Terahertz Pioneer: Mattheus (Thijs) de Graauw

"Intention, Attention, Execution"

Peter H. Siegel, *Fellow, IEEE*

MATTHEUS (Thijs) de Graauw[1] started life on his grandfather's farm in Kerkdriel, Netherlands, approximately 50 km southeast of Utrecht. Soon afterwards his family moved to the nearby village of Empel, population 500, and site of a famous battle between the Dutch and the Spanish in 1585, during the 80 Years' War. His mother was the youngest of thirteen children and his father was a local schoolmaster. Thijs himself was the third of eight brothers and sisters, and although he was always a very curious person and loved learning, he never planned on having an academic career. However, there happened to be one person in his village who subscribed to *Hemel en dampkring*[2] and he would generally pass on his copy of this rather high technical level science magazine, to Thijs. Thus began a lifelong interest in astronomy and a career that anyone involved in "big" science would envy.

THIJS DE GRAAUW

When Thijs began to specialize his studies at the lyceum,[3] he chose physics and mathematics. However he loved his classes and took on as many other subject areas as he could. He was a good student and managed to get a scholarship to attend the University of Utrecht in 1961. His first two years went smoothly, but several distractions, including a fanatic interest in crew[4], caused his course work to suffer and he lost his scholarship. He took a job as a teacher at a boarding school, redid his failed classes, and finally passed his exams in mathematics (all of them in one swoop) in 1966. He then entered mandatory military service, and over the next two years, while dutifully playing his role as fire-control officer of an anti-aircraft unit, took a long hard look at his past life and for a direction in which to go forward. After this extended introspection, he concluded that astronomy excited him most, and that no matter how his choice came out, he would not regret following his interests.

Thijs re-entered Utrecht University in 1968 and completed his Masters and Ph.D. degrees in 1970 and 1975, respectively. What was particularly prescient about Thijs's time at Utrecht, was his shift in focus from pure theory [2], [3] to astronomical instrumentation [4]. He concluded that to do significant science, one needed state-of-the-art instruments. His thesis was on heterodyne detection in the far infrared [5] and he used his new found experimental skills to build both a 10.6 micron [6] and a 337 micron [7] receiver for astronomical observations. The 10.6 micron receiver used a cooled silicon photoconductor and a CO_2 laser as the local oscillator source. The 890 GHz receiver used an HCN laser for the LO, and a GaAs photoconductor for the heterodyne element.

His work on heterodyne receivers brought Thijs in contact with several members of the small clique of submillimeter-wave spectral line astronomers at the time, including NASA Goddard's Mike Mumma, UC Berkeley's Al Betz, and Chalmers University's, Erik Kollberg. In yet another prophetic moment, Thijs took his receiver to La Silla, the site of the European Southern Observatory's first telescope facility. La Silla is located near La Serena, at the southern end of the Atacama Desert in Chile—a region that would later become Thijs's home away from home! de Graauw spent six days and nights on the 1.5 meter optical telescope at La Silla observing planets and the interstellar medium [8]. He soon realized that a much larger submillimeter-wave telescope was needed to do really significant work in this wavelength range.

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[1]This interview was conducted in the small town of San Pedro, perched on a high flat plateau in the Atacama Desert of northern Chile between November 18th and 20th, 2013. San Pedro is the closest town to the site of the Atacama Large Millimeter Array (ALMA), without doubt the most complex and technically ambitious astronomical science project ever undertaken. Dr. **Thijs de Graauw**, generously agreed to fly up from his home in Santiago to meet, talk, and take me to see this fabulous facility that he famously described as [1], "the largest science project ever, where nobody was in charge, but we have made it work." Of course, Thijs was in charge, and was responsible for making ALMA work. As you shall see in this article, it was not the only thing that Thijs made "work".

[2]Literally "Sky and Atmosphere," a fairly high level technical science magazine published in the Netherlands from 1903 to 1973 by Joh. G. Stemler Cz., Algemeene Boekhandel, Amsterdam.

[3]Secondary school in the Netherlands. Ages 12–18.

[4]This interest in boating would stay with Thijs to present day—he purchased and restored an 1892 built, 25 m schooner which he uses for commercial outings, and has been working on restoring a second 19 m ship, circa 1902, since 2002.

