Elements de cosmologia moderna: del Big Bang al futur de l'Univers

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SIR World Report 2011 :: Normalized Impact Report

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 regions.

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 fields.
## Normalized Impact Report

[Source: SIR World Report 2011](http://www.scimagoir.com)

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Guió

- Fa cent anys: Einstein i les seves Equacions de Camp (GR)
- El Gran Debat del 26 d’abril de 1920
- El dia que va néixer la Cosmologia Moderna (23 Nov 1924)
- L’expansió de l’Univers i, mirant enrera, el Big Bang
- L’origen de l’Univers: una singularitat clàssica en un món quàntic
- L’expansió de l’Univers s’accel.lera!
- Hi ha proves directes de la inflació i del propi Big Bang?
- Del futur de l’Univers: diverses possibilitats
- La Cosmologia i la Bíblia: Ciència i Fe
Ciència

- Observació de la natura, exp. laboratori
  - No és suficient

- Teoria científica
  - No és suficient

Observacions + Teoria → Comprensió de l’Univers!

»Il libro della natura è scritto in lingua matematica«
Galileo Galilei (1564-1642)
\[ F = G \frac{Mm}{r^2} \]

\[ E = mc^2 \]

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \lambda g_{\mu\nu} = -\frac{8\pi G}{c^4} T_{\mu\nu} \]

\[ \Omega_{\text{tot}} = \Omega_r + \Omega_m + \Omega_k + \Omega_\lambda \]
The Universe

Model:
- Surface (2-dimensional, balloon)
- Inside or outside do not exist; no 'center'
- 'Balloon' expands ...accelerately!
- Radial direction of the balloon is time
- Any object around us goes away (redshift)
- Tension is gravity
• But... the Universe was **static**! ...and very small

• What was λ? Non-physical

• At that time:

  \[
  \text{UNIVERSE} = \text{MILKY WAY (+ nebulae)}
  \]

• Ptolemy 150 DC, *Almagest*: mentions five nebulae

• Persian, Arabic, Chinese astronomers: more nebulae

• Edmund Halley *six* in 1715

• Charles Messier *103* in 1781

• William and Caroline Herschel 3 catalogs, 1786-1802, with a total of *2510* nebulae
SMITHSONIAN
WASHINGTON
26 APRIL 1920

HARLOW SHAPLEY VS HEBER CURTIS

GREAT DEBATE

WORLD HEAVYWEIGHT CHAMPIONSHIP
WBA / IBF / WBO / IBO
MOSCOW 2013
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 nebulae, 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"

FINDS SPIRAL NEBULAE ARE STELLAR SYSTEMS; Dr. Hubbell Confirms View That They Are 'Island Universes' Similar to Our Own.

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, Hubble's law

Henrietta S. Leavitt's 1912 period-luminosity relationship of Cepheid variable stars: linear dependence of luminosity vs. log of period of variable 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)

Teoria, 1927: Sol·lució (de Friedmann) de les Eqs d’Einstein

Observacions: V. Slipher redshifts + E. Hubble distàncies

"hypothèse de l'atome primitif"

àtom primigeni, ou còsmic
• Karl Schwarzschild: Black Hole solution (22 Dec 1915)

• Willem de Sitter: massless univer expand solution (just cc,1917)

• Alexander Friedmann: expanding universe solution (1922)

• Georges Lemaître: expanding universe (MIT ‘25, AF solution); visited Vesto Slipher (Lowell Obs, Arizona, 1912 redshifts) and Edwin Hubble (Mount Wilson, Pasadena); Keeler-Slipher-Campbell 1918, redshifts

• Theory, 1927: Annales Société Scientifique Bruxelles 47, 49 (1927), Eddington MNRAS (1930)
At meeting in Brussels, 1927, Lemaître said to Einstein: Universe is expanding, no need for $\lambda$. Answer: no error but... It took Einstein over two years to understand.

