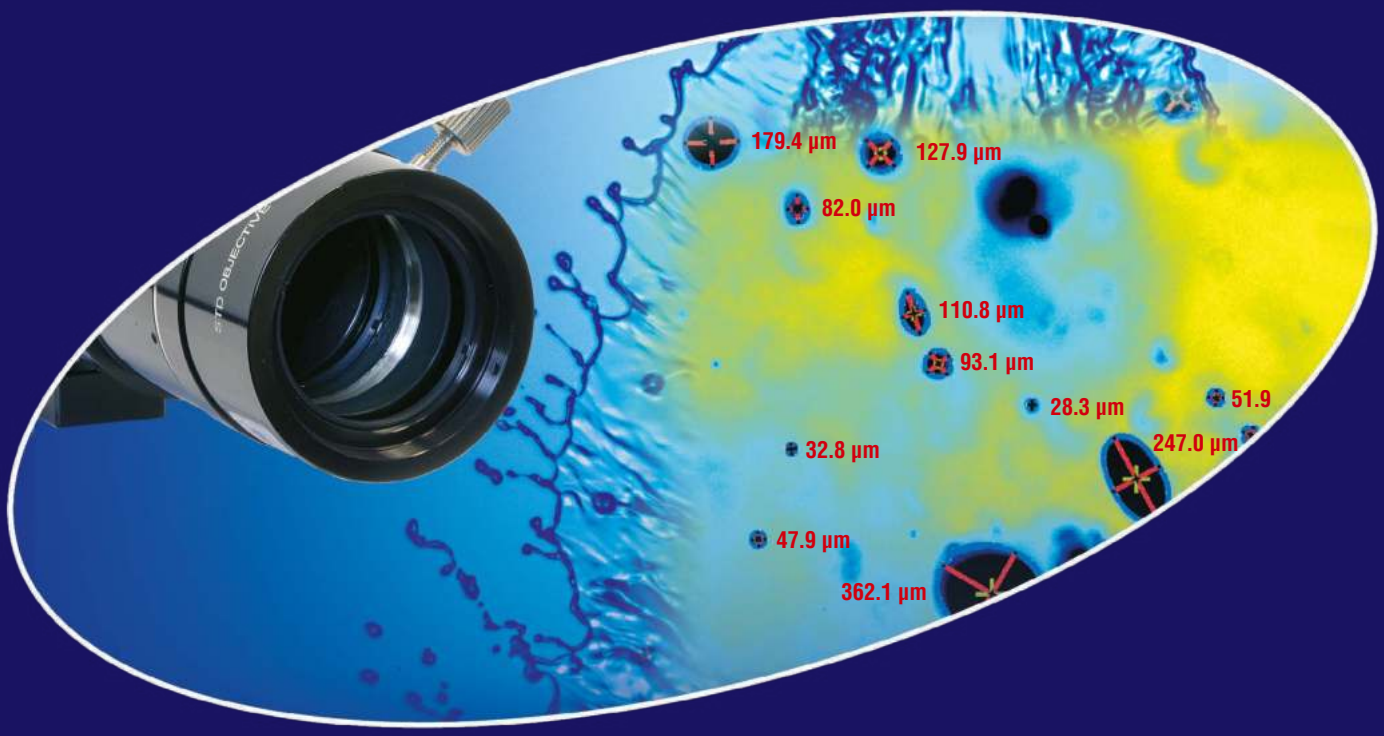
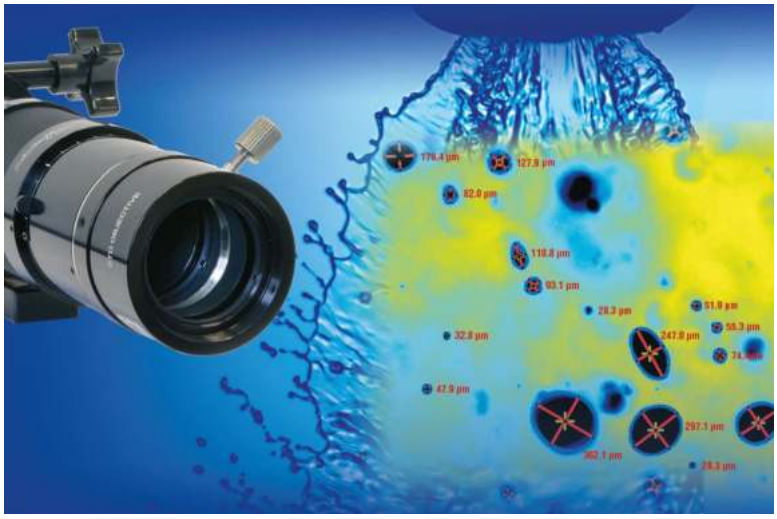


ParticleMaster

Intelligent Imaging for Particle and Droplet Characterization

LAVISION

FOCUS ON IMAGING

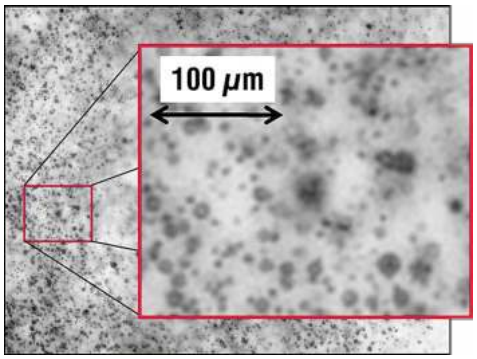


High-magnification shadow imaging

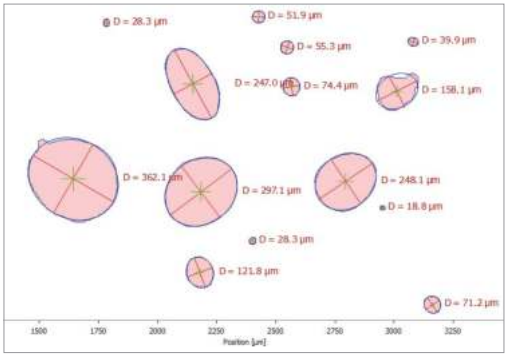
High-magnification shadow imaging

LaVision's **ParticleMaster** imaging systems measure simultaneously size, shape and velocity of individual particles, droplets or bubbles dispersed in gas, liquid or multiphase flows. High-magnification shadow imaging with pulsed backlight illumination of the particles is applied giving confidence in the measurement method, as the user can directly see the results of this particle imaging process ("seeing is believing").

