



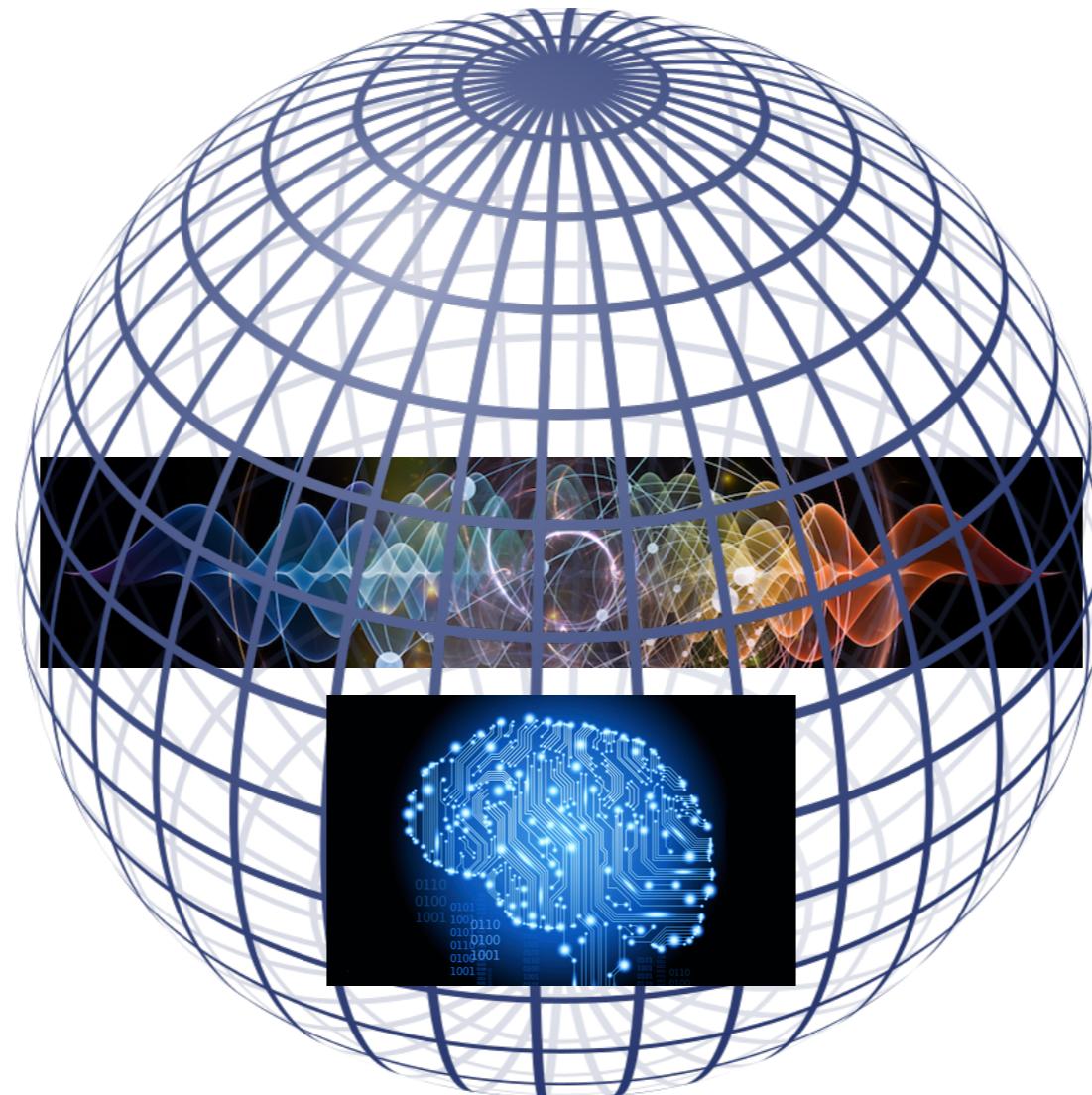
Neuroscience

A combination of Mathematics, Physics, and Biology

$$a^2 + b^2 + c^2 = d^2$$

$$E = mc^2$$

$$e^{i\theta} = \cos(\theta) + i \sin(\theta)$$



Hosted by Pierros Ntelis

Speakers: Georgios Bardanikas, Laura López Galdo, and Salvatore Giancani

Dr. Pierros Ntelis

2008-2013, Bachelor of Applied Mathematics and Physics
at National Technical University of Athens, Greece

2013-2014, Master in Astrophysics & Cosmology
at University of Paris, France

2014-2017, PhD in Fundamental Physics & Cosmology
at University of Paris, France

2018-2020, PostDoc in Observational Cosmology
at Aix-University, CPPM, France

Since 2022, Teacher of Math and Physics at IBS

Specialised in

- Astrophysics
- Cosmology
- Teaching



Welcome 3 PhD student from

Institut de Neurosciences de la Timone



Speakers: Georgios Bardanikas, Laura López Galdo, and Salvatore Giancani

Institut de Neurosciences de la Timone

Georgios Yorgos Bardanikas (PhD student)

BSc. Physics (Aristotle University of Thessaloniki – Greece)

MSc. Neuroscience (Radboud University of Nijmegen- The Netherlands)

A physicist with background in Neurosciences
keen interest in the study of brain areas connectivity.



Institut de Neurosciences de la Timone

Laura López Galdo (PhD student)

BSc. Biomedical Engineering (uc3m – Spain)

MSc. Neuroengineering (TUM – Germany)

A biomedical engineer interested in research and development of medical devices, especially in technology applied to the brain.

“Focused on field of neuroscience because the deeper understanding of brain signals is key to improve neurotech in the future.”



Institut de Neurosciences de la Timone

Salvatore Giancani (PhD student)

BSc. Biomedical Engineering (University of Cagliari - Italy)

MSc. Neuroengineering (University of Genoa- Italy)

Neuroengineer worked on artificial neural networks, artificial reinforcement learning, language models and semantics.





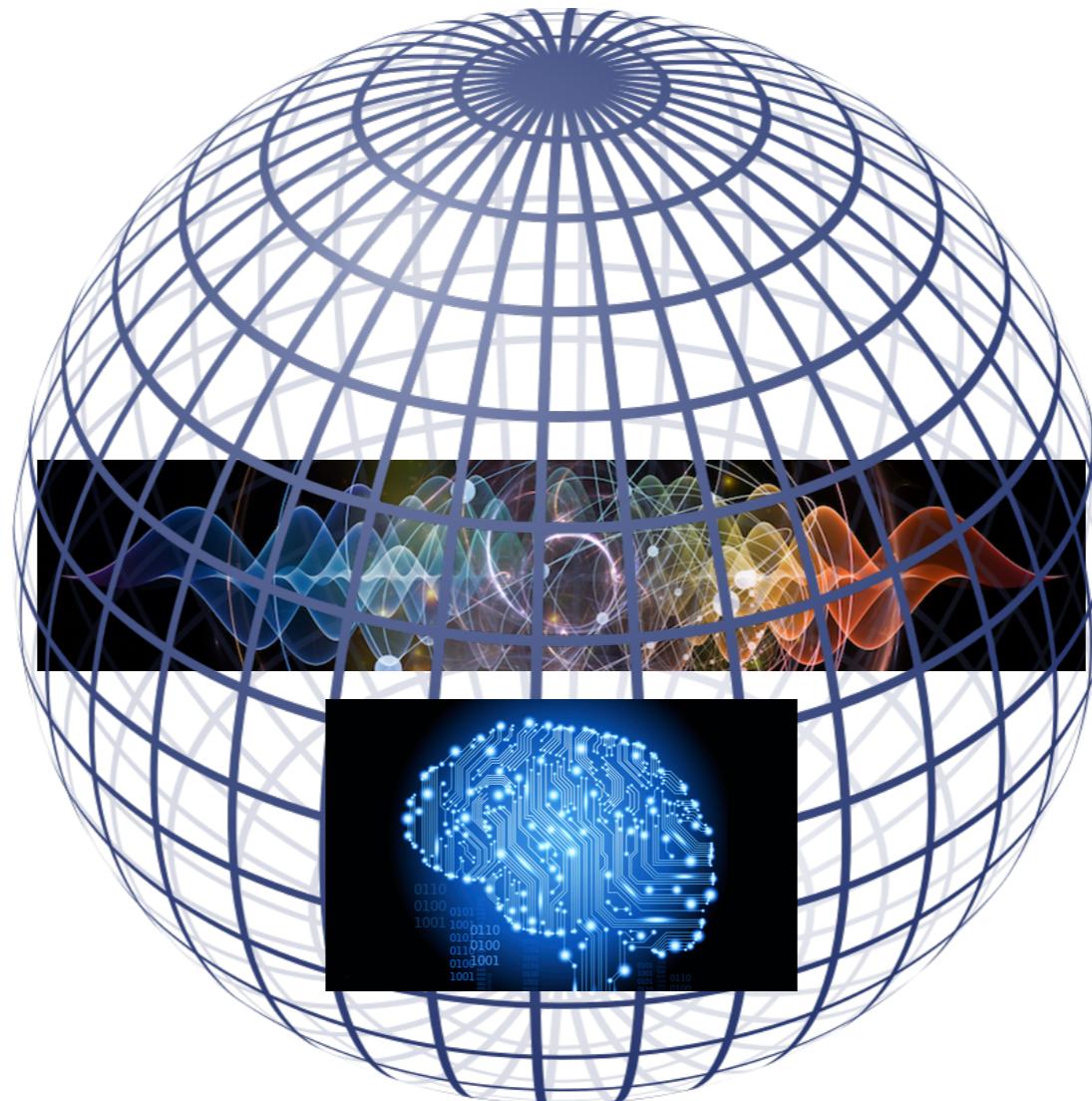
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Physics

