Precise characterization of the Performance of CHARM-F during Ground-based and Airborne Measurements

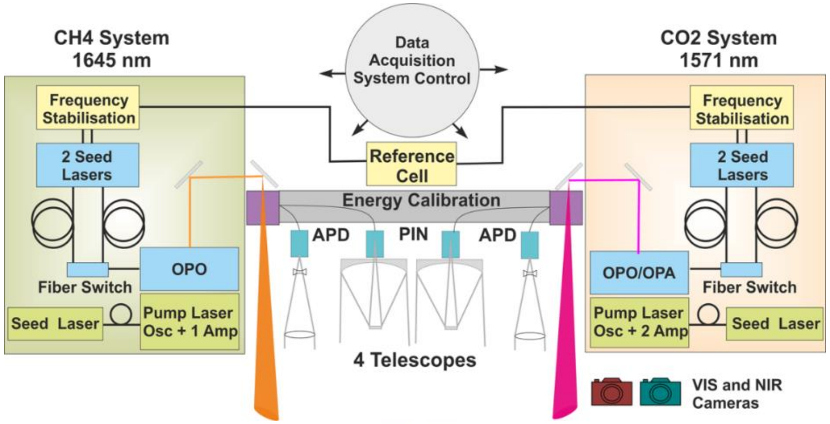
Mathieu Quatrevalet[1], Christian Fruck[1], Martin Wirth[1], Christian Büdenbender[1], Christoph Kiemle[1], Nina Burgdorfer[1], Sebastian Wolff[1], Gerhard Ehret[1], Andreas Fix[1]

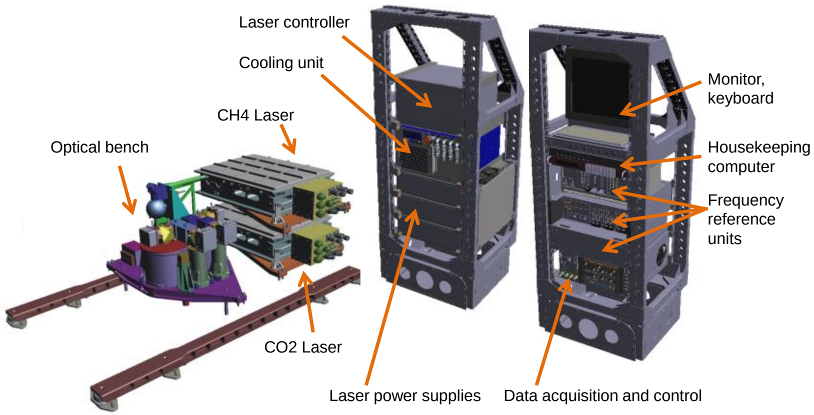
[1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, 82234 Weßling-Oberpfaffenhofen, Germany, E-mail : mathieu.quatrevalet@dlr.de

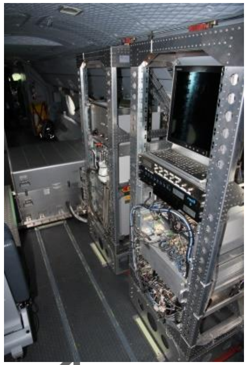
DLR

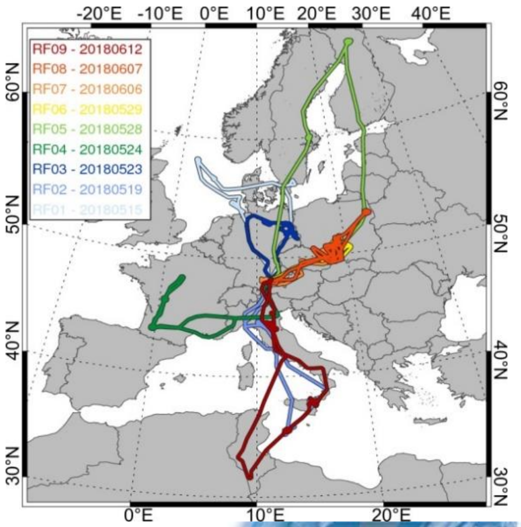
CHARM-F is DLR's IPDA lidar for simultaneous measurements of the weighted column averages of carbon dioxide and methane, XCO_2 and XCH_4. It consists of two largely independent lidar systems, each of which emits pulse pairs, one at the online and one at the offline wavelength, with a time separation of 500 µs, at a pulse pair repetition rate of 50 Hz.

