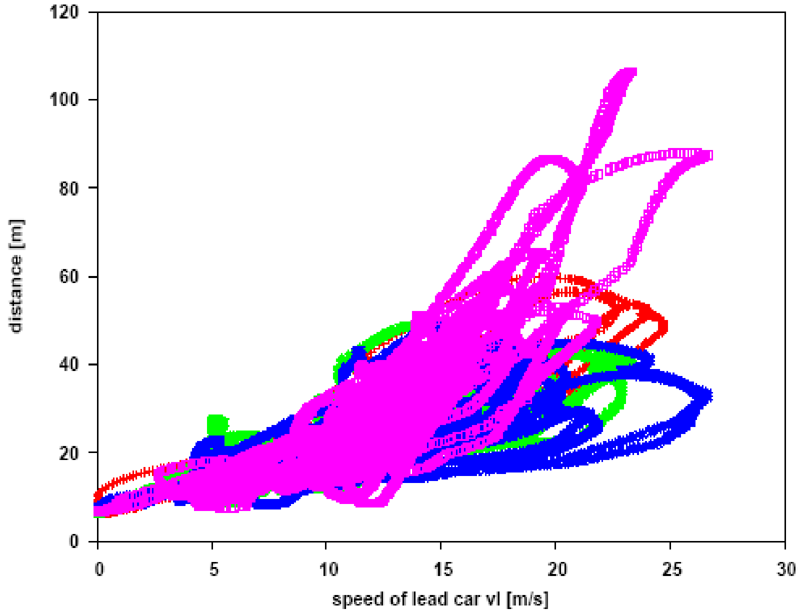
From Experiments to Modeling (II) ("those scaring data")



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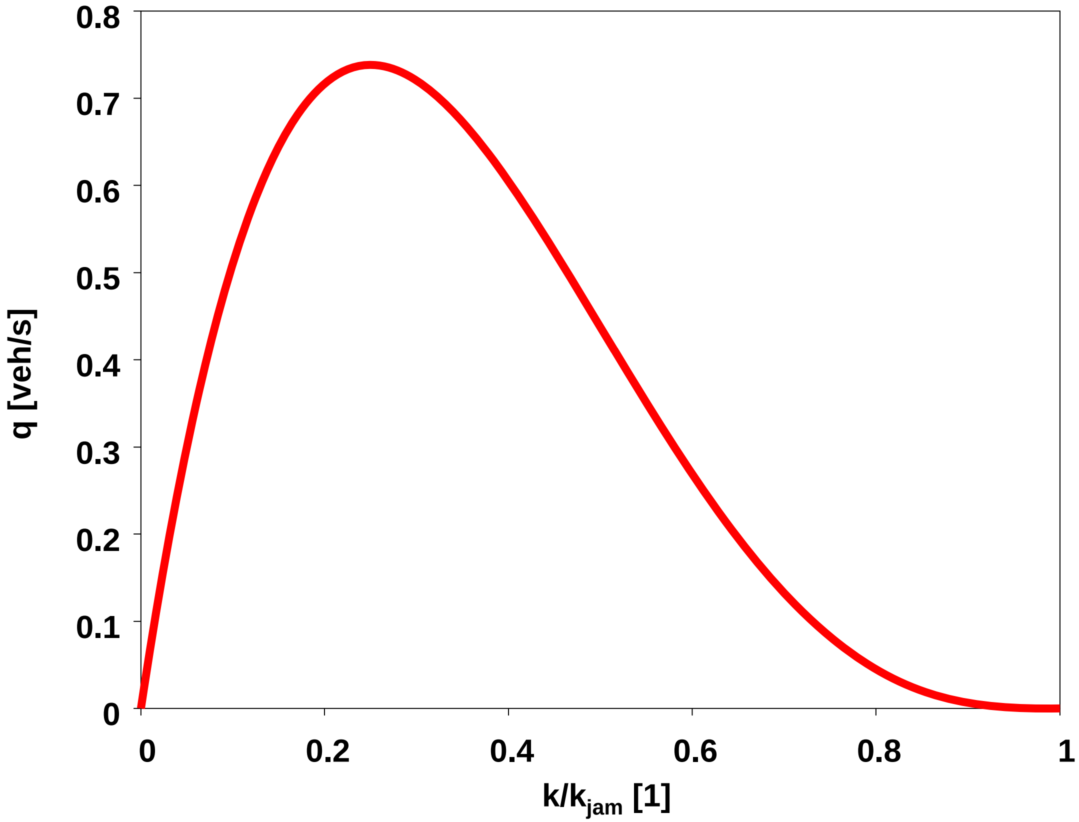
What this presentation is all about

- data,
- data,
- and data!

- I will try to avoid ANY theory (where ever possible), and especially ANY model.

Theory: Fundamental diagram (FD)

- You have seen it over and over by now: the fundamental diagram.
- Theoreticians love it in its flow q versus density k version, depicted here:
- practioneers prefer speed v versus flow q (q and k can be measured, k mostly not)
- sometimes, another k-surrogate named occupancy is used
- this function is a fiction: it is difficult to map it out completely with real data
- has an interpretation

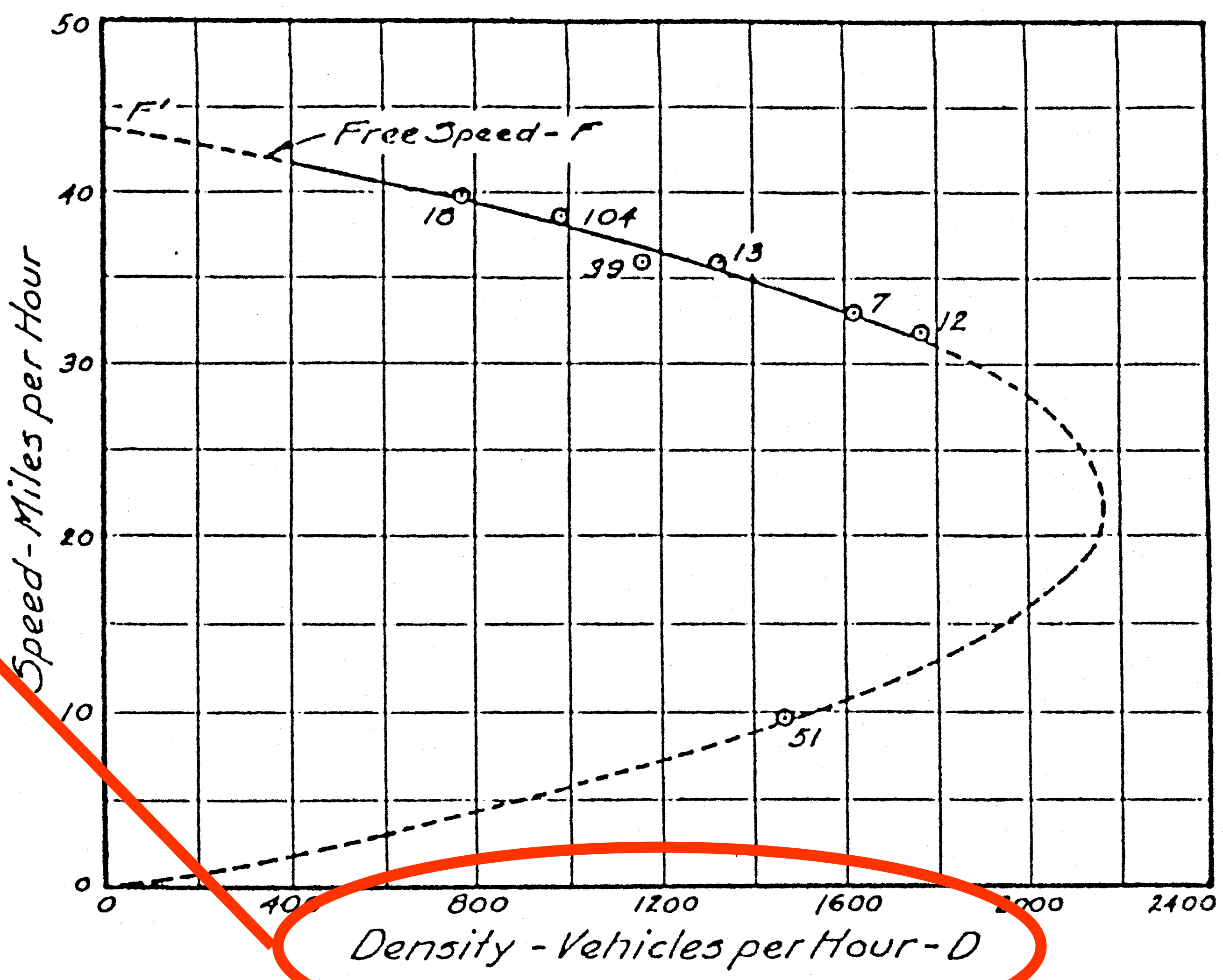


Empirics: Fundamental diagram

- Greenshields, who has started it all in 1934

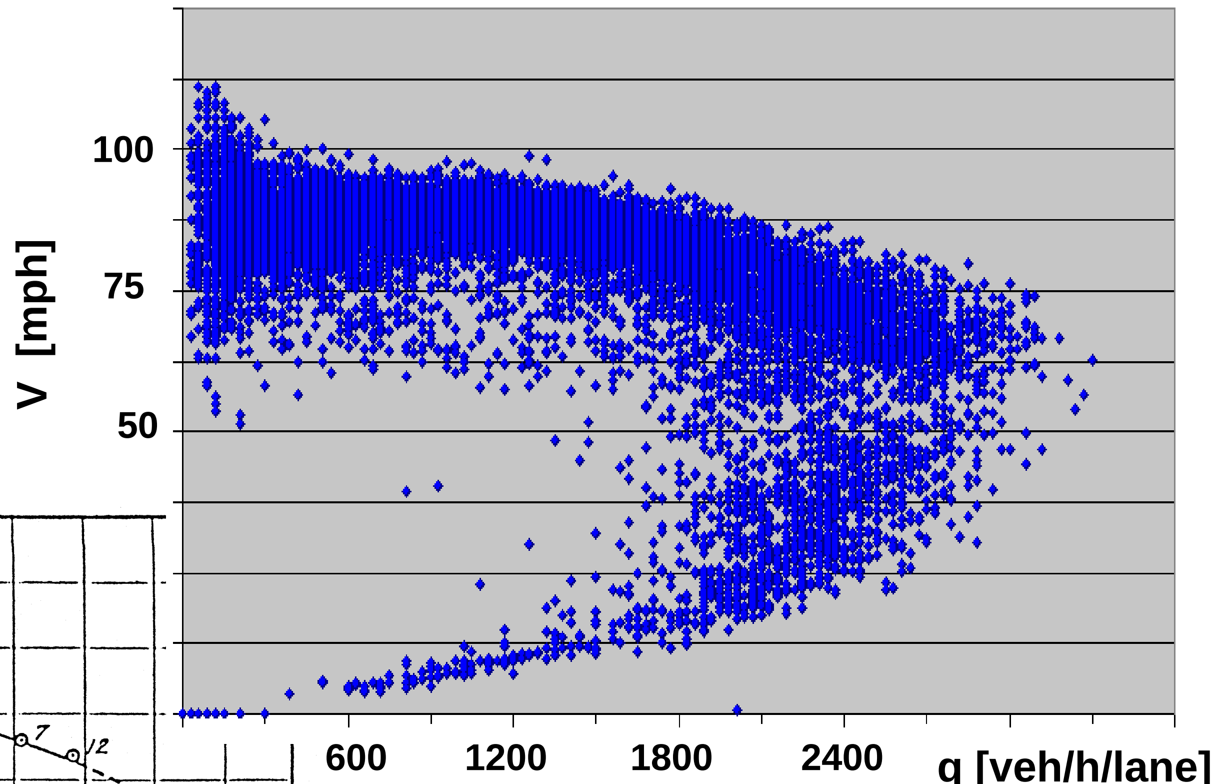
Note: there will be a conference celebrating FD's 75 birthday in July 2008

