Particulate Sensor Technology Development at NASA Glenn Research Center

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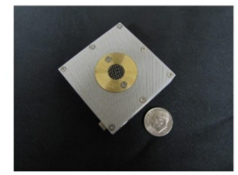
GRC has a history of innovative particulate sensor technology development

GRC has developed multiple innovative particulate sensor technologies for spacecraft cabin environmental monitoring, spacecraft fire safety, and lunar dust characterization. This has been driven by a lack of commercial (COTS) devices to meet the volume, mass, power, reliability, and measurement requirements of any given application.

- ***Multi-Parameter Aerosol Scattering Sensor (MPASS):*** An ensemble scattering sensor based upon angle-dependent light scattering for the determination of statistical moments of aerosol size distributions for d > 200 nm. [R&D 100 recipient 2011]



- ***Miniature Optical Particle Counter (mOPC):*** A single particle optical scattering sensor for particulate counting and sizing for d > 200 nm.

- ***Microscale Particle Classifier***: A differential mobility classifier for ultrafine particle detection and sizing (10 nm < d < 200 nm). [R&D 100 recipient 2009]

- ***Foldable Optical Confocal μScope (FOCμS):*** A compact long working distance microscope that enables surface inspection and imaging of deposited lunar dust.

- Members of the team working on these technologies include:

  David Fischer / NASA GRC
  Paul Greenberg / NASA GRC
  D.Y.H. Pui / University of Minnesota
  Da-Ren Chen / Virginia Commonwealth University
  George W. Mulholland / NIST (retired)
  Donald Duncan / Portland State University
  James A. Berilla / Case Western Reserve University
  Christopher Shorter / Case Western Reserve University
  Chaolong Qi / NIOSH
  Jacqueline Jordan / Clayton State University (respiratory toxicologist)

- The emphasis has been on ultra-compact, physically robust packages, making them suitable for a variety of scientific and mission applications, both in terrestrial and planetary environments.

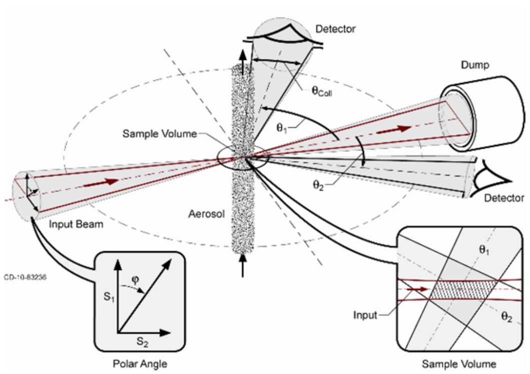
- GRC is currently funded under a STMD CIF to develop a sensor architecture for discriminating lunar dust from combustion precursor particles, providing reliable fire detection as well as monitoring respirable air quality.

I. Multi-Parameter Aerosol Scattering Sensor (MPASS)

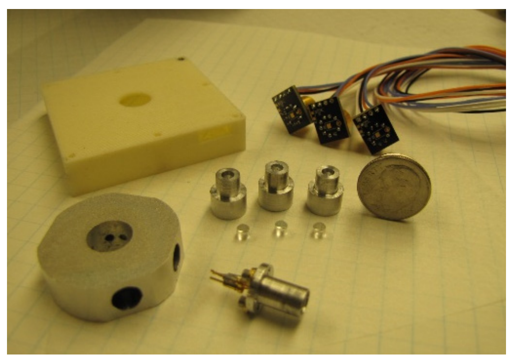
- A fixed angle, multiple detector photometer.
- Measures scattering from ensemble particles to determine integrated moment quantities (e.g. total mass concentration).
- Can be configured and optimized to measure various moment quantities, i.e. number, surface area, mass.
- Provides bound on measurement uncertainty for specified classes of aerosols.

Unique, state-of-the-art attributes:

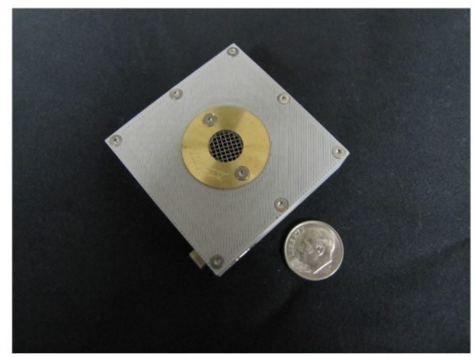
- Lowest size and power consumption photometer available.
- Only technology that is *extensible*: can be applied to different aerosols without the need for re-calibration.
- Passive architecture does not require active sampling pumps.
- Stand alone battery power with wireless smartphone compatible bi-directional interface.



