The Abdus Salam
International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

International Atomic Energy Agency

SMR 1655 - 8

WORKSHOP ON QUANTITATIVE ECOLOGY
9 to 20 May 2005

Determination of motion and demographic characteristics of rodents

"The Hantavirus-Rodent model: observations, implications and the problem of mouse transport"

Guillermo ABRAMSON
Statistical Physics Group, Centro Atomico Bariloche and CONICET
Bariloche, Argentina

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

The Hantavirus-Rodent model: observations, implications, and the problem of mouse transport

WORKSHOP ON QUANTITATIVE ECOLOGY – ICTP 2005

Guillermo Abramson

Statistical Physics Group, Centro Atómico Bariloche and CONICET
Bariloche, Argentina.

Conicet

cnea

Instituto Balseiro 50 Años

with L. Giuggioli and V.M. Kenkre

OUTLINE

- The basic model
  - Implications of the bifurcation
  - Lack of vertical transmission
  - Temporal behavior
  - Traveling waves
- The diffusion paradigm
- Analysis of actual mice transport
- Model of mice transport

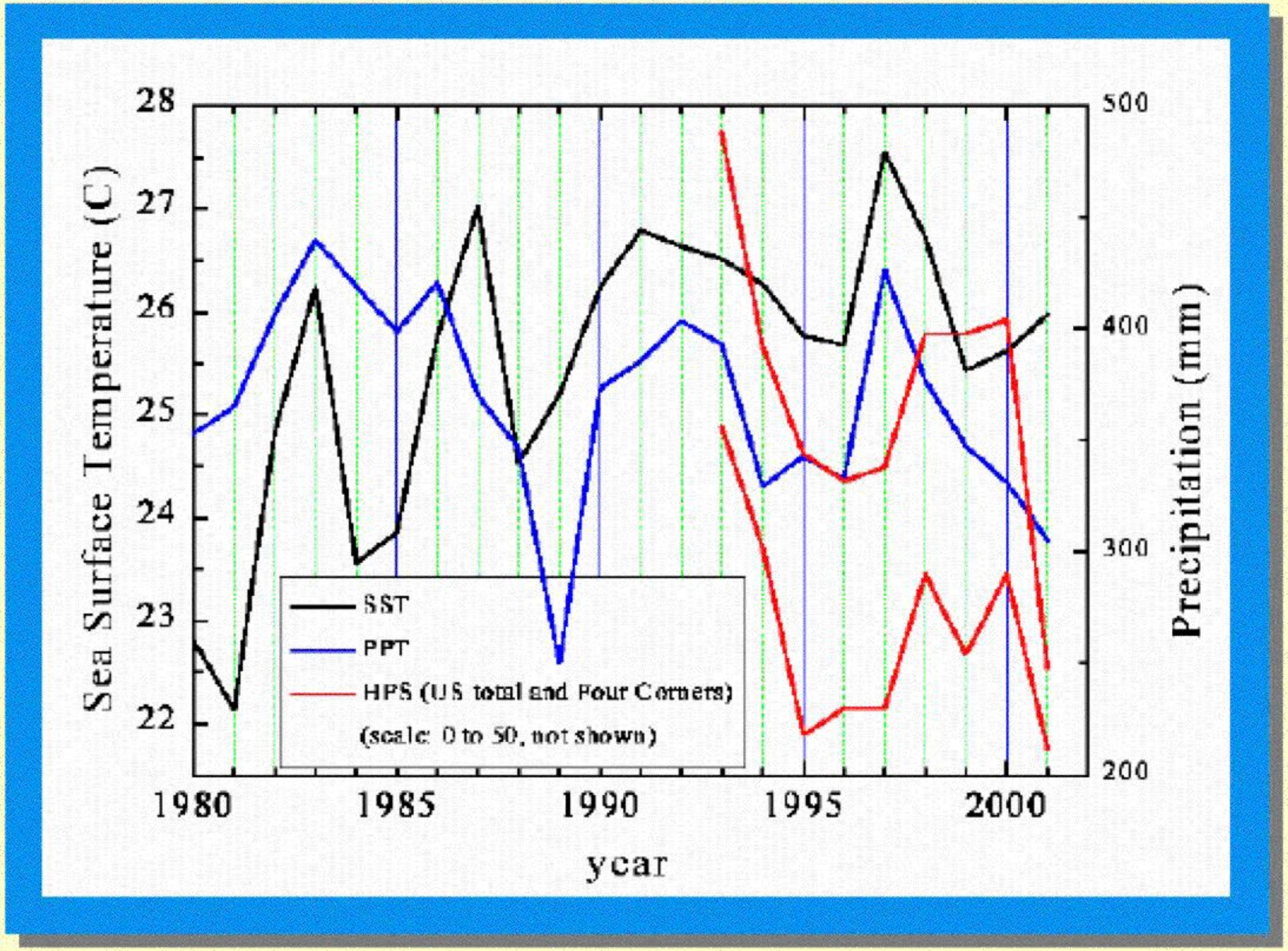
THREE FIELD OBSERVATIONS AND A SIMPLE MODEL

- Strong influence by environmental conditions.
- Sporadical dissapearance of the infection from a population.
- Spatial segregation of infected populations (refugia).

Population dynamics + Contagion + (Mice movement)	➡	Mathematical model

Single control parameter in the model simulate environmental effects.

The other two appear as consequences of a bifurcation of the solutions.



Sea Surface Temperature (C)
Precipitation (mm)
year
SST
PPT
HPS (US total and Four Corners)
(scale: 0 to 50, not shown)

BASIC MODEL (no mice movement yet!)

$$\frac{dM_S}{dt} = bM - cM_S - \frac{M_S M}{K} - aM_S M_I,$$

$$\frac{dM_I}{dt} = -cM_I - \frac{M_I M}{K} + aM_S M_I,$$

↑ carrying capacity

$M_S(t)$: Susceptible mice

$M_I(t)$: Infected mice

$M(t)= M_S(t)+M_I(t)$: Total mouse population

Rationale behind each term

Births: $bM \rightarrow$ only of susceptibles, all mice contribute to it

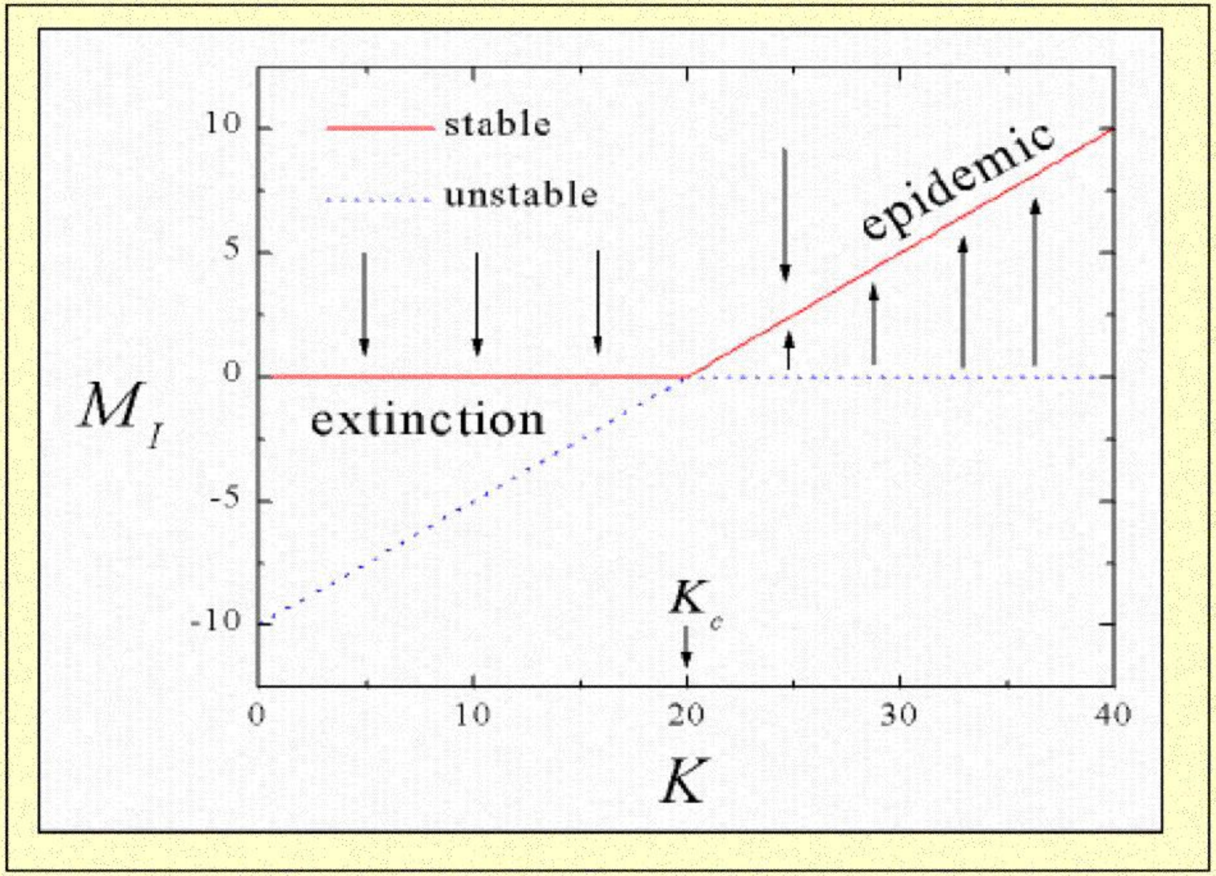
Deaths: $-cM_{S,I} \rightarrow$ infection does not affect death rate

