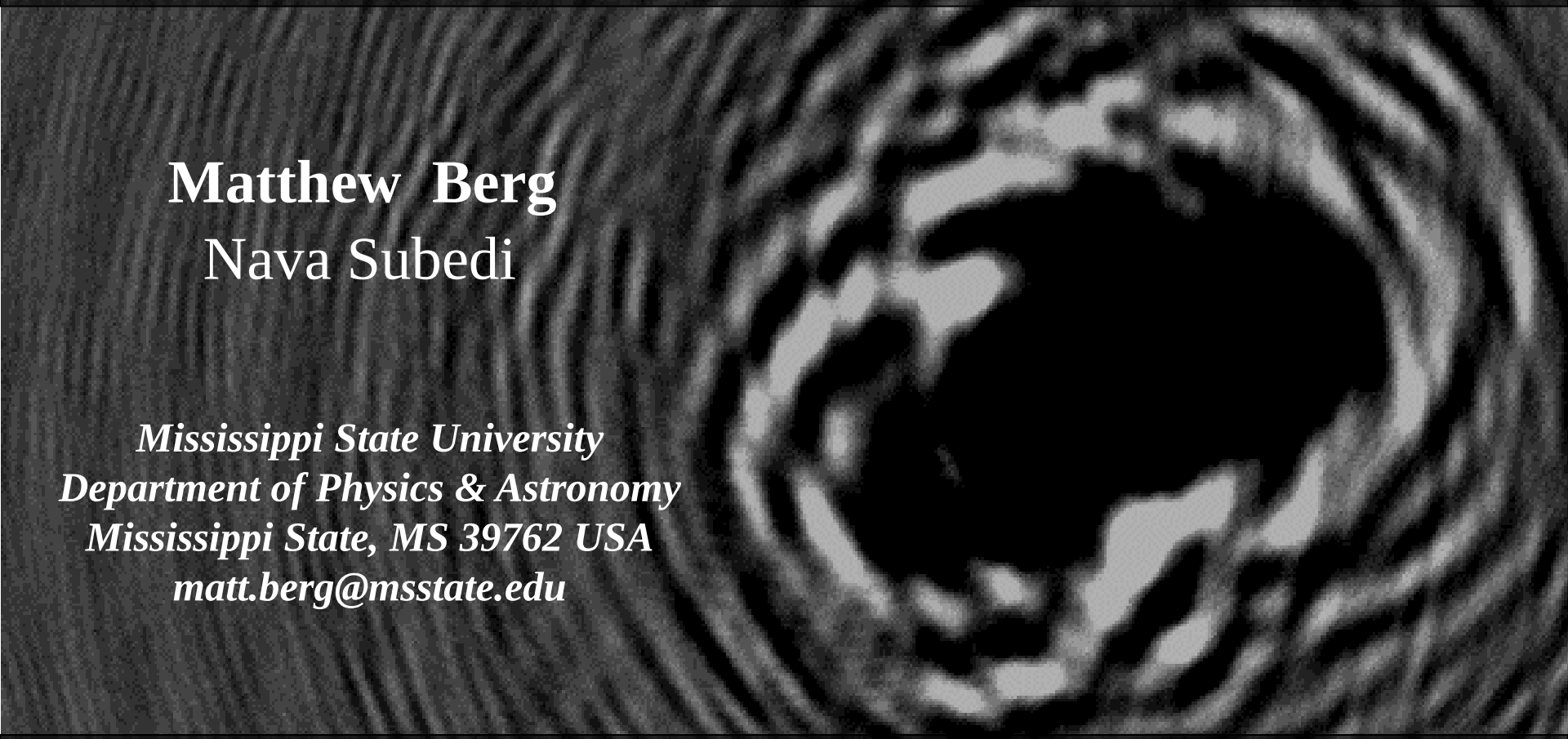
# Characterization of Aerosol Particles with Digital Holography



**Matthew Berg**
Nava Subedi

***Mississippi State University***
***Department of Physics & Astronomy***
***Mississippi State, MS 39762 USA***
***matt.berg@msstate.edu***

*Optical Characterization of Atmospheric Aerosols*
*Smolenice, Slovakia 7 November 2013*

# Motivation

Goal: Characterization of aerosol particles *in situ*, e.g.,

particle size,

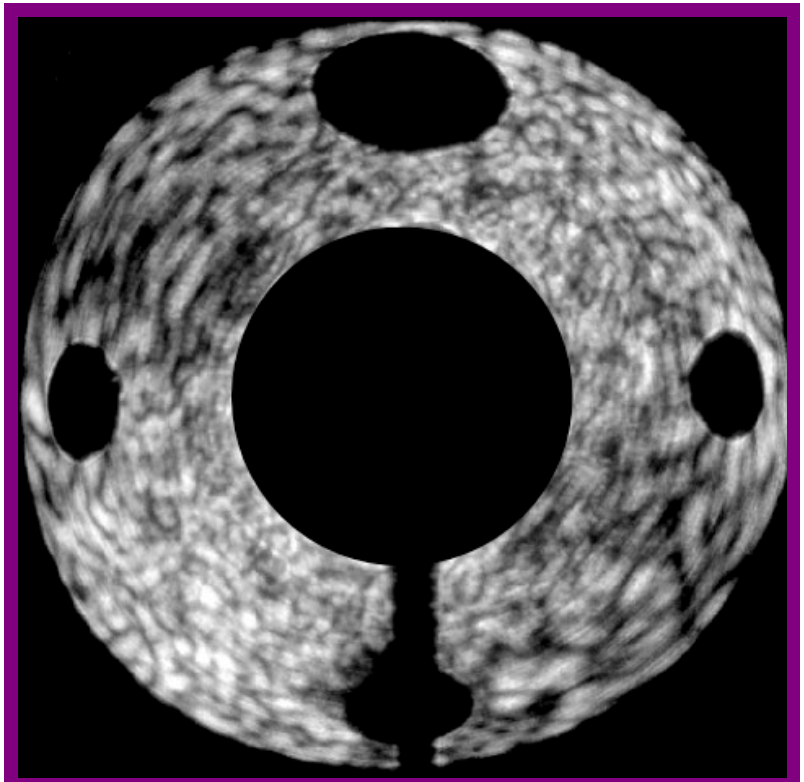
shape,

composition.

In principle, this information is contained in the elastic scattering pattern.

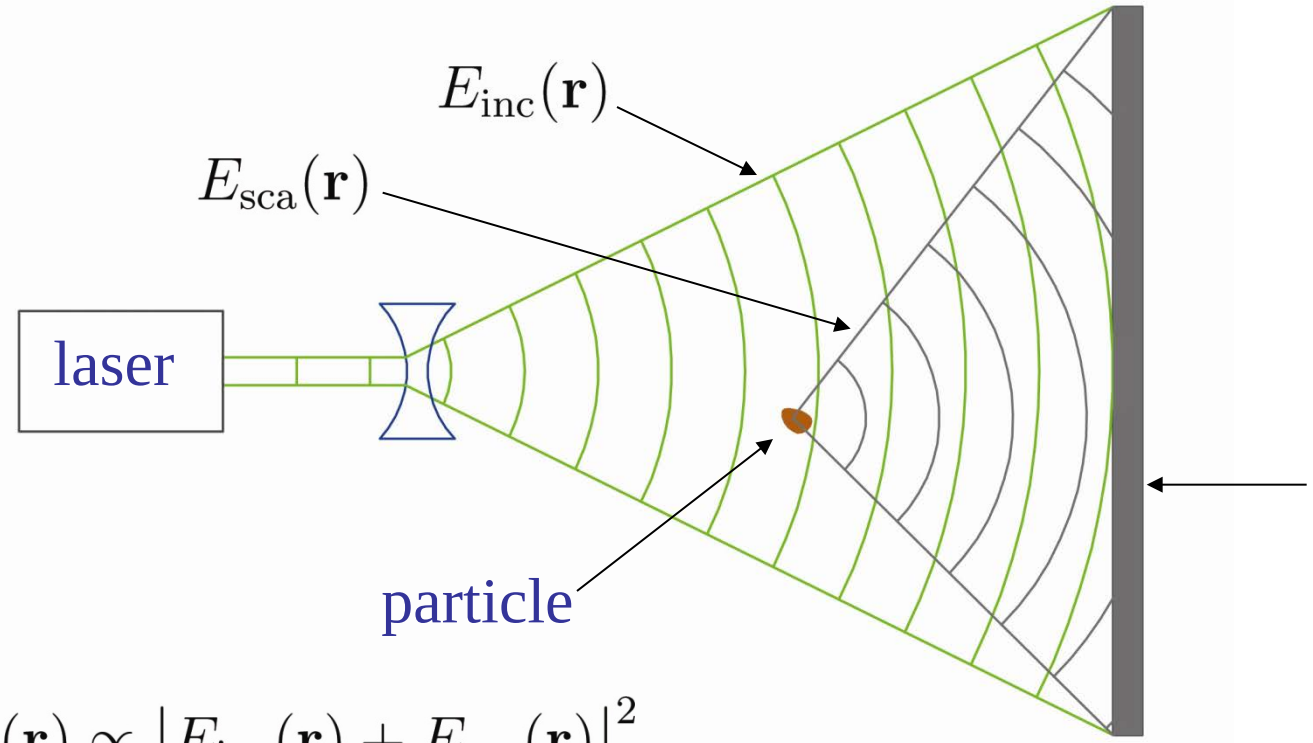
Unfortunately, such patterns can be very complicated, and thus difficult to interpret, i.e., *there is no **general** inversion technique*.

two-dimensional (TAOS) scattering pattern of a single urban aerosol particle



K. B. Aptowicz, *et al.*, J. Geophys. Res. 111 D12212, pp, 1-13 (2006).

# An alternative approach - digital holography




$$I(\mathbf{r}) \propto \left|E_{\text{inc}}(\mathbf{r}) + E_{\text{sca}}(\mathbf{r})\right|^2$$

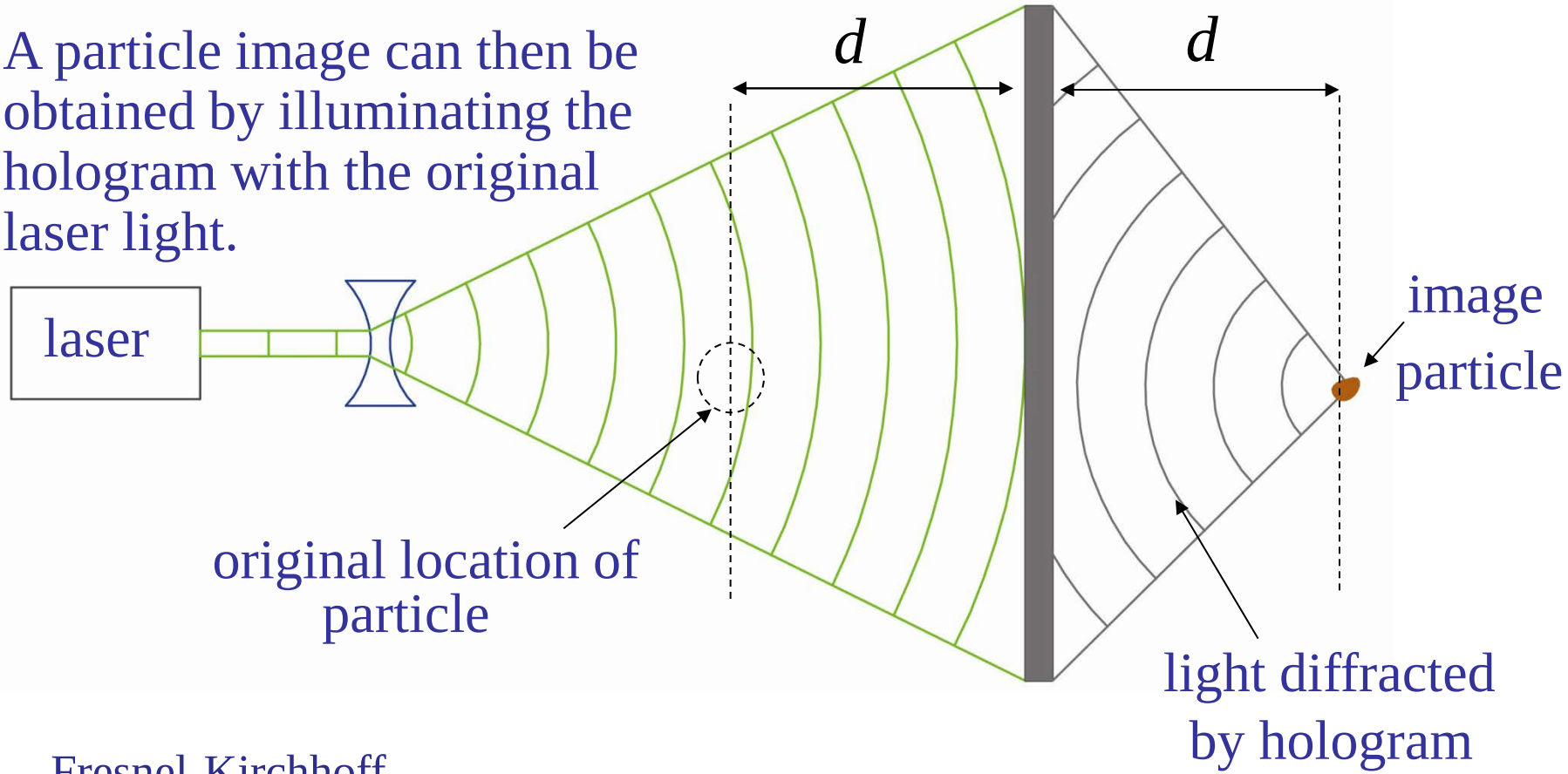
$$I(\mathbf{r}) \propto \cancel{\left|E_{\text{inc}}(\mathbf{r})\right|^2} + \cancel{\left|E_{\text{sca}}(\mathbf{r})\right|^2} + \left[E_{\text{inc}}(\mathbf{r})\right]^* E_{\text{sca}}(\mathbf{r}) + \text{c.c.}$$

$$I(\mathbf{r}) \simeq \left[E_{\text{inc}}(\mathbf{r})\right]^* E_{\text{sca}}(\mathbf{r})$$ ← proportional to filed amplitude, not the square

⇨ This means that field **phase** is encoded in the measurement.

Once chemically processed, the hologram becomes a transmission diffraction-grating.

A particle image can then be obtained by illuminating the hologram with the original laser light.

