Loops05 – Albert-Einstein-Institut, Potsdam: October 10, 2005

Before Time: Loop Quantum Cosmology and Philosophy of Science

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Abstract

Quantum Cosmology seeks to explain what happened at the Big Bang – or even before.
But how can initial conditions be both necessary for physical explanations (as an explanans), and yet have to be explained themselves in Big Bang cosmology (as explananda)?
And what is the relationship between boundary conditions, constants of nature, and physical laws – are they all mere initial conditions?
The talk shall address these questions on a conceptual level and compare the approach of Loop Quantum Cosmology (LQC) with other quantum cosmological proposals. The advantage of LQC shall be shown from a Philosophy of Science perspective, and with regard to a possible solution of the question whether our universe did or did not have a beginning. Some problems of most recent results in LQC are also discussed.

Some remarks on Philosophy of Nature and Natural Science

- relationship to the natural sciences: often unfortunately between arrogance of competence and superfluous (low-level) reduplication
- very broad questions or controversial ones in science
- not as competition, but addition to science
- but also part of science (more or less explicit), because science is not only description
- division of labor
- not restricted to (academic) philosophers

ontological

- what is the nature of nature if specific scientific theories are true?
  → Socrates' advice: "we must follow the argument wherever, like a wind, it may lead us" (Plato: *Republic 394d*).
- interpretational issues (e.g. quantum physics)
- empirical underdetermination (e.g. cosmology)

epistemological

- applied philosophy of science and epistemology
- conceptual commentaries
- reflections about e.g. assumptions, principles, explanatory issues (kinds, limits, justifications), and methodology
- foundational issues of (scientific) knowledge

historical

- importance during formative phase of a new theory
- synthesis, unity of science?
- connections with other fields (trans/interdisciplinary), humanities, broader public
- relativity and broader context due to historical perspective

[cf. Bartels 1996]

Against dogmatism:

The Münchhausen trilemma

(Hans Albert 1968)

… of reasoning, justification, and explanation

• either **stop/break**
• or **infinite regress**
• or **(vicious) logical circle**

[epistemology/methodology]

… and cosmology

– singularity, instanton models
– eternal (e.g. cyclic) universe
– self-creation via time-loop

[ontology]

→ no final explanation possible
→ ultimate contingency, no sufficient reason
→ science may never stop

[cf. Albert 1968, Vaas 2004f & 2006]

Scheme of explanations in physics

initial/boundary conditions & law(s)/theory $\rightarrow$ facts/events

Explanans ***Explanandum***
(retrodiction/prediction)

Many different kinds of scientific explanation are within this scheme, e.g.:
– deductive-nomological explanation (covering law model) for deterministic laws
– inductive-statistical explanation for probabilistic laws (any probability?)
– causal explanation

Other kinds of explanation (needed?):
anthropic, functional, teleological, transcendent?

Cosmology

observations (expansion of space, cosmic background radiation, ratios of light elements etc.)
& laws/theories (general relativity, thermodynamics, high-energy physics)
$\rightarrow$ Big Bang (as a retrodiction)

However: the observations are explained by the Big Bang theory, not vice versa!

But how could the Big Bang be explained?

Explanandum:
Big bang – and its (causal) connections to the present/observable universe
Explanans:
• initial conditions (e.g. dimensionality, metric, values of the fundamental fields, fluctuations)
• fundamental physical constants (e.g. c, h, G)
• fundamental laws (e.g. of M-theory, GRT, susy-GUTs etc.)

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.

- 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&d]

Different notions of "universe"

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

(2) **the observable region we inhabit** (the Hubble volume, roughly 27 billion light years in diameter), 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) **other 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, 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

- 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 to talk of several universes within the multiverse.

- In principle, these universes – mostly conceived in the meanings 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.

[Vaas 2003b & 2004a&d & 2005c]

Relativistic cosmology

- If there was a singularity (cf. Hawking-Penrose theorems) than it cannot be explained in the framework of General Relativity
- It is the breakdown of GR cosmology (i.e. all classical laws), GR's inherent limitation

$\rightarrow$ seek for other explanations, go beyond classical relativistic cosmology!

Quantum cosmology

In quantum mechanics, any system – the universe included – is described by a wave function ψ. There are two issues:

- **a universal dynamical law** (which makes no predictions by itself), e.g. a Hamiltonian specifying the form of the Schrödinger equation
  $ih(d\,|\psi(t)\rangle / dt) = H\,|\psi(t)\rangle$
- **the initial quantum state**
  for the universe it is $|\psi(0)\rangle$ as a boundary condition
  for the wave function ψ of the universe,
  which satisfies (i.e. is a solution of) the Wheeler-DeWitt equation
  $H\psi = 0$.
  It might be introduced as a separate law.

