Title: Multiversal Pictures: Science and Signs of Other Universes

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Abstract:

Multiversal Pictures

Science and Signs of Other Universes

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„A Debate in Cosmology - The Multiverse“
Perimeter Institute, September 2 – 4, 2008

Multiversal Pictures

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Universal Pictures – the past ...

Multiveral Pictures – the future?

The Multiverse – Just a matter of faith?

The Edge Question 2005:

- **"What Do You Believe Is True Even Though You Cannot Prove It?"** (Nicholas Humphrey)

From ~ 120 answers 7 were related to the multiverse:

- "Believers":
  Alex Vilenkin, Lawrence M. Krauss, John D. Barrow
- Explanations assuming the existence of other universes:
  Paul Steinhardt, Lee Smolin
- Suggestions about the Multiverse:
  Gregory Benford (intelligent designs by cosmic engineers),
  Rudy Rucker (infinite series of different universes)

Why (should) we believe in other universes (?)

- **Empirical evidence?**
  But: Extraordinary claims require extraordinary evidence! (David Hume)

- **Theory forces us to do so?**
  - Quantum Theory? – Many World, Many Histories...
  - Inflationary Cosmology – Bubble/Pocket universes
  - String Theory? – The Landscape
  - Big bang explanations with precursor universe or fluctuation models

- **Philosophical arguments? (... and prejudice)**
  - explanatory power and depth – not-just-so-stories, selection principles (e.g. cosmic darwinism), anthropic reasoning ...
  - anti-copernicanism, principle of mediocrity ...
  - principle of fecundity/plentitude

- → *Just philosophy or also science?*

Science and Signs of Other Universes

- Can there be a science of other universes (in principle)?
  - No, e.g. because such a hypothesis cannot be falsified
    → Is this true? Is this relevant?
    → What is science?
  - Yes (and perhaps we doing this science already)

→ **Signs of science**, i.e. of a science of other universes

- Can there be signs of other universes?
  Can we detect and recognize them?

→ **Science of signs**, i.e. of finding signs of other universes

Are other Universes a (legitimate) *Object* of Science?

As long as it is pure speculation without any (observational) evidence?

Are other Universes a (legitimate) Object of Science?

- **Distinguish between**
  (1) objects, and
  (2) theories/hypotheses about objects!

- It can (should) not be demanded that the existence of objects is established (proven?) for taking them as a legitimate part of science.
- This would be an unreasonable restriction!
- The hypothetical character of science and scientific progress ultimately demands thinking about *not* established (proven?) entities!

Are other Universes a (legitimate) Object of Science?

- Distinguish between
  (1) objects, and
  (2) theories/hypotheses about objects!

→ **Their (still) speculative status does *not* imply that other universes are *not* a legitimate object of science!**

But, of course, this does not necessarily mean that they are such an object!

→ **Further arguments are required!**

Are other Universes a (legitimate) *Part* of Science?

- If so: Why?
- If not: What are they?
- And what is „Science“?

Are other Universes a (legitimate) Part of Science?

My short answer is: Yes!

Are other Universes a (legitimate) Part of Science?

The longer and (hopefully) more interesting answer is: It depends...

Are other Universes a (legitimate) Part of Science?

It depends on...

- ... what „universe“ means ...
  - not all kinds of (claims of) other universes can be part of science
- ... what „science“ means ...

- If they are part of: why? – I shall review and discuss some arguments
- If not: What are they? – I shall discuss other options
- And what is „science“? – I will not (even try to) answer this, but I shall discuss some useful criteria

- From a *philosophy of science* point of view:
  The challenge of other universes is helpful for a better understanding what „science“ is

Three Perspectives on Science

sociological:

- social practice
  what scientists do (as scientists),
  and what is published in (usually peer-reviewed)
  science journals and books

methodological:

- demarcation criteria
  (e.g. being intersubjective, reproducible, falsifiable)

topical:

- well-established disciplines

Are other Universes a (legitimate) Part of Science?

sociological:

- **Yes**

topical:

- **Yes ...**
- **and No** – but increasing; allow for change and additions!

methodological:

- **most relevant question here!**
  -- the criteria are somewhat arbitrary, controversial, evolving, too restrictive, too special ...
  -- and are there necessary or sufficient criteria for science?

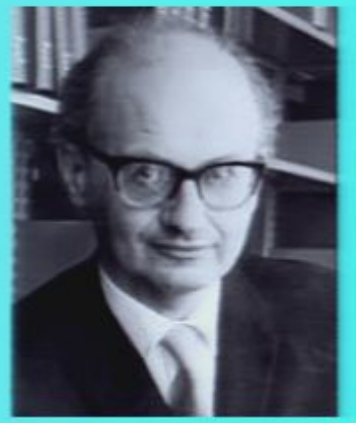
Falsificationism

Scientific statements, refering to reality, must be falsifiable.
Karl R. Popper 1932

- **Demarcation criterium** of science
  (in contrast to metaphysics, logic, pseudoscience...)
- But: falsifiability of theoretical systems, or of parts of such a system, not of single statements
- **Scientific laws** must be falsifiable, e.g. Newton's law
- **Hypothetical universal existence statements**
  need not and cannot be falsifiable, but must be verified
  e.g. Hafnium (element # 72): Popper 1935
  Niels Bohr predicted it in 1922,
  Dirk Coster and George de Hevesy found it in 1923
- not sufficient!
  otherwise fictive ghosts or unicorns would also be part of science
- **Theoretical embedding**
  e.g. wormholes & General Relativity

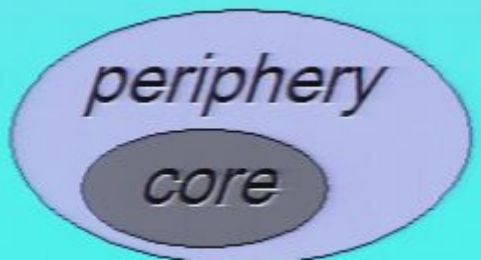
Research Programs (I)

Refutations are not the sign of empirical progress, because research programs grow in a permanent ocean of anomalies. Imre Lakatos 1973 &1978



- Data are theory-dependent, not just empirical;
  they might be simply false or interpreted wrongly
  → do not throw away theories too quickly
  e.g. Newton's law of gravity (Uranus anomalies, Neptune discovered!)
- **give theories a chance!**
  to develop, to get rid of errors, to get more complete
- Often, theories are ahead of data
  → observers: get data!
  → theorists: make testable predictions!
- **sophisticated falsificationism:**
  struggle between theories and data interpretation (quasi-darwinistic)

- problems?



--- modify first! – **auxiliary assumptions**
--- save this! – **immunization**

Research Programs (II)

Criteria for successful research programs:

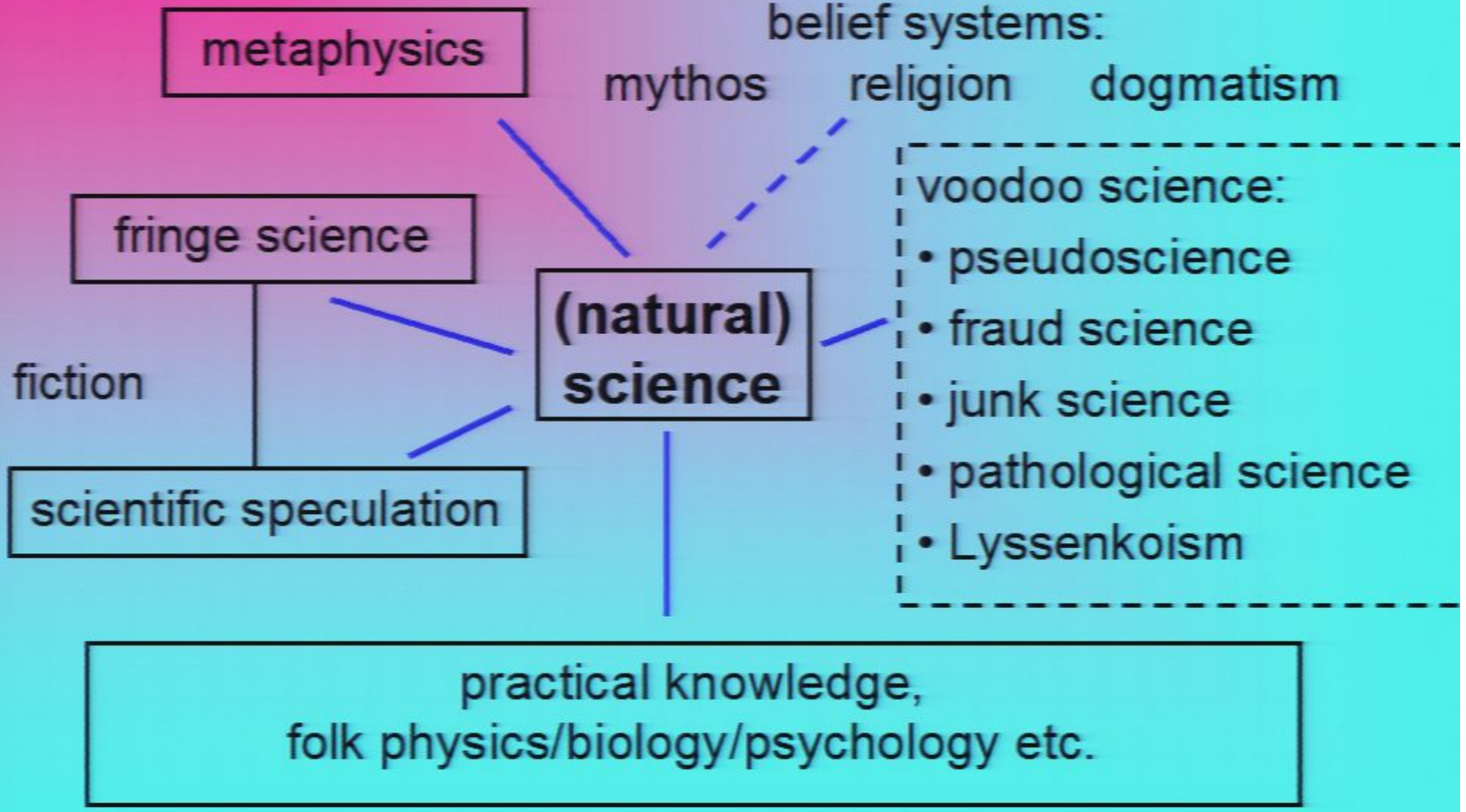
- many applications
- novel predictions
- new technologies
- answering unsolved questions
- consistency
- elegance
- simplicity
- explanatory power/depth
- unification of distinct phenomenon
- truth – *how can we know? just via the criteria above?*

Research Programs & multiverse

Criteria for successful research programs:

• many applications	*well, no*
• novel predictions	*(yes)*
• new technologies	*not yet*
• answering unsolved questions	*yes*
• consistency	*hopefully*
• elegance	*depends on taste*
• simplicity	*(yes)*
• explanatory power/depth	*yes*
• unification of distinct phenomenon	*yes*
• truth	*???*

Science, no science, and nonsense



Features of Science in Contrast to Pseudoscience (I)

Vaas 2008

√ ? – (perspective to) discover new phenomena of nature
√ ? – no vague, exaggerated, obscure claims
√ – no undefinied, vague or ambiguous vocabulary
(√) – embedding in established scientific theories
√ – embedding in established scientific research program
√ (√) – logical (internal) coherence and consistence
√ – open source: no secret data, methods, knowledge...
√ ? – Occam's razor
√ – methodological reflexivity
√ – no questionable "factoids" (Norman Mailer)
√ – no reversal of the burdon of proof
√ ? – testability (verification, falsification) as appliable
(√) – rigorously derived predictions

Features of Science in Contrast to Pseudoscience (II)

- √ – no overemphasis of verifications, anectodes, rumours, ignorance...
- √ – not belief, faith, hope, obedience, but observations, measurements, arguments, mathematical reasoning, inference to the best explanation...
- √ – replication, reproduction of measurements, calculations...
- – statstical significance, double-blind studies ...
- √ – distinction between correlation and causality
- √ – progress, self-corrections, revisions, error analysis
- √ – publications in scientific journals etc. (peer reviewed)
- √ – quotations of scientific literature, no dubious references
- √ – no selective quotes of obsolete or questionable experiments
- √ – demarcation of popular science
- √ – demarcation of pseudoscepticism
- √ – systematicity

Science as Systematicity

Paul Hoyningen-Huene 2008
Vaas 2008

- descriptions
- explanations
- predictions
- the defense of knowledge claims
- epistemic connectedness
- an ideal of completeness
- knowledge generation
- the representation of knowledge
- critical discourse

Summary: Are other Universes a (legitimate) Part of Science?

yes!

