Droplet synchronization in multiple interconnected parallel channels

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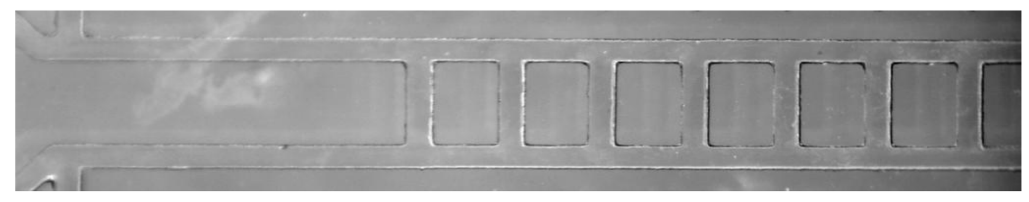
Droplet synchronization

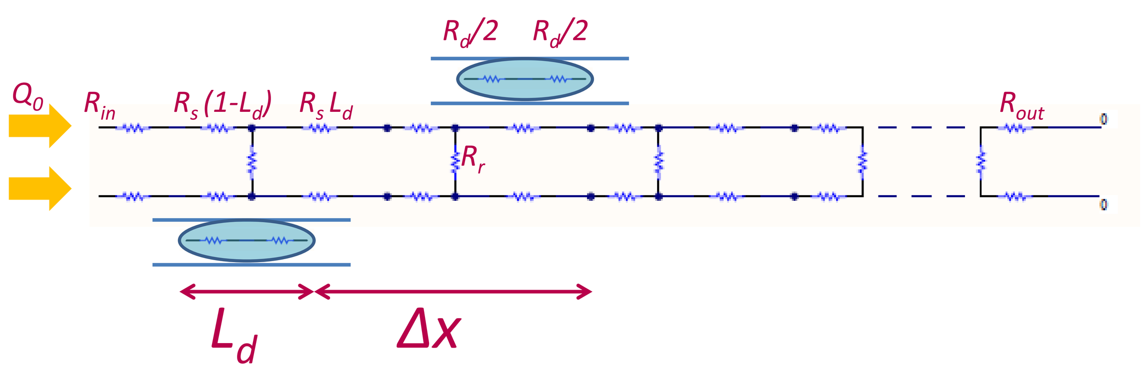
= Pairing of droplets flowing in parallel channels
- Required to promote position control, encounter and coalescence
- Passive synchronization achieved with bubbles [1] and droplets [2] in a ladder-like channel network

Our goal: understand, find the limits, optimize and generalize passive synchronization



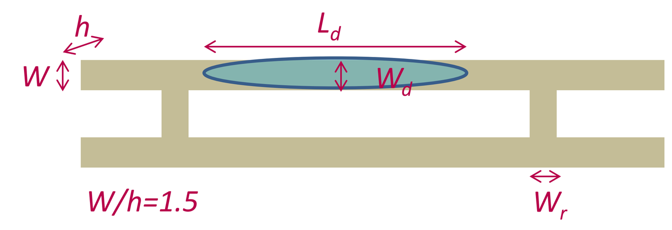
Lumped-element modeling

- Two parallel channels, each one conveying water drops in continuous oil phase
- Interconnecting rungs ➔ ladder-like network allowing oil transfer only



Hypotheses

- Droplet production in two flow-focusing structures
- Droplets sufficiently separated ➔ one droplet per channel



