On the Origin of the Universe: Chaos or Cosmos?

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Athens, 11 June 2021

Abstract

I would like to consider the Universe according to the standard Big Bang model, including various quantum models of its origin. In addition, using the theory of nonlinear dynamics, deterministic chaos, fractals, and multifractals I have proposed a new hypothesis (Macek, 2020). Namely, I have argued that a simple but possibly *nonlinear* law is important for the creation of the Cosmos at the extremely small Planck scale at which space and time originated. It is shown that by looking for order and harmony in the complex real world surrounding us these modern studies give new insight into the most important philosophical issues beyond classical ontological principles, e.g., by providing a deeper understanding of the age-old philosophical dilemma (Leibniz, 1714): *why does something exist instead of nothing?* We also argue that this exciting question is a philosophical basis of matters that influence the meaning of human life in the vast Universe.

Keywords: Chaos, Cosmos, Universe, Creation

Plan of Presentation

1. Introduction
2. The Universe in Modern Science
   - The Geometry of Spacetime
   - The Big Bang Model
   - The Standard Model of Elementary Forces
   - Quantum Models for the Creation of the Universe
   - String Theory
3. Nonlinear Dynamics and Fractals
   - Deterministic Chaos
   - Rayleigh-Bénard Convection and the Lorenz Model
   - Hyperchaotic Convection
   - The Generalized Lorenz Model for a Magnetized Fluid
   - Possible Applications
   - Fractals and Multifractals
4. Implications for Cosmology and the Creation of the Universe
5. Conclusions
6. Epilogue

Introduction

In science evolution the Universe is based on the Big Bang model, which has now become a standard scenario. However, very little is known about the early stages of this evolution, where we should rely on some models, because the required quantum gravity theory is still missing.

On the other hand, creation of the World is usually an important issue of philosophy. Hence, one should return to great philosophers starting from the Greeks asking the questions about the origin of existence of the world.

- Plato's creation: a Demiurg transformed an initial chaotic stuff into the ordered Cosmos

- Aristotle's universe is eternal: the world always existed, but needed the (atemporal?) First Mover or First Cause

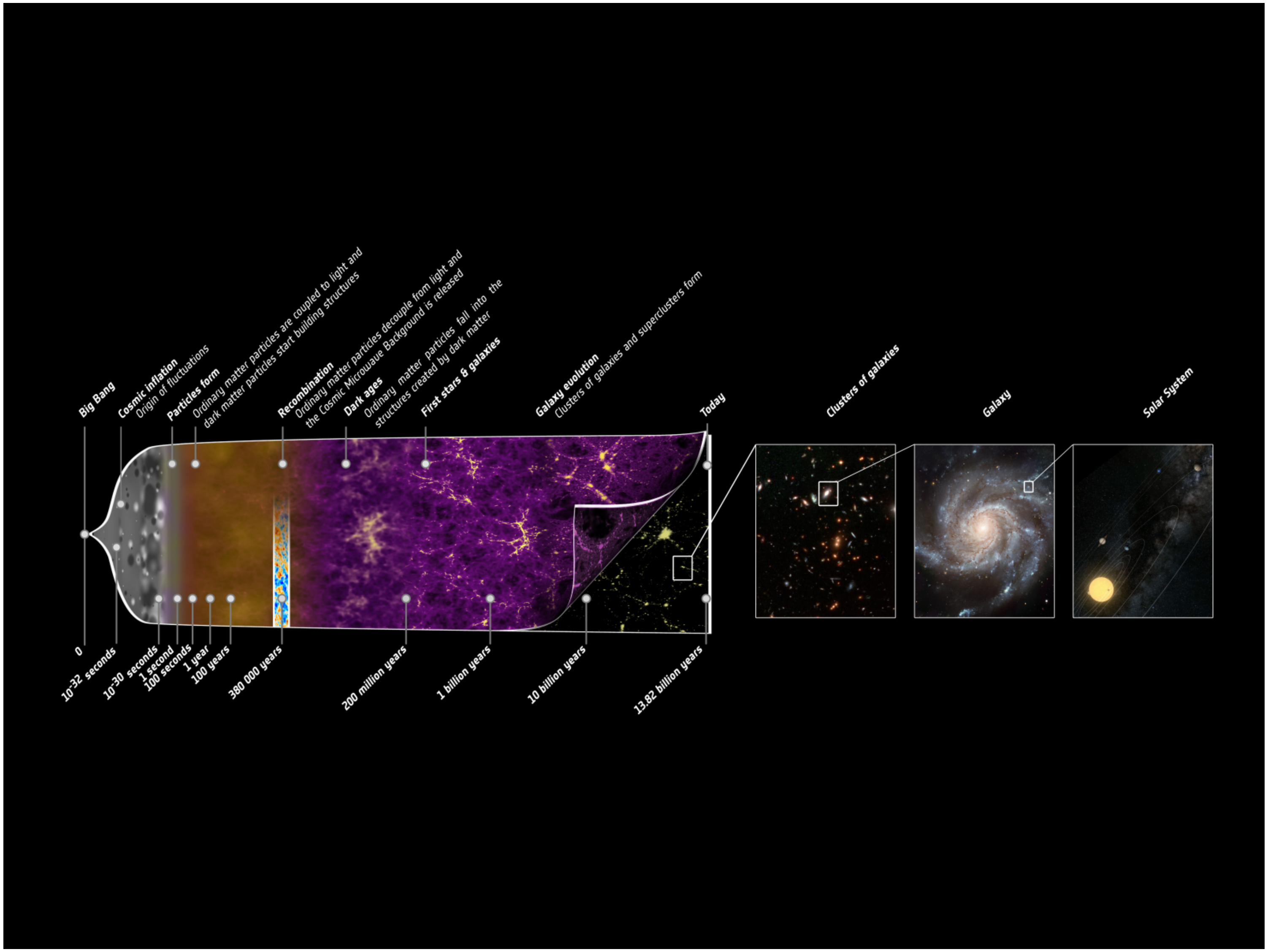
In this paper, I would like to consider the origin of the Universe in view of the modern science, including quantum models of creation, and recent theory of nonlinear dynamics, deterministic chaos, and fractals. We hope that these modern studies give also new insight into the most important philosophical issues exceeding the classical ontological principles, e.g., providing a deeper understanding of an old philosophical question:

Why does something exist instead of nothing?

