Physics of the City:
An exponential individual mobility law

A. Bazzani, B. Giorgini, S.Rambaldi, L. Giovannini

Physics of the City Lab - Dept. of Physics – CIG
University of Bologna and INFN - Bologna

www.fisicadellacitta.it

The City as a complex super-organism

The urban mobility is a realization of individual propensities using mobility network in a dynamical environment.

Mobility is the City life, but modern metropolis suffer for traffic problems.

The Physics of urban traffic

- To understand the relation between individual dynamics macroscopic states.
- To study the role of cognitive behaviors in the evolution of self-organized states.
- To look for statistical laws.

The classical OD approach

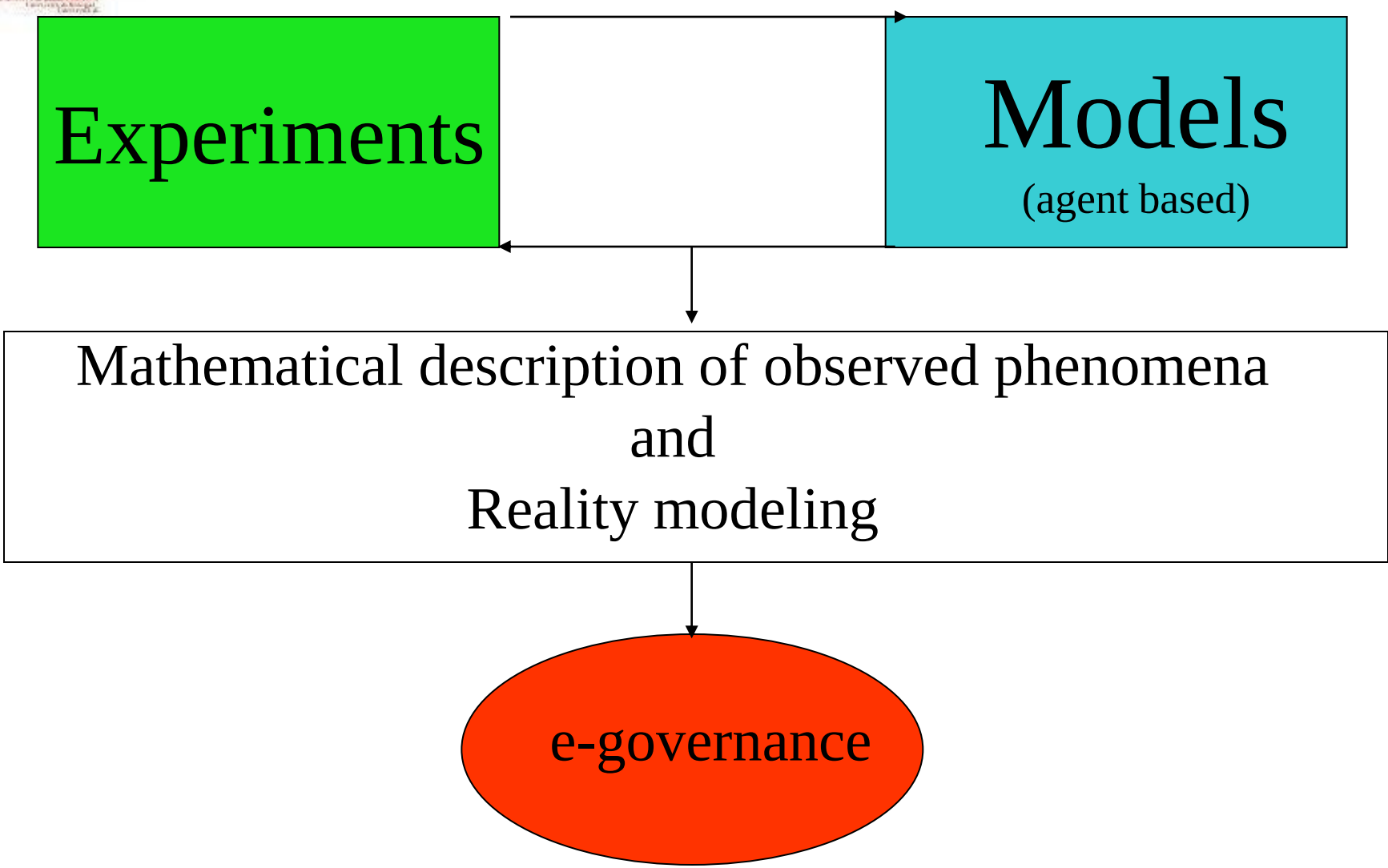
The Origin-Destination approach assumes the existence of a global spatial organization in the city that determines the mobility request: it is possible to compute OD matrices.

The traffic govern is reduced to the problem of building transportation infrastructures.

The crisis of OD models

- The City is a dynamical system in a non-equilibrium state.
- The modern cities develop according to an internal rationality.

New models for a complex urban mobility



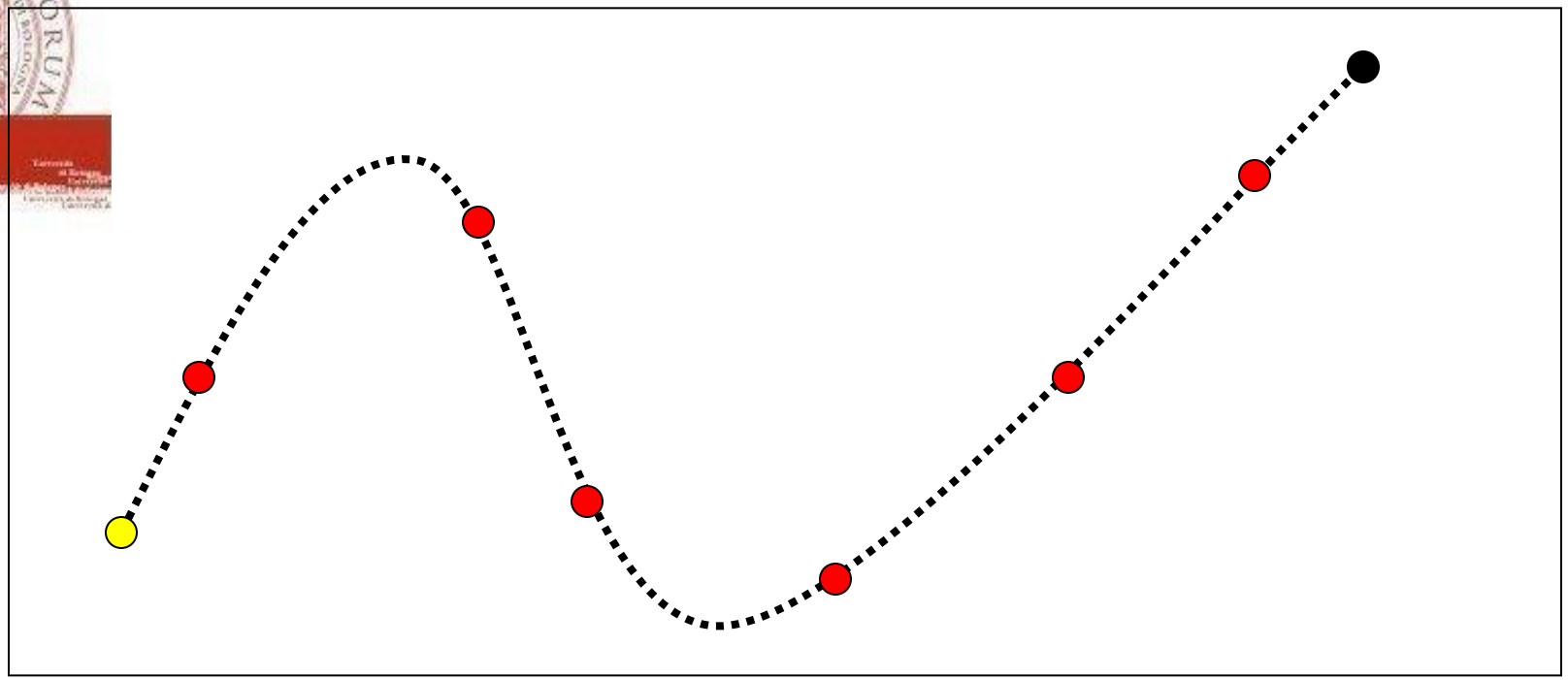
Statistical Physics of an automata gas

The idea is to understand some aspects of biological systems as the result of cognitive “particle” behavior in a collective interaction framework.

New experimental observations

The introduction of GPS technology on vehicles for commercial or control use opened the opportunity of collecting experimental data on single vehicle trajectories.

Collaboration between the “Physics of the City” Laboratory and Octotelematics srl.