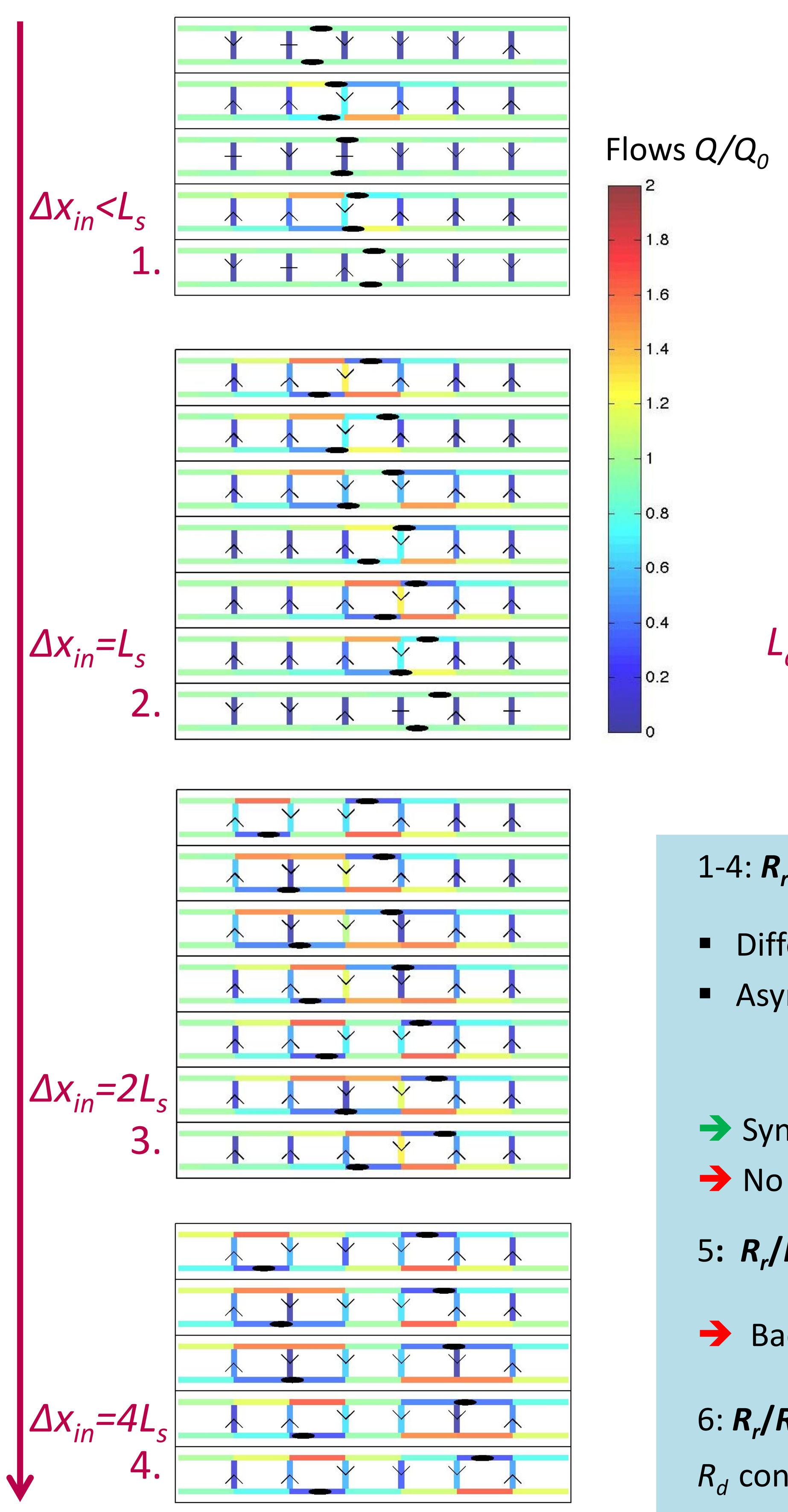
- $W_r/W < 1$ & $L_d > W$ ➔ Droplets can not flow in the rungs

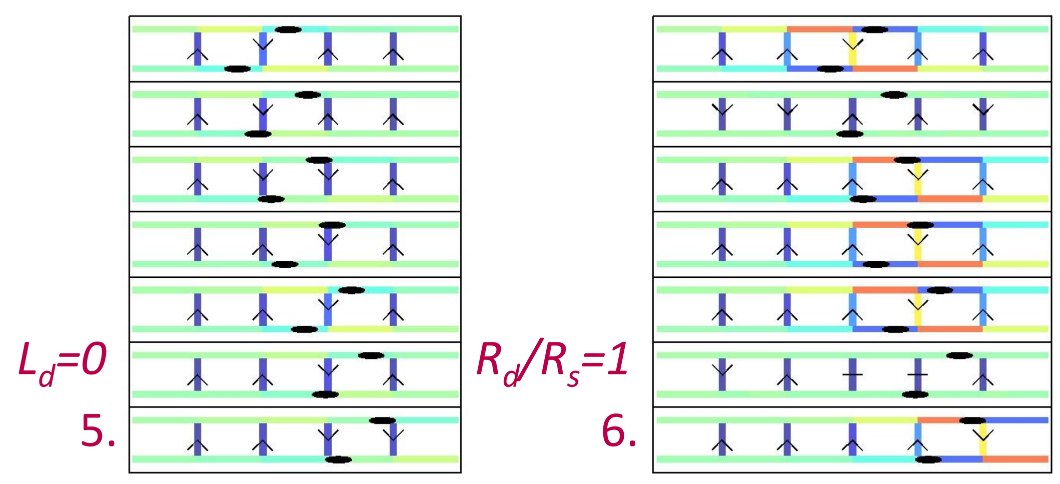
Droplet = localized resistance R_d
- Mainly due to end caps
- Independent on L_d (ok if $L_d > W$) [3]
- Rung crossing➔ $R_d/2$ on each side of the rung
- Additional resistance R_b in the rung when blocked ➔ not required