Gottfried Wilhelm von Leibniz (1646–1716)

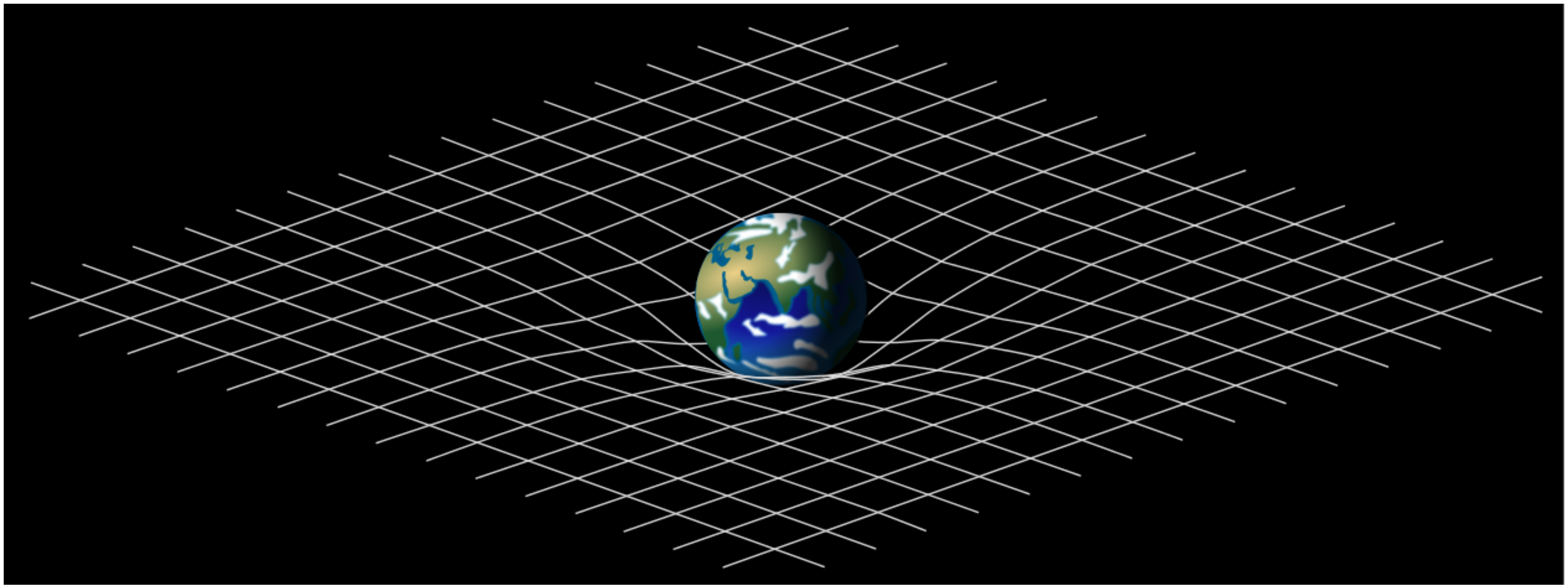
Chaos is the score on which reality is written.

Henry Miller (1891–1980)



History of the Universe based on Planck mission, NASA, 2009.

Spacetime in General Theory of Relativity



- Gravitation and spacetime geometry (Riemann)
- Mass (energy) tells spacetime geometry about its curvature;
- Curved spacetime tells the mass how to move.

Gravitational Waves

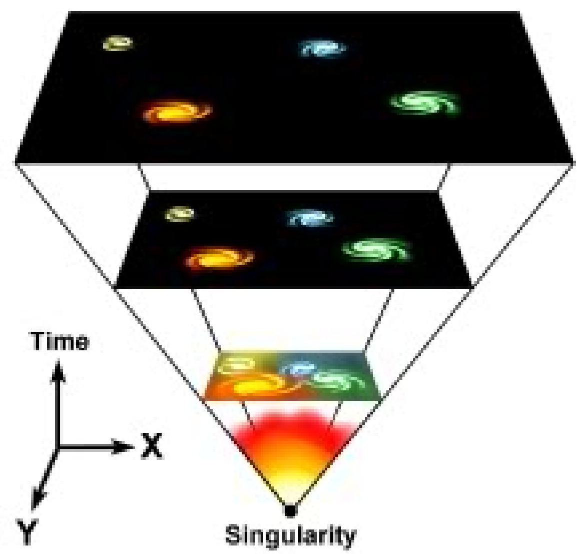
The generation of gravitational waves (LIGO, 2016) during the merger of two massive black holes ($\sim$30 Sun's masses).

Evolution of the Universe in Modern Science

According to the Big Bang model, the Universe expanded from an extremely dense and hot state and continues to expand today.

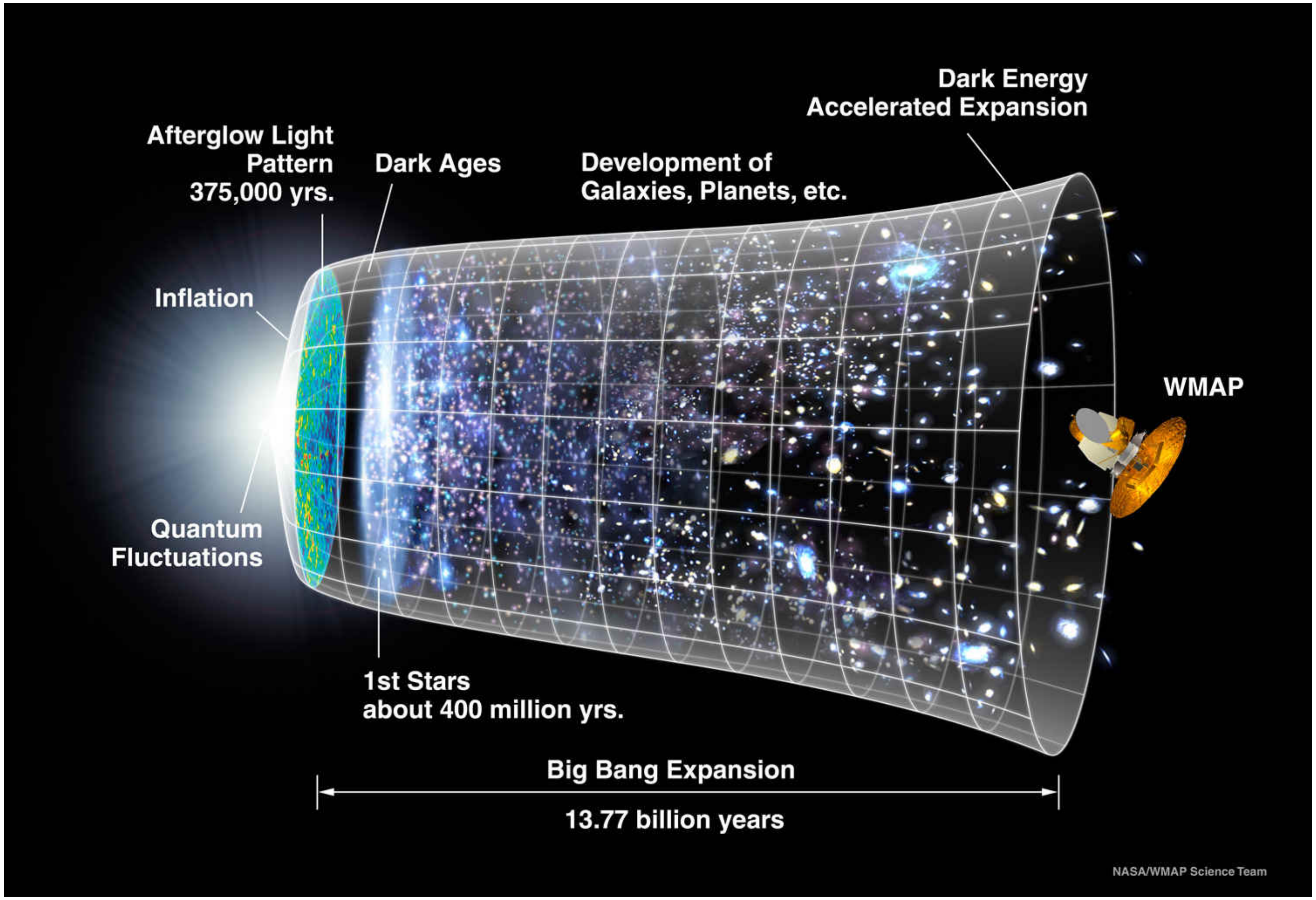
A common analogy explains that space itself is expanding, carrying galaxies with it, like spots on an inflating balloon.

