MICHAEL WERNER
(Born 1942)

INTERVIEWED BY
SARA LIPPINCOTT

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Abstract

Interview on July 25, 2008, with infrared astronomer Michael Werner, project scientist for the Spitzer Space Telescope. Dr. Werner received his BS from Haverford in 1963 and his PhD from Cornell in 1969 under M. Harwit. As a postdoc with C. H. Townes at UC Berkeley 1969-1972, he performed early infrared studies of the cosmic microwave background with P. L. Richards and J. Mather. Taught physics at Caltech 1972-1979 and worked on the Kuiper Airborne Observatory. Began working on SIRTF [Shuttle Infrared Telescope Facility] in 1977, first at NASA's Ames Research Center and after 1990 at the Jet Propulsion Laboratory. Dr. Werner discusses the history of infrared astronomy and the evolution of SIRTF into the Spitzer Space Telescope. He remarks on its discoveries since its August 2003 launch, including the bar at the center of our galaxy, the characteristics of extrasolar planetary atmospheres, and the discovery of numerous large galaxies in the early universe. Recalls his appointment as George Darwin lecturer at the Royal Astronomical Society. Comments on upcoming observatory launches by NASA and the European Space Agency.

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CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES

ORAL HISTORY PROJECT

INTERVIEW WITH MICHAEL WERNER

BY SARA LIPPINCOTT

PASADENA, CALIFORNIA

TABLE OF CONTENTS

INTERVIEW WITH MICHAEL WERNER

CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES
ORAL HISTORY PROJECT

Interview with Michael Werner **by Sara Lippincott**
Pasadena, California

Session 1 July 25, 2008

Begin Tape 1, Side 1

LIPPINCOTT: We're here with Dr. Michael Werner, project scientist for the Spitzer Space Telescope, who began working in 1977 on what was then called SIRTF, for Space Infrared Telescope Facility—

WERNER: Shuttle Infrared Telescope Facility.

LIPPINCOTT: Shuttle Infrared Telescope Facility—and has, since 2003, been renamed the Spitzer Space Telescope.

WERNER: When I started working on SIRTF in 1977, it was to be on the [Space] Shuttle. Then sometime later, we got permission for it to be a free flyer, and then it was called the Space Infrared Telescope Facility. And then after launch and the initial success, we changed the name to Spitzer Space Telescope.

LIPPINCOTT: The launch being in August 2003?

WERNER: That's correct.

LIPPINCOTT: Did you go down to Cape Canaveral?

WERNER: I was there, yes.

LIPPINCOTT: Any memories of that? Were you nervous?

WERNER: Well, actually, I think I was in an alternate universe. My wife's memories are much more vivid than mine, because I wanted to be in the control room, so I didn't actually see the launch. But my wife, Edwenna, was on the beach, and she saw the launch and has very vivid memories of it—because when a rocket launches, there's a big ball of flame and it looks like the thing has exploded. And then the rocket rose out of this ball of flame and off into space.

LIPPINCOTT: While we're on that subject, it's a strange orbit, isn't it? Not an Earth orbit but a heliocentric orbit?

WERNER: That's right. A heliocentric orbit, which means we're orbiting the sun, and we follow the Earth around, getting a little farther away each year. Right now, we're about half an astronomical unit away from Earth; an astronomical unit is the distance between Earth and the sun. So we're quite far away but still able to communicate quite readily.

LIPPINCOTT: Doesn't it have to go a heck of a lot farther up than something that's being put into Earth orbit?

WERNER: Sure, but in many cases it takes a lot less energy to get into this orbit, because you don't have to carry the fuel to put yourself into an Earth orbit. I'm not a real expert on launch dynamics, but typically to put a spacecraft into any kind of orbit, you launch it and then you do a second burn to establish the orbit, and if you have to carry fuel for that second burn with you, particularly if you're going into a high Earth orbit—that's not very favorable energetically. It's much better just to keep on going, which is what we did.

LIPPINCOTT: Let's go back to the beginning a little bit and talk about yourself. You were a physics major at Haverford?

WERNER: Haverford College, yes.

LIPPINCOTT: And you developed an interest in astronomy there?

WERNER: That's correct.

LIPPINCOTT: Who is this Louis Green you mention in your [Spitzer Web site] profile?

WERNER: Louis Green was an astronomy professor at Haverford while I was there, and he was charismatic, in a very low-key and unassuming way. He didn't attract a coterie of followers, but he was very impressive in his approach to science and his personality and his warmth. And so, over the years, a number of well-known astronomers have graduated from Haverford, which is quite a small college. One of my classmates, in fact, was Joe [Joseph H.] Taylor, who won the Nobel Prize [in physics, 1993], basically for work in astronomy, on binary pulsars.

LIPPINCOTT: So when you entered Haverford, you weren't headed toward astronomy.

WERNER: I was pre-med, but I evolved away from that. And one day I was—this is a true story, it sounds kind of corny. I was a physics major; and Louis Green, who was basically a physicist, taught one of the physics courses, but it was in his observatory. He had a small observatory, as many colleges do, and when I was a junior I was taking that course, and I was walking through the library at this small observatory, and I picked up a book called something like *Frontiers of Astronomy*, or *Introduction to Astronomy*, by somebody like Fred Hoyle or George Gamow. Those kinds of books, about the nature of the universe or whatever, were very popular in those days—this was 1961 or '62. And I thought to myself, "Gosh, I've always been interested in astronomy. If I had it to do all over again, I'd be an astronomer. Wait! I'm only nineteen! [Laughter] I haven't done it yet!" So that was the moment in which I—forgetting that corny story I just told you—that's when I got interested enough in astronomy to pursue it seriously.

LIPPINCOTT: A lot of people have epiphanies in college. So that was very lucky, that you were one of them.

WERNER: Right!

LIPPINCOTT: Then you did your graduate work at Cornell. Did you then know what you were interested in doing, or did you—?

WERNER: Well, since I hadn't studied much astronomy, I took a year off after college and worked at the U.S. Naval Research Laboratory, which—

LIPPINCOTT: Where's that?

WERNER: That's in Washington, D.C. It was one of the early locations for space astronomy, actually, in the United States, starting with captured V2 rockets right after World War II. Because they were part of the military, they were pretty heavily involved in this. And there was a fellow named Martin Harwit, who was a professor at Cornell, who was taking a sabbatical there, and he worked in infrared astronomy, and he persuaded me to go to graduate school at Cornell. So that all came together, and I've been working in infrared astronomy ever since.

LIPPINCOTT: Space science, in the very early sixties, was in a fairly primitive state, wasn't it?

WERNER: It was pretty primitive compared to what goes on today, right. We'd launch a rocket and the data would come telemetered down, put on a strip chart, like a big roll of kitchen towels, and you'd spread it out in the hall and walk up and down and look at it. One of my first jobs was to count the pulses on such a strip chart.

LIPPINCOTT: And we had things in Earth orbit just since Sputnik. That was '57, wasn't it?

WERNER: That's right.

LIPPINCOTT: But the idea of space-based astronomy. Was that—?

WERNER: Well, space-based astronomy, as an idea, had been around since 1946. In fact, that's why our observatory is now named the Spitzer Space Telescope. I tell people it's not Eliot Spitzer [laughter], it's Lyman Spitzer. Lyman Spitzer was an astronomer initially at Yale, later at Princeton—a very brilliant man. In 1946, he wrote a prescient paper ["Astronomical Advantages of an Extra-Terrestrial Observatory"]—I think it was probably a classified report for the RAND Corporation; it was subsequently published in the open literature—envisioning the use of space as a place from which to do astronomy in all parts of the spectrum, not just infrared but also visible and X-ray and so forth. So the idea has been around for a long time, but the first actual space observatories didn't come to be until the 1960s, and I couldn't really tell you which was the first.

LIPPINCOTT: Martin Harwit, then—his infrared astronomy would have been from ground-based telescopes?

