Two-Dimensional Angular Scattering Instrument for Aerosol Characterization

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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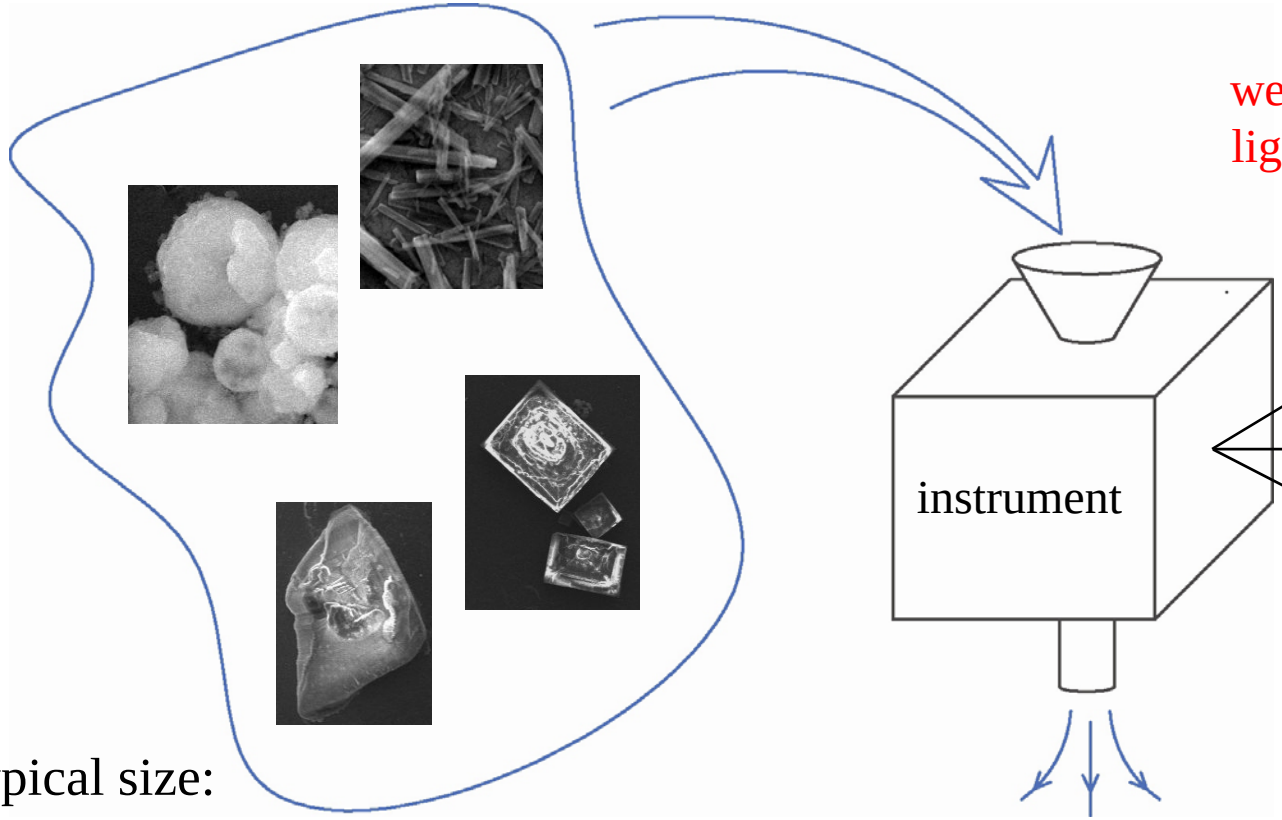
The concept

Use elastic light scattering to characterize ambient aerosol particles *in situ*.



typical size:
0.5 to 10 μm

Advantages of light scattering:

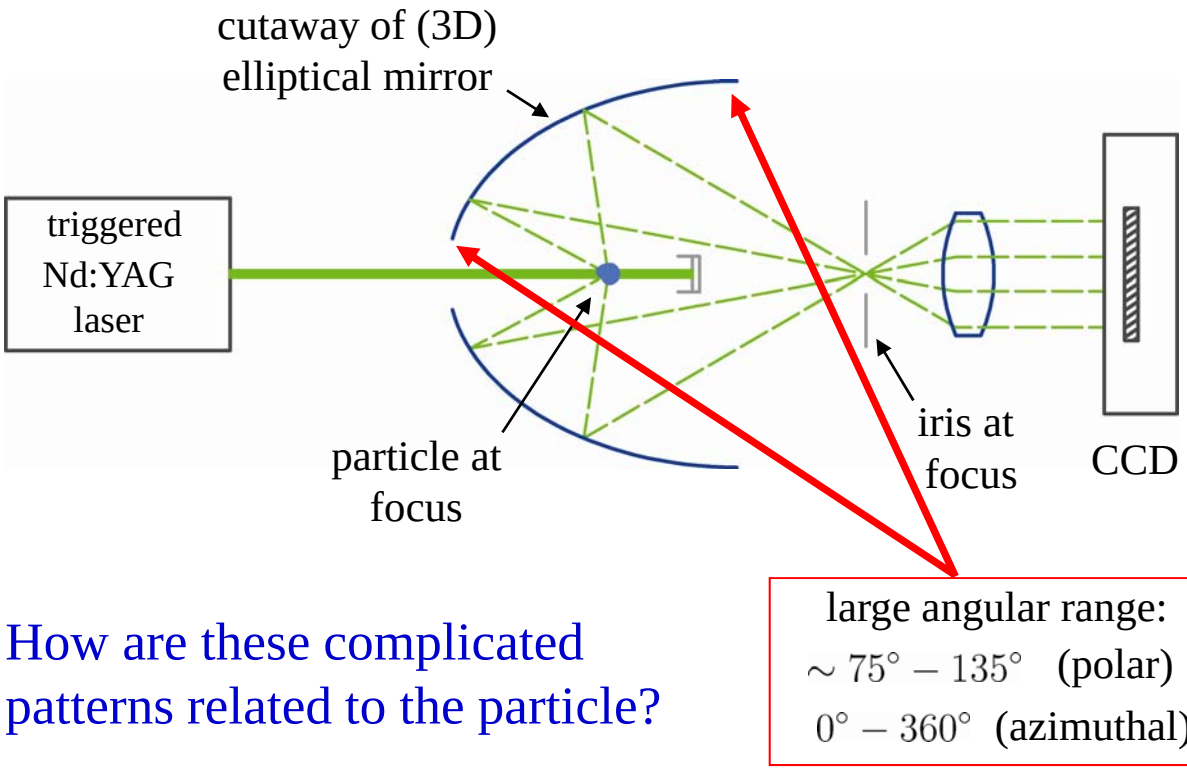
- Requires no collection surfaces or reagents.