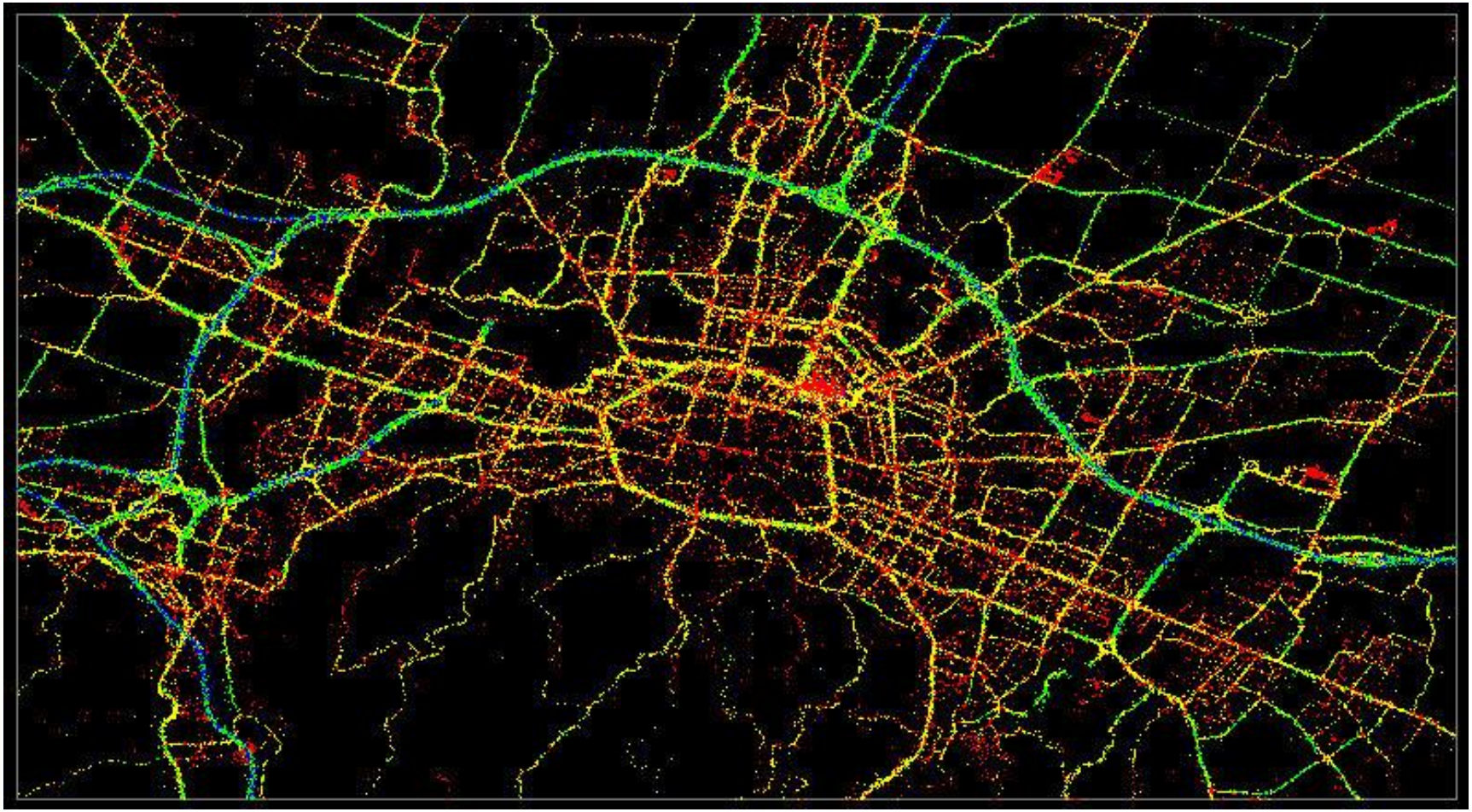


	latitude	longitude	speed	direction	quality	engine
●	last	last	0	0	low	on
●	yes	yes	yes	yes	high	working
●	yes	yes	0	0	high	off

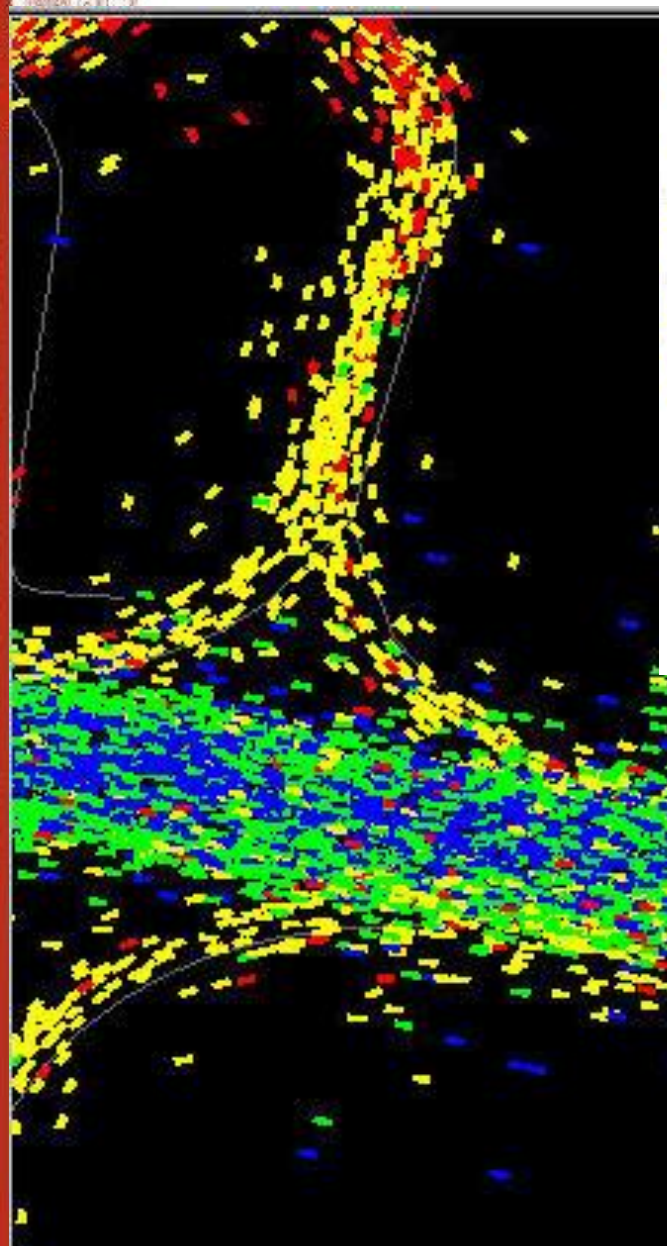
GPS Data Set Reliability

1. At present 1% of the italian vehicles are monitored, but this number is rapidly growing.
2. A priori knowledge of the sample properties is not possible.
3. Time resolution is “perfect” and spatial resolution is “adequate”.
4. A dynamical “velocity” map of urban road network can be computed.
5. Information on the individual mobility demands and congested traffic.

