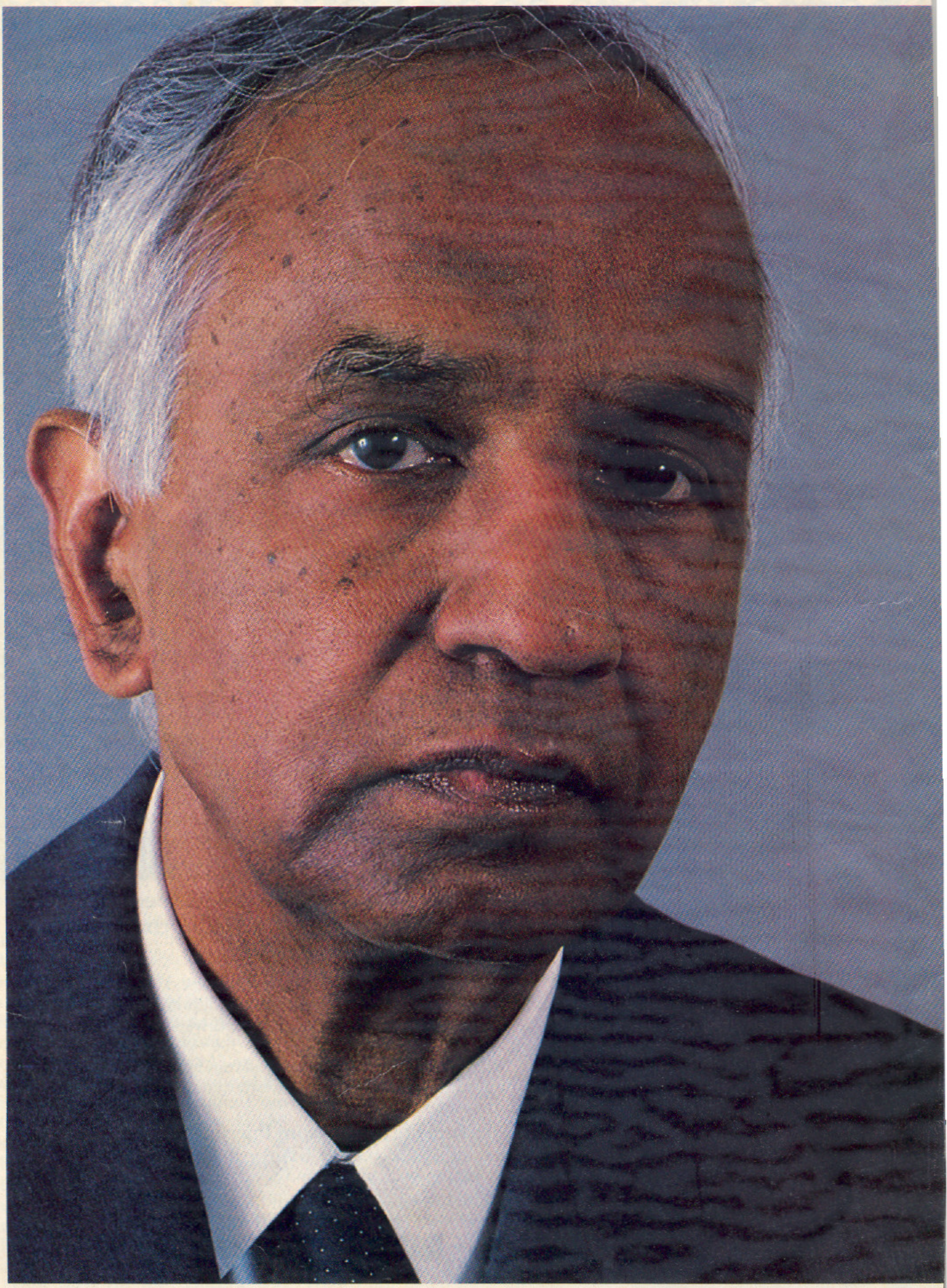


Richard Marin

Subrahayam Chandrasekhar is not sure what comes next. He survived a heart attack and open heart surgery during his latest project, an eight-year study of black holes. When he finished it this spring he was 71, twice the age of practically everyone else in the field, a time of life when most scientists are either retired or enjoying an emeritus title—serving on committees, reminiscing at

QUEST FOR ORDER

S. Chandrasekhar meditates on black holes, blue skies, and scientific creativity.

by John Tierney

award dinners, directing graduate students, toying with a few leftover problems. That kind of scholarship would be impossible for Chandrasekhar. It would be the moral equivalent of going to the office without a plain dark suit, dark tie, and white shirt, the clothes that he has worn every working day for nearly half a century at the University of Chicago.