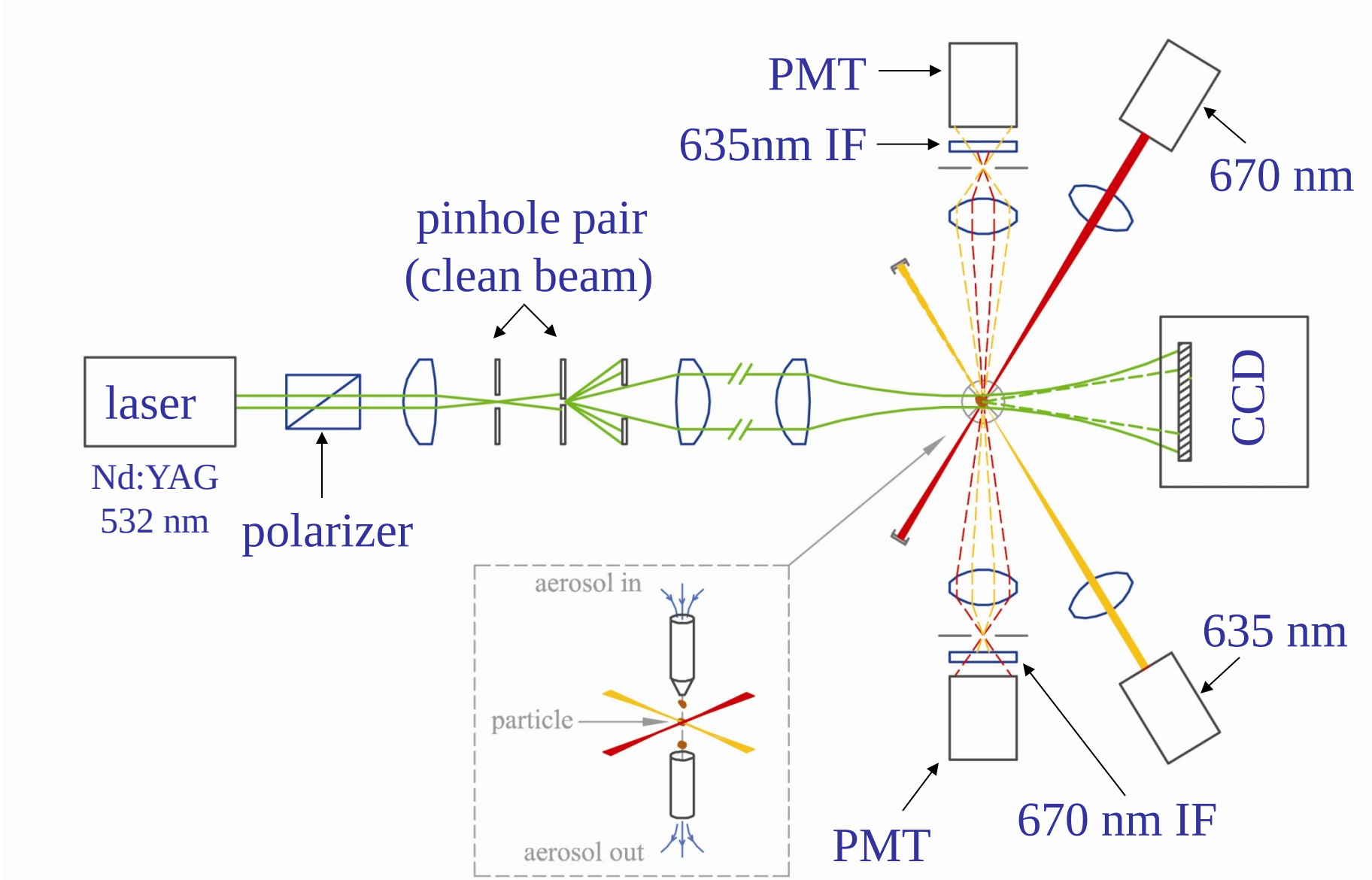


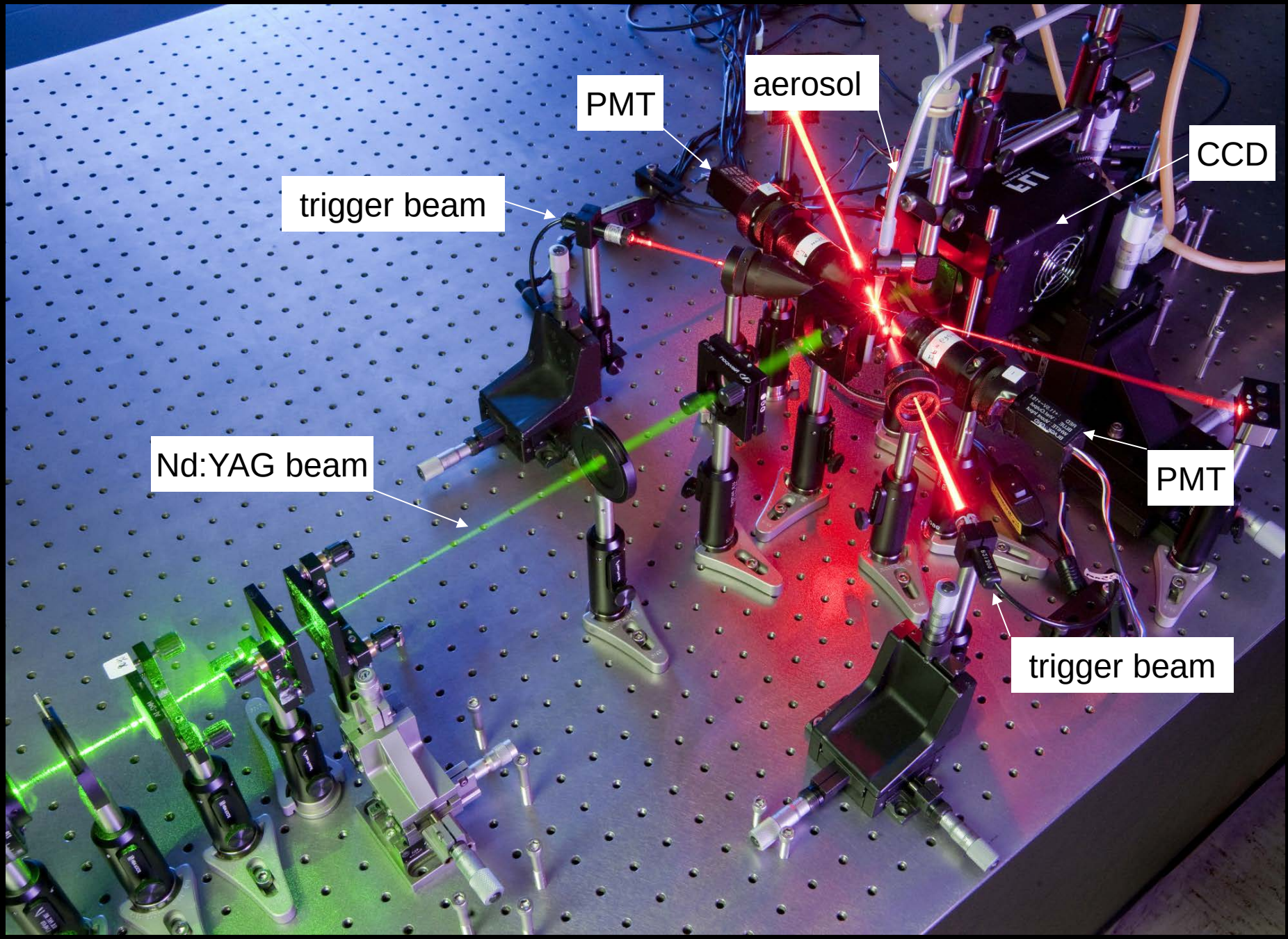

Fresnel-Kirchhoff

$$K(\mathbf{r}) = \int_S I_{\text{holo}}(\mathbf{r}') \exp\left(\frac{ik\mathbf{r}' \cdot \mathbf{r}}{\mathbf{r}'}\right) \mathrm{d}\mathbf{r}'$$