Science as Systematicity

Paul Hoyningen-Huene 2008
Vaas 2008

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yes!

Controverses and Universes (I)

Other universes (like them or not) might be ...

- the implication of a slippery-slope argument Rees 2001
  e.g. galaxies beyond our telescopes, beyond the horizon ...
- the implication of a (well-established) theory e.g. Linde, Susskind
- the ultimate anti-anthropocentrism - Copernican principle completed
- an important explanans (or part of that)
  e.g. explaining the big bang, the "fine-tuning" of nature's constants, quantum measurement problem, no time-paradoxes...

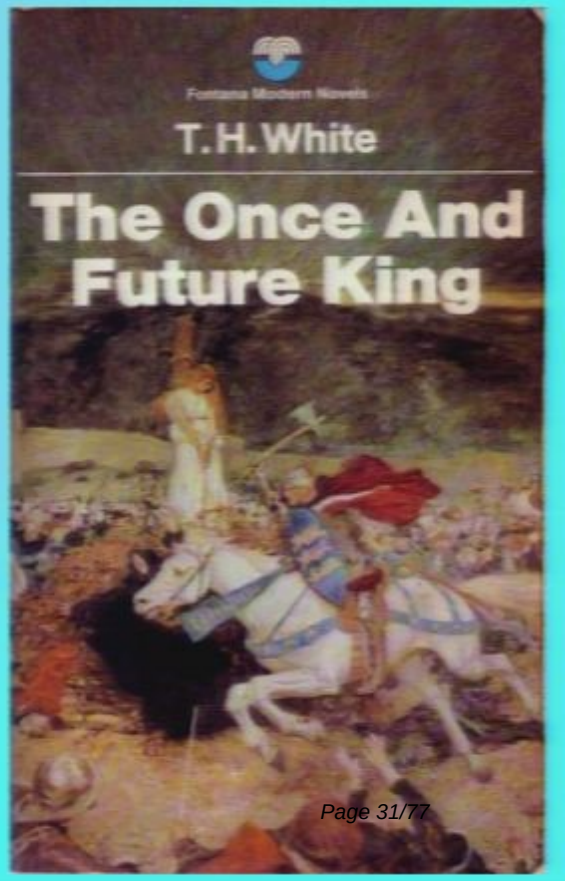
Controverses and Universes (II)

- physical **extravagance**?
  – yes, but there are many (e.g. in relativity, quantum theory...)
- straightforward **extrapolation**?
  or transcendence of speculative reason?
- an **explanation** of anything, therefore nothing?
  or just something?
- against simplicity and parsimony (**Occam's razor**)
  – only many objects, but there is (or might be) a parsimony in relation to principles, restrictions, algorithms, kinds of entities (still: naturalism/physicalism)
- **actual infinities** – is this a problem? (Hilbert, Ellis etc.: yes)

Controverses and Universes (III)

- **principle of plentitude/fecundity**
  everything is real, if it is not explicitly forbidden by laws of nature, e.g. symmetry principles
  Richard Feynman, Dennis Sciama

  Terence H. White:
  The Once and Future King (1958):
  "everything not forbidden is compulsory"



– **so what is forbidden?**

– slippery slope (Davies 2007):
  could there be universes containing magic,
  a theistic God, simulations of every weird fantasy

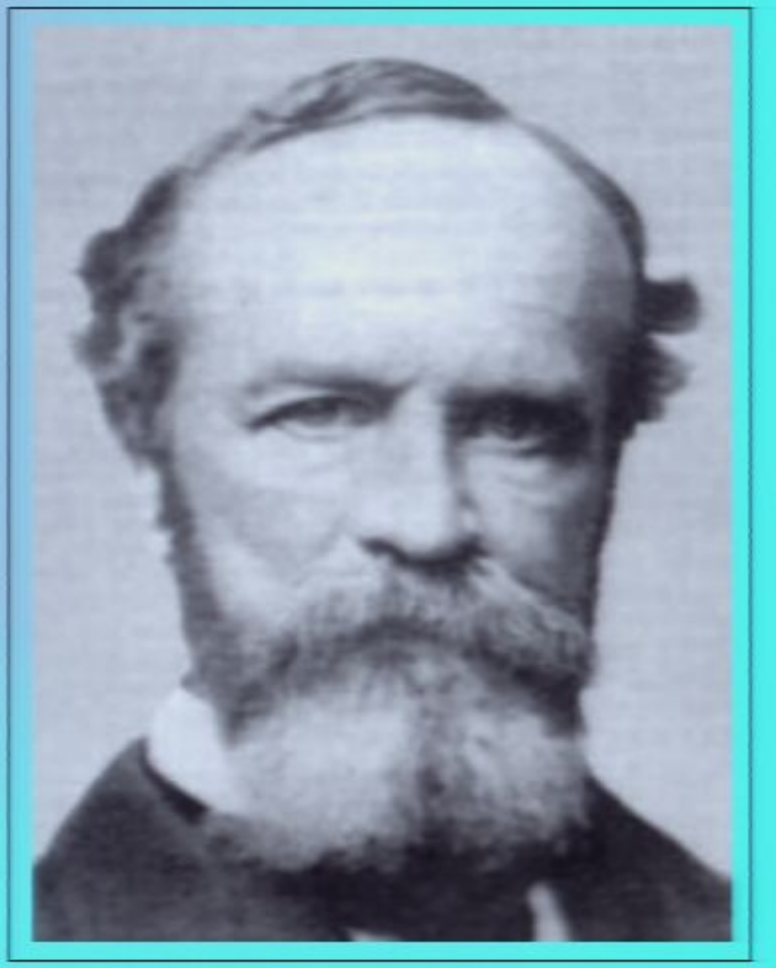
→ some restrictions are necessary!

A Brief History of „Multiverse“ (I)

1895:

William James wrote in his essay *Is Life Worth Living?* (International Journal of Ethics, Vol. 6, No. 1, pp. 1-24):

"Visible nature is all plasticity and indifference, a multiverse, as one might call it, and not a universe."



A Brief History of „Multiverse“ (II)

December 1960:

Andy Nimmo, then vice chairman of the British Interplanetary Society, Scottish Branch, invented the term „multiverse“ for a talk on Hugh Everett III's Many-Worlds Interpretation of quantum physics.

This talk was given in February 1961, and the word was then first used with its original definition:

„an apparent universe, a multiplicity of which, go to make up the whole universe“.

This was because the then dictionary definition of the word „universe“ was: „All that there is".

A Brief History of „Multiverse“ (III)

From 1962 on:

Michael Morcoock, a British science fiction writer, used „multiverse“ as the totality of all universes in his *Eternal Champion* short stories and in his novel *The Blood-Red Game*.

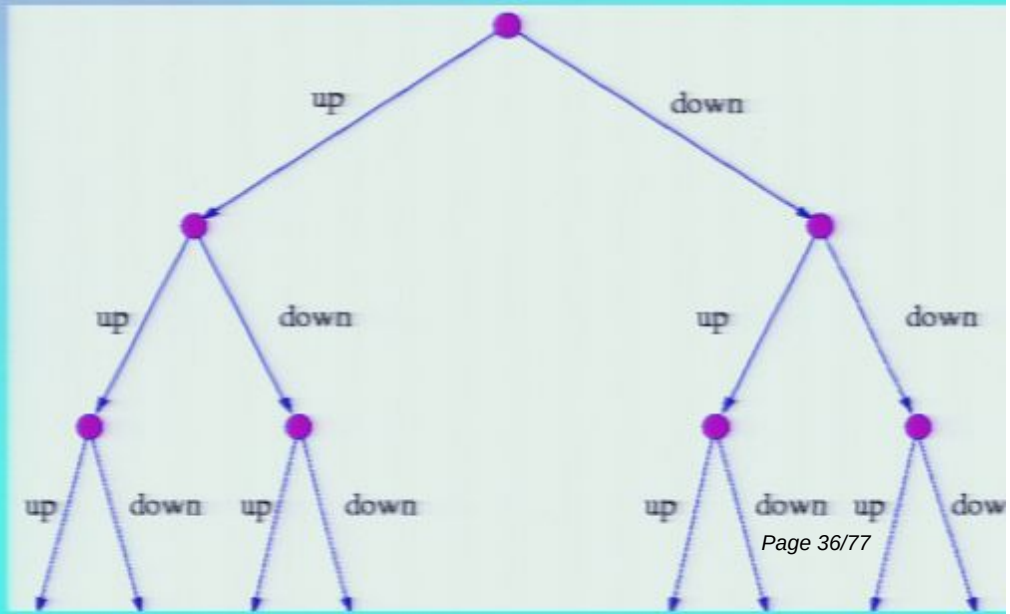
Of course there where many other parallel universe SF stories earlier, e.g. *Sidewise in Time* by Murray Leinster aka William F. Jenkins (1934).

A Brief History of „Multiverse“ (IV)

David Deutsch, a quantum physicist at Oxford University, read Moorcock's novel and introduced „multiverse“ into quantum physics – in the opposite meaning of Nimmo's suggestion.

Many Worlds (not Many Words)

Hugh Everett III
(1957)



A Brief History of „Multiverse“ (V)

Multiversal cosmology

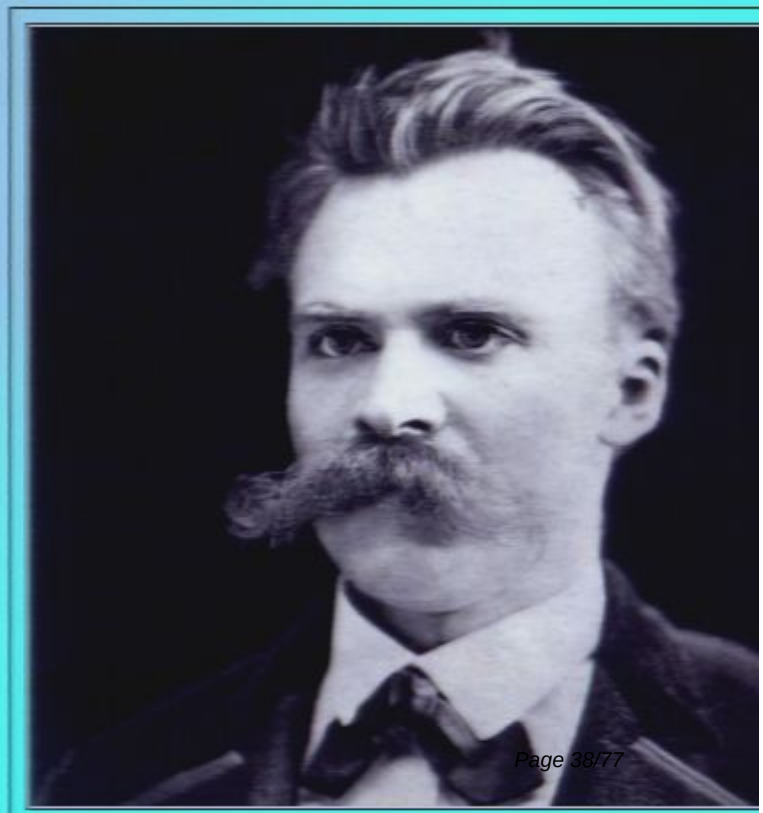
- Cyclic (oscillating) universe(s)
- Eternal Inflation
- „Brane New Worlds“
- „The Landscape“ in String Theory

Eternal recurrence?

