Properties of SiO_2 Aerogels Suitable for Astrophysical Experiments

S. L. SUBLETT

University of Rochester
Laboratory for Laser Energetics

Collaborators

J. P. Knauer, D. D. Meyerhofer, and S. Skupsky

Laboratory for Laser Energetics
University of Rochester

A. Frank and A. Y. Poludnenko

Department of Physics and Astronomy
University of Rochester

Abstract

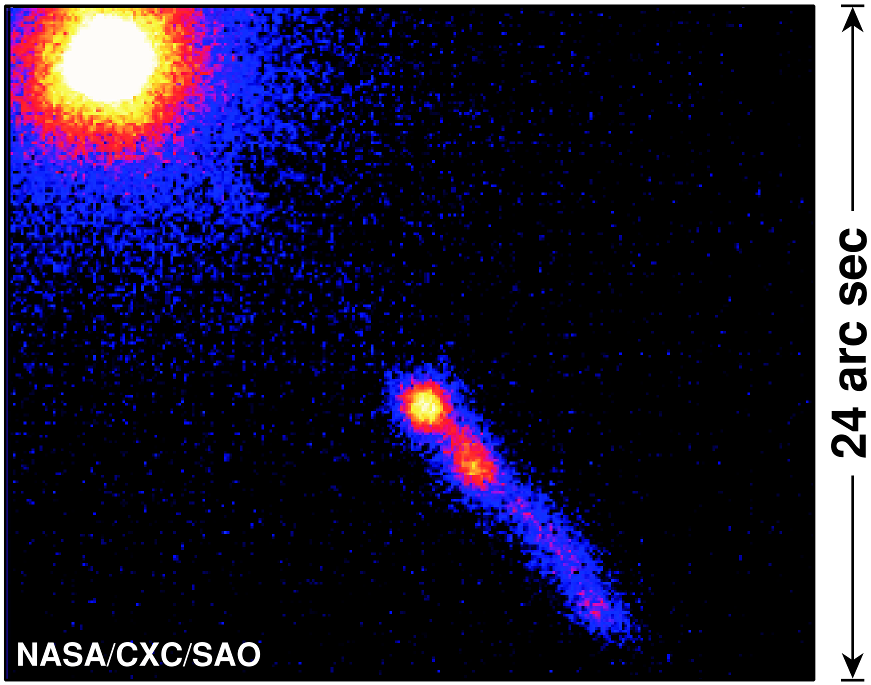
We are studying inhomogenieties in SiO_2 aerogel. The aerogel has been treated in our hydrodynamic simulations as a material with uniform density but is modeled to grow by diffusion-limited cluster-cluster aggregation (DLCA) during the sol-gel process. We have modified DLCA C++ code to grow a SiO_2 aerogel model to be used as input in established hydrodynamic code in order to calculate the propagation of a converging conical shock wave through the foam. The foam has an average density of 100 mg/cm^3 and consists of roughly spherical globules of silicon-dioxide molecules with an average radius of 110$\pm$8 nm. This foam is being tested for plasma jet experiments relevant to astrophysics wherein a conical shock wave propagating through the foam is driven by one to six OMEGA laser beams. Fluid downstream of the shock wave is forced through an aperture to create a plasma jet imaged by self-emission and silicon x-ray absorption.

Astronomical plasma jets are ubiquitous

- Low-density materials are required to simulate scale-independent astronomical conditions.
- Astrophysical jet experiments offer a unique opportunity to bridge the gap between astrophysical theory, simulation, and observations of a variety of scale-independent, shock-driven plasma jet morphologies.
- The flexibility of the OMEGA laser targets and diagnostics allows for the exploration of the relevant parameter space.
- The properties of the materials for these experiments are not well established.
- Foams are potentially useful in a number of other experiments and applications.

Young and old galaxies exhibit jets

Quasar 3C273



This very distant quasar is the core of an active galactic nucleus.

Galaxy M87

This is a nearby giant elliptical galaxy of the most highly evolved class, E0.

