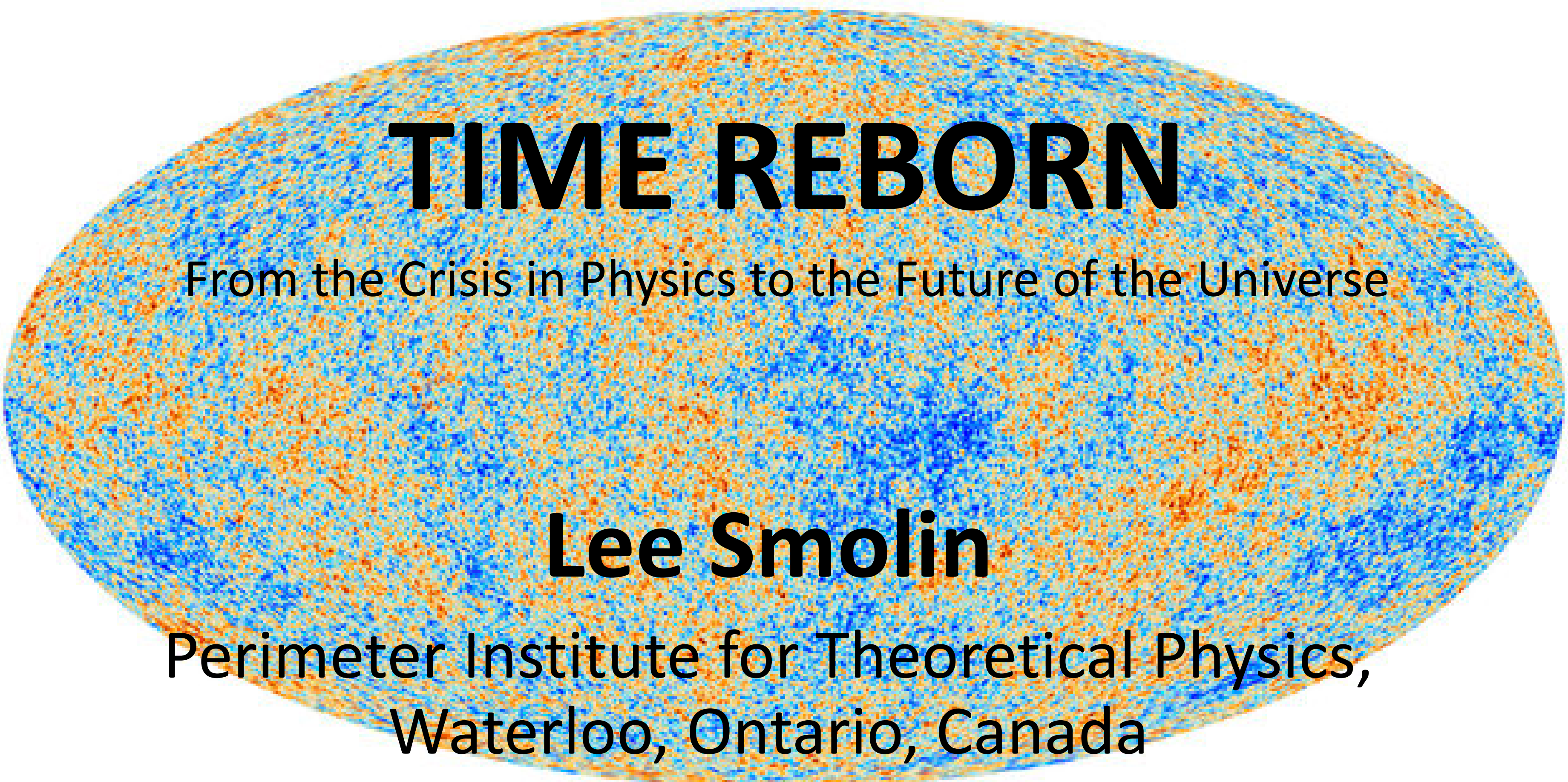

TIME REBORN

From the Crisis in Physics to the Future of the Universe

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Planck CMB

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Author and Content

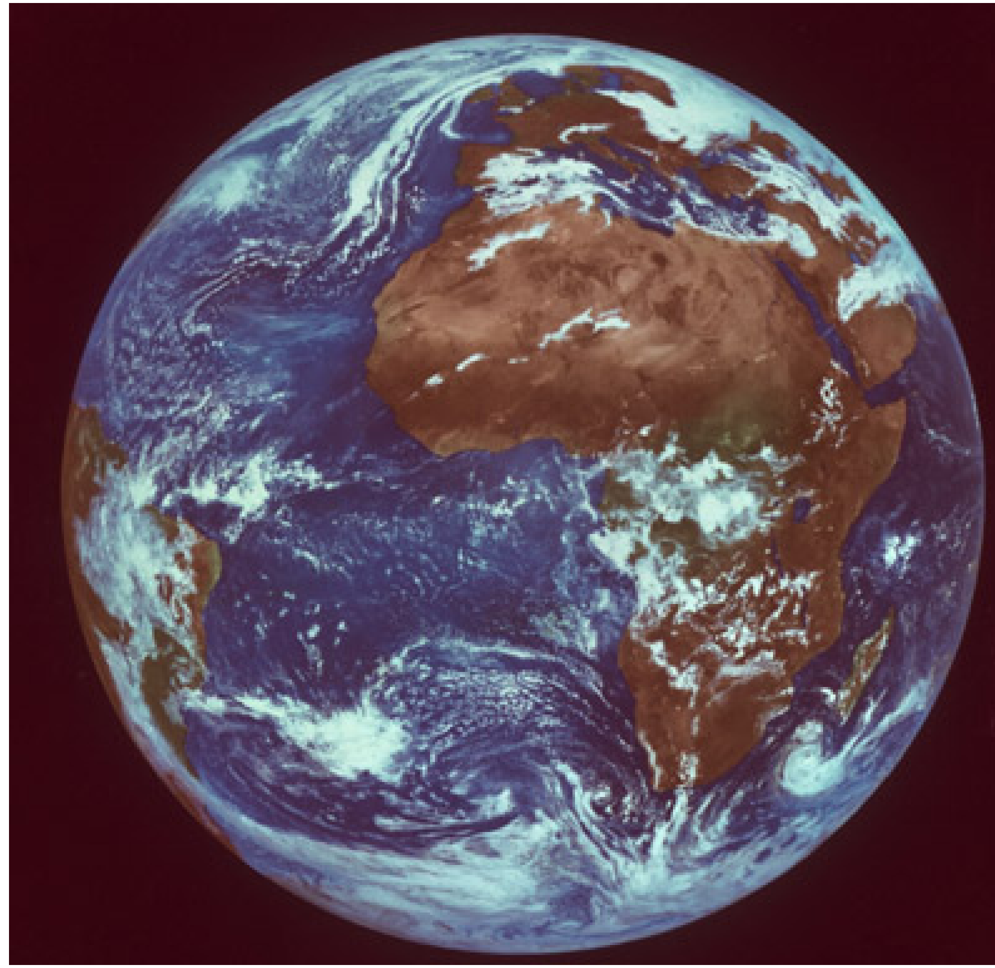
PART I
Weight:
The Expulsion of Time

PART II
Light:
Time Reborn

All things originate from one another,
and vanish into one another
according to necessity…
in conformity with the order of time.

Anaximander, *On Nature*

610 – 546 B.C. in Milet



Earth orbiting the Sun due to gravity

Preface: What isTime?

- All mysteries of physics come down to the nature of time.
- Time is the most pervasive aspect of everyday experience.
- Many (physicists and philosophers) believed that time is an illusion, which must be transcended to perceive the real and the true (eternity and unchanging laws of physics and nature)

When Smolin means time is real, he is saying that:

- Whatever is real is just real in a moment of time, being one in a succession of moments.
- The past was, but no longer is, real. We can, however, interpret the past by finding evidence of past processes in the present.
- The future does not yet exist, and thus it is open. We can, however, make predictions, yet the future may produce genuinely novel phenomena.
- Nothing transcends time, not even the laws of nature, which therefore can evolve over time.

Introduction: Time, illusive or real?

Newton's classical framework: **Nature consists of nothing but particles with unchanging properties, whose motions and interactions are determined by timeless laws!**

This framework is suited to describe parts (apple, planet, galaxy) of the world, but it fails when being applied to the universe as a whole. It is impossible to stay outside of the system studied when it is the entire universe. All major physical theories are about parts of the universe, and we leave ourselves and the measurement tools outside of the system.

Gottfried Wilhelm Leibniz' principle to frame science: Principle of sufficient reason

There must be a rational reason for every apparent choice made in the construction of a scientific theory, in particular of the universe.