- Rapid particle on-the-fly characterization possible.

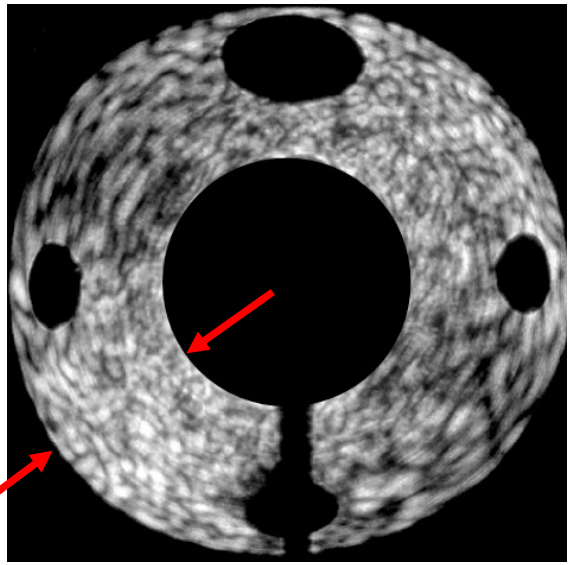
The *"inverse scattering"* approach

Measure scattering pattern over large angular range:

TAOS (two-dimensional angular optical scattering) [1]



scattering pattern on CCD



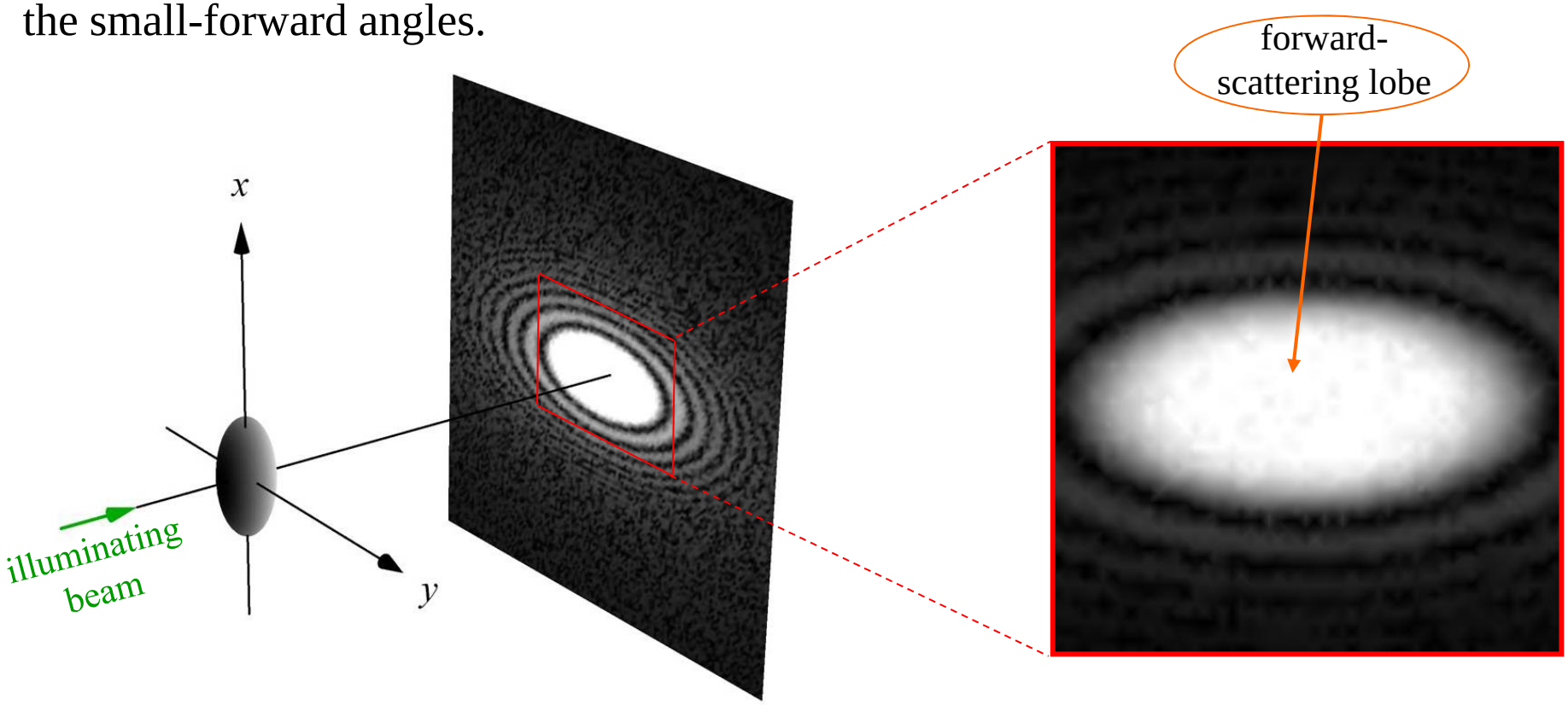
How are these complicated patterns related to the particle?

This leads to cumbersome, and often slow, inversion techniques.

[1] K. B. Aptowicz, R. G. Pinnick, S. C. Hill, Y.-L. Pan, and R. K. Chang, "Optical scattering patterns from single urban aerosol particles at Adelphi, Maryland, USA: A classification relating to particle morphologies," J. Geophys. Res. 111 D12212, pp, 1-13 (2006).

An alternative

Rather than collecting large angular range of the scattering pattern, focus more on the small-forward angles.

