Instrument Development at the Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison
1965-2015
An oral history
Moderated by Fred A. Best

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Panel:
Fred A. Best (Moderator)
Executive Director for Technology
Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison

Henry (Hank) Revercomb, PhD
Director
Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison

Evan E. Richards
Retired Engineer
Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison

Kenneth Walker
Retired engineer
Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison

Anthony Wendricks
Honorary Associate/Fellow
Space Science and Engineering Center (SSEC)
University of Wisconsin-Madison

FB: Good morning. We're gathered here this morning, September ninth 2015, at the University of Wisconsin-Madison Institute for Discovery to conduct an oral history titled An oral history of Space Science and Engineering Center instrument developments from 1965 to 2015. I'd like to introduce the panelists now.

Down at the end of the table on my left is Tony Wendricks. He's an honorary associate fellow at SSEC. Tony is one of the first hires, starting work in 1967. Over the course of forty years he's been a draftsman, a drafter, a CAD specialist, a project coordinator lending his experience to numerous programs. A very diverse portfolio.

To my immediate left is Ken Walker. Ken is retired. He was hired as an electronics technician in the early '60s at the UW Electrical Standards and Instrumentation Laboratory and worked on the development and construction of the flat plate radiometers used on the TOS and ESSA satellites. He's among the first employees of Space Science and Engineering Center.

And I'm Fred Best, executive director at Space Science and Engineering Center. I started with a hardware group in 1978 as a mechanical engineer working on the Hubble Space Telescope High Speed Photometer. And I worked on other flight projects after that including the Diffusion X-ray Spectrometer and the Net Flux Radiometer that went to Jupiter. I went on to work on the development of high spectral resolution instruments for remote sensing of the atmosphere and currently I'm involved with efforts to make highly calibrated infrared climate benchmark measurements from space using technologies we developed at Space Science.

To my right is Hank Revercomb. He's the director of SSEC. Hank was named director of Space Science and Engineering Center in 2004 after having served as an interim since 1999. He earned his PhD in 1972 from UW-Madison. He specializes in the study of planetary atmospheres and in remote sensing using high spectral resolution instruments and has led the design of spacecraft-, aircraft-, and ground-based instruments.

And then last but not least, Evan Richards, retired. I'm sorry, Evan, you are retired. [laughter in background] Retired engineer. Evan was hired in 1970 to help SSEC deal with the NASA spaceflight project requirements for the OSO soft X-ray experiment. He subsequently worked on Pioneer Venus, the Hubble Space Telescope and many other projects within the Center. So that's our panel.

And before we get started I wanted to just say that today's oral history covers the entire history of key instrument developments at SSEC. I will read the questions that are targeted toward individuals but of course anybody will chime in and the proceedings with be generally chronological. So we'll start from the beginning and move on. And then I'd also like to point out that there was another related oral history conducted in September of 2008 that honored Verner Suomi, father of satellite meteorology. This is complimentary to that oral history and there will be some overlap but the focus of this will be how we got into our hardware projects, how we conducted them, and what kind of interesting problems we ran into along the way.

So I guess with that background we're ready to start off and the first series of questions is from the early flight radiometers at Space Science, the first Earth radiation budget, the hemispherical and the flat plate active cavity radiometer. And I'll start off with you, Hank. Vern Suomi's experiment on Explorer 7 flown in 1959 was the first measurement of Earth's radiation budget or heat balance. Why was this measurement so important and can you put this experiment into historical context of follow-on projects at Space Science, including work that's going on today?

04:53

HR: Well it's somewhat of a long story but certainly it was important because it was the first measurement from space to look at the Earth. So just because of the fundamental nature of it, it was important. But more than that, at that time people really didn't understand quantitatively how the circulation and climate of the Earth worked with regard to the energy coming in from the Sun and the energy given off to space by heat from the Earth. And so this was a measurement of how that balance worked. The most important question is how reflective the clouds are. And that was something that was very difficult to model and Vern wouldn't have trusted the models if they'd been there. You have to measure these things. So that kicked off kind of a long series of Earth radiation budget measurements with, started out with spheres and then went to flat plates and this went on for over a decade. It lead to a program which Vern got us involved with for designing the next best Earth radiation budget experiment. NASA Langley was in there with an experiment called WZB [?] [La ZB?] that really took Vern's first spheres as their concept. Colorado State was there, Tom Vonder Haar with imaging concepts, and we had an experiment we called ERBOS [is this Earth Radiation Budget Observing System in the 1970s?]. And the idea of that that Vern really infused was to make small simple satellites so we could put many and get good coverage of the Earth so we would suppress sampling errors. And in the process of doing that we also emphasized high accuracy because the difference between the Sun energy coming in and the emitted energy is so small that to detect anything you really had to do it with very high accuracy. So we brought on what are called active cavity radiometers. Since then we've really recognized that even that is inadequate. And experiences that we'll talk about later with high spectral resolution, where instead of averaging over all the solar spectrum you measure the details of it and especially our role is measuring the detailed spectra of the infrared, you can get much more sensitivity and higher accuracy by doing it a different way. So we'll deal with that as the day goes on.

FB: OK, Hank, what are the key elements of Verner Suomi's vision of SSEC that made it so successful for five decades?

HR: I think he was pretty much doing what came naturally. One of the statements we often associate with him is "no amount of planning succeeds like dumb luck." But then when we look at it in retrospect I think there are a number of really key elements. One is addressing important problems, problems that are important for society and important for science. And then to do that, getting good people and letting them do their thing. And good people means talented people independent of their formal training, independent of their degrees and having people free to do what they're good at. And then I think maybe a third is team work. That we're doing it not in competition with each other but by working together.

08:43

FB: OK. Ken, you worked on the flat plate radiometers that flew on numerous satellites in the '60s and '70s. Can you describe the work team and the climate at SSEC during that time? And also highlight some of the challenges that you had to overcome to make these projects successful.

Ken: Sure, Fred. Well it was a pretty interesting time for a young guy like myself who was hired as an electronic technician. Some years before Space Science and Engineering was actually formed as a department of their own, it was under a group called the Electrical Standards and Instrumentation Laboratory headed up by Professor Robert Parent who was a colleague of Professor Suomi. And Professor Parent being the electrical engineer and did the hardware engineering and the support that Suomi needed. There was a handful of us and anyway the time I came on board the generation of the flat plate radiometer was just beginning and I've got a little sample of it here if you don't mind. And this is an example of one of four sensors that actually flew on the TOS series of spacecraft and did the measurement of the Earth's heat budget, the albedo that Hank described earlier. And anyway, kind of simple from the outside but it was an idea that really Suomi's concept of trying to do something elegant and very simple. And here's a drawing of what this little thing looks like inside. But I had the opportunity to start off and work with some really talented colleagues, learned a lot from. The radiometers was a part of it. The electronics that supported it. A little tape recorder had to be built and perfected. And other technicians were doing that. Some of whom are no longer with us. But anyway it was an exciting time. A lot to learn. The presence of Professor Suomi and Parent on a daily basis made life very interesting. Left us alone to do our thing and a lot of trust was involved, I don't know why, but anyway I guess you just felt that and all of us I think felt as a team that gee whiz we have this awesome job to do. The beginning of the space program, something that we'd seen on television. Few of us have ever touched anything or seen anything that actually become part of flight hardware. And so it was a great opportunity and then that followed on with being further involved not only constructing the radiometers but then we had to integrate the package onto the spacecraft itself. That was done at the manufacturing level of the spacecraft, RCA in Hightstown, New Jersey. And testing, calibrating, that sort of thing and even to the point of doing, participating, and observing the launch. And so, wow. This was all in the 1960s. And along came all of this great news about a possibility of this big new department forming, Space Science and Engineering. And here we started off in the humble beginning in the basement of the Electrical Engineering Building below the mechanics department in a few little rooms that you wouldn't expect to be building space hardware in but that's what we had. And then eventually moved into some rental space, then on up to this fifteen story building that being enjoyed today. So anyway it was extremely exciting time and really, really felt fortunate to be associated with some very talented fine people in that organization. A lot of work to do and no time to do it but somehow things happened.

13:12

FB: Tony, what are your memories from the work culture back in those days?

TW: Very much like Ken said. It was very enthusiastic. Very energetic. Everybody was excited about what they were doing. In fact I started in January of 1967. The first week that I was on the job I was to make some diagrams for a flat plate radiometer. And during the course of that week I was so enthused and so excited and the timeline was such that I stayed till eleven o'clock two of the first five nights I worked for Space Science. It became what I believe is in Space Science it's whatever it takes. When it's your turn, you step up and you really do whatever it takes to get the job done. Everyone there was very enthusiastic about it. Dr. Suomi was a great leader. I tell a story about how he doesn't like to be called boss. One morning when he came in the drafting room I was feeling particularly good and I said "Good morning, boss." He let go on me. He said "I'm not the boss. I'm the leader. I'm the coworker." And set me straight and it's been like that ever since. Now, engineers and associates and others, graduate students for instance may have been driven a little harder than the technicians and the draftsmen and the machinists and that kind of stuff but he always appreciated everything that was done for him. And the enthusiasm came right from the top.

