

# Cosmology 101

## Modes of thinking in cosmology

### Old and New

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# The challenge of Cosmology

The logos of the cosmos has held an eternal fascination with the thinking mind.

Interestingly enough, the more advanced amongst us (no matter when and where they were) never felt shy of speculating on the substance and logic of the universe- Not all believed in a creator

It was a prime intellectual challenge- in fact without delving into the ``working'' and ``mysteries'' of the universe one could hardly aspire to be amongst the elite of the era- you could certainly not become a BrahmaRishi without flirting with the cosmic

We will walk with the cosmologists- ancient and modern-examine the intellectual processes and threads that unite and divide them

And in a profound sense it is true today- cosmologists, in general, do not win many Nobel prizes, but they fascinate folks, often, far beyond their scientific achievements- Astronomy 101 is, for instance, the most attended ``Science'' course for non-science majors ( in most American universities)

# Looking for shared thinking traits

What really impresses a student of cosmology, however, is that the thinkers of time memorial and the “architects” of modern “cosmological models” have thought processes that may have a considerably overlap.

It is true only in the realm of thinking and speculation and certainly not in what may be called cosmography- mapping of the universe.

*Early cosmography is essentially absurd and had to be so*



Without the sophisticated and far-reaching technological tools of today, “seeing” the universe was not possible.

So I will not worry whether the universe is supported by a turtle or how its various parts correspond to those of the sacrificial horse.

We will probe only the thought processes of yesterday and today

# Creation Hymn Rigveda, Mandal 10 – Nasadiya sukta

## Beginning: Grand pronouncement and a Statement of the scope of enquiry

Then even nothingness was not, nor existence, There was no air then, nor the heavens beyond it.  
What covered it? Where was it? In whose keeping? Was there then cosmic water, in depths unfathomed?

## A qualitative descriptive model

Then there was neither death nor immortality nor was there then the torch of night and day.  
The One breathed windlessly and self-sustaining. **There was that One then, and there was no other**

At first there was only darkness wrapped in darkness. All this was only unilluminated water.  
That One which came to be, enclosed in nothing, arose at last, born of the power of heat. -  
**DYNAMICS**

In the beginning desire descended on it -that was the primal seed, born of the mind.  
The sages who have searched their hearts with wisdom know that which is kin to that which is not

## Invoking authority

And they have stretched their cord across the void, and know what was above, and what below.  
Seminal powers made fertile mighty forces, Below was strength, and over it was impulse.

# The Questioning /Humility of the Cosmologist

को अद्धा वेद क इह प्र वोचत्कुत आजाता कुत इयं वसृष्टिः ।  
अर्वाग्देवा अस्य वसिर्जनेनाथा को वेद यत आबभूव ॥६॥

But, after all, who knows, and who can say

Doubts

Whence it all came, and how creation happened?

the gods themselves are later than creation,  
so who knows truly whence it has arisen?

Good company

इयं वसृष्टिर्यत आबभूव यि वा दधे यि वा न ।  
यो अस्याध्यक्षः परमे व्योमन्त्सो अङ्ग वेद यि वा न वेद ॥७॥

Whence all creation had its origin,  
he, **whether he fashioned it or whether he did not,**  
he, who surveys it all from highest heaven,  
he knows - or maybe even he does not know.

Conclusion in great humility  
Questions His omnipotence?

There is no unraveling of the dynamics; there are no testable ( even in principle)  
predictions. No if-then statements

# An Upanishadic Cosmological Discourse

## Gargi Vacakanvi ``questioning’’ Yagyavalkaya

- A hallowed Upanishadic (brihda-aranyaka, for example) modality- King Janaka of Videha throws an intellectual party – the winner of the discourse will get 1000 cows as an award
- The great sage Yagyavalkaya is almost always the winner. Even before the contest begins he is known to ask his disciples to drive the cows home!
- Of course he is challenged (very politely but how dare he) that he cannot do it till he answers the questions from the other learned sages who have gathered for the competition.
- I will report here the challenge from a particularly astute questioner- a woman intellectual Gargi Vacakanvi. She decides to take Y on after he has ``authoritatively’’ disposed off a horde of luminaries (Asvala, Arthabhaga, Lahyayani, Cakrayana, Kaushtikeya)
- Gargi’s questions are, really, the most relevant to our current query
- Prior to her questioning, the specialness of the Water Worlds had been established