Leibniz' vision: **Everything is immersed in a network of relationships!**

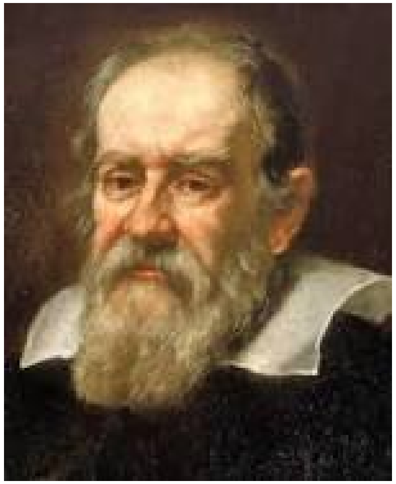
Time must be a consequence of change governed by causality. Space and time are relational.

Emergence is an important term in a relational world:
Rocks are hard and water flows, but the atoms they are made of are neither solid nor wet!

1. Falling

Gravity is the only fundamental force whose effects everyone observes with no need for special instruments. (Already small kids struggle with gravity.)

Galileo not only discovered how objects fall but also explained it. Falling objects on Earth trace a parabola, a simple curve that is the set of points equidistant from a point and a line.



Galileo's observation that bodies fall along parabolas is one of the first examples we have of a **law of nature**. But what is mathematics about, and why does it come into physics?

Even if curves and numbers resemble objects in nature they are not the same as natural objects, which exist for a limited time span. Mathematical objects seem to exist in a separate timeless realm (of ideas after Plato). However, things and humans live bounded in time and in contact with other things similarly bounded.

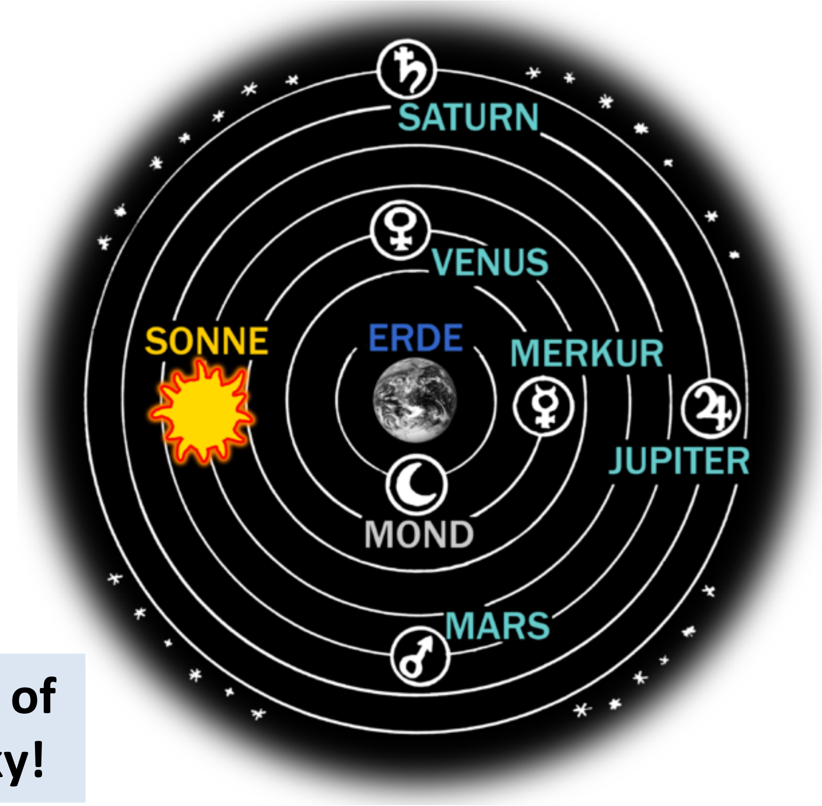
This vision of transcendence via physics to the timeless is fataly flawed, related to its claim to explain the time-bound by the time-less.

2. The Disappearance of Time

Ptolemy's epicycle framework: Earth is at rest at the center of the universe. Planets move on epicycles, i.e. small cycles rotating with a one-year period around points that move on bigger cycles around the Earth. Copernicus then put Earth as a planet and the Sun in the center. Finally, Kepler found that Mars traces an ellipse, not a circle, in space!

- Why do planets move in elliptical orbits?
- What compels them to move at all?

Newton:
The force that impels everything on Earth to fall toward it is universal and acts also to pull the planets toward the Sun and the Moon toward the Earth: **Gravity.** All planetary motions are consequences of a **single law** of motion.



Timeless mathematics was found at the heart of everything that moved, on Earth and in the sky!

3. A Game of Catch

Motion is change in position over time. But what is position and what is time?

Two answers that physicists have given:

- Position of an object is relative to a spatial landmark of some sort (Einstein).
- Position is absolute in space beyond its relation to something else (Newton).

- Time of an event is measured relative to another event, by reading the dial of a clock.
- Time is absolute, as perceived by God and hidden behind all change (Newton).

*The process of recording a **motion,** which takes place in time, results in a record, which is frozen in time – a record that can be represented by a graph, also frozen in time.*

Some physicists see the graph as a
- deep insight into the nature of reality (mystic)
- useful mathematical tool (pragmatic)

Kid's ball throw recorded and graphed

Throw graphed as curve in space and time -> spacetime.

Confusing spacetime with reality means committing the fallacy of spatialization of time!

4. Doing Physics in a Box

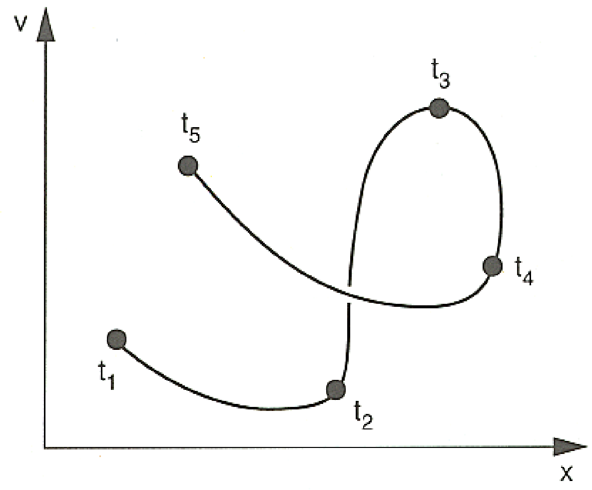
Most what we know about nature comes from experiments in which we articficially isolate a phenomenon from the „rest“ of the universe. The method of restricting attention to a small part of the world has enabled the success of physics from the time of Galileo and Newton. We call it *„doing physics in a box“*.

To apply mathematics to a physical system we have to separate it from the complexity of motions that is the real world. Thereby we try to decrease, but can never fully eliminate, the outside influences on our system. Part of its definition is a list of all variables which make up an abstraction, we call the configuration of the system (phase space). It determines everything we want to or can know at a moment of time.

Newtonian paradigm:

- What are the possible configurations of the system?
- What are the forces that the system is subject to?

This is based on the assumption that the configuration and the laws (forces) are timeless!



5. Expulsion of Novelty and Surprise

Laplace onces claimed that if he were given the precise positions and motions of all atoms in the universe, together with a precise description of the forces they were subject to, he could predict the future of the universe with total accuracy. This claim today includes the Standard Model of Elementary Particle Physics, containing all we know of nature.

→ The future is completely determined by the present!
→ But as you seek the reasons for things to be as they are and not otherwise, you are driven deeper and deeper into the past, and to consider ever larger systems.
→ The argument for determinism is thus a question about cosmology!
→ Is there any space for novelty and surprise?

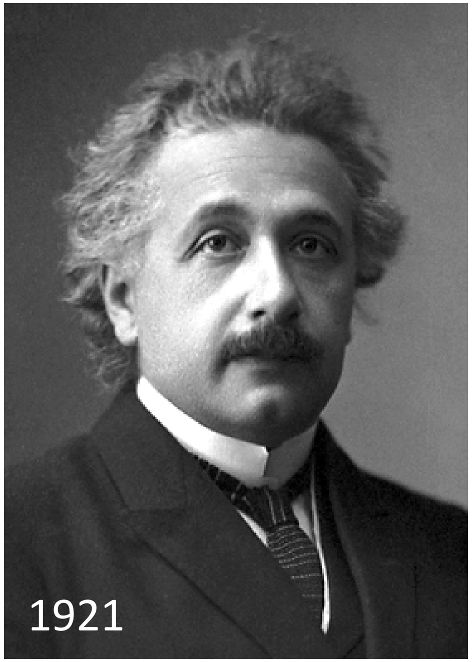
- Can our theories be scaled up to theories of the complete universe?
- Do initial conditions really determine everything?

Nonlinear theory tells us that small changes in initial conditions are amplified exponentially to very big changes in outcome. „A flap of a butterfly‘s wing can influence the weather oceans away and months later“.

