# Phase Transition in traffic jam experiment

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# Collaborators

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# On traffic flow, we have been conducting researches

- Microscopic models and simulations
  - CA models
  - Optimal velocity (car-following) model
- Analyses of observed data from highways
  - Tomei and Meishin highways
  - Statistical analyses
    - Fundamental diagrams
    - Reverse lane usages
  - Time sequence
    - Long range correlations
- Experimental studies of traffic jam
  - Today's presentation

# Vehicle Traffic Flow

- Familiar phenomena in daily life
  - Two features: free flow and jam
- Free flow
  - Cars run with their desired speed
  - Homogeneous
- Traffic jam
  - Not homogeneous slow flow
  - Jam cluster: sequence of motionless (slow) cars

# Misunderstanding of the origin of jam

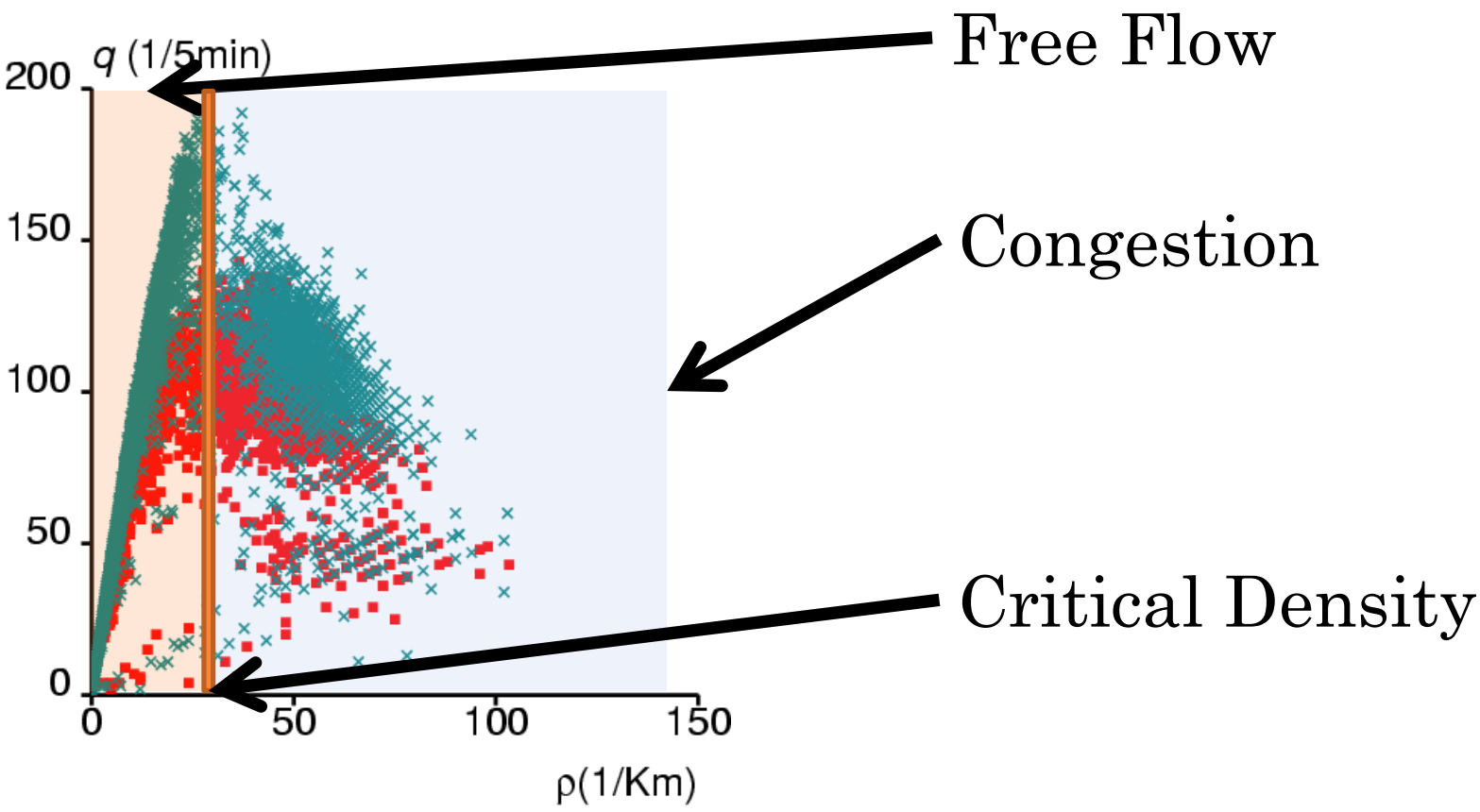
- Fake origins
  - Bottlenecks such as tunnels
  - Slow car leading a sequence of cars

  - If the density is low, these can not lead to traffic jam.
  - These induce the density increase.

