Modern Cosmology: Assumptions and Limits

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KIAS Colloquium
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The Universe

"The universe is real but you can't see it. You have to imagine it."

Alexander Calder (1898-1976)

Cosmology

"cosmology - the study of the universe at large, its history and its future."

J. Bernstein, et al
Cosmological Constants (1986) p1

"There is a widespread conviction that the new teachings of astronomy and physical science are destined to produce an immense change on our outlook on the universe as a whole, and on our views as to the significance of human life. The question at issue is ultimately one for philosophic discussions."

Sir James Jeans
The Mysterious Universe (1932) p9

Roles of Philosophy

"Philosophy, in one of its functions, is the critic of cosmologies."

Alfred North Whitehead
Science and the Modern World (1925) p. vii.

pure thought↔ empirical

"Kant's conclusion that [rational] cosmology is an intrinsically contradictory pseudoscience, driven by an illusion of reason."

Roberto Torretti
"Spacetime Models for the World"
Studies in History and Philosophy of Modern Physics **31**, 171 (2000)

"Philosophy is not a cognitive pursuit; there are no new facts to be discovered by philosophy; only new insights."

Ludwig Wittgenstein
Philosophical Remarks (1975),
Philosophical Grammar (1978) 256p
Quoted in "Has cosmology advanced in recent years?" by Saurabh Sanatani

"Philosophy hitherto has confined itself to interpreting the world: the point, however, is to change it."

Karl Marx
The Eleventh Thesis
Theses on Feuerbach (1845)

Situation in Cosmology

- ❖Single view
- ❖Uncontrollable
- ❖Unrepeatable
- ❖Inaccessible
- ❖Distorsion
- ❖Unique

"Given this situation, we are unable to obtain a model of the Universe without some specifically cosmological assumptions which are completely unverifiable."

G. F. R. Ellis (1975)

Assumptions and Limits

❖ **Good luck assumption**

"The normal physical laws we determine in our space-time vicinity are applicable at all other space-time points."

G. F. R. Ellis (1975)

Unverifiable!

❖ **Scientific policy**

"Ockham's razor", minimal assumption attitude.

Unverifiable!

❖ **Uncertainty**

Both random (in measurements) and systematic (in assumptions) errors.

❖ **Further loophole**

Any explanation may not be unique.

"The problem [is that] there is only one universe to be observed, and we effectively can only observe it from one space-time point."

G. F. R. Ellis (1975)

Science in Reality

"Science in reality is more related with the art of ignoring and selecting observations, and manipulating experiments, in accordance with preconceived theory. Detailed observation is often a hindrance to scientific reasoning. Ignore apparent phenomena and grasp the essence. … The trick is to treat the subject as an isolated, simplified, idealized and abstract (preferably mathematized) model, and test and materialize it by fitting data to the model using the method of analysis and statistical technique."

JH, *KIAS Newsletter* (2011)

Metaphysical Assumptions

- ❖ "All science presupposes some metaphysical system of beliefs"
- ❖ "As used by Aristotle the word 'metaphysics' meant 'beyond physics', that is beyond the scope of physical science."
- ❖ "Metaphysical theories are absolutely essential to scientific inquiry."
- ❖ "[M]odern science is based not only on observation and experiment but also on metaphysical beliefs. … faith or trust is necessary for understanding the natural world."

J. Trusted *Physics and Metaphysics: Theories of Space and Time* (1991)

Laws of Physics

"People make the mistake of talking about "natural laws". There are no natural laws. There are only temporary habits of nature."

Alfred North Whitehead
Dialogues of Alfred North Whitehead (1954)

"We have no right to assume that any physical laws exist, or if they have existed up to now, that they will continue to exist in a similar manner in the future."

Max Planck (1858-1947)

"It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we say about Nature."

Niels Bohr (1885-1962)

"Physical concepts are free creations of human mind, and are not, however it may seem, uniquely determined by the external world."

Albert Einstein (1936)

Theoretical World Models

Four ingredients (**assumptions**):

1. **Gravity:** Einstein gravity or generalized gravity
2. **Spatial geometry:** homogeneous and isotropic, or more complicated geometries.
3. **Matter contents**: dust, radiation, fields, and others.
4. **Topology (global geometry):** undetermined in the gravity level.

"The sciences do not try to explain, they hardly even try to interpret, they mainly make models. By a model is meant a mathematical construct which, with the addition of certain verbal interpretations, describes observed phenomena. The justification of such a mathematical construct is solely and precisely that it is expected to work."