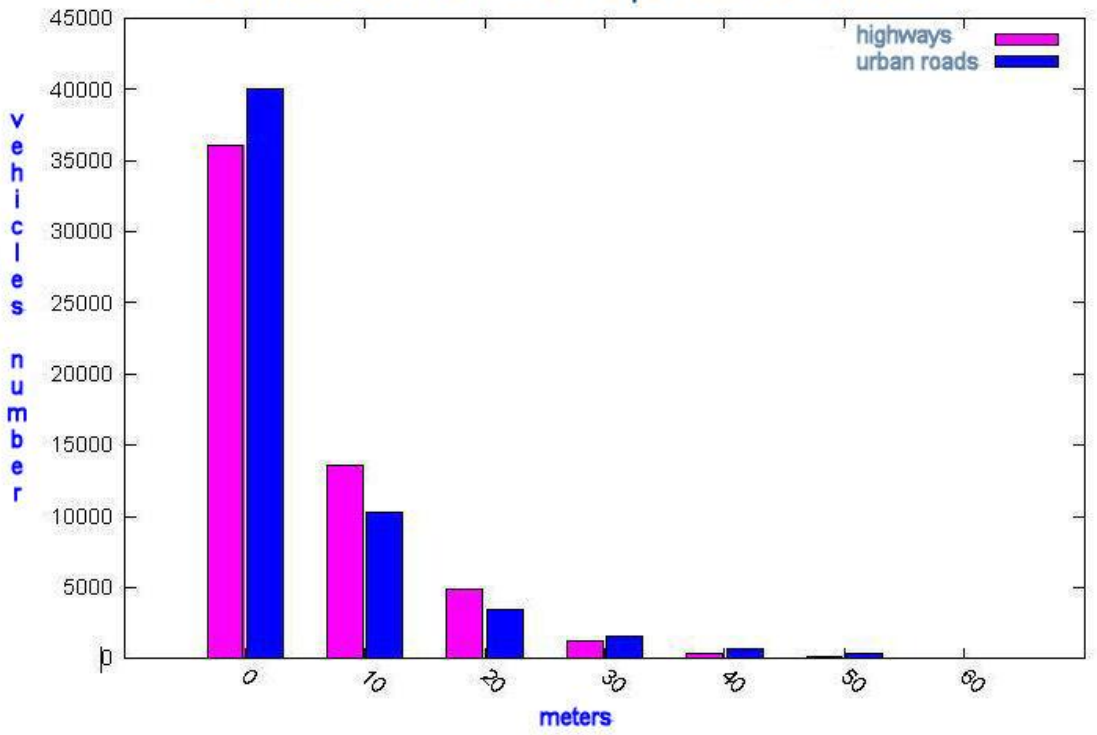
June 2006 Bologna Gps data

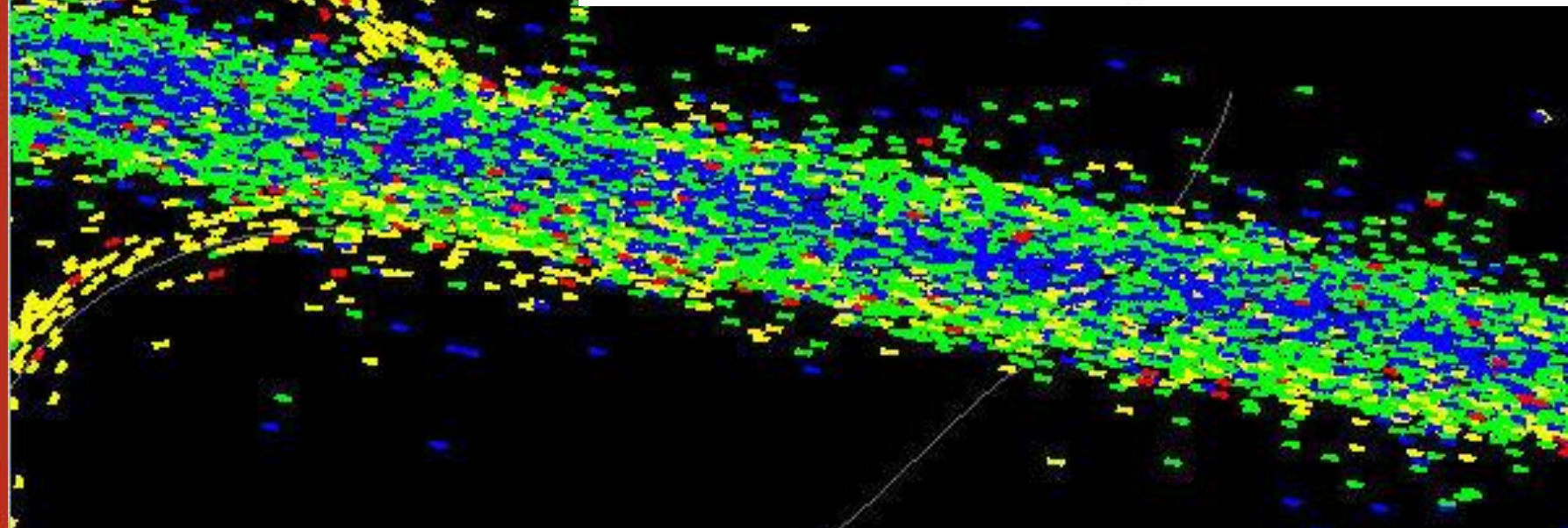


Data by OctoTelematics srl

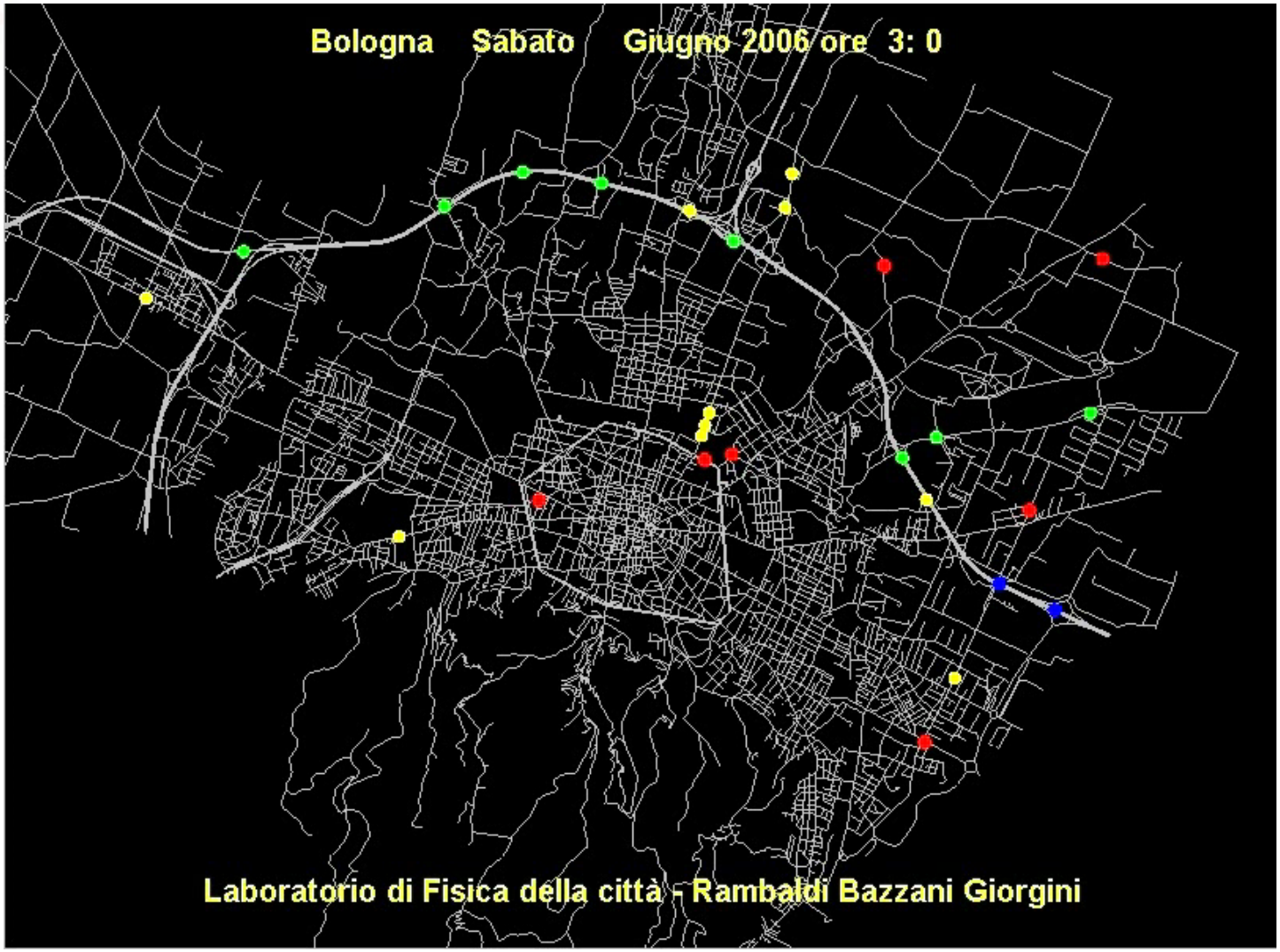


Correction for the Gps data errors

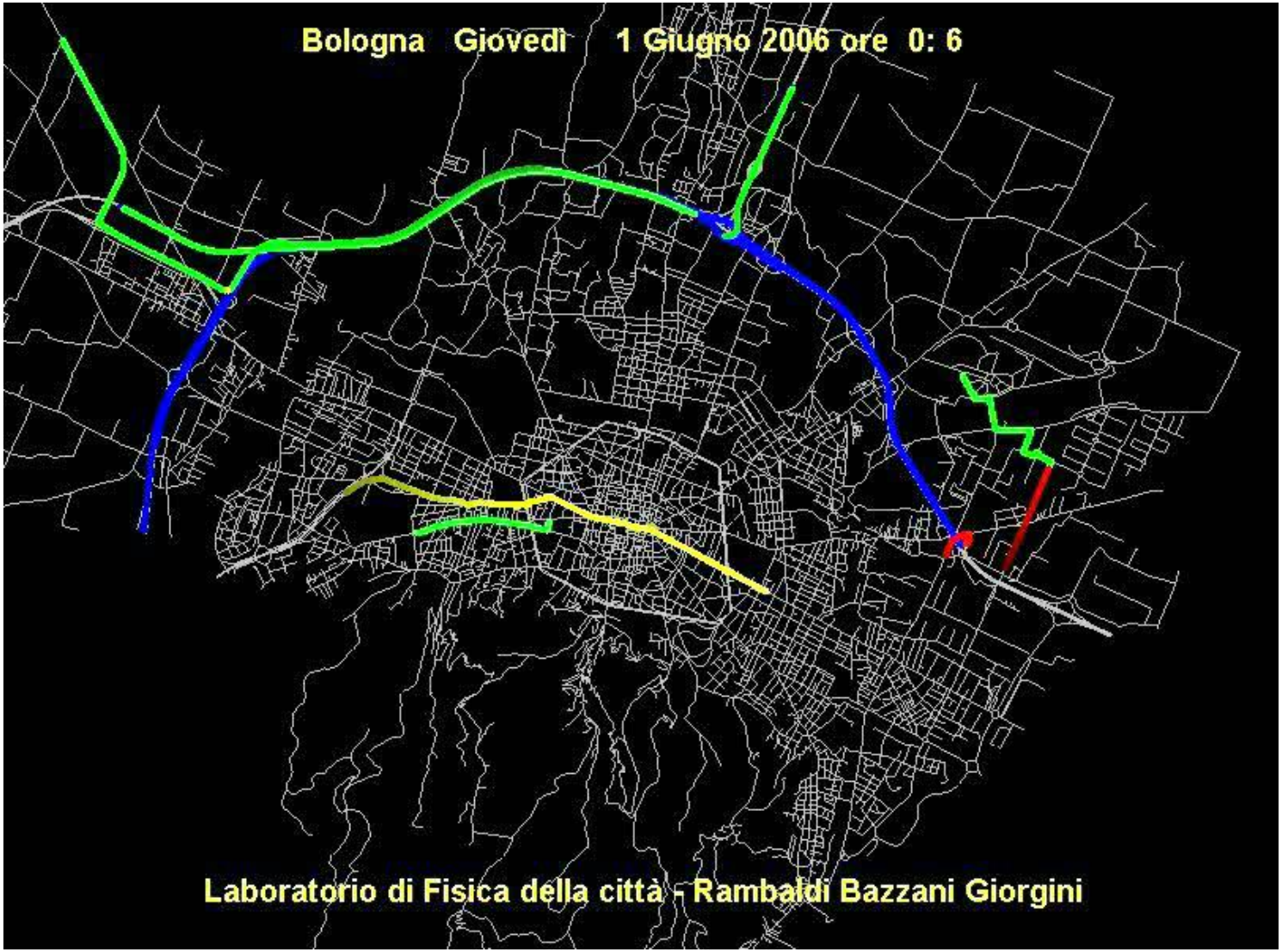


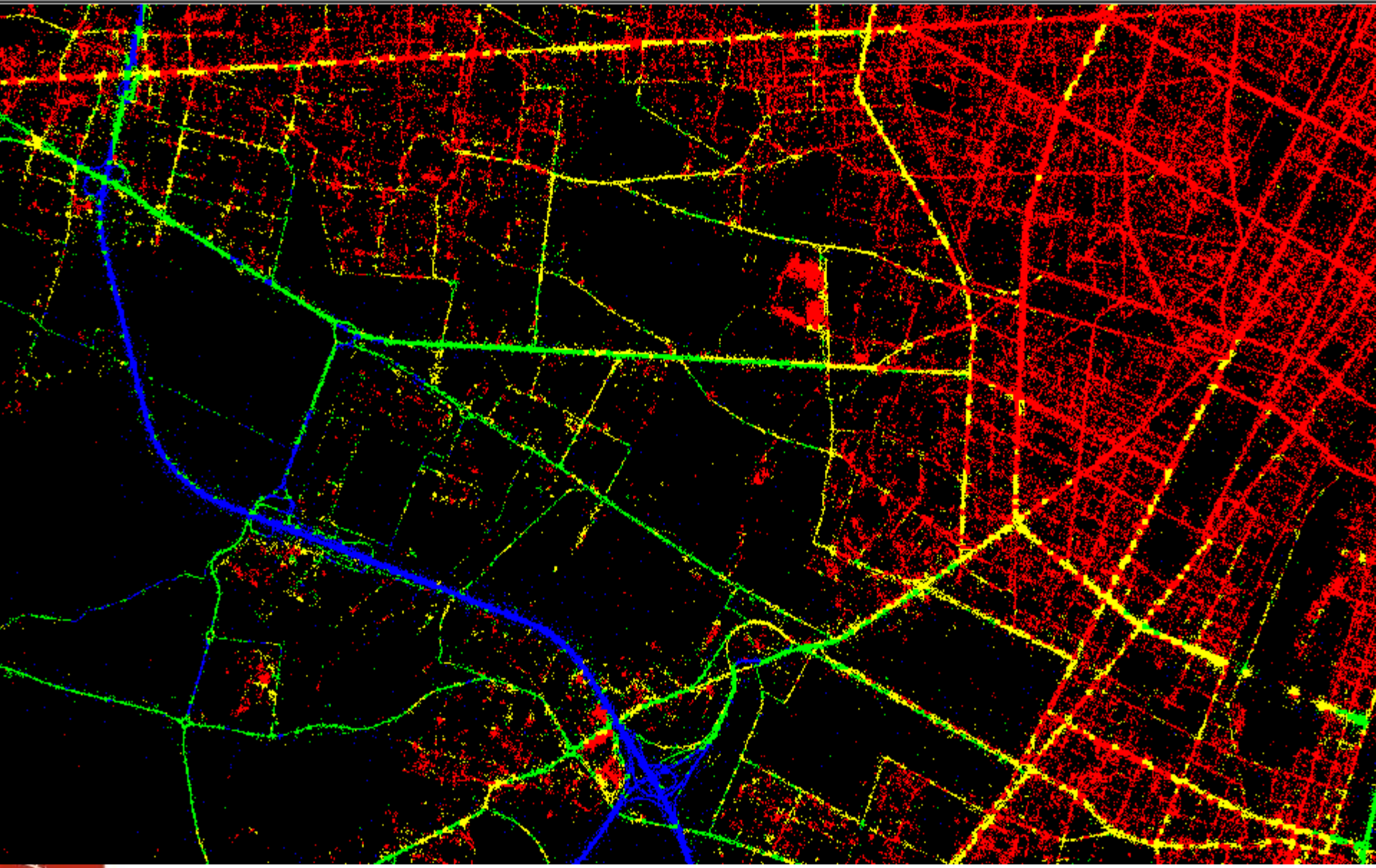


Bologna Data June 3 2006



Bologna Data June 1 2006





Torino September 2007 Field velocity

Chronotopic description of the urban space

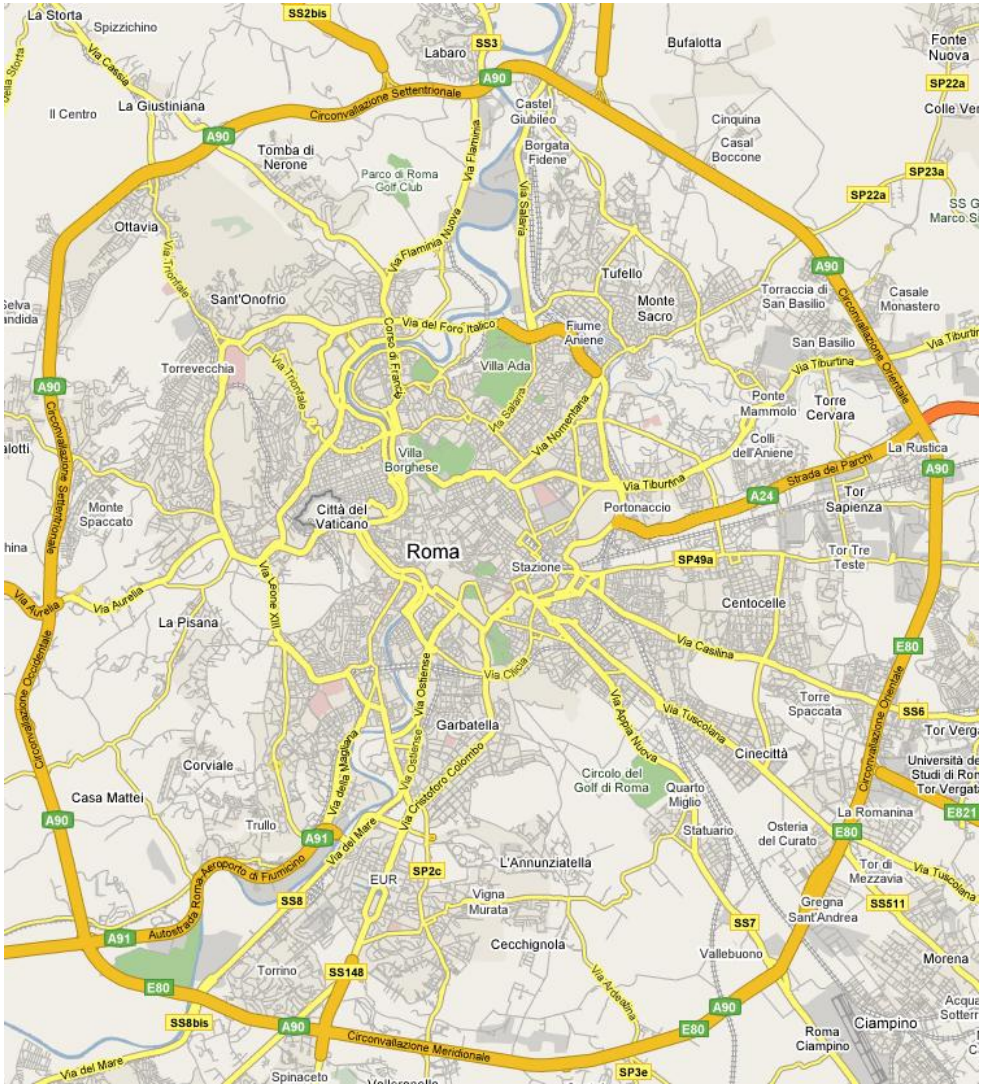
