International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

Edited by George Otrio

A solid state Doppler wind lidar system on ISSa

J. Mees, U. Johann, M. Huffaker, J. Streicher, et al.

International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570, 105702H · © 1997 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2326643

A solid state Doppler Wind Lidar system on ISSα

J. Mees, U. Johann
Dornier Satellitensysteme GmbH
D-88039 Friedrichshafen

M. Huffaker
Coherent Technologies Inc.
Lafayette, Colorado 80026, USA

J. Streicher, C. Werner
DLR - Institut für Optoelektronik
D-82230 Wessling

Global wind field measurements can improve significantly climatological and meteorological modelling and forecasting. Of particular interest are altitude resolved wind profiles in troposphere and lower stratosphere. Climatological research, i. e. earth radiation budget investigations will benefit from cloud top altitude profiles and aerosol content data.

A Doppler wind lidar (DWL) can measure wind profiles in the atmosphere with excellent accuracy. Lidars are proposed for spaceborne application. The backscatter lidar technology experiment in space LITE was successfully tested in 1994. A Doppler wind lidar in space can give both, wind and backscatter information. It contributes to research areas of utmost importance in the upcoming decades

- atmospheric and ocean dynamics (wind fields)
- earth radiation budget at lower latitudes (aero ol content and cloud tops)
- diurnal cycle over three years at latitudes covered by the space station

Wind fields are identified as most important parameter. The last ten years have seen a significant improvement in our ability to forecast the weather and simulate the general circulation of the atmosphere. This success has been served to expose and underline the need for a significant improvement in the global and regional observing system. In this connection special mention should be made for observations of wind fields in three dimensions as these are of special importance to both operational weather forecast and studies of the Earth´s climate.

A coherent DWL emits a short, close to transform limited laser pulse, a fraction of which is backscattered from atmospheric aerosols carried along with the wind stream, coherently mixed with a local oscillator laser in a photodetector. After spectral analysis of the Doppler shifted signal, altitude resolved wind fields are yielded which provide fix references for atmospheric forecast and climate modelling.

The Doppler Wind Lidar CLAAS (Coherent LAser Anemometric System) is proposed as a first step towards an autonomous operational mission, commencing sometime in the next decade. It is proposed as the first functional verification of a Doppler wind lidar in space. It will fulfil the objectives quoted above albeit at reduced quantitative performance imposed by developmental, cost, schedule and accommodation constraints. As such, emphasising its role as precursor to potential follow on operational missions, CLAAS will focus on the essential lidar detection and data evaluation process under favourable atmospheric conditions (lower layers, planetary boundary layer, near clouds: high haze and aerosol contents). CLAAS is designed for maximum scientific return under the limitations and constraints imposed by the space station schedule and accommodation issues (see Table 1 and 2).

Table 1: ISSα - Parameters

Parameter	Value	Comment
Orbit inclination	51.6°	earth coverage incomplete
Orbit altitude	335-460 km	higher signal budgets
Position knowledge	915 m (3-σ), update 1 Hz	not critical
Velocity knowledge	0.9 m/s (3-σ)	not critical
Attitude variation per orbit	3.5° per axis	ground track deviation
Attitude variation rate	±0.02° /sec per axis	not critical
Attitude knowledge	3° (3-σ)	critical - requires star sensor

Based on all solid-state laser technology operating at 2 μm wavelength CLAAS cannot meet objectives and requirements of the ALADIN mission. ALADIN is a more complex instrument which should provide close to operational performance accurate wind field measurements also in the upper atmosphere (15 km). This is on the cost of a larger, heavier and more expensive instrument design based on high power (10-15 J) CO_2 laser technology. CLAAS has in contrast no scanning capability and a reduced coverage. It comprises only a single line of sight and measures in low atmospheric layers. Based on promising technology CLAAS will validate key elements of a lidar system and provide representative scientific data.