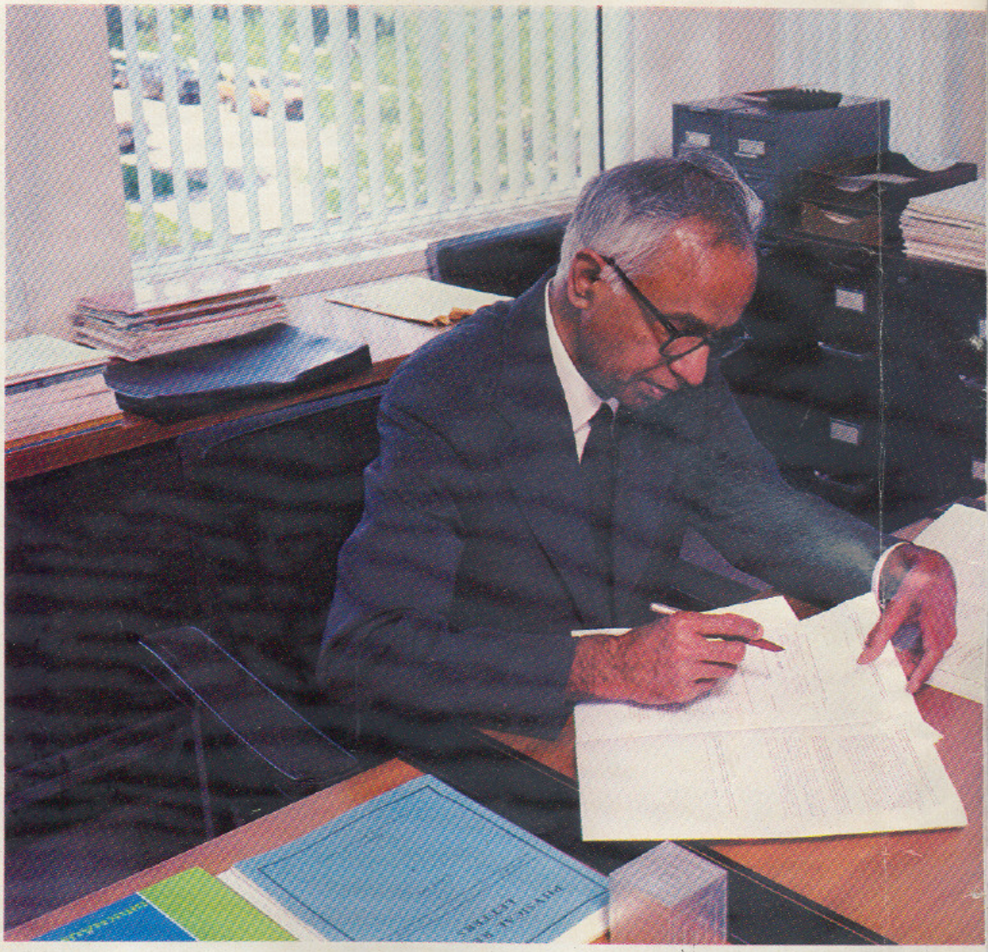
No, when he decides to work, he sits at a relentlessly neat desk searching for mathematical order for at least 12 hours a day, usually seven days a week, until after about a decade he has attained what he calls "a certain perspective"—

which is to say, until some aspect of the universe has been completely reduced to a set of equations. Then, having written the definitive book on the subject, he puts all his files in the attic and looks for a totally different area of astrophysics to teach himself. Just talking about "Chandra's style" makes other astronomers tired. They can't understand how he regularly forces himself to abandon a subject and start over—how, in a discipline where a 40-year-old theoretician is considered way past his peak, a man of 63 could profitably *begin* analyzing what happens when things disappear down a black hole.

