# Moumita Das

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## *Education*

**Doctorate in Physics,** Indian Institute of Science, Bangalore, India (1999-2004).
Thesis: ***Ordering, Stochasticity, and Rheology in Sheared and Confined Complex Fluids.***
Advisor: Prof. Sriram Ramaswamy. Co-advisor: Prof. G. Ananthakrishna.

**Master of Science** (Physics), Jadavpur University, Calcutta, India (1996-1998).

**Bachelor of Science** (Physics), Jadavpur University, Calcutta, India (1993-1996).

## *Employment*

**Postdoctoral Fellow** Dept. of Chemistry and Biochemistry, UCLA (2005 NOV – Present)

**Postdoctoral Fellow** Division of Engineering and Applied Sciences, Harvard University (2004 SEP-2005 OCT)

## *Research Interests*

- **Equilibrium and Non-equilibrium statistical physics of soft materials with emphasis on**
    - Filamentous networks with applications to the biophysics of the cytoskeleton.
    - Collective dynamics and stochasticity in driven systems.
    - Hydrodynamics and Rheology of structured fluids.
- **Physics and geometry of elastic sheets and shells.**

## *Awards*

- University Gold Medal, First Rank in Master of Science, 1998, Jadavpur University, Calcutta, India.
- University Gold Medal, First Rank in Bachelor of Science, 1996, Jadavpur University, Calcutta, India.

## *Fellowships*

- Senior Research Fellow, Council of Scientific and Industrial Research, India, 2001 - 2004.
- Junior Research Fellow, Council of Scientific and Industrial Research, India, 1999 – 2001.

***Publications***

- Effective medium theory of semiflexible filamentous networks, ***M. Das***, F.C. Mackintosh and A.J. Levine, **submitted to Phys. Rev. Lett**.
- Curvature condensation and bifurcation in an elastic shell, ***M. Das***, A. Vaziri, A. Kudrolli and L. Mahadevan, **submitted to Phys. Rev. Lett**.
- Persistance of a pinch in an elastic pipe, L. Mahadevan , A. Vaziri and ***M. Das***, **submitted to Europhysics Lett.**
- Brownian-drag induced particle current in a model colloidal system, ***M Das***, S. Ramaswamy, A.K. Sood and G. Ananthakrishna, **Phys Rev. E 73, 061409 (2006).**
- Routes to spatiotemporal chaos in the rheology of nematogenic fluids, ***M. Das***, B. Chakrabarti, C. Dasgupta, S. Ramaswamy, and A. K. Sood, **Phys. Rev. E 71, 021707 (2005)**.
- Rheological Chaos in Wormlike Micelles and nematic hydrodynamics, ***M. Das***, R. Bandyopadhyay, B. Chakrabarti, S. Ramaswamy, C. Dasgupta, and A. K. Sood, in **Molecular Gels**, ed. P. Terech, and R. G. Weiss (Springer, 2006).
- Spatiotemporal rheochaos in nematic hydrodynamics, B. Chakrabarti, ***M. Das***, C. Dasgupta, S. Ramaswamy and A. K. Sood, **Phys. Rev. Lett. 92, 055501 (2004)**.
- Collective stochastic resonance in shear-induced melting of sliding bilayers, ***M. Das***, G. Ananthakrishna, and S. Ramaswamy, **Phys. Rev. E 68, 0161402 (2003)**.
- Melting-freezing cycles in a relatively sheared pair of crystalline monolayers, ***M. Das***, S. Ramaswamy, and G. Ananthakrishna, **Europhys. Lett. 60, 636 (2002)**.

***Work in progress***

- Novel behavior in the melting of two dimensional crystallites- disclinations, cracks and magic sizes, with D. Blair and A. J. Levine.
- Effect of the surrounding membrane and elastic matrix on the dynamic instability of microtubules, with L. Mahadevan.
- On the stability of the cell front, with E. Hohlfeld.

***References***


Prof. Sriram Ramaswamy
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Prof. A. J. Levine,
Department of Chemistry and Biochemistry, UCLA.
Los Angeles, CA, USA.
Email: alevine@chem.ucla.edu

Prof. F. C. Mackintosh,
Department of Physics,
Vrije Universiteit,
The Netherlands
Email: fcm@nat.vu.nl

Prof. L. Mahadevan
Division of Engineering and Applied Sciences, Harvard University
Cambridge MA, USA.
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Prof. Chandan Dasgupta
Department of Physics
Indian Institute of Science
Bangalore, India.
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Prof. G. Ananthakrishna
Materials Research Centre
Indian Institute of Science
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***Summary of research***