Parameters

- Design: R_r/R_s, R_d/R_s
- Input : Flow-rate and/or pressure-driven, ΔQ_0 (flow rate imbalance), L_d
- Initial condition: Δx_{in} = position shift

Flow analysis and synchronization mechanism





1-4: R_r/R_s=1.1, R_d/R_s=10, Δx_{in}<Ls ➔ Δx_{in}=3 Ls
- Different recirculation mechanism for each Δx_{in}
- Asymmetric flow (one droplet blocks, the other not)

➔ Synchronization until $\Delta x_{in} = 2\ L_s$
➔ No synchronization from $\Delta x_{in} = 3\ L_s$

5: R_r/R_s=1.1, R_d/R_s=1, $\Delta x_{in} = L_s$.

➔ Bad synchronization

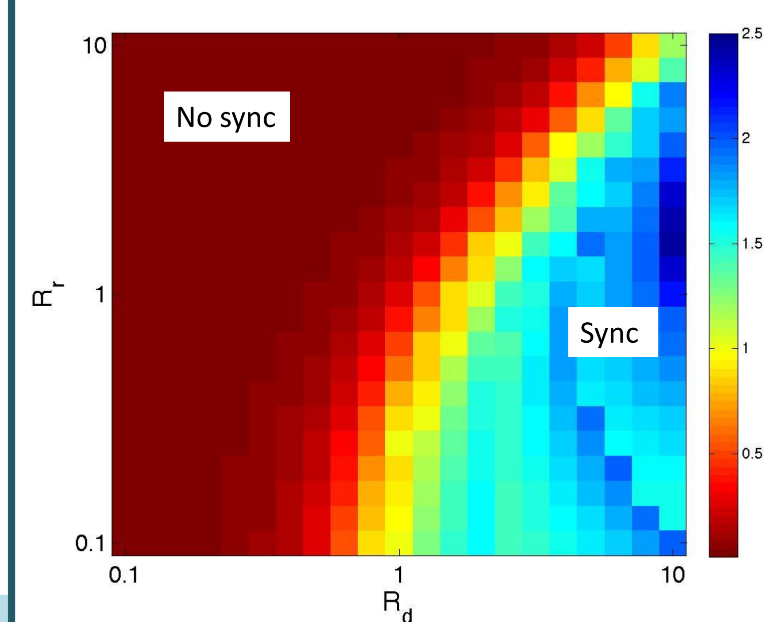
6: R_r/R_s=1.1, R_d/R_s=10, $\Delta x_{in} = L_s$, L_d=0