Despite warnings from his friends and colleagues about taking a "multi-national government" job when he completed his dissertation, de Graauw went to ESTEC, the European Space Research and Technology Center in Noordwijk, Netherlands. His mission was to build astronomical instruments and to do far-infrared space science. He started with a completely empty lab. In the short term, he was to develop heterodyne spectral line receiver technology starting at 230 GHz (CO, $J = 3 - 2$ transition) and move up the carbon monoxide ladder ($J = n$ to $n - 1$ transitions) to 345 and 460 GHz. His long term goal however was to go up to the THz frequency range and into space. There was already a proposal floating about for a large infrared telescope on an envisioned space shuttle-launched space lab (LIRTS) [9], and plans for a ground based 10 m diameter submillimeter-wave telescope at Caltech [10]. These would form the groundwork for a U.S. led concept for a large deployable space-based far infrared telescope mission (LDR), and the ultimately realized, European Space Agency's Herschel Space Observatory—only a very distant dream for de Graauw at this time.

In the late 1970's, Thijs made several trips to Hawaii with his 230 and 460 GHz CO receivers to do some observations at the telescope field on Mauna Kea. On one of these occasions he happened to overhear a discussion between noted astronomer Ian Gatley (just out of Caltech and at that time a project manager for the U.K.'s infrared telescope facility) and colleagues, on the U.K. proposal for a 15 m submillimeter-wave telescope (what would eventually be the James Clerk Maxwell Telescope—JCMT). The Netherlands had just become a 20% partner and a decision had been made to site the telescope on Tenerife in the Canary Islands. Having experienced how wonderful the atmospheric conditions were in Hawaii at 230 GHz, Thijs suggested that perhaps the JCMT site decision should be reconsidered. Gatley told de Graauw that he was just the person to make this happen—and so it was! In 1987 the JCMT saw first light at Mauna Kea.

During this period Thijs was making a lot observing trips, and on several passes through California he met up with three groups of heterodyne instrument developers that would influence and help further his career in submillimeter waves.

The team of Joe Waters and Jack Hardy from JPL, along with consulting antenna engineer Jack Gustincic, were developing and fielding millimeter and submillimeter wave receivers for Earth atmospheric work. Gustincic [11] took an immediate shining to de Graauw, and they exchanged lengthy visits (California and Netherlands) remaining friends until Gustincic's tragic death in a mid-air plane crash over Santa Monica, CA, USA, in 1978.[5] Waters, who would later become the principal investigator for the two NASA Microwave Limb Sounder instruments—the first millimeter-wave [12], and then the first THz (above 1000 GHz) heterodyne spectral line receivers in space [13], invited de Graauw to accompany him and Caltech astronomer Tom Phillips [14], on two NASA high altitude aircraft platforms. The Convair CV990 Flying Laboratory and the C-141 Kuiper Airborne Observatory (KAO) were used by Waters to search for several key lines of the chlorine monoxide radical (ClO), considered a major player in the ozone depletion cycle [15].[6] Waters brought along heterodyne Schottky receivers at 160 [16] and 240 GHz [17], de Graauw supplied his 230 GHz receiver tuned high to 260 GHz, and Tom Phillips fielded his 280 GHz InSb hot electron bolometer receiver [18]. These were the first attempts to directly measure ClO emission lines in the stratosphere [19].

On this same trip, Thijs also stopped over with his equipment for a weekend at UCLA to team up with Neville Luhmann and to carry out a number of advanced diagnostic tests on the UCLA tokomak. Luhmann was developing heterodyne receivers for electron cyclotron emission measurements in hot plasmas—part of a campaign to characterize fusion reactions [20], [21]. It was Gustincic who introduced Luhmann and the JPL team to de Graauw.

As a result of these visits to southern California, Thijs was invited back for an extended stay in the summer of 1977 to work on receivers. This began a close, and very long term collaboration with submillimeter-wave astronomers and instrument engineers at Caltech and the NASA Jet Propulsion Laboratory, which included Tom Phillips, Bob Leighton, Anneila Sargent, Peter Wannier, Tom Kuiper, and Frank Israel (who would later work with de Graauw in the Netherlands).

