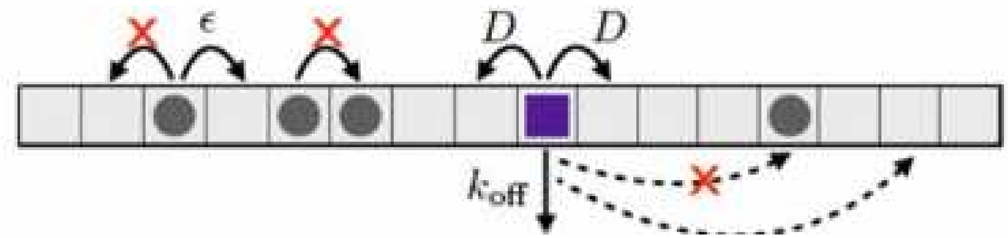
Dynamic roadblock particle in an exclusion process



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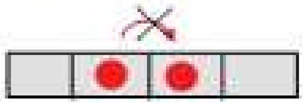
Exclusion Process

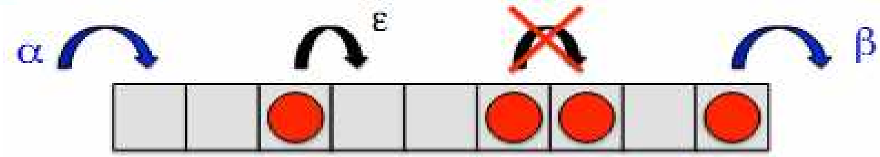
- Simple exclusion process: Nonequilibrium driven diffusive system of particles $\rightarrow$ exclusion interaction.
  - No multiple occupancy in one site



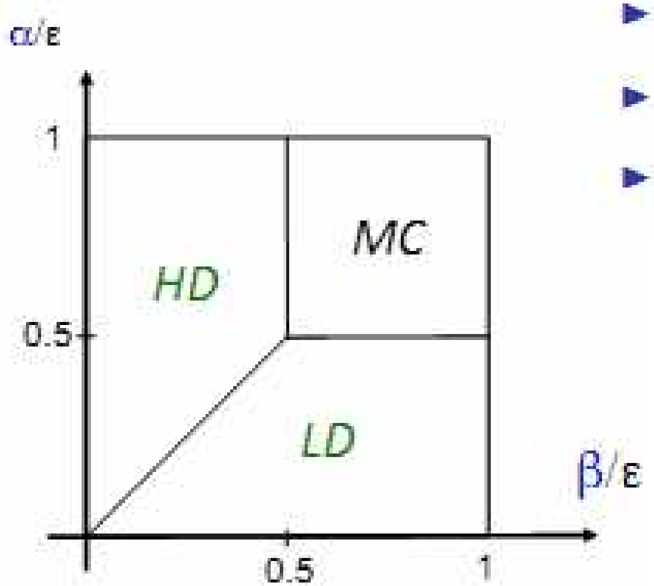
- Asymmetric Simple Exclusion Process(ASEP): Particles may hop to the right or left with a bias to one direction.
- Symmetric simple exclusion process (SSEP): Equilibrium process where the particles hop in both the directions with equal rates.
- Totally asymmetric simple exclusion process (TASEP): Particles hopping to the nearest-neighbor sites in one direction.

Models for dense traffic:TASEP etc.

Totally Asymmetric Exclusion Process



- Periodic Boundary Condition → Trivial steady state
  - Particle flux, $J = \epsilon\rho(1-\rho)$
- Open Boundary Condition → Boundary-induced phase transition

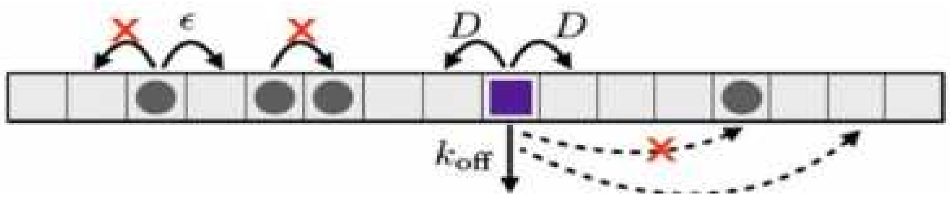


- LD $\rightarrow J = \alpha(1-\alpha/\epsilon)$.
- HD $\rightarrow J = \beta(1-\beta/\epsilon)$
- MC $\rightarrow J = \epsilon/4$

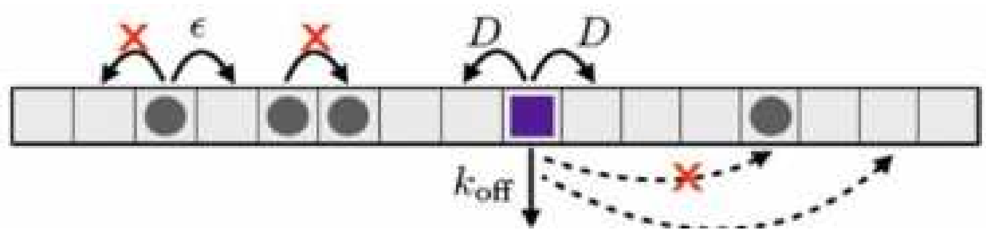
MacDonald et al. 1968,
Spitzer 1970, Krug 1991
exact solution: Derrida et al. 1993,
Schütz & Domany 1993
...
many TASEP variants

