Supplementary material for Physical Review E

Viscoelastic response of contractile filament bundles

Achim Besser, Julien Colombelli, Ernst H. K. Stelzer, and Ulrich S. Schwarz

I. DETAILS ON EXPERIMENTS AND DATA FITTING

Experiments: The experimental protocols have been described earlier in [1]. We used Ptk-2 cells transfected to express G-actin-GFP. Through a 63x/1.2W lens, a stripe photobleaching was performed by scanning a diffraction limited 488 nm laser beam along a user defined grid with periodicity of 3 μm, 10 laser lines were used to bleach each stripe. A single scan could take approximately 1 s, and was repeated 2 to 3 times for efficient bleaching. The grid was always aligned perpendicularly to the stress fiber axis and stress fibers were selected in cells showing very aligned stress fiber networks. Laser nanosurgery was performed less than 10 s after photobleaching, positioned in the middle of a bleached stripe to conserve the edge of the first stripe on each side. Images of the retracting fibers were taken with a frequency of about 1 Hz.

Image processing: Kymographs were constructed with ImageJ by calculating the intensity along a spline line designed along the fiber axis, with a line thickness fitting roughly the stress fiber thickness. Multiple edge detection was reported before [1]. In brief, the positioning of bleached actin-GFP subunits in stress fibers was performed on kymographs by detecting multiple positive maxima positions of the derivative of the intensity profile along the axis of stress fibers. When needed, kymographs were background subtracted, and smoothed in the spatial dimension before taking the derivative. The accuracy of edge detection was estimated to be roughly $200 - 500$ nm, smoothing included. The variance in the accuracy results from cell to cell differences in the expression level of the fluorescently labeled actin altering the signal to noise of the photobleached pattern.

Data fitting: The model solution for the displacement field $u(x,t)$, Eq. (6), was fitted to the position information of in total four bands, the first two bands $n = 1, 2$ and two more bands farther away from the cut as specified for each fiber in Fig. S2 to Fig. S6. For data regression, we used the function *lsqnonlin* of the MATLAB optimization toolbox (version 3.0), which is a specialized algorithm to solve nonlinear least-squares data-fitting problems. To check for local minima, we started the global optimization algorithm 50 times with random initial sets of positive parameter values $(\kappa, f_s, \tau, \Gamma)$. For all analyzed datasets, the algorithm converged always to the same fiber specific least-squares minimum defining one set of parameter values $(\kappa, f_s, \tau, \Gamma)$. Parameter values are specified for each fiber in the captions of Fig. S2 to Fig. S6. The mean and standard deviations for the obtained parameter values are summarized in Tab. SI. The presented data ($N = 6$) are a subset of the 86 stress fibers analyzed in [1]. In [1] we focused on the movement of the first three bands and thus missed the subtle features of bands farther away from the cut. The parameters used here relate to those in [1] as follows: $(\kappa, f_s, \tau, \Gamma) = (k_{ext}/k_{int}, \delta/a, \tau, \tau_\epsilon/\tau)$ with $a = 1$ μm. Comparison of the parameter distributions yields that the data presented here is, within error bounds, a representative subset of the whole sample used in [1].

parameter	mean $\pm$ std
κ	0.061 ± 0.049
f_s	0.56 ± 0.21
τ	$(37 \pm 14)s$
Γ	$(0.52 \pm 0.23) \cdot 10^{-3}$
Γ/κ	0.013 ± 0.021

TABLE SI: Parameter statistics: given are mean and standard deviation for the four model paramters obtained from fits to the $N = 6$ datasets provided in Fig. S2 to Fig. S6. In addition we evaluated the ratio $\Gamma/\kappa \ll 1$ used in the main text.