Within a couple of years, with help from Sverre Lidholm, Frank Israel, and others, de Graauw had amassed at ESTEC, a full complement of working submillimeter-wave heterodyne receivers reaching beyond 500 GHz [22]–[24]. These consisted of a variety of detector and source technologies, including waveguide and quasi-optical Schottky diodes and cooled InSb bolometers [25]–[27], pumped by both solid-state multipliers and backward wave oscillators. The instruments were deployed on the KAO, at the 2.2 m University of Hawaii optical telescope and the 3 meter NASA Infrared Telescope (IRTF) on Mauna Kea, at the Owens Valley Observatory (up to 345 GHz), the 3.6 m at La Silla and the Las Campanas 2.5 m telescope in Chile. Significant observations included a CO survey in southern hemisphere HII regions [28], [29]; CO, $J = 4 - 3$ at 460 GHz in Hawaii; a search for atomic carbon at 490 GHz on the KAO in competition with Tom Phillips; and stratospheric water at 360 and 380 GHz from the back of the KAO (with Joe Waters).

By 1979, as a result of Bob Leighton's and Tom Phillips' ambitious goals for a 10 m diameter submillimeter-wave telescope at Mauna Kea, and significant lobbying in the U.S. by JPL's Paul Swanson, Sam Gulkis and Tom Kuiper, also Mike Kiva, at NASA Ames Research Center, and Tom Phillips and other astronomers, plans for a large diameter (20 m), actively controlled, segmented, deployable submillimeter-to-far-infrared space telescope were taking shape [30], [31]. Thijs was present both at the early discussions (which began at JPL in 1977), and later attended the focused workshops at Asilomar, Pacific Grove, CA, USA, on the LDR (large deployable reflector) concept, the last one of which was held in June 1982 [32].

In May 1982, just prior to the Asilomar meeting, Thijs organized and held a workshop in Noordwijkerhout, Netherlands on

[5]Jacob Joseph Gustincic and all 144 people onboard Pacific Southwest Airways flight 182 were killed when a Cessna 172 flew into the commercial airliner over Santa Monica, CA, USA on Sept. 25, 1978.

[6]Mario Molina and Frank Rowland received the 1995 Nobel Prize in Chemistry for their work on this chemical process

the scientific importance of submillimeter-wave observations [33]. Many prominent European and US astronomers and spectroscopists attended, and there were lots of discussions on a space-based telescope as a follow up to earlier interest in LIRTS (no longer under serious consideration). As the U.S. planning for LDR continued without any serious commitment of resources, the European Space Agency (ESA) released a general scientific mission call on July 6, 1982 [34]. Thijs immediately began organizing a science team to respond. He wrote a letter to attendees of the Noordwijkerhout workshop and included some of the papers on LDR from the Asilomar conference. In the letter he suggested that a formal proposal to ESA be submitted for a "large infrared and submillimeter space project".[7]

Thijs quickly followed the letter with a meeting of interested scientists that September. Fifteen members of the European astronomy community then backed a *Letter of Intent* submitted to ESA by de Graauw on October 15, 1982, for a "Far IR and Submillimeter space Telescope—FIRST [35]. The development of the FIRST proposal and its subsequent acceptance in the European Horizon 2000 mission queue is, as they say, history. Gisbert Winnewisser [36] was the proposal science PI (principal investigator) and Thijs put together the satellite and mission concepts. Twenty-one European astronomers and seven members of ESTEC, Thijs included, were on the proposal coversheet,[8] which was submitted in November 1982. The aperture was a segmented 8 m deployable dish, rather than the ambitious 20 m reflector proposed for LDR. This would later (1994) be further restricted to a 3.5 m solid mirror. In late 1983, ESA's science director, Roger Bonnet, gave the go ahead for an assessment study. By 1984, FIRST had become one of ESA's four Cornerstone missions [37] and significant funding for study work was flowing by 1986 [38]. NASA's support of LDR and several smaller alternate far-IR space telescopes slipped away, and the U.S. team joined up with the ESA project team in 1990. The program name was changed to the Herschel Space Observatory (HSO) in 2000, and Thijs became the principal investigator for the HIFI instrument (heterodyne instrument for the far infrared), one of three major instruments carried on the mission.[9]

In the midst of all the discussions and the proposal processes for FIRST, Thijs was "sidetracked" by another space mission he had been involved with since his first days at ESTEC. He had been part of a proposal to ESA (from Netherlands) for an infrared space observatory mission (ISO), which was submitted in 1978, but which did not get selected for the first phase of development until February 1983. ISO was baselined with detector technology between 5 and 65 microns, and employed Michelson interferometers for the spectroscopy. However, ISO never represented high priority science within ESA, whose program managers had been much more excited about an X-Ray telescope mission. To make matters worse, as it was entering its final approval and initial implementation phase, it was clear that most of the space radiant flux of interest in this wavelength range was not between 5 and 65 microns, but rather at 100 microns and beyond (the THz region!).