Jets are part of stellar birth

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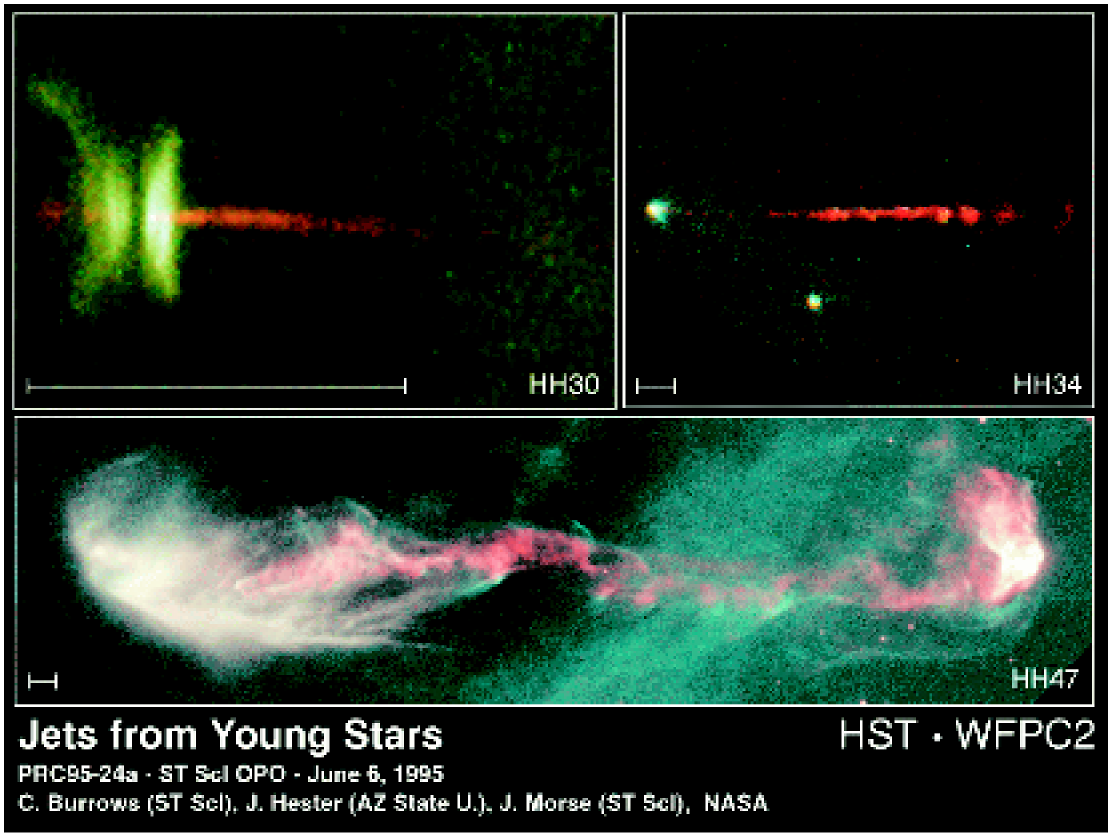
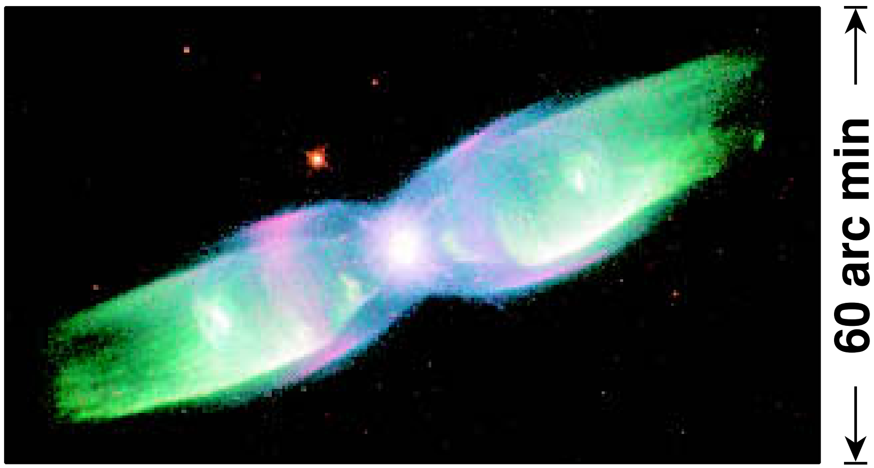


Jets from young stars show a range of jet sizes and morphologies; each scale bar is 1000 AU.

