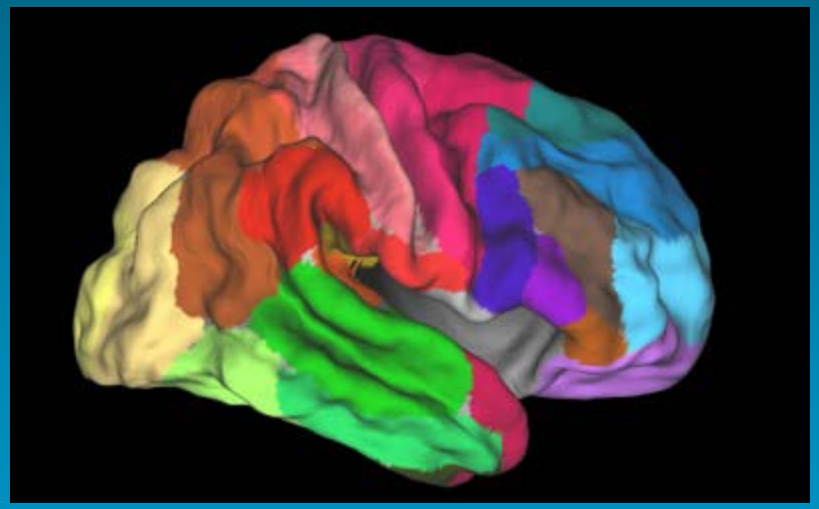
SISSA

SPACEBRAIN

where in our inner space,
among its multiple areas,
do we construct our internal
representations of outer space?

