Rheology of Soft Solids: LAOS

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Asian Particulate Technology 2009, Delhi

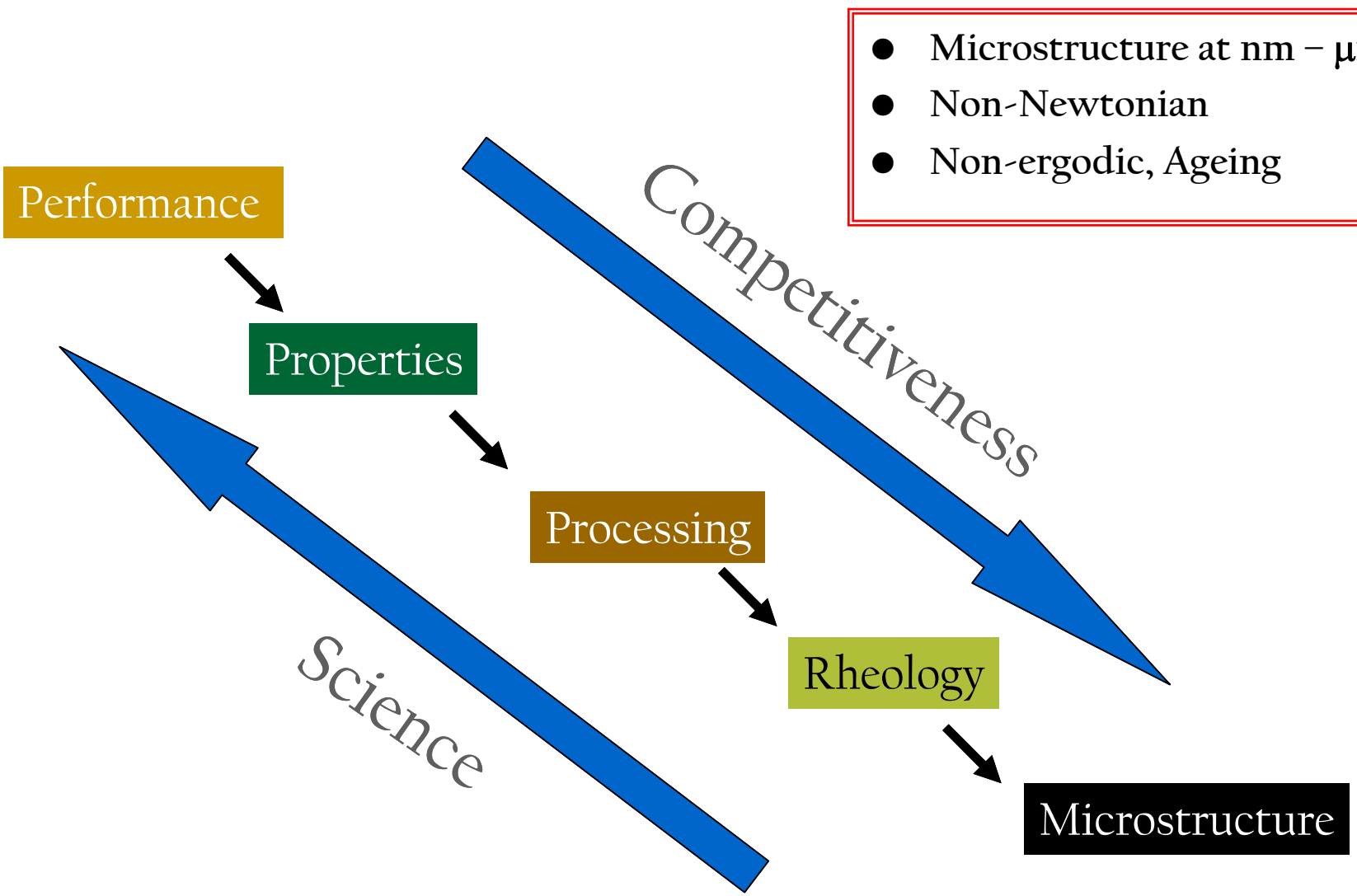
Soft Solids


Dove
Revitalising Shampoo
Vitaliserende Shampoo
Normal Hair
Normaal haar

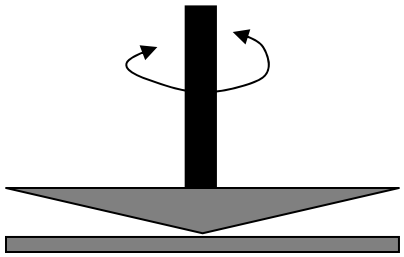

bidran

Soft Solids

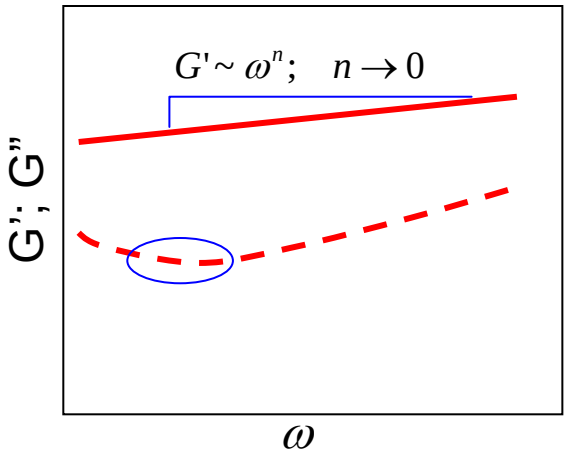
- Microstructure at nm – μm scale
- Non-Newtonian
- Non-ergodic, Ageing

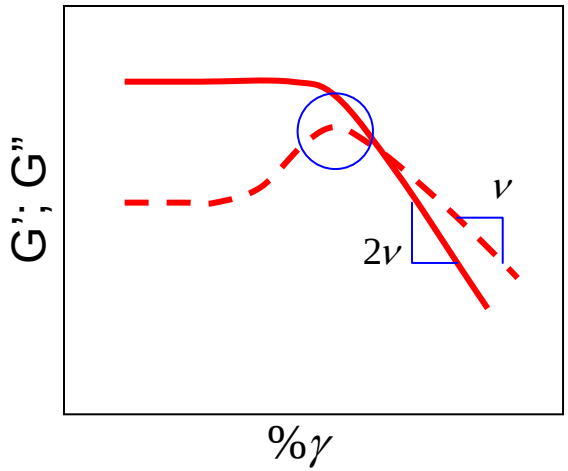


Rheology of SS



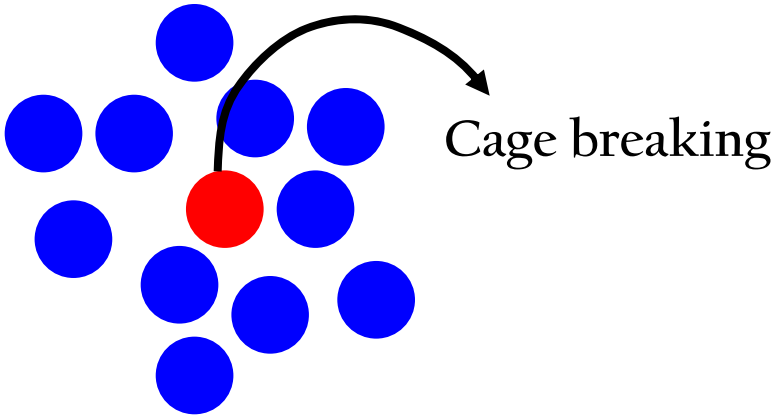
$$\gamma = \gamma_0 \sin(\omega t)$$





- Παντα...→ "*Everything flows*"
- Rivlin → "*Mountains flow before the Lord*"