R_d considered as pointlike ➔ does not distribute around the rung

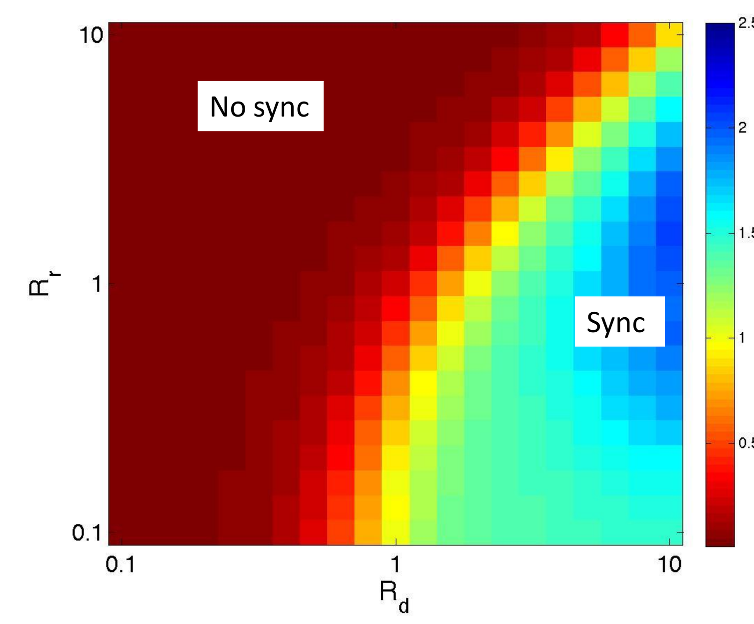
➔ No synchronization

Optimization

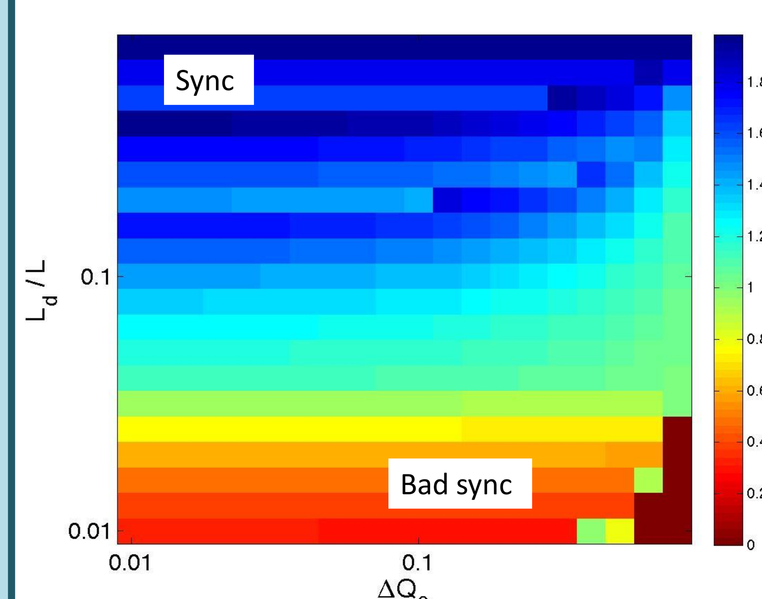
***E* = Synchronization efficiency = *max* (Δx_{in}) allowing synchronization in 19 rungs**