# Gargi (G)-Yagyavalkaya (Y)

- Oh Yagyavalkaya, Since all the world is woven warp and woof on water, on what pray is the water woven warp and woof Y---- On wind, Oh Gargi  
On what then, pray, is the wind woven warp and and woof--on the atmosphere worlds Oh G  
On what then, pray, are the atmosphere worlds woven warp and and woof  
on the worlds of the Gandharvas, Oh G

On what then, pray, are the world of Brahma woven warp and woof

Y- Gargi do not question too much *lest your head fall off*. In truth you are questioning too much about a divinity about which *further questions cannot be asked*. Gargi, do not over-question.

There upon Gargi held her peace !

Yagyavalkaya is, then, grilled by another big name sage, Uddalaks Aruni (also addressed as Gautama) and the dialogue reveals the nature of the immortal self (atman)- the unseen Seer, the unheard hearer, the unthought thinker, the ununderstood understander-----

# GARGI-2

- Gargi, however, believes that she can put Y to more stringent tests than other learned folks-
- Venerable Brahmins-I have two questions. If he can withstand the foe-piercing arrows that I, like a noble prince, will throw, **not one of you will surpass him in discussions of Brahma**
- **So she throws the gauntlet - O Y** which is above the sky and which is beneath the earth, and which is in between the two, the sky and the earth, and which people call the past present and future, across what it is woven warp and woof  
*Across space is that woven warp and woof*
- Gargi offers adorations to Y for ``solving'' the first – exhorts him to get ready for the next  
*Across what then, pray, is the space woven warp and woof*  
*That, O, Gargi, Brahmins call the Imperishable (akshara)-----*
- Yagyavalkaya then goes on a long uninterrupted, deeply philosophical address that develops, *inter alia*, the profound concept ``**neti neti**'' for the Imperishable-the reality- the essence of the universe.
- We are told then that *Gargi held her peace* after telling the venerable gathering ``you better escape this man with a simple bow-none will ever match him in the knowledge of Brahma''<sup>8</sup>



# Yagyavalkaya and the modality of discourse

- It seems infinite regress is the primary mode into which these dialogues devolve- Upa intellectual feasts
- Neither the questioner nor the answering sage seems uncomfortable with the modality- the questioner (G) plays the game as willingly and as enthusiastically as the answerer(Y)
- During this ``transferring the responsibility- from waters to wind- ---- to Brahma'' exercise, profound thoughts are expressed, questions posed and commented upon- *But there is never a ``real'' resolution of any fundamental original question-* Regress statements often followed by deep discourses.
- **A very bold Assertion** - It seems that there is a tacit agreement amongst all contenders that *really fundamental questions* about the universe or its essence *have no answers* – As we ponder on them, however, it sharpens the tools of analysis, and we may derive some unintended benefits
- Otherwise how could **Gargi hold her peace, the second time adoringly, after total non-answers she gets from Yagyavalkaya**
- If it were so this message has the same essence as the Vedic poet cosmologist – one expresses it simply in ethereal poetry and the other in a very complicated, convoluted dialogue- The great genius lies in posing so many ``essential'' questions and boldly seeking answers with the only ``scientific'' tools available to them- the intellect and the imagination

