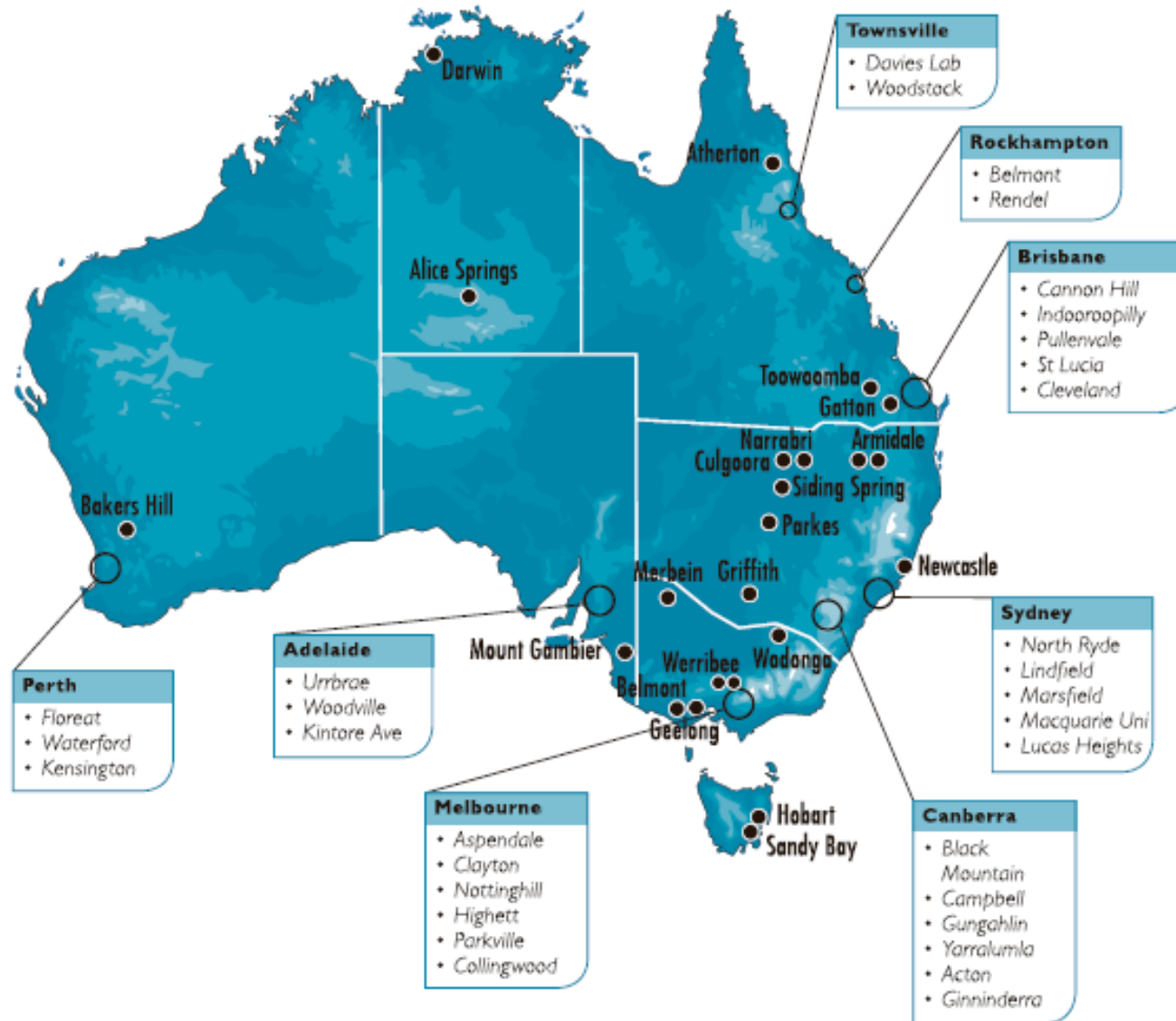


Plant cell wall particle dispersions: modelling of structure and rheological properties

Li Day, Yacine Hemar and Leif Lundin
CSIRO Food and Nutritional Sciences
29 Sept 2010

Commonwealth Scientific and Industrial Research Organisation (CSIRO)



CSIRO today: a snapshot

Australia's national science agency

One of the largest & most diverse in the world

6500+ staff over 52 locations

Ranked in top 1% in 14 research fields

20+ spin-off companies in six years

160+ active licences of CSIRO innovation

Building national prosperity and wellbeing



Division of Food and Nutritional Sciences



Adelaide

Brisbane

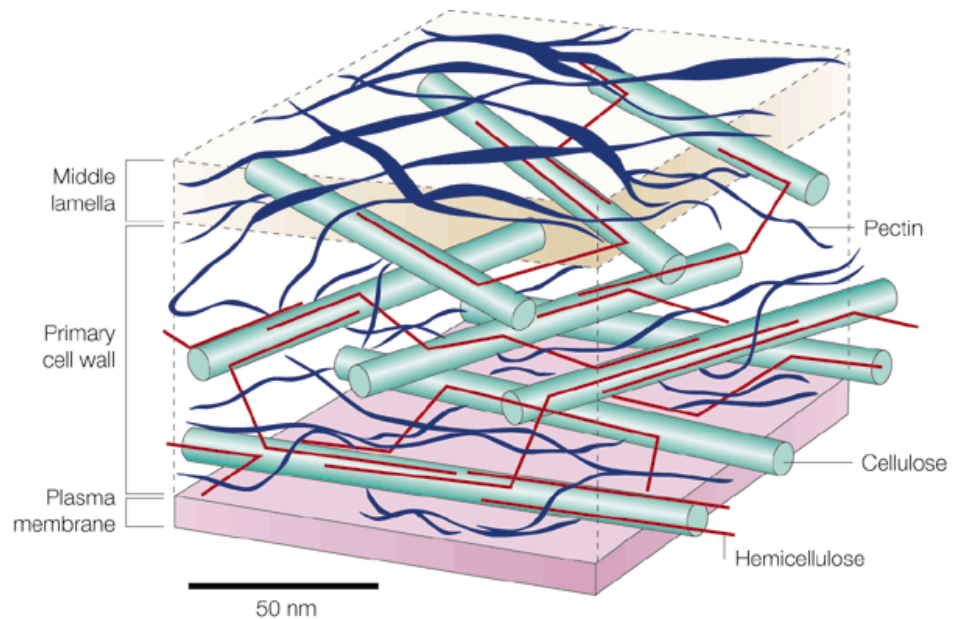
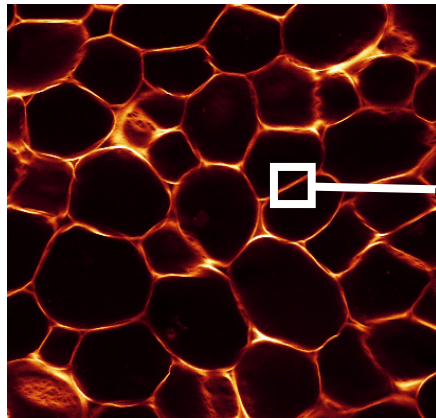
Sydney

Melbourne



Plant cell wall

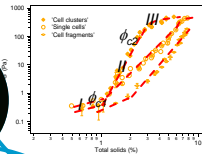
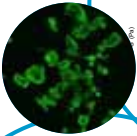
- Major contributor to the dietary fibre part of our food intake
- Complex and highly sophisticated composite materials made of cellulose, hemicellulose and pectin, that form a scaffold matrix with intertwined structure



Structuring manufactured food with natural plant materials

Biomaterials

- Plant cell wall structure
- Functional properties



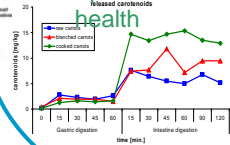
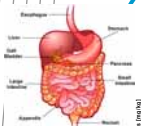
Sensory

- Clean mouthfeel
- Better product texture



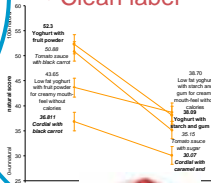
Health benefit

- micronutrient bioavailability
- plant fibre for colon health



Consumer

- Natural foods
- Clean label



Calorie reduce



- Quick service restaurant

Starch replacement



- Biscuit, cookies, muffins

High fibre stabiliser



- Yoghurt, dessert

Natural colour palette



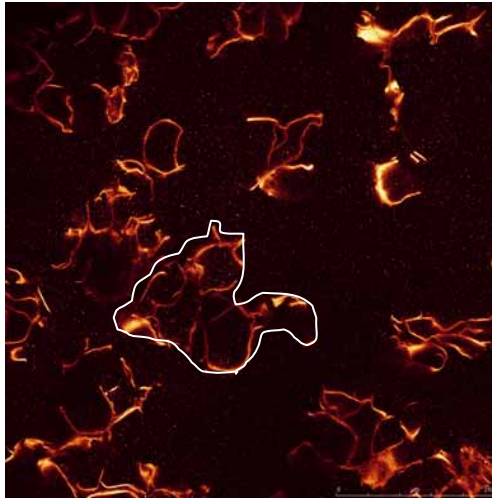
- Beverages

Questions / challenges

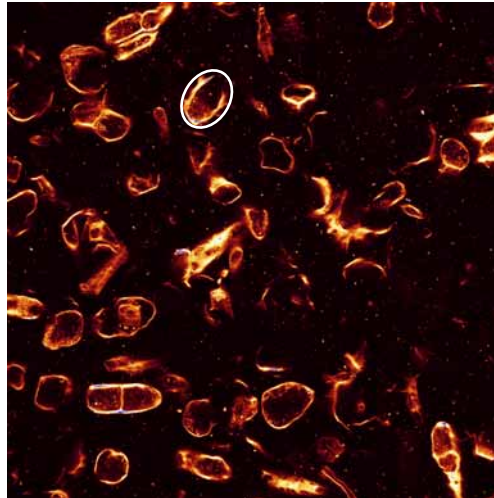
- How to control plant cell/tissue structures, particle sizes and biopolymer/chemical compositions to enhance texture and mechanical properties of biomaterials?
- How to characterise 'soft' cell wall particle structure and what is the relationship between the microstructure and their intrinsic functional properties?
- How (through processing) to utilise plant cell and tissue structures to impart texture and mechanical properties in foods?

Cell wall particle dispersions

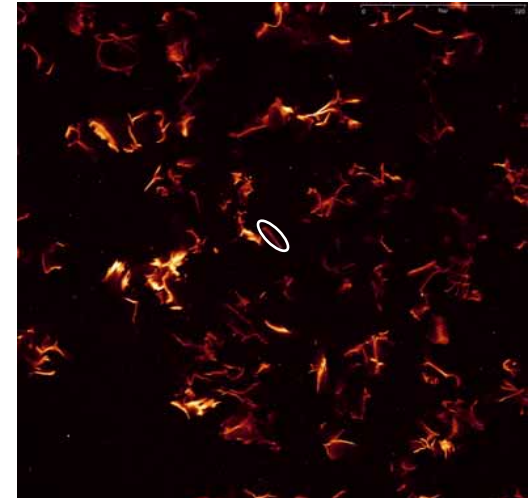
Particle clusters
(~200-300 μm)



Single cells
(~70-80 μm)



Cell fragment
(~32 μm)



Heat, shear

Scale = 775 μm x 775 μm

Day, L. et al. (2010) Food and Bioprocess Technology, DOI: 10.1007/s11947-010-0346-0.