Competition: $-M_{S,I} M/K \rightarrow$ population limited by environmental parameter

Contagion: $\pm aM_S M_I \rightarrow$ simple contact between pairs

BIFURCATION

$$K_c = \frac{b}{a(b-c)}$$



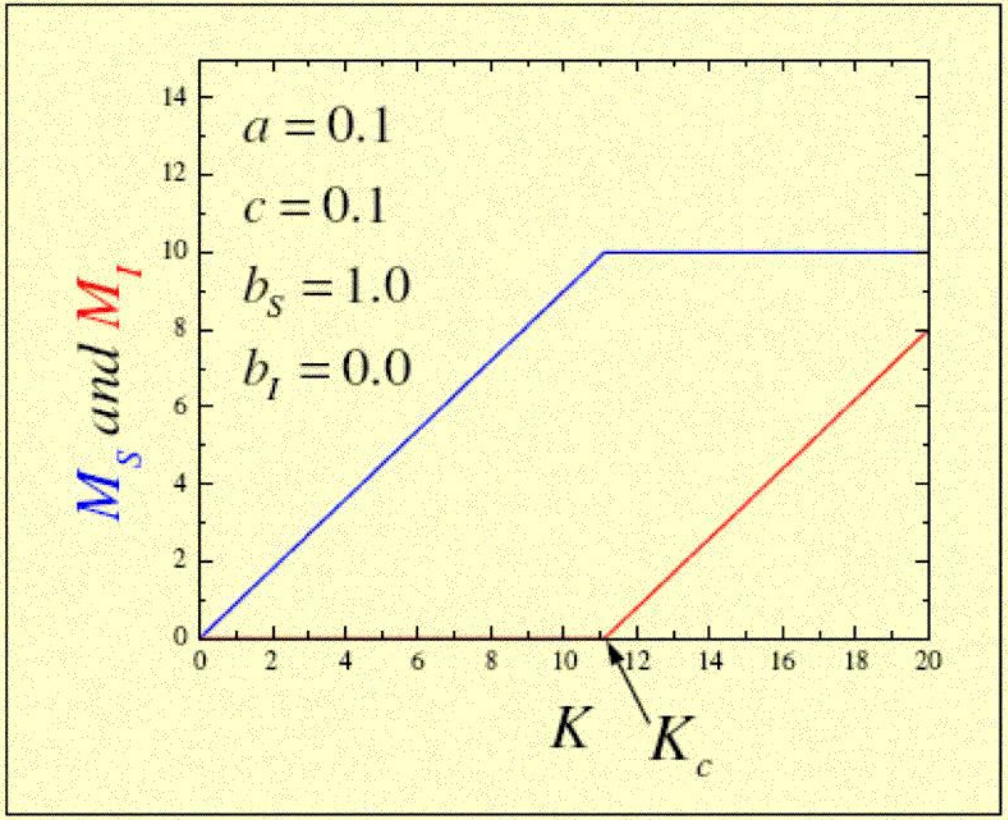
The carrying capacity controls a bifurcation in the equilibrium value of the infected population.

The susceptible population is always positive.

The same model, with vertical transmission

$$\frac{dM_S}{dt} = b_S M - cM_S - \frac{M_S M}{K} - aM_S M_I,$$

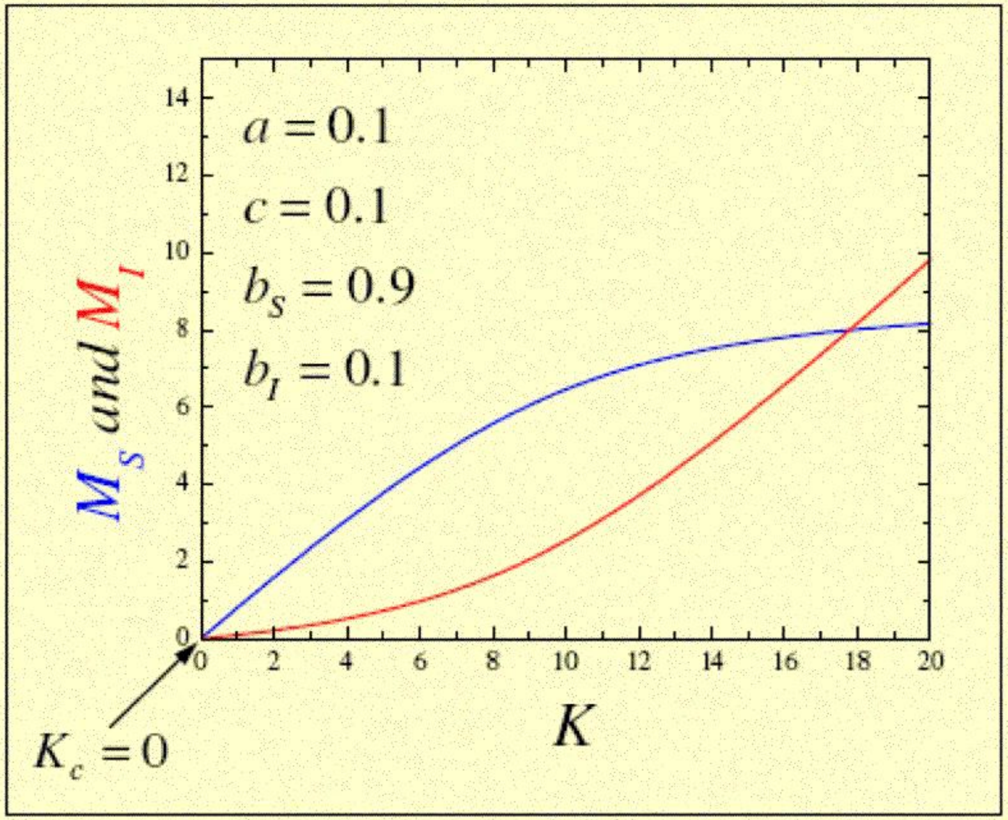
$$\frac{dM_I}{dt} = b_I M - cM_I - \frac{M_I M}{K} + aM_S M_I,$$



The same model, with vertical transmission

$$\frac{dM_S}{dt} = b_S M - cM_S - \frac{M_S M}{K} - aM_S M_I,$$

$$\frac{dM_I}{dt} = b_I M - cM_I - \frac{M_I M}{K} + aM_S M_I,$$



The same model, with vertical transmission

$$\frac{dM_S}{dt} = b_S M - cM_S - \frac{M_S M}{K} - aM_S M_I,$$
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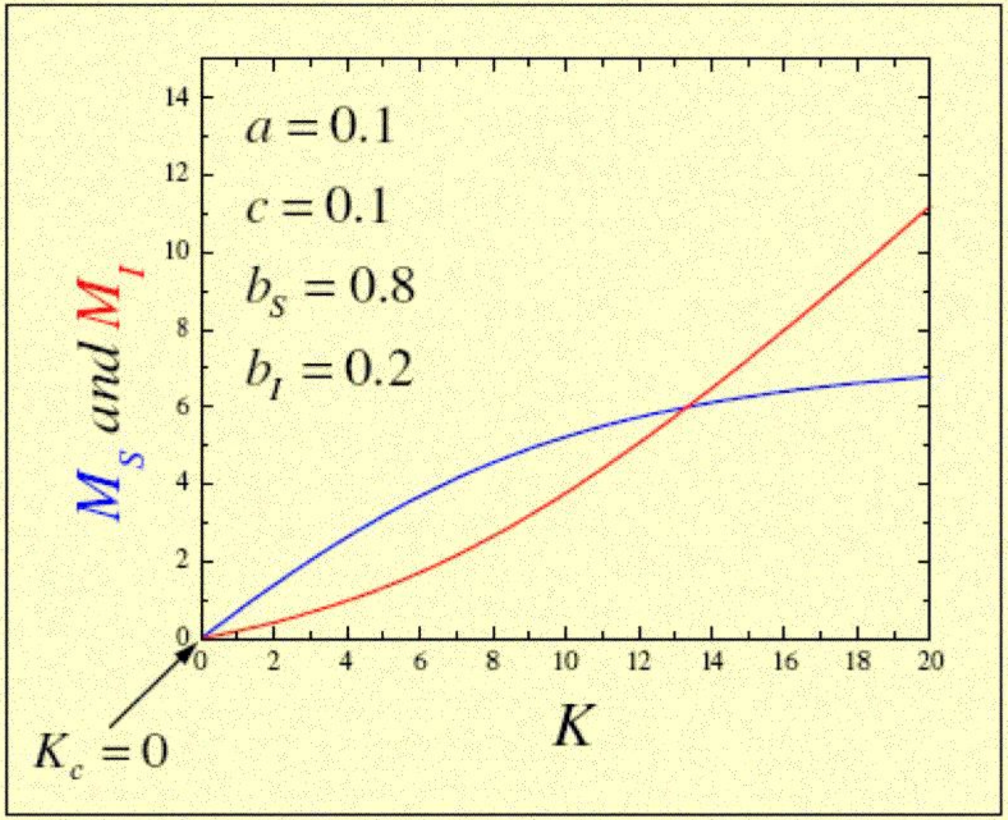