The time-reversibility of the laws of physics removes time from the conception of nature!

6. Relativity and Timelessness I

Einstein assumed in 1905 that the speed of light is universal (nothing can travel faster than light in vacuum and everybody measures that same speed), and he utilized a strategy called operationalism: The only meaningful way to define time is to stipulate how to measure it. You must describe what a clock is and how it works.



Observers in motion with respect to each other will reach different conclusions about whether two events are simultaneous or not when those events are distant from each other.

Two fundamental concepts stem from special relativity:

- Relativity of simultaneity (big blow to the notion that time is real)
- Block universe (pictured as a system of events connected by causal relations)

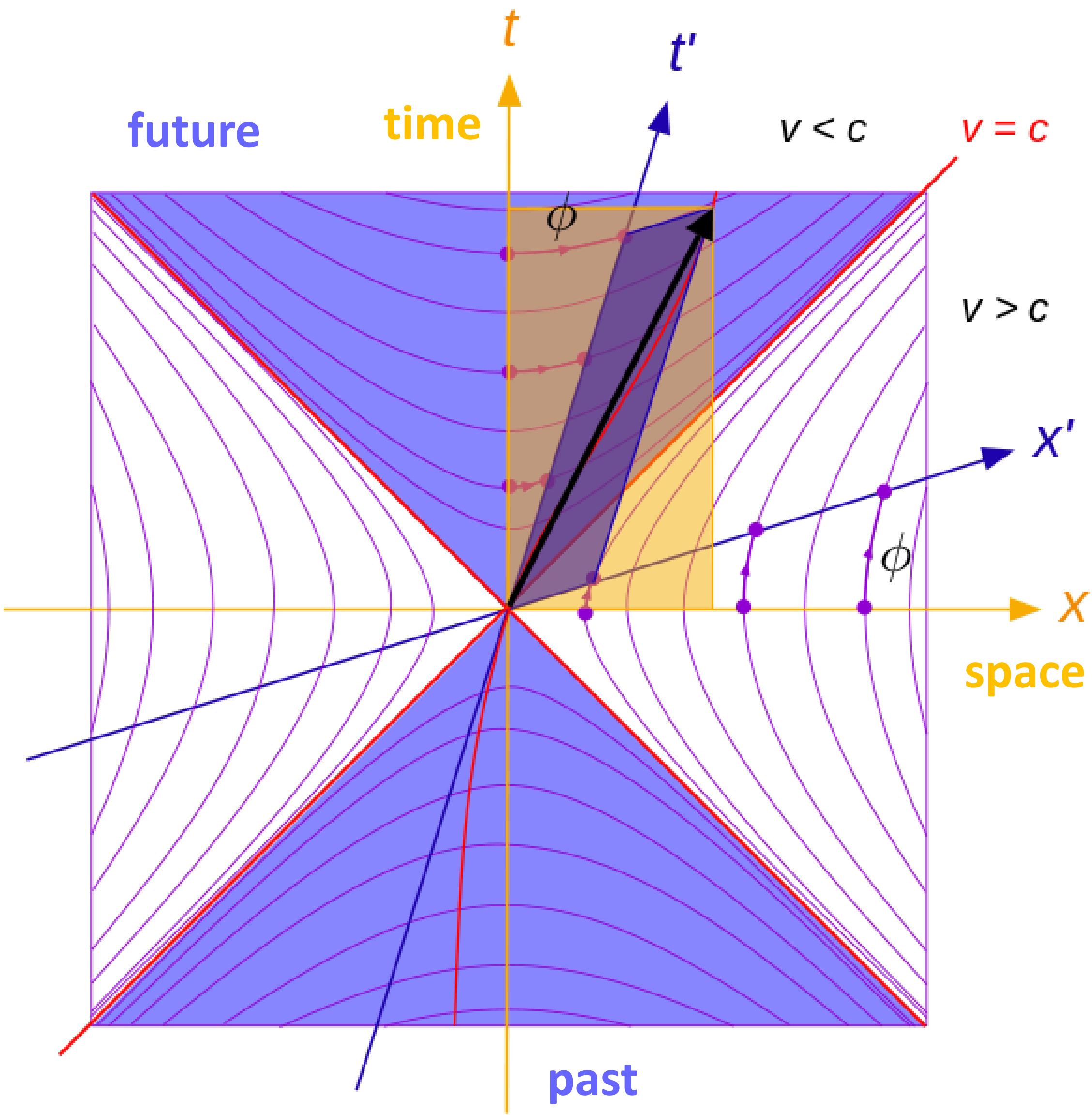
The principle of relativity holds that speed (other than the speed of light) is a purely relative quantity. There is no way to tell who moves and who is at rest.

The block universe describes the whole history of the universe as a mathematical object which is timeless! It marries space and time in the 4-D Minkowski spacetime.

6. Relativity and Timelessness II

Block-universe or spacetime

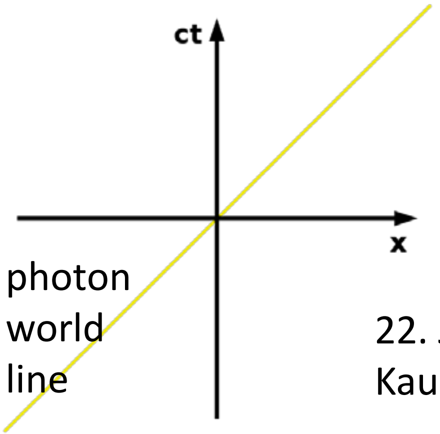
Region causally disconnected from the origin



Minkowski diagram with resting frame (x,t), moving frame (x′,t′), light cone, and hyperbolas marking out time and space with respect to the origin, $t^2-x^2=1$, for unit proper time.

tan ϕ= V/c

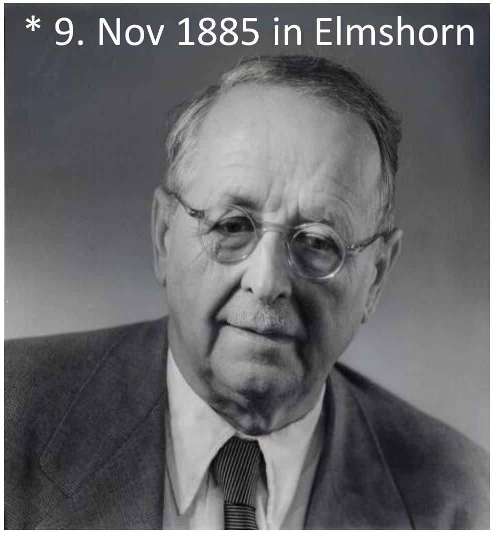
6. Relativity and Timelessness III



22. Jun 1864 in
Kaunas, Litauen

H. Minkowski (mathematician, 1908): *„Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.“*

H. Weyl (mathematician): *„The objectice world simply is, it does not happen. Only to the gaze of my conciousness, crawling upward along the world line of my body, does a section of the world come to life as a fleeting image in space which continuously changes in time.“*



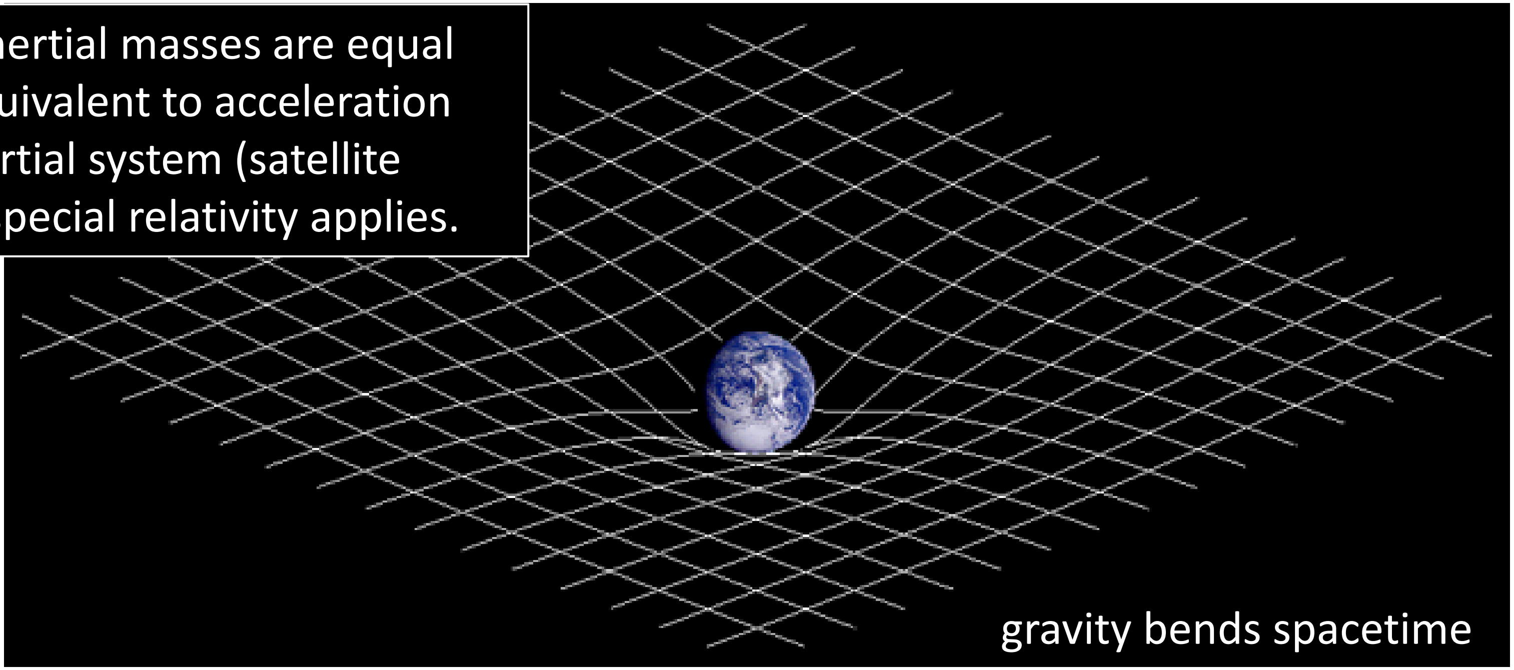
J.R. Lucas (philospopher): *„The block universe gives a deeply inadequate view of time. It fails to account for the passage of time, the pre-eminence of the present, the directedness of time and the difference between the future and the past.“*