II. ADDITIONAL DATA SETS

In Fig. S1 to S6 we provide additional experimental evidence for the predicted oscillatory behavior of the cut stress fibers. In these figures, we plot the time courses of the first two bands $n = 1, 2$ and two more bands farther away from the cut. At least the most inner band ($n > 2$) shown in each figure indicates the first oscillation, depicted by a minimum of the displacement curve before it approaches its stationary state. This first minimum is at the onset of the predicted damped oscillations of inner fiber bands around their approached steady state. The initial band positions x_n before cutting are given in the figure captions. The position x_1 of the band $n = 1$ is located at the fiber tip and thus denotes the initial fiber length L. The model curves, obtained by fitting the shown data, are plotted as solid lines with the corresponding color. Parameter fit values are given in the figure captions. The amplitude of the first oscillation can reach several hundreds of nanometers which is about the accuracy of the band position measurement of $200 - 500$ nm. The second oscillation has a predicted amplitude of a few tens of nanometers which is below our resolution limit. Thus, higher oscillations cannot be resolved with our experimental technique.

[1] J. Colombelli *et al.*, J. Cell Sci. **122**, 1665 (2009).

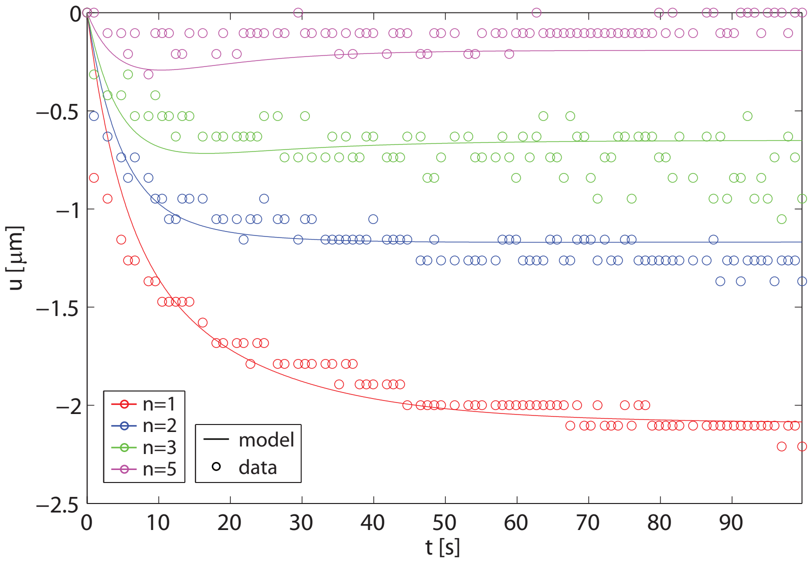

FIG. S1: The initial band positions before cutting are: $x_{n=1,2,3,5} = (20.6, 17.3, 13.9, 7.3)\mu\text{m}$; fit parameter values are: $(\kappa, f_s, \tau, \Gamma) = (0.03, 0.36, 22\text{ s}, 0.0013)$ with $a = 1\ \mu\text{m}$.

