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THERMODYNAMIC COSMOLOGY Rh = ct

A Pedagogical and Non-Relativistic Introduction to the Linear Universe

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"A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Therefore the deep impression that classical thermodynamics made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts."

— **Albert Einstein**

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PREFACE

For a century, cosmology has been dominated by a geometric approach inherited from general relativity. This vision has enabled major advances, but it leaves several fundamental questions unanswered: Why does the Universe have the temperature we observe today? Why does energy density follow simple laws? Why do cosmological quantities seem linked to Planck scales?

These questions are not geometric. They are thermodynamic.

This booklet proposes an alternative approach, based exclusively on:

- **Causality,**
- **Thermodynamics,**
- **Planck scales,**
- **Classical mechanics,**
- **Dimensional arguments.**

No field equations, metrics, or curvature are used. The goal is to show that the Universe can be described as a **self-similar thermodynamic system**, and that the simple relation:

$$R_h = c \times t$$

is sufficient to reconstruct a complete, coherent, and predictive cosmology. The model does not claim to replace general relativity, but to offer a complementary thermodynamic description, valid on a large scale

CHAPTER 1 — Why a Thermodynamic Cosmology?

1.1. The Fundamental Question

Traditional cosmology describes the Universe as a space that expands, curves, and deforms. While this geometric approach is powerful, it does not answer several essential questions:

- Why does the Universe have a measurable temperature?
- Why does energy density follow simple thermal laws?
- Why does the Hubble constant seem linked to quantum scales?
- Why do cosmological quantities and Planck quantities correspond?

These questions are thermodynamic, not geometric.

1.2. The Principle: A Linear Cosmology

The model is based on a simple relationship:

$$R_h = c \times t$$

where R_h is the Hubble radius, c is the speed of light, and t is the cosmic age. This relationship expresses that the causal horizon grows linearly with time: the observable Universe expands at the speed of light in terms of information.

1.3. Why Thermodynamics Is the Natural Language of the Universe

The Universe has:

- A measurable temperature (CMB),
- An energy density governed by the Stefan–Boltzmann law,
- A horizon endowed with entropy and temperature,
- A microscopic scale defined by Planck units.

These properties are thermodynamic.

1.4. The Role of Haug and Tatum

They converge toward a common vision:

- **Haug** links Planck scales to cosmological scales.
- **Tatum** develops a cosmology based on energy and thermodynamics.

1.5. Why a Thermodynamic Cosmology Is Necessary

Current observational tensions (notably the *Hubble tension*) suggest that the ΛCDM model may not be complete. A thermodynamic approach:

- Naturally links cosmic temperature to the Hubble radius,
- Explains why H is stable,
- Provides a physical interpretation of horizons,
- Predicts the CMB temperature without adjustment.

1.6. Objectives of the Booklet

This booklet aims to:

- Present $R_h = ct$ as a thermodynamic cosmology,
- Show how Planck scales determine cosmological quantities,
- Demonstrate the CMB temperature without general relativity,
- Build a complete cosmology based on thermodynamics.

CHAPTER 2 — Fundamental Constants and Planck Units

2.1. Why Fundamental Constants Are Essential

Thermodynamic cosmology relies on three universal constants:

- c: the speed limit for information propagation,
- $\hbar$: the quantum granularity of action,
- k_B: the link between microscopic energy and temperature.

These three constants suffice to define Planck units.

2.2. The Three Fundamental Constants

- **Speed of Light (c)**: Sets the maximum speed of interactions.
- **Reduced Planck Constant ($\hbar$)**: Imposes granularity on energy and action.
- **Boltzmann Constant (k_B)**: Links microscopic energy to macroscopic temperature.

2.3. Planck Units

- **Planck Length (l_P)**:

$$l_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1{,}616 \times 10^{-35}\text{m}$$

- **Planck Time (t_P):**

$$t_P = \frac{l_P}{c} \approx 5{,}391 \times 10^{-44}\text{s}$$

- **Planck Mass (m_P):**

$$m_P = \sqrt{\frac{\hbar c}{G}} \approx 2{,}17 \times 10^{-8}\text{kg}$$

- **Planck Temperature (T_P):**

$$T_P = \frac{m_P c^2}{k_B} \approx 1{,}417 \times 10^{32}\text{K}$$

2.4. Why Planck Units Are Essential

The ratio:

$$\frac{R_h}{l_P} \sim 10^{61}$$

encodes the energetic structure of the Universe.

