Terahertz Pioneer: Thomas G. Phillips

"The Sky Above, the Mountain Below"

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IT IS perhaps surprising that the son of a Public House owner in post-war London would set his sights on understanding the structure and evolution of the stars, but Thomas Gould Phillips[1] did just that. Maybe there was a suggestion of a scientific bend in the family. His father had studied mechanical engineering before being forced to give up his formal education to assist his widowed mother at the Public House. However, Professor Phillips cannot recall ever having had a serious scientific discussion with either of his parents. His early interest in physics was thrust upon him by his primary school teachers, who recognized his talents from his marks on standardized tests he took at the conclusion of his grammar school years. His course being set, he did not disappoint. Tom worked hard in secondary school, rapidly catching up with colleagues who had a more supportive career start. Ultimately he earned a place at St. Edmund Hall, Oxford University, Oxford, U.K., where he enrolled in 1958 as one of the few students in his college who was not there under a sports fellowship.

At Oxford, Phillips discovered books, and making good use of an extensive library for the first time in his academic career, he graduated with first class honors in physics. He entered Clarendon Laboratory at Oxford in 1961 where he began his graduate work on radar pulses in quartz crystals, converting microwaves to acoustic vibrations. This work soon turned to creating and measuring spin waves (collective lattice modes) in ferromagnetic thin films under strong microwave magnetic fields and at low temperature [1], [2]. This was Phillips first exposure to spectroscopy and to the superheterodyne receiver, which was used to detect the applied 9.5 GHz signals as they interacted with the acoustic modes.

Upon completing his doctorate in 1964, Phillips took up a fellowship at Jesus College, Oxford University, where he had his first brush with *infrared* spectroscopy [3] using a Gebbie cube [4]. This instrument was a version of a Michelson interferometer and was developed by H. Alastair Gebbie at the National Physical Laboratory at Teddington, U.K. The Gebbie cube was the

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first commercialized Fourier transform spectrometer to employ a computer to perform the data conversion from the time domain to the frequency domain [5]. Towards the end of his research fellowship, Phillips travelled to California to work for a year with Stanford University Professor Robert L. White (Chairman of the Electrical Engineering Department and later, Director of the San Francisco Exploratorium) on microwave excited electron paramagnetic resonance in Rare Earths and other crystals, under high pressure and/or low temperature [6], [7]. At Stanford, Phillips was recruited by scouts from Bell Laboratories, NJ, but his J Visa required him to return to the U.K. for two years before he could take up a permanent post in the US. He spent the time as a lecturer at Magdelan College, Oxford, and continued his work at Clarendon on magnetic material properties [8] and infrared spectroscopy [9].

Fortunately, the Bell Laboratories recruiters were still waiting outside the doors of the Clarendon Lab when in 1968, Phillips made the voyage to Murray Hill, NJ. At Bell, he began working on electron spin resonance and wave propagation in cryogenic thin films [10], but now reaching up to much higher frequencies—above 100 GHz [11].

For millimeter-wave sources, Phillips used reflex klystrons that provided up to 100 mW of RF power and were easily modulated. The most prevalent room temperature detector technology at the time was the crystal rectifier (point-contact metal-semiconductor diode) that could be used in heterodyne mode to reach

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[1]Thomas G. Phillips shares his life and his love of radio astronomy with his wife, astronomer and former Caltech staff member Jocelyn Keene, in Pasadena, CA, USA. At 75, he is still "commuting" to the observatory on the top of Mauna Kea, HI, that he first began working on in 1979, and that he is now in a life and death struggle to save from being closed down. Professor Phillips kindly consented to interrupt his "friends of the observatory" fund raising efforts, for this interview at his office in the new Thom Mayne designed Cahill Center for Astronomy and Astrophysics at the California Institute of Technology, Pasadena, on June 29th, 2012.

sensitivity levels from 10^{-19} to 10^{-20} W at 1 Hz bandwidth. In working on wave penetration through cold metal films at high frequencies, however, sensitivity was critical, and it was natural to employ cooled bolometric detectors inside of the cryostat. Indium Antimonide (InSb) direct detectors had been pioneered by Bernard Rollin and Michael Kinch at Clarendon Lab [12] for millimeter-wave frequencies (the Rollin or Kinch-Rollin detector), by Ernest Putley [13] at the Telecommunications Research Establishment at Malvern, U.K., for the infrared, and by adding a strong magnetic field, for submillimeter wavelengths by Maurice Kimmitt [14] (Putley detector). Phillips recognized the value of using the InSb detector with a local oscillator in a homodyne mixer mode, and he constructed a detector that could reach a noise limit (heterodyne noise equivalent power) of 10^{-21} W per Hertz up to 120 GHz for his electron spin resonance measurements [10], [11].

