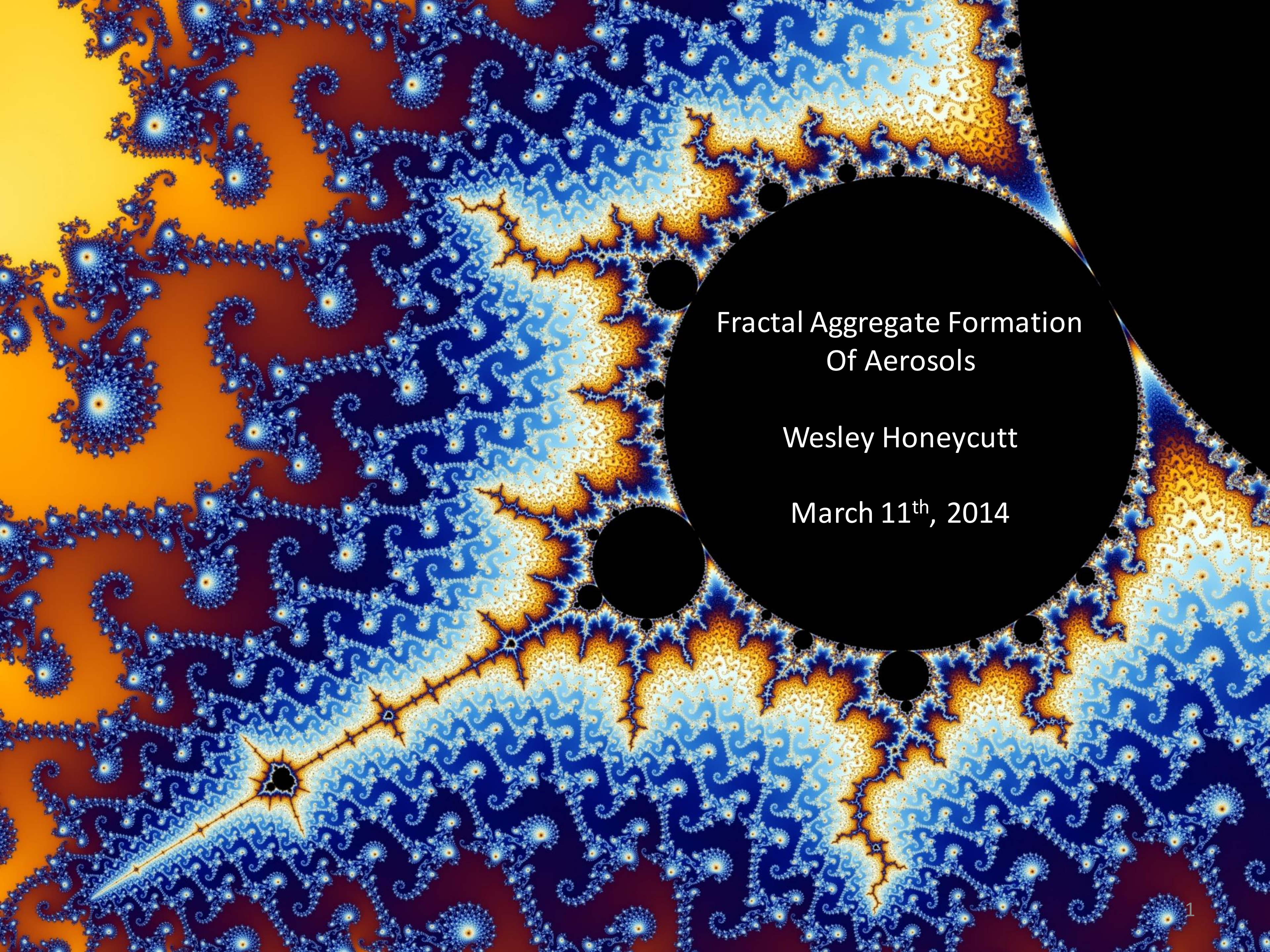


Fractal Aggregate Formation Of Aerosols

Wesley Honeycutt

March 11th, 2014

Presentation Overview

Review: What is an aerosol? What is a fractal?

Size and growth of aggregating particles

Aerosol to aerogel

Estimating size of aggregates with fractal math

Ball Lightning

- Oxidation of particles in air
- Electric field effects
- Soil aggregates in air
- Spectral analysis

Defining Aerosols

An aerosol is a suspension of fine particles (1-10nm) in a gaseous media.

i. Can be described as in terms of concentration
ii. Particles can exist outside of suspension for long periods of time

Aerosol	Not an Aerosol
A cloud of superfine dust	A flock of birds
Campfire smoke	Clouds

Aerosols are termed based on their origin

i. Primary aerosols – product of a chemical reaction
ii. Secondary aerosols – product of gas-to-particle conversion

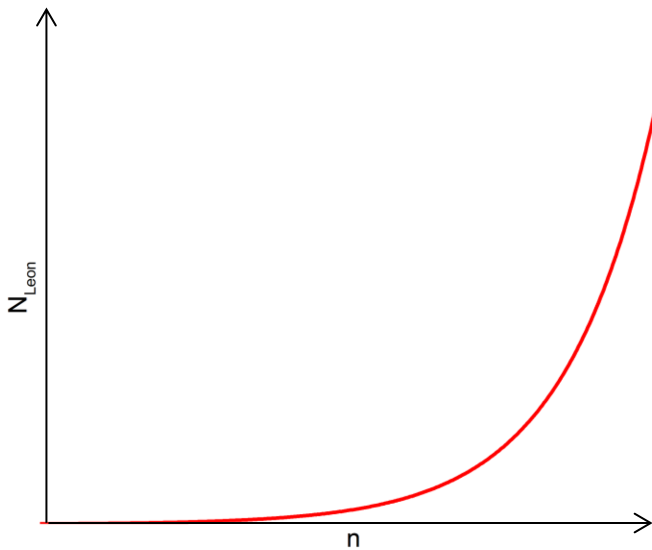
Primary	Secondary
Combustion releasing soot	Aggregates caused by lightning strikes

Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.