Exclusion processes with roadblock

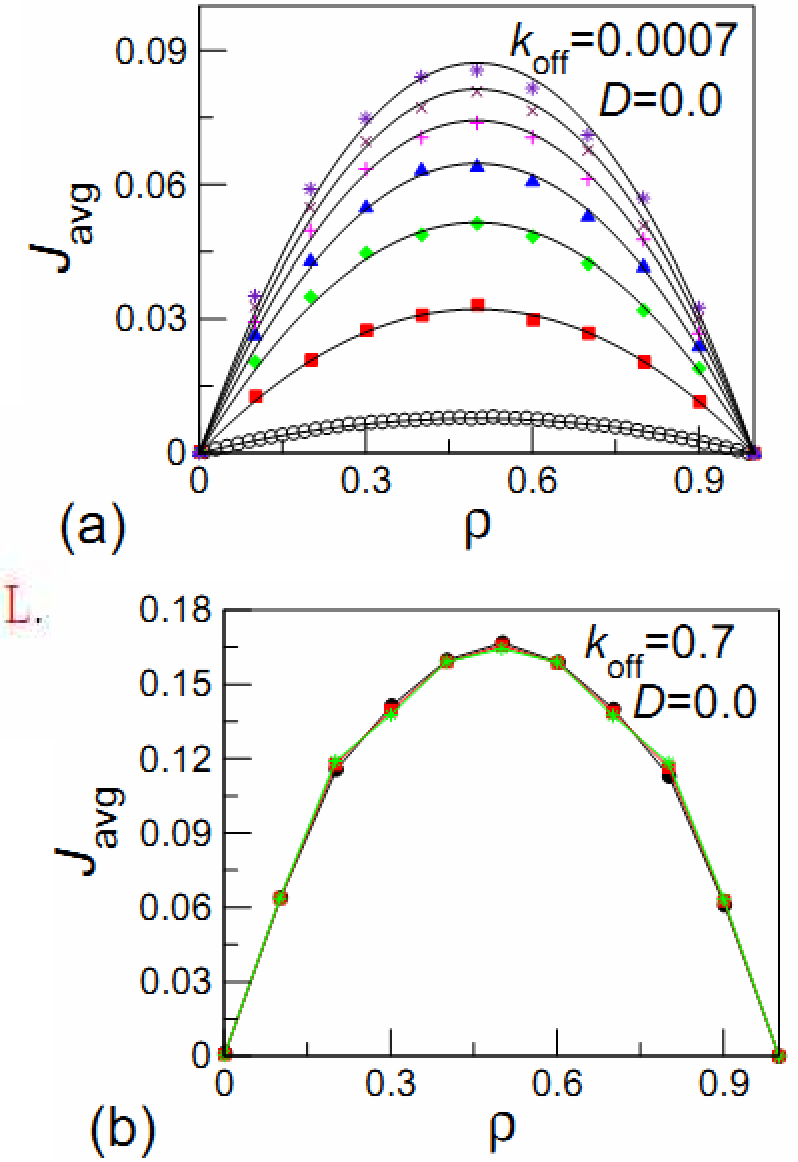
- Static Roadblock → No transport
- Dynamic roadblocks
  - open/close
  - on/off
  - diffusing (→ ratchet)
  - hopping → reduced hopping at defect site
  - paused particle



