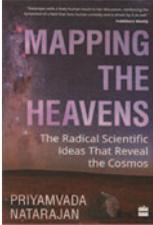


Mapping the Heavens

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Priyamvada Natarajan
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Mapping the Heavens written by Priyamvada Natarajan is the story of humanity's exploration of the cosmos using the physics that we know, as well as the quest to understand our place in the universe, which, the author argues, is deeply "primordial".

Natarajan describes how scientists have moved from thinking about "all there is"¹ as consisting only of our serene Milky Way, to something that contains billions of galaxies, and which originated precisely about 14 billion years ago, and how the door has now been opened to the tantalising speculations on multiple universes. She makes use of the metaphor of cartography to perfection. She gradually increases the boundary and moves from the solar system outwards, to bring the results of astrophysical mapping along multiple dimensions of space and time that determine the distribution, shapes, and movement of different things in the cosmos on larger and larger scales. She thus builds a beautiful, ac-

cessible, and cogent story of what we currently know and don't know. The book is a compelling exposition of how science is the best approach that humanity has today to understand the physical world around us and our place in it, because the scientific method is explicitly tentative as well as self-correcting, and a constant journey towards consensus.

While sticking within the boundaries of those advances that have radically altered the frameworks of the astrophysics discipline, the book evocatively charts out the enormous impact of these advances on human culture, in that our concept of our place in the universe too has been radically altered by them. They have given us both perspective (e.g., what we can see is only a small chunk that is about 4% of the universe), and discomfort (e.g., in grappling with a universe which is a restless home rather than a stable one, and whose expansion is clearly speeding up, but for which we have no explanation).

The book is much more than a lucid, rigorous, and widely accessible survey of state-of-the-art knowledge of the universe. In the 267 pages of text, the author not only highlights the key astrophysical developments from the last century, but also foregrounds the socio-historical scaffolding of the processes of discovery. She cogently frames the scientific developments against the backdrop of the world wars, the holocaust, and the launch of *Sputnik*. She highlights the human element. She

1 Roberto Trotta's phrase, in *The Edge of the Sky*, Basic Books 2014.



perceptively brings alive the riveting story of how we have come to our current understanding.

In conceiving and writing this book, Natarajan brings to bear her intimate knowledge of the subject as an accomplished leader in her field, to distill the essence of the exciting scientific questions, the methodology and the outcomes. And her evocative writing skills make the descriptions of these various discoveries come alive.

The book's hallmark, however, is the strong perspective of the critical insider. Armed with her training in the history and philosophy of science, Natarajan chronicles not just the outcomes, but the processes of how the scientific ideas developed, how they were debated and resisted, how human and institutional failings often played a significant role, and how new ideas finally took root. She says that her goal is to "recount how scientific ideas have been developed, tested, debated and eventually accepted", and she is eminently successful in this effort.

Many a Bollywood song makes reference to "*Jab Tak Suraj Chaand Rahega...*"² when alluding to permanence in our world that 'contrasts' with the impermanence of life. Natarajan argues that the desire to latch on to permanence is deep in the human psyche. Her book begins with a historical chapter that covers imaginings of the cosmos from several different cultures worldwide. This narrative is more

than just an exposition of what the ancients thought of our place in the universe. The various historical threads show that the human psyche constantly seeks the comfort of permanence while navigating through life, while at the same time, is quite comfortable in attributing causation to unseen figures or imagined forces. The affinity with permanence, however, results in resisting highly disruptive ideas that might bubble up during the scientific exploration of the cosmos, even when firmly rooted in solid empirical work, and even by icons such as Einstein. On the other hand, there are also counter-examples, such as the prescient idea of a dynamic universe that was an outcome of pure thought from quite unexpected quarters, viz., the poet Edgar Allan Poe.

The subsequent chapters of the book narrate the stories behind the key frontiers of astrophysics today, starting with the expansion of the universe (Chapter 2) and black holes (Chapter 3), both of which have consensus in the main, though with many as yet unanswered questions of detail. In Chapter 4 of the book, the author describes how groping for dark matter, the 'unseen' component of the universe that expresses itself only gravitationally, happened in fits and starts, despite the evidence for it being entirely empirical. She explores the reasons for this nonlinear progress, in both the nature of the thing itself and in science praxis. The chapter is extremely comprehensive, does due diligence to the counter

2 Translated from Hindi: "until there is the Sun and the Moon...."



hypothesis known as ‘Modification of Newtonian Dynamics’, and also to the various yet-undemonstrated candidates for what dark matter might actually be. It makes for a powerful story that can be read almost independently of the other chapters.

The discovery of the largest component of the universe whose nature is unknown - viz., ‘dark energy’, which was inferred from the evidence for a universe that is accelerating, is shown in Chapter 5 to contrast in many ways to the story of dark matter, though it too is a case of a ‘crime without the body’. This is another riveting narrative, but the common thread again is empirical evidence. The key to the discovery of the acceleration of the universe was the design of the experiment using exploding stars which was done by two rival teams. The book outlines how the rivalry had its negatives but also resulted in two very independent paths to the same result that put it on very solid ground. The author argues how the outcome was startling and yet was “almost akin to the final piece of a jigsaw puzzle”, because it resolved some of the earlier debates such as that on the age of the universe and the fraction of matter in the universe.