CHAPTER 3 — The Hubble Radius and Linear Cosmology

3.1. A Thermodynamic Definition of the Hubble Radius

The Hubble radius is the maximum distance from which information can reach us since the beginning of cosmic time:

$$R_h = c \times t$$

3.2. Why $R_h = ct$ Is Inevitable

In any physical system:

- Information propagates at finite speed,
- Energy diffuses at finite speed.

Thus, no interaction can influence a region beyond R_h.

3.3. The Hubble Parameter

Combining:

$$H = \frac{c}{R_h} \text{ and } R_h = c \cdot t$$

we obtain:

$$H = \frac{1}{t}$$

3.4. A Self-Similar Universe

Linearity implies:

- $R_h \propto t$,
- $H \propto \frac{1}{t}$,
- $T \propto \frac{1}{t}$.

The symbol ∝ means "is proportional to."

CHAPTER 4 — Temperature, Energy, and Density in a Universe

4.1. Introduction

In a linear Universe:

$$R_h = c \times t$$

4.2. Energy Density: The Stefan–Boltzmann Law

$$\rho = aT^4$$

where:

$$a = \frac{8\pi^5 k_B^4}{15h^3c^3}$$

4.3. Evolution of Energy Density

The causal volume:

$$V \propto R_h^3$$

and energy arguments lead to:

$$\rho \propto \frac{1}{t^2}$$

4.4. Evolution of Temperature

Combining:

$$\rho \propto T^4 \text{ and } \rho \propto t^{-2}$$

we obtain:

$$T \propto \frac{1}{t}$$

4.5. Temperature as a Function of the Hubble Radius

Since:

$$R_h = c \times t$$

we have:

$$T \propto \frac{1}{R_h}$$

CHAPTER 5 — The Planck ↔ Hubble Link: A Fundamental Scale Relation

5.1. Introduction

The Universe has two natural scales:

- **Microscopic scale** (Planck units),
- **Macroscopic scale** (Hubble radius).

5.2. The Two Extremes of the Universe

- **Planck Scale**: $l_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.616 \times 10^{-35}$ m

- **Hubble Scale**: $R_h = c \times t \approx 1.3 \times 10^{26}$ m

5.3. A Universal Scale Relation

The ratio:

$$\frac{R_h}{l_P} \approx 8 \times 10^{60} \sim 10^{61}$$

5.4. Thermodynamic Interpretation

This ratio links:

- The current cosmic temperature,
- The Planck temperature,
- The energy contained in the causal horizon.

CHAPTER 6 — Horizon Temperature and the Thermal Structure of the Universe

6.1. Introduction

A causal horizon has:

- A temperature,
- An entropy,
- An energy flux.

6.2. Why Does a Horizon Have a Temperature?

A causal horizon is a boundary beyond which no information can be transmitted. In thermodynamics, any limit on access to information is associated with a temperature.

6.3. Relation Between R_h and T

Using the Stefan–Boltzmann law and the scale relation $R_h = c \times t$, we show that:

$$T_{CMB} = \frac{T_p}{8\pi}\sqrt{\frac{2\ell_p}{R_h}} \approx 2{,}72\ \mathrm{K}$$

see :

- **Tatum, E. T., Seshavatharam, U. V. S., Lakshminarayana, S.** *The Basics of Flat Space Cosmology.* International Journal of Astronomy and Astrophysics, 2015.

- *Espen Gaarder Norwegian University of Life Sciences Haug, Stéphane Wojnow. How to predict the temperature of the CMB directly using the Hubble parameter and the Planck scale using the Stefan-Boltzman law. 2023. ⟨hal-04269991⟩*

- *Haug, E.G. CMB, Hawking, Planck, and Hubble Scale Relations Consistent with Recent Quantization of General Relativity Theory. Int J Theor Phys* ***63****, 57 (2024). https://doi.org/10.1007/s10773-024-05570-6*
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The horizon temperature plays a central role:

- It sets the minimum accessible temperature,
- It imposes a large-scale thermal structure.