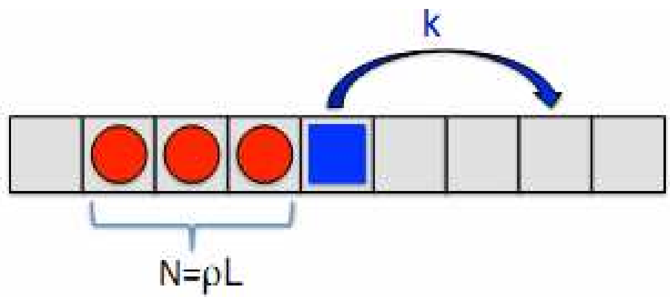
TASEP with a jumping roadblock

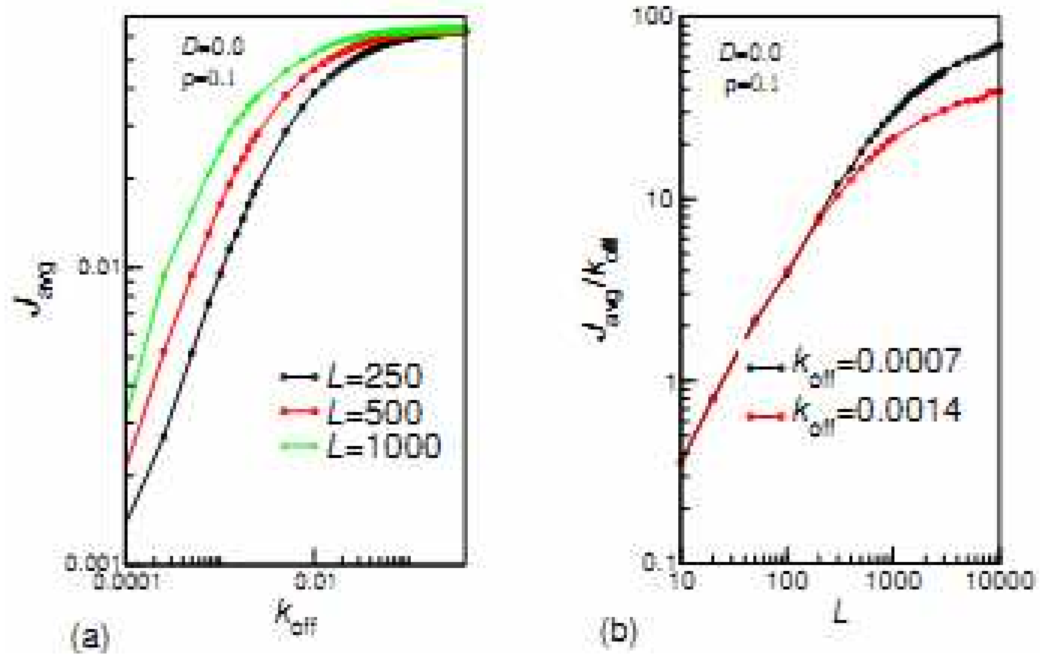


- Periodic Boundary Condition
- Rate k_{off} → long-range jumps
- Small k ($k < \frac{\epsilon}{L}$) → Flux depends on system size, L.
- Large k → TASEP



TASEP with a jumping roadblock

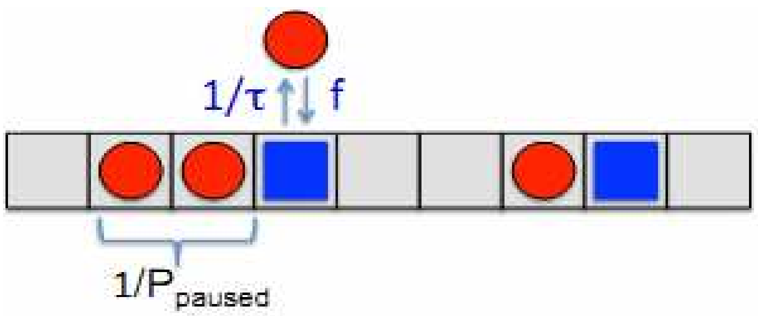




Sahoo, Dong, Klumpp, J Phys A 2015

- Jump over $\frac{L(1-\rho)}{2} \rightarrow$ All the particles follow
- Flux, $J_{avg} = v\rho = k_{off}\frac{N}{L}(\frac{L-N}{2})$
- $= \frac{k_{off}L}{2}\rho(1-\rho) = \frac{k_{off}L}{2\epsilon}J_{TASEP}.$
- Crossover to TASEP behaviour $\Rightarrow \frac{k_{off}L}{2\epsilon} = 1.$