- Observational facts
  - Free flow and jam separated by some density
  - Jam clusters propagate upstream

# Observational facts:1

- Fundamental diagram

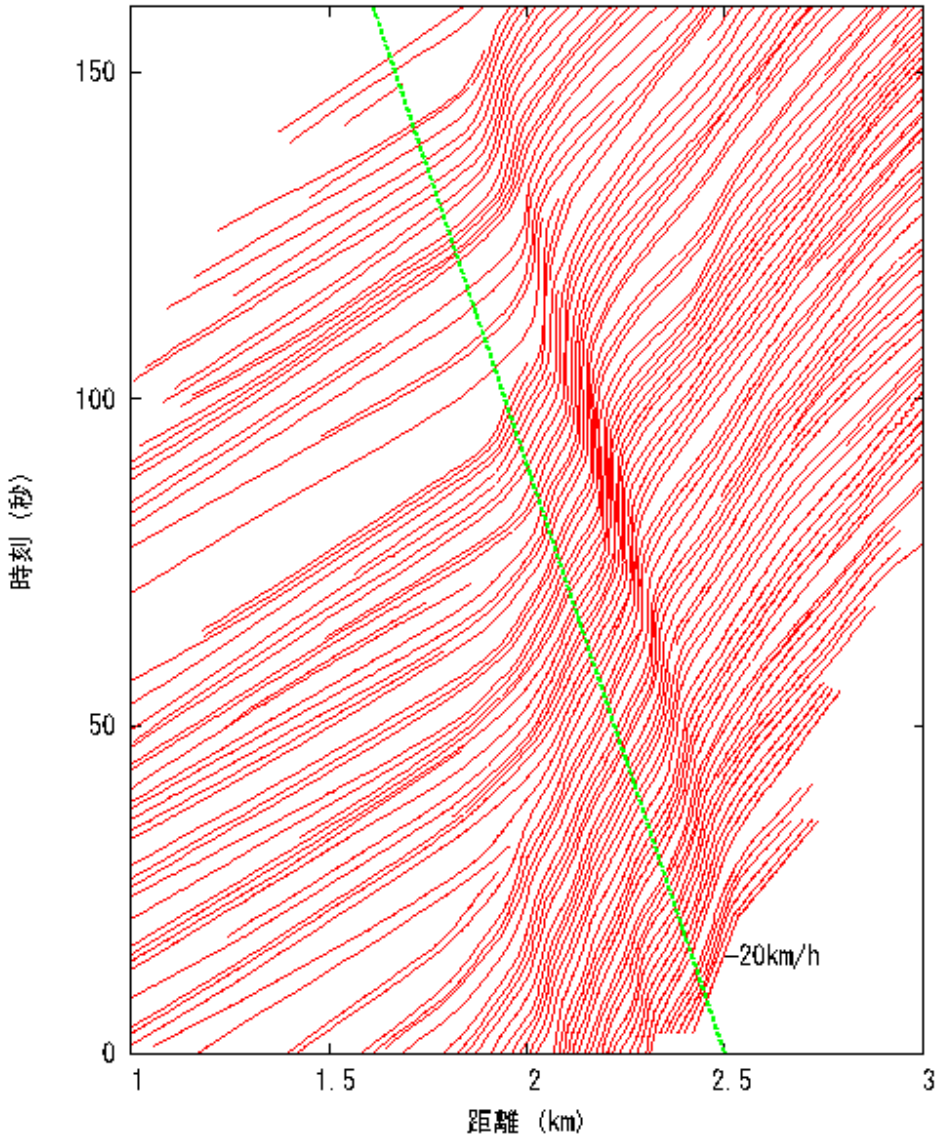



Data from Meishin Highway