Physics (φυσική) originates from the greek word, φύση, and it means the study of nature.

Newton 2nd Law of motion

$$F = ma$$

$$\frac{\partial p}{\partial t} = m \frac{\partial^2 x}{\partial t^2}$$

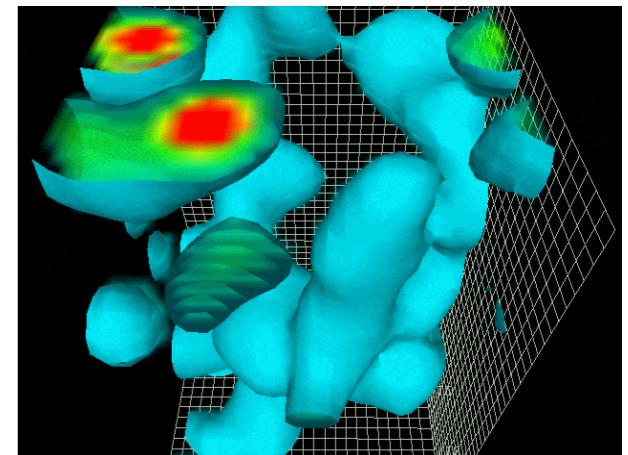


Quantum mechanics (Special Relativity)

Energy is a manifestation of matter

$$E = mc^2$$

Small world



Cosmology is the study of the smallest to largest objects



Electric force

$$F_{12} = k_e \frac{q_1 Q_2}{r_{12}^2}$$

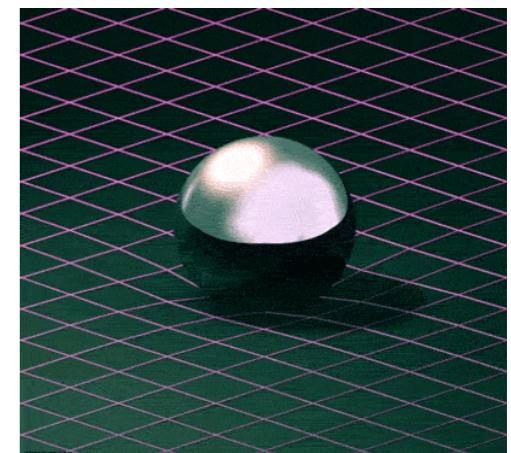


Gravity (General Relativity)

Geometry is a manifestation of Energy

$$G_{\mu\nu} \simeq E_{\mu\nu}$$

Large world

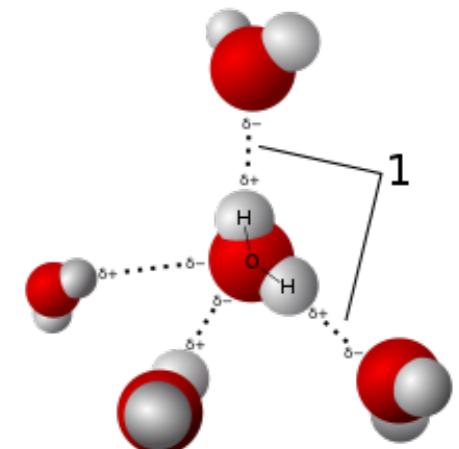


Physics; Cosmology

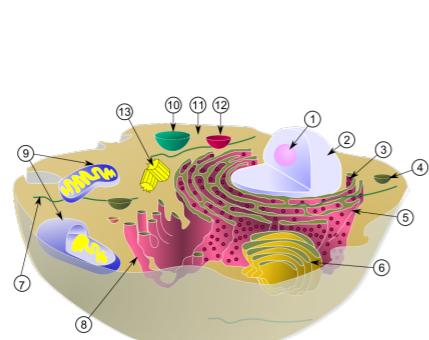
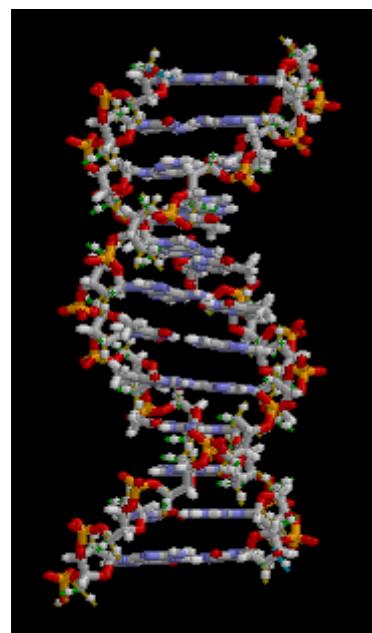
Biology

Biology (βιολογία) originates from the greek word, βίος, and it means the study life.

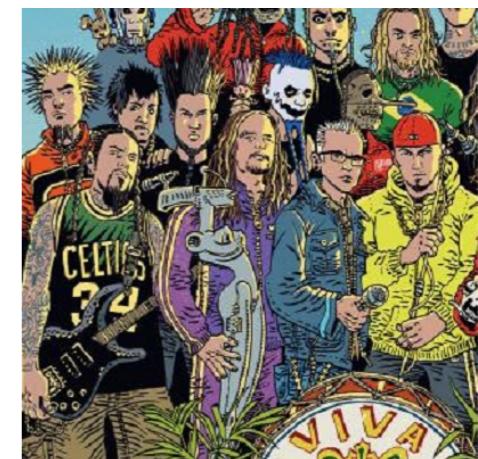
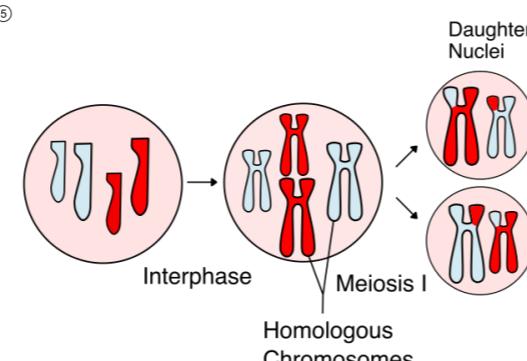
All organisms are made up of **chemical elements**; oxygen, carbon, hydrogen, and nitrogen (96% of the mass of all organisms)



Deoxyribonucleic Acid → cell → cell cycle → **plants and animals** → **humans**



cell:
membrane
nucleus
cytoplasm



Neuroscience

Neuroscience (νευροεπιστήμη), originates from the greek word, νεύρο, which means neuron

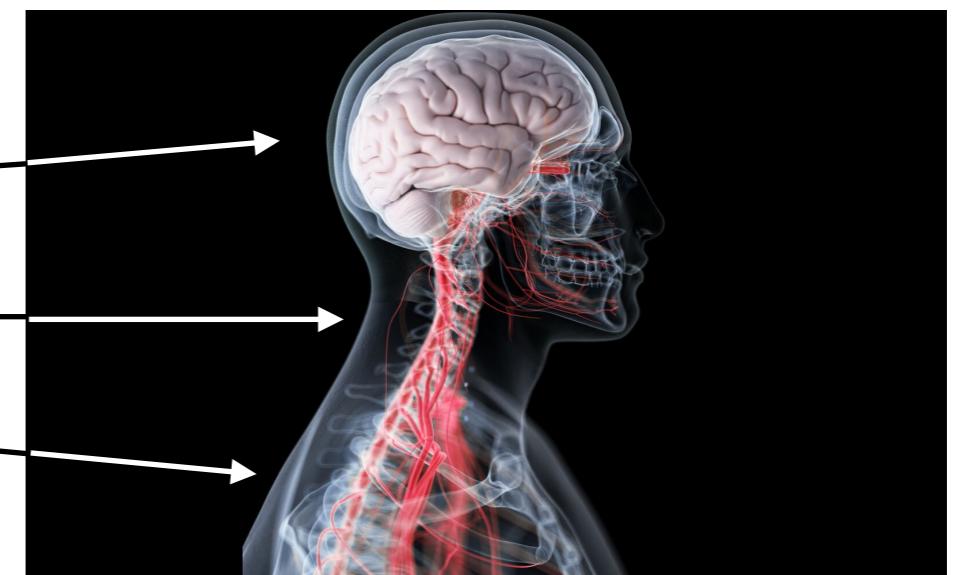
is **the study of the nervous system**, its development, its structure, and what it does.

