Netherlands Organisation for Scientific Research

Statistical crowd dynamics

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Where innovation starts

Crowds observation and modeling ?

https://bertspiertz.files.wordpress.com/2010/11/amsterdam-centraal-station-intercity-211403.jpg

Table of contents

- Our **motivations**
- Our **approach** to crowd dynamics
- **Modelling** pedestrians as active Brownian particles
- "Collisional cross section" of pedestrians at NS station
- Ongoing projects and ideas for the future

Crowd experiment: "in vitro"

Credits: Juelich

Our (general) motivations

- Basic question: **how do people move** ?
- Can we (statistically) define **"normal" behaviors** ?
    - ➢ **Average behaviour**
    - ➢ **Normal variability** around average behavior
    - ➢ **Emergent behaviour**: from single pedestrian to crowds
    - ➢ Physics / mathematical modeling of crowds
- *Can we **quantify** the **influence of environmental factors** (light, temperature, etc) on crowds ?*
- *Can we (in real-time) **stir a crowd** ?*

Our approach

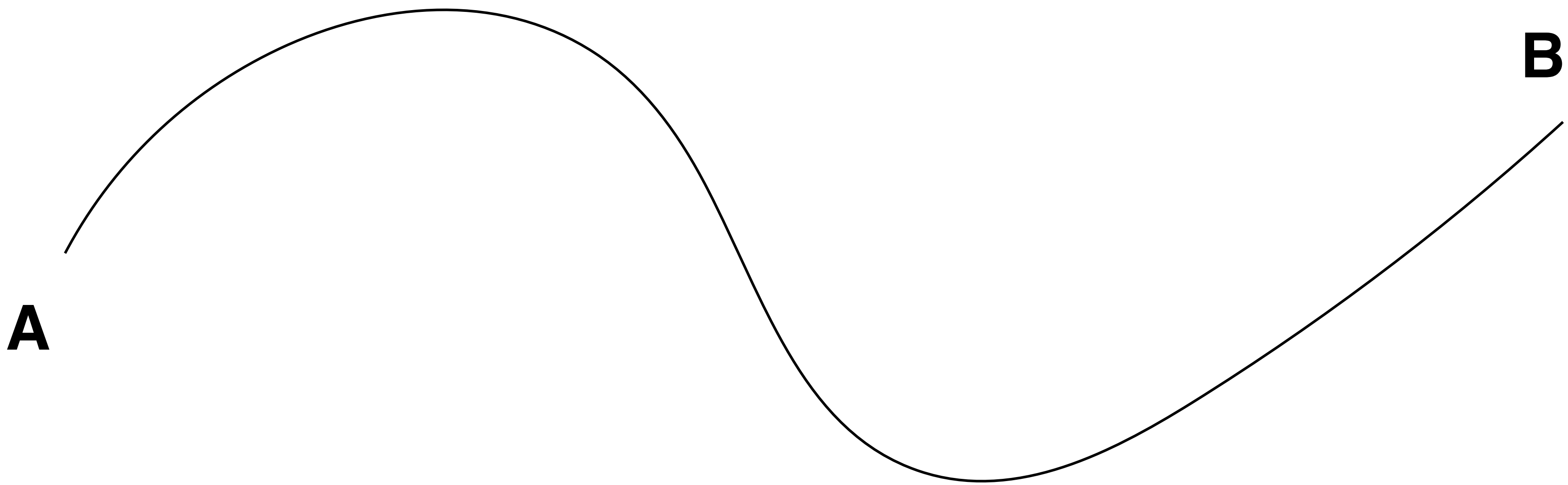
1. Study **simple** but “**real life**” setting(s)

2. People should **not be aware** of taking part in an experiments (psychological factor)

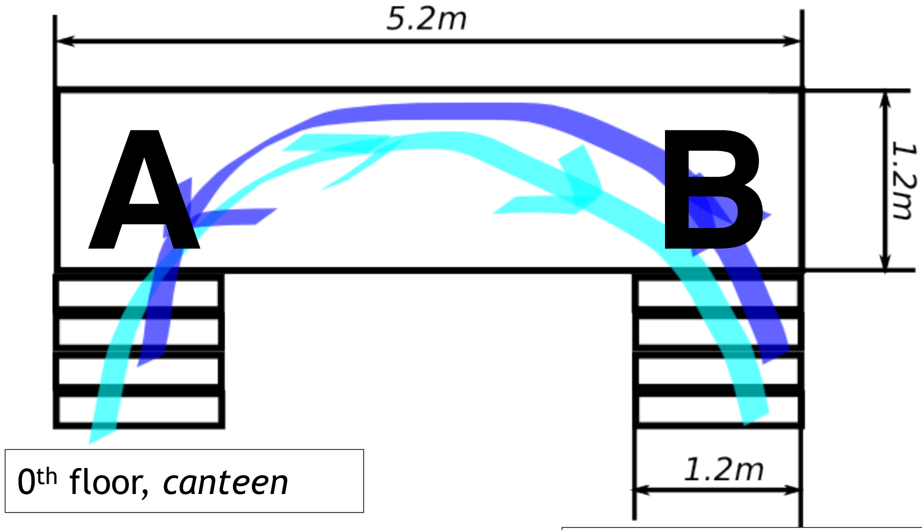
3. **Outstanding statistical samples** from (temporally) homogenous setting (i.e. dynamics repeats itself over days)

Simplifying the problem… (?)

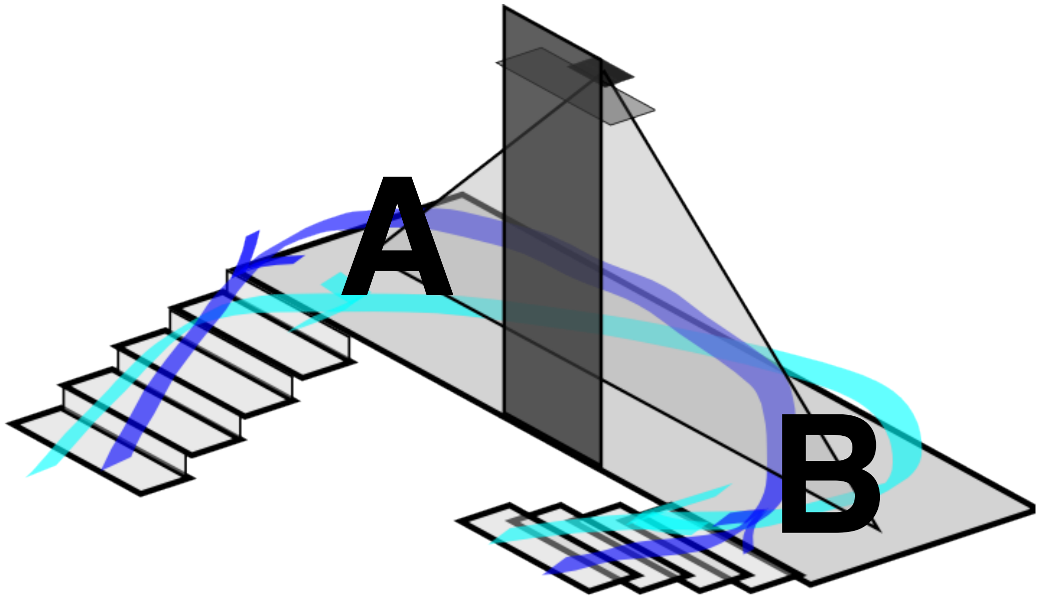
Pedestrians walking from A to B



Where are A and B?



(a)



(b)

Rec. win.: 2.2m x 1.2 m

Metaforum building, TU/e

- Recording Oct'13-Oct'14, ~h24, all weekdays
- ~2.2K people every day
- **~200K people** tracked

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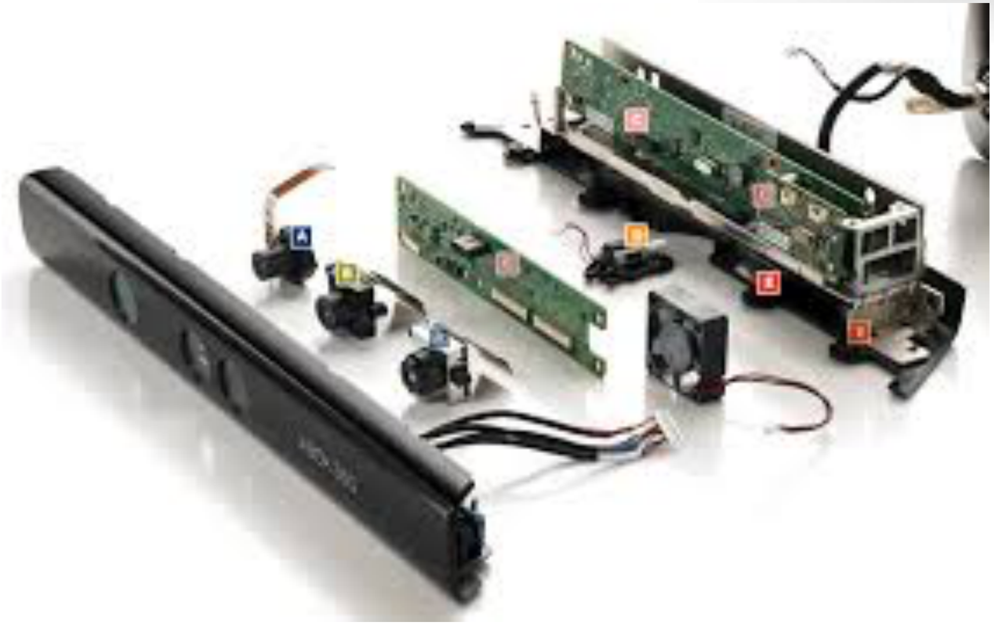
How?

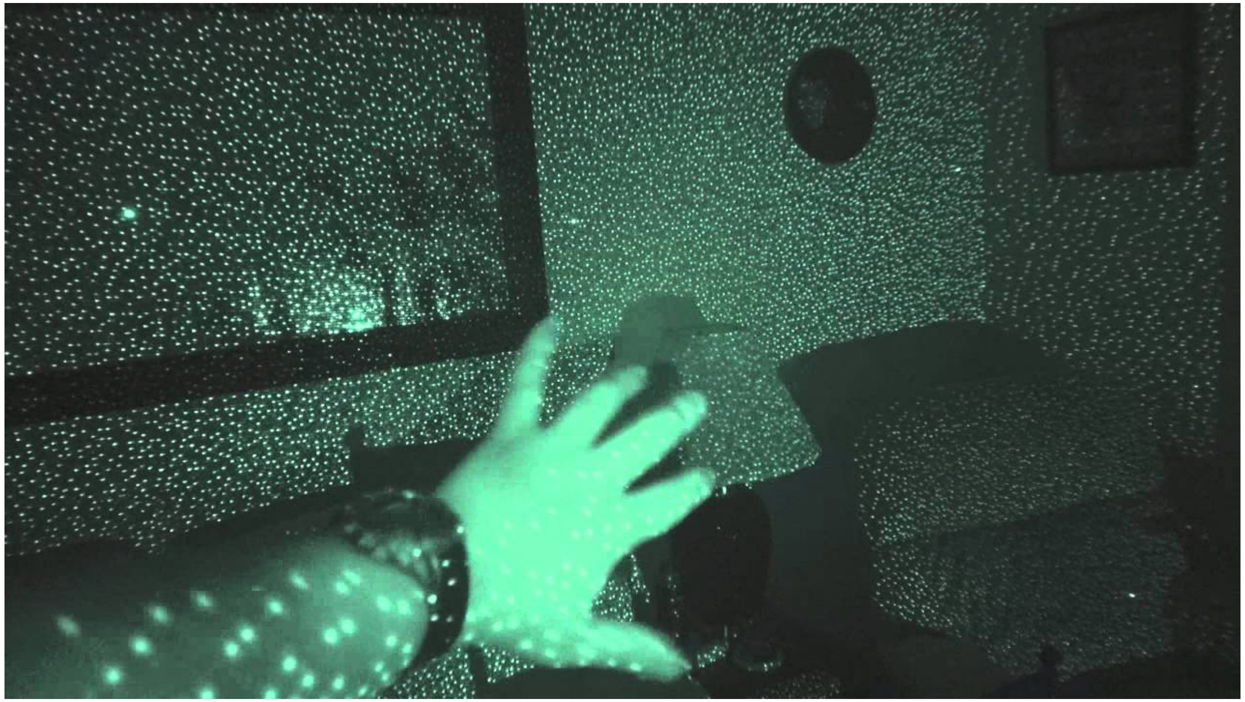
Microsoft Kinect

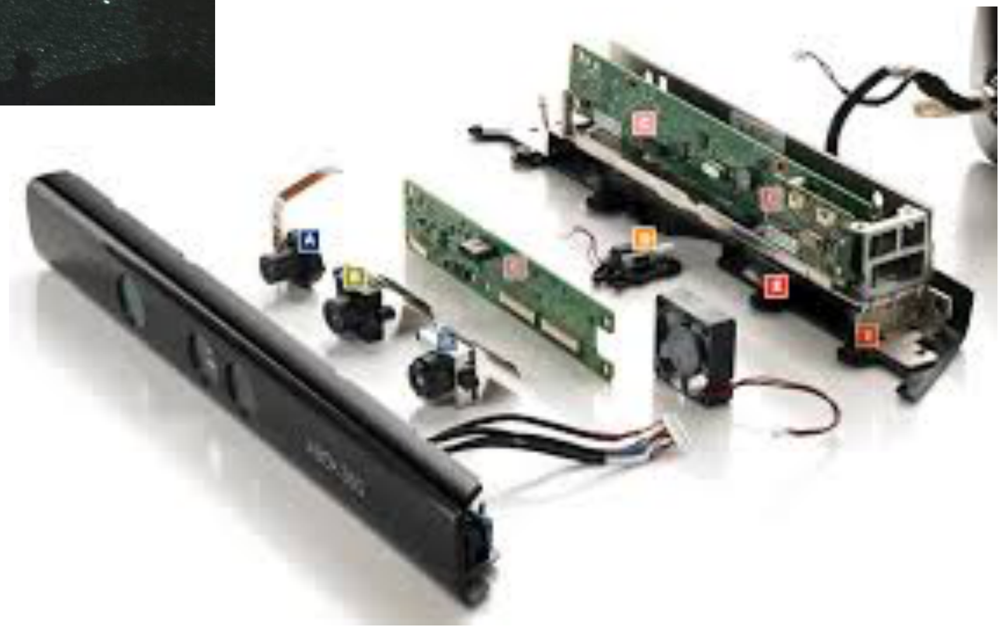


~100 $

(Now) out of production !

Microsoft Kinect 360





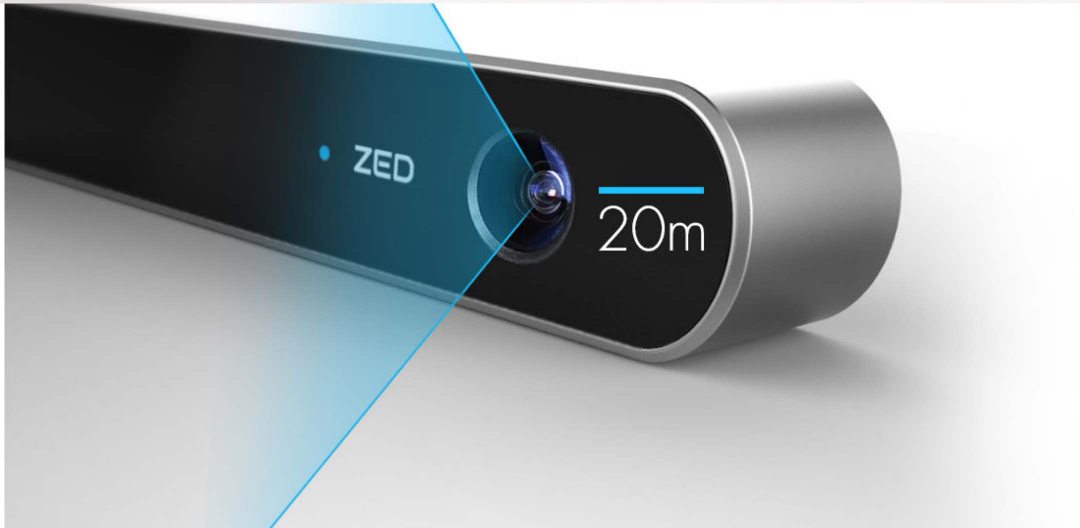
Light coding technique

Kinect one: time of flight!

~200 $

ZED 2K stereo camera

~500 $



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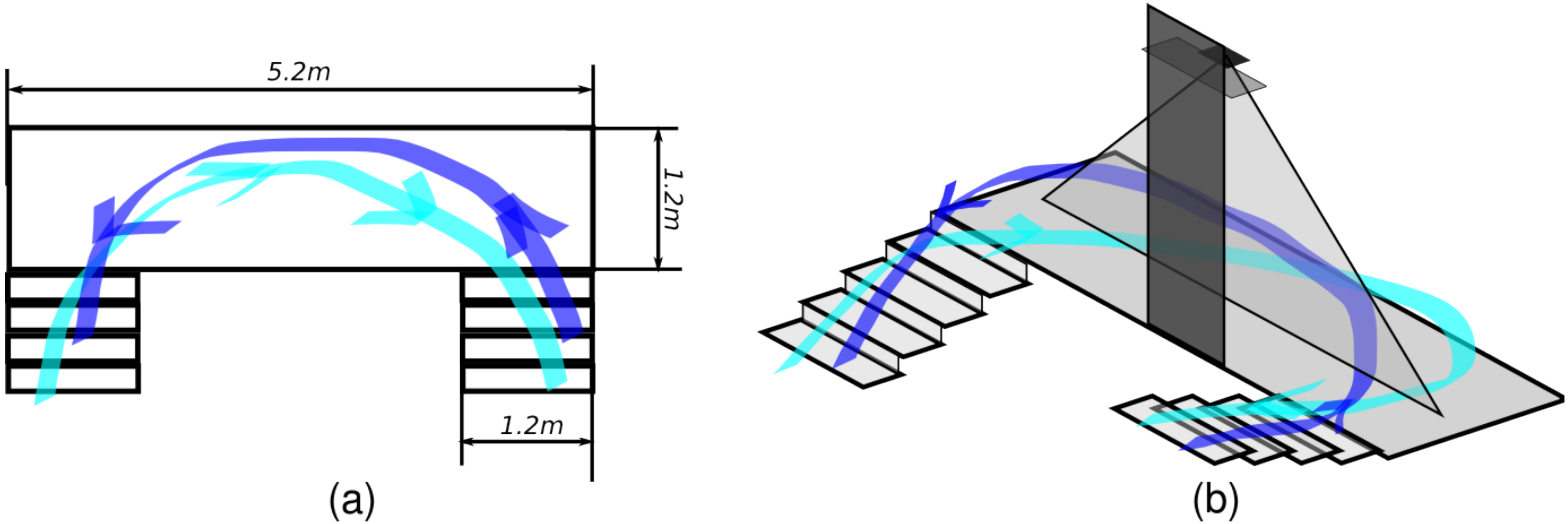
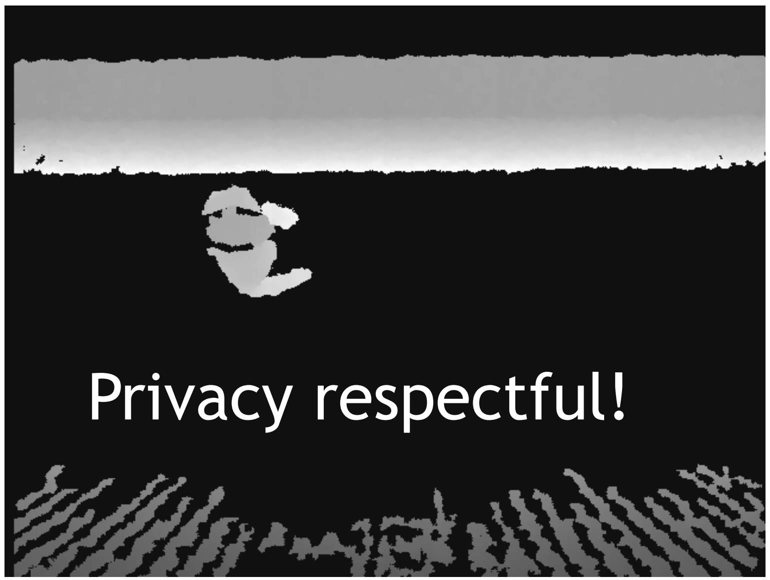
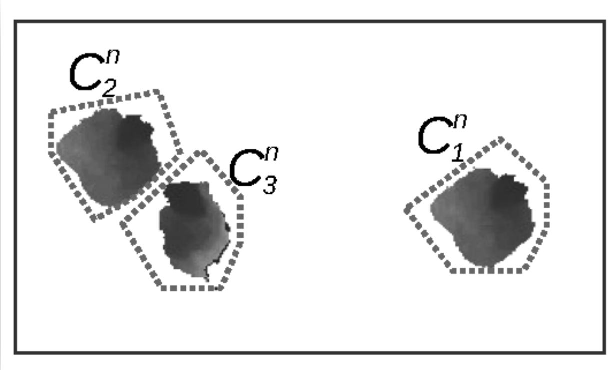
What do we see?

