Outline

• One hundred years ago: Einstein’s Field Equations (GR)
• The Great Debate of Apr 26, 1920
• The Day Modern Cosmology was born (Nov 23, 1924)
• The Universe expansion and, by looking back, the Big Bang
• On the origin of the Universe: a classical singularity in a quantum world
• The Universe expansion accelerates!
• Are there direct proofs of inflation and of the Big Bang itself?
An Island Universe

Apr 26, 1920: The Great Debate – Shapley vs Curtis

Harlow Shapley – the Milky Way was the entire Universe

Heber Curtis – many novae in Andromeda: “island Universe" (I Kant)

Edwin Hubble, 1922-1924, Cepheid stars in some nebuale, as Andromeda and Triangulum. Was 35, published in the New York Times, on Nov 23, 1924; then at 1925 meeting of AAS

Henrietta S Leavitt 1912 period-luminosity relationship of Cepheid variable stars: linear dep luminosity vs log of period of variab stars (Eddington valve) “standard candles" for measuring H

In 1929 Hubble derived his famous velocity-distance relationship for nebulae using, as he wrote to Vesto Slipher (got results since 1912): “your velocities and my distances"

WASHINGTON, Nov. 22. -- Confirmation of the view that the spiral nebulae, which appear in the heavens as whirling clouds, are in reality distant stellar systems, or "island universes," has been obtained by Dr. Edwin Hubbell of the Carnegie Institution's Mount Wilson observatory, through investigations carried out with the observatory's powerful telescopes.

In 1929 Hubble formulated the Redshift Distance Law, "A relation between distance and radial velocity among extra-galactic nebulae", PNAS 15, 168–173
Henrietta S Leavitt 1912 period-luminosity relationship of Cepheid variable stars: linear dep luminosity vs log of period of variab stars (Eddington valve) “standard candles" for measuring H
On September 17, 1912, obtained the first radial velocity of a "spiral nebula" - Andromeda. Using the 24-inch telescope at Lowell Observatory, AZ, he got more Doppler shifts, establishing that large velocities, usually in recession, were a general property of the spiral nebulae.

Slipher presented his results of the speed of 15 nebulae to the Am Astronomical Society in 1914, and received a standing ovation.
Big Bang

“Condició primigènia en la qual existien unes
condicions d’una infinita densitat i temperatura”
[Wikipedia CAT]

“At some moment all matter in the universe
was contained in a single point” [Wikipedia]

Georges Lemaître (1894-1966)

Theory, 1927: Solution (Friedmann’s) of Einstein’s Eqs
Annales Société Scientifique Bruxelles 47, 49 (1927), Eddington MNRAS (1930)

Observational evid.: V. Slipher redshifts + E. Hubble distancies

“hypothèse de l’atome primitif” Nature 127, 706 (1931)

primeval atom, cosmic egg
Alternatives:


**Cyclic model (or oscillating universe):** In a poem by Erasmus Darwin, 1791: universe that expanded and contracted in a cyclic manner. Edgar Allan Poe, 1848, similar cyclic system in his essay *Eureka: A Prose Poem*. Richard C. Tolman, 1934, showed cyclic model failed because the universe would undergo inevitable thermodynamic heat death.

**New cyclic model:** brane cosmology model of the creation of the universe (derived from the ekpyrotic model) proposed in 2001 by Paul Steinhardt (Princeton) and Neil Turok (Cambridge). Evades entropy problem by net expansion in each cycle, preventing entropy from building up.
Big Bang: Evidences

- Expansion according to Hubble’s law
- CMB Radiation 1964 A Penzias R Wilson
- Abundancy of primordial elements: helium-4, helium-3, deuterium, lithium-7
- Evolution & distribution of galaxies
- Primordial gas clouds
- Distant quasars
- Detection of primordial gravitational waves?

17 March 2014

WS Adams i T Dunham Jr 37-41; G Gamow 48; RA Alpher, RC Herman 49
On the very origin

A mathematical singularity.