limbo

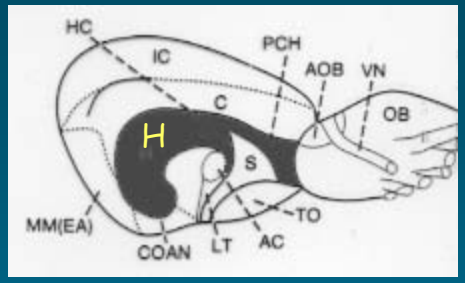


TABIS 2013, Beograd

September 20, 2013

Alessandro Treves

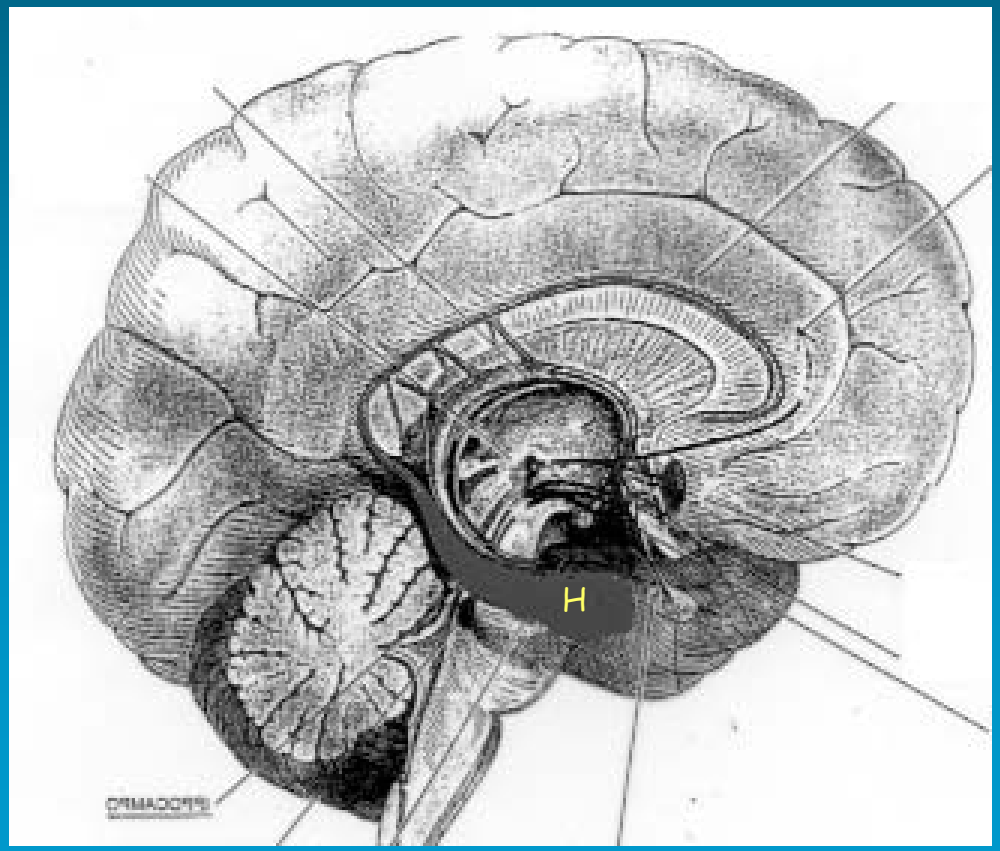
THE HIPPOCAMPUS

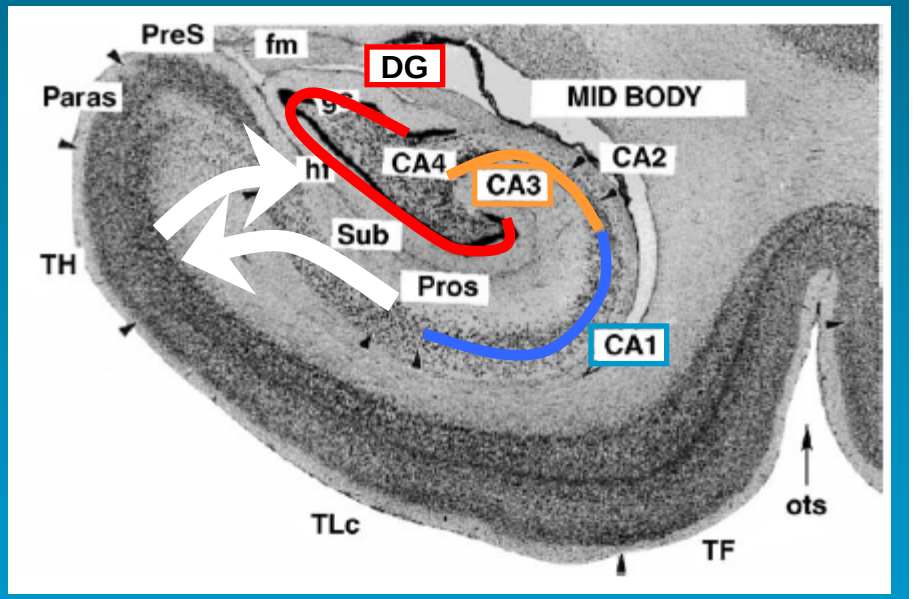


opossum

a structure which remains stable and self-similar across mammalian species

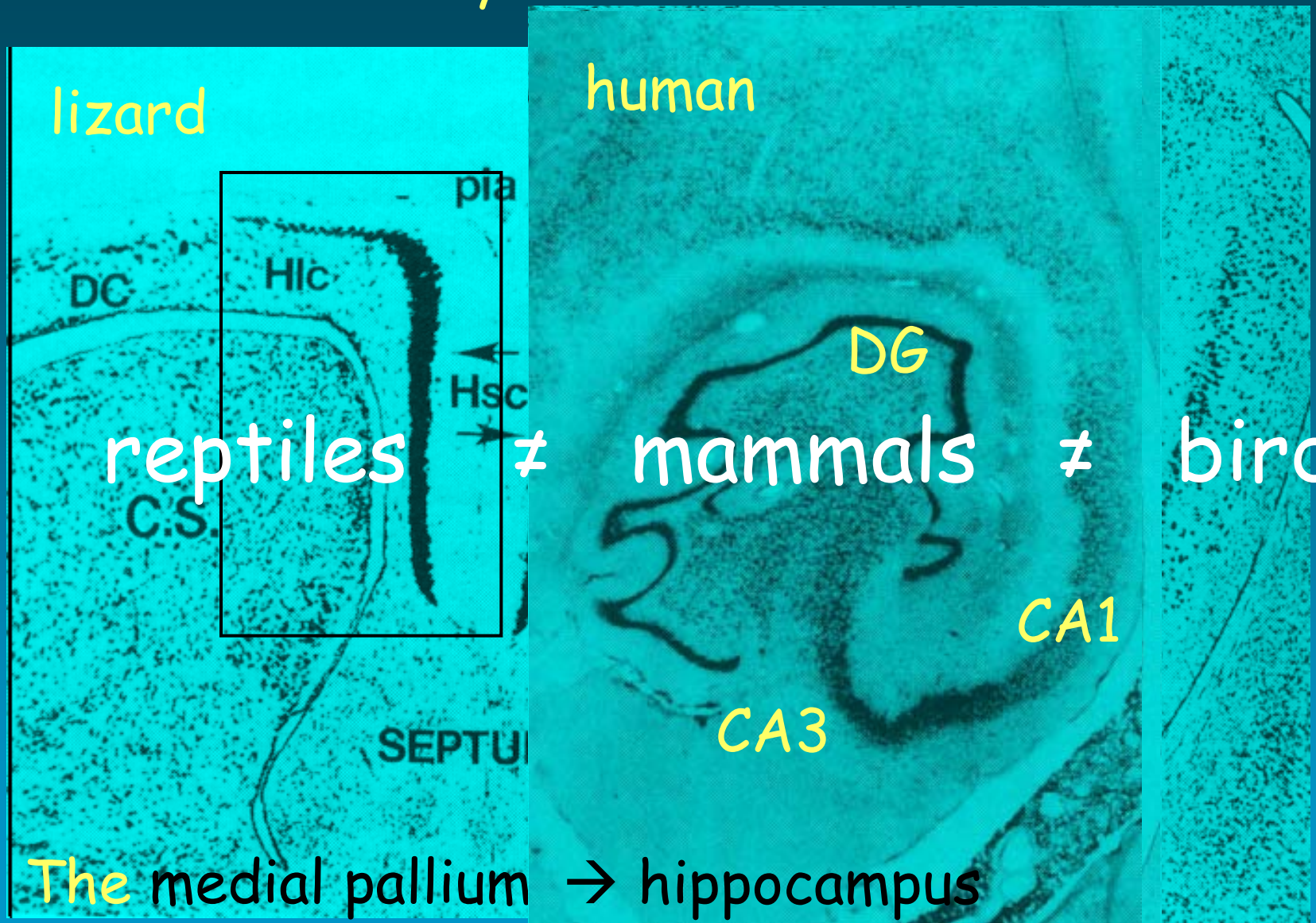
human





monkey

but… has it always been like that?



reptiles ≠ mammals ≠ birds

The medial pallium → hippocampus
has been with us for over 200 million years…

Is the **hippocampus** what we use to navigate?

John O'Keefe
1971
Univ Coll London

SPACEBRAIN

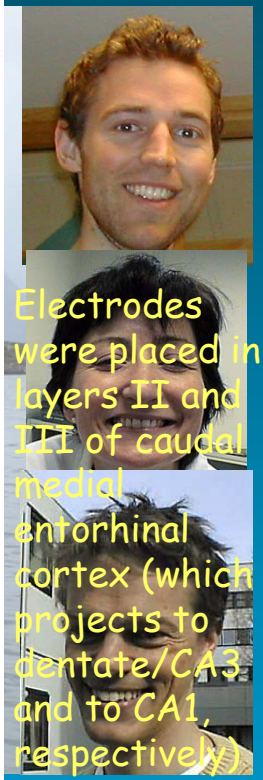
…or is it used to recollect from the past salient episodes of our lives?

Laura and a rat

Place cells

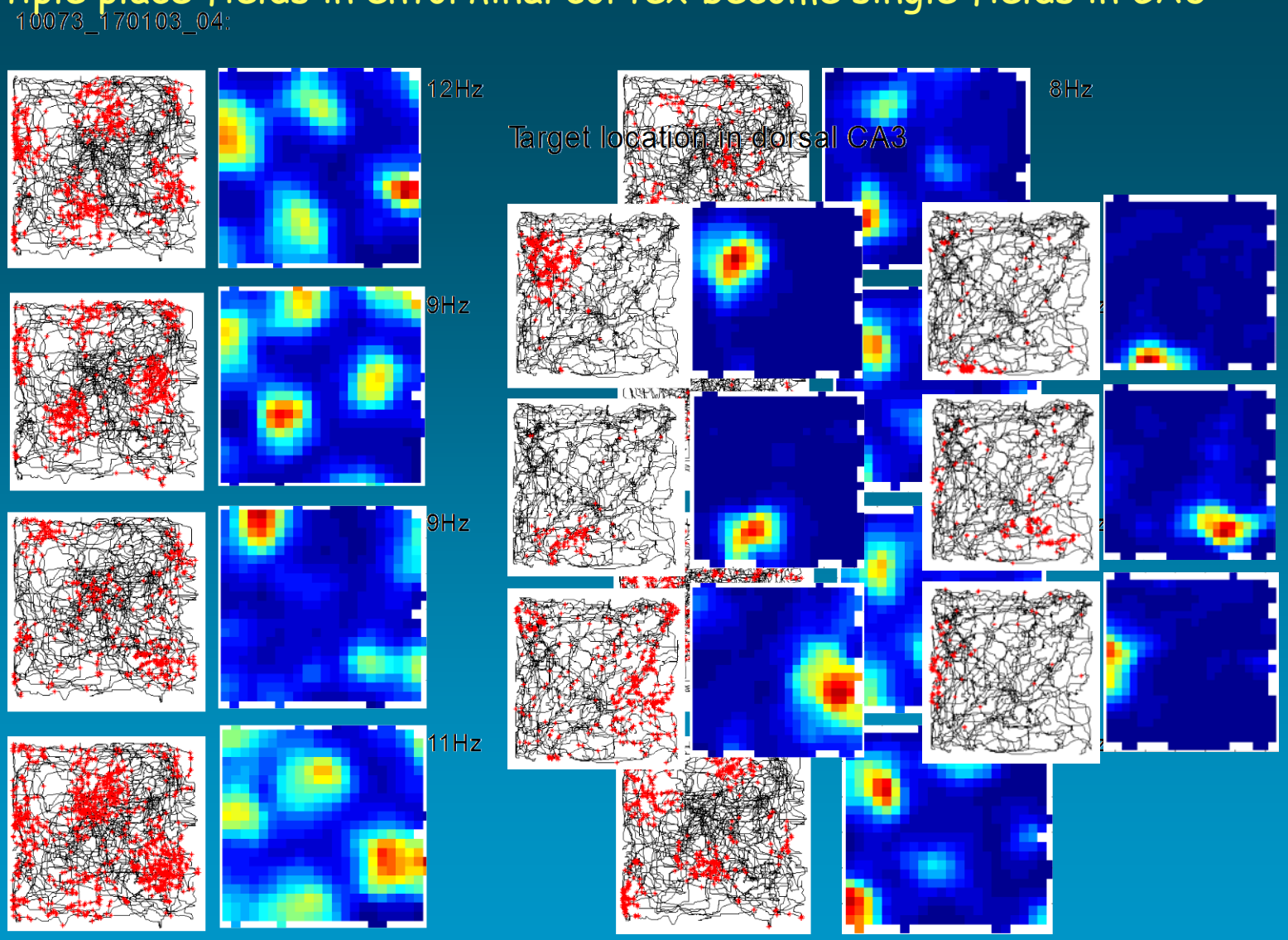
Neurophysiology + Neuroanatomy

Marianne Fyhn
in the Mosers' lab
with Menno Witter
(Science, 2004)



Electrodes were placed in layers II and III of caudal medial entorhinal cortex (which projects to dentate/CA3 and to CA1, respectively)

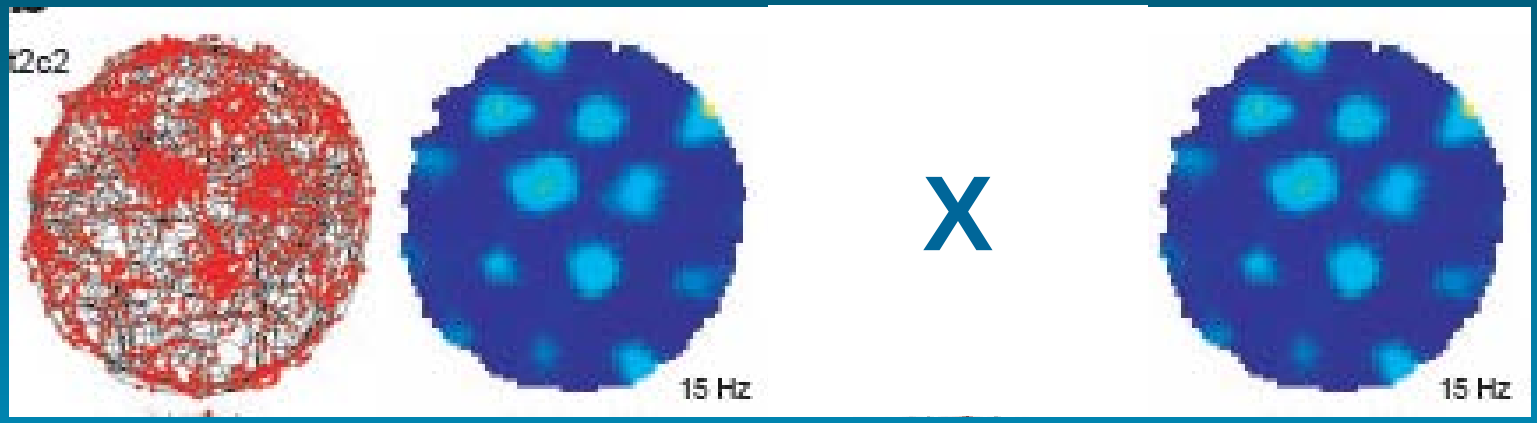
Multiple place fields in entorhinal cortex become single fields in CA3