Then he said his very famous sentence: "Weg mit der kK..." (biggest blunder)

Looking backwards in time: The Universe had an origin! Primeval atom or cosmic egg (Nature 127, 706 (1931)). The Catholic Church was happy with Lemaître's scenario: Monsignor and later President of the Pontifical Academy of Sciences
Annales de la Société Scientifique de Bruxelles, 1927: "Un Univers homogène de masse constante et de rayon croissant rendant compte de la vitesse radiale des nébuleuses extragalactiques", G. Lemaître

Member of the Pontifical Academy of Sciences
• Led to **Big Bang theory** (Fred Hoyle, BBC radio 3rd progr, 18:30-50 GMT, 28 Mar 1949): refuted "that the whole of the matter in the universe was created in one big bang at a particular time in the remote past."

• Fred Hoyle, Thomas Gold, Hermann Bondi: Steady State ’48, “C-field” with a negative pressure, to be consistent with energy conservation (anticipated inflation)

• **Richard Tolman** ’32: the negative energy of gravity could supply the positive energy for matter of the Universe
- Friedmann-Lemaître-Robertson-Walker (FLRW 1931-37)
- **Dark matter:** Fritz Zwicky 1933, evidence of ‘missing mass’ in the orbital velocities of galaxies in Coma cluster (virial th, also Jan Oort ’32 MW):
  
  *dunkle Materie* (dark matter)

- Now lots of evidence: galactic rotation curves (Vera Rubin, Kent Ford ‘75), gravitational lensing, Bullet cluster, etc
• Or maybe Newton’s laws need to be modified at large distances (modified gravities, MOG, MOND, etc.) VR

• Arno Penzias, Robert Wilson (1964 at Bell Labs NJ); Princeton (< 40 miles) Dicke, Peebles, Wilkinson writing paper on how CMB should be — Burke (MIT) told Penzias of Peebles’ work:

and the Big Bang was there!

Previous: 48-49 WS Adams, T Dunhan

’30s G Gamow, Alpher & Herman
• Alan Guth ‘80, Katsuhiko Sato ‘81, Andrei Linde inflation But also: A Albrecht, P Steinhardt, A Starobinsky. And add Ya B Zel’dovich, S Coleman (decay of false vacuum), ...

• Quantum fluctuations + chaotic inflation → multiverse

• Hawking+Turok instanton ’98

NoBoundary (Hartle-Hawking) vs chaotic inflation

• A Riess, B Schmidt ’98, S Perlmutter ’99: acceler expan! → Dark Energy
Friedmann equation (matter, radiation, curvature)

\[ H^2 = \left( \frac{\dot{a}}{a} \right)^2 = \frac{8\pi G}{3} \left( \frac{\rho_{M0}}{a^3} + \frac{\rho_{R0}}{a^4} \right) - \frac{\kappa}{a^2} \]

Multiply by \( a^2 \) to get

\[ \ddot{a} \propto \frac{\rho_{M0}}{a} + \frac{\rho_{R0}}{a^2} + \text{const} \]

When \( a \) increases, each term on rhs decreases: the universe should be decelerating (\( \ddot{a} \) decreases)

Sean Carroll, Caltech
SSI 2009
Two groups looked for the 'deceleration' of the universe expansion, using type Ia supernovae as standardizable candles.
Result: supernovae are dimmer than expected

The universe is not decelerating
It is accelerating

Cannot be explained by matter+radiation (see before)

Riess, Schmidt et al. '98
Perlmutter et al. '99
Trying to solve these puzzles!

