GLEME: GLOBAL LIDAR EXPLORATION OF THE MESOSPHERE

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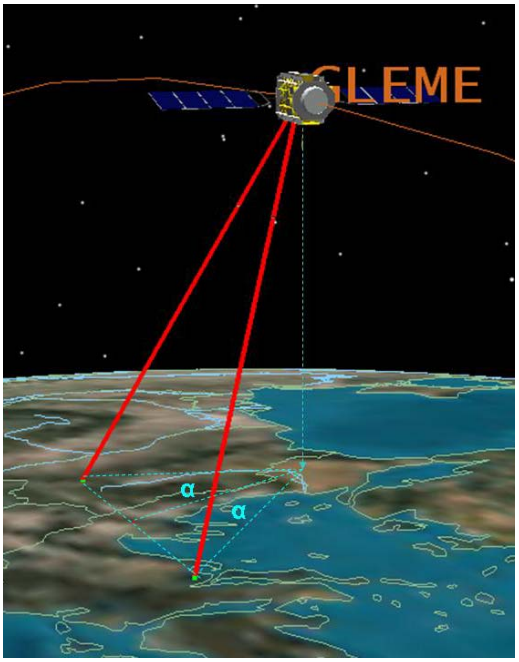
ABSTRACT: The Space Programmes Unit of the ATHENA Research Center (ATHENA-SPU) in Greece has lead a study towards the development of a spaceborne lidar mission designed to study mesospheric dynamics and chemistry. Determination of small scale waves in the mesosphere is the primary motivation and science focus of this mission and has driven the preliminary mission design. The mission concept proposed herein, called *GLEME (Global Lidar Exploration of the Mesosphere)*, is designed to obtain temperature and horizontal winds in the mesosphere with the highest ever spatial and temporal resolution, allowing the determination of gravity wave characteristics, heat and momentum wave flux, and their effects on the background atmosphere. As part of this study a novel measurement scheme has been developed, and details of the instrument and mission concepts have been outlined.

WHY STUDY THE MESOSPHERE? Even with new advances from remote-sensing measurements from spacecraft missions dedicated to mesospheric studies, the mesosphere remains an under-sampled region with many open questions. Being the “gateway” that connects Earth’s environment and space, the mesosphere is a region of great importance in energy balance processes and a link in vertical energy transfer, as it is in these layers that great surges of energy meet: solar radiation and particles contribute to downward energy transfer, whereas atmospheric tides and waves contribute to upward energy transfer from the stratosphere. Thus this region is a boundary layer that determines the temperature and density characteristics of the surrounding layers. Many fascinating features are associated with this layer, which can be described as a region of superlatives: the coldest naturally occurring temperatures, the highest ice clouds, the sharpest transitions, are all observed in the mesosphere. Interestingly, as modeling has shown, in response to increased greenhouse gases mesosphere temperatures are expected to drop even further, in sharp contrast to the warming of the lower atmosphere; thus, in a time of increased concern about global climate change, the study of the mesosphere is an increasingly pressing matter.

SCIENCE OBJECTIVES: Gravity waves are believed to be an important mechanism for energy and momentum flux from the lower atmosphere into the mesosphere, lower thermosphere, and ionosphere. Dynamical forcing by gravity waves plays a substantial role in controlling the mesosphere thermal structure. The cold polar summer mesopause (necessary for the formation of NLCs) is thought to result ultimately from momentum deposition by gravity waves from the lower atmosphere, which reverse the zonal wind and drives upwelling and adiabatic cooling at high latitudes; they are also responsible for the semi-annual oscillations at lower latitudes, as well as for the higher eddy mixing that is estimated through modeling in the mesosphere. The main Scientific Objective of the proposed mission is to determine the momentum and heat flux of Gravity waves by performing simultaneous wind and temperature measurements. The key Science Questions that will be addressed are:

1. **What is the global gravity wave distribution in the mesosphere?**
2. **What is the gravity wave forcing in the mesopause region?**
3. **What is the relationship between gravity waves, the zonal mean structure and planetary waves & tides?**
4. **What are the properties of Noctilucent Clouds over the globe?**
5. **What is the global distribution and variability of Na?**