Jets occur upon the death of average and massive stars

Planetary Nebula M2-9



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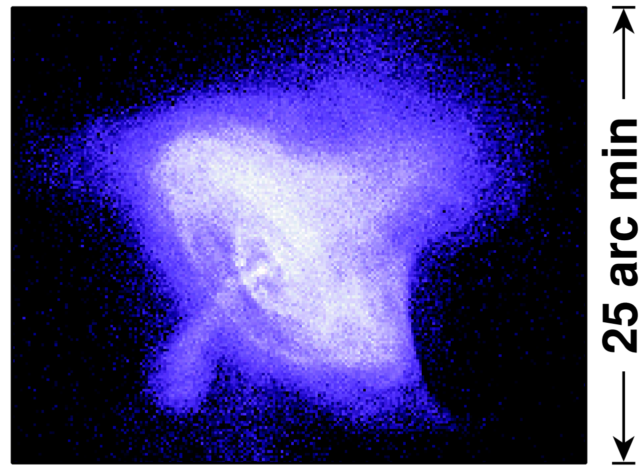
The "twin jet" nebula M2-9 is a typical butterfly morphology Planetary Nebula.

Crab Nebula



NASA/CXC/SAO

The Crab Nebula has a pulsar emitting jet of particles at nearly the speed of light.

OMEGA astrophysical jet experiments are designed to study pulsed outflows relevant to planetary nebulae

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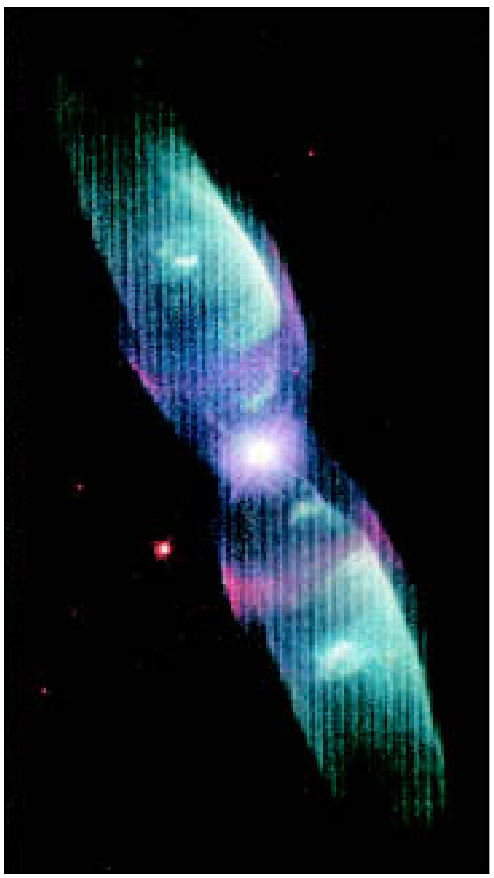
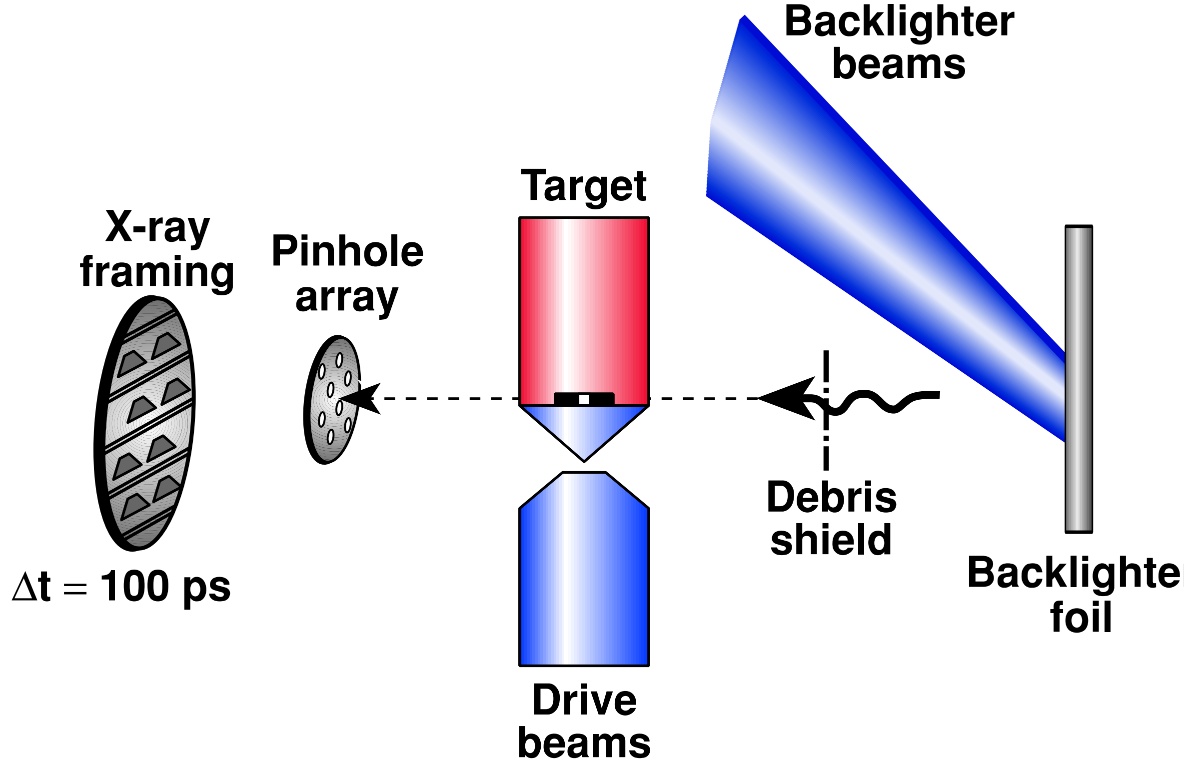
Planetary nebula