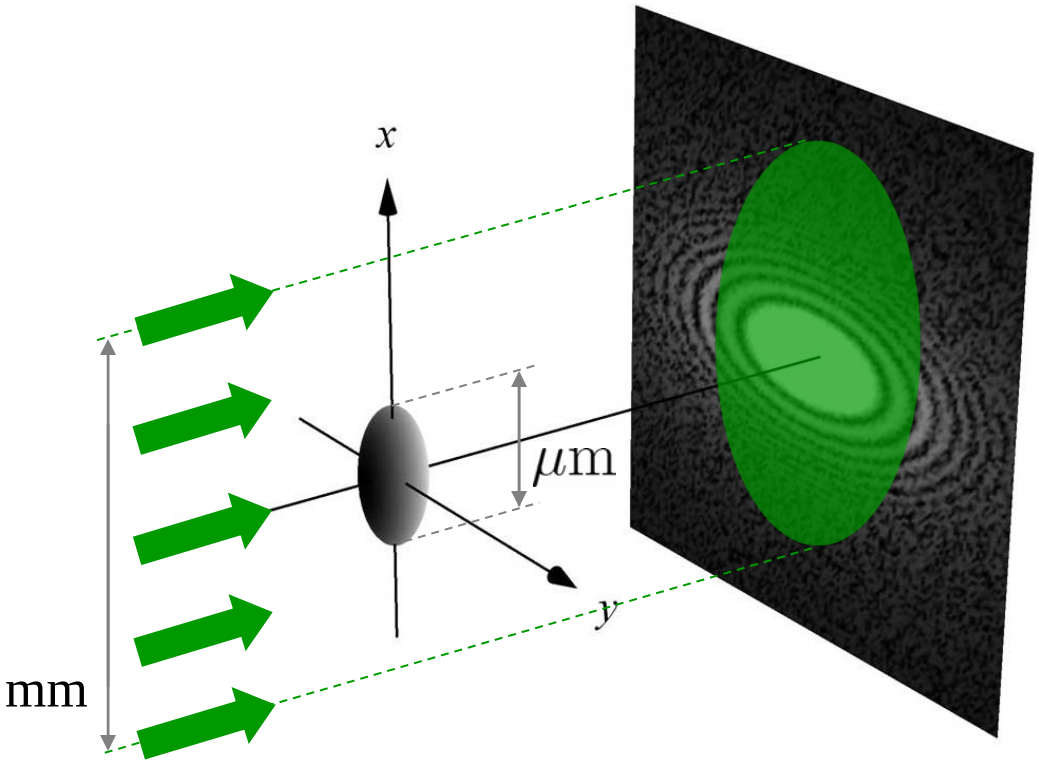


Pattern is simplest in forward direction because it is largely determined by diffraction from particle's profile. ➡ Contains size & shape information.

Can exploit the inverse relation between particle length and angular width of the forward-scattering lobe – Guinier's law.

A problem

Forward scattering pattern is difficult to separate from the (much brighter) illuminating beam:



Solutions:

- *Use a beam stop to block beam from reaching CCD camera?*

  This would also block much of the forward scattering pattern.

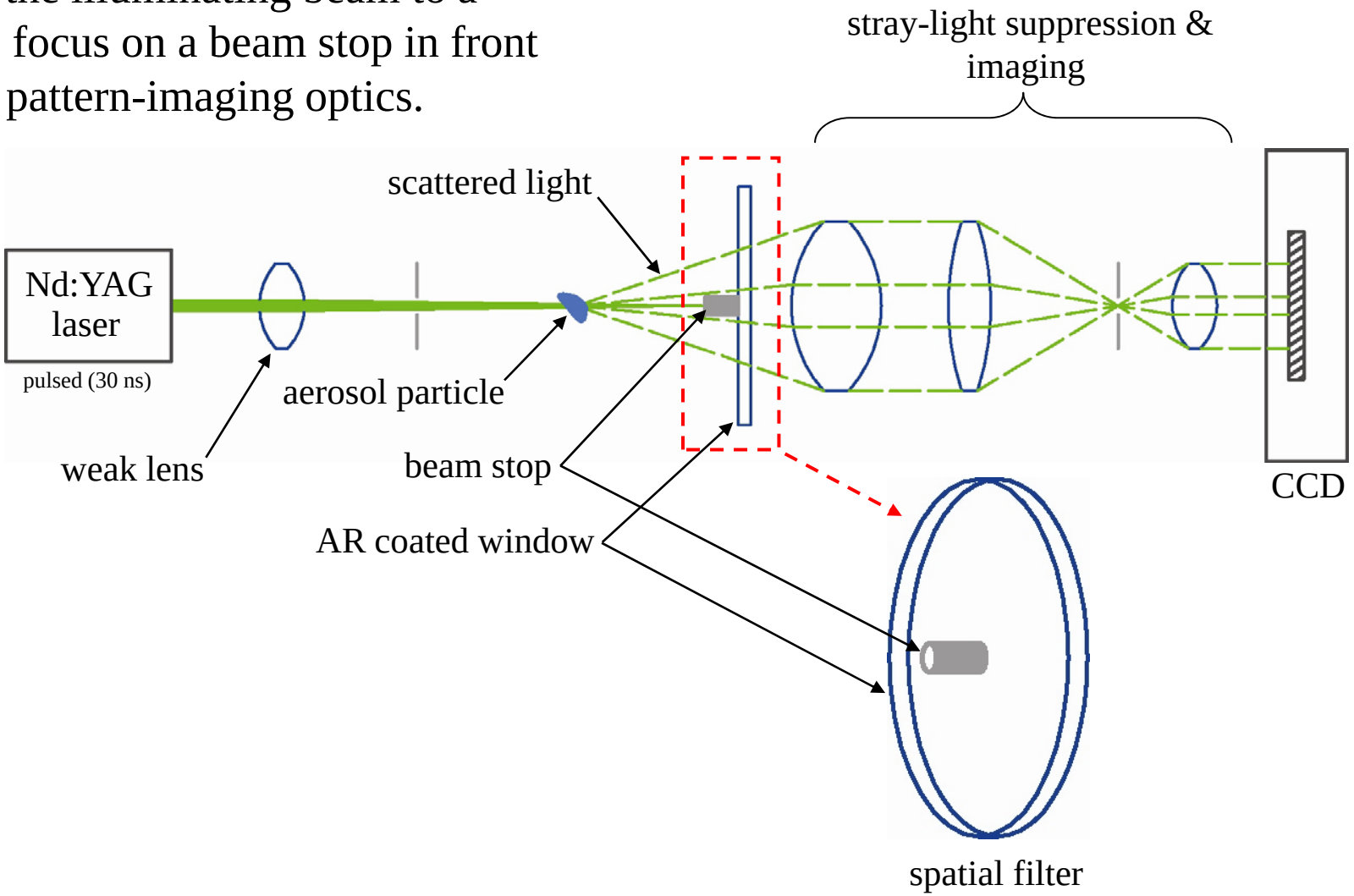
- *Shrink the width of the beam and use a smaller beam stop to block it?*

  This requires tighter control of the particles as they flow through instrument. Hard to do.