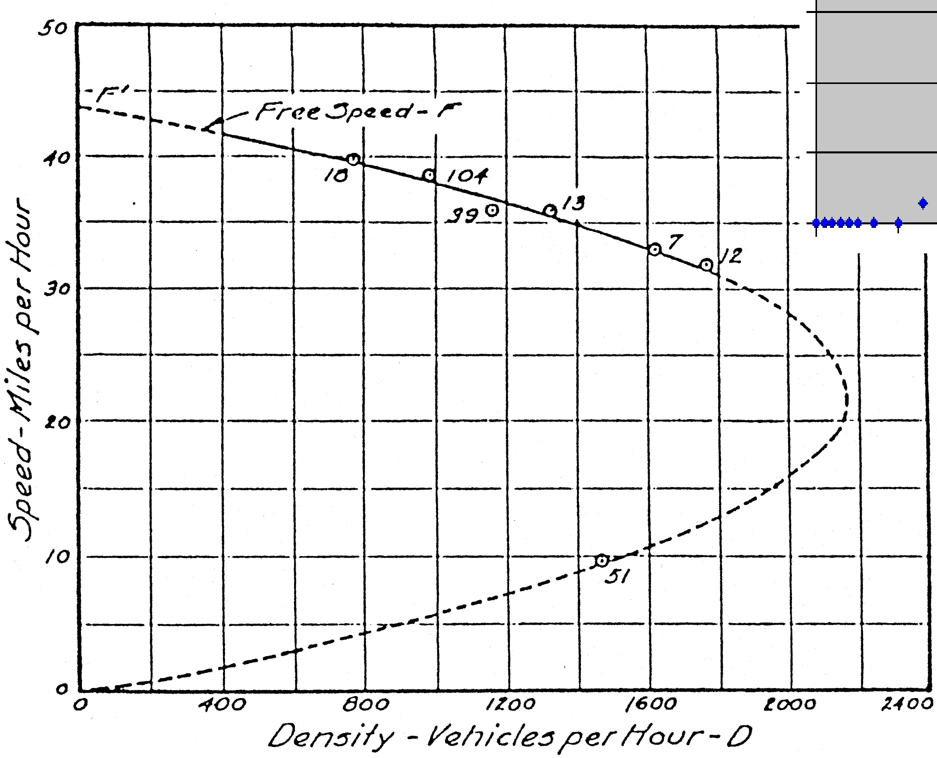
The first fundamental diagram



we name this flow today (unit ok!)

Some fifty years later...





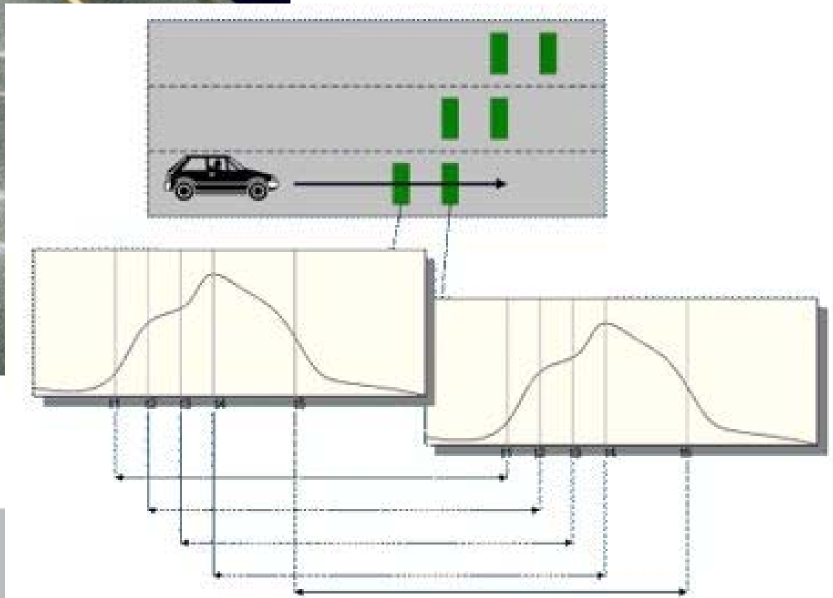
- not that much has changed!

Micro-macro connection in the FD

- traffic flow q, traffic speed v and density k have microscopic counterparts
- traffic flow: basically it's the expectation value of the inverse gross headway τ_i, so:
- $$q = \left\langle \frac{1}{\tau_i} \right\rangle_{t \in [a,b]} \qquad \tau_i = t_i - t_{i-1}$$
- where t_i is the passing time of the i-th vehicle
- the density k is just the expectation value of the spatial distances; strictly, the following equation is valid only under stationary conditions
- $$k = \left\langle \frac{1}{x_{i-1} - x_i} \right\rangle_{t \in [a,b]} = \left\langle \frac{1}{v_{i-1}\tau_i + \ell_i} \right\rangle_{t \in [a,b]} \qquad \text{with } x_{i-1} = x_i + v_{i-1}\tau_i + \ell_i$$
- but note: in a jam, vehicles move strange, and loop detectors cannot be trust entirely

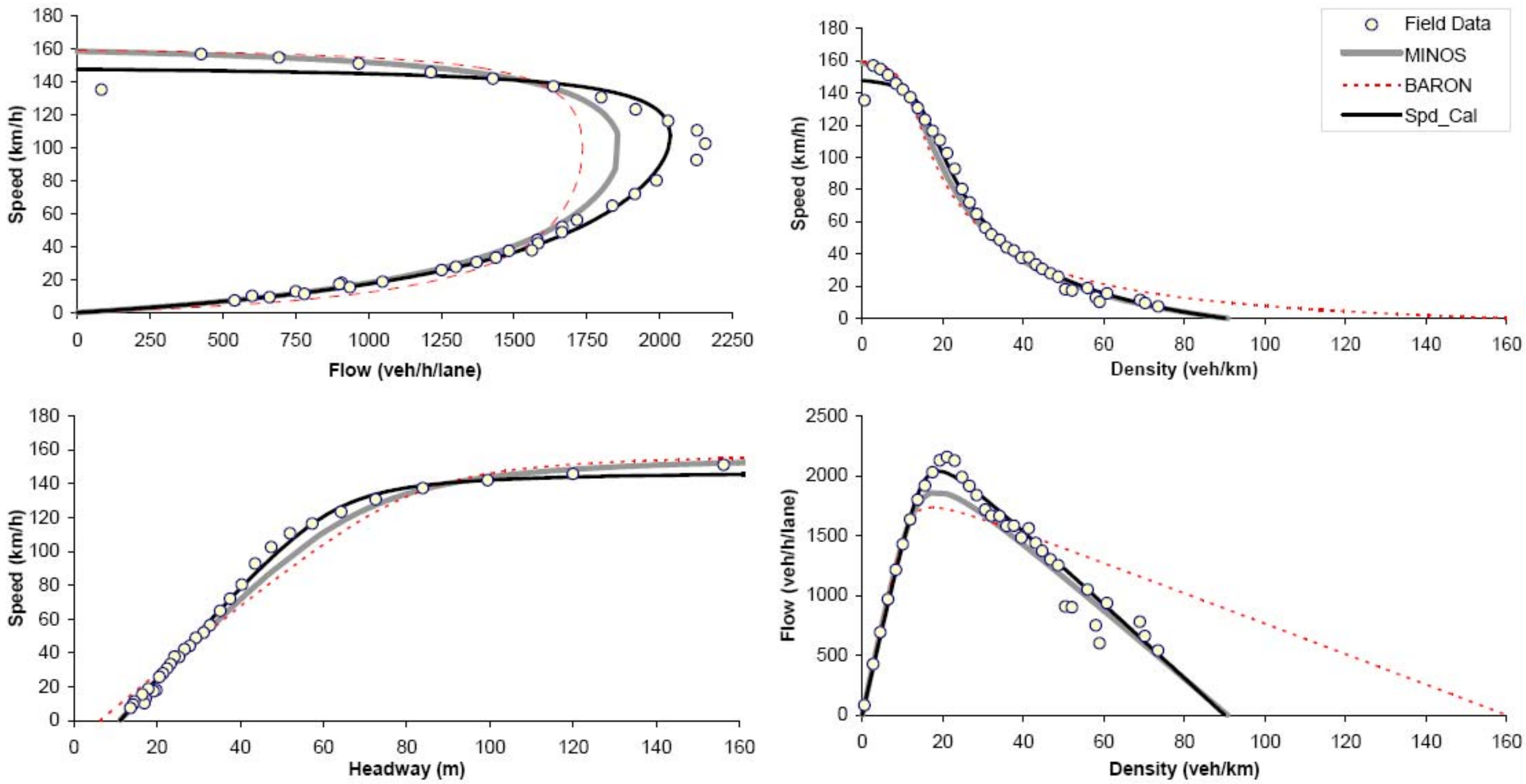
Loop detectors

- most of the data we have at hand are measured by so called loop induction devices;
- these are complex machines themselves, they measure something that has some relation to reality (at least we hope for that it has)



Fitting the FD

- functions to fit the FD – that's a kind of almost magical business, to find the REAL function which "explains" an FD (from a recently submitted paper)