Cells in dorsal medial entorhinal cortex have multiple dispersed fields

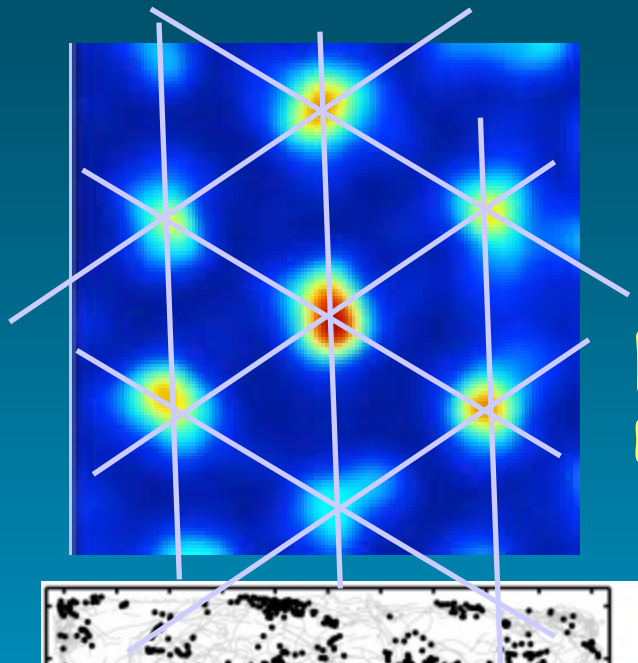
Torkell Hafting
(with Marianne Fyhn
et al in the Mosers' lab
Nature, 2005)

recorded units in a larger environment and looked at the map autocorrelation

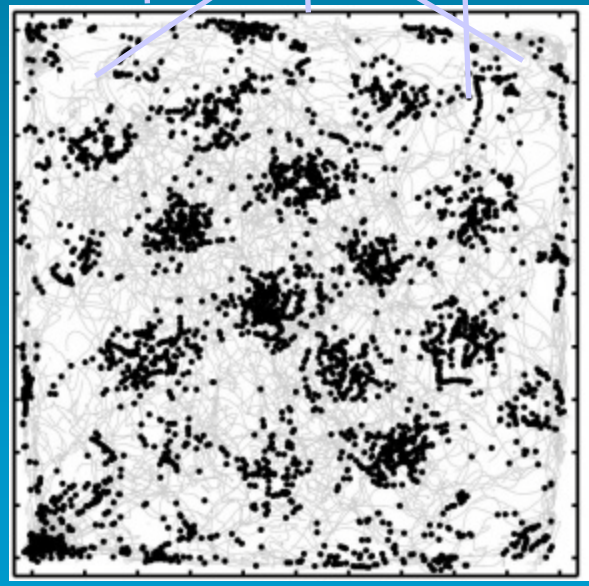


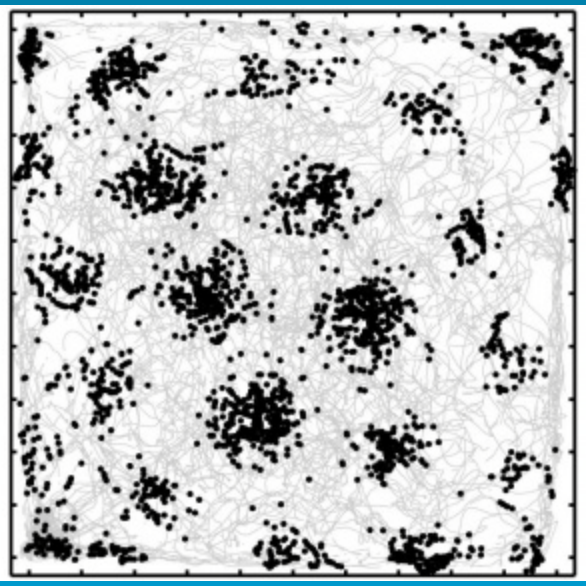
Grid cells !