The nervous system is composed of the

brain

spinal cord

peripheral nervous system



Neuroscience

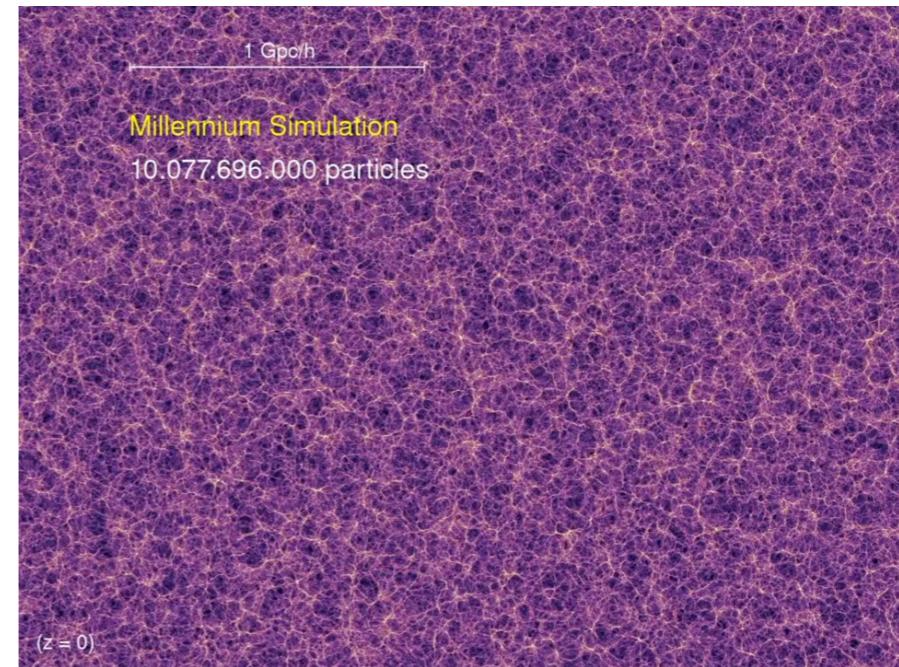


Neuroscience and cosmology

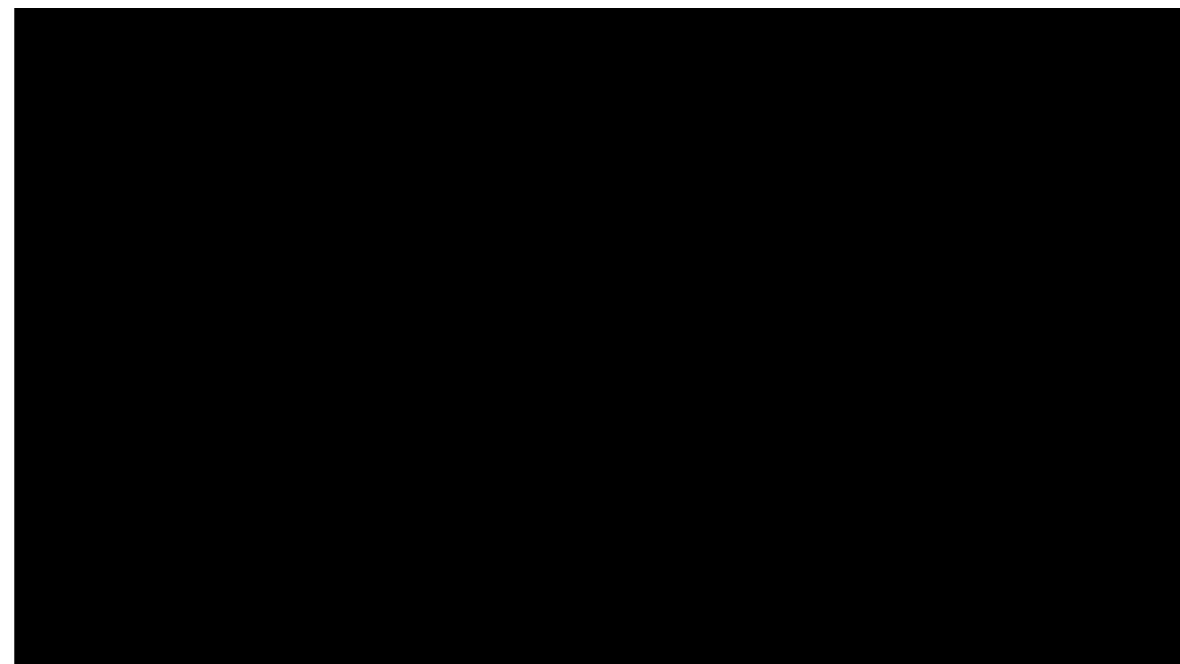
Brain neurons simulation



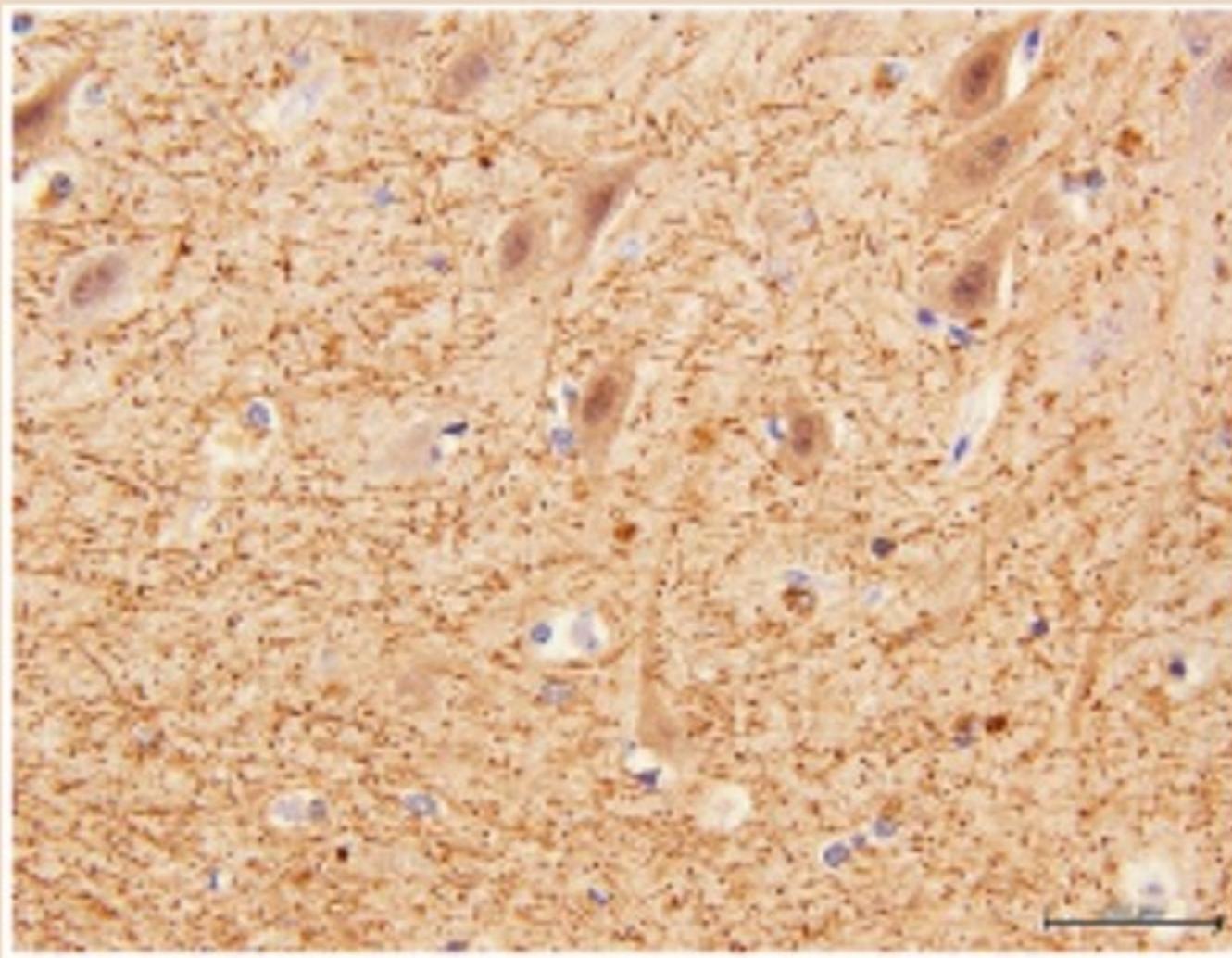
Dark matter simulation