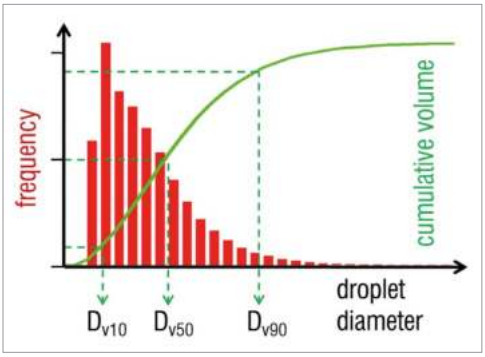
The measurement volume is defined by the camera field of view in the focal plane and the depth of field of the imaging system detecting only focused particles inside this probe volume. The shadow technique is independent of the shape and material (either transparent or opaque) of the particles and allows the detection of sizes down to the micro scale using appropriate optical imaging systems



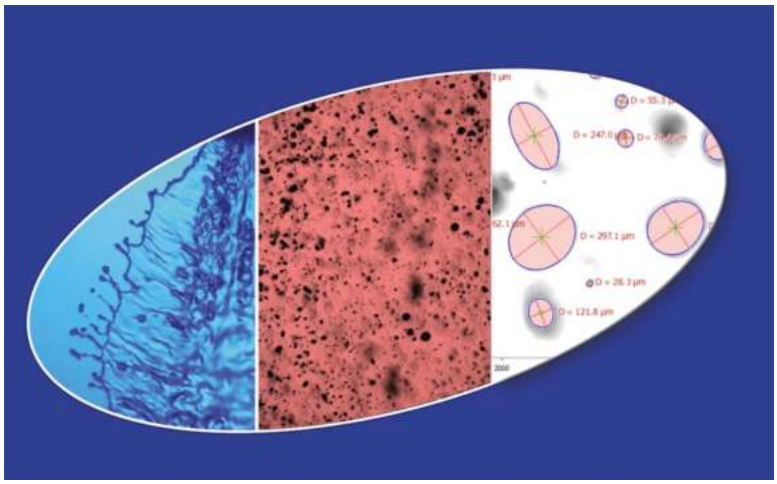
High resolution shadow image



Detected particles



Particle size histogram



In-situ measurement

Sample preparation is not needed, because the **ParticleMaster** imaging systems measure the particles in-situ, i. e. in their original environment.

While the spatial resolution is defined by the camera-lens system the exposure (illumination) time is given by the pulsed light source. With a choice of different light sources - from fast lasers to eye-safe pulsed LEDs - and a variety of interchangeable lenses a wide range of particle sizes and velocities are captured using the **ParticleMaster** shadow systems.

Applications

- sprays (water, fuel, paint, household)
- spray breakup (ligaments and droplets)
- powder, solid particles (alloys, ceramics, grains)
- bubbles (heat exchanger, industrial processes)
- quality control applications

ParticleMaster Shadow system

LaVision's **ParticleMaster** is the most advanced shadow imaging system for particle characterization. The key components are a dedicated high-magnification imaging system combined with a shortly activated, motion stopping backlight illumination source.

The camera and high-magnification lens are selected according to various experimental conditions, like working distance, magnification, size range and desired image frame rate. To freeze the particle motion the **ParticleMaster** systems include a high efficient LED spotlight or a speckle-free laser pulse for ultra short exposures.

A double exposure system featuring a double pulse light source combined with a double frame camera measures also the velocity of individual particles additionally to the size and shape information.

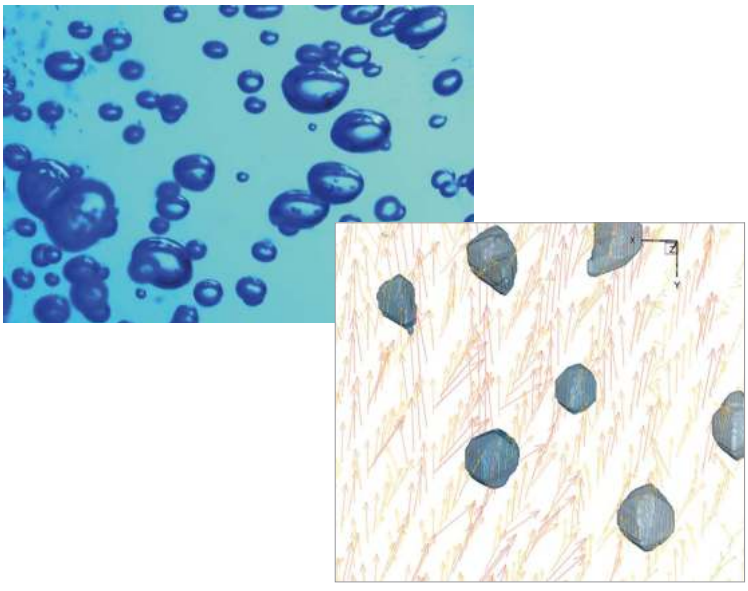
High-speed tomographic shadow imaging in multiphase flows

A calibration target for particle sizing is standard for every system. The **Depth-of-Field** (**DOF**) calibration kit is needed to determine the probe volume of the instrument for absolute density and volume fraction measurements. After being calibrated in such a way, the **ParticleMaster** system can deliver absolute number density, volume fraction and - together with the double exposure option - absolute mass flux of the particle flow.

3D particle imaging is realized in combination with a multi-camera setup supporting tomographic shadowgraphy.

The **ParticleMaster** software package automatically identifies valid particles in an image and calculates all particle properties with outstanding processing speed including statistical information in real-time.

LaVision's **ParticleMaster** can be upgraded from most other laser imaging systems, e. g. from **FlowMaster** PIV systems. Main additional parts are the high efficiency diffusor and the high-magnification lens.



