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REFLECTIONS ON KEY BOOKS AND SELECTED PAPERS
by Martin Rees

[The Stuff of the Universe](#) (with John Gribbin). Heineman (UK); Bantam (USA) under the title "[Cosmic Coincidences](#)," 1989; various languages; revised by Penguin, 1995

A survey of cosmology emphasizing the explanations of "dark matter" and the apparent tuning of the constants of physics, co-written with Rees' friend John Gribbin, a prolific science writer (before he realized he was capable of writing a book by himself).

[Gravity's Fatal Attraction: Black Holes in the Universe](#) (with Mitchell Begelman). W.H. Freeman, 1995; completely updated 2nd ed. Cambridge University Press, 2010; translated into 10 languages

Co-authored with former student Mitchell Begelman (now Professor at University of Colorado), this book described the astrophysical role of Einstein's theory and the properties of its most remarkable prediction: black holes. It discusses many of the topics on which Rees has worked – quasars, radio sources, and gamma ray bursts – in a level accessible to non-specialist students and general readers.

[New Perspectives in Astrophysical Cosmology](#). Cambridge University Press, 1995; expanded edition, 2000; 2nd edition, 2002

This was a straightforward text on cosmology, at a level appropriate to physics majors or those beginning graduate study in astrophysics. The fact that it is now drastically out of date testifies to the extraordinary progress and vibrancy of cosmology in the last decade – which is owed to advances in instrumentation and computer power rather than to newer and deeper insights.

[Before the Beginning: Our Universe and Others](#). Simon & Schuster (UK); [Perseus](#) (USA), 1997; various languages

This was Rees' first single-authored book. It ranged widely and included historical reflections and personal reminiscences. It described the then-current understanding of cosmology, quasars and dark matter. But its most distinctive theme was the speculation that what we traditionally call 'the universe' could be just one 'island' in a (possibly infinite) archipelago. This book was one of the earliest popular expositions of the 'multiverse' concept. Critics generally praised it for the way it covered both standard and speculative topics while always distinguishing clearly which were which.

[Just Six Numbers: The Deep Forces that Shape the Universe](#). Wiedenfeld & Nicolson (UK); Basic Books (USA), 1999; translation into approximately 20 languages

This book, in the 'Science Masters' series created by John Brockman, highlights six numbers whose values determine the nature of the cosmos and the micro-world and describes how the potentialities for emergent complexity (including life) require these numbers to lie within a range that is in some cases very narrow. The apparent tuning has been interpreted by various authors as coincidence, 'happenstance' or 'design.' Rees argues that we need to address two questions: "Was there one big bang or many?" and "If there were many, are they governed by different laws so that what we call 'fundamental laws' may be just bylaws prevailing in our cosmic patch?" If the answers to both these questions were 'yes' the apparent fine tuning of the six numbers could be merely 'anthropic selection.' Rees emphasizes that these questions are scientific ones – albeit still highly speculative and far from being answered.

[Our Cosmic Habitat](#). Princeton University Press (USA), 2001; Wiedenfeld & Nicolson (UK), 2002; translated into 10 languages

Most of Rees' books were prepared by meshing together general articles or lecture notes he had already prepared. This book was in some respects more coherent, as it was an expanded version of the inaugural series of Scribner Lectures given at Princeton University in March/April 2000.

[Our Final Century](#). Random House (UK); Basic Books (USA) under the title "[Our Final Hour](#)," 2003

Ever since the 1980s, Rees has frequently written and spoken on general issues impinging on politics, policy global threats and the social and ethical responsibilities of scientists. He came to appreciate that, though our Earth has existed for 45 million centuries, the coming century is a special one: it's the first when one species (ours) has the power and impact to determine the future of the entire biosphere. The book received highly favorable notices in the UK; in the US (where the title was changed to "*Our Final Hour*"!) it earned the 'lead' review in the *New York Times Book Review*. The book argued that humans are threatened by their collective environmental impact, and also by the greater vulnerability of our inter-connected world to high-tech disruptions ('error' or 'terror') that could be caused by very few. These themes have risen even higher on the agenda in 2011.

[DK Illustrated Encyclopedia of the Universe](#) (general editor). Dorling Kindersley, 2005; updated 2007, 2008

This is a comprehensively illustrated and information-packed volume. Rees' role was general editor, and though it is about the best single-volume book of its kind, he can claim little personal credit for its quality.