Rheology – which geometry to use?

Gap?

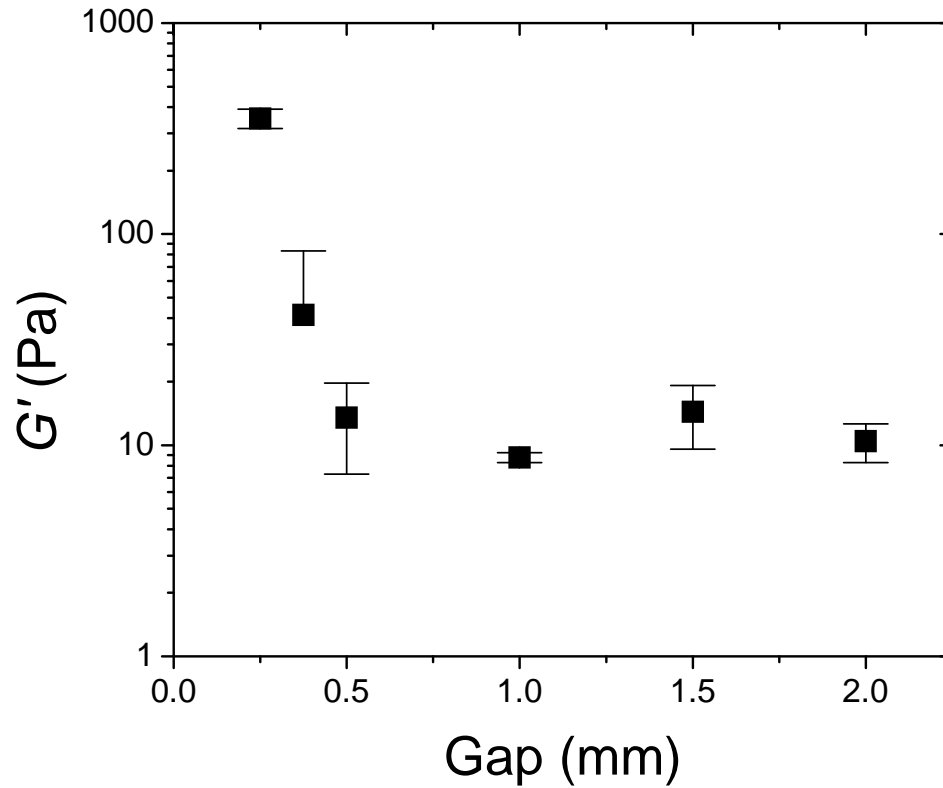
Slippery?



Concentration?

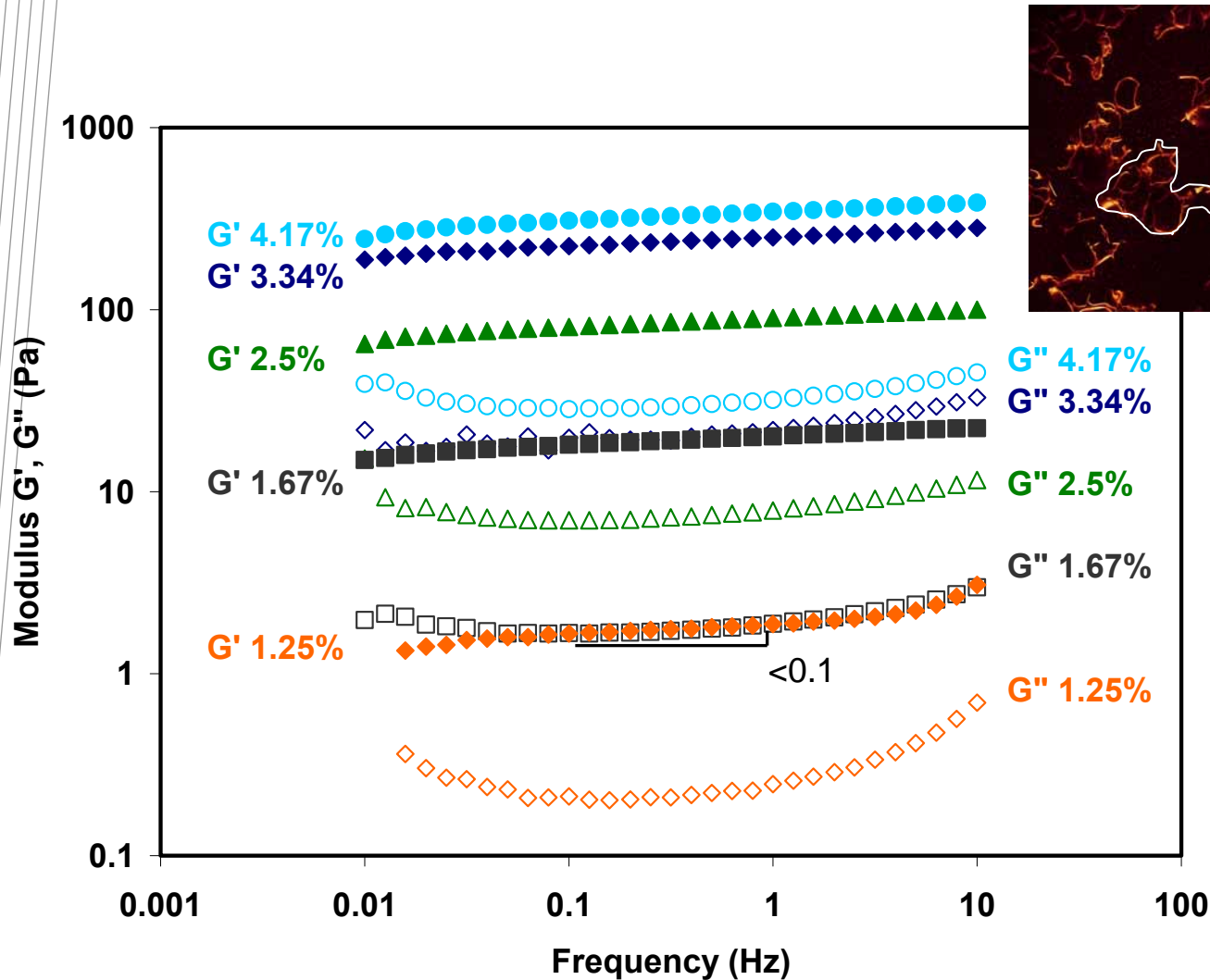
Practical?

Rheology – which geometry to use?



Rheological behaviour

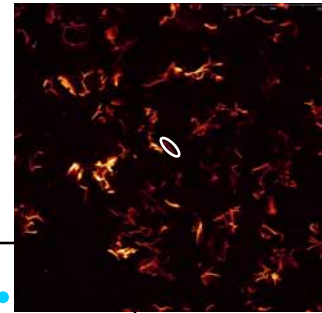
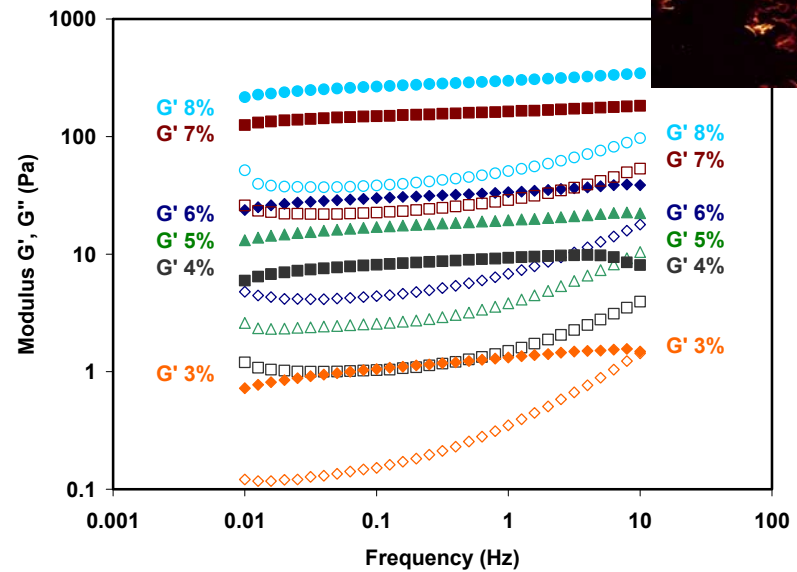
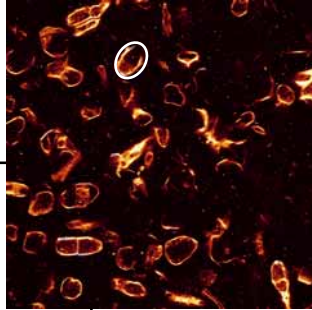
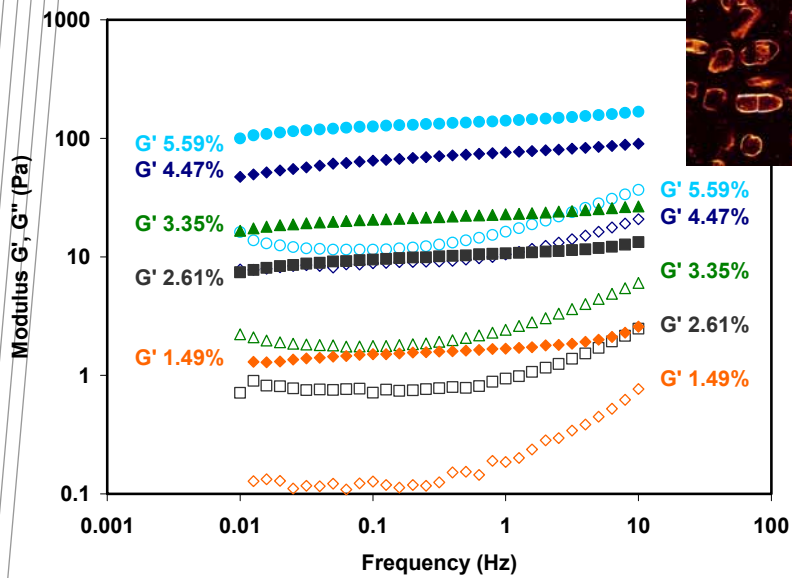
– Frequency (in)dependence of modulus