Special relativity cannot be applied to the whole universe because it does not contain gravity!

6. Relativity and Timelessness IV

General relativity (Einstein, 1915) is based on the simplest of all scientific ideas, which is that ***falling is a natural state.***
All bodies fall with the same acceleration, regardless of their mass or any other properties!
Equivalence principle: *When you fall freely you can not feel your motion*!

1. Heavy and inertial masses are equal
2. Gravity is equivalent to acceleration
3. In a local inertial system (satellite laboratory) special relativity applies.



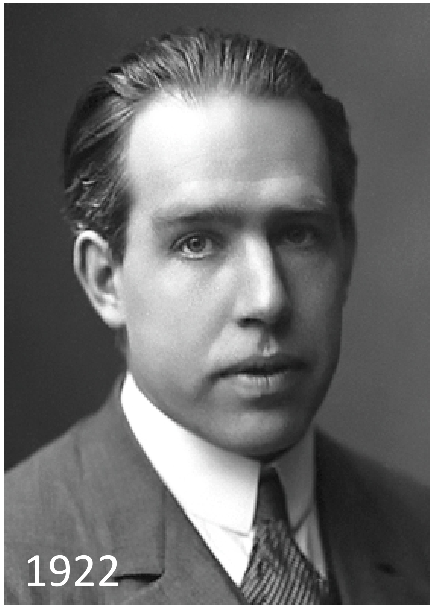
Objects falling in a gravitational field move along geodesics.

In general relativity spacetime is not euclidic but gravity determines the metric of spacetime!

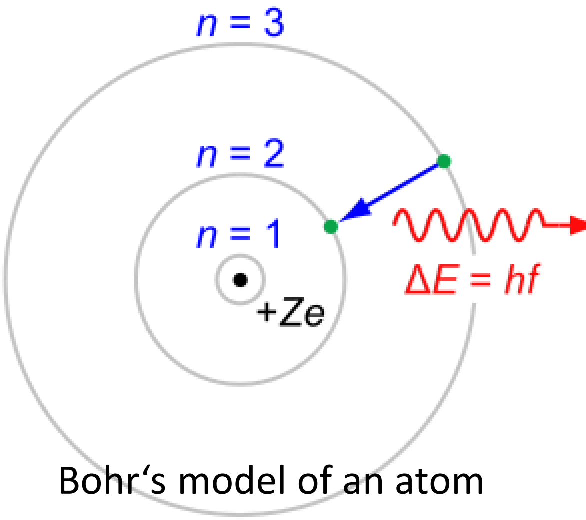
7. Quantum Cosmology and the End of Time I

Many of us think the purpose of science is to describe how nature really is – to give a picture of the world that we can believe would be true, even were we not here to see it.

Niels Bohr: The purpose of a scientific theory is not to describe nature but only to give us rules for manipulating objects in the world and a language we can use to communicate the results.



Quantum mechanics describes a system by its quantum state, the temporal evolution of which is governed by the Schrödinger equation. The quantum state gives us only probabilities, which contain the information an observer can possibly obtain by preparing and measuring a system.



Bohr's model of an atom

Like in Newtonian also in quantum physics, clocks and measuring instruments must be outside of the system. Can we apply quantum theory to the whole universe?

7. Quantum Cosmology and the End of Time II

In quantum theory, the change in time is connected with energy, and energy is proportional to frequency, E = hν. Because there is no clock outside the universe, its quantum state cannot change in time, so its frequency of oscillation must be zero, and thus the energy of the universe must be zero. Then the quantum state of the universe is frozen. It simply is!

There is a negative amount of energy in any system held together by gravity.

The universe can have zero total energy if the total gravitational potential energy holding its parts together exactly cancels all the positive energy in the universe, expressed in the masses and motions of all its matter.

$$\hat{H}(x)|\psi\rangle = 0$$

The Wheeler–DeWitt equation is an attempt to meld the ideas of quantum mechanics and general relativity, a step toward a theory of quantum gravity. Here I*ψ*> is a functional of field configurations on spacetime, and $\hat{H}(x)$ is the hamiltonian.

E. Mielke with John Wheeler (right) at a conference for the 100th birthday of H. Weyl in Kiel (1985)

Interlude: Einstein‘s Discontent

The Viennese philosopher R. Carnap reported a conversation with Einstein on time, who once said that the problem of the „now“ worried him seriously, and explained that the „now“ means something special for man, something essentially different from the past and the future, but that this important difference does not occur in physics.

Einstein‘s discontent comes down to a simple insight:
Science should include our experience of the world as a flow of moments.

Previous arguments in the expulsion of time from the physicist‘s conception of nature:

- The freezing of motion by graphing records of past observations
- The invention of timeless configuration space
- Predicting the future from initial conditions and universal laws
- Determinism and time-reversibility

Newtonian arguments

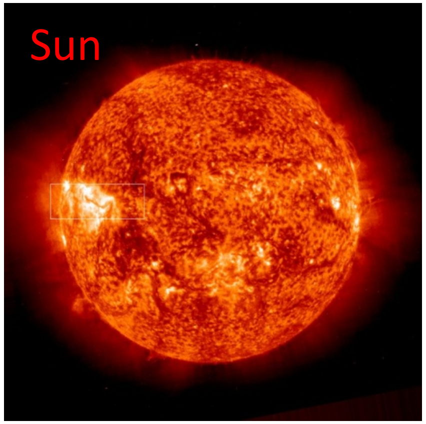
- The relativity of simultaneity
- The block-universe picture of spacetime
- The beginning of time in the Big Bang

Einsteinian arguments

- Quantum cosmology and the end of time

Cosmological arguments

8. The Cosmological Fallacy



It remains a great temptation to take a law or principle we can successfully apply to all the world's subsystems and apply it to the universe as a whole. To do so is to commit a fallacy, which Smolin calls the cosmological fallacy.

Applying the Newtonian paradigm to the universe as a whole is an impossible task!

No theory based on the Newtonian paradigm can answer these questions:

- Why is the universe governed by a particular set of laws?
- Why does the universe start off with a particular set of initial conditions?
- What mechanism selected them out of the infinite set of possibilities?

Within the Newtonian paradigm these questions will remain mysteries forever!

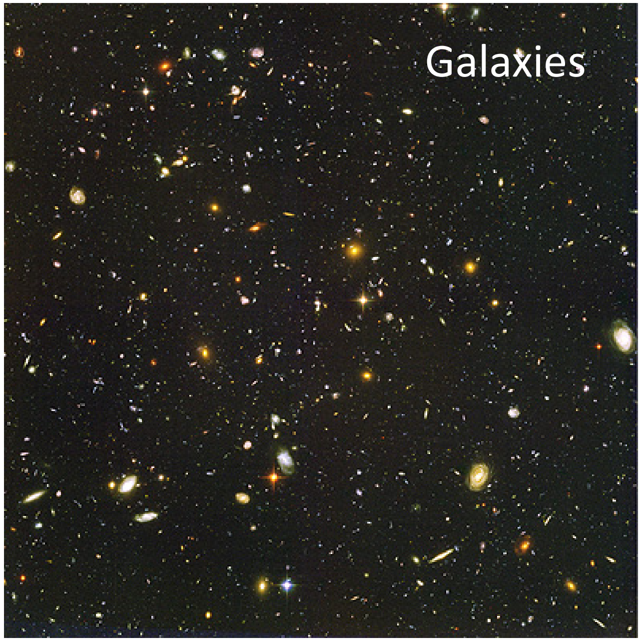
We need a new theory in which the reality of time is a central element!