The graphic scheme here is an artist's concept illustrating the expansion of a portion of a simple model of the flat Universe with two space dimensions.



The expanding Universe.

The Big Bang Model



Schematic of the evolution of the Universe, Credit: NASA / WMAP Science Team.

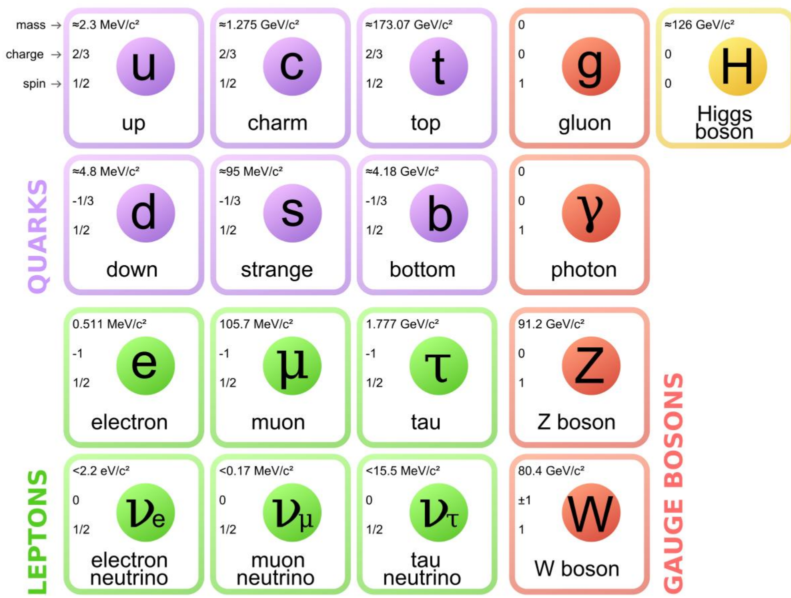
A representation of the evolution of the universe around 13.77$\pm$0.06 billion years, when the Big Bang occured. This was possibly followed by ‘inflation’, producing a burst of exponential growth in the size of the Universe. The far left depicts the earliest moment we can now probe: size is depicted by the vertical extent of the grid in this graphic.

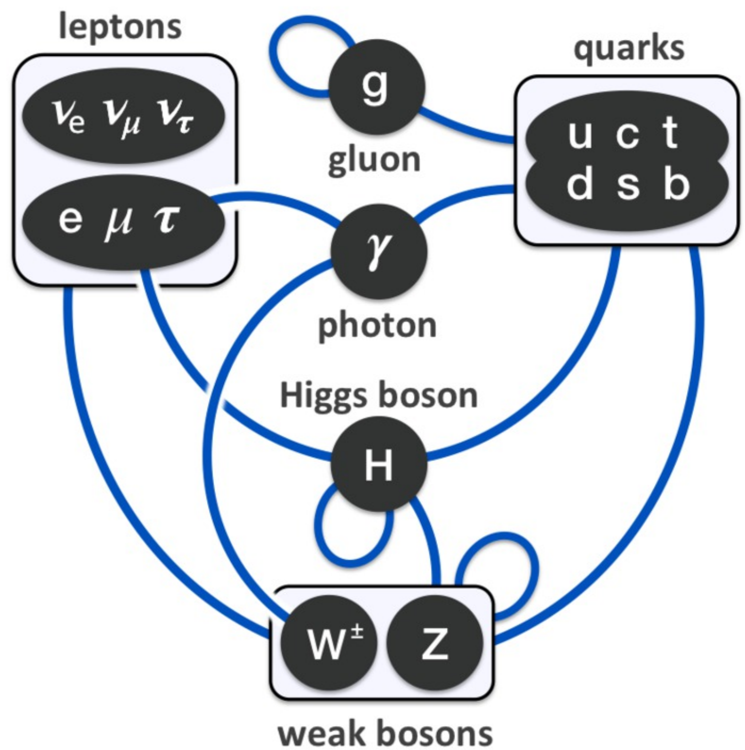
For the next several billion years, the expansion of the universe gradually slowed as the matter in the Universe pulled on itself by gravity. More recently, the expansion has begun to speed up again, as the repulsive effects of **dark energy** have come to dominate the expansion of the Universe.

The afterglow light seen by WMAP (Wilkinson Microwave Anisotropy Probe) was emitted about 375,000 years after inflation and has traversed the Universe largely unimpeded since then. The conditions of earlier times are imprinted on this light; it also forms a backlight for later developments of the Universe.