SRON, the Netherlands Institute for Space Research (Stichting RuimteOnderzoek Nederland) had a laboratory on the campus of Groningen University and was heavily involved in the ISO instrument development with Jan Wijnbergen, Willem Luinge, and Klaas Wildeman as main participants. Thijs, who had just decided to relocate from ESTEC to SRON, was a natural choice for leading the science and instrument development at SRON.

de Graauw realized that the current ISO science drivers were outdated and he understood the importance of revamping ISO's instrumentation to match the new science needs. He decided to start a process to recast the original ISO instrument package and to go back to ESA, essentially with a completely new proposal. In 1983 he started the international ISO spectroscopy working group and in 1984, he organized, with Catherine Cesarsky, the ISO Alpbach workshop [38]. He solicited participation from "all laboratories and persons in Europe who were interested in the ISO mission". Their goal was to re-assess and optimize the instrument in view of the new science results that were now coming in from NASA's Infrared Astronomical Satellite (IRAS) – see paragraph to follow. Study teams were formed for extending the ISO wavelength range. The two Michelson interferometers were replaced by two grating spectrometers, covering 2.5 to 200 microns. As a result two instrument teams were formed, one for the long wavelength spectrometer (LWS-45 to 200 microns) and the other for the short wavelength spectrometer (SWS-2.4 to 45 microns). A broad band polarization photometer (ISOPHOT-2.5–240 microns) and an infrared camera (ISOCAM-2.7 to 17 microns) completed the instrument suite. Thijs took on the role of instrument PI for the SWS, which was ultimately designed and built by SRON and MPE (Max Planck Institute for Extraterrestrial Physics in Garching, Germany) [40]. P.E. Clegg (UK) became the PI for LWS, which was a collaboration between UK, France, Italy, Canada, and USA [41]. Catherine Cesarsky and Dietrich Lemke took the PI role for ISOCAM and ISOPHOT respectively. ESA's Martin Kessler was the overall mission project scientist [42].

In an interesting act of fate, according to Thijs, during a presentation of the nascent ISO instrument to an ESA selection committee in 1983, there was a strong contingent of committee members who were extremely uncomfortable with the cryogenic mission that was being proposed, and were leaning towards selecting a less risky option with greatly reduced science. It was exactly at this moment that IRAS, NASA's extremely successful Infrared Astronomical Satellite (a joint U.S., U.K., and the Netherlands project),[10] saw first light. The very first data package, processed at JPL, immediately faxed over to Fokker Space (now Dutch Space) and then driven by car to the meeting in Scheveningen, reached the floor of the committee room just as the gathering was breaking up. When the viewgraph machine was turned back on and the image was projected, the exodus stopped, the room went silent, and everyone present was floored

[7]Copy of the letter available from the author.

[8]A copy of the proposal cover sheet is available from the author.

[9]PACS—Photodetector Array Camera and Spectrometer, and SPIRE—Spectral and Photometric Imaging Receiver, are the other instruments. More details on Herschel are available from ESA's Herschel Science Center (www.herschel.esac.esa.int).

[10]The Infrared Astronomical Satellite. [Online] Available: www.irsa.ipac.caltech.edu/IRASdocs/iras.html

by the spectacular data that was being presented—the first ever infrared full-circle scan of the sky, including a cut through the Galactic plane. ISO's approval was not only secured, it became the first unanimously approved ESA project!

Before getting too heavily involved with ISO, Thijs was working on several smaller technology programs at SRON. As scientific lead of the Space Research lab from 1983 onwards, he directed, in close collaboration with Teun Klapwijk, a Professor in the neighboring Applied Physics department at Groningen and now at Technical University of Delft, and with Herman van de Stadt, the SRON submillimeter-wave group leader, research and development on submillimeter-wave superconducting receivers using Josephson junctions [43], [44]. Later the research shifted to much more successful superconducting-insulator-superconducting (SIS) devices [45]–[51], and hot electron bolometers [52], which would form the basis for the receivers on FIRST. de Graauw also participated in many observational campaigns [53]–[60], including use of the new 15 m SEST (Swedish ESO Submillimeter Telescope) at La Silla, Chile, and he was chair of the receiver working group for the JCMT.