Interpretation

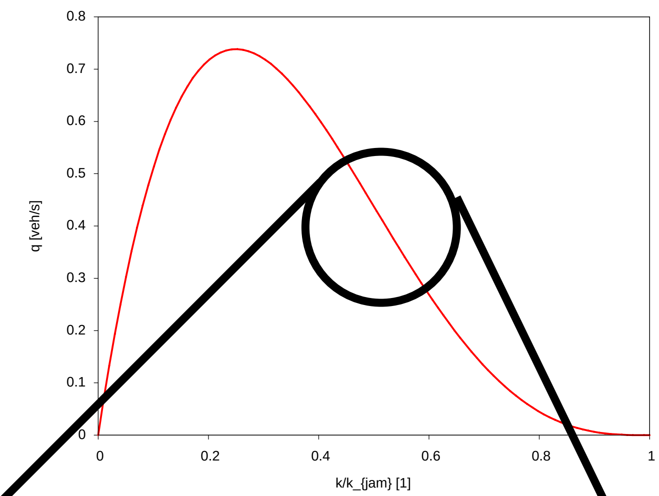
- the interpretation of the FD is that it is the EQUILIBRIUM curve of an underlying microscopic car following dynamics:
- $\dot{v}_i = f(x_i - x_{i-1}, v_i, v_{i-1})$

$$\dot{v}_i = 0 \quad \Rightarrow \quad \langle v(k) \rangle = g\left(k = \left\langle \frac{1}{x_i - x_{i-1}} \right\rangle \right) =: g(k)$$

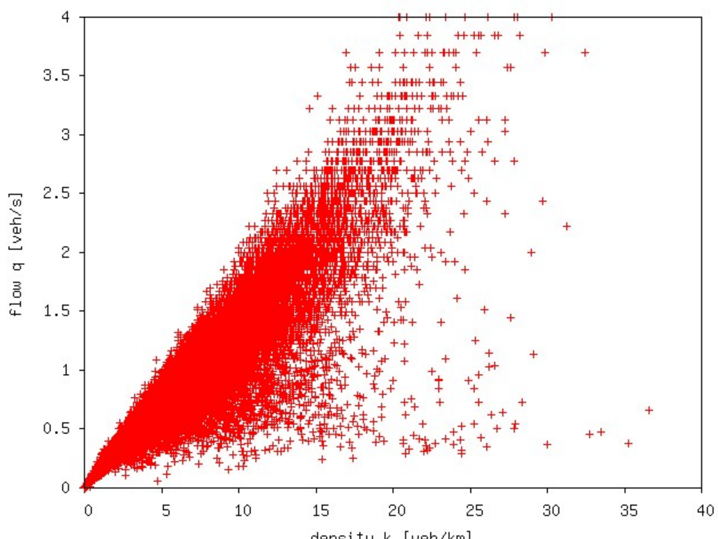
$$v_i = v_{i-1} \quad \text{must hold}$$

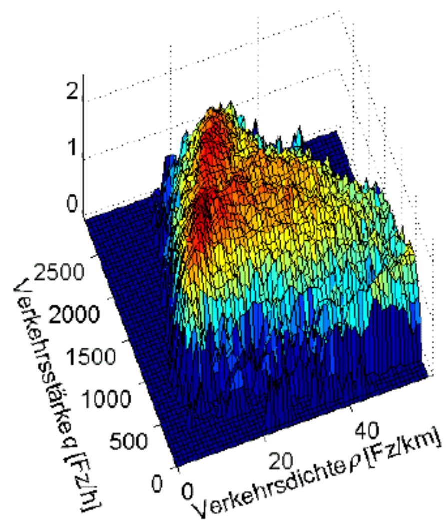
- (Remark I: to me, the FD for a very long time was simply a plot of q versus k; not more, but no less.)
- (Remark II: this equation explains why Boris Kerner created such a fuss by stating that this equilibrium relationship is a fiction)
- (Remark III: remark I explains, why a lot of people were watching this discussion with a certain bewilderness – what the heck do they discuss about this stuff so long and engaged?)

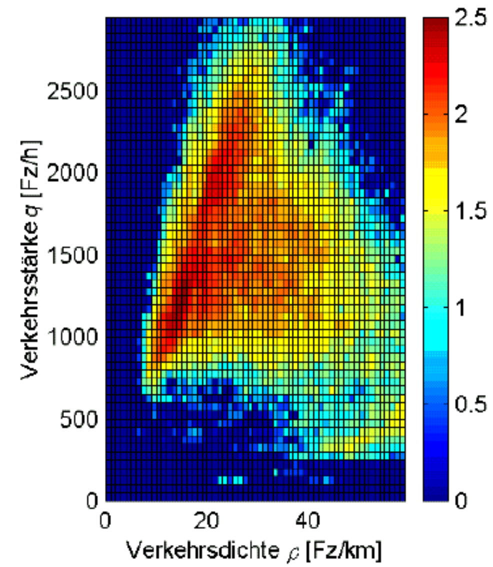
Zoooming in



- Martin Treiber has demonstrated a lot of data on spatio-temporal patterns; I will go into the opposite direction
- I love disaggregate data!. So, lets do a “microscopic FD”;
- however, this mass of data has to be organized in some manner, so instead of the big scatter plots look at distributions

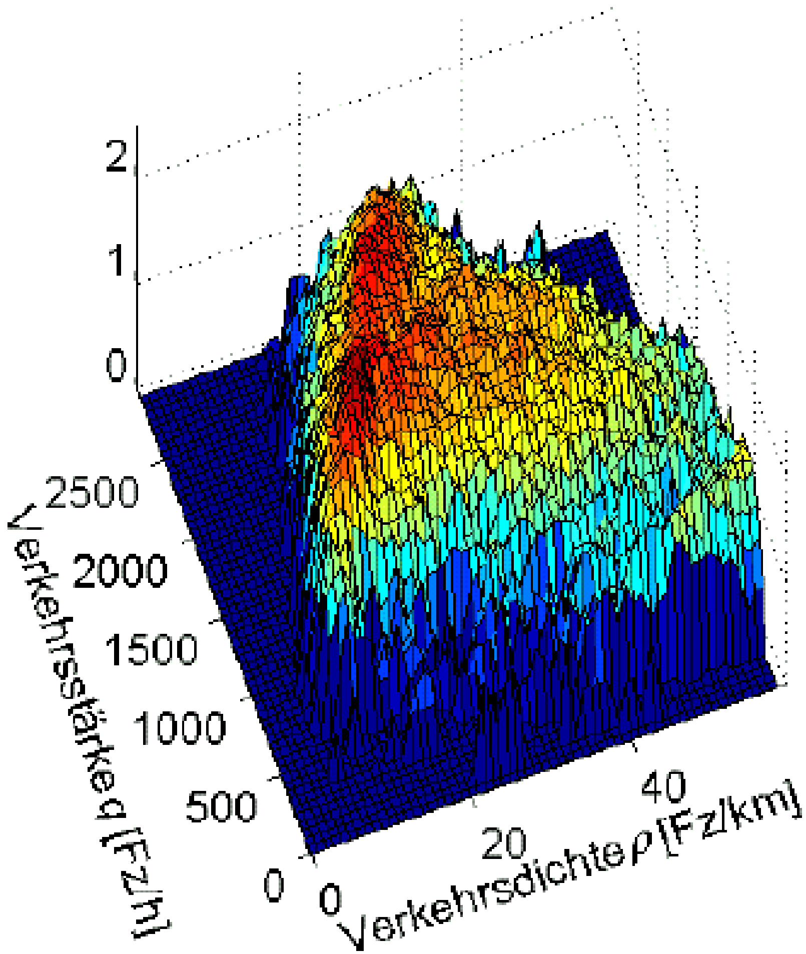


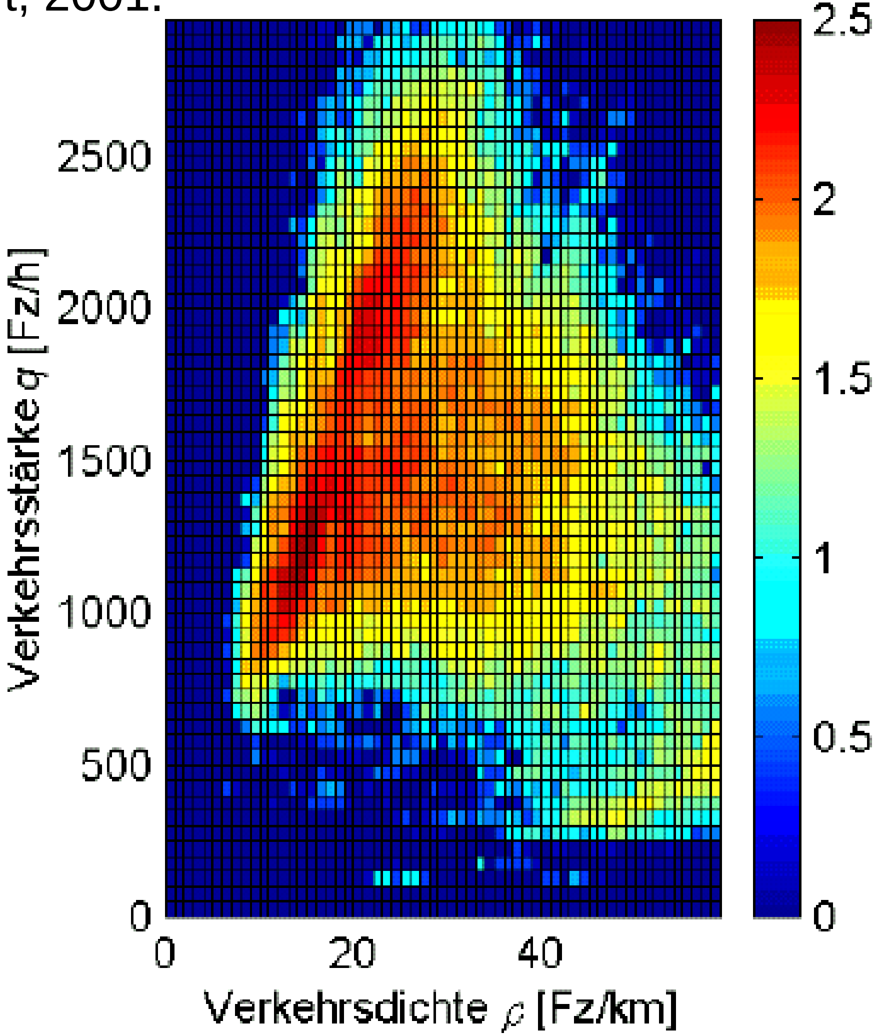




Probabilistic microscopic FD – p(q,k)

