Summer School Alpbach 2010

Team Red

Mission Design

Atmospheric water Vapor from Active Limb sounding Observation Network

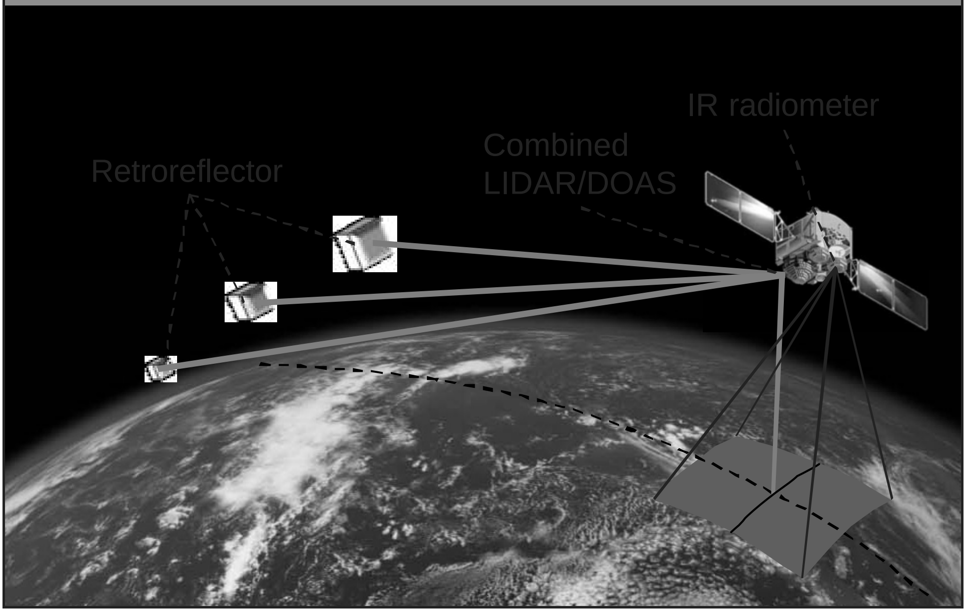
Main objective

Measurements of water vapor and aerosols in the Upper Troposphere / Lower Stratosphere (UTLS)

for a better understanding of

- Direct radiative forcing from water vapor and aerosols
- Indirect radiative forcing from aerosols through the formation of cirrus clouds and contrails
- Troposphere-stratosphere exchange mechanisms

Mission concept



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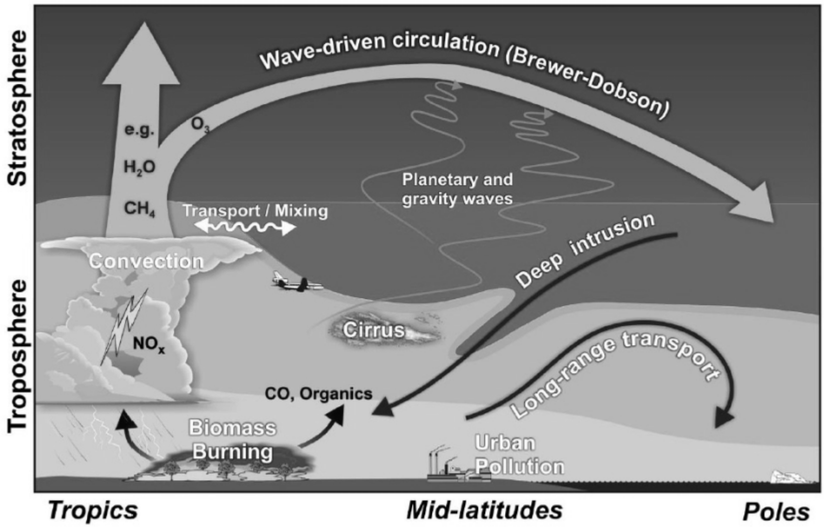
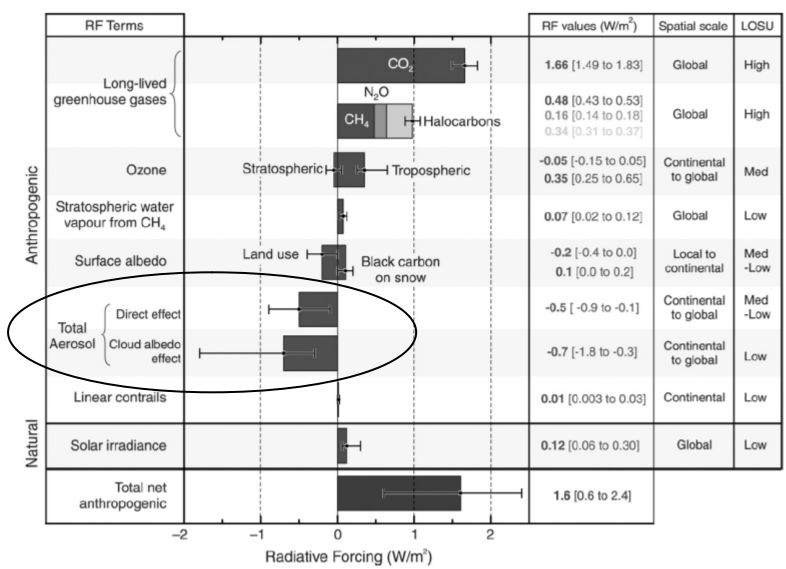
Scientific case