CHAPTER 7 — Observational Consequences of the Model

7.1. Introduction

The model makes several robust predictions:

- Absence of the horizon problem,
- Natural homogeneity of the CMB,
- The $R_h = ct$ relation,
- Predicted CMB temperature.

7.2. Homogeneity of the CMB

In $R_h = ct$, all observable regions have been in causal contact.

7.3. The $R_h = ct$ Relation

This relation is verified by current observations.

CHAPTER 8 — Physical Interpretation: A Self-Similar Universe

8.1. Introduction

The scale relation:

$$R_h = c \times t$$

shows that the Universe is a self-similar system.

8.2. Self-Similarity of Thermodynamic Quantities

- $T \propto R_H^{-1/2}$
- $\rho \propto R_H^{-2}$
- $E \propto R_H$

CHAPTER 9 — General Synthesis

9.1. What We Have Saw that

1. The Universe can be described as a thermodynamic system.
2. The relation $R_h = ct$ is a consequence of causality.
3. The CMB temperature is predicted; $T_{\text{CMB}} \approx 2.72$ K

9.2. A New Way of Thinking About Cosmology

This approach:

- Does not depend on any geometry,
- Relies solely on thermodynamics,
- Connects microphysics and cosmology.

GLOSSARY

This glossary gathers the essential concepts used in this booklet. Each entry is written concisely and independently of general relativity.

Autosimilarity

Property of a system whose structure remains identical when the scale is changed. In $R_h = ct$, the Universe preserves the same thermodynamic structure at all time scales.

Comoving (Observer)

A **comoving observer** moves with the expansion of the Universe, without peculiar velocity relative to the cosmic fluid. In $R_h = ct$, a comoving observer:

- Sees the Universe evolve homogeneously,
- Experiences an effective acceleration linked to the causal horizon,
- Measures cosmic temperature and horizon temperature.

It constitutes the natural reference frame of thermodynamic cosmology.

Boltzmann Constant (k_B)

Fundamental constant linking microscopic energy to macroscopic temperature. It defines the Planck temperature and appears in the Stefan–Boltzmann law.

Reduced Planck Constant ($\hbar$)

Quantum constant defining the granularity of action. It appears in the definition of Planck units and horizon temperature.

Radiation Constant (a)

Constant relating the energy density of thermal radiation to its temperature:

$$\rho = aT^4$$

with:

$$a = \frac{8\pi^5 k_B^4}{15h^3c^3}$$

Energy Density (ρ)

Energy contained per unit volume. In a Universe:

$$\rho \propto \frac{1}{t^2}$$

Hubble Scale

Cosmological scale defined by the causal radius:

$$R_h = c \times t$$

It represents the size of the observable Universe.

Planck Scale

Set of fundamental quantities defined from c, $\hbar$, and k_B. They represent the quantum limits of physics.

Causal Horizon

Boundary beyond which no information can be transmitted. In $R_h = ct$:

$$R_h = c \times t$$

Thermal Horizon

Causal horizon with an effective temperature, a consequence of limited access to information. Its temperature is:

$$T_H = \frac{T_p}{8\pi}\sqrt{\frac{2\ell_p}{R_H}}$$

Planck Length (l_P)

Smallest significant physical length:

$$l_P = \sqrt{\frac{\hbar G}{c^3}}$$

Planck Mass (m_P)

Fundamental mass defined by:

$$m_P = \sqrt{\frac{\hbar c}{G}}$$

Hubble Parameter (H)

Cosmic expansion rate. In $R_h = ct$:

$$H = \frac{1}{t}$$

Hubble Radius (R_h)

Maximum distance reachable by information since the origin of cosmic time:

$$R_h = c \times t$$

Cosmic Temperature (T)

Average temperature of the Universe's thermal radiation. In $R_h = ct$:

$$T = \frac{T_p}{8\pi}\sqrt{\frac{2\ell_p}{R_H}}$$

Horizon Temperature (T_H)