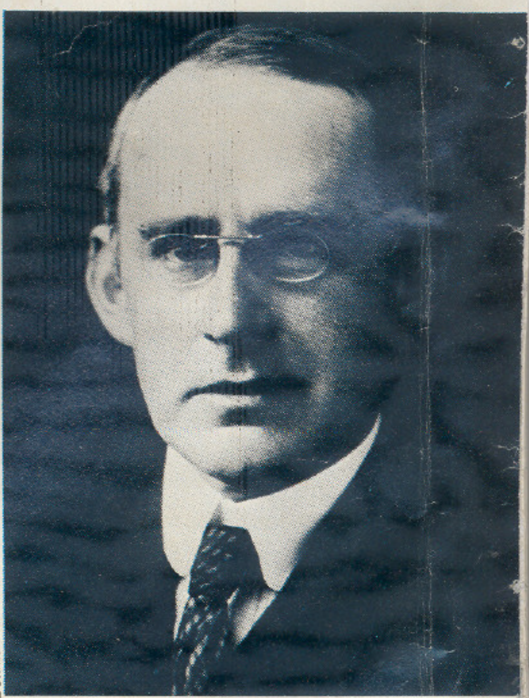
"He just batters his way through problems no one else could do," says his closest friend, Martin Schwarzschild, an astrophysicist at Princeton University. "Chandra's concentration is unbelievable—a mixture of sheer mathematical intelligence and phenomenal persistence. There is not one field that he's worked in where we are not now daily using some of his results."

Chandrasekhar, who is a great one for philosophizing about creativity and the aging scientific mind, turns uncomfortable when asked to explain his own professional longevity. But he allows that it probably has something to do with the meeting of the Royal Astronomical Society on January 11, 1935.

He arrived in London that Friday with great expectations for himself and mild suspicions concerning Sir Arthur Eddington. For months he and Eddington had been getting together, about twice a week after dinner, to discuss Chandrasekhar's latest calculations about the behavior of dying stars. They made an odd couple: the famed Eddington, eloquent, prepossessing, at 52 generally acknowledged as the world's finest astronomer, listening eagerly to a shy 24-year-old from India who felt himself something of an outcast at Cambridge University. Chandrasekhar had been studying stellar structure for just a few years, ever since he won Eddington's classic book on the subject as a prize in a physics contest at Madras University in India. Now he was convinced that he had made a significant and startling discovery. That Friday afternoon he was to announce it.



But the day before, when a copy of the program for the meeting had arrived in Cambridge, Chandrasekhar had been amazed to discover that Eddington would also be speaking at the meeting. On the same subject. During all their discussions, while Chandrasekhar had been spewing out his figures, Eddington had never mentioned any work of his own in this area. It seemed an incredible breach of faith, yet Eddington offered no apology or explanation when the two men saw each other in the dining hall Thursday evening. His only remark was that he had used his influence to get Chandrasekhar extra time at the meeting—"so that you can present your work properly," as Chandrasekhar remembers him saying solicitously. Chandrasekhar was too deferential to mention Eddington's own paper, but the next day in London, at the



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Chandrasekhar is a deskbound astronomer who has never used a telescope. His career was altered when Sir Arthur Eddington, left, objected to an early theory.

tea before the meeting, another astronomer asked Eddington what he planned to say. Eddington wouldn't answer. He just turned to Chandrasekhar and smiled.

"That is a surprise for you," Eddington said.

Chandrasekhar's paper dealt with a fundamental question: What happens after a star has burned up all its fuel? According to the prevailing theory of the day, the cooling star would collapse under the force of its own gravity into a dense ball called a white dwarf. A star with the mass of the sun, for instance, would shrink to the size of the Earth, at which point it would reach equilibrium. Chandrasekhar studied this collapse by considering what happens when a star's gas becomes so compressed that electrons move at nearly the speed of light—a state called relativistic degeneracy. He concluded that the enormous gravitational forces at work in a large star—any star more than 1.4 times as massive as the sun—would cause the star to go on collapsing beyond the white dwarf stage. The star would simply keep getting smaller and smaller and denser and denser until . . . well, that was an interesting question. Chandrasekhar delicately avoided it.

"A star of large mass cannot pass into the white dwarf stage," he concluded, "and one is left speculating on other possibilities."

Then it was Eddington's turn.

"I do not know whether I shall escape from this meeting alive, but the point of my paper is that there is no such thing as relativistic degeneracy," said Eddington, and proceeded to tear apart Chandrasekhar's paper. The speech was frequently interrupted by laughter. Eddington couldn't quarrel with Chandrasekhar's logic or calculations. But he claimed that the whole theory had to be wrong simply because it led to an inevitable and outlandish conclusion: "The star has to go on radiating and radiating and contracting and contracting until, I suppose, it gets down to a few kilometers radius, when gravity becomes strong enough to hold in the radiation, and the star can at last find peace."

Today, of course, such an object is called a black hole. That afternoon Eddington said it couldn't possibly exist.