[From Here to Infinity: Scientific Horizons](#). Profile Books; to be published June 2011

Rees was invited to give the BBC's prestigious Reith Lectures in 2010. He was chosen primarily because, in recognition of the Royal Society's 350th anniversary, the BBC had made 2010 a 'year of science' and had made genuine efforts to increase their serious output on scientific themes. This book is an expanded version of the lectures (about double the length). The four lectures were entitled 'The Scientific Citizen,' 'Surviving the Century,' 'What We May Never Know' and 'A Runaway World'.

What We Still Don't Know. Penguin (UK); Pantheon (USA); to be published in 2012

This long-gestating book is very loosely based on a TV series presented by Rees on Channel 4 in 2004. It deals with several scientific 'grand challenges,' addresses whether there are intrinsic limits to scientific knowledge set by human brains, and explores the possibility of 'posthuman' evolution (organic or inorganic), extraterrestrial life, and the multiverse.

Selected Papers

My research papers (more than 500) have spanned a range of topics. Listed below are key papers on some themes that I have pursued most intensively. (Key to publications abbreviations below.)

RADIO SOURCES AND JETS

One of the most remarkable features of compact objects is that much of their energy is emitted in narrow jets moving at close to the speed of light. Ever since student days, this phenomenon has been one of my enduring interests.

- Appearance of Relativistically Expanding Radio Sources. *Nat* **211**, 468 (1966).

This paper presented indirect evidence that radio sources must involve ejection of material at close to the speed of light. This was only directly verified from the 1970s onwards, with the advent of VLBI (very long baseline interferometry) techniques.

- New Interpretation of Extragalactic Radio Sources. *Nat* **229**, 312 (1971) (errata, p. 510).
- A 'Twin-Exhaust' Model for Double Radio Sources. *MNRAS* **169**, 395 (1974) (with R.D. Blandford).

These two papers introduced and developed the conjecture (which is all it was at that time) that the lobes of double radio sources were energized by continuous jets from the centre of the host galaxies.

- Ion supported tori and the origin of radio jets. *Nat* **295**, 17 (1982) (with M.C. Begelman, R.D. Blandford and S.L. Phinney).

A model that relates jet production to the physics of gas near a black hole.

- Theory of Extragalactic radio sources. *Rev. Mod. Phys.* **56**, 225 (1984) (with M.C. Begelman and R.D. Blandford).
- Black hole models for active galactic nuclei. *Ann. Rev. Astr. AstroPhys.* **24**, 471 (1984).

These are two comprehensive reviews, both still frequently cited, of theories and models for radio sources, jets and quasars.

- SS 433: a double jet in action. *MNRAS* **187**, 13P (1979) (with A.C. Fabian)

A short paper that presented the first conjecture that the unique object SS433 was actually a double jet.

COSMOLOGY

Listed here are papers on aspects of fundamental cosmology.

- Cosmological Significance of the Relation between Redshift and Flux Density for Quasars. *Nat* **211**, 1283 (1966) (with D.W. Sciama)

A paper, written while still a student, which identified strong evidence against the 'steady state' theory, which was taken seriously at that time.

- The Collapse of the Universe: An Eschatological Study. *Observatory* **89**, 193 (1969)

One of the first papers in the serious literature addressing the long-term future of the universe.

- The Cosmological Significance of e^2/Gm^2 and Related Numbers. *Comm. Astrophys. and Space Phys.* **4**, 179 (1972)

An early paper addressing "large numbers" in cosmology and astrophysics.

- Anthropic principle and the Physical World. *Nat* **278**, 605 (1979) (with B.J. Carr)

An influential and still-much-quoted survey which addressed the various 'large number coincidences' in astronomy and cosmology, relating them to fundamental constants and showing which are related by simple physics and which involve apparent 'tuning' of parameters.

- Our Universe and others. *Q.J.R.A.S.* **22**, 109 (1981)

Some early speculations on the multiverse.

- How stable is our vacuum? *Nat* **302**, 508 (1983) (with P. Hut)

Arguments that accelerator experiments pose no danger because more extreme natural phenomena, involving cosmic ray collisions, have occurred repeatedly in the cosmos and the universe has survived.

- The large-scale smoothness of our Universe *Nat* **394**, 225 (1999) (with K. Wu and O. Lahav) astro-ph/9804062

A survey of all the observational arguments constraining the deviations from large-scale uniformity in the density and flow patterns within the observable universe.