A CHARM-F special feature: two receivers per gas, one based on a 1-mm, four-quadrant InGaAs PIN diode behind a 200-mm field imaging optic, and one based on a 0.2-mm InGaAs APD behind a 60-mm aperture imaging optic.





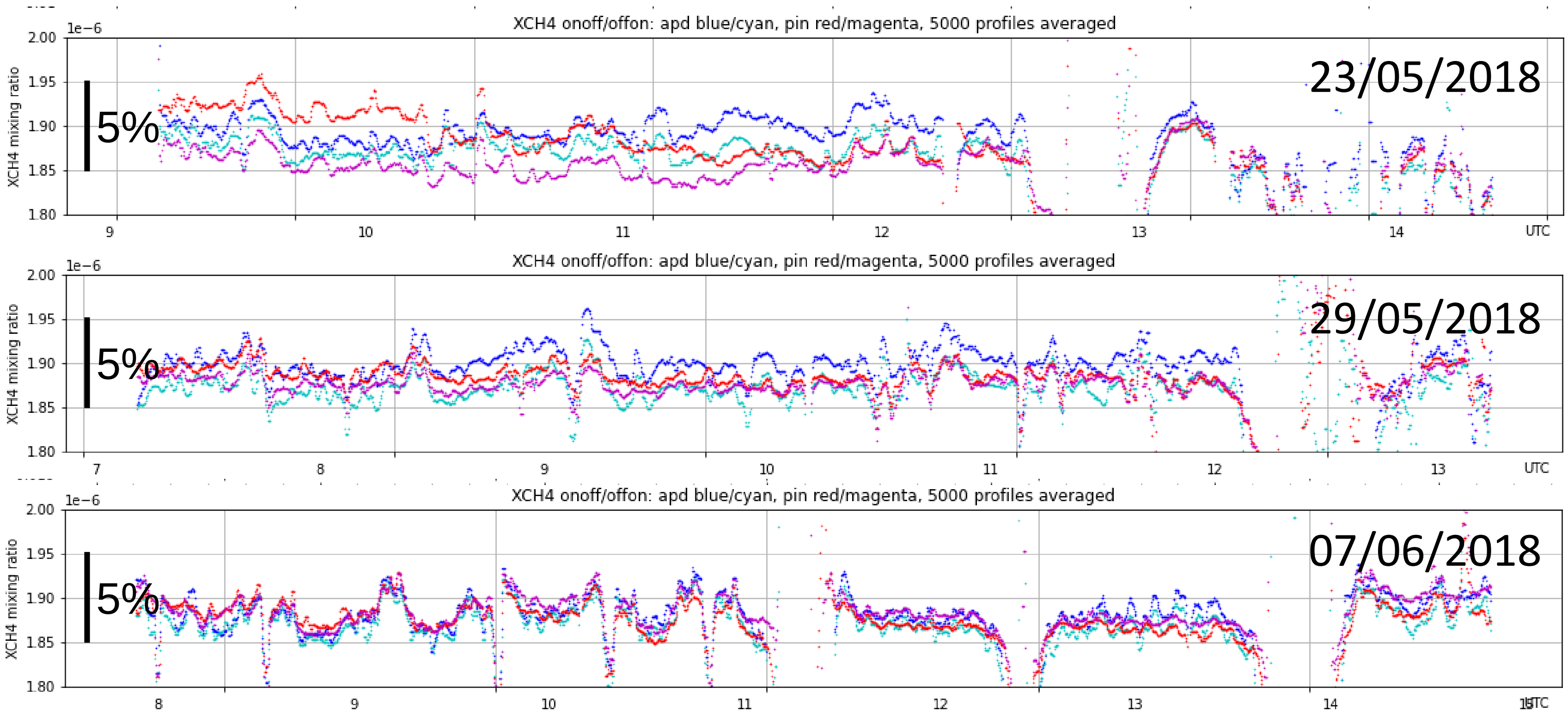




CHARM-F serves as a technology testbed and as a demonstrator and future validation tool for MERLIN and other future spaceborne IPDA lidars. It has already accumulated over 85 flight hours onboard DLR's HALO aircraft in the frame of a test campaign and of the CoMet 1.0 campaign, focusing on anthropogenic sources in Europe.