14:47

FB: OK. Thanks, Tony. OK. The next series of questions have to do with the early imagers. The imaging Spin Scan Camera, the VISSR, and the beginning of McIDAS. Hank, the next phase of the instrument involvement in SSEC originated from Suomi's interest in looking at clouds from space to better understand and predict weather. What was the key idea behind the imaging spin scan cloud camera and the follow on Visible Infrared Spin Scan Radiometer? And what was SSEC's role in these projects?

HR: Now this was a total change of pace from the radiation budget measurements where you were looking at very broad features on the Earth. And here you were trying to look at details on the Earth. And especially what inspired Vern Suomi was the ability to watch clouds. If you're in geostationary orbit you're over the same point of the Earth so you're watching things in the atmosphere change. And the concept was to be able to track those clouds and then have the winds to understand the circulation. But the problem was that these spacecraft were stabilized by spinning. And so taking a picture from a spinning thing, if you tried taking a picture from your car out the side isn't always so easy. So he came up with the idea that really is very similar to the original concept of television where you map out one line at a time as you spin by the earth. And you move down and so you create an image. That's what's been known as the spin scan camera for spacecraft applications and it's still used on many spacecraft today. So a lot of the things for many years that you saw on your normal weather program on TV were from the spin scan camera that was the concept of Vern Suomi. The instrument was actually built at Santa Barbara Research but a lot of the early design concept for the instrument was done at Space Science and Engineering. And what it led to was a recognition that to be able to track these clouds and really get winds you were going to have to do it quickly so that you could get it in time to influence weather forecasting and so Vern's concept was to bring in computers. And that lead to something that maybe we'll talk about later but the Man Computer Interactive Data Access system which is a combination of software and hardware at that time which still exists today and we have a McIDAS users group and it's used all over the world and in NOAA for a lot of weather applications still. So the spin scan camera had a lot of follow on applications of getting weather and computers married as well.

17:48

FB: OK. We're going to move on to OSO-8 now. Evan, the OSO-8 soft x-ray background radiation experiment was the first in a long line of instrument developments that we did for Bill Kraushaar group over at Space Physics Department. It also represents the first time SSEC took on the role of contractor for an outside organization. Was this something originally envisioned for the Center? It certainly has strengthened us over the years.

ER: It has and that was an important role for collaborations that we had later with Astronomy and other departments. I don't know what the real background of setting that up was at the Center but I do know that Bill Kraushaar came from MIT and the reason he, or one of the reasons he got here, he was a principal investigator on an x-ray instrument on OAO-1 and another principal investigator was Art Code.

And there was a time back in the late ‘60s, mid 60s, that being interested in doing science from space wasn’t maybe the most respectable thing. It was consider a little out there, a little crazy. So if you were on a solid career path at a place like MIT maybe your primary interest would not be physics from space. Well, with Suomi here and Art Code here in Astronomy, Kraushaar found a very space-friendly environment. And with the Space Science and Engineering Center already set up and places having experience with space, they were extremely eager to take advantage of our capabilities which were pretty impressive at that time. And including this culture you talk about. It was remarkable to come here and find this sort of can-do attitude with stuff that just didn’t look like it could possibility work when you take your first look at it but somehow we made it work.

FB: Can you give us a brief overview of the instrument and describe what infrastructure was needed at SSEC to design, build, and test it.

ER: Well, when I walked in the door that was on August 24, 1970 and that was the day there was something else going on here at the university. That was the day that Sterling Hall was bombed so I showed up at SSEC’s front door literally hours after that happened. So it was a pretty exciting time. I kind of wondered what had I gotten myself into here. But I came from Collins Radio in Cedar Rapids, Iowa where I spent some time working on the Apollo Program and the idea is that I understood some of these disciplines that NASA would require for these formal programs that we hadn’t done yet, like quality assurance, configuration management, reliability, drawing control and all that sort of stuff. And fortunately when I left Collins, on very good terms, they had a project with the electrical engineering department, a troposcatter radio communication research project, and they wanted, a high priority at Collins Radio was keep that relationship with the University of Wisconsin as good as it possibly can be. So when the word kind of got around Collins that I was going to be working for the University of Wisconsin, the word also went out give this guy whatever he needs. So I kind of got that vibe and I had never been in charge of quality, reliability, configuration management and all that stuff so I went around to these various department heads and got this gold mine of documentation and quick coaching and I left Collins with a car full of just the greatest manuals for this stuff. So that was my jump start. And that was what we were trying to do. What we didn’t have at the Center before I came was a formal way to deal with those NASA requirements and we somehow managed to do it on a very tight budget, small scale, which was unique.

22:12

FB: Well, we’re going to move on to next hardware project at the Center, Pioneer Venus. And Hank, chronologically the next major hardware project was the development of the Net Flux Radiometer for the small probe that was part of the Pioneer Venus mission. Vern Suomi was the principle investigator. What was the scientific motivation for this mission and the Net Flux Radiometer in particular?

HR: The main motivation, the overview, was that it had been recently learned that the Venus atmosphere super rotates at a tremendous rate at about two hundred miles per hour even though the planet itself barely rotates at all. And so it was a big mystery how this dense atmosphere has ninety bars at its surface, ninety times the Earth’s atmospheric pressure at the surface., how that manages to spin up and rotate at a rate like that. The connection with the Net Flux Radiometer is that circulations are driven by energy and so understanding the energy balance of the planet was important. Of course you couldn’t understand the whole planet with four probes but that was the idea, that because it’s super rotated it was a pretty uniform planet and you could sample it in the north and the south and on the equator and day and night and get an idea of how it worked. And Vern had learned, actually in doing his thesis in a cornfield in Wisconsin that a net flux radiometer was a good way of sampling the radiative energy budget of the cornfield and he decided to apply that to a planet. Why not? So a big extrapolation but a very important one. And so when you measure the different between the radiation going down and the radiation going up you can measure that as a function of altitude as a probe enters a planet and how that varies with altitude tells you the radiative heating and cooling of the atmosphere. And its radiative heating and cooling that causes circulation. So it was a very general way of trying to explore what caused the super rotation on Venus.

24:40

FB: Evan, describe the overall instrument and what some of the interesting challenges were that you guys overcame.

ER: Well, the instrument was a little box with electronic controls. It was inside the probe. And a thing that was sort of like this long with a little lollipop thing. One of the challenges was we were having this thing that has motion suppose to work in basically inside a pizza oven, about a thousand degrees, right? And, what was it, sulfuric acid in the atmosphere? [voice in background agreeing] So for starters all the normal materials you'd use, like solder, no it's too hot, you can't use that. So just the whole discipline of getting things to work in that environment. Another one was this, what was it, once a second, every half second it was a one hundred and eighty degree flipping. It was a extremely clever way to null out all the errors but it was a nightmare to get that to work because how to you have lubrication that works. We found the normal kind of lubrication would pile up with this back and forth motion. You kind of create these little mountains of lubricant, unlike when you have continuous motion it distributes it. So we ended up, aha gold plating. That will do it. And the first time we tried that, they heated the bearing up to Venus temperatures, the gold dissolved in to the stainless steel. So the guys at Goddard Space Flight Center suggested oh, put a thin layer of tungsten on that steel and then the gold over that. And so getting that all arranged and getting the Barden Bearing, I think was the bearing vendor to give us a bearing kit that we could take to a plating company in Dayton, Ohio to get that plating done and then get it back to Barden for assembly and all of that with no time so a lot of quality time running back and forth on airplanes and stuff. That was fun. But I think another challenge was Suomi, he had great ideas, multiple ideas every day. So getting him to agree on a design early enough to get it made, a multilayer board, that was a challenge. I remember we had a meeting once. We had I think it was three or four competing designs. And the object of the meeting is we've got to get down to the last thing because we've got to get this multilayer board ordered. We left the meeting with twelve possible designs. [laughter in background] So that's the way it was. So that was a challenge. It eventually worked.

HR: That little sensor was like a piece of jewelry. The machining for that was done in the basement by Bob Sutton. It had sapphire ball bearings. It had a diamond window so it would see out at a wide range of radiation. Titanium I think to withstand the temperatures [voice in background: yes] And it really was like a little piece of jewelry that was very tough to put together because it was very small.

27:55

FB: Hank, I understand that there was some challenges right down to the wire with this instrument right before launch. Can you tell us about the last minute repair down at the Cape?