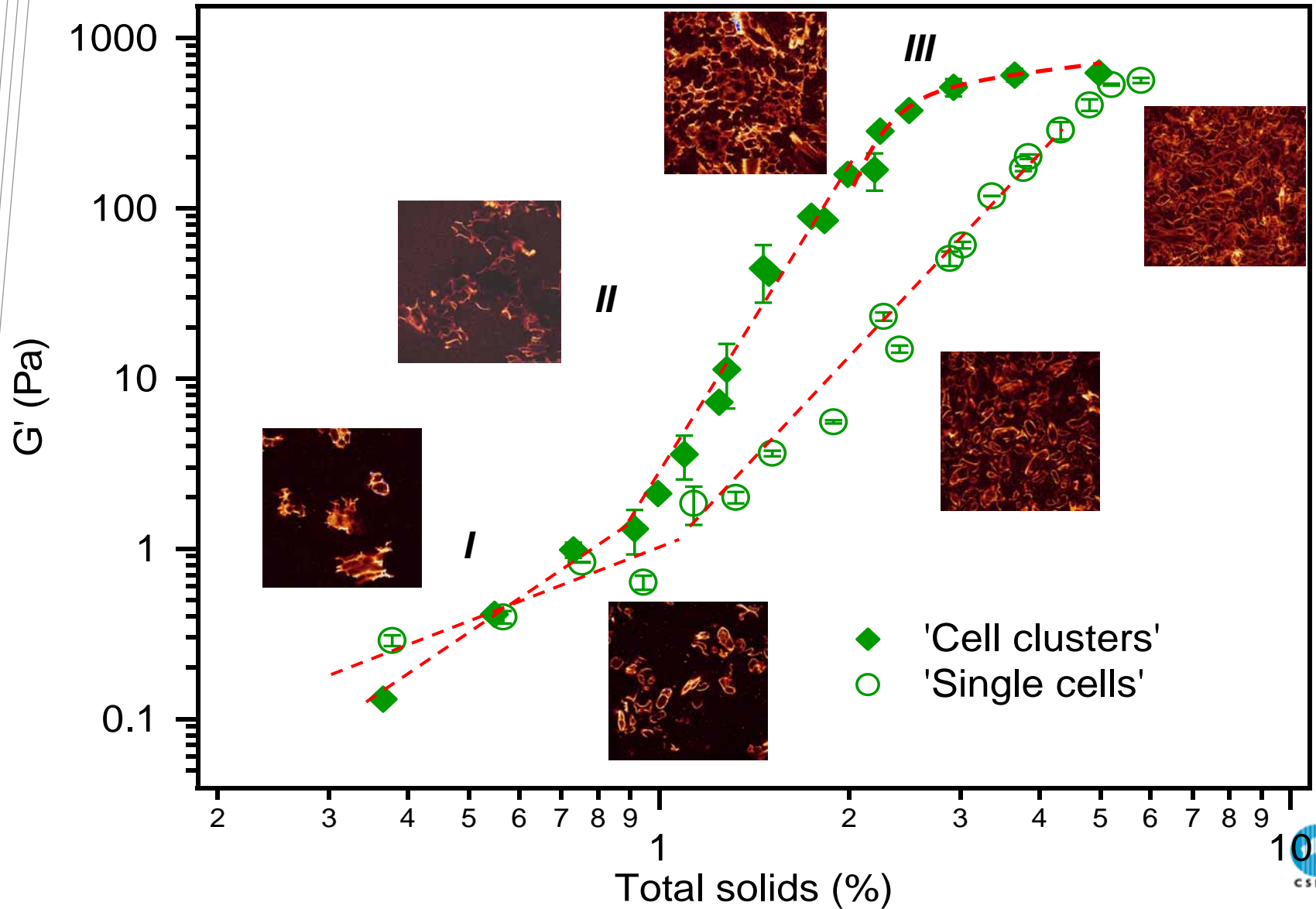
$$G' \sim f^\alpha$$
$$\alpha < 0.1$$

Rheological behaviour

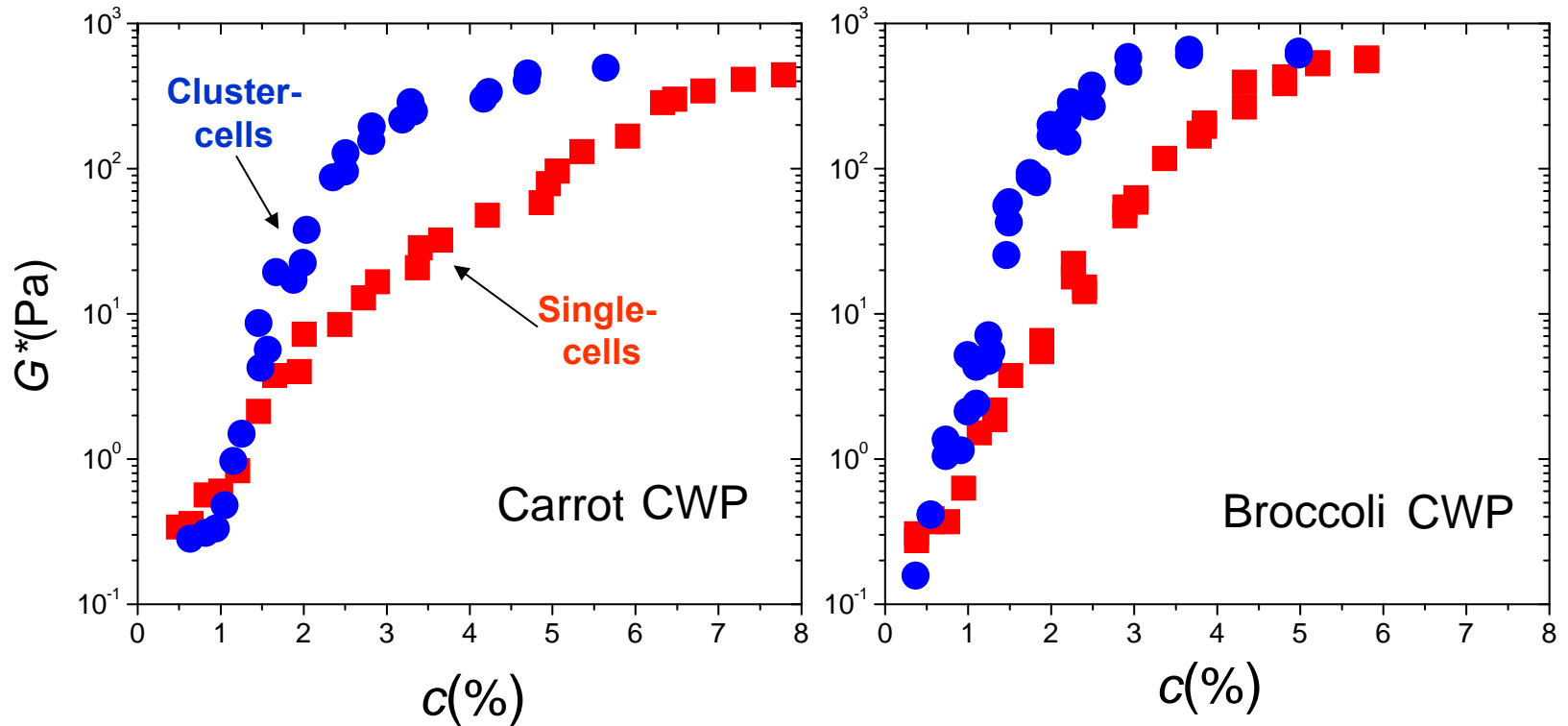
– Frequency (in)dependence of modulus



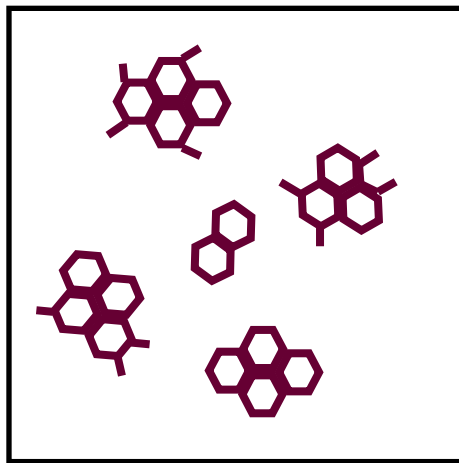
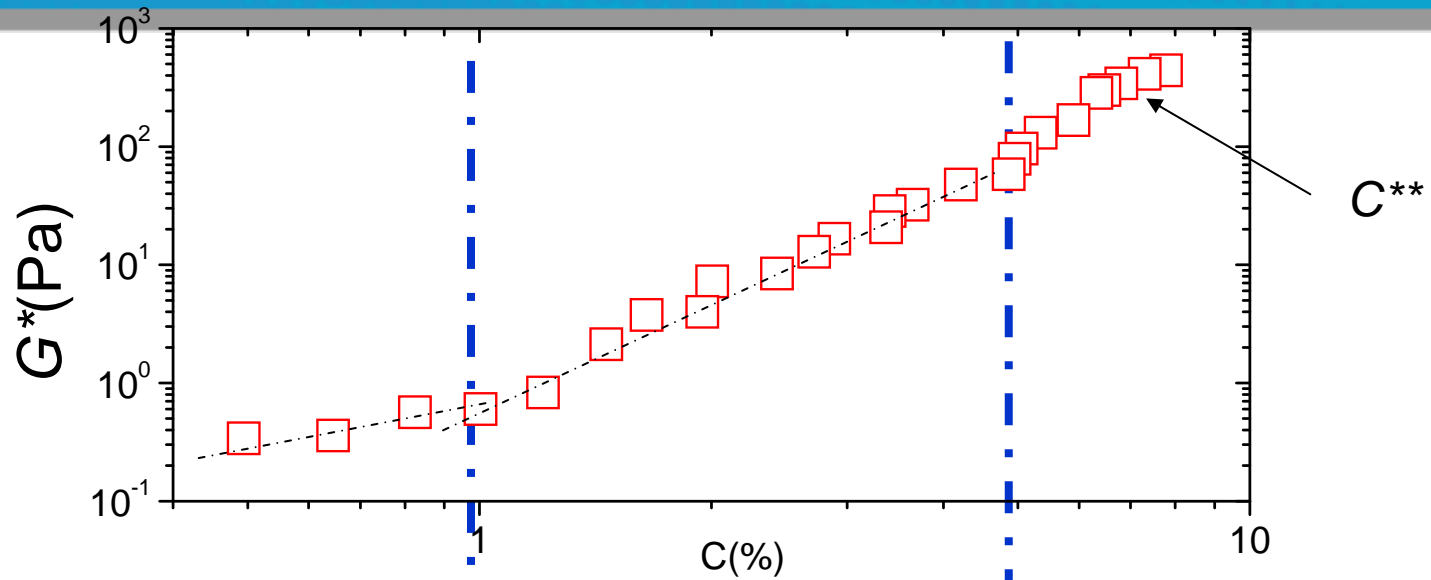
Concentration dependence of storage modulus