The story of the discovery and detailed study of the hiss which is the afterglow of the Big Bang or the birth of the universe, viz., the cosmic microwave background, is the topic of Chapter 7. It is once again an illustration of the power of experimental design and cre-

ativity, but laced with the pitfalls of the institutional divisions between different disciplinary pursuits, resulting in the process fumbling rather than coasting along, and losing some of its creative minds.

In the final chapter, the author juxtaposes the investigation driven by the search for sentient life that is similar to our own, with the cosmological strand that has measured six key cosmological quantities that can explain all the properties of our universe. This leads to speculation about ‘multiverses’ and whether we have reached the limits of the scientific method itself. She links this strand to the different but uncannily related question of whether there is merit in the ‘anthropic principle’³, how unique our universe is, and further, whether we are alone in the universe.

Throughout the book, Natarajan debunks the popular understanding of scientific research as a systematic, entirely objective, and smooth path to new knowledge. With striking honesty, she demonstrates how the practice of science is a strongly human endeavour with its strengths, but also frailties and failings. For example, she describes how a lucky set of circumstances allowed Joseph Fraunhofer to grow from a glassworks apprentice into a scientist of high standing, and develop the spectrograph that was the keystone of the discoveries in the story. She points out how inadvertently missing out on relevant earlier scholarship has resulted in unnecessary slowing down

³ The philosophical claim that observations of the universe must be compatible with the conscious life that observes it.



of the progress of ideas. This happened to the path-breaking work of Rubin and Ford on dark matter in galaxies, that did not derive strength from the earlier conclusions of Jan Oort on the Milky Way or that of Kahn and Woltjer on our neighbour, the Andromeda galaxy. Edwin Hubble, on the other hand, did not acknowledge the important measurements of Vesto Slipher, even though he used them directly, and upon which he built his own measurements and interpretations – an unfortunate case of the desire to claim credit dominating over the fundamental norm of acknowledging previous work. Arthur Eddington, an accomplished senior practitioner, was surprisingly hostile to the creative mind of the then young Chandrasekhar, which makes a strong case for building nurturing rather than competitive environments in institutions.

The book concludes on a highly positive note. Natarajan describes how state-of-the-art investigations perforce require extremely large global collaborations, high levels of funding and exceptional teamwork, changing the culture of science to one wherein the individual is less salient. “A single person might have influence, because science is still somewhat hierarchically organised, but I’d argue that intellectual power and sway are more evenly spread among institutions around the globe today than they were even twenty years ago”, she writes. This also makes individual-based recognition such as the Nobel Prize anachronistic. Earlier in the book, the author chronicles the democratisation of science praxis post World War II that resulted from the profes-

sion being liberated from the confines of elite spaces into more open forums for debate and into institutions with wider and inclusive access. She describes how this process has been accelerated by current global connectivity through the internet and social media, which has the potential to make the scientific profession far more transparent and accountable. It has resulted in a sometimes willing and sometimes forced two-way engagement between professionals and the public, which brings to the fore the ethos that science is not just about pushing the frontiers of knowledge but also deeply about questioning.

Though mathematics is the language of astrophysics, the author stays away from mathematical equations and esoteric allusions while lucidly narrating her story in a crystal-clear conversational style, which makes the book highly accessible to a broad audience. Natarajan thus does full justice to the richness of the topic. The book has ideas repeated across chapters, which might seem redundant, but in fact, these repetitions make explicit the important connections between strands of the different stories. Further, the repetitions and cross-referencing make the book modular, with each chapter becoming an independent story in itself.

The book contains a good index and a comprehensive set of suggested readings, both historical and contemporary, popular and technical. A majority of the figures are in black-and-white. While colour would have added significant clarity to many of them, corresponding figures are accessible on the internet, of-



ten with 3D and animated views, and the relatively low cost of the paperback version of the book is certainly a plus. A statement or two might be slightly confusing, such as “black holes exist in the centers of most galaxies”, while what was clearly meant was that giant (supermassive) black holes exist in the centres of most galaxies; this might merit a correction in the next edition. Some jargon words such as ‘O and B stars’ and ‘parallax’ would have benefitted from a footnote that explained them, but such words are very few and far between.

The corresponding audio-book is available too. While regrettably not in the voice of Natarajan herself, the voice of Elisabeth Rodgers is often uncannily similar, and the audio book is very effective as the evocative text overcomes the listeners’ inability to see the figures.

Mapping the Heavens is thus a ‘must-read’. It is a must-read for the thinking citizen, because it is a *simhaavalokana*⁴ of a human scientific

endeavour, viz., astrophysics, which has unfolded by harnessing human intellect, technology and historical processes, to bring quite an unsettling perspective on our place in the universe. It is a must-read for students of science and science buffs, because it shows the ups and also the downs in pushing the frontiers of one of the most mesmerising and inspirational sciences, distant to humans and nearby, at the same time. It is a must-read for the potential astrophysicist, because it captures the essence of the big picture and the state-of-the art in the field, and because it contains within it a sub-text of do’s and don’ts of science practice. In other words, it is a compelling history from which there are profound lessons to be drawn.

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⁴ Translated from Kannada: The backward glance by the lion when it pauses to survey the landscape that it just traversed.

