Stick-slip Dynamics and Extreme-value statistics: from solid contact friction, moving contact line, to cargo transport in living cells

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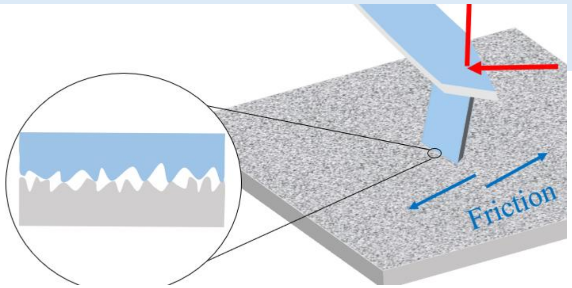
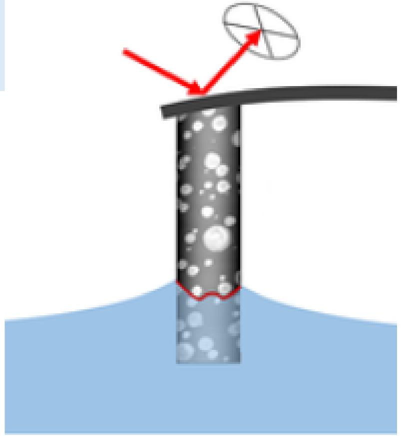
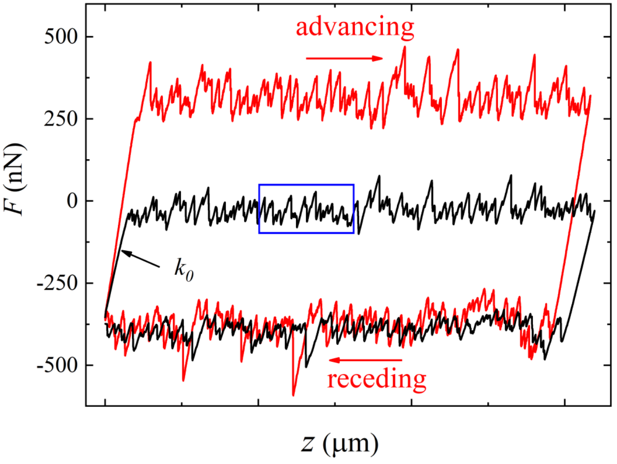
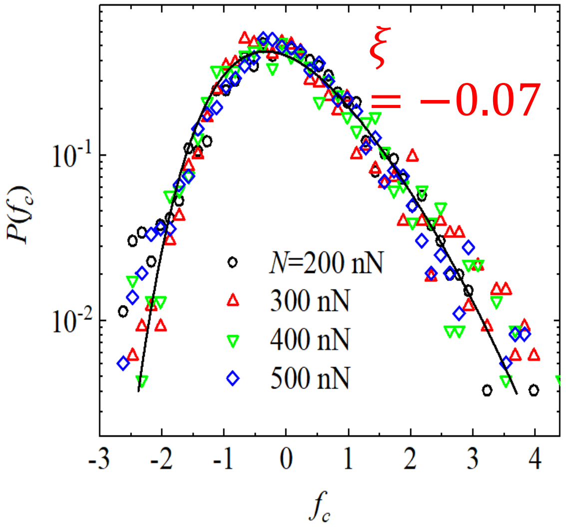


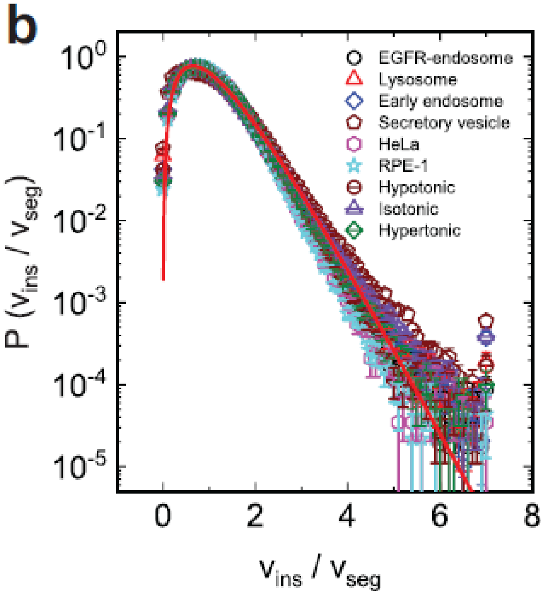


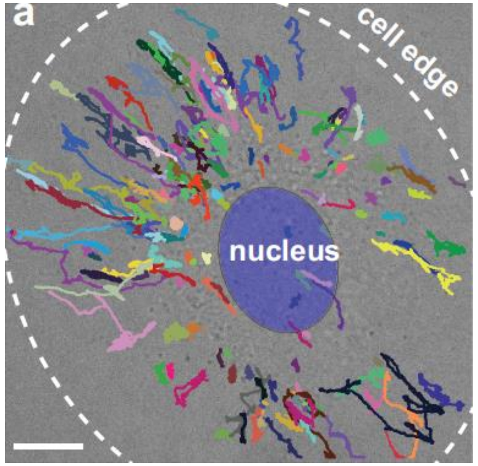
- Stick-slip motion of dry friction at mesoscale
- Stick-slip dynamics of a mesoscale moving contact line

- Universal statistics of cargo velocities emerged from Stick-Slip dynamics in cells





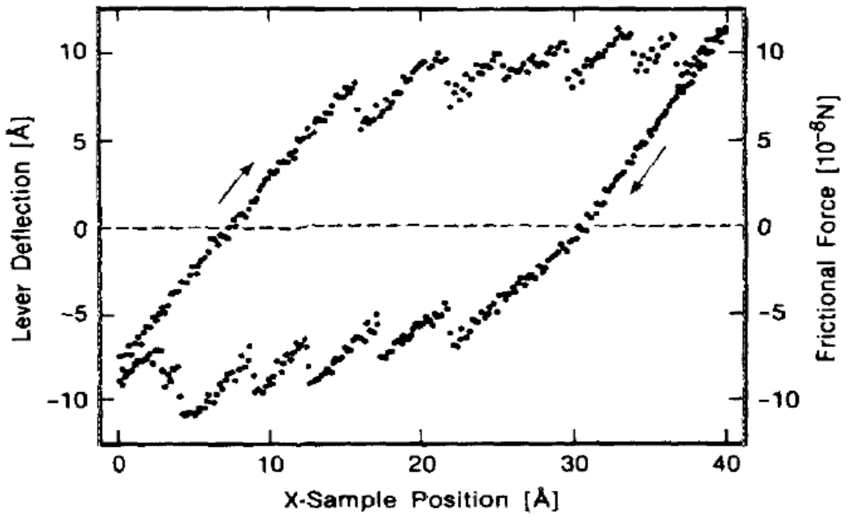




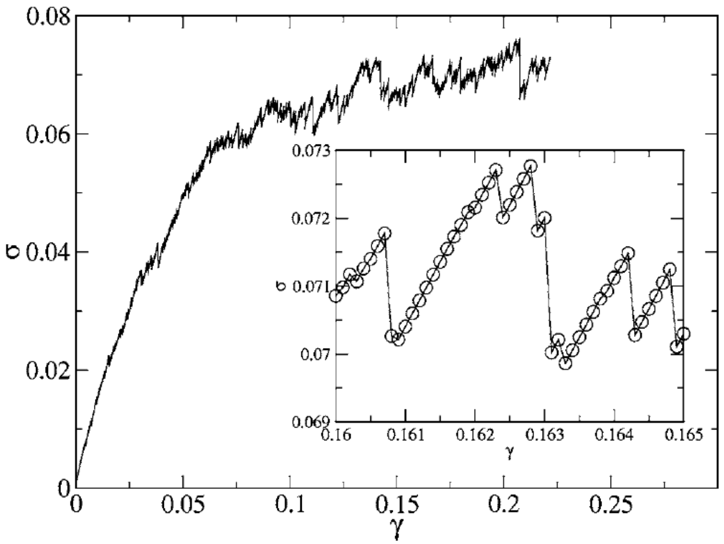
Kyoto, May 2026

Stick-slip and avalanche dynamics

- Stick-slip is a class of phenomena characterized by intermittent jerky movement in out-of-equilibrium disordered systems, as a yield response to a smoothly-varying external force.



Erlandsson *et al.* (1988)

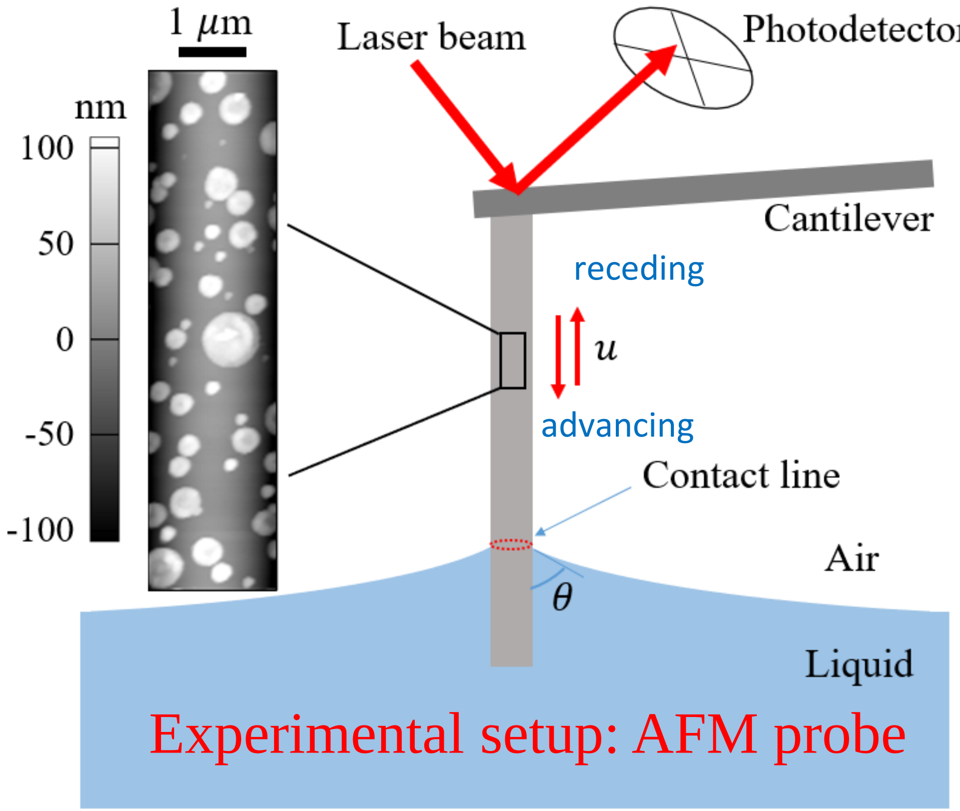


Maloney & Lemaitre (2006)

- It is observed in nature and many engineering applications that span a wide range of scales, from the nanoscale contacts and fractures in nano- and micro-machines/devices to the geophysical scale of snow avalanches, landslides and earthquakes.

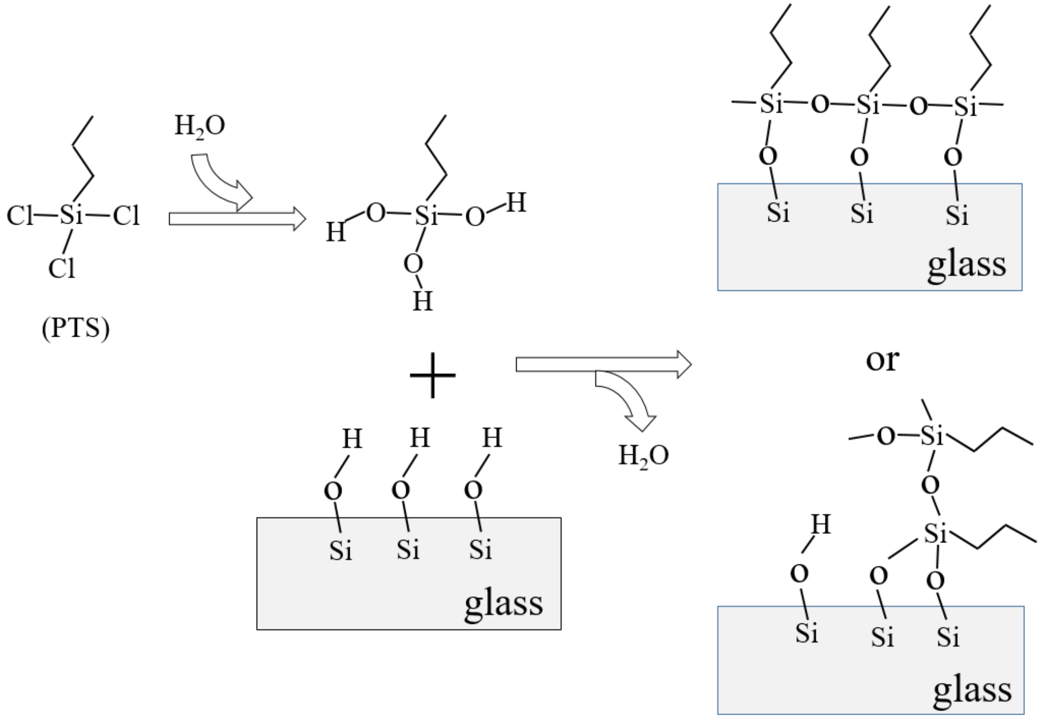
Expt: stick-slip dynamics of a moving contact line at mesoscales

small enough to resolve the slip events at the single slip resolution but is also large enough to allow the individual slips to have a broad range of slip sizes in a well-characterized defect landscape