HR: We did a lot of testing. And we tested at ninety bars in the lab at Space Science. You had to have a big pressure vessel in the floor so that if something happened, if it came loose, it wouldn't kill everybody. But we were testing it to the last moment and we realized that the little wires running down the lollipop were likely to break before the probes got to the surface. So Larry Sromovsky was really the key guy for designing this instrument and detail and incredible testing details. And he and I spent a lot of time in the basement. But when we realized that we thought we've got to go tell Vern and try to fix it. So we went into Vern's office and we told him what was going to happen because the wires were twisted going down there they were going to break. And he picked up a phone book. This was after one of his heart surgeries. He picked up a phone book and literally ripped it halfway through. A Madison phone book. And we thought oh dear he's not happy about this one. [laughter in background] But that wasn't it. He was demonstrating the principle. He had incredible instinct of why the wires were going to break. Because the trick of ripping a phone book is you put It and crease it and you rip it page by page with each page ripping against the other pages. And he knew that because those wires were twisted that they were going to break and he said "go fix it." So it was a very quick decision, a very instinctual decision and a correct decision. So we drove a welder down to the Cape, these sensors were already on the probes. They let us take them off. Bob Herbsleb came down and repaired them. Put them back on. And it worked.

ER: We had several instances with things that came up like that. One of the challenges and you and others kind of drove some of us crazy trying to manage this thing. You'd come up with test data and there would be a decimal point and four or five zeros and a number out there and you weren't comfortable with that. [HR laughs in background] Well, I'll tell you it drove us crazy but that's why it works. The high standards.

HR: It's between science and engineering that makes this stuff work. This was very big challenge because the atmosphere as you get deep gets very hot and very black in the infrared. So the flux coming from the top and the flux coming from the bottom are almost equal. And you're trying to measure the difference. A very, very tough measurement.

30:57

FB: Well, Hank, also I'd heard a story about the final alignment before it was put back on the spacecraft and these were techniques that aren't typically used today in the spaceflight world.

HR: Well, we were at the Cape and we were doing something the procedure wasn't complete on from a quality control stand point. So when we got the sensor back together we had to make sure it was flipping one hundred eighty degrees and we weren't quite sure how to do that. Well, we ended up taking the mirror off the wall in the john in the men's bathroom, put in on the floor under the sensor and used that to align it to one hundred eighty [much laughter in background] and it was done pretty well I think.

FB: Well, Evan, we understand there was an export issue with the diamond windows. Can you tell us that little story?

ER: Yeah, there's some kind of very strict regulations about importing diamonds and paying duties. And this was a diamond window and I think we got it from some vendor in Holland. And there was going to be a huge import tariff and that was going to bust our budget of course. And we were exploring ways around that and I don't know who thought of this but there was a provision that let you out of the tariff if you were going to export that particular diamond. So yeah, we said we're exporting it. Where are you exporting it to? Venus. [laughter in background] So the form was kind of interesting, you know, what's the carrier to Venus? NASA is. Atlas rocket.

HR: Beautiful. It's kind of a funny feeling to think that those things are still sitting on the surface of Venus.

ER: They are. They are still there.

HR: because the materials would allow them to be intact.

ER: Yeah.

32:55

FB: Hank, the mission turned out to be a great success. What was the key finding?

HR: You know, it's hard to make one key finding here. The answer to the super rotation was really not found and is still outstanding. But there was a lot of distributed information about the nature of the clouds, the cloud particle size which influences radiative exchange, the composition of the atmosphere, the stability of the atmosphere through temperature measurements as a function of altitude. And one thing that we thought might be very important was that there appears to be a water vapor distribution in the deep atmosphere as a function of latitude. And we showed that that could in principle help enhance the circulative drive from the Sun. So in some sense the jury's still out but we learned a lot.

33:54

FB: And we learned a lot in the process of building an instrument. It really helped the Center move on. Which the next project is our involvement with the Hubble Space Telescope. Now Evan, a lot of people are surprised to learn that we developed one of the original instruments for Hubble, called the High Speed Photometer, with Bob Bless from Astronomy as principle investigator. Can you tell us the story about how we got involved with Astronomy for this project?

ER: They had been talking about doing a big telescope in space for a long time. And when it got in to the '70s it got rather serious. We helped the Astronomy Department put together a proposal, it was in 1977, for a very simple photometer. What they had proposed was what they referred to as a thermos bottle in a shoe box. One detector. And the idea was to put it in one of the other large instruments. Well, they sent the proposal in. NASA had some budget issues. They thought they wanted the photometer. They couldn't afford four full instruments but they said ah, we'll make this simple one a full instrument. So when we were selected they said oh the good news is you're selected; the bad news is you're not building a shoebox and a thermos bottle, you're building a phone booth. A six hundred pound

HR: requirements creep.

ER: Yeah. And they said there are a bunch of other astronomers from other places that proposed variations on photometric observations so they sort of had a forced shotgun marriage to form a team. Which was great. They contributed a lot to the effort. But the reason people are surprised is the instrument, the output was a light curve, a graph. And other guys were coming out with these beautiful, stunning pictures. Well we didn't have beautiful, stunning pictures so people kind of lost track of it. And unfortunately with the spherical aberration problem with the telescope that really effected the High Speed Photometer more than the other instruments because they didn't reimage the focal plane. So the High Speed Photometer was the first instrument removed to make room for an instrument that had the corrective optics for the other instruments. But, in spite of that, they got some great data.

36:40

FB: Can you give us a brief description of the instrument and tell us what are the biggest challenges we ran into on really a high profile mission for anybody.

ER: It was a long deal. We started in 1977 and with the Challenger problems and budget problems and all kinds of things, it didn't get launched until 1990. And the post flight analysis and data and everything, it was almost a twenty year start to finish. So that was a challenge, just keeping things together. But it was a great ride because we participated in I think what can reasonable, fairly be called one of the great scientific ventures of all time. And it had been one of the most productive. And it was really fun to see how that all went together. Because we were a full instrument we were a participant in the interface meetings and the various meetings to decide what to do. And to see how that all worked, a huge project like that, that was just fascinating. And challenging.

TW: Yeah, but as I recall we were even asked to make the replacement, the dummy replacement

ER: Right

TW: because of the delivery we had done with

ER: Yes.

TW: the High Speed Photometer.

ER: Because we could do things really better than the standard aerospace contractor, I would say.

TW: Better, cheaper, faster.

ER: and cheaper. And we're very nimble. We were asked to put together a set of mechanical ground support equipment for another instrument maker. We made a thing called STAR which was the Space Telescope Axial Replacement. And the idea was if one of the instruments failed and they didn't have a replacement, they needed to have something in the space so we had to build something that would dissipate the right amount of heat and meet the interface. And we did that. And so we were asked to do more things as we went along. It was kind of fun to be able to step up.

TW: And again, built in the basement of Space Science.

ER: Exactly. That's unique. We did build that hardware here.

39:07

FB: Well, I'm going to tell you a little bit about it. This is my first job out of school. One of Vern Suomi's friends over in engineering said that they were looking for a mechanical engineer in space science and so that afternoon I walked over and talked to Suomi and he brought me down to see you guys and Evan was the program manager. So that how it all got started. You know, it was a very small core group in the beginning. There really wasn't a full production mode at Space Science but we really ramped up to meet the needs of building a very sophisticated instrument. I would say during that time it was an incredibly cohesive talented group of people. And once again that can-do attitude is, you know, you can't think of anything else. You realize you're working on Hubble so you're giving it double extra careful attention. I know that we'll always remember the stories and the people behind that instrument. So Evan, I was going to say we made more contributions to the Hubble than just delivering this instrument. We were part of a interface working group that developed the interface between all the instruments in the telescope. And I think that kind of stands out in my mind as somewhere we really made some major contributions with you and Jerry Sitzman in particular.

ER: We did. We had a kind of unique position being from the University of Wisconsin where this culture that Suomi and people in Astronomy and Physics had that it just had to work. We were going to make it work. It was going to be better than required. And we weren't interested in the quarterly financial statement for the stockholders and that gave us a whole different freedom and we could be candid with the NASA guys. And we often were the conduit of bad news. We could hear things from some of the other partners that they were reluctant to pass on. Well, we didn't care. We could be the messenger for that. So there was a little bit of that and it was very interesting, the dynamics about that. I remember in particular I started, the schedule was kind of a standing joke. And they had these quarterly meetings down at Marshall Space Flight Center in the officer's club. And people got a little bit liquored up at those things. And there was always the official schedule and then there was the schedule that we kind of knew what was going on. And I started taking an informal poll. I wait till people had a couple drinks. And so I'd go to all these contractors and they wouldn't say this officially. What's your best guess? I'd go around and so I'd say alright it seems like the reasonable average is we're now eight months behind schedule. When the NASA guys heard that. One time a guy got really upset. Came over, got right in my face at this meeting. People were standing around. "You're wrong. I heard you say it was eight months." I said well let's put some money on it. Let's make it interesting. [laughs] He wouldn't do it.

42:42

HR: You know, the willingness to tell it like it is happened on Pioneer Venus, too, apparently. This is a story from Bob Dombrowsky that maybe you guys lived. But apparently there was a time where all the engineering group and the science group decide that what we were trying to do couldn't be done in the time available and the budget available. And there was a showdown with Vern to tell him this bad news. He apparently sat down and wrote out two pieces of yellow paper. One is We found that we can't do this and in the interest of saving the taxpayer's money we're going to give it back, what we have left. And then the other one was We've run into a few difficulties; we think if we're given a little extra resources and time we can solve them. And he left the room and asked the engineers which one to turn in.