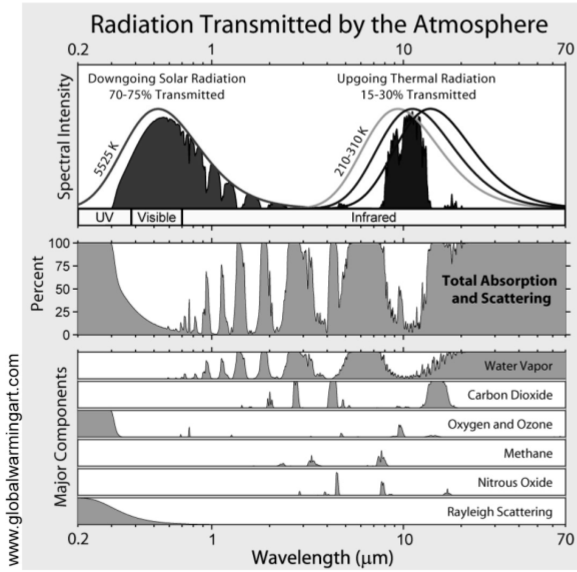
Processes in the UTLS



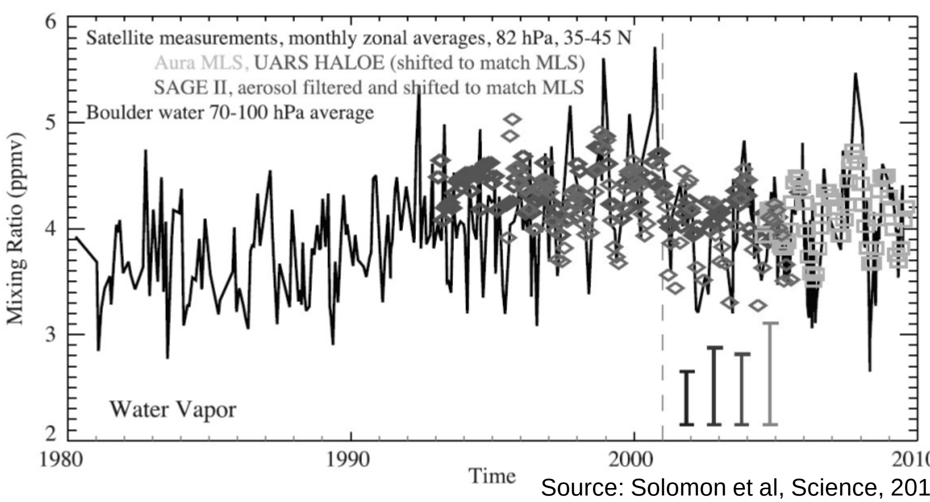
Radiative forcings (IPCC, 2007)



Absorption spectra



Boulder balloon soundings



Source: Solomon et al, Science, 2010

→ The increase of H_2O in the lower stratosphere in the 1990's contributed to about 30% of the observed global warming

Existing H_2O measurements

Technique	Main advantages	Main limitations
Balloon soundings	Vertical resolution	Spatial coverage
Ground-based LIDAR	Vertical resolution	Upper limit at 7-10 km
Ground-based Microwave	Vertical coverage	Vertical resolution
Aircrafts	Use of existing network	No vertical resolution
Space-b. Microwave Limb	Vertical coverage	UTLS
Space-b. IR Limb	Vertical coverage	UTLS
Space-b. IR Nadir	Horizontal resolution	Vertical resolution
Space-b. Stellar Occult.	Vertical resolution	Lower atmosphere

Existing aerosol measurements

Technique	Main advantages	Main limitations
Balloon soundings	Vertical resolution	Spatial coverage
Ground-based LIDAR	Vertical resolution	Spatial coverage
Aircrafts	Use of existing network	No vertical resolution
Space-b. LIDAR Nadir	Spatial resolution	Thick clouds
Space-b. Stellar Occult.	Vertical resolution	Lower atmosphere

