboard processor for Ka-band	2004	Demo	High	FFP Demo	CSA	Telesat	Boeing	Anik F2
Navigation, Communication & Meteorological imager on same platform	2005	Imager, Navigation, Comms	High	Interagency	Japanese Gov't	Japanese Gov't	SS/L	MTSAT -1 / -1R
WAAS/GCCS	2005	Navigation	Moderate	FFP + 10yr lease	FAA	Telesat	EADS Astrium	Anik F1R
WAAS/GCCS	2005	Navigation	Moderate	FFP + 10yr lease	FAA	Intelsat	Orbital	Galaxy 15
Military relay terminals	2006	Comms	High	Civil-Military shared	South Korea	South Korea?		
AIS Demo	2008	Receiver demo	Moderate	Funded demo S/C & optional operations	Coast Guard	Orbcomm	Orb.Sci./ Polyot /OHB	Orbcomm CDS-3
AIS Operational	2008	Receiver	Moderate	Self-funded for commercial service	Orbcomm	Orbcomm	Orb.Sci./ Polyot /OHB	6 Orbcomm spacecraft
CCD Camera	2008	Camera	Low	Self-funded	EchoStar	EchoStar		EchoStar 11
CCD Cameras	Various	Camera	Low	Various	Multiple	Multiple	Multiple	Multiple
IRIS - Internet Router in Space	Sched: 2H2009	Router	High	JCTD	Stratcom	Intelsat	SS/L	Intelsat 14
CHIRP Payload	Sched: 2H2009	Imager	Moderate	3-yr Firm Fixed Price	USAF SMC	SES	Orbital Sciences	
UHF Payload	TBD	Comms		Out for bid	DoD	TBD		

No NASA payloads

GeoTRACE and Hosted Payload Proposal Experience

- Hosted payloads are less scary to NASA now than in 1996 when we first proposed.
- Hosted access to space is suitable for mission operating concepts which are systematic and low impact to the host. → Must define the planned concept of operations.
- Hosted payloads engage industry for appropriate cost effective services. → Lease of broadcast services is the business model.
- Hosted payloads implemented in a commercial manner would provide more resources for science and support continuity of data.

Neil 2009