$$\text{image} \propto \left|K(\mathbf{r})\right|^2$$

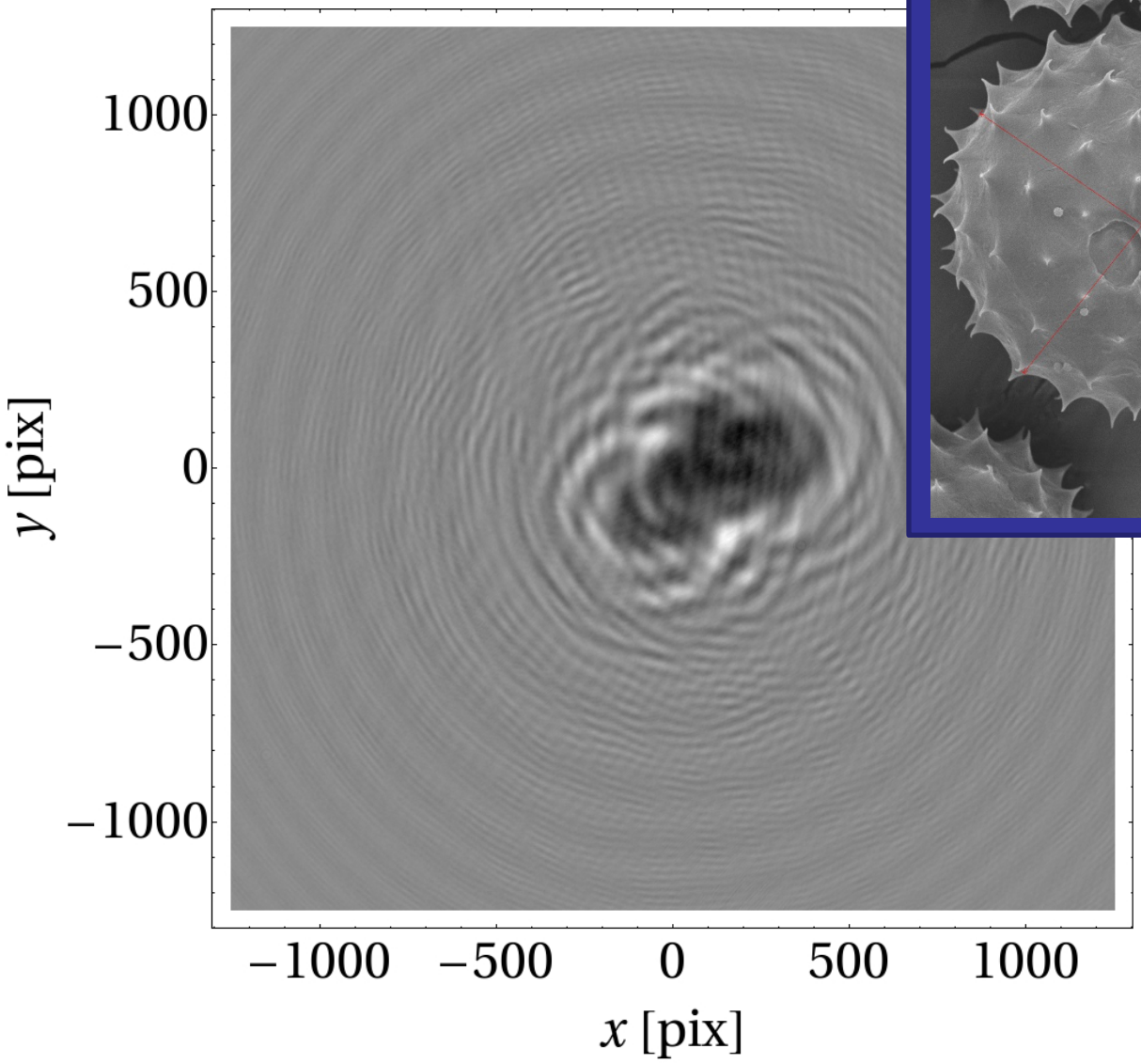
# Experiment 1

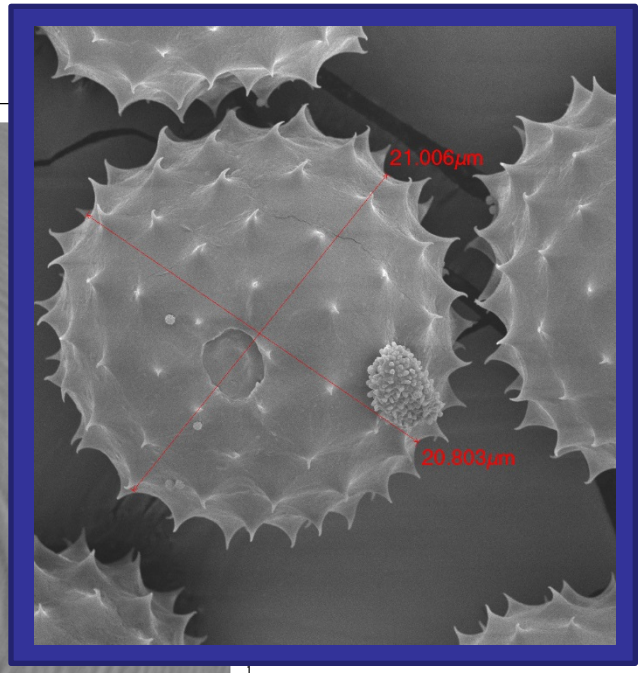



PMT
aerosol
CCD
trigger beam
Nd:YAG beam
PMT
trigger beam

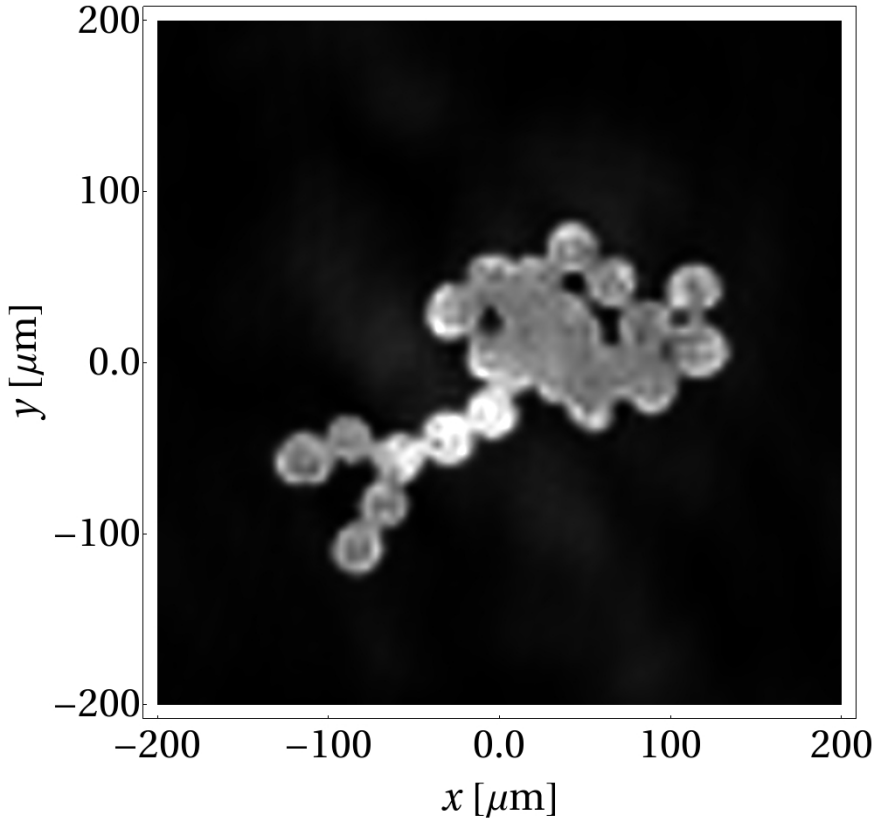
# Example: ragweed pollen cluster

digital hologram

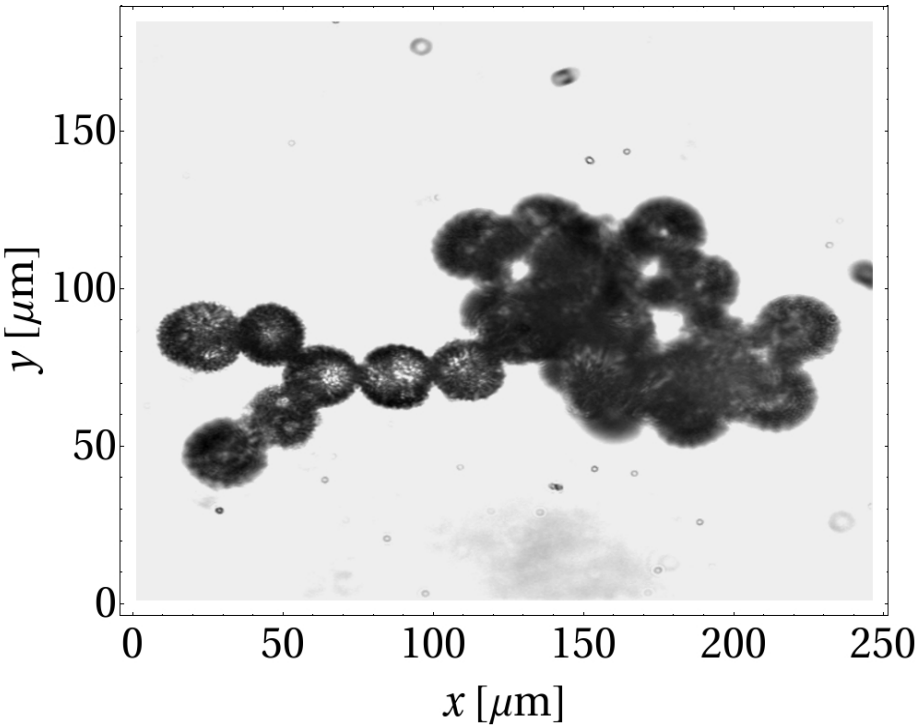


# Validation




Cluster image reconstructed from the contrast hologram.

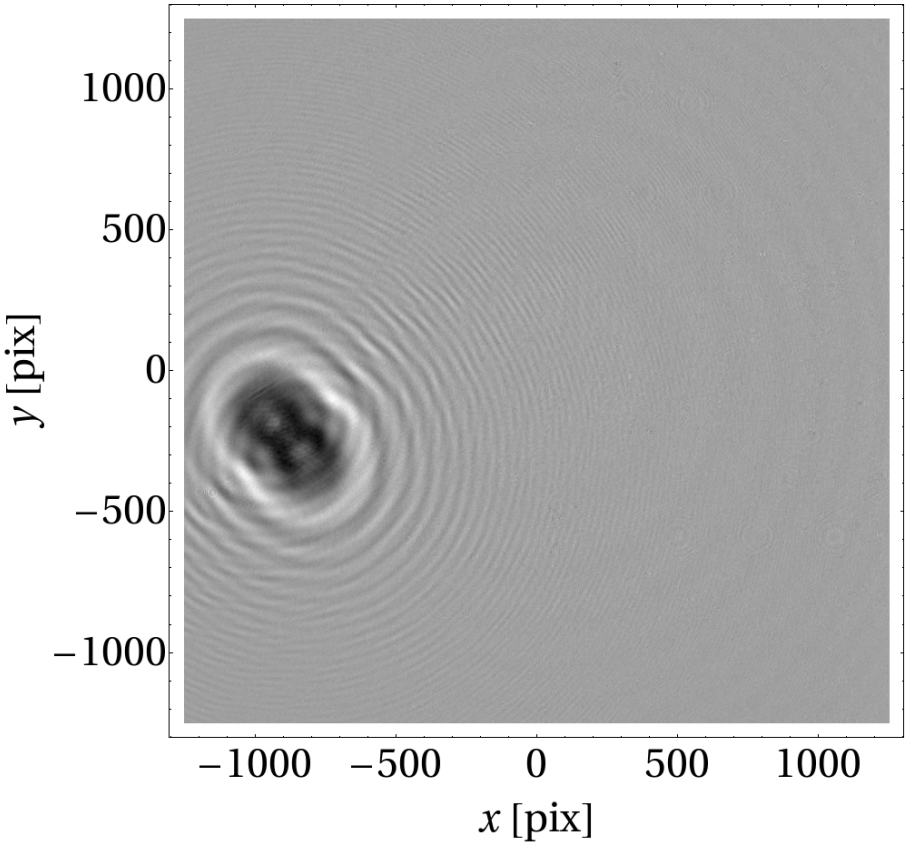



Standard optical microscope image of same particle cluster.

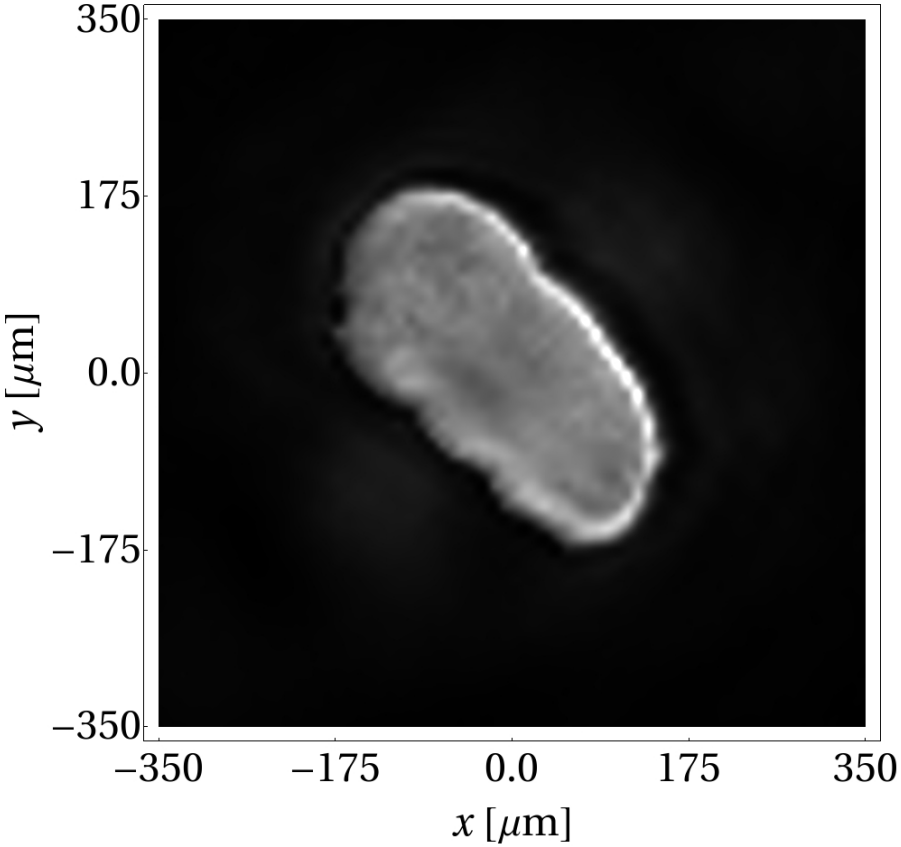
But we would like to do this without collecting particle on a slide…