Starting in 1986, the demands of ISO took hold, and Thijs began working nearly full time on the SWS instrument. The infrared focal plane array for the SWS was built at SRON and it was by no means free of problems. As the delivery date for the instrument was approaching on Christmas 1992, some of the detectors had severe glitches, others had very long hysteresis effects and the Fabry–Pérot was leaking signal power. The new improved germanium BIB (blocked impurity band) detectors that were supposed to be coming in from the U.S. (noted IR engineer Stephen Donald Price[11] at U.S. Air Force Cambridge Research Lab—now AFRL, in Bedford, MA was acquiring them for ISO), were held up because they had no export license, and on top of this, SWS did not have sufficient funds to purchase them. Thijs sent a Christmas greeting card to ESA in which he nicely stated that, "unfortunately he was not quite ready to deliver the SWS instrument."

"How the Grinch Stole Christmas,"[12] was not the holiday card ESA program managers were expecting, and everyone was notably upset. Thijs stood his ground however, and even though he felt completely alone in the decision, he knew it was the right course of action. In the end, his judgment was proven to be correct. The lenses turned out to have a radioactive coating that was wreaking havoc with the detectors, many other small problems were dealt with, and a deal was worked out with the Americans to get the BIB detectors delivered in time. ISO launched in November 1995, approximately 2 years behind schedule (SWS took advantage of the additional spacecraft delays), and it operated until it ran out of cryogen (2286 liters of superfluid helium) in April 1998, well beyond its estimated lifetime.

ISO was a scientific and technical success.[13] For distant objects the 60 cm collecting area of the ISO telescope was a bit too small, and the available satellite resources for the instruments were extremely limited, but in the end the ISO teams managed to deliver a superior instrument with unique scientific results. The SWS instrument in particular, had a high spectral resolution that will not be repeated for a long time (even Spitzer,[14] with its higher sensitivity, cannot match the resolution from SWS). A few of the many highlights [61] and hundreds of papers and Ph.D. dissertations (> 50) from the SWS instrument are: precise spectra of interstellar ice, allowing comparisons with lab spectra, and yielding important insight into interstellar chemistry [62], [63]; the observation of the crystalline state of silicates, which opened up the whole new research field of astromineralogy [64]; SWS provided diagnostics for understanding the power source for luminous infrared galaxies [65]; the supply of oxygen to the atmospheres of the giant planets [66]; and a definitive detection of water in the atmosphere of Titan [67] and other places in interstellar space [68].

In 1990, Thijs took the post of Program Director at SRON. In the meantime, all the study and development activities for FIRST, partly funded from the ESA Technology Research Program budget, began way back in the mid 1980's, had been moving forward. By the late 1990's there was a consortium of 23 institutes from 11 countries developing and building various pieces of the technical hardware. de Graauw was involved in both coordinating these international teams and research activities, as well as spending time himself on the detectors [45]–[52]. Between 1993 and 1995, he also served as Co-Principal Investigator for the Dutch contribution to the European Southern Observatory's Very Large Telescope (VLT) mid-IR imager and spectrometer (VISIR).[15]

1998, the year ISO completed its observing run, was shaping up to be a very big year for de Graauw. ESA had established a FIRST technical working group in 1990 led by SRON's Nick Whyborn in Europe and Caltech's Tom Phillips in the U.S. In 1996 a straw man payload and a list of consortium partners for the mission was drawn up and ESA gave the approval for detailed instrument development. At the time, the heterodyne portion of the FIRST instrument package was to extend to 1250 GHz using SIS receivers (later 1.4 and 1.9 THz channels were added). Although Thijs was a natural choice to lead the development, the SRON directors did not want him as a PI. Managing the international consortium however turned out to be a much more difficult task than expected, and by December 1996, it was clear that someone of de Graauw's experience was needed in a lead role. At first Thijs was offered a two year position, but he wisely negotiated a continuing contribution with stated review gates at which he could be replaced if SRON management was unhappy!

The die was cast, and de Graauw stepped in, drawing upon his usual open and upfront approach of getting partners to say what they were going to do, signing them up to do it, and then holding them to their commitments "*Intention, Attention, Exe-*

[11]Price was largely responsible for the U.S. Air Force rocket-borne infrared sky survey in the early 1970's and 1980's. He participated in MSX (midcourse space experiment), ISO, and Spitzer. He passed away in 2012.

[12]Theodore Geisel (Dr. Suess), *How the Grinch Stole Christmas*!, Random House, 1957 – a classic!