Relaxation

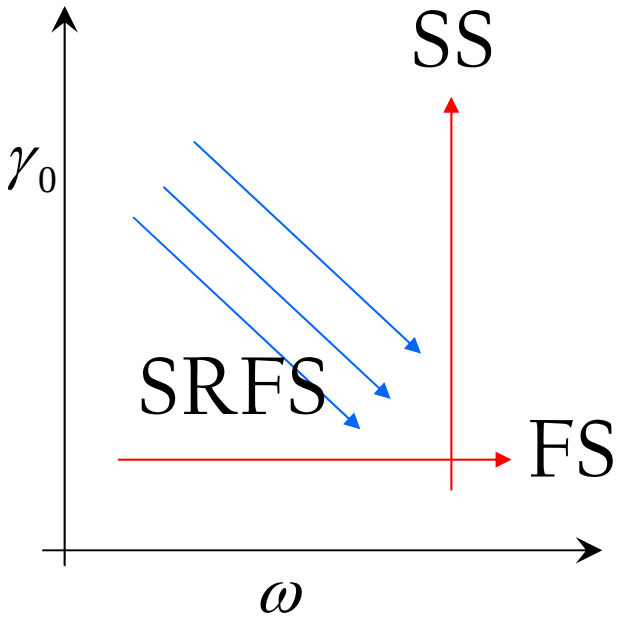


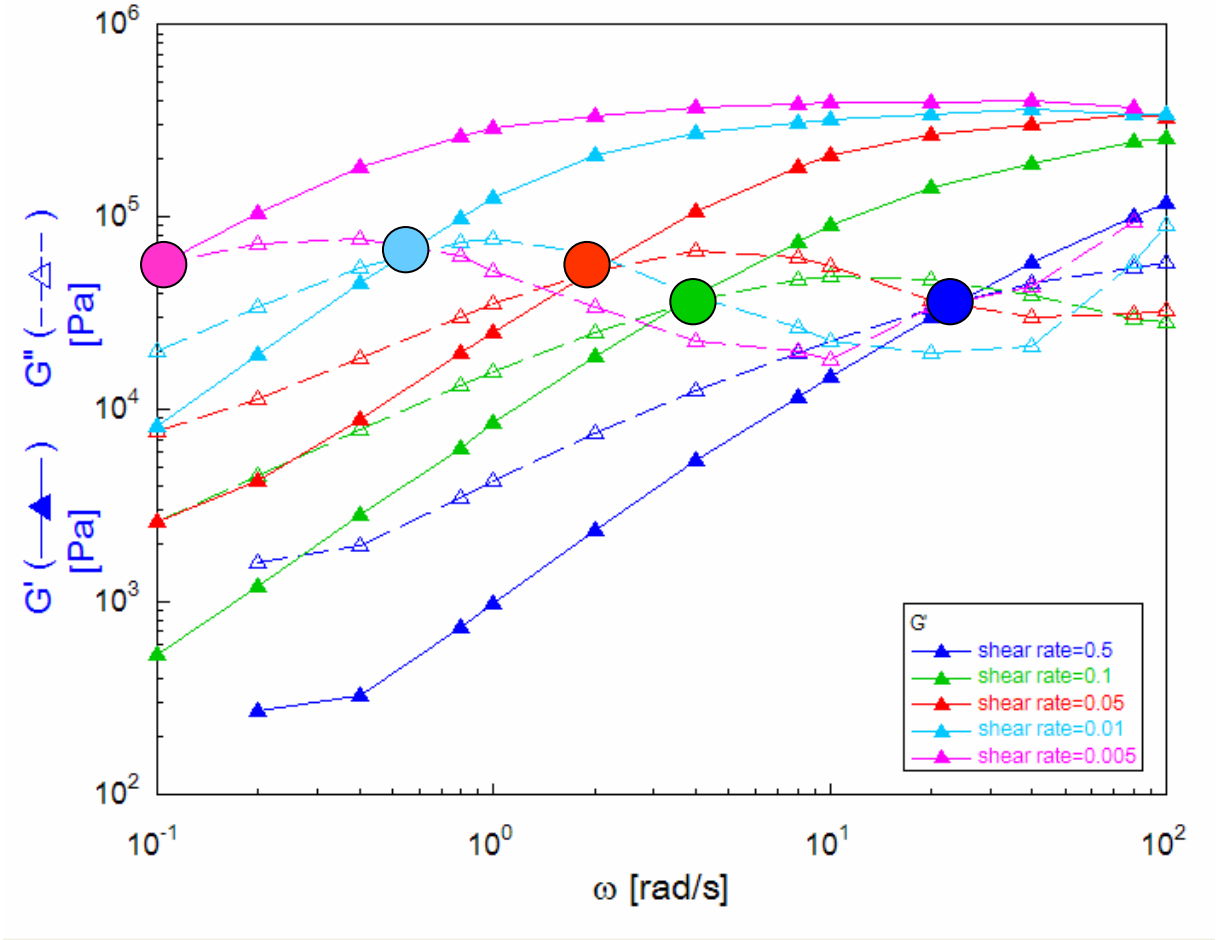
$$\frac{1}{\tau(\dot{\gamma})} = \frac{1}{\tau_o} + k\dot{\gamma}^n$$