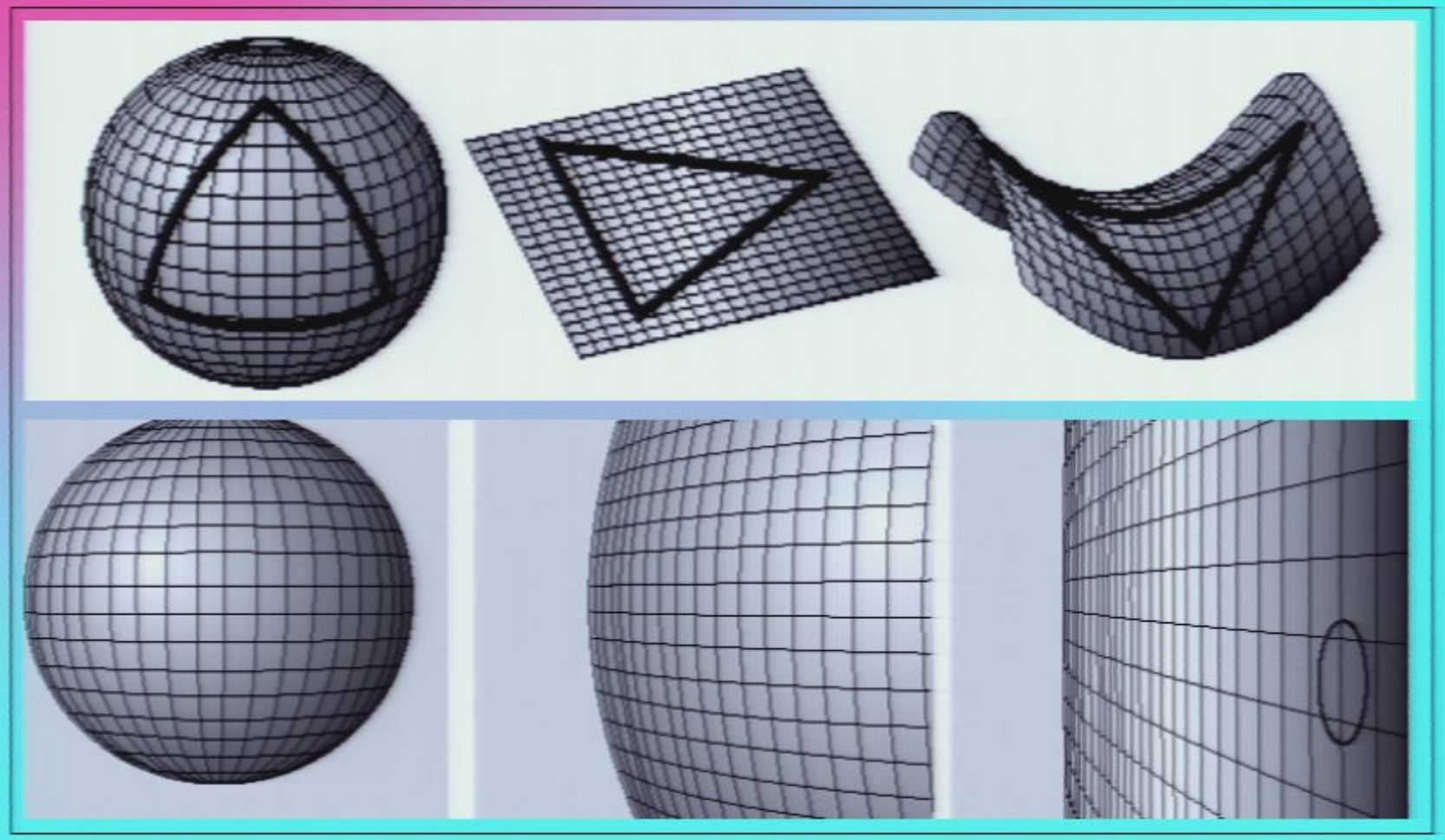
- **(Quasi)Ergodicity**
  - classiscal mechanics, quantum mechanics
- **„Many Worlds in One “** (Alexander Vilenkin
  - next Doppelgänger: $(10^{10})^{29}$ Meter,
    next Doppelgänger universe: $(10^{10})^{115}$ Meter

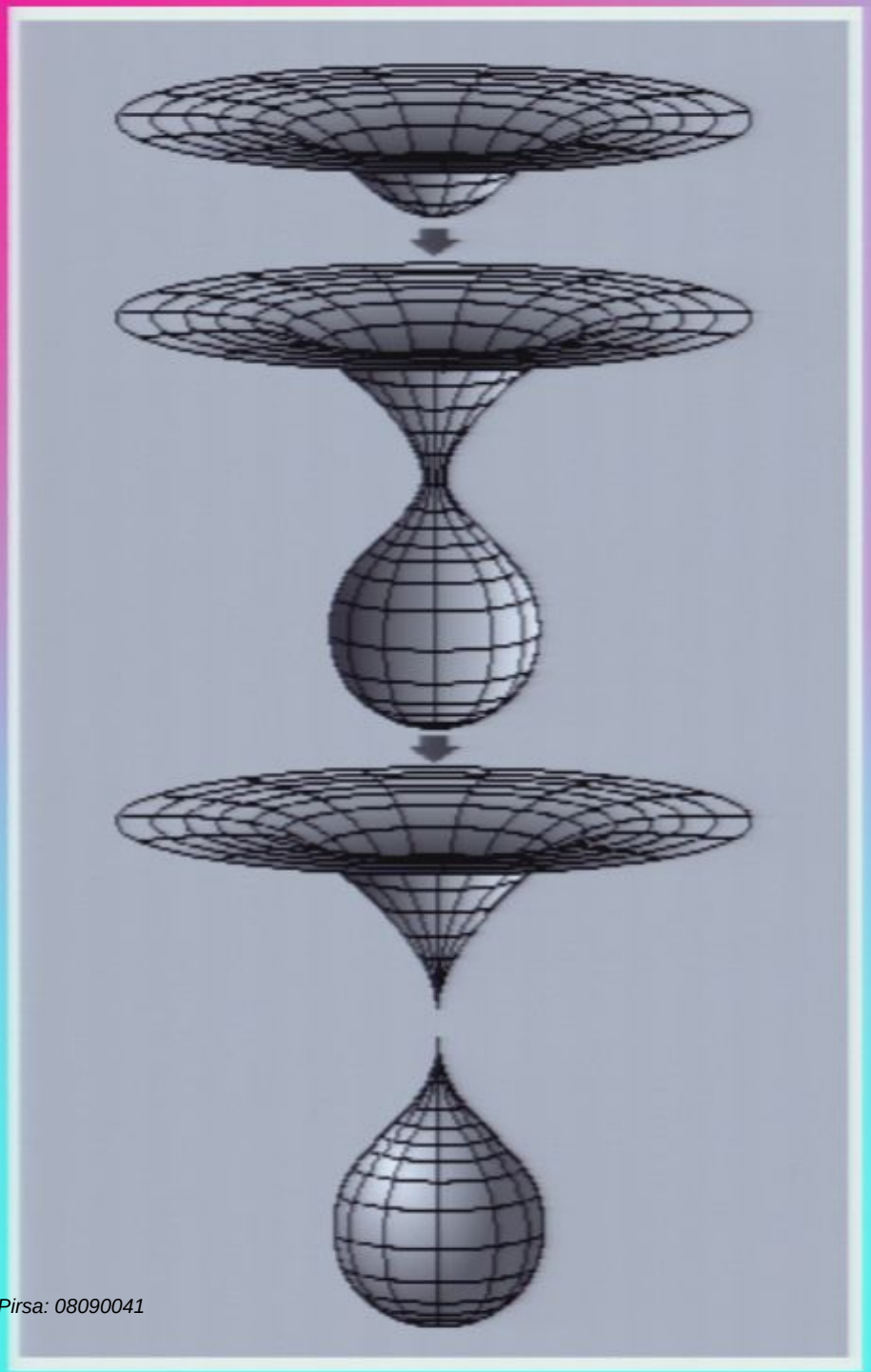
Und diese langsame Spinne, die im Mondlicht kriecht, und dieser Mondschein selber, und ich und du im Torwege, zusammen flüsternd, von ewigen Dingen flüsternd – müssen wir nicht alle schon dagewesen sein? – und wiederkommen und in jener anderen Gasse laufen, hinaus, vor uns, in dieser langen schaurigen Gasse – müssen wir nicht ewig wiederkommen?
War *das* das Leben? Wohlan! Noch einmal!

Friedrich Nietzsche
(Also sprach Zarathustra III, 1883)