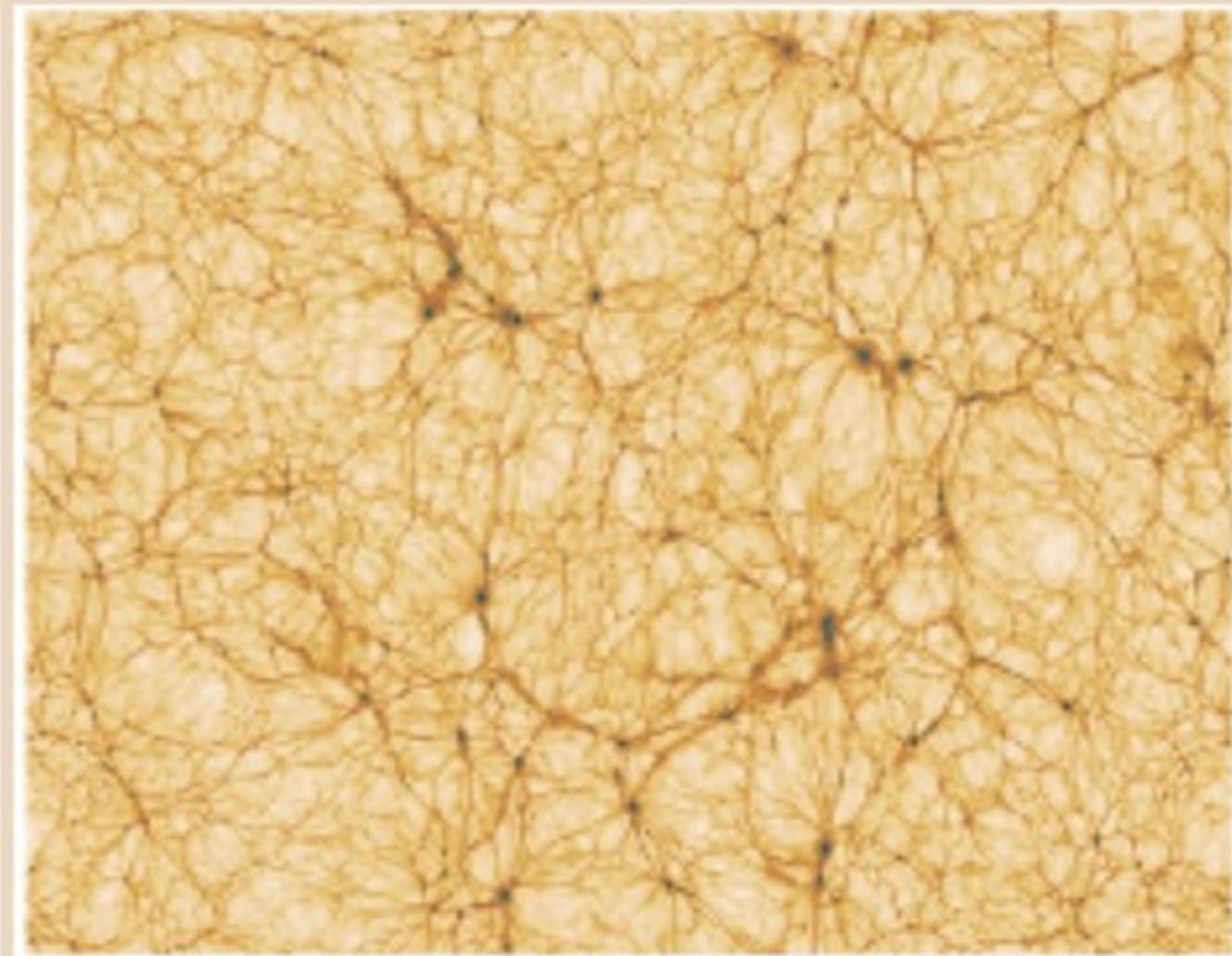
observed galaxies



Cosmology and Neuroscience => Cosmic Neuroscience



Brain cells



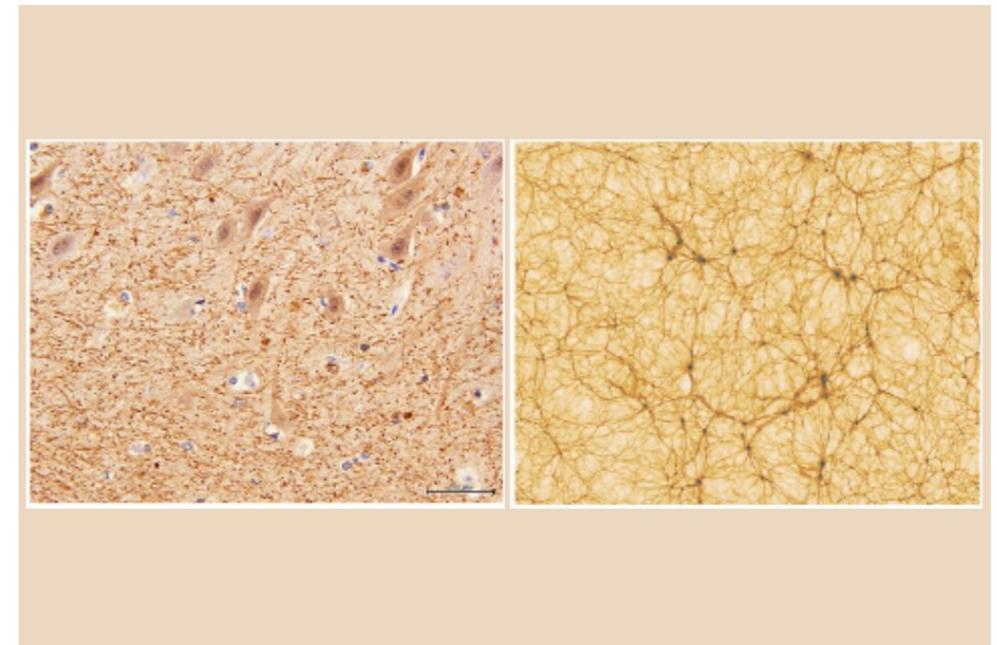
Galaxies

Cosmology and Neuroscience => Cosmoneuroscience

Despite difference in scale between the networks (>27 orders of magnitude)