3D imaging of bubbly flows

System features ParticleMaster Shadow

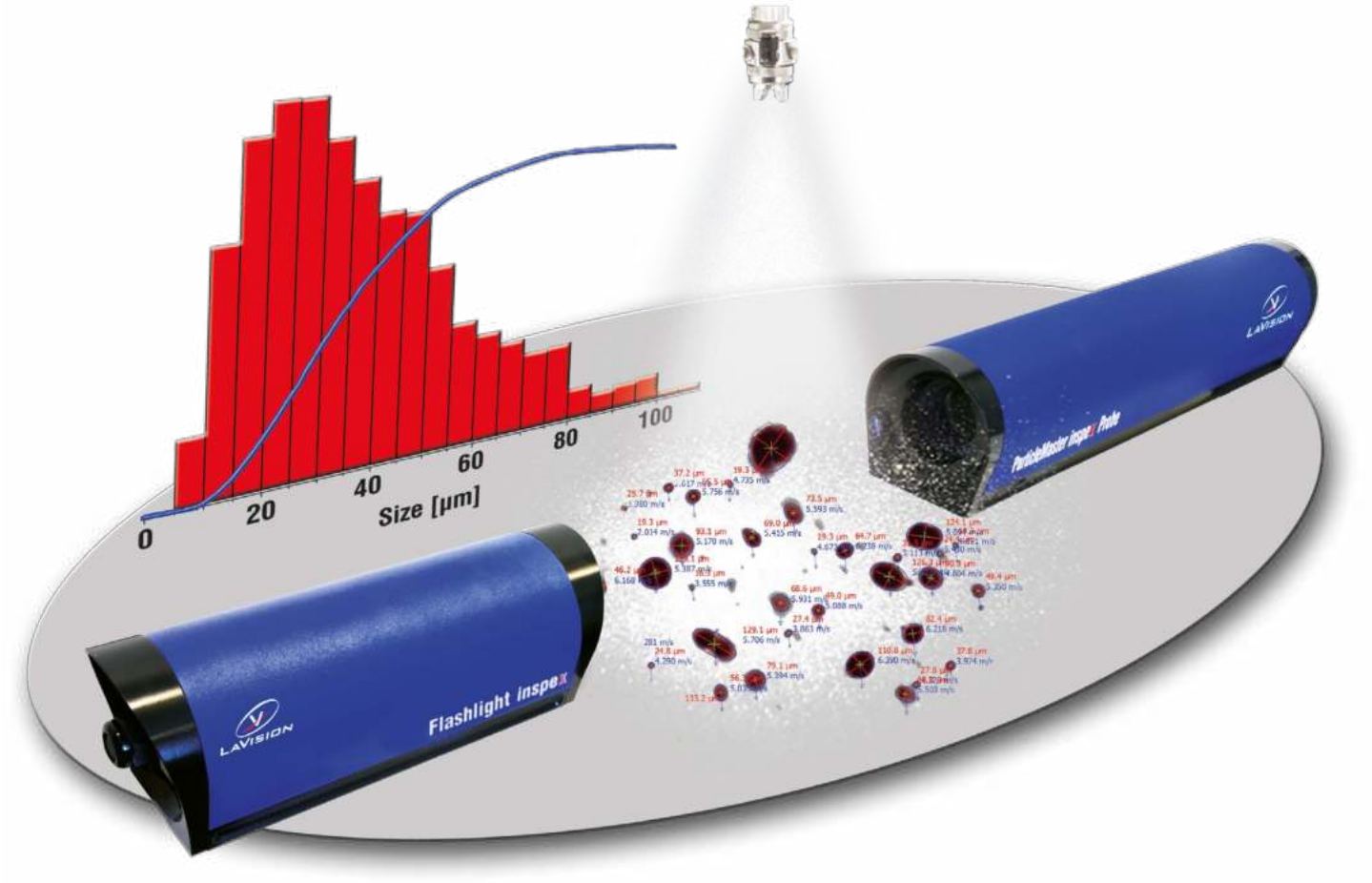
- simultaneous size, position and shape
- particle number density (corrected for different size classes)
- particle velocity derived from double frame exposures
- velocity - size correlations, histograms, scatterplots
- mass flux
- visualization of ligaments, spray break-up and atomization

LaVision's **ParticleMaster *inspex*** system is especially designed for quality control applications in industrial environments. It serves as a highly integrated laboratory and testing tool for the measurement of size, shape and velocity of spray droplets, particles and grains.
The **ParticleMaster *inspex*** combines the advantages of high-magnification shadow imaging with an easy-to-use design. When particle properties are important process parameters and have to be monitored in real time or in-line, our **ParticleMaster *inspex*** shadow systems are the right choice.

The compact and highly integrated design of the **ParticleMaster *inspex*** aims for daily laboratory use and quality control testing. The system is ready to use out of-the-box, splash-proof and eye-safe. A well-defined mechanical interface allows the integration into existing test benches.

ParticleMaster *inspex* measured quantities

- size, shape, orientation, perimeter of individual particles and droplets
- velocity and mass flux from dual frame images
- cumulated statistics D_{10}, D_{32}, percentiles D_{v10}, D_{v50}, D_{v90}
- size histograms, scatterplots



System features ParticleMaster *inspex*

- in-situ particle imaging: size, shape and velocity
- no sample preparation required
- compact self-contained probes and lights
- fully factory aligned – no customer calibration needed
- includes size and depth-of-field calibration
- eye-safe LED operation
- splash proof IP54 design

Factory calibration

The **ParticleMaster *inspex*** is delivered with a factory calibration including

- size and velocity calibration
- depth-of-field calibration for absolute density and flux
- center of measurement location

The **ParticleMaster** software recognizes each individual **ParticleMaster *inspex*** probe and loads the corresponding calibration data automatically. Due to the factory calibration a probe can be easily swapped and replaced by another one in shortest time and with high reproducibility.

ParticleMaster *inspex* components

ParticleMaster *inspex* probes are the heart of each system. They contain a high-resolution camera with a high-magnification lens in a solid splash-proof enclosure. The factory aligned and calibrated probes allow a quick and reproducible setup.

The probes are available with a camera for sizing only („S“ series) or for additional flow measurements with double-exposure included („F“ series). Different working distances are available: for small droplets a short working distance is favorable, while larger working distance can be more convenient for larger scale sprays or for measurement in spray chambers.

The **ParticleMaster *inspex*** flashlight is an eye-safe LED optimized for ultra-short illumination. Flashes as short as a 100 ns freeze any motion blur of most particles. Its splash proof rugged design makes it feasible for in-situ measurements and industrial applications.

The integrated double pulse feature of the LED supports the velocity measurement capabilities of the „F“ series probes. A high-current mode for maximum brightness turns on automatically for the short pulses. The flashlight is compatible with all **ParticleMaster *inspex*** probes but also with high-speed cameras for research systems.

The **ParticleMaster *inspex*** controller integrates powerful computing hardware with precise triggering and all required power supplies. The entire system is unboxed and operational within a few minutes time.

- quad core CPU, fast SSD, large HDD
- **PTU X** timing unit for system control and versatile triggering
- power supply and interface to probe and flashlight
- **DaVis 10** software for data acquisition, management and visualization
- **ParticleMaster** software package for particle image analysis

ParticleMaster *inspex* in automated quality control

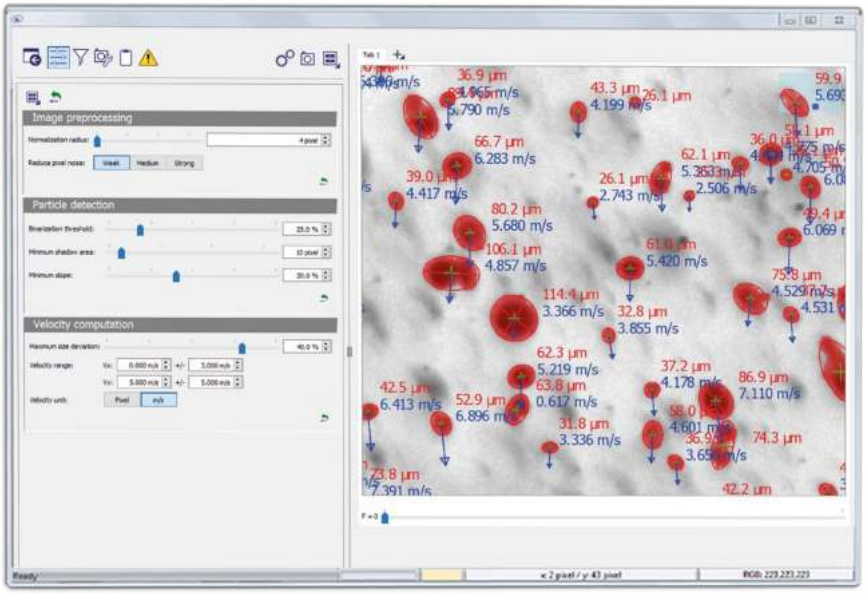
LaVision‘s imaging software **DaVis 10** can be integrated into 24/7 fully automated production environments. A customizable remote control interface turns the system into a production line testing tool. Either manually operated or machine integrated operation the interface speeds up testing with predefined operation templates and integrated PDF report generation.