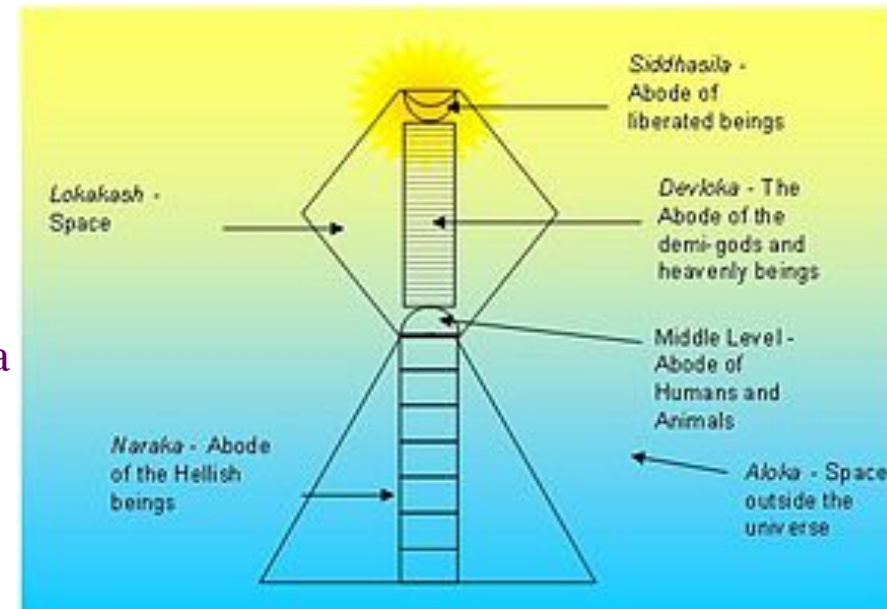
# More Indian (Jain) Cosmology – would you believe it?

- Jain Cosmology is just as fascinating- it spans the entire creativity span- from unimaginably wild pronouncements to totally hard headed profound logic
- NO one, including the rest of the ancient Indians, could play with numbers so large
- The era of absolute bliss (susama-susamaa) lasted for 400 trillion units of time –people were six miles tall and had life spans of -----

And there is this fantastic cosmography

But let us go to the more ``mundane’’ writings of a phenomenal thinker- Jain monk Acharya Jinasena - 8<sup>th</sup> Century CE- author of Mahapurana

Begins with a Bang



*Some foolish men declare that Creator made the world. The doctrine that the world was created is ill-advised, and should be rejected. If god created the world, where was he before creation? If you say he was transcendent then, and needed no support, where is he now?*

# Acharya Jinasena- Mahapurana 1- continued

- No single being had the skill to make the world - for how can an immaterial god create that which is material? How could god have made the world without any raw material? If you say he made this first, and then the world, you are faced with an endless regression.
- If you declare that the raw material arose naturally you fall into another fallacy, for the whole universe might thus have been its own creator, and have risen equally naturally.
- If god created the world by an act of will, without any raw material, then it is just his will made nothing else and who will believe this silly stuff?
- If he is ever perfect, and complete, how could the will to create have arisen in him? If, on the other hand, he is not perfect, he could no more create the universe than a potter could. If he is formless, actionless, and all-embracing, how could he have created the world?
- Such a soul, devoid of all modality, would have no desire to create anything. If you say that he created to no purpose, because it was his nature to do so then god is pointless.
- If he created in some kind of sport, it was the sport of a foolish child, leading to trouble. If he created out of love for living things and need of them he made the world; why did he not make creation wholly blissful, free from misfortune?
- **Thus the doctrine that the world was created by god makes no sense at all.**

# Acharya Jinasena- Mahapurana 2

- Jinasena, surely, was not a part of the intellectual compact of the Vedic-Upanishadic period!
- VC speaks in awe and wonder- AJ is bold and definitive – VC shares with us his musings while AJ is full of if-then (what we would call conventional logic) statements- VC ends on a note of indecision – while AJ drives remorselessly towards a big bold conclusion-----
- He soundly rejects any attempts to associate Brahma (or any other One) to have anything to do with the material cosmos – he rejects the “infinite regress” approach of Y and G
- *And yet there may be a profound commonality – perhaps it is not possible to “know” the answer to this deepest of queries-* The commonly held cosmogony model makes little sense
- Indian cosmology did depart from the Vedic-Upanishadic speculations- to take a form more consistent with what we find in Jinasena- that is a god-free cosmology

# Indian Cosmology- Some Salient and Striking features

Relentless and regulated cycles of birth, being and destruction- the period of the cycle is called a kalpa~  $4.32 * 10^9$  years – Current estimate for the age of the universe~~  $14 * 10^9$  years

The birth, evolution, and destruction take place via natural processes, each step in this chain is a certainty

*Natural is not explicitly defined- contextually , however, anthropomorphic intervention and also that of a divine designer, is rejected.*

The evolution is entirely purposeless – there is no raison d'etre, no goal –no promises to keep- only endless mechanical repetition- **Very powerful qualitative attributes**

This is a cosmology with a cosmogony in which anthropomorphic Gods play no role

Has elements of modernity. There is no, however, no attempt to offer a real dynamical model with predictions and testable consequences!