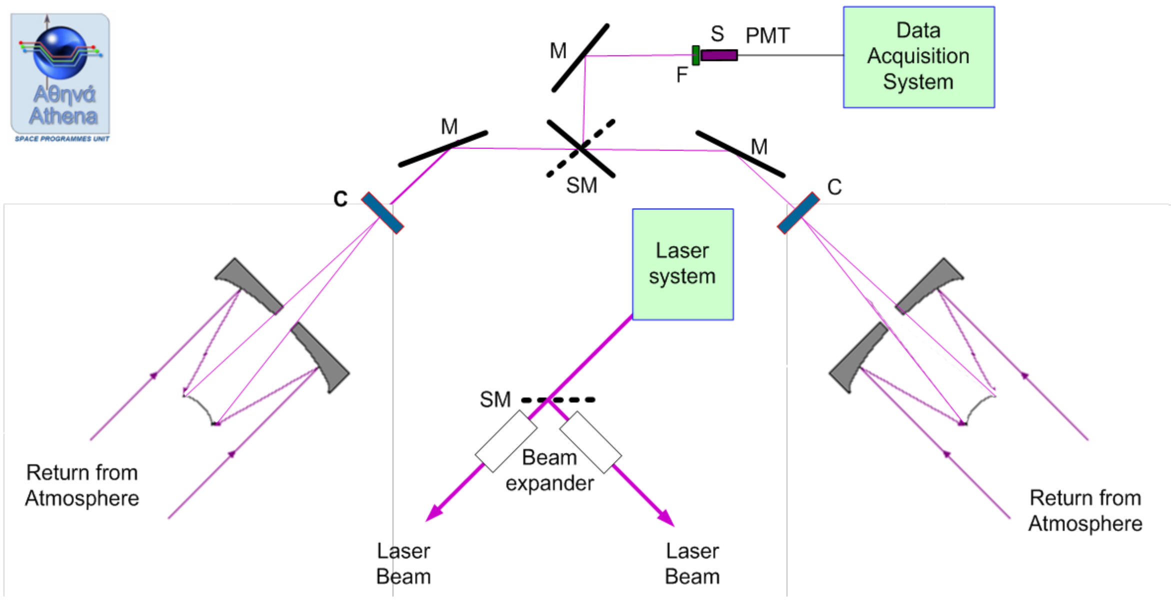
MISSION CONCEPT OVERVIEW:



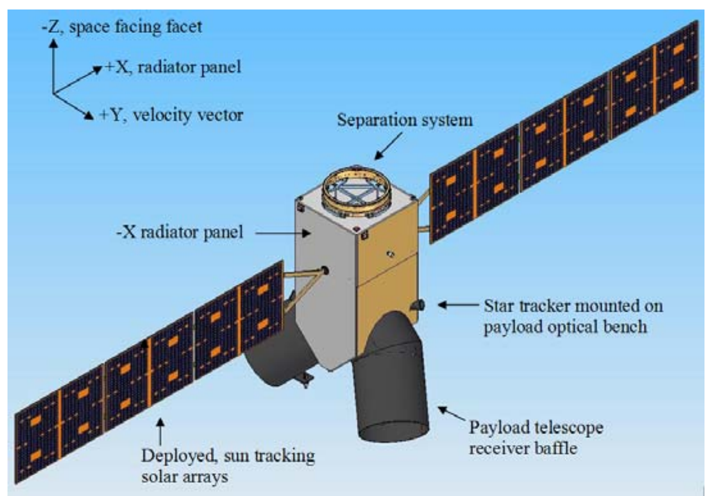
GLEME is a satellite mission flying in a sun-synchronous, 475 km altitude orbit carrying a resonance fluorescence wind-temperature lidar instrument as the primary payload. *GLEME* performs measurements at two lines-of-sight, one forward and one backward with respect to the satellite velocity vector, in a plane that is tilted by 30^o with respect to the orbital plane. In that way both components of the mesospheric horizontal winds can be characterized as a function of altitude. At the same time, mesospheric temperatures are also obtained at the same locations as the wind vectors. One of the key points of the mission concept is that all returning photon counts can be stored and post-processed with different integration times, enabling us to obtain different parts of the gravity wave spectrum, depending on the desired spatial or temporal resolution.