Our Universe
vs. the (vast, infinite?) Universe

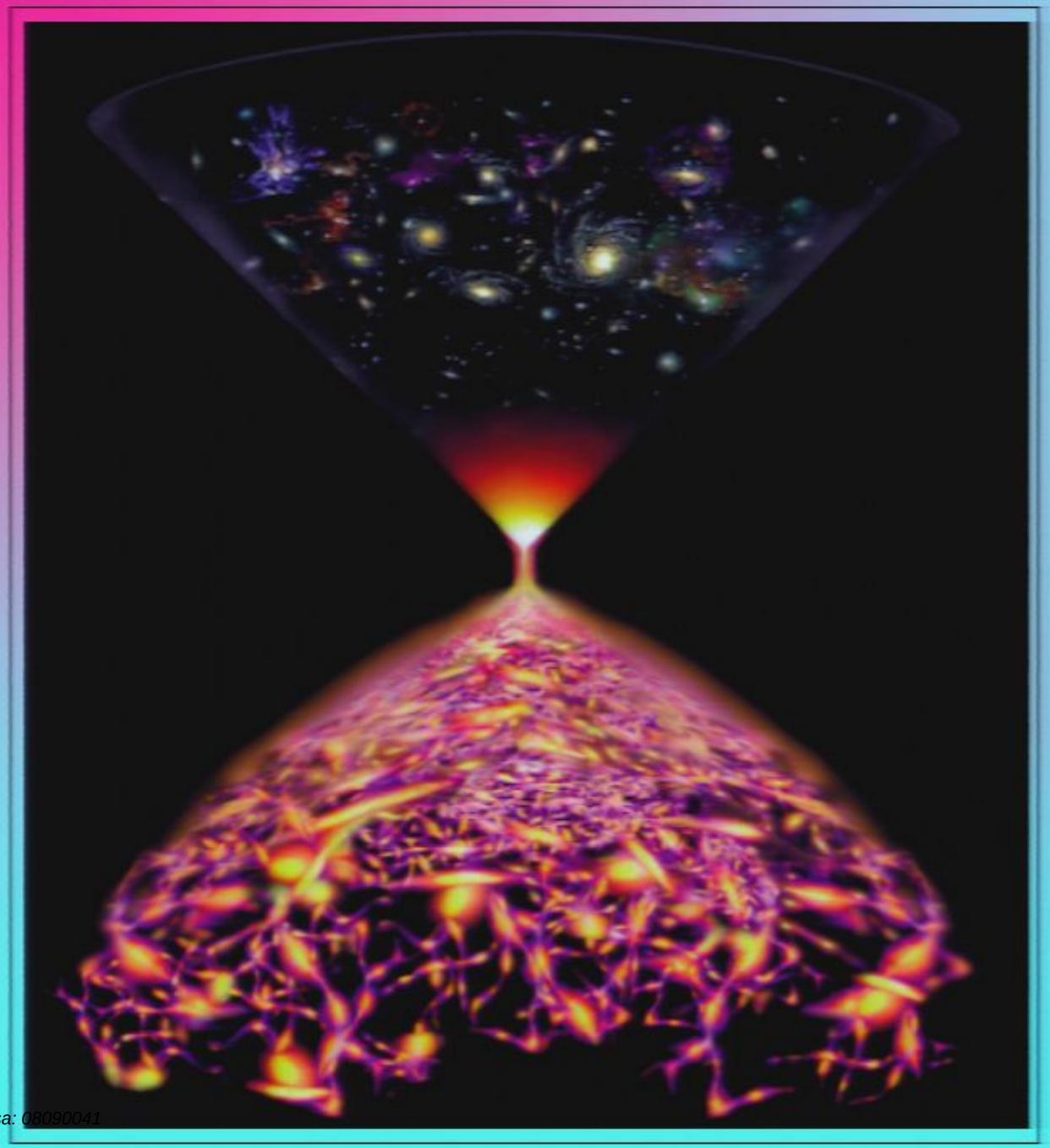




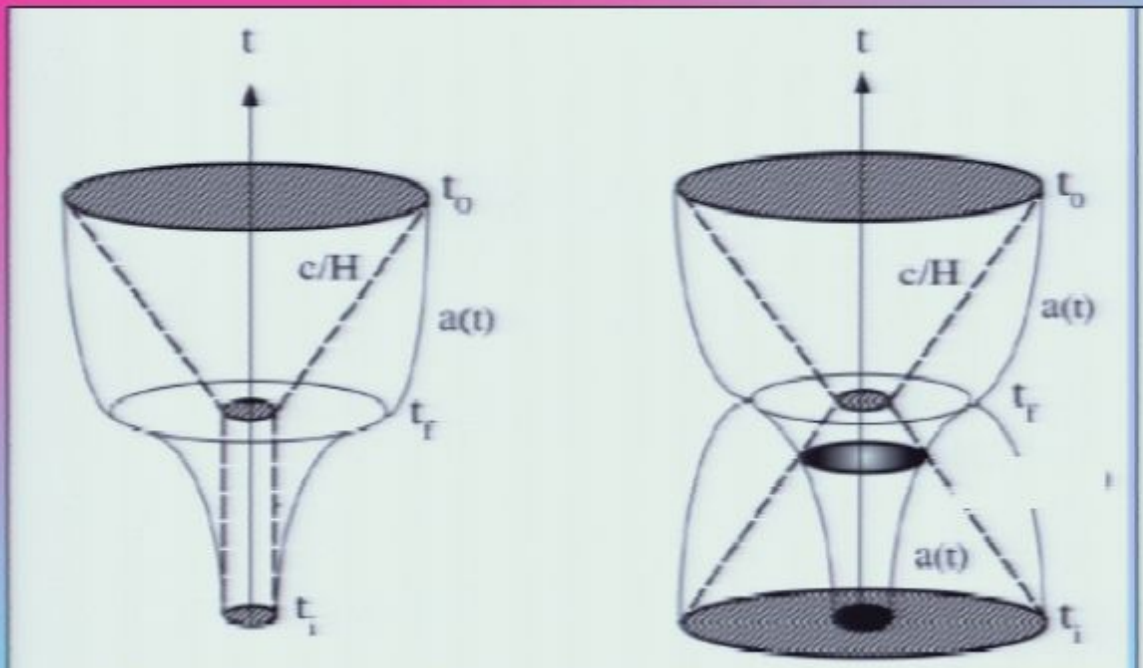
Baby Universes Recycling Universe

The Big Bang as an experiment?

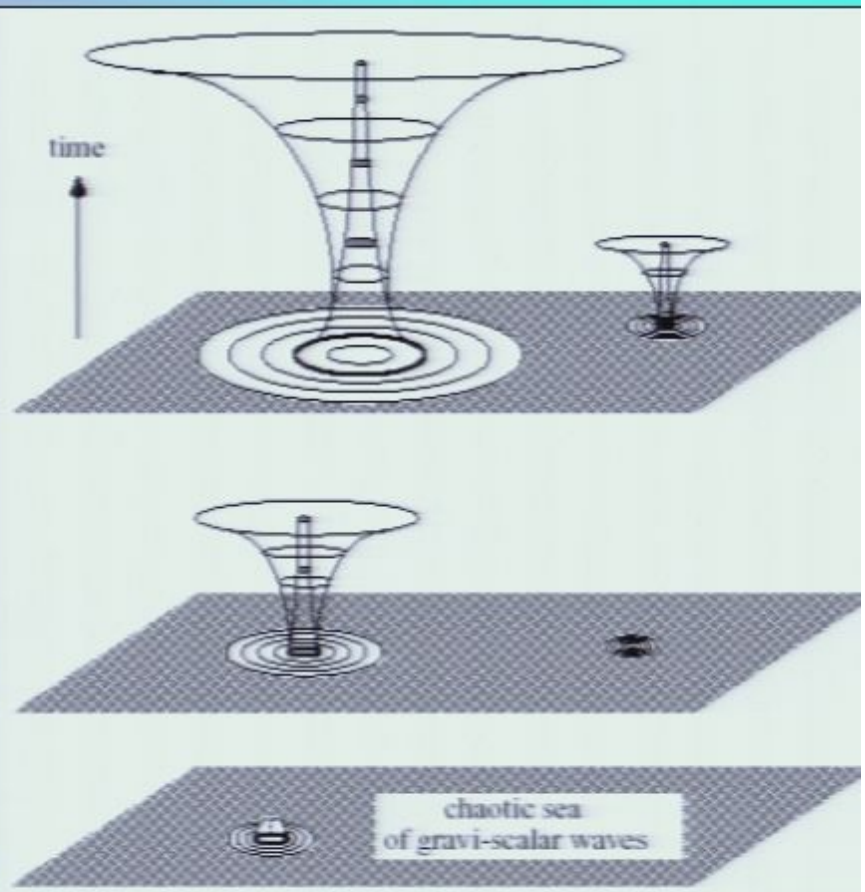
universes out of a quantum vacuum?



Pre-Big Bang cosmology



Comparison between the time evolution of the Hubble horizon c/H (dashed lines) and of the scale factor $a(t)$ (solid curves) in the conventional inflationary scenario (left) and in models of pre-big bang inflation (right). For the pre-big bang phase we have plotted the evolution of both the expanding string-frame scale factor $a(t)$ and the contracting E-frame scale factor $a_E(t)$. The vertical axis is the time axis, and the shaded areas represent causally connected spatial sections of Hubble size c/H at various epochs. The evolution from the end of inflation, t_f, to the present epoch, t_0, is the same in both cases. However, during inflation (i.e. from t_i to t_f) the Hubble horizon is constant (or slightly increasing) in conventional models (left), while it is shrinking in pre-big bang models (right). As a consequence, the size of the initial inflationary patch may be very large (in string or Planck units) for a phase of pre-big bang inflation, but *not* larger than the horizon itself, as illustrated in the figure.



Maurizio Gasperini &
Gabriele Veneziano
2003 & 2009

In the beginning ... a time-loop?

(J. Richard Gott III, Li-Xin Li)

Universal Time-machine?

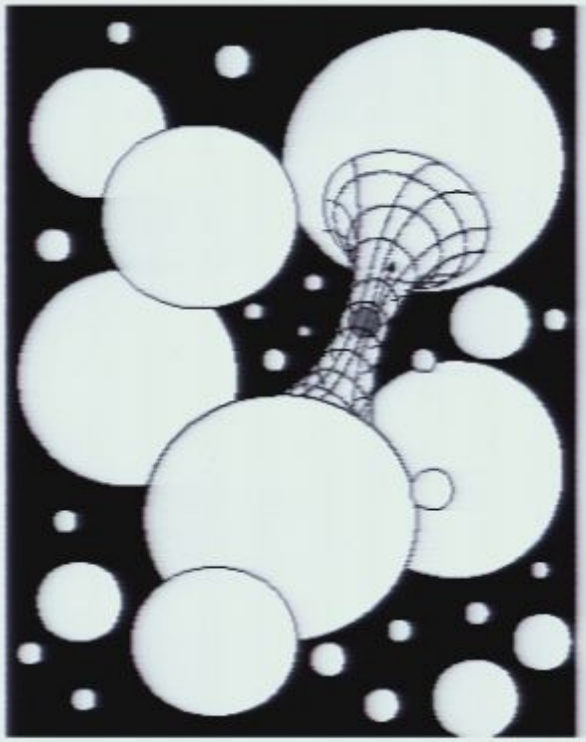


FIG. 6: Pictorial representation of the big trip process when it is carried out by a single grown-up wormhole within the framework of a multiverse picture. In this case the universe does not travel along its own time but behaves like though if its whole content were transferred from one different larger universe to another, also larger universe.

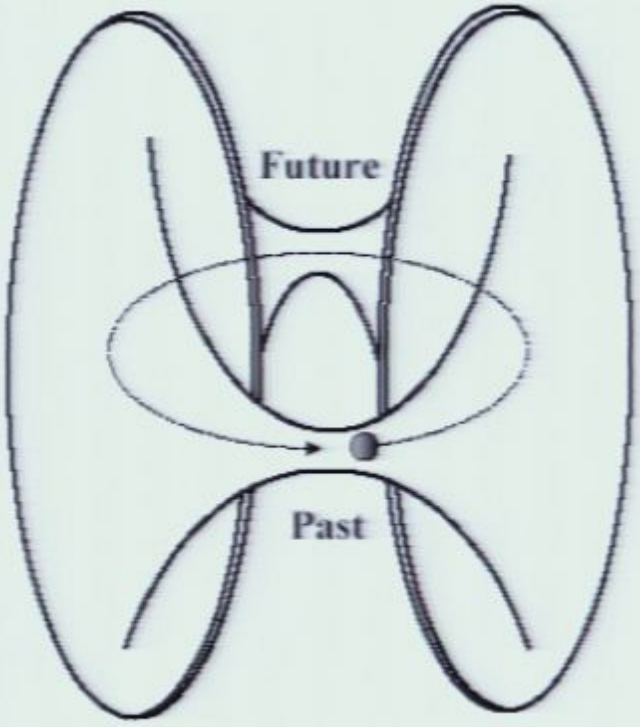


FIG. 7: Pictorial representation of the big trip process when two grown-up wormholes are used, one in the past and the other in the future. In this case the two wormhole connect their mouths in such a way that they form a compact tunnel through which the universe can travel along its own time, into the past or future.

Big Trip – into another universe or back to the big bang...

Yurov, A. V., Moruno, P. M., González-Díaz, P. F. 2006: New "Bigs" in cosmology. Nuclear Physics B759, 320-341.

Different notions of "Big Bang"

(1) the **hot, dense early phase** of our universe
where the light elements were formed

(2) the **initial singularity**

(3) an **absolute beginning** of space, time, and energy

(4) the **beginning of our universe**,
i.e. its elementary particles, vacuum state,
and perhaps its (local) space-time

• That our universe originated from a Big Bang in the sense of (1) is almost **uncontroversial**.

• (2) is the **relativistic cosmology's limit** of backward extrapolation where the known laws of physics inevitably break down.

The singularity is the mathematical limit where density and temperature approach infinity and space and time fall into the quantum regime.

Different models of quantum and string cosmology or a theory of quantum gravity try to overcome this limit,
and (3) and (4) classify their different scenarios.