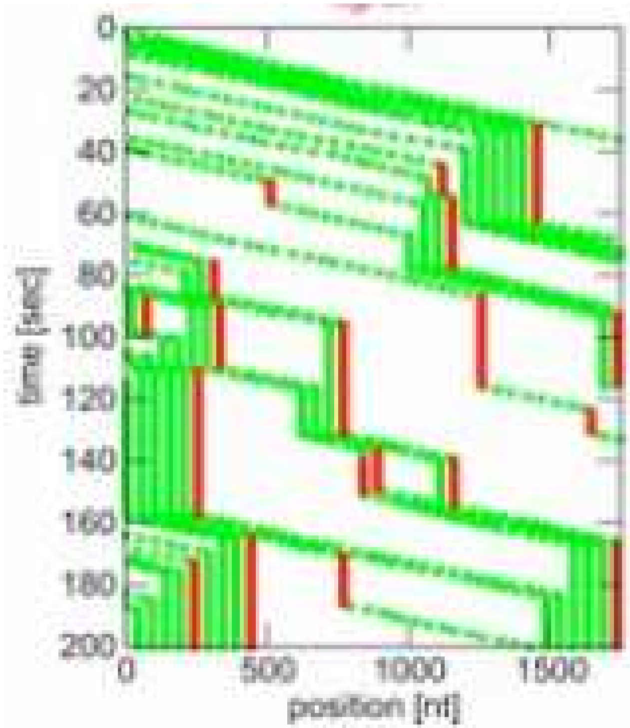
TASEP with pausing



- Pausing in transcription
  - Klumpp & Hwa 2008
  - Yuzenkova et al 2015

$$J = \frac{1}{\tau}(1-\rho) \times \frac{1}{P_{paused}}$$

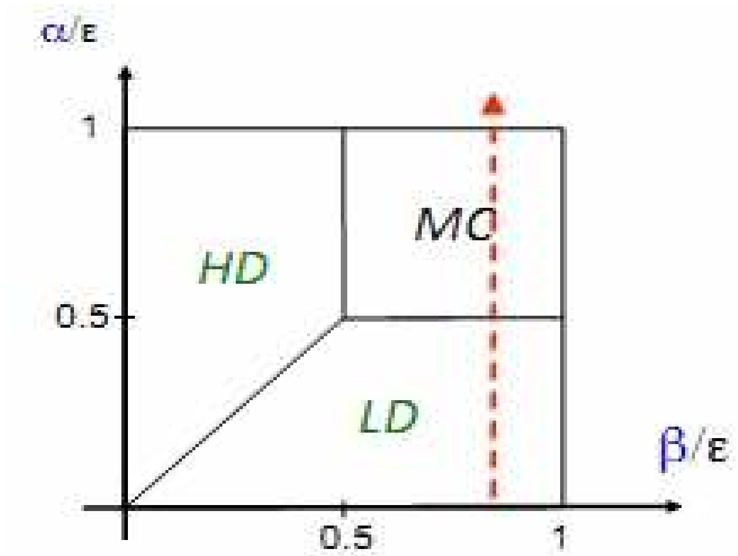
$$= \frac{1}{\tau}(1-\rho) \times \frac{1+f\tau}{f\tau}$$