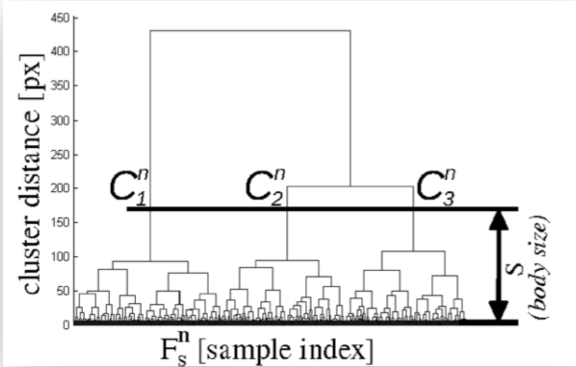




Pedestrians detection/tracking

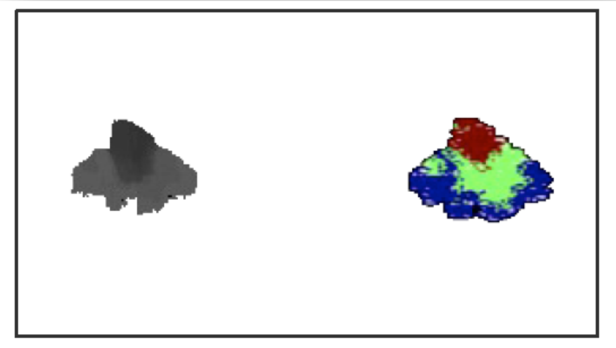
1





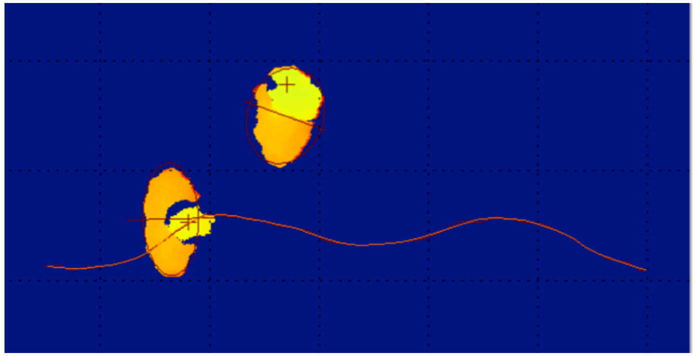
Foreground clusterization

2



Depth based head detection

3

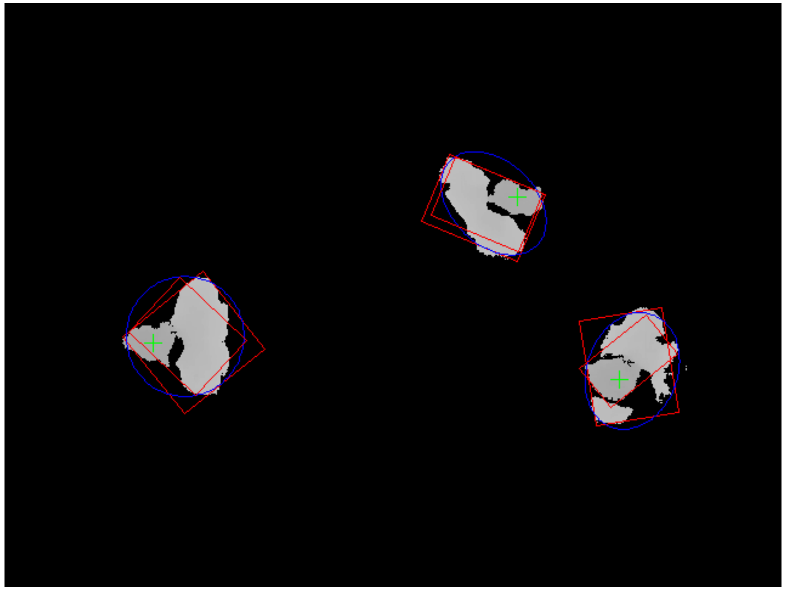


OpenPTV

Head tracking

[Seer et al. 2014, Willneff et Al. 2002, Willneff 2003]

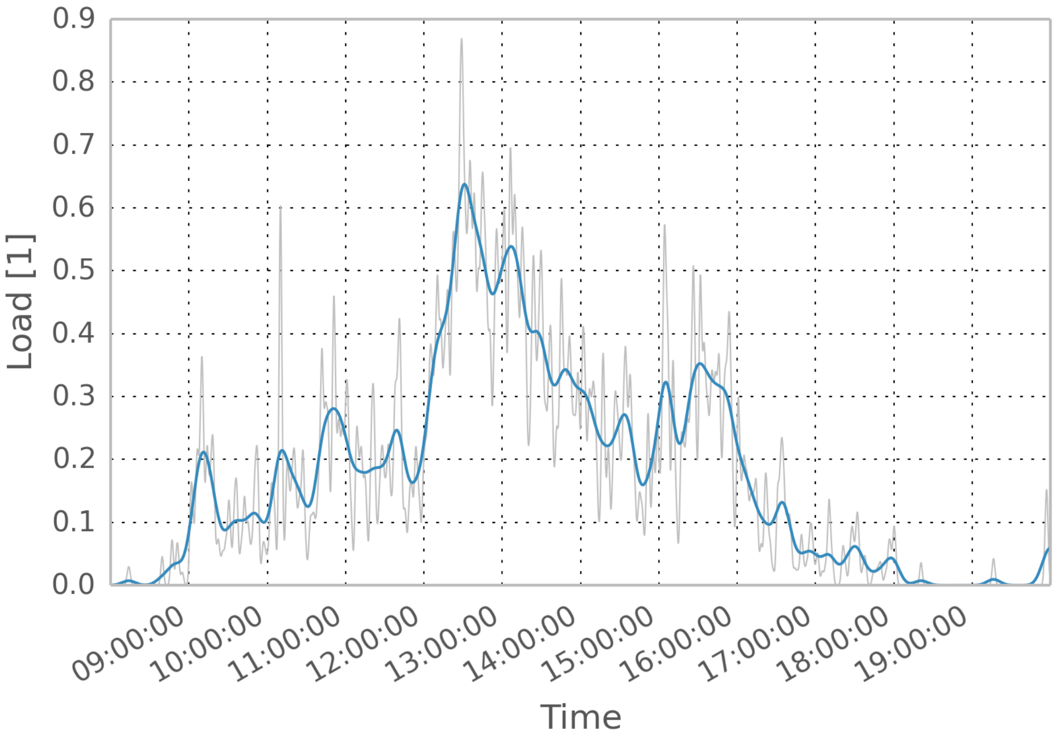
Typical dynamics @ MF



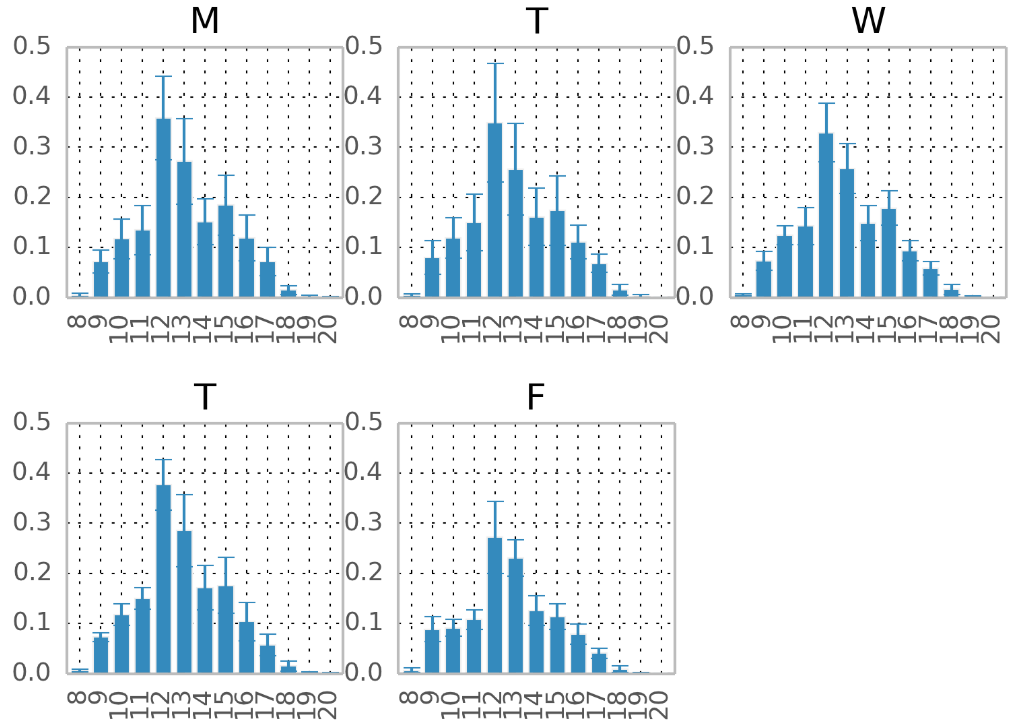
Dataset specs:

- 108 days of continuous recording
- ~250K trajectories collected
- ~2.2K traj/day
- Multiple, heterogeneous, traffic scenarios
    - *"Undisturbed"* pedestrians
    - Multiple pedestrians
        - *"Co-flows"*
        - *"Counter-flows"*

Load of the structure

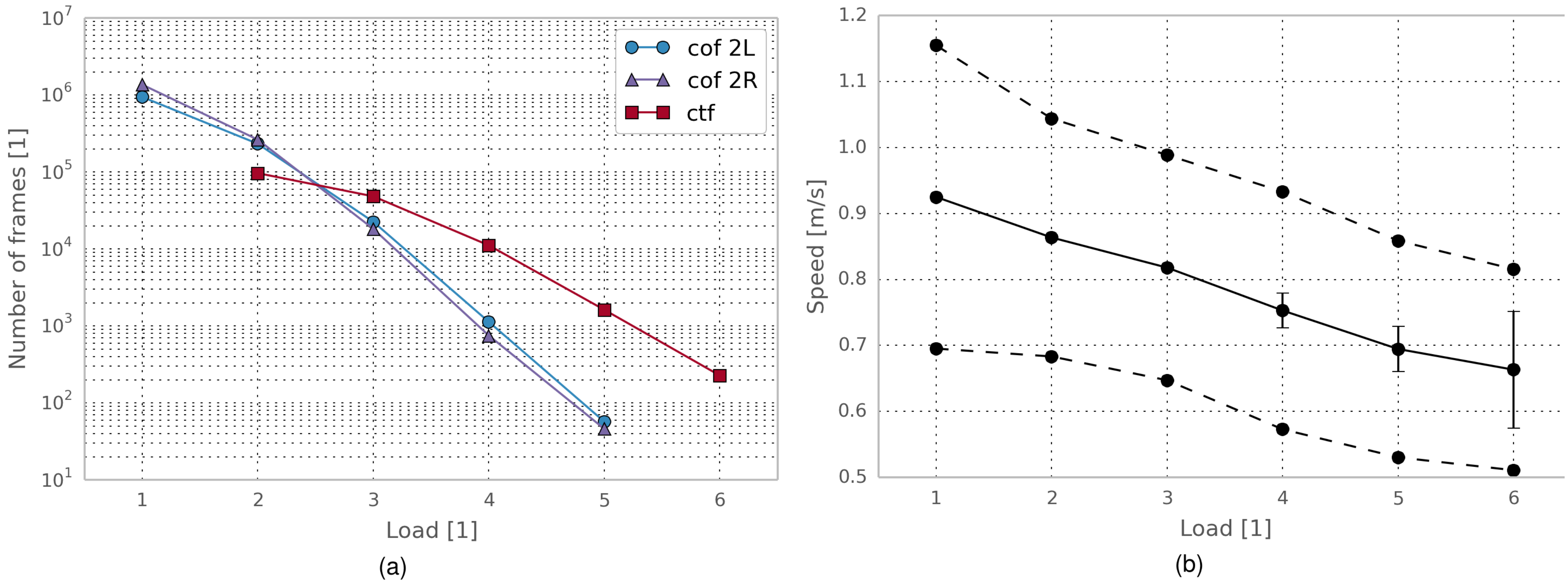


(a)

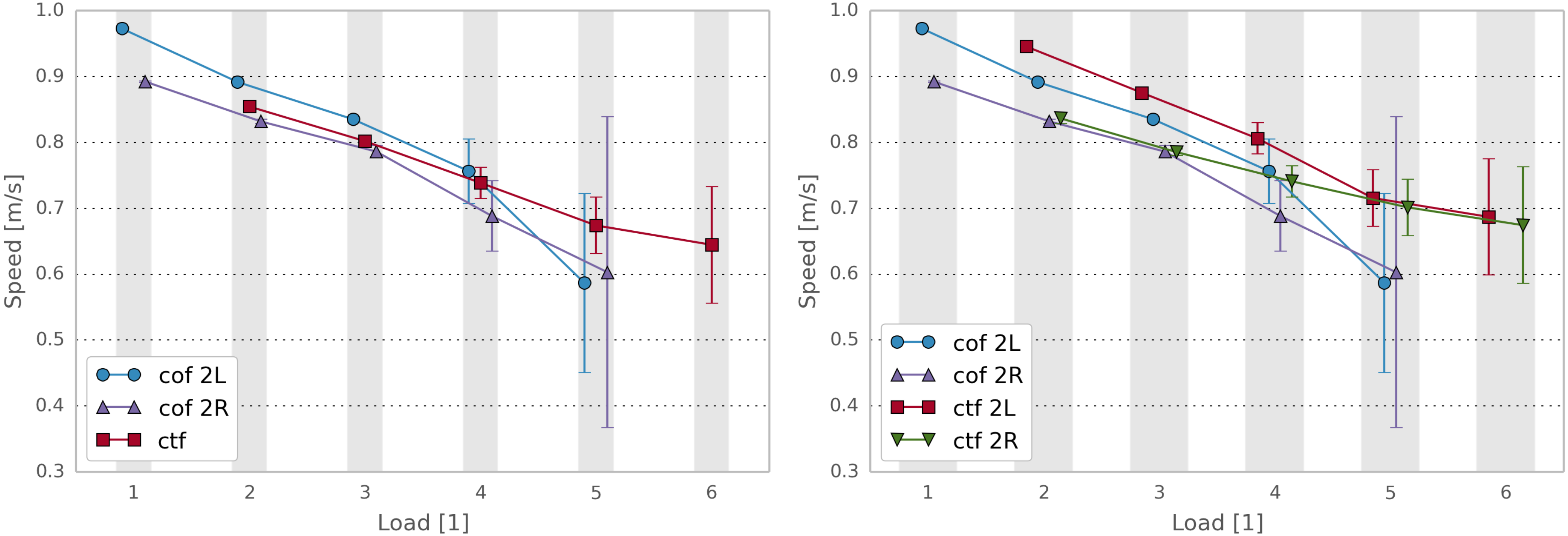


(b)

Fundamental diagram



Fundamental diagram



(a)

(b)