# Greeks- Post Homeric Cosmologies-Beyond the whims of Gods

Greeks began to seriously believe, quite early, that regularities in heavens and change of seasons resulted, not from the whims of the gods, but from physical laws.

Two fascinating examples from Anaxagoras: 1) **Meteors fall from heavens and yet they are of the same material as found on earth- Ergo** heavens are made of the same material as earth- **Highly speculative:** heavenly bodies must have sheared off earth!

2) Moon shines through reflecting the sun light inundating it; the lunar eclipses occur when the earth comes in between blocking the sunlight. Sun and moon are by no means on the same footing.

The evolution of the thinking mode – that one must adhere closely to the observed facts, and that nature works on rational principles- is the basis of modern science

# PreSocratic- Parmenides and Heraclitus-Creativity through conflict

Two contemporary giants (fifth century BCE)

Parmenides: Reality is one, and change is impossible- Eternal Statics

Easy definition of truth: `reality' is truth

Heraclitus: Everything is in a state of flux, is constantly evolving- Dynamics in toto-

Truth becomes hard to define- unless there are well-formed laws of change

and these laws are accepted as the `truth'

The phenomenon of such conflicting contemporary giants ( or schools ) occurs again and again in our intellectual history.

Epicurus- and Zeno the stoic (306-301)

Shared intellectual space- Limited capacity of intellectual space-Law of small numbers

This very theme- the forever and the ever changing will play a fundamental role in the emergence and sharpening of modern cosmology.

# Glimpses of Modern Cosmology

Cosmology – The study of the universe as a whole- It is not just the study of stars or galaxies – it is on a bigger scale than all of these

Driving Force – The hallowed and compelling ancient traditions of attempts to understand how the world originated, where is it headed, and why it does what it does. **Astronomy** and **Physics** must creatively combine to unravel, if at all, even fragments of this grand picture

**Astronomy explores the physical content of the universe-** and physics provides the framework in which such information can become knowledge, hopefully, communicable knowledge.

The primary distinguishing features form ancient cosmology:

MC constructs (provisional) quantitative models whose consequences (predictions) must match what is actually observed – if not, the model has to be improved upon, even rejected- *All models are provisional*

*The most amazing fact is that the tiny elementary particle as well as the immense cosmos (as an entity) can be analyzed within the framework of similarly framed stringent mathematical theories*



# Building a Cosmological Model

There are many features of the physical system that one has to assume to construct the simplest / first theories. **Cosmology is no exception**- But much has gone into developing just such a picture that we can construct a mathematical framework for calculations

To the leading order the universe ``is'' remarkably simple- If one concentrated on sufficiently large scales, the universe is both homogeneous and isotropic

**You will surely scream : What nonsense** – When I look out in the sky I do not see stars distributed uniformly. And even if it were true how can you get much out of a theory so content less

So the cosmologist asks for some indulgence: Astronomers have been able to show that if we averaged the mass over what is called a Hubble length (a measure of the size of the universe) than the inhomogeneity is violated by only one part in 10000!

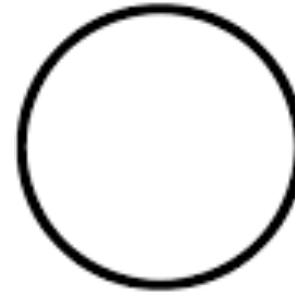
Greatest wonder of all- That even the foundation provided by as little as homogeneous and isotropic allows us to construct a theory that leads to profound testable results- observations confirm one of the most profound predictions.

# Physicists' First Theories – You got to be kidding

A spherical elephant

Even

a point elephant



First calculations on the universe are done with equally profound assumptions

Perfect Cosmological Principle

A uniform isotropic universe, filled with a perfect isotropic fluid

Perfect isotropic fluid – This will be the crucial input into making the first cosmological model based on Einstein's theory of General Relativity

Such a fluid has only two defining physical quantities : The energy density  $E$  and the pressure  $P$

# The Cosmological Model- Key Element – theory of gravity

Key element: **Einstein's formulation of a theory of gravity (General Relativity)** - way more potent than Newton's grand but relatively primitive theories.