The instrument

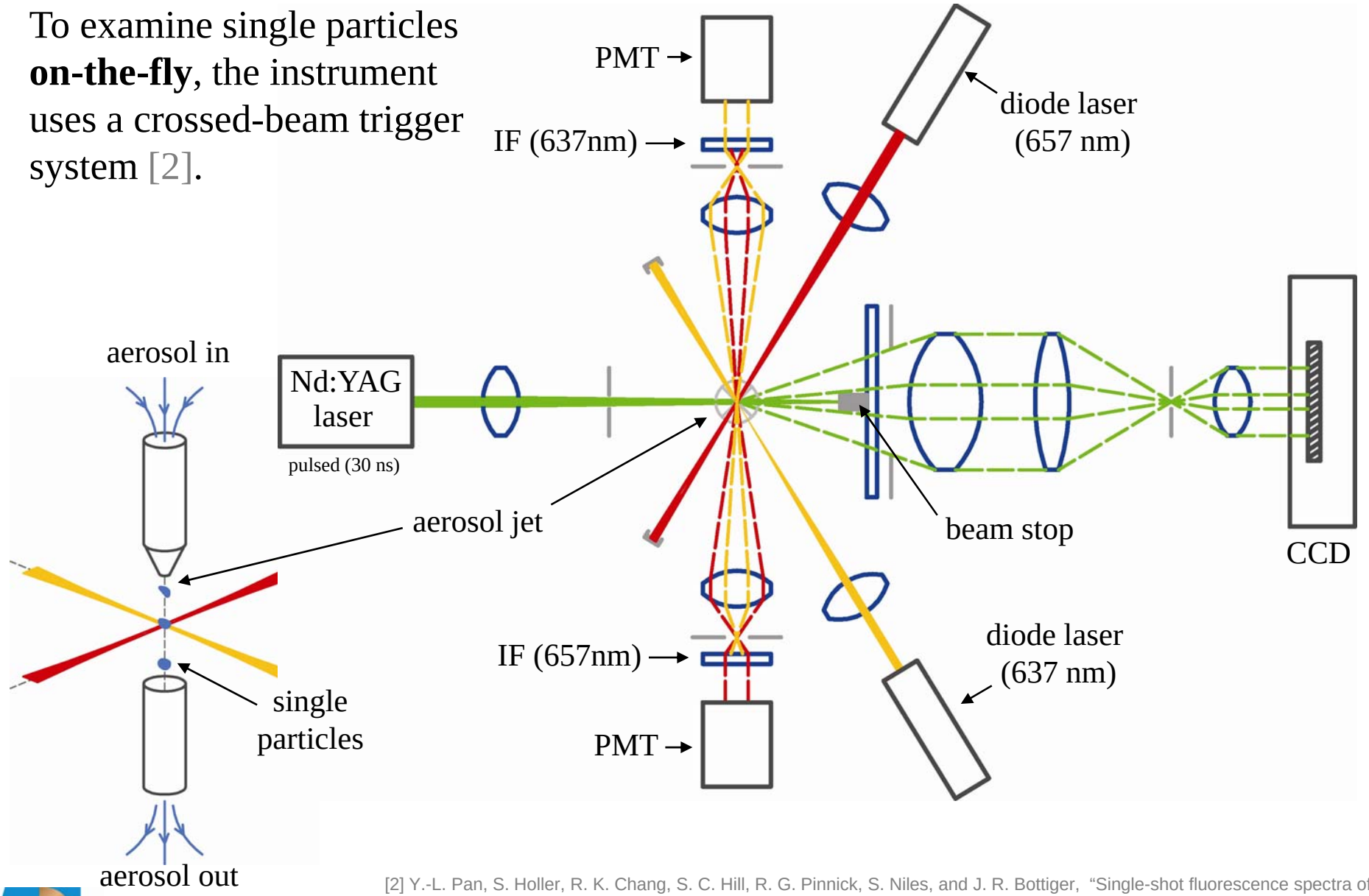
The solution is to use *spatial filtering*:

Bring the illuminating beam to a gentle focus on a beam stop in front of the pattern-imaging optics.



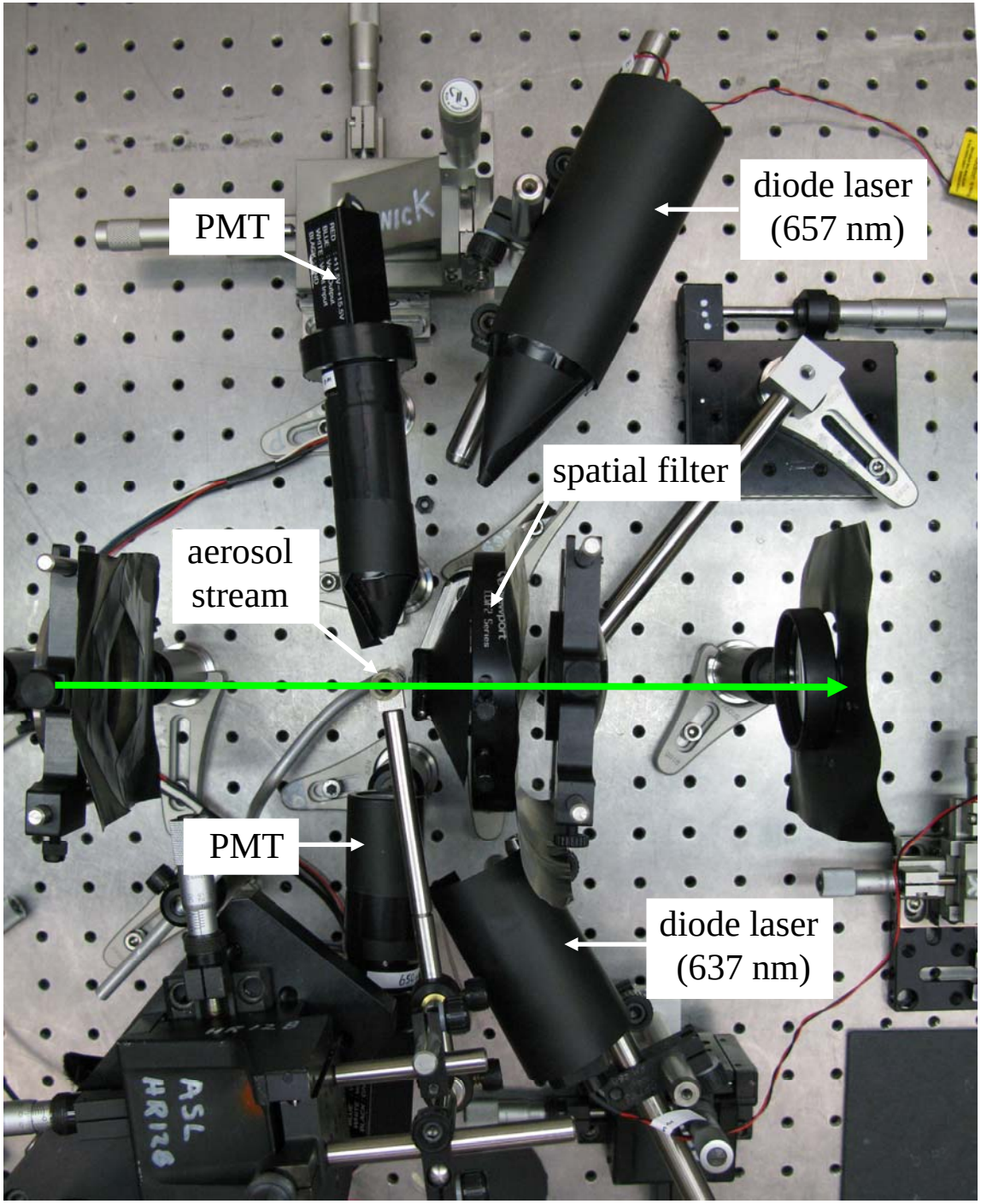
The instrument…

To examine single particles **on-the-fly**, the instrument uses a crossed-beam trigger system [2].