"A *reductio ad absurdum*," he called it. "I think there should be a law of nature to prevent a star from behaving in this absurd way."

And there the matter rested, at least for the next few decades. Eventually the theory would be vindicated, black holes would be accepted, and the dividing line mentioned in the paper (a stellar mass 1.4 times that of the sun) would go down in textbooks as the Chandrasekhar Limit. But not for a long time after Eddington's speech.

"At the end of the meeting," recalls Chandrasekhar, "everybody came up to me and said, 'Too bad, Chandra, too bad.' I had gone to the meeting thinking that I would be proclaimed as having found something very important. Instead, Eddington effectively made a fool of me. I was distraught. I didn't know whether to continue my career. I returned to Cambridge late that night, probably around one o'clock. I remember going into the common room, the place where the fellows would meet. Of course nobody was there. There was a fire still burning, and I remember standing there in front of it and repeating to myself, 'This is how the world ends, not with a bang but with a whimper.'"

Today he has a different perspective on that afternoon.

The argument with Eddington dragged on for years, ruined any chance of his getting a tenured position in England, and finally persuaded him to give up the subject altogether. (Although the two men, remarkably enough, remained friends throughout.) He believed in his theory, but others didn't. So, shortly after arriving at the University of Chicago in 1937, he put the theory in a book and stopped worrying about it. He instead began studying the probability distributions of stars in galaxies and discovered the curious property called dynamical friction—the fact that any star hurtling through a galaxy tends to slow down because of the gravity of the stars surrounding it. Then he switched again and considered why the sky is blue. The simple answer to this problem—that the atmosphere's molecules scatter the short-wavelength blue light while allowing other colors to pass through—had been found last century by Britain's Lord Rayleigh. But Rayleigh and a succession of physicists had all failed to unravel the exact mathematics of how light is scattered. By the middle of the 1940s, Chandrasekhar had worked it all out. And he enjoyed it so much, this switching fields, that he decided to make a career of it. He went on to more topics: the behavior of hot fluids in magnetic fields, the stability of rotating objects, the general theory of relativity, and finally back to black holes (but from a completely different approach). He now thinks he was lucky to be driven out of his original specialty.

"Suppose Eddington had decided that there were black holes in nature," he says, pausing to consider this proposition as precisely as possible. He is impeccably formal, true to his Brahmin roots, determined to keep his conversation as structured as everything else in his life. He actually speaks in complete sentences and logical paragraphs. He does this with a soft-spoken, gentle charm, digressing occasionally with jokes and allusions to everything from Picasso to Mother Goose to Keats, but always sternly bringing himself back to the original question.

"It's very difficult to speculate. Eddington would have made the whole area a very spectacular one to investigate, and many of the properties of black holes might have been discovered 20 or 30 years ahead of time. I can easily imagine that theoretical astronomy would have been very different. It's not for me to judge whether that difference—well, the difference would have been salutary for astronomy, I think I would say that.

"But I do not think it would have been salutary for me. My position in science would have been radically altered as of that moment. Eddington's praise could make one very famous in astronomy. But I really do not know how I would have reacted to the temptation, to the glamour.

"How many young men after being successful and famous have survived for long periods of time? Not many. Even the very great men of the 1920s who made quantum mechanics—I mean Dirac, Heisenberg, Fowler—they never equalled themselves. Look at Maxwell. Look at Einstein."

Chandrasekhar hastily interrupts himself to say that he is not comparing himself to these scientists or trying to criticize them. "You must not confuse things large and small. Who am I to criticize Einstein?" It is the problem in the abstract, he insists, that interests him. He is struck by the fact that, at age 47, Beethoven told a friend, "*Now* I know how to compose." Chandrasekehar doesn't think there has ever been a 47-year-old scientist who announced, "*Now* I know how to do research."

"When you discuss the works of a great artist or writer, the assumption always is that there is a growth from the early period to the middle period to the mature work and the end. The artist's ability is refined. Clearly he's able to tackle difficult problems. It obviously required an enormous effort, an enormous emotional control, to be able to write a play like *King Lear*. Look at the contrast between that and an earlier play, *Romeo and Juliet*.

"Now why is a scientist *unable* to refine his mind? Einstein was one of the great scientific minds. He discovered special relativity and a number of things in 1905. He worked terribly hard and did the general theory of relativity in 1916, and then he did some fairly important work until the early 1920s. From that point on he detached himself from the progress of science, became a critic of quantum theory, and effectively did not add to science or to his own enlargement. There is nothing in Einstein's work after the age of 40 which shows that he attained a greater intellectual perception than what he had before. Why?