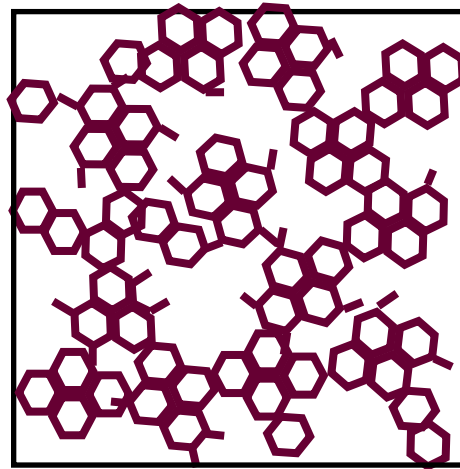
Concentration dependence



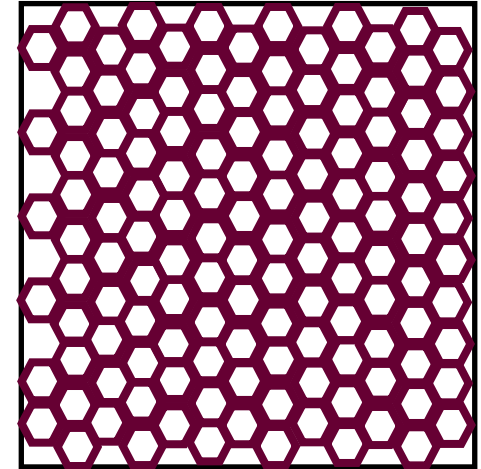
Theory



$$G^* \propto \phi$$



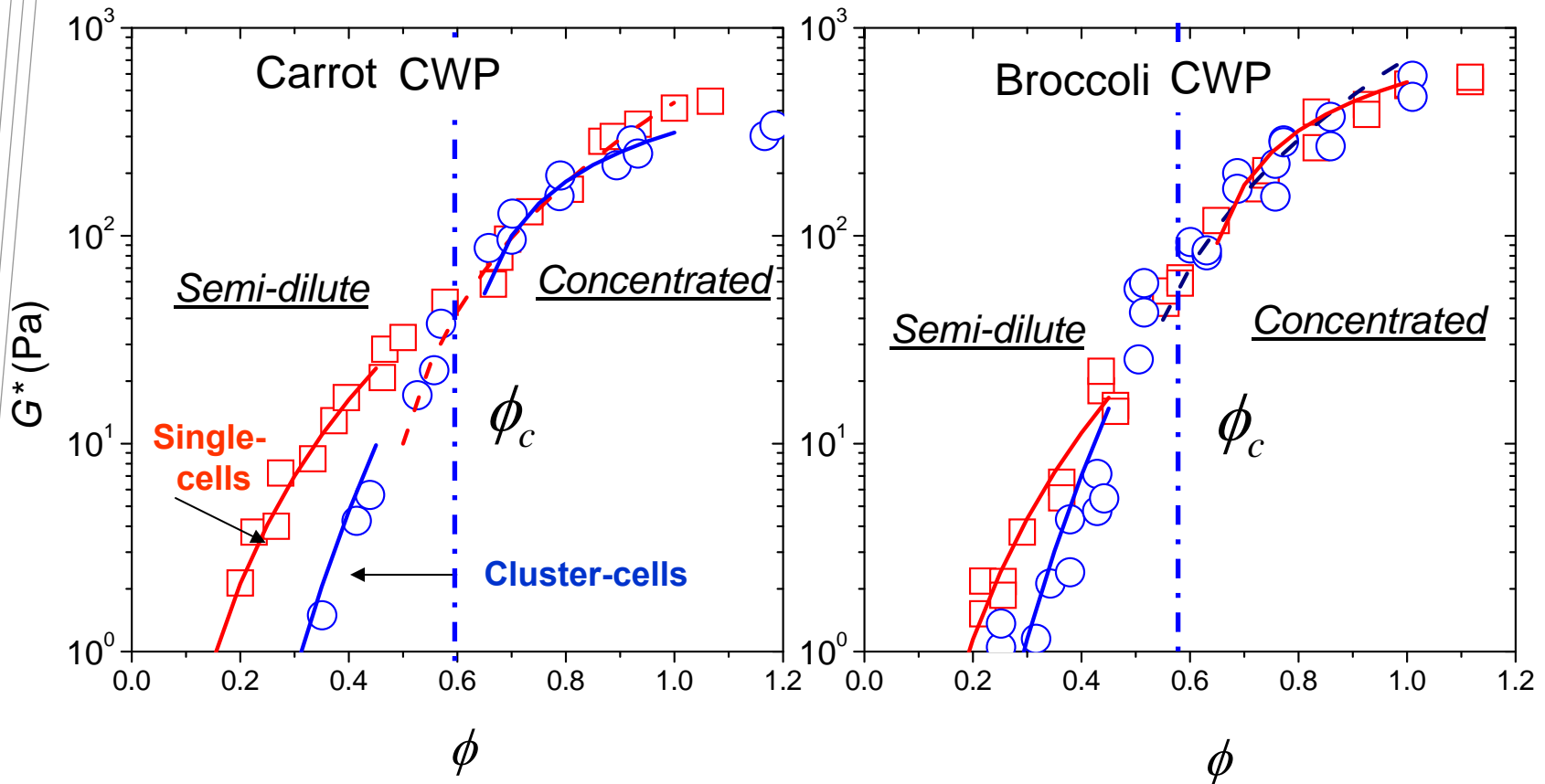
$$G^* = (\phi - \phi_c)^\alpha \propto \phi^\alpha$$



$$G^* = \Gamma \phi^2 (\phi - \phi_c)$$

Modelling – semi-diluted region

$$\phi \leq \phi_c \quad G^* = (\phi - \phi_c)^\alpha$$



Cell clusters (200-300 μm):
Single cells ($\sim 80 \mu\text{m}$):

$\alpha = 6.2$
 $\alpha = 3.0$

$\alpha = 6.4$
 $\alpha = 3.0$

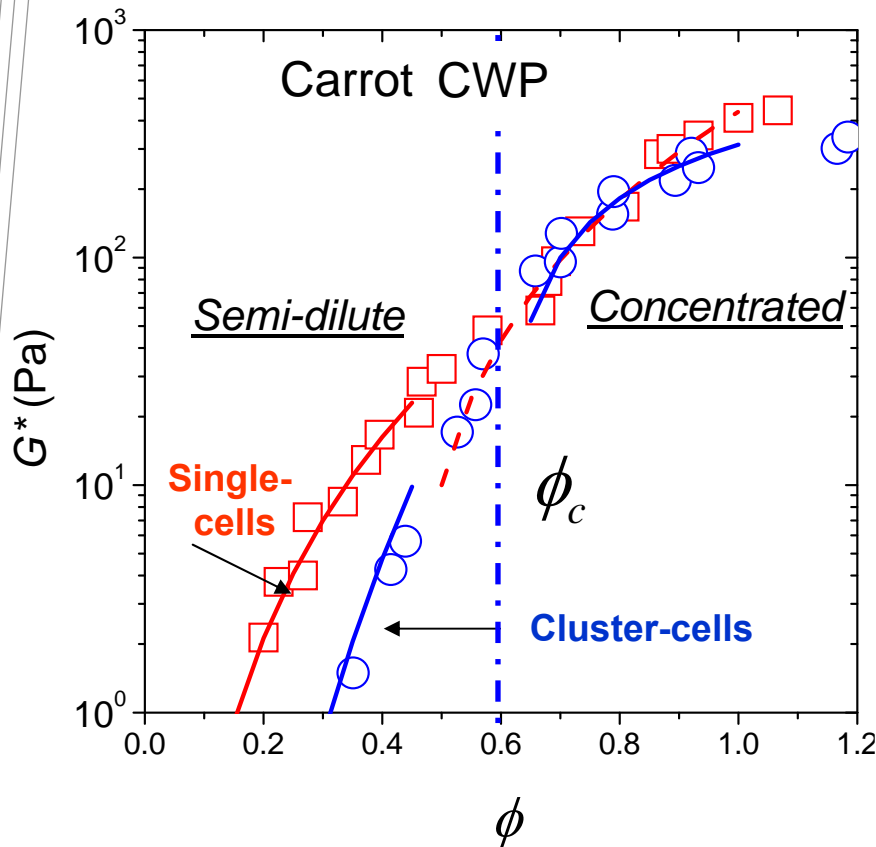
Modelling – concentrated region

$$\phi \geq \phi_c$$

$$G^* = \Gamma \phi^2 (\phi - \phi_c)$$

$$\Gamma = 1.77\sigma / R$$

$$G^* = A \left[1 - \left(\frac{\phi_c}{\phi} \right)^{1/3} \right]$$



$$R \propto \phi^{1/3}$$

Mason et al. (1995) Phys Rev Lett, 75, 2051-2054.

Adams et al. (2004) J. Rheol. 48, 1195-1213.

Modelling – concentrated region

| | Carrot cell wall dispersion | Broccoli cell wall dispersion |
|--------------|------------------------------------|--------------------------------------|
| $\Gamma(Pa)$ | 1046 ± 132 | 1208 ± 127 |
| $A(Pa)$ | 1833 ± 146 | 1706 ± 149 |
| Γ / A | 0.6 | 0.7 |

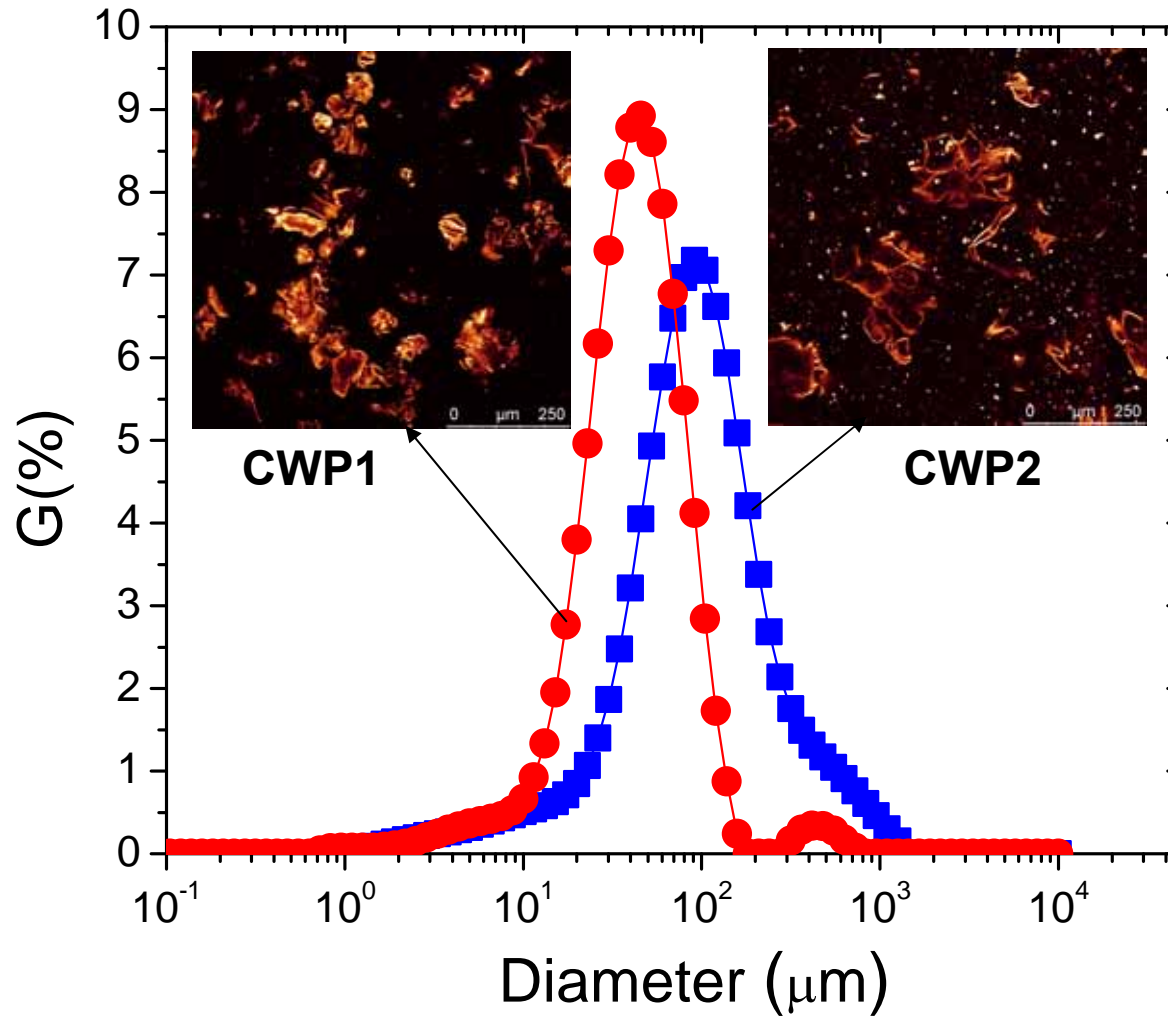
Summary

- The rheology of cell wall particle dispersions determined by
 - Particle shape and size distribution
 - Volume fraction
 - Particle deformability
- Particle interactions at low solid contents (phase volumes $\phi \leq 0.1$)
- Three regimes:
 - Dilute-regime
 - Semi-dilute regime where the particles formed network
 - Concentrated regime highly packed particles
- Similar rheological behaviour to fluid gel particles