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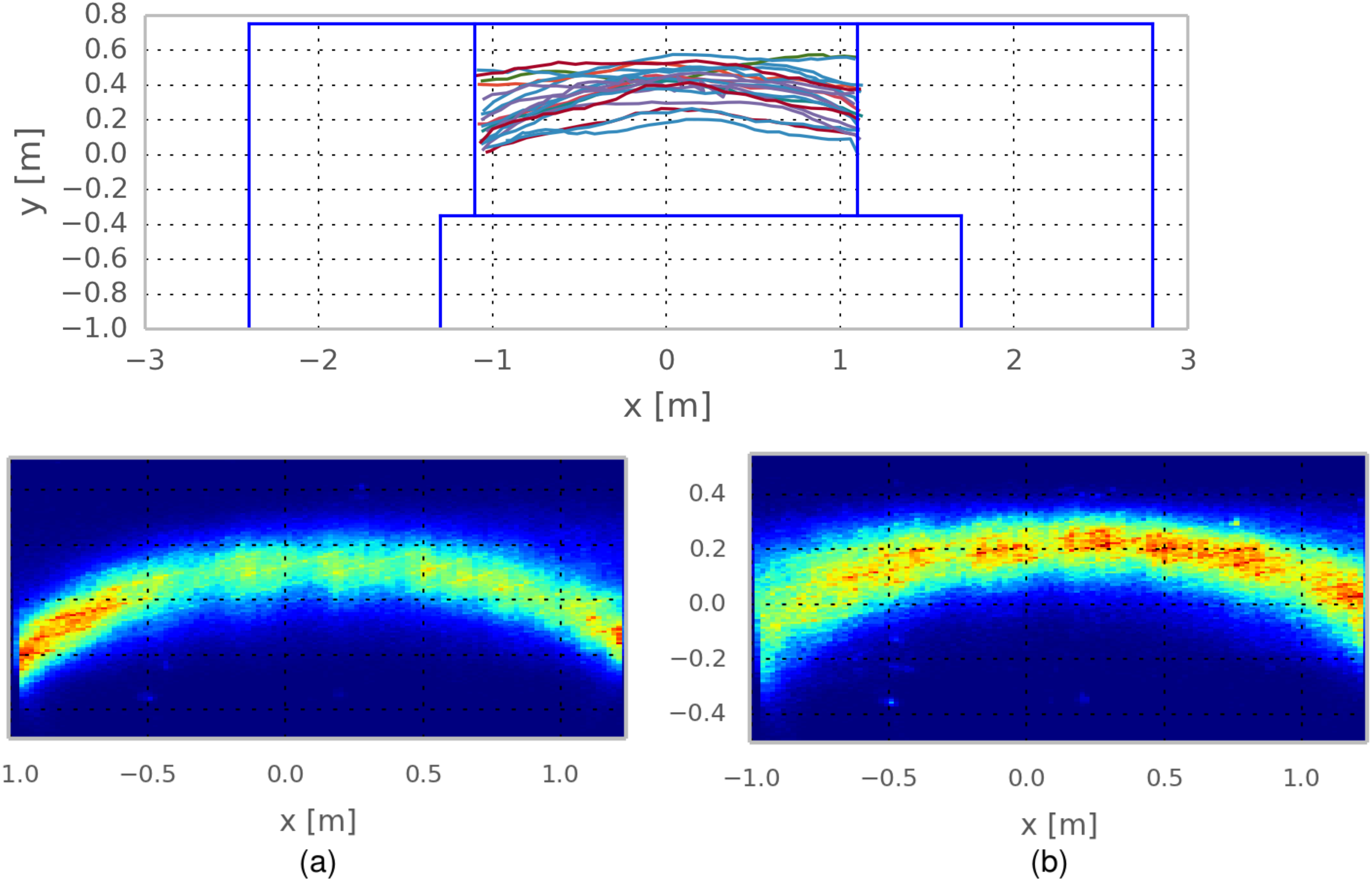
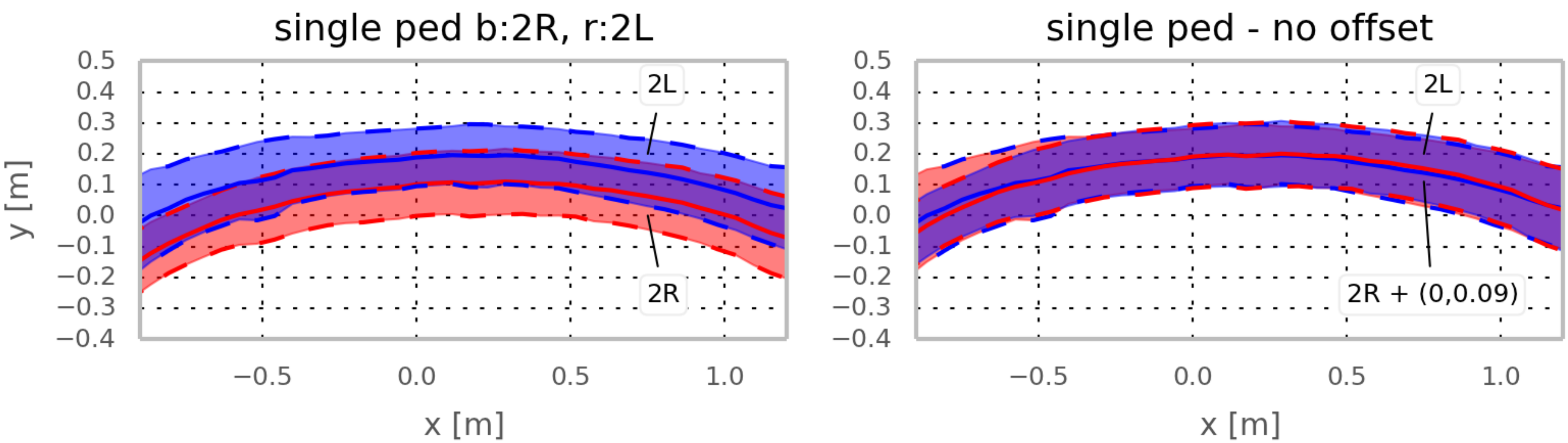
Heat map



0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
y [m]
−3
−2
−1
0
1
2
3
x [m]
0.4
0.2
0.0
−0.2
−0.4
y [m]
−1.0
−0.5
0.0
0.5
1.0
x [m]
(a)
0.4
0.2
0.0
−0.2
−0.4
−1.0
−0.5
0.0
0.5
1.0
x [m]
(b)

Heat maps



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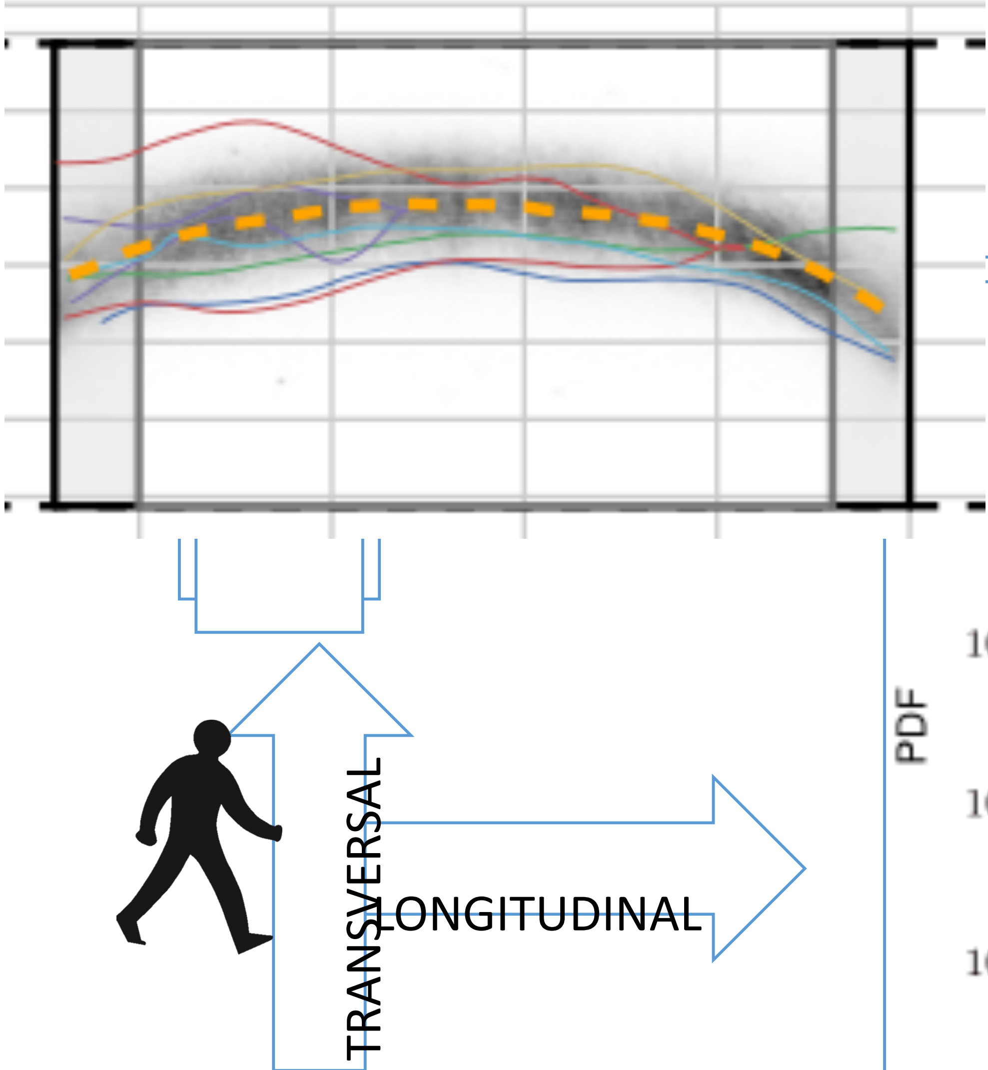
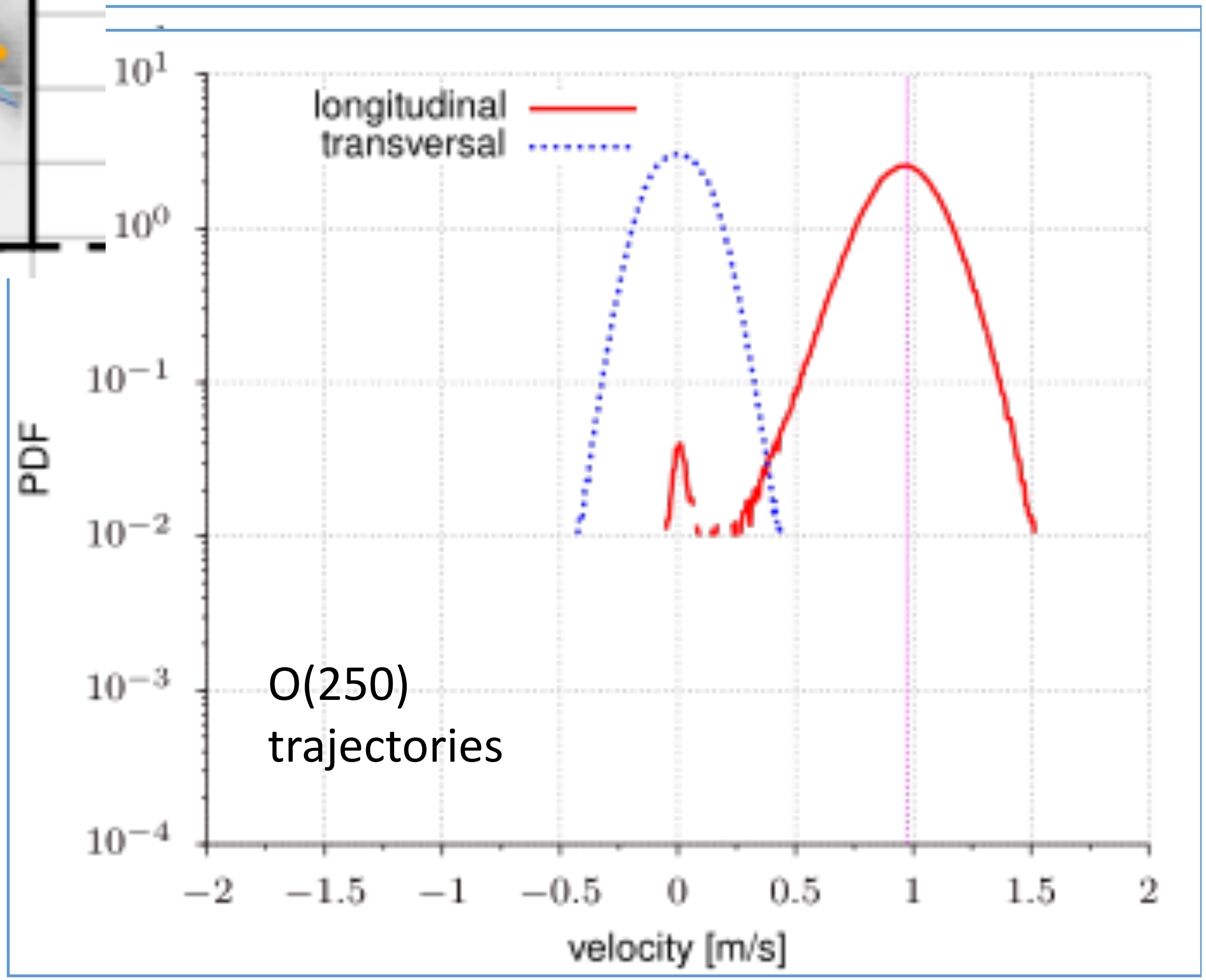
The role of statistics