ER: [laughs] That's true.

HR: So you did experience that. And then of course the second one was chosen. But it was forthright with telling NASA where the situation was and they really needed some more time and money. And it worked.

ER: The technique there, he got everybody in buy in.

HR: Yeah.

ER: so it wasn't him telling us what to do. And I think that was a big part of why it worked cause we all felt like we were in it.

44:12

FB: Evan, I want to go back to one thing you said about building it better than it had to be. This is back on Hubble now, when we built that instrument which was the size of a phone booth, we had an incredible craftsman in the basement, Bob Sutton, and we had an incredible mechanical designer, Nick Ciganovich. And they, when we were all said and done and we delivered, all of the instruments were delivered. There was a big fixture at NASA called the quarter panel that simulated plugging into the telescope. And we had a little alignment mirror that everyone was supposed to position where they thought the focal point was on their instrument. And we came closer than any other instrument. And you know there were multi-billion dollar companies building these things, including European Space Agency.

ER: We got this a lot. When we'd deliver something there would be this big inspection with the NASA people there and the company and all that. And more than once they would maybe take a panel off, look at the wire harness and whatever. And the word we'd get back was this is better stuff than we get from anybody else. I made sure that word got around because that's what we did.

FB: Yeah, and that was a tribute to our technicians, Gene Buchholtz and Bob Herbsleb. The harder the problem, the harder they worked.

ER: You know, those guys got certified early in the process to train other people to do the work with those standards. And their standards I'd have to say were higher than NASA's standards. So our stuff was always better.

FB: It paid off because we have a very nice record of reliability.

KW: You had mentioned the name Bob Sutton and wonderful work. This flat plate radiometer machine work, Bob did that back in the early 1960s. And take a look at that. It's perfect. It's absolutely perfect. That's not machining, that's done by an instrument maker. And truly it's an instrument. And a lot of things didn't have to be that precise but they really were.

46:25

FB: Well, the one thing that we often remark is it would always come back from the shop better than it was asked to be made. And more than half the time it would pay dividends. Because it was better than it was asked to be it bailed you out of a problem later on that you didn't see coming. Evan, tell us the story behind how the HSP's demise and where is it now.

ER: Right now it's down at Space Place on South Park Street and you can go see it. It came back from Goddard Space Flight Center some years ago and there was a bit of a celebration. I unfortunately missed that but it's there. It was removed in the first servicing mission. I believe that was 1993. It worked perfectly, no problem. But since it was the most affected, the minimum impact on science, remove anything to put these corrective optics was ours, so ours got removed. And that's why. The program politically was in a lot of trouble. There was a lot of press, cartoons about the waste of money and you know, the Hubble was blind and on and on and on. And Congress was getting pretty fed up with it. It was really important for NASA to get up there with better imaging and to fix this. And they did. They had a wonderful news conference when they released the first pictures with the new wide field camera and the better resolution. They went from goats to heroes.

48:12

FB: Well, I think that was an incredible technical achievement and that fact that they did it so quickly. But one of the features of Hubble that really impacted how we built our instrument was this concept of orbital replaceable units and that's why the telescope launched in the early '90s and it's still going on today. Multiple instruments have been pulled out and put back in with, just think of an instrument being transported to the telescope, pull out one and plug in another one and get perfect optical alignment.

ER: Yeah, the astronomers that worked on the concept for the telescope realized that all the great telescope around the world had been around for a long time. They keep current and useful because you use different instrumentation. And instrumentation is a rapidly developing field. The first wide light field camera was developed in the mid '70s, CCDs. Can you imagine what a digital camera in 1975 is like compared to the present day. The wide field camera on there now is the third one and that was installed in 2009. And what they're doing with that and the instruments is just amazing. They've got pictures of objects that are, well the age of the universe they figured out with Hubble. One of the fruits of that thing was to nail it as thirteen point seven billion years. They can look at objects that are thirteen point three billion light years away. So we're within about four hundred million years from the beginning of time. It's mind boggling what they're doing with it.

50:01

FB: Well, we're going to move on to the Diffuse X-ray Spectrometer which is our next big space flight mission, again operating the in the contractor mode. This was for Space Physics again, so Bill Kraushaar, Dan McCammon and Wilt Sanders group. We were asked to, they had developed some x-ray detectors to look at very low energy x-rays and they wanted to put together a Shuttle instrument and fly for ten days on the Shuttle. And we won that proposal to do that. It used detectors that had been developed by Dan McCammon and had flown on sounding rockets. But, and I think in the early days of the Shuttle the mentality was well you can just fly old rocket hardware and if things don't work we'll relaunch you, because the thinking back then was that the cost per launch was trivial and we'll just keep banging off Shuttle launches but it really didn't turn out that way. So can you tell us a little bit about what the challenges were in taking like this non-flight rated hardware and getting it ready to go on the Space Shuttle.

ER: Well somehow the NASA people had to get to the point where they said it was kosher when there wasn't any pedigree because the deal was to use this existing hardware. It had flown. It worked. It had been in vacuum chambers a lot. But they didn't have the paperwork, the kind of things that you normally have for space flight hardware. So there was a lot of discussion about that. And always kind of having to go back to well that was the deal originally, yes but you can't fly anything on the Shuttle that doesn't have you know on and on. And so it was just kind of back and forth and test it and try to figure out what these materials were and get people comfortable with it. It was not a problem. It didn't fall apart. Astronaut safety was a big issue. It was certainly strong enough.

FB: Yeah, that really drove a lot of the design, too, the man-rated aspects of the instrument. Including the, there was a pressurized tank for the gas that the proportional counter s needed and the gas that was in there was argon with a little methane but once you used the word methane with the Space Shuttle then everybody's ears kind of pick up. So we really had to do the tank right.

ER: We had to point out to them that the astronauts themselves, if you do the biological analysis and go to those papers, produce more methane, if you know what I'm saying, than the instrument. And another issue was the way those detectors moved. At one part of the rotation it would have interfered with closing the doors and that's a biggie. And so you must not have a failure mode that will leave you unable to close the doors.

53:20

FB: Well, there was a mechanical crank. So if we did lose power there was that tool the astronauts could go out and wheel it in. Ken, you had left the Center for a while but then we were running into some trouble. It was a really sophisticated harnessing job for this instrument and everybody goes we got to get Ken Walker on this. And so we called you up. Tell us a little bit about that.

KW: Well, it's pretty humbling again. Once again you guys must have been desperate to give Ken Walker a call but anyway it was just the right timing to come back for a bit and another great honor. Here I'd been away for a few years. Come back. Fred and Evan. Tony was still there. Had all the same excitement. The same synergy that I remember back in the early '60s in that little room below the Engineering Department. When you had this team of guys you had some super talented people. There was Howard Hagens [spelling?]. Dave Nelson was the engineer, extremely enthusiastic. Howard and Stan Sitz [spelling?] anyway built the little tape recorders and electronics that did this thing. And parts being made by Bob Sutton that we mentioned earlier. And now here it is years later and same atmosphere, some enthusiasm, and new generation. Things are much more sophisticated now. A lot more is known. But it was really neat to come back and get your hands on something that was going to be part of flight hardware, especially for the Shuttle program. That was the big program at the time. It was really fun to be part of it and I hope everything worked out.

55:25

FB: Well, it certainly did. It was a very successful instrument. One of the things that was kind of interesting about that instrument, as I was mentioning, we had to carry a supply of this gas because the detectors, the x-ray proportional counter had this gas in it but even a quarter inch of air would absorb the low energy x-rays we were trying to measure so this detector had to have a very thin window. So basically this gas was diffusing through that quite rapidly and so we had to carry a supply that would keep refurbishing that. So that meant that when we were integrated into the Shuttle and even when we were vertical and down on the pad right before launch we had to go and top off the tanks every three days. And it was really quite interesting to be part of that. It took six check points to go from outside Kennedy Space Center to get on top of the pad. Once you were there there was a big clean room. Basically it was a seven story clean room that was wheeled right up to the open bay Shuttle and then we'd take an elevator up and top off your tanks. A lot of interesting stories about the protocols involved, the safety and the paperwork but it was very interesting. I found the can-do attitude of the Cape people was just, I'd never seen anything like that. I think every NASA center has its own personality but when some hardware comes down to the Cape, they can't pass it on to anyone else. They'd got to get it launched. And that permeates the whole mentality of the place so it's very refreshing to working down there.

ER: And there's an urgency because when you're down there you're down to the last things before launch. It's a whole different deal.

TW: So Fred, during that project, toward the end of that project they needed a mission patch. And that was one of the most interesting things that I got involved in. It was a whole different attitude about just getting that patch approved through the NASA chain of command. It took six months [laugher in background] and several iterations but it was a treat to have been involved in that to make a patch that everybody that worked on the program got to have a copy of. And it's the kind of stuff that the astronauts wear on their uniforms. So that was part of being in the space program.