### *Biomechanics of the actin cytoskeleton*

Semiflexible polymer networks form a distinct class of gels whose mechanical properties remain at the frontier of both biophysical and materials research. These cross-linked polymer networks differ substantially from the flexible polymer gels and rubbers due to the rigidity of the individual polymers. Because the thermal persistence length of the constituent filaments is much longer than the typical distance between cross-links, these materials can store elastic strain energy in both stretching and bending deformations of the filaments. The cytoskeleton of eukaryotic cells is a ubiquitous example of such a semiflexible network since it is composed of densely cross-linked, stiff protein aggregates. This network dominates the mechanical properties of the cytosol and lies at the heart of the cellular force production and morphological control. We develop an effective medium approach to the mechanics of such disordered, semiflexible polymer networks and study their response to both spatially uniform and nonuniform strain. We identify distinct elastic regimes in which the effective filament bending stiffness or stretch modulus vanishes. We also show that our effective medium theory predicts a crossover between affine and non-affine strain, consistent with both prior numerical studies and scaling theory [DA Head, AJ Levine, FC MacKintosh, *Physical Review Letters* **91** 108102 (2003) and *Physical Review E* **68**, 061907 (2003)] .

### *Global and local modes of deformations in thin elastic shells*

The geometry and physics of elastic surfaces is of interest in many overlapping fields: in mechanics of thin sheets and shells and statistical behavior of membranes. The mechanics of thin elastic shells affords many examples of the complexity induced by geometry in what are otherwise relatively simple physical systems. A dramatic example of this is seen in the localization of stress and energy in crumpled shells. Here we use a combination of experimental and numerical methods to study the formation of structures such as creases and dimples during the deformation of a semi-cylindrical elastic shell, clamped along its lateral edges and subject to a localized indentation at the midpoint of one its free boundaries. For small indentations, we start out with a global mode of deformation, which then localizes to a parabolic crease upon further indentation. Further indentation for very thin shells leads to bifurcation of the crease to two defects that move apart on either side of the line of symmetry. We characterize these geometry driven analogues of first order phase transitions, and develop a simple theory to explain the main features of the experiments and numerical simulations.

### *Anomalous persistence of a pinch in a pipe*

The response of low-dimensional solid objects combines geometry and physics in unusual ways, exemplified in structures of great utility such as a tubular shell that is ubiquitous in nature and technology. We study a particularly surprising consequence of this confluence of geometry and physics in tubular structures: the anomalously large persistence of a localized pinch in an elastic pipe whose effect decays very slowly as an oscillatory exponential with a persistence length that scales as $R^{3/2} / t^{1/2}$, diverging as the thickness of the tube vanishes. The result is more a consequence of geometry than material properties, and is thus equally applicable to carbon nanotubes and cytoskeletal microtubules as it is to aircraft fuselages and geological plates, with a number of interesting consequences.

### *Dynamics of a growing microtubule in the presence of a fluctuating membrane*

We study the dynamics of a growing microtubule interacting with a fluctuating membrane and other cytoskeletal elements. We observe that the stochastic switching between growing and rapidly shrinking states (dynamic instability) of the microtubule is regulated by the pushing force generated by the microtubule when growing against the membrane. We also study how the bending modes of the microtubule are modified by the coupling with the height fluctuations of the membrane and other cytoskeletal components and a simple linear stability calculation shows that the presence of an elastic medium surrounding the microtubule gives rise to a purely relaxational mode. A detailed study of the full nonlinear equations is currently underway.

***Collective dynamics of relatively sheared soft monolayers: Shear induced melting re-entrance, and melting-freezing cycles***

We have studied the far-from-equilibrium dynamics of two crystalline two-dimensional monolayers driven past each other using Brownian dynamics simulations. A dynamical phase diagram in the space of interlayer coupling and drive is obtained. For low and high driving forces, we obtain macroscopically ordered, steadily drifting states. In a suitable range of driving rates we see that the system switches between crystalline and liquid like states. The residence times are comparable in an intermediate range of values of the interlayer coupling. We have seen that the interlayer coupling essentially determines the barrier each particle has to surmount in order to keep pace with the applied drive. Our simulations show that the switching between the crystalline and liquid like states maintains the spatial coherence (or the lack of it in the liquid state) and thus is an example of *cooperative stochastic resonance* (SR). Although there is no external imposed time-periodic potential present in our system, its role is played by the drive which shears the two layers past each other. Thus, each moving layer provides a time-varying potential. To make the connection to SR more concrete, we have introduced a density wave model for the dynamics of amplitude and phase of the crystalline order parameter. It mimics all the features of the particle model in addition to showing the main feature of SR namely the enhancement of signal to noise ratio for optimum values of noise strength. This relation between the particle model and the reduced model makes a convincing case that the melt-freeze cycles observed in the former are indeed a manifestation of stochastic resonance of a spatially extended noisy interacting system subjected to a constant drive.

***Spatiotemporal chaos and intermittency in the rheology of nematogenic fluids***

With a view to understanding the "rheochaos" observed in recent experiments in a variety of orientable fluids, we have studied numerically the equations of motion of the spatiotemporal evolution of the traceless symmetric order parameter of a sheared nematogenic fluid. In particular we establish, by decisive numerical tests, that the irregular oscillatory behavior seen in a region of parameter space where the nematic is not stably flow-aligning is in fact spatiotemporal chaos. We outline the dynamical phase diagram of the model and study the route to the chaotic state. We find that spatiotemporal chaos in this system sets in via a regime of *spatiotemporal intermittency*, with a power-law distribution of the widths of laminar regions, consistent with the ideas of H. Chate and P. Manneville, Phys. Rev. Lett. **58**, 112 (1987). Further, the evolution of the histogram of band sizes shows a growing length-scale as one moves from the chaotic towards the flow aligned phase.