Inter-comparisons of independently-derived XCO_2 and XCH_4 with PIN and APD receivers during the flights hints at time-varying biases of the instrument

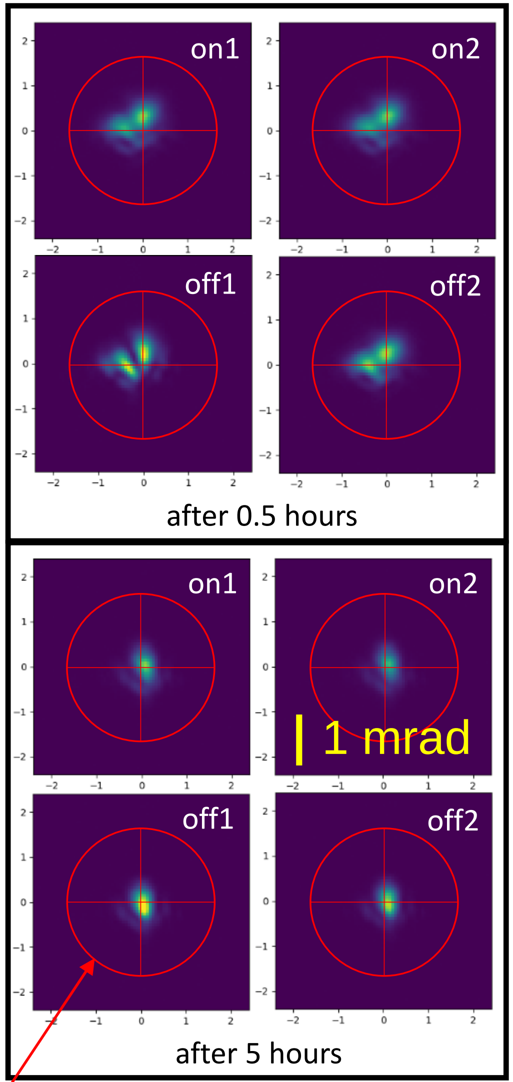
A further distinction is made based on the wavelength order within a pulse pair, on/off or off/on, which is swapped from one pair to the next in order to detect asymmetries in the two pulses. Example with methane and three different flights during the CoMet 1.0 campaign:



Depending on the flight and the point in time, biases can be observed from below 1% up to a few percent.