9. The Cosmological Challenge

The great theories of the 20th-century physics - relativity, quantum theory, and the standard model - represent the highest achievements of physical science, and are confirmed to amazing accuracy!
However, they cannot be considered as fundamental, since each divides the world into the „box“ and the „rest of the universe“, which is implicitly there by giving us rulers and clocks to measure space and time in the isolated system.

- **Experimental physics is the study of truncations of nature.**
- **Theoretical physics designs *effective theories*, considering a (box) subset of degrees of freedom and ignoring the rest.**

But there is no such thing that is isolated from influence by the rest of the universe. *„Principle of no isolated systems“*.
Decoherence (decorrelation) produces the transition from a quantum to a classical system (through multiple interaction).



The cosmological challenge is to formulate a background-independent theory that can be applied to the whole universe, which is not part of a vastly larger system.

10. Principles for a New Cosmology

The new theory must

- contain what we already know about nature,
- be scientific, i.e. imply specific testable predictions,
- answer the „Why these laws?“ question, and explain fundamental parameters and constants,
- Answer the „Why these initial conditions?“ question.

1. No chains of explanation can point outside the universe, *„Principle of explanatory closure“*, for which we rule out fixed background structures.
2. All influences or forces should be mutual, *„Principle of no unreciprocated action“,* saying that every entity in the universe interacts with everthing else (**relationalism**).
3. Two things that have the same relationship with everything else in the universe must actually be the same thing, *„Principle of identity of the indiscernables“* (Leibniz).

There can be no fundamental symmetries in nature, as they arise from treating a subsystem of the universe as if it were the only thing that existed. Symmetries are approximate, and so are the laws of energy, momentum and angular momentum conservation!

The laws of nature are results of evolution, which implies that time is real!

11. The Evolution of Laws

The new cosmological theory: Should explain the choices of laws and initial conditions and be testable by doable experiments and even vulnerable to falsification (Popper).

The theory in which laws evolve is called *„cosmological natural selection“* (Smolin, 1992) and based on the theory of population biology. This requires:

- A **space of parameters** that vary among a population (genes in biology, parameters and constants in physics);
- A mechanism of **reproduction** (quantum gravity does away with the singularities where time begins and ends; black holes lead to the birth of new universes) ;
- **Variation**, each time a new universe is created there is a small random (mutation) change in the parameters (Λ, α, m) of the laws;
- **Difference in fitness**, which is a measure of how many black holes a universe creates;
- **Typicality**, assuming that our universe is a typical member of the population of universes.

Laws will change in time as the population evolves. The resulting parameter variations can lead, e.g., to different carbon and oxygen abundances, different critical masses of neutron stars, different numbers of black holes, or affect the rate of star formation!

12. Quantum Mechanics and the Liberation of the Atom

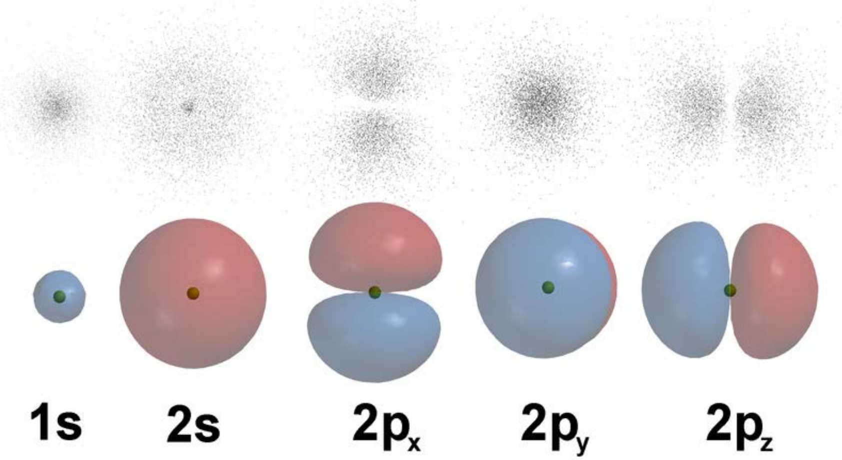
Taking time as fundamental and real may help resolve the puzzle of making sense of quantum theory, which is the most successful theory yet invented but is probabilistic and seems incomplete, and it is a challenge to our attempts to comprehend the world.

- Incompatibility (non-commuting variables such as position and momentum)
- Entanglement (compound systems are more than their parts; the origin of novelty)
- Nonlocality (entangled pairs of photons interact at a distance by nonlocal correlations)

Smolin believes that the strange features of quantum theory arise because it is a truncation of an unknown cosmological theory, and reality of time makes a new formulation possible.

„The principle of precedence“ sees the laws of nature as habits developed over time (C.S.Peirce).

„The free-will theorem“ says: Suppose there is a sense in which two experimenters are free to choose which measurement they make on their atoms. Then the response of the atoms to the measurements is free in the same sense (Conway and Kochen)! Quantum mechanical systems have maximal possible freedom from classical determinism by their being probabilistic.

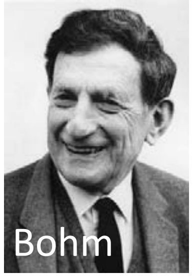


13. The Battle between Relativity and the Quantum

The *principle of sufficient reason* is central to the program of extending physics to the scale of the universe as a whole, because it sets a goal of discovering a rational reason for every choice that nature makes. The apparently free, uncaused behaviour of individual quantum systems presents a formidable challenge to that principle.

Could there be a deterministic cosmological theory that gives rise to quantum physics whenever we isolate a subsystem and ignore the rest? One example is the *hidden variables theory* by deBroglie (1927) and Bohm, which today is persued by few people.

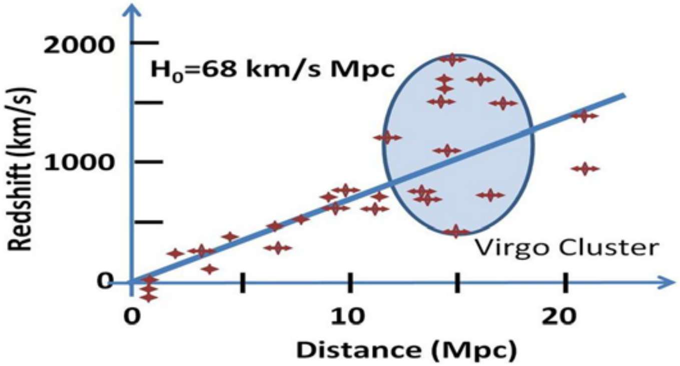
In quantum mechanics a special status is assigned to time in the sense that it is treated as a classical background parameter, external to the system itself. All measurements of observables are made at certain instants of time and probabilities are only assigned to such measurements. Special relativity has modified the notion of time. But from a fixed Lorentz observer's viewpoint time remains a distinguished, external, global parameter.

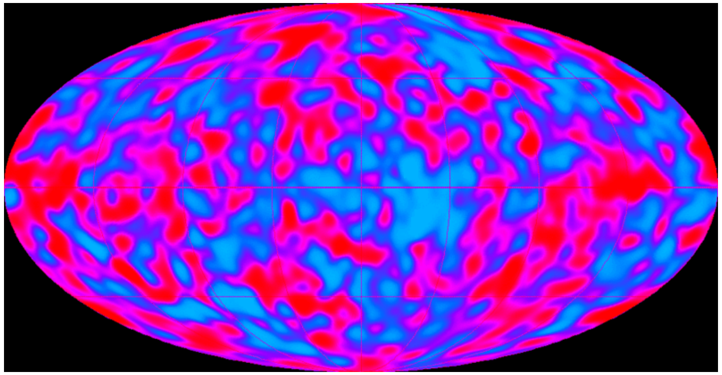


There is a successful marriage of special relativity with quantum theory called quantum field theory. It is the basis of the Standard Model of Particle Physics and makes a great many precise predictions, which have been upheld by the results of many experiments (Higgs boson).

14. Time Reborn from Relativity

- At each point in space there will be one special observer who sees the galaxies moving away from him in all directions (Hubble flow: $v=H_0d$).
- Another way to fix a preferred family of observers is the CMB which is coming at them at **the same temperature from all directions in the sky**.





The „relativity of motion“ is a symmetry principle of GR, yet some solutions of theories can break their symmetries! But Einstein‘s theories of SR and GR rule on smaller scales (experimentally confirmed in our solar system).