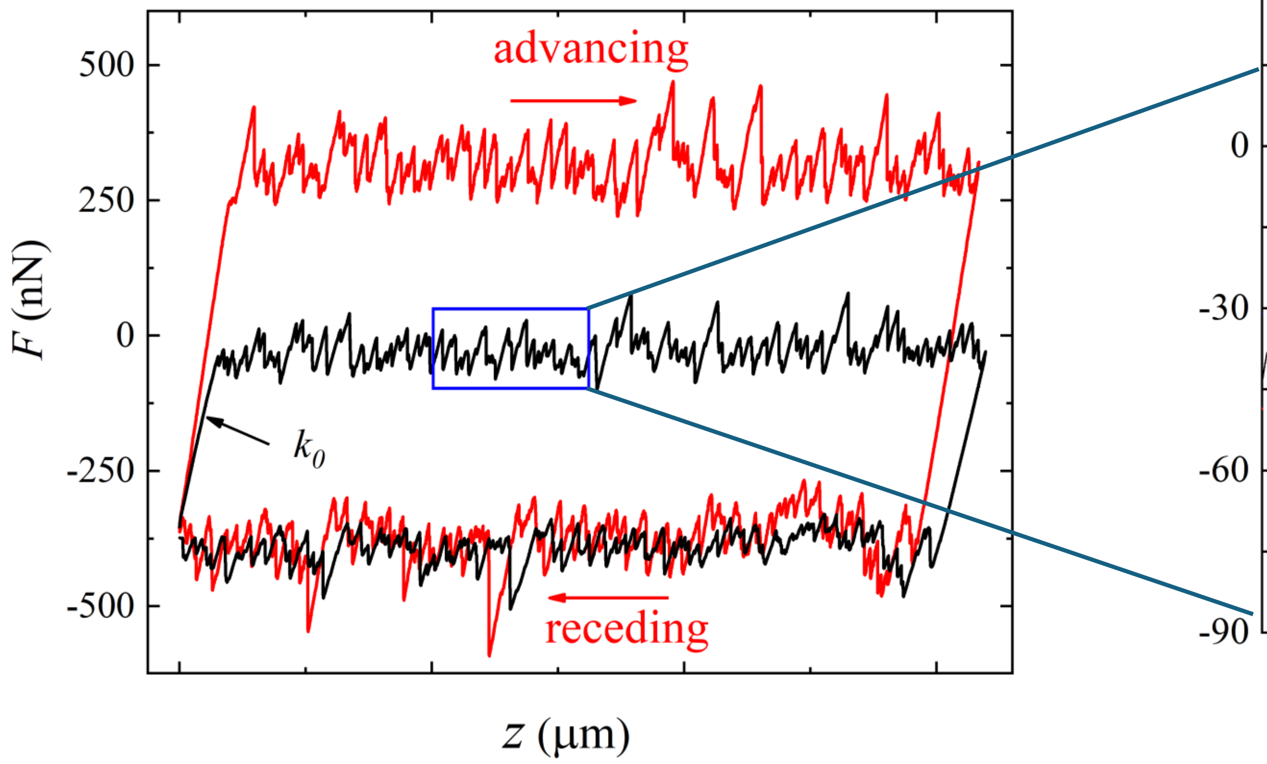
Experimental setup: AFM probe

Surface coating: propyl trichlorosilane (PTS)

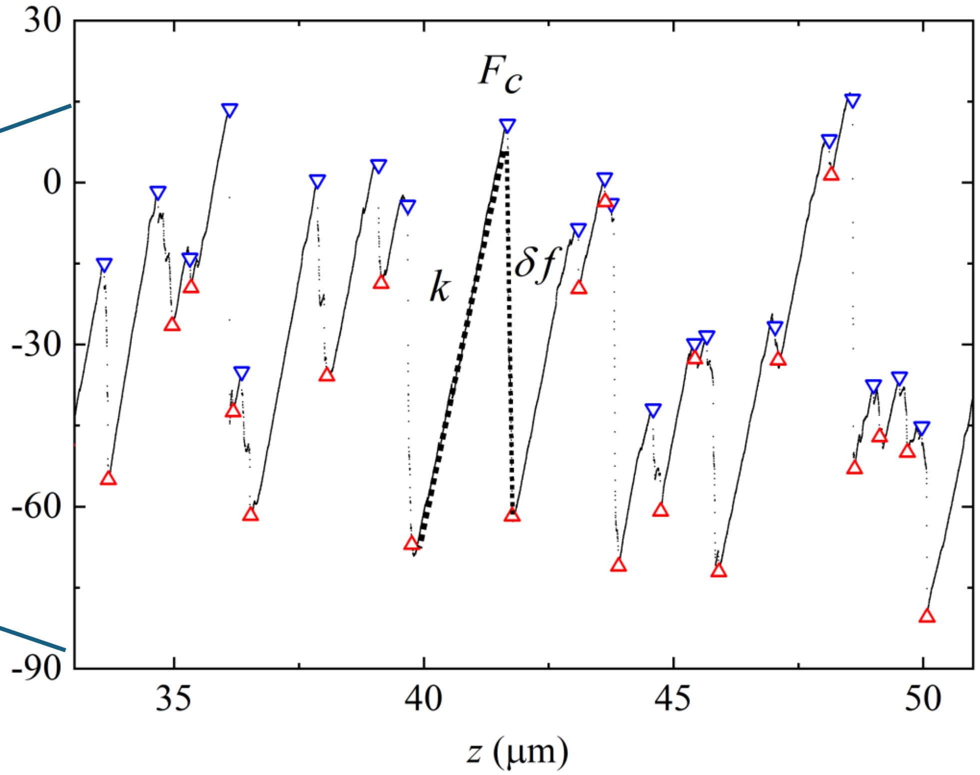


- Long glass fiber diameter *d*: 0.4-4 μm, at mesoscale to resolve single slip events
- fiber length *L*: 100-300 μm
- Low-speed limit: u~0.62 μm /s (viscous drag is negligible)

Stick-slip dynamics of a moving contact line



Fluctuating stick-slip dynamics:



Capillary force hysteresis loop for water (red) and ethylene glycol (black)

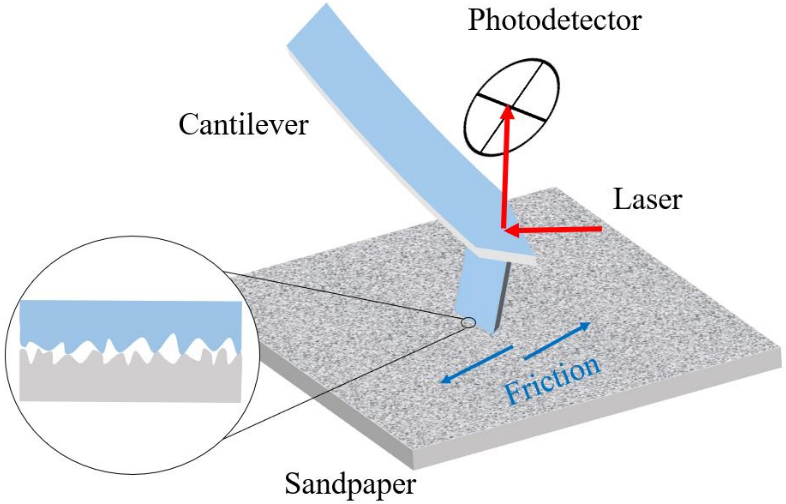
Static spring constant of the liquid interface, $k_0 \sim \gamma$

F_c: critical depinning force (onset of slip)

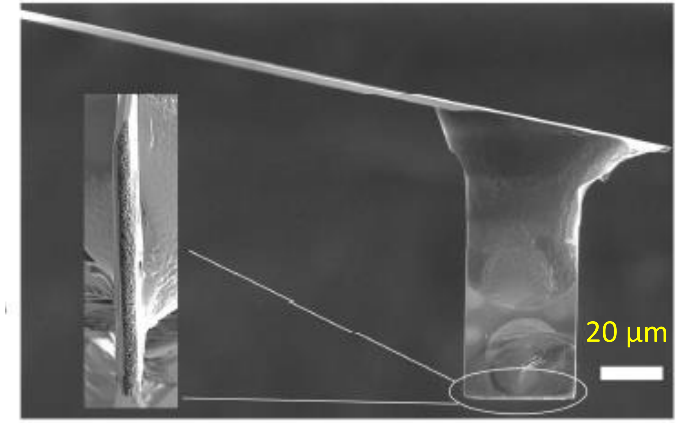
δf: force release during the slip

k: dynamic spring constant of the interface (linear force accumulation)

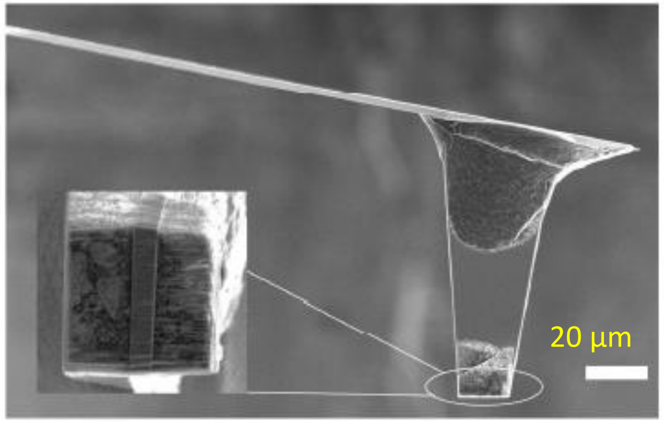
Expt: stick-slip dynamics of friction between 2 solid surfaces



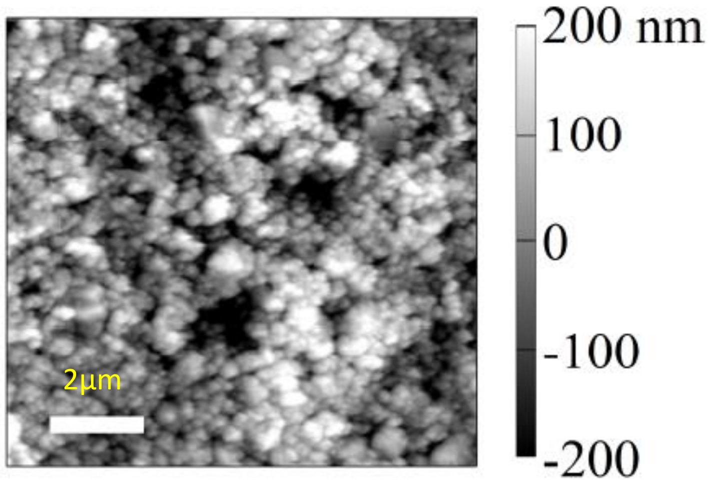
Lateral hanging-beam AFM



Quasi-1D scanning probe with an end contact area of 34×3 μm^2 (UV glue)

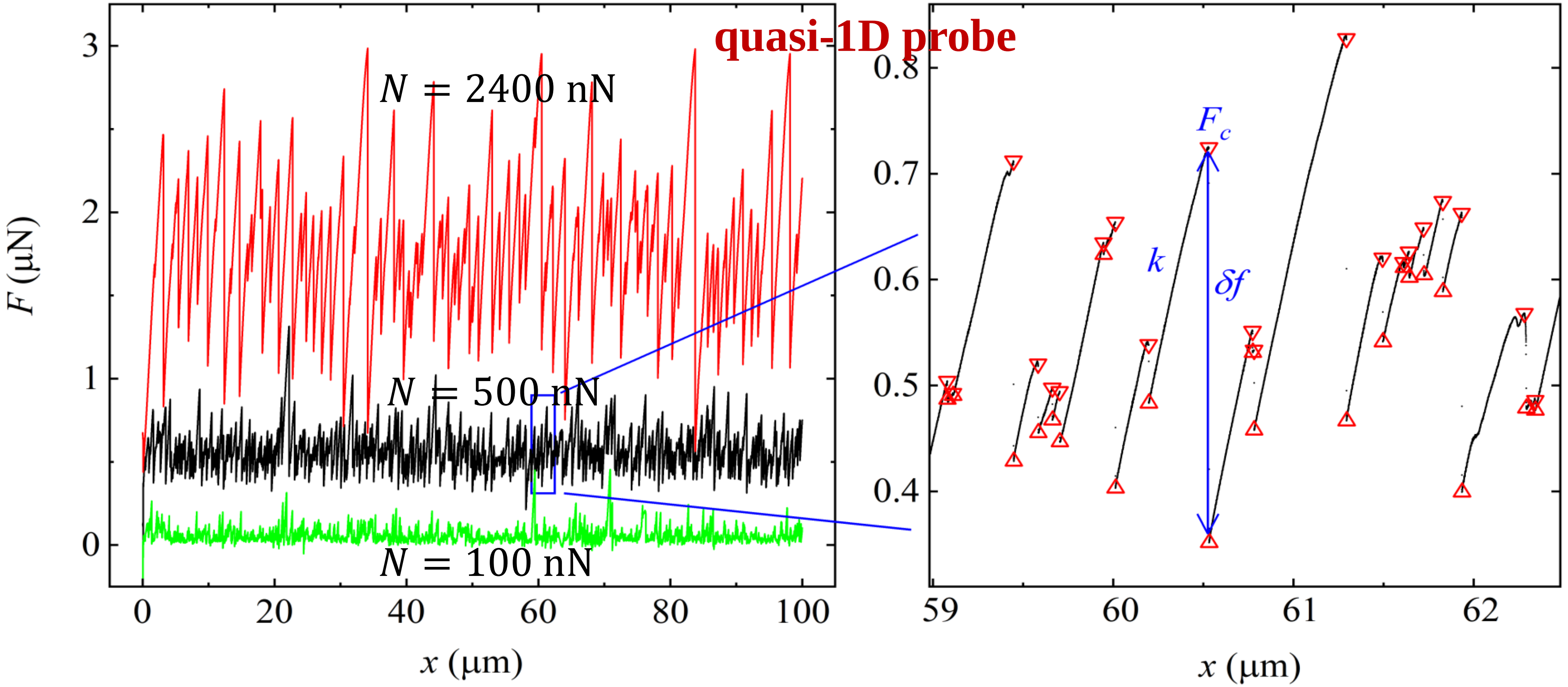


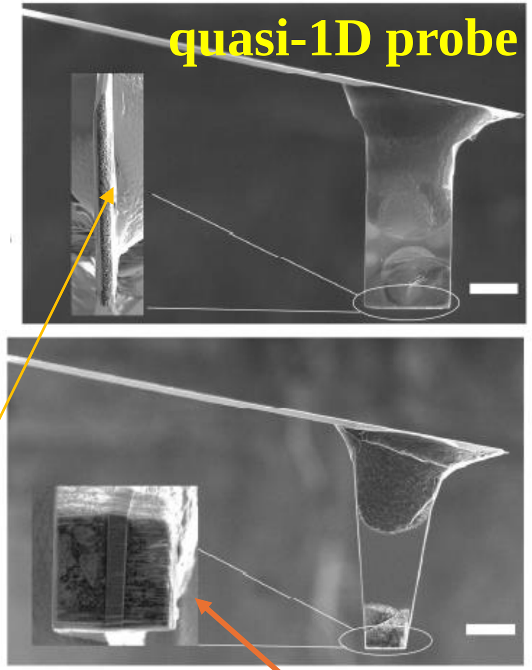
2D scanning probe with an end contact area of 12×12 μm^2(UV glue).