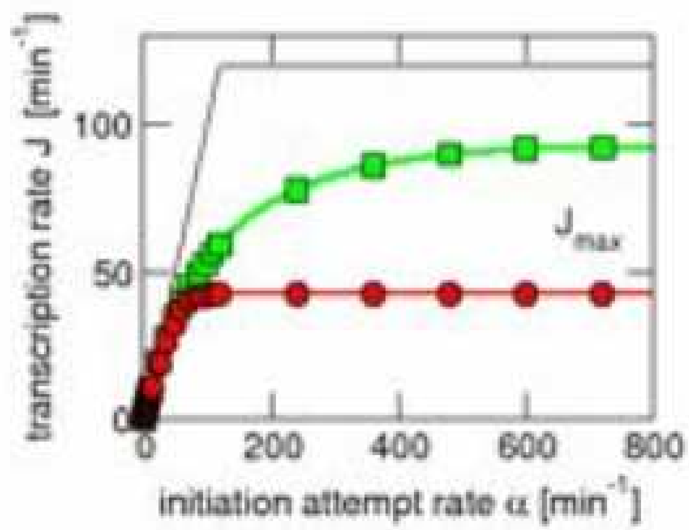


also: Wang et al.
PRE 2014
3-state model

for tsx: generaliz.
to particle size >1

Open Systems

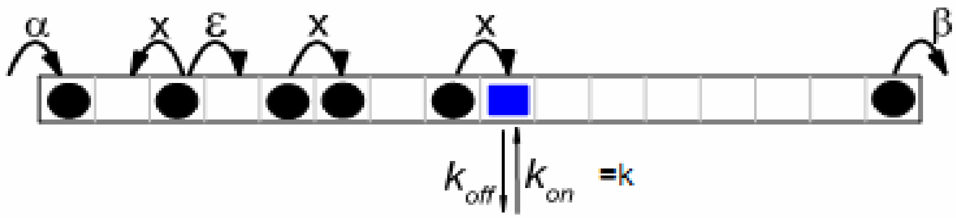


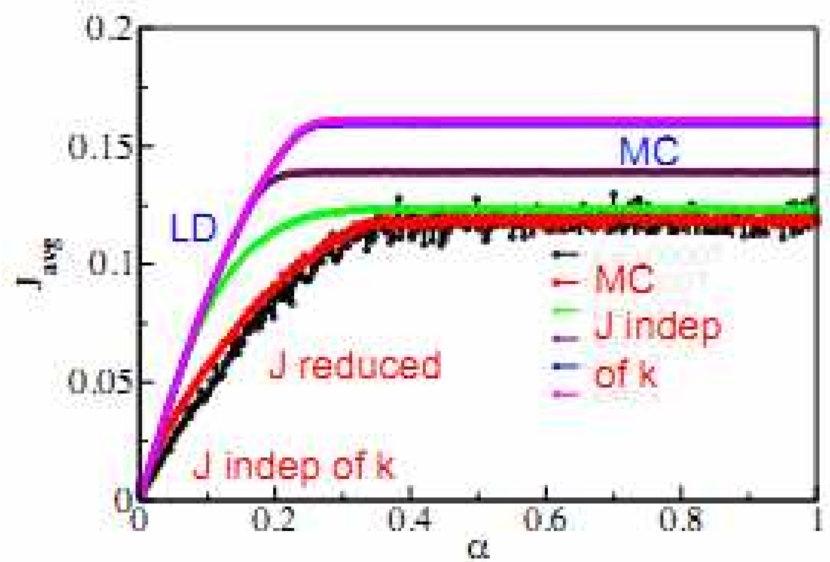


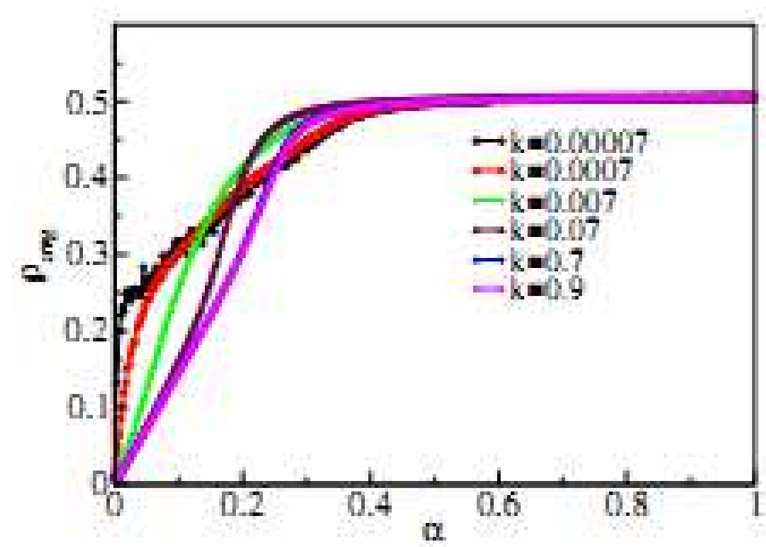
- No effect of the roadblock/defect/pausing on LD and HD phase.
- MC phase → Reduced flux → limited by the roadblok/pause/defects.

Janowsky & Lebowitz 1992,
Kolomeisky 1998, ...

Open System with on/off roadblock





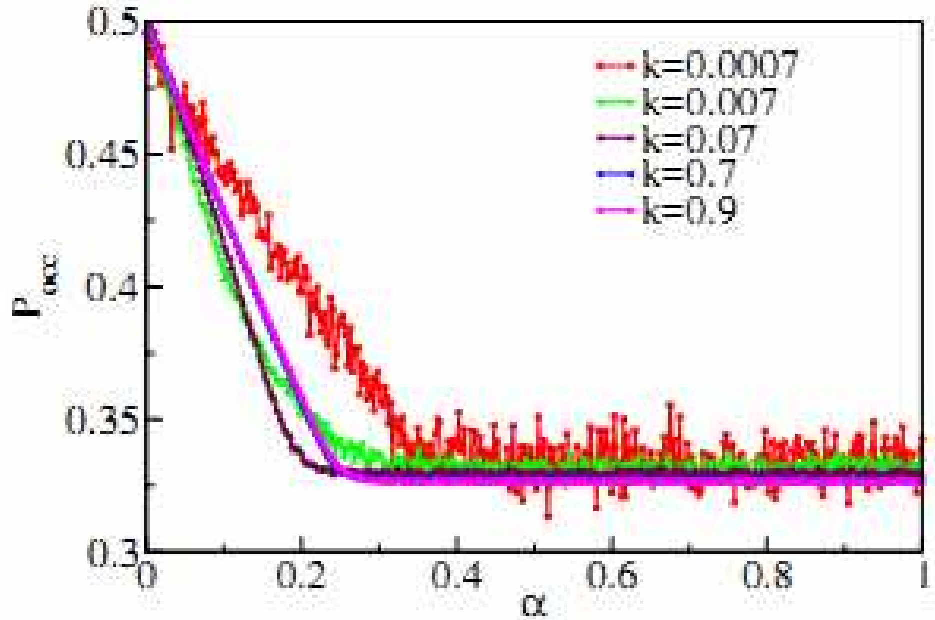


Sahoo & Klumpp, J Phys A 2016

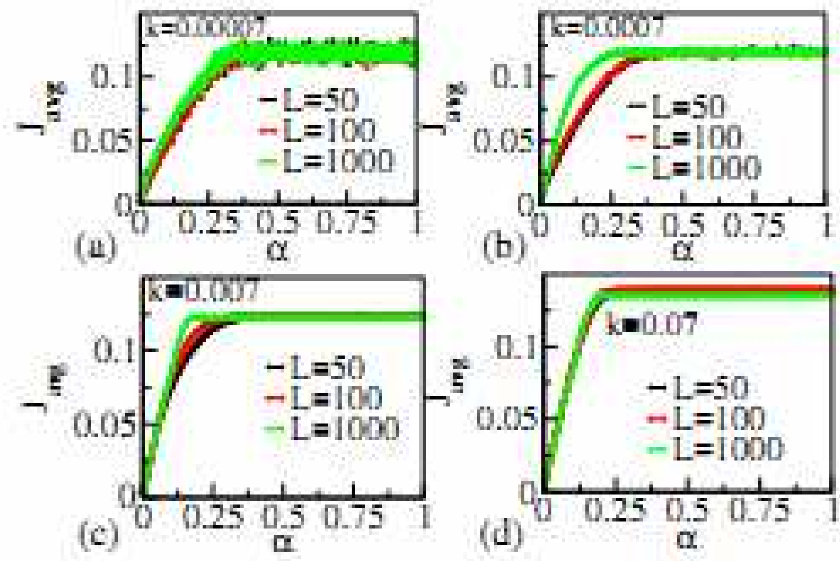
- Large k → Only MC affected → MC(d)
- Rapid roadblock ($k \geq \epsilon$)Slow site scenario
- small k →3 regimes
- how small ? $k \leq \epsilon/L$ and $k \leq \alpha/L$

