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THE STUDY OF IMMENSITY

A non-scientific interview between Jesse L. Greenstein, professor of astrophysics and staff member of the Mt. Wilson and Palomar Observatories, and British science writer Gerald Leach. Adapted from a BBC Third Programme broadcast on October 19, 1965.

LEACH: I went to see Dr. Jesse Greenstein because I'd heard that he was one of the most gifted talkers on the whole American continent. The reports were correct. We sat in the living room of his house in Pasadena, and we talked all morning. In those few hours he managed to convey more deeply than I have ever heard before a real sense of the total involvement of doing science: a personal tie with the objects one studies that is perhaps unique to science. To put it bluntly, Dr. Greenstein *knows* stars, and feels for them, as other people know other people.

Yet I was not concerned just in asking him about *what* astronomers have found. I wanted to know what it is like to do astronomy. How does the study of immensity affect one's personal values? How does one arrive at the great speculative ideas from which astronomy advances? And so, to start our conversation, I asked him how it feels to work in a subject that is exploding intellectually probably faster than any science has ever exploded before.

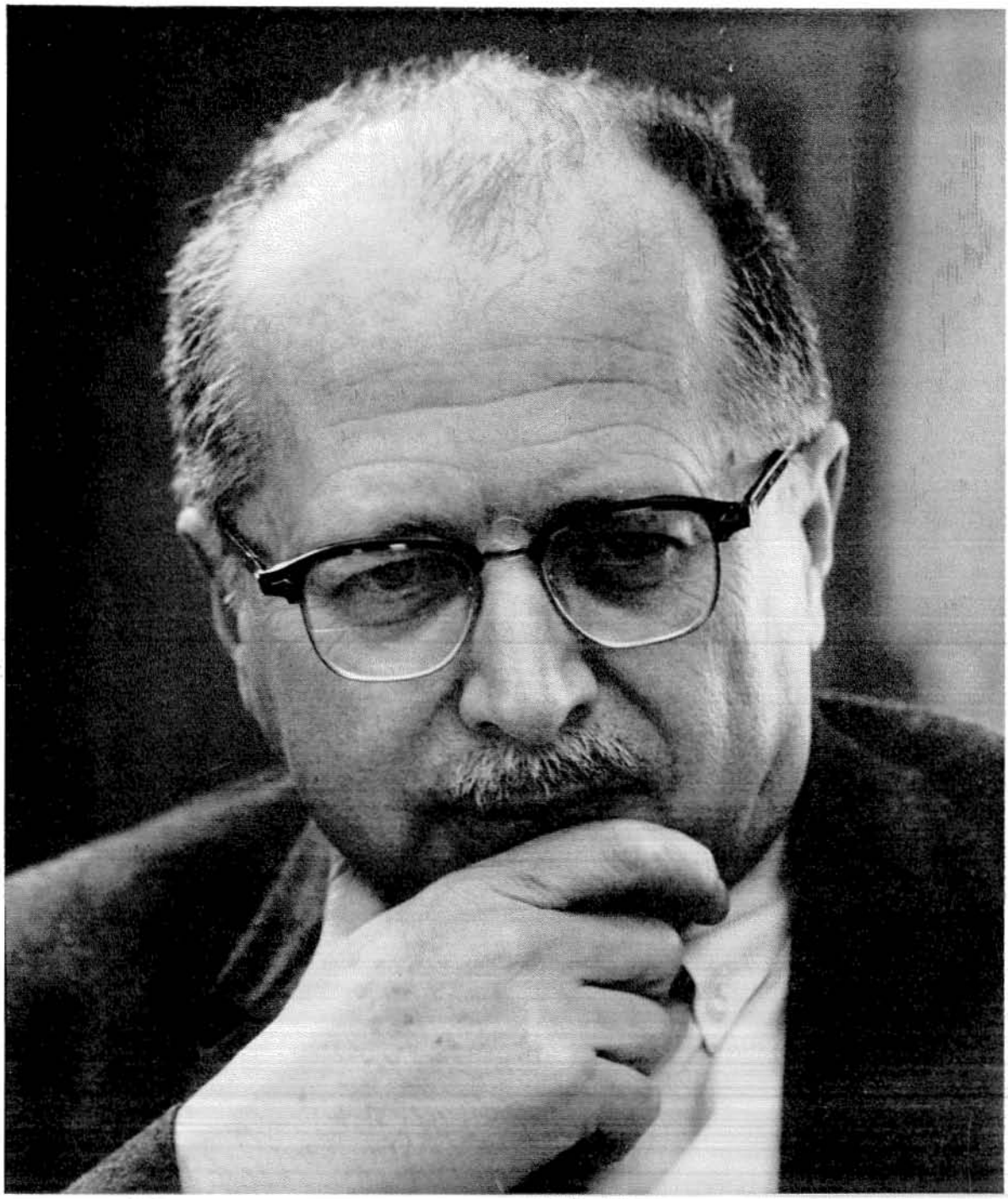
GREENSTEIN: It's a very happy time to be alive. And it really is viewed by most of us as an opportunity to share the great and explosive pleasure of novelty and change. I think the stimulation of a new discovery, the realization that not everything is known, that one doesn't need to go over the old ground again and again, push one into free imagination and create the pleasure of the work.