$E(R_r, R_d)$ in flow-rate-driven regime



$E(R_r, R_d)$ in pressure-driven regime



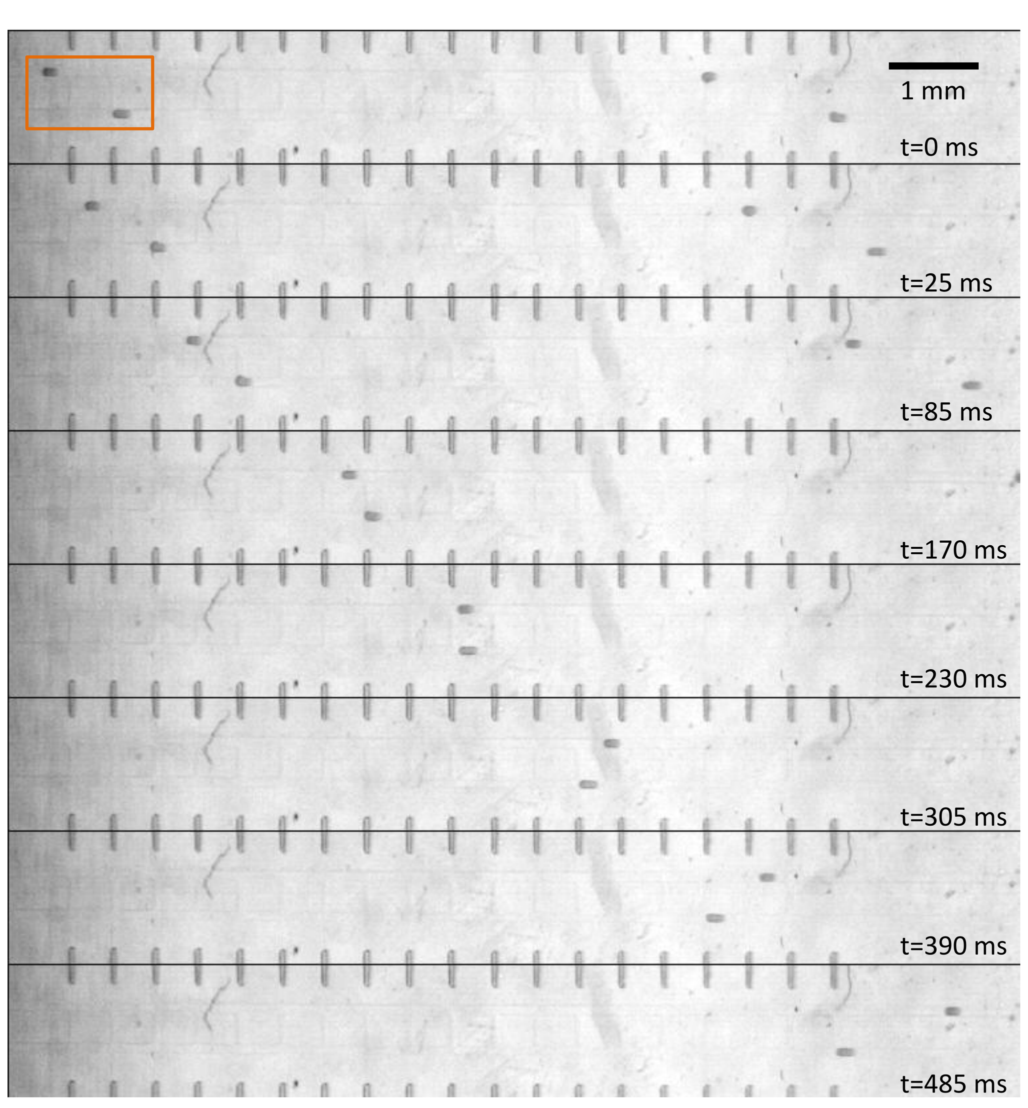
$E(L_d, \Delta Q_0)$ in flow-rate-driven regime

- Synchronization in flow-rate
- & in pressure-controlled regime

Optimal synchronization when:
- $R_d / R_s >> 1$
- $R_r / R_s \approx 1$
- $L_d > 0.1$

