The MARs Boundary Layer Lidar experiment (MARBLL): Winds at last!

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MARBLL is an optical remote sensing instrument using a mature state-of-the-art Doppler wind lidar technology specifically designed to operate at the surface of Mars. The instrument includes an emitting device (laser) and a spectral analyzer (Mach-Zehnder interferometer). Wind profiling is inferred from the 1064 nm beam emitted by the laser and subsequently backscattered to the telescope by the suspended aerosols. The received signal has a Doppler shift induced by the radial velocity component of the particles, which is quantified by the interferometer.

Introduction:

Doppler wind lidars (DWL) offer a unique combination of accuracy and spatial resolution making them the most efficient technique to profile winds in the terrestrial boundary layer (see e.g. Gentry, 2000; Frehlich, 2008). Existing DWL methods usually require a quasi-monochromatic laser emission and a precise frequency locking between the emitter and the spectral analyzer to infer the wind Doppler shift. These requirements lead to specific laser designs (single mode emission) associated with delicate servo-loops. The technical readiness level (TRL) of such systems remains too low to plan their use in the upcoming Mars missions. The conceptual approach of MARBLL started from this consideration: instead of developing space-qualified lasers to meet specific system detection requirements, MARBLL concept was led by the idea to design a detection system matching the specifications of an existing space-qualified laser (ChemCam) and by the need to guarantee high performances in the harsh Martian environment. The mature MARBLL design, which has undergone five years of Research and Development (R&D), ensures high performances for a large range of temperature and for any atmospheric condition (e.g. dust opacity) known to prevail on Mars. The relative detection method of MARBLL does not require the use of frequency control for both the emitter and the spectral analyzer.

Functional description:

MARBLL is an optical assembly consisting of five sub-systems described as follows: the External Scanning Mirror (ESM) provides a pointing facility for the emitted and the backscattered beams; the Receiver TElescope (RTE) collects and focuses the backscattered beam at the focal plane; the Mach-Zender Interferometer (MZI) performs the spectral analysis of the emitted and received beams as well as the detection; the Emitting LAser (ELA) includes the laser assembly and its power board; the Main Electronics Block (MEB) controls the entire instrument and handles power/data interfaces. MZI is harnessed to RTE and ELA by optical fibers and by cables connecting the MEB with all the other subsystems.

Optical design:

The uniqueness of the MARBLL patented concept stands in its capability to infer a Doppler shift, free from the common wind lidar constraints (see Bruneau et al., 2013, for the detailed optical design). The spectral analysis is performed through the MZI whose optical path difference (OPD) is matched to the laser free spectral range (defined by the laser cavity length). Laser specifications impose a constant OPD of 294 mm due to prism refractive index. With this concept, MZI response can be obtained with a multimode laser (such as ChemCam laser), regardless of the emitter spectral position. No frequency stabilization for the laser or for the interferometer is needed, and no moving part is used for the spectral analysis.

Doppler shift spectral analysis:

The Doppler shift is obtained by comparing the measured interference phase of the atmospheric signal with that of a reference pulse extracted at the laser output. Both signals are conveyed by optical fibers connecting MZI on one end to RTE (signal) and ELA (reference) on the other. The optical fiber of the signal has a 60-meter loop to force a temporal separation with the reference before acquisition. The two fibers are connected together to the MZI coupler (90% for signal and 10% for reference), allowing the use of a single port at the interferometer input. The mode scrambler inserted between the coupler and the interferometer ensures optimal laser mode mixing and beam depolarization. Reference and signal beams are thus sequentially injected into the prisms. Each beam is separated into the two arms of the interferometer. A quarter-wave plate is inserted in one arm that yields a $\pi/2$ phase difference between the four detectors. At the output, split beams recombine and interfere with the 294 mm OPD and is then focused to the APDs.

Photometric efficiency:

Mach-Zehnder design offers the highest possible throughput since all input photons reach the output.

Because the interferometer FSR matches the laser mode width, the contrast of interference for one laser mode is exactly the same for all the others, assimilating the transmission pattern to that of a single-mode laser. This optical design guarantees that all the laser modes contribute to the signal analysis and detection. This optimization in the use of the emitter and the receiver implies that performances eventually depend on the primary mirror diameter (with a direct relation between SNR and mirror area). The 70 mm diameter allows required performances to be exceeded and maintains accommodation constraints at a level commensurate with its use on a landing platform or on a rover.

Performances:

MARBLL is able to derive wind velocity and orientation with a typical accuracy of respectively 0.1 to 10 m/s and 1 to 10°, a dynamic range of ±272 m/s and with a vertical resolution of 50 m up to 1 km within the first 5 km above the surface. Aerosol abundance can be retrieved up to 10 km with a vertical resolution ranging from 50 meters to 1500 m.

Atmospheric dust loading affects MARBLL performances in a quantified way: high dust opacities (>2) reduce the sounding depth capability by >1 km, but increases SNR in the lowest atmospheric layers. At the laser wavelength, dust is non-absorbing and all photons are scattered, maintaining high levels of backscattered flux even at high dust opacity. MARBLL thus guarantees that performances exceed baseline requirements for all dust opacities (from 0.2 to 5), with an optimum estimated around 0.7, lying close to the average dust conditions prevailing on Mars.