LEACH: I'd like to talk to you about quasars, which are only about two or three years old now. What is the current situation?

GREENSTEIN: Enormous ignorance, alleviated by splashes of light. What we think we find is a large group, almost 100 objects, of an extraordinary class. They are extremely luminous in both radio frequencies and in light, and very much brighter than our own galaxy.

LEACH: What are the current ideas on how this enormous amount of energy is produced?

GREENSTEIN: Well, the facts seem to indicate that what we see is not really the source of the energy. So we leave the great speculators to speculate about what is going on inside what we see. What we see is a gas cloud, not very massive—perhaps a million times as heavy as the sun—very small, hot, and pouring out energy at this enormous rate. The mystery is that under no conceivable circumstance could this gas cloud be the only thing that is producing energy. If you take its temperature and measure its total heat content and let it turn into light in the most efficient way, it could last only a few years before it would fade. It must be replenished. And so several of us invented an invisible object—perhaps forever invisible—a thing much smaller than a light year, buried in this gas cloud, and producing energy, and we call it Object X. We have good reason to know that it has produced energy for at least some hundreds of



years, because the brightest of these objects has been observed photographically on old plates taken at random over almost 80 years now. These plates show that the light has varied in a rough 10-year cycle. But it hasn't changed systematically.

LEACH: But this Object X must be a very extraordinary object.

GREENSTEIN: Yes, and that's where I find myself, surrounded by good friends—physicists and astrophysicists—of great intellectual depth who have had a wonderful time thinking what Object X might be. They listen respectfully to the very few facts we have, and then they go on enormous branching paths of speculation. I don't mean to sound cynical or contemptuous, because these are brilliant men and brilliant ideas. I think the main

thing that I draw my pleasure from is that we have forced brilliant people to extreme solutions. There is no easy way out of this problem.

LEACH: Probably more than in any other science, such crazy speculative ideas have been produced in the last two years that this is almost becoming like a game.

GREENSTEIN: Well, all good science is a game of free intellectual play. Fortunately we have enough boundary conditions so that the play is not completely a game without rules.

These are not extraordinarily speculative ideas; I think the existence of the universe is an extraordinary fact. The existence of quasars is not more extraordinary. One theory, proposed by Yuval Ne'eman, who was visiting Caltech last year, holds that instead of a gravitational collapse, or a superstar, we are seeing little bits of the universe before it started to expand. The bits were so dense that they never started expansion, and maintained themselves in quasi-stable form for 10 or 15 billion years.

LEACH: This is an idea about as far out as one can get.

GREENSTEIN: Yes, but you make it sound a lot stranger than you need to. If you say the universe exists and there was a big bang 15 billion years ago, you've made so extraordinary a statement that the simple and quantitative statement that parts could have been stabilized for billions of years is not relatively extraordinary. If you believe in the universe's existence, you have enough mystery.

LEACH: The thing that fascinates me is that you astronomers can make such strange, speculative statements, which may turn out to be wrong, but the community of astronomers doesn't laugh at you for being wrong.

GREENSTEIN: Well, when you make your statement based on limited information—and in astronomy we are certainly always living with a minimum amount of information—you have an operative, temporary, partial truth. Then you make an interpretation on the basis of even fairly well-established fact. You are quite privileged to be wrong a very large majority of the time. It is the intellectual free play of new ideas that provides the stimulus for theoretical people and for other experimentalists to check these ideas. You are privileged in theoretical work to build up an enormous world picture in which there is never any contact with an observable fact, but it's risky. I really feel that the novelty and depth of your fantasy and theory are what are important. Since the world is so difficult to know and since we are always finding such new and strange things in it, it is the duty of the theoretical person to break free from the apparent fact with which he might conceivably be so limited that he could not think of something new.