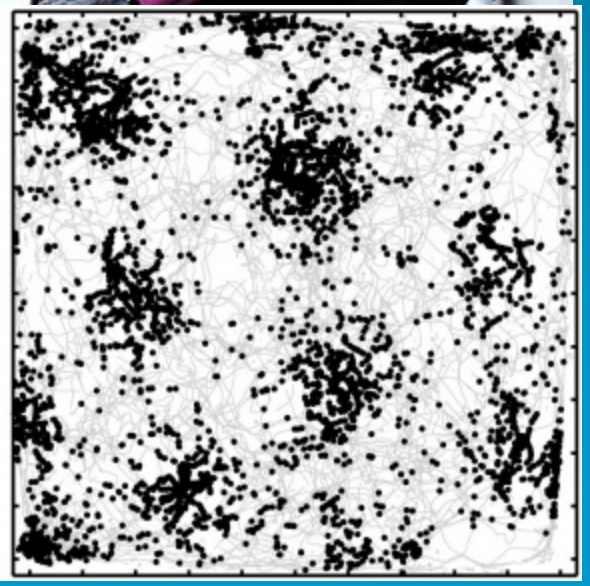
Just look at one grid cell…

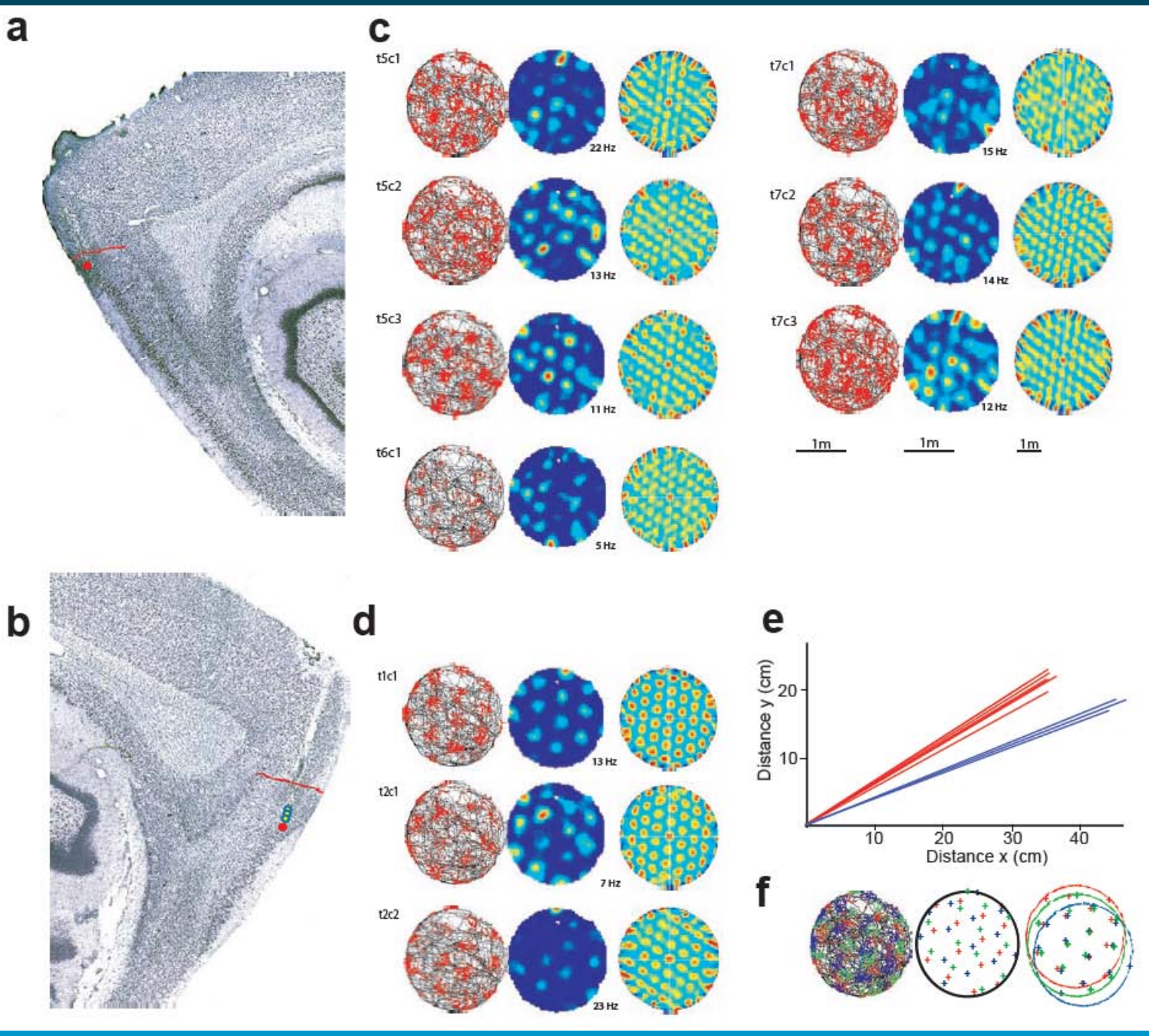


Is it just more beautiful than a place cell, more metrical, more…

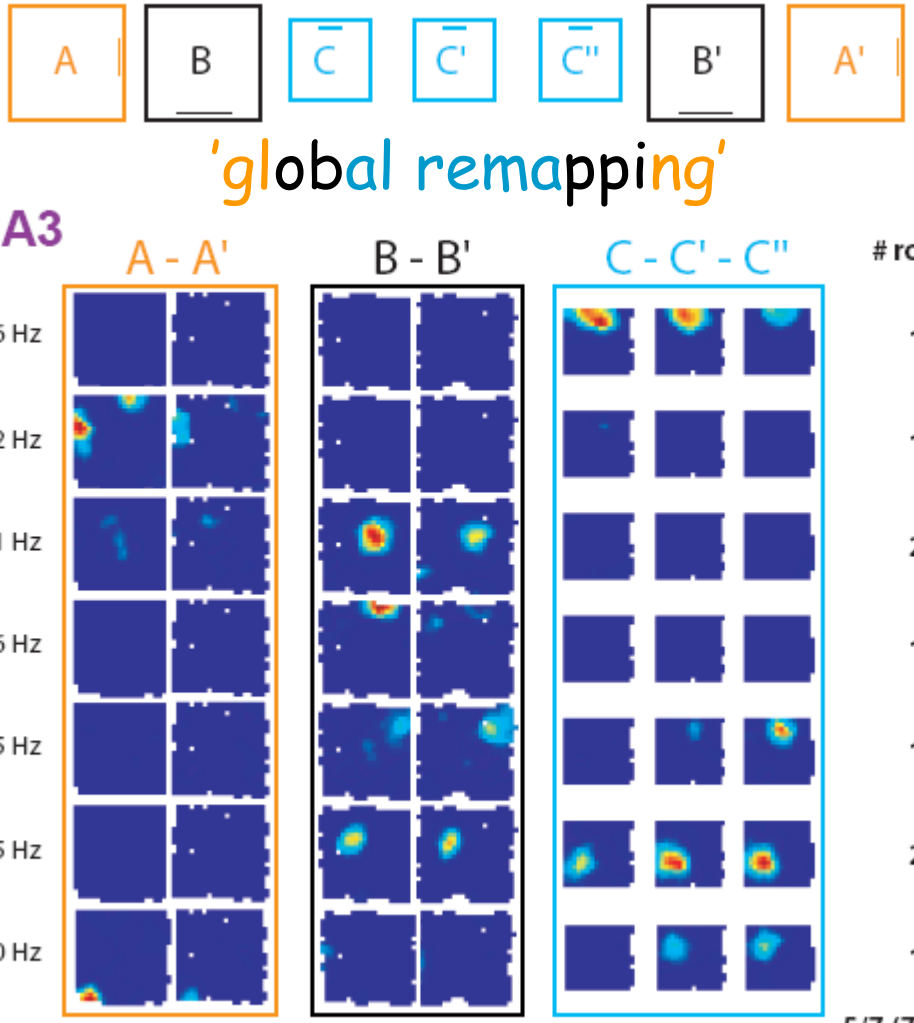




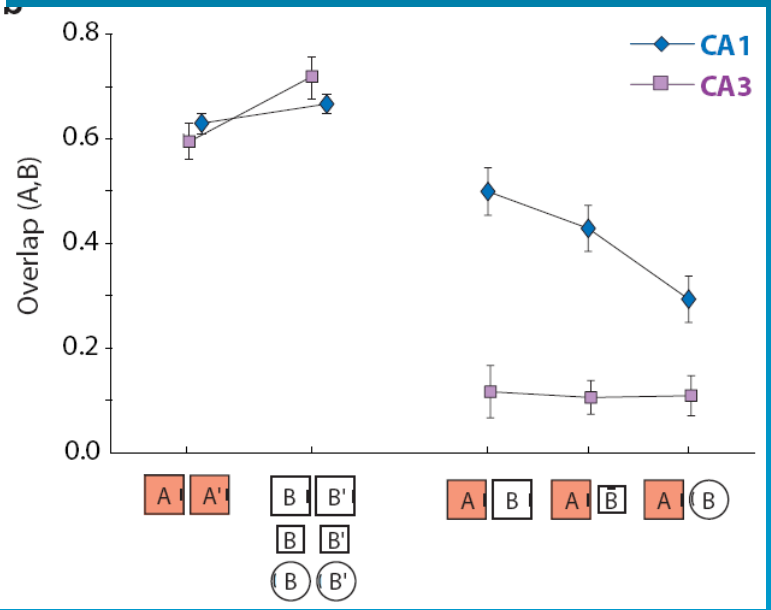



a
b
c
t5c1
22 Hz
t5c2
13 Hz
t5c3
11 Hz
t6c1
5 Hz
t7c1
15 Hz
t7c2
14 Hz
t7c3
12 Hz
1m
1m
1m
d
t1c1
13 Hz
t2c1
7 Hz
t2c2
23 Hz
e
Distance y (cm)
20
10
10
20
30
40
Distance x (cm)
f

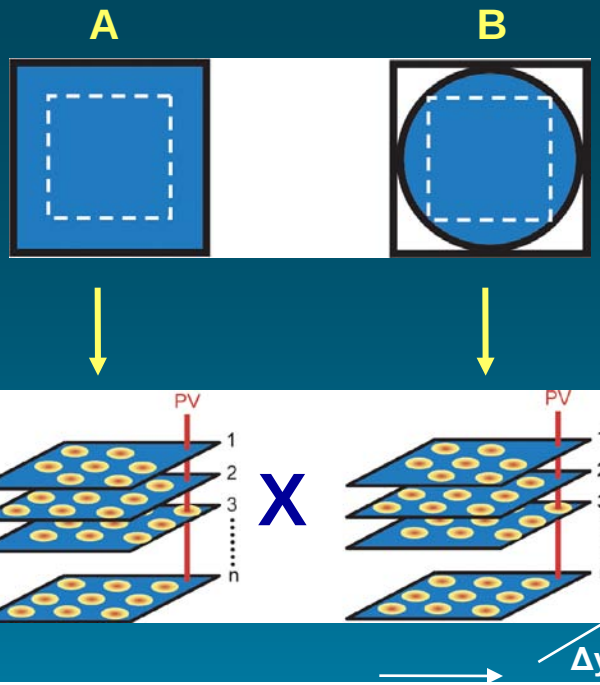
Consider what happens in the hippocampus when changing context



CA3 charts can be described as a (discrete?) number of continuous attractors, with minimal overlap among them