Scientific requirements

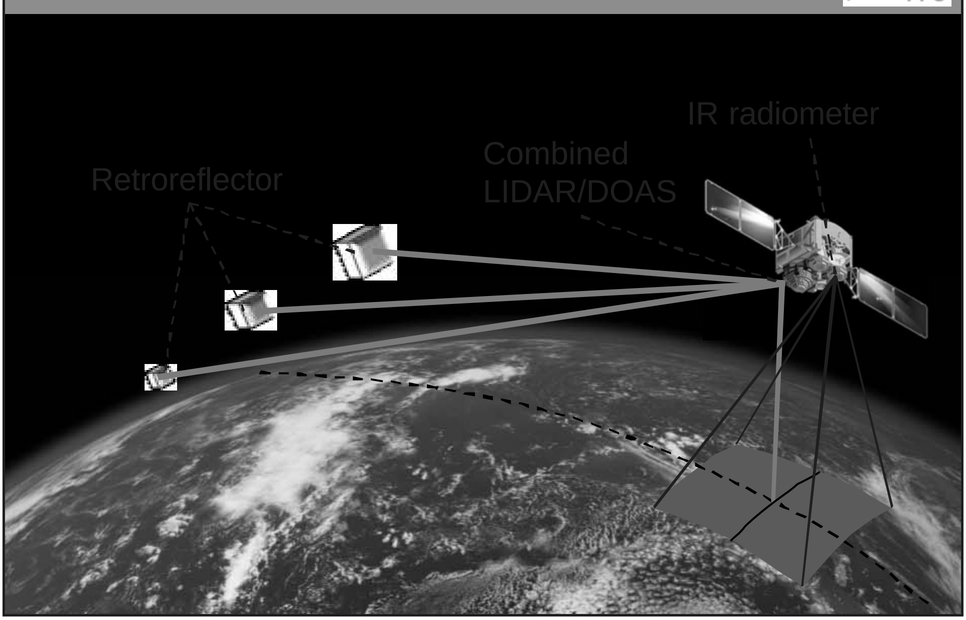
	Requirement
Horizontal coverage	Global
Horizontal sampling	100 km
Vertical coverage	5 – 35 km
Vertical sampling	100 m
Dynamic range	Aerosols: 0 – 0.005 km^{-1} [10^{-4} – 0.0025 km^{-1}] H_2O: 0.5 – 20 ppm [1 ppm]
Mission duration	> 4 years

Secondary Objectives

- Volcanic eruptions and stratospheric aerosols
- Aircraft emissions
- Detection of small particles (where LIDARs fails)
- Polar stratospheric clouds
- Polar mesospheric clouds (Noctilucent clouds)
- Proof of technological concept

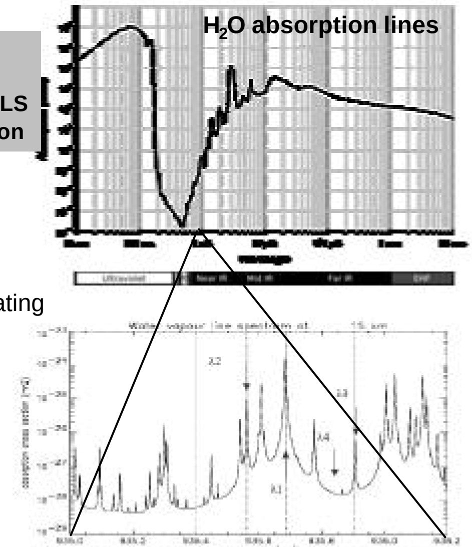
Space segment

Mission concept



Why active DOAS in the UTLS?

OBJECTIVE:
detect and retrieve low levels (weak signature!) of H_2O and aerosols in the UTLS with good accuracy and vertical resolution

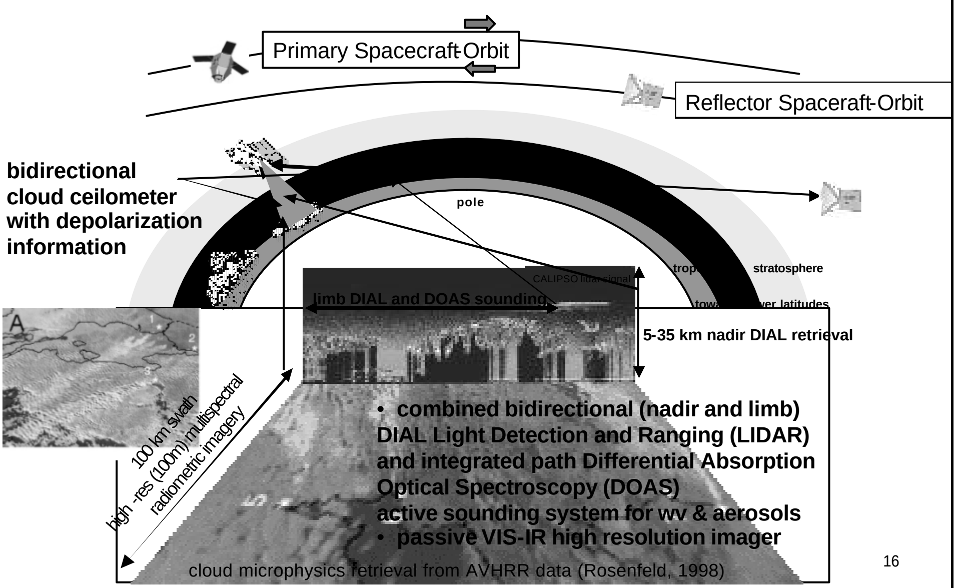


differential absorption systems self-calibrating

$$P(\lambda_L,R)=P_L\xi(\lambda_L)e^{-2\int_0^R \alpha(\lambda_L,R)dR}\xi(R)\frac{A}{R^2}\beta_\pi(\lambda_L,R)\frac{c\tau_L}{2}$$