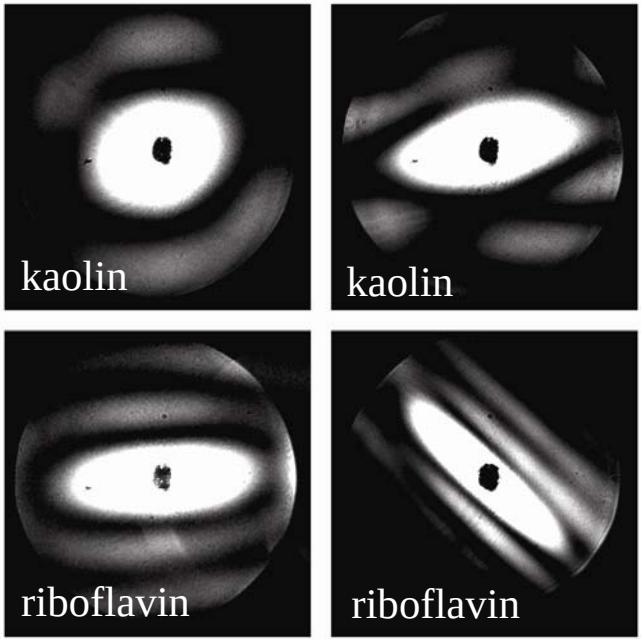


[2] Y.-L. Pan, S. Holler, R. K. Chang, S. C. Hill, R. G. Pinnick, S. Niles, and J. R. Bottiger, "Single-shot fluorescence spectra of individual micrometer-sized bioaerosols illuminated by a 351- or 266-nm ultraviolet laser," Opt. Lett., **24**(2), p. 116-8 (1999).

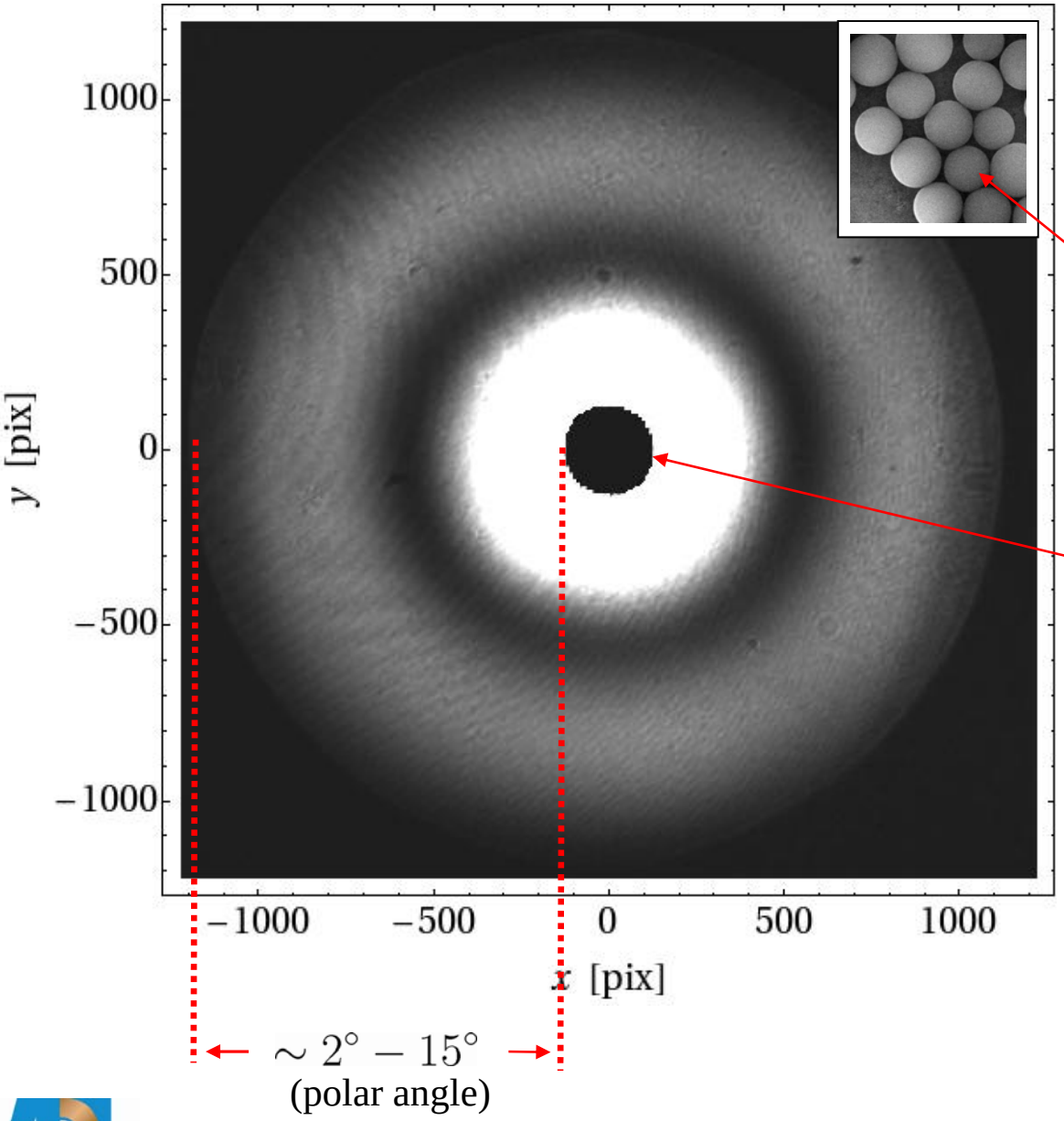
The instrument



example single particle patterns



Example: spherical particle



Able to capture most of the forward-scattering lobe.

polystyrene-latex microspheres, $\sim 4\,\mu\mathrm{m}$ diameter.