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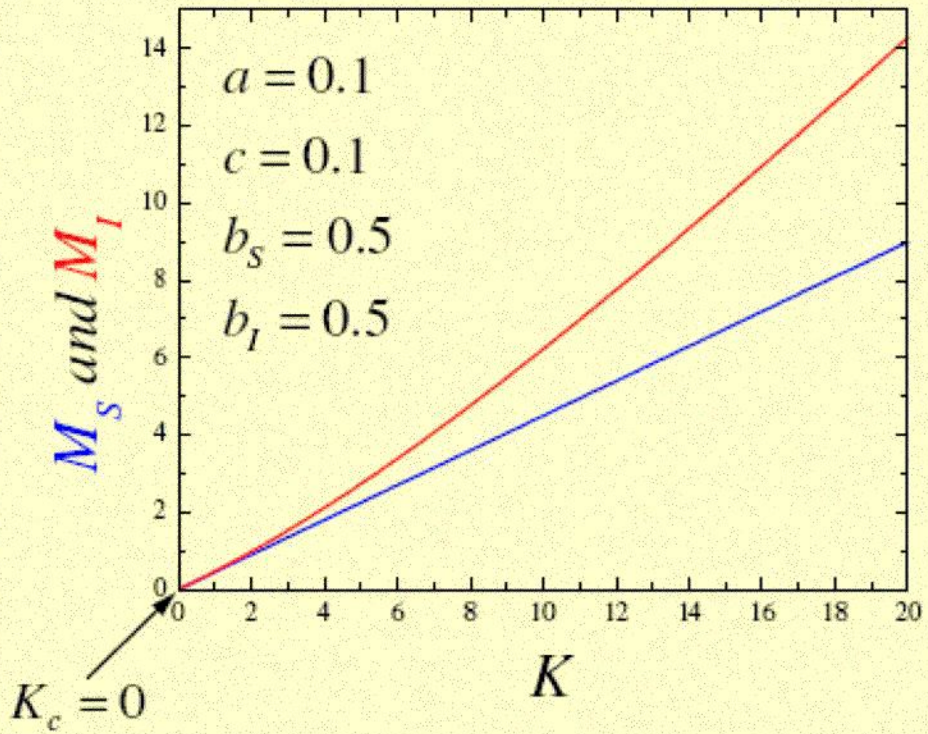
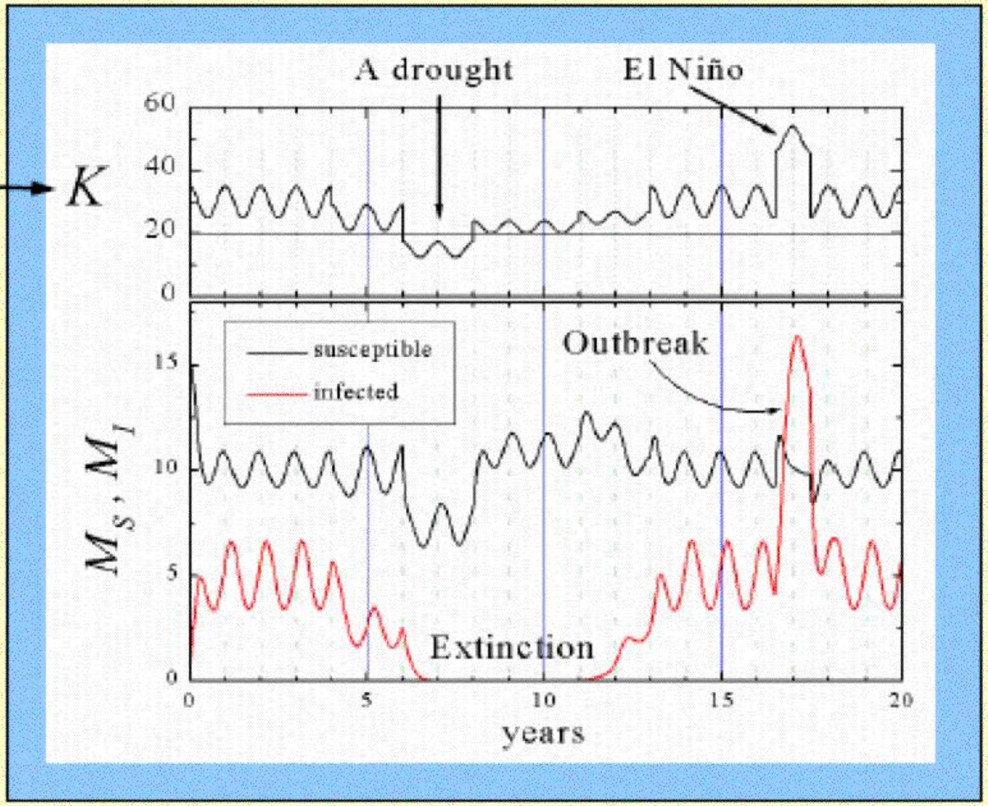


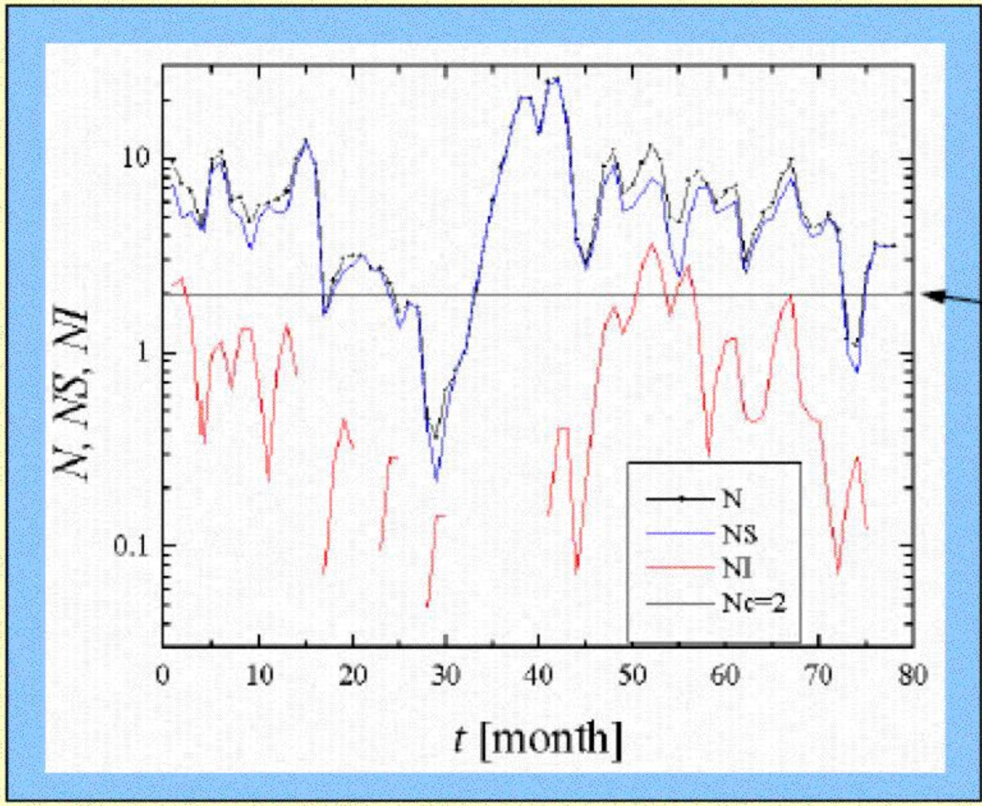
Temporal behavior

$K = K(t)$



A "realistic" time dependent carrying capacity induces the occurrence of extinctions and outbreaks as controlled by the environment.

Temporal behavior of real mice



critical population $N_c = K_c(b-c)$

Real populations of susceptible and infected deer mice at Zuni site, NM. *Nc*=2 is the "critical population" derived from approximate fits. (Data from Yates et al., Bioscience, 2002.)

TRAVELING WAVES

How does infection spread from the refugia?

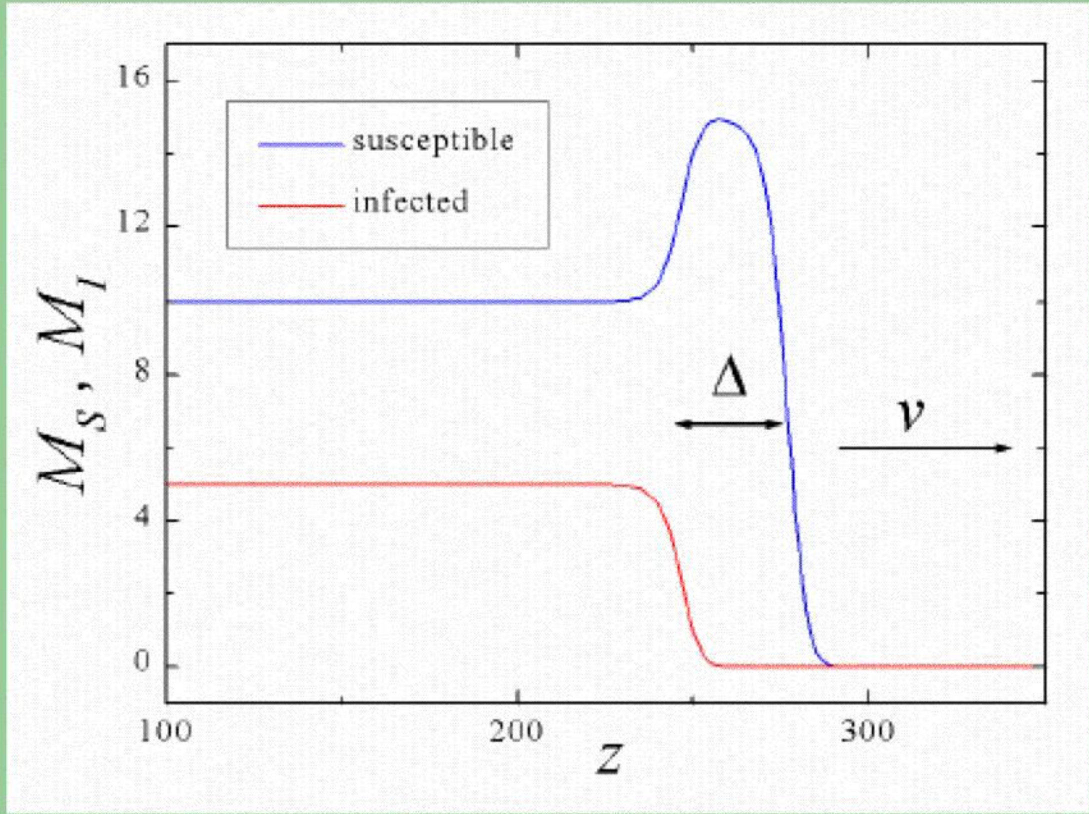
The sum of the equations for M_S and M_I is Fisher's equation for the total population:

$$\frac{\partial M(x,t)}{\partial t} = (b-c)M\left(1-\frac{M}{(b-c)K}\right) + D\nabla^2 M$$

(Fisher, 1937)

There exist solutions of this equations in the form of a front wave traveling at a constant speed.