58:00

FB: Well, it's an interesting, we had the astronauts come and visit the hardware in our clean room because it was mounted to the sill of the orbiter. They were going to be out doing space walks actually as a practice for the Hubble repair so they wanted to make sure if there were any hazards or anything like that. One of the things we had on our instrument was a little arm that stood up for the sun sensor, to close the detector if something happened. Anyway when we got those back they came back after the mission and they went into the clean room again and they pointed out that they had scratched some of the white paint off of there with their tether and he said well I owe you a case of beer on that one. [laughter in background]

HR: It was not a small instrument, size of a washer dryer combination or something like that?

FB: Yeah. And that's also at Space Place right now. So if you're interested in flight hardware that's a good place to stop off. You got any other DXS interesting tidbits, Evan?

ER: Well, I just happened to think, you mentioned these two things down at Space Place. If people are interested in this history that is a good place to go and I would recommend Jim Lattis who is still the director at Space Place. He's a history of science guy and an astronomer. He wrote just an incredibly good article in the 2009-2010 Wisconsin Blue Book. Suomi's in there, Kraushaar's in there, how they got together. Lots of stuff. Sort of all the space kind of science that's done at UW. It's excellent. I know the Center had some input to that because they're given credit. Our activities are mentioned. It's really interesting to see how this stuff goes together and how there was sort of a critical mass of space activity here early in part because it was a little bit disrespectable. It wasn't quite, if you were on a career path to be a really serious physicist or an astronomer someplace maybe the best choice wouldn't be running around saying well we could do this from space. That was considered a little crazy, but we had enough of these crazy people, Suomi was one of them, Code was another, Kraushaar was another one. And they attracted other people who just assumed it could be done and by golly we did it. We're punching way above our weight here at Wisconsin on that stuff.

KW: That's a culture and the culture is still here. Back in the beginnings the word "can't" didn't exist. I don't ever remember hearing that word from day one.

01:01:07

FB: The next project we're going to talk about is the Galileo Net Flux Radiometer. This is an instrument that SSEC inherited but we took it on and successfully got it integrated into the telescope for the Galileo mission to Jupiter. Hank, can you tell us the circumstances behind how we ended up inheriting this instrument.

HR: The unfortunate story behind this one is the original principle investigator, Bob Boese from NASA Ames passed away. We had competed to do this job originally for flying a net flux radiometer on Jupiter as a carry on to what we'd done on Venus. Larry Sromovsky would have been the principle investigator on that. So when Bob Boese passed away they came to Larry and asked him if he would take over the principle investigatorship for the mission. The instrument had already been put together at Martin Marietta and in fact it was known that there were various issues with the instrument that needed to be worked on. At the same time the Challenger disaster occurred and it all meant that the Jupiter mission was going to be delayed. So as a result of that Larry knew that he had time to do some of these improvements that he wanted to do. Martin Marietta was very cooperative in planning to do that, so we took it on. A lot of the instrument, there were instrument changes made and then the calibration of the instrument in both the solar and the infrared were redone but all at Space Science. So the whole laboratory for doing that calibration and testing had to be put together.

01:03:04

FB: And the idea behind this instrument is to make similar measurements at Jupiter to what was done at Venus?

HR: Right. And the instruments we built for Venus were simpler in the sense that they looked at the whole infrared spectrum, actually looked at the whole spectrum at once and so you could separate solar and infrared by flying a day probe and a night probe. These instruments had spectral resolution and so they were more similar to what was flown on the large probe in Pioneer Venus that actually Bob Boese was the principle investigator for. So what was really different was that the spectral windows had to be chosen for the characteristics of the Jupiter atmosphere but in principle it was a very similar instrument.

01:03:58

FB: I was program manager and mechanical engineer on that effort. Just to go into a little more detail on the scope of the works. So there were some problems that were identified. I think Larry Sromovsky made his agreeing to be principle investigator that they would be willing to fix some of these problems. One of them was that the instrument that was, Galileo was integrated into a different Shuttle on the pad, ready to take off after Challenger so it was going to go to Jupiter in the state that we inherited it and there were problems. One of the big ones were the detectors themselves, lithium tantalite detectors were breaking, cracking and so that was not a good thing. And then there was some dynamic problems between the assembly rotating up and down that had to be taken care of. As Hank mentioned the characterization and calibration of the whole instrument was completely done over. We built a lab from scratch to duplicate simulating going into the Jupiter atmosphere. Really did a nice job of that. And the detectors presented a challenge because the company that had built those detectors was no longer in operation and we ended up putting together a team of the people that kind of scattered to other organizations, some of them on a moonlighting basis. Some came from Connecticut, New York and New Jersey so it was really a crazy thing but it actually worked out. And we figured out why they were breaking and we figured out how to manufacture them so they wouldn't break.

HR: You actually lived out there for a while didn't you?

FB: Yeah.

HR: at the detector vendor's

FB: Yeah. Spent a lot of time out there. I guess one of the interesting stories is that the reason they were breaking was because they were diamond saw cut. These are one by two millimeter one thousandth of an inch thick detectors and they were very brittle material so any little imperfection on the side would initiate a crack. And what we did is we figured out a way to ion mill the sides and so it was perfectly smooth. You could look at the original detectors and they'd break. You could take the ones that we ion milled and you could bend them into significant curvature and they wouldn't break. They were that strong. However, when we integrated them into the instrument and ran our test, our descent simulation test where the temperature changed very rapidly, the way these detectors work is they, the temperature change over time is detected and there's a signal proportional with that. Well, we saw all kinds of spikes in the data as we went through this descent simulation and as it turned out that charge that was being produced on the detector as a result of the temperature change wasn't able to bleed off because there weren't imperfections in the side anymore. And so it was building up to a high value and then it would arch off and ruin the data so we had to at the last minute, we thought we were going to do the final testing and deliver the instrument, we had to figure out a way to solve that problem which we did. Part of it involved rebuilding the detector, disintegrating and flying a gas that would aid in the bleed-off. And then having to prove that gas was going to remain sealed for the six year ride to Jupiter. So that was kind of a interesting challenge. And so I guess, I don't know, Hank what were the other interesting challenges you remember from that?

HR: I don't know if I can add very much to the testing challenges. It was very detailed testing that was required because it had to cover not only the solar spectrum, but the infrared spectrum so they are very different ways of performing calibration and all of that had to be put together in the lab at Space Science.

01:08:48

FB: You know the overriding challenge was the schedule because we really were at the mercy of a launch window. We were using the Earth and Venus for sling shotting out to Jupiter and we had to catch a certain launch window so there really wasn't any room for failure. That went right down to the wire.

HR: I really should mention Pat Fry in there.

FB: Pat Fry. Yes

HR: All of the enormous numbers of tests and the late night testing.

01:09:19

FB: Yeah, and Jeff Lyon [spelling?] and Don Thielman. That was a very small, tightly knit group. Larry just did an incredible job of orchestrating, getting this thing done. And then when we finished, this is how tight it was, we got to the airport. Our flight was a little bit delayed. We went to St. Louis and were catching our final ride out. We were going to go integrated this at Jet Propulsion Lab in California and we had to run. We saw that the gate was closed and we ran down the ramp and banged on the door. You could do that back then. And they let us on. Actually when we arrived at JPL we had our pre-ship review, with the instrument on the table. So there was a three hour review where we went through all our findings and then they said you pass. We walked into the cleanroom and screwed it onto the probe. So that's how down to the wire that exercise was. Hank, can you tell us about, well, after a six year journey we got back the data. What did it tell us?

01:10:34

HR: It was a very exciting time. Of course, Larry Sromovsky was a very hands-on principle investigator, not only in understanding the details of the instrument and assuring that the testing was very rigorous and complete but also in analyzing the data and developing models of the Venus atmosphere to allow you to do that. It's a complex analysis because for understanding net flux measurements you have to understand the composition of the atmosphere. You have to understand the nature of the clouds, the detailed spectral character of all of that. So a very complex set of analyses. And by the way the Venus atmosphere is so dense and hot that of course ultimately and there's almost no solid surface. Ultimately these instruments entered the atmosphere and were vaporized. So they're not sitting on the surface; they're molecules again. But a lot was learned and I'm just going to read a little bit here and Larry might record a little more detail but we learned about unexpected solar absorption below three bars. So as you enter the atmosphere there are hazes but you're already at three Earth's atmospheres. We discovered that there was an absorber there that was unknown at that time. It contradicted the idea that was prevalent in the science community at that time that there were water clouds at five bars, so five Earth's atmospheres. Found that the water vapor was much lower than solar amounts, six percent of solar at ten bars. So rather than reflecting the solar composition of materials it was quite deviant from that. And then also constrained the particle sizes that have a big impact on the radiation we see at Earth from the planet. So that's a cross section of some of the things that were learned.