CATNIP
Not even once

Original Photo used with permission from Janet Honeycutt

Structure and the Fractal Sum

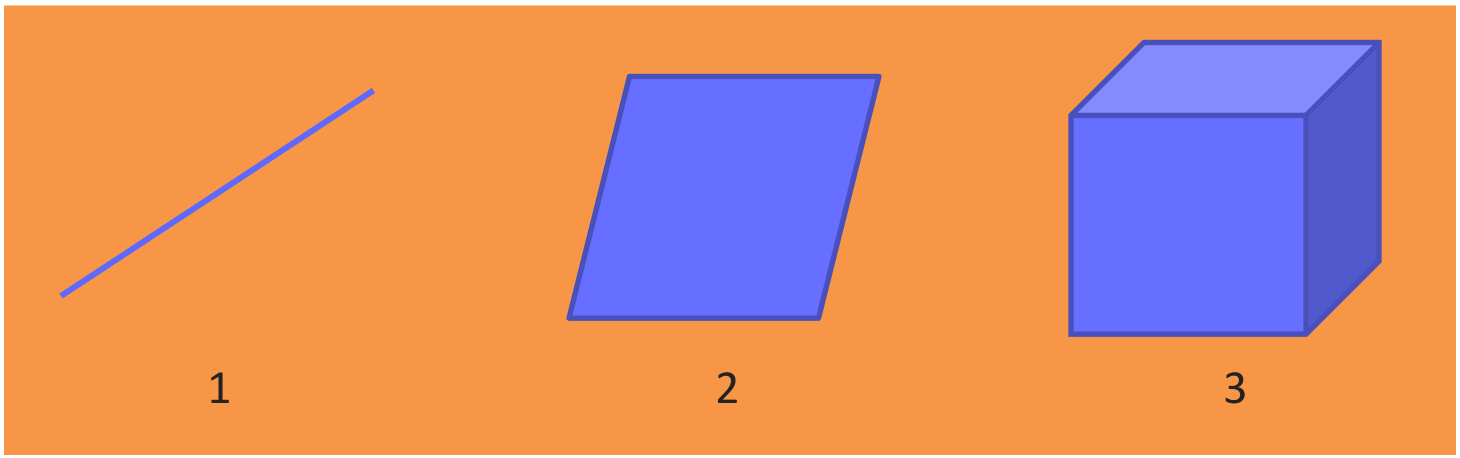


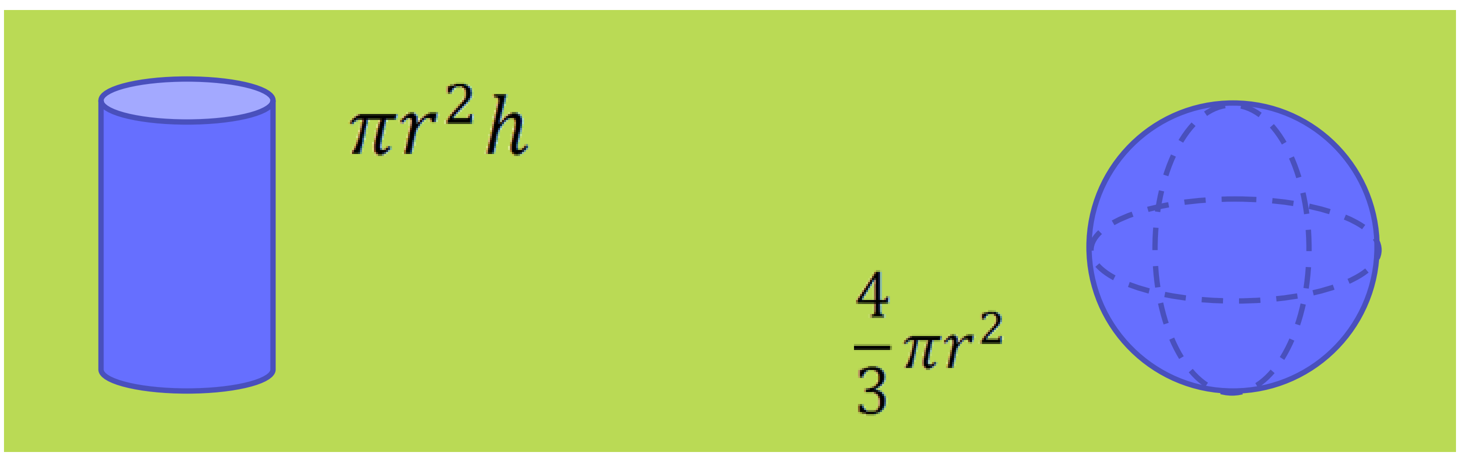
$$N_{Leon} = \sum_{i=0}^{n} 2^{n} - 1$$

$$\lim_{n \to \infty} N_{Leon} = \infty$$

$$N = k_0 \left(\frac{R_g}{a}\right)^{D_f}$$

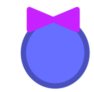
R_g	radius of gyration
a	radius of single primary particle
k_0	scaling prefactor
D_f	fractal dimension





Sorensen, C.M., 2011. The Mobility of Fractal Aggregates: A Review. Aerosol Science and Technology 45, 765–779.

Probability to find another particle certain particle within distance *r*



?

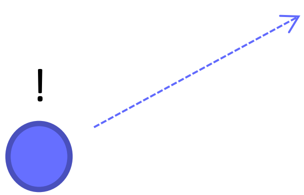
$$g(r) \sim r^{D_f - d}\, h\left(\frac{r}{R_g}\right)$$

Where $h(x)$ is our finite size cutoff function

Which is bound by:

$$h(x) = e^{-x^{\gamma}} \begin{cases} x \ll 1 \rightarrow h(x) = 1 \\ x \gg 1 \rightarrow h(x) < g(r) \end{cases}$$

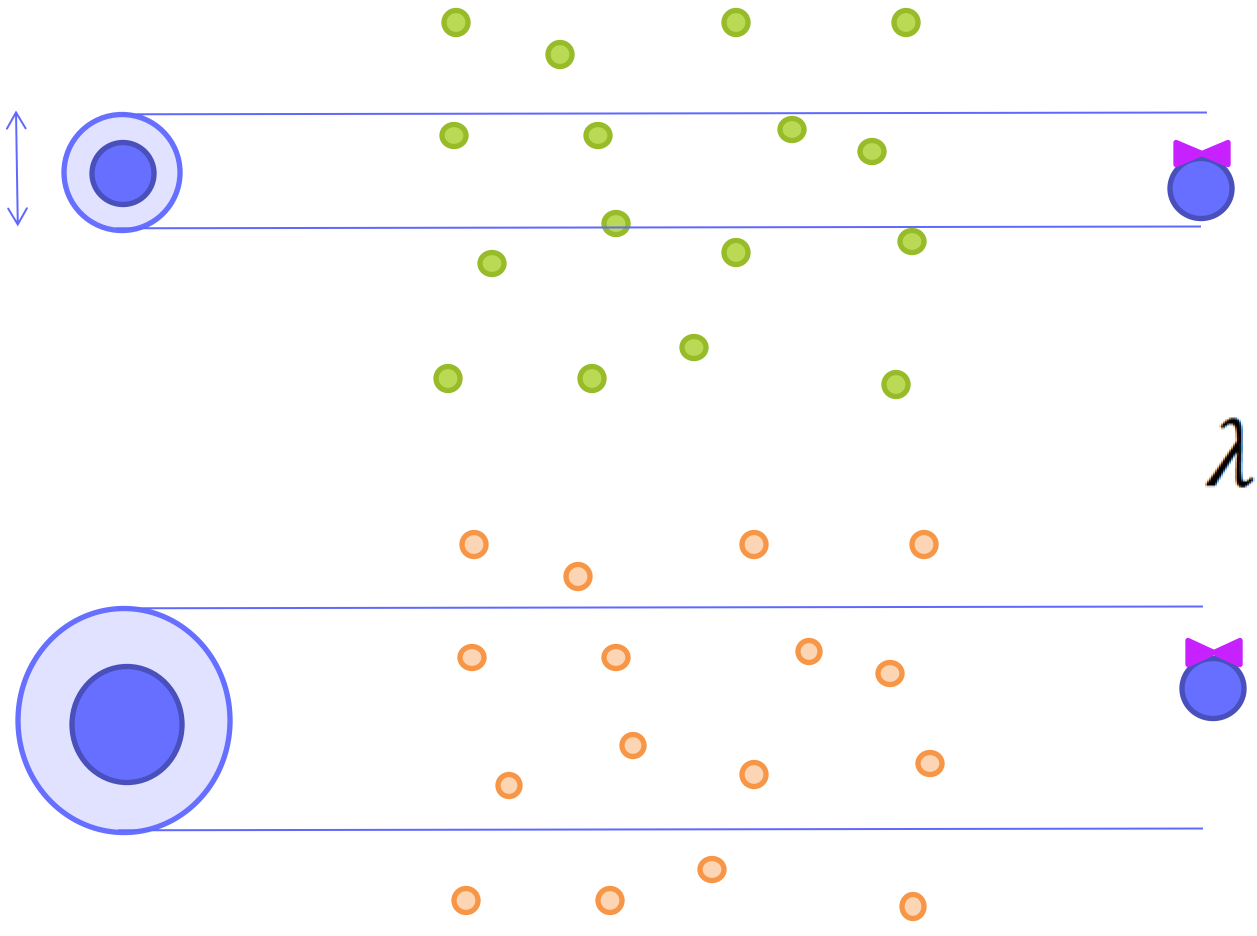
!



$$2 < \gamma < 2.5$$

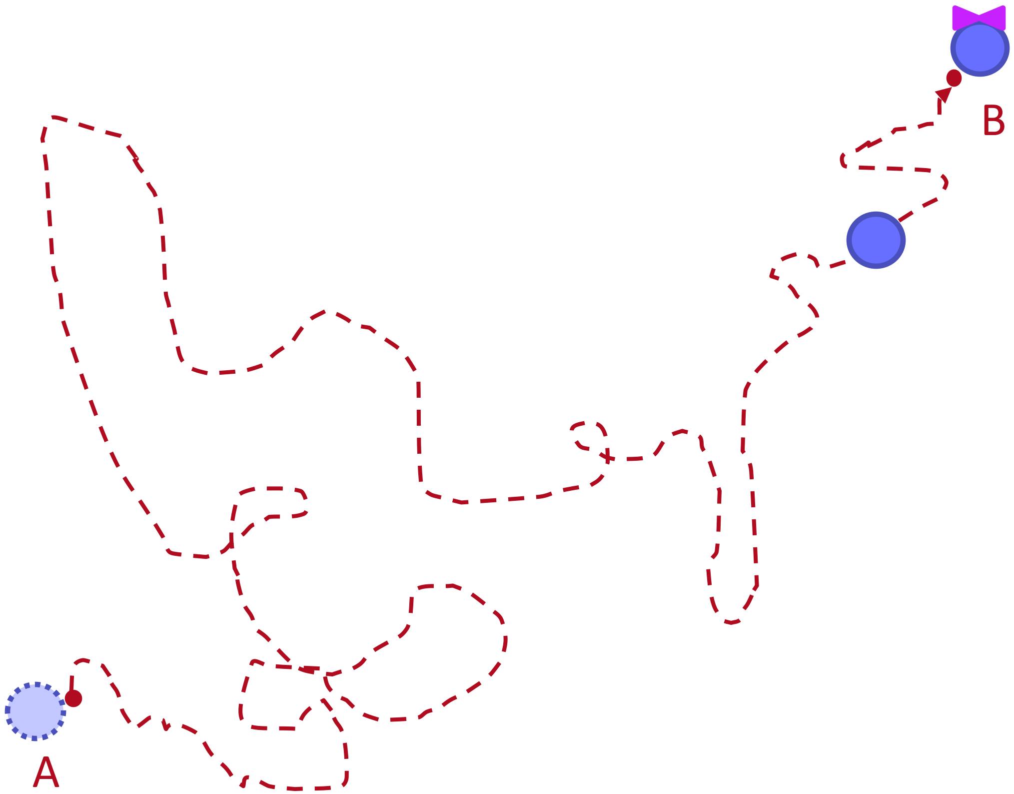
Sorensen, C.M., 2011. The Mobility of Fractal Aggregates: A Review. Aerosol Science and Technology 45, 765–779.

