Earth Observation Telescope at L2 Final Report

Science and Instrumentation

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Science Objectives

- Monitor changes in the Forcing and Response of the Earth's Atmosphere
- Understand the mechanisms of change and quantify the attribution of change be it of chemical or dynamical origin
- Improve the short and long term predictive capability of weather and climate models through the use of near real time measurements and an improved understanding of the dynamical, chemical, radiative Feedbacks and Responses of the Climate System

Monitor Changes

- Monitor changes in Chemical Composition and Dynamics of the Earth’s Atmosphere
- Problem: While changes in the global distribution of radiatively important species are being measured, dynamical changes are not.
- Requirements: Measure distribution of O3, CO2, H2O, & aerosols. Derive age of air. Infer dynamics near the tropopause using tracer-tracer relationships.

Understand Mechanisms

- Understand the mechanisms of change and quantify the attribution of change
- Problem: Lack of suitable data limits the ability to separate direct chemical (forcing) from dynamically driven (feedback) change
- Requirements: Fine scale observations and trending of trace species (CLx, NOx, ...) as well as dynamical drivers over a solar cycle.

Improve Predictions

- Improve the short and long term predictive capability of weather and climate models
- Problem: Some physical processes are still unknown and others are poorly quantified or lack suitable density (timeliness) of data.
- Requirements: Provide high spatial density of data promptly for short-term forecasting. Monitor trends in forcing for climate change. Incorporate new mechanisms into models.

Measurement Objectives

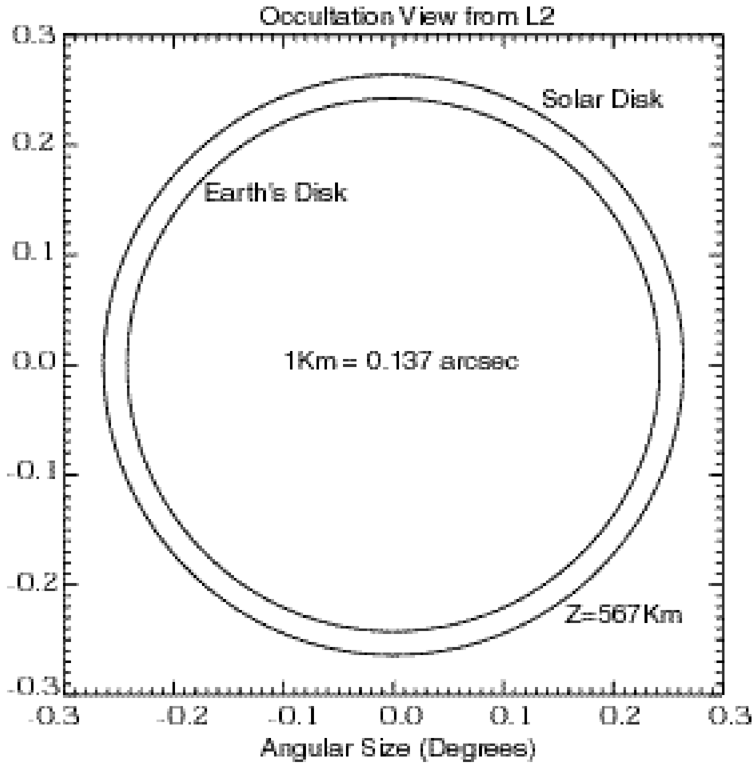
- Global maps of the vertical distribution of O_3, CO_2, CH_4, H_2O, N_2O, key members of the NO_x & CL_x, Upper tropospheric and stratospheric clouds, Sulfate aerosol mass, temperature, and pressure with at least 1 degree spatial sampling and 1 km vertical sampling near the tropopause, twice/day
- Use long lived species to monitor the global circulation (mean meridional and planetary wave dynamics) at a lower vertical resolution in mid- to upper-stratosphere
- Observe changes in the tropopause region and strat-trop exchange processes
- Provide near real time input of H_2O, O_3, Thin Cloud/Aerosol, T, & P to Data Assimilation models

Measurement Approach

- Use the solar occultation technique for trend-quality measurements on decadal time scales.
- Locate observatory near the Earth-Moon L2 Lagrange point to obtain continuous coverage with high spatial resolution/sampling.
- Nearly continuous spectral coverage from 0.38 to 10.0 microns (µm) from at least 3 instruments.
- Utilize the dense sampling with tomographic or stereographic techniques to improve horizontal resolution.