But there is still a separation between dynamics and state. Could they be connected?

Yes, e.g.

– in the Hawking-Hartle wave function
$\psi(g,\varphi) = \int^{(g,\varphi)} e^{-S}$ (unbounded, divergent integral)

– or in Vilenkin's tunneling wave function
$\psi(g,\varphi) = \int_{\varnothing}^{(g,\varphi)} e^{iS}$

– or in Linde's wave function
$\psi(g,\varphi) = \int^{(g,\varphi)} e^{S}$ (unbounded, divergent integral)

where $\int$ is the integration over paths (path integral, sum over histories) interpolating between a vanishing 3-geometry Ø ("nothing", no classical spacetime) and the 3-metric g and matter fields φ, and S is the Euclidean instanton action of a 4-sphere

But is there a principle/law that determines *both* the dynamics and the state?

[cf., e.g., Hartle 2003, Vilenkin 2003]

Initial conditions

- inaccessible due to deterministic chaos?
- ... and inflation? (if > 60 e-foldings)
- but was there an initial state = a beginning nevertheless?
  (Borde-Guth-Vilenkin theorem)
- or past-eternal inflation? (cf. Linde, Aguirre)
- or at least traces from "before"?
  (Pre-Big-Bang, LQC, Cyclic Universe scenarios)
- underdetermination of cosmological models?

Only theory test possible without sufficient empirical confirmation?
(but what could be "sufficient"?)

Where the (pre-inflationary) initial conditions
- specific ("ordered"), improbable (?)
  - cf. instantons
    (Hawking-Hartle/Moss/Turok, Coleman-DeLucca, Vilenkin ...)
- general, diverse ("chaotic")
  - cf. chaotic inflation

Constraints from initial conditions (or the laws determining them):
– Lorentzian-signature of 4D spacetime
– inflation (necessary?)
– near-critical energy density
– low anisotropies
– small inhomogeneities
– low entropy

- contingent brute facts without any explainability?
- caused by earlier conditions? (problem-shift only, and no strict initial conditions) (e.g. Big Bang as a transition; or intentionally selected)
- irrelevant because of attractor solution? (e.g. inflation, Cyclic universe) or "forgetting" (e.g. inflation, Mixmaster cosmology)
- retrodictable? (e.g. top-down cosmology, LQC)
  → present boundary conditions enough?
- final conditions – additional to or instead of initial conditions?
  (cf. extremal principles)
- specific and part of the law(s)? (e.g. no boundary proposal)
- differently realized by a physical principle of plentitude
  (and observational selection, WAP)?

[Vaas 2005b]

Micro- and macrotime and the pseudo-beginning proposal

At least conceptually, time could *both* have a beginning,
in the macroscopic notion of an arrow,
and might be eternal,
in the microscopic notion of a steady state with statistical fluctuations

This offers a middle course between
the Scylla of a mysterious, secularized "creatio ex nihilo" (absolute beginning, initial cosmology),
and the Charybdis of an equally inexplicable eternity of the world

macroscopic time scale

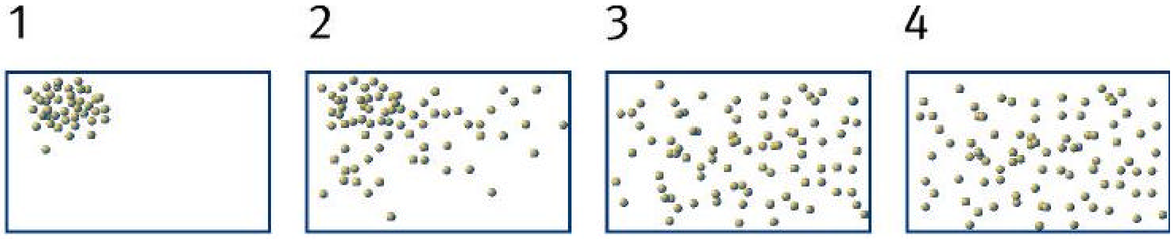
- characterized by an **asymmetry of nature under a reversal of time**, i.e. the property of having a global (coarse-grained) evolution – an **arrow of time** – or many arrows, if they are independent from each other

microscopic time scale

- **only local, statistically distributed events *without* dynamical trends**, i.e. a global time-evolution or an increase of entropy density, exist
  - e.g. quantum or string vacuum, spin networks, twistors
- if the system is **in thermodynamic equilibrium** (e.g. there is a huge number – or **degeneracy** – of microscopic states identifiable with the *same* coarse-grained state) and/or, if the system is in an extremely **simple, but meta-stable state**
- due to **accidental fluctuations**, which exceed a certain threshold value, universes can emerge out of that state
  they get – and, thus, are characterized by – **directed non-equilibrium dynamics, specific initial conditions, and, hence, an arrow of time** (definable, e.g., by the cosmic expansion parameter or by the increase of entropy)