figure courtesy: European Space Agency

Observational principle: a synergistic approach



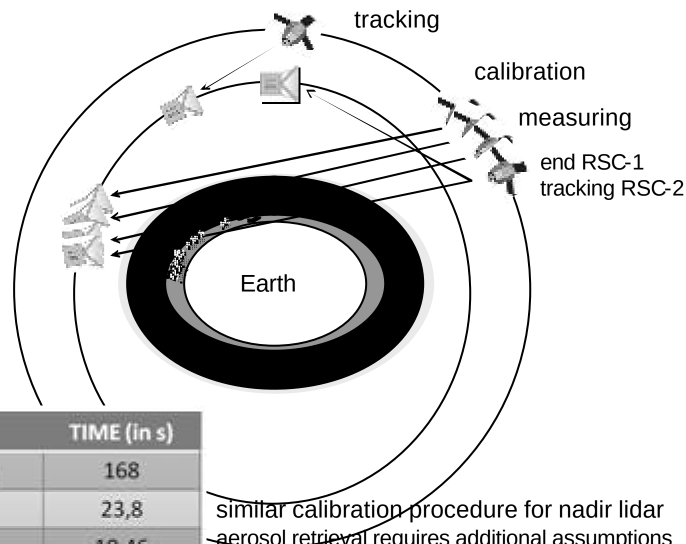
- combined bidirectional (nadir and limb) DIAL Light Detection and Ranging (LIDAR) and integrated path Differential Absorption Optical Spectroscopy (DOAS) active sounding system for wv & aerosols
- passive VIS-IR high resolution imager

cloud microphysics retrieval from AVHRR data (Rosenfeld, 1998)

Orbit concept for active limb occultation

esa

FFG



PHASE	TIME (in s)
Search (< 337 s)	168
Calibration	23,8
Measurement	10,46

similar calibration procedure for nadir lidar

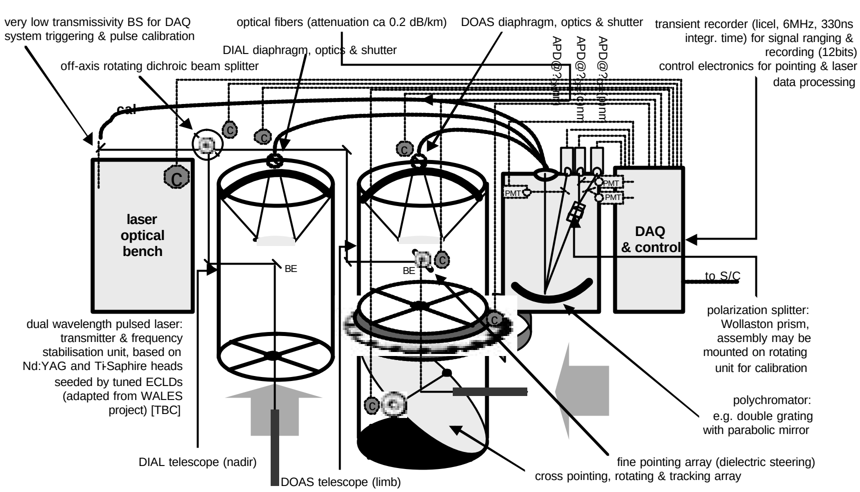
aerosol retrieval requires additional assumptions