Gravity was much more complicated structure (albeit in a supremely elegant mathematical way) than Newtonian gravity. Totally necessary to even begin to understand the universe as if it were a single entity

Understanding Universe is understanding the “structure” of space-time-the motion of matter and energy is dictated by the structure of space-time- the structure of space-time is equivalent to gravity– **the structure is created by matter and energy**-matter and energy are in constant motion due to gravity- this motion effects gravity-----

This is the essence of what is called Nonlinearity- Non linearity makes a theory very difficult and very interesting and potent. **General Relativity-queen of nonlinear theories**

# Glimpses of Modern Cosmology-Curved space time, Einstein Eqs.

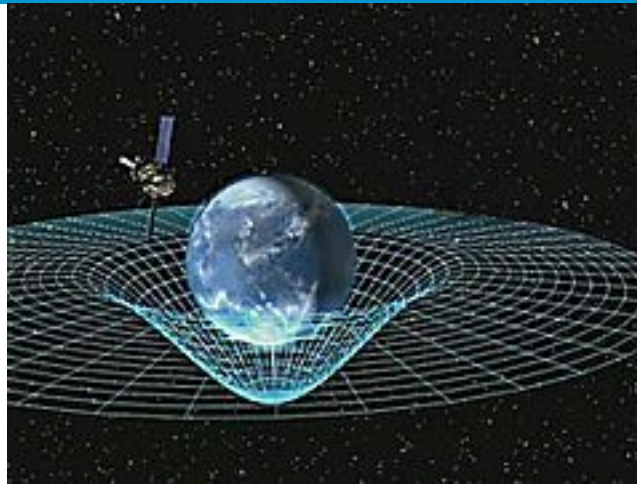
## Flat and Curved Space time

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$\Lambda$ =Cosmological constant

deeply held prejudice

Perfect Cosmological principle



Einstein Equation

A cosmic blunder

A Grand Insight Now

The perfect Isotropic assumption specifies exactly what the matter/energy source of gravity

One then solves these equations to predict, simultaneously, the structure of space time and the the evolution of matter and energy

A fundamental result of calculations gave the name big bang to the cosmological model

*The universe is expanding and if extrapolated backwards, the universe will be found in a very very hot state. What is equally remarkable is that for such an evolving universe we can construct the time history of matter and radiation.*

# Testing the Model - Physics from Relics

Einstein equations are the foundation stone for our current theories of cosmology

But there are three other momentous events that led to the grand result I stated

Friedman, Lemaitre, Robertson, Walker solution: Einsteinian universe is an expanding universe

Hubble's Astronomical observations ( with great telescopes just available- technology advancing science) that universe is indeed expanding

*Then there was the cosmic triumph: Accidental discovery of the Cosmic Radiation -the predicted relic of an initial very very hot and very very small universe*

*The very simplest model passed a crucial test- the approach was sound!*

This event, more than anything else, boosted up the cosmology enterprise

Tension between steady state and big-bang sharpened the development

# Unification Mania

Is it a Scientific or a Cultural necessity

Let us Talk

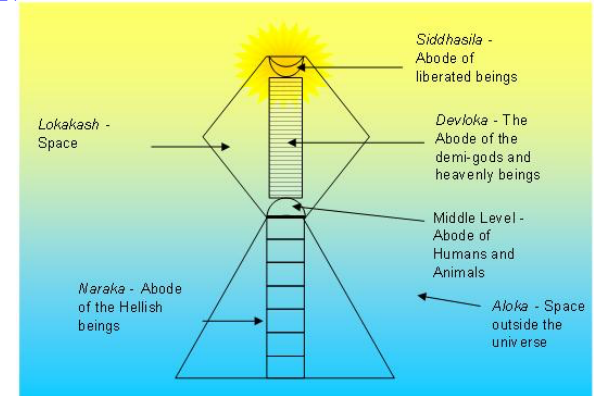
Thank you

# A glimpse from Jain Cosmology

An eternal and ever-existing world which works on universal natural laws

Acharya Jinasena (800 CE)- Mahapurana

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