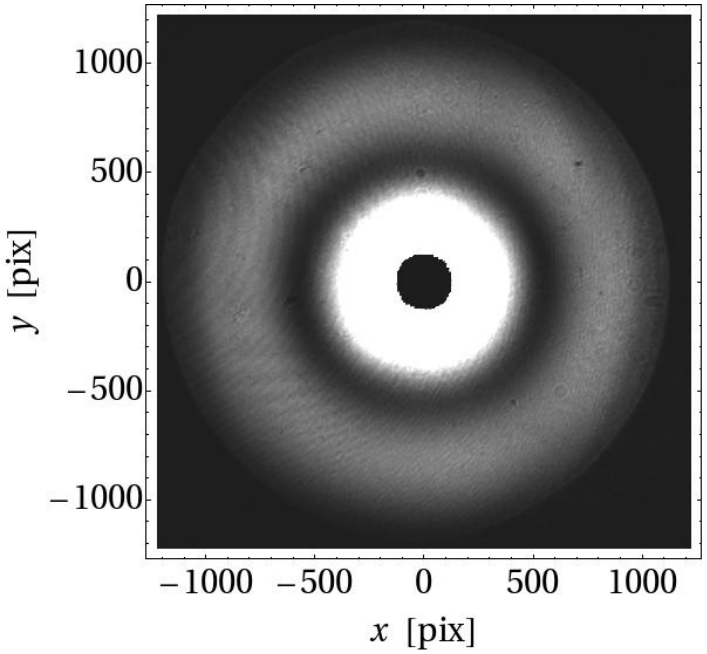
shadow of beam stop

Need complete forward lobe.

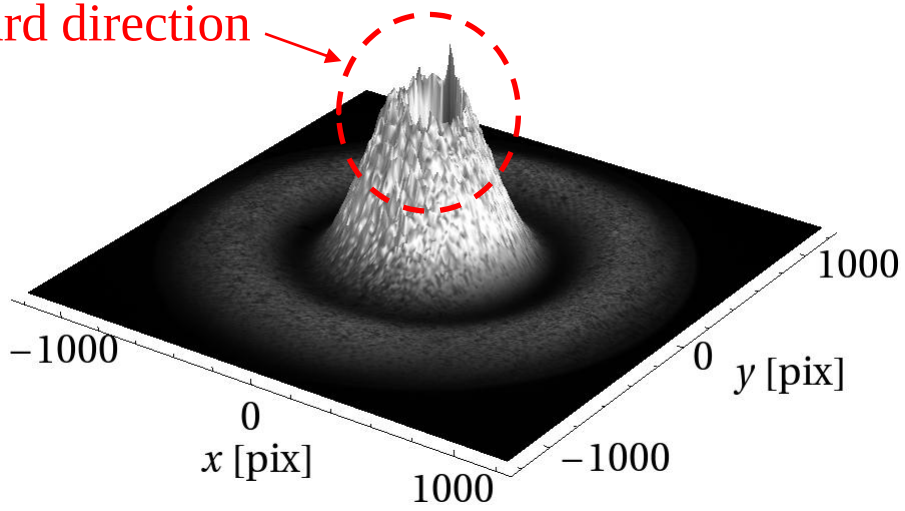
Reconstruct missing pattern in beam-stop shadow…

Forward pattern reconstruction

measured pattern

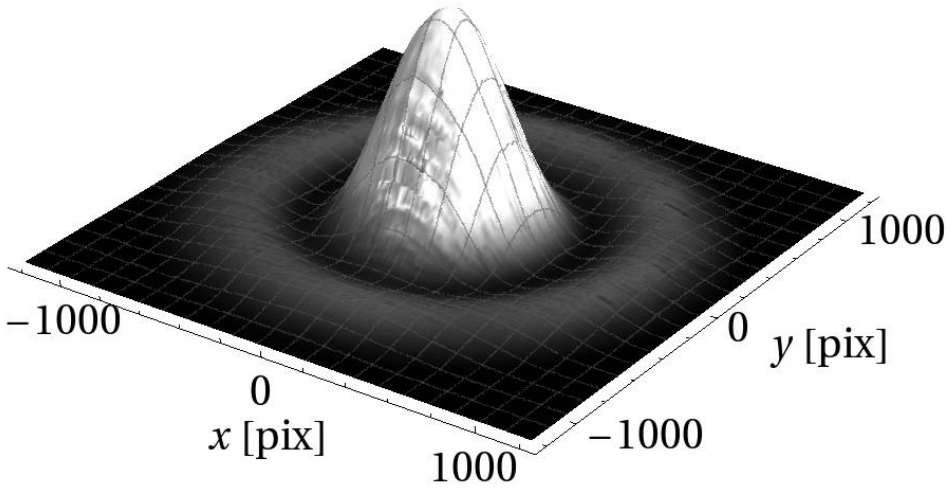


select data near
forward direction



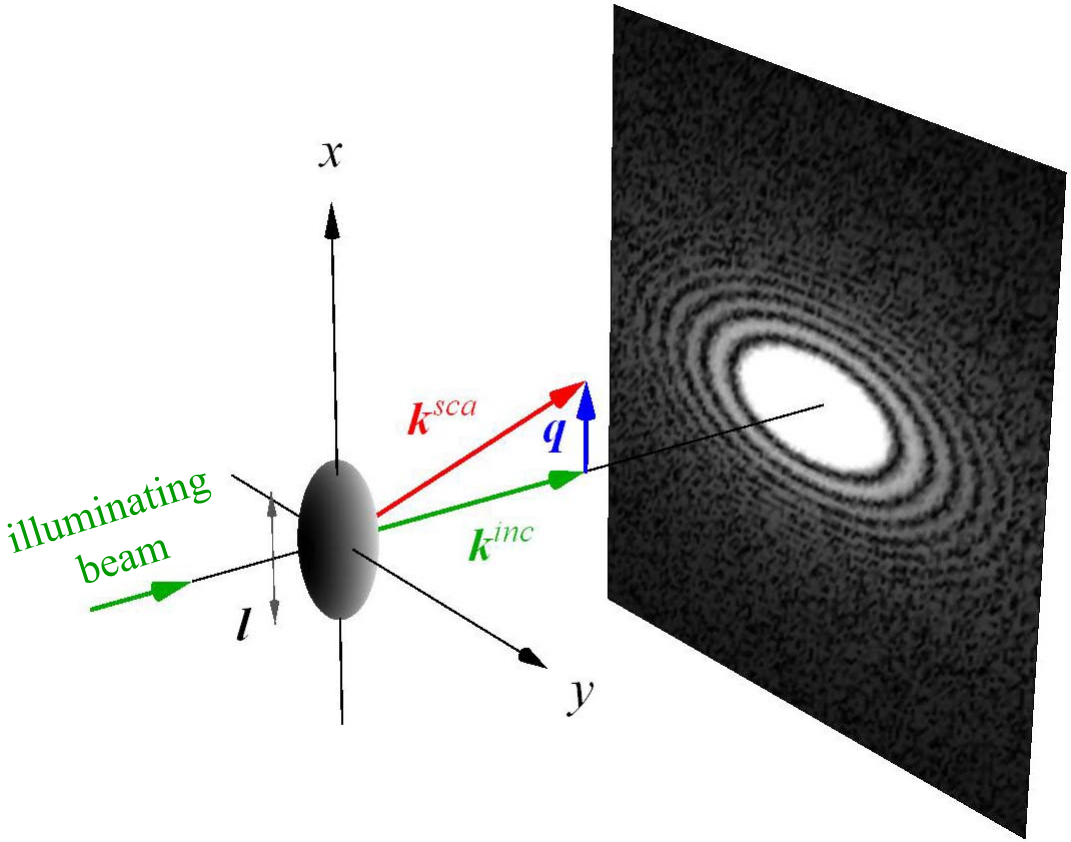
Approximate forward pattern by a polynomial for small angles.