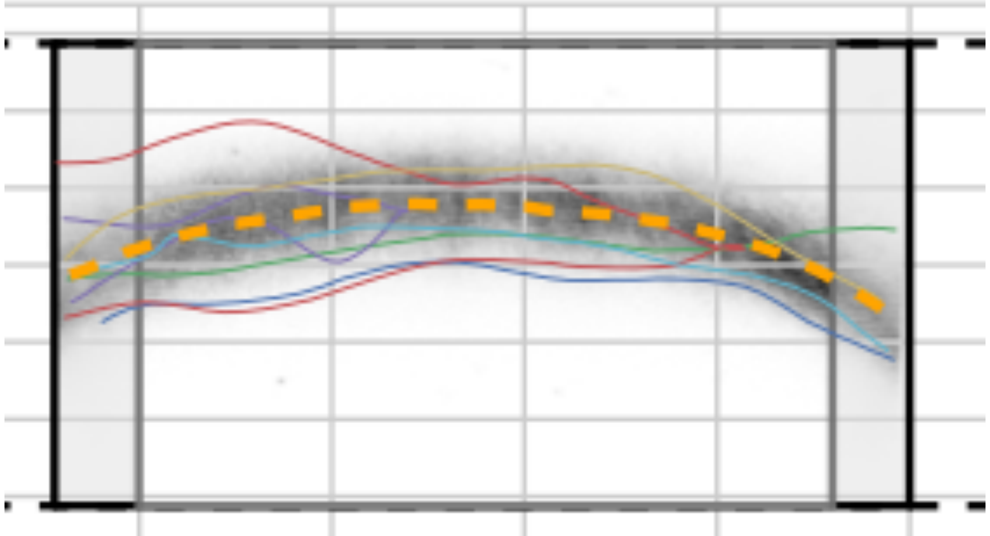
Diluted crowds with low statistics

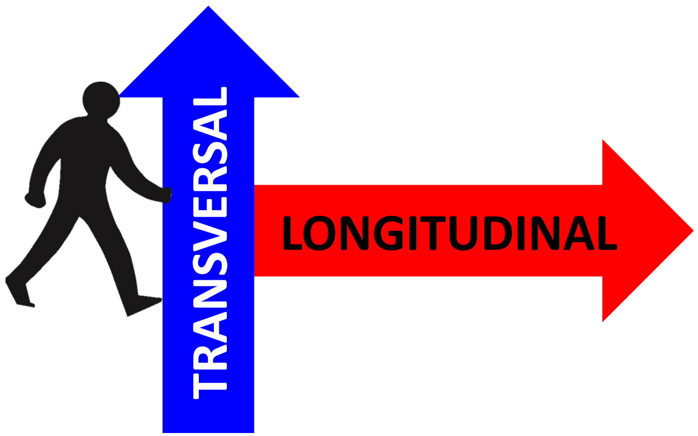




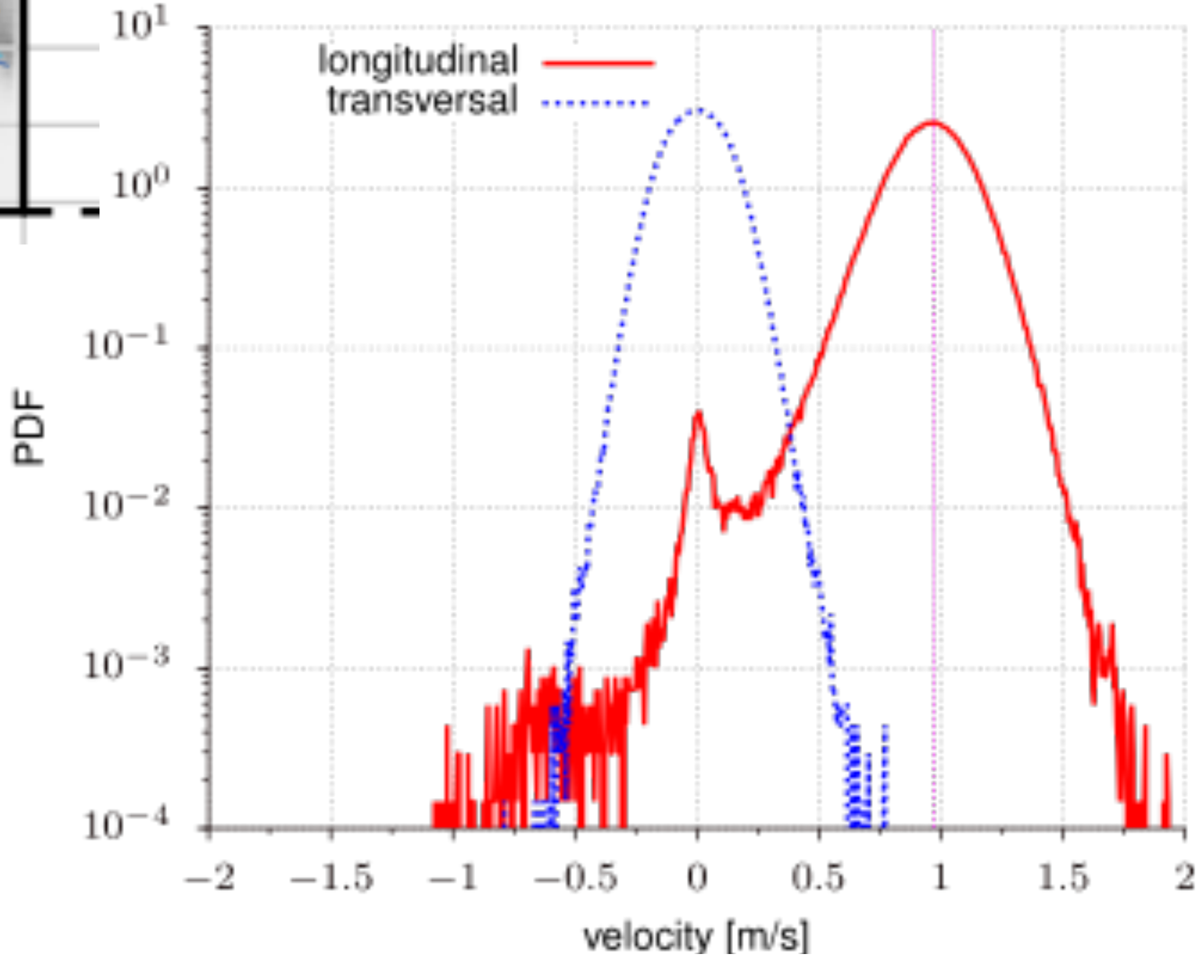
Fluctuations around preferred paths

Diluted crowds with high statistics

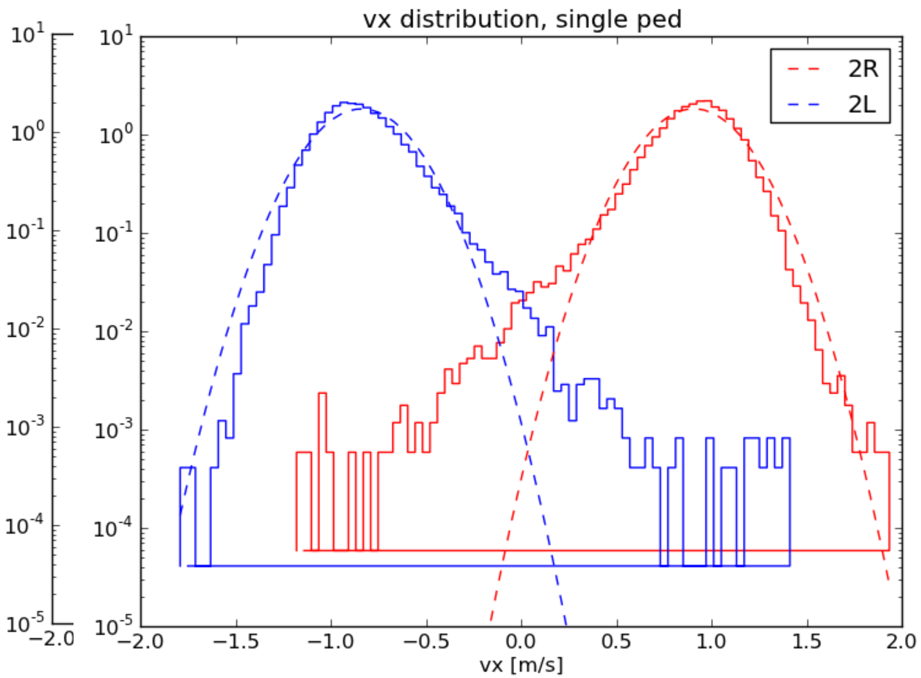


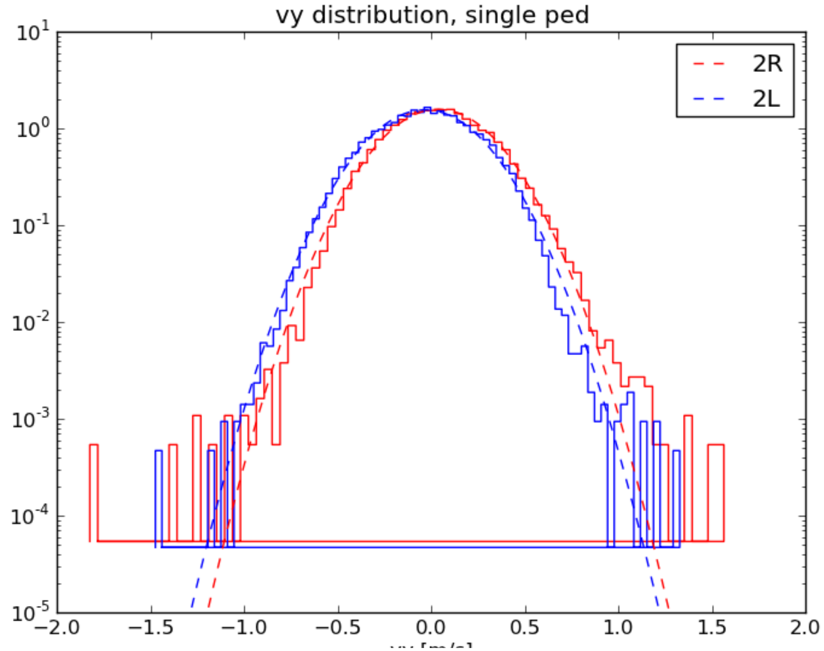


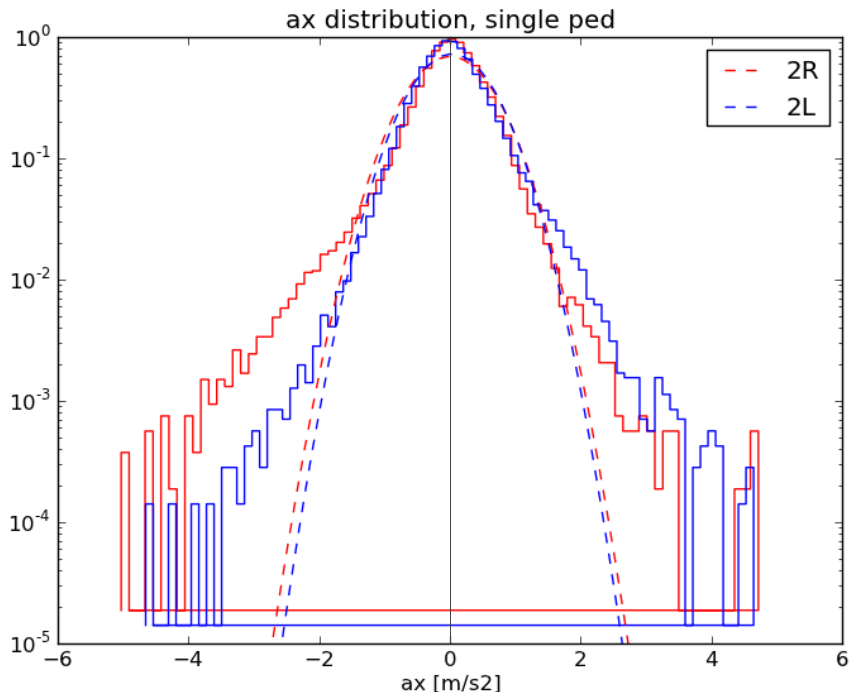
O(250.000) trajectories

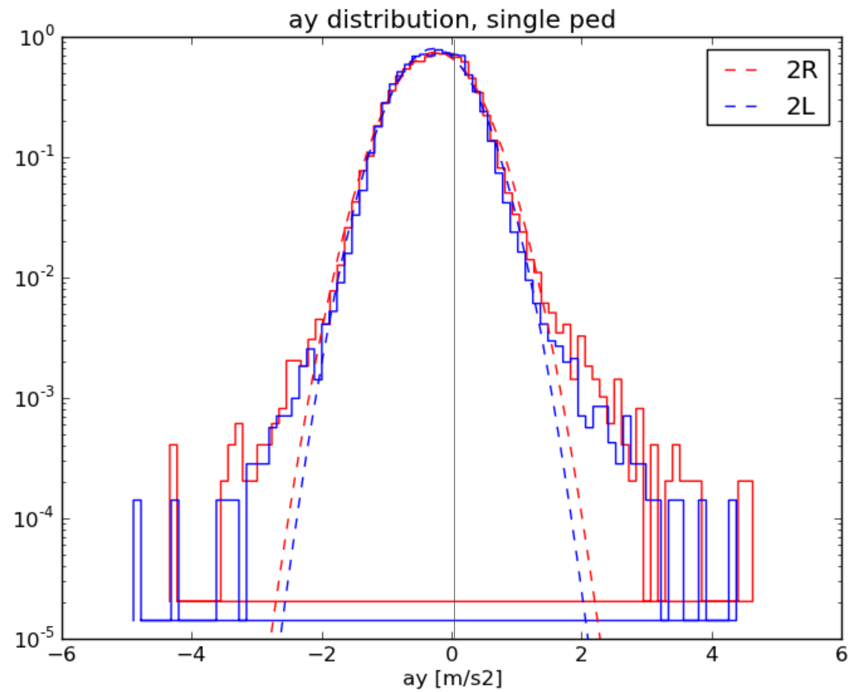


Lagrangian statistics – single ped









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Model for Brownian active particles

- The model is analytically soluble (Langevin equation)
- Longitudinal and transversal dynamics are decoupled
- Turn-around probability is connected to noise

$$\dot{x} = v_x \qquad \dot{y} = v_y$$

$$\dot{v}_x = -4\alpha(v_x^2 - v_0^2)v_x + \eta_x \qquad \dot{v_y} = -2\beta(y - y_0) - 2\gamma v_y + \eta_y$$

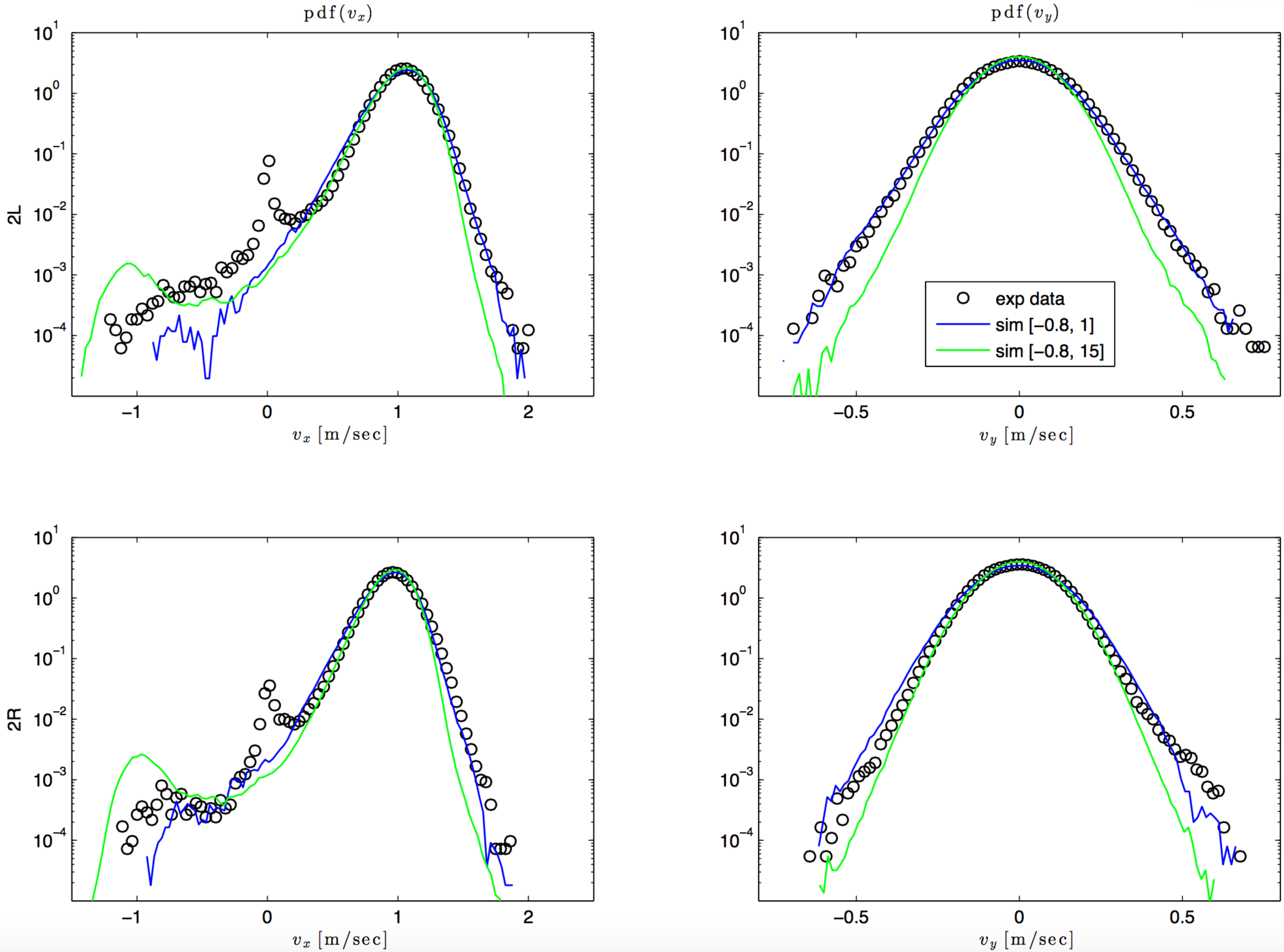
$$\eta_x = \eta_x^{rms}\ \dot{W} \qquad \eta_y = \eta_y^{rms}\dot{W}$$

$$\langle y(t)^2\rangle = \frac{(\eta_y^{rms})^2}{8\beta\gamma} \qquad \beta = \frac{\langle v_y(t)^2\rangle}{2\langle y(t)^2\rangle} \qquad \langle (v_y(t))^2\rangle = \frac{(\eta_y^{rms})^2}{4\gamma}$$

Time correlations

$$\langle v_y(t+\tau)v_y(t)\rangle = \langle (v_y(t))^2\rangle e^{-\gamma\tau}\left[\cos(\sqrt{2\beta-\gamma^2}\tau) - \frac{\gamma}{\sqrt{2\beta-\gamma^2}}\sin(\sqrt{2\beta-\gamma^2}\tau)\right]$$

[Corbetta et al. 17, Phys. Rev. E]



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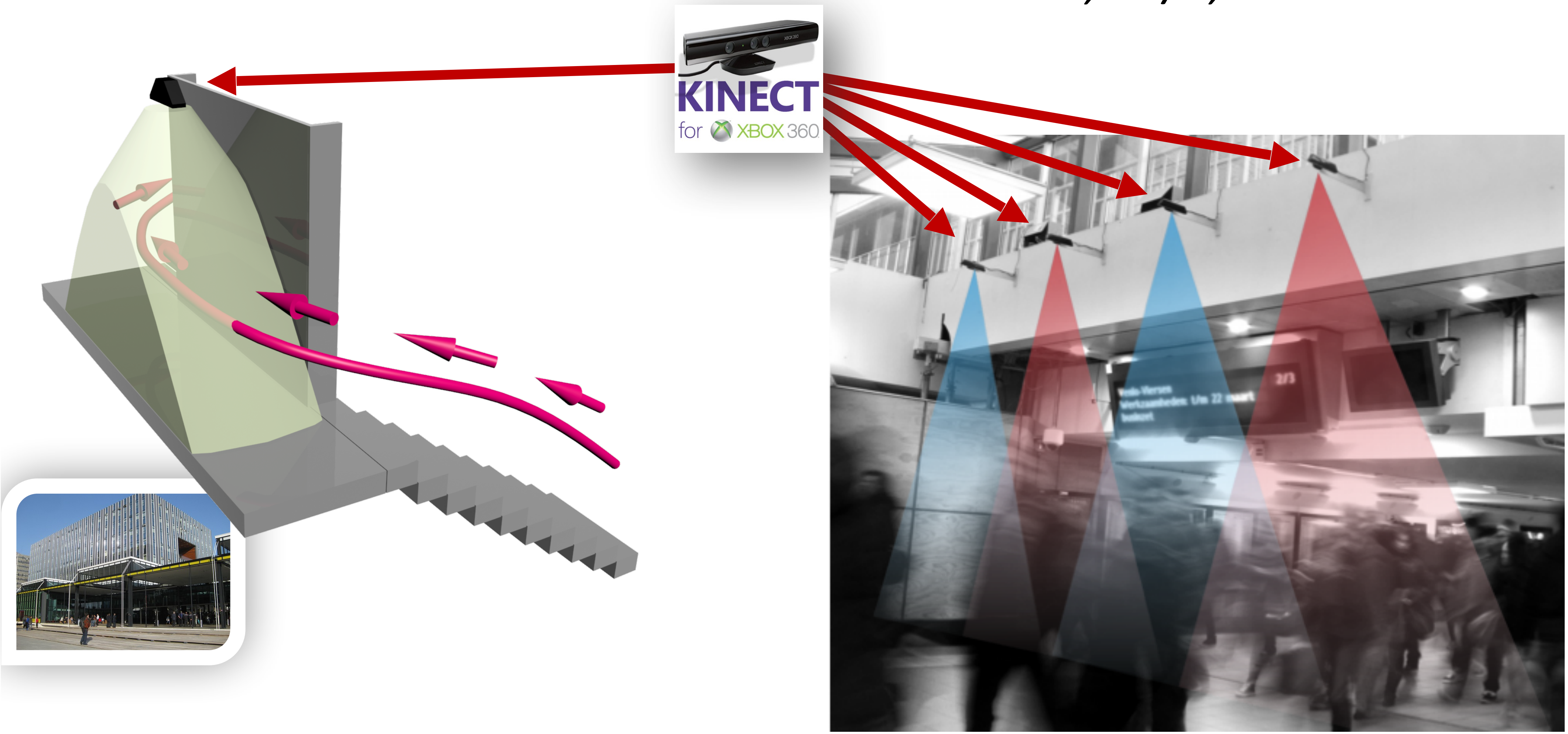
[Corbetta et al. 17, Phys. Rev. E]

Crowd measurements in real-life

Continuous, 24/7, measurement



Metaforum @ TU/e *Sept. 13 – Sept. 14*

2.2K trajs/day => 220K trajs in total

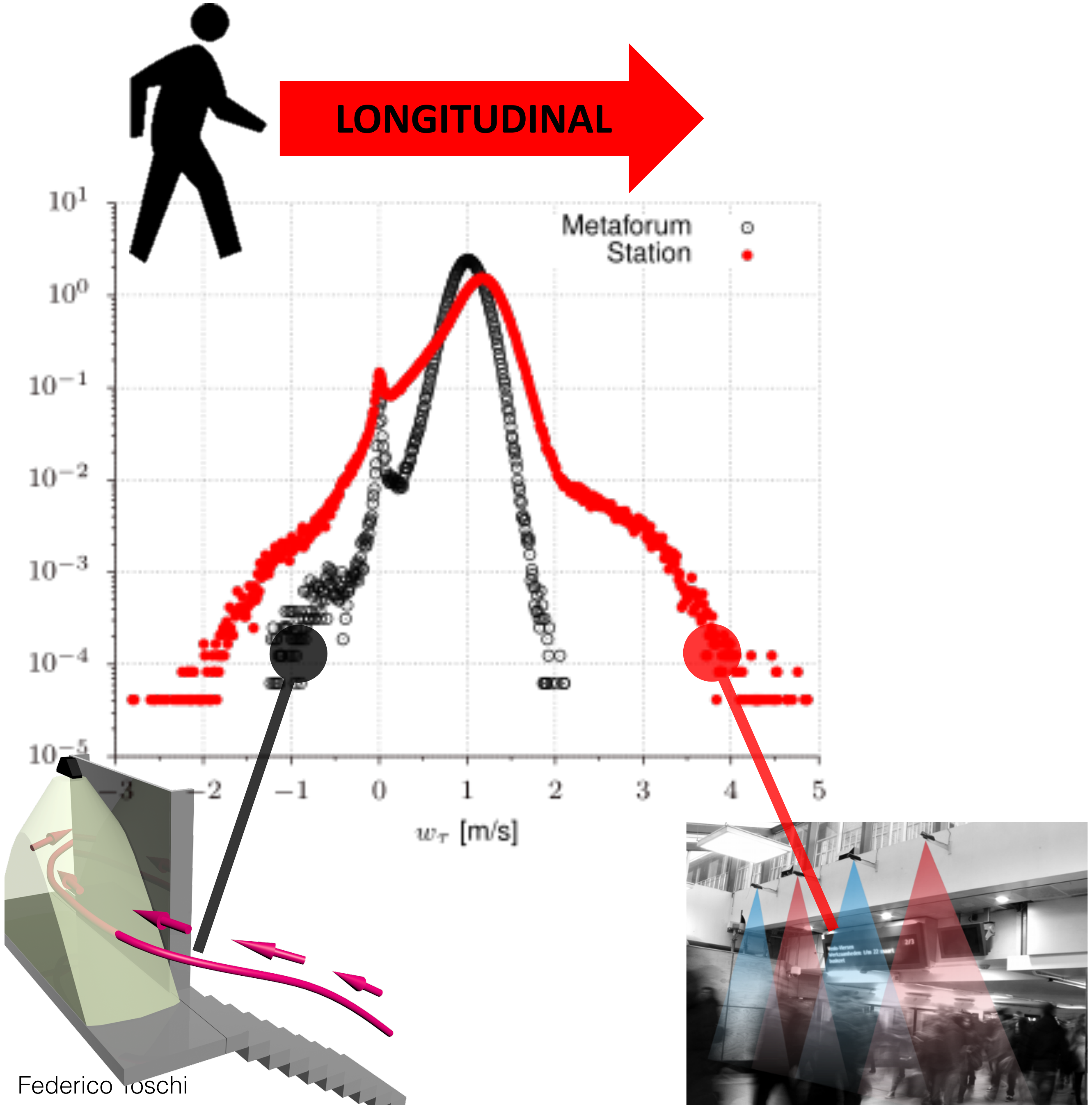
[Corbetta et al. 14,15,16,16,17,17] + Phd thesis