or

$$b = \frac{\tau_o}{\tau(\dot{\gamma})} = 1 + k'\dot{\gamma}^n$$

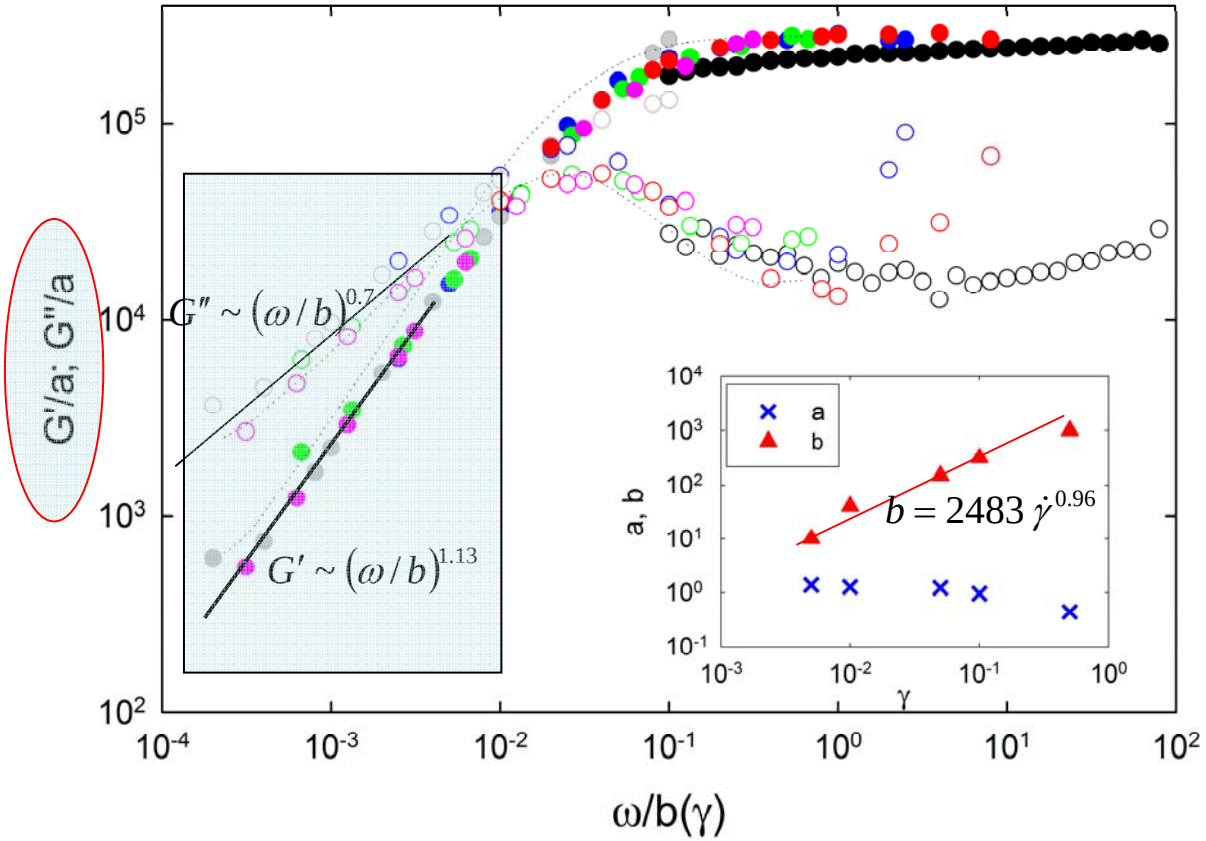
SRFS

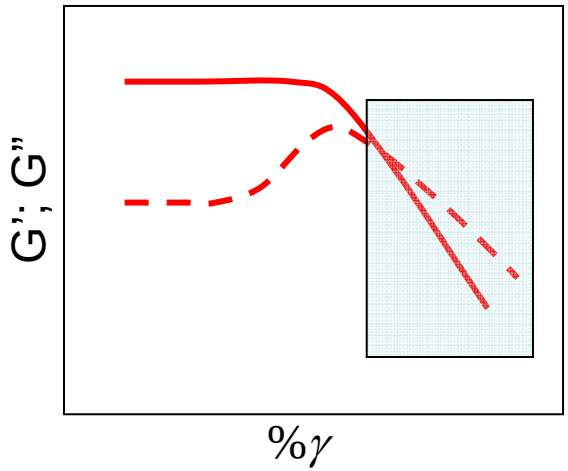




Wyss et al. (2006), Desai et al. (2008)

SRFS





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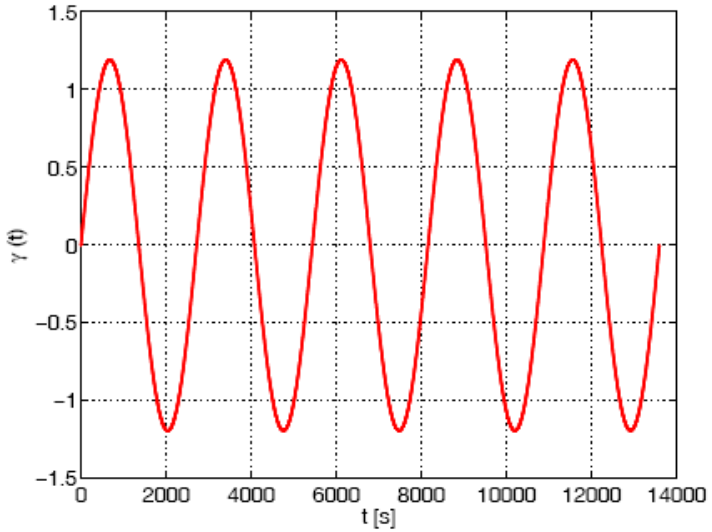
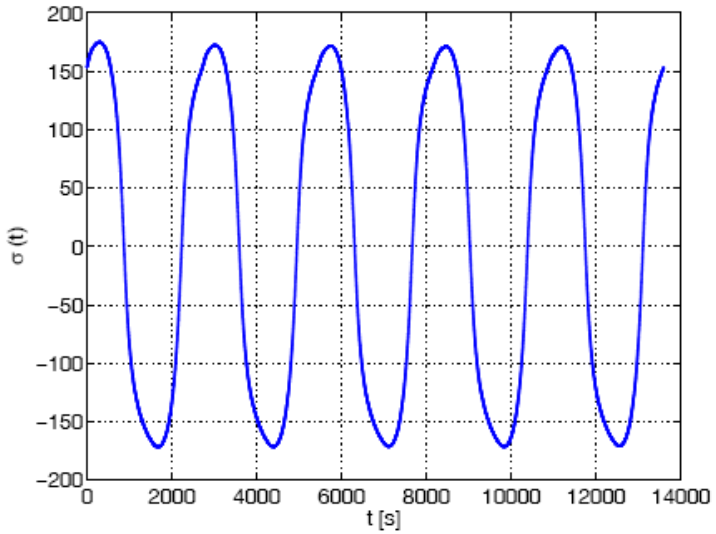
LAOS



$$\gamma(t) = \gamma_0 \sin(\omega t)$$

$$\omega = 2.3\,\text{rad/s};\ \gamma = 1.2$$



$$\sigma(t) = \sum_{n,odd} \left[G_n' \gamma_0^n \sin(n\omega t) + G_n'' \gamma_0^n \cos(n\omega t) \right]$$