The city dynamics is introduced by the chronotopos concept: the primary cause of the mobility demand.

Chronotopoi are agents that interact with individuals assuming the existence of a cognitive city maps.

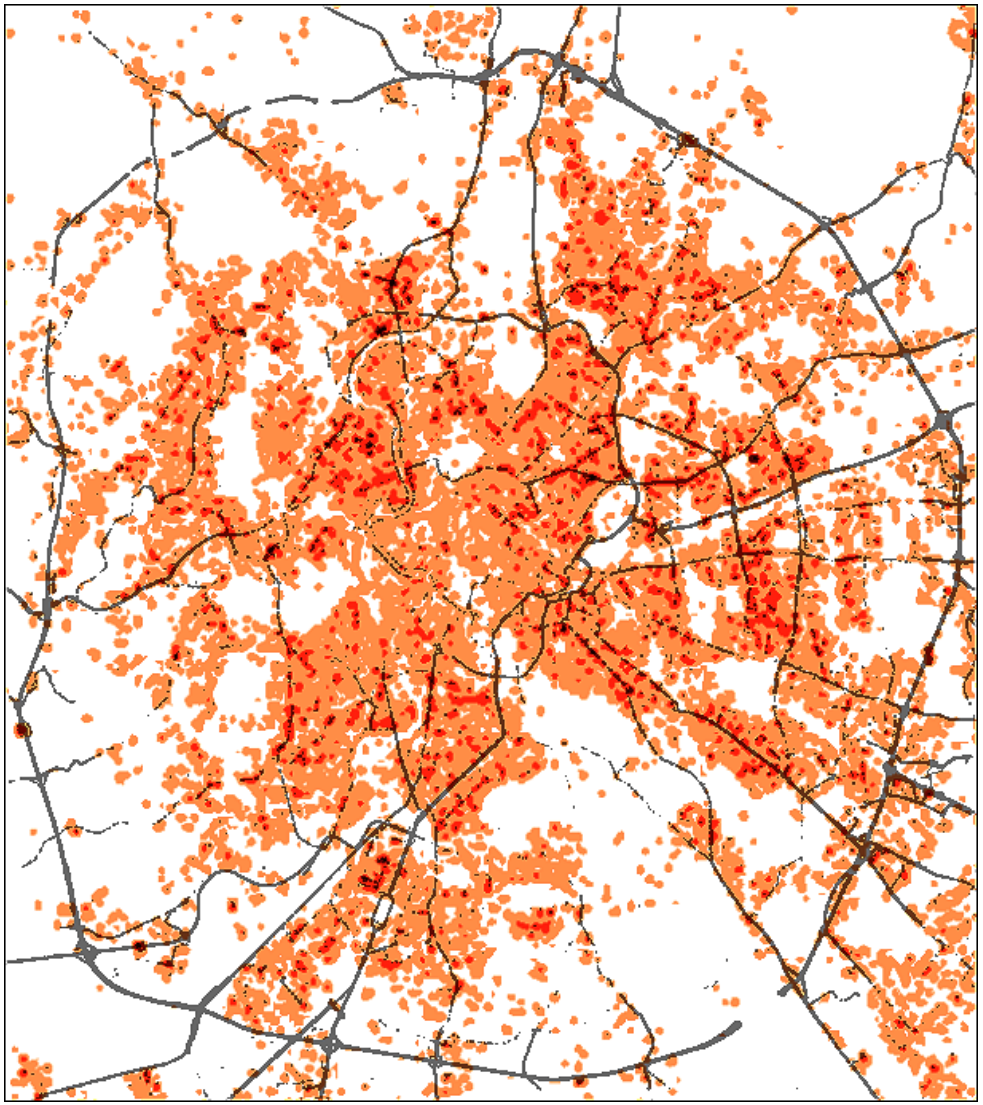
In the chronotopic city the mobility has a relevant asystematic component.

Chronotopic Bologna map

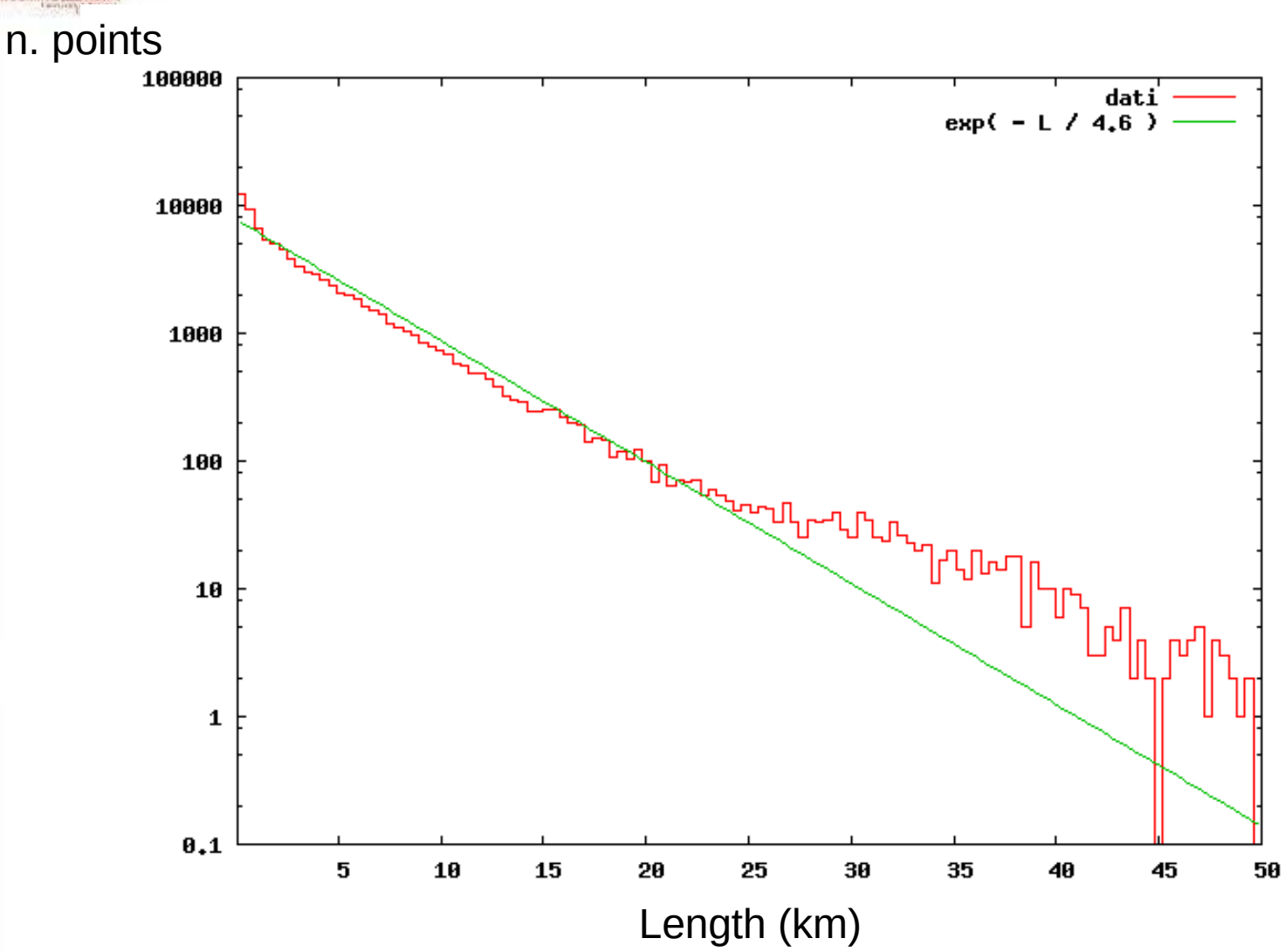
Considered area in Rome



Density of urban destinations (9600 vehicles)