ParticleMaster Shadow software

All **ParticleMaster** systems are based on DaVis 10 and the powerful **ParticleMaster** analysis software package.
The **ParticleMaster Shadow** software offers interactive particle detection and statistics generation. Images taken live from the camera or loaded from recordings on disk are processed automatically in the background, while the operator can fine-tune particle detection parameters or live filters. Any action will be immediately reflected in the displayed results. Giving instant feedback provides an intuitive approach to high-magnification shadow imaging with a quick learning phase.

The **ParticleMaster Shadow** software includes

- direct feedback on operation interaction
- live camera processing
- user customized layout
- result export
- automated mass processing using DaVis 10 hyperloop function
- detailed insight into each detected particle or droplet

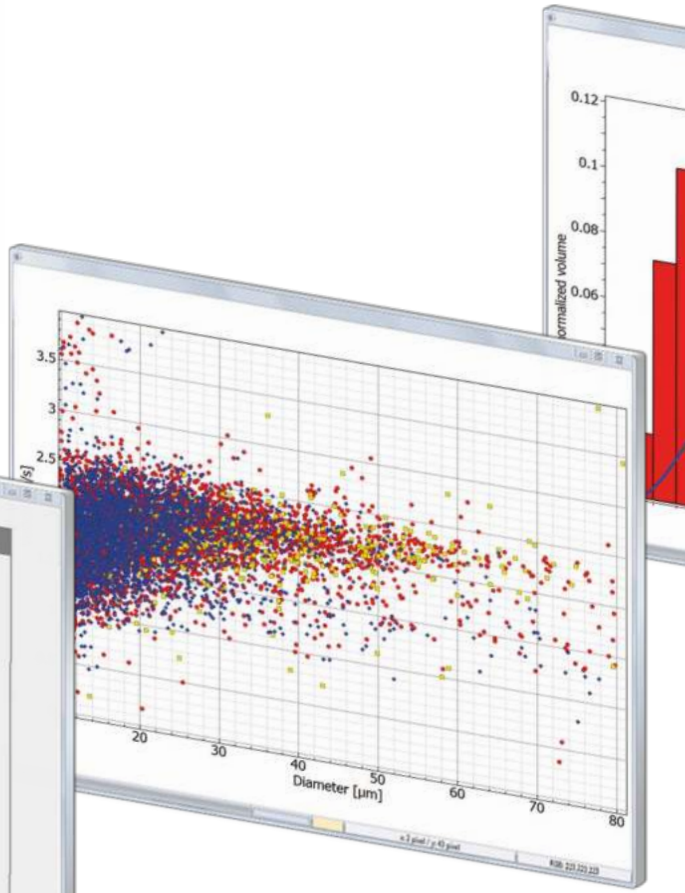


Interactive particle recognition

Particles, droplets and bubbles are detected by their shadow image. The detection can be optimized for contrast, brightness and size. Any operator interaction leads to an immediate recalculation and gives highly intuitive instant feedback.

Particle filters

Once particles or droplets are detected, their contribution to any statistics can be filtered based on size or morphology with immediate effect on the result output. A time based filter allows investigating the temporal evolution of transient phenomena like pulsed sprays.



Scatterplots

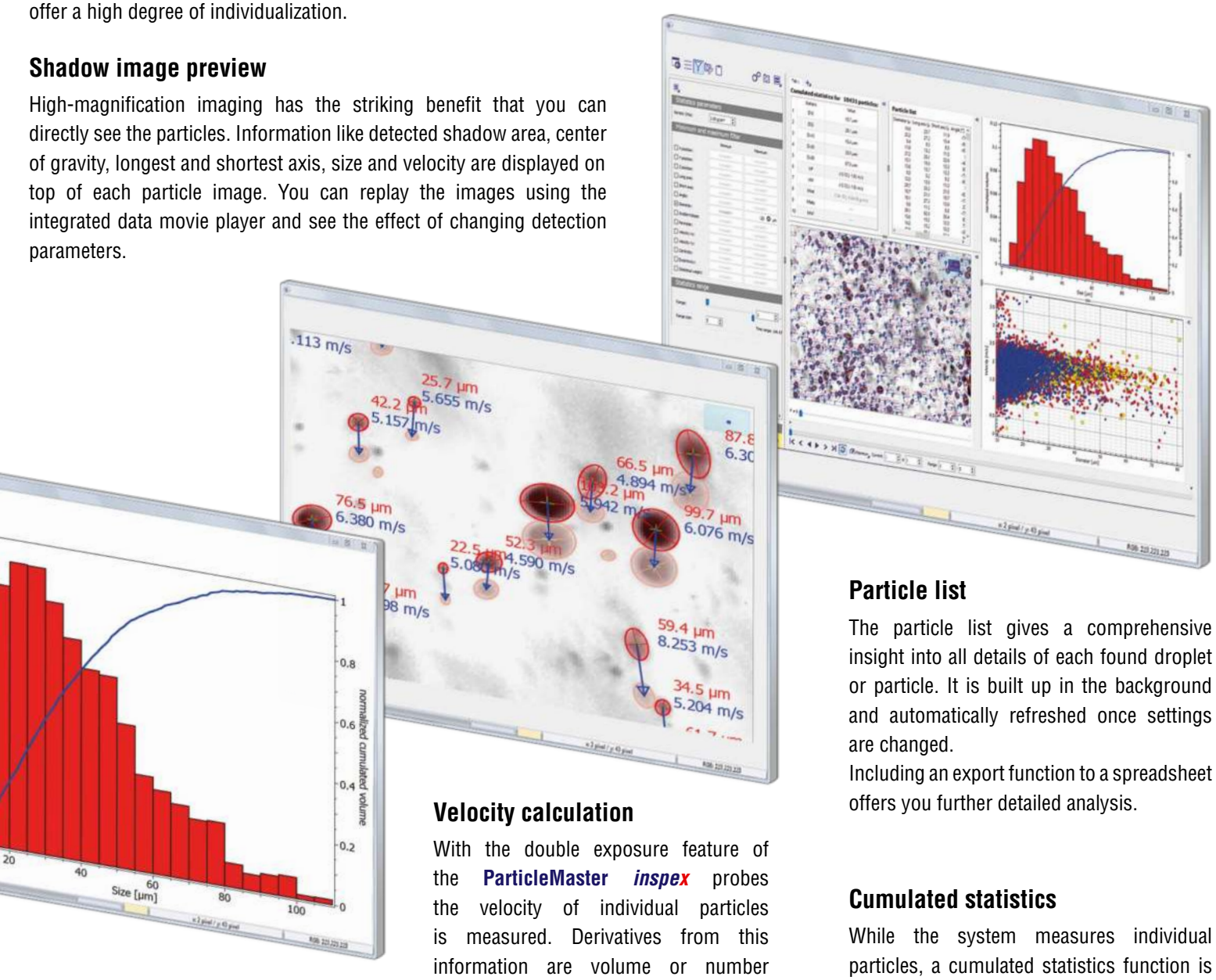
Scatterplots show general trends in the particle distribution. With an extra filter for classification analysis of complex data is even simpler.