Mechanically and thermally robust optical design



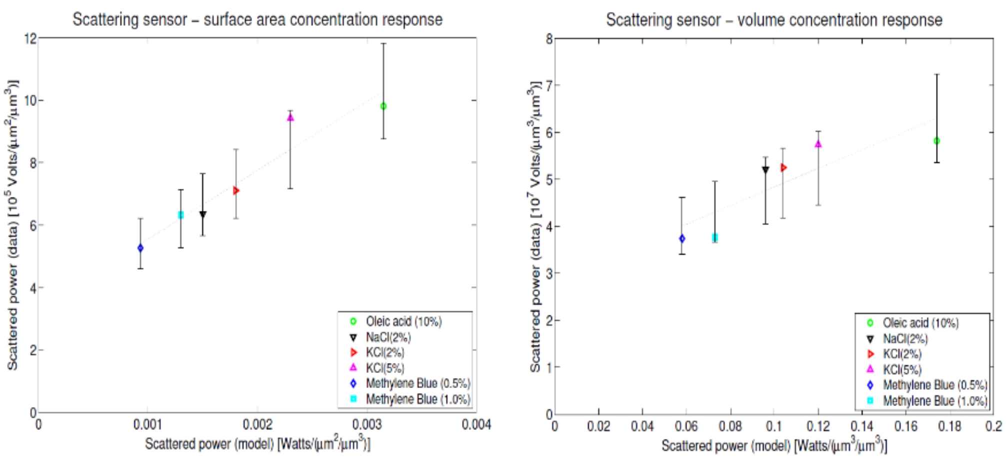
Internal micro-optical components



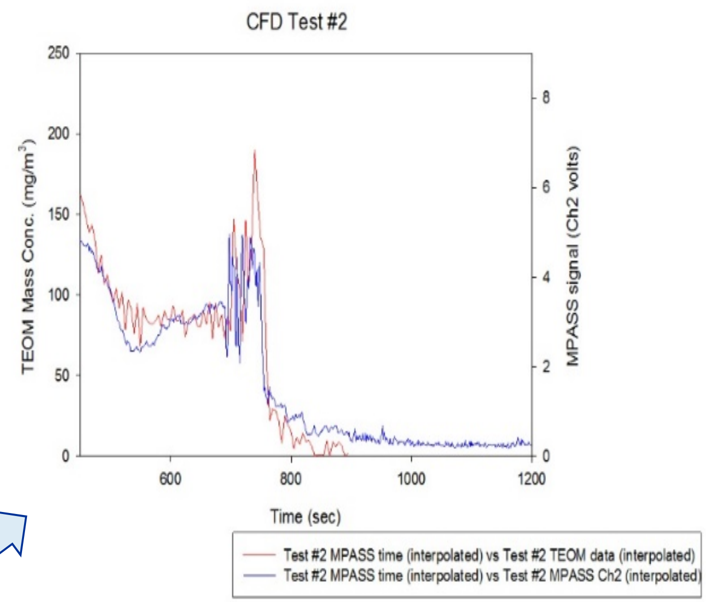
Most compact multichannel photometer ever produced

Multi-Parameter Aerosol Scattering Sensor (cont'd):

- In addition to advancing the state-of-the-art in the physical package, the development also provides advancements in performance (increased measurement accuracy, detection sensitivity, and dynamic range).



Measured vs. modeled performance
2nd and 3rd Moments



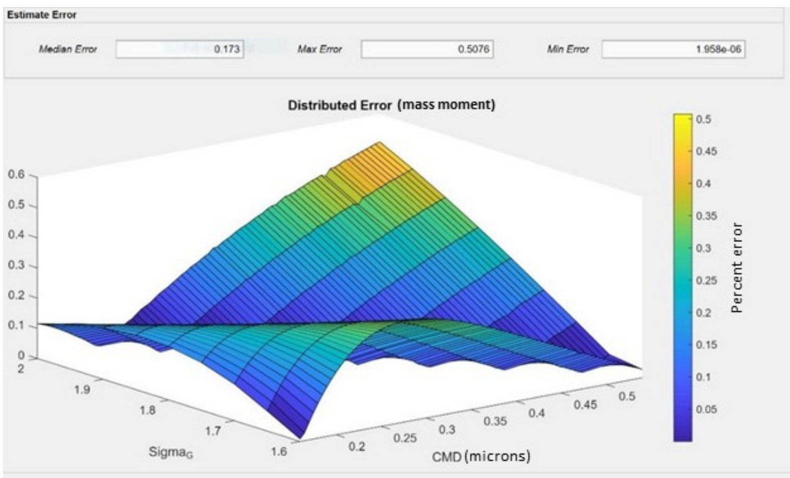
Field test data from Cleveland Fire Department controlled residential fire simulation.

Comparison of MPASS 3rd moment (mass) with direct reading TEOM mass reference.

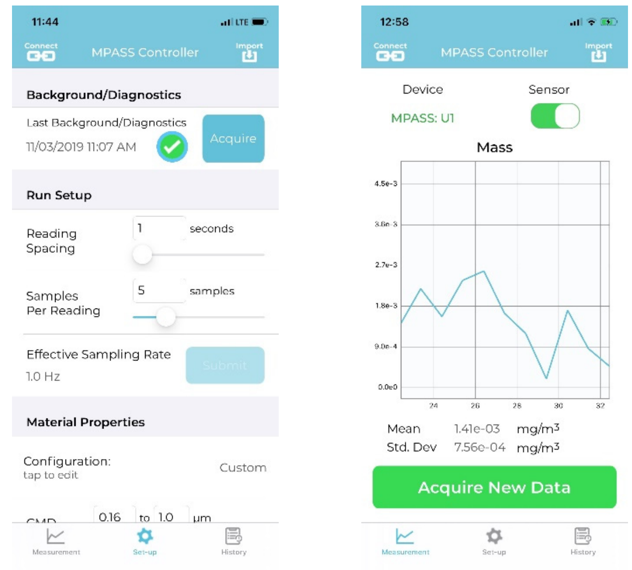
Note that the MPASS measurement of mass concentration accurately tracks the TEOM measurement over the course of a test ***where the size distribution parameters and composition of the aerosol are constantly changing in time.***

Multi Parameter Aerosol Scattering Sensor (cont'd):

- Also developed is a user friendly graphical interface to facilitate:
  - All aspects of hardware calibration and status checks.
  - Configuration of targeted aerosols and desired moment properties.
  - Data logging and retrieval.
  - Analysis and plotting.
  - Calculation of measurement error bounds.