Schematic of OMEGA experiment



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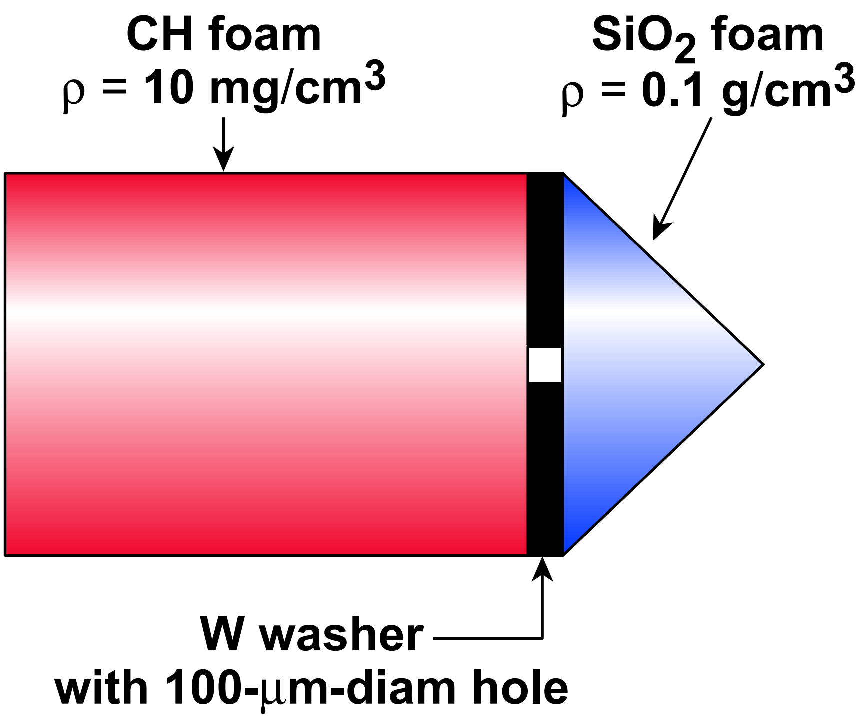
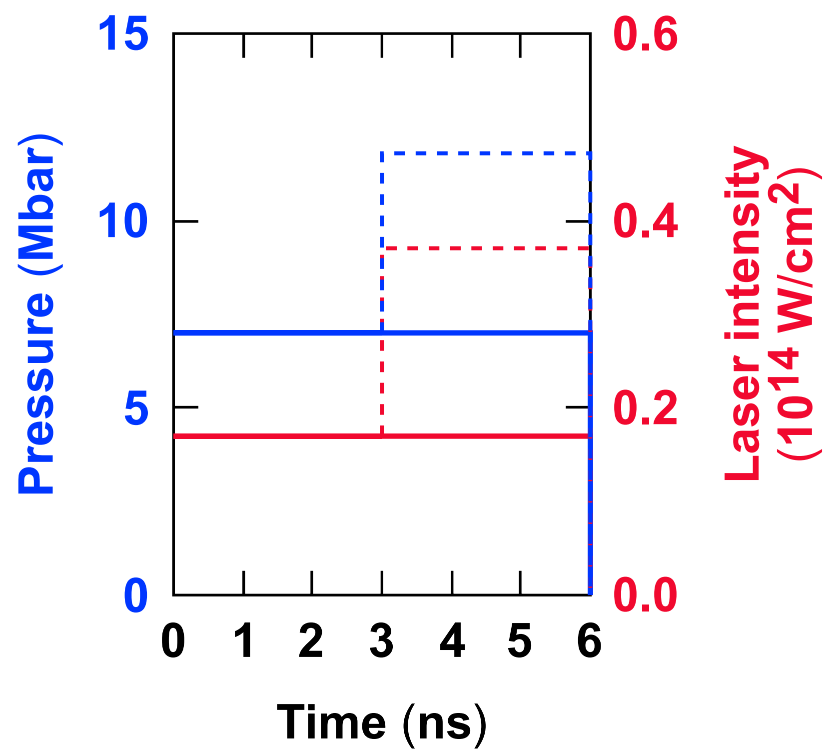
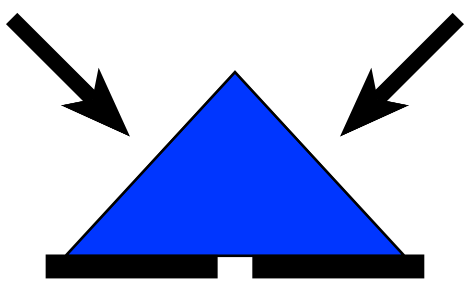
The first experiments on OMEGA studied the convergent stock targets





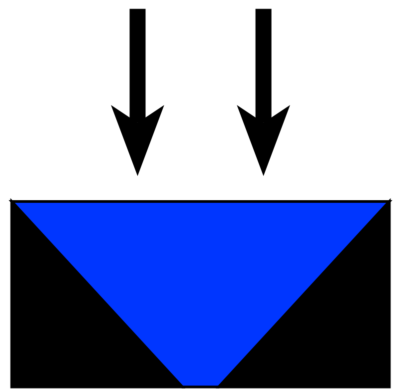
Outflows can be simulated with a variety of target configurations

Incident laser beams



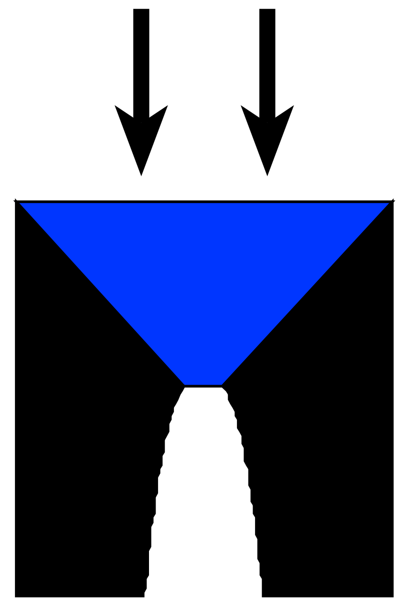
Convergent shock waves

Mach # < 1



Convergent flow through nozzle

Mach # = 1



Convergent–divergent flow through nozzle

Mach # > 1

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Properties of target materials must be established in order to design experiments

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- The first attempts to create a jet were imaged too early in time because the velocity of the shock through the aerogel was overestimated.
- One cannot assume a uniform density for aerogel in simulations.
- Some laser energy will go into homogenizing the aerogel rather than producing a shock.