Individual layout

Every measurement task is different. Therefore, the **ParticleMaster Shadow** software offers a user definable layout. Windows can be arranged to show all relevant information on a single screen. All display features of particle images, histograms and scatterplots are easily adjusted. Once a setting is to your satisfaction, you can conserve it using a DaVis 10 shelf. Multiple tabs allow changing quickly between different layouts and offer a high degree of individualization.

Shadow image preview

High-magnification imaging has the striking benefit that you can directly see the particles. Information like detected shadow area, center of gravity, longest and shortest axis, size and velocity are displayed on top of each particle image. You can replay the images using the integrated data movie player and see the effect of changing detection parameters.



Histograms

Size histograms belong to the most important results. Histograms can be linear, logarithmic or according to ISO 565 sieves. Probability is shown based on number or volume. Once the **DOF** calibration is applied, the histogram reports absolute number and mass densities. Multiple size histograms can be shown at the same time, each with individual settings.

Velocity calculation

With the double exposure feature of the **ParticleMaster *inspex*** probes the velocity of individual particles is measured. Derivatives from this information are volume or number weighted average velocity and mass flux.

Export

Export of screenshots and data tables including the entire particle list is part of the processing chain. This allows to automate the export of larger data sets using the DaVis hyperloop feature.

Particle list

The particle list gives a comprehensive insight into all details of each found droplet or particle. It is built up in the background and automatically refreshed once settings are changed.
Including an export function to a spreadsheet offers you further detailed analysis.

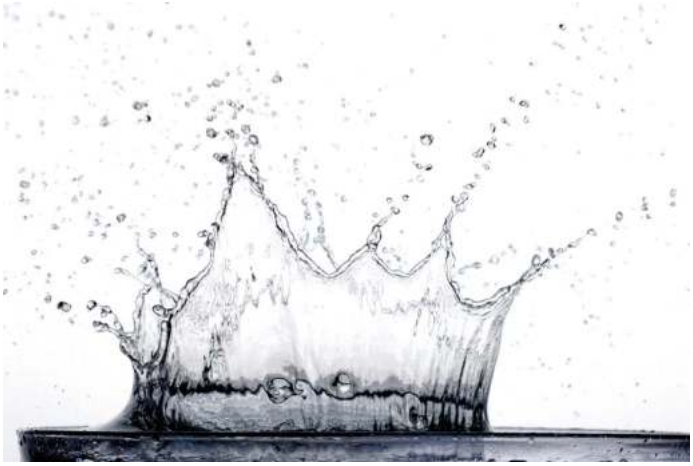
Cumulated statistics

While the system measures individual particles, a cumulated statistics function is built up for data aggregation. This includes the commonly reported mean diameters, but also average velocity and mass flux information for double pulse and **DOF** calibrated systems.

ParticleMaster Shadow system components

ParticleMaster Shadow systems can be built of almost any LaVision camera and laser. This modular approach of all LaVision laser imaging systems opens a convenient and cost effective upgrade path from existing systems. All solutions benefit from high flexibility, especially required in research environment.

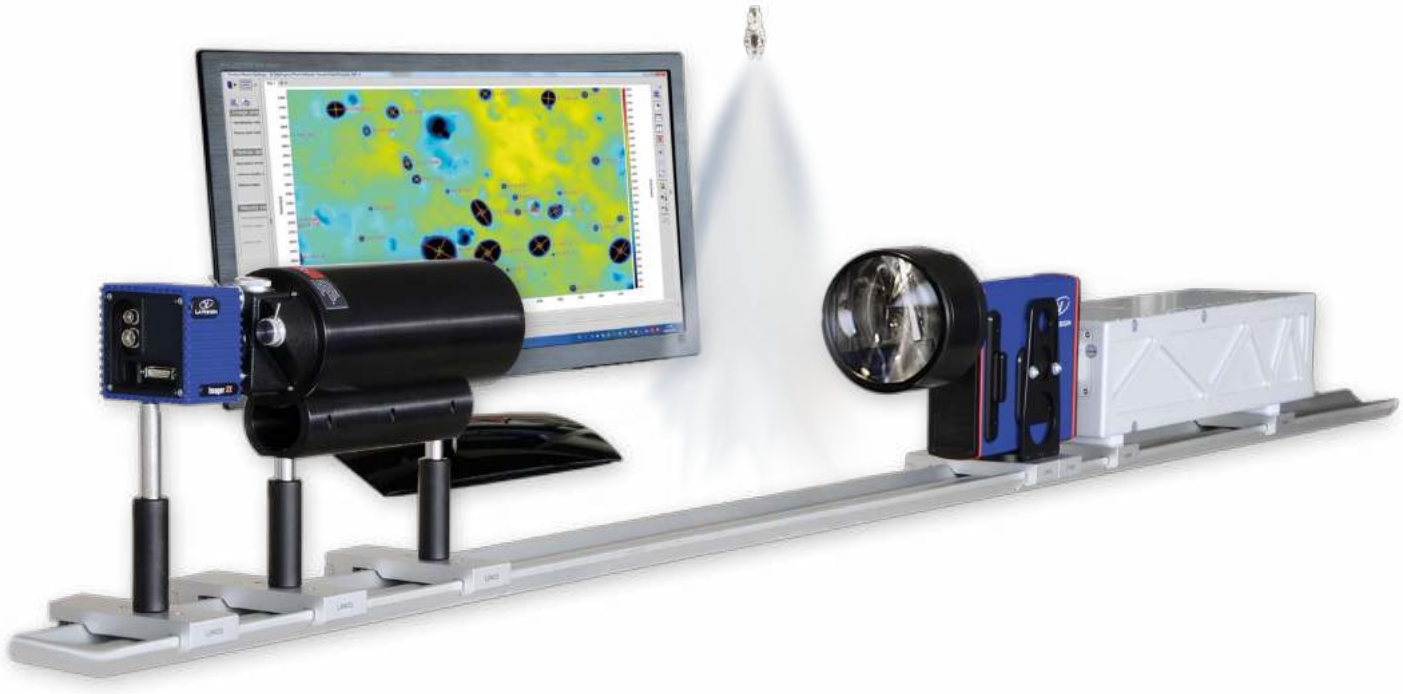
A **ParticleMaster Shadow** system can be designed based on a common principle from a large variety of cameras, lenses and illuminations.