Mean Free Path with Increasing Mass



$$\lambda = \frac{2\mu}{\rho v}$$

Diffusion Limited Cluster Aggregation



$$\lambda = \frac{2\mu}{\rho v}$$

$$\bar{v} = \sqrt{\frac{8k_B T}{\pi m}}$$

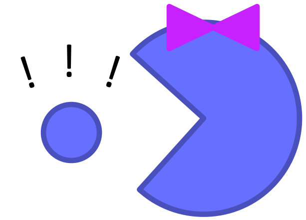
$$\lambda \gg d_p$$

$$\sqrt{d_p^5} = \sqrt{d_{p_0}^5} + \frac{10}{\pi}\sqrt{\frac{6k_B T}{\rho_p}}Vt$$

Pratsinis, S.E., 1998. Flame aerosol synthesis of ceramic powders. Progress in Energy and Combustion Science 24, 197–219.

Reaction Limited Cluster Aggregation

What if $\lambda \ll d_p$?



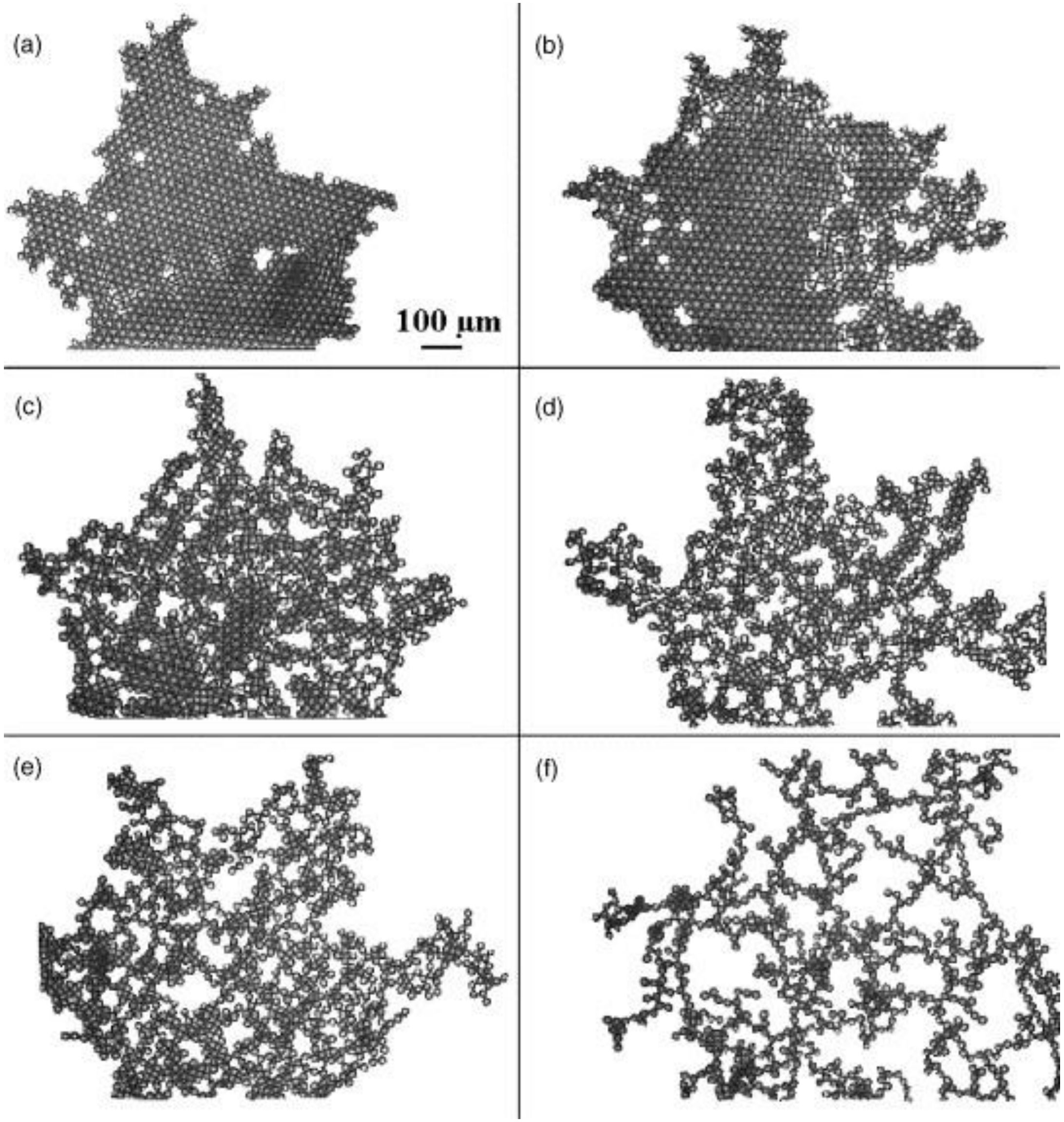
$$d_p = d_{p_0} + \frac{2k_s M_{W_p} C t}{a}$$

$$C = C_0 e^{-kt}$$

Commonly found in colloids, but has never been observed in aerosols.

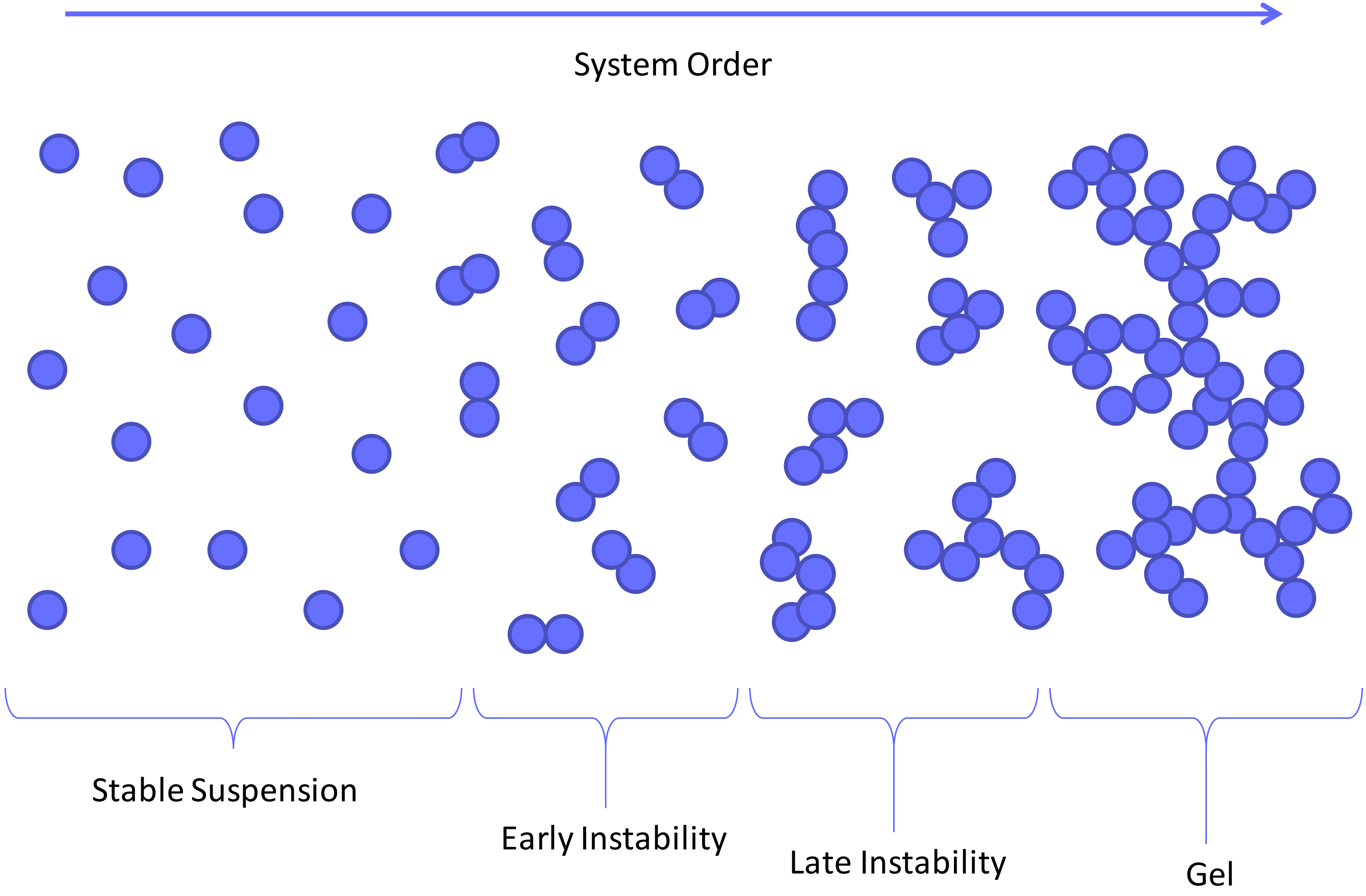
Pratsinis, S.E., 1998. Flame aerosol synthesis of ceramic powders. Progress in Energy and Combustion Science 24, 197–219.
Sorensen, C.M., 2011. The Mobility of Fractal Aggregates: A Review. Aerosol Science and Technology 45, 765–779.