Traveling waves of the complete system



Allowed speeds:

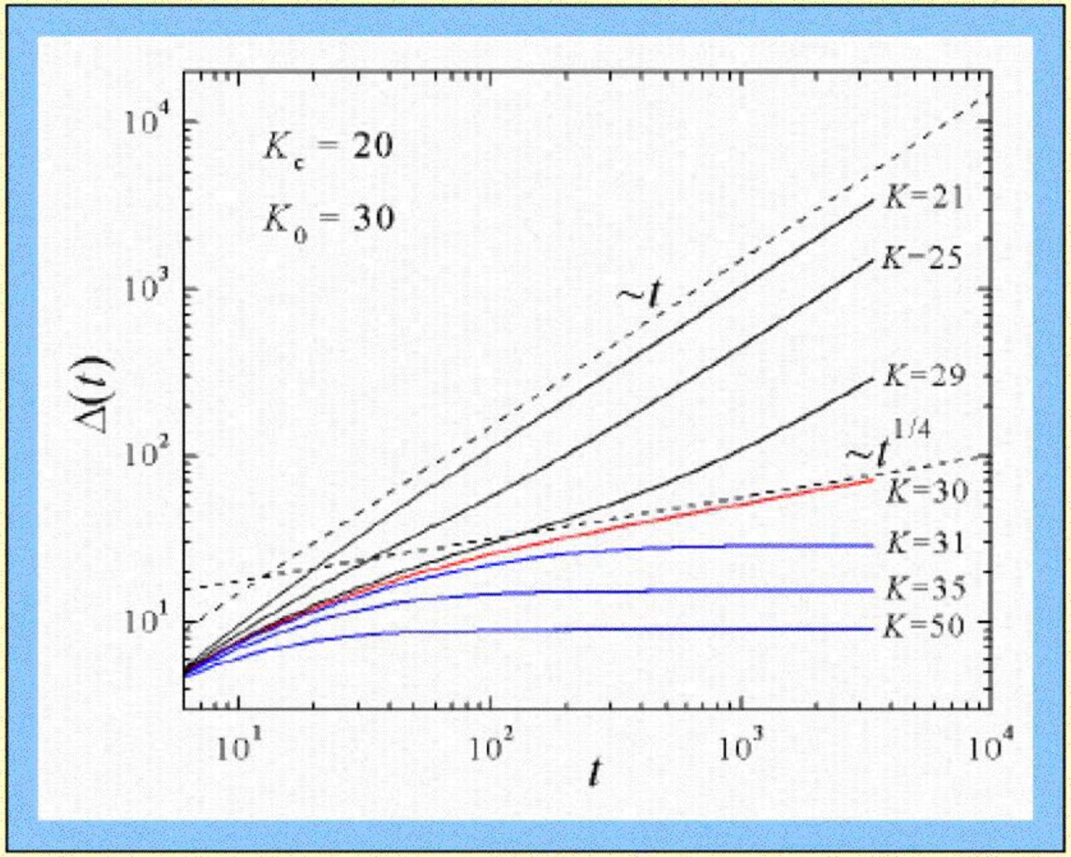
$$v_S \geq 2\sqrt{D(b-c)}$$

$$v_I \geq 2\sqrt{D\left[-b+aK(b-c)\right]}$$

Depends on K and a

Two regimes of propagation:

$$v_I < v_S \quad \text{if} \quad K < K_0$$
$$v_I = v_S \quad \text{if} \quad K > K_0$$



$$K_0 = \frac{2b-c}{a(b-c)}$$

The delay Δ *is also controlled by the carrying capacity*

THE DIFFUSION PARADIGM

$$\frac{\partial u(x,t)}{\partial t} = r\,u\,(1-u) + D\nabla^2 u$$

(Fisher, 1937)

nonlinear “reaction” (logistic growth)

diffusion

Epidemics of Hantavirus in *P. maniculatus*

Abramson, Kenkre, Parmenter, Yates (2001-2002)

$$\frac{\partial M_S(x,t)}{\partial t} = bM - cM_S - \frac{M_S M}{K(x)} - aM_S M_I + D_S \nabla^2 M_S,$$

$$\frac{\partial M_I(x,t)}{\partial t} = -cM_I - \frac{M_I M}{K(x)} + aM_S M_I + D_I \nabla^2 M_I,$$

Three categories of wrongfulness

Okubo & Levin, Diffusion and Ecological Problems

Wrong but useful: the simplest diffusion models cannot possibly be exactly right for any organism in the real world (because of behavior, environment, etc). But they provide a standardized framework for estimating one of ecology most neglected parameters: the diffusion coefficient.

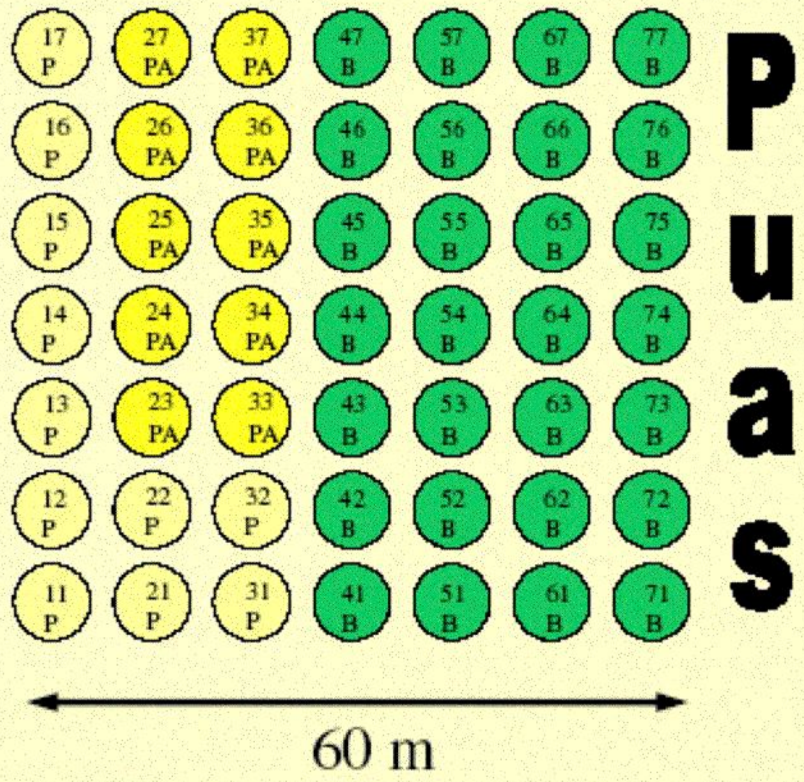
Not necessarily so wrong: diffusion models are approximations of much more complicated mechanisms, the net displacements being often described by Gaussians.

Woefully wrong: for animals interacting socially, or navigating according to some external cue, or moving towards a particular place.

THE SOURCE OF THE DATA

Gerardo Suzán & Erika Marcé, UNM

Six months of field work in Panamá (2003)

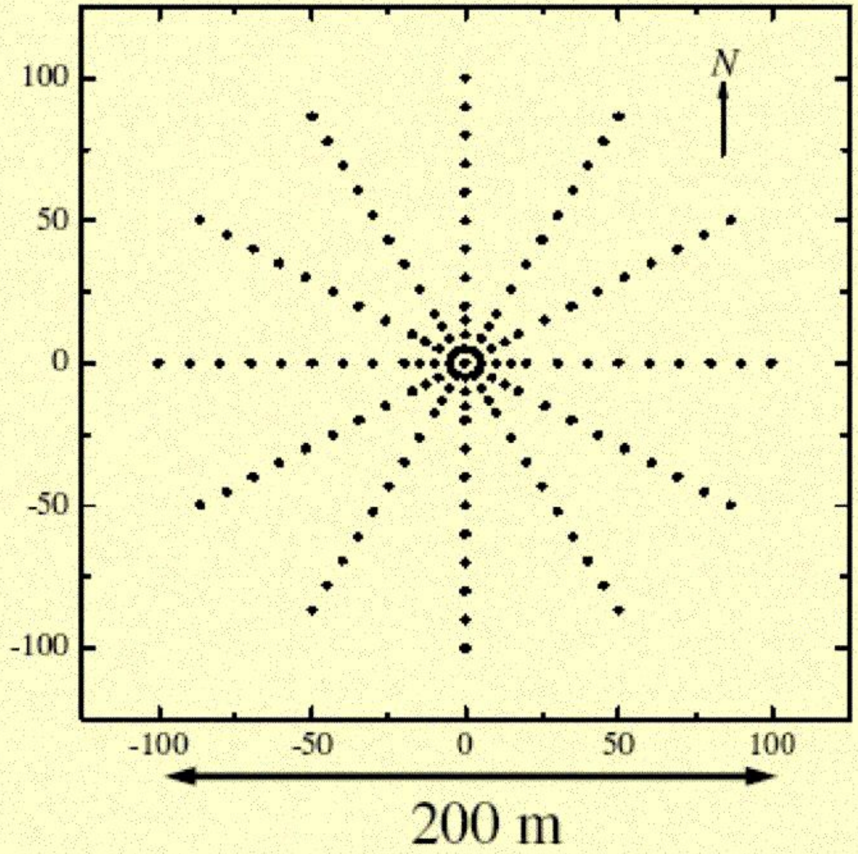


Zygodontomys brevicauda

Host of Hantavirus Calabazo

THE SOURCE OF THE DATA

Terry Yates, Bob Parmenter, Jerry Dragoo and many others, UNM



Ten years of field work in New Mexico (1994-)