- The cc $\lambda$ is indeed a peculiar quantity
- has to do with cosmology Einstein’s eqs., FRW universe
- has to do with the local structure of elementary particle physics stress-energy density $\mu$ of the vacuum

$$L_{cc} = \int d^4 x \sqrt{-g} \, \mu^4 = \frac{1}{8\pi G} \int d^4 x \sqrt{-g} \, \Lambda$$

- In other words: two contributions on the same footing
  [Pauli 20’s, Zel’dovich ’68]

$$\frac{\Lambda \, c^2}{8\pi G} + \frac{1}{\text{Vol}} \frac{\hbar \, c}{2} \sum_i \omega_i$$

- For elementary particle physicists: a great embarrassment
  no way to get rid off
  Coleman, Hawking, Weinberg, Polchinski, ... ’88-’89

THE COSMOLOGICAL CONSTANT PROBLEM
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
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)]

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

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

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

\[
= 6.58211928(15) \times 10^{-16} \text{ eV s}
\]
Max Planck & Albert Einstein

E = mc²

I(ν) = \frac{2hν^3}{c^2} \frac{1}{\exp\left(\frac{hν}{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”
Com s’ha pogut originar l’Univers?

- Miracle de la física n.1: la gravetat pot ser repulsiva energia pot camp escalar → pressio negativa → grav repulsiva

- Miracle de la física n.2: el camp gravitatori té energia negativa

* Energia de la matèria positiva: Energia total 0

- ”A free lunch!”

- Instantó de Hawking-Turok: “una espècie d'espurna que dispara la inflació en una sopa primigènia de gravetat, espai, temps i matèria”

- Reproducció dels universos: Multiversos ...
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 $10^{-32}$ seconds.

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 equations 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 A. 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

- Gravitational Waves
- Density Waves
- Waves Imprint Characteristic Polarization Signals
- Free Electrons Scatter Light
- Earliest Time Visible with Light
- Baryon Acoustic Oscillations (BAO)

- Inflation Generates Two Types of Waves
- Quantum Fluctuations
- Quark-Gluon Plasma
- GUT epoch
- e-weak epoch
- hadron epoch
- lepton epoch
- Photon epoch
- Matter dominance
- Cosmic Microwave Background
- Neutral Hydrogen Forms
- Recombination
- Reionization
- Modern Universe
- Solar system

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 electromagnetic field at thermal equilibrium

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

- 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

BC e.g. periodic
\[\rightarrow\] all kind of fields
\[\rightarrow\] curvature or topology

Universal process:
- Sonoluminiscence (Schwinger)
- Cond. matter (wetting $^3$He alc.)
- Optical cavities
- Direct experim. confirmation
- Van der Waals, Lifschitz theory

- Dynamical CE \[\leftrightarrow\]
- Lateral CE
- Extract energy from vacuum
- CE and the cosmological constant \[\leftrightarrow\]
Some Books

2nd Ed June 2012

Emilio Elizalde
CSIC, UB
IEEC, UAB

Emilio Elizalde
in Moscow, May 20, 2009, during the Fourth International Sakharov Conference on Physics.

Diego Sánchez-Gómez • Sergei Odintsov • Sebastiá Xambó
Editors

Cosmology, Quantum Vacuum, and Zeta Functions

Papers in honor of Emilio Elizalde on the occasion of his 60th Birthday

Springer
Ten Physical Applications of Spectral Zeta Functions

Second Edition
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 large scale 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

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

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

Linear approximation, space is nearly flat

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

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


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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 correspond 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.
Un final apocalíptic?

• Expansió accelerada per sempre:
  l’Univers es dilueix, illes en torn a forats negres, objectes isolats, pols intergalàctica

• Big Crunch

• Big Rip:
  models *phantom*, singularitat futura a temps finit

• Little Big Rip

• Univers ciclic (polsant)

• I a tot això: *univers o multivers*?
Six science stories we can't wait to follow in 2015 - LA Times

6. The search for ripples in the structure of spacetime continues

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.
SUPLEMENT

LA TERRA

A L’UNIVERS

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Sota la direcció científica de
Josep Maria Trigo i Rodríguez

ENCICLOPÈDIA CATALANA

Barcelona, 2012
Mercès
Thank You
Shokran