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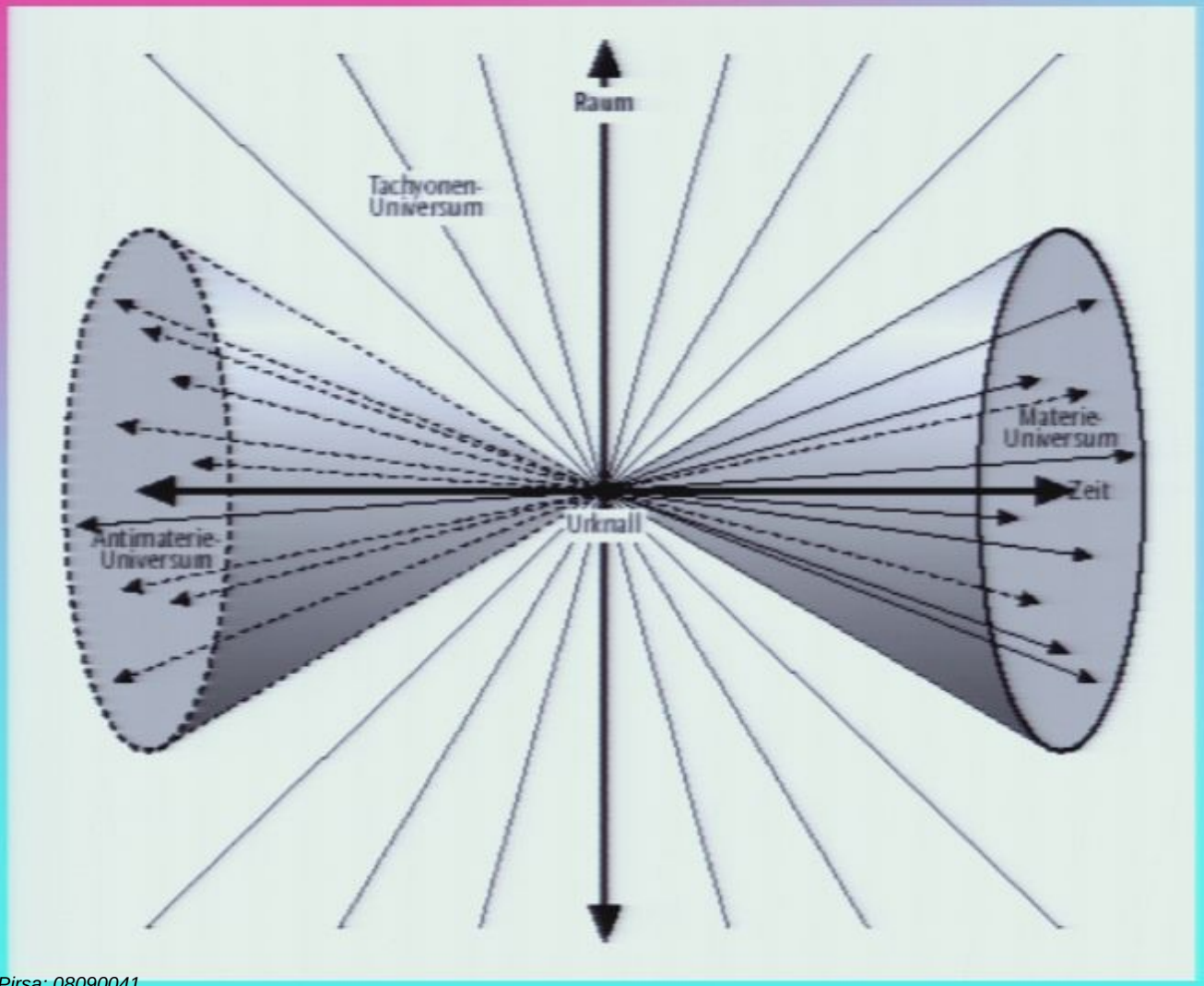
• Those characterized by (3) might be called ***initial cosmologies***; they postulate a very first moment.

• Those characterized by (4) are ***eternal cosmologies***; there are different kinds of them both in ancient and in modern cosmology:
• *static*,
• *evolutionary* (with cumulative change),
• and *revolutionary* (with sharp phase-transitions) ones.
And they could have either a *linear* or a *cyclic time*.

The option (4) also allows the possibility that our universe neither exists eternally, nor that it came into being out of nothing or out of a timeless state,
but that space and time are not fundamental and irreducible at all,
or that there was **a time "before" the Big Bang** (in the sense of (1)),
as well as that there are **other universes**.

[Vaas 2004a&b]

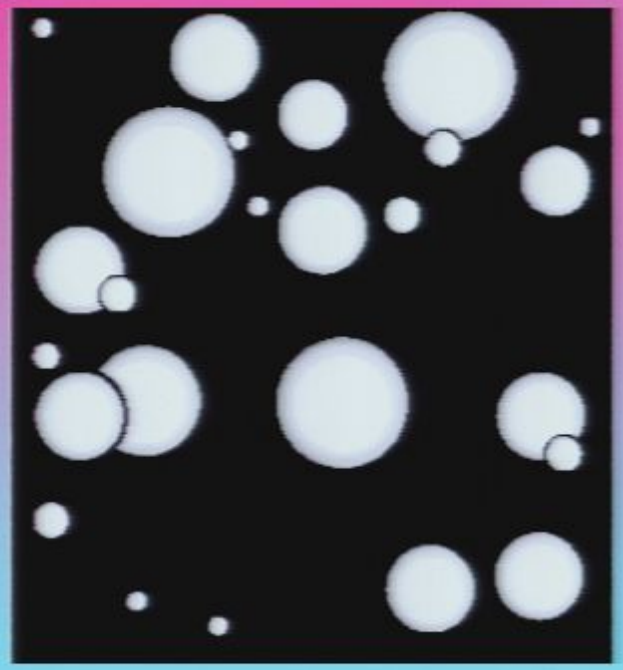
Cosmic Trinity?

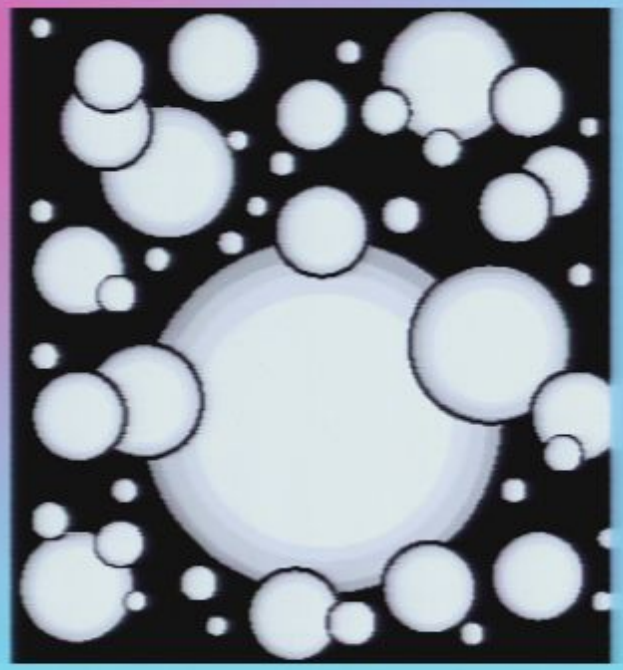


- matter universe
- antimatter universe
- tachyon universe

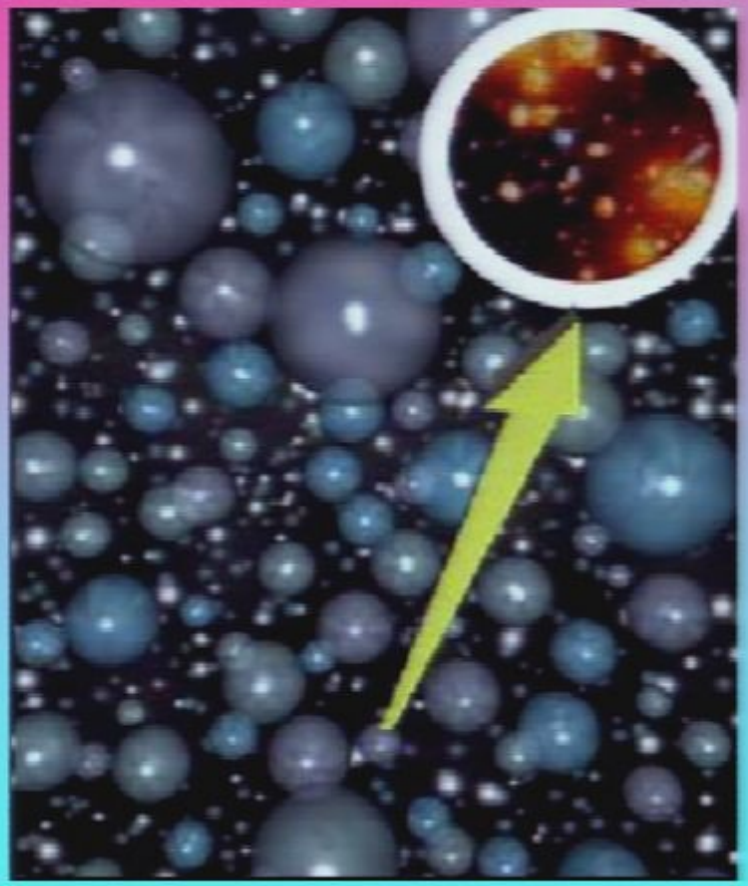
J. R. Gott III

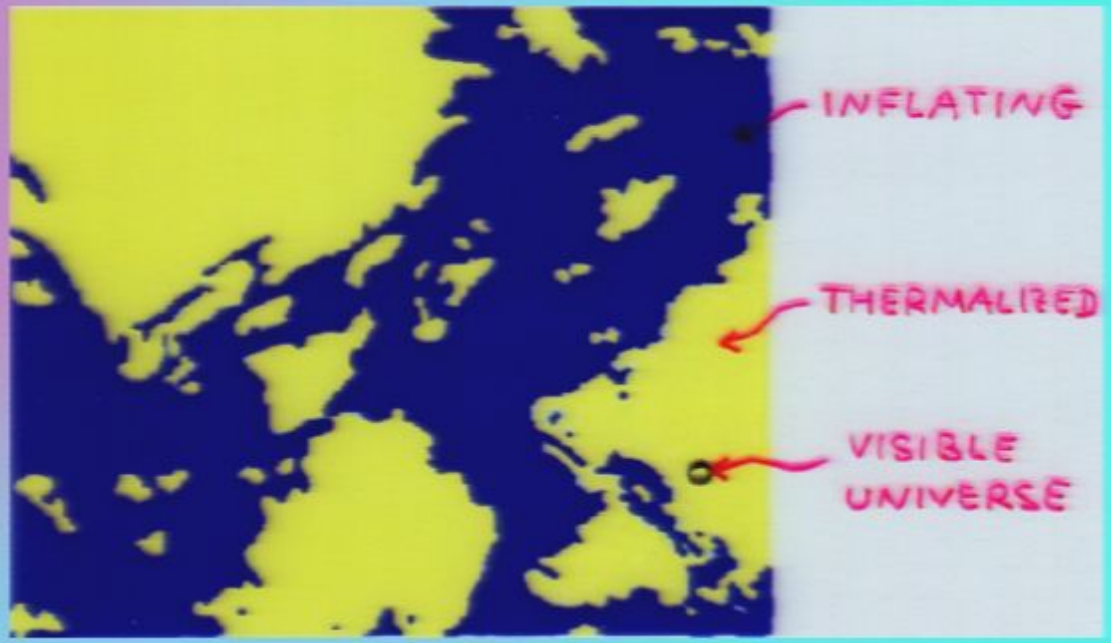
Eternal Inflation (I)





Eternal Inflation (II)