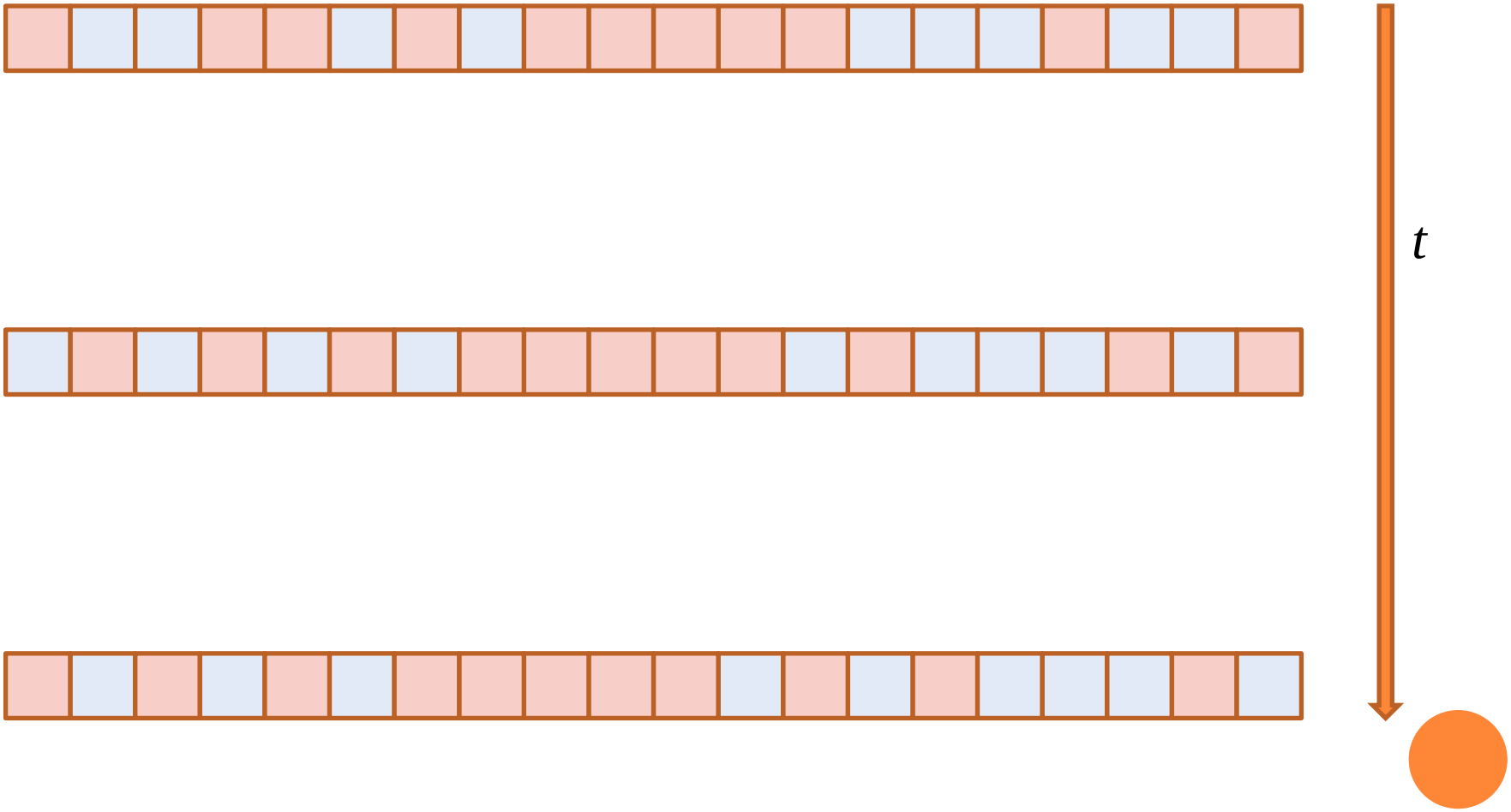
# Observational facts:2

- Jam cluster propagates upstream

Treiterer & Myers 1967



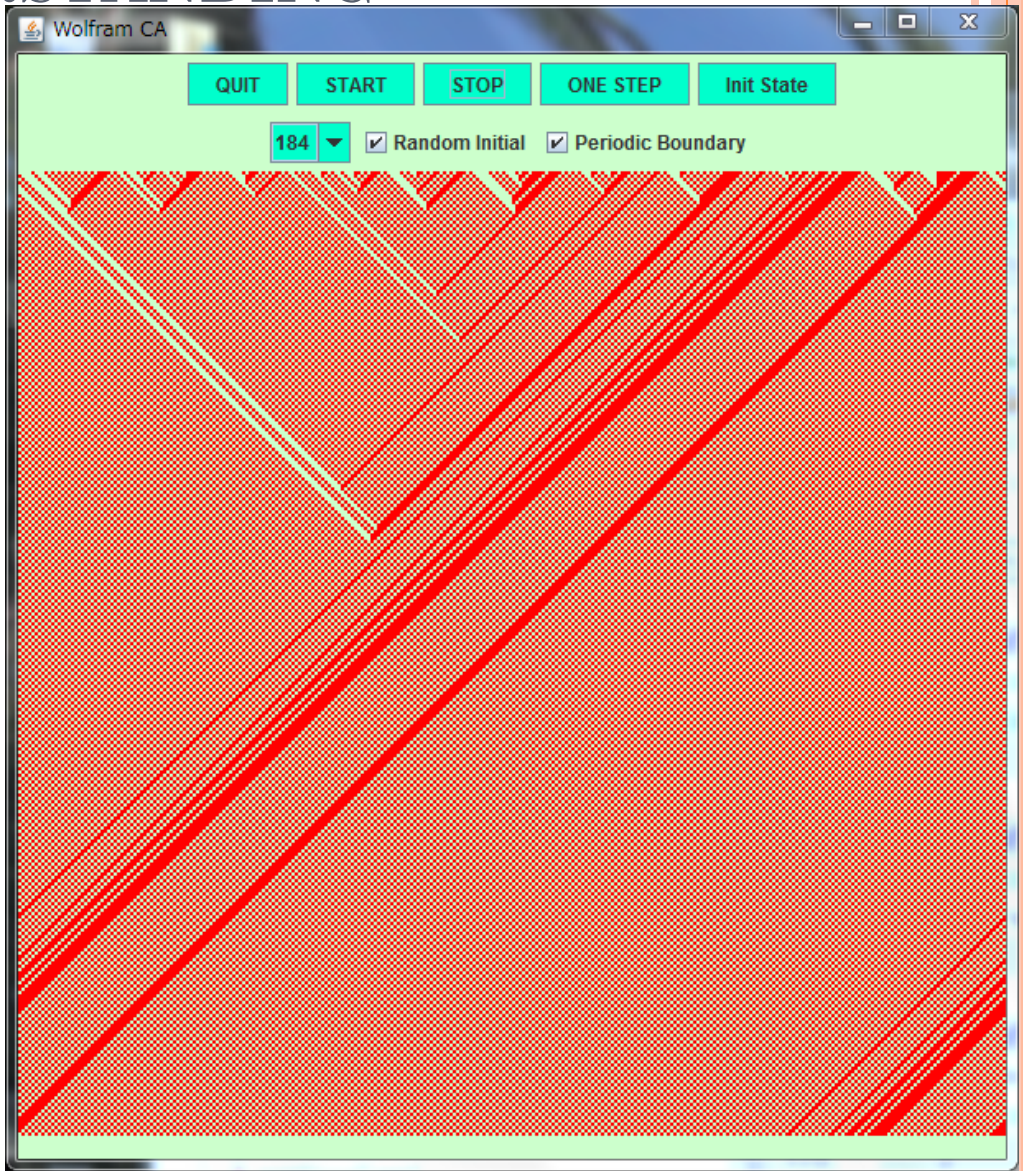
# Simplest Traffic Flow Model (R184)