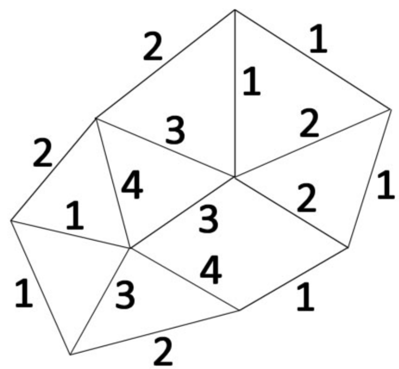
If time is real, in the sense of a *real present moment*, there is a boundary all observers can agree on between the real present and the not yet real future. This implies a physical notion of simultaneity that includes distant events and, indeed, the whole universe! This time can be called a *preferred global time*. Its choice is determined by how matter/energy is distributed across the universe. The expansion rate can be taken for a universal clock.

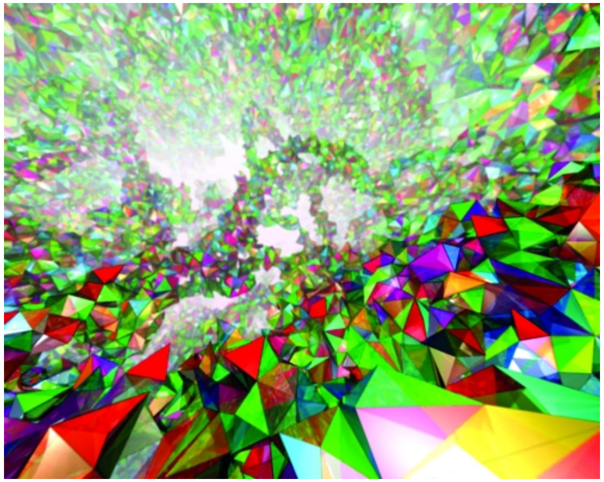
15. The Emergence of Space I

Nothing is more commonplace than space, yet when we examine it closlely, nothing is more mysterious. Space will likely turn out to be an illusion - of the sort that temperature and pressure are - a usefull way to organize our impression of things on a large scale. Relativity theory merged space with time, leading to the block-universe picture of a four-dimensional reality. But the hypothesis of the reality of time frees time from this false unification. Thus we can develope very different ideas of space (emergent) and time.

Loop quantum gravity (LQG) describes space as a dynamical network of relationships. According to LQG regions of space can only have discrete values, that is space is quantized and granular. Areas of surfaces are also quantized on the natural Planck scales, which is the Planck length (ca. 10^{-35} m), respectively time (ca. 10^{-43} s).

Starting with Einstein's theory of GR, the LQG theory provides a way to quantize GR. The spin-foam model gives a quantum version ot the block-universe picture. However, it is limited to a small region of space-time.

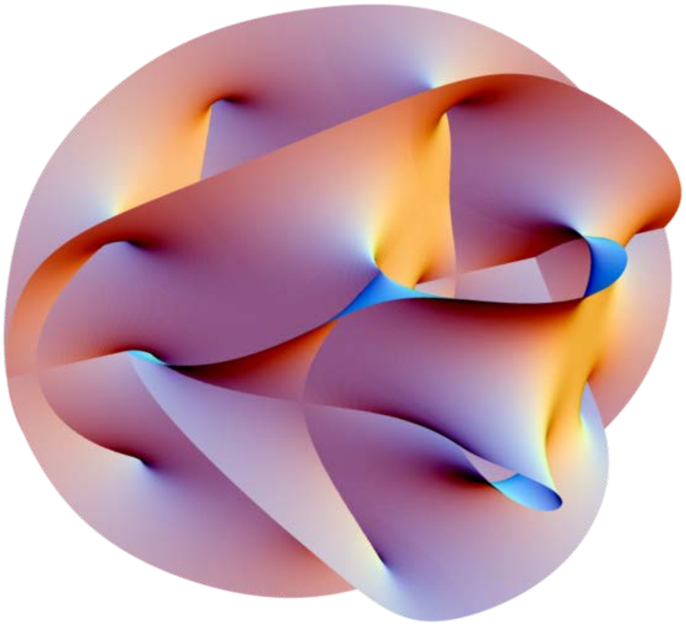




Spin network and quantum foam

15. The Emergence of Space II

Both loop quantum gravity and ***string theory*** suggest that quantum gravity can be understood as describing regions of spacetime with boundaries. Their strongest results are achieved in the context of physics in a box, without addressing the issue of whether or not the description can be scaled up to a theory of the whole, closed universe.



Projection of a Calabi–Yau manifold, one of the ways of compactifying the higher dimensions posited by string theory

In LQG there are about 10^{180} nodes in the quantum foam, one per Planck-length cubed. *Disordering locality* by introducing *nonlocal links* (geometrically implying higher than three spatial dimensions) may generate inumerable new connections. ***Might the universe be full of such nonlocal connections?***

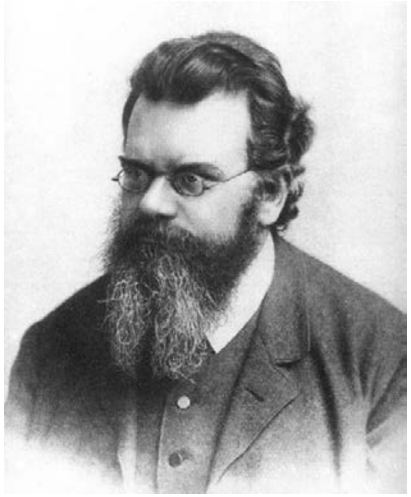
Triangulation of a smooth surface, say a sphere, i.e. covering it by randomly sized triangles is easy, but the inverse, namely to create a sphere by attaching many triangles randomly to each other, is very unlikely. ***So why does the real world look like three-dimensional space and not a complex network?***

16. The Life and Death of the Universe I

Why is the universe hospitable to life? Our universe has a history of evolving from the simple to complex. Complexity is improbable and requires a series of steps, implying ordering of events in time. This gives time a strong directionality , i.e. *the arrow of time*.

In past views, the universe is fated to end in a state of equilibrium called the *heat death of the universe*, which would be without change and impulse toward organization. This requires understanding the meaning of *entropy* and the second law of thermodynamics.

Boltzmann's famous formula for entropy is $S = k_B \ln W$, where k_B is his constant, and *ln* is the natural logarithm. *W* is the *Wahrscheinlichkeit*, meaning the probability or frequency of occurrence of a macrostate or, more precisely, the number of possible microstates corresponding to that macrostate.
W is the number of (unobservable) "ways" in which the (observable) thermodynamic state of a system can be realized, for example by assigning different positions and momenta to the various molecules of a gas. *W* is very large for the universe!



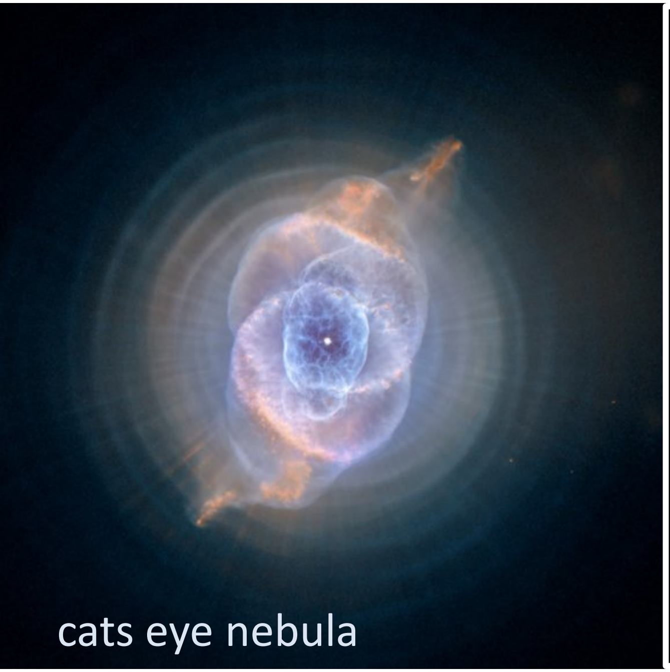
1844-1908

L. Boltzmann

Entropy is extensive and emergent.

16. The Life and Death of the Universe II

The **second law of thermodynamics** states that the **entropy** of an isolated system never decreases, because isolated systems always evolve toward thermodynamic equilibrium, a state with maximal entropy. Thus the entropy of the universe tends to a maximum.



The question of why the universe is interesting, and appears to be getting more so, is akin to the question of why the second law of thermodynamics has yet to act to randomize the universe into thermal equilibrium, in spite of billions of years of apparent opportunity to do just that.