[Vaas 2003a & 2004d&e]

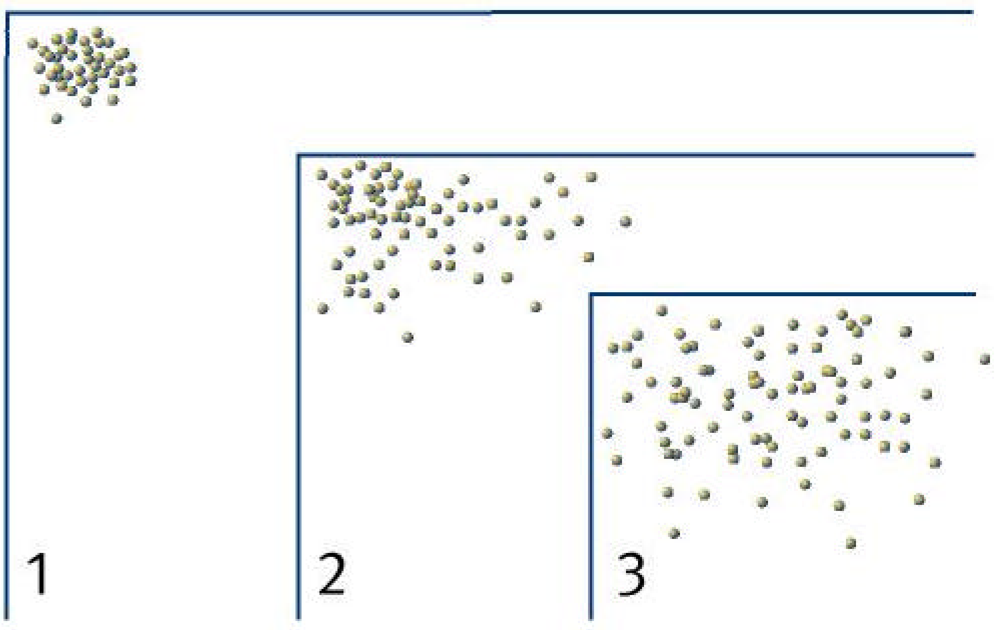
Micro- and macrotime illustrated



Systems have an arrow of time if they undergo a directed development. This is manifest only on a macroscopic level and is called macroscopic time here (or macrotime for short). It comes along with an increase of entropy which is a measure for the disorder of the system.

For example molecules in a closed box (figure above) spread from a corner (1) – if they were released there, for instance, from a gas cylinder – in every direction and eventually occupy the whole space (3). Then a state of equilibrium is reached which has no directed development anymore and thus no macrotime. Coarse-grained „snapshots" of the whole system or sufficiently large parts of it show no difference (3 and 4). On a fine-grained level there are still changes (3 versus 4). Thus, a microtime always remains. Due to accidental, sufficiently large fluctuations – which happen statistically even in a state of equilibrium if there is enough microtime available – local structures can arise (from 3 to 1) and a macrotime temporarily comes into being again.

If the system is not closed but open (figure below), a state of equilibrium does not necessarily develop and macrotime does not vanish. For instance, in the universe this is the case because space expands. Whether there were specific, improbable initial conditions at the big bang (1) or whether order and a directed development could have come out of quite different initial configurations is controversial. Possibly the whole universe is an accidental fluctuation in a macrotimeless quantum vacuum.



[Vaas 2004d&e]

The pseudo-beginning proposal in Philosophy and Cosmology

- The micro/macrotime distinction offers also a **solution of Kant's First Antinomy of Pure Reason** if some kind of metaphysical realism is true, including an observer-independent and relational time.

- Immanuel Kant argued that it is possible to prove (!) *both* that the world has a beginning *and* that it is eternal (*Critique of Pure Reason A426f/ B454f*), which seems to be mistaken!
- Kant believed he could overcome this "Widerspruch der Vernunft mit ihr selbst" (*A740*) by the help of what he called "transcendental idealism".