Temperature associated with the causal horizon:

$$T_H = \frac{T_p}{8\pi}\sqrt{\frac{2\ell_p}{R_H}}$$

Planck Temperature (T_P)

Maximum possible temperature in a physical system:

$$T_P = \frac{m_P c^2}{k_B}$$

Planck Time (t_P)

Smallest significant time interval:

$$t_P = \frac{l_P}{c}$$

Linear Universe

Universe whose causal radius grows linearly with time:

$$R_h = c \times t$$

This linearity is the signature of $R_h = ct$cosmology.

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APPENDIX: Self-Similarity in the Universe (Rh = ct)

Self-similarity is a fascinating property that means a system (like the Universe) retains the **same structure** at different scales of time or space. For a thermodynamic system like the Universe, this implies that the laws and relationships between physical quantities (temperature, density, energy, etc.) remain **unchanged** when the scale is altered.

1. Definition of Self-Similarity

A system is **self-similar** if its structure or properties remain identical when "zoomed in" or "zoomed out." For example:

- A **fractal** (like a snowflake or coastline) looks the same whether viewed up close or from afar.
- In the Universe, this means that the **relationships between physical quantities** (such as temperature, energy density, or the Hubble radius) remain the same at any age of the Universe.

2. Self-Similarity in $R_h = ct$

In your $R_h = ct$ model, self-similarity manifests as follows:

- **Hubble Radius (R_h)**: $R_h = c \times t$ — The Hubble radius grows linearly with time. This means the size of the observable Universe is always proportional to its age.
- **Hubble Parameter (H)**: $H = \frac{1}{t}$ — The Hubble parameter (measuring expansion rate) is inversely proportional to time.
- **Temperature (T)**: $T \propto \frac{1}{t^2}$— The Universe's temperature decreases proportionally to the inverse of the square of the time.
- **Energy Density (ρ)**: $\rho \propto \frac{1}{t^2}$— Energy density decreases with the square of time.

3. Concrete Example: The Cosmic Microwave Background (CMB)

- Today, the CMB temperature is **2.7 K**, and the Hubble radius is about **13.8 billion light-years**.
- 10 billion years ago, the Universe was younger and hotter. The CMB temperature was higher, but the **relationship between $T$and R_h**remained the same:
  - $T \times R_h^2 =$ constant (since $T \propto \frac{1}{R_h^2}$).
- This shows that the Universe "grows" and "cools" in a self-similar way: its thermal structure remains the same, only the scales change.

4. Why Self-Similarity Matters

- **Simplicity**: It allows the Universe to be described with **universal and timeless laws**, without adjustable parameters.
- **Predictability**: If we know the state of the Universe at one time, we can predict its state at any other time by simply scaling.
- **Micro-Macro Link**: It connects Planck scales (the smallest) to cosmological scales (the largest), showing that the same laws apply everywhere.

5. Analogies to Visualize Self-Similarity

- **An Inflating Balloon**: If you draw dots on a balloon and inflate it, the distances between the dots increase, but their **relative distribution** remains the same.
- **A Campfire**: The heat felt 1 meter from a fire is 4 times less intense than at 0.5 meters (inverse square law). The relationship between distance and heat is self-similar.
- **A River**: Eddies in a river have the same structure, whether they are 1 cm or 1 meter in diameter.

6. Implications for Thermodynamic Cosmology

In your $R_h = ct$model, self-similarity implies:

- The Universe **does not need "inflation"** (an ultra-rapid expansion phase) to explain its homogeneity: its structure is naturally self-similar.
- The **CMB temperature** is a direct consequence of the $T \propto \frac{1}{R_h^2}$ relationship, without arbitrary adjustment.
- The **laws of thermodynamics** (such as energy conservation and entropy) apply at all scales, from particles to galaxies.

Summary

The self-similarity of the Universe means:

"The Universe is a scaled-up or scaled-down version of itself at different epochs. Its thermodynamic properties (temperature, density, energy) evolve predictably and proportionally, like the notes of a melody that remain harmonious even when the key changes."