# Saharan sand aerosol particle

## digital hologram

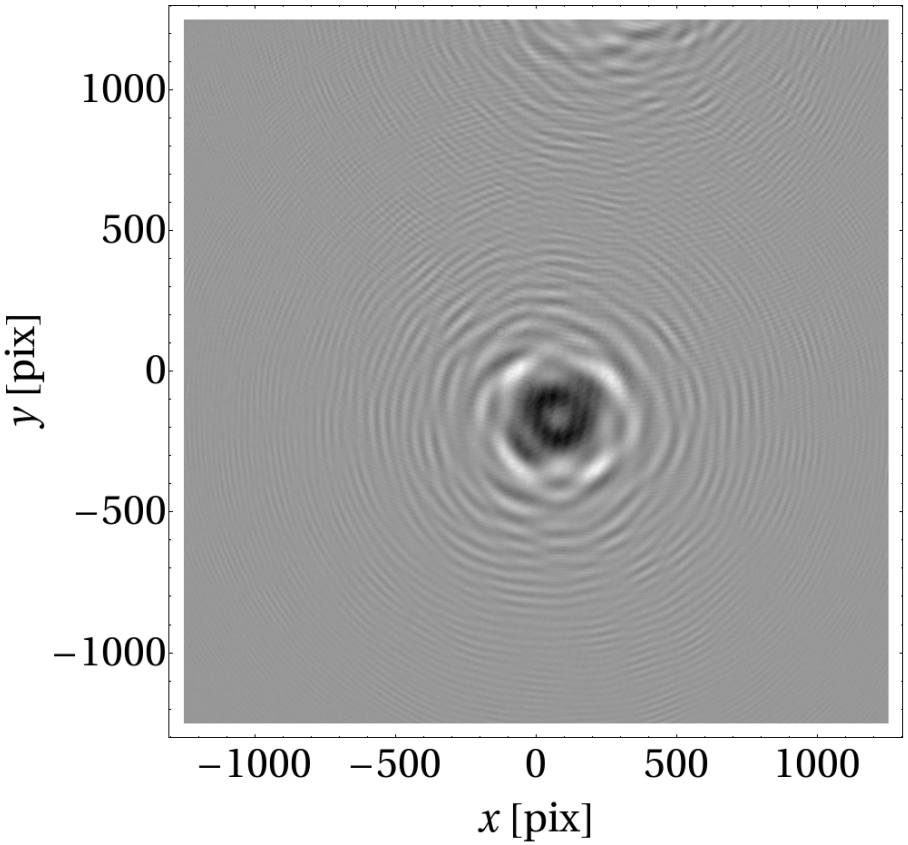



## reconstructed image

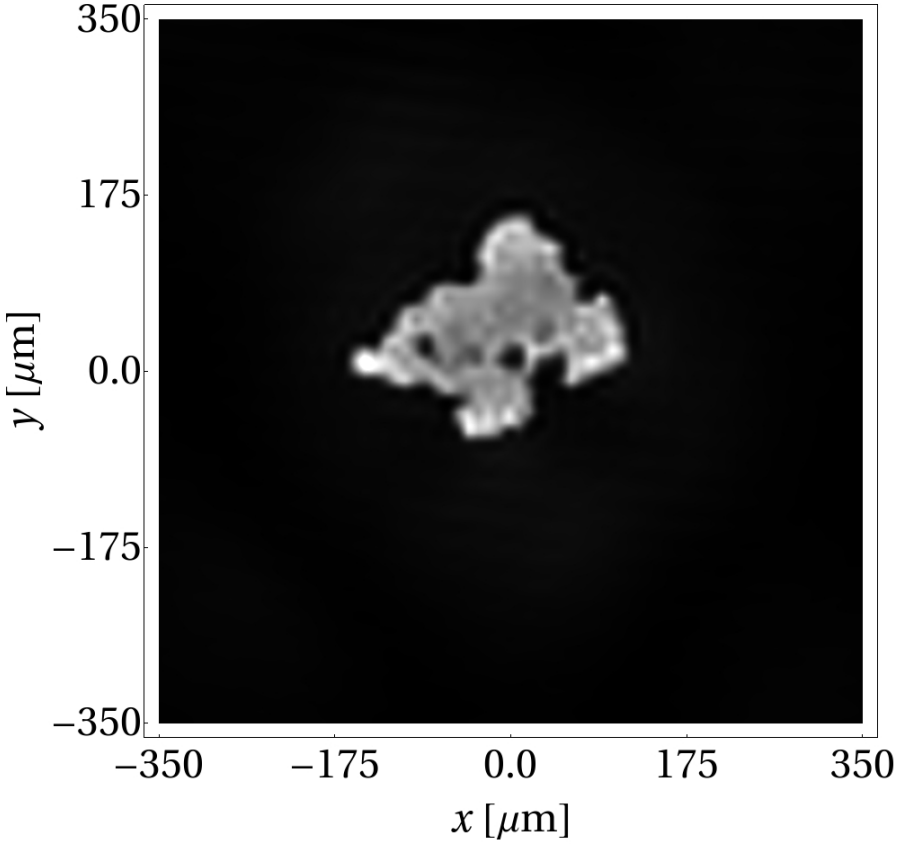


# Tunisian sand aerosol particle

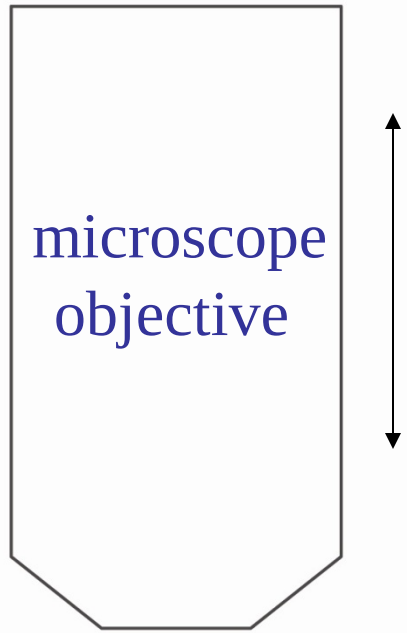
## digital hologram

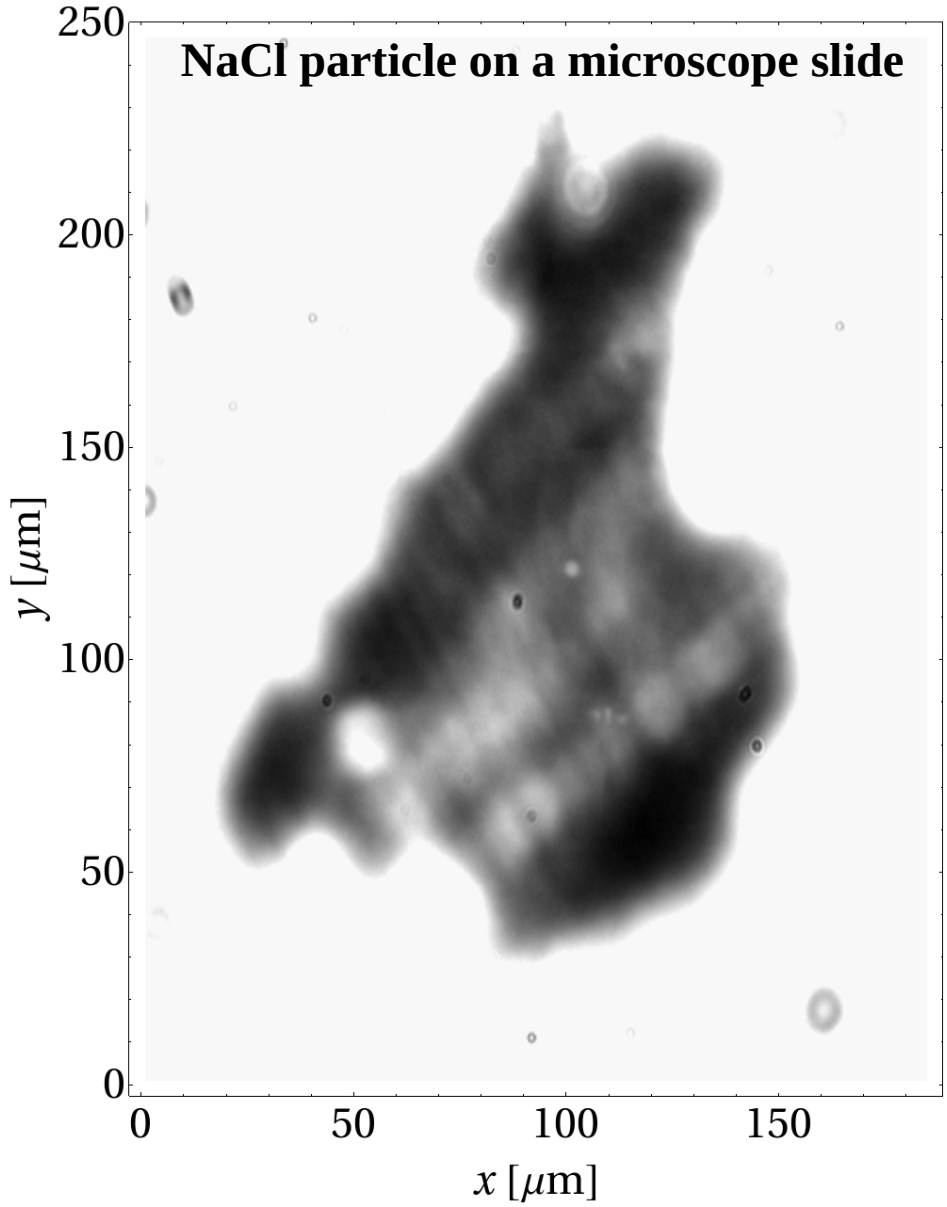



## reconstructed image



# Focusing properties of holographic imaging



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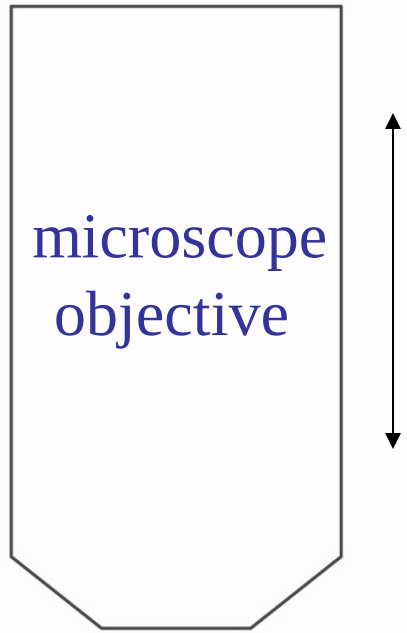


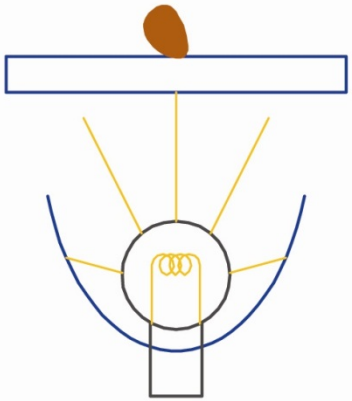

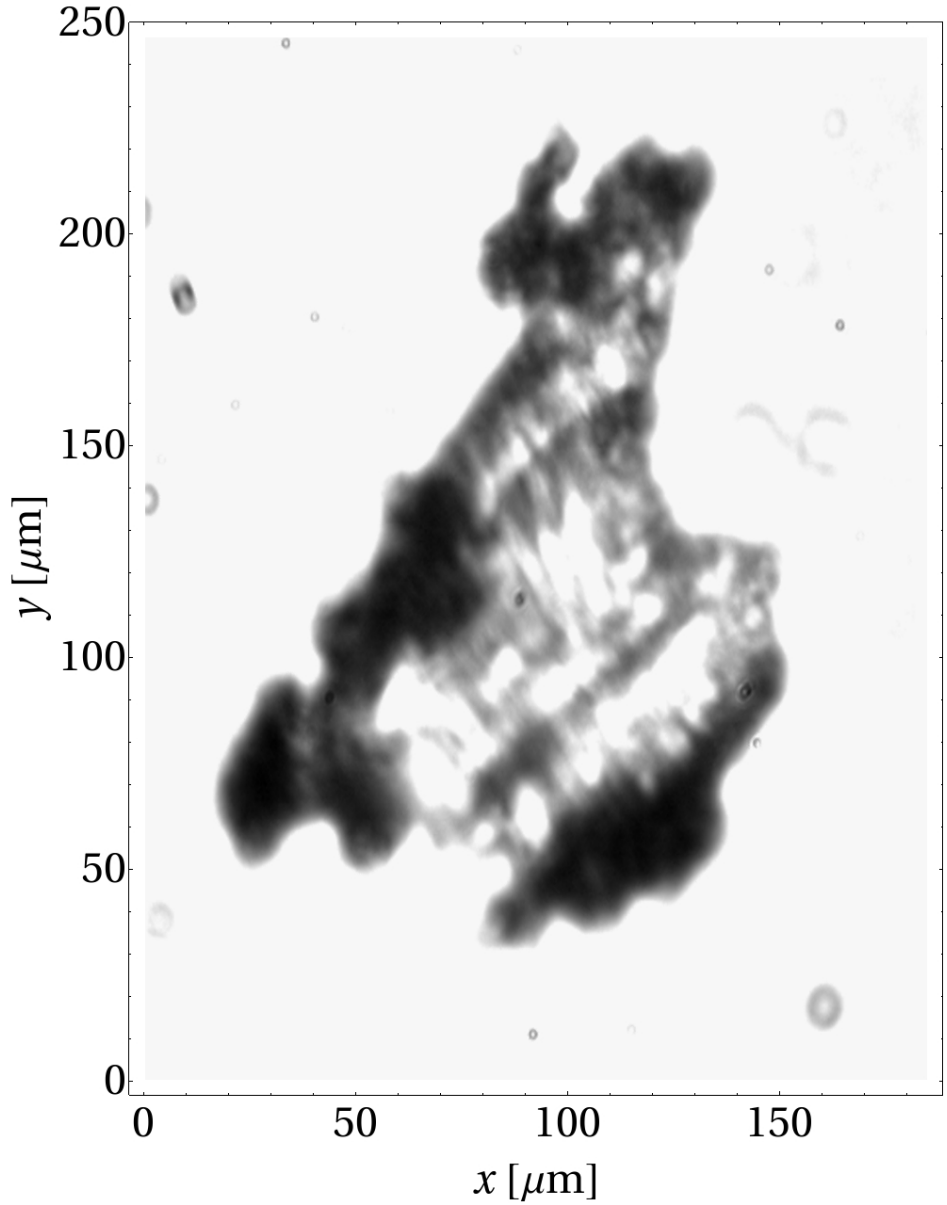

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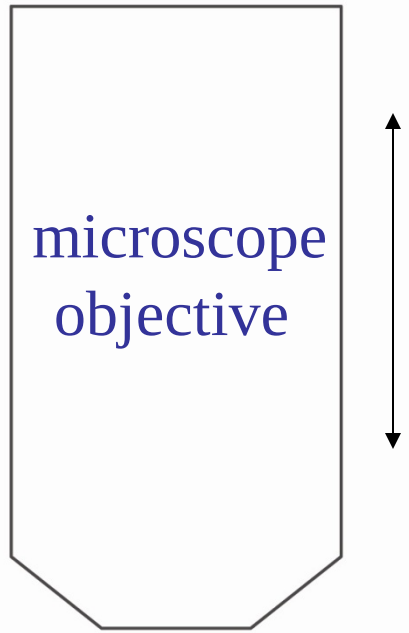


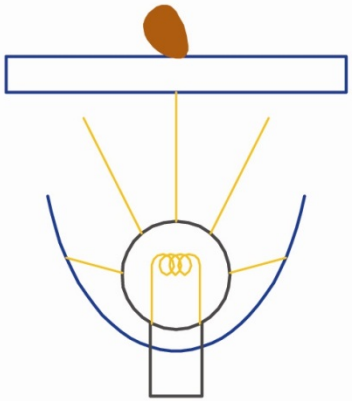

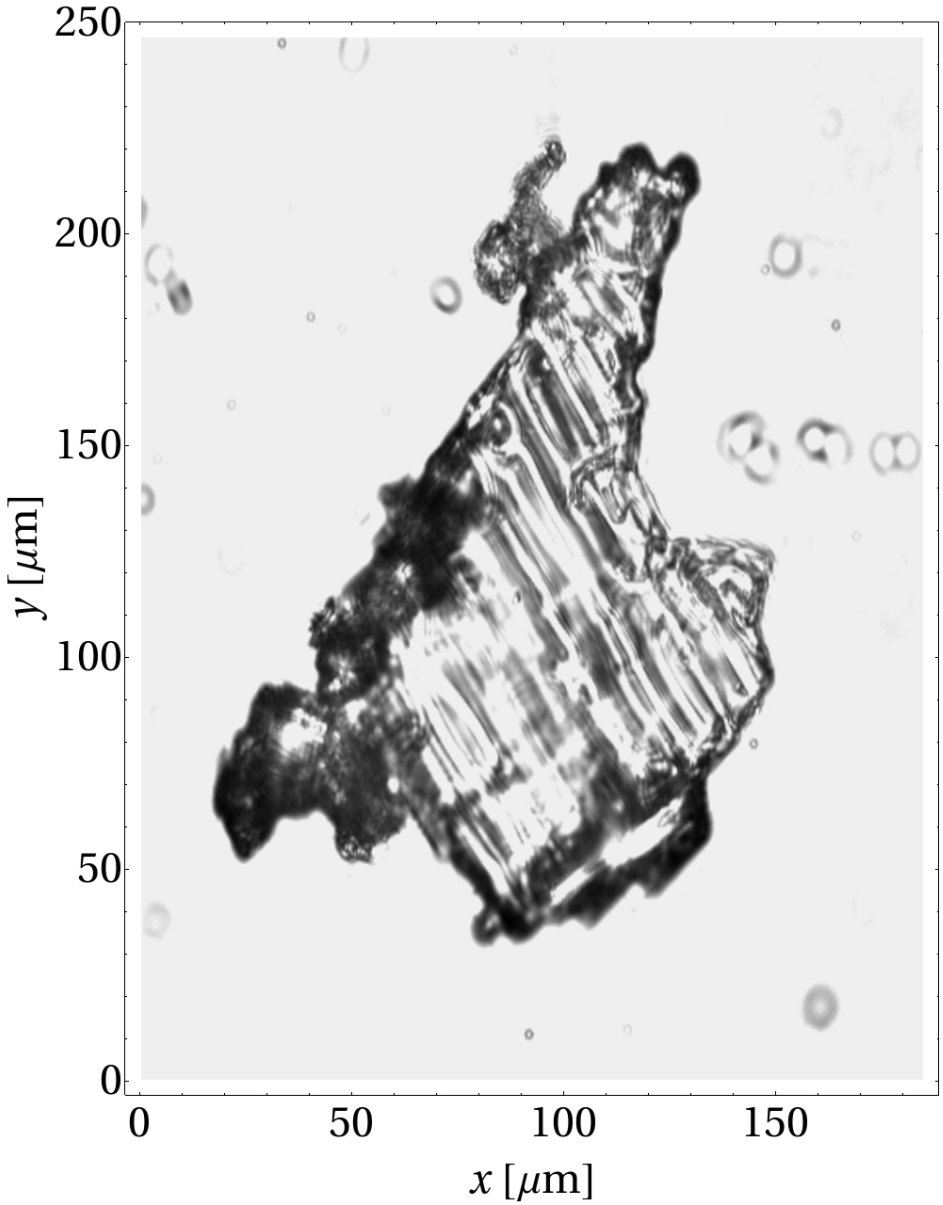

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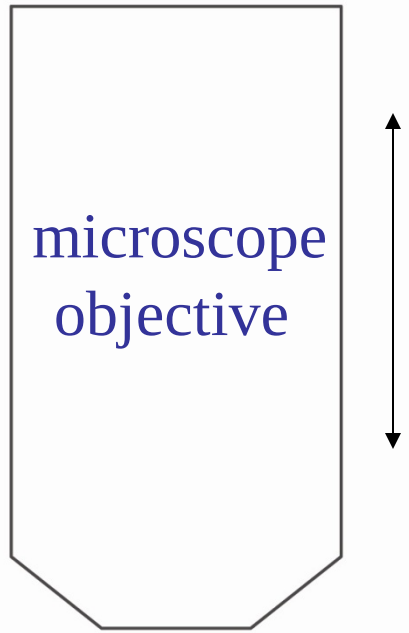