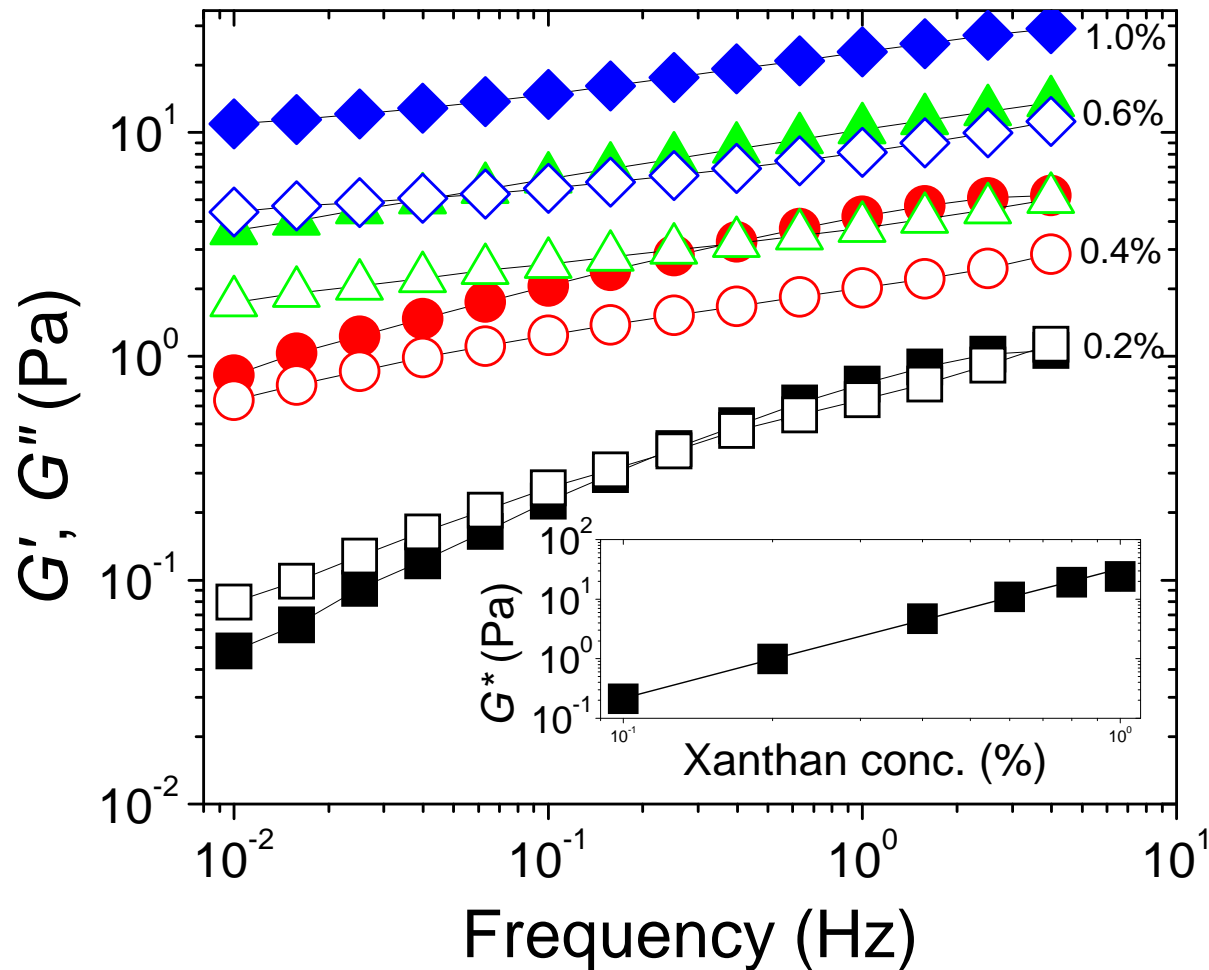
Plant cell wall particles – xanthan



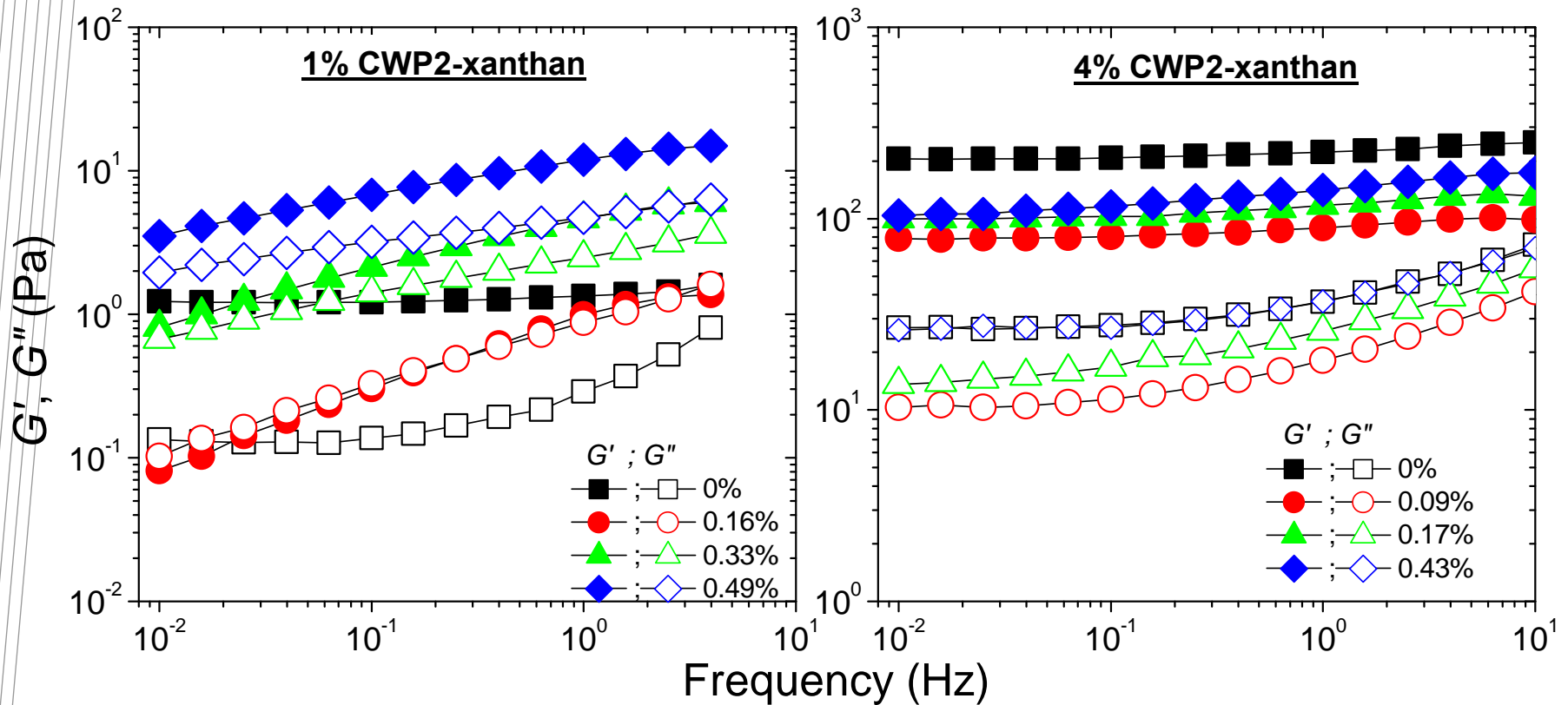
Particle size and particle morphologies



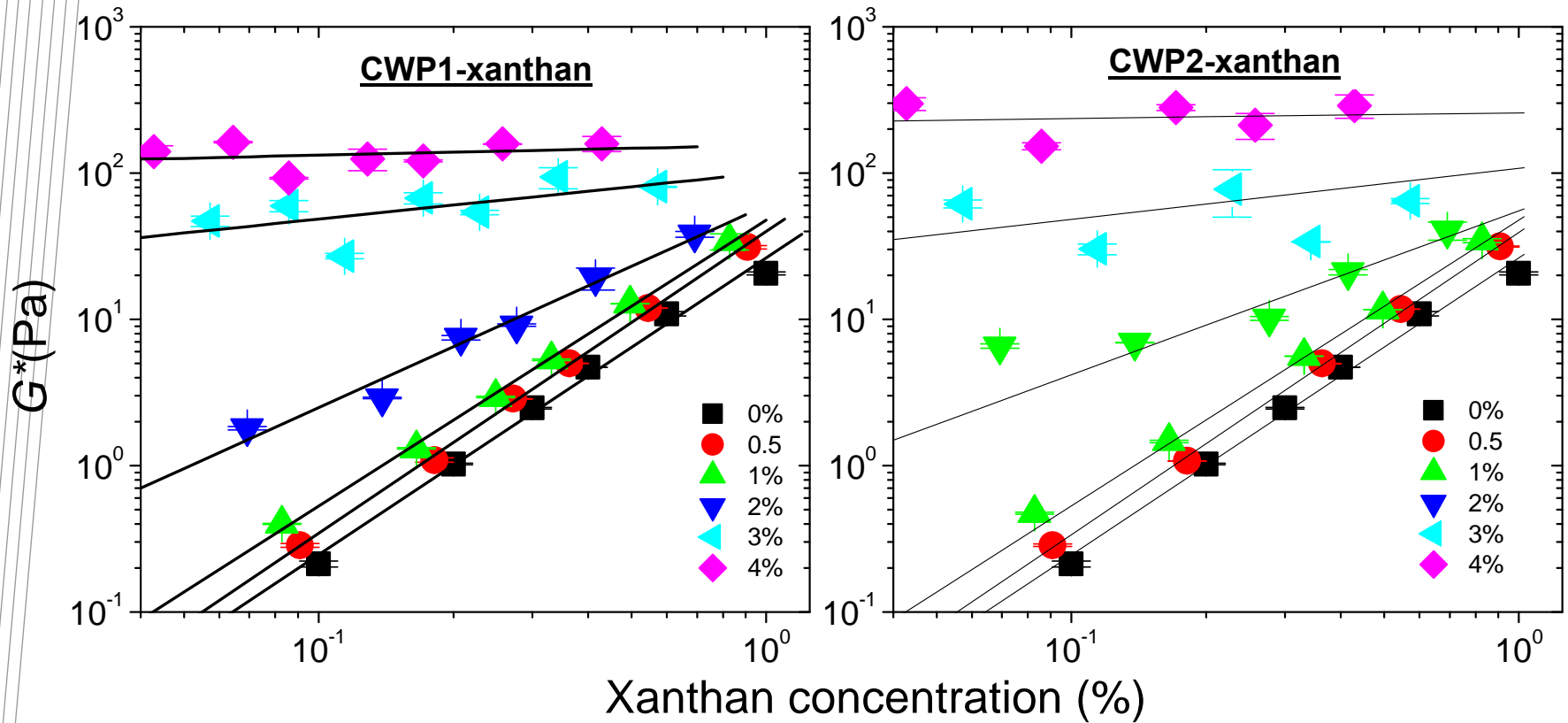
Frequency-sweep behavior of xanthan