[13]The Infrared Space Observatory. [Online] Available: iso.esac.esa.int

[14]Spitzer Space Telescope. [Online] Available: www.spitzer.caltech.edu

[15]The VLT is a group of four 8.2 m diameter optical and IR telescopes on Cerro Paranal in the Atacama Desert of northern Chile. VISIR is a mid IR imaging spectrometer operating at 10 and 20 microns. VLT is second only to the Hubble Space Telescope in generating scientific papers amongst the world's optical observatories (en.wikipedia.org/wiki/Very_Large_Telescope).

cution". A competitive approach to lining up consortium members for key FIRST deliverables was put in place. Proposals were requested and evaluated on both technical merit and cost. A short development period was established for groups to prove out their approaches. Thijs helped significantly by cajoling consortium members to sign up for those tasks that they were best at, and could deliver with the highest certainty. He also worked with the Co-Investigators behind the scenes to get funding agencies in the various member countries to support their local teams and he stayed involved in technical research whenever possible [69]–[71].

In 1998, de Graauw took on the official role of PI for HIFI—the Heterodyne Instrument for the Far-Infrared [72]. The formal proposal was accepted by ESA, but was deemed extremely risky. Thijs became a member of the FIRST science team and Nick Whyborn took on the role of HIFI Instrument Scientist. In the same year Thijs also signed up to be a Co-Investigator for the ALMA band 9 (602–720 GHz) heterodyne receiver cartridges (66 units!) and he took on an editorial role for the international journal, *Experimental Astronomy*—but more on all this *after* FIRST.

The development phase of FIRST was to take several years and was fraught with many problems. ESA considered the consortium approach to the instrument deliverables to be unworkable. Thijs thought most of the problems were with ESA! de Graauw began to slowly wind down his connections with ISO (although dozens of his papers were still coming out each year from the project), and he began focusing on this new and much larger challenge for infrared space science [73], [74]. He also took on a role as part-time Professor at the University of Leiden in 2003, which helped expand his research areas and bring students into his projects. Leiden's Observatory (in the city itself) had served as an astronomical home base for Thijs when he was at ESTEC (1975–1983), and brought him together with long time research partner, Ewine van Dishoeck, at that time a student in chemistry and astronomy.

By 2000, major funds began to flow into the project. FIRST was renamed the Herschel Space Observatory.[16] Its 3.5 m passively cooled infrared telescope would be the largest ever launched and the price tag for the whole mission, including companion instrument Planck[17] would exceed $1.5 billion.

From the beginning SRON felt the costs for HIFI were too high and they kept asking Thijs to descope the instrument. Thijs responded by lowering the cost without removing any hardware! He also offset whatever expenses he could onto ESA. There was so much confusion at SRON in the HIFI project office at this time (financially managed out of SRON's Utrecht facility), that no one really knew how much was being spent, or on what. Thijs repeatedly asked for transparency on the accounting, but he never got anywhere. In the end it turned out that one of the financial managers at Utrecht had been less than honest about where funds were going and had to be replaced. Sanity finally came to the project when a professional manager, Kees Wafelbakker, joined Thijs in 2002. They went over the schedule and finances nose-to-tail and realized they were at least €10M short out of the originally budgeted €60M at SRON (the total HIFI costs for all the consortium participants—each of which brought in their own funding, was somewhere in the neighborhood of €200M, as a reference). Fortunately there had been funds set aside for a post-HIFI project, and of course it had not been implemented yet, so that money became available!

Countless other problems arose, political, and technical, as well as finances and scheduling, as the project developed. Thijs was always honest about his own HIFI schedule, which rarely matched what ESA carried on their books. In a project the size and scope of Herschel with so many individuals involved (986 are listed on the Herschel web site!) the number of issues that arose over the 10-year instrument build phase would fill a library. Suffice it to say, that on May 14, 2009, the Herschel Space Observatory was launched on a special vertically stacked double-satellite package (with Planck) on an Ariane 5 ECA from the Guiana Space Center in Kourou, French Guiana. Both satellites reached their separate L2 orbits, and both satellites have been wildly successful. As Thijs stated, and perhaps it is undeniable in this case, "Miracles exist!" Planck just ended its observing this past October 2013 and HSO ran out of helium on April 29, 2013.