John von Neumann, quoted in *Chaos* by James Gleick (1988) 273p

"Physics is mathematical not because we know so much about the physical world, but because we know so little; it is only its mathematical properties that we can discover."

Bertrand Russell

"[Model is a] scientific approximation of reality."

"[W]hen a researcher begins to be not a methodological, but an ontological materialist, … when he considers his models, useful in other contexts, as cosmic realities, then he has started on a path that, in the end, can lead only to scientific decadence."

Konrad Rudnicki
The Cosmologist's Second (1982)
11, 92p

Beginning of Modern Physical Cosmology

"If we are concerned with the structure only on a large scale, we may represent matter to ourselves as being uniformly distributed over enormous spaces, …"

A. Einstein (1917)
"Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie (Cosmological Considerations in the General Theory of Relativity)", *Königlich Preussische Akademie der Wissenschaften*

"Einstein's first cosmological paper is purely theoretical exercise containing not a single astronomical constant."

Paul Feyerabend *Against Method*
3rd ed. (1993) 239p

Isotropy Around Us

- Radio source count, background X-ray sources, deep sky map, gamma-ray bursts, and especially CMB are quite isotropic (same in all directions) around us.
- 2D projected isotropy does not imply 3D isotropy.
- Do we have any evidence that the same isotropy holds in other places?
  unverifiable, locally in practice, globally in principle!

We need a dogma†: the part we see is representative of the whole

†dogma: a belief or set of beliefs held by a group or organization, which others are expected to accept without argument."
The Oxford Advanced Learner's Dictionary, 6th Edition

Cosmological Principle A Dogma

- **Cosmological principle:** "The universe is spatially homogeneous." Global assumption. Leads to a highly idealized complete world model.
  Completely unverifiable outside horizon.
- **Copernican principle:** "We are not at the centre of the universe." Local assumption. Leads to a model of the observed part of the universe.
  No assumption outside horizon. Still difficult to prove.

G. F. R. Ellis (1975)

"Principles in cosmology have often connoted assumptions unsupported by evidence, but without which the subject can make no progress."

Martin Rees (2000)

"Truth is much too complicated to allow anything but approximations."

John von Neumann (1903-1957)

"The aim of science is to seek the simplest explanations of complex facts. We are apt to fall into the error of thinking that the facts are simple because simplicity is the goal of our quest. The guiding motto in the life of every natural philosopher should be, Seek simplicity but distrust it."

Alfred North Whitehead
Concepts of Nature, p. 163.

"Our ability to describe the universe with simple, elegant models stems in large part from our lack of data, our ignorance."

J. Horgan *The end of science: Facing the limits of knowledge in the twilight of the scientific age* (1996)

Cosmological Principle

On a sufficiently large scale the Universe is homogeneous and isotropic in space.

Perfect Cosmological Principle

On a sufficiently large scale the Universe is homogeneous and isotropic in space and time.

➡ Steady-state theory

~ Laws of physics are valid always everywhere.
Impossible to prove!

Ancient Hindu Cosmological Principle

"The Universe is infinitely heterogeneous; our [place] is not an exceptional feature, neither in space nor in time, but it is also not typical, not average (it is impossible to obtain any mean, any average value out of infinitely dispersed parameters)."

Rudnicki (1982)

The universe cycles between expansion and total collapse, with an infinite number of universes at one given point of time.

"There are *innumerable universes* besides this one."

Bhagavata Purana 6.16.37

We need Testable Measures

- **Homogeneity measures**
- **Isotropy measures**
- **Linearity measures**

Observational Facts

1. Our Universe Exists

We know for sure.

"Not how the world is, is the mystical, but that it is."
Ludwig Wittgenstein (1922)

It is a philosophic statement.

"Philosophy begins in wonder. And, at the end, when philosophic thought has done its best, the wonder remains."
A. N. Whitehead (1861-1947)

"Science is what you know, philosophy is what you don't know."
Bertrand Russell (1872-1970)

2. Darkness of the Night Sky

The darkness of the night sky is in conflict with a homogeneous, infinite and eternal static universe.

The finite age of our observable patch plus finite speed of light resolves the issue in the standard model.
Johannes Kepler (1610)
Olbers' paradox
Edgar Allen Poe (1848) *Eureka*

3. Large-scale Distribution

- Observations find not much inconsistency with these assumptions on scales larger than, say, ~100Mpc.
- Observed inhomogeneities can be approximated as small deviations.
- We do not know!