Rome inner trajectories: path lengths distribution



Exponential path lengths distribution

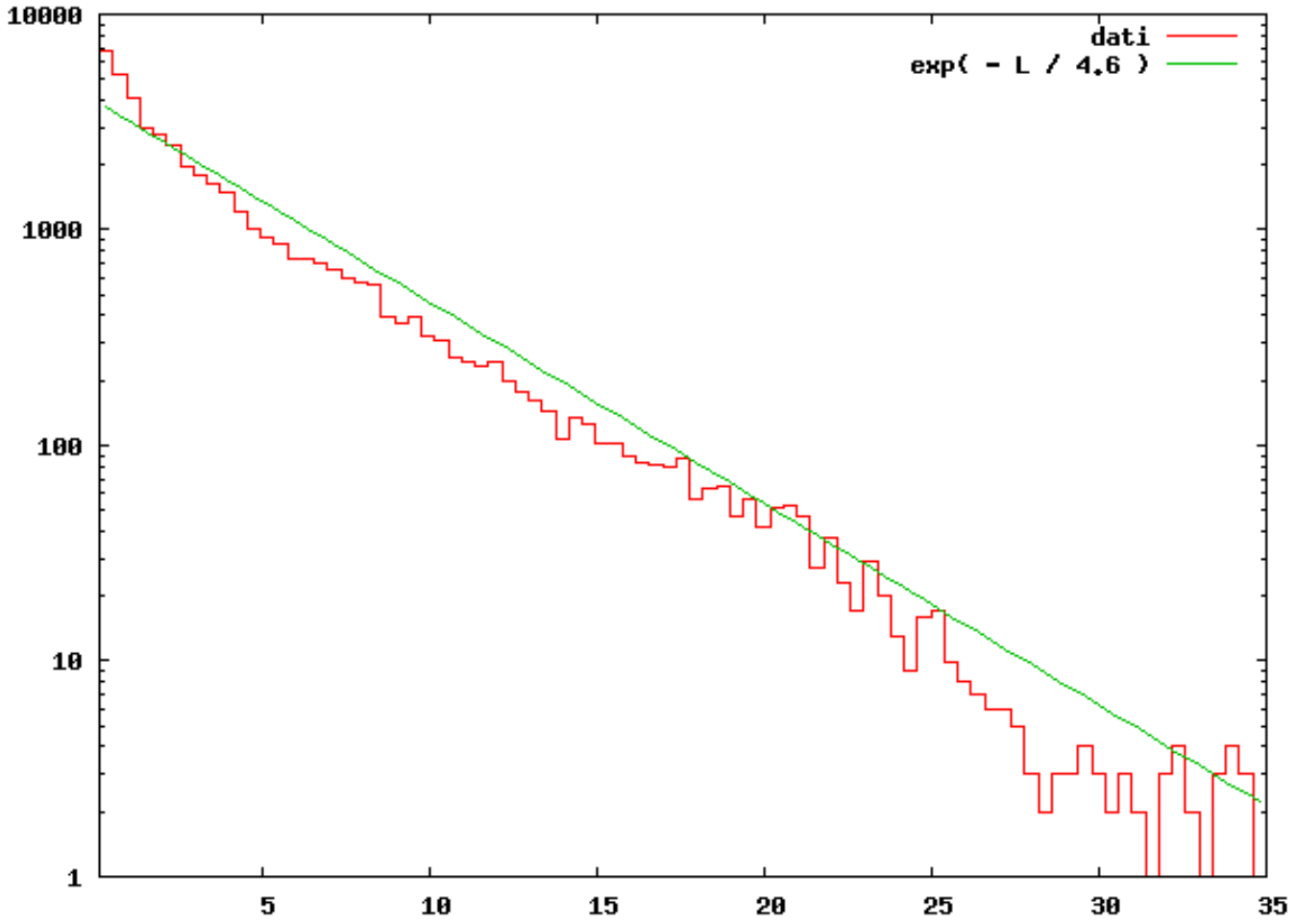
The exponential law can be derived by a maximal entropy principle if:

I) there exists an average length;
II) the different paths are decorrelated.

It is remarkable that the average length is a “universal constant” ~5 Km.

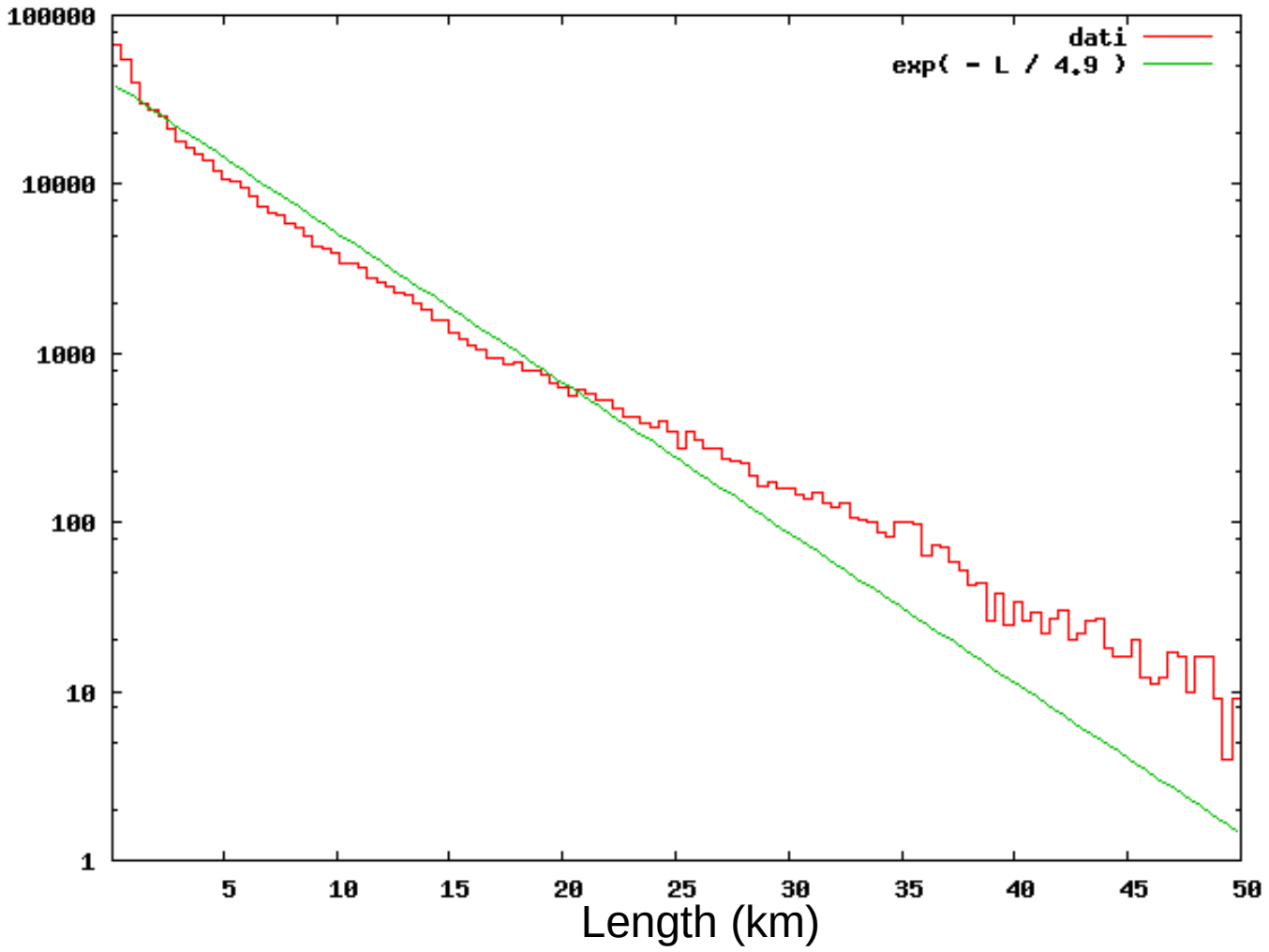
Genova inner trajectories

n. points



Torino inner trajectories

n. points



The existence of an utility function U(s) for the individual travel demands

(T.A. Domencich, D. McFadden 1975)

$$\rho(s) = A \exp\left(-\frac{U(s)}{T}\right)$$

Where T is a “mobility temperature”.

The exponential character is consistent with the existence of a universal energy law in human travel behavior.