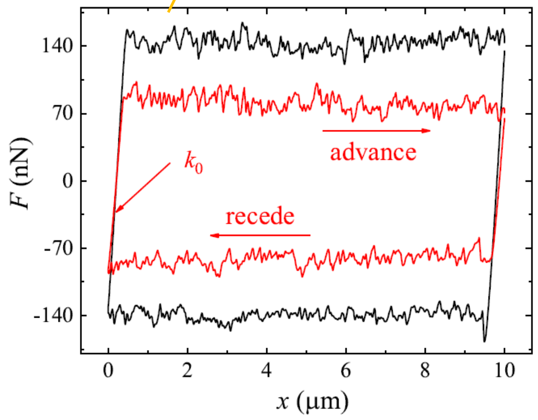


Ultra-fine sandpaper (silicon carbide) surface with an average grain size 0.1 μm

Stick-slip dynamics of friction between 2 solid surfaces







2D probe

- Increasing normal load *N*: smooth sliding → stick-slip

- focus on the intermediate range of normal load (200–600 nN) at an "optimal contact" with the sandpaper so that it can sense the full range of the rough landscape with negligible wear

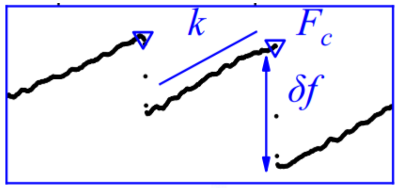
k, F_c, and δf reveal universal statistical properties for dry friction & CL

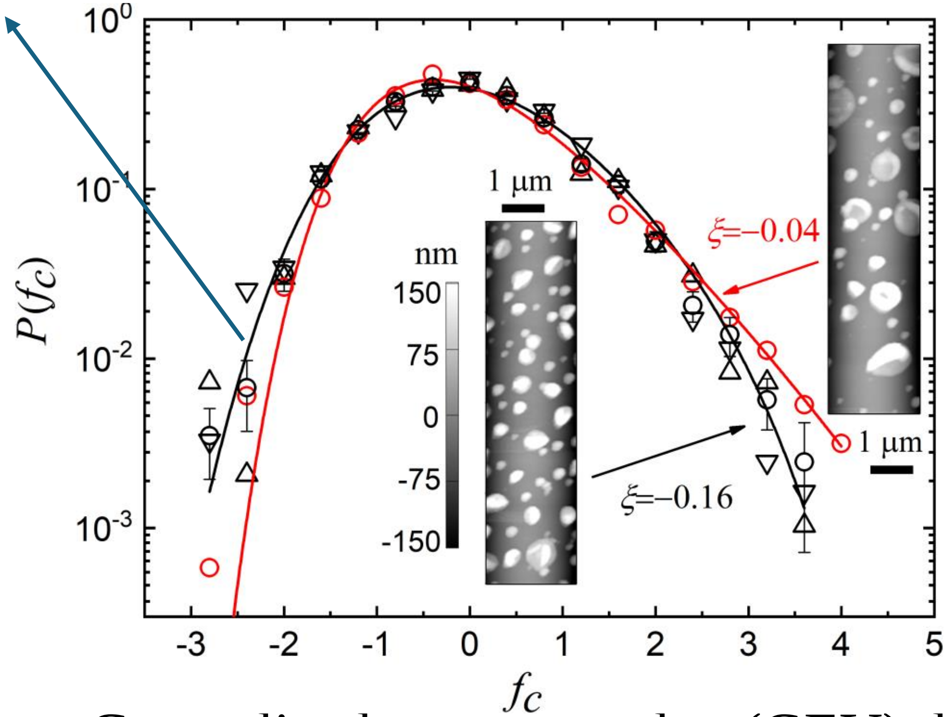
Distribution of the stick-slip events: Depinning force $f_c = \frac{F_c - \langle F_c \rangle}{\sigma_{F_c}}$

Contact line

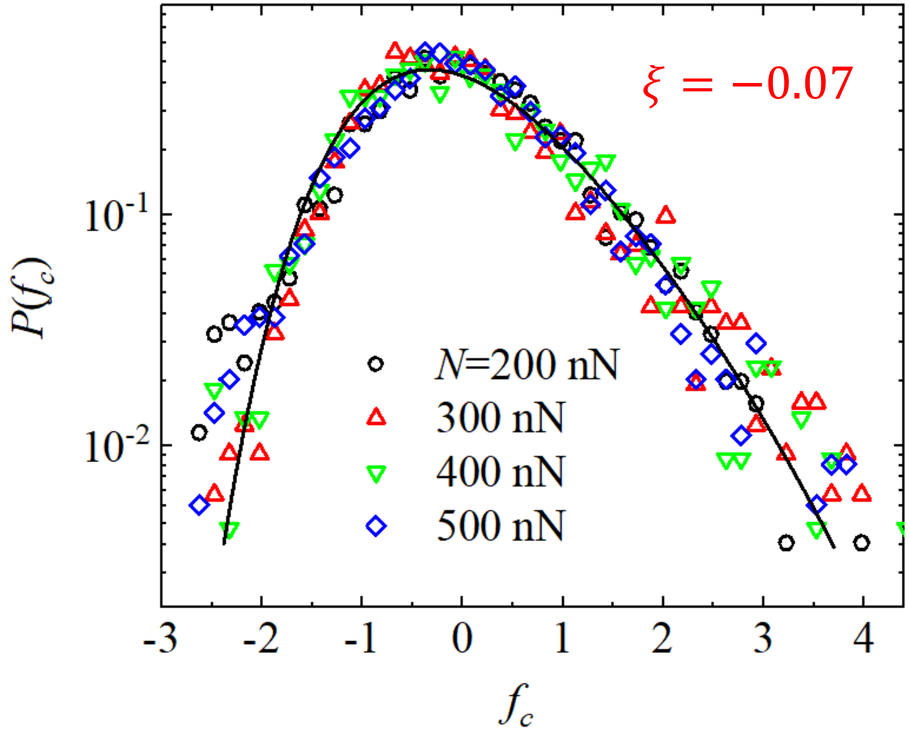
water, 66 wt.% glycerol aqueous solution, and ethylene glycol

Fluids	η (cP)	ρ (g/cm^3)	γ (mN/m)	θ_a (deg.)
Ethylene glycol	16	1.1	47	85±15
Aqueous glycerol	15	1.2	65	99±10
Water	0.89	1.0	72	115±10





Solid friction (quais-1D probe)



Generalized-extreme-value (GEV) distribution: (one parameter fit)

$$p(f_c) = \frac{1}{\beta}\left(1 + \xi\,\frac{f_c - \mu}{\beta}\right)^{-1/\xi} \exp\left[-\left(1 + \xi\,\frac{f_c - \mu}{\beta}\right)^{-\frac{1}{\xi}}\right],$$

$$\left(\begin{array}{c} \mu = \beta(1 - \Gamma(1-\xi))/\xi \\ \beta = \xi/\sqrt{\Gamma(1-2\xi) - \Gamma^2(1-\xi)} \end{array}\right)$$

Generalized Extreme Value (GEV) distribution

- GEV models the distribution of extreme values in a dataset. Commonly used in environmental science, economics, and engineering to analyze events such as extreme weather conditions or financial market crashes.
- Help to understand how likely the extreme(the highest or lowest) values are to occur.
- Examples: predicting the maximum wind speed in a particular location, estimating the size of the worst floods in a river, or analyzing the extreme values of stock market returns during a financial crisis.

Statistics or distribution of the maximum (or minimum) of n (a large number) samples drawn independently from an identical probability distribution.

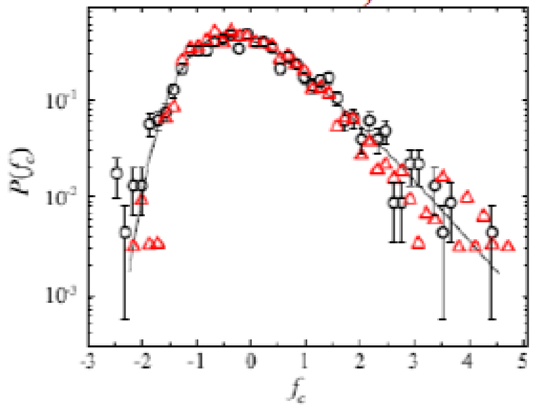
Extreme-value Theorem: the random variable $x=max\{X_i\}^n_{i=1}$ follows one of the **generalized extreme value** (**GEV**) **distributions** (the Gumbel, Fréchet and Weibull families also known as type I, II and III extreme value distributions)

$$\mathrm{GEV}(\mu, \sigma, \xi) = \frac{1}{\sigma} t(x)^{\xi+1} e^{-t(x)},$$

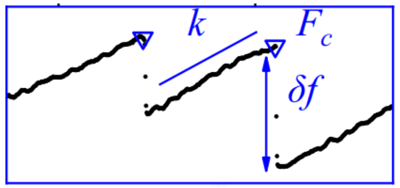
where

$$t(x) = \begin{cases} \left(1+\xi\left(\frac{x-\mu}{\sigma}\right)\right)^{-1/\xi} & \text{if } \xi \neq 0 \\ e^{-(x-\mu)/\sigma} & \text{if } \xi = 0 \end{cases}$$

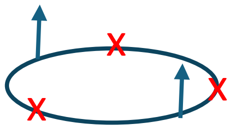
$\xi \approx 0$

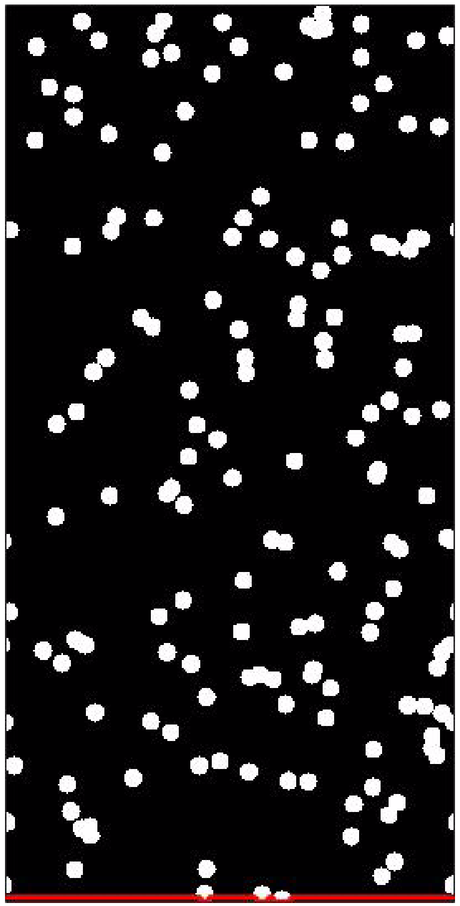


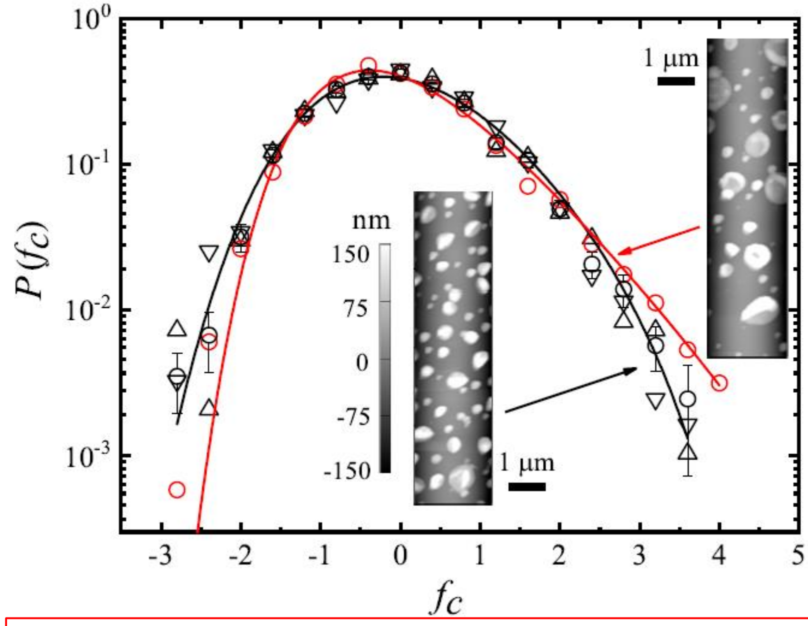
Extreme Value Statistics in moving contact line: contact line deforms and eventually depinning occurs



- contact line deforms to accumulate stronger force to depin
- A large number of pinning sites along the contact line loop
- F_c ~ maximum of the pinning forces
- As the contact line is pulled: sample the maximum of the (~independent pinning forces) on the contact line → GEV







Normalized depinning force $f_c = \frac{F_c - \langle F_c \rangle}{\sigma_{F_c}}$

F_c contains an eqm. (capillary) force

$$F_{eq} = -\pi d \gamma \cos\theta$$

ξ = -0.17 (black line) ξ = -0.06 (red line)

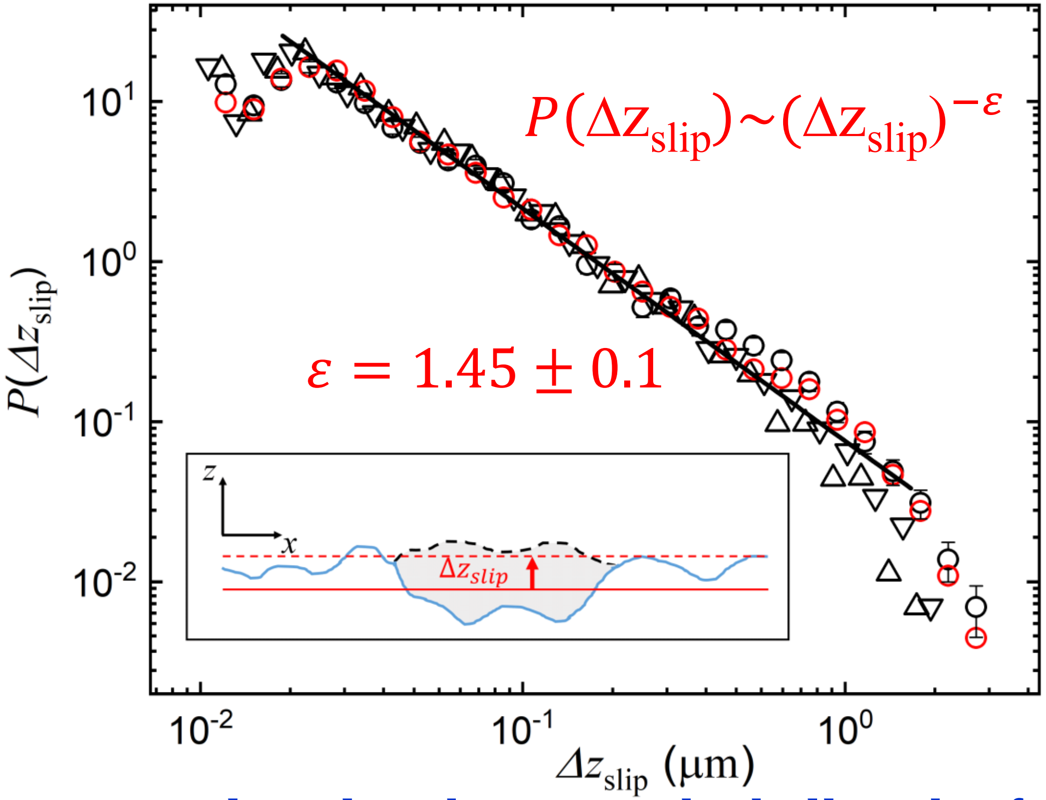
ξ < 0 reversed Weibull distribution: has an upper bound $(f_c)_M = (\mu - \beta)/\xi$ beyond which $P(f_c) = 0$ → an upper bound for $(F_c)_M$. Roughness-induced maximal pinning force = $(F_c)_M - F_{eq}$, larger for the rougher surface(750 vs. 402 nN)