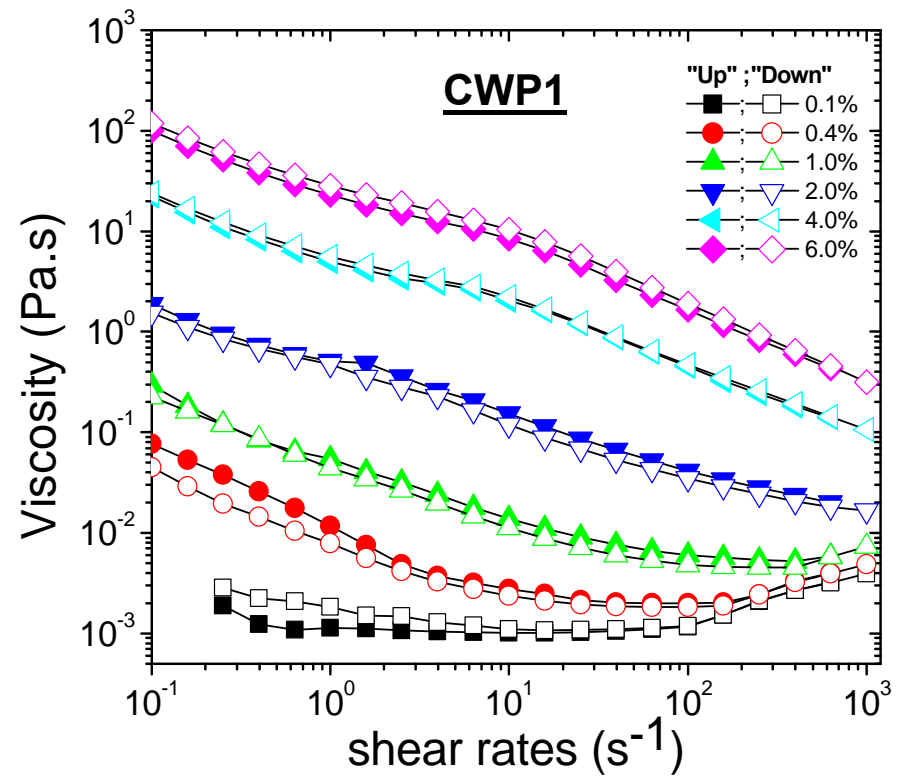
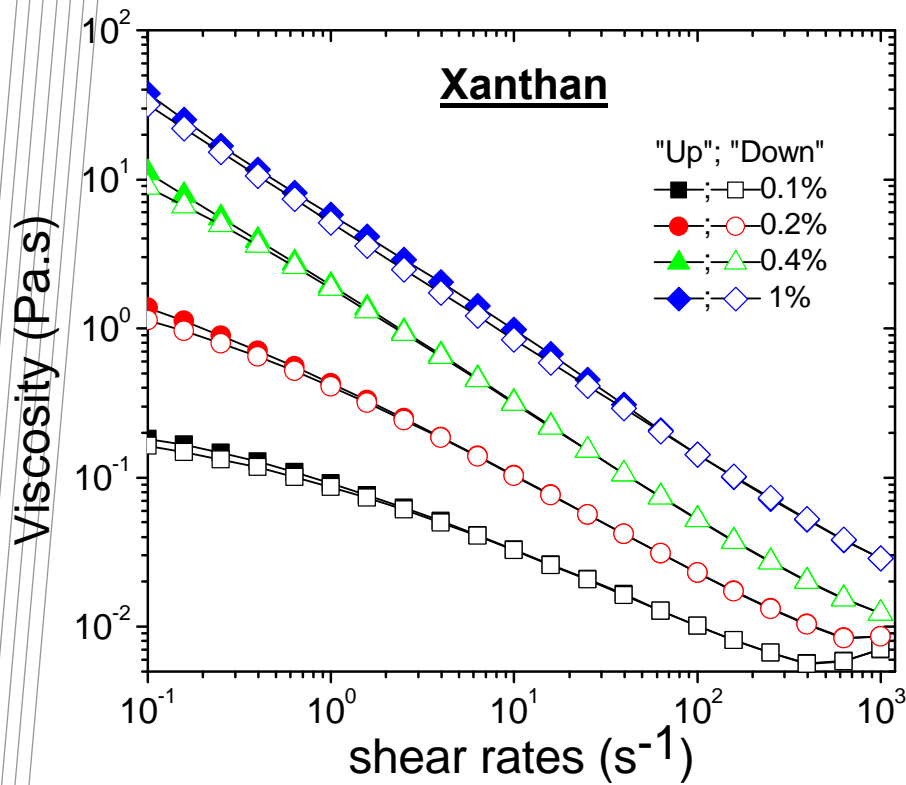
Frequency-sweep of CWP-xanthan mixtures



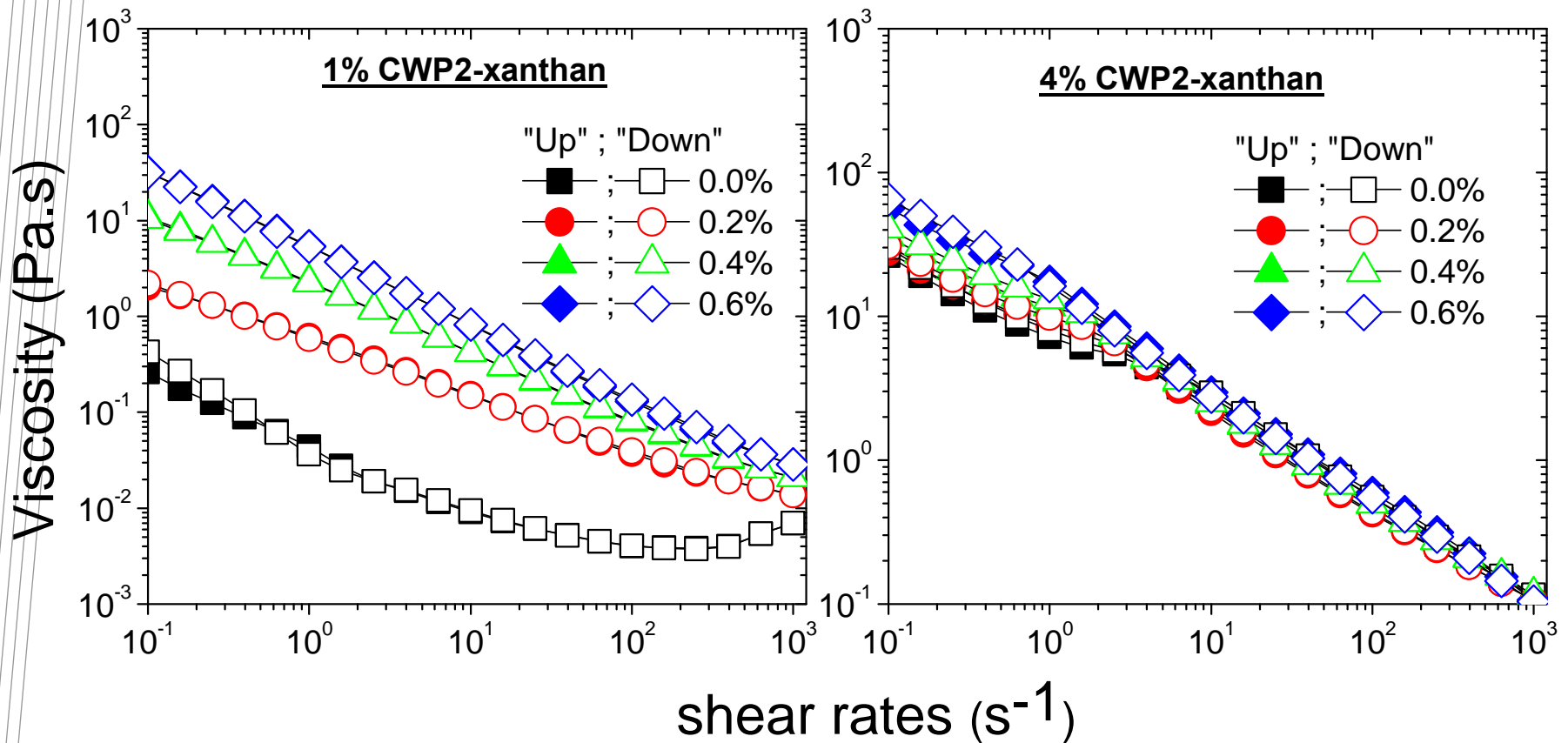
Mixtures elasticity vs xanthan concentration