(D.Helbing and R. Kolbl - 2003)

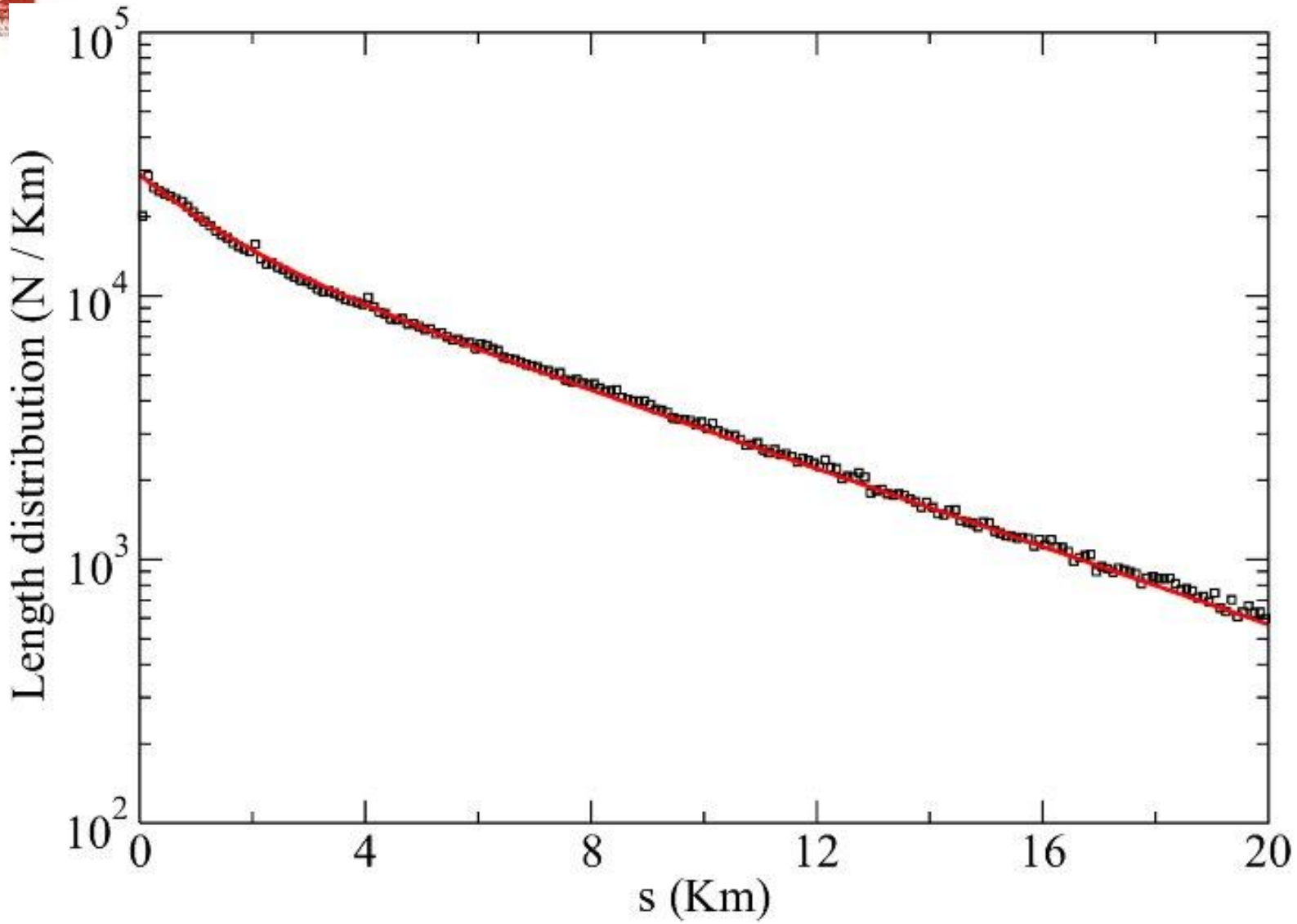
An interpolation of the path lengths distribution in Rome provides

$$\rho(s) = A\left(\exp(-\alpha_l s) + c\exp(-\alpha_s s)\right)$$

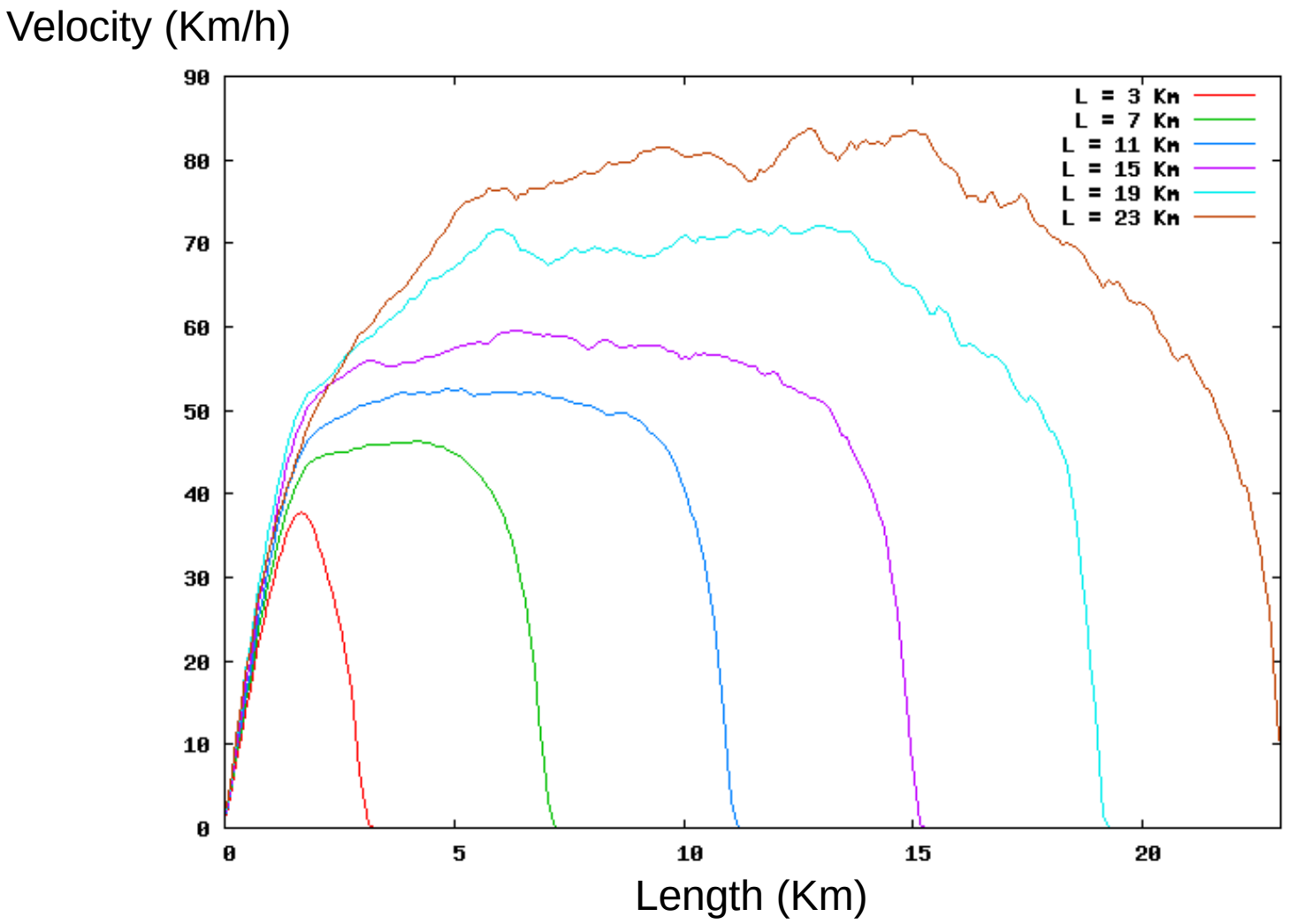
$$\alpha_l = .15 \quad \mathrm{km}^{-1},\ \alpha_s = .6 \quad \mathrm{km}^{-1},\ \text{and } c = .7$$

The distribution could to be related to two different paths classes.

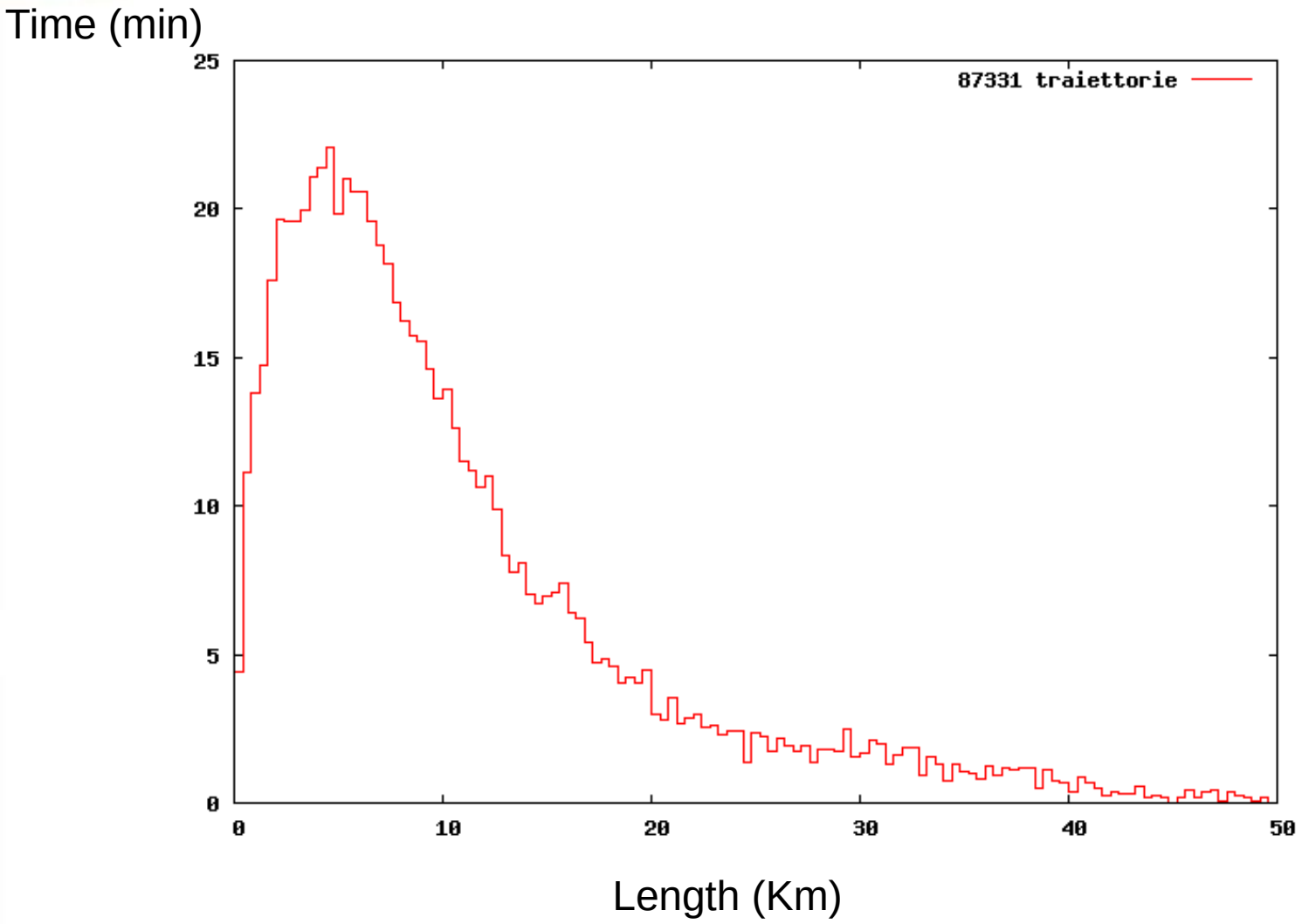
Roma inner trajectories length distribution