LEACH: And you would go so far as to call this a fantasy?

GREENSTEIN: I call it fantasy at first, certainly. The word fantasy or intuition in science means that you create a possible imaginary world, and then you look at the real world to see if there is any point of contact.

LEACH: Which is the difference between science and the arts.

GREENSTEIN: Yes, except that if it is a fantasy in the arts, it has to have some human relevance; no matter how abstract the painting, either the painter or some viewers must be able to feel that there was some action or feeling.

LEACH: There's a much more tenuous anchoring back to earth as it were?

GREENSTEIN: Oh, yes. Now, when a good astrophysicist makes a theory which is fantastic, he does not set out in a few paragraphs a word picture of a world, but he makes a mathematical model. This mathematical model, following the rules of normal mathematics and logic, is internally consistent. It must be consistent; otherwise it is no theory. Ultimately, it reaches a certain prediction, which may be merely a new way of viewing an old fact.

LEACH: Doesn't it ever surprise you that an idea based on mathematics and obviously internally consistent should be consistent with the real world of today?

GREENSTEIN: Yes, the existence of mathematical pattern in the real world seems to me implausible and almost immoral. Since Newton's time, the world has fit first into a geometrical and then later an algebraic picture; now the more tenuous theory of fields, group theory, and more and more abstract parts of mathematics become part of the model.

Whether or not the reality behind the appearance has anything to do with the mathematical model is somewhat irrelevant, just as long as the input is the real world, the output is the observable real world, and the connection between is a consistent mathematical structure. There are many alternative structures.

LEACH: This is a pragmatic view? As long as it works, it works.

GREENSTEIN: Not really. If the Lord is a mathematician is a reasonable question; it was said that he was, but it seems clearly rather arrogant. If so, he is a better and more applied mathematician than the real ones that we have. But this oddity, that the natural world seems to have some logic which we can understand in part, is a permanent mystery of science.

LEACH: Yet it could be said that one only finds those irregularities that one is looking for.

GREENSTEIN: That's also true. Could we believe in the existence of a self-contradictory, nonlogical, random universe? Could we know it?

LEACH: An idea I've always had is that our mathematics, our whole search in nature, is based on a faith in order and regularity.

GREENSTEIN: Yes.

LEACH: There could be an intelligent race who didn't put order so high but put irregularity higher —and then they would search for randomness. Would they get a different universe?

GREENSTEIN: Well, they certainly would have found quantum theory before they found billiard-ball Newtonian mechanics. The real world of atoms and nuclei is a quantum world, which is a randomness world, in a sense. Imagine a world composed not of discrete human beings with hard frames walking on earth, but of highly organized collections of marine organisms floating in the sea. There, shape does not count, gravity does not count, solidity does not count; what counts is the exchange of, say, food between the liquid medium outside you and the liquid medium inside you. You are a wave of organization rather than a hard-shelled animal. I wonder if science for such people wouldn't have been different, just as art would be very different for those living in the darkness of the seas where sight is not an important sense. It would be a very odd universe, although the mathematics of patterns would be the same—with an increased emphasis on randomness.

LEACH: Do you see the universe as a great piece of clockwork?

GREENSTEIN: No and yes—I can't say—I can't answer really sensibly. It certainly isn't a simple bunch of solid bodies going around each other according to the laws of Newton. Life has changed that a great deal.

LEACH: Astronomy in the last 30 or 40 years has changed this, and you have helped change it. Your work with others on the evolution of matter in stars —the nuclear reactions and so forth, which build the elements from simple hydrogen right on to the heavy elements—this in a kind of way is a piece of clockwork.

GREENSTEIN: Well, it is different clockwork. The clockwork of the 16th through 19th centuries was that of classical mechanics, matter in motion. Now it is the clockwork of atoms and nuclei—which is a lot vaguer clockwork—and instead of balls of dirt like the earth going around the sun, we concentrate on what goes on in the sun. The sun is not a simple mechanism that we can describe by the laws of mechanics; they are relevant, but more important laws are those of thermodynamics. The life of the universe is the destruction of matter, the production of energy, and its conversion into light. The sun and other stars, hot balls of gas, are the fundamental entities of the universe. I hate to hear you call it clockwork; it is more like a swarm of radiant, flying balls of fire than cold planets are, so the word clockwork irritates. But it is still, of course, clockwork.