ξ = 0 Gumbel distribution: exponential tail with an infinite upper bound [$(f_c)_M \to \infty$].

$$P(f_c) = \frac{1}{\beta}(1+\xi z)^{-(1+1/\xi)} e^{-(1+\xi z)^{-1/\xi}}$$

$$z = \frac{f_c - \mu}{\beta} \qquad \begin{pmatrix} \mu = \beta(1 - \Gamma(1-\xi))/\xi \\ \beta = \xi/\sqrt{\Gamma(1-2\xi) - \Gamma^2(1-\xi)} \end{pmatrix}$$

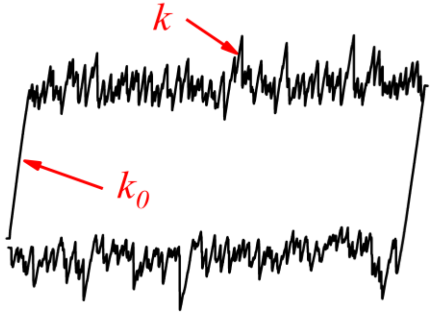
Distribution of the stick-slip events for the contact line:

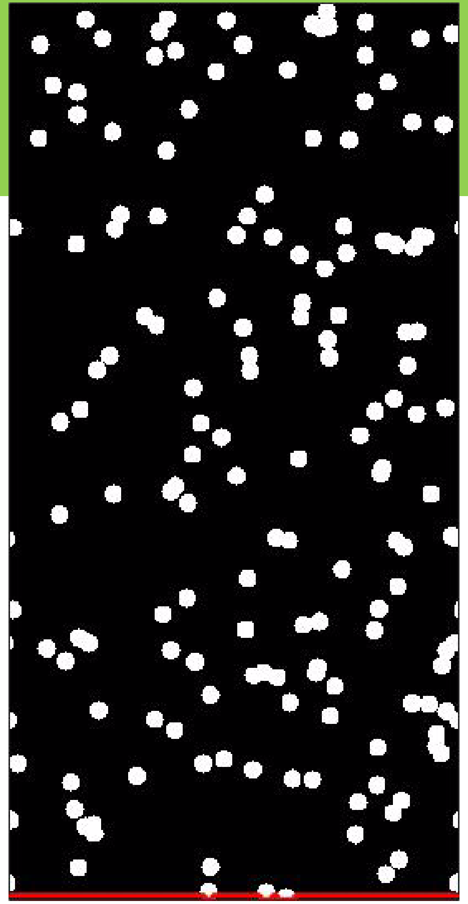


slip length $\Delta z_{slip} = \frac{\delta f}{k_0}$

center-of-mass displacement of the CL

Static spring constant of the liquid interface, k_0



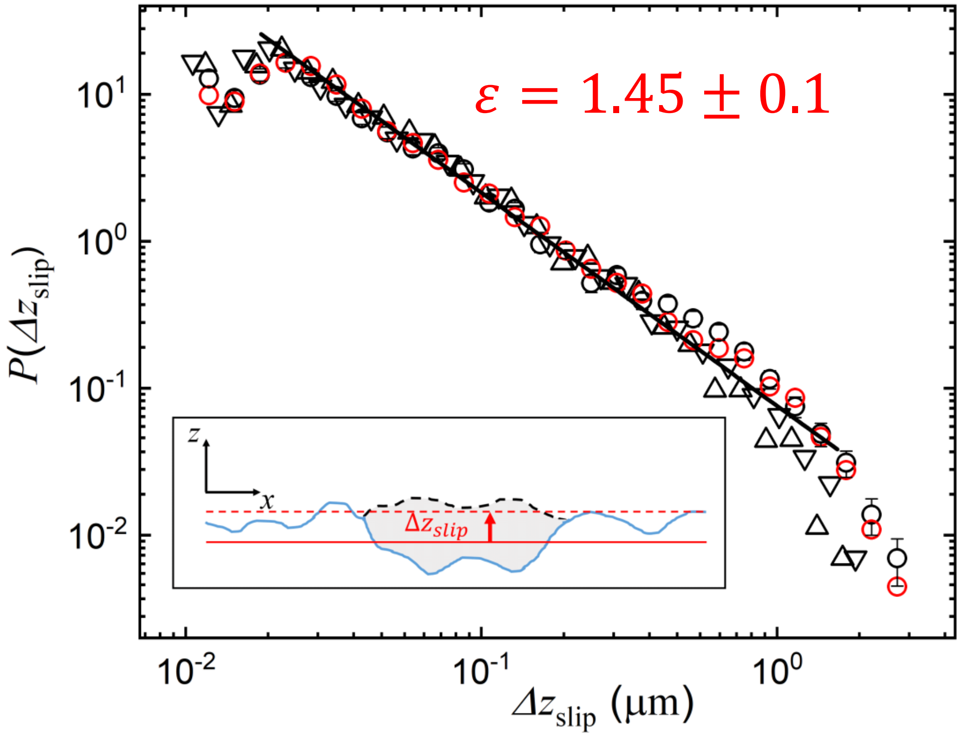


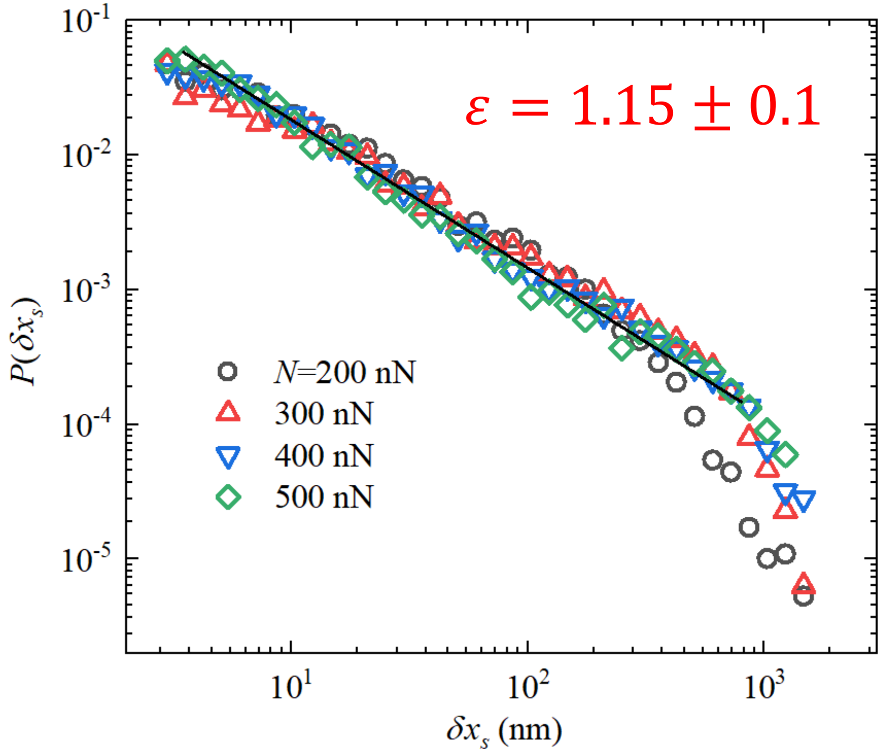
- Power-law distribution is the hallmark of avalanche dynamics.
- when a strong defect slips, the released large stress is partially transferred to its neighboring defects and triggers their slips→ avalanche
- ε is unchanged for fibers with different roughness and in contact with different liquids
- In the low-speed limit, the Alessandro-Beatrice-Bertotti-Montorsi(ABBM) model predicts ε=3/2 → slow CL motion obeys the ABBM model

J. Appl. Phys.68, 2908-2915 (1990)

Distribution of the stick-slip events: Slip length= $\frac{\delta f}{k_0}$

Contact line $P(\Delta z_{slip}) \sim (\Delta z_{slip})^{-\varepsilon}$ Solid friction





- Power-law distribution is the hallmark of the avalanche dynamics.
- The power-law exponent $\varepsilon \sim 1.5$ (ABBM) of the CL is larger than that of the solid friction: $\varepsilon \sim 1.2$ (quasi-1D), $\varepsilon \sim 0.72$ (2D probe).

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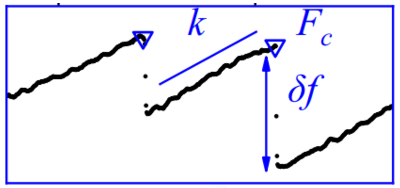
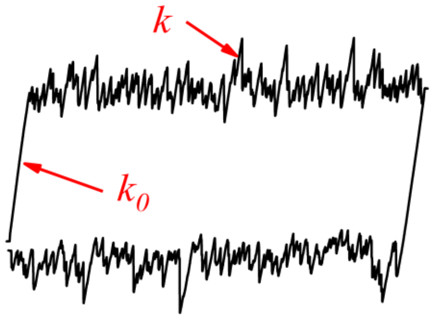
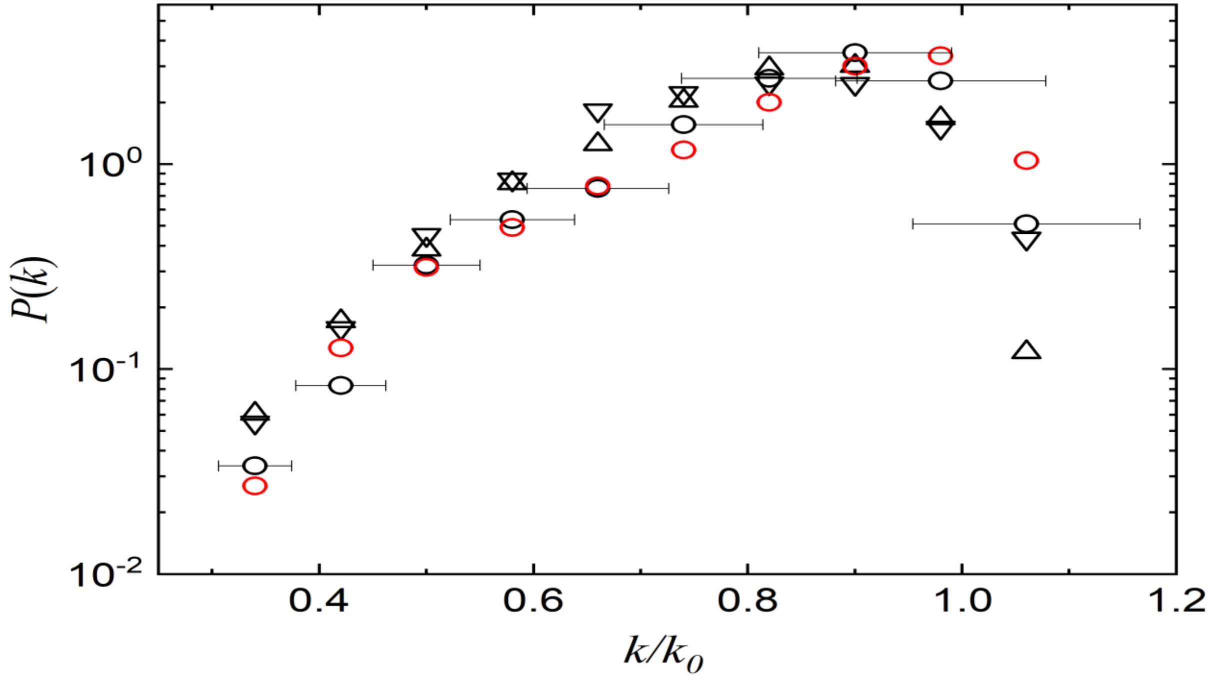
Distribution of the stick-slip events: Dynamic spring constant *k*

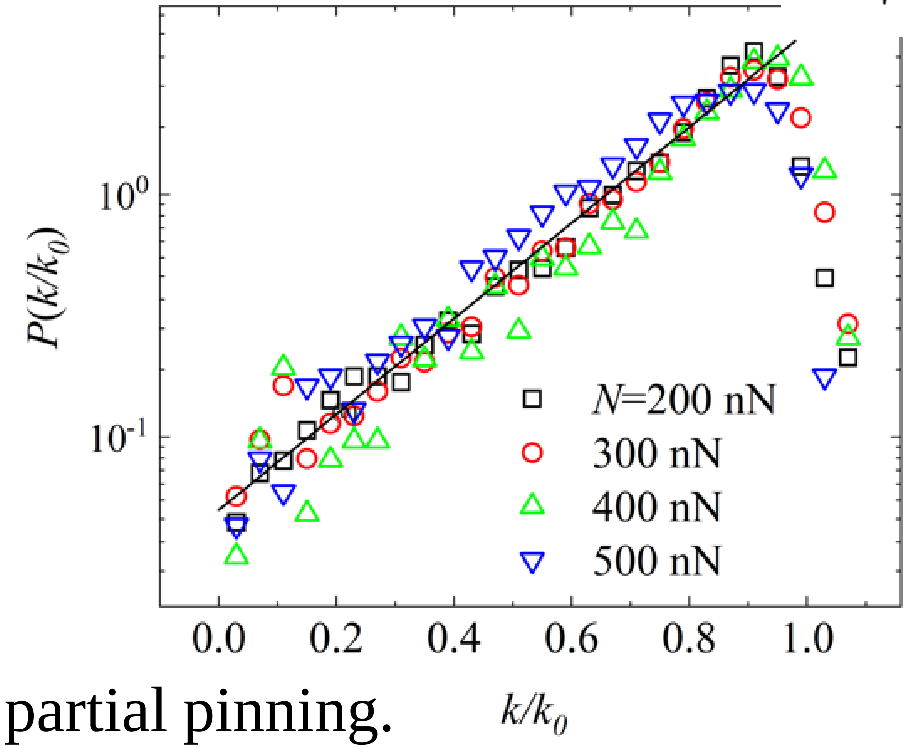
Contact line



Solid friction







k is the dynamic spring constant at partial pinning.

k_0 is the static spring constant at complete pinning.