Block diagram of optical layout

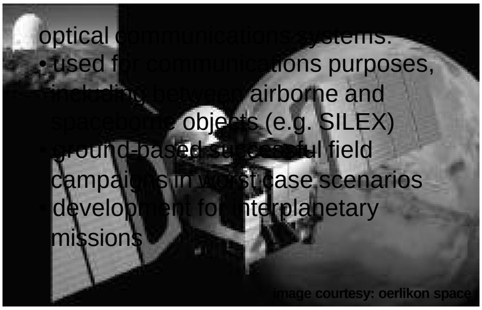
esa

FFG

Primary payload only, standard technology used for secondary payload



Tracking & Transmitter System Heritage



NASA LASE DIAL water vapour lidar

ESA WALES Earth Explorer Candidate

Performance: Active limb sounding link

- Based on LAGEOS formulas and values

$$N = \frac{E}{hf} G_T A_S G_S A_R \frac{T^2}{R^4} ?$$

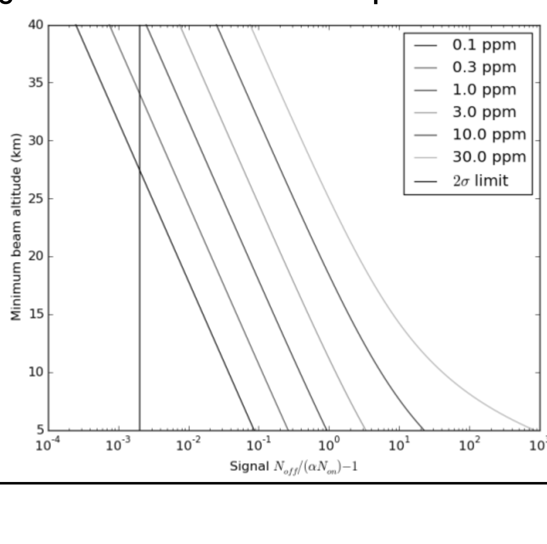
- Free-space reflector return signal for a 110 mJ pulse from 5300 km is approximately 5 million photons
  - High S/N ratio achievable with single pulses
  - Short integration time permits superior vertical resolution

Limb sounding: Detectability 1/2

- Measure the ratio of return signals at "on" and "off" wavelengths
  - Reduces calibration needs
  - Eliminates effects of pulse energy instability and reflector inhomogeneity
- Two-way attenuation can be calculated for the different wavelengths in a model atmosphere

Limb sounding: Detectability 2/2

- Ratio noise can be derived from Poisson distribution
- Ratio signal for various water vapour amounts

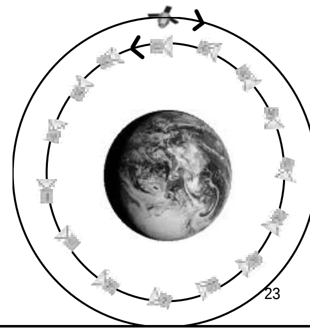


Orbit design

Main constraints :

o **LEO** (observation/limb budget)
o **counter-rotating circular orbit** (sampling of limb LIDAR occultation system)
o **polar orbits** (no relative precession between PSC & RSCs)
o **10-day repeat-cycle** (time series of observations at given places)
o **orbits are close** (performances/collision risks)

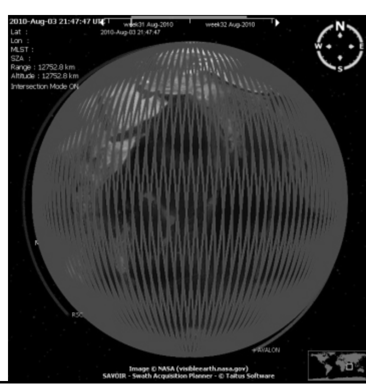
	PSC	RSC
altitude	582 km	550 km
e	0	0
i	90°	270°
number	1	15



Orbit performances

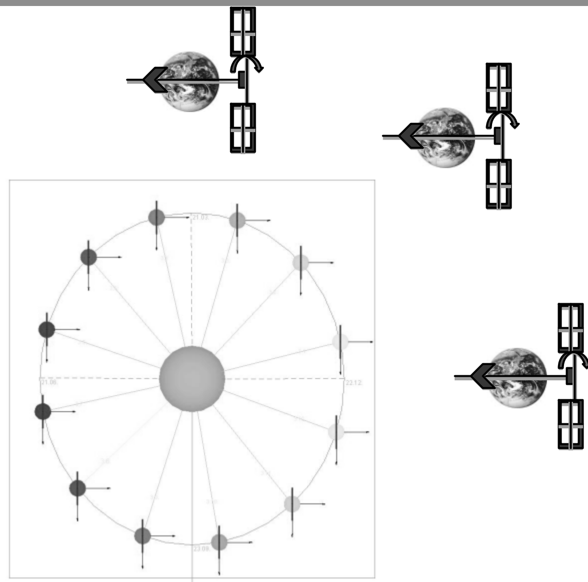
Sampling :

- Nearly global (Maximum inter-track : 266 km)
- ˜ **4500** occultations per 10-day period