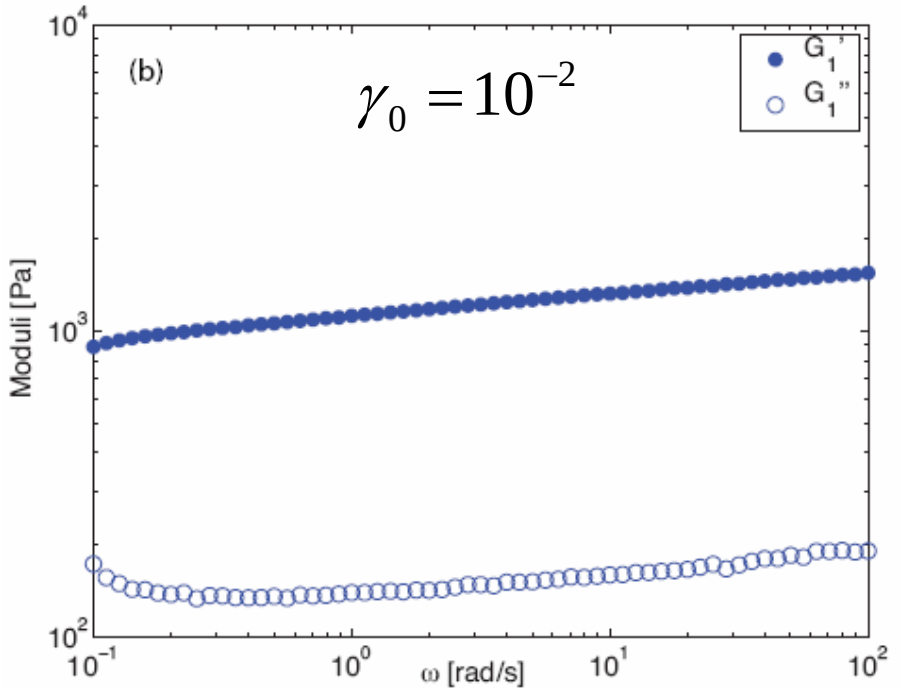
What happens to G_n' & G_n'' ?

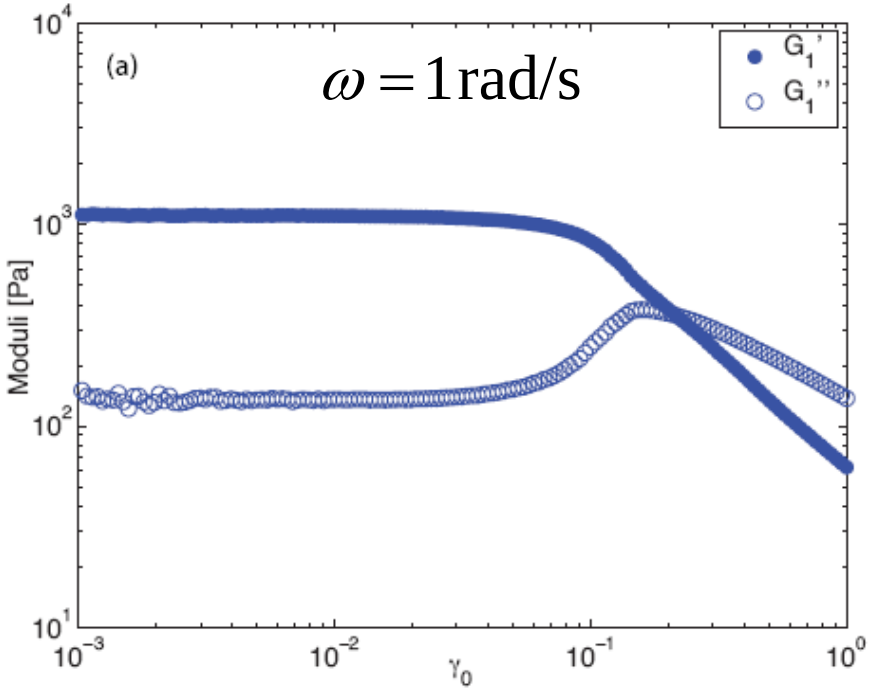
Materials and Methods

- PNIPAm nano-gel suspension
- Xanthan gum
- Brylcreem

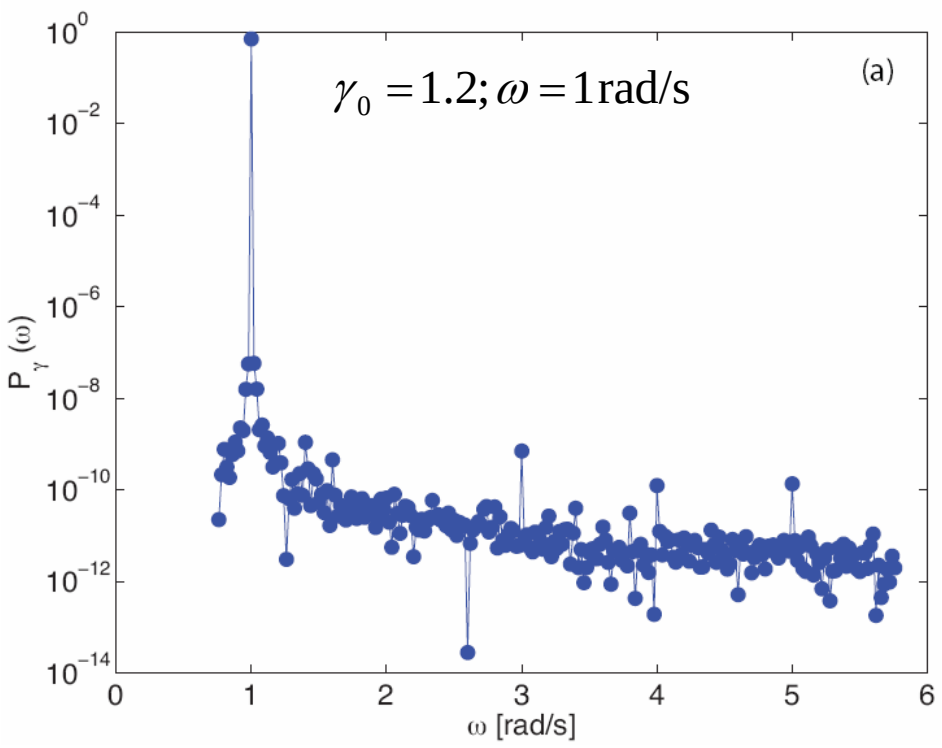
- ARES rheometer, raw data @ 10^3 pt/s, 50 cycles
- Conversion to stress & strain; noise filtration
- FFT, no inertia/compliance corrections