$0.3 \lesssim k/k_0 \lesssim 1.1$ and peaks around $k/k_0 \simeq 0.94$

→ k_0 sets a cutoff value for k

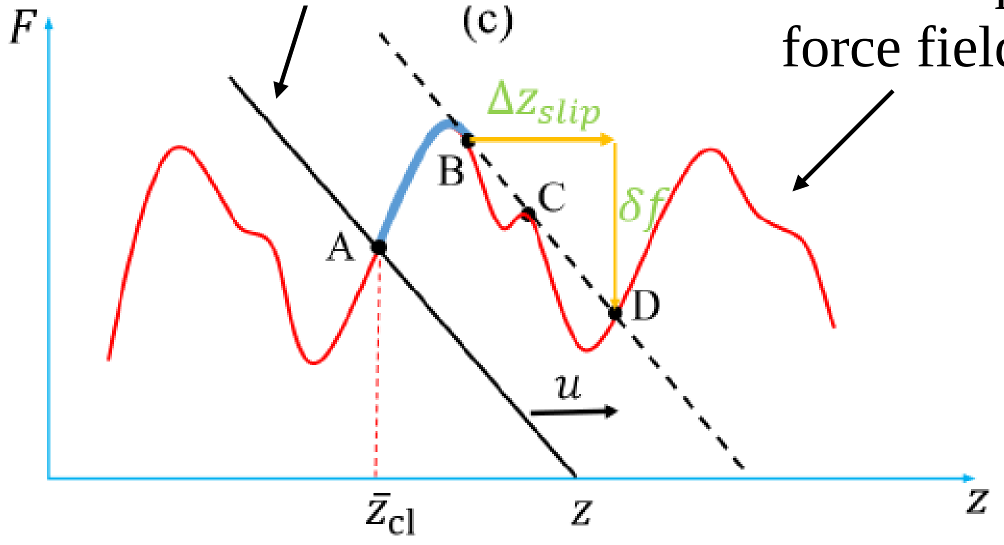
Theoretical model: Stick-slip motion in a random pinning field

$h(x; z)$: defect-induced heterogeneous interfacial tension difference between the solid-air and solid-liquid interfaces

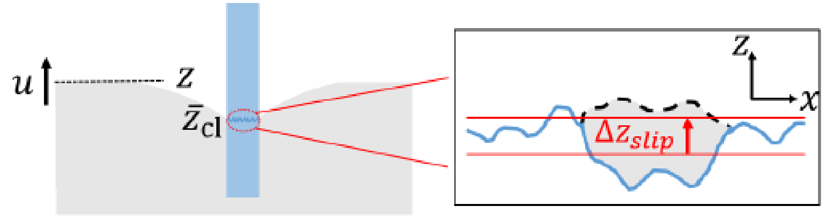
Elastic pulling force

$$F_{\rm pin} = \int_0^{\pi d} h(x; z_{cl}(x))dx.$$

$$F_{\rm pull} = k_0(z - \bar{z}_{cl}),$$



Random pinning force field $F_{\rm pin}(z)$ → k'



$$\bar{z}_{cl} = (1/\pi d)\int_0^{\pi d} z_{cl}(x)dx$$

Dynamic balance between $F_{\rm pull}$ and $F_{\rm pin}$

Uphill (A→B):

$$k' = dF_{\rm pin}/d\bar{z}_{cl} > 0$$

Measured dynamic spring constant is related to the local force gradient, with (in series)

$$\frac{1}{k} = \frac{1}{k_0} + \frac{1}{k'}$$

Downhill (B→C):

Slip instability occurs when $k_0 < k'$.

Slip length $\Delta z_{slip} = \frac{\delta f}{k_0}$.

Microscopically: $\delta f = -\langle \partial h/\partial z \rangle_A \int_A dxdz \; = \frac{k_0}{\pi d}\int_A dxdz = k_0 \Delta z_{\rm slip}$

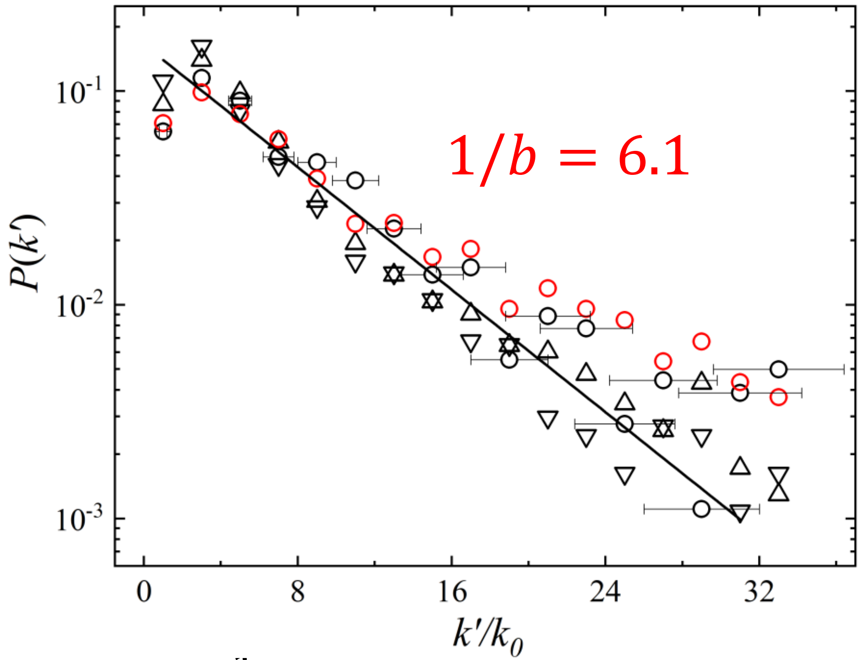
the slip area

Distribution of the stick-slip events: local pinning force gradient k'

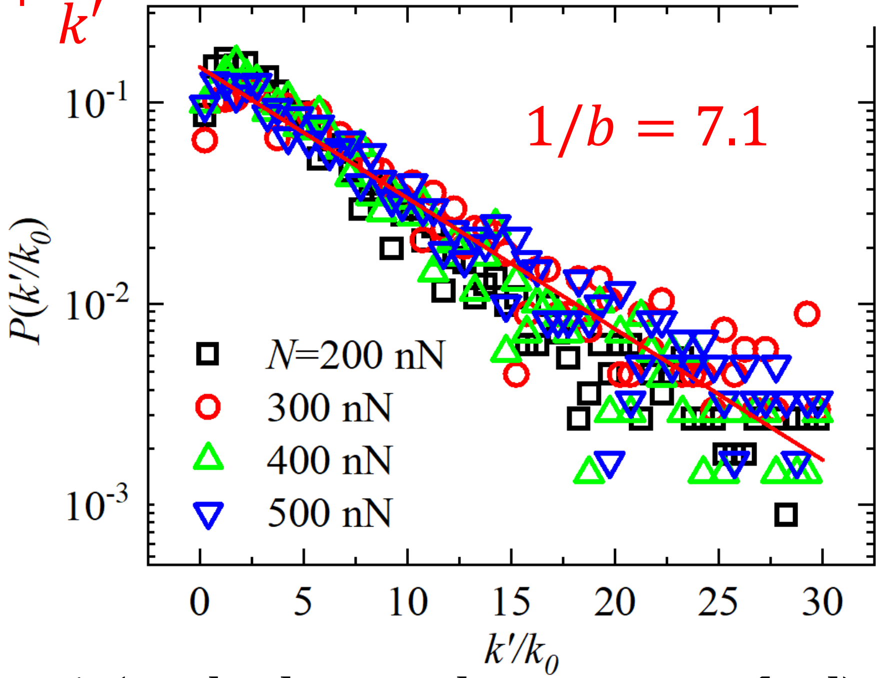
$$\frac{1}{k} = \frac{1}{k_0} + \frac{1}{k'}$$

$$k' = dF_{\text{pin}}/d\bar{z}_{cl}$$

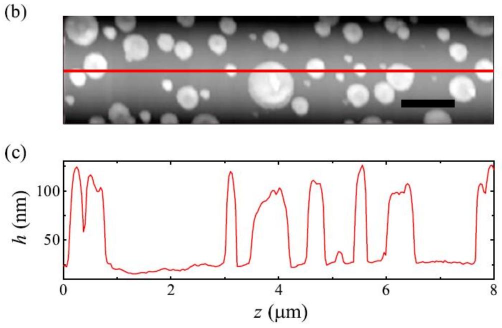
Contact line

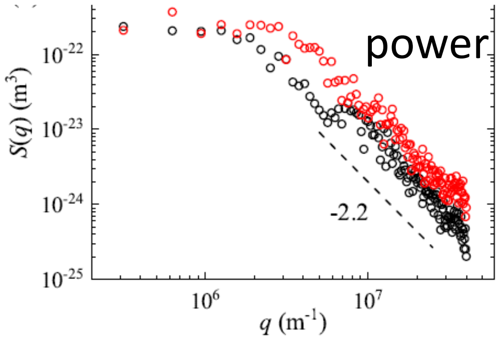


Solid friction



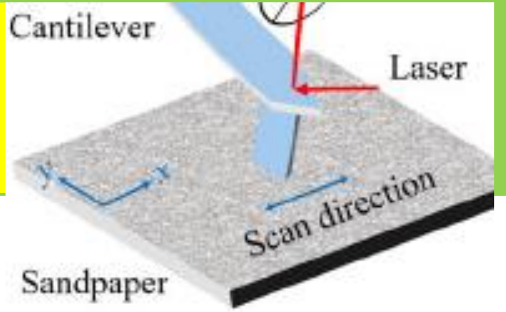
- $P(k') = \frac{1}{b}\exp[-b(k'/k_0)]$, with $\langle k'/k_0 \rangle = \frac{1}{b} \gg 1$ (stick-slip condition is satisfied).
- Exponential distribution of k' is common in dynamically or spatially heterogeneous systems
- Broad surface height roughness distribution:





power spectrum

Damped spring-block model for stick-slip dynamics



Governing equation of the stick-slip motion (center-of-mass of scanning probe x_s):

$$m\frac{d^2x_s}{dt^2} = -\gamma\frac{dx_s}{dt} + k(u_0 t - x_s) - F_{\text{pin}}(x_s)$$

Brownian-correlated pinning force:

$$\langle|F_{\text{pin}}(x_s) - F_{\text{pin}}(x_s')|^2\rangle = 2D|x_s - x_s'|$$

- an extension of the Prandtl and Tomlinson model (widely used in the study of atomic stick-slip friction), in which $F_{\text{pin}}(x_s)$ was assumed to be of a sinusoidal form for atomic friction over a single crystalline surface.
- scanning probe is a running average of the individual pinning forces→ Brownian correlated

$U = \frac{dx_s}{dt}/u_0$ → Langevin-type equation with multiplicative noise:

$$\alpha\frac{d^2U}{dT^2} = -\frac{dU}{dT} + 1 - U + \sqrt{U}\xi(T); \qquad \langle\xi(T)\rangle = 0, \langle\xi(T)\xi(T')\rangle = 2D'\delta(T - T')$$

$$\alpha = mk/\gamma^2 \begin{cases} = 0, & \text{overdamped, ABBM} \\ \geq 1/4, & \text{underdamped} \end{cases}$$

$$D' = D/k\gamma u_0 \begin{cases} \gg 1, & \text{strong pinning} \\ \leq 1, & \text{weak pinning} \end{cases}$$

Numerical solution:

$$U(T = 0) = 0; U(T = T_s) = 0$$

Slip length: $\delta x_s \equiv \int_0^{T_s} U(T)dT$

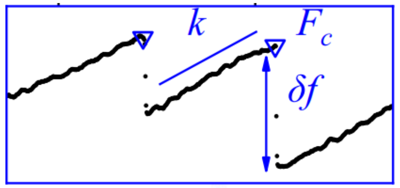
“Statistical laws of stick-slip friction at mesoscale”, Nature Comm. **14**:6221 (2023).

Summary (I)

$\delta f = k_0 \delta x_s$

- Stick-slip friction and contact line pinning-depinning at mesoscale (at the single slip resolution) obey the statistical laws that are often associated with the avalanche dynamics at a critical state.

- seemingly chaotic stick-slip friction at the mesoscale obeys precise statistical laws
- the avalanche dynamics is caused primarily by fluctuations in the random pinning force field
- The avalanche (stick-slip) dynamics of a contact line or solid are governed by three statistical laws:
  1) GEV distribution for the depinning force;
  2) Power-law distribution of the slip length; $P(\delta x_s) \sim (\delta x_s)^{-\varepsilon}$
  3) Exponential distribution of the local pinning force gradient k'



- The proposed models under a Brownian-correlated pinning force field capture the essential physics of the stick-slip friction and contact line dynamics at mesoscale

Collaborators: Penger Tong (HKUST), Hsuan-Yi Chen (NCU, Taiwan),
Dr. Caishan Yan(U. Chicago), Dr. Dongshi Guan(CAS), Dr. Yin Wang(Princeton)

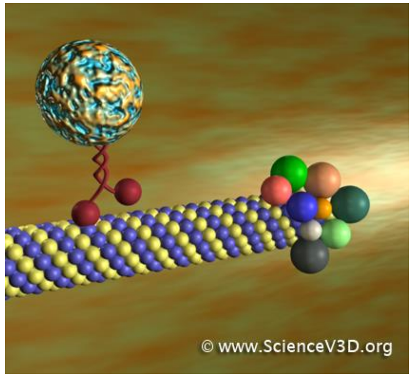
- "Statistical laws of stick-slip friction at mesoscale", Nature Comm. **14**:6221 (2023).
- "Avalanches and extreme value statistics of a mesoscale moving contact line, PRL **132**, 084003 (2024) (Editor's suggestion)

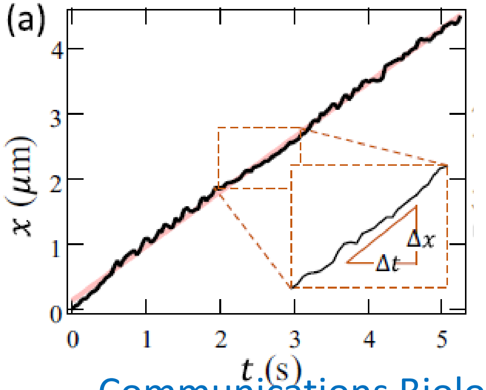
Universal statistics of cargo velocities emerged from Stick-Slip dynamics in cells

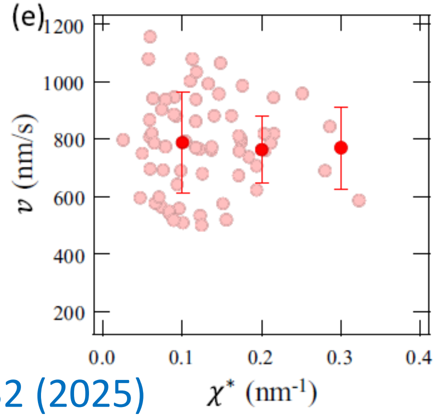
Molecular motor-powered cargo transport in living cells