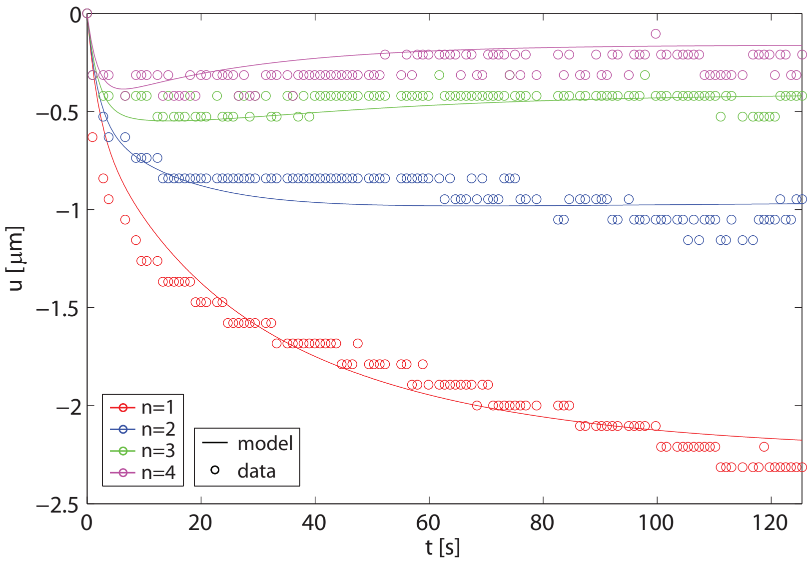

FIG. S2: The initial band positions before cutting are: $x_{n=1,2,3,4} = (31.2, 28.0, 24.7, 21.1)\mu\text{m}$; fit parameter values are: $(\kappa, f_s, \tau, \Gamma) = (0.068, 0.58, 53\text{ s}, 0.0)$ with $a = 1\ \mu\text{m}$.

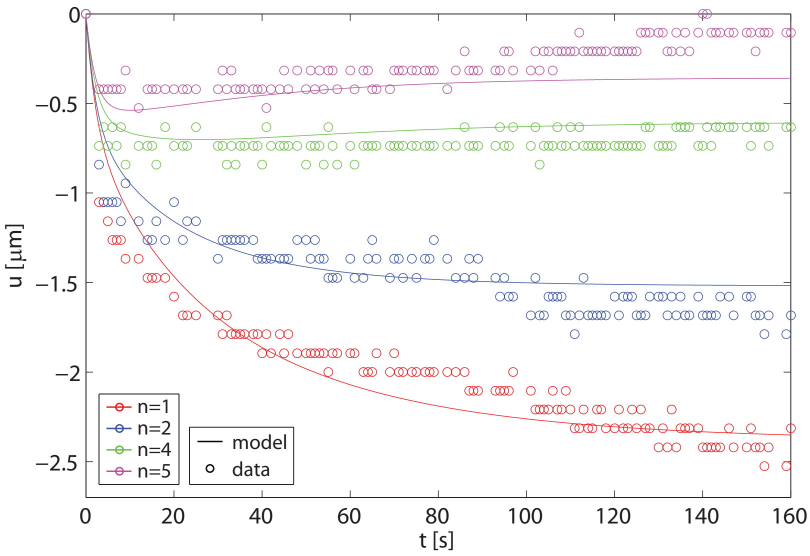

FIG. S3: The initial band positions before cutting are: $x_{n=1,2,4,5} = (42.4, 39.9, 34.7, 31.8)\mu$m; fit parameter values are: $(\kappa, f_s, \tau, \Gamma) = (0.032, 0.43, 53\text{ s}, 0.0)$ with $a = 1$ μm.

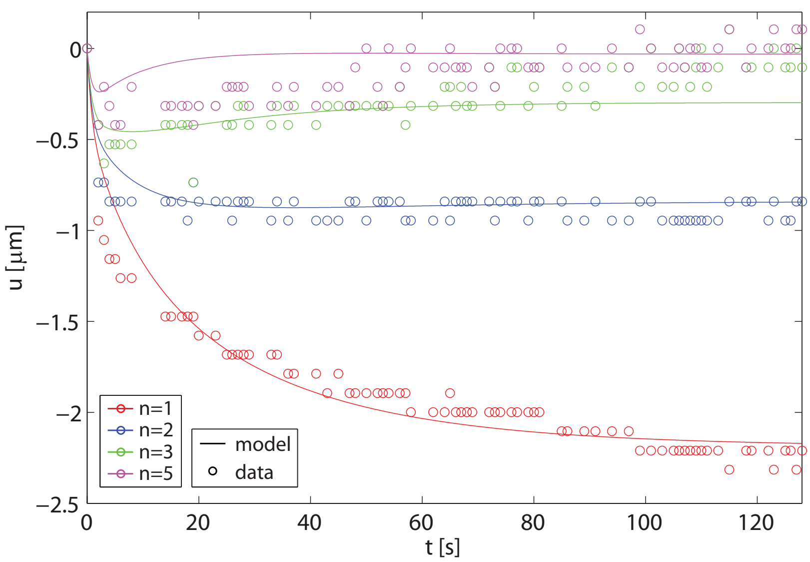

FIG. S4: The initial band positions before cutting are: $x_{n=1,2,3,5} = (26.5, 24.1, 21.5, 15.8)\mu$m; fit parameter values are: $(\kappa, f_s, \tau, \Gamma) = (0.16, 0.87, 37\text{ s}, 0.0)$ with $a = 1$ μm.