Eindhoven Train Station

Sept. 14 – Mar. 15

80K trajs/day => 5M trajs in total

Diluted crowds with high statistics



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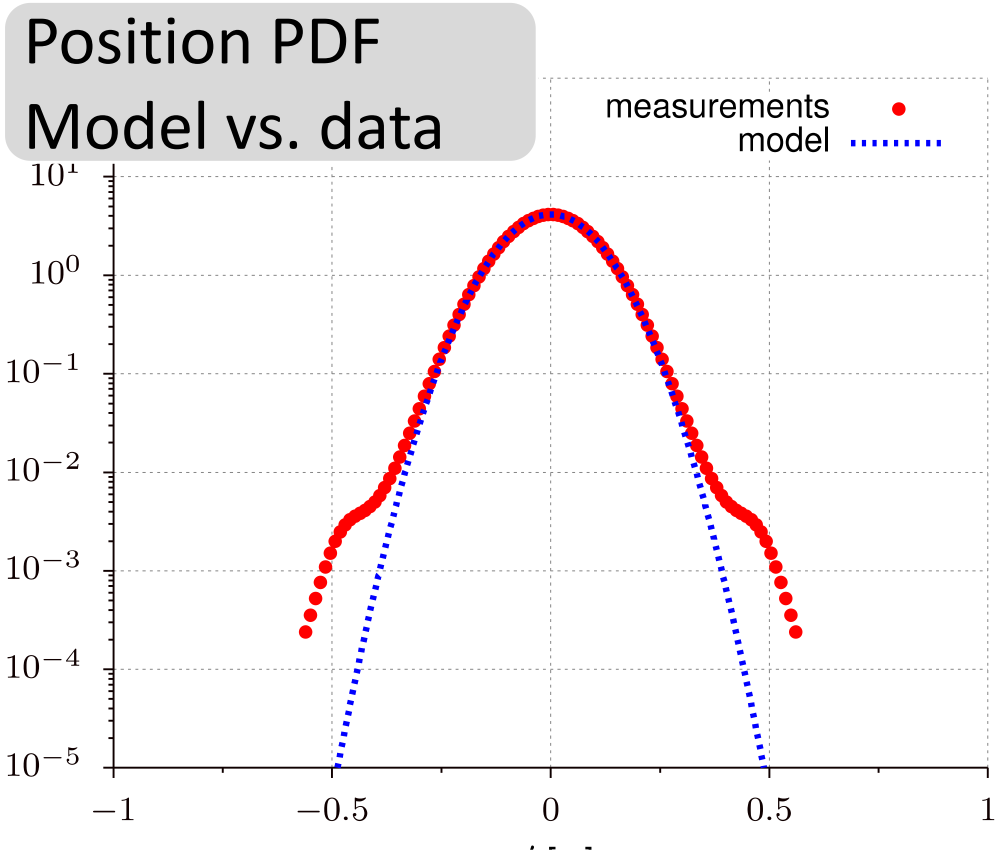
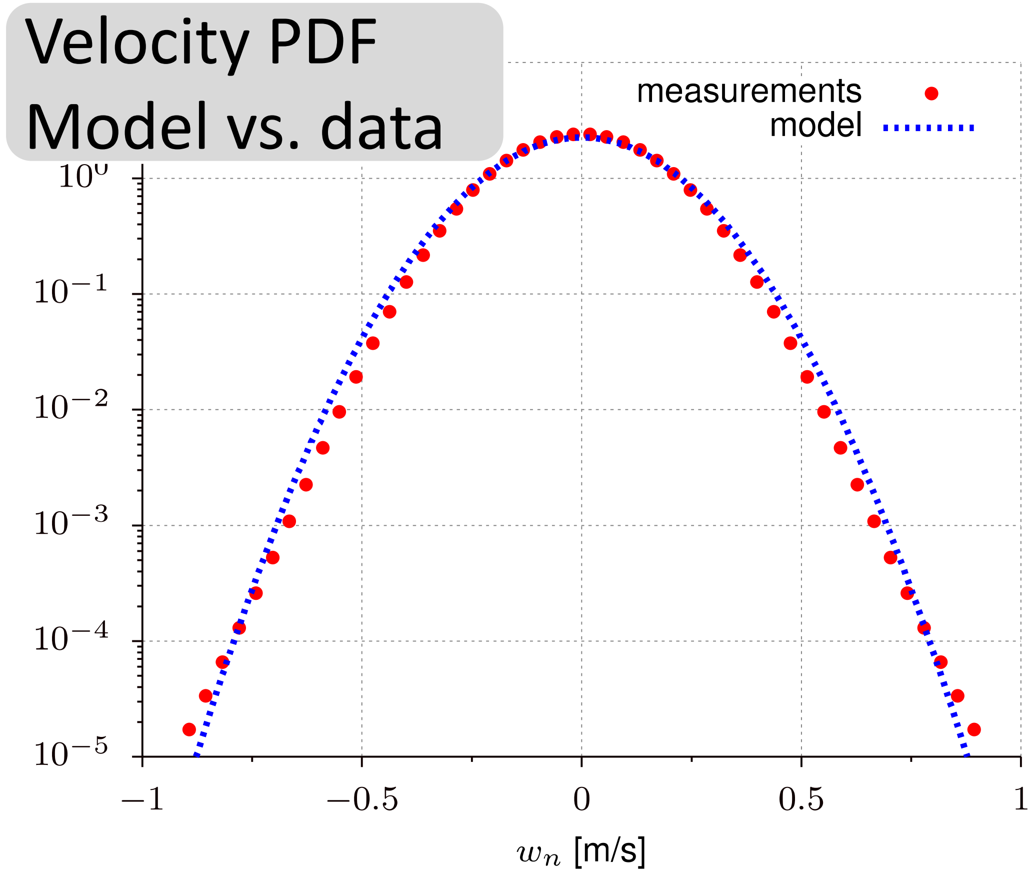
Transversal fluctuations

Stochastic motion around preferred path:

Quadratic potential for position (V) and velocity (K)





Confined Gaussian fluctuation: $\dot{v} = -2\gamma v - 2\beta y + \sigma_y \dot{w}$

[Corbetta et al. 17, Phys. Rev. E]

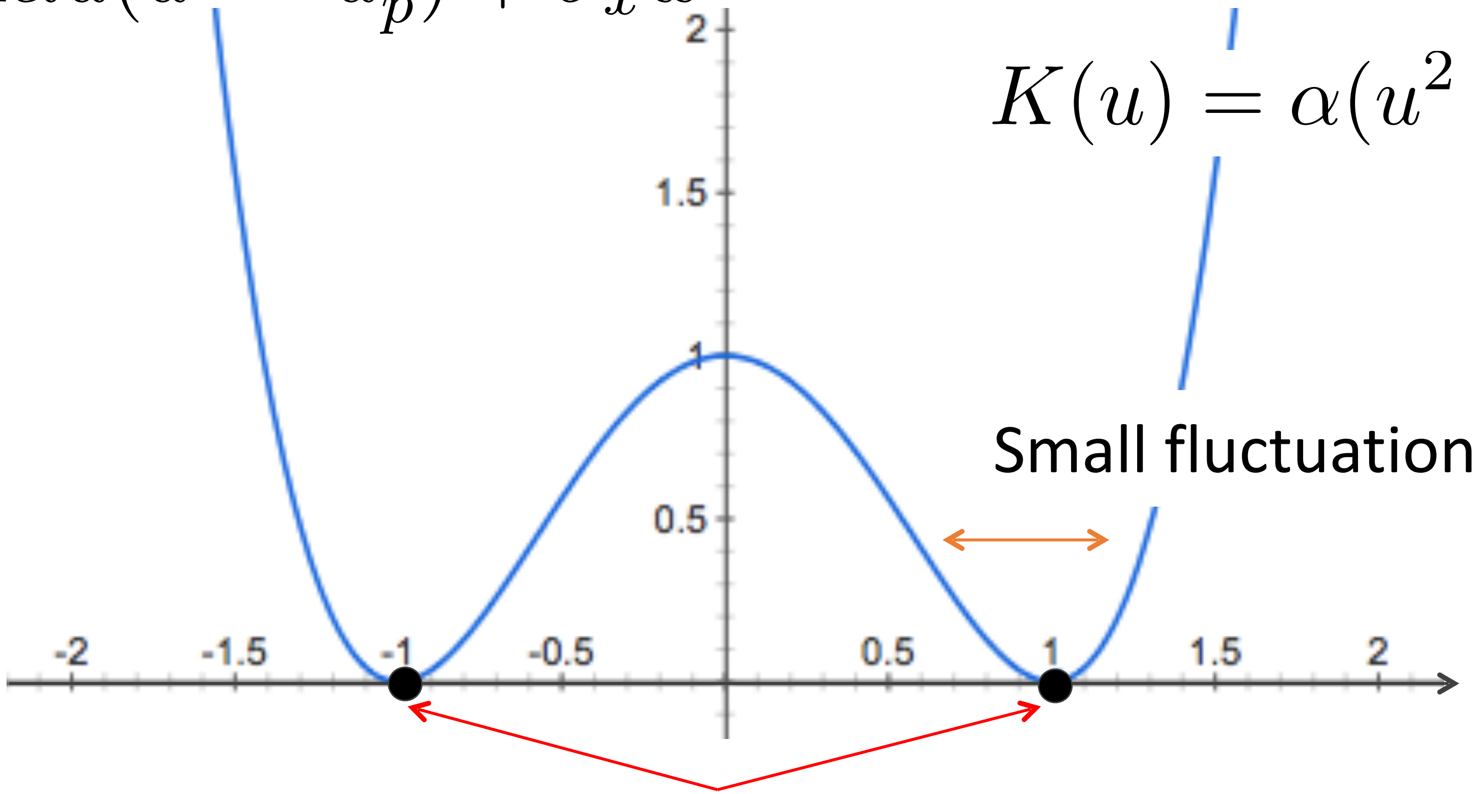
Bi-stable longitudinal motion

4th order velocity potential velocity (K)

Simplest bi-stable stochastic velocity dynamics

$$\dot{u} = -4\alpha u(u^2 - u_p^2) + \sigma_x \dot{w}$$

$$K(u) = \alpha(u^2 - u_p^2)^2$$



Stable velocity states

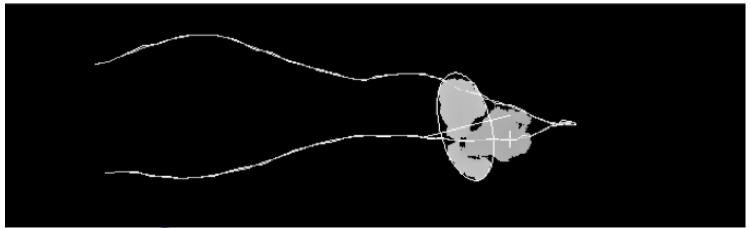
[Corbetta et al. 17, Phys. Rev. E]

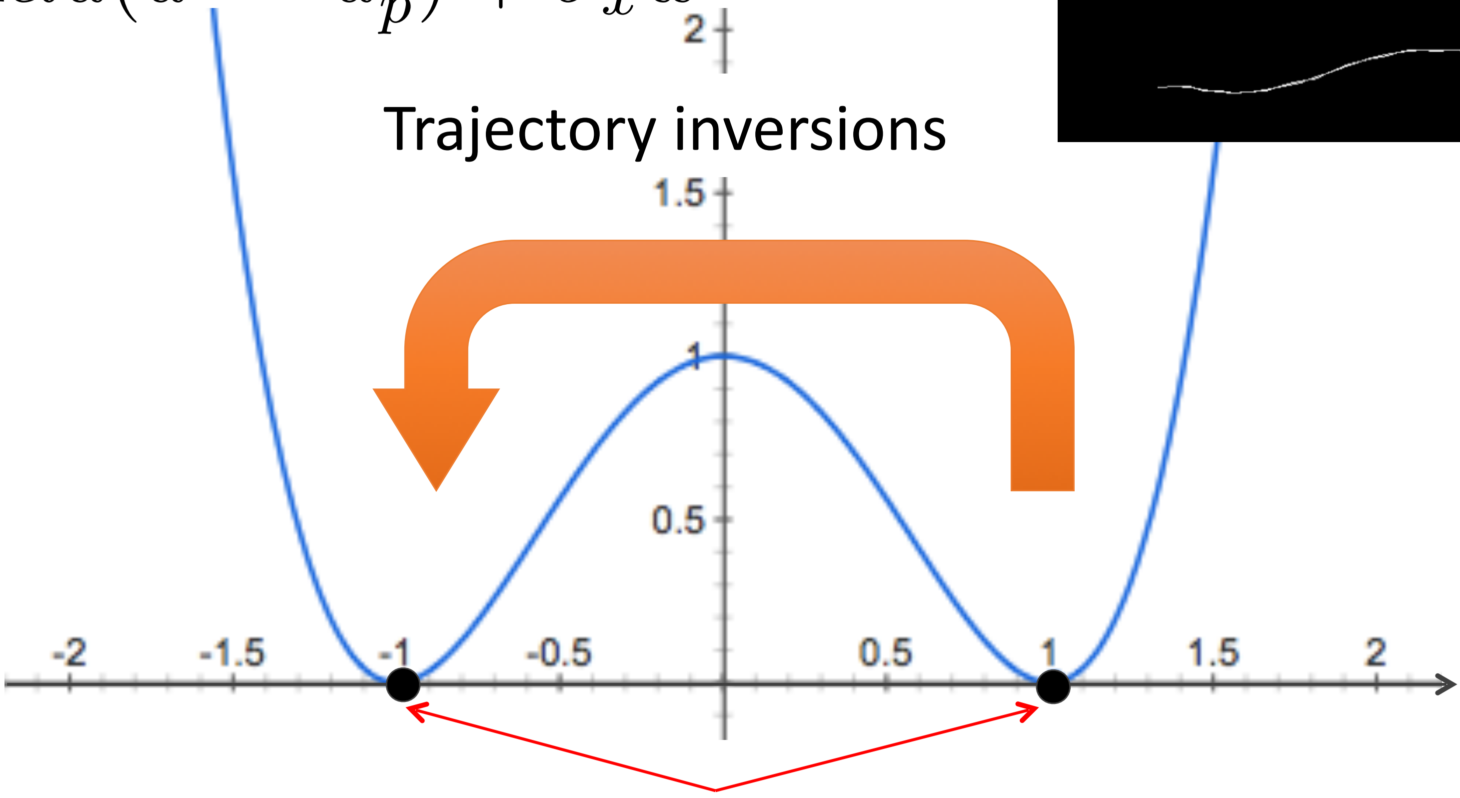
Bi-stable longitudinal motion

4th order velocity potential velocity (K)

Simplest bi-stable stochastic velocity dynamics

$$\dot{u} = -4\alpha u(u^2 - u_p^2) + \sigma_x \dot{w}$$





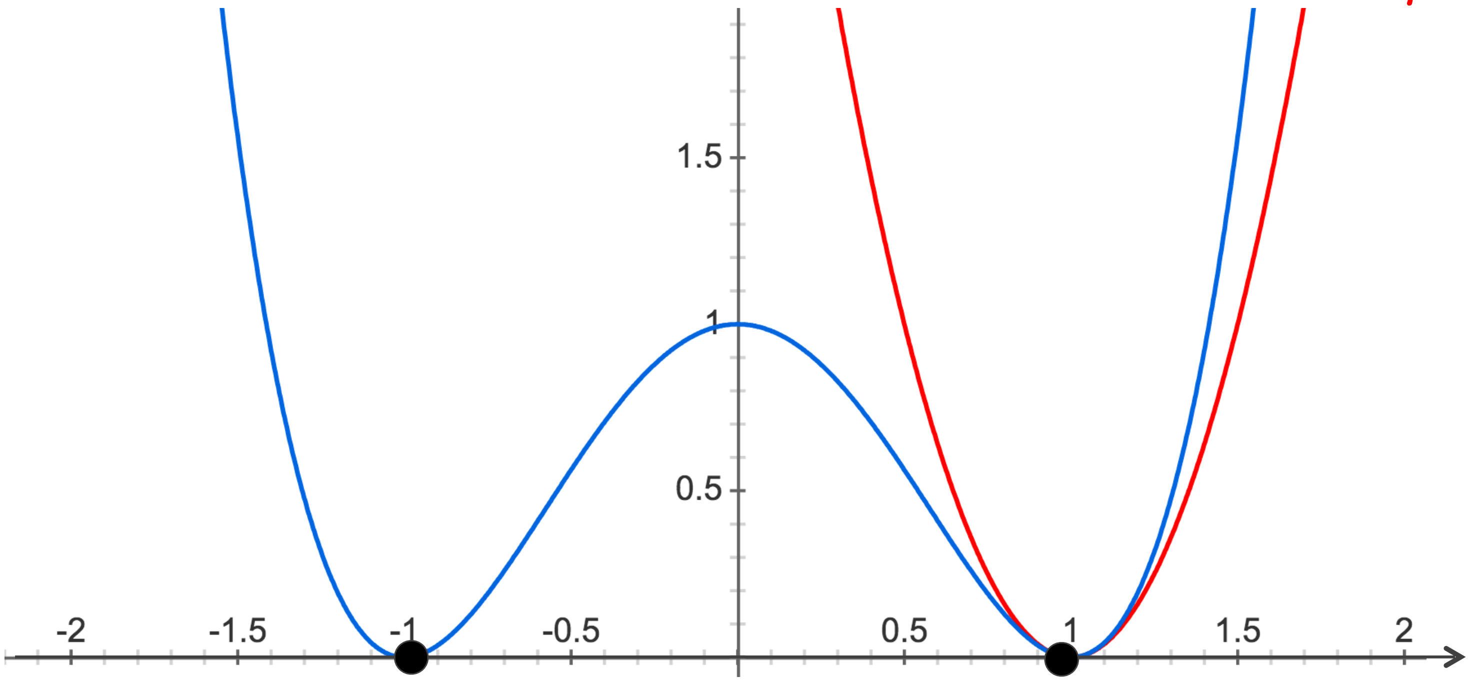
[Corbetta et al. 17, Phys. Rev. E]