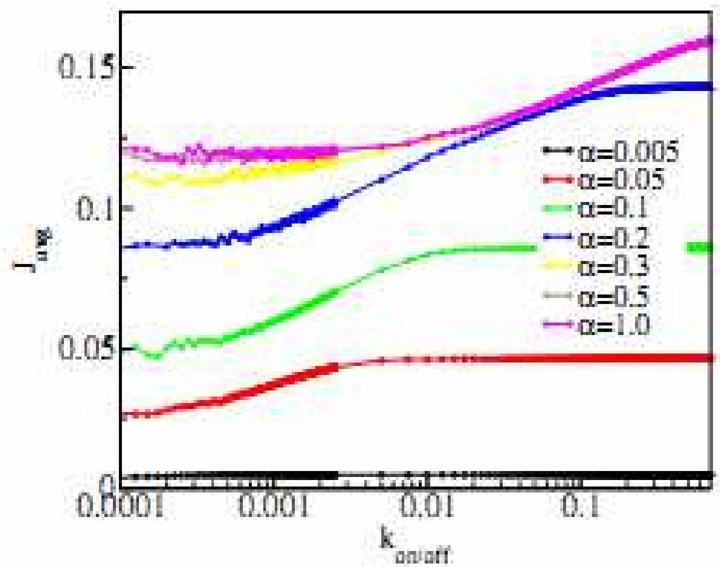
Open System with on/off roadblock

- Roadblock density →Prob. of roadblock occupying
- Decreases with increase in α



Open System with on/off roadblock





Sahoo & Klumpp, J Phys A 2016

- System size dependence
- Plateau at large k $\rightarrow$ LD phase
- Plateau at smaller k $\rightarrow$ Limiting cases

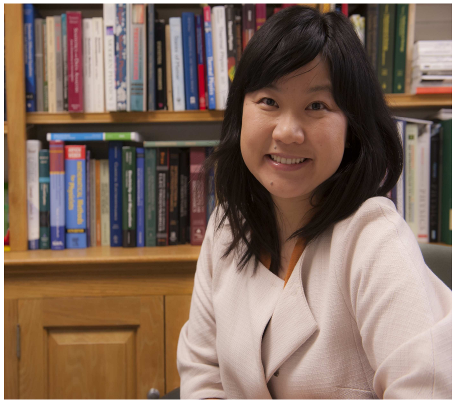
Concluding remarks & Outlook

- Dynamic roadblock particles/defects $\rightarrow$Rich dynamic behavior
- System size effects seems typical
- Applications:Transcription and translation dynamics, regulatory mechanisms.

Acknowledgement

- Stefan Klumpp
  (Institute for Nonlinear Dynamics,Gttingen University)

- J J Dong
  (Bucknell University, USA)

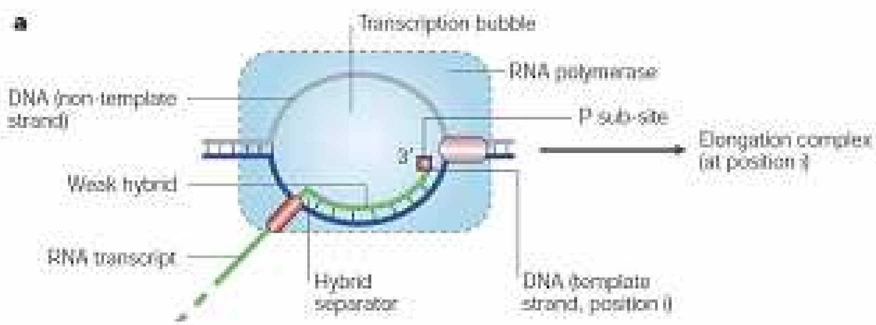


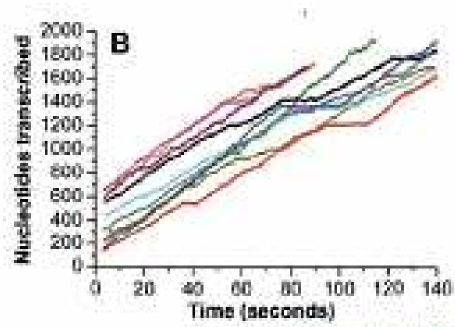
THANKS

??????????

Transcription & Blockage in Transcription

- Transcription → RNA polymerase moves along the length of a DNA template by a single base pair → creating a complementary RNA.
- One single nucleotide elongation step
  - appropriate binding of NTP
  - single step forward