Extrapolation of the expansion of the universe backwards in time using General Relativity yields an infinite density and temperature at a finite time in the past [Hawking and Ellis, *The Large-Scale Structure of Space-Time* (Cambridge U.P., 1973)]

\[
\ell_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.616199(97) \times 10^{-35} \, \text{m}
\]

\[
t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5.39106(32) \times 10^{-44} \, \text{s}
\]

\[\hbar = 1.054571726(47) \times 10^{-34} \, \text{J s}\]

\[= 6.58211928(15) \times 10^{-16} \, \text{eV s}\]

inside Planck region
Max Planck & Albert Einstein

\[ E = mc^2 \]

\[ I(\nu) = \frac{2h\nu^3}{c^2} \frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1} \]

- Max Planck to his son: “Today I made a discovery which could be as important as that of Newton” Physics NP 1918

- Albert Einstein got the Physics NP 1921 not for Relativity but “… for the discovery of the photoelectric effect”
**Inflation**

App. $10^{-36}$ seconds after the origin, a phase transition caused a cosmic inflation, during which the universe grew very quickly. The inflationary epoch lasted from $10^{-36}$ to $10^{-35}$ seconds after the origin to some $10^{-33}$ to $10^{-32}$ s.

De Sitter space (1917) is the analog in Minkowski space (spacetime) of a sphere in ordinary, Euclidean space. It is the maximally symmetric, vacuum solution of Einstein's eqs, corresponding to a positive vacuum energy density and negative pressure.

De Sitter space can be defined as a submanifold of a Minkowski space of one higher dimension. Take Minkowski space $\mathbb{R}^{1,n}$ with the standard metric:

$$ ds^2 = -dx_0^2 + \sum_{i=1}^n dx_i^2. $$

De Sitter space is the submanifold described by the hyperboloid of one sheet

$$ -x_0^2 + \sum_{i=1}^n x_i^2 = \alpha^2 $$

where $\alpha$ is some positive constant with dimensions of length.

In the early 1970s, Zeldovich: flatness and horizon problem.

In the late 1970s, Sidney Coleman applied the instanton techniques of Polyakov et al to study the fate of the false vacuum in quantum field theory. Like a metastable phase in statistical mechanics—water below the freezing temperature or above the boiling point—a quantum field needs to nucleate a large enough bubble of the new vacuum (new phase), to make a transition.

(In QFT, a false vacuum is a metastable sector of space that appears to be a perturbative vacuum, but is unstable due to instanton effects that may tunnel to a lower energy state. This tunneling can be caused by quantum fluctuations or the creation of high-energy particles. This is analogous to metastability for first-order phase transitions.)
History of the Universe

Inflation Generates Two Types of Waves

Gravitational Waves

Density Waves

Waves Imprint Characteristic Polarization Signals

Free Electrons Scatter Light

Earliest Time Visible with Light

Baryon Acoustic Oscillations (BAO)

Recombination

Reionization

Solar System

Modern Universe

Cosmic Microwave Background

Neutral Hydrogen Forms

Matter Dominance

Photon Epoch

Lepton Epoch

Hadron Epoch

Protons Formed

Nuclear Fusion Begins

Nuclear Fusion Ends

Quark-Gluon Plasma

GUT Epoch

Inflation

Quantum Fluctuations

Radius of the Visible Universe

0 10⁻³² s 1 μs 0.01 s 3 min 380,000 yrs 13.8 Billion yrs

Age of the Universe
**Zero point energy**

QFT vacuum to vacuum transition: \( \langle 0 | H | 0 \rangle \)

Spectrum, normal ordering (harm oscill):

\[
H = \left( n + \frac{1}{2} \right) \lambda_n \ a_n \ a_n^\dagger
\]

\[
\langle 0 | H | 0 \rangle = \frac{\hbar c}{2} \sum_n \lambda_n = \frac{1}{2} \text{tr} \ H
\]

gives \( \infty \) physical meaning?