Motor-driven cargo transport

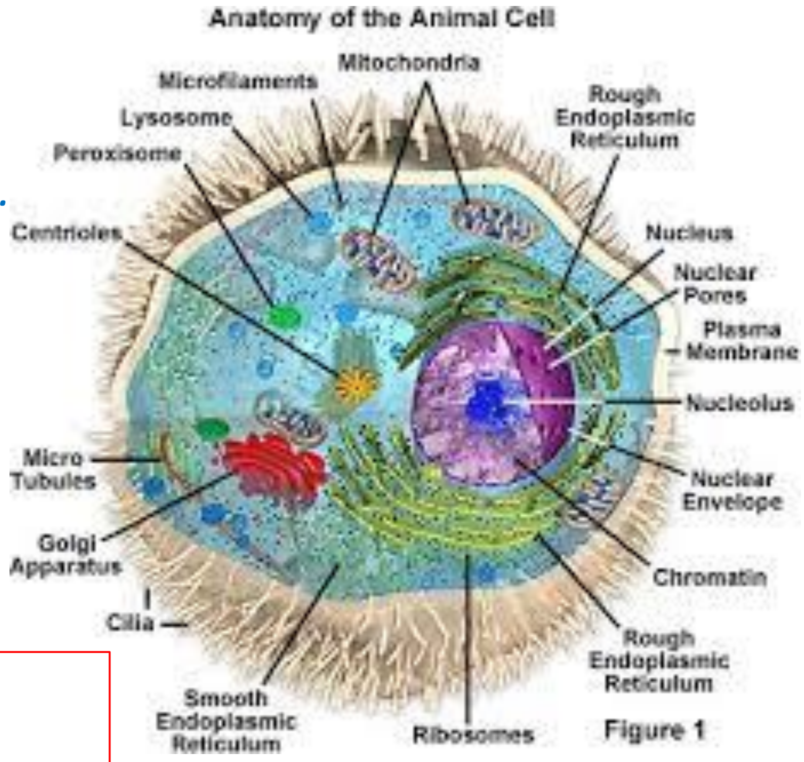
- Motor dynamics *in vitro:*
- Kinesin(s) bind to polystyrene beads and tracked. *Cargo speed is narrowly distributed.*



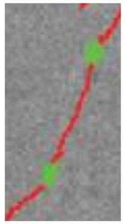




Communications Biology 8, 232 (2025)



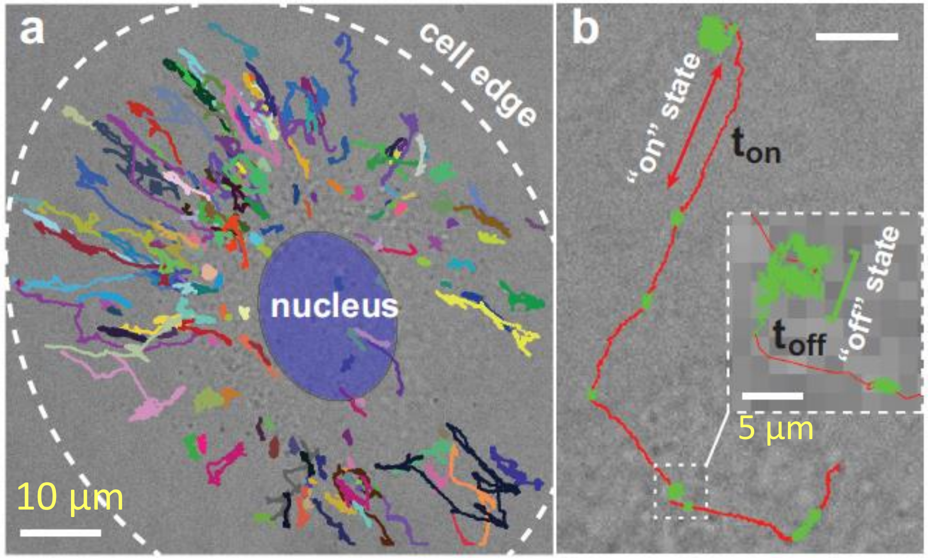
- Much more complicated for live cells *(in vivo):*
- intracellular environment is very crowded
- cellular interior is filled with macromolecules and entangled cytoskeletal networks, occupying 10-40% of the total volume
- motor proteins group together to transport submicron-sized vesicles (cargo) filled with proteins and nutrients to designated destinations reliably
- how vesicles maneuver and function within the congested environment remains a pivotal challenge in cell biology and biological physics
- intracellular cargo transport often exhibits intermittent changes between directed "runs" and diffusive "pauses"(~ up to 80%)
- Cargo dynamics in live cells tracked by quantum dots



W. He *et al*., Nat. Comm. 2016

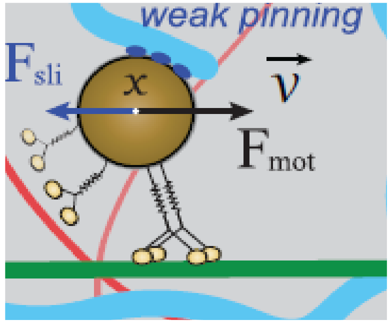
Motor driven cargo transport within living cells – single particle tracking

photostable EGF-conjugated quantum dots. EGFR-EGF-QDs form endocytic vesicle→ trajectories tracked



Cell type	Vesicle type	Cell treatment	No. of cells	No. of mobile trajectories
BEAS-2B	EGFR-endosome	No treatment	83	9946
BEAS-2B	Lysosome	No treatment	42	17465
BEAS-2B	Early endosome	No treatment	39	20780
BEAS-2B	Secretory vesicle	No treatment	35	19106
HeLa	EGFR-endosome	No treatment	51	6007
RPE-1	EGFR-endosome	No treatment	44	7917
BEAS-2B	EGFR-endosome	Hypotonic	63	9217
BEAS-2B	EGFR-endosome	Isotonic	49	8846
BEAS-2B	EGFR-endosome	Hypertonic	48	4752
BEAS-2B	Secretory vesicle	Isotonic	18	7167
BEAS-2B	Secretory vesicle	Hypertonic	16	4523
		Total:	488	115726

As the cargo moves, it continuously breaks the bonds with the surrounding protein networks →pinning-depinning or stick-slip motion along the trajectory (but stick-slip dynamics is NOT resolvable, force on vesicle NOT (directly) measurable !)



two-state behavior as stick-slip dynamics:

- **Off-state**: $F_{mot} < F_{sli}$ → cargo trapped
- **On-state**: $F_{mot} > F_{sli}$ → stick-slip (cargo in motion)

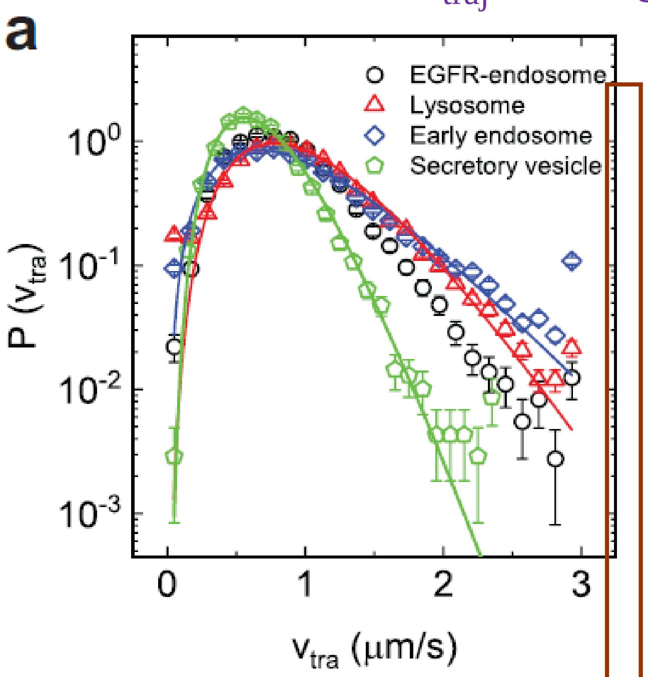
extensive dataset of vesicle trajectories from live cells across diverse vesicle types, cell lines, and cytoplasmic environments

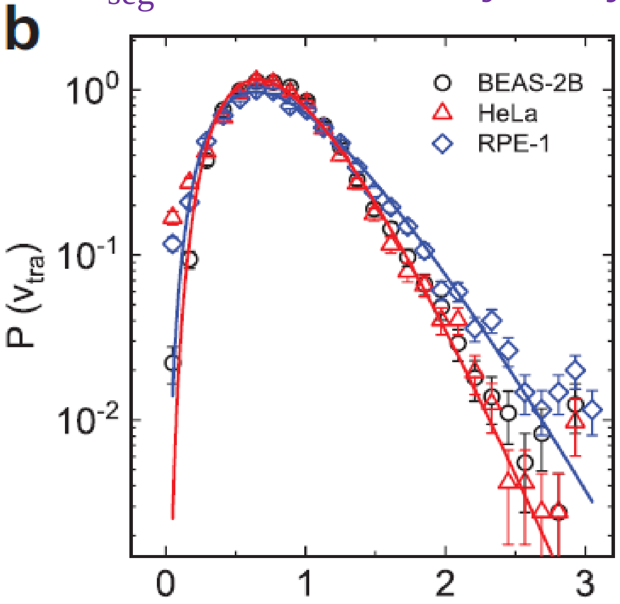
Universal velocity statistics of cargo transport within living cells

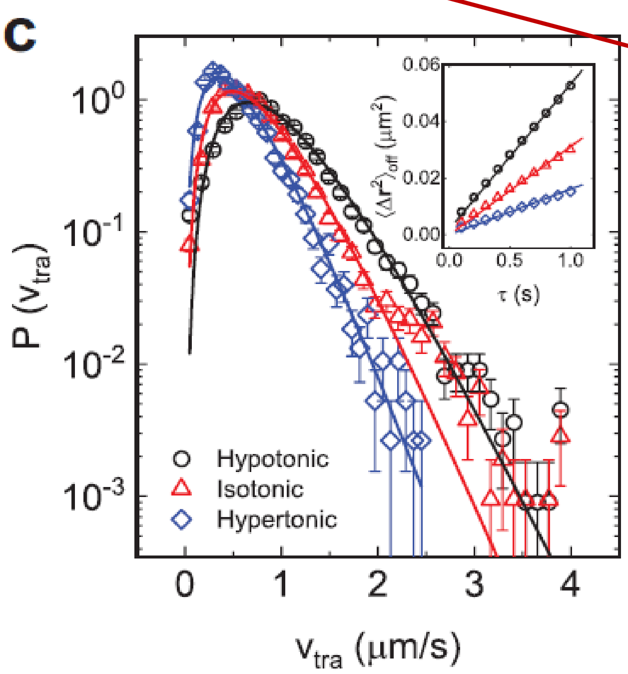
velocity statistics in the "on"-state:

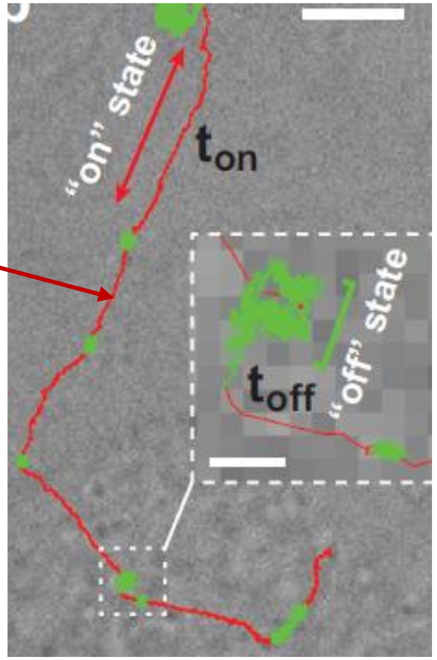
v_{ins}=instantaneous velocity; v_{seg}=average of v_{ins} within a on-state segment

v_{traj}=average of v_{seg} within each trajectory









Gamma distribution:

$$P(v) = P_0 v^{\alpha-1} e^{-v/\theta}$$

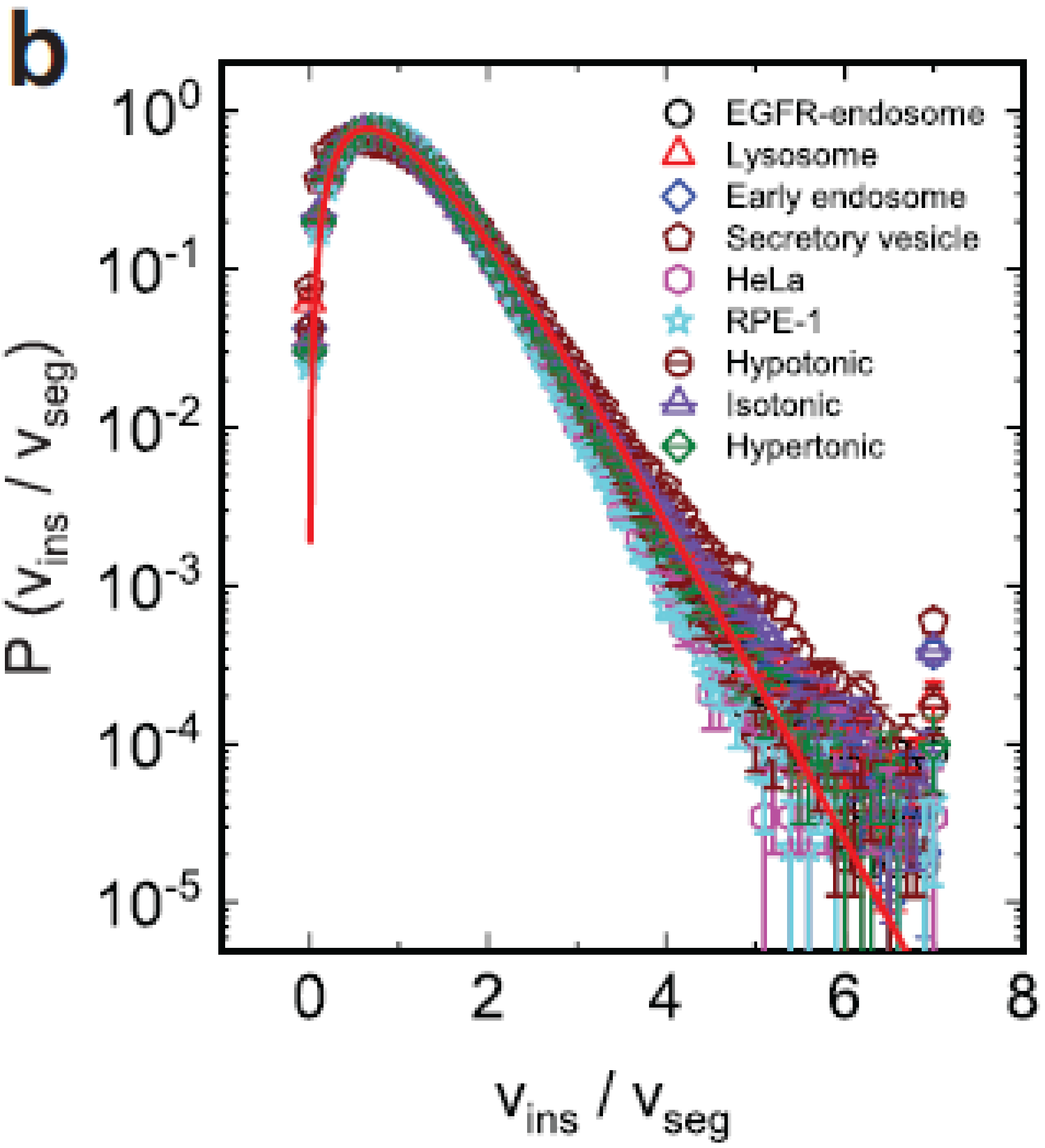
interact differently with cellular networks,
transported by distinct sets of motors

unlike *in vitro* systems where motor/cargo velocities follow (narrow) Gaussian statistics