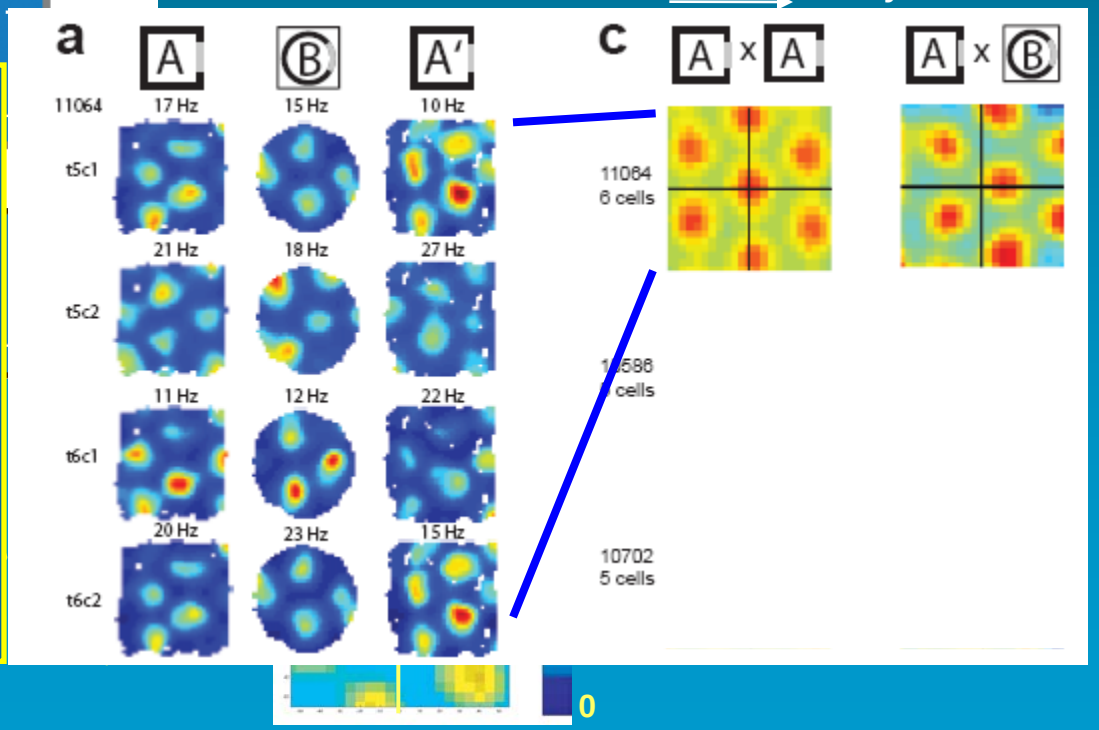


Neurophysiology + Neural Computation



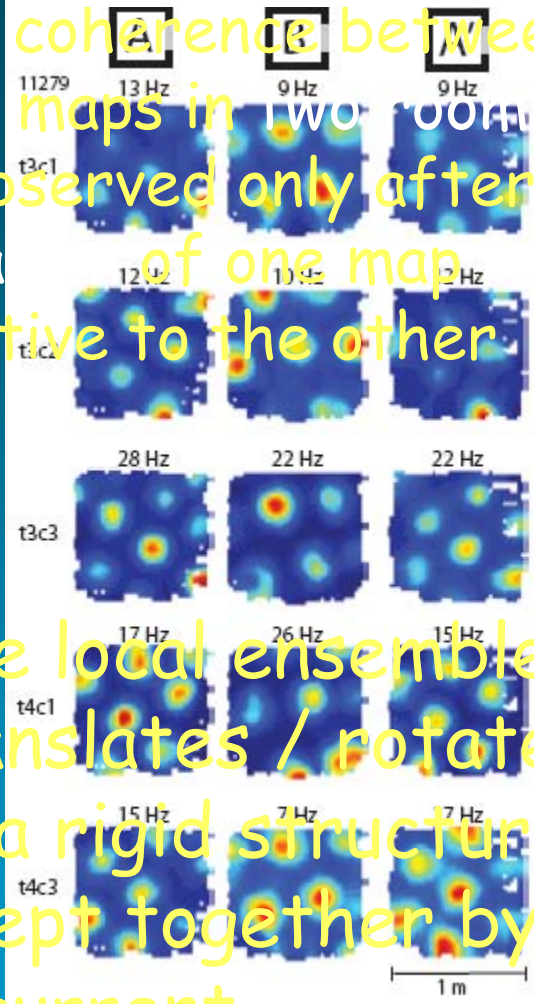
Matrices of population vectors were cross-correlated between two boxes

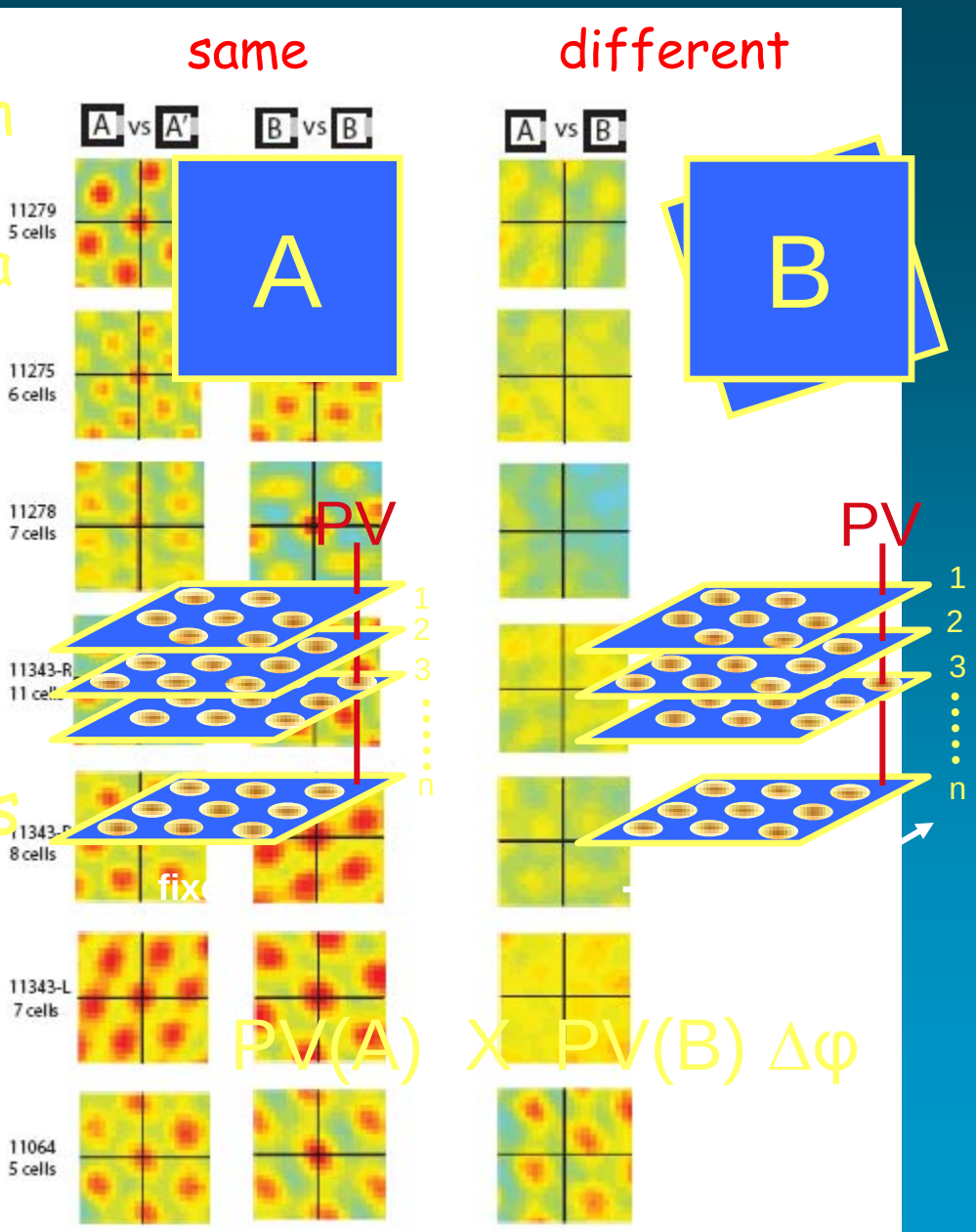
coherent displacement of the entorhinal map during global remapping in the hippocampus !

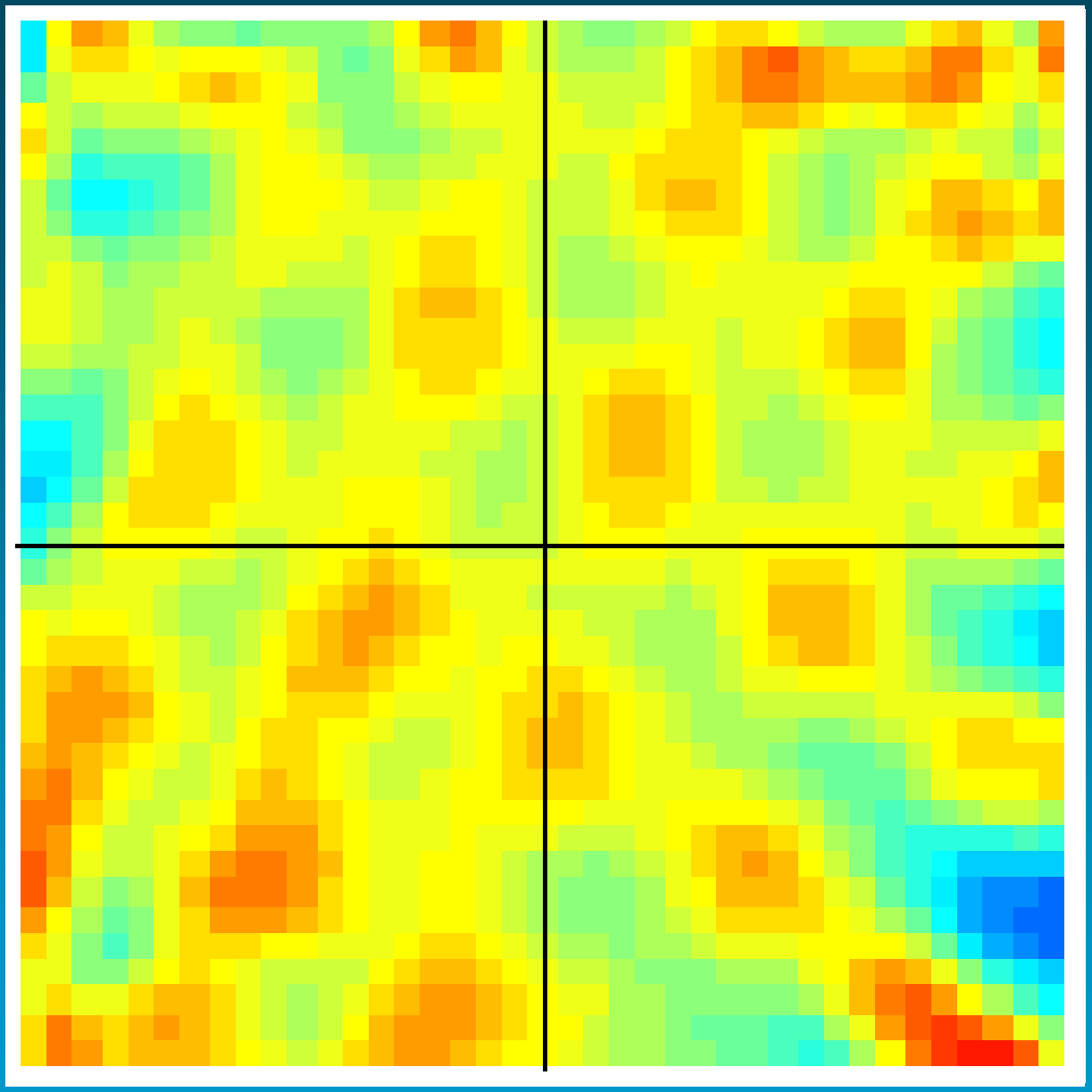


The coherence between grid maps in two rooms is observed only after a rotation of one map relative to the other

The local ensemble translates / rotates as a rigid structure …kept together by recurrent connections ?