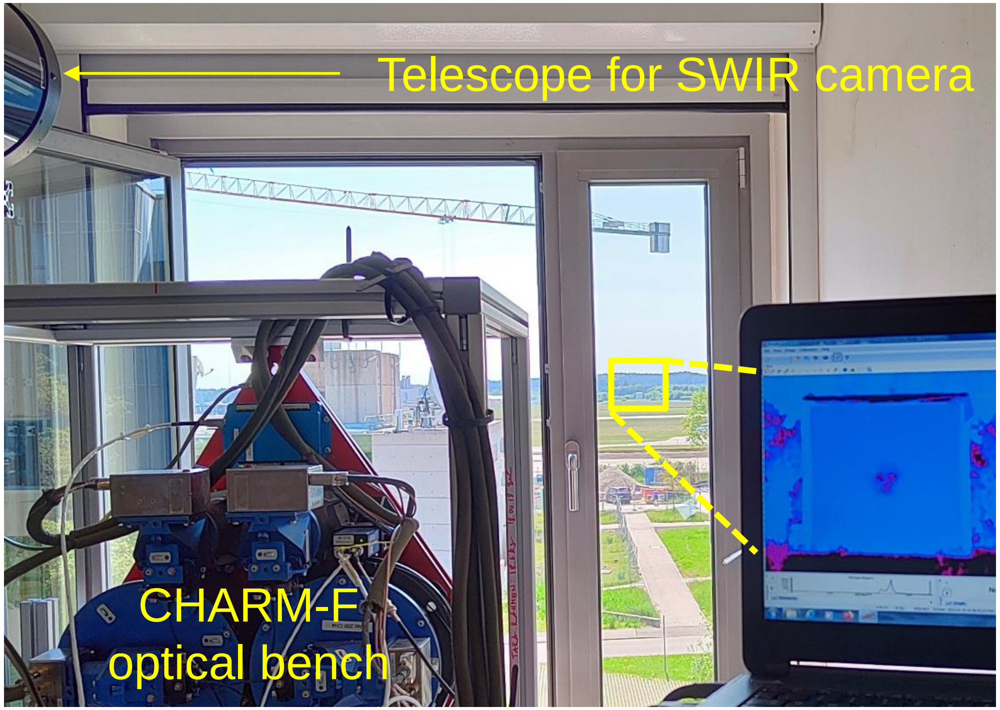
Theory: time-varying beam profile differences between the four types of pulses, together with clipping or field-dependent receiver responses, cause the biases

- Thermal and wavelength effects cause pointing/beam cross-section differences between first and second pulse within a pulse pair, and these differences vary over time due to thermal evolution of the lasers over time.
- Even minimal *differential clipping* of the laser beam‘s pedestal by the field of view may give rise to biases in the percent range.
- Dead zones between the quadrants of the PIN diode produce a similar, differential clipping effect.
- The sign and magnitude of these *imaging biases* strongly depends on the wavelength order within a pulse, on the beam size at the target and on the position in the field of view of each receiver.



Far-field laser beam cross-sections measured in the lab 0.5 hours and 5 hours after laser startup

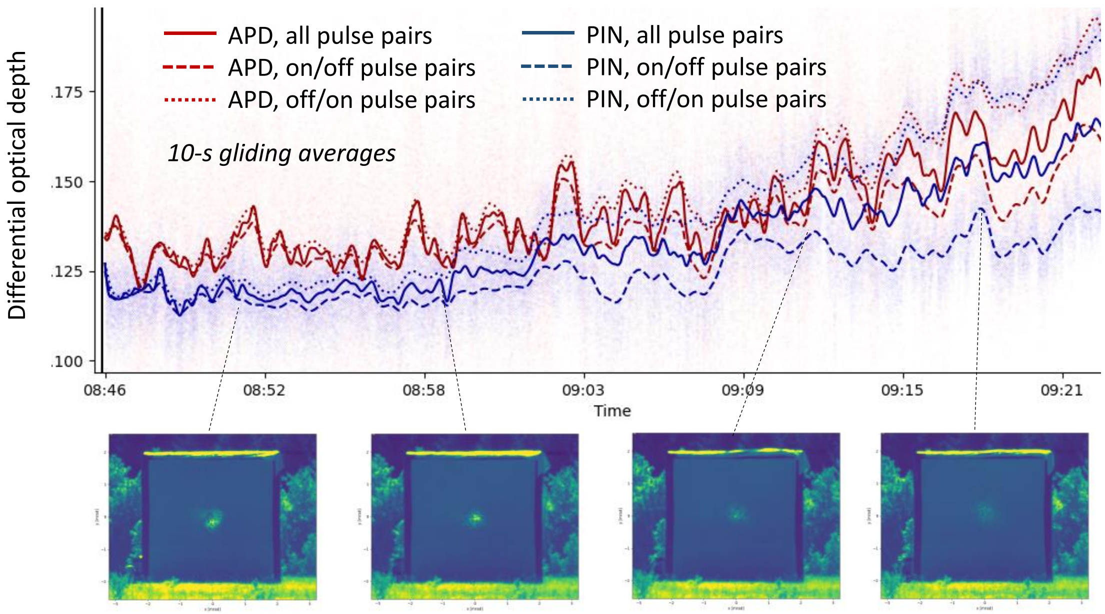
Field of view of the receivers and dead zones of the PIN receiver