RLCA vs. DLCA

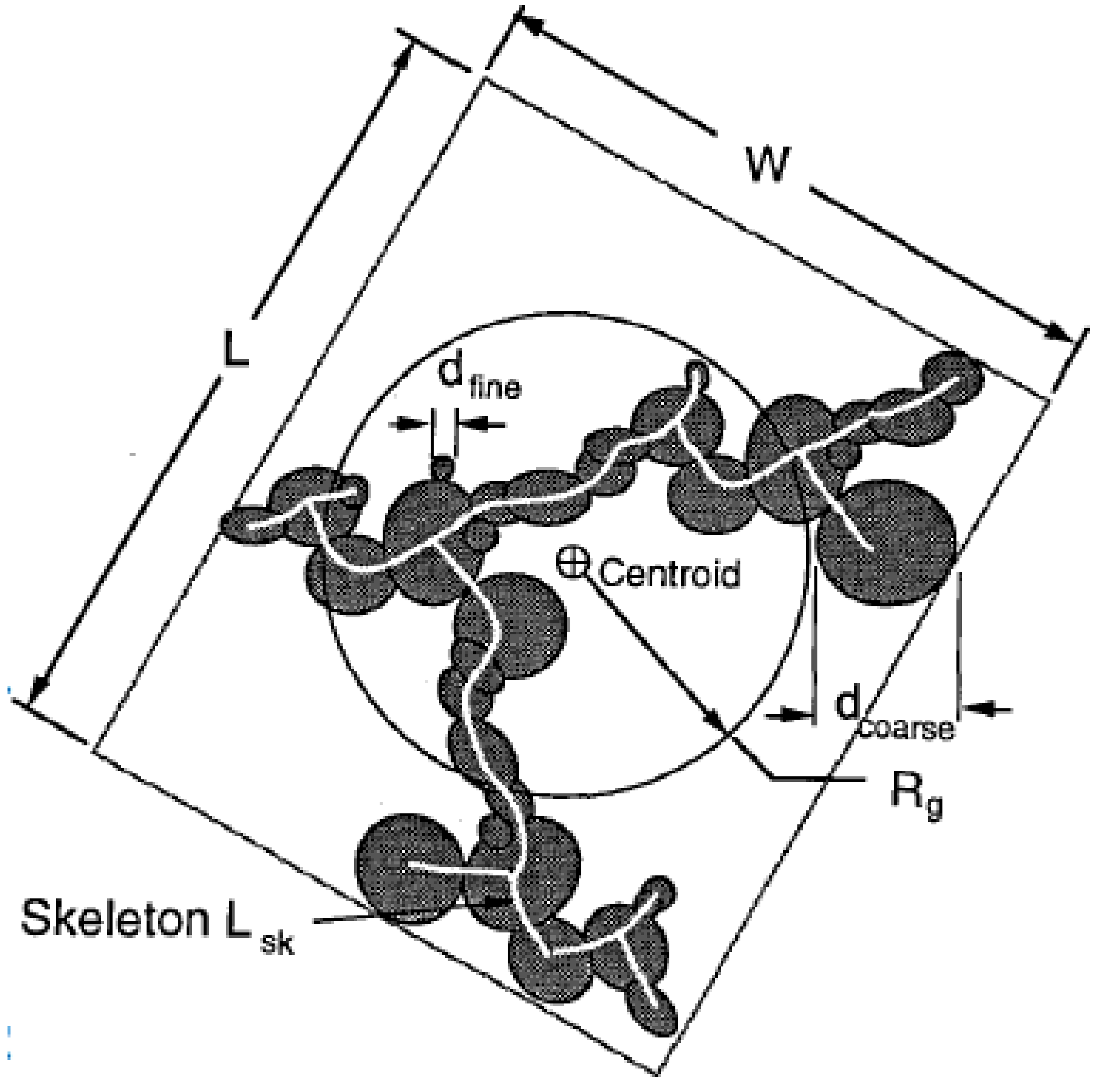


Bazou, D., Coakley, W.T., Meek, K.M., Yang, M., Pham, D.T., 2004. Characterisation of the morphology of 2-D particle aggregates in different electrolyte concentrations in an ultrasound trap. Colloids and Surfaces A: Physicochemical and Engineering Aspects 243, 97–104.

The Size Threshold

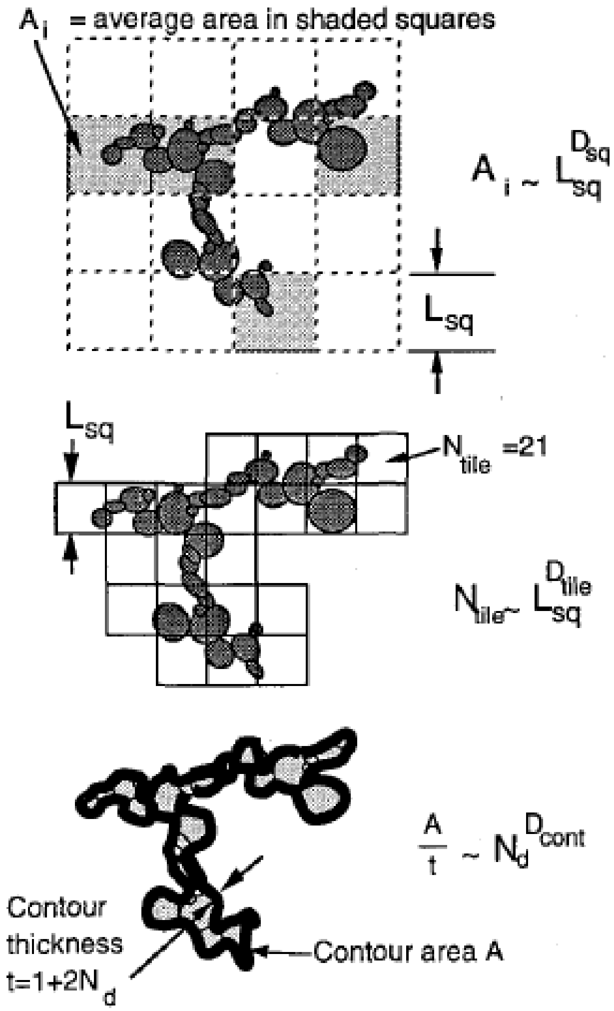


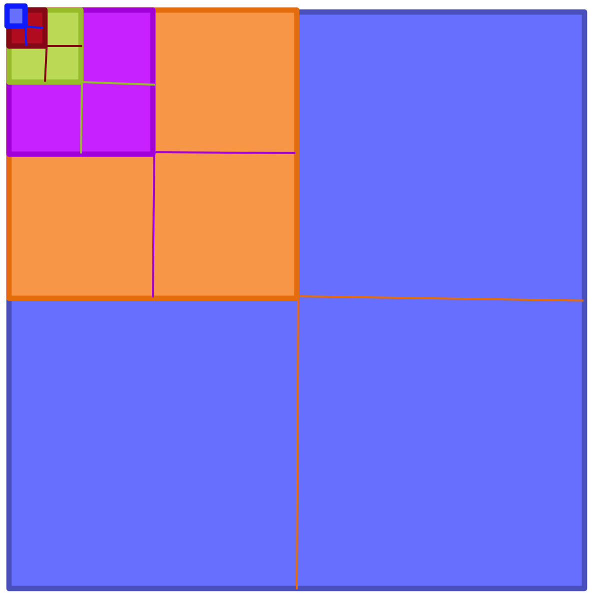
Characterizing with Non-Uniform Particles



Rogak, S.N., Flagan, R.C., Nguyen, H.V., 1993. The Mobility and Structure of Aerosol Agglomerates. Aerosol Science and Technology 18, 25–47.

Tile Estimation



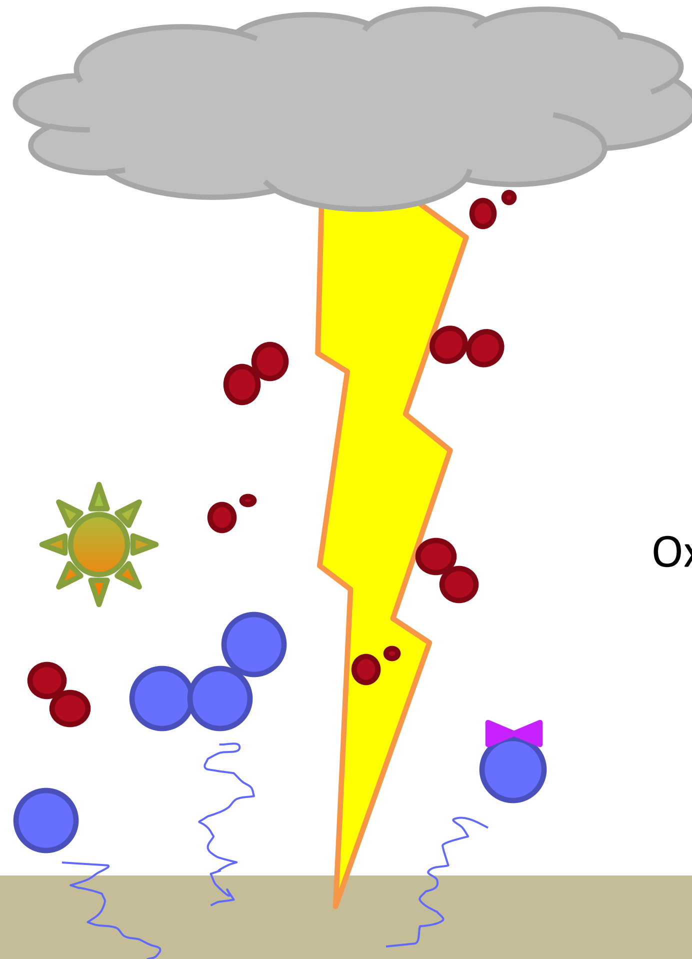


Smaller and smaller
Boxes estimate outline
Of the aggregate

Rogak, S.N., Flagan, R.C., Nguyen, H.V., 1993. The Mobility and Structure of Aerosol Agglomerates. Aerosol Science and Technology 18, 25–47.