WERNER: And rockets—I was talking about satellites. Martin was involved with rocket flights in the early sixties.

LIPPINCOTT: The ground-based observatories aren't very good in the infrared, is that right?

WERNER: Well, the problem is that because infrared is heat radiation, you want to be someplace cold, and you can't do that on the ground.

LIPPINCOTT: There's *some* ground-based, though, isn't there?

WERNER: Oh, yes. In addition, there are parts of the infrared spectrum that don't get through the atmosphere.

LIPPINCOTT: At all?

WERNER: At all, right; large parts of it. Nevertheless, the pioneer work in infrared astronomy was of course done from the ground, much of it by Gerry Neugebauer and Bob [Robert B.] Leighton and Eric Becklin—here at Caltech in the sixties. And even now, for certain types of observations, particularly those requiring either high spatial resolution, which means a large telescope, or high spectral resolution, which requires collecting a lot of light, ground-based observatories are superior to space observatories. But for raw sensitivity, looking deep into space and time, studying the entire spectrum, space observatories are far ahead of anything on the ground.

LIPPINCOTT: What attracted you to the infrared part of the spectrum?

WERNER: [Pause] I really can't say exactly—except maybe that it was new and different, not many people were doing it. It was the first thing I learned, and I kind of stuck with it. And I think subsequently it's been very exciting working on a project like Spitzer, because a lot of the technical expertise required to do this type of project is contained in the brains and the experience of the scientists who've been doing it. And, on the other hand, corralling that expertise and putting it into space in a usable fashion is something that engineers at a place like JPL [Jet Propulsion Laboratory] are very good at. And as the project scientist on Spitzer, I was the interface, if you like, between these two forms of expertise. It was very exciting to help the scientists and the engineers work together to produce a very well-optimized and very powerful observatory.

LIPPINCOTT: Yes. Well, before we get to that, tell me what your thesis was on at Cornell.

WERNER: My thesis was a search for molecular hydrogen in the interstellar medium.

LIPPINCOTT: There must be a lot of it.

WERNER: We know now that there's a lot of it. At the time, we weren't sure. That is, there was indirect evidence that there was a lot of it, but no direct evidence.

LIPPINCOTT: When you say "molecular hydrogen," are you talking about— Hadn't we known for quite a while that hydrogen was seventy-five percent of what's there?

WERNER: Well, it's known that hydrogen is by far the most abundant element in the universe, yes.

LIPPINCOTT: But molecular hydrogen is something different?

WERNER: The easily observed forms of hydrogen are atomic hydrogen and ionized hydrogen, which can be observed when it recombines with an electron. Molecular hydrogen, which is two hydrogen atoms paired together in a molecule, is in fact rather difficult to detect, but it was inferred that it should be present in space, and so we went out to look for it. Without a great deal of success, I might add—tantalizing indications, but no real detection.

LIPPINCOTT: But today we know there is—

WERNER: Oh, yes, today it's been very well studied. In fact, the same Lyman Spitzer whom I was talking about earlier was responsible for a satellite called Copernicus, which worked in the ultraviolet and made many observations of molecular hydrogen in the ultraviolet. And [molecular hydrogen] has now been seen in the infrared as well.

LIPPINCOTT: How come there's so much molecular hydrogen? Why doesn't it get broken up?

WERNER: It's pretty durable. And also it protects itself by a process called self-shielding, which is a little hard to explain for your tape recorder, but which is something I worked on. Basically, if you have a cloud of molecular hydrogen, under the right circumstances, the outer part will have a transition from atomic to molecular, but the inside will be molecular, and the part on the outside protects the part on the inside. Another point is that in order to destroy a hydrogen molecule directly, you need a photon more energetic than what's called the Lyman limit—more energy than is required to ionize hydrogen atoms. And photons like that don't get very far in interstellar space.

LIPPINCOTT: Oh. Well, that's nice. That's good, isn't it?

WERNER: Yes.

LIPPINCOTT: [Laughter] That's why we're here, basically.

WERNER: Yes.

LIPPINCOTT: OK. Let's talk a little bit about what you did at Berkeley with Charles Townes. He's the maser guy, right?

WERNER: Right. Charlie Townes is not just the maser guy, he's an amazing guy. I had a postdoc with him from 1969 to 1972. He'd just gone to Berkeley from MIT and was starting a program in infrared and microwave astronomy, which had many successes. Some of the first detections of molecules in interstellar space, for example, were done by that group around that time, or maybe a little before I got there. The thing I worked on in Berkeley was an experiment to study what's called the cosmic microwave background radiation, which had been discovered in 1964 by [Arno] Penzias and [Robert] Wilson. People were trying to establish the black-body nature of this radiation by looking to see—shortward of the wavelength of about one millimeter—looking to see it turn over, as it would if it were true black-body. Those measurements were very hard to make, and there was some evidence—from experiments that later were proven to be erroneous—that there was some spectral structure in that radiation. In other words, it wasn't a smooth black-body but had peaks in certain places. So I headed up an experiment to go to White Mountain, in eastern California near Bishop, to look for this peak in the radiation, which you could do from a high, dry mountaintop site. Again, we were unsuccessful in finding a peak, which is good, because we now know there is no such peak. Probably a noteworthy thing about that experiment is that I did it jointly with Paul [Linford] Richards, who was a physics professor at Berkeley, and John Mather, who was his graduate student. John recently won the Nobel Prize [in physics, 2006] for his work on the COBE [Cosmic Background Explorer] experiment to study the microwave background, and the work we did together was his first foray into that type of scientific work. Of course, he's gone far beyond that now. But our White Mountain adventure was pretty exciting even at the time, and certainly in retrospect. Similarly, Paul Richards went on to be one of the leaders in the field. So we all got started together.

LIPPINCOTT: And—what was that guy's name? George—

WERNER: Smoot?

LIPPINCOTT: Smoot! He was the COBE guy.

WERNER: He was another COBE guy.

LIPPINCOTT: Did you know him?

WERNER: Not very well.

LIPPINCOTT: I think he's at Berkeley, too.

WERNER: He's at Berkeley, too.

LIPPINCOTT: And COBE went up when? In the nineties?

WERNER: COBE went up in either the late eighties or the early nineties. [Launched November 18, 1989—ed.]

LIPPINCOTT: Were those—I should know this—but were those infrared observations?

WERNER: Well, COBE had several experiments. There was the microwave experiment that George Smoot headed up, to measure the structure, the spatial distribution, of the cosmic microwave background radiation. The second, which John Mather headed up, was a spectral experiment to look at the shape of the radiation, to study its black-body nature—and that was also basically a submillimeter, longward of about 100 microns, type experiment. And then there was also an infrared experiment called DIRBE [Diffuse Infrared Background Experiment], which measured the cosmic infrared background; and that was headed by a fellow named Mike [Michael G.] Hauser, whom I actually met at Caltech when I was on the faculty here. That was a true infrared experiment; the other two were at longer wavelengths, sort of beyond what we typically think of as infrared. But it's all kind of a matter of definition.

LIPPINCOTT: Did you have much interaction with Townes himself?

WERNER: Quite a bit then and quite a bit since then. He's a very fine gentleman, and he's really interested in students and in education, so he was constantly popping into one's office—into my office or his students' offices—and saying, "Have you tried this?" and "Have you thought about that?" and so forth and so on. And subsequently I continued to work with him.

LIPPINCOTT: Well, that's kind of exciting. Then you came to Caltech. How did that develop? This was with Gerry Neugebauer?

WERNER: I got invited to give a talk in—gosh, it must have been in the fall of '71 or the spring of '72. There was a postdoc here, a fellow named Gary Steigman, whom I'd worked with at Cambridge when I was there for a year.

LIPPINCOTT: Cambridge, England?

WERNER: Cambridge, England. And so I came down, and I was talking to a few people, and Gerry Neugebauer, who was very direct, asked me if I was interested in coming to work at Caltech.