Laboratory and field setup for ground-based validation of the *imaging bias* theory:

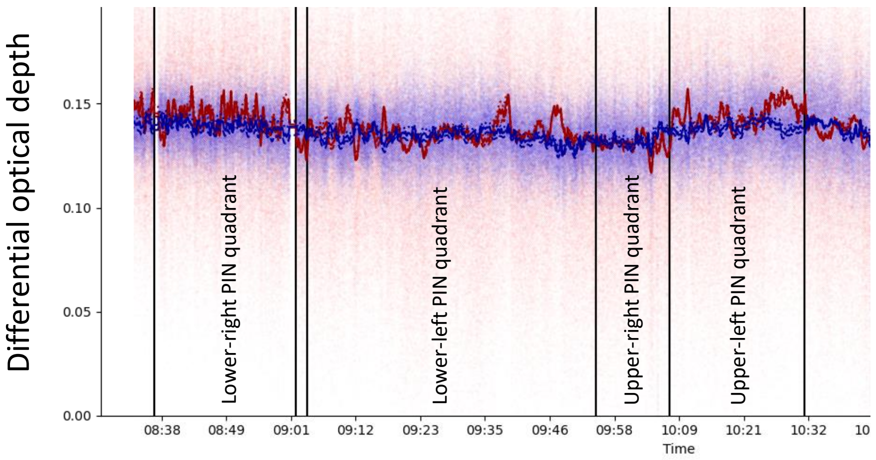
- 1.6 km range for far-field operation
- 7x7m screen with uniform reflective surface covering the whole field of view of the receivers
- SWIR camera for live monitoring of beam position and size at the target

Preliminary results with the recently setup test range



As expected, **the laser divergence (which can be controlled by means of motorized beam expanders in the lasers) must be kept small with respect to the field of view to avoid differential clipping**. Closer examination of the SWIR images also shows that a diffuse pedestal around the central mode is the cause for this rapid degradation with increasing divergence.

However, **at the smallest divergence an enhanced sensitivity of the magnitude of the APD receiver biases to the position in the field is observed**. This may be caused by a position-dependent response of the 2-nm bandpass filter for solar background reduction, located close to the field stop within the aperture-imaging APD receiver.



DLR

Conclusion and outlook

- Preliminary results from on-going ground tests of the CHARM-F system using a recently set up 1.6 km test range are consistent with **discrepancies in the beam cross-sections between the first and second pulses within a pulse pair giving rise to time-varying, inter-receiver biases depending on the beam size and position in the field.**

- This work will be used to develop a **methodology to correctly set the divergence and position of the laser beam within the field, both of which can be controlled in flight, to minimize this error source.** This will be important to maximize the instrument performance, especially as far as methane is concerned, in the frame of **the upcoming CoMet 2.0 campaign in Canada, which will focus on extended natural sources of methane.** Indeed, **the expected gradients in the column concentrations for diffuse sources are weaker than the point-source anthropogenic sources** in Europe which were the focus of the CoMet 1.0 campaign.

- In order to support this approach and later the data processing and analysis, the CHARM-F internal NIR camera, originally intended to provide contextual information, has been fitted with a longpass 1500-nm filter for solar background rejection, and re-programmed to be triggered by the laser electronics, allowing to capture single pulses. These modifications have been validated on the test range.