Particle Aggregates and Ball Lightning

In 1987, Smirnov calculated from physical data from ball lightning occurrences, that particles may be the cause.

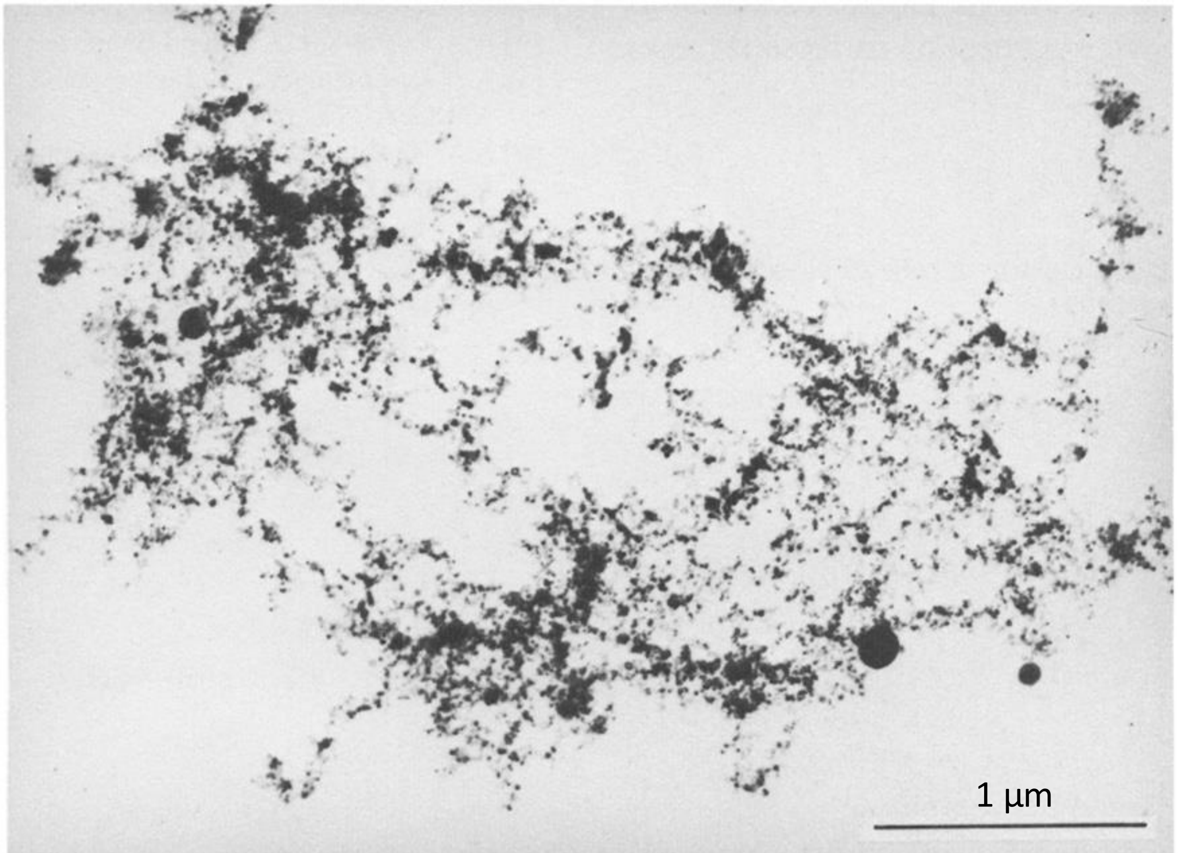


Oxidizing Aggregates

Silicon?

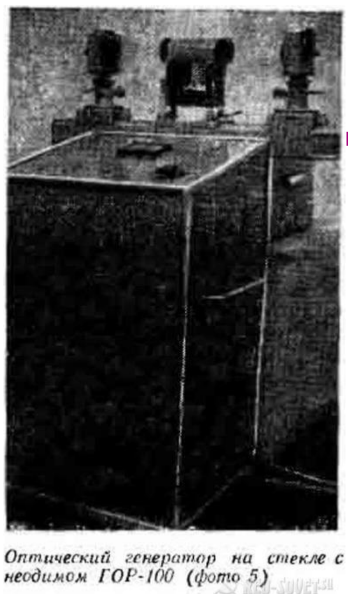
Smirnov, B.M., 1987. The properties and the nature of ball lightning. Physics Reports 152, 177–226.

Aggregates in Electric Fields
Aerosol to Aerogel



Lushnikov, A.A., Negin, A.E., Pakhomov, A.V., 1990. Experimental observation of the aerosol-aerogel transition. Chemical Physics Letters 175, 138–142.

Experimental Setup



GOR-100 (100J Ruby laser)
Operating Conditions:
70J, λ=694.3nm,
Pulse Length τ=.001s