As it turned out, Arno Penzias and Robert Wilson (1978 Nobel Prize winners in Physics), together with Keith Jefferts, were working just down the hall from Phillips at Bell Laboratories. At the time, they were trying to find DCN in the interstellar medium, which, together with the already found HCN transition, was thought to give the cosmologically interesting D/H ratio. But it was expected to be very weak (requiring a very high sensitivity receiver). Phillips attended a talk by Penzias on the team's recent (1970) measurement of the $J = 1 - 0$ (ground state) transition of carbon monoxide (CO) at 115 GHz, that had just been observed in the Orion nebula from the Kitt Peak 12 m radio telescope [15]. After the talk, Phillips brazenly walked up to Penzias and told him that his diode mixer had very poor sensitivity, and that he should be able to do much better with an InSb device—perhaps even measure the elusive DCN transition [16]. Penzias reacted in a very positive way to the criticism of this rather brash young physicist—he challenged Phillips to go and make a better receiver!

After all, this was Bell Laboratories in its glory days, and a challenge of this sort would not be taken lightly. Working with Wilson and Penzias team member, Keith Jefferts, Phillips scrambled to put together a spectral line receiver for the telescope at Kitt Peak. The two (Phillips and Jefferts) had set their sights on the $\mathrm{J} = 2 - 1$ transition of CO at 230 GHz, but first rapidly assembled a full receiver covering the 3 mm band (90–140 GHz) using the InSb bolometer mixer as the detector element. The classic, triumphant instrument paper appeared in Review of Scientific Instruments in 1973 [17]. The achieved receiver noise temperature was 250 K double sideband (DSB) at 115 GHz (mixer noise of 150 K DSB at a local oscillator power level of only 0.4 μW)—three times lower than the Schottky diode systems that were in use at the time, and more easily scaled to higher frequencies because of the very low local oscillator power requirement.

The problem with the InSb mixer was the very slow response time, which set a limit on the intermediate frequency output bandwidth of approximately 4 MHz (1 MHz in practice). This meant that measurements of GHz wide spectral regions had to be performed in very small frequency steps. It also meant that local oscillator noise power (very prevalent in reflex klystrons) could easily leak into the signal observation band, raising the overall receiver noise and limiting sensitivity. Nevertheless, Phillips and Jefferts, teamed up with Peter Wannier (then at nearby Princeton University, NJ, and now at Jet Propulsion Laboratory, Pasadena, CA), and put together a 230 GHz InSb receiver for Kitt Peak that could reach the $J = 2 - 1$ transition of CO, which was anticipated to be present in the Orion Nebula. After the Wilson, Jefferts and Penzias discovery of ground state CO at 115 GHz [18], this first excited state transition became the goal of several competing radio astronomy groups at the time.

Phillips realized that he could reduce the local oscillator (LO) noise power by working at a harmonic of the reflex klystron. Since the InSb mixer needed very little LO drive, a frequency doubled 115 GHz klystron had more than enough power to optimally pump the detector. The team also added a new phase lock loop system developed by Sandy Weinreb (then at National Radio Astronomy Observatory in Charlottesville, VA, and currently working at JPL and Caltech). With their receiver in hand, Phillips and Jefferts went out to Kitt Peak for a full week of observing in early July 1973.