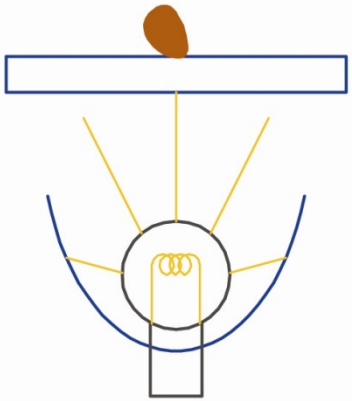

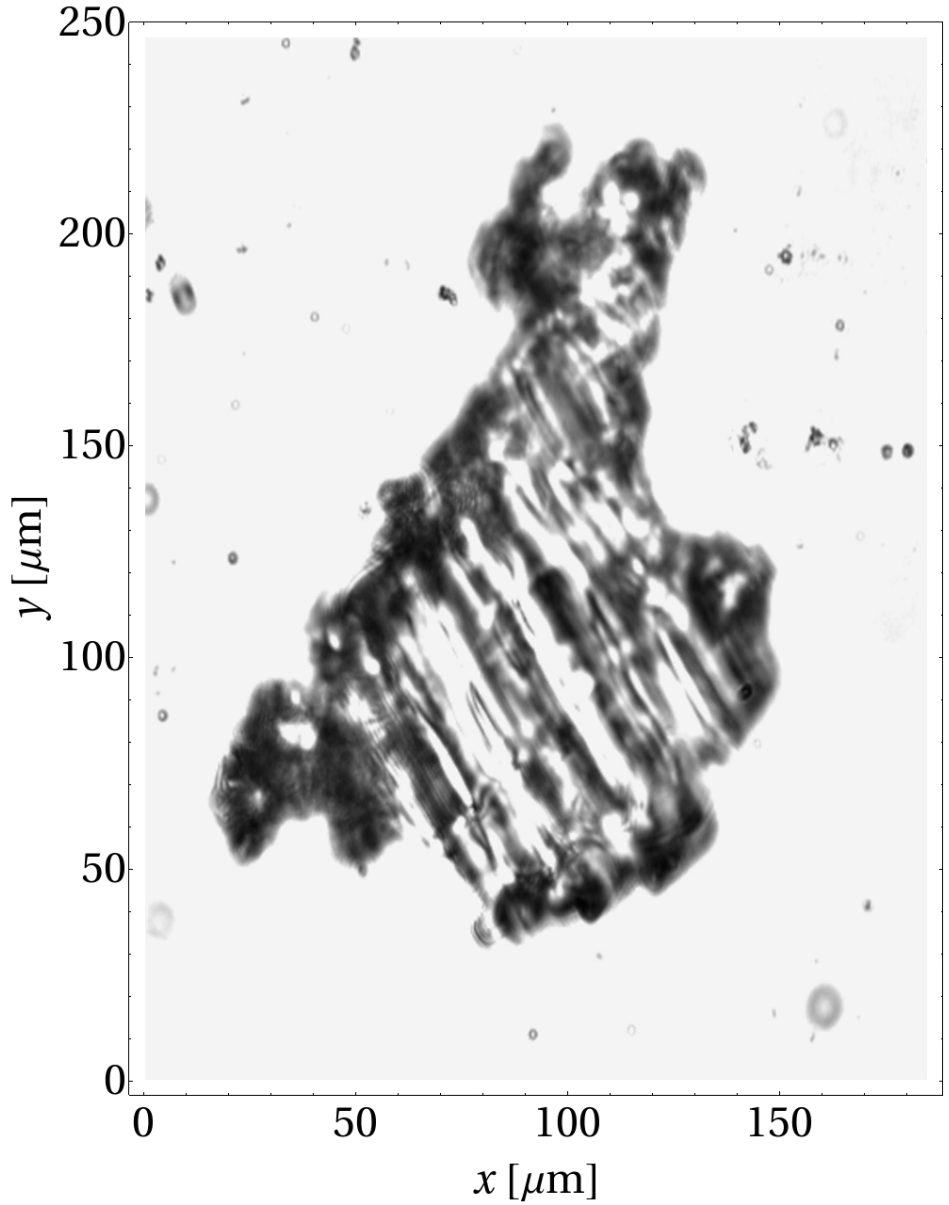

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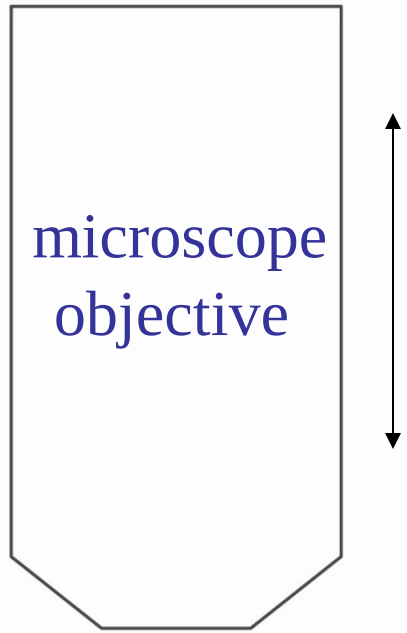
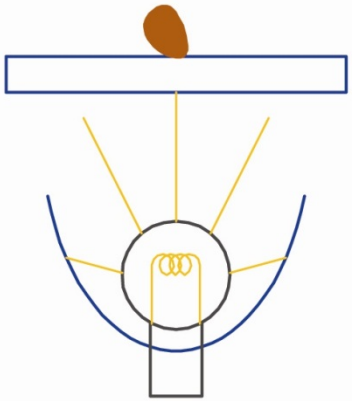
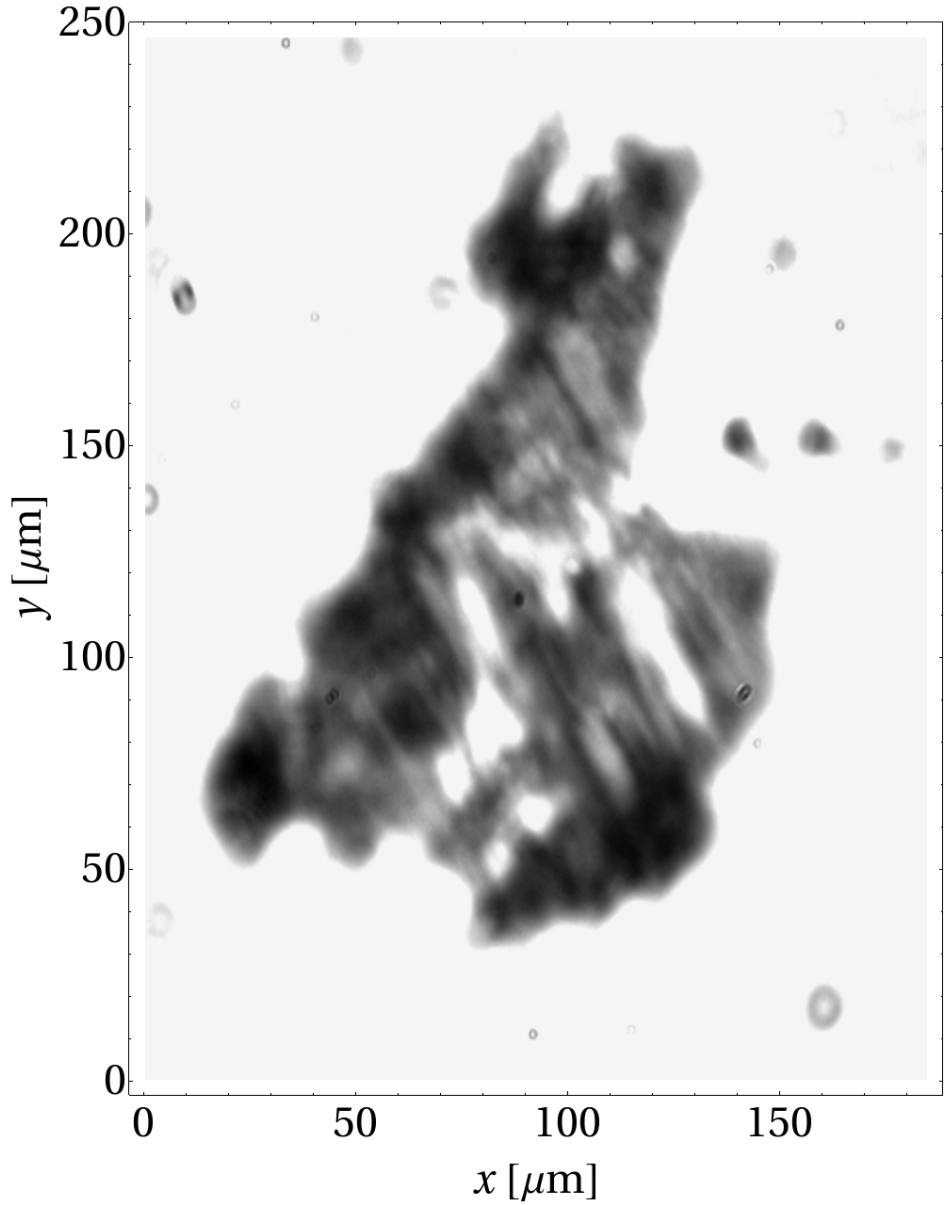


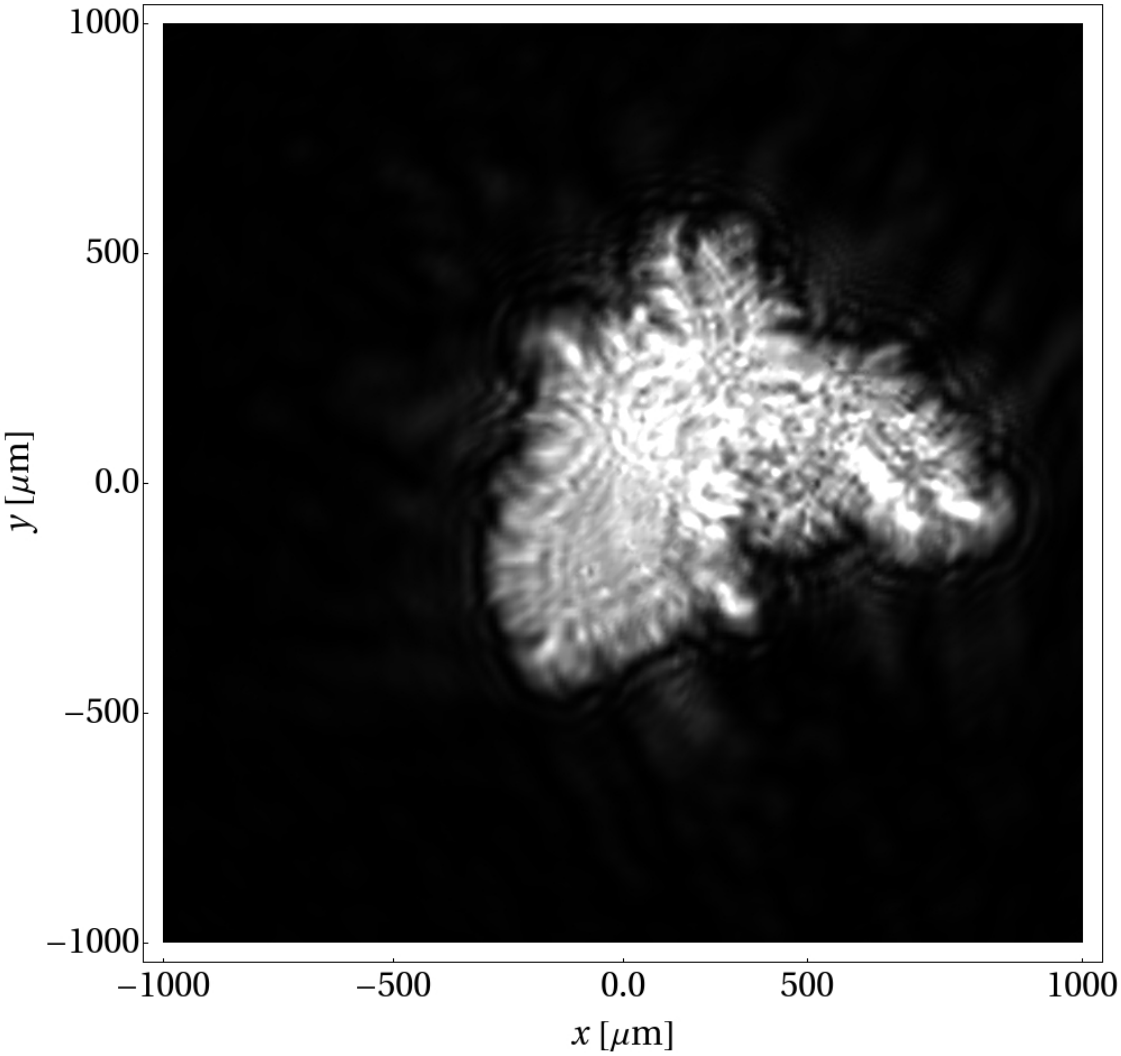





# Focusing properties…

From a single contrast hologram of an aerosol, the particle image can be focused just like if it were in a microscope…

This is done computationally by varying the distance between the hologram and reconstruction plane.