***Brownian-drag induced particle current in a model colloidal system***

We numerically study the behavior of a collection of overdamped Brownian particles in a channel, in the presence of a flow field applied on similar but slower particles in a wide chamber in contact with the channel. For a suitable range of shear rates, we find that the flow field induces a unidirectional drift in the confined particles, and is stronger for narrower channels. The average drift velocity initially rises with increasing shear rate, then shows saturation for a while, thereafter starts decreasing, in qualitative agreement with recent theoretical studies [S. Ghosh *et. al.*, Phys. Rev. B **70**, 205423 (2004)] based on Brownian drag and ``loss of grip''. Interestingly, if the sign of the interspecies interaction is reversed, the direction of the induced drift remains the same, but the flow-rate at which loss of grip occurs is lower, and the level of fluctuations is higher.

***Mode-coupling theory of the enhancement of viscosity by strong confinement***

Experiments have found that confining a fluid to a thin layer on the scale of a few molecular dimensions leads to a large increase in the apparent shear viscosity and stress relaxation time. We have studied the "mode-coupling" enhancement of viscosity for a simple fluid confined in one direction between parallel walls but free to move in the other two, and show that reducing the confinement thickness slows down the relaxation of density fluctuations in a manner similar to lowering temperature or increasing density. As in bulk fluids, this drives a nonlinear feedback leading to a large increase in the shear viscosity at confining distances of the order of a few molecular dimensions.

***Talks***

- Curvature condensation and twinning in an indented elastic shell, March APS meeting, Baltimore, 2006.
- Anomalous persistance of a pinch in an elastic pipe, March APS meeting, Baltimore, 2006.
- Global and local modes of deformation in an indented elastic shell, Clark University, May, 2005.
- Routes to spatiotemporal chaos in the rheology of nematogenic fluids, March APS meeting, Los Angeles, 2005.
- Mode coupling theory of the enhancement of viscosity by strong confinement, March APS meeting, Los Angeles, 2005.
- Soft sliding bilayers: shear induced melting and collective stochastic resonance, University of Massachusetts, Amherst, February, 2005.
- Spatiotemporal rheochaos and intermittency in nematohydrodynamics, 21st New England Complex Fluids Meeting, Harvard University, December, 2004.
- Collective dynamics of relatively sheared soft monolayers: shear induced melting, re-entrance and melting-freezing cycles, STATPHYS 22, Bangalore, July, 2004.

***Workshops and Conferences***

August 2006, Extreme Mechanics: Current Issues in Continuum and Fluid Mechanics, Aspen Center for Physics, Aspen, Colorado.

March 2006, March Meeting of the American Physical Society, Baltimore.

May 2005, Frontiers of Soft Condensed Matter Workshop, ExxonMobil Research and Engineering Facility, New Jersey.

March 2005, March Meeting of the American Physical Society, Los Angeles.

December 2004, 82nd Statistical Mechanics Meeting, Rutgers University.

December 2004, New England Complex Fluids Meeting, Harvard University.

September 2004, New England Complex Fluids Meeting, Brandeis University.

July 2004, Statphys 22, Indian Institute of Science, Bangalore, India.

June 2004, Unifying Concepts in Glasses, Statphys 22 Satellite Meeting, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, India.

Jan 2004, International Symposium on Molecules, Machines and Networks, National Centre for Biological Sciences, Bangalore, India.

Jan 2002, International Conference on Statistical Physics (Statphys - Kolkata IV), Indian Association for the Cultivation of Science and S. N. Bose National Centre for Basic Sciences, Kolkata, India.

Jan 2002, India and Abroad: A Conference on Condensed Matter Physics, Jawaharlal Nehru Centre for Advanced Scientific Research and Indian Institute of Science, Bangalore, India.

Aug 2001, Boulder School on ‘Nonequilibrium Statistical Physics: Glasses, transport and friction, biological systems and turbulence’, University of Colorado (Boulder), U.S.A.

Feb 2001, Interdisciplinary Workshop on ‘Probability and Statistical Physics’, S. N. Bose National Centre for Basic Sciences, Calcutta, India.

Dec 2000, International Discussion Meeting on ‘Mesoscopic and Disordered Systems’, Indian Institute of Science, Bangalore, India.

Jan 2000, Fifth Kumari L. A. Meera Memorial Meeting on ‘Frontier Areas in Physics of Soft Condensed Matter’, Mysore, India.

Nov 1999 Discussion Meeting on ‘Recent Trends in Nonequilibrium Statistical Physics’, Indian Institute of Science, Bangalore, India.