In a story very similar to that of Bob Wilson's [15 p. 164], Phillips and Jefferts spent almost the entire week chasing down receiver electronics problems. Ultimately, they had to abandon the new phase-lock loop for a less stable frequency lock scheme. On the last night they were finally ready to start observing, when it began to rain heavily on the mountain. Desperate to try and make at least one good observation, they pointed the telescope through a protective cloth covering on the side of the dome (the main doors being shut to keep out the rain). They managed to acquire the Orion nebula and immediately detected a huge spectral emission line near 230.5 GHz ($^{12}C^{16}O$ $\mathrm{J} = 2 - 1$)! They also found $^{13}C^{16}O$ $\mathrm{J} = 2 - 1$ near 220.4 GHz [19].

This was a great coup for Phillips and Jefferts. It led Phillips and other collaborators to many more observations with the InSb receiver at Kitt Peak [20]–[26] several telescopes capable of making high observations at the time. These included the 200 inch Hale optical telescope at Mt. Palomar, CA, where Phillips made his first submillimeter-wave detection of CO $\mathrm{J} = 3 - 2$ at 346 GHz [27] and several other higher frequency molecular emissions [28]. He also took his receiver to Australia, where he could observe CO in the southern sky using the 3.9 m optical mirror of the Anglo-Australian Telescope (AAT), Siding Spring Observatory. Key observations at the AAT included HII regions [29], nebulae [30] and the first observations of CO in another galaxy—the large Magellanic Cloud [31].

In the midst of this very exciting time for observational radio astronomers in the U.S., Phillips took a leave of absence from Bell Laboratories in 1975 and returned to U.K., as a Reader in Physics at London University, so his wife could complete a Bar degree. This turned out to be a *career guiding* decision. While in London, Phillips was asked by noted Cambridge University professor and Astronomer Royal, Sir Martin Ryle (1974 Nobel prize in Physics for his pioneering work in radio science), to help lead a campaign to upgrade submillimeter-wave telescope capabilities in the U.K. Ryle was sitting on what he suggested to Phillips was a very mediocre proposal to upgrade the surface of the Mark II 38 $\times$ 25 m radio telescope at the University of Manchester's Jodrell Bank Observatory so it could be used to observe at submillimeter wave frequencies. He asked Phillips to come up with a competing proposal for a whole new dedicated submillimeter wave telescope that could be championed by Cambridge.

Phillips came back with a proposal for a 20 m dish to be located on a high mountain top site, where the water vapor absorption would be low enough to allow higher frequency observations without being severely limited by atmospheric attenuation. He recalled one critical review board meeting in London, where the two proposals were being compared. After the presentations, Phillips was prodded by the Cambridge team to ask some critical questions of the Jodrell Bank team. He asked them what they planned to do scientifically with their facility if it were funded. After an extended pause, their reply was "to look for molecules in the galactic center." Phillips pointed out if that were the case, they had better plan on cutting down trees around the observatory, because the galactic center only reaches a few degrees above the horizon at Manchester! As it turned out the U.K. review committee decided that Phillips' proposal should be pursued, and the UK should look at joining up with Europe on IRAM (Institut de Radioastronomie Millimetrique). IRAM was a French-German-Spanish collaboration to place a six dish millimeter-wave interferometer on the Plateau de Bure in the French Alps, plus a 30 m telescope on Pico Veleta in Spain. At this point, Ryle made a decision to pull out, and to pursue a separate UK-only program.

Phillips continued work on the Cambridge telescope proposal with help from one of Ryle's protégé's at Cavendish Lab, Richard Hills (most recently project scientist for ALMA—Atacama Large Millimeter Array). The project was soon picked up by the UK government, and realizing it would be a huge bureaucratic program, Phillips himself pulled out and returned to Bell Laboratories. Hills stayed on and became the project scientist for what ultimately ended up as the largest single dish submillimeter-wave telescope constructed to date—the 15 m diameter James Clerk Maxwell Telescope (JCMT) situated on Mauna Kea, Hawaii at an altitude of 4092 m. Under Hills, the JCMT was successfully completed and began operations in 1987 as a UK-Netherlands-Canadian partnership. Ironically, it quickly teamed up with the smaller 10.4 m submillimeter-wave telescope next door, that Tom Phillips was to complete in 1986 from his post at Caltech (more on this a bit later), to form the first submillimeter-wave interferometer.