- But if the pseudo-beginning proposal is true, Kant's First Antinomy makes the **error of the excluded third option**,
  i.e. it is not impossible that the universe could have *both* a beginning *and* an eternal past.

- Some models of **Loop Quantum Cosmology** and **String Cosmology** can be interpreted as examples for such a local beginning of our macroscopic time out of a state with microscopic time, but with an eternal, global macroscopic timelessness

[Vaas 2003a & 2004d]

Kinds of explanations for the Big Bang

- past-eternal, initial, and pseudo-beginning cosmologies have a different explanatory status with specific advantages and disadvantages
- regarding the usual explanatory scheme, past-eternal cosmologies are most conservative, initial cosmologies most radical (incompatible), pseudo-beginning cosmologies in between

cosmologies	**physical laws (and fundamental constants)**	**initial conditions**
past-eternal	could be physically instantiated	no (but transition conditions)
initial	only Platonic and creative?	yes, in the strict sense
pseudo-beginning	could be physically instantiated	yes, in a weak sense

Big Bang as a transition:

- Explanation by laws and earlier conditions
  e.g.
  – classical Big Bounce (via GR, $k = +1$, $\Lambda > 0$)
  – Pre-Big-Bang (via string theory, principle of asymptotic past triviality)
  – Cyclic Universe (via M-theory, brane collision, dilaton etc.)
  – LQC (via LQG, certain assumptions and constraints)
- Shifts problem (infinitely far) back in time…?
- But is in accordance with usual physical explanations

Big Bang as the absolute beginning:

- Explanation by laws only?
  e.g.
  – Instanton (via quantum cosmology and certain constraints)
  – Self-creation (via GRT and a temporal loop constraint)
  circular causality = circular explanation?
- But: constants and laws as a kind of initial condition, too!
- And: must laws have a Platonic status? how could they be creative?
- And: not in accordance with usual physical explanations

Big Bang as pseudo-beginning:

- Explanation by laws and initial conditions in a weak sense
  (micro-, but no macro-time)
  e.g.
  background-dependent:
  – soft bang/emergent universe: Rebhan (2000), Ellis & Maartens (2003)
  – quantum fluctuation, de Sitter instability etc.:
  Tryon (1973), Brout et al. (1978 ff), Starobinsky (1979 ff),
  Atkatz & Pagels (1982), Gott III (1982), Israelit (2002)
  background-independent:
  – pregeometry: Wheeler (1975), Atkins (1981), Wolfram (2002)
  – loop quantum cosmology: Ashtekar & Bojowald et al. (2002 ff)
- Presupposes some physical ground state
  (quantum vacuum, spin network, empty Minkowski space)
  and fluctuations, i.e. also some generic initial conditions and laws
- But this is in accordance with usual physical explanations

[Vaas 2004d and references therein]