4. Redshift-distance Relation

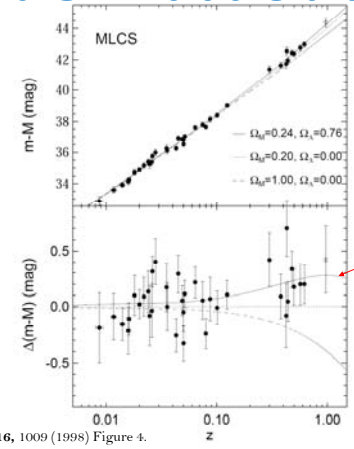
- The redshift z is proportional to the distance d:
  $z\, c \sim H\, d$
- Interpreted as due to the recession of the galaxies:
  $v \sim z\, c$ for $v \ll c$.

Difficult to prove!

Alternatives: Expanding space, Receding motion, Gravity, Decreasing c or h, Increasing mass or e, Shrinking atom, Tired light, …

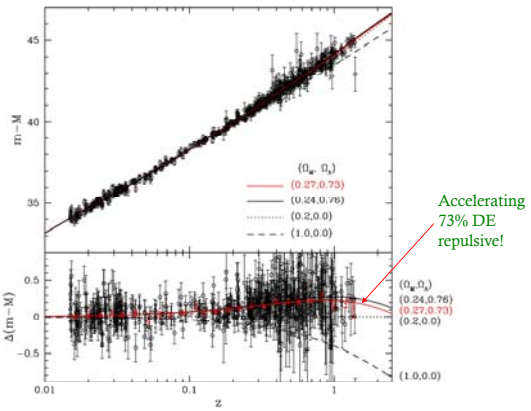
- Currently favored value shows
  $H_0 = 72 \pm 7$ km/sec/Mpc (HST)
- And acceleration ➡ Dark Energy?

Type Ia SN Hubble diagram



Reiss, A. G. et al, ApJ **116,** 1009 (1998) Figure 4.

Recent UNION2 data



557 SNe data in Amanullah, R., et al, ApJ **716,** 712 (2010). Figure by Dr. Chan-Gyung Park

Dark Energy Interpretation

"Its nature (whether constant, or varying) is a major problem for theoretical physics"

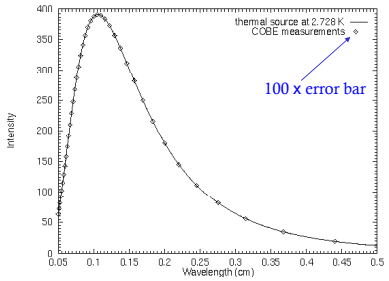
"The deduction of the existence of dark energy is based on the assumption that the universe has a Robertson-Walker geometry - spatially homogeneous and isotropic on a large scale."

G. F. R. Ellis (2009)

5. CMB

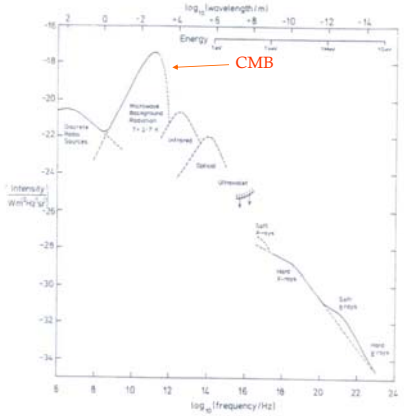
- Black-body with T~2.725K: implies 'hot' early stage.
- Dipole anisotropy at 10^{-3} level: perhaps due to our own motion relative to the CMB rest frame
- Multipole anisotropies at 10^{-5} level: due to physical processes and the gravitational clustering properties at recombination.
- Anisotropy spectrum: consistent with the Harrison-Zel'dovich's suggestions in the 70's.
- According to the 'standard scenario' we are looking at the last scattering (recombination) surface which occurred at z ~1,000 and t ~380,000yrs.
- Is CMB cosmological? **No direct proof!**

CMB Spectrum

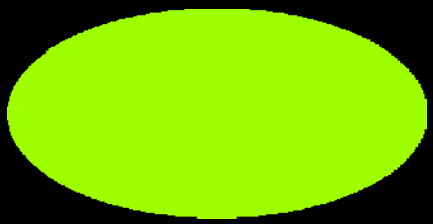


COBE (1989)