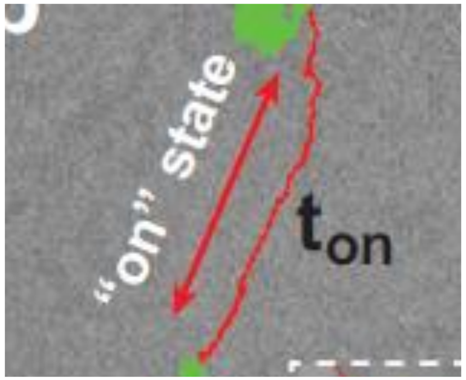
Universal Statistics: motor-powered cargo velocities in living cells consistently follow Gamma distribution

Biological Robustness: Mechanism is conserved across vesicles, cell types, and environmental conditions

Universal Gamma statistics of cargo velocity for various vesicles in different cells under different cellular crowdedness



Gamma distribution: $$P(v) = P_0 v^{\alpha-1} e^{-v/\theta}$$



extensive dataset of vesicle (>10^5) trajectories from over 480 live cells across diverse vesicle types, cell lines, and cytoplasmic environments

→ cargo velocities follow a Γ distribution, despite biological variability

→ robust statistical pattern highlights a universal transport mechanism applicable to various vesicles across different cell types

P(v) follows the Γ distribution over 4 decades

Universal Gamma statistics of cargo velocities in live cells emerged from Stick-Slip dynamics

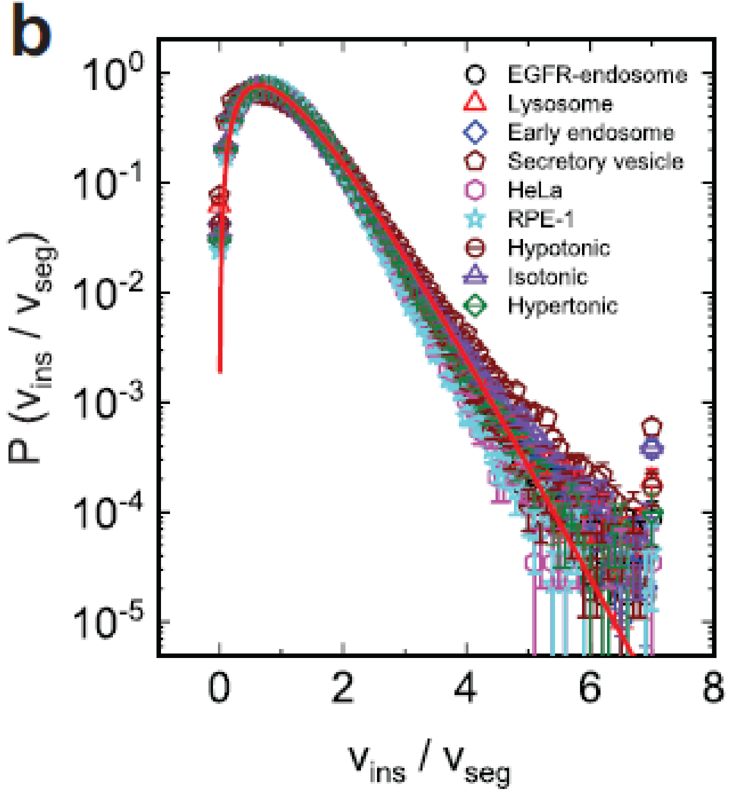
Γ distribution in velocity can be derived from the Alessandro-Beatrice-Bertotti-Montorsi (ABBM) model for overdamped avalanche dynamics

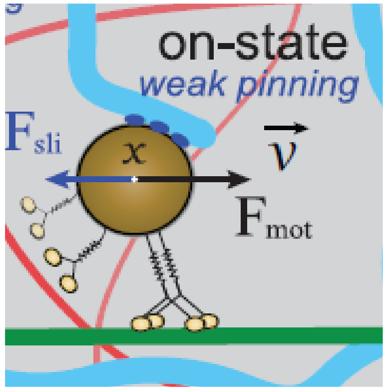
J. Appl. Phys.68, 2908-2915 (1990)

$$P(v) = P_0 v^{\alpha-1} e^{-v/\theta}$$

ABBM model: $\gamma \frac{dx}{dt} = k(v_0 t - x) - F_{\mathrm{sli}}(x)$

$$\langle |F_{\mathrm{sli}}(x) - F_{\mathrm{sli}}(x')|^2 \rangle = 2\mathrm{D_F}|x - x'|$$





v_0 =speed of an effective motor moving along a microtubule
γ = drag coefficient
$F_{\mathrm{sli}}(x)$ = sliding frictional force field, a running sum of individual pinning forces associated with the pinning sites on the vesicle surface

According to the running average (sum) theorem, $F_{\mathrm{sli}}(x)$ is spatially correlated across some range: cumulative sum of individual pinning forces on the cargo
→ spatially correlated random force field

Stochastic $v = \frac{dx}{dt}$ follows Γ distribution in the steady state → $\alpha\theta = v_0$

Universal Gamma statistics of cargo velocities emerged from Stick-Slip dynamics in cells

$$P(v) = P_0 v^{\alpha-1} e^{-v/\theta}$$

Stochastic $v = \frac{dx}{dt}$ follows Gamma distribution in the steady state → $\alpha\theta = v_0$

speed of an effective motor

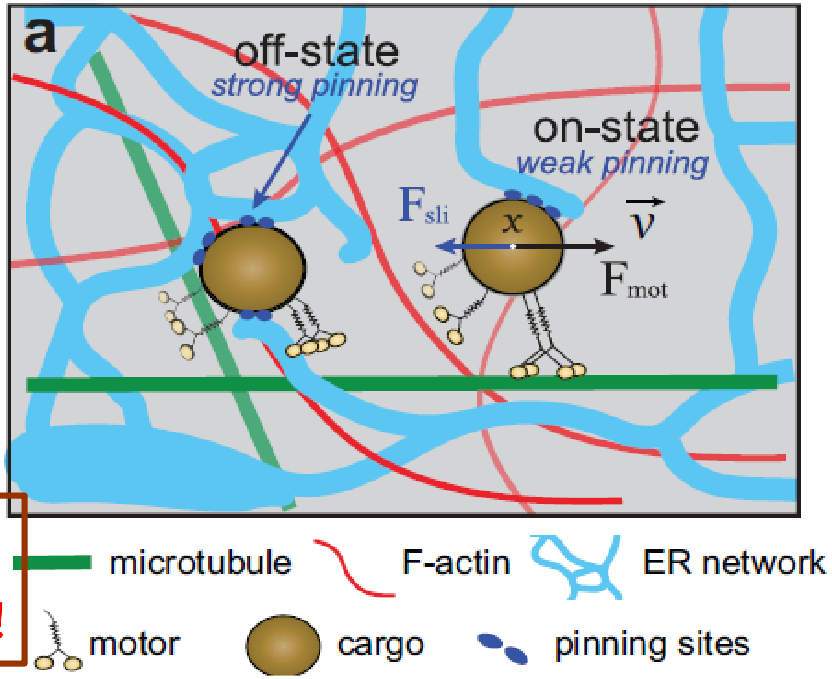
Vesicle type, cell type & treatment		EGFR-endosome BEAS-2B	Lysosome BEAS-2B	Early endosome BEAS-2B	Secretory vesicle BEAS-2B	EGFR-endosome HeLa	EGFR-endosome RPE-1	EGFR-endosome BEAS-2B hypotonic	EGFR-endosome BEAS-2B isotonic	EGFR-endosome BEAS-2B hypertonic	Secretory vesicle BEAS-2B isotonic	Secretory vesicle BEAS-2B hypertonic
V_{tra} (μm/s)	α	4.7 ± 0.05	4.7 ± 0.06	3.1 ± 0.05	5.9 ± 0.06	4.7 ± 0.05	3.6 ± 0.04	3.6 ± 0.06	3.2 ± 0.05	2.8 ± 0.06	5.5 ± 0.06	5.5 ± 0.09
	θ	0.18 ± 0.01	0.21 ± 0.02	0.31 ± 0.02	0.11 ± 0.02	0.18 ± 0.01	0.25 ± 0.01	0.25 ± 0.02	0.22 ± 0.01	0.20 ± 0.02	0.15 ± 0.01	0.12 ± 0.01
	$\alpha\theta$	0.85 ± 0.05	0.99 ± 0.09	0.96 ± 0.06	0.65 ± 0.12	0.85 ± 0.05	0.90 ± 0.04	0.90 ± 0.07	0.70 ± 0.03	0.56 ± 0.06	0.83 ± 0.06	0.66 ± 0.06
	$\sqrt{\alpha}\theta$	0.39 ± 0.02	0.46 ± 0.04	0.55 ± 0.04	0.27 ± 0.05	0.39 ± 0.02	0.47 ± 0.02	0.47 ± 0.04	0.39 ± 0.02	0.33 ± 0.03	0.35 ± 0.02	0.28 ± 0.02

- the same vesicle (EGFR-endosomes) has similar v_0 in different cell types
- secretory vesicles, primarily transported by kinesin,exhibits a smaller v_0 when compared with other vesicles whose transport involves more than one kind of motor
- v_0 is larger (smaller) when the cell is under hypotonic/swollen (hypertonic/shrunken) conditions

Stick-slip motion of a motor-powered vesicle in a crowded living cell

- viscous drag from the surrounding mobile protein solution
- elastic pinning from interactions with adjacent cytoskeletal & membrane networks:-

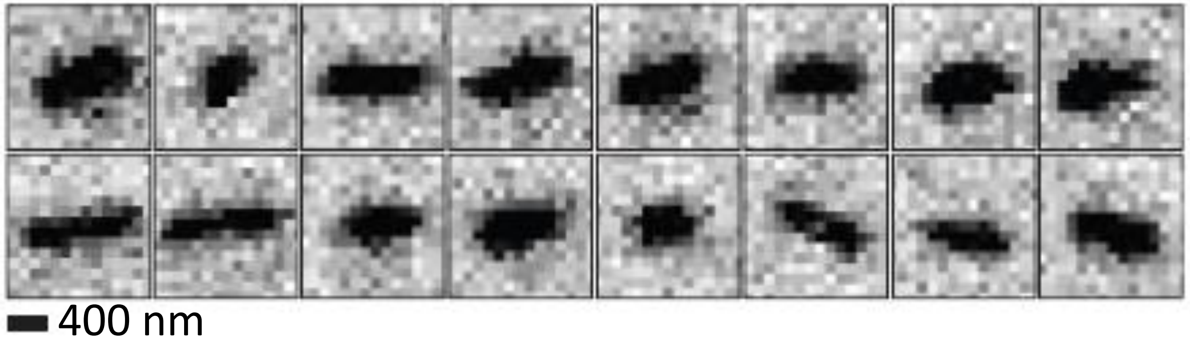
(i) physical tethering of vesicles to the endoplasmic reticulum via membrane contact sites
(ii) steric obstructions from actin patches, microtubule intersections, and other cytoskeletal elements
(iii) opposing forces from bidirectional motor activity (tug-of-war) or motors bound to oppositely oriented microtubules.



Stick-slip motion ←→ pinning-depinning
$(F_{sli})_{max}$ should obey GEV, but force not directly measurable !

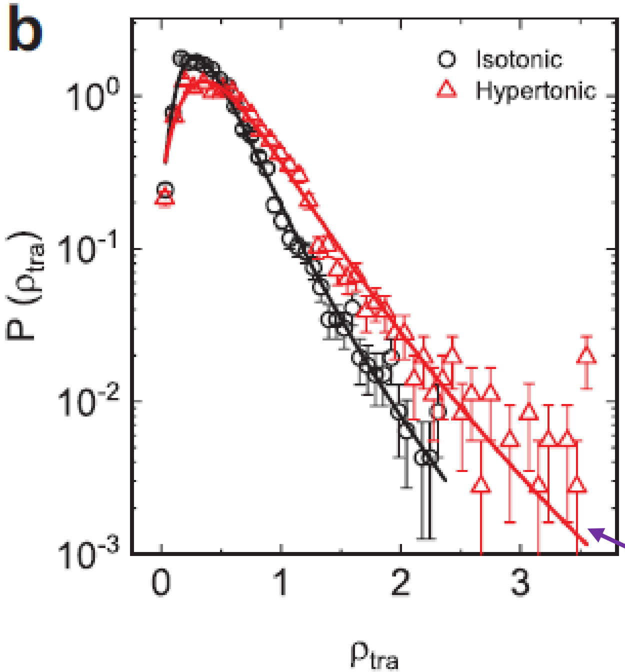
- During directed (on-state) motion, the vesicle continuously forms new adhesions with adjacent cytoskeletal elements & membrane networks while simultaneously breaking existing interaction bonds to maintain forward motion.
- Repeated cycle of pinning–depinning (stick-slip) produces the jerky, intermittent motion of vesicles along microtubules. Deformable vesicles are soft →repeated pinning–depinning induces transient shape deformations

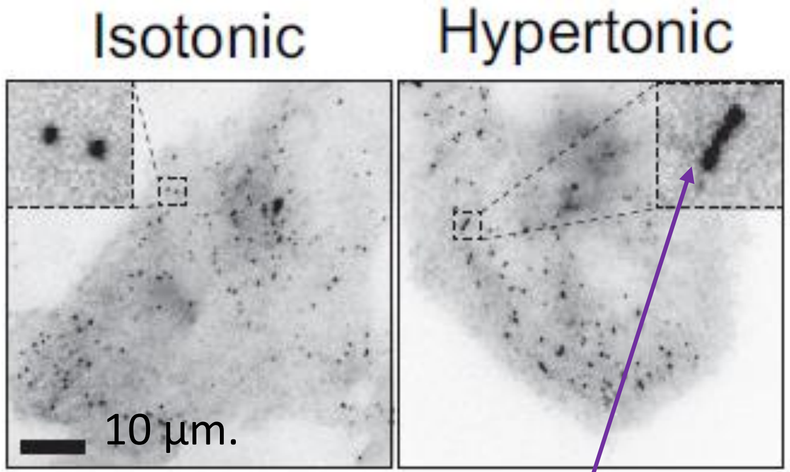
cargo transport within living cells - Stick-slip motion