LIPPINCOTT: How had he heard about your work?

WERNER: I'm really not sure—apart from the colloquium I gave. But at the time, infrared astronomy was a very small field, so I expect everybody knew everybody else; things are a little different now. But I'm really not 100-percent certain.

LIPPINCOTT: Was he embarking on this kind of work himself?

WERNER: By that time, the Caltech group that Gerry headed was well established as one of the leading groups in infrared astronomy.

LIPPINCOTT: Who else was working with Neugebauer then?

WERNER: Well, Bob Leighton worked with him initially, and they got started with what's called the Two Micron Sky Survey, which they did from Mount Wilson. Gerry's first or second student, who stayed on as a postdoc and worked with him for many years, was a fellow named Eric Becklin, and Eric and Gerry were the heart of the group. No other faculty were regularly involved with it, although they [Eric and Gerry] did work occasionally with astronomers like Jesse Greenstein or Nick Scoville, who was a postdoc here then, and some with Gordon Garmire, who was mainly working in the X-ray. But it was largely Gerry and Eric heading the effort, with the occasional participation of other folks. And of course they had very good students in those days, too.

LIPPINCOTT: Yes. Now, was this, again, rocket-based?

WERNER: No. Eric and Gerry used ground-based telescopes, including the 200-inch.

LIPPINCOTT: Where were they, these telescopes?

WERNER: The 200-inch is at Mount Palomar.

LIPPINCOTT: Oh! [Laughter] Yes.

WERNER: They used the 60-inch and the 100-inch at Mount Wilson. They used to go down to Chile to work on the Carnegie Observatories' telescope. And I got involved in two programs. One was the Kuiper Airborne Observatory, which was a telescope in an airplane, which was just coming into use.

LIPPINCOTT: Was this when you came here?

WERNER: When I came here, yes. And also working at very long wavelengths—wavelengths of about one millimeter—which you could do from Palomar when it was reasonably dry. We started a type of observing there called twilighting, where we would observe when the sky was too bright in the afternoon, or in the morning, for the regular nighttime astronomers to work because they couldn't see the stars. We could work then at millimeter wavelengths, so we did quite a bit of that.

LIPPINCOTT: Tell me about the Kuiper Airborne Observatory. How high up did it go?

WERNER: It went up to between 41,000 and 45,000 feet. The Kuiper Airborne Observatory was a great success. It was operated by the Ames Research Center, in Northern California, based on some earlier work they'd done with CV-990s and those types of commercial transports.

LIPPINCOTT: So it was a NASA—

WERNER: It was a NASA plane. It was a C-141 aircraft, which was a transport aircraft. They cut a hole in the side and basically put a—a re-entrant cavity in the side of the airplane, so the telescope was below the level of the skin of the airplane.

LIPPINCOTT: It was under the fuselage?

WERNER: No, it was up above. This was a high-wing aircraft, and it was in front of the wing. This cavity was put in that could open up when you were at a high altitude. And of course therefore the cavity was in equilibrium with the outside, so it was totally surrounded by a pressure container that kept the air in the airplane when you opened up the cavity door. Flying in an airplane like that, you get access to parts of the infrared spectrum that don't get through to the ground.

LIPPINCOTT: But you're not actually in space at that point?

WERNER: No, no, no, by no means. The atmospheric pressure is maybe about a quarter to a tenth of the pressure on the ground, but the water vapor, which is what you're primarily trying to get rid of, sticks closer to the ground, so you can fly above most of the water vapor.

LIPPINCOTT: Oh. Did you fly in this plane?

WERNER: Oh, yes, many times. It was a lot of fun. They got the airplane from Lockheed. It was an early C-141 that wasn't worthy of being delivered to the military for some reason, and NASA bought it for a dollar or something like that.

LIPPINCOTT: It wasn't good enough for the military, so they—

WERNER: I don't know what the problem was. Maybe it was a prototype or something like that. It worked fine for us. And lots of infrared astronomers of my generation, or within ten or twenty years of my age, did a lot of their first work on that observatory.

LIPPINCOTT: How big a crew would go up with you?

WERNER: There were two pilots and a navigator—they flew the plane—and then there were typically three to five technicians and telescope operators and three to five astronomers.

LIPPINCOTT: What were you looking for?

WERNER: Anything at all. It was all new. Everything you did was something that hadn't been done before. A lot of the work was done on regions of our galaxy where stars are forming, where there's infrared radiation due to the dust, which is heated by the stars that are forming.

LIPPINCOTT: Yes. You do a lot of dust work, don't you?

WERNER: Well, dust is an infrared astronomer's best friend.

LIPPINCOTT: Yes, we have to talk about that. Why is it significant?

WERNER: Well, for two reasons. One is that dust is ubiquitous in space, and maybe half the heavy elements—that is, anything heavier than, say, hydrogen and helium, so stuff like silicon and oxygen and carbon and those sorts of things—coalesces into these small particles, which is what we call dust, OK? And they're typically about a micron in size, give or take a factor of ten or one hundred. The reason it's so important is that dust is very, very efficient at absorbing optical and ultraviolet radiation, and that warms the dust up, and then the dust re-radiates in the infrared. So you don't need a lot of dust in a galaxy—or in a circumstellar envelope, or whatever—to turn an ultraviolet source into an infrared source. And the reason it absorbs so efficiently is because, being a solid, it can absorb continuously. It doesn't absorb just in a few spectral lines, the way an atomic material would.

The second reason it's interesting is because of the fact that the heavy elements are tied up in the dust. If you want to study the heavy elements, the mineralogy—or look for biogenic materials in mantles, or carbonaceous grains, and so forth—a lot of interesting stuff is going on in the dust itself.

LIPPINCOTT: Uh-huh—like hydrocarbons?

WERNER: Hydrocarbons and things like that.

LIPPINCOTT: But on the other hand, it obscures a lot of things that one might want to—

WERNER: It obscures them at the optical and ultraviolet wavelengths, but the same cloud of dust that might be quite opaque at those wavelengths would still be transparent in the infrared. So you can look *through* the dust in the infrared at what are called the near-infrared, or shorter infrared, wavelengths. And then at longer wavelengths, you see the radiation from the dust. The cooler something is, the longer the wavelength it radiates at. Dust in space typically is heated to a temperature of fifty degrees—just to pick a number—and that radiates out at wavelengths around thirty microns, or twenty microns and beyond. Shortward of that, you can look *through* the dust, and of course the best example of that is the fact that the center of our galaxy cannot be seen at all in visible light but can be studied in great detail in the infrared, because the infrared radiation penetrates through the foreground dust to the dense stellar cluster at the heart of our galaxy.

LIPPINCOTT: I read something about some [Spitzer] scientists finding that there was a bar across the center of our galaxy. What does that mean?

WERNER: That's a bar of gigantic dimensions. There's a class of spiral galaxies where the spiral arms wind right into the center.

LIPPINCOTT: Like ours.

WERNER: No.

LIPPINCOTT: *Not* like ours.

WERNER: Not like ours. And there's another class called barred spirals, where there's a bar of stars in the center and the spiral arms radiate outward from the ends of that bar.

LIPPINCOTT: Is that what the Milky Way is like?

WERNER: We now think that the Milky Way might have that geometry, due to these observations of Spitzer, which have been able to look at the bar, and confirmed and strengthened earlier suggestions that there is a bar. Because although stars like the sun radiate more in the optical and ultraviolet than in the infrared, stars that are much cooler than the sun—of which there are many, and which is a stage that other stars will go through—radiate primarily in the infrared. Now, this is in the shorter-wavelength infrared. That radiation allows you to use infrared observations to look at the stellar distribution in a galaxy like our own.

LIPPINCOTT: Yes. But I find this puzzling. It's a funny conformation, isn't it? I mean, if there's a big black hole in the middle of the galaxy, how could this bar formation persist?