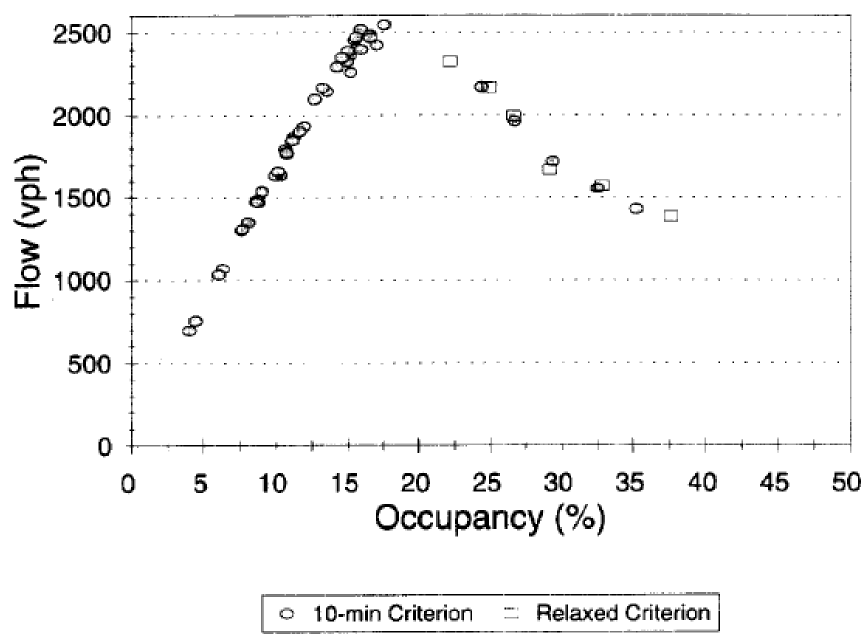
- plots are taken from J. Kienzle, Analyse von Einzelfahrzeugdaten, Diploma thesis, University Stuttgart, 2001.





Aggregation

- of course, if one computes for any density k the average flow q, one can compute a function q(k)
- big question: under which assumptions is this a valid process?
  - stationarity
  - p(q; k=fixed) should be at least mono-modal, otherwise the mean value does not make sense
- the second point is not critical, albeit the distribution is VERY broad
- the first one seems very hard, so far I haven't seen anything convincing yet
- plot is from Cassidy, TRB **32**, 49 (1998)



Zooming in: a first glimpse on vehicle / vehicle interaction

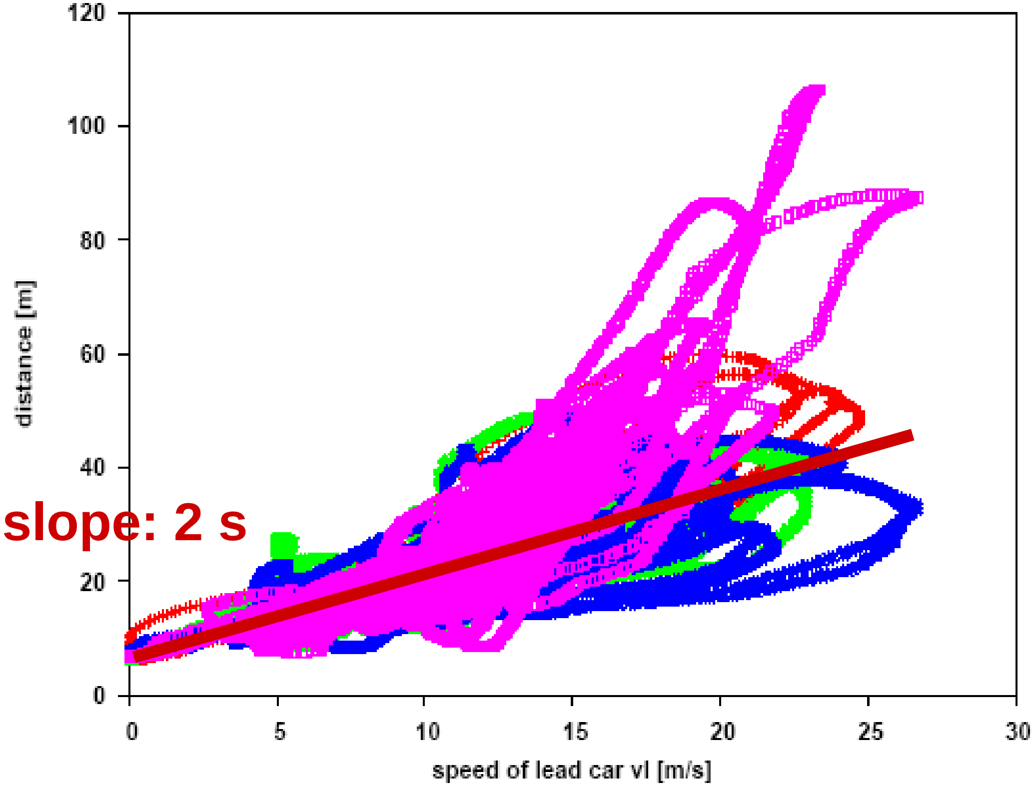
Zooming in even more

- what does the driver do?
- something can be learned even from freeway data (really!),
- however, equipped vehicles are more convenient to find out what’s going on here
- either in a quite simple manner (DGPS equipped vehicles on a track)
- or, much more elaborate:
  - DLR’s ViewCar (R),
  - driving simulator (care needed!)

- a guided tour through the microscopic data zoo...
- ...which may help building better models

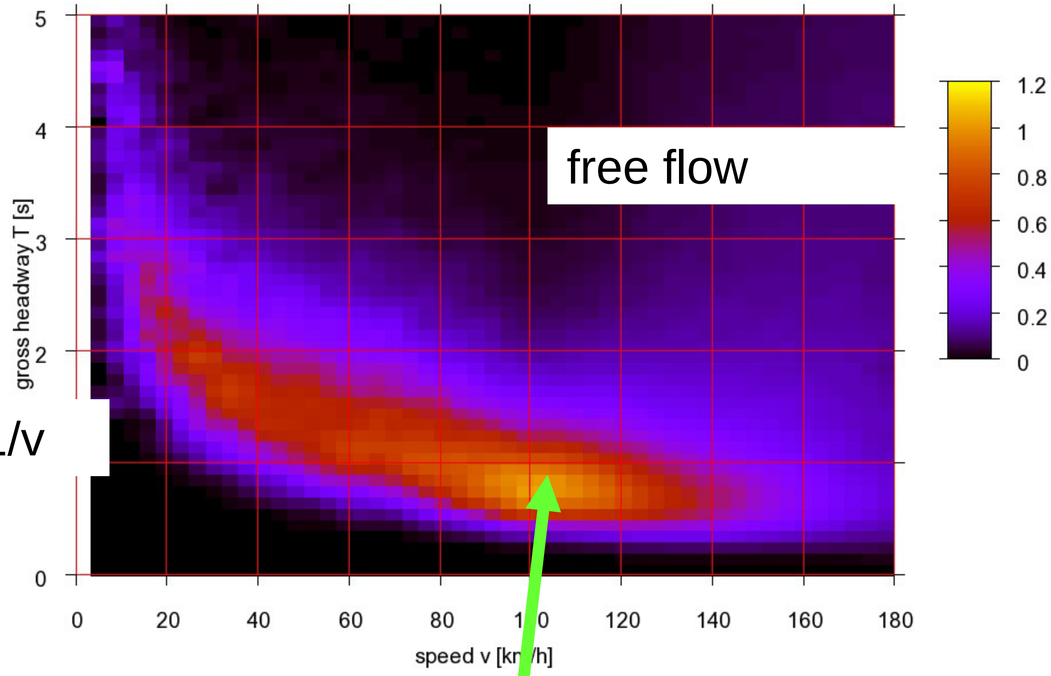
Driving relation: distance versus speed
(another microscopic fundamental diagram)

- this is test track data, the color denote different drivers (20 min of driving are plotted here);
- but freeway data (would) look similar
- of course, drivers are different, but even a single driver has a lot of different 'parameters'
- (e.g. preferred time headway,...)
- of course it makes sense to discuss this again in terms of probability distributions



Probability distribution in speed/headway
(flow versus speed microscopic FD)

- these are data from a German freeway A3
- and it is a first approach to understand the interaction between vehicles
- as has been stated already, the acceleration of a vehicle depends on the interaction to the lead car
  - on speed difference
  - and distance
  - may other things
- $\dot{v}_i = f(x_i - x_{i-1}, v_i, v_{i-1})$



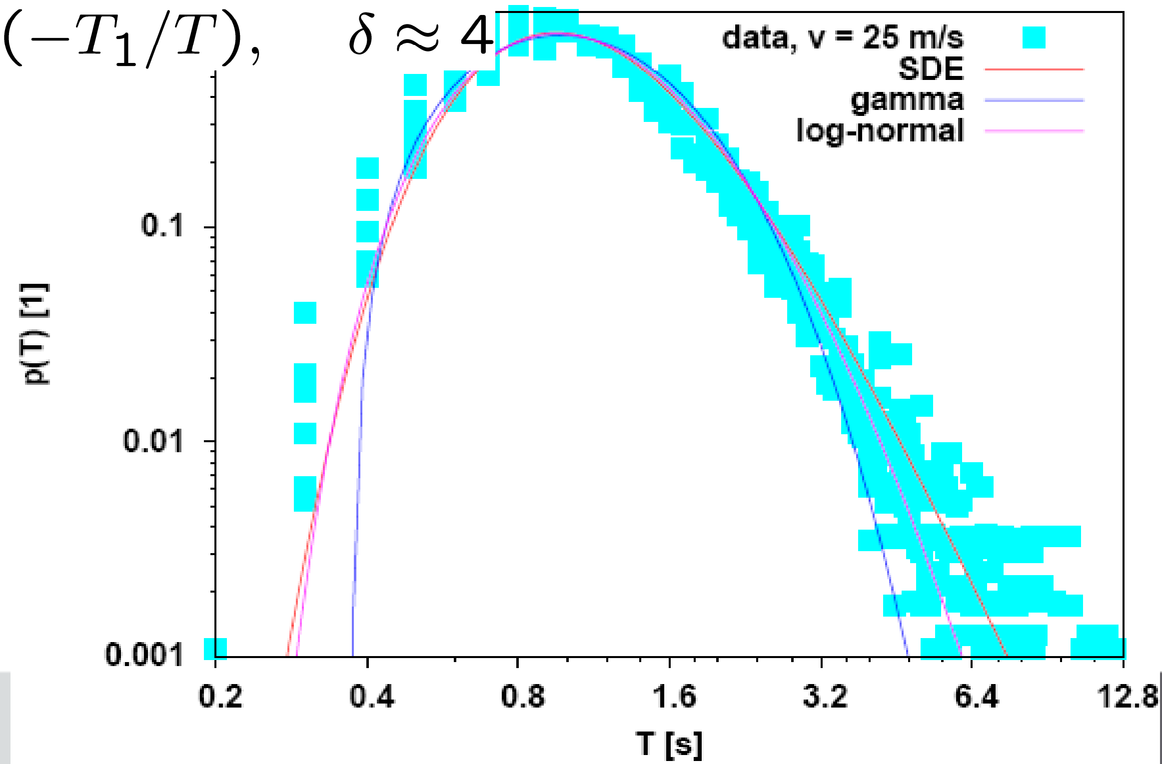
jammed flow T ~ 1/v

most efficient driving (0.8s)