$$\frac{I(\rho,\phi)}{I(0,0)} \simeq 1 - a(\phi)\rho^2 + b(\phi)\rho^3 + \ldots$$



reconstructed pattern

Guinier analysis



Guinier law:

$$\frac{I(q)}{I(0)} \simeq 1 - \frac{q^2 l^2}{3}$$

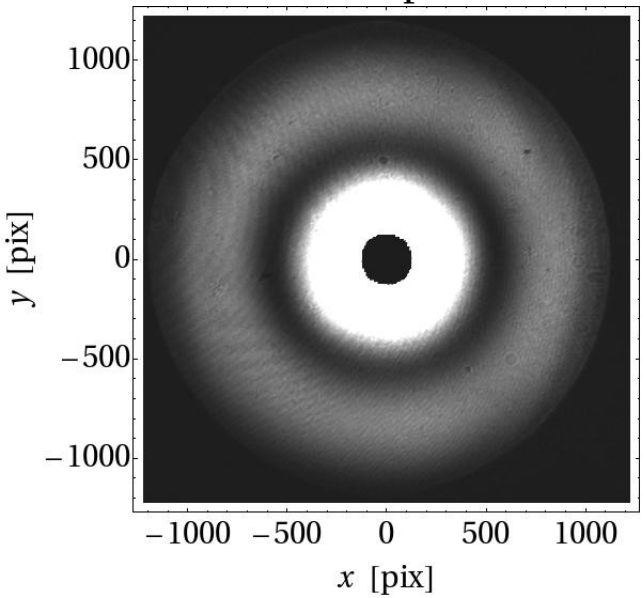
$$\mathbf{q} = \mathbf{k}^{inc} - \mathbf{k}^{sca}$$

The rate of decrease of the forward-scattering peak in the **q** direction is inversely related to an approximate measure of the particle's length in that same direction.

Applying this law in 2D generates a contour representing the particle's geometrical shadow.