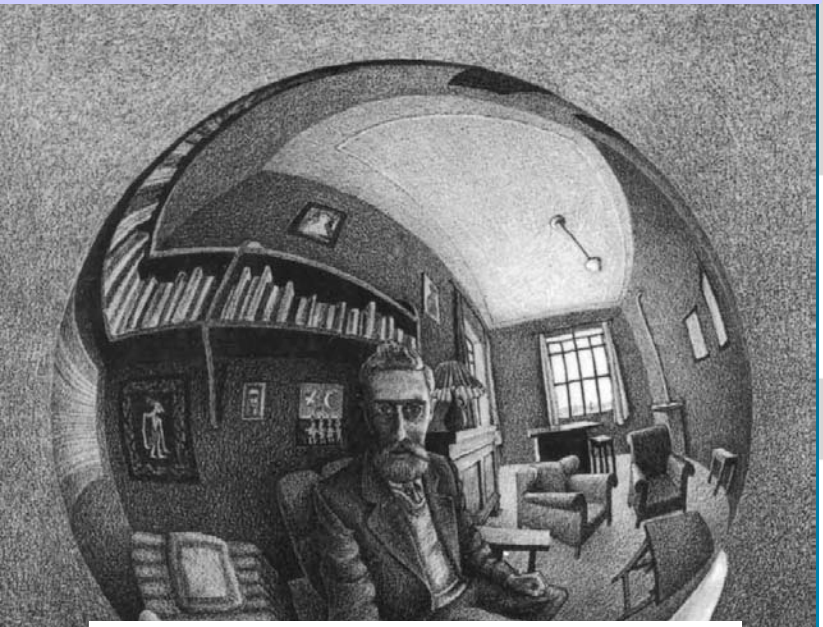


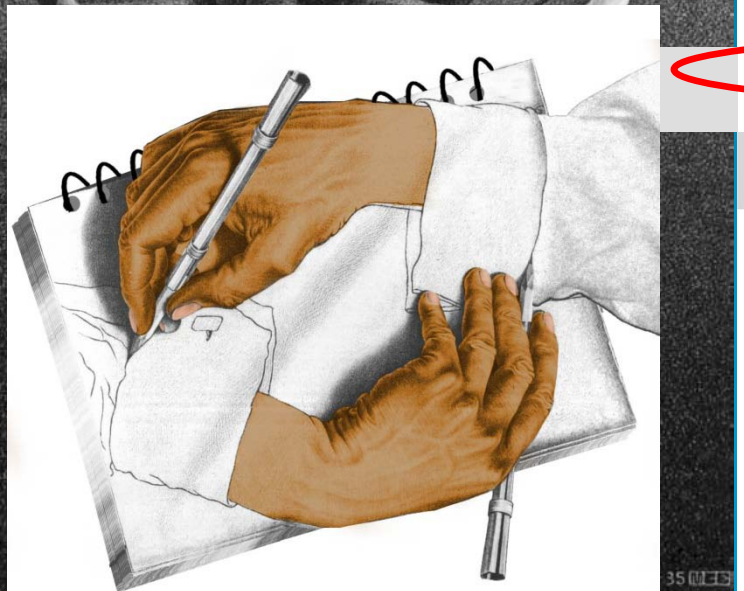
Thus, the intrinsic structure of the map (spacing, orientation, spatial phase) is retained,

i.e. a single map may be applied rigidly in all environments

..millimeter paper

Many models have been proposed..





Grid cell model	Position representation	Updating mechanism
Conklin and Eliasmith (2005)	Torus attractor, single bump	Direction-conjunctive cells
O'Keefe and Burgess (2005)	[Torus attractor, single bump]	[Direction-modulated recurrent connections]
Fuhs and Touretzky (2006)	Aperiodic attractor, multi-bump	Direction-conjunctive cells
McNaughton et al. (2006)	[Torus attractor, single bump]	[Direction-conjunctive cells]
Blair et al. (2007)	[Theta grids]	–
Burgess et al. (2007)	Sinusoid phase difference	Frequency modulation
Gaussier et al. (2007)	Firing rates as coordinates	Firing rate modulation
Giocomo et al. (2007)	Sinusoid phase difference	Frequency modulation
Guanella et al. (2007)	Twisted-torus attractor, single bump	Dynamic recurrent connections
Blair et al. (2008)	[Biased ring attractor phase difference]	[Direction-conjunctive cells]
Burgess (2008)	Sinusoid phase difference	Frequency modulation
Hasselmo (2008)	Sinusoid phase difference	Frequency modulation
Hasselmo and Brandon (2008)	Firing rate	Frequency modulation
Burak and Fiete (2009)	Torus and aperiodic attractors, multi-bump	Direction-conjunctive cells
Mhatre et al. (2012)	[Unbiased ring attractor]	[Direction-conjunctive
Zilli and Hasselmo (2010)	on pha	frequency ion
Navratilova et al. (2012)	tractor	n-conjunctive cells
Welday et al. (2011)	actor p	n-conjunctive

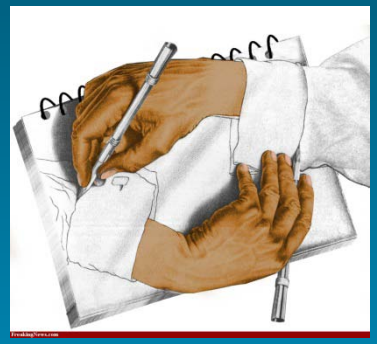
Most models require an engineer inside the brain to set them up

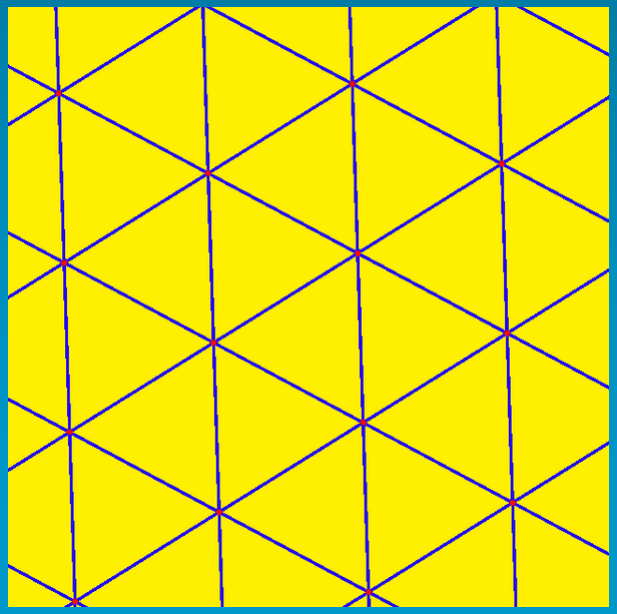
Emilio Kropff

Bailu Si

How to decide which model is right?