Calculated error bounds as a function of distribution parameters

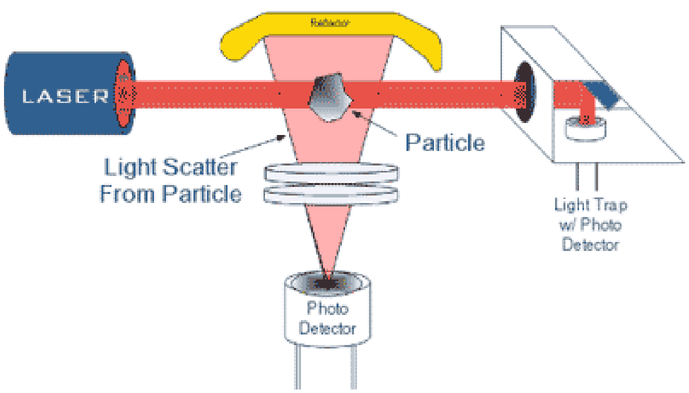


Screen shots of smartphone configuration and real-time data displays

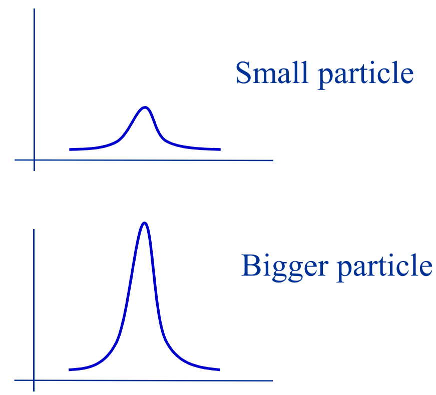
- Present efforts focus on fire detection and respirable dust monitoring in Lunar and Martian environments (CIF funding).
  - Fire signatures and false triggers (dust) overlap in size.
  - Discrimination must be performed on basis of composition and shape.

II. Miniature Optical Particle Counter (mOPC)

- Optical sensor for counting and sizing individual particles.
- Applicable to particles 0.15 – 10 µm (can be extended to larger sizes).
- Primary thrust is major reduction in size and power consumption (i.e. a sensor)
- Additional development concerns novel approach to signal detection and processing.
- Parallel development of compact, seal-less sampling pump.

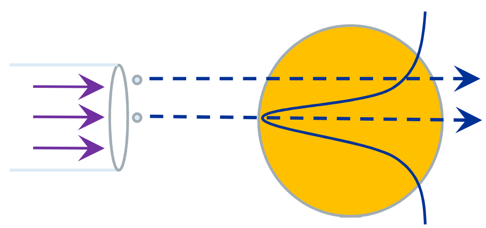


Simple concept: measure light scattered by particle



Bigger particles scatter more light

Primary design driver:
Relationship between curvature in spatial distribution of input beam vs. diameter of particle stream

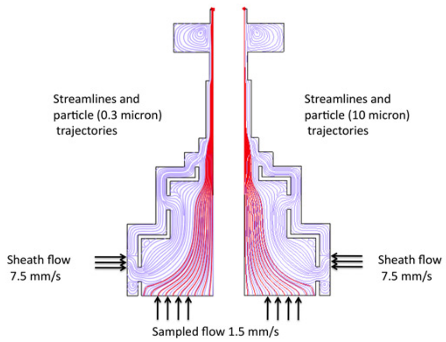


Equal size particles will scatter different amounts of light.
(this design would work badly)

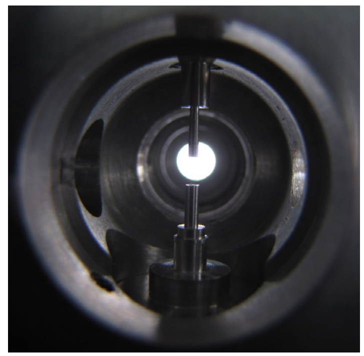
Tighter focused particle stream → more focused laser beam → lower laser power for specified peak energy density → smaller laser source → smaller overall package and power consumption.