The Standard Model

Elementary Particles

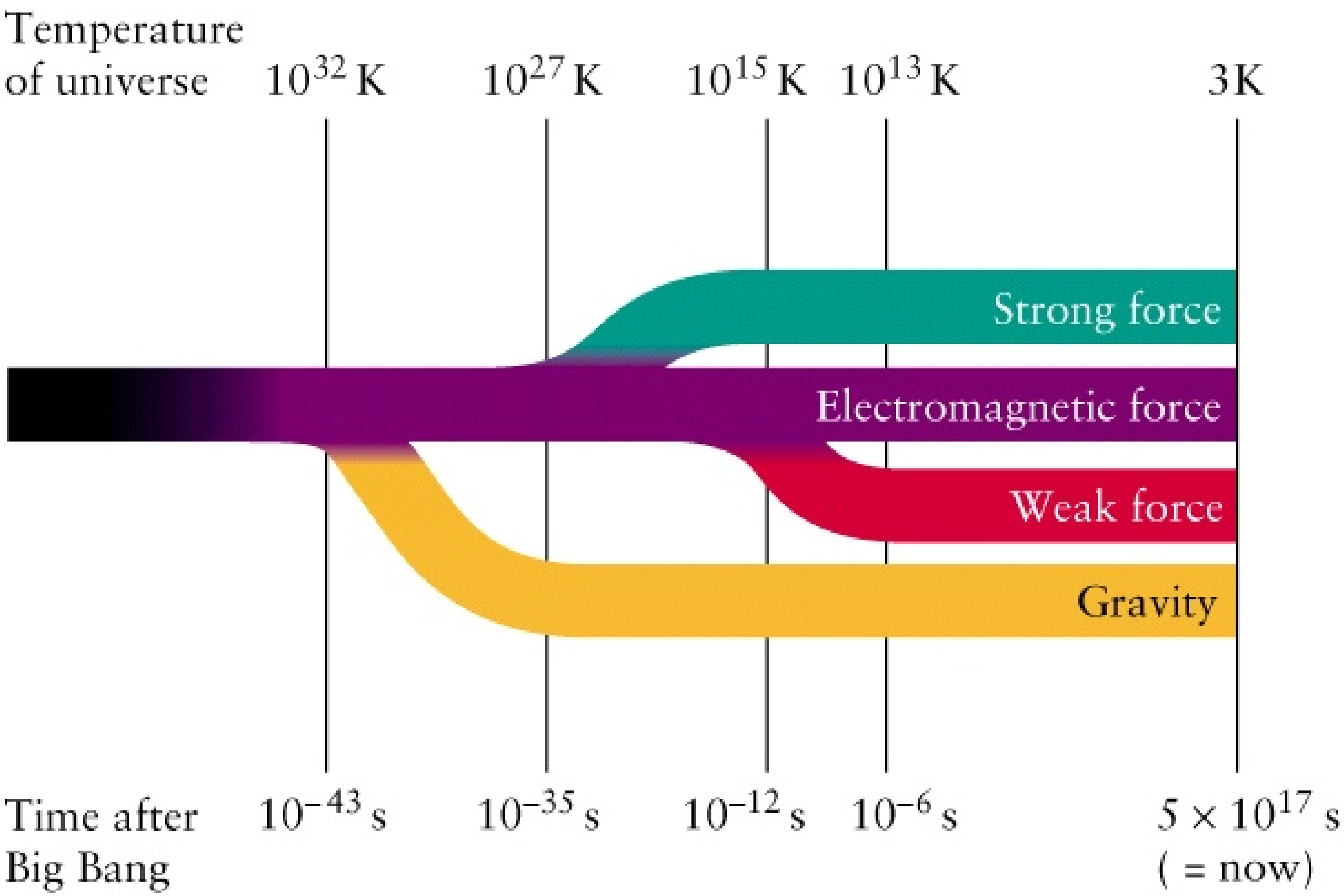




Three generations of particles, with gauge bosons in the fourth column and the Higgs boson in the fifth.

A summary of interactions between particles.

The Birth and Evolution of the Universe



Great Unification Theory of elementary forces and the evolution of the Universe.

Models for the Creation of the Universe

- The quantum model (Hartle & Hawking, 1983)
  creation from 'nothing', ex nihilo

- Noncommutative geometry (Heller & Sasin, 1996)
  beginning is everywhere

- String theory (M-theory, Witten, 1995)
  collision of branes

- Cyclic (*ekpyrotic*) model (Steinhardt & Turok, 2002)
  big bangs and crunches

- Eternal chaotic inflation (Linde, 1986)
  bubble of universes

Deterministic Chaos

CHAOS (χάος) is (Strogatz, 1994)

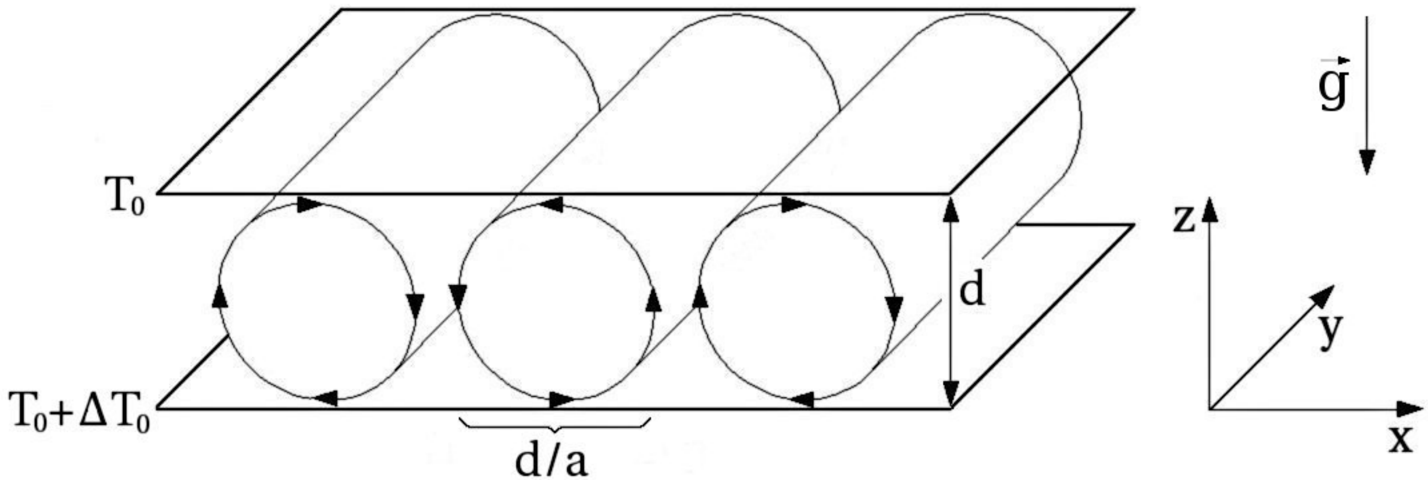
- NON-PERIODIC long-term behavior
- in a DETERMINISTIC system
- that exhibits SENSITIVITY TO INITIAL CONDITIONS.

We say that a bounded solution $\mathbf{x}(t)$ of a given dynamical system is SENSITIVE TO INITIAL CONDITIONS if there is a finite fixed distance $d > 0$ such that for any neighborhood $\|\Delta\mathbf{x}(0)\| < \delta$, where $\delta > 0$, there exists (at least one) other solution $\mathbf{x}(t)$ + $\Delta\mathbf{x}(t)$ for which for some time $t \geq 0$ we have $\|\Delta\mathbf{x}(t)\| \geq d$.

There is a fixed distance d such that no matter how precisely one specify an initial state there is a nearby state (at least one) that gets a distance r away.

Given $\mathbf{x}(\mathbf{t}) = \{x_1(t), \ldots, x_n(t)\}$ any positive finite value of Lyapunov exponents $\lambda_k = \lim_{t\to\infty} \frac{1}{t} \ln \left| \frac{\Delta x_k(t)}{\Delta x_k(0)} \right|$, where $k = 1, \ldots n$, implies chaos.

Rayleigh-Bénard Convection



Navier-Stokes equation $$\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla p + \nu\,\Delta\mathbf{v} + \mathbf{g},$$

Heat conduction equation $$\frac{\mathrm{d}T}{\mathrm{d}t} = \kappa\,\Delta T,$$

Continuity equation $$\nabla\cdot\mathbf{v} = 0.$$

Deterministic Nonperiodic Flow[1]

EDWARD N. LORENZ

Massachusetts Institute of Technology

(Manuscript received 18 November 1962, in revised form 7 January 1963)

ABSTRACT

Finite systems of deterministic ordinary nonlinear differential equations may be designed to represent forced dissipative hydrodynamic flow. Solutions of these equations can be identified with trajectories in phase space. For those systems with bounded solutions, it is found that nonperiodic solutions are ordinarily unstable with respect to small modifications, so that slightly differing initial states can evolve into considerably different states. Systems with bounded solutions are shown to possess bounded numerical solutions.

A simple system representing cellular convection is solved numerically. All of the solutions are found to be unstable, and almost all of them are nonperiodic.

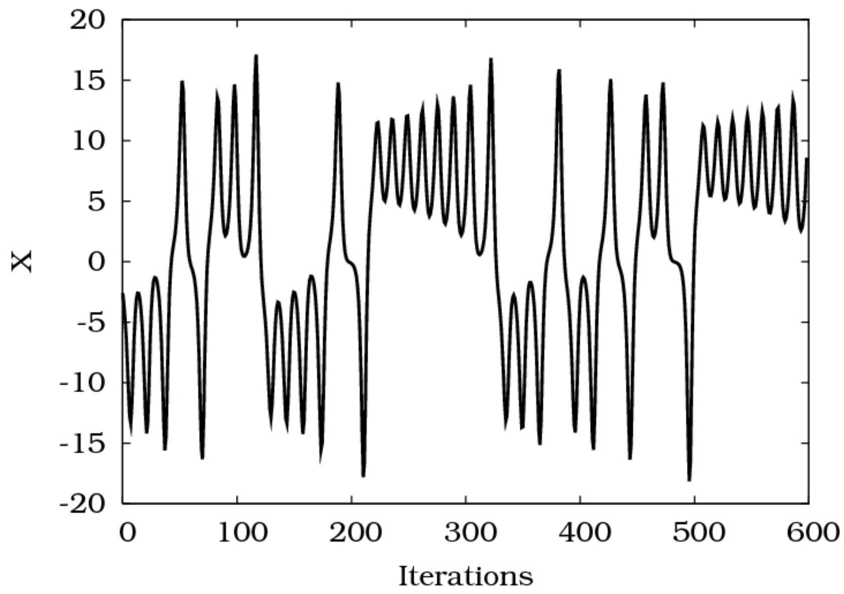
The feasibility of very-long-range weather prediction is examined in the light of these results.