Periodic boundaries

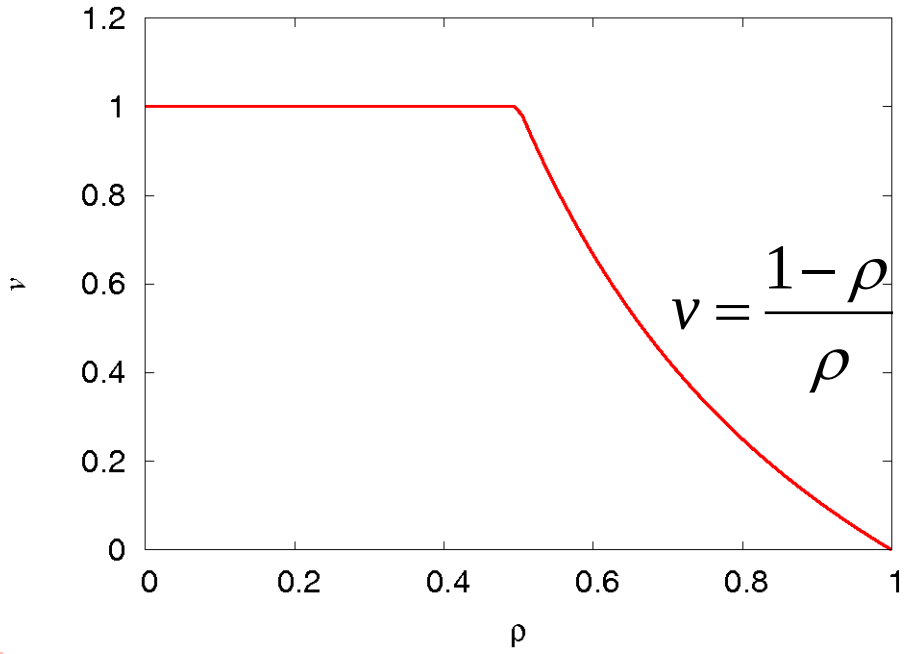
# Theoretical understanding

- Example (Simplest model): Wolfram's rule-184
  - Jam cluster propagates upstream

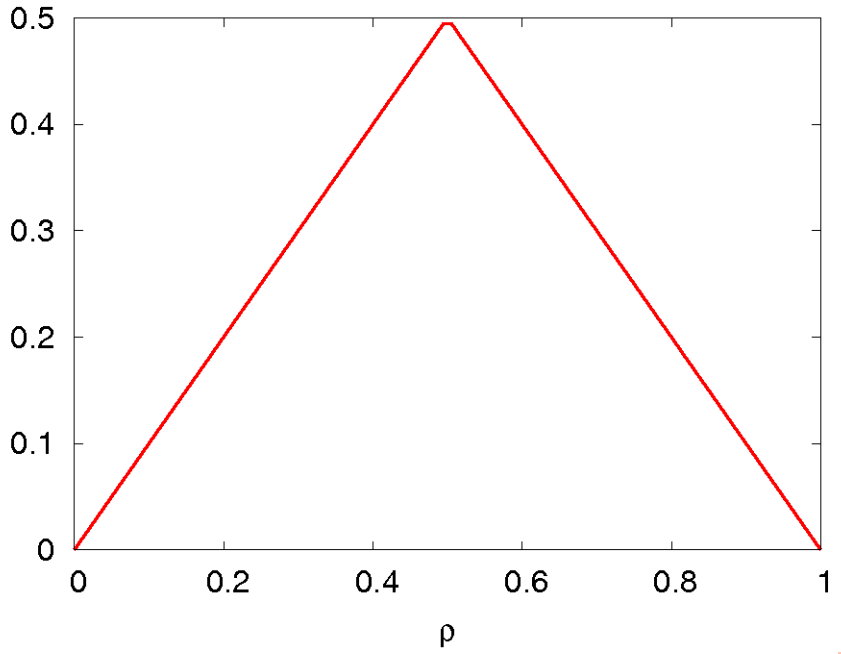


# Theoretical understanding

- Example (Simplest model): Wolfram's rule-184
  - Phase transition at $\rho_C=1/2$




Density-Speed relation




Density-Flow relation

# Physical Understanding

- Emergence of traffic jam
  - Phase transition controlled by density
- Low density
  - Smooth and homogeneous
- High density
  - Homogeneous flow becomes unstable
  - Inhomogeneous
    - Low density area : free running
    - High density area : jam cluster
    - Jam cluster propagate upstream