Miniature Optical Particle Counter (cont'd.):

- Initial design uses novel aerodynamic focusing nozzle



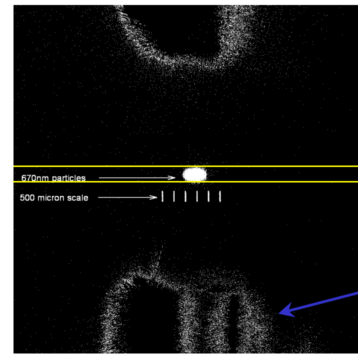
Design model



As built

Exit nozzle

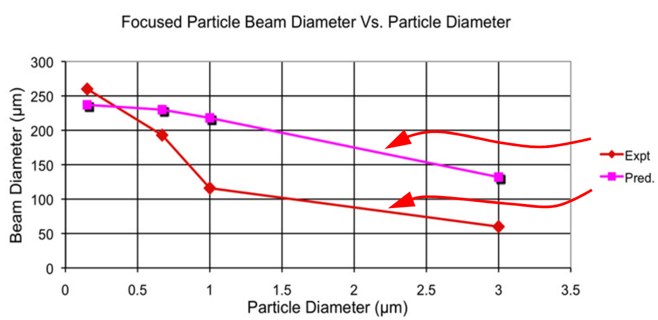
Laser light sheet

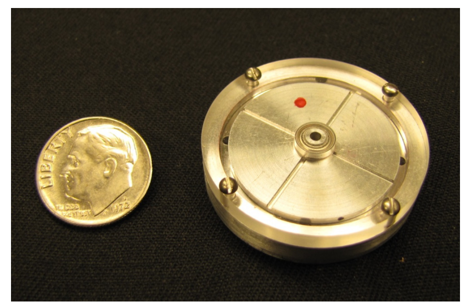


Inlet nozzle

Imaged sample volume

Measured performance





Driven by seal-less
Von Karman micropump
(parallel development)

- Current efforts concern:

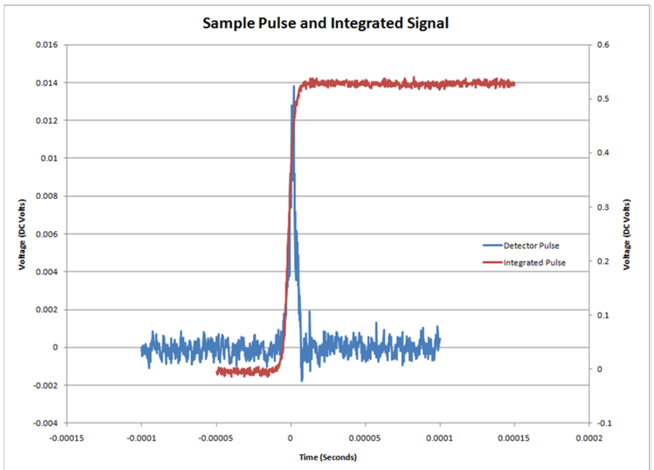
  (i) Free-space, optically defined sample volume (no nozzle)

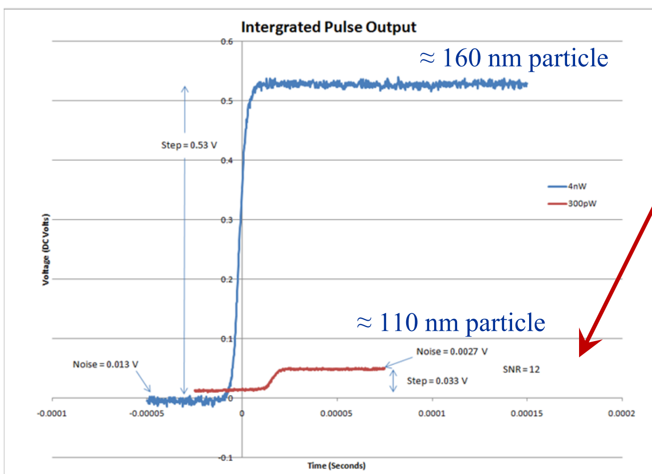
  - Less complex, less prone to clogging, requires no active pump.
  - Applicable to aircraft icing and dust studies, near surface planetary deployment.

  (ii) Collection mirror zonal apodization for increased dynamic range

Miniature Optical Particle Counter (cont'd.):

- ***Advancing the state-of-the-art****: Novel pulse energy detection scheme.*





- Two mantras of low noise signal detection:

  i) Thou shalt not carry excessive bandwidth.
  ii) Thou shalt restrict your bandwidth at the earliest possible stage.

- Direct analog integration of pulse energy accomplishes both.

- Affords favorable output SNR for exceptionally low input SNR.

- Challenge: every integrator ultimately needs to be reset.

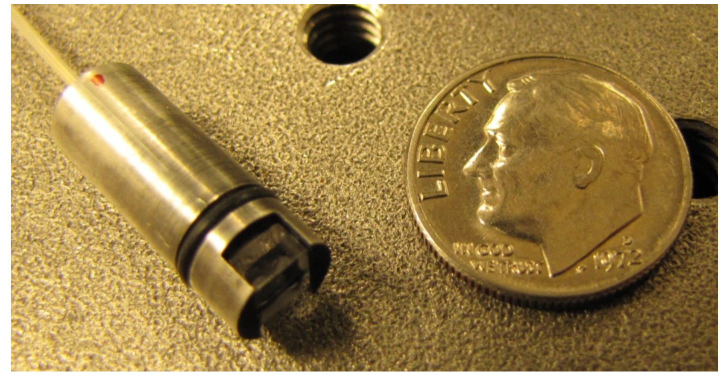
  - For small signals, cannot be accomplished with discrete switch due to capacitive inrush.
  - Novel, active push-pull reset (patent submission in progress).

- Finite reset interval (4 msec) introduces size-dependent dead-time, resulting in potential spectral biasing at high data rates.