Why Occultation from L2?

- Solar Occultation is best Suited for Long-Term Climate Change Studies
- In terms of sampling, L2 is the optimal place to deploy solar occultation instruments.
- Provides high vertical and spatial resolution maps twice per day.
- Sun is a hot, bright source and the optics will be at very low temperatures: an optimal situation for IR measurements



From L2 the Sun is slightly larger than the Earth and places the annular ring of the Earth’s atmosphere into permanent occultation. Spatial sampling is limited primarily by the speed of the instruments and the down-link bandwidth.

Observation Strategy/Orbit

- Remain close (within 200km) to the Earth-Sun axis for 24/7 100% duty cycle.
- Scan around the annular ring of the Earth's atmosphere at least 360 times per day for ~1° "longitudinal" sampling
- Sample each rotation at least 360 times to provide ~1° "latitudinal" sampling
- Refraction will limit the lowest altitude to ~8km
- Co-align all instruments and synchronize operation to provide sampling of the same air mass over all wavelengths (0.38 to 10 microns)

Improvements over Current Practice

- Spatial resolution can approach 0.1 degrees (10x improvement over Aura) through a combination of increased instrument sampling and algorithmic techniques (tomography).
- Trend-Quality observations of the dynamical response of the middle atmosphere (10-70km) to climate change.
- Similar capability would require multiple spacecraft in low Earth orbit.
- Near Real-Time production of final products for time-critical consumption (forecast models)

Science Comparison

Item	LEO*	GSFC-L2	RASC-L2
Science Objectives	Broad Range	Age of Air Low Res Dynamics	Climate Forcing Climate Response Forecast Model Input Lowest Strat Dynamics Upper Trop Composition Age of Air Strat-Trop Exchange
Vertical Resolution	0.5 to 2.0 km	2 to 4 km	1 km
Vertical Range	2 to 100 km	8 to 30 km	8 to 100 km
Altitude Knowledge	50 to 200 m	1000 m	100 m
Latitude Sampling	1 to 5 deg	> 0.5 deg	0.25 to 1 deg
Longitude Sampling	1 to 24 deg	< 15 deg (sparse)	0.25 to 1 deg
Global Maps	0 to 2 per Day	0 to 2 per Day	2 per Day
Continuous Mapping	Yes	No	Yes
Profiles per Day	30 to 200,000	est < 15,000	160,000 to 2,000,000
Duty Cycle (monthly Avg)	6 to 100%	est ~20% ??	100%

*** LEO instruments include HiRDLS, HALOE, MLS, SAGE, ACE-FTS**

Science Comparison (cont)

Item	LEO*	GSFC-L2	RASC-L2
Spectral Range	0.2 to 500 μm	1 to 4 μm	0.38 to 10 μm
Measurement SNR	500 - 2000	500	4000
O_3, H_2O, CO_2, CH_4, N_2O, O_2	Yes	Yes	Yes
NO_x, ClO_x, HO_x	Yes	No	Yes
NO_x, ClO_x, HO_x Sources / Reservoirs	Yes	No	Yes
Temperature & Pressure	Yes	Yes	Yes
Aerosols	Yes	No	Yes
Sulfate/Water/Ice/NAT/…	Yes	No	Yes
Needs	Multiple Platforms, Instruments, & Techniques	Increased Sampling Larger Aperture	Technology Advance

*** LEO instruments include HiRDLS, HALOE, MLS, SAGE, ACE-FTS**

Design Drivers

- Spectral coverage from 0.38 to 10µm:
  - Employ at least three instruments covering the Visible, NIR, & Mid-IR
- Radiometric performance to support sampling
  - 0.5 seconds per profile measurement
  - 25 meter diameter filled aperture
- Pointing knowledge:
  - Coarse Pointing derived from Sun & Earth limb
  - Fine pointing derived from profiles of O_2
- Stringent Jitter control – No Moving Parts:
  - Spectrometers must image the annulus radially
  - Passive cooling