Complete Photon Spectrum



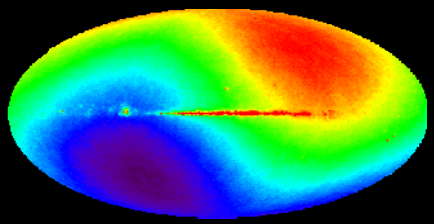
CMB Complete Sky



isotropic

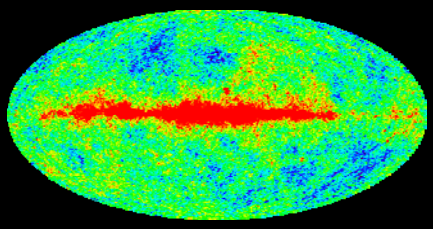
2.725 K

δT/T ~10^{-3} level



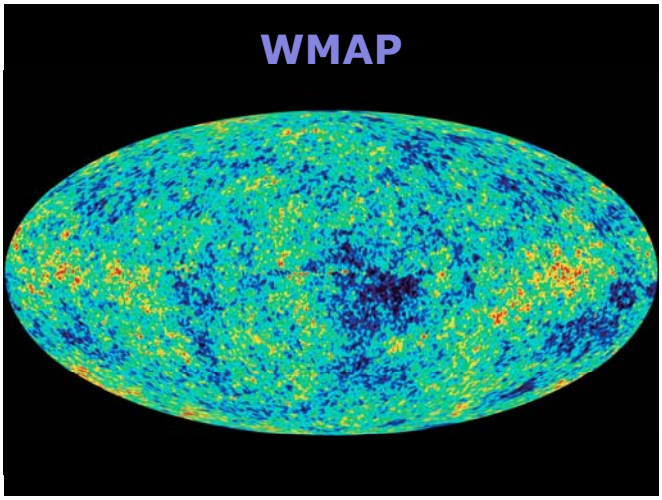
Dipole: perhaps due to our motion relative to CMB rest frame

$\delta T/T \sim 10^{-5}$ level



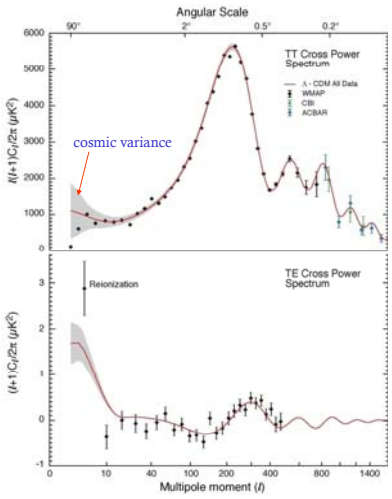
WMAP Satellite

WMAP



WMAP

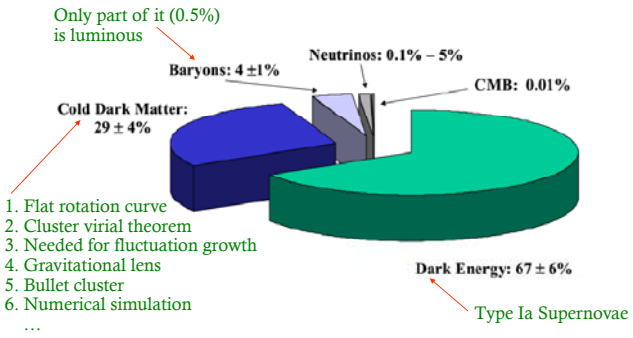
Temperature-polarization anisotropies



6. Amount of Matter

- Minimum amount of the baryons observed.
- The rotation curve of spiral galaxies, and the virial theorem in clusters of galaxies indicate violation of Newton's (Einstein's) gravity.
- Assuming Newton's (Einstein's) gravity demands presence of non-luminous dark matter (DM).
- Recent observational and theoretical studies show presence of unclustered dark energy (DE) driving accelerated expansion.

Matter Contents



1. Flat rotation curve
2. Cluster virial theorem
3. Needed for fluctuation growth
4. Gravitational lens
5. Bullet cluster
6. Numerical simulation

…

Freeman and Turner, astro-ph/0308418 (2003)

7. Ages

- Age estimation of the globular clusters reduced by ~15%
- Age of the world model increased due to the acceleration.
- Recent estimation:

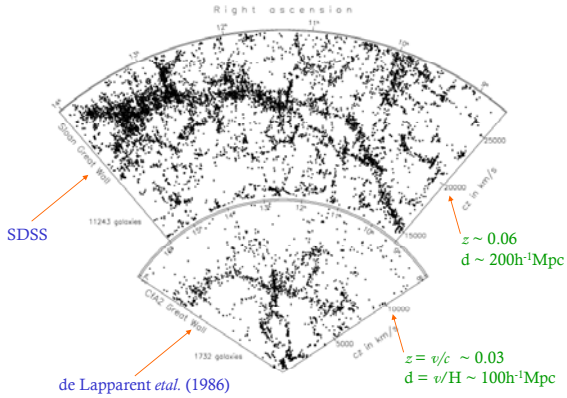
  $t = 13.7 \pm 0.2$ Gyr (WMAP)

- The proximity of the age of the world model and the age of the oldest stars is a big triumph of the standard world model.