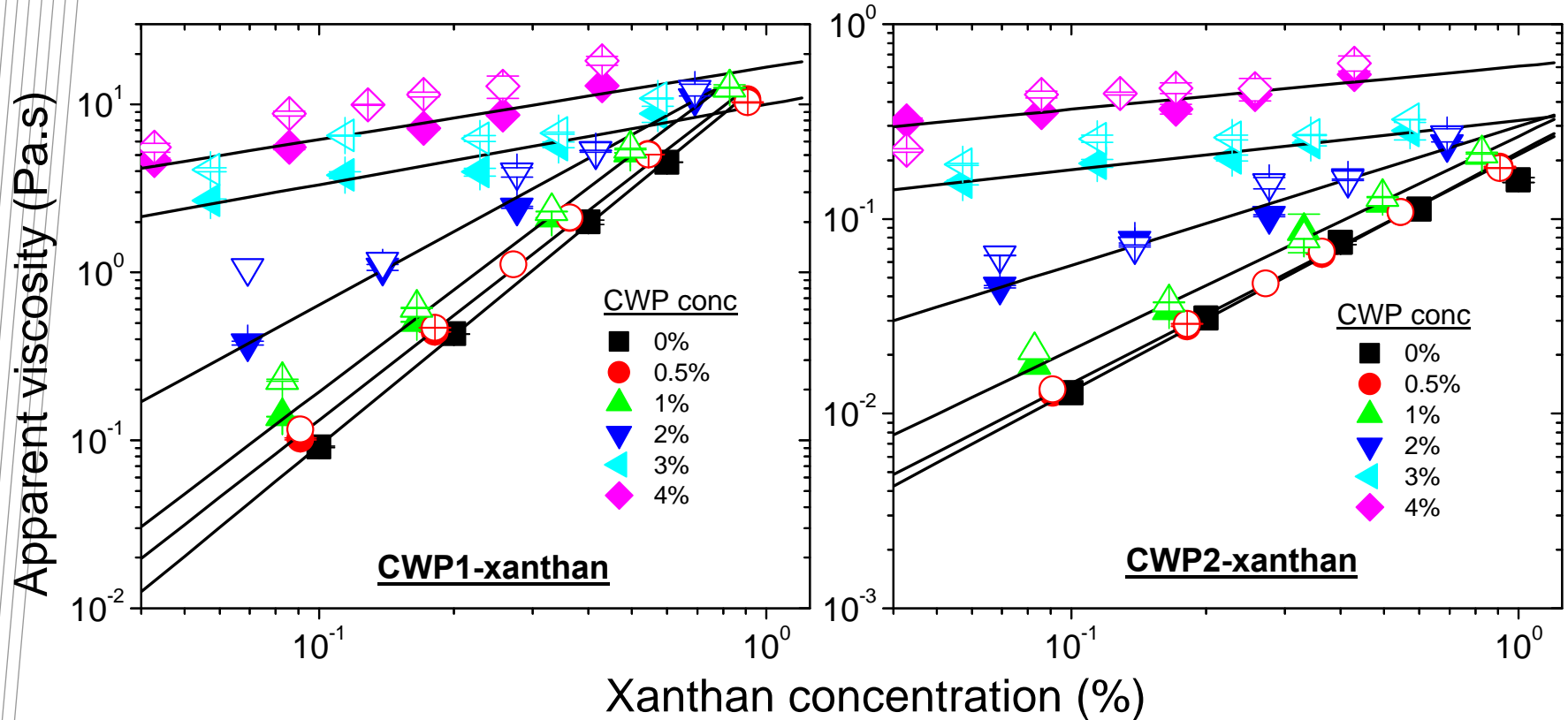
Flow behaviour



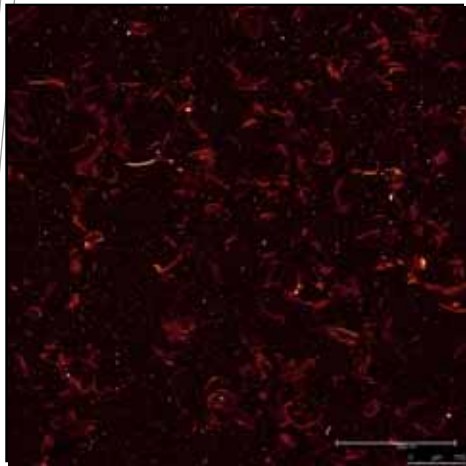
Flow curves of CWP-xanthan mixtures



Mixtures Viscosity vs xanthan concentration

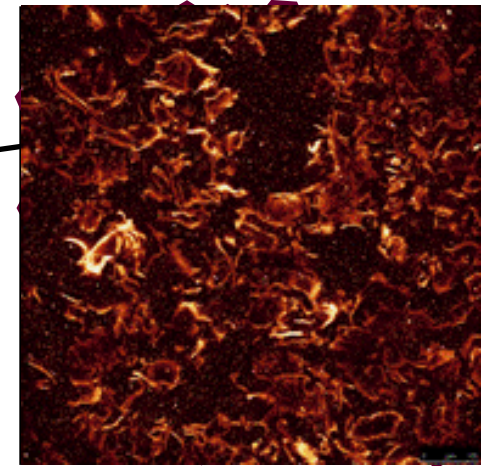
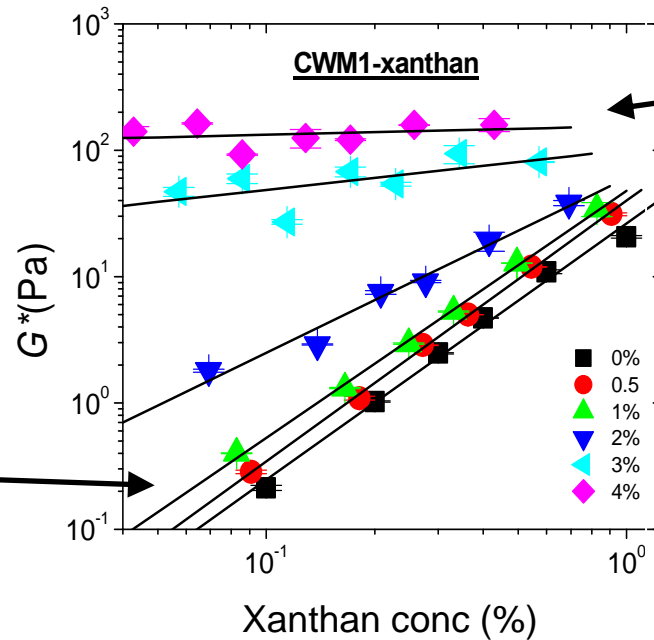


Modelling



Dilute dispersion

$$G^* = G^*_{matrix} (1 + 2.5\phi)$$



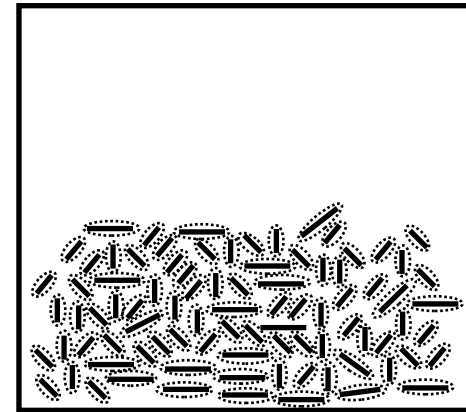
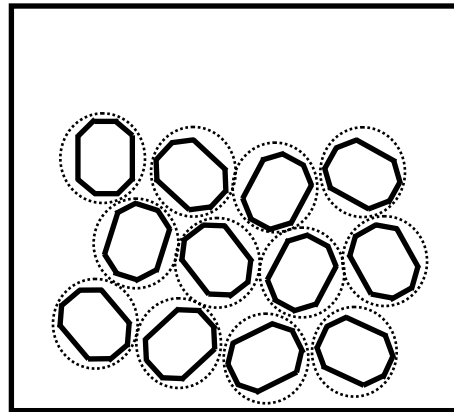
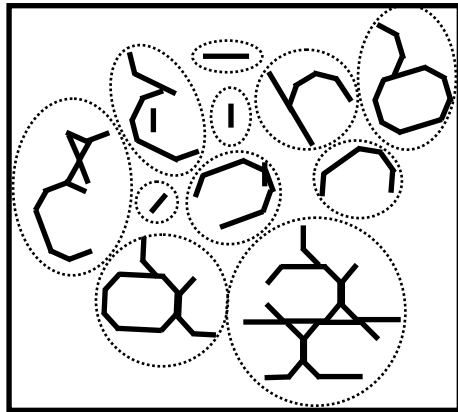
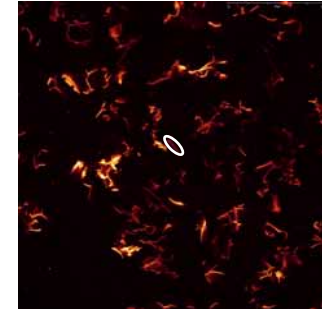
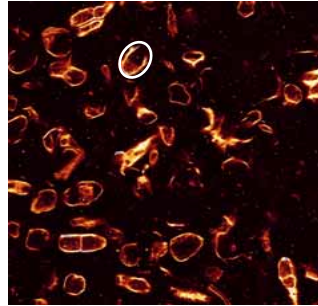
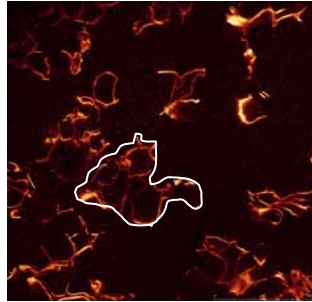
Semi-diluted dispersion

$$G^* = (\phi - \phi_c)^\alpha \propto \phi^\alpha$$

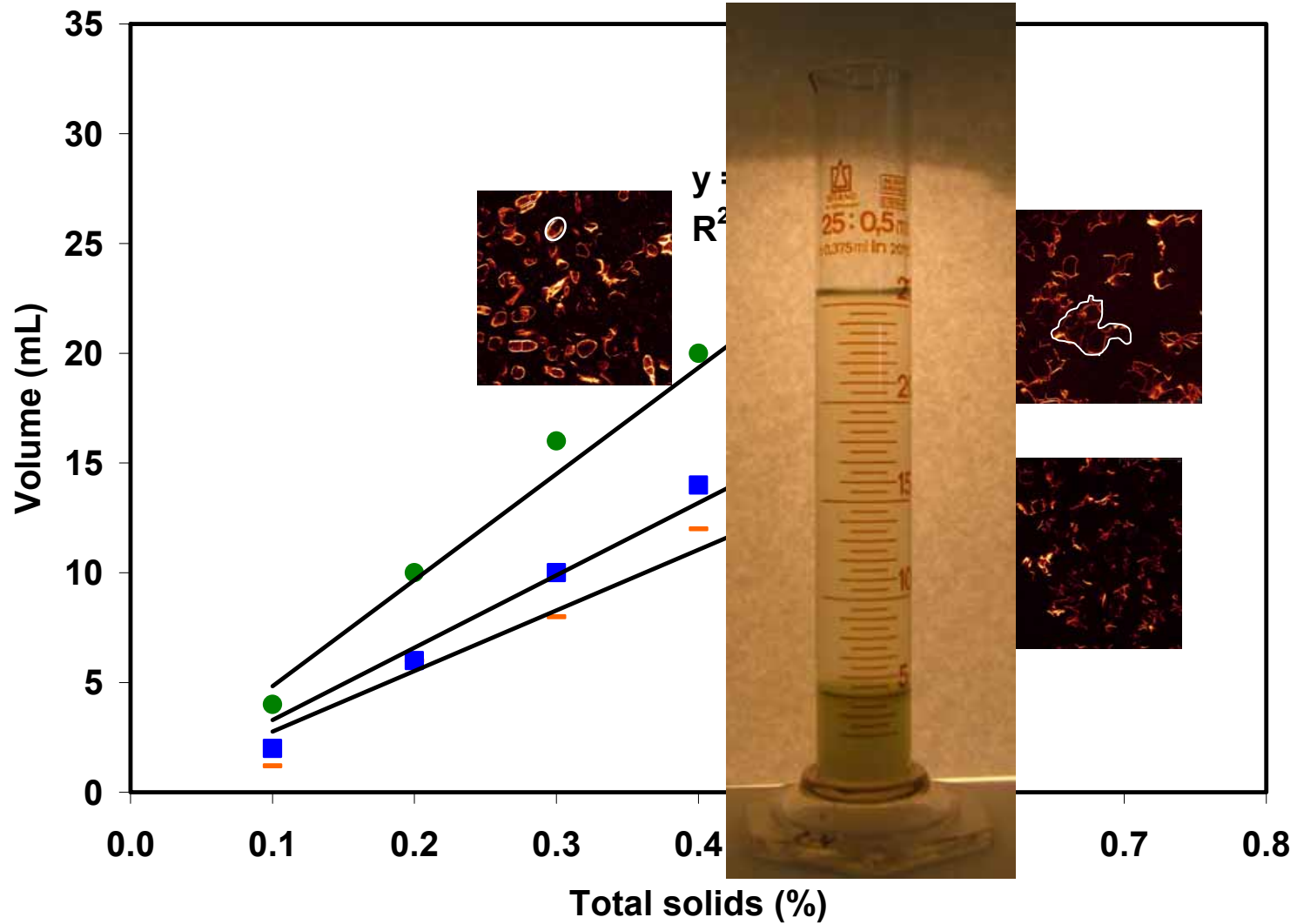
Summary

- Addition of xanthan to CWP dispersions:
 - Delayed particle network formation at low CWP concentration
 - Rheological properties of xanthan
 - At high CWP concentrations, cell wall particle network dominates
 - Rheological properties of CWP
- No phase separation was observed