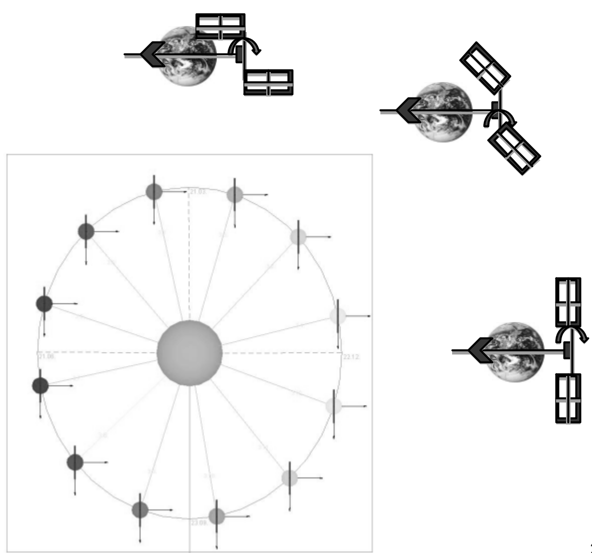
Last minute problem : Solar panel orientation

Polar orbit =>
need for an extra degree of freedom for the solar panels

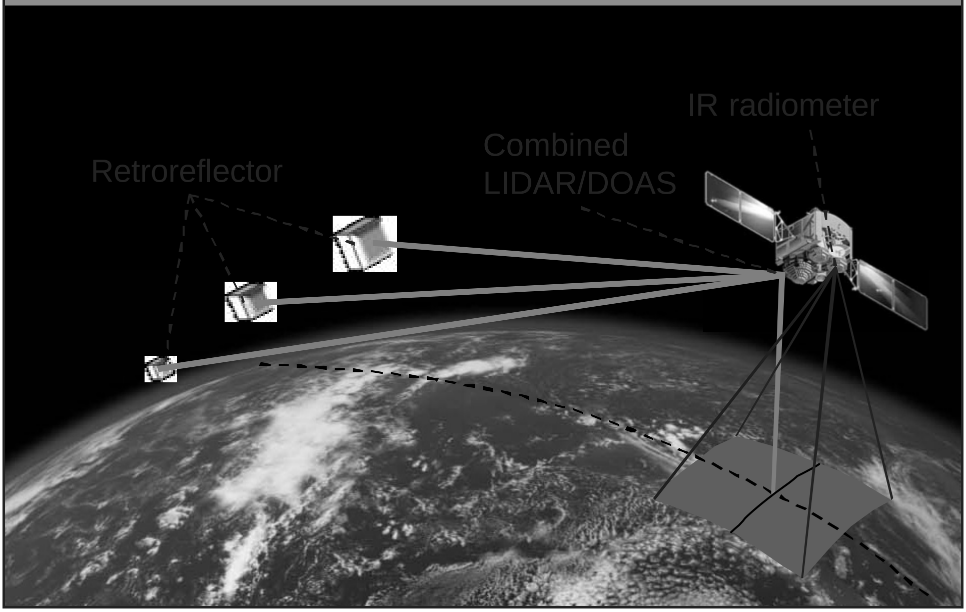


Last minute problem : Solar panel orientation

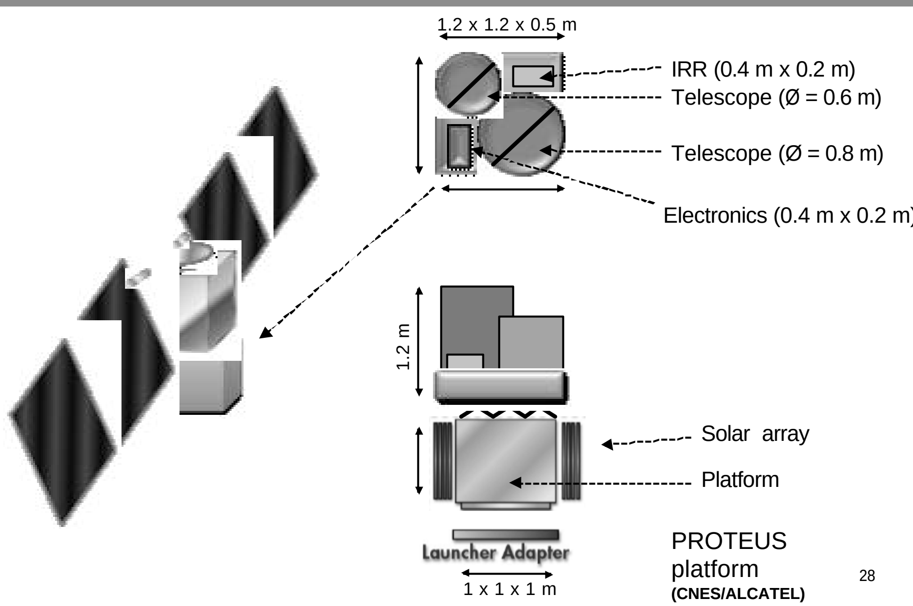
1st approach :



Mission concept



Primary Spacecraft (PSC)



PSC Design: Power

PSC estimates:

Power Estimate Component	Power		with margin	
IR radiometer	70	W	84	W
Lidar	1500	W	1800	W
Platform	300	W	360	W
Subtotal	1870	W	2244	W
Total (with system margin)			2692.8	W

Standard Platform Characteristics

PROTEUS	Performances
Volume	1 x 1 x 1 m
Mass	300 kg (Solar Arrays included)
Allowed Payload Mass	~500 (marginal) kg
Power	1065 W

Possibility to upgrade to 3000 W!