8. Galaxy Clustering

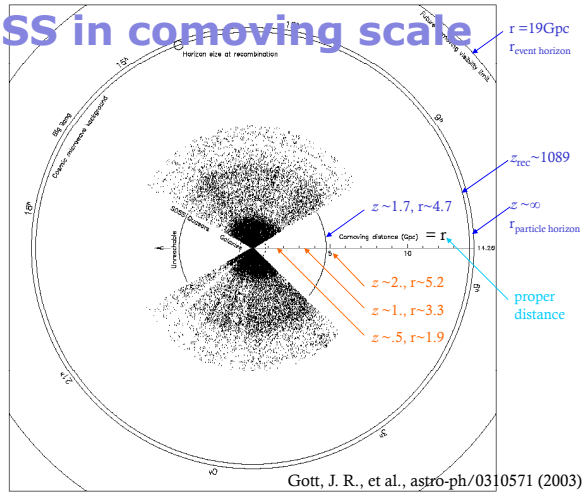
- Statistical patterns of the large-scale distributions of the observed (luminous) and gravitating (causing radial velocity) matter.
- Demand violation of Newton's gravity or presence of dark matter in galactic and cluster scales.

LSS: non-linear structure



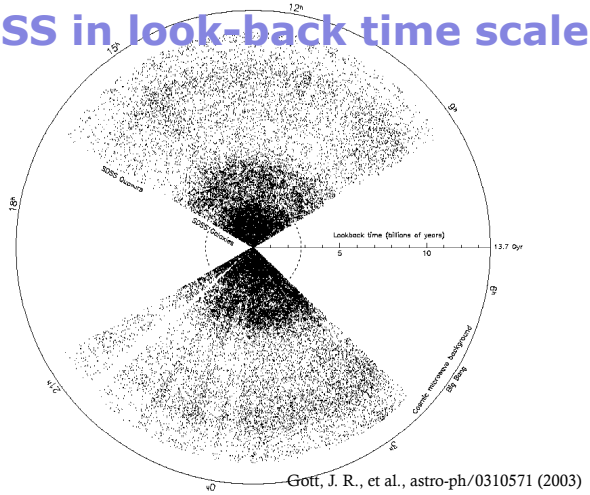
http://www.sdss.org/

SDSS in comoving scale



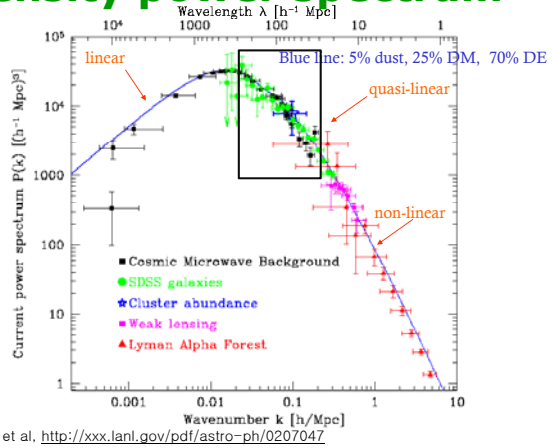
Gott, J. R., et al., astro-ph/0310571 (2003)

SDSS in look-back time scale



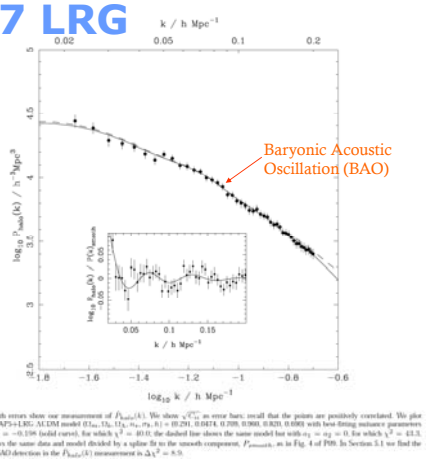
Gott, J. R., et al., astro-ph/0310571 (2003)

Density power spectrum



Tegmark, M., et al, http://xxx.lanl.gov/pdf/astro-ph/0207047

SDSS DR7 LRG



Reid et al, arXiv:0907.1659v2

9. Element Abundances

- We have theoretical range of the abundances of the Hydrogen, Helium and Litium which are consistent with observation.