The **High-Efficiency Diffuser Optics** yields more than a factor of 10 more light compared to the standard model. As a result, much less laser power is needed for e.g. particle sizing with LaVision's **ParticleMaster** systems. A laser with 15 mJ output power or even less is sufficient to analyze typical fields of view of a few mm.

The integrated collimating lens is ideally designed for high-magnification particle sizing applications. A laser interlock is included for safe use of the device together with a laser source. A fiber optics cable for remote positioning of the collimator head is available as an option.

High-magnification lens optics pick up the shadow image out of the measurement volume from a remote distance. Long-distance microscope lenses allow to measure tiny droplets and particles up to a meter stand-off distance, while close-up lenses and telecentric lenses grant high image magnification for the smallest particles down to the resolution limit of optics.



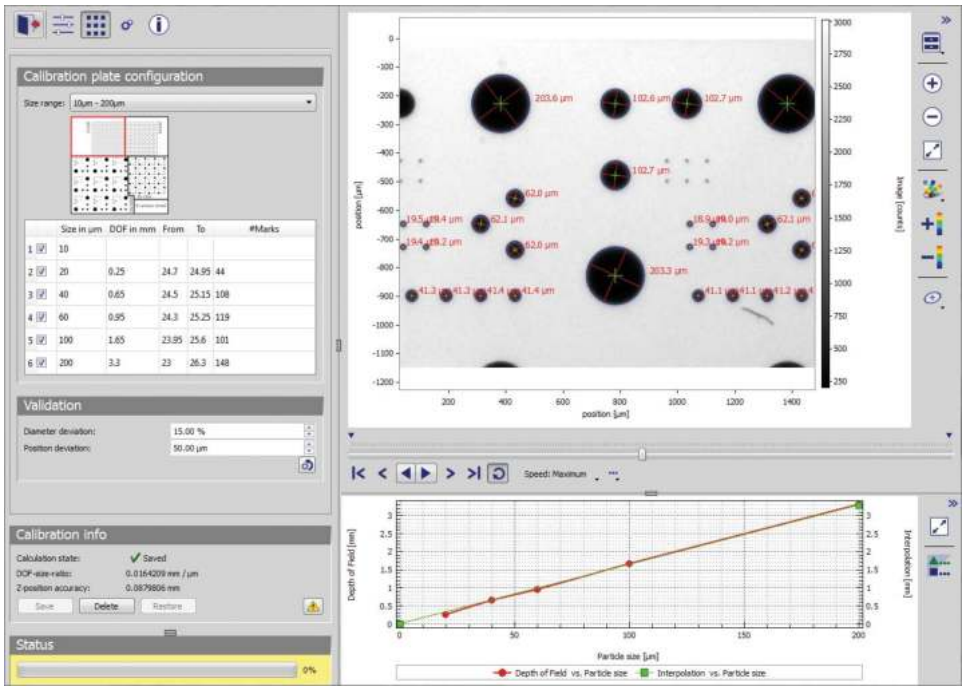
ParticleMaster add-on package

The **Depth-of-Field** (**DOF**) calibration is an add-on package to the **ParticleMaster**. It enables the **ParticleMaster** for the measurement of absolute number densities and derivatives from that based on the knowledge of the sample volume size. This volume is defined by the camera field of view in the focal plane and the size-dependent depth of field of the imaging system detecting only focused particles.

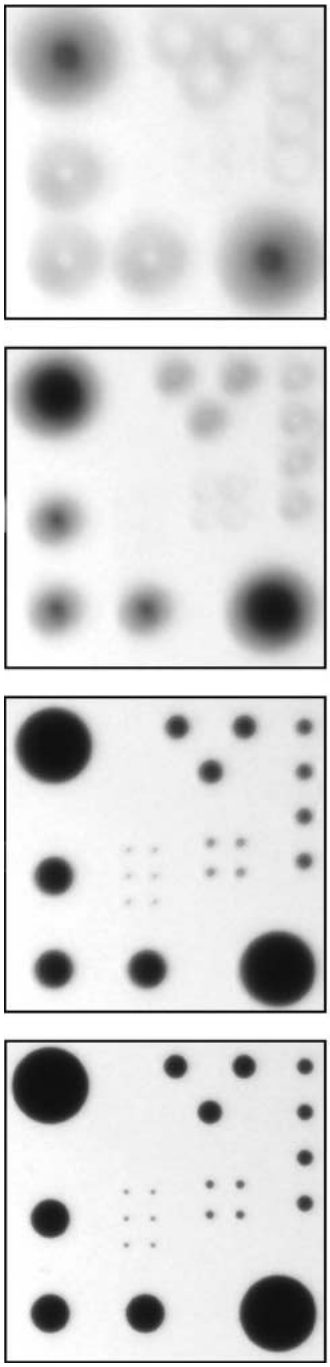
Without **DOF** calibration the **ParticleMaster** is counting detected particles and generating statistics, like size histogram (size spectrum) and weighted size averages (D_{10}, D_{32}, D_{v50}, etc…). But all these numbers are relative in the way that the sample volume the information has been derived from is of unknown size. The **DOF** calibration tests several diameter particles with a dedicated **DOF** calibration target. Performing the **DOF** calibration the sample volume is known and the **ParticleMaster** system measures absolute number density related values.