WERNER: Oh, well, the black hole is only a few million solar masses. The bar is, say,—

LIPPINCOTT: Much more massive?

WERNER: The bar is much bigger. It's maybe four kiloparsecs, that's 12,000 light-years, in extent or something.

LIPPINCOTT: Oh. So it's not threatened by—

WERNER: Exactly right. And it contains maybe 10^{10} solar masses of stars. So it and the black hole are just, well, not in contact with each other.

LIPPINCOTT: OK, thanks. So, when you were here at Caltech, were you part of the research faculty?

WERNER: I was on the faculty. I was a regular faculty member.

LIPPINCOTT: And you taught?

WERNER: I taught physics.

LIPPINCOTT: This was in the late seventies?

WERNER: This was ’72 to’79.

LIPPINCOTT: You taught physics or astronomy?

WERNER: Largely physics. I taught one astronomy course.

LIPPINCOTT: Who was the division [Physics, Mathematics, and Astronomy] head at the time?

WERNER: Bob Leighton [1970-1975], when I started, and then Maarten Schmidt [1976-1978].

LIPPINCOTT: How did you like teaching?

WERNER: I enjoyed teaching very much.

LIPPINCOTT: Did you teach Physics 1?

WERNER: I taught Physics 1 and Physics 2, exclusively.

LIPPINCOTT: Would you have used the Feynman text?

WERNER: We used it some, yes.

LIPPINCOTT: I think it might have been being just put together then.

WERNER: It was still pretty fresh, yes.

LIPPINCOTT: So then you somehow got over to JPL, did you not—in ’77?

WERNER: No, no. What happened was the following, in not correct chronological order. I didn’t get tenure. But what is now called the Spitzer project had begun in the early seventies, through a series of studies of various kinds. And in fact my colleague Eric Becklin, whom I mentioned earlier, was on one of the very early study teams, and I remember him talking about that at one of our sack lunches up in 469 Lauritsen, which we had every week. But in January 1977, because of the success of my work on the Kuiper Airborne Observatory, I was asked whether I wanted to head a sub-team of one of these study groups that was helping to define SIRTF. So I said, “Sure, I’d like to do that.” And it turned out to be something I really enjoyed doing and was at least moderately good at.

LIPPINCOTT: Who asked you to do this? Was it NASA people or—

WERNER: Well, it was people from Ames. The heads of this committee were Fred [C.] Witteborn, from Ames, and Dave [David M.] Rank, from UC Santa Cruz. And Dave, actually, asked me—I knew Dave from Berkeley. So I started working on what was then SIRTF, and when I didn’t get tenure at Caltech—and I guess I would have found out about that in the spring of 1978—I was able to get a job at Ames, which at the time was both the locus of the work on SIRTF and also the home of the Kuiper Airborne Observatory. There was a reasonable infrared astronomy group at Ames which I helped to develop a bit.

LIPPINCOTT: I have the date of 1977 for your joining SIRTF.

WERNER: Yes, that’s when I joined SIRTF, but I was still at Caltech.

LIPPINCOTT: Oh, dual.

WERNER: Yes. I was at Caltech and I was on a committee, basically—like many Caltech professors are and were. This was the committee involved with SIRTF. And then I went up to Ames and started devoting more and more time to SIRTF.

LIPPINCOTT: That’s up in Mountain View?

WERNER: Mountain View, California. I started there in ’79 and I worked there until 1990, at which point the project—SIRTF—was moved to JPL, and I came along with it.

LIPPINCOTT: There’s something at Caltech called the SIRTF Science Center, which opened in 2001. Where is that?

WERNER: That’s in the Keith Spaulding Building, above the post office.

LIPPINCOTT: Is that where you work now?

WERNER: No, I work at JPL. SIRTF—now called Spitzer—is one of NASA’s Great Observatories, which is why we have what is now called the Spitzer Science Center.

LIPPINCOTT: Yes, we should talk about that program.

WERNER: The Great Observatories are really observatories intended for the use of the entire scientific community. And for a project with the scope of Spitzer or Hubble [the Hubble Space Telescope] or the Chandra X-ray Observatory, it’s clear that there [needs to be] a central location for managing the science program, for processing the data and distributing it to the community and so forth. Soliciting proposals from people who want to use the observatories—these kinds of things. That’s what goes on at the SIRTF Science Center, and it’s headed by Tom Soifer, a longtime friend and colleague of mine who is a professor of physics here at Caltech and who is the head of the current infrared astronomy program here.

LIPPINCOTT: And that’s exclusively concerned with Spitzer? It doesn’t arrange time on the three other observatories?

WERNER: That’s right. It’s just for the Spitzer Space Telescope. It’s part of what’s called IPAC [Infrared Processing and Analysis Center], which was an outgrowth of IRAS [Infrared Astronomical Satellite], which is yet another subject we might get to.

LIPPINCOTT: And I just want to mention the Compton Gamma-Ray Observatory, which is the fourth of the Great Observatories.

WERNER: That's right, although Compton has long since been de-orbited, as the euphemism goes, into the ocean and was replaced recently by a new gamma-ray observatory, called GLAST [Gamma-ray Large Area Space Telescope], which is quite a bit more powerful. It's been launched [June 11, 2008], and it's being checked out right now.

LIPPINCOTT: It hasn't started getting data yet?

WERNER: It may have, but no results have been announced. [As of September 9, 2008, results have been released and look very good. GLAST has been renamed Fermi. –M.Werner]

LIPPINCOTT: OK. So you moved up to JPL, and I guess Bruce Murray was the director at that time?

WERNER: No, I came to JPL in 1990, when Lew Allen was the director.

LIPPINCOTT: Oh, right. You were at Ames up until then and you're at JPL now. And you became project scientist in 1984.

WERNER: Actually in '83, I think.

LIPPINCOTT: What did that entail? That was a big step up, wasn't it? A lot more work?

WERNER: Well, it wasn't so much more work, because I'd been pretty much working on SIRTF— Well, it was. It was in a sense, because in 1983 there was a solicitation by NASA for people to build instruments on SIRTF, which at that time was still viewed as a shuttle payload, so the idea was that it would fly a few times a year and [when it came] back we would put a new instrument in, or whatever—all a bit of a pipe dream. So a science working group [was formed] to advise NASA on how to do this, and they solicited people to develop instruments to put into the observatory. The project scientist was chairman of this science working group. So that was really the new part of my job. Working with the project team at Ames I'd been doing all along. Working with the outside science community, planning the meetings, keeping things moving forward, doing advocacy for the telescope—all these sorts of things were some of what came with the project scientist's job.

LIPPINCOTT: There *was* a launch on the shuttle, wasn't there?

WERNER: There was a launch of something called Spacelab 2. Spacelab 2 was a motley mixture—a hodgepodge of instruments, one of which was an infrared telescope. It didn't work very well. It had one flight [1985], I think, and produced a small amount of data.

LIPPINCOTT: Yes, and that was because there was a bit too much heat radiation from the shuttle itself?

WERNER: Right. It became clear in this time period that the shuttle was not a good place to do infrared astronomy. The other big thing that happened was the launch of IRAS [Infrared Astronomical Satellite] in 1983.

LIPPINCOTT: You had nothing to do with that, did you?

WERNER: I worked on the data; I didn't have anything to do with the observatory. It was a joint US-UK-Netherlands project, with the NASA part being headed eventually by JPL and Caltech.

LIPPINCOTT: And that was not on the shuttle, that was—

WERNER: That was a free flyer. IRAS orbited the Earth, and there were some technical problems which it showed could be overcome. So that combination led people to the idea, right away, that we should put SIRTF into orbit and not fly it on the shuttle. And during the time these proposals were being solicited, and these people were being selected, the change was made from a shuttle-attached payload to a free flyer.

LIPPINCOTT: Now, wasn't the size reduced at some point?

WERNER: The size has been reduced several times, yes.

LIPPINCOTT: Why is that?