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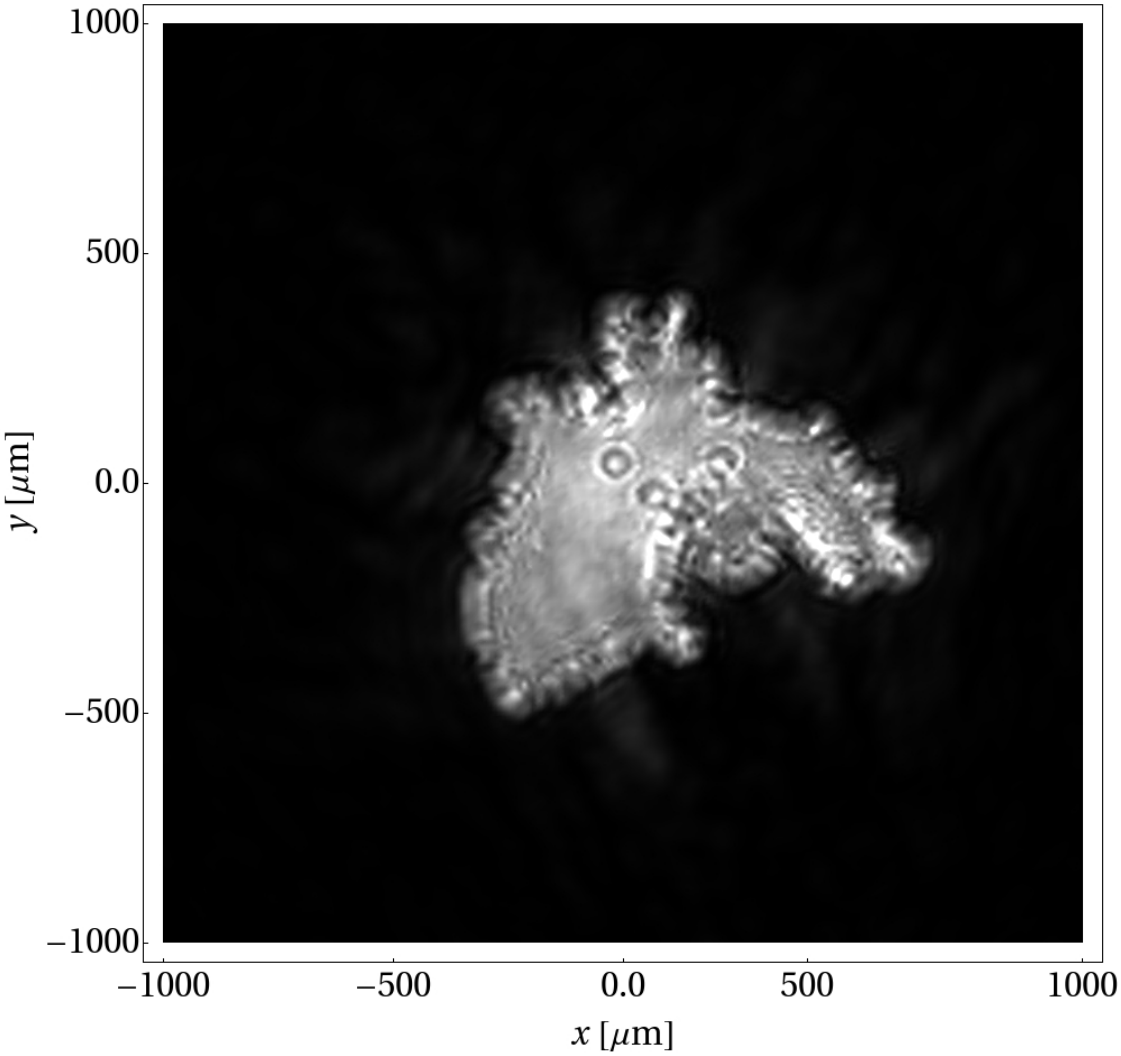

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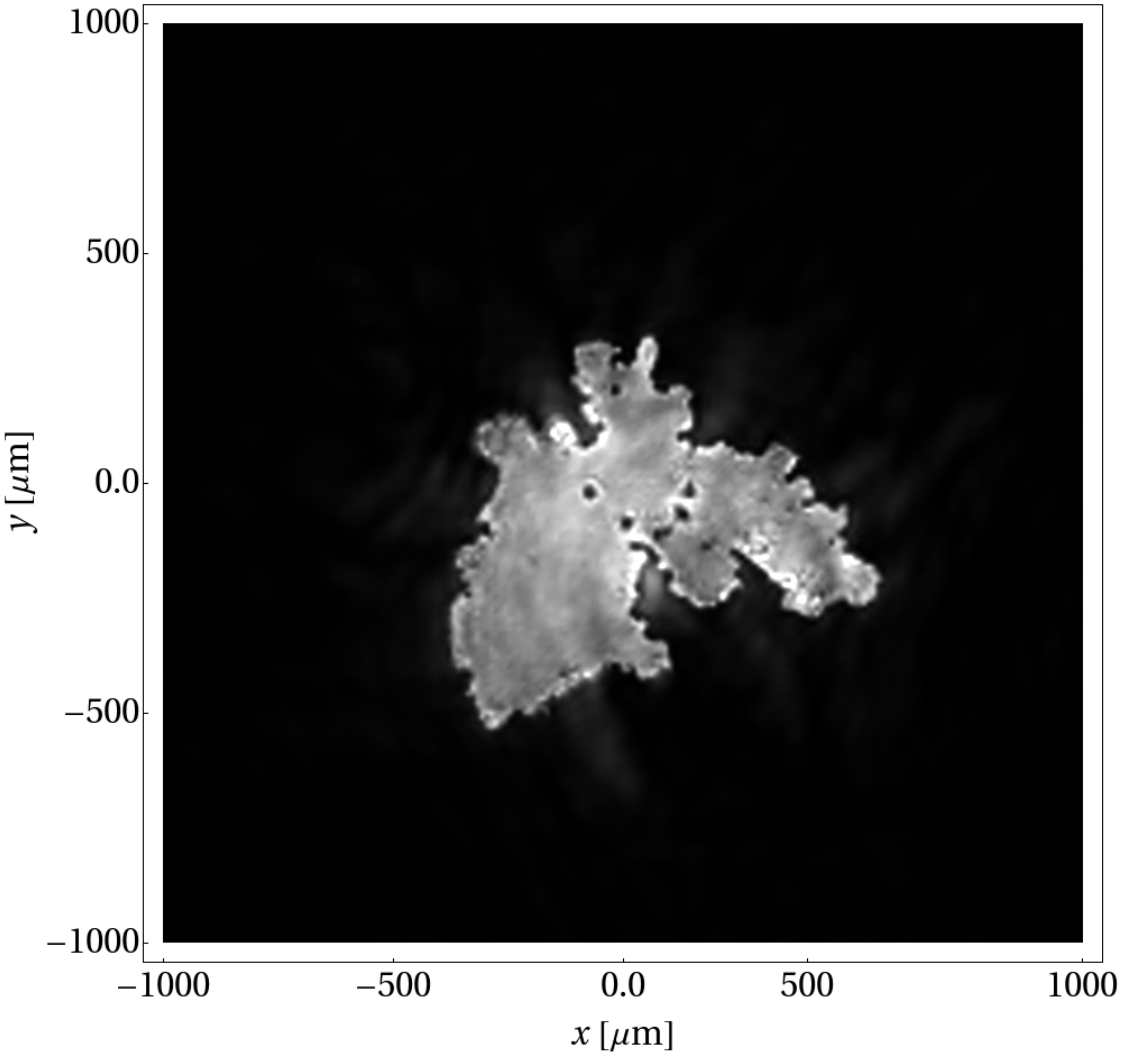

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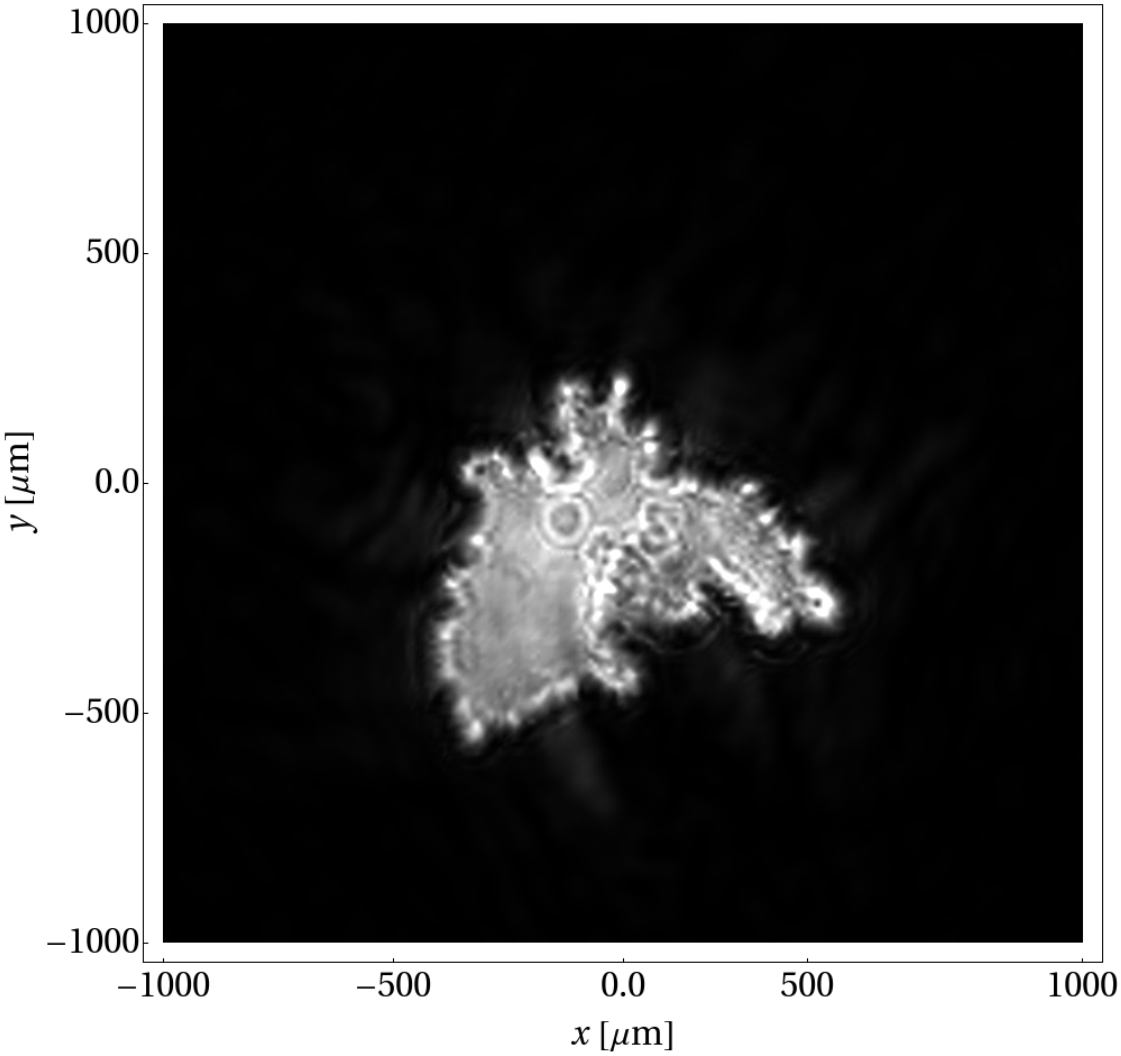

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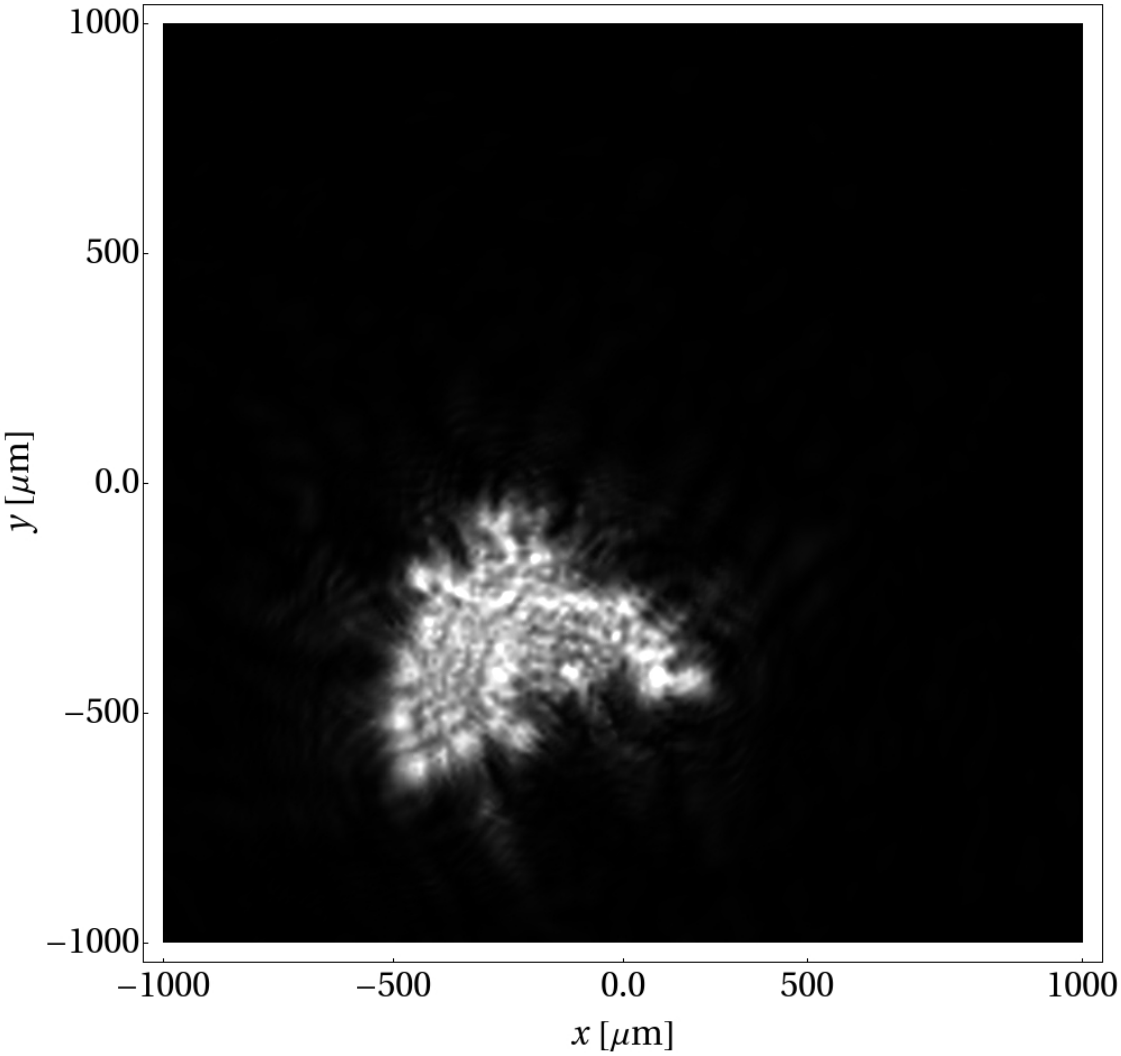