01:12:39

FB: OK, well I think we'll move on to our next topic which is the Magnetic Refrigerator Salt Pill. Dan McCammon over in Space Physics was working on an x-ray detector for after OE and after E-2 [spelling?] project with the Japanese x-ray astronomy department and part of this instrument design he needed to remove the unwanted background signal which required getting the detector very cold so the detector had to run at below, I think it ran at something like sixty three millikelvin above absolute zero. So the whole assembly is bathed in liquid helium and then there's a magnetic refrigerator inside of that that got it from 4 point 2 Kelvin down to the level that they were looking at. And he came to us just based on previous working with us, knew that we could build one of the key ingredients which was called a salt pill which was about the size of a tall-boy. Tony was very much involved with figuring out how to put that together and it was a lot of very creative things that were involved. Can you do into that a little bit, Tony?

TW: Yes, there was and I might add one thing, Fred. Dan McCammon was on a group that was trying to design this salt pill but the Goddard Space Flight Center cryogenics people had been trying to do it for a long time, approaching ten years. They were trying to seal it up. It had to be hermetically sealed because the crystal that was grown in there was a ferric crystal, a magnetic crystal that could not get any outside air so it had to be hermetically sealed. They had been trying to do it with epoxies and glues and friction fits and that kind of stuff but it never worked out for them. Dan McCammon at one of those meetings came up with an idea of an intricate set of welds and braising and silver soldering and gold plating and all these kinds of things. And that's when he brought it to us. We were on a very short time line. We were not scheduled to be the instrument on the flight but NASA had decided that it wasn't such a good track record and they needed a back-up. So we were scheduled to be the back-up. But we put this together in six months time. It was a short time line. But I recall the first meeting that we had. So if you take a tall-boy or something about this size and you have to have two disks that house one thousand six hundred gold wires and they weren't to touch each other because they'd create eddy currents. Well, as I sat there and hearing in that first meeting that's what had to be done I kept thinking boy, that's impossible. That's impossible. How are you possibly going to do that? Well, then I came to the conclusion that I was not going to be the one to say it can't be done. We went away from that meeting trying to find all sorts of ways to do it and finally someone came up with a perforated stainless steel disk. And then Dave Jones, who was a technician on it, painstakingly strung those wires. They had to go through eight different locations and he did it all. Not only once, but when you have a piece of spaceflight hardware you have to have a back-up. He did two. So to grow it you had to take a solution of ferric ammonia alum and melt it into a solution and put it into this, for a better word, can. There was only two fill ports. Had to let it grow the crystal. The crystal would grow at a couple millimeters at a time. Then you'd have to drain it off and rinse it so that you'd get a good clean surface and then put in new solution. We spent a lot of time doing that. We had to do it twenty four hours a day just to build it up in the timeframe that we needed. So Dave and I also did that. But in order to develop this it was very difficult to get the solution in and out. So here's a little bit, we needed some sort of a fill tube. Looked all over. Seemed like a straw should work but McDonald's straws were too big and other straws were too small and the like. Well, Dave was at one of his local watering holes and he noticed the drink straw; it was the perfect size. It fit on the end of a syringe. It was the right length. We were able to fill in and withdraw the solution out with that. But anyhow that went on and there was a lot of other processes in it. I got to carry that piece to platers in Chicago for several steps along the way where gold had to be on it. The solution would attack any other thing, any other material other than stainless steel or gold so we used stainless steel and gold. The wires were gold. There was a cooper base mount that had to gold plated and all the silver braising had to be gold plated and everything. It was very intricate and it was more art than it was a cookbook recipe that you could just lay down and do. Well, we had such success with that that they had a couple of airplane-based experiments that required a similar piece only this one was a breeze; it only had eight hundred wires in it because they could allow it to cool down without putting it into the liquid helium right away. So, that was quite an exciting project.

01:18:55

FB: Thank you, Tony. We're going to move on to the VIISR Atmospheric Sounder which kind of picks up a theme that we started with our earlier. Hank, how creating VIISR with sounding capability was a giant leap, what is the idea behind atmospheric sounding, and what was SSEC's role in this project? And how did this set the stage for some of the future work that we're even doing today?

HR: Well, atmospheric sounding in our field is used as a term for measuring the temperature, water vapor, and other properties of the atmosphere as a function of altitude. And the principle for doing that was already know before this, where you use characteristics of the spectrum of absorption of gases in the atmosphere especially CO2 in order to be able to lay things out in the vertical. What wasn't known at that time was whether it was practical to do such a detailed measurement from a geostationary altitude where you're forty-five time further away from the Earth than you are from a polar altitude so the energy content of emissions from the Earth, the heat radiated from the Earth, is forty-five squared times smaller. And that was Vern's instinct and his genius to recognize that this could be done and to pursue doing it. Our role was really the conceptual design of the instrument and it started very early with Bob Krauss but Larry Sromovsky in the end did an extremely detailed design that was then built at Santa Barbara Research Corporation on the West Coast. But he kept hands-on with that for the whole time it was being built. In fact he hired myself to work on that project. That's how I came to Space Science and the year after that we hired Paul Menzel who's been a mainstay in the science of the Center and of NOAA ever since. So it was a project that Larry really focused on and made happen for Vern. That's an example of how he found good people and gave them the opportunity take things forward. Now this has become a major mainstay of what we're doing. The VAS launched in 1980. Even before that we realized it was going to be a big job to process the data from this instrument. NASA wanted us to do it because we had McIDAS. We had already developed the computer system to bring satellite data in from Vern's earlier work with cloud tracking. And Larry was actually quite skittish about doing it because he was smart about how big a job it was. But then Vern got Bill Smith, who had gotten his degree here at Wisconsin and ran a group at NOAA and was doing sounding from polar instruments, to come back to Wisconsin. It was Bill's group, half a dozen people from NOAA that were very talented in sounding that came back to process VAS, that ended up leading to the Cooperative Institute with NOAA being founded at the Center in 1980. And that also lead us to recognize that we could do this sounding a lot better if we could use high spectral resolution instead of these filter measurements. That was Bill's concept and Larry and I looked at the types of instruments that could do this and it got us into this whole Mickelson Interferometer Fourier Transform Spectrometer arena of activity.

01:23:01

FB: So that bring us to the HIS and the Scanning HIS. So the High-resolution Interferometer Sounder, the project was led by Bill Smith and you as a proof of concept instrument that flew on NASA's U2 and ER2 research aircraft. What advantages are provided by an interferometer versus the traditional filter wheel and what products come from the instrument?

HR: The main advantage for temperature and water vapor sounding in the atmosphere was you got much higher vertical resolution. Almost of factor of three more levels that you could understand the information content of the temperature structure and water vapor structure of the atmosphere. But the more we worked with it the more we realized there was also a tremendous advantage in the accuracy. Just the fact that you were accurately measuring the spectral dimension, not just the radiance dimension, not just the power dimension but the wavelength dimension meant that you weren't making errors because you didn't know what the wavelength really was. And that led us to realize we could do measurements that instead of accurate to a degree or two in temperature they could be accurate to ten times better than that, a tenth or two tenths of a degree. And that's led to a lot of the new things that we're doing at the Center even now. And the measurements are a wide range of things in addition to temperature and water vapor. Trace gases, so methane, nitrous oxide, ozone. And also surface and cloud properties that are very important for understanding the way the planet works in a climate sense.

01:24:51

FB: This was a new technology for Space Science and it did present some challenges and a big learning curve because Mickelson Interferometers which do the spectral splitting are inherently susceptible to vibration and of course we were going to be flying on a high altitude aircraft where there's a _______________ vibration from a jet engine. We had to get pretty sophisticated about how we handled that. We also were flying arsenic doped silicone detectors that had to be cooled to liquid helium temperatures as we had a liquid helium dewar that required a lot of, well there's a lot of engineering discipline that goes in to how you mount the optics inside of something that gets that cold to make sure that you maintain alignment and you don't crack the glass elements. So those were two of the big challenges. And then dealing with the high altitude aircraft fly at about a twentieth of an atmosphere and the temperature is minus fifty five up there so you would think that you would be heating things but in reality one of the biggest problems is getting rid of the heat from the electronics because there's not much air convection that can carry the heat away so all those things make it challenging. And in fact what we've learned was that flying on a aircraft was a lot more challenging than flying in space

HR: It sure was.

FB: in many aspects.

HR: One thing I should mention in that regard was one of the solutions to that problem of dealing with vibrations came out of a company in Quebec that was started by Henry Buijs and he had a concept for an auto-aligning interferometer. If you've ever worked with an interferometer in a physics lab or anything you're dealing with distances that are wavelengths of light, so if you breathe on it or have any kind of fan or vibrations it's not going to be happy. And this concept made it possible to make measurement when you're basically bolted to a jet engine.