WERNER: It all has to do with how much money you've got. [Laughter] The size on the viewgraphs was reduced.

LIPPINCOTT: Yes. Well, I think they discovered they could go into this heliocentric, Earth-trailing orbit and then they wouldn't have to carry so much helium with them. Was that it?

WERNER: First of all, that wasn't "them," that was us.

LIPPINCOTT: Oh, you did it.

WERNER: Yes, I and my colleagues. Right. The evolution was [the following]: Once we got off the shuttle and became the Space Infrared Telescope Facility, there was a long period of time when we had to stay light on our feet, to keep up with the trends at NASA. You know, there were versions for space platforms, there were versions for space stations, there was an equatorial-orbit version, there was a polar-orbit version, there was a whole library of versions of SIRTF that never got beyond the viewgraph stage. Toward the end of the eighties, Ames was working with JPL to develop a concept that was more of a high Earth orbit—instead of being close to Earth, it would be far from Earth but still in Earth orbit, to cut down the heat load from Earth.

LIPPINCOTT: Like the geostationary satellites?

WERNER: Yes, but even higher than that. And then it became apparent that Ames was not capable of managing a project of that size, and the project was moved to JPL, and it continued to grow conceptually, until we had an observatory that was very large. It had a one-meter mirror, thousands of liters of liquid helium, and a price tag of $2.2 billion, not counting the $500-million rocket that would be required to launch it. And that's what we presented to the Bahcall committee. The Bahcall committee was the committee recommending priorities for astronomy for the decade of the 1990s.

LIPPINCOTT: Oh. What they call the decadal—?

WERNER: The decadal review, exactly. John Bahcall was the chair of that.

LIPPINCOTT: He's at Princeton?

WERNER: He *was* at Princeton; he died a couple of years ago. Also, he'd been at Caltech earlier, actually.

That observatory crashed, under a combination of its own weight and problems with other missions—like Galileo, the Mars Observer, the problem with the Hubble primary mirror, the problem with the Galileo antenna. All these kinds of things made—

LIPPINCOTT: This was all happening around the early nineties?

WERNER: The early nineties, right. This all made large, monolithic missions—kind of behemoths—pretty unattractive.

LIPPINCOTT: This was when NASA got into this faster-cheaper-better mode?

WERNER: Exactly right. And then somehow we were reborn, through a set of circumstances I can't re-create too well but which are well documented in a book by George Rieke, my colleague from the University of Arizona [*The Last of the Great Observatories: Spitzer and the Era of Faster, Better, Cheaper at NASA* (University of Arizona Press, 2006)]. The history of all this is pretty well covered there. We were re-created as a much smaller observatory in solar orbit, as opposed to Earth orbit, with the final refinement being that a colleague of ours—Frank Low, also from the University of Arizona—realized that in the solar orbit you could make very good use of radiative cooling.

LIPPINCOTT: What's that?

WERNER: That's where you cool not with a refrigerant—

LIPPINCOTT: Not with the helium.

WERNER: —but by radiating into space. So, much of the cooling on Spitzer as it now exists is achieved by radiating into space, and we use only a small amount of helium to keep the instruments cold.

LIPPINCOTT: But can't *anything* radiate into space?

WERNER: Anything can radiate into space, but when you're close to the Earth it's hard to be in a geometry where you have part of the observatory continually facing cold space and you're still able to do any significant amount of re-targeting and observing. Whereas the way Spitzer is set up, there's a hot side, which is always pointed toward the sun, and a cold side, which is always pointed into deep space, and that's where the radiative cooling occurs.

LIPPINCOTT: That's very smart!

WERNER: Yes, it's a very ingenious and sophisticated and elegant engineering solution. It works extremely well, and therefore we have much less liquid helium and a much longer lifetime than any other infrared observatory.

LIPPINCOTT: So is this what the Bahcall committee recommended?

WERNER: Well, the Bahcall committee actually endorsed the big fella—the $2.2-billion observatory. And in fact something else happened that helped SIRTF a lot. There was a period when we were pretty much persona non grata, and we didn't get very good attention or management support from JPL. But in the fall of 1993, a fellow named Larry Simmons, who managed the development of the WFPC2 camera that saved Hubble—

LIPPINCOTT: The Wide-Field Planetary Camera?

WERNER: The modified one that could deal with the inaccurate telescope optics. He became the SIRTF project manager. He was very, very good, and he brought very good people with him. He led the process by which we put some flesh on the bones of the radiatively cooled concept. And then in the spring of 1994, we had to go to a committee of the National Academy of Sciences, which found that we were… [Tape ends]

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WERNER: …still powerful enough to be the number-one recommendation, which the old version had been. And that reaffirmed our position as the highest-priority mission for the 1990s. And then we were sort of off and running.

LIPPINCOTT: So you got funded?

WERNER: Yes, things started to turn in our direction.

LIPPINCOTT: In 2003, you have the launch. But things happened between 1994 and 2003.

WERNER: A lot of things happened between 1994 and 2003.

LIPPINCOTT: You had to decide what instruments were going into—

WERNER: No, the instruments had been selected back in 1984, and those instrument teams had stuck with us. When they were selected, in 1984, we were supposed to have our first shuttle flight in 1988 or something. What we did in the intervening fifteen or sixteen years, before we had to kind of button everything up, was continue to work on the technology of the Spitzer instruments, and the prime technology is what are called detector arrays. Instead of the single, individual detectors that were used back when I came to Caltech—and, for example, in the initial discovery of the galactic center in the infrared that was done by Becklin and Neugebauer—the infrared arrays, the ones we have on Spitzer, have tens of thousands of pixels. It's very similar to the camera you might have in your cell phone, or your home video camera, or your electronic digital camera. Same idea. You've got lots of individual pixels. They are each read out and they produce images, and because they're on this cold telescope in space, they're very much more sensitive than they would be on the ground. That combination of factors makes Spitzer remarkably sensitive. It's hard to quantify how much better it is that what you can do from the ground, but factors of a million are not unreasonable, depending on what figure of merit you're using. So we were able to develop those detectors over this time period, working with the detector fabrication houses, or sometimes more in-house. By "we," I mean our teams of scientists, not just me and JPL. And because of that, as the observatory grew smaller and somewhat simpler, it remained very powerful scientifically, because we had these tremendously powerful detectors, which we're using. Instead of having a complicated observatory with a few detectors, we have a very simple observatory with a whole mess of detectors. And that's a good trade-off.

LIPPINCOTT: OK. I'll just go through the three instruments, for the record. There's the IRAC, the Infrared Array Camera; and the IRS, the Infrared Spectrograph; and a MIPS.

WERNER: The Multiband Imaging Photometer for Spitzer. And actually, in addition to being the project scientist for Spitzer, I'm a member of the MIPS instrument team.

LIPPINCOTT: What is the MIPS looking for, specifically?

WERNER: At the long wavelengths, it's mainly looking for circumstellar material—dust around stars, associated with planetary systems—and also the infrared radiation from star-forming regions both within our galaxy and star-forming galaxies throughout the universe. So for example, a census of the cosmic history of star formation requires observations with the MIPS, because much star formation occurs in galaxies that are shrouded in dust and can best be seen in the infrared.

LIPPINCOTT: Now, you're looking very deep with the MIPS—way back?

WERNER: Well, we're looking pretty far back with the MIPS. We're looking back to a redshift of the order of three, which means the universe was a quarter of its present size.

LIPPINCOTT: So that's about four billion years after the Big Bang?

WERNER: Something like that. But we've looked even farther back in space and time with the IRAC. The IRAC, working in the near-infrared, can look at starlight from very distant galaxies, and we've seen, basically, objects at red shifts of six or greater—as far back in space and time as Hubble looks.

LIPPINCOTT: But you can't look back to the plasma era, can you—like 300,000 years after the Bang?

WERNER: No. Well, that radiation has shifted to very long wavelengths and that's what COBE is all about.