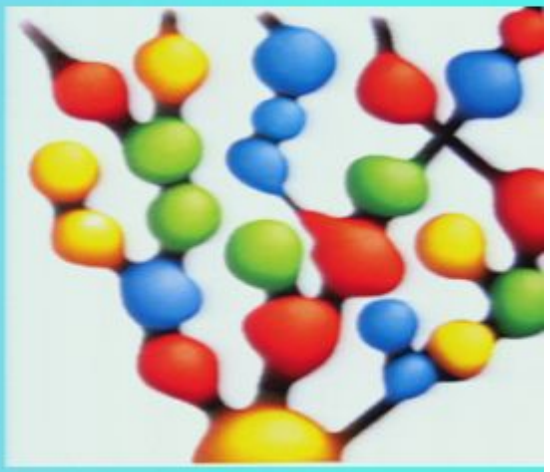




Vilenkin, Vanchurin
& Winitzki 2000

The Landscape

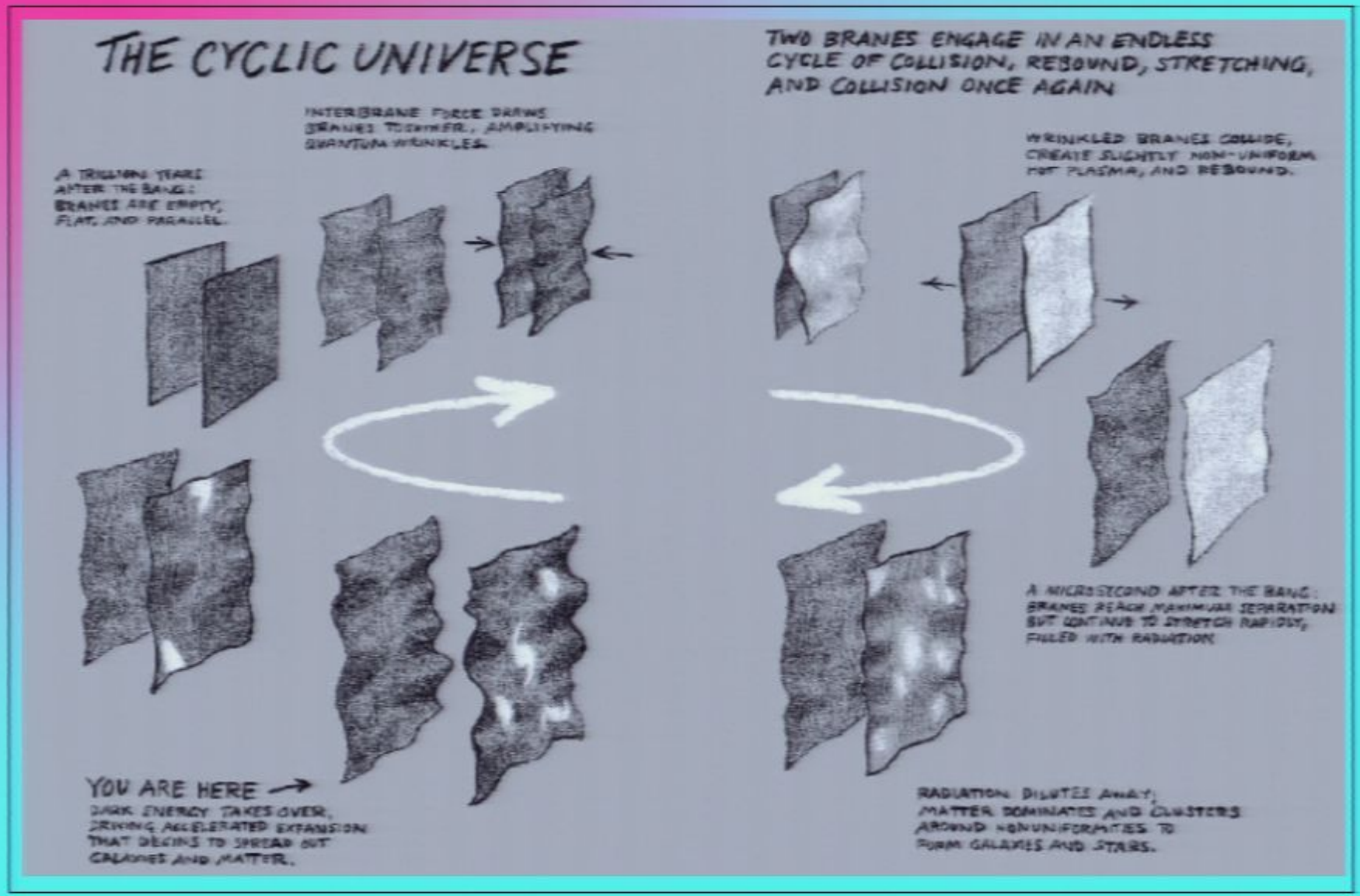
Eternal Inflation marries The Landscape



Linde 2007:

> Eternal inflation and string theory joined each other in the context of the string theory landscape. The resulting picture changes the way we look at our place in the world. This is one of the most exciting and mysterious parts of modern science.

The Cyclic Universe



Different notions of „Universe“

(1) **everything** (physically) in existence, ever, anywhere

(2) **the observable region we inhabit** (the Hubble volume, roughly 46 billion light years in radius), plus everything that has interacted (for example due to a common origin) or will ever or at least in the next few billion years interact with this region

(3) **any gigantic system of causally interacting things** that is wholly (or to a very large extent or for a long time) isolated from others

(4) **any system that *might* well have become gigantic**, etc., even if it does in fact recollapse while it is still very small

(5) **separate branches of the wave function** (if it never collapses) in unitary quantum physics, i.e. different histories of the universe or different classical worlds which are in superposition

(6) **completely disconnected systems** consisting of universes in one of the former meanings (2) – (5), which do or do not share the same boundary conditions, constants, parameters, vacuum states, effective low-energy laws, or even fundamental laws, e.g. different physically realized mathematical structures

Different notions of Universe“

- With (1) there are no other universes – by definition.

- In principle, other universes – mostly conceived in the notions of (2), (3), or (4) – **might or might not be spatially, temporally, dimensionally, and/or mathematically separated** from each other. Thus, there are not necessarily sharp boundaries between them.

- Nowadays, the term "**cosmos**" or "**multiverse**" or "**world**" (as a whole) might be used to refer to Everything in Existence, while "**universe**" (or "sub universe") permits talking of several universes within the multiverse.

Different notions of „Universe“

(1) **everything** (physically) in existence, ever, anywhere

(2) **the observable region we inhabit** (the Hubble volume, roughly 46 billion light years in radius), plus everything that has interacted (for example due to a common origin) or will ever or at least in the next few billion years interact with this region

(3) **any gigantic system of causally interacting things** that is wholly (or to a very large extent or for a long time) isolated from others

(4) **any system that *might* well have become gigantic**, etc., even if it does in fact recollapse while it is still very small

(5) **separate branches of the wave function** (if it never collapses) in unitary quantum physics, i.e. different histories of the universe or different classical worlds which are in superposition

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Multiversal Taxonomies

For example:

- Max Tegmark (2003): 4 Levels
- George F. R. Ellis, Ulrich Kirchner, William R. Stoeger (2004)
- Rüdiger Vaas (2004)
- Laura Mersini-Houghton (2008): 3 Types

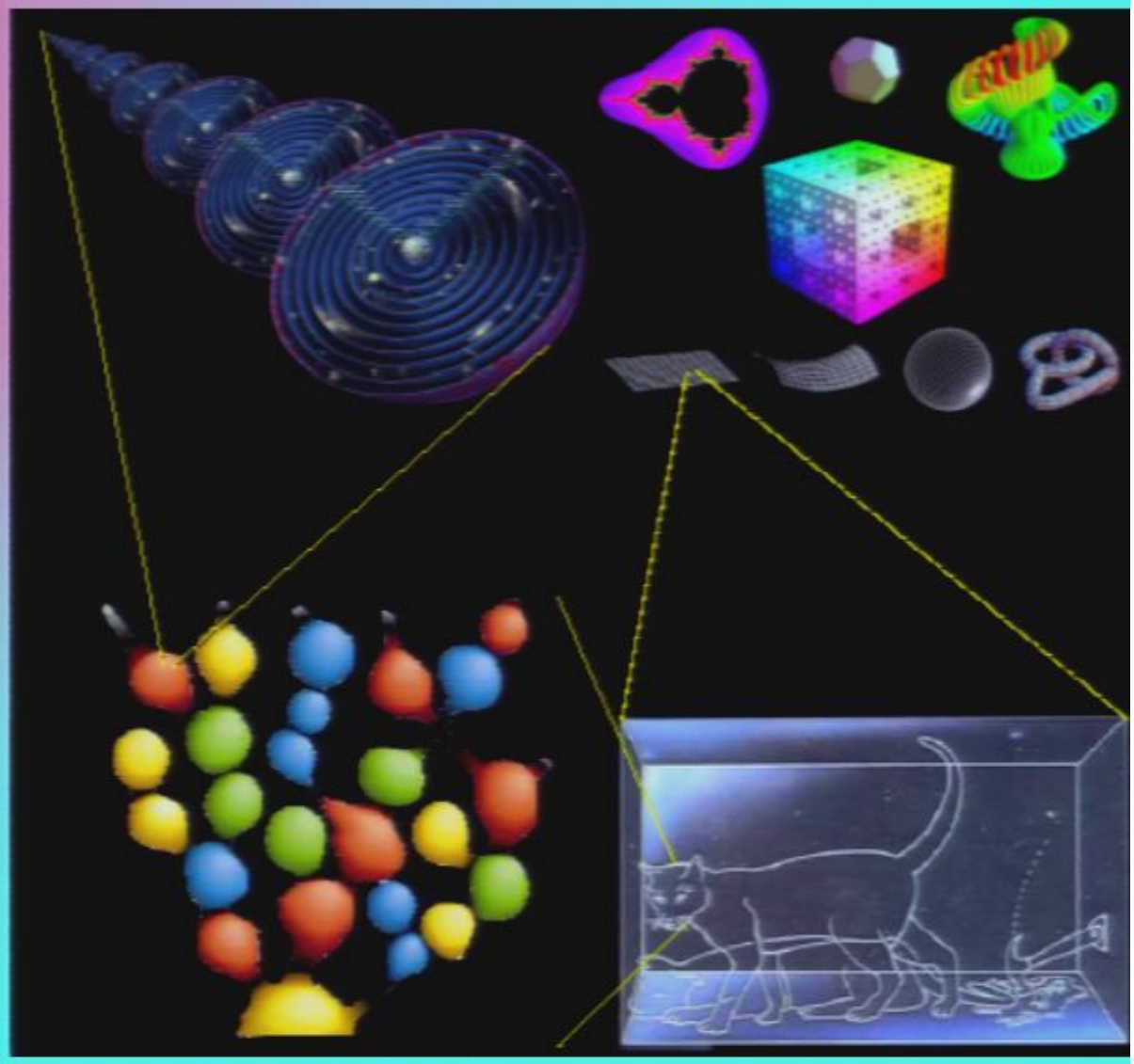
Max Tegmark's Multiverse (I)

Level 1: Regions beyond our cosmic horizon
Features: Same laws of physics, different initial conditions
Assumptions: Infinite space, ergodic matter distribution
Evidence: - Microwave background meaurements point to flat, infinite space, large-scale smoothness
- Simplest model

Level 2: Other post-inflation bubbles
Features: Same fundamental equations of physics, but perhaps different constants, particles and dimensionality
Assumptions: Inflation occurred, multiple "vacua" exist
Evidence: - Inflation theory explains flat space, scale-invariant fluctuations, solves horizon problem and monopole problems and can naturally explain such bubbles
- Explains fine-tuned parameters

Level 3: The Many Worlds of Quantum Physics
Features: Same as level 2
Assumption: Physics unitary
Evidence: - Experimental support for unitary physics
- AdS/CFT correspondence suggests that even quantum gravity is unitary
- Decoherence experimentally verified
- Mathematically simplest model

Level 4: Other mathematical structures
Features: Different fundamental equations of physics
Assumption: Mathematical existence = physical existence
Evidence: - Unreasonable effectiveness of math in physics
- Answers Wheeler/Hawking question: "why these equations, not others"



Max Tegmark's Multiverse (II)