Although Phillips went back to New Jersey in 1976, the seed for constructing and operating a large submillimeter-wave telescope had been firmly planted. As it began to take root and grow however, Phillips continued to push his InSb bolometer technology for higher frequency observations. He knew that he had to get above the atmosphere in order to make observations in the THz domain, and fortuitously a new astronomical research platform had just recently come on the scene. The NASA operated Kuiper Airborne Observatory (KAO) was a converted C-141 transport plane with a 91.5 cm high accuracy (1 micron) Cassegrain telescope that could point skywards through a cutout in the fuselage. It began flying in 1974 on long (up to 11,000 km) high altitude (up to 14 km) flights and was perfect for both infrared and submillimeter-wave observations. Phillips jumped at the opportunity to bring his InSb receiver on board, and between 1980 and 1985, he and colleagues made more than 10 flights on the KAO. This was not a "picnic" however, as there was an enormous amount of preparation required for each flight. Participants on board worked in very difficult environmental conditions, for long durations, sometimes having to don flight suits and breathing equipment, or ear mufflers to cut down on aircraft noise.

Phillips recalls one flight where NASA had brought along some television news reporters, and he was sure his equipment would fail him just when the cameras were turned on. However as he was about to be put in the spotlight, one of the KAO flight engineers came running down the fuselage and started pouring cans of oil into a spigot in the wing. A hydraulic line had apparently ruptured! The observation run came to an abrupt end, as the plane was manually guided down—no hydraulics for the flaps or even the undercarriage—to a rough but safe landing. The team's reputation was preserved, and the news reporters had plenty to write home about!

Despite the occasional aborted mission, these observational experiments on the KAO produced a wealth of important new spectral lines and many theoretical papers. Some key submillimeter-wave measurements include the first detection of the $\mathrm{J} = 4 - 3$ CO emission line at 460 GHz, and water at 380 GHz [32]. Also observed were the first lines of interstellar atomic carbon at 492 GHz [33], a very important result for astrochemists trying to understand the composition of giant molecular clouds [34], and the ground state rotational transition of ammonia $(\mathrm{NH_3})$ at 572 GHz [35], HCl $\mathrm{J} = 1 - 0$ at 626 GHz [36] and many other high frequency emission lines [37], [38].

The success of the InSb bolometer receiver in allowing many of the first observations of high frequency molecular line signatures was, as already mentioned, limited because of the narrow spectral bandwidth. As a practicing observationalist however, Phillips always had his eye on potential new receiver technology. When high quality superconducting tunnel junction devices started coming out in the early 1970's (they were being pushed by superconducting computer projects at both IBM and AT&T), Phillips realized that these very fast switching devices might make excellent high frequency detectors. He focused on the photon assisted quasi-particle tunneling effect that had been discovered by Dayem and Martin [39]. The associated superconducting energy gap of typical quasi-particle junctions in these new devices was only a few meV, corresponding to photon energies in the millimeter and submillimeter-wave bands. In addition, the very sharp turn-on current for a small shift in voltage, meant that the quasi-particle tunnel junction might also work effectively as a THz switch or mixer. The detector community focus at the time had been on the superconducting Cooper-pair tunneling process that makes up the AC and DC Josephson currents [40], for which Brian Josephson, working at Cavendish Lab, Cambridge, received the 1973 Nobel Prize in Physics. Josephson tunneling, it was thought, could be used to make a very sensitive THz mixer, if the capacitance could be reduced sufficiently to allow the device to operate at high frequencies. Josephson point-contact detectors, as they were called, were already being investigated at several research laboratories. Ultimately however, the Josephson junction mixer proved to be very noisy, and it was eventually abandoned by most radio astronomy groups (see discussion in [41] page 344 for example).