Particle packing phase volume



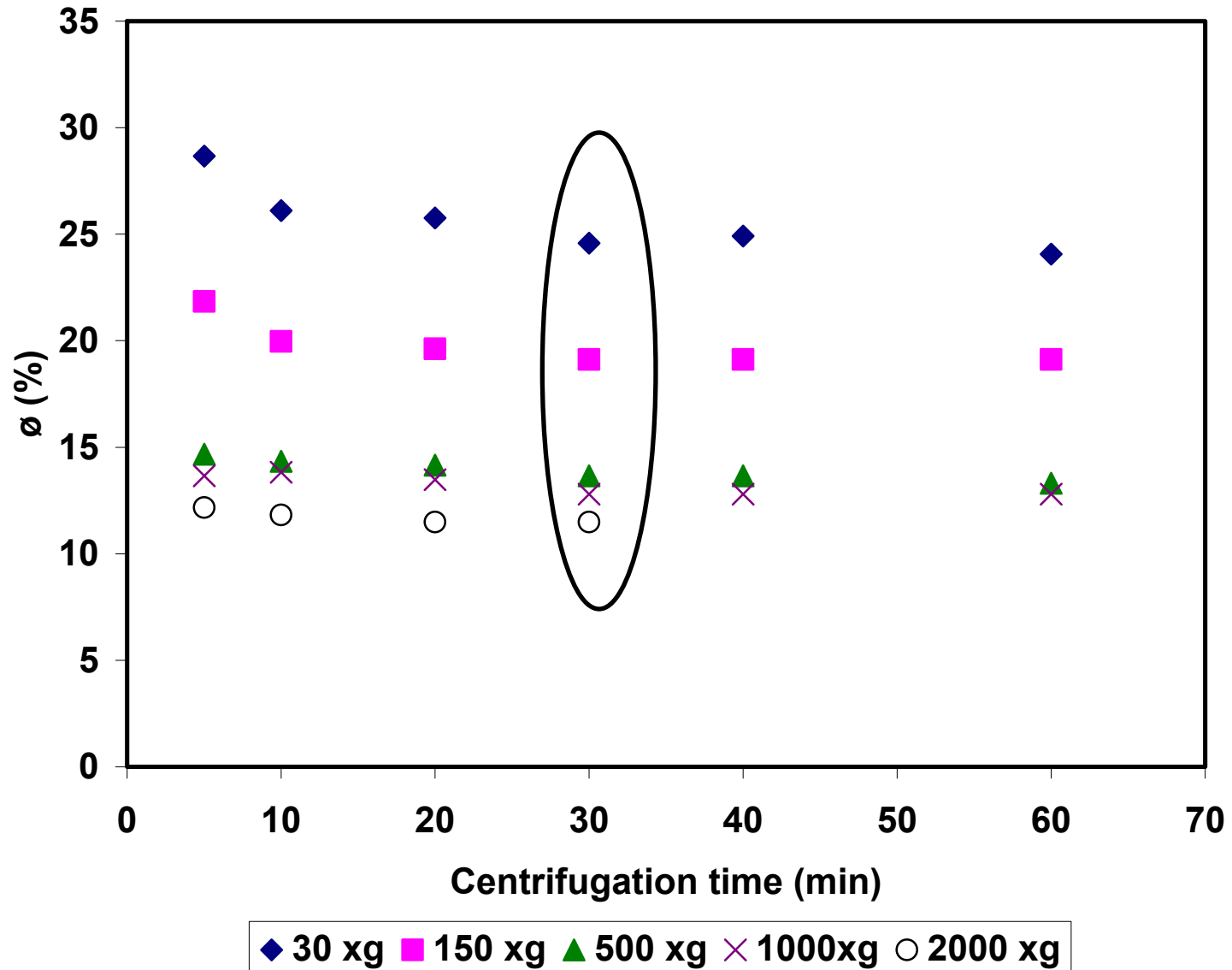
Particle phase volume – sedimentation



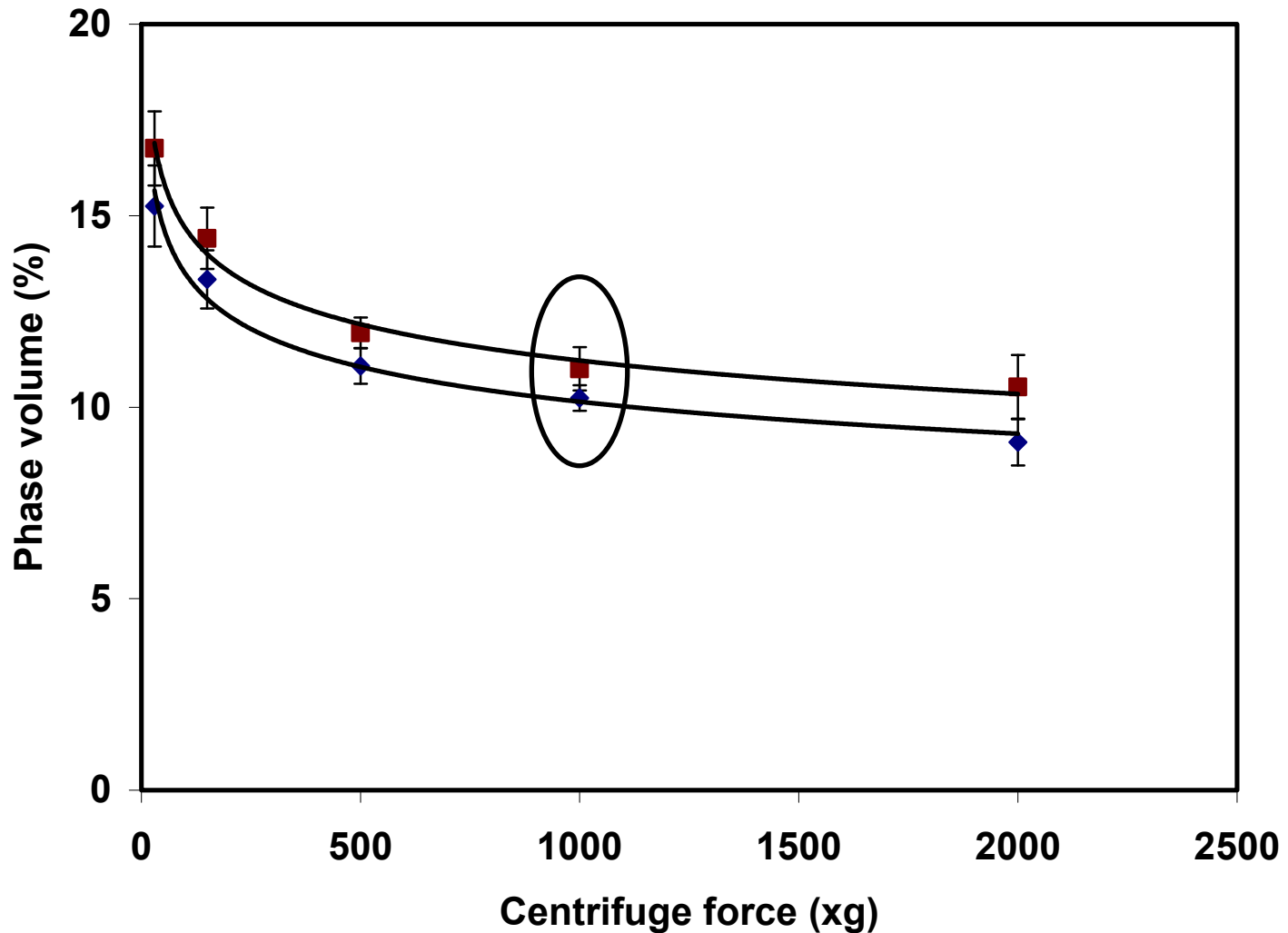
Phase volume – centrifugation

- Time?
- Speed?
- Concentration?

Phase volume – centrifugation

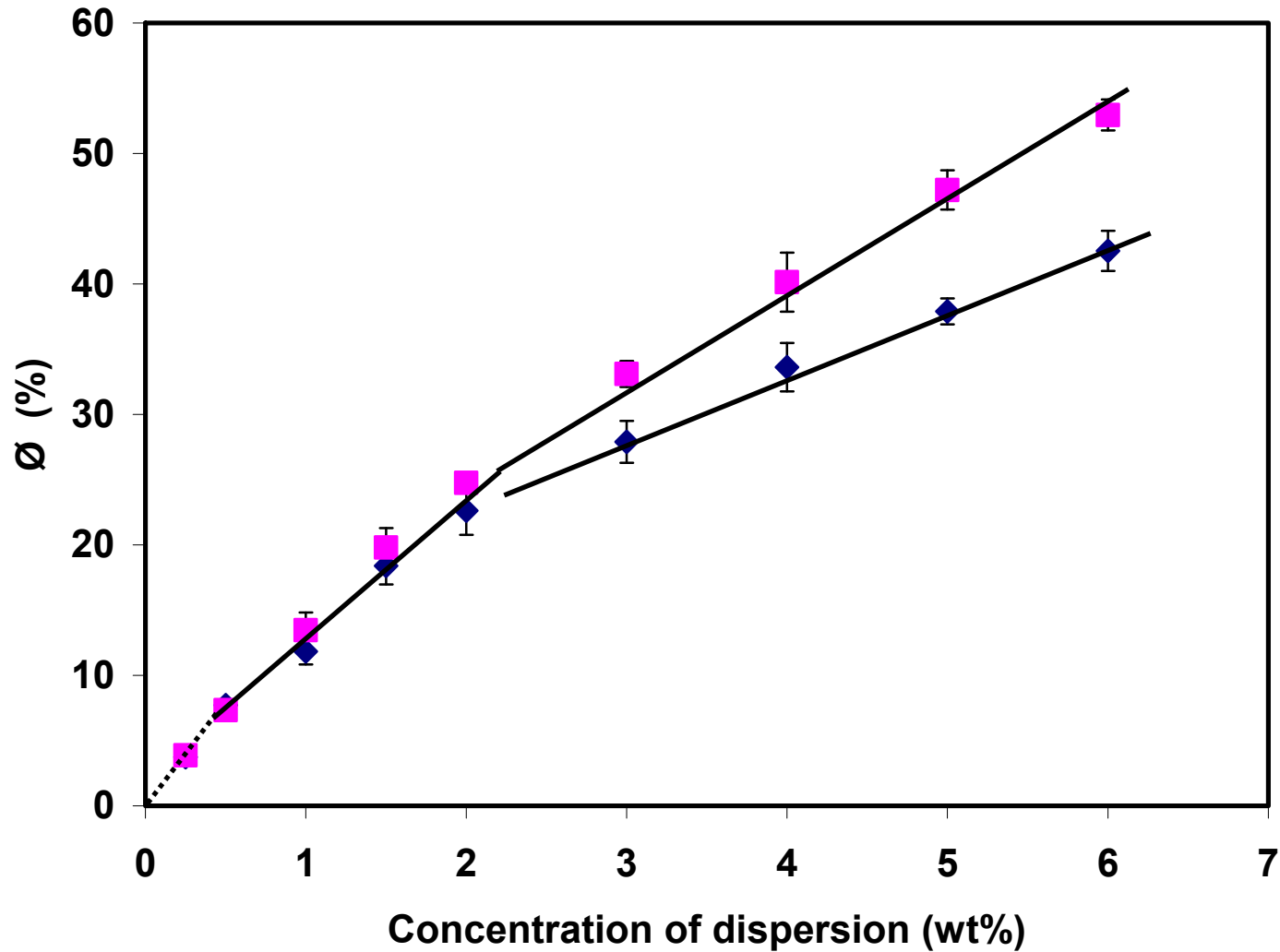


Phase volume – centrifugation



1% dispersion for 30 min

Phase volume - centrifugation



Centrifugation at 1000 xg for 30 min



Acknowledgement



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- Sarah Lebreton



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Thank you

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