The simplest sign that our universe is not in thermal equilibrium is that there is an **arrow of time**. The flow of time is marked by a strong asymmetry: **We feel and observe ourselves moving from the past into the future.**

16. The Life and Death of the Universe III

- The universe is expanding and not contracting. We call this the *cosmological arrow of time*.
- Small bits of the universe, left to themselves, tend to become more disordered in time. We call this the *thermodynamic arrow of time.*
- People, animals, plants are born, grow up, and die. We call this the *biological arrow of time*.
- We experience the time flowing from past to future. This is the *experiential arrow of time.*
- Light that reaches our eyes gives us a view of the world in the past, not the future. This is called the *electromagnetic arrow of time*.
- Our universe contains many black holes that formed late from the collapse of massive stars. This irreversible accretion produced a lot of entropy. Why did the universe not start of filled with them? There is a *black-hole arrow of time*.

These distinct arrows of time are facts that require explanation!
But how can we do that if the laws of nature are reversible in time?

17. Time Reborn from Heat and Light I

Can the universe contain two identical moments? The fact that there is an arrow of time means that every moment is unique. No moment ever repeats. Looked at enough detail, every event in the universe is unique. There is never a complete realization of the conditions needed to make sense of the Newtonian paradigm.
No experiment can be an exact copy of another!

- We call a universe that satisfies the principle of the indiscernables a *Leibnizian universe*.
- We call a universe in which structure and organization arise due to statistical fluctuation, and then dissipate due to the tendency of entropy to increase, a *Boltzmannian universe.*

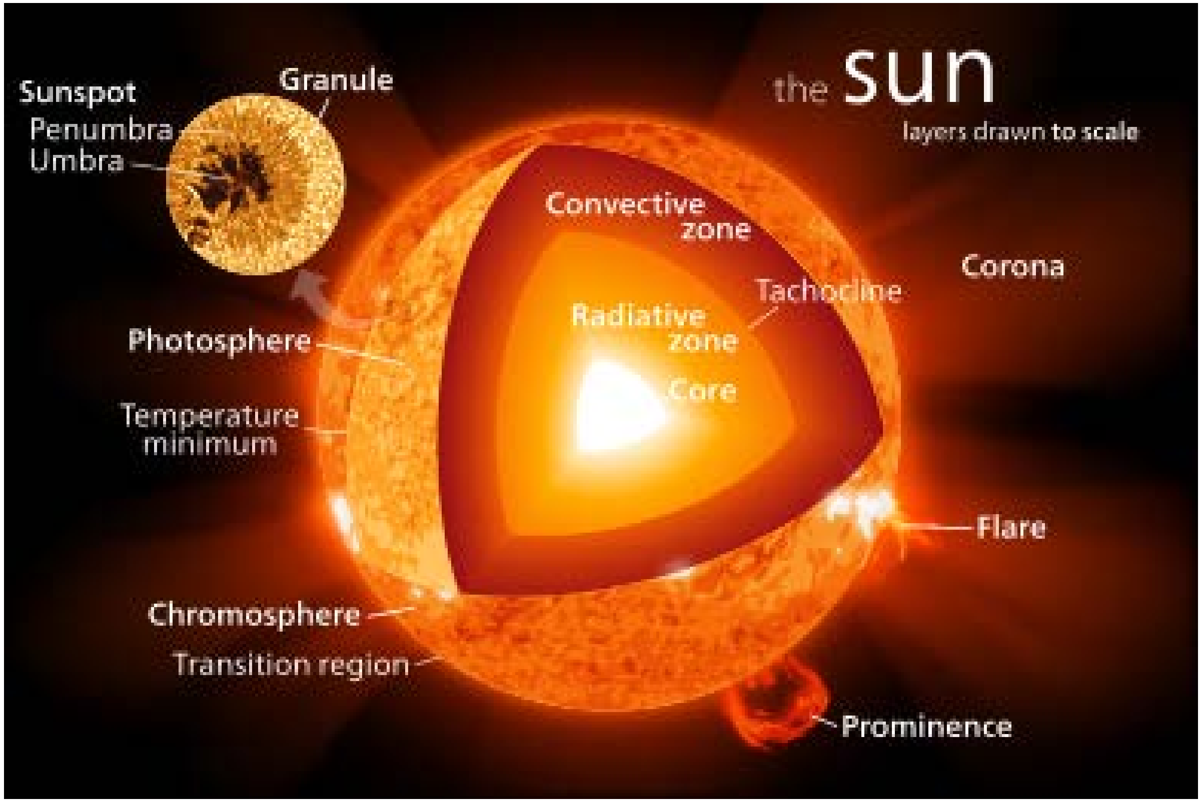
In a Leibnizian universe time is real, but in a Boltzmannian universe there are lots of recurring moments, because all moments in near thermal equilibrium are roughly the same. Our universe can not be of both type, so which is it? A Leibnizian universe will be full of complexity that generates unique patterns and structures, from dust to life.

One component of our present Leibnizian universe is nearly in thermal equilibrium, the cosmic microwave background (CMB), which is a 400000-years-old relic of the early universe.

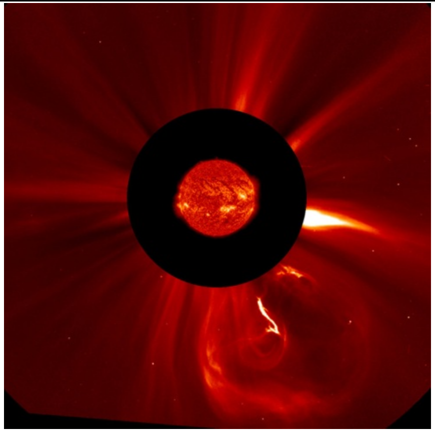
17. Time Reborn from Heat and Light II

The most common objects in our universe are **stars**. A star is not in equilibrium with its surroundings, and it is in a dynamical balance between the energy generated by nuclear reactions in the core, which would blow it up, and gravity, which would collapse it.

The **Sun** is a system far from thermal equilibrium by a steady flow of energy through it. The generated sunlight illuminates the surfaces of planets like Earth, driving them into a far-from-equilibrium state of their own and supplying them with energy (light).



Flows of energy through open but bounded systems tend to drive them to states of higher organization and create patterns and structures; the ***principle of self-organization***



Coronal mass ejection

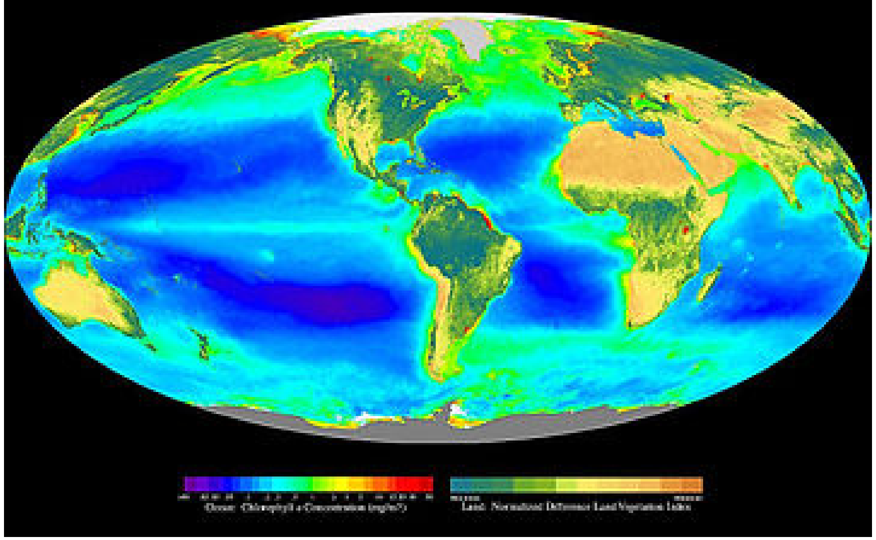
17. Time Reborn from Heat and Light III

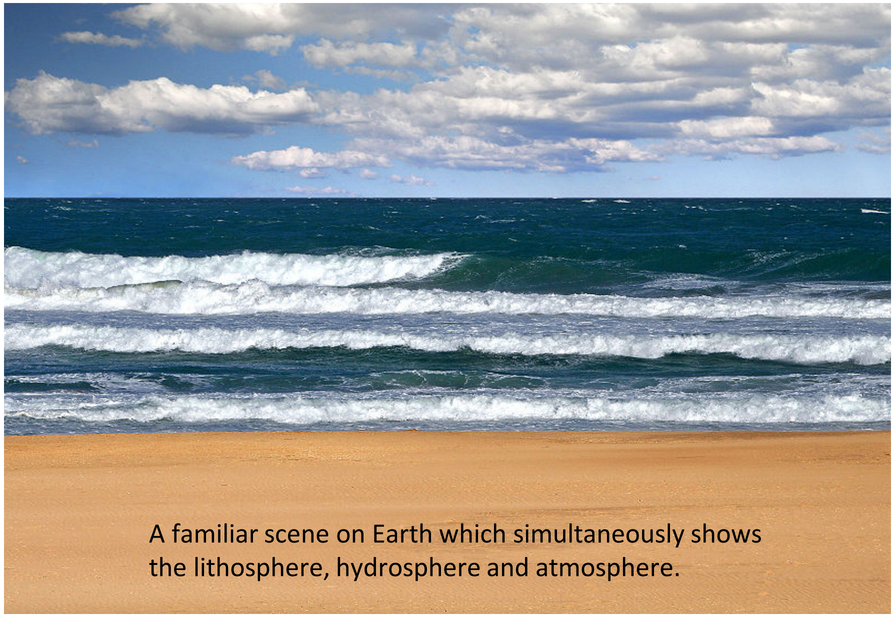
Highly complex systems cannot be in equilibrium, because order is not random, and so high entropy and high complexity cannot coexist! Self-organizing systems are stabilized by feed-back mechanisms. Feedback processes regulate and channel flows of energy and matter.