LIPPINCOTT: You don't see that stuff.

WERNER: That's correct.

LIPPINCOTT: That's what Tony Readhead [Anthony C. S. Readhead, Rawn Professor of Astronomy] is looking at?

WERNER: Tony Readhead is studying that as well, and there is a big group at JPL interested in that type of research.

LIPPINCOTT: So you'd be mainly looking at the era when the galaxies formed?

WERNER: We look at everything, from the very first galaxies, basically, to objects in our own solar system and everything in between.

LIPPINCOTT: OK. If you launched in 2003, and they thought Spitzer would have a two-and-a-half-year life, but it's still producing data—? [Tape is turned off briefly]

LIPPINCOTT: We were talking about the lifetime of Spitzer.

WERNER: Well, the Spitzer cryogenic system, because it relies on radiative cooling, was going to be very hard to test on the ground. We predicted—and we turned out to be right—that in space the outer shell, the coldest part of the external observatory, would be at a temperature of around thirty-four degrees above absolute zero, which is very cold. The inside is colder yet.

LIPPINCOTT: How so? Because of the helium?

WERNER: Exactly. And in order to test this contraption, you'd need a test chamber on the ground that is much colder than thirty-four degrees Kelvin. And, it's a whole separate story, but it really wasn't very feasible—and still isn't very feasible—to provide testing at the level you'd need to really verify performance. So we had modeling, and we were conservative. Although we had a two-and-half-year lifetime requirement with the cryogen, we predicted a five-year lifetime, and in fact we're getting a little more than five years. Now, when we run out of cryogen, in about May of '09 perhaps, we're still going to be in this very favorable orbit, and the outer shell will still be at thirty-four degrees Kelvin, because it achieves that cooling by radiation. And we expect that the inside will only warm up to about twenty-five or thirty degrees Kelvin, and we'll still be able to operate with our two shortest-wavelength IRAC bands.

LIPPINCOTT: So just the one instrument will be working then?

WERNER: Just the half of the one instrument, but that will still be very, very powerful. That's our instrument for looking at distant galaxies. That instrument can be used as well to study planets around other stars. So for a long time we've had the idea that we could continue to operate in what we would call the warm Spitzer mission, and in fact relatively recently we've been approved to do that. So we have the prospect of at least an additional two years beyond 2009 in warm Spitzer, which would carry us at least to mid-2011, and the chance to apply for yet an additional extension of lifetime before the now-scheduled end in 2011. We hope to go to the start of 2014.

LIPPINCOTT: You have different scientists asking for time on this observatory?

WERNER: There's an annual cycle in which people propose. Typically, we get hundreds of proposals, an oversubscription of about a factor of five—five times more time is requested than is available.

LIPPINCOTT: Are you the ultimate authority on who gets picked?

WERNER: No, the ultimate authority is Tom Soifer, the head of the Spitzer Science Center. That's their job over there, which they do very, very well. There's a well-established process—more-or-less pioneered by Hubble, which is managed by the Space Telescope Science Institute—involving peer review and so forth, which works quite well.

LIPPINCOTT: What is it that you have to do, after these people have been chosen?

WERNER: I personally have to do very little. [Laughter] Actually, in fact—although for many years Spitzer was my main preoccupation, both my vocation and my avocation—since about early 2004 I've had another job, which is as chief scientist for astronomy and physics at JPL. I spend maybe half my time doing that job, maybe a quarter of my time working on Spitzer project issues, and a quarter of my time working on research with Spitzer. But Spitzer has operated so smoothly and flawlessly since launch that there's really relatively little I have to do as project scientist. If we had issues like having to decommission an instrument or having to give up some capabilities or some functionality, or when there's an anomaly—when something goes wrong—then I have to get involved. I'm also involved in reporting to headquarters; I give a lot of talks about Spitzer and write a lot of papers about the observatory per se. But on a day-to-day basis, the management of the science programs is done entirely at the Spitzer Science Center.

LIPPINCOTT: So you haven't had any bugs on this observatory. No communication problems?

WERNER: We've had a small number of anomalies, as they're called. And there's continual back-and-forth with the Deep Space Network, which is providing our data. We send the data down to the DSN, and occasionally things get lost along the way. But basically Spitzer has been remarkably smooth and flawless in its operation.

LIPPINCOTT: When you say *you* send the data down, you mean the spacecraft?

WERNER: Exactly right.

LIPPINCOTT: Spitzer may still be operating when some of these other advanced things go up that are going to be looking for extrasolar planets—is that right?

WERNER: Yes. Well, Kepler, for example, is launching next year to do that. We'll certainly still be up there while they're running.

LIPPINCOTT: And didn't your observatory find the first visible picture of extrasolar planets?

WERNER: No. Our observatory has not imaged extrasolar planets.

LIPPINCOTT: I thought there was some detection of big, gas, Jupiter-type planets? Before, they were only indirectly seen, and you saw it directly, in some way?

WERNER: Right. Probably the most exciting and unexpected work we've done with Spitzer has been on extrasolar planets, which we're able not to *discover* but to characterize. "Characterize" means understanding what the planet is all about. That we're able to do this with Spitzer relies on the fact that many of the planets that are being discovered—though it's a bit of a selection effect—are large planets, close to their parent stars. Because of that, these planets themselves have an appreciable infrared signature, and they're bright enough to be seen by Spitzer, excepting that they're next to this really bright star. However, there's a subset of these planets that are in orbits called transiting, or eclipsing, orbits—so that, as seen from Spitzer, they go in front of and then behind the star they're orbiting. And when they go behind the star they're orbiting, because of the fact that they have some infrared radiation of their own, there's a drop in the infrared signal from the star-plus-planet system—which we see as a single object, from Spitzer—and that drop is a measure of the infrared radiation from the planet.

LIPPINCOTT: And that tells you what, about this big planet?

WERNER: How hot it is.

LIPPINCOTT: And how big it is?

WERNER: No. How big it is you can get from the fraction of the starlight it obscures when it goes in front of the star. But [in the infrared], you can figure out how hot it is, you can figure out things about the structure of the atmosphere, you can figure out things about the composition of the atmosphere, you can figure out whether there are winds on it and how energy is transported around the planet—an extraordinary amount of stuff! And you can look at the chemistry of the atmosphere.

LIPPINCOTT: Which of the Spitzer instruments picks this up?

WERNER: Well, it's been done with all three instruments, in fact. The first measurements were done both with IRAC and with MIPS, and then people started doing it with the spectrograph. So you can look at not just the broadband signature of the eclipse but at the eclipse in many different wavelengths at the same time, and that tells you about the composition of the planetary atmosphere.

LIPPINCOTT: Would Spitzer be able to pick up any terrestrial-type planets, rocky planets?

WERNER: In a favorable situation, where the planet is pretty close to the star, and orbiting an M star, so it's a cool star—

LIPPINCOTT: What's an M star?

WERNER: That's a cool star, a star that's maybe half the temperature of the sun, and it's also much smaller than the sun. So its infrared contribution, relative to the planet, will be quite a bit smaller [than that of a larger star]. In those circumstances, Spitzer could certainly see a planet a few times the size of Earth, at least.

LIPPINCOTT: Has it?

WERNER: We haven't done that yet, no.

LIPPINCOTT: How do you feel about how many of these things there are? I was just thinking about the Drake equation. Are you one of the people who thinks there's tons and tons of other worlds?

WERNER: Oh, there's no question that there are tons and tons of other worlds. I don't think anybody would disagree with that; because so many planets have been seen around stars. First of all, the formation of planets is an expected by-product of the formation of stars.

LIPPINCOTT: Right.

WERNER: And so many planets have been seen around other stars and by searches that are still sensitive only to a small fraction of the actual planets that could be present. There can be no doubt that there are lots and lots of planets around other stars. Whether it's 10 percent of stars, 20 percent, 50 percent that have planets, it's still a whole lot of planets.