# The next step…

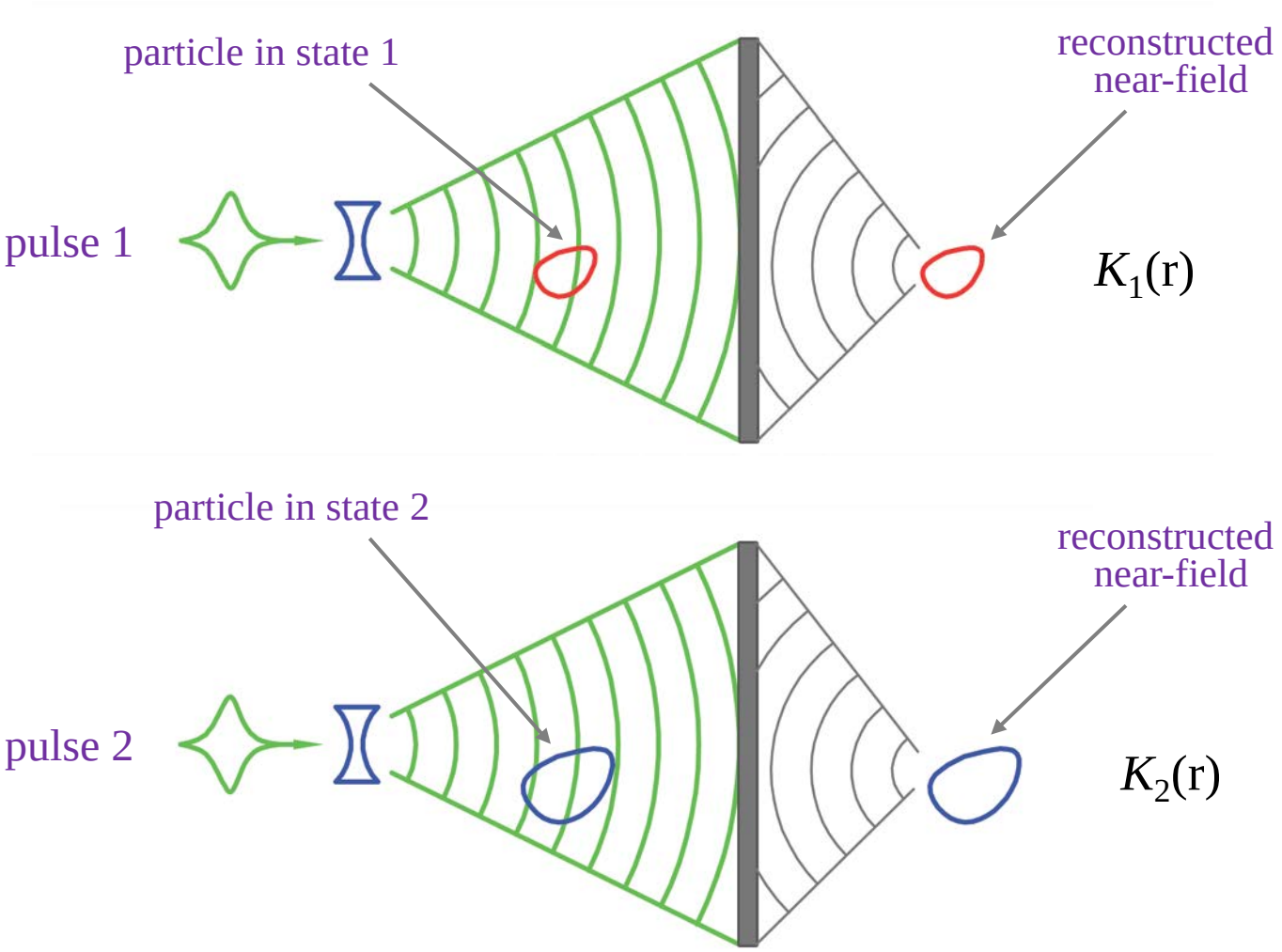
- A highly useful capability would be is to get a particle image *simultaneously* with some information about its composition.

- To do this, we propose to measure optical absorption by the particle using digital holography.

- The basic idea involves *interfering* two holographic images of a particle undergoing some change.

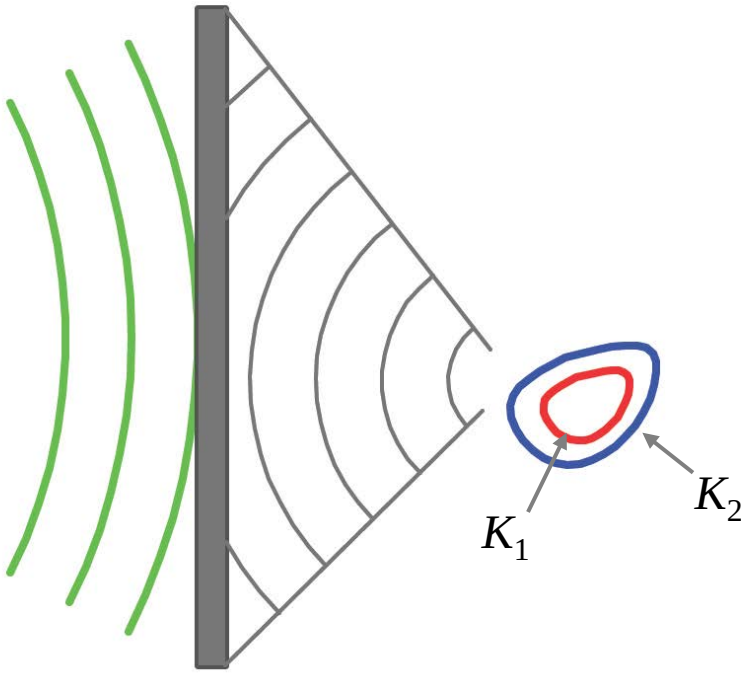
# Particle absorption

Consider the particle in 2 different physical states:



# Particle absorption…

If the CCD is deliberately double-exposed, then reconstruction will produce both near-field waves superimposed.




$$K_{tot}=K_1+K_2$$

The image produced will then be proportional to:

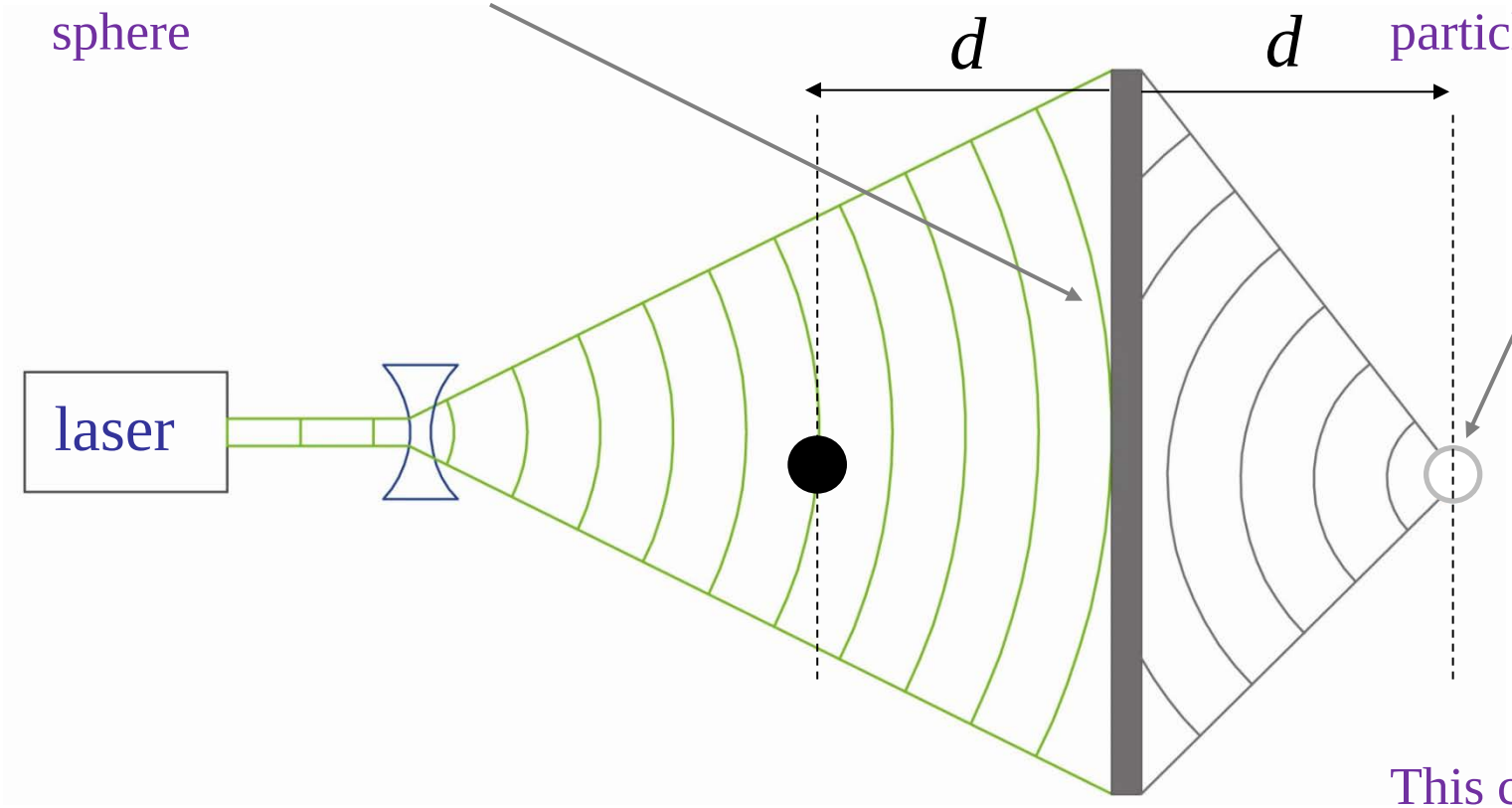
$$|K_1+K_2|^2$$

which should show a profile of the particle superimposed with interference fringes.

# Computational test

Use Mie theory to produce a simulated digital hologram for a highly **absorbing** sphere

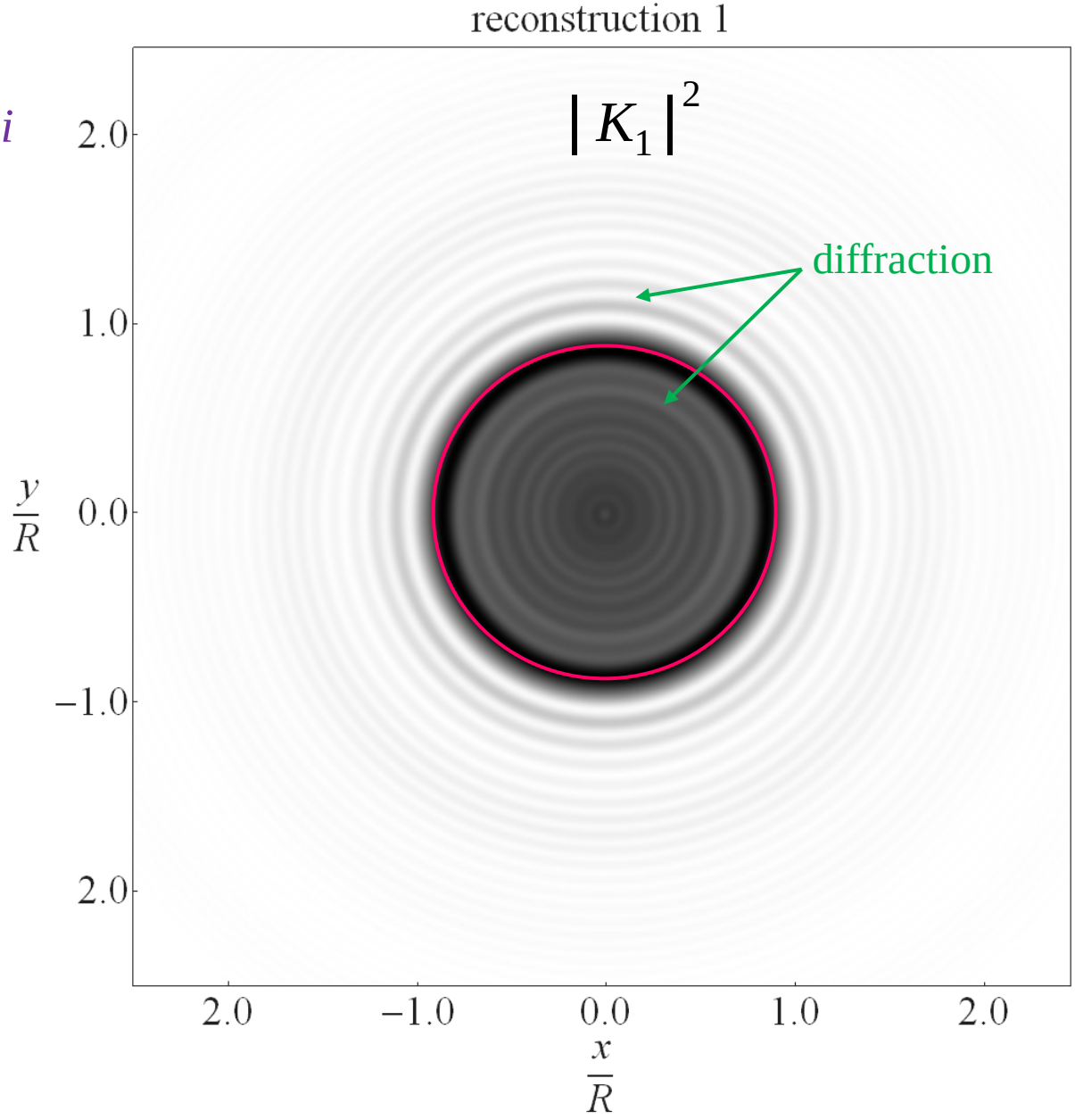
Reconstruct particle image from simulated hologram in plane passing through the particle center.