The Chandrasekhars' apartment faces Rockefeller Chapel at the University of Chicago. A 1968 lecture in India drew congratulations, right, from President Husain and Prime Minister Gandhi.

"For lack of a better word, there seems to be a certain arrogance toward nature which people develop. These people have had great insights and made profound discoveries. They imagine afterwards that the fact that they succeeded so triumphantly in one area means they have a special way of looking at science which must therefore be right. But science doesn't permit that. Nature has shown over and over again that the kinds of truth which underlie nature transcend the most powerful minds.

"Take Eddington. He was a great man. He said that there must be a law of nature to prevent a star from becoming a black hole. Why should he say that? Just because he thought it was bad? Why does he assume that he has a way of deciding what the laws of nature should be? Similarly, this oft-quoted statement of Einstein disapproving of the

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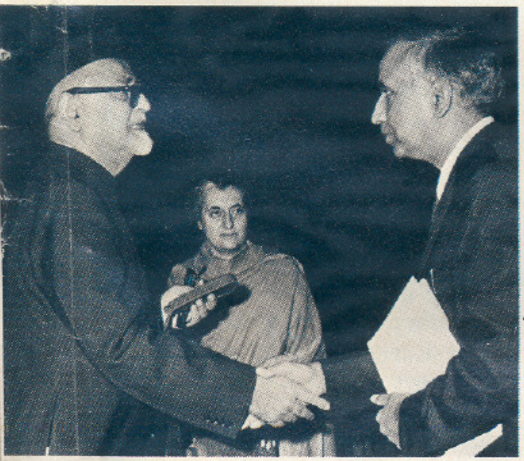


courtesy S. Chandrasekhar

quantum theory: 'God does not play dice.' How does he know?"

The exception that Chandrasekhar likes to talk about is Lord Rayleigh, the 19th-century physicist who did the original study on the color of the sky. He remained steadily productive in a variety of fields for 50 years and turned out some of his best-known work (such as the discovery of argon gas) in the latter part of his career.

"You know, when Rayleigh was 67, his son asked him what he thought about the famous remark by Thomas Huxley—that a man of 60 in science does more harm than good. Rayleigh thought about it a great deal and said, 'Well, I don't see why that should be so, provided you do what you understand and do not contradict young people.' I don't think Einstein could have said that, or Dirac, or Heisenberg. Eddington wouldn't have said that. There is a certain modesty in that remark. Now on the other hand you could say, as Churchill said when somebody told him that Clement Attlee was a very modest man, 'He has much to be modest about.' The really great discoveries have been made by people who have had the arrogance to make judgments about nature. Certainly Rayleigh did not add any really great fundamental insights like Einstein or Maxwell. But his influence on science was enormous because he added to the great body of knowledge, constantly inventing many things that were not spectacular but were always important. I think one could say that a certain modesty toward understanding nature is a precondition to the continued pursuit of science."

He again insists that he is speaking in the abstract, not about himself. But he could just as easily have been describing his own career. Plunging into a new field every decade is guaranteed to produce modesty: How can you contradict young men when they've been in the field longer than you have? And like Rayleigh, he concerns himself with important but unspectacular work, with rigorous studies that enlarge a body of knowledge rather than overturn it. He doesn't go for quick hits, for the single blinding insight or the revolutionary discovery that wins a Nobel Prize. He has always insisted on a long and complete analysis of a whole field, no matter how useless it may seem to others.

In the 1960s, for instance, he wrote a book on tangerine-shaped geometric figures called ellipsoids, which at the time were guaranteed not to win anyone fame or fortune. His reason for writing this book, he said in the introduction, was that all the previous research had left the subject "with many gaps and omissions and some plain errors and misconceptions. It seemed a pity that it should be allowed to remain in this destitute state." So he tidied it up by systematically analyzing the forces acting on a rotating ellipsoid—the gravity holding it together, the centrifugal force pulling it apart, and the point at which it becomes unstable. Other scientists thought he was wasting his time studying these idealized objects. Why study an abstraction that doesn't exist in the universe? Yet today, 20 years later, the book is being applied in ways that couldn't have been anticipated. It turns out, for example, that the properties of these imaginary objects are shared by many real galaxies, and scientists are using the book to under-