The Lorenz Model

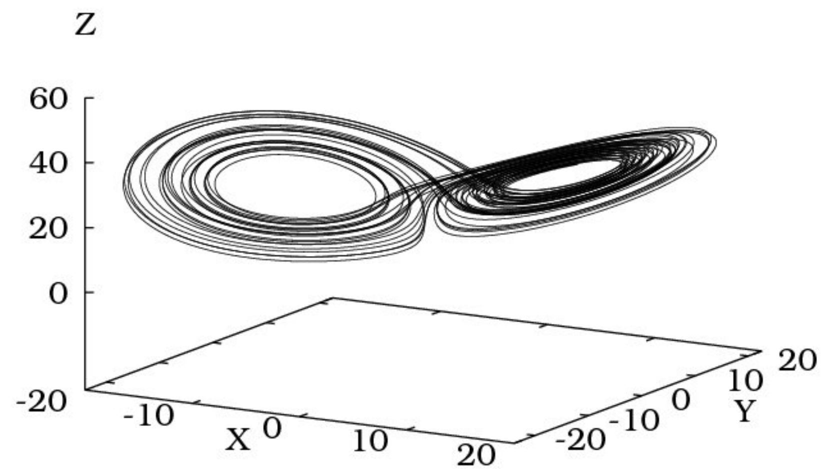
$$\dot{X} = \sigma(Y - X)$$
$$\dot{Y} = -XZ + rX - Y$$
$$\dot{Z} = XY - bZ$$

Parameters:
$r = 28$, $\sigma = 10$, $b = 8/3$

Time series for X



Attractor



Hydromagnetic Convection

Dynamics of irregular flows in viscous magnetofluids is still not sufficiently well understood. Our published papers sheds light on hydromagnetic convection.

- Macek W. M., Strumik, M., Model for hydromagnetic convection in a magnetized fluid, Physical Review E **82**, 027301, 2010, doi = 10.1103/PhysRevE.82.027301.

- Macek, W. M., Strumik, M., Hyperchaotic intermittent convection in a magnetized viscous fluid, Physical Review Letters **112**, 074502, 2014. doi: 10.1103/PhysRevLett.112.074502, http://link.aps.org/abstract/PRL/v112/e074502.

- Macek, W. M., Nonlinear Dynamics and Complexity in the Generalized Lorenz System. *Nonlinear Dynamics*, 94: 2957–2968, 2018. ISSN 0924-090X, https://doi.org/10.1007/s11071-018-4536-z.

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Hyperchaotic Intermittent Convection in a Magnetized Viscous Fluid

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We consider a low-dimensional model of convection in a horizontally magnetized layer of a viscous fluid heated from below. We analyze in detail the stability of hydrodynamic convection for a wide range of two control parameters. Namely, when changing the initially applied temperature difference or magnetic field strength, one can see transitions from regular to irregular long-term behavior of the system, switching between chaotic, periodic, and equilibrium asymptotic solutions. It is worth noting that owing to the induced magnetic field a transition to hyperchaotic dynamics is possible for some parameters of the model. We also reveal new features of the generalized Lorenz model, including both type I and III intermittency.

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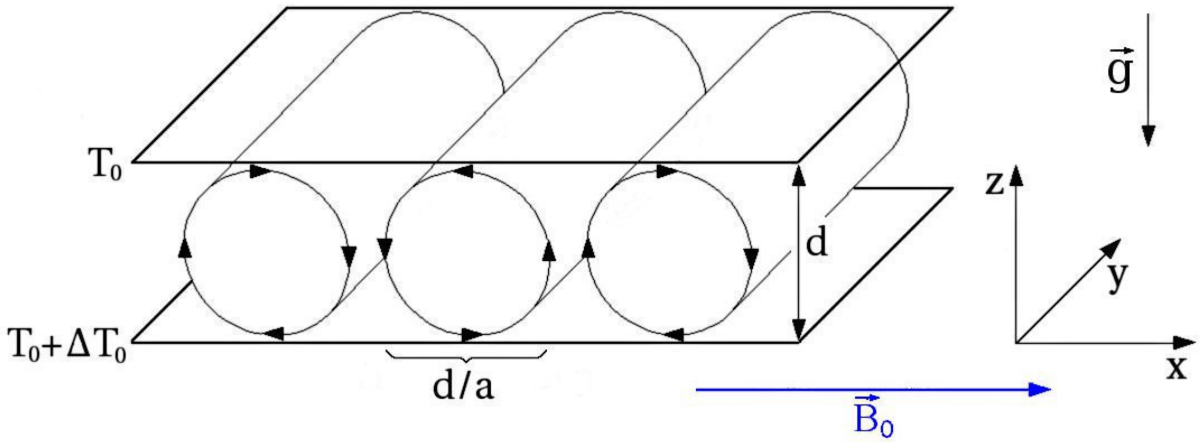
Convection in a Magnetized Fluid



$$\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla\left(p + \frac{\mathbf{B}^2}{2\mu_o}\right) + \frac{(\mathbf{B}\cdot\nabla)\mathbf{B}}{\mu_o\rho} + \nu \triangle\mathbf{v} + \mathbf{f}, \tag{1}$$

$$\frac{\mathrm{d}\mathbf{B}}{\mathrm{d}t} = (\mathbf{B}\cdot\nabla)\mathbf{v} + \eta \triangle\mathbf{B}, \tag{2}$$

$$\frac{\mathrm{d}T}{\mathrm{d}t} = \kappa \triangle T. \tag{3}$$

The Lorenz Model for a Magnetized Fluid

Using the approximations fluid dynamics can be described by a simple set of four ordinary differential equations

$$\dot{X} = -\sigma X + \sigma Y - \omega_0 W, \tag{4}$$

$$\dot{Y} = -XZ + rX - Y, \tag{5}$$

$$\dot{Z} = XY - bZ, \tag{6}$$

$$\dot{W} = \omega_0 X - \sigma_{\rm m} W, \tag{7}$$

where a dot denotes an ordinary derivative with respect to the normalized time $t' = (1+a^2)\ \kappa(\pi/h)^2\ t$, using a geometrical factor $b = 4/(1+a^2)$.

Control parameter $r = R_{\rm a}/R_{\rm c}$;
Rayleigh number $R_{\rm a} = g\beta h^3 \delta T/(\nu\kappa)$, critical number $R_{\rm c} = (1+a^2)^3(\pi^2/a)^2$.
Magnetic control parameter
$\omega_o = \upsilon_{{\rm A}o}/\upsilon_o$;
$\upsilon_{{\rm A}o} = B_o/(\mu_o\rho_o)^{1/2}$, $\upsilon_o = 4\pi\kappa/(abh)$
Prandtl number $\sigma = \nu/\kappa$;
Magnetic Prandtl number ν/η, $\sigma_{\rm m} = \eta/\kappa$.