On the other hand, the ALADIN development line can benefit from CLAAS, because the lidar detection process from space has been validated and the data evaluation process has been initiated, when the programme reaches critical development stages.

Table 2: ISSα - Specific Resources and Constraints

Aspect	Constraint
Operations	orbit maintenance
Environment	vibrations, debris
Field of view	caused by rotating arrays
Resources	to be shared with other payloads
Thermal control	instrument own radiator (except JEM-EF)
Safety	instrument shut down during EVA and rendezvous manoeuvring and docking phase

CLAAS measures accurate altitude resolved one line of sight wind profiles in the lower atmosphere up to about 3 km regularly and elsewhere under favourable atmospheric conditions. Aerosol profiles and cloud top heights are measured simultaneously and water vapour content can be probed optionally in a DIAL mode.

The wind measurements are performed by time resolved measurements of Doppler shifted laser light which is backscattered from aerosols in different atmospheric layers. Shot averaging will improve the SNR. Focus of the measurements will be on dedicated observation areas of high interest and suitable backscatter.

CLAAS is designed to meet the space station constraints in terms of volume envelope, available prime power, and weight. Existing data handling capabilities and operational time slots are taking into account. The thermal environment on the space station is rather complex. Additional cooling is required, since the laser amplifier efficiency is increasing with decreasing temperatures. Therefore, a passive radiator measuring 0.5 m^2 in size will cool the laser rod down to approximately 250 K.

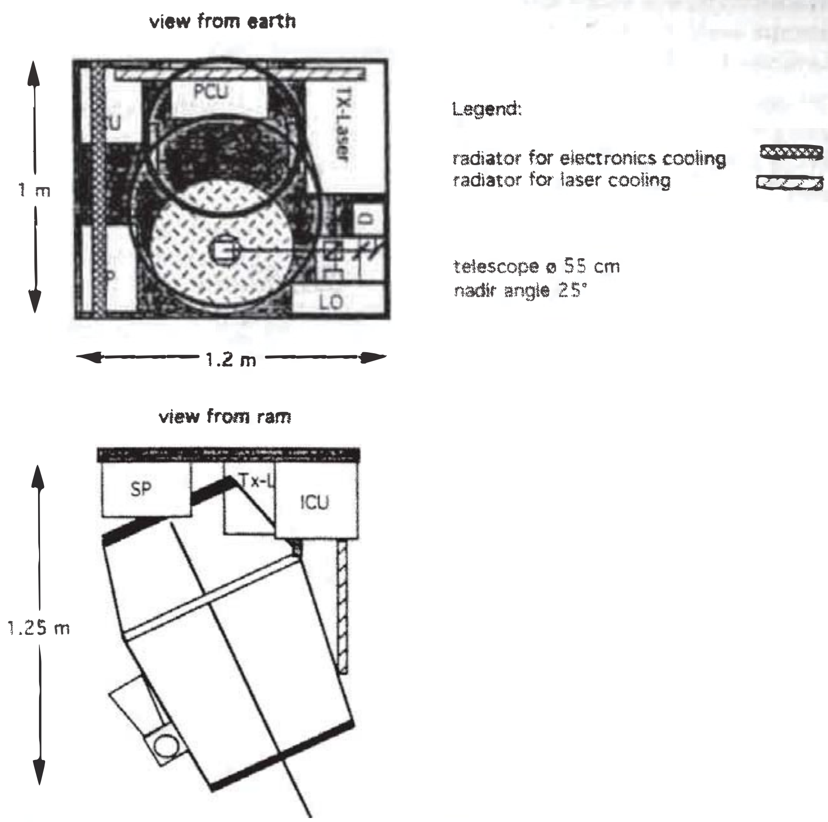

Figure 1: Accommodation of CLAAS on a single Express Pallet

The compact size of CLAAS (Fig. 1) fits on one express pallet adapter. It measures 1 x 1.2 x 1.25 m^3 in size. Prime power is 250 W on the average. Higher peak power allows increased shot frequency. The weight is 205 kg and an average data rate is 200 kB/s.