Reality bites:
The problem with
Platonism

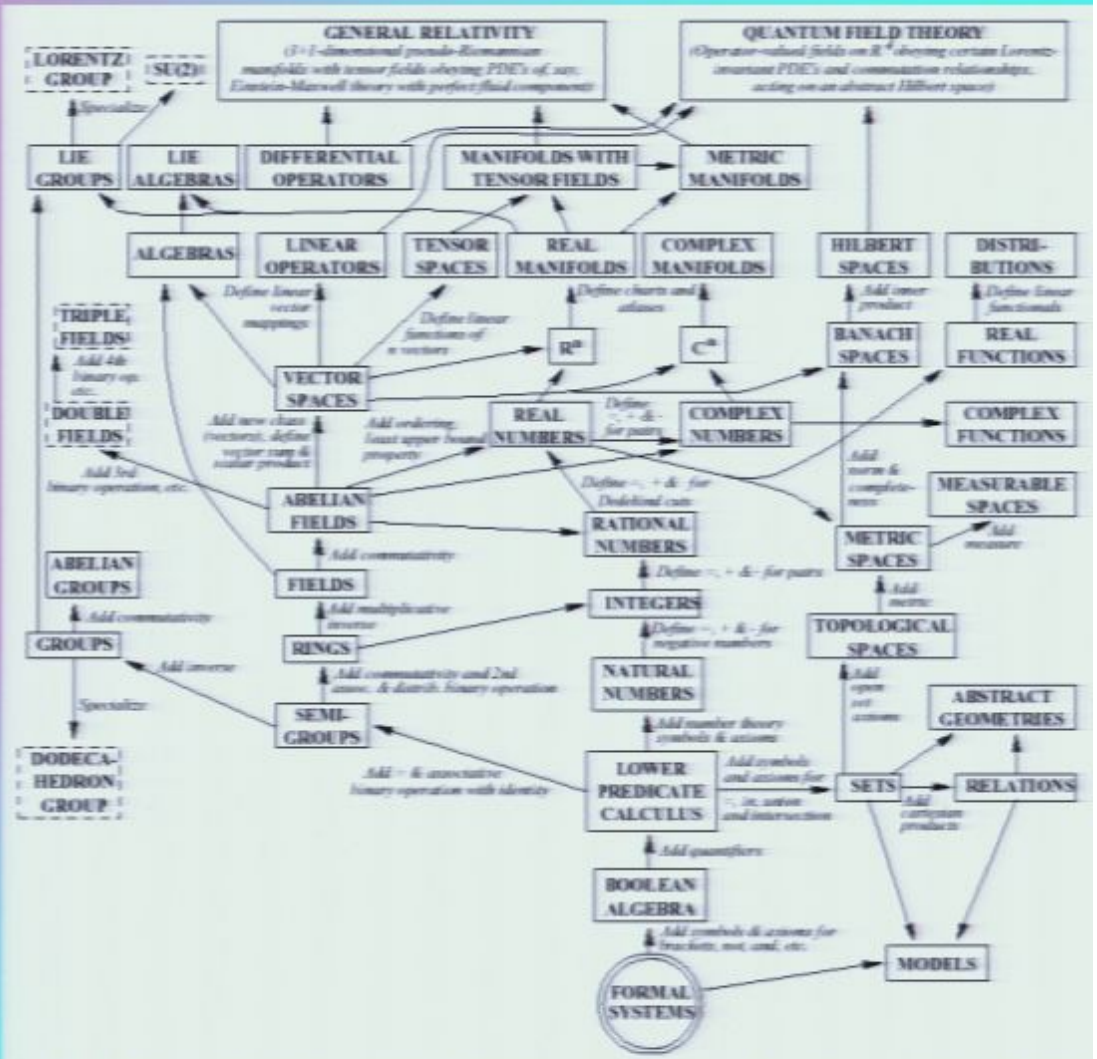


FIG. 8. Relationships between various basic mathematical structures (Tegmark 1998). The arrows generally indicate addition of new symbols and/or axioms. Arrows that meet indicate the combination of structures — for instance, an algebra is a vector space that is also a ring, and a Lie group is a group that is also a manifold. The full tree is probably infinite in extent — the figure shows merely a small sample near the bottom.

A multiversal taxonomy

- should be abstract enough to include all kinds of cosmological scenarios
- **Suggestion:** classification in respect of the separation/distinction of the different universes: [Vaas 2004, with additions]
  - *spatial*
  - *temporal*
  - *causal*
  - *modal*
  - *mathematical*
- not mutually exclusive aspects (but some are)
- this is just a conceptual issue, it explains/proves nothing!
- is it useful? sufficiently complete? not too arbitrary?

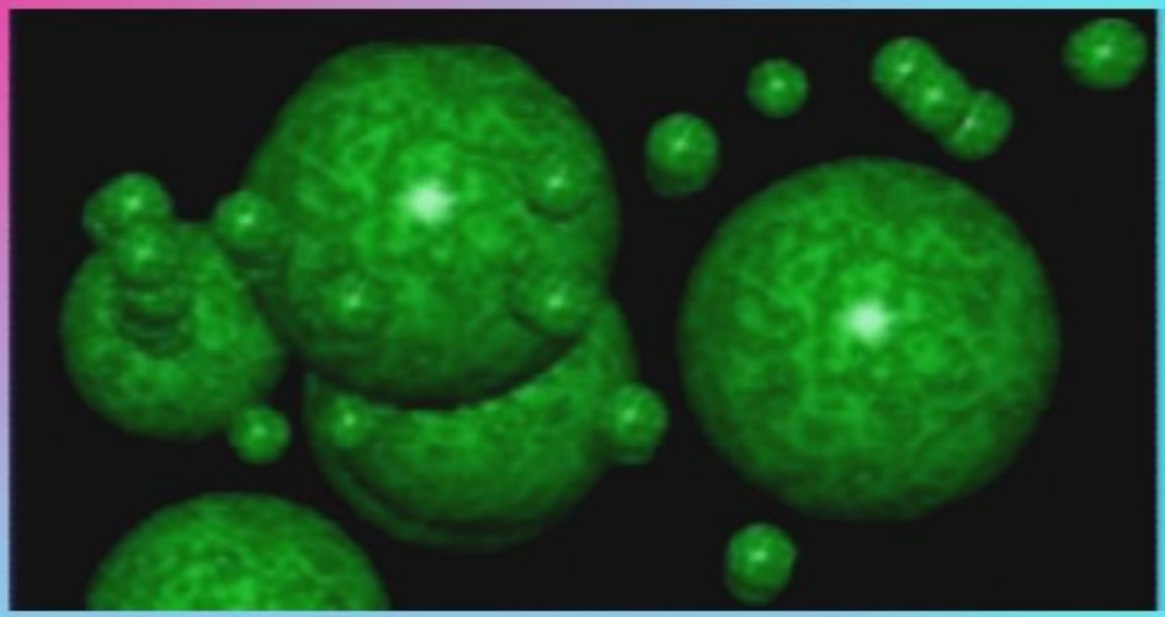
- Rutherford: "Science is either physics or collecting stamps"...

Wurmloch-Reisen in andere Universen?

separation	aspects	examples *and comments*
spatiotemporal	**spatial**	*see also causal separation*
	• exclusive	eternal inflation, stringscape, different quantum tunnel universes
	• inclusive	*embedding:* universes in atoms, black holes, computer simulations...
	temporal	oscillating universe, cyclic universe, recycling universe, universes (or parts) with different arrows of time
	• linear	*in a causal or acausal series*
	• cyclic	*within circular time or due to exact, global recurrences*
	dimensional	*mostly spatial, but there are also two-time-dimensional scenarios*
	• strict	tachyon universe?
	• inclusive	*lower-dimensional world as part or boundary of a higher-dimensional world:* flatland, brane-worlds, large extradimensions, holographic universe
	• abstract	„leafs in superspace"
causal	**strict**	„parallel universes", Everett's many-worlds
	• without a common generator	different universes/multiverses in instanton, big bounce, soft bang scenarions; different „bundles" of (eternal) inflation
	• genealogical	eternal inflation, cosmic darwinism, many-worlds/histories without interactions
	continuous	*due to an increasing horizon*
	• all the time	infinite space, eternal inflation, infinite branes
	• past	*because of inflation*
	• future	*because of accelerated expansion due to dark energy*
	simulated	universes as computer simulations
modal	**potential (possible)**	*separated in imagination or conceptual representation – otherwise not real!*
	actual (real)	modal realism: physically (nomologically), metaphysically or logically separated
nomological	**structural/regularities**	*different laws or different constants of nature*
mathematical	**structural/axiomatic**	Platonism, mathematical democracy, ultimate ensemble