In a plain box,
with nothing inside
all models work fine

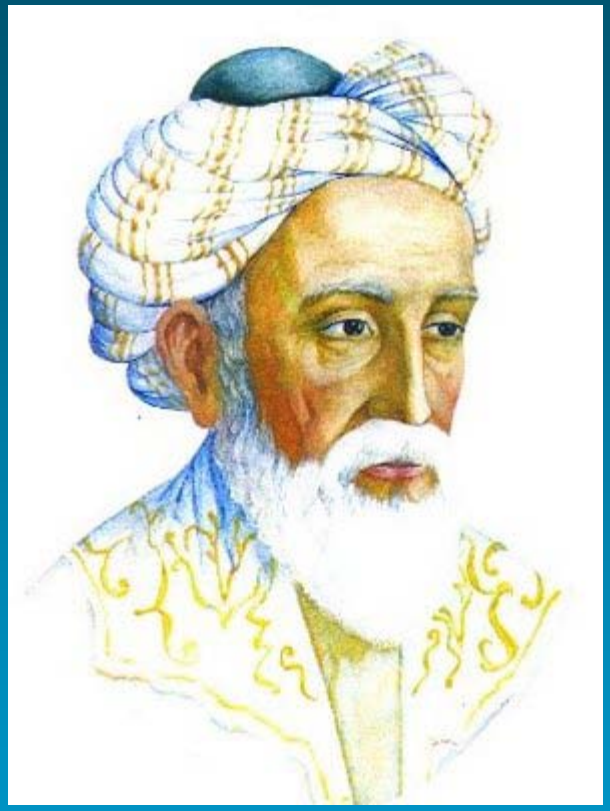




Grande Escursione Appenninica

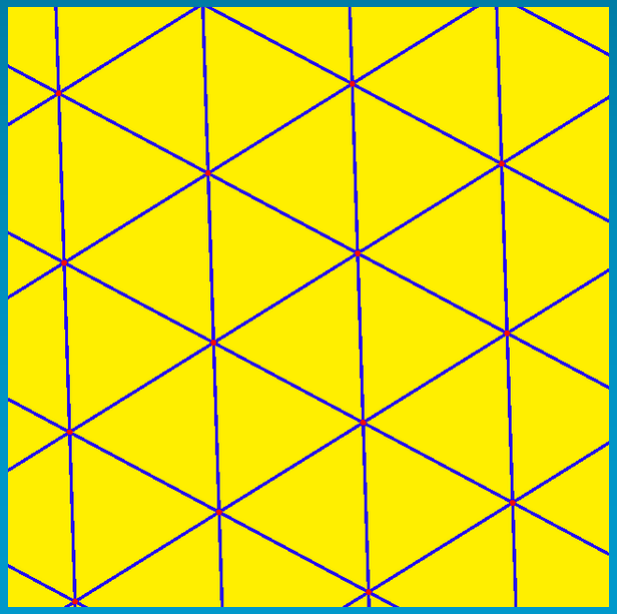
..no straight lines

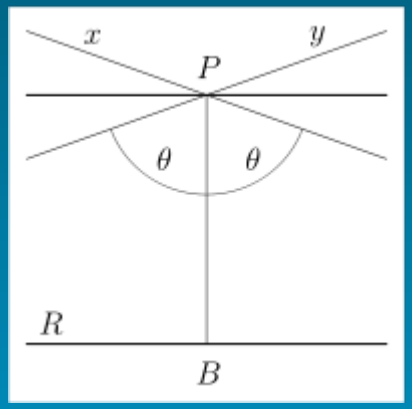
Is it true that through a given point there can only be one parallel line?



Omar Khayyam

ca. 1080

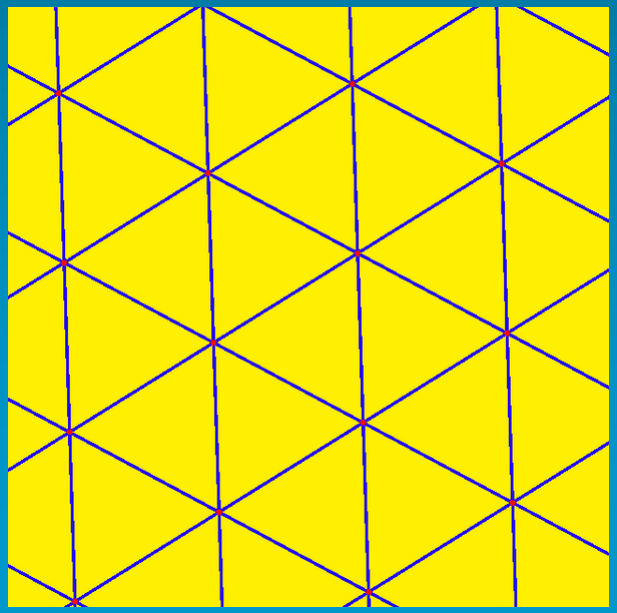


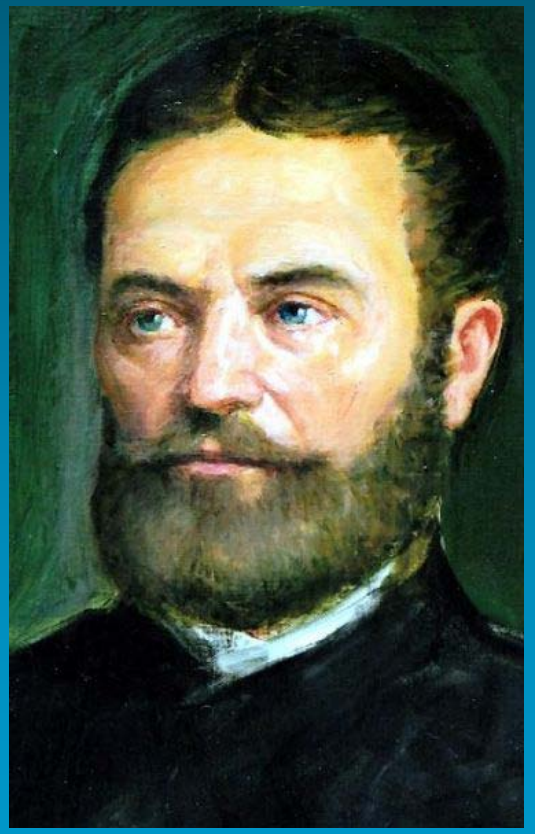


mmmhh…
…thinking about it…
…**no** !
There can be more

ca. 1830

Lobachevsky

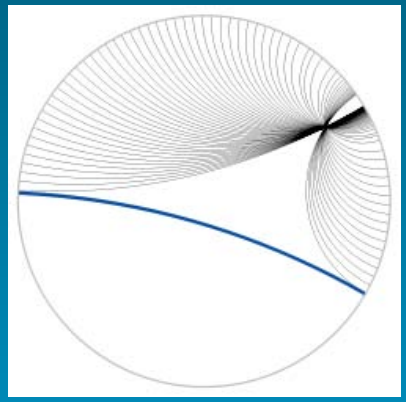




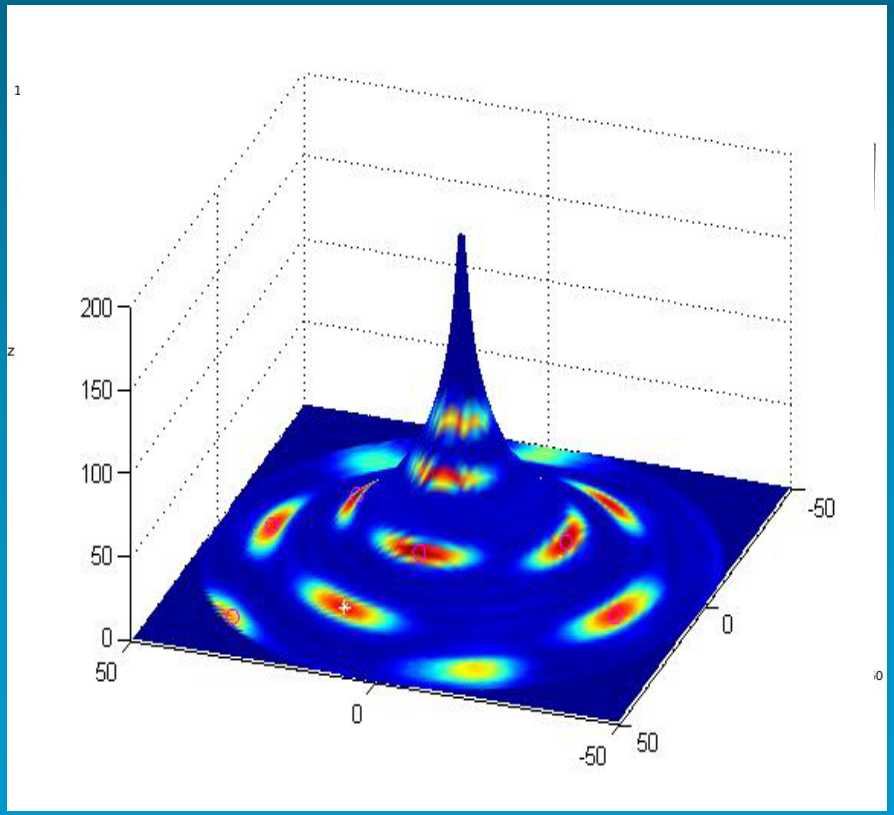
Bolyai

In fact !
It all depends what
you mean with
a line
Think of projecting it..

Hyperbolic disk



Hyperbolic
"pseudosphere"



..a simpler experimental test of the adaptation model is to raise rodents either in or on a ball

Spherical harmonics

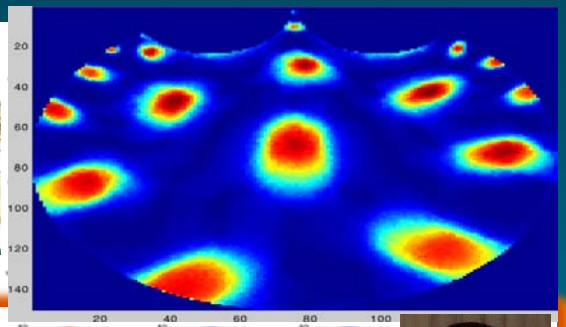
$$\Psi_{l^*}(r) = \sum_{l=0,l^*} \sum_{m=0,m^*} a_{lm} Y_l^m(r)$$

$$\Psi_6(\theta,\varphi) = d[cY_0^0 + [aY_6^0 + \frac{b}{2}(Y_6^{-5} - Y_6^5)]]$$

$$= d[c\frac{1}{2}\sqrt{\frac{1}{\pi}} +$$
$$+ [\sqrt{\frac{143}{137\pi}}\frac{1}{32} * (231\cos^6(\theta) - 315\cos^4(\theta) + 105\cos^2(\theta) - 5) +$$
$$+ \frac{143}{137\pi}\frac{21}{6} * \cos(5\varphi)\sin^5(\theta)\cos(\theta)]] \quad (9)$$

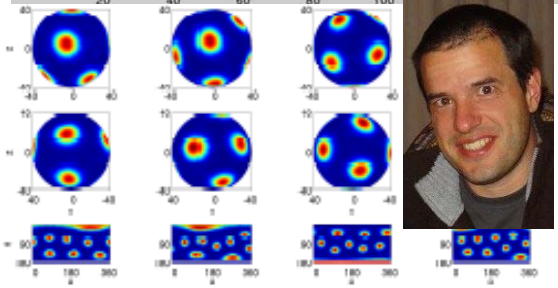
what do we expect to see on the ball?