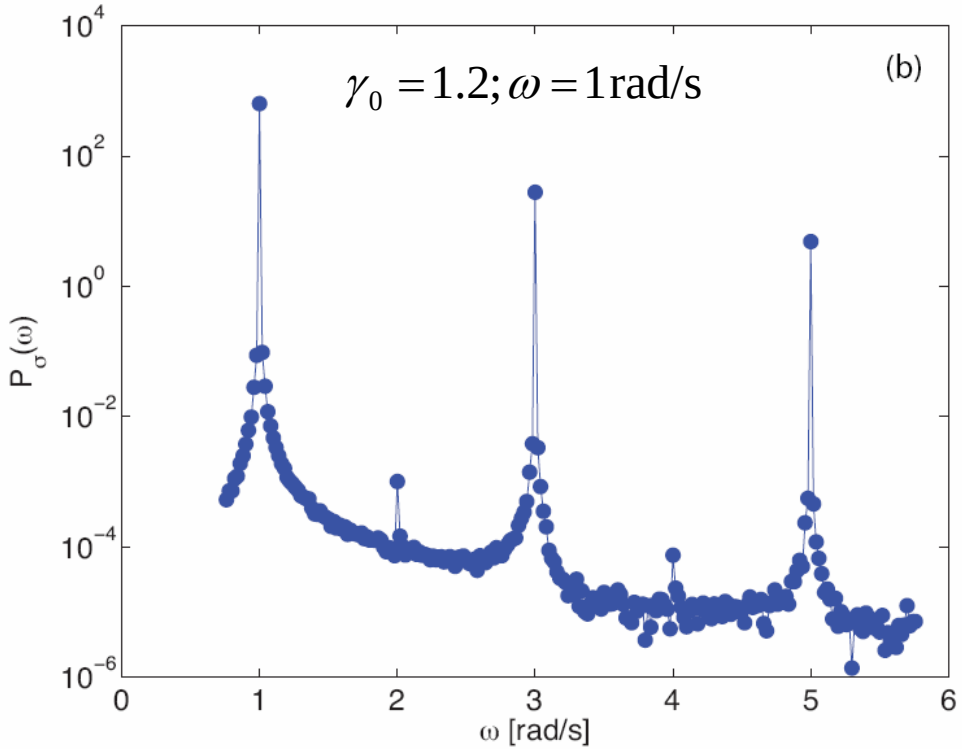
DFS and DSS


(b)
$\gamma_0 = 10^{-2}$
G1'
G1''
Moduli [Pa]
ω [rad/s]