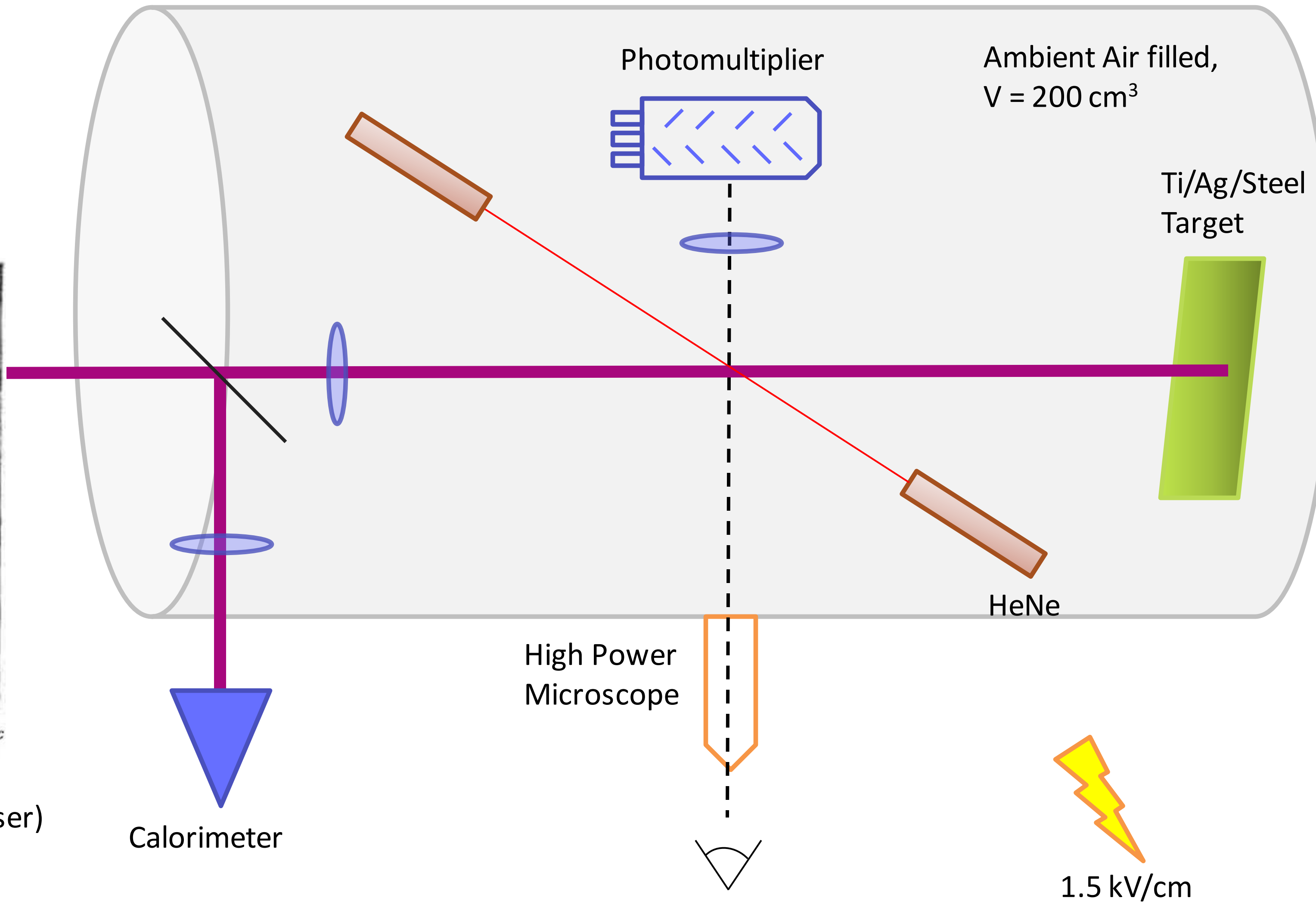
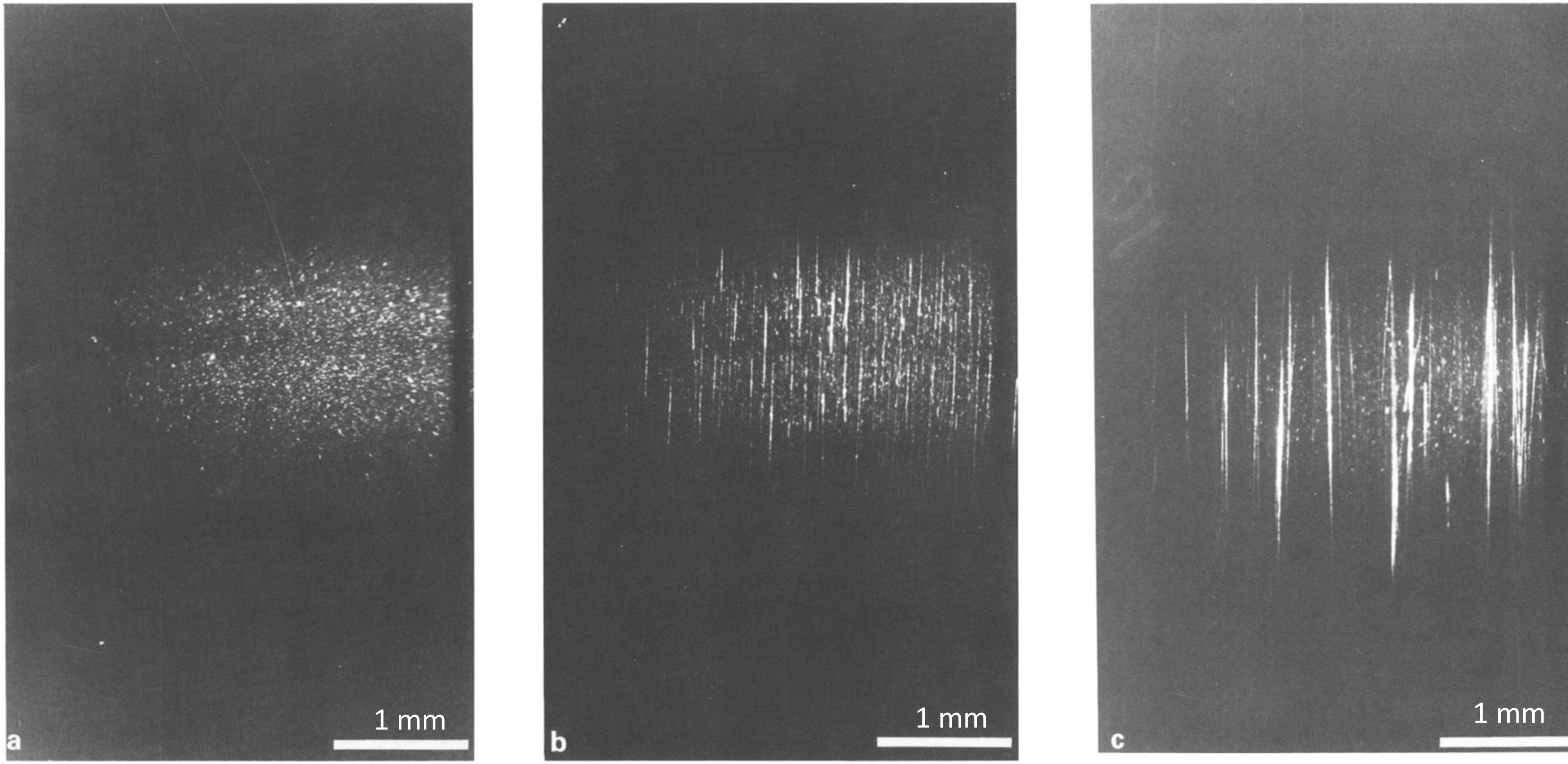
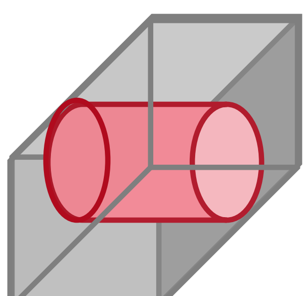


Photo: Vasiliev, A., Ryasin, V., 1965. Working Professional Laser [Translated]. Radio 38, 3–5.

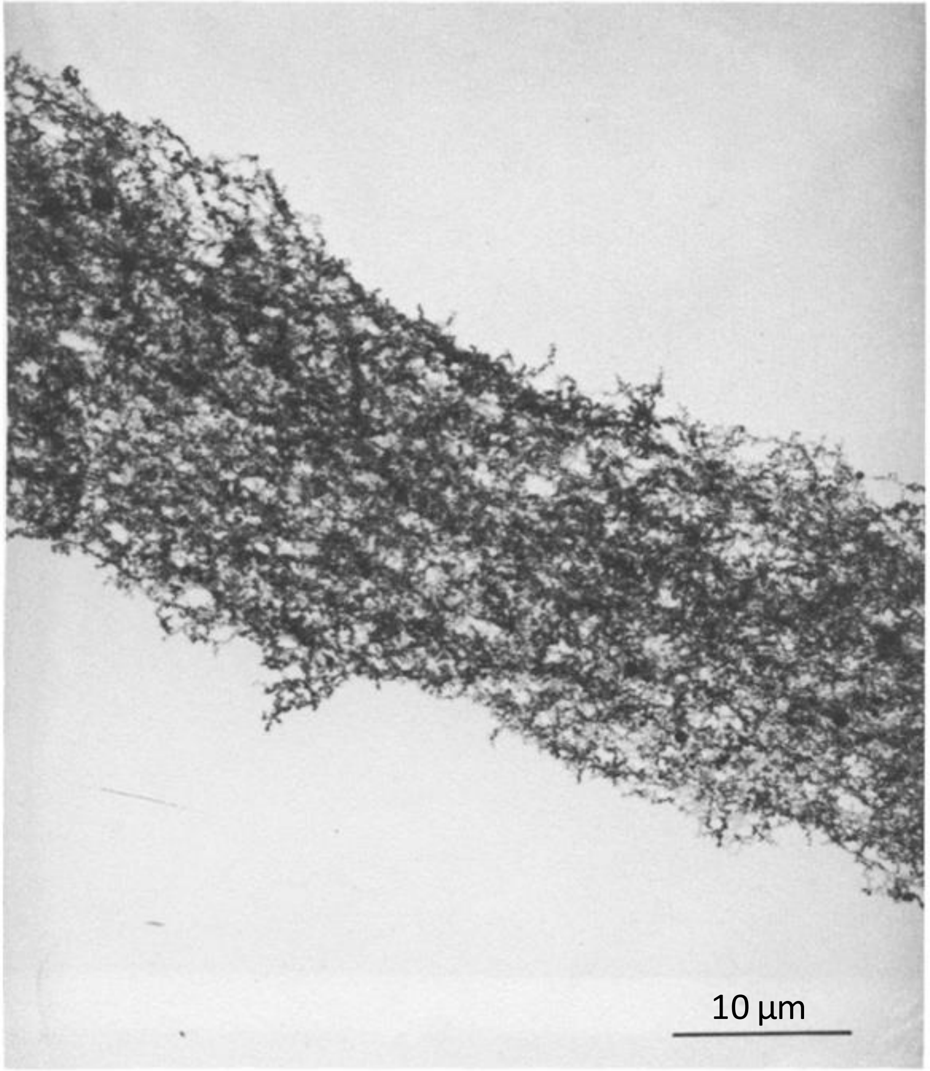
Fiber Formation





Lushnikov, A.A., Negin, A.E., Pakhomov, A.V., 1990. Experimental observation of the aerosol-aerogel transition. Chemical Physics Letters 175, 138–142.

Fibers Up Close



Lushnikov, A.A., Negin, A.E., Pakhomov, A.V., 1990. Experimental observation of the aerosol-aerogel transition. Chemical Physics Letters 175, 138–142.