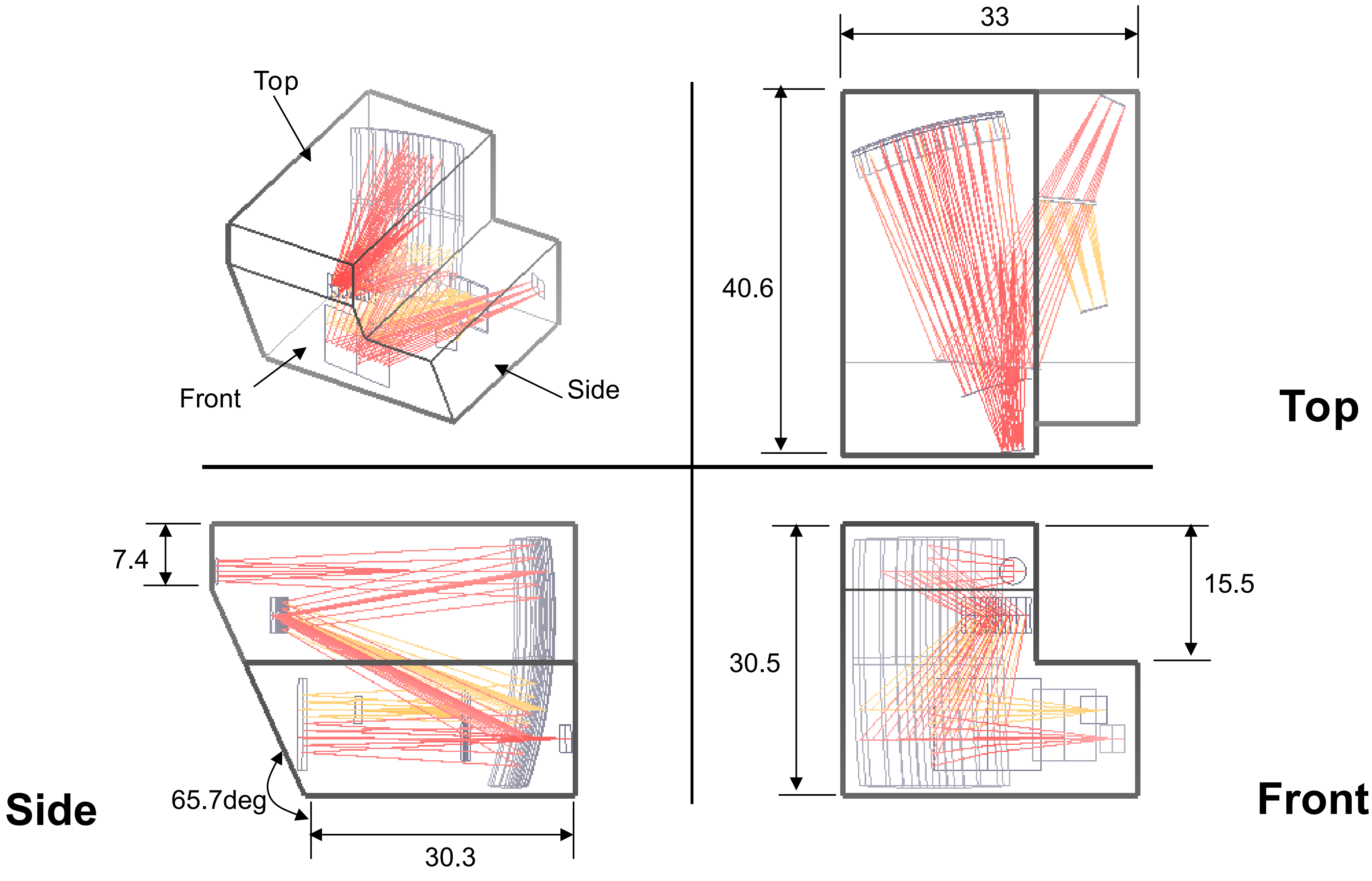
Design Drivers (cont)

- Mass and Power constraints:
  - Compact designs that share optics
  - Passive thermal control
  - Innovative design for Mid-IR instrument
- High bandwidth and continuous operation:
  - Optical link to LEO relay?
- Low latency end-to-end data system:
  - Straight-pipe data system & minimal buffering
  - Verified Real-Time algorithms prior to launch