Peromyscus maniculatus

Host of Hantavirus Sin Nombre

Recapture and age

Zygodontomys brevicauda, 846 captures: 411 total mice, 188 captured more than once (2-10 times)

P. maniculatus: 3826 captures: 1589 total mice, 849 captured more than once (2-20 times)

Recapture probability:

	J	SA	A
Z. Brevicauda	0.13	0.37*	0.49
P. maniculatus	0.32	0.48	0.58

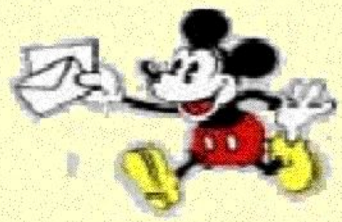
J: juvenile
SA: sub-adult
A: adult

*One mouse (SA, F) recaptured off-site, 200 m away

Different types of movement

Adult mice ⇨ diffusion within a home range

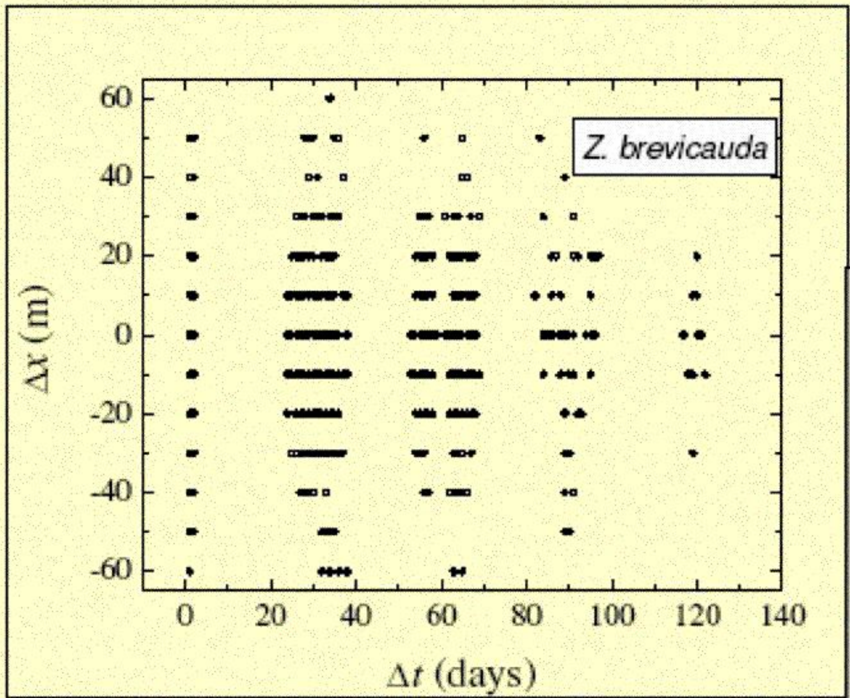
Sub-adult mice ⇨ run away to establish a home range