The transmitter laser is a solid state laser with Tm:YAG as active medium, which emits light at the eye safe wavelength of 2.01 µm. The laser has 0.5 J energy with 10 Hz pulse repetition frequency. The laser offers beside a compact volume, low mass also a long life time. The laser is supplied with a low voltage power supply. It consists of two main parts: the injection seeder (IS) and the laser amplifier (LA).

The receiver subsystem consists of the two detectors, the local oscillator laser (LO), the intermediate frequency electronics and the signal processor. The received signals are preprocessed, buffered and stored together with appropriate time, position, attitude and other housekeeping data on mass storage and will be dumped on ground later.

In contrast to 10 µm detectors, 2 µm detectors do not need active cooling and should have a higher intermediate frequency (IF) bandwidth due to the shorter wavelength. The injection seeder has to be tuned so, that the frequency difference between transmitted signal and the Doppler shifted backscattered signal will fit within the detector IF bandwidth. The local oscillator shall be locked to a frequency standard if its stability can not be guaranteed during the signal round trip time interval.

Apart from the required higher precision of the optical elements the complexity of the instruments optics at 2 µm is reduced drastically in comparison to the longer wavelength. Baseline telescope type is a Cassegrain system which could be very similar designed like the ATLID telescope system (Fig. 2). While the ATLID primary mirror was specified to a wavefront error of lambda/4 (at 1 µm) this mirror would need a wavefront error of lambda/10 (at 2.02 µm).

The optical axis of the telescope is pointing down to earth with a nadir angle of 25° in a direction along the ISSα truss structure. This minimizes the spacecraft induced Doppler shifts components. Doppler shifts induced by earth rotation and ISSα attitude variations must be taken into account of the LO frequency tuning.

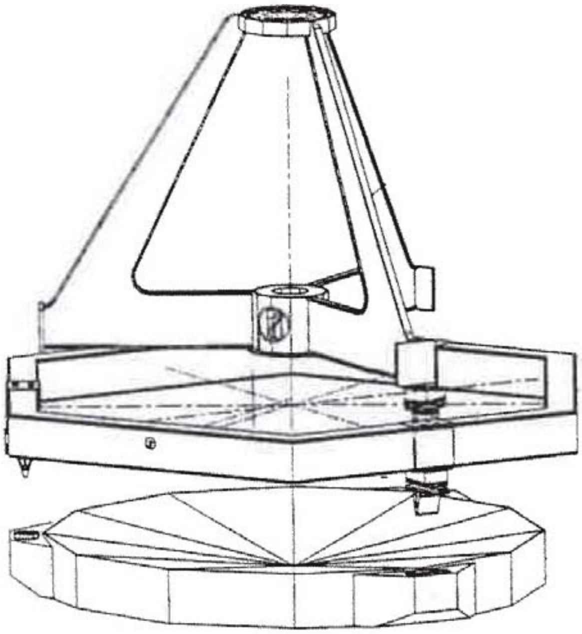

Figure 2: ATLID primary mirror with a focal length of 5658 mm

Table 3 shows a summary of the CLAAS instrument parameters.

Table 3: CLAAS - Instrument parameters

Effective telescope aperture	0.55 m diameter (0.24 m^2)
Far-field laser energy/pulse	0.5 J (0.5 µsec pulse width)
Wavelength	2.02 µm @ 10 Hz PRF
Instrument prime power	250 W (Laser 100 W)
Instrument mass	205 kg
Instrument envelope	1 m x 1.2 m x 1.25 m (height)
Nadir angle	25° (30° if payload envelope can be exceeded)
Data rate	200 kb/s
Pointing stability (during round trip)	±0.66 µrad
Beam divergence	7.1 µrad
Laser wall plug efficiency	0.[illegible]5