LEACH: Just now, you put a sense of purpose into the sun and universe; you said its object was to produce energy.

GREENSTEIN: We look at everything through the eyes of the use of energy by man, I guess. But I also feel that the life of a star is as romantic as the life of an individual. It isn't as various or complicated, just bigger. But it is beautiful; it has the glamour of contrasts, of light contrasted with the cold of interstellar space. But meaning, purpose, goal—certainly not.

LEACH: Astronomers throw off phrases like "4,000 million years old" or "energies millions of times our own sun" very casually. Do you really feel so casual yourself?

GREENSTEIN: No. It is easy to hide behind big numbers, but more important to try to feel what they really represent. That, I think, is one of the pleasures of being a scientist—having a visual, imaginative grasp of the range of physical conditions in which matter can find itself. If you really feel what these things mean, if you try to imagine the conditions in space, the incredible emptiness of things, you get a genuine emotional reaction. It is nothing that you can feel dispassionately; if you do, you are losing half the pleasure of being a scientist.

LEACH: Do you find you can imagine them at all?

GREENSTEIN: Well, I try hard, but a billion or a million is an absolutely meaningless concept. I think all you can do is try to extrapolate them within the limitations of the human senses. The heartbeat of our galaxy, a single rotation, might be viewed as something like the earth turning on its axis—a day. But that's 200 million years for a galactic day. Our whole galaxy has turned only 50 times on its axis since it was formed. That's graphic; our young giant spiral pinwheel turning only 50 times since the beginning of all the stars in our system. But each turn is 200 million years, and no one can visualize, feel, what that means. Stars live and die in a tenth of that time; the brighter stars of our own galaxy, if you took a photograph, would come and go. In fact, the only analogy for the very brightest objects is something like a St. Catherine's wheel, a firework that spins rapidly; you see all the sparks, and every spark lasts a tiny fraction of a turn; the spark is a star.

LEACH: The whole life of a star?

GREENSTEIN: The whole life of a star. Such short-lived stars clearly never had planets with intelligent living things developed on them; the older stars may well have done so, but these young ones do not. But the whole life of even quite a reasonable star is often a small fraction of a galactic day—as brief as the life of a butterfly.

LEACH: The enormous expansion in our view of the universe has only taken place in the last 40 years.

GREENSTEIN: The enormous scale of things has been found just in the last few decades. Within a human life, the possibility of understanding each new discovery has strained our fantasy more. At a certain point you might say, "Well, give up, become numb; the whole thing is inhuman." But you can't, because you have to keep yourself placed in it; you have to keep responding to it as a scientist, not only emotionally. I feel very small compared to the earth; the fact that the sun and the space to the stars are a lot bigger than the earth doesn't make me feel any more inferior. I'm looking at the sun; it isn't looking at me. This human, anthropocentric pride has to persist if you're going to be a scientist.

LEACH: But I think a lot of people who aren't scientists do blank off at these enormous distances.

GREENSTEIN: Escape is a nice refuge, but this is clearly impossible. Human beings have had to face the realities of the world philosophically and emotionally. What one has to do is to try to absorb the real material universe as much as possible and try to take a proper attitude towards it. What this proper attitude is, each person must find for himself.

LEACH: When you are on top of Palomar Mountain at night—"sitting up with the universe" as you've described it—looking at the stars, you don't see them as cold, rational things at all. Do you see stars as important as men?

GREENSTEIN: I would say very often that to me an important new concept (which in an experimental subject would be a new particle) is as exciting as, say, another human being. Of course, there's much more in the realm of values in people. But the significance of discovery and the excitement of novelty—which I'm sure exist in the arts also—is so great that if I find an exciting individual object I respond to it as much as to new people. If it is a significant step forward in scientific knowledge—maybe not revolutionary, but part of the accumulation—this strange new thing which permits one step forward in human knowledge is to me really emotionally significant. I guess I must really feel as if it contributes to my well-being. I think most people who work in science find it that way or they would not work—at least in the abstract and speculative sciences. People who want to work for people are engineers or moralists. This is a different kind of response.

LEACH: Do you find yourself very cut off from non-scientists and non-astronomers? I don't mean in your personal, everyday life— I mean, you spend your life sitting on Palomar Mountain looking at these enormous scales and sizes and distances; can you communicate this to your wife or to others?