# Origin of traffic jam

- Bottlenecks and slow cars are not the origin
- Human factors are not important

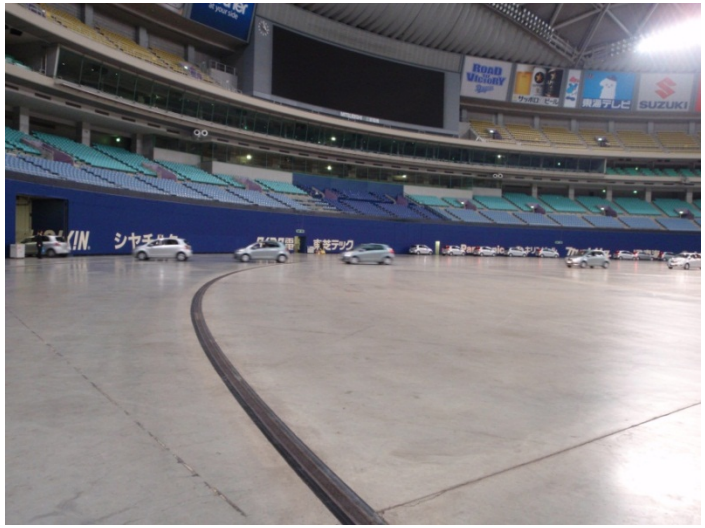
- Traffic jam without any bottlenecks
  - High density flow is unstable
  - Small fluctuation grows exponentially

- Traffic jam ⇔ phase transition

# Purpose of the experiment

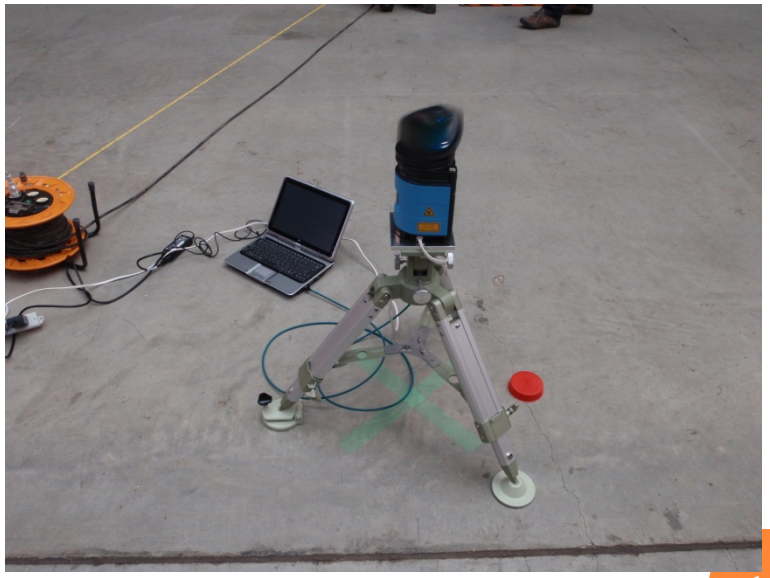
- Validate physical understanding
  - High density traffic flow is unstable
  - Traffic jam emerges without bottlenecks