  H, D, ^{3}He, ^{4}He, ^{7}Li

- Primordial Nucleosynthesis: one of pillars of hot big-bang cosmology.
- A modern myth.

10. Matter vs. Antimatter

- Apparently the observed universe is mainly composed of the matter instead of the antimatter:

  $n_{\text{Baryon}}/n_{\text{Photon}} \sim 10^{-10}$

- Coincidence or Baryogenesis?

11. Existence of Observers

One should not forget possible significance of our presence in our observed patch in the universe.

Possible answers (G.F.R. Ellis):
1. Design (from Designer)
2. Good Luck (from ToE)
3. Anthropic Principle (from Multiverse)

"What we can expect to observe must be restricted by the conditions necessary for our presence as observers. (Although our situation is not necessarily *central*, it is inevitably privileged to some extent.)"
Brandon Carter (1974)

Doctrinaire (Anthropic, multiverse)

"The world is the way it is, at least in part, because otherwise there would be no one to ask why it is the way it is."
S. Weinberg (1989)

For a balanced view (Good Luck, coincidence)

"It is much better to find a simple physical resolution of the problem rather than speculate that we can live only in the universes where the problem does not exist. There is always a risk that the anthropic principle does not cure the problem, but acts like a painkiller."
A. Linde (2002)

Still (Design, providence)

"The conditions necessary for human existence impose narrow limits on the design of the universe."
E. Harrison (1992)

Some Issues

1. Before the Big Bang

"Nothing can ever be created by divine power out of nothing."
Lucretius (~100-55 B.C.)

"First God made heaven and earth, …"
Genesis 1, *The Bible*

"What was God doing before the creation of the world? Some people say that before He made the Heaven and Earth, God prepared Gehenna (hell) for those who have the hardihood to inquire into such high matters. … There was no time before creation, and hence the question was not cogent. Simultaneously with time the world was made."
Saint Augustine (354-430)

"The universe is created with time, not in time."
J. D. Barrow (1999)

It is a far-fetched interpretation. As we approach the singularity classical gravity and quantum mechanics are not valid.

"… danger of strongly believing in ideas not confirmed by observation, … without this confirmation we lose the only way we can distinguish science from metaphysics."
M. R. Ribeiro, etal (1998)

"Cosmologists are often in error, but never in doubt."
L. D. Landau (1908-1968)

2. Boundary of the Universe

"Learn, therefore, that *the universe is not bounded in any direction.* If it were, it would necessarily have a limit somewhere. But clearly a thing cannot have a limit unless there is something outside to limit it, … Since you must admit that there is nothing outside the universe, it can have no limit and is accordingly without end or measure."
Lucretius (~ 100-55 B.C.)

Expanding Friedmann world model has a finite horizon, the light travel distance during the age of the universe, which is about 14Gly. In this world model we do not need to assume anything which encompasses beyond the horizon from the outset.

"Many of today's problems awaiting solution are more sophisticated versions of puzzles discussed by the philosophers and mathematical astronomers of ancient Greece over two thousand years ago. They too worried about the limits of time and space, the elements that make up the whole, how (or if) the universe began, and whether cosmic events are random or meaningful, chaotic or maintained by balance and order."
M. R. Wright
Cosmology in Antiquity (1995)

"Buddha has remained silent on two cosmological questions. These are questions about 'temporal and spatial finiteness or infiniteness' of the universe. Buddha has undeclared on these questions, as being metaphysical speculations irrelevant to attain liberation and to reach nirvana, and discouraged his disciples from wasting time and energy on those."
JH, *KIAS Newsletter* (2011)

"In the search for truth there are certain questions that are not important. Is the universe eternal? … Are there limits or not to the universe? … If a man were to postpone his search and practice for Enlightenment until such questions were solved, he would die before he found the path."
Gautama Buddha (563-483 B.C.)

"Socrates didn't spend his time discussing the nature of everything as most others did, wondering about what the experts call the *kosmos* and the reasons for all the things in the sky necessarily coming about as they do; on the contrary he pointed out the foolishness of those who were concerned with such matters."
Xenophon, cited in *Cosmology in Antiquity* by M. R. Wright (1995)

3. Beyond the Horizon

Untestable extrapolations beyond the horizon:
Cosmological principle, Chaotic inflation, Landscape, Multiverse, Island universe, Topological complications, …
Testable alternative: Small universe, Closed model, …

What's beyond the present horizon is, by definition, beyond our recognition at present, strictly untestable.