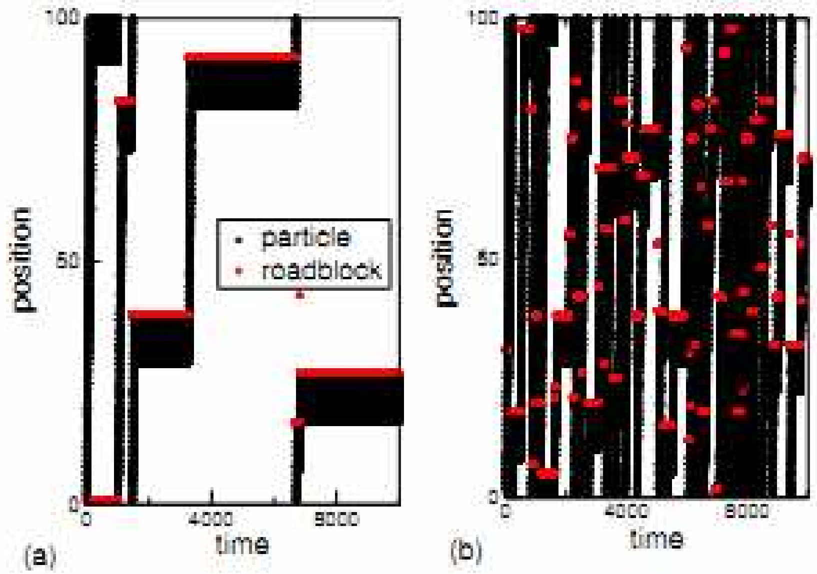




Adelman et al. 2002

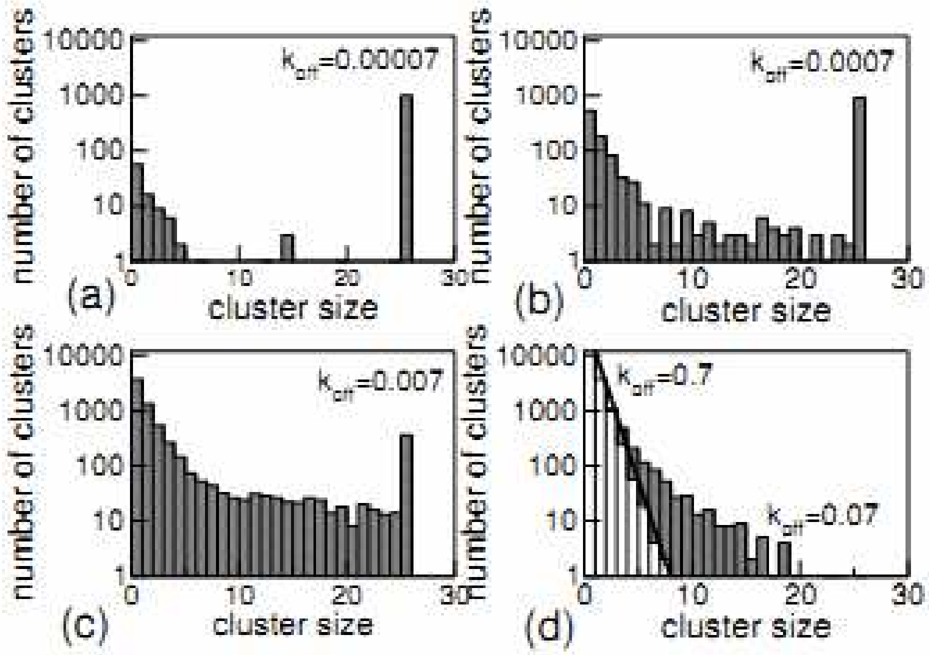
- Transcriptional elongation is interrupted with pauses/errors/blockages.
- Pauses are of stochastic in nature → different kinds → DNA binding proteins/transcription factors.

Space-time trajectory of the dynamics



- For small k_{off} → Sudden (short-lived) burst of particle flow → until dense cluster of particles has formed again behind the roadblock.
- For large k_{off}. Flow of particles is more contineous.

Cluster size distributions

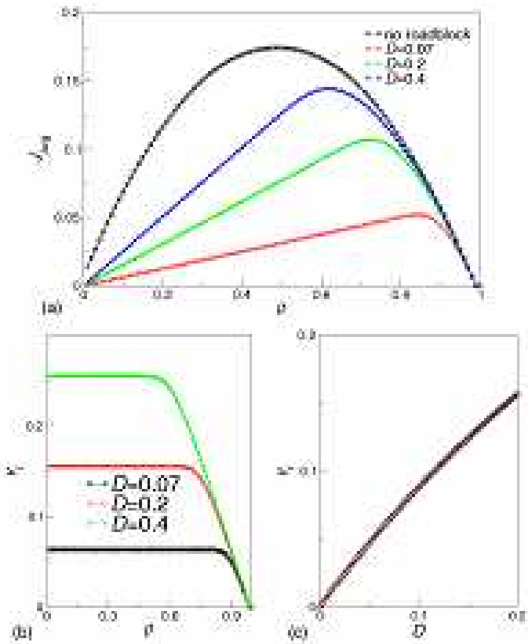


- For small k_{off}
  - Distributions $\rightarrow$ dominated by a peak cluster size, N.
  - A minor peak (smaller clusters) $\rightarrow$ Breaking up of clusters.

.