ParticleMaster measured quantities

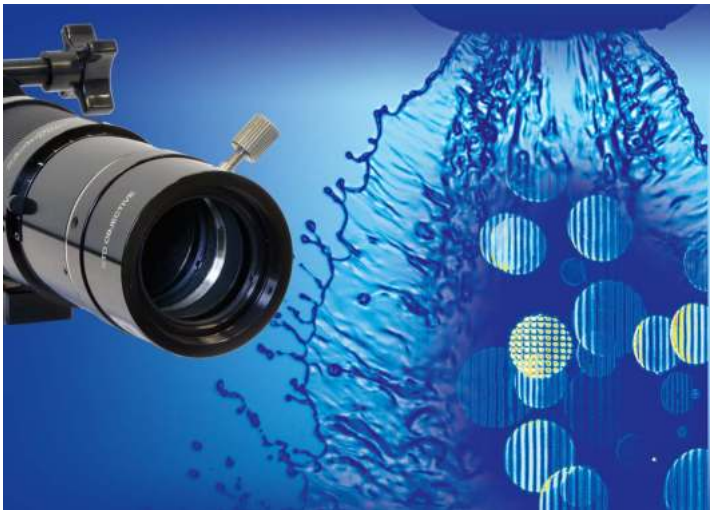
Measured quantity	Single exposure	Double exposure	Depth-of-Field calibration
Particle diameter [µm]	✓		
Short/long axis, perimeter [µm]	✓		
Particle velocity [m/s]		✓	
Weighted average diameters D_{10}, D_{32}, D_{v10}, D_{v50}, D_{v90} [µm]	✓		
Number/volume weighted average velocity [m/s]		✓	
Relative size spectrum [#/µm]	✓		
Number density [#/cm³]			✓
Mass density [g/cm³]			✓
Volume fraction [vol%]			✓
Number density spectrum [#/cm³µm]			✓
Mass flux [g/cm²s]		✓	✓



A dedicated Depth-of-Field calibration dialog interactively leads through the process using the **DOF** calibration kit.

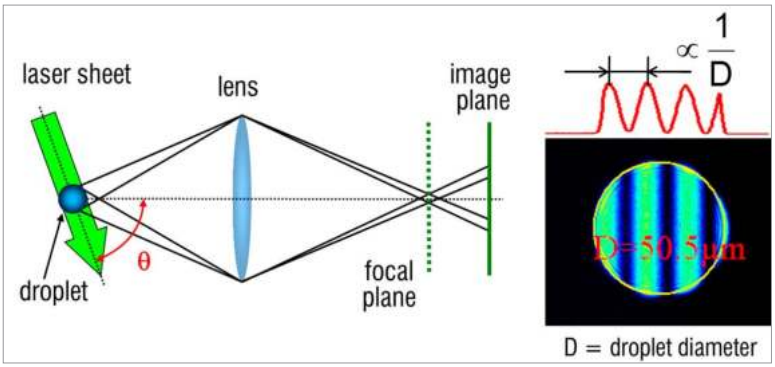


Size dependent DOF calibration image sequence



ParticleMaster IMI system

LaVision's **ParticleMaster IMI** imaging system is optimized for spray investigations of smaller droplets at low and medium droplet densities. Defocused Mie imaging is used to generate a fringe pattern from each droplet with its fringe spacing related to the droplet size. This intererometric sizing method is applicable to transparent and spherical particles. The **ParticleMaster IMI** system is hardware compatible with LaVision's **FlowMaster** PIV systems.

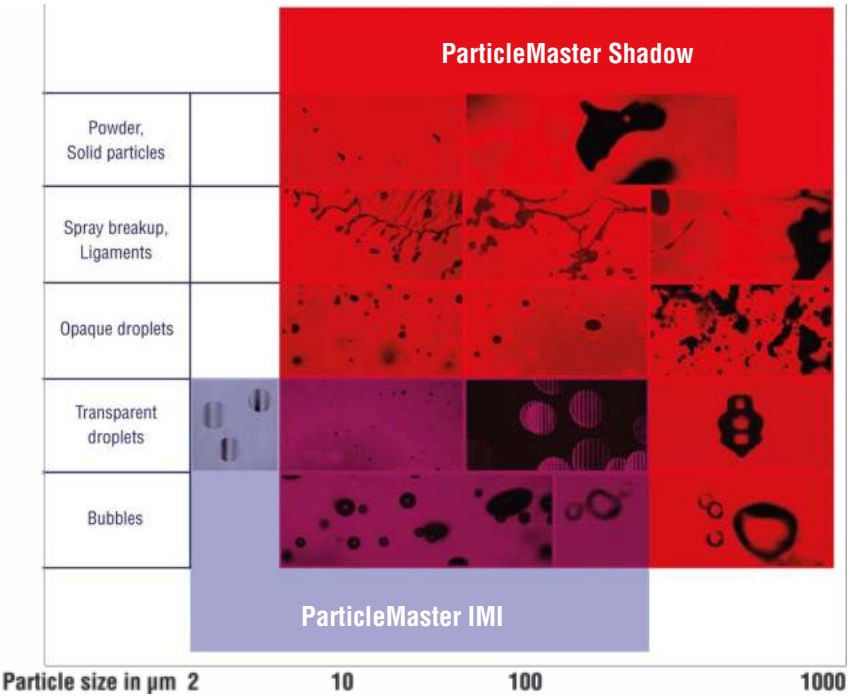


Interferometric Mie Imaging: IMI
(aka Interferometric Laser Imaging for Droplet Sizing, ILIDS)

System features ParticleMaster IMI

- auto-detection with droplet location from a single camera
- droplet size from fringe pattern analysis
- droplet velocity derived from double frame exposures
- velocity - size correlations, histograms, scatterplots
- hardware compatible with FlowMaster PIV systems

Interferometric **M**ie **I**maging (**IMI**) is a sizing technique for the evaluation of the diameter of spherical droplets and bubbles. It is based on the out-of-focus imaging of particles illuminated by a laser light sheet. While moving the camera to an out-of-focus position an interference fringe pattern becomes visible from the nature of Mie scattering. The number of fringes within the aperture image increases with droplet or bubble size determined by analysis of the fringe patterns. The size of the aperture image itself is a measure for the z-position of the particle along the line-of-sight.



Shadowgraphy vs. Interferometric Mie Imaging

Both, **ParticleMaster Shadow** and **IMI** are based on imaging techniques to measure particle size. Their limit to smaller size is determined by the nature of light.

While the shadowgraphy technique uses a direct image, IMI is based on coherent light scattering and allows to extend the range of detectable droplets to even smaller sizes. It requires spherical transparent droplets (or bubbles) while the shadowgraphy technique is more universal in applicable media and shape.

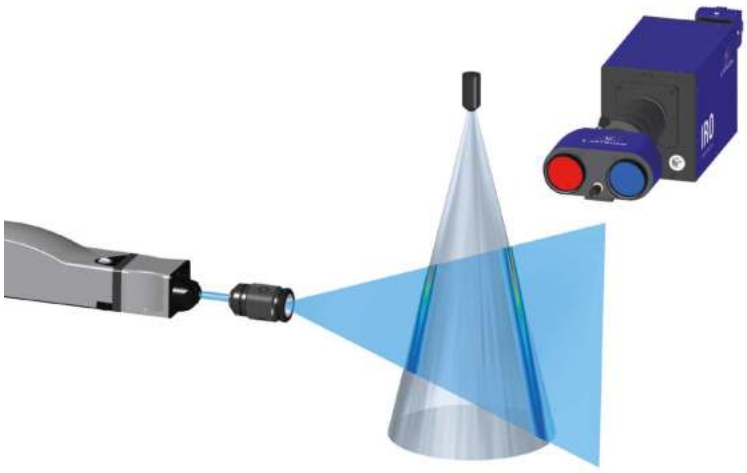
In very sparse sprays IMI has a potentially higher data rate due to the larger field-of-view compared to high-magnification shadowgraphy.