(a)
$\omega = 1\text{rad/s}$
G1'
G1''
Moduli [Pa]
γ0

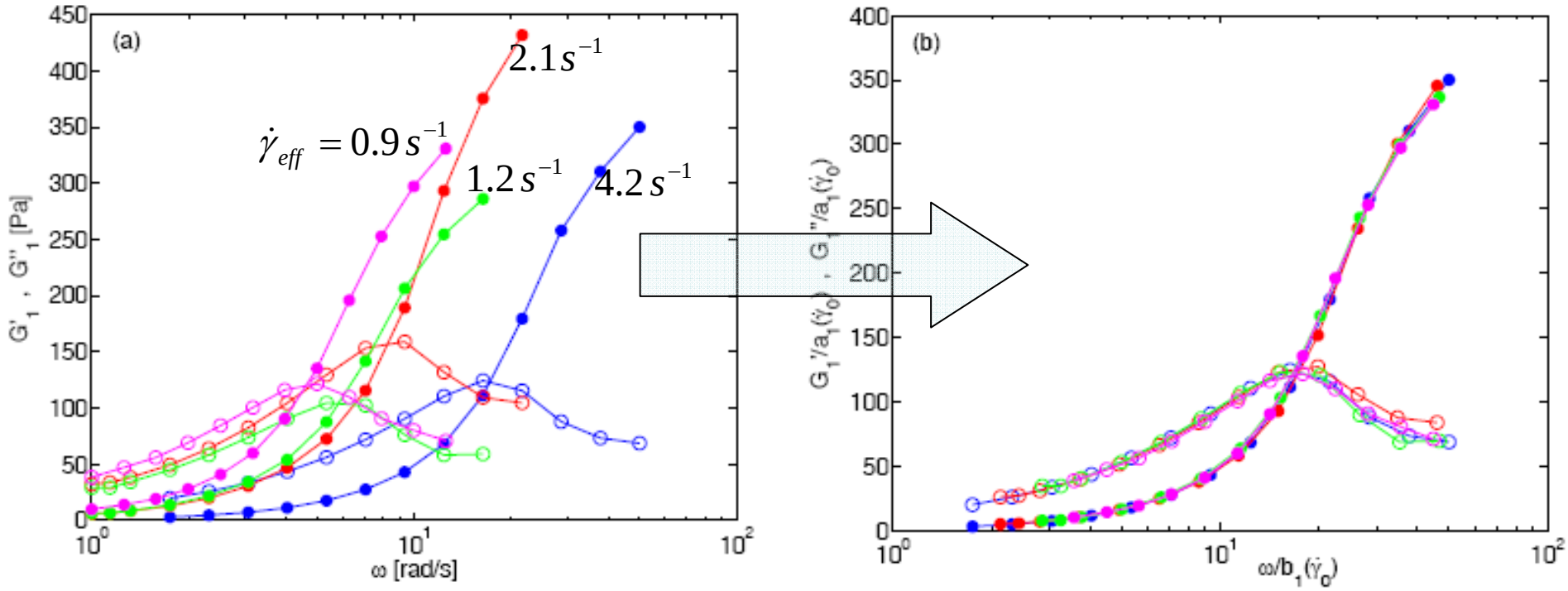
Typical Data



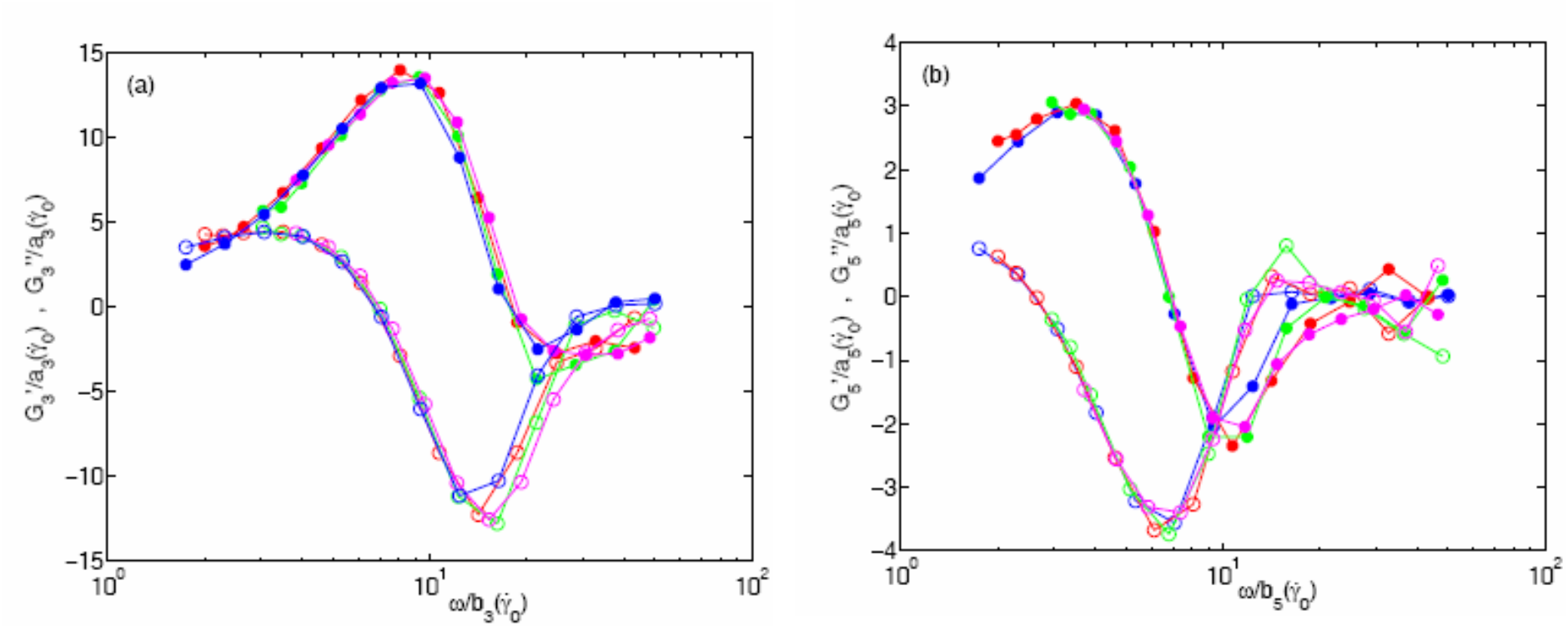


$$G_n' = \frac{\sigma_n \cos\delta_n}{\gamma_1^n}; \quad G_n'' = \frac{\sigma_n \sin\delta_n}{\gamma_1^n}$$

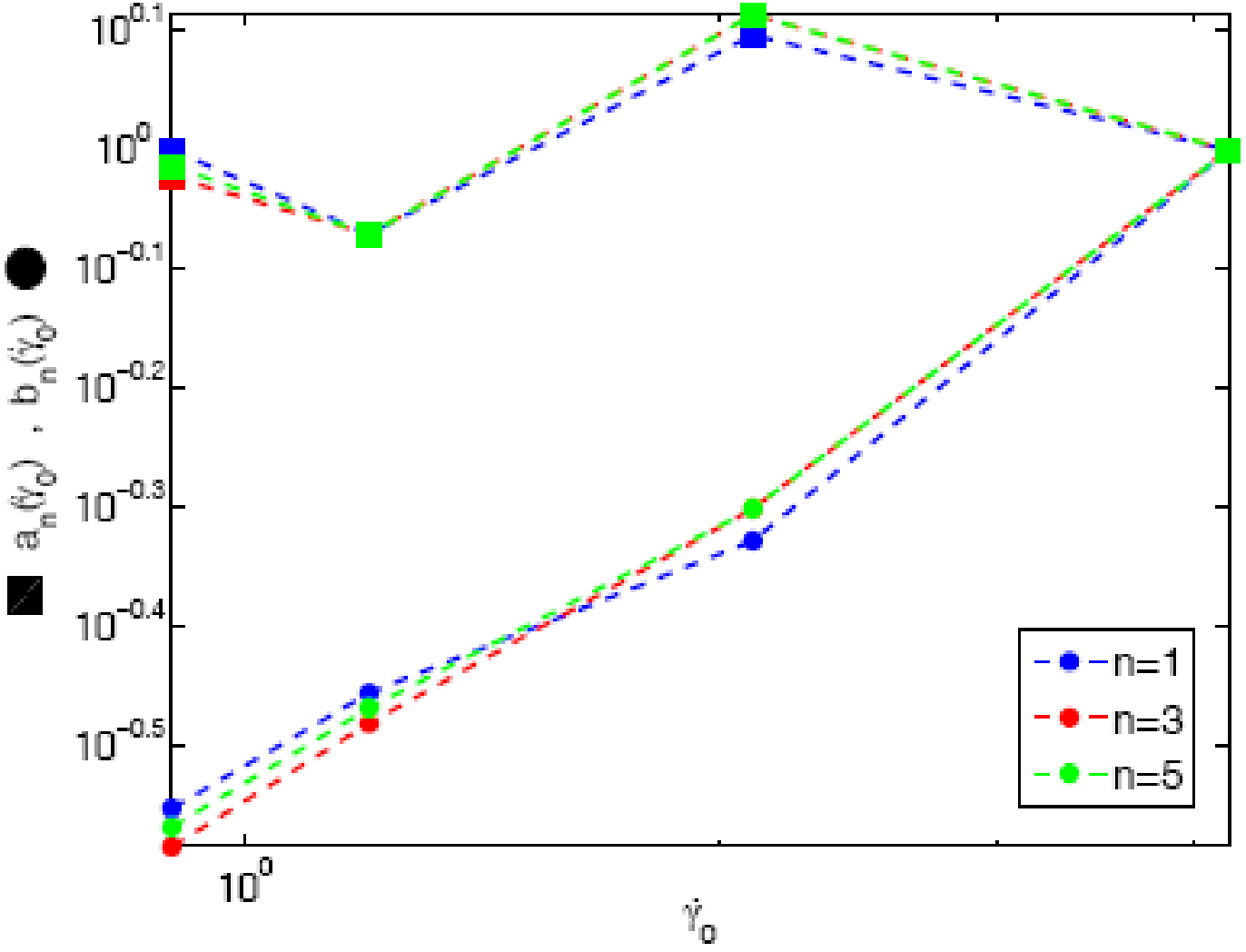
SRFS: G_1


(a)
$\dot{\gamma}_{eff} = 0.9\,s^{-1}$
$1.2\,s^{-1}$
$2.1\,s^{-1}$
$4.2\,s^{-1}$
G'1 , G''1 [Pa]
ω [rad/s]
(b)
G1'/a1(γ̇0) , G1''/a1(γ̇0)
ω/b1(γ̇0)