LIPPINCOTT: Yes. I think some scientists think that half the stars are binaries—that is, two stars together—and the other half have these disks around them that could wind up as planets.

WERNER: Absolutely. And even the binaries might have planets—who knows?

LIPPINCOTT: Oh! Really?

WERNER: Sure. It's possible. Anyhow, that's a lot of planets, and I personally think that with so many planets and so many galaxies and so many stars, there are bound to be other places where life has formed. But it may not be anything like the life we have here.

LIPPINCOTT: Yes. This is totally beside the point, but a lot of biologists— The biologists are the only ones who are dragging their feet here because they think it's so difficult to grow anything—you know, that the chances against getting some kind of arrangement, like DNA, that reproduces itself are astronomically high, if you'll pardon the pun. But I don't think so. I mean, they're not looking at it from the point of view that you and I might look at it, which is that there's so much space.

WERNER: Exactly. You have so many chances. Even though the probability per chance is small, the number of chances and the length of time you have over which life can evolve is quite long. But the fact is, we know very little about this. We'll know more when life is discovered elsewhere.

LIPPINCOTT: Yes. But your principal interest is in finding out how the structures evolved, right? The structures in the universe.

WERNER: I don't know what you mean by my principal interest.

LIPPINCOTT: Oh. Well, it isn't biological, is it?

WERNER: Oh. No. No, that's right. [Laughter] We're not doing biology. Although some of the most interesting work I've done, with and without Spitzer, has been vaguely astrobiological. There's a new field called astrobiology, which is a kind of intersection of astronomy and biology.

LIPPINCOTT: Yes, it used to be called exobiology, which is a much better name for it.

WERNER: Probably. But I mentioned earlier the hydrocarbon molecules. I've devoted a fair amount of time to studying hydrocarbon molecules in space and understanding where they are and are not found, and how they are excited, and so forth and so on.

LIPPINCOTT: They're found on comets, aren't they?

WERNER: Well, the molecules I'm thinking of are a class of molecules called polycyclic aromatic hydrocarbons, which are found throughout space, in fact.

LIPPINCOTT: Just all by themselves.

WERNER: Yes. They're also found in places like soot and tar and car exhausts and on your barbecue grill.

LIPPINCOTT: [Laughter] And they have nitrogen in them, don't they, and carbon and hydrogen—

WERNER: Well, the pure polycyclic aromatic hydrocarbons are just hydrogen and carbon.

LIPPINCOTT: Oh, is that all?

WERNER: But I'm sure that in reality they have lots of side groups and impurities.

LIPPINCOTT: Yes, and then they kind of collect into— On comets? Because they've found amino acids, I think, on meteorites.

WERNER: That's right. The polycyclic aromatic hydrocarbons are only one of a number of classes of hydrocarbon molecules found in space and that we might expect to find on the mantles, or the surfaces, of grains, and that might be brought into comets in that fashion, as the comet formed from material in the outer solar system.

LIPPINCOTT: And that's what you're principally interested in?

WERNER: Not principally, but that's one of the things I'm interested in, yes.

LIPPINCOTT: Tell me about some of the latest discoveries of Spitzer.

WERNER: OK. Well, certainly the result I mentioned earlier—our ability to characterize the extrasolar planets—has been very, very exciting. The fact that we can talk about winds on the surface; construct the temperature distribution on the surface of an extrasolar planet; talk about how we need winds to redistribute the energy that's falling from the star onto the surface of that planet; look at the time response of the planet to an impulse of energy, as it approaches close to the star and then moves away. We can do all these kinds of things, and it's really quite remarkable.

LIPPINCOTT: Can you tell something about their orbits?

WERNER: No, the orbits you get from— This is a good example of synergy between different tools: The orbits you get from the people who discover the planets and look at the radial velocity and so forth. Once you know the orbit, you can say, "Well, we'll look at the planet at *this* time, because it will be close to the star." And at some later time, it will be far away from the star. And how does its infrared radiation vary over that time period?

Another area where we've gotten very surprising results has been in the study of the very distant universe, where we find very large galaxies at a very early age. So, even much less than a billion years after the Big Bang, we find galaxies which have fairly immature stellar populations and must have formed within a few hundred million years of the Big Bang. And that's sort of a threat to, or a constraint on, theories of how structure formed in the early universe. Things must have gotten organized pretty quickly.

LIPPINCOTT: So it was surprisingly early?

WERNER: Right, and there are surprisingly large numbers of these things.

LIPPINCOTT: Are they all spirals, or are some of them elliptical?

WERNER: We can't resolve them spatially, but they have a stellar population characteristic of ellipticals.

LIPPINCOTT: Oh. And not characteristic of the spirals?

WERNER: Right, characteristic of stellar bulges.

We've discovered, as you mentioned earlier, a stellar bar at the center of our galaxy. We've looked at cometary material in our own solar system and compared that with material around other solar systems, to understand the similarities and differences—in general, the similarities are pretty striking. If you take a recipe based on observations, say, of comet Tempel 2, the comet [hit by] NASA's Deep Impact [spacecraft], that material can pretty well reproduce the signature of dust in extrasolar planetary systems that we're able to study with Spitzer. We've just had a paper accepted for *Scientific American* on evidence we found for planets around planet-size stars.

LIPPINCOTT: Planet-size stars?

WERNER: Yes. Start with brown dwarfs, which are objects not much bigger than Jupiter that never became robust enough—or heavy enough, massive and hot enough—to become stars. They have 1 percent of the mass of the sun. Nevertheless, they can radiate, and you can see them in the infrared, because when they're young, they radiate the heat with which they formed—the heat of the collapse that formed them. And these objects have disks around them within which planets can form, which look very similar to the disks around young stars, within which planets form. So that's an example of a planet-size object that might have its own planets around it. Moving to the other end of the spectrum of stellar evolution, there's an object called a white dwarf, which is the endpoint of the evolution of a star like the sun. We've found disks of dust around white dwarfs, which are probably produced when an asteroidal-type object comes so close to the white dwarf that it's shredded by the white dwarf's strong gravity—a white dwarf is a very compact star, a stellar remnant. And some of this shredded material actually falls onto the white dwarf, and if you look at the atmosphere of the white dwarf, you can study the composition of this asteroidal material that was orbiting the white dwarf. And, again, it's remarkably similar to the composition of our own solar system. Spitzer's been studying these white-dwarf disks, as well as the brown-dwarf disks and the young-stellar-object disks.

LIPPINCOTT: Now, our sun is going to be a red giant in about five billion years?

WERNER: And then it will become a white dwarf, about the size of Earth.

LIPPINCOTT: And then it will become a white dwarf. Do you know that that's going to be its final stage? Or if enough stuff falls into it when it's a white dwarf, mightn't it reignite and turn into a decent sun again?

WERNER: Well, that kind of thing happens when the white dwarf has a star companion, but the sun isn't a binary star. I don't think enough stuff can fall onto it to make it much of anything.

LIPPINCOTT: When it gets to be a red giant, it's going to encompass Mars, isn't it?

WERNER: It will be in one hundred times its current size, which makes it about as big as the Earth's orbit and close to Mars.

LIPPINCOTT: And so what will happen to Jupiter and Uranus and Neptune?

WERNER: They may be safe.

LIPPINCOTT: We'll be elsewhere by then.

WERNER: We better be.

LIPPINCOTT: Oh, we will be. I'm sure we will be.

I want to talk about the Terrestrial Planet Finder. That goes up—?

WERNER: Those programs—the so-called planet-finder programs—are quite uncertain now, in terms of their timing and how they're going to be done. I think a lot depends—

LIPPINCOTT: Because of money?

WERNER: Yes, because of the funding—or the lack of funding. The fate of that particular line of activities depends a lot on the decadal review committee, which is just starting up and will produce a report for the coming decade. Its recommendations will have a big effect.

LIPPINCOTT: Who's running those, now that Bahcall is gone?