Similarities discovered

	Human brain neurons	Observable universe galaxies
number of objects (in billions)	100	100



neurons and galaxies arrange themselves in **nodes** or long **filaments**

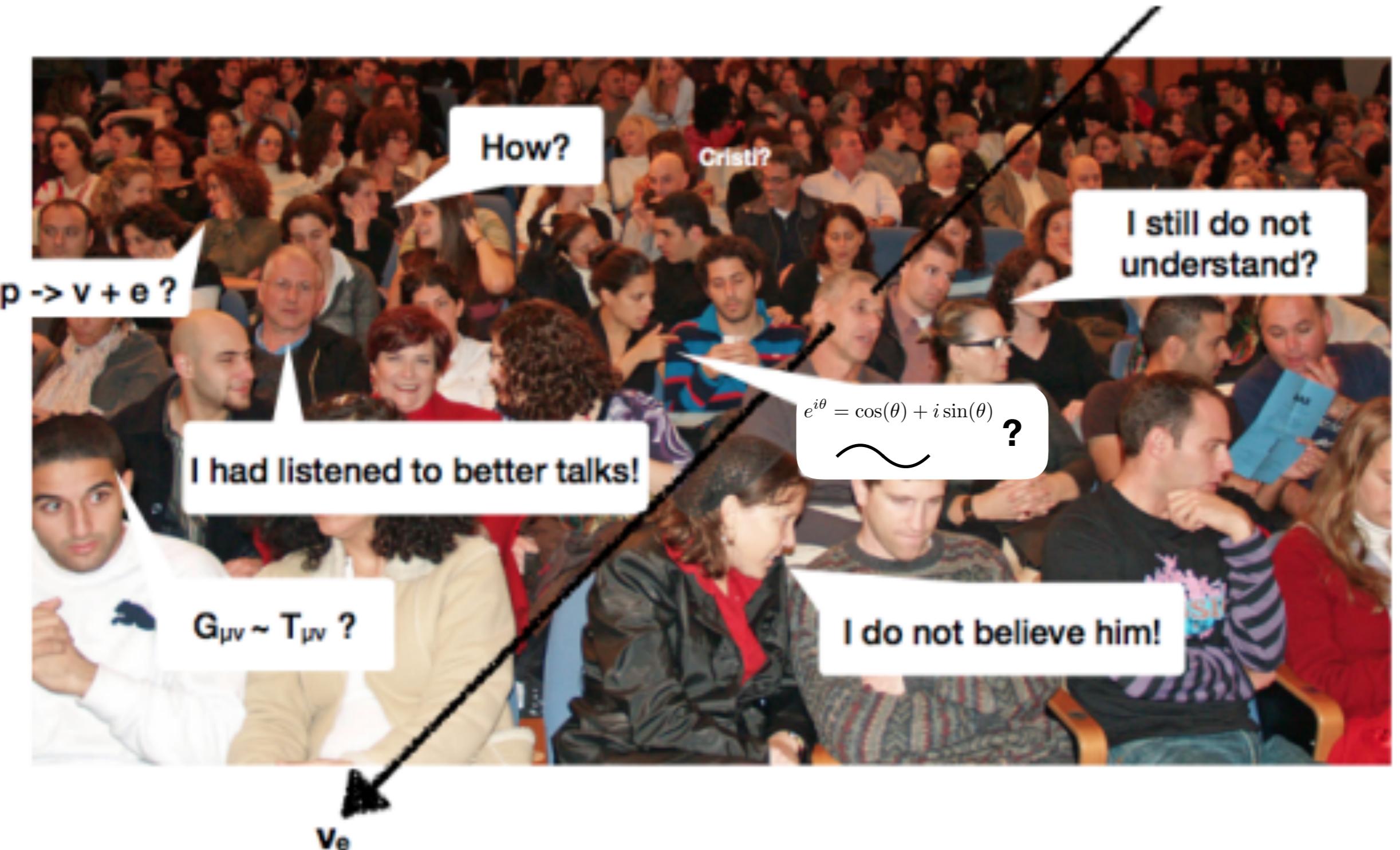
30% of their masses are composed of neurons or galaxies

70% of mass (or energy) is important passive role component:

water in the brain

dark energy in the observable Universe

Thank you for your attention!



Thank you for your attention!

After a short quiz let's Welcome 3 PhD student from

Institut de Neurosciences de la Timone

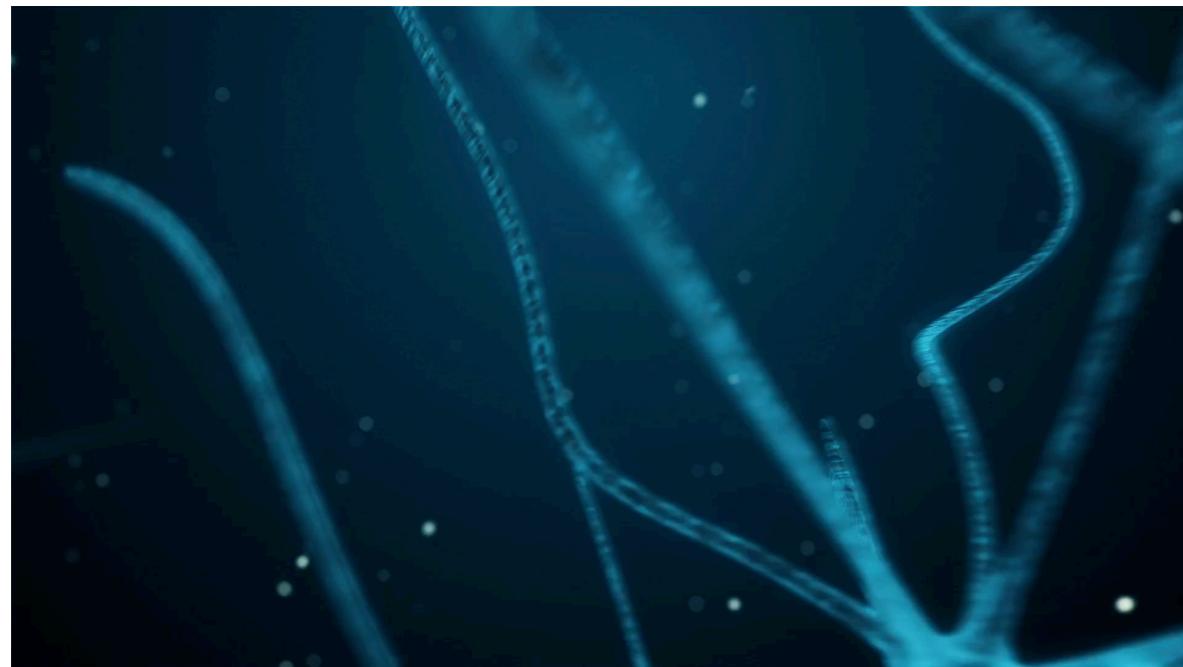


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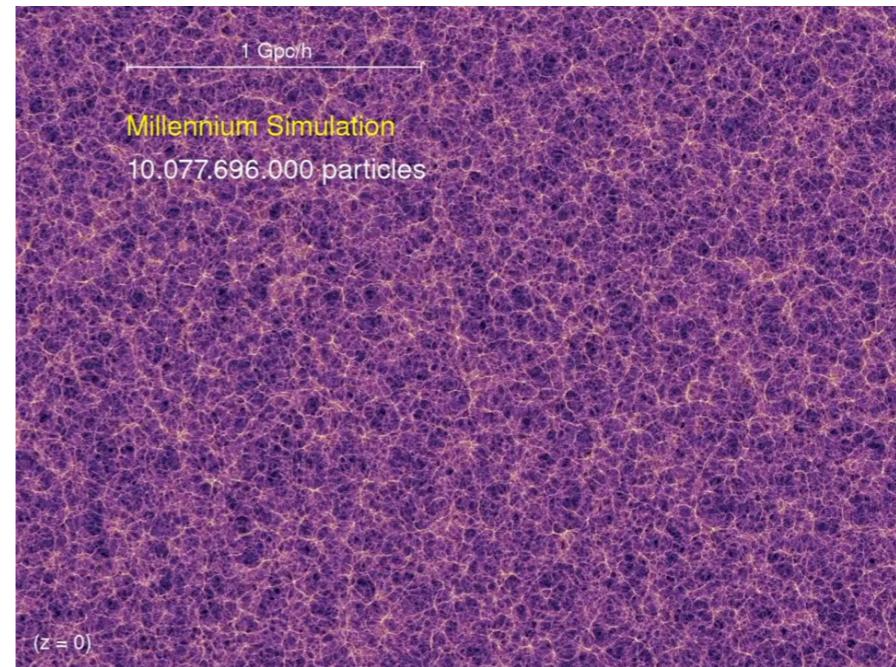
Back up

