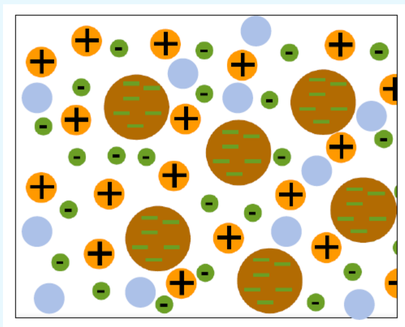
Hands-On Research in Complex Systems
Advanced Study Institute --- 17-29 June 2012
Shanghai Jiao Tong University (Shanghai, People's Republic of China)
Sponsored by *Abdus Salam International Centre for Theoretical Physics* and *Shanghai Jiao Tong University*

Fractal analysis of dynamics light scattering intensity fluctuation in disordered dusty plasmas

W.X. Chew, S.S. Safaai, S.V. Muniandy, S.L. Yap and C.S. Wong.
Plasma Technology Research Centre, Department of Physics, University of Malaya, 50603 Kuala Lumpur, Malaysia.

Introduction



Dusty or complex plasmas are plasmas containing charged micron-sized dust particles [1]. The charged dust particles experience complex interactions with each other and the background plasma as well. By controlling the charge or temperature of the dust particles, one can alter the physical state of dusty plasma that range from highly-ordered crystal-like, partially ordered liquid-like and highly disordered gas-like states. One way to differentiate such physical state experimentally is by calculating the radial pair correlation function, g(r), from the snapshot of dust layer. However, pair correlation fails in describing disordered gas-likes state.

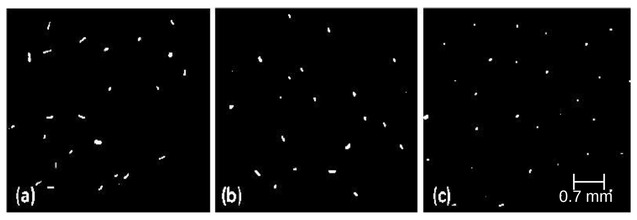
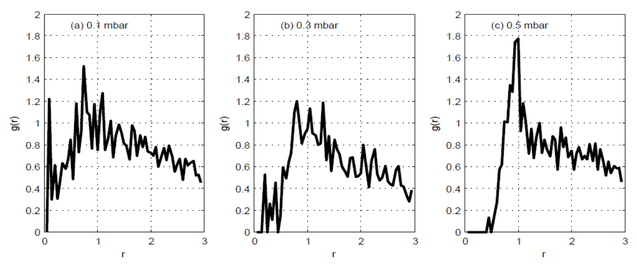
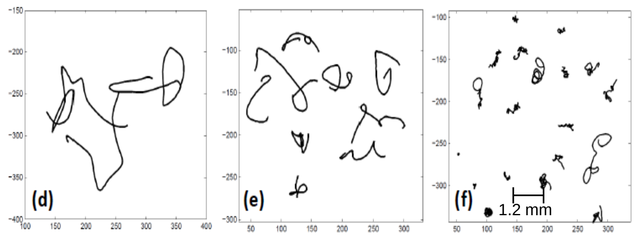
Here, we propose the use of dynamic light scattering technique together with fractal analysis of the signal as an alternative way to probe the state of dusty plasma. Fractal analysis is a powerful tool for understanding complex system and dynamics. Characteristics in time series $X(t)$ can be described through scale invariance property, namely $X(at) \equiv a^{-H}X(t)$, where a is a scale factor, $0< H <1$ is the H-self-similar exponent [2].

Objectives

The main objectives of this study are:

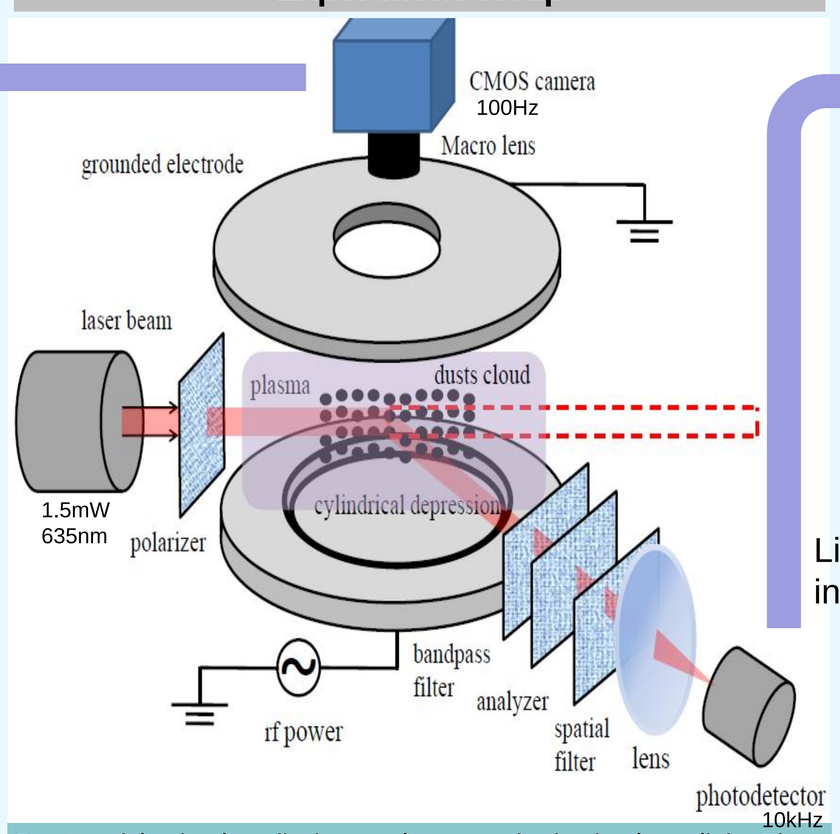
- ❑ to characterize physical state of dusty plasma especially the disorder state through fluctuation behavior in dynamic light scattering signal.
- ❑ To characterize the light intensity fluctuation using wavelet based fractal analysis.