Miniature Optical Particle Counter (cont'd.):

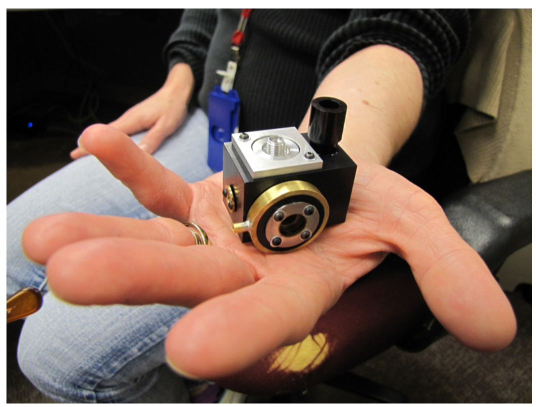
Diamond turned ellipsoidal mirrors

Custom microlenses



Laser transmitter assembly

In-house fabricated micro-optical elements



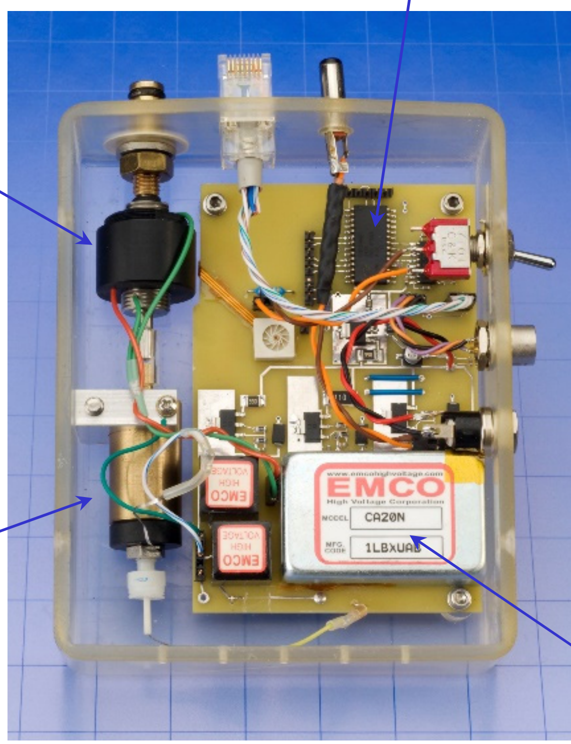
Complete optics and fluidics package

III. Microscale Particle Classifier

- Provides ability to size classify particles 20 nm – 10 µm.
- Includes internal unipolar field charger (alternative to isotope diffusion charging).
- Orders of magnitude reduction in size and power consumption.
- Novel algorithm for inverting size distribution.
- Can be coupled with improved SNR, ultra-compact charge sensitive preamplifier.
- Can perform counting when classifier is used as front end to CNC (condensate nuclei counter), or used as fixed-band prefilter for optical or charge-based detection.

Internal microprocessor

Disc classifier



Unipolar charger

HV supply

Real-time graphical display

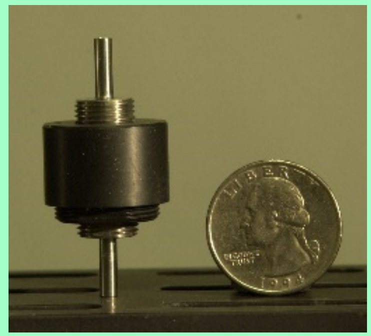
Microscale Particle Classifier (cont'd.):

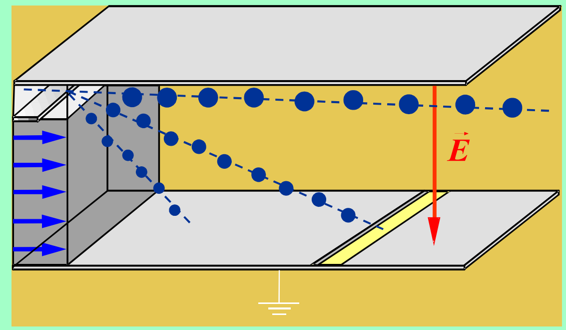
- *Classifier with charge –sensitive detection*