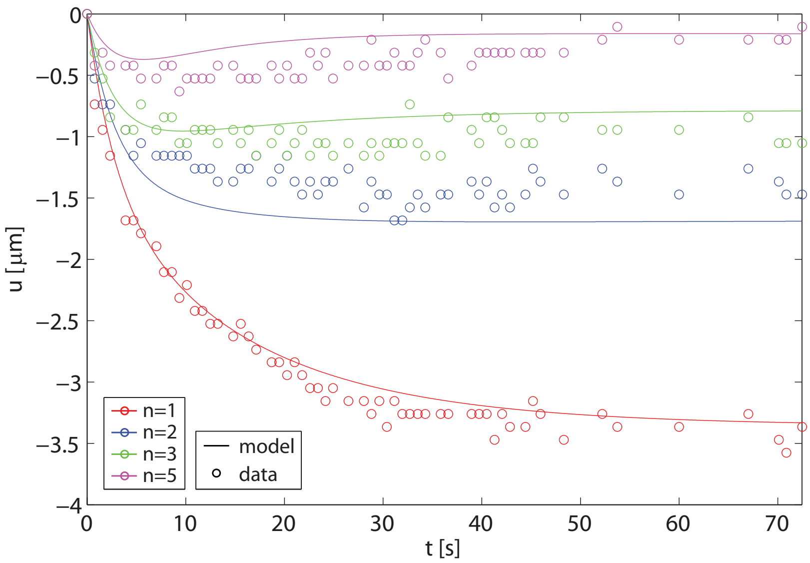

FIG. S5: The initial band positions before cutting are: $x_{n=1,2,3,5} = (20.9, 17.9, 14.5, 7.7)\mu$m; fit parameter values are: $(\kappa, f_s, \tau, \Gamma) = (0.051, 0.76, 21\text{ s}, 0.0018)$ with $a = 1\ \mu$m.

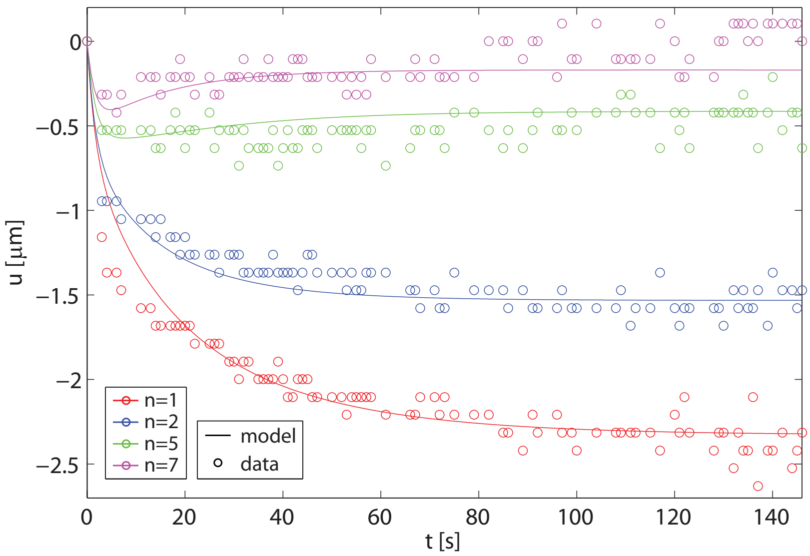

FIG. S6: Same dataset as shown in Fig. 3. The initial band positions before cutting are: $x_{n=1,2,5,7} = (42.2, 39.7, 31.8, 26.4)\mu$m; fit parameter values are: $(\kappa, f_s, \tau, \Gamma) = (0.028, 0.39, 34\text{ s}, 0.0)$ with $a = 1\ \mu$m.