Our present universe is characterized by structure and complexity on a wide range of scales, From the organization of molecules in living cells to the organization of galaxies into clusters. What we see when we look back is a universe evolving from equilibrium to complexity! Evolving complexity means time! There has never been a static complex system.

The increasing organization of the Earth's biosphere is driven by flow of energy from the Sun.

A false-color composite of global oceanic and terrestrial photoautotroph (chlorophyll) abundance, from September 1997 to August 2000





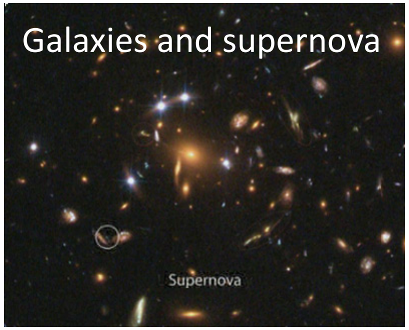
A familiar scene on Earth which simultaneously shows the lithosphere, hydrosphere and atmosphere.

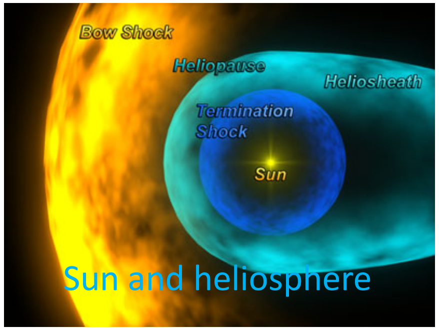
17. Time Reborn from Heat and Light IV

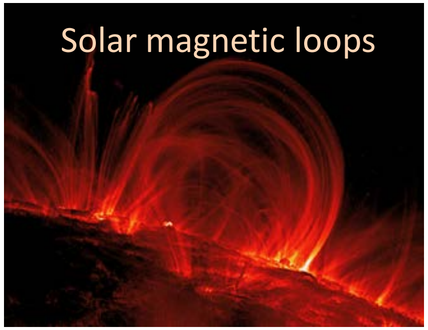
Why are there stars? They rely on two unusual features of the laws of physics:

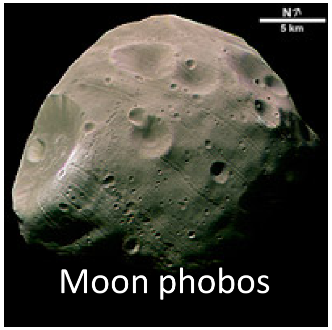
- Fine tuning of the strengths of the four forces (enabling nuclear fusion and stable atoms)
- Non-thermodynamic behaviour of gravity (enabling complex bound systems)

Systems held together by gravity behave strangely. Stars, stellar systems, galaxies, and black holes are all *anti-thermodynamic*. They cool down when you put energy into them, and heat up if you take it out. Thus they are unstable, which leads to the formation of patterns in space and time.









The reason that the universe is interesting (alive and not dead) is threefold:

- *Driven self-organization* *(acting over a myriad of subsystems and scales)*
- *Anti-thermodynamic nature of gravity* *(leading to instability and accretion)*
- *Fine-tuning of the fundamental laws* *(in nuclear and atomic physics)*

18. Infinite Space or Infinite Time

We have seen that by embracing the reality of time we can comprehend why the universe is full of structure and complexity. But how long can ist stay like that? Can equilibrium be held off forever? This brings us to the most speculative subjects in modern cosmology: ***the very far away and the far future.***

By various reasons, it seems plausible to hypothesize that the universe is finite in spatial extent and has an overall topology of a closed surface, like a sphere or a torus. Which topology is correct depends on the average curvature of space and energy distribution. Smolin concludes that models of the universe must be spatially closed without boundary.

The literature of cosmologist is filled with anxiety about the future. Perhaps in the long term not only we all will die but so will the universe. We can reliably deduce the following:

- Eventually the galaxies will stop making stars (spiral galaxy makes around a star a year).
- The stars will burn out (as they all have finite lifetimes).
- Once the last stars have died, the universe is filled with relic baryonic matter, dark matter, radiation, and dark energy (cosmological constant Λ of empty space).

The cosmological constant could decay to zero. The universe might become eternal and static. Λ might become negative and the universe collapses, followed by a bounce (cyclic models) and re-expansion. The bounce could be due to quantum gravity.

19. The Future of Time I

To make further progress in cosmology and fundamental physics we need a new conception of a *law of nature*, valid on the cosmological scale, which avoids fallacies and answers the questions that the old framework cannot address. Moreover, it must be a scientifc theory, i.e., make falsifiable predictions for new, but doable, experiments.

The guides in this endeavour should be the principles of:

- sufficient reason,
- identity of the indiscernables,
- explanatory closure,
- no unreciprocated action.

To realize these principles in a relational approach of all the properties of things in nature, ***time must be real and global.*** This is also required for a *deeper understanding* of

- the quantum phenomena in the micro world (time inversion symmetry),
- the emergence of thermodynamics in the macro world (directed arrow of time).

The idea of a global time means that our experience of the time is passing is shared across the universe, but of course it conflicts directly with the relativity of simultaneity of SR and GR.

19. The Future of Time II

The reality of time has important implications for the role of mathematics in physics. What mathematics corresponds to are not the actual physical processes but only records of them once completed – which are also, by definition, timeless. Yet the world remains, always, a bundle of processes evolving in time, and only small parts of it are representable as mathematical objects.

Because the Newtonian paradigm cannot be scaled up to include the universe as a whole, there need be no mathematical object corresponding to the history of the entire universe.

J.A. Wheeler used to write equations on the blackboard and say:
Now I'll clap my hands and a universe will spring into existence.

S. Hawking asked in *„A Brief History of Time"* : *What is it that breathes fire into the equations and makes a universe for them to describe?*

Logic and mathematics capture aspects of nature, but never the whole of it. There are aspects that will never be representable by mathematics and need not be stated mathematically. An example is the theory of natural selection. Mathematics is only one language of science. The links between experiments and the real world must be stated in ordinary language.

19. The Future of Time III

To illustrate the choices before us, we list some *contrary assertions* that we encountered:

Time is an illusion	**Time is real**
Space and geometry are real	Space is emergent and approximate
Laws of nature are timeless and inexplicable.	Laws evolve in time and may be explained by their history.
Future is determined by physical laws acting on initial conditions.	Future is not totally predictable, hence partly open.
Universe is spatially infinite.	Universe is spatially finite.
Initial singularity is the beginning of time.	Big Bang is actually a bounce which is to be explained by the history before it.
Equilibrium is the natural state and inevitable fate.	Gravitationally bound systems evolve to heterogenous configurations.
Complexity and order are random and due to rare fluctuations.	Parts of the universe organize themselves to complexity driven by gravitation.
History of universe is identical to some mathematical object.	Not every property of nature has a mirror in mathematics.

Epilogue: Thinking in Time

The progress of human civilization is the result of the disciplined application of imagination, which let us to adapt to novel environments. The bargain of human life is to thrive on the cusp of uncertainty. But imagination enabled us to extend our domain across the planet, and to develope technologies, sciences and civilizations. The speciation that divided us from animals and other primates is culture, which is perhaps another word for imagining and striving for a better way to live.

We are accustomed to seeing ourselves as part from nature and our technologies as impositions on the natural world. We have to understand the roots of the distinction between the artifial and the natural. These have a great deal to do with time. The false idea we have to put behind us is the idea that what is bound in time is an illusion and what is timeless is real.

Science is one of the great human adventures. The growth of knowledge is the spine of any telling of the human story. While the future of science is unpredictable the only certainty is that we will know more in the future. For on every scale, from an atom's quantum state to the cosmos, and at every level of complexity, the key is time, and the future is open.