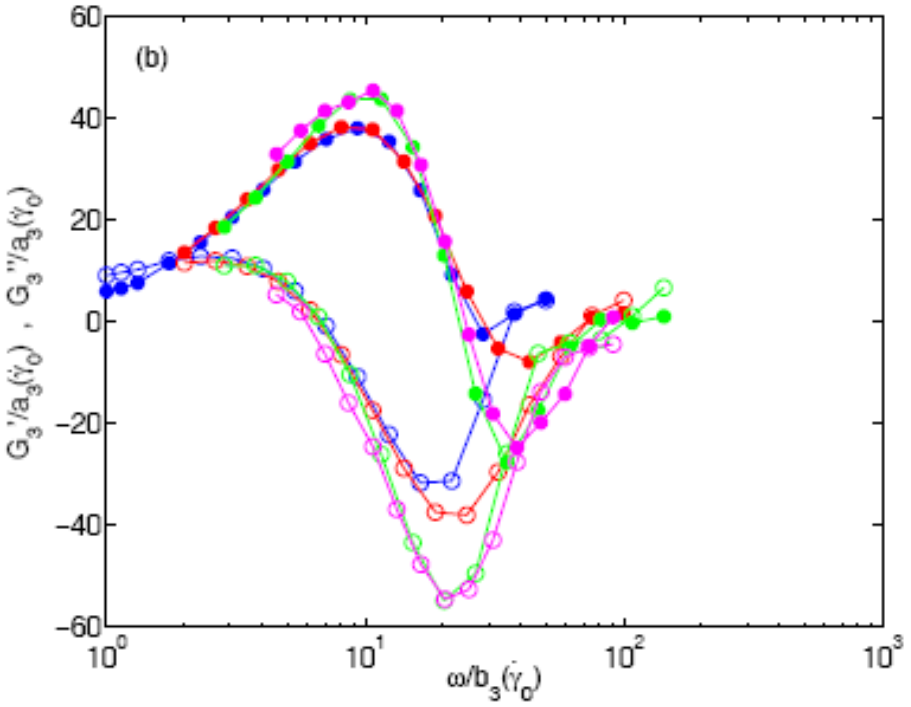
SRFS: G_3 & G_5

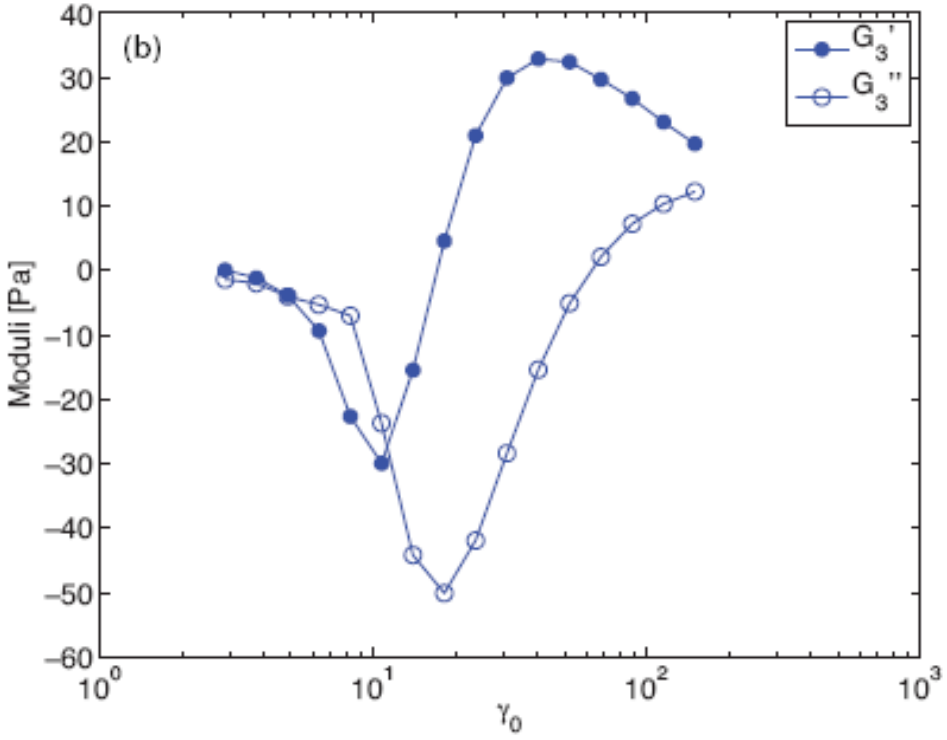

(a)
15
10
5
0
−5
−10
−15
10^0
10^1
10^2
$G_3'/a_3(\dot\gamma_0)$, $G_3''/a_3(\dot\gamma_0)$
$\omega/b_3(\dot\gamma_0)$
(b)
4
3
2
1
0
−1
−2
−3
−4
10^0
10^1
10^2
$G_5'/a_5(\dot\gamma_0)$, $G_5''/a_5(\dot\gamma_0)$
$\omega/b_5(\dot\gamma_0)$