"When our models give predictions of the nature of the Universe on a larger scale than the Hubble radius, these are strictly unverifiable, however appealing they may be."
G. F. R. Ellis (1993)

"Because we wish to talk about regions we cannot directly influence or experiment on, our theory is at the mercy of the assumptions we make."

G. F. R. Ellis (1975)

"When a feature of a model is ascertained through imposition rather than by experimental or observational check it is unscientific because it is *only* based on personal choices. In other words, a certainty achieved that way becomes a dogma."

M. R. Ribeiro, etal (1998)

"There is perhaps no beguilement more insidious and dangerous than an elaborate and elegant mathematical process built upon unfortified premises."

Thomas Chamberlain
American geologist (1899)
Cited in "Our Cosmic Habitat"
by Martin Rees (2001) 4p

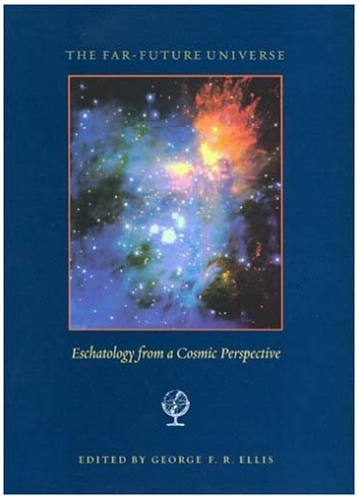
"There is no more common error than to assume that, because prolonged and accurate mathematical calculations have been made, the application of the result to some fact of nature is absolutely certain."

A. N. Whitehead

4. Future of the Universe

"Definite predictions may be made for finite (though very large) intervals of time only, as well as in other branches of science. … we see that the future of our Universe may be not simply *very* complicated but even *infinitely* complicated."

A. A. Starobinsky (2000)



5. Metaphysical Cosmology

Ironic (speculative, untestable) cosmology:

- Before inflation: creation out of nothing, no boundary proposal, cyclic, …
- Outside the horizon: cosmological principle, multiverse, chaotic inflation, eternal inflation, many worlds, megaverse, string landscape, …
- Other dimensions: string theory, M-theory, braneworld, Kaluza-Klein, parallel universes, …
- Far future: big crunch, big chill, big rip, cyclic, …

Without observationally testable consequences

Untestable Models

Multiverse claims:

Unobservable universe domains,
Untested claimed physics (hypothetical)
What tests are possible of the claims?
No observational data whatever are available!
Theory takes precedence over observations
Reasonable philosophical proposal.
Not provable science.
Scientifically irresponsible!

Which is more important in cosmology?
Theory (explanation) or
Observations (tests against reality) ?

G.F.R. Ellis "Unity of the Universe" meeting Portsmouth (2009)

Genuine Science

"We should stand firm and insist that genuine science is based on observational testing of plausible hypothesis. … Theory must be subject to experimental and/or observational test; this is the central feature of science."

G. F. R. Ellis
"Dark matter and dark energy proposals: maintaining cosmology as a true science?" (2008)

6. The Ultimate Question

"On the ultimate origination of things: why there is a world at all? Why is there something rather than nothing?"
Gottfried Wilhelm Leibniz (1646-1716)

"I wonder at the existence of the world: how extraordinary that anything should exist, or, how extraordinary that the world should exist."
Ludwig Wittgenstein (1889-1951)

"Why is there any Being at all - why not far rather Nothing?"
Martin Heidegger (1889-1976)

These are philosophic questions.

7. More Tractable Ones

"Where do we come from? What are we? Where are we going?"
Paul Gauguin (1897)

These must belong to the most profound questions raised by humankind, especially the middle one.

Meanwhile, we also have

"It is better to inquire about 'light' things, finding some truth, than keeping to wonder about the 'maximal questions' without reaching anything."
Galileo Galilei (1564-1642)

➡ This attitude heralded the beginning of modern science! However, **cosmology is inevitably concerned with the 'maximal questions'.**

"Where do we come from? What are we? Where are we going?"
Paul Gauguin (1897)

8. Pointlessness

"The more the universe seems comprehensible, the more it also seems pointless."
S. Weinberg
The First Three Minutes (1977)

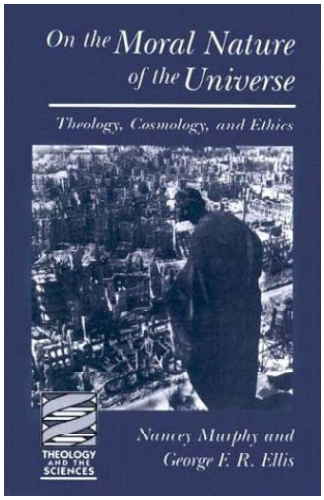
Physics is not the right tool if one is interested in the 'point (purpose, meaning, value) of the universe'. Modern sciences have been trying to avoid the term 'purpose' intentionally.