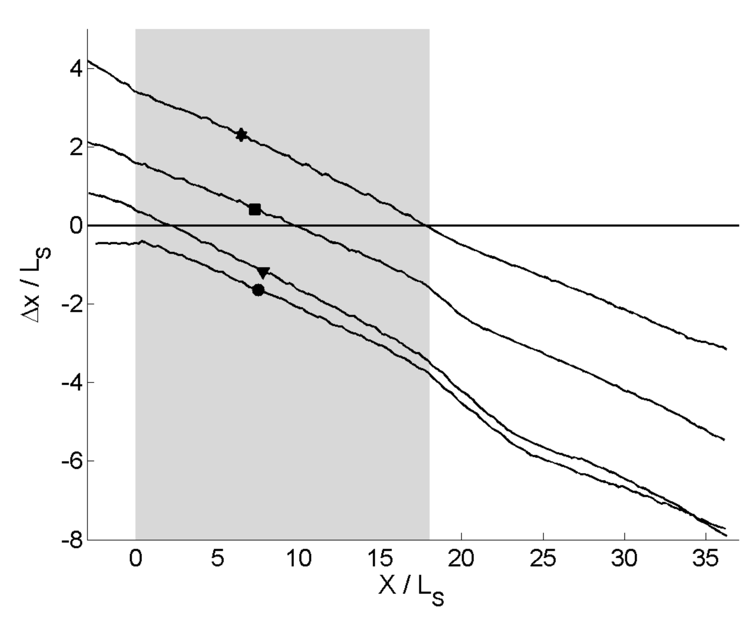
Weak influence of ΔQ_0

Experimental results

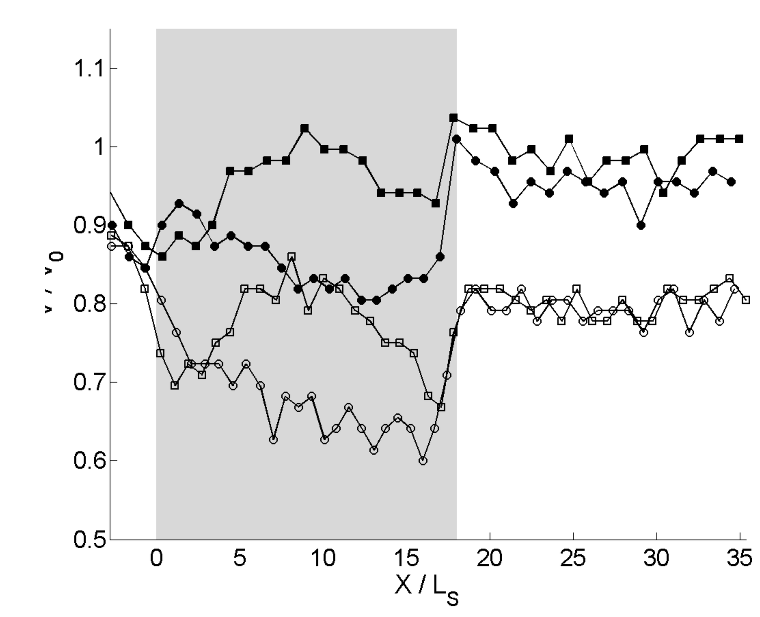


High speed recording. Two droplets enter the top and bottom channels with $\Delta x_{in} = 2L_s$.
No synchronization
Resulting channel speed : top > bottom, despite $\Delta Q_0 = 0$

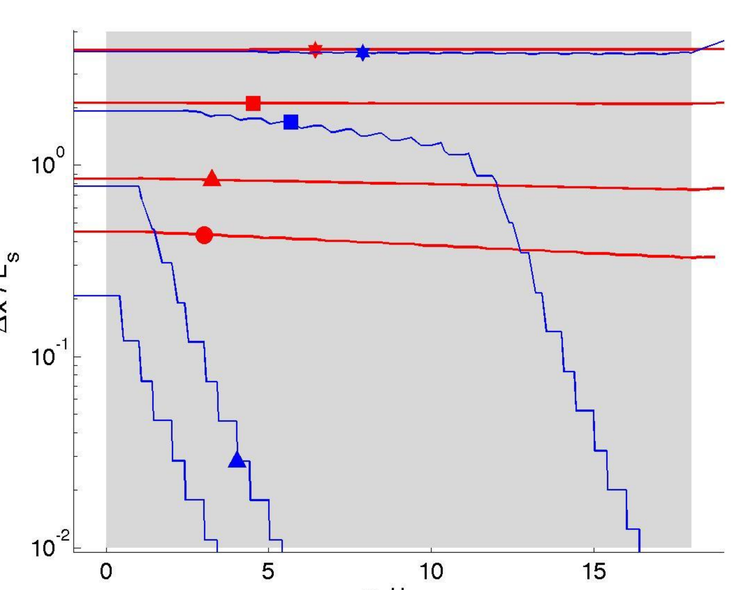
Evolution with droplet position



Observed Δx for different Δx_{in}.
(• ½ L_s, ▾ 1 L_s, ▪ 2L_s, ✱ 4 L_s)



Observed individual speed V of paired droplets in top and bottom channels, for two Δx_{in}
● ½ L_s, top; ○ ½ L_s, bottom
■ 2 L_s, top; □ 4 L_s, bottom



Predicted $\Delta x/Ls$ for different Δx_{in}
(• ½ L_s, ▾ 1L_s, ▪ 2L_s, ✱ 4 L_s)

Conclusion - Challenges – Future work

We used lumped-element modelling to better explain the synchronization mechanism.
We showed that pressure-driven regime should also provide synchronization.
We encountered several experimental issues that are not solved yet.
Our next move is to generalize to more complex ladder networks (incl. three channels) .

Ackowledgments

This research has been funded by the FNRS (FRIA) and the Interuniversity Attraction Poles Programme (IAP 7/38 MicroMAST) initiated by the Belgian Science Policy Office.

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References:
[1] M. Prakash and N. Gershenfeld, Science 2007, 315, 832-835
[2] B. Ahn et al., Lab-on-a-chip, 2011, 11, 3956-3962
[3] S. Vanapalli et al., Lab-on-a-chip, 2008, 9, 982-990

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