Air

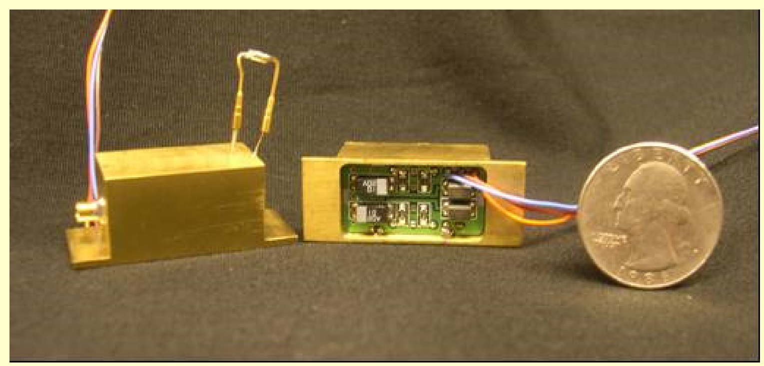
Compact field charger

Differential mobility classifier



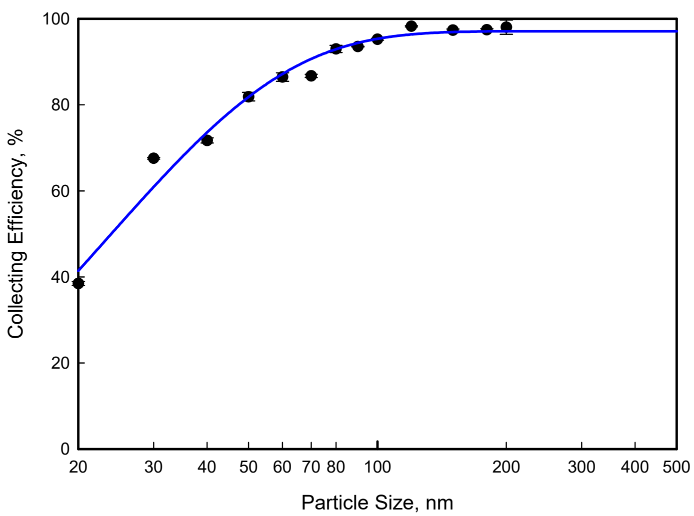


Femtoamp charge – sensitive preamplifier

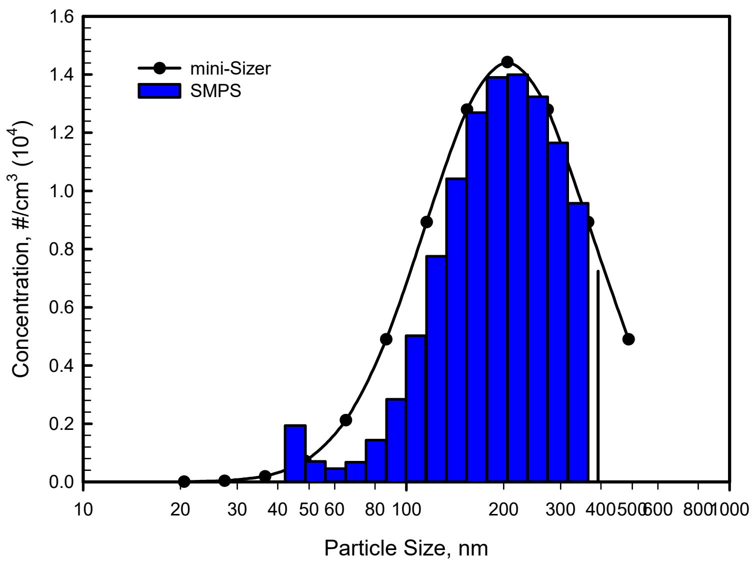


Microscale Particle Classifier (cont'd.):

- *Excellent performance relative to existing laboratory instruments*



High collection efficiency and low inlet losses down to 20 nm

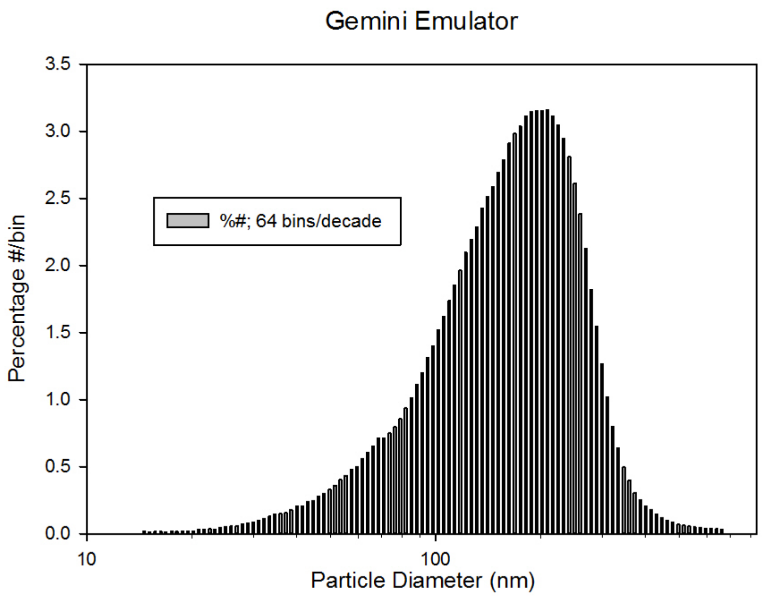


	Total Concentration (#/cm³)	Geo Mean (nm)	Stand Deviation
Mini-Sizer	73826.5	205.35	1.8
SMPS	77300	194	1.62