The idea of working on superconducting quasi-particle tunneling detectors came to Phillips around 1975. By the late

1970's he had teamed up with Bell Labs microfabrication experts, Ron Miller and Jerry Dolan, as well as physicist Dave Woody, who had recently come over from Paul Richards group at UC Berkeley. The AT&T supercomputing group had been working with lead alloy tunnel junctions (lead plus small amounts of indium, gold, and bismuth). Using newly available photolithographic processes [42], the Phillips team was able to fabricate lead–lead oxide–lead (superconductor–insulator–superconductor—SIS) tunnel junctions with areas below 0.1 μm^2. Their successful demonstration of a 115 GHz SIS mixer with a single sideband noise temperature below 100 K [43] and its subsequent demonstration in June 1979 at the Owens Valley Radio telescope facility [44]–[46], launched a revolution in the low-noise astronomical receiver community. The Bell Labs team's first receiver paper [43] was published side-by-side in *Applied Physics Letters* with the simultaneous, independent, and equally important, SIS quasi-particle mixing results of Berkeley Professor Paul Richards *et al.* at 35 GHz [41], [47]. Shortly afterward, John Tucker published his well-cited theoretical paper on SIS mixers [48].

The demonstration and fielding of the SIS receiver was a major technical achievement. SIS devices quickly spread to every major observatory in the world, and gradually ramped up in frequency to beyond 1 THz with wider bandgap superconductors [49]. They eventually found their way into the two most technically complex submillimeter wave astronomical platforms ever fielded—the Heterodyne Instrument for the Far Infrared (HIFI) on the European Space Agency's Herschel Space Observatory [50] (to which NASA is a major contributor), and the Atacama Large Millimeter Array, now in the early stages of continuous operation on the Chajnantor plateau in the mountains of northern Chile [51]. SIS mixers do not suffer from the limited bandwidth of InSb and other bolometer-based devices, and even today, they remain the most sensitive narrow band detectors ever fielded. Despite the many physicists and technologists who later analyzed, perfected and extended the performance of the SIS mixer, the role that Phillips and his colleagues at Bell, and later at Caltech, played (as well as Paul Richards and his colleagues at UC Berkeley), in bringing these devices to the attention of the THz community, can never be overshadowed.

With all of his ongoing observational and theoretical projects in molecular astronomy, and with this incredibly useful new SIS receiver technology coming on line, the desire to build a dedicated submillimeter-wave telescope platform again rose to the top of Phillips priorities. In 1979, Caltech physicist Robert B. Leighton [52], then very interested in large aperture telescopes, called on Phillips and asked him if he would come out to California to help him complete the Owens Valley radio observatory dishes which were already a funded US National Science Foundation (NSF) project. According to Leighton, the NSF had approved three large diameter millimeter-wave telescopes to be configured as an interferometer array, and one stand alone submillimeter-wave telescope that could be located on a separate mountain top site.

This was enough of an incentive for Phillips to make the move across country, where he joined the faculty at Caltech. Unfortunately, Leighton had interpreted the NSF mandate slightly differently than Caltech management. Two days after arriving in Pasadena, Phillips was called into a late night meeting with then Division Chair Rochus (Robbie) Vogt. Vogt told Phillips that there was a serious problem with the NSF project at Owens Valley. Despite what Leighton had told Phillips, NSF was not building four telescopes, but only three—the large dish interferometer. NSF had indeed financed the Caltech proposal, but at roughly three fourths of the requested funding. Leighton, like many confident scientists, had assumed that he could simply build all four telescopes at the lower allocation. This was not what NSF had in mind. Vogt told Phillips he had to go to Owens Valley, take charge of the project and get the three dish interferometer working *before* he could even think about building a submillimeter-wave telescope. Phillips did take on the task of supervising the construction and testing of the interferometer, but it cost him four years. The Owens Valley Radio Observatory (OVRO) was completed and operational in 1984.

During this time, even though they had no funding from NSF to do so, Leighton and Phillips worked on plans for the submillimeter-wave telescope. They chose a sight (Mauna Kea, HI), submitted an environmental impact statement, started designing and prototyping all kinds of hardware, and managed somehow to scrape together enough bits and pieces of funding from private and public sources to actually fabricate the entire dish—10.4 m, the back-up structure and the bearings, in the same Caltech facility that was earlier used for the 200 inch Palomar telescope.