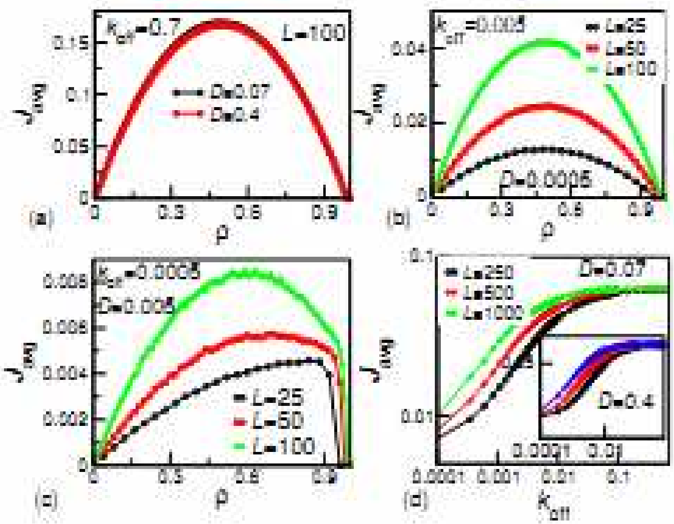
- For large k_{off} $\rightarrow$ The cluster size distribution is exponential $\rightarrow$ Conventional TASEP.

Diffusive dynamics of roadblock without unbinding



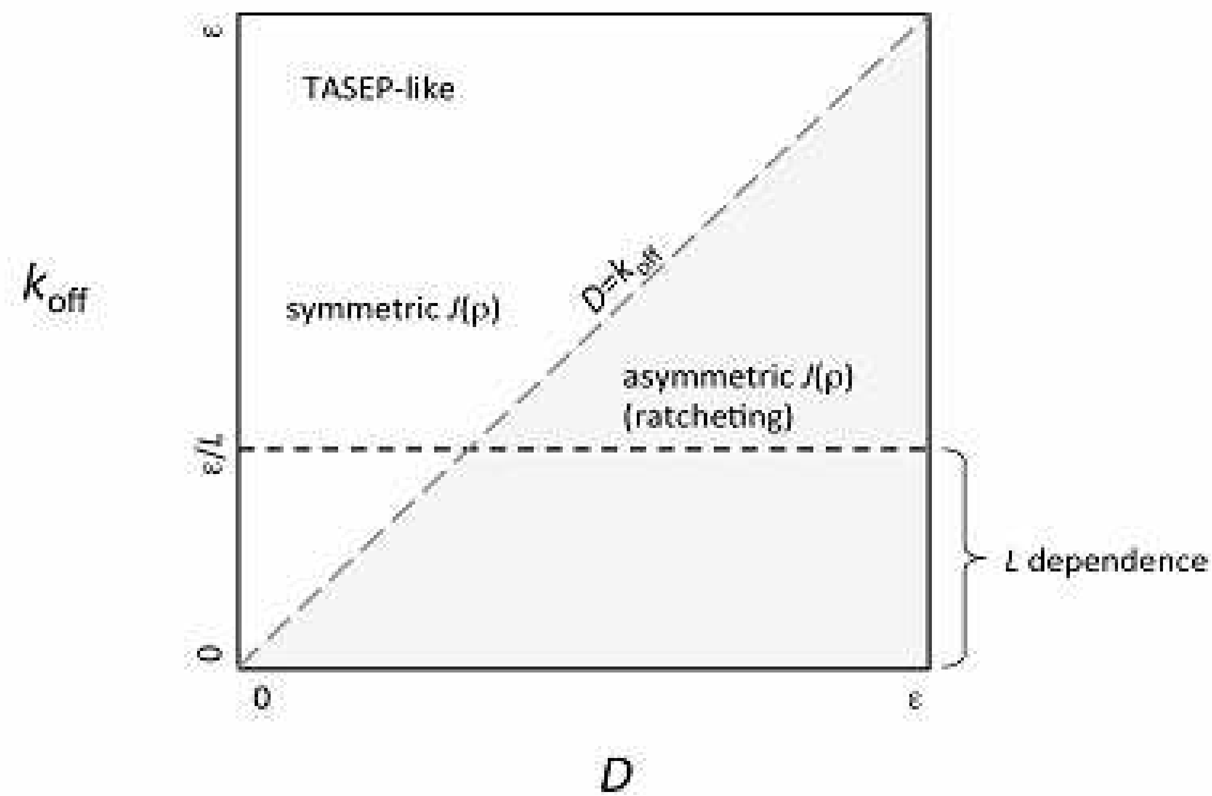
- Current-density relation$\Rightarrow$ Asymmetry with maximal current at $\rho > 0.5$.
- Roadblock velocity, $v_r \rightarrow$constant over wide range of particle density$\rightarrow$decreases at higher densities.
- Analytical estimate,$v_r = \frac{D\epsilon}{(D+\epsilon)} \rightarrow$ Good agreement with simulation.

Combined effect of diffusive dynamics and unbinding



- Largek_{off} ($k_{off} > \epsilon/L$)→TASEP like behavior →indipendent of D as well as system size, L.
- Small k_{off} ($k_{off} < \epsilon/L$)→ System size dependence, indipendent of D.
- Both k_{off}, $D << \epsilon/L$,
  - $k_{off} < D$→ Ratchet like behavior
  - $k_{off} < D$→ Current density relation symmetric.

Schematic summary of different dynamic behavior



- Different dynamic behaviour → New phase diagram in (k_{off},D) space.