Physical state

Pressure	0.1mbar |	0.3mbar |	0.5mbar
Snapshot of dust particles			
radial pair correlation function, g(r)			
Particle trajectories (0.01s-0.6s)			

Images

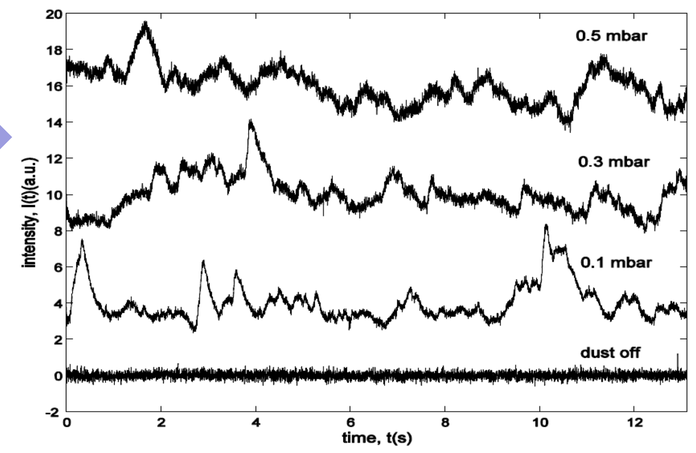
Experiment setup



Dust particles in glow discharge plasma probed using laser light. The total scattered light is detected and monitored with time. Video camera is used to capture the spatial arrangement of particles.

Light intensity

Intensity fluctuation



Dynamic light scattering signals at different gas pressure and without the presence of dust in plasma.

Wavelet based fractal analysis

A multiscale wavelet decomposition of signal $X(t)$ using wavelet and scaling function is given by [3]

$$X(t) = \sum_{k=0}^{2^{J_o}} U_{J_o,k}\varphi_{J_o,k}(t) + \sum_{j=J_o}^{J}\sum_{k=0}^{2^j-1} W_{j_o,k}\psi_{j_o,k}(t)$$

with orthogonal bases $\{\varphi_{j,k}(t), \psi_{j,k}(t)\}$, obtained from dilation and shift operations of 'father' scaling function and 'mother' wavelet:

$$\varphi_{j,k}(t) = 2^{j/2}\varphi(2^j t - k) \qquad \psi_{j,k}(t) = 2^{j/2}\psi(2^j t - k)$$

Scaling coarse coefficients $U_{j,k}$ and wavelet detail coefficients $W_{j,k}$ are given by

$$U_{j,k} = \int X(t)\varphi_{j,k}(t)dt$$

$$W_{j,k} = \int X(t)\psi_{j,k}(t)dt$$

Details coefficient at each scale j is squared and averaged:

$$S(j) = \frac{1}{N_j}\sum_{k=0}^{2^j-1}|W_{j,k}|^2,$$

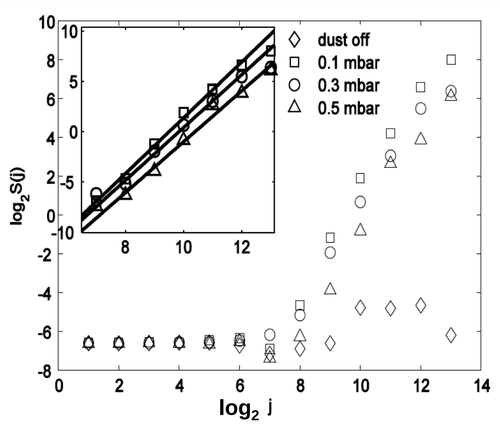
If $X(t)$ is a fractal signal, then $S(j)$ will obeys a power law relation [4]:

$$S(j) \sim (2^j)^{2H+1}$$

Pressure	Physical state	H fractal exponent
0.1 mbar	disorder	0.89
0.3 mbar	disorder	0.81
0.5 mbar	Short range order	0.68

Slope=2H+1

H exponents of intensity fluctuation of different dusty plasma state.



Log log plot of S(j) with scale,j of intensity signal with dust at 0.1, 0.3 and 0.5 mbar and without dust in the plasma. The inset is the linear regression lines.

Conclusion

- ❑ Disordered dusty plasma phase is characterized by higher H fractal exponent (more regular fluctuation in dynamic light scattering intensity signal). While H exponent decrease (more irregular fluctuation) as spatial orderliness increase.

Acknowledgement

This work is partially supported by the Malaysian Ministry of Higher Education (MOHE) under Exploratory Research Grant Scheme (ER011-201A) and University of Malaya Research Grant (RG162-11AFR).

References

[1] P. K. Shukla and A. A. Mamum, *Introduction to Dusty Plasma*. (IOP, Bristol, 2002).
[2] B. B. Mandelbrot and J. W. van Ness, SIAM Rev. **10,** 422 (1968).
[3] I. Daubechies, *Ten Lectures on Wavelets*, (SIAM, New York, 1992).
[4] P. Abry and D. Veitch, IEEE Trans. Inform. Theory **44,** 2 (1998).