By 1984, when the Owens Valley interferometer was up and running, NSF finally came in with funding for the Submillimeter facility. However, even this decision was only by a stroke of good fortune. According to Phillips, the NSF had received more funding in 1984 than they had asked for in then President Ronald Reagan's budget proposal to the US Congress. The Submillimeter telescope was an add-on program at a much lower than planned funding level. In the original NSF plan, the Mauna Kea radio observatory project included the 10 m submillimeter-wave telescope alongside a much larger 25 m lower frequency dish that was to be built and managed by the National Radio Astronomy Observatory. The project proved to be too expensive, even with the extra funds from the Congressional allocation, so the more expensive 25 m telescope was cut. Fortunately, due to all their hard work, planning, and advanced fabrication efforts over the prior six years, Phillips and Leighton were poised to move ahead quickly and with minimal funding. They immediately used the NSF program to procure the last remaining major piece of what would soon become the Caltech Submillimeter Observatory (CSO)—the dome.

The dome had to ultimately be assembled on the mountain top at Mauna Kea, in what would be severe environmental conditions and potentially extremely strong winds. Phillips wisely convinced the team—and the contracting company—that they should try a practice assembly in Pasadena before shipping out all the parts to Hawaii. The Caltech football team may never provide as exciting a moment to its fans! Fortunately football does not carry as much priority at Caltech as it sometimes has at other US universities, and the CSO was, for a short time, fully assembled near the 50 yard line. It turned out to be a good decision, as several planned assembly techniques did have to be modified to enable reconstruction at the mountain top sight. The dome was shipped to Hawaii late in 1984, and even after all the planning and prep work, it did not go up quite as smoothly as hoped. The contracting company went bankrupt during construction and Phillips, with a handful of staff and students, were left to complete the final assembly (surfacing the dome) by themselves! After a very hard year, the telescope was completed, and in early 1987, astronomical operations began with the observation of Centaurus A using an SIS receiver at 230 GHz [53].

The CSO, with Phillips as Director, has been in nearly continuous operation ever since that first observing session in 1987, and Phillips has been commuting between Pasadena and Kona on roughly a monthly schedule for almost 25 years. The observatory has served as the basis for more than 75 doctoral theses and is the reference platform for countless scientific papers from facility users, colleagues and data miners from around the globe. Phillips feels that some of the most exciting results are observations of deuterated molecules in dense regions of interstellar gas and dust, like ammonia [54] and hydrogen sulfide [55], which have much higher abundances than predicted by prevailing theories. The CSO was also able to measure deuterated water (HDO) in comet Hyakutake [56], shedding light on the origins of water, in comets, and by extension, to the Earth's oceans. Other observatory related information can be found in a wonderful symposium volume honoring Phillips' long career [57] and in a short paper he wrote himself on the CSO for a special THz session at the 2007 IEEE MTT-S Symposium [58]. The reader is left to ruminate on the many scientific and technical contributions that have come from this herculean, and very personal accomplishment that is the CSO, while we step back to yet another multi-decade long accomplishment that was a long term goal of Professor Phillips.

Although it is hard to imagine how one could fit in any additional tasks while managing work at Owens Valley, designing and building parts of the CSO, teaching, directing grad students and post-docs, serving on a variety of university, national and international science committees, writing proposals and papers, and doing observing runs on the KAO and at remote ground based observatories; there was yet one other very significant venture that drove Phillips to push himself just as hard as he had in realizing his dream of establishing a submillimeter-wave mountain top observatory—a submillimeter-wave *space* observatory. Phillips knew that the amount of THz spectral data that could be retrieved from a continuously observing platform that operated above the Earth's atmosphere, was far more than he could ever obtain from even a lifetime's worth of flights on the KAO—which by 1995 was already out of service, with its replacement—the Stratospheric Observatory for Infrared Astronomy (SOFIA), more than 15 years away.

In 1979, Phillips participated on a scientific advisory panel for the National Research Council of the US National Academy of Sciences on the prioritization of astronomical science for the upcoming decade. In this Astronomy and Astrophysics Decadal Survey report [59], Phillips convinced both the radio and infrared science subcommittees to push for a large submillimeter and infrared space telescope facility which was then called Large Deployable Reflector (LDR). A comprehensive workshop, sponsored by the US National Aeronautics and Space Administration (NASA), was held in 1982 at Asilomar, CA, to better define the mission [60]. The meeting was attended by astronomers and technologists from around the world. Afterwards, an excited European group even brought the submillimeter-wave space telescope concept back to the European Space Agency, where it was soon embraced as a Horizon 2000 cornerstone science mission under the acronym FIRST—Far Infrared Space Telescope. Although no one admits to it officially, the acronym was clearly a jab at NASA, and FIRST became a competing mission proposal that ultimately would be *first* into space.