Major contributions from Herschel in general, and HIFI in particular [75], are so numerous the author cannot hope to cover them, or even categorize them by impact. Over 1000 publications have already been generated and this number will surely double within the next two years. A recent symposium on Herschel science results, *The Universe Explored by Herschel* [76] is a good place to start a search for details. The ESA press releases are also a quick way to get an overview, year by year [77]. My perspective - *think water*! We on the other hand, must get back to Thijs, who in 2009, despite the success of Herschel, is still far from finished with "big" science.

In 2007, before Herschel had launched, Thijs turned 65 and he was forced to retire from SRON. He was allowed to stay on part time (30%), but he was not content to simply relax a bit, and perhaps finish the historic (circa 1902) 19 m ship he had been restoring in his front yard/harbor since 2002! He alternately worked on a follow on mission plan to Herschel, ESPRIT [78], a large orbiting submillimeter-wave interferometer, and a very large single dish submillimeter wave telescope, Millimetron [79], which was being planned in Russia. Thijs strongly felt that he was most valuable in bringing big projects to fruition, rather than guiding them during their operational phases. He had been overlapping with just such a project for more than 10 years—ALMA (Atacama Large Millimeter Array), and it was just about the time that this enormously complex *ground based* submillimeter-wave astronomy project was about to enter its most difficult period—the implementation phase.

In 2008, Thijs was invited to take on the role of ALMA Director for one year. He knew the project not only from the band-9 development, but also because since 2005 he had been serving as chair of the ALMA Management and Advisory Committee. He resigned as PI of HIFI and turned the instrument over to SRON's Frank Helmich, who expertly guided it through final checkout, launch, and mission operation. He and

[16]Herschel. [Online] Available: herschel.esac.esa.int

[17]A separate Cosmic Microwave Background mission, and the third in the ESA Horizon 2000 program (also of notable interest to the THz community). Planck Science Team Home page: www.rssd.esa.int/index.php?project = Planck.

his wife then moved from rainy Netherlands to Santiago, Chile, and Thijs began working in one of the driest places on Earth, the Atacama Desert.

ALMA [80] will ultimately consist of 66 mostly 12 m diameter radio telescopes able to observe at frequencies up to 1 THz. Each antenna will have up to 10, helium-cooled state-of-the-art receivers that observe in frequency bands between 40 and 950 GHz. The antennas can be individually placed on platforms to form a coherent phased array with baselines up to 16 km. ALMA is financed and run by a triumvirate consisting of the U.S. National Science Foundation operating through Associated Universities via the National Radio Astronomy Observatory, based in Charlottesville, Virginia; the European Southern Observatory, a 15 member state European governments consortium; and the National Astronomical Observatory of Japan. Additional partners include the National Research Council of Canada, the National Science Council of Taiwan, the National Institutes of Natural Sciences of Japan and the government of Chile. ALMA is located on the Chajnantor plateau at an altitude of 5000 meters and approximately 2 hours from the nearest airport at Calama. Ground breaking began in November 2003 and the final consortium agreements were in place in 2004. Although the first antenna components had arrived in 2006/7 none of the antennas was ready for hand-over to the observatory, and Thijs arrived just as final build-up of instrumentation at the site began.

With his experience managing large multinational consortiums from HIFI, and his matching technical background in heterodyne technology, Thijs felt he could readily handle the complex political, financial, and technical challenges that were facing ALMA. Little did he realize how daunting these challenges were to be—even compared to a major space program! After the first 100 days in charge however, he fell in love with both Chile, and the challenges of getting ALMA up and running. He applied for, and was granted an extension of his directorship in 2008, and he used all of his combined talents as a manager and a technical leader to negotiate the many landmines that stood between ALMA's then current status—no operational antenna—to its opening ceremony on March 13, 2013, with more than 57 operating antennas in place (the last of the planned 66 antennas was delivered to ALMA in October 2013). In an interview at the opening ceremony, conducted by Sebastian Piñera, President of Chile, de Graauw is now famously quoted [1] as stating that ALMA is "the largest science project ever, where nobody was in charge, but we have made it work."

A major part of ALMA's science objectives are aligned with Herschel-HIFI, as is its receiver technology. Unfortunately Thijs was so busy with the details of getting ALMA through to first light, that he did not have time to participate in the science. However both ALMA and Herschel will continue to deliver the science that Thijs de Graauw has devoted his long career to fostering and developing, long after his role in each of these projects had ended.