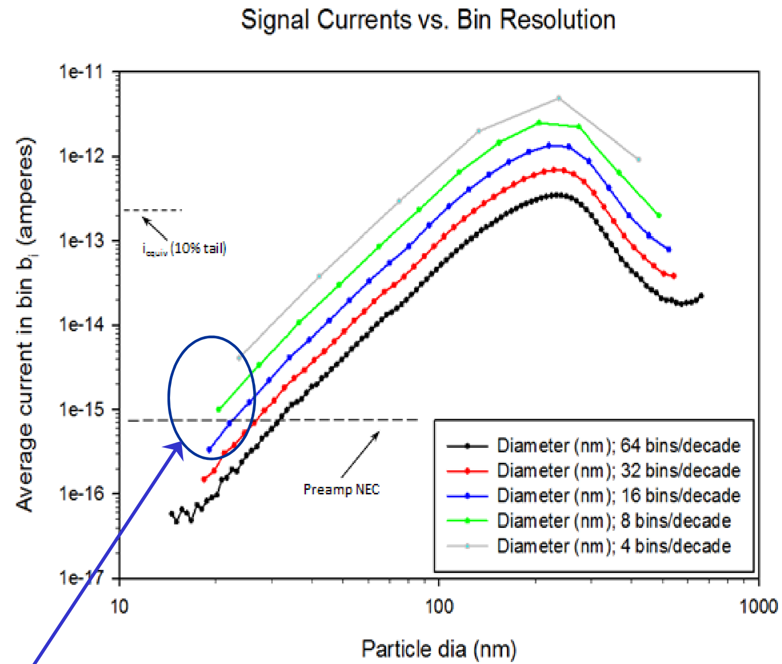
Close agreement on total concentration and modal properties relative to laboratory reference instrument

Microscale Particle Classifier (cont'd.):

- *A useful example: Characterization of spacecraft fire signatures*



Generic early warning (pyrolysis) particle size distribution



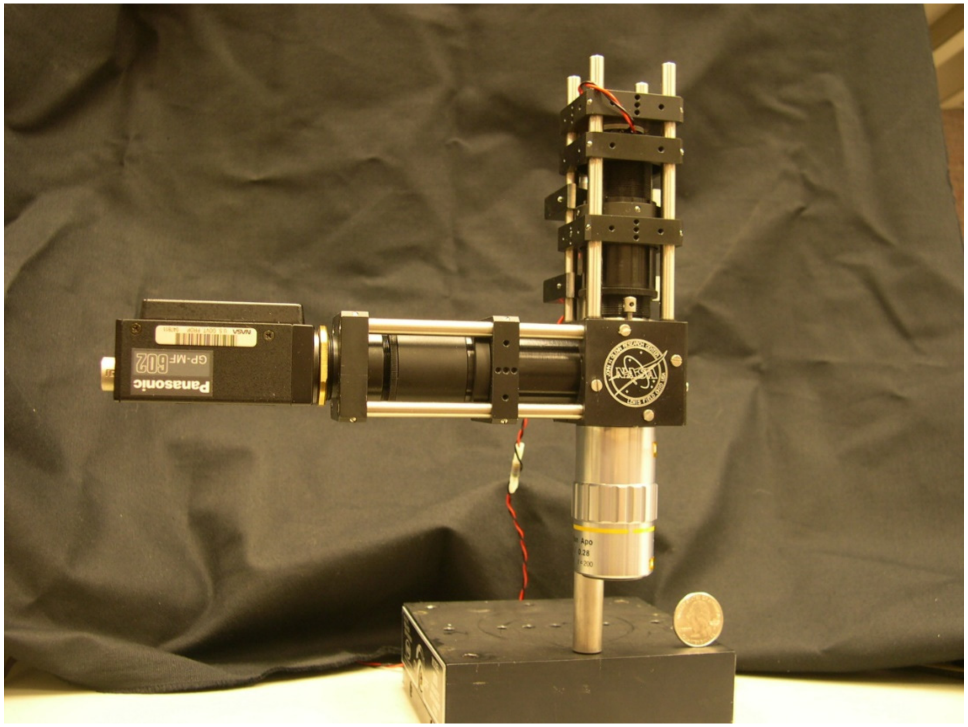
Detection threshold of micro-classifier with charge sensitive detection vs. bin resolution

Minimal truncation at small end of spectrum even at 8 – 16 bin resolution.

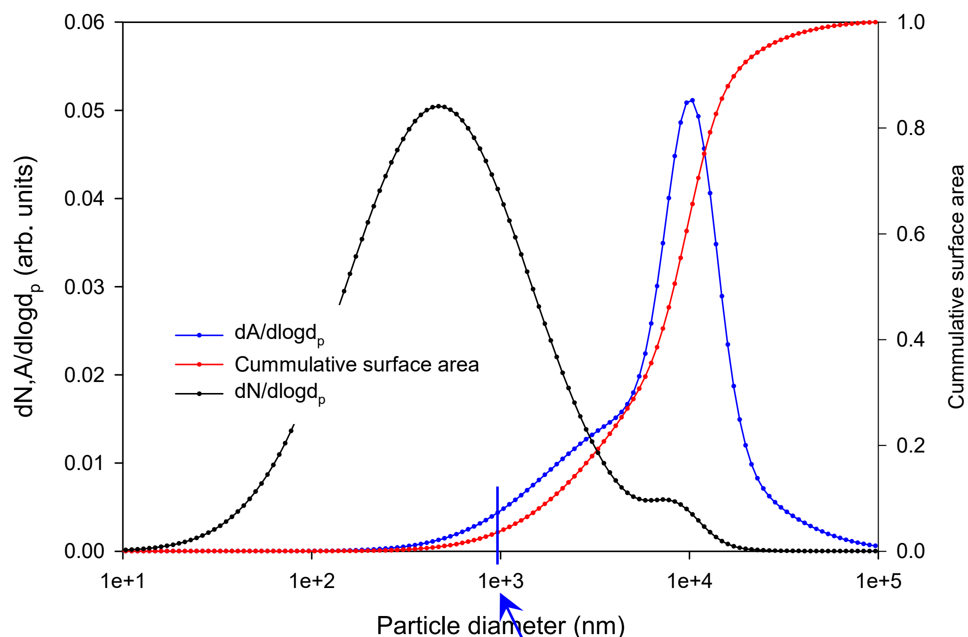
IV. Foldable Optical Confocal μScope (FOCμS)