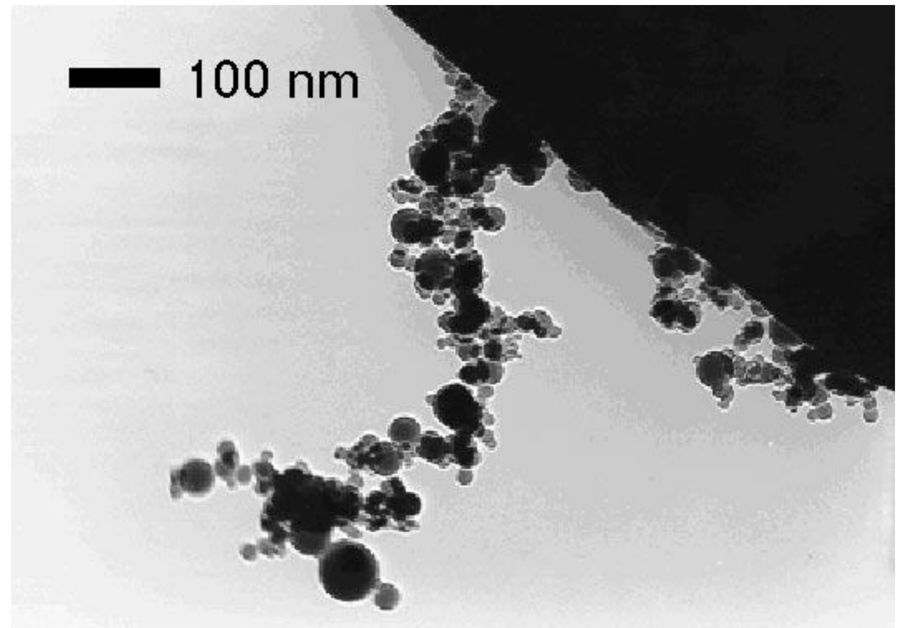
Oxidation of Networks

Based on Soviet experiment producing short lived ball lightning from carbonaceous loam (1977) – paper no longer available

Did not match lifetime of observed

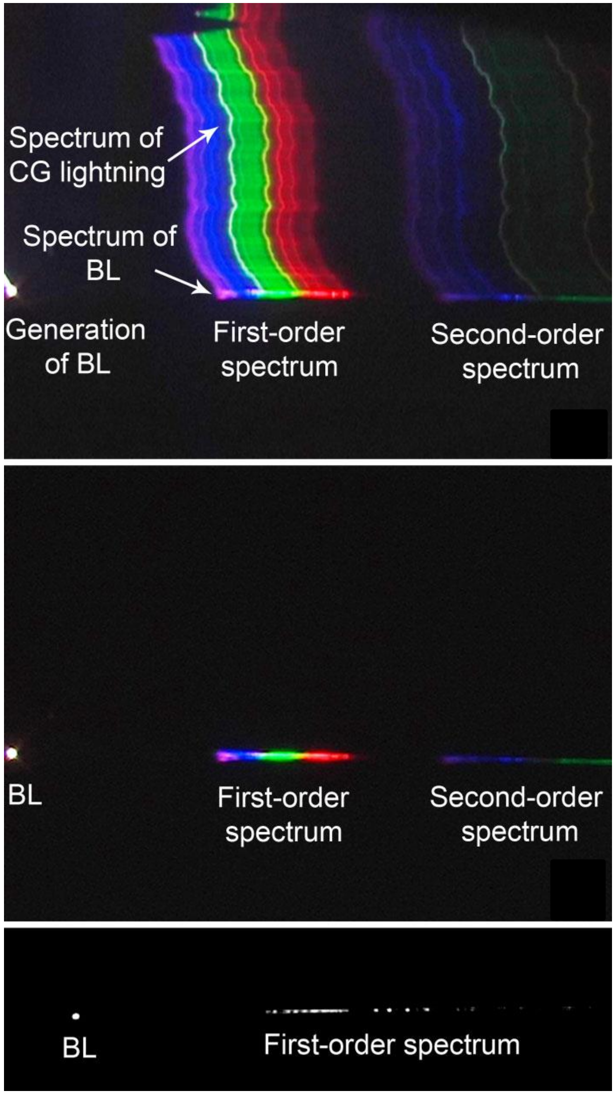
Created models based on Si oxidation, as suggested by Smirnov (1987)

Used cooling techniques found in industrial processes



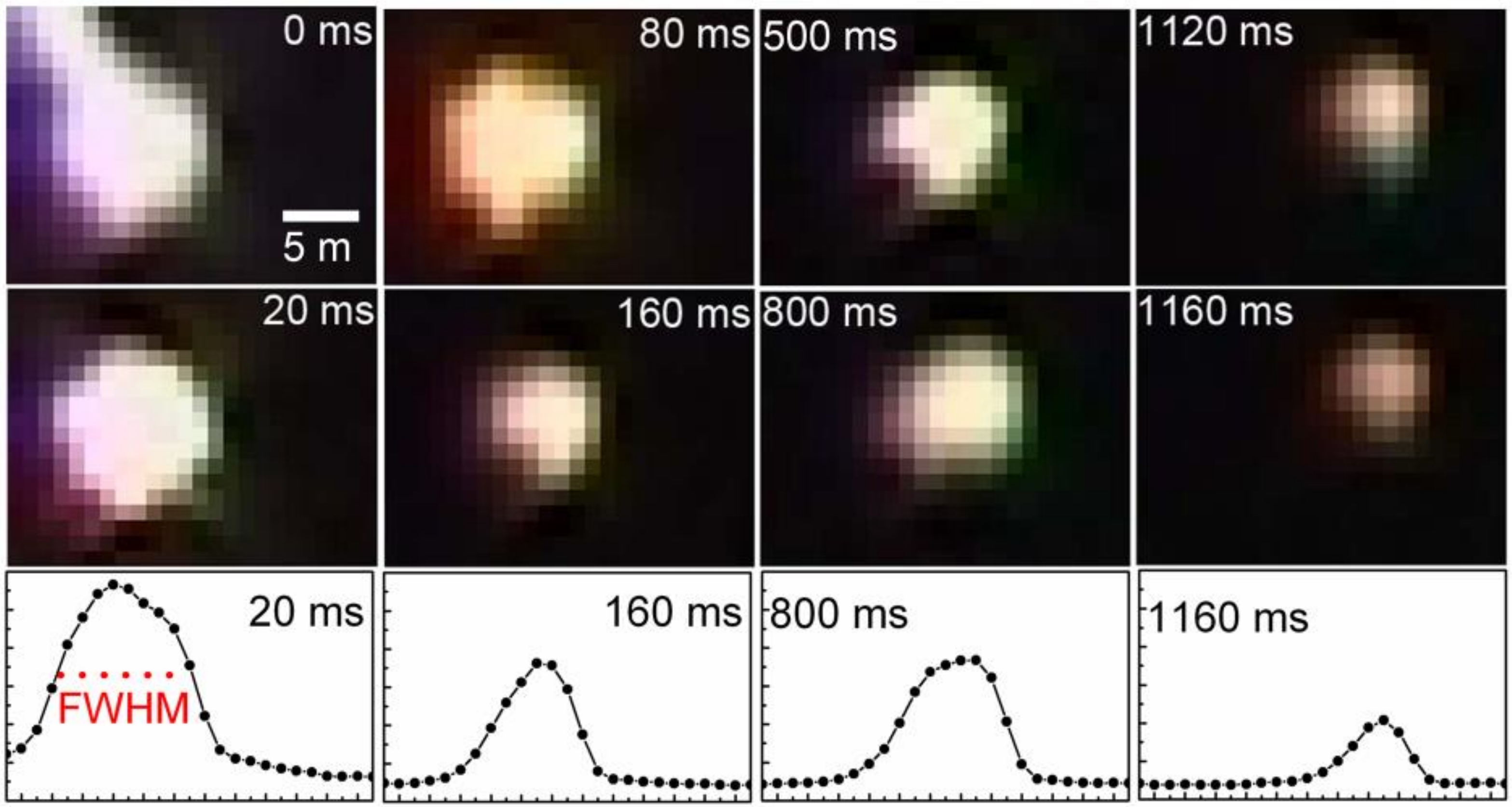
Abrahamson, J., Dinniss, J., 2000. Ball lightning caused by oxidation of nanoparticle networks from normal lightning strikes on soil. Nature 403, 519–521.