GREENSTEIN: Well, I certainly hope so. I hope I'd be able to communicate both what I have found and what it means to anybody. If you can't do it, you probably don't understand it; if you can't say it clearly, it is your fault, not theirs. People are quite stupid since they don't know much about science, but on the other hand, people are very fine and do know a great deal. If you cannot clarify the story by some analogy, which may be loose—though not incorrect scientifically—but which is humanly valid, it is your responsibility and not theirs.

LEACH: This is the tragedy of many scientists. I can think of no other people who really cannot communicate to their wives what they are doing.

GREENSTEIN: Well, the scientists are people first; many became scientists because they could not communicate. Many people evade the world by hiding behind science. It is quite true that there are parts of science which are incommunicable; I do not think that modern mathematics, or the advancing front of high energy physics, or even molecular biology are genuinely communicable. But if you cannot give people the feeling of what is going on in these subjects, it is because you are unable to and not because the people are too stupid.

"Seeing a star at night is a very small sight indeed compared to seeing it with eye of the mind."

LEACH: Do you think the beauty and adventure, particularly of astronomy, have got across to most people and changed their views?

GREENSTEIN: Oh, I think so . . . I think so . . . I think we have been very fortunate in the number of astronomers who have been able to communicate well, who can write and talk well, and who have felt the public need to tell their story. I think we are much luckier than the other sciences in that way, because the story of being so small in a universe that is so large and old is a story that most people like to hear—even if it hurts them.

LEACH: And we can, after all, all see stars, even if we can't all see atoms.

GREENSTEIN: That's true, but seeing a star at night is a very small sight indeed compared to seeing it with the eye of the mind.

LEACH: I am trying to get behind your use of the word "creation," which is obviously something you use technically, in terms of the evolution of the universe, and this also goes with our whole conversation about clockwork. I want to know whether you see the creation as something that comes entirely out of physics, out of fields and particles, or whether there's an extra something.

GREENSTEIN: A very good, difficult, horrible question. In the beginning the Lord created, and I don't know very much more than that. I don't know enough about deep theoretical physics to have confidence that sometime it will be possible to show that the universe must be. That I do not really know, and I don't know that anybody knows.

LEACH: Can't one accept that it just *is*?

GREENSTEIN: That is not enough because the universe runs downhill. Because of our continuous work with finite time spans and beginnings and one-way evolution, most astronomers think more in terms of some mystery before physics began than do most physicists, who don't have to worry about it. Physicists say, "the universe is, and here are the laws." This strangeness of the finiteness in time of everything we know in our own galaxy—and that is all I can really talk about—is such that I guess most of us unconsciously accept the idea of a beginning. That this almost occupational disease of acceptance of a mystery before "our" world began must lead to God, in the sense of a personal god, is a little difficult to accept. It just leaves an enormous, early step of mystery, and there are many people who think along such lines. You can imagine all kinds of weird things. The total energy of the universe is zero, and this is practically true. Things fluctuate, and if nothingness fluctuates, positive and negative energies adding up to zero might separate in some unknown way. But I am spilling words that don't mean anything. One must say that zero is the total of everything.

LEACH: And zero split into plus and minus . . .

GREENSTEIN: . . . in the beginning of the world.

LEACH: Do you yourself believe in God?

GREENSTEIN: Probably not. Probably not in the conventional sense. I have what I guess would be described as a vague theistic kind of feeling of the drive from material evolution into the emergence of some kind of value. To me, however, this does not necessarily involve a personal god, or a revealed god, or a revealed religion. It involves very largely an ethical concept, and I wonder whether there is any relation between ethics and religion now. I doubt it for myself.

LEACH: Do you think it unfair that the public should always come to astronomers and ask them theological questions?

GREENSTEIN: Yes, I think it is extremely unfair. I think they should ask these questions of themselves because the interesting questions of theology, it seems to me, are those that affect your own belief in your own significance, in your own value and responsibility, and in the contribution that your existence has made to something you feel external to yourself and permanent. We are not really the intellectual or spiritual masters of the universe. We can't hold that position; we haven't been able to for a long time. Once you give this up, once you really de-center yourself, the rest of knowledge seems to me just to increase the beauty and wonder of human existence and accomplishment. If there are intelligences billions of years more advanced than ours somewhere, then it is our problem to do the same thing, to become the same. In other words, it seems to me that the typical human love for perfection is only given greater strength by a knowledge of the vastness of the universe and the infinite possibilities of evolution. That everything must come to an end is always a dim and lurking and very depressing kind of thought, just as death is richly behind every human value. But to me, the complexity and variety enrich my experience rather than diminish it.