Rendered DLCA output can be compared to observed aerogel properties

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- Small scale
  - the average size of a particle
  - the distribution of particle sizes
- Large scale
  - the pore size and spacing
  - the fractal dimensions

DLCA code simulates the sol-gel process by means of fractal growth

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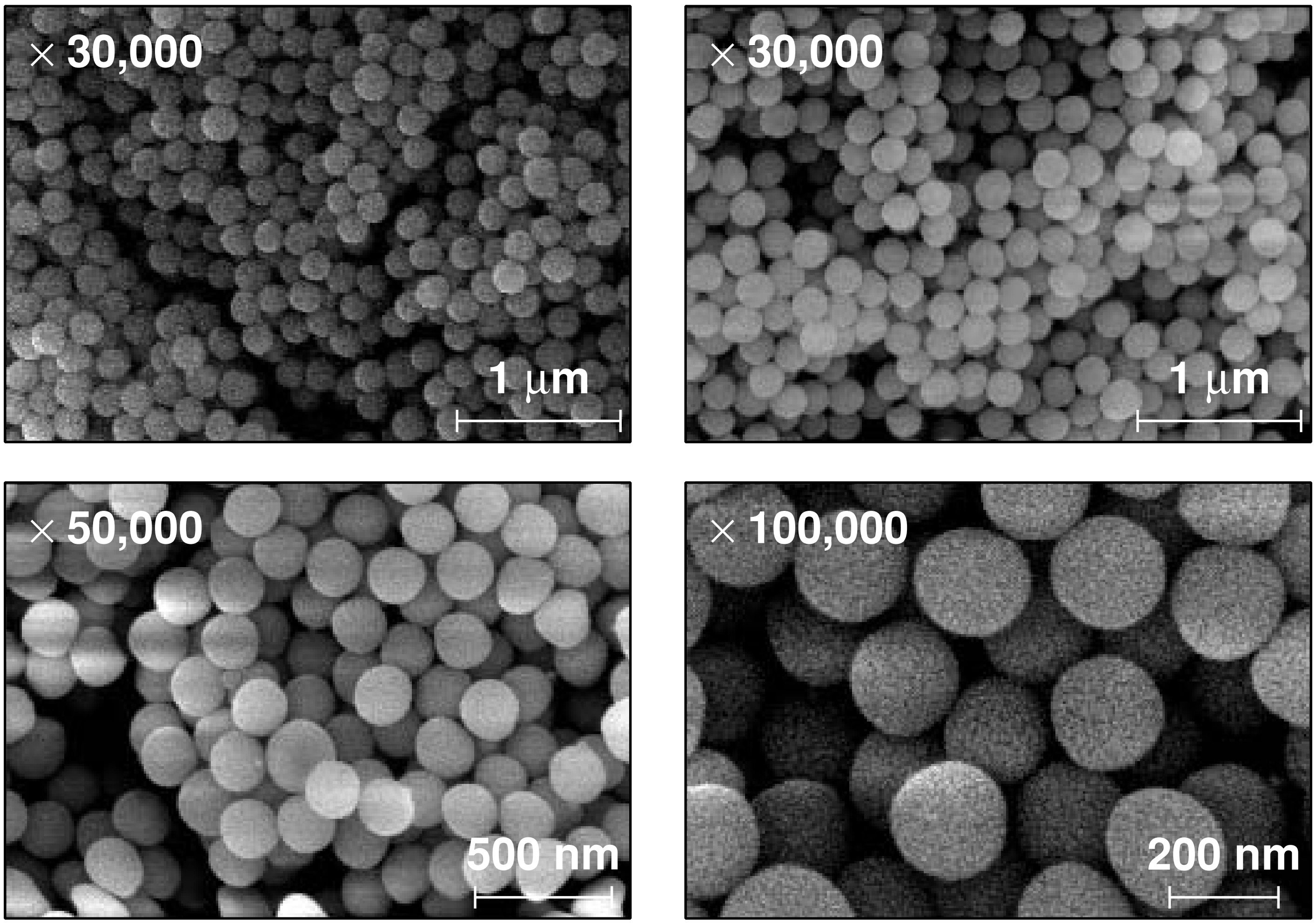
- A bounding box with a given number of particles is specified.
- During polymerization, the particles move about the box via brownian motion.
- During gelation, the particles clump when they get close.
- During supercritical drying, the particles and clumps stick together.