"Science is wonderfully equipped to answer the question "How?" but it gets terribly confused when you ask the question "Why?""
Erwin Chargaff

"Physical cosmology confines its attention to the 'how' of the universe and does not deal with the 'why'."
R. A. Alpher and R. Herman
Genesis of the Big Bang (2001)

However,

"Cosmology that could not answer the various why-questions would immediately be felt as lacking something."
Konrad Rudnicki
The Cosmologist's Second (1982) 73p



"Everything's got a moral, if only you can find it."

Lewis Carroll, *Alice's Adventures in Wonderland* (1865)

The Bombing of Dresden

9. Golden Age Rhetoric

"It's often said … that today we are in a golden age of cosmology. That's really true. Cosmology at this present time is undergoing a transition from being a bunch of speculations to being a genuine branch of hard science, where theories can be developed and tested against precise observations."

Alan Guth *A Golden Age of Cosmology* in Edge (12.4.01)

Earlier one:

"There is a special reason for believing that the twentieth-century universe is the universe; that further discoveries will add much in detail but will not alter the general picture."

D. W. Sciama *The unity of the universe* (1961)

10. Precision Cosmology?

Observations are determining theoretical parameters in standard cosmological model to percent-level precision.

Standard model "modestly" **assumes (∴unverified)**:

1. **Dark matter (savior1)**
2. **Dark energy (savior2)**
3. **Inflation (savior3)**
4. **Einstein's gravity**
5. **Cosmological principle**
6. **Universality of local laws of physics**
7. **Materialism (no non-material cause)**

However, in observation, only 0.5% is visible, 99.5% invisible!

Precision of Unknowns? (categorical mistake)

11. Future of Cosmology

"What if cosmologists already had, in the big bang theory, the major answer to the puzzle of the universe? What if all that remained was tying up loose ends, those that could be tied up? One does not become a cosmologist to fill in the details left by the pioneers."

"Given this possibility, it is no wonder that 'strong' scientists such as Hawking have vaulted past the big bang theory into postempirical science."

J. Horgan *The end of science: Facing the limits of knowledge in the twilight of the scientific age* (1996)

"Prediction is very hard, particularly of the future."

Neils Bohr (1885-1962)

"Wormholes? Baby universes? Infinite dimensional superspace of string theory? … it is ironic science, science that is not experimentally testable or resolvable even in principle … Its primary function is to keep us awestruck before the mystery of the cosmos. … Ironic cosmology will continue, of course, as long as we have poets as imaginative and ambitious as Hawking, Linde, Wheeler, … Their visions are both humbling, in that they show the limited scope of our empirical knowledge, and exhilarating, since they also testify to the limitlessness of human imagination. … **But it is not science**."

J. Horgan *The end of science: Facing the limits of knowledge in the twilight of the scientific age* (1996)

Not a genuine one, perhaps…
But still science in reality.

Conclusion

"Cosmology itself, like all arts and sciences, is a construct of human intelligence, subject to social and linguistic conditioning and dubious means of communication."

M. R. Wright
Cosmology in Antiquity (1995)

"All our knowledge however valid it seems in the present, is in a cosmic sense transitory because it is tied to the social conditions out of which it was learned and constructed."

Immanuel Wallerstein
The Uncertainties of Knowledge (2004) 78p

In any case,

"It is open to every man to choose the direction of his striving; and also every man may draw comfort from Lessing's fine saying, that the search for truth is more precious than its possession"

Albert Einstein (1940)

Particularly true in cosmology where fundamental questions are unanswerable.

Another comfort:

"The charm and importance of a study of the heavens was matched only by the uncertainty of the knowledge produced."

Aristotle (384-322 B.C.)

Modern Cosmology: Assumptions and Limits

"Physical cosmology tries to understand the universe at large with its origin and evolution. Observational and experimental situations in cosmology do not allow us to proceed purely based on the empirical means. We examine in which sense **our cosmological assumptions in fact have shaped our current cosmological worldview** with consequent inevitable limits. Cosmology itself, as in other branches of science and knowledge, is a construct of human imaginations, subject to social conditioning, and reflecting popular belief system of the era. The question at issue deserves further philosophic discussions."

JH, *KIAS Newsletter* (2011) Abstract