Higher derivative gravity: Alexey Starobinsky and beyond

Victor Berezin
Institute for Nuclear Research of Russian Academy of Sciences

Lecture One

Part I. Genesis = pre-historic epoch

- Adam + Eve: "The First Apple"
- Ancient shepherds: discovery of planets
- Egyptian priests: first measurements
- Ptolemaeus: first theoretical model – geocentric system
- Copernicus: Heliocentric system
- Galileo: first telescope looking at the sky
- More and more powerful telescopes: bottomless abyss full of myriads of stars
- Homogeneous and isotropic Universe: "cosmological principle" – first cornerstone for classical cosmology
- Olbers paradox: "Why the night sky is dark?" – any reliable cosmological model ought to remove this obstacle
- Kepler: three laws for motion of planets
- Hooke + Newton: law of gravity for planets
- Newton: "The Second Apple" - universality of gravitational interactions
- The Universe is governed by gravity – second cornerstone for classical cosmology
- Gravitational instability

Part II. Classical cosmology = historic epoch

- Einstein: Special Relativity – "The Third Apple"?
- Einstein: General Relarivity – gravity = curves spacetime,
- Einstein equatons + Einstein-Hilbert action integral
- Einstein: first really cosmological model – cosmological term, instability, no solution to Olbers paradox
- Friedmann: first nonstationary cosmological model
- Hubble: galactic red shifts
- Lemaitre: Hubble law is due to Universe expansion, Big Bang
- Gamow: hot Universe – cosmic microvawe background (CMB)
- Big Bang: initial singularity
- Penrose, Hawking: singularity theorems – energy dominance condition
- Belinsky, Lifshits, Khalatnikov: oscillatory regime when approaching singulariry – highly anisotropic
- Zel'dovich: isotropization due to particle production

Part III. Alexey Starobinsky and higher derivative gravity

- Zel'dovich and Starobinsky: cosmological particle creation by quantum scalar field
- Conformal anomaly: renormalization – appearance of R^2 term in action integral, forth order detivatives of metric tensor in equations of motion
- Sakharov: gravity is stresses of vacuum oscillations of all other quantum fields – emergent phenomenon = induced gravity
- Starobinsky: first inflationary model – no initial singularity, unstable de Sitter spacetime in the beginning + particle creation, instability is good for cosmology, equivalence of $R + R^2$ theory to $R + scalar field$ one, no need for extra scalar field, "Occam's razor", "creation from nothing"

- Inflation – what is it? and is it for?
- Kirzhnits and Linde: cosmological phase transitions
- Guth: introduced the very word “inflation” into cosmological science, explained how old cosmological problems could be solved “in one fell swoop” (per saltum), false and true vacuums, bubbles
- Linde and Steinhard: new inflation, rolling down
- Linde: chaotic inflation – new dynamical regime for scalar field, seems extremely simple
- Is it possible to create universe in laboratory?
- Inflaton – where from?

Lecture Two

Beyond Starobinsky

- Hoyle and Narlikar: “Steady state Universe” – particle creation, scalar C-field with “wrong” sign of kinetic term, Lagrange picture for hydrodynamics
- Myself: phenomenology for particle vretion, Euler picture for hydrodynamics, “creation law” in action integral
- Zel'dovich and Starobinsky: rate of creation is proportional to Weyl tensor squared (C^2)
- Conformal invariance: Weyl conformal gravity, action intgral and energy-momentum tensor
- In the spirit of Sakharov: conformally invariant model for particle creation – appearance of C^2 and R in action integral
- Weyl conformal gravity: spherical symmetry, vacuum solutions, electro-vacuum sulution, Vaydia-like solution
- Weyl + Einstein gravity: thin shells and double layers