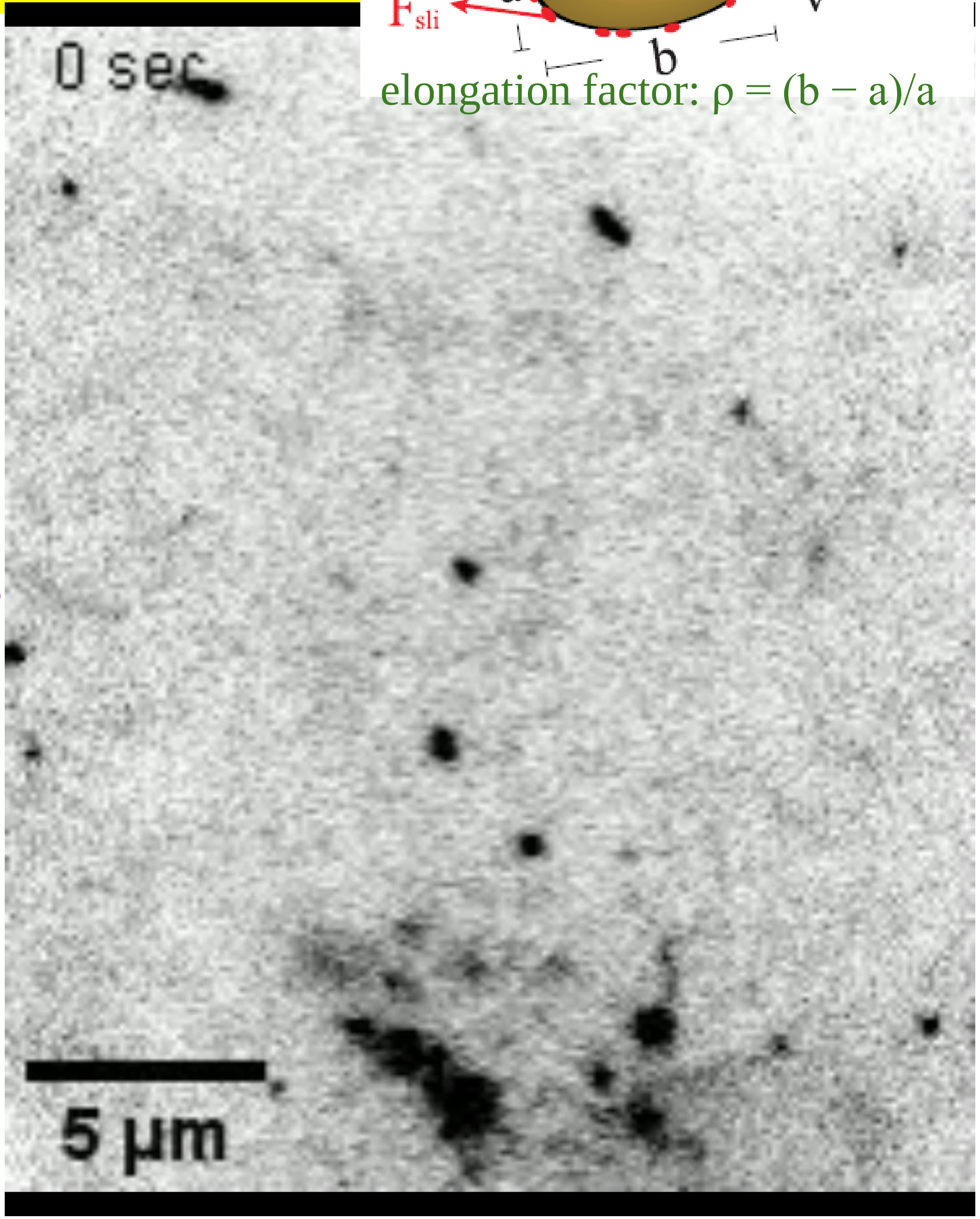
- quantify shape changes in vesicles by TIRF microscopy
- deformations arise from mechanical stretching between the motor-generated pulling force at the vesicle's leading edge and the opposing elastic pinning forces exerted by contacted cytoskeletal structures

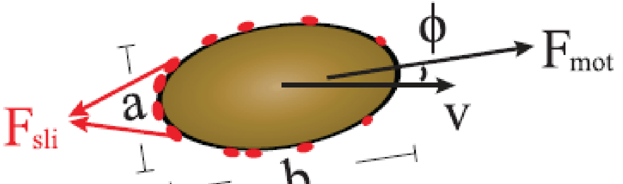
Shape elongations of secretory vesicles with increasing cytoplasmic crowding





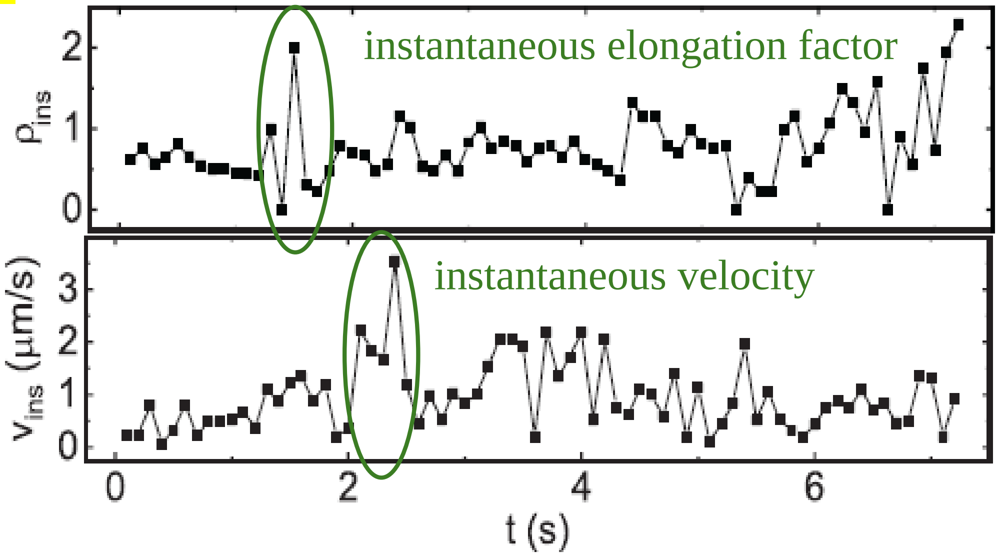
Vesicle is more stretched in crowded cytoplasm (stronger pinning)



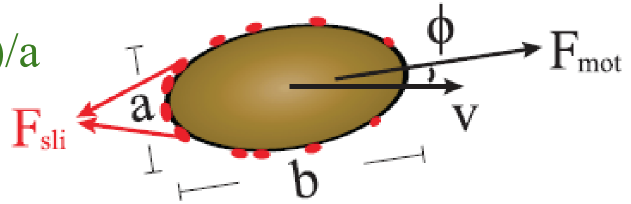


elongation factor: $\rho = (b - a)/a$

Stick-slip motion in vesicle transport



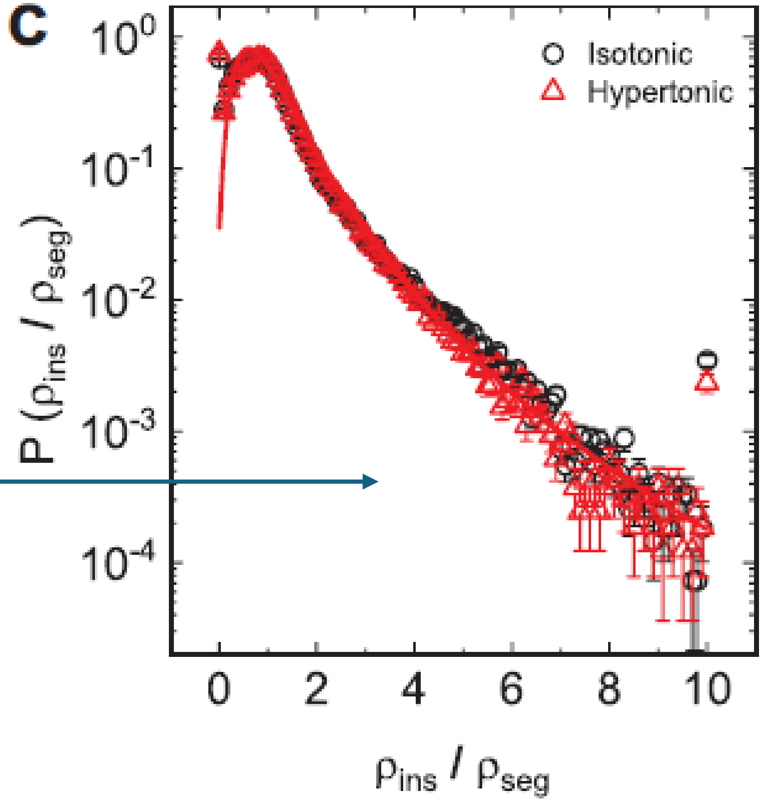
- elongation factor: $\rho = (b - a)/a$



- on average $\rho \sim 0.5$ ($b \sim 1.5a$) during transport
- stick-slip dynamics: relatively smooth & low-speed motion sustains steady elongation during sliding phases
- rapid release from strong pinning triggers bursts in velocity

- change in its elastic energy due to elongation approximated as $\Delta G \simeq (1/2)k_0(b - a)^2$, where k_0 is the effective spring constant -- can serve as local force sensors quantifying depinning (or pinning) forces via $F_{sli}(x) \simeq k_0 (b-a) = k_0\, a\, \rho_{ins}$.
- As vesicles traverse the cell, they probe the spatially varying pinning force field $F_{sli}(x)$
- $\rho_{ins} \propto$ the maximum force required for local depinning (slip)
- $\Rightarrow$ $P(\rho_{ins})$ follows GEV distribution

$$P(x) = \frac{1}{\sigma}\left(1 + \xi\frac{x-\mu}{\sigma}\right)^{-(1+1/\xi)} e^{-(1+\xi\frac{x-\mu}{\sigma})^{-1/\xi}}$$



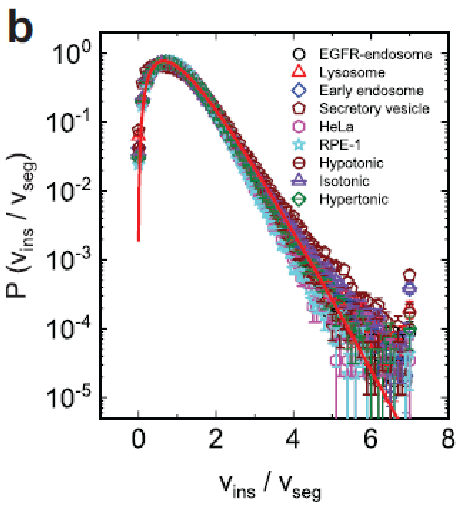
Summary (II)

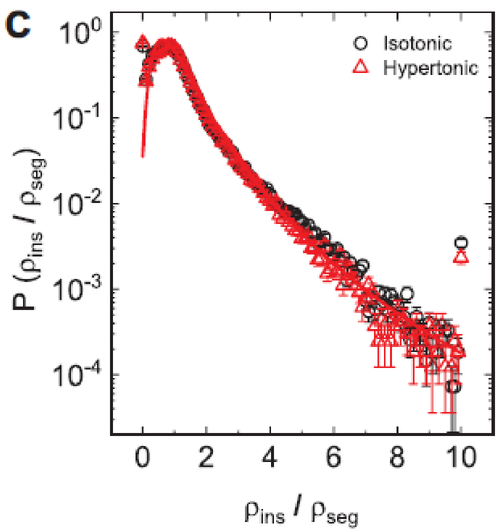
Stick-slip motion in vesicle transport within living cells

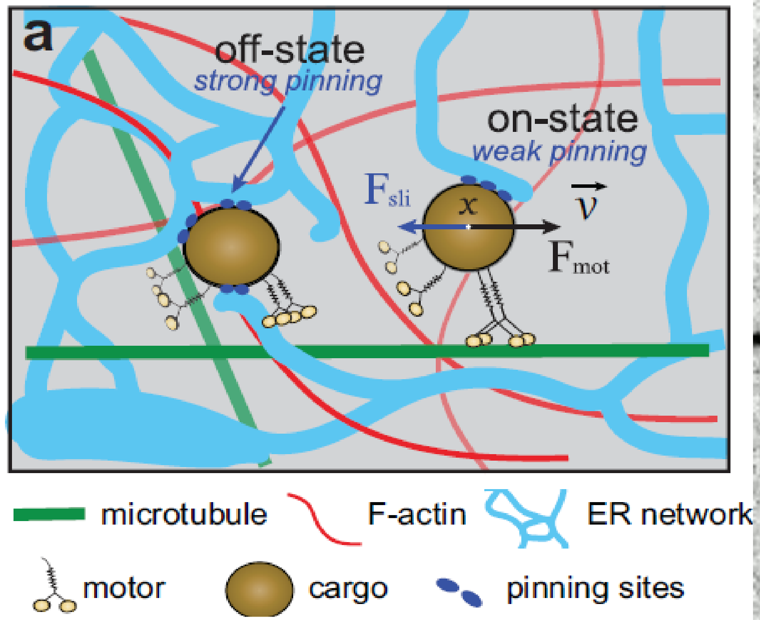
- stick-slip model of motor-driven cargo transport, in which active pulling overcomes viscous drag and elastic pinning forces in the crowded cytoplasm, provides a unified mechanistic framework with broad biological implications in various cellular processes.

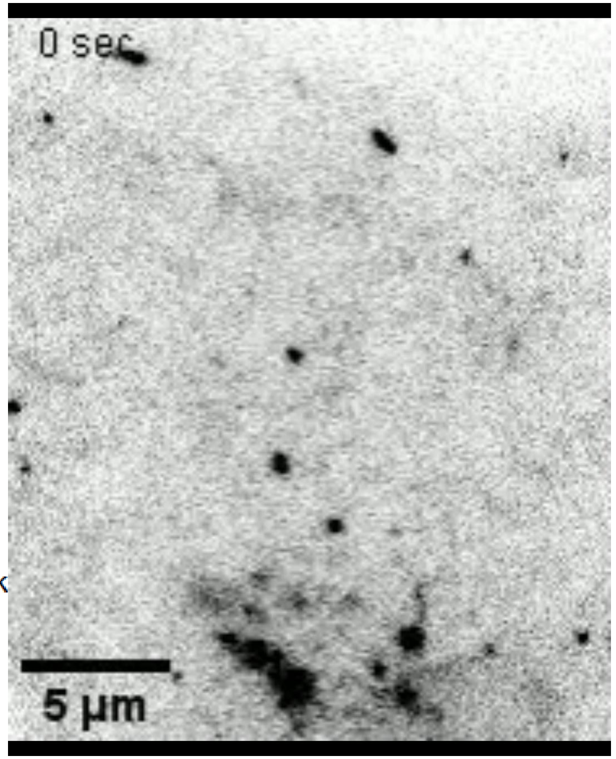
Universal Γ distribution for vesicle velocity

GEV distribution for vesicle deformation









Collaborators: Penger Tong (HKUST), Pingbo Huang(HKUST), K. M. Ori-McKenney(UC Davis), Dr. Yu-Sheng Shen(HKUST), Dr. Caishan Yan(U. Chicago) “Universal Gamma Statistics of Cargo Velocities Emerging from Stick-Slip Friction in Cells", under review.