Modern initial and eternal cosmologies

possibilities	**models (spacetime)** and their main proponents
beginning and an end	• **classical big bang/big crunch**: Alexander Friedmann (1922), Stephen Hawking & Roger Penrose (1965 ff) • **quantum tunnel effect**: Alexander Vilenkin (1982 ff) • **no boundary instanton**: Stephen Hawking & James Hartle (1983)
beginning, but no end	• **classical big bang/big whimper**: Alexander Friedmann (1924), Georges Lemaître (1927), Stephen Hawking & Roger Penrose (1965 ff) • **phoenix universe** (global!): Georges Lemaître (1933), Richard C. Tolman (1934) • **quantum tunnel effect and eternal inflation**: Alexander Vilenkin (1982 ff) • **cosmic Darwinism:** Lee Smolin (1992 ff) • **no boundary instanton**: Stephen Hawking & Neil Turok (1998)
no beginning, but an end	• **collapse out of a static universe**: Arthur S. Eddington (1930)
no beginning and no end (static. vs. evolutionary vs. revolutionary)	• **static universe**: Albert Einstein (1917) • **empty expanding universe**: Willem de Sitter (1917) • **eternal expansion out of a static universe**: Arthur S. Eddington (1930) • **steady state**: Hermann Bondi, Thomas Gold & Fred Hoyle (1948 ff) • **quasi-steady state**: Fred Hoyle, Geoffrey Burbidge & Jayant V. Narlikar (1993 ff) • **chaotic inflation** (global!): Andrei Linde (1983 ff) • **Planckian cosmic egg** (global!): Mark Israelit & Nathan Rosen (1989 ff) • **big bounce**: Hans-Joachim Blome & Wolfgang Priester (1991) • **ekpyrotic and cyclic universe** (global!): Paul Steinhardt & Neil Turok et al.(2001 ff) • **loop quantum cosmology**: Abhay Ashtekar, Tomasz Pawlowski & Parampreet Singh (2005)
cycle (recurrence)	• **oscillating universe** (local!): Mark Israelit & Nathan Rosen (1989 ff), Redouane Fakir (1998) • **cyclic universe** (local!): Paul Steinhardt & Neil Turok et al. (2002 ff) • **circular time in a rotating universe**: Kurt Gödel (1949 ff) • **big brunch/time-reversal**: Claus Kiefer & H. Dieter Zeh (1995) • **spontaneous inflation**: Sean M. Carroll & Jennifer Chen (2004) • **loop quantum cosmology**: Abhay Ashtekar, Tomasz Pawlowski & Parampreet Singh (2005)
time-loop with/without end	• **self-creating universe**: John Richard Gott III & Li-Xin Li (1998)
pseudo-beginning with/without a local end	***background-dependent:*** • **soft bang/emergent universe**: Eckard Rebhan (2000), George F. R. Ellis & Roy Maartens et al. (2003) • **quantum fluctuation, de Sitter instability etc.**: Edward Tryon (1973), Robert Brout et al. (1978 ff), Alexei A. Starobinsky (1979 ff), David Atkatz & Heinz R. Pagels (1982), John Richard Gott III (1982), Mark Israelit (2002) • **pre-big bang**: Gabriele Veneziano & Maurizio Gasperini (1991 ff) ***background-independent:*** • **pregeometry**: John A. Wheeler (1975), Peter W. Atkins (1981), Stephen Wolfram (2002) • **loop quantum cosmology**: Abhay Ashtekar & Martin Bojowald et al. (2002 ff)

[cf. Vaas 2004d&e and references therein]

Some cosmological possibilities and their evaluation

Cosmologies	*GR: FRW (without further assumptions)*	*Quantum Cosmology*		
		Wheeler-DeWitt	*String Cosmology*	*LQC*
eternal *Big Bang as a phase-transition*	**+** • Big Bounce contraction from infinity if $\Lambda > 1$ (Eddington-Lemaître, Priester et al.)	**?** • past-eternal inflation (Linde) • Aguirre-Gratton • Phoenix *new principle (e.g. exotic matter)*	**?** • Cyclic Universe (Steinhardt-Turok) *new principle*	**+** Ashtekar et al.: • contraction from infinity if $k \leq 0$, $\Lambda \geq 0$ • oscillation if $k > 0$, $\Lambda \leq 0$
initial *absolute beginning*	**–** *singularity is no physical explanation*	**+** • Instanton Hawking-Hartle Hawking-Turok Vilenkin *new principle (e.g. no boundary)*	**+** • Instanton Hawking *new principle*	**?**
pseudo-beginning *micro-time, but no macro-time*	**–** *static beginning is not stable*	**?** • Quantum Foam models *new principle*	• Pre-Big Bang (Veneziano-Gasperini) *new principle (Asymptotic Past Triviality)*	**?** Riemannian Quantum Geometry • Bojowald et al. • Ellis et al.

[cf. Vaas 2004d&e & 2005a]

Loop Quantum Gravity and Cosmology

= Riemannian Quantum Geometry = Quantum Spin Dynamics

• background-independent quantized General Relativity

[for a technical introduction see, e.g., Ashtekar & Lewandowski 2004, Rovelli 1998, for a popular introduction see Vaas 2003c, for comparison with other theories of quantum gravity, especially string theory, see, e.g., Smolin 2003 and the popular introduction of Vaas 2004b]

• LQG makes it possible to avoid the ominous beginning of our universe with its physically unrealistic – infinite – curvature, extreme temperature, pressure, and energy density

• It perhaps even opens a window into a time before the Big Bang – space itself may have come from an earlier collapsing universe that turned inside out or inverted and began to expand again

• Gravity becomes repulsive in the deep Planck regime

• Ashtekar: "Classical spacetime "dissolves" near the Big Bang, but the spin network is still there." – "Physics does not stop at the Big Bang."