01:27:02

FB: And this instrument was developed in the mid to late '90s and it's still flying. Last year it was flying in a series of hurricane missions going out of Wallops Field on a Global Hawk drone to over the north coast of Alaska on thirty six hour flights to look at developing hurricanes and ones that had already set up into the full hurricane force to study how they're formed and what their trajectories end up being. It's also recognized as a very sophisticated radiance standard. We under fly a lot of NASA satellites to verify their calibration. NASA funds us to do that. So it's still flying and I think that all goes back to the engineering and construction. I don't think there's anybody who could have even figured out how to get all the electronics into the box that we got it except for Bob Herbsleb. We've had very little problems over the years. It's just remarkable how robust that instrument is.

HR: Let me just say one thing about that early HIS. It demonstrated for the first time this principle that you could get three times the vertical resolution by increasing the spectral resolution. And that's now the basis for measurements that are made on the NASA E-O-S, Earth Observing System platforms starting in 2002 with AIRS and now on Suomi NPP with an instrument that's called CrIS. And we hope ultimately again on geostationary orbit but that one hasn't happened yet.

01:28:57

FB: So the HIS and Scanning-HIS kind of set the stage for what I would say four fertile veins of research and instrument development at SSEC. Hank, can you give us an overview of these? Two of them the AERI and the CLARREO ARI [?] will be talked about in more detail later.

HR: I'm not sure I know the four you're counting but I'll tell you four. Then you can add them if you have a different set. The first area is improving temperature soundings from space on both polar satellites and geostationary satellites. And we're actively involved with doing that with Suomi NPP and preparing for the future. Another is atmospheric research from field programs with aircraft where just the temperature measurements, the water vapor measurements, what we've learned about surface properties, surface emissivity, all are a massive science endeavor that we have been conducting at the Center for some time. It's really a valuable exercise for young scientists and students as well. We all learn something every time we go into the field definitely. And then we turned the instrument upside down, this was Bill Smith's idea, and learned that we could sound the boundary layer of the Earth which is the most actively changing part of the atmosphere very well and make contiguous measurements, semi continuous measurements very frequent in time of what's happening in the boundary layer. That's the area that we'll talk about later. And finally this understanding that we could make much more accurate measurements led us to realize that we could do this earth radiation budget, or really climate benchmarking, much better than has been done up to now. And that led to the CLARREO program which is Climate Absolute Radiance and Refractivity Observatory that we've been very active with since about 2004.

01:31:07

FB: OK. So the instrument that was generated from this tipping the aircraft instrument upside down was called the Atmospheric Emitted Radiance Interferometer. Right about the time that we did that experiment on the roof to show that that was a useful thing to do, the Department of Energy came out with an announcement looking for an instrument that would do that. So we built an instrument based on off-the-shelf interferometer. Again that was the Bomen interferometer. We ended up building on the order of a dozen of those for that program starting in the early '90s. And then we built a derivative of it called the Marine AERI to measure sea surface temperature very accurately for the University of Miami. So that really was, I think when we got into a big thing that we paid a lot of attention to there was our calibration black bodies, our radiance standards. We started learning a lot about that. The AERI instrument is really, we've done a lot of intercomparison work with the National Institute for Standards and Technology and it's recognized as a very accurate instrument by them. In fact they bought one of them.

HR: A key property of the AERI was it also had to be robust and run all the time. So it wasn't something where you take it out in the field and run it and say you succeeded; you had to run twenty four hours a day every day of the year in order to take the kind of measurements you wanted for climate. And that was a major challenge of AERI.

FB: We put a lot of our experience in spacecraft development into the instrument. Mostly with regards to what's called housekeeping data. So we monitored virtually every important parameter and it was all sent over the Internet. Then if a certain parameter went out of line we would have a notification right away and we could address it. So we always knew when the instrument properly.

HR: They've run all over the world so they really are like having a satellite in orbit. We get the data back at Space Science and make sure it's working right.

01:33:28

FB: Well, I'm going to move on CLARREO. This is a program that we're, we started in I think 2008 and we're still working on. Give us an overview of that program, Hank, and how we got into it.

HR: CLARREO really started as a continuation of many things we've been doing but as a notion from Jim Anderson at Harvard and we started working with him on promoting this notion in about 2004. There was a new way of doing business in earth science starting in 2007 which was called the Decadal Survey where the science community would get together and recommend missions that should be flown as a consensus. Jim was really the active player in making sure this got into the Decadal Survey. After it got into the Decadal Survey, and this is to benchmark the climate, it's if you like like putting a stake at the end of a glacier so you can come back years later and find out that it moved back. We do much more sophisticated things than driving in a stake but on the Earth we really needed a better stake to say what's the Earth's climate now so that when we measure it ten years from now we know quantitatively how it's changed. That's the concept of CLARREO. And that we do it in a way that we prove it. While we're making the measurements we don't just say we have this accuracy, we've proven on orbit. So it got built into the Decadal Survey and the way NASA handled those was to hand those off to a NASA center to lead. And so we became part of that activity at the NASA center and independently we won an instrument incubator program which is what NASA calls these programs to develop new technologies. So we built four new technologies for CLARREO that became the heart of the infrared part of the CLARREO instrument. CLARREO fundamentally has both a solar and infrared and even a GPS radio occultation component. The infrared is one of the major ones. We ended building a very flight-like prototype of the instrument that's needed for CLARREO. Unfortunately various budgets and things became a problem and so it hasn't happened yet. But very recently the notion of doing this on the International Space Station and doing it with university activity, university inputs, has been accepted and so it's in the President's budget and if it gets through Congress we hope that our next big challenge in space flight instruments is going to be to build this instrument.

01:36:24

FB: Just to go into a little bit about the technologies that were developed. As Hank said, the important feature that sets CLARREO apart is to verify your measurements on orbit. And so we used one of our blackbody radiance standards, we're measuring radiance, and came up with a technique to show that the radiance, we basically, there's two parts of that device that need to be calibrated on orbit. One is the temperature scale and the other is how well it reflects, how black it is if you will. We came up with some ideas on integrating little teeny phase change cells into the blackbody cavity itself in order to establish a temperature scale by looking at the melt signature. This technology, it really doesn't' add any mass whatsoever and it gets the temperature accuracy to within 5 millikelvin absolute on orbit. So you don't have to rely on your prelaunch calibration that you did in the laboratory where things could drift. Any time you want on orbit you could check, you can go through, self calibration.

HR: By the way this was Fred's concept. It's proven extremely successful and it really establishes a broad temperature scale going all the way from melting points of

Voice in background: Mercury to gallium

HR: mercury to gallium which covers much of the temperature of Earth on orbit. It's a fantastic concept.

01:38:16

FB: There were other technologies to look at what's called the emissivity, or how black this radiance standard is, that we've developed and tested in the laboratory. All of these things have been integrated into a prototype instrument as Hank said, and tested under vacuum. We've now demonstrated the level of accuracy required for this climate mission so we feel like we don't have to rely on new developments to take the next step.

HR: And that's a tenth of a degree, what we call three sigma which means not to exceed a tenth of a degree type of brightness temperature accuracies in climate products. That's a very tight scale.

01:39:02

FB: I think we covered that. Why don't we go on to another couple little projects that kind of interweaved with this work that was going on. The first one is the WIYN Telescope control system. Evan, tell us a little bit about that project, what we did there for them.

ER: The WIYN Telescope, WIYN is an acronym. It's a nested acronym actually. It's Wisconsin Indiana Yale and the nested part N-O-A-O. And N-O-A-O is National Optical Astronomy Observatories. So there were four partners, one of the partners was a lot of other partners, that conspired to put a new observatory down on Kitt Peak. They divided up the work. Somebody else, I think N-O-A-O made the mirror. Other people worked on the building and the mountain and on and on. Our part at Wisconsin was the control system. And part of the reason for that, is like the High Speed Photometer for the Space Telescope, there's a history of controlling telescopes. And I think that kind of grew up along with photometry because here in Wisconsin when you're trying to control a telescope and for a very long times with photometric observations and with precision that will limit how good those photometric observations are, you need really good telescope guidance. And given our climate there's a very strong incentive to do it some way where you don't have to have somebody sitting up on a ladder when it's twenty below outside. So we have these Wisconsin advantages for these technologies, this motivation. So there's a history at the Astronomy Department of developing guidance systems and control systems for telescopes so you could do that and not freeze to death while you're doing it. Not have somebody out actually at the telescope. And their idea was for the first time in a serious ground observatory to be able to do it all remotely. You maybe have somebody there watching to make sure something didn't go crazy but the actual astronomer could be anywhere. So that was an interesting project. It was a very short time. It was in the early '90s. The budget was very limited. But it worked very well and is still working today.