- Estimate the critical density
  - The density as the control parameter

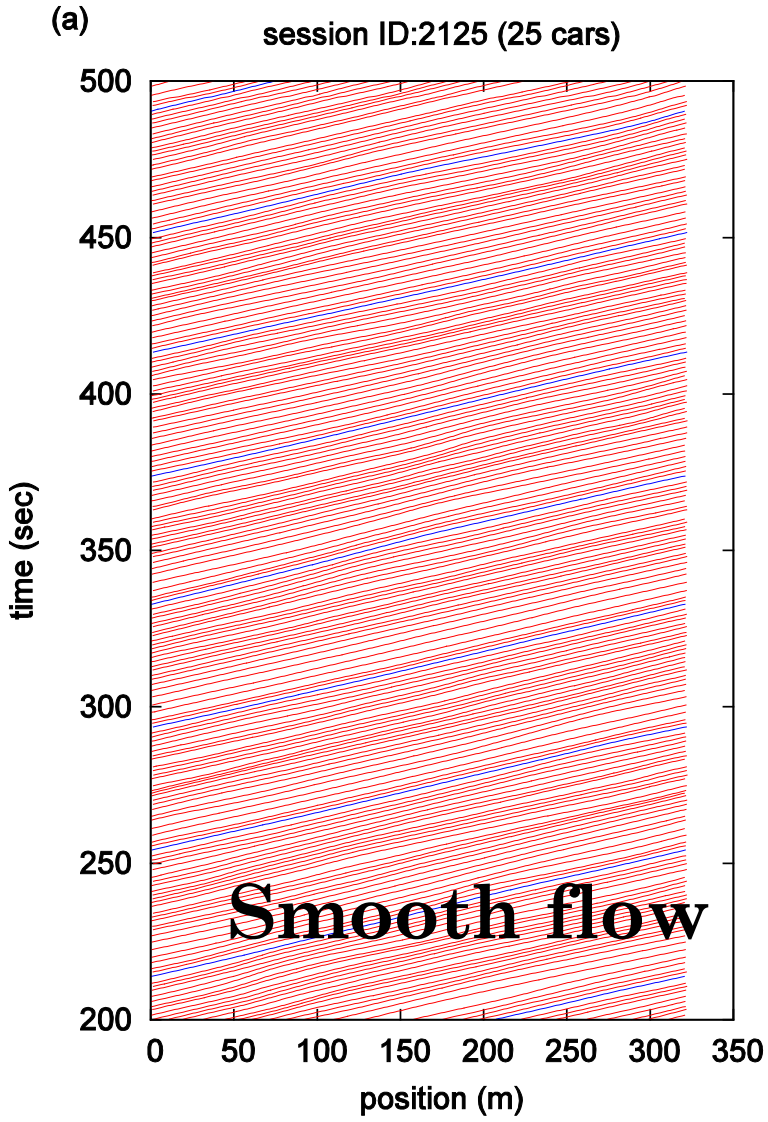


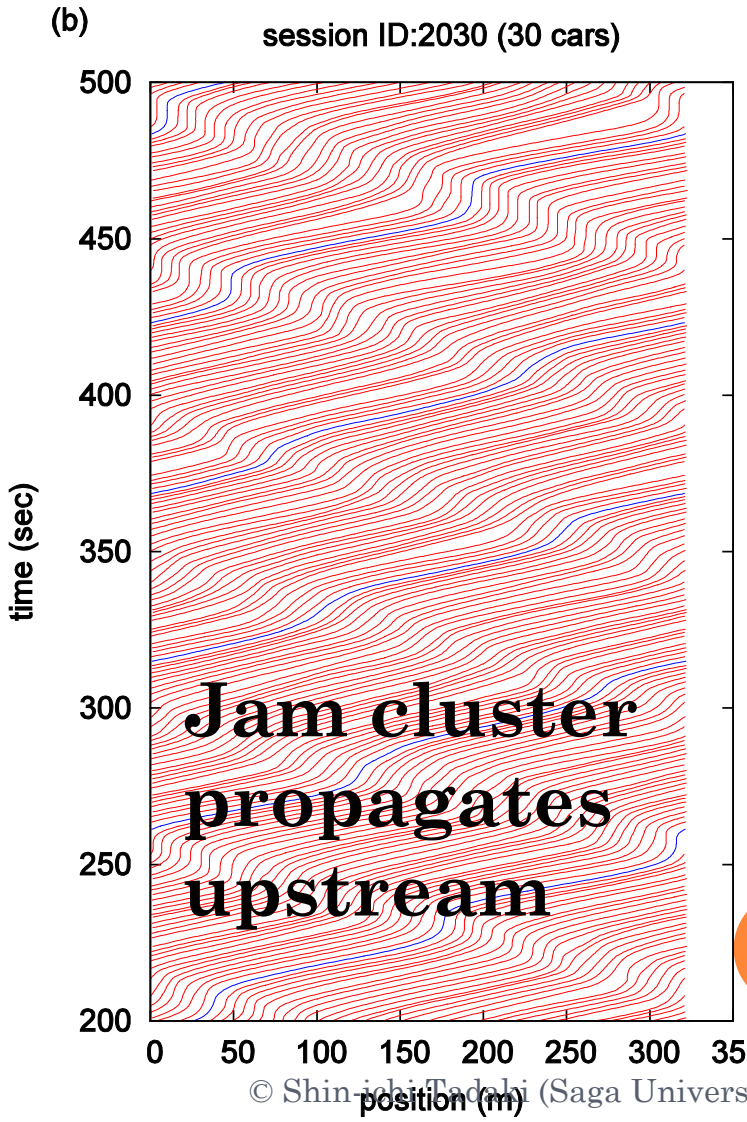
# The experiment

- Circuit with 50 m radius in Nagoya Dome (2 days)
- 50 TOYOTA Vitz
- High resolution positioning using laser scanner