Distribution of headways $p(T)$

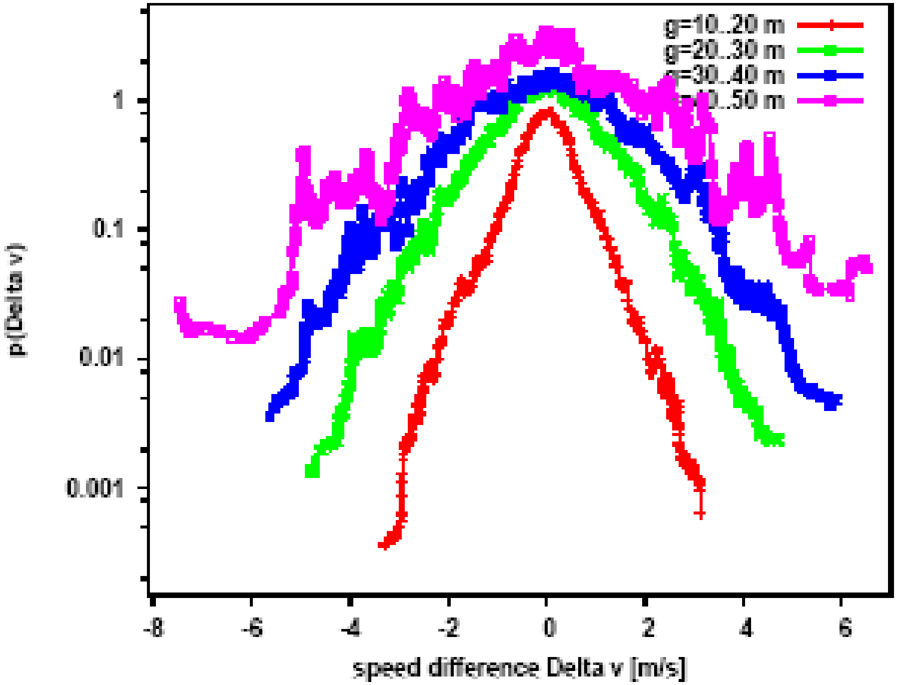
- what to expect for p(T)? Since T>0, it could be a log-normal distribution
- or a generalization of the Poisson distribution, which avoids to small distances (named Gamma or Pearson III)
- However it seems, that it's something different

$$p(T) \propto T^{-\delta} \exp(-T_1/T), \quad \delta \approx 4$$

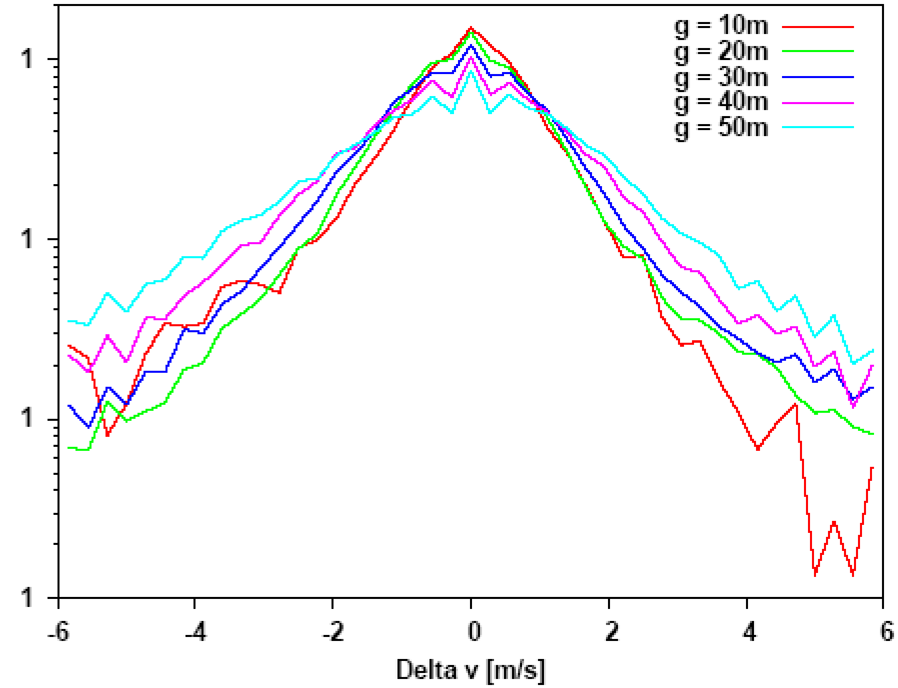


Distribution of speed differences

- a specific pattern in the distribution of speed differences – they are definitely not normally distributed:
- $p(\Delta v) \propto \exp\left(-\lambda\left|\Delta v\right|\right)$ (Laplace distribution)
- (for small distances, at least)



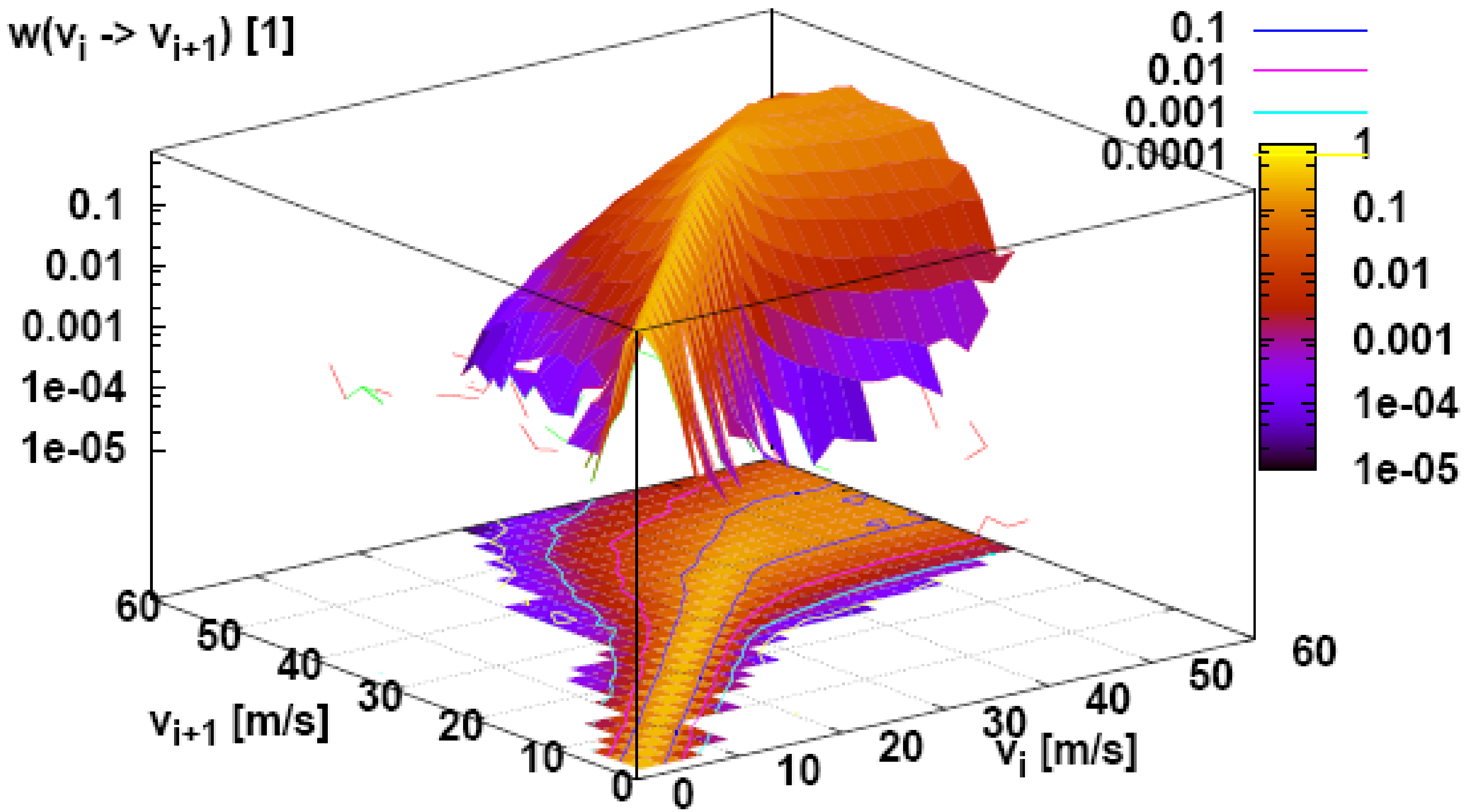
- Test-track



- Freeway data

$p(\Delta v)$ versus speed itself

- distribution of speed differences versus speed itself: this tells us something about the interaction between two vehicles:

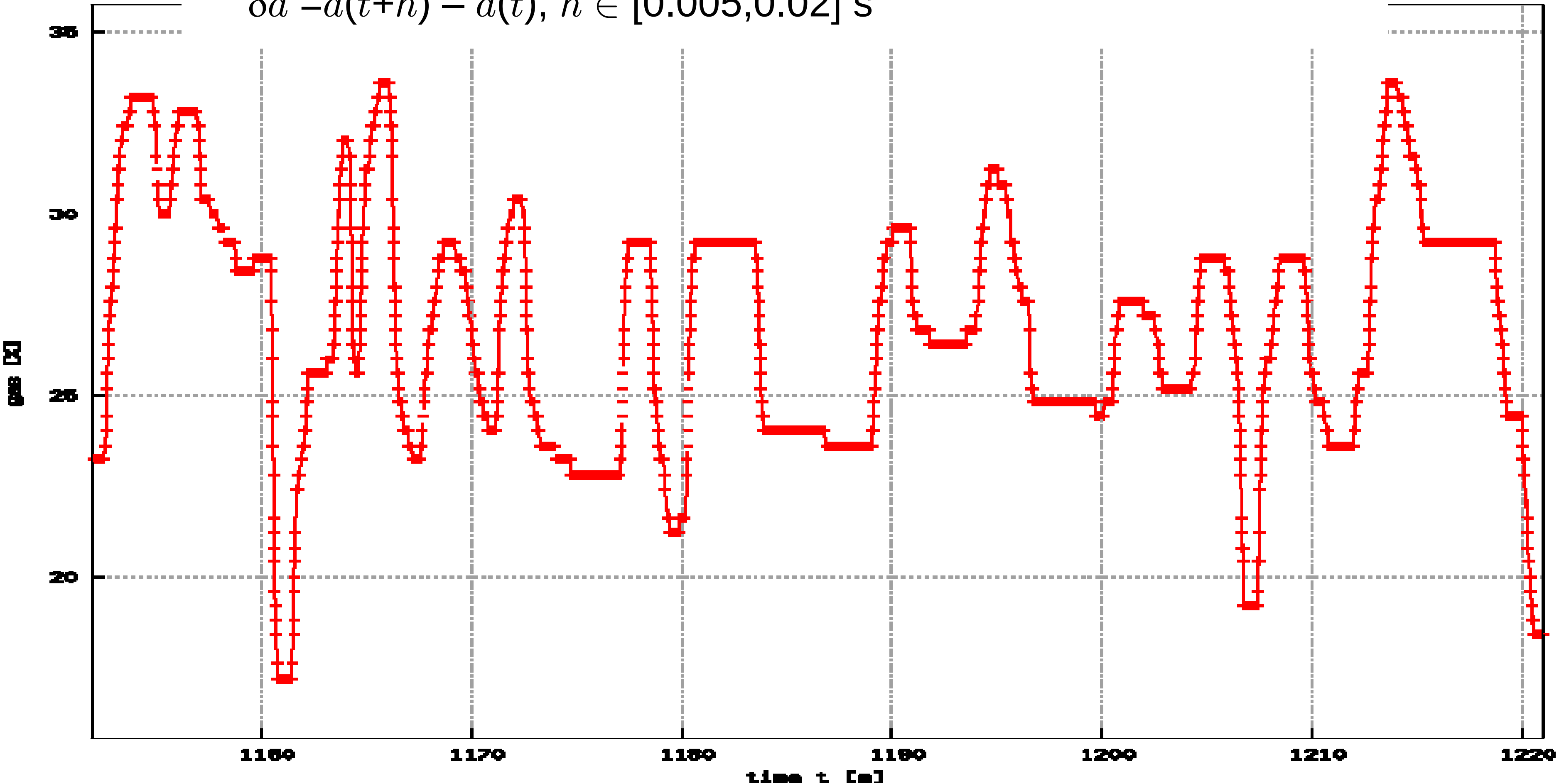


To see even more, we have to go beyond the loop detectors

The action points

- ViewCar data (6 subjects on a rural road), gas pedal a(t)
- 71036 of 75778 data-pts: δa = 0, where

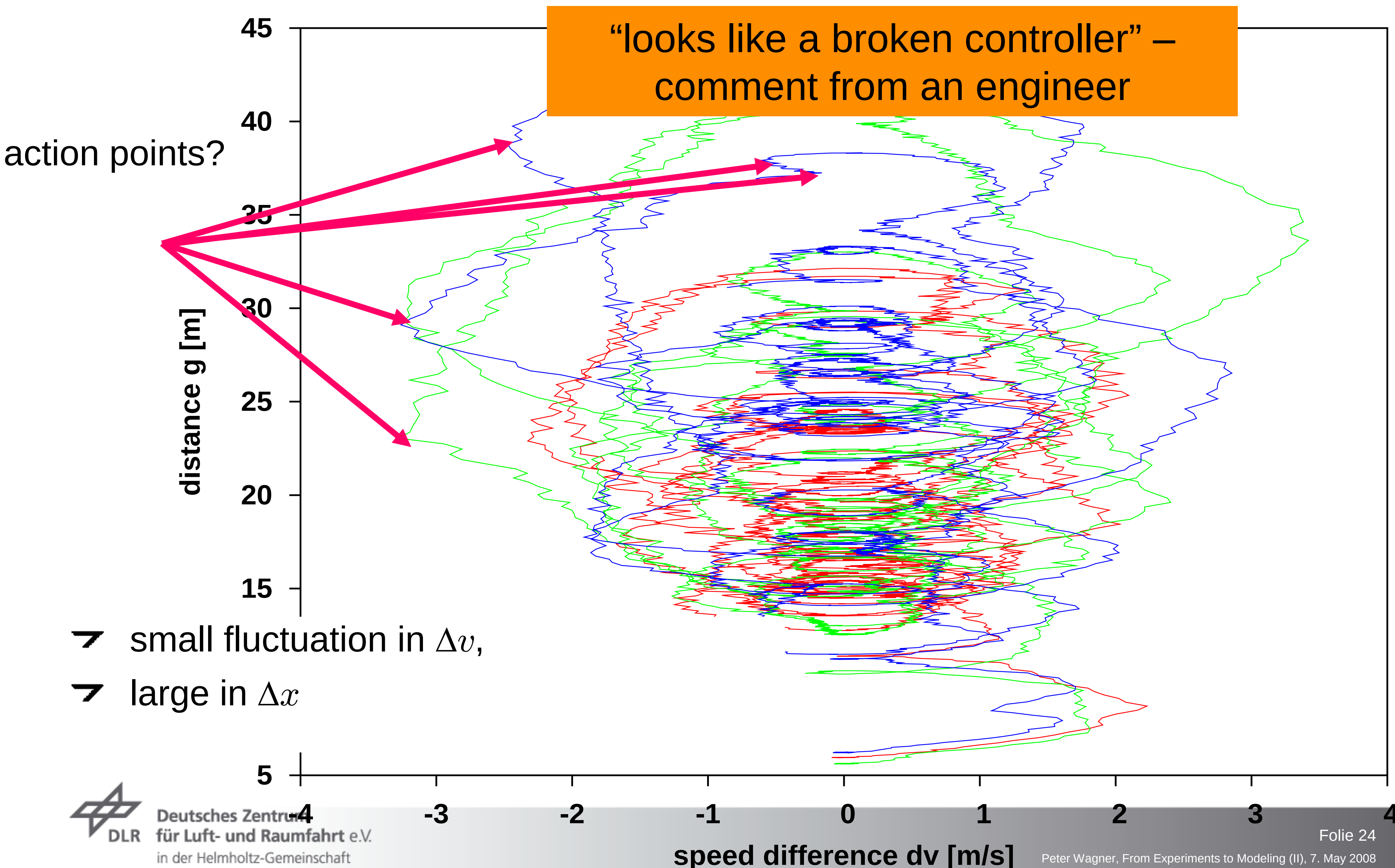
$\delta a = a(t+h) - a(t)$, $h \in$ [0.005,0.02] s



Equilibrium?

- with such a behavior, it is quite unlikely to find any fixed point or equilibrium behavior in the simple sense $\dot{v}_i = 0$
- the jumps have been named action points already in 1963 by Todosiev, who was first to observe this behavior
- it is typically for human control action (have seen it in other occasions):
  - don't do anything, until you are forced to
  - if you do, do it sloppy (see below)
  - (completely different from how a automatic driver would handle this issue – they do it like a differential equation)
- however, the main modeling work in research during the past 40 years has ignored this observation – may be, it can be tackled as a kind of noise?
- once you know this, you see it immediately even in the distance versus velocity difference phase space of car following

Oscillations in $(\Delta v, \Delta x)$



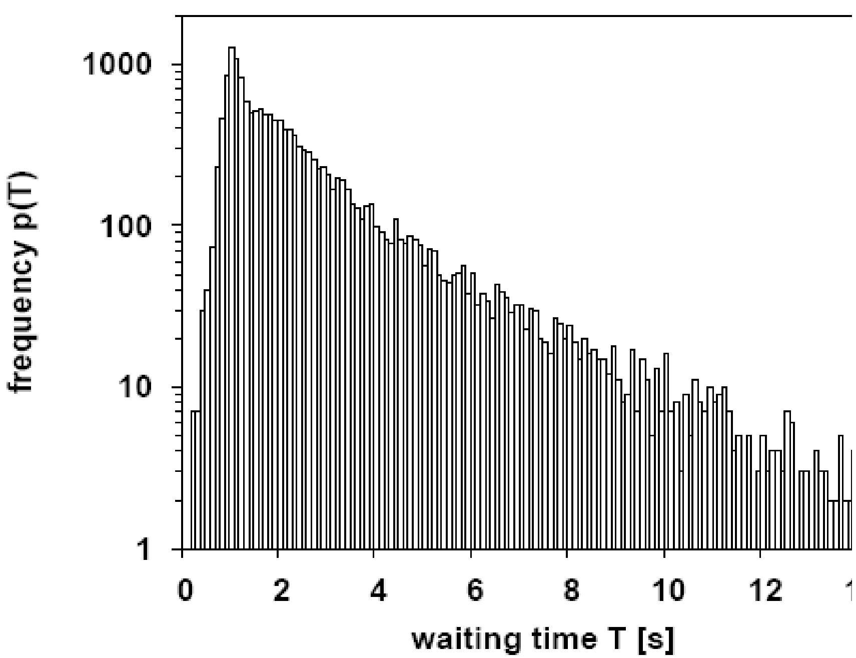
- small fluctuation in Δv,
- large in Δx

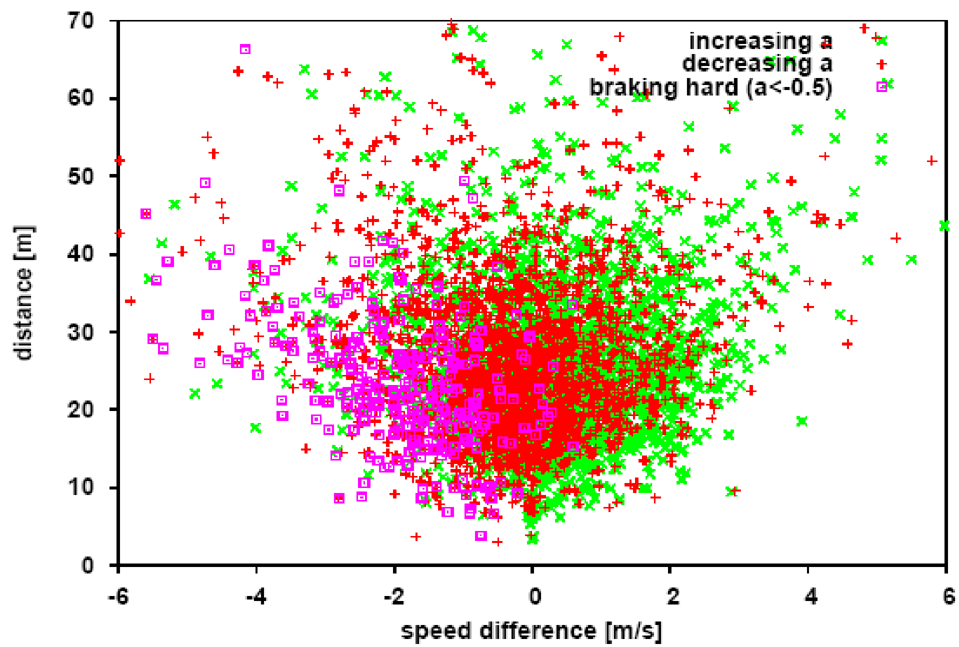
stabilization

- ...and this means, that we have at least an explanation for the scatter apart from that's due to different drivers;
- it is of a purely dynamical origin
- big question (I do not know yet): does this stabilize traffic flow, or is it finally the cause of any break-down?