PSC Design: Mass

PSC estimates:

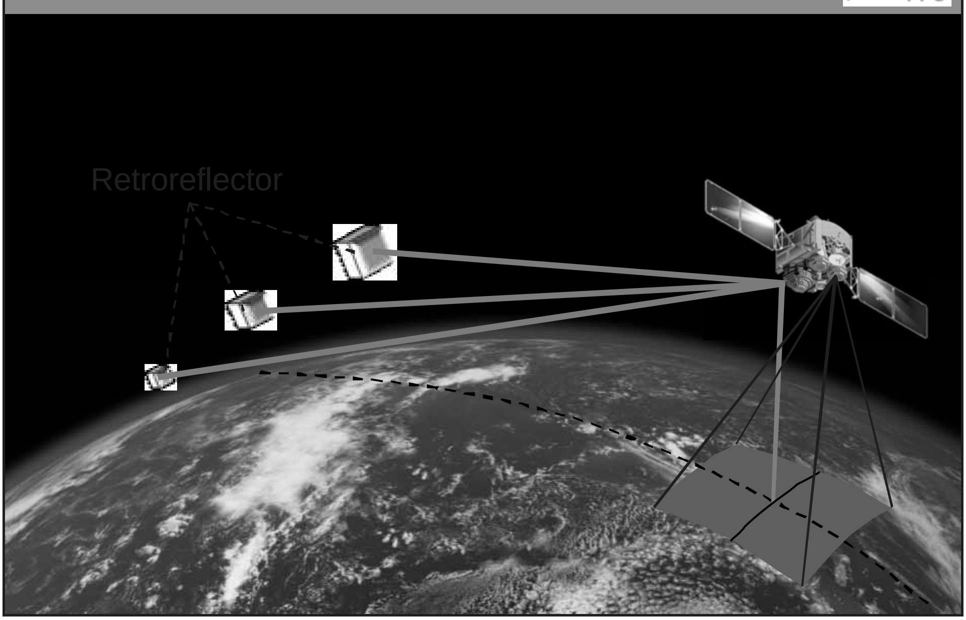
	Subsystems dry mass (kg)	subsystems dry mass + 20% margin (kg)
Payload:		
PSC		
IRS	41	49,2
LIDAR, Laser, telescopes (0.8 & 0.6 m) and receiver chain	240	288
added structure	40	48
subtotal	321	385
Platform: *e.g* PROTEUS		
naked, including propellant	300	360,0
2 solar panels/wing	40	48
power supply	40	48
Structural stiffening	40	48
subtotal	420	504
TOTAL	741	889
20% margin + System	889,2	1067,0

Compatible with launch on small launcher

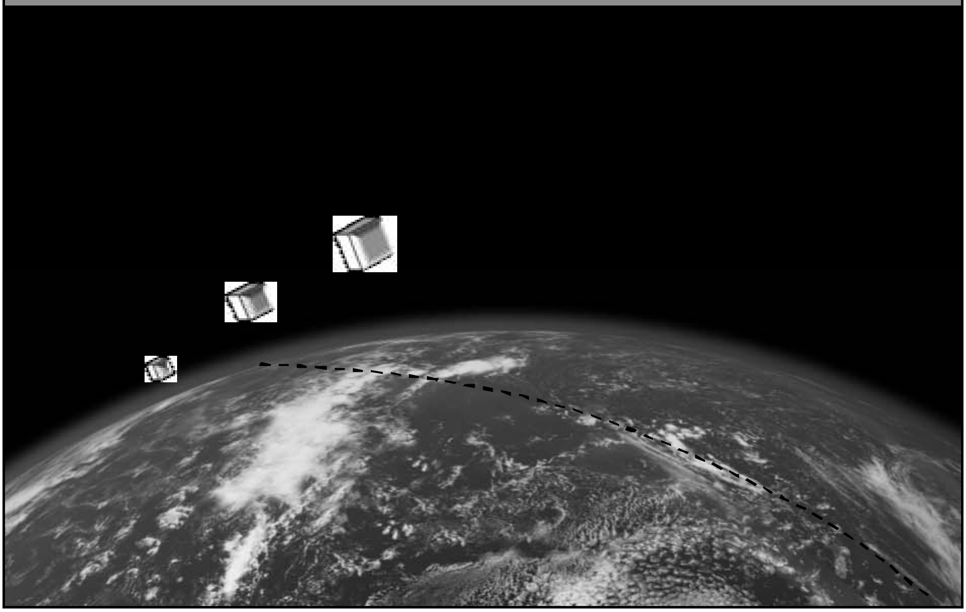
PSC Design

- Structure
- Thermal Control: Laser
  - Radiators
  - Heat Pipes
- Telecommunication
  - HK, TC: 8 Mbps in S band
  - Science data: 150 Mbps in X-band
- AOCS
  - Control not demanding
  - Determination needs to be precise