01:40:30

FB: Another little interesting project was Vern Suomi's Ocean Heat Flux Sensor. This is a project that he started on his own, worked on it for six years right till his death in 1996. Even though he was working on it on his own, he was writing proposals and did get some pretty good funding. And in between some of those he got an agreement with the Center to give him bridge funding and so we kind of got our hardware development group kind of got involved with that. A lot of the careful good work done on that was by Larry Sromovsky. He really analyzed the original data and showed that in certain circumstances this instrument that Vern developed to measure the heat flux of the ocean surface was agreeing with independent calculations of heat flux. So the Center got involved and added, because it became a Center project we added more scientific and engineering rigor to the sensor. It did get deployed around the world in several places and ultimately I think it was done in by sea birds. It was a sea bird magnet. They just went and chewed up the sensors. So a long term operation would need to address that and I think the other conclusion was we really needed more intercomparison testing with independent means in various environments but it was a great Suomi elegant solution that you talked about before. It was deceptively simple, this sensor that floated in a fiberglass mesh on the surface of the water.

01:43:19

HR: Great scientific instincts. Because you had to take a net flux sensor and have it in the top millimeter, fraction of a millimeter, of the water for it to work. And at one point Larry and I decided we've got to show that can't work because we were convinced that there's no way. But this web that the sensor, the mesh that it resided on, the surface tension sucked it right to the top of the water and he was exactly right. It measured what it was supposed to by forcing it into the very top faction of a millimeter of the water. Very remarkable.

ER: One of the problems that we never got a chance to resolve was the seagulls liked to eat that mesh. But we were trying to take advance of the resources of the university. They have all kinds of, remember we had Scott Craven, the wildlife biologist over, we had a meeting with him. You know, how can we make this unattractive to seagulls. And he thought well, don't paint it white for one thing. [laughs]

01:44:22

FB: We're going to move on to some, there's a group at the Center led by Ed Eloranta who's been building state-of-the-art lidar systems. We just want to touch on that a little bit. Can you give us a little overview of the lidar technology, Hank?

HR: This will be a little overview but it goes back a long way. It started in the Meteorology Department, the Atmospheric and Oceanic Sciences Department. Actually Ed still works there but his whole team is Space Science and Engineering. They initiated a brand new concept that the lidar needed a way to be calibrated, the backscatter. The idea of lidar is you send light up with a given wave length and it bounces off things and comes back and tells you something about what it bounced off of and where it is, how far away it is. That's what you need to study the details of clouds and the properties of clouds that are very important for understanding radiation in the atmosphere. They came up with the idea that they could calibrate the backscatter by using both molecular backscatter and the scatter off aerosols and dust and things like that in the atmosphere. Because the molecules move around very fast they broaden the wavelength of the radiation coming back and when it bounces off something solid it doesn't. So that was the technique for distinguishing them. But this is all very, very small differences in wavelength. And it's taken now since 1967 I think to take this technology from residing in the back of a tractor trailer truck to being small enough to fly on an airplane and I think Fred can say more about all of the various applications now. So it has lead the way for activities in a lot of other institutions to use this high spectral resolution lidar with calibrated backscatter to learn a lot more about clouds in the Earth's atmosphere. Ed Eloranta has been the guru of both the optics, the detailed electronics, the software processing, the scientific processing and all of that over these years. He's had a great team from Space Science, too.

01:46:58

FB: The history of the group goes back to '67 so they've been working on constantly evolving the technology. But the high spectral resolution stuff, I think that started with a white paper in '75 by Ed. I guess the most recent generation of instruments are I think funded by the Department of Energy ARM program so they purchased a couple units. I think Hank mentioned there is one on the, NCAR runs a research aircraft; it's a Gulfstream 5. So we had to repackage something that would fit on that and it's been taking very successful data now. It's a facility instrument for that aircraft. It's still actively going on and taking good measurements. And there are in the planning, ways to take the next step involved in more sophisticated measurements but using available technology to reduce the cost. Another interesting project that we got involved in around the year 2000 was Ice Coring and Drilling developments. Tony, can you give us a little bit of overview on our Ice Coring and Drilling activities?

TW: Well, our activities require us to have support for anyone who gets funded by NSF to do ice coring or drilling anywhere high latitude or high altitude. That usually means in glaciers or Antarctica or Greenland. One of the things that we have to do is design, build, deploy, and staff drilling equipment. Some of the drills that have been designed, one of them was a RAM drill, Rapid Air Movement. It was pretty unique in that it ran off an air motor with a cutter at the bottom and it would go down through the ice. It was capable of reliably doing sixty meters every fifteen minutes. It would just be an open hole but that's what glaciologists put their seismic charges in. Previous to that drill it would take two to four hours to make a hole that was maybe ten meters, twenty meters deep. So that was a big improvement. The DISC drill which is the Deep Ice Sheet Coring drill, that was the new US deep drill and it was successful going to three thousand four hundred and five meters. But even more successful with that drill was the deviation drilling that was done. Previous to that you'd have to drill a hole and get an ice core continuous column of ice but if you wanted some special segments you had to drill an entire new hole. To do that it takes like six years to get to that depth because the season is so short in Antarctica. At any rate deviation drill could go off to the side and take an ice core and not ruin the main drill hole. So that was a big advance and no one else had ever done that. There was large volume drill for shallow drilling that researchers use to melt the ice and get gas measurements out of them and the like. And now our crew is working on the intermediate depth drill which is to go to the depth of fifteen hundred feet. It will be deployed to Antarctica this coming season. That's probably enough so we can get moving.

01:50:30

FB: OK. Ken you were part of the team that used the SSEC developed hot water drill for deploying the IceCube optical sensors.

KW: That's right, Fred. I thought I retired and this was 2006. Tony threw my name in a hat. I was lucky enough to be part of the one of the drillers, electronics technicians, specialist whatever you wanted to call me, anyway on the IceCube project which was the construction of a neutrino telescope. And by the way the thing I understand is working great. Now the environment at the South Pole obviously cold. We have to learn how to work outside, three shifts a day. Involved outside work, inside work, trouble shooting electrical things, manhandling drilling equipment and hoses and all of that sort of thing. Quite a project. I could talk a long time about it but again it got its start at SSEC and anyway I was very, very fortunate to be deployed five times in the course of the drilling program.

FB: We'll have to figure out how to get you back, Ken.

KW: [laughter]

HR: Don't let him retire.

01:51:54

FB: I think we're ready to wrap this up now. And I think I'd like to ask all of you each one by one what you consider the most important aspects of the Center that have contributed to its long term success. You want to start out, Evan?

ER: Sure. Its high standard and I think the Center really implements this thing we call The Wisconsin Idea where you take knowledge, advance that knowledge, and for the benefit of mankind. Look at what's happened with weather forecasting and how many people have so much more valuable information. Just as one example. Look at how we understand the universe and on and on. High standards, great team, high expectations, and The Wisconsin Idea. It's an unbeatable combination.

HR: It's had to beat that summary. I think I said this before but I think it's taking on problems that are important for society and important for science and getting a good team of can-do people to work together. And it's that teamwork that does a lot.

01:53:02

FB: And I would say two things. Primarily I believe it's the fusion between the engineering and the science which is really built in from the way Vern Suomi structured the Center. And in that way a scientist isn't going to propose to build something that can't be built because he's working hand in hand with the people who implement technology to get it to happen.

ER: You know when he does propose something that can't be built these engineers help him actually build it.

FB: Also during the development process you find a solution by making trade-offs with the whole group, not just dictating a solution because you want to do this. It's a marriage of the science and the technology. And secondarily I think it's because we're involved with the entire process of an instrument design. From the scientific idea to designing the instrument, building it, testing it, calibrating it, deploying it, getting the measurements, analyzing the data. And it's a cycle and that creates the next generation of successful instruments.

HR: That probably does make us somewhat different from most research organizations, that we tackle end-to-end things that go from the idea to building something and then applying it.

FB: Ken.

KW: Yes.

01:54:25

FB: How would you like to answer that question.

KW: Wow. That's a tough one. Again it's the idea that getting back to the culture of saying it has to be done. And wanting to do it. The principle investigators and engineers and so on are just fantastic people to be involved with on a project.

FB: Thanks, Ken. Tony?

TW: Well, I think it's a reflection on the brilliance of the people who organized it, Professor Parent, Professor Suomi. And how it was organized and the way they assembled a team and they passed that on to the next generation and it continues. It just continues. The attitude of whatever it takes to get done. It just continues. And it's self-perpetuating almost at Space Science.

ER: Could I toss in one more thing, because you had an important point there about the life cycle of the project and we keep building on that. There's also the other dimension of the entire project that we have at any moment in time most people at the Center have some involvement or at least knowledge of all aspects of the project. And you don't find that in big companies. So we got it both dimensions and I think that's why there's a better understanding . There a better feeling of commitment.

01:56:00

HR: A lot of these things we've mentioned we're still doing are threads that go back to Vern's early science questions with new technology and new perspectives but really it's a continuation. That's really important.

ER: And there are threads that go back way further in the university's history, too, that we stand on.

FB: We're hoping that those threads continue. And many more of them develop. And I think we got the foundation to do it. So that wraps it up. Thanks.

HR: Thanks, Fred.

01:56:30

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Project Directors
Fred A. Best
Space Science and Engineering Center
University of Wisconsin-Madison

Jean M. Phillips
Space Science and Engineering Center
University of Wisconsin-Madison

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Wisconsin Public Television
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