Analyzing action-points

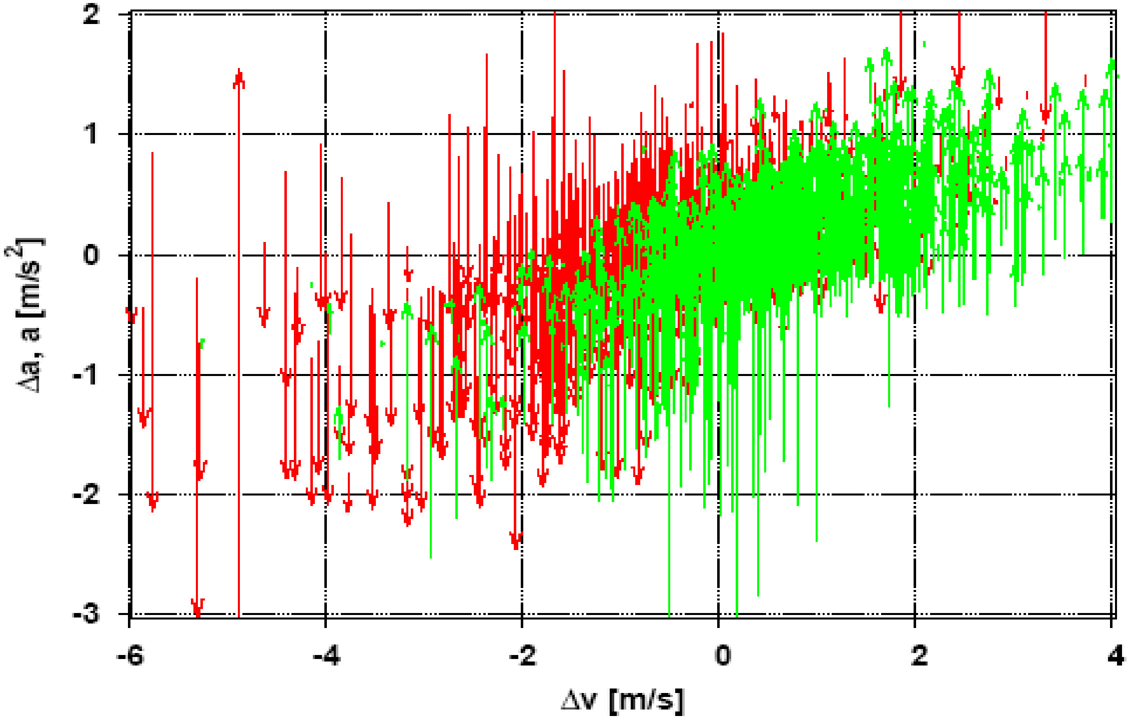
- look for their distribution (again) in time and phase-space
- exponential distribution in time-difference between action-points ➔ they seem to be drawn randomly, as if the driver decides in any smallest time-step "should I change acceleration or not" with some prob. p
- distribution in phase-space seems "flat" ➔ action-points can happen anywhere, and positive and negative points are only slightly different

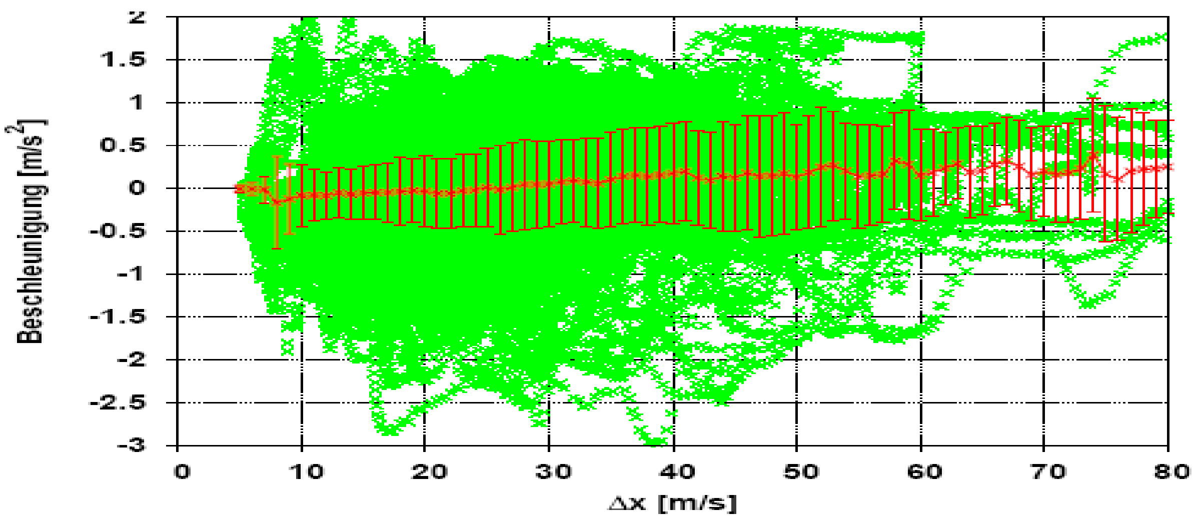




Finally, the acceleration itself

- again, no clear and no deterministic behavior can be seen





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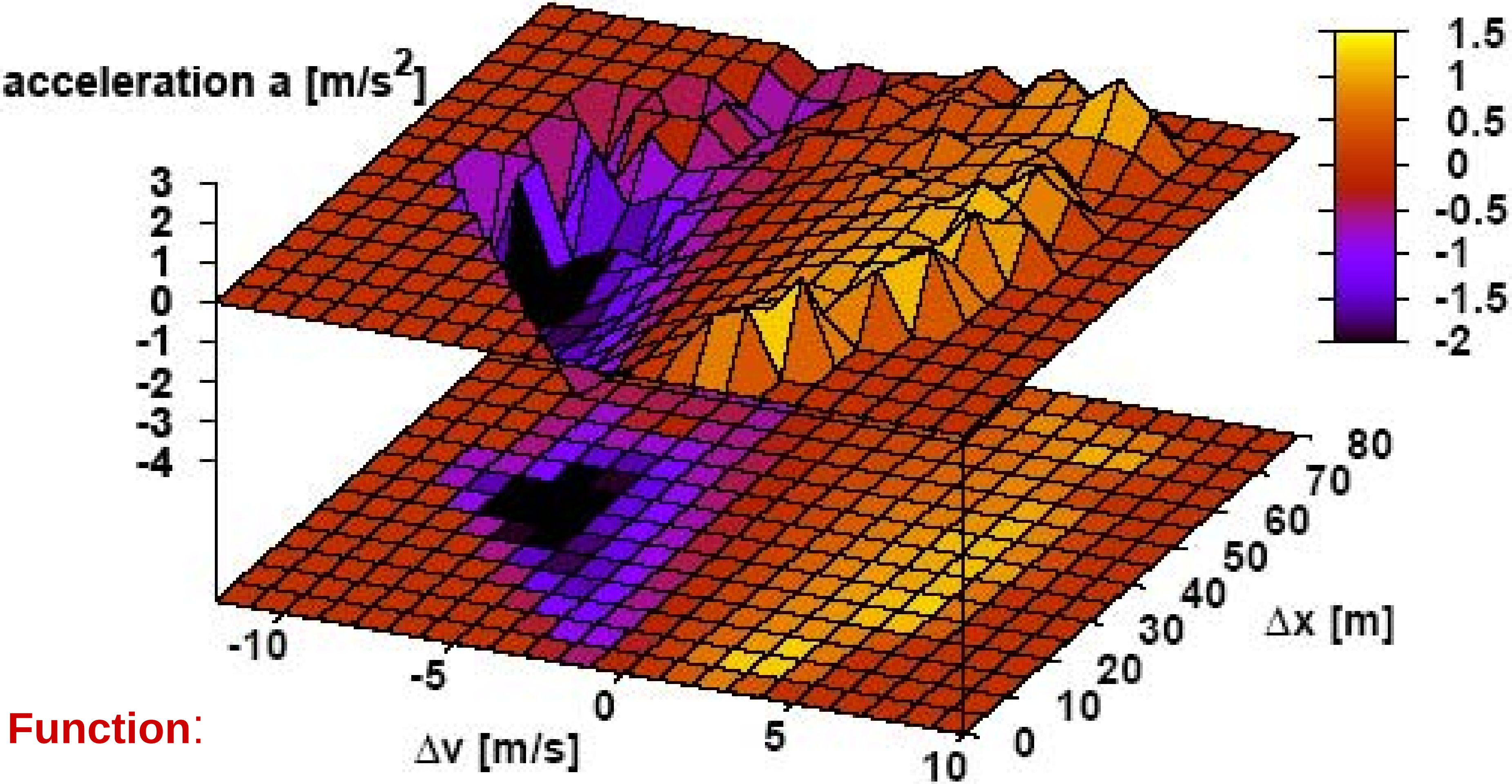
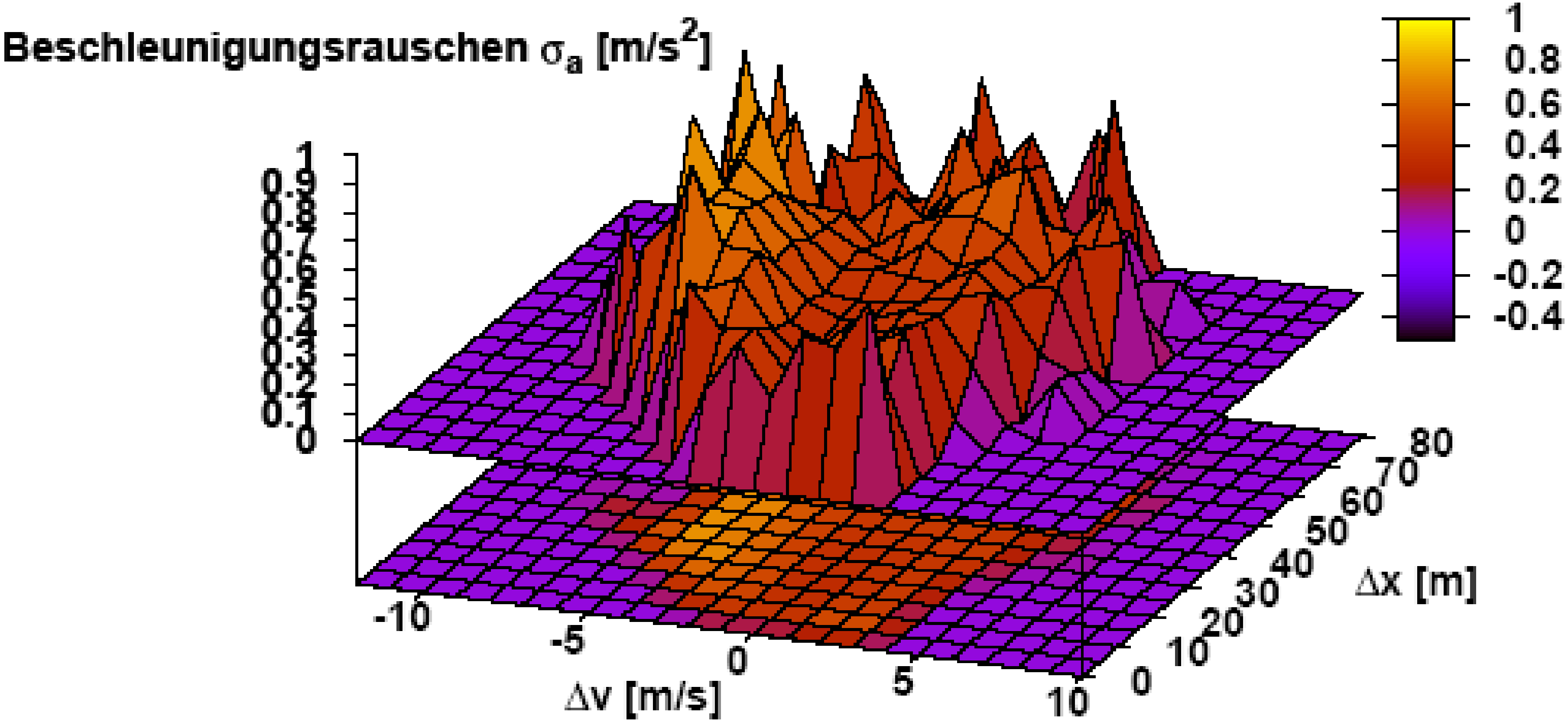
Acceleration in phase space