Mission concept: Reflector S/C

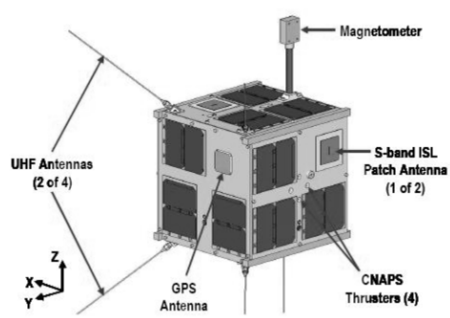


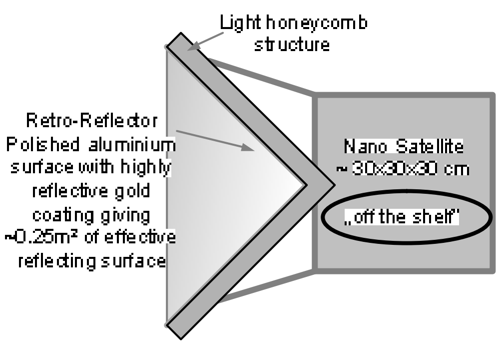
Mission concept



Cubical Laser Targets

- Attitude control (pointing)
- Formation flight capability
- Shape beneficial for launch
- Space qualification needed





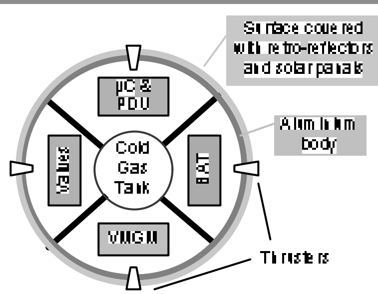
Option A: Passive Spherical Targets

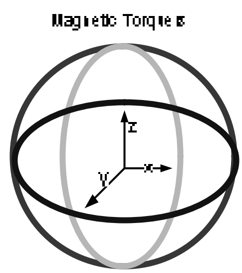
- Completely passive
- Low technological risk

- No orbit and no attitude control
- Space debris issues

Option B: Smart Spherical Targets

Basic attitude control and orbit correction

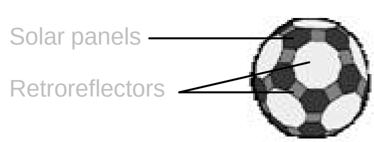




For a sphere of 60 cm of diameter:

Power budget	13% solar panels
Link budget	87% retroreflectors

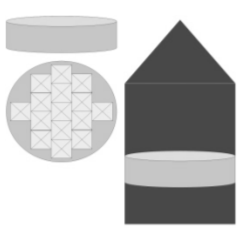
- Low technological risk
- The surface pattern must be optimized



Mission analysis and design

Launcher

- 2 (small) launchers
    - Two satellite packages
    - Counter-rotating orbits
- VEGA, DNEPR or ROCKOT?
- DNEPR has most benefits:
    - Favorable launch site
    - Space for reflector package
    - Reignitable



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Programmatic issues

Risk Assessment

HIGH	• Laser feasability • mass / power budget → Need for preparatory programme
MEDIUM	• CanX Nanosats with RR • Passive RR (constellation dispersion, disposal) → Subject of studies / demonstrations
LOW	• IR Spectrometer • End to end retrieval → Subject of refinement / optimization

Descoping

- Removal of the IR radiometer
- Removal of nadir LIDAR, pure DOAS system
- Less retroreflectors
- No retroreflectors, i.e. only LIDAR looking towards limb and/or nadir

Costs

Description	Cost [Million €]
Launcher 1: Dnepr	25
Launcher 2: Dnepr	25
Main satellite project	150
RSC Prototype	5
Retroreflector spacecrafts	2.5 * 15 = 37.5
TOTAL (with margins)	**250 Million €**

Calibration and validation

Calibration:

- LIDAR & IR radiometer
  - Existing techniques

Validation:

- Airborne measurements
- Balloon soundings
- Other satellites (intercomparison)
  - Limb: e.g. GOMOS, SCIAMACHY
  - Nadir: e.g. SCIAMACHY, CALIPSO

Summary

- Accurate measurements of water vapor and aerosols in the UTLS are crucial for the understanding of their effects on climate.
- A novel measurement concept of active limb sounding has been presented.
- The active limb sounding results in a better signal-to-noise ratio than passive limb sounding, better accuracy and vertical sampling
- The DOAS limb sounding can detect very small amounts of water vapor and aerosols.
- The AVALON mission will advance the scientific understanding of the processes in the UTLS.

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Thank you for your attention!