Bi-stable longitudinal motion

Note: extension of social force approach for undisturbed motion ≅ Taylor exp. around positive velocity state

$$\dot{u} = -4\alpha u(u^2 - u_p^2) + \sigma_x \dot{w}$$

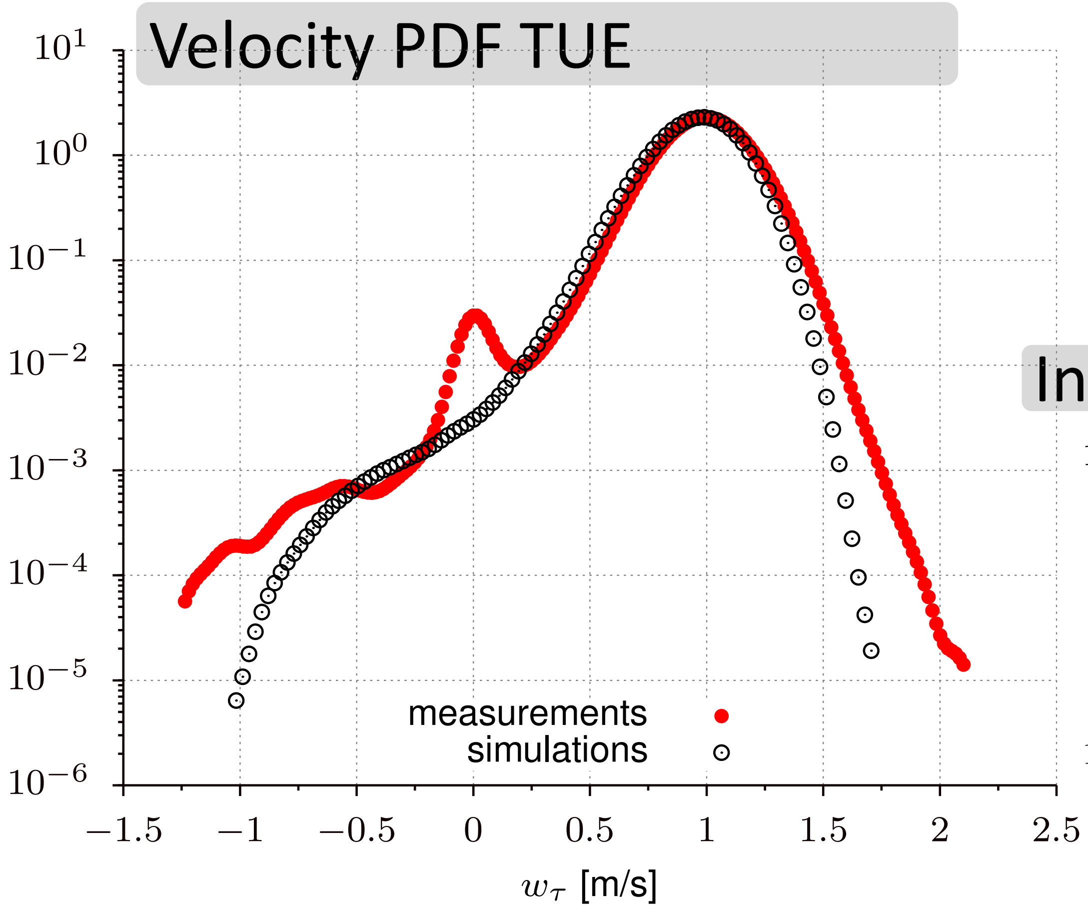
$$\dot{u} = -\frac{u - u_p}{\tau} + \sigma_x \dot{w}$$

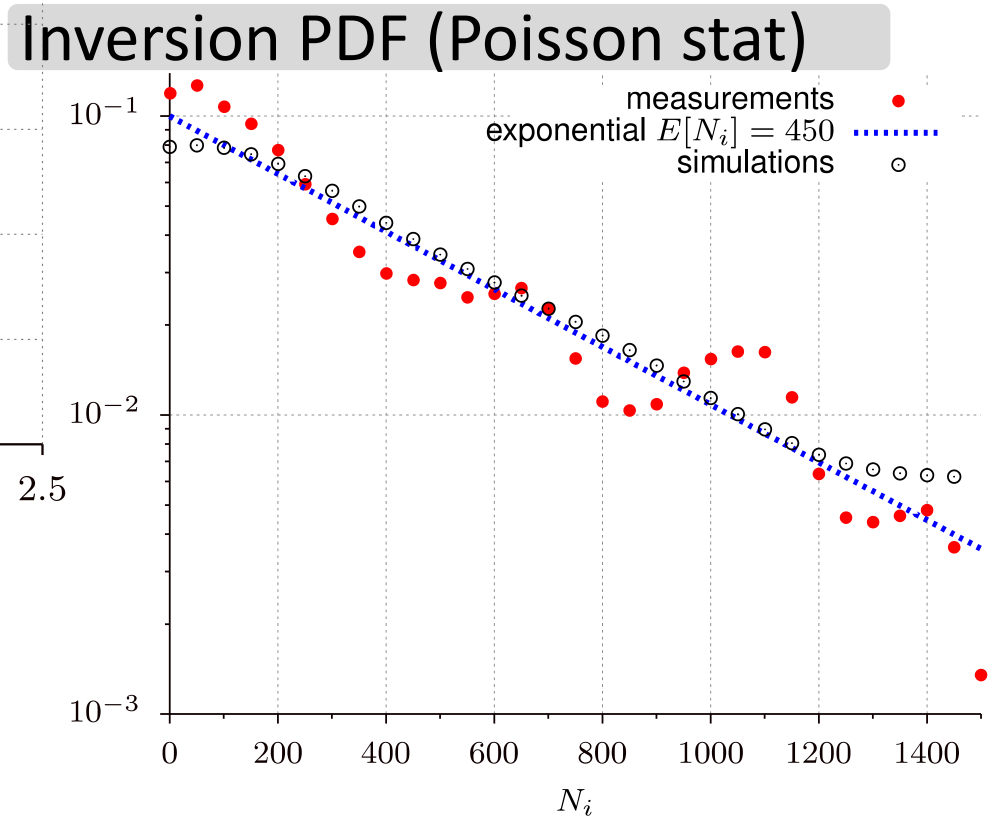


$$K(u) = \alpha(u^2 - u_p^2)^2 \cong K(u) = \frac{(u - u_p)^2}{2\tau} \qquad \tau = \frac{1}{8\alpha u_p^2}$$

[Corbetta et al. 17, Phys. Rev. E]

Bi-stable longitudinal motion

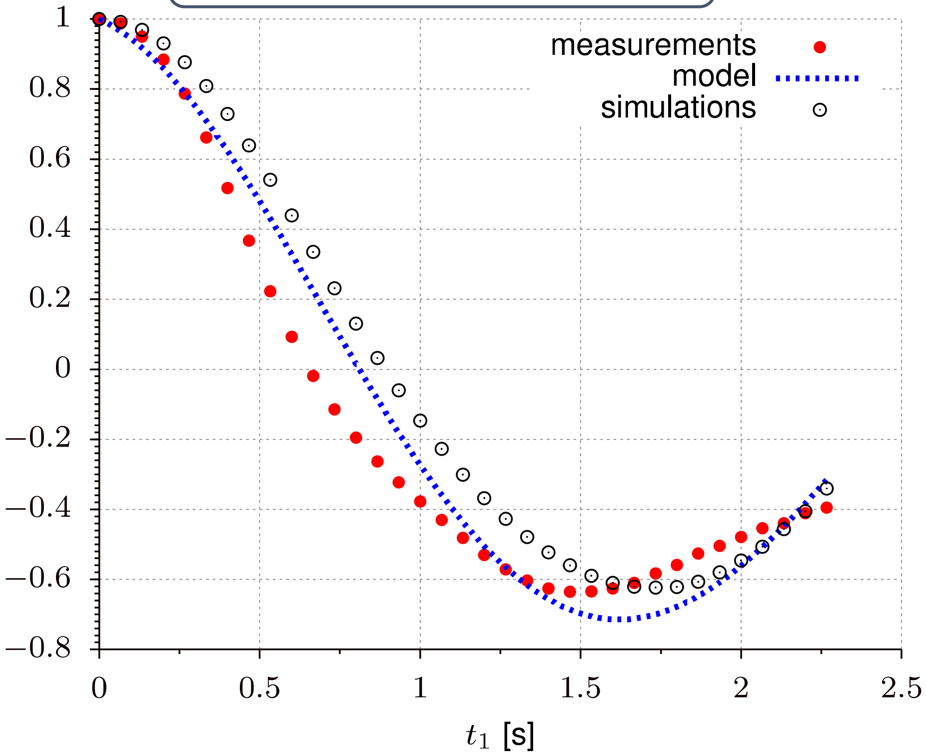




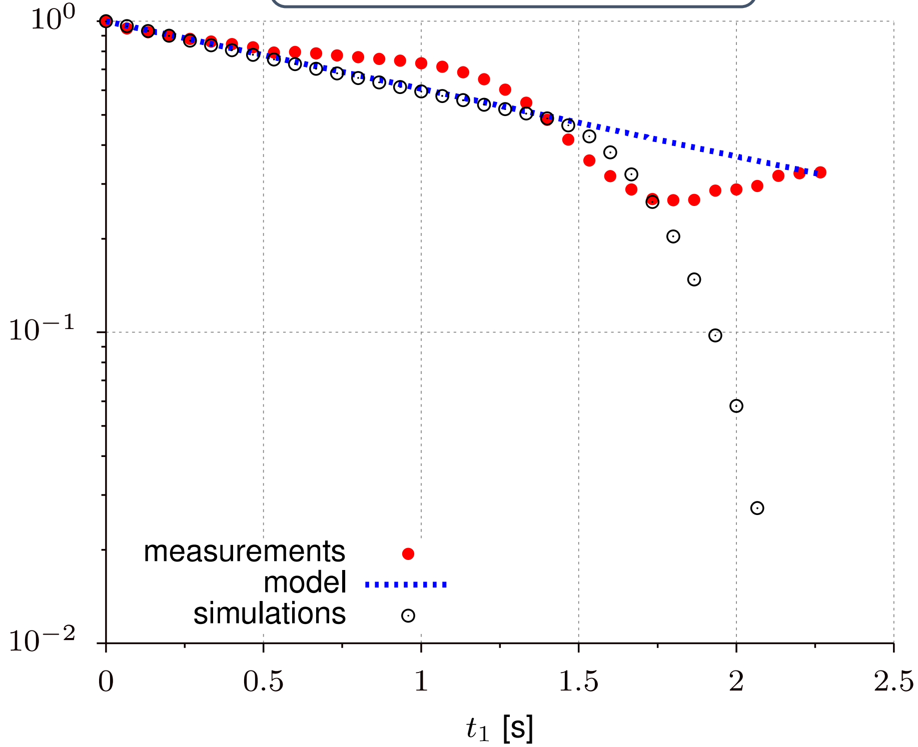
[Corbetta et al. 17, Phys. Rev. E]

Time-Correlation functions

Transversal displacement



Longitudinal velocity



Furthermore:

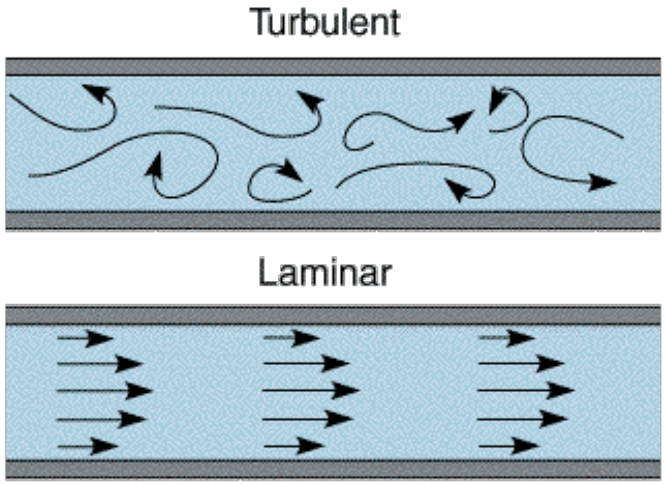
$$\sigma_x \approx \sigma_y$$

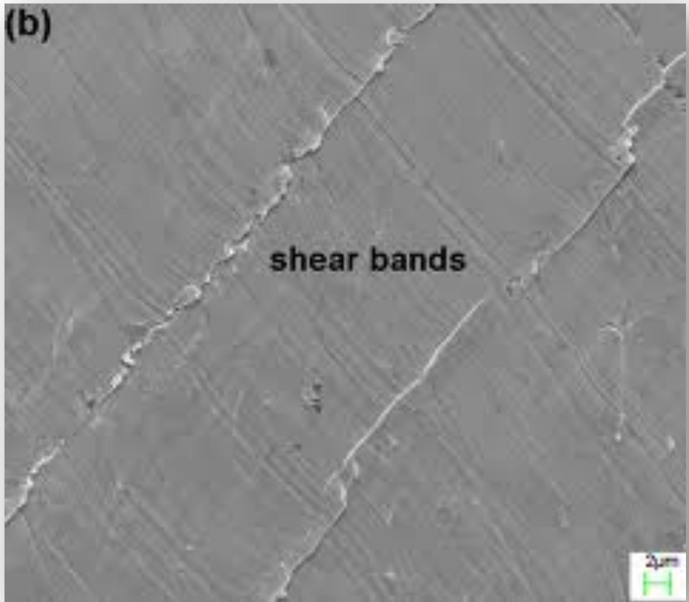
$$T_x = 2s \approx T_y = 2.5s$$

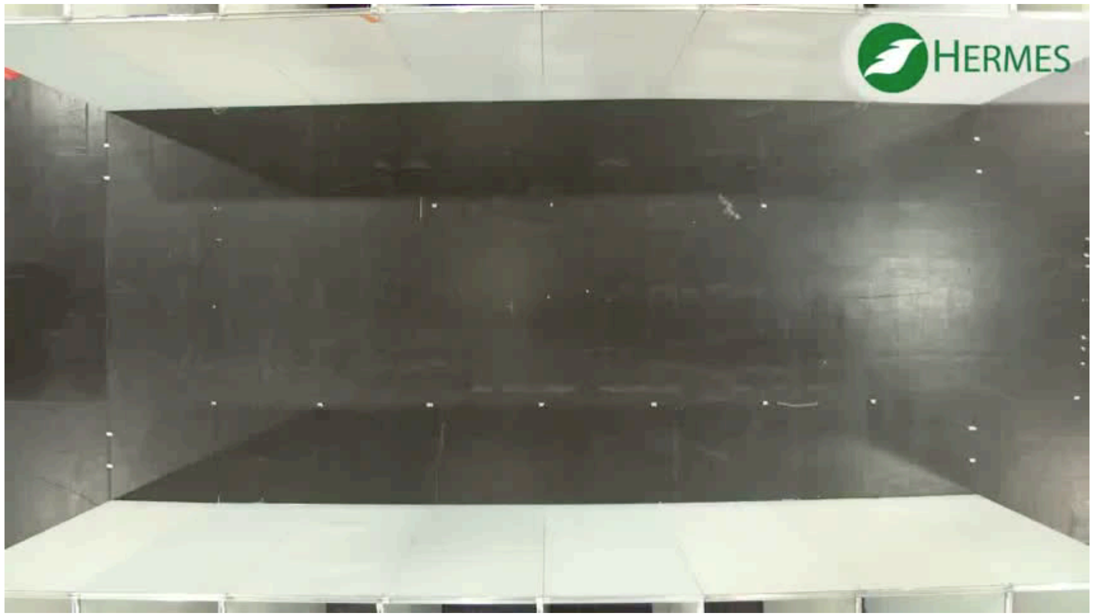
[Corbetta et al. 17, Phys. Rev. E]

High density + higher statistics data?

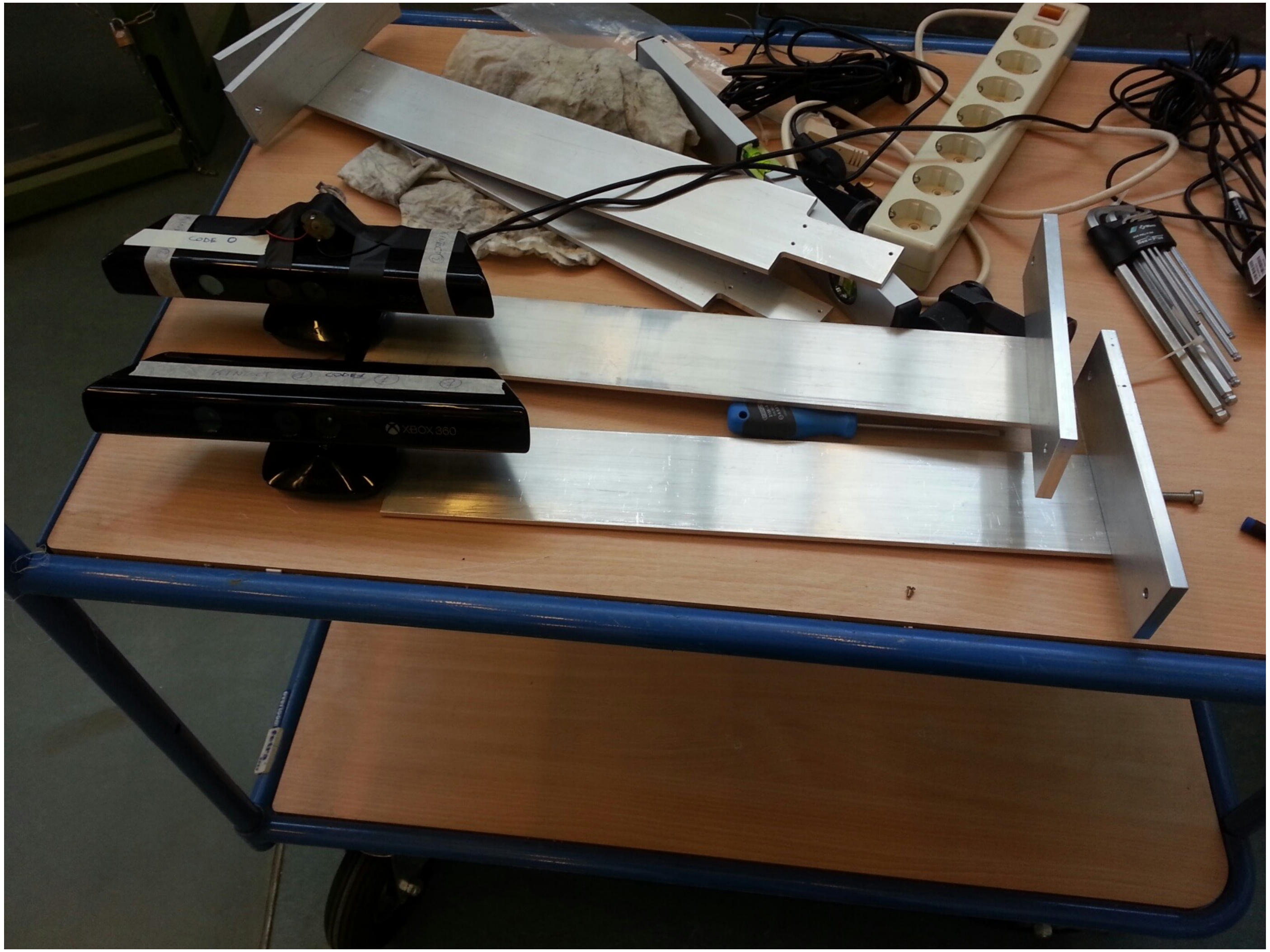
Crowd: a simple or complex fluid ?