Visible Spectrometer Concept

- Imaging spectrometer based on the Offner design covering 380 to 980nm.
- Dual 512 x 512 element Active Pixel Sensor arrays operating up to 100Hz.
- 0.6 nm spectral sampling
- Each 60 um square pixel maps to a 1 km square footprint at the Earth’s limb.
- 16-bit ADC operating at up to 26MHz.
- 8.4 Mbps minimum continuous data rate

Visible Spectrometer



NOTE: All dimensions in cementers

NIR Spectrometer Concept

- Imaging spectrometer based on the Offner design covering 980 to 2480nm.
- Dual 512 x 512 element Active Pixel Sensor arrays operating up to 100Hz.
- 1.5 nm spectral sampling
- Each 60 um square pixel maps to a 1 km square footprint at the Earth’s limb.
- 16-bit ADC operating at up to 26MHz.
- 8.4 Mbps minimum continuous data rate

Mid-IR Concepts

- A broad-band spectrometer covering 2.5 to 10 μm for major absorbers and narrow-band high resolution Imaging FTS (DASI derivative) for minor trace species.
- MEMS cantilever bolometer and/or multi-color array detectors
- Passive cooling
- Real-time processing of IFTS data in FPGA
- Allocated 8.4 Mbps data rate

Theoretical Concerns

- Forward Scattering vs. Direct Solar: Is Limb Scattering a significant interference or a scientific plus for determining particle phase & composition?
- What are the effects of small scale waves on altitude registration and vertical resolution
- Development and validation of algorithms for simple retrievals and tomography prior to launch
- High spatial variability within solar Fraunhofer lines and their impact on species and aerosol retrievals

System Trades

- Sparse vs. filled aperture as it impacts sampling
  - Filled aperture required to meet 1° spatial sampling
- Active “orbit” control vs. Halo orbit
  - Active control provides 24/7 operation with twice daily maps
- Mass & Power constraints favor fewer/smaller instruments
  - Technology development of Multi-color detectors & instrument designs that employ them would reduce mass by at least 2x
- On-Board processing vs. High Bandwidth Down-link
  - Science community favors retention of Raw Level-0 data
  - No clear winner in terms of power consumption

Trades and Alternatives

- Gas Filter Correlation vs. Broadband Radiometer vs. Imaging FTS for the Mid-IR
  - Lifetime & mass issues of GFCR
  - Sensitivity and selectivity of broadband devices
  - Development of a fast Imaging FTS
- Question remains open as to whether an L2 mission can be more cost effective than a few LEOs
  - Are SABRE, MLS, DIAL, or HRDLS –type approaches capable of trend quality measurements?

Technology Roadmaps

- Fundamental Limitations and Algorithm Issues
  - Study atmospheric waves and their impact on vertical resolution
  - Study impact/interference from Limb-Scattered solar light
  - Assess the impact of spectral variability from fine scale spatial structures on the solar disk on retrieval accuracy
  - Development of tomographic techniques
- Detector Focal Planes
  - Large format (512x512 with 60µm pixels)
  - Fast 100Hz readout with 14-bit SNR
  - Improved performance in the 3 - 10µm spectral region
  - Multi-color detector arrays
- Instruments
  - Develop a high speed narrow-band imaging FTS
  - Real-time processing of FTS data in FPGAs

Detector Roadmap

Large Pixel APS

IR APS / MEMS Cantilever

Space Qualified ADC Development

Multi-Color detector arrays

Pixel Size (µm) 12 25 60

SNR @ 100Hz 1000 2000 4000

16-bit rate (MS 0.1 1 10 30+

Multi-Color Unilayer 3+ Layers out to 10µm

2003 2005 2007 2010 2020 2030

Recommendations

- Study the impact of atmospheric waves on refraction/vertical- resolution
- Study the impact of limb-scattered light
- Technologies to invest in:
  - Large pixel/format APS for Vis & NIR
  - APS-like Passively cooled arrays for the Mid-IR
  - 30+ MSps Space Qualified 16-bit ADC
  - Develop fast IFTS instrument for Mid-IR
- LEO mission to acquire data to develop algorithms and demonstrate L2-like tomographic capability