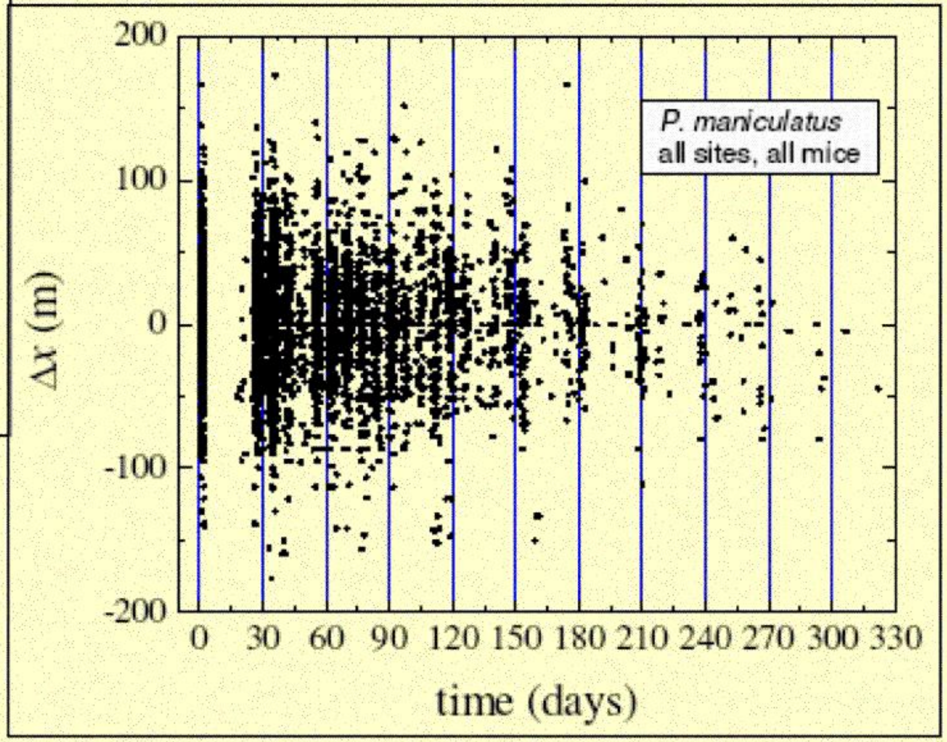


Juvenile mice ⇨ excursions from nest

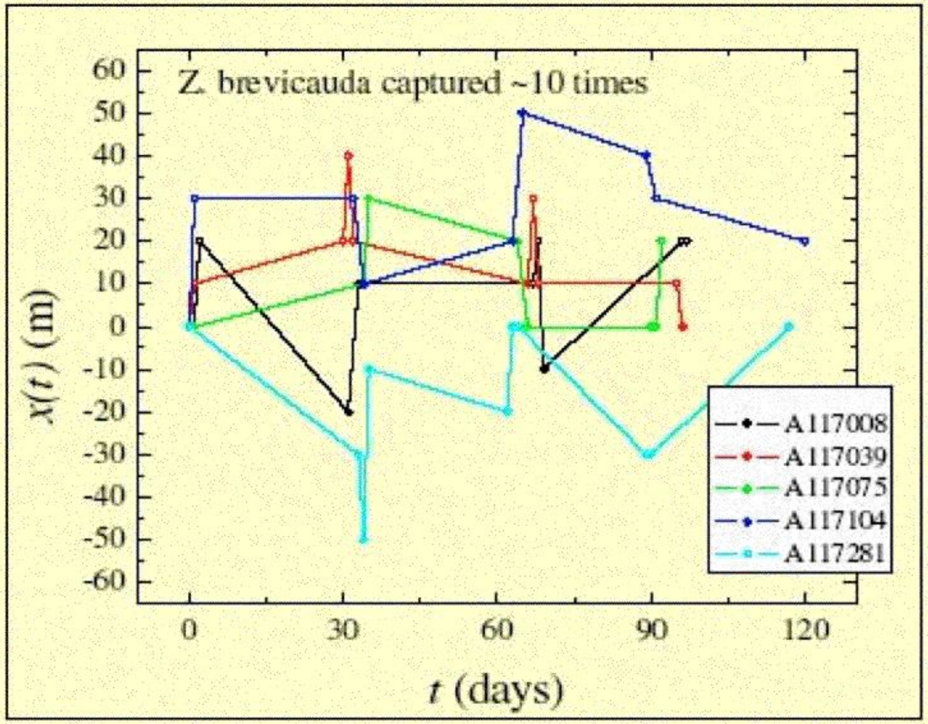
Males and females…

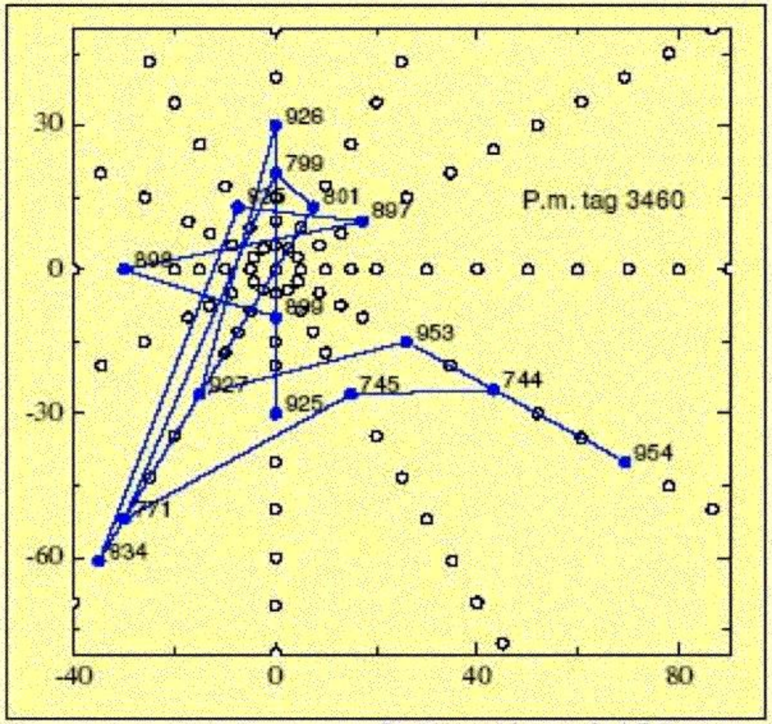
The recaptures





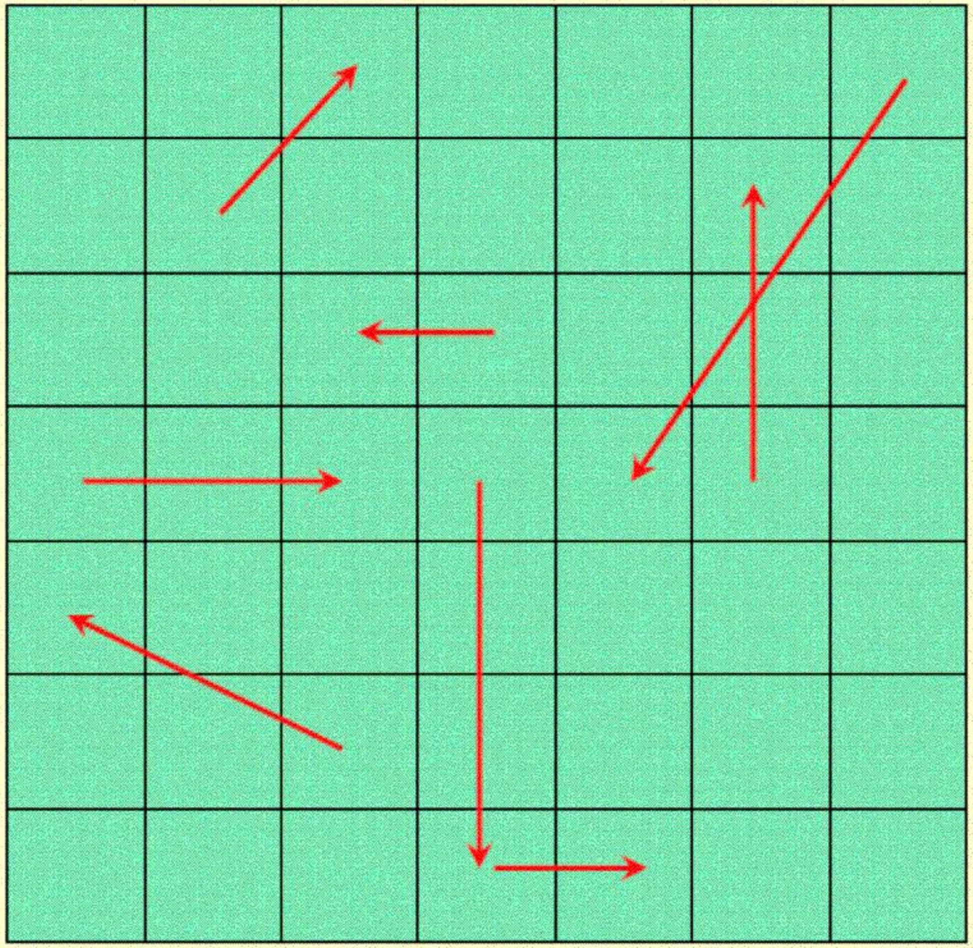
MOUSE WALKS

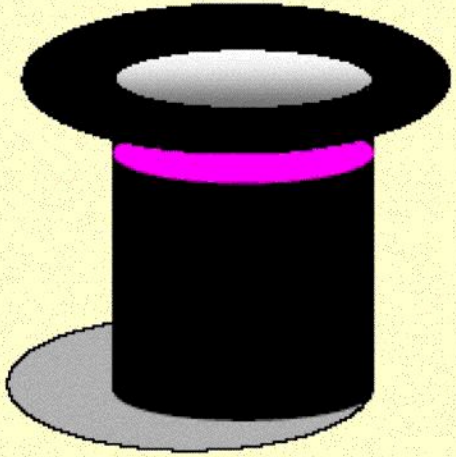




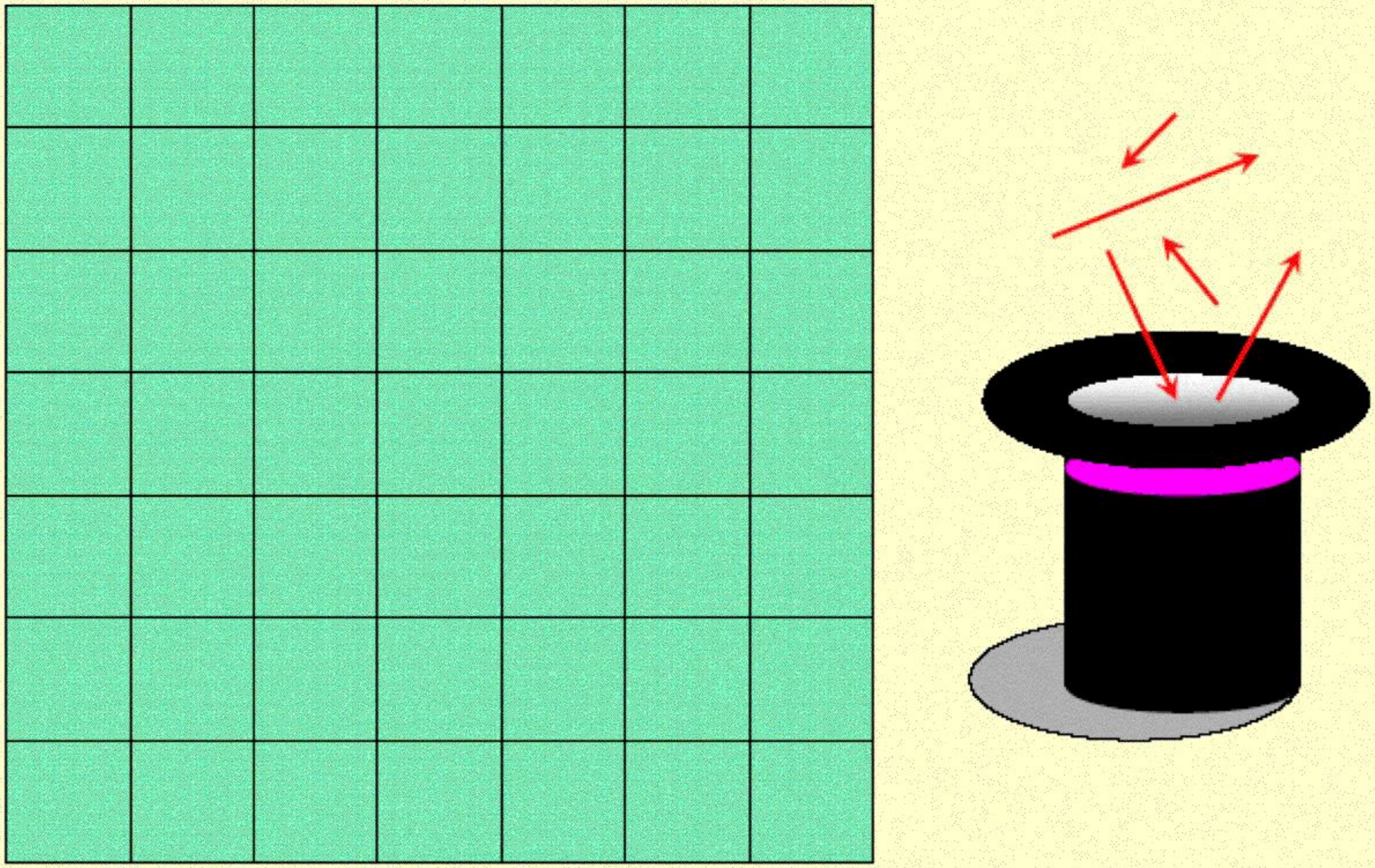
Julian date 2450xxx
(Sept. 97 to May 98)