MEASUREMENT CONCEPT: Extensive simulations have shown that a resonance fluorescence lidar targeting the Na layer provides the lowest measurement errors, and is thus the optimum choice among mesospheric metal species. Measuring at two lines of sight is a key science requirement in order to resolve the horizontal winds. Pointing knowledge and stability is key to the measurement concept: in order for the lidar to sample the same region of atmosphere with the forward looking and reverse looking components of the payload, a pointing requirement of 0.01^{o} has been set. Finally, due to the spacecraft velocity and the earth's rotation, significant Doppler shifts appear in the laser frequency that have been taken into account in the instrument design.

INSTRUMENT CONCEPT: A schematic representation of the instrument concept is shown below, in which the two-look direction lidar concept is presented: this concept includes one laser subsystem, but two telescopes and two outputs of the laser beam, in order to perform measurements in two different lines of sight. The concept is a monostatic but biaxial design with independent telescopes for transmitter and receiver. The transmitter generates the laser pulses which are sent out to probe the atmosphere. The receiver consists of a telescope and the detector & filter unit. The data acquisition system controls both transmitter and receiver and interfaces to the spacecraft. A solid-state narrowband Na resonance fluorescence Doppler lidar is baselined as the best choice for a spaceborne mesosphere lidar. Taking advantage of the coincidence that the sum frequency of 1064 and 1319 nm Nd:YAG lasers matches the Na resonance frequency at 589 nm, a diode-laser-pumped, Nd:YAG laser SFG beam is selected. Diode-laser-pumped Nd:YAG lasers have been developed significantly over the past years, and are considered to be of nearly mature status.



SPACECRAFT DESIGN:



The design of all subsystems is driven by the instrument requirements, the most important of which are: a) instrument power consumption, b) instrument heat dissipation and c) spacecraft attitude knowledge and stability. The major items in the mechanical overview are: deployable solar arrays that track the sun by rotating when deployed; radiator panels; and payload baffles. The inertial axis of the satellite is aligned so that the satellite structure is nadir pointing, and the payload transmitter laser and receiver telescope and baffles are aligned 30^{o} from the nadir pointing direction. The two payload receivers are also angled 45^{o} in the along and reverse track directions.

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OVERVIEW OF MISSION PARAMETERS: An overview of the mission parameters and key instrument parameters are presented below:

SPACECRAFT PARAMETER	Value
Orbit	475 km altitude Sun-synchronous orbit minus 0.1^{o} inclination 12:00 LTAN
Lifetime	Sized for > 1.5 years in orbit
Spacecraft Mass	1070 kg (Total)
Payload Mass	500 kg
Data Rate	80 Mbits/s (X-Band)
S/c Power	2514W peak, 1561 Orbit Ave
Propellant	94 lt hydrazine; 2x1N thrust.
Power System	12.3 m^2 solar array area
Battery	166 Amp.Hour Li Ion Battery
Attitude Knowledge	2 x 3-ax mags (coarse) 4 x sun-sensors (coarse) 2 x Star Trackers (fine) 2 x GPS receiv. (orbit)
AOCS	8 x Reac. Wheels (fine) 3 x magnetorquers (coarse; reaction wheel desaturation)

INSTRUMENT PARAMETER	Value
Wavelengths	λ_0 = 589.158 nm (vacuum) $\lambda_{1,4}$ = l0 ± 4.7 GHz $\lambda_{2,3}$ = l0 + 4.7 GHz ± 630 MHz $\lambda_{5,6}$ = l0 – 4.7 GHz ± 630 MHz $\delta\lambda$ = 275 MHz shift (Earth rotation)
Pulse energy	$\geq$ 10 mJ
Bandwidth (FWHM)	$\leq$ 100 MHz
Cent. Freq. stability	$\leq$ 2 MHz
Bandwidth stability	4 MHz
Repetition frequency	500 Hz
Pulse duration	20 ns
Beam divergence	250 μrad
Ave. optical power	5 W
power consumption	$\leq$ 1000 W
	0.01^{o} (3 sigma) attitude knowledge 0.05^{o} (3 sigma) attitude control