Innovations:

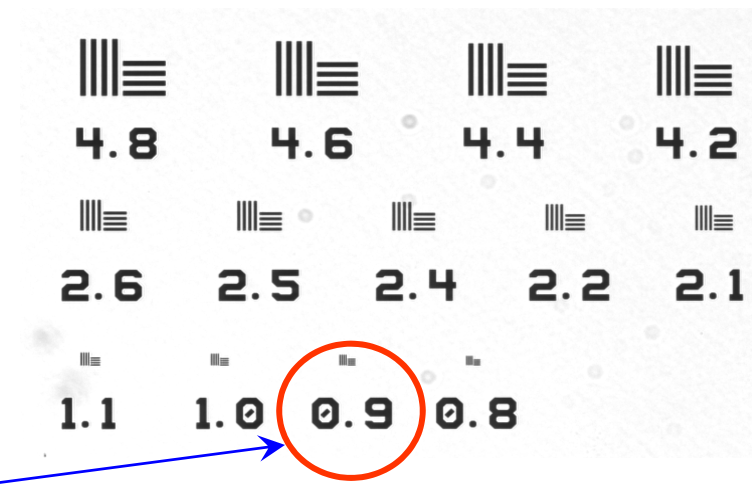
- Ultra-compact footprint relative to state-of-the-art (can be significantly reduced with folding prism).
- Long working distance
- Matched incoherent Kohler illumination
- Easy access to Fourier plane for implementation of enhanced contrast techniques



Foldable Optical Confocal µScope (FOCµS) cont'd.:



Number density, surface area distribution, and cumulative area (JSC1A lunar simulant)



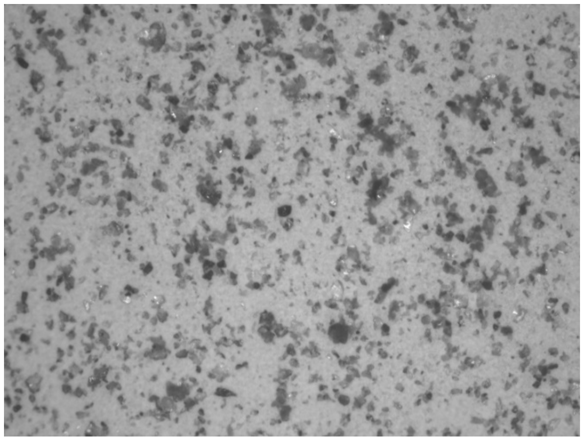
Diffraction-limited resolution: <1µm @NA 0.28

As measured performance resolves > 97% of area convected by simulant material.

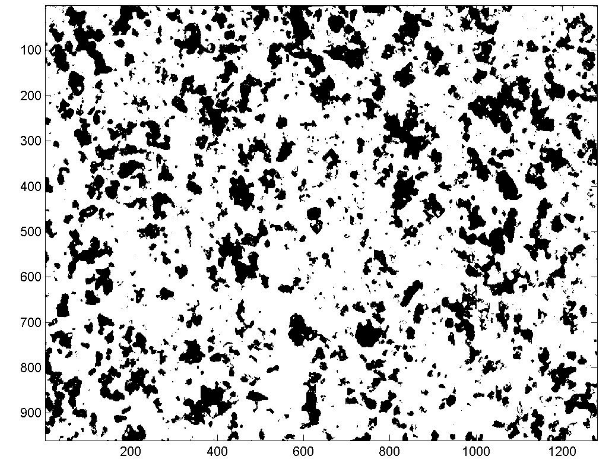
Foldable Optical Confocal µScope (FOCµS) cont'd.:

Specific Application: Z93 Thermal Radiator Coating with JSC1A Simulant

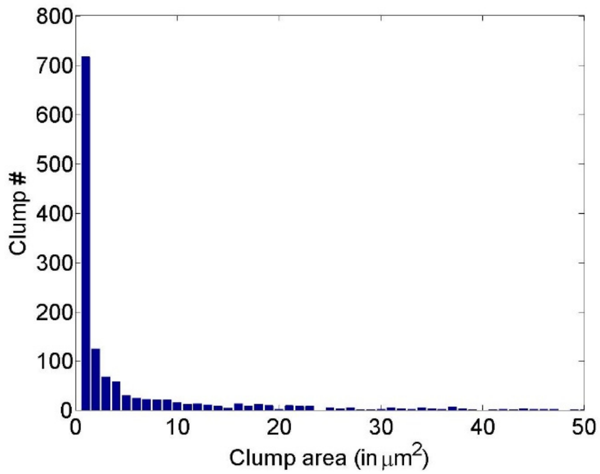
Surface occlusion radiant emission study



Raw digitized image w/Kohler Illumination



Thresholded/Binarized Image (Ohtsu method)
Occluded area: 25.8%



Derived histogram of surface occlusion