- Why is the CMB fluctuation level $\sim 10^{-5}$? *ApJ* **499**, 526-32 (1998) (with M. Tegmark) astro-ph/9709058

Discussion of the unexplained value of the key cosmological parameter Q , which determines the structural features of the universe.

- Dimensionless constants, cosmology, and other dark matters. *Phys. Rev. D.* **73**, 023505 (2006) (with M Tegmark, A Aguirre and F Wilczek) astro-ph/0511774

A study of anthropic constraints on the ratio of baryons and dark matter in the universe – another key number which is not yet understood.

- "Cosmology and the Multiverse" in "Universe or Multiverse?", ed. B J Carr (CUP 2007)

A survey of multiverse theory, published in a comprehensive volume containing papers from two conferences held in Cambridge.

MASSIVE BLACK HOLES

- On Quasars, Dust and the Galactic Centre. *MNRAS* **152**, 461 (1971) (with D. Lynden-Bell)

Two years before this was written, D Lynden-Bell had published a very important paper arguing that 'dead quasars', in the form of massive black holes, should lurk in the centres of most galaxies. In this paper we suggested that there should be a hole as massive as a few million suns in the centre of our own Galaxy -- something which is by now firmly established.

- Quasar theories. (invited lecture at 8th 'Texas' conference) *Ann. N.Y. Acad. Sci.* **302**, 613 (1977)

A comprehensive survey of the evidence (which built up during the 1970s) that active quasars involve flows onto and around massive black holes, and that the formation of such holes is a natural expectation.

- Massive black hole binaries in active galactic nuclei. *Nat* **287**, 307 (1980) (with M.C. Begelman and R.D. Blandford)

- Galaxies and their nuclei: Bakerian Lecture. *Proc. Roy. Soc. A.* **400**, 183 (1985).

- Tidal disruption of stars by black holes of 106 - 108 solar masses in nearby galaxies. *Nat* **333**, 523 (1988).

- "Dead quasars" in nearby galaxies. *Science* **247**, 817 (1990).

- Formation of nuclei in newly-formed galaxies and the evolution of the quasar population. *MNRAS* **263**, 168 (1993) (with M. G. Haehnelt)

- The distribution and cosmic evolution of massive black hole spins. ApJ **620** (2005) 69-77 (with M Volonteri, P Madau and E Quataert) astro-ph/0410342
- Rapid growth of high redshift black holes. ApJ **633**, 624 (2005) (with M Volonteri) astro-ph/0506040
- Massive black holes as population III remnants. ApJ **551**, 27 (2001) (with P. Madau) astro-ph/0101223
- Quasars at $z=6$: the survival of the fittest. ApJ **650**, 669-678 (with M Volonteri) (2006) astro-ph/0607903

These papers all deal with the formation of black holes in galaxies.

- Quasars and galaxy formation. Astr. Astrophys. **331**, L1 (1998) (with J. Silk) astro-ph/9801013

A short pioneering paper, which has been surprisingly highly cited, discussing in general terms the feedback processes that might lead to a correlation (such as is observed) between the mass of a central hole and the properties of its host galaxies.

GALAXY FORMATION

I have had a long-standing interest in galaxy formation (dating back to a lecture course I gave at the Varenna International School while still a postdoc. Initially, in the early 1970s, little was known about the initial fluctuations that are the 'seeds' of cosmic structures, though the 'big bang' was well established – and the evidence for dark matter was not yet firm until the 1980s when the Cold Dark Matter (CDM) model was developed..

- A Theory of Galaxy Formation and Clustering. *Astron. and Astrophys.* **45**, 365 (1975) (with J.R. Gott)

General discussion of how the early fluctuations would imprint characteristic scales on the clustering in the present-day universe.

- Cooling, dynamics and fragmentation of massive gas clouds: clues to the masses and radii of galaxies and clusters. MNRAS **179**, 541 (1977) (with J.P. Ostriker)

A generic argument that basic physics imprints a characteristic upper limit on the mass of galaxies.

- Core condensation in heavy halos: a two-stage theory for galaxy formation and clustering. MNRAS **183**, 341 (1978) (with S.D.M. White)

Further development of the Rees/Ostriker argument in the context of a model with dominant dark matter and heirarchical clustering.

- Formation of galaxies and large scale structure with cold dark matter. Nat **311**, 517 (1984) (with G. Blumenthal, S. Faber and J. Primack)

One of the key papers codifying (and prefiguring future developments of) the now-generally-accepted CDM model.