Regularization + Renormalization (cut-off, dim, \( \zeta \))

Even then: Has the final value real sense?
The "vacuum energy catastrophe"

- The mean energy density per unit volume of electromagnetical field at thermal equilibrium

\[
\rho = \sum_{\text{modes}} \bar{n}_\omega \hbar \omega + \sum_{\text{modes}} \frac{\hbar \omega}{2} = \frac{\pi^2 (k_B T)^4}{15 (hc)^3} + \frac{(\hbar \omega_{\text{max}})^4}{8\pi (hc)^3}
\]

- is finite for the first Planck law (1900)
- is infinite when accounting for zero-point fluctuations (Planck 1912)
- is much too large to be compatible with gravity observations for any reasonable cutoff frequency \( \omega_{\text{max}} \) (Nernst 1916)

A major problem for fundamental physics known since 1916, still unsolved today …

S. Weinberg, Rev. Mod. Phys. 61 1 (1989)
The Casimir Effect

- Dynamical CE
- Lateral CE
- Extract energy from vacuum
- CE and the cosmological constant

BC e.g. periodic

⇒ all kind of fields

⇒ curvature or topology

Universal process:

- Sonoluminiscence (Schwinger)
- Cond. matter (wetting $^3$He alc.)
- Optical cavities
- Direct experim. confirmation

Van der Waals, Lifschitz theory
baryonic (Plausibly it is made up of the hypothetical elementary particles postulated in the 1980s, for example axions or the lowest mass supersymmetric partner of the known particles.) incompatible with the flat geometry predicted by inflation unless the Universe contains an additional unclustered and dominant contribution to its energy density, for example a cosmological constant $\Lambda$ such that $\Omega_m + \Omega_\Lambda \approx 1$. Two largescale structure surveys carried out in the late 1980s, the APM (automated photographic measuring) photographic survey and the QDOT redshift survey of infrared galaxies, showed that the power spectrum of the galaxy distribution, if it traces that of the mass on large scales, can be fitted by a simple CDM model only if the matter density is low, $\Omega_m \approx 0.3$. This independent confirmation of the dynamical arguments led many to adopt the now standard model of cosmology, $\Lambda$CDM. The supernova evidence is consistent with $\Omega_\Lambda \approx 0.7$, just the value required for the flat universe predicted by inflation. [The large-scale structure of the Universe, Volker Springel, Carlos S. Frenk & Simon D. M. White, NATURE, 440, 27 April 2006]

Gravitational waves

\[ h^{\alpha\beta} \equiv \eta^{\alpha\beta} - \sqrt{\det g} g^{\alpha\beta} \]

\[ \Box h^{\alpha\beta} = -16\pi T^{\alpha\beta}, \quad T^{\alpha\beta} \text{ stress–energy tensor plus quadratic terms involving } h^{\alpha\beta} \]

Linear approximation, space is nearly flat

\[ h^{\alpha\beta} = \frac{1}{r} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & A_+(t-r, \theta, \phi) & A_\times(t-r, \theta, \phi) \\ 0 & 0 & A_\times(t-r, \theta, \phi) & -A_+(t-r, \theta, \phi) \end{bmatrix} \]

The pattern of polarization in the cosmic microwave background can be broken into two components. One, a curl-free, gradient-only component, the E-mode (named in analogy to electrostatic fields), was first seen in 2002 by the Degree Angular Scale Interferometer (DASI). The second component is divergence-free, curl only, and is known as the B-mode (named in analogy to magnetic fields). The electric (E) and magnetic (B) modes are distinguished by their behavior under a parity transformation $n \rightarrow -n$. E modes have $(-1)^l$ parity and B modes have $(-1)^{l+1}$. The local distinction between the two is that the polarization direction is aligned with the principal axes of the polarization amplitude for E and crossed 45° for B.
On 17 Mar 2014, John Kovac announced that, by looking at the CMB signal, BICEP2 had found the imprint of gravitational waves from the Big Bang:

* polarization of the CMB
* curly patterns known as B modes
* generated by gravitational waves during inflation
Detection of B-Mode Polarization at Degree Angular Scales by BICEP2


(BICEP2 Collaboration)

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3Joint ALMA Observatory, Vitacura, Santiago, Chile
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(Received 4 April 2014; revised manuscript received 13 June 2014; published 19 June 2014)
Very latest developments:

- B2P realized B2 had **exceptionally bad luck**
  - S Pole region has **huge dust stream** (inter Magellanic clouds)
  - Dust polariz $r = .2$ as corresp to GUTs ($10^{16}$ GeV): **fatal coincidence !!**
  - **Only 1 frequency, no discrim power against dust**
  - Needed to involve astronomers: multidisciplinary team

- Combining B2 and UpKECK: $r = .06 \pm .04$
  - B2P $r < .13$ at 95%
  - UpKECK alone: $r = .03$
  - The probably wisest guess: $r = .01 \pm .005$ (optimistic)

- Wait for B3 and full KECK at 100 GHz:
  - **discriminating power against dust**
  - from 150 to 100 dust signal 4 times less
  - If this scaling is broken: some **cosmological signal remnant !!**
The Magellanic Clouds

Known since prehistoric times, since there is no bright south polar star, these two glowing patches in the southern sky helped navigators to mark the pole. Europeans heard of them during Magellan's expedition around the world, early 16th C. The two clouds are small galaxies moving in orbits around the Milky Way.

They are connected by a bridge of diffuse hydrogen gas: the Magellanic Stream. This long filament also extends from the small cloud in an arc beyond the south galactic pole, reaching in the other direction into the plane of the Milky Way, and resembles a bridge between the two clouds themselves. The Magellanic Clouds are satellites of our own galaxy and their orbits are likely to take them through the Milky Way disk. Astronomers speculate that the Magellanic stream is a tail of gas drawn out during such an encounter about half a billion years ago.
Scientists in the **BICEP2** collaboration rocked the astrophysics world when they announced in March that they had picked up signs of cosmic inflation -- the universe's giant growth spurt shortly after the Big Bang -- as well as evidence of gravitational waves, ripples in the structure of spacetime that have been theorized but never detected. Data from the European Space Agency's Planck spacecraft, however, allowed other researchers to poke holes in the findings, leaving the discovery up for debate.
NORMALIZED IMPACT REPORT

This document is an attachment extracted from SIR World Report 2011, it contains exactly the same information but the ordering variable has been set to Normalized Impact. All the values as well as institutions coincide with those included in SIR World Report 2011 :: Global Ranking also available at http://www.scimagoir.com

This report uses two decimal values for the Normalized Impact variable instead just one as it is usual in SIR Reports in order to avoid an extremely high number of identical ranks in institutions. For those institutions which have identical NI values using two decimals, the alphabetical order has been set.

Introduction

The current report involves the third release of our annual series Scimago Institutions Rankings World Reports, that based on quantitative data of citation and publication shows bibliometric indicators that unveil some of the main dimensions of research performance of worldwide research-devoted institutions. As in former editions, SIR World Report 2011 aims at becoming an evaluation framework of research performance to Worldwide Research Organizations.

The report shows six indicators that will help users evaluate the scientific impact, thematic specialization, output size and international collaboration networks of the institutions.

The period analyzed in the current edition covers 2005-09. The tables include institutions having published at least 100 scientific documents of any type, that is, articles, reviews, short reviews, letters, conference papers, etc., during the year 2009 as collected by worldwide leader scientific database Scopus by Elsevier. The report encompasses Higher Education Institutions (HEIs) as well as other research-focused organizations from different sizes, with different missions and from different fields.

Indicators

Selected indicators seek to reveal main aspects of research size, performance, impact and internationalization at Worldwide Research Institutions.

O::Output

An institution's publication output reveals its scientific outcomes in terms of published documents in scholarly journals.

IC::International Collaboration

IC shows an institution's output ratio that has been produced in collaboration with foreign institutions. The values are computed by analyzing the institution's output whose affiliation includes more than one country address over the whole period.

NI::Normalized Impact

The values, expressed in percentages, show the relationship of an institution's average scientific impact and the world average, which is 1, i.e. a score of 0.8 means the institution is cited 20% below average and 1.3 means the institution is cited 30% above average. More on NI.

Q1::High Quality Publications

Ratio of publications that an institution publishes in the most influential scholarly journals of the world; those ranked in the first quartile (25%) in their field.
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Shokran