SRFS: Shift Factors



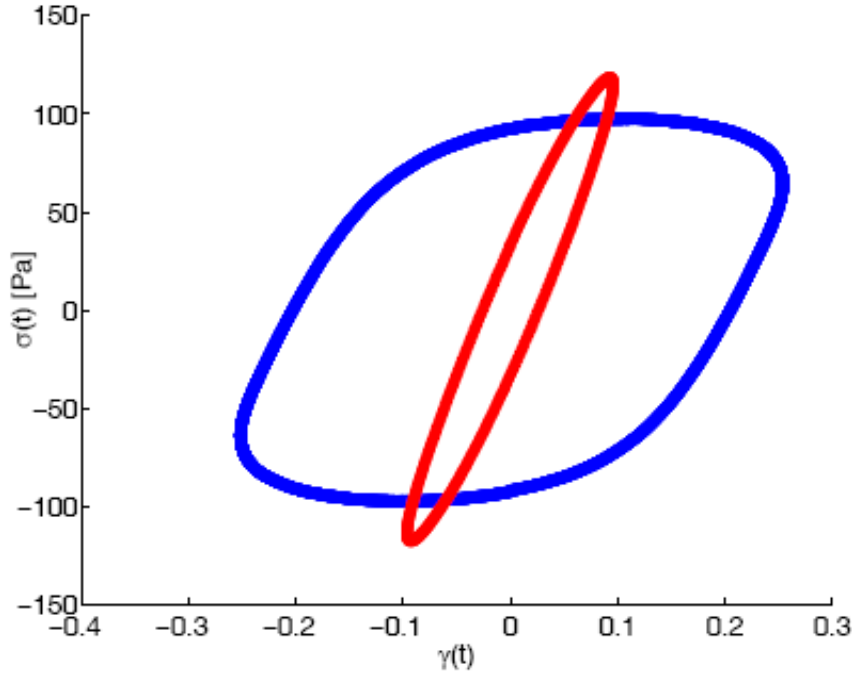
SRFS & DSS

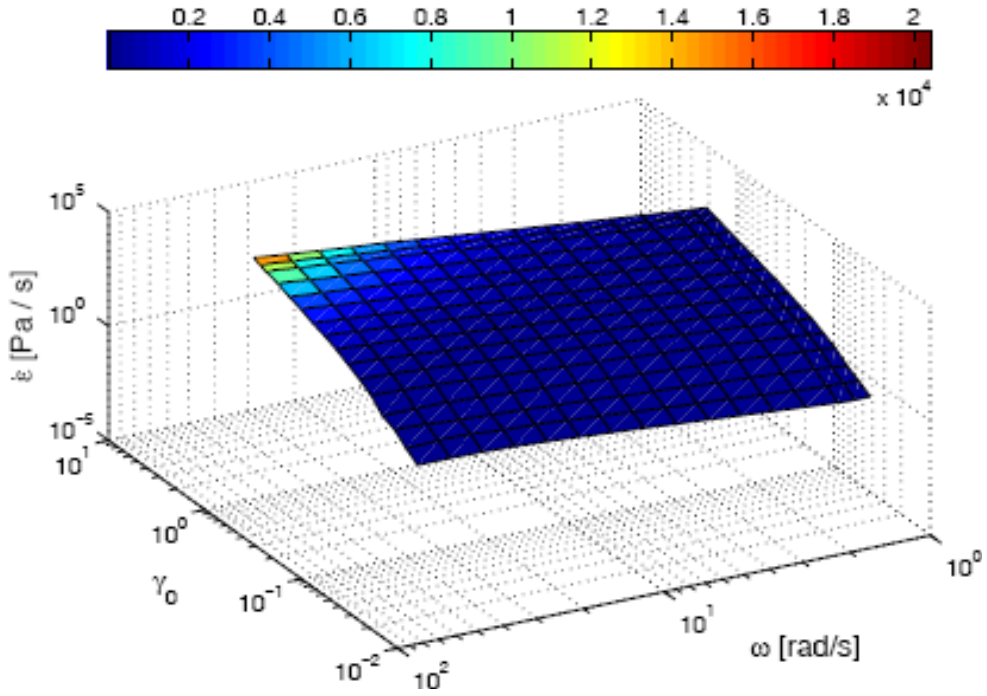

(b)
$G_3'/a_3(\dot{\gamma}_0)$, $G_3''/a_3(\dot{\gamma}_0)$
$\omega/b_3(\dot{\gamma}_0)$


(b)
G_3'
G_3''
Moduli [Pa]
γ_0

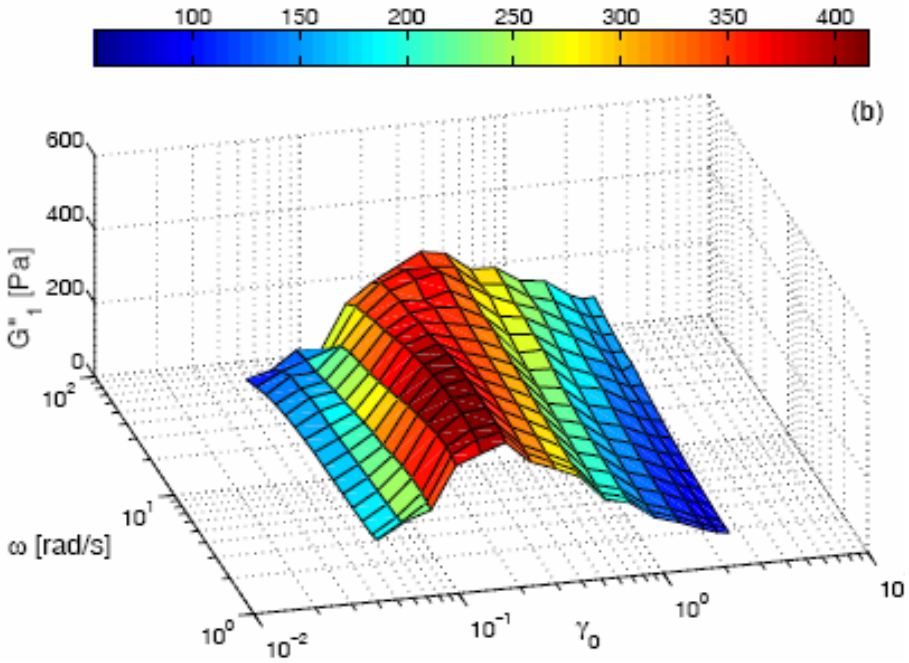
Energy Dissipation

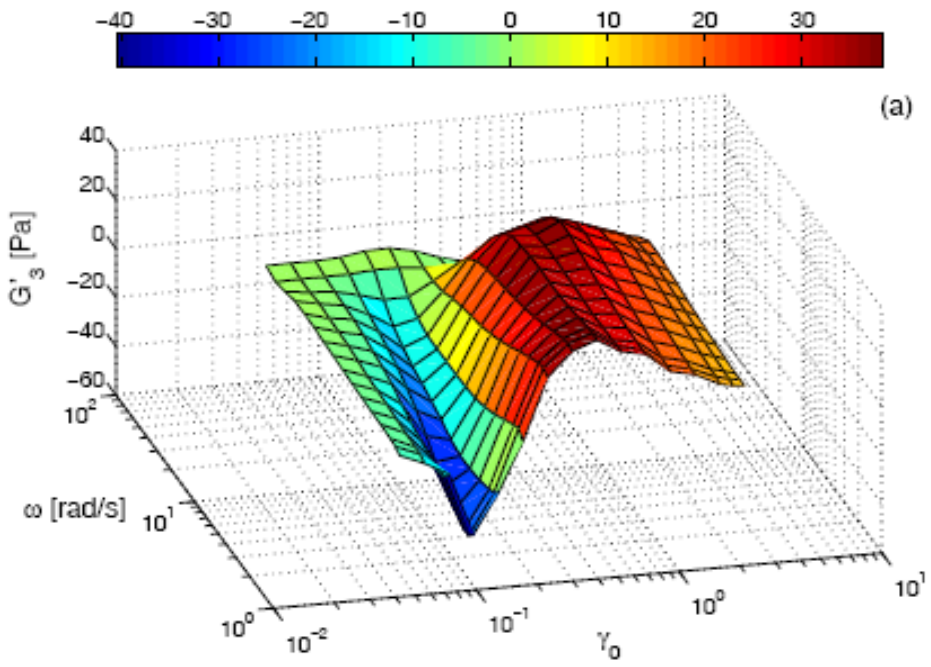
$$\dot{\varepsilon} = \int_0^{2\pi/\omega} \sigma(t)\dot{\gamma}(t)dt = \omega\gamma_0^2 G_1''$$





Moduli: Surface Plots





Concluding Remarks

- The non-linear rheology of soft solids is characterized by SRFS superposition of all harmonic moduli.

- The shift factors of all harmonic moduli are identical.

- $G_n', G_n''\big|_{T,t} = f\left(\omega\lambda, \gamma_0\right); \quad \lambda = \dfrac{\lambda_0}{1 + k\lambda_0\dot{\gamma}}$

- SRFS-MC's of Fourier coefficients are mirror images of DSS.

- All energy dissipation occurs in the first mode G_1''