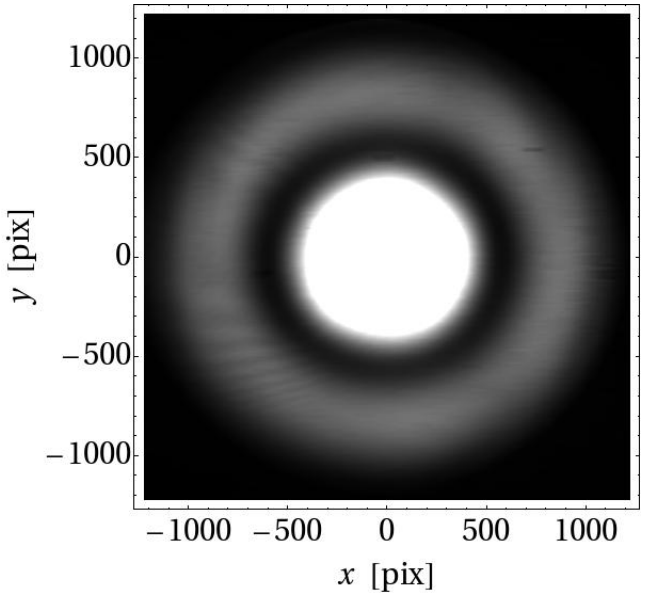
Example 1: PSL spherical particle

measured pattern

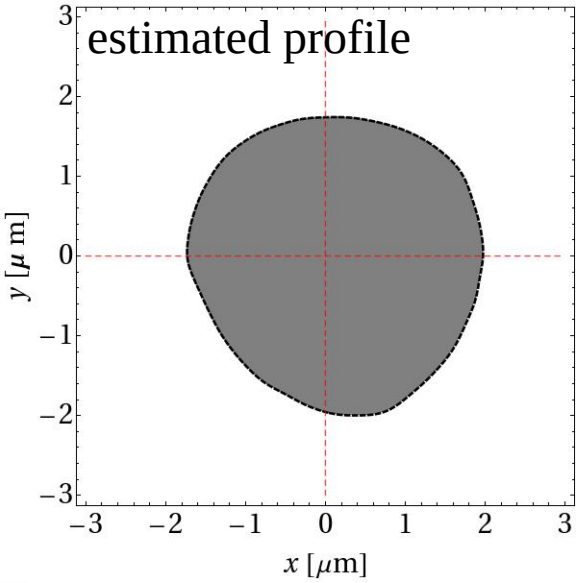


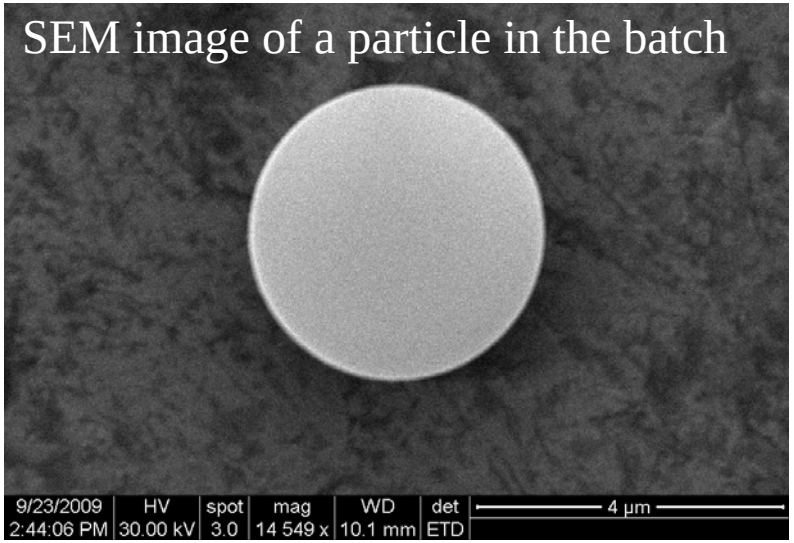
polynomial fit

reconstructed pattern



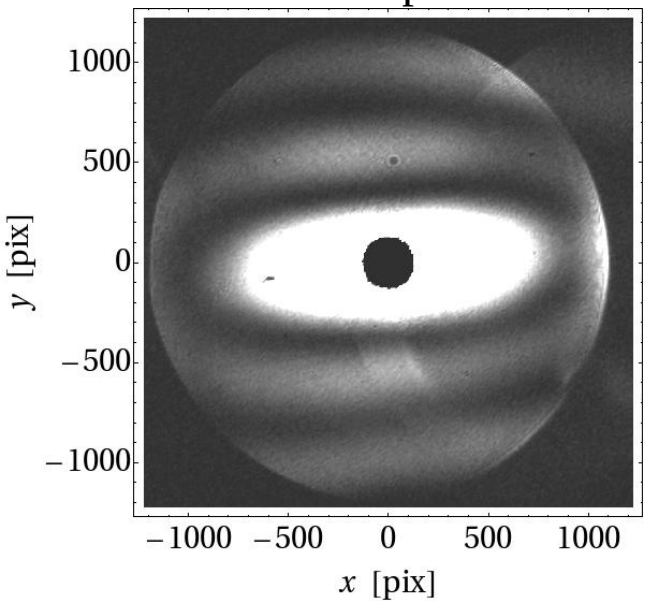
Guinier law





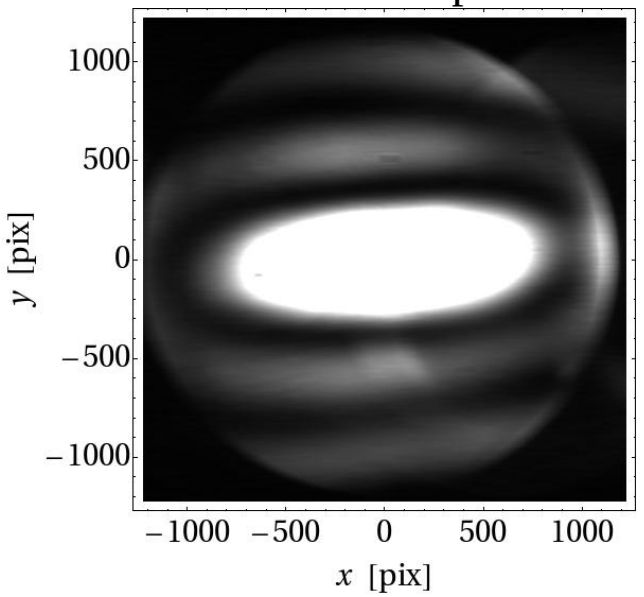
Example 2: riboflavin fiber-like particle

measured pattern

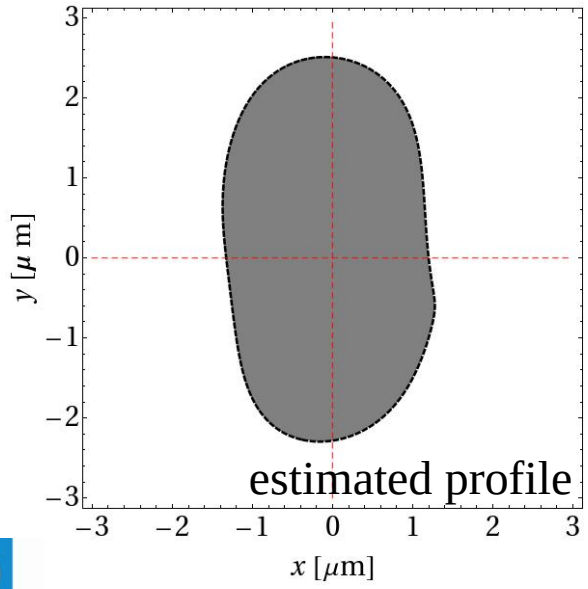


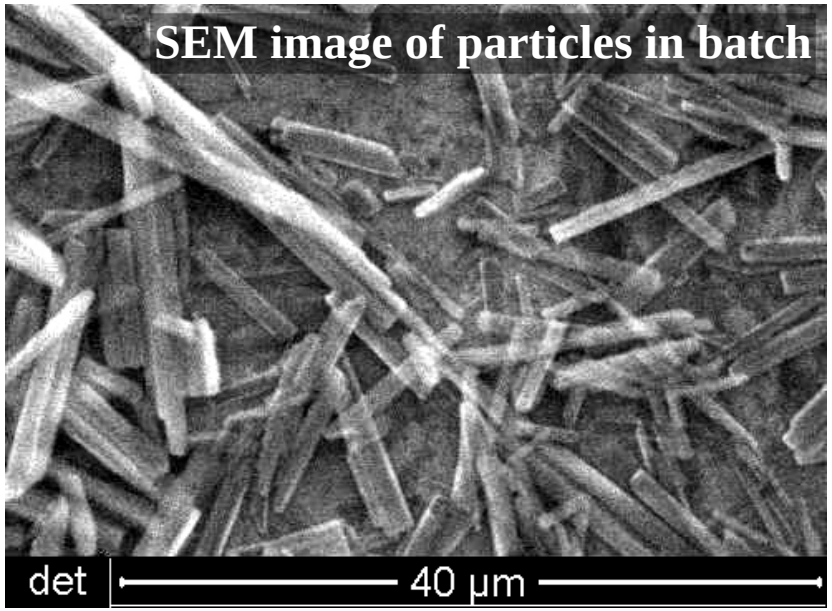
polynomial fit

reconstructed pattern



Guinier law





Summary

Developed an instrument to measure two-dimensional light scattering patterns from *single* aerosol particles.

This is done rapidly, *on-the-fly*, as an aerosol flows through the instrument.

Estimation of size and shape has been obtained from test particles.

Further work is planned to improve these characterization methods and estimate their potential usefulness for biological defense applications.

Acknowledgments

DTRA

The National Academies

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Questions?