His major challenge completed, Thijs resigned as Director of ALMA in April 2013, and at age 71 has just taken on two new major tasks. His love of Chile, and South America, has pushed him to help build up the technical infrastructure there, through an initiative to establish a multi-nation millimeter-wave astronomy capability. Thijs has defined for himself the role of Project Mentor for the bilateral Brazilian/Argentinian astronomy project LLAMA, Large Latin American Millimeter Array project. At the same time he has accepted a position as the Deputy Science Lead and co-Principal Investigator for the very exciting Millimetron mission[18] (led by Nikolai S. Kardashev, deputy director of the Russian Space Research Institute, Moscow), a Russian submillimeter-wave space science telescope for L2 orbit with a projected 10 m diameter cooled deployable antenna.

Shortly after the conclusion of this interview, Thijs was off to several LLAMA related meetings in South America, and then to Moscow for work on Millimetron. He and his forever supportive wife, Herma, plan to spend half their time in Chile and half their time in the Netherlands, where their children and grandchildren reside. But clearly, Thijs means to spend half his time on airplanes traveling from place to place, helping his colleagues worldwide to continue to advance the field of submillimeter wave astronomy and instrumentation! I only hope he has time to complete the restoration work on his 1902 sailing ship, still in his front yard at Groningen, and to get a chance to use his already restored and operational 1892 25 m sloop, currently taking guests around on Dutch lakes and canals! A more dedicated and competent advocate for THz science would be hard to find.

Acknowledgment

Thijs would like to make it clear that all his work and accomplishments were achieved with the help of many people, and any success, which he now enjoys, came from their efforts. He considers himself to be merely an orchestra conductor, with the pretensions of a composer.

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Mattheus (Thijs) de Graauw graduated from University of Utrecht, the Netherlands, with a Ph.D. degree in astronomy in 1975. He immediately took a position at the Space Science Division of ESTEC, the European Space Research and Technology Center in Noordwijk, Netherlands, where he began working on millimeter- and submillimeter-wave receiver technology, and on radio science observations at various observatories and airborne platforms around the world. In 1978 he was part of a proposal to the European Space Agency (ESA) for an Infrared Space Observatory platform (ISO). In 1982, he initiated and coordinated a proposal to ESA for a Far Infrared Submillimeter Space Telescope (FIRST). Both of these proposals would eventually be funded and resulted in extremely successful space astrophysics missions. In 1983, Dr. de Graauw relocated to SRON (the Space Research center for Netherlands) at Groningen University. By this time ISO had become a full space project and de Graauw was named Principal Investigator for the Short Wavelength Spectrometer instrument (SWS). He rose to Program Director at SRON in 1990 and continued to manage and work on ISO, FIRST and many other ground based observing and instrument tasks. ISO launched successfully in 1995 and De Graauw devoted his time to development activities on FIRST. He was appointed Principal Investigator for the Heterodyne Instrument for the Far Infrared (HIFI) on FIRST in 1998. At the same time he started working on the Atacama Large Millimeter Array project in Chile as a co-investigator on one of the submillimeter-wave receiver channels and as a member of the ALMA Steering Committee. He also edited the international journal, *Experimental Astronomy*. In 1998, he was a visiting professor at ISAS in Tokyo, and from 2003 to 2008 he served as a faculty member at University of Leiden, the Netherlands. FIRST became the Herschel Space Observatory in 2000 and was successfully launched and deployed in 2009. In 2008, de Graauw was offered the position of Director at the ALMA Observatory and he relocated to Chile. He guided ALMA through its final development and deployment phases until the official opening of the observatory in March 2013. de Graauw is now spending part of his time setting up the LLAMA project, the Large Latin American Millimeter Array program in South America and the rest of his time as the Deputy Science Lead and co-Principal Investigator for the Millimetron project, an advanced Russian space telescope program.

Dr. de Graauw is the author of more than 300 papers and conference publications on both astronomical science and astronomical instrumentation. He is frequently invited to give international talks and to participate in international review boards, meetings and planning activities in the astronomical sciences. He is a member of the European Astronomical Society, the American Astronomical Society, the European Physics Society, the Nederlandse Vereniging voor Natuurkunde and the Nederlandse Astronomen Club. In 2012, he was awarded the Joseph Weber Prize of the American Astronomical Society for "leadership in the construction of powerful new astronomical instruments on ISO and Herschel.

de Graauw spends part of the year in Chile, and part of the year in the Netherlands. When he is not working on the restoration of his antique (1902) sailboat on his front yard in Groningen, you will undoubtedly find him on an international flight heading for a meeting, workshop, conference or professional visit somewhere on the globe!