SEM images of SiO_2 aerogel were taken at three magnifications



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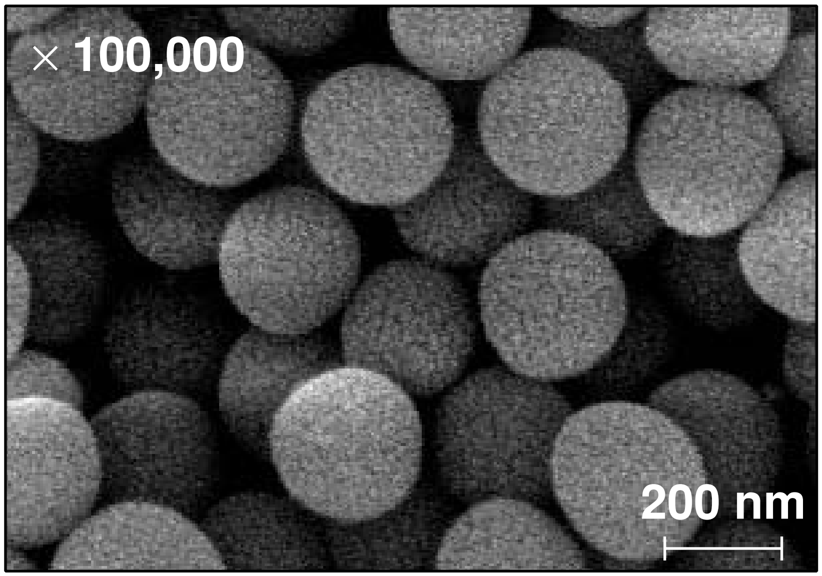
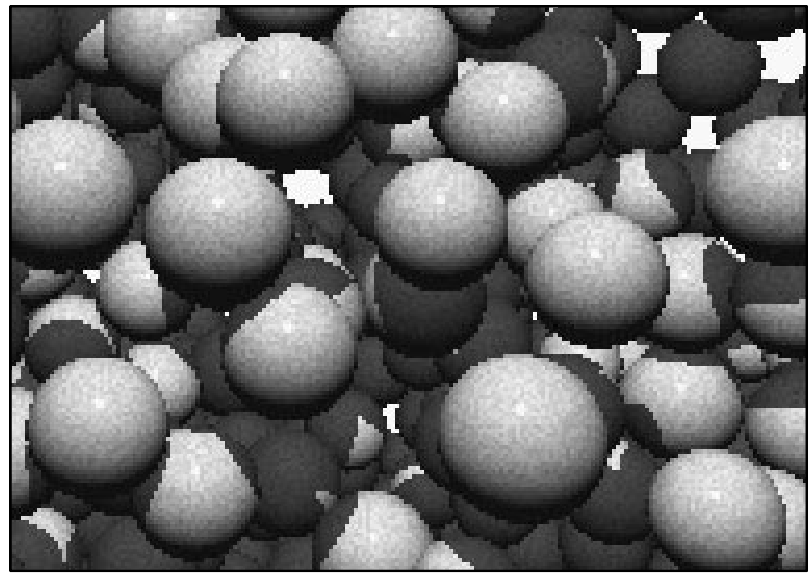
The structure of the simulated data is comparable to the SEM image