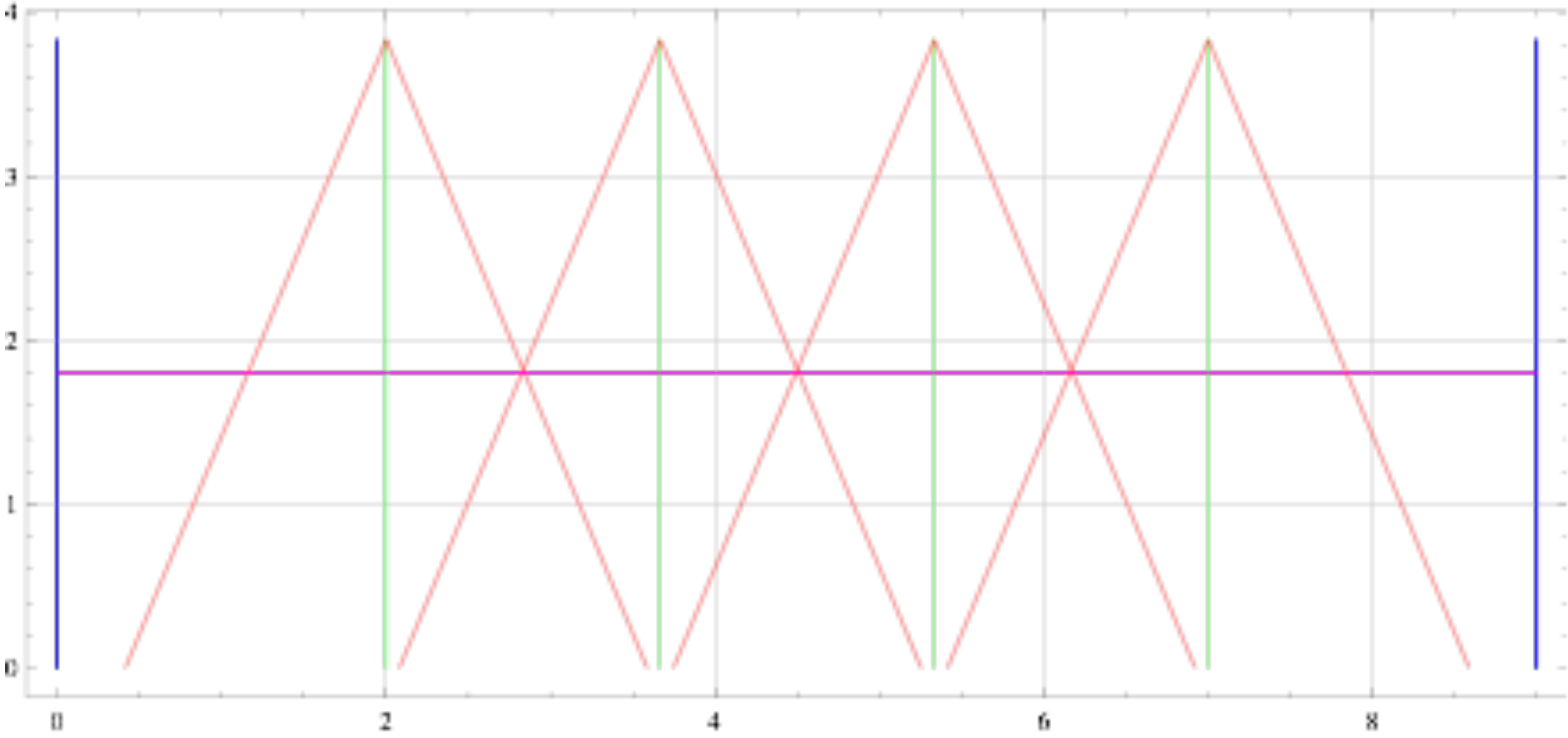




Preparing the installation…



Overlapping fields of view



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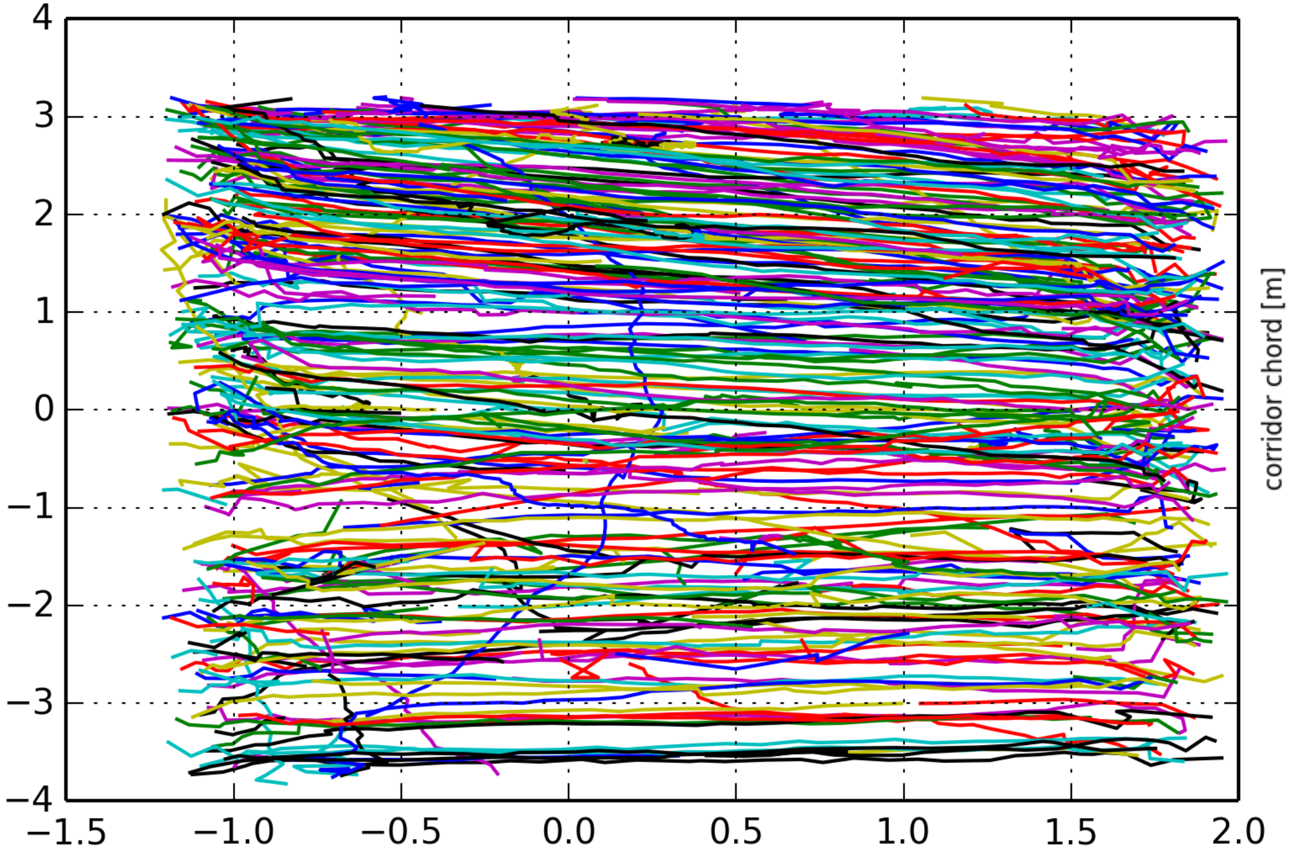
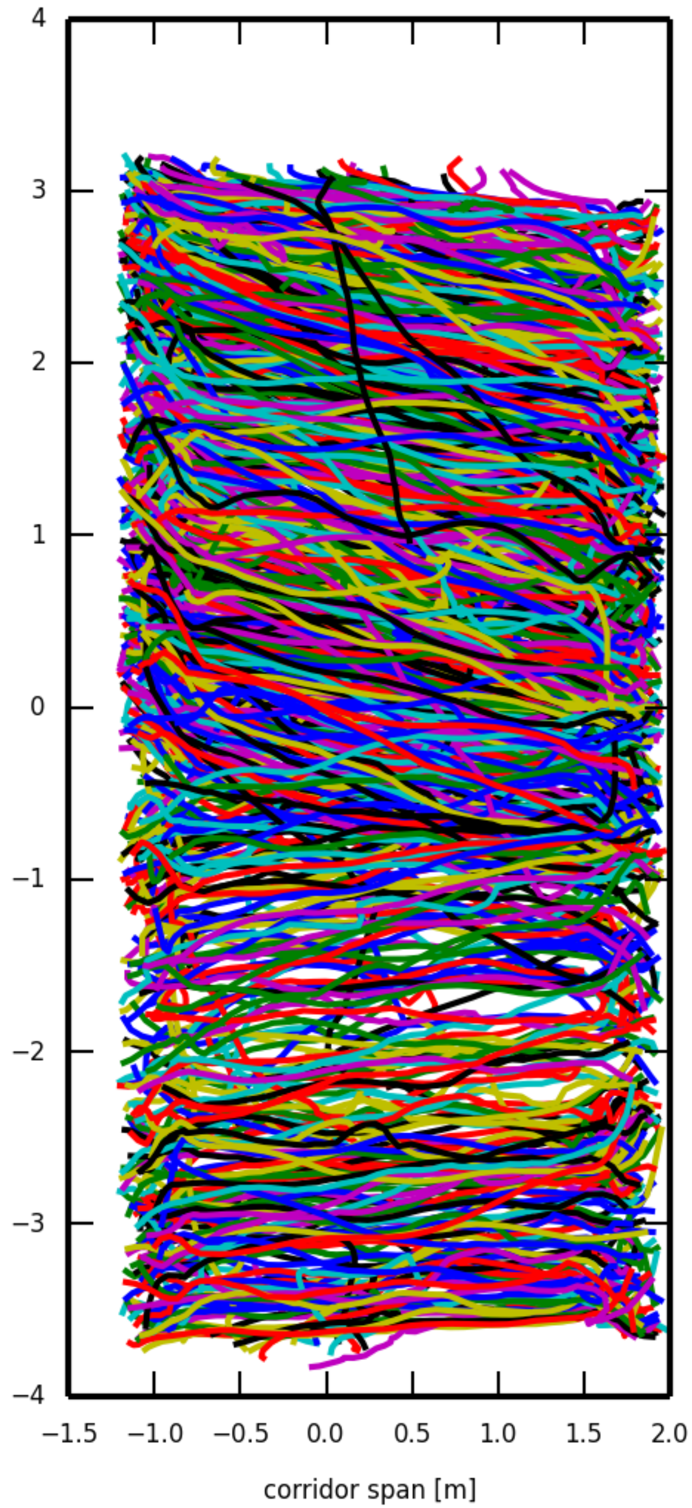
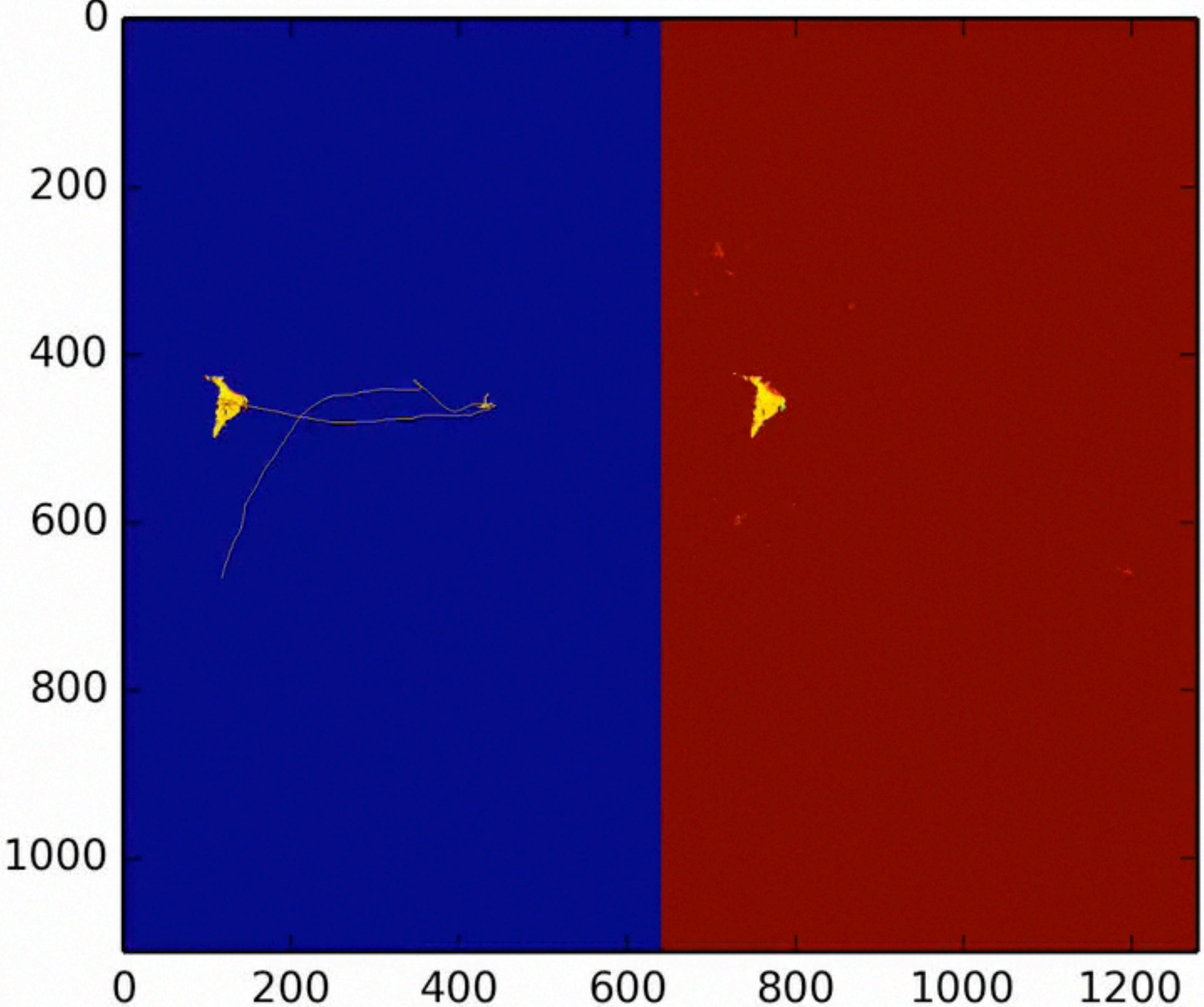
Trajectories





Going back…



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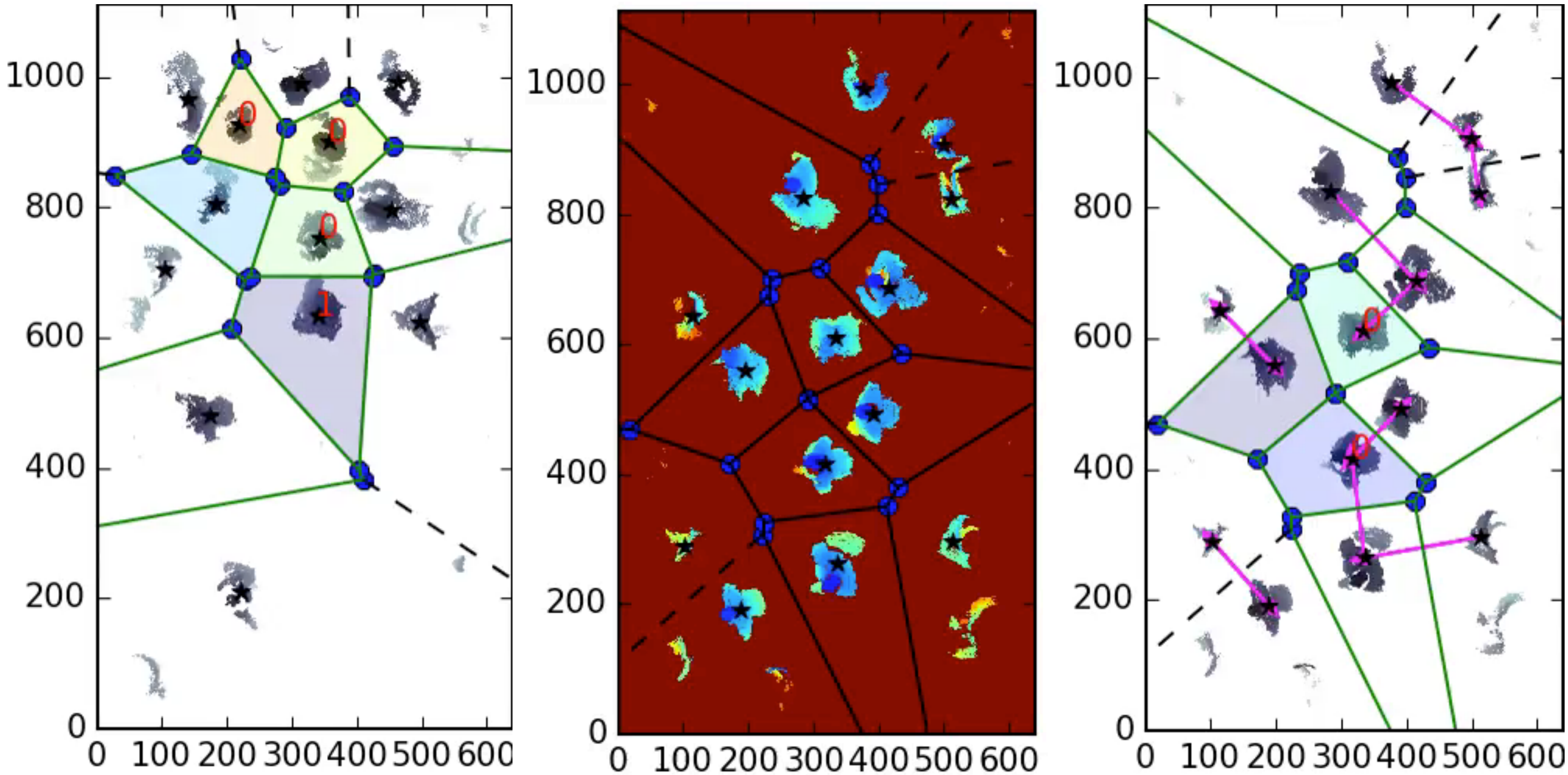
Local density estimate