HOW DID THE DARK AGE END? POPULATION III

The universe became literally dark about half a million years after the big bang, when the primordial radiation shifted into the infrared. It remained dark until the first objects (stars or superstars) formed and lit it up again. When and how these first "Population III" objects formed has been one of my long-standing interests, ever since a key conference at Yale in 1977.

- Formation of Population III stars and pregalactic evolution. MNRAS **205**, 955 (1983) (with A. Kashlinsky).

A specific model for formation of massive stars in subgalactic clusters

- Pregalactic evolution in cosmologies with 'cold dark matter'. MNRAS **221**, 53 (1986) (with H.M.P. Couchman).
- How small were the first cosmological objects? ApJ **474**, 1 (1997) (with M. Tegmark *et al.*) [astro-ph/9603007](#)

Two papers on how the formation of the first stars is affected by cooling processes involving molecular hydrogen.

INTERGALACTIC MEDIUM

Part of my PhD thesis discussed the intergalactic medium. Later papers have discussed how this diffuse gas can be probed by studying quasar absorption lines and also by the potentially powerful (albeit futuristic) technique of 21 cm tomography. The latter technique is important as a way of probing when the "dark age" ended -- and even probing the dark age itself by detecting the 21 cm line in absorption against the microwave background.

- The 21-cm line at high redshift: a diagnostic for the origin of large-scale structure. MNRAS **247**, 510 (1990) (with D. Scott).

Among the first papers to address the importance of 21cm tomography.

- 21cm tomography from warm IGM at high redshifts. ApJ **475**, 429 (1997) (with P. Madau and A. Meiksin) [astro-ph/9608010](#)

One of three detailed papers discussing 21cm tomography in detail.

- Reionization of the inhomogeneous universe. ApJ **530**, 1-16 (2000) (with J. Miralda-Escudé and M. Haehnelt) [astro-ph/9812306](#)

One of a series of papers addressing the ionization of the intergalactic medium by quasars, and how this can be studied using quasar spectra.

GAMMA RAY BURSTS

Until the 1990s, it was unclear how far away gamma ray bursts were. When they were established to be at cosmological distances, it became clear that they manifested the most extreme physics of any known cosmic objects. Over the last 15 years I have worked in this topic, especially in collaboration with Peter Mészáros of Penn State University in the USA. The physics has links with earlier work on radio jets; recently a link with Population III has become apparent. Among the relevant papers are the following:

- High entropy fireballs and jets in gamma-ray sources. MNRAS **257**, 29P (1992) (with P. Mészáros)
- Relativistic fireballs: energy conversion and timescales. MNRAS **258**, 41P (1992) (with P. Mészáros)
- Relativistic fireballs and their impact on external matter: models for cosmological gamma-ray bursts. ApJ **405**, 278 (1993) (with P. Mészáros)
- Gamma-ray bursts: multiwaveband spectral predictions for blast wave models. ApJ **418**, L59 (1993) (with P. Mészáros)
- Optical and long wavelength afterglow from gamma-ray bursts. ApJ **476**, 232 (1997) (with P. Mészáros) [astro-ph/9606043](#)
- Thermalisation in relativistic outflows and the correlation between spectral hardness and apparent luminosity in gamma ray bursts. ApJ **666**, 1012-1023 (2007) (with C Thompson and P. Mészáros) [astro-ph/0608282](#)
- Population III gamma ray bursts. ApJ **715** 967, (2010) (with P. Mészáros) [astro-ph/1004.2056](#)

Key to publication abbreviations:

ApJ	The Astrophysical Journal
Ann. N.Y. Acad. Sci.	Annals of the New York Academy of Sciences
Ann. Rev. Astr. AstroPhys.	Annual Review of Astronomy and Astrophysics
Astr. Astrophys	Astronomy & Astrophysics
Astron. and Astrophys	Astronomy & Astrophysics
Comm. Astrophys. and Space Phys.	Comments Astrophysics and Space Physics
CUP	Cambridge University Press
MNRAS	Monthly Notices of the Royal Astronomical Society
Nat	Nature
Phys. Rev. D.	Physical Review D
Proc. Roy. Soc. A.	Proceedings of the Royal Society A
Q.J.R.A.S.	Quarterly Journal of the Royal Astronomical Society
Rev. Mod. Phys.	Reviews of Modern Physics
Science	Science