An ensemble of displacements

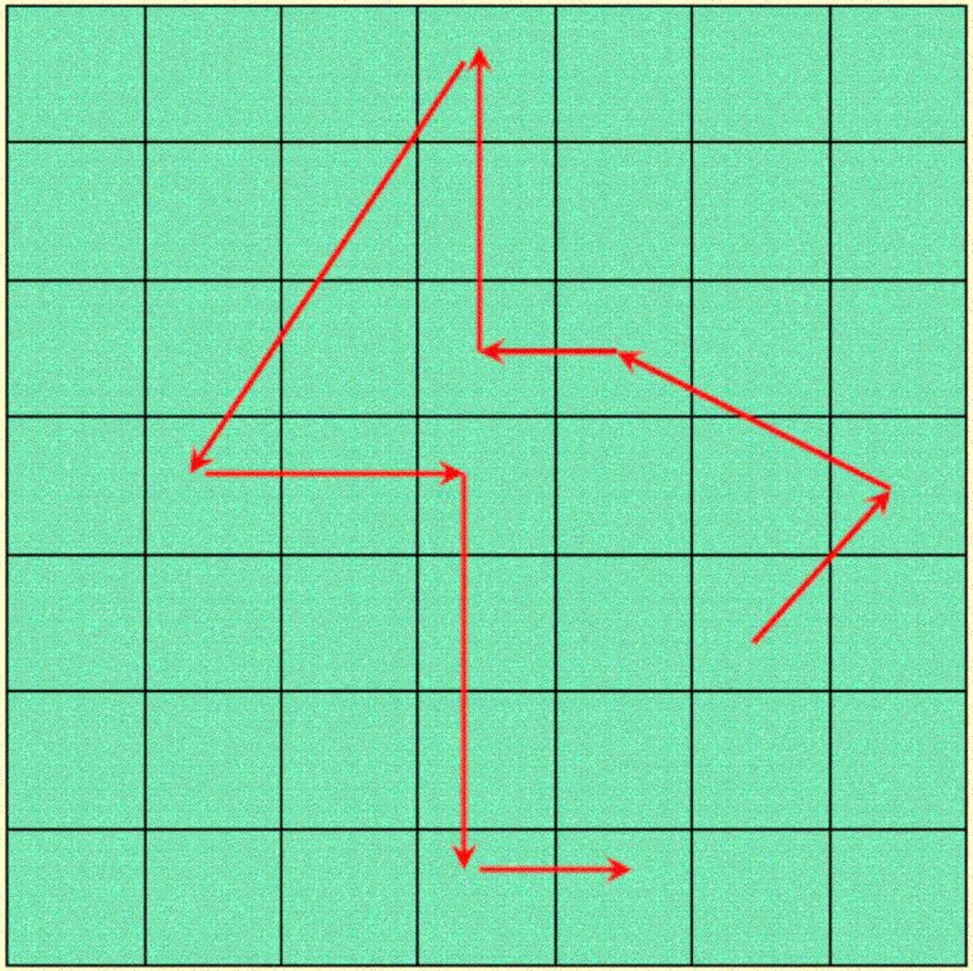




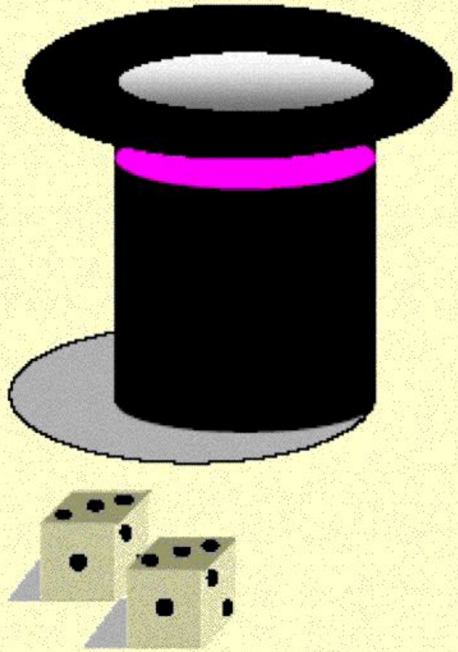
An ensemble of displacements



An ensemble of displacements

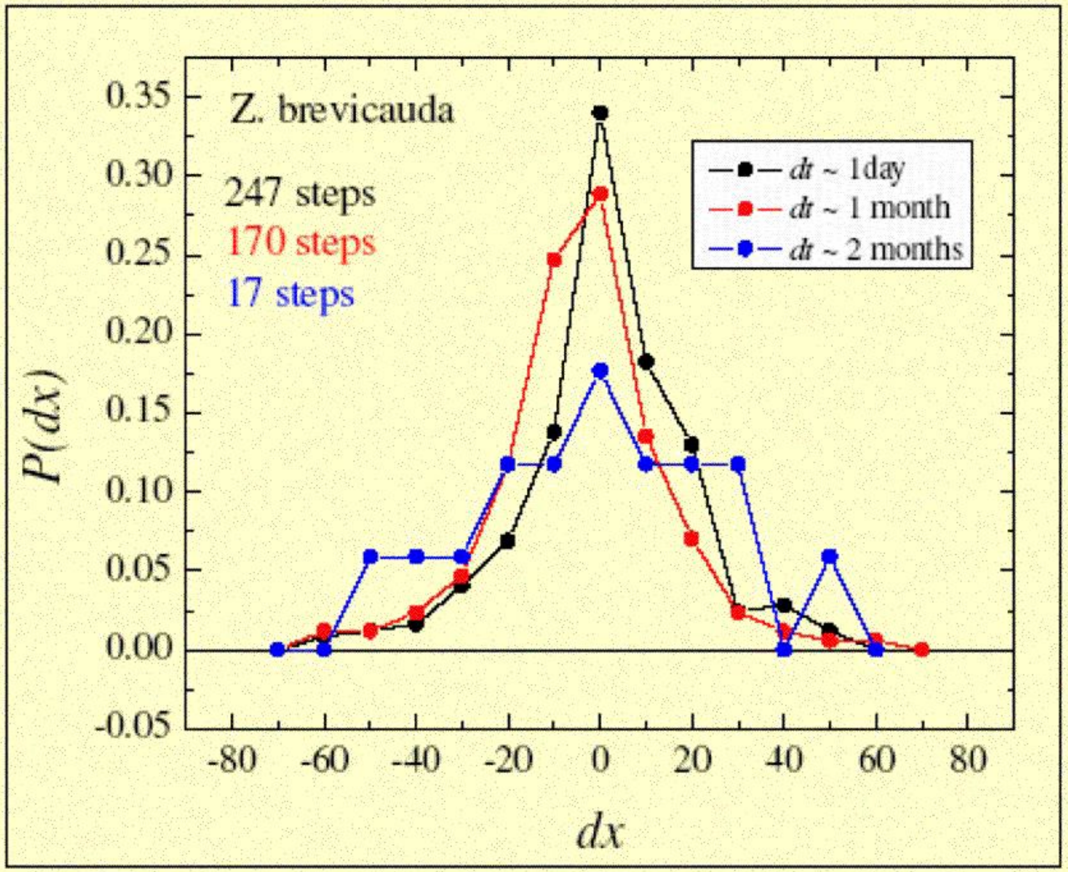


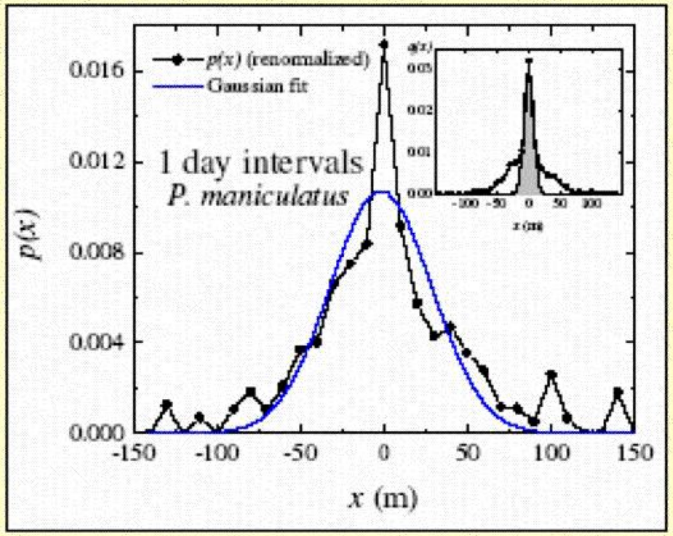
…representing the walk of an "ideal mouse"



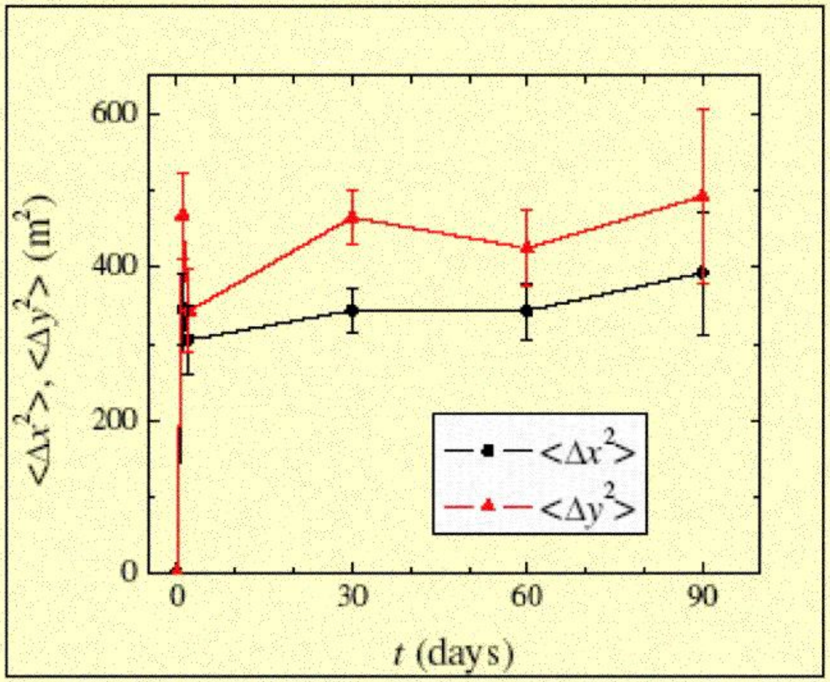
PDF of individual displacements

As three ensembles, at three time scales:

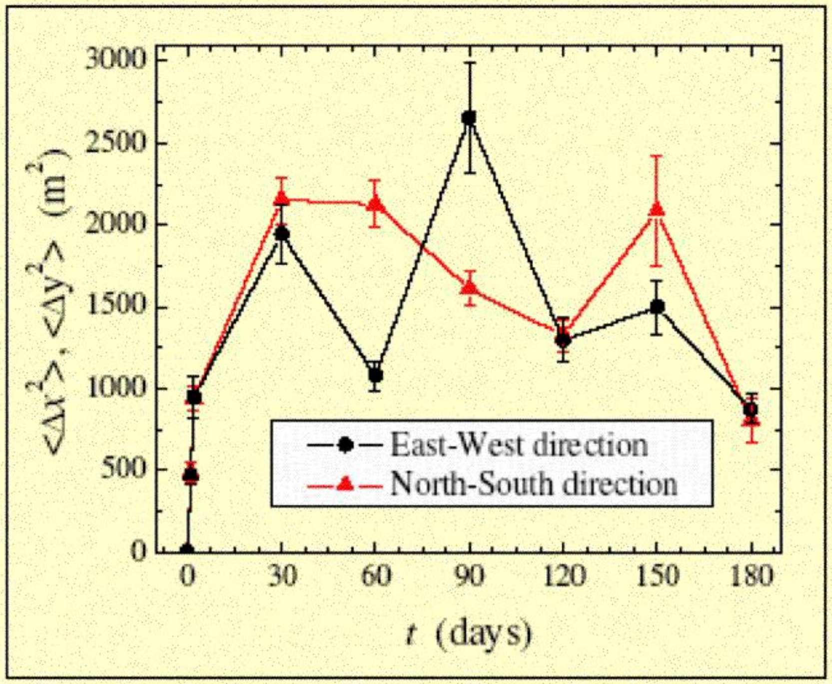




Mean square displacement



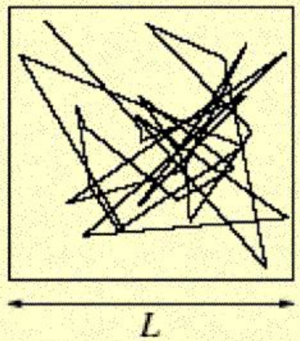
Z. brevicauda (Panama)



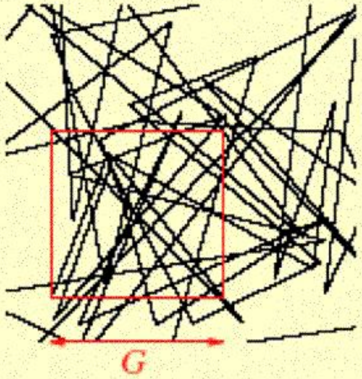
P. maniculatus (New Mexico)

Confinements to diffusive motion

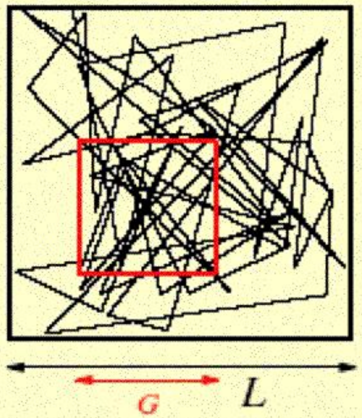
- Home ranges



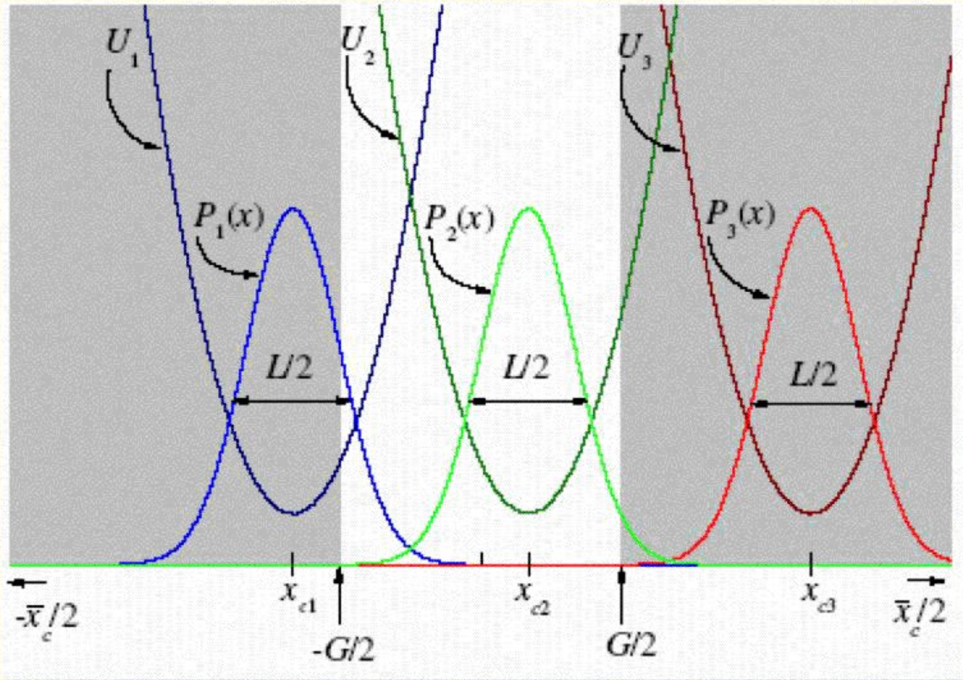
- Capture grid



- Combination of both



A harmonic model for home ranges

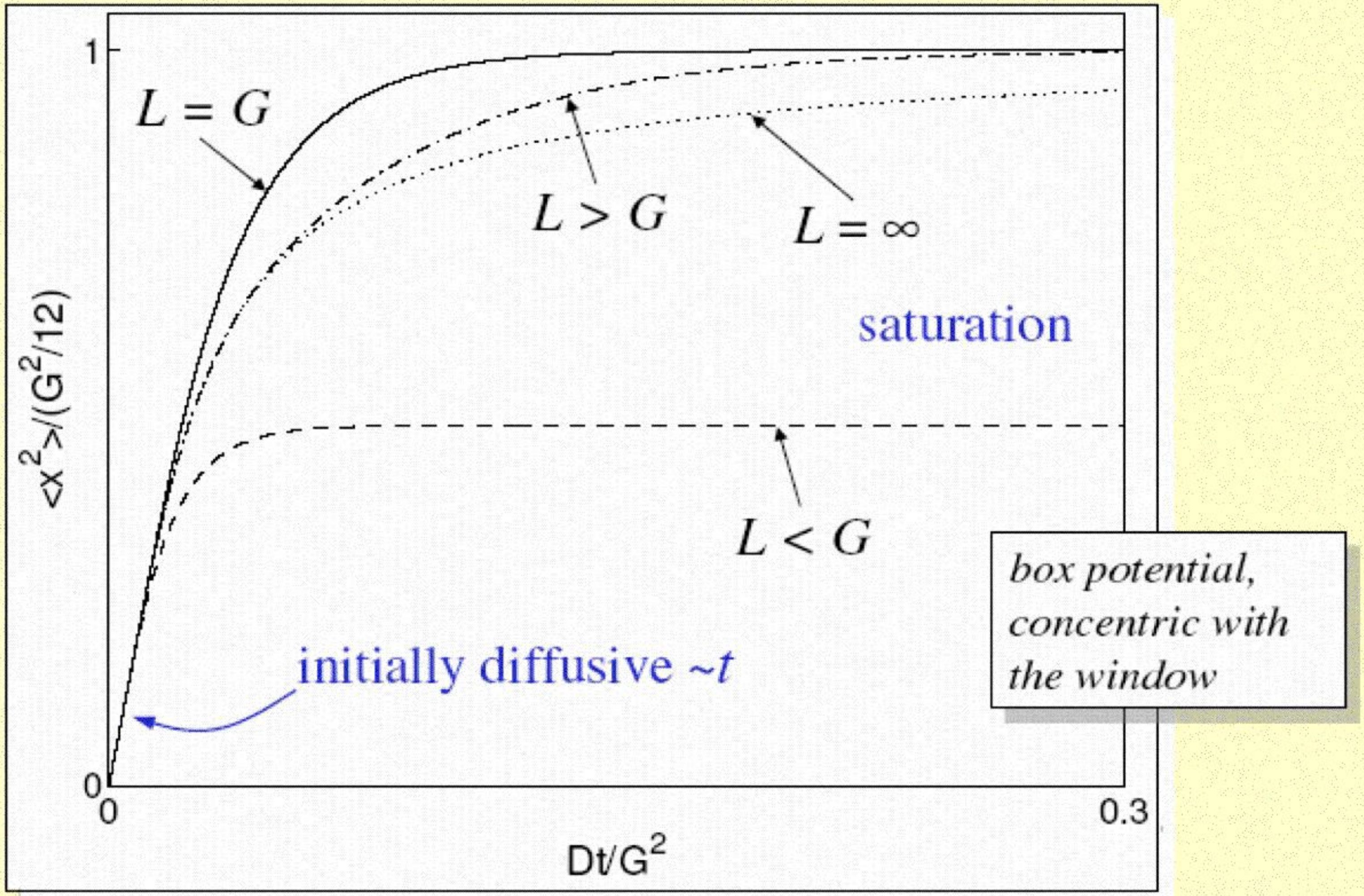


$$\frac{\partial P(x,t)}{\partial t} = \frac{\partial}{\partial x}\left[\frac{dU(x)}{dx}P(x,t)\right] + D\nabla^2 P(x,t)$$

PDF of an animal

FPE → **MSD**

Time dependent MSD



SUMMARY

- Simple model of infection in the mouse population
- Important effects controlled by the environment
- Extinction and spatial segregation of the infected population
- Propagation of infection fronts
- Delay of the infection with respect to the suceptibles
- Mouse "transport" is more complex than diffusion
- Different subpopulations with different mechanisms
    - Existence of home ranges
    - Existence of "transient" mice
- Limited data sets can be used to derive some statistically sensible parameters: D, L, a
- Possibility of analytical models

Thank you!

References

Published papers and preprints can be downloaded from my web page:
http://cabfst28.cnea.gov.ar/~abramson