IMI is most suitable for sparse distributions of small transparent spherical droplets or bubbles.

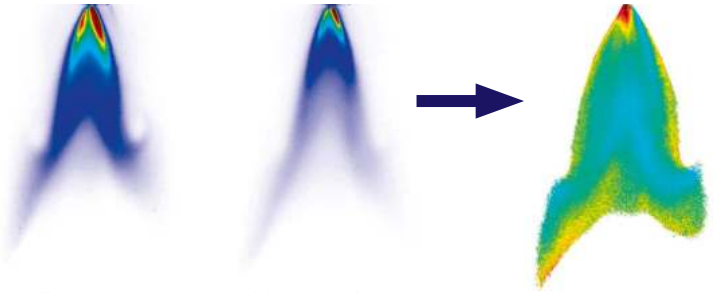
Laser imaging in sprays - Global Droplet Sizing

Laser light sheet imaging applied to sprays reveals instantaneous 2-dimensional maps of the relative Sauter Mean Diameter (SMD or D_{32}). Each snapshot represents the 2D distribution of the average droplet size, showing the dynamic behavior and the spatial structure of spray evolution.

A **ParticleMaster** system can be used as a calibration device to convert the relative size information from the LIF/Mie technique into absolute numbers.



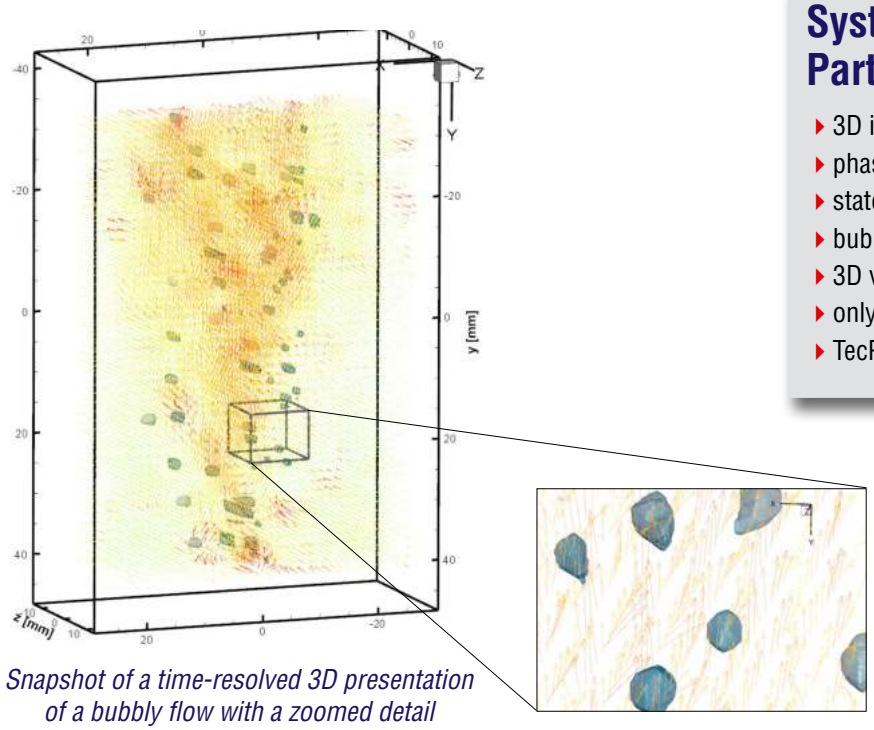
LIF/Mie imaging setup for global droplet sizing



LIF = volume *Mie = surface* D_{32}

Tomographic shadowgraphy in multi-phase flows

Tomographic shadow imaging is used to reconstruct the bubbles in 3D space as well as the locations of the much smaller seeding particles dispersed in the liquid phase. Phase separation is performed using a software filter sensitive to the size difference between the seeding particles and the bubbles.



Snapshot of a time-resolved 3D presentation of a bubbly flow with a zoomed detail

System features ParticleMaster Tomo-Shadow

- 3D imaging based on tomographic shadowgraphy
- phase separation based on shadow image size only
- state-of-the-art "**Shake-the-Box**" 4D-PTV algorithm
- bubble shape, size and velocity
- 3D velocity and acceleration field of the liquid phase
- only one backlight for volumetric illumination
- TecPlot™ presentation of both phases in one coordinate system

movie and more

3D snapshot imaging of the two-phase flow shows nicely the interaction between rising bubbles and the induced flow field in the water tank. The tomographic shadow imaging technique is scalable in space and time: larger and smaller volumes can be investigated depending on the desired spatial resolution. With a selection of high-speed cameras the recording rate can be increased to study faster flow phenomena at a higher time resolution.

ParticleMaster

Intelligent Imaging for Particle and Droplet Characterization

Droplets

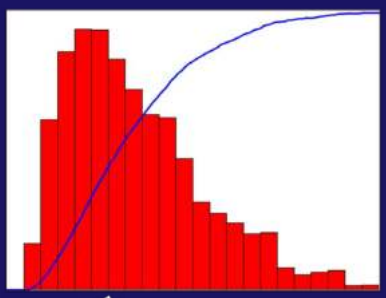
- sprays
- melts
- spray drying

Bubbles

- heat exchangers
- multi-phase flows
- cavitation

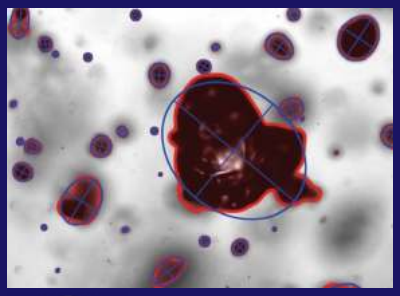
Particles

- grinding
- powders
- grains



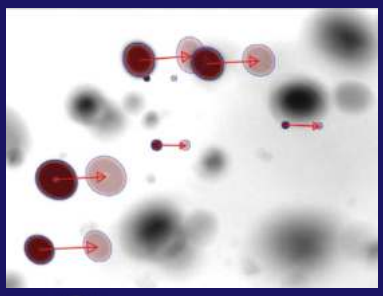
Size

- diameter, D_{32}, D_{v50}, etc
- size histogram



Shape

- axis orientation
- perimeter



Velocity

- spray dynamics
- mass flux

Research

- flexible system design
- upgradable hardware

Industry

- production monitoring
- safe operation

DAVIS 10

Quality Control

- automatic & quick testing
- process control interface

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