Typical sizes

Brain neurons simulation



Dark matter simulation



Human Brain neuron cell

cell body $100 \mu\text{m} \sim 0.1 \text{ mm} \sim 10^{-4} \text{ m}$

axon $1 \text{ m} \sim 1000 \text{ mm} \sim 10^0 \text{ m}$

Dark matter particles

nodes $100 \text{ Mpc} \sim 100 \text{ Million ly} \sim 10^{22} \text{ m}$

filaments $1 \text{ Gpc} \sim 10 \text{ Billion ly} \sim 10^{26} \text{ m}$

4 orders of magnitude between node and filament



Physics; Cosmology

1 Gpc/h

Millennium Simulation

10.077.696.000 particles

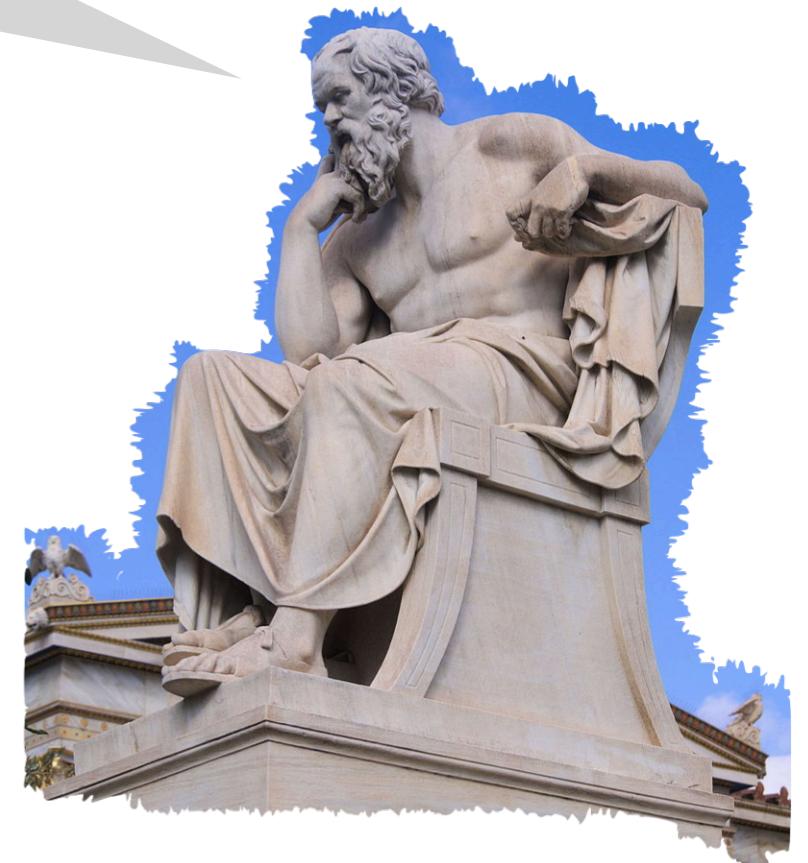
(z = 0)

Philosophy originates from the greek word, **φιλοσοφία**
Which is a compound word, composed by
The word **φιλο-**, **friendly**, and word, **-σοφία**, **wisdom**.
Ergo, philosophy means being friends with wisdom

Officially, modern Philosophy is the study of general and fundamental questions:

abstraction, existence, reason, knowledge, values, mind, and language.

Such questions are often posed as problems to be studied or resolved.



Cosmology and Neuroscience => Cosmoneuroscience

University of Bologna Astrophysicist

Franco Vazza

and

University of Verona neurosurgeon

Alberto Feletti

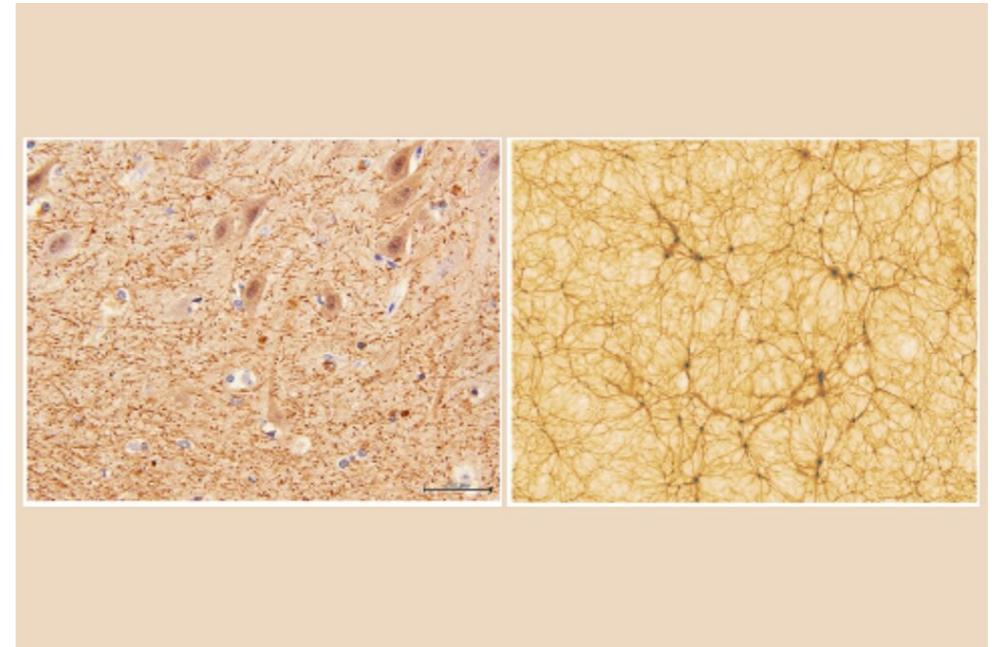
compared
network of neuronal cells in human brain
with
cosmic network of galaxies in universe

surprising similarities emerged

Despite difference in scale between the networks (>27 orders of magnitude)

they found:

diverse physical processes can build structures characterized by similar levels of complexity and self-organization in both structures



Mathematics

Mathematics (μαθηματικά) originates from the greek word, μάθημα, which means learning.

Axioms . / $1 \in \mathbb{N}, \pi \simeq 3.14 \in \mathbb{Q}', e^\pi \in \mathbb{R}, e^{i\pi} \in \mathbb{C}$ Numbers

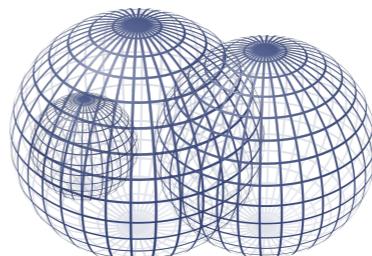
Functions $f(x) : \mathbb{R} \rightarrow \mathbb{R}^+$ $(a \pm b)^2 = a^2 \pm 2ab + b^2$ Algebra

$f'(x) = \frac{\partial f}{\partial x}$



Geometry

$f''(x) = \frac{\partial^2 f}{\partial x^2}$



Sets

Derivatives $\dots = \dots$

$f^{(n)}(x) = \frac{\partial^n f}{\partial x^n}$ $f'(x) = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x)}{h}$ Limits

Integrals $F(x) = \int_0^x f(s)ds$ $P(x; \mu, \sigma) \propto e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2}$ Probabilities

Statistics $\lim_{s \rightarrow +\infty} \int_{-s}^{+s} dx P(x) = 1$ $a^2 + b^2 + c^2 = d^2$ Theorems

with proofs !

Mathematics

Hypothesis testing => least square method

$$\chi^2 = \sum_{i=1}^N \left(\frac{O_i - E_i}{U_i} \right)^2$$

↑ ↓
Observation Uncertainty
 ↑ ↓
Number of observations Expectation

ndf = Number of degrees of freedom
= Number of data - number of expectation parameters

Conditions of the test:

Finally Calculate

$$\chi_\nu^2 = \frac{\chi^2}{ndf}$$

- | | |
|------------------|-----------------|
| $\chi_\nu^2 < 1$ | Underestimation |
| $\chi_\nu^2 = 1$ | Good fit |
| $\chi_\nu^2 > 1$ | Overestimation |

Mathematics

Hypothesis testing => least square method

Numerical example

Given the observations

$$x_i \in (x_1, x_2, x_3) = (1.0, 2.0, 3.0)$$

$$O_i \in (O_1, O_2, O_3) = (2.8, 5.2, 6.5)$$

$$U_i \in (U_1, U_2, U_3) = (0.8, 0.4, 0.6)$$

and a model

$$y = a x + b$$

Perform a least square method

Guess $a = 2$ and $b = 1$

$$y_i \in (y_1, y_2, y_3)$$

$$y_1 = 2 \times 1 + 1 = 3$$

$$y_2 = 2 \times 2 + 1 = 5$$

$$y_3 = 2 \times 3 + 1 = 7$$

$$y_i \in (y_1, y_2, y_3) = (3, 5, 7)$$

$$\begin{aligned}\chi^2 &= \sum_{i=1}^3 \left(\frac{O_i - E_i}{U_i} \right)^3 \\ &= \left(\frac{O_1 - E_1}{U_1} \right)^2 + \left(\frac{O_2 - E_2}{U_2} \right)^2 + \left(\frac{O_3 - E_3}{U_3} \right)^2 \\ &= \left(\frac{2.8 - 3}{0.8} \right)^2 + \left(\frac{5.2 - 5}{0.4} \right)^2 + \left(\frac{6.5 - 7}{0.6} \right)^2 \\ &= 1.01\end{aligned}$$

$$\text{ndf} = 3 - 2 = 1$$

Mathematics

Hypothesis testing => least square method

Numerical example

Given the observations

$$x_i \in (x_1, x_2, x_3) = (1.0, 2.0, 3.0)$$

and a model

$$y = a x + b$$

$$O_i \in (O_1, O_2, O_3) = (2.8, 5.2, 6.5)$$

$$U_i \in (U_1, U_2, U_3) = (0.8, 0.4, 0.6)$$

Perform a least square method

Repeat for different a,b guesses
until you find the chi2 which is closer to the ndf.