Average velocity distribution



Congestion effects: lost time in traffic



Analysis of the travel time distribution

$$\dot{v} = -\gamma(v - \overline{v}) + \sigma\xi(t)$$

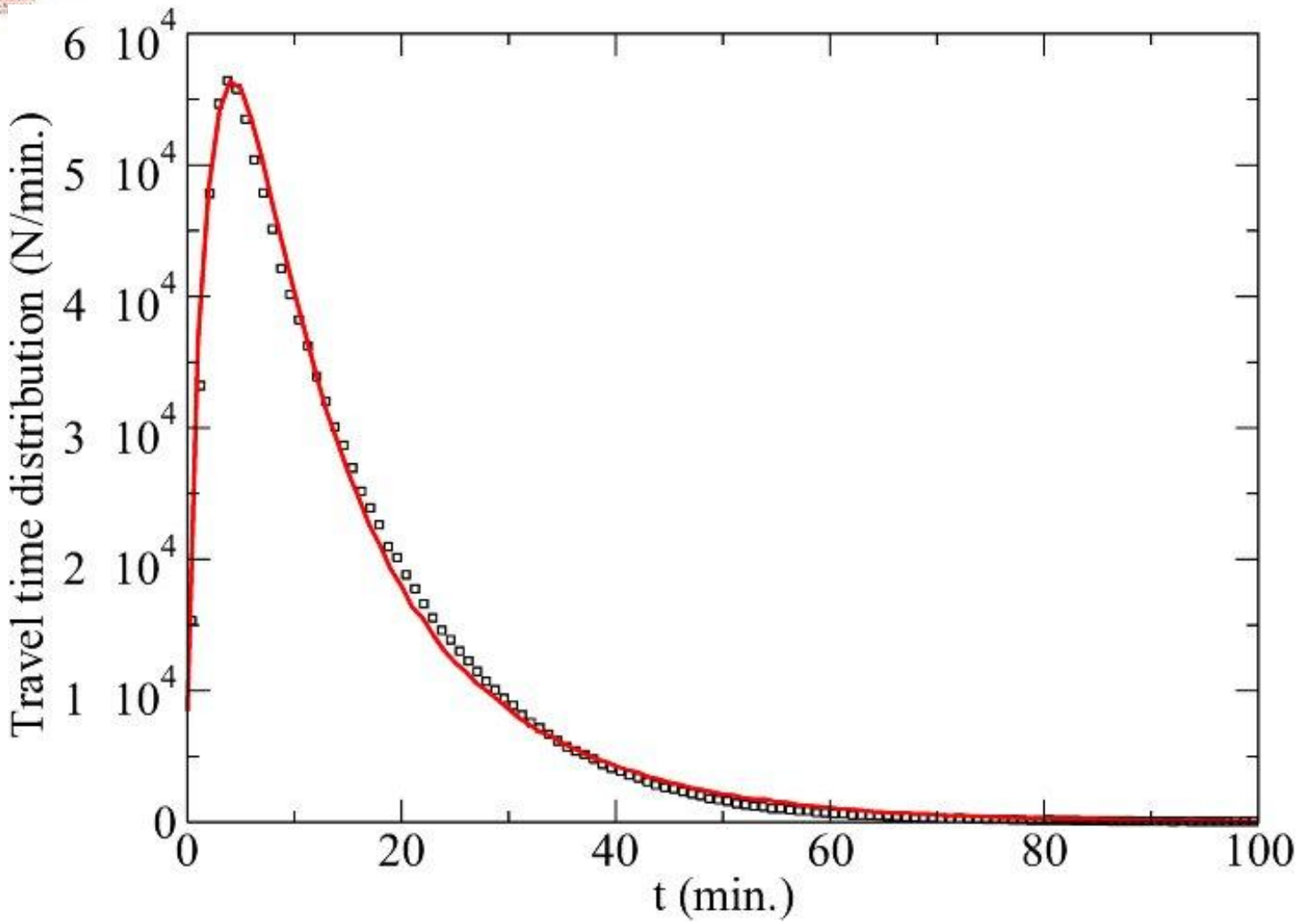
$$\dot{s} = |v|$$

Effective Ornstein-Uhlenbeck equation for a vehicle velocity

We have the following approximation for the travel time distribution

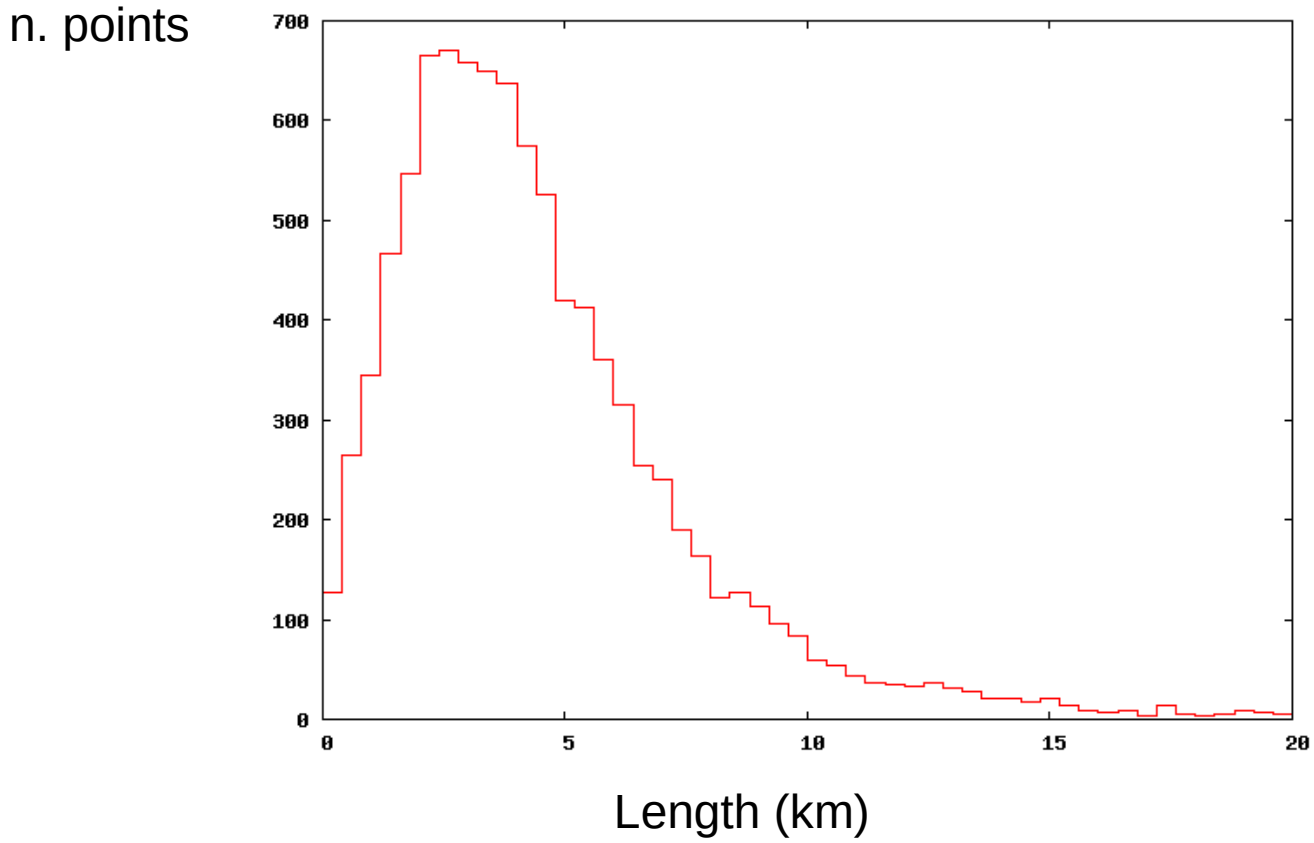
$$\rho(t) \propto \begin{cases} \sqrt{t}\exp(-\alpha_s \sigma t^{3/2}) & t \ll 1/\gamma \\ \exp(-\alpha_l \overline{v} t) & t \gg 1/\gamma \end{cases}$$

Travel time distribution in Roma



Single vehicle behavior

Average path length for single vehicle



The role of Models

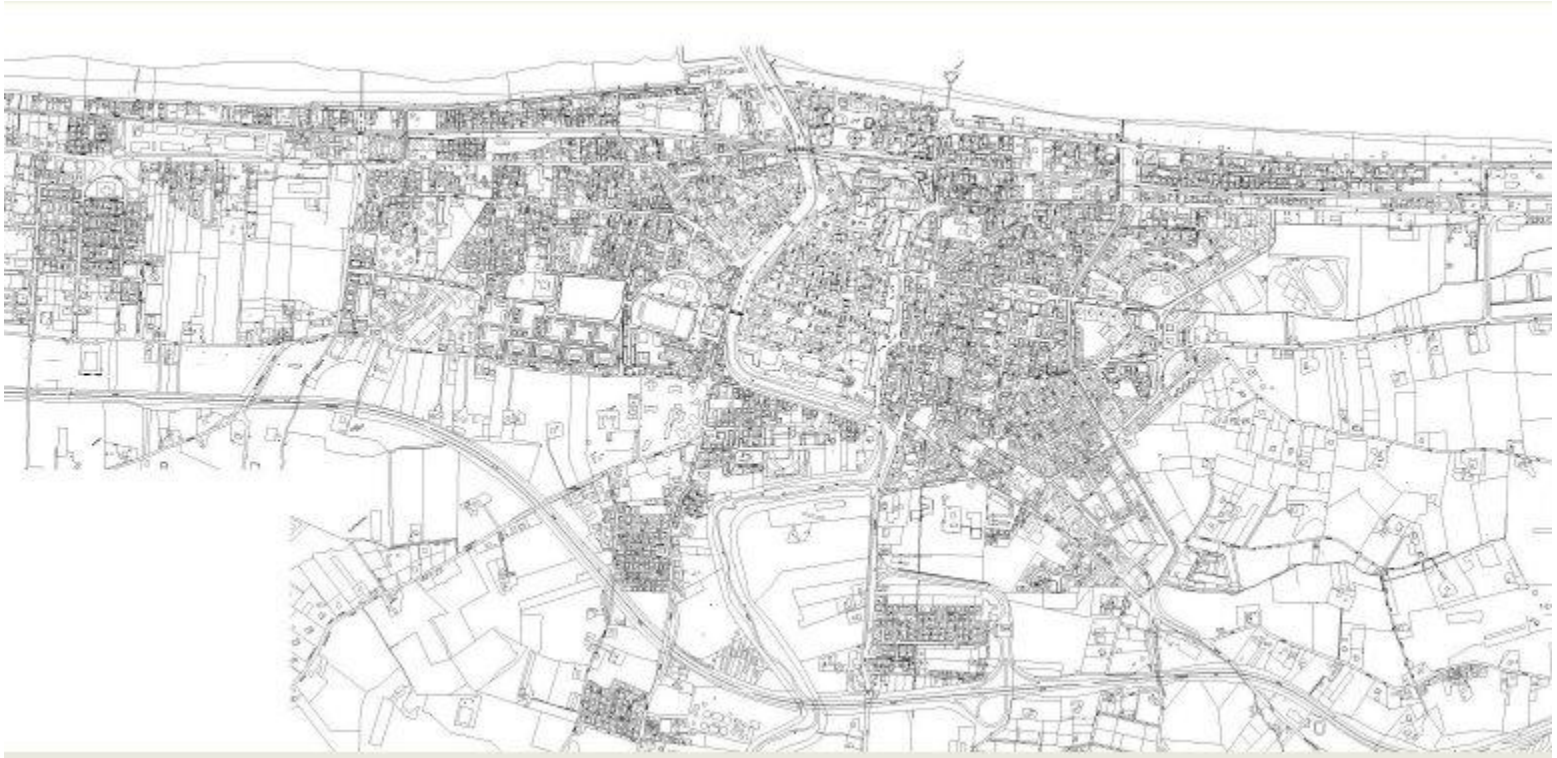
How many data? (Ticho Brache - Newton)

Nowcasting <------> Statistical approach.