Function:

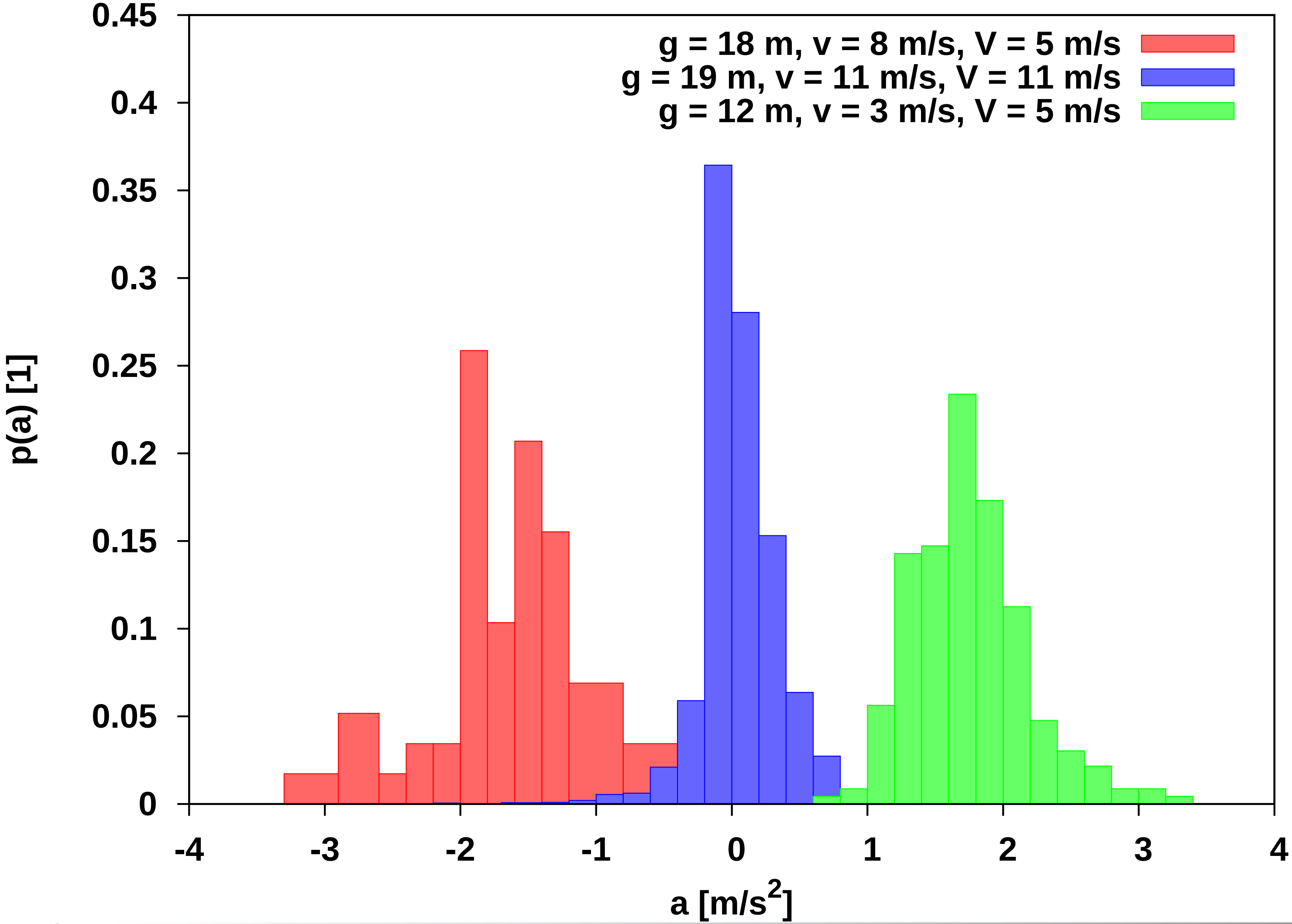
$a(\Delta v, \Delta x) = a_0 + a_1 \Delta v + a_2 \Delta x$, (a_2 **fairly small)**

and acceleration noise



- fluctuations around mean ~ 0.5 m/s^2 (fairly homogeneous)

Acceleration distribution in a small phase-space interval



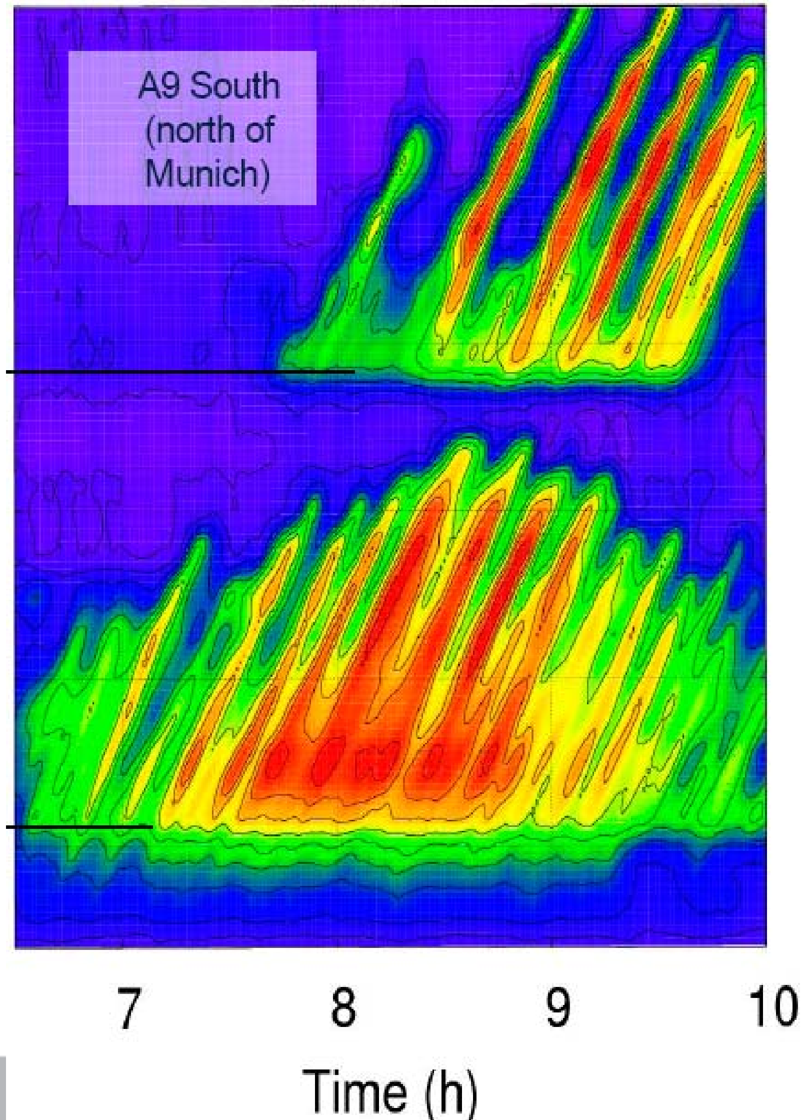
Model, which model?

- of course, it is not too difficult to construct models with the features described above;
- but do we really believe, that human behavior can be that random?

Finally, after all...

- it is amazing, that this microscopic chaos (which nevertheless has its laws & rules) finally averages out to the patterns demonstrated e.g. in Martin's (Treiber) talk
- but does it really?
- and, what always puzzled me:

- one can see the patterns,
- they look differently,
- putting again the magnifying glass on and look into vehicle's behaviour: is there a measurable difference between red and green?
  (apart from speed)



Thanks for listening

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