the conditions

$$\chi_{\nu}^2 < 1 \text{ Underestimation}$$

$$\chi_{\nu}^2 = 1 \text{ Good fit}$$

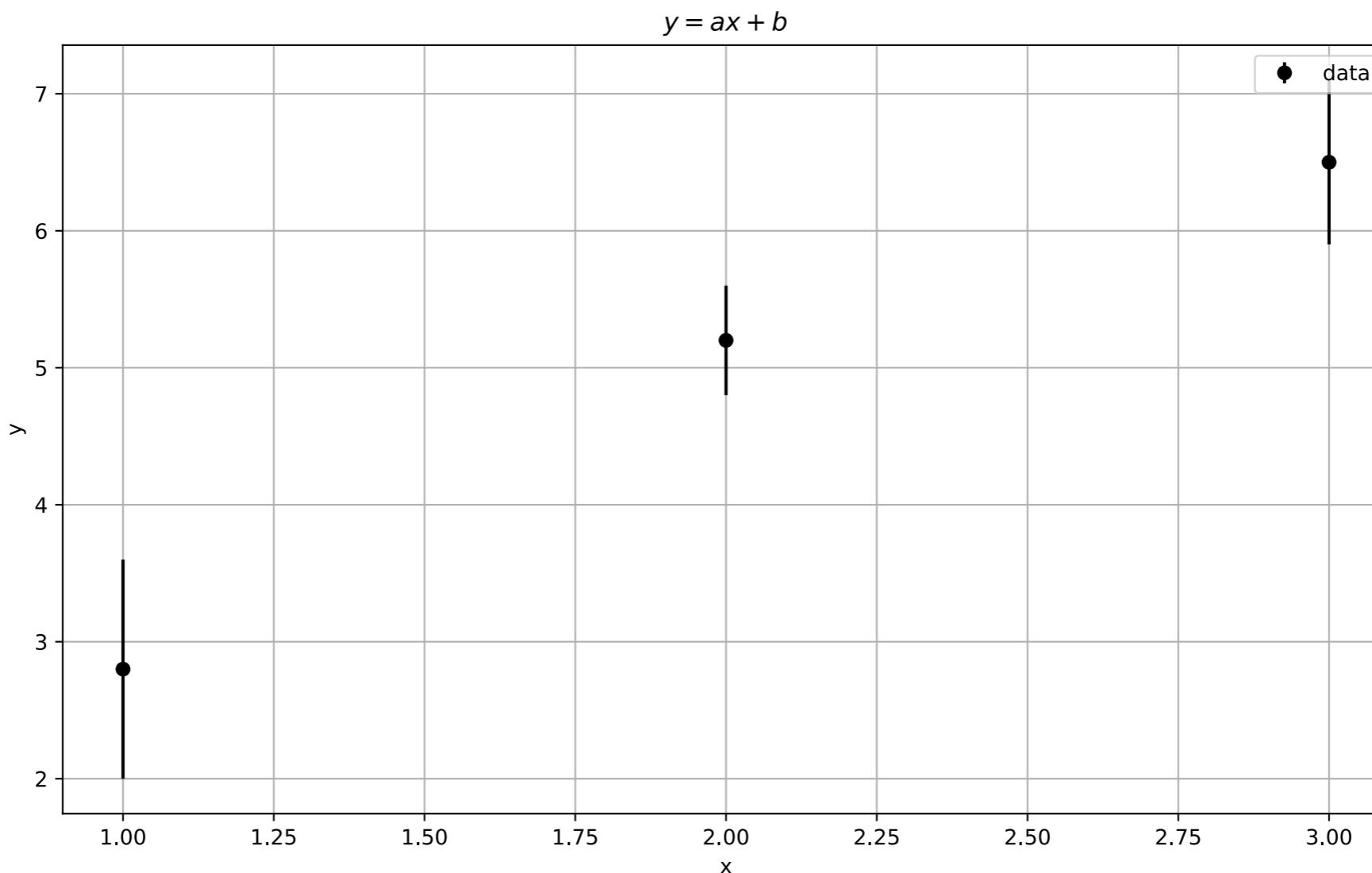
$$\chi_{\nu}^2 > 1 \text{ Overestimation}$$