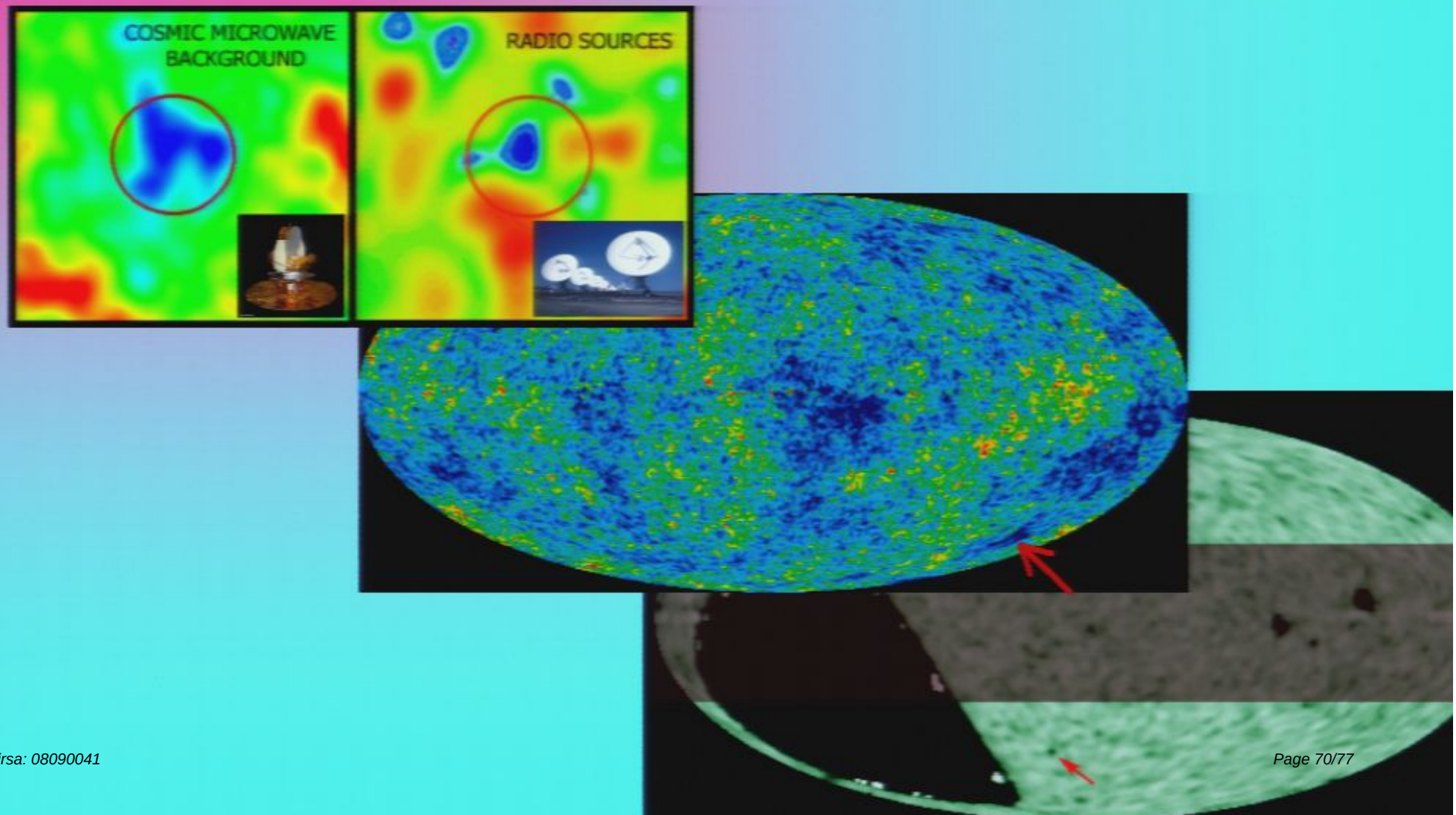
Signs of Other Universes? - Wormholes

Signs of Other Universes? – Bubble Collisions

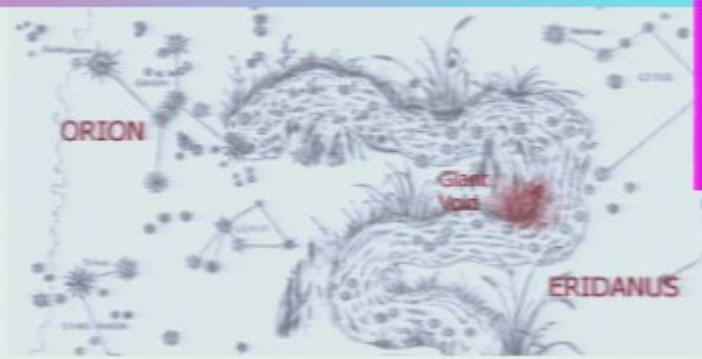


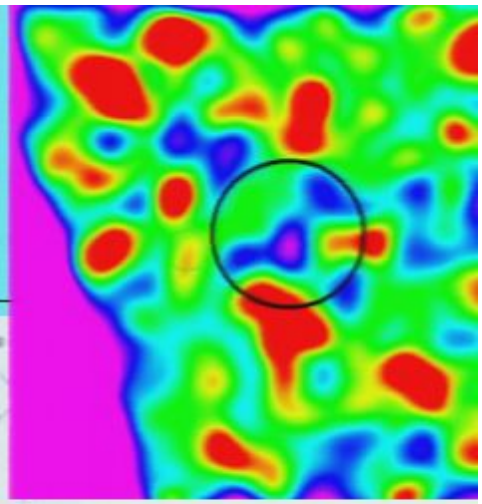
Alan Guth, Alexander Vilenkin, Jaume Garriga
Anthony Aguirre et al.

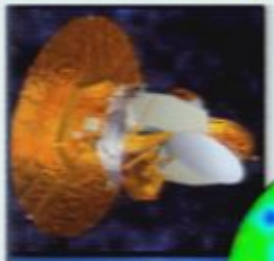
Signs of Other Universes? – Voids

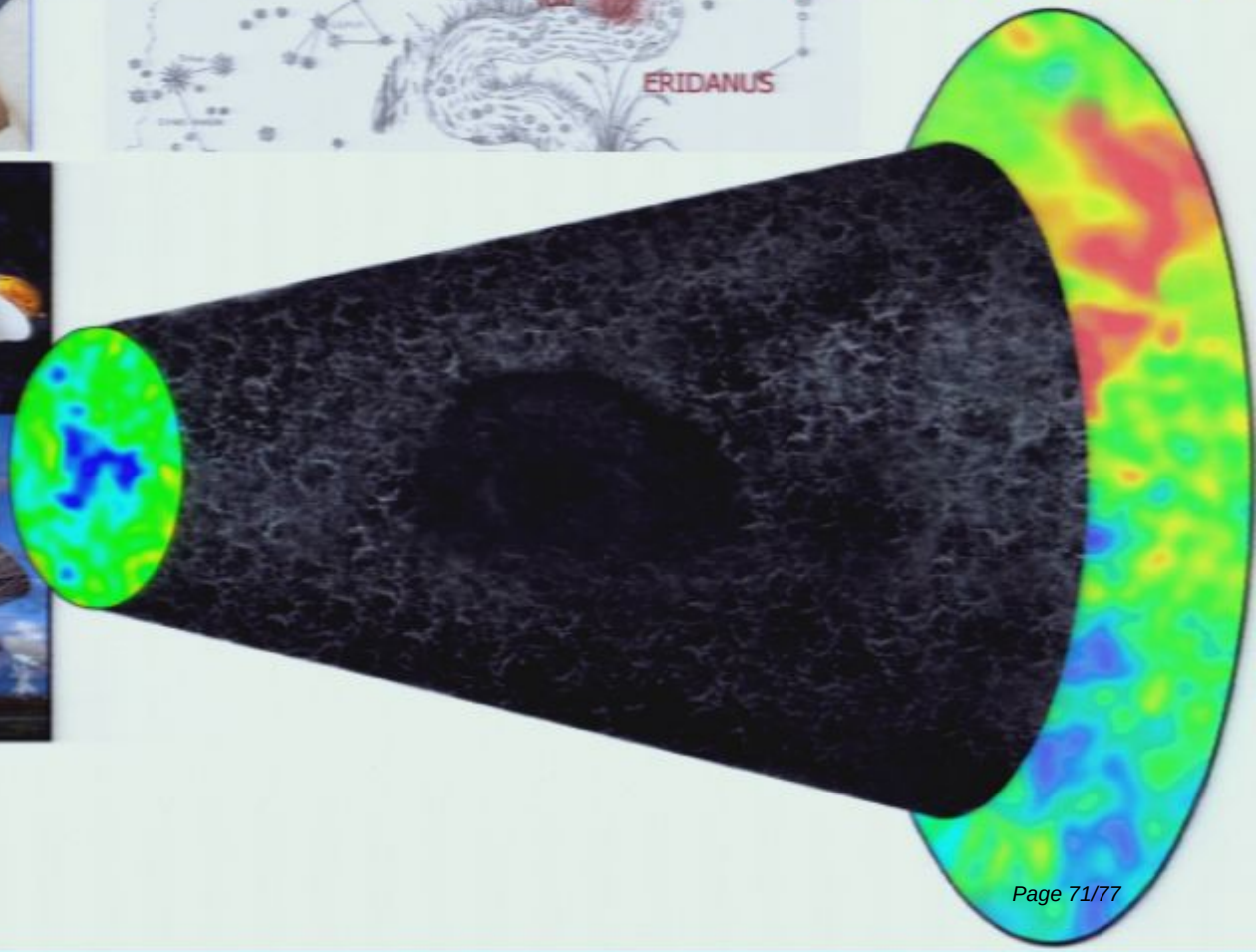


WMAP Cold Spot







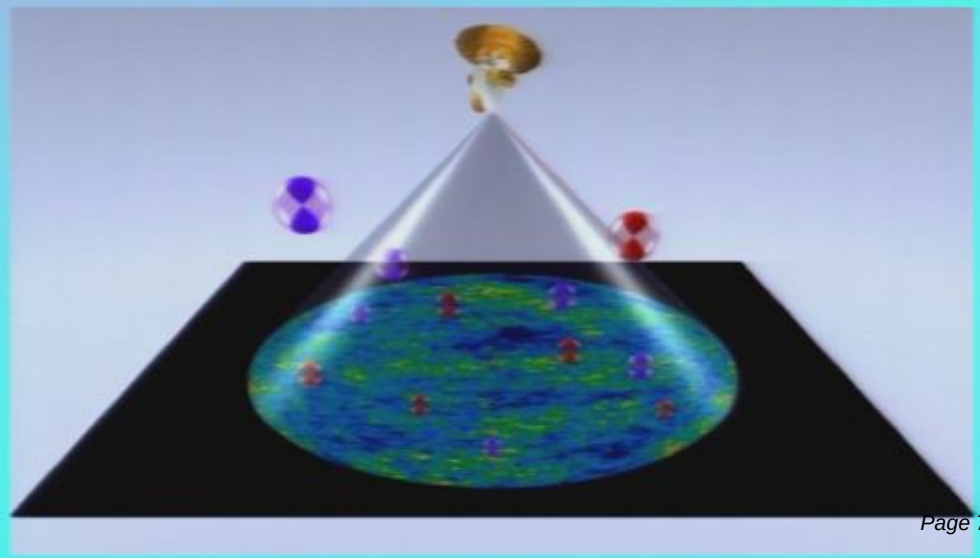


Signs of Other Universes? – Gates

Antonio Lopez Maroto et al.

arXiv:0803.0694

"This type of textures known as brane-skyrmions can be understood as holes in the brane which make possible to pass through them along the extra-dimensional space."



A Cosmic Gate?

Antonio Lopez Maroto et al.

arXiv:0803.0694

"This type of textures known as brane-skyrmions can be understood as holes in the brane which make possible to pass through them along the extra-dimensional space."

Münchhausen's trilemma

Karl Friedrich Hieronymus, Freiherr von Münchhausen (1720 – 1797) was a German baron who told a number of outrageous tales about his adventures - including riding cannonballs, travelling to the Moon, and escaping from a swamp by pulling himself up by his own hair.

against dogmatism

Münchhausen's trilemma

(Hans Albert 1968; cf. Vaas 2006)

of reasoning, justification, and explanation…

... and cosmology

- **stop/break** – singularity, instanton models
- **infinite regress** – eternal universe, e.g. cyclic
- **(vicious) logical circle** – self-creation with time-loop

[epistemology/methodology]

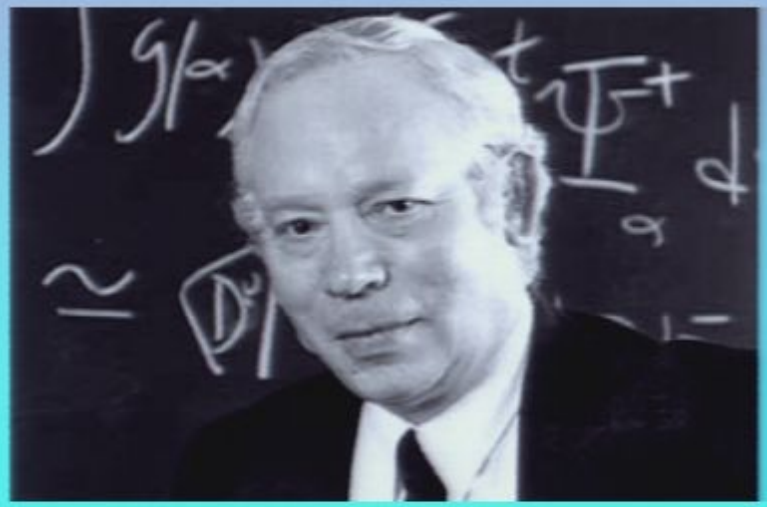
[ontology]

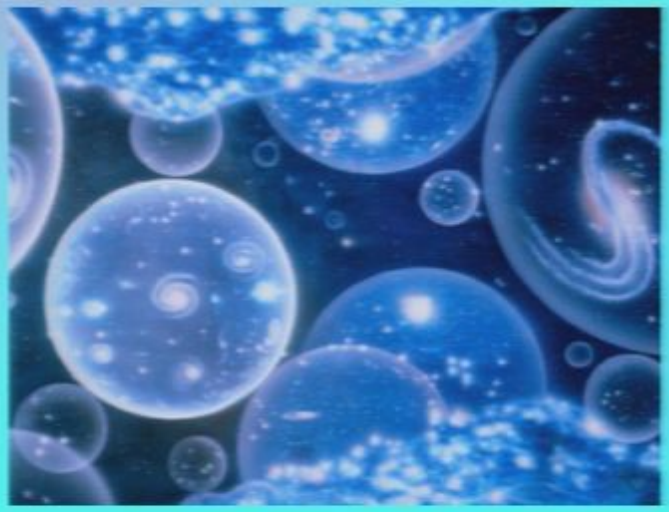
→ ultimate contingency,
no sufficient reason, no final explanation

→ science may never stop

“our mistake is not that we take our theories too seriously, but that we do not take them enough”

Steven Weinberg (1977)





Thanks for listening !