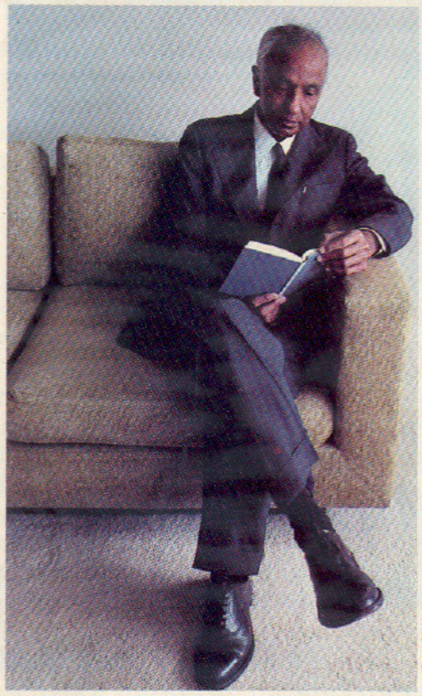
"I've never found the time to read all of Shakespeare. I know I could have been different had I done this."

stand what holds the Milky Way together as it spins.

"I think my motivations are different from many scientists," he says. "James Watson wrote that when he was a young man, he wanted to solve a problem that would win him the Nobel Prize. So he went ahead and discovered DNA. Clearly that approach justified itself in his case. But my motive has not been to solve a single problem but instead to acquire a perspective of an entire area.

"I started studying black holes eight years ago, particularly the theory of how a rotating black hole reacts to external perturbations such as gravitational and electromagnetic waves. If you know that, you can determine what happens to a black hole when an object such as a star falls into it. Well, there are individual pieces of this work that have attracted attention, but to me what is important is the final point of view I have of the subject. That is why I wrote the book. I see it as a whole with a perspective. Obviously there are a number of problems in the area that I can still work on, but I don't feel inclined. If you make a sculpture, you finish it—you don't want to go on chipping it here and there."

So what next? This is a problem for a man of 71. The chief drawback to his style of research is that it requires enormous amounts of time and energy. It has meant starting work every day at six A.M. and continuing as late as midnight. One of his collaborators, a graduate student who had the misfortune of living in an apartment visible from Chandrasekhar's office, used to be surprised by late night calls at home when Chandrasekhar needed help with a problem. This went on until Chandrasekhar happened to mention to the student's wife that he felt free to call when he could see a light in the couple's window. From then on the window was heavily shielded with a curtain.



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"He hasn't really had time for other things, for travel and friends. He's always had an intense discipline about his work, an insistence that everything be neat and perfect," says Chandrasekhar's wife, Lalitha, who met him when they were both physics students at Madras University. She speaks uncomplainingly about his career and the sacrifices required of her—the long hours spent by herself, the abandoning of her career to follow him to the United States, the many years between visits to their families in India. But she also thinks that by now he has earned the right to relax, and so do his colleagues.

"Chandra's had to pay an enormous price, and it's steadily increased as he's gotten older," says Schwarzschild. "This last book was a *tour de force*—an example of willpower conquering exhaustion. I don't really know what he can do after that. His contributions have all come from this ability to keep pushing through problems that nobody else could push through. For Chandra, it would be completely out of character to drop down to something he knows a whole bunch of us could do."

Chandrasekhar tends to agree. "If I cannot pursue a subject in earnest," he says, "I would rather not make the effort at all." It is tempting for him to stop after this book if only for esthetic reasons, to end with a study of the black holes that seemed so absurd at the beginning of his career. It would be a nice finale, especially since he regards it as perhaps the most difficult work he has ever undertaken. Yet he also talks about going into still another new field, maybe this time cosmology. "That's my habit of life, and it requires enormous discipline to change a habit of life. I haven't decided."

Although he doesn't consider himself a Hindu anymore—he classifies himself as an atheist—he sometimes wonders if he should follow the Hindu tradition of retirement: renouncing all worldly connections and going into the forest for solitary contemplation. To him, of course, this simply means giving up science, the ultimate change of field.

"One of the unfortunate facts about the pursuit of science the way I have done it is that it has distorted my personality. I had to sacrifice other interests in life—literature, music, traveling. I've devoted all my time, every living hour practically, to my work. I wanted to read all the plays of Shakespeare very carefully, line by line, word by word. I have never found the time to do it. I know I could have been a different person had I done this. I don't know if regret is the right term for what I feel. But sooner or later one has to reconcile these losses. One has to come to terms with oneself. One needs some time to get things in order." S

John Tierney is a staff writer.