• LQG reaches beyond the singularity (which marks only the limit of GR)

• quantized, discrete instead of semi-classical spacetime

• difference equation instead of differential equation
$\rightarrow$ discrete "time" steps

$$(V_{|n+4|/2} - V_{|n+4|/2-1}) \cdot e^{ik} \cdot y_{n+4}(f) - (2 + g^2 k^2) \cdot (V_{|n|/2} - V_{|n|/2-1}) \cdot y_n(f) + (V_{|n-4|/2} - V_{|n-4|/2-1}) \cdot e^{-ik} \cdot y_{n-4}(f) = -8p/3 \cdot G \cdot g^3 \cdot l_{Pl}^2 \cdot H_f(n)\, y_n(f)$$

• Wheeler-DeWitt equation as an approximation for larger spacetime

$$[-1/6 \cdot l_{Pl}^4 \cdot ((a \cdot y(a, f))' \cdot 1/a)' \cdot 1/a + 3/2 \cdot k \cdot a]\, y(a, f) = 8pG \cdot H_f(a)\, y(a, f)$$

[see, e.g., Ashtekar, Bojowald & Lewandowski 2003, Bojowald 2005, for a popular introduction see Vaas 2004c]

Important new discovery: past-eternal Loop Quantum Cosmology

Abhay Ashtekar, Tomasz Pawlowski, Parampreet Singh 2005

- Ashtekar: "vast classical regions bridged deterministically by quantum geometry"

assumptions:
- homogeneous isotropic (or anisotropic) models, simple topology
- gravity coupled to a massless scalar field (as a tracer for "time")

$\rightarrow$ complete analytical and numerical treatment possible
$\rightarrow$ "evolve backwards" using quantum Einstein equation

result:
- state remains semi-classical until very early times (before inflation)
- it enters a quantum regime
- and it re-emerges as a semi-classical state

if the universe is semi-classical and expanding today,
it was semi-classical and contracting before the Big Bang
and vice versa

advantages:
- no new principle needed beyond LQG (but LQG needs new principles!) i.e. no exotic matter, no ad-hoc assumptions
- fluctuations under full control (unlike WKB methods)
- deterministic, unambiguous evolution
- precise notion of semi-classicality

problems:
- how to extract observables?
- inhomogeneous perturbations
- too simplistic in comparison to full theory of LQG?
- role of dark energy
- role of scalar field potentials

Past-eternal LQC – some remarks

Big Bang singularity has to be avoided/resolved

But what is gained?

– less than expected?
– back to philosophy?

- Assumption: semi-classical expanding universe today
  $\rightarrow$ where does it come from?
- **Big Bang as a phase-transition**
- **eternal cosmology (past, future)**

- contraction from past-eternal infinity !
  if $k \leq 0$, $\Lambda \geq 0$
- past-eternal infinity of expansion/contraction cycles ?
  (eternal resurrection, oscillating universe)
  if $k > 0$, $\Lambda \leq 0$

- stability of the cycle? entropy increase?
- simple model is stable and time-symmetric, but not very realistic
- role of anisotropies, perturbations, inhomogeneities, massive fields, and potentials has to be considered in more realistic models
- nothing is trivial here!
- importance of numerical simulations
- opposite orientation of triads – irrelevant or predictive?
  (e.g. CP violation)

Past-eternal LQC and (dis)advantages of cosmological conservativism

features	***philosophical evaluation:*** *a matter of taste?*
no assumptions beyond the theory (LQG) however: LQG require new assumptions; new quantum theory (von Neumann's uniqueness theorem by-passed)	+ –
ordinary explanation scheme: laws & boundary conditions	+
known boundary conditions: semi-classical expanding universe today initial data problem circumvented	+ +
deterministic backward-extrapolation however: LQG simplified…!	+ –
semi-classicality until very early times (well before inflationary epoch, if there was any)	+
problem of time circumvented fields as internal and relational clocks ("tracers")	+
unique universe approach: no multiverse scenario needed (but not impossible) however: eternal inflation?	+
shifts burden of explanation into past-infinity actual infinity?!!	–
no explanation of laws and boundary conditions (apart from trivial shift into an infinite regress)	–
TOE? fine-tuning? law-condition-connection no anthropic (i.e. observational) selection	+/–
distinction between (physical) real and possible	+/–
no principle of plentitude ("get most from less")	+/–
economical – or not?	+/–
contingency (of laws, constants, boundary conditions) why is there something rather than nothing? why is something as it is?	(–)

Acknowledgments:

It is a pleasure to thank Abhay Ashtekar and Martin Bojowald for many discussions and their support. Thanks also to Thomas Thiemann for discussion and invitation.

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