Feder
on the

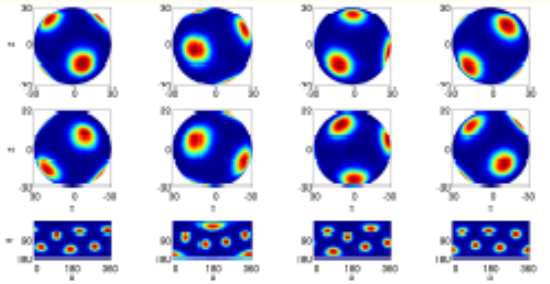


$R = 40cm$

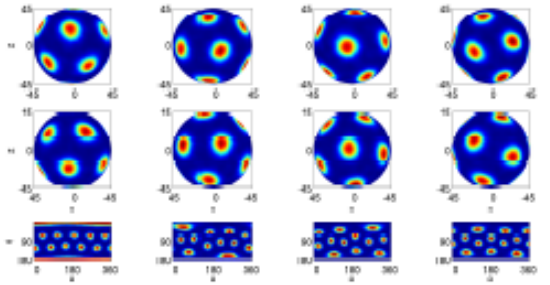
Also for mixed states



(d)
$R = 30cm$



(e)
$R = 45cm$

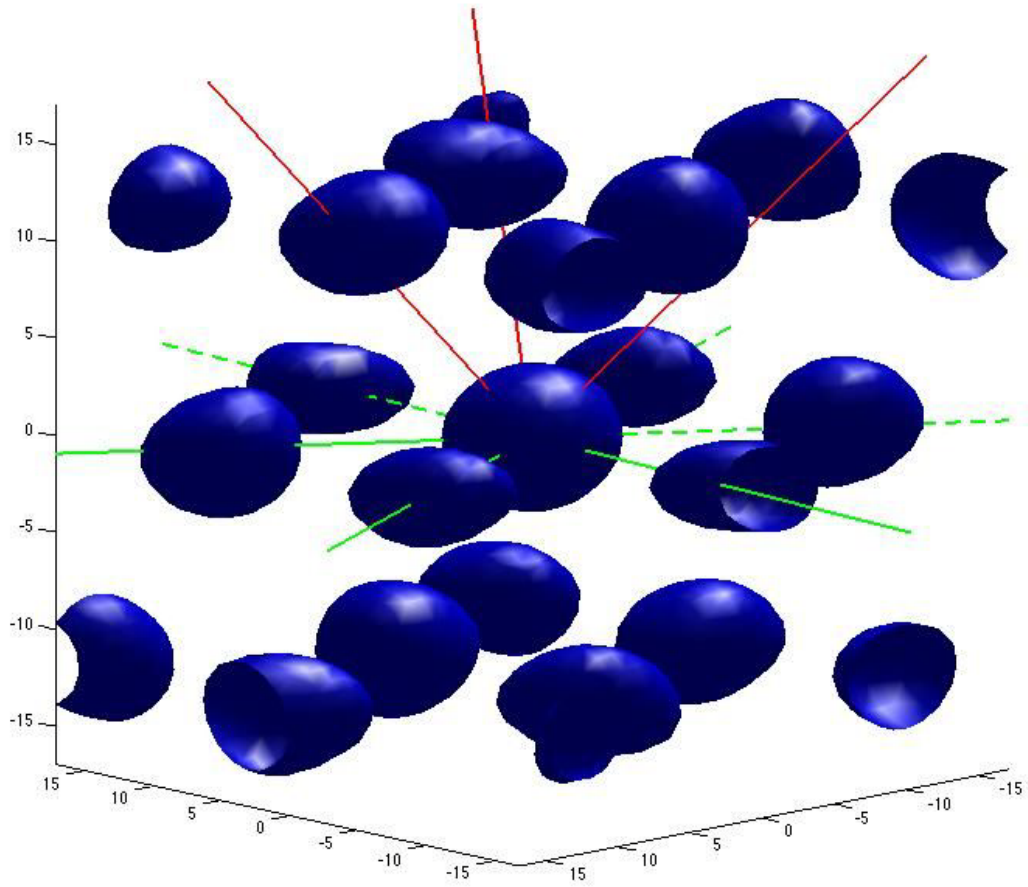


Simulations confirm the analysis

What to expect in 3D?

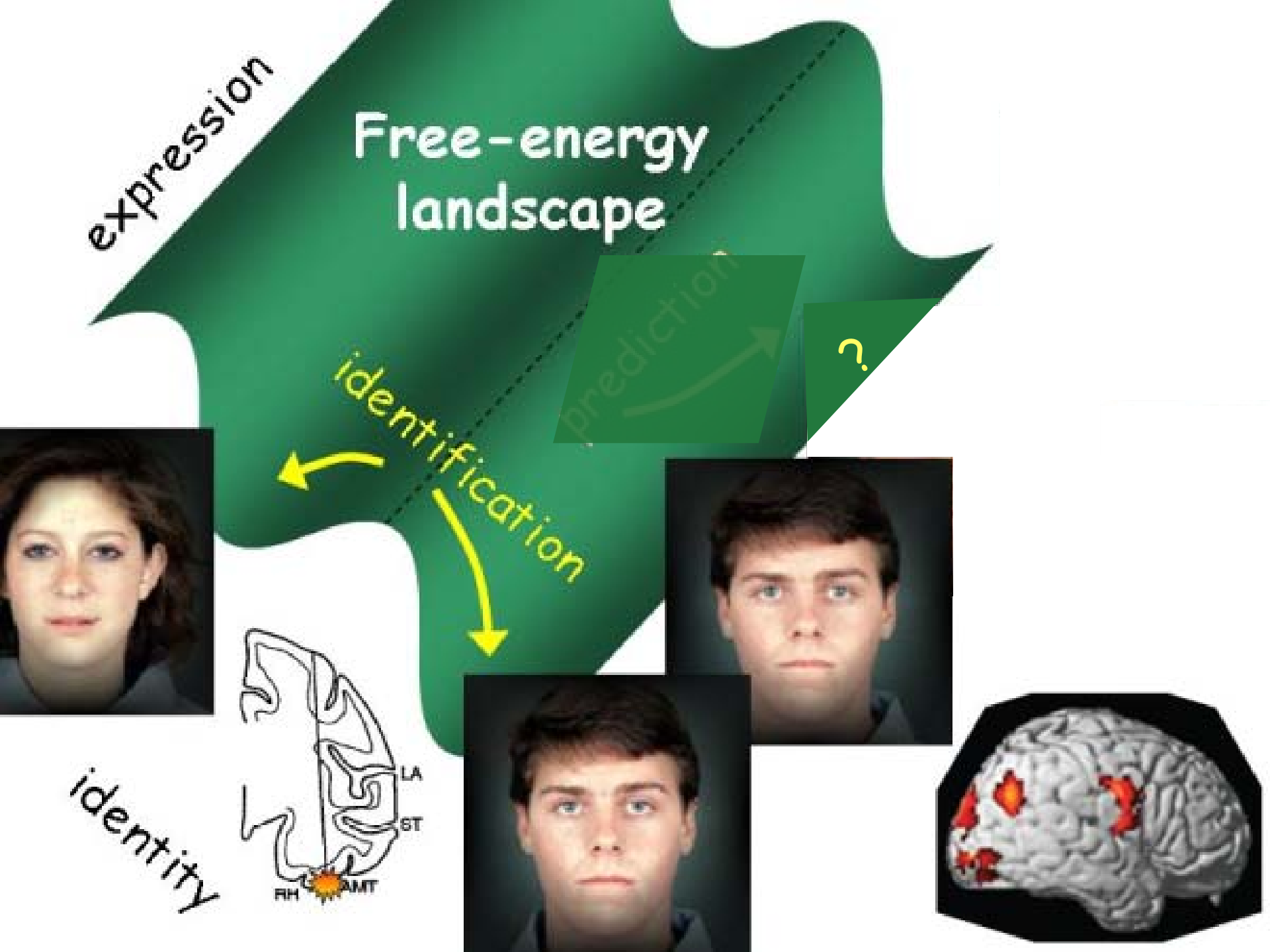
(soon to be discovered by Nachum Ulanovsky)

FCC lattice



(or HCP or mixed)

Rather than Euclides or Kant, the space of one's experience


Free-energy
landscape
expression
identification
prediction
?
identity
LA
ST
RH
AMT