Observation with Modern Techniques

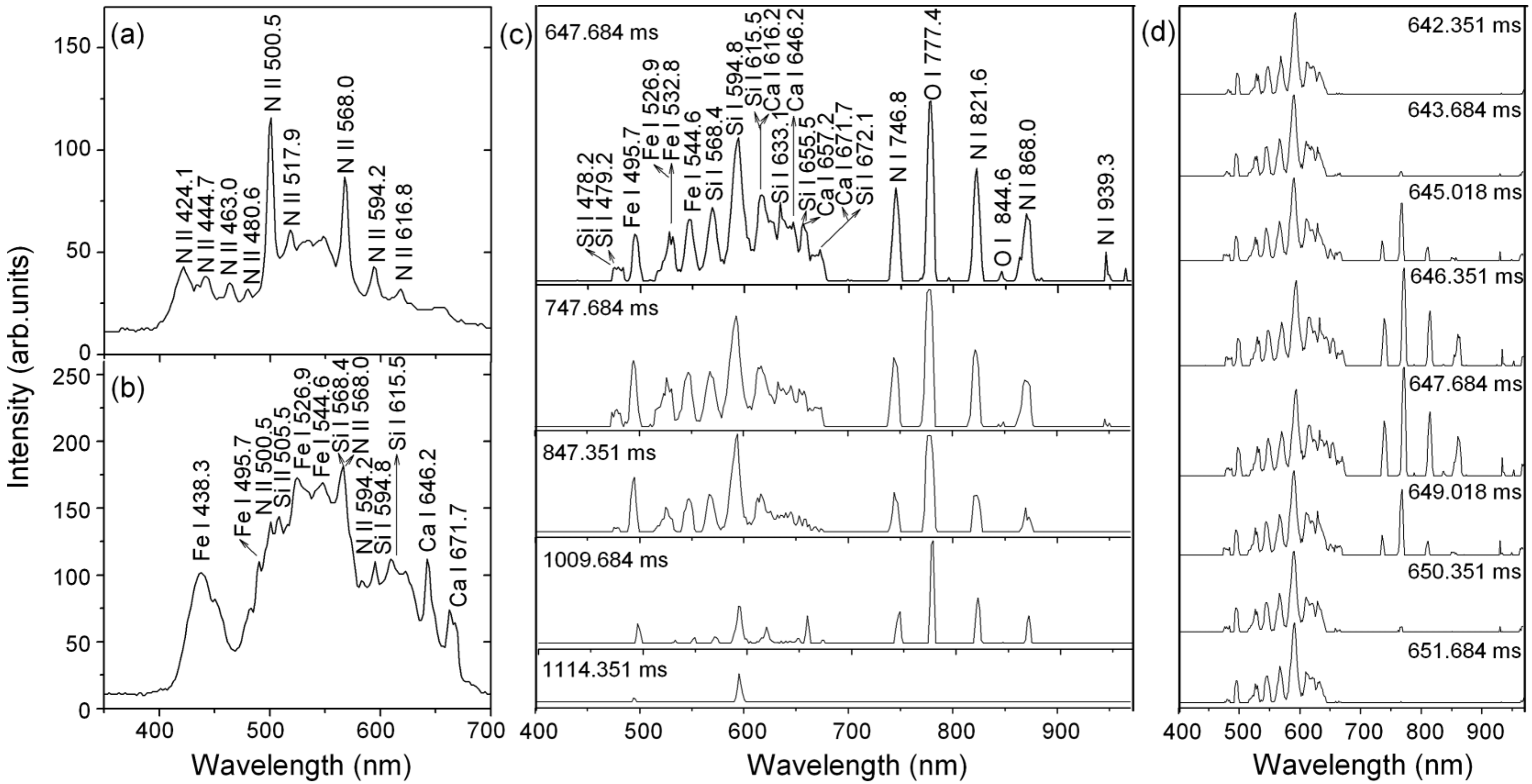


Cen, J., Yuan, P., Xue, S., 2014. Observation of the Optical and Spectral Characteristics of Ball Lightning. Phys. Rev. Lett. 112, 5.

Zoom, Enhance



Spectral Analysis



Iron, Silicon, and Calcium all detected in the emission spectra

Can Ball Lightning Be Traced to Aggregates?

Known

Ball lightning due to metal oxidation

Fractal aggregation of particles occurs in high electric fields, to gel level of structure

Metal emission spectra observed in real occurrence

Unknown

The role of structure in aggregate

The role of size of structure

Possible changes in light scattering due to fractal aggregates

Ratios of metal atoms to carbon atoms in ejected particulate matter

Duration of charge field required for sufficient aggregation

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GRA Funded by Xplosafe

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- Dr. Henry Kanarek
- Oklahoma State University Department of Chemistry
- My gracious audience
- The illustrious Leon

No kitties were harmed in making this presentation, only bothered by cameras

Structure	$R_g^2 =$	Parameters
Gaussian Coil	$\frac{Nb^2}{6}$	Degree of polymerization *N* Statistical segment length *b*
Gaussian Star	$\frac{3f-2}{f}\frac{N_{arm}b^2}{6}$	Arm degree of polymerization *Narm* Number of arms *f* Statistical segment length *b*
Gaussian Ring	$\frac{Nb^2}{12}$	Statistical segment length *b* Degree of polymerization *N*
Solid Sphere	$\frac{3}{5}R^2$	Sphere radius *R*
Solid Ellipsoid	$\frac{1}{5}(R_1^2+R_2^2+R_3^2)$	Ellipsoid principal radii *Rn*
Thin Rod	$\frac{1}{12}L^2$	Rod Length *L*
Cylinder	$\frac{1}{12}L^2+\frac{1}{2}r^2$	Cylinder radius *r* Length *L*
Thin Disk	$\frac{1}{2}r^2$	Disk radius *r*

Hiemenz, P.C., Lodge, T.P., 2007. Polymer Chemistry, 2nd ed. CRC Press, Boca Raton, Fl.

Reynolds Number

$$Re = \frac{ua}{v}$$

Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.

Stokes Number

$$Stk = \frac{2a^2u}{9vL}$$

Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.

Knudsen Numbers

$$Kn = \frac{\lambda}{a}$$

$$Kn = \frac{2D_f}{\sqrt{\frac{8kT}{\pi m}}\,a}$$

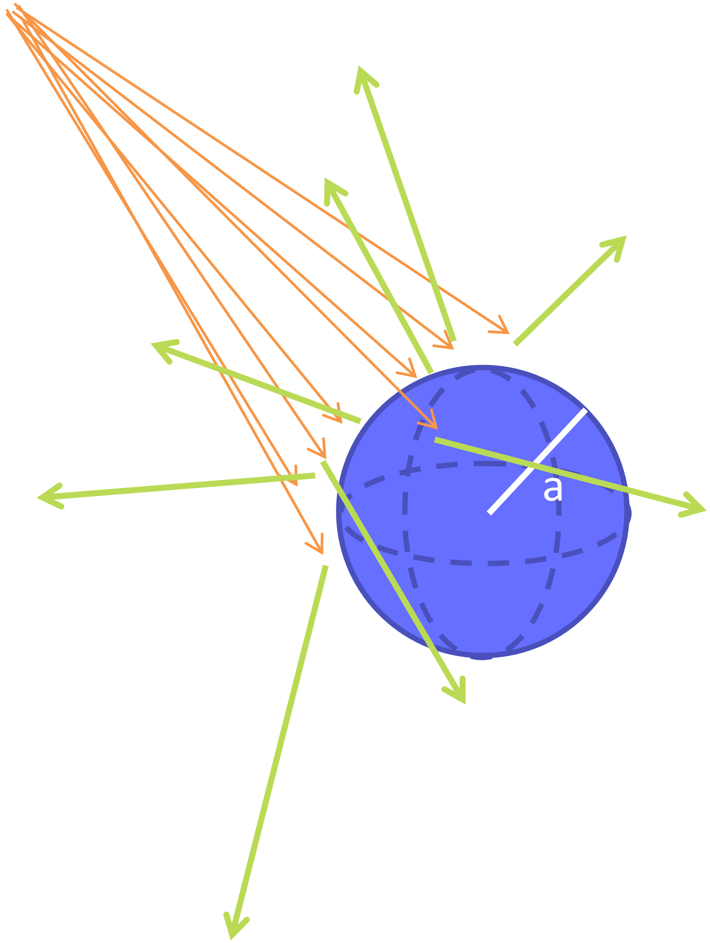
Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.

Peclet Number

$$Pe = \frac{2\Lambda}{\sqrt{\frac{8kT}{\pi m}}a}$$

Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.

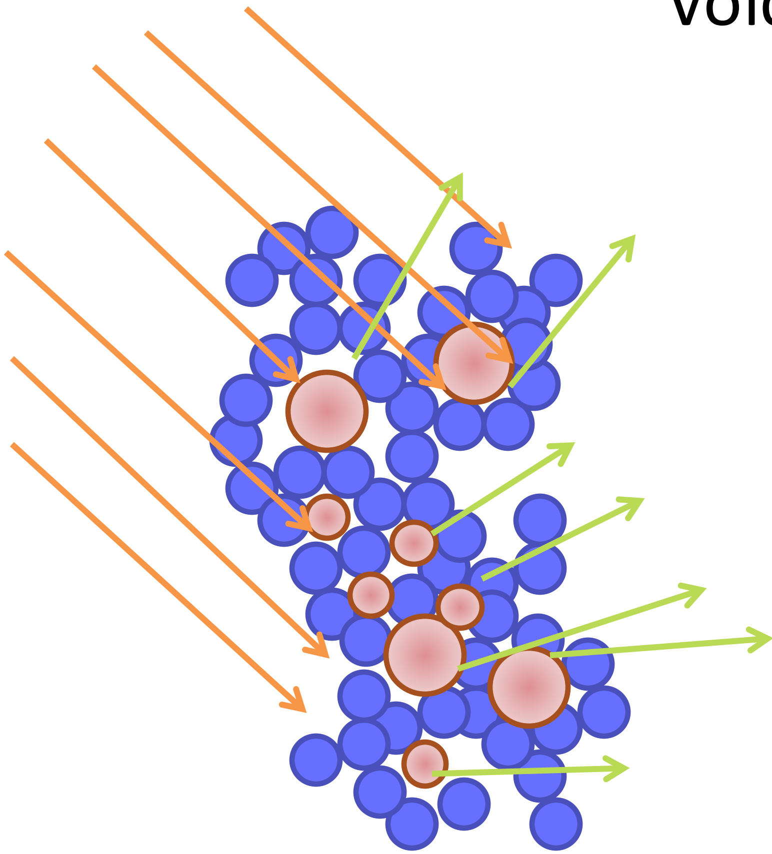
Mie Scattering



$$Mie = \frac{2\pi\lambda_w}{a}$$

Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.

Void Optics



$$n_{void}(a) = \frac{3 - D_f}{R_g^{3-D_f}} a^{2-D_f}$$

$$V_{void}(a) = \frac{4\pi(6 - D_f)}{3(3 - D_f)} a^3$$

$$\sigma_{abs} = \frac{6\pi Im\left(\frac{m^2 - 1}{m^2 + 2}\right)}{\lambda_w \rho}$$

Lushnikov, A.A., 2010. Introduction to Aerosols, in: Aerosols - Science and Technology. Wiley-VCH Verlag GmbH & Co. KGaA, pp. 1–41.