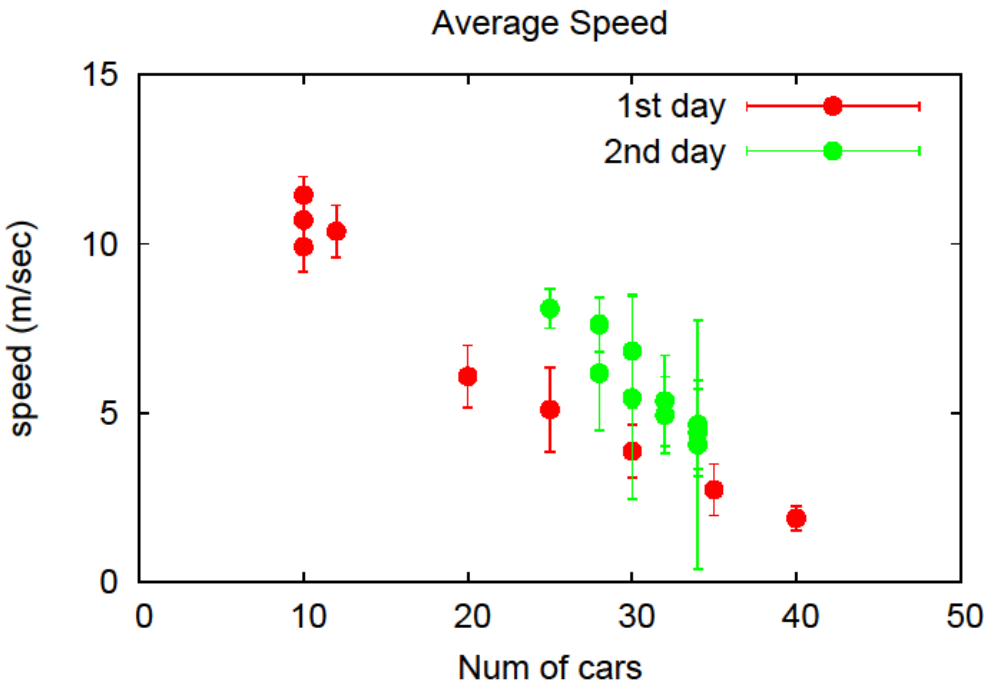


# SPACETIME DIAGRAM



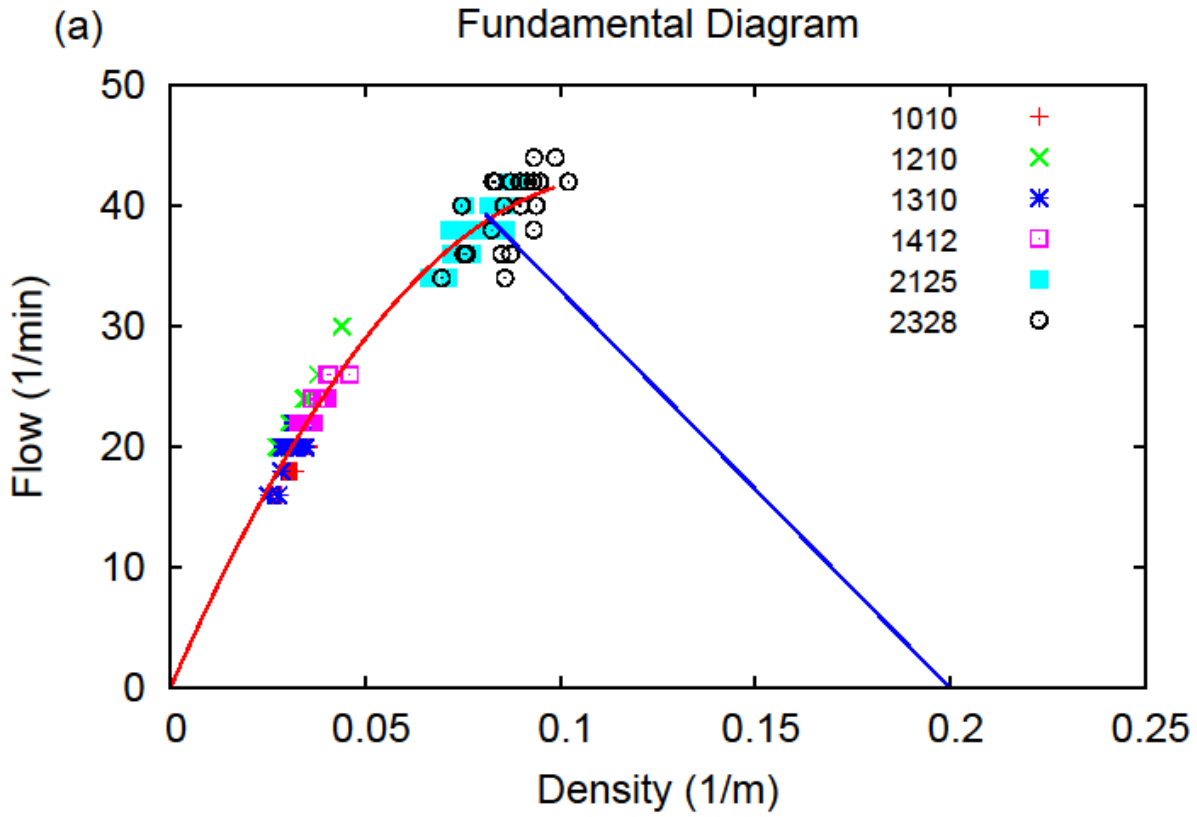



# Average speed

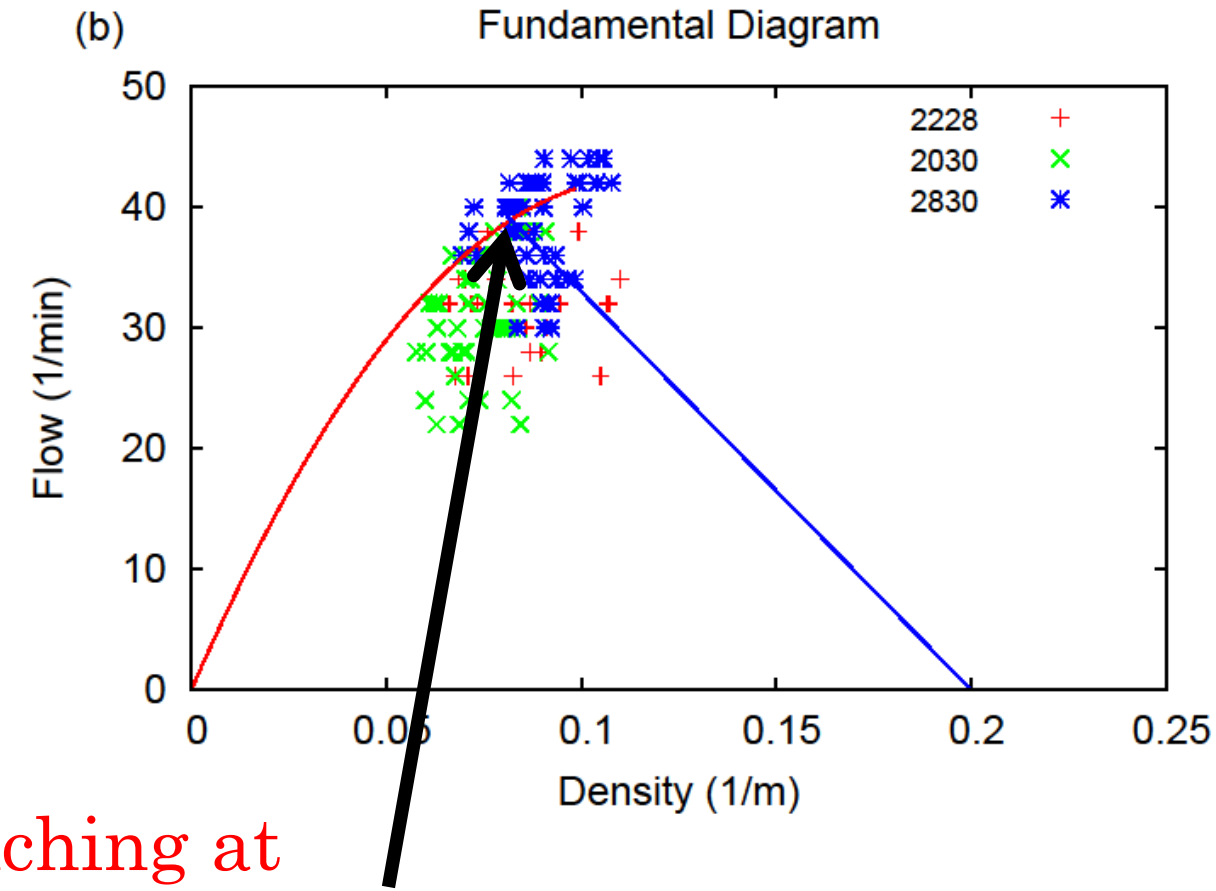



- Average speed decreases with # of cars.
- Fluctuation becomes large for high density flow.

# Fundamental diagram : free flow

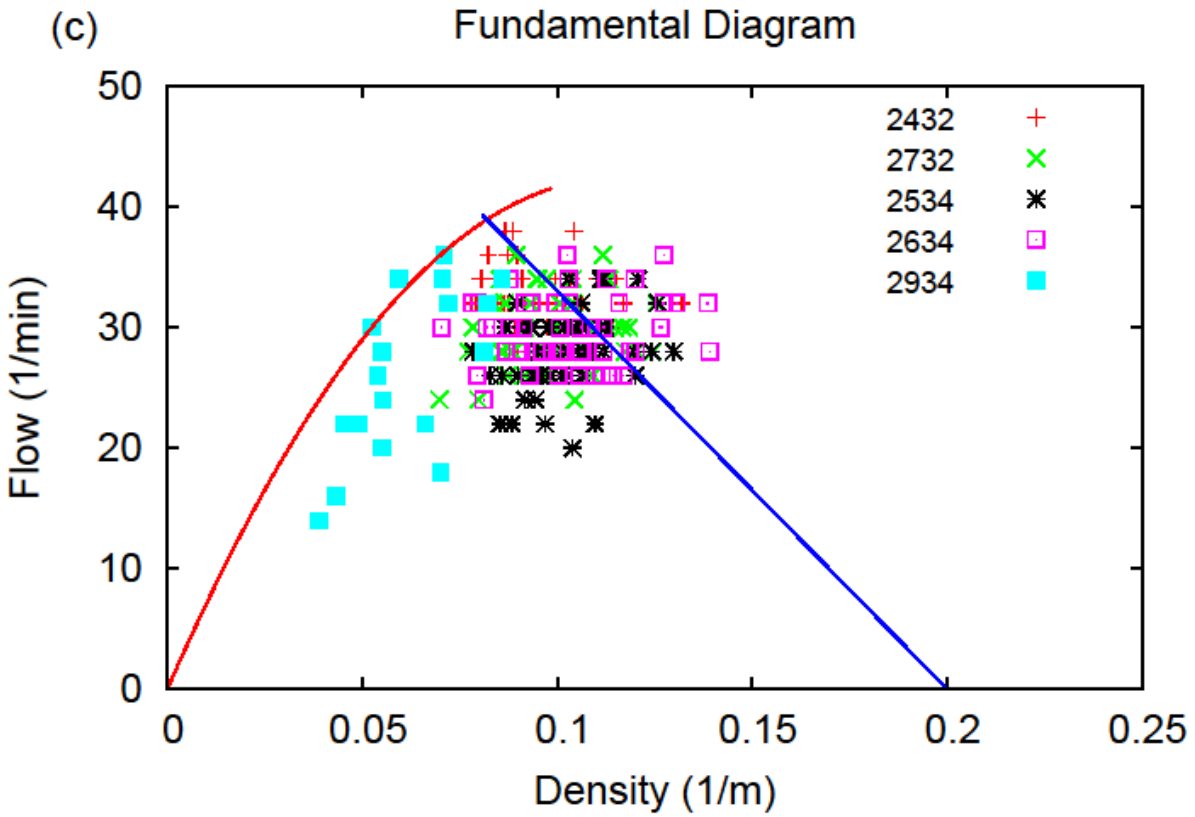


# Fundamental diagram : intermediate




Branching at
Critical density

# FUNDAMENTAL DIAGRAM : HIGH DENSITY



# Summary

- Experiment at Nagoya Dome
  - Spontaneous emergence of traffic jam without bottlenecks
  - Phase transition between free flow and jam
- Strong supports for physical viewpoints of traffic flow
  - Exclusion effects
  - Delay in response
  - Main contribution is not human factors

# Future Plans

- Estimating parameters in Optimal Velocity Model

- Optimal Velocity Model

$$\frac{d^2x}{dt^2} = \alpha\left[V_{\text{optimal}}(\Delta x) - \frac{dx}{dt}\right]$$

$$V_{\text{optimal}}(\Delta x) = v_{\max}\left[\tanh\left(\frac{\Delta x - d}{w}\right) + c\right]$$