The Lorenz Model for a Magnetized Fluid

Combining the set of the generalized Lorenz system we can write

$$\ddot{X} + \sigma \dot{X} + (\sigma r - \omega_o^2) X = -\sigma (Y + XZ) + \sigma_{\rm m} \omega_o W,$$

$$\ddot{W} + \sigma_{\rm m} \dot{W} + \omega_o^2 W = \sigma \omega_o (Y - X).$$

Hence formally both variables X and W satisfy the equations of two familiar damped linear oscillators with nonlinear driving forces. Moreover, we can see that the coupling between X, W and Y, Z is enhanced owing to the magnetic field $\mathbf{B}$. Obviously, when $\omega_o = 0$ this coupling ceases and the variable W is damped by the magnetic viscosity.

It appears that behavior of this system can rather be complex: from equilibrium or regular (periodic) motion, through intermittency (where irregular and regular motions are intertwined) to nonperiodic behavior. Two types of such nonperiodic flows are possible, namely chaotic and hyperchaotic motions. As discovered by Lorenz (1963), deterministic chaos exhibits sensitivity to initial conditions leading to unpredictability of the long-term behavior of the system (butterfly effect).

Obviously, hyperchaos is a more complex nonperiodic flow, which has been discovered in the generalized Lorenz system, we have proposed in 2010. I would only like to illustrate how all these complex motions can be studied by analyzing this simple model. In particular, it will be shown that various kinds of complex behavior are closely neighbored depending on two control parameters of the model. But let us begin with the simplest analysis of fixed points of the generalized Lorenz system.

Fixed Points (Equilibrium)

$$\dot{\mathbf{x}} = \mathbf{F}(\mathbf{x}), \quad \mathbf{F}(\mathbf{x}^*) = \mathbf{0}, \quad \mathbf{x}^* = \{X^*, Y^*, Z^*, W^*\}$$

$C^0 = \{0,0,0,0\}$,
$C^{\pm} = \{\pm d/\sqrt{1+e}, \pm\, d\sqrt{(1+e)}, r-(1+e), \pm(\sigma/\omega_o)de/\sqrt{1+e}\}$,
where $d = \sqrt{b((r-1)-e)}$, and $e = \omega_o^2/(\sigma\, \sigma_{\mathrm{m}})$.

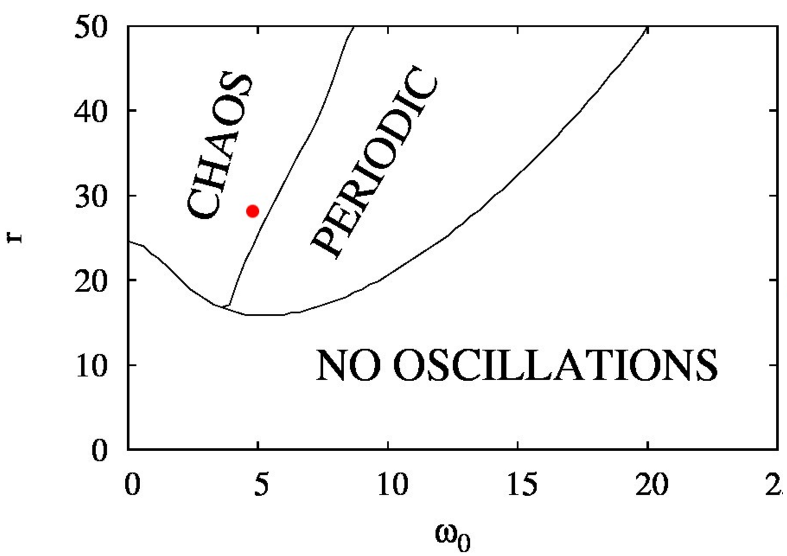
C^0 stable for $0 \le r < r_o$,
$C^{\pm}$ stable for $r_o \le r < r_H$,
$r_o = 1+e$ is a critical value for the onset of convection,
$r = r_H$ is a critical value, where a Hopf bifurcation takes place.

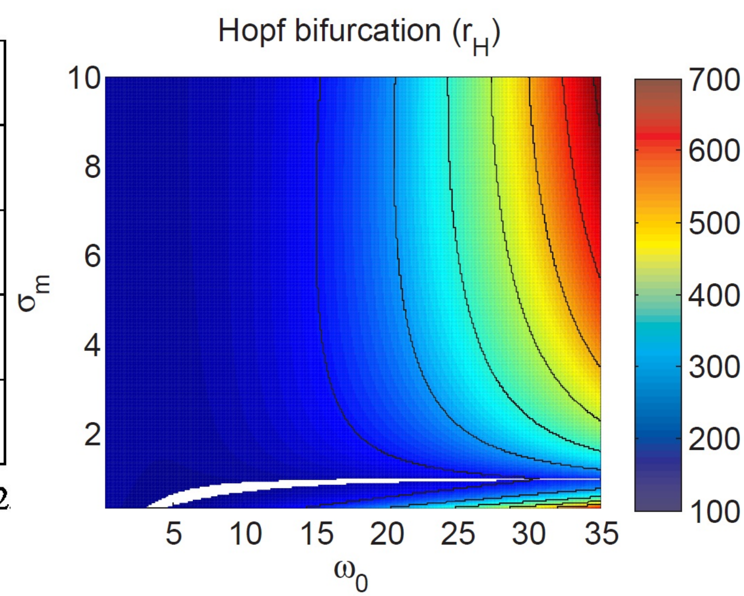
The critical number r_o for the onset of convection increases with the magnetic field, thus the magnetic field should stabilize the convection as regards to the appearance of convective rolls.