This can be repeated after expanding the particle size…

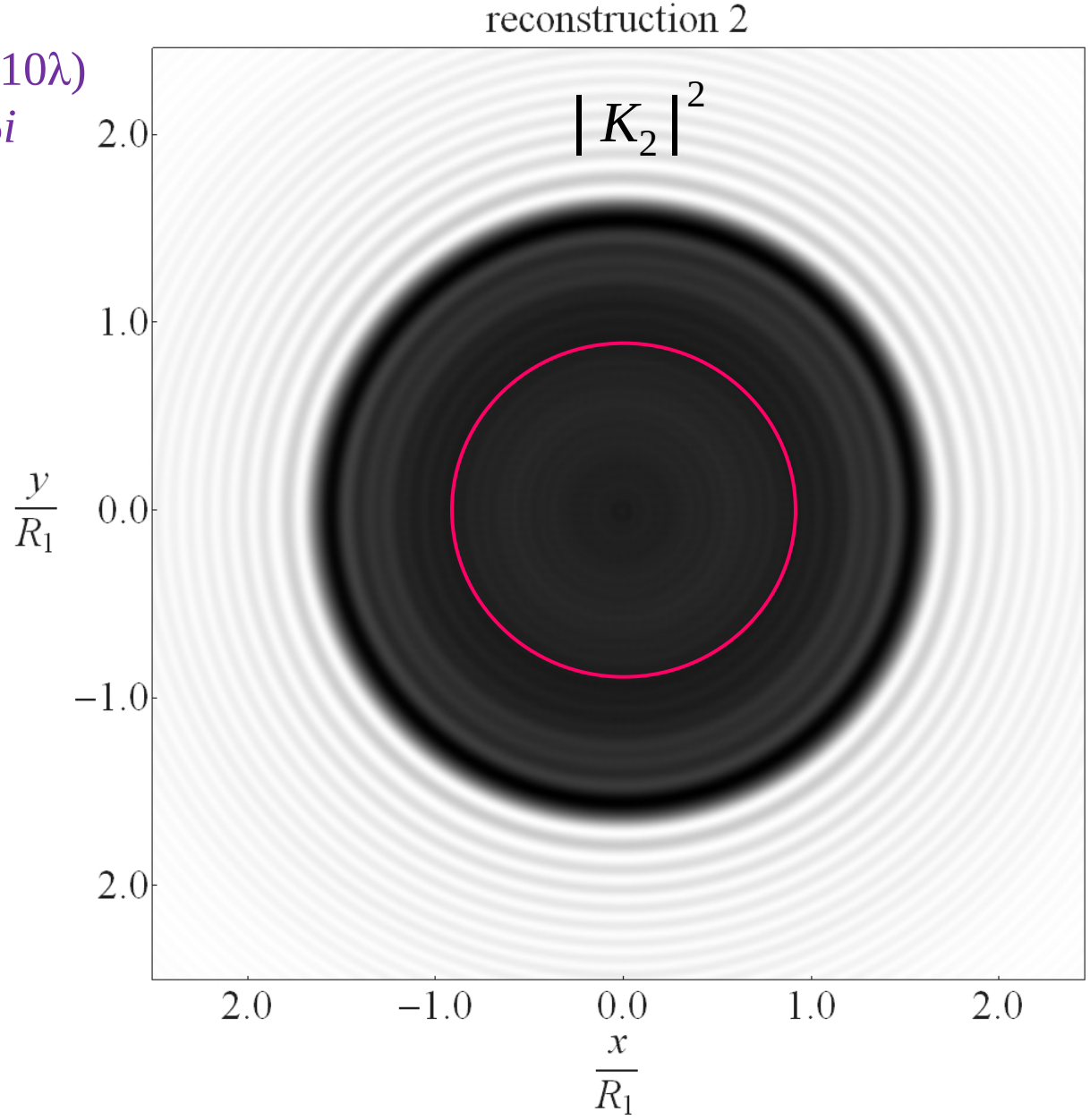
# Computational test…

$kR$=170
$m$=1.33+0.05$i$



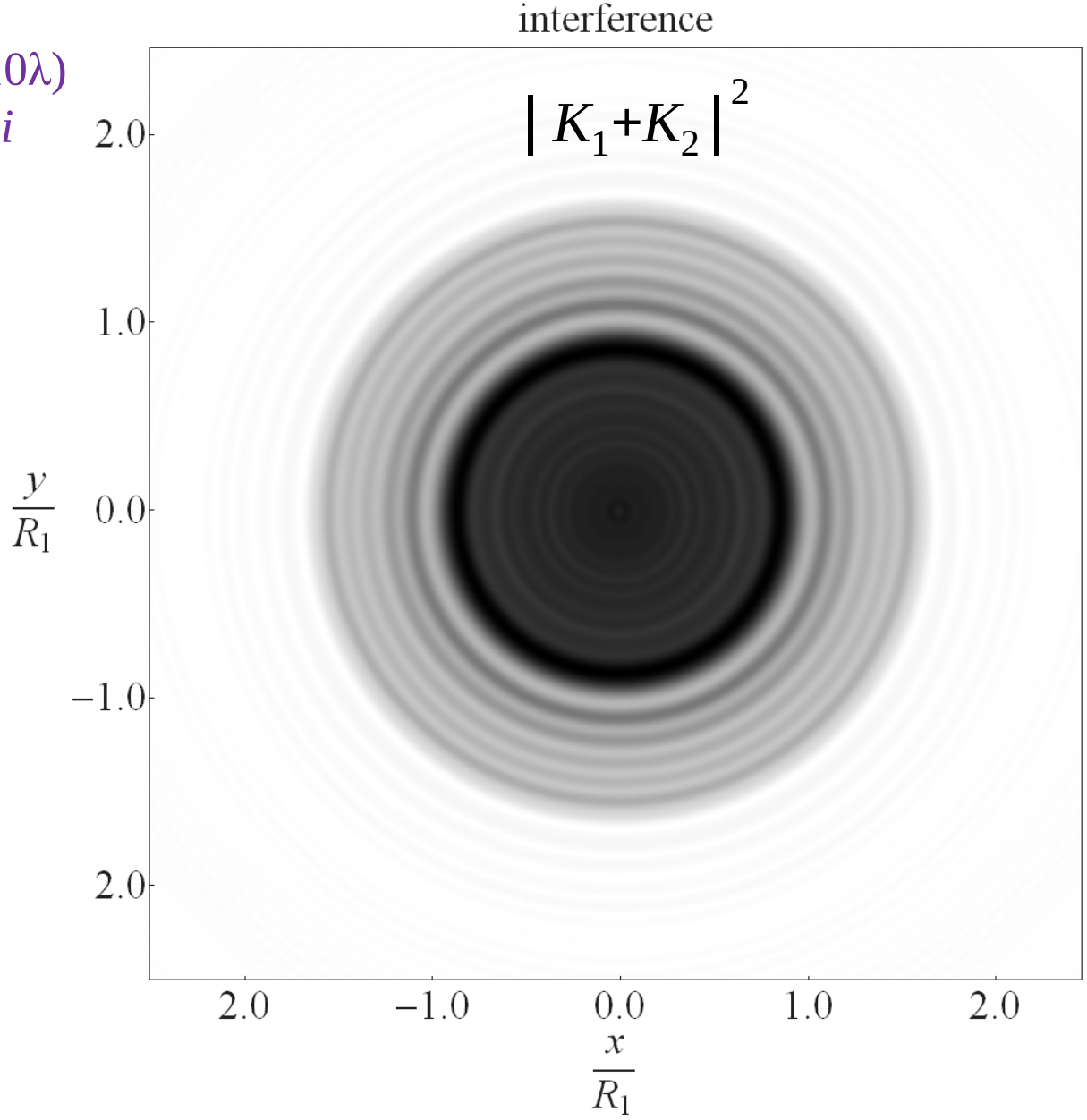
# Computational test…

$kR$=**295** ($R_1$+10λ)
$m$=1.33+0.05$i$



# Computational test…

$kR$=**245** (R+10λ)
$m$=1.33+0.05$i$



# How to change the particle state

Illuminate the particle with a $CO_2$ laser pulse (10.6 um IR).

This heating will perturb the particle changing its physical state:

expansion is size

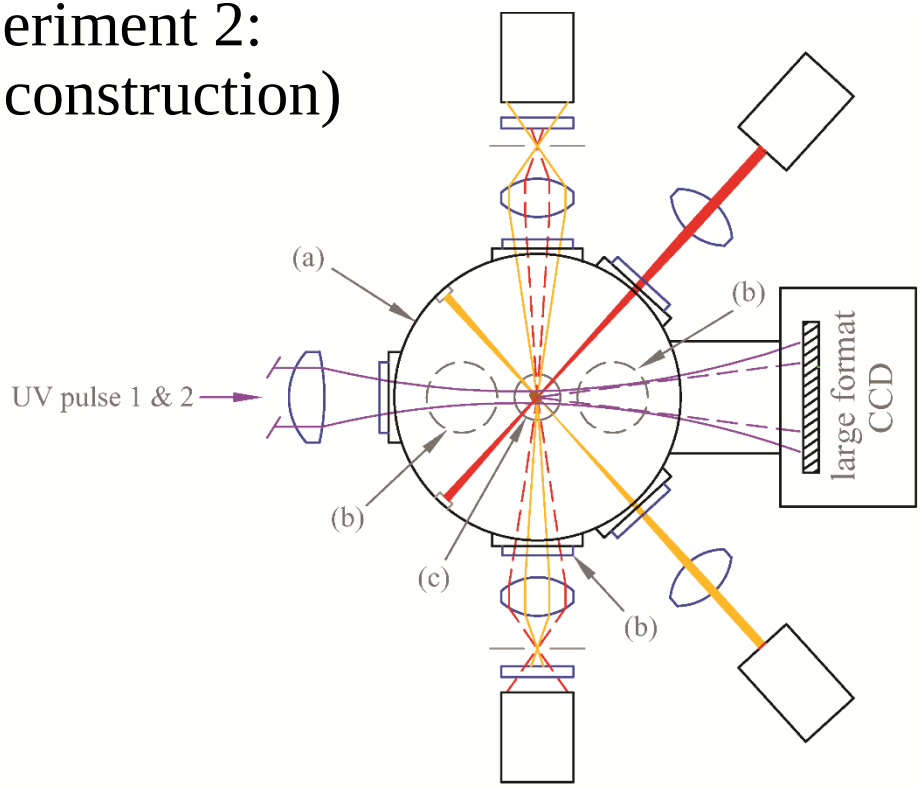
change in refractive index

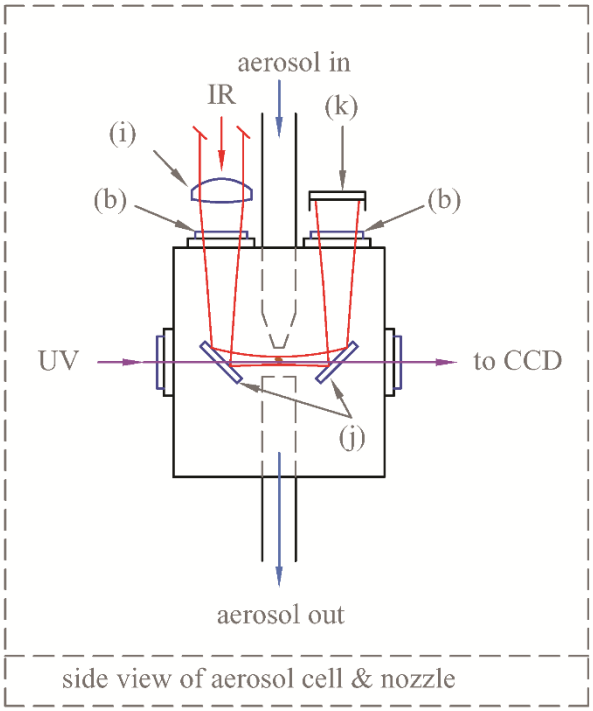
heating of the surrounding air (schlieren)

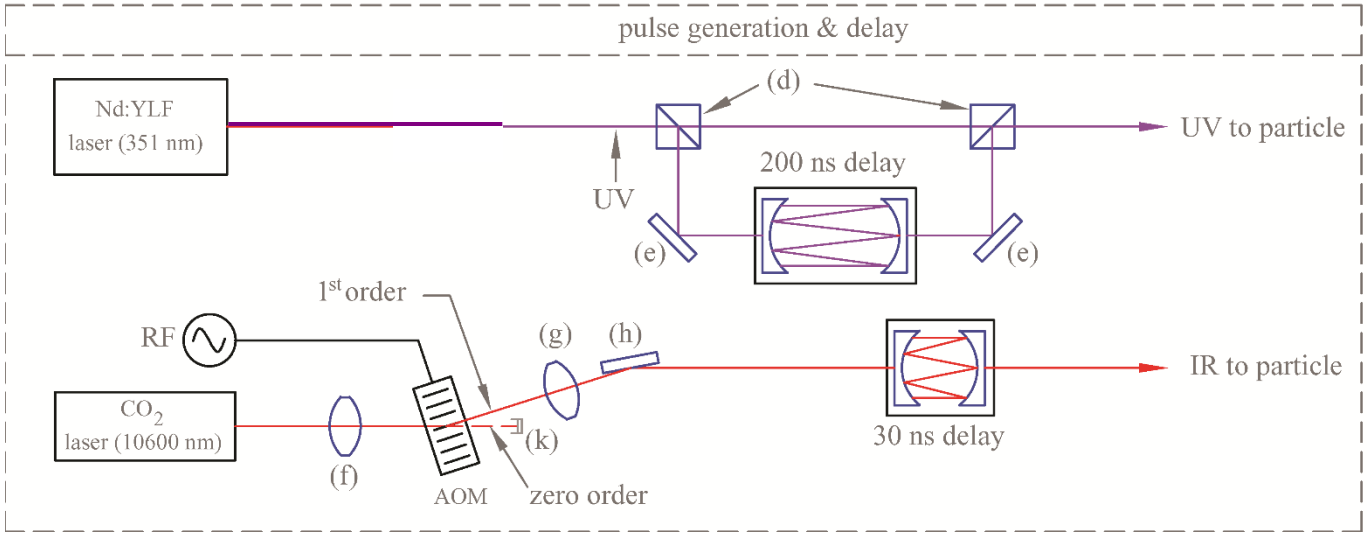
The perturbation of the particle will be related to its absorption of the IR heating pulse.

Thus, the interference fringes in the reconstructed particle image (due to this perturbation) should be connected to the absorption properties of the particle: a material-dependent quantity.

# Experiment 2:
# (under construction)




(a) aerosol cell
(b) window
(c) aerosol inlet
(d) beamsplitter
(e) Ag mirror
(f) focusing lens
(g) collimating lens
(h) Au mirror
(i) ZeSe lens
(j) IR dichroic mirror
(k) beam stop

# Summary

- Digital holographic imaging of aerosol particles can be done *in situ* with a simple optical arrangement.
- This imaging technique completely avoids the difficulties associated with interpreting scattering patterns.
- It may be possible to obtain particle image and composition information simultaneously.

a recent paper…

"Digital holographic imaging of aerosol particles in flight"

*J. Quant. Spectrosc. Radiat. Transfer* **112** p. 1776-83 (2011)

which is freely available at:

**http://sites.google.com/site/emscattering/**

Acknowledgements

US Army Research Office