WERNER: Well, Bahcall ran one, but there's a new chairperson every time around. In 1990 it was Bahcall. In 2000 it was Chris [Christopher F.] McKee and my college classmate Joe Taylor, whom I mentioned earlier. They're in the process of deciding on the chair for the next review, but it hasn't been announced yet.

LIPPINCOTT: OK. What about SOFIA [Stratospheric Observatory for Infrared Astronomy]?

WERNER: SOFIA is an airborne observatory, a successor to the Kuiper Airborne Observatory, which I mentioned earlier. SOFIA was in the same [decadal] review I mentioned earlier. In 1994, when Spitzer was revalidated as a top Bahcall committee priority, SOFIA was given a big boost forward. It's a joint project with the Germans. It's had a rather troubled history. Hopefully it will start flying within a year and will continue, with a larger telescope and more capable instruments, the tradition of work with the C-141—the Kuiper Airborne Observatory which we call the C-141.

LIPPINCOTT: Will it have instruments comparable to Spitzer's?

WERNER: It will have the same types of instruments, but because of the fact that it's going to be warm and within the atmosphere, it won't be as sensitive. It will have somewhat higher spatial resolution—higher visual acuity, if you like—and it will carry instruments that provide higher spectral resolution. Because it's a very robust platform, in terms of what you can mount on it. Spitzer is no bigger than a car, and I mean a Corolla, not a Hummer. [Laughter] The SOFIA is in a 747 aircraft, so it's going to be a big observatory, with big instruments.

LIPPINCOTT: Would you be doing any work on that, do you think?

WERNER: I'm hoping to do at least a little work on SOFIA, yes. We have a plan at JPL to develop a module to do polarimetry to measure the magnetic fields in space, which will considerably enhance the capability of SOFIA—sort of an add-on to one of the instruments. More generally, SOFIA will be supporting instrument and technology development, and I think the people at JPL whom I help in my chief scientist's role will certainly be interested in participating in the SOFIA instrument program.

LIPPINCOTT: Since Spitzer has worked so well, are there any plans—when this particular piece of equipment dies—to send up a new one, duplicating it?

WERNER: No. You don't want to duplicate, you want to go beyond. The detectors available now, the arrays, are much more powerful in terms of the number of pixels. The telescope that's in work to succeed both Spitzer and Hubble is what's called the James Webb Space Telescope.

LIPPINCOTT: Is that going to be optical also?

WERNER: It will be optical-slash-infrared. It will overlap Hubble and Spitzer, but not their extremes, just the middle—that is, the longer wavelengths observed by Hubble and the shorter wavelengths observed by Spitzer is what JW—the James Webb Space Telescope—will observe.

LIPPINCOTT: And when will that be launched?

WERNER: 2013 if things go well.

LIPPINCOTT: Is Hubble still producing?

WERNER: Hubble is still doing good science. It will be doing much better science, and much more viable and exciting science, when the new instruments that are scheduled to be launched in [October] 2008 are installed.

LIPPINCOTT: Good. Have I not covered anything you'd like to talk about here?

WERNER: Yes, a couple of things just quickly. One is, of course, that I recognize that the work we do is supported by the taxpayers of the country, so we're fortunate to have this type of program that enables us to fulfill our dreams, and I think we return good value for money, in terms of the science, the technology, the scientific literacy, the young scientists we train, and the way we inspire people to keep looking forward. The second thing about Spitzer is that although we've talked about it as a scientific experiment, to my mind it's equally successful as a management experiment. We operate in a very open and transparent fashion. We use the best capabilities not just of the scientists but of the engineers and the managers. We didn't set artificial boundaries about who could talk to who about what; and that openness is a large part of the reason for the success of Spitzer. A project like Spitzer requires the very best capabilities of the very best people, and we were able to achieve that by picking good people and empowering them, or by a winnowing-out process by which the not-so-good people fell by the wayside. It's really the people that make something like Spitzer happen. Everybody who worked on Spitzer should feel proud and excited about the contribution they made to this great scientific mission.

LIPPINCOTT: Who is the project manager?

WERNER: Right now, the project manager is a gentleman named Robert [K.] Wilson. But the project managers who really brought Spitzer to life were Larry Simmons, who got us well into the development cycle, and Dave Gallagher, who took us from there through launch. They're the guys who deserve the credit. And we were well supported by NASA. We made it easy for NASA to support us by maintaining good communication with NASA headquarters.

LIPPINCOTT: What are your plans for yourself when Spitzer finally gets a little too warm to—

WERNER: It won't get too warm, only too distant—it's continuing to move away.

I'm a little uncertain about my plans, to be honest with you. I'm now sixty-five, and my wife's sixty-six, so we can certainly retire in the near future, but we're not planning to. So we'll just see what happens.

LIPPINCOTT: How far away is Spitzer? And it will just— It will never fall to Earth?

WERNER: Oh, no. It will come back around in about sixty years.

LIPPINCOTT: Come back around in our vicinity?

WERNER: Yes. It's falling behind the Earth and—

LIPPINCOTT: We'll catch up to it.

WERNER: Exactly. We'll lap it.

LIPPINCOTT: Will it then tumble down?

WERNER: No, it's not going to hit the Earth. That's very unlikely. It will just go past and keep on going.

LIPPINCOTT: That's kind of sad.

WERNER: Well, it will have had a glorious life by then. It's had a glorious life already.

LIPPINCOTT: We have a little bit more time here. I just wanted to mention one honor that came your way, and that is being appointed the George Darwin lecturer by the Royal Astronomical Society in 2006.

WERNER: Yes. That was a very pleasant surprise, I have to say, and quite an honor.

LIPPINCOTT: Yes! Who were some of your predecessors?

WERNER: Well, interestingly enough, Lyman Spitzer himself was the George Darwin lecturer a long time ago. Joe Taylor—my college classmate, whom I mentioned earlier—has been the George Darwin lecturer. Both Wal [Wallace] Sargent and Anneila Sargent, from the Caltech faculty, have been the George Darwin lecturer. Of course, the first thing I did when I was appointed George Darwin lecturer was to see who else has been appointed George Darwin lecturer. [Laughter] And it's a group of astronomers amongst which I am very proud to be listed.

LIPPINCOTT: Yes, that's terrific! What did it entail? Just going over to London and delivering one lecture?

WERNER: Yes. Well, they paid my way, so we made an occasion of it. We visited Cardiff, and I gave a lecture at Cardiff, where there's an infrared astronomy program. And in England, we went up to Cambridge, where we'd lived for the year when I was there after graduate school. I gave a lecture in Cambridge, which was a lot of fun. And the George Darwin Lecture itself was a lot of fun. It was followed by a typically English dinner at a club—interestingly enough, called the Athenaeum—which was one of the swanky private clubs in London. Up until recently, they had to smuggle women members of the society in through the back door; now they can go through the front door. And you know, there were the usual roasts and speeches and so forth. It was a good time.

LIPPINCOTT: Is there a lot of infrared astronomy going on in Britain?

WERNER: There is, in fact. There's a major British contribution to the James Webb Space Telescope, which I mentioned earlier. There was a European mission called the Infrared Space Observatory, ISO, which was in between IRAS and Spitzer and did a lot of very interesting science—and which also provided a strong community of infrared astronomers in Europe and in England to use Spitzer. So we got a lot of international partners scientifically. And there's an upcoming mission called Herschel [Space Observatory], which is a larger observatory than Spitzer, working at somewhat longer wavelengths, which JPL has a big part in.

LIPPINCOTT: Is Herschel a NASA mission?

WERNER: No, it's primarily an ESA [European Space Agency] mission, and it has a lot of British participation. It's being launched on an Ariane, jointly with another observatory called Planck, which is a cosmic-microwave-background instrument following up on COBE, basically. That launch should occur in February 2009, so it's coming right up.

LIPPINCOTT: That's all pretty exciting! Well, thanks very much. I've enjoyed this. [Tape ends]