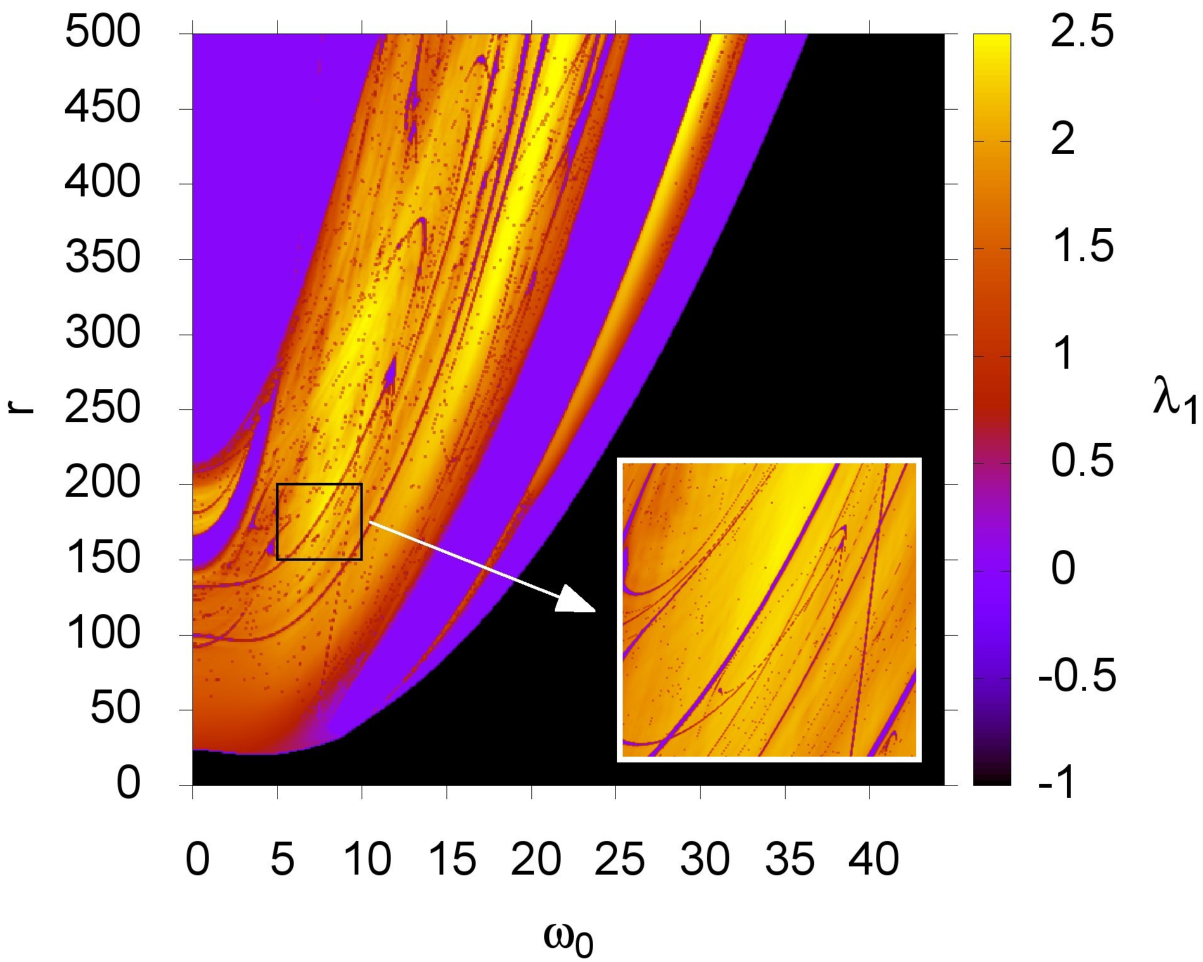
However, if we consider oscillations of the convection rolls, the influence of the magnetic field is more intricate.

Long-term Behavior Depending on Control Parameters

$$r = R_a/R_c, \quad R_a = g\beta h^3 \delta T/(\nu\kappa),\ R_c = (1+a^2)^3(\pi^2/a)^2$$
$$\omega_o = \upsilon_{Ao}/\upsilon_o, \quad \upsilon_{Ao} = B_o/(\mu_o\rho_o)^{1/2},\ \upsilon_o = 4\pi\kappa/(abh)$$







Dependence of the largest Lyapunov exponent λ_1 (color-coded) on ω_0 and r parameters of the generalized Lorenz model for $\sigma_{\mathrm{m}} = 3$. Other parameters of the system have fixed values: $\sigma = 10$, $b = 8/3$. Convergence of the solutions of Eqs. (4)–(7) to equilibria (fixed points) (wit $\lambda_1 < 0$) is shown in black, periodic solutions ($\lambda_1 = 0$) – in violet/blue color (see the color bar for $\lambda_1 = 0$), and (nonperiodic) chaotic solutions ($\lambda_1 > 0$) – in a color, on the color bar scale, from violet/blue to yellow (fine structures are shown in the inset), as taken from (Macek and Strumik, 2014).

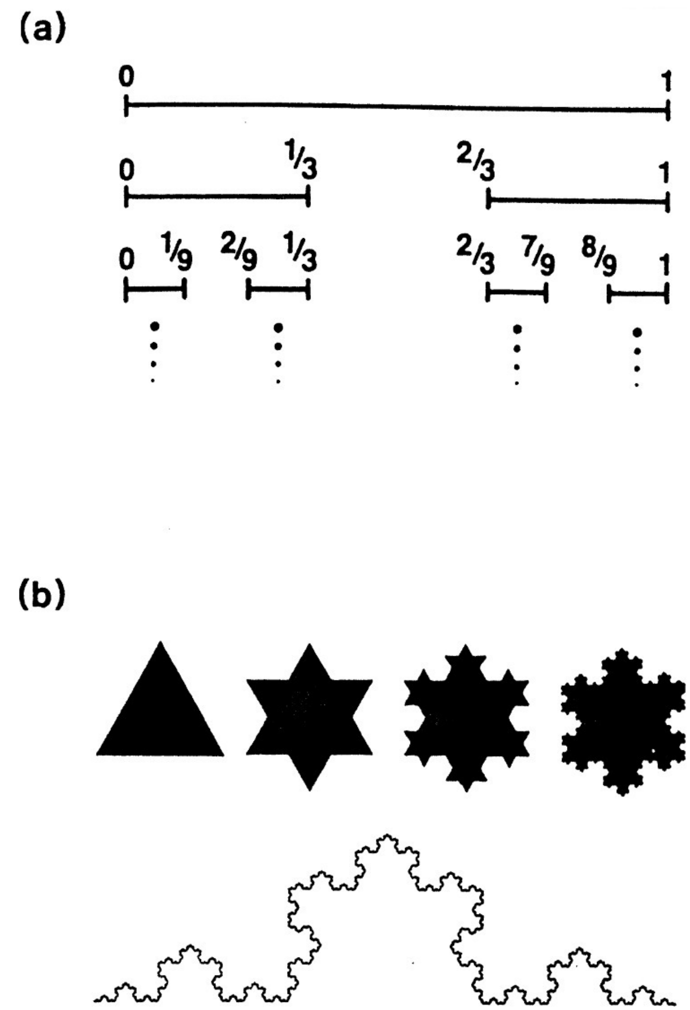
Possible Applications of the Model

- liquid interiors of the Earth’s core (the geodynamo model),
- interiors of the Sun and stars,
  including massive stars with heavy elements,
- solar sunspots and coronal holes, granulation;
- the flow in the magnetosphere and heliosphere,
  and even in interstellar and intergalactic media;
- magneto-confined plasmas in nuclear fusion devices;
- nanodevices and microchannels in nanotechnolgy.