After the Asilomar conference, NASA embraced the LDR mission concept, and in 1984 funded a very long term, comprehensive receiver technology development program at Caltech that was proposed under Phillips and post-doctoral fellow Dan Watson (now a professor at University of Rochester) and continued all the way through 1995. JPL was also funded under this same NASA initiative, and it was this program that in 1987, brought your current T-THz editor from National Radio Astronomy Observatory, Charlottesville, VA, to Pasadena, CA.

The first Asilomar meeting was followed by two others, but in 1985 the Challenger Space Shuttle disaster ended US astronomers' dreams for the LDR. From that point forward US science missions were expected to launch on much smaller unmanned Delta class rockets. A large aperture, or multi-faceted telescope, could not be accommodated on such a launch vehicle. Under Phillips leadership, LDR ultimately morphed into a series of much smaller mission concepts, none of which were able to gain a permanent foothold within the NASA queue.

In December 1990, at an astrophysics gathering in Liege [61], Belgium, Phillips, noted astrophysicist Reinhard Genzel (Berkeley professor and a Director at the Max Planck Institute for Extraterrestrial Physics, Garching, Germany) and spectroscopist Charles Townes (Berkeley professor and 1964 Nobel Laureate in Physics), proposed a joint program that would blend the existing NASA submillimeter-wave telescope mission concept with FIRST. The European Space Agency would play the lead role, and NASA would come on board with science, telescope, and receiver technology that would reduce mission cost and risk for the European community. Within a short time there was an agreement between the two space agencies and NASA dropped all competing submillimeter-wave space telescope proposals. FIRST became the European Space Agency's Herschel Space Observatory, and the real work to build up the never-before-realized THz telescope and new THz receiver technologies, required to implement this ambitious science mission, began. Thiijs de Graauw (formerly a professor at Leiden University, Netherlands, a principal investigator on the Infrared Space Observatory and a director for submillimeter wave and infrared research at SRON—Netherlands Institute for Space Research) was the principle investigator for the Heterodyne Instrument for the Far Infrared (HIFI) instrument on Herschel, and Tom Phillips became the US HIFI contribution principal investigator.

The rest, as they say, is history. After more than two decades of development activity, the Herschel Space Observatory was launched on an Ariane V rocket from the Guiana Space Center (ESA/CNES) facility in French Guiana and was successfully deployed in an Earth-Sun L2 point orbit on May 14, 2009. It is expected to be operational through February 2013, when its helium cooled detectors and cooled telescope dish will likely run out of cryogen. A description of Herschel, its instruments and its incredibly rich science are beyond the scope of this article. Some THz specific mission results are contained in a recent article from the July issue of this journal [62] and on the comprehensive web sites maintained by the European Space Agency [63] and by Caltech [64].

In the midst of all the excitement that has finally coalesced around the many projects that have been conceived, nurtured, promoted, started, stopped, started again, and ultimately kept alive in the face of exasperating odds, Tom Phillips is finally thinking about retiring. We have barely touched on his many more recent scientific contributions to astrophysics [65]–[71] notably, the establishment of turbulence and intermittency [72]–[74] and the use of line-surveys in the interstellar medium [75]–[78], his wonderful review article [79] that is a mainstay for young researchers entering the field of molecular astronomy, or his many technical and engineering contributions to THz [80]–[88]. With over 400 publications and almost 10,000 citations there is necessarily much left unreferenced in this short article.

In closing our discussion, I asked Professor Phillips for any advice he might like to give to young scientists. He replied with three suggestions. 1). In any endeavor it is essential to make prototypes (Phillips considers himself an experimentalist). 2). Don't believe everything you read (this does not apply to his own papers)! 3). Don't worry whether the work you are doing seems important (this one is rather hard to take to heart, as all the work Phillips has done seems important to me).

Phillips' concern now is the closing of the CSO. After our discussion, I can fully understand both how much this observatory is part of the man, and how much this man is part of the observatory. This editor can only wish that both will exist forever.

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