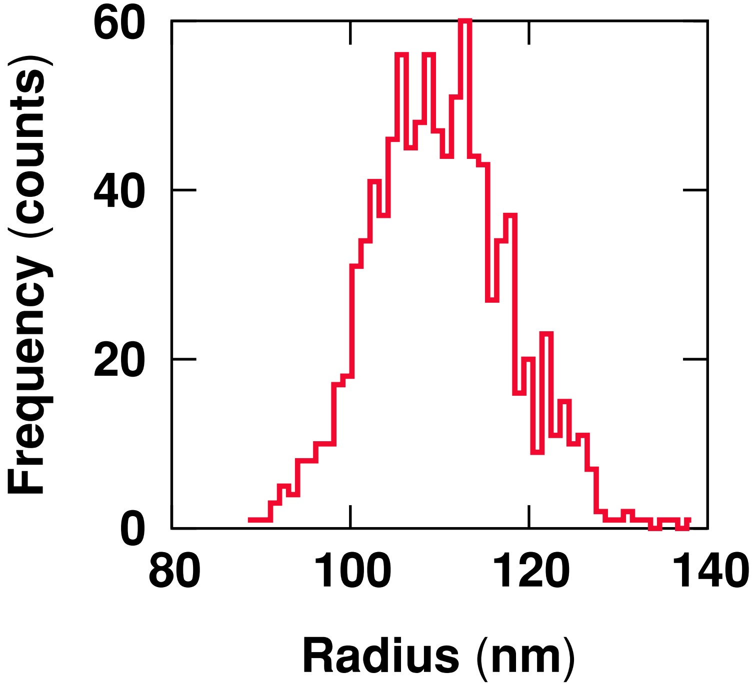
Scanning electron microscope image



Close-up of POV-Ray 3.1 rendering of 1000 spheres generated by DLCA code

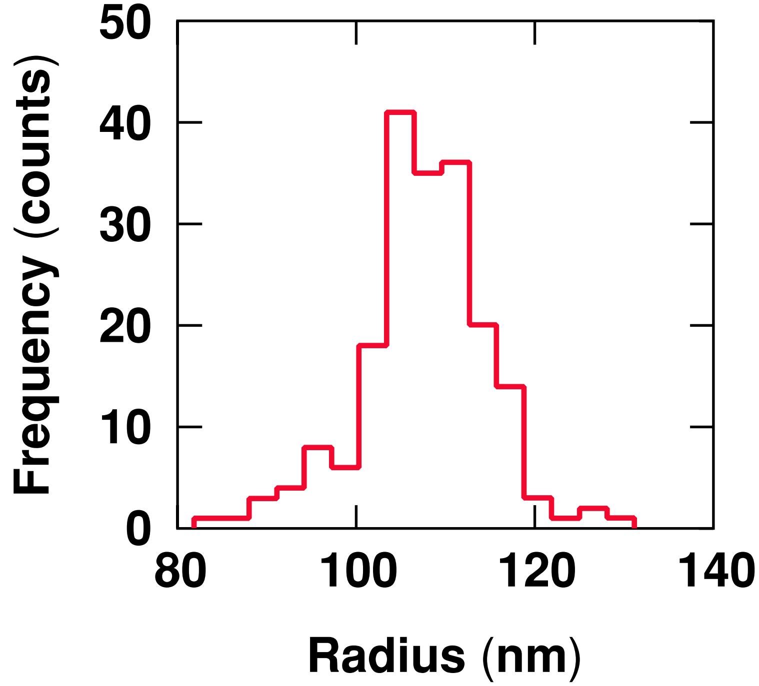
DCLA input parameters are determined by fitting circles to a SEM image

Histogram for the radii of 1000 simulated particles



Mean radius = 110.27 nm
Standard deviation = 7.64 nm

Histogram for the radii of 196 measured SEM spheres



Mean radius = 109.7 nm
Standard deviation = 8.0 nm

Future work will refine the modeling of foam and make use of foam parameters in hydrodynamic simulations

- Compare log normal distribution of particle radii to Gaussian distribution.
- Measure fractal dimensions of this aerogel and adjust Brownian motion parameter of DLCA code to reflect these.
- Perform similar analyses of CH foam and other foams used in experiments.
- Input circles/spheres into Adaptive Mesh Refinement code and hydrodynamic simulations of shocks propagating in media to examine homogenization, ionization, etc.
- Use foam in OMEGA laser targets to form small-scale astrophysical plasma jets.
- Use aerogels and foams in EOS and RTI experiments.

References

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