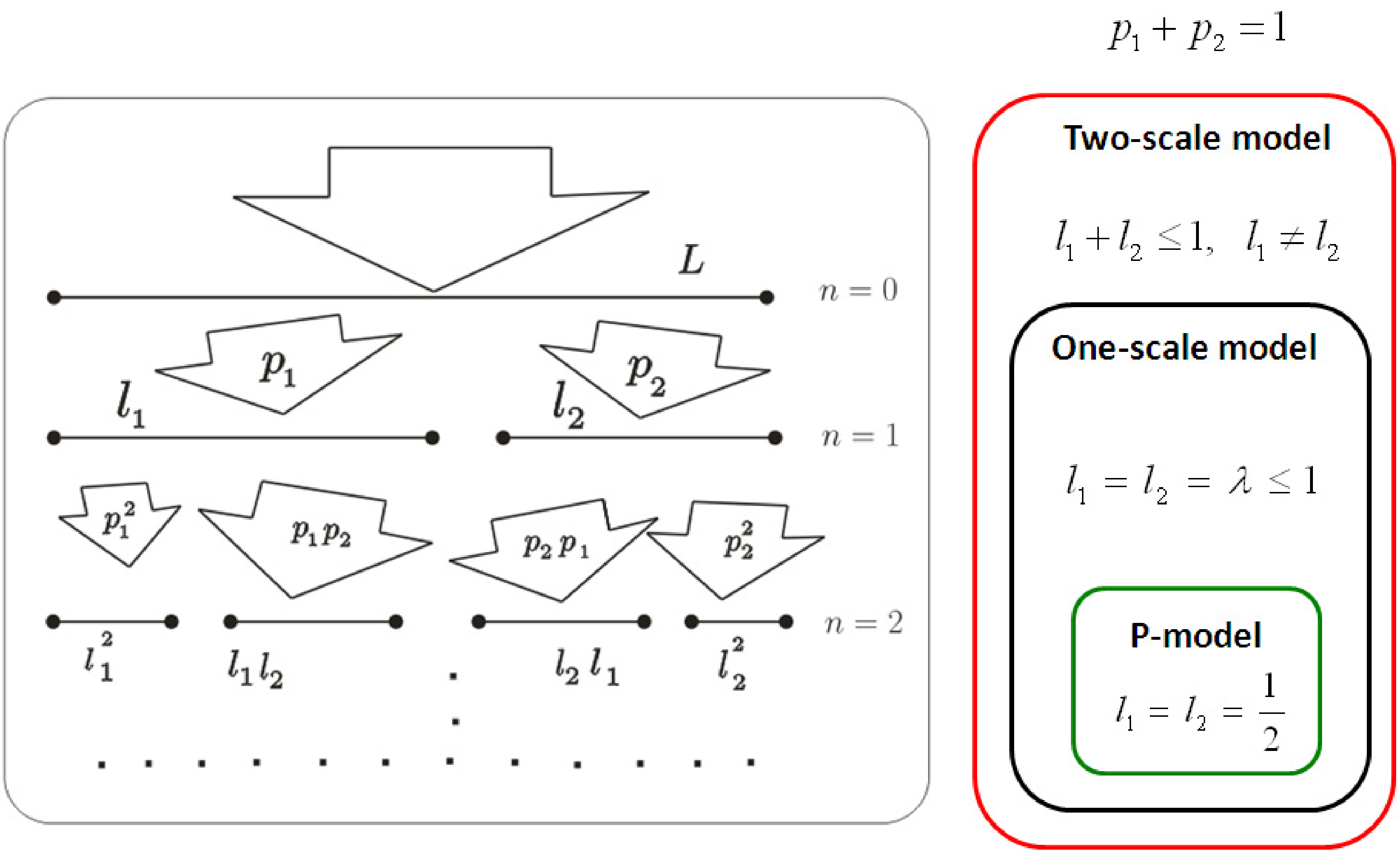
Fractals and Multifractals

A **fractal** is a rough or fragmented geometrical object that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally *self-similar* and independent of scale (fractal dimension).

A **multifractal** is a set of intertwined fractals. Self-similarity of multifractals is scale dependent (spectrum of dimensions). A deviation from a strict self-similarity is also called INTERMITTENCY.



Multifractal Models for Turbulence



The generalized two-scale weighted Cantor set model for turbulence (Macek, 2007, 2012).

Implications

- **Nonlinear** systems exhibit complex phenomena, including chaos, where the effect is not proportional to the cause. This should influence the classical Aristotelian concept of the First Cause.
- Fractals resulting from simple mathematical rules can describe complex shapes in the real word.
- Strange chaotic attractors have fractal structure and are sensitive to initial conditions. Therefore, this should also be taken into consideration for the ultimate explanations of the Universe.
- Within the complex dynamics of the fluctuating intermittent parameters of turbulent media there is a detectable, hidden ORDER described by a Cantor set that exhibits a fractal structure.
- Based on that scientific experience here we also argue that a simple but possibly a **nonlinear law**, within theory of chaos and fractals, can describe a hidden ORDER for creation of Cosmos, at the Planck epoch, when space (at scale of 10^{-35} m) and time (10^{-43} s) were originated (Macek, 2020).

Conclusions

- We therefore hope that the modern studies together with the original thought of Plato and Aristotle should give us a new insight into the most important philosophical issues exceeding the classical ontological principles (Macek, 2020), providing a deeper understanding of the age-old philosophical conundrum, formulated by Leibniz (1714): *why does something exist instead of nothing?*

- We also argue that if we do not like to continue philosophical studies in separation from science, then classic philosophy should open its thought to the most important ideas and achievements of the modern mathematical-natural sciences.

Epilogue

- We argue that the scientific theories of **nonlinear** dynamics, *chaos* and *fractals* help us to understand the origin of the Universe.
- We hope that the philosophy of science should open philosophy to the mathematical natural sciences that would admit a better understanding sense of man in his relation to the Universe and the Reality. Thank you!

Adopted from *Bible moralisée* (1220–1230) by Mandelbrot (1982)

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Wiesław Marian Macek is a Full Professor at the Faculty of Mathematics and Natural Sciences, Cardinal Stefan Wyszyński University (UKSW) in Warsaw, Poland, and at the Space Research Centre, Polish Academy of Sciences. He specializes in astrophysics, space physics, and applied mathematics. His recent research interests focus on nonlinear dynamics, deterministic chaos, and fractal structures in space plasmas, and include studies in theology in the context of contemporary science. He also received a Ph. D. in theology and has delivered a general university lecture on *Science and Religion*. Wiesław Macek was a member of the Plasma Wave Science team on the Voyager mission to Neptune in 1989. He has published about 100 original scientific papers in journals such as *Nature*, *Science*, *Astrophysical Journal Letters, Geophysical Review Letters,* and *Physical Review Letters,* and authored two books (in Polish): *Theology of Science according to Michał Heller* (2010, 2014), *The Evangelization of Japan* (2013), and edited a Jubilee Book, *Fifteen Years of the Exact Sciences at UKSW* (2016). www://cbk.waw.pl/~macek

This little book is aimed at all who are interested in the natural sciences, philosophy, religion, and theology. Even though the Big Bang has now become the Standard Model of the evolution of the Universe, its origin is still a Big Mystery. This monograph focuses on the basic question: *Are the Biblical description of the creation of the world and modern science mutually exclusive, or can they rather be a source of joint search and inspiration?* In this way, the author will help to enrich the reader's scientific view and shape his/her feelings about religion.

After a thorough and clear discussion of various quantum models for the origin of the Universe, Prof. Wiesław Macek proposes his own bold, novel hypothesis. He argues that a simple but possibly nonlinear law is important for the creation of the Cosmos at the extremely small Planck scale at which space and time originated.

Prof. Dr hab. Jan Błęcki, Space Research Centre of the Polish Academy of Sciences

Prof. Wiesław Macek deals with the fundamental issue for science, philosophy, and religion: the origin of the Universe. The monograph provides an original, valuable contribution to research on the relationship between the mathematical/natural sciences and religious faith. The clear language and transparent explanations help the reader to complete an 'accelerated' course in modern physics. The author's key assumption is that the basic concepts of contemporary science can bridge science and religion and could shed light on the philosophical and religious questions of the birth of the Universe, in particular. W.M. Macek, who is an internationally recognized expert in the field of the theory of chaos and fractals, argues that nonlinear dynamics and fractal geometry could describe a hidden order and simple nonlinear laws which underlie the complexity and the origin of the world.

Dr hab. Stefano Redaelli, Faculty of '*Artes Liberales*' at the University of Warsaw

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The Origin of the World

Cosmos or Chaos?