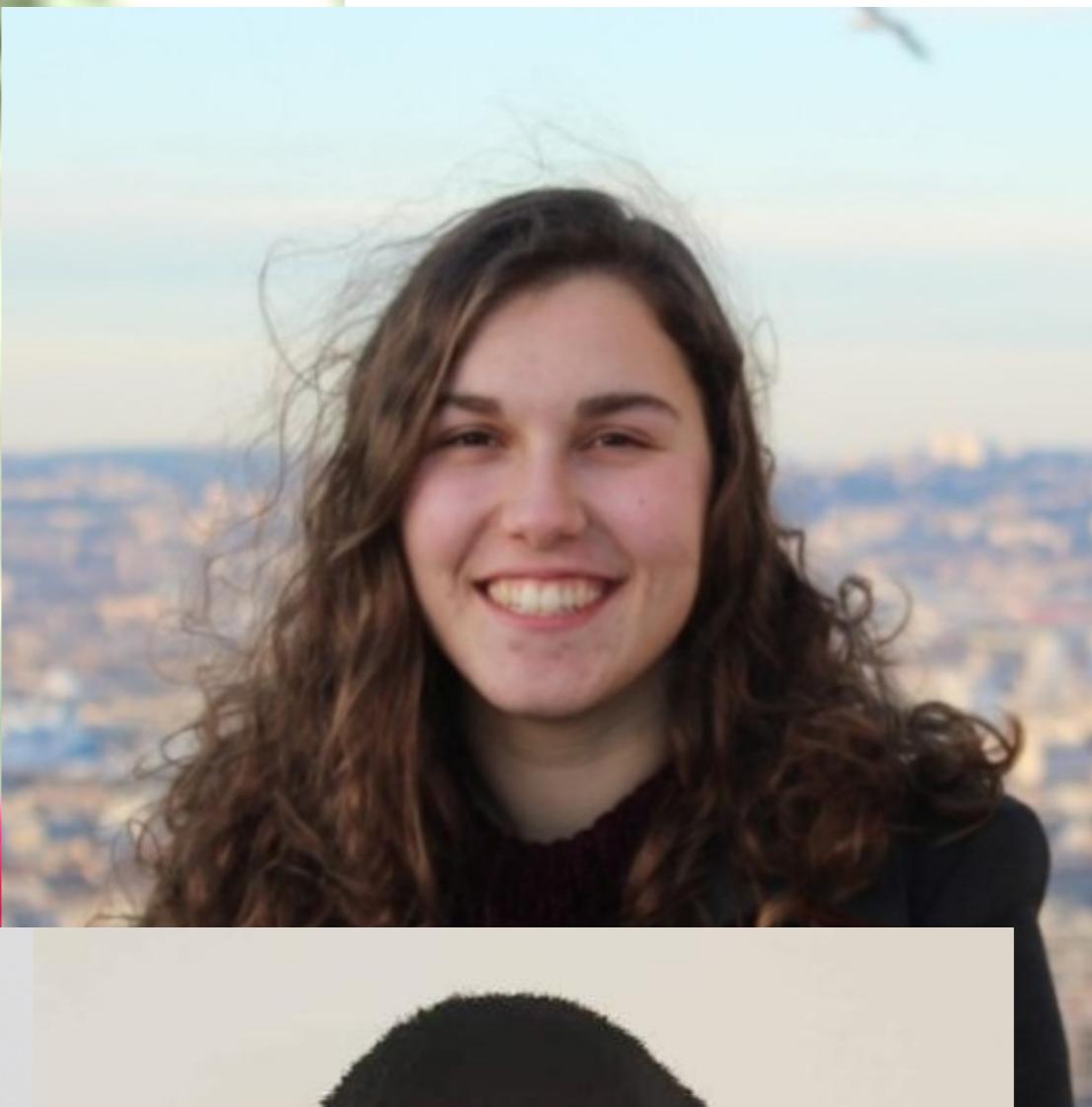
will tell you if you did a good job

Mathematics

Hypothesis testing => least square method

Numerical example

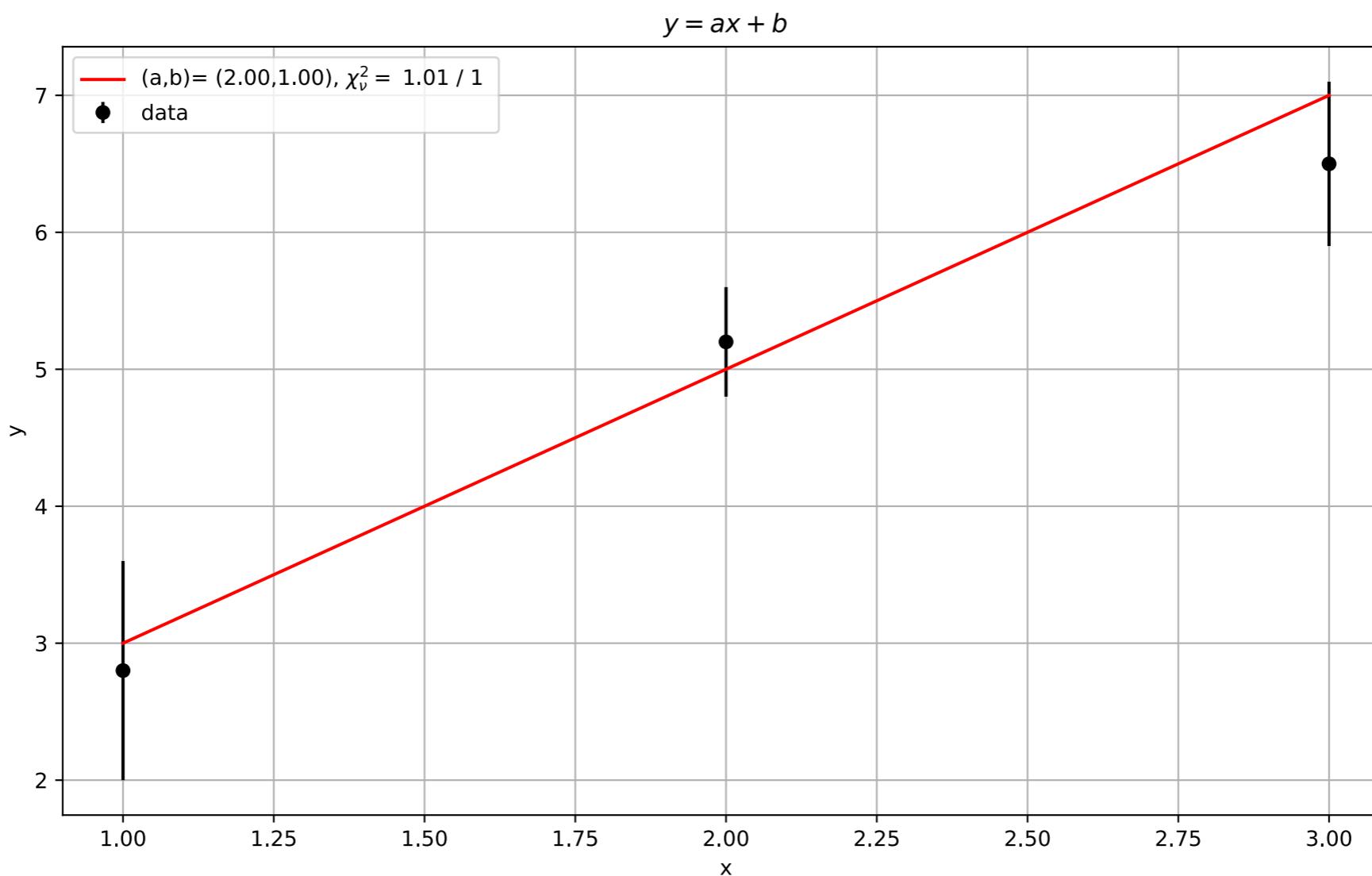




Mathematics

Hypothesis testing => least square method

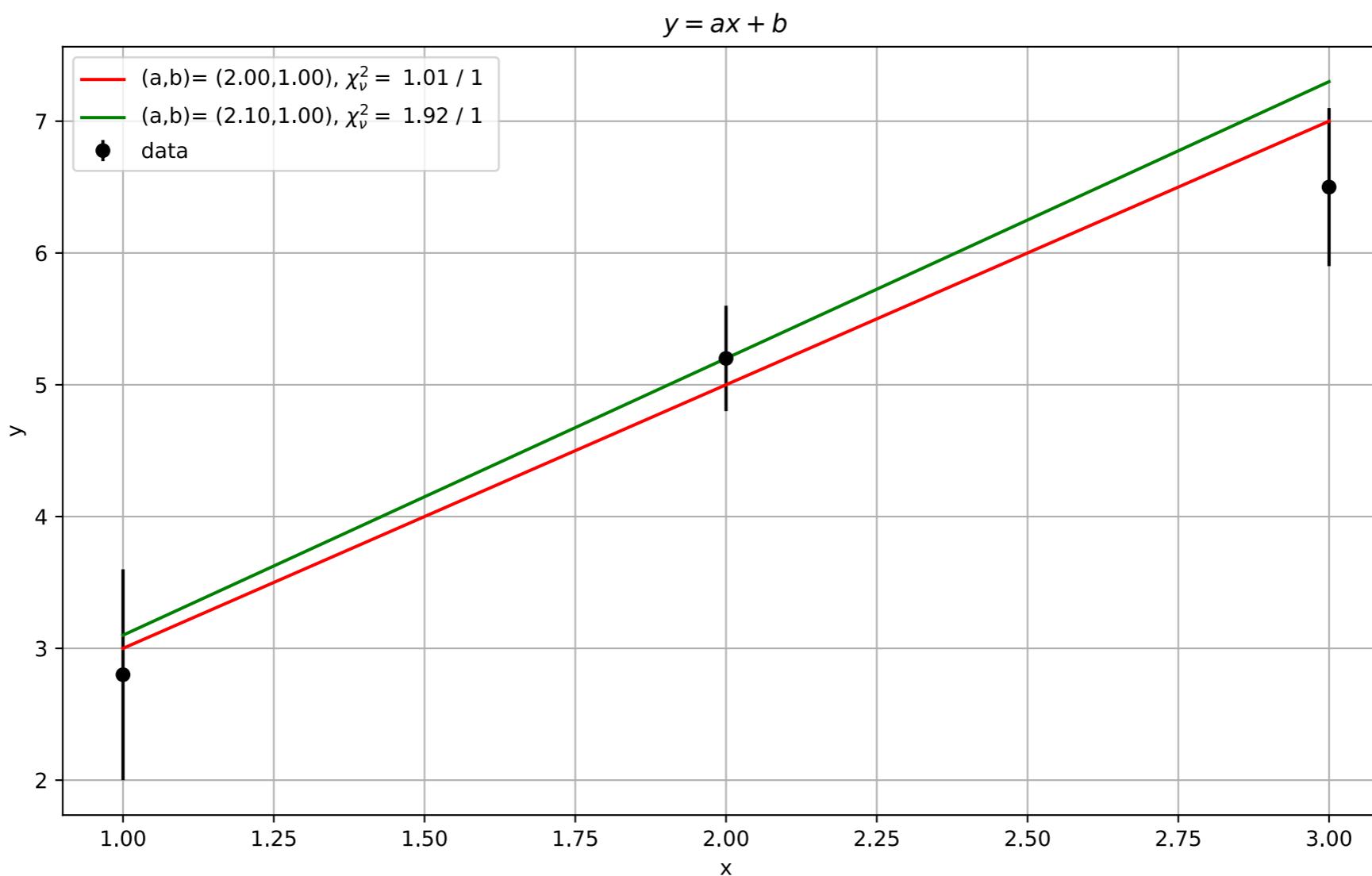
Numerical example



Mathematics

Hypothesis testing => least square method

Numerical example



Mathematics

Hypothesis testing => least square method

Numerical example