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What happens out of the lab…

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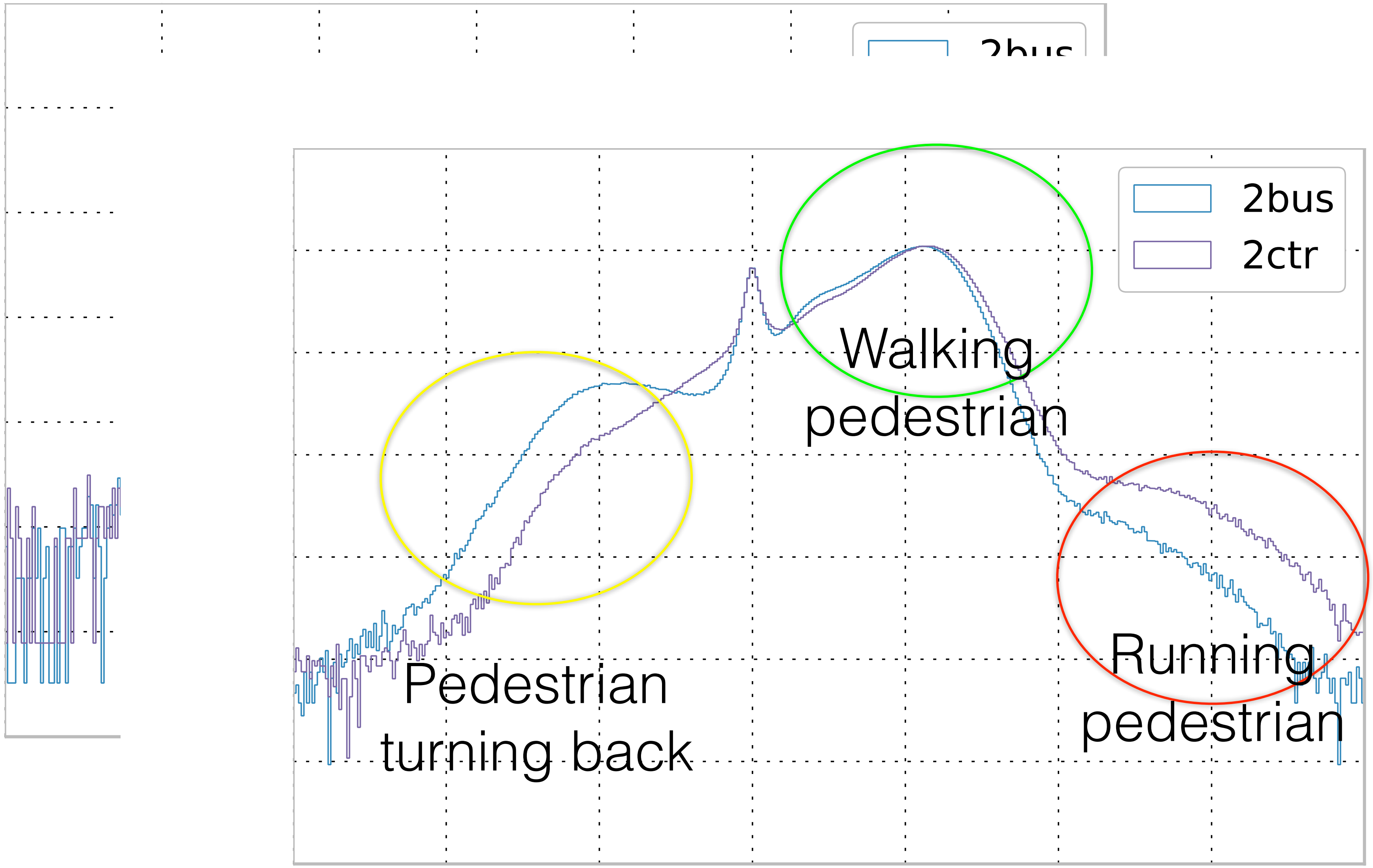
PDFs of velocity at NS station

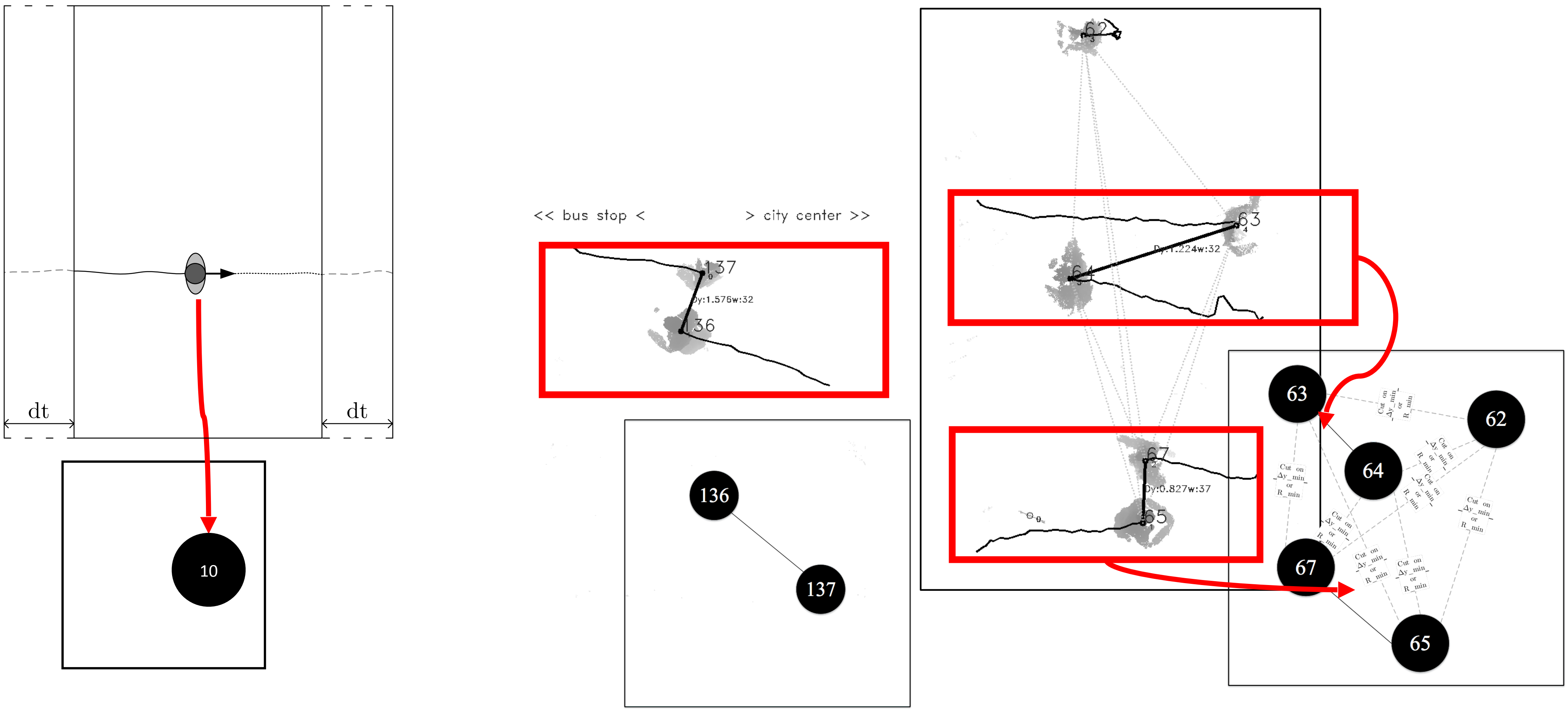


Pedestrian collisional cross section?

Interaction dynamics

Graph queried for connected components

(interacting subnets)



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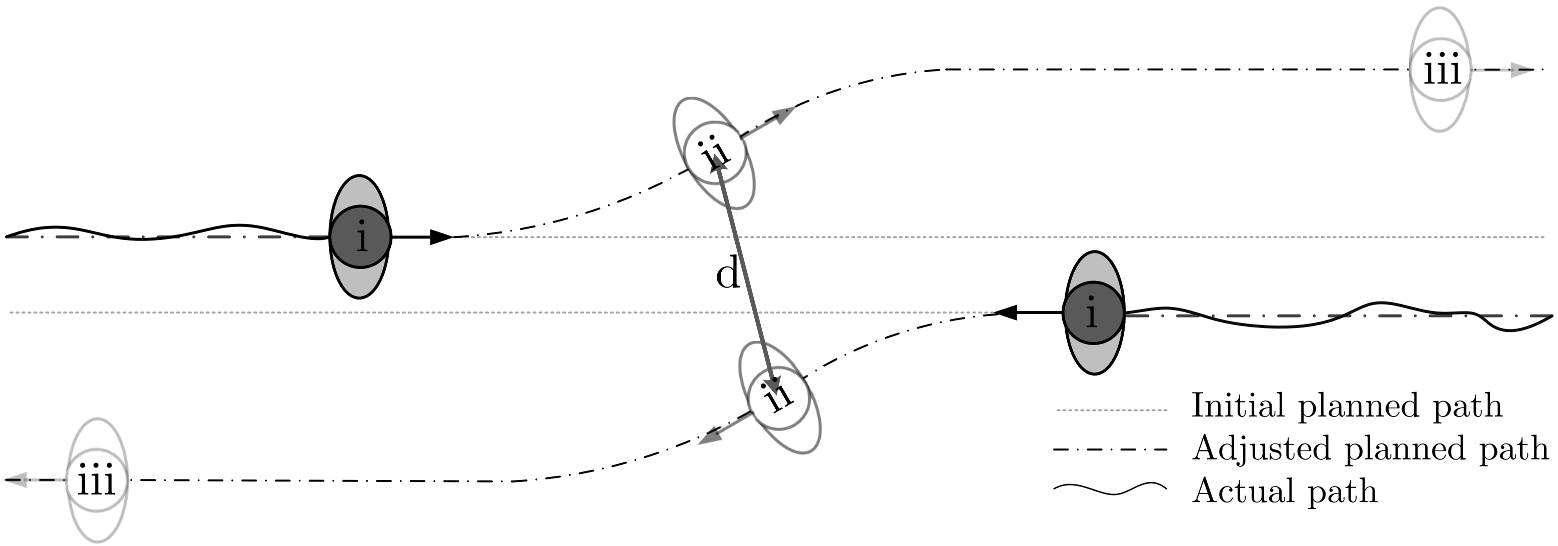
Collision between pedestrians



$$\frac{\mathrm{d}y_p}{\mathrm{d}t} = \dot{y_p}$$

$$\frac{\mathrm{d}\dot{y}_p}{\mathrm{d}t} = -\mathrm{sign}(dy)F_{y,vision} - 2\mu\dot{y}_p$$

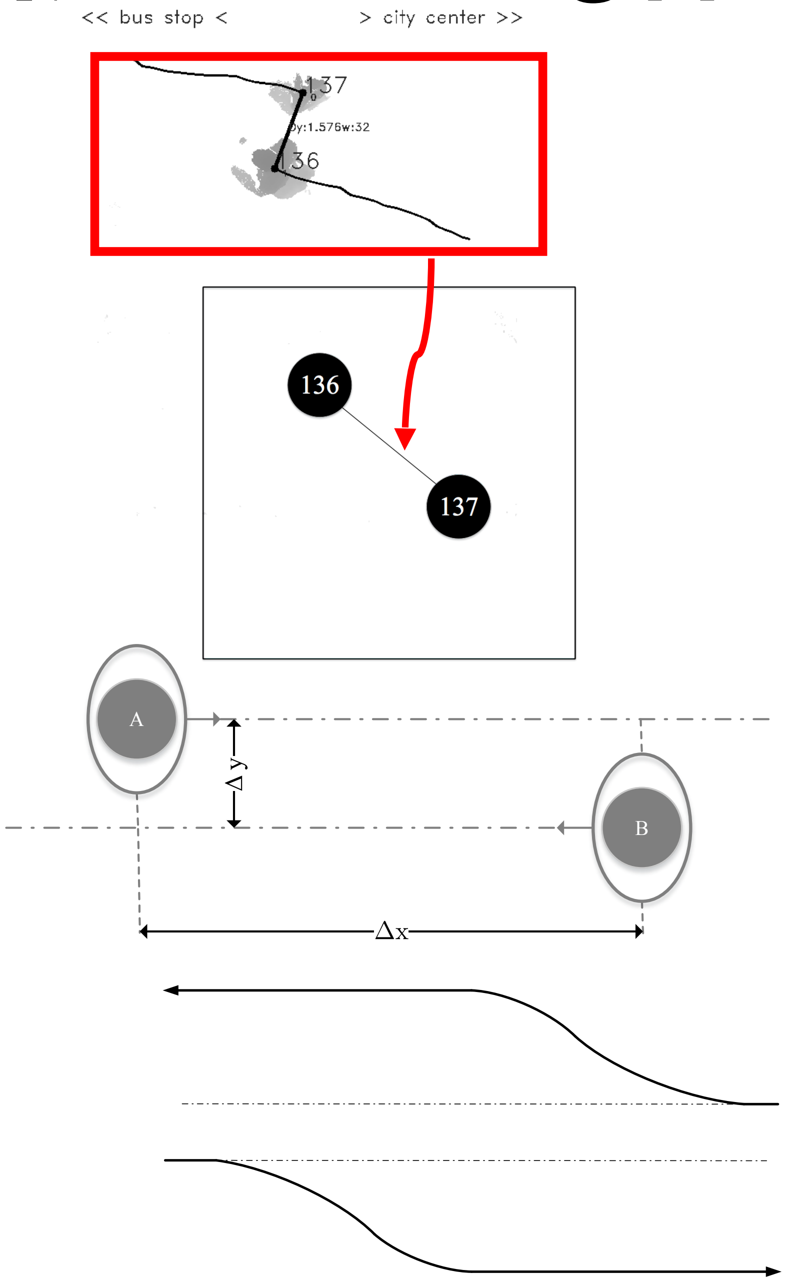
$$\frac{\mathrm{d}x}{\mathrm{d}t} = u$$

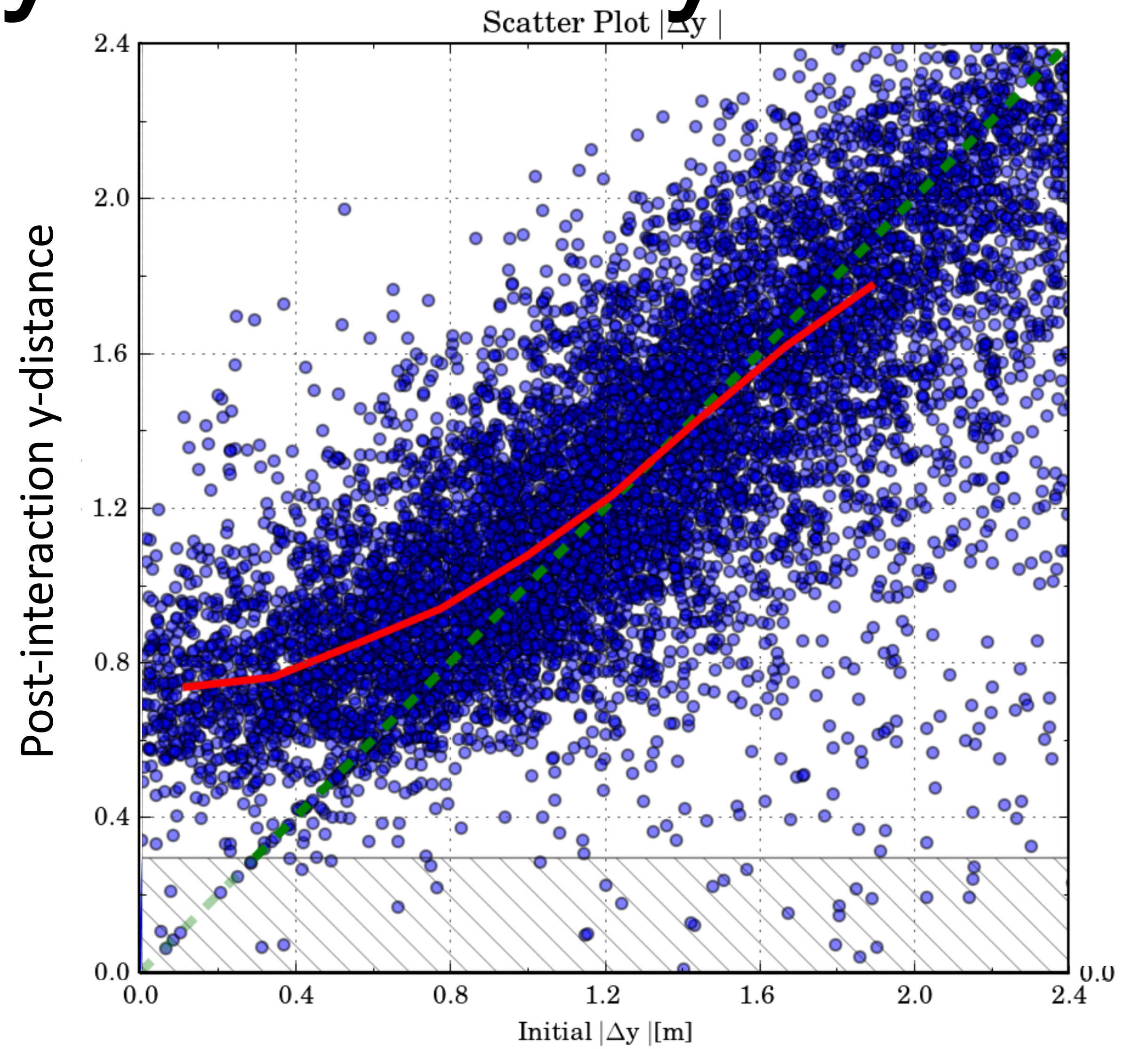
$$\frac{\mathrm{d}y}{\mathrm{d}t} = v$$

$$\frac{\mathrm{d}u}{\mathrm{d}t} = -4\alpha u(u^2 - u_p^2) + \xi_x - e_x F_{short}$$

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -2\nu v - 2\beta(y - y_p) + \xi_y - e_y F_{short} - \mathrm{sign}(dy)F_{vision}$$

Interaction dynamics: “y offset”





Pre-interaction y-distance

Aligned peds. ⟷ Infinitely far

[Corbetta et al. to be subm]

Thank you.

- Alessandro Corbetta
- Chung-min Lee
- Roberto Benzi
- Jasper Meeusen
- Adrian Muntean