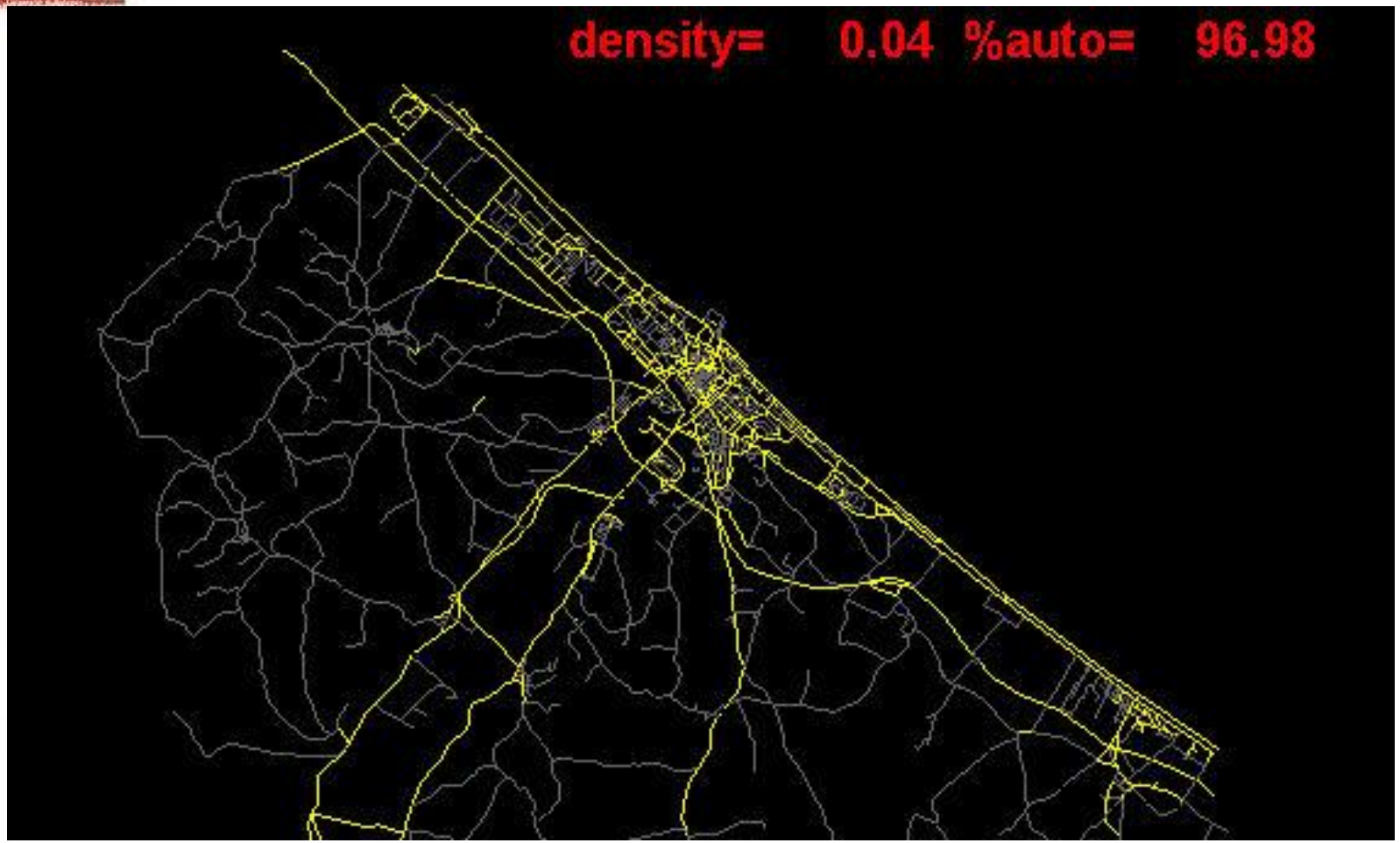
Forecasting <-------> Dynamical systems approach (decision mechanisms)

Governance <------> Thermodynamics (control parameters, phase transitions, criticalities …)

Microscopic models

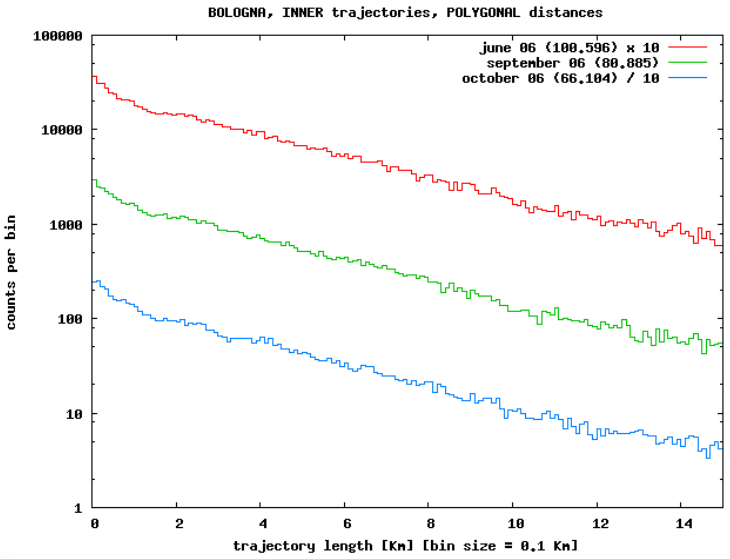


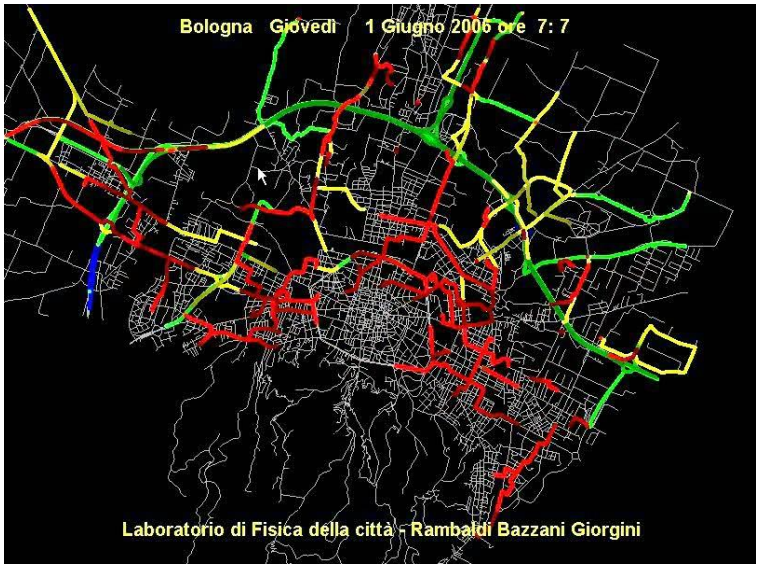
Hierarchical structure in the road choice

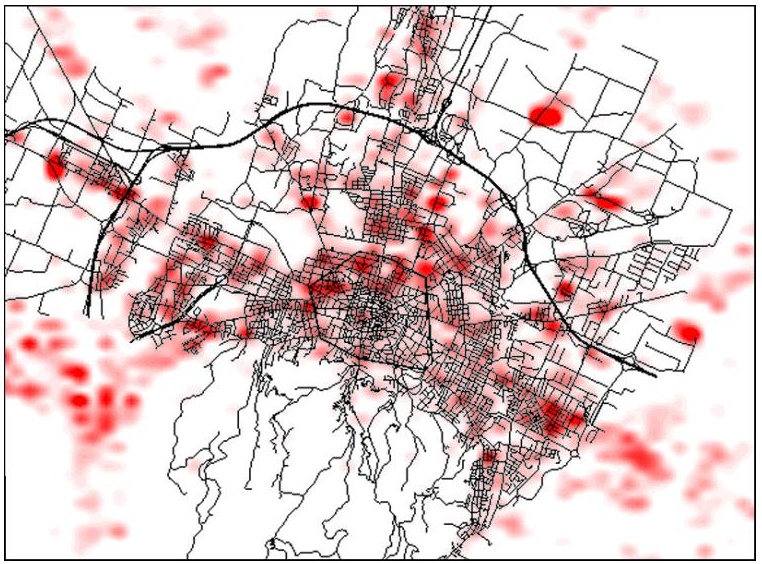


Senigallia model

"It can be …. done!"(Frankenstein Junior- G.Wilder)







Knowledge instruments for decisions based on a common rationality

Opening day of a new commercial center

Quartiere 8 Rome

Concerning "the most complex phenomena of common experience" Majorana wrote:

Il determinismo che non lascia alcun posto alla libertà umana e obbliga a considerare come illusioni […] tutti i fenomeni della vita, racchiude una reale causa di debolezza: la contraddizione immediata e irrimediabile con i dati più certi della nostra coscienza […].

Sarà nostro scopo ultimo l'illustrare il rinnovamento che il concetto tradizionale delle leggi statistiche deve subire in congruenza del nuovo indirizzo seguito dalla fisica contemporanea.

Ettore Majorana
Il valore delle scienze statistiche nella fisica e nelle scienze sociali.
Scientia -1942- vol. 36 pag. 55-66